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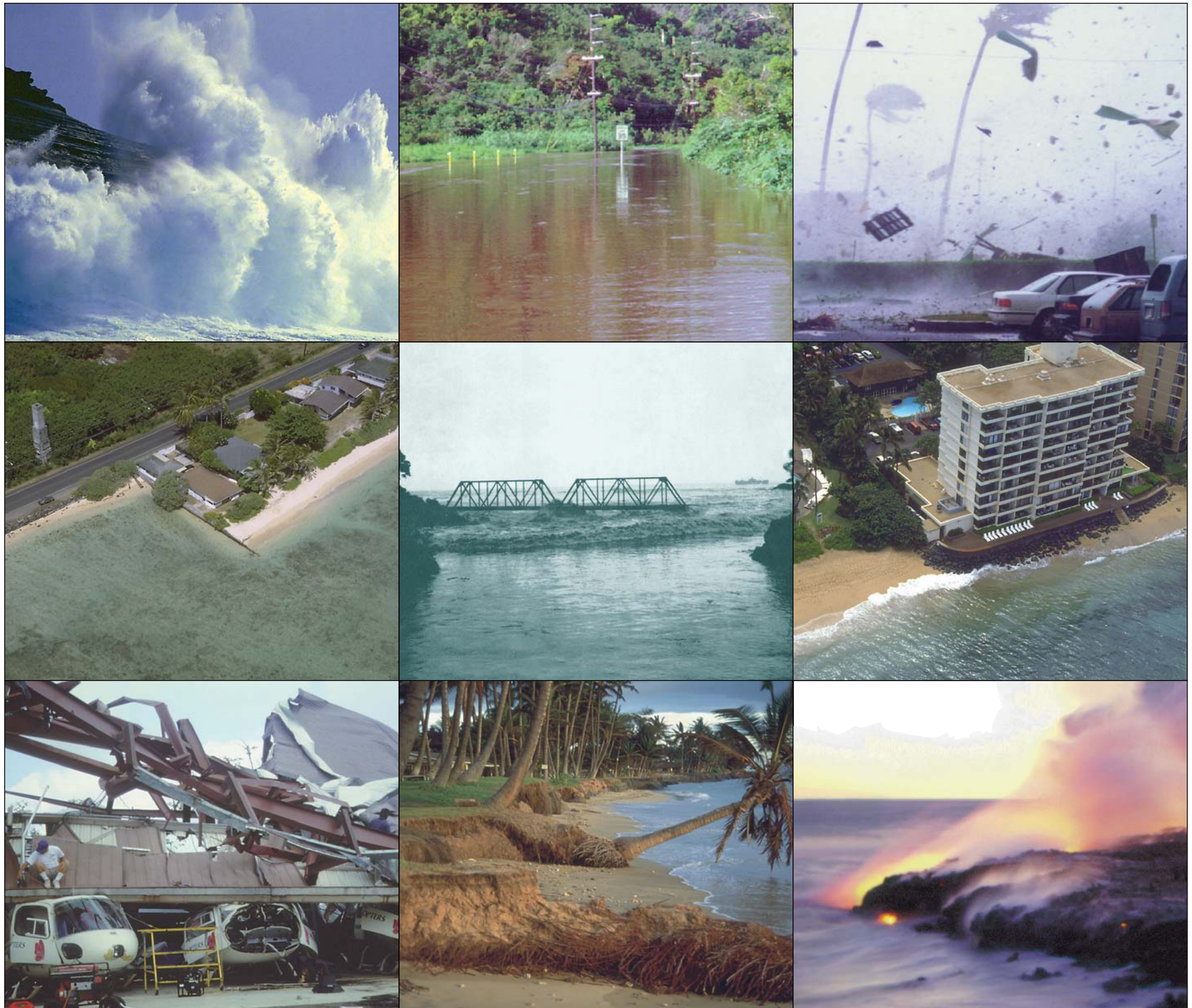

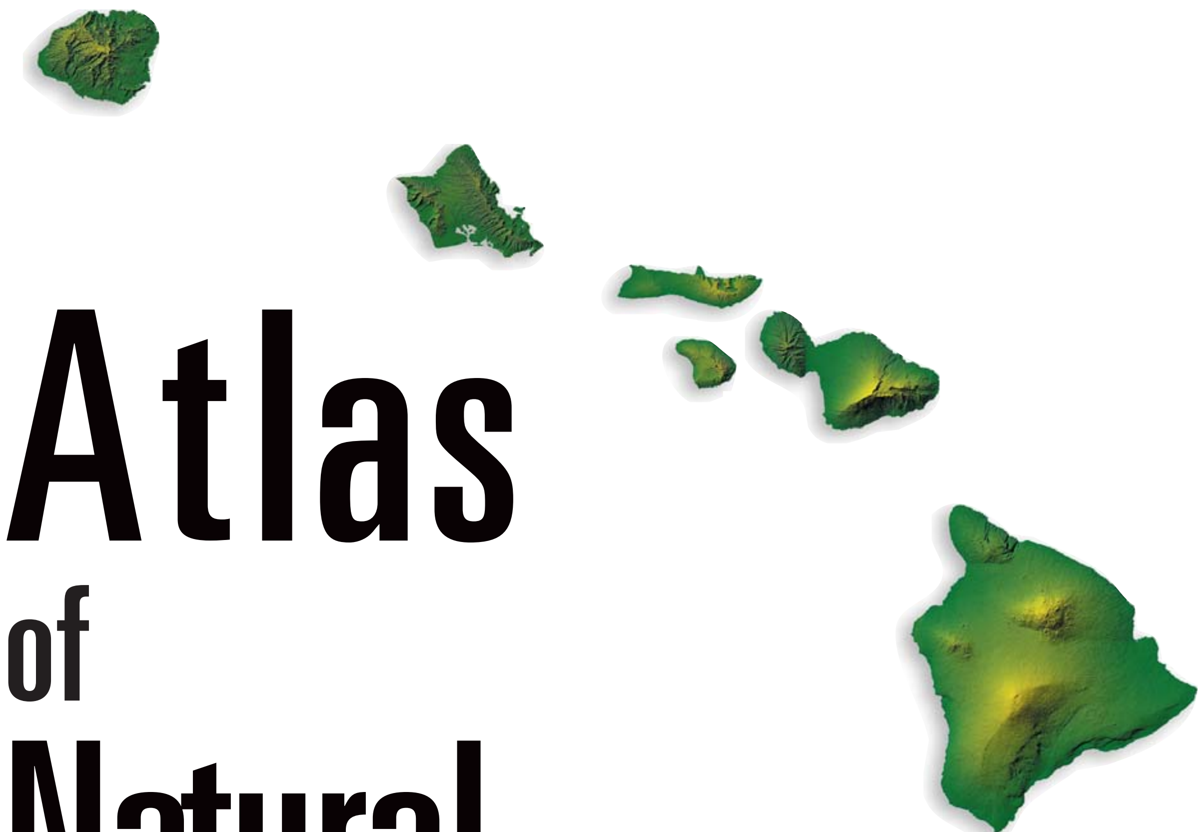

Atlas of Natural Hazards in the Hawaiian Coastal Zone

U.S. Department of the Interior
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Geologic Investigations
Series I-2761

Cover Photos

High waves at Koko Head, Oahu. (Photo, Steve Businger.)	Stream flooding along the Hanalei River, Kauai. (Photo, Scott Calhoun.)	Flying debris in Lihue, Kauai, during Hurricane Iniki. (Photo, Bruce Asato.)
Beach loss is more common along hardened shorelines (left) than along unhardened shorelines (right), Kaaawa, Oahu. (Photo, Charles Fletcher.)	Tsunami bore entering the mouth of the Wailuku River, Hilo, Hawaii, on April 1, 1946. (Photo, Shigeru Ushijima.)	Sea-level rise and coastal erosion threaten much of the coastline and infrastructure in Hawaii, Honokowai Point, Maui. (Photo, Charles Fletcher.)
Destruction at Princeville Airport, Kauai in the wake of Hurricane Iniki. (Photo, Bruce Richmond.)	Coastal erosion at the Halama shoreline in Kihei, Maui. (Photo, Charles Fletcher.)	Lava entering the sea near Kalapana, Hawaii. (Photo, Scott Rowland.)

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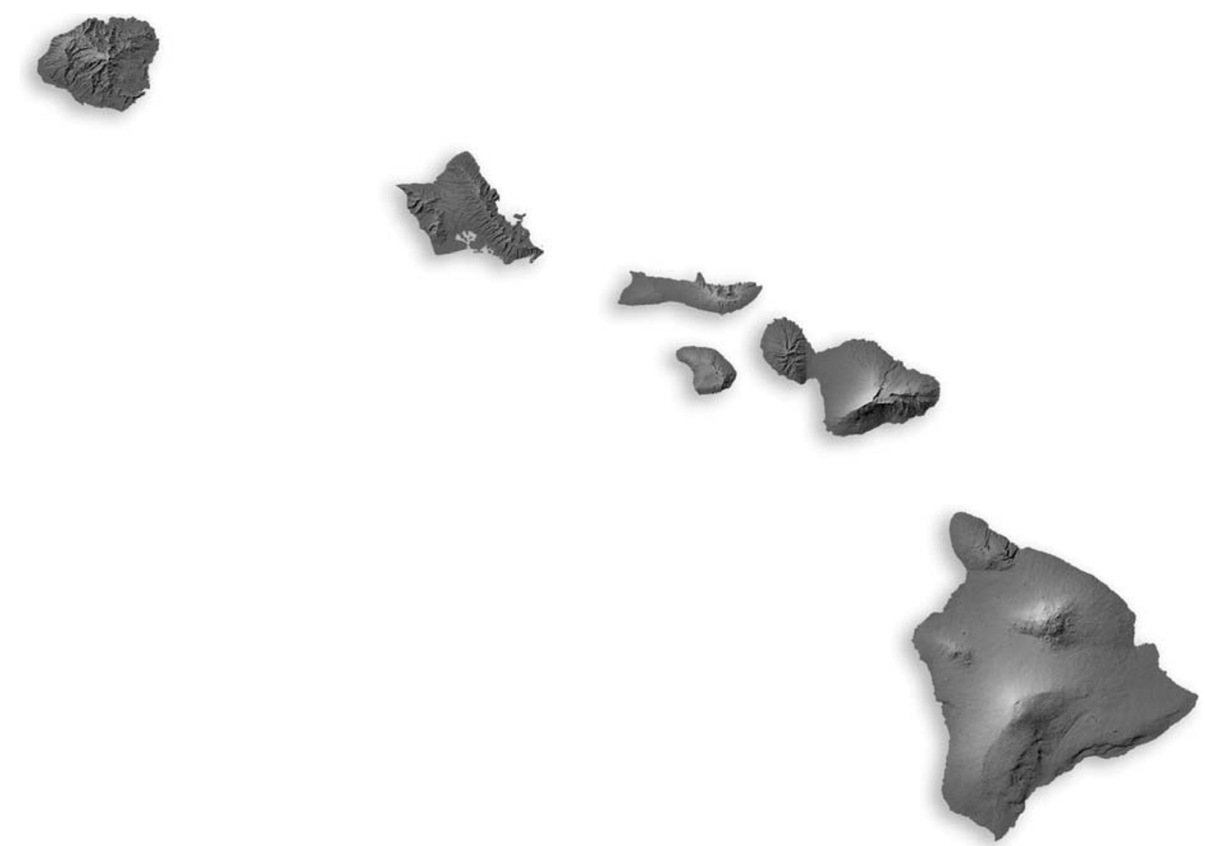
By Charles H. Fletcher III, Eric E. Grossman, Bruce M. Richmond, and Ann E. Gibbs



Prepared in cooperation with University of Hawaii, State of Hawaii Office of Planning, and National Oceanic and Atmospheric Administration

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Purpose and Structure

This atlas reports on a program of research that assigns a relative ranking scale to seven natural coastal hazards. The ranking is based on the historical trends and natural factors influencing site vulnerability and hazard intensity in the Hawaiian coastal zone.

The Hawaii Coastal Zone Management Program (Office of Planning) has identified the prevention and minimization of threats to life and property from episodic and chronic coastal hazards as a priority deserving research and scientific definition. Other than the general requirements of the state shoreline setback provisions and the National Flood Insurance Program, Hawaii lacks specific policies regarding rebuilding storm-damaged structures away from high-hazard areas. There is no restriction on the use of public funds for projects that allow or encourage development in high-hazard areas. Without specific policies or restrictions, development will continue to occur in high-hazard areas at the taxpayer's expense (U.S. Fish and Wildlife Service, 1993).

Introduction

Coastlines are nature's great laboratory of equilibrium. Coastal environments have the capacity to undergo swift and powerful changes in response to meteorological and oceanographic forces. Consequently, students of coastal processes learn that the first principle of coastal science is, "The only reliable constant on the shoreline is a condition of perpetual change." A healthy coastal environment is one with the ability to change when change is needed. Sea levels rise and fall, storms come and go, beaches retreat and advance, and change occurs on timescales from a few seconds to the entirety of Earth history.

Unfortunately, the same dynamic natural processes that characterize coastlines also pose a hazard to the human use of coastal resources. The citizens of Hawaii live and play along island shores. Their right to use the coast and enjoy its benefits are guaranteed in the state constitution, which entrusts the state with the obligation to conserve coastal lands for the people of Hawaii. Yet the coast can be a hazardous environment with a capacity for swift change that can threaten life and property.

To improve our understanding of this problem and its remediation, we have investigated the history and character of natural hazards on the Hawaiian coast. This report contains a history and ranks the intensity of seven potentially hazardous coastal processes in Hawaii. These hazards are:

1.) Tsunamis
2.) Stream flooding
3.) High waves
4.) Storms
5.) Erosion
6.) Sea level
7.) Volcanic/seismic

All sectors of the Hawaiian coast have some degree of hazard history and vulnerability. The responsibility, then, is on the land user or developer to shape their development plans to reduce the impact of a recurrence of specific hazards with high-ranked intensity on human life and economic investment. Those coastal segments that have a high or very high overall hazard ranking must be viewed as especially dangerous for human use or development. A high ranking in any one of the individual hazard categories warrants cause for heightened awareness and concern for implementing mitigation with specific design elements into user plans.

Purpose

The purpose of this report is to communicate to citizens and regulatory authorities the history and relative intensity of coastal hazards in Hawaii. This information is the key to the wise use and management of coastal resources. The information contained in this document, we hope, will improve the ability of Hawaiian citizens and visitors to safely enjoy the coast and provide a strong data set for planners and managers to guide the future of coastal resources.

This work is largely based on previous investigations by scientific and engineering researchers and county, state, and federal offices and agencies. The unique aspect of this report is that, to the extent possible, it assimilates prior efforts in documenting Hawaiian coastal hazards and combines existing knowledge into a single comprehensive coastal hazard data set. This is by no means the final word on coastal hazards in Hawaii. Every hazardous phenomenon described here, and others such as slope failure and rocky shoreline collapse, need to be more carefully quantified, forecast, and mitigated. Our ultimate goal, of course, is to make the Hawaiian coast a safer place by educating the people of the state, and their leaders, about the hazardous nature of the environment. In so doing, we will also be taking steps toward improved preservation of coastal environments, because the best way to avoid coastal hazards is to avoid inappropriate development in the coastal zone.

Technical Map Series

We have chosen maps as the medium for both recording and communicating the hazard history and its intensity along the Hawaiian coast. Two types of maps are used: 1) small-scale maps showing a general history of hazards on each island and summarizing coastal hazards in a readily understandable format for general use, and 2) a large-scale series of technical maps (1:50,000) depicting coastal sections approximately 5 to 7 miles in length with color bands along the coast ranking the relative intensity of each hazard at the adjacent shoreline.

The authors intend for this report to be used as a reference atlas of coastal hazards in Hawaii. We have constructed a set of technical hazard maps (example follows) of the entire shoreline of the islands of Kauai, Oahu, Molokai, Lanai, Maui, and Hawaii at a scale of 1:50,000 (1 inch on the map equals approximately 0.8 miles). The technical map series displays the nominal relative intensity (on a ranked scale of 1 to 4, where 4 is most intense) of each of the seven hazards following a set of specific definitions (Table 1). These are used as a guide in assigning an intensity level to each hazard. Where a lack of data precludes establishing a specific ranked definition, the rankings are applied as a relative scale based on a logical interpretation of environmental variables. Each map also depicts the geology of the coast using a simple alphabetical code. In addition, the slope of the coastal zone is mapped from sea level to an elevation of approximately 200 feet, or the first major change in slope. Both geology and slope are important variables in determining the hazardous character of the coastal zone.

Ranking Hazard Intensity

Ranking hazard intensity in a region requires applying scientific judgement grounded in a thorough understanding of the specific history of hazardous phenomena and a familiarity with local environmental processes. Consequently, a major effort of this study was the compilation and construction of a history of hazards in the Hawaiian Islands. Scientific literature, agency reports, newspaper accounts, and miscellaneous records of hazardous episodes since the beginning of the nineteenth century are compiled here into a single report. It is our hope that the hazard data set will continue to be maintained and updated in the interest of eventually achieving a statistically robust capability to predict hazard chronology and intensity.

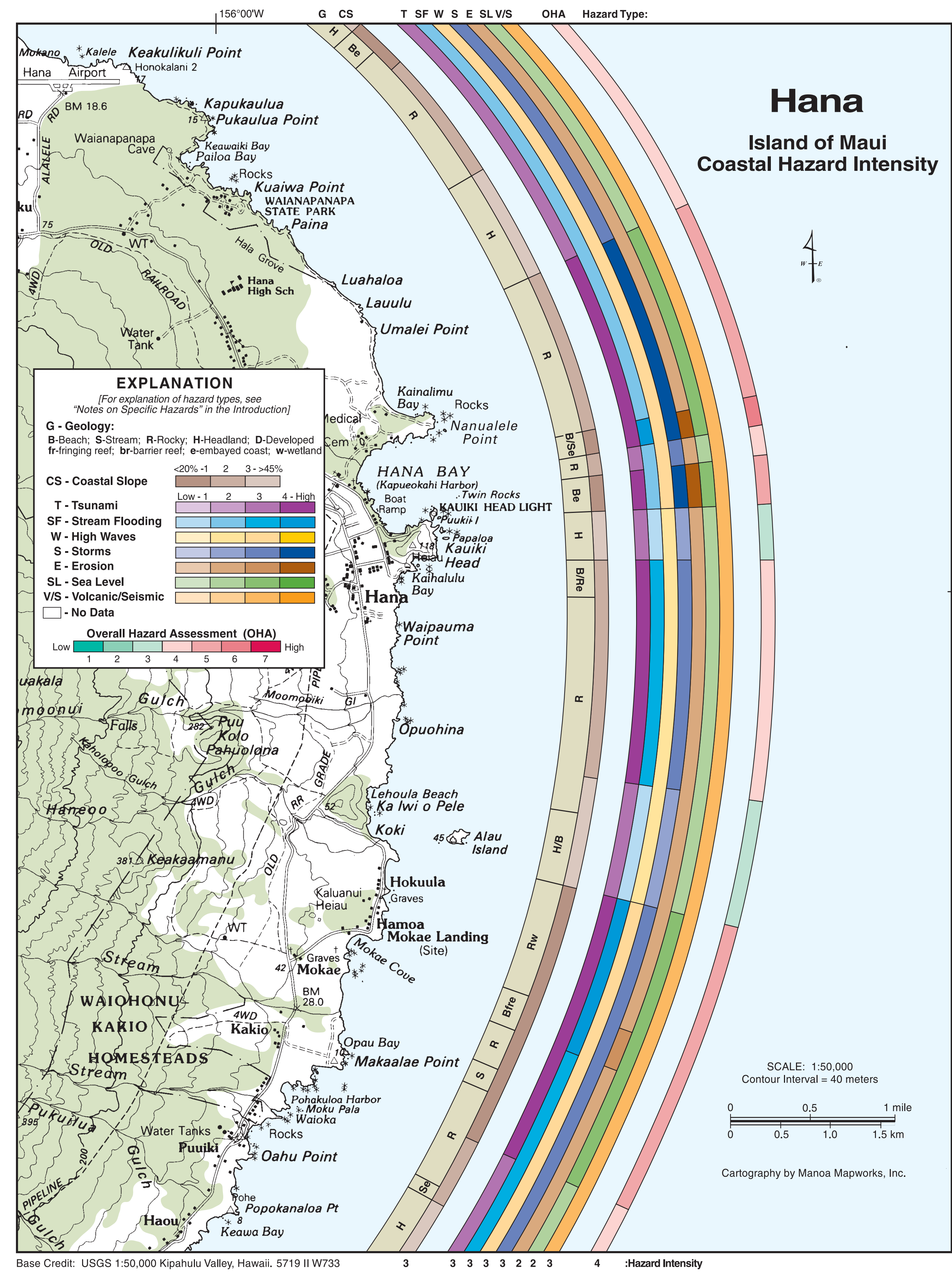
There exists no established methodology for determining the hazardous nature of a coastline. We have designed our system following the general procedure used by the U. S. Geological Survey in their National Coastal Hazard Map (Kimball and others, 1985). Our design has the advantage of being tailored specifically to the Hawaiian coast and the drawback that it does not benefit from a history of testing and revision that leads to improvement and optimization. We sought to design a methodology subject to the standard tests of scientific validity, which are reproducibility and testability. We were successful in this. Our ranking method is reproducible through the specific definitions of each hazard intensity (Table 1), and it is subject to the test of time (comparison of our rankings to future events) and the constraints of the historical data. Although certain hazards such as stream-flooding frequency and hurricane overwash can be successfully modeled, it is beyond the scope of this project to construct numerical approximations of each hazard for the entire Hawaiian coast. Rather, our goal is to present a usable, understandable, yet detailed characterization of coastal hazards within a scientific framework and with historical accountability.

Ranking hazard intensity is based on a number of variables (Table 1), some of which are not always available for consideration because much of the Hawaiian coast is remote and little is known about its hazard history. However, in nearly all settings lacking historical data we have been able to use environmental features and regional patterns as a sufficient basis for determining the likely intensity of each hazard. For example, beach erosion rates are not known for the entire state, yet there are some beaches where abundant beachrock is exposed and the vegetation line is awash during high tide. These are strong environmental indicators of chronic erosion. In such localities, this is sufficient data for assigning a ranking of 3 or even 4 to the beach erosion hazard.

TABLE 1
Hazard Intensity Rank Definitions

Hazard	Low (1)	Moderately Low (2)	Moderately High (3)	High (4)
Tsunami	no history of tsunami flooding; steep coastal zone slope (≥45%)	history of tsunami flooding; steep coastal zone slope (≥45%)	history of tsunami flooding; historical damage; steep coastal zone slope (≥45%)	history of tsunami flooding; historical damage; gentle slope (<45%)
Stream Flooding	no history of coastal stream flooding and no reasonable basis for expected flooding due to low seasonal rainfall in watershed (<4.9 in per month); or steep coastal slope (>45%)	history of nondamaging flooding where streams or highlands with seasonal high rainfall are present (>7.9 in per month) and coastal slope >20%; or history of flood damage with full mitigation since last major flood	abundance of streams and high seasonal rainfall in watershed (>7.9 in per month) and history of damaging floods with partial mitigation or no mitigation where slope >20% and <45%	historically high flood damage on gentle slope, high watershed rainfall (>7.9 in per month) and no mitigation efforts or improvements since last damaging flood
High Waves	no reasonable basis to expect high waves	seasonal high waves 4-6 ft	seasonal high waves 6-8 ft with hazardous run-up and currents	seasonal high waves >12 ft, characterized by rapid onset
Storms	no history of overwash or high winds and no reason to expect them	minor historical overwash (<10 ft), and/or high winds (~40 mph gust)	historical overwash >10 ft on steep slope, and/or high winds with localized (isolated cases) structural damage (~40 mph sustained)	historical overwash >10 ft on moderate to gentle slope and/or high winds with widespread structural damage (~75 mph gust)
Erosion	long-term accretion (>10 yr) with no history of erosion, or dynamic cycles with consistent annual accretion	long-term stable or minor erosion/accretion cycles with erosion fully recovered by accretion; low rocky coasts; perched beaches	long-term erosion rate <1 ft/yr or highly dynamic erosion/ accretion cycles with significant lateral shifts in the shoreline	chronic long-term erosion >1 ft/yr, or beach is lost, or seawall at water-line for portions of the tidal cycle
Sea Level (0.04 in=1mm)	steep coastal slope where rise >0.04 in/yr or gentle slope where rise <0.04 in/yr	gentle or moderate slope where rise >0.04 in/yr or steep slope where rise >0.08 in/yr	gentle or moderate slope, where rise >0.08/yr or steep slope where rise >0.12 in/yr	gentle or moderate slope where rise >0.12 in/yr
Volcanic/ Seismic	no history of volcanic or seismic activity, *UBC seismic zone factor ≤ 2	no volcanic activity in historical times; *UBC seismic zone factor ≤ 2, minor historic seismic damage	limited history of volcanism, *UBC seismic zone factor ≥ 2 recommended, historic seismic damage	frequent volcanism, *UBC seismic zone factor ≥ 2 recommended, frequent historic damage

*UBC, Uniform Building Code seismic zone factor



3

Intensity Variables

Variables that were considered when assigning hazard intensities include the history of a particular hazard, local and regional environmental processes, arguments for or against future occurrences of the hazard, and mitigating or exacerbating circumstances that are relative to future hazard intensity. For example, throughout the state a number of streams with a history of flooding have undergone channelization by the U.S. Army Corps of Engineers to mitigate the threat of future flooding. These efforts are generally successful measures in decreasing the downstream flood hazard to local residents. We have ranked the intensity for these locations with consideration of the level of mitigation and the flooding history since mitigation was enacted. Some of these locations are also subject to flooding because of extremely heavy rainfall that quickly collects on the ground due to insufficient permeability in the underlying substrate. This is different than stream flooding. Clearly, in these regions, stream channelization does not fully mitigate the flooding hazard. Thus a region may be fully channelized, but the hazard is only partially mitigated. Our ranking depicts the continued presence of a hazard despite the mitigation effort.

Overall Hazard Assessment

In addition to ranking individual hazards, we have calculated a nominal Overall Hazard Assessment (OHA) for the coast by squaring each intensity value, doubling the squared value of the dynamic hazards, and averaging the seven weighted values. Squaring each intensity level gives greater emphasis to high-intensity hazards, which generally constitute the greatest threat. Certain hazards are more dynamic than others, including volcanism and seismicity, coastal stream flooding, seasonal high waves, marine overwash and high winds, and tsunami inundation. These hazards may achieve a high level of severity in a relatively short time. Long-term sea-level rise and beach erosion do not constitute a life-threatening hazard, although they certainly may exacerbate the others. The dynamic hazards constitute a greater risk and thus are assigned an additional weighting factor of x2, after they are squared. The sum of the squared and doubled values are averaged and the resulting value is used to assign a nominal overall hazard rank with the following guidelines:

Rank	OHA	Level
1	2-4	Very Low OHA
2	4-8	Low OHA
3	8-12	Moderate to Low OHA
4	12-16	Moderate OHA
5	16-20	Moderate to High OHA
6	20-24	High OHA
7	24-28	Very High OHA

Report Structure

The main body of this report presents an island by island review of coastal hazards. Each island is given its own chapter beginning with a general introduction that presents a brief but informative review of each hazard. The centerpiece of the discussion is a series of historical summary maps describing the intensity, date, and known consequences of island hazard history. These maps are provided in color as a means of optimizing the relative information, yet they readily reproduce to black and white for ease of distribution.

The second section of each chapter provides technical maps of relative hazard intensity. More than 120 maps have been constructed that depict relative hazard intensity, coastal geology and slope, and the Overall Hazard Assessment, which is a weighted average of all seven hazards (as previously discussed).

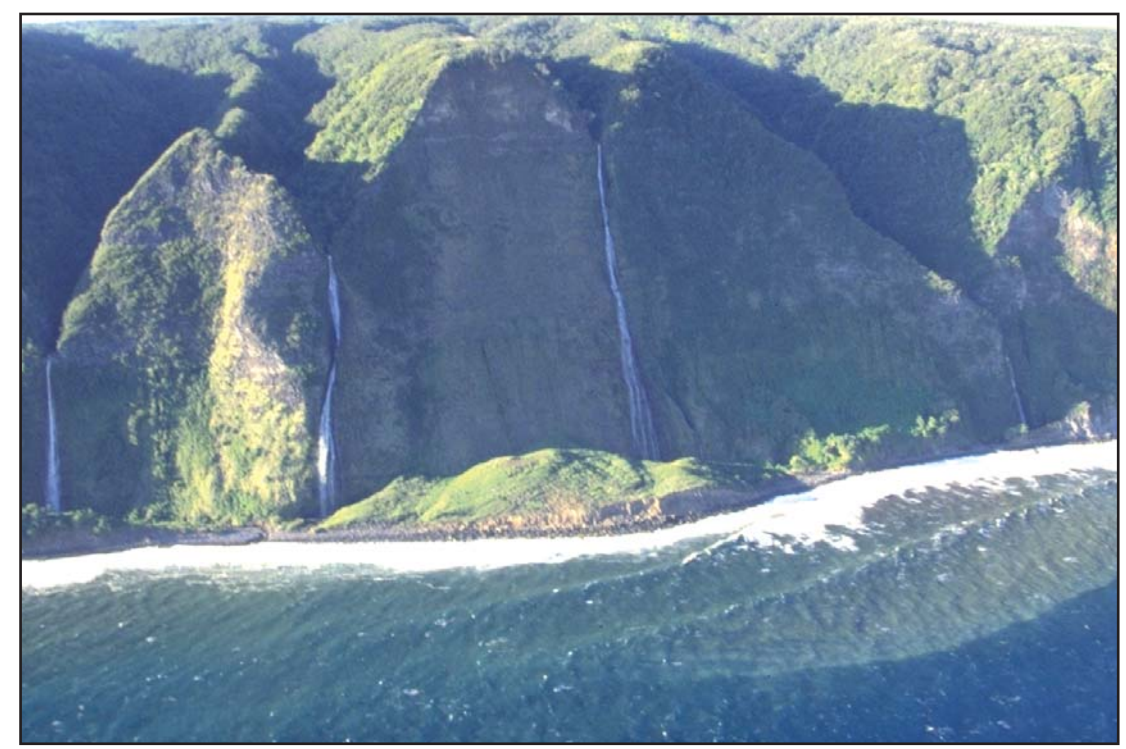
Notes on Specific Hazards

The following discussion details the assumptions, limitations, and variables that influenced our ranking determinations and the mapping of coastal geology and coastal zone slope. Although understanding the technical mapping format may initially require a period of familiarization, once learned, each map embodies a large amount of detail and becomes a rapid and ready source of information.

Coastal Slope

The coastal-slope ranking assignments are made for the coastal plain in the elevation range of 0 to 200 ft above sea level. In many locations, a steep coastal headland or cliff less than 200 ft high presents an effective barrier to inland storm overwash, tsunami inundation, erosion, stream flooding, and sea-level rise. Because this mitigates against the highest hazard ranking for those processes it is assigned the highest slope value (no. 3) even though it is less than 200 ft high. In other words, in such instances we have mapped the effective coastal slope, which is often not the average slope of the first 200 ft but instead is the slope of the effective portion of the coast with regard to hazard mitigation.

Technical maps, showing intensity rankings, depict the coastal zone slope in one of three shades of brown (see technical map example, p.3): the darkest shade (no. 1) indicates a gentle slope with a gradient less than or equal to 20% (<11.5°); the middle shade (no. 2) indicates a moderate slope with a gradient greater than 20% and less than 45% (>11.5° and <26.7°); the lightest shade (no. 3) indicates a steep slope with a gradient greater than 45% (>26.7°). We use the darkest shade for the gentlest slope because it is more hazardous than a steep slope with regard to stream flooding, tsunami inundation, storm overwash, erosion, seasonal wave hazards, and sea-level rise. This is in keeping with the color ranking system wherein greatest hazard intensity is mapped with the darkest shade.



The Hamakua shoreline, on the northeast coast of the Big Island, displays both gentle and steep coastal zone slopes.

Geology

The geologic framework of the Hawaii coast is complex and exhibits frequent changes and a variability in detail that is not fully mappable at a 1:50,000 scale. Our determinations of coastal geology are broad based and generalized, incorporating those features that are important in assigning hazard severity rankings. These features have lengths greater than 1000 ft in most instances.

The coastal geology was mapped in a field program using aerial videotapings of the Hawaiian coastal zone from an elevation of 300-500 ft, at an airspeed averaging 70-100 knots. These tapes are available from the Office of State Planning. They provide an excellent and detailed archive of the Hawaiian coastal environment in late 1993.

We recommend that a more comprehensive geologic mapping research program be implemented to determine those variables that may play an additional role in hazard severity such as risk from slope instability, grain size variations that may control oil spill clean-up efforts, freshwater discharge sites that modify reef character and coastal sedimentology, channel systems in fringing reefs that allow high onshore wave energy, rocky sectors of shoreline that may be seasonally exposed by shifting sands, and other geologic variables. We have used the developed shoreline designation (D) to identify coastlines stabilized with revetments and seawalls. Fringing reef (fr) includes seafloor in the coastal zone supporting a shallow reef platform.

Geologic features (Table 2) are depicted using an alpha code with the dominant geology capitalized and associated secondary geologic features in lower case:

TABLE 2
Geology

(Upper Case = primary feature)

B -	sandy beach, may include minor amounts of beachrock
R -	low-lying rocky shoreline (beachrock, boulder beach basalt, or limestone), may include a perched beach above high-tide line on a rocky platform
S -	prominent stream mouth (including adjacent areas subject to stream flooding)
H -	steep and rocky headland, often with a boulder beach or debris cone at its base
D -	developed shoreline, often where former beach has been lost to seawall construction or former natural environment cannot be determined due to urbanization

(lower case = secondary feature)

fr -	fringing reef adjacent to shoreline
br -	barrier reef (only one barrier reef is found in Hawaii; it is along the seaward margin of Kaneohe Bay, Oahu)
e -	embayed coast, designates pocket beaches, narrow embayments, and coast leeward of prominant headlands
w -	wetlands, designates coasts with adjacent terrestrial wetlands and ponds
d -	development is a secondary feature of the shoreline
s -	stream mouth is a secondary feature of the shoreline

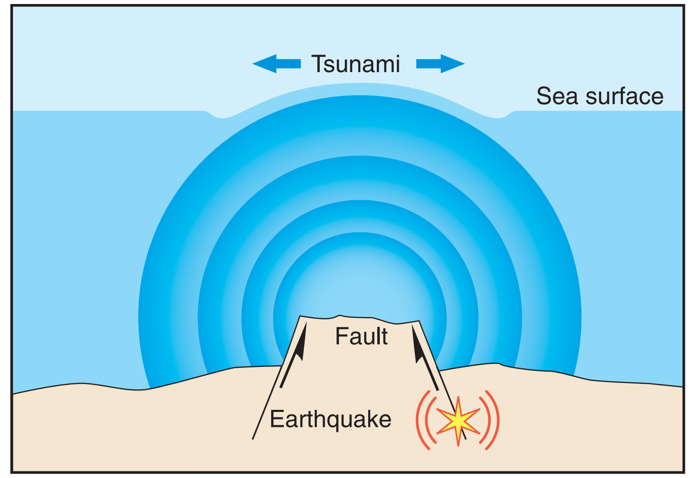
The Diamond Head and Waikiki coast on Oahu is an example of a developed coastal plain with beaches and a broad fringing reef tract (D/Bfr).

Along the Hamakua and Upolu coasts of the Big Island, embayments comprised of a stream mouth and beach (S/Be) are often interspersed between steep headlands (H).

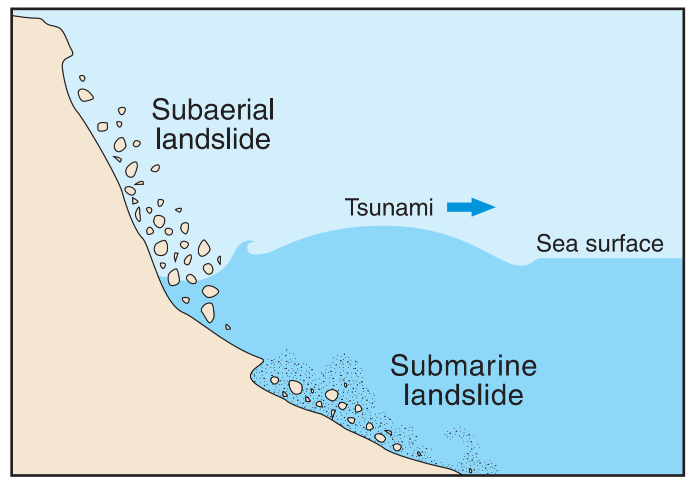
Tsunamis

Tsunamis are caused by a sudden movement of the seafloor that generates a wave, or actually a series of waves, that travel across the ocean until they reach a coast. Seafloor movements may include faulting, landsliding, or submarine volcanic eruptions. Submarine faulting, often consisting of the vertical movement of a block of oceanic crust, may cause the seismic tremors that are known as earthquakes. The tsunami, then, is the result of the faulting, not the earthquake. Landslides originating either under the sea or above sea level and then sliding into the water may also generate a tsunami. On July 9, 1958, a massive rockslide at the head of Lituya Bay, a fjord in Alaska, produced a tsunami that surged more than 1,700 ft up an adjacent hillside. It is thought that large tsunami were generated from time to time during the early history of the Hawaiian Islands when massive portions of the young islands slid into the sea. Tsunami are also caused by explosions or sudden seafloor movements related to submarine volcanism. The violent explosion of the island volcano Krakatoa in 1883 produced tsunami waves 130 ft high on the shores of Sumatra and Java, killing over 36,000 people in all. The high degree of volcanism and seismic instability in and around the Pacific Ocean have led to a long history of tsunami occurrences. Because this is one of the most geologically active regions on Earth, the Hawaiian coast is under the continuous threat of tsunami inundation.

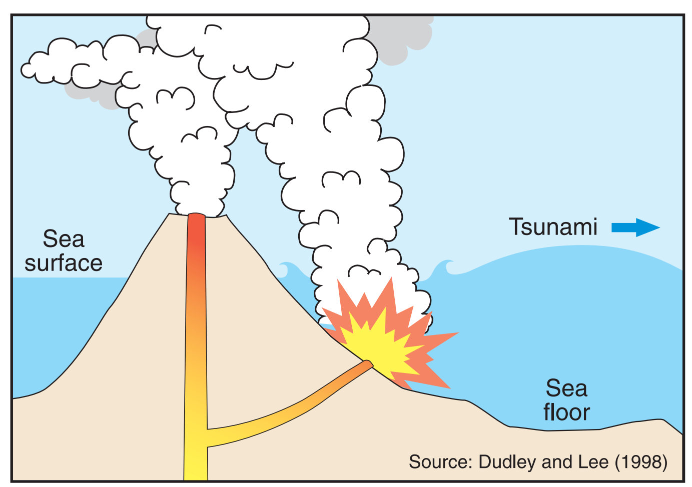
Submarine faulting, landslides, submarine slides, and submarine volcanism are common geologic processes in Hawaii, and all are capable of generating hazardous tsunami. In addition, these processes acting on coastlines around the Pacific have historically produced tsunami that traveled to Hawaii resulting in massive damage and loss of life.



Faulting of the ocean floor may produce a tsunami.

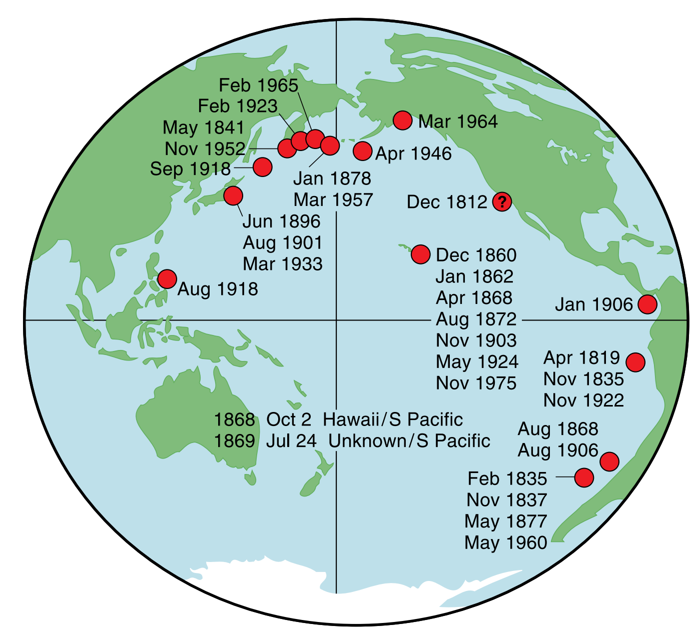


Subaerial or submarine landslides may produce a tsunami.



A submarine volcanic explosion may produce a tsunami.

Laupahoehoe Peninsula, north of Hilo on the Big Island, experienced waves 30 ft high during the Aleutian tsunami of 1946. Twenty-one people lost their lives here, 16 school children and 5 teachers. Statewide 159 people died in the disaster.



Tsunami-generating earthquakes in the Pacific basin and their epicenters (red dots).

Tsunami pose a significant hazard in the Hawaiian coastal zone. According to Dudley and Lee (1998) Hawaii has experienced a total of 95 tsunami in 175 years (1813-1988), however, for our analyses we have adopted the listing of Lander and Lockridge (1989). The last truly large seismic sea wave was in 1960. Tsunami manifest themselves as either large breaking waves, often largest around headlands where they are concentrated by wave refraction, or as rapidly rising sea level like a flooding tide. The geography of the shoreline often plays an important role in the form of the tsunami. Unlike storm waves, tsunami waves may be very large in embayments, actually experiencing amplification in long funnel-shaped bays. Fringing and barrier reefs appear to have a mitigating influence on tsunamis by dispersing the wave energy. Within Kaneohe Bay, Oahu, protected by a barrier reef, the 1946 tsunami reached only 2 ft in height, while at neighboring Mokapu Head the wave crest exceeded 20 ft. Despite complex differences in the geography and orientation of Hawaii's many coastlines, several locations have historically been subject to severe tsunami impacts, including Hilo Bay, Hawaii; Kahului Bay, Maui; and Kakiaka Bay, Oahu.

At sea level on the coast there is no safe place during a tsunami. On low-lying shorelines such as in the river and stream valleys that characterize so much of Hawaii, a tsunami may occur as a rapidly growing high tide that rises over several minutes, perhaps 10 minutes, and inundates low coastal regions. The return of these flood waters to the sea causes much damage. At headlands the refractive focusing of the wave crest leads to energy concentration and high magnitude run-up. Our intensity definitions are conservative. With an historical run-up height of approximately 10 ft (3 m above low tide) and a gentle to moderate coastal zone slope, in the absence of mitigating factors we assign our highest intensity (no. 4) to the tsunami hazard. Mitigating factors include large headlands, barrier or broad fringing reefs, and protective structures such as the jetties and breakwaters found in Hilo and Kahului harbors. The ranking of 3 is assigned to localities where there may be a history of high tsunami run-up, but little chance of damage because of the presence of an exceedingly steep slope preventing building development. Our 10-ft criteria is guided by the minimum overwash elevation during Hurricane Iniki that produced significant damage to the first row of dwellings. This is also a reasonable estimate of the elevation of many beachfront homes and structures in Hawaii.

Stream Flooding

Coastal stream flooding is only ranked in the immediate coastal zone, up to the 200-ft contour. In certain localities, such as eastern Maui, the Big Island Hamakua coast, and north Kauai, streams hang above the sea in valleys that discharge as waterfalls rather than as tidal stream mouths. Although these localities may be susceptible to flooding, we have not ranked them as high hazard sites because they are not at sea level and the flooding hazard is a terrestrial process rather than a coastal process.

The hazard ranking for stream floods depends on a number of factors including the history of flooding at the site, coastal zone slope, the seasonal rainfall in the adjacent watershed, and the level of mitigation by the Army Corps of Engineers and/or the county public works departments. The highest intensity ranking is applied to low-lying streams with high rainfall watersheds (seasonal monthly max. >7.9 in [200 mm]) where an historically high level of flooding has occurred, and where no mitigation improvements have been attempted since the most recent damaging flood. Lower rankings are based on flood history, watershed climatology, and mitigation levels.

In 1983 the Department of Land and Natural Resources (DLNR) reported that floods in Hawaii had claimed more than 350 lives and caused more than $475 million in damages. Planning for flood control strategies requires a consideration of accommodating development in flood-prone regions through measures such as building code requirements, land use regulations, relocation, and emergency evacuation. In addition, an approach consisting of mitigants such as levees and dikes, improved channels, flood water storage structures and other types of drainage diversion features are employed. Together these two approaches constitute the flood control and flood plain management approach typically utilized by regulatory authorities. Little effort has been made by authorities to lessen the impact of these mitigations on riverine and paludal ecosystems. In fact, little is known of the long-term degradation to both freshwater and coastal saltwater ecosystems that results from the widespread use of flood control techniques (Hawaii Stream Assessment, 1990).

Floods caused by heavy rainfall and strong winds normally occur during the winter months with January typically being the most frequent flood period. Heavy rainfall can also be associated with the tropical storm and hurricane season between the months of June and October. Areas subject to recurrent rainstorm floods are the coastal plains and flood plains of Maui, Kauai, and Oahu. Flooding tends to be less intense by comparison on Hawaii, Molokai, and Lanai. Lanai, lying in the rain shadow of Molokai receives relatively less precipitation. Molokai is relatively unpopulated and the town of Kaunakakai has adequate flood control measures so that flood damage on the island is effectively reduced. The sparse population in the humid regions of Molokai presently reduces the flood hazard, but is no guarantee for the future. On the Big Island, regions of high precipitation are characterized by deep valleys that effectively channelize floodwaters. Elsewhere, the high porosity of the geologically young lavas are a deterrent to frequent flooding. Hilo is susceptible to periods of heavy rainfall and may experience flooding on the low coastal plain. Exceptionally heavy flooding from intense rainfall in the Hilo area in November 2000 led to a declaration of a state of emergency. Damage to bridges and roadways reached $20 million.

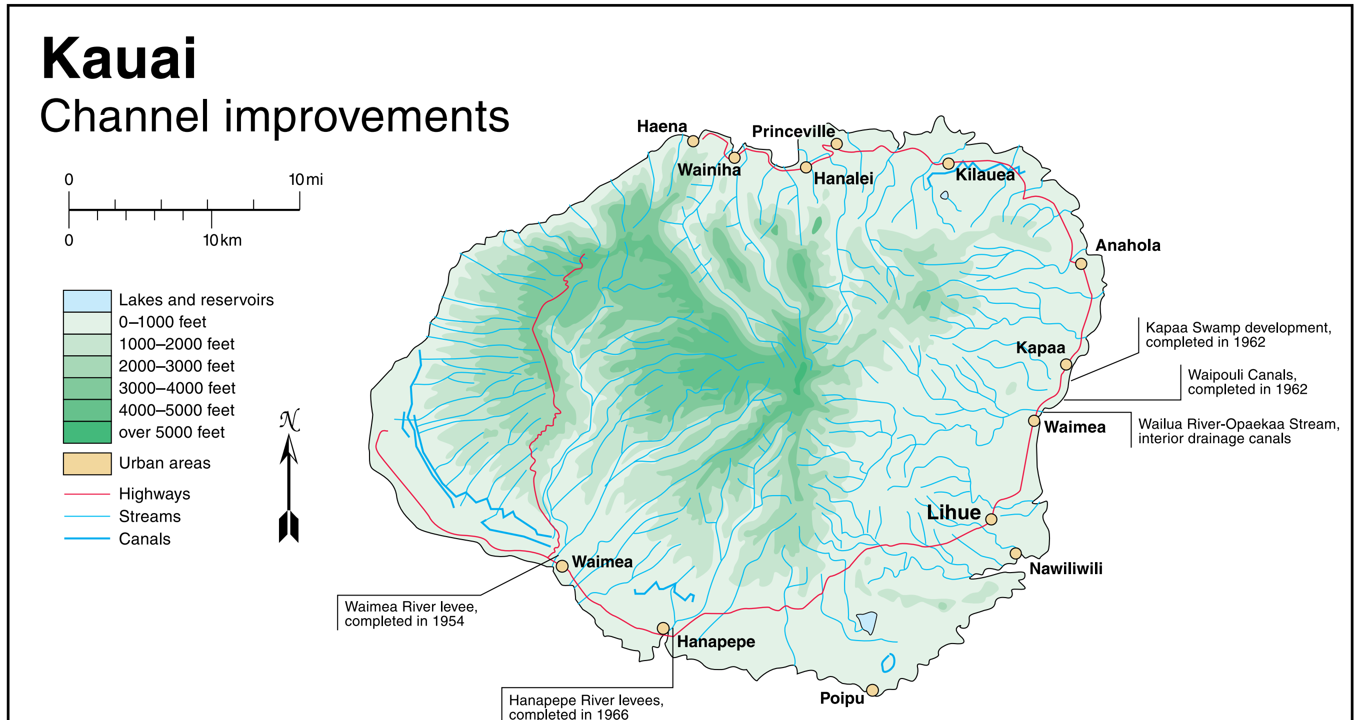
Table 3 is an unofficial tabulation of flood damages and lives lost for the state derived from the 1983 DLNR Report on Floods and Flood Control and the monthly Storm Data publication of the National Climatic Data Center, National Oceanic and Atmospheric Association (NOAA) (visit their web site at http://www.ncdc.noaa.gov/ol/ncdc.html). These data provide an effective summary of the severity of the flood hazard in Hawaii.

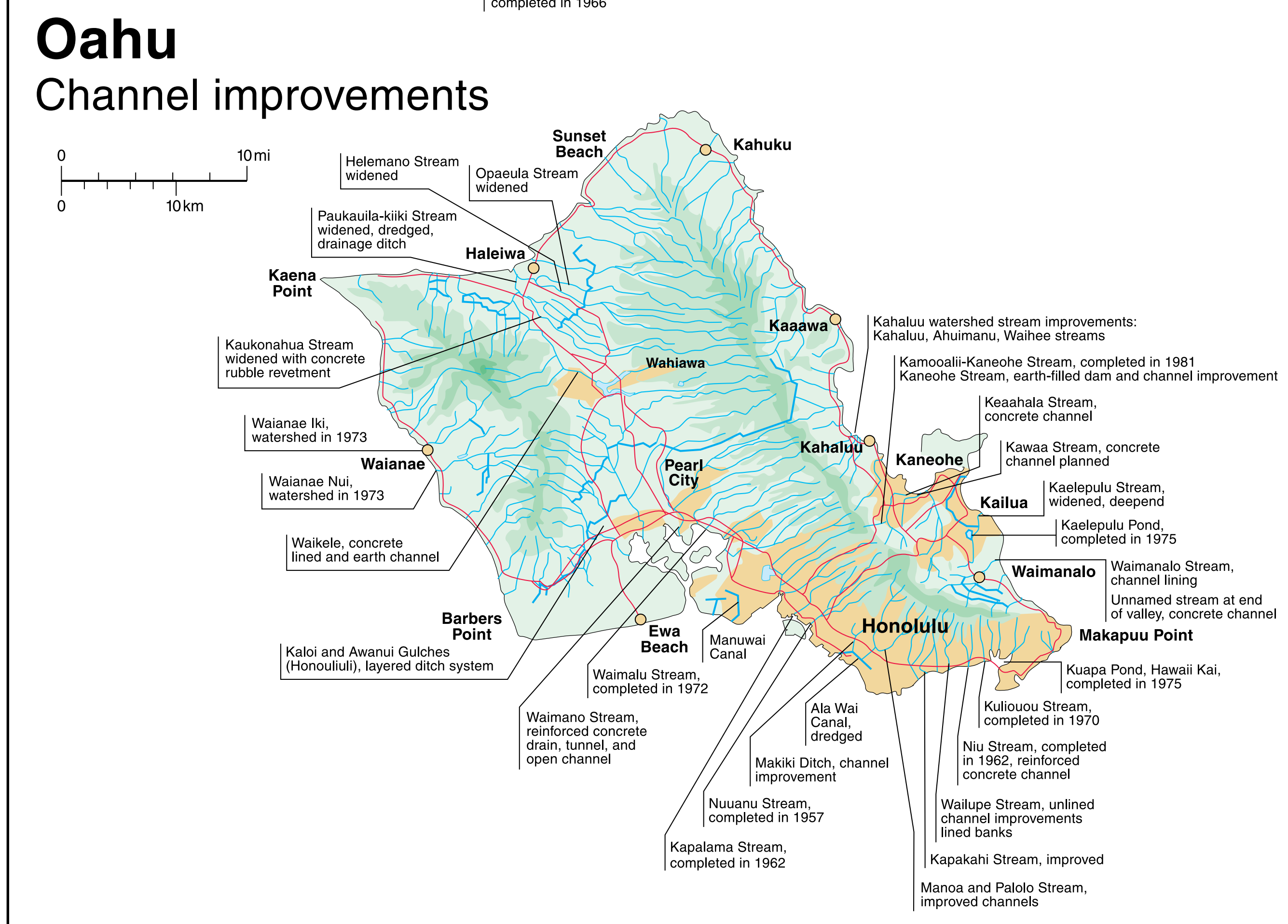
Heavy rainfall combined with an abrupt transition in coastal slope often leads to coastal stream flooding in Hawaii's low-lying coastal zones including Hanalei, Kauai.

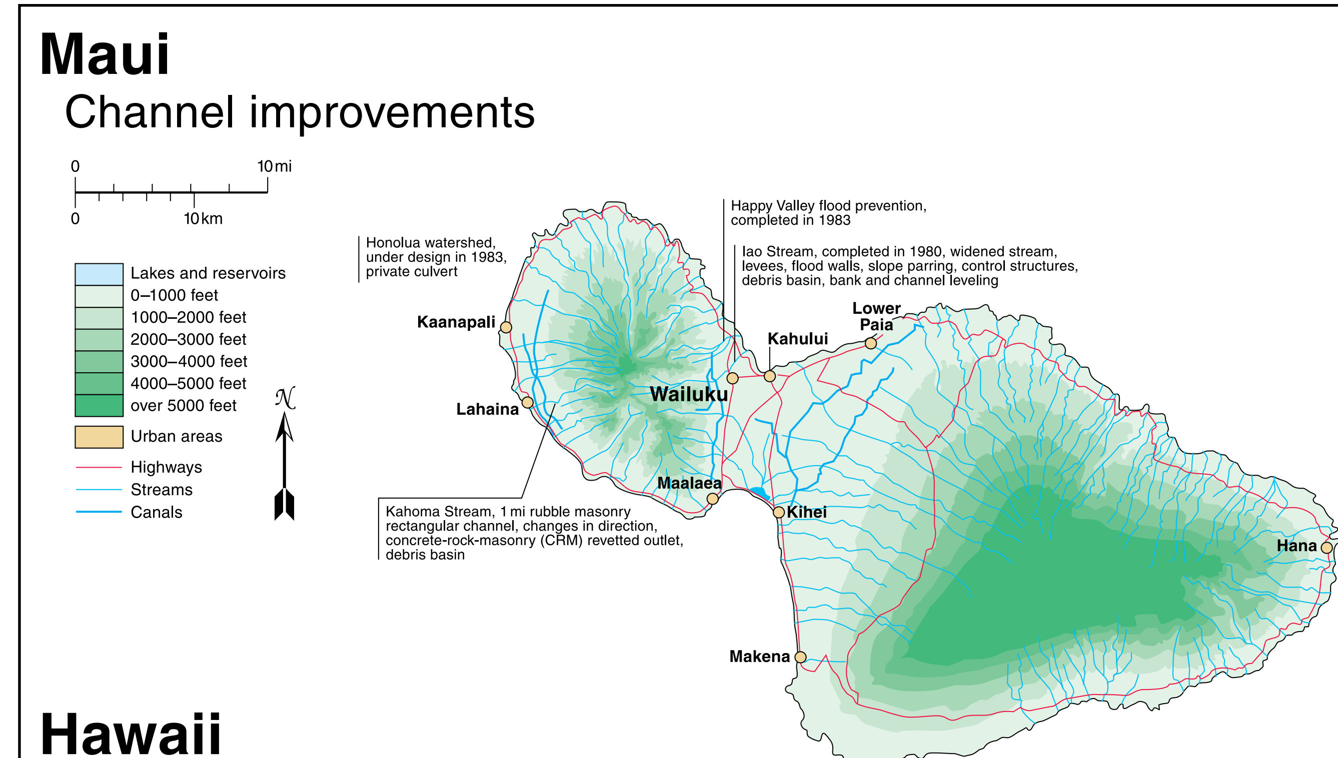
TABLE 3
Major Stream Floods and Damages, 1915-1998 (- , no data available)

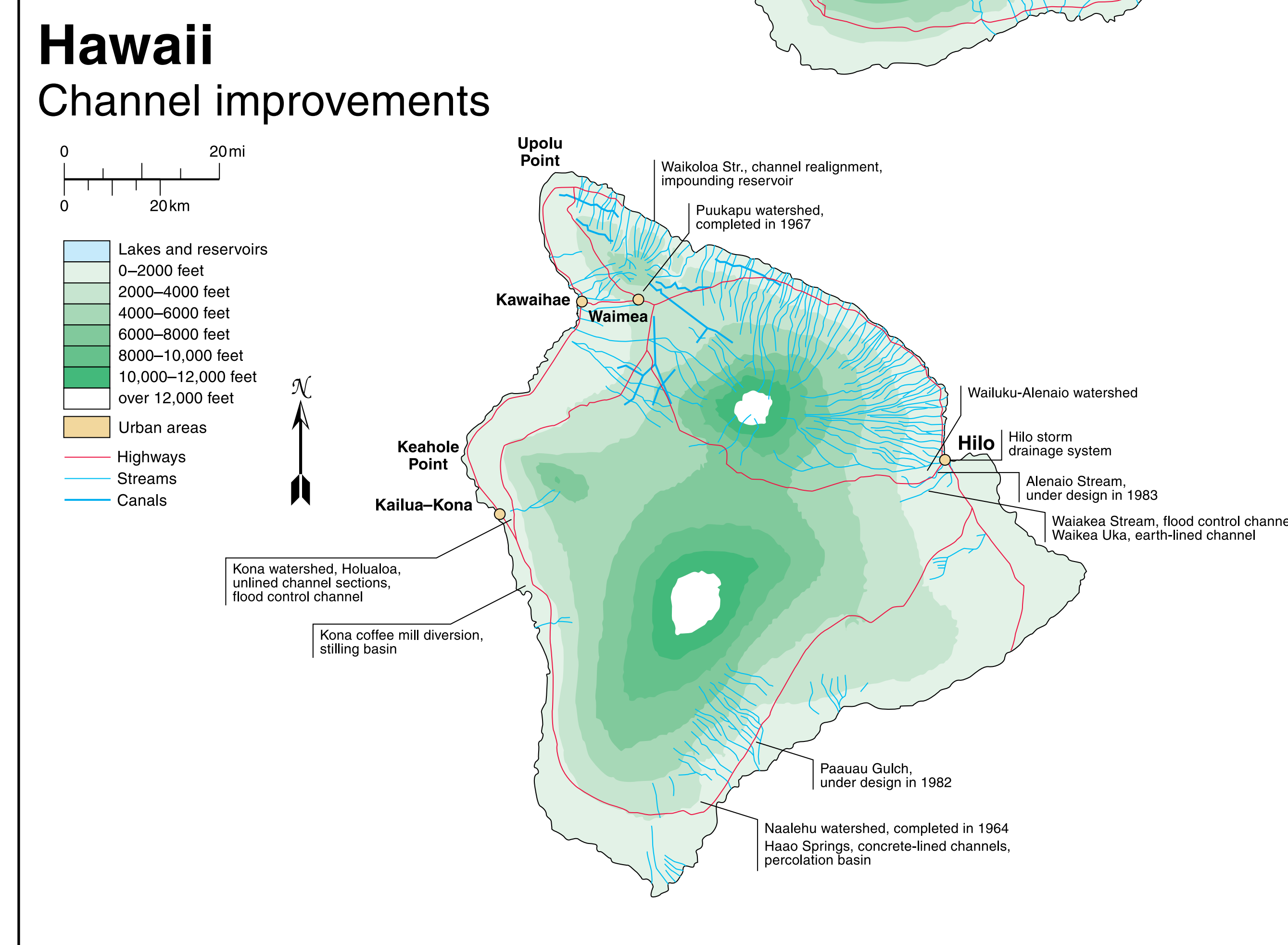
Date	Statewide Lives Lost	Location	Damages 1998 $	Cause
1915	10	Statewide	-	Cloudburst
1/14/1916	-	Iao Stream, Maui	$250,000	Heavy rains
1/17/1916	16	Statewide	$1,000,000	Heavy rains
1917	3	Statewide	-	Heavy rains
1/16/1921	4	Honolulu	$500,000	Heavy rains
1922	1	Statewide	-	Heavy rains
1927	5	Statewide	-	Heavy rains
1928	1	Statewide	-	Heavy rains
1929	1	Statewide	-	Heavy rains
11/13/1930	30	Kalihi, Moanalua, Halawa Valleys, Oahu	-	Heavy rains
1932	3	Statewide	-	Rainstorm
2/27/1935	14	Oahu	$1,000,000	Severe rainstorm
1938	2	Statewide	-	Severe rainstorm
1/4-5/1947	1	Hawaii, Maui, Oahu	$2,200,000	High seas
1/23-26/1948	1	Hawaii, Maui, Oahu	$250,000	Strong winds and rainstorm
1/15-17/1949	4	Kauai, Oahu	$550,000	Intense Kona storm
11/30/1950	4	Maui, islandwide	$322,120	Heavy rains
3/26-27/51	1	Oahu	$1,303,000	Heavy rains and strong winds
1/21/1954	2	Oahu	$500,000	Heavy rains and strong winds
11/27-28/1954	-	Kauai, Oahu	$810,000	Heavy rains
12/19-21/1955	7	Statewide	-	Kona storm*
1/24-25/1956	1	Wailua, Kauai, Oahu, Hawaii	$700,000	Heavy rains
2/25/1956	-	Sunset Beach, Oahu	$250,000	Flash flood
2/7/1957	2	Honolulu, Waimanalo, Aina Haina, Oahu	$400,000	Flash flood
12/1/1957	-	Kauai, Oahu, Maui, Hawaii	$1,056,000	Hurricane
3/5/1958	-	Oahu	$500,000	Heavy rain
8/6-7/1958	2	Oahu, Maui, Hawaii	$552,000	Heavy rain, strong wind, high seas
1/17-18/1959	-	Oahu, Molokai, Maui, Hawaii	$1,393,000	Heavy rain, strong wind, high seas
8/4/1959	2	Kauai, Oahu, Maui, Hawaii	$11,524,000	Hurricane
5/12-13/1960	-	Oahu, Maui	$250,000	Kona storm
4/2-4/1961	-	Hawaii	$1,744,000	Heavy rains
10/27/1961	1	Oahu, Maui, Hawaii	$2,045,731	Heavy rain, strong wind, high seas
10/31/1961	-	Molokai	$ 1,958,380	Heavy rains
11/1-2/1961	-	Lahaina, Maui	$1,600,000	Heavy rains
1/15-17/1963	3	Statewide	$790,000	Heavy rains, strong winds
4/15/1963	-	Kauai	$2,192,000	Heavy rains
5/14/1963	-	Pearl City, Oahu	$300,000	Heavy rains
12/19-23/1964	1	Statewide	$439,000	Heavy rains, strong winds, high seas
2/4/1965	-	Oahu, Molokai, Maui	$674,000	Heavy rains
4/25/1965	-	Hana, Maui	$288,000	Heavy rains
5/3/1965	-	Kahaluu, Oahu	$711,300	Heavy rains
11/10-15/1965	4	Oahu	$500,000	Heavy rains, strong winds
7/25/1965	-	Hilo, Hawaii	$660,000	Heavy rains
1966	2	Statewide	-	Heavy rains
12/17-18/1967	1	Kauai, Oahu	$1,354,850	Heavy rain, high seas, tornado
1/5/1968	-	Pearl City, Oahu	$1,243,000	Heavy rains
4/15-16/1968	-	Hana, Maui	$293,000	Heavy rains
10/3-4/1968	-	Hawaii	$735,000	Heavy rains
11/30-12/1/1968	-	Kauai	$427,000	Heavy rains
1/5/1969	-	Barking Sands, Kauai	$359,000	Heavy rains, strong winds
2/1/1969	-	Keapuka, Oahu	$705,100	Heavy rains
1/28/1971	-	Maui	$553,000	Heavy rains
1/28/1971	2	Kona, Hawaii	$1,766,550	Waterspout, tornado, heavy rains
4/19/1974	11	Kauai, Oahu, Maui	$3,868,300	Heavy rains
1/30-2/1/1975	-	Kauai, Oahu	$566,000	Heavy rains
2/5-7/1976	-	Oahu	$802,000	Heavy rain, high seas, strong winds
11/6-7/1976	2	Oahu	$270,000	Heavy rain and strong wind
1978	2	Statewide	-	Rainstorm
2/17-22/1979	-	Hawaii	$6,050,000	Heavy rains
11/15-28/1979	-	Hawaii	$3,752,720	Heavy rains
1/6-14/1980	-	Statewide	$42,578,000	Heavy rains, high seas, strong winds
3/14-26/1980	-	Hawaii	$4,320,1000	Heavy rains
10/28/1981	-	Waiawa Stream, Oahu	$786,350	Heavy rains
12/26-27/1981	-	Hawaii	$2,000,000	Heavy rains
11/23/1982	1	Statewide	$307,859,000	Hurricane,
12/31/1987-1/1/1988	-	Oahu	-	Heavy rains
7/21-23/1993	-	Statewide	-	Heavy rains, remnants of hurricane

*Kona storms are storms associated with the passing of mid-latitude fronts (low pressure) in the vicinity of Hawaii.









Stream channelization projects by the U.S. Army Corps of Engineers have provided important mitigation for much of the stream flooding hazard in populated regions of the Hawaiian coast. However, these have caused the loss of miles of natural ecosystems in wetlands and stream channels.

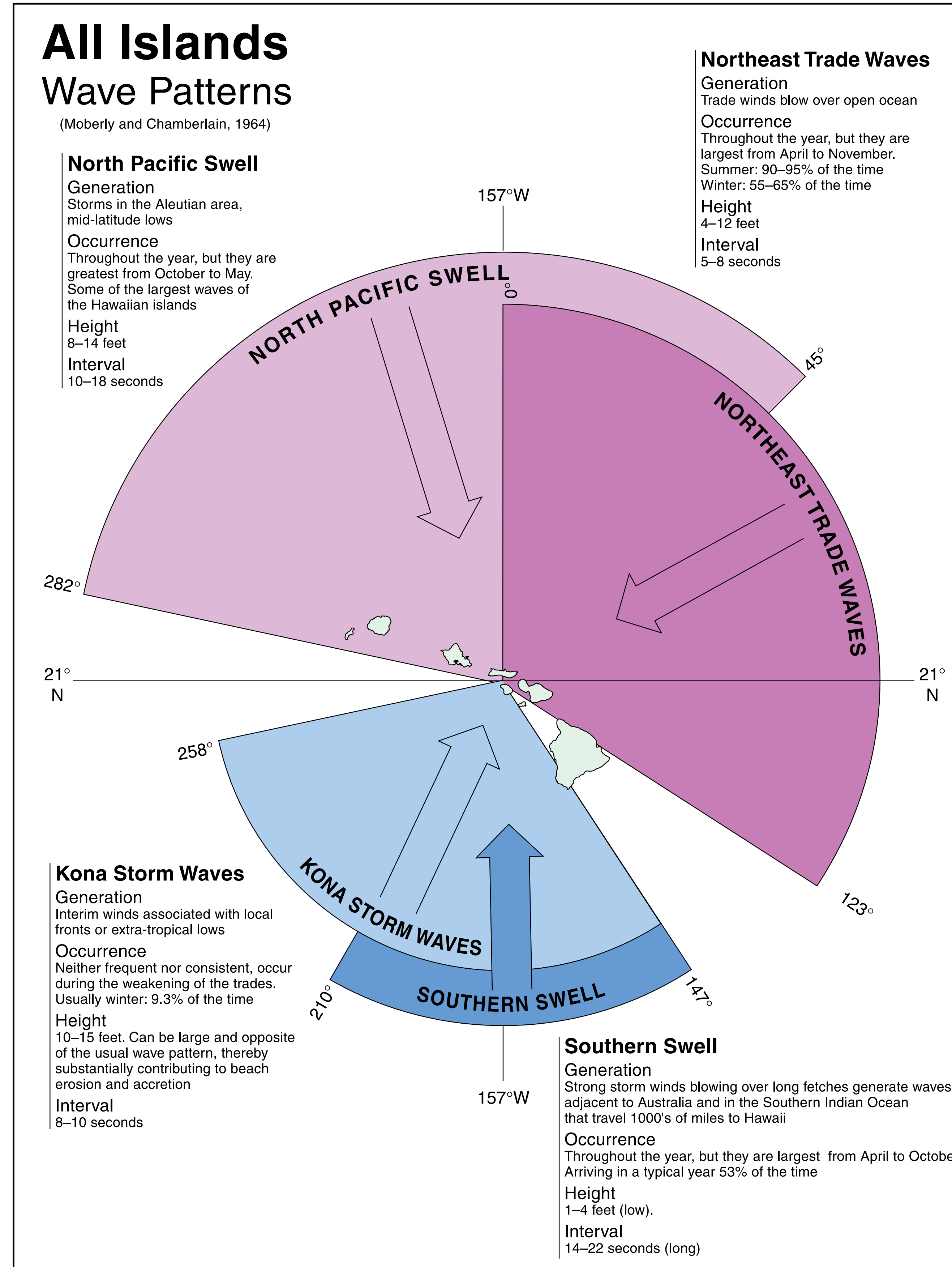
High Waves

Sudden high waves, and the strong currents they generate in the nearshore region, are perhaps the most consistent and predictable coastal hazard in Hawaii. They account for the greatest number of actual injuries and rescues on an annual basis than the other hazards. It has been said that picking intertidal molluscs (opihi) from coastal rocks is the number one hazard in the state. The Oahu Civil Defense Agency classifies high surf as a condition of very dangerous and damaging waves ranging in height from 10 ft to 20 ft or more. These waves result from open ocean swell generated by storms passing through the north and south Pacific Oceans.

Annually, waves that reach Hawaii's shores originate from four primary sources, north Pacific swell, northeast trade wind swell, south swell, and Kona storm swell. Hurricanes and tropical storms are also important sources of waves that impact Hawaii's coasts on an interannual basis. North Pacific swell deliver the highest waves annually (8-20 ft) with moderate- to long-wave periods (10-18 seconds), due to the high intensity and proximity of sub-polar and mid-latitude storms in the north Pacific. North swell occur throughout the year, but are most common between October and May and have the greatest impact on north-facing coasts. Northeast trade-wind swell range 4-12 ft in height ~70% of the year (April to November) and can reach slightly greater heights during intense trade-wind events that occur for 1-2 weeks each year. Because trade wind waves have short wave periods (5-8 seconds), they are only moderately energetic when they reach the shoreline. Waves from south Pacific swell travel great distances and have very long wave periods (14-22 seconds) and moderate wave heights (1-4 ft). Long-wave periods associated with south swell, however, translate into very energetic waves when they reach Hawaii's shores, especially along south-facing coastlines. South swell is most common between April and October, but occur all year. Waves from Kona storms, central Pacific storms associated with fronts passing just north of the main Hawiian Islands, are commonly very steep with moderate heights (10-15 ft) and short to moderate periods (8-10 seconds). Kona storm waves have the greatest impact on south- and west-facing coasts. Waves from hurricanes and tropical storms (June-November) can reach extreme heights (10-35 ft) and occur mostly on east-, south-, and west-facing coastlines, however, occasionally north-facing shores are impacted.

Our ranking no. 4 is reserved in most cases for north-facing shorelines where winter swell arrives with regularity in heights exceeding 12 ft (often exceeding 20 ft). Sets of these large waves are characterized by rapid onset so that within a few seconds they can double in size, often catching unaware swimmers, fishermen, and hikers walking along the shoreline. The water level on the coast increases with these sets of large waves and rip currents are generated as this excess water surges seaward. Although rip channels are used by experienced surfers as a free ride offshore, they are extremely hazardous for the tired swimmer to navigate. It is not unusual for lifeguards to perform a dozen rescues in one day under these conditions. Lower rankings of the wave hazard are based on reduced wave heights, such as swell generated by southern storms in the summer that can reach a height of 8 ft along south coasts. Ranking no. 2 typically characterizes windward coasts, which can have large waves of 6 ft, but normally do not exceed 4 ft, generated by hurricanes passing to the east of Hawaii. These are also hazardous to the uninformed who use the coast for recreation. The sad aspect of this hazard is that most injuries and drownings could be avoided if only the recommendations of lifeguards were more carefully heeded.

Annual high waves from both north and south swell are common in the Hawaiian coastal zone and pose a significant hazard, especially where they break at the shoreline.



Storms

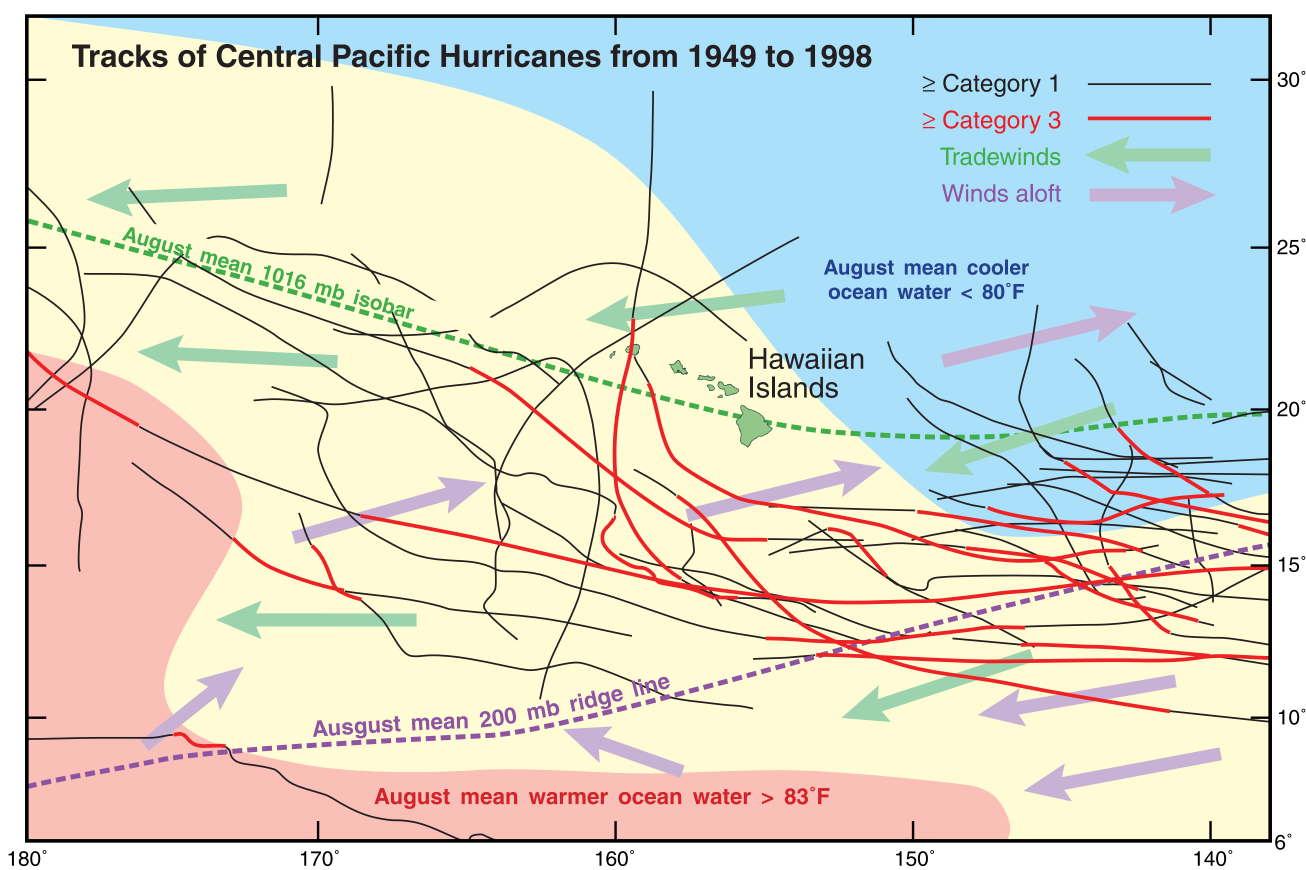
The extreme damage and economic loss associated with hurricanes Iwa (1982) and Iniki (1992) have increased the general level of public awareness of the threat from tropical cyclones (hurricanes, tropical storms, and tropical depressions) and Kona storms (storms associated with passing of mid-latitude low pressure fronts) in Hawaii. The damage and injury associated with these meteorological phenomena is the result of high winds, marine overwash, heavy rains, tornadoes, and other intense small-scale winds and high waves (Schroeder, 1993). Rather than ranking each of these phenomena separately, we have created a single category consisting principally of the overwash and high wind hazards related to storms.

Research by T.T. Fujita at the University of Chicago has identified the important role of dangerous high intensity, small-scale wind bursts during hurricanes in producing high levels of damage. Termed microbursts and mini-swirls, these localized winds may reach speeds in excess of 200 mph. In the wake of Hurricane Iniki, Fujita identified damage patterns and debris indicating that as many as 26 microbursts (sudden intense downdrafts) and two mini-swirls (a violent whirlwind, not a tornado) had occurred on the island of Kauai. In addition, it was found that downslope winds were more damaging than upslope winds. Mitigation against such high winds is difficult, but numerous and relatively simple construction and retrofit techniques (FEMA Construction Manual) can significantly increase the ability of a building to withstand hurricanes.

Our historical knowledge of tropical cyclones in the central Pacific is a direct function of technology (Table 4). Samuel Shaw of the Central Pacific Hurricane Center has written a comprehensive survey of documented tropical cyclones (of all intensities) over the period 1832 through 1979 (Shaw, 1981). Using written accounts of various observers he records nineteen storms over the period 1832-1949 and seventeen storms between 1950 and 1959. By 1960 early satellite data became available and thirty-four tropical cyclones were identified between 1960 and 1969. The following decade (1970-1979) again produced thirty-four identified tropical storms in the central Pacific, and during the decade of the 1980's (1980-1989) the number increased to fifty-three storms. Between 1970 and 1992, 105 tropical cyclones have been identified in the central Pacific region at an annual average of 4.5 storms (Schroeder, 1993). Damaging hurricanes and tropical storms that have affected the Hawaiian islands are listed in Tables 5 and 6.

Of course not all of these storms intersect Hawaii, and actual hurricane strikes on the Hawaiian Islands are relatively rare in the modern record (Schroeder, 1993). More commonly, near-misses that generate large swell and moderately high winds causing varying degrees of damage are the hallmark of hurricanes passing close to the islands. Impacts from these can be severe and lead to beach erosion, large waves, high winds, and marine overwash despite the fact that the hurricane may have missed the island. Communities on the Waianae coast of Oahu suffered severe damage from hurricanes Iwa and Iniki, yet neither of these storms actually hit Oahu. Indeed, the highest wind speeds recorded during Iwa were in windward Oahu where a line of squalls spawned by Iwa on the leeward side moved over the Koolau Range and accelerated down the Pali in a waterfall effect ripping the roofs off homes in Kaneohe. Thus, storms on one side of an island may have significant impact on the other side.

It is commonly believed from recent history that Kauai lies in a more vulnerable position than the other islands. However, in his recent analysis of Hawaiian hurricanes, Dr. Tom Schroeder of the University of Hawaii, Meteorology Department, concludes that every island has been affected by hurricanes and that no island is without risk. The randomness of nature plays a key role in which islands are at highest risk during any given hurricane. In 1988, Hurricane Uleki was poised to hit Oahu or Maui but passed to the south. Hurricane Iniki in 1992, could have hit Oahu or missed the islands altogether, but instead tracked right over Kauai. Tropical depressions and storms at various times have intersected the Big Island on windward, northern, and southern coasts. In the summer of 1993, tropical storms (formerly hurricanes) Fernanda and Eugene passed along both the windward and leeward coasts of all islands within three weeks of each other, clearly demonstrating that either side of any island might have sustained a direct hit had these storms been diverted by a shift in the large-scale atmospheric flow.



Hurricanes in the Central Pacific (140° W to 180 ° W) generally travel from east to west, however, some including Hurricanes Iwa (1982) and Iniki (1992) track in a northerly direction. (mb, pressure in millibars).

TABLE 4
Total tropical cyclones in the central Pacific 1970-2000

Year	Total Storms
1970	5
1971	5
1972	7*
1973	2
1974	3
1975	1
1976	4*
1977	0
1978	7
1979	0
1980	2
1981	2
1982	10*
1983	6
1984	5
1985	8
1986	7*
1987	4
1988	5
1989	4
1990	4
1991	3
1992	11*
1993	5
1994	10*
1995	1
1996	0
1997	7*
1998	3
1999	3†
2000	4

138 storms in 31 years. [*- El Niño onset year; † - third storm died soon after entering central Pacific waters] (source: Schroeder, 1993; National Weather Service, Storm Reports, 2000)

TABLE 5
Hurricanes in the Pacific that affected Hawaii since 1950

Year	Date	Name	Track	Closest island	Wind average (mph)	Wind gust (mph)	Low BP (mbar)	Rate of travel (kts)	Eye (nmi)	Rain (in)	Stream	Marine surf (ft)	Tidal surge (ft)	Max. run-up (ft)	High water (ft)	Type of damage	Damage (1998 $)	Comments
1993	8/16	Fernanda	WNW, Disintegrated 400 mi E of Oahu	Hawaii	105	125	*970	10-15		Locally heavy		10-15				Hawaii: 3 small boats broke their moorings, high waves closed roads in Hilo and Puna, 1 home damaged by water. Oahu, Windward side (Kaaawa): some coastal flooding, debris on highway. Maui, Molokai: High waves, 1 house damaged on E Molokai.		Hurricane warning issued for Hawaii.
1992	9/11	Iniki	S-N, passed just W of Port Allen, crossed over Kauai	Kauai	130	160	945			Heavy	No flooding	20-35	4.5-6.2	26.3	18.5	Kauai: 1,421 houses destroyed, 13,000 homes with minor to heavy damage, 3 people dead. Oahu: Some flood/wind damage SW shore. Hawaii: Twelve houses damaged by surf.	$500M–$5B	Strongest and most destructive hurricane to hit islands in this century. Sixth costliest hurricane in U.S. history. $1.8 billion in damage to Kauai alone.
1991		Fefa				105										Maui: SW shoreline hit by surf.		
1989	7/17-7/21	Dalilia	NW, passed 100 mi S of Hawaii	Hawaii	75		989					10-15				Hawaii, S shore: 40 kts. Wind downed trees and powerlines, rains caused minor flooding. Oahu, Kauai: Heavy rain (1.5-9 in), esp. NE shores.		
1988	8/28-8/29	Uleke	NW, passed S, threatened			120						High				Oahu: High surf along S shores. Kauai: Two people drowned.		
1988	8/2-8/9	Fabio	W, passed south of Hawaii	Hawaii		125				12-18		High				Hawaii: High surf along SE, heavy rains.		Heavy rains
1986	7/21-7/25	Estelle	W, passed S		132			20				10-20				Hawaii: 10-20 ft surf and 50 mph winds demolished 5 houses, SE shores evacuated. Oahu: Two drowned. Maui: Stretch of dirt road washed away.	$2M	Steadily weakened as she directly aimed at Hawaii.
1985	10/23-10/29	Nele	S-N, then W, passed S	Kauai								10				Kauai: 10 ft surf S shore, esp. Poipu.		
1985	9/9	Rick	N, passed to the NE	Hawaii								Minor swell						
1985	9/5-9/9	Pauline	W, turned N, passed E of Hawaii	Hawaii				10				10-15				Hawaii: 15 ft surf along Puna and Kau, debris on roads. All Islands: High surf on E shores.		Hurricane watch was issued.
1985	7/21-7/26	Ignacio	NW, passed to the S	All								10-15				Hawaii, Maui: 10-15 ft surf on SE shores, some road/structure damage.		
1983	10/14-10/20	Raymond	NW, passed over islands as Tropical Depression	Molokai	138	167	968			1-2		10-15				Maui, Molokai, Oahu: 1-2 in rain. Hawaii: 10-15 ft surf on Kalapana and Kaimu.		Posed a serious threat to Hawaii, but weakened.

[BP, barometric pressure; mph, miles per hour; mbar, millibars; kts, knots; nmi, nautical miles; in, inches; ft, feet; $, dollars; M, million; B, billion]

TABLE 5 (continued)
Hurricanes in the Pacific that affected Hawaii since 1950

Year	Date	Name	Track	Closest island	Wind average (mph)	Wind gust (mph)	Low BP (mbar)	Rate of travel (kts)	Eye (nmi)	Rain (in)	Stream	Marine surf (ft)	Tidal surge (ft)	Max. run-up (ft)	High water (ft)	Type of damage	Damage (1998 $)	Comments
1982	11/23	Iwa	NE, passed NW of Kauai	Kauai	92	126	964	18		3-6.5	No flooding	20-30	5-6	600 ft		Kauai: Flooding from Kekaha to Poipu, 67% damage. Oahu: Flooding from Makaha to Koko Head, 1 dead as ship was hit by 30 ft wave, 30% damage. 465 houses demolished, 1,712 damaged. 1 dead. No damage for Maui, Hawaii, Molokai, Lanai.	$312M	Kauai, Oahu, Ni'ihau federal disaster areas. Most destructive hurricane to date, 1,591 acres flooded in state.
1978	7/17-7/28	Fico	WNW, passed 175 mi S of South Point	Hawaii	115		955	10	30			30				Hawaii: 30 ft surf caused heavy damage. Other Islands: 8-12 ft surf, 65 ft tugboat went aground, brought 6 in rain to Oahu.		
1978	6/26-7/3	Carlotta								6								
1976	9/19-10/1	Kate	NW, passed NE of Hawaii	Hawaii								8-15				Hawaii, Maui, Oahu: 8-15 ft surf NE shores.		
1972	8/18-9/3	Fernanda	WNW, passed 150 nmi NE of Hawaii	Hawaii		115										Hawaii: Flash food in Waipio Valley, high surf damaged 3 small boats.	$2,000	
1972	8/2-8/22	Celeste	W, passed S of islands	Hawaii	138		943	6	22			High						
1972	8/8-8/20	Diana	NW, passed 300 mi E of Hawaii	Hawaii		63	982			8-10	No flooding	30	4-5			Hawaii: 30 ft surf struck Puna, 4 houses swept off, 1 flooded, overwash, road damage. Maui: 6 in rain, 20 ft surf eroded Hanoa Beach.		
1971	7/2-7/13	Denise	WNW, passed 150 mi S of South Point	Hawaii			999.5	16	30	1						Hawaii: Heavy rains blocked Kuakini Hwy.		
1966	9/7-9/17	Connie	W, passed 120 mi S of Hawaii	Hawaii				5								Hawaii, Maui: Moderate to heavy rainfall		
1959	8/4-8/7	Dot	NNW, Eye passed over Kauai, then turned west	Kauai	75	165	984	9	20-30	5						Kauai: Agricultural losses of $5.5-6M,100's houses, trees damaged, coastal areas flooded. Oahu, Hawaii: Minor wind, flood damage.	$5-6M $150,000	Eye over Kauai.
1957	11/30-11/31	Nina	NNW, passed south of Kauai	Kauai	92			8		21		35				Kauai: 20 in rain in 14 hrs, 12 homes damaged by 35 ft surf. Oahu: 3 fisherman missing, some damage. All Islands: High winds.	$1,056,000(?)	
1957	9/1-9/17	Della	NW, passed 300 mi SW of Kauai	Kauai				6	16							Kauai: 16 ft surf at Nawiliwili.		
1950	8/12-8/16	Hiki	WNW, passed 120 mi NE of Kauai	Hawaii	68	90	982.7	5	20-25	52	Waimea R flood					Kauai: 52 in rain over 4 days, flooding. Maui: 12 in rain, flooding.		

[BP, barometric pressure; mph, miles per hour; mbar, millibars; kts, knots; nmi, nautical miles; in, inches; ft, feet; $, dollars; M, million; B, billion]

TABLE 6

Tropical Storms that affected the Hawaiian Islands in historical times

Year	Date	Name	Track	Closest island	Wind average (mph)	Wind gust (mph)	Low BP (mbar)	Rate of travel (kts)	Eye (nmi)	Rain (in)	Stream	Marine surf (ft)	Tidal surge (ft)	Max. run-up (ft)	High water (ft)	Type of damage	Damage (1998 $)	Comments
1993	7/23	Eugene	W, aimed at Hawaii	Hawaii	35		*1008	25		~ 3						Hawaii: Up to 3 in rain in Hilo, Kau, Kona, some flooding. All islands: showers with isolated thundershowers.		Hurricane downgraded to tropical depression on 21st, disintegrated E of Hawaii.
1993	7/22	Dora	W, hit Hawaii	Hawaii						Heavy						Oahu: Heavy rain caused floods and power outages, especially on windward side, Polynesian Cultural Center closed, lightning over west/central Oahu, 3 in rain in 8 hrs in Nuuanu. Maui: Flooding closes Honoa-piilani Hwy, clogged drainage channel, silt in water supply, 1 family evacuated. Hawaii: Snow on Mauna Kea/Mauna Loa, some roads flooded, some damage.		Tropical storm.
1988	9/20-9/25	Wila	W, recurved NE	Hawaii	40		*1007			6-12	Wide-spread					All islands: Some heavy showers.	$50,000	Tropical storm, widespread minor floods
1988	8/8-8/9	Hector	W	Hawaii	35		*1008			6						Kauai: 6 in rain on slopes and N shore.		
1988	7/30-8/3	Gilma	NW, passed along Maui, over Oahu, just S of Kauai	Oahu	35		*1008			2-4						Oahu, Kauai: Showers, thundershowers, local stream flooding.	$500-5,000	Tropical depression.
1985	8/4-8/8	Linda	W, passed 150 mi S of South Point	Hawaii	46		*1005	17		5-10						Hawaii, Maui: 5-10 in rain on windward slopes.		Tropical storm.
1985	7/1-7/5	Enrique	SW, passed 350 mi S of Hawaii	Hawaii	29		*1010	17		Local heavy rain		10 ft				Hawaii: Local heavy showers on windward/Kona slopes. All islands: 10 ft surf on S shores, minor damage to roadways, minor injuries to surfers.	$50,000	Tropical depression.
1984	8/18-8/20	Kenna	NW, passed to the S of Hawaii	Hawaii	58		*1000			6-8 in						Hawaii: 11 ft surf on S shores, minor damge to roadways, minor injuries to surfers.		Tropical storm, downgraded to depression.
1984	7/3-7/6	Douglas	NW, dissipated 500 mi E of Honolulu	Hawaii	35		*1008			2 in						Hawaii, Maui: 2 in rain on slopes.		Tropical depression, was powerful hurricane.
1983	9/27-9/30	Narda	W, passed 150 mi S of South Point	Hawaii	52		*1003						Higher than normal			All islands: High surf on E and SE shores, high wind, rain.		
1983	8/3	Gil	NW, passed 10 nmi N of Kilauea Point	Kauai	63		1011	20		Heavy		High surf				Kauai: Heavy rains, surf, N and E shores. Oahu: High winds and surf, vessel lost.	$500-5,000	Tropical storm.
1982	7/16-7/22	Daniel	SW, curved NNE, dissipated in Alenu-ihaiha Channel	Hawaii	35		*1007				Flash floods					Hawaii: Flash floods, wind damage. Maui, E shore: flash floods, wind damage.	$1-5M crop, property	Tropical storm.
1982	7/12-7/15	Emilia	NW		55		*998	12-14		Heavy						Hawaii: Heavy rains over Hamakua, Hilo, Puna, Kau. Maui: Heavy rains island wide.	$50-500,000	Tropical storm.
1978	8/19-8/21	Iva	E	Hawaii						5-6.5						Hawaii, Maui: 5-6.5 in rain on E shores.		Vortex.

[BP, barometric pressure; mph, miles per hour; mbar, millibars; kts, knots; nmi, nautical miles; in, inches; ft, feet; $, dollars; M, million; B, billion]

TABLE 6 (continued)

Tropical Storms that affected the Hawaiian Islands in historical times

Year	Date	Name	Track	Closest island	Wind average (mph)	Wind gust (mph)	Low BP (mbar)	Rate of travel (kts)	Eye (nmi)	Rain (in)	Stream	Marine surf (ft)	Tidal surge (ft)	Max. run-up (ft)	High water (ft)	Type of damage	Damage (1998 $)	Comments
1978	8/6-8/9	#10	W, passed 300 mi SSW of Oahu		35		*1008			3-5						All islands: Heavy rains, local thunderstorms.		Tropical depression.
1978	7/3-7/11	Daniel	W							5-7						Hawaii, Maui: 5-7 in rain on windward/mountain sides. Other Islands: Spotty rainfall up to 2 in.		Ex-hurricane/vortex
1978	6/26-7/3	Carlotta	W, passed over Alenuihaha Chnl	All						6						Brought 6 in of rain, especially to Oahu.		Ex-hurricane, major weather producer of the season.
1976	8/3-8/17	Gwen	W, then WNW, passed 90 mi N of Kauai	Kauai	52		*1003			1-2						Kauai: 1-2 in of rain over entire island.		Tropical storm.
1972	9/28-10/3	Unnamed	W, then passed 150 mi S of South Point	Hawaii						up to 10.5						Hawaii: Up to 10.5 in rain on E slopes of Mauna Kea/Mauna Loa.		Tropical depression.
1971	1/8-1/18	Sarah	NW		69		987	69		3-6						Oahu: Powerlines and trees downed, 28 houses damaged, 2 injured as tree fell on car. Molokai: Five houses damaged, Lanai airport closed. Kauai: 61-66 mph winds at Kokee.	$100,000	Tropical storm, moved on to Pacific NW.
1970	8/17-8/26	Maggie	W, passed 90 mi of South Point	Hawaii	58		1003		17	25 8-14		25				Hawaii: Up to 25 in on Mauna Loa/Mauna Kea, 25 ft surf on Kapoho Beach, minor flooding landslides, crop damage. Kauai: 8-14 in rain on Mt. Waialeale, Paakea.		Tropical storm.
1967	1/1-12/31																	1967 was the year Diamond Head stayed green.
1967	8/10-8/14	"D"	NW, passed 250 mi W of all islands					14-15		2-3						All islands: Spotty rainfall of 2-3 in.		Tropical vortex.
1967	8/2-8/11	"B"	W, passed over South Point, moved NW.	Hawaii						~12 3-4	Floods in Hilo. Kipapa, Waiawa. Hanapepe, Hanalei, Wailua					Hilo, Hawaii: 12 in rain in 36 hrs, flash flooding, landslides. Oahu: 3-4 in rain, rockslides (Pali), mudslide in Aina Haina nearly destroyed house. Kauai: 2-3 in rain, especially in Princeville, some floods.	$50,000	Tropical cyclone.
1967	7/11-7/21	Eleanor	WNW, passed 250 mi S of Oahu		63		*998			~ 9						Hawaii: Up to 9 in rain, heavy hail on Mauna Kea. Maui: 2 in rain, small hail on Haleakala, flooding between Napili and Honolua. Other Islands: 2 in rain.		Tropical storm.
1967	7/5-7/18	Denise	WNW, passed 180 mi S of South Point	Hawaii	63		*998			~ 6						Hawaii: Up to 6 in rain Other Islands: Moderate to heavy.		Tropical storm.
1967	7/4-7/8	Unnamed	W, passed S							8-10						Hawaii: 8-10 in rain in Kipa, Papaikou, Mauka, Kaumana. Other Islands: 2-3 in rain.		Tropical depression.

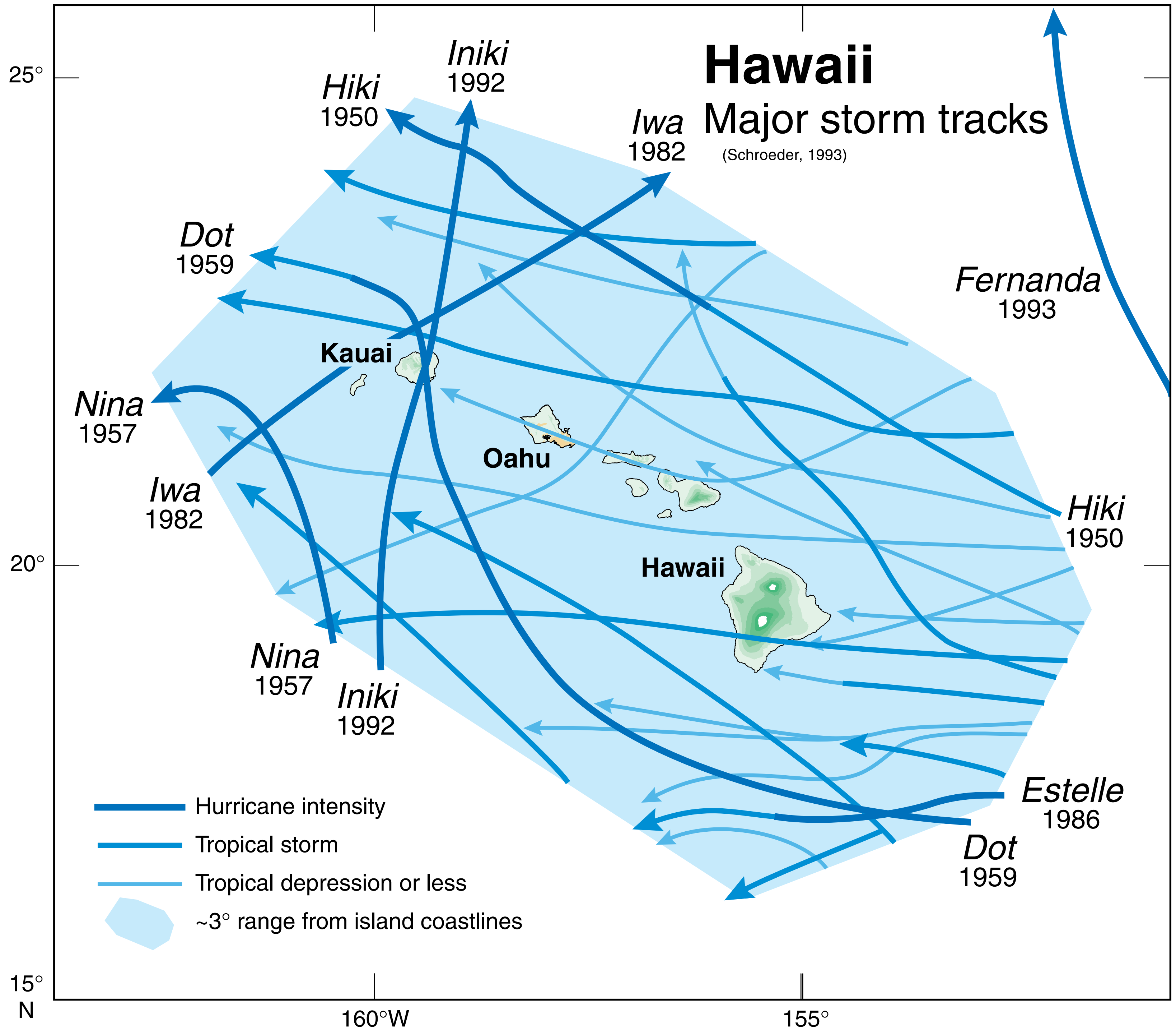
[BP, barometric pressure; mph, miles per hour; mbar, millibars; kts, knots; nmi, nautical miles; in, inches; ft, feet; $, dollars; M, million; B, billion; Chnl, Channel]

TABLE 6 (continued)
Tropical Storms that affected the Hawaiian Islands in historical times

Year	Date	Name	Track	Closest island	Wind average (mph)	Wind gust (mph)	Low BP (mbar)	Rate of travel (kts)	Eye (nmi)	Rain (in)	Stream	Marine surf (ft)	Tidal surge (ft)	Max. run-up (ft)	High water (ft)	Type of damage	Damage (1998 $)	Comments
1966	9/10-9/12	#22	W, passed 240 mi S of South Point	Hawaii						Moderate, heavy						All islands: Moderate to heavy rainfall.		Tropical depression.
1963	9/12-9/19	Irah	Center moved into Molokai channel		52		*1003									All islands: Moderate rainfall, wind 36 mph at Honolulu airport. Tropical Storm.		
1958	8/7-8/9	Unnamed	Appeared off Hilo, moved across islands	Hawaii	58	86	*1000									Hawaii: Torrential rain, houses, 3 bridges destroyed, 100's trees, powerlines down; crop damage, 1 dead in plane crash. Other Islands: Heavy rains scattered damage.	$552,000 $50,000	
1938	8/18-8/19	Mokapu Cyclone				61	1008			4						Oahu: Thunder and lightning, winds up to 61 mph. Some damage to Waimanalo plantation. Oahu, Maui: 4 in rain.		
1925	7/31-8/4	Ramage Cyclone										High				Hawaii: Honuapo and Punaluu flooded, strong winds. Oahu: Very high surf on S shore (Honolulu, Diamond Head), Fort Kam flooded		
1911	9/29	Ship Cyclone														Oahu: Rough seas capsized boat off Waikiki		
1906	10/2-10/9	Makawa Cyclone	WSW, 60 mi S of Hawaii NW to Niihau	Niihau			998.7			12.7						Maui: 12.7 in in 4.5 hrs at Makawao, low BP.		
1874	11/17-11/20	Die Deutsche Seewarte III						1002.4			20					Oahu: 20 in in Honolulu in 2 days. Molokai: 23 houses destroyed, 50 destroyed at Kalaupapa.		
1871	8/9	Kohala Cyclone		Hawaii							Heavy					Hawaii: 150 houses, and fields destroyed in Waimea, Kohala, 27 houses at Waipio. Maui: Heavy rains, stream flooding, gale winds, rain squalls.	$10,000	(1871 dollars)
1870	9/21-9/24	Die Deutsche Seewarte II	WNW, passed 50 mi S of South Point	Hawaii														

[BP, barometric pressure; mph, miles per hour; mbar, millibars; kts, knots; nmi, nautical miles; in, inches; ft, feet; $, dollars; M, million; B, billion]

*Values are calculated from $Po = 1013 - v^2/14^2$, where Po = minimum pressure (mbar), and v = maximum sustained winds (kts). This empirical relationship relating minimum pressure to maximum wind speed was determined by the National Hurricane Center.



Tracks of the major storms that have affected the main Hawaiian Islands.

Our rankings are based on levels of windspeed, historical structural damage, and overwash elevation. In the absence of any meteorological theory or process to the contrary, we have assumed that all Hawaiian coasts are equally vulnerable to hurricane impacts and that the only mitigating variables are local in nature (that is, slope, elevation, geology, offshore barriers). The highest intensity ranking (no. 4) is based on overwash exceeding 10 ft (~3 m above low tide) in elevation, which is sufficient on most Hawaiian beaches and low-lying coastlines to flood the area landward of the beach, often including the lower level of the first row of structures behind a beach. This was the case on Kauai during both Iwa and Iniki. We have also included a wind gust value of ~75 mph as an approximation of the minimal speed that will cause extensive structural damage to single family homes and other small dwellings. Intensity no. 3 is again related to an overwash above 10 ft in elevation and a sustained windspeed sufficient to cause localized damage to individual dwellings, estimated to be ~40 mph. Note that sustained winds of 39 to 73 mph are used by meteorologists to classify tropical storms, while hurricanes have sustained wind speeds of 74 to 149 mph.

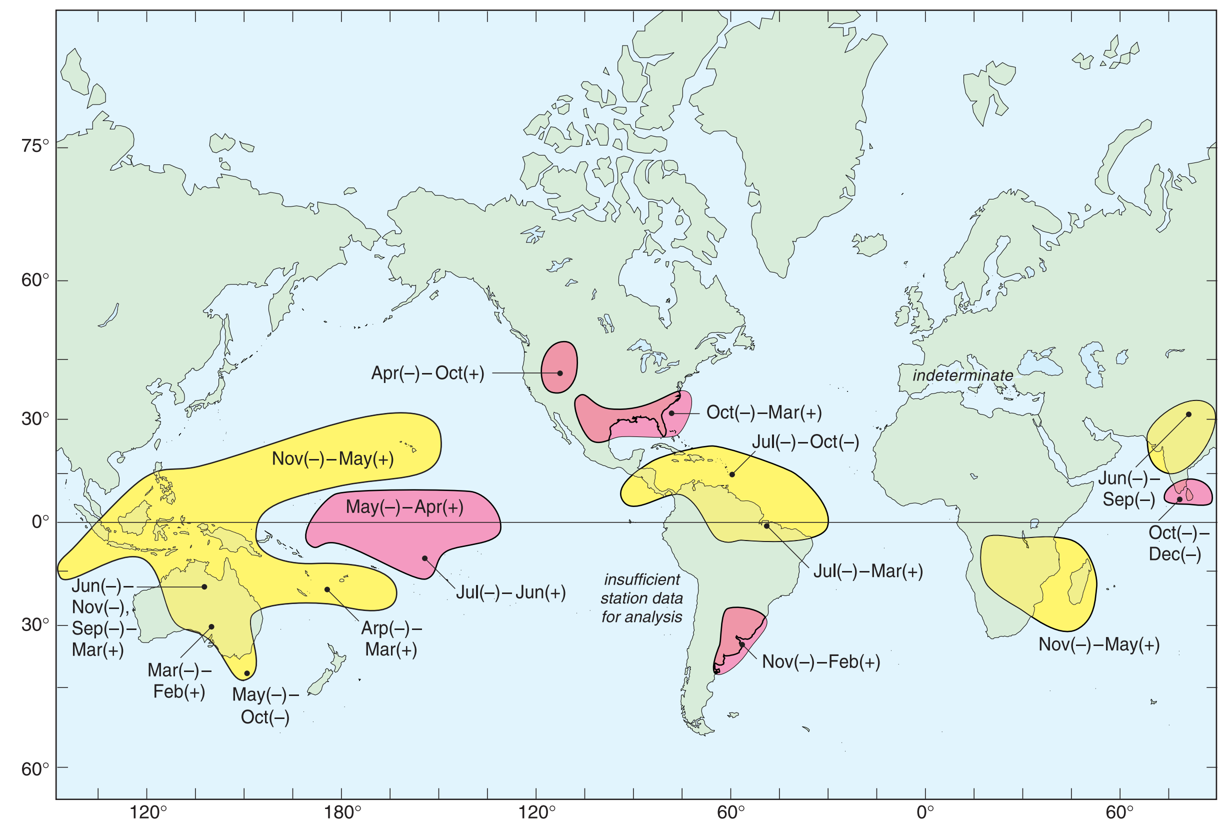
In studying the aftermath of Hurricane Iniki it was discovered by researchers at the Army Corps of Engineers and the University of Hawaii (Fletcher and others, 1994) that the greatest threat related to hurricane overwash in the Hawaiian Islands is due to water-level rise from wave forces rather than wind forces. This differs from the mainland where the wind in a hurricane is known to drive water against the coast and cause flooding, called wind set-up. During Iniki, the strongest component of the overwash was the result of large waves, called wave set-up. Wind set-up appeared to be relatively less important. Other factors leading to coastal overwash are the low atmospheric pressure, the tide stage, coastal topography, and the location relative to the eye of the hurricane. Unfortunately few of these can be predicted before a hurricane is in the neighborhood and thus overwash mitigation must be enacted prior to the event. This would include adequate building setbacks so that development does not occur in high hazard areas of the coastal zone, elevation of existing structures to recommended levels, break-away ground floors that permit overwash flooding without compromising an entire structure, and other construction techniques designed to reduce flood damage.

EL Niño

A large-scale meteorological pattern governs temperature and precipitation trends in the Pacific Ocean. This pattern is called the Southern Oscillation and it is related to the pressure difference between a body of dry air (a high pressure system) located in the southeast Pacific over Easter Island and a body of wet air (a low pressure system) located over Indonesia in the southwest Pacific. Under normal conditions, air flows from the high pressure to the low pressure and creates the trade winds. These blow east to west across the surface of the equatorial Pacific and drive a warm surface current into the western Pacific. This water is replaced in the east by deep cold ocean water (a process called upwelling) that is rich in nutrients fueling an important fishing industry off the coast of South America.

On occasion, the pressure difference between the two centers decreases and the trade winds die. This is known as El Niño. As a result, the warm water of the west Pacific surges to the east and heats up the ocean surface in the central and eastern Pacific. Precipitation in the east increases because the warmer water evaporates more readily. Upwelling temporarily comes to an end. Torrential rains and damaging floods across the southern U.S. have resulted, and the Peruvian fishing industry falters, leading to nationwide economic hardship in that country.

During an El Niño the Hawaiian Islands usually experience a decrease in rainfall. In fact, the ten driest years on record are all associated with El Niño years. Rainfall decreases because of a southerly shift in the atmospheric circulation system of the north Pacific, a feature called the Hadley Cell. The Hadley Cell is a large continuous belt of air that rises, moisture-laden, from the warm waters north of the equator at about 8° latitude, and moves north across the subtropics where the Hawaiian Islands are located. During its journey the air cools, losing its ability to hold moisture, and produces abundant rainfall. Eventually it descends back to Earth's surface as a column of dry, cool air and creates a pressure system known as the Pacific High. Under normal conditions the Hawaiian Islands experience a wet climate, while to the north and northeast, the Pacific High creates a dry climate. However, during El Niño the surface waters at the equator become significantly warmer and the rising motion of the Hadley Cell shifts to the south. This brings the Pacific High south as well, and the Hawaiian Islands experience a decrease in rainfall.

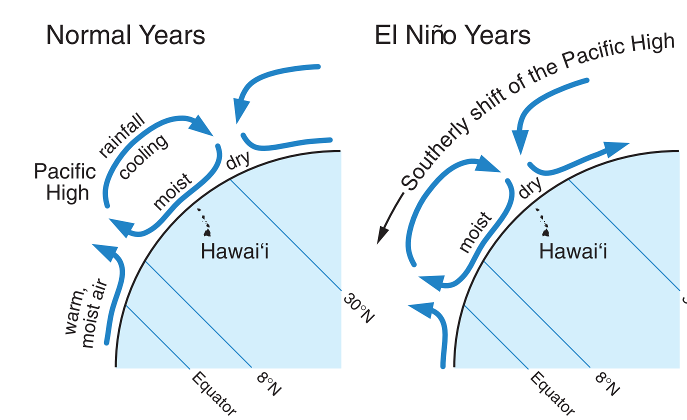


During El Niño, precipitation is enhanced in some (pink) areas and diminished in other (yellow) regions. The months indicate when these regions are affected, typically coinciding with local rainy seasons. The year that unusually high sea-surface temperatures first appear is indicated by (-); (+) refers to the following year. (Source: Philander, 1992).

As reported by T. Schroeder (1993) nearly all major statewide droughts have coincided with El Niño events (Table 7).

TABLE 7
The ten driest years in Hawaii

Percentile Rank	Year	El Niño Event
1	1897	1896-1897
2	1926	1925-1926
3	1919	1918-1919
4	1953	1953
5	1912	1911-1912
6	1941	1941
7	1903	1902-1903
8	1905	1905
9	1977	1976-1977
10	1925	1925-1926

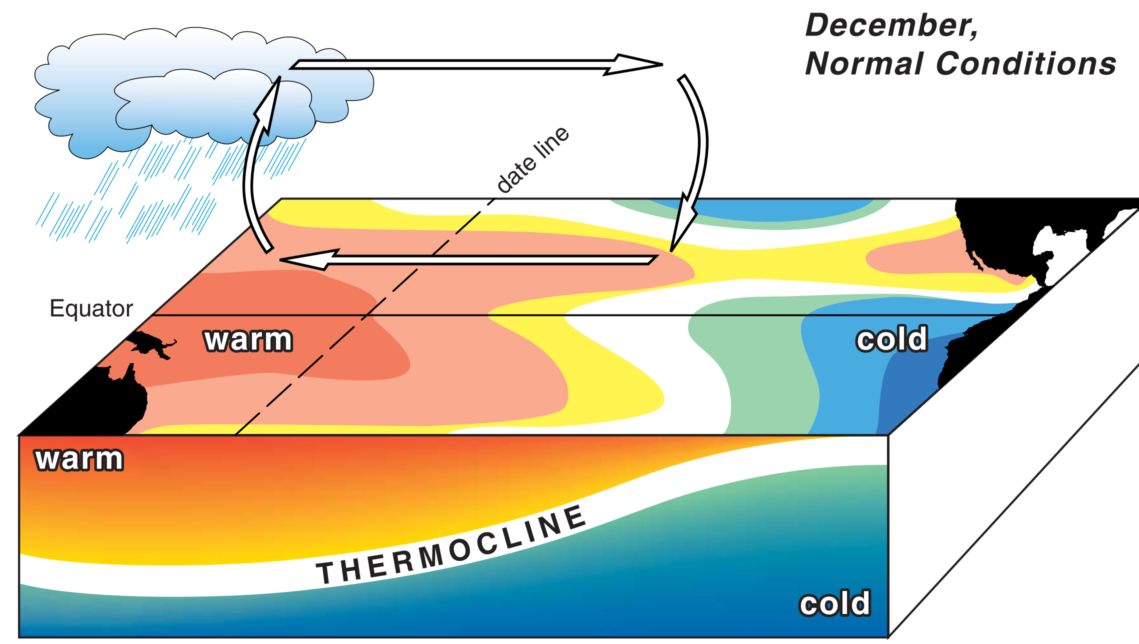


Latitudinal location of Hadley Cells for normal (left) and El Niño years (right).

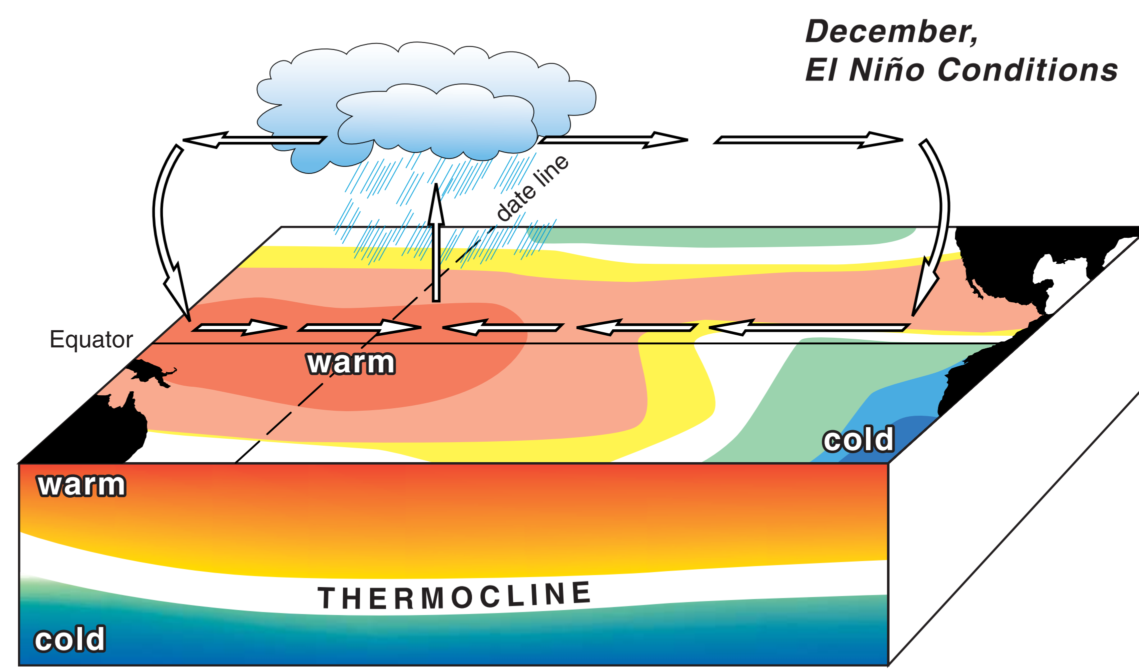
El Niño, in addition to controlling Hawaiian episodes of major drought, plays an important role in the location of hurricane genesis in the Pacific. The primary source of central Pacific hurricanes are cyclonic disturbances that form in the eastern Pacific and move west, steered by the winds in their surrounding environment (Schroeder, 1993). During the onset year of an El Niño, changes in the equatorial wind pattern of the central Pacific create a shear zone between equatorial west-flowing winds and subtropical east-flowing winds. This shear zone may cause cyclonic disturbances that can grow into hurricanes. Under normal conditions, waters of the central Pacific are warm enough to permit hurricane genesis but lack the necessary initial atmospheric disturbance. During the onset of an El Niño, tropical storms gradually form farther eastward as the shear zone migrates from the west Pacific into the central Pacific.

The impacts of El Niño on specific coastal segments by its influence on storms, waves, and sea-level changes are not entirely predictable, and as a result, El Niño does not directly enter our hazard rankings. We offer the previous discussion to illustrate that El Niño is a vital and recurring climatic event which influences the magnitude and frequency of coastal hazards.

Schroeder reports (Table 4) that El Niño warm phases in the Southern Oscillation have corresponded to some of the largest annual storm counts in the central Pacific. However, the relationship is not unique because 1972, 1982, and 1992 were warm phase years and major storm years. 1978 was not an El Niño year, yet it still had as many storms as the warm phase years. 1977 was a warm phase year and the central Pacific storm count was zero.



In a normal year, intense westward winds (white arrows) drive equatorial currents that push warm Pacific surface waters steadily to the west and expose colder waters from the deeper water column, to the surface in the east. (Source: Philander, 1992)



In an El Niño year, the trade winds relax, allowing a surge of warm water eastward across the Pacific and changing the characteristics of waters in the eastern part of the ocean basin. (Source: Philander, 1992)

Erosion

Coastal erosion and beach loss are chronic and widespread problems in the Hawaiian Islands. Typical erosion rates in Hawaii are in the range of 0.5 to 1 ft/yr (15 to 30 cm/yr) (Hwang, 1981; Sea Engineering, Inc., 1988; Makai Ocean Engineering, Inc. and Sea Engineering, Inc., 1991). Recent studies on Oahu (Table 8; Fletcher and others, 1997; Coyne and others, 1996) have shown that nearly 24%, or 17.1 mi of an original 71.6 mi of sandy shoreline (1940's) has been either significantly narrowed (10.7 mi) or lost (6.4 mi). Nearly one-quarter of the islands' beaches have been significantly degraded over the last half-century and all shorelines have been affected to some degree. Oahu shorelines are by far the most studied, however, beach loss has been identified on the other islands as well, with nearly 8 mi of beach likely lost due to shoreline hardening on Maui (Makai Engineering, Inc. and Sea Engineering, Inc., 1991).

The original sandy shoreline along many segments of coast has been replaced by shoreline hardening structures of various designs and construction materials (such as seawalls, revetments, groins of concrete, stone, and wood). The presence of a shoreline structure is indicative of an erosion hazard, but in many places the structure probably exacerbates the problem and changes a condition of shoreline erosion into one of beach loss (Fletcher and others, 1997). Coastal lands are typically composed of carbonate sand in Hawaii, therefore when they experience chronic erosion and the shoreline shifts landward, a supply of sand is released to the adjoining beach and nearshore region. The beach then remains wide even as it moves landward with the eroding shoreline. If sand is not available to the beach, such as when a wall is built to protect the land (when sand is trapped behind the wall), then beach erosion will ensue as a result of sand impoundment, which leads to beach narrowing and eventually beach loss.

TABLE 8
Beach Narrowing and Loss on Oahu

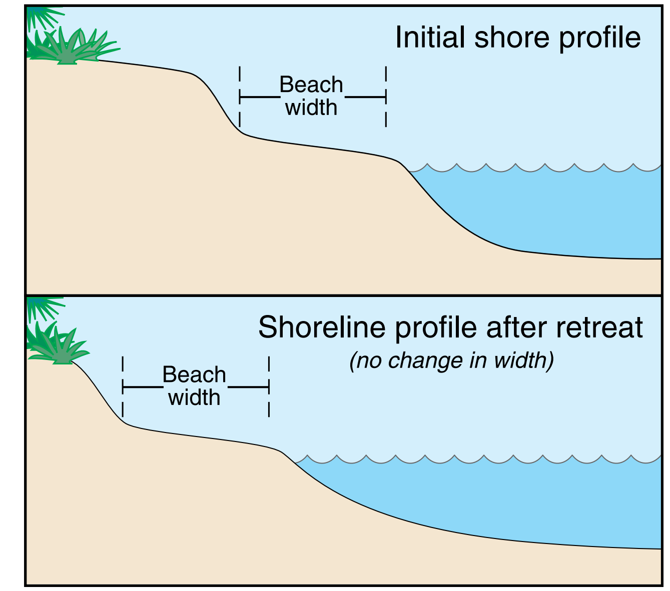
	Mokuleia	Kaaawa	Kailua-Waimanalo	Maili-Makaha	Island-wide
A. Originally sandy (km)	12.2±1.0	7.5±0.6	15.5±1.3	6.0±0.5	115.6±9.8
B. Narrowed beach (km)	2.1±0.2	3.2±0.3	0.9±0.1	1.3±0.1	17.3±1.5
C. Lost beach (km)	0.2±0	0.8±0.1	1.6±0.1	0.2±0	10.4±0.9
D. Degraded beach	18.7%	53.6%	16.3%	24.9%	23.9%
E. Short-term, maximum shoreline change rate (m/yr)	-5.1 to 7.7	-5.8 to 14.0	-6.4 to 5.1	-2.2 to 4.0	not calculated
F. Net shoreline change rate (m/yr)	-0.2 to 0.3	-1.7 to 1.8	-0.9 to 0.6	-0.4 to 0.6	not calculated
G. Non-armored mean sandy beach width	26.8 m	13.2 m	22.4 m	43.7 m	not calculated
H. Armored mean sandy beach width	12.8 m	8.9 m	7.1 m	24.5 m	not calculated
I. Mean long-term shoreline change rate for armored sites (m/yr)	-0.2	-0.3	-0.6	-0.5	not calculated
J. Range of shoreline change rates for armored sites (m/yr)	-0.1 to -0.3	0 to -1.7	0.2 to -1.8	-0.2 to -1.0	not calculated

- 97.4 per cent of armored beaches experienced chronic erosion prior to the period of narrowing.
- 92.1 per cent of armored beaches experienced long-term (>12 yr) chronic erosion prior to narrowing.
- Island-wide, all narrowed beaches are on armored shorelines.

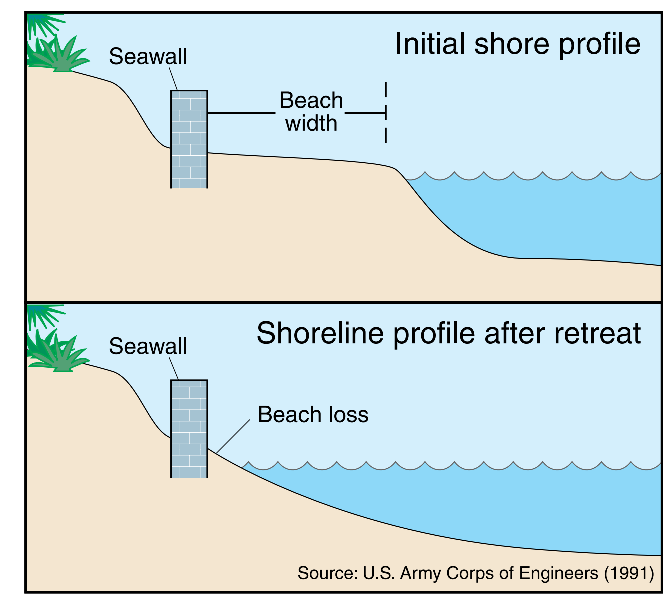
Most beach sand in Hawaii is composed of bioclastic carbonate grains derived from the skeletons of corals, mollusks, algae, and other reef-dwelling, carbonate-producing organisms. Studies indicate relatively low modern sand production on Hawaiian reefs compared to 2000 to 4000 years ago when sea level was higher and our reef systems made larger volumes of sand. The formation of beachrock, storage of sand in coastal dunes, and irretrievable sand loss to deeper water beyond the reef crest all contribute to a relatively low volumes of sand available to the beach system. On many Hawaiian beaches the available sand ends beyond the toe of the beach in a water depth of 4-6 ft where the bottom becomes reef or a reef pavement. In contrast, on mainland beaches the sand deposits often extend a considerable distance (hundreds to thousands of yards) offshore.

Causes of coastal erosion and beach loss in Hawaii are numerous but, unfortunately, are poorly understood and rarely quantified. Construction of shoreline hardening structures limits coastal land loss, but does not alleviate beach loss and may actually accelerate the problem by prohibiting sediment deposition in front of the structures. Other factors contributing to beach loss include: a) reduced sediment supply; b) large storms; and, c) sea-level rise. Reduction in sand supply, either from landward or seaward (primarily reef) sources, can have a myriad of causes. Obvious causes such as beach sand mining and structures that prevent natural access to backbeach deposits, remove sediment from the active littoral system. More complex issues of sediment supply can be related to reef health and carbonate production which, in turn, may be linked to changes in water quality. Second, the accumulated effect of large storms is to transport sediment beyond the littoral system. Third, rising sea level leads to a landward migration of the shoreline (see next section).

Dramatic examples of coastal erosion, such as houses and roads falling into the sea, are rare in Hawaii, but the impact of erosion is still very serious. The signs of erosion are much more subtle and typically start as a "temporary" hardening structure designed to mitigate an immediate problem which, eventually, results in a proliferation of structures along a stretch of coast. The natural ability of the sandy shoreline to respond to changes in wave climate is lost. It appears obvious that the erosion problem in Hawaii would be much less severe if adequate setback rules were established.



A beach undergoing net longterm retreat will maintain its natural width.



Beach loss eventually occurs in front of a seawall on a beach experiencing net longterm retreat.

Sea Level

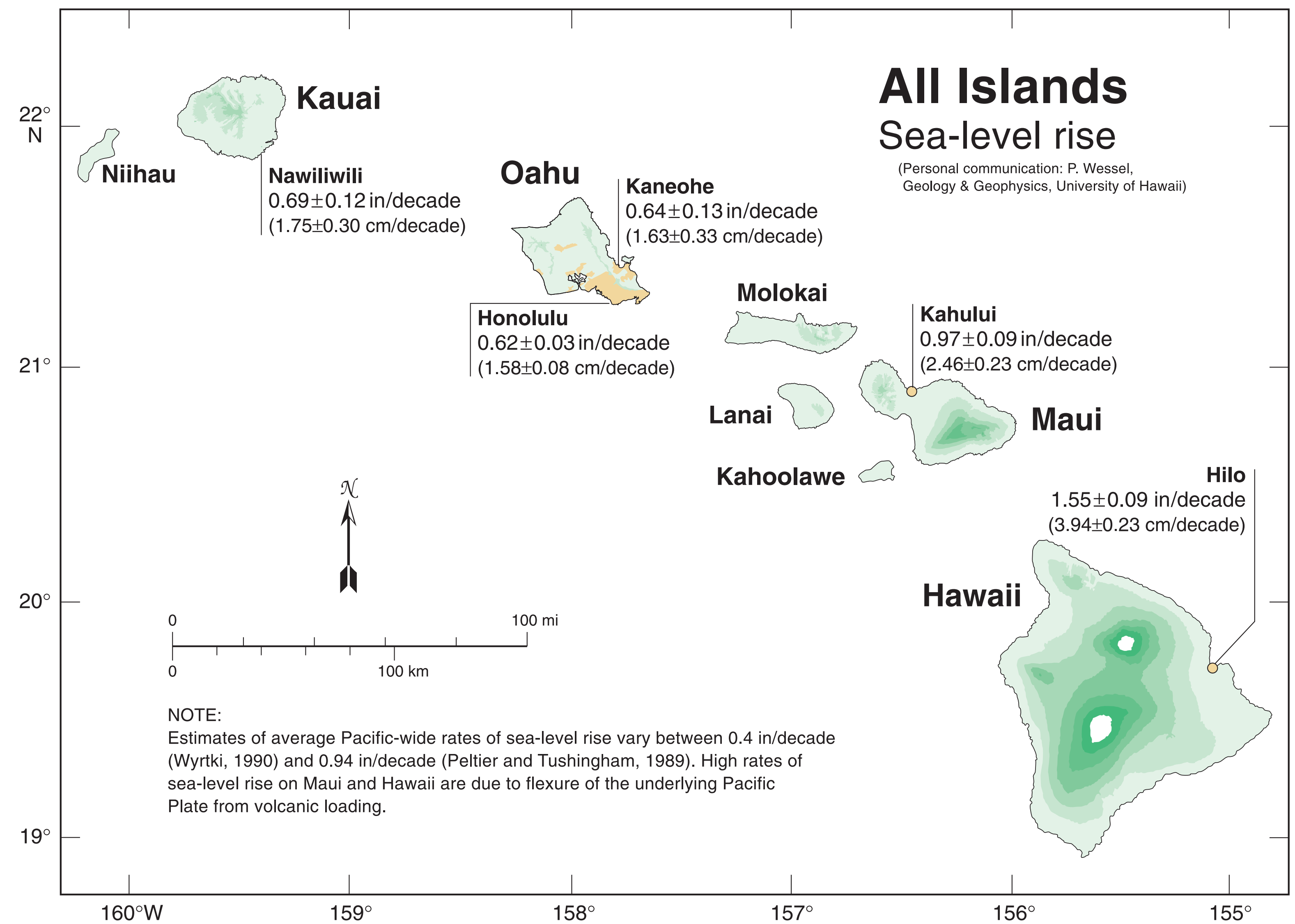
Hawaii has a system of tide gauges, maintained and operated by the federal National Ocean Service, located on the islands of Kauai, Oahu, Maui, and Hawaii that record fluctuations in sea-level. Analysis of these records provides scientists with rates of long-term sea-level rise around the state. A fascinating outcome of this has been the realization that each island has its own rate of rising sea level. This is not because of ocean behavior, it is due to island behavior. The Big Island, because of the heavy load of geologically young volcanic rocks, is flexing the underlying lithosphere causing the island to subside. This creates a relatively rapid rate of sea-level rise, on the order of 1.5 in/decade. Because it lies near the Big Island and is also geologically youthful, Maui is affected by the flexure process and is experiencing rapid sea-level rise, nearly 1 in/decade. Oahu and Kauai lie outside the area of subsidence and have lesser rates of rise, approximately 0.6 in/decade.

Sea-level rise is not presently a cause for alarm. Questions regarding future rates of rise resulting from an enhanced greenhouse effect have been discussed by scientists, planners, and policymakers throughout the 1980's and 1990's. At present, sea level is projected to rise 2 ft over the 21st century. This is more than twice the rate of rise of the 1900's. The impact of rising sea level in the Hawaiian Islands will be severe unless planners and resource managers incorporate sea-level rise scenarios into their coastal management efforts. As sea-level rise accelerates in the future, low-lying, low relief, readily erodeable, and low slope coasts will be the most vulnerable to sea-level hazards. These locations can be readily determined using our data on slope zone ranking and coastal geology. A more complete discussion of future sea levels and impacts is available in Fletcher, 1992.

Present rates of sea-level rise play a role in coastal retreat. The engineers' "Bruun Rule" (relating sea-level rise to beach retreat (Bruun, 1962)) predicts a retreat of 4-5 ft/decade on Oahu and Kauai (Hwang and Fletcher, 1992). This finding is supported by aerial photographic measurements of beach retreat and suggests that presently narrow beaches fronting seawalls on these islands are likely to be lost over the next quarter century.

Sea-level rise has not been evaluated here as a dynamic or energetic hazard. It is, however, an agent in exacerbating rather than mitigating each of the other hazardous processes. We have used a rate of 0.12 in/yr as a ranking variable, in conjunction with coastal slope. Where the rate is high and the coastal zone slope is low, sea-level rise is ranked at high intensity. Moderate rates of rise on steeper slopes define less intense ranking levels.

Many examples of natural beaches (right of groin) exist in stark contrast to narrow stretches of lost beach (left of groin) owing to shoreline harding (Kualoa, Oahu).



Seismicity and Volcanism

The Hawaiian Islands are located in a more complex and hazardous seismic setting than is generally realized. Volcanism is the source of energy for approximately 95% of the earthquakes on the Big Island. However, in the central region, defined by Furumoto and others (1990) as the area encompassing Maui and Oahu, the seismicity is generally related to tectonic activity on the seafloor near the Hawaiian Islands, although the potential for volcanic-related seismicity on Maui's Haleakala Volcano is considered significant. The northwestern, or Kauai-Niihau region, has experienced tremors from earthquakes originating farther south but no known seismic activity has originated among these northern islands. The earthquake risk for the northwestern islands has been evaluated as minimal.

According to Heliker (1991) the Island of Hawaii experiences thousands of earthquakes each year. Although most are too small to be noticed, one or more quakes are felt in the state annually, and minor damage resulting from a stronger shock is not an infrequent occurrence. The majority of Big Island seismicity is related to the movement of magma within Kilauea or Mauna Loa. A few quakes are related to movements along fault zones located at the base of the volcanoes or deeper within the crust due to the gravitational adjustment of the volcanic edifice. Seismic tremors on the Big Island have caused ground cracks, landslides, ground settlement, damaging tsunami, and mudflows. Buildings, bridges, and water tanks have been destroyed or damaged, and utility, sewer, and water lines have been disrupted.

Strong earthquakes of magnitude 5 or higher, based on the Richter Scale, can cause property damage and endanger lives. Because much of the Big Island is rural and sparsely developed, the majority of significant damage is usually caused by larger earthquakes. Table 9 lists damaging Big Island earthquakes of magnitude 6 or greater.

Furumoto and others (1990) analyzed the record of Big Island seismicity and found that earthquakes of magnitude 6 or greater tend to occur in clusters with recurrence intervals of 10 to 12 years. The research of Wyss and Koyanagi (1988) identified two regions, the East Kona Block and the South Kona Block, as not having seismically ruptured in the last one hundred years. Such areas are called seismic gaps, and the potential of large earthquakes occurring in these regions is high.

Two damaging earthquakes on the Big Island are especially notable, the Great Kau Earthquake of 1868 and the Kalapana Earthquake of 1975. These were the most destructive earthquakes in recorded Hawaiian history.

Six days of foreshocks preceded the Great Kau quake before the main shock hit at 3:40 pm on April 2, 1868. Every stone wall in the District of Kau, on the southeast flank of Mauna Loa, was knocked down, and nearly every wooden house was moved off its foundation. Stone walls were knocked down along the coast from Hamakua to Hilo, and pendulum clocks stopped in Honolulu. The tremors were felt as far away as Kauai. Fissures opened in the streets of Hilo. In the Kau District the earthquake triggered a mudflow that killed 31 people. A tsunami that accompanied the main shock washed away 180 houses on the Kau-Puna coast on the Big Island and drowned 46 people. The port town of Keauhou, near Halape on the Big Island was completely destroyed, and is no longer found on maps of the region.

The Kalapana Earthquake of 1975, with a magnitude of 7.2, occurred on November 29 at 4:48 am in the District of Puna. Damage was relatively small because of the sparse population of the region. Losses amounted to 2.7 million dollars, and 23 houses were damaged. Unfortunately a deadly tsunami was generated when the Kalapana coast subsided as much as 11 ft. Two campers were killed by the wave at the Halape Campgrounds in Kau, boats and piers were damaged in Hilo, houses were destroyed on the Punaluu coast, and fishing boats were sunk in Keahou Harbor south of Kona. Because of the extensive history of seismicity on the Big Island related to both volcanism and gravitational adjustment of the growing volcanic edifice, the Big Island has upgraded their Uniform Building Code (UBC) seismic zone factor to 4. The UBC seismic zone factor is used in calculations of shear and impact to structures due to ground motion relating to seismic activity. The value prescribed for this factor in Hawaii ranges between 0.2 (for a seismic zone factor of 2) and 0.4 (for a seismic zone factor of 4) depending on a number of ground characteristics (rock type, consolidation of sediment). In certain instances, subtle divisions within this ranking scheme are designated with alphabetic suffixes (2A, 2B).

