8. DROUGHT

8.1 HAZARD PROFILE

8.1.1 HAZARD DESCRIPTION

This section provides a description of the hazard, including causes, hazard or incident characteristics, and potential impacts.

Overview

A drought is a prolonged period of unusually dry weather caused by an extended lack of precipitation, typically spanning a season or more, which can lead to water shortages (National Integrated Drought Information System [NIDIS] n.d.). Drought diminishes natural stream flow and depletes soil moisture, which can cause social, cultural, environmental, and economic impacts. While some droughts may seem like extreme and rare events, drought is a normal and recurring part of the climate on O‘ahu. Assessing drought conditions in the City can be slightly different than other locations in the United States due to the island’s topography, climate regime, as well as available monitoring tools and water availability on the island (NIDIS n.d.).

Drought Causes and Types

The climate and associated rainfall patterns on O‘ahu are primarily influenced by the northeasterly trade winds. These winds originate from the northeast and carry moisture as they travel. Upon reaching the island, the winds first encounter the windward (eastern) side. This region receives substantial rainfall as the moist air is forced up the mountains, where it cools and condenses, resulting in precipitation. When these winds reach the leeward (western) side, most of the moisture has already been released as rain on the windward side. Consequently, the leeward regions tend to be drier and sunnier. This variation in rainfall between the windward and leeward sides can lead to drought conditions on the leeward regions.

On O‘ahu, drought conditions are frequently linked to El Niño events, a natural climate phenomenon that occurs in the Pacific Ocean that typically results in reduced trade winds and precipitation (NIDIS n.d.). El Niño events are characterized by the warming of the ocean’s surface in the central and eastern tropical Pacific Ocean near the equator. This warming affects the trade winds, which normally blow from east to west across the equatorial Pacific, but weaken, or even reverse, during El Nino. (NOAA 2025).

For O‘ahu, El Niño typically results in decreased precipitation due to a southerly shift in the atmospheric circulation system known as the Hadley Cell, which moves the rain-bearing winds away from the island. Historical data shows that the ten driest years on record for O‘ahu are associated with El Niño events. Studies

indicate a 90 percent chance of a dry winter and an 80 percent chance of a dry spring following the onset of El Niño (Lu, et al. 2020).

The National Drought Mitigation Center (NDMC) defines several types of droughts, as summarized in Table 8-1.

Table 8-1. Types of Droughts

Type of Drought	Definition	Impact
Meteorological	Meteorological drought is defined by a significant reduction in precipitation over a specific period, compared to the long-term average for the region.	Meteorological droughts are often the first indication of drought conditions and can lead to other types of.
Agricultural	Agricultural drought occurs when soil moisture is too little to meet the needs of crops at a particular time, especially during the growing season.	This type of drought can lead to food shortages and economic losses in farming communities.
Hydrological	Hydrological drought is characterized by reduced water levels in rivers, lakes, reservoirs, and groundwater supplies due to a lack of precipitation over an extended period.	This type of drought impacts water supply for human uses and can also affect aquatic ecosystems.
Socioeconomic	Socioeconomic drought happens when the demand for water exceeds the available supply due to drought, with impacts on society and the economy.	This type of drought can lead to water rationing, increased water costs, loss of income, and forced migration.
Ecological	Ecological drought focuses on the impact of prolonged water deficits on ecosystems, including plants, animals, and habitats.	This type of drought can lead to loss of biodiversity, degradation of habitats, increased wildfire risk, and long-term damage to natural landscapes.

