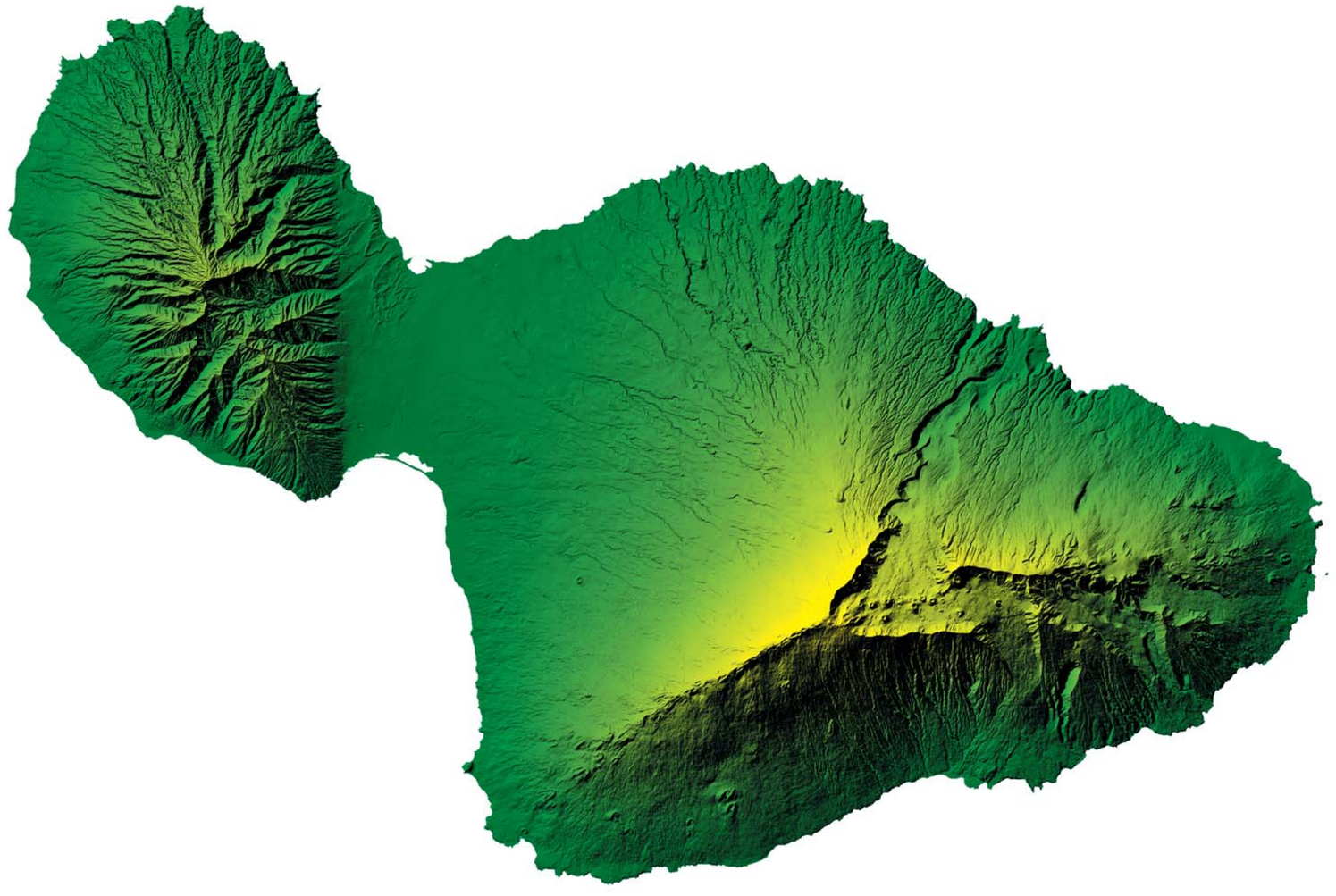
Maui

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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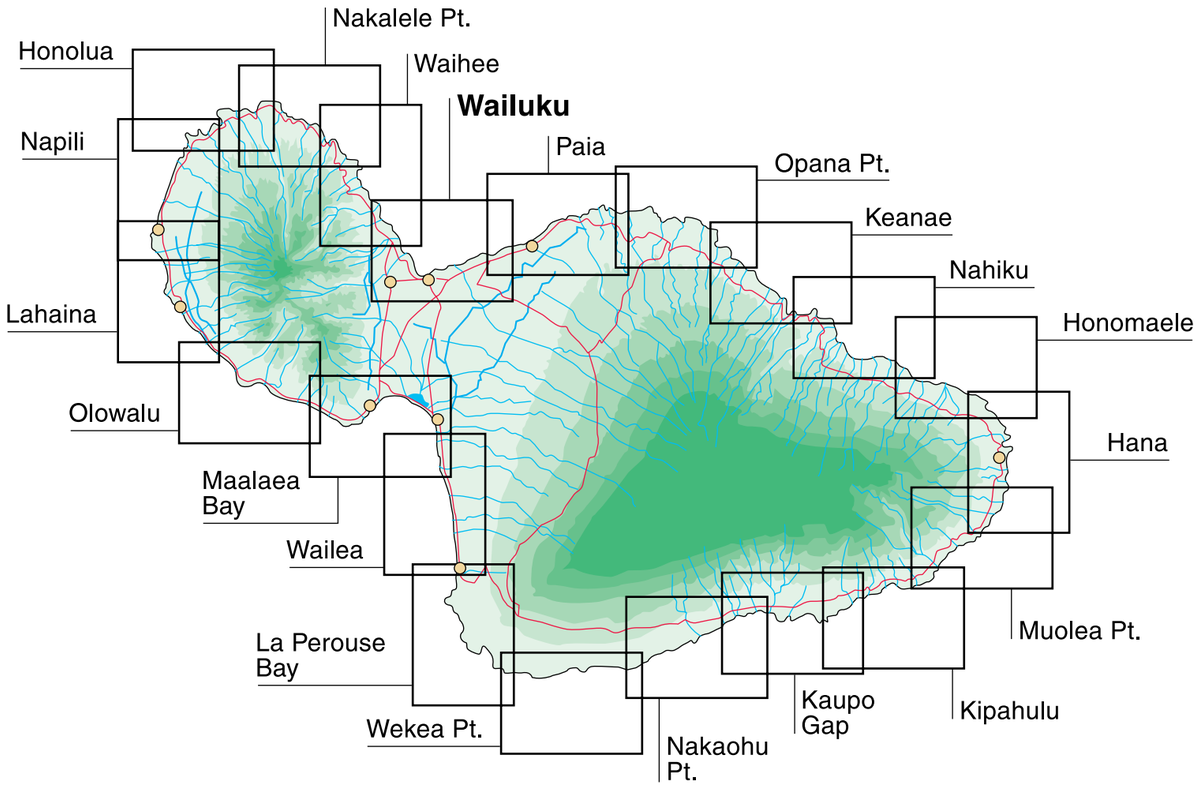


Tsunamis

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.

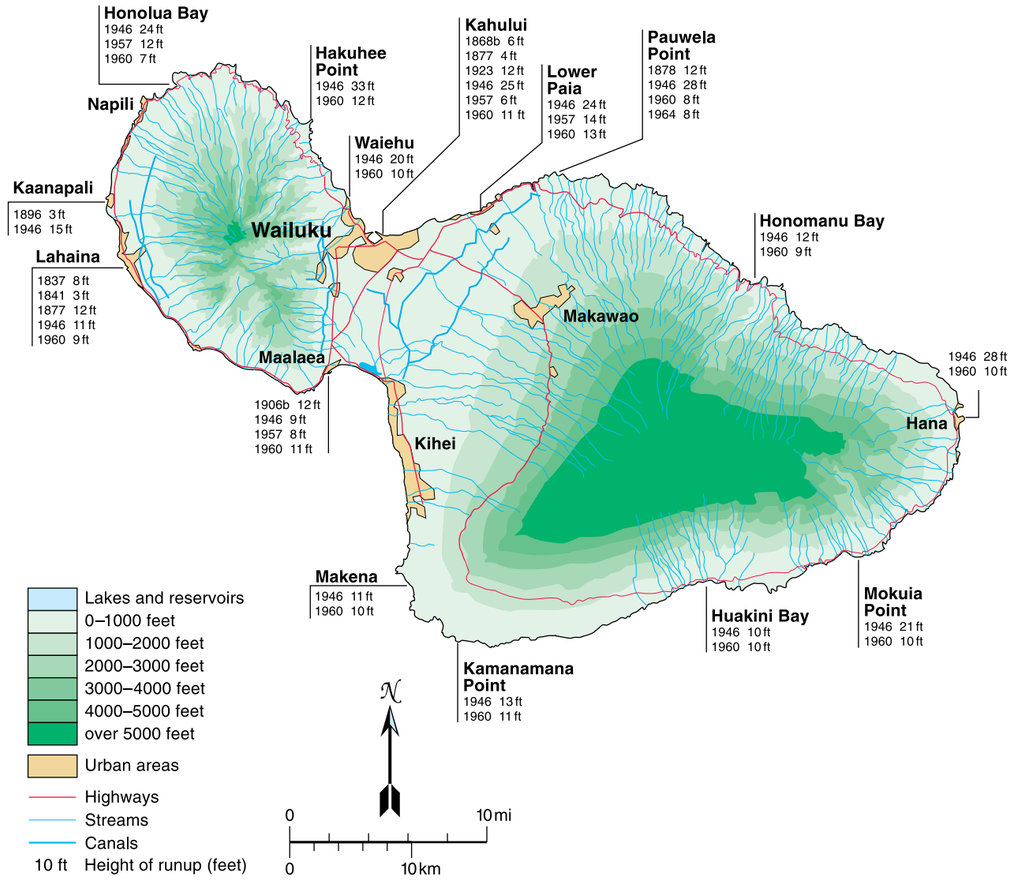
Tsunamis reaching Maui have exhibited tremendous variability in terms of their runup heights, inundation distances, and the damage they have inflicted. During the 1946 tsunami, for example, runup heights within only a few miles along the south shore varied by over 10 ft between Huakini Bay and Mokuia 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.

Maui
Stream flooding

Islandwide stream flooding because of heavy rains

1900 Nov 14 Flash flood
1906 Dec 23 Flash flood
1916 Jan 14 Flash flood
1918 Apr 18 Flash flooding
1930 Aug 10 Flash flooding
1930 Nov 18 Flash flooding
1946 Jan 2 Flood
1946 Dec 20 Flash flooding
1948 Apr 2 Flash flood
1950 Nov 30 Flash flood
1951 Feb 22 Flash flood
1960 May 12–13 Flooding
1961 Oct 24 Flash flooding
1963 Mar 13 Flooding
1965 Jan 23 Flash flood
1968 Mar 13–16 Flooding
1968 Nov 28 Minor flooding
1971 Jan 28 Flooding
1974 Apr 19 Flash flooding
1980 Jan 6–14 Flooding
1981 Aug 3–4 Flooding
1981 Oct 27–28 Flooding
1982 Mar 30–31 Flooding
1982 Apr 1–3 Flooding
1982 Jul 16–17 Flooding
1982 Dec 23–24 3–5" rain
1984 May 23 Minor flash floods
1984 Dec 24–25 Flash flooding
1985 Oct 17–18 Flash floods
1985 Nov 18 Minor flash flooding
1986 Feb 15 Flash floods
1986 Nov 10–11 Minor flash flooding
1987 Apr 21–22 Minor flash flooding
1987 Apr 26 Flash flooding
1987 May 5–6 10" rain, flash flooding
1988 Jan 28–29 Flash floods
1988 Nov 4–5 Extensive flooding
1988 Dec 5–6 Flash flooding
1989 Feb 10–11 Minor flash floods
1989 Mar 1–4 Minor flash floods
1990 Jan 14–22 Up to 20" rain, flooding
1991 Jan 27 Flooding
1991 Mar 19–21 Flooding
1993 Jul 21–23 Flooding, remnants of H Dora

Northwest Maui

1961 Nov 2 Flash flooding at NW Maui, Napili, Honolua
1964 Dec 19 NW Maui
1967 Mar 17 Napili Bay
1967 Mar 24 Napili Bay, heavy rains
1968 Mar 13–16 24" in 48 hours at Napili Beach, Honolua, Paakea

North Central Maui

Wailuku and Iao Stream are frequently flooded. Kahului frequently inundated by sheetflow

1900 Nov 14 Kahului
1903 Feb 13 Flash flood at Wailuku
1916 Jan 14 17000 cfs at Iao Valley
1920 Dec 24 Storm, flooding at Wailuku
1930 Nov 18 Iao Stream
1948 Jan ? Iao Stream
1950 Nov 30 Flash flooding at Iao Valley, Wailuku
1950 Dec 3 7550 cfs, 5" rain in 2 hours at Iao Stream,
1961 Nov 2 5700 cfs at Iao Stream
1965 Feb 4 Sheetflow
1971 Jan 27–28 5820 cfs at Iao Stream, 2 ft at Paia
1972 Feb 8 3.5" in 1 hr at Wailuku,
1978 Nov 12 Flash flooding at Iao Valley, Kahului
1982 Mar 30–31 Iao Valley
1987 Mar 5–6 Over 10" rain, flash flooding at Wailuku, Kahului
1989 Feb 3–5 Flash flooding near Haiku
1994 Apr 12–13 Flash flood, mudslide

West Maui

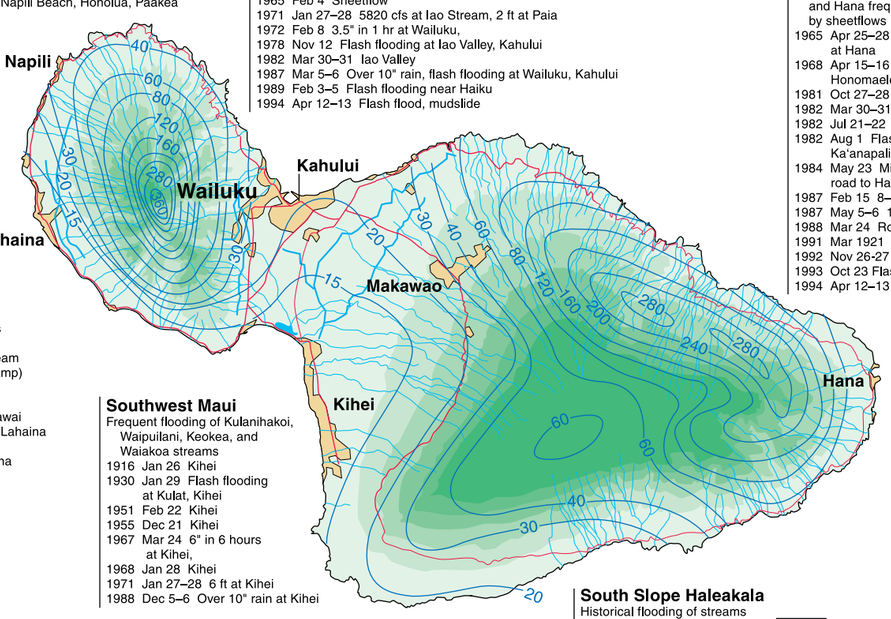
Honokawai and Lahaina are frequently flooded
Since 1879, 19 damaging floods occurred in the Lahaina area

