SECTION 4. HAZARDS

4.10 High Wind Storms

2018 HMP UPDATE CHANGES

- The hazard profile has been significantly enhanced to include a detailed hazard description, location, extent, previous occurrences, and probability of future occurrence (including climate change).
- High wind storm events that occurred in Hawai'i from January 1, 2012, through December 31, 2017, were researched for this 2018 HMP update.
- New and updated figures from federal and state agencies are incorporated.
- Provided a qualitative vulnerability assessment at the state level of damage to state assets and critical facilities from high wind events.
- Provided a qualitative vulnerability assessment at the county level of risk to the population, general building stock, and environmental resources and cultural assets from high wind events.
- Included a qualitative vulnerability assessment of high winds in regard to factors that could impact future vulnerability.

4.10.1 Hazard Profile

Wind is defined as the horizontal component of natural air moving close to the surface of the earth. This hazard profile and associated vulnerability assessment addresses high wind storms, in general, while Section 4.10 Hurricane addresses risk from tropical storms and hurricane force winds in more detail.

HAZARD DESCRIPTION

Types of Winds

Winds in the State of Hawai'i originate from three main sources: trade winds, Kona winds, and hurricanes/tropical storms. High winds from trade winds (which blow 70% of the time), Kona winds (30% of the time), and rare winds from hurricanes and tropical storms passing through Hawaiian waters all affect the State. The hazards from hurricanes and tropical storms are discussed in Section 4.10 Hurricane. This section focuses on the other two wind patterns: trade and Kona.

Trade Winds

The trade wind pattern over the Pacific Ocean is one of the largest and most consistent wind fields in the world and these winds play a major role in defining the climatology of the region. The northeast trade winds prevail over the Hawaiian Islands throughout the year with an average speed of 15.7 mph, with speeds ranging between 10 and 25 mph (Vitousek et al. 2009). Occasional extreme events reach 40 to 50 mph when the subtropical high-pressure cell north of the Hawaiian Islands intensifies (Western Regional Climate Center 2018).

Average wind speeds in the State of Hawaiʻi are the highest during the summer trade wind period (May through September) when trade winds are present 85% to 95% of the time and wind speeds over the ocean exceed 12 miles per hour (mph) 50% of the time. During the winter (October through April), when trade winds are not as prevalent (present 50% to 80% of the time), wind speeds are in excess of 12 mph about 40% of the time (Graza et al. 2011; Western Regional Climate Center 2018).

These persistent winds became known as trade winds long ago when clipper ships carrying cargo depended on the broad belt of easterly winds encircling the globe in the subtropics for fast passage; however, strong, gusty trade winds can cause problems for mariners. Strong trade winds, blowing from the northeast, funnel through the major channels between the islands--Kauaʻi, Kaiwi, Pailolo, Kalohi, ʻAuʻau, and ʻAlenuihāhā Channels—at speeds 5 to 20 knots (about 5.7 to 23.0 miles per hour) faster than the speeds over the open ocean. North Pacific high-pressure systems are responsible for the majority of the gusty trade wind episodes over Hawaiian waters, which commonly persist for several days before tapering off (Hawaiʻi State HMP 2013).

Kona Winds

Kona winds is a Hawaiian term for the stormy, rain-bearing winds that blow over the islands from the southwest or south-southwest in the opposite direction of trade winds. Kona is the Hawaiian word for leeward. When Kona winds blow, the predominant wind pattern is reversed so that the western, or leeward sides of the islands, become windward. This type of wind is associated with a class of extratropical weather systems known as Kona low pressure systems or Kona storms, which develop northwest of the State of Hawaiʻi and move slowly eastward. Kona storms can produce heavy rains, hail, floods, landslides and other severe weather hazards in addition to the high winds discussed in this hazard profile (Businger et al. 1998). Strong Kona winds can last for a day or for a week or more (State of Hawaiʻi HMP 2013; Pacific Disaster Center 2007; Businger et al. 1998).

Wind Speed and Wind Pressure

There are several ways to measure the speed at which air is moving, or wind speed. The most commonly used methodologies for measuring wind speed are (Hawaiʻi State 2013 HMP):

- **The Fastest Mile Wind**—The Fastest Mile Wind speed is the average recorded speed during a time interval in which one mile of wind passes a fixed measuring point. The measurement is taken at an elevation of 33 feet in open terrain. The Fastest Mile Wind speed measurement was historically used in many older building codes and design standards such as the Uniform Building Code (all editions) and the American Society of Civil Engineers (ASCE) Minimum Design Loads for Buildings and Other Structures (until the 1993 edition).
- **Sustained Wind**—Sustained Wind is the wind speed averaged over 1 minute. This is the measurement standard used by the National Weather Service.
- **Peak Gusts**—Peak Gusts are the maximum wind gust speeds averaged over a period of two to five seconds. This is the measurement standard used by modern Hawaiian building codes.

It is important to understand though, that it is wind pressure, and not wind speed, that causes wind damage. There are three types of wind pressure: positive, negative, and internal (Hawaiʻi State 2013 HMP):

- **Positive Wind Pressure**—Positive wind pressure is the direct pressure from the force of the wind that pushes inward against walls, doors and windows.

- **Negative Wind Pressure**—Negative wind pressure occurs on the sides and roof of buildings. This negative pressure is also known as lift. Negative pressure causes buildings to lose all or a portion of their roofs and side walls, and pulls storm shutters off the leeward side of a building.
- **Interior Pressure**—Interior pressure increases dramatically when a building loses a door or window on its windward side. The roof feels tremendous internal pressures pushing up from inside the building together with the negative wind pressure lifting the roof from the outside.