Source: (NDMC 2024)

Potential Impacts

Droughts can trigger a range of impacts:

- Water Resources—O‘ahu is less susceptible to drought risk and associated vulnerabilities compared to the islands of Hawai‘i and Maui, where water systems rely in part on surface water sources such as streams and rivers that are more vulnerable to decreased rainfall and increased evaporation during dry periods. Groundwater aquifers, formed as rainwater seeps through porous volcanic rock, are the sole source of potable water. This reliance on groundwater contributes to the decreased risk of the public water supply in comparison to other Hawaiian islands. However, prolonged drought conditions can deplete this resource and affect drinking water availability. Prolonged drought conditions can also affect drinking water quality, by elevating the risk of contamination in the waterways that recharge the aquifers, coupled with the potential for inadequate water retention within the aquifers themselves. Droughts reduce the volume of water in rivers and streams, leading to a higher concentration of pollutants in the remaining water that recharges aquifers (CDC 2024).

- Agriculture—Farms and ranches can experience crop failures and poor pasture conditions, leading to economic losses and the need for supplemental feed and water.
- Ecosystems—Droughts can reduce streamflow and damage natural habitats, including coral reefs, as runoff carries sediment when rains return.
- Wildfires—Dry conditions can increase the risk of wildfires by making vegetation more flammable. Wildfires not only destroy native plants but also support the spread of fire-adapted invasive species, creating a cycle of increasing risk.

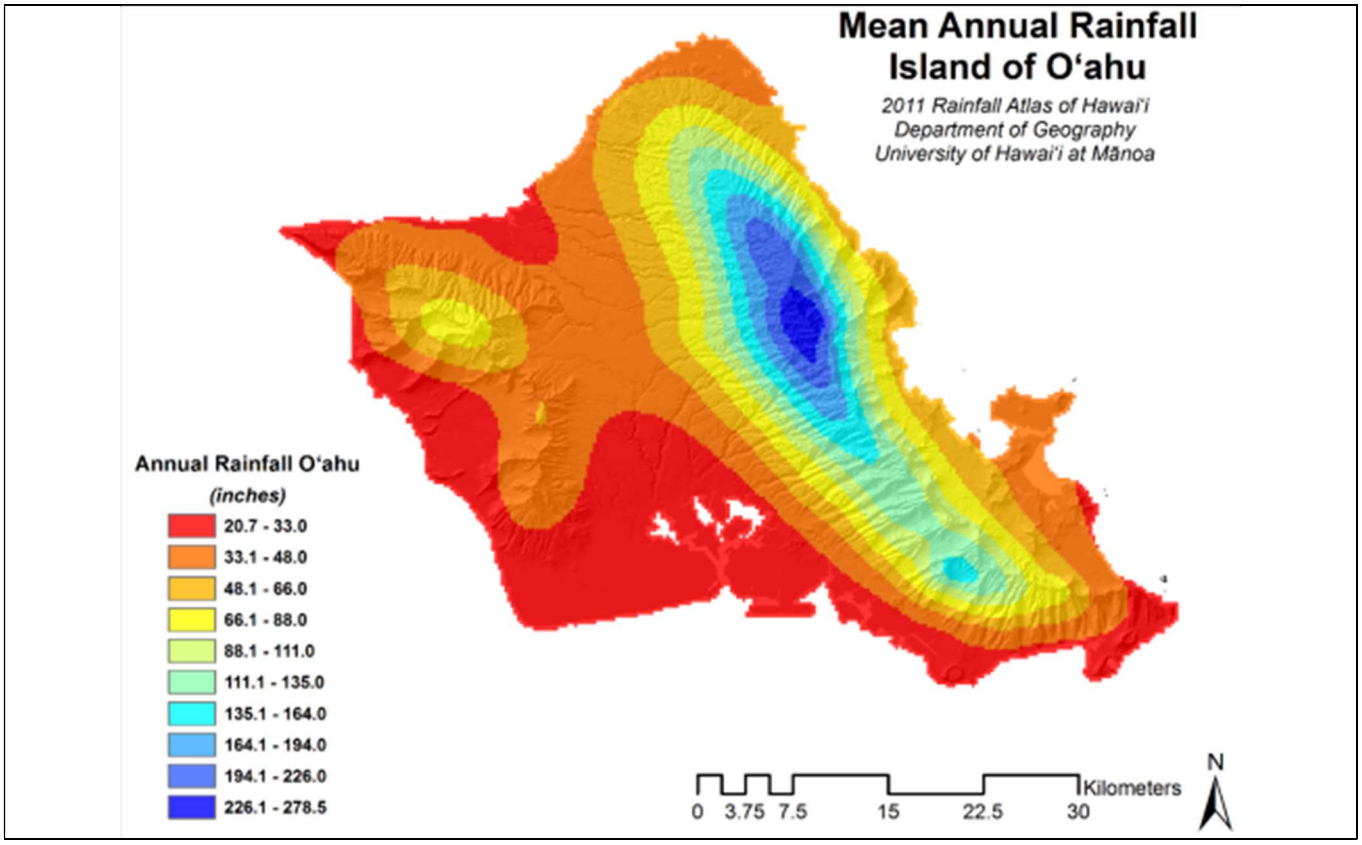
Lack of rainfall is not the only factor contributing to the impacts of drought. The demands placed on water systems and supplies by societal activities also play a significant role. Factors such as population growth, irrigation, and environmental needs create additional demands on available water resources.