Studies of the seismic history of the central region over the last two decades have concluded that the seismic risk to the islands of Maui, Molokai, Lanai, Kahoolawe, and Oahu is greater than generally perceived by the public. The region has experienced three damaging earthquakes within historical times. Building codes and earthquake mitigation measures, although continually upgraded, have been characterized as inadequate for the potential seismic risk. In 1994, Maui County upgraded their UBC seismic hazard ranking for Maui Island from 2 to 2B and for Molokai, Lanai, and Kahoolawe Islands from 1 to 2B. Oahu and Kauai Counties raised their UBC seismic hazard rankings to 2A and 1, respectively.

TABLE 9
Damaging earthquakes of magnitude 6 or greater since 1868 on the Big Island of Hawaii

Year	Date	Location	Magnitude
1868	Mar. 28	Mauna Loa south flank	6.5-7.0*
1868	Apr. 2	Mauna Loa south flank	7.5-8.1*
1929	Oct. 5	Hualalai	6.5*
1941	Sept. 25	Kaoiki between Kilauea and Mauna Loa	6.0*
1950	May 29	Mauna Loa SW rift zone	6.2
1951	Apr. 22	Kilauea	6.3
1951	Aug. 21	Kona	6.9
1952	May 23	Kona	6.0
1954	Mar. 30	Kilauea south flank	6.5
1962	Jun. 27	Kaoiki	6.1
1973	Apr. 26	Honomu	6.2
1975	Nov. 29	Kilauea south flank	7.2
1983	Nov. 16	Kaoiki	6.6
1989	Jun. 25	Kilauea south flank	6.1

Source: Heliker, 1991; *estimated from eyewitness accounts

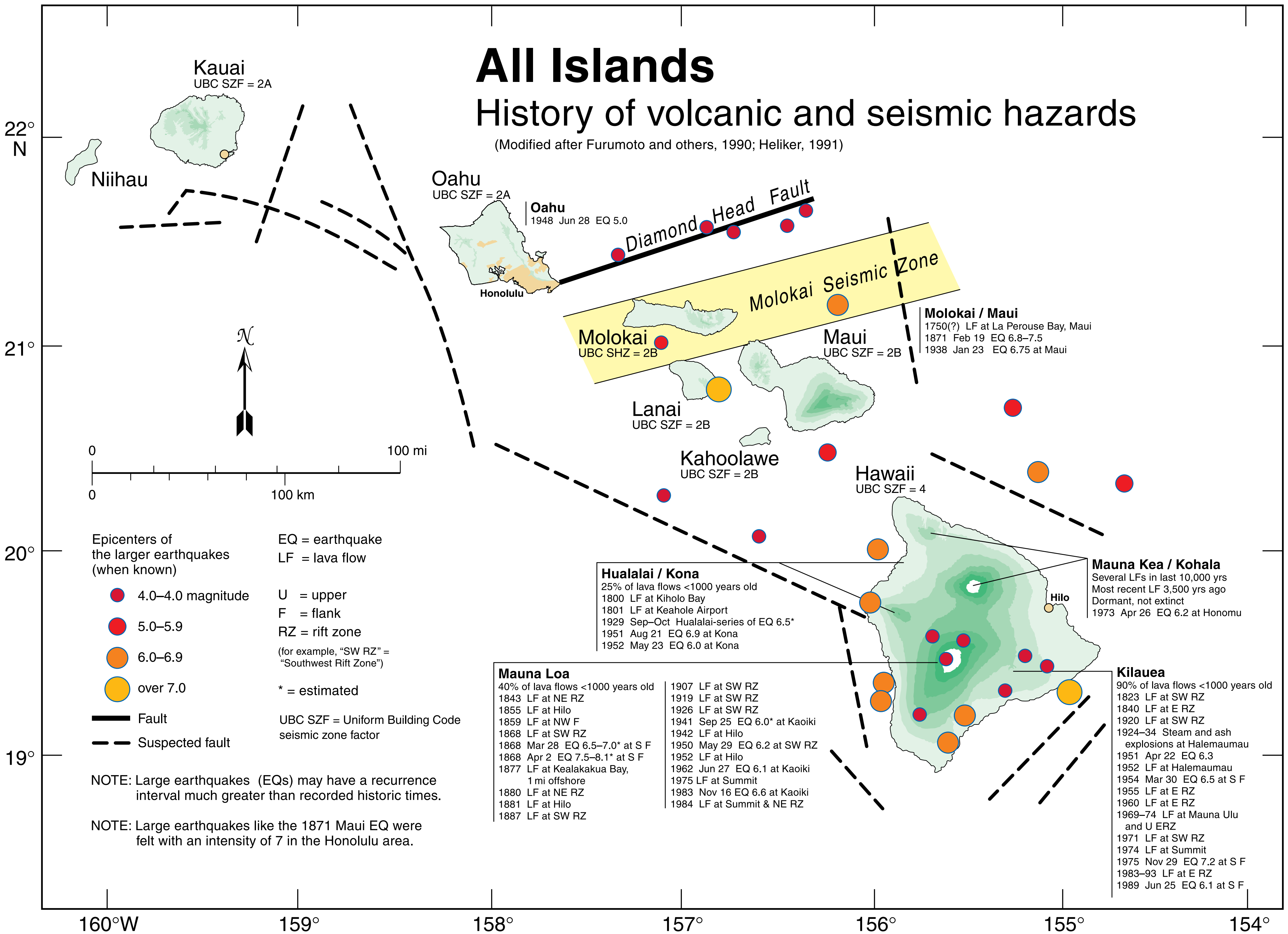
Of special concern is the nature of the sedimentary layer under the commercial sector of Honolulu, which will tend to experience heightened ground motion relative to adjacent regions where the bedrock is less prone to seismic acceleration. We have incorporated these recommendations in our ranking of the combined volcanic/seismic risk and assigned a ranking of 3 to the southern half of Oahu from Makaha around Diamond Head and Makapuu Head to Kaneohe Bay. The remainder of the island is ranked a 2 with respect to the volcanic/seismic hazard.

Tectonic activity capable of generating hazardous earthquakes in the central region is related to seafloor fractures and suspected faults around the islands. The largest of these, the Molokai Seismic Zone and the Diamond Head Fault have been the locus for a number of earthquakes of 4.0 magnitude or larger.

The Oahu Earthquake of 1948, which occurred along the Diamond Head Fault, resulted in broken store windows, plaster cracks, fissures and ruptures to building walls, and a broken underground water main. Cox (1986) assigned a magnitude of 4.8 to this earthquake, while Furumoto (1980) estimated a magnitude of approximately 5.0. Landslides generated by the quake-blocked roads in Kipapa Gulch were quickly cleared. The Diamond Head Fault also passes through Koko Crater and extends along the seafloor northeast of Oahu. Several earthquakes of 4.0 to 5.0 magnitude have been detected along this fault.

The Molokai Fracture Zone is an extension of a transform fault from the East Pacific Rise that reaches from Molokai to the Gulf of California. Because this fracture is tectonic in origin, and thus associated with seismically active seafloor spreading processes, it is suspected to contribute to central region seismicity. Two known earthquakes (1871 and 1938) have occurred along the fracture, leading Furumoto (1980) to designate this the Molokai Seismic Zone.

The Lanai Earthquake of 1871 had a magnitude of 7 or greater with vibrations that have been described as lasting 55 seconds in a northeast to southwest rocking motion. Walls were severely cracked and damaged and two houses were reported to have split open on Oahu. At Punahou School (Oahu) chimneys were thrown down, and in Ewa (Oahu) the belfry tower of the Catholic Church collapsed. Ground fractures and land slippage



occurred in Waianae (Oahu) and Lahaina (Maui). Massive rockfalls and cliff collapse occurred on Lanai, and houses and churches were flattened on the islands of Maui and Molokai. Damage was also reported from the Big Island.

The 1938 Maui Earthquake was assigned a magnitude of 6.7-6.9 with an epicenter located only 6 miles north of the island of Maui, in the Molokai Seismic Zone. Numerous landslides closed the road to Hana, and long sections of the Hana highway collapsed into the sea. Waterpipes and a reservoir were severely damaged and ground cracks opened on Maui, Molokai, and Lanai. Damage on Oahu was reported to be slight, confined mainly to broken objects shaken from shelves and local landslides.

In a major report in 1986, Cox compiled statistics on Hawaiian seismicity and listed 113 felt earthquakes on the island of Oahu between 1859 and 1983. An earthquake is felt on Oahu nearly annually. Recurrence probabilities of a major earthquake (magnitude 7 or greater) in the central region were estimated in Furumoto and others (1990). The probability for a major earthquake occurring from 1989 to 1998 is estimated at 6%. If no quake occurs by 1998, a 78% probability is estimated for a major quake for 1999-2008. A probability greater than 99% is estimated for 2009-2018 if no major earthquake occurs by 2008.

Klein and others (2001) have recently mapped the probability distribution of seismic hazards among the main Hawaiian Islands, utilizing improved earthquake catalogues and giving special consideration to the variation in seismic activity found among the different source areas surrounding the island chain. They give the 10% and 2% probability of peak ground acceleration exceeding predicted values in 50 years, which correspond to return times of about 500 and 2500 years, respectively. The hazard assessments are for firm rock conditions so the predicted motions for unconsolidated sediments that characterize a significant portion of the Hawaiian coastal zone, including the filled region of downtown Honolulu, should be considered minimal. While subtle lithospheric variations certainly must exist and result in distinct seismic responses on a local scale, a general predicted trend exists. The seismic hazard is highest along the southeast coast of the Big Island, followed by the Kona coast, and decreases exponentially toward the northwest. Peak horizontal ground acceleration is predicted to be 50% in Hilo and 13% in Honolulu relative to the southeast coast of the island of Hawaii (100%).

Our volcanic/seismic hazard intensity rankings attempt to account for the variability in (1) geology, (2) UBC seismic zone factor rankings for each island, (3) history of volcanic and seismic activity, and (4) recent scientific predictions of the probability distribution of seismic hazards among the main Hawaiian Islands. The volcanic/seismic hazard ranking generally increases uniformly from Kauai toward the Big Island, because of the increase in volcanic and seismic activity found along the southeast coast of the Big Island.

Volcanic hazards are, of course, greatest on the south shore of the Big Island where the volcanoes are active. But active seismicity on Haleakala Volcano, Maui, and Mauna Loa Volcano on the Big Island, apparently dormant volcanoes, indicate that these volcanoes should continue to be perceived as potentially hazardous. Indeed, because we base our hazard intensities on the historical record, the eruption on the southwest flank of Haleakala in the late 1700's elevates that region to a high ranking for volcanism and seismicity.

The U.S. Geological Survey has completed an extensive mapping program to determine the history and severity of the volcanic hazard on the Island of Hawaii. Hawaiian volcanoes erupt either at their summits where lava collects, and may overflow from craters called calderas, or along their flanks where lava issues through fractures called rift zones. The volcanic hazard is associated with lava flows, explosive eruptions, airborne lava fragments, poisonous and corrosive volcanic gases, and ground cracks and settling.

The lava flow hazard zone map divides the island of Hawaii into nine zones that are ranked 1 to 9 based on the occurrence probability of lava flows (Table 10). Although the other volcanic hazards are not ranked, these hazards also tend to be greatest in the areas where lava flows are ranked at highest probabilities.

Lava flows present the most frequent hazard associated with Hawaiian volcanoes, however they rarely endanger human life. Property loss and economic devastation are the most frequent consequences of lava movement. At the coastal zone, flowing lava tends to slow and spread laterally, because of the diminished slope, causing damage along the shoreline.

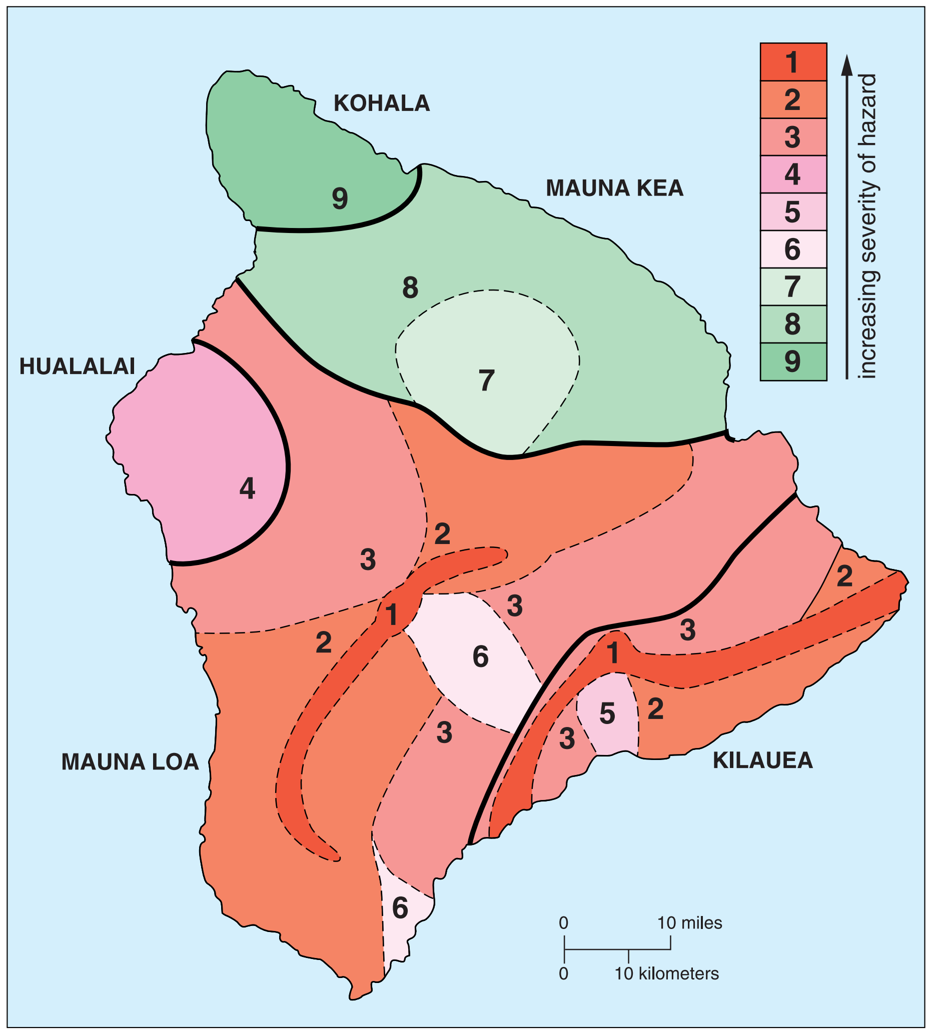
TABLE 10
Hazard zones for lava flows

Zone	Percent of area covered by lava		Explanation
	since 1800	in last 750 yrs	
Zone 1	> 25%	> 65%	Includes the summits and rift zones of Kilauea and Mauna Loa where vents have been active in historic time.
Zone 2	15–25%	25–75%	Areas adjacent to and downslope of active rift zones.
Zone 3	5%	15–75%	Areas gradually less hazardous than Zone 2 because of greater distance from recently active vents and/or because topography makes it less likely that flows will cover these areas.
Zone 4	1-5%	<15%	Includes all of Hualalai, where the frequency of eruptions is lower than on Kilauea and Mauna Loa. Flows typically cover large areas.
Zone 5	none	about 50%	Areas currently protected from lava flows by the topography of the volcano.
Zone 6	none	very little	Same as Zone 5.
Zone 7	none	none	20% of this area covered by lava 3,000–5,000 years ago.
Zone 8	none	none	Only a few percent of this area covered in the last 10,000 years.
Zone 9	none	none	No eruption in this area for the past 60,000 years.

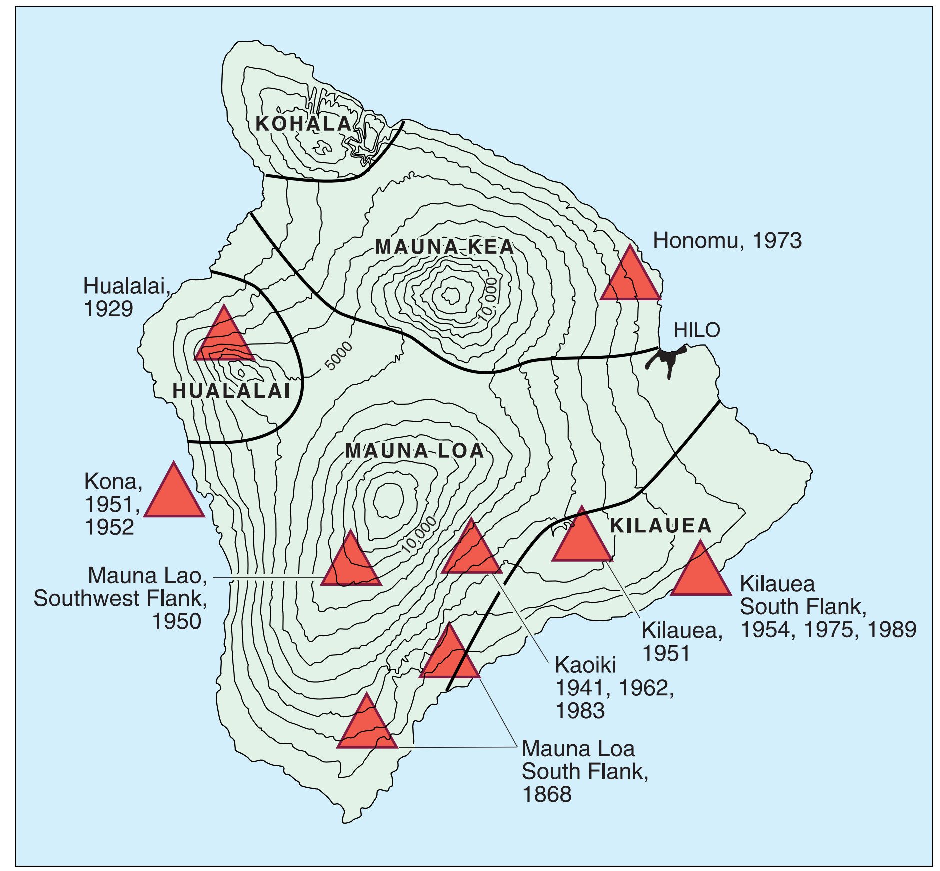
Airborne ash, cinders, and other lava fragments are usually only hazardous in the immediate vicinity of an eruption. Volcanic gases generated by the present eruptions at Kilauea are composed mostly of water vapor, with lesser amounts of sulfur dioxide, carbon dioxide, and hydrogen. Small quantities of carbon monoxide, hydrogen sulfide, and hydrogen fluoride have been measured, but not in health-threatening concentrations. These gases, particularly sulfur dioxide, can mix with rainwater to create a corrosive acid rain downwind of the Kilauea eruptions, and higher than average acidity has been documented in drinking water samples but not at hazardous doses. Water-catchment systems, however, often have lead-based metals such as roof flashing, lead-headed nails, and pipe solder that can be leached into solution by high-acidity water. Widespread testing in 1988 found that many water-catchment systems on the island of Hawaii, especially those down-wind of the main eruption center, contained elevated concentrations of lead.

Explosive eruptions are not common at Kilauea but they have occurred within historical times. The interaction of ground water and hot magma can lead to a violent explosion, and the resulting magnitude of the event can be catastrophic in the wrong circumstances. In 1790 turbulent avalanches of hot gases and rock fragments, called pyroclastic surges, flowed several miles to the southwest from the summit of Kilauea. These can move at speeds approaching 200 miles per hour and kill any living thing in its path. A band of approximately 80 Hawaiian warriors traveling from Hilo to the Kau District at the time to engage King Kamehameha in battle were killed by one of these surges. Geologists have analyzed thick deposits from pyroclastic flows around both Mauna Loa and Kilauea and determined that widespread surges have occurred in the recent past.

Although volcanism and seismicity pose a significant risk in the Hawaiian Islands, the hazard level can be reduced and, in places, mitigated. Programs of public education can teach the citizens of the state about the proper behavior around volcanically active regions and of life-saving steps to take during an earthquake. Proper building codes and frequent re-evaluation of the appropriate level of construction techniques are a key component in public safety. Land-use zoning that restricts development on or near steep slopes that may fail during earthquakes and away from areas characterized by sedimentary and/or saturated materials that are likely to amplify ground motions during an earthquake are important steps to reducing hazard levels. Loss of life and damage to communities can be reduced by proactive management and public awareness.



Lava flow hazard zone map for the five volcanoes on the Island of Hawaii.



Historical earthquake epicenters on the Island of Hawaii.

Concluding Notes

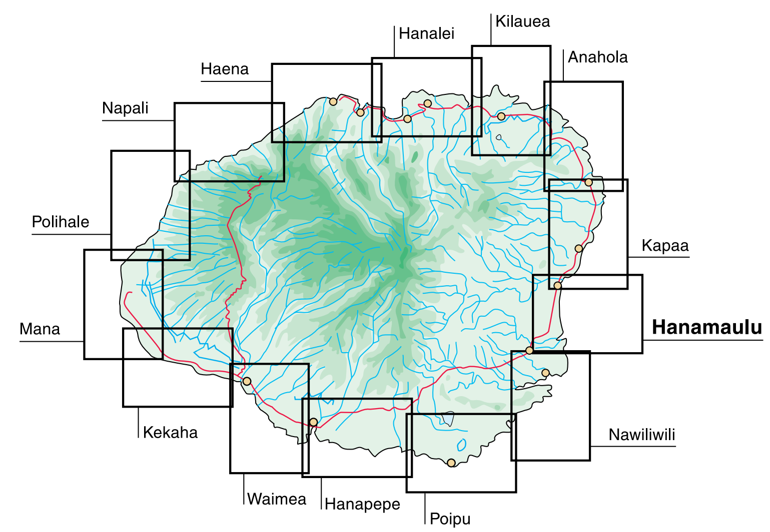
A few minor concluding notes are in order at this point before we move on to an analysis and assessment of the natural hazards in the Hawaiian coastal zone.

Part of our criteria in assigning severity rankings is based on historical observations of hazard intensity and magnitude. The damage history related to all hazards only covers the late 19th to 20th centuries, and only the era of satellite technology (1960 to present) allows controlled coverage of meteorological hazards. For instance, volcanic and seismic hazards probably have longer recurrence intervals than reported in the short history available for this study. Also, hurricanes and other meteorological events have only been uniformly detected since 1960. Our understanding of storm intensity and frequency is therefore skewed towards this dataset, and a broader understanding of hazard history in Hawaii is not possible.

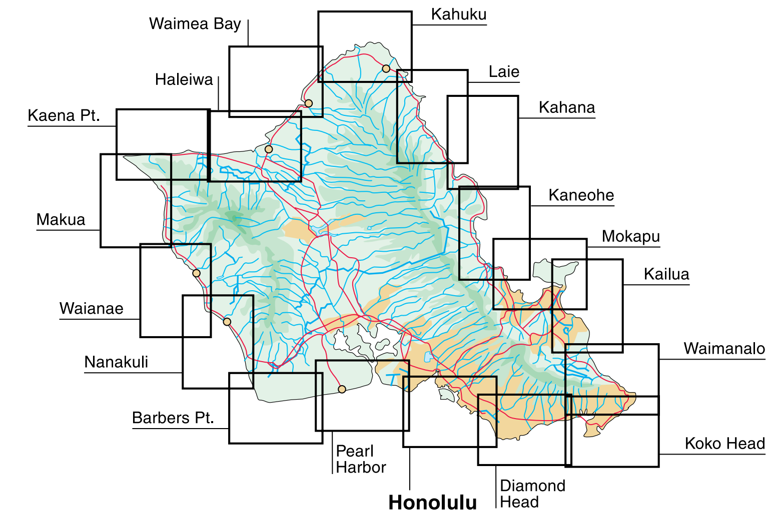
Damage in areas hit by natural hazards during early years (prior to 1960) was generally only recorded in populated regions, thus a significant (and unknown) hazard history may exist for areas that are only recently populated. Because of this, newly populated areas may have been assigned a lower severity ranking than may be appropriate.

Index to Technical Maps

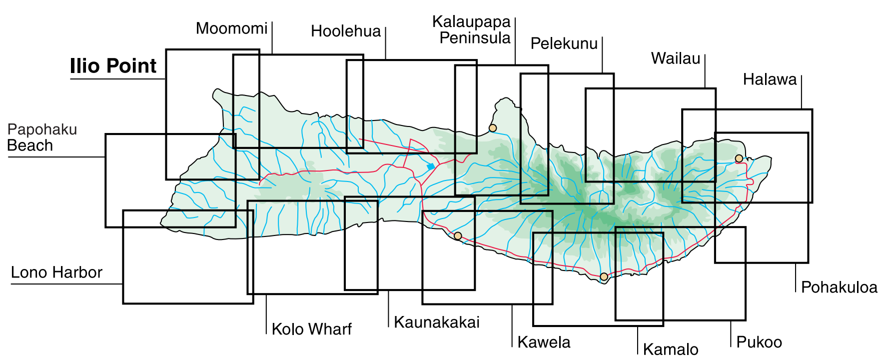
Kauai

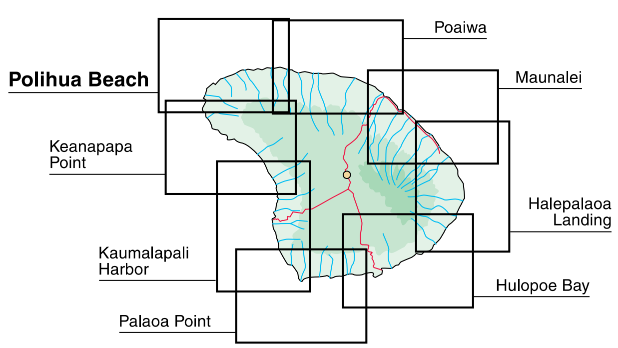


Oahu

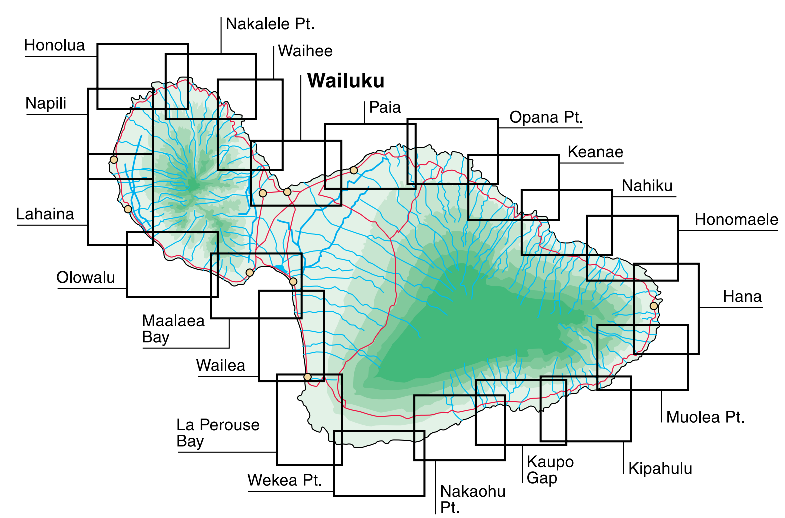


Molokai and Lanai

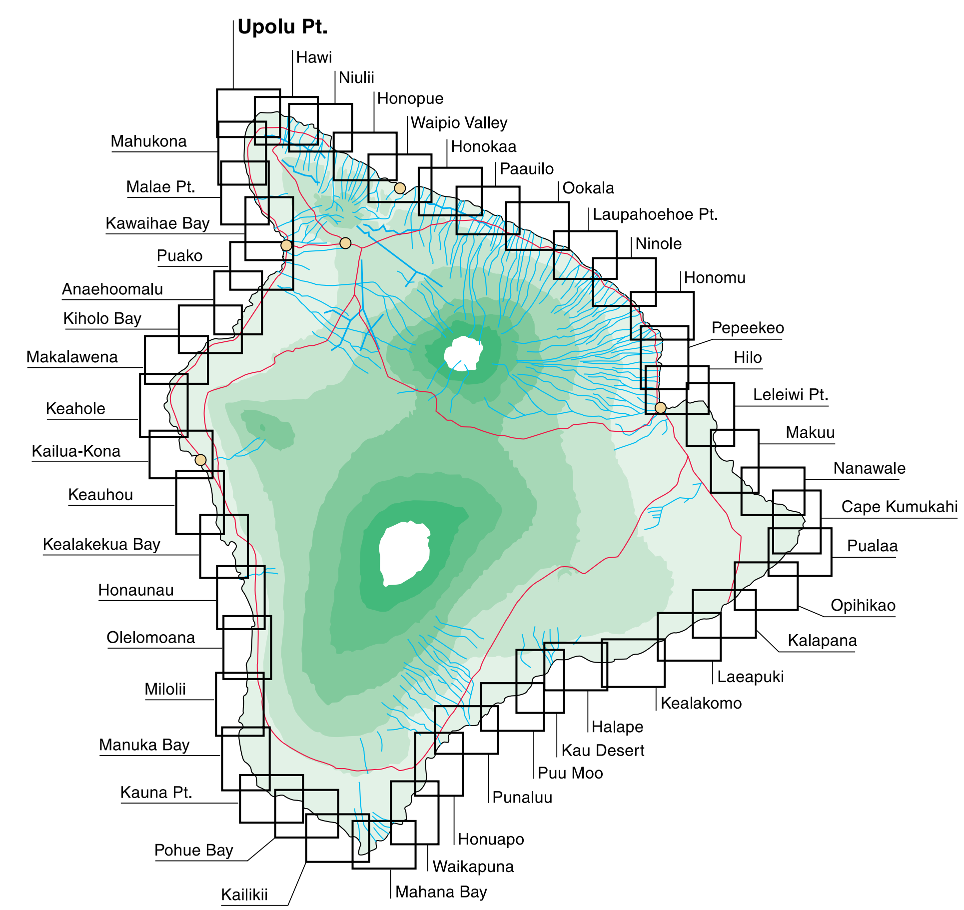




Maui

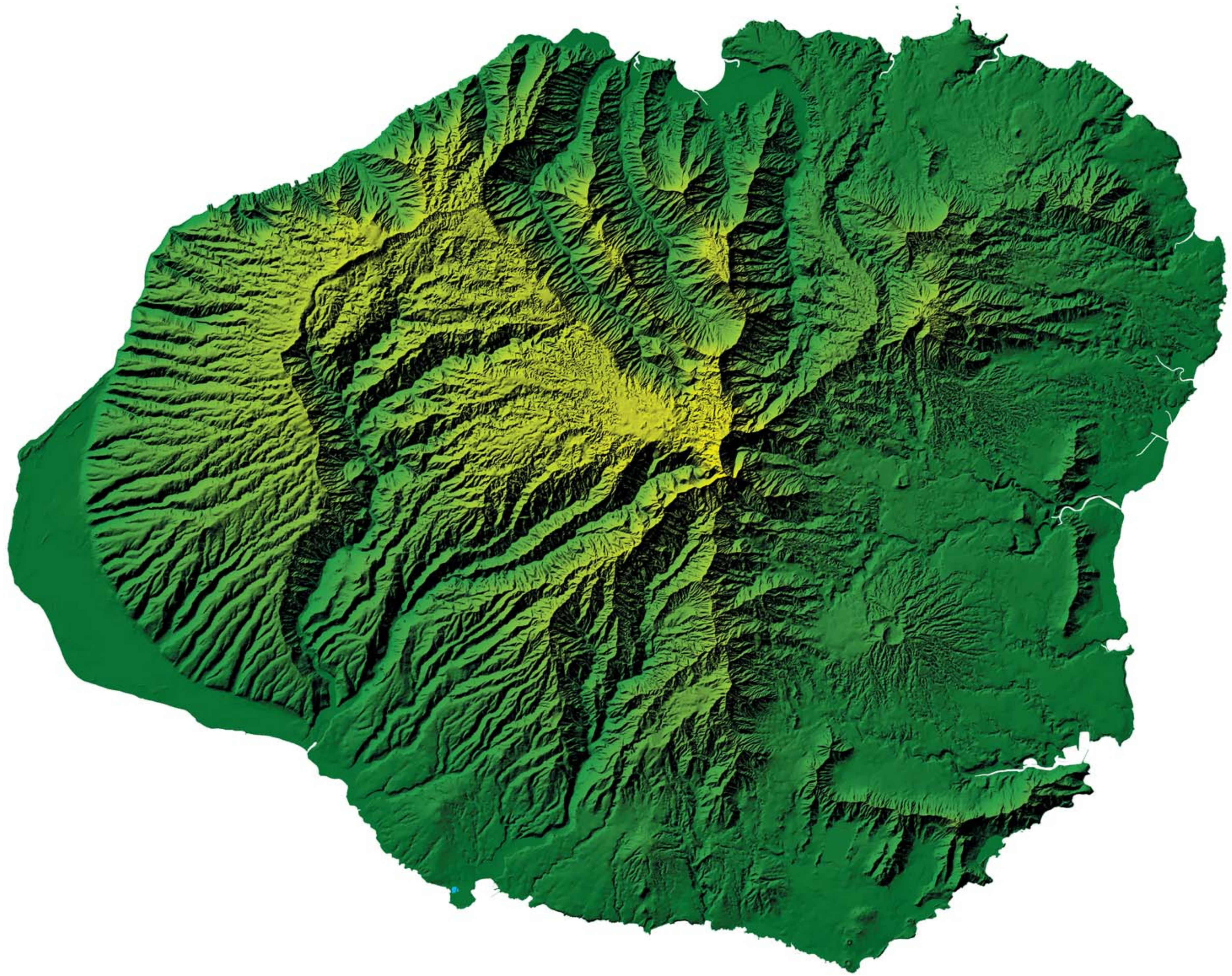


Hawaii



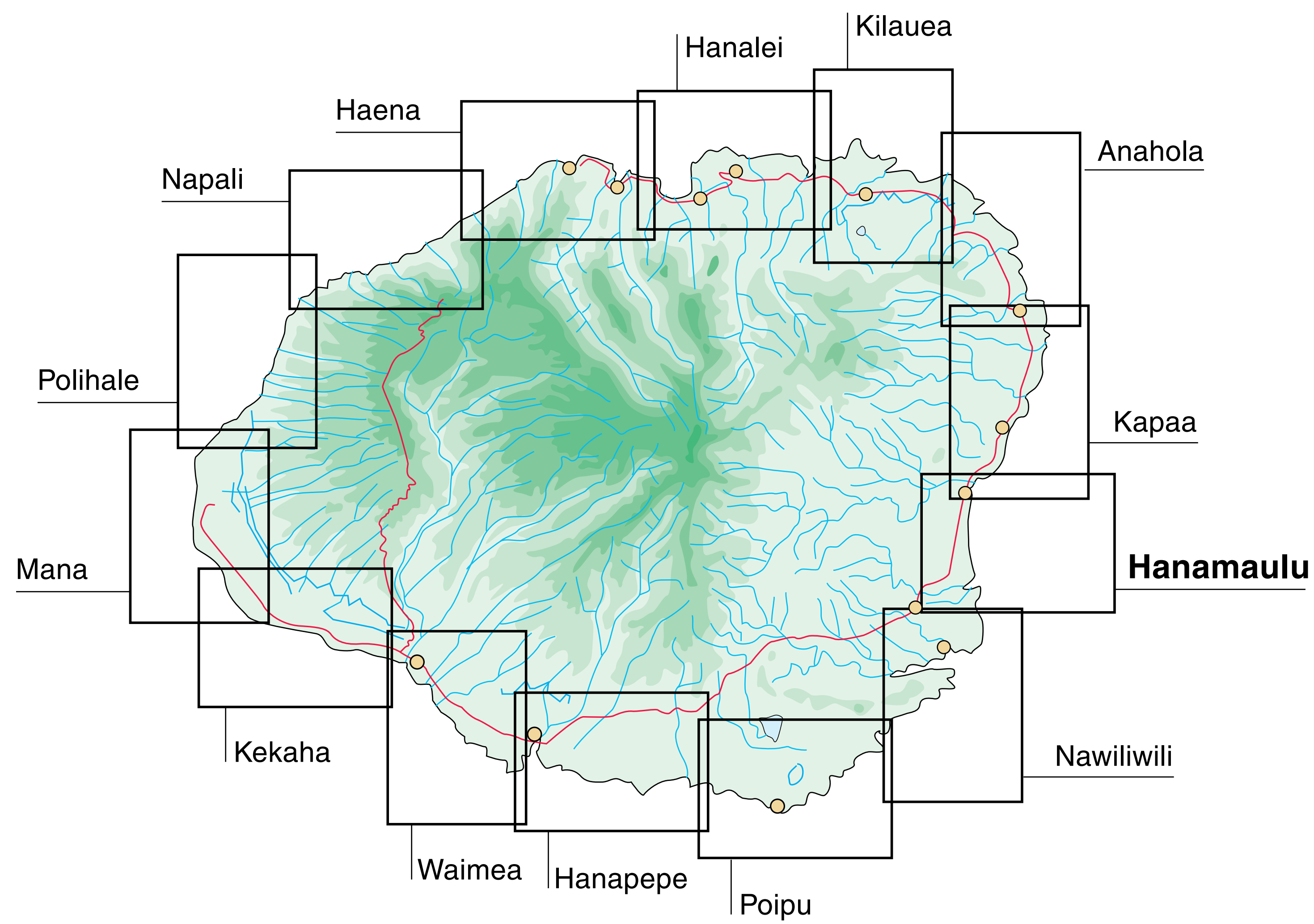
Kauai

The Garden Isle of Kauai is the oldest and most eroded of the main Hawaiian Islands. Mount Waialeale, located in the middle of the island, is one of the wettest places on Earth. As a result, stream erosion and flooding are common, carving deep valleys and canyons and transporting abundant sediment to the coast. Flooding is especially prominent in the coastal zone, where the steep slopes of the central mountains meet the low-lying coastal plains.



Kauai

Index to Technical Hazard Maps



Tsunamis

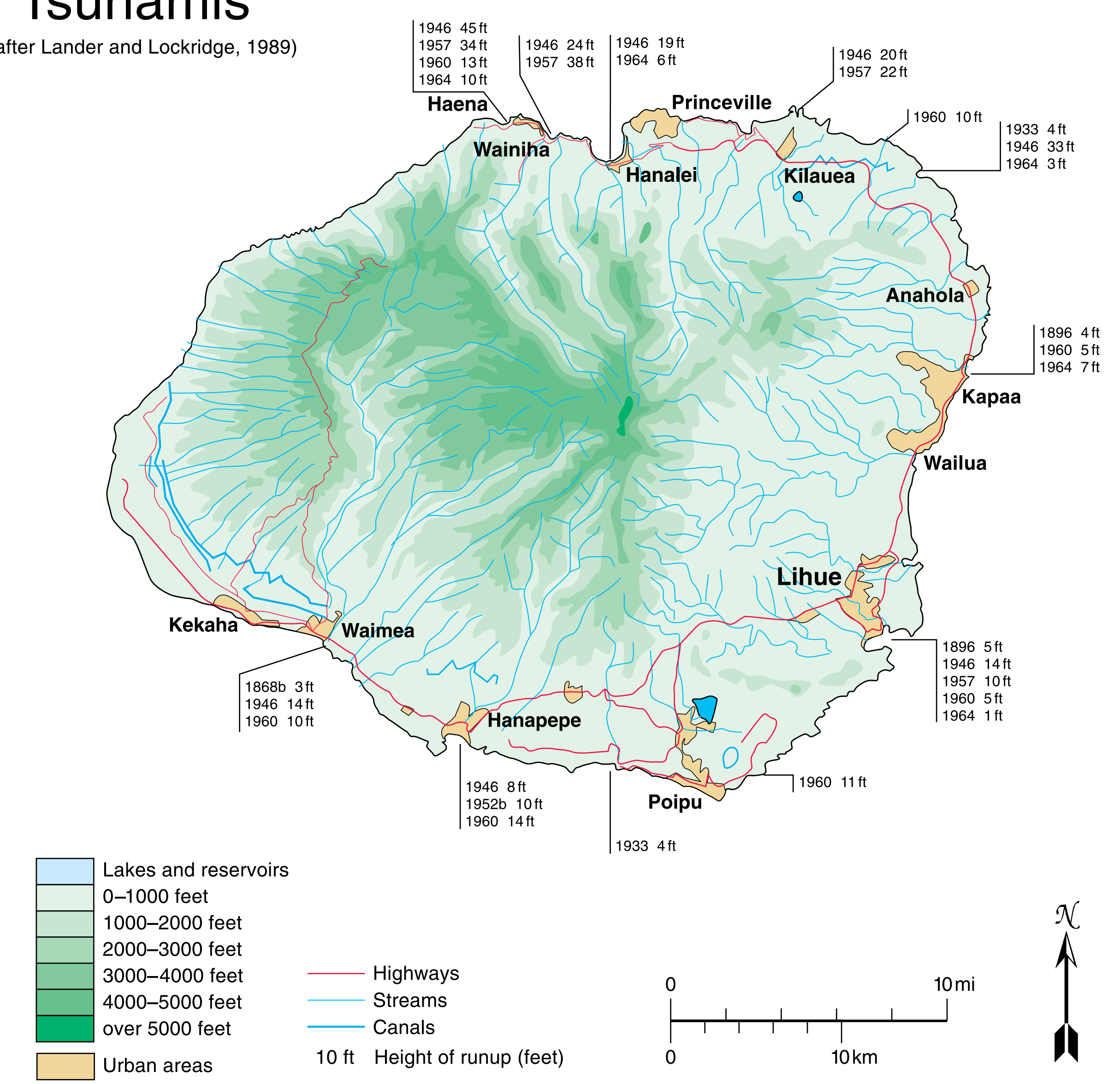
A tsunami is a series of great waves most commonly caused by violent movement of the sea floor. It is characterized by high speed (up to 590 mph), long wave length (up to 120 mi), long period between successive crests (varying from 5 min to a few hours, generally 10 to 60 min), and low height in the open ocean. However, on the coast, a tsunami can flood inland 100's of feet or more and cause much damage and loss of life. Their impact is governed by the magnitude of seafloor displacement related to faulting, landslides, and/or volcanism. Other important factors influencing tsunami behavior are the distance over which they travel, the depth, topography, and morphology of the offshore region, and the aspect, slope, geology, and morphology of the shoreline they inundate. Their behavior is chaotic and relatively unpredictable. As a result, their expression at the shoreline can be considerably different within very short distances. This has been observed throughout Hawaii. The only general rule is that runup heights tend to be greatest near headlands, where the offshore bathymetry is steeper, enabling greater wave energy to reach the shore. Along gently sloping coasts, runup heights are reduced as wave energy is dissipated upon shoaling. Even so, inundation can be significant and is usually greatest along low-lying coastal plains. This is because tsunami waves have extremely long wavelengths. As they pass, the water level can rise for several minutes and/or tens of minutes, pushing far inland.

An important historical example that demonstrates the variability of tsunami impact at the shoreline occurred during the 1946 tsunami on the north shore of Kauai. Despite the same north-facing exposure at Haena and Hanalei, a runup height of 45 ft was recorded at Haena, while only a few miles away in Hanalei Bay, runup was 19 ft. In some cases, the runup height has been nearly equal on opposite sides of the island, suggesting that shoreline orientation (facing the tsunami source) is not always an important control. For example, during the 1960 tsunami, generated by an earthquake in Chile far to the southeast, a runup of 13 ft was recorded at Haena, only 1 ft lower than the maximum of 14 ft for the entire island reported at Hanapepe. Despite these variations, each side of Kauai has observed tsunami runups of over 10 ft with significant damaging effects.

The recorded history of Hawaiian tsunamis shows that 26 large tsunamis have made landfall within the islands and 8 have had significant damaging effects on Kauai. The last of these damaging tsunamis occurred in 1964, yet before this time (since 1868), a damaging tsunami reached Kauai on average once every 12 yr. It is important to note that the frequency of tsunami occurrence is chaotic or unpredictable and particular periods of time may be characterized by significantly different tsunami activity than others. For example, between 1868 and 1933, only three major tsunamis impacted Kauai's shores with an average reccurrence interval of 22 yr. However, during the more active period between 1946 and 1964 five tsunamis had damaging impacts to Kauai at an average frequency of 3.5 yr. Regardless of which time period we analyze, an important observation of the data is that since 1964, Kauai has not experienced a damaging tsunami. One might conclude that a damaging tsunami is long overdue to hit Kauai. Interestingly it has been precisely in this time that tremendous coastal development has occurred, raising the risk of damage from future tsunamis.

Kauai Tsunamis

(after Lander and Lockridge, 1989)



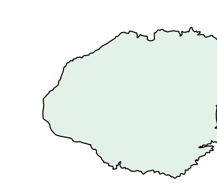
Large tsunamis* (>1m, 3.3 ft) with reported damage in the Hawaiian Islands

Year	Date	Area of origin	Magnitude**
1819	Apr 12	N Central Chile	M= 2.0
1835	Feb 20	Southern Chile	M = 4.0
1837	Nov 7	Southern Chile	M = 3.0
1841	May 17	Kamchatka	M = 2.0
1868a	Apr 3	SE Hawaii	M = 4.1
1868b	Aug 13	Northern Chile	M = 4.3
1868c	Oct 2	South Pacific	
1869	Jul 24	South Pacific	
1877	May 10	Northern Chile	M = 4.0
1878	Jan 20	Aleutian Is (?)	
1896	Jun 15	Japan	M = 4.0
1901	Aug 9	Tonga	
1906a	Jan 31	Colombia/Ecuador	M = 1.0
1906b	Aug 17	Central Chile	M = 2.0
1918	Sep 7	Kurils	M = 3.6
1919	Oct 2	Hawaii (H = 14 ft)	
1922	Nov 11	N Central Chile	M = 3.0
1923	Feb 3	Kamchatka	M = 3.0
1933	Mar 2	Japan	M = 3.0
1946	Apr 1	Eastern Aleutian Is	M = 5.0
1952a	Mar 17	Hawaii (H = 10 ft)	
1952b	Nov 4	Kamchatka	M = 4.0
1957	Mar 9	Central Aleutian Is	M = 3.5
1960	May 22	Chile	M = 4.5
1964	Mar 28	Gulf of Alaska	M = 4.5
1975	Nov 29	Big Island/Hawaii (H = 47 ft)	

*Reliability of ≥ 3 (of 4)(Lander and Lockridge, 1989), runup > 1m (3.3 ft), and reported damage.

** Tsunami magnitude is defined by $M = \log_2 H$ as revised by Iida and others (1967), where H is the maximum runup height or amplitude on a coastline near the generating area.

Other tsunamis have occurred, such as that of Oct 1994, however, because of their low (<1 m) runup, insignificant damage, and/or uncertainty surrounding their timing and magnitude as noted in Lander and Lockridge (1989), they were not included here.



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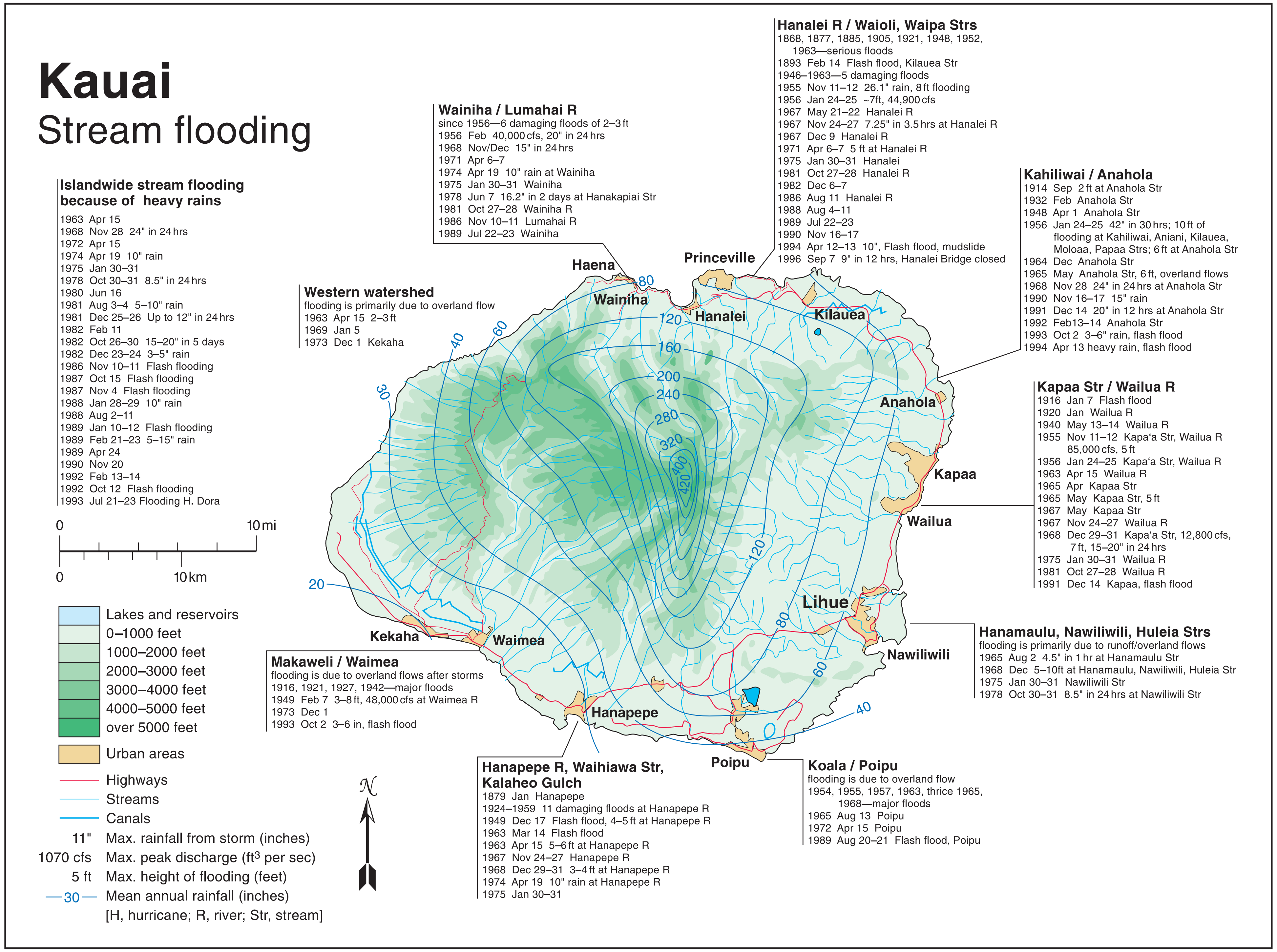
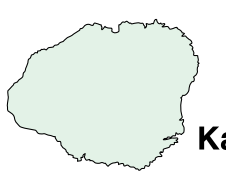




Stream flooding

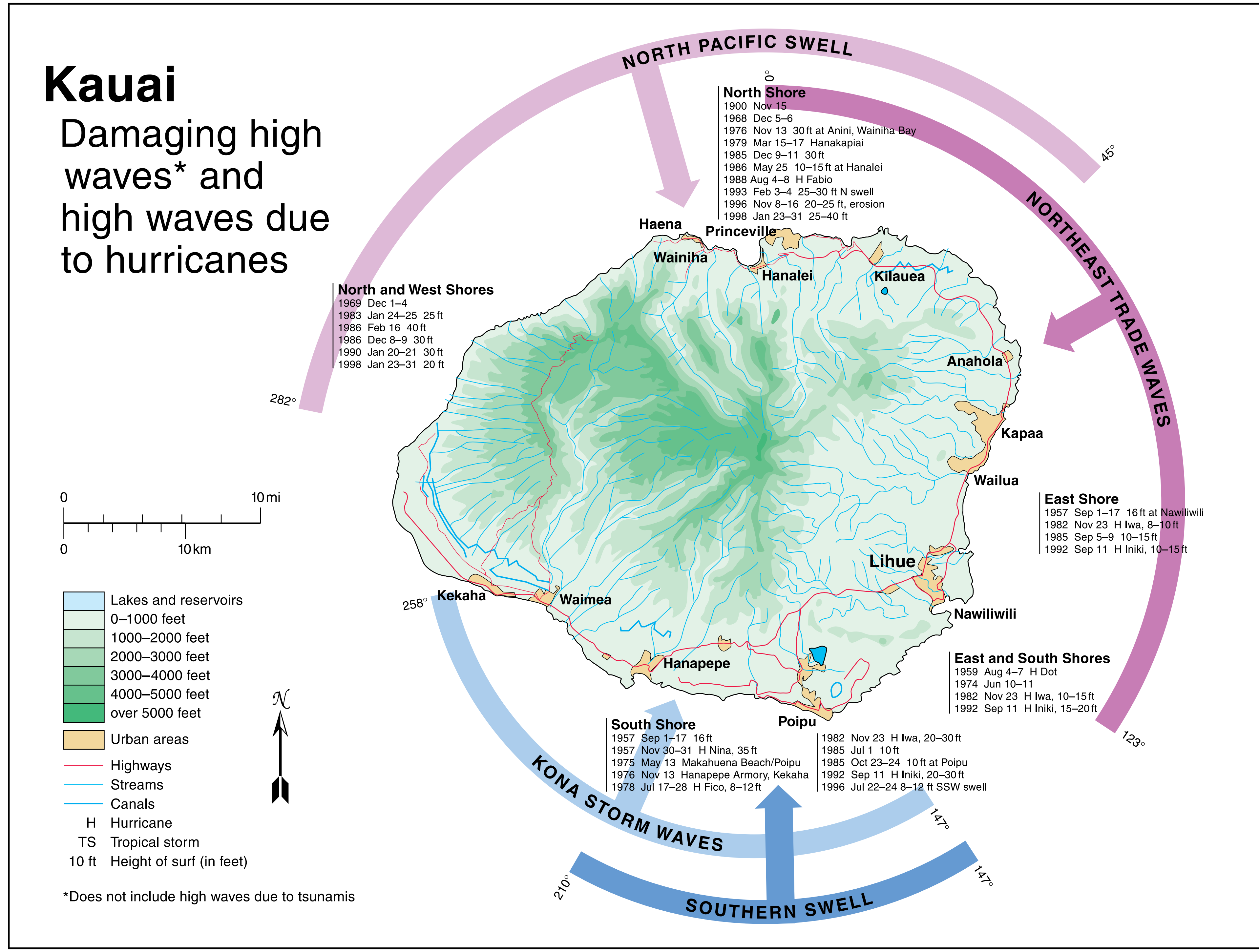
Stream flooding on Kauai is characterized by numerous flash floods as well as prolonged flooding associated with slowly passing rainstorms that saturate the soils. Kauai, famous as one of the wettest places on Earth, receives between 20 and 80 in of annual rainfall along the coast and more than 400 in at the higher elevation of Mt. Waealeale. Because of the abrupt transition from steep mountain topography to narrow, low-lying coastal plains, high precipitation often results in extremely high runoff on the mountain sides and channel overflow in the gently sloping streams at the coast. During prolonged rainfall, precipitation often exceeds absorption into the soil, which also transpires into high runoff and occasional mud slides. There is a long history of settlement in and near active stream valleys on Kauai, primarily for the agricultural benefit of naturally irrigating taro and other wetland crops. However, with the increase in development of homes, resorts, and public infrastructure along low-lying stream lands during the past two decades, flooding is not considered as beneficial today as it once was. As a result, many floodprone regions are now being artificially channelized to the detriment of wetland and floodplain ecosystems.

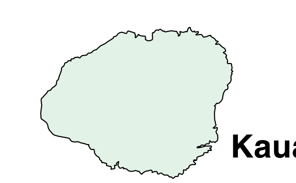
Flash floods resulting from a storm on December 14, 1991, that dropped over 20 in of rain in 12 hr over Anahola caused five deaths, intense flooding, bank failures, erosion, and slides totaling more than $5 million in property damages. During recent recorded history, such events are not uncommon. On January 24-25 1956, 42 in of rain fell in 30 hr on the northeast side of Kauai leading to 10 ft of floodwaters in the streams between Kilauea and Anahola. The Hanalei River, which most directly drains the wettest region of Mt. Waialeale, overflows its banks at the coast nearly every year. Some years are considerably more damaging than others, for example, November 1955, January 1956, April 1994, and September 1996. In September of 1996 for instance, 9 in of rain were recorded in 12 hr along the coast, and an uncertain amount fell in the uplands. This event led to flooding of Hanalei town and temporary closure of the Hanalei Bridge, the residents' sole access to the rest of the island. In the western portion of Kauai, the flooding hazard is primarily due to overland flows, especially after storms. Waimea River, for example, has a long record of flooding dating back to 1916 and includes numerous occasions when its channels overflowed after storm-fed precipitation in Waimea Canyon above. The challenge to mitigating the hazard due to stream flooding is in large part one of obtaining adequate warning in the case of flash floods and in improved planning of developments in areas of known flood history.

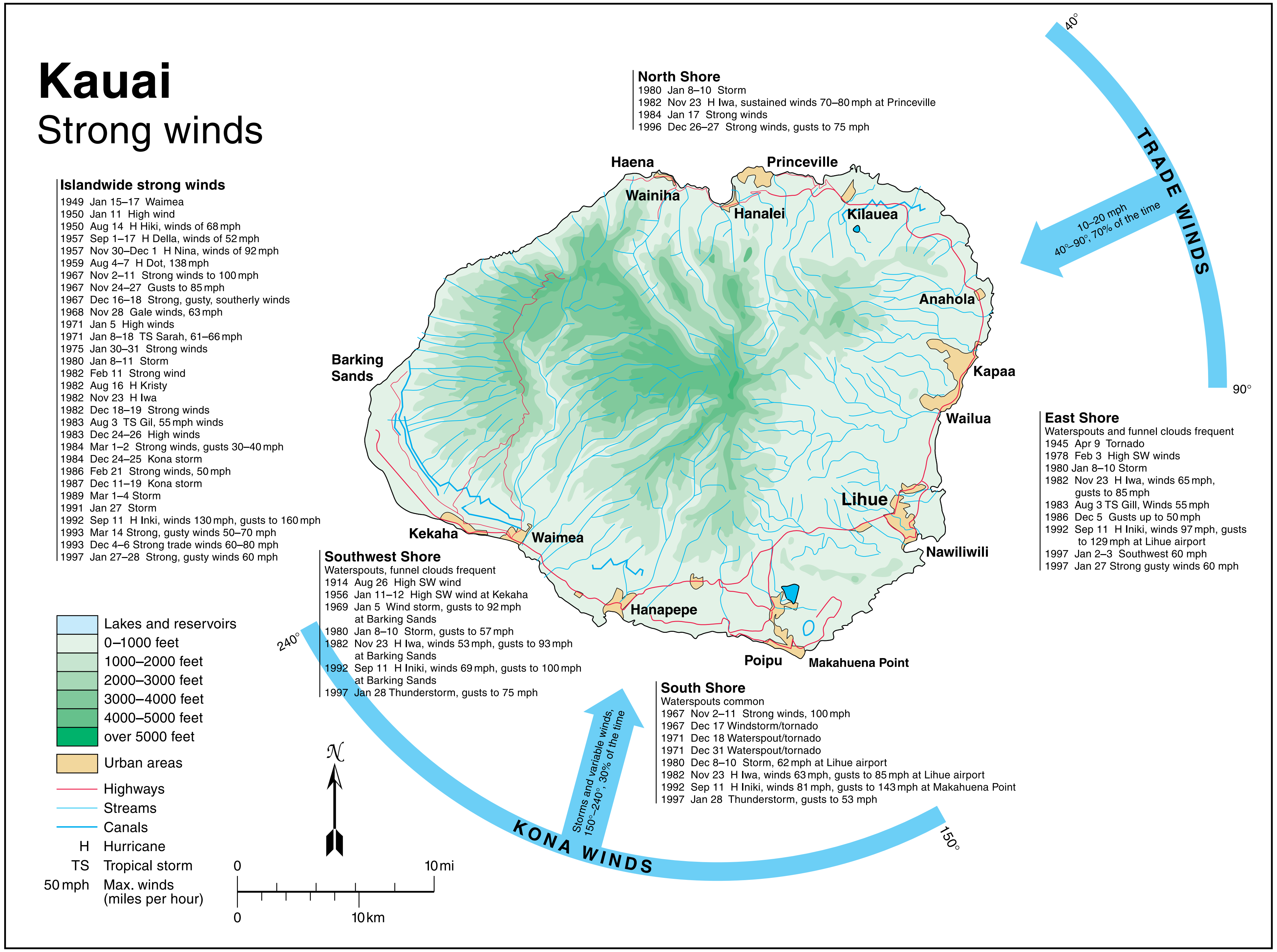
High waves

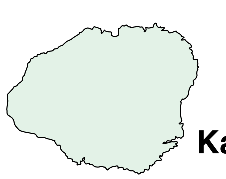
Each year the Hawaiian Islands receive high waves originating from distant regions in the Pacific Ocean as well as passing storms in close proximity to Hawaiian shores. The north shore of Kauai, like the north shores of all of the islands, is subject to extraordinary wave heights each winter ranging between 20 and 40 ft due to north and northwest swell. The south shore on average sees waves of 4 to 8 ft each summer from south and southwest swell. High waves in Hawaii are also generated by approaching storms, including tropical storms and hurricanes in summer and fall, as well as winter Kona storms. Strong trade wind events also stir up high waves that influence the east-facing shorelines. High waves can be damaging to life and coastal property and, when they coincide with high tides and/or storm surges, can inundate far inland. Nearly each year in Hawaii, high waves are reported to overwash and flood coastal lands and erode beaches and coastal property. The behavior of surface waves at the shoreline is determined by a large number of factors including swell height, period and direction, nearshore bathymetry and morphology, and shoreline aspect and slope. The interaction of these factors makes it difficult to accurately predict the hazard outcome at individual shorelines. Because of Hawaii's isolation in the central North Pacific Ocean, and the lack of inhabited islands north of Kauai, the magnitude and threat of high waves from north swell is often only recognized as the waves crash upon Kauai's shores. New technologies, including offshore wave sensors, are helping to provide adequate warning to approaching high waves with damaging potential.

The historical record of high wave events on Kauai spans the 1900s but the majority of observations have been made only since the late 1950s. The largest wave events occurred on the north shore due to strong storms in the north Pacific, like those in December 1985, February 1993, November 1996, and January 1998. The events, like most north swell, had high wave amplitudes in addition to long wave periods and transferred enormous energy across the nearshore and onto the shoreline. They were associated with beach erosion and overwash of coastal property and, in the case of the November 1996 event, 20-25 ft waves and a high tide swept a rental home off of its foundation. The west shore on average sees waves of 15-20 ft each year, but occasionally waves as large as 40 ft, like in February 1986, reach west Kauai. South and southwest swell, while typically of lower height, generally have longer period, and the energy they transmit can be sufficient to impact the shoreline. Wave heights of 8-12 ft occasionally reach the south and southwest shore from distant storms in the Southern Hemisphere and overwash the low-lying regions. Passing hurricanes, however, have generated the highest wave heights along the south- and east-facing shores and may coincide with a high tide and typically generate a strong storm surge. Waves ranging from 20-30 ft were associated with Hurricane Nina (35 ft) in November 1957, Hurricane Iwa in November 1982, and Hurricane Iniki in September 1992 along the south coast near Poipu. Runup of ~29 ft above sea level was recorded near Poipu during Hurricane Iniki, which left a debris line more than 800 ft inland of the shoreline and landward of the coastal road. Waves as high as 15 and 20 ft were reported along Kauai's east shores during Hurricanes Iwa and Iniki.









Kauai

Strong winds

Strong winds on Kauai are associated with exceptionally strong trade wind events, winter Kona storms, and passing tropical storms and hurricanes. Trade winds dominate on average 70% of the year with easterly and northeasterly winds ranging between 10 and 20 mph. However, occasionally the subtropical high pressure cell to the north of Hawaii intensifies such that the trade winds strengthen to between 25-40 mph for several days. Strong winds associated with Kona storms generally occur in the winter and originate out of the south and southwest as areas of low pressure pass the islands. Kona winds can reach great velocities. The highest winds are typically associated with passing tropical storms and hurricanes and have been reported at over 100 mph. All of these winds can accelerate as they descend from the mountains to the coastal plains. In many instances, the highest recorded gusts associated with passing storms have occurred on the side of the island opposite the storm approach as winds burst in downdrafts across ridge crests from the steep palis (cliffs) to the coast below.

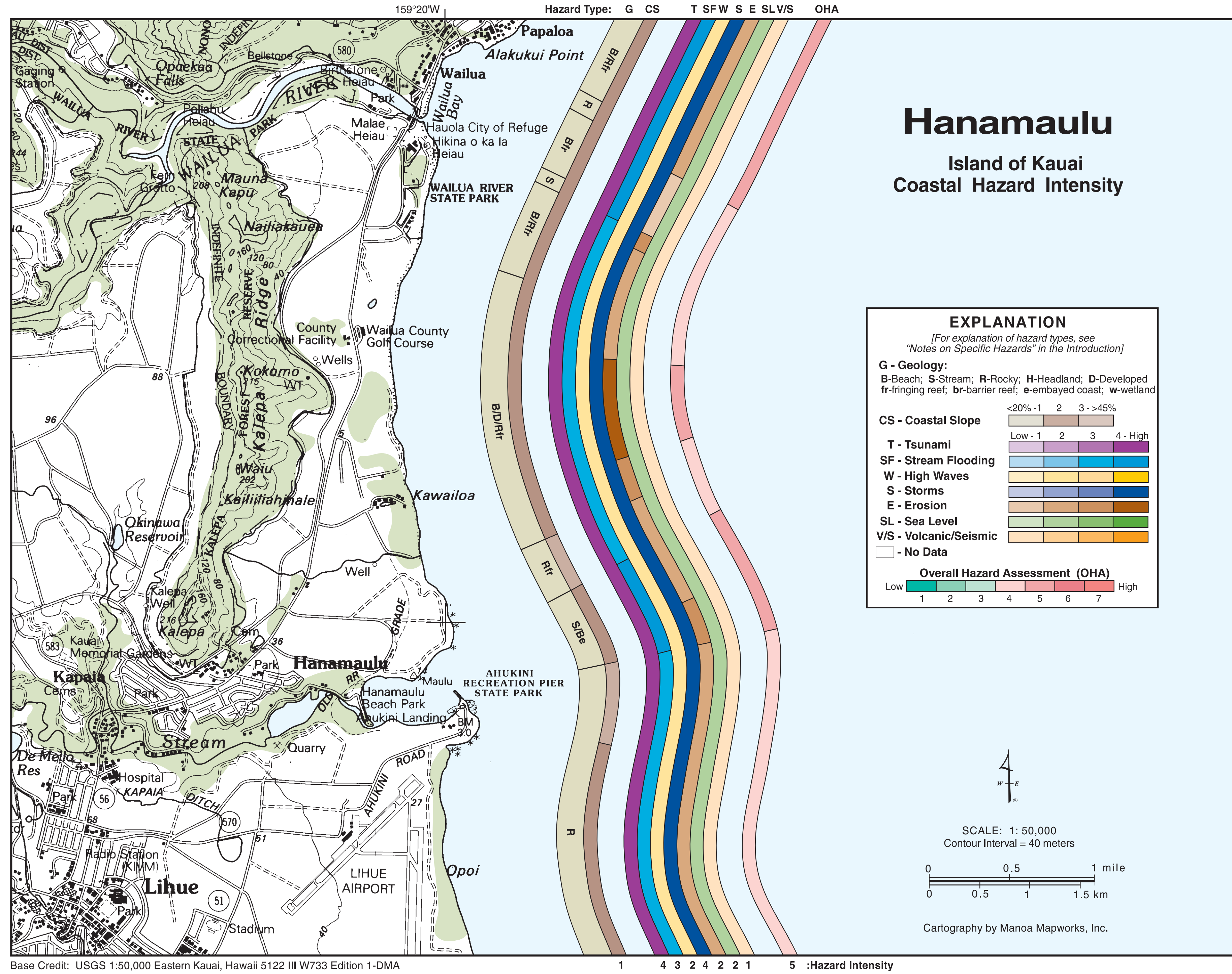
On Kauai numerous high wind events have affected the entire island, and many of these events were associated with passing storms. Hurricanes Dot in August 1959, Iwa in November 1982, and Iniki in 1992 were exceptionally damaging. Hurricane Dot packed sustained winds of 75 mph with gusts of 165 mph as it passed directly over Kauai. While the storm-generated surf was not particularly damaging, winds and flooding led to $5.5-6 million in agricultural losses and hundreds of houses and trees were damaged. Hurricanes Iwa and Iniki both produced high waves ranging 20-30 ft in addition to winds over 125 mph. Although Hurricane Iwa passed to the northwest of Kauai, the high surf it produced, combined with a 5-6 ft storm surge, flooded 600 ft inland in areas between Kekaha and Poipu and caused $312 million in damage. Ironically, despite the massive flooding and wind damage to the Poipu area, redevelopment following Iwa occurred in precisely the same location, only to be devastated 10 yr later by Hurricane Iniki. Today, these same areas are once again densely developed. On September 11, 1992, Hurricane Iniki, the strongest and most destructive hurricane to hit the Hawaiian Islands, made landfall just west of Port Allen on Kauai's south shore. Iniki's winds were sustained at 130 mph and gusts topped 160 mph. Winds and waves destroyed 1,421 houses and caused minor to heavy damage to 13,000 other houses.

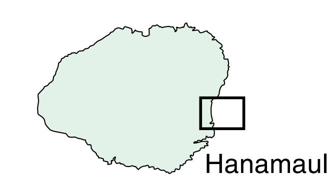
Hanamaulu

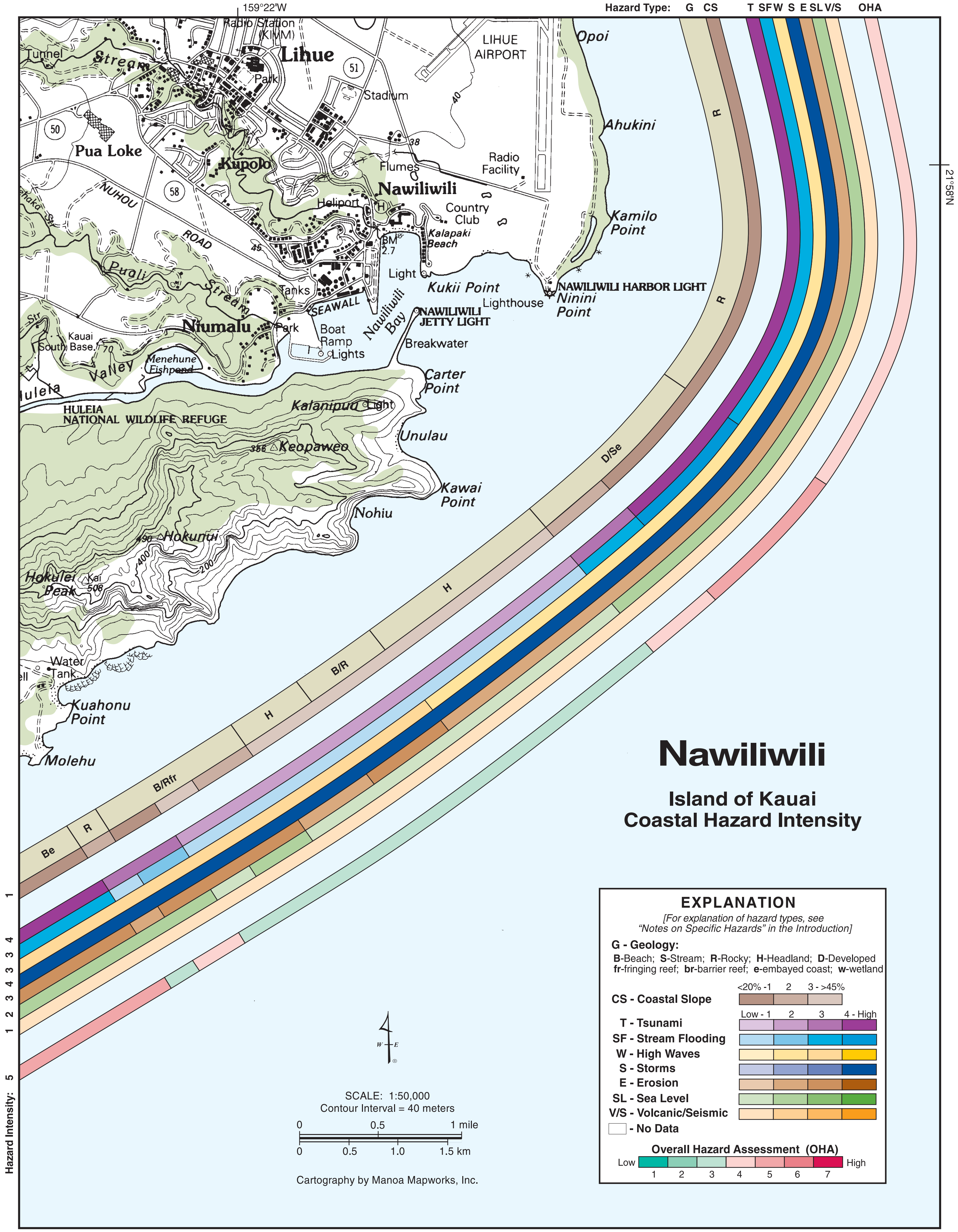
The Hanamaulu coast, from Alakukui Point south to Opoi, is lightly developed with several resorts, the Wailua County Golf Course, and Lihue Airport. The region has a relatively low slope, except along the rocky headlands bordering Hanamaulu Bay. Two prominent beach systems are located at Wailua and Hanamaulu Bays, which lie at the mouths of Wailua and Hanamaulu Rivers, respectively. Wailua River is one of the few navigable rivers in Hawaii. It is wide and during floods it can have significant discharge which can reshape the southern portion of Wailua Beach and the sandbar that forms at its mouth. Hanamaulu Beach is a 1500 ft long arcuate beach at the head of Hanamaulu Bay. The inner portion of the bay is covered mostly with sand, but small fringing reefs occur near the rock headlands. A relatively narrow fringing reef parallels the Hanamaulu coast 200 to 300 ft offshore. Facing east, this trade-wind swept coast is relatively arid, receiving on average 40-60 in of rainfall each year.

The Overall Hazard Assessment (OHA) for the Hanamaulu Coast is moderate to high (5) north of and including the northern half of Wailua Bay and moderate (4) to the south. This distinction is largely dictated by the higher stream-flooding hazard in the low-lying Wailua embayment and to the north. Except at the river mouth, Wailua Bay has a lower erosion hazard than to the north of Alakukui Point, resulting in a moderate (4) OHA for the Wailua Bay segment of the Hanamaulu coastline. The tsunami hazard is high along the entire Hanamaulu coast. The potential for stream flooding is high north of the Wailua River and moderately high to the south except in Hanamaulu Bay where it is also high. The threat of high waves and sea-level rise are moderately low, while storms are high along this entire east-facing coast. Erosion is moderately low, except between the Wailua River and just south of Alakukui Point where it is low, at the headland south of the Wailua River where it is moderately high, between the Wailua County Golf Course and Kawailoa where it is high, and immediately south of Kawailoa where it is moderately high. Erosion is also moderately high along Hanamaulu Beach Park. The volcanic-seismic hazard is ranked low along the Hanamaulu coast as it is around the entire island of Kauai.

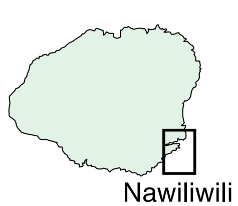
The narrow, wind-swept shoreface of the Wailua County Golf Course is composed of a narrow sandy beach eroding against a long seawall protecting the fairway. To the north and south, beach erosion has left the shoreline mostly rocky.







Base Credit: USGS 1:50,000Eastern Kauai, Hawaii 5122 III W733 Edition 1-DMA



Nawiliwili

South of the Lihue Airport to Molehu Point, the coast is highly irregular; its shape is controlled by the elongated and drowned Huleia Stream valley forming Nawiliwili Bay. This embayment is largely protected by a rocky headland at Ninini Point and a breakwater that extends into the bay from Carter Point. Between Carter and Kuahonu Points, relatively steep-sloping hills meet the sea in three beautiful pocket coves. Nearly the entire Nawiliwili coast is rocky with headlands, except for two beaches in the southernmost coves near Kuahonu Point, and the gently-sloping Kalapaki Beach inside Nawiliwili Bay. A narrow fringing reef exists offshore of Kuahonu Point, otherwise most of the Nawiliwili region is open to approaching south, southwest, and refracting trade wind swell. Nawiliwili Bay is relatively industrial, while the region to the southwest is primarily undeveloped.

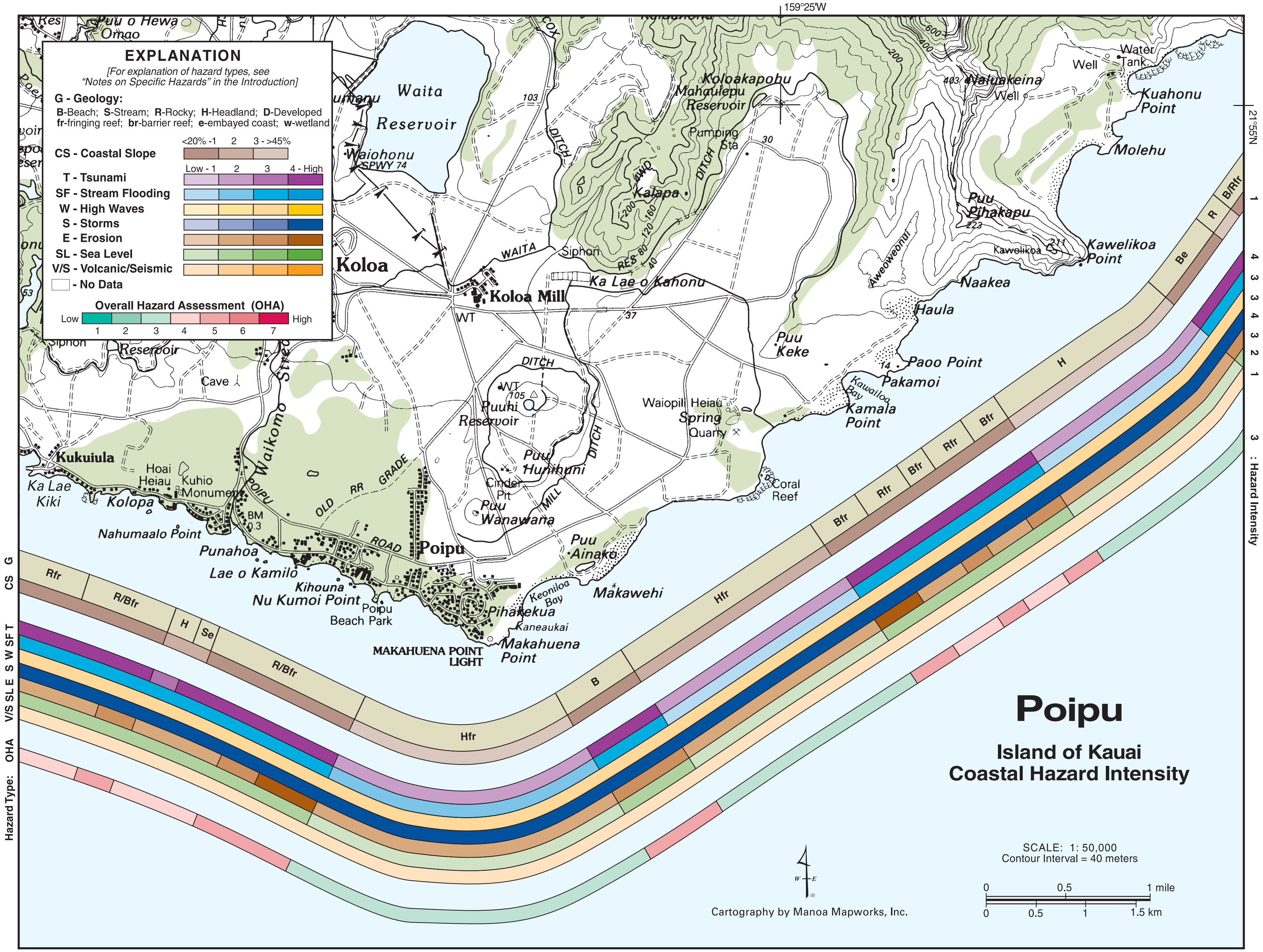
The Overall Hazard Assessment for the Nawiliwili coast varies between moderately high (5) in Nawiliwili Bay and southwest of Molehu, to moderately low (3) between Kawai and Kuahonu Points and along the Molehu headland. A moderate (4) OHA is assigned to the region north of Ninini Point, between Carter and Kawai Points, and between Kuahonu Point and Molehu. The tsunami hazard is high north of the Nawiliwili breakwater, moderately high along the breakwater and moderately low along the steep sea cliffs to the south. It is increased to moderately high along the less steep coastal plain between Kuahonu Point and Molehu. Stream flooding increases from moderately high in the north to high in Nawiliwili Bay. Along the breakwater it is moderately high, and to the south it is moderately low until the Kuahonu coastal plain where it is moderately high. High waves are ranked moderately low along the east-facing coast north of Nohiu and moderately high to the south, where south swell approach is more direct. Storms are ranked high along the entire coast. Erosion is moderately low along most of Nawiliwili except at the low-lying beaches south of Nohiu and Kuahonu where it is moderately high. The sea-level threat is moderately low north of Kawai Point and low along the steeper rocky coast to the south, except for the lower-lying beaches near Kuahonu Point where it is moderately low. The volcanic-seismic threat is low along the entire Nawiliwili Coast.

Relatively steep, rocky cliffs with some sea caves form the shoreline south of Nawiliwili Bay and Kawai Point.

Poipu

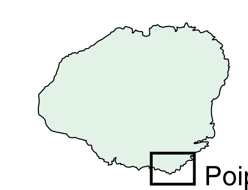
Makahuena Point in Poipu is the southern tip of Kauai. This is primarily a rocky headland coast with small, arcuate coves carved into the steep-sided hills. Small sandy pocket beaches are found at Kolopa, Kihouna, Keoniloa Bay, and just to the south of Kamala Point, Haula, and Molehu Point. A strip of sand, known as a tombolo, connects the Poipu coast to a shallow rock islet just offshore of Nu Kumoi Point, creating a scenic and protected low-tide swimming area. A narrow fringing reef is well developed in this area making the nearshore zone relatively shallow. Resorts, golf courses, and tourist attractions have been built along this coast at the base of Puu Hunihuni, the site of the last volcanic eruption on Kauai. However, it is the memories of Hurricanes Iniki (1992) and Iwa (1982) that live strongest in the minds of residents and visitors of Poipu. In addition to severe wind damage, the inundation resulting from the combined tide and wave surge during Hurricane Iniki in the Poipu and Kukuiula vicinity reached 50 to more than 800 ft inland and between 12 and 29 ft above sea level.

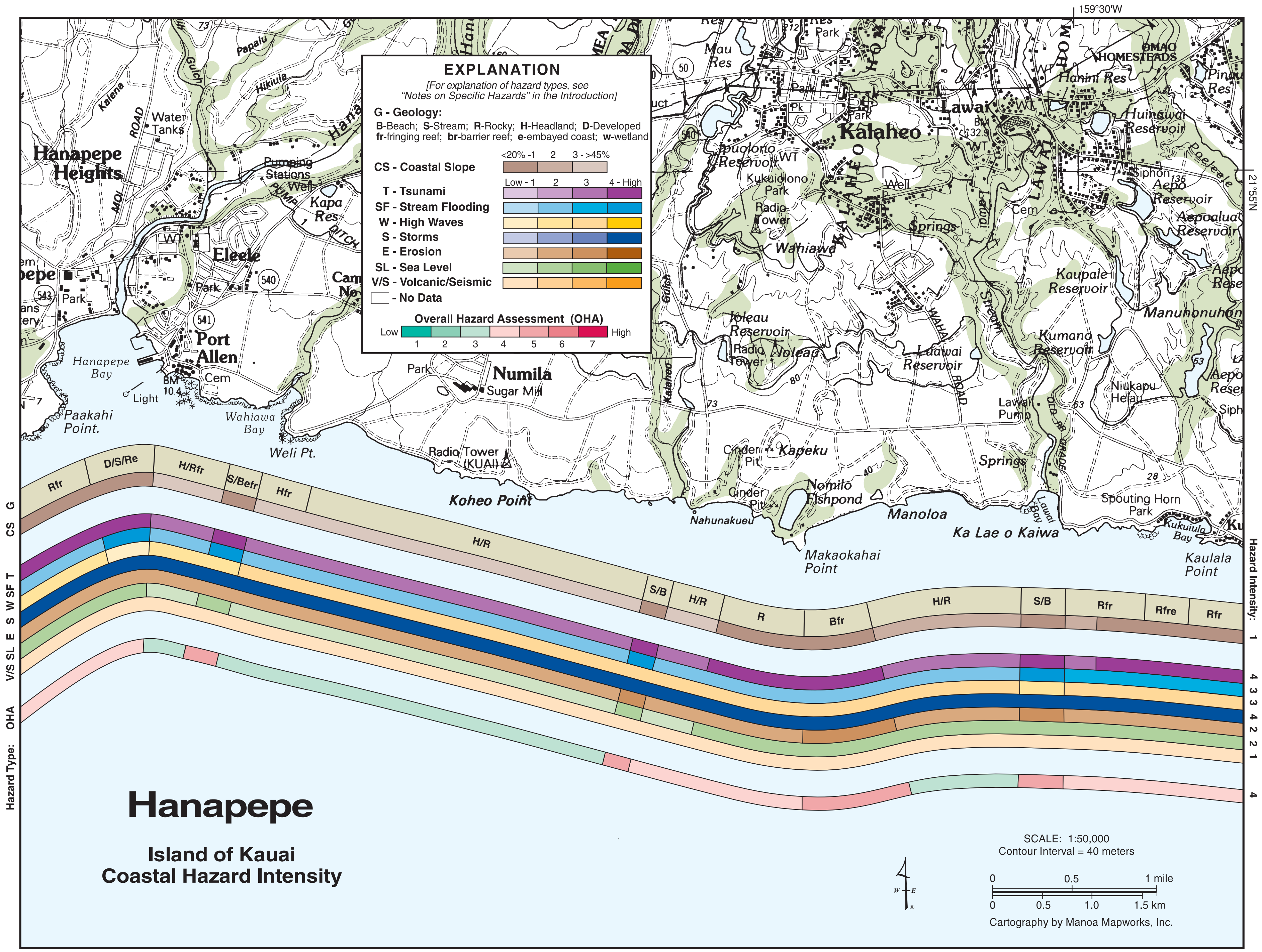
The Overall Hazard Assessment (OHA) for the Poipu coast varies between moderate to high (5) and moderate to low (3). It is moderate to high (5) immediately north of Paoo Point, within Kawailoa Bay, along the southern side of the embayment south of Kamala Point, within Keoniloa Bay, between Poipu Beach Park and Lae o Kamilo, and between Nahumaalo Point and Kolopa. The OHA is moderate (4) between Paoo Point and Pakamoi, immediately south of Kamala Point, at Punahoa, and west of Kolopa. It is moderate to low (3) along the steeper headlands northeast of Paoo Point, northeast of Makawehi, and around Makahuena Point. The tsunami hazard is high along the low-lying embayed sections of coast and moderately low along the steeper headlands in between. At Nahumaalo Point the embayed coast is relatively steep, so the tsunami hazard is moderately high. Stream flooding varies between low along the headland segments of the coast of Naakea and Makawehi, and moderately high along the low-lying embayments. It is moderately low along the Makahuena Point headland. The high wave hazard is moderately high, storms are high, and the sea-level and volcanic-seismic hazards are moderately low and low, respectively, along the entire Poipu Coast. Erosion is moderately low along the steep headlands and high at the southwestern beach of the Kamala Point area and at Poipu Beach Park. It is moderately high immediately north of Paoo Point, at Kawailoa and Keoniloa Bays, and inside the small bays immediately west of Kihouna and Nahumaalo Point.



Base Credit: USGS 1:50,000 Eastern Kauai, Hawaii 5122 III W733 Edition 1-DMA

The extensively developed region of Poipu is built on the rocky basalt coastal plain of Puu Hunihuni forming Makahuena Point, the southernmost point on Kauai.





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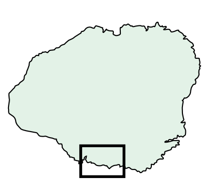


Hanapepe

The Hanapepe coast between Hanapepe Bay and Kaulala Point is lined with gentle to moderately sloped, rocky coastal cliffs separated by four stream mouth embayments: Wahiawa Bay, Nahunakueu, Lawai Bay, and Kukuiula Bay. Many small beach systems occur along this coast, with more significant ones at Wahiawa Bay, the mouth of Kalaheo Gulch, just east of Makaokahai Point, and Lawai Bay. Small patch and fringing reefs border the coast, except in the more deeply incised embayments, such as Wahiawa Bay, where sand fields predominate. Hanapepe Bay is largely infilled with terrigenous-rich sediment and is a common breeding site for hammerhead sharks. A unique fishpond, Nomilo Fishpond, has been created inside the Nomilo volcanic cinder cone just landward of the shoreline at Makaokahai Point. On the rocky shore at Spouting Horn Beach Park, just west of Kukuiula Bay, is one of Hawaii's most famous blowholes and a popular tourist attraction on Kauai. This region was devastated by the heavy winds and high storm surge of Hurricane Iniki in 1992. To some degree, the low coastal cliffs here mitigated the marine flooding to lower levels than the shoreline to the east (Poipu).

The Overall Hazard Assessment (OHA) for the Hanapepe coast varies between moderate to low (3) east of Port Allen to moderate to high (5) at the low-lying coastal areas of Waiawa Bay, Nahunakueu, Makaokahai Point, and Lawai Bay. The OHA is moderate (4) inside Hanapepe Bay, between the western, rocky edge of the Kalaheo Stream mouth and Makaokahai Point, and east of Ka Lae o Kaiwa. The tsunami hazard is high, except along the relatively steep rocky headlands, where it is moderately high. Stream flooding is moderately high to the east and moderately low to the west of Lawai Bay except at Lawai Stream mouth, Kalaheo Gulch, Wahiawa Bay, and Hanapepe Bay, where it is high. The high wave hazard is moderately high east of Weli Point except at Lawai Bay where it is moderately low; to the west it is moderately low, except in Hanapepe Bay where it is low. The storm threat is high and the volcanic-seismic hazard is low along the entire Hanapepe Coast. Erosion varies between moderately high at Lawai Bay, Makaokahai Point, and the Kalaheo Stream mouth to moderately low along the surrounding coastline. Sea-level rise is moderately low east of Nahunakueu and low to the west, except at the Kalaheo Stream mouth, Wahiawa Bay and west of Port Allen.

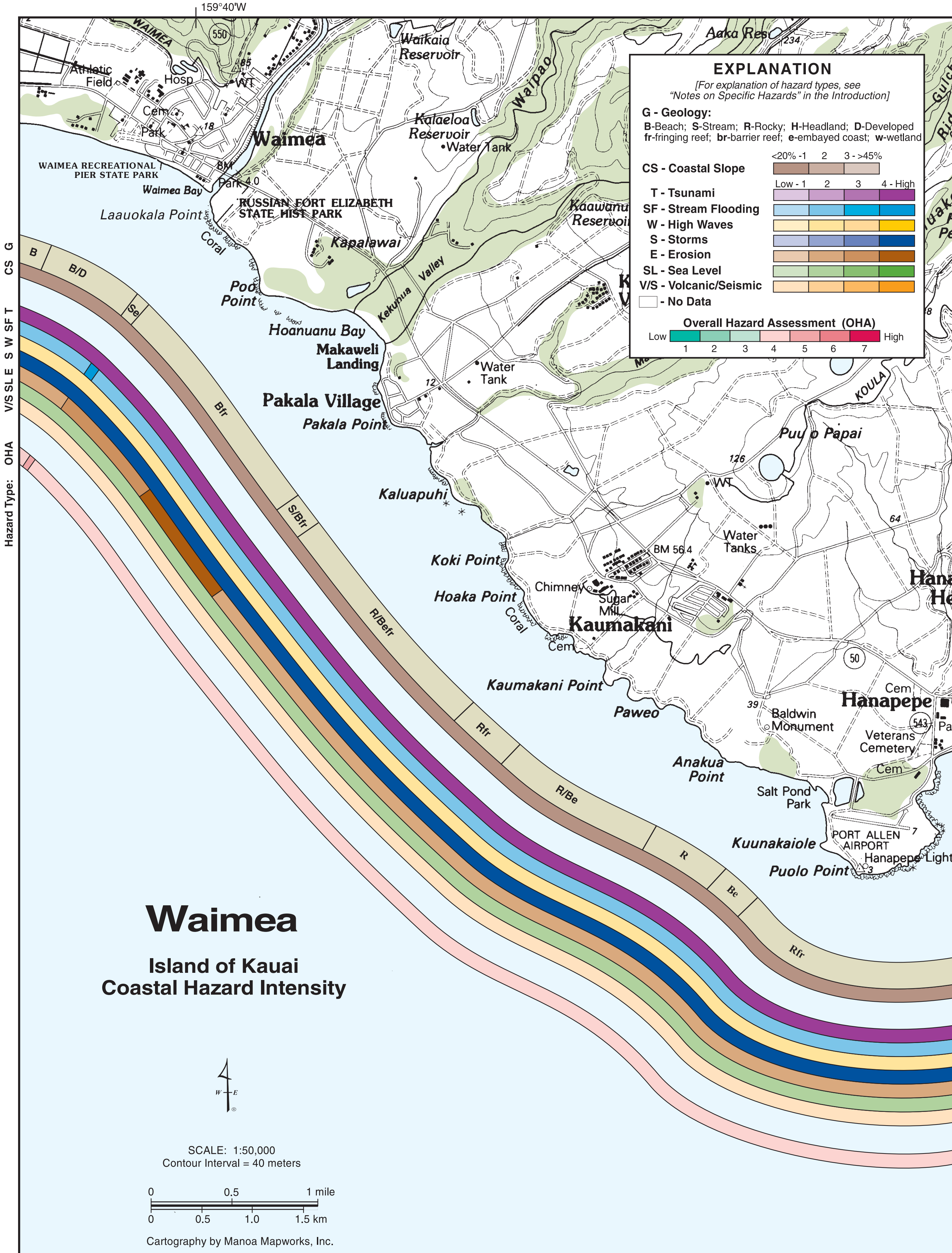
Much of the Hanapepe Coast is agriculturally developed and terrigenous sediment (along with many nutrients and pesticides) is often delivered to its nearshore waters by wind, surface runoff, and stream runoff.

Waimea

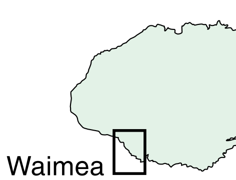
Between Waimea and Puolo Point (Port Allen Airport) the Kauai coast is relatively gently sloping with an extensive fringing reef offshore. Rocky promontories at Hoaka, Kaumakani, Paweo, Anakua, and Puolo Points protect small isolated pocket beaches that grade into narrow, nearly continuous, sand beaches that line the Pakala and Waimea shore. The beach along Waimea is primarily derived of terrigenous sand and debris washed down from the Grand Canyon of Hawaii by the Waimea River, which empties into the Waimea Bay just west of Laauokala Point. A predominant westward longshore current is responsible for transporting sediments to the west toward Kekaha just west of the map. The fringing reef extends about 700 ft offshore of Pakala, which makes good surfing at the reef crest and a relatively protected nearshore zone. The only traditional Hawaiian salt pond still in use is located just west of Kuunakaiole where a relatively arid climate and optimal elevation allows for salt production at Salt Pond Park during the summer months.

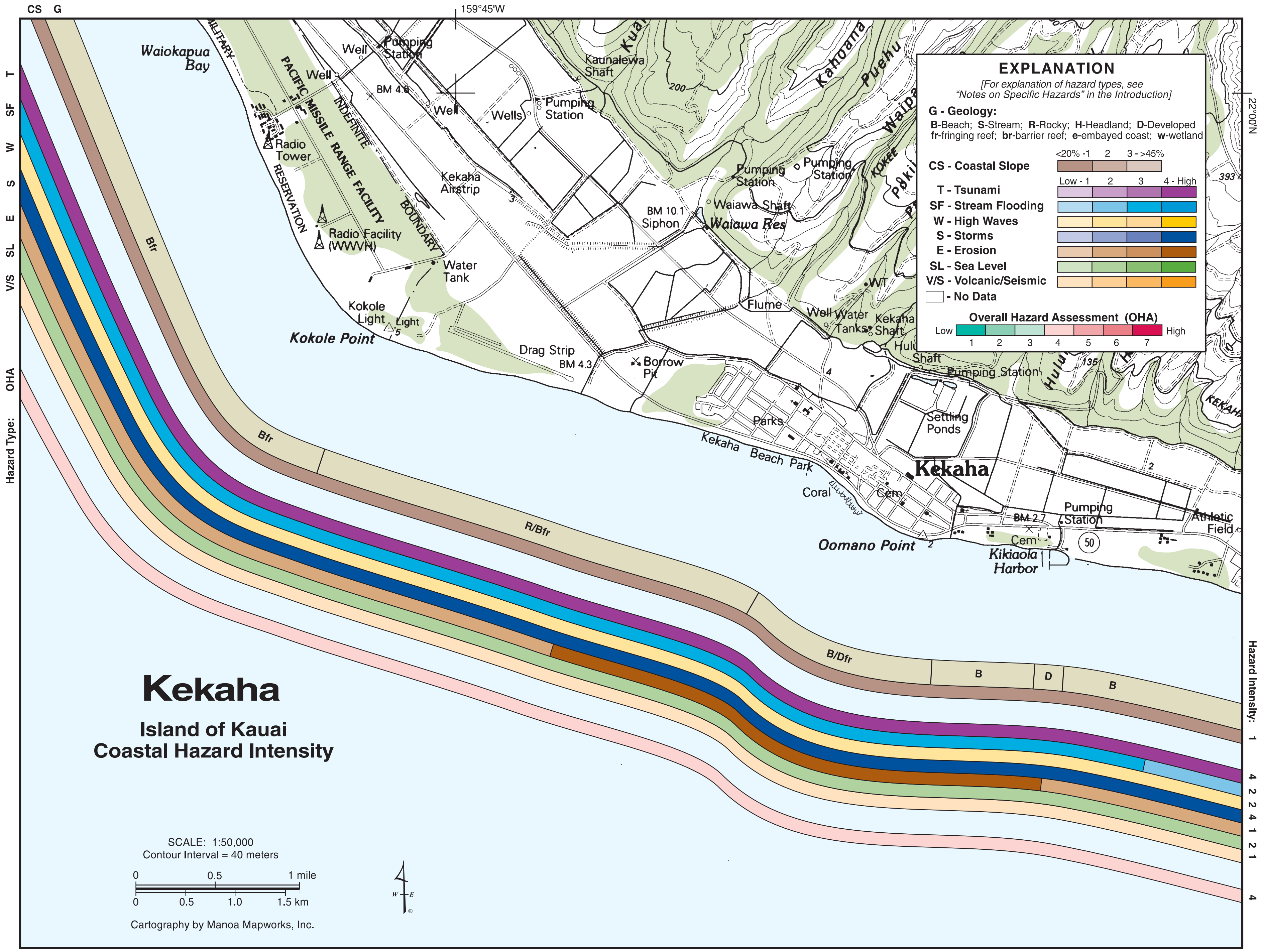
The Overall Hazard Assessment (OHA) of Waimea is moderate (4), except for a thin sliver of coast at the Waimea River mouth, where it is moderate to high (5) because of the high stream-flooding hazard there. The tsunami hazard is high along the entire low-lying Waimea coast and stream flooding is moderately low, except at the Waimea River mouth, where it is high. Facing southwest, the hazard due to high waves is moderately low, while the threat from storms is high. In 1992, the eye of Hurricane Iniki made landfall across the village of Kaumakani. Erosion is moderately low east of Pakala Point and moderately high to the west, except between Pakala Point and the west end of Hoanuanu Bay, where it is high and seawalls line the shore. Erosion is also moderately low west of Waimea River mouth. The sea-level and volcanic-seismic hazards are moderately low and low, respectively.

The town and shoreline of Waimea is founded on the flood plain of the Waimea River, which is constructed of river sediments deposited during past large floods.



Base Credit: USGS 1:50,000 Western Kauai, Hawaii 5022 II W733 Edition 1-DMA





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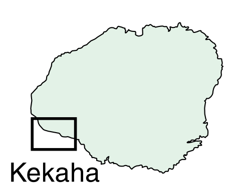


Kekaha

Kikiaola Small Boat Harbor in Kekaha marks a transition between the rocky coves and intermittent beaches to the east and a 15 mi long, continuous, and relatively wide sand beach that extends northwest to Polihale (see Polihale map). The harbor, built in 1959, has been implicated in causing and/or exacerbating beach erosion to the immediate west, threatening several homes. A strong west-moving longshore current develops during high surf. To the northwest of Kekaha, the U.S. Navy's Pacific Missile Range Facility is fronted by a gently-sloping beach with active and vegetated dunes. During seasonal high waves and temporary erosion events, long beachrock ridges become exposed at the water line. Offshore, a fringing reef parallels the coast around Kokole and Oomano Points to Kikiaola Harbor, while landward of the reef, sand bars often develop near Kekaha Beach Park. This portion of Kauai is the most arid, receiving on average less than 20 in of rainfall each year. Nearly all of the streams that drain the mountains of Waimea have been channelized and redirected toward Waimea town (see Waimea map) by the Waimea and Kekaha irrigation ditches.

The Overall Hazard Assessment for the entire Kekaha Coast is moderate (4). This reflects a uniformly high ranking for tsunami and storms and a moderately high assessment for stream flooding, except along the Waimea Recreational Pier State Park (see Waimea map), where stream flooding is moderately low. The threat from high waves is moderately low. Erosion is also moderately low, except for the segment of coast west of Kikiaola Harbor and including Kekaha Beach Park, where it is high. The hazard from sea-level rise is moderately low and the volcanic-seismic threat is low along the Kekaha Coast.

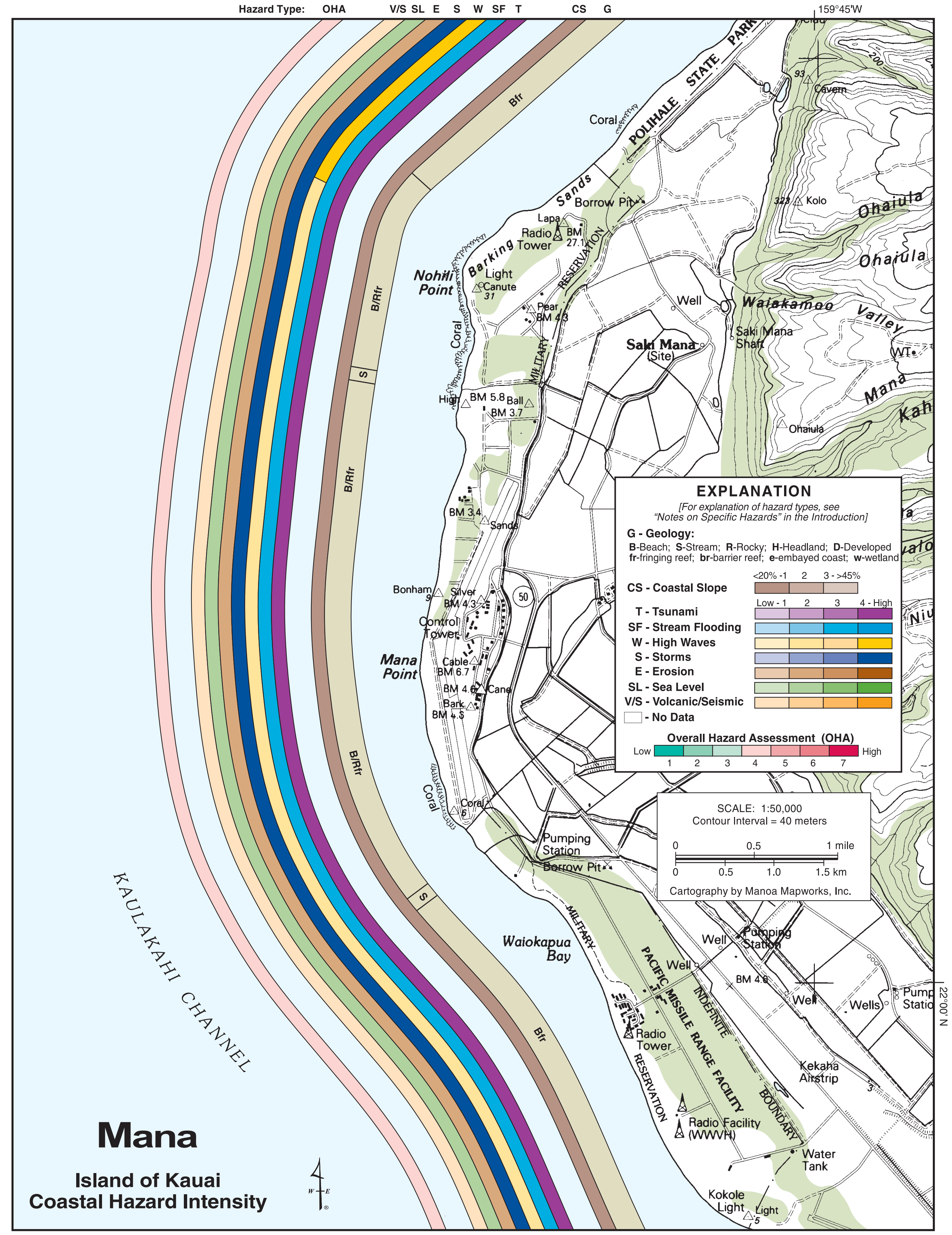
Erosion has narrowed the beaches of Kekaha and sediment-rich runoff, especially during heavy rain events, often leaves the nearshore waters silty.

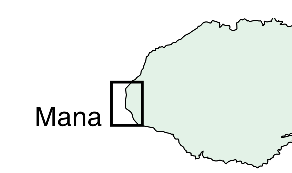
Mana

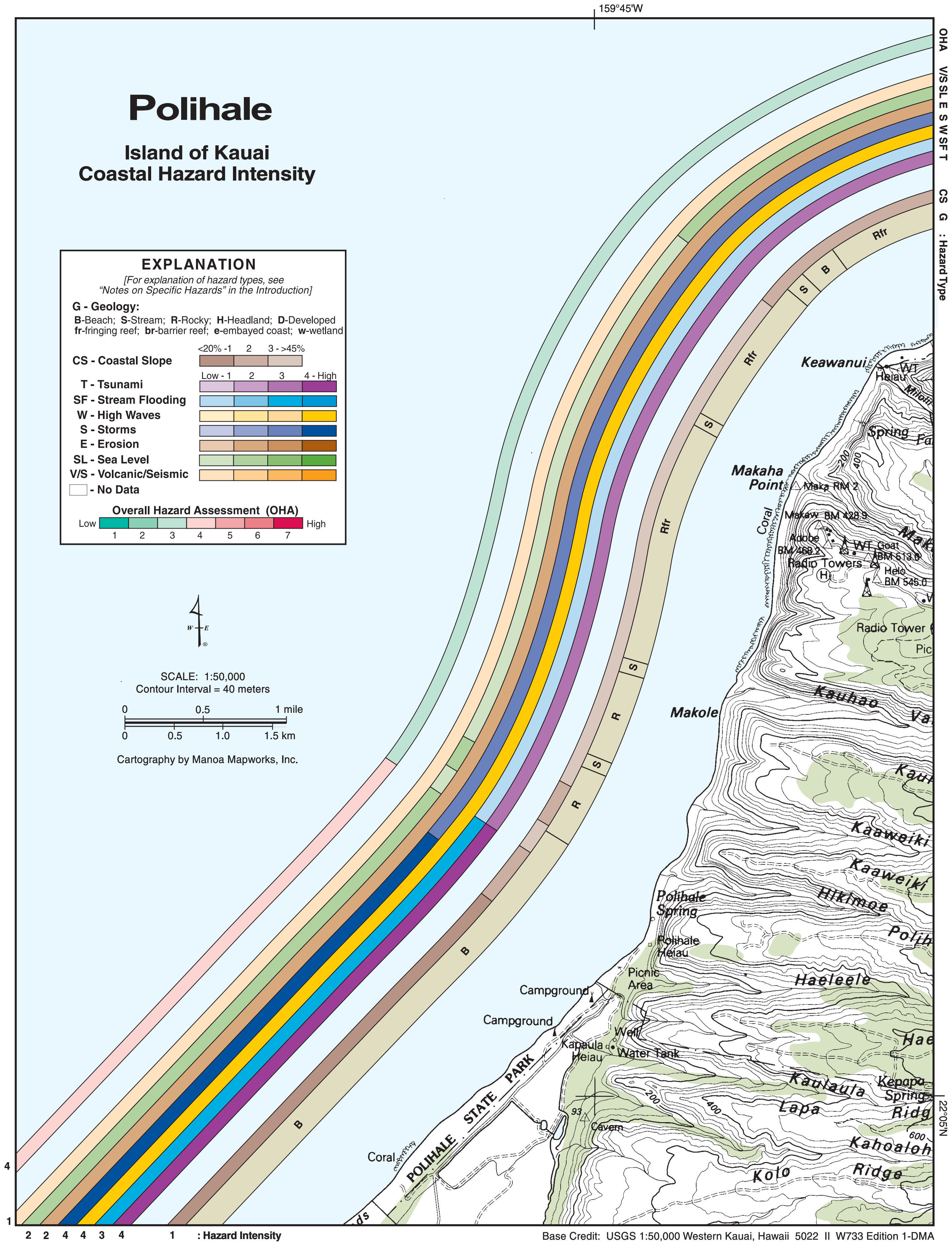
At the westernmost corner of Kauai, the Mana coast provides great vistas of the steep sea cliffs of eastern Niihau (to the west of Kauai) across the Kaulakahi Channel. One of Hawaii's longest continuous beaches extends south along the Mana coast from Polihale State Park beyond the U.S. Navy's Pacific Missile Range Facility. Extensive dunes and sands are known to sing and vibrate with resonant sounds when set in motion by the wind and gravity. For this reason the beautiful sand coast near Polihale was named Barking Sands. Two prominent points, Nohili and Mana Points, face west toward an extensive fringing reef that buffers the long beaches from large northwest and moderate southwest swell. Two streams enter the sea just south of both Nohili and Mana Points. Extensive outcrops of beachrock occur near Nohili Point, a sign that recent beach erosion has taken place to exhume the underlying lithified sands. The coastal plain along the Mana shore slopes gently and is relatively arid.

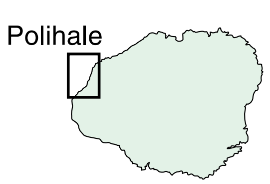
The Overall Hazard Assessment (OHA) for the Mana Coast is moderate (4) reflecting the uniform ranking of the coastal hazards throughout this low-lying coastal segment of Kauai. The only hazard that changes along the length of the Mana Coast is that of high waves. It is moderately low south of Nohili Point, which is partly sheltered from northwest swell by the island of Niihau (to the west), and high to the north which faces directly into approaching north and northwest swell. The tsunami hazard is high along the low-lying Mana coastal terrace and storms are ranked high because the Mana coast receives significant wind and waves generated by tropical storms that generally pass to the west of Kauai. Stream flooding is moderately high along the low-lying coastal zone. Erosion is moderately low, although there can be large seasonal variations in beach width. Sea-level rise is moderately low and the volcanic-seismic threat is low here as it is along the entire Kauai shoreline.

The broad low-lying Mana coastal plain consists of marine carbonate sands deposited by the convergence of two coastal currents from the north and south and the fall of sea level 3000 yr ago. Longshore parallel exposures of beachrock near the water's edge are evidence of recent erosion.









Polihale

Along the Polihale coast the long sandy beaches of west Kauai end and the rugged Na Pali Coast begins. Na Pali is Hawaiian for "the cliffs" and represents 15 mi of tremendously scenic coast accessible only by foot or boat. Here, intense wave energy wears away at the north side of the island, producing steep cliffs that send waterfalls cascading 100's to a 1000 ft to the sea. A narrow fringing reef extends north-northeast offshore of Makole past Keawanui and is broken only in a few locations by streams draining Waimea Canyon State Park and the Kuia Natural Area Reserve. During large rainfall events, these streams transport significant quantities of sediment from the mountains and valleys to the ocean, creating extensive brick-red sediment plumes in the nearshore zone.

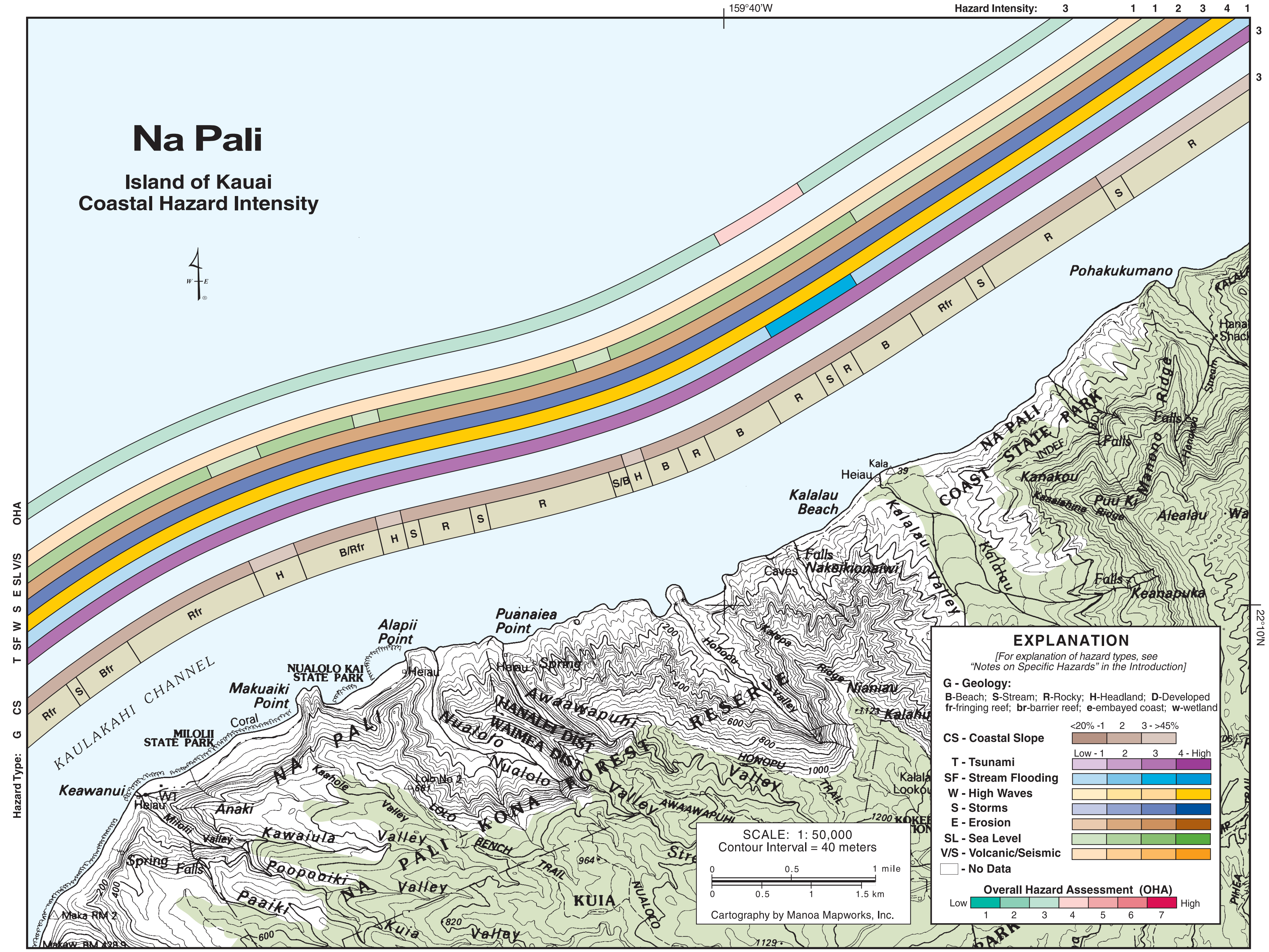
The Overall Hazard Assesment (OHA) for the Polihale Coast is moderate (4) along the beach of Polihale State Park and moderate to low (3) to the north along the steep rocky headlands of the Na Pali Coast. The tsunami hazard is high and stream flooding is moderately high along the low-lying coast of Polihale, whereas to the north, the tsunami ranking is moderately high and stream flooding is low. High waves are a serious threat due to the Polihale coast's exposure to north and northwest swell. The hazard from storms is high along the low-lying Polihale Beach and moderately high along the steeper Na Pali headlands. Erosion is moderately low along this entire coastal segment. The sea-level hazard is moderately low except at the steepest headlands found at Polihale Spring and along the Makole and Makaha Point areas where it is low. The volcanic-seismic hazard is low along the entire Polihale coastline.

The long, white, carbonate sand beaches of west Kauai meet the steep northwest cliffs of Na Pali at Polihale Spring.

Na Pali

The Na Pali Coast and wilderness area is world famous for its steep coastal cliffs and rugged terrain, accessible only by walking and boating. Between Keawanui and Pohakukumano, several sand beaches lie inside small isolated bays such as between Milolii and Kalalau. Knife-edge ridges descend from the upper reaches of the Pali Kona Forest Reserve to form prominent rock headlands that separate the bays. Numerous small streams cut deep v-shaped valleys between the ridges and across the narrow Na Pali coastal plains after cascading 1000's of feet in dramatic waterfalls. Small patch reefs and/or fringing reefs exist inside some of the small bays, and between Keawanui and Alapii a fringing reef lines the coast. The steep, north-facing cliffs attest to intense wave energy and erosion, especially during the winter months when north swell can reach breaking heights of 30+ ft. As a result of high waves, and the funneling of trade winds through the Kaulakahi Channel offshore, longshore and rip currents can be very strong along this coast.

The Overall Hazard Assessment (OHA) for the Na Pali Coast is moderate to low (3) except at the Kalalau Stream mouth, where it is moderate (4) due to the increased stream-flooding hazard at the low-lying stream delta. The tsunami hazard along the entire steep Na Pali coast is moderately high, while stream flooding is low except at Kalalau where it is high. The threat of high waves along this northwest-facing coast is high, while that of storms is moderately high. Erosion is moderately low along the remote and natural Na Pali coastline. The hazard due to sea-level rise is moderately low except at the steepest headlands of Makuaiki Point, Alapii Point, immediately east of Honopu Valley, and near Pohakukumano where it is low. The volcanic-seismic hazard is low along the Na Pali coast as it is along the entire Kauai coast.



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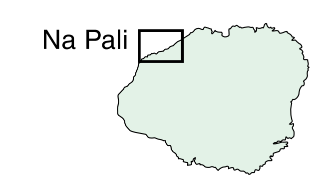
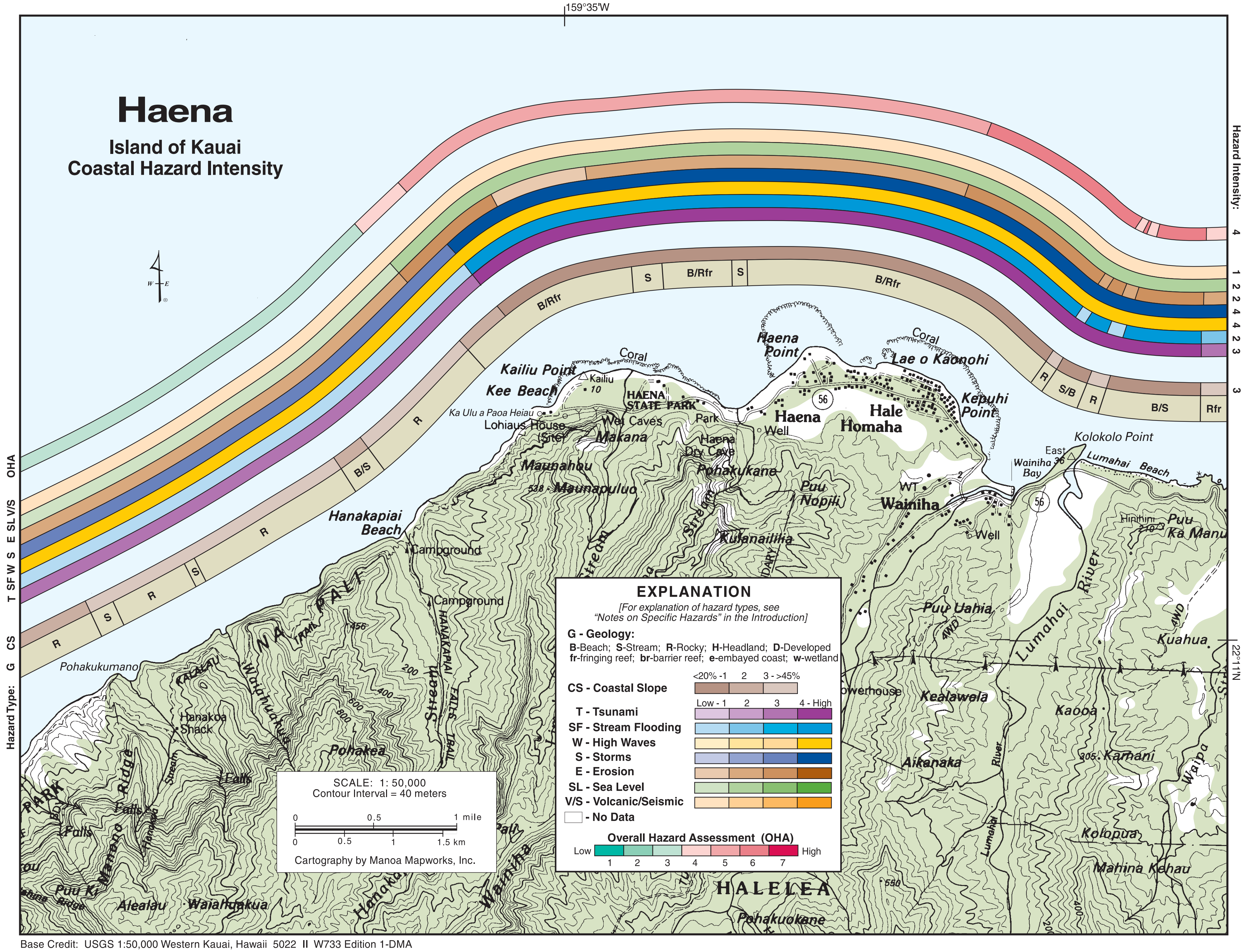
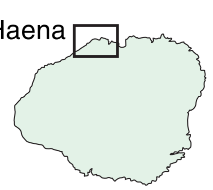


Steep, rocky cliffs interspersed with small pocket beaches line the Na Pali Coast west of Haena Point (see Haena map).





Haena

At Haena, the knife-edge ridges of Na Pali that descend as steep sea-cliffs to the ocean, become broader, more moderately sloping, and spaced by wide valleys, to the east. The road that runs west around the north shore of Kauai ends at Kee Beach. The rocky, cliffed coast west of Makana is only accessible by foot or boat. Hanakapiai Beach is the only beach along the Na Pali coast northeast of Pohakukumano. Several stream mouths, however, have created small embayments in this region. Northeast of Kee Beach, the valleys and coastal plains between ridges are wider and the beaches longer. Wide fringing reefs have developed offshore of the rocky points, but are sometimes cut where streams discharge, as in Haena and Wainiha Bays. The beach at Lumahai is also an exception; its steep beach face is the product of intense wave energy due to the absence of a fringing reef. A small settlement exists at Haena, otherwise, most of this coast is undeveloped.

The Overall Hazard Assessment (OHA) for Haena varies between moderate to low (3) along the steep Na Pali headlands west of Kee Beach, to high (6) along the low-lying coastal terraces of Kepuhi Point, Wainiha Bay, and Lumahai Beach. The OHA is moderate (4) at Kee Beach, moderate to high (5) between Kailiu Point and Lae o Kaonohi, and moderate (4) at the two steep, rocky headlands, surrounding Wainiha Bay. Tsunami hazards are moderately low west of Kailiu Point and high to the east. Stream flooding is low west of Kailiu Point and high to the east, except at the two steep headlands surrounding Wainiha Bay where it is low. The hazard due to high waves is high along this entire north-facing coast. The storm threat is moderately high along the steep Na Pali headlands west of Kailiu Point and high along the low-lying coast to the east. Erosion is moderately low except along Kee Beach and the sandy portion of Kailiu Point where it is moderately high. Along the rocky eastern corner of Kailiu Point, erosion is low. Erosion is moderately high along the Lae o Kaonohi coastal plain, Wainiha Bay, and Lumahai Beach. Sea-level rise is low along the Na Pali headlands and moderately high along the lower-lying coast to the east. The volcanic-seismic threat is low along this coast and all of Kauai's shoreline.

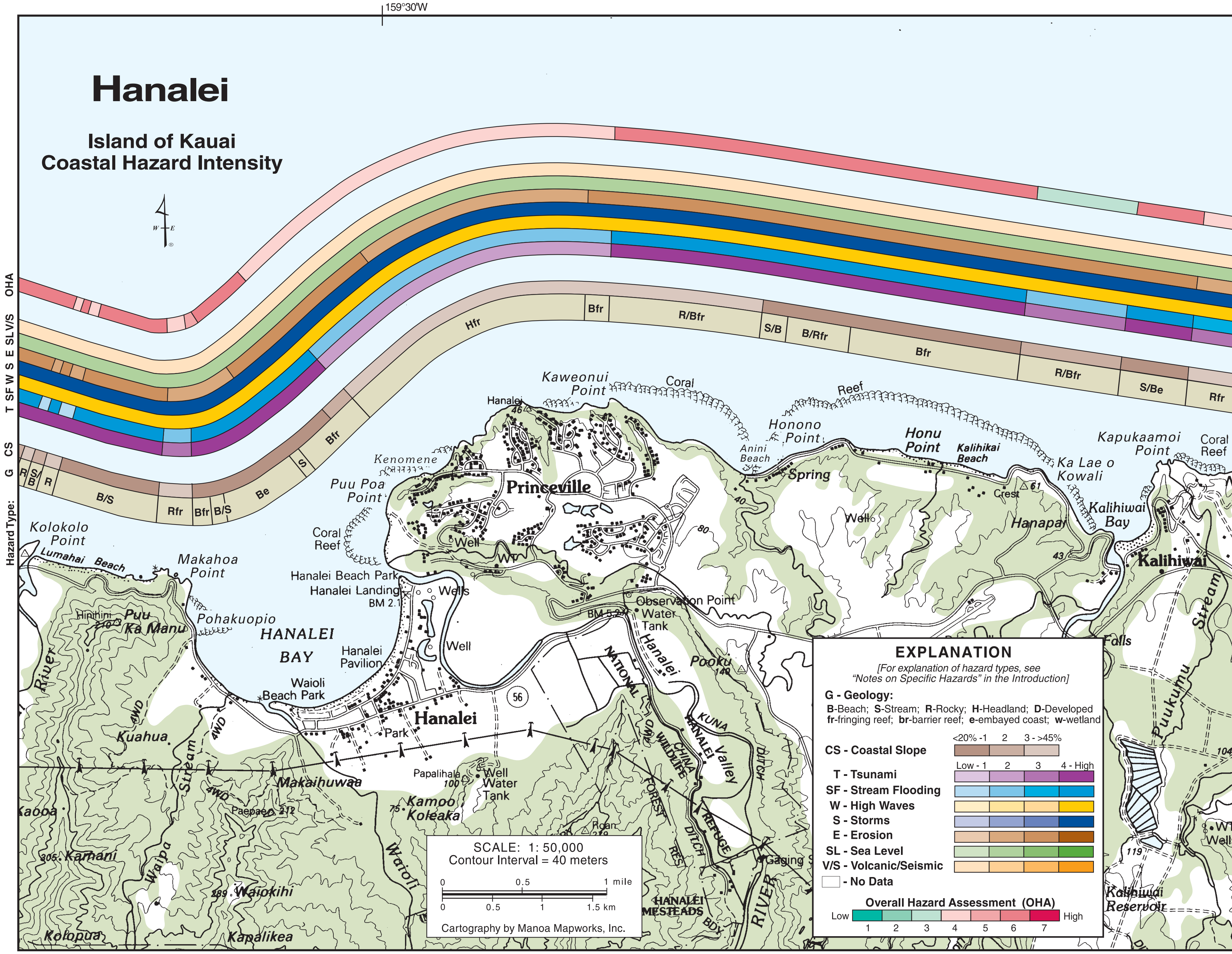
Extensive and wide fringing reefs have become well established along the Haena Coast and most of the northern half of Kauai.

Hanalei

One of the most scenic views in Hawaii is that of Hanalei Bay, with Haena (see Haena map) in the background, viewed from the Princeville headland. The Hanalei River carries nutrient-rich sediment along its broad meanders to the taro-cultivated Hanalei coastal plain, a series of fossil shorelines resulting from a higher sea between 1500 and 4000 years ago. The shoreline has evolved as a classic embayed semi-circle. It supports a long, sand beach between Puu Poa Point, a remarkable surfing site on the east side of the bay, and Makahoa Point on the west. A well-developed fringing reef extends 500-1000 ft offshore along the generally rocky headland coast of Princeville east to Kapukaamoi Point. It is broken only at the stream mouths at Anini Beach and Kalihiwai Bay, where there are small sandy beaches. Sand beaches also reside upon the narrow coastal plains surrounding Anini and Kalihikai. The Hanalei region, on average, receives between 80 and 120 in of rainfall annually, but sustained rains and/or flash flooding in the precipitous interior often generate flooding in the coastal zone. Three decades of stream gauge data show that the Hanalei River overflowed its banks at the Hanalei Bridge 29 out of the last 32 yr!

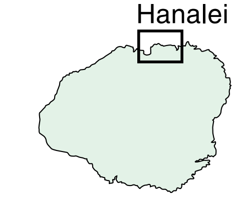
The Overall Hazard Assessment (OHA) for Hanalei ranges between high (6) along Lumahai Beach, Hanalei, and Kalihiwai Bays and along the Anini Beach and Honu Point coastal terrace and moderate to low (3) along

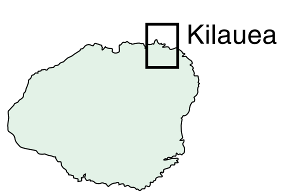
Hanalei Bay is bordered by a steep headland and prominent fringing reef immediately north of the river mouth.

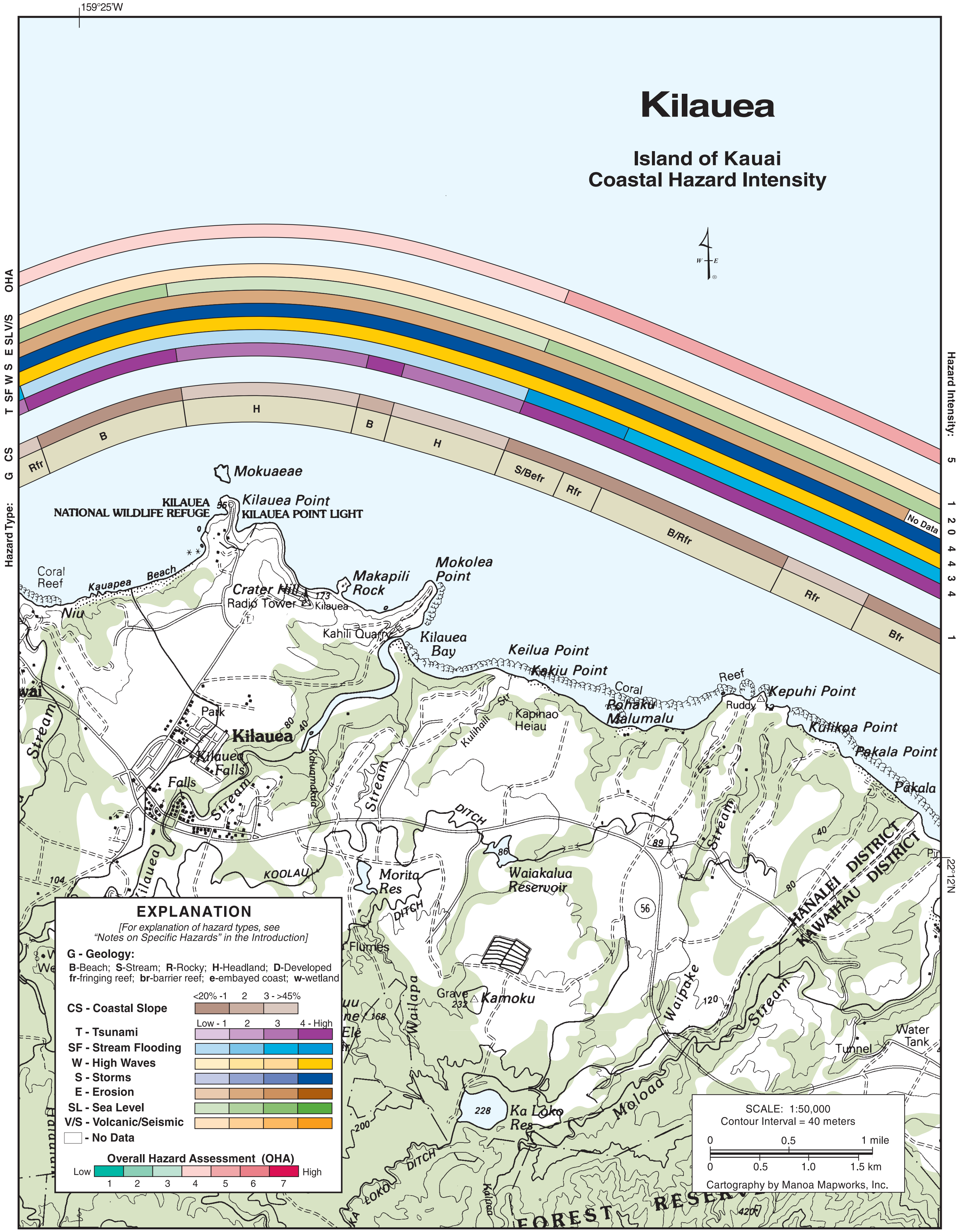


Base Credit: USGS 1:50,000Eastern Kauai, Hawaii 5122 III W733 Edition 1-DMA

the steeper rocky coast of Ka Lae o Kowali. The OHA is moderate (4) at the rocky Makahoa Point and along the steep Princeville headland where tsunami and stream flooding are lower. The tsunami hazard is high except at Makahoa Point, Ka Lae o Kowali, and immediately east of Ka Lae o Kowali at Niu, where it is moderately high. Along the Princeville headland tsunami hazard is moderately low. Stream flooding is high except at Makahoa Point, Ka Lae o Kowali, and the Princeville headland where it is ranked moderately low. Immediately east of Ka Lae o Kowali, along Niu, stream flooding is moderately high. The hazards due to high waves and storms are high. Erosion is moderately high except for Makahoa Point, Hanalei Beach which appears to be stable, the Princeville headland, and the Niu region, where it is moderately low. The sea-level rise and volcanic-seismic hazards are moderately low and low, respectively.