1916 Jan 26 Lahaina and Olowalu flooded
1950 Nov 30 Flash flooding at Lahaina
1960 May 13 Kahoma Stream
1961 Oct 31–Nov 3 West Maui, Kahoma Stream
1967 Mar 17–18 7" in 5.5 hours at West Maui
1971 Jan Lahaina, Kauaula Stream (Hale, Cannery, Kelawe Camp)
1972 Feb 24 5–8" in 5 hours at West Maui, Lahaina
1974 Nov 21 Kaanapali, Honokawai
1987 May 5–6 Flash flooding at Lahaina
1988 Dec 5–6 Over 10" of rain
1997 Jan 19–20 Flooding Lahaina

Windward Haleakala

Makawao, Kaupakulua, Wailua and Hana frequently flooded by sheetflows

1965 Apr 25–28 Flash flood at Hana
1968 Apr 15–16 East Maui esp. Honomaele Stream
1981 Oct 27–28 Road to Hana
1982 Mar 30–31 Road to Hana
1982 Jul 21–22 Flash flooding
1982 Aug 1 Flash flooding esp. Ka'anapali
1984 May 23 Minor flash flooding, road to Hana
1987 Feb 15 8–10" at Hana area
1987 May 5–6 10"
1988 Mar 24 Road to Hana
1991 Mar 1921 Road to Hana
1992 Nov 26-27 Severe flooding
1993 Oct 23 Flash flood, mudslide
1994 Apr 12–13 Flash flood, mudslide



Southwest Maui

Frequent flooding of Kulanihakoi, Waipuilani, Keokea, and Waiakoa streams

1916 Jan 26 Kihei
1930 Jan 29 Flash flooding at Kulat, Kihei
1951 Feb 22 Kihei
1955 Dec 21 Kihei
1967 Mar 24 6" in 6 hours at Kihei,
1968 Jan 28 Kihei
1971 Jan 27–28 6 ft at Kihei
1988 Dec 5–6 Over 10" rain at Kihei

South Slope Haleakala

Historical flooding of streams between Kipahulu and Nuu

1968 Apr 15–16
1986 Nov 10–11

N

0 10 mi
0 10 km

11" Max. rainfall from storm (inches)
1070 cfs Max. peak discharge (ft^3 per sec)
5 ft Max. height of flooding (feet)
—30— Mean annual rainfall (inches)
[H, hurricane; R, river; Str, stream]

Lakes and reservoirs
0–1000 feet
1000–2000 feet
2000–3000 feet
3000–4000 feet
4000–5000 feet
over 5000 feet
Urban areas
Highways
Streams
Canals

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.

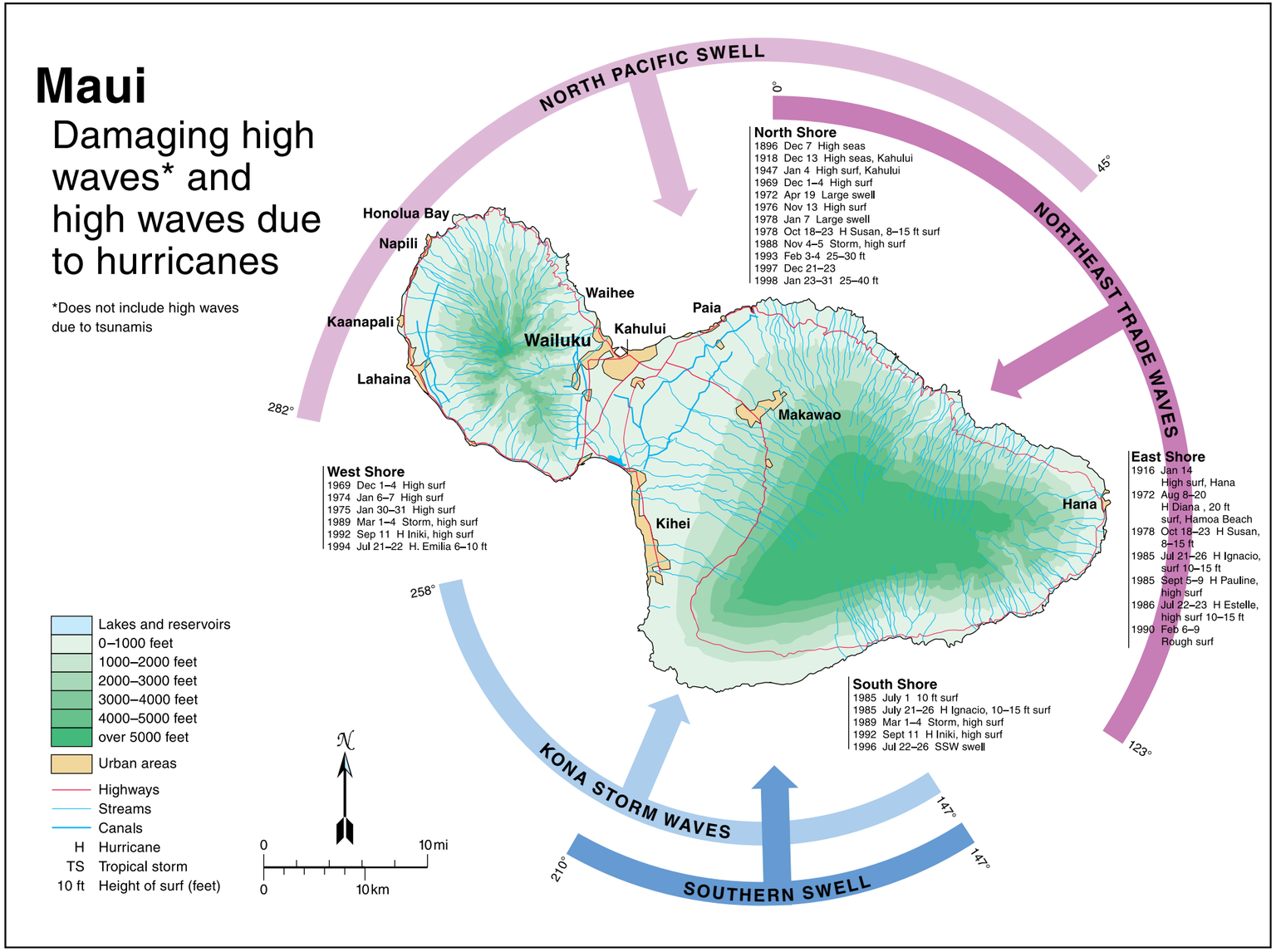
Despite the general trend of fewer historic stream floods along the arid south slope of Haleakala and more, severe floods in the wetter regions of central Maui, flooding in dry areas such as west and southwest Maui are common. Flooding in areas around Lahaina and Kihei are in part a result of the abrupt 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.

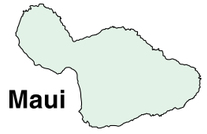
In addition to flooding from stream channels, portions of Maui, notably the Lahaina regions and Kihei, are vulnerable to standing surface water flooding. This may interrupt transportation and damage low elevation buildings. Standing surface water develops after intense rainfall events where poor soil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





Maui

Strong winds

Islandwide strong winds
1871 Aug 9 Kohala Cyclone, gale winds
1896 Dec 7 Strong winds
1906 Jan 21 High winds
1906 Oct 2–9 Makawao Cyclone
1916 Jan 14 High wind
1930 Nov 18 Flash flood
1938 Aug 18–19 Mokapu Cyclone
1948 Jan 17 High wind
1948 Jan 23–26 High wind
1955 Dec 21 High wind
1957 Nov 30–31 H Nina, gusts to 92 mph
1958 Aug 6–9 TS
1959 Jan 17–18 Storm
1959 Aug 4–7 H Dot, strong winds
1963 Jan 15–17 Strong winds
1963 Jan 30–31 Strong wnds, gusts to 84 mph
1963 Sept 12–19 TS Irah, strong winds
1964 Dec 19–23 Strong wind
1967 Aug 8–10 TS
1967 Nov 2–11 High trade winds
1967 Dec 9 High winds
1967 Dec 12 Strong winds
1968 Dec 5–6 Storm
1969 Feb 20–21 Strong wind
1970 Dec 25–29 High wind, 50–60 mph
1971 Jan 5 Strong wind
1975 Nov 23–27 Storm
1976 Feb 5–7 Storm
1979 Jan 11–19 Storm, 50+ mph winds
1980 Jan 8–10 Storm, high winds
1982 July 21–22 TS David
1982 Aug 1 TS Gilma
1982 Dec 18–19 Strong, gusty, trade winds
1983 Oct 15–20 H/TD Raymond
1983 Dec 24–26 Strong wind gusts, 50 mph
1984 Dec 24–25 Kona storm
1985 Mar 1–11 Gale force trade winds
1986 July 22–23 H Estelle
1988 Nov 4–5 Storm gusts 40–50 mph
1988 Dec 5–6 Storm, southerly winds to 50 mph
1988 Dec 17-18 Gusty winds
1988 Dec 30–31 40–50 mph winds
1989 Mar 1–4 Storm, strong winds
1989 Dec 9–11 Gusty winds
1991 Jan 27 Strong winds
1993 Dec 4–6 Strong trade winds 60–80 mph
1996 Dec 23–25 SW winds 40 mph
1997 Jan 27–28 S–SW winds

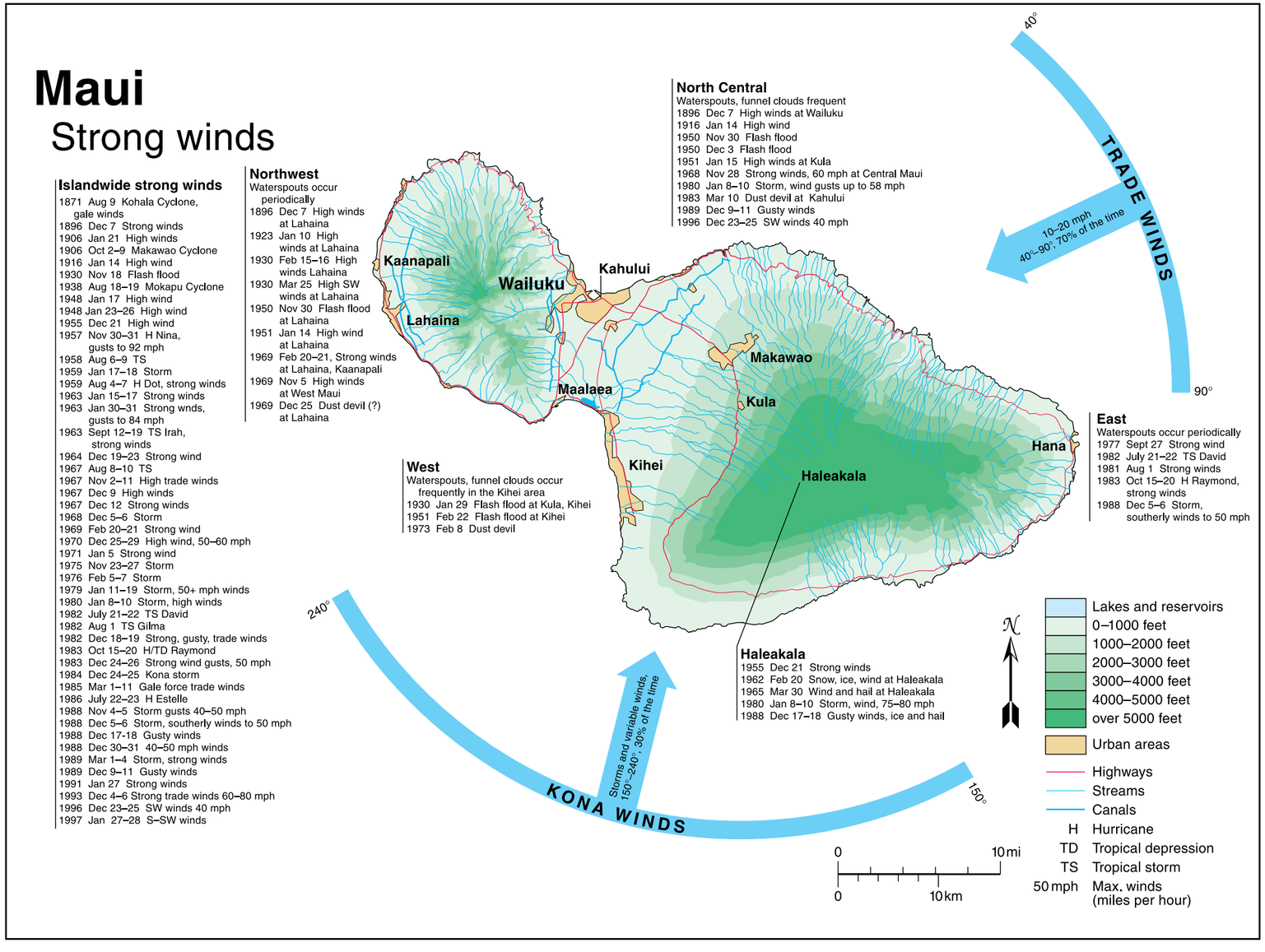
Northwest
Waterspouts occur periodically
1896 Dec 7 High winds at Lahaina
1923 Jan 10 High winds at Lahaina
1930 Feb 15–16 High winds Lahaina
1930 Mar 25 High SW winds at Lahaina
1950 Nov 30 Flash flood at Lahaina
1951 Jan 14 High wind at Lahaina
1969 Feb 20–21, Strong winds at Lahaina, Kaanapali
1969 Nov 5 High winds at West Maui
1969 Dec 25 Dust devil (?) at Lahaina

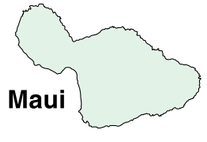
North Central
Waterspouts, funnel clouds frequent
1896 Dec 7 High winds at Wailuku
1916 Jan 14 High wind
1950 Nov 30 Flash flood
1950 Dec 3 Flash flood
1951 Jan 15 High winds at Kula
1968 Nov 28 Strong winds, 60 mph at Central Maui
1980 Jan 8–10 Storm, wind gusts up to 58 mph
1983 Mar 10 Dust devil at Kahului
1989 Dec 9–11 Gusty winds
1996 Dec 23–25 SW winds 40 mph

West
Waterspouts, funnel clouds occur frequently in the Kihei area
1930 Jan 29 Flash flood at Kula, Kihei
1951 Feb 22 Flash flood at Kihei
1973 Feb 8 Dust devil

East
Waterspouts occur periodically
1977 Sept 27 Strong wind
1982 July 21–22 TS David
1981 Aug 1 Strong winds
1983 Oct 15–20 H Raymond, strong winds
1988 Dec 5–6 Storm, southerly winds to 50 mph

Haleakala
1955 Dec 21 Strong winds
1962 Feb 20 Snow, ice, wind at Haleakala
1965 Mar 30 Wind and hail at Haleakala
1980 Jan 8–10 Storm, wind, 75–80 mph
1988 Dec 17–18 Gusty winds, ice and hail





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.