Location

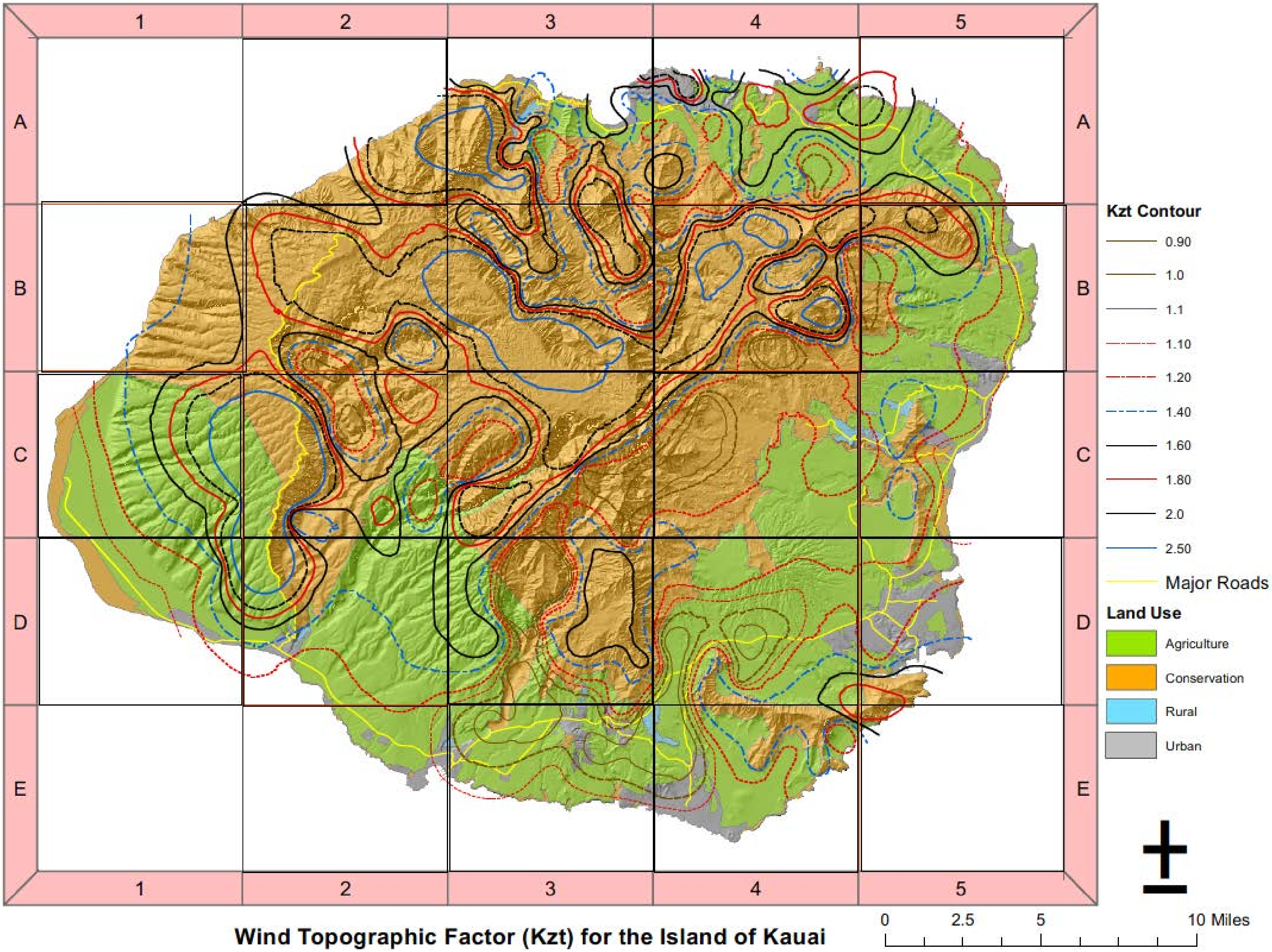
High wind storms can occur anywhere in the State of Hawaiʻi; therefore, the entire State and all its counties are susceptible to the direct and indirect impacts of high wind storms; however, topography plays a significant role in where the impacts of high wind storms are most severe. For example, strong Kona storms bring wind and rain and can cause extensive damage to south- and west-facing shores (Vitousek et al. 2009). The Kāneʻohe-Kahaluʻu area, on the windward coast of the Island of Oʻahu (City and County of Honolulu), has had extensive wind damage due to strong Kona winds (State of Hawaiʻi HMP 2013). In the case of the Island of Maui, trade winds appear to be stronger when passing through the isthmus between the West Maui Mountains and Haleakalā, so that wind speeds at location such as Māʻalaea and north Kīhei may be higher than locations along the island's north shore due to wind channeling that often occurs when wind passes between two mountains or into a valley (Hawaiʻi State HMP 2013). In general, wind speeds vary with height above ground—the higher the elevation, the stronger the wind. As a result, the mountainous areas of the State of Hawaiʻi generally experience the highest wind speeds (State of Hawaiʻi HMP 2013).

Topographic Effects on Windspeed

Wind speed increases over hills, ridges and escarpments (steep slopes or long cliffs). This phenomenon is known as wind speed-up. Because wind speed is related to wind pressure, structures in wind speed-up areas will experience more severe damages than those on located on flat, open terrain if building codes do not take the local topographic factor into consideration. In the past, the magnitude of wind speed-up caused by topography in the State of Hawaiʻi has not been well understood and it was not historically considered in any building code used in the State (State of Hawaiʻi HMP 2013).

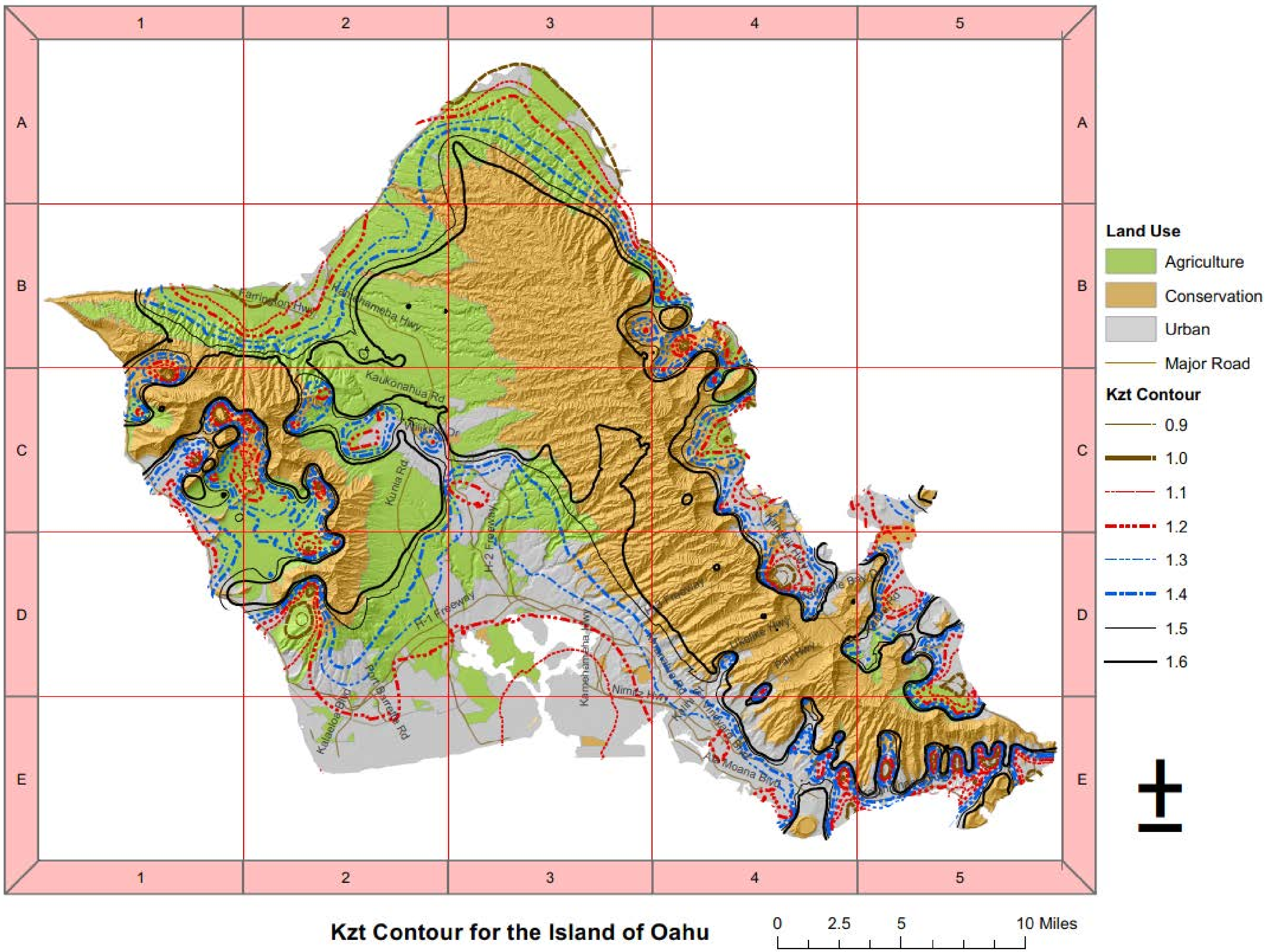
In the early 2000s, an assessment of wind speed-up in the State of Hawaiʻi was conducted and it was determined that existing mapping and standards were insufficient to adequately determine design wind pressures due to the complex topography in the State (Martin & Chock, Inc. No Date). In short, the topography has speed-up effects that cannot be adequately portrayed by a single statewide value of wind speed nor at the macro-scale of a national map. This factor, coupled with the designation of the State of Hawaiʻi as a special wind region in American Society of Civil Engineers (ASCE) standards, resulted in the development of a procedure and associated mapping to determine design wind pressures in the State that could be incorporated into State and county building codes. The State of Hawaiʻi wind design provisions for new construction are included in Appendix W of the Hawaiʻi State Building Code (State Building Code Council 2018). The requirements are complex and include design provisions for windborne debris, ultimate design wind speeds, directionality factors, and exposure categories. Figure 4.10-1 through Figure 4.10-6 show the wind topographic factors for each island that are included in these design requirements. The topographic factor (K_{zt}) acts as a multiplier in determining peak gusts relative to mild, flat terrain. As a result, buildings of all types constructed under this code are built to a uniform level of risk, that is, all occurrences of amplified wind are addressed in the design of that building, so that no building has disproportionate risk (State of Hawaiʻi 2018; Chock et al. 2002).

