SECTION 4. RISK ASSESSMENT

4.5 Drought

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).
- Drought events that occurred in the State of 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 droughts.
- Provided a qualitative vulnerability assessment at the local (county) level of risk to the population, general building stock, and environmental resources and cultural assets from droughts.
- Included a qualitative vulnerability assessment of droughts in regard to future changes in development.

4.5.1 Hazard Profile

Hazard Description

A drought is a period of abnormally dry weather. Drought diminishes natural stream flow and depletes soil moisture, which can cause social, cultural, environmental and economic impacts. In general, the term "drought" should be reserved for periods of moisture deficiency that are relatively extensive in both space and time.

Drought can be characterized from the perspectives of meteorology, agriculture, hydrology, and socio-economic impacts. For example, the meteorological perspective would describe drought as a rainfall deficit compared with some normal or expected rainfall amount. The agricultural perspective could describe drought by its impacts on the agricultural industry due to reduced rainfall and water supply (e.g., crop loss, herd culling, etc.). Hydrological descriptions of drought may compare stream flows, ground water, and reservoir levels to normal conditions. Drought can also be described from the socio-economic perspective by the direct and indirect impacts droughts have on society and the economy (e.g., increased unemployment due to failure of an industry because of drought).

Lack of rainfall is not the only factor contributing to the impacts of drought. Both natural events and human activities; such as expanding populations, irrigation, and environmental needs; put pressure on water supplies. Lack of rainfall combined with the demands society place on water systems and supplies contribute to drought impacts.