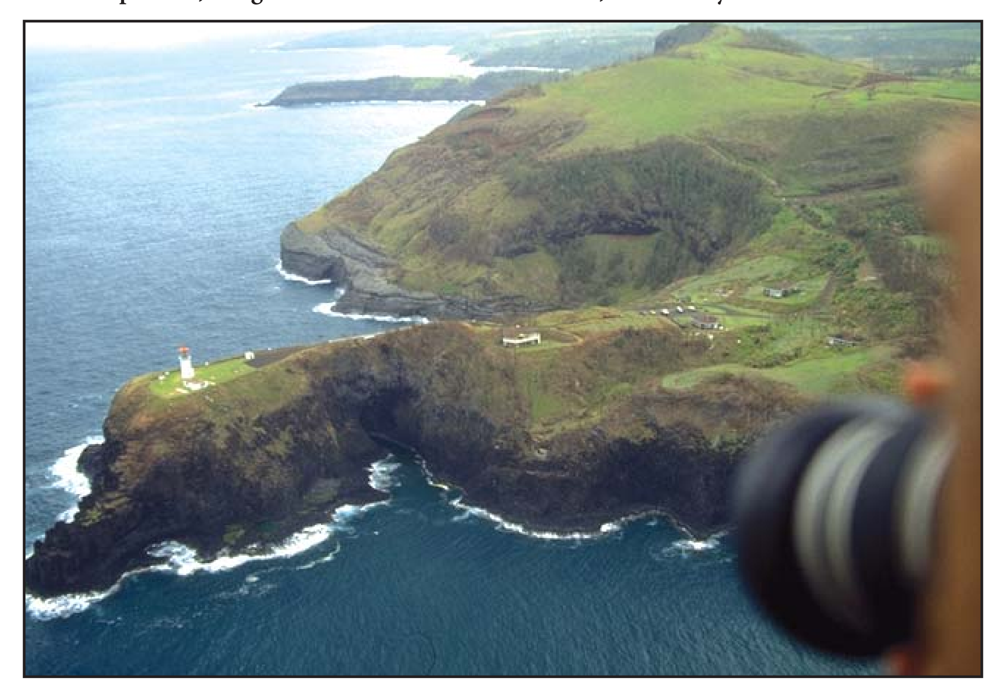
Base Credit: USGS 1:50,000 Eastern Kauai, Hawaii 5122 III W733 Edition 1-DMA

Kilauea

Kilauea Point is the northernmost point on Kauai. In addition to the point, the rock island Mokuaeae that sits offshore of the Kilaeua Point lighthouse, Crater Hill, and Mokolea Point form the Kilauea National Wildlife Refuge. The refuge harbors numerous species of central Pacific seabirds. Among these rock headlands lie the beautiful sand beaches of Kauapea, Makapili, Kilauea Bay, Kakiu Point, and Pohaku Malumalu. The coastal slope is steeper between Kilauea and Mokolea Points than along the eastern portion between Kilauea Bay and Pakala Point. The relatively large Kilauea Stream drains into Kilauea Bay after cascading in two sets of falls just landward of the low-lying coastal plain. An extensive fringing reef runs east between Mokolea Point and Pakala. Facing northeast, the Kilauea region is heavily swept by trade winds, and as a result, currents generally travel east to west. Kilauea's coast is only lightly developed with few villages along the shore.

The Overall Hazard Assessment (OHA) for the Kilauea coast is moderate (4) west of Mokolea Point and moderate to high (5) to the east. The higher overall hazard to the east is largely a function of the lower coastal slope, which results in higher hazards due to flooding and inundation associated with high waves. The tsunami hazard is moderately high west of Mokolea Point except at the lowest-lying beaches near Makapili Rock and at Kauapea Beach, where it is high. East of Mokolea Point tsunami is ranked high. Stream flooding is low west of Mokolea Point and moderately high to the east, except for the low-lying Kilauea Bay coastal plain where it is high. The hazards due to high waves and storms are both high along this coast, which receives high north and northwest swell as well as significant wind and wave energy from tropical storms approaching from the east. Erosion is moderately low along the entire Kilauea coast. The sea-level rise threat is moderately low except along the steep headlands between Kilauea Point and Mokolea Point where it is low. The volcanic-seismic threat is low.

The Kilauea Point lighthouse and the surrounding steep, rugged rocky cliffs are an important refuge for many Pacific sea-faring migratory birds, including the Red-tailed tropic bird, Wedge-tailed and Newell's shearwaters, and the Laysan Albatross.

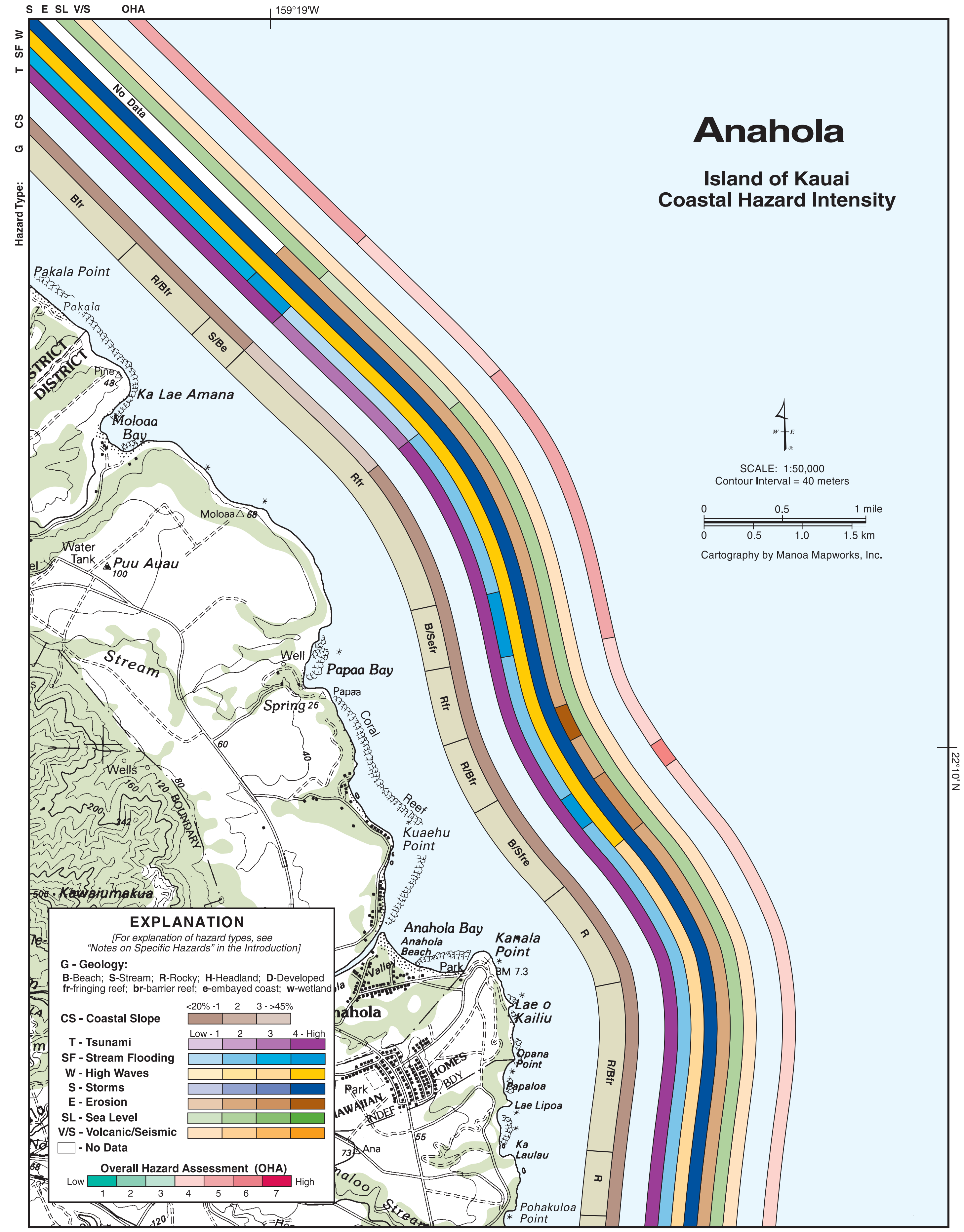


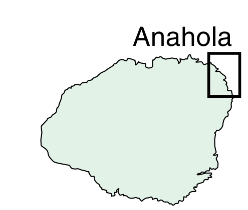
Anahola

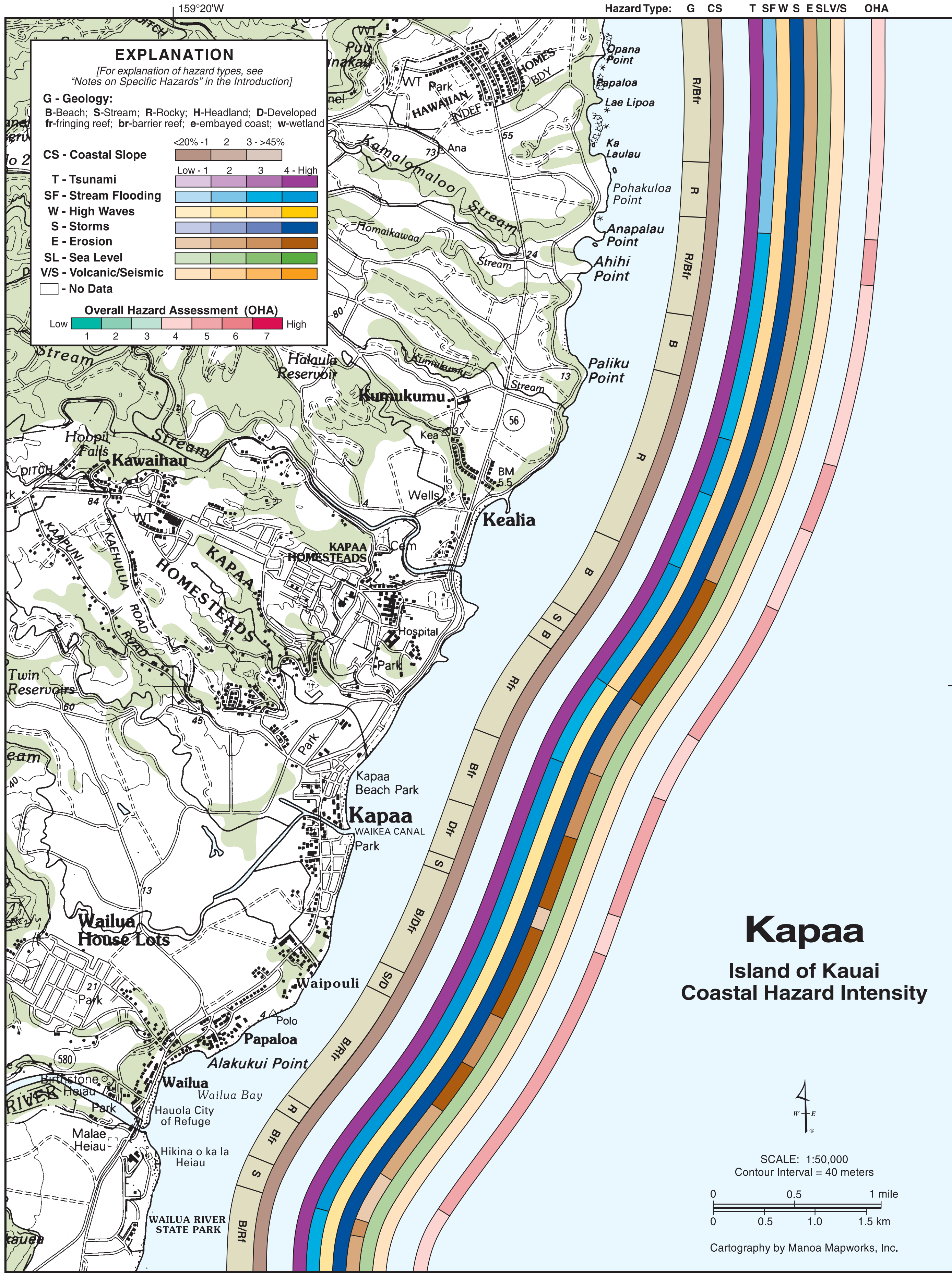
The Anahola coast, extending from Pakala south to Pohakuloa Point, is characterized by a relatively narrow coastal plain at the foot of moderately steep hillsides that reach 100 to 200 ft above sea level. It is one of the windiest coasts on Kauai, facing directly into the northeast trade winds, but some of the embayed beaches are sheltered by the surrounding headlands. The Moala, Papaa, and Anahola Streams dissect the high coastal hillsides and discharge their waters into Moala Bay, Papaa Bay, and Anahola Bay, respectively. Despite its attempt to transport runoff through its channels to the sea, the Anahola River frequently overflows and floods the village of Anahola when there is intense precipitation in the mountains. Several times in the historical past upwards of 20+ in have fallen in a matter of a day or two, resulting in damaging floods in the Anahola area. Low rocky headland cliffs front the Moloaa coast, Kuaehu Point, and the region between Kamala and Pohakuloa Points. Extensive but relatively narrow fringing reefs exist along this coast except at the major stream mouths. Inside Papaa Bay coral cover is moderately high around a central sand-bottom channel.

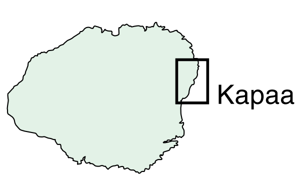
The Overall Hazard Assessment (OHA) for the Anahola coast ranges between high (6) inside Anahola Bay and moderate (4) along the Moloaa rocky shoreline, between Papaa and Kuaehu Point, and south of Kamala Point. This is due to a combination of higher waves north of Kamala Point and the influence of slope on flooding and inundation. The OHA is moderate to high (5) north of and including Moloaa Bay, and between Moloa and Papaa, where there is greater stream flooding than the areas to the immediate north and south. The tsunami hazard is high except along the steeper rocky southern Moloaa shore where it is moderately high. Stream flooding is high in Moloaa, Papaa, and Anahola Bays. It is moderately high north of Moloaa Bay and moderately low to the south except along the steeper southern Moloaa segment where it is low. The threat from high waves is high north of Kamala Point and moderately high to the south where north swell refracts and looses energy when reaching the shore. Storms are ranked high along the entire Anahola Coast. Erosion hazard is moderately low except in Anahola Bay where it is moderately high and immediately north of Kuaehu Point where it is high. Sea level hazard is moderately low except along the steeper rocky Moloaa shoreline where it is low. The volcanic-seismic hazard is low along the entire Kauai coast.

The Anahola Coast is generally low lying with numerous sandy beaches lining small embayments. Debris lines high on the beach attest to the wave-swept nature of this northeast-facing shoreline.









Kapaa

The low-lying coastal plain around Kapaa is developed with moderate density resorts, golf courses, beach parks, and residences. South of Kealia the coastline is relatively straight with the exception of Wailua Bay which is an arcuate-shaped embayment. It is a little more irregular north of Paliku Point where several small coves, formed between wind-swept rocky headland points, create a winding shoreline. Numerous streams drain into the sea near Kapaa, the largest being the Kapaa Stream and Wailua Rivers. These streams form tidal inlets that influence the beach processes at Kealia and Wailua. The Wailua River is a wide river by Hawaiian standards and floods often reshape the southern portion of Wailua Beach and the sandbar that forms at its mouth. Low dunes exist behind Kealia Beach and have been mined for sand in the past. Beachrock occurs at the water's edge along the beach at Waipouli and erosion along Kapaa Beach has led to the emplacement of revetments and seawalls that have temporarily protected coastal property at the expense of losing the sandy beach. Fringing reefs parallel most of the coast, but considerable wave energy still reaches the shore face. Overall, the beaches from Waipouli to the north end of Kapaa town are largely deficient of sand and experience chronic erosion.

The Overall Hazard Assessment (OHA) for the Kapaa coast is moderate (4) except at the stream mouths immediately south of Anapalau Point, Paliku Point, and inside Kealia Bay where stream flooding is higher and the OHA is moderate to high (5). The OHA is also moderate to high (5) along the majority of coast between the Kapaa Beach Park and Wailua River State Park, where there is higher erosion and stream flooding. Tsunami and storm hazards are high along the entire Kapaa Coast. Stream flooding is moderately low north of Anapalau Point and moderately high to the south except at the Kamalomaloo and Kumukumu Stream mouths and along the Kealia Bay, Kapaa, and Wailua Bay shorelines, where it is high due to stream flash flooding and urban flooding on the flat coastal plain. The hazard due to high waves is moderately high north of and including Kealia Bay and moderately low to the south. Erosion is moderately low to the north of Kealia. To the south, erosion is high, as evidenced by the numerous seawalls that exist between Kapaa and Wailua, except north of Kapaa Beach Park, Waipouli, and Papaloa where it is moderately high, near Kapaa hospital where it is moderately low, and at the Waikea Canal and the Wailua River mouth, where it is low. The sea-level and volcanic-seismic hazards are moderately high and low, respectively.

Low-lying coastal plains lined with narrow sandy beaches characterize the Kapaa Coast, which has experienced chronic erosion during the 1980s and 1990s.

Oahu

Oahu, the Gathering Place, is the most populated island and Hawaii's government and business center. While it is removed from the active volcanism and seismicity of the Big Island, natural hazards associated with high waves, storms, and flooding annually threaten Oahu's coastal inhabitants and infrastructure. The primary difference between the nature of coastal hazards on Oahu and the rest of the islands is the magnitude of the risk involved. While Oahu has not witnessed a direct hit by a hurricane force storm in its history or suffered damage from a tsunami since 1960, extensive development of the shoreline has continued, apparently as a result of a high level of complacency among developers and the public.

Oahu

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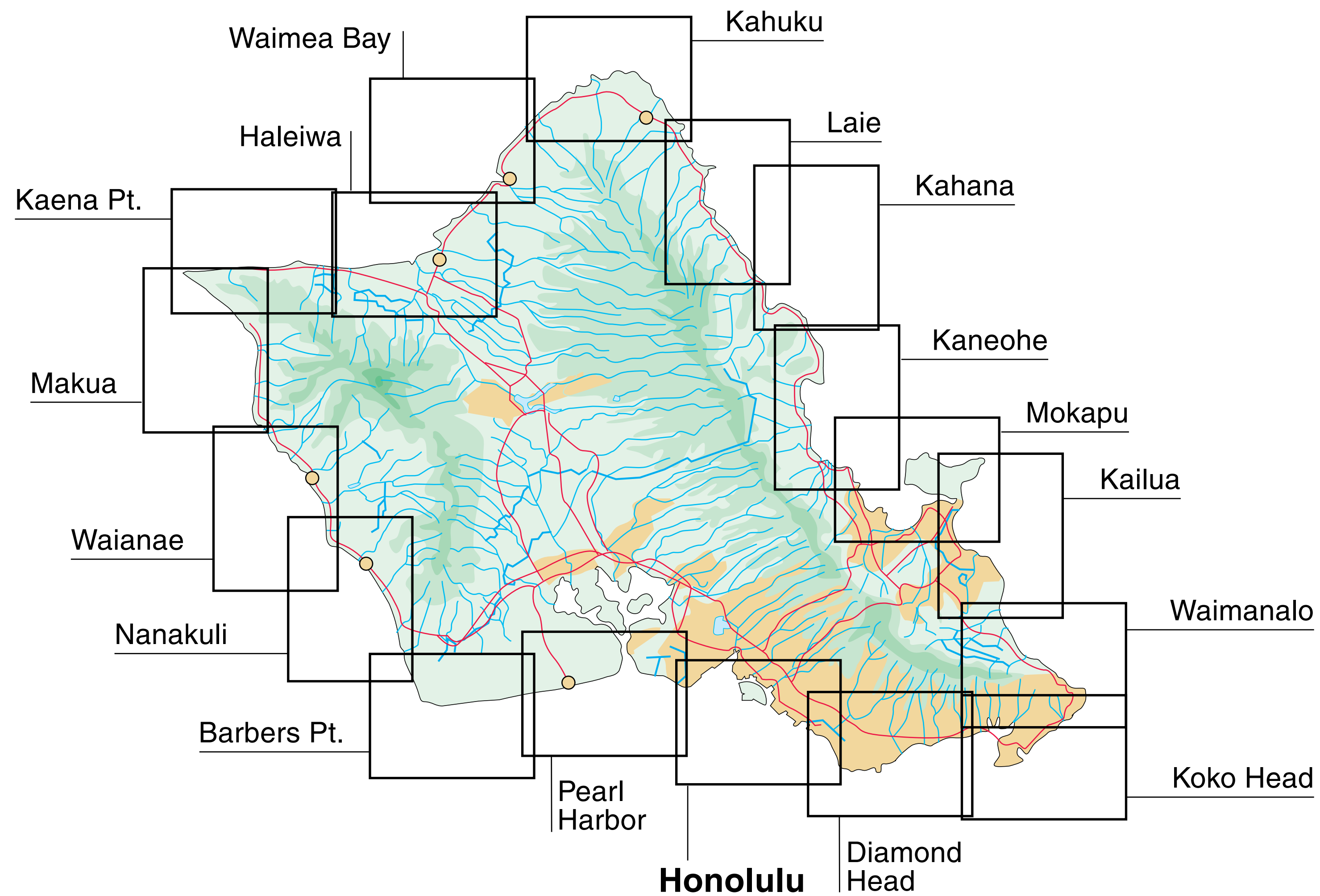
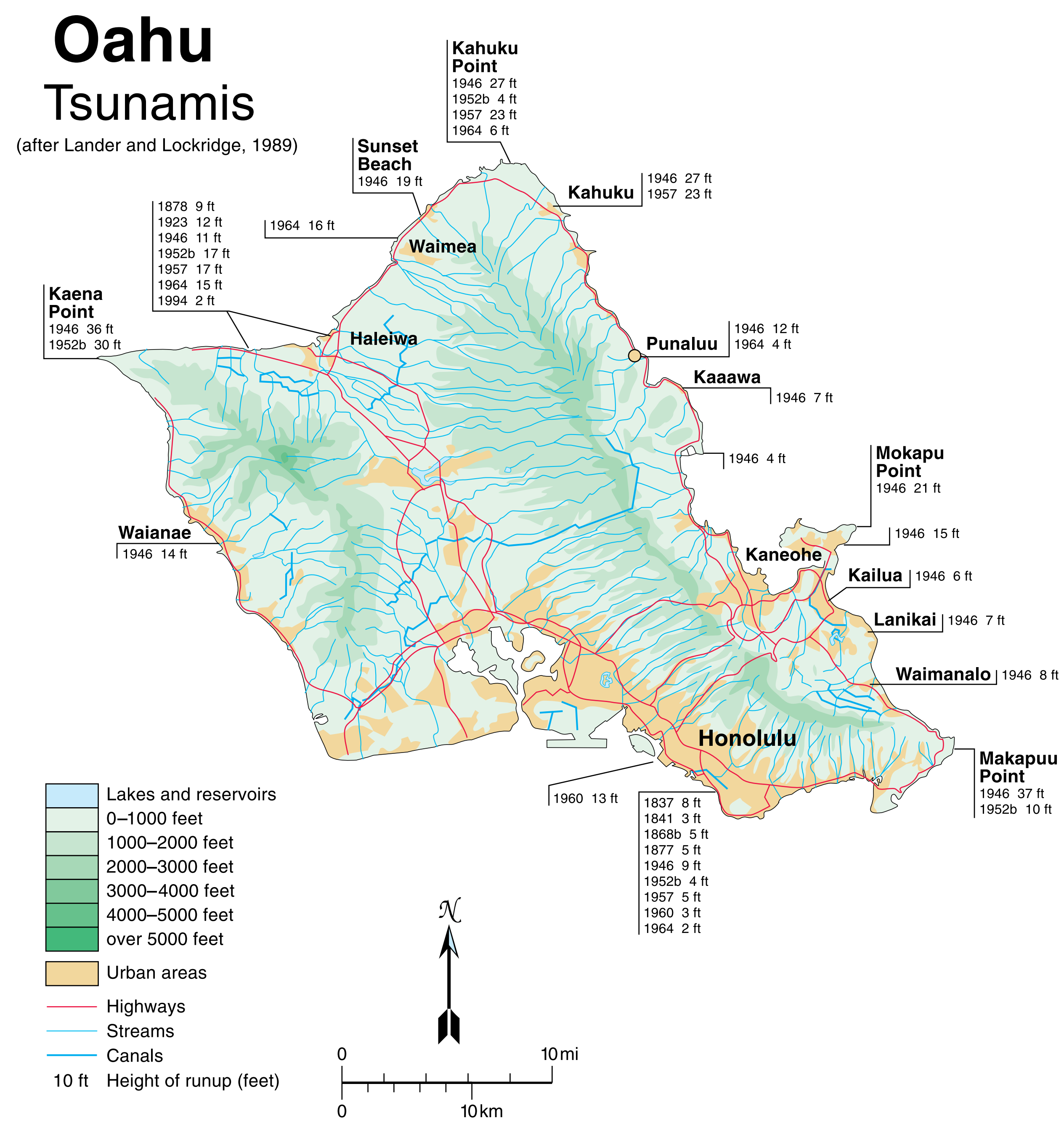


Tsunamis

A tsunami is a series of great waves most commonly caused by violent movement of the sea floor. It is characterized by speed (up to 590 mph), long wave length (up to 120 mi), long period between successive crests (varying from 5 min to a few hours, generally 10 to 60 min), and low height in the open ocean. However, on the coast, a tsunami can flood inland 100's of feet or more and cause much damage and loss of life. Their impact is governed by the magnitude of seafloor displacement related to faulting, landslides, and/or volcanism. Other important factors influencing tsunami behavior are the distance over which they travel, the depth, topography, and morphology of the offshore region, and the aspect, slope, geology, and morphology of the shoreline they inundate. Predicting the specific form of a tsunami at a shoreline is not yet possible because of many factors. History has shown that these factors contribute to a wide range of tsunami runup heights and associated damage even within a very small geographic region. For example, the tsunami generated by the 1946 earthquake in the Aleutian Islands was recorded at Makapuu Point to be 37 ft while in Waimanalo, a mere 3 miles away, the maximum runup was only 8 ft. An important difference between tsunami and ordinary wind-generated waves is that the wavelength (distance between successive crests) of a tsunami can be several orders of magnitude larger. This means that as a tsunami passes an island the water level can rise for several minutes. As a result, tsunami can cause significantly greater flooding than ordinary wind waves of the same height.

History has also shown that damaging tsunamis in Hawaii are generated from distant locations around the Pacific Ocean margins, as well as locally in Hawaiian waters. The source region of tsunami genesis has important implications for the amount of damage caused by a tsunami and for our ability to detect them and respond to their impact. Models show that a tsunami generated in Alaska can travel to Oahu in 5 hr, while a locally generated tsunami, like the 1975 tsunami in Halape, Hawaii, may take only minutes or seconds. Five hours may seem like sufficient time to detect and respond to a tsunami, however, there are few locations above sea level between Hawaii and Alaska where its height and potentially damaging effect can be detected. The island of Midway is the first land a tsunami wave originating in Alaska encounters on its way towards Hawaii. Detection of a tsunami on Midway leaves only 1-2 hr for Hawaiian residents to respond. And even if a tsunami is detected prior to its arrival, predicting its flood magnitude and impact is a difficult challenge because of its chaotic behavior when it makes landfall.

Twenty-six tsunamis with flood elevations greater than 3.3 ft (1 m) have made landfall in the Hawaiian Islands during recorded history, and 10 of these had significant damaging effects on Oahu. This translates into a recurrence interval of one large tsunami reaching Hawaiian shores every 7 yr and one damaging tsunami reaching Oahu every 19 yr. Since the terrible tsunami of 1946, 6 large tsunamis have been recorded in the Hawaiian Islands, and 4 have caused damage on Oahu. The three highest tsunami wave runups recorded on Oahu occurred during the last 53 yr. If one analyzes the last 53 yr in two time slices, 1945 to 1975 and 1976 to the present, a very different tsunami history exists. Between 1945 and 1975, a total of 7 large tsunamis hit the Hawaiian Islands, or one every 3.3 yr, and a damaging tsunami hit Oahu every 6 yr. However, since 1976 not one large tsunami has been recorded in all of Hawaii (1986 and 1994 had 2 small events that were less than 3 ft). The historical record suggests that a damaging tsunami is overdue to reach Oahu's shores. Ironically, it has been during this last 20 yr that development within the Hawaiian coastal zone has proliferated. If wave runups like those of the 1957 or 1960 tsunamis occurred today, there exists a high probability that low-lying coastal areas such as Waikiki, Waimanalo, Kaaawa, Punaluu, and Nanakuli would suffer damage, primarily because of the risk that has been taken by developing within these inundation zones.



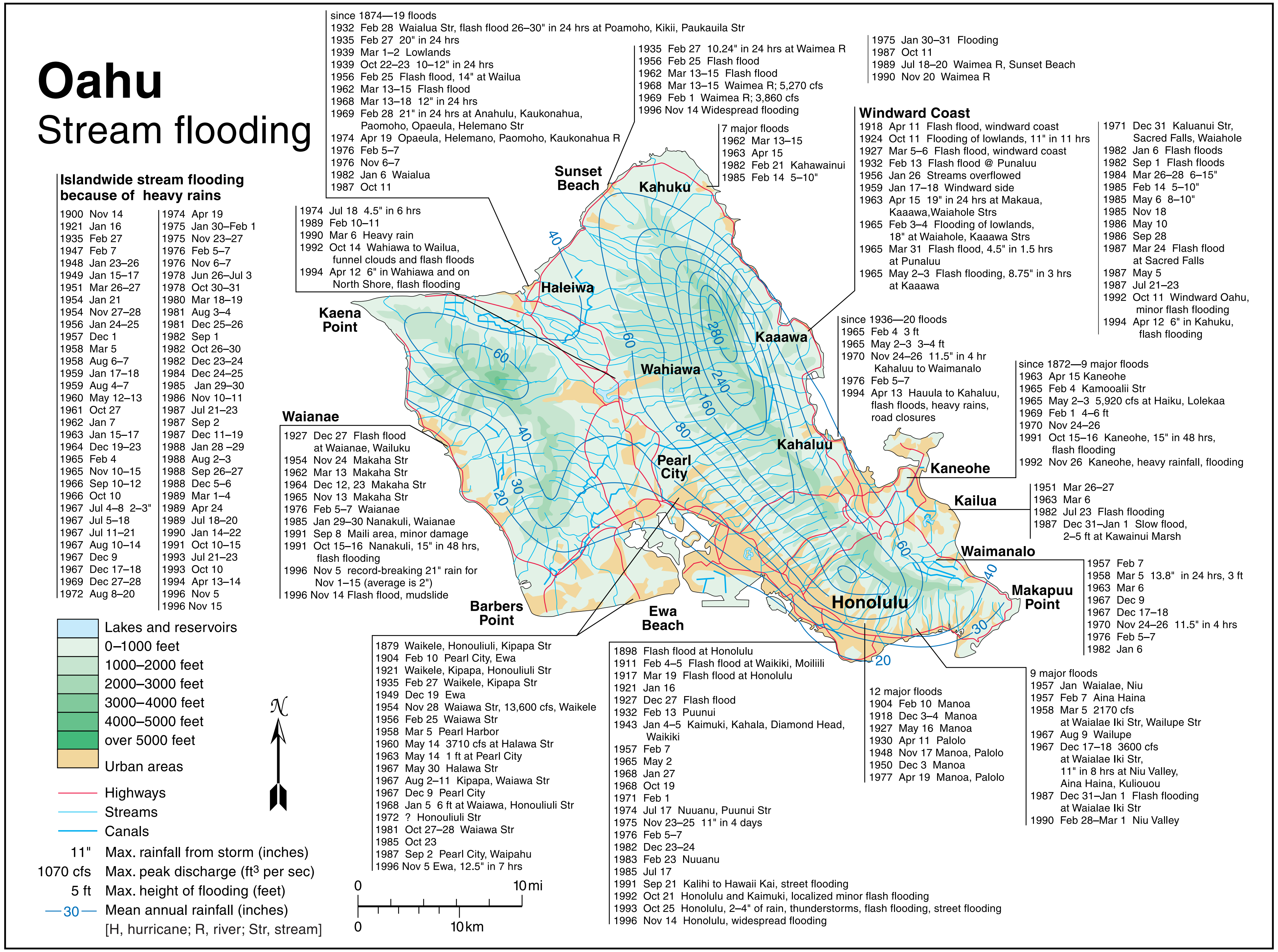
Large tsunamis* (>1m, 3.3 ft) with reported damage in the Hawaiian Islands

Year	Date	Area of origin	Magnitude**
1819	Apr 12	N Central Chile	M= 2.0
1835	Feb 20	Southern Chile	M = 4.0
1837	Nov 7	Southern Chile	M = 3.0
1841	May 17	Kamchatka	M = 2.0
1868a	Apr 3	SE Hawaii	M = 4.1
1868b	Aug 13	Northern Chile	M = 4.3
1868c	Oct 2	South Pacific	
1869	Jul 24	South Pacific	
1877	May 10	Northern Chile	M = 4.0
1878	Jan 20	Aleutian Is (?)	
1896	Jun 15	Japan	M = 4.0
1901	Aug 9	Tonga	
1906a	Jan 31	Colombia/Ecuador	M = 1.0
1906b	Aug 17	Central Chile	M = 2.0
1918	Sep 7	Kurils	M = 3.6
1919	Oct 2	Hawaii (H = 14 ft)	
1922	Nov 11	N Central Chile	M = 3.0
1923	Feb 3	Kamchatka	M = 3.0
1933	Mar 2	Japan	M = 3.0
1946	Apr 1	Eastern Aleutian Is	M = 5.0
1952a	Mar 17	Hawaii (H = 10 ft)	
1952b	Nov 4	Kamchatka	M = 4.0
1957	Mar 9	Central Aleutian Is	M = 3.5
1960	May 22	Chile	M = 4.5
1964	Mar 28	Gulf of Alaska	M = 4.5
1975	Nov 29	Big Island/Hawaii (H = 47 ft)	

*Reliability of ≥ 3 (of 4)(Lander and Lockridge, 1989), runup > 1m (3.3 ft), and reported damage.

** Tsunami magnitude is defined by $M = \log_2 H$ as revised by Iida and others (1967), where H is the maximum runup height or amplitude on a coastline near the generating area.

Other tsunamis have occurred, such as that of Oct 1994, however, because of their low (<1 m) runup, insignificant damage, and/or uncertainty surrounding their timing and magnitude as noted in Lander and Lockridge (1989), they were not included here.



Stream flooding

Floods from stream overflow and high surface runoff (non-channelized flow) are common on all of the Hawaiian Islands and are primarily a result of torrential rains that fall on the steep slopes and small drainage basins characteristic of island drainage systems. The most frequent and severe flooding occurs where steep sloping hillsides abruptly meet flat or low-lying coastal plains, such as those found in Waimanalo, Kailua, Kaneohe, and Laie. Stream mouths are also commonly susceptible to flooding, especially during marine storm or high wave events, as runoff from streams reach a sea that is partly elevated by the combination of high waves, winds, and storm surges. Nearly every year flash floods and prolonged flooding damage property, homes, highways, and crops on each island. Although floods are caused by natural events, most flood damage is a result of human occupation and development of lands that are susceptible to flooding without having provided for adequate protection. As of 1983, floods in Hawaii had claimed more than 350 lives and caused more than $475 million in damage.

Some of the largest rainfall counts and most severe flooding events have occurred in the last several years. During the first 15 days of November 1996, record-breaking rainfall occurred along the Waianae Coast, where 21 in fell in an area where the average annual rainfall is only 2 in. In Ewa, 12.5 in fell in 7 hr on the 5th of that month, inducing flooding of the low coastal plain. On October 25, 1993, 2–4 in of rainfall caused flash flooding and extensive street flooding throughout the Honolulu area. On the windward side of Oahu, flooding has been common after heavy precipitation such as on April 12, 1994, in Kahuku, November 26, 1992, in Kaneohe, and October 11, 1992. The heaviest rainfall during the last decade in Kaneohe occurred on October 15–16, 1991, when 15 in fell in 48 hr leading to intense flash flooding. A series of slow-moving storms with prolonged rains that saturated the soils of south-central Oahu culminated on New Years Day of 1988 in severe runoff and hillside erosion, resulting in catastrophic damage to stream flood mitigation channels, homes, and roads in Aina Haina and Niu Valleys. Other recent severe events on Oahu include October 1981 flooding of Waiawa Stream after heavy rains that led to $786,000 damage and January 1968 flooding in Pearl City, which caused $1.2 million damage. The hazards resulting from stream flooding are significant on all of the islands and should be seriously considered for planning development, as well as for recreation activities.

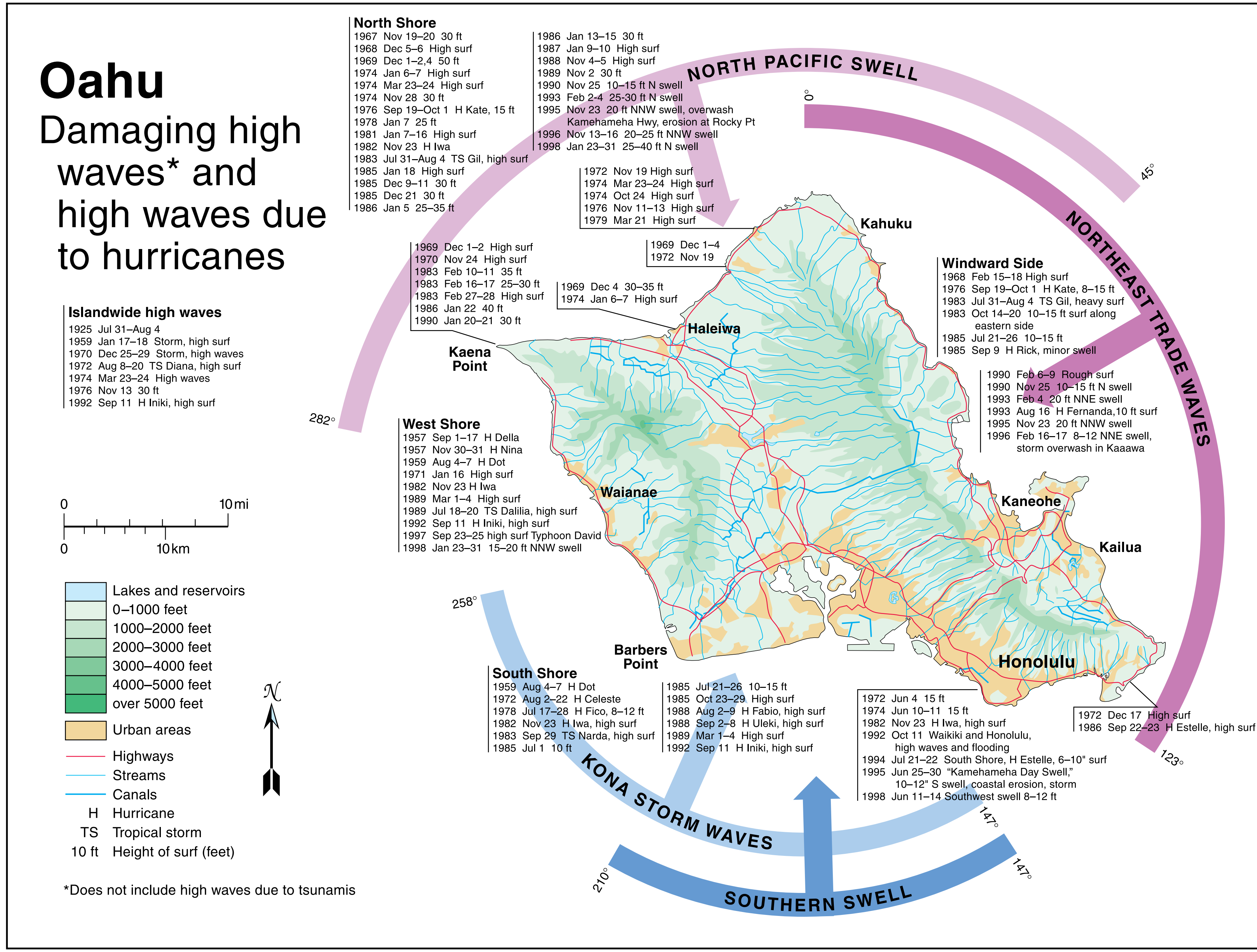
Many formerly flood-prone streams on Oahu have now been artificially channelized to protect development situated on the adjacent flood plain. Although the threat of flood hazard is reduced by this measure, there is a resultant destruction of wetland and stream channel ecosystems that occur. The result is to promote building on former floodplains and the destruction of the riverine environments and estuaries that connect the island's watersheds and reefs.

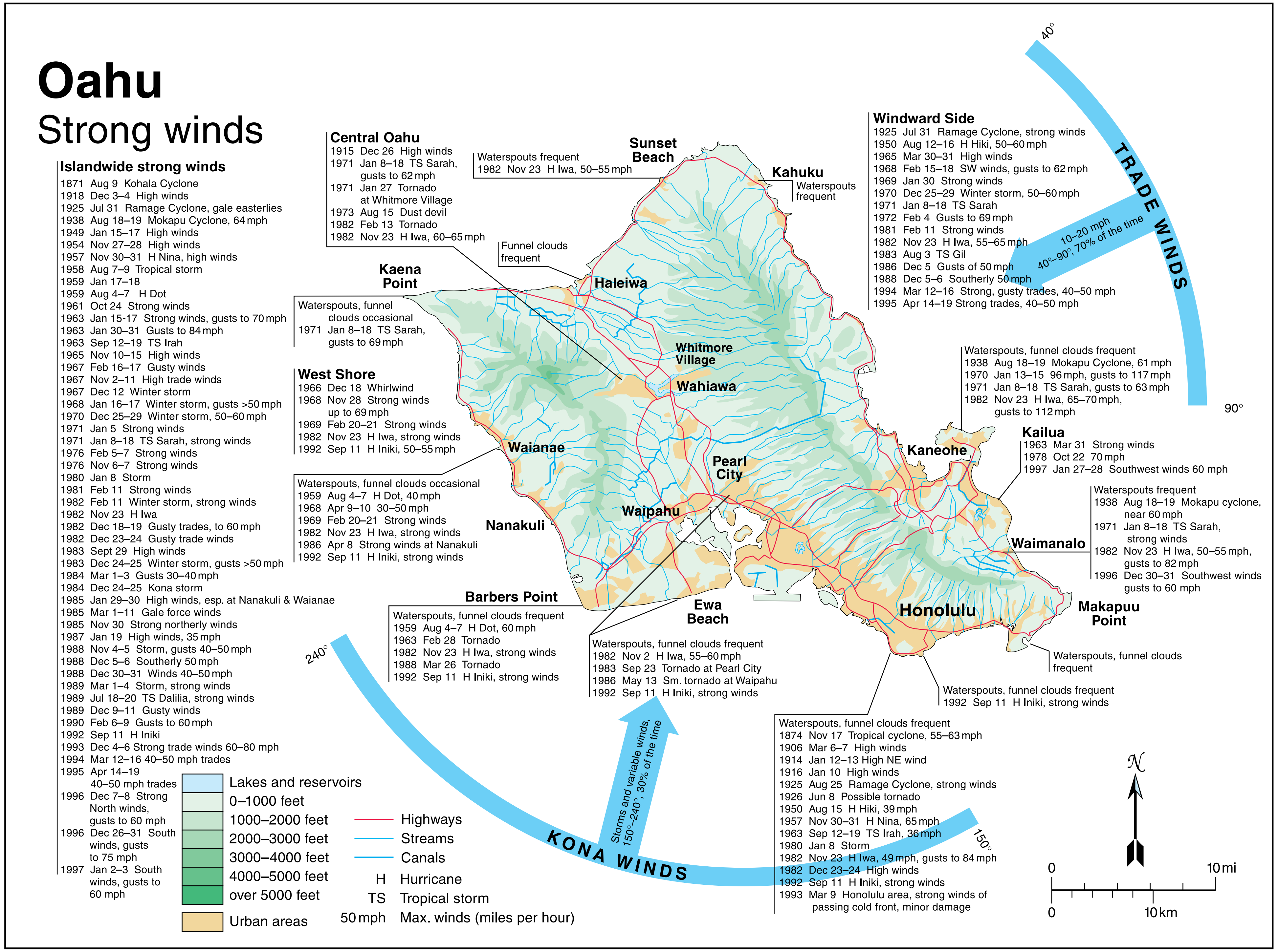
High waves

High waves are common along Hawaiian shores, making the islands perhaps the most popular destination for big wave surfing in the world. Lying in the center of the North Pacific Ocean, Hawaii receives high waves from distant storms in the northern and southern hemispheres and from tropical cyclones passing in the vicinity. The hazards associated with high waves include debris overwash, flooding, erosion, high wave energy and turbulence in the nearshore zone, and strong currents. Waves that reach the shoreline are determined by the energy inherent in the approaching swell (a function of wave height and wave length-the distance between successive wave crests), shoreline aspect, slope, morphology and geology, and offshore characteristics including seafloor depth, morphology, and barriers (islands, rocks, reefs, sandbars). When deep-water ocean swells encounter the shallow island margins they rise to great heights because their tops stack up on their slower moving bottoms due to friction along the shallower seafloor. Because the contact between deep water and the shallow margins around the Hawaiian Islands is abrupt, surface waves can grow very tall, very rapidly. Large waves tend to travel in sets, and after breaking they rush up onto the beach temporarily elevating the sea surface near the shoreline. Rip currents form as the water that is pushed up on the shore by successive large waves, tries to flow back to the sea.

The largest waves that reach Oahu generally arrive in winter as a result of intense storm activity in the North and Northwest Pacific. The high amplitude and long wavelength associated with these swells create very large waves with considerable energy. Along the north shore of Oahu, it is common to see wave heights between 15–20 ft annually from winter swell. However, wave heights of 50 ft have been reported, for instance in December 1969 and January 1998. This high wave energy pounds the north and west shorelines as it hits head on, but it can also refract and produce high waves around the entire island. Often, winter north and northeast swells wrap around Makapuu Point and generate waves at Sandy Beach that are as high as the largest summer surf found there. Periodically, as winter mid-latitude storms track northeast of the islands toward the mainland, they will generate swell that impacts the east sides of the islands. In the summer, south-facing shorelines receive 4–6 ft swell from distant storms in the Southern Hemisphere. South swells tend to have less energy than winter swells, but because their source can be as far away as New Zealand, they can have very long periods. Trade wind waves can be high, but because of their shorter wavelengths, they have less energy than north and south swell. Trade wind swell has a greater easterly directional component, which enables them to refract around to south and southwest-facing shorelines producing wave heights of 1–4 ft.

High waves from hurricanes present a more complex hazard, as they may coincide with high tide, storm surge, and wind and wave setup, to produce a combined threat. High waves from hurricanes generally occur during hurricane season between June 1 and December 1. High waves from hurricanes most often hit the eastern shores as hurricanes approach the islands from the east, and south- and west-facing shorelines as the storm passes to the south and west. Hurricane generated waves have exceeded 15 ft along east Oahu and 20 ft on Oahu's southern shores. Combined with storm surge and high tides, hurricane waves can overwash coastal roads and properties, as they did along the Kaaawa and Kaneohe coasts during Hurricane Fernanda in 1993 and along the Honolulu and Waianae coasts during Hurricane Iniki in 1992.





Strong winds

Winds on Oahu originate from three main sources: trade winds, Kona winds, and hurricanes or tropical storms. Northeast trade winds are dominant throughout most (70%) of the year and generally range in velocity between 10 and 20 mph. However, trade winds of 40–60 mph occasionally occur for several days at a time when the sub-tropical high-pressure cell located in the central North Pacific Ocean intensifies. During the 1993–1994 and 1994–1995 winter seasons, for example, strong and gusty trade winds of 40 to 50 mph lasted several days and inflicted damage to roof tops, tree limbs, and telephone equipment. The east-facing coastlines, as a result, are the windward coasts and most impacted by trade wind energy. Kona winds are southerly winds and occur as light and variable winds during summer months when trade wind circulation breaks down, but in winter they can be very strong when storm systems moving across the central North Pacific draw air from the south toward their low pressure troughs. Damaging Kona winds from storms generally occur during the winter and spring seasons and have reached velocities of 50 mph for several days on end.

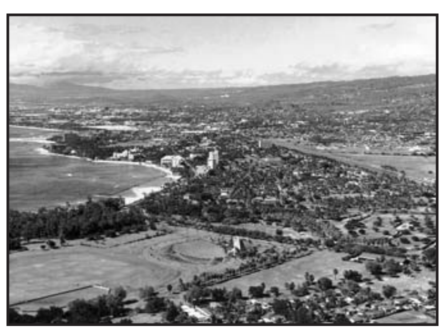
Damaging winds on Oahu and in Hawaii are most commonly associated with passing tropical cyclones (hurricanes, tropical storms, and tropical depressions). Historically, most tropical cyclones have passed the Hawaiian Islands to the south and west. Because they spin counter-clockwise in the Northern Hemisphere, east-facing coastlines in Hawaii receive the brunt of strong onshore winds as storms approach the islands, while the south and west coastlines feel onshore winds as the storms pass to the west. The highest wind speeds, however, may occur on the side opposite the storm approach, as localized microbursts and downdrafts accelerate downslope as they descend over the palis (cliffs). As Hurricane Iwa passed west of Oahu the highest winds were observed at the base of the Pali in Kaneohe. Even so, coastlines facing the passing storms usually are adversely impacted by both wind and storm surge damage, like the Waianae Coast was as Hurricane Iniki passed to the west, before slamming into Kauai. History has shown that the islands do not have to take a direct hit from a storm to sustain a high level of damage. Wind strength, storm diameter, timing, and proximity, are important factors that control storm impact to the coastal zone.

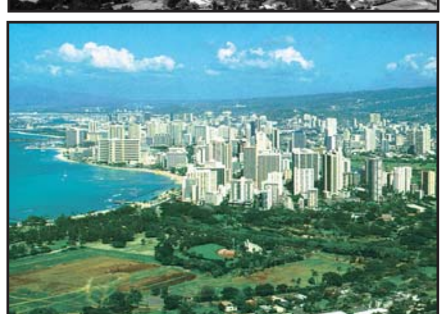
Honolulu

The heavily developed coastal metropolis of Honolulu and Waikiki is built on a low-lying coastal plain, which was submerged by a higher relative sea level approximately 125,000 yr ago and again as recently as 1,500 to 4,000 yr ago. In response to erosion and other hazards, an extensive complex of shoreline protection structures, including groins, seawalls, and revetments has been implemented to protect the densely developed seaside. Once home to Hawaii's legendary surfer and Olympic gold-medal swimmer, Duke Kahanamoku, Waikiki attracts many visitors each year who relax on the beautiful white sand beaches. Ironically, these beaches are also largely a human fabrication. Early in the 1900s, sand was imported to create an extensive artificial beach where only a narrow sand strip fronting coastal wetlands and tidal marshes formerly existed. They continue today to be nourished by sands brought in from elsewhere on the island.

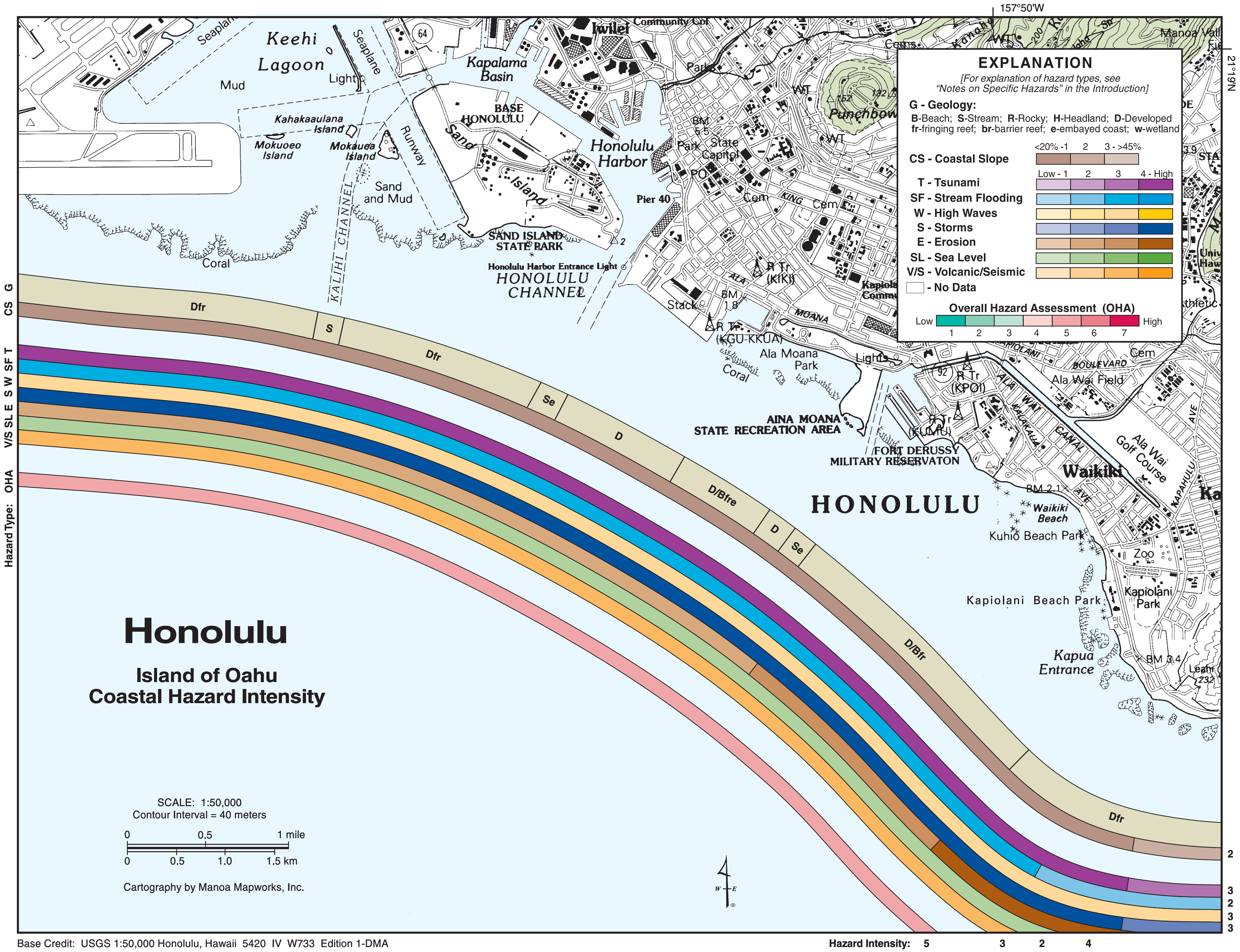
The coast steepens at the foot of the prominent and geologically-young crater of Diamond Head, known as Puu Leahi. A nearly continuous fringing reef parallels the coast at Diamond Head, and widens to the west. The bottom remains shallow far offshore along this entire region. The reef has been dredged to form a channel at the outflow of the Ala Wai Canal, which empties the Manoa and Palolo streams, and on both sides of Sand Island, to provide for commercial shipping. Land reclamation on the reef has occurred at the airport, Sand Island, and Ala Moana.

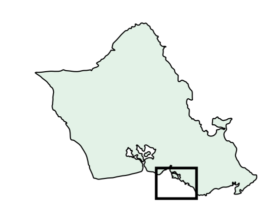
A moderate to high (5) Overall Hazard Assessment (OHA) for the Honolulu coastal zone is principally dictated by the low coastal slope which is especially susceptible to damage resulting from tsunami, stream flooding, hurricane storm surge, and seasonal high-wave flooding. Tsunami and storms are ranked high while stream flooding and high seasonal waves are moderately high. These rankings are supported by a history in Honolulu of severe flooding from both storm surge and stream runoff from the steep surrounding hillsides of the Koolau Range. Although Honolulu has yet to experience a direct hit from a major hurricane or tsunami, a complacency may exist among its inhabitants that hurricanes and tsunamis are not major threats to this coast. Facing southwest, however, coastal Honolulu is extremely vulnerable to strong winds and waves generated by tropical storms that most frequently pass the Hawaiian Islands just west of Oahu. While observations of tsunami flooding have not exceeded 8 ft, Honolulu has experienced extraordinary coastal development within the elevation range of historical tsunami runups. The threat from high waves is moderate to high because this region regularly receives wave heights on the order of 6 ft from south swell. As recent as the summer of 1995, however, waves as high as 12 ft pounded the Honolulu shoreline causing significant flooding and erosion along the waterfront of Waikiki's seaside hotels and Kuhio Beach Park. Erosion is high at the foot of Diamond Head (at the southeast corner of this map) and moderately high throughout Waikiki, where seawalls and groins have been placed to reduce coastal erosion. West of Ala Moana Park, erosion is reduced to moderately low, because of the buffering effects of the wider fringing reef offshore. Sea-level rise in this region is ranked moderately low relative to the higher rates on Maui and the Big Island. Seismicity along the Honolulu coastline, like the southern half of Oahu, is ranked moderately high because it is within the Molokai Seismic Zone.



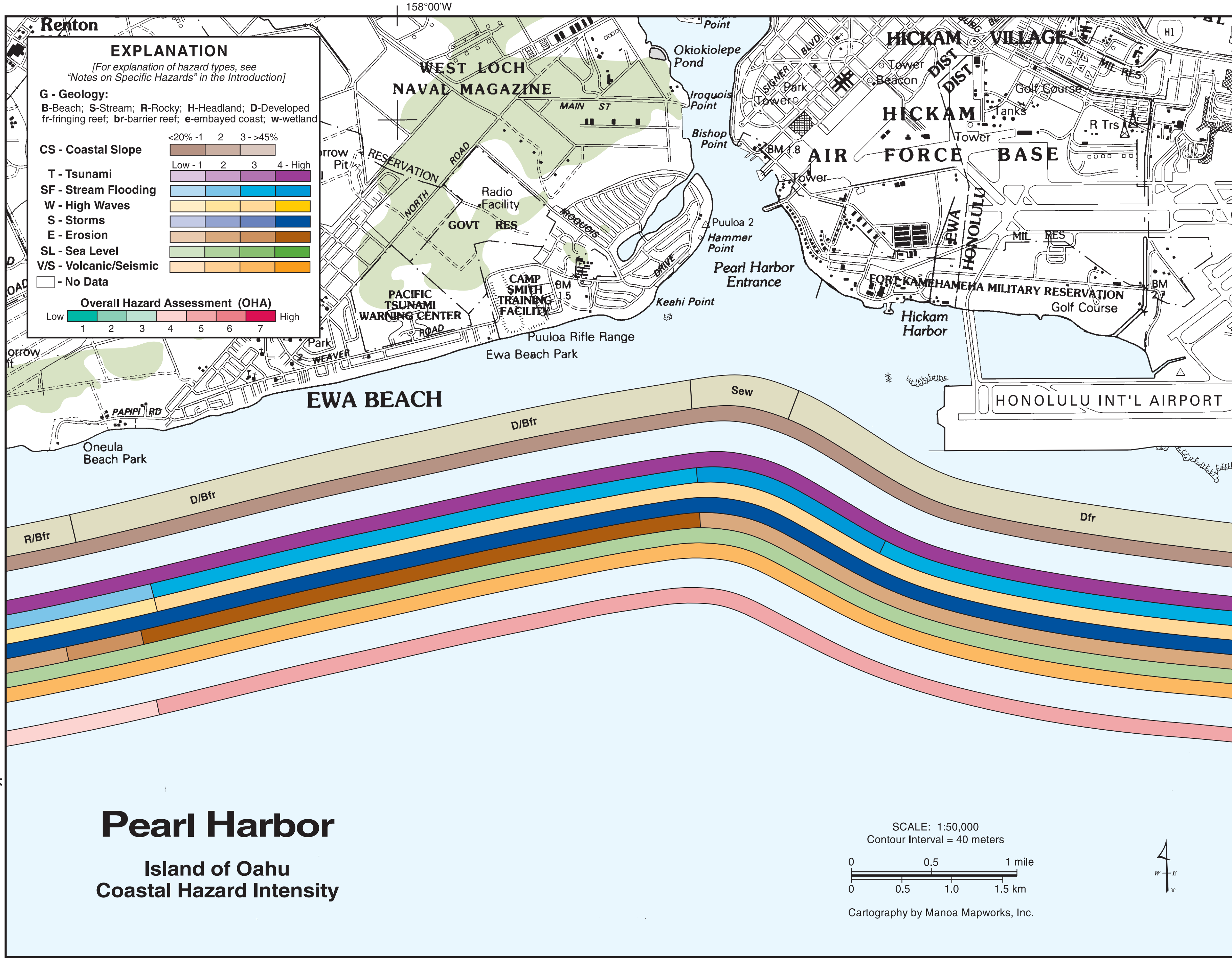


TOP: Waikiki, about 1958
BOTTOM: Waikiki, about 1984





Honolulu



Base Credit: USGS 1:50,000 Nanakuli, Hawaii 5320 I W733 Edition 1-DMA and USGS 1:50,000 Honolulu, Hawaii 5420 IV W733 Edition 1-DMA

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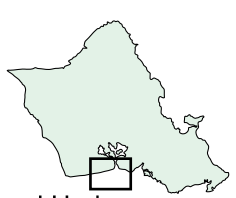
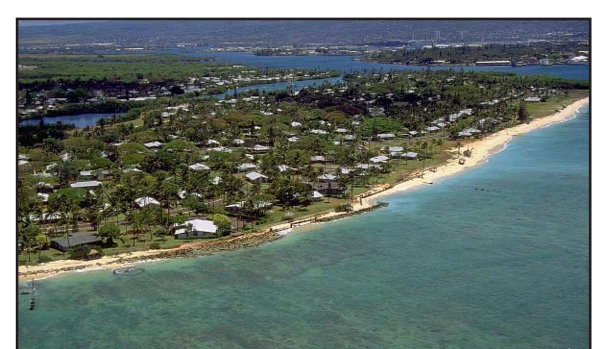


Pearl Harbor



The low Ewa coastal plain is fringed by narrow sandy beaches and a wide, shallow reef flat offshore.

Pearl Harbor

The entrance to Pearl Harbor separates the beaches along the coastal plain of Ewa to the west from the isolated and less accessible shores of Hickam Air Force Base and the Honolulu International Airport to the east. Fringing reefs parallel the coastline extending nearly one mile offshore, except at the mouth of the harbor. Here, sediments transported from the central plain of Oahu by streams descending from both the Koolau and Waianae ranges meet the sea and form an embayed wetland environment ringing the shores of Pearl Harbor. The shallow nature of the broad fringing reef at Ewa is effective at intercepting waves and dissipating their energy far offshore of this low-lying and very gently sloping coast. Extensive land reclamation has transformed the coastline near the airport and Pearl Harbor entrance. The coastline in the vicinity of Ewa Beach appears to be actively eroding even under relatively low wave activity. Seawalls and rock-piles surround the harbor entrance and airport runways in the east, while small jetties, groins, and seawalls have been emplaced along the narrow sandy beaches of Ewa.

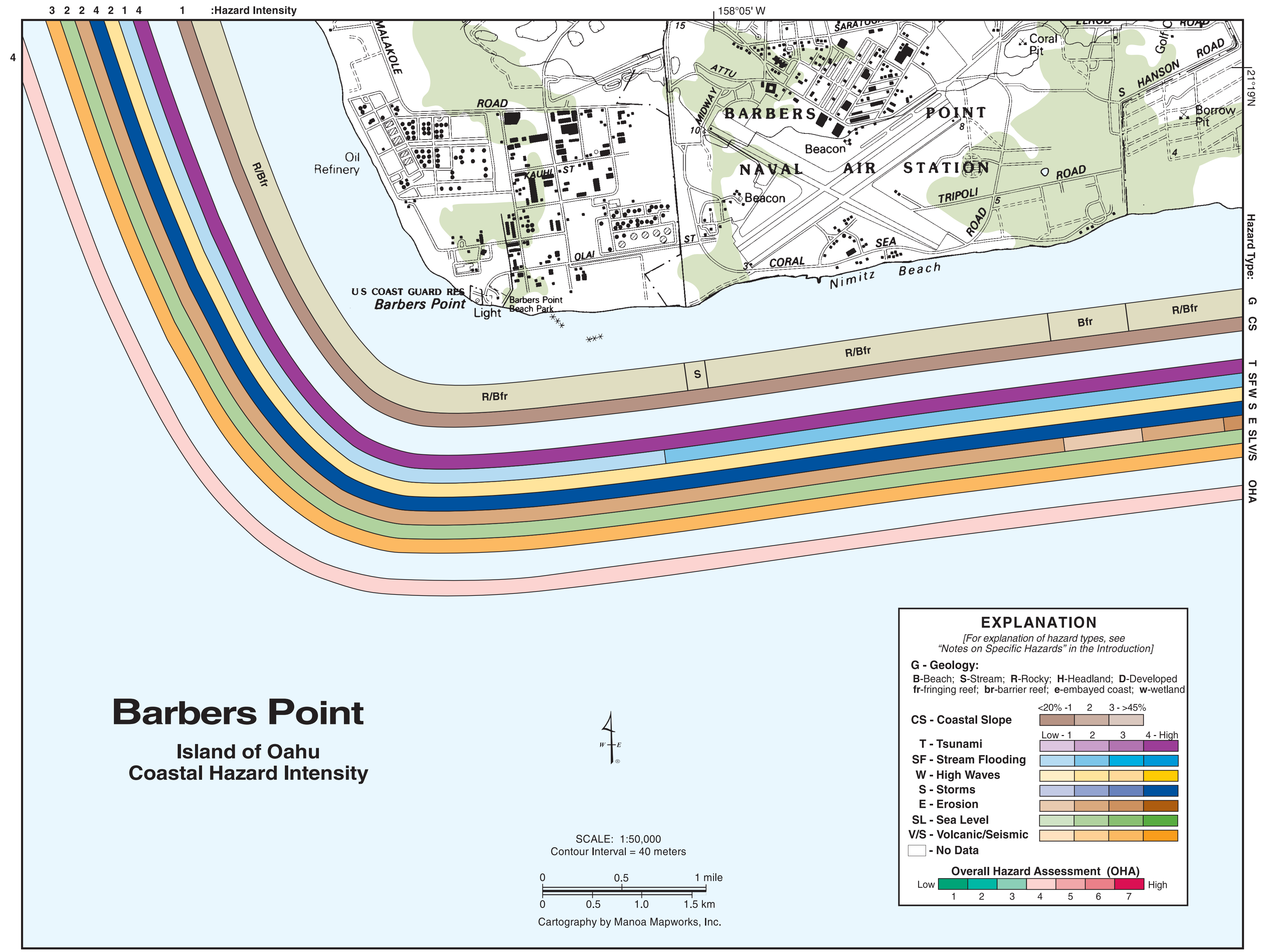
The Overall Hazard Assessment (OHA) for the Pearl Harbor coastal region ranges from moderate to high (5) at the mouth of Pearl Harbor to moderate (4) west of Oneula Beach Park, primarily as a result of the low slopes found along the seaward edge of Oahu's largest drainage basin. The low-lying coastal plain surrounding Pearl Harbor is susceptible to wave inundation so the tsunami threat is ranked high. This coast becomes increasingly arid to the west, and as a result, the stream flooding hazard is reduced from high near the harbor mouth to moderately high on each side and moderately low west of Oneula. Although annual wave heights reach 4-6 ft from south, southwest, and refracting northwest swell, the hazard from high waves is reduced to the west of Oneula Beach Park, where shallow fringing reefs extend far offshore and help to dissipate wave energy. As a result, the high-wave hazard is moderately high east of Oneula and moderately low to the west. Historically, the region has yet to experience the direct hit of a hurricane, however, because it faces south it is vulnerable to high winds and waves generated by tropical storms that commonly pass to the west of Oahu. Erosion is moderately low east of the harbor mouth, and high along the Ewa Beach coastline, where a recent proliferation in seawalls and revetments has exacerbated beach loss. It is moderately high along Oneula and moderately low to the west. The threat of sea-level rise is ranked moderately low, while the seismic hazard is moderately high due to the nature of the unconsolidated sediments upon which portions of this area are developed. The volcanic/seismic hazard along the Pearl Harbor coastline is moderately high.

Barbers Point

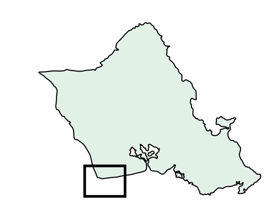
The remote coast of Barbers Point is a broad nearly flat marine terrace underlain by reefs formed by the Waimanalo Stand of the Sea, 125,000 yr ago. It is also one of the driest areas on Oahu. Small 3-6 ft rocky outcroppings of fossil reefrock extend from Nimitz Beach in front of Barbers Point Naval Air Station around the point to the oil refinery in the west. This coastal zone has a very low slope. Poorly defined fringing reefs run the length of this coast where the nearshore zone is largely comprised of a hard coral and calcareous algae reef bottom interrupted in a few locations by small sand channels. Because Barbers Point faces due south, it is susceptible to Kona storms, tropical storms, and waves coming from the south. It also extends sufficiently to the west that it can experience significant swell wave energy refracting around the island from the north. The Alaskan earthquake of 1946 brought 12 ft tsunami waves to Barbers Point, while just to the east at Ewa Beach, the highest recorded tsunami runup was 3 ft.

The Overall Hazard Assessment (OHA) for the Barbers Point coast is moderate (4), primarily due to the high storm and tsunami hazards. The low coastal slope of Barbers Point makes this region vulnerable to inundation and flooding associated with high waves and tsunamis. As a result, the hazard due to tsunami is high. The storm threat is also ranked high along this coast, as hurricane inundation, including that from Iniki (1992) and Iwa (1982), has historically been damaging to this and other south-facing coastlines. Stream flooding, however, is ranked moderately low to low because it is very arid in this region and far removed from the drainages of the Koolau and Waianae ranges. The hazard due to high seasonal waves is ranked moderately low because this region largely experiences moderate wave energy from south swell. The hazard due to erosion is slight and is ranked moderately low along the rocky cliffs of Barbers Point and low in front of the isolated sandy beach at Nimitz Beach. The threat from sea-level rise is somewhat mitigated by the rocky coastline and is ranked moderately low here as in most of Oahu. The volcanic/seismic hazard is ranked moderately high, as is the southern half of Oahu, due to a history of occasional significant seismic activity.

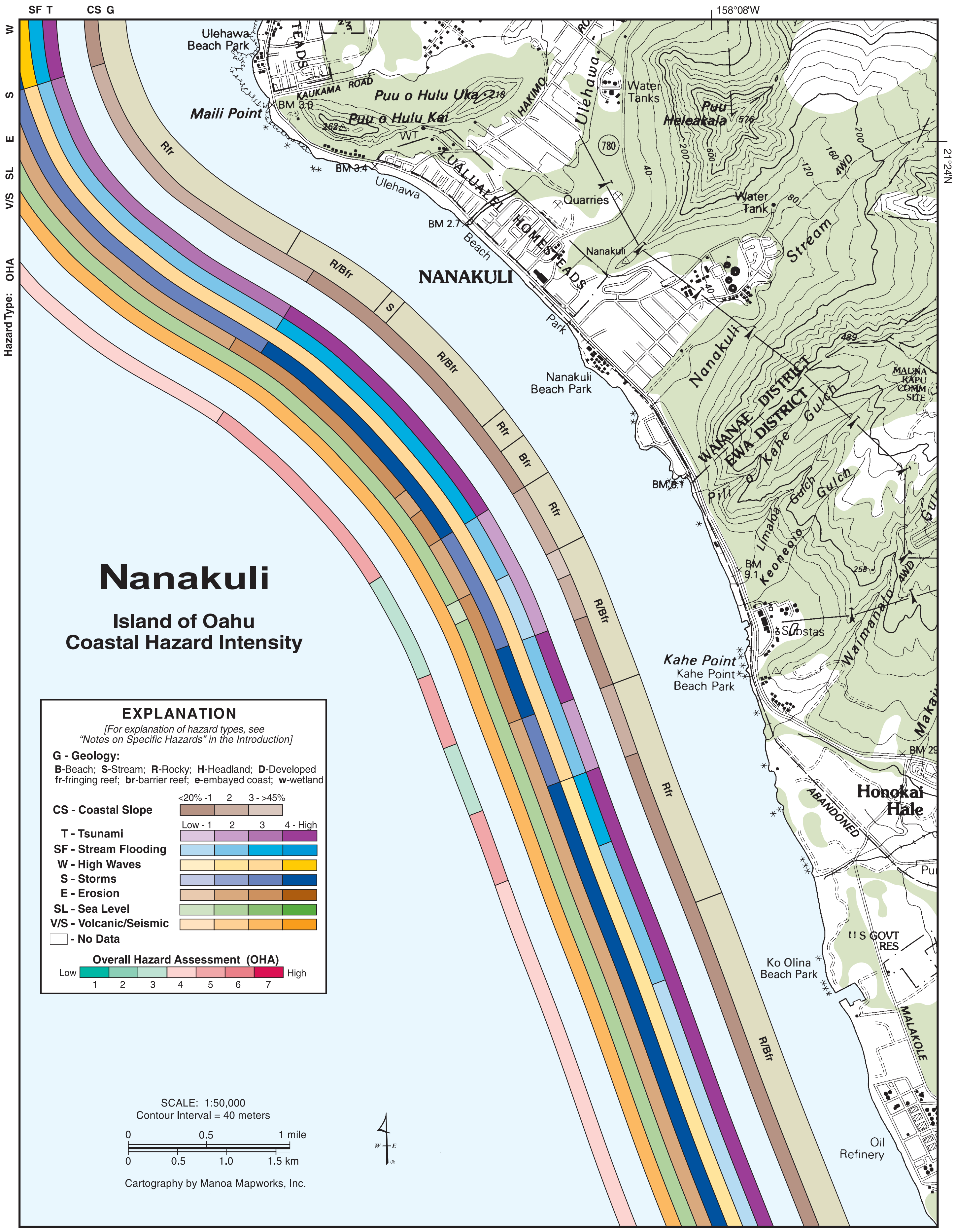
Oahu's oil refineries are built on this low-lying Barbers Point coastal plain, which rises only ~1–2 m above sea level.

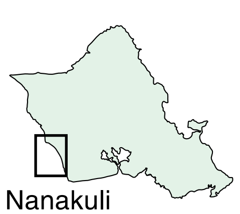


Base Credit: USGS 1:50,000 Nanakuki, Hawaii 5320 I W733 Edition 1-DMA, and USGS 1:50,000 Honolulu, Hawaii 5420 IV W733 Edition 1-DMA



Barbers Point





Nanakuli

The Nanakuli coastline from Maili Point to the oil refinery and power plant south of Honokai Hale, marks the southernmost portion of the west coast of Oahu. Small pocket beaches of sand and/or basalt boulders lie between lengthy expanses of 6-10 ft high rocky cliffs of old reefrock and/or beachrock. Several sandy beaches are perched on top of reefrock and beachrock at the water's edge. Offshore, the seafloor is largely a hardground of reef separated by occasional small sand channels and a few larger sand fields inside an extensive complex of submerged fringing reefs. The slopes are relatively gentle along this coast but steepen around Maili Point, where signs of headland slumping can be seen on Puu o Hulu Kai. Seemingly protected behind Maili Point, the town of Nanakuli actually has experienced considerable inundation from high waves. Tsunami heights of 20 ft from the 1946 Alaskan earthquake were recorded in Nanakuli, whereas farther northwest in Waianae (see Waianae map) the same event produced only 12 ft floodwaters.

The Overall Hazard Assessment (OHA) for the Nanakuli coastline is moderate to high (5) in the low-lying coastal town of Nanakuli and at the two isolated beaches just north and south of Kahe Point Beach Park. These areas are most susceptible to tsunami, stream flooding, high winds, and storm surge. The OHA is moderate to low (3) at Kahe Point and along the small rocky shore where Pili o Kahe Gulch meets the sea. The OHA is moderate (4) south of Kahe Point Beach Park to Ko Olina, and along Maili Point. Tsunami and storm hazards along this coast are ranked high from Ulehawa to Nanakuli Beach Park, just north of Kahe Point Beach Park, and the southern region near the oil refinery and power plant, where the coastal slopes are lowest. Both are ranked moderately high along the steeper rocky areas between. Stream flooding is ranked moderately high for the Nanakuli coastal plain and the beach seaward of Honokai Hale, and moderately low and low for the steeper areas. The high wave hazard is ranked moderately high along low-lying Nanakuli, which receives larger winter waves, and moderately low to the south where the slope is relatively steeper and the coast farther removed from influence of winter swell. Erosion is moderately high for sandy and rocky low-lying beaches and moderately low where rocky cliffs help mitigate loss of coastal land. Sea-level rise is moderately low throughout this coast, except at the isolated and steep rocky outcrop just south of Nanakuli Beach Park where it is ranked low. The volcanic/seismic hazard here, like the southern half of Oahu, is ranked moderately high because of its proximity to the Molokai Seismic Zone and history of seismicity during the last 200 yr.

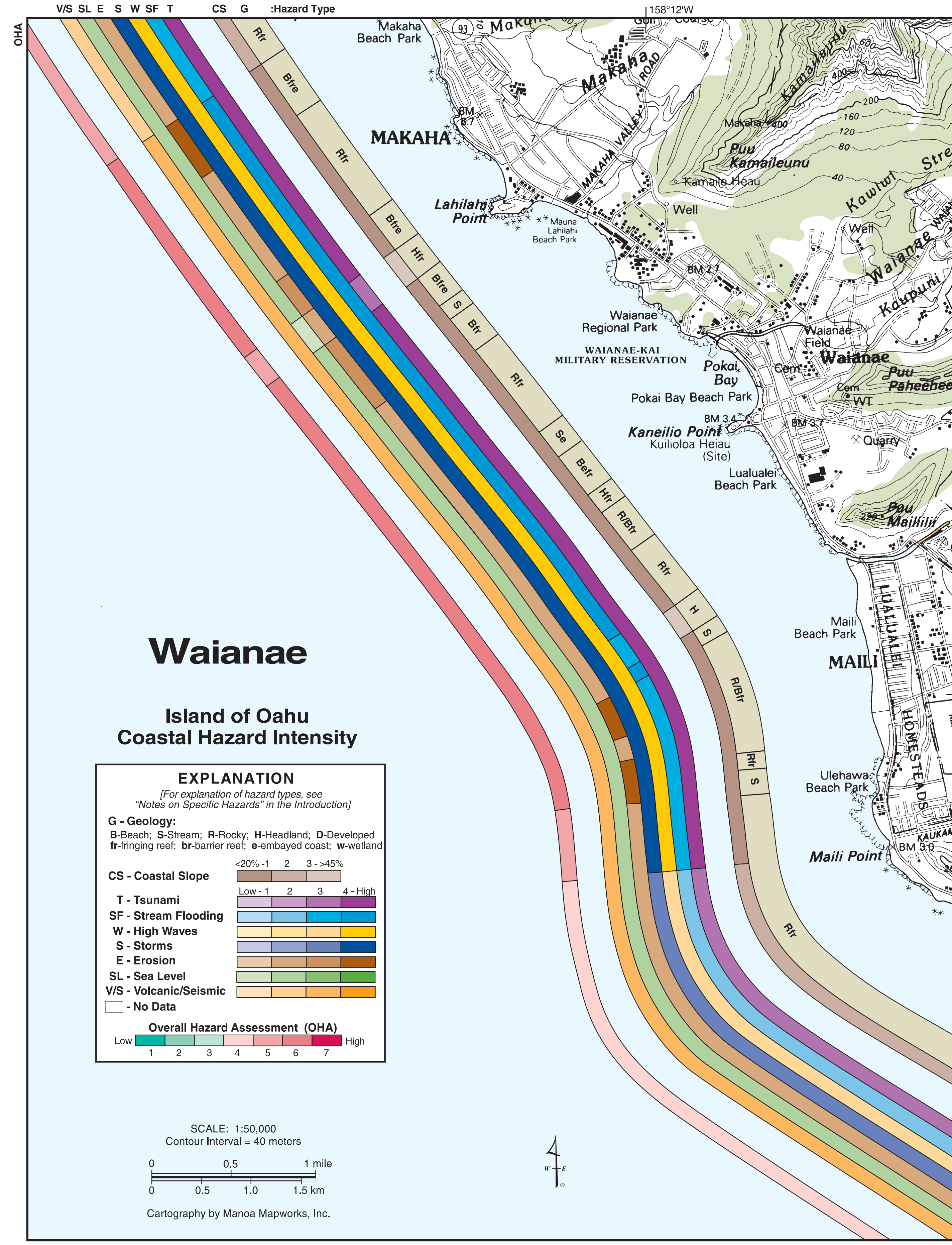
The artificial coves of Ko Olina provide sandy beaches along an otherwise rocky shoreline.

Waianae

Beautiful sandy beach embayments separated by spectacular basaltic headlands mark the Waianae coast. Streams, most channelized into drainage canals, empty deeply incised valleys on a low-lying but narrow coastal plain of emerged fossil limestone reef rock that formed about 125,000 yr ago when sea level on Oahu was higher than present. Seawalls have been built along many of the seaside properties, and large boulder breakwaters guard Pokai Bay and the Waianae Small Boat Harbor. Beach widths at Maili and Makaha can vary by 145 ft annually due to seasonal changes in wave energy. In the long term it appears that the central portions of these beaches have accreted at the expense of their margins. Fossil reefs separated by scattered sand-rich channels and scoured surge channels lie offshore just landward of a relatively extensive fringing reef. Except for Lahilahi Point (Black Rock), a volcanic headland, the majority of this coast maintains very low slopes, and as a result, has experienced damaging floods from streams and inundation by hurricane storm waves. Facing southwest, the Waianae coast has historically received significant wind and wave energy associated with passing tropical storms that tend to track just west of Oahu as they pass the Hawaiian Islands. Two storms of recent memory, Hurricanes Iwa (1982) and Iniki (1992) generated damaging high waves, and the associated storm surge produced coastal flooding to an elevation of 11 ft above mean sea level and higher.

From Makaha to Maili Point, the Overall Hazard Assessment (OHA) is high (6) where hazards due to tsunami, stream flooding, high waves, and storms are individually ranked high, largely because of the low-lying, gradually sloping coastal plain. Flood inundation heights of 12 and 14 ft were recorded in this region during the 1946 and 1957 tsunamis, respectively. Flash floods and stream floods, sometimes lasting two or three days, have occurred relatively frequently along the Waianae coast. As a result, stream flooding hazard is ranked moderately high south of Maili, and high north of Maili Beach Park, where several streams drain inland valleys along the low coastal plain. Only at the headlands of Lahilahi and Maili Points is the overall hazard assessment reduced to moderate to high (5), due to the moderately high tsunami threat and moderately low erosion hazard there. South of Maili Point, where the tsunami, high waves, and storm hazards are reduced to moderately high, and stream flooding is moderately low, the overall hazard is ranked moderate (4). Erosion is ranked high at the west end of Ulehawa Beach Park and Makaha, and moderately high along the low-lying beach embayments on either side of Lahilahi Point. Sea-level rise is ranked moderately low and low throughout the region. The volcanic/seismic hazard here in the southern half of Oahu is ranked moderately high.

Waianae Small Boat Harbor and Lahilahi Point (Black Rock) to the west.



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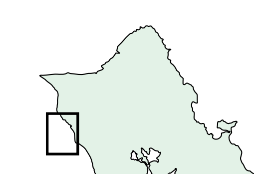
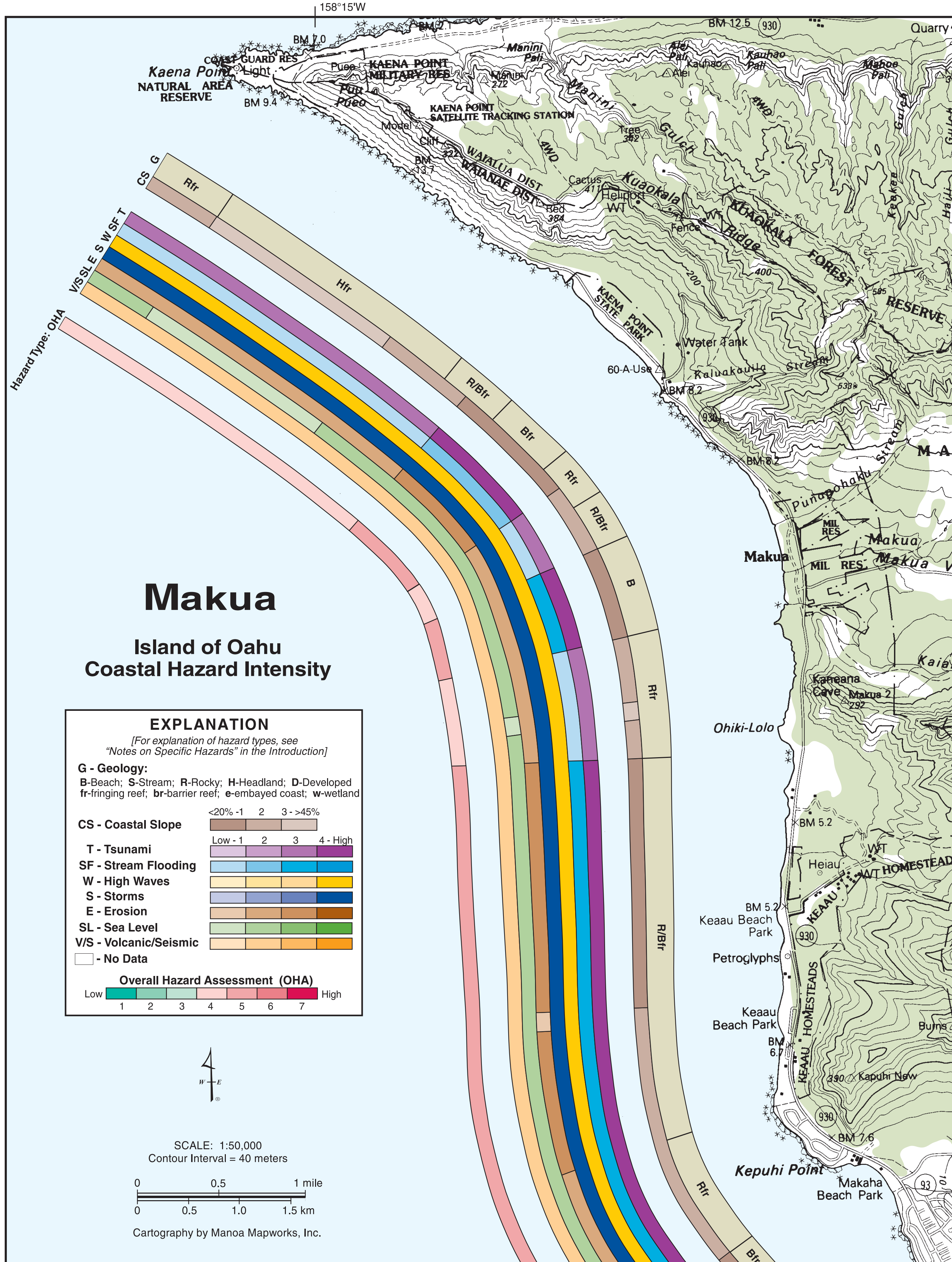
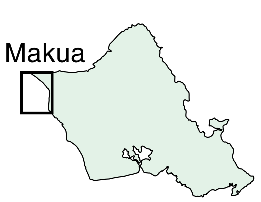






Makua

The Makua coast from Makaha Beach Park to the remote and rugged Kaena Point, is mostly rocky and narrow. Emerged Waimanalo-age carbonate reefrock borders the coastline near Makaha while, beneath the steep headlands of Kaena, basalt boulders dominate the coast. Features that appear to be alluvial fans or rock slides along the Kaena coast reveal that these cliffs are actively eroding. A few isolated pocket beaches exist between these rocky outcrops. At Makua, a platform of subtidal beachrock supports a perched sandy beach. The low-lying coastal road, which was overwashed by storm waves from Hurricane Iniki, gives way to a foot trail along the steep headland northwest of Kaena Point State Park. Scattered fringing reefs surround the rocky points and small sandy embayments. Large sand fields offshore of Makaha Beach Park merge with smaller elongated sand channels to the west. This region is dominated by high wave energy from North Pacific swell, especially in the winter and spring, however it is largely sheltered from active trade winds. The Makua coast is dominated by a fairly arid climate and stream flooding, while not a perennial threat, does occur from time to time.

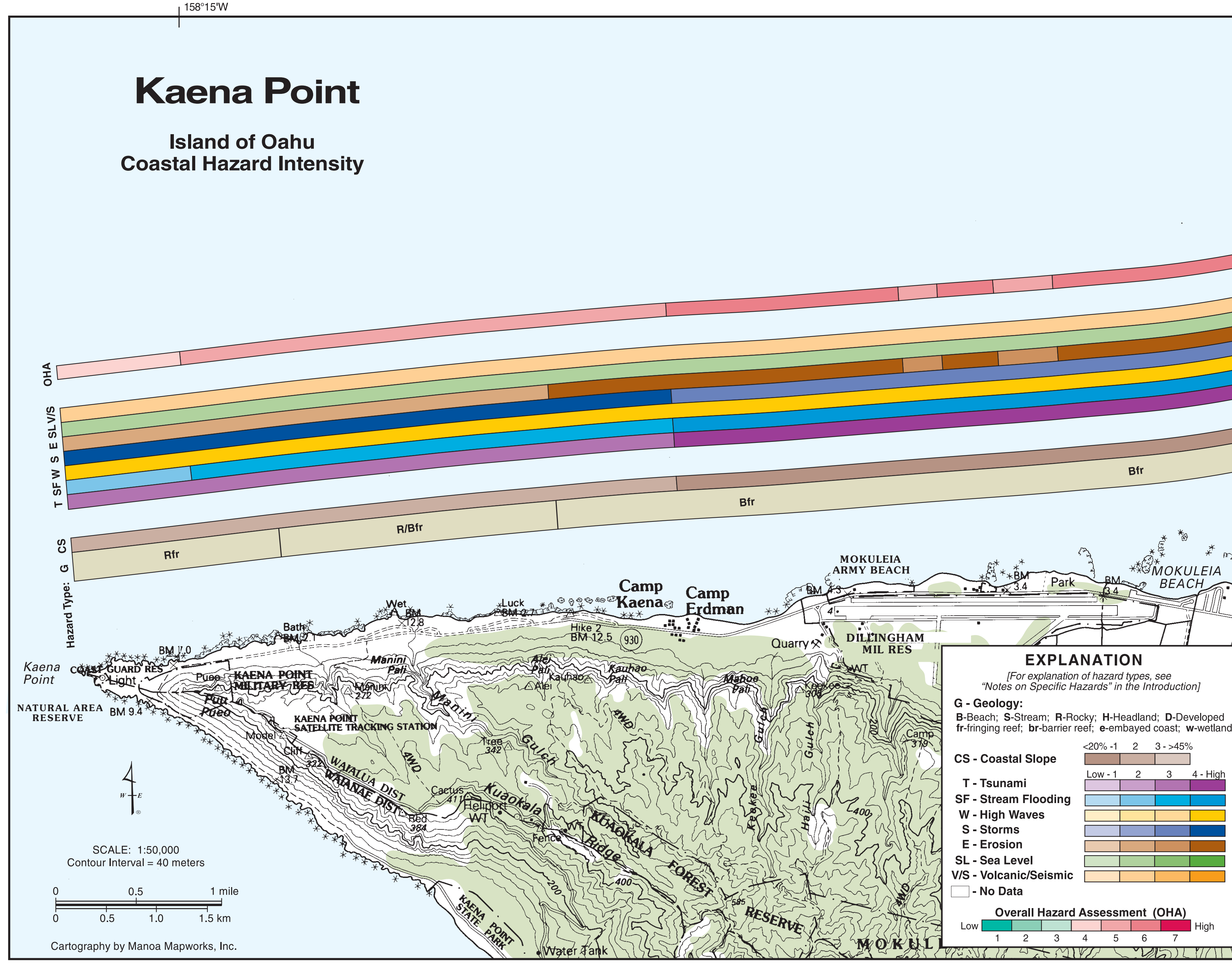
The Overall Hazard Assessment (OHA) is moderate to high (5) along Keana Point State Park beach , Makua beach, and south of Ohiki-Lolo where the threat of tsunami is high and stream flooding is moderately high, except along Kaena Point State Park where it is moderately low because of a lack of coastal streams. The OHA is moderate (4) along the steeper headlands between Kaena Point State Park and Makua and near Ohiki-Lolo where the tsunami hazard is moderately high and stream flooding is low. The threat of high waves, up to 20 and 25 ft on the outer reefs, comes annually during the winter and spring, and as a result, is ranked high. The Makua coast is vulnerable to both Kona storms and hurricanes tracking to the west of the Hawaiian Islands, and in the past has experienced considerable flooding, overwash, and wind damage from these events. As a result, a high hazard ranking has been given to storms along this coast. Erosion is ranked moderately low along the rocky cliffs in the western portion of Kaena State Park and south of the park to Ohiki-Lolo. Erosion is ranked moderately high for the lower-lying regions and beaches just inside Kaena Point State Park, and the entire shoreline south of Ohiki-Lolo, except for the steep-sided and rocky Keaau Beach Park, where it is ranked low. Sea-level rise is also a low to moderately low threat due to the rocky coastline. The volcanic/seismic hazard is ranked moderately low here as it is for the whole northern half of Oahu, from Makaha to Kaneohe Bay, which is removed from the Molokai Fracture Zone and other known regions of seismicity.

Sandy beachs are separated by rocky headlands along the Makua Coast.

Kaena Point

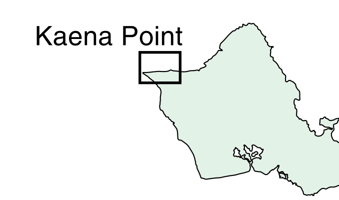
Along the north coast, from Kaena Point to Mokuleia, broad intertidal and subtidal wave-abrasion platforms are carved into Waimanalo-age limestone, reflecting the long history of great wave activity along this shoreline. A low-lying platform of fossil reefrock is elevated 3-6 ft above mean sea level and extends from Mokuleia to within 0.5 mi of Kaena Point. Isolated sandy beaches are found at breaks in the rocky bench and widen toward Mokuleia where they connect with small offshore sand fields. Modern intertidal erosion cuts into the elevated limestone testifying that wave energy and bioerosion are high at the shoreline. Offshore lies an extensive fringing reef complex. At Kaena Point, a partially vegetated Holocene dune field lies near sea level and is active in the trade winds and southerlies. Efforts to reduce erosion along the Mokuleia shoreline by implementing seawalls have essentially failed and instead have led to substantial beach loss.

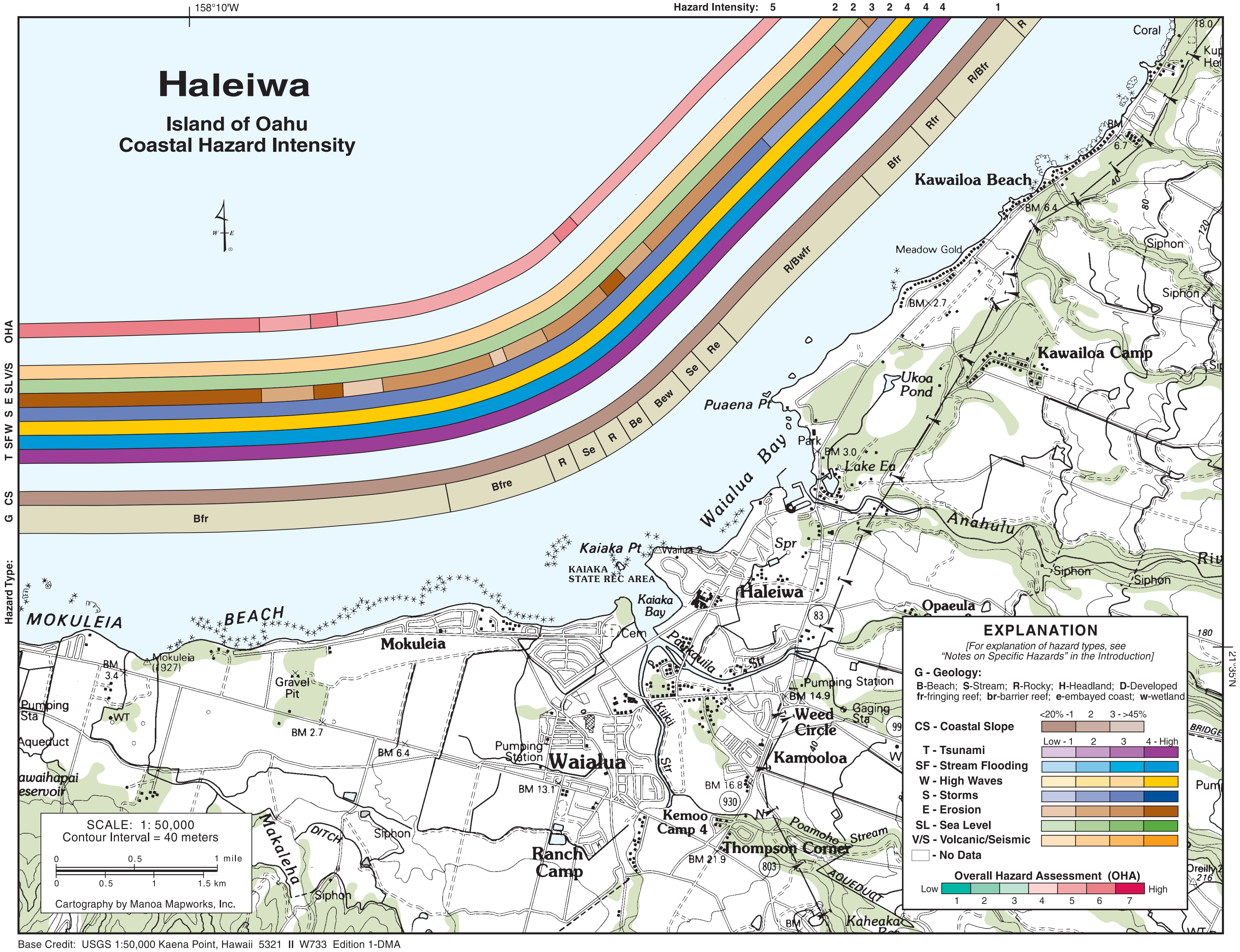
The rugged, rocky coast between Kaena Point and Mokuleia experiences trade winds nearly 70% of the year.



Base Credit: USGS 1:50,000 Kaena Point, Hawaii 5321 II W733 Edition 1-DMA

The Overall Hazard Assessment (OHA) along the Kaena Point coast increases from moderate (4) at the point to high (6) along the low-lying sandy beaches of Camp Erdman and Mokuleia Beach, where the coastal slope is lowest and chronic erosion is diminishing Mokuleia's sandy beach. Between Kaena Point and Camp Erdman, where stream flooding is greatest, and along the hard limestone shoreline west of Mokuleia Beach, the OHA is moderate to high (5). Tsunami and stream flooding are ranked high along the lower slopes between Camp Erdman and Mokuleia, while towards Kaena Point they are only moderately high because of the higher coastal slope. Tsunami flood heights of 36, 30, and 22 ft were observed at Kaena Point in 1946, 1952, and 1957, respectively. Stream flooding at Kaena Point is reduced further to moderately low, as this region is far removed from the drainage of the Kuaokala uplands. The hazard due to high waves is high throughout this region on the North Shore, where winter swells commonly reach heights between 20 and 25 ft. Kaena Point, at the northwestern tip of Oahu, is vulnerable to Kona storms and high trade winds, as well as hurricanes. As a result the storm hazard is ranked high along the western half of the region, where hurricane force winds from hurricanes passing along the west shore of Oahu may be encountered. It is ranked moderately high toward the east, where the coast becomes sheltered from hurricane and Kona storm energy. Erosion is high along the isolated sandy beaches of Camp Erdman and Mokuleia, but moderately low along the hard limestone shoreline and rocky Kaena Point. The sea-level rise and volcanic/seismic hazards are ranked moderately low.





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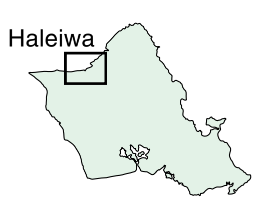


Narrow beaches and wide fringing reefs line the Mokuleia and Haleiwa coastal areas.

Haleiwa

The Haleiwa coastline is dominated by the embayments associated with the confluence of the Kiikii and Paukauila streams and the Anahulu River. A long and narrow beach, bordered in many places by deteriorated seawalls and revetments, extends from Mokuleia to Kaiaka Bay. Rocky outcrops of limestone compose both Kaiaka and Puaena points. To the northeast, the coast toward Kawailoa Beach consists mostly of interspersed sand beaches and 3-6-ft rocky escarpments of basalt or limestone. Broad wave abrasion platforms extend offshore of Mokuleia Beach, but narrow toward Kawailoa Beach. This is a high wave-energy coastline that receives some of the largest breaking waves in the state. In 1969, for example, wave heights of between 30 and 35 ft were recorded offshore of Haleiwa, and in 1998 as high as 50 ft. It is also a low-sloping coast, and near the stream mouths wetlands and ponds are found. The only boat harbors along the entire North Shore of Oahu are found inside Kaiaka and Waialua Bays.

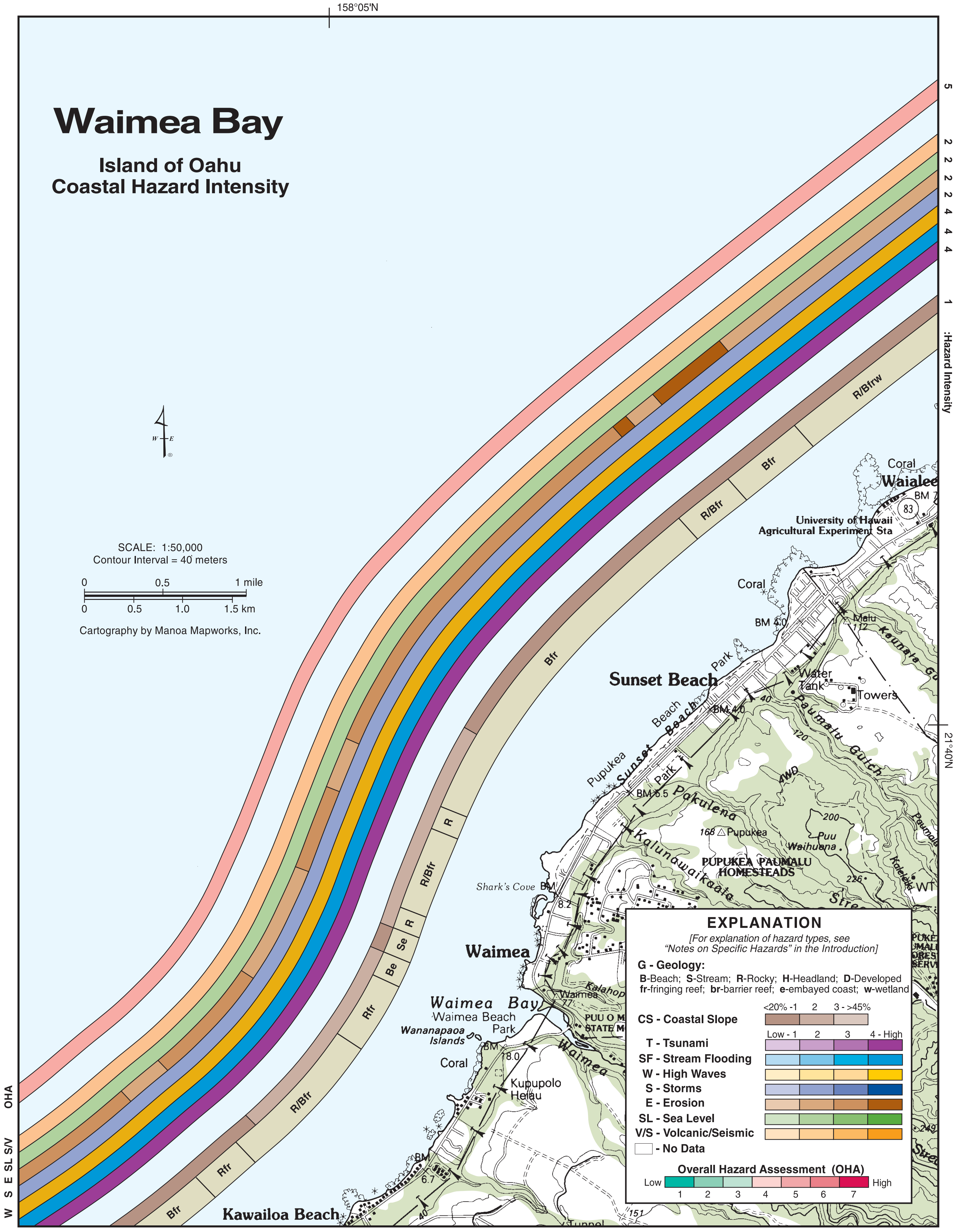
The moderate to high (5) to high (6) Overall Hazard Assessment (OHA) for the Haleiwa coast is largely influenced by the low coastal slope and a history of high wave energy and stream flooding. Additionally, where erosion is ranked high along Mokuleia, and Alii Beach Park in Haleiwa, the OHA is ranked high (6). The tsunamis of 1946, 1952, and 1957 generated flood heights of 11, 17, and 17 ft, respectively, along the Haleiwa coastline. In 1932, between 26 and 30 in of rain fell in a 24 hr period, resulting in extensive local flooding. Because of this history and the low coastal slopes found here, hazards due to tsunami, stream flooding, and high waves are ranked high along this coast. The storm hazard along this coast is moderately high, except northeast of Kawailoa Beach where the threat from hurricanes is reduced because of higher slopes and local sheltering. Erosion is high along the western segment of the Mokuleia shoreline and at the Anahulu River mouth, and moderately high along the eastern portion of Mokuleia and between Puaena Point and Kawailoa Beach. It is reduced to moderately low and low at three sites in Mokuleia, where the wide offshore reefs and scattered rocky carbonate outcrops onshore help buffer the coastline from wave energy. Sea-level rise is ranked moderately low throughout this region compared to Maui and the Big Island. The hazard due to volcanism and seismicity is also ranked moderately low as it is throughout the northern half of Oahu.

Waimea Bay

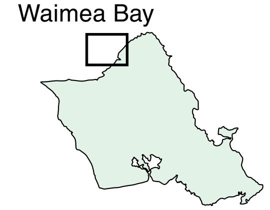
Some of the world's best surf breaks are found along the Waimea Bay coastline, where winter waves annually reach breaking heights of 20 to 25 ft. Small pocket beaches along the Kawailoa Shoreline give way to a rocky basalt coast south of the beautiful wide beach and stream mouth at Waimea Bay. Long, coarse-grained sand beaches extend between Sunset Beach and Waialee. Isolated outcrops of basalt and reefrock harden the shoreline near Pupukea, Sunset Point, and Waialee Point. The coastal slope is steeper near Waimea Bay, but gradually decreases toward Sunset Beach where it coincides with a low coastal terrace that reaches northeast to Kahuku (see Kahuku map). Fringing reefs (mostly fossil) cover most of the offshore region of this coast.

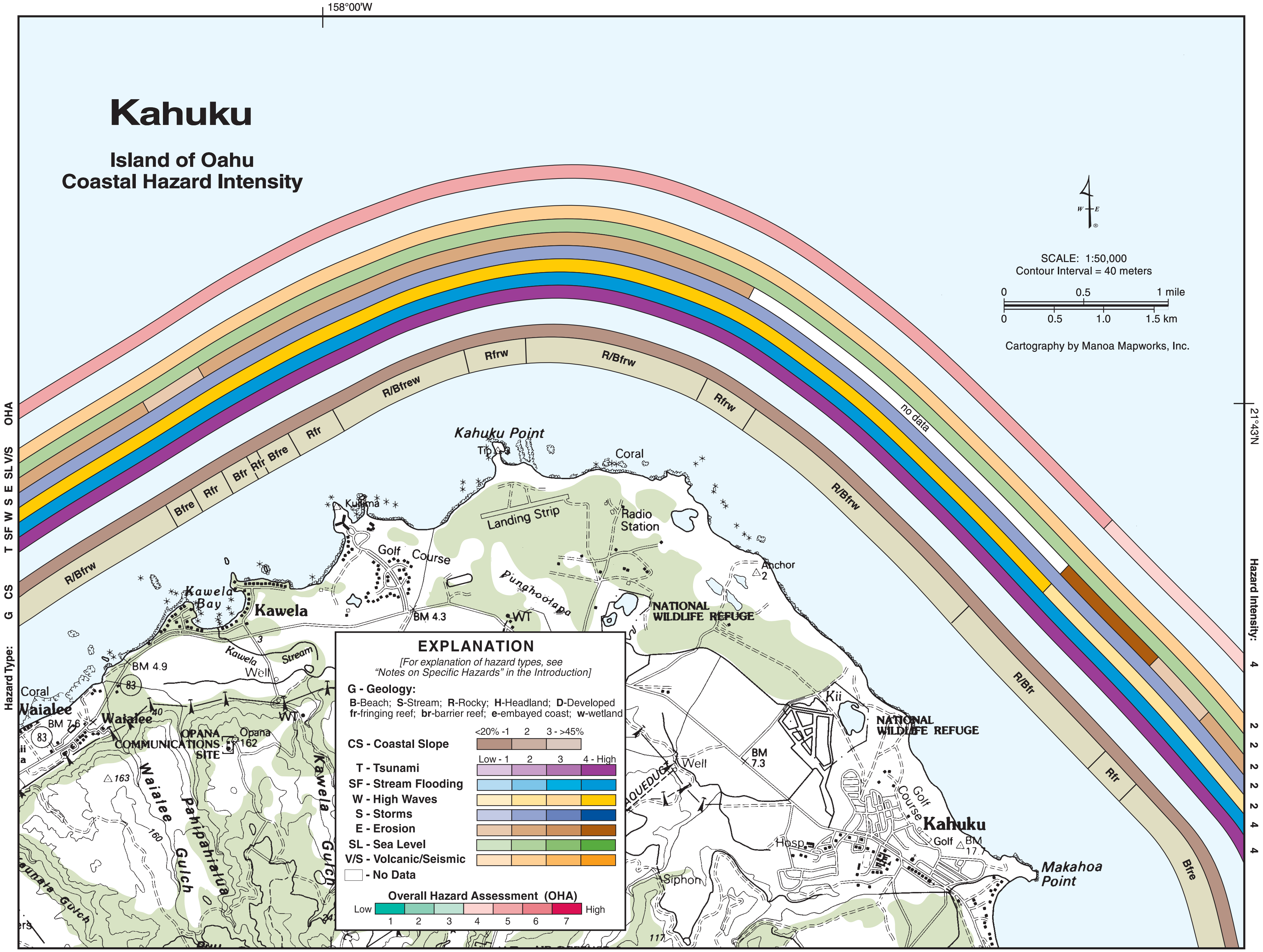
The Overall Hazard Assessment (OHA) for the Waimea coast is moderate to high (5), which is primarily a result of the susceptibility to high wave energy and stream flooding. In 1946, 1952, and 1957, tsunami runup of 19, 20, and 22 ft, respectively, inundated Waimea Bay. Stream flooding, especially in the flash flood prone Waimea River Valley, historically has been significant, and high wave events annually overwash the coastal road and cause damage to coastal property. For these reasons, the hazard due to tsunami, stream flooding, and high waves are ranked high. While storms like Hurricane Iwa have been known to produce 50-55 mph winds along this coast, the hazard due to storms is ranked moderately low relative to other areas in Hawaii. Erosion is ranked moderately low in Waimea Bay and along hardened coastlines, and moderately high for most of the long sandy beaches to either side of Waimea and along Pupukea Beach to Sunset Beach. It is also ranked high at the sandy beaches along the coastal terrace near Waialee. The hazard due to sea-level rise is ranked moderately low here as it is for most of Oahu, which is experiencing only moderate rates of rise. The volcanic/seismic hazard is also ranked moderately low here in the northern half of Oahu.

The Waimea coast looking southwest toward Kawailoa.

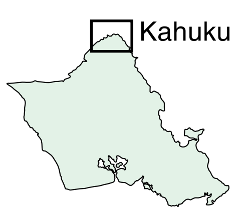


Waimea Bay





Base Credit: USGS 1:50,000 Kaena Point, Hawaii5321 II W733 Edition 1-DMA and USGS 1:50,000 Laie, Hawaii 5421 III W733 Edition 1-DMA



Sand dunes and perched beaches along Kahuku Point are continuously reshaped by the persistent trade winds.

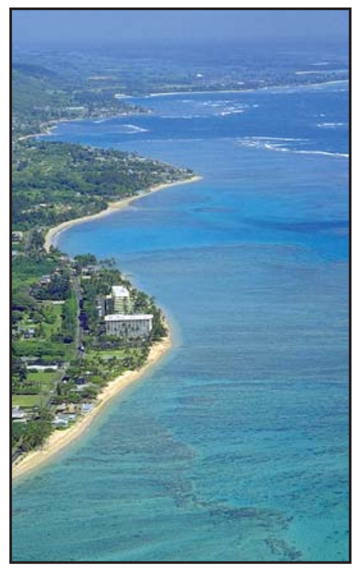
Kahuku

The northernmost tip of Oahu reaches around Kahuku Point where low coastal terraces host one of the most extensive wetlands in the state. Relict and modern dune fields lie seaward of mixed-use aquaculture ponds and a wildlife sanctuary that provides habitat for birdlife. Rocky limestone cliffs encircle the embayments at Kawela and Kuilima bays. Lithified outcrops of eolianite along Kahuku and Makahoa points are scoured by solution weathering, intertidal bioerosion, and the relentless trade winds, creating a sharp and jagged surface that makes access to the shoreline difficult. Extensive ridges of beachrock on the foreshore are found along the entire area and are evidence of recent coastal erosion and retreat. Spectacular wind-swept sand formations mark much of the windward coast and have left limestone outcrops and islets offshore. Sand beaches are perched on benches of eolianite and old reefrock or beachrock between Kahuku Point and Makahoa Point. Here some active dunes also exist seaward of vegetated Holocene dunes. The fringing reefs widen east of Kahuku Point due to the decreased wave energy away from the winter swell of the north shore.

The Overall Hazard Assessment (OHA) is moderate to high (5) from Waialee around Kahuku Point to just north of Kahuku town, while south to Makahoa Point, where the wave energy is lower, it is reduced to moderate (4). The tsunami and stream flooding hazards are ranked high along the entire Kahuku coastline. During the 1946 and 1957 tsunamis, flood inundation heights of 27 and 23 ft were recorded at Kahuku Point. The hazard associated with high waves is ranked high around the entire Kahuku Point, but is reduced to moderately low southeast of the Point where the coast is partly sheltered from north swell. The storm threat is ranked moderately low along the Kahuku coast because it is partly sheltered from the impact of the majority of tropical storms that historically track to the west and south of Oahu. Erosion is ranked moderately low for the small embayments lining the western portion of Kahuku Point, except along the rocky point immediately northeast of Kawela Bay beach where it is low. Along the northeast side east of Kahuku Point there are no available data, except at the town of Kahuku, where erosion is ranked high, but is then reduced to low along Makahoa Point. The hazard due to sea-level rise here is moderately low. The volcanic/seismic hazard here in the northern half of Oahu is also ranked moderately low.

Laie

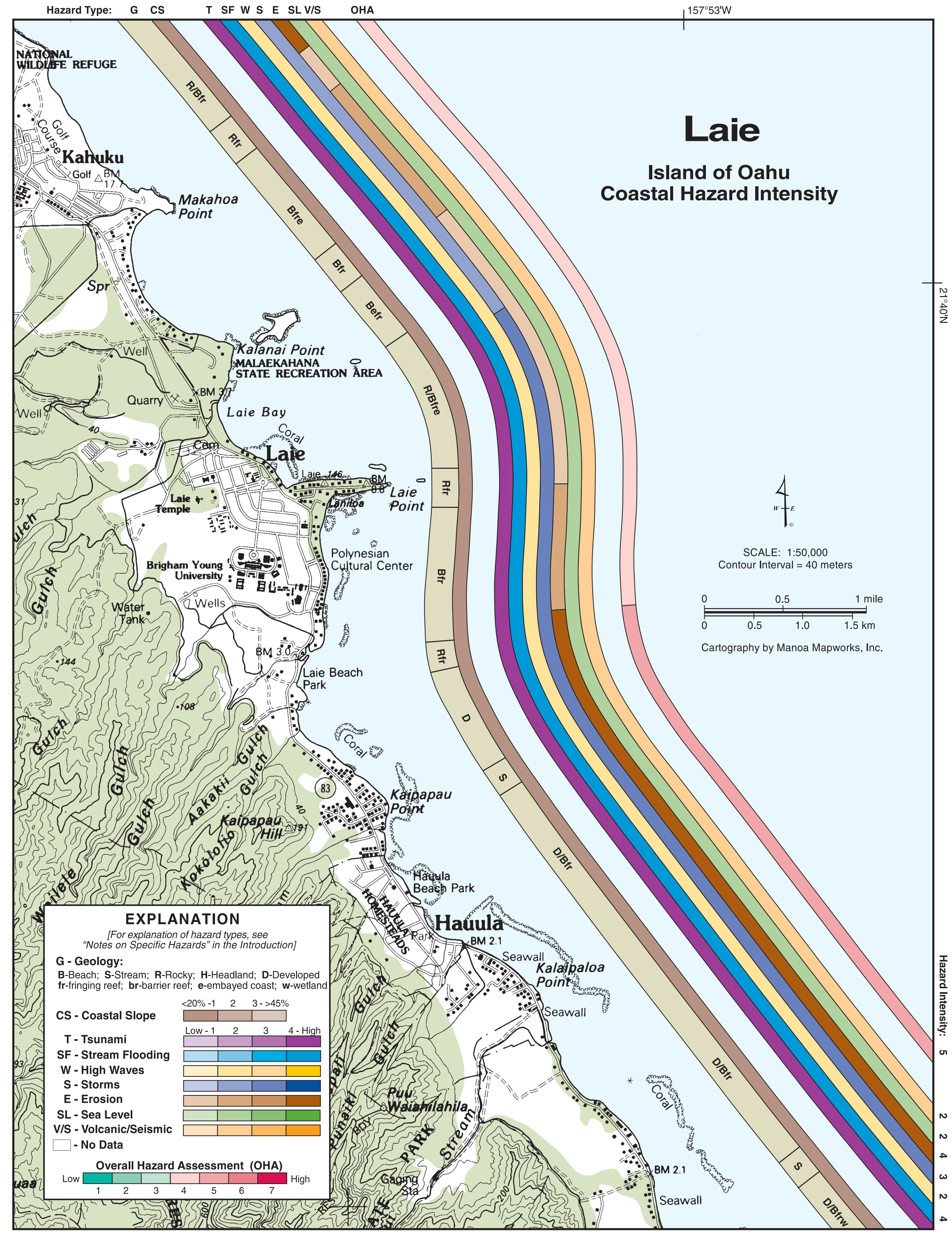
South of Kahuku, along the windward coast to Hauula, the narrow coastal plain is marked by deeply-carved bays separated by prominent rocky points that reach seaward. The embayments of Malaekahana and Laie Bay consist of relatively pristine sandy beaches, while those farther south at Laie and Hauula have been severely altered by development and suffer from chronic erosion. This is a strong trade wind environment, and eolian features, both modern and relict, are pervasive throughout the region. Small emerged carbonate islets formed of lithified sandstone (eolianite) lie offshore of Kalanai and Laie Points. The shoreline is characterized by an extensive fringing reef complex associated with a broad, shallow, and generally smooth reef flat. Near Hauula the beach is highly developed with seawalls and revetments, many of which are aged and appear to be failing in their attempt to protect seaside properties. Vertical relief along this coastline is relatively low, but does increase slightly towards the south and near the rocky outcrops of Makahoa and Laie Points. Several streams that empty the Koolau Range transport upland sediments to the coastal zone during intense rainfall events. This is reflected in the beach sediment composition.



Narrow beaches are being rapidly lost to sediment difficiencies, sea-level rise, and waves and currents along the low coastal plain between Hauula and Laie.

Chronic erosion and beach loss south of Laie Beach Park is responsible for the difference in the Overall Hazard Assessment (OHA) of moderate (4) for the northern half of this region and moderate to high (5) for the southern portion. Tsunami flood heights of 27 and 23 ft associated with the 1946 and 1957 tsunamis were recorded just south of Kahuku. Flash floods and overflowing streams in this region are common. For example, in 1929, 11 in of rain falling in 11 hr brought floods to the lowlands, and on March 31, 1965, 4.5 in of rain was recorded in 1.5 hr at Punaluu! For these reasons, a high ranking is given to both the tsunami and stream flooding hazards. High waves become a significantly lesser threat south of Kahuku, as the coast becomes increasingly sheltered from winter swell. As a result, it is ranked moderately low.

The hazard due to storms, however, is ranked moderately high south of Kalanai Point and moderately low to the north where the coast is more sheltered because storms usually approach from the east-southeast and have brought high winds and waves to this coast in the past. Erosion is significantly greater in the south near Hauula and Punaluu where shore-hardening structures, installed to stop coastal erosion, have exacerbated beach loss. Reflected waves off seawalls, revetments, and groins along Hauula and Punaluu often splash up onto the seaside properties and the coastal road at high tide, removing what little sand remains. Erosion of the embayed beaches in the north is ranked moderately low to low because it is partly mitigated by long rocky points that provide protection from extreme wave energy. Sea-level rise and volcanic/seismic threats are ranked moderately low along the entire region, as they are in most portions of northern Oahu where they are relatively low compared to other areas in Hawaii.



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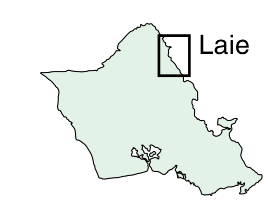
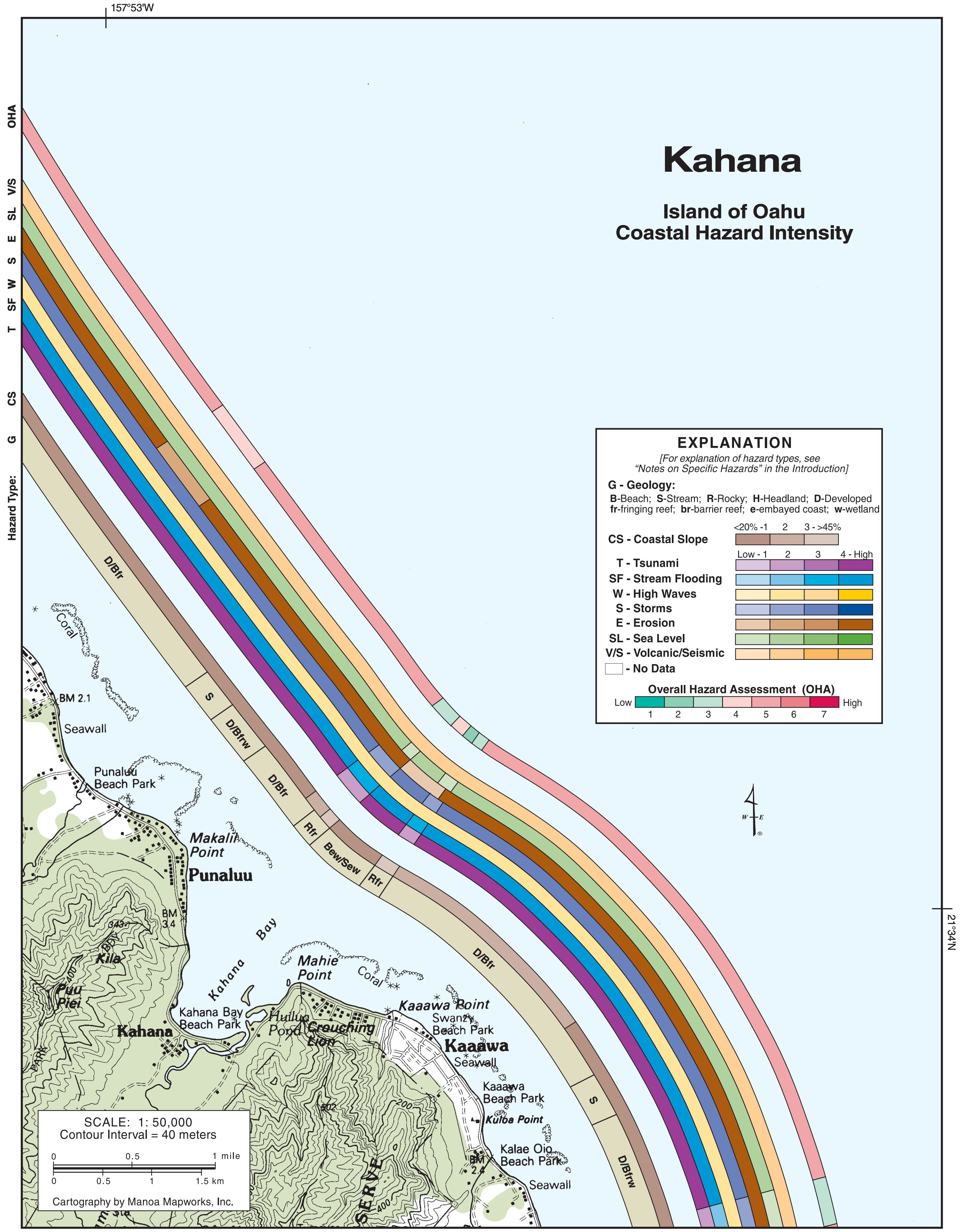
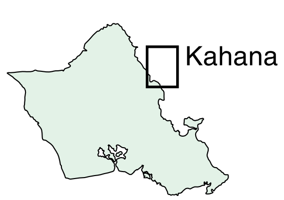






Kahana

The Kahana coastline is dominated by low-lying, narrow beaches with broad shallow fringing reefs extending offshore. This region is extensively developed and its narrow beaches suffer from chronic erosion and are nearly devoid of sand. Seawalls, revetments, and groins have been constructed along Punaluu and Kaaawa to protect coastal property at the expense of the sandy beach that provides a natural buffer for active shorelines. A broad reef flat extends seaward to a well developed fringing reef complex. Streams transport surface runoff and upland sediments to the coastal areas at Punaluu and Kalae Oio Beach Parks. Steeper rocky ramparts and basalt boulder piles surround Kahana Bay. The beach at the mouth of Kahana Stream is the widest in the region and consists of very fine mixed volcanic and carbonate sand that grades into carbonate-dominated sand offshore. A wetland exists at the stream mouth and fish ponds are still visible along the southern flanks of the bay. After heavy rainfall, Kahana Stream transports enough upland sediment to create a large plume of suspended silt that extends into the center of the bay.

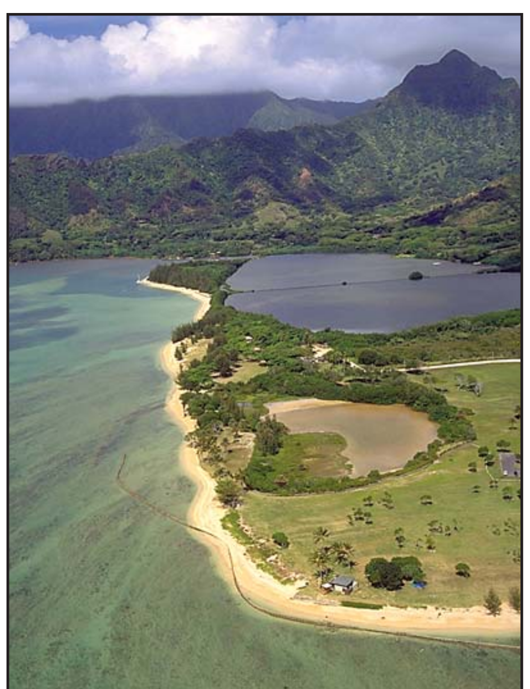
The Overall Hazard Assessment (OHA) is moderate to high (5) north and south of Kahana Bay, where the lower coastal slopes are more susceptible to tsunami inundation. Inside Kahana Bay, the OHA is moderate (4) while on the north side it is low (3) and along the southern side out to Mahie Point it is very low (2), due to the reduced threat of waves and flooding along the steeper rocky cliffs that flank the bay sides. The tsunami and stream flood hazards are high along the Kaaawa coastal zone and at the mouth of the Kahana Stream, where the coastal slopes are low. On both sides of the bay, these threats are reduced by the presence of steep rocky headlands. The stream flooding hazard is high due to stream floods and flash floods that frequently inundate the coastal plain. For example, in 1963, 19 in of rain in a 24 hr period brought torrential floods to the lowlands. The high wave threat is ranked moderately low throughout the region because it is relatively sheltered from winter swell. High winds and waves associated with hurricanes and tropical storms as well as intensive trade wind storms passing through the area, however, have caused considerable damage along this coast. In fact, the highest winds on Oahu during Hurricane Iwa (1982), which passed to the west of the island, were recorded along this portion of coast and are thought to have been accentuated as they descended over the steep windward cliffs of the Koolau Range. As a result, the storm hazard is moderately high, except at the steep headlands surrounding Kahana Bay, where it is moderately low. Erosion is ranked high along the entire coast except at the beach inside Kahana Bay, where it is downgraded to low. Sea-level rise and volcanic/seismic hazards are moderately low throughout the region as they are in most of the northern half of Oahu.

Very little sand remains along the narrow beaches of Kaaawa.

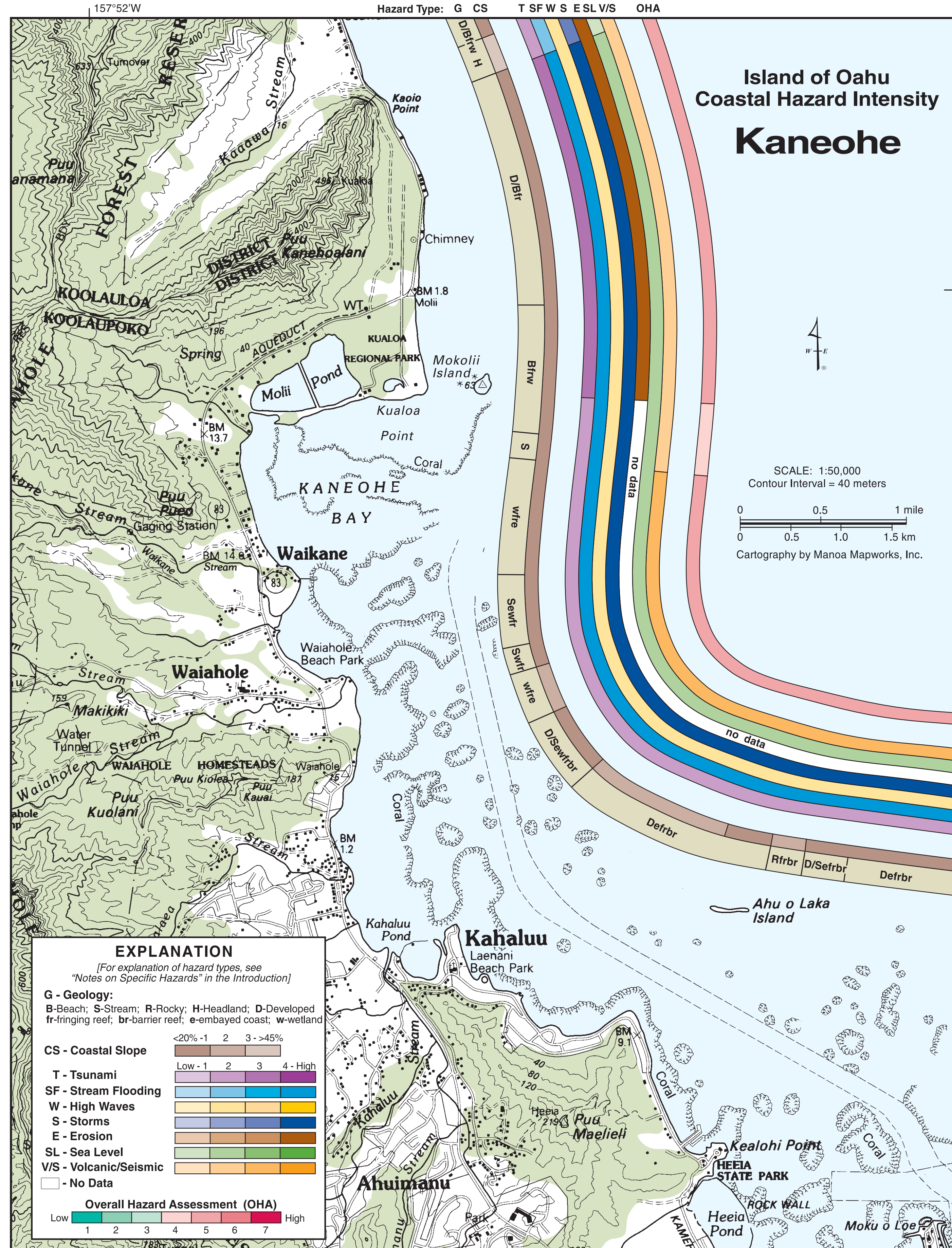
Kaneohe

South of Kualoa Point, the coast is deeply embayed and bordered by isolated beaches of gravely mud, fish ponds, small mangrove forests, and shallow deltas of upland sediment deposited by the many rivers emptying the Koolau Range. This low-lying coastal plain is especially prone to, and has experienced, considerable damage from flash floods generated by intense runoff from the very steep slopes of the Koolau Range. In November of 1970, 11.5 in of rainfall were recorded in 4 hr in Kahaluu. Near Kahaluu, where Kaneohe Bay reaches its greatest depths, the fringing reef lies far offshore and is, in form and function, Hawaii's only barrier reef. A very shallow and broad subtidal shelf of fossil reef rock extends nearly a mile offshore, just seaward of the barrier reef. A prominent sand bar, Ahu o Laka Island, in the central portion of the coast parallels the shore and becomes exposed at low tides. Mokolii (Chinaman's Hat) Island, an erosional remnant of Koolau basalt, lies offshore near the seaward edge of the barrier reef. Wave energy at the shoreline is generally very low, but along the outer reef it is higher and dominated by trade wind swell, and under moderate storm conditions such as during the distant passage of Hurricane Fernanda in 1993, waves overwash the coastal road along the Kualoa Point.

The Overall Hazard Assessment (OHA) for Kaneohe is moderate to high (5) except for the short stretch of coastline sheltered behind Kualoa Point that is ranked moderate (4). Tsunami activity in Kaneohe has historically been very low. It is ranked moderately high in the northern portion where Kaoio and Kualoa points are exposed to swell. South of Kualoa Point the tsunami threat is ranked moderately low where the coast is more sheltered. The low-lying Kaneohe Coast has had 20 major stream floods since 1936. As a result, the stream flooding hazard is ranked high throughout the area. The hazard due to high waves is ranked moderately low throughout the area, because it is largely reduced by the barrier reef complex and broad reef flat bordering the shoreline. The threat of storms along this low-lying, east-facing coastline is ranked high, because it faces tropical storms and trade wind storms that approach from the east. Erosion threatens the sparse sandy beaches that remain north of Kualoa Point and hence has been ranked high there. Little data exists on erosion rates within Kaneohe Bay, where development has changed the shoreline, and so a ranking has not been given. Hazards associated with sea-level rise are relatively low along this entire coastal segment. The volcanic/seismic hazard is moderately high in the south, due to its proximity to the Molokai Seismic Zone, and moderately low in the north.



A sand spit extending west from Kualoa Point functions like a barrier island to the Molii Fish Ponds.