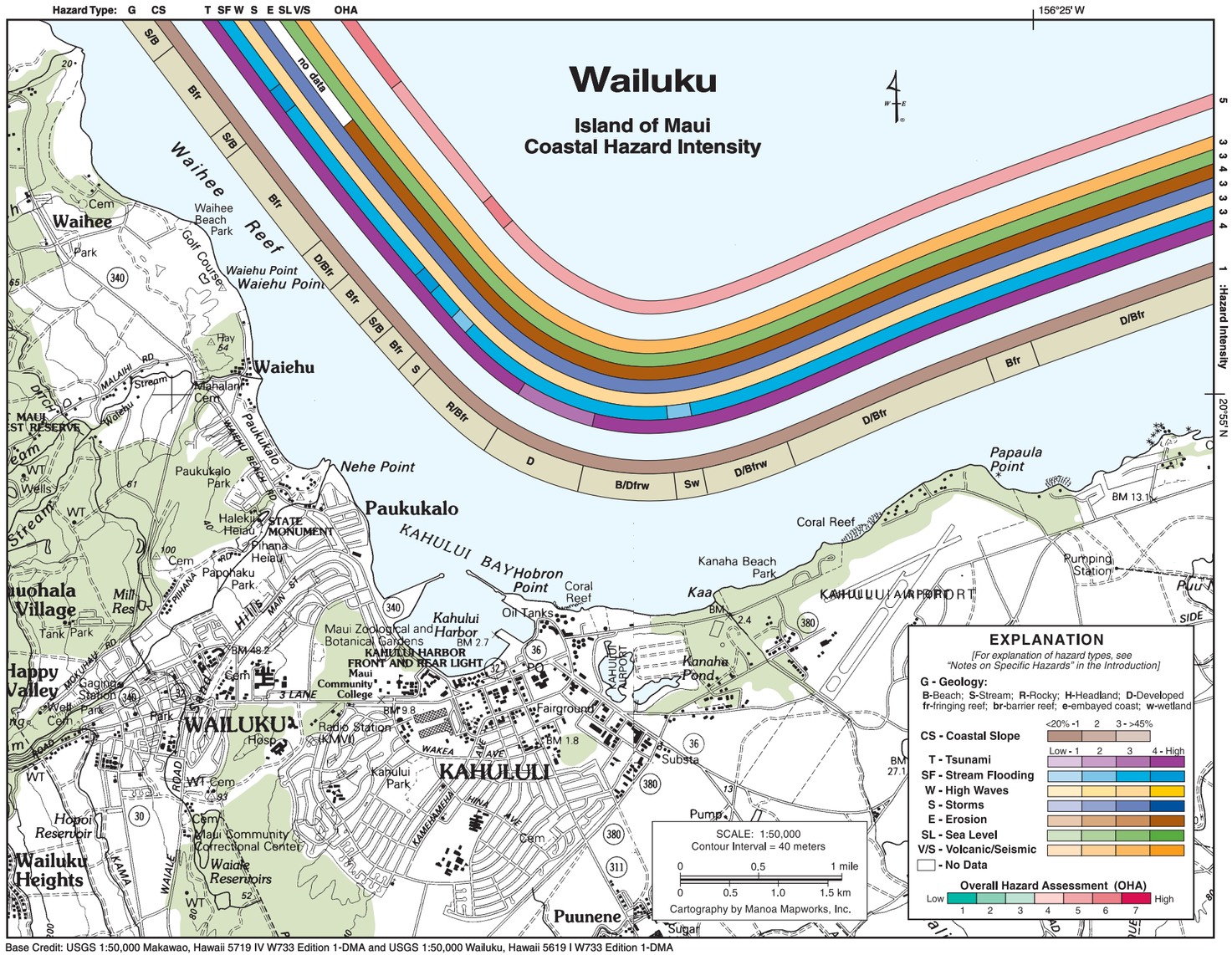
Since 1871, at least 47 strong wind events have impacted the entire island of Maui. Of these, 34 were associated with extreme trade winds and/or Kona storm winds, while 13 occurred during passing tropical storms and hurricanes. The strongest trade wind events hammered the north and east shores with winds 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

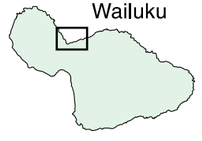
The coastal embayment of Wailuku, centered around Kahului Harbor, is Maui's industrial and commercial hub. Trade winds are strong and persistent along this coast as they funnel across the isthmus between Haleakala and West Maui volcanoes. Flash flooding is a serious hazard in this region. In January 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.

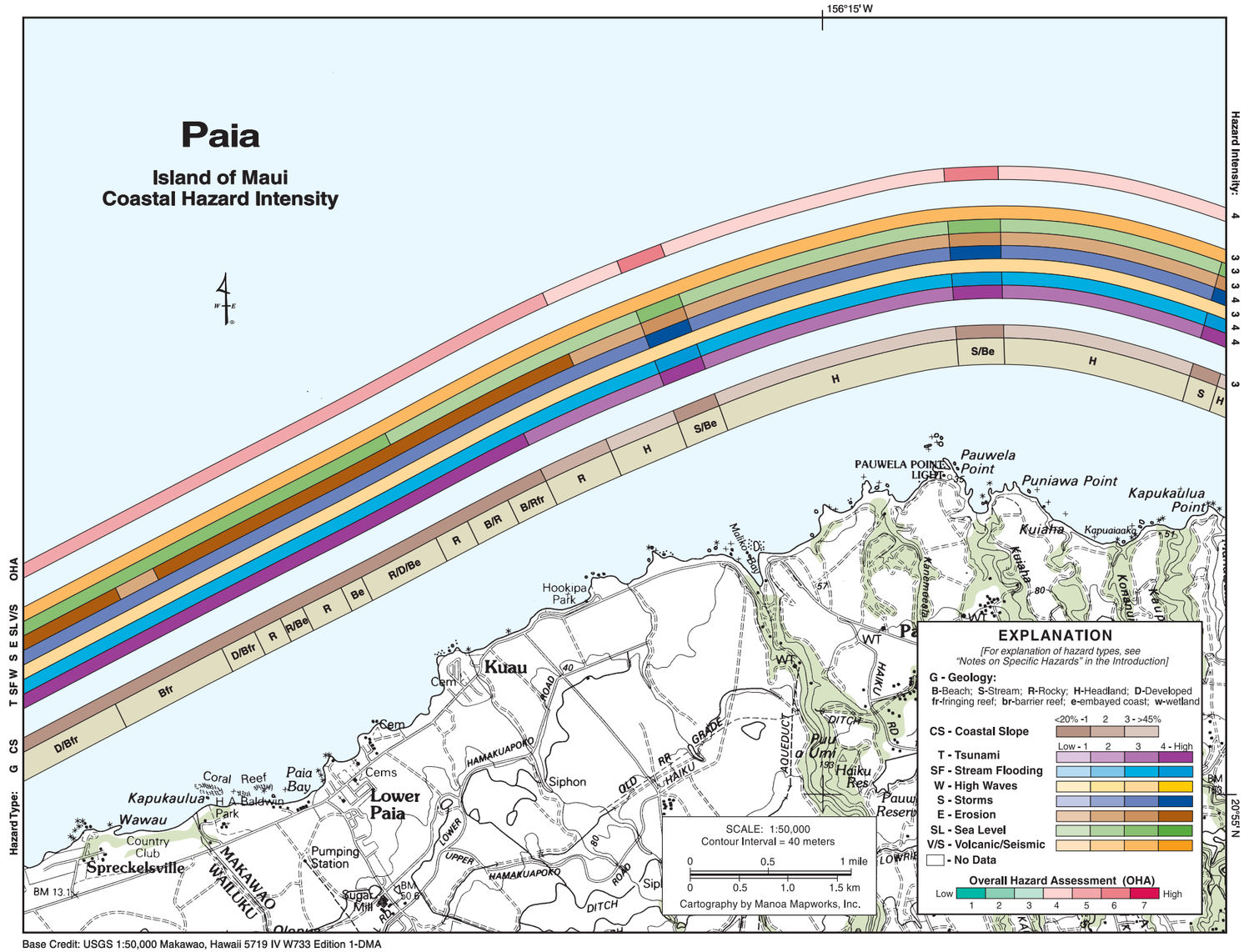
Seawalls line much of the Wailuku waterfront to protect urban and commercial infrastructure as well as county and municipal lands such as the Waiehu Municipal Golf Course at Waiehu.

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.



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





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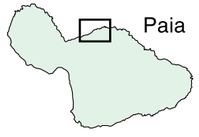
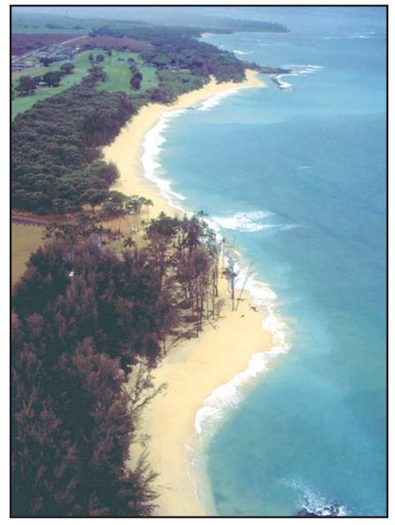


Despite rapid and chronic beach loss along the Paia coast and toward the west, beautiful sandy beaches appear to erode and accrete seasonally along Baldwin Beach (shown here), where development and shoreline hardening has been minimal.

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.

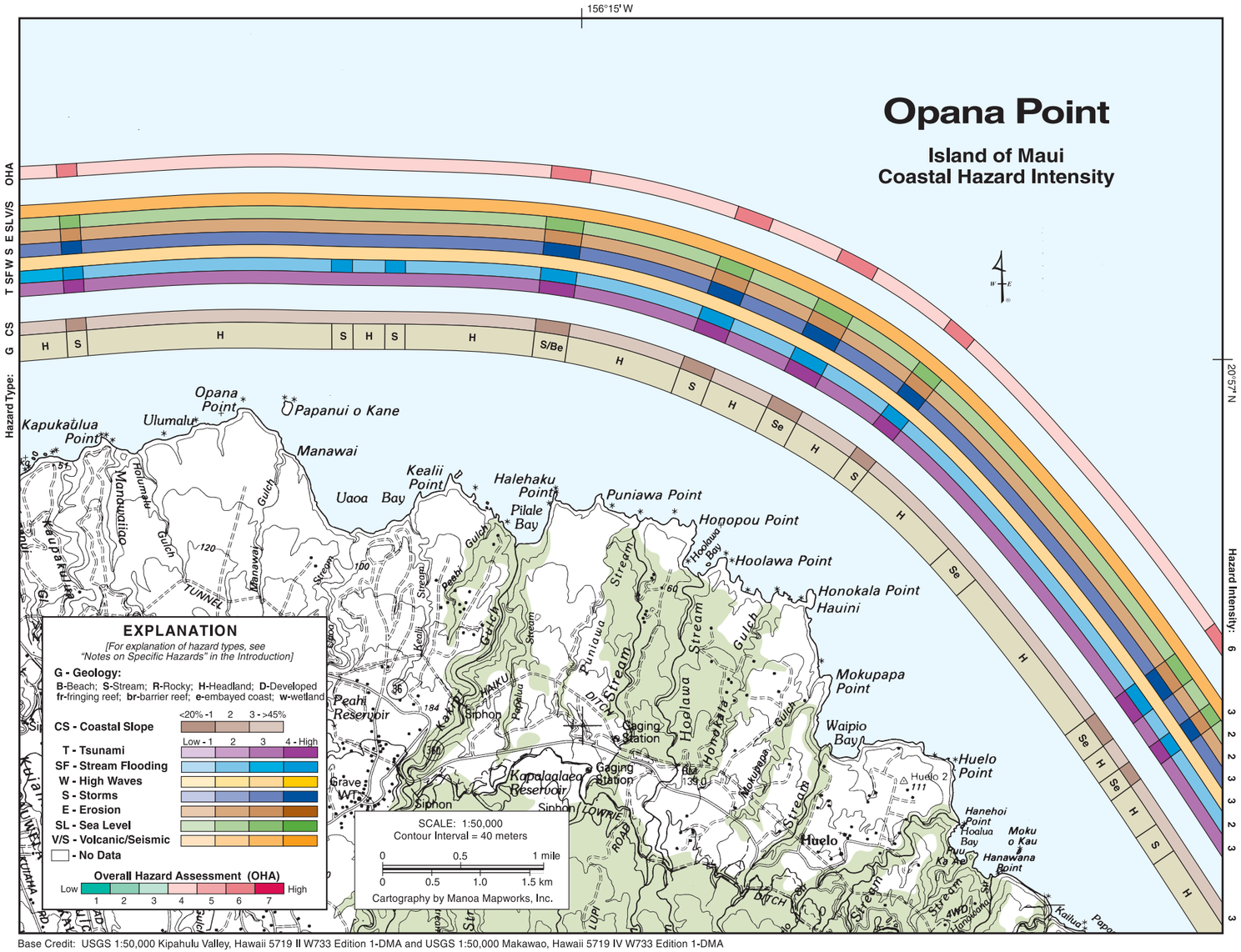
The Overall Hazard Assessment (OHA) primarily reflects the gradient and morphology of the Paia coastal area. It is ranked moderate to high (5) between Spreckelsville and Hookipa. To the east, it is ranked moderate (4) except at the low-lying Maliko and Pauwela Bays, which are more susceptible to tsunami, 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.



Opana Point

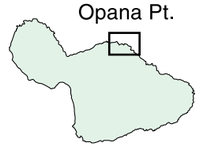
The Opana coast marks the eastern corner of the north shore of Maui. Rocky headlands border small coastal embayments, where active streams and gulches that incise their way across the slopes of Haleakala finally reach the sea. The streams carry rounded boulders down their channels, helping to form the 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.