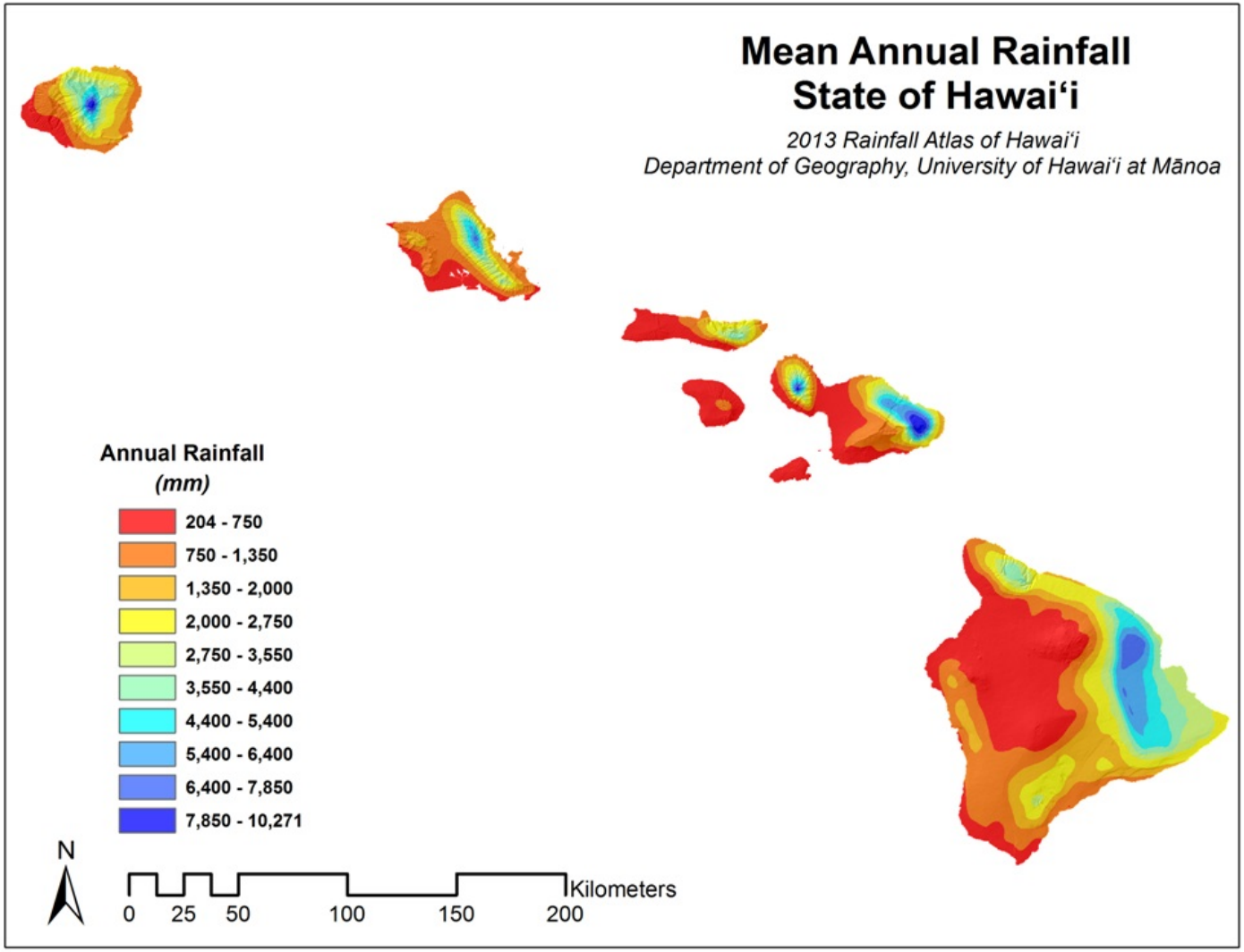
Average Rainfall

The climate, and hence the amount of rainfall, of the Hawaiian Islands is directly influenced by the northeasterly trade winds. Typically, leeward locations (south and west shores) are much drier and sunnier than windward

locations (north and east shores). Within leeward and windward locations, however, rainfall varies considerably according to elevation. It should be noted that a recent study has shown fewer days with northeast trade winds than 40 years ago (Garza et al., 2012). Fewer days of northeast trade winds leads to more muggy weather and volcanic haze and results in longer-term effects for the state. The trade winds are responsible for much of the rainfall, especially in windward areas. As their occurrences decrease, so will the total rainfall, leading to more drought conditions. Over the last 30 years, the State of Hawaiʻi has experienced more frequent droughts and nearly half the state experienced some degree of drought in 2012 (University of Hawaiʻi at Mānoa Sea Grant College Program 2014; Gutierrez 2012).

Figure 4.4-1 shows a map of the main Hawaiian Islands indicating the average annual precipitation for the 30-year period between 1982 and 2011.

Figure 4.5-1. Mean Annual Precipitation Rainfall for the Main Hawaiian Islands



Source: Giambelluca et al. 2013

El Niño and La Niña

During El Niño, summers can have above average rainfall that extends the growing season and increases fuel loads, especially in drier areas where plant growth is limited by lack of rainfall. Extended drought through the winter months then causes vegetation to dry out, which can significantly increase wildfire risk, especially for windward parts of the state that are usually wet year-round (Trauernicht 2015).

La Niña is the opposite end of the oscillation. During these events, most of the tropical Pacific Ocean is cooler than average, and surface winds are stronger than normal. Rainfall decreases over the cooler central Pacific Ocean, including the State of Hawai‘i. While La Niña is historically associated with wetter than normal rainfall in Hawai‘i, drought conditions are still possible during these events.