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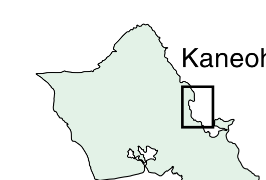

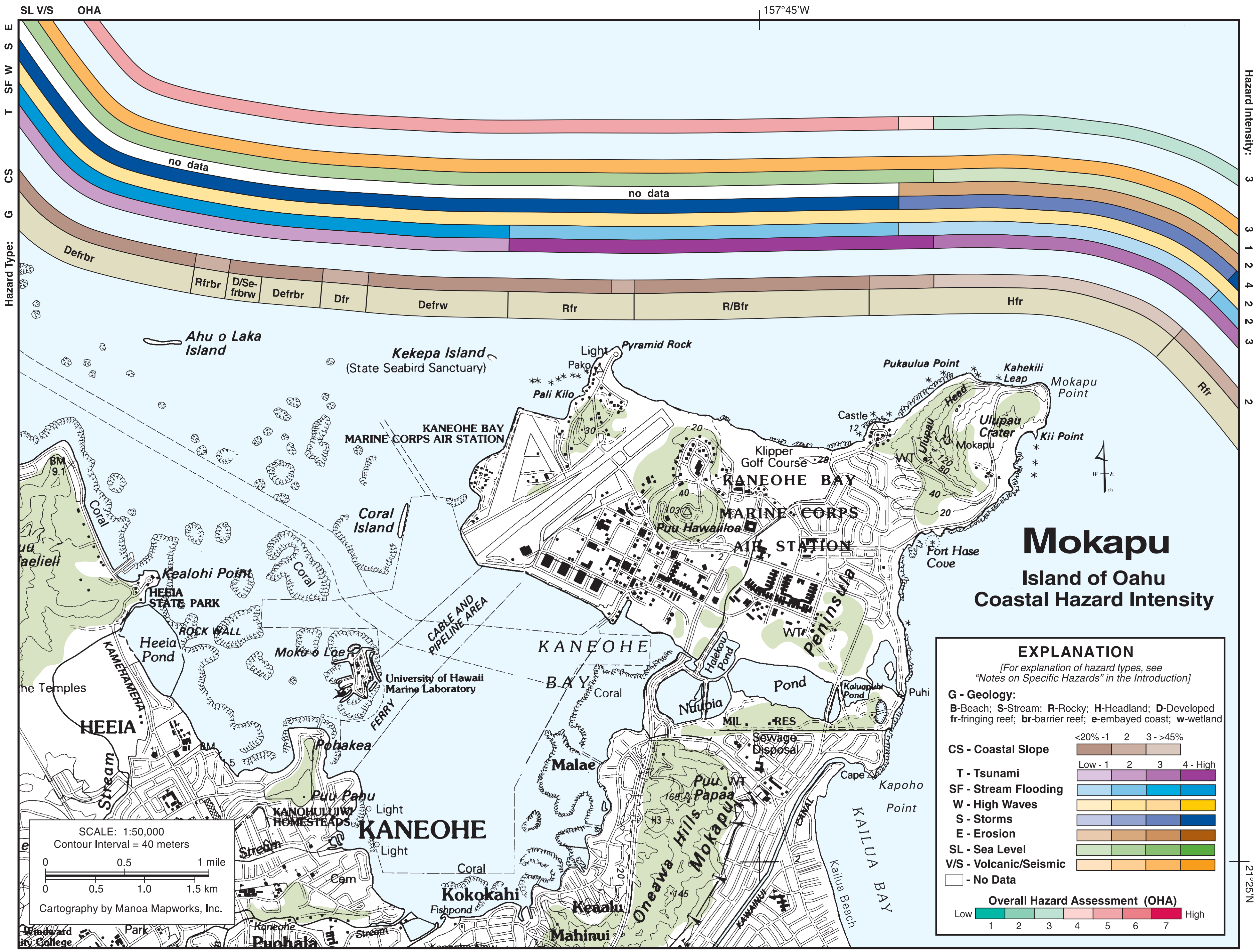

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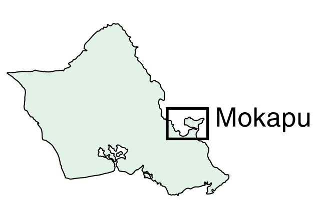


A bird's-eye view of Mokapu Peninsula, home to the Kaneohe Bay Marine Air Corps Station.

Mokapu

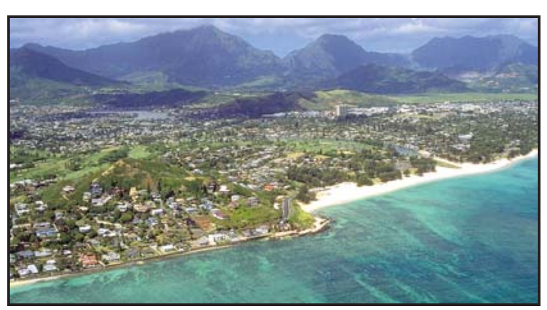
The Mokapu Peninsula, site of the Kaneohe Bay Marine Corps Air Station, separates Kaneohe Bay from Kailua Bay. It was formed by a group of secondary volcanic eruptions that produced Ulupau Crater, Puu Hawaiiloa, and Pyramid Rock sometime since the middle Pleistocene. The shoreline is steepest at the rocky headland where cliffs seaward of Pyramid Rock and Ulupau Crater are pounded by high waves. A long beach lies at the north end of the peninsula, and some active dunes exist above isolated basalt boulder outcrops. Several fish ponds occupy the low-lying isthmus of the peninsula, which may have been submerged by a higher relative sea level during the late Holocene, isolating the headland from the rest of Oahu making Mokapu an island. The shoreline is low and flat along the Kaneohe side and heavily developed with seawalls, fish ponds, seaplane ramps, and dredged channels. A basaltic outcrop, Moku o Loe (Coconut Island) and an emerged limestone platform, Kekepa Island, lie within Kaneohe bay along the northwest side of Mokapu Peninsula. The Kailua side of the peninsula consists primarily of a small rocky limestone escarpment between Kapoho and Kii Points with some beachrock and perched beaches. The north end of Kailua Beach begins at the mouth of the Kawainui Canal, which drains the Kawainui Marsh. An extensive fringing reef borders the entire coastline.

The Overall Hazard Assessment (OHA) north of Pukaulua Point on Mokapu Peninsula is moderate to high (5) reflecting the low coastal slope and proximity to the drainages of the Koolau Range. The OHA is reduced to moderate (4) for the short stretch near Pukaulua Point where the coastal slope steepens, and is further reduced to moderate to low (3) at the rocky Mokapu Point where the coast is steepest and farthest removed from potential stream flooding originating in the Koolau range. A 21 ft runup, recorded at Mokapu Point, was generated by the tsunami of 1946. However, because the barrier reef complex and broad reef flat of Kaneohe Bay help to dissipate high wave energy, the tsunami hazard is ranked moderately low north of Pyramid Rock. At the low-lying beach on the north edge of the peninsula, tsunami flooding is ranked high, and at the rocky headland at Mokapu Point where the slope is steeper, it is ranked moderately high. Stream flooding is ranked high along the low coastal plain of Kaneohe, but is reduced to the south, where the Mokapu headland becomes removed from the drainage of the Koolau Range, and along the steep slopes at Mokapu Point. The wave hazard is ranked moderately low along the entire portion of Mokapu because it is relatively sheltered from winter swell. Combined with high winds, the storm hazard is ranked high throughout the region except at the steep, rocky Mokapu Point, where it is moderately high. Erosion data is unavailable for the Kaneohe coast. However, along Mokapu Point, erosion is ranked moderately low because of the hard rocky headland. The threat of sea-level rise is moderately low along the Kaneohe coast and low at the steep rocky point. The volcanic/seismic hazard here resembles that of southern Oahu, which is ranked moderately high in accordance with its proximity to the Molokai Seismic Zone.

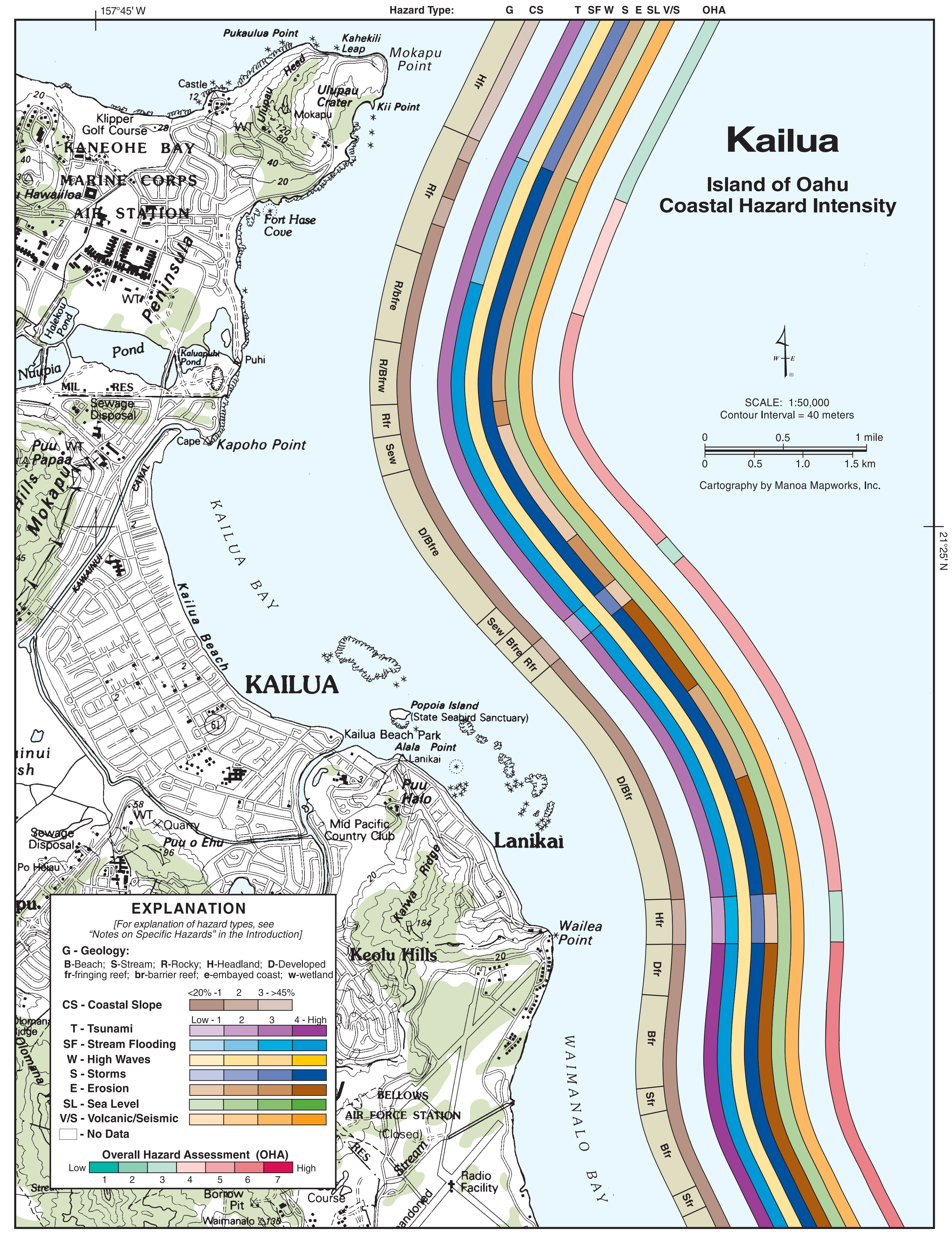
Kailua

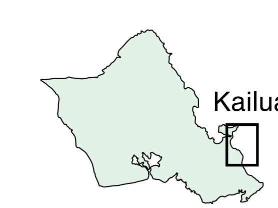
South of Mokapu Point to Kapoho Point, the rocky volcanic headland gives way to emerged reefrock and eolianite, and then to the long, sandy beaches of Kailua, Lanikai, and Waimanalo. Canals that drain the interior valley, separate these beaches from isolated outcrops of basalt and emerged limestone. The densely developed coastal plains of Kailua, Lanikai, and Waimanalo are gently sloping and believed to have been submerged by a higher relative sea level between 1,500 and 4,000 years ago. Relict and modern dune ridges and fossil beaches compose most of the coastal plain at Kailua and Waimanalo. Popoia Island, an emerged limestone islet, lies along an extensive fringing reef complex offshore. The wave energy here is moderate. A substantial proliferation of seawalls and revetments south of Alala Point has accelerated beach loss in Lanikai, no doubt by impounding sand. Revetments, emplaced in front of the airfield at Waimanalo, also appear to have exacerbated beach loss on the north side of Waimanalo Beach and possibly led to impacts in south Lanikai.

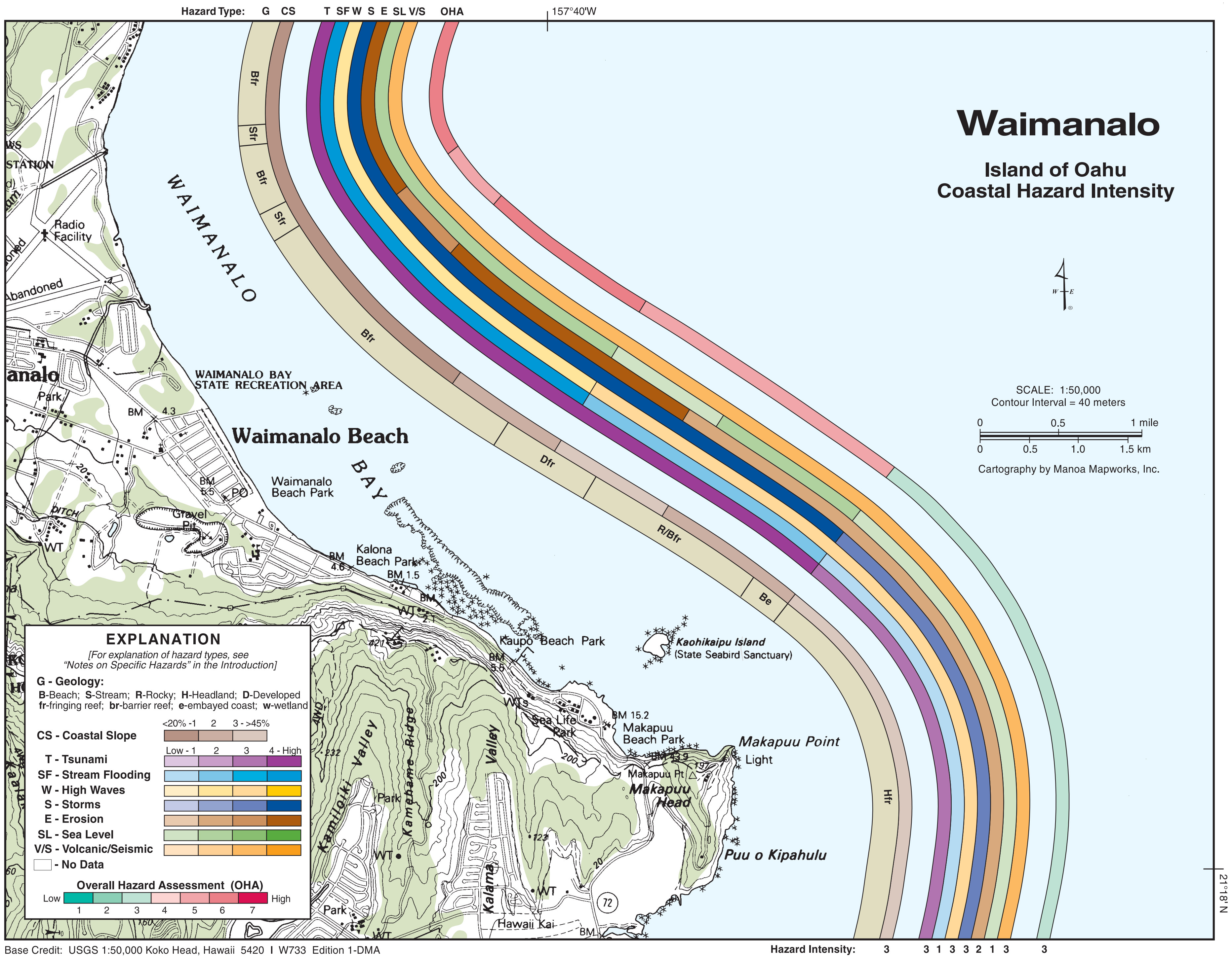
The Overall Hazard Assessment (OHA) along the Kailua coast reflects the variable nature of alternating steep, rocky outcrops, stream mouths, and low-lying sandy beaches. The OHA increases from moderate to low (3) along Mokapu Point to moderate (4) between Kii Point and Fort Hase Cove where stream flooding is moderately low. Along the low-lying sandy beaches of Kailua and Lanikai, where stream flooding and erosion are ranked high in places, the OHA is moderate to high (5), except at Alala and Wailea Points where it is moderate to low (3) due to the lower tsunami, stream flooding, storm and erosion hazards at those steep, rocky headlands. South of Wailea Point, the OHA is ranked high (6) due to the high tsunami hazard along Waimanalo. Tsunami inundation along the Kailua waterfront historically has not been as high as in Waimanalo, and as a result, the tsunami hazard is ranked moderately high along Kailua and Lanikai exept at the Alala and Wailea Points and high in Waimanalo. Stream flooding is ranked low at the north end of Mokapu Point, moderately low near the south side of Mokapu Point, and high along the low-lying developed coastline of Kailua, Lanikai, and Waimanalo, where prolonged and flash flooding are frequent, year-round occurrences. During the winter of 1987, for example, a slow-moving storm brought about 2–5 ft of flooding to Kawainui Marsh (just west of the town of Kailua) and surrounding area, while in 1970, over 11 in of rain fell on Waimanalo in only 4 hr. The Kailua coast, facing east and protected by the extensive fringing/barrier reef offshore, is relatively sheltered from winter north swell, so the high wave hazard is ranked moderately low. Erosion is low and moderately low along the rocky outcrops. It is also moderately low in the central portion of Lanikai, where the beach is presently accreting at the expense of beach loss along its margins. At stream mouths and especially along the northern and southern ends of Lanikai, where there is chronic beach loss, the erosion hazard is ranked high. Sea-level rise is ranked moderately low here as it is along most of Oahu's shores, where rates of rise are moderate. The volcanic/seismic threat is ranked moderately high in Kailua, due to its proximity to the Molokai Seismic Zone.

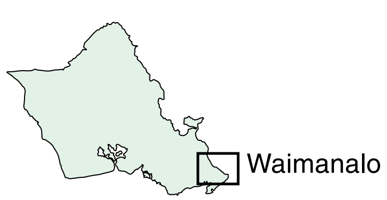


Chronic beach loss along north Lanikai since the 1980's has left the shoreline lined with seawalls. In the distance, a wide beach at the Kailua Beach Park is a favorite island playground.









Fine, white sands border the nearly perfect cresent of Waimanalo Bay.

Waimanalo

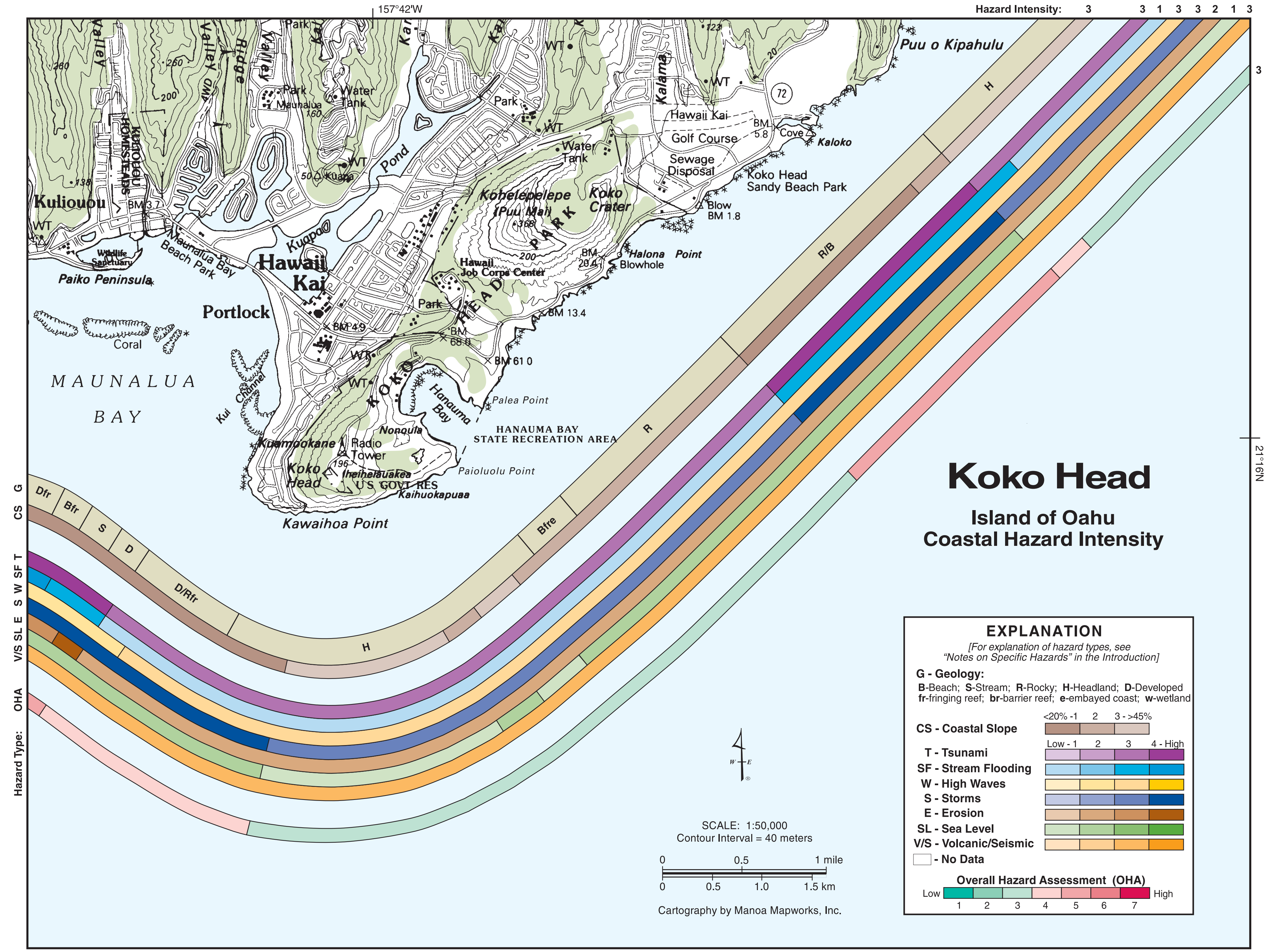
The long Waimanalo Beach, backed by vegetated dune ridges, lies on a developed coastal plain that narrows south toward Kalona Beach Park. There it abruptly changes to a rocky limestone coast with isolated basalt boulder deposits and small pocket beaches south to Kaupo Beach Park. A large basalt flow extends towards Kaohikaipu Island (Rabbit Island), just north of the last sandy beach found on the windward coast at Makapuu Beach Park. The relatively low topography at Waimanalo abruptly steepens at Makapuu where the southern end of the Koolau Range abuts the shore and culminates at Makapuu Head. The wide fringing reef of Waimanalo works to effectively dissipate trade wind wave energy. The fringing reef is absent at Makapuu Beach enabling larger waves to reach the shore there. Stream flooding poses one of the greatest threats along the Waimanalo coastline, where intense rainfall over the steep Koolau Range may generate high rates of surface runoff that collects on the low coastal plain. In November of 1970, for example, 11.5 in of rain fell in only 4 hr, and in March of 1958 13.8 in of rainfall were recorded in 24 hr, flooding Waimanalo with 3 ft of standing water. To the north, beach loss occurs at the 800 ft-long Bellows revetment, and along the southern shore where coastal properties are protected by seawalls, beaches suffer sand deficiency and chronic erosion.

The Overall Hazard Assessment (OHA) varies between high (6) along Waimanalo Beach, where erosion and stream flooding are highest, to moderate to high (5) south of Kalona Beach Park, where erosion and stream flooding are moderately low. The OHA is further reduced to moderate to low (3) south of Makapuu Point, where few streams exist and runoff is low. The tsunami hazard for the Waimanalo coast is high along the low-lying embayment south to the headland at Makapuu Point. The storm hazard is also ranked high along this portion of the coast, where hurricanes, such as Hurricane Kate in 1976, have brought waves as high as 15 ft to these shores. Winds up to 82 mph, associated with Hurricane Iwa in 1982, were also recorded in the Waimanalo area. Trade wind gales are also common, though not annual events. Stream flood hazard is high north of Kaupo Beach Park, where flash flooding such as in March of 1958, can inundate the town of Waimanalo with several feet of water. It is moderately low between Kaupo Beach Park and Makapuu Point and low south of the point. The threat of high waves is moderately low in the northern portion, which is partially sheltered from winter swell and protected by the extensive fringing reef offshore. To the south of Kaupo Beach it is ranked high, due to its greater exposure to trade wind swell and both winter and southern wave energy that refracts towards Makapuu Beach. Erosion is high to moderately high throughout the beach system of Waimanalo, where retreat of the coast is intense, but moderately low south of Kaupo Beach Park where it is mitigated by the rocky basalt coastline. Sea-level rise, while ranked only a moderately low hazard for Waimanalo and Makapuu Beaches, is ranked even lower for the rocky, resistant headlands at Kaupo Beach Park and Makapuu Point. The volcanic/seismic hazard is ranked moderately high being so close to the Molokai Sesimic Zone.

Koko Head

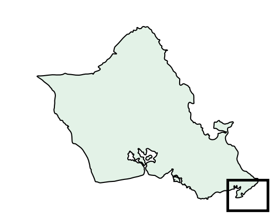
The steep and rocky headland of Makapuu Point (see Waimanalo map) flattens out westward to a coastal terrace but remains rocky and partly covered by perched beaches and dune fields before reaching Sandy Beach Park. West of Sandy Beach to Hawaii Kai, the coastline is steep and rocky, with cliffs and small embayments. Sandy Beach is the most prominent beach system in this region and maintains a small sand field offshore. Sandy Beach is famous for its intense shorebreak. The shoreline northeast of Sandy Beach consists primarily of basaltic boulders and volcanic outcrops but to the west is bordered by a low-lying bench that contours the coast through Hanauma Bay. Above lie steep cliffs of Pleistocene volcanic tuff deposits. Several blow holes near Holona Point provide exciting views of water plumes that are sent billowing high into the air as waves force water through naturally formed cracks in the basalt and tuff. A broad reef flat inside Hanauma Bay offers divers access to the most beautiful and perhaps most sensitive wildlife spectacle on Oahu. Around Koko Head, the Portlock coast is heavily developed along steep cliffs and is devoid of sandy beaches below. Seawalls and minor groins exist along a sand spit at the mouth of Kuapa Pond and the Hawaii Kai coastline. The patchy fringing reef that exists along the Sandy Beach coast, fades away seaward of Hanauma Bay and Koko Head, but is well-established in Maunalua Bay.

The Koko Head coast is largely rocky, except for the central portion surrounding Sandy Beach.

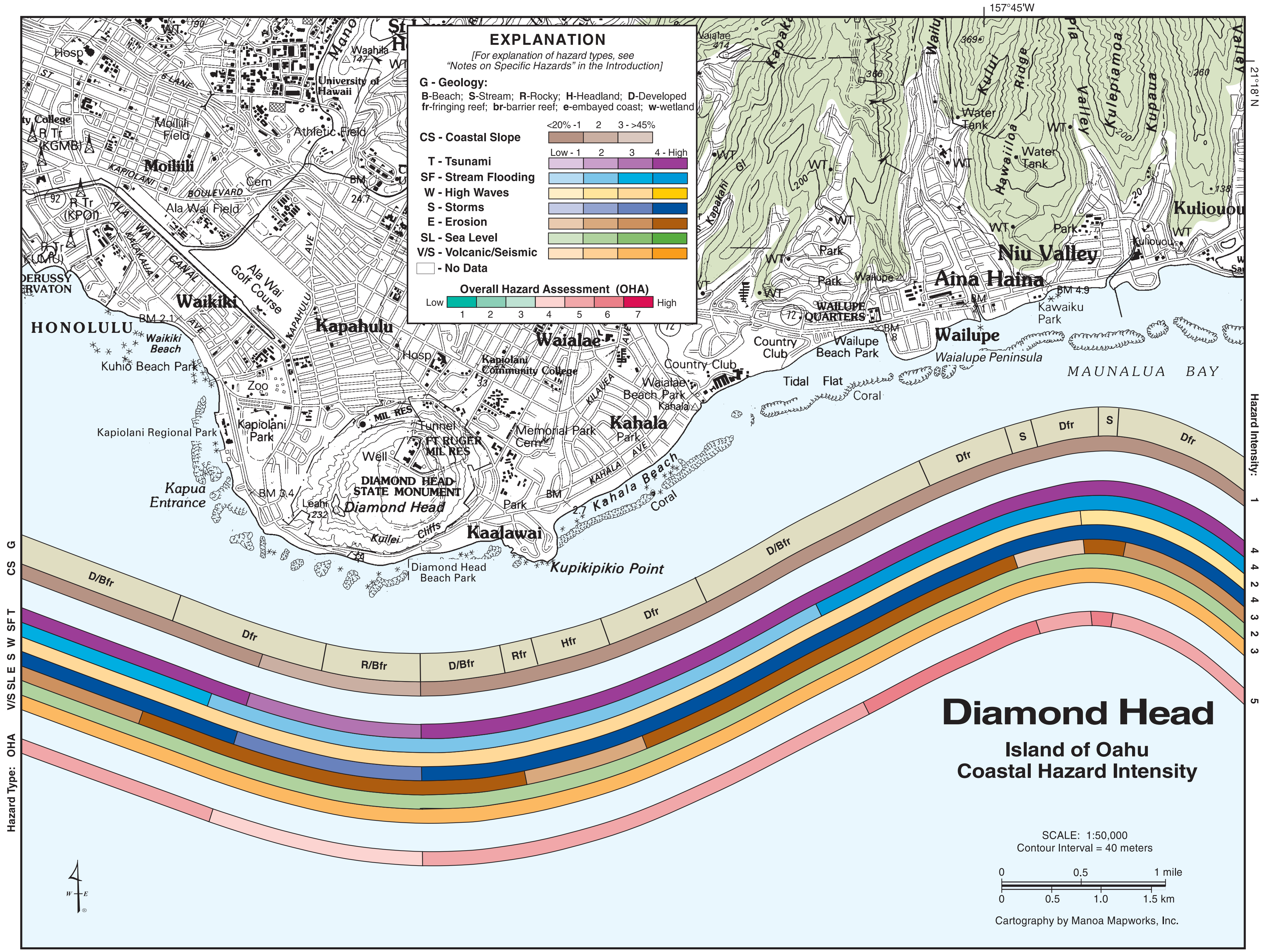


Base Credit: USGS 1:50,000 Koko Head, Hawaii 5420 I W733 Edition 1-DMA

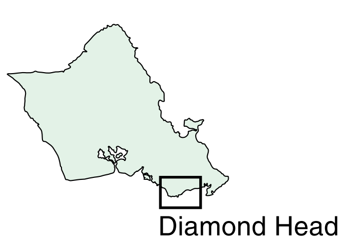
The Overall Hazard Assessment (OHA) for the majority of this coastline is ranked moderate to low (3), due to the steep and resistant nature of the cliffs and headlands that flank the south shore. However, at the low-lying area of Sandy Beach the OHA is elevated to moderate to high (5), where the tsunami, stream flooding, and storm hazards are higher. Between Kaloko and Puu o Kipahula, and just west of Kawaihoa Point, the OHA is moderate (4). The tsunami and stream flooding hazards are high and moderately high, respectively, for the short stretch of low-lying coast between Kaloko and Halona Points. Elsewhere, the coastal slope is sufficiently high that the tsunami hazard is moderately low and the stream flooding hazard is low. This coastline borders the 35 mi wide Molokai Channel that is known for its rough sea conditions throughout the year. Winds and waves traveling through the channel are often intensified as they accelerate between Oahu and Molokai. While wave heights do not often surpass 10 to 12 ft, they can build very rapidly as they make landfall from the very deep water of the channel. This makes for intense wave energy as waves stack up at the shore and collide with the steep Sandy Beach and rocky cliffs to the west. The threat from waves is high throughout this coast as it receives substantial swell in winter and summer. The storm hazard is greatest for the low coastal areas near Sandy Beach and west of Koko Head, where it is ranked high. For the rocky cliff coastline between, it is moderately high. Erosion is moderately low throughout the entire region, as the rocky shoreline mitigates this threat. The sea-level rise hazard is moderately low throughout the region, except at the steeper headlands at Koko Head where it is reduced to low. The volcanic/seismic hazard here is ranked moderately high in accordance with its proximity to the Molokai Seismic Zone.



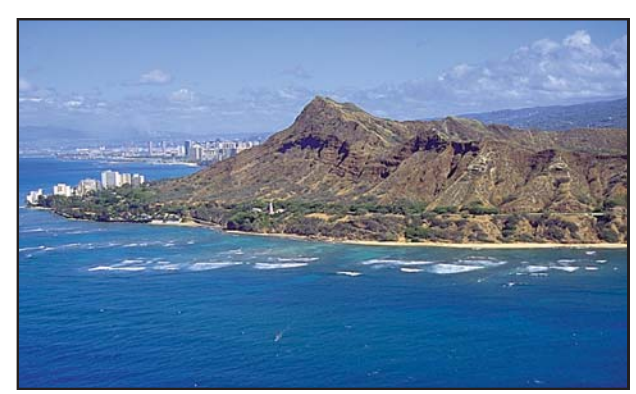
Koko Head



Base Credit: USGS 1:50,000 Honolulu, Hawaii 5420 IV W733 Edition 1-DMA and USGS 1:50,000 Koko Head, Hawaii 5420 I W733 Edition 1-DMA



Very narrow beaches are slowly being lost to chronic erosion and shoreline hardening along Maunalua Bay between Diamond Head and Hawaii Kai to the southeast.



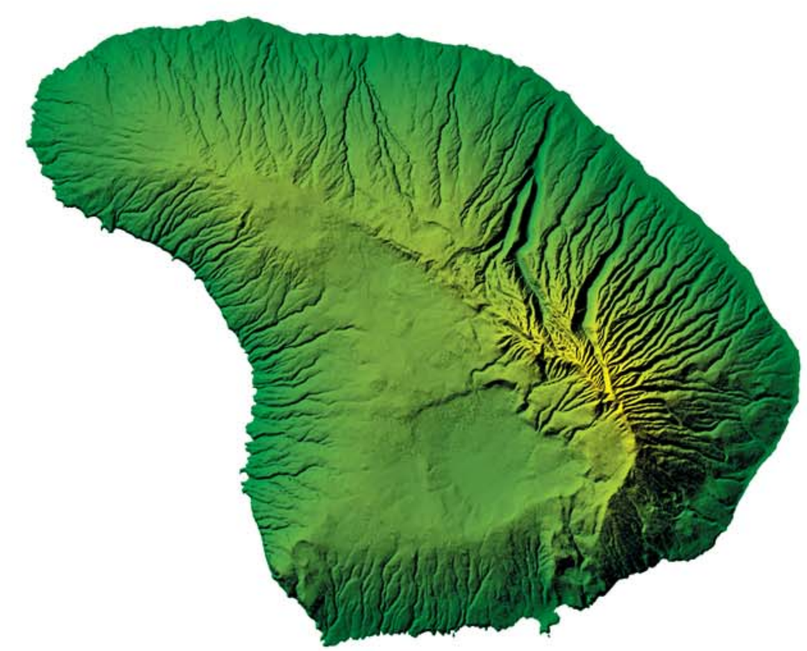
Diamond Head

The Diamond Head coastal zone stretches from Waikiki to Hawaii Kai, in the eastern portion of Maunalua Bay. One of Hawaii's shallowest and widest reef flats exists along Maunalua Bay. Residential and commercial development is widespread along the low-sloping terrace comprised of emerged fossil coral reef. Diamond Head Crater and Kupikipikio Point (Black Point), formed by recent volcanic eruptions, are steep headlands that separate the beaches of Waikiki from the narrow sand and gravel beaches of Kahala. Intensive development and construction of seawalls, revetments, and groins along the Kahala and Niu coasts have been accompanied by chronic beach loss. In many locations, the waterline at low tide coincides with the base of a seawall. Streams and drainage canals carry surface runoff and upland sediment from the Koolau Range and urbanized valleys to the sea, in some places creating deltas of silt and volcanic sand.

The Overall Hazard Assessment (OHA) for the Diamond Head coastline is moderate to high (5) except along the low sloping coastal areas of Niu Valley and between Wailupe and Kahala which are most susceptible to flooding and wave damage, and are ranked high (6). At the steep headland of Diamond Head Crater, the OHA is moderate to low (4). The tsunami and storm hazards along the Diamond Head coast reflect the influence of topography. They are both ranked high except at Diamond Head, where they are reduced to moderately high. The stream flooding hazard is ranked high east of Kahala, where stream discharge in Niu Valley and Aina Haina have reached rates of 3600 ft^3/sec. The saddle-like topography west of Waialae Beach Park, directs runoff either toward Honolulu through the Ala Wai canal or east toward the canal at Waialae Beach Park. This area is also far removed from the Koolau Range and the coastal slope is great, so stream flooding is ranked moderately low. The threat of high waves that annually reach this coast in spring and summer is ranked moderately high. Erosion is high along the entire coast except at the steep Wailupe and Kupikipikio Point headlands. The hazard of sea-level rise is moderately low here where it is experiencing low rates of rise compared to other areas in Hawaii. The volcanic/seismic hazard is ranked moderately high as it is along all of Oahu's southern shores, due to their proximity to the Molokai Seismic Zone.

Molokai and Lanai

Molokai and Lanai are the least populated and smallest of the main Hawaiian Islands. Both are relatively arid, except for the central mountains of each island and northeast corner of Molokai, so flooding are not as common hazards as on other islands. Lying in the center of the main Hawaiian Islands, Molokai and Lanai are largely sheltered from high annual north and northwest swell and much of south-central Molokai is further sheltered from south swell by Lanai. On the islands of Molokai and Lanai, seismicity is a concern due to their proximity to the Molokai Seismic Zone and the active volcano on the Big Island. Storms and high waves associated with storms pose a threat to the low-lying coastal terraces of south Molokai and northeast Lanai.



Molokai and Lanai

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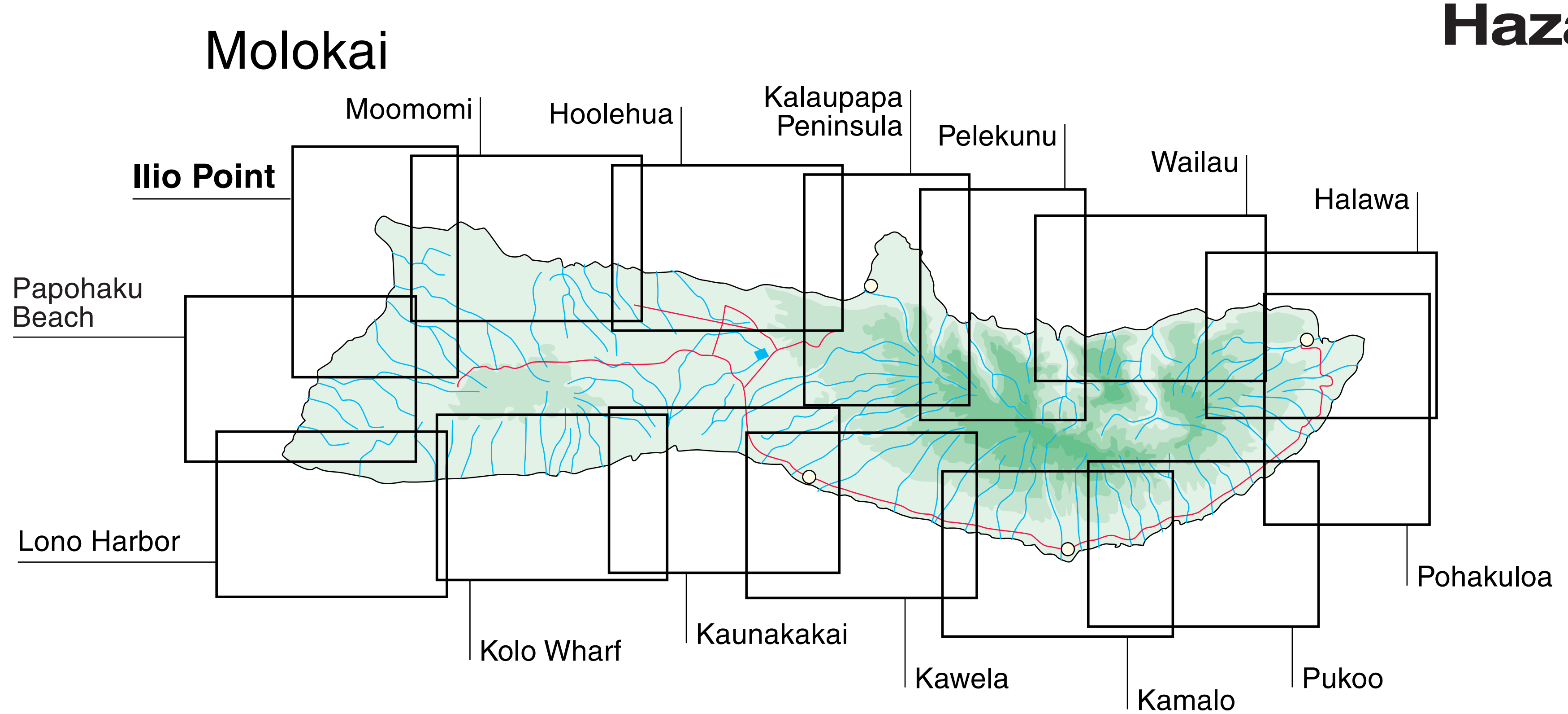
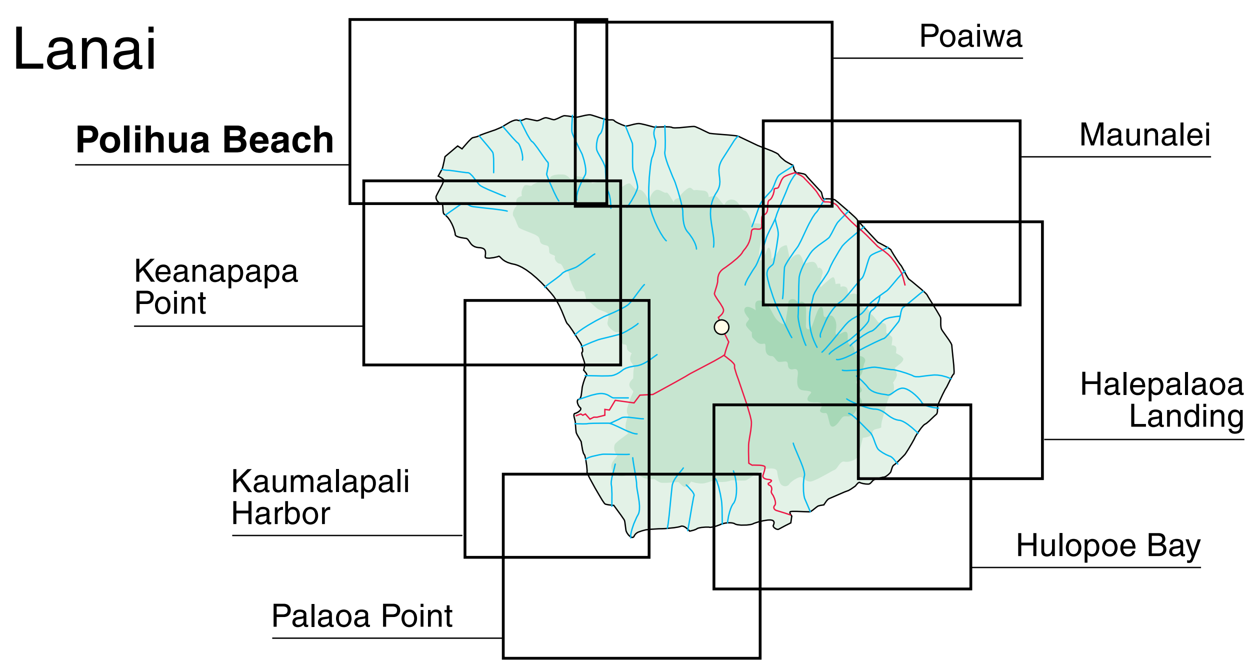




Tsunamis

A tsunami is a series of great waves most commonly caused by violent movement of the sea floor. It is characterized by speed (up to 590 mph), long wave length (up to 120 mi), long period between successive crests (varying from 5 min to a few hours, generally 10 to 60 min), and low height in the open ocean. However, on the coast, a tsunami can flood inland 100's of feet or more and cause much damage and loss of life. Their impact is governed by the magnitude of seafloor displacement related to faulting, landslides, and/or volcanism. Other important factors influencing tsunami behavior are the distance over which they travel, the depth, topography, and morphology of the offshore region, and the aspect, slope, geology, and morphology of the shoreline they inundate. Predicting the specific form of a tsunami at a shoreline is not yet possible because of many factors. Because they can be miles in length, when a tsunami passes, the water level can rise for 10's of minutes at a time. As a result, even small tsunamis can have a tremendous impact on the shoreline because the elevated water levels enable more wave energy to reach the shore and the peak of the tsunami wave to push farther inland than ordinary waves.

History has shown that their impact on the shore can be considerably different within very short distances. This has been observed throughout Hawaii and especially on Molokai. During the 1946 tsunami, for example, the runup height on the west side of Kalaupapa Peninsula was recorded at 6 ft while on the east side it was 54 ft! The only general relationship found in the database of Hawaiian tsunami observations is that the runup heights tend to be greatest near headlands where the steeper offshore bathymetry enables greater wave energy to reach the shore. Along gentle-sloping coasts, runup heights are reduced as wave energy is dissipated upon shoaling. Inundation, however, can be significant along low-lying coastal plains and is usually greatest there.

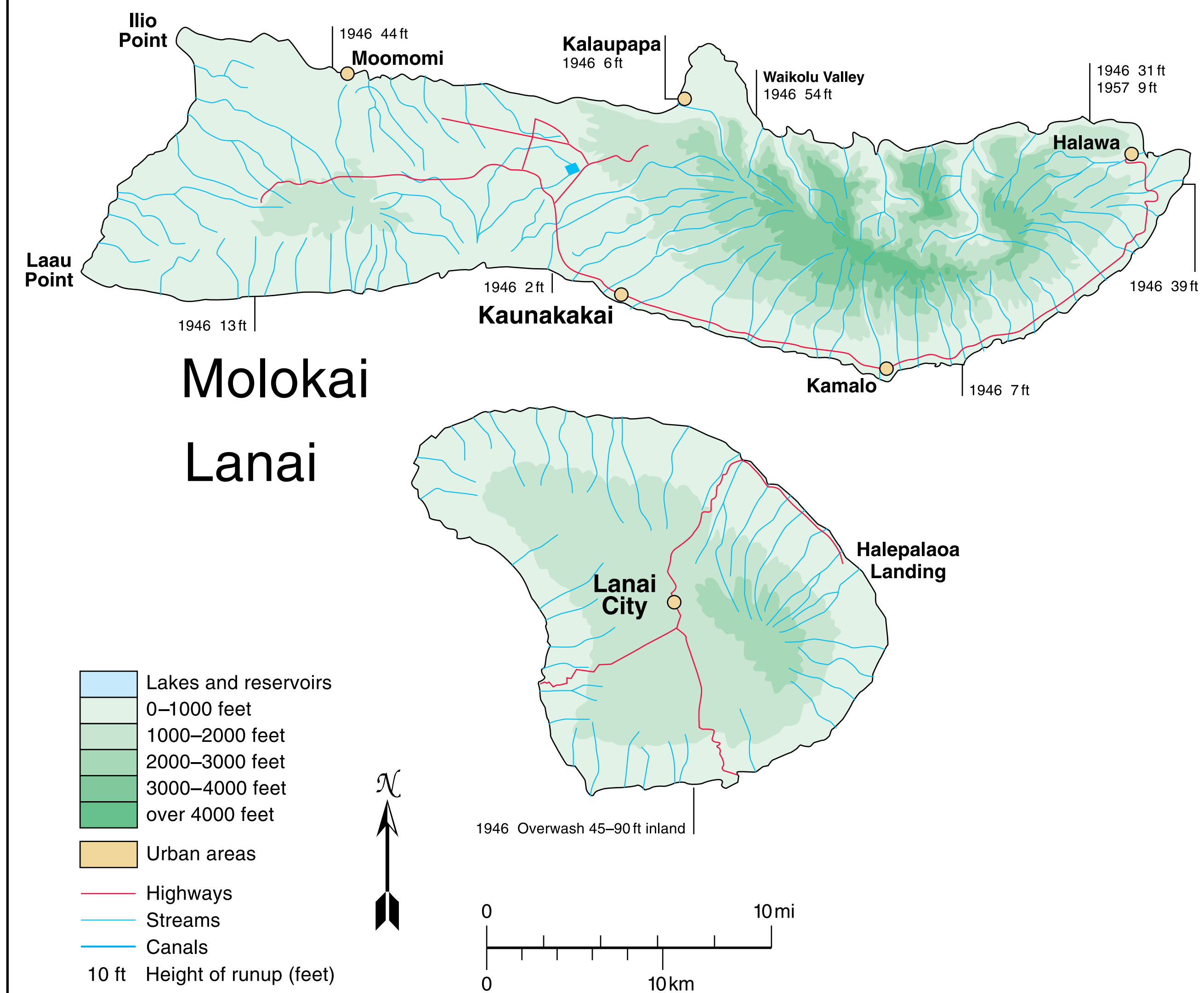
Since 1812, 26 tsunamis have made landfall within the Hawaiian Islands and 8 have had significant damaging effects on either Molokai or Lanai. This translates into one tsunami reaching the Hawaiian Islands on average every 7 yr, and a damaging tsunami reaching Molokai or Lanai once every 23 yr. However, the four last tsunamis that had a damaging effect occurred during the period 1924 to 1960. During this time, a damaging tsunami occurred once every 9 yr. An important observation is that since 1960 no damaging tsunamis have affected either island, and with an average return interval of 23 yr, one could claim that a damaging tsunami is overdue. Another important observation of the historical tsunami data is that they can originate from seafloor displacements as far away as Alaska and Chile or as close as the Island of Hawaii, like the 1975 and 1868 tsunamis that were generated by earthquakes along the flanks of Kilauea Volcano. The travel time of tsunamis from distant sources can be on the order of 10's of hours, while those originating on the Big Island can arrive within minutes.

Molokai and Lanai
Tsunamis

(after Lander and Lockridge, 1989)

Tsunamis with reported effects on Molokai and Lanai

1946 Apr 1
1957 Mar 9
1960 May 22



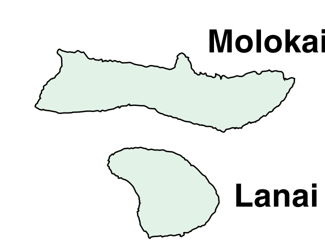
Large tsunamis* (>1m, 3.3 ft) with reported damage in the Hawaiian Islands

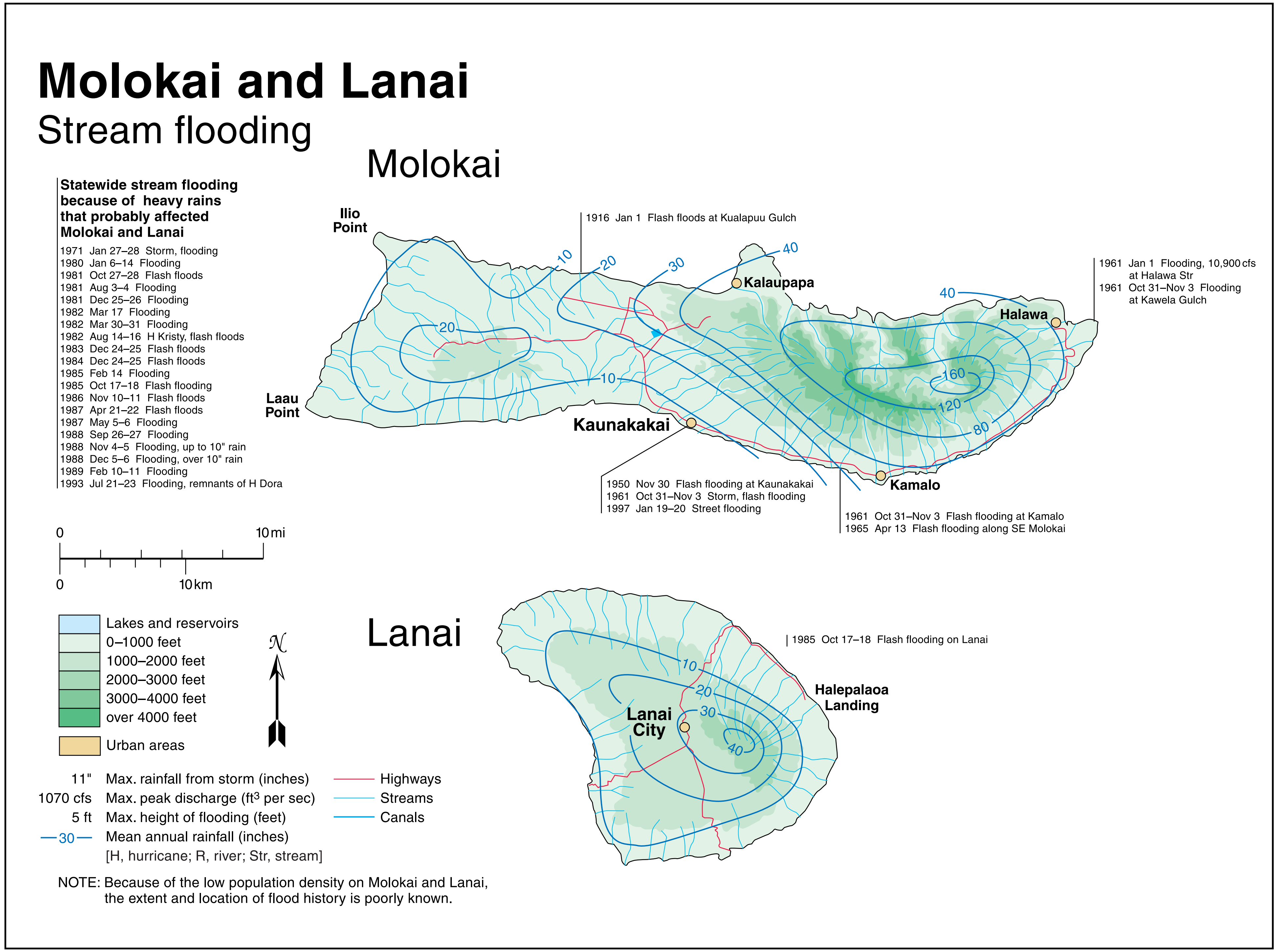
Year	Date	Area of origin	Magnitude**
1819	Apr 12	N Central Chile	M= 2.0
1835	Feb 20	Southern Chile	M = 4.0
1837	Nov 7	Southern Chile	M = 3.0
1841	May 17	Kamchatka	M = 2.0
1868a	Apr 3	SE Hawaii	M = 4.1
1868b	Aug 13	Northern Chile	M = 4.3
1868c	Oct 2	South Pacific	
1869	Jul 24	South Pacific	
1877	May 10	Northern Chile	M = 4.0
1878	Jan 20	Aleutian Is (?)	
1896	Jun 15	Japan	M = 4.0
1901	Aug 9	Tonga	
1906a	Jan 31	Colombia/Ecuador	M = 1.0
1906b	Aug 17	Central Chile	M = 2.0
1918	Sep 7	Kurils	M = 3.6
1919	Oct 2	Hawaii (H = 14 ft)	
1922	Nov 11	N Central Chile	M = 3.0
1923	Feb 3	Kamchatka	M = 3.0
1933	Mar 2	Japan	M = 3.0
1946	Apr 1	Eastern Aleutian Is	M = 5.0
1952a	Mar 17	Hawaii (H = 10 ft)	
1952b	Nov 4	Kamchatka	M = 4.0
1957	Mar 9	Central Aleutian Is	M = 3.5
1960	May 22	Chile	M = 4.5
1964	Mar 28	Gulf of Alaska	M = 4.5
1975	Nov 29	Big Island/Hawaii (H = 47 ft)	

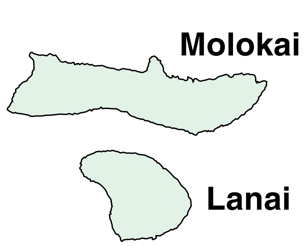
*Reliability of ≥ 3 (of 4)(Lander and Lockridge, 1989), runup > 1m (3.3 ft), and reported damage.

** Tsunami magnitude is defined by $M = \log_2 H$ as revised by Iida and others (1967), where H is the maximum runup height or amplitude on a coastline near the generating area.

Other tsunamis have occurred, such as that of Oct 1994, however, because of their low (<1 m) runup, insignificant damage, and/or uncertainty surrounding their timing and magnitude as noted in Lander and Lockridge (1989), they were not included here.







Stream flooding

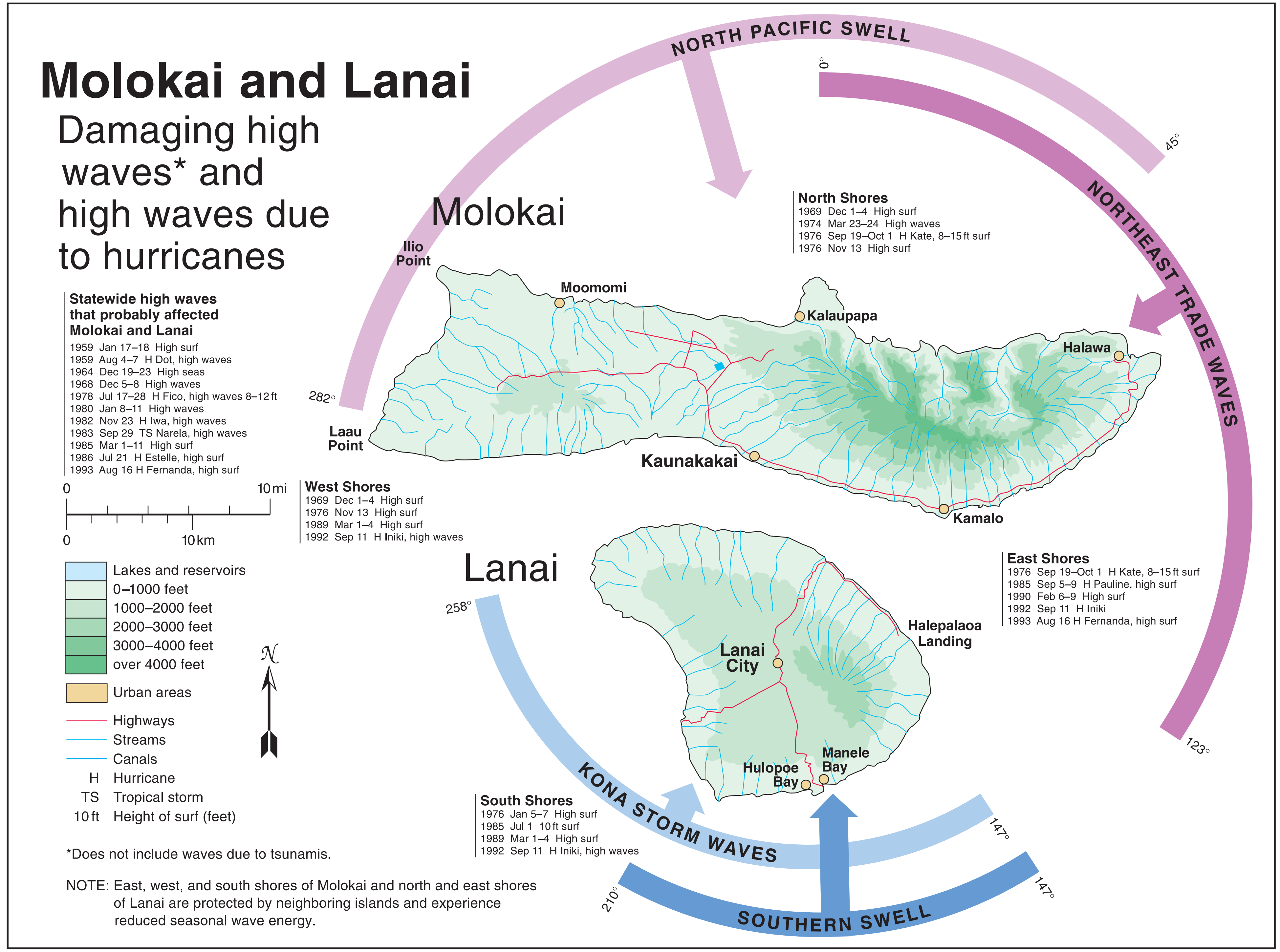
While East Molokai receives on average 160 in of rainfall each year, West Molokai and Lanai are relatively arid and experience only 20 and 40 in of rain, respectively. Even though records of flooding on Molokai and Lanai date back to as early as 1916, most of the reports are from the period 1970 to present. In addition, rainfall and stream flooding measurements have been relatively sparse on these two islands. The observational data shows that flash flooding and street flooding do occur in the arid regions of Molokai and Lanai, and as a result it is probable that stream flooding in the more isolated and wetter areas of both islands also results. However, there are only a few locations on either island that stream flooding can have an impact on the coastal zone, and these coincide with low-lying coastal plains where streams empty to the sea. On Molokai, they include Halawa Valley, the low coastal plains of Kamalo and Kaunakakai, and isolated embayments along the southwest, west, and northern shores. On Lanai, low coastal plains susceptible to flooding occur only along the northern and eastern shores and inside Hulopoe and Manele Bays.

Amidst the sparse data for flooding on Molokai and Lanai, a few observations show that flash flooding occurs in the arid, low-lying regions, like the events of November 1950, October 1961, and January 1997 in Kaunakakai. Intense, short-lived rainfall that produces flash floods can trigger street flooding, as on January 19 and 20 of 1997. Because of the limited development in the coastal zone on Molokai and Lanai, the hazard due to stream flooding might be better considered one that affects the natural environment rather than coastal development. Some of the most expansive fringing reefs in the state occur along the southern coast of Molokai. From the air on rainy days, one can observe plumes of red-brown sediment lining the entire south shore. Where the shoreline progrades seaward, the reef flat becomes buried in mud which often hosts large communities of alien mangroves. Much of the mud comes from excessive soil erosion in watersheds that have been denuded by deforestation and feral ungulates. Continued siltation on the reef because of poor upland management may impact coral habitats.

High waves

High waves from winter North Pacific swell, trade wind swell, summer South Pacific swell, tropical storms and hurricanes, and Kona storms affect shorelines on Molokai and Lanai. While the largest waves that reach Molokai are typically associated with north swell and hurricanes, Lanai is partly sheltered from north swell by the island of Molokai. High waves from large northwest swell refract into Lanai's northwest coast. The north shore of Molokai is dominated by steep sea cliffs east of Kalaupapa Peninsula, so high waves from north swell ranging 15-20 ft are a greater threat to more accessible and frequented areas along the north-facing shores between Ilio Point and Moomoomi, and near Halawa. High waves from trade wind swell range 3-5 ft along the eastern shores, but are considerably less energetic than waves from north swell, due to their shorter wave period. Waves from south swell generally range 3-6 ft and affect Lanai's south shore, but are dampened along Molokai's southern coast due to the presence of Lanai to the south. The only low-lying area along Lanai's south coast is within Hulopoe and Manele Bays, so the greatest threat from high waves occurs there. Winter Kona storms kick up winds and waves from the south and southwest, which can reach heights of 3-6 ft along south-facing shorelines of both Molokai and Lanai.

By far the highest waves that impact shorelines along Molokai and Lanai are generated by hurricanes as they approach and pass the islands. Since the 1970s, several hurricanes including Kate in 1976, Fico in 1978, Pauline in 1985, Iniki in 1992, and Fernanda in 1993, have produced high waves that have impacted Molokai and Lanai shorelines. Most recently, Hurricane Fernanda generated high waves ranging 8-10 ft that damaged one house on East Molokai. While no damage was sustained during Hurricane Iniki, high surf was observed on the east-, south-, and west-facing shores of both islands. Hurricane Pauline generated waves of 10-15 ft along eastern shorelines, while Fico kicked up 8-12 ft surf which was observed on many coastal segments on Molokai and Lanai coastline. Hurricane Kate produced 8-15 ft surf along Molokai's north and east shores.



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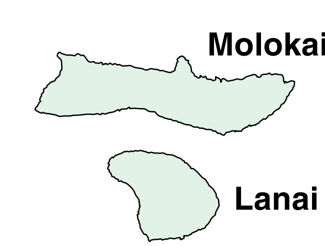
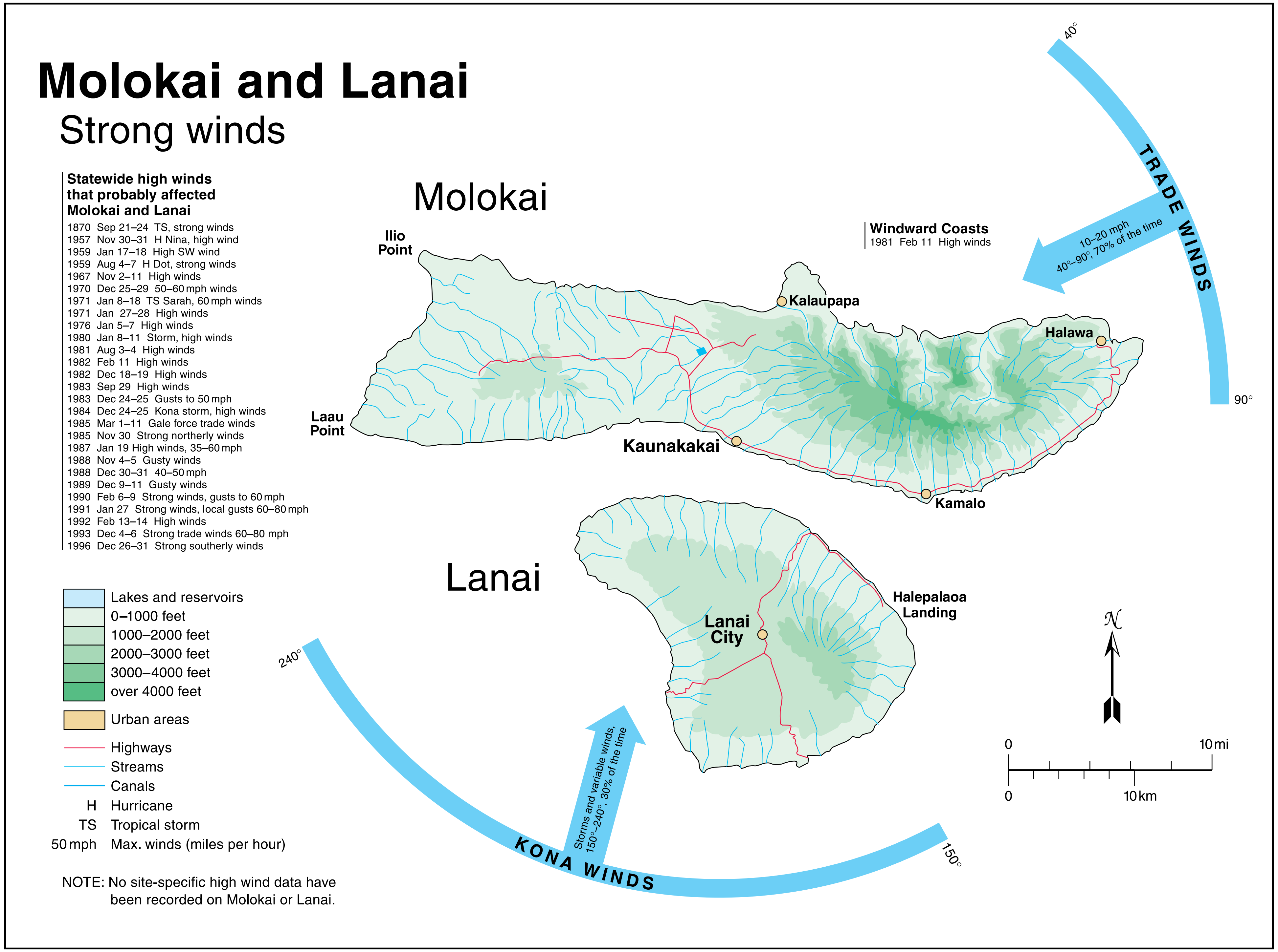
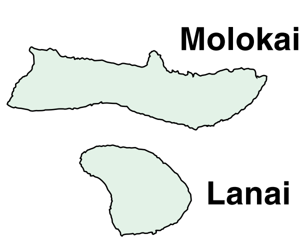






Strong winds

Strong winds on Molokai and Lanai derive from passing tropical storms and hurricanes, strong trade wind events, and winter Kona storms. While hurricanes have dealt winds greater than 150 mph to Kauai, Molokai and Lanai have been spared a direct hit by a hurricane. Tropical storms and depressions have passed in close proximity and have caused damage to isolated locations on both islands. Hurricanes and tropical storms are largely summer and fall events and because they usually approach from the east and swing around the islands to the northwest, the east-, south-, and west-facing shores are most vulnerable. However, Molokai's elongated orientation east to west, makes its north shore more variable to high winds out of the east. Trade winds, which dominate on average 70% of the year blow from the east and northeast and usually range from 10-20 mph. Periodically, they intensify and strengthen to 25-40 mph for several days on end. Kona storms originate out of the south and southwest generally in the winter and can reach significant velocities, impacting south and southwest shores.

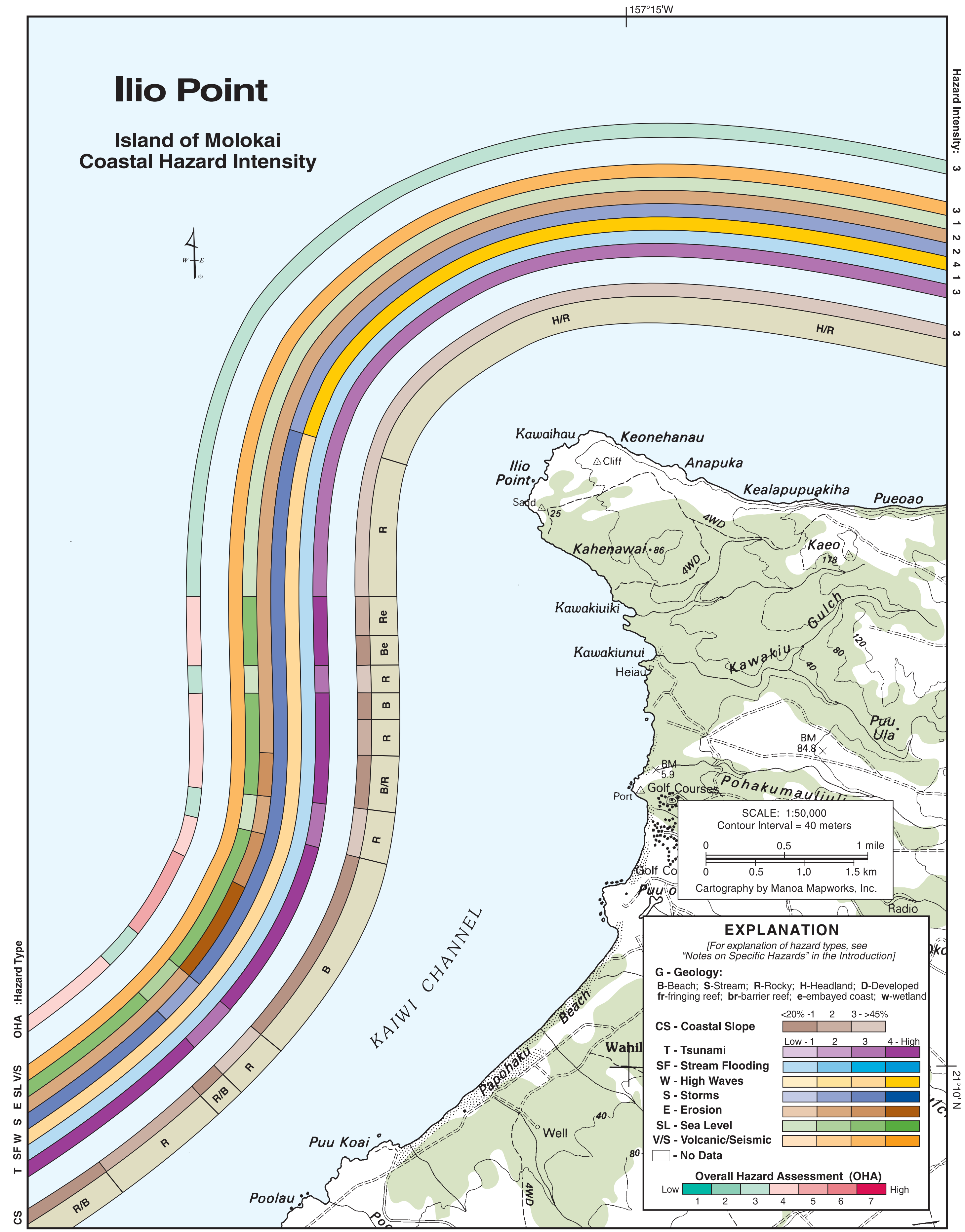
The most damaging high winds to affect either Molokai or Lanai were those associated with tropical storms Sarah in 1971 and Die Deutsche Seewarte III in 1874. Tropical storm Sarah destroyed 5 houses while the earlier storm destroyed 50 houses at Kalaupapa. While data of high wind events is relatively scarce for Molokai and Lanai, it is safe to say that since 1870 at least 25 high wind events, which affected the rest of the main Hawaiian Islands, probably affected these two islands as well. Several of these include strong and gusty trade wind events, a few extraordinary north winds, and many Kona storm winds. Lanai is somewhat fortunate in that it is partly sheltered from high winds and associated waves emanating from a northeasterly direction due to the location and massive size of Maui to the northeast. Lanai also serves as a small barrier to southerly winds and waves for the southeastern coastal zone of Molokai.

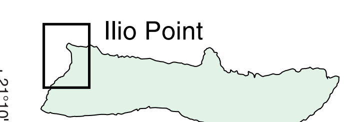
Ilio Point

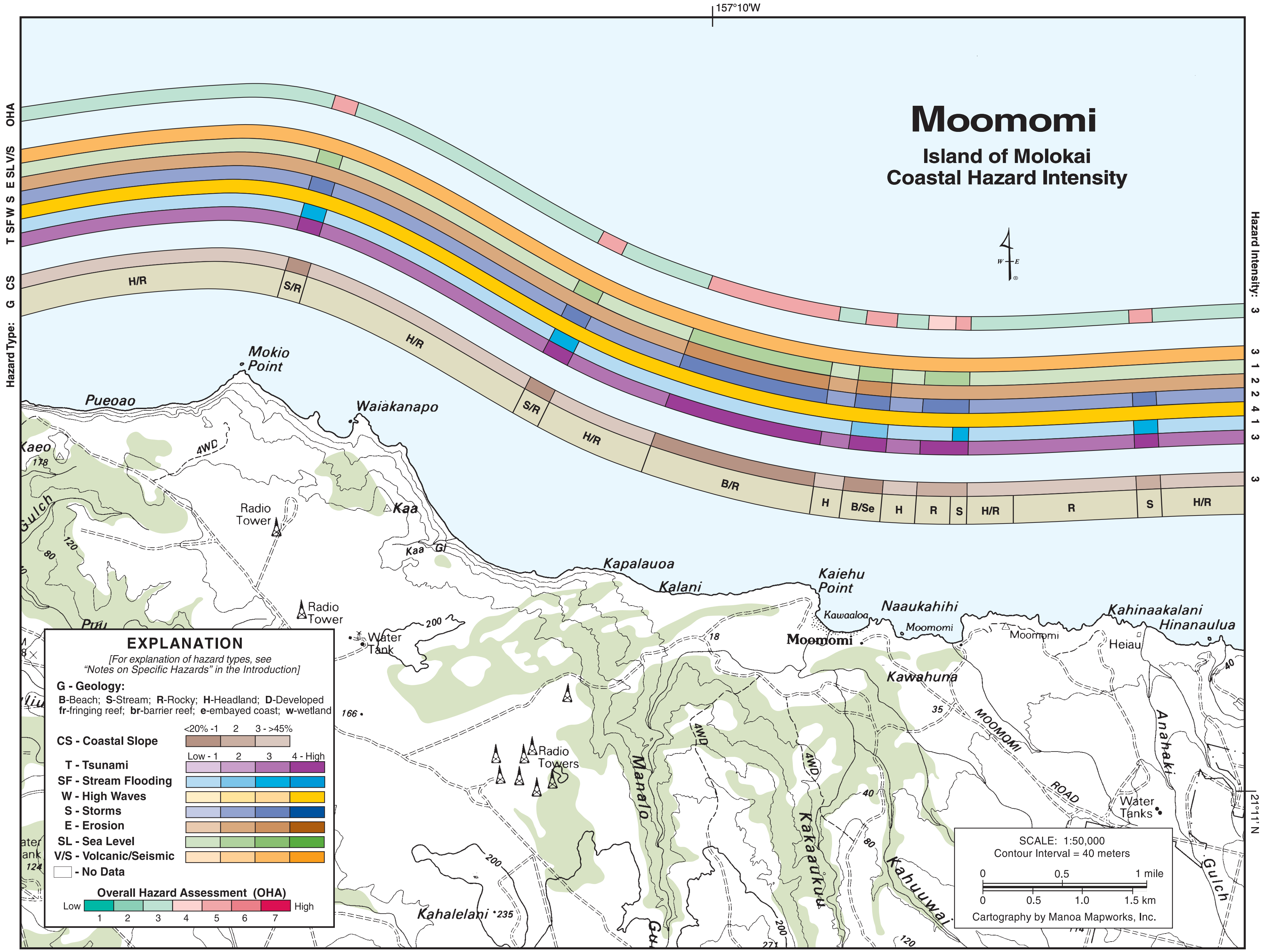
From Puu Koai to Pueoao, the coast makes a broad curve toward the northwest tip of Molokai at Ilio Point, which looks out across the Kaiwi Channel toward Oahu. Beyond Ilio Point, the coast trends due east. The long and beautiful white sandy beach of Papohaku extends two miles northeast from the basalt headland at Puu Koai. Small patch corals grow on either side of a large sand field offshore of Papohaku, while small rocky islets are found near Poolau, Puu Koai, and Puu o Kaiaka. During the 1960s and 1970s Papohaku's carbonate sands were extensively mined for Oahu's construction industry. Low-lying isolated beaches occur along Ilio Point and at Kawakiunui, the starting point of the first interisland Molokai to Oahu canoe race in 1952. East of Ilio Point the coast is rocky and relatively steep. This western region of Molokai is the most arid of the island and only few intermittent streams enable small wetlands to form near Kawakiuiki and Kawakiunui. The Ilio Point area is relatively undeveloped except for the resort located immediately north of Papohaku Beach. Access to the surrounding parts of Ilio Point is by four-wheel drive trails and footpaths.

The Overall Hazard Assessment (OHA) for Ilio Point is moderate to low (3) north and east of Ilio Point where the coast is rocky and relatively steep and the threat of tsunami flooding is moderately high, high waves is high, storms are moderately low, erosion is moderately low, and sea-level rise is low. Stream flooding is low and the volcanic/seismic threat is moderately high throughout the entire Ilio Point region. To the southwest of Ilio Point, the threat from high waves is reduced to moderately high while the storm hazard is increased to moderately high, although the OHA between Ilio and Kawakiuiki Points does not change. South of Kawakiuiki Point, however, the OHA is moderate (4) along the low-lying beaches, where the tsunami threat is high and sea-level rise is moderately high. It is moderate to low (3) along the headlands of Kawakiunui and Puu Koai, where tsunami and sea-level rise are reduced to moderately high and moderately low, respectively. In addition, erosion is increased from moderately low to moderately high along Kepuhi and the northern portion of Papohaku beach. In the southern portion of Papohaku where erosion is high, the OHA is increased to moderate to high (5).

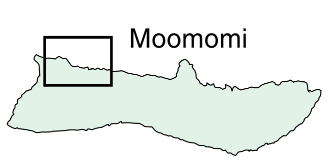
Ilio Point (foreground) is wind-swept with active linear dunes extending landward from the coast. The shoreline is bordered by fossil and lithified dunes that are eroding into steep 30-50 ft cliffs. The long, white sandy Papohaku Beach and west Molokai are in the background.







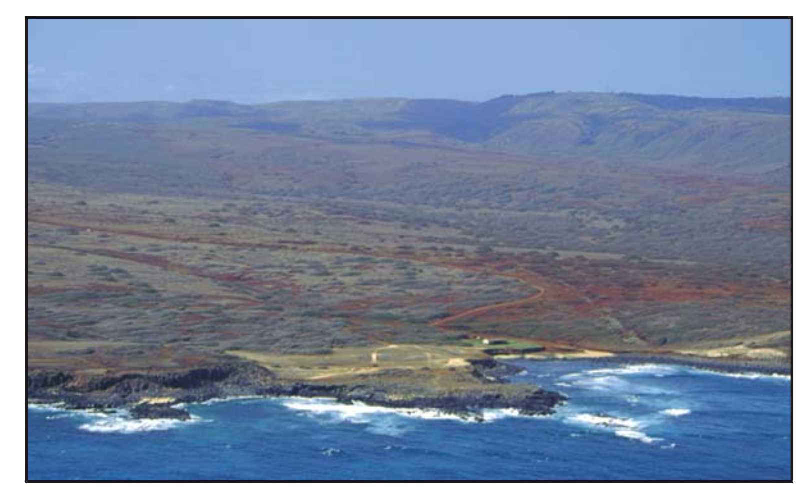
Base Credit: USGS 1:50,000 Western Molokai, Hawaii 5520 II W733 Edition 1-DMA



Moomomi

The north coast of Molokai between Pueoao and Kahinaakalani is a wind swept, rocky coast with a few isolated beaches and tall, vegetated sand dunes. The rocky headlands range between 50 and 100 ft at Mokio and Waiakanapo, and 30 to 50 ft at Kaiehu, and gradually become less steep toward Kahinaakalani. A long sandy beach occurs at Moomomi; whereas rocks and a terrace of beachrock often protrudes from beneath a thin veneer of sand along Kalani. Despite a very arid climate, several streams that experience flash floods have incised deep gulches in the coastal zone. A small wetland has developed at Moomomi. This region of north Molokai is undeveloped and access is by four-wheel drive vehicle, foot trail, or boat. Trade winds and north swell create rough seas along this coast for a large portion of the year. Only small patch corals grow under these conditions.

The Overall Hazard Assessment (OHA) for the Moomomi coast alternates between moderate to low (3) along the steep rocky headlands and high (5) at the low-lying beaches and stream mouths found at Kaa Gulch, Kalani, and the eastern sides of Mokio Point and Naaukahihi. This increase is primarily a result of the high tsunami and stream flooding, moderately high storm, and moderately low sea-level threats found in the lower coastal plain environments. Despite low stream flooding along Kalani, erosion is moderately high and contributes to the moderate to high (5) OHA there. Erosion is also moderately high at Moomomi and contributes with the moderately low stream flooding there to an OHA ranking of moderate to high (5). Where stream flooding is low along the western half of Naaukahihi, the OHA is reduced to moderate (4). Similarly, the OHA is moderate (4) at the steeper Anahaki Gulch mouth where the storm and sea level threats are moderately low and low, respectively. Along the steeper rocky headlands of the Moomomi region, tsunami is moderately high, stream flooding is low, storms are moderately low, and sea-level rise is low. The high waves and volcanic/seismic threats are high and moderately high, respectively, throughout the entire Moomomi coastal area.

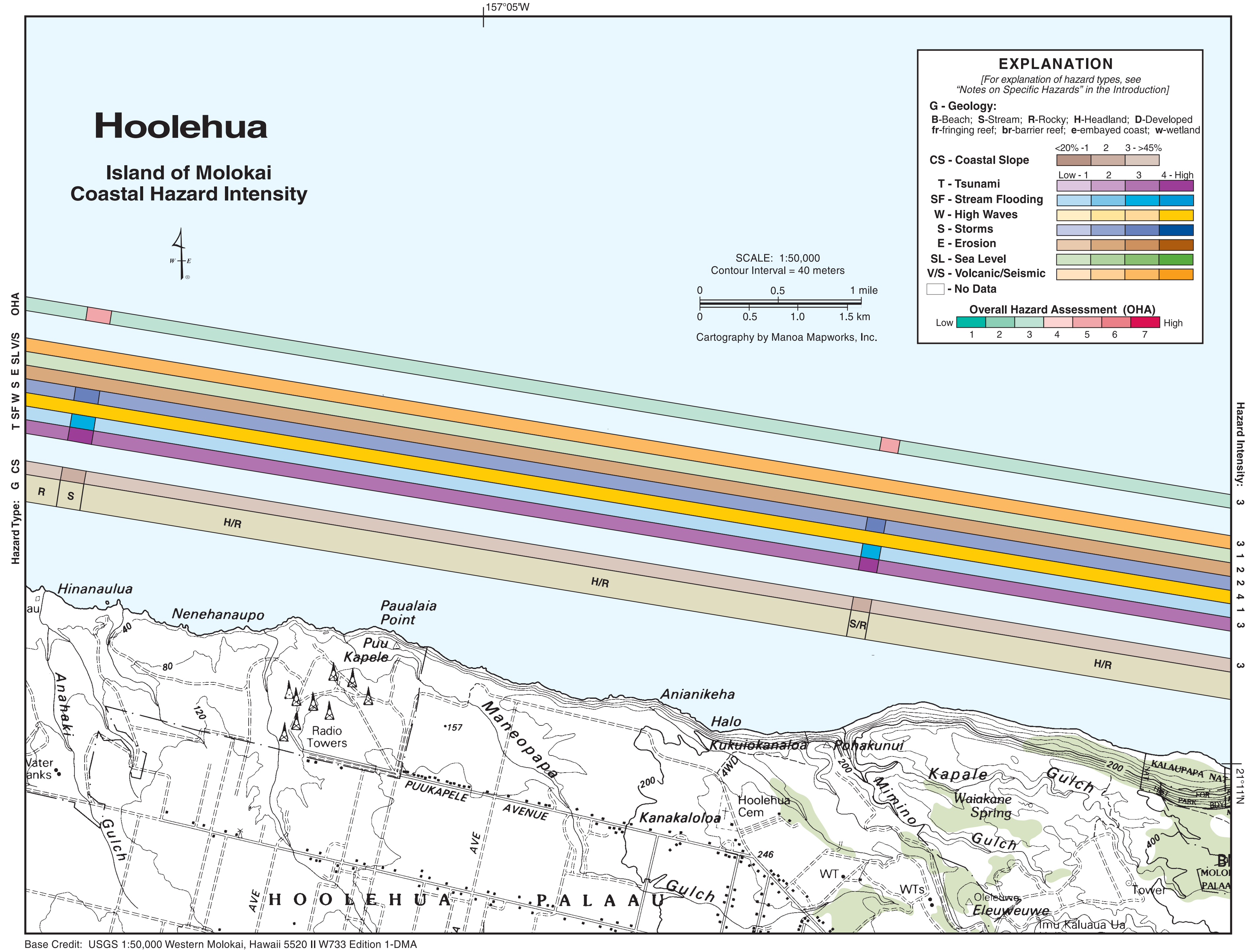


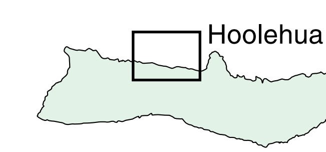
A small pocket beach and headland near Moomomi give way to sparse vegetation and eroded landscape in the hinterland.

Hoolehua

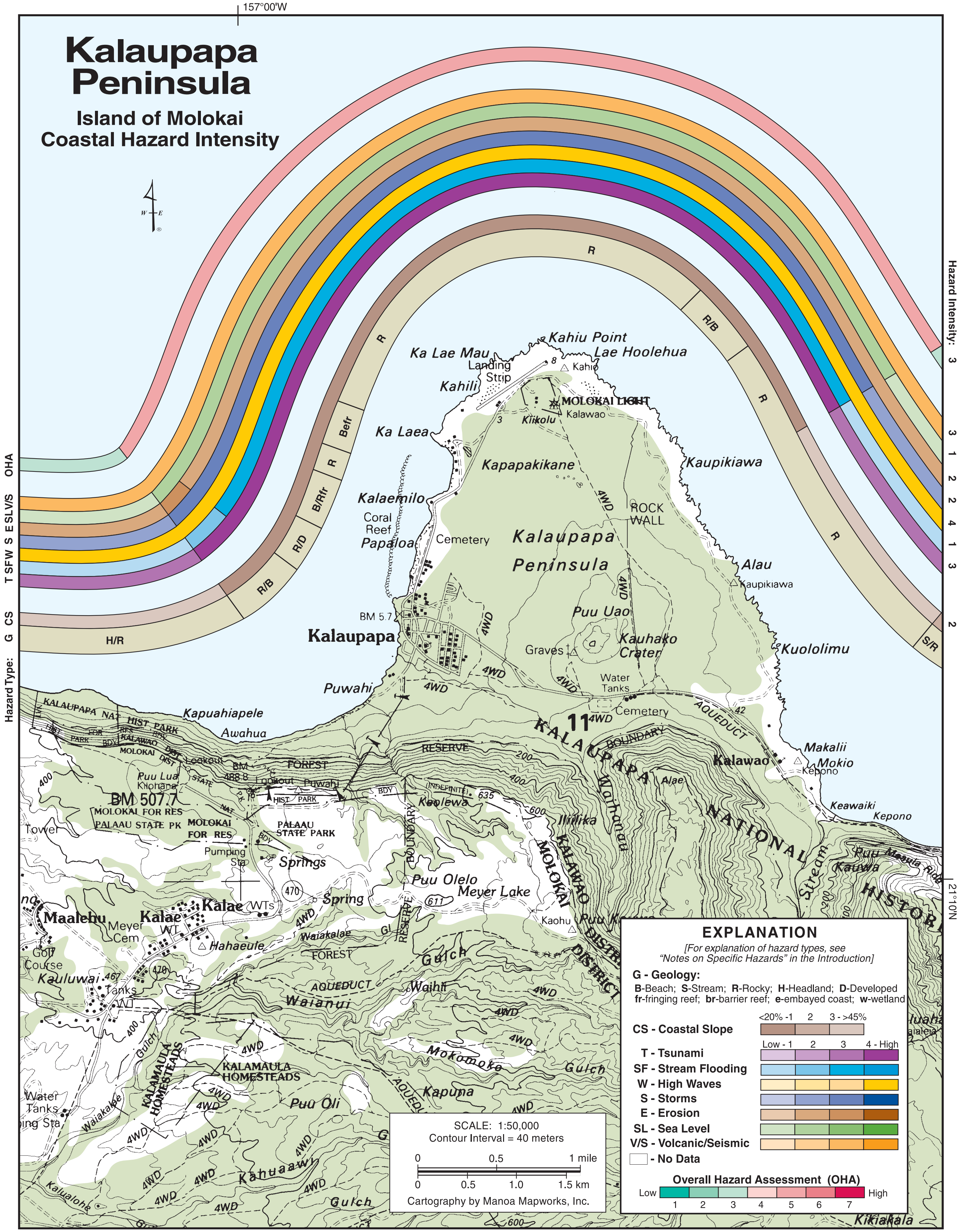
The rocky Hoolehua coast gradually becomes steeper between Hinanaulua and the west edge of Kalaupapa National Historic Park where grand sea cliffs drop more than 1000 ft to the sea. The only low-lying areas are the embayments at the mouths of the Anahaki stream in Hinanaulua and the Mimino stream at Pohakunui. Trade winds and waves, as well as north swell in winter make the ocean difficult to access in anything other than calm conditions. Few corals grow in this high-energy coastal environment which drops off rapidly to deep water. There is greater precipitation toward Kalaupapa where air masses rising up the steep sea cliffs are able to entrain moisture until condensation occurs and the moisture falls as rain. Only the central portion of Hoolehua is developed, and only above the sea-cliff bluffs.

The Overall Hazard Assessment (OHA) for the Hoolehua coast is moderate to low (3) except for the stream mouths of Anahaki and Mimino Gulches, where it is moderate (4) and moderate to high (5), respectively, and the tsunami, stream flooding and storm hazards are higher. Along the steep rocky headlands of Hoolehua tsunami is moderately high, stream flooding is low, the high wave threat is high, storms are moderately low, erosion is moderately low, sea-level rise is low, and the volcanic/seismic hazard is moderately high. The important difference in the rankings for the Mimino Gulch mouth is that tsunami and stream flooding are high, and storms are moderately high, translating into a higher OHA there.

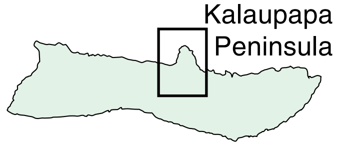




Steep seacliffs along the Hoolehua coast expose layers of lava and show several large landslide scars.



Base Credit: USGS 1:50,000 Western Molokai, Hawaii 5520 II W733 Edition 1-DMA and USGS 1:50,000 Eastern Molokai, Hawaii 5620 III W733 Edition 1-DMA



Kalaupapa Peninsula

Kalaupapa Peninsula is a large, isolated coastal plain built of lavas that eminated from Kauhako Crater, now a 450-ft-deep pit that extends below sea level and is filled with brackish water and lush vegetation. The peninsula's isolation, more than 1000 ft below the towering sea cliffs of central North Molokai, led the Hawaiian Board of Health in 1866 to establish this area as a colony for the growing number of people in Hawaii with leprosy, now referred to as Hansons Disease. Kalaupapa's shoreline is cliff-faced west of Puwahi and low and rocky to the east. Between Kalaupapa and Ka Laea an extensive fringing reef protects the rocky coast. Between Ka Lae Mau and Kaupikiawa the rocky shore is rugged and wind blown. Small perched carbonate beaches and narrow vegetated sand dunes exist on the west side of the peninsula between Kaulapapa and Ka Laea and on the east side just south of Lae Hoolehua. At Awahua, known as Black Sands Beach, the sand has a large terrigenous detrital component compared to the white carbonate sands of Papaloa, Kahili, and Hoolehua, born of storm-deposited rubble from offshore. Only small streams reach the sea west of Puwahi, however, there can be significant runoff to the east. Development is concentrated at the town of Kalaupapa and the airstrip near Ka Lae Mau. Kalaupapa is only accessible by plane, boat, or foot trail.

The Overall Hazard Assessment (OHA) for Kalaupapa Peninsula is moderate to high (5) except to the west of Puwahi, where it is moderate (4). The threat of high waves is high and the volcanic-seismic threat is moderately high throughout the entire region. Tsunami is high and stream flooding is moderately high along the low-lying peninsula and moderately high and low, respectively, on either side, except for stream flooding at Puwahi which is moderately low. Storms are moderately high and the threat from sea-level rise is moderately low along Kalaupapa Peninsula, while to either side they are moderately low and low, respectively. Erosion is moderately low for the entire Kalaupapa coast except for a small section of coast at Puwahi where it is moderately high. At Puwahi, stream flooding is moderately low, however, this and the higher erosion there do not alter its OHA of moderate to high (5). The volcanic/seismic hazard is moderately high in this vicinity which lies within the Molokai Seismic Zone.

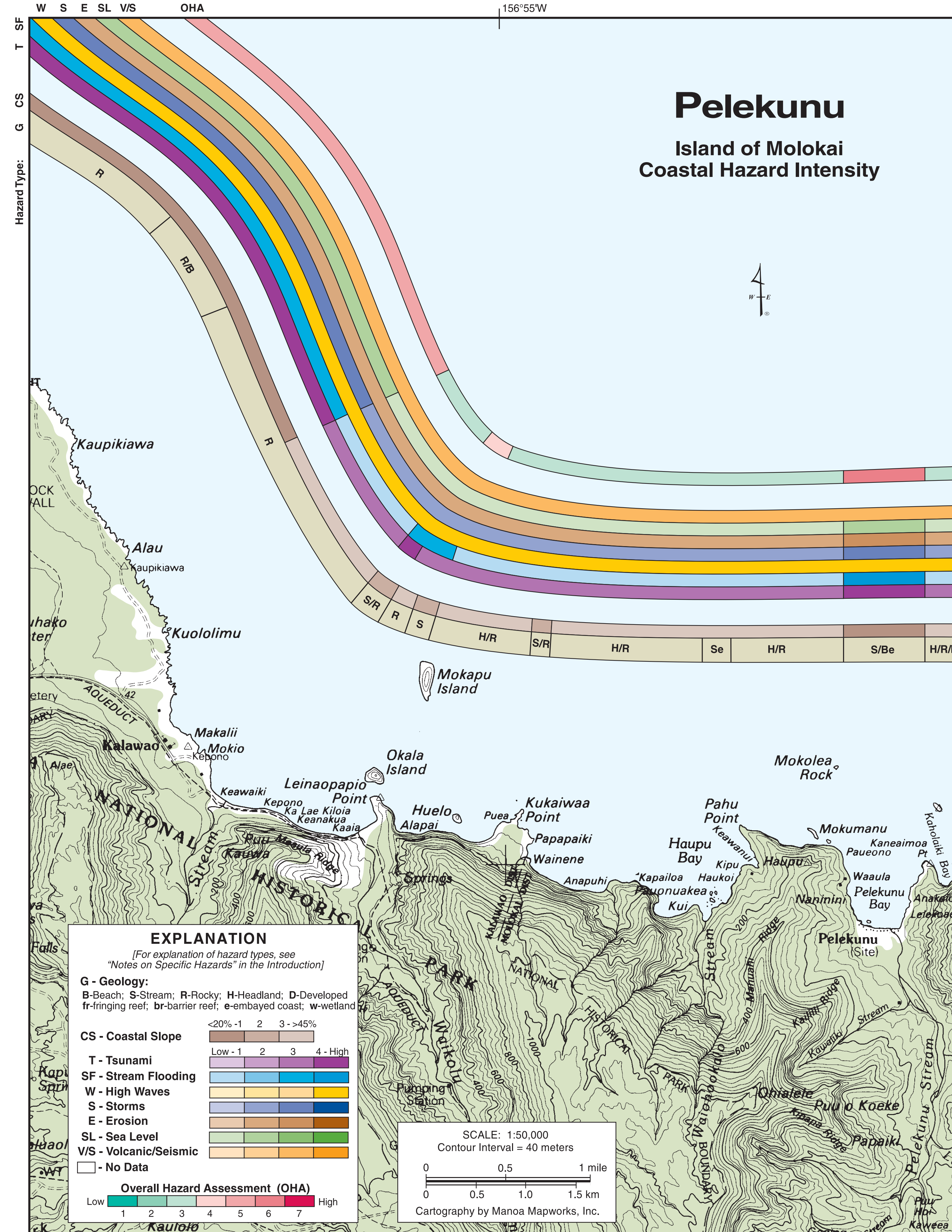
A view of the western shore of the Kalaupapa Peninsula shows the narrow fringing reef, low-relief of the peninsula, and steep terrain of the forest reserve in the background.

Pelekunu

The low-lying coastal peninsula along Kaupikiawa and Kuololimu gives way to the steep coastal cliffs of North Molokai east of Kalawao. Deep and narrow stream valleys have been cut into this steep, rocky, headland coast and the only low-lying areas are at the stream mouths at Keawaiki, Kaaia, Wainene, and inside Pelekunu Bay. Beaches along this stretch of coast are mostly rocky boulder beaches with temporary dark detrital sand during periods of sustained calm conditions. Beautiful rock islets, including Mokapu and Okala Islands, Mokolea Rock, Huelo, and Mokumanu stand just offshore of the towering coastal cliffs that in places rise 2000 - 2500 ft from the shoreline. Only patchy corals have developed in the more protected areas along this high-energy coastline. While archaeological evidence shows this coast was once populated by large numbers of Hawaiians and cultivated with taro, today development is largely absent and access is only by boat or foot trail.

The Overall Hazard Assessment (OHA) for the Pelekunu coast is moderate to high (5) west of Alau and moderate to low (3) to the east, except at Keawaiki where it is moderate (4), and at Pelekunu Bay where it is high (6). West of Alau, where tsunami and high waves are high, stream flooding and storms are moderately high, and erosion and sea-level rise are moderately low, the OHA is moderately high (5). The OHA is moderately low (3) east of Alau to Mokio and between Huelo and Pelekunu Bay where tsunami and storms are reduced to moderately low, and stream flooding and sea-level rise are reduced to low. The volcanic/seismic threat is moderately high throughout the entire region. At Keawaiki, both tsunami and stream flooding are high and the OHA is increased to moderate (4). At Pelekunu Bay, tsunami and stream flooding are high, whereas storms, erosion and sea-level rise are moderately high, resulting in the high (6) OHA within the low-lying Pelekunu coastal plain and embayment.

A view looking south at Pelekunu Bay and up the valley of Pelekunu Stream shows the steep coastal cliffs and deep, narrow stream valleys of north Molokai.



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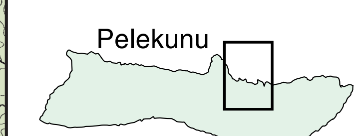

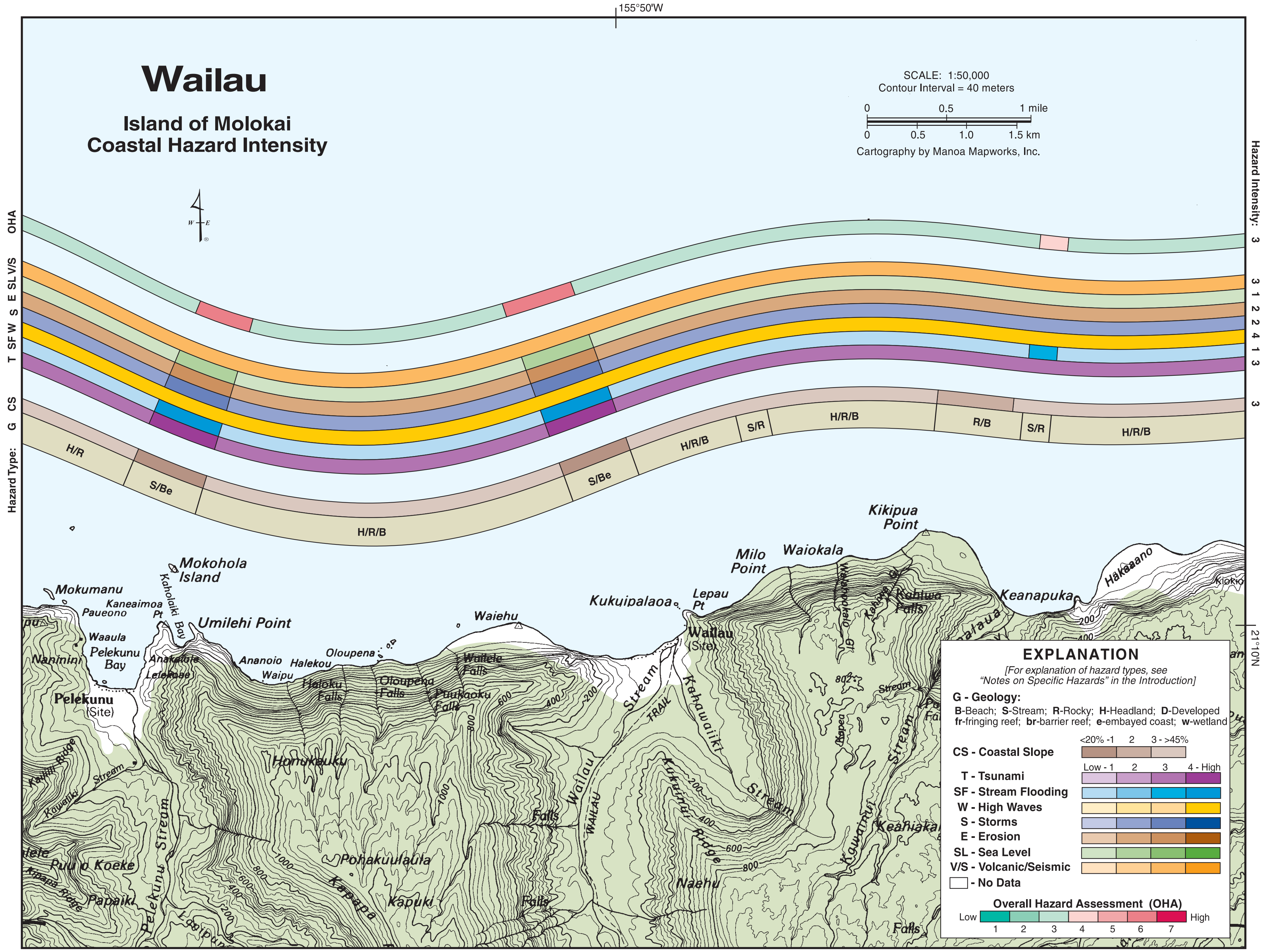

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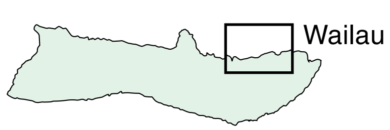


Wailau

Between Umilehi Point and Hakaaano, the beautifully scenic amphitheater valley of Wailau dominates the North Molokai coast, which is mainly cliffs. Its valley walls are often adorned with numerous waterfalls that feed the valley floors 3000 - 4500 ft below. Springs, streams, and waterfalls contribute enormous amounts of water to Kahawaiiki and Wailau Streams that drain across Wailau's low-lying coastal plain. In the 1800's and early 1900's, Wailau was populated and taro was grown commercially. However, the 1946 tsunami inundated the valley with wave runup heights of 25 ft and destroyed the agricultural infrastructure. Today it is undeveloped and access is by boat or foot trail. Sea conditions are often very rough as trade wind waves and north swell persistently modify the shoreline. To the east, the small embayment of Keanapuka (Papalaua) sits amidst two rocky boulder beach points of Kikipua and Hakaaano. Only small patchy corals exist along this coast.

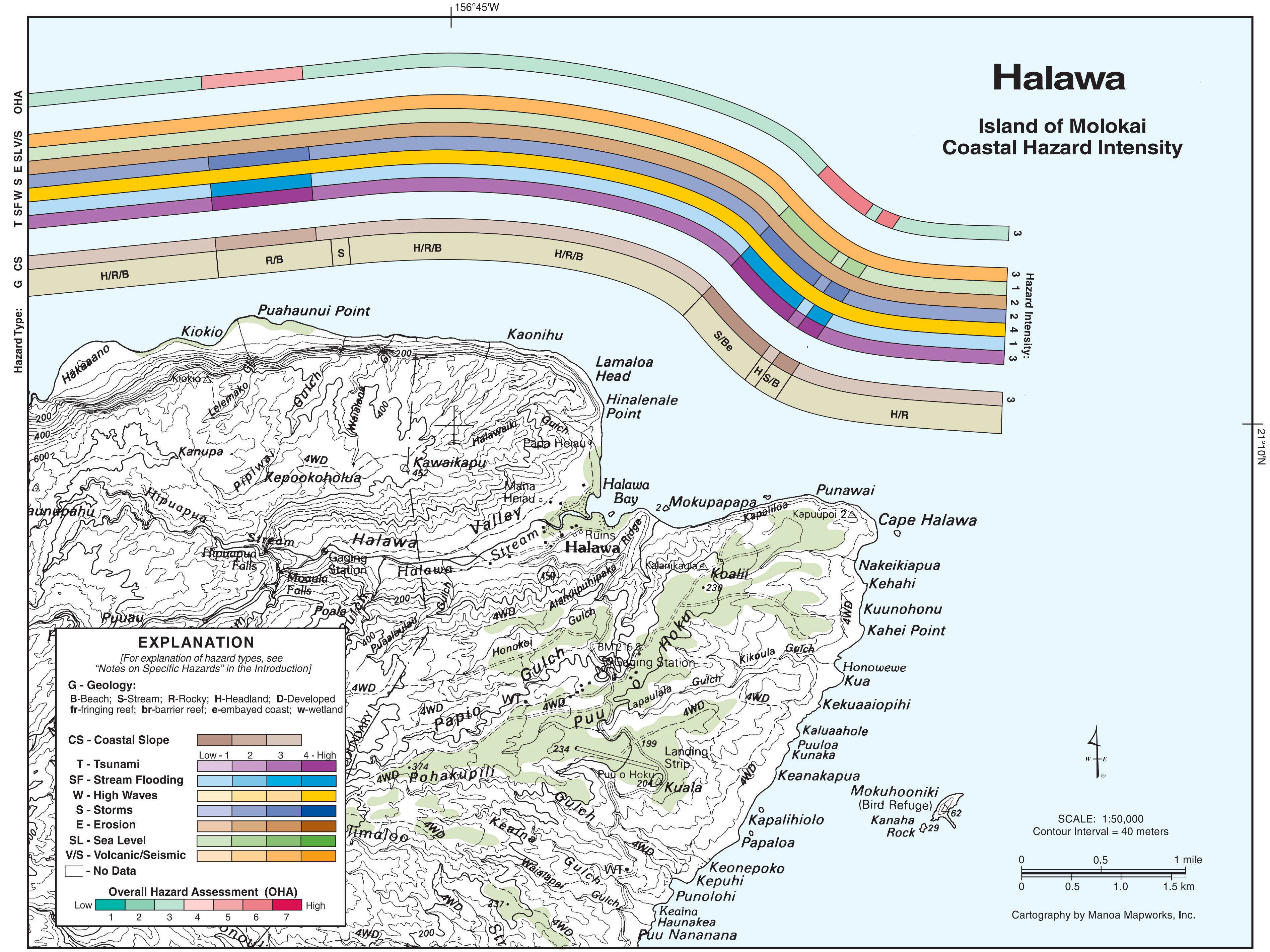
The Overall Hazard Assessment (OHA) of Wailau alternates between moderate to low (3) along the steep rocky headlands and high (6) in the Pelekunu and Wailau embayments. This is the result of the increase in tsunami, stream flooding, storm, erosion, and sea-level threats at the low-lying coastal embayments. Inside the bays, tsunami and stream flooding are high, while storms and erosion are moderately high, and sea-level rise is moderately low. Along the steep cliffs of the headlands, tsunami is moderately high, while storms and erosion are moderately low, and stream flooding and sea-level rise are low. The high wave and volcanic/seismic threats are high and moderately high, respectively, throughout the entire Wailau region. At Keanapuka, only the high ranking for stream flooding is greater than along the surrounding rocky headlands, and as a result, the OHA there is moderate (4).

A view of the rugged Wailau coast of northern Molokai (looking west) shows the steep cliffs and peninsulas, which are sites of ancient landslides.

Halawa

East of Hakaaano, the steep, towering rocky sea cliffs taper off toward Halawa, the last of the deep stream-cut valleys of the North Molokai coast. The coastal slope is steep along most of the Halawa coast, except near Puahaunui, where it is moderate, and inside Halawa Bay, where it is low lying. The beaches along this region of north Molokai are rocky boulder beaches except within Halawa Bay, which comprises a mixture of detrital terrigenous and marine carbonate sands. The sandy beaches of Halawa Bay occur along two inlets, which are separated by a rocky boulder point in the middle of the bay. Trade winds blow directly into Halawa and have formed sand dunes that line the back beach. Offshore of the rocky point a small patch reef of coral has developed amidst the rocky bay bottom. East of Halawa, the shoreline is a rocky headland coast to Punawai and Cape Halawa.

The Overall Hazard Assessment (OHA) for Halawa is moderate to low (3) along the steep cliffs to the west and east of Halawa Bay. Along the Puahaunui Point coastal plain it is moderate to high (5) and to either side of the rocky ridge protrusion in the center of Halawa Bay, it is high (6). Along the rocky headlands tsunami and the volcanic/seismic threats are moderately high, while stream flooding and sea-level rise are low. High waves and erosion are ranked high and moderately low, respectively. The moderate to high (5) OHA at Puahaunui Point is a result of the high tsunami and stream flooding and moderately high ranking for storms along this lower-lying portion of coast. At the two low-lying beaches inside Halawa Bay, tsunami and stream flooding are high, while storms are moderately high and sea-level rise is moderately low. This results in the high OHA ranking on either side of the central rocky outcrop in the bay.



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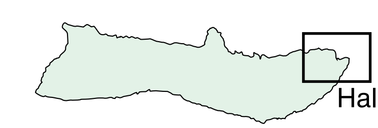
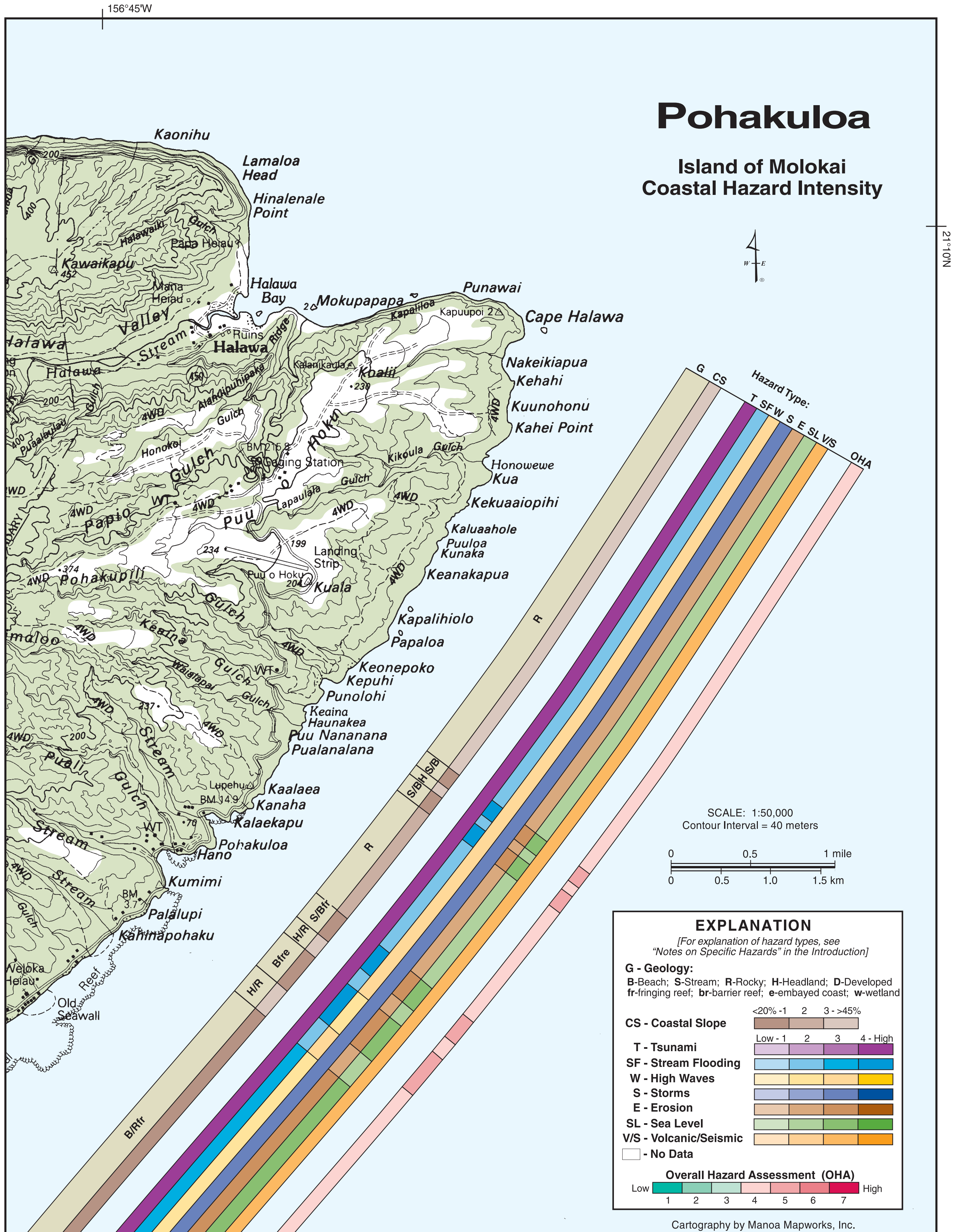


The coastline along Halawa Bay is rocky and in the center of the bay a small rocky point separates two stream mouths that empty significant amounts of terrigenous sediment into the bay from the deep valley in the background.



1 4 3 2 3 3 3 3 4 :Hazard Intensity

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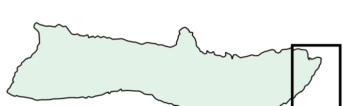
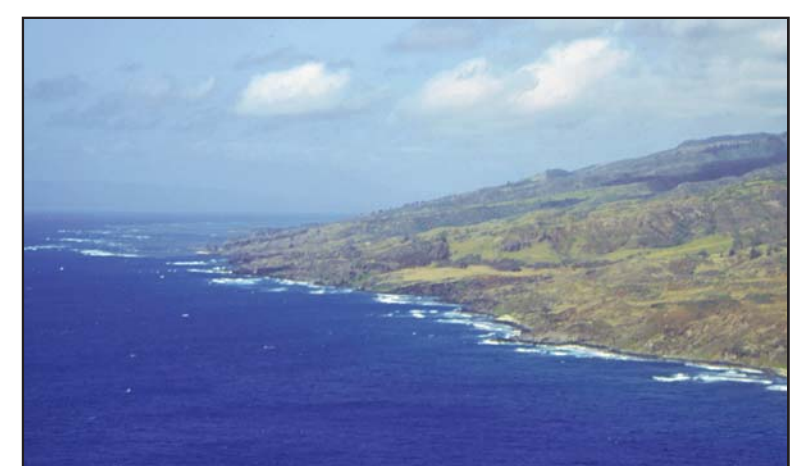


Pohakuloa

The Pohakuloa coast is rocky with numerous small coves and rocky headlands that are steepest between Kahinapohaku and Kaalaea. Several small streams cross the coastal zone and transport terrigenous sediments to the shoreline. Often nearshore waters run brown with silt runoff while offshore the waters are crystal clear. Trade-wind waves and refracting north swell persistently erode the rocky shoreline leaving sea stacks strewn offshore from Papaloa to Cape Halawa. Between Kumimi and Kalaekapu, the wave energy associated with trade wind waves and north swell diminishes sufficiently that an extensive fringing coral reef flourishes. Small isolated sand and boulder beaches occur at Punolohi, Kalaekapu, Pohakuloa, Kumimi, and Kahinapohaku. Several forsaken fishponds lie submerged offshore in ruins from waves and lack of upkeep, while a few refurbished ponds stand strong above the waves maintaining a long heritage of Hawaiian fishing culture.

The Overall Hazard Assessment (OHA) for Pohakuloa alternates between moderate to high (5) at the low-lying beaches and stream mouths of Punolohi, Haunakea, Pohakuloa, and Kumimi, and moderate (4) along the surrounding rocky headlands. Along the entire Pohakuloa coast the tsunami hazard is high, while storms and the volcanic/seismic threats are moderately high. Inside the four small embayments at Punolohi, Haunakea, Pohakuloa, and Kumimi, stream flooding, erosion, and sea-level rise are ranked moderately high, while along the headlands they are moderately low, except for stream flooding to the west of Kahinapohaku where it is moderately high because of the lower coastal slope. The threat of high waves is moderately high east of Kumimi and at Palalupi, but is reduced to moderately low at Kumimi and to the west of Kahinapohaku where significant north swell and trade-wind swell refraction reduces its impact.

Beyond the steep, rugged east coast of Pohaku (foreground, looking southwest), the longest continuous fringing reef in the main Hawaiian Islands stretches from Kumimi (background) nearly 30 miles to the west end of southern Molokai.

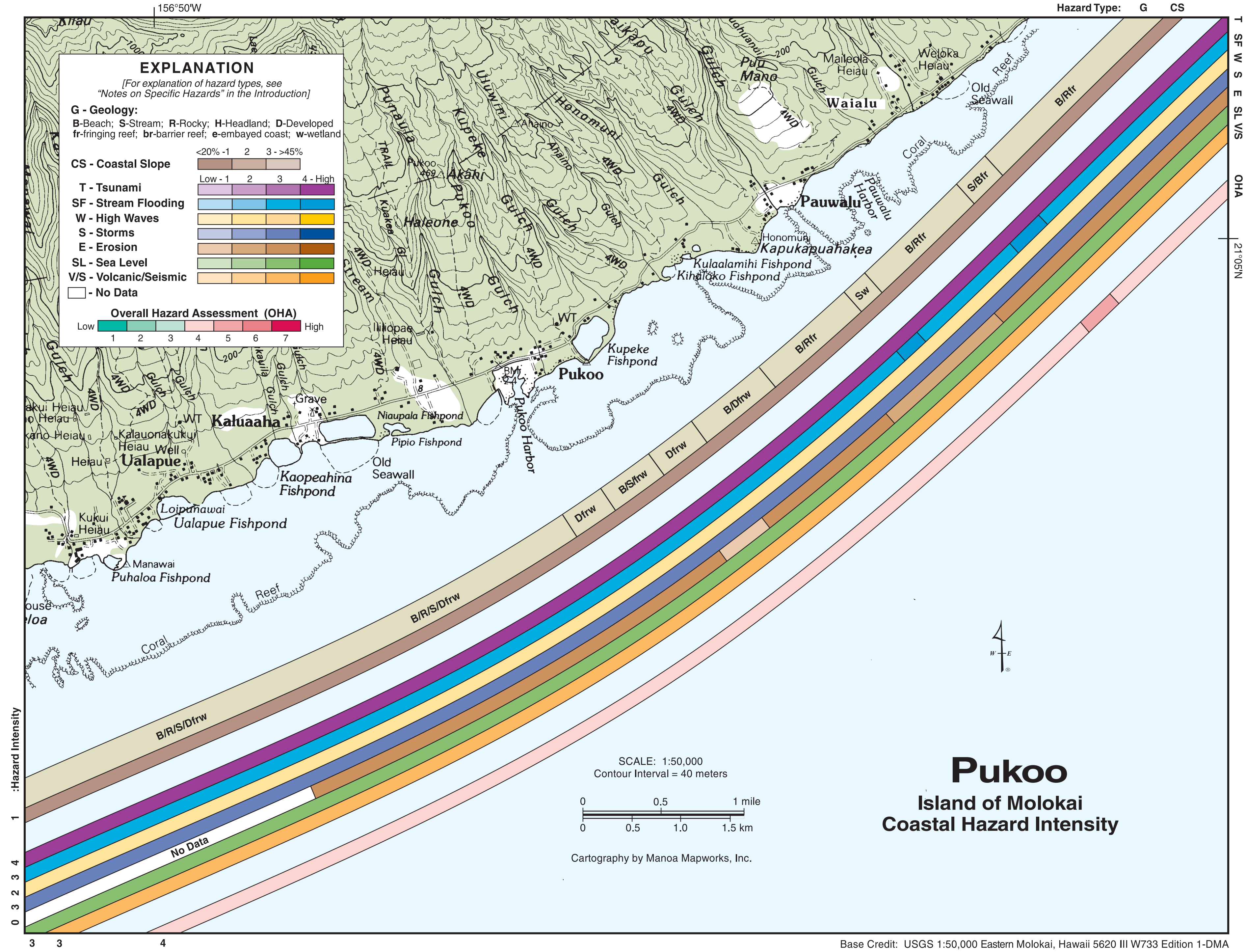


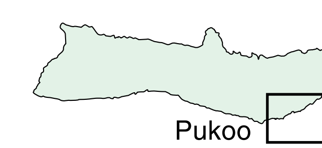
Pukoo

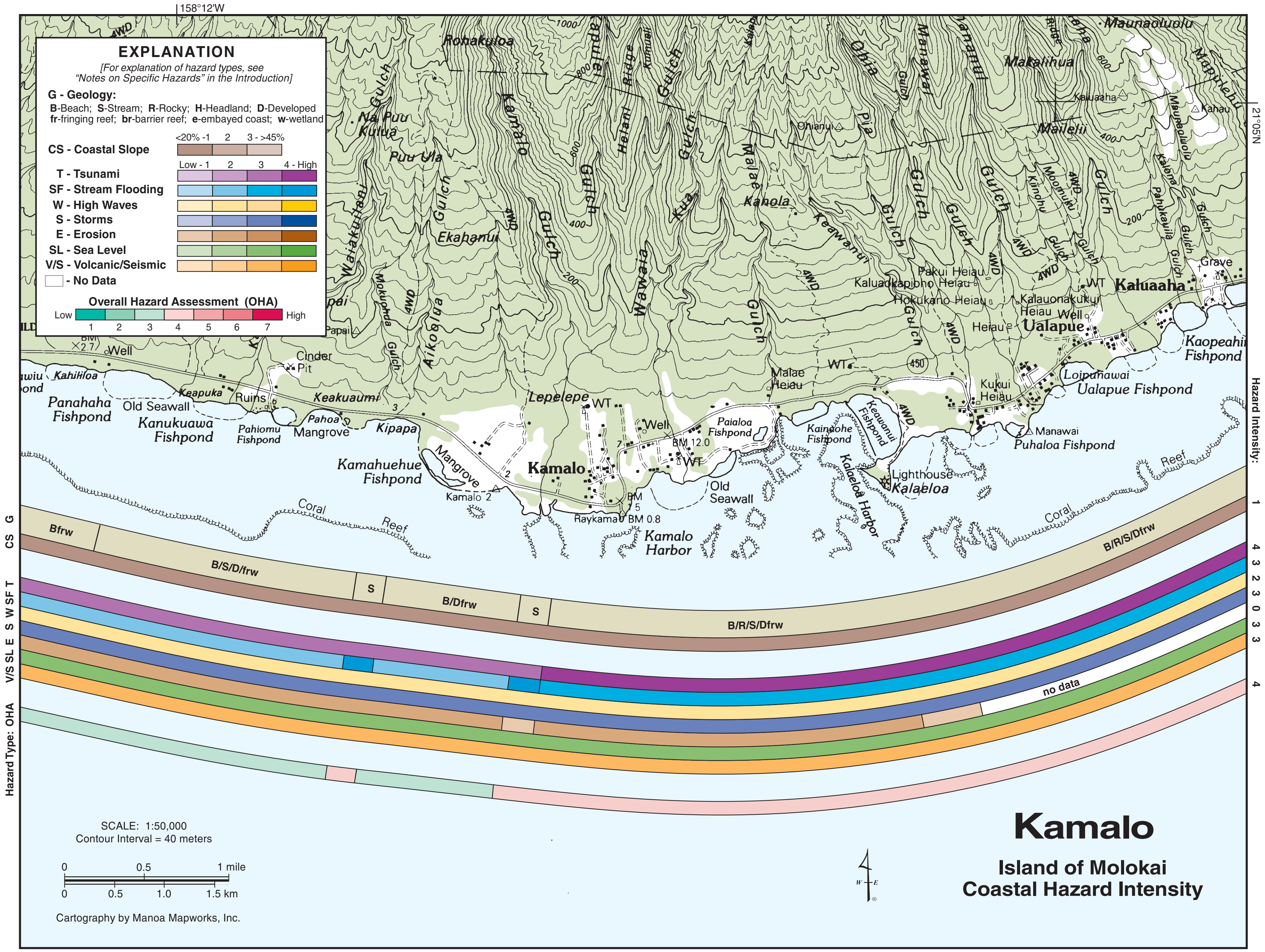
Between Waialu and Ualapue, the Pukoo coast is low-lying and comprises a relatively narrow coastal terrace with an increasingly wider fringing reef toward the west. The uplands are gently sloping and incised by numerous small streams that generally have low flow but do experience flash flooding with heavy precipitation. Despite a relatively arid climate (<40 in average annual rainfall) and low stream discharge, significant amounts of fine terrigenous sediment are transported to the nearshore zone, clouding the inner reef flat waters in red and brown. In places, this sedimentation has formed small mud flats that are becoming colonized by mangroves. The entire length of the Pukoo nearshore fringing reefs are developed with fishponds, most of which were constructed by Hawaiian residents prior to European contact. Several narrow white sandy beaches are found between the fishponds and small wetlands have developed near the stream mouths at Puawalu, Kupeke, and Pukoo, and near the Kaopeahina and Puhaloa Fishponds. Pukoo is lightly developed with small private residences and the small Pukoo Harbor.

The Overall Hazard Assessment (OHA) for Pukoo is moderate (4), except at Waialu where it is moderate to high (5) due to the increased stream flooding hazard there. The tsunami hazard is high along the entire Pukoo coast. Stream flooding is high at the stream mouths of Waialu and Puawalu, and moderately high everywhere else. The threat from high waves is moderately low along the Pukoo coast because of the buffering effect of the wide fringing reef offshore and because it receives only moderately low south swell and refracted trade-wind waves. Storms are moderately high along the Pukoo coast, which receives significant winds and storm-generated waves from passing tropical storms. Erosion is moderately high throughout most of Pukoo, except at Pauwalu and Kupeke Fishpond, where it is moderately low and low, respectively. The hazards from sea-level rise, volcanism, and seismicity are moderately high throughout this entire section of Molokai's south coast.

The broad fringing reef of southeast Molokai near Kupeke Fishpond is generally very shallow and often brown with sediment shed from the land. Blue holes occur within the reef platform.







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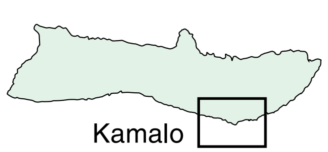


Kamalo

Molokai's southern shoreline around Kamalo is constructed of a low-lying coastal plain with a wide fringing reef offshore. Numerous small, isolated patch reefs amidst sand fields occur between Kalaeloa Harbor and Kamahuehue Fishpond. This region of the southern coast of Molokai is relatively arid, but intermittent stream flow and basal groundwater flow feed wetlands near the mouths of most of the streams. Mangrove forests have formed near Kamahuehue Fishpond and Keakuaumi within terrigneous silt deposits. The majority of this coast is rocky and lined with seawalls and fishponds. Only small, narrow sand beaches occur near Kanukuawa, Kamahuehue, Paialoa, and Puhaloa Fishponds. Most of the Kamalo coast is privately developed except for the Kalaeloa and Kamalo Harbors.

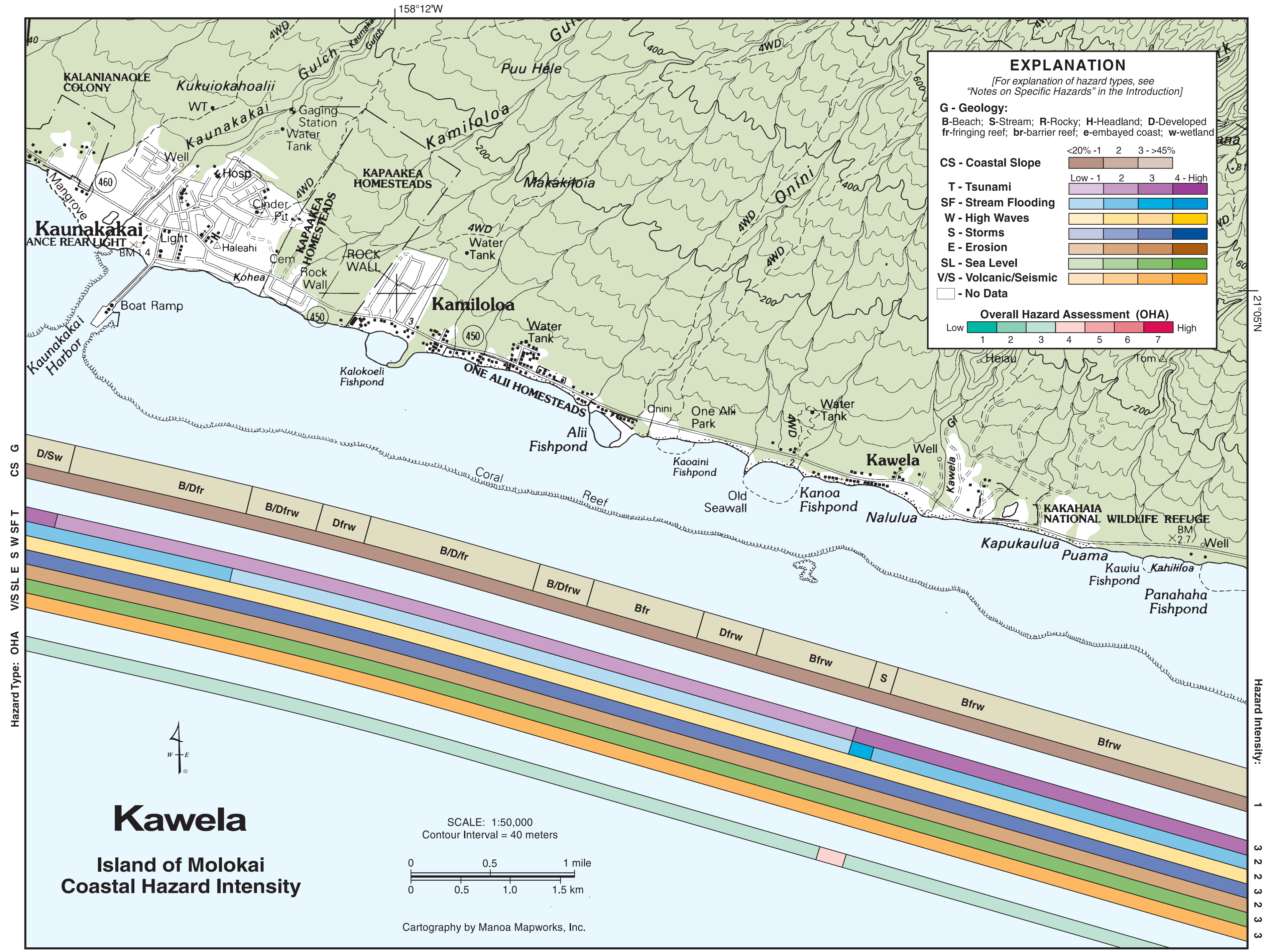
The Overall Hazard Assessment (OHA) for Kamalo is moderate (4) east of Kamalo, and generally moderate to low (3) to the west, except at the stream mouth at Kipapa, where it is moderate (4). The tsunami hazard is high east of Kamalo, and reduced to moderately high to the west, because of the shadowing effect of the island of Lanai. Stream flooding is moderately high east of Kamalo where it is wetter, and moderately low in the more arid region to the west. Exceptions are at the stream mouths at Kamalo and Kipapa where it is high. High waves are moderately low along the Kamalo coast, which is relatively sheltered from northwest swell by west Molokai, Oahu, and Kauai to the west, and from south swell by the island of Lanai to the south. Storms, sea level, and the volcanic/seismic hazards are ranked moderately high. Erosion varies between moderately low along most of the rocky coast, to low at Kalaeloa, which appears to be stabilized by sedimentation within and around Keawanui Fishpond and at Kamalo where the coast is prograding in response to sedimentation at the stream mouth.

The broad and low-lying coastal plain of Kamalo (background) is fronted by a fringing reef which has a natural reef passage offshore of Kamalo Harbor (foreground).

Kawela

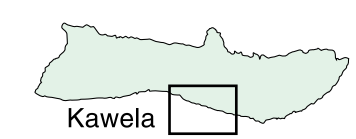
The Kawela shoreline along Molokai's southern shore is generally low-lying with a wide fringing reef offshore. Despite an average annual rainfall between 10 and 20 in, a significant volume of terrigenous sediment makes its way into the nearshore waters. Where this sediment has prograded out into the shallow, low-energy reef flat environments at stream mouths, mangrove forests have developed. Commonly, immediately landward of these mangroves, wetlands have formed. Narrow carbonate beaches line most of the Kawela coast, except at stream mouths where the sand has a high terrigenous component and where fishponds harden the shoreline, although there appears to be some sedimentation along the eastern edges of Alii and Kalokoeli Fishponds. Development increases to the west with the urbanization of Kamiloloa and Kaunakakai extending up to the shoreline.