8.1.2 LOCATION

This section describes mapped hazard areas and areas of greater vulnerability based on their physical location.

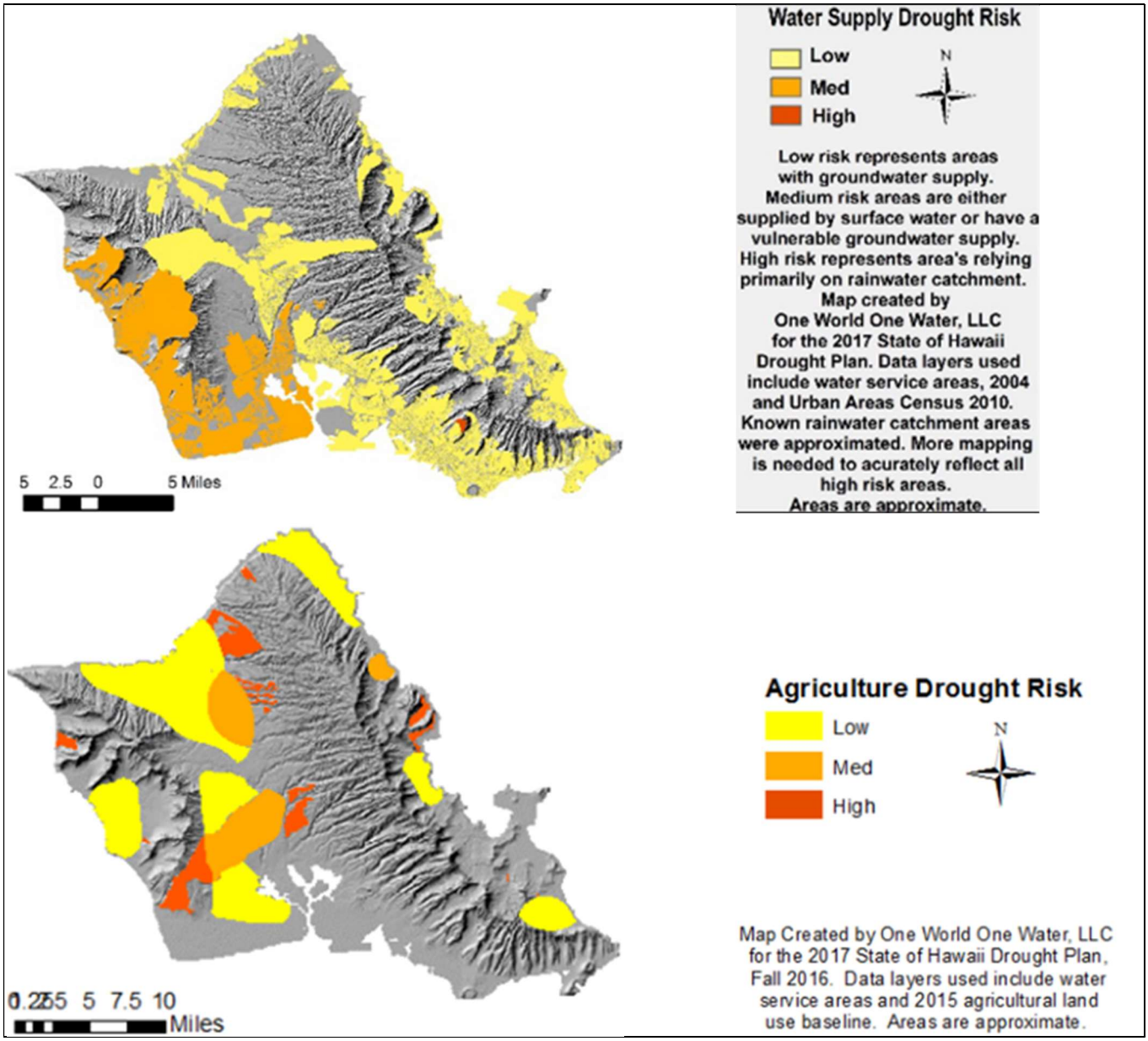
As discussed previously, trade winds significantly influence precipitation across the island, resulting in greater rainfall amounts on the windward (eastern) side of the island in comparison to the leeward (western) side of the island. Figure 8-1 illustrates the average rainfall distribution throughout the island, highlighting that leeward areas receive significantly less rainfall than the windward side. This difference in rainfall increases the susceptibility of drought conditions in the west, particularly during El Nino conditions. Additionally, the growing population in the leeward and central portions of the island, where rainfall is low, poses further challenges in regard to water supplies and demands (DLNR 2017).