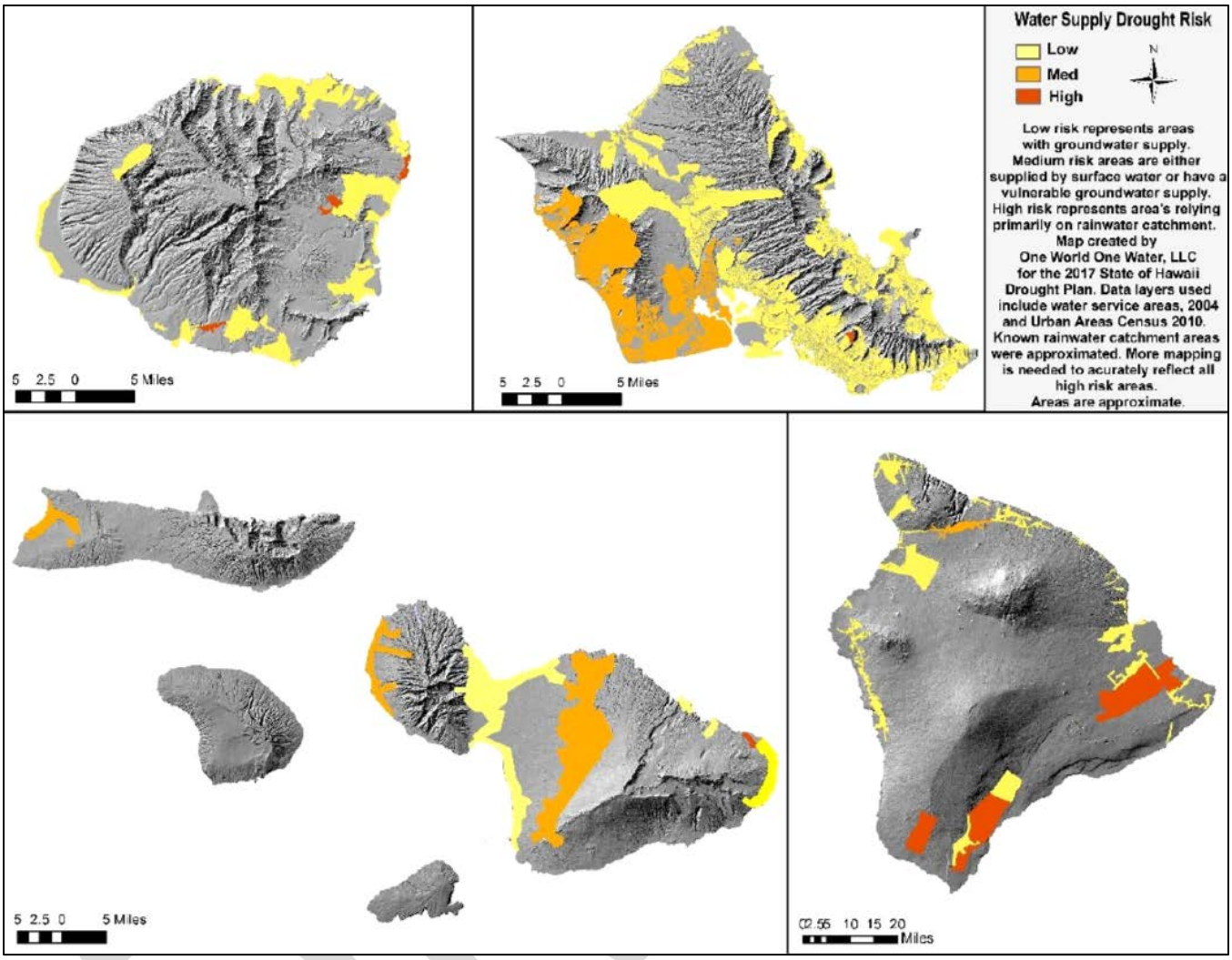
LOCATION

All areas of the state are susceptible to drought, although the extent and severity of the drought will depend on the variance of rainfall throughout the state based on location. The identification of areas that are vulnerable to drought impacts is difficult due to the differences in microclimate and impact sectors. Figure 4.5-2 and Figure 4.5-3 show general risks to the water supply and agriculture and commerce sectors, respectively. For water supply, residents who rely primarily on rainwater catchment are at the highest risk (shown in red in Figure 4.5-2) to drought because they could run out of water from a week or two of reduced rainfall. The lowest risk to drought are those water supply areas that have adequate groundwater sources. Only a severe extended period of drought would affect these sources. It should be noted that water supply sources will only become more vulnerable with climate change. For further information, refer to the Hawai‘i Drought Plan 2017 Update. The ‘Impacts on Climate Change’ subsection presented below details on how climate change will impact drought throughout the State of Hawai‘i.

Figure 4.5-3 identifies agricultural areas that are more vulnerable to drought conditions. If the water supply source for the region is groundwater, it has a lower risk during periods of drought as it can most likely still withdraw water from groundwater to irrigate crops. Areas that rely on surface water have a medium drought risk as they typically have some ability to store water, although sources can run out in an extended drought period. Unirrigated areas, mostly pastures, are at highest risk because they rely directly on rainfall for productivity. Drought risk may change in the future due to changes in land use, water access, and climate change.