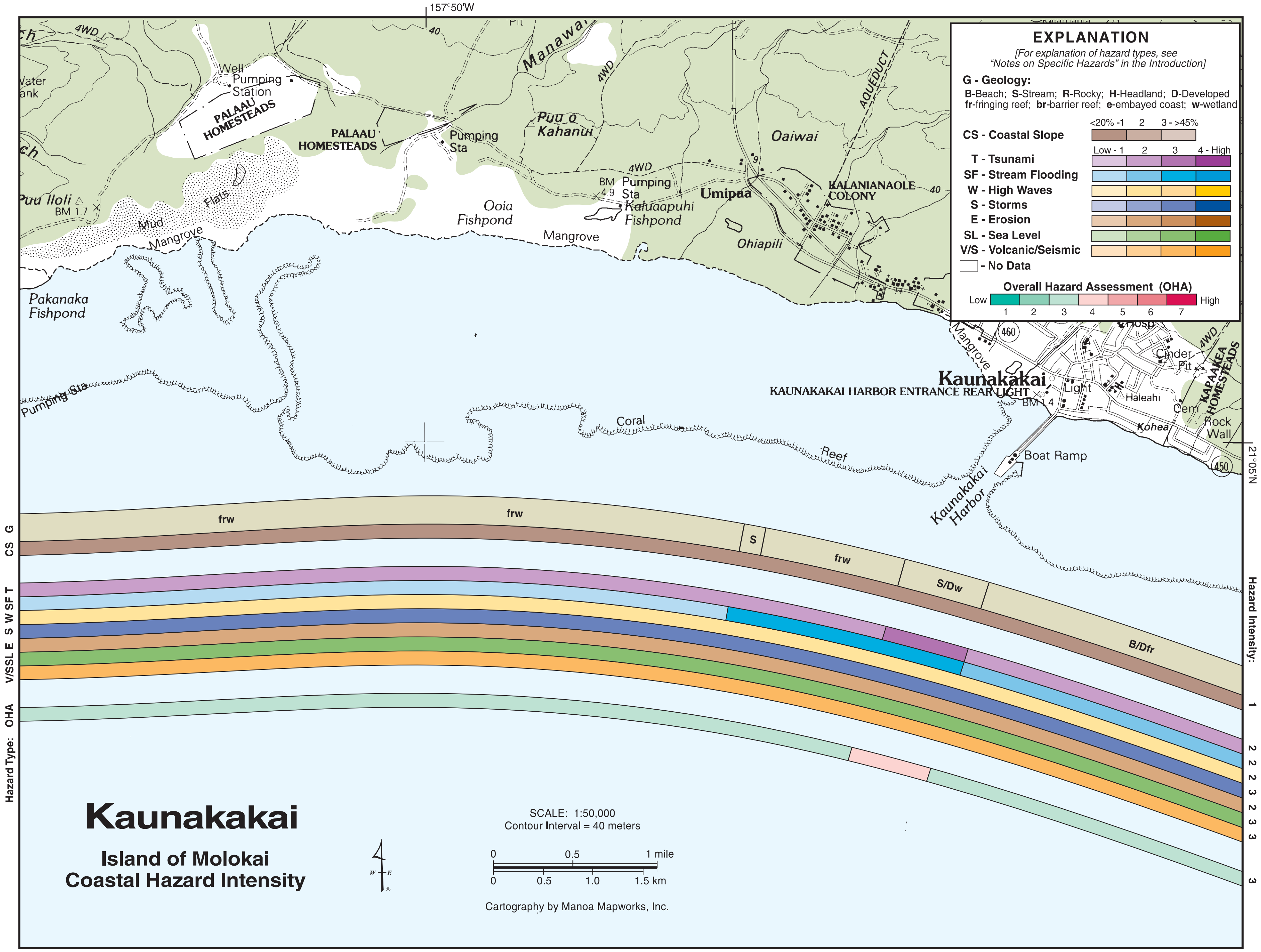
The Overall Hazard Assessment (OHA) for the Kawela coast is moderately low (3), except at the Kawela stream mouth where it is moderate (4). This is primarily because of the high stream-flooding hazard at Nalulua, which has a history of flash flooding and sedimentation at the outflow of Kawela stream. Tsunami is moderately high east of Nalulua and moderately low to the west to Kaunakakai. Stream flooding east of Nalulua is moderately low while to the west it is low to the Kamiloloa stream mouth. Beyond the Kamiloloa Stream it is moderately low. Wave energy is generally low along Molokai's southern coast, where it is sheltered from south swell by the islands of Lanai and Kahoolawe. The storm hazard is moderately high because storms that often pass to the west generate modest winds and waves along this coast. Erosion is moderately low due to the rocky nature of the coast, while the sea-level hazard is moderately high because of the low elevation and slope of the coastal zone. The volcanic/seismic threat is moderately high in this part of Molokai which lies within the Molokai Seismic Zone.



Base Credit: USGS 1:50,000 Eastern Molokai, Hawaii 5620 III W733 Edition 1-DMA, and USGS 1:50,000 Western Molokai, Hawaii 5520 II W733 Edition 1-DMA

Numerous fishponds like the Alii Fishpond (foreground) line the south coast of Molokai. The hillslopes of south Molokai (background) are arid and sparsely vegetated. Extensive erosion occurs during episodic high rainfall events and as a result of excessive grazing, bringing soil and sediment from the land which settles on the reef flat and in the fishponds.





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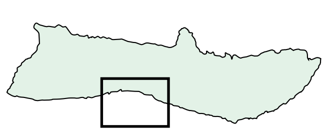


Kaunakakai

The Kaunakakai shoreline is built on a low-lying coastal terrace that reaches nearly 1 mi in width near Ooia Fishpond. An extensive fringing reef offshore buffers approaching swell. It is composed of diverse coral gardens near its crest, however, in the nearshore waters, the reef flat suffers from widespread siltation. Land use practices including deforestation, overgrazing, and open-ground agriculture have accelerated erosion and runoff of the uplands, which reaches the nearshore with high sediment concentrations, altering the water clarity during the entire year. West of Kaunakakai, a prograding shoreline comprised of mudflats and mangrove forests is forming from continued deposition of terrigenous sediments. Associated with many of these mangroves are extensive wetland areas. Kaunakakai is relatively arid, receiving on average less than 10 in of rain each year. Only a few streams reach the coastline, mainly in the vicinity of the town of Kauanakakai. Most of the shoreline is muddy or sandy, except immediately east of Kauanakakai Harbor where there is a small carbonate beach. Development on the coast is centered near the harbor.

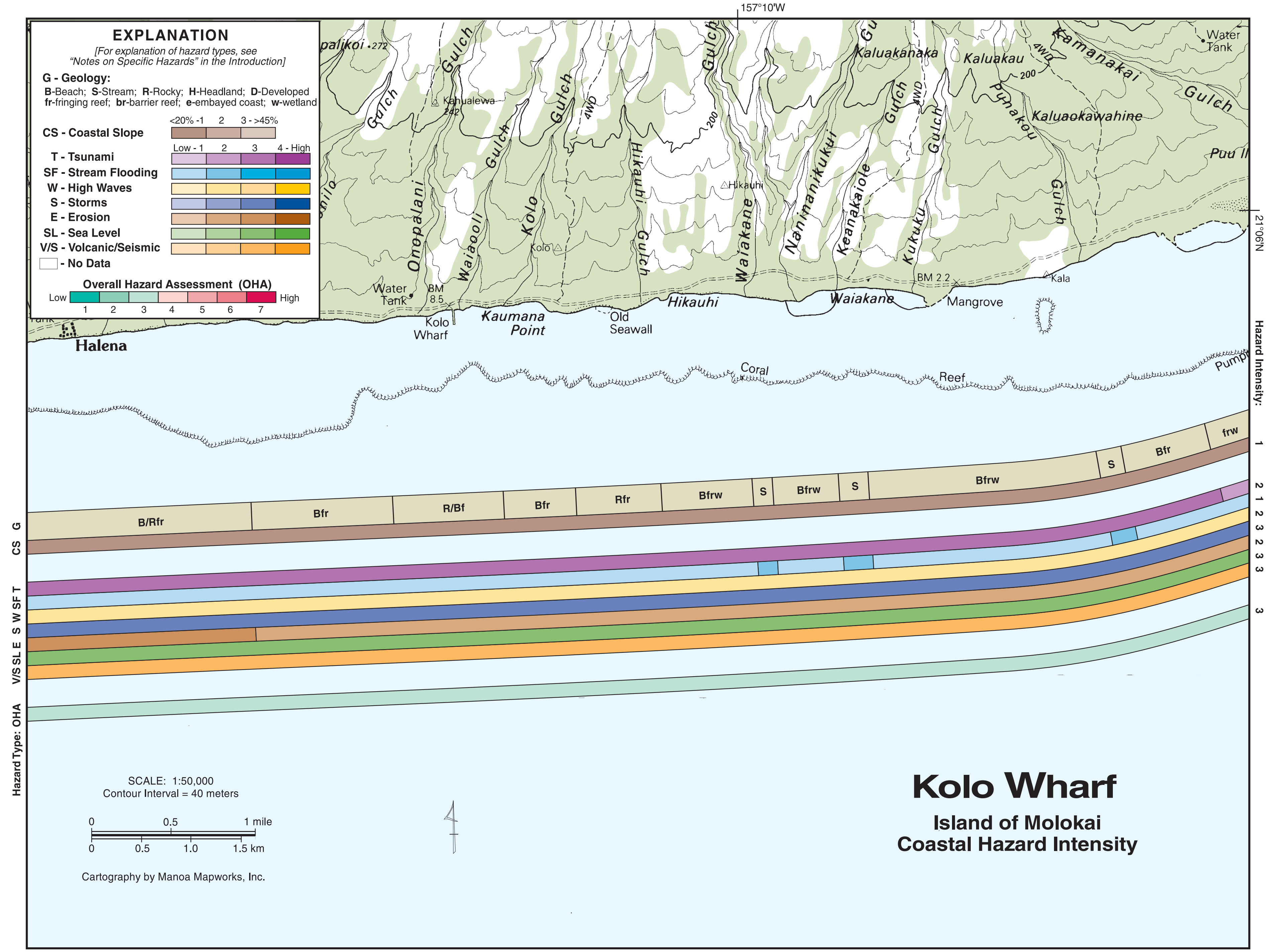
The Overall Hazard Assessment (OHA) for the Kauanakai Coast is moderate to low (3), except at Kaunakakai Harbor where greater tsunami and stream flooding hazards translate into an OHA of moderate (4). While the entire Kaunakakai coastal zone is low-lying, the tsunami hazard is greater at the harbor because the deep reef pass there allows greater wave energy to reach the shore. As a result, the tsunami hazard is moderately high at the harbor and moderately low to either side. Stream flooding generally decreases to the west. It is moderately low east of Kaunakakai and low to the west. In the immediate vicinity of Kauanakakai, where several streams reach the sea, the flooding hazard is moderately high. High waves are only a moderately low threat while storms are moderately high along most of the south shore of Molokai. Erosion is moderately low along this shore, while the sea-level hazard is moderately high due to the low slope of the coastal terrace. The volcanic/seismic hazard is also moderately high, as this region of Moloaki lies within the Molokai Seismic Zone.

The main port for Molokai is the Kaunakakai Harbor (foreground), which is situated within a dredged reef pass that extends across the entire reef flat of south Molokai. Mangroves continue to colonize much of the central south Molokai coast as excessive sediment resulting from erosion of the interior hillsides builds the shoreline out across the reef.

Kolo Wharf

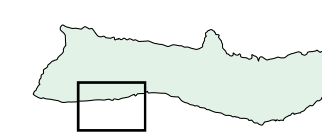
Along the relatively undeveloped Kolo Wharf coast, the offshore fringing reef narrows slightly to the west, siltation decreases, and mud flats give way to carbonate beaches. The widest beaches occur west of Kolo Wharf, an old dilapidated pier. Extensive outcrops of beachrock along the shore and sometimes stranded offshore, suggest recent erosion. Scarped dunes and fallen trees west of Hikauhi support this interpretation. Many of the beaches west of Kolo Wharf are perched upon beachrock. Only a few streams make it to the coast in this arid region of Molokai, which on average receives less than 10 in of rainfall annually. Numerous wetlands have formed behind the coastal dunes and mangroves, which help trap runoff and groundwater flow from the west Molokai mountains above.

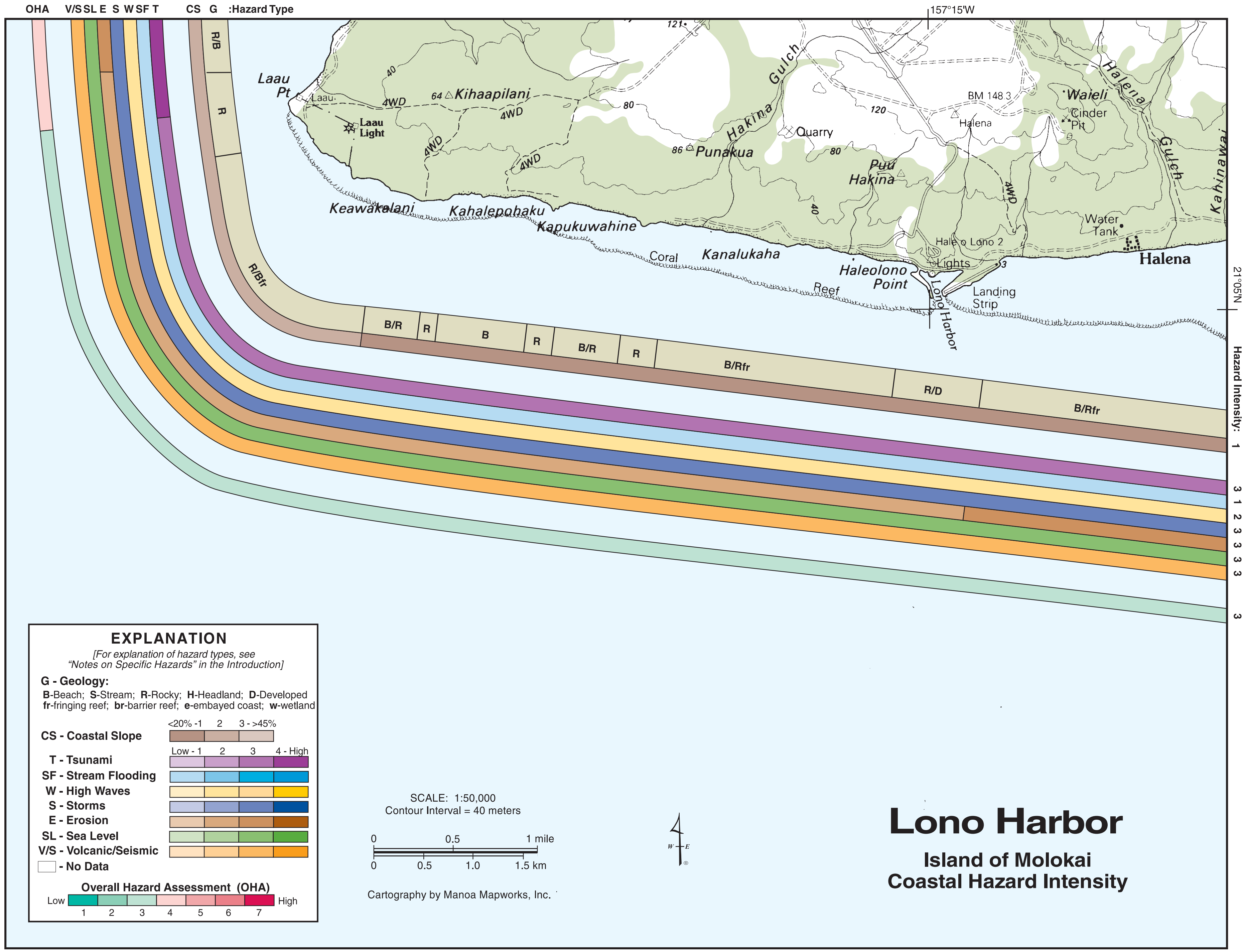
The Overall Hazard Assessment (OHA) for the Kolo Wharf region is moderately low (3). The tsunami hazard increases from moderately low in the east to moderately high in the west, away from the shelter provided by the islands of Lanai and Kahoolawe. Stream flooding is low along the Kolo Wharf Coast, except at the Punakou, Keanakaoile, and Waiakane Stream mouths where it is moderately low. High waves are ranked moderately low, while storms are moderately high, like most of the south coast of Molokai. Erosion is moderately low along the coast east of Kolo Wharf but moderately high to the west, where beachrock exposures and scarping of dunes suggest active retreat. The sea level and volcanic/seismic threat is moderately high, as it is along the entire Molokai coast due to its location within the Molokai Seismic Zone.



Base Credit: USGS 1:50,000 Western Molokai, Hawaii 5520 II W733 Edition 1-DMA

The formation of an alluvial fan at the shoreline near Waiakane (center) results from the erosion of the arid and sparsely vegetated west Molokai mountains (background) during episodic rainfall events. Although some of the sediment accummulates in the alluvial fan much of it also makes its way to the sea, settling on the reef and filling in abandoned fishponds (foreground).





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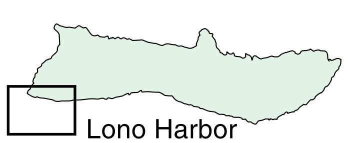


Lono Harbor

West of Halena, the Lono Harbor coast reaches to Laau Point, the southwestern-most corner of Molokai. Lono Harbor is famous for being the starting point of the annual inter-island Molokai to Oahu canoe race. Long carbonate sand beaches give way to pocket beaches between rocky volcanic headlands west of Haleolono Point. Many of the pocket beaches are perched above old and low-lying wave abrasion terraces formed in the volcanic rock west of Keawakalani and above beachrock between Lono Harbor and Keawakalani. East of Lono Harbor, exposures of beachrock at the shoreline and immediately offshore, along with scarped dunes and fallen trees near Halena, suggest recent erosion. Water clarity generally improves to the west, due to greater circulation and less siltation of the nearshore waters and inner reef flats. The fringing reef narrows toward the southwest corner of the island and aridity increases. The only development along this coast is Lono Harbor and the small village of Halena.

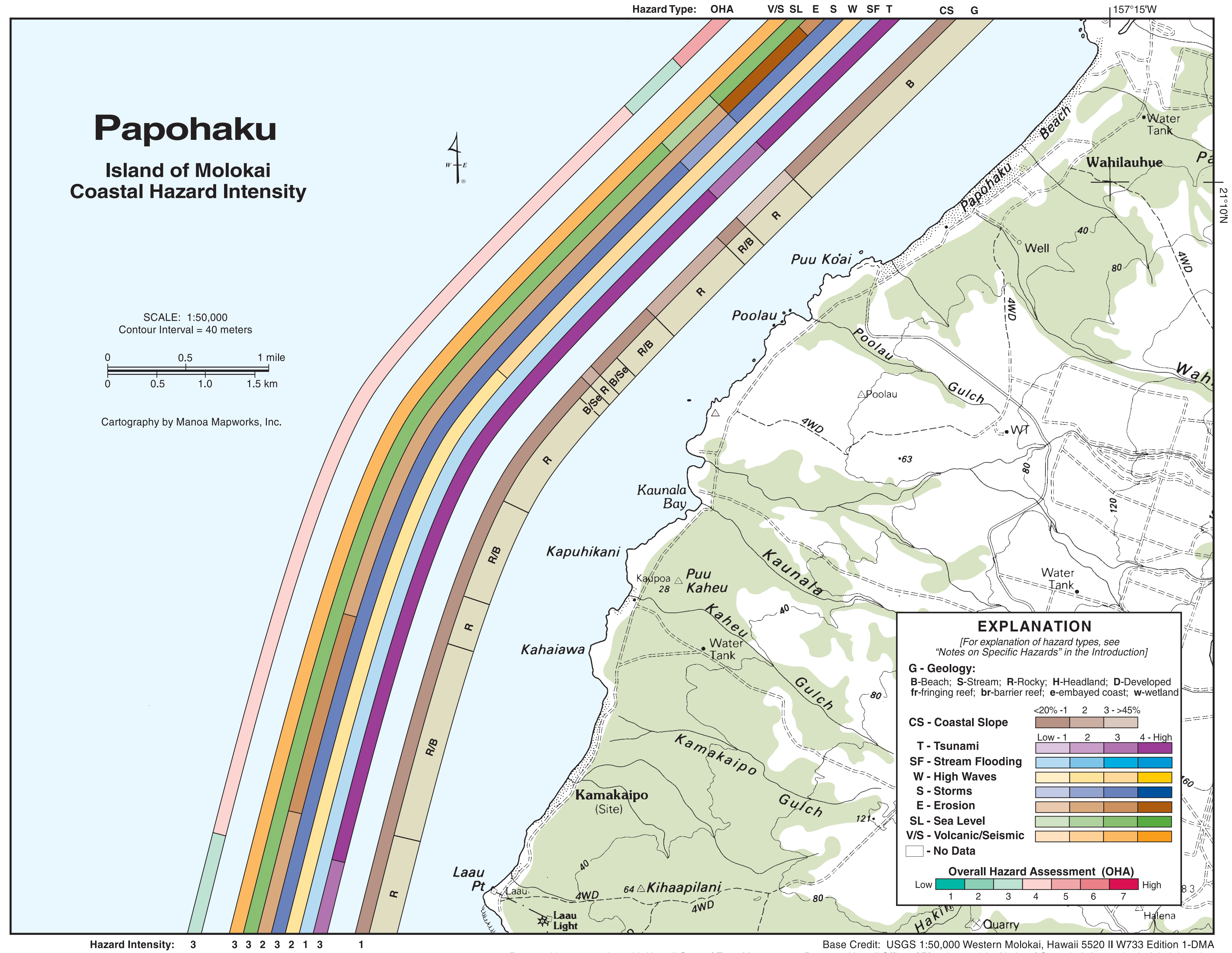
The Overall Hazard Assessment (OHA) for Lono Harbor region is moderately low (3) between Halena and Laau Point and moderate (4) northwest of Laau Point. This increase is due to the increased tsunami hazard along the lower-lying coast northwest of Laau Point where the tsunami hazard is ranked high; it is only moderately high along the steeper coast to the east. Because of very low rainfall and few streams, stream flooding is ranked low. The high wave hazard is moderately low here where most wave energy reaching the shore is from south swell or refracting northwest swell. Because tropical storms most often track to the west of the islands, the storm threat along the west-facing Lono Harbor coast is moderately high. Because of the low coastal slope and proximity to the Molokai Seismic Zone, the sea-level and the volcanic/seismic hazards, respectively, are moderately high along this coast. Erosion is moderately high at Halena, where dunes are scarped and offshore beachrock ridges marking the past position of the shoreline are exposed. Erosion is moderately low to the west of Lono Harbor where beaches are perched above fossil wave abrasion terraces.

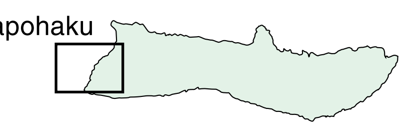
A view of Lono Harbor at Haleolono Point, developed along a narrow coastal terrace at the base of the west Molokai mountains.

Papohaku

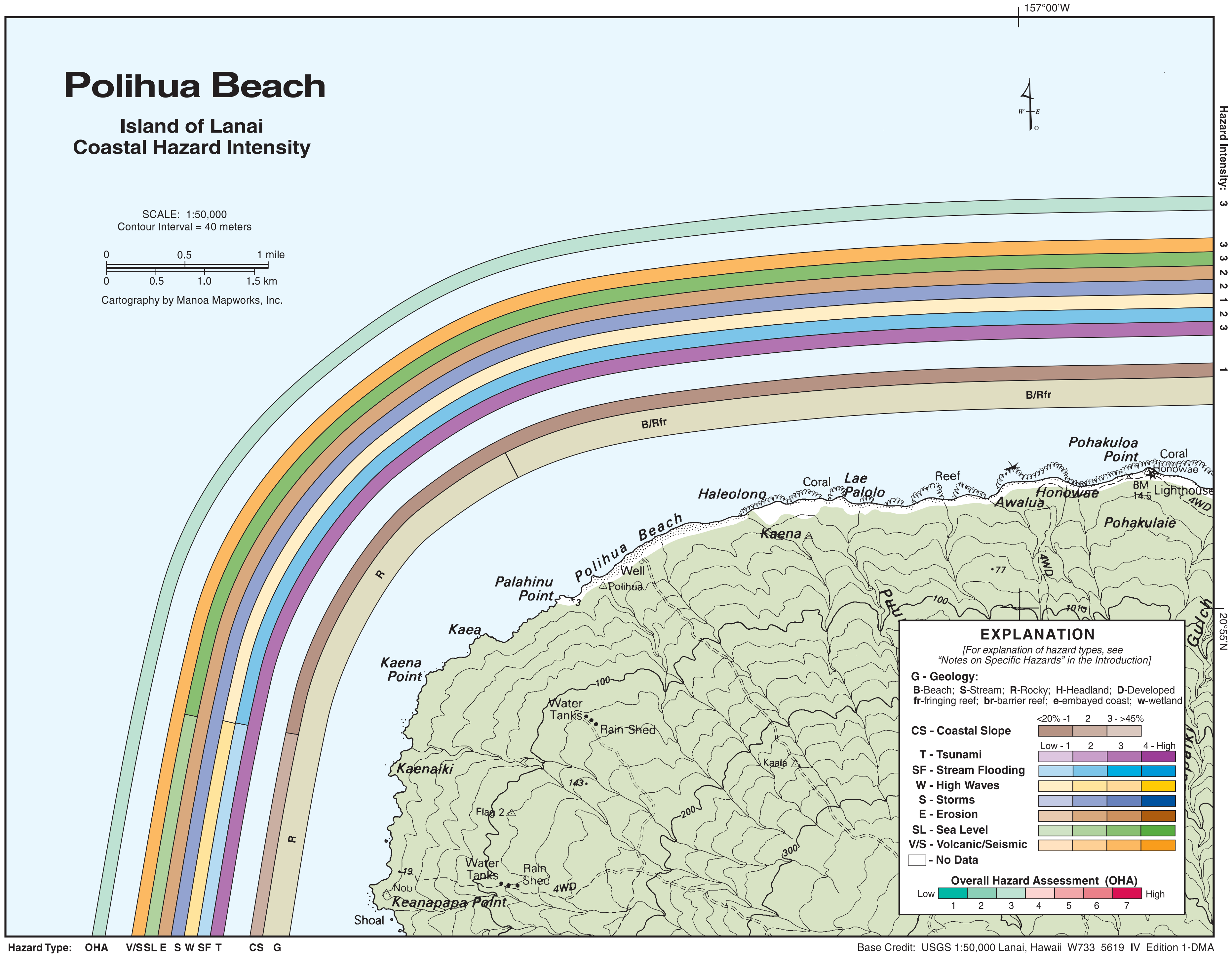
Rocky, low-lying wave abrasion terraces and headlands interspersed with pocket beaches characterize the Papohaku coast between Laau Point and Puu Koai. Northeast of Puu Koai lies Papohaku Beach, one of Hawaii's most beautiful white sandy beaches. A rocky boulder and sand beach exists at Kamakaipo, and small carbonate beaches occur inside the three small, isolated embayments at Kaunala Bay and Poolau. These are also areas where small streams, although often dry, reach the sea. Development along the rocky portion of this coast is minimal and access is by four-wheel drive or footpaths. It is interesting that reefs are not well established along this portion of the west Molokai shore, yet there appears to be abundant carbonate material available for beaches as evidenced by Papohaku Beach. Despite an abundant source of carbonate sands, Papohaku Beach has suffered extensive human-induced erosion, as significant volumes of sand were removed in the early 1900s to nourish beaches on Oahu. It is now of interest to researchers to see if Papohaku can recover in the face of natural erosion associated with global sea-level rise.

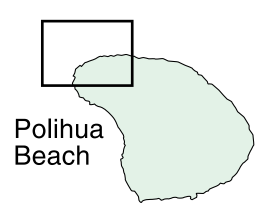
The Overall Hazard Assessment (OHA) between Laau Point and Papohaku Beach is moderate (4) except for the Puu Koai headland which is relatively steep and where the OHA is moderately low (3), and Papohaku Beach where it is moderately high (5). Tsunami is high along the low-lying rocky terraces and moderately low at Puu Koai. Stream flooding is low along the entire coast, where few streams and low rainfall occur. High waves are moderately low from Laau Point to Kaunala Bay and moderately high to the north and east, where greater wave energy from northwest swell reaches the shoreline. The storm hazard is moderately high along this coast except at Puu Koai where it is only moderately low. Erosion varies between moderately high between Laau Point and Kahaiawa, low north to Puu Koai, and high along Papohaku Beach, which has undergone significant beach loss this century. Sea-level rise is a moderately high threat along the low coastal terraces and only low at the headland of Puu Koai. The volcanic/seismic hazard is moderately high between Laau Point and Papohaku Beach, in accordance with its location within the Molokai Seismic Zone.





A view of the broad, extensive carbonate beach at Papohaku (foreground) and Ilio Point (background) on Molokai's west shore.





Polihua Beach

The gently sloping rocky points between Keanapapa and Palahinu Points give way to the longest white sand beach on Lanai at Palihua Beach. It is a narrow strand beach along Lanai's north shore with patchy corals offshore that become more extensive to the east. The nearshore deepens rapidly. Although the coast faces north, it is protected from large northwest, north, and northeast swell by the islands of Molokai and Maui. This coast receives significant wind energy that can set up strong currents immediately offshore. The winds and currents have taken their toll on boats here in the past, as evidenced by several shipwrecks found along Polihua and Pohakuloa Point to the east. The Polihua Beach coast on average receives less than 10 in of rainfall. Streams do experience flash flooding at times and can carry vast amounts of terrigenous sediment to the shoreline. This remote region of Lanai is undeveloped and access is by four-wheel drive, footpath, or boat.

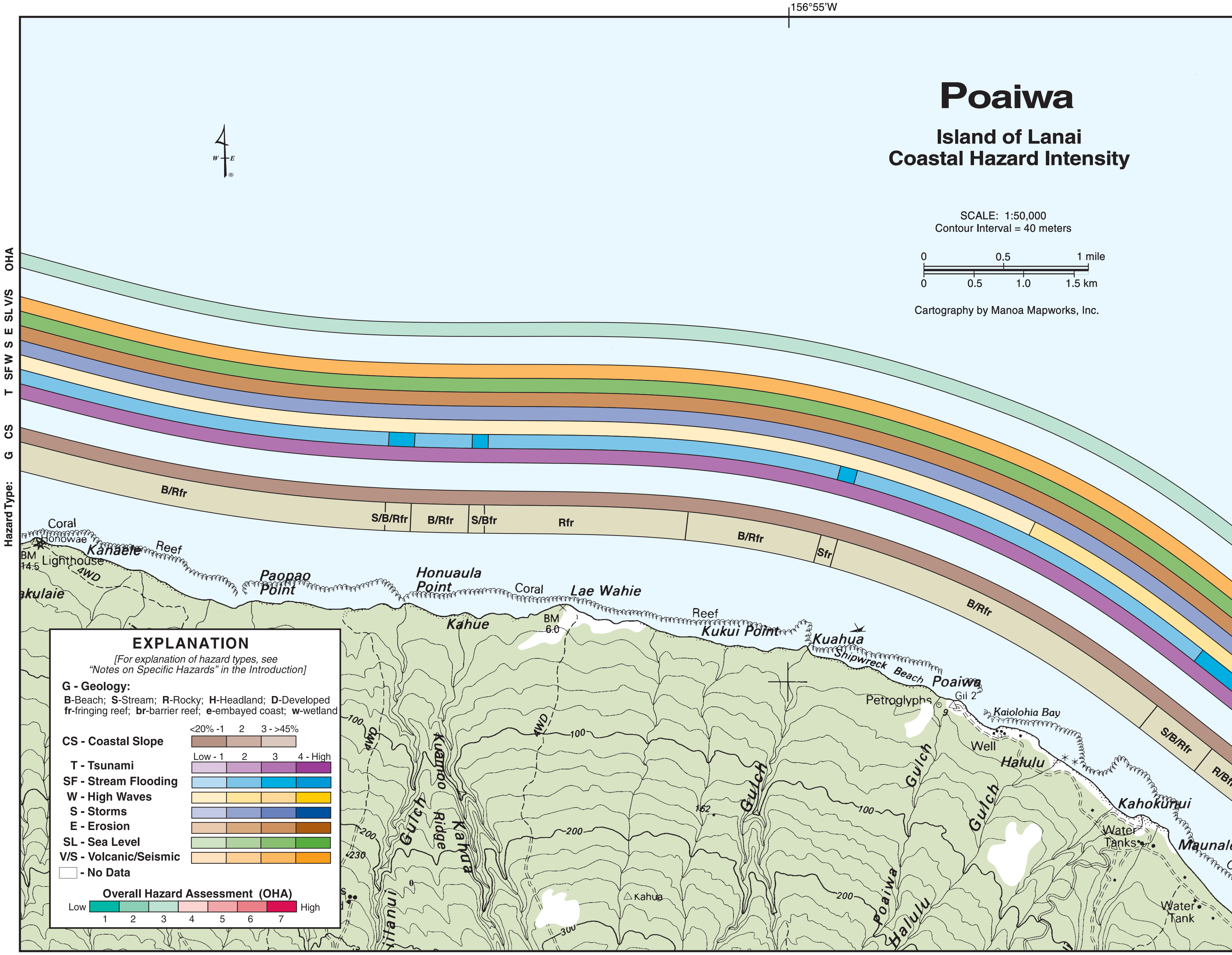
The Overall Hazard Assessment (OHA) for the Polihua Beach coast is moderate to low (3). The tsunami hazard is uniformly moderately high along Polihua Beach. Stream flooding is low southwest of Kaenaiki, where streams reach the sea along moderately steep sea cliffs, but is increased to moderately low to the east along Polihua Beach and on to Pohakuloa Point where streams enter the sea along a low coastal terrace. The high wave hazard is moderately low southwest of Kaenaiki, and low to the east, where wave energy is reduced by the islands of Molokai and Maui to the northwest and northeast. Storms and erosion are moderately low. The sea-level-rise hazard is moderately low along the steeper rocky coast southwest of Kaenaiki and moderately high along the low-lying beach of Polihua. The volcanic/seismic threat is moderately high here as it is along the entire Lanai coastline, because of its position within the Molokai Seismic Zone.

A view of the remote west end of Polihua Beach (looking south) that reaches to the low volcanic bluffs of northwest Lanai.

Poaiwa

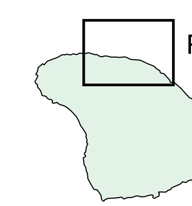
Between Kanaele and Poaiwa, the coast is a low-lying coastal terrace with a long, narrow sand and gravel beach west of Lae Wahie and numerous pocket beaches to the east. Small rocky headlands occur at Kukui Point and Halulu. Several small streams drain the arid mountains to the south. Rocky cobble and boulder deltas often occur at their mouths, reflecting periodic high stream discharge. A narrow fringing reef fronts the entire length of this coastal segment and water clarity generally improves immediately offshore of the sediment-loaded nearshore waters. Trade winds blow persistently along this coast and small dunes that are often vegetated have formed behind the beach. These dunes provide a large sand resource for natural beach nourishment during shoreline migration. This remote area of Lanai is mostly used for recreational purposes. One of the attractions along this coast is the large shipwreck at Kuahua, otherwise known as Big Shipwreck Beach.

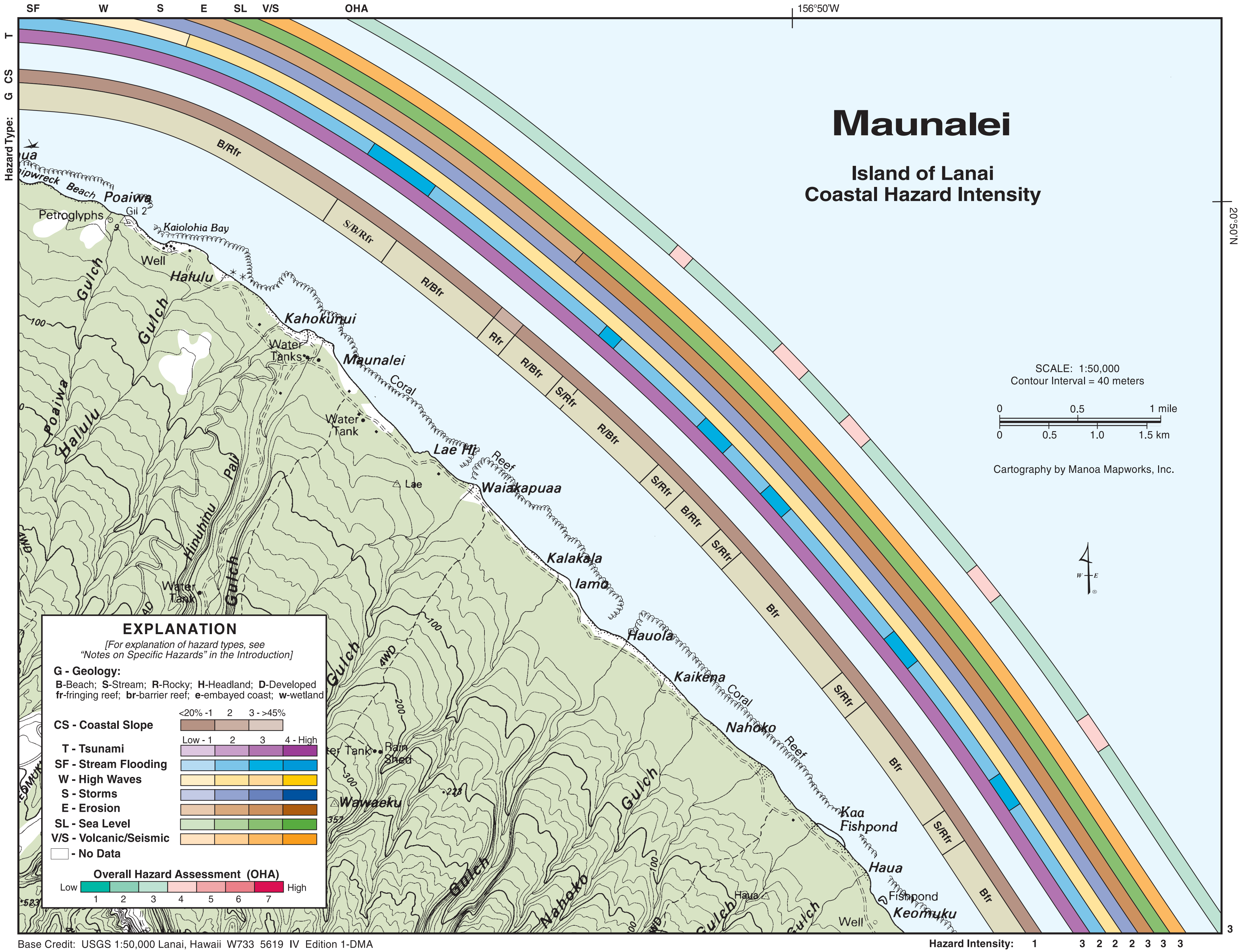
The Overall Hazard Assessment (OHA) for the Poaiwa Coast is moderate to low (3), reflecting the relatively low stream flooding, wave, and storm hazards. The tsunami hazard is moderately high along this low-lying coast. Stream flooding is moderately low except at the three stream mouths. The high waves threat is low between Kanaele and Poaiwa and moderately low to the east, where south swell refracts and reaches the shore. Storms are ranked moderately low along this shoreline which is sheltered from storms approaching from the east by Molokai and Maui. The erosion hazard is moderately low, due to the generally rocky nature of the shoreline. The sea-level rise hazard is moderately high due to the low coastal slope, while the volcanic/seismic threat is moderately high as it is along the entire Lanai coastline, which lies within the Molokai Seismic Zone.

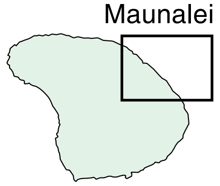


Base Credit: USGS 1:50,000 Lanai, Hawaii 1-DMA W733 5619 IV

One of several shipwrecks along the north coast of Lanai is found at Kuahua (foreground) just offshore of the shallow fringing reef and Shipwreck Beach.







Maunalei

Strong trade winds shape the shoreline and its vegetation along the Maunalei coast which extends from Poaiwa to Haua. Along this segment of coast the beach is narrow with occasional rocky outcroppings, usually found at stream mouths, but also as small protrusions where the descending mountain ridges meet the sea. The beaches narrow toward the southeast, whereas the fringing reef widens. Erosional scarps in the beachface are prominent southeast of Lae Hi, indicating recent retreat of the shoreline. Several ancient fishponds that lie offshore, are now infilled with sediment. This coast is undeveloped and popular for recreation. It is accessed by a paved road that descends from central Lanai to the coast at Mauanalei. The road continues unpaved along the narrow coastal terrace to the southeast.

The Overall Hazard Assessment (OHA) for the Maunalei Coast is moderate to low (3) along the narrow beaches and moderate (4) at the stream mouths southeast of Lae Hi. The tsunami hazard is moderately high along this low-lying coast, and stream flooding is relatively low, except at the stream mouths where it is moderately high. The hazard due to high waves increases from low to moderately low toward the southeast of Poaiwa because south swell can refract around eastern Lanai and reach the Maunalei shore. Storms are ranked moderately low throughout the entire area, because of the sheltering effect the islands of Molokai and Maui provide when tropical storms pass by, usually from the east to the west. The erosion hazard is moderately low west of Lae Hi, and moderately high to the east, where scarping is clearly evident along the already narrow beaches. The sea-level and volcanic/seismic threats are moderately high along the Maunalei coast which is low sloping and within the Molokai Seismic Zone.

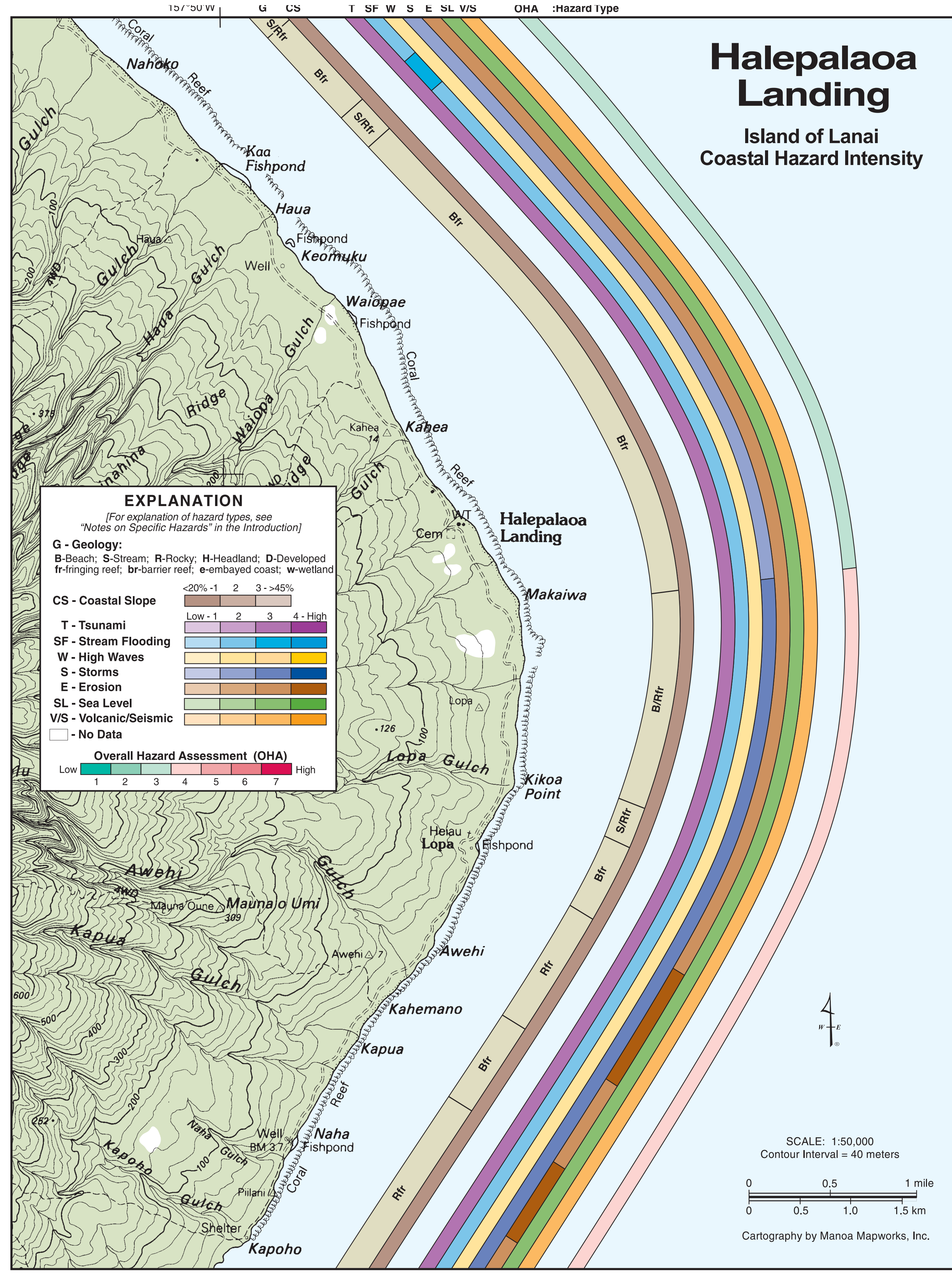
Erosion of the large stream valley inland of Maunalei (background) has led to the development of an alluvial fan at the shoreline.

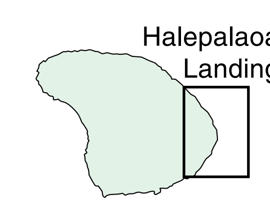
Halepalaoa Landing

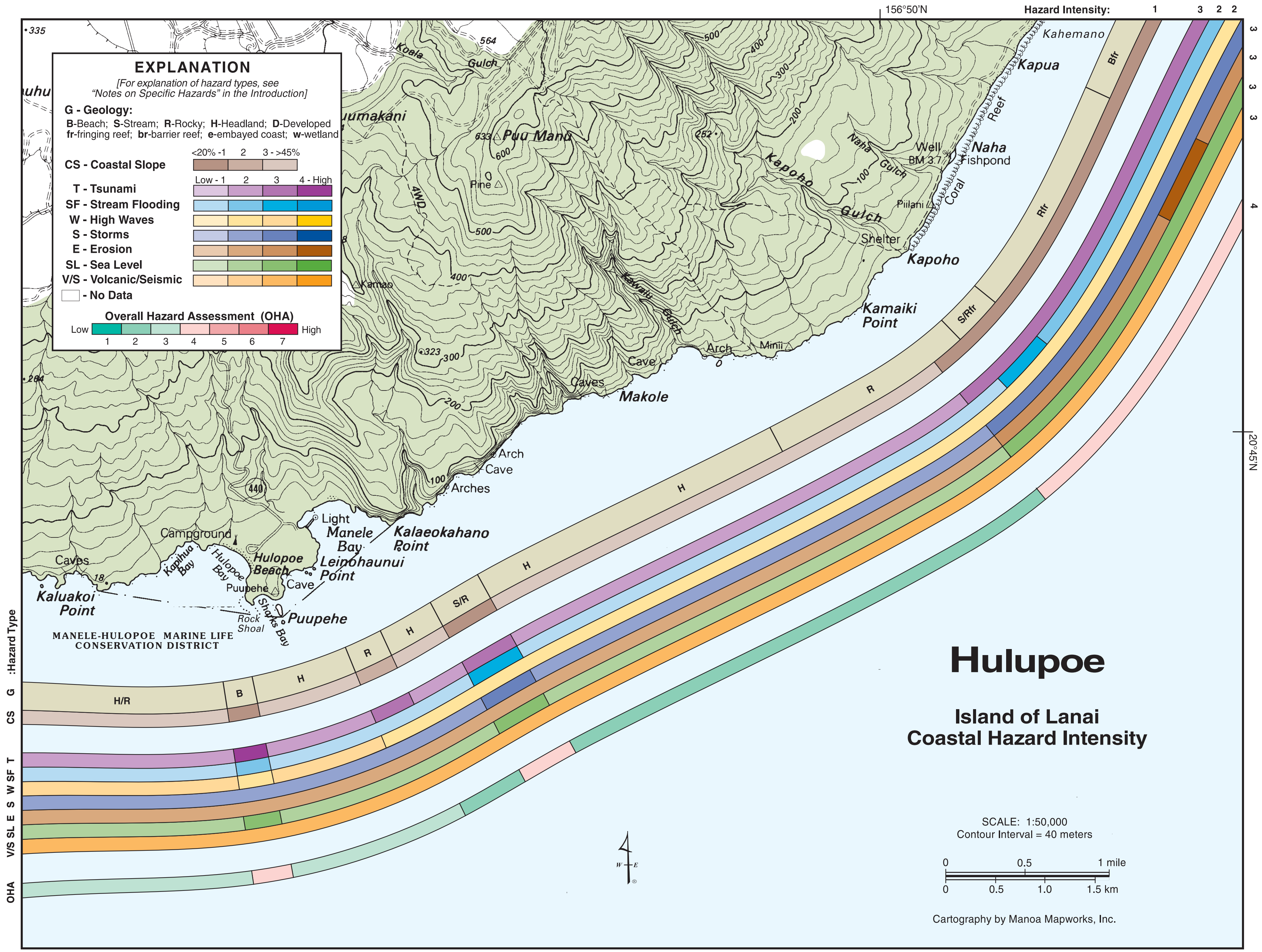
Between Haua and Naha, the Halepalaoa Landing coast wraps around the easternmost portion of Lanai along a long narrow beach at Kikoa Point. The coast slopes very gently and most of the shoreline is a low-lying coastal terrace with vegetated dunes and small forests in the backshore. The long continuous beach of Halepalaoa changes to a rocky coast near Awehi, where overhanging vegetation indicates rapid coastal retreat in the recent past. A short and narrow beach extends from Kahemano to Kapua but ends abruptly just south of Kapua. The waters are often turbid at the shore but can be very clear out at the fringing reef crest. The fringing reef becomes narrower south of Kikoa Point, a sign that wave energy increases to the southeast. Most of the beaches have small rocky outcrops where streams reach the coast.

The Overall Hazard Assessment (OHA) for the Halepalaoa Landing coast is moderate to low (3) northwest of Makaiwa and moderate (4) to the south. This increase is primarily due to the higher storm intensity along the southern portion of this coast, because of its greater exposure to storms that usually pass to the south. For this reason, the storm hazard is ranked moderately low northwest of Makaiwa and moderately high to the south. Tsunami is moderately high throughout the area and stream flooding is moderately low, except at the Haua Stream mouth where it is moderately high. High waves are ranked moderately low because of the sheltering effect of Molokai and Maui to the northwest and north. Erosion is moderately high along most of this narrow shoreline, except at the rapidly eroding areas of Awehi and Naha, where it is high. The threat of sea-level rise is moderately high because of the low elevation and slope of the coastal terrace. The volcanic/seismic hazard is moderately high here and along the entire Lanai coast because of its location within the Molokai Seismic Zone.

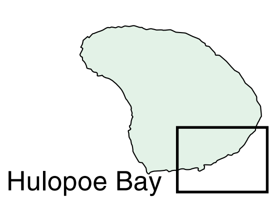
Gentle and sparsely vegetated hillslopes meet the east coast of Lanai at Halepaloa Landing (center) where the coastal plain and offshore fringing reef are narrow.







Base Credit: USGS 1:50,000 Lanai, Hawaii W733 5619 IV Edition 1-DMA



A view of Hulopoe Bay (background) and the rocky headland surrounding Shark's Bay (foreground).

Hulopoe Bay

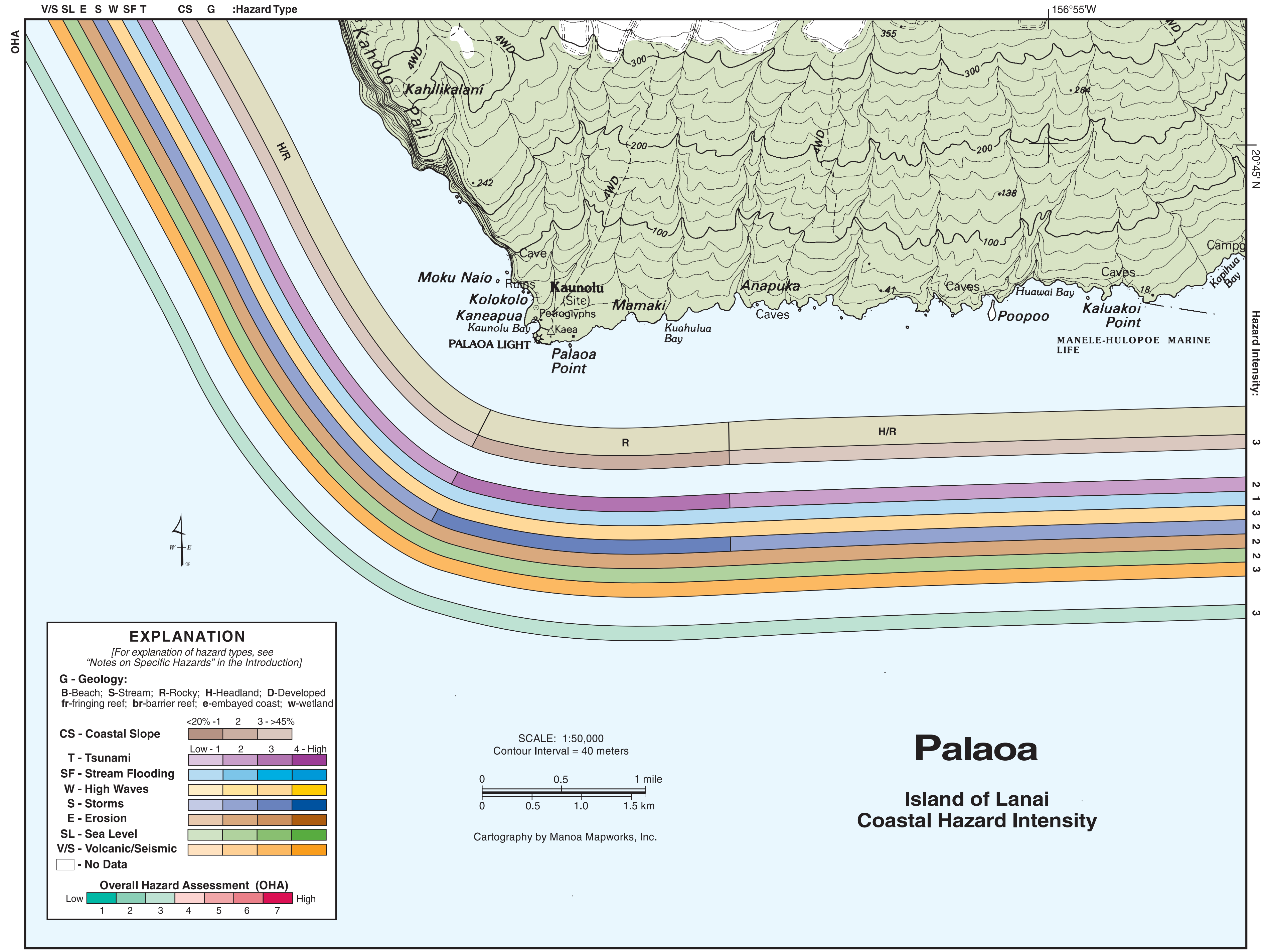
The low-lying and narrow coastal terrace of Naha and Kapoho abruptly gives way to steep sea cliffs at Kamaiki Point. Between Kamaiki and Kaluakoi Points, the Hulopoe Bay coast is extraordinary and scenic, with arches and caves awash with waves, and tall, sheer rocky cliff faces that are often lined with perching birds. The coastline here is arid, like most of Lanai's coast, receiving on average less than 10 in of rainfall annually. Even so, many gulches cut through the relatively young rocky slopes. Several streams that have not yet eroded valleys to the shoreline can be found hanging above the steep headland sea cliffs. The fringing reef of Lanai's north and east coast ends near Kapoho and only small patch reefs are found strewn amidst many small rock remnants or sea stacks along the southeast corner of the island. Several small embayments occur along this coast, including Manele and Hulopoe Bays. Manele Bay is the primary harbor on Lanai and Hulopoe Bay is famous for being frequented by spinner dolphins that can often be seen showing off their agility and grace as they flip and twist above the water.

The Overall Hazard Assessment (OHA) for the Hulopoe Bay coast varies between low (2) along the steep sea cliffs of Makole to moderate (4) at the low-lying coastal terrace of Naha and inside Manele and Hulopoe Bays. The OHA is moderate to low (3) along the coastal cliffs of Puupehe and Kaluakoi Point where the high wave hazard is increased due to a more direct exposure to south swell. The tsunami hazard is moderately high northeast of Kamaiki Point and moderately low to the southwest, except at the stream mouth of Kalaeokahano Point and Manele Bay, where it is moderately high, and inside Hulopoe Bay, where it is high. Stream flooding is moderately low northeast of Kapoho and low to the west, except at the stream mouths at Kapoho and Kalaeokahano Point where it is moderately high. Inside Hulopoe Bay it is moderately low. The high wave threat is moderately low northeast of Leinohaunui Point and moderately high to the west, except for Hulopoe Bay where wave diffraction reduces this threat to moderately low. Storms are ranked moderately high northeast of Kamaiki Point and moderately low to the southwest, except at Kalaeokahano Point where it is moderately high. Erosion is moderately high northeast of Kamaiki Point, except at Kapua where it is high. Southwest of Kamaiki Point, erosion is moderately low. Sea-level rise is moderately high along the low coastline northeast of Kamaiki and moderately low along the steep sea cliffs to the southwest. At the stream mouth of Kaleaokahano Point and the beach of Hulopoe Bay, the sea-level threat is moderately high. The volcanic/seismic hazard is moderately high along the entire Hulopoe Bay coast because of its location within the Molokai Seismic Zone.

Palaoa Point

The coast gradually steepens toward the west from Kaluakoi Point to Palaoa Point, Lanai's southwest corner. Beyond Palaoa Point to the northwest, dramatic sea cliffs ranging from 500 to 1000 ft high descend straight down into the sea. Beautiful exposures of dike intrusions and individual volcanic flow units can be seen amidst the steep Kaholo Pali walls. Rock slumps along the steep headlands suggest slope failures are common. Numerous rock islets and sea caves line the rocky south coast, which has only a few very small boulder beaches at stream mouths. The steep, cliffed coast to the northwest of Palaoa Point has no beaches and instead has a narrow wave abrasion terrace with only occasional slump deposits, perhaps a sign that wave overwash removes fallen debris. Offshore, the water depth increases rapidly but patchy corals colonize the submerged rocky points and ridge protrusions. Several stream channels cut through this arid portion of Lanai and generally flow only after significant rainfall.

The Overall Hazard Assessment (OHA) for the Palaoa Point coast is moderate to low (3). Tsunami is moderately low, except for the lower coastal terrace between Kuahulua Bay and Kaneapua where it is moderately high. Stream flooding is low along this arid coast. High waves are ranked moderately high where northwest swell refracts to the shoreline. Storms are moderately low along the steep rocky shore and moderately high along the lower coastal terrace between Kuahulua Bay and Kaneapua. Erosion and the sea-level hazard are moderately low along this relatively steep, rocky coast around Palaoa Point. The volcanic/seismic hazard is moderately high as it is along the entire Lanai coast, due to its proximity to the Molokai Seismic Zone.



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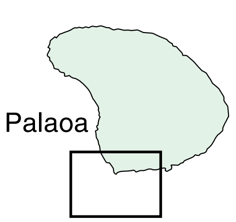
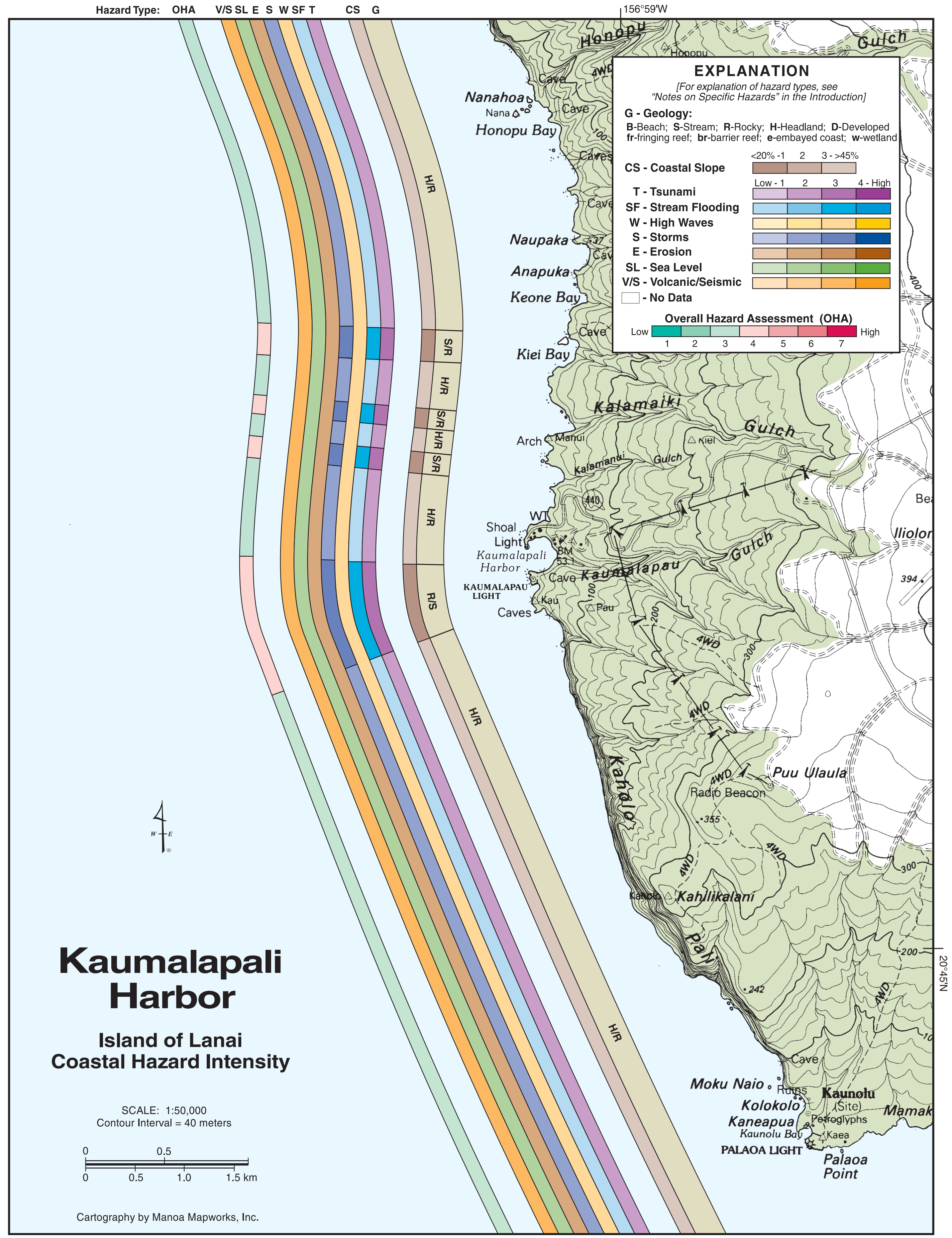
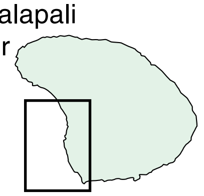


West of the lighthouse at Palaoa Point (lower left) the southwest coast of Lanai is lined by the steep and high Kaholo Pali (cliffs) and small rocky islets offshore, like Moku Naio.





Kaumalapali Harbor

The west Lanai shoreline around Kaumalapali Harbor is a rocky headland coast with steep sea cliffs along Kaholo Pali to the south of Kaumalapau Lighthouse and numerous rocky embayments north to Nanahoa. The near vertical walls of Kaholo Pali reach in places 100 ft above the sea and show signs of slumping with talus cones and rock-fall debris at their base. The embayments of Kiei, Kalamaiki, Kalamanui, and Kaumalapali Bays are low-lying, while the rocky points and steep cliffs 30 to 50 ft high surround them. Like most of Lanai, this coast is very arid and the primary streams empty into the bays listed above. Numerous small rocky islets occur along this coast and are probably a result of cliff collapse or landward erosion of the headlands. Although a paved road reaches Kaumalapali Harbor, Lanai's primary shipping port, access to the surrounding coast is limited to four-wheel drive roads along a few of the ridge crests to the north, Palaoa Point in the south, and the top of the Kaholo Pali.

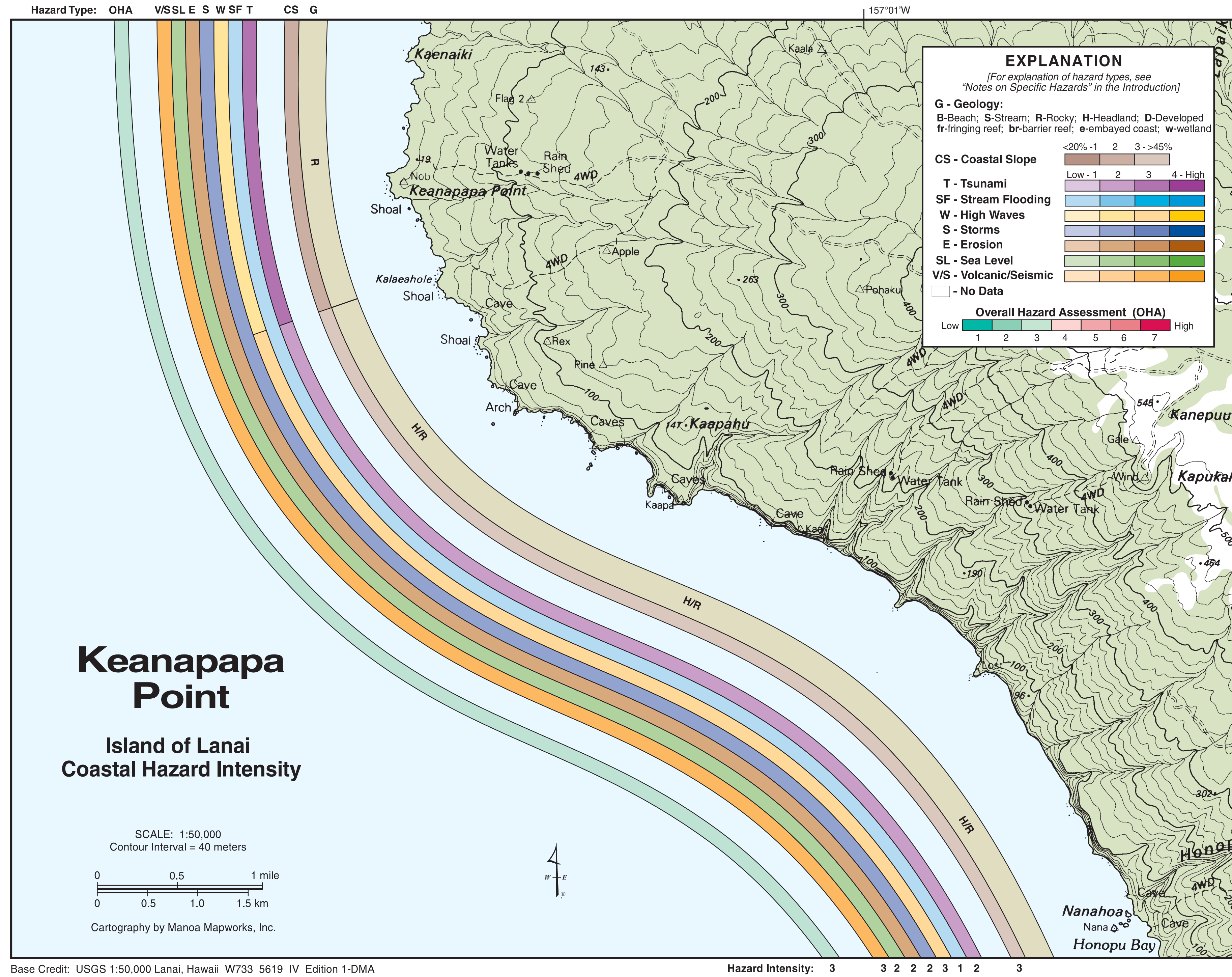
The Overall Hazard Assessment (OHA) for the Kaumalapali Harbor coast is moderate to low (3), except at the low-lying embayments of Kiei, Kalamaiki, Kalamanui, and Kaumalapali where it is moderate (4) because of the higher flooding and inundation hazards there. Tsunami is moderately low along the steep sea cliffs and rocky headlands and moderately high in the low bays. Stream flooding is low along the headland shoreline and moderately high at the stream mouths inside the embayments. The hazard from high waves is moderately high along the entire coast, which is subject to northwest swell in the winter and southwest swell in the summer. The storm threat is moderately low along the steeper rocky headlands and moderately high in the low-lying embayments. Erosion and sea-level rise are moderately low due to the rocky shoreline and steep slope. The volcanic/seismic hazard is moderately high along the entire coast around Kaumalapali Harbor, in accordance with its position within the Molokai Seismic Zone.

The Kaumalapali harbor is bordered by rugged and steep rocky cliffs to the north and south.

Keanapapa Point

Between Nanahoa and Kaenaiki, the Keanapapa Point coast is rocky with steep sea cliffs ranging 50 to 100 ft high in the south, and rocky points surrounding irregular embayments in the north. Between Kalaeahole and Kaenaiki, the coast is lower and more gently sloping than to the south. Below the steep sea cliffs between Nanahoa and Kaapa a boulder beach is perched upon a narrow wave abrasion platform cut into the volcanic headlands. Several streams cut through the steep cliffs in the south, but most are left hanging above sea level as waterfalls. To the north, the streams have incised their way to the shoreline, but the climate is relatively arid and stream flow is not common. Several caves and natural arches have formed in the rocky headwalls and protruding points. Only small patch corals have colonized the rocky bottom offshore.

The Overall Hazard Assessment (OHA) for the Keanapapa Point coast is moderate to low (3). Along the steep sea cliff coast in the south, tsunami is moderately low, while along the lower-lying coast in the north it is moderately high. Stream flooding is low throughout the entire map area due to the significant aridity. High waves are moderately high between Nanahoa and Kalaeahole and moderately low to the north because of the sheltering effect on northwest swell provided by west Molokai. Storms, erosion, and sea level are moderately low hazards along this rocky and relatively steep coast. The volcanic/seismic hazard here is moderately high as it is along all of Lanai's shoreline which lies within the Molokai Seismic Zone.



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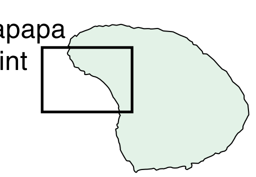
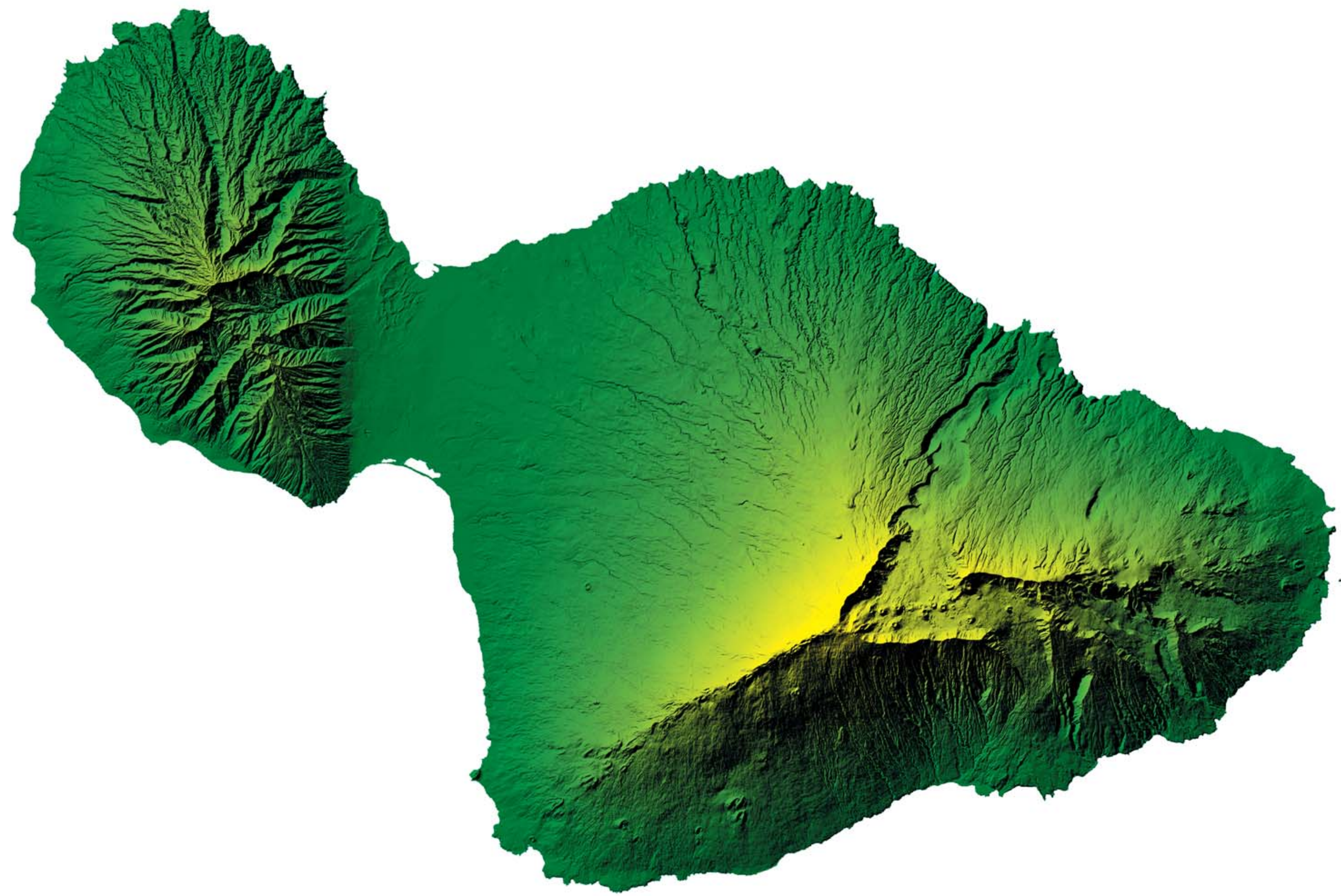
A view of the steep, rocky cliffs that line the west coast of Lanai between Kaapa and Nanahoa.



Maui

The valley island of Maui is named for its magnificent V-shaped valleys, carved by streams into the mountains of west Maui and Haleakala volcano in the east. Maui is the second youngest of the main Hawaiian Islands, indicating that stream erosion has been intense over its relatively short life. Other important geologic processes on Maui are volcanism and seismicity. As recently as the late 1700's, Haleakala volcano erupted, sending lava flowing down its southwest flank. Earthquakes are common on Maui due to its proximity to the Molokai Seismic Zone and the Big Island where active volcanism at Kilauea volcano is a source of significant seismicity. Maui is also famous among surfers and windsurfers for its high winter waves and consistently favorable trade winds. These geologic processes that contribute to Maui's spectacular coastline also represent dynamic natural hazards.



Maui

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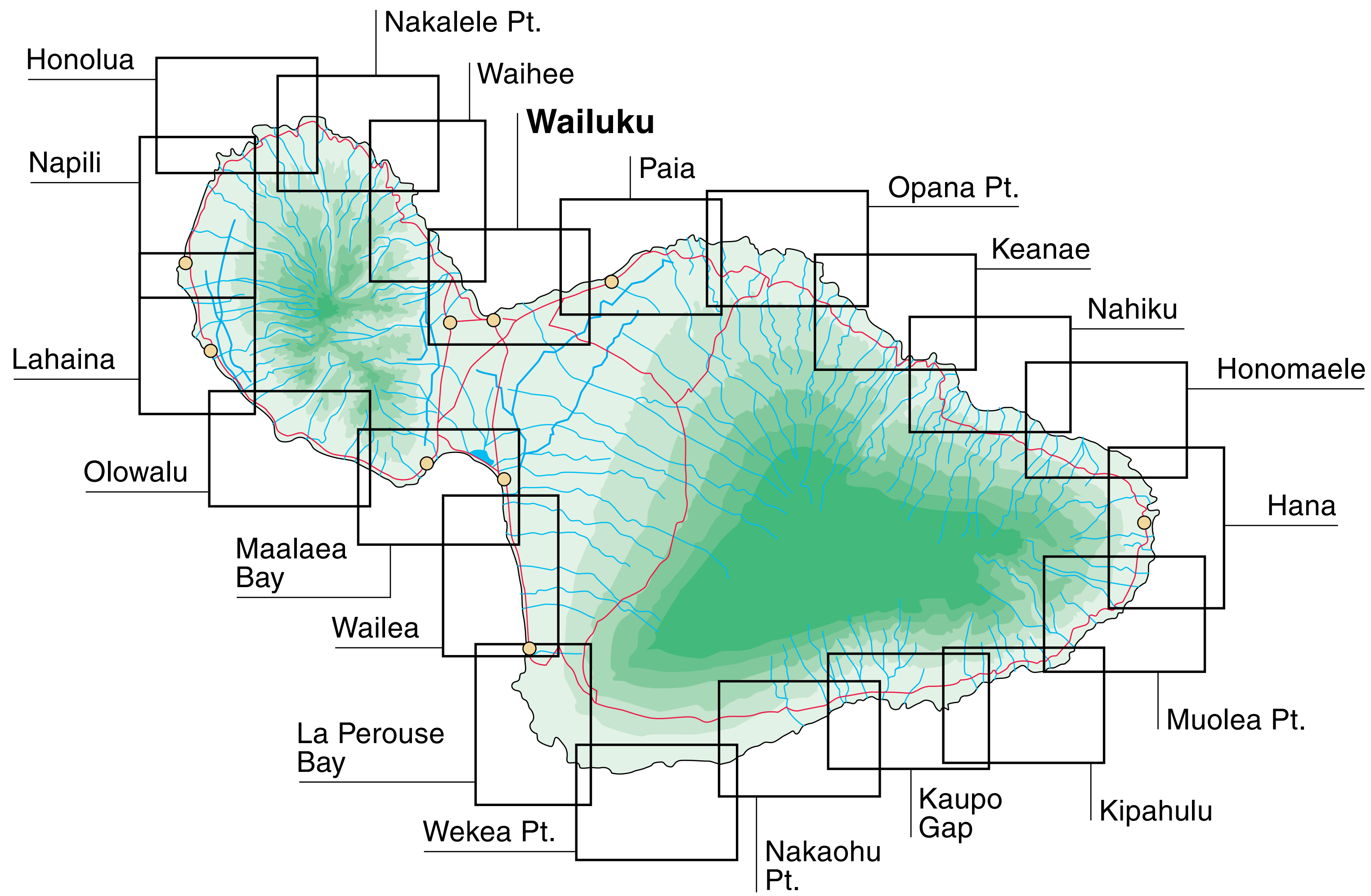


Tsunamis

A tsunami is a series of great waves most commonly caused by violent movement of the sea floor. It is characterized by speed (up to 590 mph), long wave length (up to 120 mi), long period between successive crests (varying from 5 min to a few hours, generally 10 to 60 min), and low height in the open ocean. However, on the coast, a tsunami can flood inland 100's of feet or more and cause much damage and loss of life. Faulting, landslides, and volcanic activity that cause displacements of the seafloor are common around the Pacific rim and occasionally trigger damaging tsunami waves. Depending on the magnitude of the seafloor displacement, the distance the tsunami wave propagates, and the configuration of the coastline, tsunami behavior at the shoreline can be radically different from site to site. Tsunamis reaching Hawaii originate from distant regions in the Pacific Ocean and from within Hawaii, namely the Big Island, where volcanism and tectonic activity is common. However, the direction to the source region does not always dictate which side of an island is most affected by tsunami waves. Tsunami waves are not simply large waves. Unlike wind-generated waves that have wavelengths up to several hundred feet long, tsunami waves may have very long wavelengths, sometimes with miles between crests. This means that it can take 10's of minutes for a tsunami wave crest to pass. As a result, tsunamis have considerable energy to run up and flood the coast and the ability to inundate much farther inland than ordinary wind-generated waves.

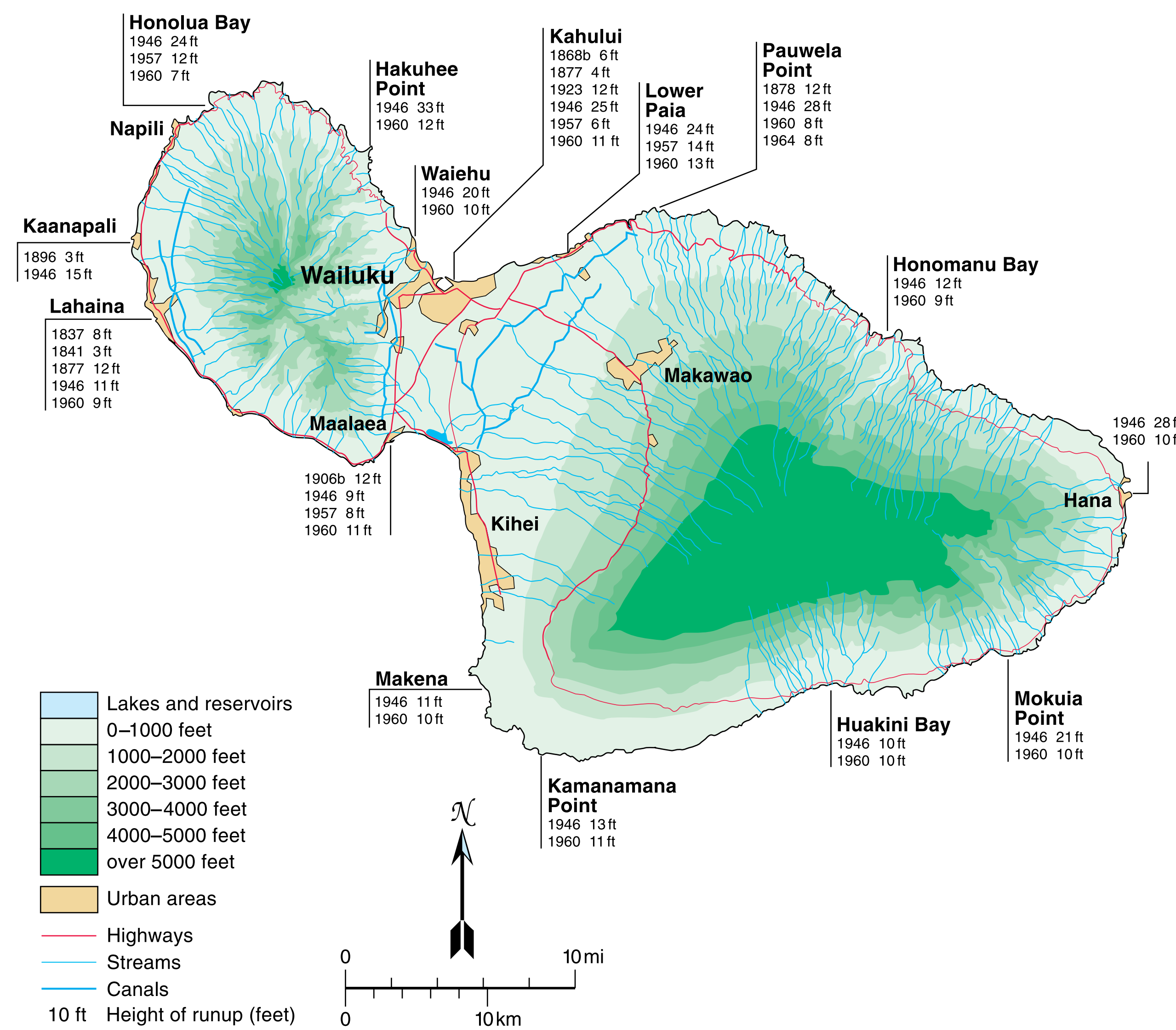
Tsunamis reaching Maui have exhibited tremendous variability in terms of their runup heights, inundation distances, and the damage they have inflicted. During the 1946 tsunami, for example, runup heights within only a few miles along the south shore varied by over 10 ft between Huakini Bay and Mokuia Point. There is no clear relationship that exists to predict what side of an island will experience the greatest runup or what location will suffer the greatest damage. However, a general rule is that the greatest runup occurs at headlands, largely because the steeper offshore bathymetry enables greater wave energy to reach the shoreline. Low-lying coastal regions are more susceptible to greater inundation, and because tsunamis have long wavelengths, the water level can rise for 10's of minutes at a time and the wave can push far inland as the tsunami passes.

Over 100 tunamis have been observed in the Hawaiian Islands since the first recorded tsunami in 1812. Twenty six have been recorded since 1819 with wave runups greater than 3.3 ft (1 m) and reported damage. These numbers signify that a damaging tsunami has reached Hawaiian shores once every 7 yr. The last damaging tsunami recorded in Hawaii, however, was in 1975. In light of these data, one could make the case that Maui and the main Hawaiian Islands are long overdue for a damaging tsunami.

Maui

Tsunamis

(after Lander and Lockridge, 1989)



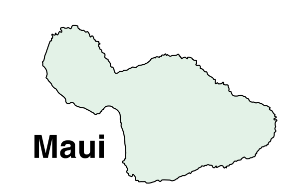
Large tsunamis* (>1m, 3.3 ft) with reported damage in the Hawaiian Islands

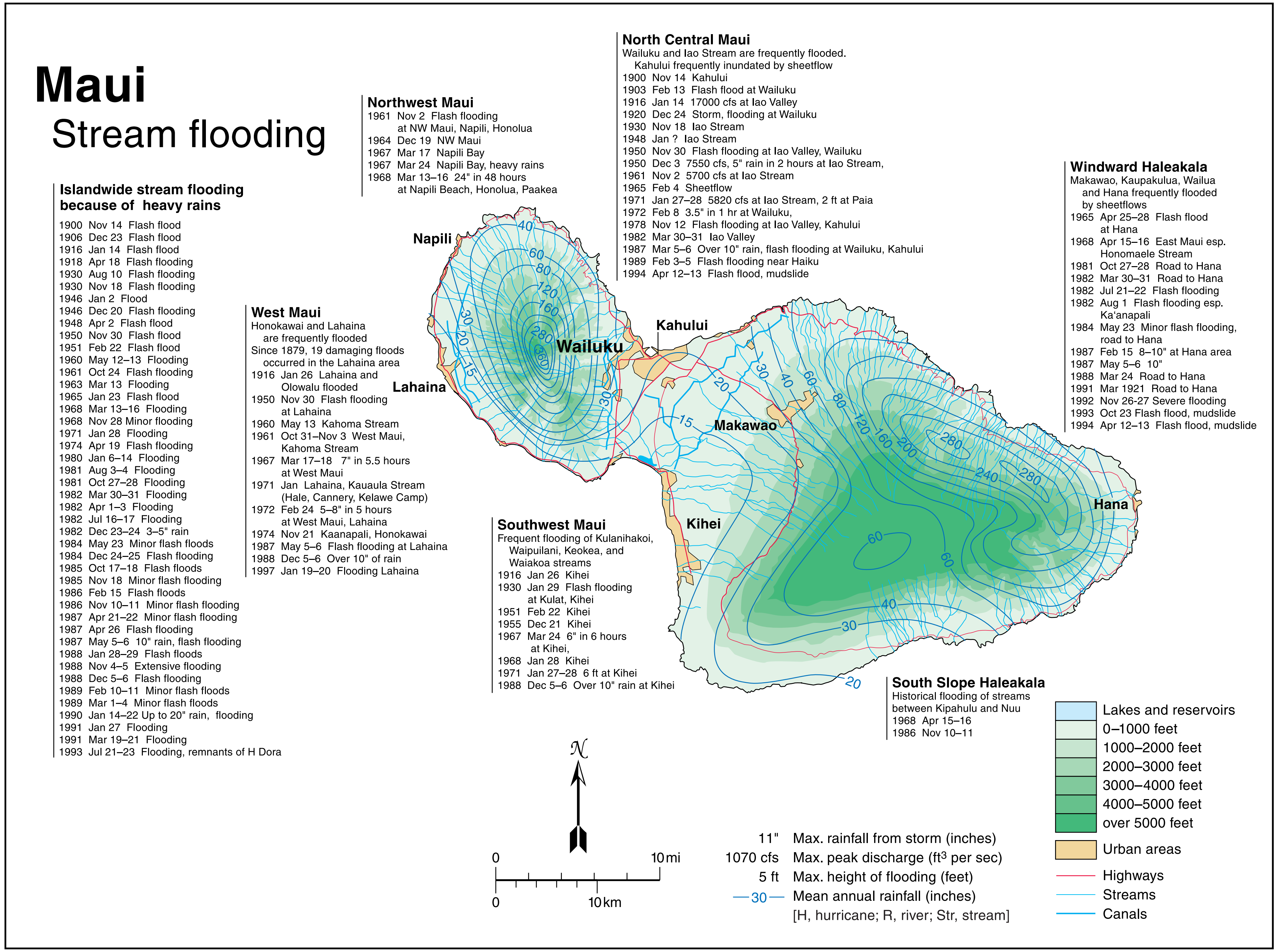
Year	Date	Area of origin	Magnitude**
1819	Apr 12	N Central Chile	M= 2.0
1835	Feb 20	Southern Chile	M = 4.0
1837	Nov 7	Southern Chile	M = 3.0
1841	May 17	Kamchatka	M = 2.0
1868a	Apr 3	SE Hawaii	M = 4.1
1868b	Aug 13	Northern Chile	M = 4.3
1868c	Oct 2	South Pacific	
1869	Jul 24	South Pacific	
1877	May 10	Northern Chile	M = 4.0
1878	Jan 20	Aleutian Is (?)	
1896	Jun 15	Japan	M = 4.0
1901	Aug 9	Tonga	
1906a	Jan 31	Colombia/Ecuador	M = 1.0
1906b	Aug 17	Central Chile	M = 2.0
1918	Sep 7	Kurils	M = 3.6
1919	Oct 2	Hawaii (H = 14 ft)	
1922	Nov 11	N Central Chile	M = 3.0
1923	Feb 3	Kamchatka	M = 3.0
1933	Mar 2	Japan	M = 3.0
1946	Apr 1	Eastern Aleutian Is	M = 5.0
1952a	Mar 17	Hawaii (H = 10 ft)	
1952b	Nov 4	Kamchatka	M = 4.0
1957	Mar 9	Central Aleutian Is	M = 3.5
1960	May 22	Chile	M = 4.5
1964	Mar 28	Gulf of Alaska	M = 4.5
1975	Nov 29	Big Island/Hawaii (H = 47 ft)	

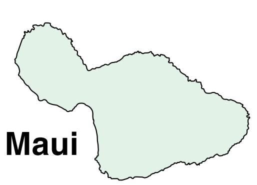
*Reliability of ≥ 3 (of 4)(Lander and Lockridge, 1989), runup > 1m (3.3 ft), and reported damage.

** Tsunami magnitude is defined by $M = \log_2 H$ as revised by Iida and others (1967), where H is the maximum runup height or amplitude on a coastline near the generating area.

Other tsunamis have occurred, such as that of Oct 1994, however, because of their low (<1 m) runup, insignificant damage, and/or uncertainty surrounding their timing and magnitude as noted in Lander and Lockridge (1989), they were not included here.







Stream flooding

Stream flooding on Maui is not only common, but is also the very agent responsible for making it famous as the Valley Island. The deep V-shaped valleys of west Maui have been carved by over 1 million years of stream flow, and the wide apron of sediments descending from Iao Valley onto the isthmus and the wide coastal plain between Kaanapali and Olowalu are the result of flood deposition over this time. Along the eastern half of Maui, the mountains and valleys are much younger and as a result the valleys and streams are not as well developed. Most of the streams cut steeply down to the narrow coastline of Hana, often in cascading waterfalls. Annual rainfall is greatest (360 in) at the summit of west Maui and nearly as high (280 in) along the eastern flanks of east Maui just below the trade wind inversion. Rainfall tapers off dramatically toward the west on West Maui and Haleakala and is lowest (<15 in) in the vicinity of Kihei and Lahaina.

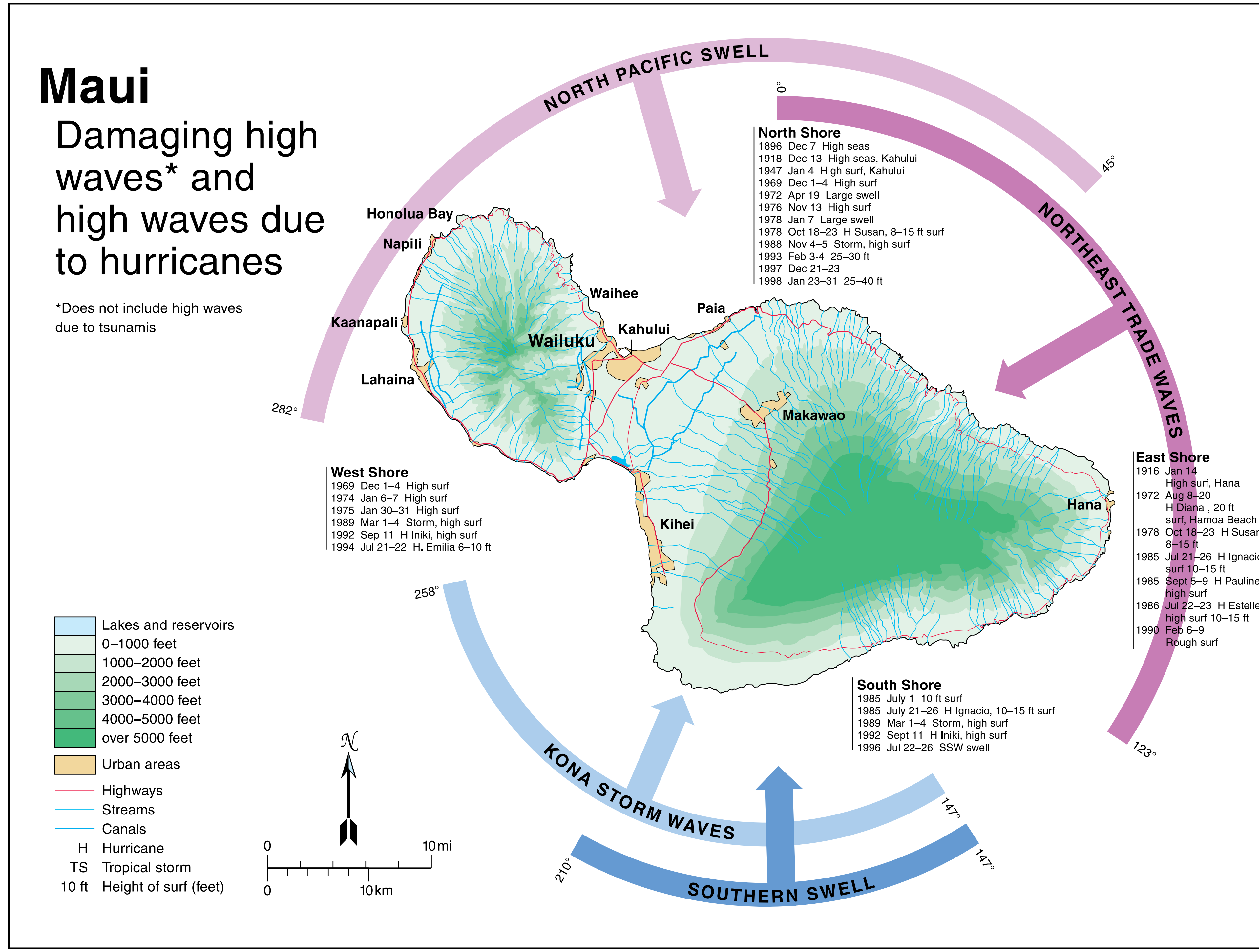
Despite the general trend of fewer historic stream floods along the arid south slope of Haleakala and more, severe floods in the wetter regions of central Maui, flooding in dry areas such as west and southwest Maui are common. Flooding in areas around Lahaina and Kihei are in part a result of the abrupt transition in slope at the coastline and the behavior of flash flooding. Many historic floods in these two areas occurred after heavy precipitation in higher elevations, which fed narrow stream channels and channelized drainages near the arid coast to the point of overflow. Flash floods due to heavy precipitation, in some cases equaling the average annual maximum, like on December 5-6, 1988, have occasionally occurred throughout the historical record. During the week of January 14-22, 1990, over 20 in of rain fell on many parts of Maui causing significant flooding in the coastal zone. The north central portion of Maui and the Hana coast, however, have the greatest stream flooding histories. Nearly once a decade, a major flood eminates from Iao Valley bringing sheets of water down into the urban centers of Kahului and Wailuku. Events such as on November 30, 1950, and November 2, 1961, produced enormous volumes of stream discharge out of the Iao Stream Valley and generated sheet flows on the coastal plain below. Along the road to Hana temporary road closures are common due to flash floods and mudslides from the steeper slopes of East Haleakala.

In addition to flooding from stream channels, portions of Maui, notably the Lahaina regions and Kihei, are vulnerable to standing surface water flooding. This may interrupt transportation and damage low elevation buildings. Standing surface water develops after intense rainfall events where poor soil permeability and urbanization prevent adequate drainage.

High waves

High waves in Hawaii are generated by distant storms in the Northern and Southern Hemispheres as well as by approaching storms in close proximity to the islands. Waves from north and northwest swell tend to be highest on an annual basis and generally occur between October and March. On Maui, breaking wave heights associated with the largest north and northwest swells range between 5 and 10 ft in the vicinity of Kaanapali and 10-20 ft near Honolua Bay in northwest Maui and along the North Shore between Waihee and Paia. Occasionally waves of 25 ft and greater occur over the deep offshore reefs of the North Shore making them popular for big wave surfing. The southern shores of Maui are partly protected from south swell in summer by the islands of Kahoolawe and Lanai, located to the south and southwest, respectively. Even so, wave heights along Maui's southern coast, range between 4 and 6 ft, and at times reach 8-10 ft. Trade wind waves, usually between 3 and 4 ft, impact the eastern shores 70 percent of the time. During winter months, Kona Storm waves can reach 5 ft along the southern coast while in the summer months, tropical storms and hurricanes can generate wave heights of 10-20 ft along any portion of coast on Maui.

Records of high waves on Maui date back to 1896. Many of the larger wave events have been associated with large tropical storms on their approach toward the Hawaiian Islands as well as during their passing. Wave heights ranging between 10 and 15 ft reached the north and east shores of Maui as Hurricanes Susan, Ignacio, and Estelle traveled through Hawaiian waters. Along the west shore, wave heights of 6 to 10 ft were recorded as a result of the passing of Hurricane Emilia in July of 1994. Annually however, it is the swell generated by distant storms in the North Pacific Ocean that bring waves commonly 15-20 ft to the north shore, and occasionally up to 30-40 ft. Two of the largest wave events occurred February 2-4, 1993, and January 23-31, 1998, when waves reached heights of 30 and 40 ft, respectively. These high wave events are hazards in themselves, threatening life and coastal property. When combined with high tides and storm surges, high waves can inundate farther landward, disturbing inland property and infrastructure. Fortunately for Maui, much of its coastline has wide fringing reefs that dissipate wave energy offshore of its northern and western shores, where wave heights are highest. Also, relative to the other islands, there are only a few locations where development along the shore is subject to direct impact by high waves. Unfortunately however, areas important for tourism and commerce between Lahaina and Napili, and along the Kihei and Kahului coasts are sited on low coastal plains, and so experience periodic wave overwash, which causes rapid erosion and temporarily disrupts transportation.



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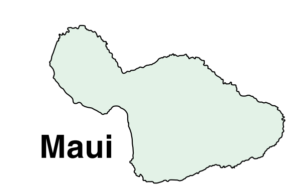
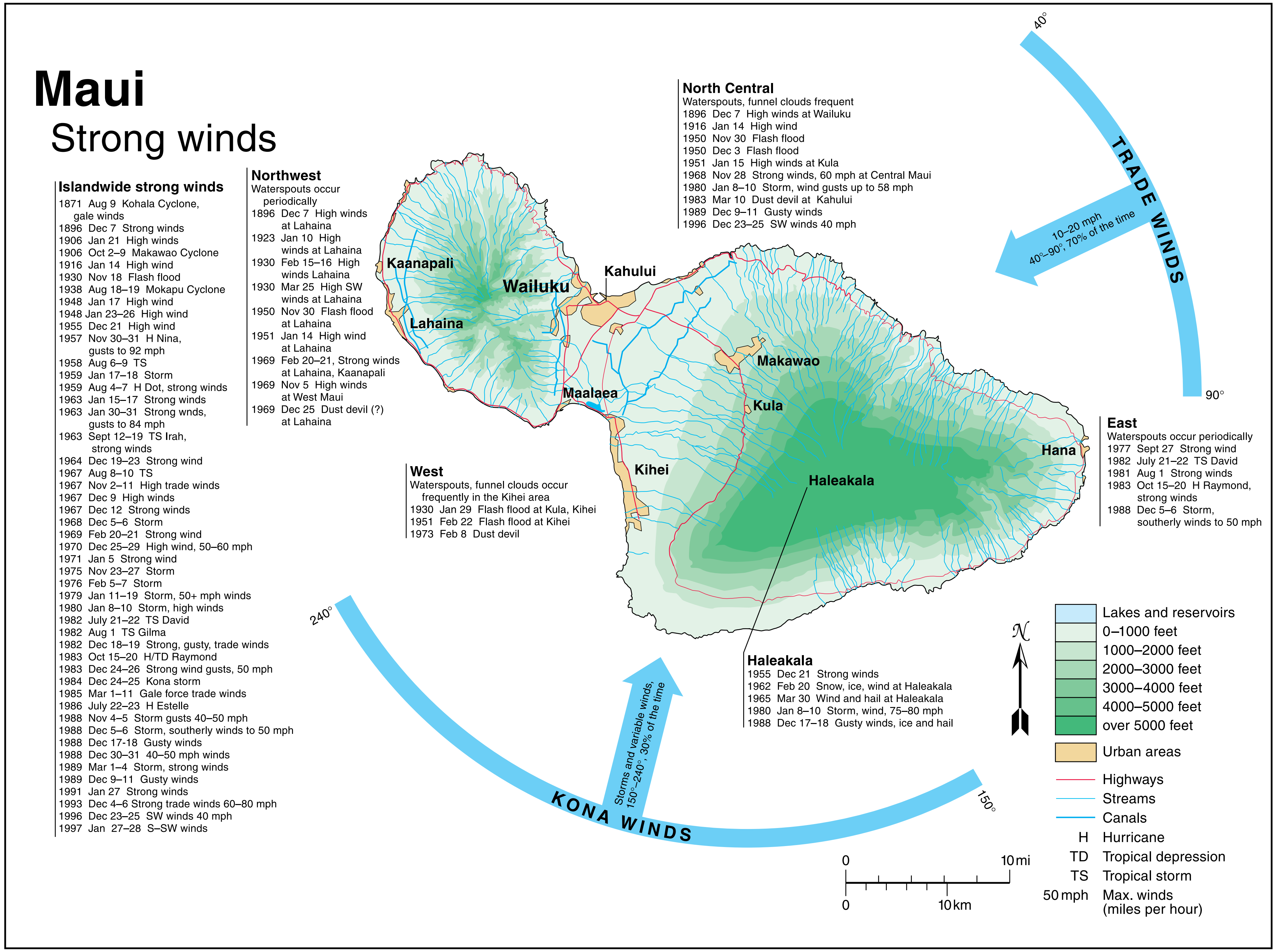
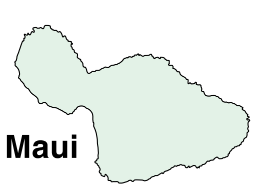




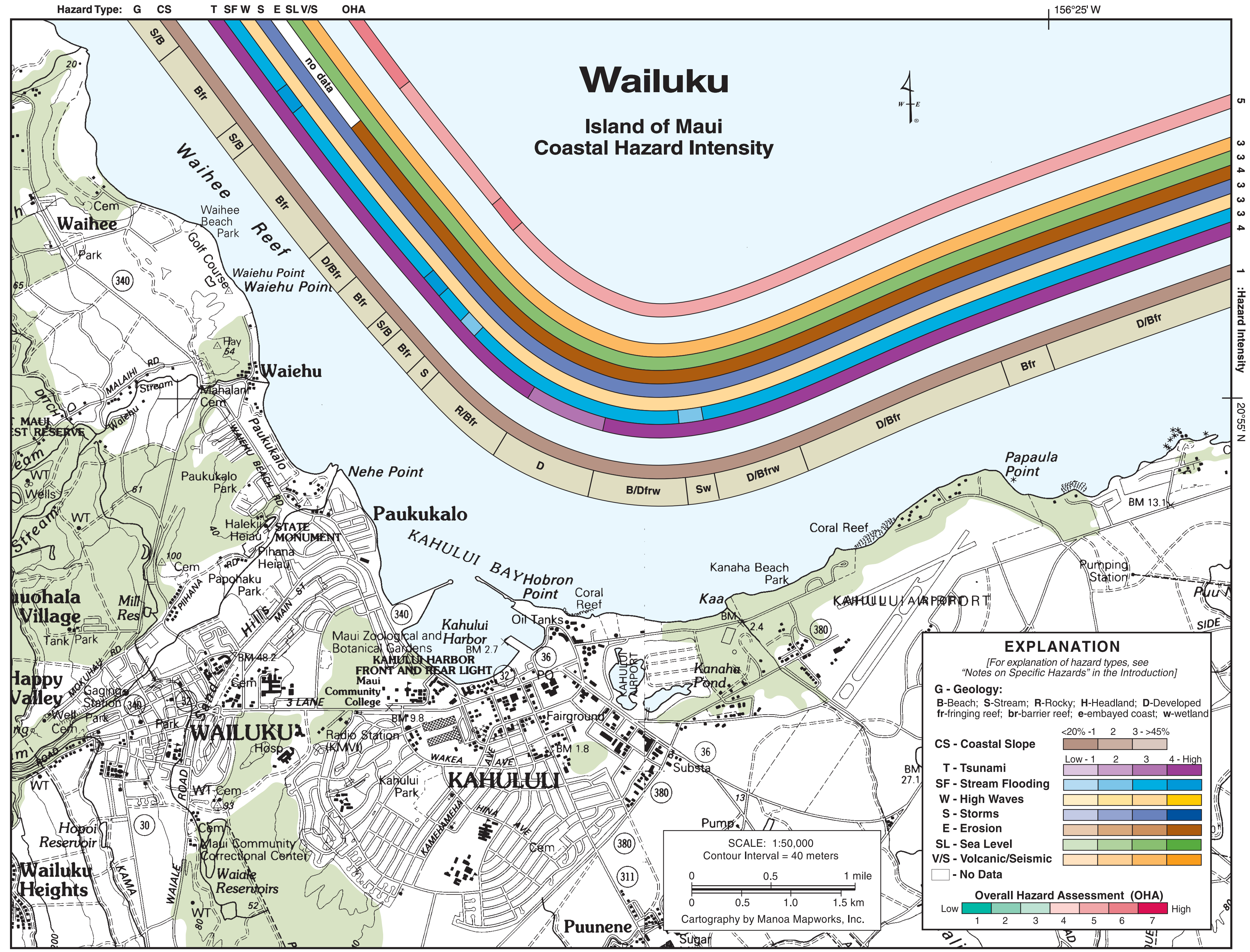


Strong winds

High winds from trade winds, which blow 70% of the time, Kona winds (30% of the time), and winds from hurricanes and tropical storms passing through Hawaiian waters all affect the island of Maui. Trade winds predominate from the northeast and generally range from 10-25 mph, although occasional extreme events reach 40-50 mph when the subtropical high-pressure cell north of the islands intensifies. There can be a slight acceleration of the trade winds as they blow across the isthmus between West Maui and Haleakala, so that wind speeds at Maalaea and north Kihei may be higher than along the North Shore. Kona winds occur as light and variable winds, most often during winter months when trade wind circulation diminishes, and as strong generally southerly winds when storm systems move across Hawaiian water. Damaging Kona winds have reached velocities of 50 mph for several days on end. The most damaging winds are those associated with passing tropical storms and hurricanes. East-facing coastlines in Hawaii generally receive the brunt of tropical storm winds as the storms approach the islands. The south and west-facing shorelines often receive strong winds and waves derived from these storms as they pass to the west. Occasionally, when such storms track to the east of the islands, the north shores are impacted. In all cases, acceleration of winds downslope often occurs such that the highest winds may in fact be recorded on the leeward side of the wind approach.

Since 1871, at least 47 strong wind events have impacted the entire island of Maui. Of these, 34 were associated with extreme trade winds and/or Kona storm winds, while 13 occurred during passing tropical storms and hurricanes. The strongest trade wind events hammered the north and east shores with winds of 40-60 mph, like early December 1993, March of 1985, and December of 1982. High southerly Kona Storm associated winds have reached speeds of 40-50 mph on several occasions including December 1996 and December 1988. These winds typically impact the south-facing shorelines, but are also potential threats to the north shore as the winds accelerate down the north slopes of Haleakala. Some of the strongest wind events on Maui have been associated with passing hurricanes, like Hurricane Nina in November 1975, which brought gusts greater than 90 mph to parts of Maui, and tropical storms like Daniel in July 1982, which caused damage along Maui's east coast. Of the 5 main Hawaiian Islands, Maui has been the most fortunate having only been brushed along its northern shores by a tropical depression, whereas the other islands have each taken the direct hit of at least one tropical depression.

Wailuku

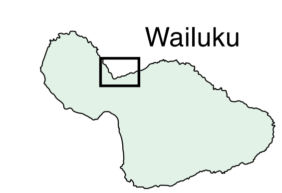


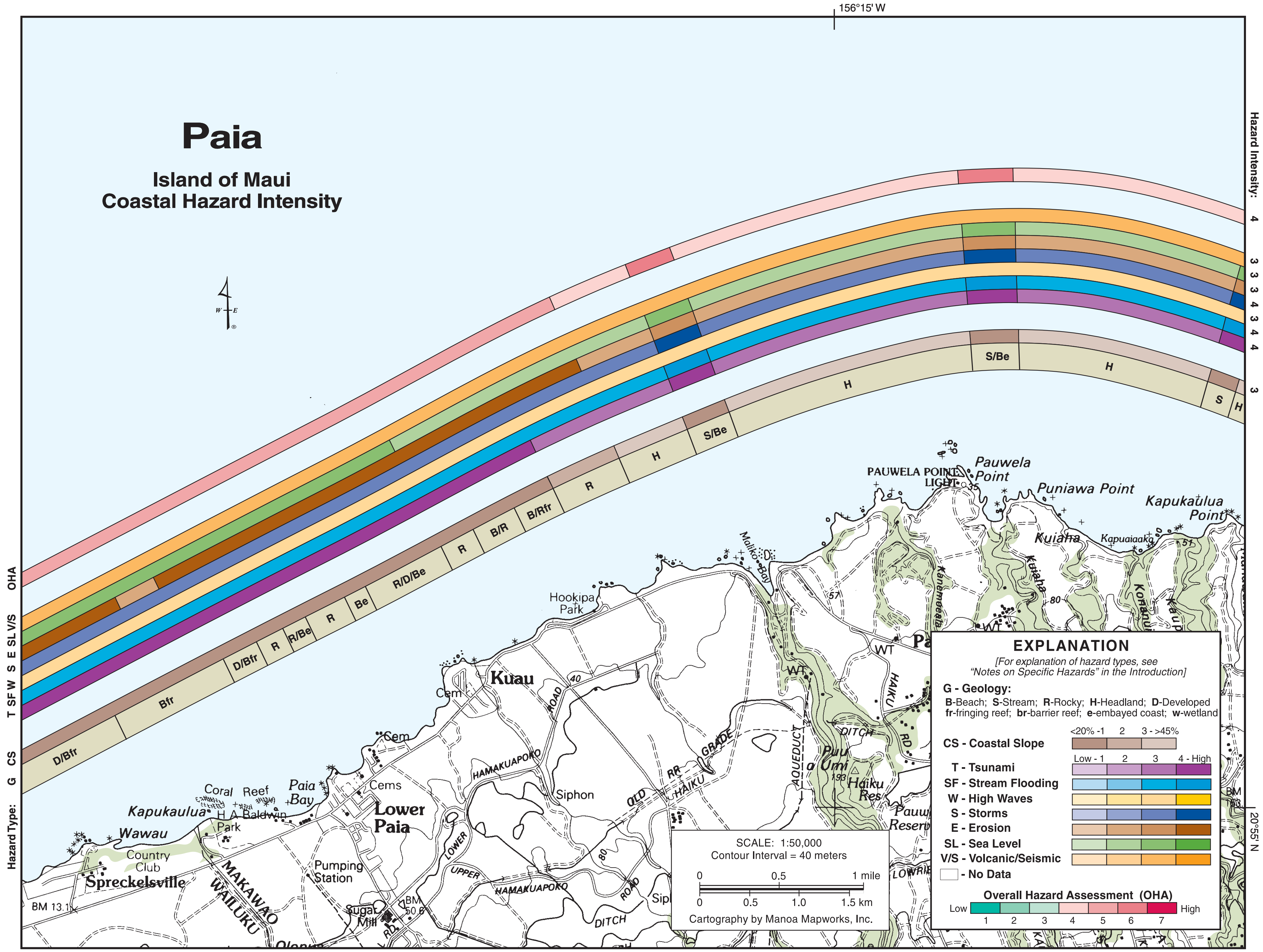
Base Credit: USGS 1:50,000 Makawao, Hawaii 5719 IV W733 Edition 1-DMA and USGS 1:50,000 Wailuku, Hawaii 5619 I W733 Edition 1-DMA

The coastal embayment of Wailuku, centered around Kahului Harbor, is Maui's industrial and commercial hub. Trade winds are strong and persistent along this coast as they funnel across the isthmus between Haleakala and West Maui volcanoes. Flash flooding is a serious hazard in this region. In January of 1916, for example, the Iao Valley was estimated to discharge 17,000 cfs, and in 1987, over 10 in of rain falling in one 48-hr period brought floods to both Wailuku and Kahului. Streams that empty the Iao Valley, one of the wettest places in Hawaii, bring rocks and boulders to the beaches near Waihee. A steep rocky headland at Waihee Point gives way to a more gradually sloping lowland coast between Waiehu and Papaula Point. Rock walls and jetties protect the central industrial area and harbor, while tall sand dunes east of Hobron Point guard the wetlands near Kanaha and long sandy beaches to the east. Fringing reefs are well established along this coast and are commonly delineated by the white water of breaking waves far offshore.

Seawalls line much of the Wailuku waterfront to protect urban and commercial infrastructure as well as county and municipal lands such as the Waiehu Municipal Golf Course at Waiehu.

The Overall Hazard Assessment (OHA) for the Wailuku coast is ranked moderate to high (5) except at the low coastal embayments near Waiehu and Waihee, where it is ranked high (6) because of the greater threat due to stream flooding. The tsunami hazard is ranked high along the low slopes of the Wailuku coastline, except at the Kahului Harbor, where it is reduced to moderately high because of the combined mitigating effects of a significantly wide fringing reef directly offshore and placement of breakwaters to reduce wave energy and inundation. Stream flooding in downtown Kahului historically has been a substantial threat. During heavy rains in Iao Valley, large amounts of water are discharged from the steep hillsides to flood the lowlands. As a result, the stream-flooding hazard is ranked moderately high along the entire coast except at stream mouths and the coastal embayments of Waiehu and Waihee where it is ranked high. The hazard of high waves and storms along the Wailuku coastline is ranked moderately high due to its exposure to annual wave heights of 20 ft during the winter and to hurricanes approaching from the east. Erosion is a serious threat to these low-lying and mostly unconsolidated shorelines due to the persistent high wave energy reaching this coast year round. Erosion is therefore ranked high along the entire Wailuku coastline. Sea-level rise is ranked moderately high here where annual rates of rise are approximately 2.4 mm per year. Seismicity and volcanism is ranked moderately high, as is the entire coastline of Maui. Haleakala is considered dormant by most geologists, rather than extinct, and so represents a considerable potential future hazard to Maui residents, of which few are cognizant. In addition, Maui is located within seismic hazard zone 2.





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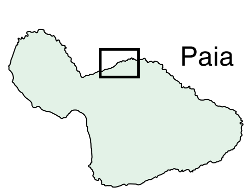
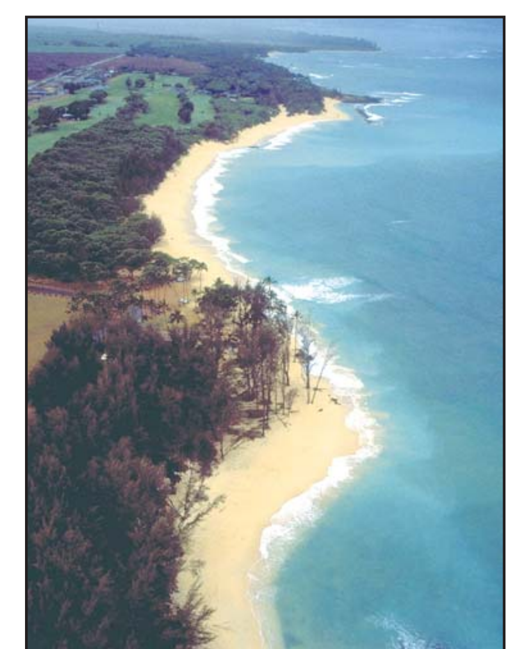


Paia

The Paia coastline dramatically changes character between Spreckelsville and Kapukaulua Point. West of Lower Paia it is marked by several relatively long white sandy beaches backed by sand dunes. Dominated by persistent trade winds that approach nearly parallel to the shore and broad fringing reefs that break the advance of oncoming swells nearly a mile offshore, this coast is considered one of the best windsurfing areas in the world. East of Paia Bay to Kapukaulua Point, the coast becomes steeper with beautiful rocky headlands and numerous small embayments fed by streams originating on the north face of Haleakala Volcano.

The Overall Hazard Assessment (OHA) primarily reflects the gradient and morphology of the Paia coastal area. It is ranked moderate to high (5) between Spreckelsville and Hookipa. To the east, it is ranked moderate (4) except at the low-lying Maliko and Pauwela Bays, which are more susceptible to tsunami, stream flood, and storm inundation. At these low coastal embayments, the overall hazard assessment ranking is high (6). The dynamic hazards along the Paia coast are closely related to coastal slope and morphology. The tsunami hazard is ranked high in the low-lying areas of Spreckelsville and Paia and only moderately high in the steeper areas to the east. Two exceptions are found at the small low-lying coastal embayments of Maliko and Pauwela Bays, where it is ranked high. The hazards due to stream flooding and storms are almost identical in that they are ranked moderately high along the entire Paia coast, except at the two embayments mentioned above, where they are ranked high. The threat due to high waves is equally great throughout the region and is ranked moderately high. Erosion is greatest and ranked high in the low coastal areas west of Paia. Extensive beachrock exposures, such as those at Hookipa Beach Park, are indicative of recent beach erosion. Erosion is ranked moderately high in Maliko and Pauwela Bays and only moderately low along the steep rocky headlands. Sea-level rise is also a threat to the low-lying and developed areas west of Paia, where it is ranked moderately high. To the east of Kuau it is downgraded to moderately low except for the low coastal embayments of Maliko and Pauwela Bays where it is ranked moderately high. The volcanic/seismic threat is ranked moderately high along the entire Paia coast as it lies in the seismic hazard zone 2.

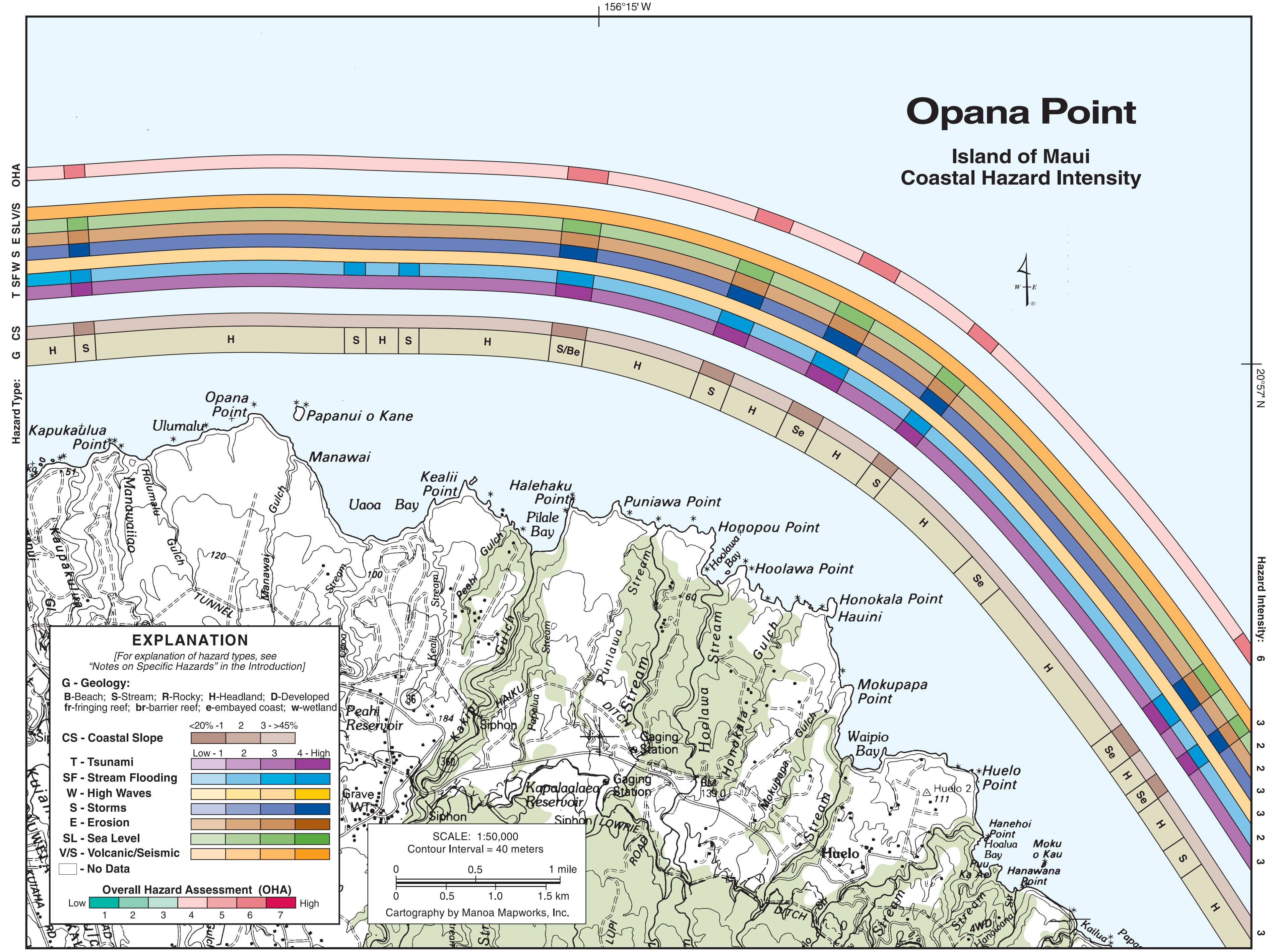


Despite rapid and chronic beach loss along the Paia coast and toward the west, beautiful sandy beaches appear to erode and accrete seasonally along Baldwin Beach (shown here), where development and shoreline hardening has been minimal.

Opana Point

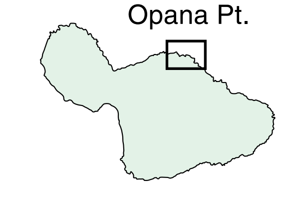
The Opana coast marks the eastern corner of the north shore of Maui. Rocky headlands border small coastal embayments, where active streams and gulches that incise their way across the slopes of Haleakala finally reach the sea. The streams carry rounded boulders down their channels, helping to form the small shingle and cobble beaches found at their mouths. The coastal slope becomes gradually steeper toward the east. The nearshore zone, lacking the broad fringing reefs found to the west, drops off rapidly along this coast, where it is predominantly windswept and rough due to the strong and persistent trade winds.

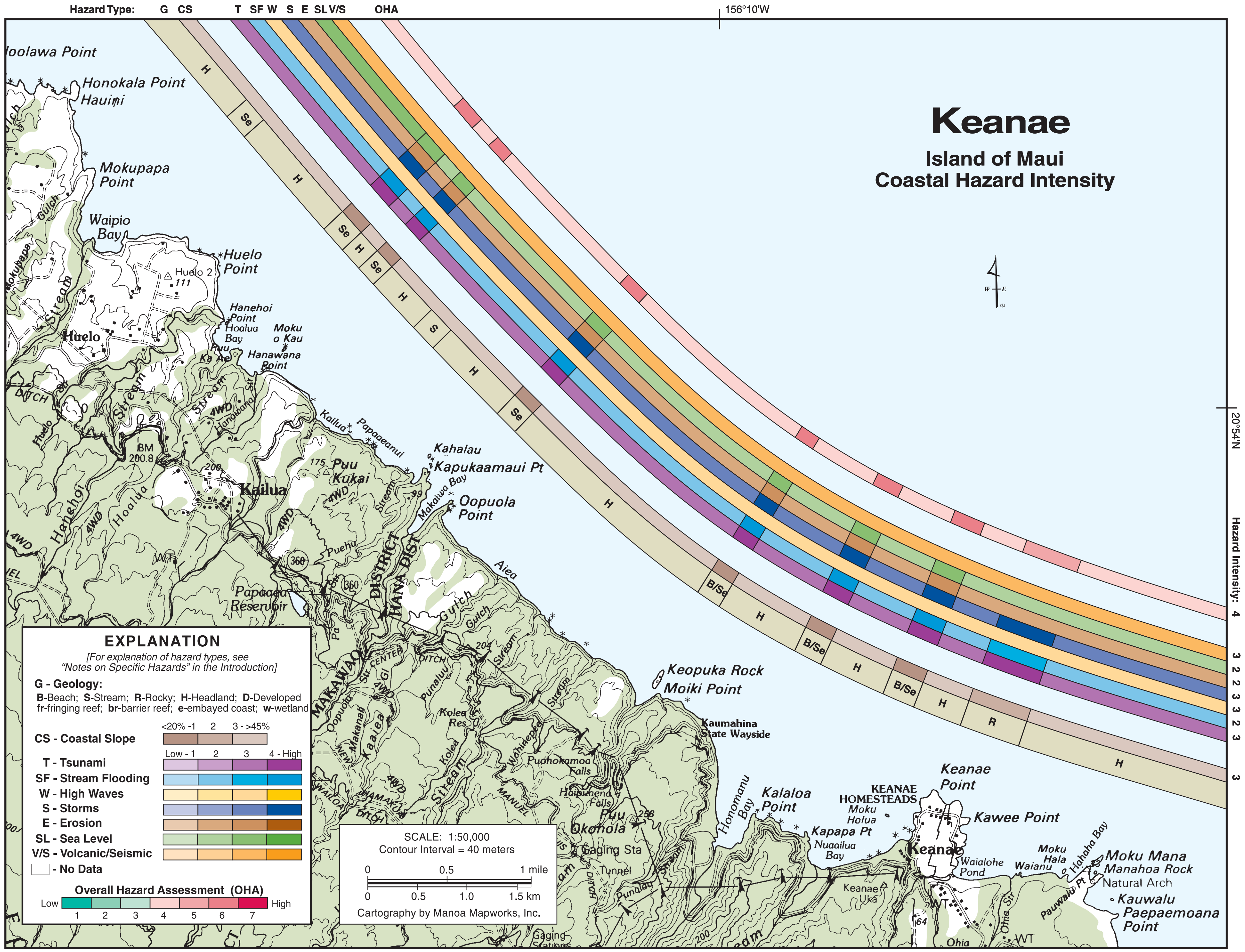
An Overall Hazard Assessment (OHA) of moderate (4) is prescribed for the steep headlands of the Opana coastal area. In the small low-lying embayments of Kapukaulua, Pilale, Hoolawa, Hoalua, and Hanawana Bays, and at the mouths of Puniawa and Honokala streams, where the threat of tsunami, stream flooding, storms, erosion, and sea-level rise is greater, the overall hazard is also greater and ranked high (6). The hazards due to tsunami, storms, erosion, and sea-level rise closely reflect the change in slope from the steep headlands to the lower-lying coastal embayments. Each of these threats will be most pronounced within the bays. As a result, tsunami and storm hazards are ranked high at the embayments and only moderately high along the headlands in between. Erosion and sea-level hazards are ranked moderately high at these embayments and only moderately low along the steep sloping headlands. The threat due to stream flooding mirrors the tsunami and storm hazards except at the two stream mouths in Uaoa Bay where only stream flooding represents a significant hazard due to the rocky nature of the shoreline. The hazard due to high waves is moderately high along this coast due to its exposure to north and east swell. The volcanic/seismic threat is moderately high along this coast as it is along the entire Maui coast due to the historical eruption of Haleakala and its location within the seismic hazard zone 2.



Base Credit: USGS 1:50,000 Kipahulu Valley, Hawaii 5719 II W733 Edition 1-DMA and USGS 1:50,000 Makawao, Hawaii 5719 IV W733 Edition 1-DMA

Rocky headlands bordering small coastal embayments are common along the Opana Point coast.





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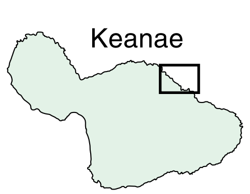


Keanae

East of Honokala Point to Moku Mana the coast is relatively steep and bordered by tall cliffs and rocky headlands. The wide headland of Kaenae Point was built by the latest of several lava flows that spilled down the slopes of Haleakala through the Koolau Gap. The cliffs here are between 5 and 10 ft high. Several streams cut through the high sea cliffs of the Hana Series lavas to form small bays, many of which are partly-drowned river valleys. Beautiful rocky sea stacks and small islets are found along this portion of the coast, where the constant battering of the trade winds and its waves leaves erosional remnants standing offshore as the coastal cliffs erode. Beaches at these river mouths are composed primarily of cobble and boulder size remnants.

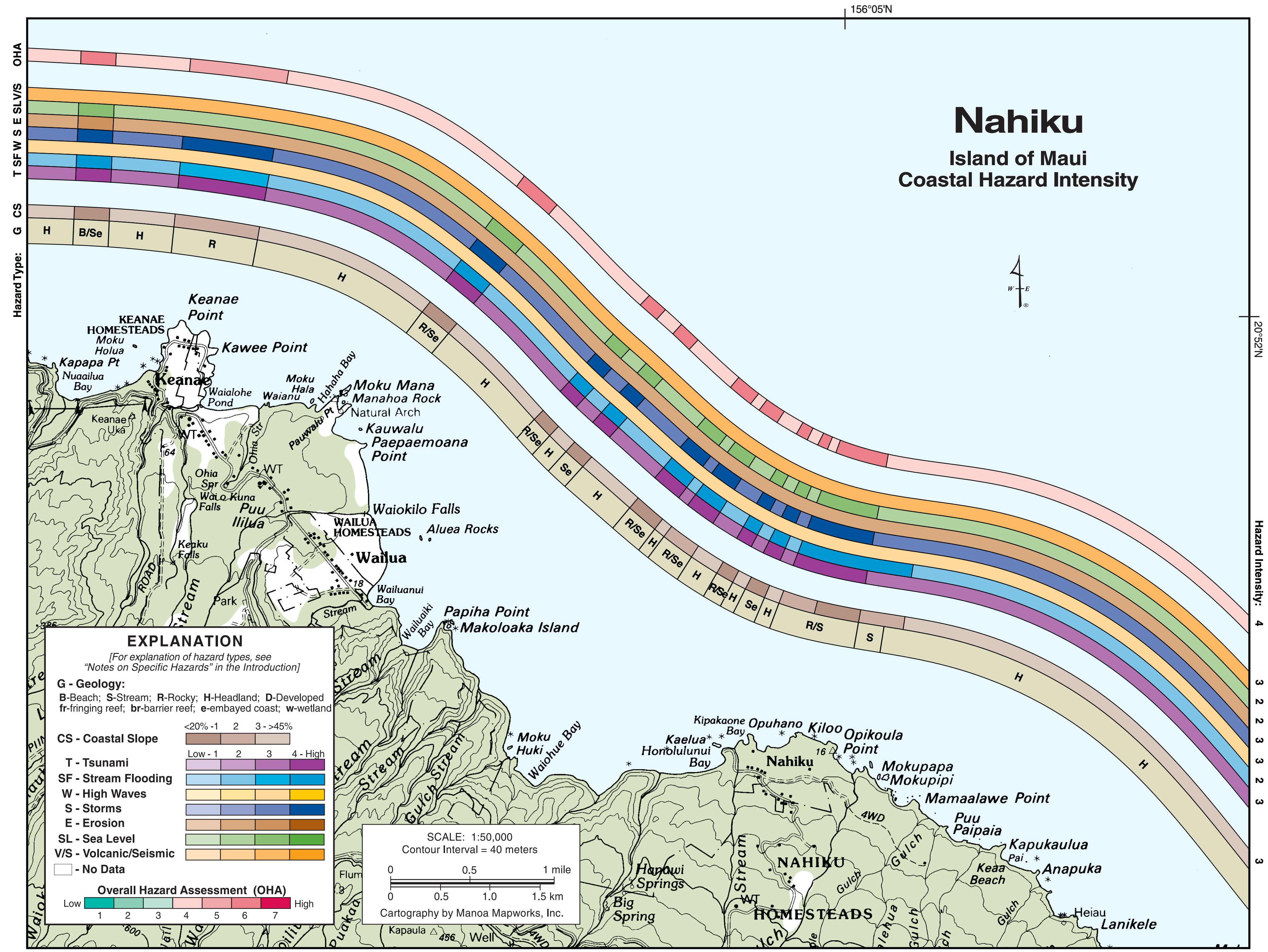
The natural hazards affecting this portion of the coast are similar to those along Opana Point to the west and Nahiku to the east. Along the headlands and cliff faces the hazards tend to be mitigated by the steeper slopes, while at low-lying embayments the threats are accentuated by low coastal slopes. As a result, tsunami and storm hazards are ranked moderately high along the steep cliffs because wave runup and wind acceleration tend to be enhanced along steep coastal slopes, while stream flooding, erosion, and sea-level threats are ranked moderately low. Where the slope is low, at Hoalua, Hanawana, Makaiwa, Honomanu, and Nuaailua Bays, tsunami, stream flooding and storm hazards are ranked high, while the erosion and sea-level hazards are only moderately high. At Moiki and Keanae Points, tsunami, stream flooding and storm hazards are ranked high, while erosion and sea-level hazards are only moderate, due to their steeper slopes. Hazards due to high waves are moderately high due to exposure to high north swell. The volcanic/seismic threat is moderately high throughout the entire region lying in the seismic hazard zone 2. The Overall Hazard Assessment (OHA) for the Keanae coast varies due to the location of coastal embayments and steep rocky headland cliffs. At stream mouths, typically found within the small low-lying embayments, a high overall hazard ranking (6) is assigned due to the greater threat of tsunami, stream flooding, storms, erosion, and sea-level rise. Along the headland coasts, the OHA is reduced to moderate (4) except for Keanae Point, where it is moderate to high (5).

A view of the low lying Keanae Point with its rocky shoreline and isolated coves. Steep headlands line the coast to either side of Keanae Point.

Nahiku

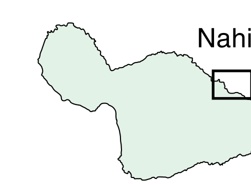
The Nahiku coast is rugged and rocky much like the Opana and Kaenae coasts. The wide headland of Kaenae Point was built by the latest of several lava flows that spilled down the slopes of Haleakala through the Koolau Gap. The cliffs here are between 5 and 10 ft high, but become taller and steeper toward Nahiku. Numerous small sea stacks flank the rocky coast, a tribute to the strong trade-wind seas forever cutting landward. Many small streams also cut through the coastal cliffs in their quest to reach the sea, creating small river mouths and transporting basalt boulders and cobbles to the rocky beaches.