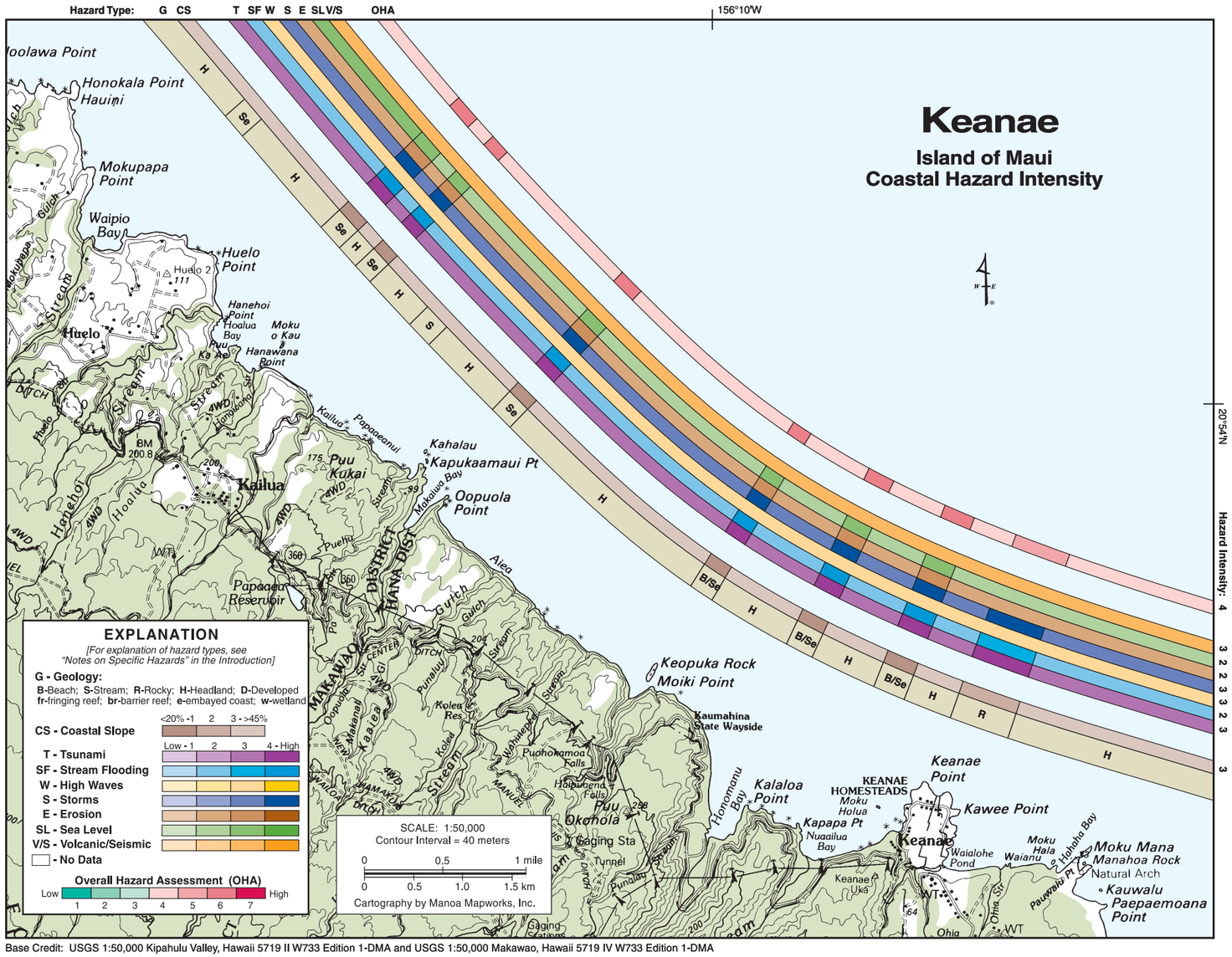
An Overall Hazard Assessment (OHA) of moderate (4) is prescribed for the steep headlands of the Opana coastal area. In the small low-lying embayments of Kapukaulua, Pilale, Hoolawa, Hoalua, and Hanawana Bays, and at the mouths of Puniawa and Honokala streams, where the threat of tsunami, stream flooding, 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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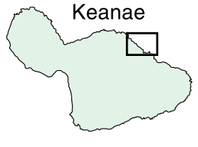


Keanae

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).

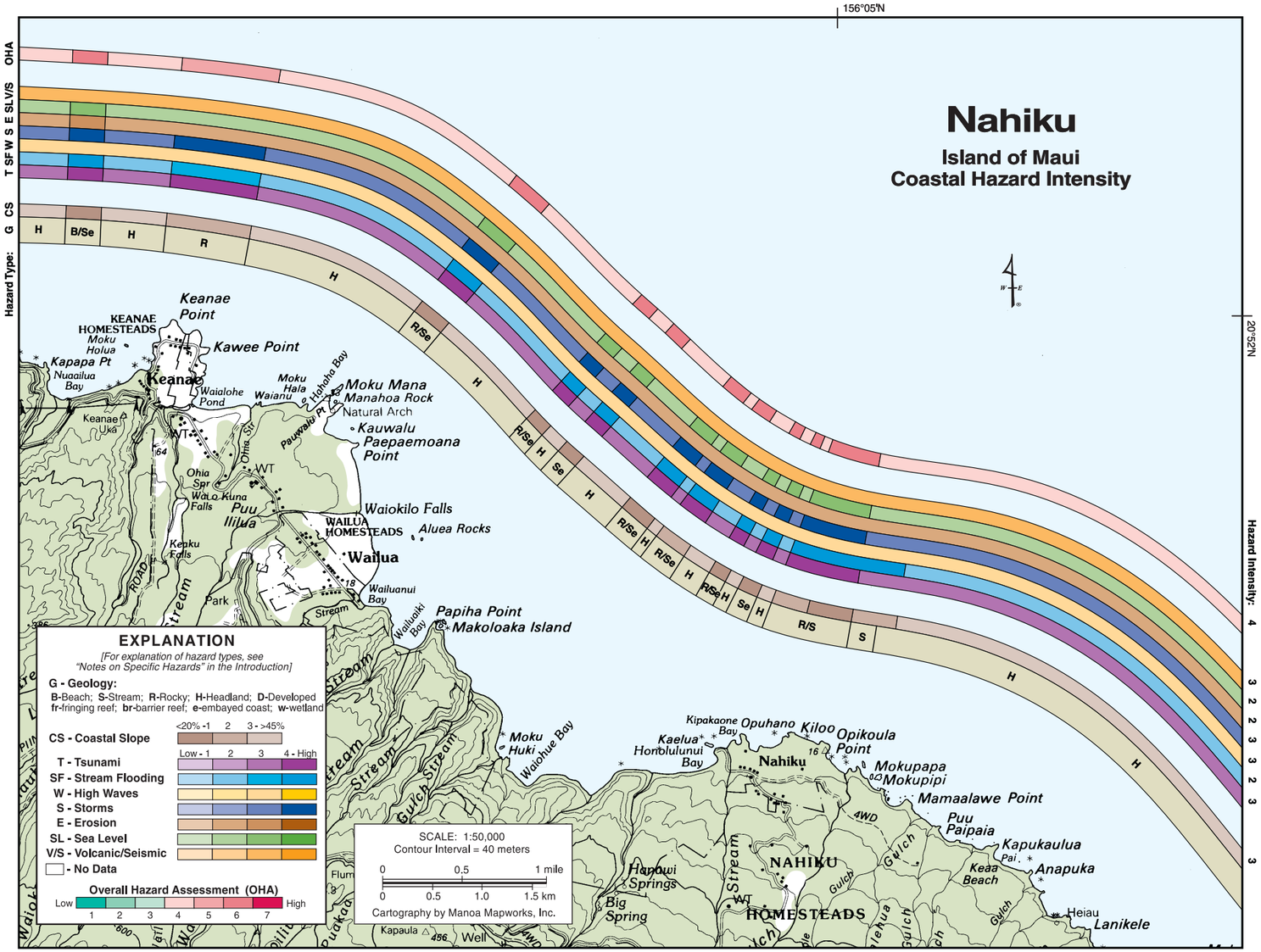
A view of the low lying Keanae Point with its rocky shoreline and isolated coves. Steep headlands line the coast to either side of Keanae Point.

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.

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



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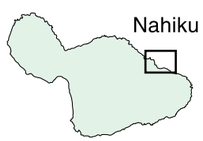

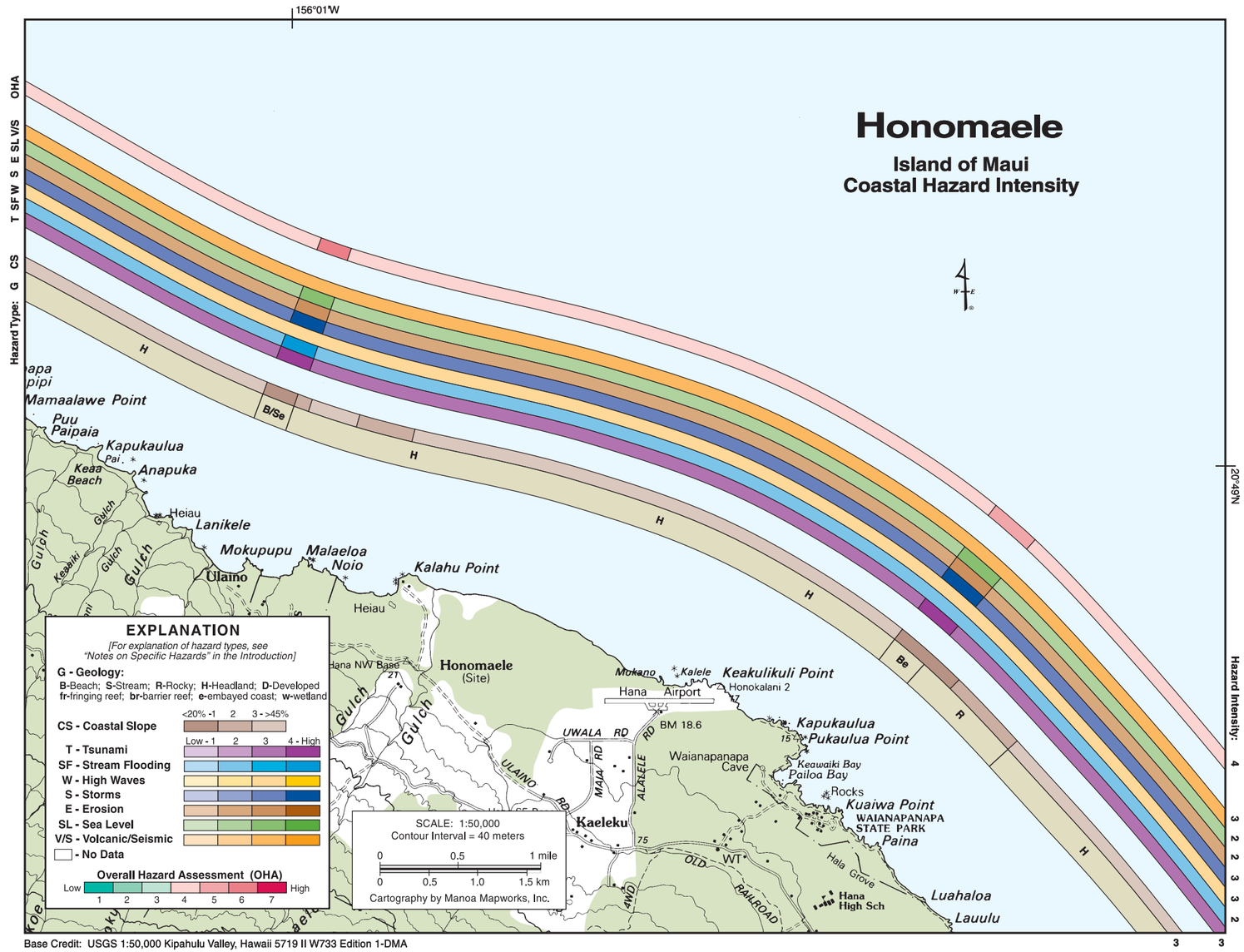

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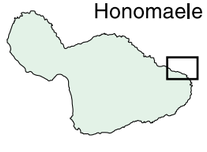


Honomaele

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.

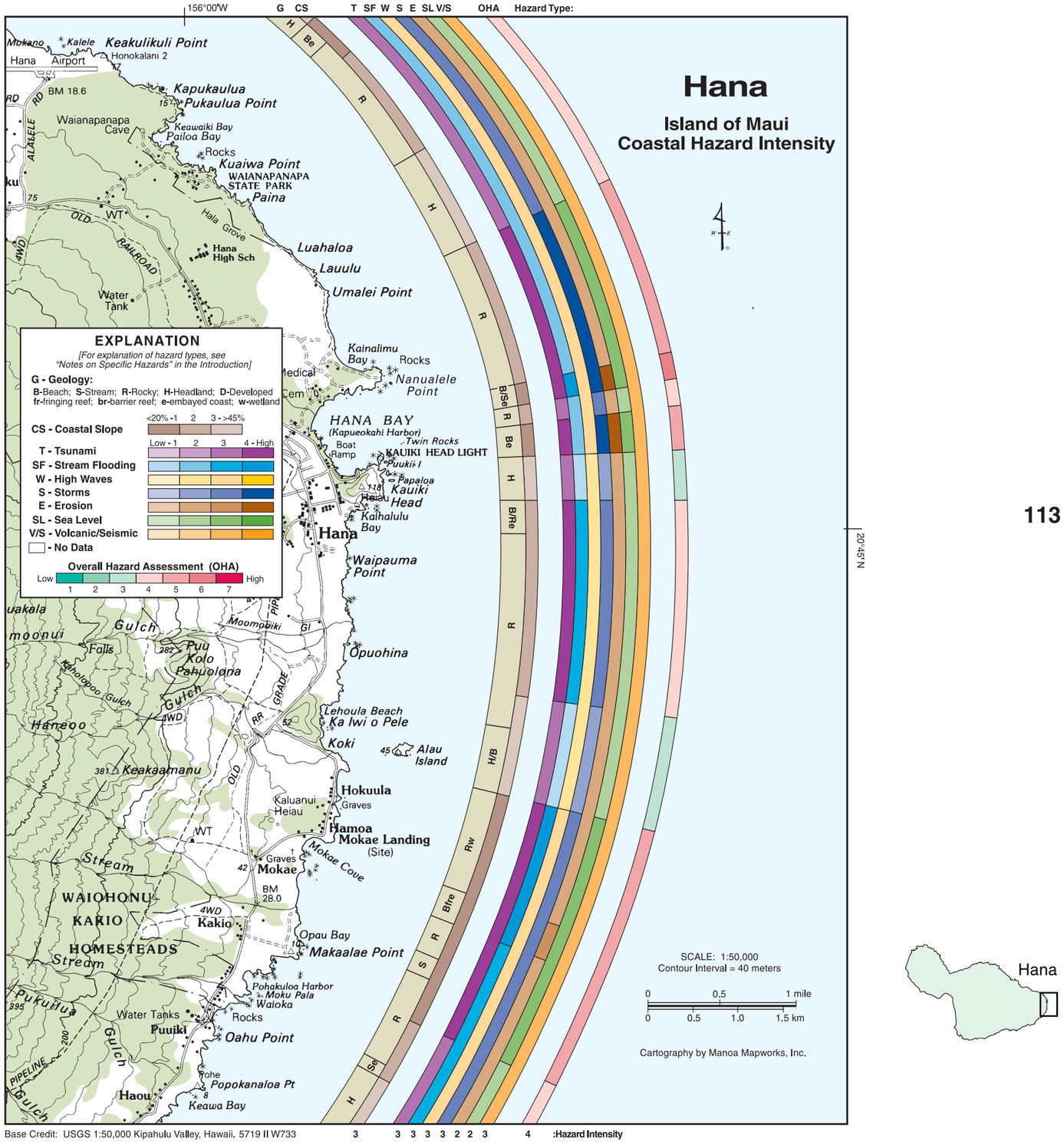
The east-facing slopes of Haleakala Volcano become more gently sloping near Honomaele and the low, broad coastal plain near Keakulikuli Point is the site of the Hana Airport.