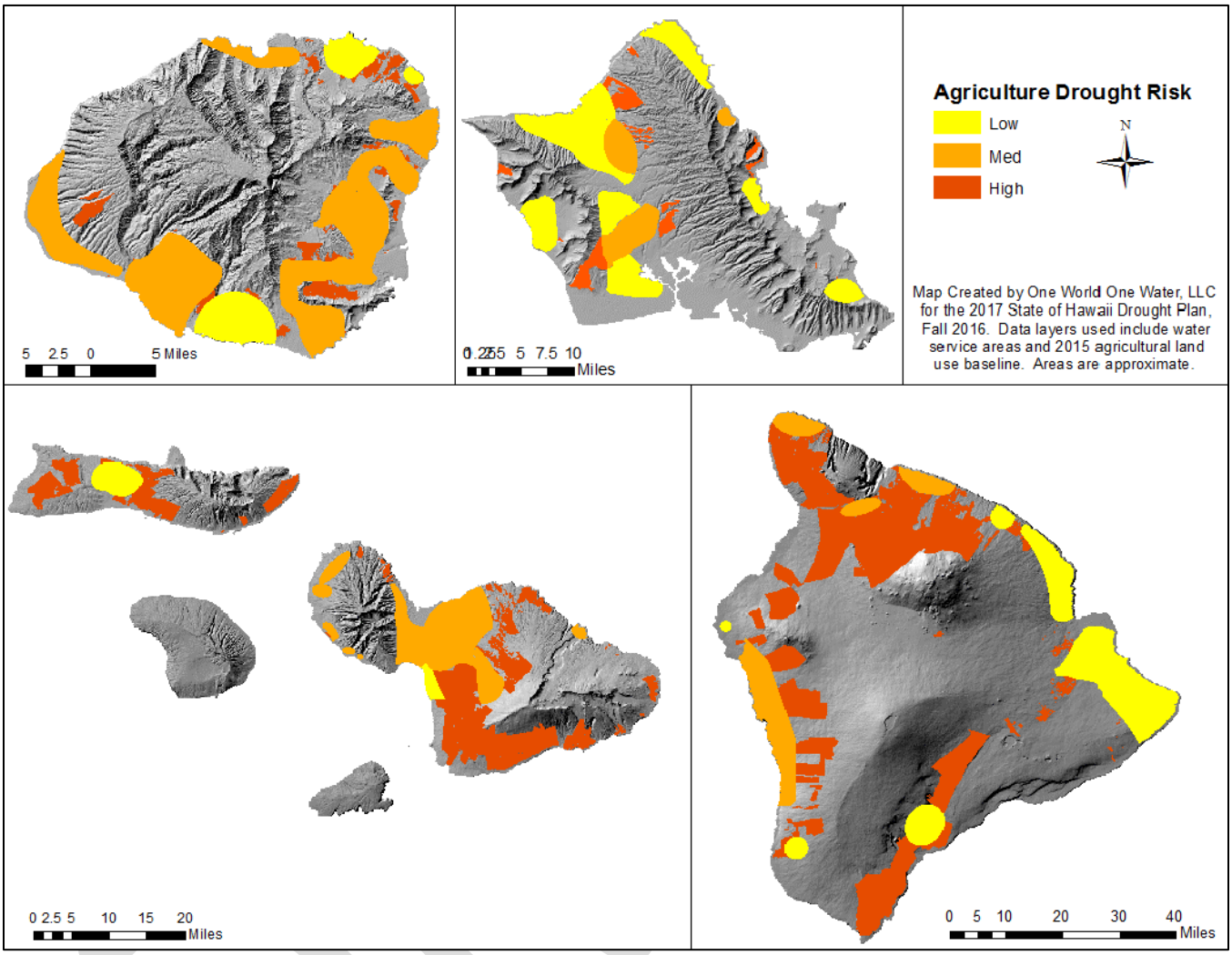
For the environment, public health, and safety sector in the state, refer to the Communities at Risk from Wildfires figure (Figure 4.15-X) found in Section 4.15 (Wildfire). This figure is beneficial for understanding areas at risk from environmental hazards of drought. During periods of drought, vegetation dries out and have an increase susceptibility to wildfire.