Figure 4.10-1. Wind Topographic Factor (Kzt) for the Island of Kauaʻi (County of Kauaʻi)



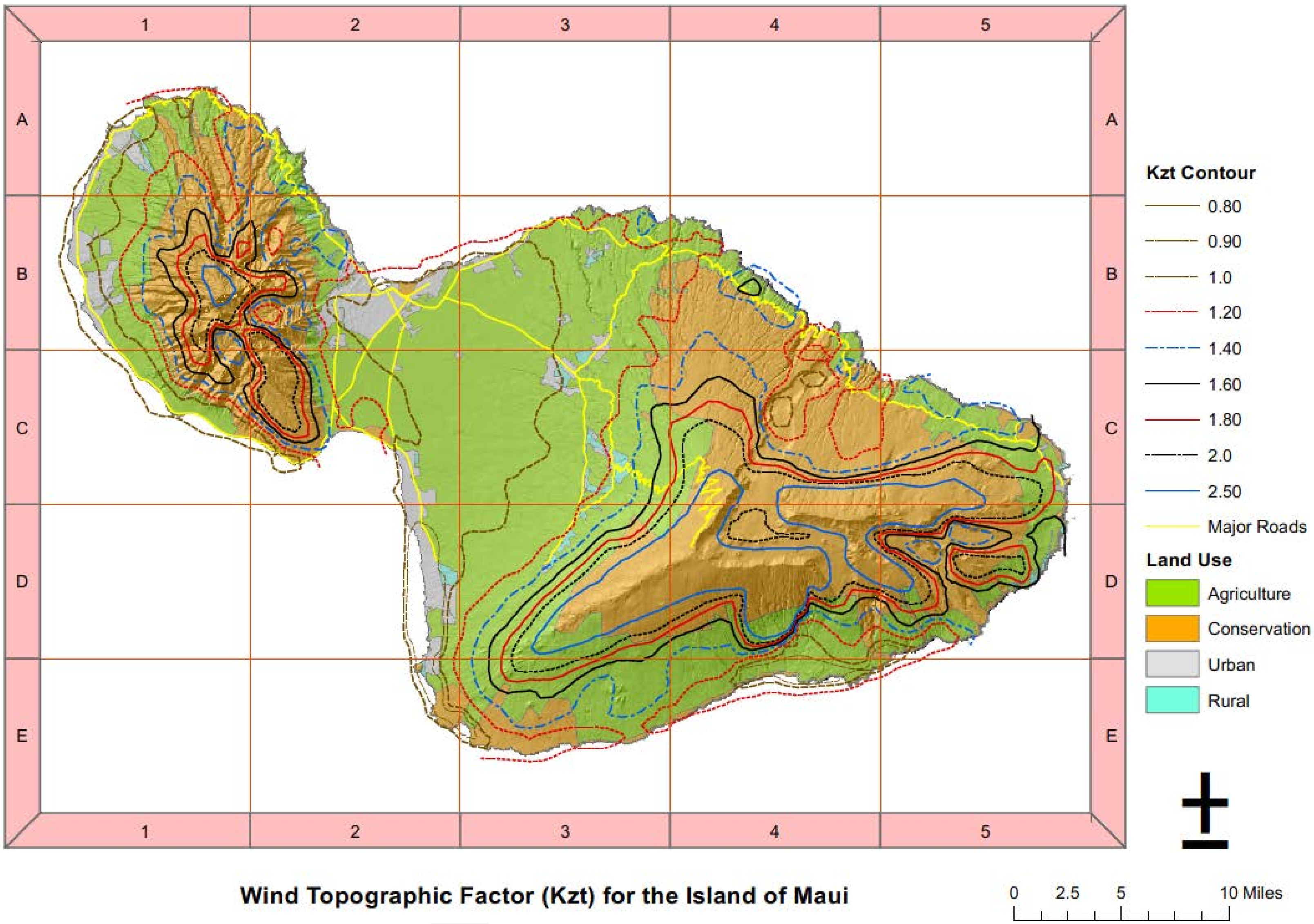
Source: State of Hawaiʻi Department of Accounting and General Services 2018

Figure 4.10-2. Wind Topographic Factor (Kzt) for the City and County of Honolulu



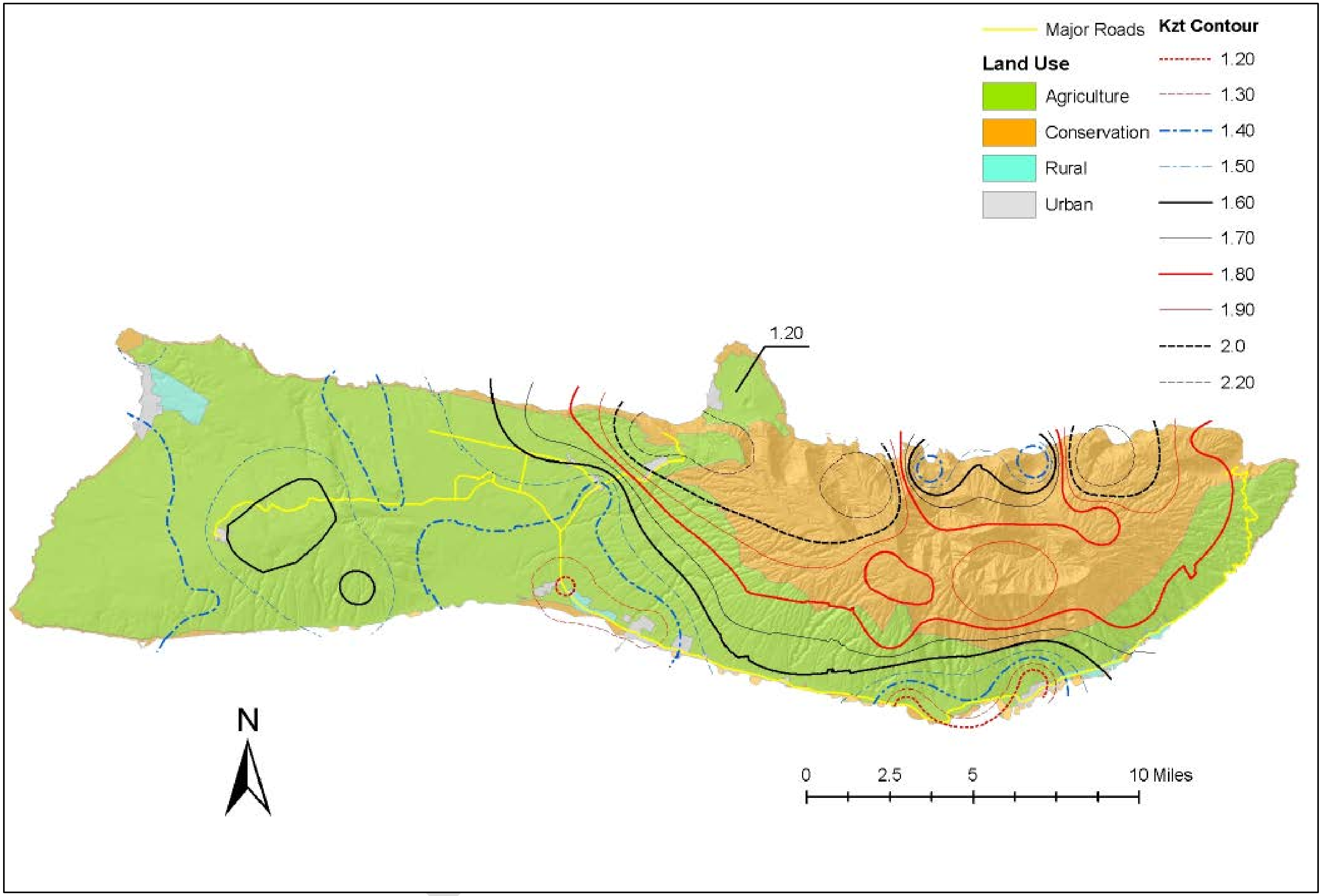
Source: State of Hawaiʻi Department of Accounting and General Services 2018