Figure 8-1. Average Annual Precipitation for O'ahu



While trade winds and El Niño phenomena offer insights into the general regions susceptible to drought, local drought conditions are also significantly affected by the island's water demand and land use practices that elevate drought risk, such as agricultural activities. For instance, the population growth in the leeward and central regions of the island contributes to increased pressure on water resources in areas that already experience lower rainfall compared to other parts of the island. Although the island's agricultural land is limited, areas such as Kunia and the North Shore, which contain larger expanses of farmland and agricultural activities are more vulnerable to drought in comparison to the more urbanized regions of the island. Figure 8-2 shows the general risks to the water supply and agricultural lands in the City.

Figure 8-2. Water Supply and Agricultural Drought Risk in the City



Source: (DLNR 2017)

8.1.3 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 severity of a drought depends on the degree of moisture deficiency, the duration, and the size and location of the affected area. The longer the duration of the drought and the larger the area impacted, the more severe the potential impacts. Droughts are not usually associated with direct impacts on people or property, but they can have significant impacts on agriculture, which can impact people indirectly. When measuring the severity of droughts, analysts typically look at economic impacts on an area (HI EMA 2023).

The U.S. Drought Monitor (USDM) identifies areas in drought and labels them by intensity. The map uses four categories of drought, from D1, the least intense, to D4, the most intense. It also highlights areas with no drought and uses the D0 category to indicate abnormally dry areas that could be entering or recovering from drought (USDM 2024). See Table 8-2 for a full description of these categories.

