20. WINDSTORM

20.1 HAZARD PROFILE

20.1.1 HAZARD DESCRIPTION

Overview

Wind is defined as the perceptible natural movement of the air, especially in the form of a current of air blowing from a particular direction. Windstorm hazards in the City involve strong, damaging winds that can result from various weather events. Winds resulting from hurricanes are discussed in Chapter 13 (Hurricane).

Causes and Types of Winds

Winds on the island of Oʻahu originate from several different sources: trade winds, kona winds, and midlatitude fronts and shear lines. High winds from trade winds, kona winds and fast-moving cold fronts can affect the island. This section focuses on two wind patterns that have the most regular impacts on Oʻahu: trade and kona winds.

TRADE WINDS

Trade winds are the most common winds over Hawaiian waters and play a major role in defining the region's climatology. Trade winds are persistent, easterly winds that blow from the northeast and east-northeast as a result of high-pressure systems that form in the North Pacific. Trade winds received their name from the clipper ships that depended on these easterly winds for fast passage. The east-facing coastlines, or windward coasts, are most impacted by trade wind energy.

The northeast trade winds prevail over the Hawaiian Islands throughout the year, with an average speed of 15.7 mph and speeds ranging between 10 and 25 mph. Trade winds greater than 25 mph, and occasionally reaching between 40 to 60 mph, occur when the subtropical high-pressure cell north of the islands intensifies.

Average wind speeds across Oʻahu are highest between May and September when trade winds are present 85 percent to 95 percent of the time. Wind speeds during this period exceed 12 mph about 50 percent of the time. From October through April trade winds are less prevalent (present 50 percent to 80 percent of the time) and wind speeds exceed 12 mph about 40 percent of the time (WRCC 2024).

KONA WINDS

Kona winds are winds that blow over the island from the southwest or south-southeast direction, which is the opposite direction from the normal trade winds. Kona winds are known to bring heavy rain, strong gusts, and even flash flooding, especially when associated with a kona low storm. Kona lows are subtropical low-pressure systems that form northwest of the state, typically during the winter, and are the primary cause of kona winds. Kona winds result as air is down toward the low-pressure trough as a storm moves across the central North Pacific. Kona winds are most likely to impact O‘ahu when a kona low is located within 500 miles northwest of the island and has an unusually low central pressure, below 1,000 millibars for the subtropics.

While kona lows are the primary cause of kona winds, other factors can also influence wind direction and speed, leading to southwest winds. For example, strong trade winds may temporarily veer due to local sea breezes or other atmospheric disturbances.

Potential Impacts

Strong winds can uproot trees, break branches, and scatter debris, creating risks for people and property. High winds pose a serious threat to structures, particularly those with older or substandard construction. The force of the wind can tear off roofs, shatter windows, and destroy older structures or those built with substandard construction, such as single-wall constructed homes and sheds. Debris propelled by high winds can cause injuries or fatalities and result in additional property damages.