Figure 4.10-3. Wind Topographic Factor (Kzt) for the Island of Maui (County of Maui)



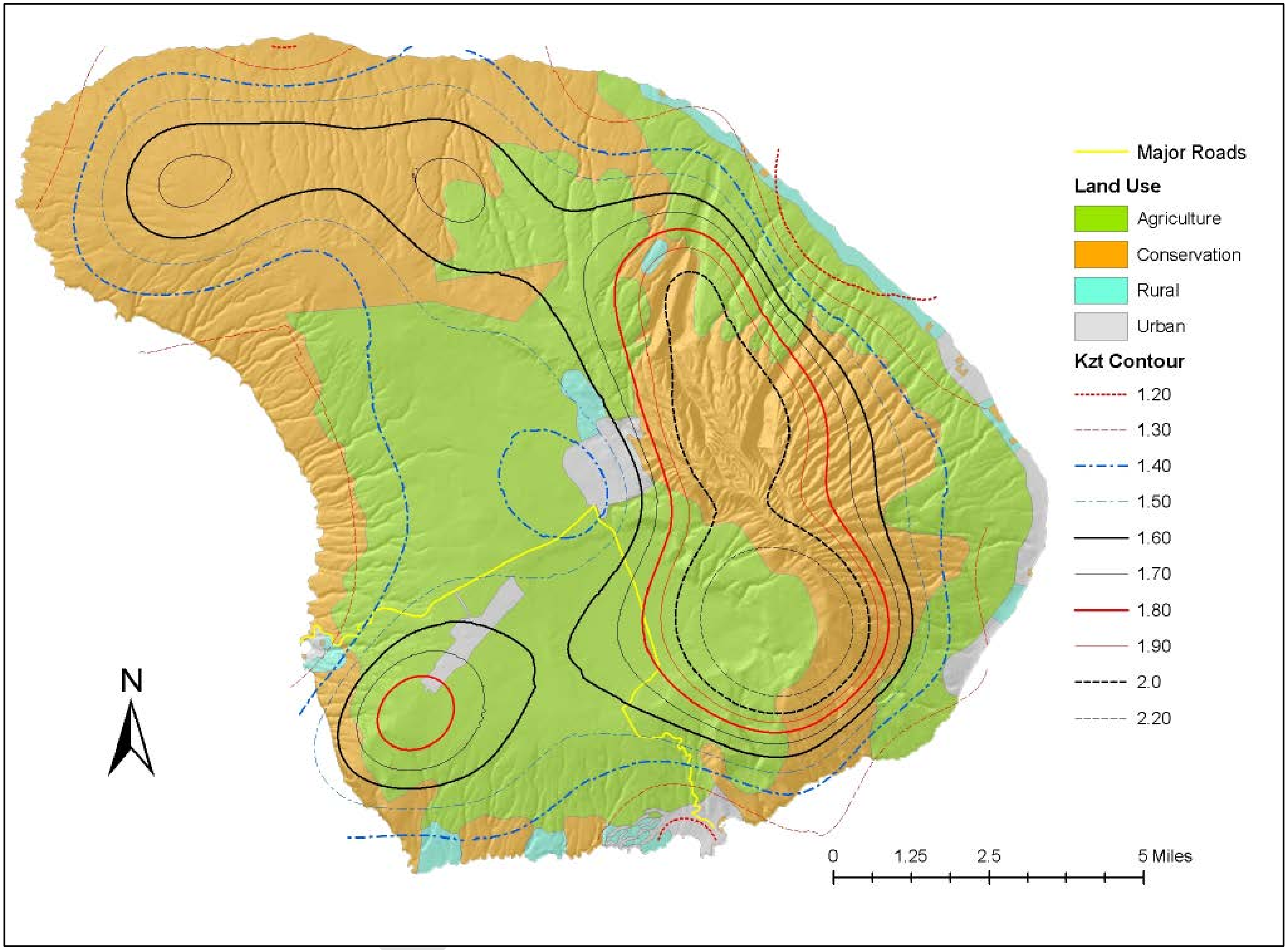
Source: State of Hawaiʻi Department of Accounting and General Services 2018

Figure 4.10-4. Wind Topographic Factor (Kzt) for the Island of Molokaʻi (County of Maui)