Figure 4.5-2. Water Supply Drought Risk in the State of Hawai‘i



Source: Hawai‘i Drought Plan 2017

Figure 4.5-3. Agricultural Drought Risk in the State of Hawai'i



Source: Hawai'i Drought Plan 2017

Extent

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.

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 is

useful in tracking drought, if submissions are adequate, to aid in better understanding and response to drought impacts. The main emphasis is for drought planning.

The Drought Impact Reporter contains information on 59 drought impacts from droughts that affected Hawai‘i between January 1, 2012, and December 31, 2017. Of those reported, 59% of them are from media reports. Most of the impacts (36) were classified as “agriculture.” Other impacts include, “relief, response & restrictions” (24), “plants & wildlife” (21), “water supply & quality” (20), “fire” (11), “tourism & recreation” (4), “society & public health” (4), and “business & industry” (3). These categories are described on the National Drought Mitigation Center, Drought Impact Reporter website http://droughtreporter.unl.edu/.

Between January 1, 2012, and December 31, 2017, the County of Maui had 34 drought-related impacts; the County of Hawai‘i had 31 drought-related impacts; the County of Kaua‘i had 8 drought-related impacts; and the City and County of Honolulu had 6 drought-related impacts.

Drought Monitoring and Forecasting

There are two popular drought indices used in Hawai‘i to monitor and forecast droughts: the Standardized Precipitation Index 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 in the State of Hawai‘i.

Standardized Precipitation Index

The Standardized Precipitation Index (SPI) has been embraced by agencies such as the National Drought Mitigation Center (NDMC) and the Western Regional Climatic Center (WRCC). The SPI considers only precipitation, which makes the index ideal for use in Hawai‘i, where there is a relatively dense network of rain gages. The SPI is computed for time scales ranging from 1 to 24 months. Because the SPI values are normalized, the wide range of rainfall conditions across the State of Hawai‘i can be assessed on an equal basis. Furthermore, SPI values can be generated for multiple time scales. This feature is extremely useful for monitoring purposes because the effects of droughts occur over wide ranges of time scales. Finally, since the SPI uses standard statistical principles, it can also be used to monitor other data such as stream flow, reservoir levels, and ground water levels. Table 4.5-1 displays the different SPI categories and their associated values.

Table 4.5-1. SPI Categories

Value	Category
≥2.00	Extremely Wet
1.50 to 1.99	Severely Wet
1.00 to 1.49	Moderately Wet
0.99 to -0.99	Near Normal
-1.00 to -1.49	Moderate Drought
-1.50 to -2.00	Severe Drought
≤-2.00	Extreme Drought

Notes: ≥ *Greater than or equal to*
≤ *Less than or equal to*
SPI *Standardized Precipitation Index*

Percent of Normal Rainfall Index

The Percent of Normal Rainfall Index (PNRI) is based on the percentage of current rainfall value compared against the long-term mean. 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 by a 30-year (typically) precipitation mean. Time scales are generally stated in months or a year. The PNRI is effective for comparing a single region or season in easily understood terms.

One of the disadvantages of using the PNRI is that the mean precipitation is often not the same as the median precipitation. The reason for this is that precipitation on monthly or seasonal scales does not have a normal distribution while the PNRI implies a normal distribution where the mean and median are considered being the same. Another disadvantage of the PNRI is that due to the variety in the precipitation records over time and location, there is no way to determine the frequency of the departures from normal or compare different locations inhibiting attempts to mitigate drought based on the departures from normal and form a plan of response.

Keetch-Bryam Drought Index

The Keetch-Byram Drought Index (KBDI) is calculated using weather station latitude, mean annual precipitation, maximum dry bulb temperature, previous 24-hour rainfall. The KBDI is used by the National Weather Service and foresters to assess fuel conditions and potential for wildfire. The 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. 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 (NOAA 2018a). The 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 (NOAA 2018b):

1. KBDI ≥ 600
2. Minimum RH ≤ 45 % (2 hours or more)
3. Wind ≥ 20 mph (≥ 17 kt) (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. Though only generalized warnings can take place, the U.S. Drought Monitor provides current and recent history of areas and populations affected by drought (U.S. Drought Monitor 2018).