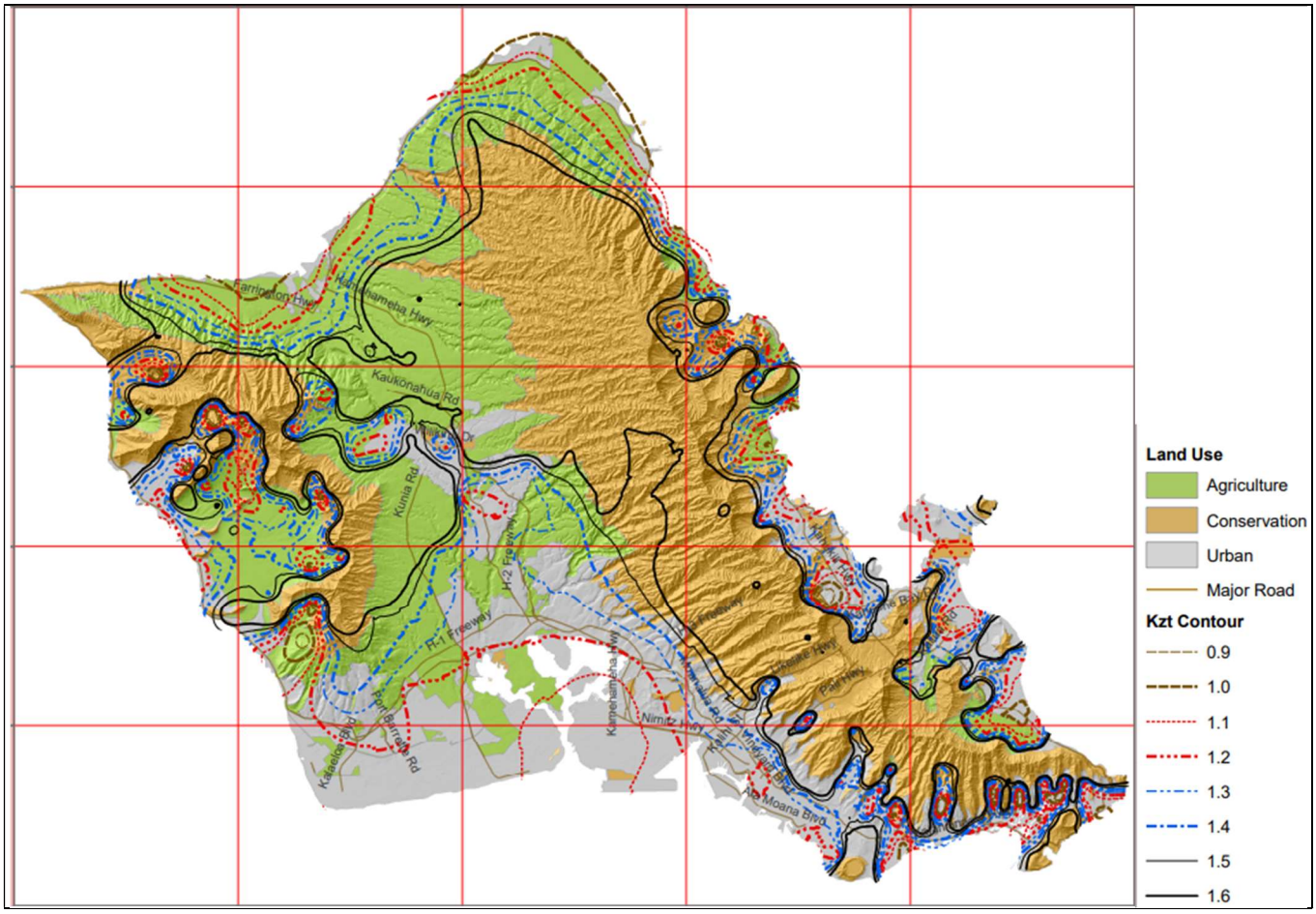
Fallen trees and debris can damage power lines, leading to power outages and utility disruptions. These outages can be prolonged, affecting essential services such as water supply, communication networks, and healthcare facilities, thereby compounding the initial impact of the windstorm.

In addition to these immediate effects, windstorms can worsen other natural hazards. For instance, when combined with heavy rainfall, high winds can increase the risk of landslides, particularly in areas with steep slopes or already saturated soils. These landslides can block roads, damage property, and pose a threat to human life.

20.1.2 LOCATION

High windstorms can occur anywhere on O‘ahu. However, topography plays a significant role in where the impacts of high windstorms are most severe. In general, wind speeds vary with height above ground—the higher the elevation, the stronger the wind. As a result, the mountainous areas generally experience the highest wind speeds (WRCC 2024). When enhanced by mountainous topography, downslope winds can increase and can be very destructive in low lying areas. Wind speed increases over hills, ridges, and escarpments (steep slopes or long cliffs), a phenomenon known as wind speed-up. Because wind speed is related to wind pressure, structures in wind speed-up areas will experience more severe damage than those located on flat, open terrain if building codes do not take the local topographic factor into consideration (HI EMA 2023). The topographical wind speed-up map for O‘ahu, provided in Figure 20-1, shows the areas subject to topographic wind amplification.

Figure 20-1. Wind Topographic Factor (Kzt) for the Island of O'ahu



Source: (HI Department of Accounting and General Services 2021)

Historically, the magnitude of wind speed-up caused by topography in Hawai'i was not well understood and was not considered in the City's building code until 2007 when the City adopted the 2003 edition of the International Building Code (IBC) and the wind maps in Figure 20-1. All buildings constructed after 2007are built to a uniform level of risk, meaning wind amplification is addressed in the building design to ensure those constructed in wind speed-up areas have the same level of risk as those constructed on mild flat terrain.

For example, strong kona storms bring wind and rain and can cause extensive damage to south and southwest-facing shores (HI EMA 2023). For example, the Kāne'ohe-Kahalu'u area has experienced extensive wind damage caused by wind speed-up from strong kona winds moving over the Ko'olau Mountains.