Table 8-2. USDM Drought Categories

Category	Description	Example Percentile Range for Most Indicators	Values for Standard Precipitation Index	Possible Impacts
None	Normal or Wet Conditions	30.01 or Above	-0.49 or above	None
D0	Abnormally Dry	20.01 to 30.00	-0.5 to -0.79	Going into drought: Short term dryness slowing planting and growth of crops or pastures Going out of drought: Some lingering water deficits, pastures or crops not fully recovered
D1	Moderate Drought	10.01 to 20.00	-0.8 to -1.29	Some damage to crops, pastures Streams, reservoirs, or wells low, some water shortages developing or imminent Voluntary water-use restrictions requested
D2	Severe Drought	5.01 to 10.00	-1.3 to -1.59	Crop or pasture losses likely Water shortages common Water restrictions imposed
D3	Extreme Drought	2.01 to 5.00	-1.6 to -1.99	Major crop/pasture losses Widespread water shortages or restrictions
D4	Exceptional Drought	0.00 to 2.00	-2.0 or less	Exceptional and widespread crop/pasture losses Shortages or water in reservoirs, streams, and wells creating water emergencies

Source: (USDM 2024) (DLNR 2017)

The National Drought Mitigation Center developed the Drought Impact Reporter in response to the need for a national drought impact database for the United States. The Drought Impact Reporter maps the effects of drought, based on reports from media, observers, and other sources. Impacts are an observable loss or change at a specific place and time due to drought. The Drought Impact Reporter is not a comprehensive set of data but can be useful in tracking drought and can potentially aid in better understanding and responding to drought

impacts. However, it is important to note that drought impacts in the Drought Impact Reporter are likely under-reported since submissions are made on a purely voluntary basis or picked up from media reports.

Drought Monitoring and Forecasting

There are two popular drought indices used in Hawai'i to monitor and forecast droughts: the Standardized Precipitation Index (SPI) and the Percent of Normal Rainfall Index. A third index, the Keetch-Byram Drought Index, is used by the National Weather Service to track wildland fire fuel conditions and to assess the potential for wildland fire.

Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) considers only precipitation and is used to measure and understand rainfall patterns. The SPI compares the actual amount of rainfall to what is normal for a specific place and time, rather than using an average of rainfall. As a result, the SPI is able to accurately represent different seasons and climates since it is not dependent on an average (NOAA/NWS Honolulu 2020).

The SPI values range is broken down into seven categories. The zero mark on the SPI scale refers to the median precipitation amount. Negative values indicate drier than average conditions, while positive values signify wetter than average conditions. The SPI for O'ahu can vary, but it generally falls between -2.00 and 2.00. Table 8-3 shows the SPI Values and their descriptions.

Table 8-3. SPI Values and Descriptions

SPI Value	Description
≥ 2.00	Extremely Wet
1.50 to 1.99	Very Wet
1.00 to 1.49	Moderately Wet
0.99 to -0.99	Near Normal
-1.00 to -1.49	Moderately Dry
-1.50 to -1.99	Very Dry
≤ -2.00	Extremely Dry

Source: (NOAA/NWS Honolulu 2020)

Percent of Normal Rainfall Index

The Percent of Normal Rainfall Index (PNRI) is a simple calculation that compares actual precipitation to the long-term average for a specific location and time period. The PNRI is one of the simplest methods of comparing current precipitation amounts to recorded historical averages. The index is calculated by dividing the actual precipitation amount, typically a 30-year precipitation mean. The PNRI can be calculated for various time scales,

including daily, weekly, monthly, seasonal, and annual. The PNRI is effective for assessing how dry a location is compared to normal but does not account for other factors that contribute to drought, such as soil moisture, temperature, and water demand. The PNRI is often used in conjunction with other drought indices.

KEETCH-BYRAM DROUGHT INDEX

The Keetch-Byram Drought Index (KBDI) describes soil moisture deficit with values ranging from 0 to 800. A value of 800 indicates extreme drought, and a value of 0 reflects saturated soil. The KBDI is calculated using weather station latitude, mean annual precipitation, maximum dry bulb temperature (usually referred to as air temperature), and previous 24-hour rainfall. KBDI at the Honolulu International Airport fluctuates through the year, while values in excess of 600 represent the highest 34% of values from 1975-2010. A KBDI of greater than 600 is typically encountered by late July and normally persists through late October. The National Weather Service (NWS) issues Red Flag Warnings when all three of the following conditions are met for two hours or more during any part of a day at the Honolulu International Airport (NWS Honolulu 2022):