El Niño events are strongly correlated with drought in the State of Hawai‘i. 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 for managers and decision makers to prepare for a potential drought. The intensity and duration of drought cannot be predicted, but an El Niño occurrence is one of the only indicators managers have to forecast drought in Hawai‘i. It is very difficult to predict an El Niño or La Niña event but scientists monitor various ocean and atmospheric elements associated with these events and utilize complex computer models to make El Niño/La Niña forecasts. The NOAA Climate Prediction Center produces a monthly El Niño/Southern Oscillation (ENSO) Diagnostic Discussion, which provides analysis of current oceanic and atmospheric conditions as well as projection summaries of ENSO prediction models. It is important to note that a La Niña event can also affect rainfall – historically related to wetter than normal conditions, however this association is not as consistent as El Niño is to drought.

Drought is a very slow-developing hazard and depending on the impact sector, it may take anywhere from months to years for the impacts and effects of drought to be felt. Scientists at this time do not know how to predict drought more than one month in advance for most locations. 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 they 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 (NDMC 2018).

Previous Occurrences and Losses

Table 4.5-2 provides a summary of drought events that have impacted the State of Hawai‘i between 2012 and 2017. Drought events that occurred prior to 2012 are included in the 2013 version of this HMP, which can be found in Appendix X.

Table 4.5-2. Drought Events in Hawai‘i, 2012 to 2017

Date(s) of Event	Event Type	Counties Affected	Description
January 1, 2012 to August 5, 2014	Drought	All	All portions of the state experienced abnormally dry to extreme drought conditions, particularly Hawai‘i and Maui Counties. In 2012, the Counties of Maui, Kaua‘i, and Hawai‘i were declared Primary Natural Disaster Area (USDA) due to drought. Between 2013 and 2014, Maui and Hawai‘i Counties were designated Drought Disaster Areas (USDA).
September 16, 2014 to September 29, 2015	Drought	All	All portions of the State experienced abnormally dry to extreme drought conditions, particularly Hawai‘i and Maui Counties. In 2015, the County

Date(s) of Event	Event Type	Counties Affected	Description
			of Hawai'i was in moderate drought. Less than one-fifth the normal average of rainfall fell at Hilo Airport in Hawai'i County.
November 10, 2015 to December 31, 2017	Drought	All	All portions of the state experienced abnormally dry to extreme drought conditions, particularly in the Counties of Hawai'i and Maui. In 2016, wildfires developed on Diamond Head on O'ahu (City and County of Honolulu) and voluntary water reductions were encouraged in certain locations in the County of Maui.

Source: USDA 2018; National Drought Mitigation Center 2017; State of Hawai'i Department of Land & Natural Resources Commission on Water Resource Management 2017

As shown in Table 4.5-2, droughts have been and will continue to be a significant concern in the State of Hawai'i. Planning for and coping with recurring, if unpredictable, drought events is complicated by the inherent water resource limitations of the islands and the uneven range of drought-related concerns and relevant priorities across counties. The statewide variability in resources, vulnerability, and risk necessitates a sectoral approach to drought mitigation. Statewide, three sectors were identified as being vulnerable to drought as well as having the potential to be ameliorated through mitigation measures: public water supply; agriculture and commerce; and environment, public health and safety.

FEMA Disaster Declarations

Between 1954 and 2017, there have been no FEMA disaster declarations due to a drought in the State of Hawai'i.

USDA Disaster Declarations

In addition to FEMA disaster declarations, the State of Hawai'i has been included in agriculture-related drought disasters. According to the U.S. Department of Agriculture (USDA), these types of disasters are quite common; between one-half and two-thirds of the counties in the United States have been designated as disaster areas in each of the past several years. The USDA Secretary of Agriculture is authorized to designate counties as disaster areas to make emergency loans (EM) to producers suffering losses in those counties and in counties that are contiguous to a designated county. In addition to EM eligibility, other emergency assistance programs, such as Farm Service Agency (FSA) disaster assistance programs, have historically used disaster designations as an eligibility requirement trigger. Table 4.5-3 and Table 4.5-4 provide the USDA Secretarial disaster declarations in all Hawaiian counties from January 1, 2012 through December 31, 2017. The Counties of Maui and Hawai'i received the most USDA declarations during this timeframe.