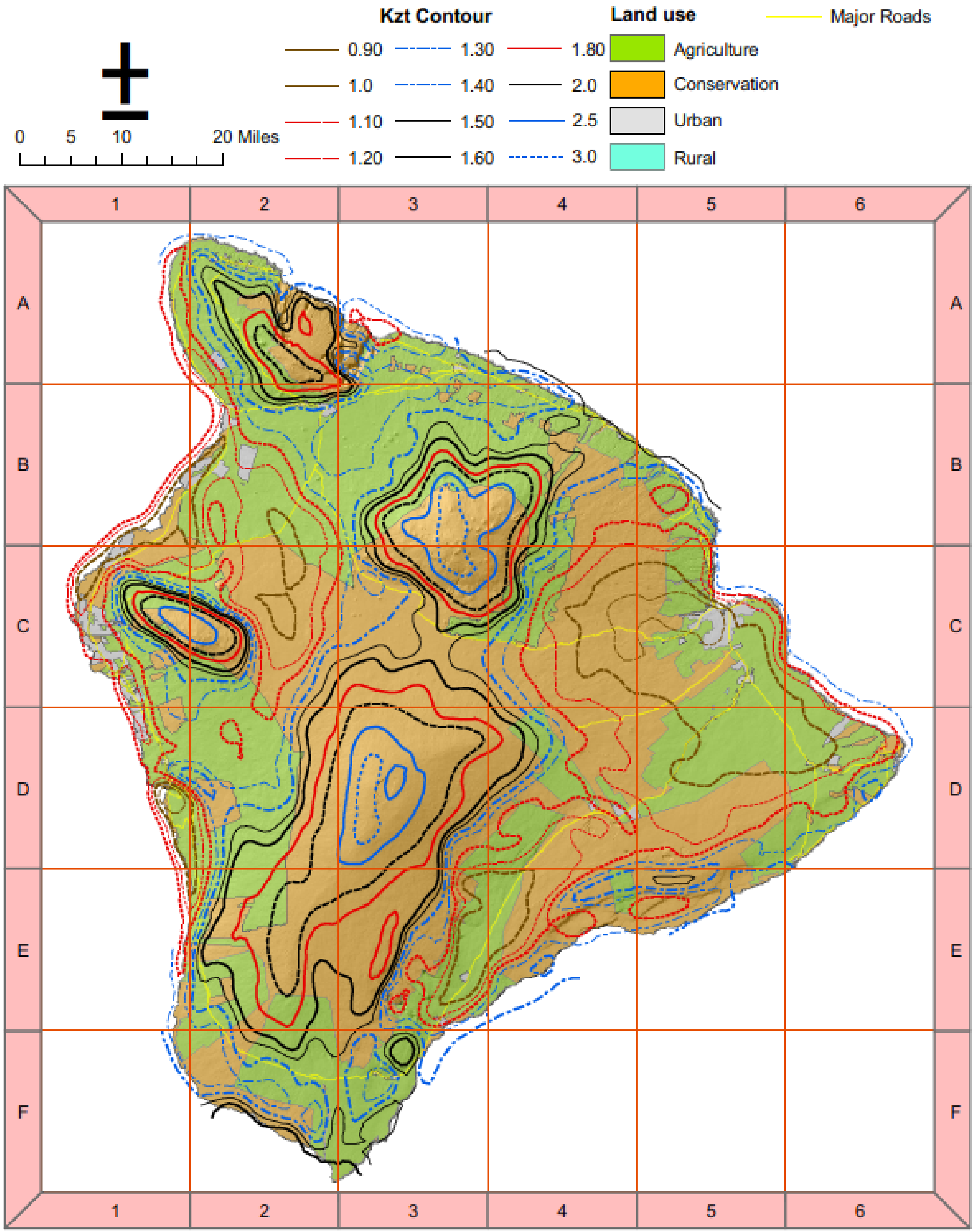
Source: State of Hawaiʻi Department of Accounting and General Services 2018

Figure 4.10-5. Wind Topographic Factor (Kzt) for the Island of Lānaʻi (County of Maui)



Source: State of Hawaiʻi Department of Accounting and General Services 2018

Figure 4.10-6. Wind Topographic Factor (Kzt) for the Island of Hawaiʻi (County of Hawaiʻi)



Source: State of Hawaiʻi Department of Accounting and General Services 2018

Extent

High wind events can be a frequent issue throughout the State of Hawaiʻi, with some areas experiencing more events and greater wind speeds than others as evidenced through the Location section of this profile.

The Beaufort wind scale (see Table 4.10-1), still in use today, was developed in 1805 to help sailors estimate the wind speed through visual observations. The scale includes a description of winds and specifications for use both at sea and on land. The average speed of the Trade Winds (15.7 mph) is considered a moderate breeze using this scale. When passing through mountain gaps and over mountains, downsloped Kona wind gusts can reach over 100 mph, which are hurricane-force winds (State of Hawaiʻi HMP 2013).

High wind storms can cause disruptions to power, uproot trees, damage boats, blow roofs off homes and have the potential to damage other structures in the State. However, damage does not typically occur until wind speeds of 40 mph or greater are reached. The State of Hawaiʻi Building Codes references the ASCE 7 Standard for *Minimum Design Loads for Buildings and Other Structures*, which requires that new buildings in the State be designed to withstand a 120 mph sustained wind or wind gusts of 130 mph. This is equivalent to a Category 3 hurricane (see Section 4.10 Hurricane for more information). In addition, the State of Hawaiʻi building code imposes additional requirements for structures to be designed to account for the topographic factors discussed previously (Department of Commerce and Consumer Affairs [DCCA] and Martin and Chock 2015).

Table 4.10-1. Beaufort Wind Scale

Force	Speed mph (knots)	Description	Specifications for use at sea	Specifications for use on land
0	0-1 (0-1)	Calm	Sea like a mirror.	Calm; smoke rises vertically.
1	1-3 (1-3)	Light Air	Ripples with the appearance of scales are formed, but without foam crests.	Direction of wind shown by smoke drift, but not by wind vanes.
2	4-7 (4-6)	Light Breeze	Small wavelets, still short, but more pronounced. Crests have a glassy appearance and do not break.	Wind felt on face; leaves rustle; ordinary vanes moved by wind.
3	8-12 (7-10)	Gentle Breeze	Large wavelets. Crests begin to break. Foam of glassy appearance. Perhaps scattered white horses.	Leaves and small twigs in constant motion; wind extends light flag.
4	13-18 (11-16)	Moderate Breeze	Small waves, becoming larger; fairly frequent white horses.	Raises dust and loose paper; small branches are moved.
5	19-24 (17-21)	Fresh Breeze	Moderate waves, taking a more pronounced long form; many white horses are formed.	Small trees in leaf begin to sway; crested wavelets form on inland waters.
6	25-31 (22-27)	Strong Breeze	Large waves begin to form; the white foam crests are more extensive everywhere.	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.
7	32-38 (28-33)	Near Gale	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind.	Whole trees in motion; inconvenience felt when walking against the wind.
8	39-46 (34-40)	Gale	Moderately high waves of greater length; edges of crests begin to break into spindrift.	Breaks twigs off trees; generally impedes progress.

Force	Speed mph (knots)	Description	Specifications for use at sea	Specifications for use on land
			The foam is blown in well-marked streaks along the direction of the wind.	
9	47-54 (41-47)	Severe Gale	High waves. Dense streaks of foam along the direction of the wind. Crests of waves begin to topple, tumble and roll over. Spray may affect visibility	Slight structural damage occurs (chimney-pots and slates removed)
10	55-63 (48-55)	Storm	Very high waves with long overhanging crests. The resulting foam, in great patches, is blown in dense white streaks along the direction of the wind. On the whole the surface of the sea takes on a white appearance. The tumbling of the sea becomes heavy and shock-like. Visibility affected.	Seldom experienced inland; trees uprooted; considerable structural damage occurs.
11	64-72 (56-63)	Violent Storm	Exceptionally high waves (small and medium-size ships might be for a time lost to view behind the waves). The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.	Very rarely experienced; accompanied by wide-spread damage.
12	72-83 (64-71)	Hurricane	The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.	Refer to Saffir-Simpson Hurricane Scale

Source: National Weather Service 2018
Note: The Saffir-Simpson Scale is Discussed in Section 4.10 Hurricane

Warning Time

Meteorologists can often predict the likelihood of a high wind storm event. This can give several days of warning time. However, meteorologists cannot predict the exact time of onset or severity of the storm. Some storms may come on more quickly and have only a few hours of warning time. The predicted wind speed given in wind warnings issued by the National Weather Service is for a one-minute average; gusts may be 25% to 30% higher.