In addition to topography, the wind direction can contribute to which area of the island experiences the most impacts.

20.1.3 EXTENT

Hazard extent refers to the potential severity or magnitude of hazard events in a given area. This section describes measurements used to indicate the extent of this hazard and the systems in place for monitoring severity and providing warnings as necessary.

The range of magnitudes for windstorm hazards in the City varies widely depending on the type of windstorm event, local geographic factors, and specific conditions associated with each storm. The magnitude of windstorms is typically measured in terms of wind speed, which can be influenced by the event's origin, duration, and intensity.

Wind Speed and Wind Load

The following are common ways to measure wind speed (HI EMA 2023):

- **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 2 minutes. This is the measurement standard used by the National Weather Service (AMS 2022).
- **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 current Hawaiian building codes.

Wind-related damage is caused by wind load, rather than wind speed. Wind load is the force or pressure that wind exerts on the outside of a structure. Wind exerts three types of load/forces on a structure:

- **Uplift**—This occurs when wind flows over and under a roof, creating a lifting effect similar to an airplane wing. The wind pressure underneath the roof pushes it upward, while the wind flowing over the roof pulls it upward. This can cause the roof to lift off if not properly secured.
- **Shear**—Horizontal wind pressure can cause shear forces, which push against the sides of a structure. This can lead to racking, where the building tilts or shifts horizontally. Proper bracing and structural design are essential to resist these forces.
- **Lateral**—Wind can exert lateral forces that push against the vertical surfaces of a structure, such as walls. These forces can cause the building to sway or even collapse if not adequately designed to withstand them.

Beaufort Wind Scale

The Beaufort wind scale, 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 (NWS 2016). Table 20-1 describes the Beaufort Wind Scale.

Table 20-1. Beaufort Wind Scale

Force	Speed (mph)	Description
0	0 – 1	CALM—smoke rises vertically
1	1 – 3	LIGHT AIR—direction of wind shown by smoke drift, but not by wind vanes
2	4 – 7	LIGHT BREEZE—wind felt on face; leaves rustle; ordinary vanes moved by wind
3	8 – 12	GENTLE BREEZE—leaves and small twigs in constant motion; wind extends light flag
4	13 – 18	MODERATE BREEZE—raises dust and loose paper; small branches are moved
5	19 – 24	FRESH BREEZE—Small trees in leaf begin to sway; crested wavelets on inland waters
6	25 – 31	STRONG BREEZE—Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty
7	32 – 38	NEAR GALE—Whole trees in motion; inconvenience felt when walking against the wind
8	39 – 46	GALE—breaks twigs off trees; generally impedes progress
9	47 – 54	SEVERE GALE—Slight structural damage occurs (chimney-pots and slates removed)
10	55 – 63	STORM—Seldom experience inland; trees uprooted; considerable structural damage occurs
11	64 – 72	VIOLENT STORM—very rarely experienced; accompanied by widespread damage
12	72 – 83	HURRICANE

Source: (NWS 2016)

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, down-sloped kona wind gusts can reach over 100 mph, which are hurricane-force winds (HI EMA 2023).

More significant wind impacts, such as blown roofs or uprooted trees typically do not occur until wind speeds of 40 mph or greater are reached. Minor impacts, such as broken tree branches, are possible with minor wind gusts of 35 mph.

Warning Time

Meteorologists can often predict the likelihood of a high windstorm 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 quickly resulting in 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 percent to 30 percent higher (HI EMA 2023).

The National Weather Service Honolulu Forecast Office issues specific watches, warnings, and advisories when weather threatens the state. For wind events not associated with a tropical cyclone, the following products may be issued (NWS 2024) to alert the public to potential on-shore wind impacts.

- **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 frequent gusts over 66 mph.
- **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.
- **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 frequent gusts over 66 mph. Wind warnings may be issued up to 24 hours ahead of the onset of high winds.

20.1.4 PREVIOUS OCCURRENCES

This section provides an overview of hazard occurrences since the publication of the previous LHMP, covering the period between January 2020 and February 2025. It identifies events that resulted in federal disaster declarations and/or state or local emergency proclamations. For events prior to 2025, refer to the 2020 LHMP.

Recent Events

Table 20-2 shows recent events for Oʻahu. This table includes events sourced from NOAA's NCEI database.