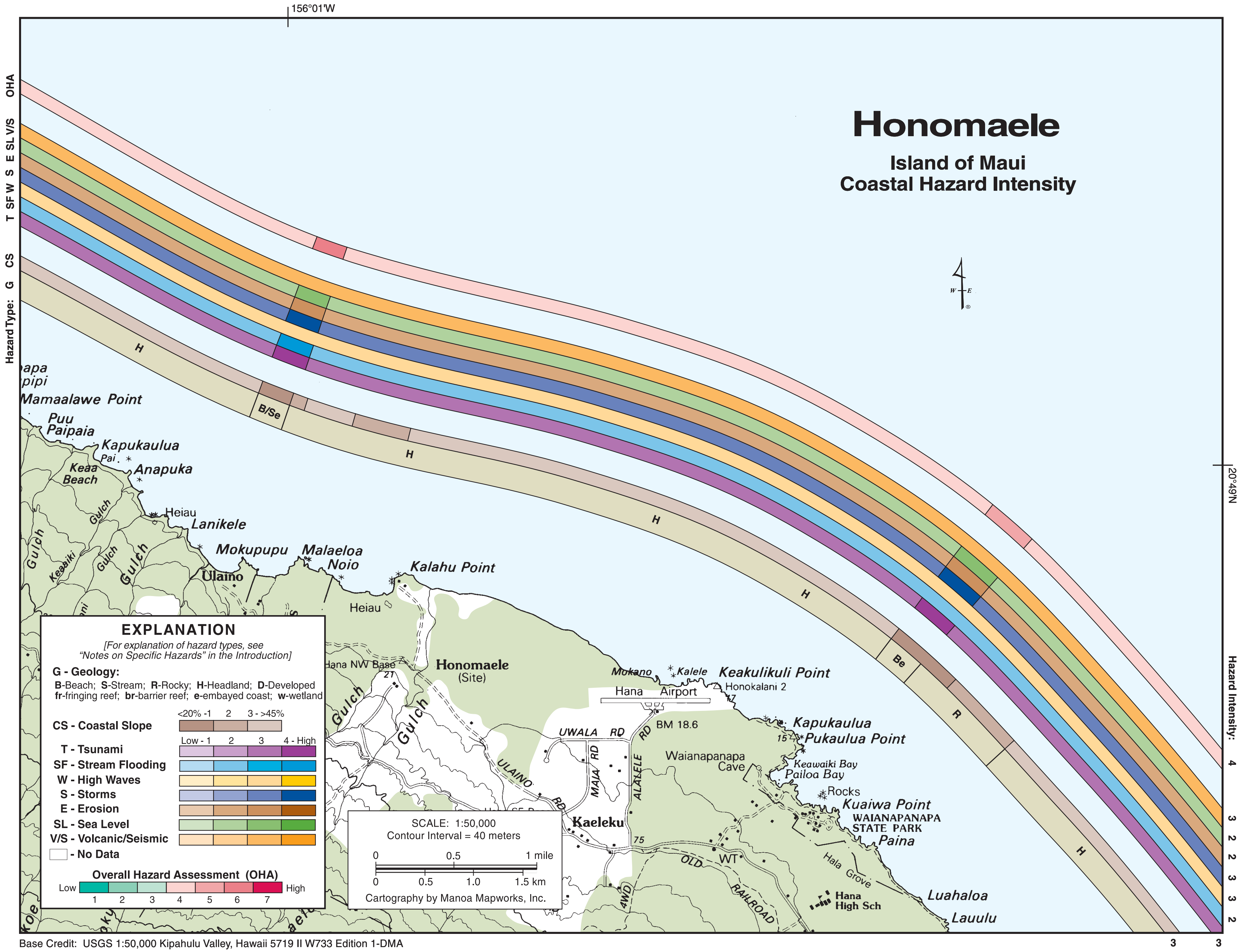
The Overall Hazard Assessment (OHA) for the Nahiku coastline varies between moderate (4) and high (6). At the low-lying coastal embayments of Nuaailua, Kauwalu, Wailuanui, Wailuaiki, Waiohue, Honolulunui, Kipakaone, Opuhano Bays and southeast of Papiha Point, the overall hazard is high, where the dynamic and long-term hazards are greatest. At Keanae Point, where erosion and sea-level hazards are moderately low, the overall hazard is moderate to high. Along the rocky headlands and cliffs the overall hazard ranking of moderate reflects the mitigating effect of the steeper coastal slopes that make individual hazards less of a threat than at the low-lying bays and stream mouths. The presence of small low-lying coastal embayments and stream mouths separated by steep headlands dictates the nature of coastal hazards along this portion of the Maui coast. Low coastal slopes at the bays and stream mouths are most susceptible to the threats of tsunami, stream flooding, and storms, so these dynamic hazards have been ranked high at Nuaailua, Kauwalu, Wailuanui, Wailuaiki, southeast of Papiha Point, Waiohue, Honolulunui, Kipakaone, and Opuhano Bays. Because of relatively rapid local relative sea-level rise on Maui, sea-level rise is also a greater threat to these low-lying areas and is therefore ranked moderately high at these embayments. Along the steep headlands, the tsunami, high wave, storm, and erosion hazards are ranked moderately high, while stream flooding and sea-level threats are ranked moderately low. The volcanic/seismic hazard is moderately high throughout the Nahiku region as it lies in the seismic hazard zone 2.

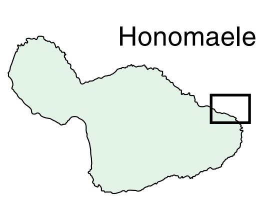


Base Credit: USGS 1:50,000 Kipahulu Valley, Hawaii 5719 II W733 Edition 1-DMA

The rugged coast near Nahiku on northeast Maui is characterized by numerous offshore rocks and sea stacks.







Honomaele

The rocky Honomaele coast consists of young lavas from the Hana Series volcanics that protrude seaward forming many small bays. The slope descends from 200 ft cliffs near Kapukaulua to 20-30 ft rocky headlands near Waianapanapa State Park. Sea stacks and caves are found around the black sand beaches of Pailoa Bay and Waianapanapa. Along the entire Honomaele coast numerous streams, originating on Haleakala's eastern flank, make their way over the coastal cliffs and spill down in beautiful waterfalls to small beaches below.

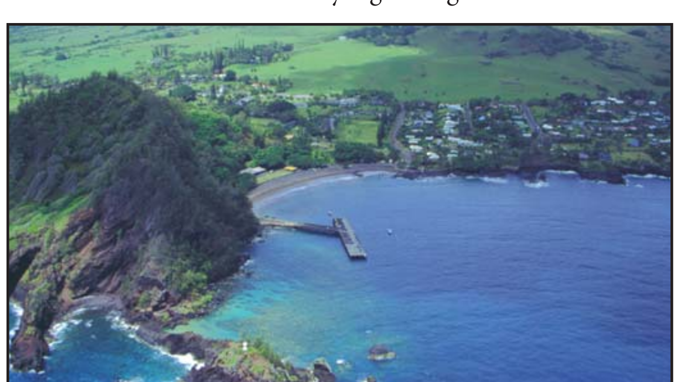
In the low-lying coastal embayment of Mokupupu Bay, where tsunami, stream flooding, storm, erosion, and sea-level hazards are greatest, the Overall Hazard Assessment (OHA) is high (6) while in Pailoa Bay, where the threat of stream flooding is less, the overall hazard is ranked moderate to high (5). Along the surrounding headlands and rocky points, individual hazards are mitigated by the steeper slopes, so the overall hazard there is given a ranking of moderate (4). The small bays along this coast are susceptible to flooding by both streams and storms and in fact, stream flooding commonly washes out the road to Hana in this area. As a result we have ranked tsunami, stream flooding, and storm hazards high at the small coastal embayments of Mokupupu and Keawaiki Bays, with the exception of Pailoa Bay, where stream flooding is ranked moderately low, because of the lack of stream drainage in this bay. Tsunami and storm threats are ranked moderately high along the headland areas between the bays, while stream flooding is ranked moderately low along the steep headlands, where streams do not flow. The threat from high waves and volcanism and seismicity are ranked moderately high throughout Honomaele due to its exposure to north swell and location in the seismic hazard zone 2, respectively. Erosion and sea-level hazards resemble each other in that they are ranked moderately high at Mokupupu and Pailoa Bays, but are reduced to moderately low along the surrounding steep headlands.

The east-facing slopes of Haleakala Volcano become more gently sloping near Honomaele and the low, broad coastal plain near Keakulikuli Point is the site of the Hana Airport.

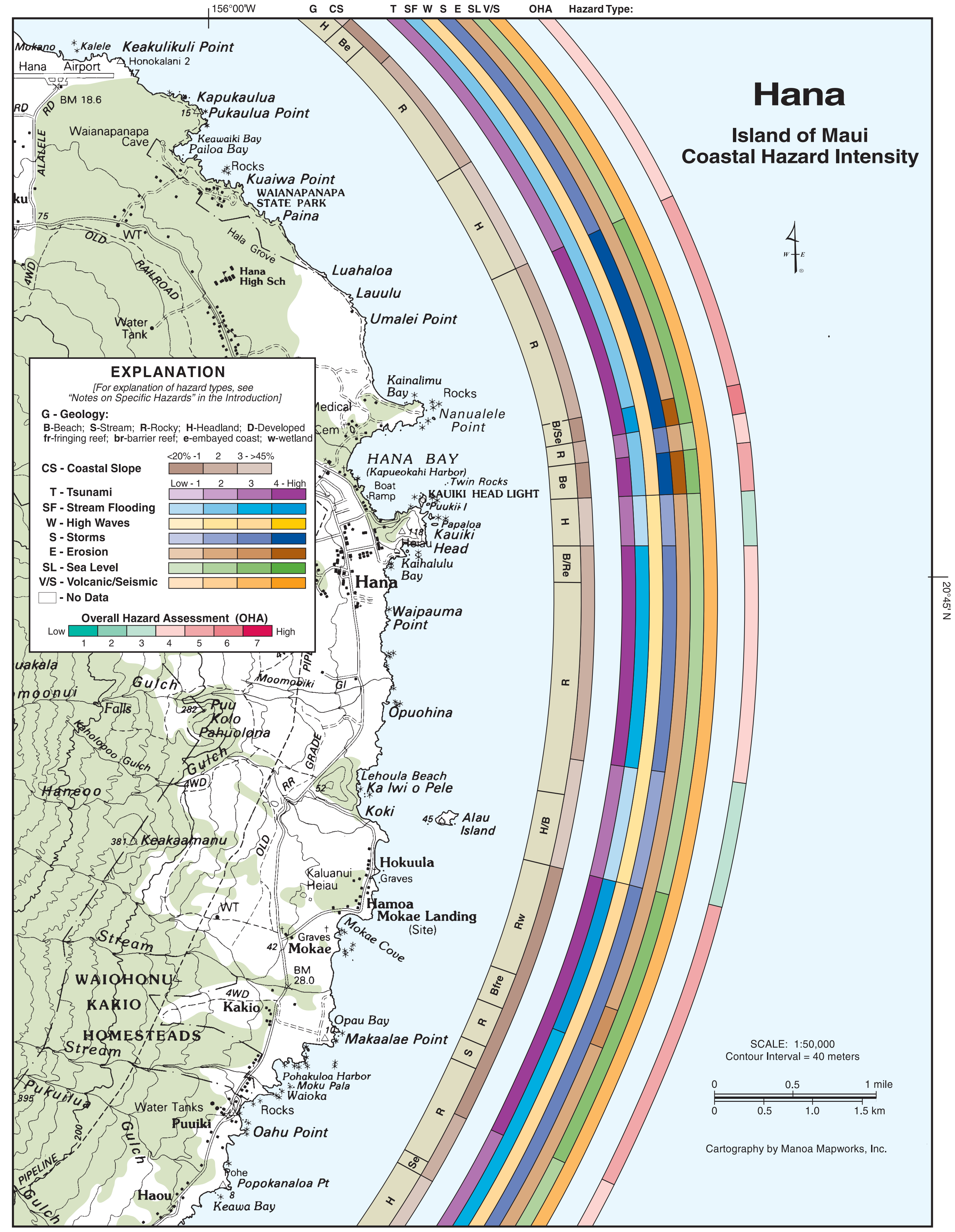
Hana

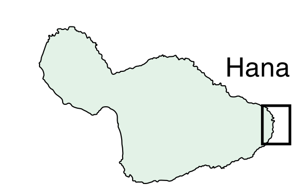
The Hana coastline extending from Pailoa Bay around the eastern corner of Maui to Oahu Point is simultaneously picturesque and daunting. It is hard to fathom how the rocky cliffs, sea stacks, and dozens of small rocky islands stand against the relentless attack of the incessant trade wind waves that create white plumes and towers of foam as they smash against the young basalt. The slope along this portion of the coast is quite variable. At Nanualele Point and Opuahina the slope is moderate, while at Mokae it becomes a relatively low-lying coastal plain. Numerous streams flow to the ocean, cutting small ravines and gulches through the young Hana Series lavas. The beaches are composed mostly of basalt cobbles and boulders, except at Hana Bay where there is a black sand beach. The wide exposure of the Hana coast to wind and waves approaching from the north, east, and south, make the dynamic hazards associated with storms and waves relatively severe. One of the highest flood heights recorded on Maui during the 1946 tsunami was in Hana Bay, where it was measured at 28 ft.

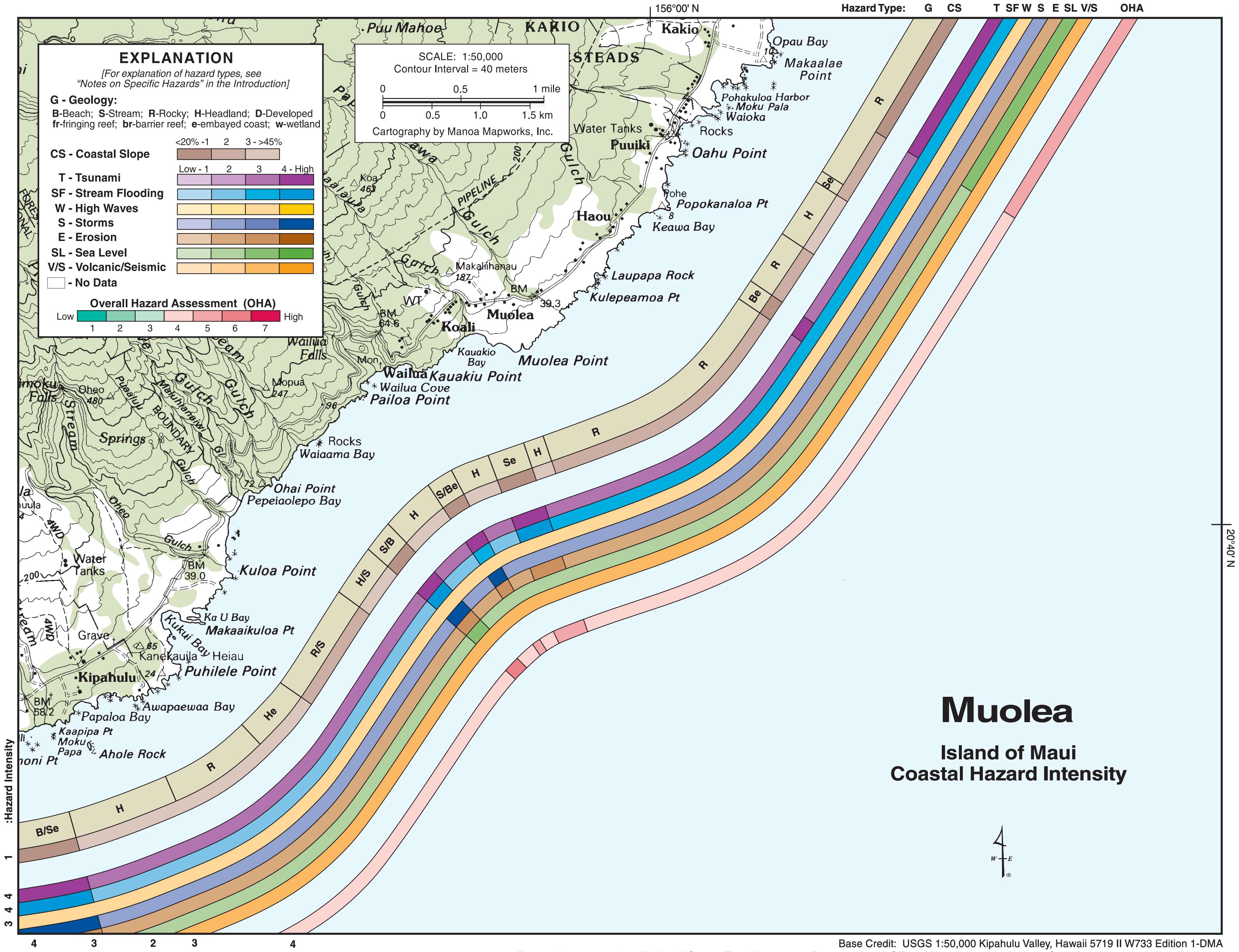
The Overall Hazard Assessment (OHA) for the Hana coastline varies from moderate to low (3) at the steep headlands of Koki and Kauiki, to high (6) at the stream mouth of Hana Bay. The high ranking in the northern portion of this coast is necessitated by the high tsunami and storm threat there, while in the southern low-lying region from Hokuula to Waioka, the high tsunami and stream flooding hazard contribute to its moderately high ranking. Between Kauiki Head and Koki, the relatively steep sea cliffs mitigate these threats, and so the overall hazard is ranked moderate (4) along the central portion of the Hana Coast. The tsunami hazard is ranked high at the low-lying coastal embayments and moderately high along the headlands in between. The stream flooding threat is also ranked high at Hana Bay and between Hokuula and Mokae Cove, where the coastal slope is low and streams empty to the sea. The stream flooding hazard is moderately high along the remaining coastline except at Lehoula Beach and Kauiki Head, where the greatest slopes are found, and it is ranked low. The threat from high waves is moderately high along most of the Hana coast except at the extreme eastern portion, where the coast is partly sheltered from the highest waves approaching from the north in winter and the south in summer. Here it is ranked moderately low. Most hurricanes and tropical storms approach from the east and pass to the south. As a result, the storm threat is ranked moderately high along the Hana coast, except between Umalei Point and Kauiki Head, where the coast faces directly toward approaching storms. The storm threat here is ranked high, while along the steeper cliffs of Kauiki Head and Koki, it is moderately low. The hazards due to erosion and sea-level rise are ranked moderately low along most of the coast, except at the lowest sloped areas, especially inside Hana Bay, where erosion is ranked high and sea-level rise is ranked moderately high. At Mokae Cove, erosion is moderately high. The seismic threat is ranked moderately high along the entire Hana coast.

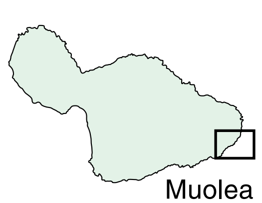


A view of Hana, the largest town on east Maui, and the Kauiki Head Light (foreground) at the entrance to Hana Bay.









Kukui Bay (foreground) is one of the numerous small, rocky embayments that line the base of deeply eroded valleys of southeast Heleakala Volcano.

Muolea

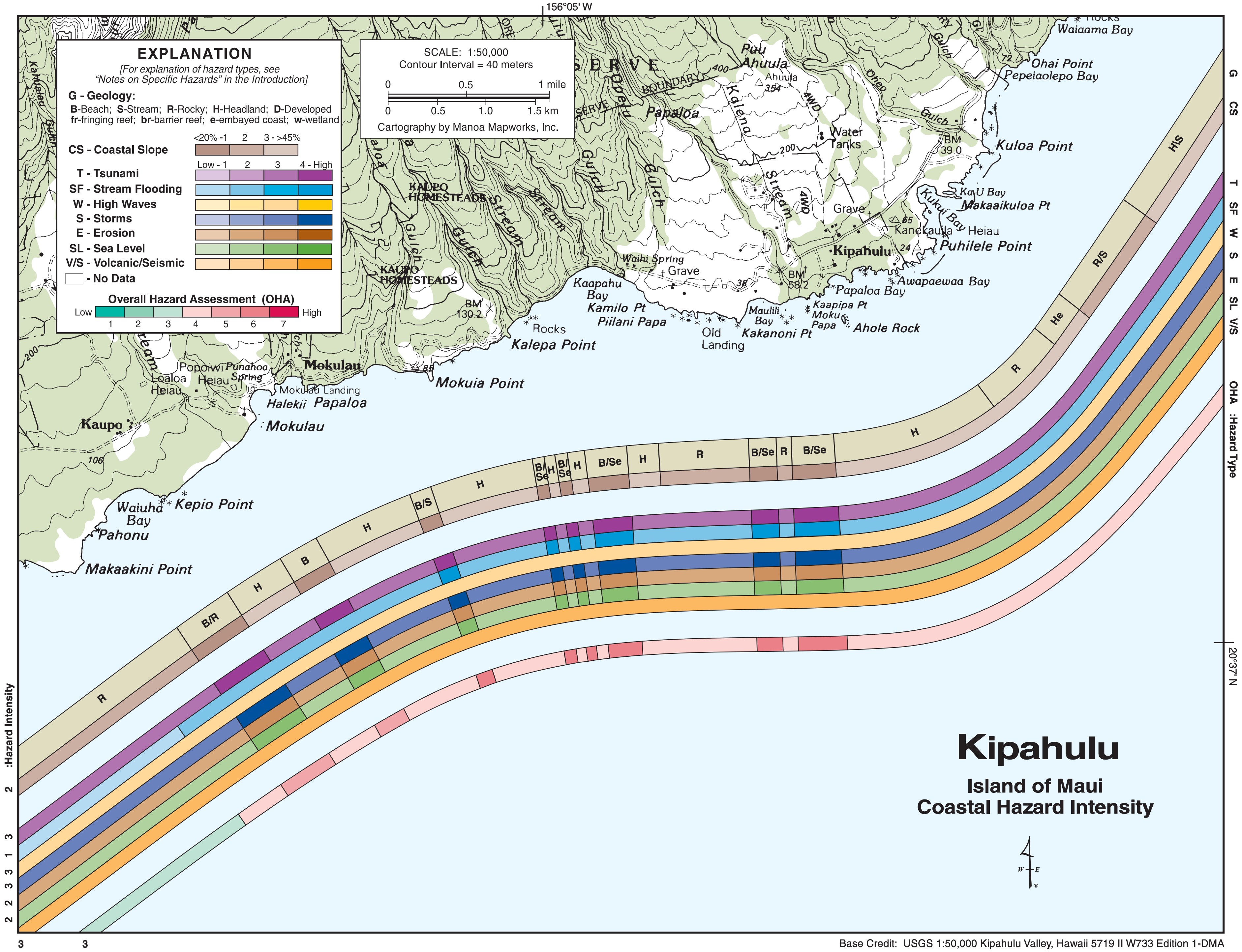
Westward of Oahu Point to Kipahulu, young lava flows and cinder cones of the Hana Volcanic Series in their type locality slope gently to the sea. Sea cliffs and rocky headlands standing 20 to 30 ft above mean sea level at Popokanaloa, Muolea, Kauakiu, Pailoa, Ohai, Puhilele, and Kaapipa Points, are separated by numerous streams, small bays, and coves. Beaches are scattered and often consist of gravel and cobbles. The trade winds sweep across this portion of the Maui coast from the northeast parallel to the shore, and are often blocked by the rocky outcrops that extend seaward. The nearshore bathymetry falls off quickly to great depths and lacks reef flat development.

A relatively uniform Overall Hazard Assessment (OHA) of moderate (4) is prescribed for the Muolea coastline with exceptions made for the small coastal embayments in the central portion of the region. At the low-lying stream mouth of Waiaama Bay, where the tsunami, stream flooding, and storm threats are high and combine with moderately high erosion and sea-level hazards, the overall hazard ranking is high (6). At Wailua Cove and Kauakio Bay, where the storm and sea-level hazards are not as great, the overall hazard is reduced to moderate to high (5). The tsunami hazard around Muolea Point is ranked moderately high along most of the higher headland area, but is increased to high for the small embayments of Wailua Cove and Waiaama, Kauakio, and Keawa Bays. The stream flooding hazard is similarly ranked moderately high in the eastern portion between Oahu and Muolea Points, but only moderately low along the steeper headlands southwest to Kaapipa Point. At the larger stream mouths that empty into Waiaama and Kauakio Bays, stream flooding is ranked a high hazard, while at the smaller stream mouth in Wailua Cove it is ranked moderately high. The high wave and seismic hazards are both ranked moderately high throughout the entire Muolea Point area. The storm threat is also ranked moderately high, with the exception that at Waiaama Bay and Wailua Cove it is elevated to high. Erosion is ranked moderately low throughout the region except at Waiaama and Kaukakio Bays and Wailua Cove, where it is ranked moderately high. Sea-level rise is ranked a moderately low threat except at Waiaama Bay where it is ranked moderately high. Volcanism and seismicity is ranked moderately high as it is along all of Maui's coastline due to its location in the seismic hazard zone 2.

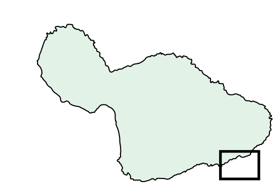
Kipahulu

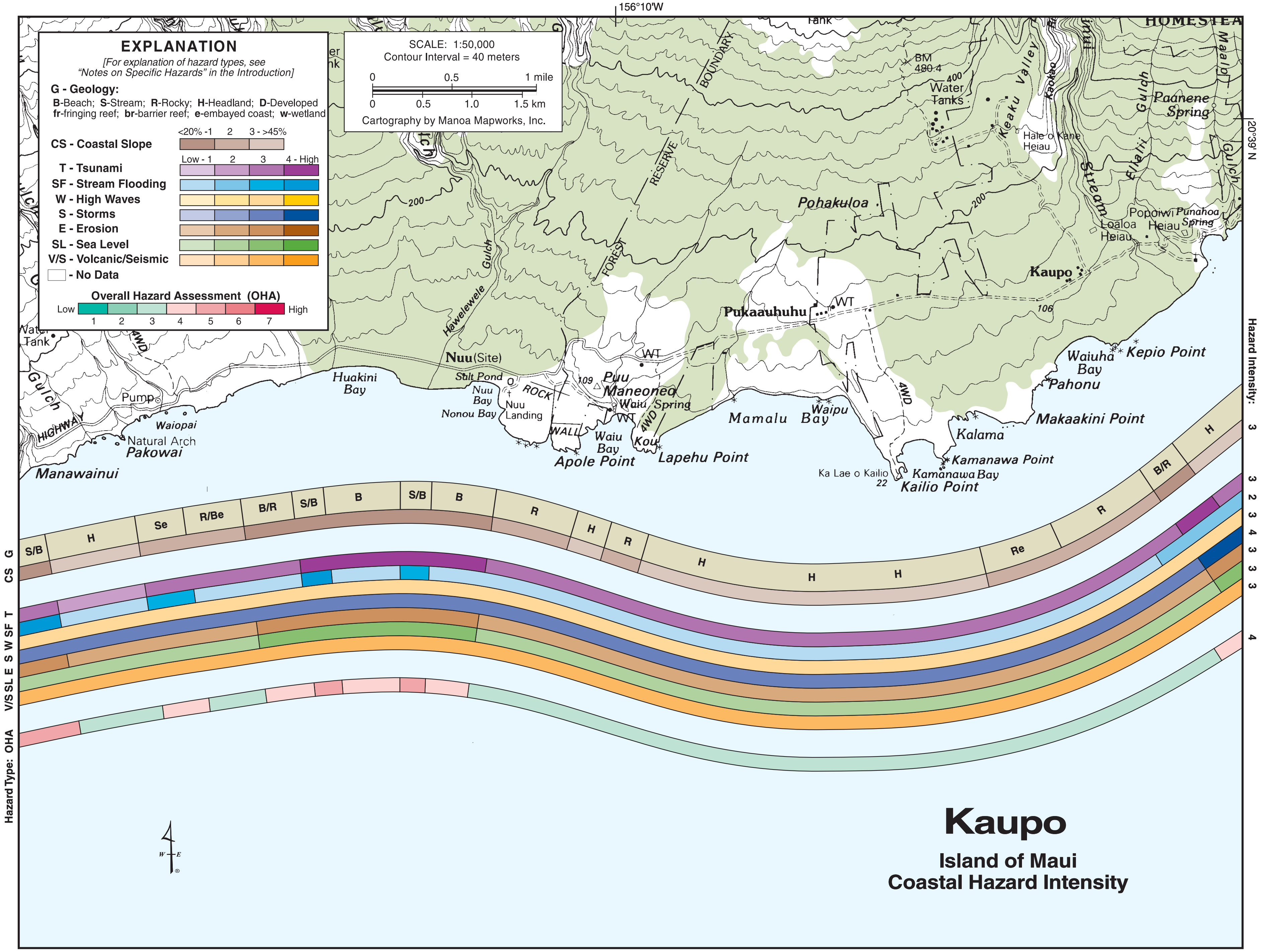
The coast from Puhilele Point west to Makaakini Point becomes increasingly arid as the coastal slope gradually flattens in the lee of Haleakala Volcano. Extensive rocky headlands along the coast near Kipahulu and Mokulau give way to isolated cliffs separated by numerous streams that reach the sea at small low-lying embayments between Kaapipa Point and Kalepa Point. There are a few small isolated beaches at Maulili Bay, Kaapahu Bay, Mokulau, and Waiuha Bay. Many small rocky islands and sea stacks fringe this coast. This region lacks fringing reefs and receives wind-generated swell from the easterly trade winds and southern swell during summer months.

The Overall Hazard Assessment (OHA) is high (6) at the low-lying embayed coasts found at the stream mouths in Maulili Bay, and Kaapahu Bay where there exists a combination of moderately high ranking for high waves, erosion, sea-level rise, and seismicity, and high threat due to tsunami, stream flooding, and storms. However, because the stream flooding hazard is substantially less of a threat in the more arid embayments west of Mokulau, the OHA is reduced to moderate to high (5). In between these bays, along the headlands near Old Landing, Kamilo Point, Kalepa Point, Mokuia Point, and Papaloa many of these hazards are reduced by the steep rocky headlands, and as a result, the OHA is reduced to moderate (4). From Puhilele Point to Kaapipa Point, tsunami and storm hazards are similarly ranked moderately high. Beyond Ahole Rock, these two threats are ranked high at the small embayments within Maulili Bay, Kaapahu Bay, and around Mokulau, and moderately high in between, where the coastal slope rises sharply into coastal cliffs. The stream flooding hazard is moderately low throughout the region except at small embayments that coincide with river mouths. At these locations, the stream flooding hazard is ranked high. The high wave threat is moderately high along the entire Kipahulu coast, which is exposed to high northeast swell, as is the volcanic/seismic hazard because of Maui's position in the seismic hazard zone 2. Hazards due to erosion and sea-level rise, however, are both ranked moderately low along the steeper rocky headlands, but are elevated to moderately high at the small, low-lying coastal embayments of Maulili, Kaapahu, Mokulau, and Waiuha Bays.

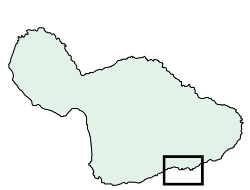


Mokulau Landing, west of Kipahulu on southeast Maui, has steep, gravel beaches and numerous offshore rocks.





Base Credit: USGS 1:50,000 Kipahulu Valley, Hawaii 5719 II W733 Edition 1-DMA



Kaupo

The coast in the Kaupo region is largely rocky with steep headlands along Mamalu Bay, Waiu Bay, and Manawainui. Small beaches occur within coves at Nuu Bay, Huakini Bay, and Waiopai. Even though annual rainfall along this coast (30-35 inches per year) is only half that of Hana, stream channels and gulches that flow during intense rain events dissect the shoreline at Waiu Bay, Huakini Bay, and Waiopai. The coastal slope is greatest at the headlands and least in the region of Huakini Bay. This south-facing coast lacks offshore reefs. The exposure to south swell and refracting trade-wind waves is manifested in numerous erosional features including sea stacks and islets near Kailio Point, rugged cliffs of Apole Point, and a natural arch at Pakowai.

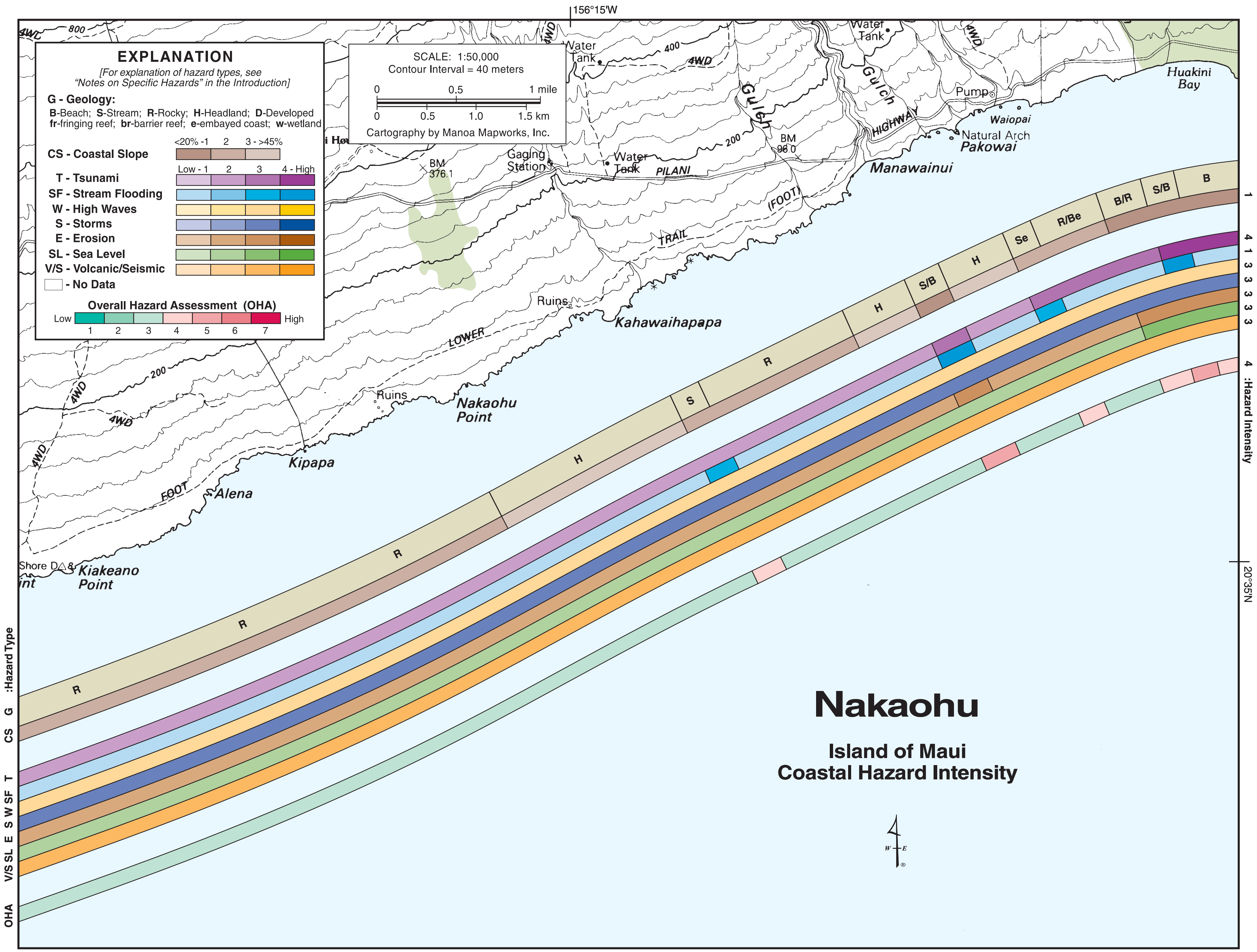
The Overall Hazard Assessment (OHA) is moderate to low (3) in the eastern half of the Kaupo coastline, where steep rocky headlands uniformly mitigate against the dynamic hazards. West of Apole Point the OHA varies primarily as a function of coastal slope and the occurence of coastal streams. In Huakini Bay, the lower slope, coincident with higher tsunami, erosion, and sea-level rise hazards, increases the overall hazard to moderate (4). In addition, at the stream mouths in Huakini Bay, where there is a higher stream flooding threat, the OHA is increased to moderate to high (5). At the stream mouth near Waiopai, the OHA is moderate (4), but along the headlands surrounding it, it is reduced to moderate to low (3). The predominance of steep headlands partly mitigates against tsunami, high wave, and storm hazards, which are all ranked moderately high along this coast, except at the low-lying Huakini Bay, where the tsunami hazard is increased to high. The stream flooding threat is ranked low due to the arid climate here, but is moderately high at the stream mouth in Nuu, and high at the stream mouths along Huakini Bay and Pakowai, which flood during intense rain events. Along the eastern half of the Kaupo coast, erosion and sea-level-rise hazards are ranked moderately low because of the mitigating effects of the steep headlands. Between Apole Point and Waiopai, where the coast has a lower slope, both are raised to moderately high. Beyond Waiopai, where there are steeper headlands, these hazards are again reduced to moderately low. The volcanic/seismic threat is ranked moderately high because of the region's location in the seismic hazard zone 2.

Low coastal cliffs and gently sloping volcanic terraces formed of numerous lava flows are common along the south-facing, arid, and windy Kaupo coast

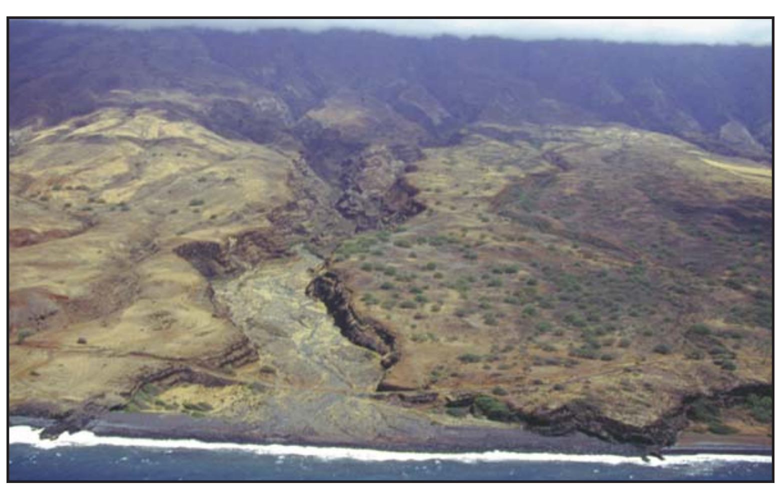
Nakaohu

The coastline surrounding Nakaohu Point is arid and relatively remote. Annual rainfall along this coast is between 25 and 30 in, making it hot and dry year round. The coastal road climbs up the southeast flank of Haleakala Volcano west of Manawainui, so coastal access is limited to foot paths and four-wheel drive trails. Three gulches cut their way to the shore between Manawainui and Kahawaihapapa; two of these have small beaches at their mouths. Otherwise, the coast is predominantly rocky with headlands and small cliffs that plunge into the sea.

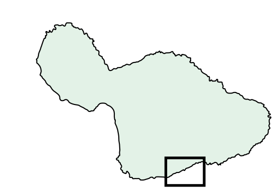
The Overall Hazard Assessment (OHA) varies between moderate to high (5) at Manawainui, where the stream mouth coincides with a relatively low-lying coastal embayment to moderate to low (3) along the steep rocky cliffs that comprise most of this coast. At the stream mouth at Kahawaihapapa it is moderate (4) due to the stream flooding hazard. The tsunami hazard is ranked moderately high at the stream mouth in the Manawainui embayment. West of Manawainui, it is reduced to moderately low. The stream flooding threat is low along this coast except at the stream mouths at Manawainui and Kahawaihapapa, where it is high and moderately high, respectively. High wave and storm hazards are ranked moderately high throughout the entire region. Erosion is greatest at the low-lying embayment of Manawainui, where it is ranked moderately high. Surrounding Manawainui, the erosion hazard is moderately low as is the sea-level rise threat along this entire stretch of coast. The volcanic/seismic hazard is moderately high along the Nakaohu coast as it is along the entire coast of Maui which lies within seismic hazard zone 2.

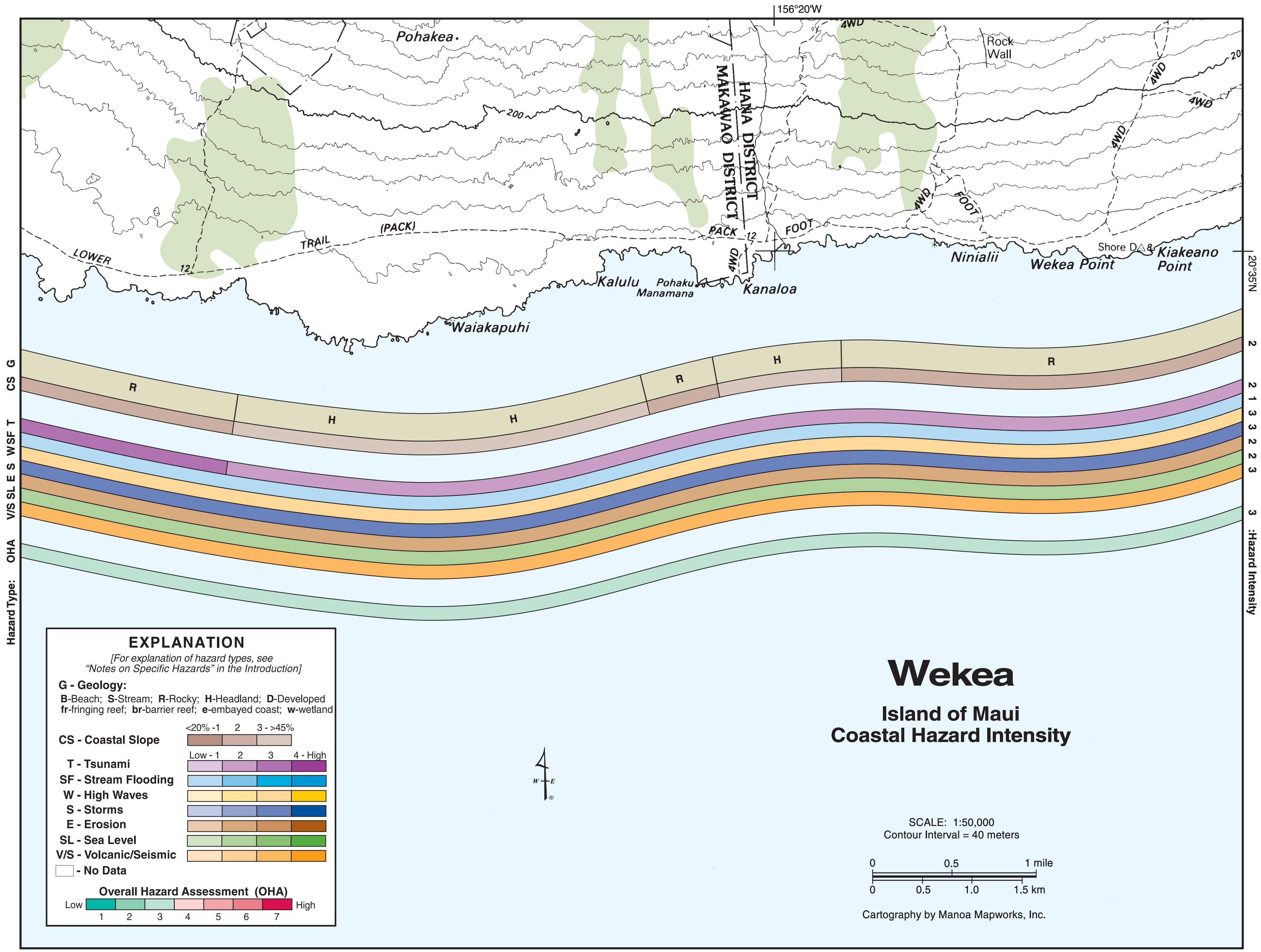


Base Credit: USGS 1:50,000 Waiakoa, Hawaii 5719 III W733 Edition 1-DMA and USGS 1:50,000 Kipahulu Valley, Hawaii 5719 II W733 Edition 1-DMA



Steep gravel beaches line most of the Nakaohu coast. The cobbles and boulders are transported to the shore from the mountain above through large gulches (foreground) that are periodically awash during high rains.





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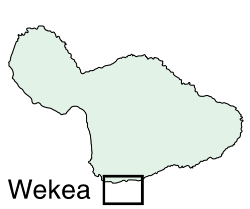


Wekea

Annual rainfall along the Wekea coast is less than 20 inches. The coastal road passes high above the shoreline as it winds west and around the southern point of Maui limiting access to this coast to small foot trails and four-wheel drive roads. This is a rocky coast with extensive headlands at Kanaloa and along Waiakapuhi. There are no sandy beaches amidst the plentiful rocky outcrops and wind-swept bluffs that reach toward the pounding surf along the shoreline.

The Overall Hazard Assessment (OHA) along the Wekea coast is uniformly moderate to low (3) owing to the relatively constant coastal slopes and extent of rocky headlands found along the entire shoreline. The cliffs and bluffs along this stretch of coast mitigate against tsunami, erosion, and sea-level rise threats, which are all ranked moderately low. The tsunami hazard is increased to moderately high west of the headland surrounding Waiakapuhi where the coastal slope is lowest. Stream flooding is ranked low due to the extreme aridity in the region. Facing due south, the Wekea Point coast is directly exposed to south swell and approaching storms and, as a result, high wave and storm hazards are both ranked moderately high. The volcanic/seismic hazard is ranked moderately high for the entire Maui coast which lies within seismic hazard zone 2.

A view of one of the many recent lava flows that mark the arid and gently sloping Wekea coast.

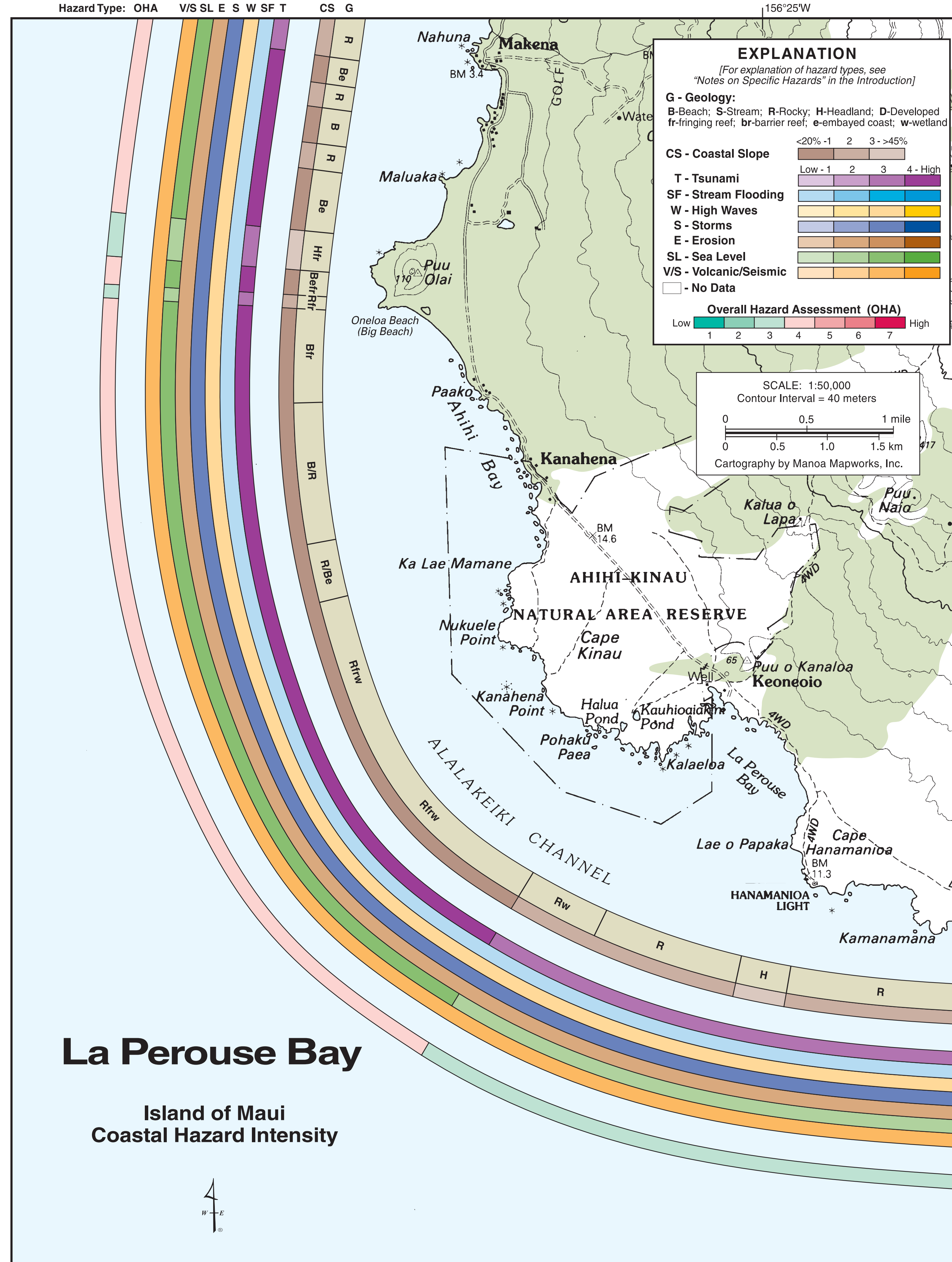
La Perouse Bay

Magnificent turquoise waters beautifully highlight the rugged basalt coastline surrounding La Perouse Bay. Lava flows extend to the sea, many ending in small 2 to 15-ft cliffs that encircle the rocky bays and points of the southwest corner of Maui. This region is relatively remote and access south of Puu Olai is only afforded by traversing a poor road by foot or a four-wheel drive vehicle. Beautiful white carbonate sandy beaches exist near Makena and just south of Puu Olai, but south of Ahihi Bay the shoreline is rocky with only isolated boulder and cobble beaches. Scattered fringing reefs extend between Kanahena Point and the point at Puu Olai. This region of Maui is relatively well protected from the trade winds and receives very little rain in the lee of Haleakala; it is also very arid.

The tsunami hazard is ranked moderately high south of Pohaku Paea, where the coast is relatively low. However, toward the northwest, where the slope is even lower, the tsunami hazard is ranked high, except at the small headlands of Puu Olai, where it is reduced to moderately high. The stream-flooding threat is low along this coast due to the extreme aridity and lack of stream channels reaching the shore. The threat from high waves, however, is ranked moderately high, because this coast receives south swell, refracted north swell, and trade-wind waves. The storm hazard is also ranked moderately high along the entire coast. The hazard due to erosion is moderately low because of the largely rocky coastline. The volcanic/seismic hazard is moderately high along this coast as it is along the entire Maui coast, which lies within seismic hazard zone 2. The threat due to sea-level rise is ranked moderately high in the lower-lying areas between Makena and Pohaku Paea, except at the headlands of Puu Olai, where it is reduced to moderately low, similar to the steeper cliffs south of Pohaku Paea.

For the southern region, where the coast is comprised of steep rocky cliffs, the Overall Hazard Assessment (OHA) is moderate to low (3). Northwest of Pohaku Paea, it is increased to moderate (4) for all but the headlands near Puu Olai. There the steep rocky slopes mitigate against tsunami and sea-level rise, and as a result the OHA is moderate to low (3).

A small black and red sand beach at the base of Puu Olai cinder cone (at right) is derived from the young volcanic flows that formed Puu Olai and La Perouse Bay in the distance.



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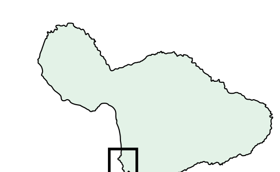
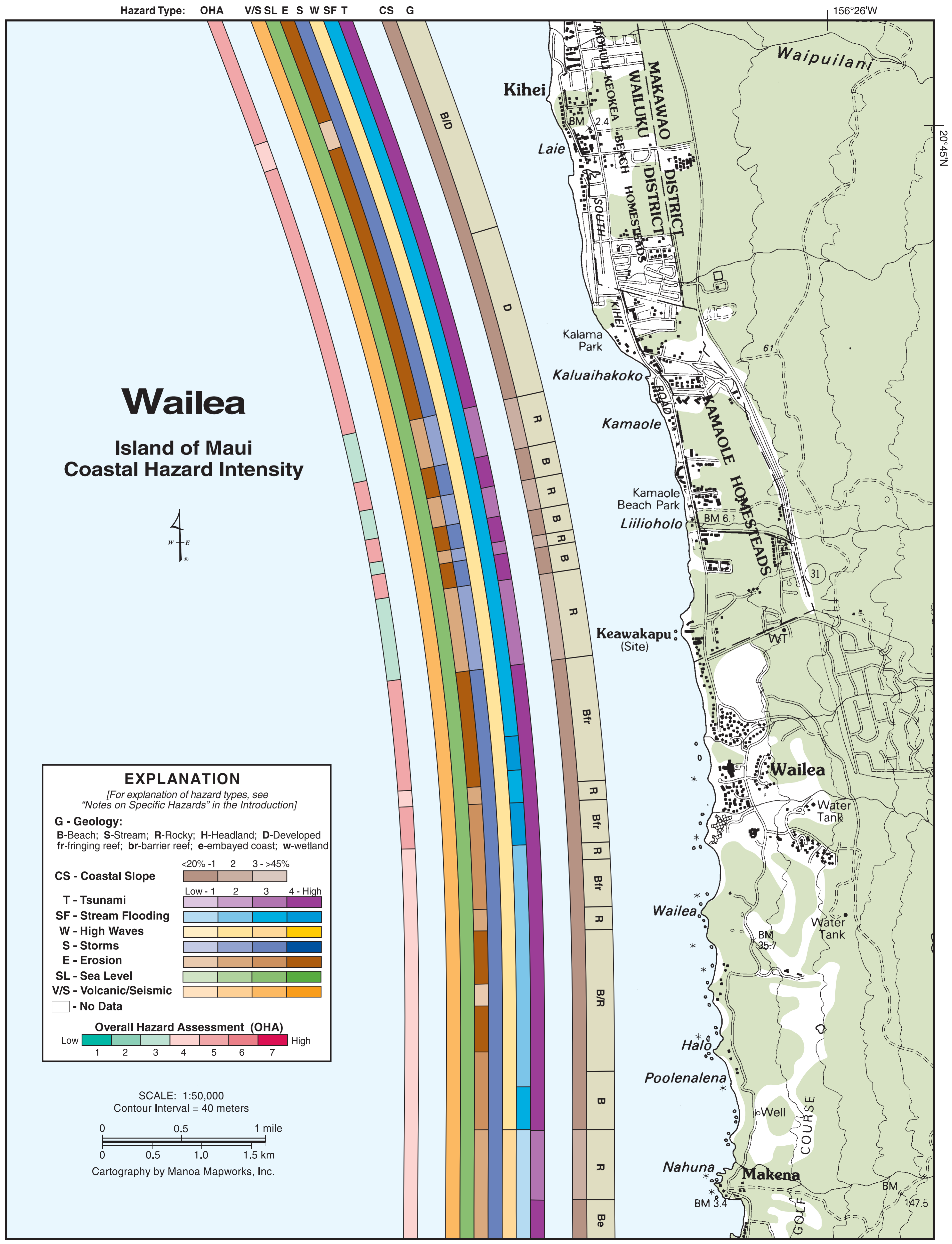
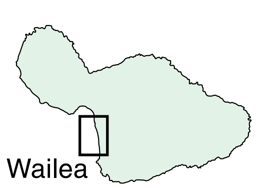


La Perouse Bay





Wailea

The intensively developed Wailea coastline, between Laie Beach in Kihei and Makena, is a center of tourism and recreation on Maui. Beautiful pocket beaches isolated between rocky outcrops provide excellent access to the south shore's warm waters and prime reefs for diving. Fringing reefs are more well developed along this coast than along the southeastern coast. Many rocky outcrops serve as small headlands to protect the generally low-lying shoreline in this region. Despite the aridity here, several stream channels exist along this coast, evidence of episodic transport of stream runoff from the wetter upper slopes of Haleakala Volcano.

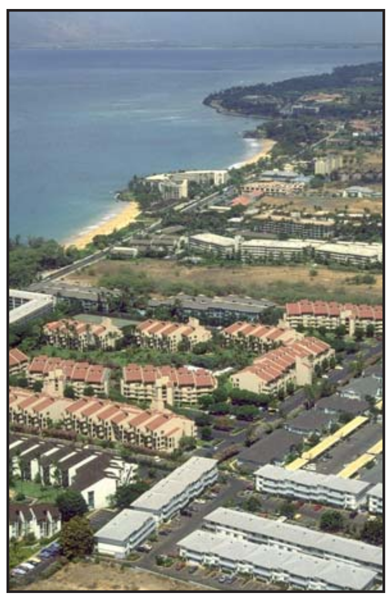
The Overall Hazard Assessment (OHA) is moderate to high (5) between south Kihei and Wialea, except at the small rocky headlands where it is reduced to moderate to low (3) reflecting the lower hazards associated with tsunami, storm, and erosion. South of Wailea, where stream flooding is moderately low, the OHA is moderate (4). The tsunami hazard is ranked high along this entire coast, except for small rocky outcrops at Kamaole, Liilioholo, and Keawakapu, where it is ranked moderately high, and at Nahuna where it is low. The stream flooding hazard is ranked moderately high north of Keawakapu to Kihei. At the small beaches that coincide with stream mouths near Wailea and in the south at Poolenalena, it is ranked high, but between them it is reduced to moderately low, and south of Nahuna it is ranked low. Facing nearly directly west, this coast is affected by limited south-swell wave energy and only slight north swell refraction, so the high wave hazard is ranked moderately low. The storm threat is ranked moderately high for the low-lying coast of Kihei and Wailea, because of its exposure to the southwest where tropical storms most frequently track as they pass the Hawaiian Islands. It is reduced to moderately low along the rocky headlands separating the beaches, except south of Wailea where it is moderately high. The hazard due to erosion is ranked high for the majority of this low-lying coast, but is reduced to moderately low at the rocky outcrops. The sea-level and volcanic/seismic hazards are both ranked moderately high along the entire coast of Wailea, which is low sloping and within seismic hazard zone 2

Small pocket beaches interspersed with irregular low-lying volcanic rocky points characterize the developed Wailea coast.

Maalaea

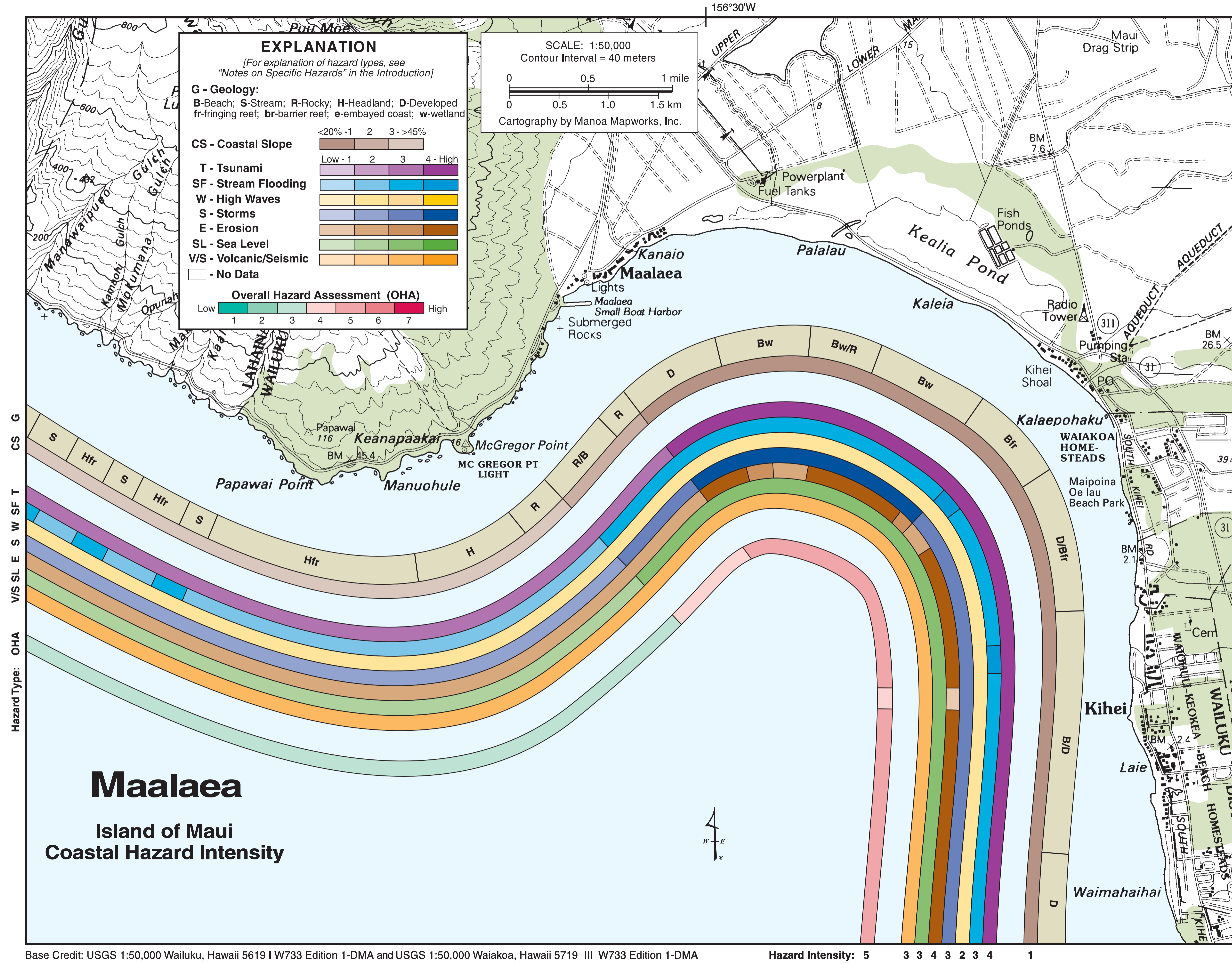
The Maalaea coast is heavily developed along the Kihei shoreline and surrounding the Maalaea Boat Harbor. Considerable development during the last several decades has been accompanied by severe erosion and beach loss around Kihei. Narrow, sand-starved beaches are common throughout Kihei, where shallow fringing reefs parallel the coast. A long but narrow sandy beach is backed by sand dunes and wetlands between Kalaepohaku and Kanaio. Here at the southern part of the Maui isthmus, enormous alluvial fans descend from Haleakala Volcano to meet older fans reaching seaward from West Maui Mountains. Kealia Pond and the surrounding low lands can be inundated by storm waves and stream flooding. Steep rocky cliffs that line the western edge of the bay beyond Maalaea Harbor flatten toward the beach on the west side of Papawai Point, where small streams empty West Maui Mountains at the sea.

The Overall Hazard Assessment (OHA) is greatest along the Kihei coastline, where the low-lying coastal slope is most prone to tsunami, stream flooding, and erosion. As a result, it is moderate to high (5) from Kihei to Kanaio, except at a region of accreting coastline in Kihei, where it

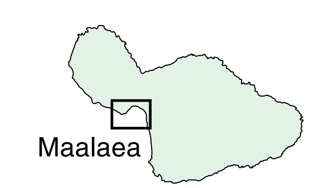


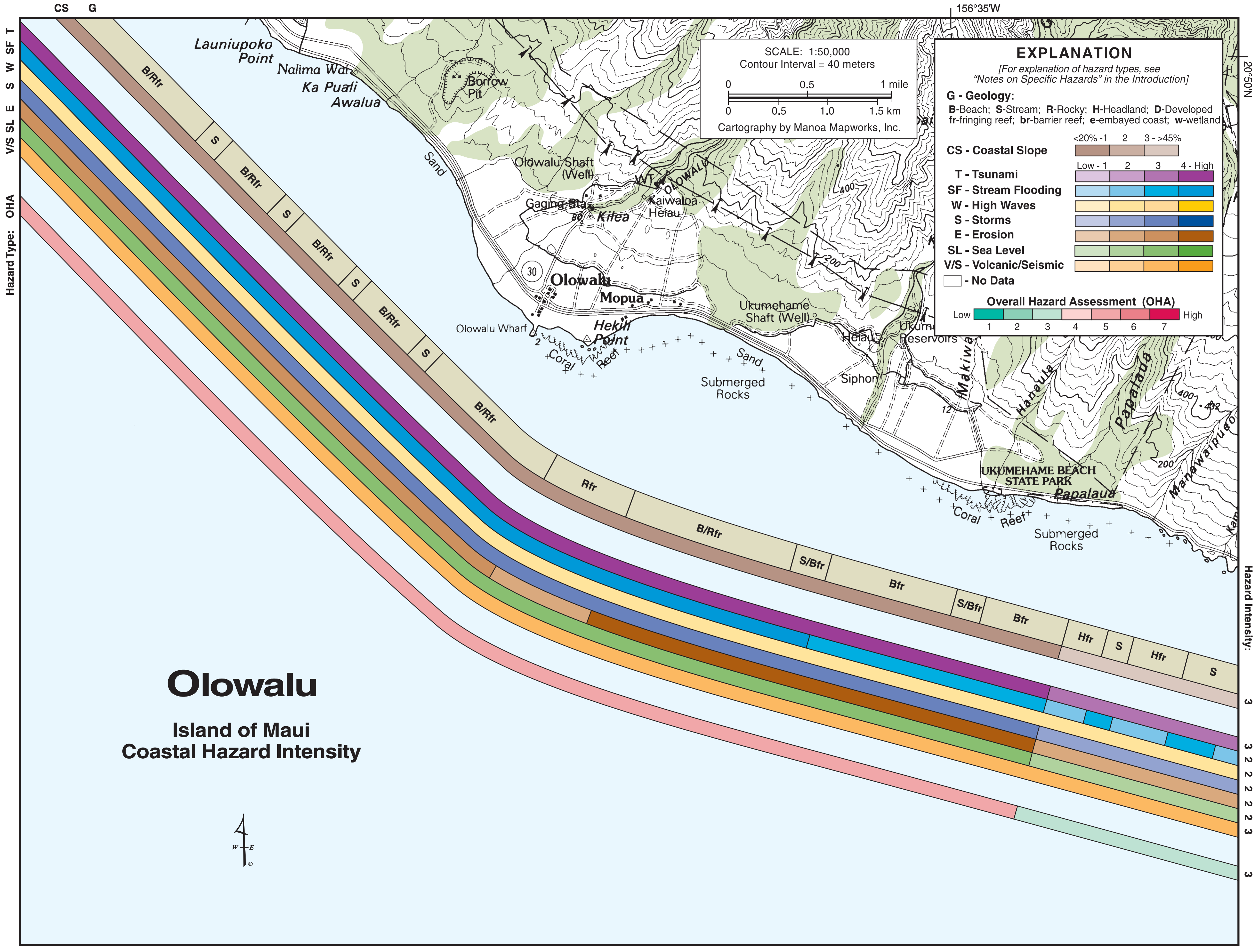
Small pocket beaches of Kihei (left) give way to a long, narrow beach fronting Kealia Pond (right) where rapid sea-level rise and chronic erosion are threatening the coastal road.

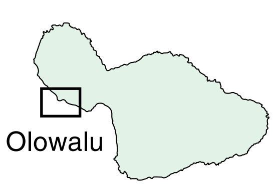
is reduced to moderate (4). Between the Maalaea Boat Harbor and McGregor Point, the OHA is moderate (4) where the steeper slopes mitigate stream flooding and storms. Beyond McGregor Point, where the steep cliffs coincide with the reduced tsunami, stream flooding, and storm threats, it is moderate to low (3). While historical tsunamis have not been as large in Maalaea Bay as on the northern and eastern shores, they tend to get focused toward the center of the bay. Because of the lower coastal slopes in Kihei, the tsunami hazard is high on the eastern side of the bay and only moderately high along the western side. Stream flooding is ranked moderately high between Kihei and Maalaea except at the stream mouths in northern Kihei and at Kalaepohaku, where it is increased to high. West of McGregor Point, the stream flooding threat is reduced to moderately low, with the exception of two stream mouths just west of Papawai Point, where it is moderately high. The hazard from high waves is moderately low because approaching waves, greatest from southern swell, lose substantial energy as they refract into the bay to reach the Maalaea shore. The storm threat, however, is high in the middle of the bay where storm winds and surge can be focused when making landfall. Along the east and west sides of the bay, the storm threat is reduced to moderately high, but beyond McGregor Point, it is reduced further to moderately low. Erosion is high throughout the Kihei region except for localized accretion. At the low-lying beaches seaward of Kealia Pond and Kanaio, it is high. It is reduced along the natural dune areas in between, and along the steep cliffs west of Maalaea Boat Harbor. The sea-level hazard is moderately high along the low Kihei coast and only moderately low west of McGregor Point. The volcanic/seismic threat is moderately high as it is along the entire Maui coast which is within seismic hazard zone 2.



Base Credit: USGS 1:50,000 Wailuku, Hawaii 5619 I W733 Edition 1-DMA and USGS 1:50,000 Waiakoa, Hawaii 5719 III W733 Edition 1-DMA







Olowalu

Between Laniupoko Point and Ukumehame Beach State Park, the coast is relatively undeveloped except for the small recreational area at Olowalu. The steep slopes east of Ukumehame Beach give way to a low-lying coastal terrace that parallels the long and narrow sandy beach with isolated regions of small boulders and cobbles. Offshore fringing reef and rocks line the shore, providing good diving when calm and a popular surf spot during summer. Numerous stream channels incise the arid coastal terrace. The channels are generally dry or low year-round, but are known to quickly flood during extreme rainfall events in the immediate area and in the West Maui Mountains just inland of the coastal zone.

The Overall Hazard Assessment (OHA) of moderate to high (5) along the Olowalu coast between Launiupoko Point and the southern limit of Ukumehame Beach State Park is a direct function of the low coastal slope of this area. To the east, where the individual hazards are mitigated by the increase in coastal slope and harder substrate, it is reduced to moderate to low (3). The tsunami hazard is ranked high along this entire low-lying coastal terrace. It is reduced to moderately high for the steeper rocky headlands to the east. The stream-flooding hazard is moderately high for the Ukumehame Beach area and moderately low only along the steep headlands to the east. Along the Olowalu coast, it is ranked high where larger streams drain the increasingly wetter mountains to the west. The threat from high waves is ranked moderately low here where the greatest waves reaching the shoreline are associated with southern swell. The storm hazard however, is ranked moderately high along this coast which faces southwest toward the majority of passing storms that track to the west. Erosion is greatest along the lowest-lying beach areas between Ukumehame Beach and Mopua, where it is ranked high. Sections of the coastal highway, the sole southern access to West Maui, are threatened by coastal erosion and have been protected with armoring by the State Department of Transportation. At Mopua, the rocky point partly mitigates erosion, so this hazard is reduced to moderately low. Beyond Hekili Point, the erosion threat is ranked moderately high. The sea level and volcanic/seismic hazards are moderately high because of the low coastal slope and Olowalu's location within seismic hazard zone 2.

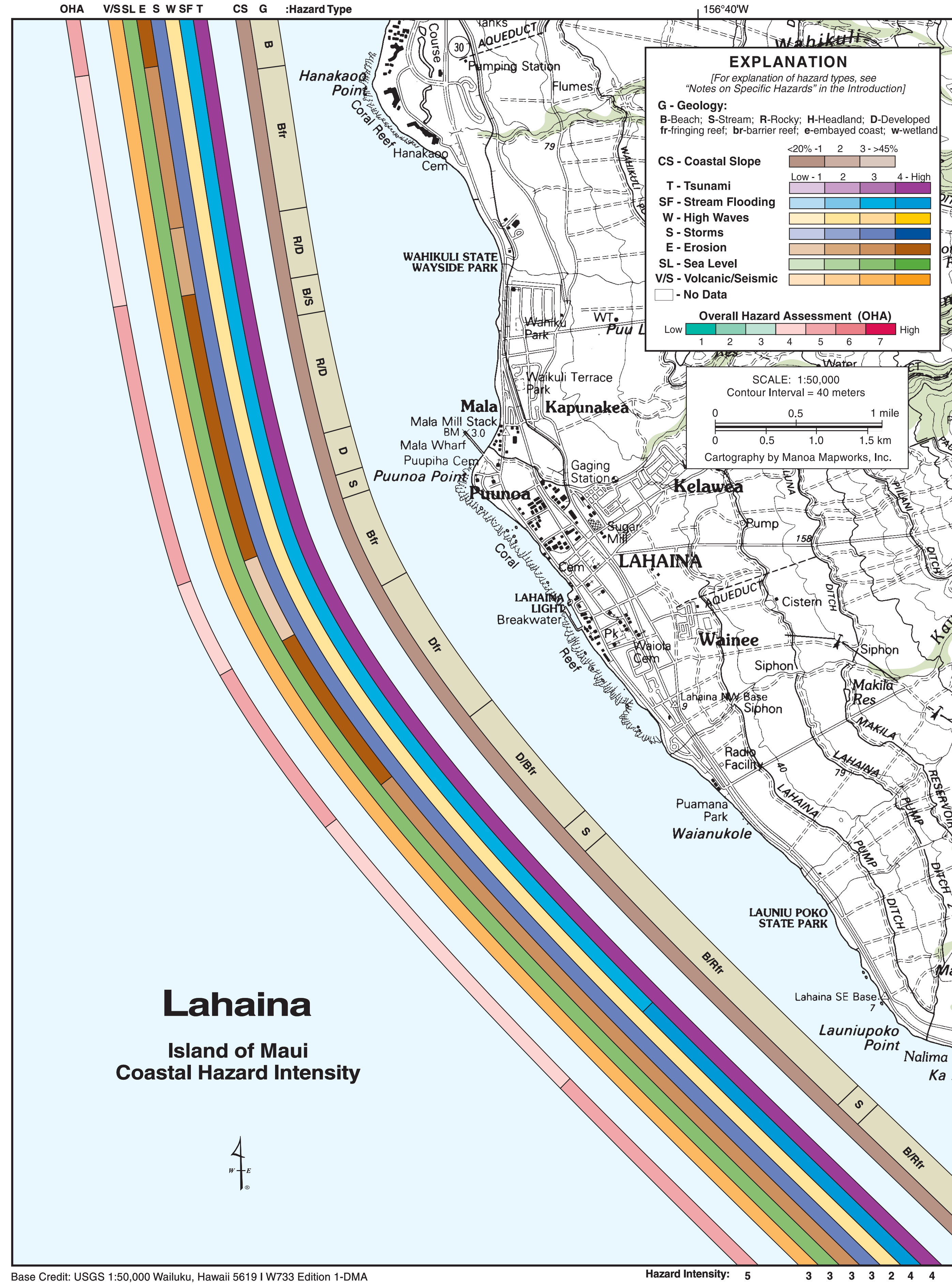
Steep cliffs form the Olowalu coastline east of Ukumehame Beach State Park (foreground). Rapid sea-level rise and annual high-wave overwash threaten access along the coastal road between west and east Maui.

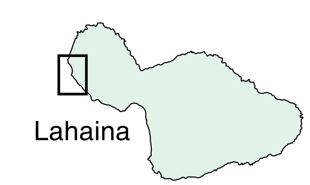
Lahaina

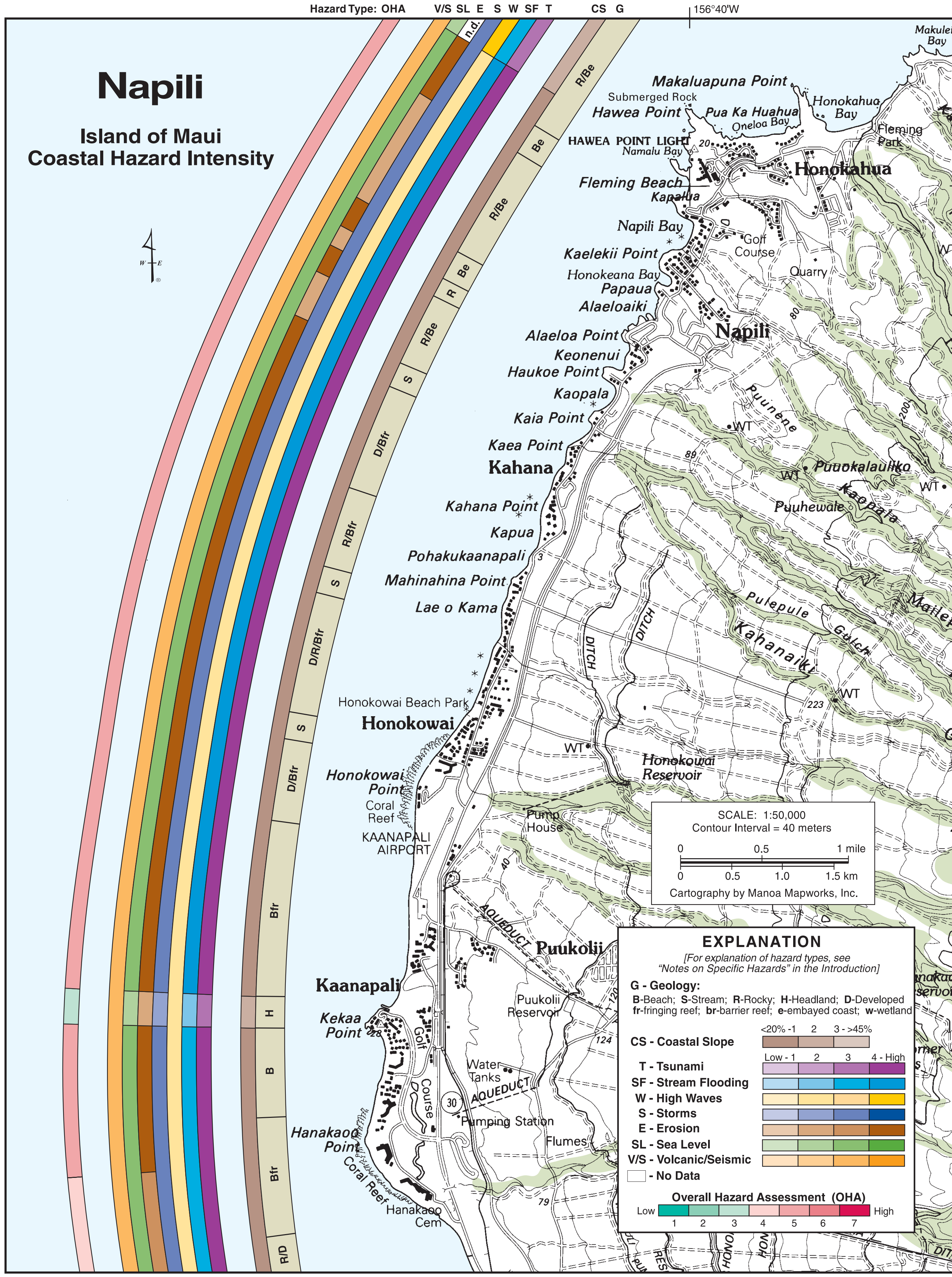
The coast of Lahaina is heavily developed with numerous seawalls and rock revetments built to protect the shorefront homes and tourist establishments surrounding Lahaina. A narrow strip of beach can be found near Mala Wharf and Wahikuli State Beach Park, but from the breakwater in Lahaina south to Puamana Park, it is often covered at high tide. The rest of the shoreline is rocky and/or lined with seawalls. Fringing reefs thrive in the clear, warm waters and break the energy associated with incoming south swell. The coastal slope is generally low and stream flow has been channelized near downtown Lahaina.

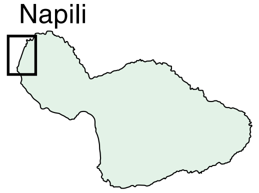
Because the coastal slope is uniformly low along the Lahaina coast, it is the implementation of flood control measures, both along the shore and hillsides, that affects the differences in the Overall Hazard Assessment (OHA). While stream channelization in the Lahaina area mitigates stream flooding and reduces the OHA, the emplacement of seawalls has accelerated beach loss and has increased the overall hazard. The OHA is moderate to high (5) between the Lahaina Harbor and Puunoa and between Mala Wharf and Wahikuli State Beach Park, where erosion rates are high. Surrounding these areas, the OHA is moderate (4). To the south of Launiu Poko State Park, it is moderate to high (5) reflecting the high stream flooding hazard associated with the natural stream channels there. During the past 100 years, 19 damaging floods have occurred in the Lahaina area. Heavy rains and poor drainage of the Lahaina coastal plain lead to standing runoff and extensive flood damage. As a result, stream flooding is high in the southern half of the region, and moderately high north of Launiu Poko State Park, where channels and flood mitigation measures have been implemented. While tsunami wave heights in Lahaina historically have not been as great as the north shore of Maui, the low slope justifies the high tsunami hazard ranking for the area. The high wave hazard is ranked moderately low, as this coast experiences, at most, wave heights of 5-7 ft from south swell and large north swell that refract around west Maui. The storm hazard is ranked moderately high along the Lahaina coast, which, facing west, is subject to high winds associated with tropical storms that normally track to the west of the islands. Erosion is ranked moderately high throughout most of the area, except in Lahaina where recent beach loss justifies the ranking of high just north of the harbor and between Mala wharf and Wahikuli State Beach Park. Near Puunoa, the erosion threat is reduced to low because of moderate shoreline accretion, and at Wahikuli State Beach Park, where there is a rocky headland, it is moderately low. The sea level and volcanic/seismic hazards are moderately high along the Lahaina coast which is low lying and within seismic hazard zone 2.

Narrow, shallow fringing reefs provide some protection from storm and high-wave overwash to the extensively developed Lahaina ocean front.





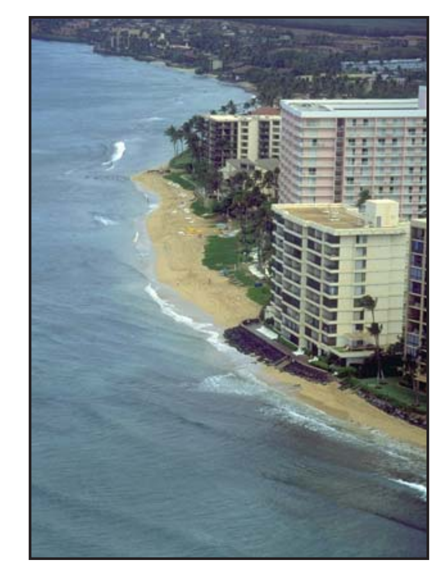




Napili

The highly developed coast of Napili is famous for its luxurious resorts, hotels, and golf courses that are built directly alongside one of Hawaii's most scenic shorelines. The relatively low coastal plain rises only slightly near Napili and Honokahua, where isolated coves are partly protected from refracting trade wind waves and northerly winter swell by steep rocky outcrops and points. Offshore, a fringing reef partly dissipates wave energy, acting as a buffer for the beaches that extend along south Kaanapali and within the bays of Kahana, Napili, and Honokahua. Numerous small streams originating in the West Maui Mountains flow across this gently sloping coastal terrace.

The Overall Hazard Assessment (OHA) for the Napili coast is moderate to high (5) and is largely influenced by high tsunami, stream flooding, and erosion hazards and moderately high storm, sea-level rise, and seismicity threats on this Maui coastline. Historically, there have been few tsunamis recorded at Kaanapali. However, a 15 ft tsunami that made landfall there in 1946 supports the high tsunami hazard ranking in this region, except at Kekaa Point, where it is reduced to moderately high. Flash floods and heavy rains, such as in March of 1968, when 24 inches fell in 48 hours, support a high stream-flooding hazard ranking, except at Kekaa Point, where it is moderately low. The threat from high waves is moderately low along the Napili coast, which is partly sheltered from approaching northwest swell by the island of Molokai. Storm and sea-level rise hazards are ranked moderately high, except at the steep Kekaa Point headland, where they are reduced to moderately low. High rates of erosion have recently led to the proliferation of seawalls and revetments to protect coastal property which in turn has exacerbated beach loss. As a result, the erosion hazard is ranked high except at the rocky headlands at Kekaa, Haukoe, Alaeloa, and Kaelekii Points, where it is moderately low. The volcanic/seismic hazard is ranked moderately high along the Napili coast due to its location in seismic hazard zone 2. The OHA is reduced to moderate to low (3) at Kekaa Point, while south of Hanakaoo Point it is increased to moderate (4), reflecting the greater hazards associated with the lower coastal slope there.



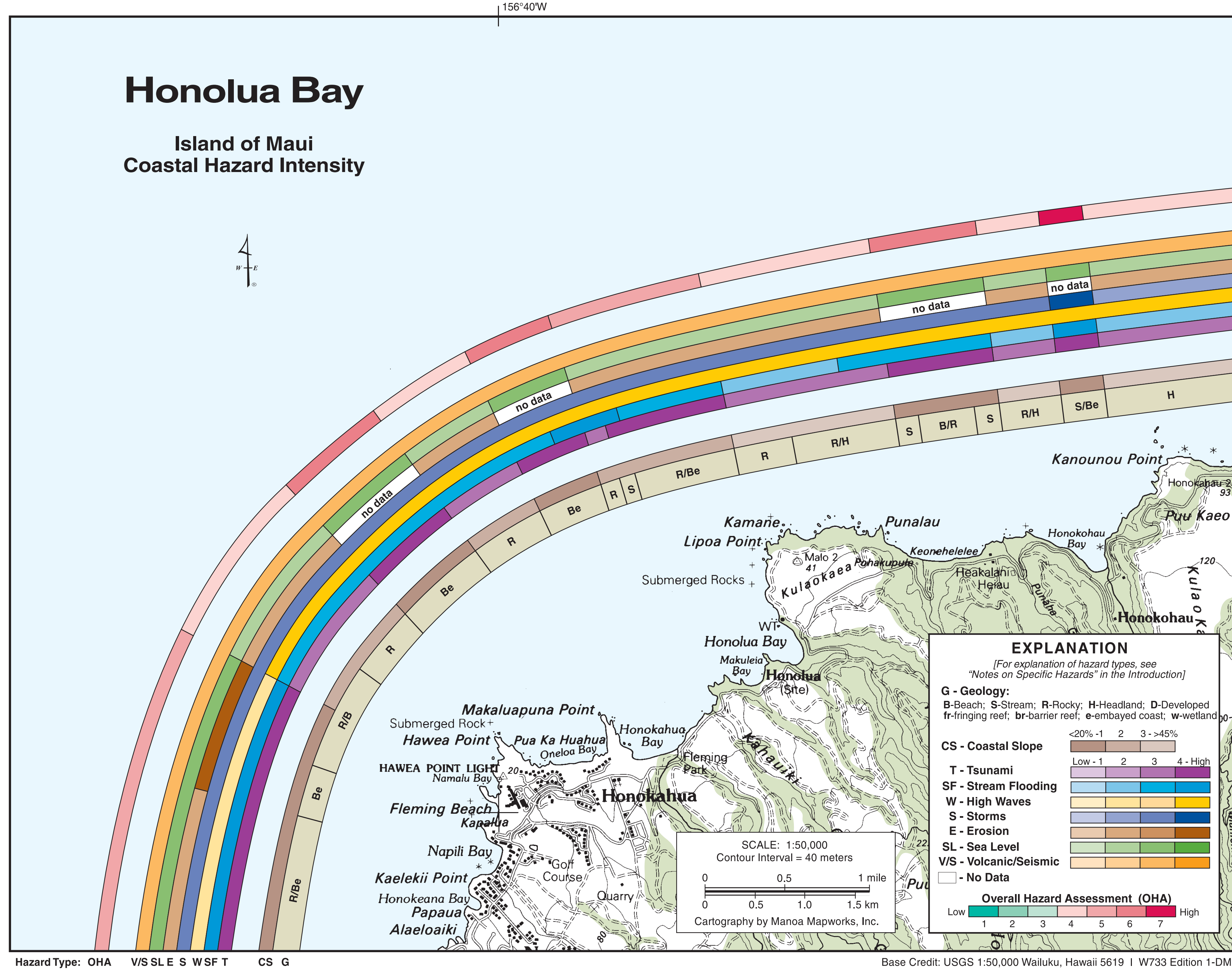
Extensive development has occurred along the small and narrow beaches of the Napili coast, while fossil beachrock ridges near Honokowai, marking the position of the former shoreline, lie submerged offshore as evidence of rapid sea-level rise and erosion.

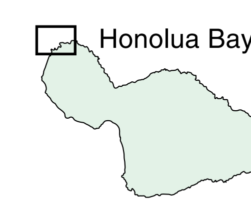
Honolua Bay

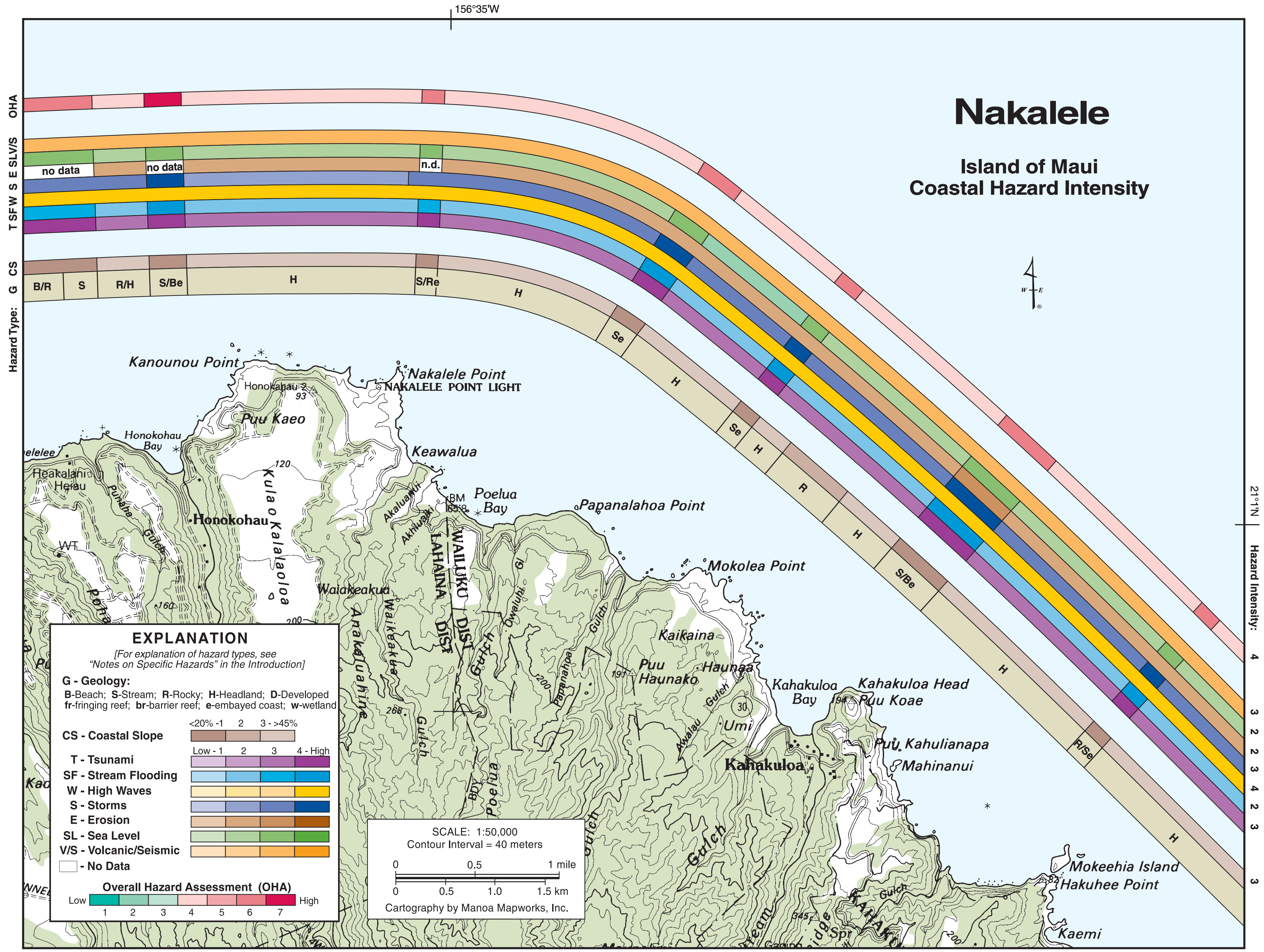
The scenic coastline of Honolua Bay northeast of Hawea Point is marked by prominent rocky headlands that reach northwest towards Molokai and shelter the bays of Oneloa, Honokahua, Honolua, and Honokohau. The headlands become significantly steeper and taller toward Honokohau, where seacliffs reach heights of 60-200 ft above the sea. Streams cut through the Honolua Volcanic Series where they meet sandy beaches at Oneloa and Honokohau Bays and Flemmings Beach and gravel beaches at Honolua and Honokahau. There are no true fringing reefs along this coast, but inside Honolua and Honokohau Bays significant reef flats have developed, providing great diving during the calm summer months and extraordinary surfing when north swells hit in winter.

The Overall Hazard Assessment (OHA) for the Honolua coast is variable but relatively high. At Honokohau Bay, it is very high (7), primarily due to its low, embayed setting that experiences flooding from both the sea and from intense rain events. The OHA at Oneloa, Honokohua, and Keonehelelee bays is reduced slightly to a ranking of high (6) due to the decreased threat from stream flooding. A moderate to high (5) OHA for the north end of Honokohua Bay is further diminished by the mitigating effects of the steeper slopes against sea-level rise. Along the steep rocky headlands between these prominent embayments, the OHA is moderate (4) reflecting the intense dynamic hazards in this area. Tsunami heights have historically been greatest along this portion of the Maui coast. The 1946 tsunami runup recorded at Honolua Bay was 24 ft! This supports a high tsunami hazard ranking at the embayments of Honolua, Makuleia, Oneloa, Honokohua, Keonehelelee, and Honokohau. It is reduced to moderately high at the rocky headlands in between. The stream-flooding hazard is ranked high at the low embayments of Honokohua and Honokohau Bays while only moderately high at the stream mouths that empty into Oneloa, Honolua, and Keonehelelee Bays. It is further reduced to moderately low at the steep headland between Lipoa Point and Punalau. The hazard due to high waves is ranked high north of Hawea Point, where north swell often generates breaking-wave heights of 10 to 20 ft in the winter months. The storm hazard is ranked moderately high for the entire region except at Honokohau Bay where it is increased to high. Because the coast largely consists of rocky headlands, the erosion hazard is ranked moderately low. Exceptions are made to several areas where there are no data available. The hazard associated with sea-level rise is clearly of greater concern at the low-lying coastal embayments of Oneloa, Honokohua, Honolua, Keonehelelee, and Honokohau Bays, where it is ranked moderately high. Along the rocky headlands between these bays, this hazard is reduced to moderately low. The volcanc/seismic hazard along the Honolua Bay coast is moderately high as it lies in seismic hazard zone 2.

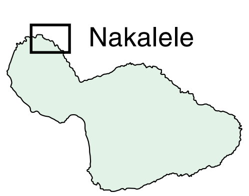
Gently sloped coves along the southern portion of the Honolua Bay coast have been densely developed, like Napili Bay, however, past Honlolua Bay and Lipoa Point to the north, the steep-cliffed coast is rugged and undeveloped.







Base Credit: USGS 1:50,000 Wailuku, Hawaii 5619 I W733 Edition 1-DMA



Nakalele

The relatively remote coast of Nakalele Point is remarkably scenic, commonly windy, and extremely rugged. The coast road winds in and out of the low-lying coastal embayments of Keawalua, Poelua, and Kahakuloa, up to steep majestic headlands in between that rise 400 to 600 ft from the ocean below. Numerous sea stacks and rocky islets sit offshore, constantly pounded by the persistent trade winds and the associated waves. Much of this coast is inaccessible except by boat or traversing steep cliffs by foot. Streams have incised deep channels through the Honolua and Wailuku volcanic series to create the beautiful valleys that make Maui famous. Only a few of the small embayments that these streams empty into have sandy beaches; most of them are characterized by gravel and cobble beaches.

While most of the individual hazards along this coast are relatively high, topography plays a substantial role in mitigating them. The low-lying coastal embayments along the Nakalele coast are at greatest risk, and it is precisely in these areas that the greatest development, mainly residential, exists. It is along this portion of the Maui coast that tsunami wave heights of 30 ft were observed during the 1946 tsunami generated in the Aleutian Islands offshore of Alaska. As a result the Overall Hazard Assessment (OHA) at these embayments is high (6). Along the steeper headlands between embayments, it is reduced to moderate (4). The stream-flooding hazard, also ranked high at the low-lying coastal embayments, is reduced to moderately low along the headlands where there are no stream mouths. The hazard from high waves is ranked high, while the storm hazard varies between moderately high at headlands and high in embayments along this coast, except between Kanounou and Nakalele Points, where it is moderately low. The erosion hazard is ranked moderately low along most of this coast except at the low-lying embayment of Kahakuloa, where it is moderately high. The threat from sea-level rise is greatest in the low-lying bays, where it is ranked moderately high. Along the rocky headlands it is ranked moderately low. The volcanic/seismic hazard is ranked moderately high throughout the entire Nakalele Point area which lies within seismic hazard zone 2.

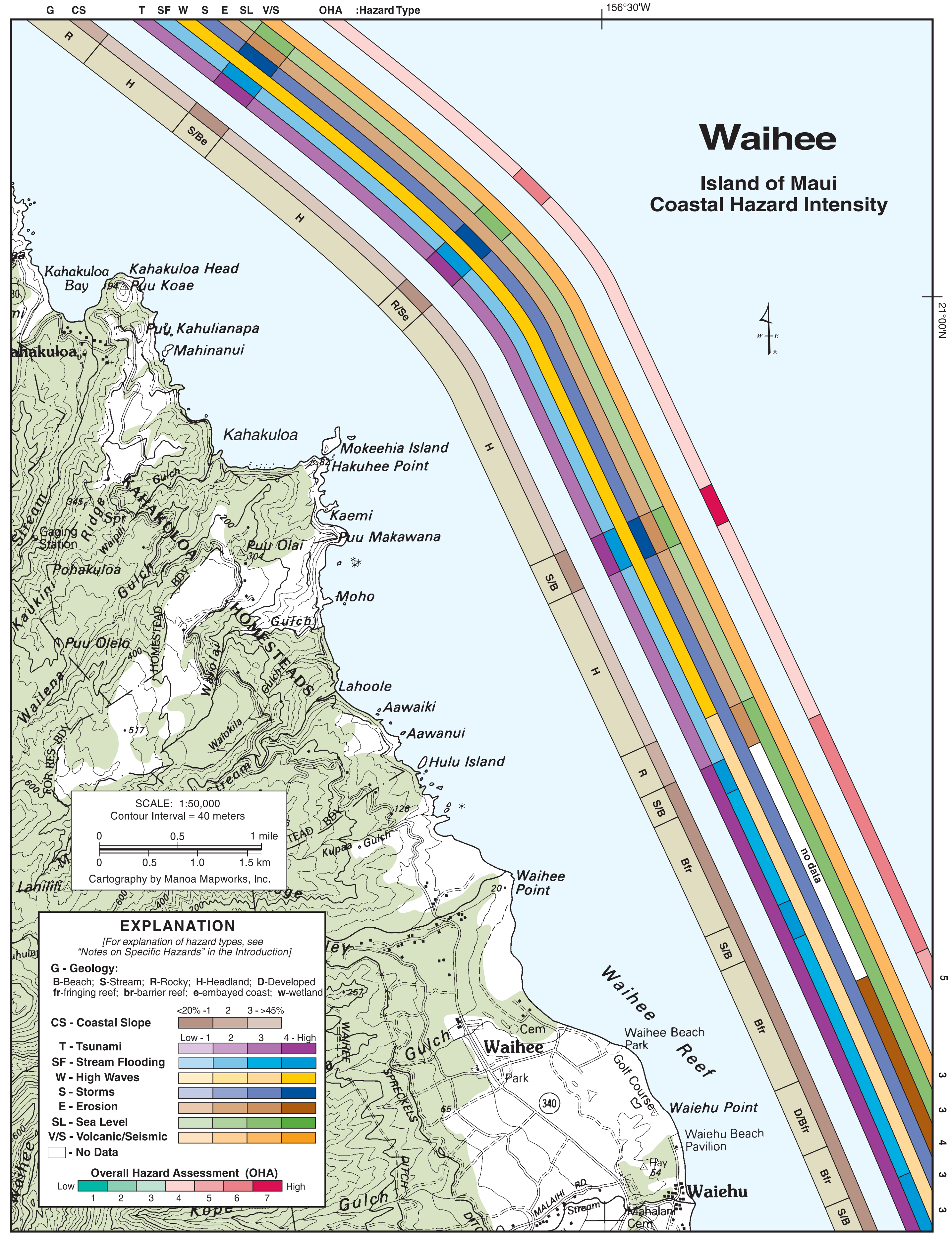
Beautiful, rocky headlands like Kahakuloa Head (shown here) mark the steep-cliffed coast of Nakalele.

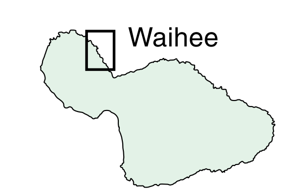
Waihee

Southeast of Kahakuloa Head, the Waihee coastline descends gradually beyond Hakuhee Point to the coastal terrace near Waiehu on the northern portion of the isthmus separating east and west Maui. Kahakuloa Head and Mokeehia Island are large, steep, rocky outcrops that stand tall against the battering of the trade winds and their waves. Many smaller rocks and islets sit offshore between Puu Makawana and Waihee Point, but to the south beyond Waihee Point, a well-developed fringing reef abruptly widens and extends east along most of the north shore of Maui. Many streams emanating from the West Maui Mountains bring rounded cobbles and boulders and rocky gravel to the beaches in this area.

The Overall Hazard Assessment (OHA) for the Waihee coast varies between moderate and high. The OHA for the embayment of Kahakuloa is moderate to high (5) and at Lahoole it is very high (7) due to the higher tsunami, stream-flooding, storm, and sea-level threats. It is along this coastline, specifically at Hakuhee Point, that a 33 ft tsunami wave height was recorded in 1946, the largest in Maui during historical times. It is also along this stretch of coast that flash floods and storm waves frequently inundate the low-lying coastal embayments that coincide with stream mouths. Between these bays, where the coastal headland slopes are great, the OHA is moderate (4). Beyond Waihee Point, the OHA is high (6) due to high tsunami and erosion hazards, and the relatively high stream-flooding, high wave, storm, sea-level rise, and seismic hazards along that low-lying portion of the Waihee coast. The tsunami hazard along the Waihee coast is moderately high along the steep headlands, high at the confluence of Waipili Gulch at Kahakuloa and in the embayments at Lahoole and Waihee Point, and high east of Waihee Point, where the coastal slope is uniformly low. The stream-flooding hazard resembles the tsunami hazard except that it is ranked moderately low along the rocky headlands. In addition, beyond Waihee Point, the stream flooding hazard is ranked moderately high along the coastal terrace, except at the stream mouths emptying near Waihee Point and Waiehu Beach Park, where it is ranked high. The hazard from high waves is ranked high along most of the Waihee coast, where waves accompanying north swell annually reach breaking wave heights of 15-25 ft between Kahakuloa Head and Waihee Point. The high wave hazard is reduced to moderately high to the east of Waihee Point, where the fringing reef offshore helps to dissipate wave energy approaching the shoreline. The storm threat is ranked high at the low-lying beaches between Kahakuloa Bay and Waihee Point, and moderately high between these embayments and east of Waihee Point. While the erosion and sea-level threats are ranked moderately low along the steep headlands and moderately high at the low coastal embayments, erosion is boosted to a ranking of high beyond Waiehu Point. Unfortunately, data to assess erosion along the Waihee area are unavailable. The volcanic/seismic hazard is moderately high along the Waihee coast due to its location in seismic hazard zone 2.

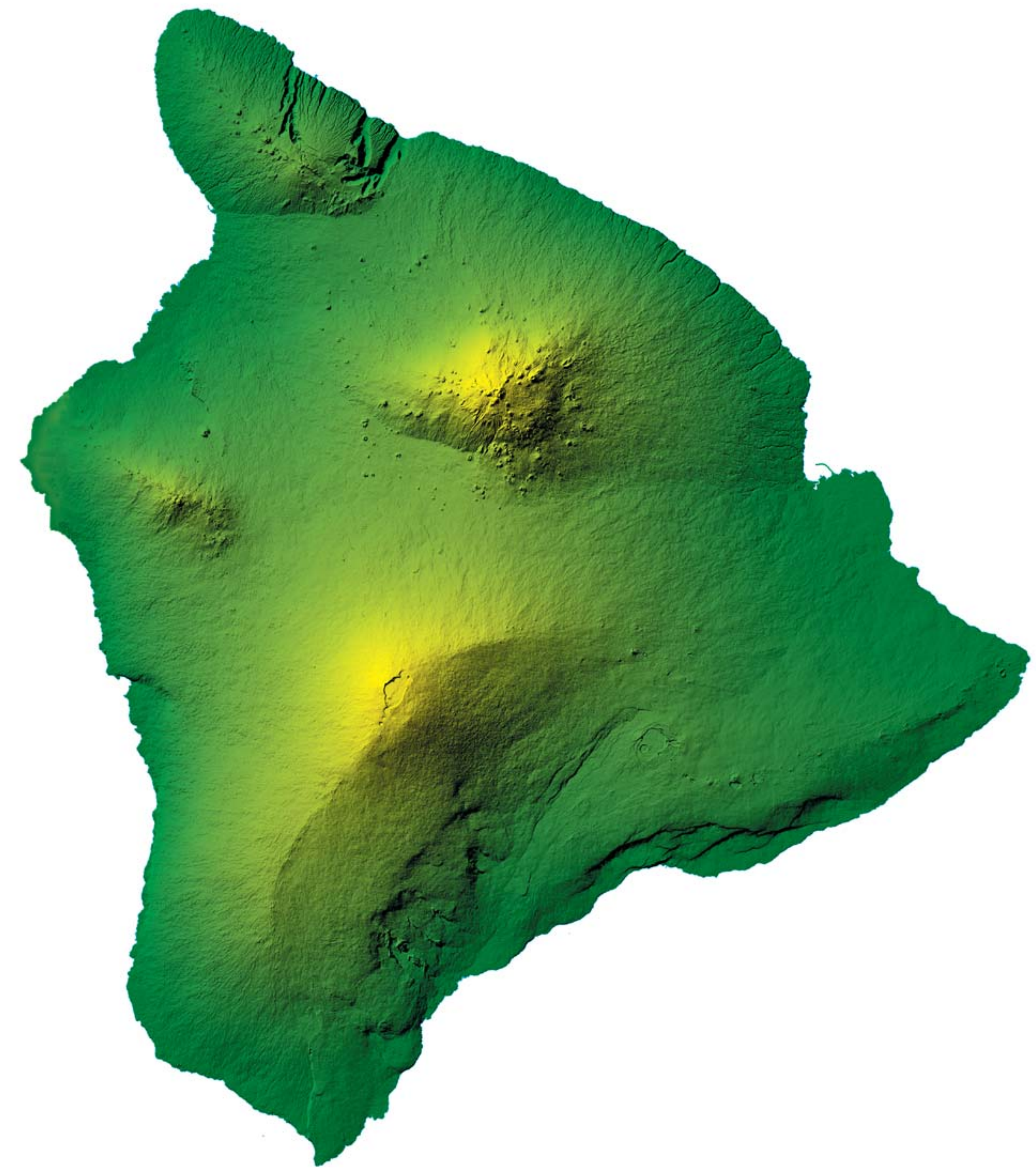
The Waihee coast is undeveloped north of Waihee Point where the rocky cliffs are steep.





Hawaii

The Big Island of Hawaii is the youngest and largest of the Hawaiian Islands. Volcanism has historically been very active on Hawaii and since 1983, Kilauea volcano has steadily erupted and sent numerous lava flows down its east and southeast flanks to the sea. These volcanic eruptions continue to enlarge the Big Island. Recent studies, however, indicate that the islands grow with episodic and often catastrophic landslides that may result in large portions of the volcano being spalled off into the sea like calving glaciers. Lava flows extend the shoreline out into the sea, sometimes at the expense of pre-existing coastal lands and settlements. For example, in 1992 lava flows buried the famous Black Sand Beach and the town of Kalapana as they formed a new coastal terrace and extended the shoreline 0.5 mi seaward. Periodically, the island foundations do not adequately support these coastal terraces, and rapid collapse or landsliding results in loss or abrupt subsidence of the coastal zone. Such events are known to produce devastating tsunamis, like those of 1868 and 1975 that inundated portions of the southeast coast of the Big Island. Earthquakes are common on the Big Island owing to the movement of magma within the volcanic edifice. Although the Big Island is geologically young, deep valleys carved into its mountain sides attest to active stream erosion. During high rainfall, floods are common along low-lying coastal zones.



Hawaii

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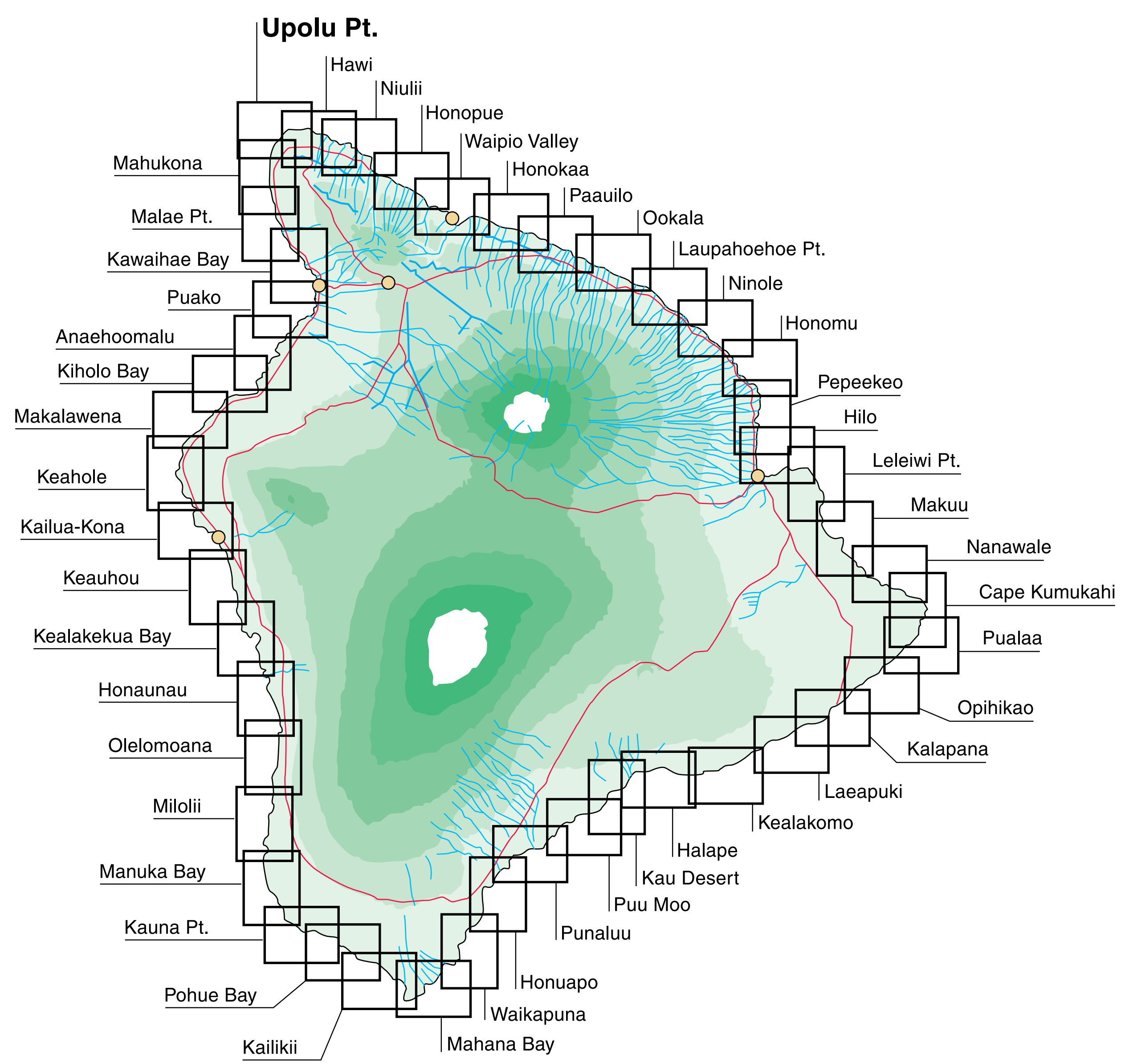


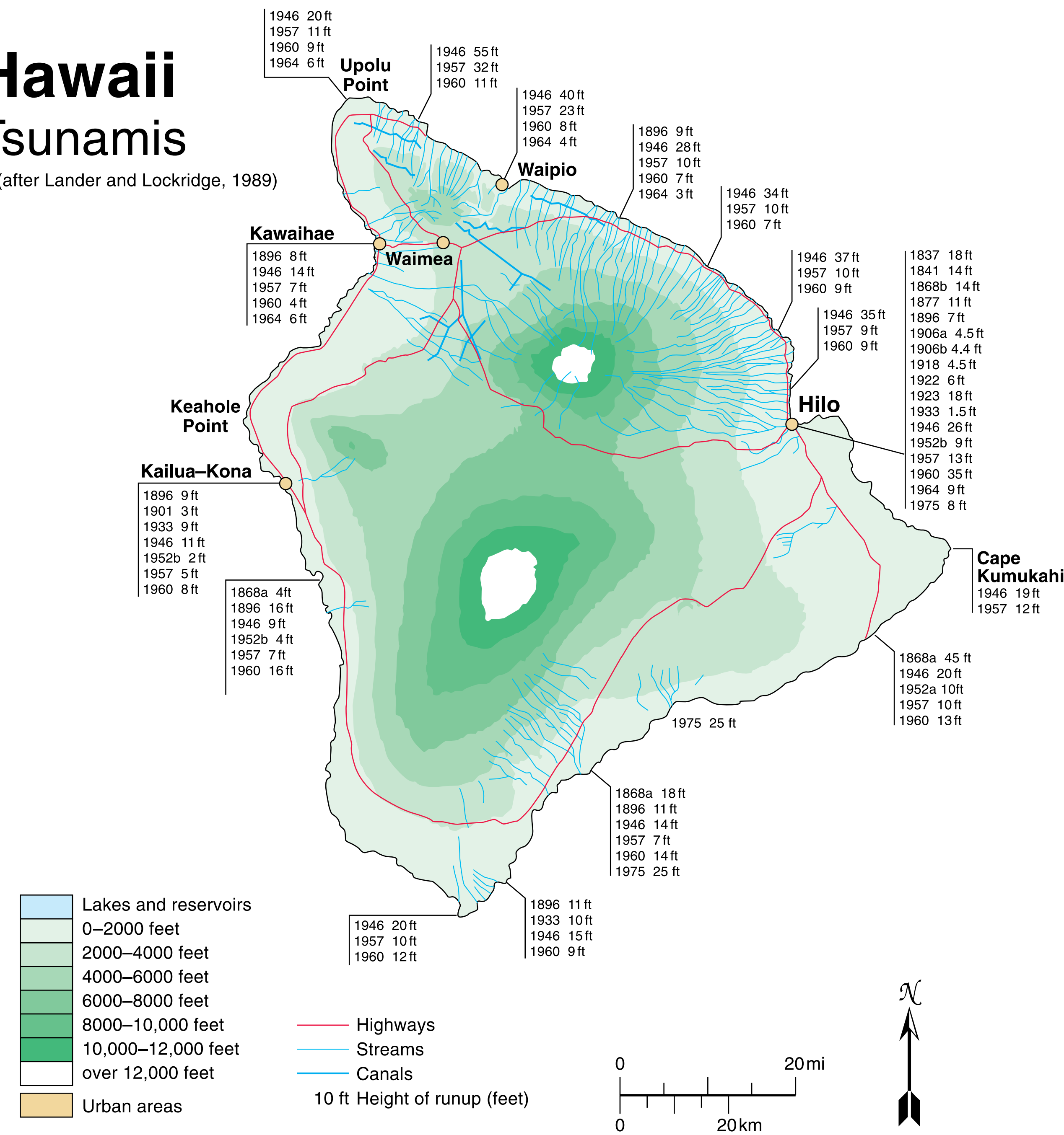
Tsunamis

A tsunami is a series of great waves most commonly caused by violent movement of the sea floor. It is characterized by high speed (up to 590 mph), long wave length (up to 120 mi), long period between successive crests (varying from 5 min to a few hours, generally 10 to 60 min), and low height in the open ocean. However, on the coast, a tsunami can flood inland 100's of feet or more and cause much damage and loss of life. Their impact is governed by the magnitude of seafloor displacement related to faulting, landslides, and/or volcanism. Other important factors influencing tsunami behavior are the distance over which they travel, the depth, topography, and morphology of the offshore region, and the aspect, slope, geology, and morphology of the shoreline they inundate. While storm-derived waves affect the shore in a generally predictable manner, tsunami waves are more chaotic. Hilo has experienced more damaging tsunamis than any other Hawaiian coastal city during recorded history. It is important to understand that tsunami waves are very different from ordinary storm waves in that their broad crests enable the water level to rise for several minutes as they pass. As a result, tsunami waves can inundate significantly farther inland than storm-generated waves of the same height. The only general rule is that runup heights tend to be greatest near headlands where the offshore bathymetry is steeper. This enables greater wave energy to reach the shore. Along gently sloping coasts, even though runup heights may be reduced due to dissipation offshore, inundation is greatest because the wave can push farther inland.

Since 1812, 26 tsunamis have had damaging consequences to Hawaiian shorelines. Of these, 25 (74%) have adversely impacted the Big Island of Hawaii. Four of these damaging tsunamis were generated by seismic displacements along Kilauea's southeastern flanks, the most recent being the 1975 Halape Earthquake. On November 29, 1975, the strongest earthquake measured in Hawaii this century caused approximately 10 ft of subsidence along the Halape coastal terrace. It produced a local tsunami wave that reached at least 25 ft in height and devastated the Halape area of the southeast coast within minutes. It sadly brought an end to the lives of two people camped at Halape. There was no warning and no time to respond. A similar local tsunami occurred on April 2, 1868, which washed away fishing villages and shipping facilities and in places displaced the nearshore seafloor such that shipping lanes could no longer be utilized. The remaining 22 damaging tsunamis traveled 1000's of miles from tectonically active regions of the Pacific including Alaska, and the Aleutian Islands, Chile, Japan, and Tonga. Even though most of these tsunamis took 10's of hours to reach Hawaiian waters from their distant source areas, very little warning, if any, was available, largely because very few islands exist between Hawaii and the Pacific Rim which could be used to detect their approach. Today, technologies including seafloor seismic and wave (pressure) sensors exist that can provide adequate warning. One of the most devastating of these distant tsunamis occurred on April 1, 1946. Runup heights of >9 ft were measured on all sides of the island and the maximum of 55 ft was reported near Upolu Point. In Hilo, the wave rushed up 26 ft and inundated the low-lying ocean front causing extensive damage, which would be relived by the 1957 and 1960 tsunamis. According to the historical database, on average a damaging tsunami reaches the Big Island's shores once every 7 years. Interestingly, the last 25 years have been extremely quiet; since 1975, not one tsunami has made landfall. Based on these data, one would conclude that a damaging tsunami is long overdue to hit the Big Island's coastal zone.

Hawaii
Tsunamis

(after Lander and Lockridge, 1989)



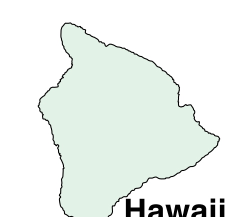
Large tsunamis* (>1m, 3.3 ft) with reported damage in the Hawaiian Islands

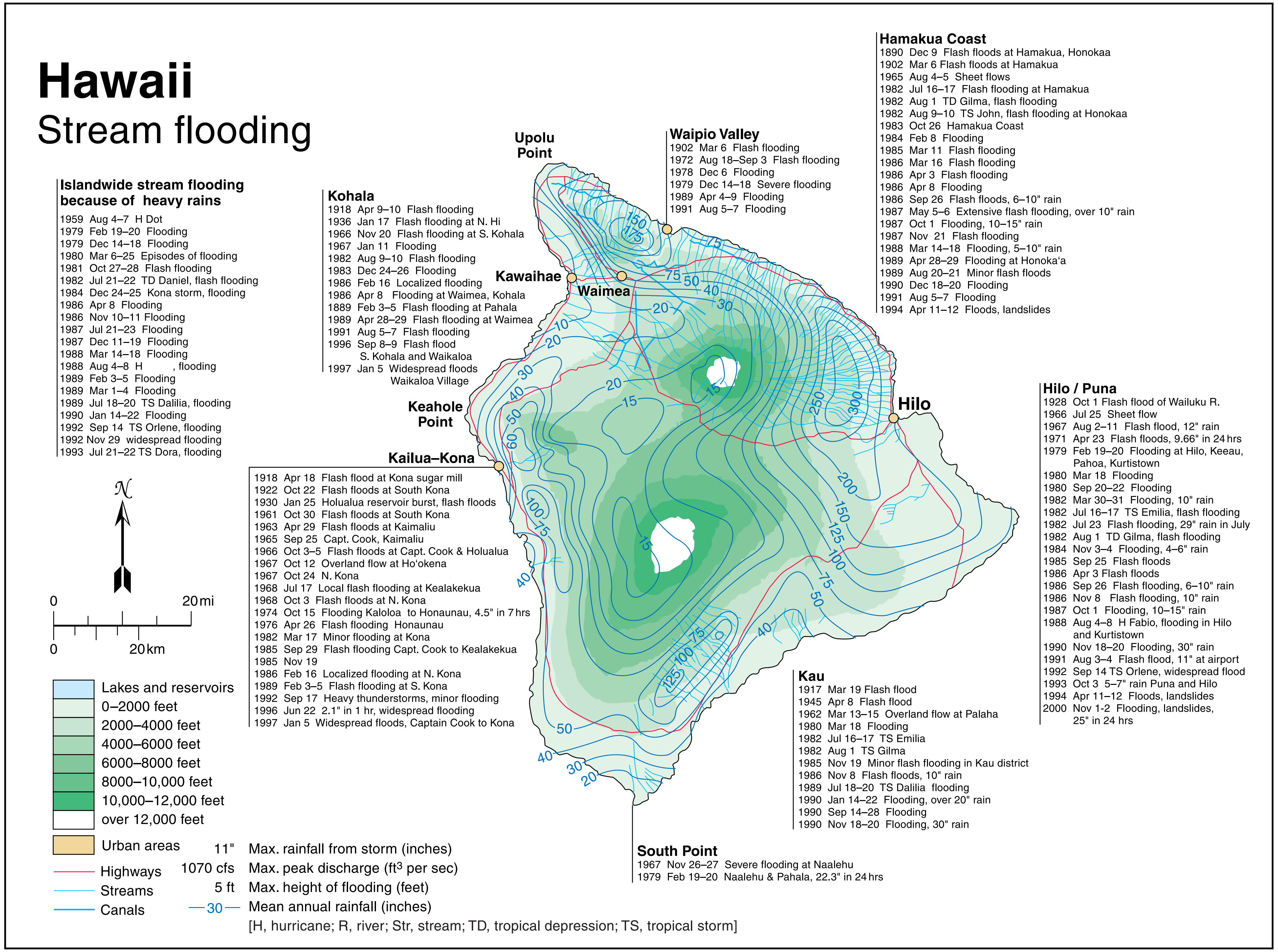
Year	Date	Area of origin	Magnitude**
1819	Apr 12	N Central Chile	M= 2.0
1835	Feb 20	Southern Chile	M = 4.0
1837	Nov 7	Southern Chile	M = 3.0
1841	May 17	Kamchatka	M = 2.0
1868a	Apr 3	SE Hawaii	M = 4.1
1868b	Aug 13	Northern Chile	M = 4.3
1868c	Oct 2	South Pacific	
1869	Jul 24	South Pacific	
1877	May 10	Northern Chile	M = 4.0
1878	Jan 20	Aleutian Is (?)	
1896	Jun 15	Japan	M = 4.0
1901	Aug 9	Tonga	
1906a	Jan 31	Colombia/Ecuador	M = 1.0
1906b	Aug 17	Central Chile	M = 2.0
1918	Sep 7	Kurils	M = 3.6
1919	Oct 2	Hawaii (H = 14 ft)	
1922	Nov 11	N Central Chile	M = 3.0
1923	Feb 3	Kamchatka	M = 3.0
1933	Mar 2	Japan	M = 3.0
1946	Apr 1	Eastern Aleutian Is	M = 5.0
1952a	Mar 17	Hawaii (H = 10 ft)	
1952b	Nov 4	Kamchatka	M = 4.0
1957	Mar 9	Central Aleutian Is	M = 3.5
1960	May 22	Chile	M = 4.5
1964	Mar 28	Gulf of Alaska	M = 4.5
1975	Nov 29	Big Island/Hawaii (H = 47 ft)	

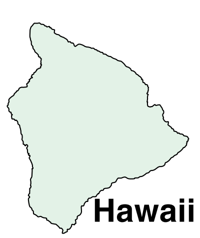
*Reliability of ≥ 3 (of 4)(Lander and Lockridge, 1989), runup > 1m (3.3 ft), and reported damage.

** Tsunami magnitude is defined by $M = \log_2 H$ as revised by Iida and others (1967), where H is the maximum runup height or amplitude on a coastline near the generating area.

Other tsunamis have occurred, such as that of Oct 1994, however, because of their low (<1 m) runup, insignificant damage, and/or uncertainty surrounding their timing and magnitude as noted in Lander and Lockridge (1989), they were not included here.







Stream flooding

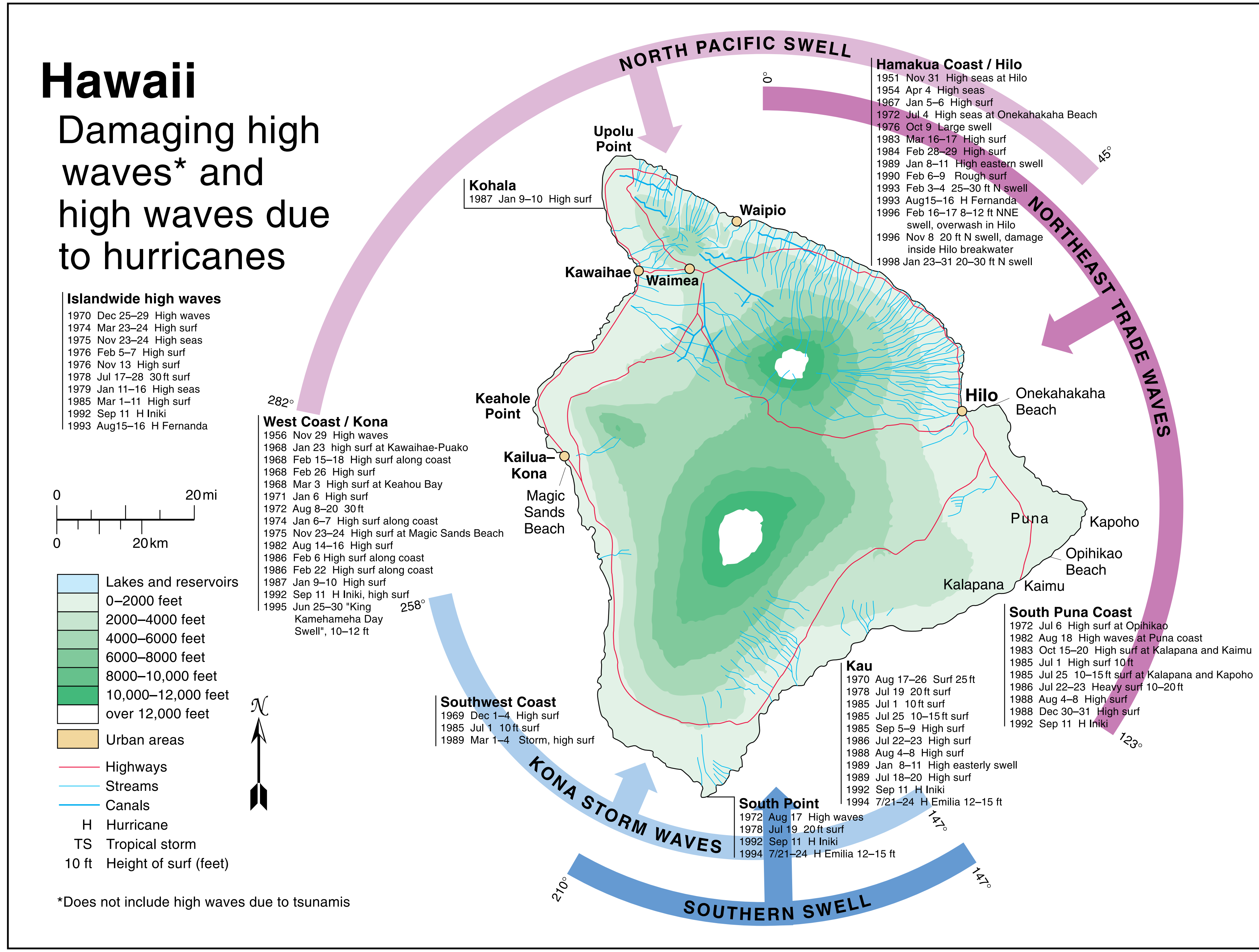
Stream flooding in the coastal zone of the Big Island of Hawaii results from heavy precipitation on the steep mountain slopes of Mauna Kea, Mauna Loa, and Kohala, as well as flash flooding from extraordinary rainfall events on the coastline itself. Kilauea and Hualalai volcanoes are located in more arid regions but occasionally do receive intense rainfall that causes flash floods downslope. Annual rainfall ranges between 300 in on the slopes of Mauna Kea above Hilo, to below 10 and 20 in in the arid regions of Kawaihae and South Point. Soils that can absorb precipitation are better developed on the older volcanoes of Kohala and Mauna Kea, so mudslides and landslides are more common along the coastal cliffs of the Waipio and Hamakua Coasts. The young lavas that comprise the coastal terraces of Mauna Loa, Kilaeua, and portions of Hualalai, are very porous and have less soil development. Often, heavy precipitation simply infiltrates into the rock and flows toward the sea in underground streams. As a result, stream flooding is generally less of a hazard on the younger coastlines and requires flash flooding due to intense rainfall events to produce overland runoff.

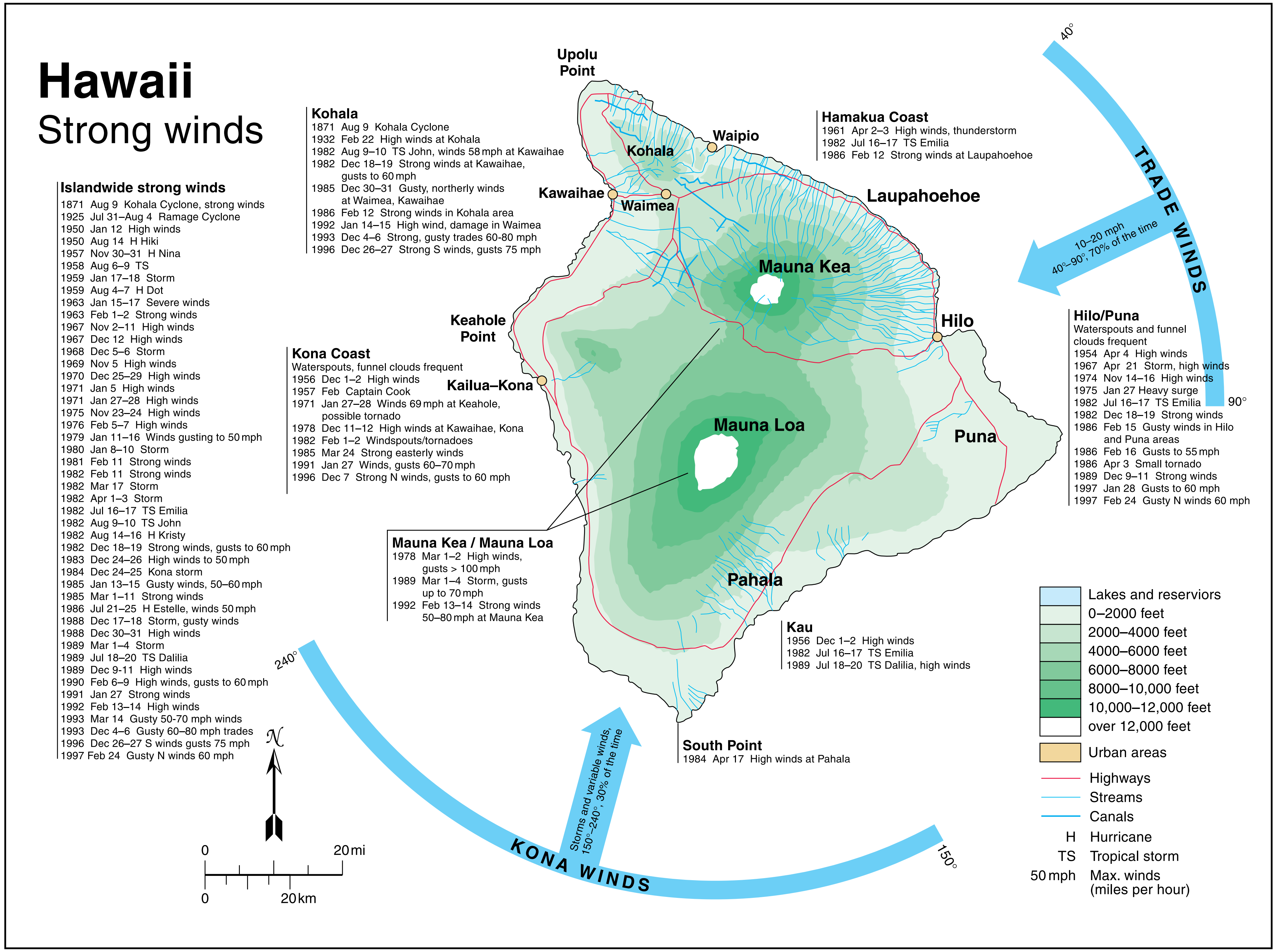
Many occurrences of islandwide stream flooding have been reported since 1959, and many are associated with precipitation associated with passing tropical storms and hurricanes or their remnants. Flooding along the wet, windward side of the island has been common and rather expected due to the large input of rainfall. Much of the windward coastline is relatively steep and so runoff occurs in deep channels that reach the shore below steep cliffs. Most of the flooding that has caused damage has been flash flooding during extreme rainfall events that bring about sheet flow between stream channels. The Hilo and Puna areas are probably the most frequently flooded and hardest hit by flash floods on the Big Island and perhaps in the state. On November 18-20, 1990, 30 in of rain fell in the region bringing about intense flooding of the low-lying coastal areas. What is more surprising is the degree of flooding that the more arid regions of the Big Island have sustained. The Kohala and Kailua-Kona Coasts have a long and active history of flooding largely due to flash flooding and intense storms. From 1997 to 2001, the South Kohala and Waikaloa areas have experienced intense flash flooding that has caused considerable damage. According to the data from the last 50 yr, on average a damaging flood event occurs on the Big Island every 2 yr. During this past 50 yr, however, the threat due to stream flooding has increased dramatically because of the risk taken to develop extensively in flood prone areas.

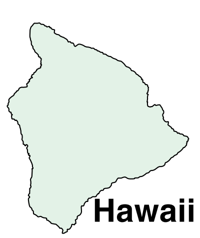
High waves

Hawaii's shorelines receive high waves that are generated by distant storms in the Northern and Southern Hemisphere and by tropical storms, hurricanes, and Kona storms that enter Hawaiian waters. Annual high waves arrive from north swell in the winter and range between 10 and 20 ft, while waves from south swell during summer generally do not exceed 4-6 ft. Occasional extreme wave events, however, do occur, such as the enormous north swells of February 1993 and January 1998 that brought 20-30 ft waves to the north facing shores. Infrequent but significant south swells also occur, such as the July 1986 swell and the King Kamehameha Day swell of June 25-30, 1995, that produced 8-12 ft surf along southern shores. High waves of 6-8 ft can be produced by well-developed trade wind swell, but usually trade wind waves are 2-4 ft. While it is Kona storms in winter that produce occasionally damaging waves ranging 4-6 ft along south and southwest shores, it is tropical storms and hurricanes during summer and fall that bring damaging high waves of 10-30 ft several times each decade to any and all shorelines in Hawaii.

Records of high wave events and waves from hurricanes or tropical storms date back to the late 1800s, but the majority of wave data reflect only the last 45-50 yr. During this time period, high waves along the north and northeast shore due to north swell have commonly reached heights of 20-30 ft, and overwash of the Hilo breakwater and flooding of the coastal roads near Hilo, caused damage in November 1996 and January 1998. High waves along the south shore of Hawaii have been damaging to isolated areas between Kailua-Kona and Kawaihae. Alii Drive in Kailua town is located particularly close to the ocean in many places, and suffers periodic overwash. Power and telecommunications lines are threatened during large wave-induced erosion events such as the King Kamehameha Day swell of June 1995.