The National Weather Service Honolulu Forecast Office issues specific watches, warnings and advisories when weather threatens the State. For high wind storms, the following may be issued:

- **High Wind Watch** is issued when sustained winds exceeding 40 mph and/or frequent gusts over 60 mph are likely to develop in the next 24 to 48 hours. For summit areas, high wind watches are issued when sustained winds are expected to exceed 56 mph and/or frequently gust over 66 mph. If you are in an area for which a High Wind Watch has been issued you should prepare by securing loose objects outdoors that may blow about and avoiding outdoor activity that exposes you to high winds.
- **High Wind Warning** is issued when sustained winds exceeding 40 mph and/or frequent gusts over 60 mph are occurring or imminent. For summit areas, warnings are issued for winds exceeding 56 mph and/or frequently gusting over 66 mph. Wind warnings may be issued up to 24 hours ahead of the onset of high

winds. If you are in an area where a high wind warning is in effect you should avoid activities that expose you to high winds. Loose objects may be blown around. Tree limbs may break and fall. Power lines may be blown down.

- **Wind Advisory** is issued when sustained winds of 30 to 39 mph and/or frequent gusts to 50 mph or greater are occurring or imminent. For summit areas, the sustained wind range is 45 to 55 mph and/or frequent gusts of 55 to 65 mph. Wind advisories may be in effect for 6 to 12 hours. If you are in an area where a wind advisory is in effect you should secure loose objects that may be blown about outdoors and limit activity that may expose you to high winds.
- **Small Craft Advisory** is issued for the coastal waters when winds of 28 to 37 mph and seas 10 feet or higher are occurring or forecast.
- A **Gale Warning** is issued for coastal, offshore, and high seas areas when winds of 39 to 54 mph not associated with a tropical cyclone are occurring or forecast (NWS 2018).

Previous Occurrences and Losses

High wind events, distinct from tropical cyclones, affect the State of Hawaiʻi on a relatively regular basis. It can be observed from more recent events that the major damage is typically: power outages due to fallen distribution poles; fallen trees, which create debris that often results in damage to structures or other property; and roof damage due to uplift of shingles, tiles or other types of cladding. Occasionally there are deaths associated with the debris and structural collapses. The storms that produce these high winds often have associated flooding and other hazards that provide further damage and losses.

Many sources provided high wind storm events information regarding previous occurrences and losses throughout the State of Hawaiʻi. The 2013 State HMP discussed specific high wind storm events that occurred in Hawaiʻi through 2012. For this 2018 HMP Update, high wind events were summarized between January 1, 2012, and December 31, 2017. Table 4.10-2 includes details of major high wind storm events that occurred in the State between 2012 and 2017. Please note, not all events are captured in the table below. Only major events that resulted in injuries or fatalities, as reported by NOAA NCEI, events that resulted in the activation of the State and/or County EOC, and/or events that led to a FEMA disaster declaration are listed. For events prior to 2012, please refer to Appendix X.

Table 4.10-2. High Wind Storm Events in Hawaiʻi, 2012 to 2017

Date(s) of Event	Event Type	Counties Affected	Description
February 7, 2012	Strong Wind	Honolulu	A cold front moving through Hawaiʻi brought strong winds and heavy rain. The winds downed power lines and trees. In Waikīkī, a tree branch snapped, injuring three people at the International Market Place.
March 9, 2012	Thunderstorm Wind	Kauaʻi and Maui	Significant weather impacted Hawaiʻi, bringing thunderstorms, flash flooding, record-setting hail, and a tornado. There were no reports of fatalities or serious injuries. In Maui County, strong winds destroyed a portion of the roof of the Hana Hotel, causing $25,000 in damages. Maui County had approximately $3.2 million in infrastructure damage from this event. Kauaʻi County had approximately $2 million in infrastructure damage.
February 13, 2015	Strong Wind	Honolulu	Gusty winds moved through Hawaiʻi, downing power lines, utility poles, and trees. The winds damaged roofs and forced roadway closures due to debris. There was one injury reported on Oʻahu (Honolulu County). A firefighter was injured when attempting to secure roof materials in Kāneʻohe in windward Oʻahu.
February 16, 2016	Strong Wind	Honolulu	Strong winds led to power outages, downed trees, and damage to roofs in parts of Oʻahu (Honolulu County), including Mānoa, Aina Haina, Kalihi, and Nuʻuanu. One injury was reported on Oʻahu when a tree fell on a home and pinned a man to his bed.
March 8, 2016	Strong Wind	Honolulu	Gusty north to northeast winds moved over Oʻahu (Honolulu County) and around the State. Power outages, downed trees and power lines were common across the State. On Oʻahu, a downed power line led to road closures. There was one reported injury from of this event. A person was injured at the Koko Head Shooting Complex when the winds blew the roof off the structure and flipped it over.
January 21 to 22, 2017	High Wind	Maui and Hawaiʻi	The Maui and Hawaiʻi County EOCs were partially activated because of this event.
February 11, 2017	Strong Wind	Honolulu	A front moving through the State produced heavy rain and thunderstorms, flash flooding, and gusty winds. This event led to downed power lines and trees, and ponding on roadways. On the south shore of Oʻahu, a tent collapsed at the community college due to the strong winds. Three individuals were injured.
October 23 to 14, 2017	Strong Wind	Honolulu and Maui	Strong winds, heavy rain, thunderstorms, and flash flooding impacted parts of Hawaiʻi. Lightning strikes led to power outages, and gusty winds knocked down trees and power lines. One injury was reported on Oʻahu (Honolulu County) when a tree fell onto a bus stop structure where a woman was standing. In Maui County, wind speeds reached 59 mph.

Sources: *FEMA 2018; NOAA NCEI 2018; SPC 2018*
Note: With high wind storm documentation for Hawaiʻi being so extensive, not all sources have been identified or researched. Additionally, loss and impact information for many events could vary depending on the source. Therefore, Table 4 1 may not include all events that have occurred in the State and the accuracy of monetary figures discussed is based only on the available information identified during research for this 2018 HMP update.
EOC *Emergency Operations Center*
FEMA *Federal Emergency Management Agency*
mph *Miles Per Hour*
NCEI *National Centers for Environmental Information*
NOAA *National Oceanic and Atmospheric Administration*
SPC *Storm Prediction Center*

FEMA Disaster Declarations

Between 1954 and 2018, FEMA included the State of Hawaiʻi in 13 wind-related disasters (DR) or emergencies (EM) classified as one or a combination of the following disaster types: severe storms, flooding, high surf, mudslides, flash flooding, and landslides. Generally, these disasters cover a wide region of the State; therefore, they may have impacted many counties. However, not all counties were included in the disaster declarations as determined by FEMA (FEMA 2018).

Known high wind events that have impacted the State of Hawaiʻi and were declared a FEMA disaster, between 2012 and 2018, are identified in Table 4.10-3. It is recognized that FEMA Declarations may not specify the event as a 'high wind storm' and may refer to the event type as a severe storm, making it challenging to distinguish the declaration from tropical cyclones. For details regarding all declared disasters, refer to Section 4.0 (Risk Assessment Overview).