Table 20-2. Windstorm Events in the City and County of Honolulu (2020 to 2024)

Event Date	Disaster Declaration/ Proclamation			Description
	Federal	State	Mayoral	
January 7, 2020	—	—	—	Gusty trade winds caused by strong high pressure centered northeast of the islands downed a tree along the H-3 Freeway on Oʻahu. For a time, the tree blocked the Kaneohe-bound lane of the roadway about five miles west of the town. Otherwise, there were no reports of serious property damage or injuries. $2,000 in crop damage was reported.

Event Date	Disaster Declaration/ Proclamation			Description
	Federal	State	Mayoral	
February 20, 2020	—	—	—	Strong winds caused several trees to fall on Tantalus Drive on O'ahu, which closed the roadway in both directions for a time. Also, gusty winds brought down a power line on the Big Island, which closed the Old Mamalahoa Highway for a time near Puaono Road in Ahualoa. There were no reports of serious injuries. $15,000 in crop damage was reported.
February 29, 2020	—	—	—	Blustery winds toppled a tree onto Waiāhole Valley Road near Waiāhole Elementary School in windward O'ahu. The road was closed for a time due to the tree blocking both lanes of the roadway. No serious injuries were reported. $5,000 in crop damage was reported.
March 25, 2020	—	—	—	Power lines and poles, and several trees, were felled by blustery trade winds on the Big Island and O'ahu. No serious injuries were reported. $10, 000 in property damage and $6,000 in crop damage were reported.
February 28, 2021	—	—	—	Gusty winds toppled a tree near the Mililani Golf Course, injuring someone in the area on the 28th. No other injuries or property damage were reported. $2,000 in crop damage was reported.
March 1, 2021	—	—	—	Gusty trade winds helped keep showers moving as an upper trough induced downpours from the Big Island to O'ahu. A large ironwood tree fell onto a vehicle on Kamehameha Highway near Kahana Bay. Two individuals were injured. $1,000 in crop damage was reported.
November 21, 2022	—	—	—	East winds around 26 kts with localized gusts over 35 kts, were reported across portions of the central Hawaiian Islands through the Big Island. County officials reported Tantalus Drive was closed in both directions due to a fallen tree. Observations showed frequent gusts to 35 knots in the area around the time of the report.
November 24 to 25, 2022	—	—	—	A period of high winds was noted across portions of the islands on Thanksgiving, Thursday November 24th. Frequent gusts between 34 and 49 kts were reported. Sporadic power outages occurred during the event. On O'ahu, approximately 760 customers were without power in the Kailua area and approximately 1300 customers were without power in the Kalihi area. The power outages were mainly between 10:00am and 1:00pm. The mesonet station in the O'ahu Forest National Wildlife Refuge reported a 45 kt wind gust.

Event Date	Disaster Declaration/ Proclamation			Description
	Federal	State	Mayoral	
December 18 to 19, 2022	—	—	—	At the summits on Big Island, sustained west winds were recorded over 43 kts with gusts over 104 kts, with a max wind gust recorded at 144 kts on Dec 19th. Otherwise, at lower elevations, southwest winds over 35 kts, with localized gusts over 60 kts, were recorded at various locations across the islands. The winds were the result of a strong early season cold front which dropped across the state from the northwest
January 29, 2023	—	—	—	An extended period of gusty trade winds developed over the western portions of the state, between a high-pressure system northwest of Kauai and a surface trough over Maui County. The gusty winds affected portions of O‘ahu, Kauai and Niihau.
February 9 to 10, 2023	—	—	—	A period of gusty east winds sustained up to 35 kts with localized gusts near 50 kts generated some damage for portions of the Hawaiian Island chain. County officials reported that Pensacola St. was closed between Nehoa Street and Piikoi Street due to a downed pole and electrical wires. It was also reported that more than 2,100 customers were without power in the Makiki area due to the strong winds.
March 8, 2023	—	—	—	An extended period of stronger wind gusts generated some damage to trees and power lines across portions of Kauai, O‘ahu and Big Island.
April 18 to 19, 2023	—	—	—	Observing equipment reported gusts as high as 39-48 kts which uprooted some trees, knocked out power, and displaced shingles. The utility company reported 24,000 customers without power on the island of O‘ahu due to strong winds.
August 8,2023	—	—	—	Strong winds impacted the Hawaiians islands. A strong high pressure to the north of the state and Hurricane Dora far to the south helped to drive the strong northeast winds. Hundreds of customers experienced power outages due to the high winds.
January 8, 2024	—	—	—	A strong cold front impacted the Hawaiian Islands and brought periods of heavy rain and gusty winds. This resulted in flooding over portions of the islands as well as wind damage. $10,000 in property damage reported.