Table 4.5-3. Drought-Related USDA Declarations, 2012 to 2017

Year	Approval Date	Designation Number	Description of Disaster	Counties Affected
2012	May 7, 2012	S3247	Drought	Maui
2012	July 12, 2012	S3273	Drought	Hawai'i, Honolulu, Maui
2012	September 26, 2012	S3403	Drought	Kaua'i
2013	January 9, 2013	S3458	Drought	Hawai'i, Maui
2014	January 15, 2014	S3628	Drought	Hawai'i, Maui
2015	August 19, 2015	S3867	Drought	Kaua'i, Maui

Year	Approval Date	Designation Number	Description of Disaster	Counties Affected
2016	April 14, 2016	S3973	Drought	Hawai‘i
2016	April 20, 2016	S3975	Drought	Maui
2016	May 11, 2016	S3978	Drought	Kaua‘i
2017	August 16, 2017	S4207	Drought	Hawai‘i
2017	October 25, 2017	S4246	Drought	Maui
2017	November 21, 2017	S4258	Drought	Kaua‘i

Source: USDA 2018
Notes: USDA U.S. Department of Agriculture

Table 4.5-4. Summary of USDA Secretarial Disasters in Hawai‘i, 2012 to 2017

County	2012	2013	2014	2015	2016	2017	6-Year Total
Hawai‘i	1	1	2	0	1	1	6
Honolulu	1	0	0	0	0	0	1
Kaua‘i	1	0	0	1	1	1	4
Maui	2	1	1	1	1	1	7

Source: USDA 2018
Notes: USDA U.S. Department of Agriculture

Insured Crop Losses

According to the USDA Risk Management Agency (RMA), insured crop losses through the State of Hawai‘i as a result of drought conditions for the six-year period of 2012 to 2017 totaled $2,829,361. In Table 4.5-5 the USDA RMA insured crop losses through the State of Hawai‘i as a result of drought conditions are shown by year, from 2012 to 2017. It shows the highest year of crop losses as 2014 in this six-year period, followed by the years 2013 and 2012. Please note that this data only applies to insured crops.

Table 4.5-5. Total Insured Crop Insurance Paid by Year, 2012 to 2017

Year	Crop Insurance Paid
2012	$692,100
2013	$726,995
2014	$1,410,266
2015	$1,365
2016	$327,496
2017	$50,835
Total:	**$3,209,057**

Source: USDA Risk Management Agency
Notes: USDA U.S. Department of Agriculture

The USDA Farm Service Agency has two programs that cover agricultural losses: the Non-Insured Crop Disaster Assistance Program (NAP), and the Livestock Forage Disaster Program (LFP). For the period of 2012 to 2016, the total payments to the State of Hawai‘i are $8,242,963 for NAP and $21,275,531 for LFP. For information on the full period of record, refer to Appendix X.

Table 4.5-6. USDA Farm Service Agency Disaster Benefits Paid by County and by Program, 2012 to 2016

County (and Year)	Non-Insured Crop Disaster Assistance Program	Ranchers	Livestock Forage Disaster Program	Ranchers
County of Kaua‘i				
2014	--	--	$918,705	61
2015	$25,000	5*	$159,435	49
2016	$15,000	5*	$382,268	52
Total for County of Kaua‘i	**$40,000**	--	**$1,460,408**	--
County of Maui				
2012	$561,729	20	--	--
2014	--	--	$2,642,304	310
2015	--	--	$134,770	80
2016	--	--	$310,977	60
Total for County of Maui	**$561,729**	--	**$3,088,051**	--
County of Hawai‘i				
2012	$2,500,000	173	$4,560,087	253
2013	$2,544,485	192	$5,026,310	253
2014	$2,596,749	205	$4,560,413	253
2015	$0	0	0	0
2016	Ongoing**	--	$2,580,262	166
Total for County of Hawai‘i	**$7,641,234**	--	**$16,727,072**	--
Total for Counties of Hawai‘i, Kaua‘i and Maui	**$8,242,963**	**--**	**$21,275,531**	**--**