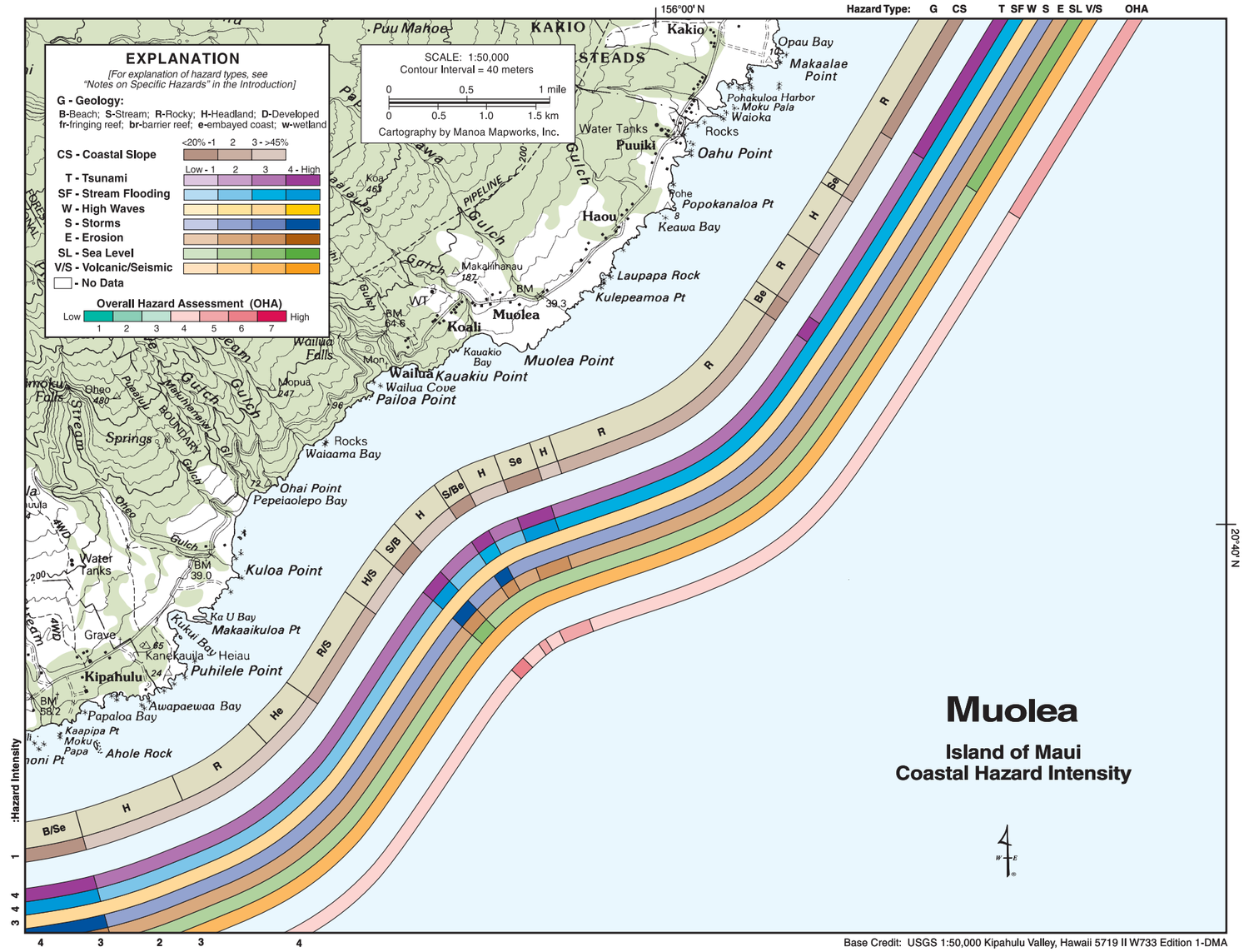
Hana

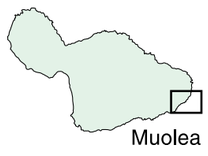
The Hana coastline extending from Pailoa Bay around the eastern corner of Maui to Oahu Point is simultaneously picturesque and daunting. It is hard to fathom how the rocky cliffs, sea stacks, and dozens of small rocky islands stand against the relentless attack of the incessant trade wind waves that 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

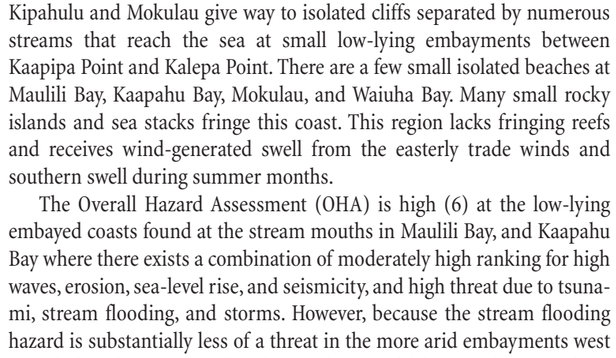
Westward of Oahu Point to Kipahulu, young lava flows and cinder cones of the Hana Volcanic Series in their type locality slope gently to the sea. Sea cliffs and rocky headlands standing 20 to 30 ft above mean sea level at Popokanaloa, Muolea, Kauakiu, Pailoa, Ohai, Puhilele, and Kaapipa Points, are separated 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.

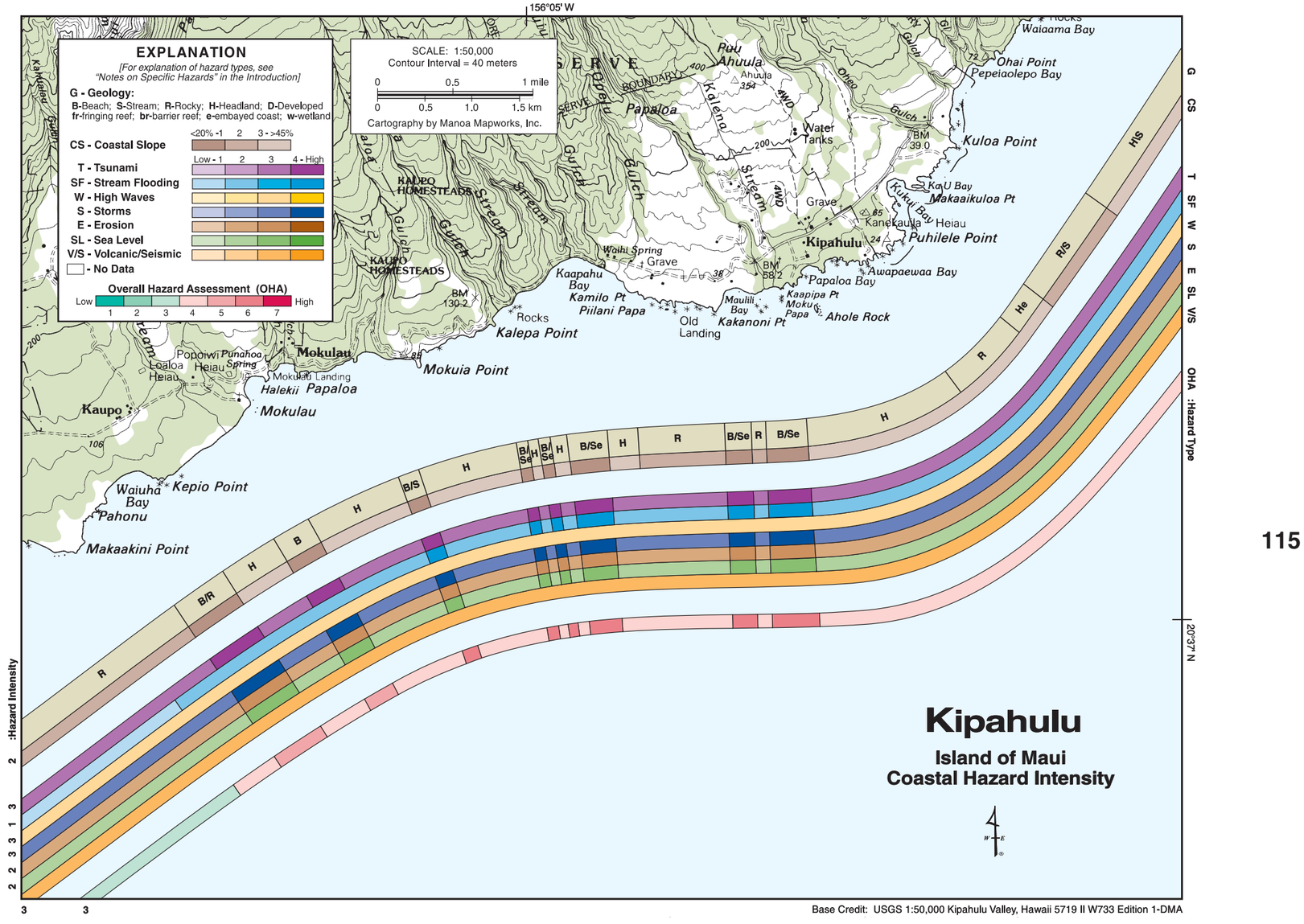
Kipahulu

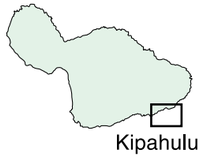
The coast from Puhilele Point west to Makaakini Point becomes increasingly arid as the coastal slope gradually flattens in the lee of Haleakala Volcano. Extensive rocky headlands along the coast near Kipahulu and Mokulau give way to isolated cliffs separated by numerous streams that reach the sea at 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.

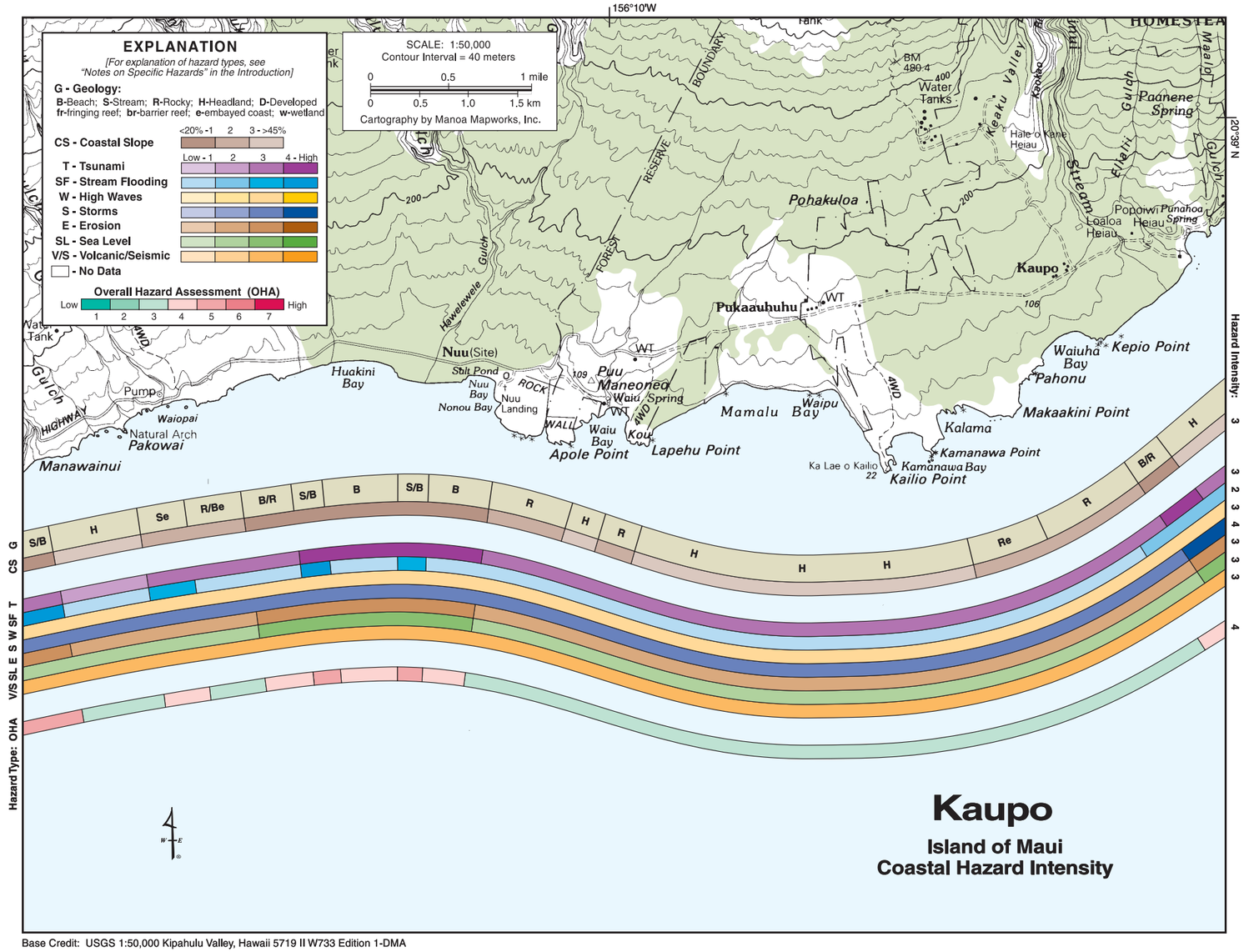
The Overall Hazard Assessment (OHA) is high (6) at the low-lying embayed coasts found at the stream mouths in Maulili Bay, and Kaapahu Bay where there exists a combination of moderately high ranking for high waves, erosion, sea-level rise, and seismicity, and high threat due to tsunami, stream flooding, 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.