Event Date	Disaster Declaration/ Proclamation			Description
	Federal	State	Mayoral	
January 16, 2024	—	—	—	A cold front caused flooding and wind damage over portions of the islands. Kaneohe had approximately 4,990 customers without power. Haleiwa had approximately 1,510 customers without power.
May 15-22, 2024	—	Emergency Proclamation Related to Kona Low Weather Event	—	On May 15, 2024, Governor Green proclaimed a state of emergency in all counties due to a forecasted kona low weather event that brought heavy and sustained rainfall to the state.

Source: (NOAA NCEI 2024)

Federal Disaster Declarations

Under the Stafford Act, the President of the United States may issue an Emergency Declaration (EM) or Major Disaster Declaration (DR) and activate certain federal assistance programs based on factors related to the magnitude of the hazard threat or impacts. No Stafford Act declarations for this hazard type that included the City occurred during this period.

State and Local Emergency Proclamations

State law authorizes the Governor to issue emergency proclamations if an emergency or disaster has occurred, or there is imminent danger or threat of an emergency or disaster in any portion of the state. County Mayors have the authority to issue local emergency proclamations when such conditions exist within any part of their respective jurisdictions. One state emergency proclamation related to this hazard was issued for the City during this period, as noted in Table 20-2.

20.1.5 PROBABILITY OF FUTURE OCCURRENCES

Information on previous windstorm occurrences in the City was used to calculate the probability of future occurrence of such events, as summarized in Table 20-3. The probability of occurrence, or likelihood of the event, is one parameter used for hazard rankings. Based on these records and input from the HMWG, the probability of occurrence for windstorm events in the City and County of Honolulu is considered “frequent.”

Table 20-3. Probability of Future Windstorm Events in the City and County of Honolulu

Hazard Type	Number of Occurrences Between 1996 and 2024	Percent Chance of Occurring in Any Given Year
Strong Wind	122	100%

Hazard Type	Number of Occurrences Between 1996 and 2024	Percent Chance of Occurring in Any Given Year
High Wind	120	100%

Source: (NOAA NCEI 2024)

Note: Windstorm events used to determine probabilities were those that are classified as strong or high winds that occurred between January 1, 1996 and August 31, 2024.

20.2 VULNERABILITY AND IMPACT ASSESSMENT

20.2.1 LIFE, HEALTH, AND SAFETY

Overall Population

The entire population of the City is exposed and vulnerable to windstorms. Certain areas are more vulnerable because of their geographic location and local weather patterns. For example, people living at higher elevations are more susceptible to experiencing damaging winds. Populated low-lying areas downslope of mountains, hills, and escarpments can experience destructive wind acceleration. Secondary impacts from wind damage, such as power outages due to downed power lines, may be more likely in these areas but can occur island wide.

Socially Vulnerable Population

Socially vulnerable populations can be particularly vulnerable to windstorm impacts. These populations include individuals over the age of 65, children under the age of 5, non-English speaking individuals, people with disabilities, and residents living below the poverty line. Additionally, those living in areas isolated from major roads are also considered socially vulnerable.

Power outages from windstorms can be life-threatening to those dependent on electricity for life support and are a significant concern. Residents living in older homes not constructed to modern codes are more likely to experience property damage and may lack the financial resources to make repairs or afford temporary housing.

20.2.2 ECONOMY AND GENERAL BUILDING STOCK

Windstorms are powerful natural events that can cause significant damage to communities. The City is particularly vulnerable to windstorm impacts. As noted earlier, it was not until 2007 that the building code adopted wind speed-up maps and required new construction to address wind amplification. There are a large number of single wall construction dwellings that are particularly vulnerable to wind impacts.

Due to the number of buildings constructed before current building codes, building stock is particularly vulnerable as many structures were constructed prior to current codes.

When estimating the potential impact on 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.

20.2.3 COMMUNITY LIFELINES AND OTHER CRITICAL FACILITIES

All community lifelines and critical facilities in the county are vulnerable to high windstorms. Loss of utilities is the most common issue with high windstorms. High winds can severely impact power transmission lines as high winds are funneled through changes in terrain, causing widespread power outages. For example, on December 26, 2008, the entire electrical grid on O‘ahu was blacked out for around 12 hours due to a kona low storm (Bachmeier 2008). Power loss results in cascading impacts on other critical utilities, such as water, wastewater and communications, which in turn can further stress the medical and safety lifelines.