- KBDI ≥ 600
- Minimum Relative Humidity ≤ 45 % (2 hours or more)
- Wind ≥ 20 mph (≥ 17 knots) (2 hours or more)

WARNING TIME

Droughts are climatic patterns that occur over long periods of time. Only generalized warning can take place due to the numerous variables that scientists have not pieced together well enough to make accurate and precise predictions. Predicting drought depends on the ability to forecast precipitation and temperature. Anomalies of precipitation and temperature may last from several months to several decades. How long droughts last depends on interactions between the atmosphere and the oceans, soil moisture and land surface processes, topography, internal dynamics, and the accumulated influence of weather systems on the global scale (Zhou, et al. 2019). Though only generalized warnings can take place, the U.S. Drought Monitor provides a current and recent history of areas and populations affected by drought (USDM 2024).

El Niño events are strongly correlated with drought on O‘ahu and are one of the only indicators available of potential drought conditions on O‘ahu. There is an approximately 70% chance of a drier than normal winter season following the onset of an El Niño event. This can give a lead time of up to 12 months or so to prepare for a potential drought, though drought intensity and duration cannot be predicted. It is very difficult to predict an El Niño event, but scientists monitor various ocean and atmospheric elements associated with these events and utilize complex computer models to make El Niño forecasts.

8.1.4 PREVIOUS OCCURRENCES

This section provides an overview of droughts 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 2020, refer to the 2020 LHMP.

Recent Events

Table 8-4 shows recent events for O‘ahu. Events listed in this table are those that resulted in a federal declaration or were categorized as D2 (severe drought) by USDM.

Table 8-4. Drought Events in the City (2020 to 2024)

Event Date	Disaster Declaration/ Proclamation			Description
	Federal	State	Mayoral	
September 15-30, 2020	USDA: S4863	-	-	A lack of rainfall hurt portions of O‘ahu and the Big Island, driving these areas into the D2 category of severe drought.
October 1-November 17, 2020	-	-	-	Portions of Niihau, O‘ahu, Molokai, Lanai, Maui, Kahoolawe, and the Big Island remained dry through October. Severe (D2) drought conditions persisted over portions of O‘ahu's South Shore through the middle of November before conditions improved. The Waianae area of leeward O‘ahu was in the D2 category for about 10 days at the beginning of November.
July 20-December 14, 2021	USDA: S5073	-	-	Dry conditions in Hawai‘i affected O‘ahu and Maui and worsened into severe drought (D2) by late July. Early September rainfall improved conditions for parts of O‘ahu, but dry conditions persisted statewide, with some areas worsening to extreme (D3) and exceptional drought (D4) by November. Mid-December saw some improvement in drought conditions.
March 15-October 18, 2022	USDA: S5185	-	-	Dry conditions across Hawai‘i in March affected O‘ahu, Lanai, the Big Island, Maui, Kahoolawe, and Molokai, moving them into severe drought (D2). The dry spell continued through April, with areas in severe (D2) or extreme (D3) drought. By June, very dry conditions affected six islands, with drought categories ranging from severe (D2) to exceptional (D4). Dry conditions continued through October, with some improvement to moderate drought (D1) by mid-October.
September 1 - November 30, 2023	USDA: S5628	-	-	Low rainfall caused severe drought conditions in parts of O‘ahu, with some areas experiencing severe to extreme drought (D2-D3).
August 1-31, 2024	-	-	-	Below average rainfall over the western portion of O‘ahu led to dry severe drought conditions.

Source: (NOAA NCEI 2024) (USDA 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. However, the U.S. Department of Agriculture (USDA) declared four drought disasters, as listed in Table 8-4.

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. No state or local emergency proclamations related to this hazard were issued for the City during this period.