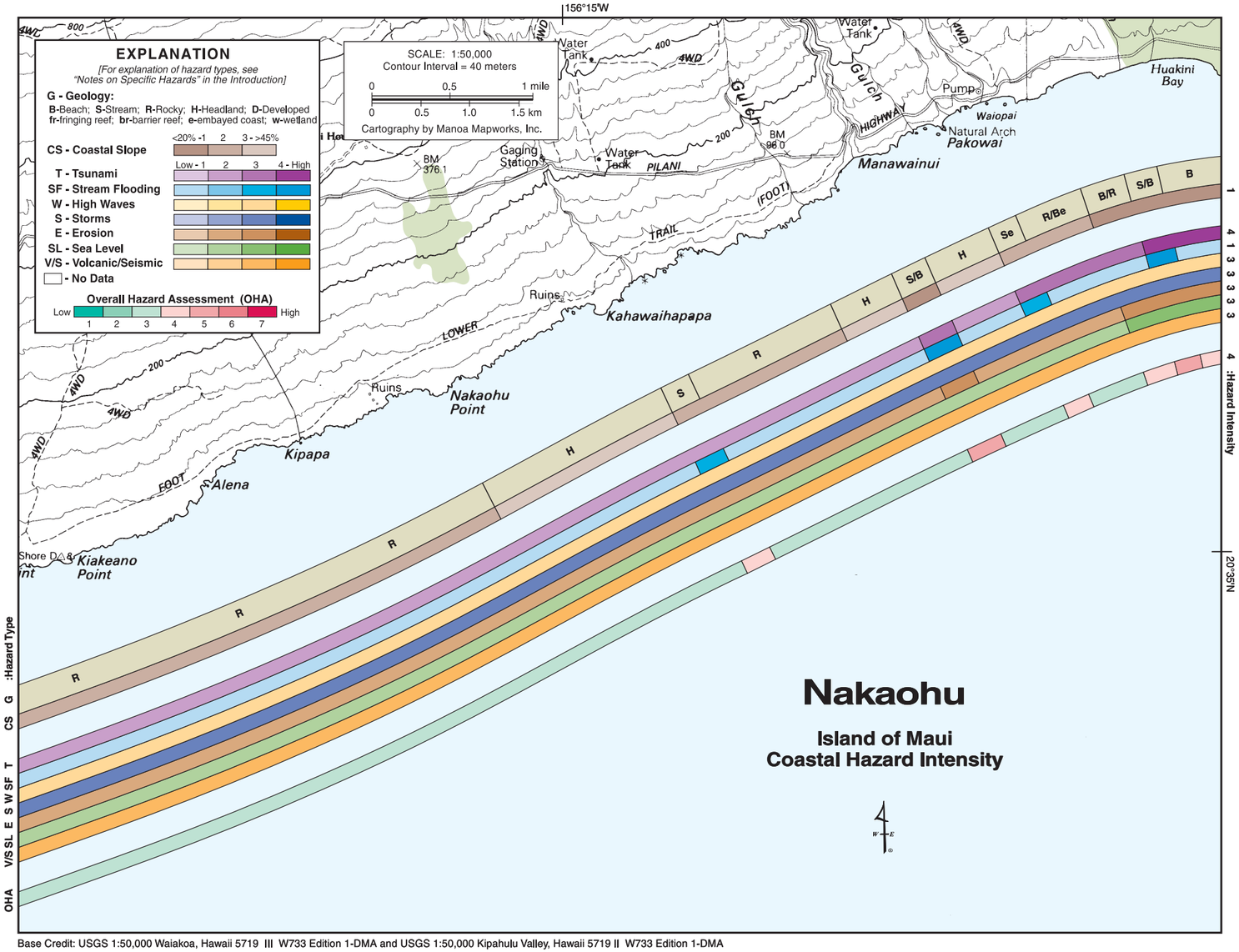
The Overall Hazard Assessment (OHA) is moderate to low (3) in the eastern half of the Kaupo coastline, where steep rocky headlands uniformly mitigate against the dynamic hazards. West of Apole Point the OHA varies primarily as a function of coastal slope and the occurence of coastal streams. In Huakini 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.

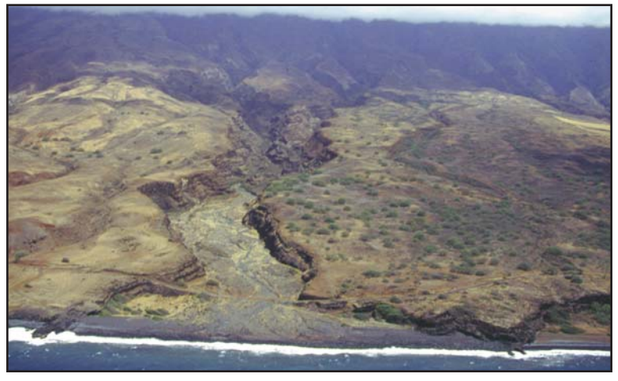
Low coastal cliffs and gently sloping volcanic terraces formed of numerous lava flows are common along the south-facing, arid, and windy Kaupo coast

Nakaohu

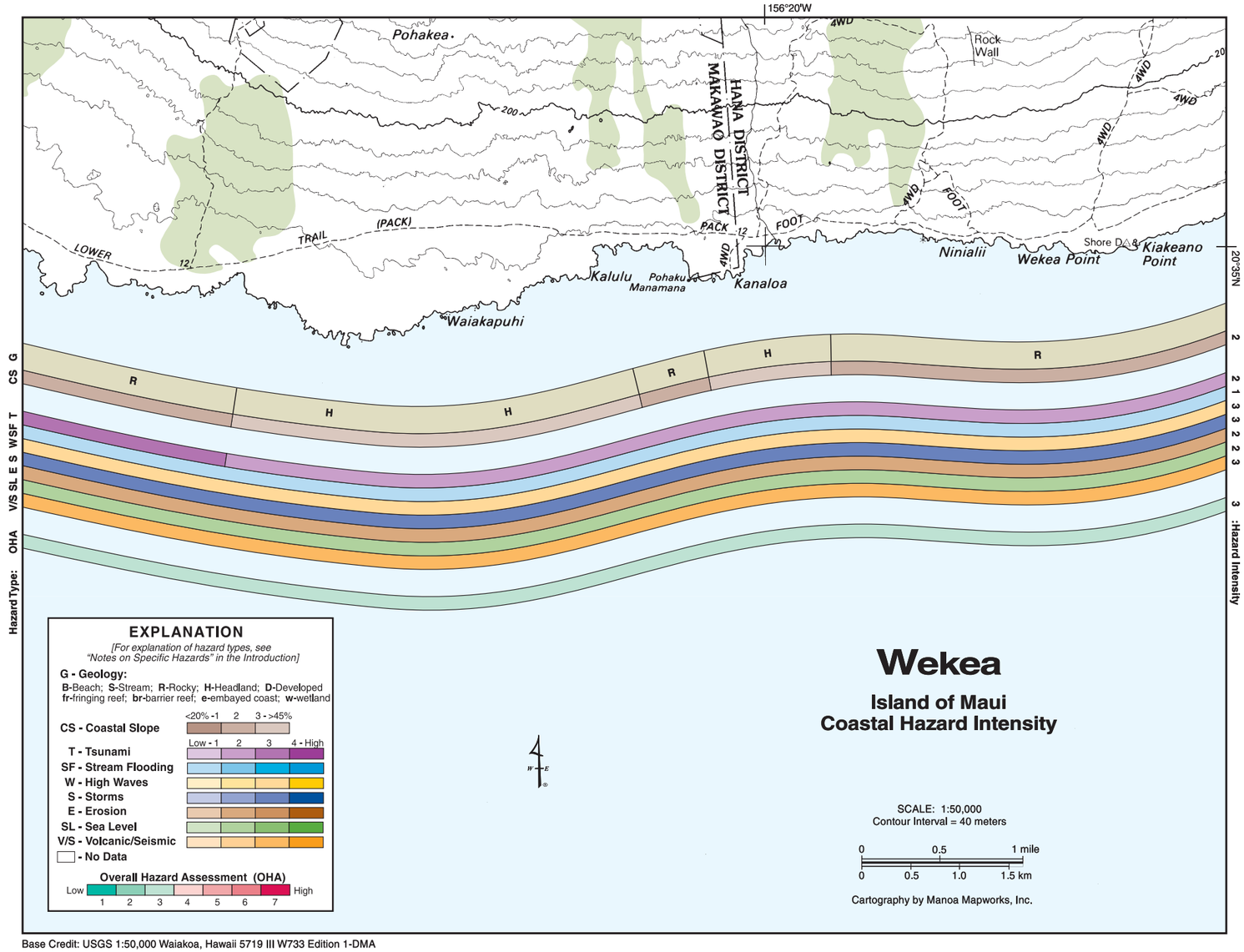
The coastline surrounding Nakaohu Point is arid and relatively remote. Annual rainfall along this coast is between 25 and 30 in, making it hot and dry year round. The coastal road climbs up the southeast flank of Haleakala Volcano west of Manawainui, so coastal access is limited to foot paths and four-wheel 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.

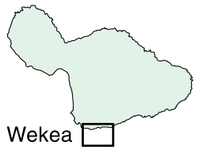




Steep gravel beaches line most of the Nakaohu coast. The cobbles and boulders are transported to the shore from the mountain above through large gulches (foreground) that are periodically awash during high rains.



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



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.

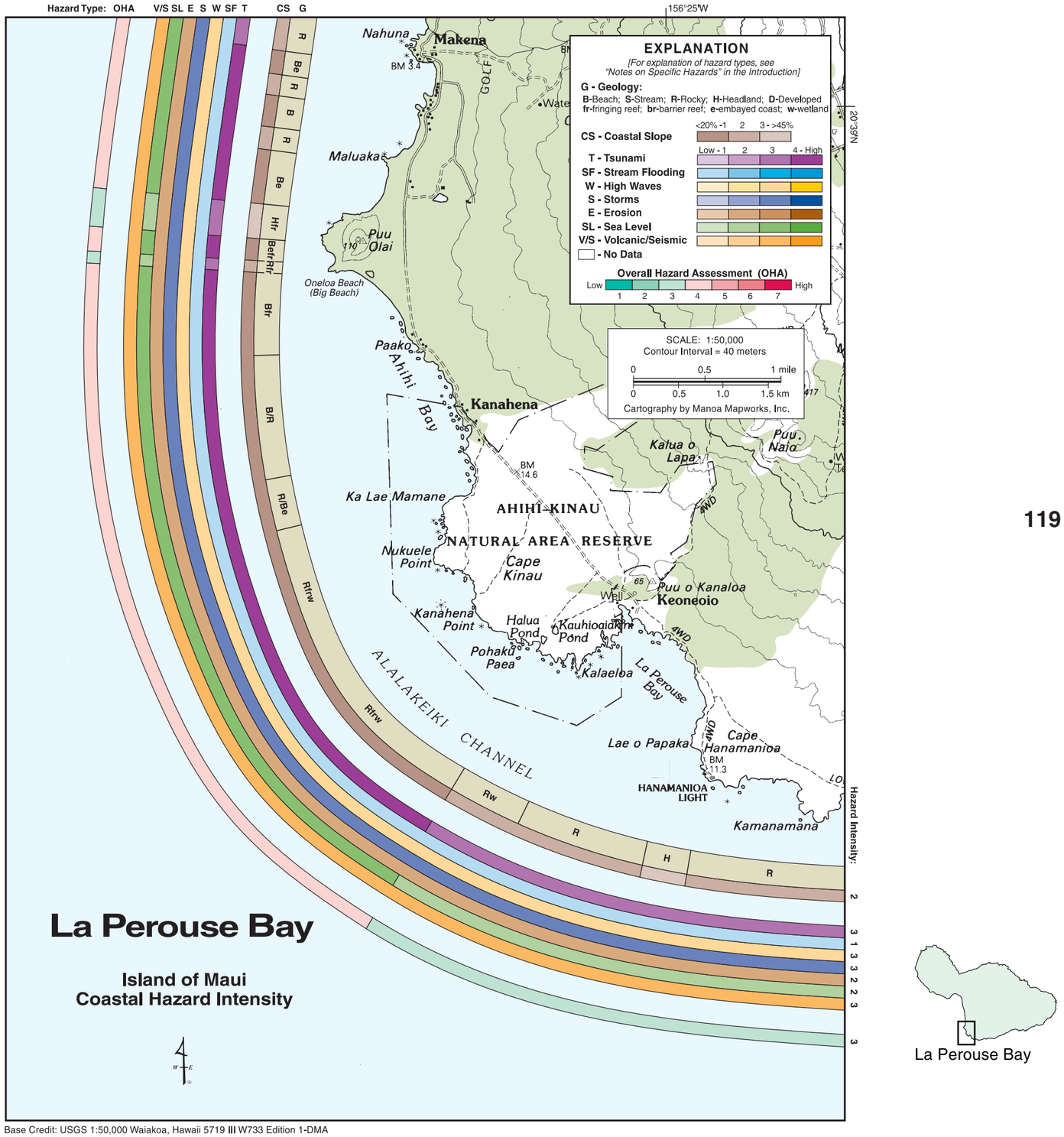
La Perouse Bay

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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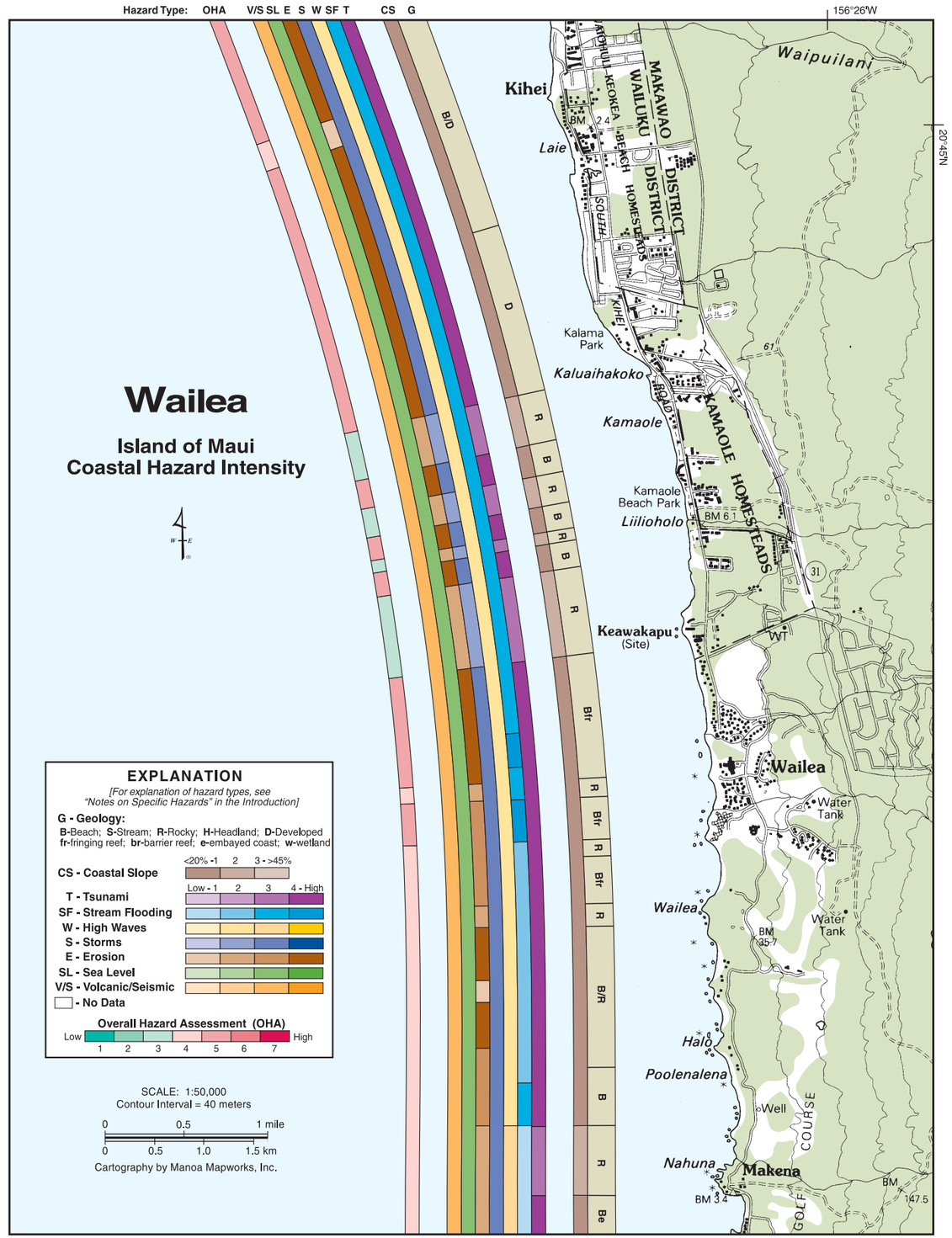
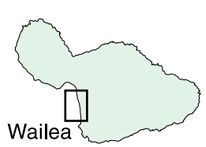




Wailea

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.