Table 4.10-3. High Wind-Related Federal Declarations (2012 to 2018)

Year	Event Type	Date Declared	Federal Declaration Number	Counties Affected
2012	Severe Storms, Flooding, and Landslides	April 17, 2012	DR-4062	Kauaʻi and Maui
2016	Severe Storms, Flooding, Landslides, and Mudslides	October 6, 2016	DR-4282	Maui
2018	Severe Storms, Flooding, Landslides, and Mudslides	May 8, 2018	DR-4364	Honolulu and Kauaʻi

Source: FEMA 2018
Note: Hurricane and Tropical Storm declarations are included in Section 4.10 Hurricane.
DR FEMA-designated disaster
FEMA Federal Emergency Management Agency

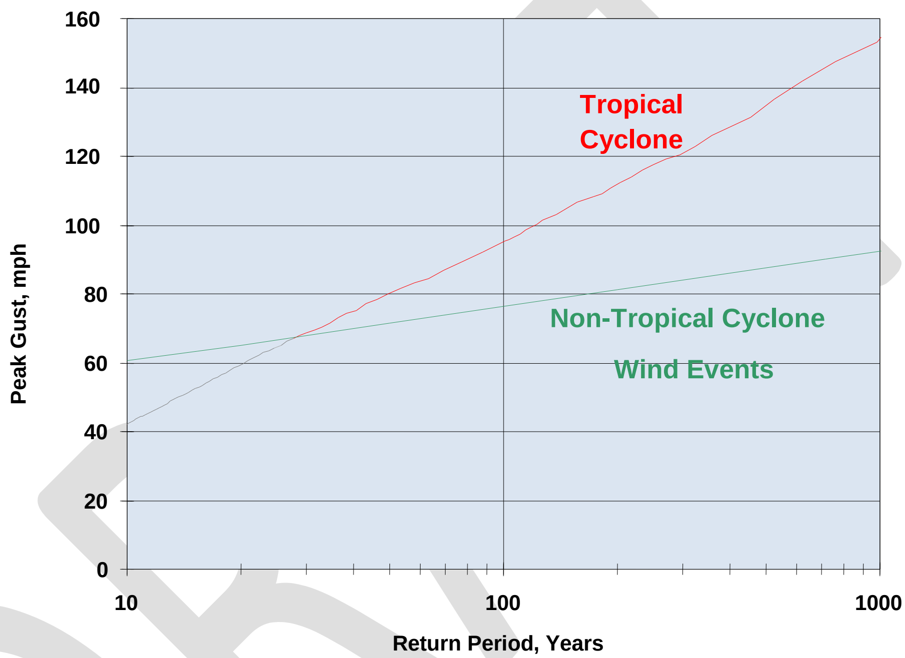
PROBABILITY OF FUTURE HAZARD EVENTS

The distinction between the tropical cyclonic winds and trade and Kona winds is illustrated by the hazard curves for the Hawaiian Islands shown in Figure 4-8. The figure shows that the relatively low wind speeds that occur more frequently are more likely to be from trade and Kona winds while the relatively high but less frequent wind speeds are more likely to be caused by tropical cyclones. The figure shows that winds of 68 mph or less, which can still be very damaging, are more likely to occur due to non-cyclonic winds. Greater wind speeds are more likely to be experienced during a tropical cyclone (tropical depression, storm or hurricane), which are more damaging, however, these events are less frequent (Hawaiʻi State HMP 2013).

For example, at the lower wind speeds, a 60 mph or greater trade wind or Kona wind event is expected to occur once every 10 years, while the 60 mph or greater tropical cyclone is expected to occur once every 20 years. At the higher wind speeds, a 90 mph or greater tropical cyclone is expected to occur 80 years, while a 90 mph or greater trade or Kona storm is expected to be extremely rare and occur only once every 700 to 800 years. Therefore, major structural damage, due to the high winds is more likely to be caused by tropical cyclones in the form of hurricanes. However, damage associated with storms with lower wind speeds, such as: minor structural damage for structures deficient compared to current building standards; non-structural water damage due to windblown rain; flooding associated with wind storms, or; damage to power distribution systems deficient compared to current building standards, is more likely to be caused by trade or Kona wind storms (Hawaiʻi State HMP 2013).

Overall, high wind events will occur regularly as part of severe weather events across the State. As noted earlier, high wind events occur on a relatively regular basis. Based on historical record, the State of Hawaiʻi has experienced 12 FEMA declarations associated with severe storms since 1954. The State can experience a major event that leads to a FEMA declaration once every five years. Looking at all high wind events, between 1955 and 2017, there have been 533 events. Based on this data, the State of Hawaiʻi may experience between an estimated eight and nine high wind events each year (Storm Prediction Center 2018; NOAA NCEI 2018). The State of Hawaiʻi can expect a 100% chance of high wind storms occurring annually.

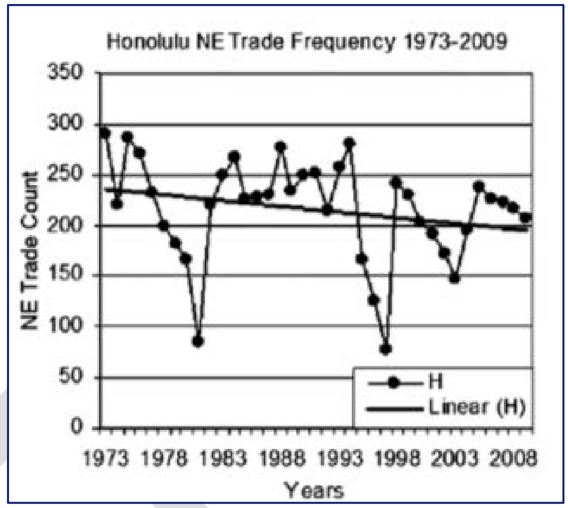
Figure 4.10-7. Wind Hazard Curves for the Hawaiian Islands for Tropical Cyclone and Non-Tropical Cyclone Winds



Source: Hawaiʻi State HMP 2013

Impacts of Climate Change on Future Probability

Although the average atmospheric and land surface temperature are increasing in the State of Hawaiʻi and are projected to continue rising, the rates will vary depending on land uses, topography, and trade wind and precipitation patterns. The effect of climate change on the trade winds, which bring a steady supply of rainfall to the Hawaiian Islands, is a source of uncertainty in local predictions (University of Hawaiʻi at Mānoa Sea Grant College Program 2014). Winds are changing over the Hawaiian Islands. Changes detected in the prevailing wind over the Hawaiian Islands, the northeast trade wind, may shift large-scale pressure and wind patterns that impact the State of Hawaiʻi in the future (Garza et al., 2011).



There are fewer days with northeast trade winds than 40 years ago. Fewer days of northeast trade winds leads to more muggy weather and volcanic haze, resulting in longer-term effects for the state (University of Hawaiʻi at Mānoa Sea Grant College Program 2014; Gutierrez 2012).

Scientists from the University of Hawaiʻi at Mānoa analyzed wind records from 1973 to 2009 at the major airports in the State of Hawaiʻi: Līhuʻe, Honolulu, Kahului and Hilo. They also collected data from four weather buoys in waters around the islands. The study found for Honolulu, northeast trade winds dropped from 291 days per year to 210 days per year over the 40-year period. The two largest decreases occurred in 1981 and 1997. In 1981, a high-pressure system shut off northeast trade winds, causing a major drought in the State. In 1997, the strongest El Niño event ever recorded weakened the northeasterly trade winds (Garza et al. 2011; Live Science 2012).

For details regarding climate change as a distinct hazard and its unique impacts to the State of Hawaiʻi, refer to Section 4.1 (Climate Change).

4.10.2 Vulnerability Assessment

High wind storms can occur anywhere in the State of Hawaiʻi; however, as previously discussed, topography plays a significant role in where the impacts are most severe. Terrain-related amplification of wind speeds have led to significant losses in the state. Kona storm events not only bring high winds, but also large amounts of rain that result in flash flooding, snow at high altitudes, hail and severe thunderstorms. For further discussion on flooding and surge impacts, refer to Sections 4.7 (Event-Based Flood) and Section 4.11 (Hurricane). This vulnerability assessment focuses on the high wind component to these storm events. No spatial data was available for the high wind storm vulnerability assessment. Therefore, a qualitative assessment was conducted and is presented below.