8.1.5 PROBABILITY OF FUTURE OCCURRENCES

Information on previous drought occurrences in the City was used to calculate the probability of future occurrence of such events. Table 8-5 lists the number of events from various sources to include the NOAA NCEI Storm Events Database and USDA from 1996 to 2024, which is the most complete period of record for all sources reviewed. Based on these records the probability of occurrence for drought in the City is considered "highly likely."

Table 8-5. Probability of Future Drought Events in the City

Hazard Type	Number of Occurrences Between 1996 and 2024	Percent Chance of Occurring in Any Given Year
Drought	218	100%

Source: (NOAA NCEI 2024) (USDA 2024)

Note: The time period presented in this table is the most complete period of record for the various data sources reviewed.

8.2 VULNERABILITY AND IMPACT ASSESSMENT

To understand risk, a community must evaluate what assets are exposed and vulnerable in the identified hazard area. The following text qualitatively evaluates the potential impact of the drought hazard on life, health, and safety; the general building stock; the economy; critical facilities; and the environment.

8.2.1 LIFE, HEALTH, AND SAFETY

Overall Population

Directly or indirectly, the entire population of O'ahu is vulnerable to drought events. Drought can have secondary impacts that affect people's health and safety. Impacts can lead to reduced quantity of drinking water supplies, water restrictions for residents, or physical safety impacts related to increased wildfire risk.

Socially Vulnerable Population

While the impacts of drought in the City are comparatively lower than in other areas within the State, the City's socially vulnerable populations may still face disproportionate challenges. A significant portion of the agricultural workforce are immigrants who are paid low wages and will be disproportionality impacted by drought impacts on the agricultural sector. Water restrictions or water quality issues created by drought can health-related effects on socially vulnerable groups, particularly those with chronic health conditions.

8.2.2 ECONOMY AND GENERAL BUILDING STOCK

Drought causes the most significant economic impacts on industries that use water or depend on water for their business, such as agriculture, aquaculture, and landscaping businesses. In addition to losses in yields in crop and livestock production, drought is associated with increased insect infestations, plant diseases, and wind erosion. Drought can lead to other losses, including reduced income for farmers and reduced business for retailers and others who provide goods and services to farmers. (NIDIS n.d.)

According to the 2022 Census of Agriculture for the City, there are 60,254 acres in agricultural use (USDA 2022). If the City loses its agricultural yield because of drought, total losses could amount to over $192,823,000. Table 8-6 shows total value of agricultural products that are exposed to drought conditions.

A drought is not expected to directly affect any structures, and all are expected to be operational during a drought event.

Table 8-6. Estimated Loss Relating to Agricultural Production

Land in Farms by Use	Impacted Farmland Acreage		Market Value of All Agricultural Products	
Cropland	22,756		Crops	$168,670,000
Pastureland	23,489			
Woodland	4,587		Livestock, Poultry, and Products	$24,153,000
Other	9,422			
Total	60,254		**Total**	**$192,823,000**

Source: (USDA 2022)

8.2.3 COMMUNITY LIFELINES AND OTHER CRITICAL FACILITIES

While drought does not directly impact structures, it can significantly affect water-dependent community lifelines and critical facilities in the City. The community lifelines that are primarily impacted by drought include water systems and food, hydration, and shelter health.

Prolonged drought in the City can have impacts on the water quality of aquifers and groundwater resources as previously discussed. Rainfall shortages during prolonged periods can exacerbate the limits placed on groundwater pumping during drought periods.

Although Oʻahu has fewer lands devoted to agriculture compared to other islands, making it less vulnerable, drought impacts are highly dependent on whether crops are irrigated. Unirrigated pastures, orchards, and other fields are most vulnerable to droughts, while irrigated agricultural areas become more vulnerable when water supplies are threatened. In agricultural areas such as Kunia, persistent shortages of rainfall and the resultant lack of soil moisture can lead to reduced ground cover and lower agricultural yields.