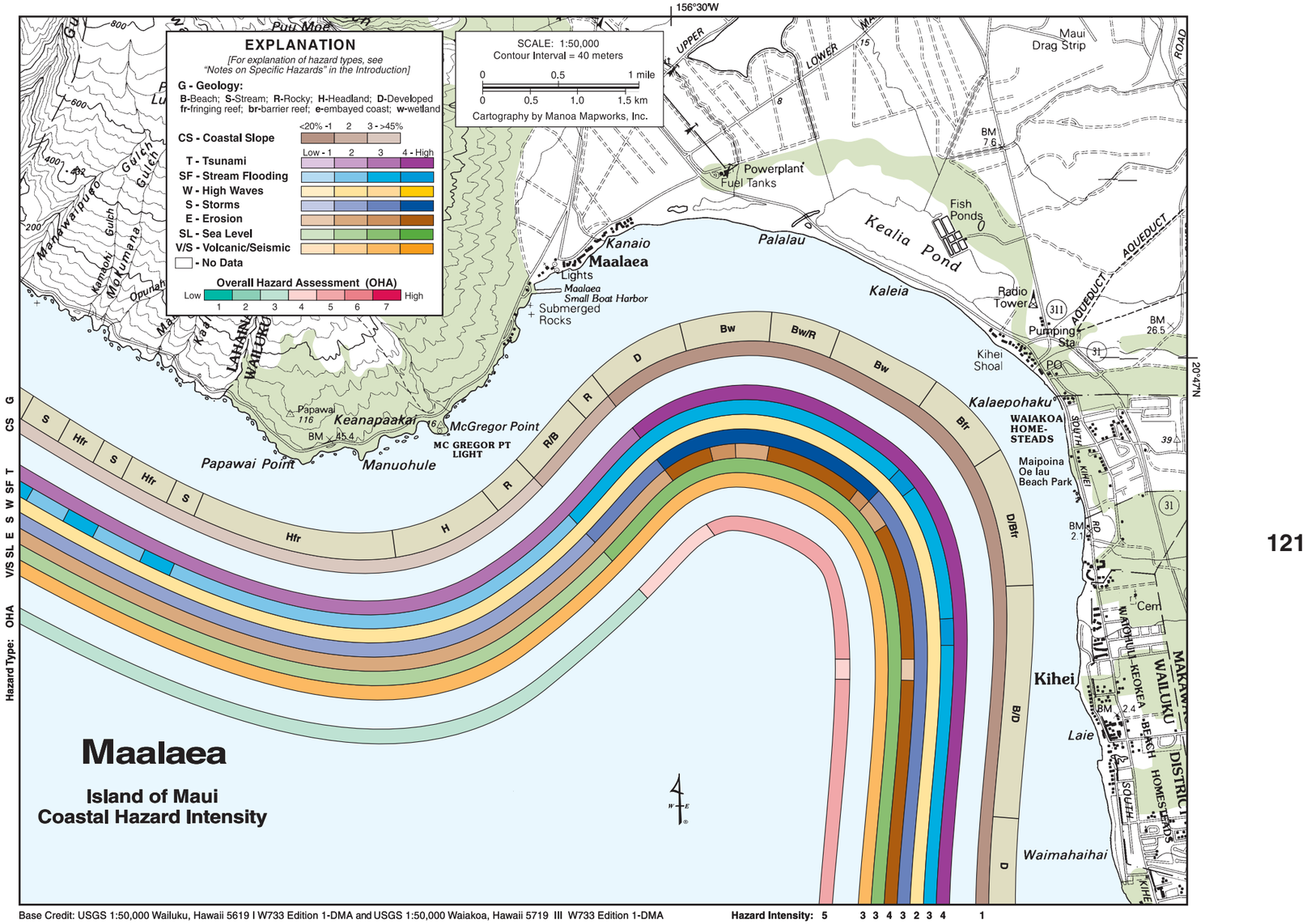
Maalaea

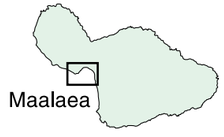
The Maalaea coast is heavily developed along the Kihei shoreline and surrounding the Maalaea Boat Harbor. Considerable development during the last several decades has been accompanied by severe erosion and beach loss around Kihei. Narrow, sand-starved beaches are common throughout Kihei, where shallow 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.

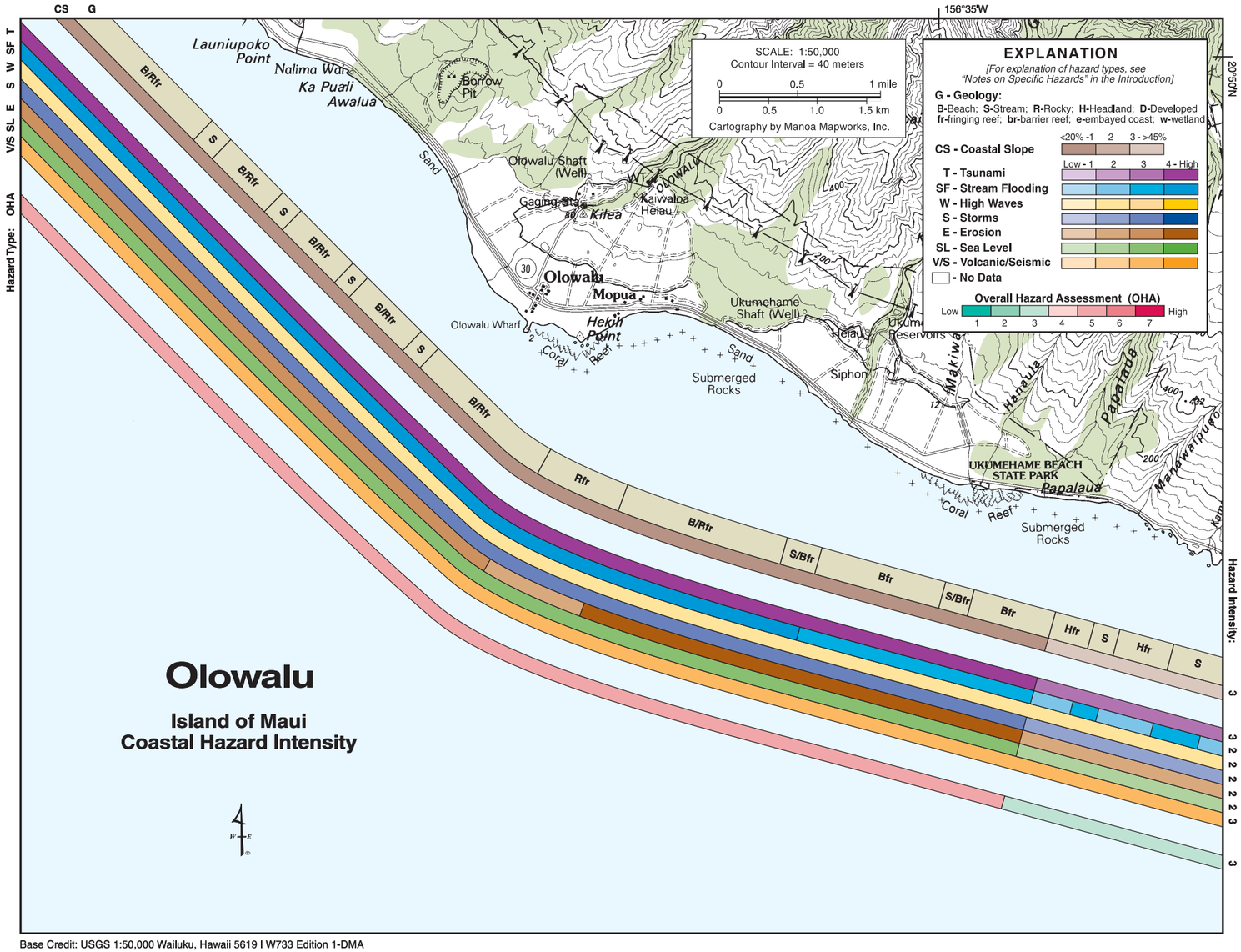
The Overall Hazard Assessment (OHA) is greatest along the Kihei coastline, where the low-lying coastal slope is most prone to tsunami, stream flooding, and erosion. As a result, it is moderate to high (5) from Kihei to Kanaio, except at a region of accreting coastline in Kihei, where it

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.

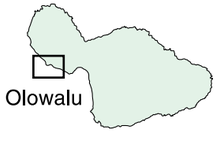
is reduced to moderate (4). Between the Maalaea Boat Harbor and McGregor Point, the OHA is moderate (4) where the steeper slopes mitigate stream flooding and storms. Beyond McGregor Point, where the steep cliffs coincide with the reduced tsunami, stream flooding, and storm threats, it is moderate to 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



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.

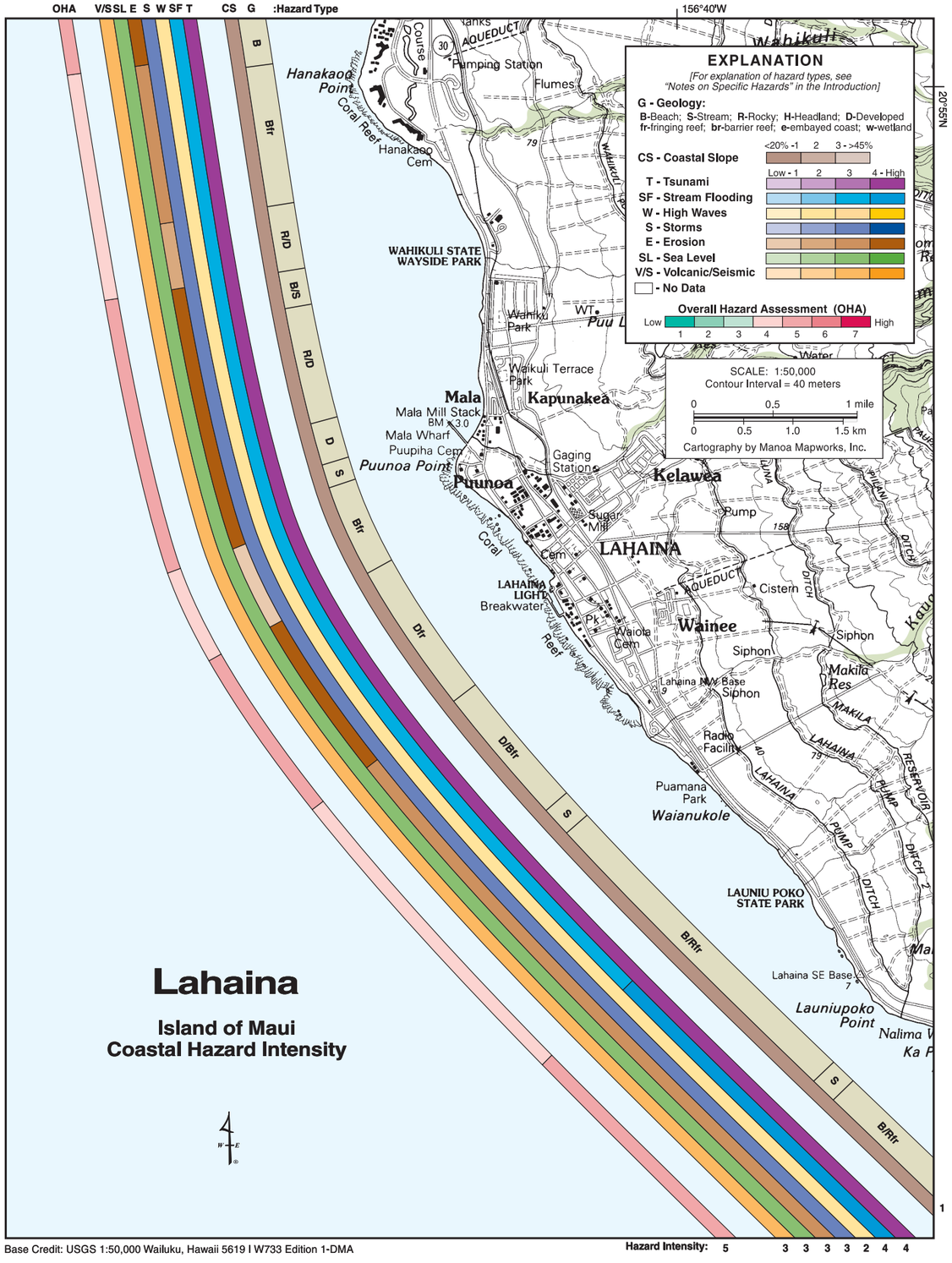
Steep cliffs form the Olowalu coastline east of Ukumehame Beach State Park (foreground). Rapid sea-level rise and annual high-wave overwash threaten access along the coastal road between west and east Maui.