Strong winds

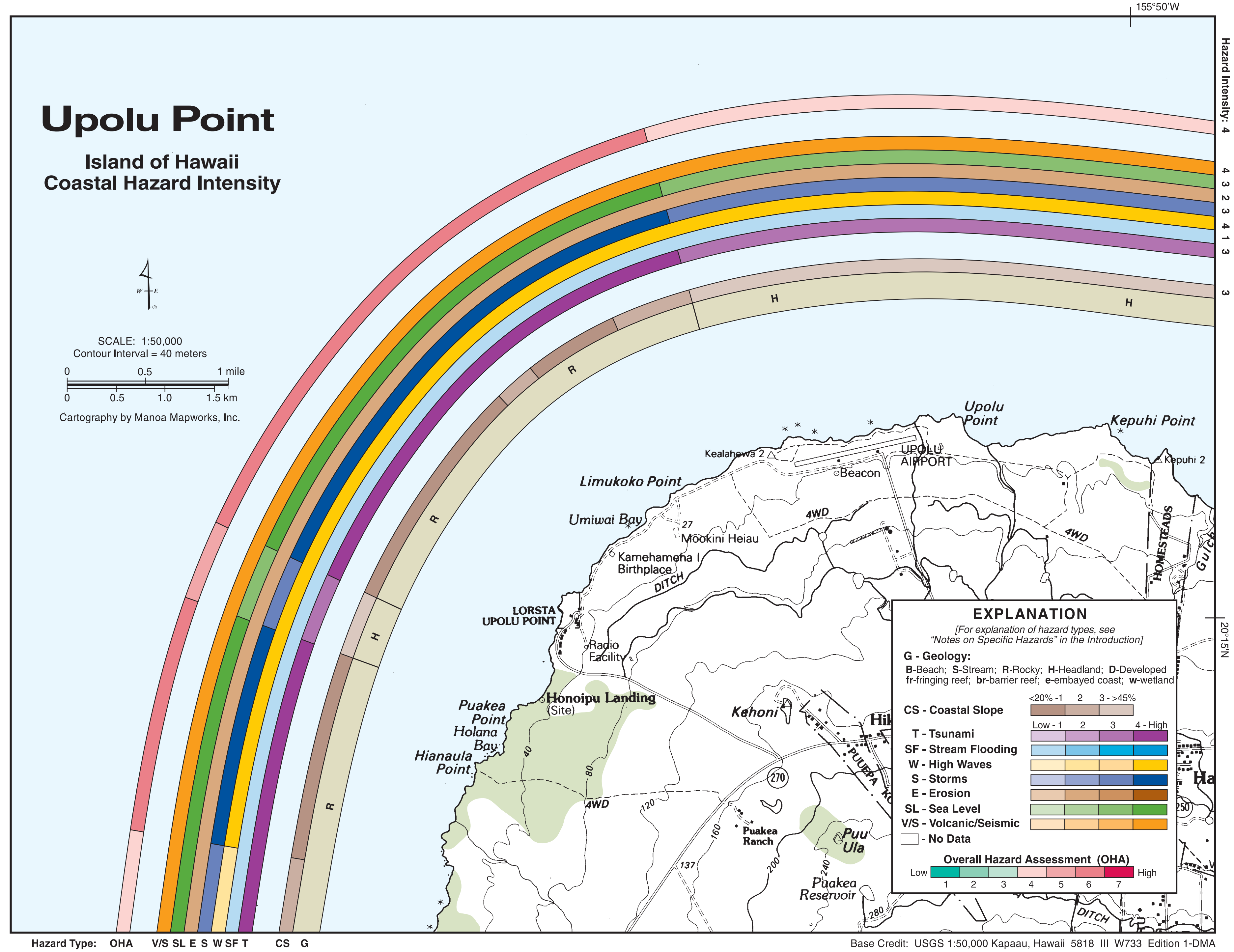
The dominant winds on the Big Island of Hawaii include trade winds, Kona winds, and winds associated with hurricanes and tropical storms. Northeast trade winds prevail most (70%) of the year and generally blow 10-20 mph. Exceptionally strong and gusty trade winds occur when the sub-tropical high of the central North Pacific Ocean intensifies. These can reach 40-60 mph in the coastal zone of Hawaii, sometimes for several days at a time. High winds associated with Kona storms tend to approach from the south and southwest as winter storms travel through Hawaiian waters and can reach greater than 50 mph. The highest and most damaging winds are most commonly associated with passing tropical cyclones (hurricanes, tropical storms, and tropical depressions). Most tropical storms approach the islands from the southeast and pass to the west, just south of the Big Island. As a result, the southeast coast of the Big Island has been subject to numerous high wind and wave events due to passing storms. Occasionally, tropical storms track east of the islands and the north-facing coast of the Big Island is impacted. An important consequence resulting from the extremely high relief on the Big Island is the acceleration of winds as they descend from the higher elevations to the coastal zones below. Localized microbursts and downdrafts often occur on the downwind side of the steep mountains. As a result, the highest wind speeds are commonly found on the side of the island opposite the approach of storms and high wind events.

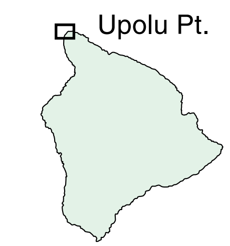
Even though the Big Island has not sustained a direct hit by a hurricane strength storm, several strong tropical storms have brought about considerable damage. Since 1871, 56 high wind events have affected the entire island. Many of these were associated with passing hurricanes and tropical storms. Most recently, Hurricane Estelle, in July of 1986, created winds of 50 mph and demolished 5 homes along the southeast coast. Other strong events include Hurricanes Dot and Nina in 1959 and 1957, respectively, and tropical storm Dora in 1993. Intense trade wind events with maximum velocities of 60-80 mph, like in December of 1993, have been reported on all sides of the island. High Kona storm winds have been recorded with hurricane strength speeds, such as in December 1996, along the Kohala coast near Kawaihae. In addition to high winds in winter from Kona storms, tornadoes were reported along the Kona Coast in February 1982 and January 1971, as well as along the Hilo and Puna coast in April 1986.

Upolu Point

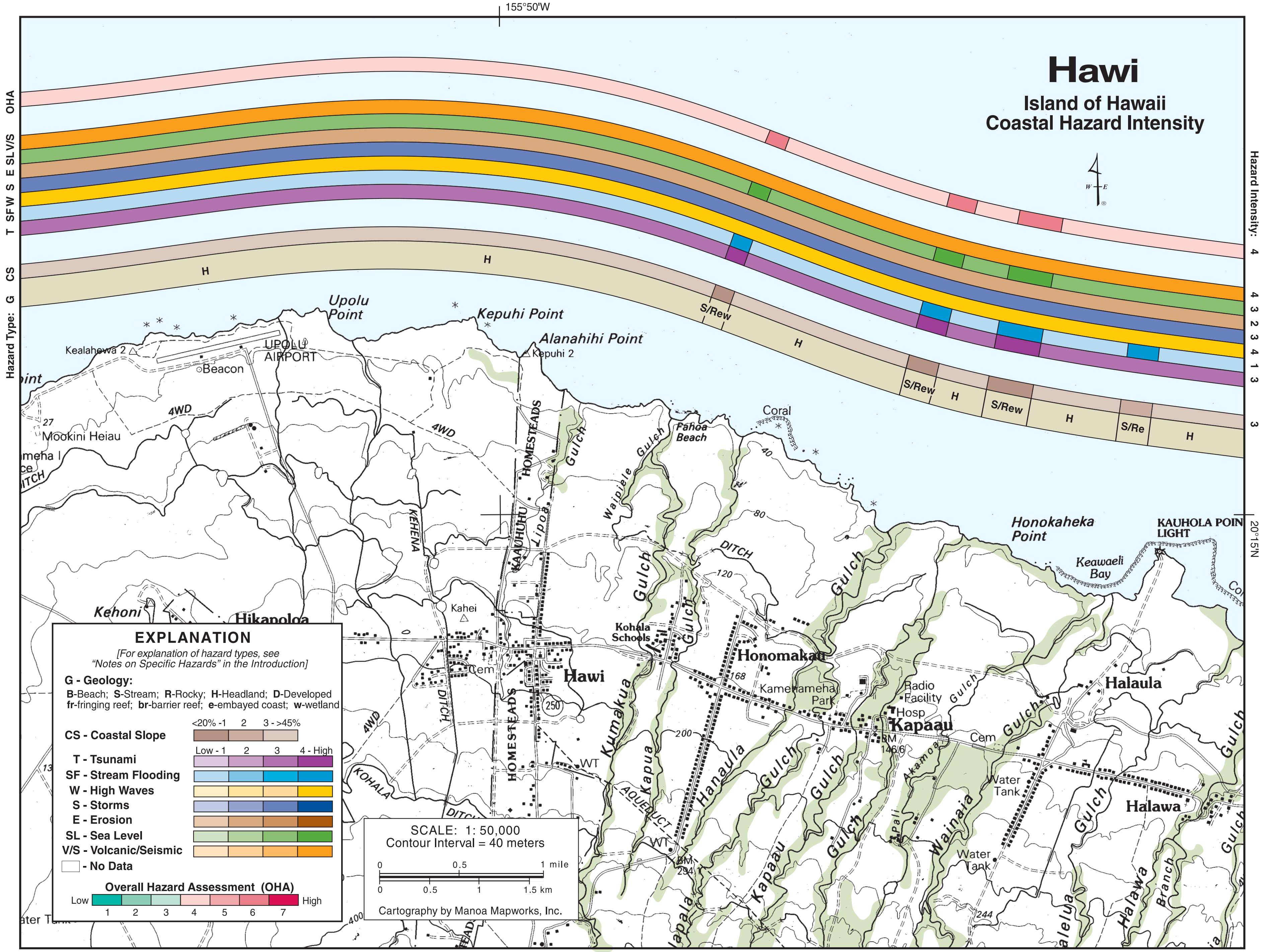
The rocky headlands of Upolu Point border the northern most shores of the Island of Hawaii. The coast slopes gently between Hianaula and Limukoko Points but becomes steeper and nearly inaccessible to the east toward Kepuhi Point. Numerous small rocky embayments separate these promontories. Sandy beaches do not exist, but boulder beaches attest to the extreme wave energy that shapes this coast. High waves from north swell in winter, ranging 10-20 ft, and moderately high trade wind waves throughout the year make Upolu's north-facing coastline a high energy coast. Despite low rainfall, several streams cut across the coastal plain transporting runoff and terrigenous sediments from the upper reaches of Kohala Volcano. The Upolu coast is relatively undeveloped except for the Upolu Airport and several heiau (temple) and historical monuments. Coral reefs are nearly absent, except for small patch reefs and isolated coral colonies in the lee of headland promintories where they are protected from high wave energy.

The Overall Hazard Assessment (OHA) for Upolu largely reflects the variation in coastal slope and aspect, which controls hazards associated with flooding and high waves. The OHA is high (6) from just south of Hianaula Point to Kealahewa except for Puakea Point where it is moderate to high (5). Along this northwest-facing, low-lying coast, the threat of tsunami, high waves, storms, and sea-level rise is high, except at the Puakea Point headland where the tsunami, storms, and sea-level rise hazards are reduced to moderately high because of the steeper slope along that headland. Stream flooding and erosion are low and moderately low, respectively. The volcanic/seismic threat for Upolu (Zone 9; Table 10, p. 24) is high, as it is along the entire coastline of the Island of Hawaii. In the southwestern portion of Upolu the OHA is moderate (4), where the high waves threat is moderately high and the storm hazard is moderately low. Along the steep slopes east of Kealahewa, the OHA is moderate (4) where the tsunami, storm, and sea-level rise hazards are reduced to moderately high.

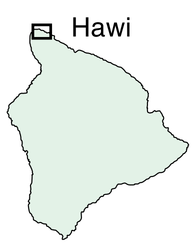




Upolu Point at the wind-swept northwest corner of Hawaii is formed of gently-sloping lava flows from Kohala Volcano that meet the sea as 10-30 ft rocky cliffs.



Base Credit: USGS 1:50,000 Kapaau, Hawaii 5818 III W733 Edition 1-DMA



Hawi

The Hawi coast is comprised of steep rocky headlands separated by numerous small embayments at the Kumakua, Hanaula, Kapaau, and Wainaia stream mouths. Wetlands have formed in the first three of these embayments where the streams deposit terrigenous sediments quarried from the deeply incised valleys above. Wave energy is high along this coast most of the year, which helps to disperse the soil and silt that is delivered from the streams. Even so, it is common to see plumes of brown sediment-rich water hugging the coast, especially after high rainfall. Despite the high sediment discharge into the nearshore zone, coral reefs become increasingly common east of Pahoa Beach. Development is low along the Hawi coast due to its difficult access. The region is relatively arid and experiences persistent trade winds.

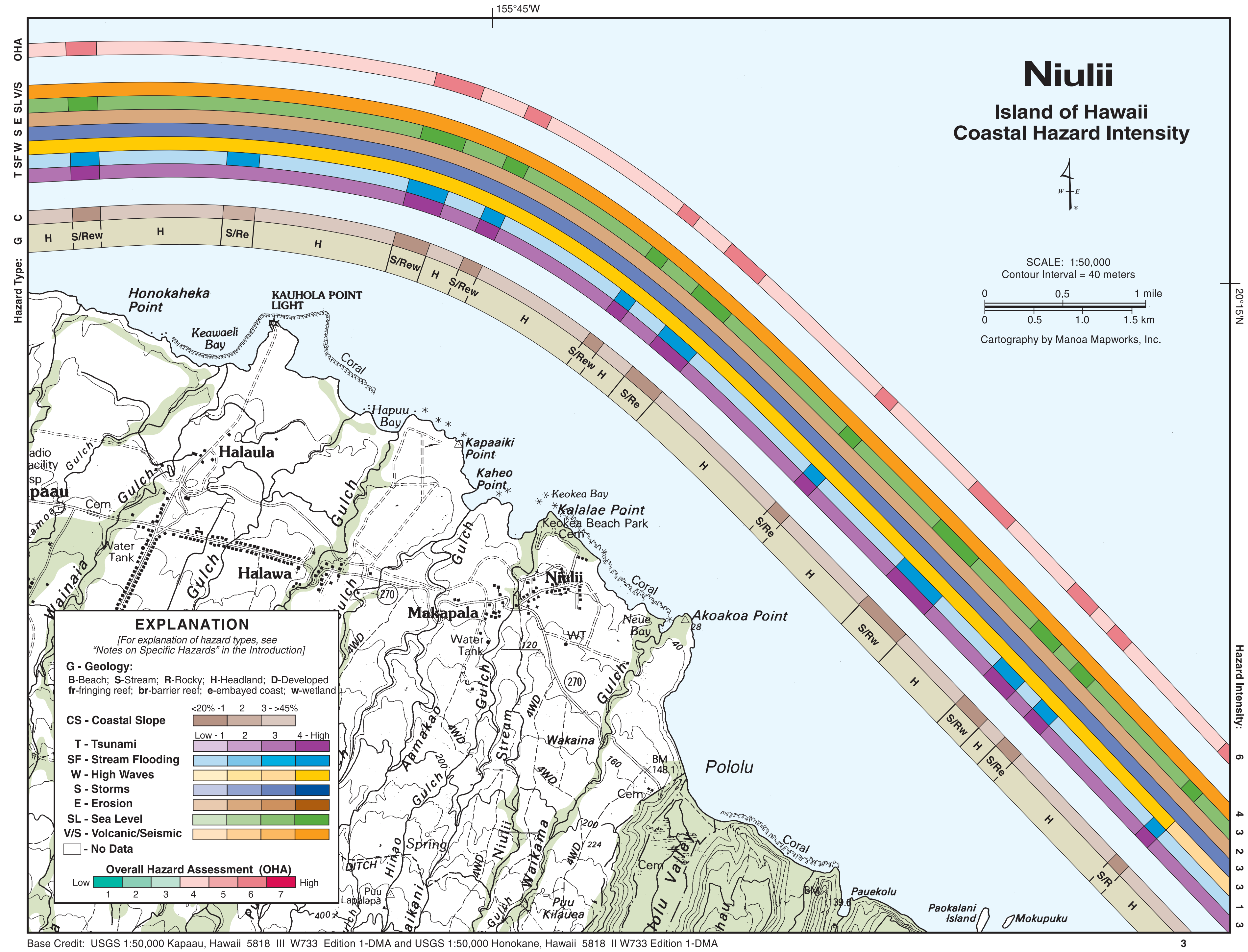
The Overall Hazard Assessment (OHA) is moderate (4) along the steep rocky coastal cliffs and high (6) at the low-lying Kumakua, Hanaula, and Kapaau stream mouths. The OHA in these coastal embayments is ranked high because the tsunami, stream flooding, high waves, and sea-level threats are high, storms are only moderately high, and erosion is moderately low. In Keawaeli Bay, stream flooding is high and the sea-level hazard there is moderately high. Along the intervening steep coastal cliffs, the tsunami and sea-level hazards are moderately high, and stream flooding is low. The Hawi coast lies in lava flow hazard zone 9 (Table 10, p. 24). The volcanic/seismic hazard is high along this coast due to its proximity to high seismic activity associated with volcanic eruptions at Kilauea Volcano to the south.

Deeply incised gulches, like Kumakua Gulch (shown here), are common along the Hawi coast, where steep 15 to 60 ft sea cliffs plunge into rough waters of North Kohala.

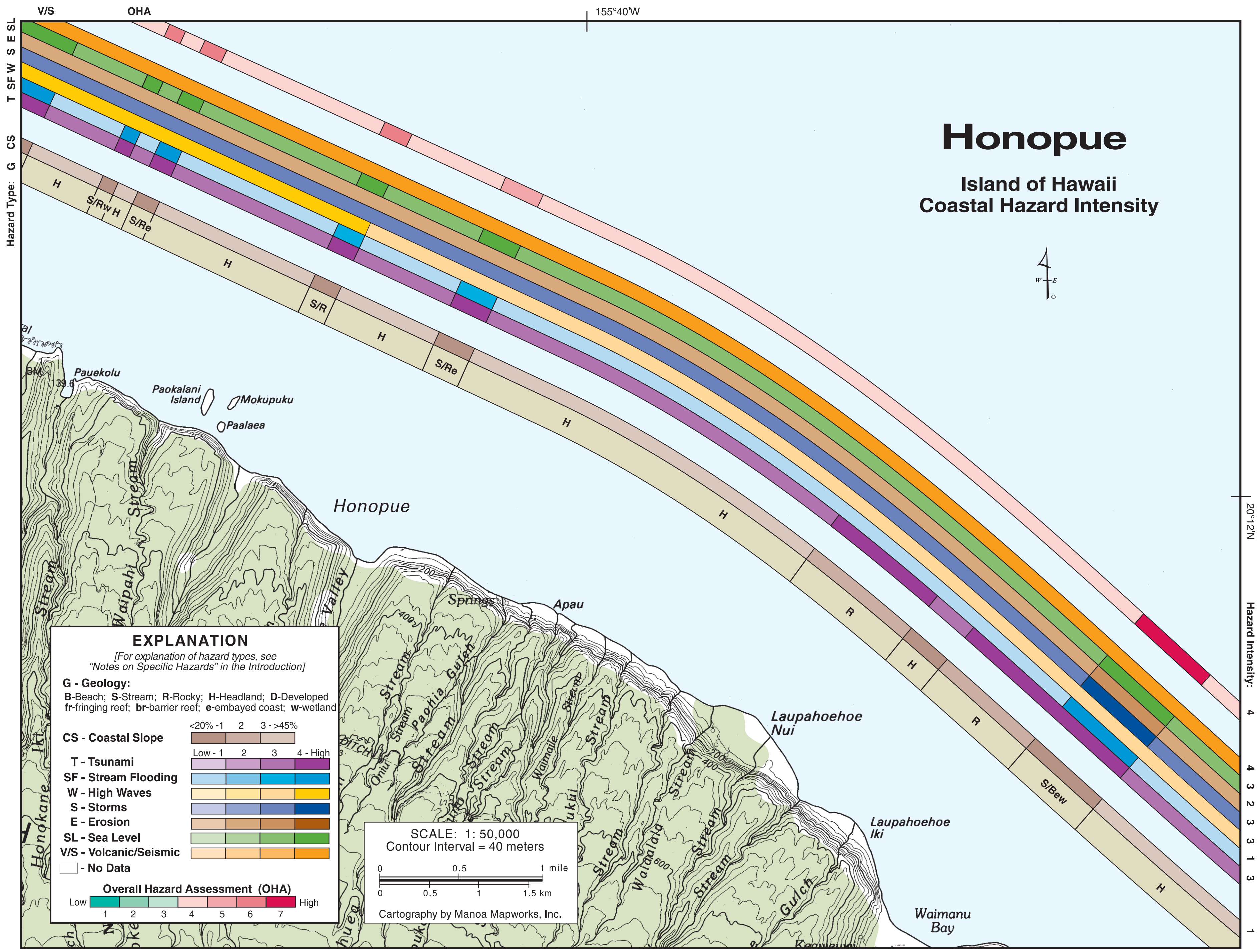
Niulii

Between Keawaeli Bay and Pauekolu in Pololu Valley, the Niulii coast is steep with rocky headlands surrounding irregular low-lying rocky embayments at stream mouths. The highest tsunami runup ever recorded in Hawaii occurred in 1946 near Kalalae Point, where it was measured at 55 ft against the coastal cliffs. Small wetlands have formed in many of the embayments where stream-deposited sediments accumulate. High waves and persistent trade winds erode this rocky coast, leaving small rocky sea stacks abandoned offshore of the retreating sea cliffs. A few boulder beaches, such as at Keokea Beach Park, also occur along this coast. The beach along Pololu to the south is comprised largely of black sand. Pololu Valley is the northernmost of seven deeply incised amphitheater-shaped valleys along the northeast coast of Hawaii. Pololu is only slightly developed, although it once flourished with taro agriculture. Well-developed fringing reefs occur at Kauhola Point and seaward of the town of Niulii. Access along the coast south of Pololu Valley is limited to foot trail and boat, as the coastal road ends at a lookout situated on the north ridge overlooking Pololu Valley.

The Overall Hazard Assessment (OHA) for the low-lying coastal embayments and stream mouths along the Niulii coast is high (6) while for the steep rocky headlands it is moderate (4). In each of the low-lying coastal embayments, except Keawaeli Bay, which is steeper and where the tsunami threat is moderately high, the tsunami, stream flooding, high waves, sea-level, and volcanic/seismic hazards are high. In between the embayments, where the coastal headlands are steep, the tsunami and sea-level hazards are moderately high, and stream flooding is low. The hazard due to high waves along this entire coast is high, while that due to storms is moderately high. Erosion is moderately low. Niulu lies in lava flow hazard zone 9 (Table 10, p. 24). The volcanic/seismic threat is high along the Niulu coast as it is for the entire coast of the Big Island due to active volcanism and seismicity associated with eruptions of Kilauea.



Beyond the Pololu Valley Lookout at Akoakoa Point (foreground), the Niulii coast becomes increasingly steeper and access is only afforded by boat and/or footpath.



Base Credit: USGS 1:50,000 Honokane, Hawaii 5818 II W733 Edition 1-DMA

Honopue

Deep stream valleys cut into spectacular sea cliffs ranging 500-1000 ft high along the Honopue coast. Two relatively low-lying coastal plains between Apau and Laupahoehoe Nui and at Laupahoehoe Iki have formed along the rocky coast. The Honopue region of the Kohala coast receives only moderate rainfall, but active streams bring considerable volumes of sediment to the coastal plains and waters of the embayments. In times past, this sediment on the valley floors provided rich soil for taro farming, however, severe flooding made it difficult to maintain the farms. Access to the beautiful amphitheater valleys is limited to foot trail and boat. Black sand beaches are common at the shoreline of these valleys. Three small islands stand against the relentless attack of high waves and trade winds just offshore and south of Pauekolu. Coral reefs occur in the northern portion of the area, but are less common in the south.

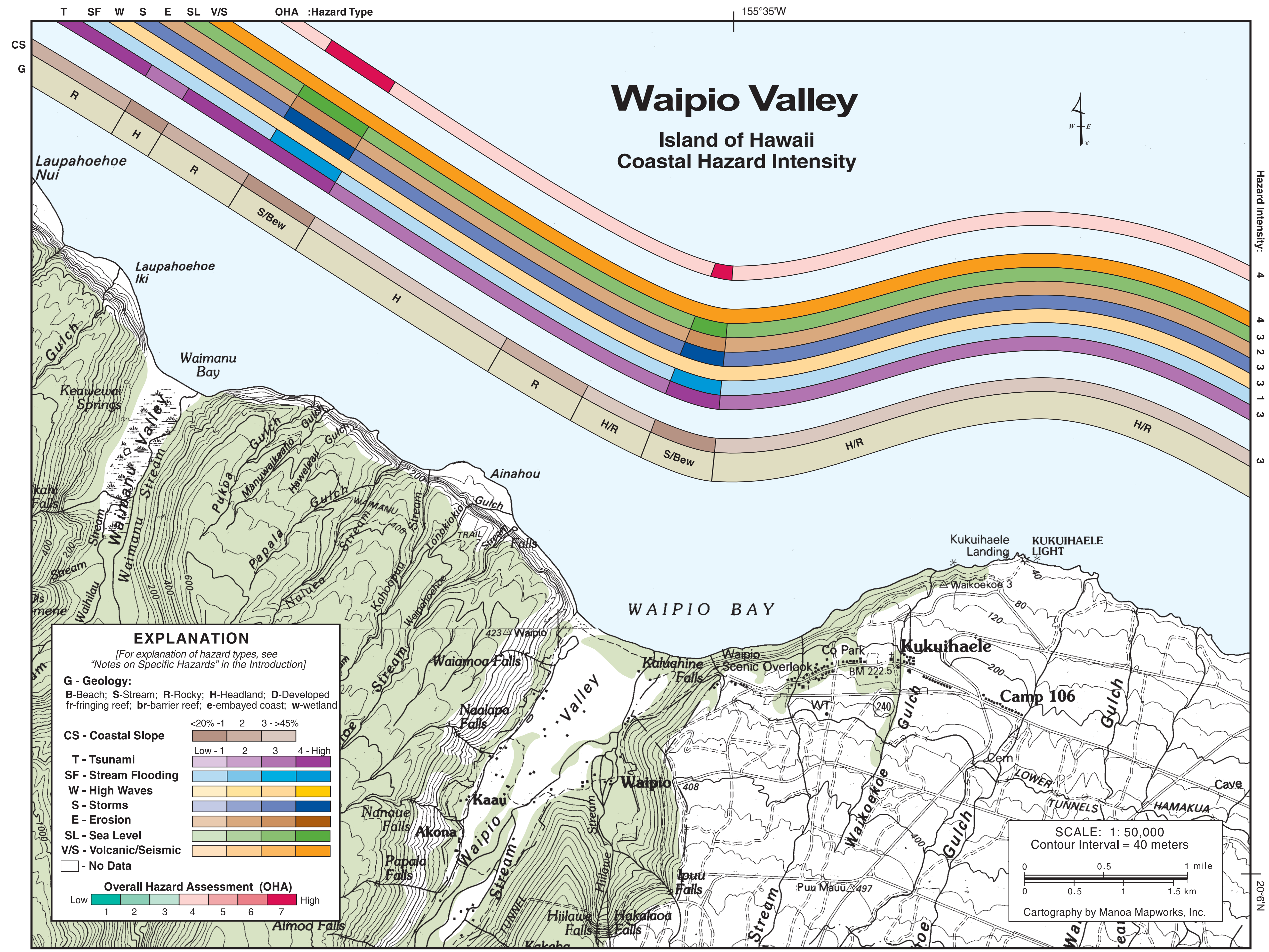
The Overall Hazard Assessment (OHA) for Honopue is moderate (4) along the steep rocky cliffs and high (6) at the small coastal embayments northwest of Apau. This difference is largely due to the high tsunami, stream flooding, and sea-level hazards within these bays. The storm threat is moderately high, erosion is moderately low, and the volcanic/seismic threat is high along the entire Honopue coast because of active seismicity associated with volcanic eruptions at Kilauea. The Honopue coast is located in lava flow hazard zone 9 (Table 10, p. 24). The hazard from high waves northwest of Mokupuku and Paalaea Islands is reduced to moderately high to the southeast, where waves associated with large north and northwest swell refract and lose energy by the time they reach the shoreline. The tsunami hazard is high along the two relatively low-lying coastal plains between Apau and Laupahoehoe Nui and at Laupahoehoe Iki.

Gulleys and clean unvegetated scarps with remnant islands and sediment-laden waters offshore attest to active erosion along the steep, rocky Honopue cliffs.

Waipio Valley

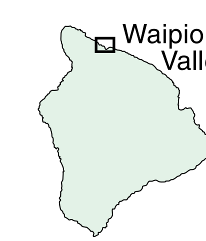
The Waipio coast abruptly changes at Waipio Bay from one dominated by steep sea cliffs and deeply incised valleys of the older Kohala volcano to a more gently sloping and younger coastline to the south. Waimanu and Waipio Valleys are famous for their scenic splendor and isolation. They were extensively developed for taro agriculture in the past but have been almost entirely abandoned due to severe flooding and tsunami inundation this century, as well as to difficult access. Today only Waipio Valley is still partly cultivated. The seaward edges of the valley floors are mostly wetlands. Access to Waipio Valley can be achieved by 4-wheel drive vehicle from Kukuihaele, but beyond this point the coast is accessible only by foot trail or boat. Wide and extensive black sand beaches occur at both Waimanu and Waipio Bays. To the south, the coast is mostly rocky except for an ephemeral small beach at Kukuihaele Landing. Coral reefs are very sparse and only exist as small isolated patch reefs.

The Overall Hazard Assessment (OHA) within Waipio and Waimanu Bays is very high (7), while along the surrounding steep rocky sea cliffs it is moderate (4). At the low-lying coastal embayments of Waipio and Waimanu the tsunami, stream flooding, storm, sea level, and erosion hazards are moderately high. These bays generally receive moderately high waves. Along the steep sea cliffs the tsunami, storm, and sea-level hazards are moderately high, while erosion is moderately low and stream flooding is low. The high wave hazard is moderately high along the steep rocky cliffs. The steeper coast north of Waipio is in lava flow hazard zone 9 while the more gradually sloping coast to the south is in lava flow hazard zone 8 (Table 10, p. 24). The volcanic/seismic threat is uniformly high throughout the entire Waipio Valley coast due to active seismicity associated with volcanism at Kilauea.

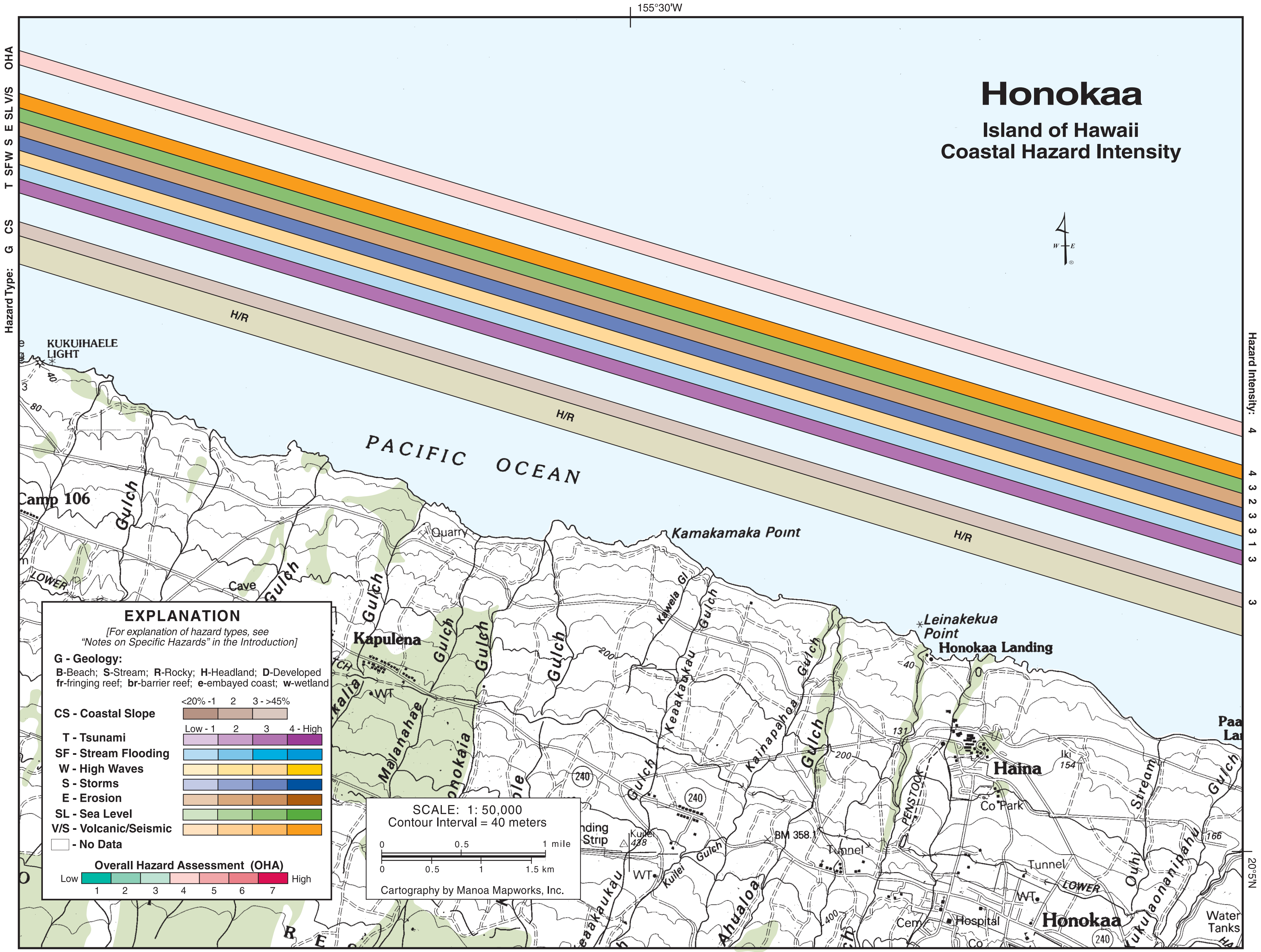


Base Credit: USGS 1:50,000 Honokane, Hawaii 5318 II W733 Edition 1-DMA, and USGS 1:50,000 Waipio Valley, Hawaii 5817 I W733 Edition 1-DMA

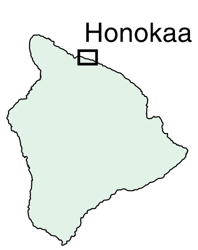
Waipio Valley is characteristic of a youthful valley with its deeply incised "V-shaped" sides. Considerable sedimentation along the valley floors has established an extensive floodplain, which has been fruitfully cultivated throughout the past but is also highly susceptible to flooding by both heavy rainfall and marine overwash.



Honokaa



Base Credit: USGS 1:50,000 Honokane, Hawaii 5318 II W733 Edition 1-DMA, USGS 1:50,000 Waipio Valley, Hawaii 5817 I W733 Edition 1-DMA, and USGS 1:50,000 Honokaa, Hawaii 5917 VI W733 Edition 1-DMA



The rocky Honokaa coast between Kukuihaele Point and Honokaa Landing is relatively steep with 80-100 ft high cliffs fronting the sea. Portions of the coast are slightly embayed. There are no unconsolidated sand beaches, only rocky platforms and boulders at the base of the coastal scarps. Trails lead down the steep cliffs from the bluffs, which are moderately developed with private residences. Numerous gulches cut across the coastal plain, draining the east-facing slopes of Mauna Kea above. Although relatively arid, rainfall is periodically intense and landslides along the steep cliffs occur. Facing northeast, the Honokaa coast receives the direct approach of the trade winds and trade-wind swell, as well as refraction of north swell. Reflection of waves off the rocky cliffs creates very turbulent seas just offshore. Little coral grows along this coast.

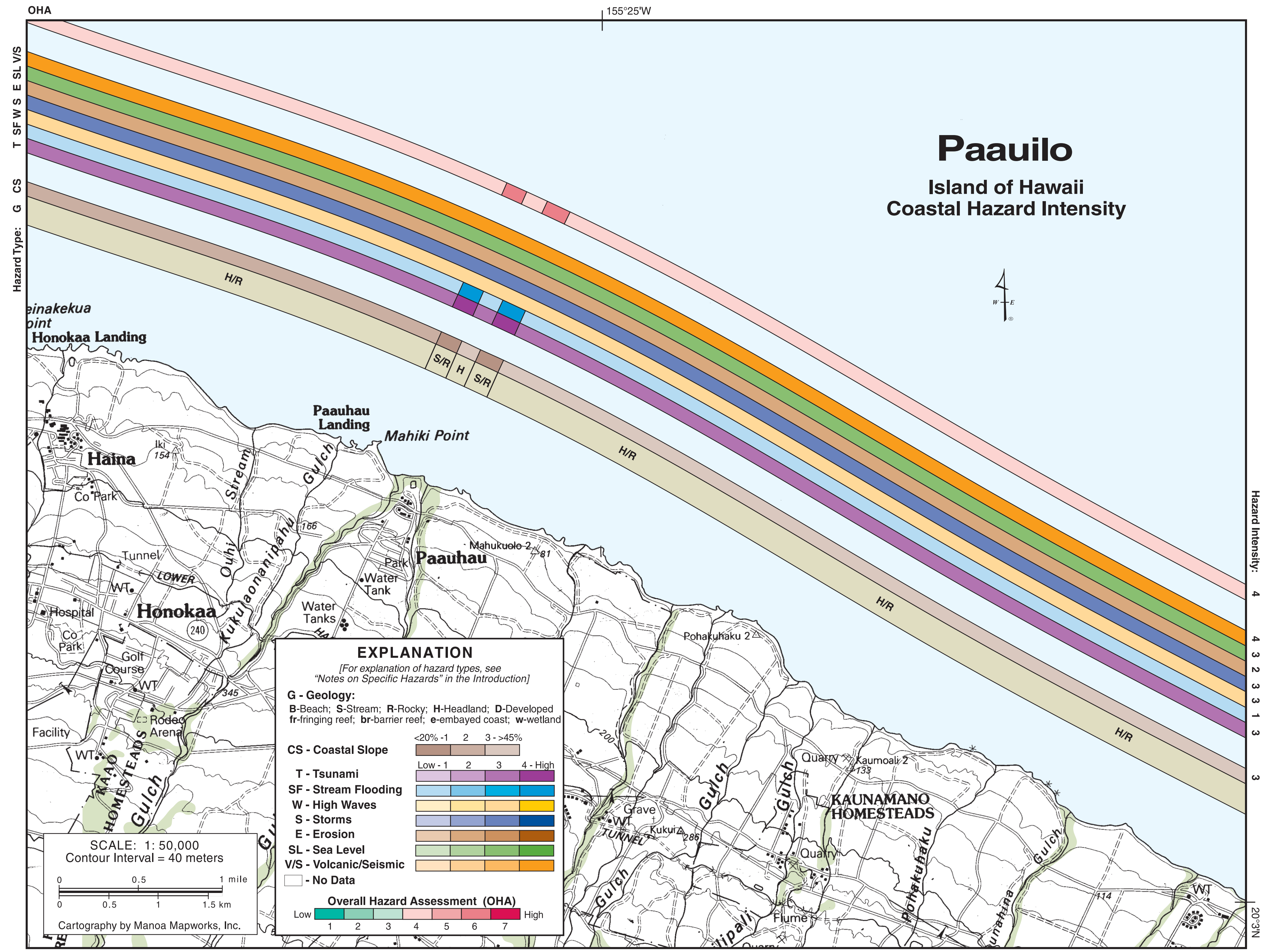
The Overall Hazard Assessment (OHA) is uniformly moderate (4) along the entire Honokaa Coast because of the consistent rocky substrate and largely unchanging coastal slope. The tsunami hazard is moderately high along these relatively steep slopes. Stream flooding is low due to the relatively steep coast. The high waves and storm hazards are moderately high, while erosion is moderately low due to the rocky substrate. The sea-level threat is moderately high where the island is subsiding and sea level is rising. Honokaa lies in lava flow hazard zone 8 (Table 10, p. 24). The volcanic/seismic threat is high along the Honokaa coast as it is along the entire coast of the Island of Hawaii due to high seismic activity and volcanism associated with the eruption of Kilauea.

South of Waimanu and Waipio, the cliffs of the Hamakua coast near Honokaa become more gently sloping and range between 10 and 30 ft high.

Paauilo

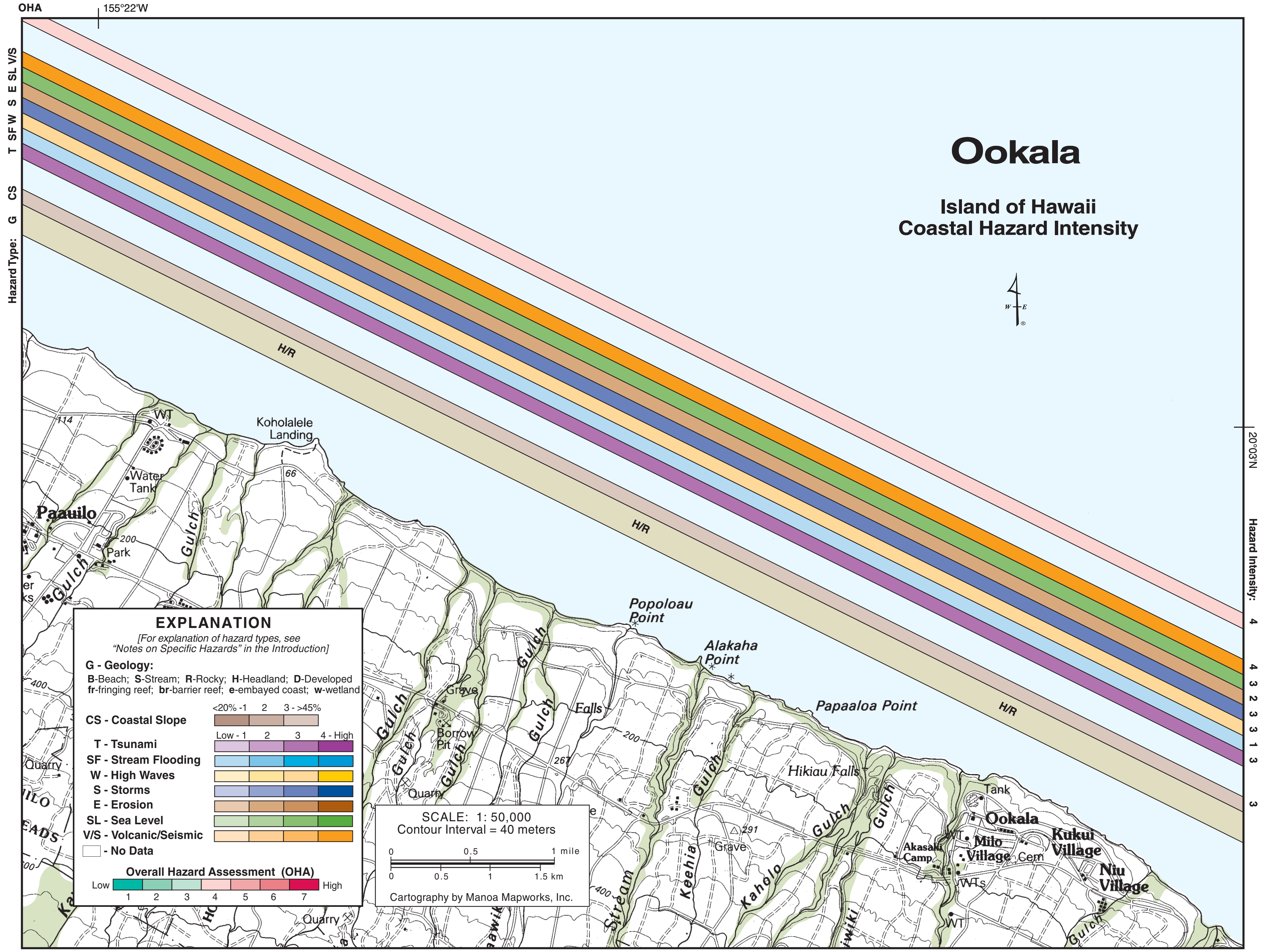
Between Honokaa Landing and Kaunamano Homesteads the coastal slope of the Paauilo region becomes increasingly more gradual despite the sea cliffs that line the entire coast. Access by auto is limited to Paauhau Landing and neighboring hillsides, otherwise one must travel by foot trail or boat to reach the coastline. The headlands are generally rocky, but in some locations soils have developed sufficiently that, when saturated with rainfall, slope failures and landslides occur. Streams draining Mauna Kea Volcano have deeply incised the coastal slopes, creating narrow gorges and waterfalls. The same streams also transport large amounts of terrigenous sediments to the coastal zone, often clouding the nearshore waters with silt after heavy rains. Many small rock outcrops line the coast, but few coral reefs have taken hold.

The Overall Hazard Assessment (OHA) for the Paauilo Coast is moderate (4) except at the two stream mouths that form low-lying coastal embayments at Paauhau, where the OHA is high (6). Tsunami is moderately high throughout the region, except at the Paauhau stream mouths, where it is high. Stream flooding is low along the Paauilo coast, except at the Paauhau stream mouths, where it is high. High waves, storms, and the sea-level threat are moderately high along the entire coast, while erosion is moderately low. The Paauilo region is located in lava flow hazard zone 8 (Table 10, p. 24). The volcanic/seismic hazard is high along the Paauilo coast due to its proximity to Kilauea which is the primary source region for active seismicity and volcanism affecting the Big Island.

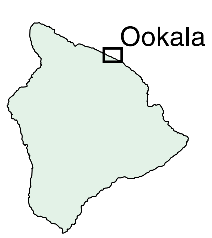


Base Credit: USGS 1:50,000 Honokaa, Hawaii 5917 VI W733 Edition 1-DMA

Nearshore turbulence is common along the Paauilo coast where persistent waves from trade winds and winter north swell abruptly meet the rocky 15 to 60 ft cliffs. In addition, runoff from heavy rains and agricultural practices may lead to sedimentation in the coastal zone.



Base Credit: USGS 1:50,000 Honokaa, Hawaii 5917 IV W733 Edition 1-DMA



Ookala

The slopes of Mauna Kea Volcano steepen near the town of Ookala and the entire coast between Koholalele Landing and Niu Village is lined by steep sea cliffs ranging 50-300 ft high. Only a few foot trails enable access to the shoreline from the headland bluffs above. Many private developments, including residences and small businesses, have been constructed on the bluffs overlooking the sea. Periodically the cliffs become saturated with heavy rainfall and may develop landslides. Several streams cut across the Ookala coastal plain creating deep gulches, beautiful waterfalls, and boulder beaches at their terminus. This region receives moderate to high wave energy from north swell and trade wind waves, limiting reef development.

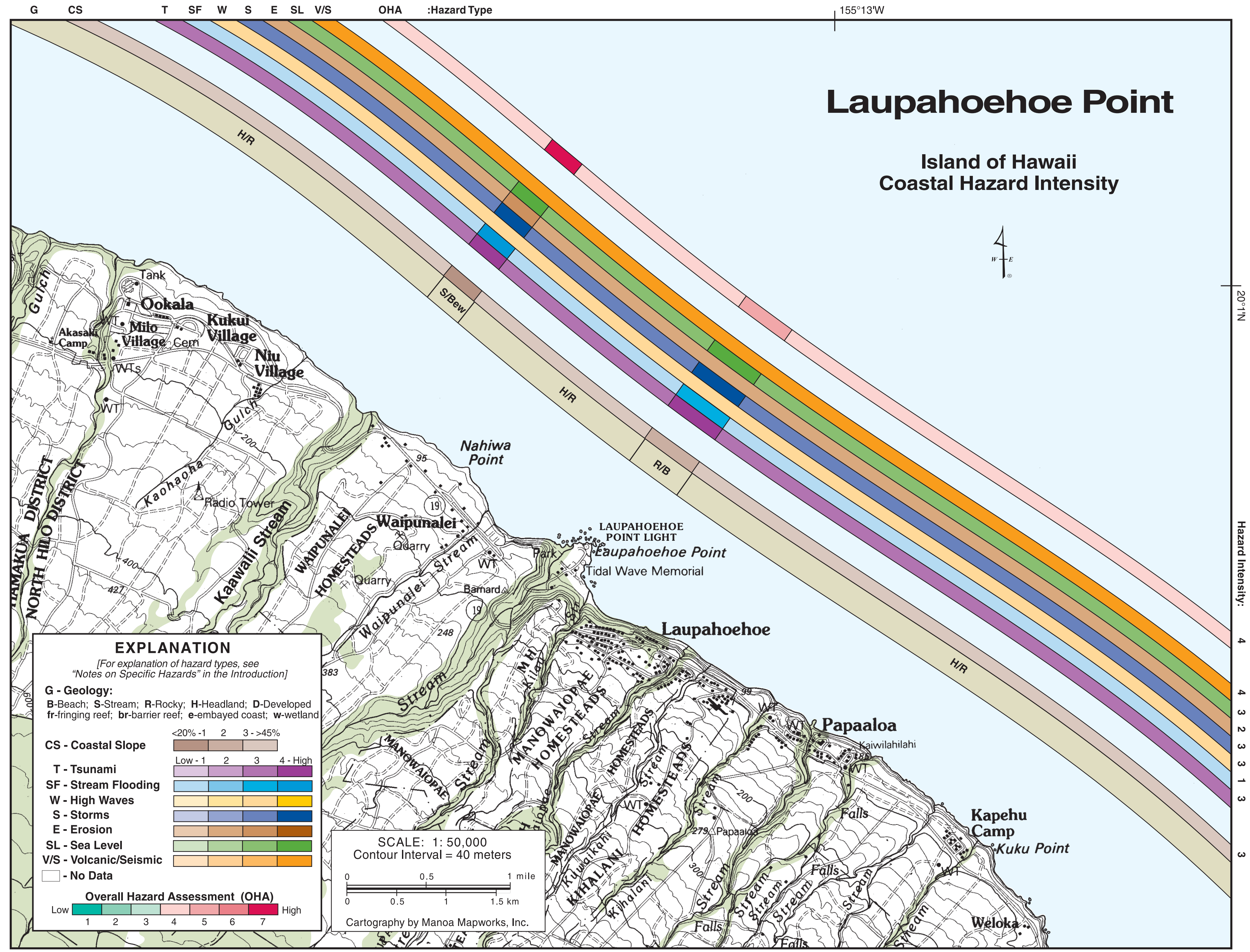
The Overall Hazard Assessment (OHA) is moderate (4) along the Ookala Coast. This ranking reflects a uniform assessment of the individual hazards due to the relatively unchanging coastal slopes and geology. Tsunami is moderately high. Stream flooding is low due to the moderate rainfall and relatively steep coastal slope. The hazards from high waves and storms are moderately high. While erosion is moderately low due to the hard rocky substrate, the sea-level hazard is moderately high because the island is sinking in addition to experiencing global sea-level rise. Ookala is within lava flow hazard zone 8 (Table 10, p. 24). The volcanic/seismic threat is high along the Ookala coast which receives episodic seismic activity associated with volcanism at Kilauea.

Steep headlands formed by active headwall erosion from wave scour and hillslope failure characterize much of the Ookala coast.

Laupahoehoe Point

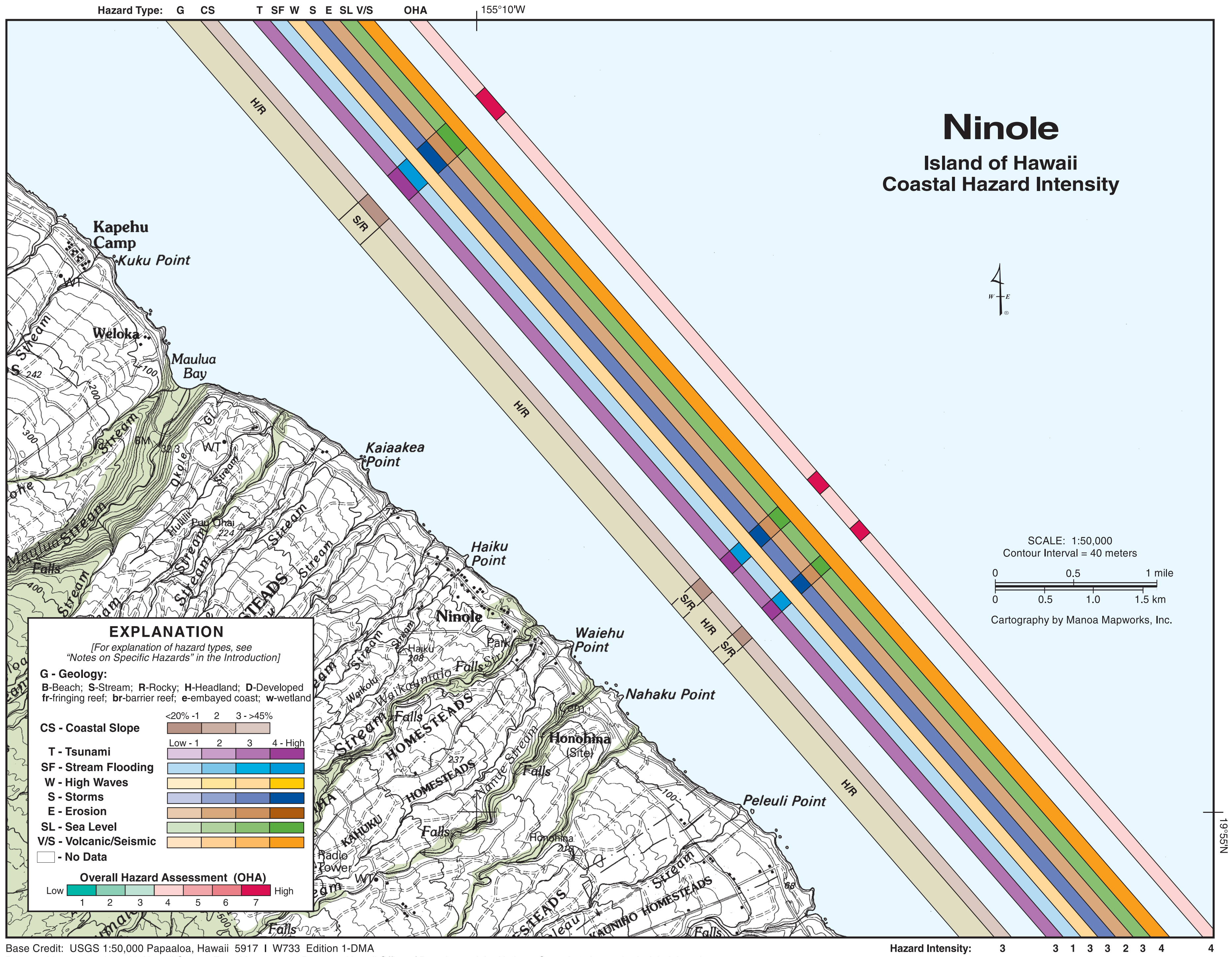
Steep coastal cliffs comprised of late stage Mauna Kea volcanics border the entire Laupahoehoe shoreline. A small rocky pebble beach exists at Laupahoehoe Point Park and at the Kaawalii Stream mouth located between Niu Village and Nahiwa Point. Laupahoehoe Point is the site of the Tidal Wave Memorial, placed there in memory of the 20-ft tsunami wave that destroyed the elementary school situated on the point and took the lives of a number of teachers and students on April 1, 1946. Only very small embayments occur along the cliffed coast where streams meet the sea, and they are difficult to reach by foot. High waves continuously assault this coastline making ocean access difficult. This region receives significant rainfall throughout the year, that often contributes to landslides along the cliff faces. Even so, development, focused between Ookala and Niu Village north of Laupahoehoe Point and between Laupahoehoe town and Papaaloa to the south, continues to creep ever closer to the cliff edges. There is no significant coral reef growth along this turbulent coast, a result of the high waves and terrigenous sediment input to the nearshore zone.

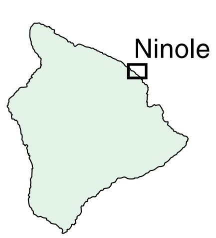
The Overall Hazard Assessment (OHA) is mostly moderate (4) along the steep cliffed Laupahoehoe coast. Even though this northeast-facing coast receives intense wave and wind energy the steep cliffs along the majority of the coast help to mitigate against flooding, marine overwash, erosion, and inundation associated with sea-level rise. As a result the hazards due to tsunami, high waves, storms, and sea-level rise are ranked moderate to high. Stream flooding and erosion are ranked low and moderate to low, respectively. At the low-lying Kaawalii Stream mouth, where the tsunami, stream flooding, storm, erosion and sea-level rise hazards are higher than the surrounding cliffed coasts, the OHA is ranked very high (7). In addition, at Laupahoehoe Point, where the Laupahoehoe and Kilau Streams empty into the sea, the OHA is high (6) reflecting higher tsunami, stream flooding, storm, erosion, and sea-level rise hazards at the low-lying beach park area. Laupahoehoe lies within lava flow hazard zone 8 (Table 10, p. 24). Volcanism and seismicity is high for the entire Hawaii coastline due to active seismicity associated with the eruption of Kilauea Volcano.



Base Credit: USGS 1:50,000 Honokaa, Hawaii 5917 IV W733 Edition 1-DMA, and USGS 1:50,000 Papaaloa, Hawaii 5917 I W733 Edition 1-DMA

Surrounded by steep, rocky cliffs to the north and south, Laupahoehoe Point is the most accessible and widely visited parcel of low-lying coastline between Niu Village and Papaaloa.





Ninole

Between Kapehu Camp and Peleuli Point, the Ninole coast is lined with steep rocky headlands, except at Maulua Bay and the outflow of the Waikaumalo and Nanue streams near Nahaku Point, where it is low lying. As a result, the Ninole coast is relatively undeveloped. All infrastructure rests upon a coastal terrace at elevations ranging between 80 and 100 ft above sea level. Spectacular waterfalls are produced as runoff drains the steep hillsides landward of the gently-sloping terrace around Honohina. High waves and steep cliffs make the sea difficult to access around Ninole. Coral growth is very limited in this region.

The Overall Hazard Assessment (OHA) for the Ninole coast is similar to most of the Hamakua coastal region. In the many isolated low-lying embayments it is higher than the surrounding steep cliffed coasts. The OHA is moderate (4) along the steep cliffs of Ninole, where tsunami, high waves, storms, and sea-level rise threats are ranked moderate to high. Because of the steep slopes, stream flooding is low and erosion is moderate to low. At Maulua Bay and the outflow of the Waikaumalo and Nanue streams near Nahaku Point the OHA is ranked very high (7) due to the high ranking for tsunami, stream flooding, storms, and sea-level rise. At these embayments the erosion threat is also ranked moderate to high. The Ninole coast lies within lava flow hazard zone 8 (Table 10, p. 24). The volcanic/seismic hazard is high along the entire coast due to active seismicity associated with volcanism at Kilauea.

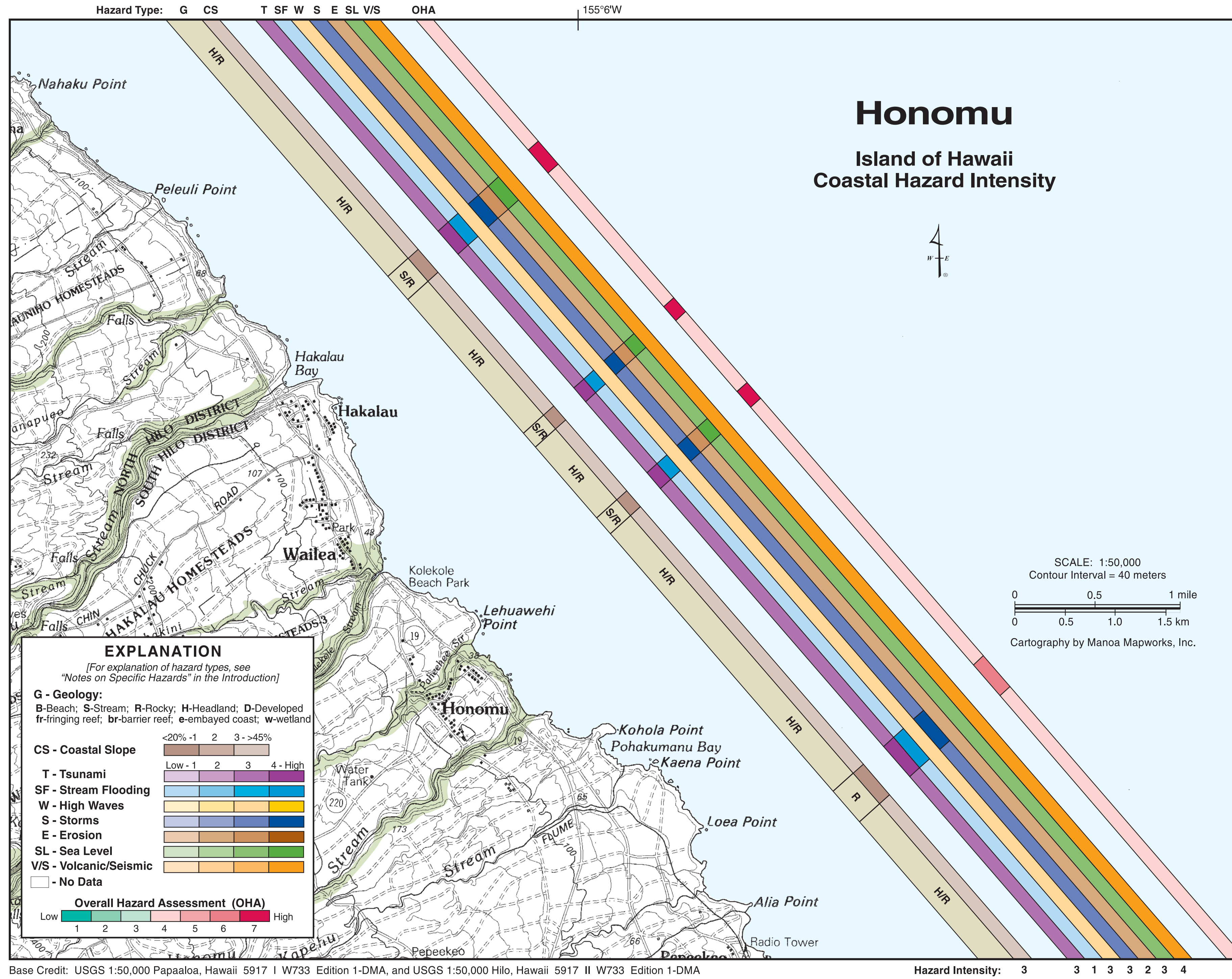
Steep sea cliffs incised by gulches and small embayments like Maulua Bay (shown here) are common along the Ninole coast.

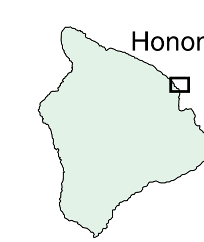
Honomu

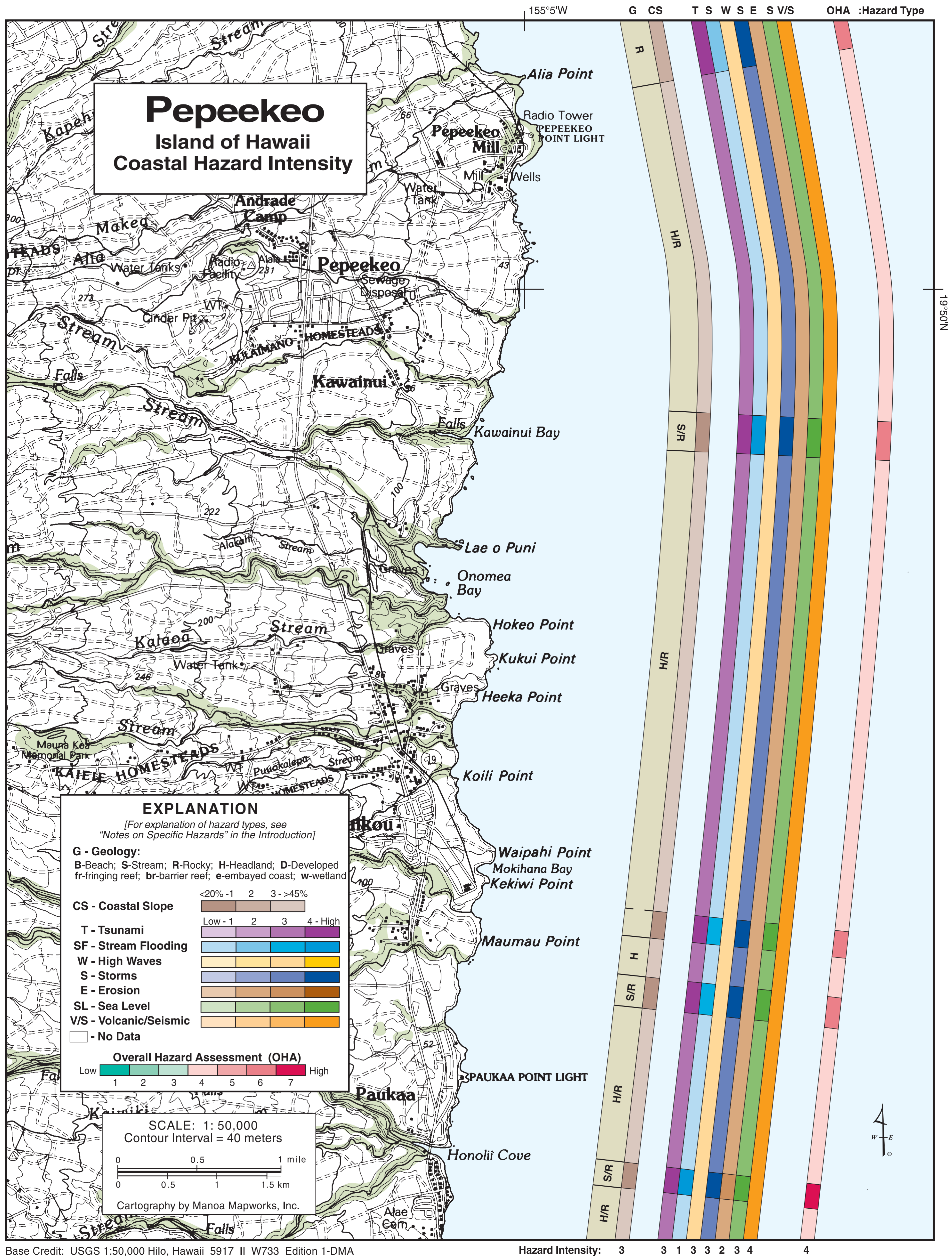
The Honomu Coast from Nahaku Point south to Alia Point is mostly a rocky headland coast with small embayments at stream mouths. The coast slopes are slightly more gentle in the southern portion of Honomu. Scenic waterfalls occur just landward of the coast. The coastal streams are important agents for transporting volcanic boulders to the stream mouths, where they become strewn along the shoreline by energetic waves that impact this coast. Small, temporary pebble and black sand beaches can occur at Hakalau Bay and Kolekole Beach Park. Heavy stream discharge into Hakalau Bay keeps the waters turbid and sediment rich. Corals are absent along this coast, while high waves and trade winds are normal.

Tsunami, high waves, and storms are ranked moderate to high along the steep-cliffed segments of the Honomu coast which faces northeast into the prevailing winds and receives significant north swell. Stream flooding is low and erosion is moderate to low where the coast is steep, whereas sea-level rise is moderate to high. The Honomu coast lies within lava flow hazard zone 8 (Table 10, p. 24) and is ranked high for volcanism and seismicity as it is along the entire Big Island coast that experiences active seismicity associated with the volcanic eruption of Kilauea. These individual rankings translate into a moderate (4) Overall Hazard Assessment (OHA) along the steep cliffs of Honomu. At the low-lying Hakalau Bay, Kolekole Beach Park, and Honomu, the OHA is elevated to very high (7) because of the increased tsunami, stream flooding, storm, erosion, and sea-level rise threats at those locations. In the embayment between Loea and Alia Points the erosion hazard is not as high as the other embayments to the north because of the rocky substrate inside the bay, therefore the OHA inside this embayment is high (6).

The Honomu coast is marked by relatively steep sea cliffs and narrow bridges spanning gulleys and small embayments.







Pepeekeo

From Alia Point south to Honolii Cove, the Pepeekeo coast is adorned with numerous rocky points that protrude seaward and shelter isolated and sometimes deeply incised coves and bays. Lae o Puni is one of these elongated rocky headlands that borders the beautiful Onomea Bay with its small rocky islets. Pebble and cobblestone beaches line the small coves within Onomea Bay and red lava rock can be seen in the cliffs along the northern side of the bay. A black pebble beach also exists at Honolii Cove, a popular surf spot along the Pepeekeo coast. Numerous streams empty into the sea along the Pepeekeo coast bringing with them significant amounts of sediment-rich waters and debris. High waves dominate this coast and help to rework the stream-transported material. Coral reefs are absent in this region. The coastal slope becomes more low-lying and gentle to the south, where development is greatest.

The variation in the hazard intensity ranking along the Pepeekeo coast primarily reflects changes in the coastal slope. Along the steep cliffs, where flooding, inundation, and marine overwash is mitigated by the high relief, the Overall Hazard Assessment (OHA) is moderate (4). Along these steep-cliffed shorelines, tsunami, high waves, storms, and sea-level rise are ranked moderately high, stream flooding is low, and erosion is moderately low. However, inside the low-lying coastal embayments of Kawainui Bay and those on either side of Maumau Point, the OHA is high (6) due to the higher tsunami, stream flooding, storm, and sea-level rise hazards. The black sand and pebble beach inside Honolii Cove is more susceptible to erosion and as a result the erosion hazard there is ranked moderately high. This translates into an OHA ranking of very high (7) for Honolii Cove. Volcanism and seismicity is high due to this region's proximity to Kilauea which is the source region for active seismicity on the Big Island. The Pepeekeo coast lies within lava flow hazard zone 8 (Table 10, p. 24).

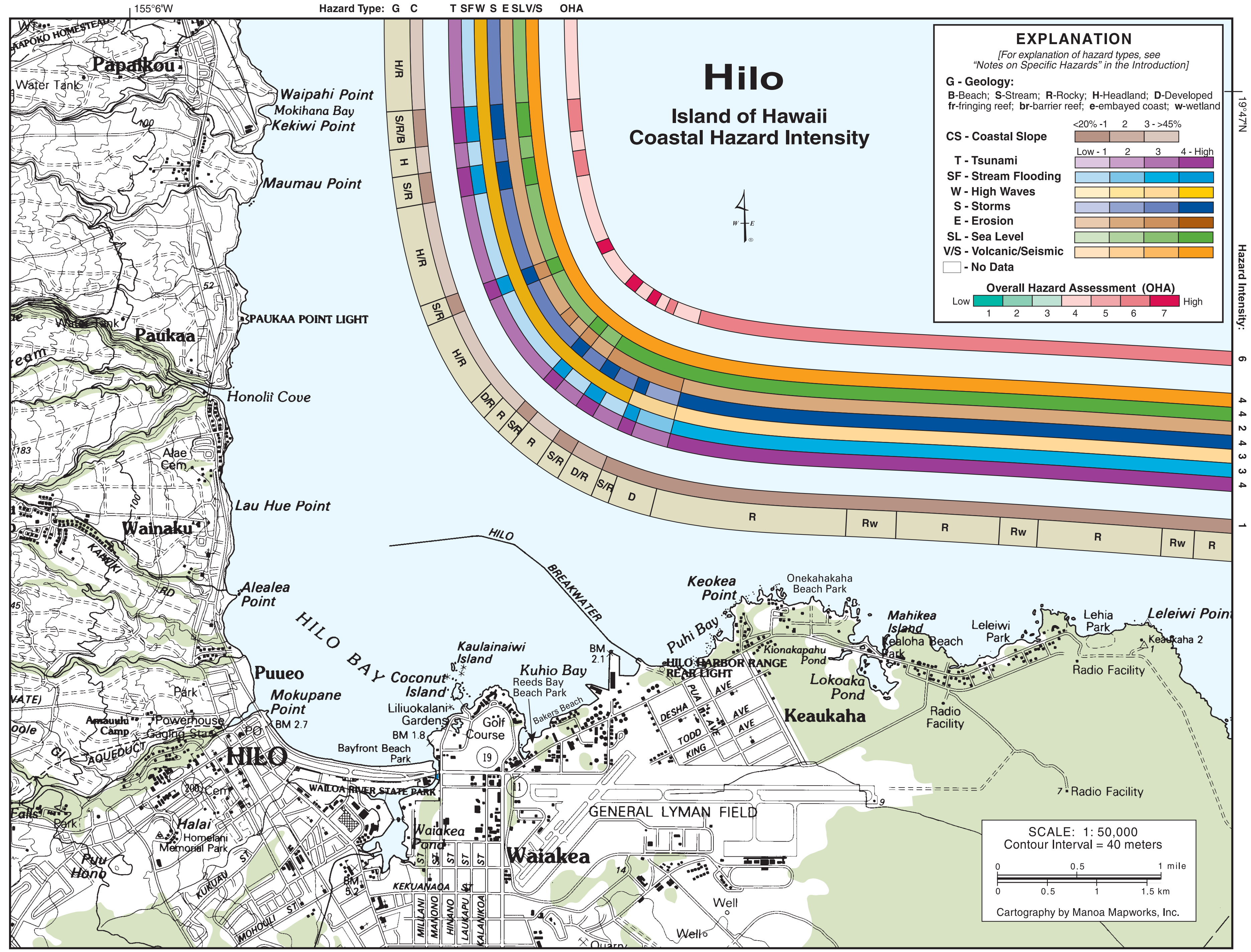
Steep sea cliffs and rocky headlands of Mauna Kea lava flows and dikes comprise the Pepeekeo coast.

Hilo

The embayed and heavily developed Hilo coast becomes progressively more gently sloping and low lying toward the south. The city of Hilo is situated in a saddle between the Mauna Kea and Mauna Loa Volcanoes. Numerous streams that drain the Mauna Kea side of the Hilo hinterland have been infilled by Mauna Loa lavas that flowed northward as recently as 1984. Fortunately for the town of Hilo, these lavas only reached the upper city limits. Perhaps more of a concern to Hilo residents is the potential future impact of tsunami. Two devastating tsunamis in roughly the last 50 yr, generated by the 1946 Alaskan and 1960 Chilean earthquakes, inundated the town of Hilo with runups of 26 and 35 ft, respectively, destroying much of the central business region.

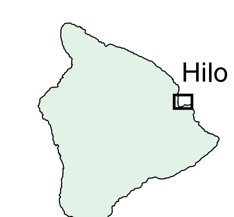
Narrow black sand beaches extend along the Hilo bayfront and at Reeds Bay Beach Park and Bakers Beach where coral sand and rubble beaches have been lost due to erosion since they were constructed in the late 1920's. To help protect the bayfront shoreline from a long history of tsunami and wave action, the L-shaped Hilo Breakwater was built in the early 1900's. Numerous small pocket beaches are found east of the breakwater, most separated from the sea by natural lava flows and/or retaining walls like the wall at Richardson Ocean Center at Leleiwi Beach Park. Erosion and sea-level rise are important components of shoreline change in the Hilo area. Nearly 50 years of tide gauge data show that the Big Island near Hilo is subsiding in addition to experiencing global sea-level rise. This makes relative sea-level rise in Hilo (1.63 inches/decade) faster than on Oahu (0.64 inches/decade) and Maui (0.96 inches/decade). Erosion along the coast is largely controlled by this rapid rate of sea-level rise.

The Overall Hazard Assessment (OHA) for the Hilo region alternates between moderate (4) along the rocky headland regions in the north to high (6) and very high (7) at stream mouths within and east of Hilo Bay. The tsunami, high wave, storm, and sea-level-rise hazards are moderately high at the rocky headlands, while stream flooding is low and erosion is moderately low. The rankings for tsunami, stream flooding, storm, and sea-level rise are high along the lower-lying coastal segments, especially stream mouths. Inside Hilo Bay, where erosion is moderately high, the OHA is very high (7). High waves are partly mitigated by the breakwater, so the coastal region of Kuhio Bay has a high wave ranking of moderately low and an OHA of moderate (4). East of the Hilo Breakwater the OHA is high (6), reflecting the uniform gently-sloping coastal zone and moderately high stream flooding hazards there. Hilo lies within lava flow hazard zone 3 (Table 10, p. 24). The volcanic/seismic hazard is high in Hilo as it is along the entire Big Island coast which experiences active seismicity associated with Kilauea Volcano.



Base Credit: USGS 1:50,000 Hilo, Hawaii 5917 II W733 Edition 1-DMA

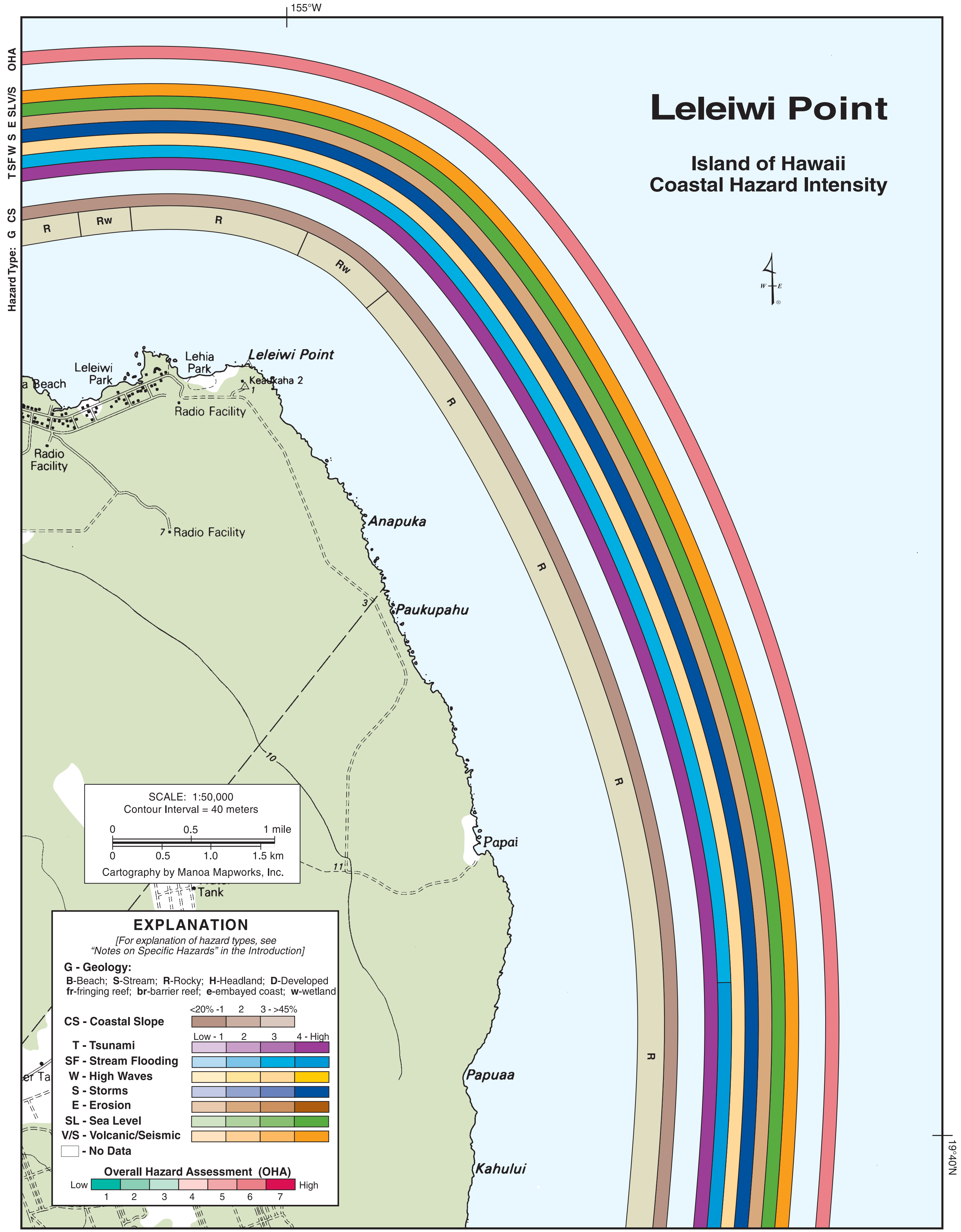
The extensively developed Hilo coast is low lying and prone to flooding by heavy rainfall and tsunami inundation. The Hilo breakwater helps to mitigate flooding from storm-wave surge associated with high annual north swell, episodic tropical storms, and tsunami inundation.



Leleiwi Point

The Leleiwi Point coastline is largely fronted by low lava cliffs formed by the Kau Basalt, which ranges between 350 and 500 yr old. These historical lava flows spread toward the sea forming jagged headland points and small rocky islets which are especially numerous between Anapuka and Papai. The elevation of the relatively undeveloped volcanic coastal terrace ranges between 10-15 ft above sea level. Leleiwi and Lehia Parks harbor small pocket beaches within the rocky coves. A narrow black and olivine-rich green sand beach lines the inner portion of Papai Bay. Freshwater springs are common along this stretch of coast, often creating a cold freshwater lens near the surface and brackish conditions in the rocky pools behind the points. The Leleiwi Point shoreline faces directly into the prevailing northeast trade winds and receives significant wave energy originating from north, east, and southeast swell. Corals are sparse in this region.

The high (6) Overall Hazard Assessment (OHA) for Leleiwi Point coast is largely a function of the low coastal slope along the entire coastline, which is susceptible to marine overwash and stream flooding. However, because it is partly removed from the watersheds that drain Mauna Loa and Mauna Kea Volcanoes around Hilo, the stream-flooding threat is ranked only moderately high. Tsunami is ranked high while the threat from high waves is only moderately high because of its northeast aspect. High winds from approaching tropical cyclones and Kona storms impact this northeast-facing shoreline and so the storm hazard is ranked high. Erosion is partly mitigated by the rocky cliffs that line the coast, so the erosion threat is ranked moderately low. Sea level is rising relative to the island land mass faster in this region than any other in Hawaii. The Leleiwi Point coast lies in lava flow hazard zone 3 (Table 10, p. 24). This portion of Hawaii also experiences very active seismicity associated with volcanism at Kilauea Volcano. As a result, these two hazards are ranked high.



Base Credit: USGS 1:50,000 Hilo, Hawaii 5917 II W733 Edition 1-DMA

Hazard Type: 1 4 4 3 4 2 4 4 6

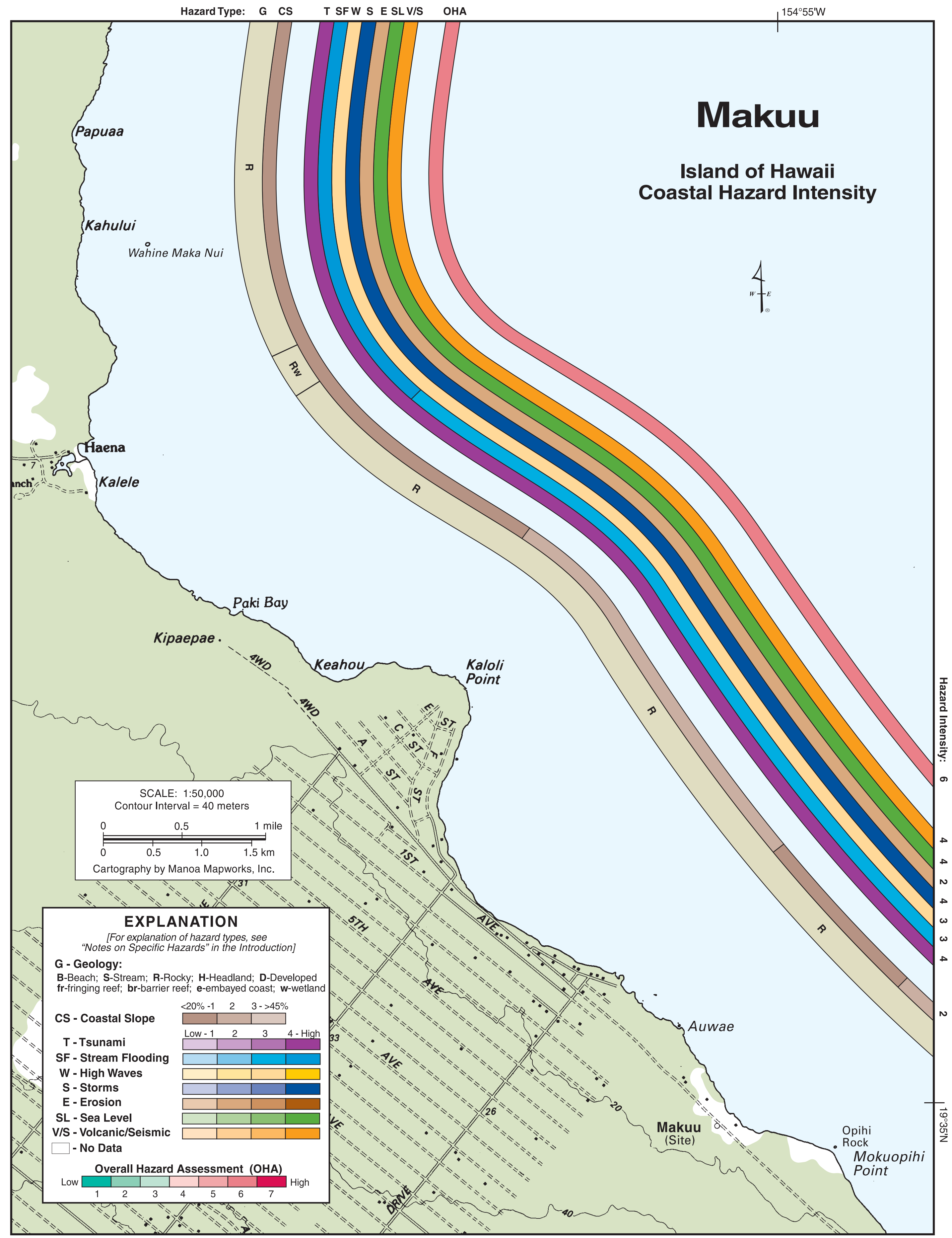
The area around Leleiwi Point consists of low lying rocky points and gravel-filled embayed beaches.

Makuu

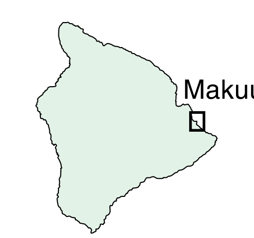
Between Papuaa and Kaloli Point, the Makuu coast is only slightly developed, however south to Auwae, the coast is well developed with the Hawaiian Paradise Park subdivision extending to the shoreline. The Makuu coastal terrace is comprised of Ai-Laau lava flows which are between 350 and 500 yr old. The entire coastline is within 20 ft of sea level and appears to be getting closer due to steady long-term and rapid periodic subsidence. In April of 1868 the region sank and was inundated by a locally generated tsunami after a 4.1 earthquake rocked the southeast portion of the island. The small spring-fed wetland pond and inlet at Haena are the products of shoreline change due to the April 1868 co-seismic subsidence. A thin veneer of carbonate sand covers the bottom of Haena Bay. Low sea cliffs border the shore between Kaloli and Mokuopihi Points. The only beaches in this region are low lying, narrow, and limited to the base of the cliffs along the Hawaiian Paradise Park subdivision and Makuu. South of Paki Bay the coastal terrace becomes slightly more arid and fewer streams cross it to the sea.

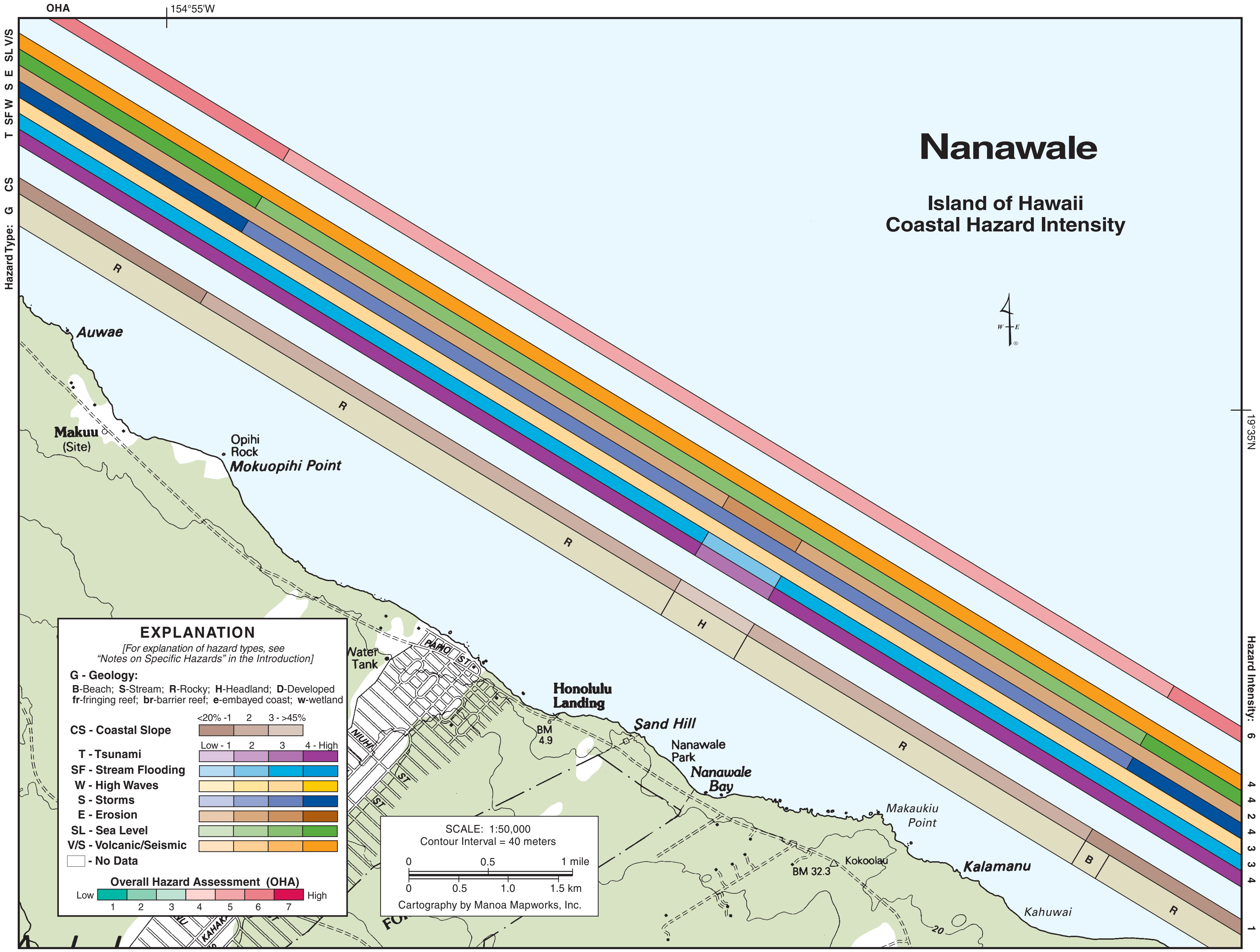
The Overall Hazard Assessment (OHA) for the entire Makuu coast is high (6), reflecting the high and moderately high hazards that affect this low-lying region. The tsunami threat is ranked high, while stream flooding is high in the northern portion but only moderately high south of Paki Bay, where fewer streams reach the sea. High waves consist generally of refracted north swell, trade-wind waves, and waves associated with approaching tropical cyclones. As a result, the high wave hazard is ranked moderately high. The storm hazard is high where the coast is exposed to both the tropical cyclone and Kona storm windows. This seismically and volcanically active coast experiences rapid long-term subsidence which enhances the rate of relative sea-level rise. For this reason the sea-level hazard is high. Makuu is located in lava flow hazard zone 2 (Table 10, p. 24). The volcanic/seismic hazard is high along the Makuu coast due to the high lava flow hazard and its proximity to significant seismic activity generated by volcanic eruptions at Kilauea Volcano.

Most of the east-facing Makuu coast consists of rugged and rocky cliffs generally less than 20 ft high.



Base Credit: USGS 1:50,000 Hilo, Hawaii 5617 II W733 Edition 1-DMA and USGS 1:50,000 Pahoa, Hawaii 6016 IV W733 Edition 1-DMA





Base Credit: USGS 1:50,000 Pahoa, Hawaii 6016 IV W733 Edition 1-DMA

Nanawale

Southeast of Auwae and Mokuopihi Point, the Nanawale coast ranges from 1000 to 1500 yr old, except the area between Honolulu Landing and Nanawale Park, which is the seaward edge of an 1840 flow that emanated from the east rift of Kilauea Volcano. Most of the coast is fronted by low rocky sea cliffs, above which is built the Hawaiian Beaches subdivision in the middle of this portion of coastline. A few small boulder beaches occur at Honolulu Landing, Nanawale Park, and along the southern stretch of coast to Kahuwai. The black sand beach at Kahuwai formed shortly after the 1960 Kapoho eruption which sent lava flowing into the sea just southeast of the Nanawale region. The Nanawale shoreline undergoes periodic morphologic changes due to tectonic and seismic activity associated with Kilauea Volcano. In April of 1924, a series of earthquakes caused the Honolulu Landing shoreline to sink, leaving the black sand beach buried in rounded basalt boulders and the boat landing less used by larger ships. High waves are common along the Nanawale coast often making the rugged coastal cliffs dangerous for fishermen.

The Overall Hazard Assessment (OHA) for the Nanawale coast is reduced from high (6) north of Makuu to moderate to high (5) south of Makuu to Kalamanu where the coast steepens and the sea cliffs help to mitigate against marine overwash and the impacts associated with sea-level rise. To the south of Makuu the tsunami hazard is ranked high while stream flooding is moderately high. An anomaly exists at the Sand Hill headland. Here the coast is even steeper, so flooding hazards are less threatening, but because the substrate is more unconsolidated it is more susceptible to erosion. As a result, tsunami and stream flooding at Sand Hill are moderately high and moderately low, respectively. The high wave threat is moderately high throughout Nanawale. The storm and sea-level hazards are ranked moderately high between Makuu and Kalamanu. Erosion is moderately low except at Sand Hill where it is increased to moderately high. The Nanwele coast is in lava flow hazard zone 2 (Table 10, p. 24). The volcanic/seismic hazard is high throughout the entire region due to its proximity to great seismic activity associated with Kilauea volcanism.

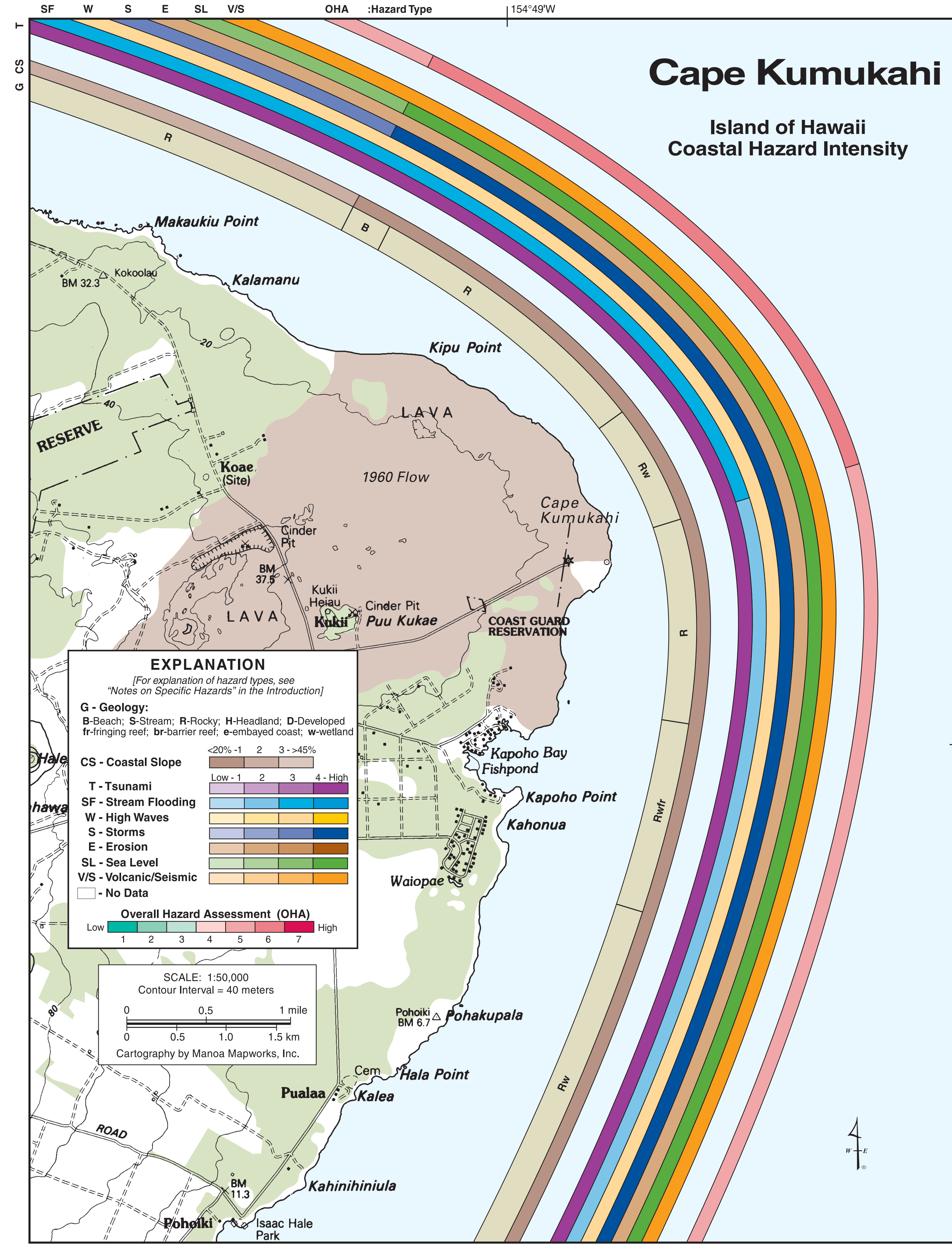
The geologically young volcanic coast of Nanawele is rocky with small cliffs and few beaches or reefs.

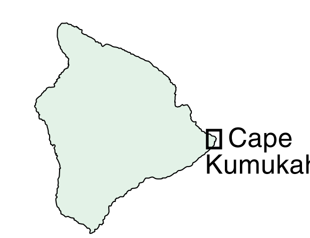
Cape Kumukahi

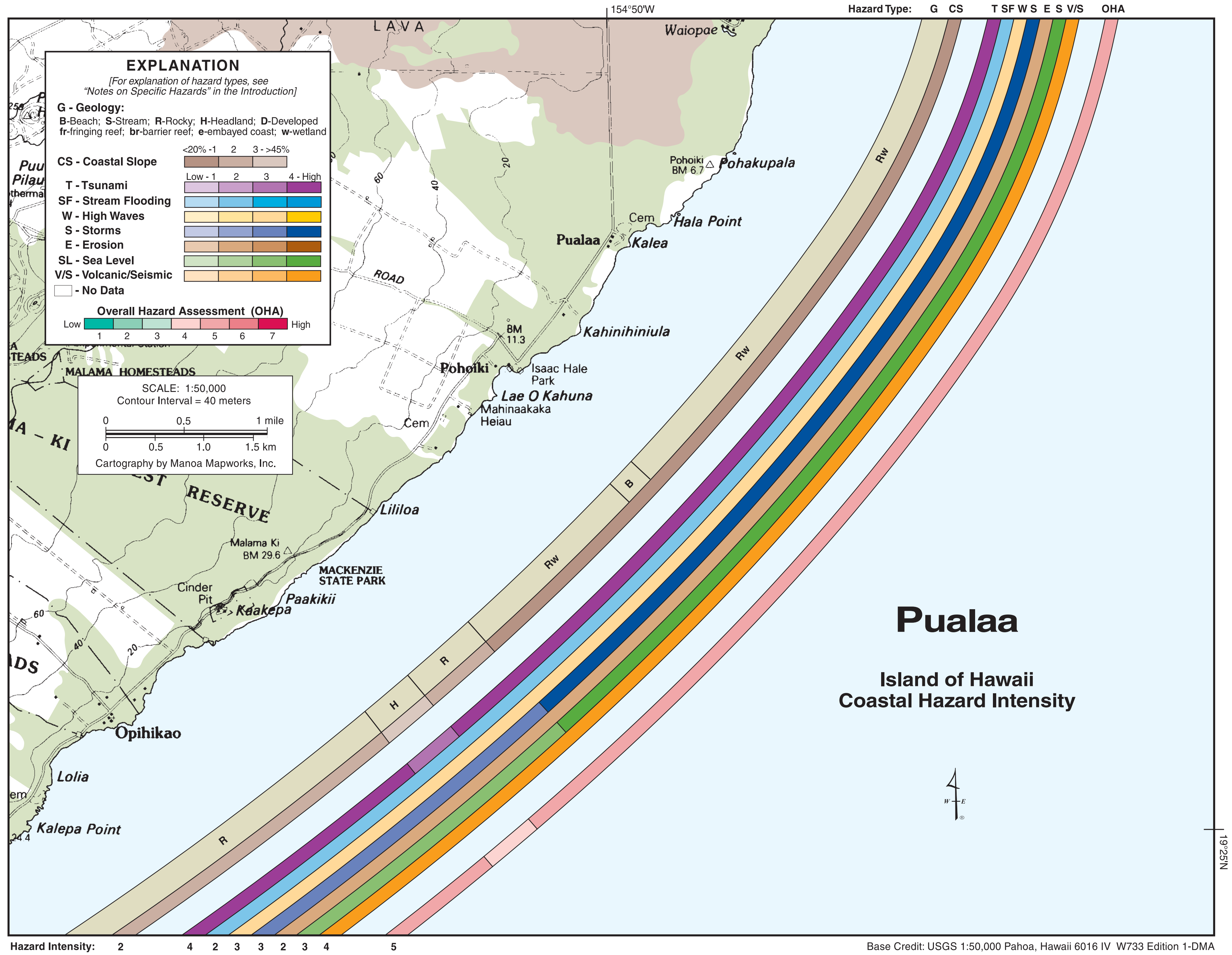
The 1960 Kapoho eruption along Kilauea Volcano's east rift zone produced lava flows that extended parts of Cape Kumukahi, the eastern-most point in Hawaii, farther seaward and eastward. The entire village of Kapoho, and most of Koae, was destroyed. Rock walls emplaced by the inhabitants of the area however, served to protect the lighthouse and houses to the south. The flow produced a black sand beach that temporarily existed along the 3 miles of Kumukahi, but was soon lost to the relentless attack of trade-wind and storm-generated waves. Cape Kumukahi is located directly on Kilauea's east rift zone and is therefore classified into lava flow hazard zone 1 (Table 10, p. 24). Development remaining along this coast is focused at Kapoho Bay where tidepools abound and a fish pond provides a wetland habitat for various species of birds. South of Kapoho Point, a fringing reef extends just past Kahonua along a generally rocky coast that borders the Pualaa coastal terrace to Kalea. Rainfall and stream flow decrease markedly south of Cape Kumukahi. This coast receives significant wave energy from trade-wind and east and south swell, as well as refracting north swell.

The Overall Hazard Assessment (OHA) for Cape Kumukahi is largely dictated by the coastal slope and presence or absence of streams. The slope decreases south of Kalamanu and the hazards associated with flooding and sea level are therefore generally higher south of this point. However, south of the lighthouse at Cape Kumukahi streams are absent thus reducing the stream flooding hazard. The tsunami hazard is high, while the high wave threat is ranked moderately high along this entire low lying coast. Stream flooding is moderately high north of Cape Kumukahi and only moderately low to the south. The storm and sea-level hazards are increased from moderately high to high south of Kalamanu where the coastal slope becomes more low lying and gentle. Erosion is ranked uniformly moderately low throughout the entire sea-cliffed coast. The volcanic/seismic hazard is high along Cape Kumukahi due to historical volcanism and seismicity associated with eruptions of Kilauea Volcano. As a result, the OHA is moderate to high (5) north of Kalamanu, high (6) between Kalamanu and Cape Kumukahi, and moderate to high (5) in the southern portion between the cape and Pualaa.

The Cape Kumukahi coast is generally low lying and formed by recent lava flows that have emanated from Kilauea Volcano's east rift zone.







Pualaa

Between Pohakupala and Opihikao, the Pualaa Coast is lined by low rocky sea cliffs that face southeast. The coast steepens south of Lililoa and at a small headland at Paakikii. Most of the lavas that form the coastal terrace and its cliffs range in age between 250 and 1000 yr, however the youngest outcropping between Lililoa and Mackenzie State Park is associated with a 1790 flow. This region, like most of the Puna district to the north, is geothermally very active. Hot springs and fumaroles or vents of escaping gas can be seen emanating through the Pualaa coastal terrace. The surfacing of these waters creates wetland environments along the entire coast. The only beach in this portion of coast is found at Isaac Hale Park inside Pohoiki Bay. Here warm water seeps into Pohoiki Bay through the bay floor. The Pualaa coast receives between 75 and 100 in of rain annually and has few streams. High waves persistently attack the coastal cliffs making access to the water relatively dangerous. No significant reef development exists on this geologically young coastline.

The Overall Hazard Assessment (OHA) for Pualaa is moderate to high (5) except at Paakikii where it is moderate (4). This variation is due to the change in coastal slope at Paakikii. Here the tsunami hazard is reduced to moderately high from a ranking of high along the rest of the coast. Stream flooding is moderately low throughout this relatively arid region. The high wave hazard is moderately high along the entire coast while the storm and sea-level hazards are high north of Lililoa and reduced to moderately high to the south where the coast is steeper. Erosion along the rocky Pualaa coast is ranked uniformly moderately low. Pualaa lies in lava flow hazard zone 2 (Table 10, p. 24). The seismicity and volcanic hazard is high due to this region's proximity to the active Kilauea Volcano.

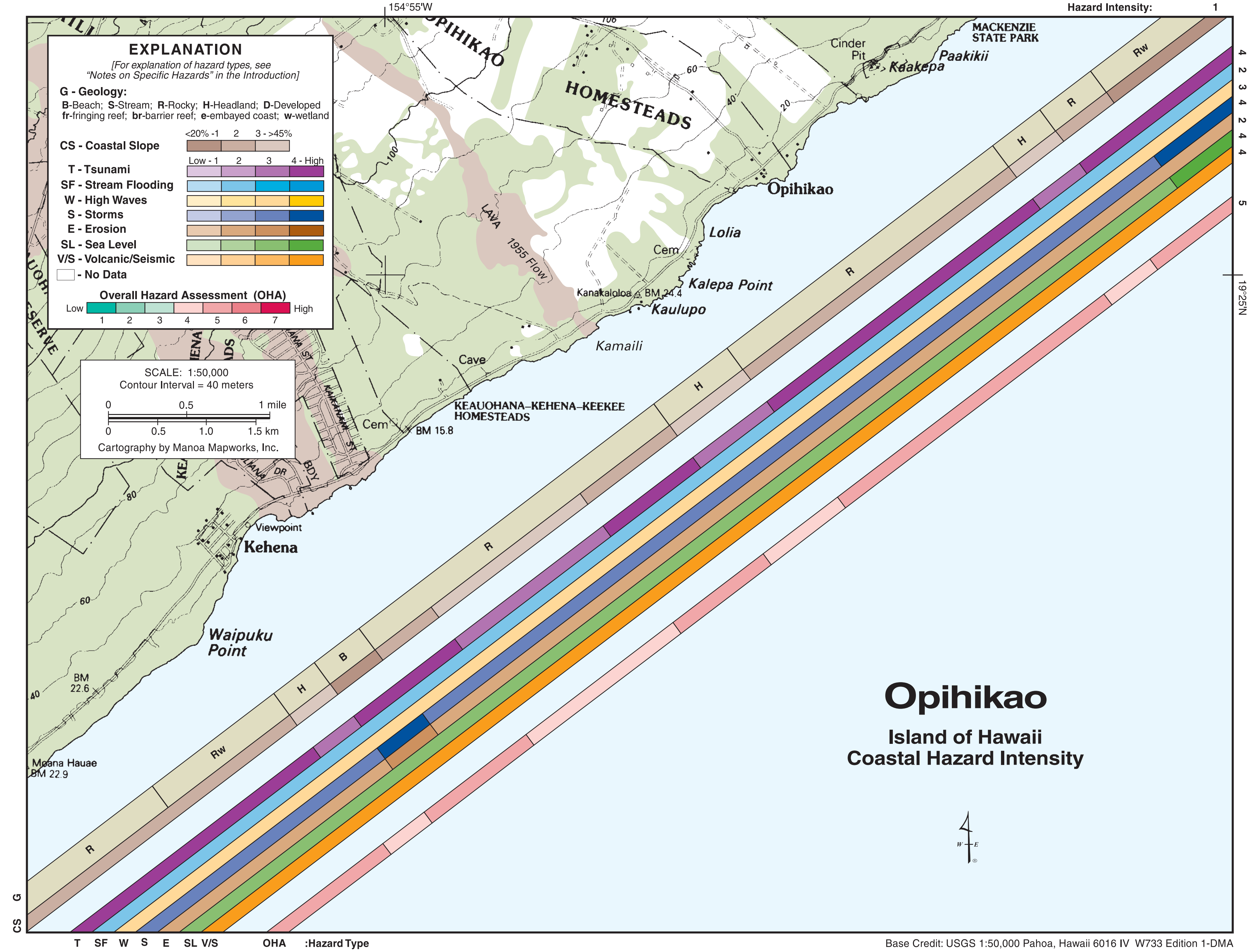
The Pualaa coast is rocky and low lying with occasional small embayments providing protection from side shore winds and generally rough seas.

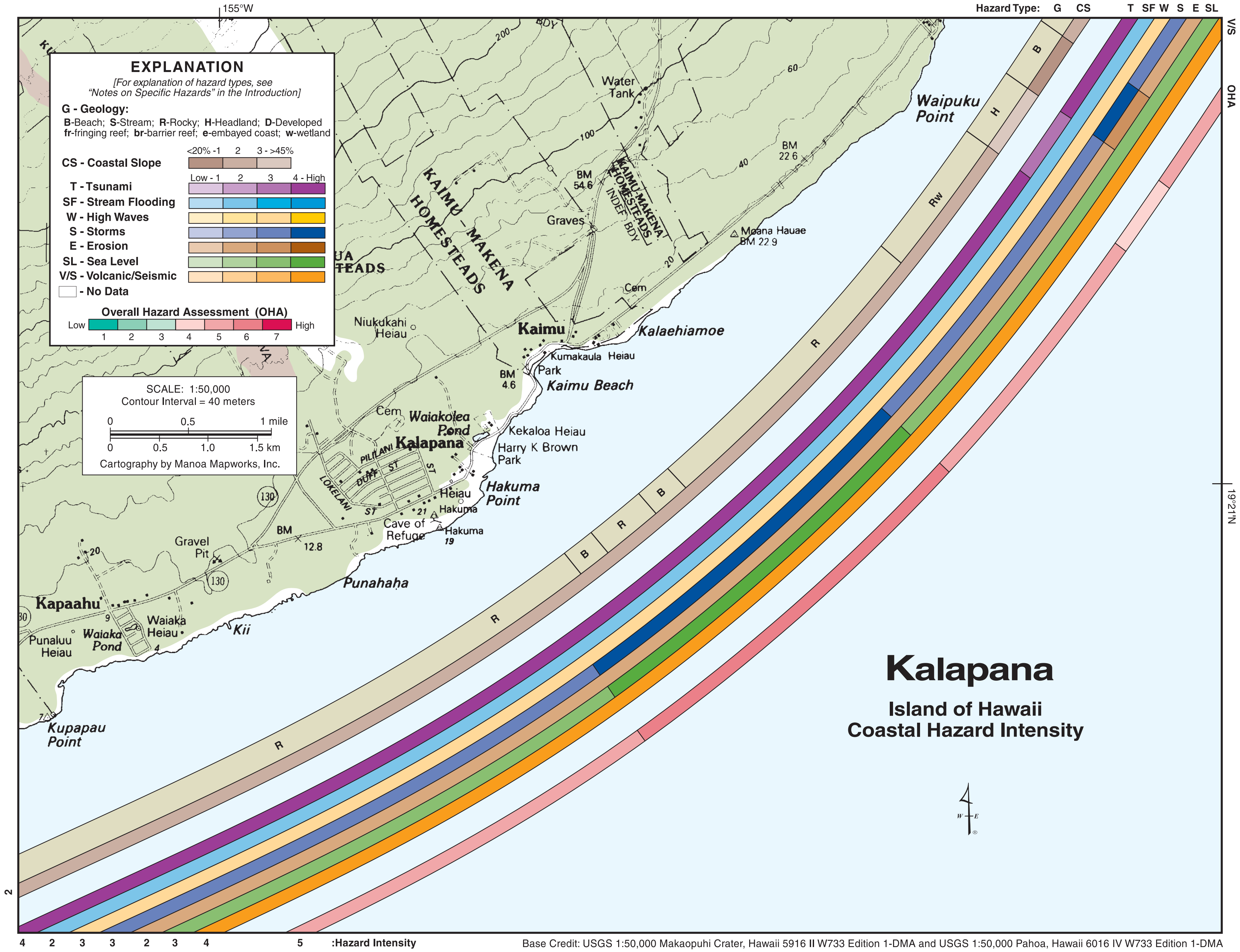
Opihikao

The Opihikao shoreline between Paakikii and Waipuku Point has been built over the past several thousand years by numerous lava flows. However, as recently as 1955, a significant volume of lava erupted from Kilauea Volcano's east rift and created new coastline at Kamaili and the Keauohana-Kehena-Keekee Homesteads. The 1955 flow is responsible for the formation of the black sand beach at Kehena and a small rocky point that appears to help mitigate against erosion of the beach. Unlike other beaches in this region, the Kehena beach has survived the attack of waves and earthquake-induced subsidence. In 1975, the beach sank nearly three feet when a 7.2 magnitude earthquake rocked the entire southern corner of the island. Relatively intense wave energy maintains a steep beachface at Kehena, where pebbles and cobbles are common. Just offshore of most of the Opihikao coast the seafloor drops off rapidly. Very few corals have managed to colonize this region of coast.

The Overall Hazard Assessment (OHA) for Opihikao alternates between moderate to high (5) and moderate (4). Stream flooding and storms are ranked moderately low and moderately high, respectively, while the volcanic/seismic threat is high throughout the entire region because of the proximity to Kilauea Volcano. Along the headlands at Paakikii, Kaulupo, Waipuku, and the rocky coast of the Keauohanaa-Kehena-Keekee Homesteads, the OHA is moderate (4) where tsunami, high waves, and sea-level rise are moderately high and stream flooding and erosion are moderately low. Between these headlands where the coast is lower, the tsunami hazard is ranked high and so the OHA is increased to moderate to high (5). At the beach inside the Kehena embayment the storm and erosion hazards are elevated to high and moderately high, respectively. The Opihikao coast lies within lava flow hazard zone 2 (Table 10, p. 24).

Recent lava flows have covered pre-existing vegetation and infrastructure along the low-lying, rocky Opihikao coast.





Kalapana

The Kalapana coast is famous for its beautiful black sand beaches. At times, these beaches are instantaneously created and at others, rapidly destroyed by the lava flows that form the coastline. In 1992, lava flows emanating from Kilauea Volcano's east rift zone buried the once popular Kalapana black sand beach and extended the coastal terrace over 1500 ft seaward in the form of a table of pahoehoe. In addition to volcanic eruptions and lava flows, earthquakes and rapid tectonic subsidence have shaped the coast here, creating and destroying beaches, bays, and points of entry for boaters and fishermen. Most of the coastline between Waipuku and Kupapau Points is bordered by cliffs that mark the seaward limit of lava flows protruding into the sea. Small black sand pocket beaches, including those at Harry K. Brown Park and Kaimu, may only exist temporarily as they appear to be losing ground to the sea since their formation in 1992. This coast is very young and, as a result, there is little coral reef development.

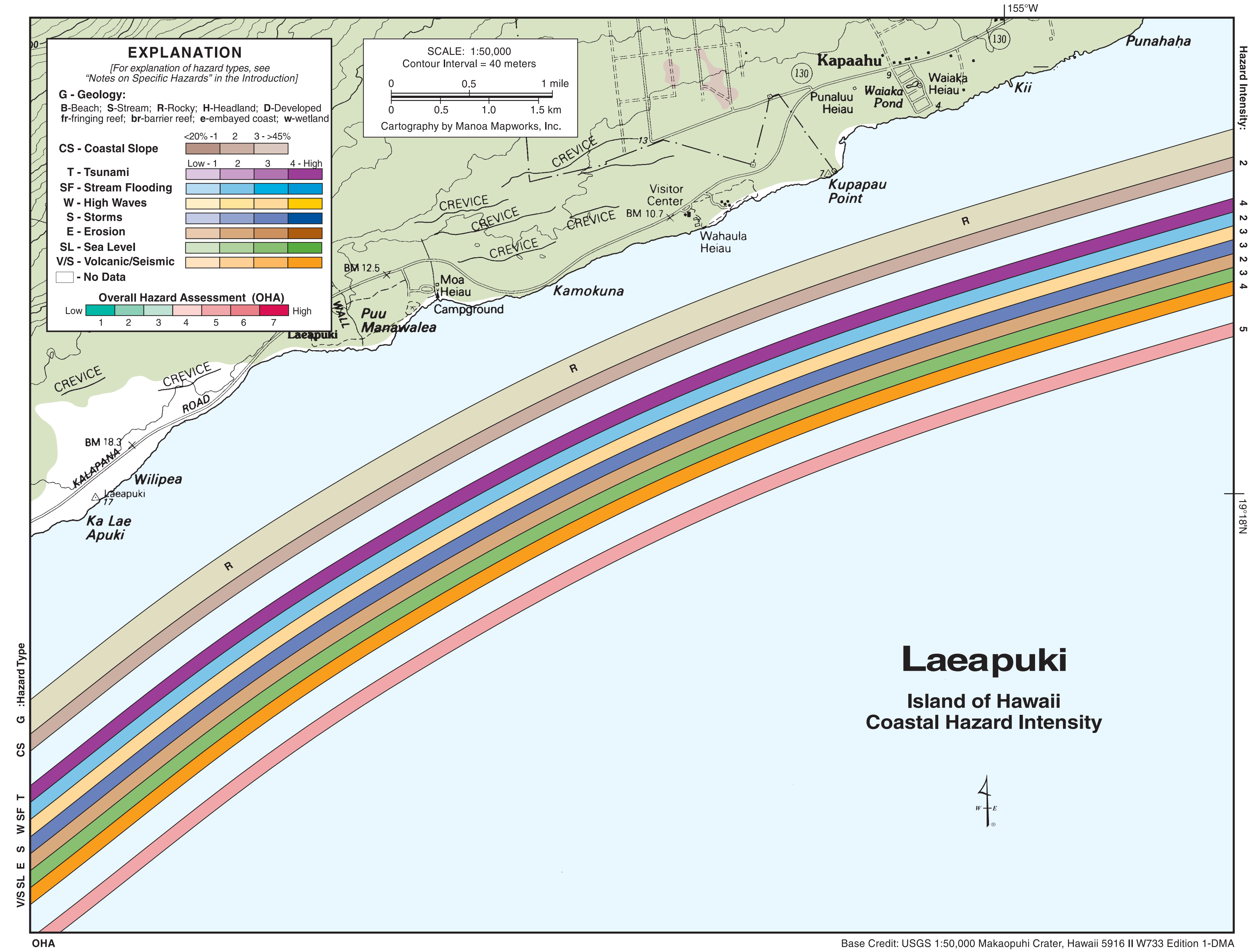
The Overall Hazard Assessment (OHA) is moderate to high (5) south of Hakuma Point and north of Moana Hauae, except for the headland of Waipuku Point where it is moderate (4), and seaward of the low-lying beach area of Kaimu Beach where it is high (6). Tsunami is high along this low-lying stretch of coast except at the headland south of Waipuku Point, where it is moderately high. Stream flooding is moderately low in this relatively arid region where few streams flow to the sea. The high wave threat is ranked moderately high. Storms are ranked high south of Kalaehiamoe, and moderately high to the north except along the beach just north of Waipuku Point where it is high. Erosion is moderately low except at this same beach where it is moderately high. Sea-level rise is moderately high along the headland coast in the north, and high along the lower-lying cliffs south of Moana Hauae. The volcanic/seismic hazard is high along the entire Kalapana coastline because of its proximity to active volcanic and seismic activity associated with Kilauea Volcano eruptions. Kalapana lies within lava flow hazard zone 2 (Table 10, p. 24).

Lava flows reached the coast at Kalapana in 1992, extending the shoreline seaward nearly 2500 ft, burying the famous Black Sand Beach under a fresh platform of black lava rock. Small transient black sand beaches have formed downdrift of the new lava coast, but have been highly susceptible to erosion due to rapid sea-level rise.

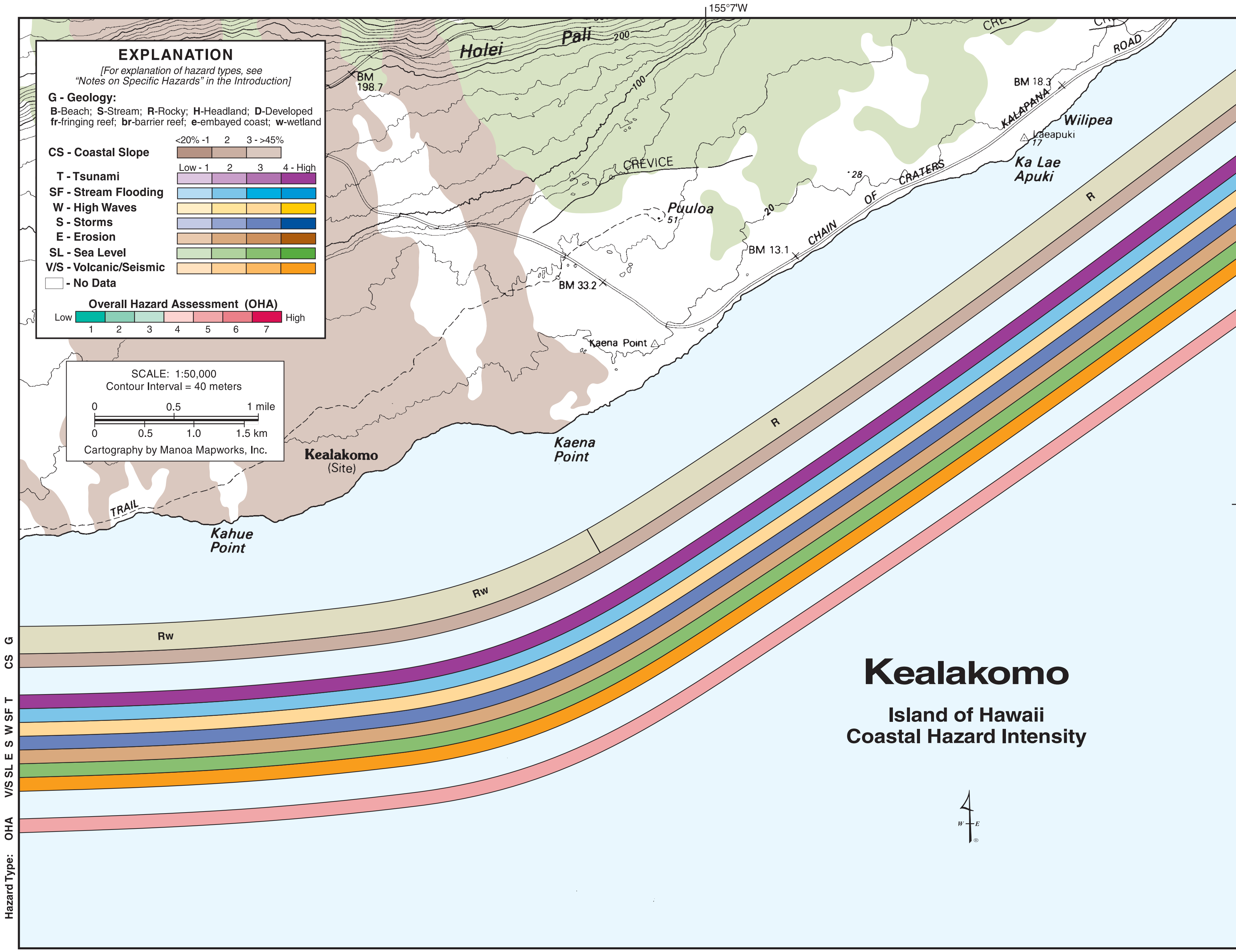
Laeapuki

The low-lying rocky Laeapuki coastline is undergoing significant change as this atlas is being printed. Since 1992, lava flows from numerous eruptions at Puu Oo along Kilauea Volcano's southeast rift have built the shoreline seaward and cut off the coastal road from the east. Billowing clouds of steam mark the entry of molten rock into the sea as it cascades over small 3-10 ft high sea cliffs. Often the flowing lava is absent on the surface as it travels through subsurface lava tubes and porous conduits. The ceilings of these lava tubes are essentially the top surface of the flow, and these can collapse if they are unable to support the burden placed upon them. This mechanism also works on a large spatial scale as the underlying porous framework of thousands of years of lava accumulation periodically gives way to the mass above in the form of slow creep and rapid subsidence. It is now believed that the entire south flank of Kilauea slides seaward at a slow uniform rate of approximately 0.5-1 in/yr and in rapid and recurrent down-faulting steps. Few corals keep up with the changing coastal environment here.

The uniform moderate to high (5) Overall Hazard Assessment (OHA) for Laeapuki reflects a similar ranking of the individual hazards along this constant sloped coastline. The tsunami hazard is high. Stream flooding and erosion are both moderately low in this arid and rocky cliffed region. The high wave and storm threats are moderately high here where the coast receives moderately high south swell and approaching storm winds and waves. Despite the high rate of island subsidence, sea-level rise is ranked only moderately high due to the mitigating effects of the rocky cliffs. The Laeapuki coast lies in lava flow hazard zone 2 (Table 10, p. 24). The volcanic/seismic hazard is high due to the active volcanism and seismicity associated with Kilauea Volcano eruptions that constantly affect the Laeapuki coast.



The Laeapuki coast is actively being transformed at the time of publication of this atlas. As lavas emanating from Puu Oo and its subsurface network of lava tubes reach the coast, the shoreline at Laeapuki temporarily extends seaward and occasionally collapses under its newly found weight, making it very unstable.



Base Credit: USGS 1:50,000 Makaopuhi Crater, Hawaii 5916 II W733 Edition 1-DMA

Kealakomo

The Kealakomo coast is currently one of the most volcanically active coasts in Hawaii. Lava flows emanating from Puu Oo, seven miles landward on Kilauea Volcano's southeast rift, have continuously reshaped the eastern portion of this area and cut off the Chain of Craters Road from the east since 1992. Here molten lava cascading down Kilauea's seaward slopes have created a 1000-1500 ft wide coastal terrace that ranges between 3 and 12 ft above sea level. Behind it a steep 60-100 ft high scarp, or pali, breaks the coastal slope. To the west, the coastal terrace widens where lavas from the Mauna Ulu eruptions of 1969-1971 extended the coast seaward. The entire stretch of coast is rocky and bordered by steep sea cliffs. Despite the aridity, the high porosity of the rocks formed by these lava flows enables fresh water to seep toward the coast sometimes making small wetlands like those west of Kaena Point. High porosity of the underlying rocks also means less structural support and sink holes and collapse features are common. Offshore the seafloor is rocky and void of any reef development.

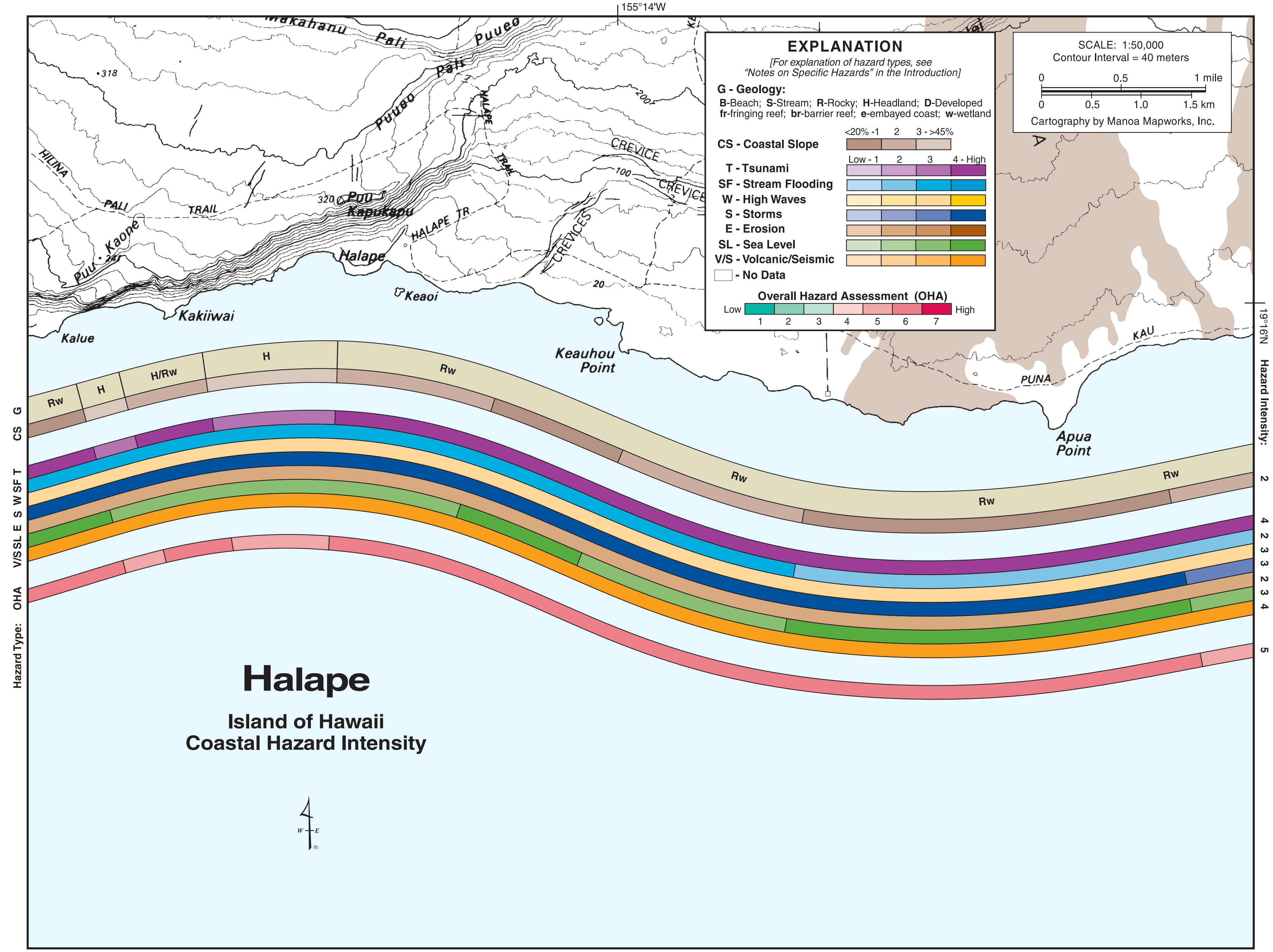
The Overall Hazard Assessment (OHA) along the entire Kealakomo coast is moderate to high (5) due to the uniform ranking for the individual hazards. This is largely a result of the uniform rocky shoreline and low slope found along the entire coast. Tsunami is high, while stream flooding is moderately low in this arid region. High waves and storms are ranked moderately high, because this coast receives significant swell from the south and winds and waves from approaching storms. Erosion is moderately low along this geologically young, cliffed coast. Sea-level rise is moderately high and the volcanic/seismic hazard is high. The Kealakomo coast lies within lava flow hazard zone 2 (Table 10, p. 24).

The undeveloped and geologically young Kealakomo coast is fronted by steep sea-cliffs ranging 5 to 15 ft high. It is low lying and gradually slopes landward to the base of the Halina and Holei palis (cliffs).

Halape

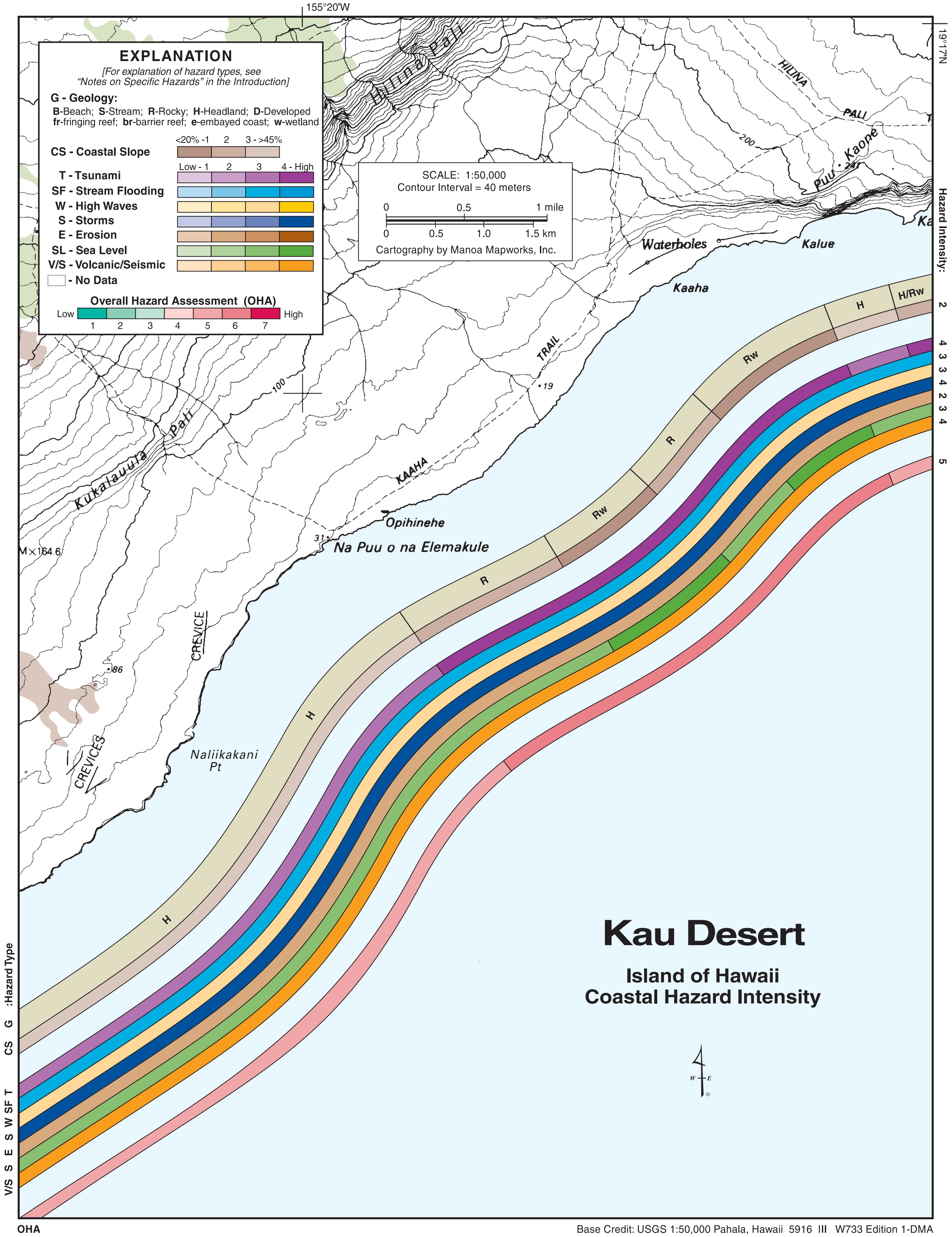
The wide volcanic coastal terrace most recently built seaward by the Mauna Ulu eruptions of 1969-1974 is generally low lying until it abuts the steep scarp of Halina Pali at Halape. The 1500 ft scarp running landward of Halape west to Kalue is located along several faults that give way periodically to accumulated stress beneath the ground surface. Subsidence occurs here at a slow uniform rate (0.5-1 in/yr) and by sudden catastrophic collapse events such as those that occurred in 1975 and 1868. The most recent of these releases was during the 7.2 magnitude earthquake of November 26, 1975, when the entire coastal plain at Halape subsided over 10 ft and produced a tsunami wave that surged shoreward killing two people. Another devastating tsunami on April 2, 1868 wiped clean most of the vegetation and fishing communities along the entire Halape coast. Small ephemeral pocket beaches like those at Halape, Apua, and Keauhou, are forcefully reshaped by these combined tectonic and wave events. Small islands lie offshore of Halape and in the lee of Keauhou Point. Wetlands produced from fresh water throughflow within the porous lava rocks and from wave overwash exist along the Halape coast.