Assessment of State Vulnerability and Potential Losses

This section discusses statewide vulnerability of exposed state assets (state buildings and state roads) and critical facilities to high wind storm events.

State Assets

As noted earlier, the Hawaiʻi State Building Code requires new structures to be built to withstand a Category 3 hurricane wind speed. Any state buildings that were built before the building code incorporated provisions for wind load and topographic factor are particularly vulnerable. Depending on the severity and duration of the storm, a high wind storm, as described earlier can cause windows and doors to be blown out, roofs to be ripped off and walls to collapse. Although it is unlikely that high winds would directly damage state roads, debris has blocked roads, isolating areas and putting already vulnerable populations at even greater risk.

Critical Facilities

All critical facilities in the State are vulnerable to high wind storms. Loss of utilities is the most common issue with high wind storms. High winds can severely impact power transmission lines as high winds are funneled through changes in terrain causing widespread power outages. For example, in December 26, 2008, the entire electrical grid on the island of Oʻahu (City and County of Honolulu) was blacked out for around 12 hours due to a Kona storm (State of Hawaiʻi HMP 2013). The interruption of power, water, wastewater, as well as critical needed services such as hospitals and other emergency services has cascading impacts residents, visitors and all forms of economic activity.

As summarized in Section 4.2 (Climate Change and Sea Level Rise), the primary transportation arteries for the entry of people and goods to the State is the Daniel K. Inouye International Airport and Honolulu Harbor. In addition, each island has critical points of entry for people and goods located along the coast. Ports, harbors and airports are especially vulnerable to the high wind storm hazard. Damages and closures to these critical facilities will likely be long-term have cascading economic impacts statewide.

Kona wind events, such as the January 1980 storm, have caused the closure of airports. The 1980 storm produced sustained winds of 40-50 mph gusting over 100 mph in certain regions due to topographical features. According to the Hawaiʻi Department of Transportation, anchorage for deep-draft vessels exist outside the Honolulu Harbor in Mamala Bay off Sand Island and west of the Main Channel (also known as Fort Armstrong Channel). However, anchorage is not possible during kona wind conditions (Hawaiʻi DOT 2018).

In February 2017, the HI-EMA conducted a series of workshops to continue its ongoing efforts to address temporary emergency power planning requirements outlined in the 2015 Hawaiʻi Catastrophic Hurricane Plan. As a result, the state identified critical facilities within each county and developed a method to prioritize the allocation of limited generator resources. The critical facilities identified through this process were used in the risk assessment for the 2018 HMP Update (HI-EMA 2017). Exposure and potential impacts to these critical facilities are reported throughout Section 4.0 resulting from natural hazard events.

Economic (monetary) losses due to high wind storms on critical infrastructure such as airports, harbors, water, sewer and power utilities were not calculated due to the variable cost of such infrastructure and the complexity and uncertainty involved based on design, siting and construction. However, estimated costs for the resiliency and hardening of electric power systems are available through the efforts being made after Puerto Rico was struck by Hurricanes Irma and Maria in 2017. These two hurricanes resulted in catastrophic damage to the island and a complete failure of Puerto Rico's power grid. Similar to the State of Hawaiʻi, Puerto Rico also experiences wind speed up due to the differences in terrain across the island. As reported in *Build Back Better: Reimagining and Strengthening the Power Grid of Puerto Rico*, the estimated cost per mile for hardening is $1.25 to $7 million, depending upon if low or high voltage lines are use.

Assessment of Local Vulnerability and Potential Losses

Overall, high wind storms can occur anywhere in the State of Hawaiʻi. In terms of vulnerability, the strong kona storms and associated wind, rain and wave heights can cause extensive damage to the south and west facing shores of the islands. This section provides a summary of vulnerability and potential losses to population, general building stock, and environmental/cultural assets by county.

Population

The entire population, residents and visitors, is considered exposed and could be impacted by high wind storms. Certain areas are more vulnerable because of their geographic location and local weather patterns. For example, people living at higher elevations with large stands of trees or nearby powerlines may be more susceptible to wind damage and loss of power. Kona winds that accelerate down the slopes of mountains, hills and escarpments, historically reaching up to 100 miles per hour, can be very destructive when they reach populated low-lying areas. It is common for trees to be uprooted, signs and utility poles to be overturned, debris to be carried by the winds and for residential roofs to be blown off. Damage can be inflicted on boats caught in the open ocean or anchored in the southwest-exposed anchorages (State of Hawaiʻi HMP 2013).

Kona winds can also bring volcanic fog (vog) from Kilauea in the County of Hawaiʻi up the island chain reaching the County of Maui and City and County of Honolulu. This makes visibility poor and causes eye and respiratory irritation. Refer to Section 4.13 (Volcanic Hazards) for a more detailed discussion of vog and human health impacts.

After high wind events, residents may be displaced or require temporary to long-term sheltering. Vulnerable populations, such as the elderly, low-income and linguistically isolated populations, are most susceptible to high wind storms. This vulnerability is based on a number of factors including their physical and financial ability to react or respond during a hazard and the location and construction quality of their housing. Other risk factors include that power outages can be life threatening to people dependent on electricity for life support. Because these vulnerable populations face various forms of isolation, they are more at risk for secondary effects from the high wind hazard.

General Building Stock

As noted earlier, the Hawaiʻi State Building Code requires new structures to be built to withstand a Category 3 hurricane wind speed. Any structures that were built before the building code incorporated provisions for wind load and topographic factor are particularly vulnerable. More vulnerable locations include: at higher elevations, on leeward sides of islands during Kona winds, on ridge lines, under or near powerlines, or near large trees. Depending on the severity and duration of the storm, a high wind storm, as described earlier can cause windows and doors to be blown out, roofs to be ripped off and walls to collapse.

Spatial data was not available to conduct an exposure analysis based on wind speed zones. When estimating the potential impact to individual structures, the structural integrity, mitigation measures in place, building construction and date of construction should be considered. Because of differences in building construction, residential structures are generally more susceptible to wind damage than commercial and industrial structures. Wood and masonry buildings in general, regardless of their occupancy class, tend to experience more damage than concrete or steel buildings. Refer to Section 4.10 (Hurricane) for further discussion on impacts resulting from high wind speeds associated with tropical cyclone events for all counties in the state.

Environmental Resources and Cultural Assets

Natural habitats such as forests and waterways are vulnerable to damage from high wind storms. Major damage can occur from downed or uprooted trees, other debris, as well as rivers and streams blocked by various types of debris. Agricultural losses have been reported due to historic Kona wind events; for example macadamia, coffee, foliage and flower farms incurred losses as a result of the January 1980 event in the County of Hawaiʻi.

A Kona storm can bring large amounts of rain in a short period of time to the leeward side of the islands that tend to be drier. In addition, major Kona storm events can bring large wave heights and resulting shoreline change which may impact environmental and cultural assets along the shore (Vistousek et al 2009).

FUTURE CHANGES THAT MAY IMPACT STATE VULNERABILITY

Understanding factors of change that impact vulnerability in the State can assist in planning for future development and ensuring that appropriate mitigation, planning, and preparedness measures are in place. The State considered the following factors to examine potential conditions that may affect hazard vulnerability:

- Potential or projected development
- Projected changes in population
- Other identified conditions as relevant and appropriate, including the impacts of climate change.

All future development in each county and statewide is vulnerable to high wind hazards. However, the ability to withstand impacts from high winds is based in appropriate land use practices and consistent enforcement of codes and regulations for new construction. As older structures are replaced with new structures built to modern building codes overall vulnerability to the high wind storm hazard will decrease.