Kona wind events can also disrupt the transportation lifeline. Wind generated debris can make roads impassable. Areas with limited transportation routes are vulnerable to temporary isolation until roads can be cleared. Temporary disruption of airport and harbor operations is also possible during kona low events that produce significant kona winds.

20.2.4 NATURAL, HISTORIC, AND CULTURAL RESOURCES

Natural Resources

Natural habitats such as forests and waterways are particularly vulnerable to damage from windstorms. Major damage can occur from downed or uprooted trees and other debris, which can block rivers and streams. Agricultural losses have been reported due to historic kona wind events. Generally, forest trees on the leeward side of the island are sheltered from the prevalent trade winds, but strong kona winds blow from the opposite direction and can topple trees that are not accustomed to that wind direction and intensity (HI EMA 2023).

Historic and Cultural Resources

Windstorms can have significant impacts on historic and cultural resources in the City. High winds can cause physical damage to historic buildings and monuments, including roofs, walls, windows, and other structural elements, compromising their integrity. Debris from fallen trees and branches can strike and damage these structures, and obstruct access, making repairs and preservation efforts challenging. Heavy rains accompanying windstorms can lead to water infiltration in historic buildings, causing wood rot, mold growth, and damage to interior finishes and artifacts.

In coastal areas, windstorms can cause erosion and flooding, undermining the foundations of historic buildings and leading to potential collapse. Shoreline changes can threaten archaeological sites and other historical

landscapes. The surrounding environment of historic resources can also be altered by windstorms, affecting the context and setting that contribute to their historical significance, such as the loss of historic trees, gardens, and other landscape features.

Damage from windstorms can make historic sites unsafe for visitors and staff, leading to temporary or prolonged closures. This impacts tourism and the local economy, as well as hinders ongoing preservation efforts.

Cultural resources are also at risk during high windstorms. Kona storms, with their potential for large wave heights and shoreline changes, can significantly affect cultural assets located along the coast. Erosion and flooding can damage or destroy sites of cultural importance, leading to a loss of heritage and history. Protecting these resources requires careful planning and the implementation of measures to mitigate the effects of windstorms and other natural hazards (HI EMA 2023).

20.2.5 FUTURE CHANGES THAT MAY AFFECT RISK

Understanding future changes that affect vulnerability can assist in planning for future development and ensure establishment of appropriate mitigation, planning, and preparedness measures. The following sections examine potential conditions that may affect hazard vulnerability.

Potential or Planned Development

All future developments within the City are vulnerable to high wind hazards. However, the ability to withstand impacts from high winds is based on 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 windstorm hazard will decrease.

Projected Changes in Population

Projected changes in population can significantly affect the risks associated with windstorms. As population density increases, particularly in urban and coastal areas, the potential for damage and disruption from windstorms also rises. As urban areas expand, as they are in the urban areas of Honolulu, the density of buildings increases, creating wind tunnels that can amplify wind speeds and cause more severe damage to structures and infrastructure. This urbanization effect can lead to higher economic losses and greater challenges in emergency response and recovery efforts. Additionally, windstorms may result in more frequent and severe disruption to daily life, including power outages, transportation issues, and damage to critical facilities. This can lead to higher economic losses and greater challenges in emergency response and recovery efforts (City and County of Honolulu n.d.).

Climate Change

The anticipated intensity, frequency, and duration of specific windstorm events resulting from climate change impacts is difficult to predict for a particular location in the City. To assess future high wind hazards for O‘ahu,

global climate models can be utilized, this method is known as dynamical downscaling. Dynamical downscaling is a technique that uses high resolution regional simulations to extrapolate the effects of large-scale climate processes to a smaller level. The projections from dynamical downscaling anticipate a significant decline in wind resources, particularly in the mid-latitudes of the Northern Hemisphere (HI EMA 2023).

Changes detected in the northeast trade wind, the prevailing wind over the Hawaiian Islands, may shift large-scale pressure and wind patterns that impact the State of Hawai‘i in the future. 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 county (Garza, et al. 2012).

Scientists from the University of Hawai‘i at Mānoa analyzed wind records from 1973 to 2009 at major airports in the State of Hawai‘i: Līhu‘e, 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 1997, the strongest El Niño event ever recorded weakened the northeasterly trade winds (Live Science 2015).