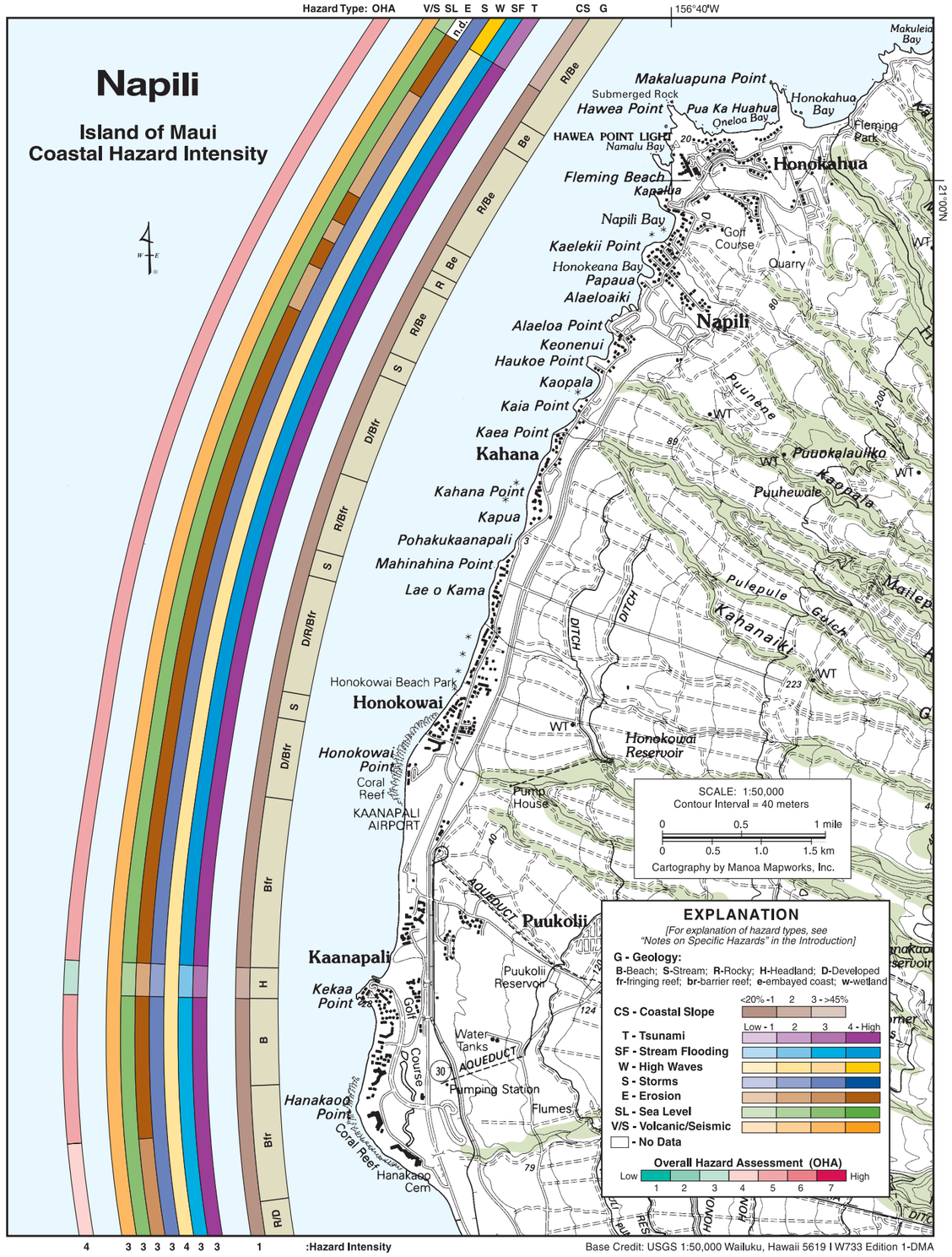
Lahaina

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.

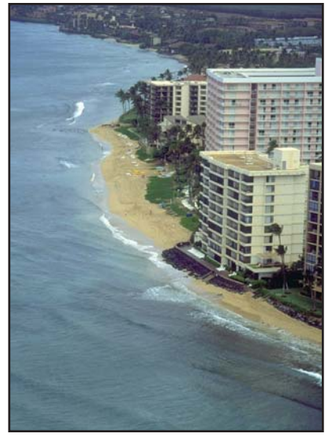




Napili

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.



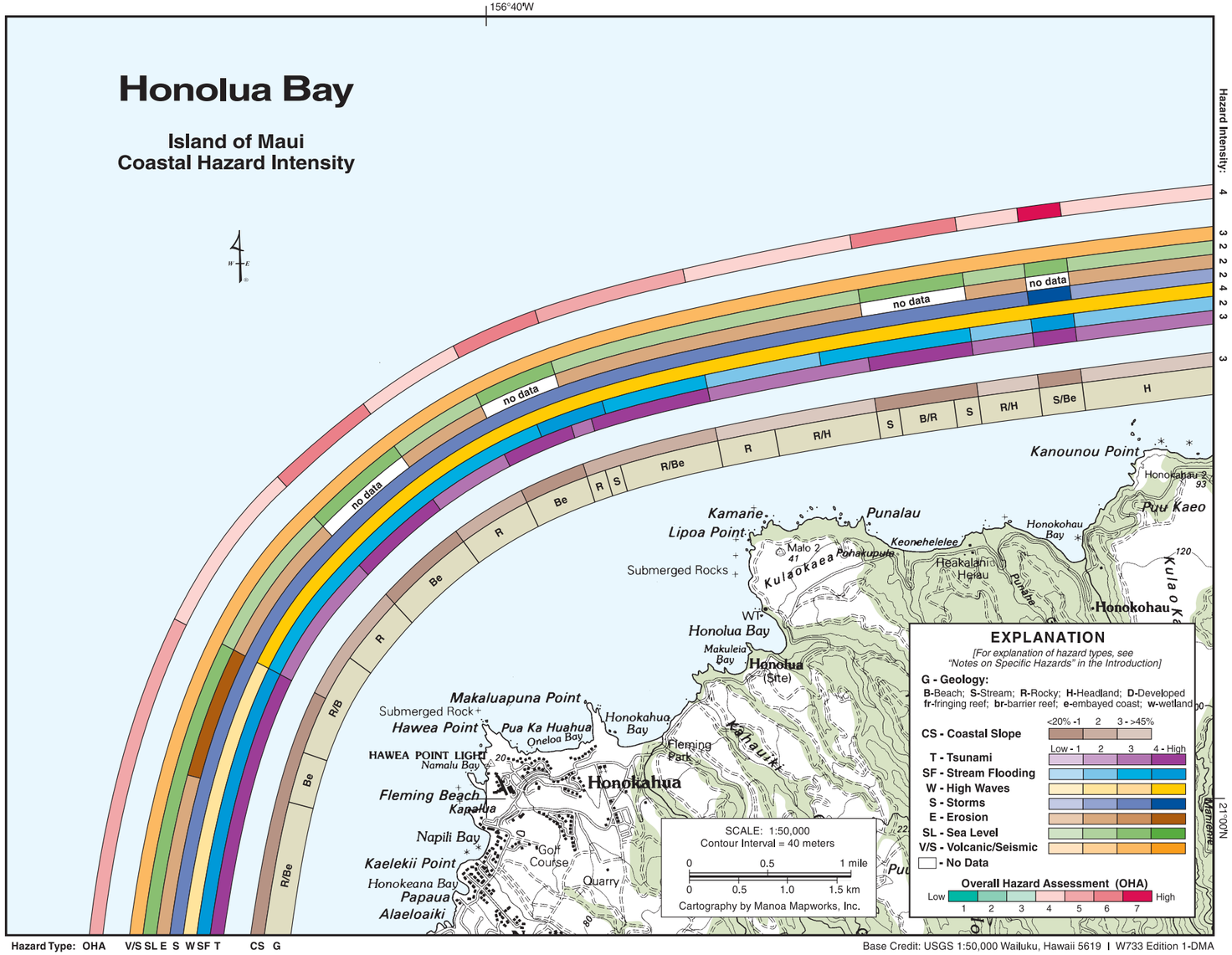
Extensive development has occurred along the small and narrow beaches of the Napili coast, while fossil beachrock ridges near Honokowai, marking the position of the former shoreline, lie submerged offshore as evidence of rapid sea-level rise and erosion.

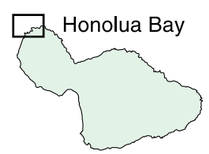
Honolua Bay

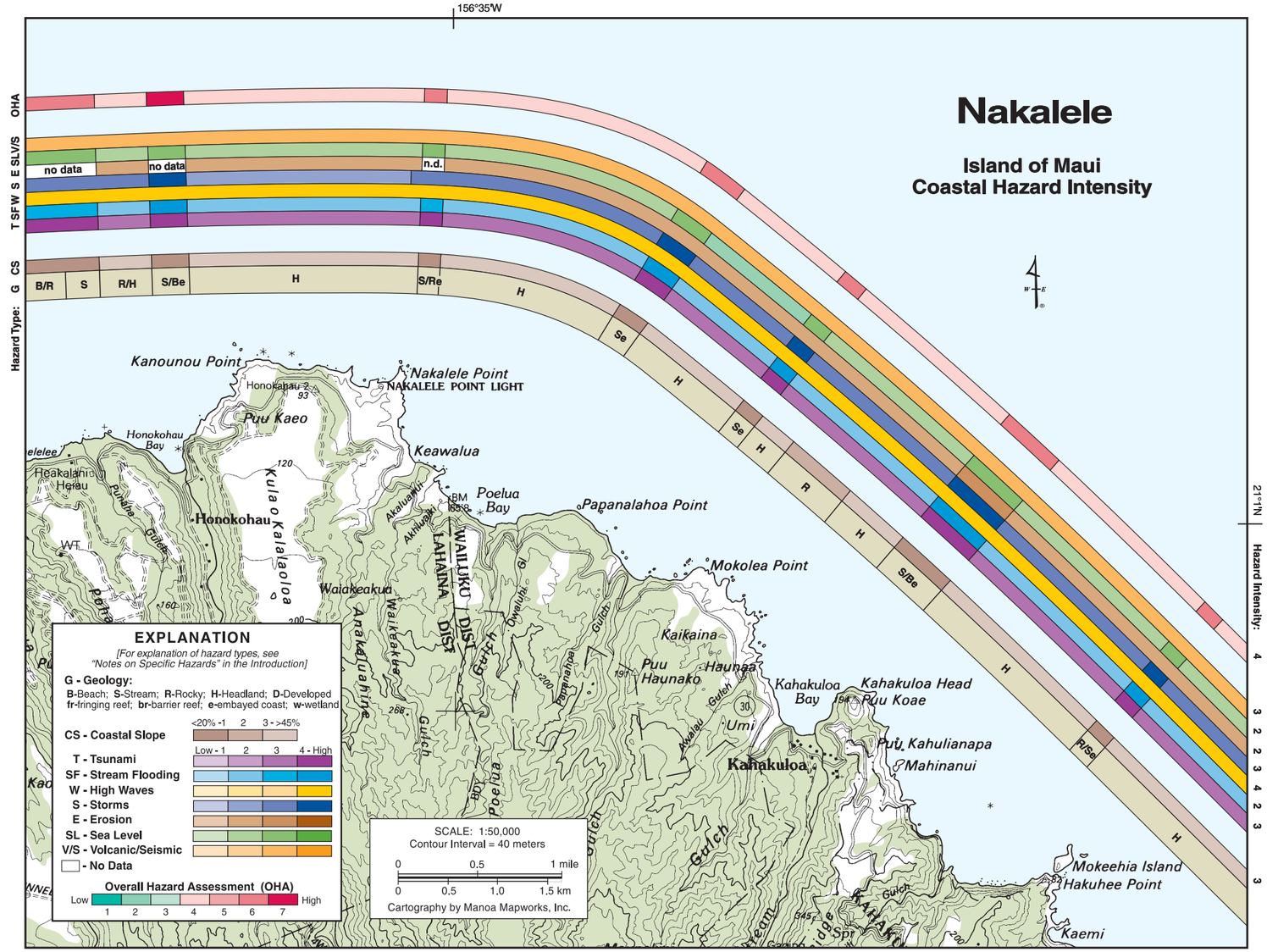
Th scenic coastline of Honolua Bay northeast of Hawea Point is marked by prominent rocky headlands that reach northwest towards Molokai and shelter the bays of Oneloa, Honokahua, Honolua, and Honokohau. The headlands become significantly steeper and taller toward Honokohau, where seacliffs reach heights 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.

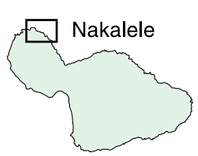
Gently sloped coves along the southern portion of the Honolua Bay coast have been densely developed, like Napili Bay, however, past Honlolua Bay and Lipoa Point to the north, the steep-cliffed coast is rugged and undeveloped.







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 very 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.

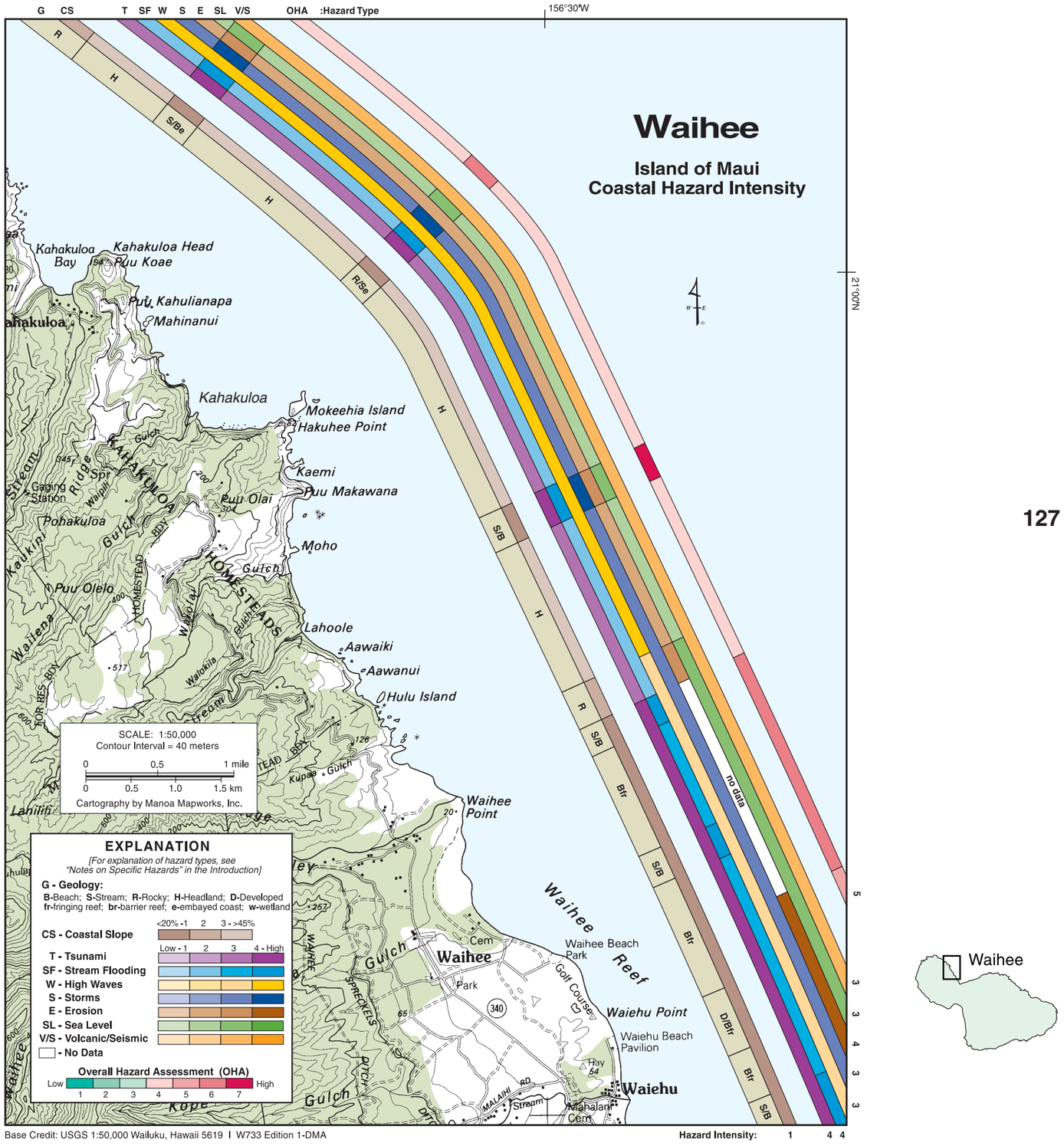
Beautiful, rocky headlands like Kahakuloa Head (shown here) mark the steep-cliffed coast of Nakalele.

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.



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