8.2.4 NATURAL, HISTORIC, AND CULTURAL RESOURCES

Natural Resources

Environmental losses from drought in the City are associated with damage to plants, animals, wildlife habitat, and air and water quality. This includes wildland fires, degradation of landscape quality, loss of biodiversity, and soil erosion. Some effects are short-term, while others may linger or become permanent (HI EMA 2023).

Watersheds are crucial for replenishing Oʻahu's groundwater aquifers, which supply most of the City's drinking water. Healthy watersheds also reduce polluted runoff into nearshore waters and support healthy stream ecosystems. Drought-induced ecosystem damage or wildfires can decrease ground and surface water supplies, harming nearshore waters and reef ecosystems.

Wildlife habitat may be degraded through the loss of wetlands, lakes, and vegetation. Many species will eventually recover, but the degradation of landscape quality, including increased soil erosion, may lead to a more permanent loss of biological productivity. Vegetation and wildlife impacts can include death from dehydration and the spread of invasive species or disease due to stressed conditions. Invasive species pose problems for the ecosystems in which they are introduced, with both direct and indirect impacts

When groundwater is not replenished, aquifer and well water levels diminish, making irrigation and drinking water difficult to obtain. Contamination of surface water sources can occur during drought conditions, leading to increased pollutant levels and lower oxygen levels in reservoirs. This contributes to higher concentrations of illness-causing bacteria, protozoa, and toxic blue-green algae blooms. Reduced aquifer recharge and depletion of aquifer storage may affect groundwater discharge to coastal nearshore waters, negatively impacting groundwater-dependent ecosystems.

Historic and Cultural Resources

Drought can have several detrimental effects on cultural historic resources. It can cause soil desiccation, leading to the destabilization of foundations and structures. This can result in cracks and other structural damage to historic buildings. Additionally, drought can increase the risk of wildfires, which can threaten historic sites and artifacts. The lack of moisture can also accelerate the deterioration of materials such as wood, stone, and adobe, further compromising the integrity of historic resources (NIDIS n.d.).

Droughts may impact Native Hawaiian traditional and customary practices, which rely on healthy terrestrial, marine, and groundwater-dependent ecosystems. These practices may include the collection of plants, animals, and minerals. Drought and its secondary impacts can damage watersheds and nearshore waters, impairing or impeding the exercise of traditional and customary practices (HI EMA 2023).

8.2.5 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

Drought conditions and development are interrelated. As water is drawn down from increased rates of use, drought can occur more readily than from lack of precipitation alone. Additionally, newly developed land or expansion into upland forested areas may reduce groundwater recharge as more land becomes impermeable. This development can lead to decreased natural water infiltration, further stressing water resources and increasing the risk of drought.

Projected Changes in Population

As the resident and visitor populations on O‘ahu continue to increase, the stresses on the City’s water sources will also rise. More resources will be needed for human use and consumption, further taxing these resources amid changing climate conditions. Increased population growth will demand more water, intensifying the risk of drought (HI EMA 2023).

Climate Change

Climate change is expected to increase the occurrence of both meteorological and agricultural droughts on O‘ahu. This will likely lead to more frequent wildfires, which can devastate native plant species and promote the spread of fire-adapted invasive species. Additionally, rising temperatures, higher levels of nutrients and sediments, and reduced dilution of pollutants will pose significant threats to local ecosystems. These changes will further strain water resources, heightening the risk of drought and impacting both the natural environment and cultural practices on the island.

Studies have shown that there are fewer days with northeast trade winds now compared to 40 years ago (Garza, et al. 2012). The northeast trade winds are crucial for much of the rainfall, especially in windward areas. As the frequency of these winds decreases, total rainfall also declines, resulting in more drought conditions. Over the past 100 years, O‘ahu has experienced longer, more severe, and more frequent droughts (Frazier, et al 2022).