Variations in coastal slope dictate the different hazard rankings along the Halape coast. The Overall Hazard Assessment (OHA) is moderate to high (5) east of Apua Point, and alternates between high (6) and moderate to high (5) to the west. The tsunami hazard is high along the entire coast except at the headlands near Kakiiwai and Kalue, where it is reduced to moderately high. The stream flooding threat increases from moderately low to moderately high west of Apua Point, where stream channels have yet to be covered by recent volcanic activity. High waves and storms are moderately high and high, respectively, west of Apua Point. Erosion is moderately low along this rocky cliffed coast, while sea-level rise is ranked high along the low-lying sections near Apua, Keauhou, and Kalue Points, and moderately low along the headlands in between. The Halape coast lies in lava flow hazard zone 5 (Table 10, p. 24). The volcanic/seismic hazard is uniformly high throughout the Halape coast due to significant seismic activity associated with Kilauea Volcano eruptions.



Base Credit: USGS 1:50,000 Makaopuhi Crater, Hawaii 5916 II W733 Edition 1-DMA and USGS 1:50,000 Pahala, Hawaii 5916 III W733 Edition 1-DMA

Faulting and hillslope failure characterize the steep palis (cliffs) landward of the low coastal plain of Halape. Active tectonics associated with the continued eruption of Kilauea Volcano and the subsidence of its southeast flank have produced destructive earthquakes and local tsunamis in the recent past at Halape and along the entire southeast coast of Hawaii.



Kau Desert

Between Kalue and Naliikakani Point, the arid Kau Desert coast is undeveloped. A low-lying coastal terrace ranging between 1000 and 1500 ft in width northeast of Opihinehe narrows to the southwest and disappears into steep coastal cliffs at Na Puu o na Elemakule. The shoreline sits at the base of several scarps that range from 500 to 1500 ft high and that extend for several miles parallel to the coast. This coast is tectonically active. It is situated seaward of Kilauea Volcano's southwest rift zone and appears to be sliding downward and seaward. In addition to the rumblings, rockslides, landslides, and subsidence associated with the tectonic activity in the area, local earthquakes periodically generate tsunamis that impact the coast, such as those in 1868 (magnitude 4.1) and 1975 (magnitude 7.2). Facing southeast, the Kau Desert coast is protected from north swell, but is exposed to east and south swell. It is generally very dry but several streams cut across the coastal plain and periodically experience flash floods. A few small wetlands have formed behind the coastal cliffs between Opihinehe and Kaaha. Water depths increase rapidly offshore and are devoid of any significant reefs.

The Overall Hazard Assessment (OHA) decreases from high (6) between Kalue and Na Puu o na Elemakule to moderate to high (5) to the southwest as a result of the greater coastal slope in the west. This change in coastal slope influences the tsunami ranking which is high in the east and moderately high in the west. Stream flooding and high waves are ranked moderately high and storms are high throughout the Kau Desert Coast. Erosion is moderately low. Sea-level rise varies from high at the rocky wetlands of Kaaha and just north of Opihinehe to moderately high along the other rocky headland stretches surrounding them. The volcanic/seismic hazard is high throughout the Kau Desert coast, which lies within lava flow hazard zone 3 (Table 10, p. 24).

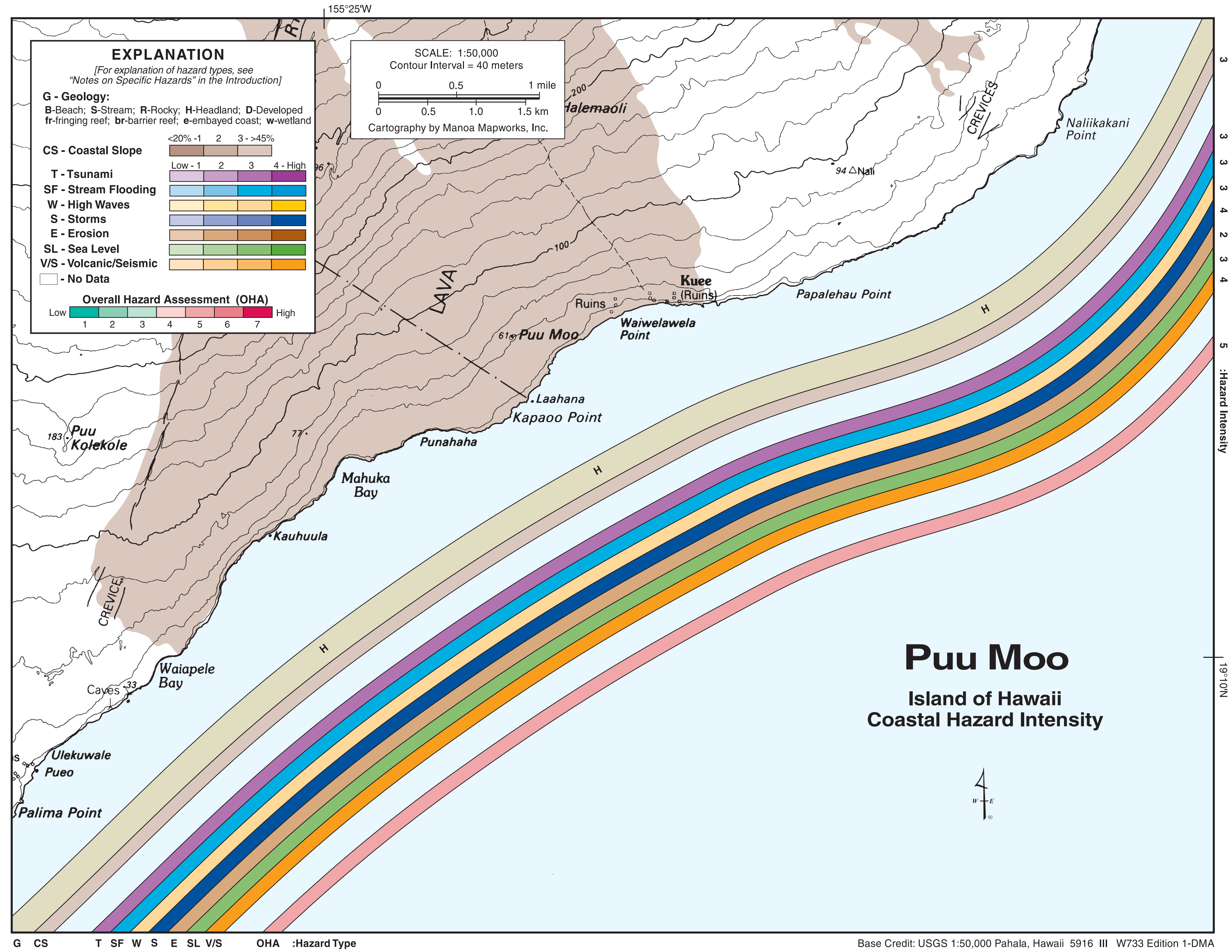
The Kau Desert coast is rocky, geologically young, and extremely arid. The young rock is so porous that what little rainfall reaches this region, quickly percolates below. As a result, stream channels and gulleys are rare.

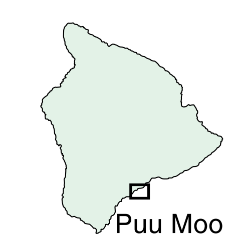
Puu Moo

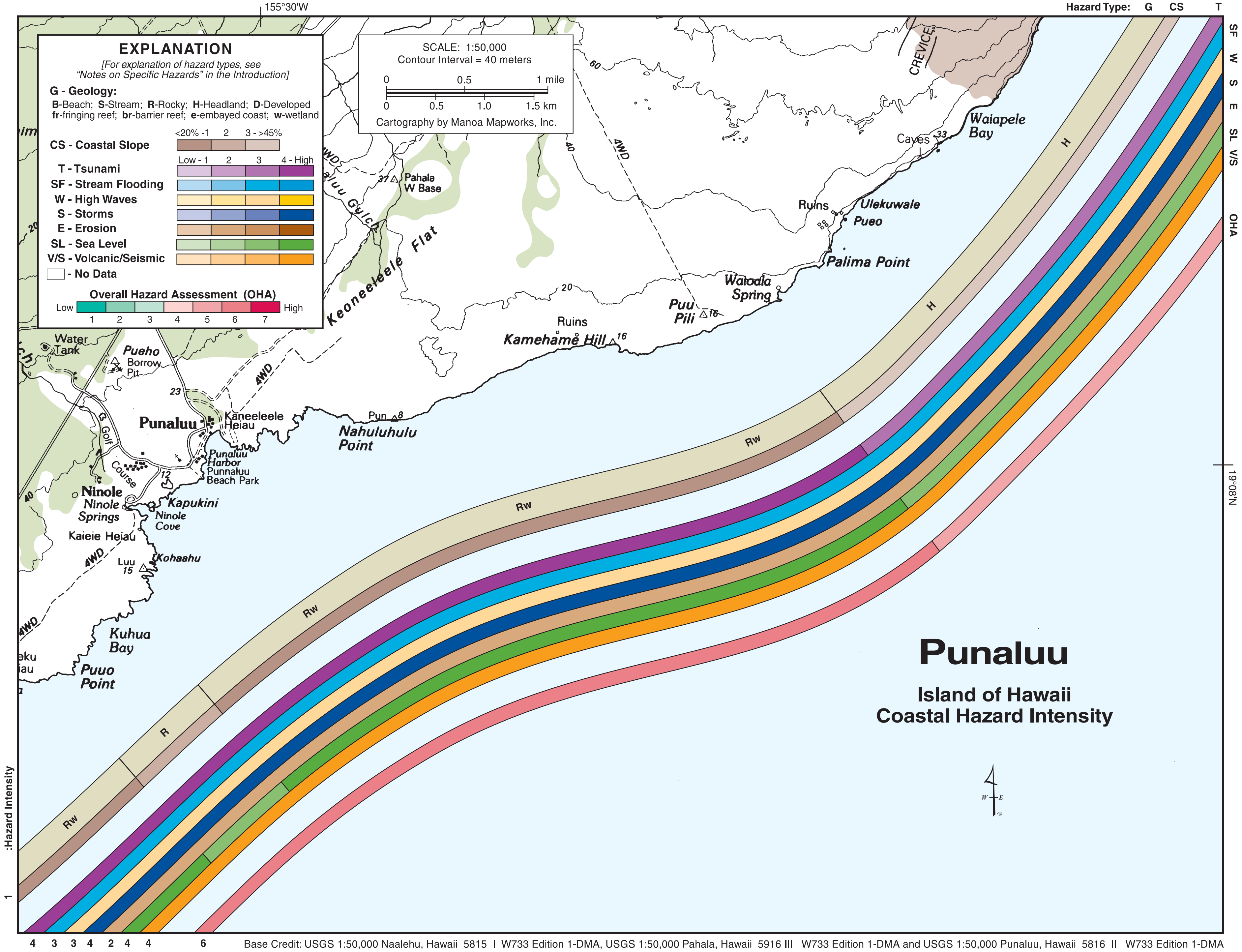
Kilauea Volcano's southwest rift zone crosses the coastline near Palima Point in the Puu Moo area. The area between Waiapele Bay and Waiwelawela Point was formed during the 1823 eruption of Kilauea's southwest rift. Rugged cliffs rise between 20 and 40 ft to the hummocky tops of aa lava flows that form the gently sloping coastal terrace. Access to the water is difficult and requires traversing the rugged topography by foot or the generally turbulent seas by boat. The few beaches that exist along this coast are small, isolated, cobble beaches near the mouths of ephemeral streams. Some fresh water springs have created small wetlands and pools behind the beaches. Numerous ancient Hawaiian ruins and rock walls stand along the coastal cliffs among what appears to be an endless desert of black lava rocks. Today the entire Puu Moo coast is undeveloped.

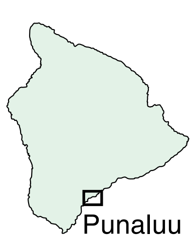
The tsunami and high wave hazards are moderately high along the steep, rocky headland coast of Puu Moo. Despite the relatively arid climate, ephemeral streams transport large volumes of water during storms, so stream flooding is also moderately high. Facing southeast and toward approaching storms, the Puu Moo coast has a high storm hazard. Erosion is moderately low along the rocky shoreline, however sea-level rise is moderately high because of the general low slope. Puu Moo lies in lava flow hazard zone 1 (Table 10, p. 24) associated with Kilauea Volcano's southwest rift zone. As a result the volcanic/seismic threat is high. This translates into an Overall Hazard Assessment (OHA) of moderate to high (5) for the entire Puu Moo coast.

Rocky sea cliffs with small caves and arches are characteristic of the Puu Moo coast bordered by recent lava flows.









Punaluu

Between Waiapele Bay and Palima Point, Kilauea Volcano's southwest rift dives through the coastline and under the seafloor. South of Palima Point, the Punaluu coastal zone is comprised of lavas between 500 and 1500 yr old. Steep coastal cliffs in the eastern portion of the Punaluu coast end just southwest of Palima Point, and a relatively low-lying coastal plain has developed and extends west from Puu Pili. The coast is entirely rocky except for small black sand and cobble beaches inside Punaluu Bay and Ninole Cove and at the base of Kamehame Hill. Springs feed fresh water to ponds behind the shoreline. Some of these turn brackish with high-wave overwash and tidal flushing. Punaluu has a long history as a shipping harbor and sugar plantation town. In early April 1868 however, a devastating tsunami triggered by a local earthquake leveled nearly everything along the Punaluu coast up to 18 ft above sea level. Again in April 1946, a wave associated with an Alaskan earthquake-generated tsunami ran 14 ft up the shore, clearing coastal structures and altering the shoreline morphology. Erosion due to long-term sea-level rise is also eating away at the Punaluu coastline. Flash floods periodically reshape the coast by rapidly eroding or simply burying shoreline features as they did in the winter of 1979-1980, near Ninole Springs.

The shift in coastal slope near Puu Pili affects the magnitude and rate of inundation by waves and sea-level rise. The variation in these two hazard rankings results in a moderate to high (5) Overall Hazard Assessment (OHA) east of Puu Pili, and a high (6) Overall Hazard to the west. East of Puu Pili tsunami and sea-level rise are ranked moderately high, whereas to the west where the coast is lower they are high. An exception occurs along Puuo Point where the coast is slightly steeper than its immediate surroundings and the sea-level hazard is reduced. Stream flooding and high waves are moderately high throughout the entire region. The storm hazard is high. Erosion is moderately low, while the volcanic/seismic hazard is high along the entire Punaluu coast due to its proximity to active seismicity at Kilauea Volcano. The Punaluu coast south of Palima Point is in lava flow hazard zone 3, while northeast of Palima it is in zone 1 (Table 10, p. 24).

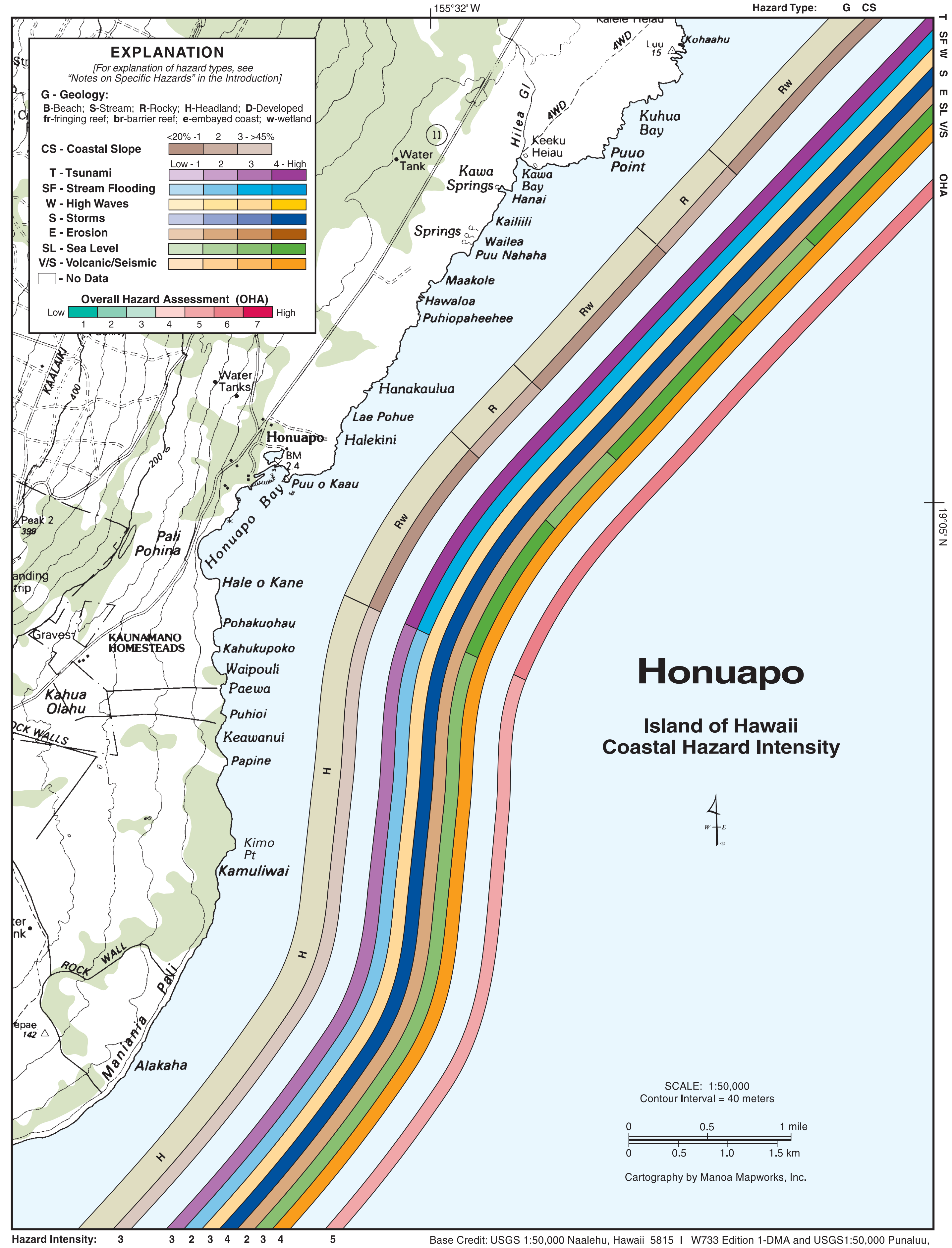
Punaluu is one of the few protected embayments along the wind-swept southeast coast of Hawaii. It is low lying with a narrow black sand and cobble beach and has experienced several destructive tsunamis.

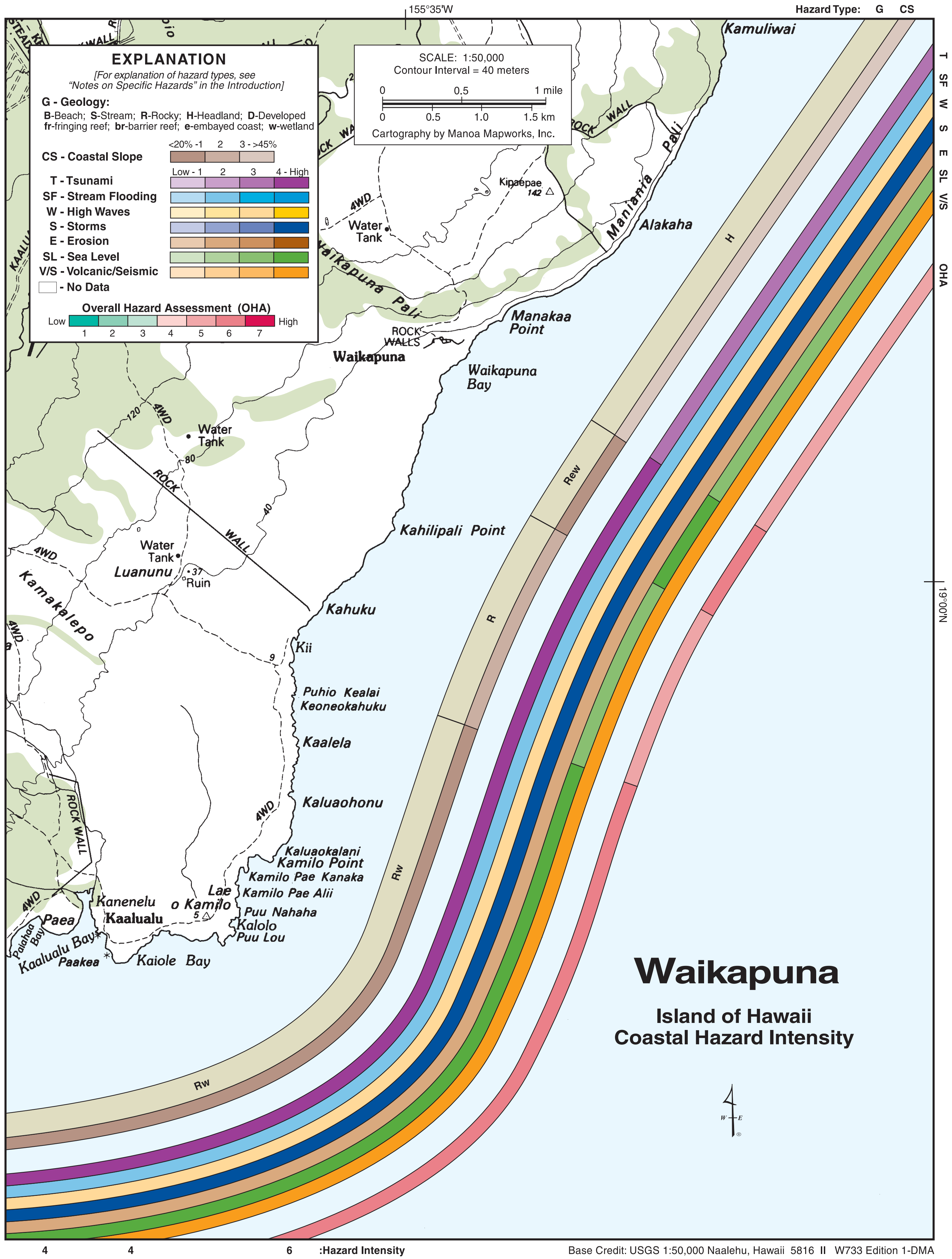
Honuapo

Between Kahua Bay and Honuapo Bay, the coast is relatively low lying and developed only with small fishing villages. South to Alakaha, the Honuapo coast is bordered by steep coastal cliffs. A few pocket cobble beaches exist near stream mouths, for example in Kawa Bay, but otherwise the coast is rocky, comprised of lavas only several thousand years old. Fresh-water springs feed wetlands at Honuapo Bay and along the coast to the north. Like most of the south coast of Hawaii, Honuapo has suffered significant damage from historical tsunamis and tectonic subsidence. The 1868 tsunami destroyed fishing villages at Kawa and Honuapo. Then the 1946 tsunami destroyed the Honuapo wharf built in 1883 for shipping and sugar transport. Facing southeast, this coast receives intense wave energy and trade-wind sea conditions prevail. Reefs are absent along this coast.

The Overall Hazard Assessment (OHA) along the Honuapo Coast is high (6) northeast of Honuapo Bay and moderate to high (5) to the southwest. This is due to the increase in coastal slope at Honuapo Bay that lessens the hazard from inundation and flooding of the coastal streams. East of Honuapo Bay, tsunami and stream flooding are ranked high and moderately high, while to the west they are reduced to moderately high and moderately low, respectively. The threat from high waves is moderately high, storm hazard is high along the entire coast, and erosion is moderately low. Sea-level rise is ranked high along the lower-lying rocky coastal segments east of Kahua Bay, between Kawa Bay and Maakole, and between Hanakaulua and Honuapo Bay. Surrounding these low-lying sections of coast the sea cliffs are steeper and as a result the sea-level-rise threat is only moderately high. The Honuapo coast is in lava flow hazard zone 3 (Table 10, p. 24). The volcanic/seismic hazard is high throughout the Honuapo region due to its proximity to seismic and volcanic activity at Kilauea Volcano.

The Honuapo coast is steep between Hale o Kane and Kimo Point (foreground) while between Honuapo and Kawa Bays the shore is comprised of a low-lying rocky coastal plain.





Waikapuna

The northeast portion of the Waikapuna coast is steep where the Maniania Pali borders the shoreline. The pali grades into a low-lying coastal plain that becomes wider at Waikapuna Bay and again at Kii. The entire shoreline is rocky with 3-10 ft high sea cliffs. It is comprised of lavas ranging between 5,000 and 10,000+ yr in age. Lavas as recent as 1868 have flowed to the coast just south of Waikapuna. A few perched beaches of loose carbonate sands exist on the coastal terrace, probably a result of wave deposition. High waves from eastern and southern swell, as well as passing storms, frequently overwash the sea cliffs making entry into the ocean difficult along this coast. Wetlands exist at Waikapuna Bay and between Kaiole Bay and Kaalela. Dunes have formed at Keoneokahuku, perhaps from the refraction of the east-northeast trade winds toward the west around this part of the island. Waikapuna is one of the most arid regions on the Big Island but intermittent streams periodically overwash during flash floods.

Along the Maniania Pali to Waikapuna Bay, the tsunami and sea-level rise hazard is moderately high. These two hazards are high to the southwest, except for the segment of coast between Kahilipali Point and Kii, where sea-level rise is only moderately high. Stream flooding along the entire Waikapuna coast is moderately low, while the high wave and storm hazards are moderately high and high, respectively. Erosion is only moderately low along these rocky shores. Waikapuna lies in lava flow hazard zone 6 (Table 10, p. 24). The volcanic/seismic hazard is high throughout the Waikapuna region which historically has experienced significant seismic and volcanic activity. As a result of the variation in coastal slope, the Overall Hazard Assessment (OHA) alternates from moderate to high (5) east of Waikapuna Bay to high (6) between Waikapuna Bay and just north of Kahilipali Point, and then back to moderate to high (5) along the central coast to Kii. Southwest of Kii the OHA is high (6) reflecting the low coastal slope along the Lae Kamilo region.

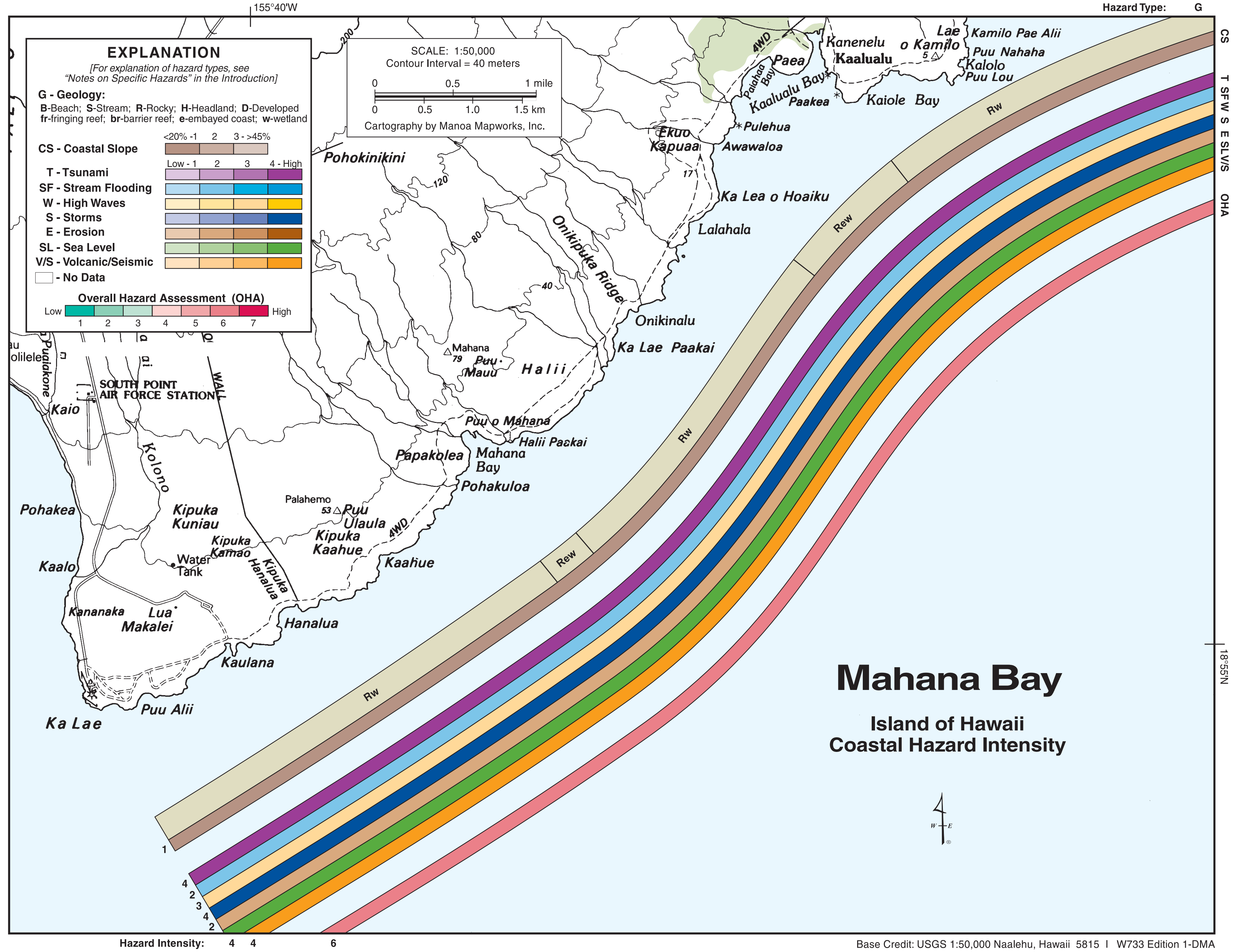
The undeveloped shoreline along Maniania Pali (shown here) is steep and rocky, while toward the south between Waikapuna Bay and Kamilo Point the rocky coast is low and flat.

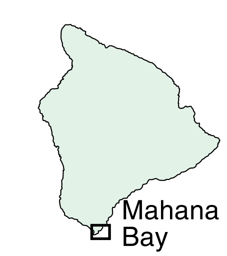
Mahana Bay

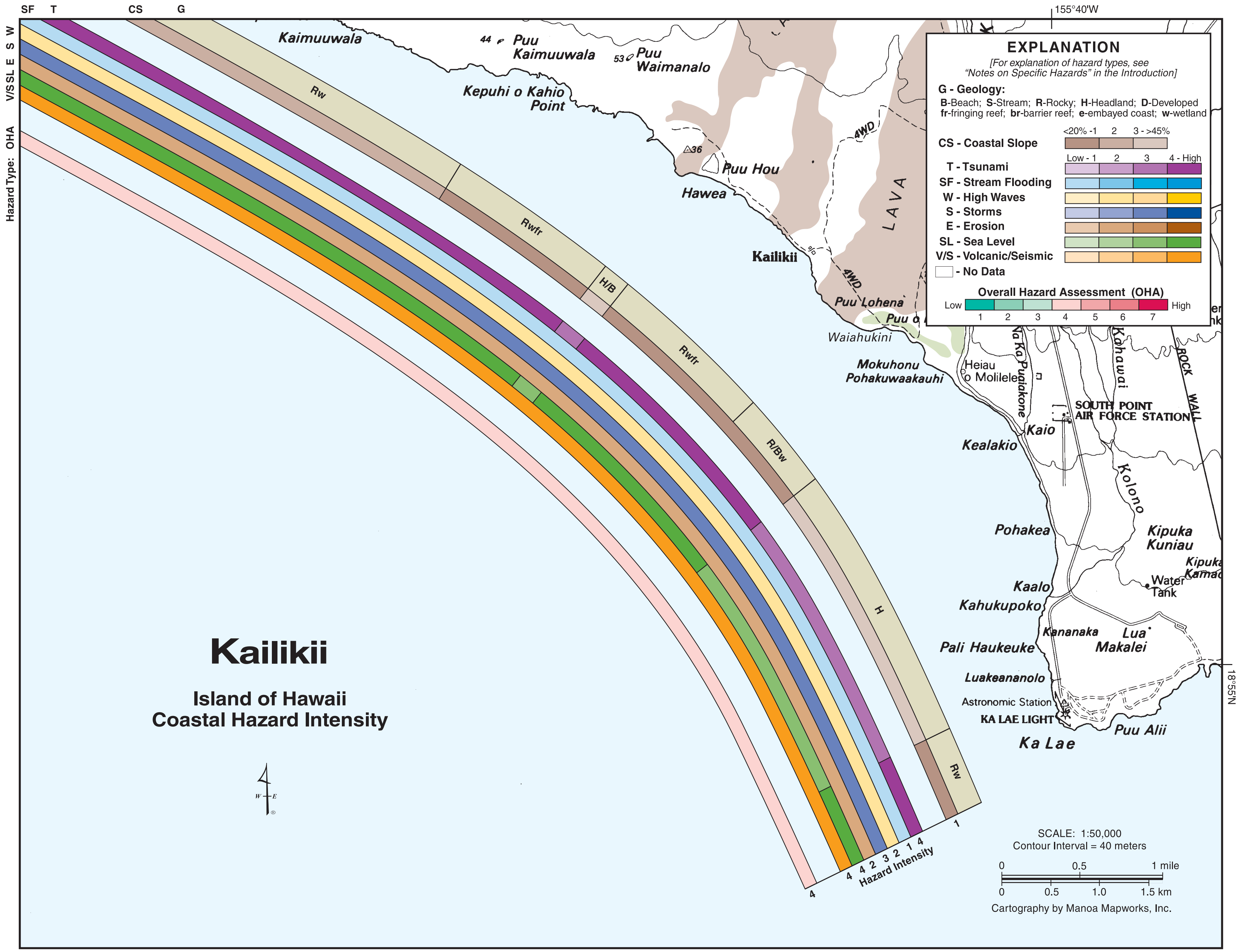
The Mahana Bay coast reaches from Kamilo to Ka Lae (South Point) the southernmost point in the 50 United States. Many small embayments line the rocky shoreline but the most notable feature along this stretch is Kaalualu Bay, an elongated waterway that reaches far inland across extensive tidal flats. It is relatively shallow and bordered by rugged aa lava flows. At the head of the bay there is a black cinder sand beach. The next bay to the south, Paiahaa Bay, has a small green sand and pebble beach. The most famous beach in this area is Papakolea, the Green Sand Beach, located in Mahana Bay. Here waves quarry the side of a volcanic cone rich in the green crystalline mineral olivine, Hawaii's most abundant mineral. Olivine is very dense and as a result is often left on beaches, while other sand components are transported away. The coast is low lying at these pocket beaches and steep cliffed in between. It is a very arid region, receiving on average less than 20 in/yr, however, there are a few intermittent streams that flow after heavy precipitation. The Mahana Bay region is highly exposed to trade winds, waves, and passing storms.

The Overall Hazard Assessment (OHA) for the Mahana Bay Coast is high (6). This is largely a result of the high tsunami, storm, sea-level rise, and volcanic/seismic rankings along this generally low coastline. Stream flooding and erosion are moderately low. The high wave hazard is moderately high along the highly exposed southern tip of Hawaii. Mahana Bay lies within lava flow hazard zone 2 (Table 10, p. 24).

Mahana Bay, famous for its green sand beach, is a small, arcuate cove set inside the remaining portion of the volcanic cone Puu o Mahana.







Base Credit: USGS 1:50,000 Manuka Bay, Hawaii 5815 IV W733 Edition 1-DMA and USGS 1:50,000 Naalehu, Hawaii 5815 I W733 Edition 1-DMA

Kailikii

The Kailikii region had lavas flowing across its coastal zone as recently as 1868. Today this area is only minimally developed. Sea cliffs ranging between 20-40 ft high near Ka Lae (South Point) terminate at Mokuhonu where a wide, low-lying coastal plain extends far inland to the headland that borders Kepuhi O Kahio Point. Small beaches are located at Waiahukini, Kailikii, and Puu Hou, and are largely green sand beaches, some with a white carbonate component. At the base of Puu Hou the beach is comprised of red sands derived from volcanic cinders. It is very arid in this region of the southern portion of the Big Island and few streams have developed west of Kahawai Kolono Stream at Kaalo. The lava rock in this area is highly porous which enables the transport of fresh water from higher elevations through the subsurface. Numerous wetlands are created when this subsurface water ponds behind the shoreline, like those near Mokuhonu, Kailikii, and Kahio. Fringing reefs become more extensive along the coast toward the western region of Kailikii.

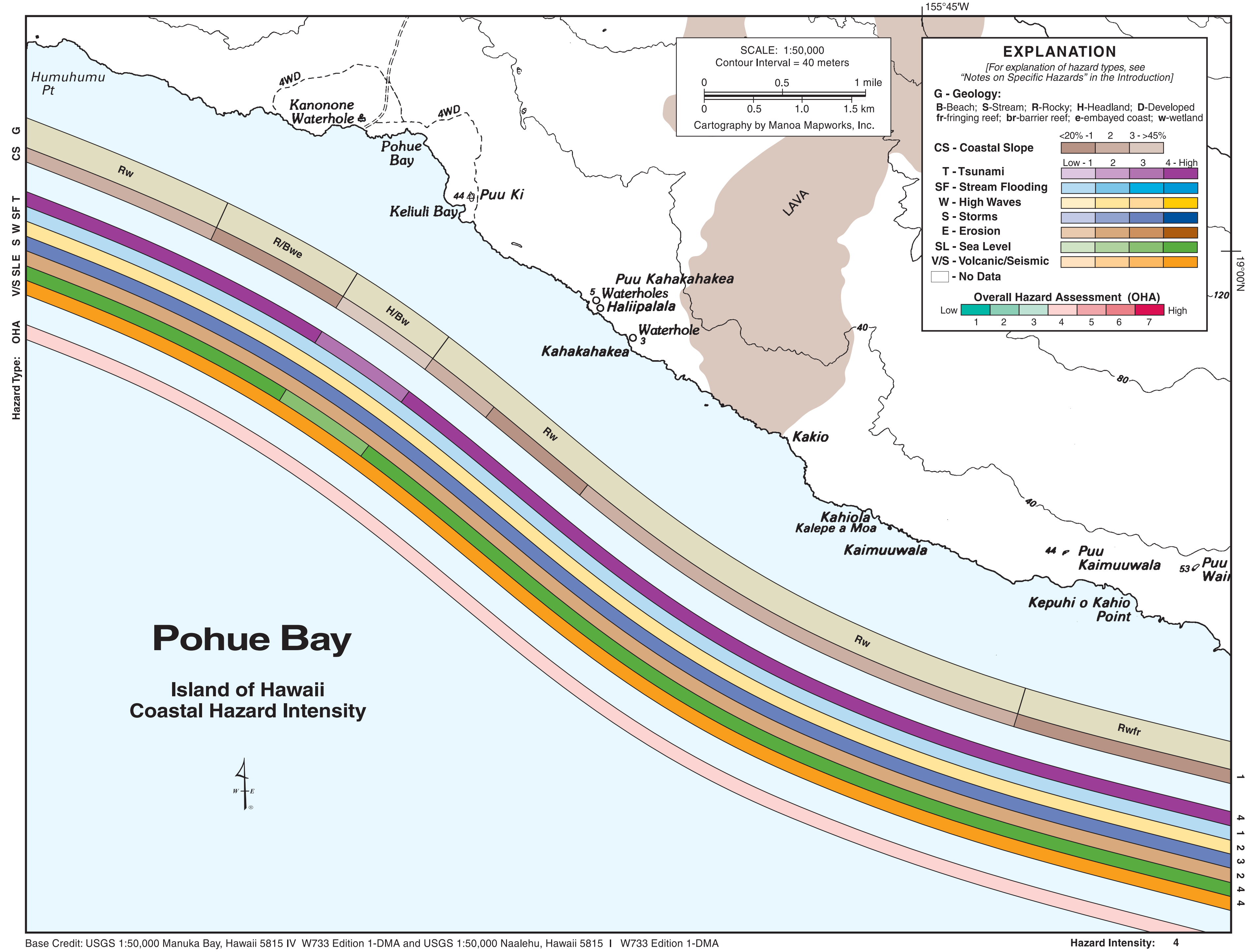
Despite variations in coastal slope that affect tsunami and sea-level rise hazards, the Overall Hazard Assessment (OHA) is moderate (4) along Kailikii. Where the coast is only 3-10 ft above sea level, between Ka Lae and Luakeananolo, Mokuhonu and Hawea, and west of Hawea, the tsunami and sea-level rise hazards are high. Along the headland segments of coast these hazards are only moderately high. Stream flooding is low on this arid coast and high waves are only moderately low because of its southwest aspect which receives only moderate south swell and Kona storm waves. Storms are ranked moderately high, because the point at Ka Lae partly protects the embayed coast from storms that primarily approach from the east and southeast. Erosion is moderately low along this rocky coast. The Kailikii coast is within lava flow hazard zone 2 (Table 10, p. 24). The volcanic/seismic hazard is high due to historic volcanic activity and its proximity to seismicity associated with Kilauea Volcano.

The rocky, undeveloped coast surrounding Kailikii is situated along the base of the Pali o Kulani (right) which extends inland from Mokuhonu Pohakuwaakauhi. Kailikii is very arid and vegetation occurs only in small isolated oases where there are springs or perched groundwater.

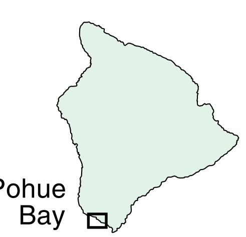
Pohue Bay

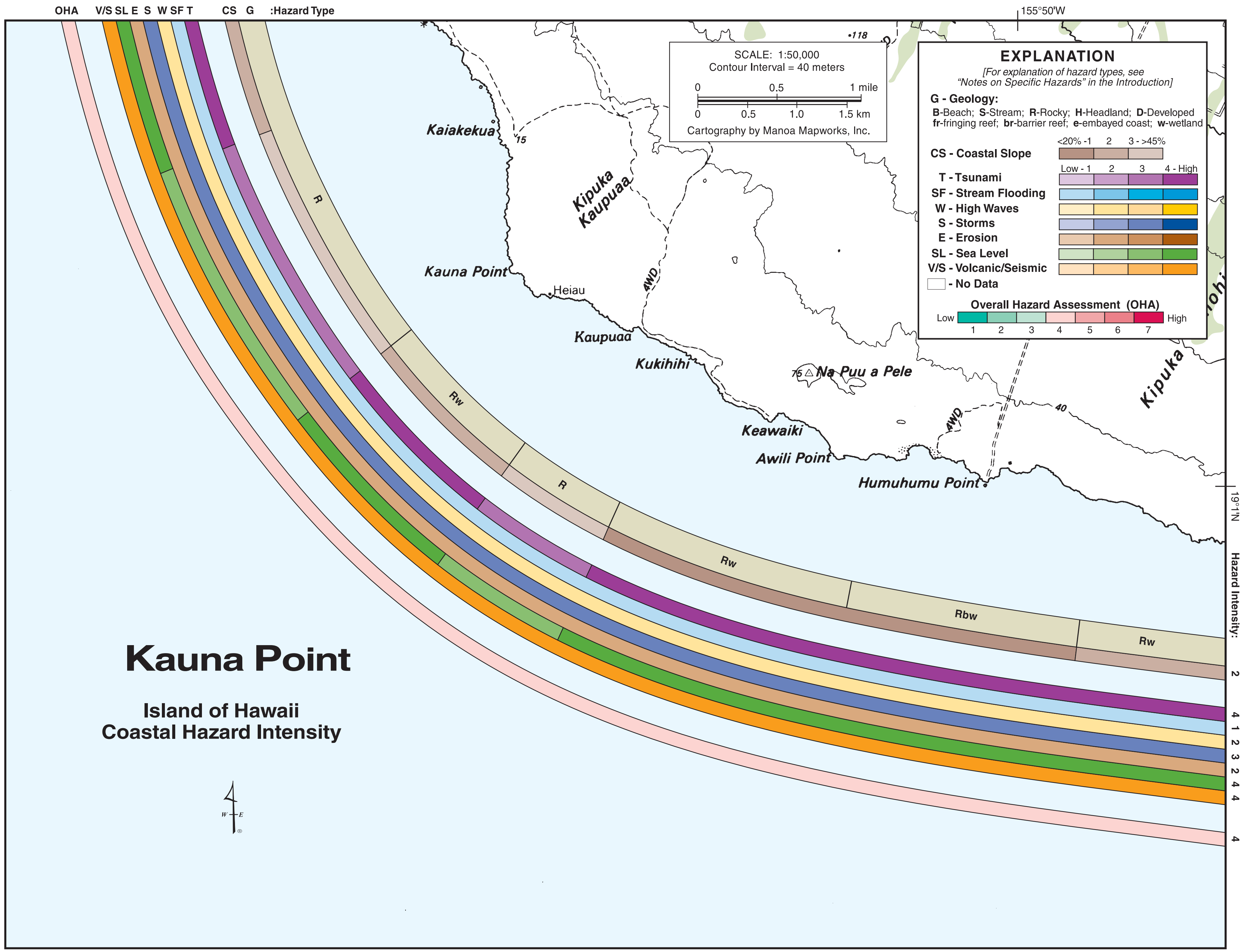
The Pohue Bay coast between Kahio and Humuhumu Point is relatively undeveloped and accessible only by boat, foot trail, or rugged 4-wheel drive vehicle. Sea cliffs ranging between 15-30 ft high border a rather wide coastal plain that slopes gently seaward, except for cinder cones that protrude through its surface. In 1887, lavas erupted from Mauna Loa Volcano's southwest rift and flowed across the coastal slopes to the coast between Kakio and Kahakahakea. The entire coast is rocky with isolated beaches deposited by storms just above the sea cliffs. A white carbonate sand beach lies inside Pohue Bay. Despite the aridity of the Pohue Bay coast, several wetlands have formed where water has ponded behind the shoreline. A small fringing reef extends along the southern portion of the area seaward of Kepuhi o Kahio Point.

The tsunami hazard along the Pohue Bay coast is high except for the headland at Keliuli Bay, where it is reduced to moderately high because of the steeper slopes. Stream flooding is low in this arid region. High waves are moderately low because only moderate wave heights associated with south swell and Kona storm waves annually reach these shores. The storm hazard is moderately high. Erosion is moderately low along this rocky sea-cliffed coast. The sea-level threat is high for the entire coast except for the headland at Keliuli Bay. The Pohue Bay coast lies in lava flow hazard zone 2 (Table 10, p. 24). The volcanic/seismic hazard is high for the Pohue Bay coast as it is for all of Hawaii Island due to active seismicity and volcanism at Kilauea Volcano. These rankings translate to a moderate (4) Overall Hazard Assessment (OHA) for the Pohue Bay coast.

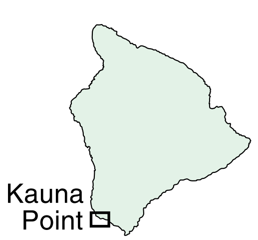


Much of the coast around Pohue Bay is rocky and low lying except for occasional bluffs and small sea-cliffs formed by remnant volcanic cones, like Puu Ki near Keliuli Bay (shown here), and old lava flows.





Base Credit: USGS 1:50,000 Manuka Bay, Hawaii 5815 IV W733 Edition 1-DMA



Kauna Point

Between Kaiakekua and Humuhumu Point the Kauna Point coast is undeveloped and largely rocky. Sea cliffs of lava rock are steeper west of Kukihihi. Awili and Humuhumu Points have small volcanic cinder beaches. The lavas that form the Kauna Point coast flowed as recently as 750 yr ago. Kauna is arid and few streams flow to the sea in this area. Instead, fresh water flows from the hillsides to the sea through underground (subsurface) crevices and voids in the highly porous lava rock. Wetlands occur at Kauna, Awili, and Humuhumu Points where this water has ponded behind the shoreline. Offshore the seafloor is mostly rocky with some carbonate sands in small sand fields or pockets.

The Overall Hazard Assessment (OHA) for Kauna Point is moderate (4). Despite this uniform ranking, the tsunami and sea-level hazards vary between high along most of the Kauna Point coast to only moderately high between Kaiakekua and Kauna Point and between Kaupuaa and Kukihihi. Stream flooding is low because of the region's extreme aridity, while high waves that generally arrive from the south and with Kona storms are moderately low. Storms are ranked moderately high and erosion along the rocky Kauna Point coast is moderately low. Kauna Point is located in lava flow hazard zone 2 (Table 10, p. 24). The volcanic/seismic threat is high along the Kaua Point coast due to historical volcanic activity and high seismicity associated with volcanism at Kilauea Volcano.

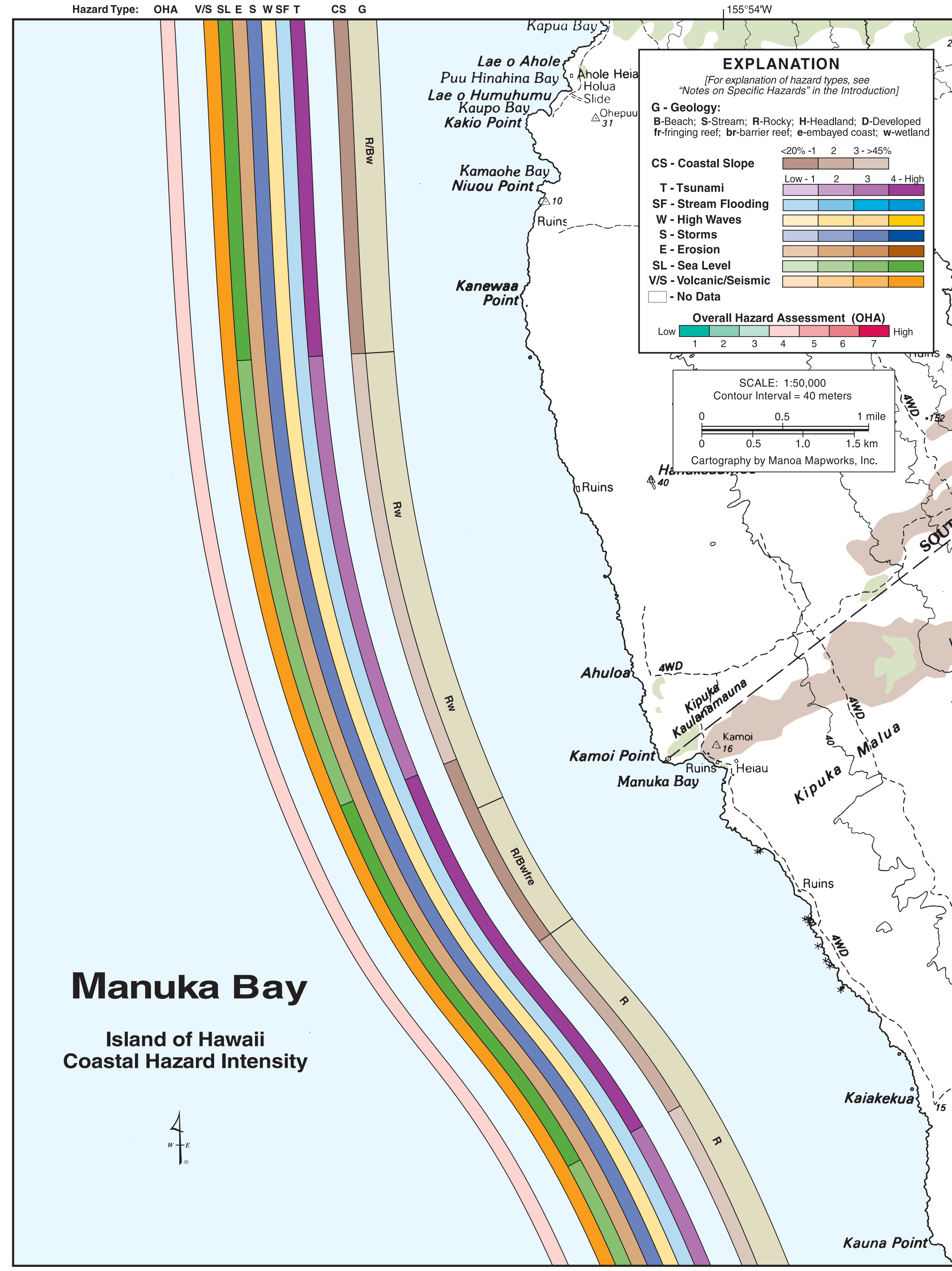
The rocky and rugged Kauna Point coast is low lying and undeveloped, formed of old aa lava flows.

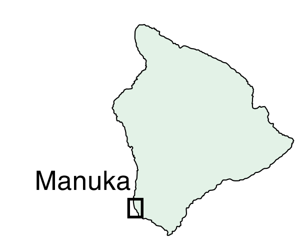
Manuka Bay

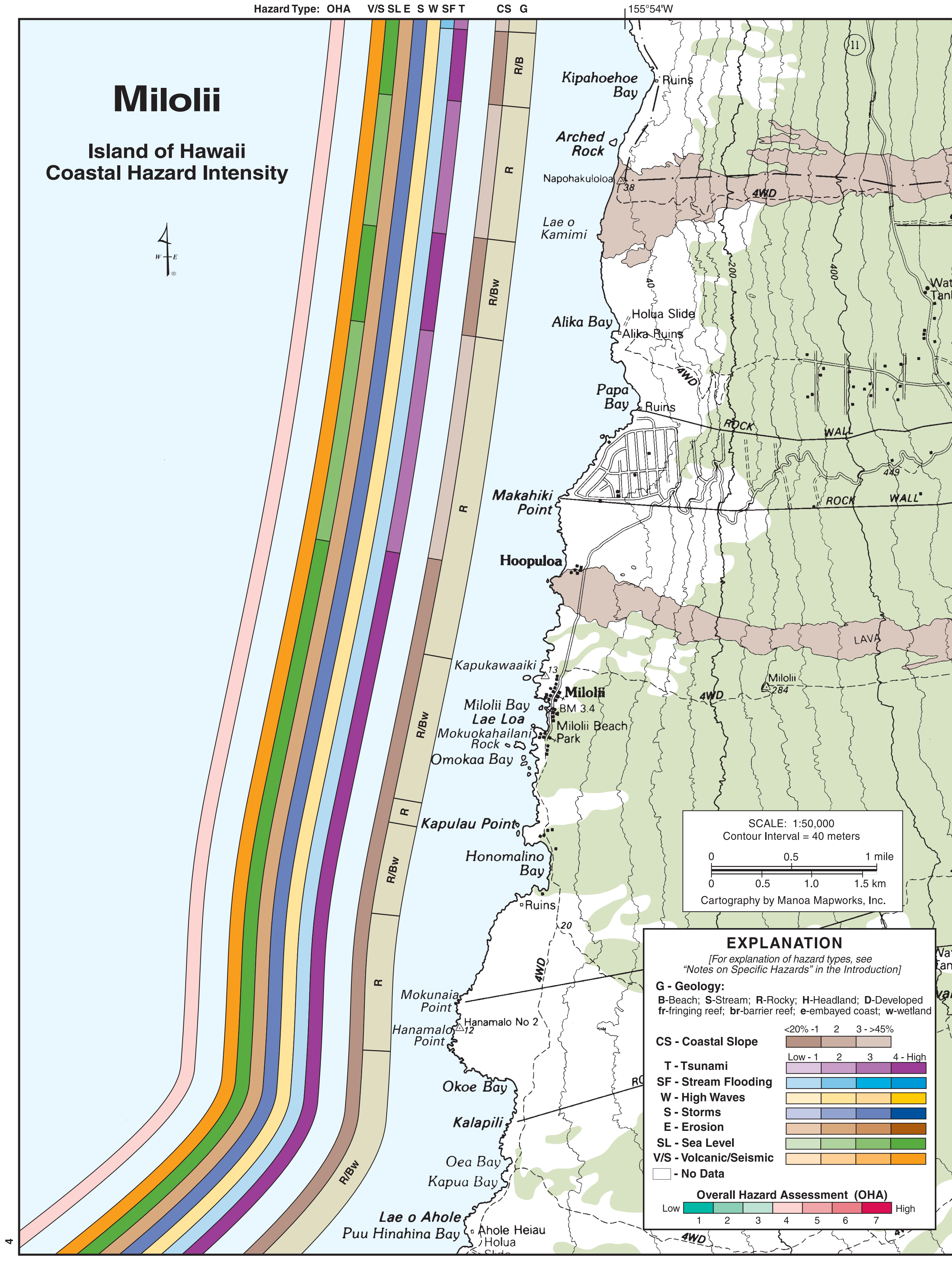
The rocky Manuka Bay coast extends between Lae o Ahole and Kauna Point. Between Ahuloa and Kanewaa Point, the coast steepens slightly from an otherwise low-lying coastal plain. While it is largely undeveloped today, the area used to be home to a large population of Hawaiian fisherman as evidenced by the many heiau (temples) and petroglyphs in the area. Narrow perched beaches occur along the rocky shore and a mixture of coral rubble, white carbonate sand, and volcanic fragments form the beaches at Manuka and Kakio Point. This part of southwestern Hawaii is situated in the lee of Mauna Loa Volcano and as a result is very arid. Few streams flow across the coast near Manuka Bay. Wetlands have formed, however, just landward of the shoreline where water flowing underground accumulates. A small fringing reef has developed at Manuka Bay. The rest of the coast has only small patch reefs. The seafloor offshore is largely rocky with small discontinuous sand fields.

The tsunami and sea-level hazards are high except south of Kaiakekua and between Ahuloa and Kanewaa where they are only moderately high because of the steeper coastal slopes. In this arid portion of Hawaii, stream flooding is low. High waves are ranked moderately low because of the moderate wave heights that reach this southwest-facing coast. Storms are a moderately high hazard because tropical cyclones commonly pass the south and west sides of the islands. Erosion is moderately low along the rocky Manuka Bay coast. Manuka Bay lies in lava flow hazard zone 2 (Table 10, p. 24). The volcanic/seismic hazard is high along the Manuka Bay coast due to recent volcanism in the area and its proximity to seismic activity associated with eruptions of Kilauea Volcano. The Overall Hazard Assessment (OHA) for the Manuka Bay coast is moderate (4).

Recent lava flows from Mauna Loa Volcano have added new ground to various portions of the coast surrounding Manuka Bay. The Manuka Bay region is undeveloped, arid, and relatively low sloping.







Milolii

Between Kipahoehoe Bay and Kapua Bay the Milolii coast has seen active volcanism this century. Lava flows associated with the 1919 and 1926 eruptions of Mauna Loa Volcano covered the coastline at Hoopuloa and Lae o Kamimi. Between Kapua Bay and Hoopuloa the coast is low and slopes gently seaward. North of Hoopuloa, the coast is higher and steeper except for Alika Bay and Kipahoehoe Bay which are relatively low lying. Numerous small rock islets and submerged rocks lie offshore of Milolii and Omokaa Bays. Small beaches of black volcanic and white calcareous sand occur at Kapua, Oea, Okoe, Honomalino, Milolii, Alika, and Kipahoehoe Bays. The Hoopuloa beach is largely comprised of pebbles and coral cobbles. Sea-level rise has had dramatic impacts on the beaches along this coast. Between 1940 and 1980, the shoreline at Honomalino beach moved 200-300 ft landward. Small wetlands exist at Kapua, Honomalino, Milolii, and Alika Bays. Lying in the rain shadow of Mauna Loa, the Milolii coast is dry and few streams have developed amidst the geologically young, porous lava fields. Only small patch reefs exist along this shore. Periodically, large wave events quarry the reefs and throw their rubble debris atop the coastal cliffs to form perched beaches.

The Overall Hazard Assessment (OHA) for the Milolii region is moderate (4). The tsunami hazard varies from high south of Hoopuloa, between Alika Bay and Lae o Kamimi, and north of Arched Rock to moderately high between Arched Rock and Lae o Kamimi and between Papa Bay and Hoopulua. Stream flooding is low throughout the region. High waves are only a moderately low threat where annual wave heights from south swell are generally only 1-4 ft. Storms are ranked moderately high because Milolii faces west toward approaching Kona Storms and the typical track of passing tropical cyclones. The rocky coast is relatively effective at withstanding denudation, so erosion is moderately low. Sea level is rising fast relative to the land, so it is ranked high in the low-lying segments south of Hoopuloa, between Alika Bay and Lae o Kamimi, and north of Arched Rock. It is moderately high along the steeper coast from Arched Rock to Lae o Kamimi and between Papa Bay and Hoopulua. Milolii lies in lava flow hazard zone 2 (Table 10, p. 24). The volcanic/seismic hazard is high along the Milolii coast due to recent volcanism and significant seismicity associated with eruptions of Kilauea Volcano.

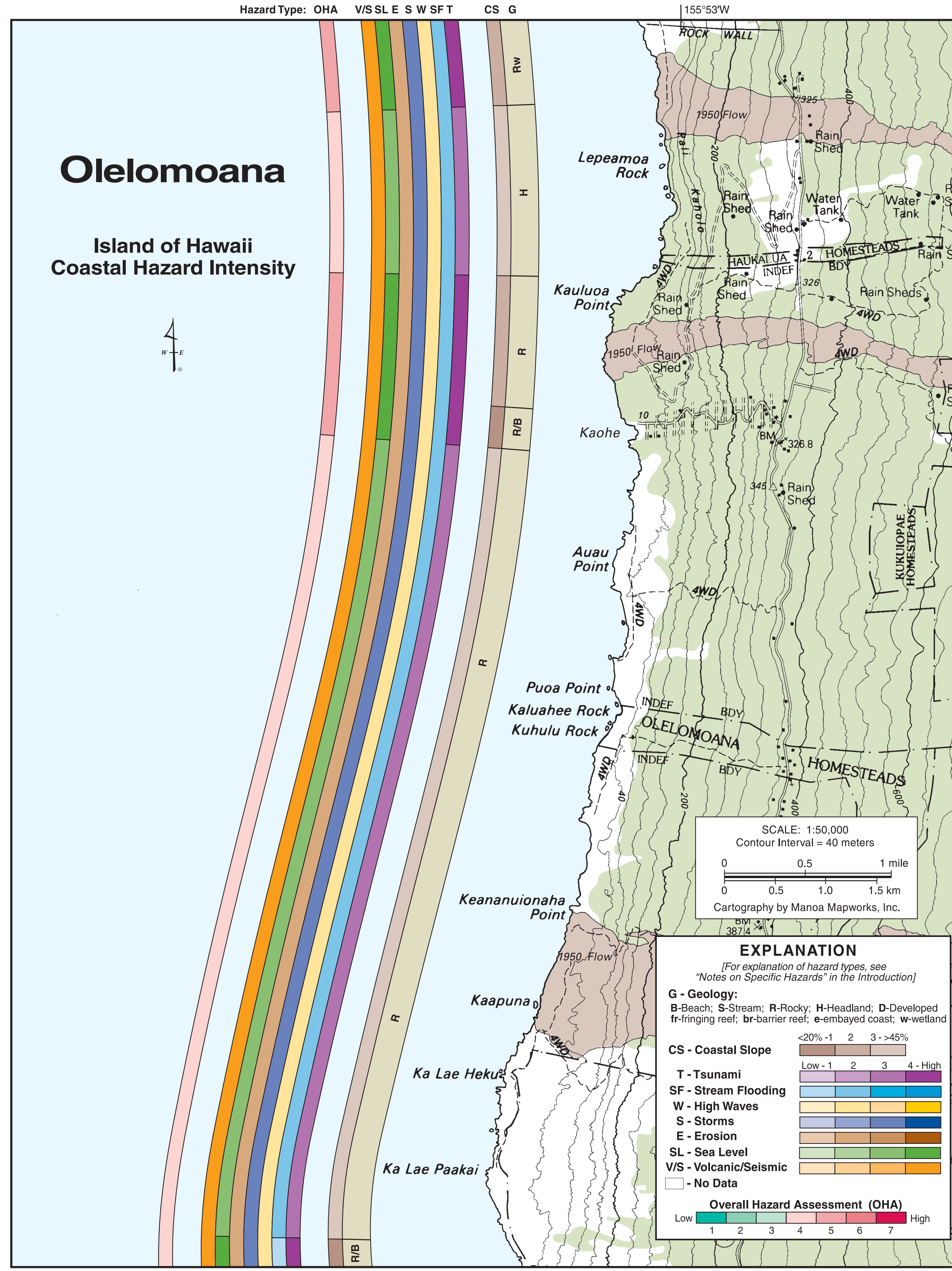
Irregular erosional remnants in the form of sea stacks and rocks as well as submerged toes of recent lava flows have produced scenic tidepools and shallow, rocky coastlines in the vicinity of Milolii.

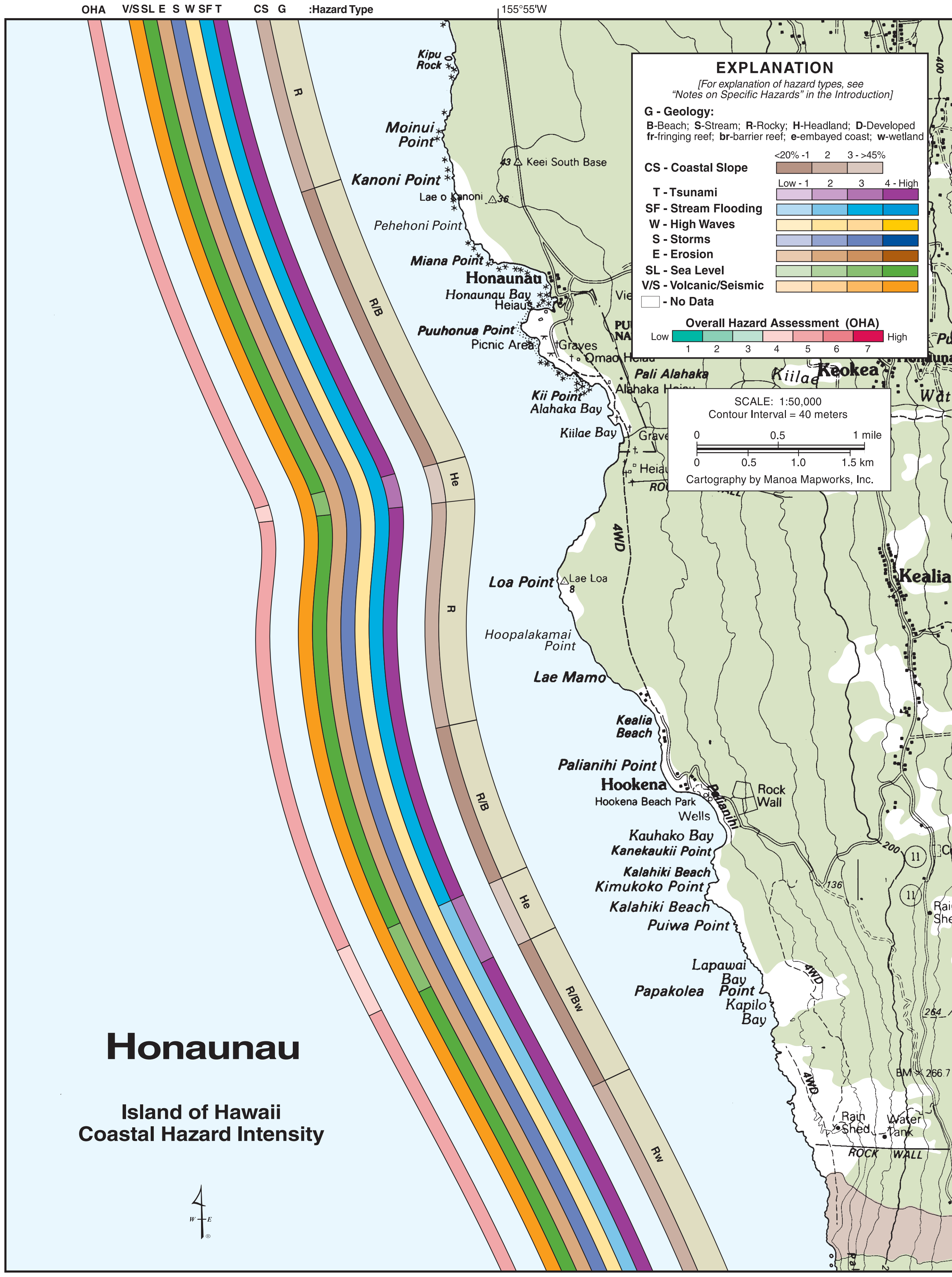
Olelomoana

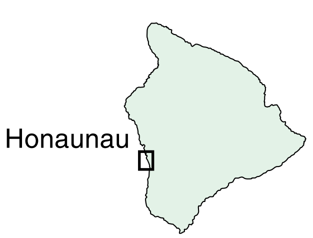
The Olelomoana coast extending between Ka Lae Paakai in the south to Lepeamoa Rock in the north is largely undeveloped except for the Kauluoa Point region. The coast gently slopes between Kauluoa Point and the pebble beach of Kaohe, otherwise the region is mostly steep with sea cliffs. Small coves have formed along the shoreline, partly due to erosion and partly the result of deposition from lava flows extending the shoreline seaward. Many small rock islets (sea stacks) lie offshore. Lava flows as recent as 1950 reached the sea at Kaapuna, just south of Kauluoa Point, and north of Lepeamoa Rock. The southwest coast of Hawaii along Olelomoana receives slightly more precipitation than the region to the south. Small patch reefs have developed along the older volcanic portions of this coast.

The Overall Hazard Assessment (OHA) of Olelomoana primarily reflects the variation in tsunami and sea-level threats to the lower coastal slopes. Between Kauluoa Point and Kaohe the OHA is moderate to high (5) where tsunami and sea level are ranked high. To either side, where the coast is steeper, the OHA is moderate (4) and tsunami and sea level are both moderately high. North of Lepeamoa Rock, the coast again is low lying and tsunami and sea level threats are increased to high, resulting in an OHA rating of moderate to high (5). Stream flooding is moderately low north of Ka Lae Paakai. Throughout the entire region the high wave and storm hazards are moderately low and moderately high, respectively. Erosion is moderately low along the rocky shores of Olelomoana, while the volcanic/seismic threat is high due to recent volcanic activity along this stretch of coast and seismicity associated with Kilauea Volcano. The Olelomoana coast lies in lava flow hazard zone 2 (Table 10, p. 24).

Mauna Loa lava flows as recent as those from 1950 have cut across the moderate sloping and rocky coast along Olelomoana Homesteads and Kahoe.







Honaunau

The Honaunau coast is developed near Hookena and Honaunau amidst beautiful rocky embayments with small cobble and sand beaches. A low, wide bench of lava rock extends along Kealia Beach and Honaunau with steeper sea cliffs in between. Generally, calm wind and wave conditions prevail, but high waves and Kona storms have left their mark by depositing coral rubble as a debris line or storm beach atop the low volcanic coastal cliffs throughout this region. Numerous tide pools have formed along the lava bench at Puuhonua Point and Honaunau Bay. This is also the site of the famous and restored Puuhonua o Honaunau National Historic Park, the City of Refuge as it used to be called. Patch reefs are well developed at Honaunau Bay and near Kalahiki Beach. Fresh water seeps occur offshore, evidence that a significant amount of fresh water is transported to the sea through the subsurface. Hookena, to the south, harbored an important interisland steamer landing for over 50 years until high waves and storms in the 1930's eventually destroyed the landing.

The Overall Hazard Assessment (OHA) for Honaunau varies between moderate to high (5) and moderate (4). Along the majority of this low-lying, gently-sloping coast the OHA is moderate to high (5) because of the high tsunami and sea-level hazards. Only at the two headlands of Kauhako and Kiilae Bays are the tsunami and sea-level threats reduced to moderately high, and as a result the OHA is also reduced to moderate (4). Stream flooding is moderately low south of Hookena and moderately high to the north, where more streams make their way to the shoreline. The high wave hazard along this and most southwest-facing shores of Hawaii is moderately low. Storms, however, are moderately high as they tend to track to the west when they pass the islands. Erosion is moderately low along the rocky sea cliffs. Honaunau lies within lava flow hazard zone 2 (Table 10, p. 24). The volcanic/seismic hazard is high due to the seismicity associated with eruptions of Kilauea Volcano.

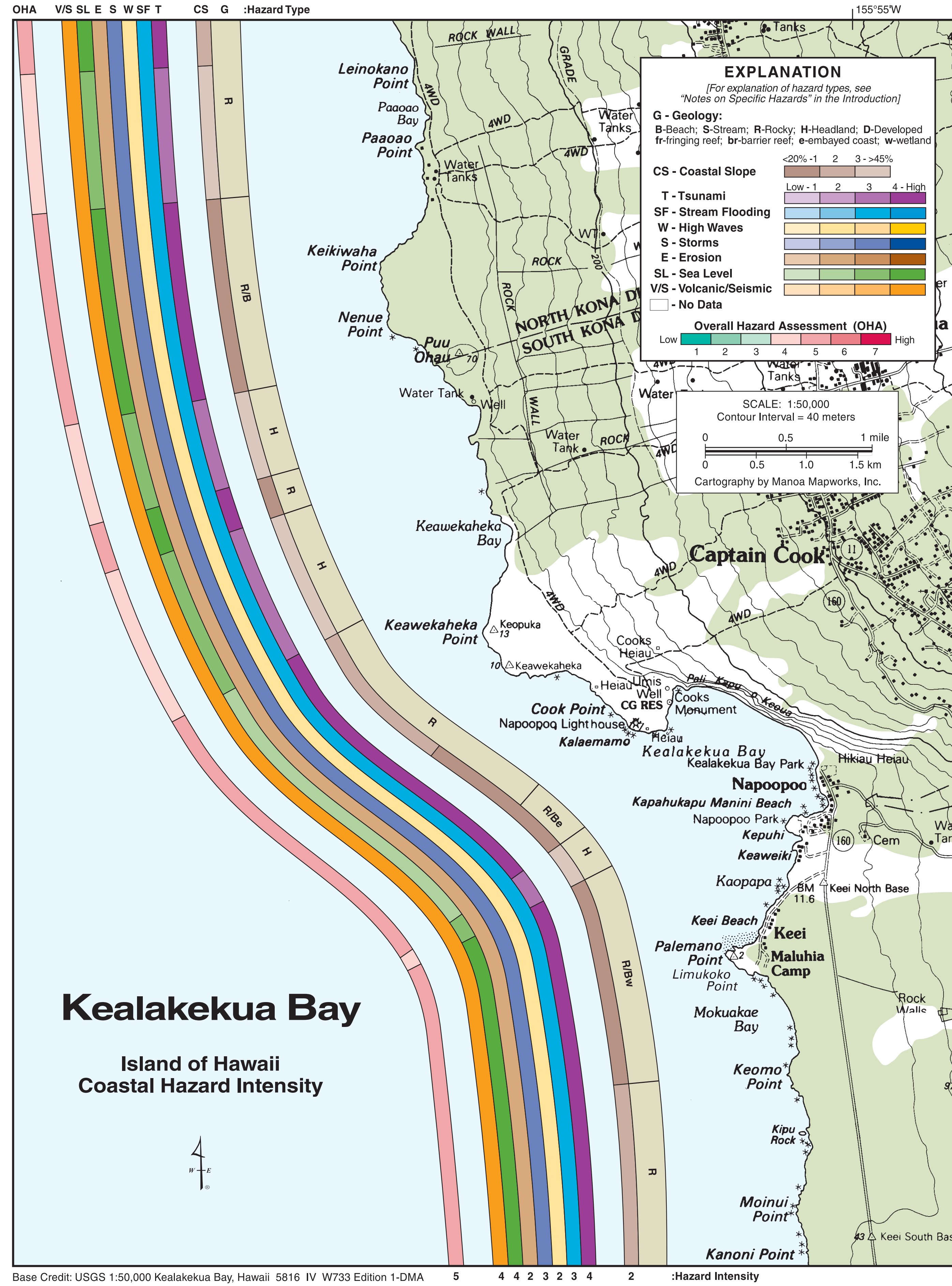
The rocky coast of Honaunau is composed of Mauna Loa lava flows ranging between 1000 and 2000 yr old. The steeper coastal slope south of Hookena gives way to a low-lying rocky coast in the vicinity of Honaunau, the City of Refuge.

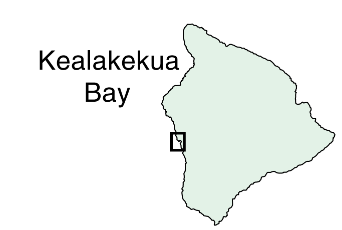
Kealakekua Bay

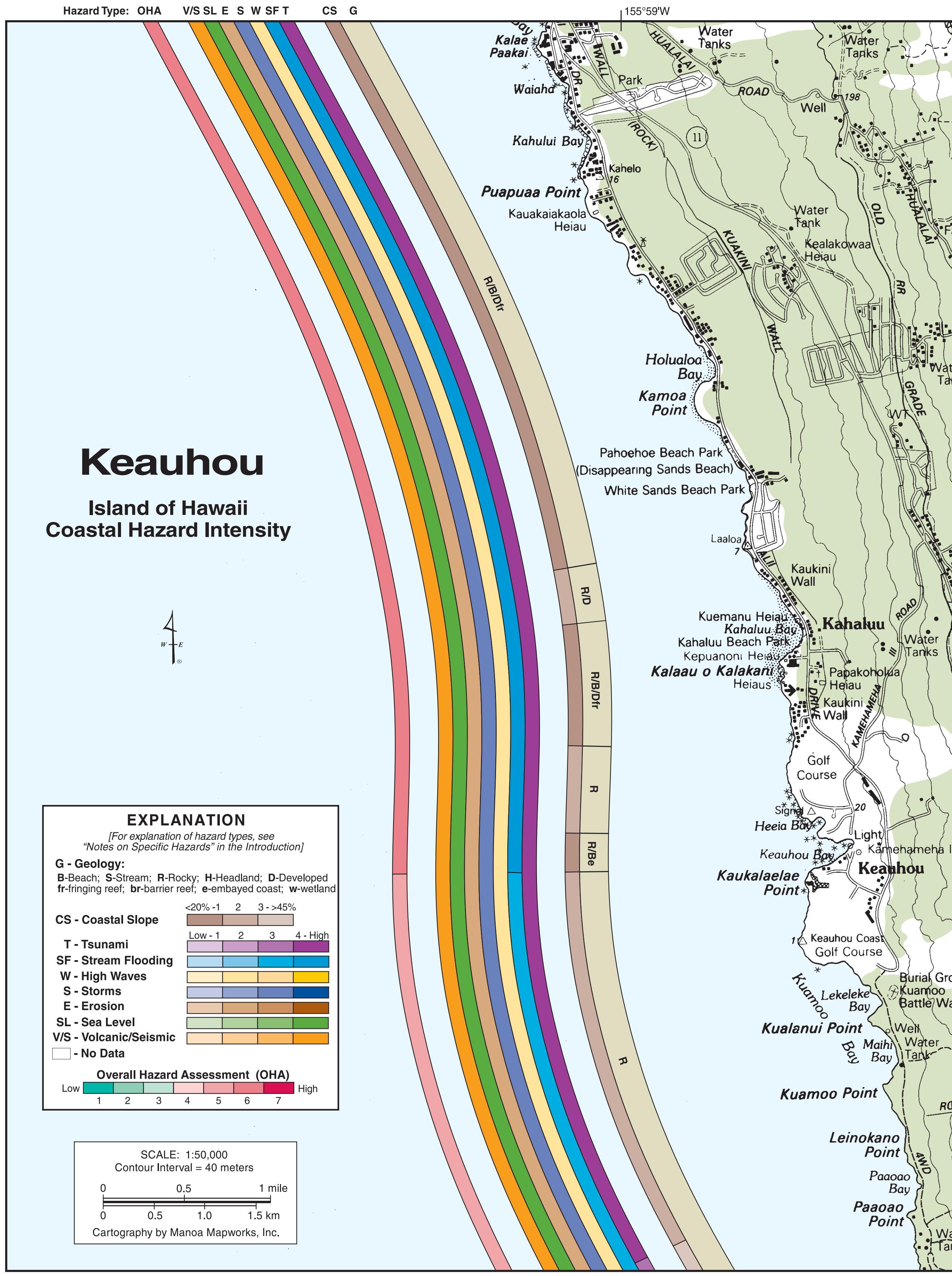
The Kealakekua Bay coast is lower lying and more gently sloping south of Napoopoo than to the north. This is primarily a rocky coast with headlands along Pali Kapu o Keoua, Keawekaheka Bay, Puu Ohau, and Paaoao Point. The Kealakekua embayment is the most notable feature along this coast and it protects a small pebble and cobble beach. White sand beaches exist at Keei and at Napoopoo, although they appear to have narrowed considerably in recent years. Storm beaches of cobbles and pebbles are strewn atop some of the rocky points and benches. Keei is historically significant for being the battle site for Kamehameha I's first attempt to gain control of the Big Island. Kealakekua is also famous for being the site where Captain Cook was killed in early 1779. Despite extensive reef growth, Kealakekua Bay periodically receives large waves that scour the bottom. In 1959, Hurricane Dot moved large boulders onshore and covered the pre-existing beach. Runup from the 1868 locally generated tsunami reached 45 ft in this bay.

The Overall Hazard Assessment (OHA) along the Kealakekua Bay coast varies systematically from moderate to high (5) along the low-lying segments to moderate (4) at the steeper headlands at Paaoao Point, Puu Ohau, Keawekaheka Bay, and the Pali Kapu o Keoua. Where the coast is low lying and more vulnerable to inundation by tsunami and sea level, these hazards are high. Along the headlands, tsunami and sea level are ranked moderately high. Stream flooding is moderately high throughout this entire coast. High waves are moderately low, while storms are moderately high. Erosion is moderately low along the largely rocky Kealakekua Bay coast. The southern section of Kealakekua Bay lies in lava flow hazard zone 3, while north of Paaoao Point the coast is within lava flow hazard zone 4 (Table 10, p. 24). The volcanic/seismic hazard is high along this coast which is seismically active due to its proximity to Kilauea Volcano.

Much of the Kealakekua Bay coast is rocky and low lying, except for the steep headland of Pali Kapu o Keoua fronting the northern end of the bay near Cooks Monument.







Keauhou

The highly developed Keauhou Coast curves around the scenic embayments of Paaoao, Maihi, Lekeleke, Keauhou, Kahaluu, Holualoa, and Kahului Bays. Most of this coast is rocky, composed of 10,000 yr old lavas. To protect development at the shoreline from wave overwash and flooding, many seawalls have been erected along the rocky shore. Small beaches occur at Keauhou and Kahaluu Bays and along portions of the coast between Kamoa Point and Waiaha; most appear to have narrowed in the recent past. Gentle slopes predominate except for small steep rocky outcrops north of Heeia Bay and at Laaloa. Several small fringing reefs have developed around Kalaau o Kalani and Puapuaa Points. Streams transport runoff from the relatively steep southwest face of Hualalai Volcano which receives on average fifty to sixty inches of rainfall each year. Amidst the sprawling urban development are numerous Hawaiian archaeological artifacts and ruins that attest to Keauhou's occupation in ancient times.

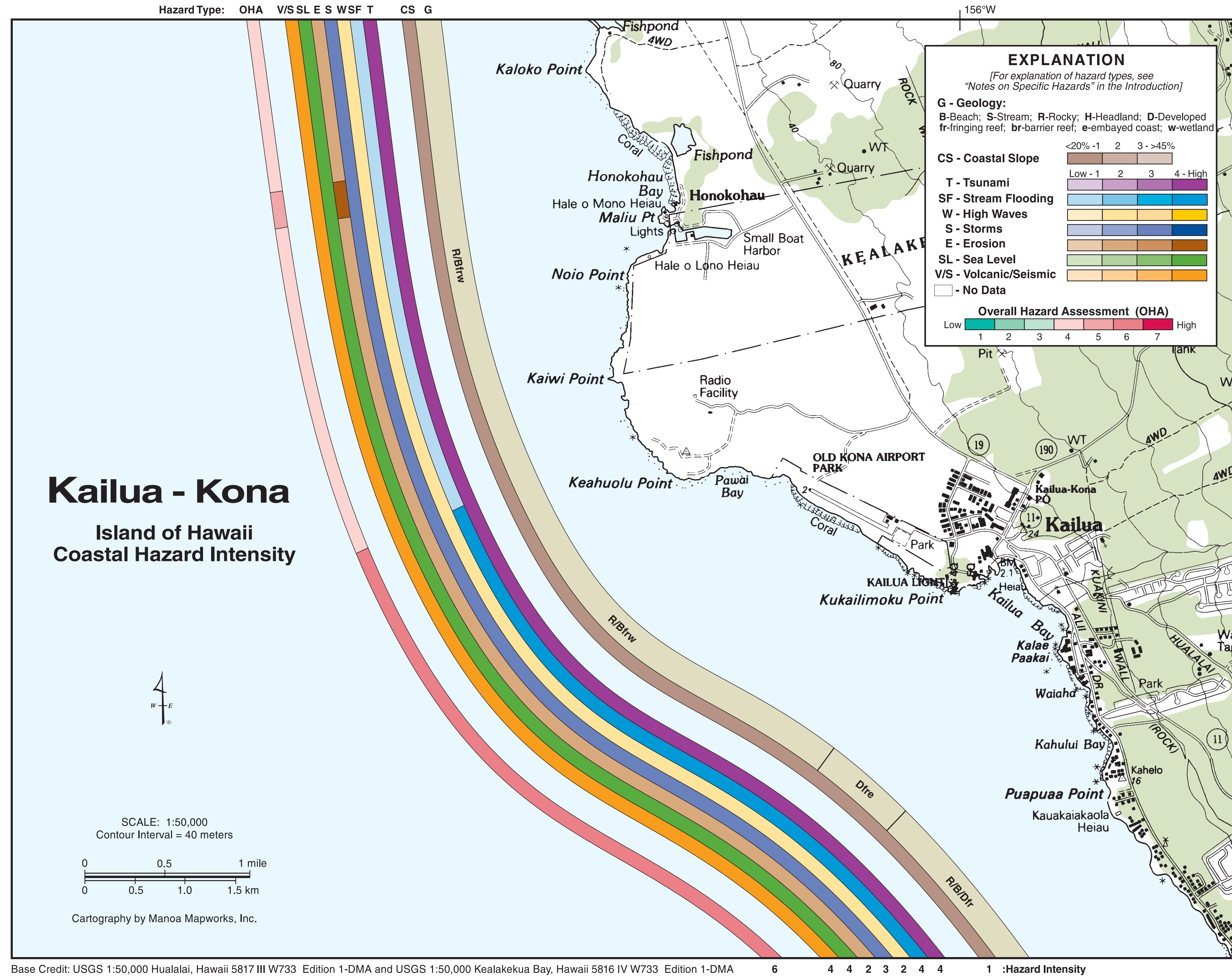
The generally low-lying Keauhou coast is vulnerable to marine overwash and inundation, so the tsunami and sea-level hazards are high. The increase in precipitation and runoff north of Kaukalaelae Point results in a high ranking for stream flooding to the north of that point and a moderately high hazard to the south. High waves are only a moderately low threat along this southwest-facing coast. Storms are moderately high, while erosion is moderately low. The volcanic/seismic hazard is high in Keauhou due to the high seismicity of the area associated with volcanic processes of Mauna Loa and Kilauea Volcanos, as well as the ever present threat of an eruption of Hualalai Volcano. The Keauhou coast lies in lava flow hazard zone 4 (Table 10, p. 24). The increase in the stream-flooding hazard north of Kaukalaelae Point results in an increase in the Overall Hazard Assessment (OHA) from moderate to high (5) south of that point, to high (6) north of Kaukalaelae Point along Alii Drive through Kahaluu and into southern Kailua-Kona to the north (see Kailua-Kona map).

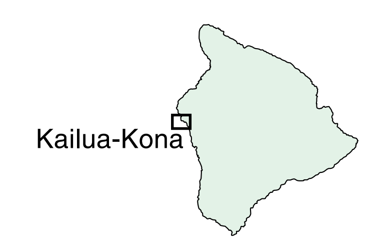
The Keauhou coast is characterized by small coves and embayments separated by 10 to 15 ft tall rocky headlands. Considerable development focused on tourism has occurred around Keauhou during the past several decades despite annual high wave overwash of Alii Drive and the ever-present threat of a Hualalai Volcano eruption or tropical storm impact.

Kailua-Kona

The Kailua-Kona region is extensively developed along its rocky waterfront. Kailua Bay cuts into 12,000 yr old volcanic rocks, whereas the region between Kukailimoku and Kaloko Points is a constructional coastal plain comprised of 2000 yr old lavas. Many coastal streams incise the older rocks south of Keahuolo Point whereas few streams exist to the north. The presence of a wetland at Honokohau Bay is evidence that fresh water flows below ground before ponding behind the shoreline. Fringing reefs extend along the entire Kailua-Kona coast. Few beaches are found within this coastal region. Just north of the pier in Kailua Bay, is a small and sheltered beach, which was the last home of King Kamehameha I. It is protected by pahoehoe rocks and reefs offshore. Several small pocket beaches exist within Kailua Bay and at the entrance to the Honokohau small boat harbor. Storm deposited rubble forms beaches perched atop the low rocky coast between Kukailimoku Point and Honokohau Bay. Despite the generally rocky shoreline, numerous seawalls have been erected to protect development along Kailua-Kona's Alii Drive from marine overwash, flooding, and coastal erosion.

The Overall Hazard Assessment (OHA) for the Kailua-Kona coast is high (6) south of Keahuolu Point and moderate (4) to the north due to the difference in the coastal flooding hazard. A portion of Honokohau Bay that is experiencing erosion has an OHA of moderate to high (5). The tsunami hazard is high along the low coast. The potential for stream flooding is high south of Keahuolu Point but low to the north where streams mostly flow through the subsurface rocks. Although high waves periodically overwash Alii Drive, the high wave hazard is moderately low because of Kailua-Kona's exposure to low to moderate wave heights associated with south swell. The storm hazard is moderately high because this coast faces directly toward oncoming Kona storms. Erosion is moderately low along this rocky coast, except at the beach of Honokohau Bay, where it is moderately high. The threat of sea-level rise is high, because of relatively rapid island subsidence in addition to global sea-level rise. Kailua-Kona lies in lava flow hazard zone 4 (Table 10, p. 24). The volcanic/seismic threat is high due to geologically recent volcanic eruptions and high seismicity.



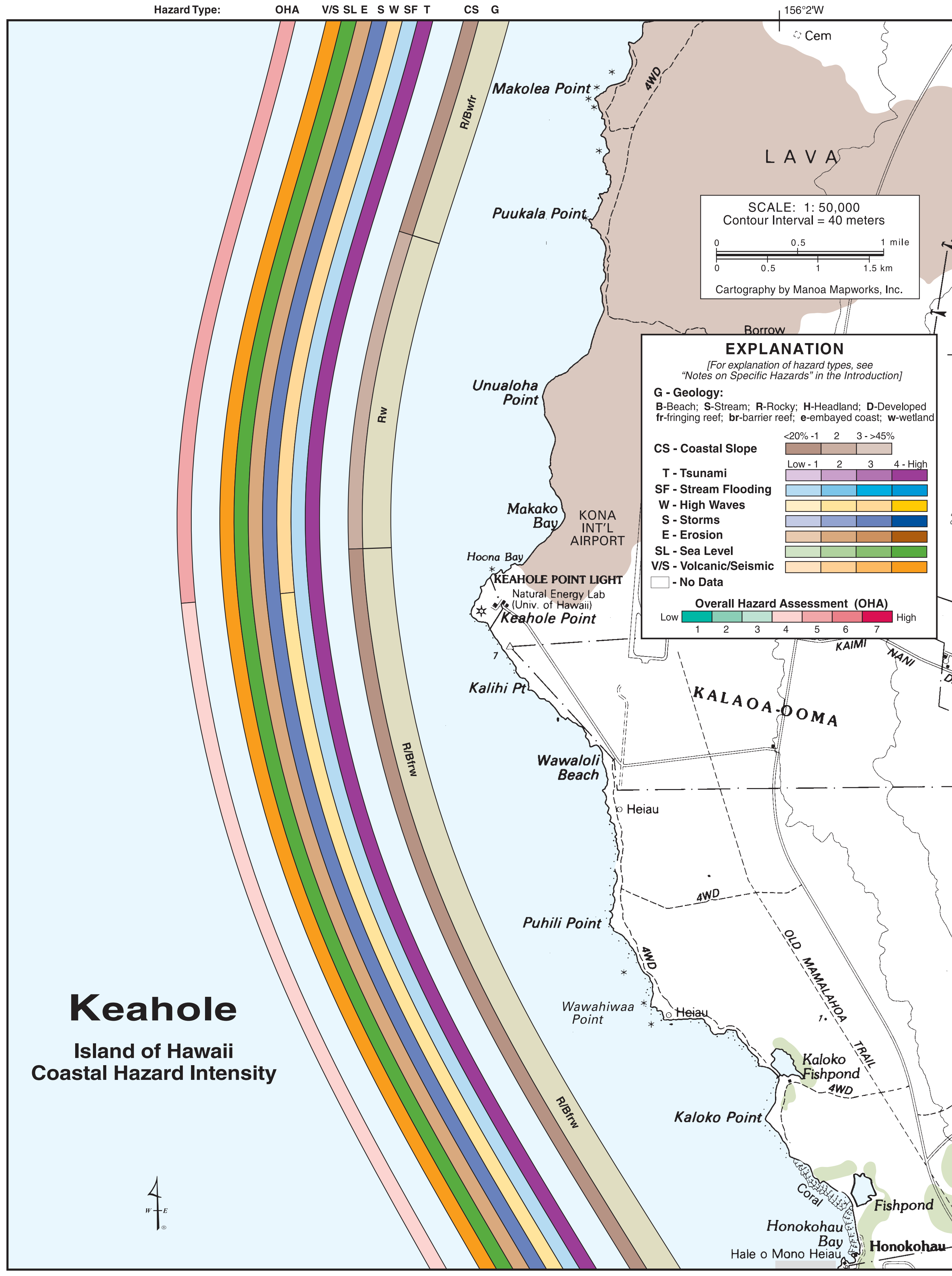


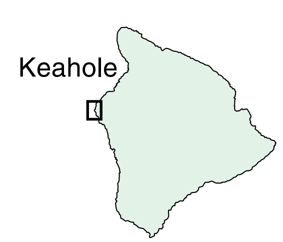
The city front of Kailua–Kona is set within the deeply embayed coast of Kailua Bay, on a narrow, low-lying coastal terrace. Near-annual high wave overwash of Alii Drive causes power outages and flooding, while the high rate of relative sea-level rise enables greater wave energy to erode the already vulnerable, developed shoreline.

Keahole

The Keahole coast is very arid, low lying, and only slightly developed. The University of Hawaii's Natural Energy Laboratory and the Kona International Airport are located amidst lava flows only a couple of thousand years old. In 1801, lava flowed to the sea just north of the airport, building Unualoha, Puukala, and Makolea Points seaward. Storm beaches of white calcareous and black volcanic sands are perched atop this generally rocky shoreline with many protected small tide pools at the water's edge. Small rock remnants exist offshore of a small embayed beach and wetland just south of Makolea Point. Fishponds, wetlands, and heiau (ancient temples) are common. A fringing reef extends along most of this coast.

The Overall Hazard Assessment (OHA) for the Keahole coast reflects the change in high wave hazard at Keahole Point, the western-most point on the Island of Hawaii. To the south, the coast faces southwest and primarily receives south and southwest swell, so the high wave threat is only moderately low and the OHA is moderate (4). North of Keahole Point, the coast faces west-northwest and receives higher west swell, so the high wave hazard is moderately high and the OHA is moderate to high (5). The tsunami hazard is high while stream flooding is low along the entire Keahole coast. Storms are ranked moderately high along this coast that is exposed to Kona storms and the primary track of tropical cyclones to the west. Erosion is moderately low along this rocky coast, while the threat of sea-level rise is high due to active subsidence of the area. The Keahole coast lies in lava flow hazard zone 4 (Table 10, p. 24). However, because of historical volcanic flows in the area and its proximity to high seismicity associated with volcanic processes of Mauna Loa and Kilauea Volcanos, the volcanic/seismic hazard is high along the Keahole coast.



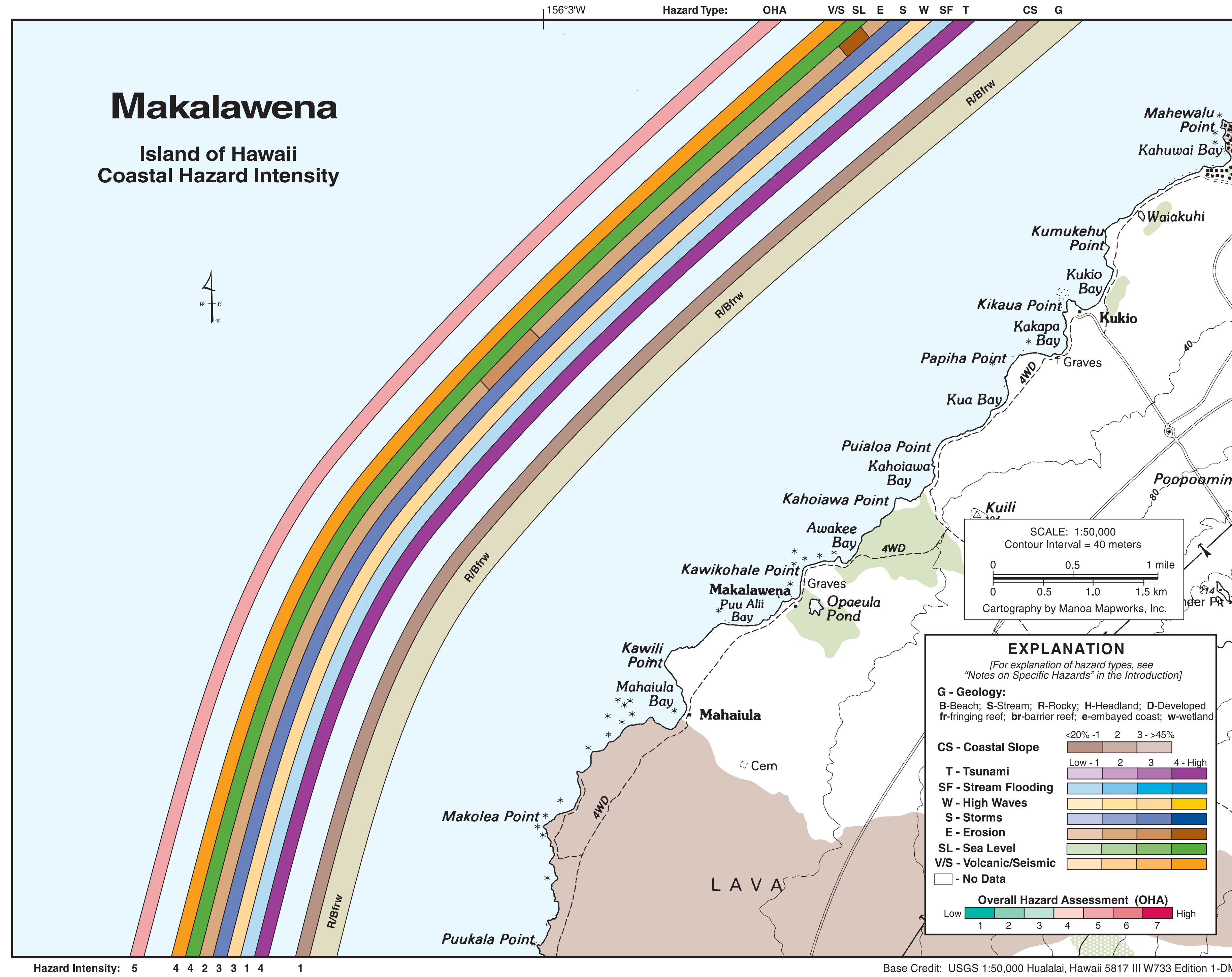


The rocky and arid coast of Keahole is low lying and developed with industry, including the University of Hawaii's Natural Energy Lab and the Kona International Airport.

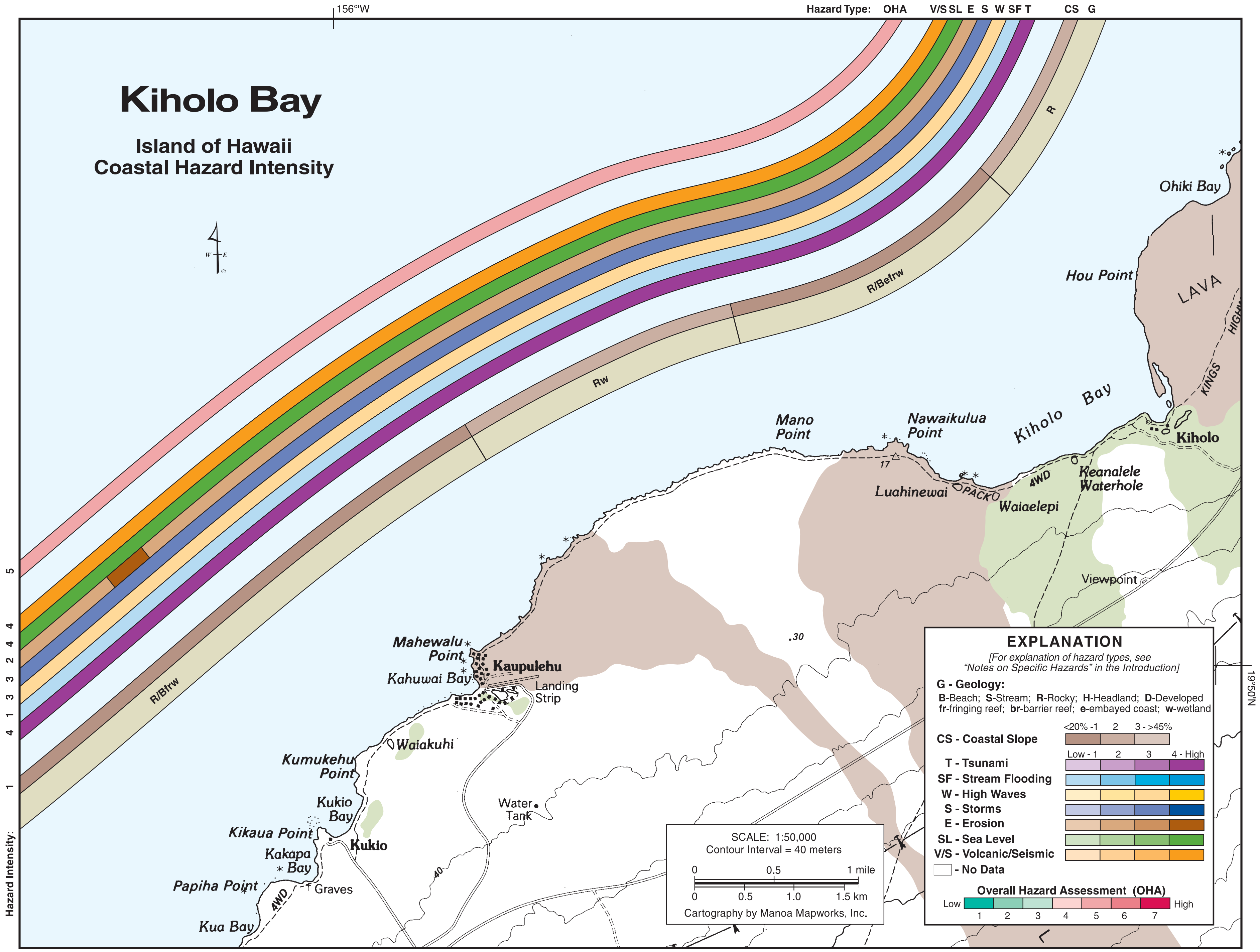
Makalawena

The Makalawena coast, stretching between Makolea Point and Kukio Bay, is comprised of lava flows ranging from 200 to 5000 yr in age. The coastal zone is low lying and mostly rocky. Sandy beaches have formed in the small embayments of Mahaiula, Makalawena, Kahoiawa, Kua, and Kukio, with narrow strips of storm rubble surrounding them. This coast is undeveloped today but was used in ancient times as evidenced by the large Opaeula fish pond and ruins in the area. Wetlands line the shore as well as numerous vegetated sand dunes. Narrow fringing reefs are present offshore of this western-most portion of the Big Island.

The tsunami hazard is high along this low-lying coast, while stream flooding is low due to the extreme aridity and lack of surface stream flow. High waves are moderately high here where the coast faces toward approaching west and northwest swell. The storm hazard is moderately high also. Erosion is moderately low except at Makalawena, where it is moderately high, and at Kukio Bay where it is high. Sea-level rise is high along this and all of the Big Island, where global sea-level rise is occurring in addition to land subsidence. The volcanic/seismic threat is high due to the active volcanism and high tectonic activity on the Big Island. Makalawena lies in lava flow hazard zone 4 (Table 10, p. 24). This translates into a moderate to high (5) Overall Hazard Assessment (OHA) for the Makalawena coast.



Rocky embayments and small points formed by Holocene lava flows from Hualalai Volcano line the arid and low-lying Makalawena coast.



Base Credit: USGS 1:50,000 Kawaihae Bay, Hawaii 5817 IV W733 Edition 1-DMA and Hualalai, Hawaii 5817 III W733 Edition 1-DMA

Kiholo Bay

The rocky Kiholo Bay coastline, extending between Kukio Bay in the south and Hou Point in the north, is composed of lava flows of various ages. Lava that emanated from Hualalai Volcano in 1800-1801 extended the shoreline seaward just north of Mahewalu Point and at Nawaikulua Point, covering older rocks ranging from 1500 to 3000 yr in age. In 1859, lava flowed over 30 mi from the north flanks of Mauna Loa and created Hou Point. A large sand and boulder spit abuts the southern boundary of this 1859 flow and partly encloses a 5-acre lagoon at Kiholo. The lagoon is shallow and carbonate sands line the bottom. The stark contrast of black basalt rock surrounding a brilliant aqua-blue lagoon, creates a beautiful sight on a sunny day. Moderately steep headlands have formed just north of Hou Point and for a 1 mi stretch of coast south of Mano Point; otherwise the coast is low lying. Few residential homes exist, but several old archaeological sites remain. Tide pools, wetlands, and black and white sand beaches line the shoreline along the small coves in the south and Kiholo Bay in the north. A fringing reef is well developed along most of the coast except seaward of Mano Point. It is very arid on this coast.

The Overall Hazard Assessment (OHA) is moderate to high (5) reflecting high tsunami, sea-level, and volcanic/seismic hazards. Stream flooding is low because of extreme aridity and lack of surface runoff; most fresh water flows through the porous rock below the surface. High waves are ranked moderately high along this coast that faces west-northwest and receives moderate wave heights from west and northwest swell. Storms are moderately high here because Kona storms and tropical cyclones, that often track west of the Big Island, send moderate winds and waves into the Kiholo Bay region. At Kiholo the lava flow hazard zone in this region shifts from 4 in the south associated with Hualalai volcanics, to 3 in the north where Mauna Loa volcanics have been more active in historic time (Table 10, p. 24).

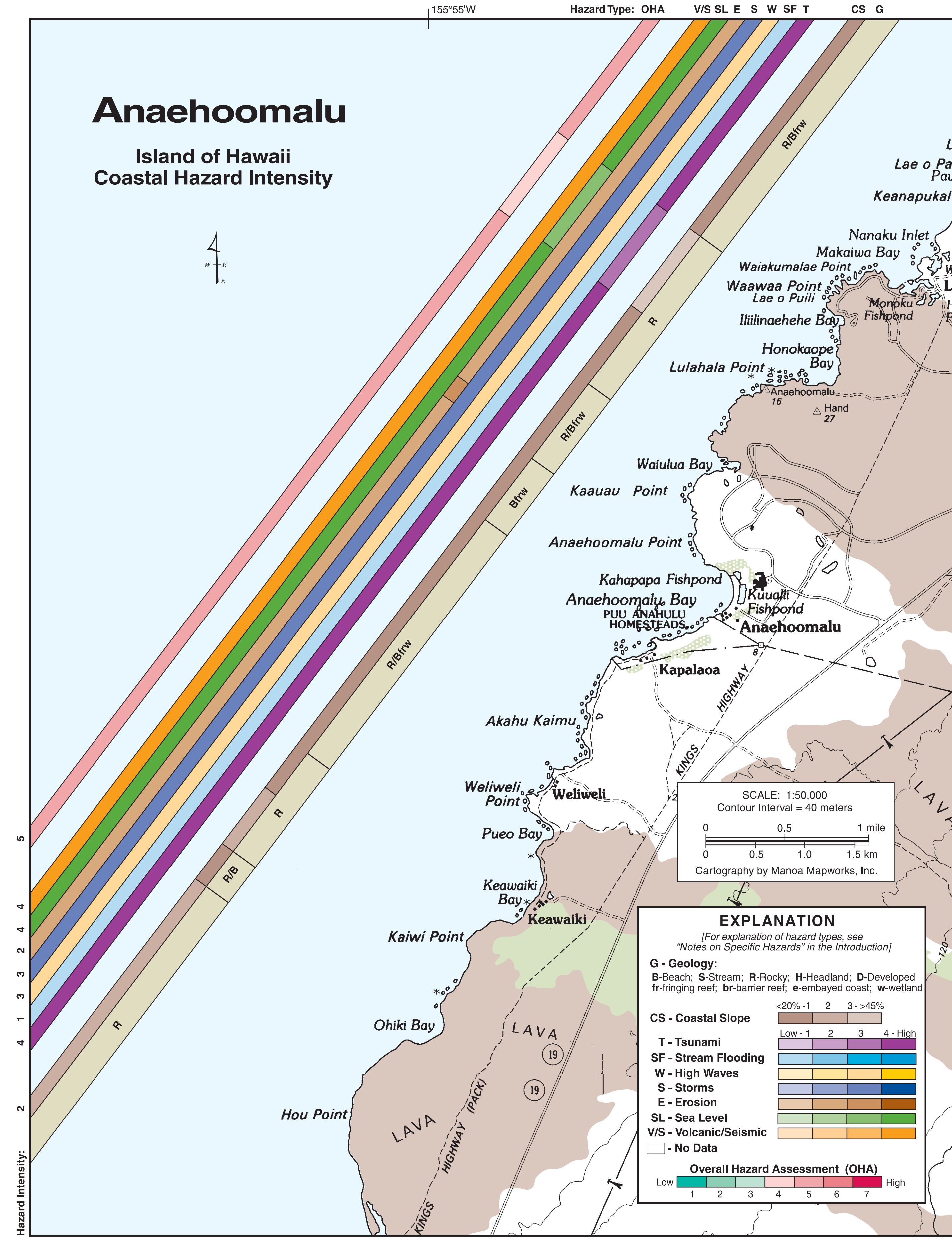
Lava flows from Hualalai and Mauna Loa eruptions in 1800 and 1859 traveled up to 30 mi to reach the sea around Kiholo, helping to form the beautiful embayment and the rocky points surrounding it.

Anaehoomalu

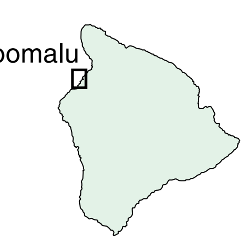
Between Hou Point and Waawaa Point, historic (1859 Mauna Loa flow) and prehistoric lava flows have created numerous coves and bays along the Anaehoomalu coast. Black and white sand beaches have formed in the low-lying Ohiki, Keawaiki, Pueo, Akahu Kaimu, Anaehoomalu, and Waiulua Bays. Most of these bays, however, have rocky bottoms or only thin veneers of sand offshore. Surrounding the bays are small but steep rocky headlands at Kaiwi and Lulahala Points. Anaehoomalu and Honokaope Bays are extensively developed with resorts and golf courses amidst wetlands and old fish ponds. Rock outcrops closely line the entire shore while an expansive fringing reef exists between Pueo and Waiulua Bays. Very little rain falls in this region and freshwater flow to the sea generally occurs within the porous rocks.

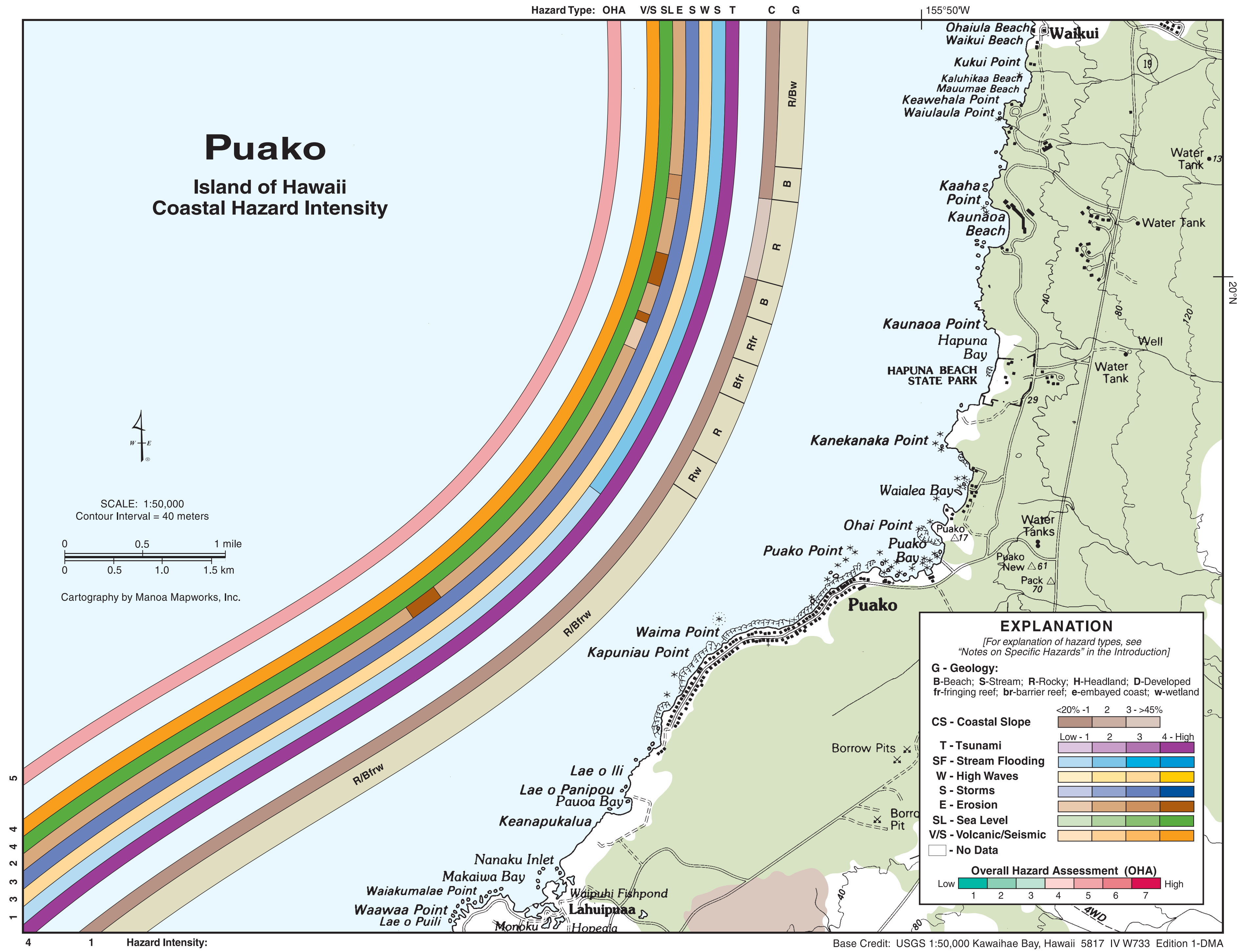
The Overall Hazard Assessment (OHA) for the Anaehoomalu coast is moderate to high (5), except between Lulahala and Waawaa Point where the rocky headland partly mitigates marine overwash and the OHA is moderate (4). Along the headland coast of Honokaope Bay, the tsunami and sea-level hazards are moderately low, while on either side they are high. Stream flooding is low along the entire coast due to the low rainfall and runoff. High waves and storms are both moderately high because this coast receives northwest and west swell as well as moderately high winds and waves from passing Kona and tropical storms. Erosion is moderately low, except at the Anaehoomalu beach immediately seaward of Kuuali Fishpond, where it is moderately high. Anaehoomalu lies in lava flow hazard zone 3 (Table 10, p. 24). The volcanic/seismic hazard is high due to recent lava flows in the area and active seismicity associated with Mauna Loa and Kilauea volcanos.

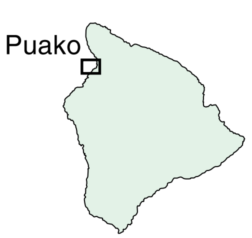
Despite a network of 1859 Mauna Loa lava flows that resemble rivers of rock and that reconfigured the shoreline, the Anaehoomalu coast has been extensively developed for tourism amidst arid lava fields.



Base Credit: USGS 1:50,000 Kawaihae Bay, Hawaii 5817 IV W733 Edition 1-DMA and Hualalai, Hawaii 5817 III W733 Edition 1-DMA







Puako

The highly developed coast of Puako is lined with resorts and beach parks. The embayed Puako Bay is partly a result of the extension of the coast to the south by the more recent Mauna Loa lava flows. This is one of the most arid regions in Hawaii, receiving on average only ten inches of rainfall a year. Even so, precipitation on the flanks of Mauna Kea creates surface runoff that erodes the older rocks north of Waima Point, while to the south most freshwater flow is subsurface. Beaches of increasingly more white carbonate sand are found in the bays to the north. The widest white sand beach on the Big Island is located at Hapuna where lava flows border to the north and south. Wetlands have formed along the southern half of the coast and at Waiulaula Point. Fringing reefs are better developed south of Puako Point and between Kanekanaka Point and Hapuna Beach than at Puako Point and along the sandy beach expanses between Hapuna and Kaunaoa Bays.

The Overall Hazard Assessment (OHA) for the Puako coast is moderate to high (5). The tsunami and sea-level hazards are high due to the low slopes which are susceptible to marine overwash. Stream flooding increases from low south of Waima Point to moderately low north of Waima Point, because of the increase in stream flow. High waves are moderately high because of Puako's exposure facing west and northwest swell directions. Storms are ranked moderately high because Kona storms and passing tropical cyclones deliver moderately high waves and winds to this portion of coast. Erosion is moderately low except at Pauoa and Hapuna Bays and the north portion of Waialea Bay where it is high. Exceptions also exist at the south end of Waialea Beach where erosion is low, and at Kaunaoa Beach where it is moderately high. South of Waima Point, amidst the younger Mauna Loa lava flows, the Puako coast lies in lava flow hazard zone 3. To the north, among the older Mauna Kea flows, it is in zone 8 (Table 10, p. 24). The volcanic/seismic hazard along the Puako coast is high due to the historical lava flows in the south near Lahuipuaa and the high seismicity associated with volcanic processes of Mauna Loa and Kilauea Volcanos.

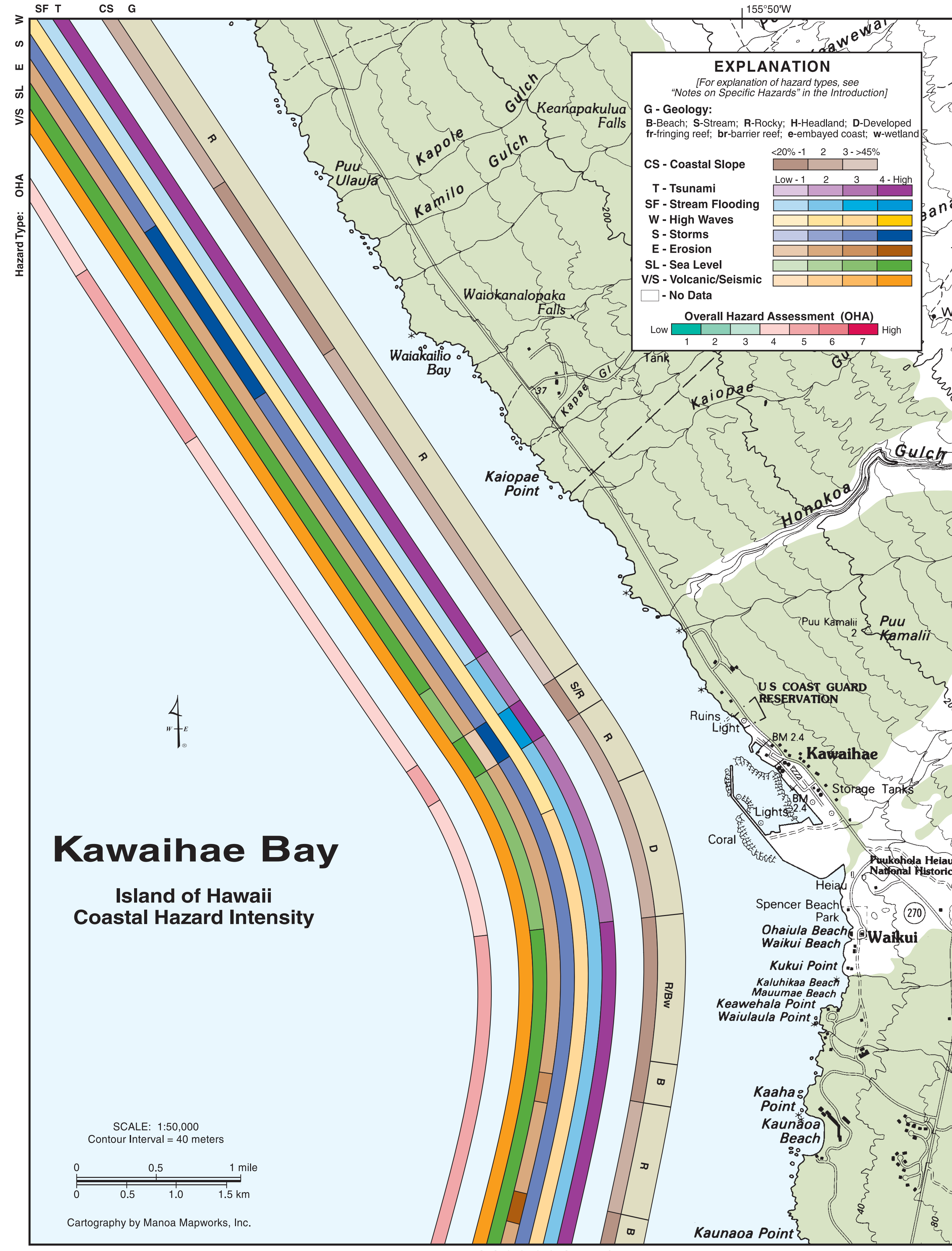
Alternating rocky points and beautiful coves containing white sand beaches adorn the gently sloping and embayed Puako coast.

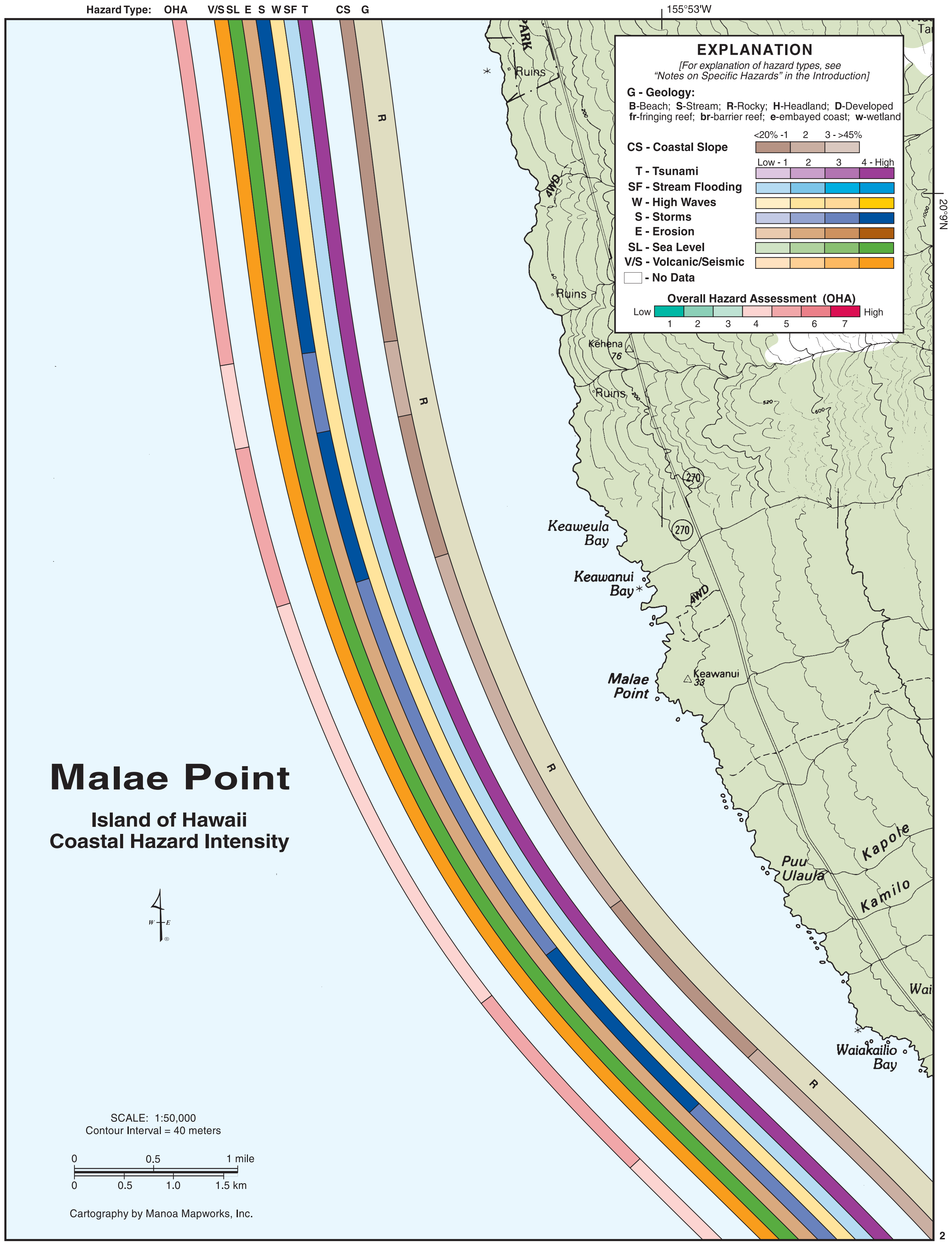
Kawaihae Bay

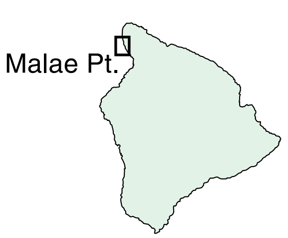
Along the Kawaihae Bay coast, Mauna Kea volcanics overlap older Kohala volcanics. The relatively low and gently sloping coast between Kaunaoa Beach and Waikui is rocky with interspersed sandy beaches including Kaunaoa, Maumae, Kaluhikaa, Waikui, and Spencer Beaches. To the north the coast is largely rocky with steeper slopes and often 10-15 ft high sea cliffs. Waikui and Kawaihae are developed with industry and Kawaihae Harbor. An extensive coral reef exists around the harbor. Wetlands have formed south of Waikui while numerous rocky remnants lie offshore to the north. Several streams and gulches make their way to the sea along the older Kohala volcanic slopes. The Kawaihae region is very arid.

The tsunami and sea-level hazards are ranked high along the Kawaihae coast except along the steeper headland from Kawaihae Harbor to just south of Kaiopae Point, where they are moderately high. Stream flooding is low north of Kaiopae Point and moderately high to the south except at the mouth of Honokoa Gulch where it is high. The wave hazard is moderately high south of Kawaihae where the coast faces west towards northwest-approaching swell. To the north it is reduced to moderately low because the coast faces smaller waves that approach from the southwest. Storms are moderately high except at the low-lying and south-facing mouth of Honokoa Gulch and the rocky stretch of coast between Waiakailio Bay and Puu Ulaula. South of Waikui the coast lies within lava flow hazard zone 8, while to the north it is located in zone 9 (Table 10, p. 24). The volcanic/seismic hazard is high due to the high seismic activity associated with volcanic processes of Mauna Loa and Kilauea Volcanos. As a result, the Overall Hazard Assessment (OHA) is moderate to high (5) south of Waikui, at the mouth of Honokoa Gulch, and between Waiakailio Bay and Puu Ulaula, and only moderate (4) along the steeper coasts in between.

Developed for industry and commerce, the low-lying Kawaihae Harbor is located where the gently sloping coast of Waikui meets the steeper and sea-cliffed coast along the flanks of Kohala Volcano.







Malae Point

The Malae Point coast consists largely of low sea cliffs and several small rocky coves and bays separated by prominent headlands. Only a few cobble beaches exist along the entire stretch. Numerous rock islets and remnants lie offshore. The region is undeveloped except for old ruins surrounding the old coastal trail. Access is only by foot trail or four-wheel-drive vehicle. It is very arid although many intermittent streams and gulches cut across these moderate slopes, evidence that periodic flooding has occurred in the past. Trade winds blow generally offshore along this coast which creates good diving conditions. Only a few patch reefs have developed, however.

The Overall Hazard Assessment (OHA) is moderate (4) along the steeper headlands of Waiakailio Bay, between Puu Ulaula and Keaweula Bay, and to the north of Keaweula Bay. The OHA is moderate to high (5) in the immediate vicinity of Keaweula Bay, Waiakailio Bay, and Puu Ulaula and along the north portion of the Malae Point coast which are moderate to low lying. While the tsunami, sea level, and volcanic/seismic hazards are high throughout the entire coast, it is the variation in the storm hazard that influences the variation in the OHA ranking. Along the low sloping coastal segments the storm hazard is high, whereas along the moderate to steep slopes it is moderately high. Stream flooding is low, while high waves are moderately low throughout the entire Malae Point coast. Erosion is moderately low along these rocky, sea-cliffed shores. The Malae Point coast lies in lava flow hazard zone 9 (Table 10, p. 24).

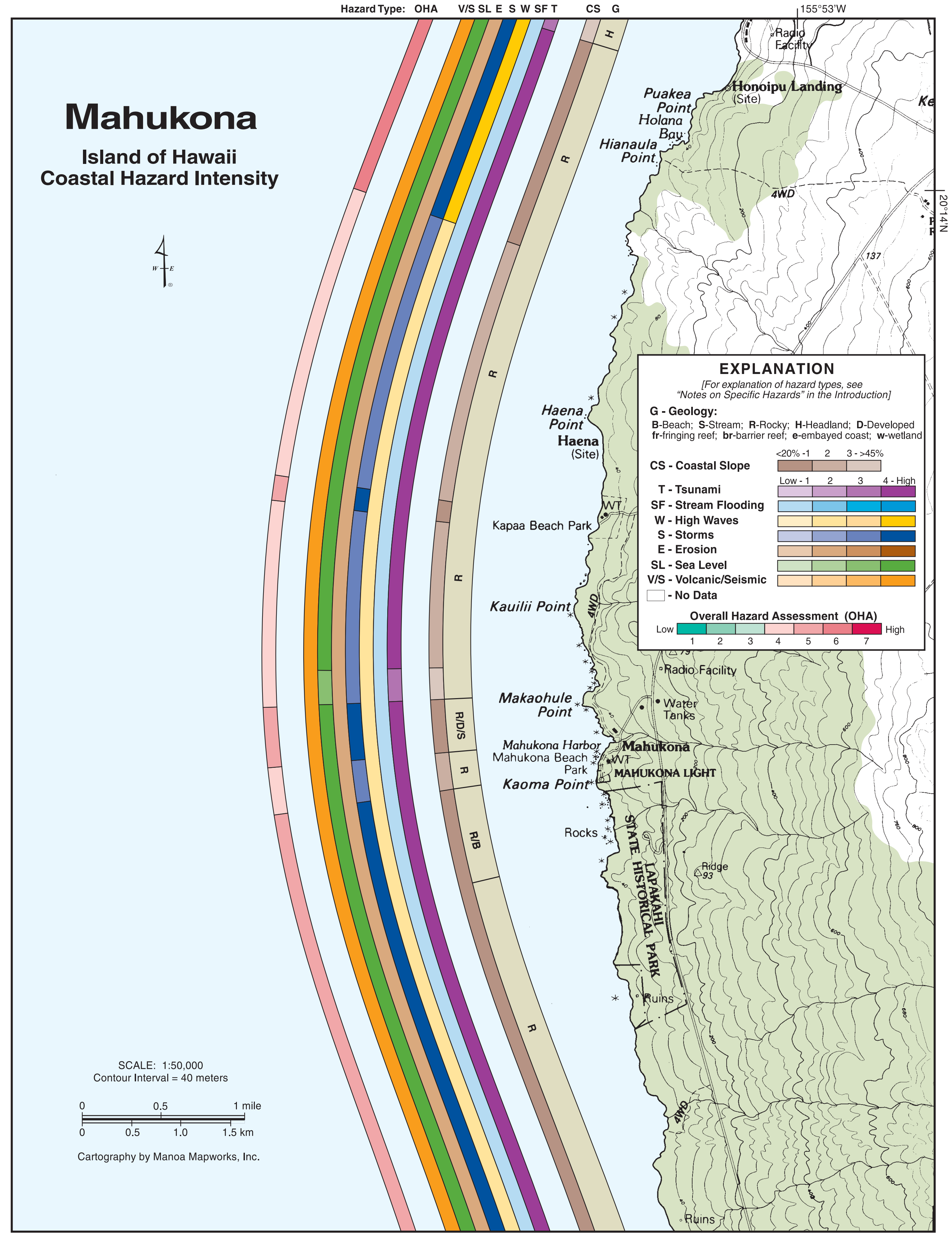
Despite the rocky sea-cliff shoreline and vegetated upland slopes, recent development in the vicinity of Malae Point has led to an increase in sedimentation in the coastal zone during periodic heavy rains.

Mahukona

Between Lapakahi State Historical Park and Hianaula Point, the Mahukona coast is arid and generally rocky, with numerous small headlands. Near Lapakahi State Historical Park the coast gently slopes into the water, while to the north the coast is mostly bordered by sea cliffs. Cobble beaches exist just south of Kaoma Point and at Mahukona Beach Park. The harbor at Mahukona used to serve the Kohala sugar plantations, but the April 1946 tsunami destroyed its railroad link to the Hamakua coast. The harbor now provides a small winch and chain hoist for use by recreational boaters. Archaeological structures and ruins remain strewn across this coast, evidence that it used to be significantly populated.

The tsunami hazard is high except at Makaohule Point headland where it is moderately high. Stream flooding is low along the entire Mahukona Coast. The wave hazard is moderately low in the southern portion but is increased to high halfway between Haena and Hianaula Points and to the north, where north and northwest swell impact the coast. Storms are high along the lower slopes south of Kaoma Point, between Mahukona Harbor and Makaohule Point, at Kapaa Beach Park, and in the northern region. Along the steeper slopes north of Kapaa Beach Park for about two miles, between Kapaa and Makaohule Point, and at Mahukona Harbor, the storm threat is reduced to moderately high. Erosion is moderately low while the volcanic/seismic threat is high due to high seismicity associated with volcanic processes within Mauna Loa and Kilauea Volcanos. Mahukona lies within lava flow hazard zone 9 (Table 10, p. 24). Sea level is high except at the Makaohule Point headland where it is moderately high. As a result, the Overall Hazard Assessment (OHA) is moderate to high (5) south of Kaoma Point, between Mahukona Beach Park and Makaohule Point, and at Kapaa Beach Park due to the increased storm hazard. The OHA is reduced to moderate (4) at Mahukona Harbor and between Makaohule Point and Kapaa Beach Park. A moderate (4) OHA extends from Kapaa Beach Park to the midpoint between Haena Point and Hianaula Point, where it is elevated to high (6) because of the increased high wave and storm hazards that extend toward the north.

Once an important shipping port for the sugar industry, Mahukona Harbor suffered significant damage during the 1946 tsunami and is now used only for small boating.



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