Source: State of Hawai‘i Department of Land & Natural Resources Commission on Water Resource Management 2017
Notes: Only years that had disaster benefits paid in the time range are shown.
** Estimated*
*** Data from 2017 report noted above therefore, information for 2017 not available.*

Probability of Future Hazard Events

During the entire time period for the 2018 HMP Update, from January 1, 2012, to December 31, 2017, drought conditions existed somewhere in the State of Hawai‘i. Based on the history of droughts in the state, the State of Hawai‘i can expect drought conditions on an ongoing basis.

Impacts of Climate Change on Future Probability

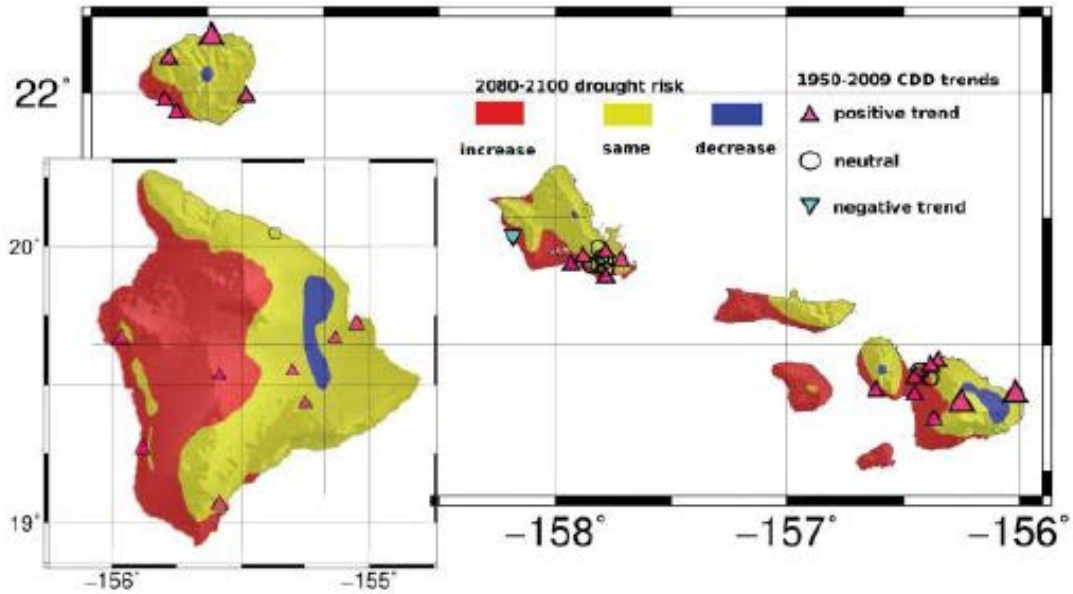
The effects of climate change on the drought hazard in the State of Hawai‘i are described in detail in *Hawai‘i Drought Plan 2017 Update* (State of Hawai‘i Department of Land & Natural Resources Commission on Water Resource Management 2017). Climate change threatens the quality and quantity of fresh water available. Increasing temperatures, increased nutrient and sediment loads, and decreased dilution of pollutants during periods of drought threaten the availability of fresh water.

Over the past 93 years, the average annual rainfall has decreased, receiving almost one foot less rainfall today than a century ago. When trends are analyzed seasonally and spatially, much larger dry season declines are found, particularly on the leeward side of islands, up to a 10% decline per decade. Streamflow and base flow have also declined during this period of time, with impacts to groundwater storage–which supplies 99% of the State’s drinking water. In addition, the State of Hawai‘i is at risk to sea level rise (see Section 4.2 – Climate Change and Sea Level Rise). Rising sea levels may contaminate fresh water with salt water (Department of the Interior Pacific Islands Climate Science Center, 2017). Rising sea levels may also impact buried water and wastewater infrastructure near the shoreline.

Drought can also increase the likelihood of wildfire. An increase in wildfire events will destroy native plants and support the spread of fire-adapted (and often fire-promoting) invasive species (Department of the Interior Pacific Islands Climate Science Center, 2017).

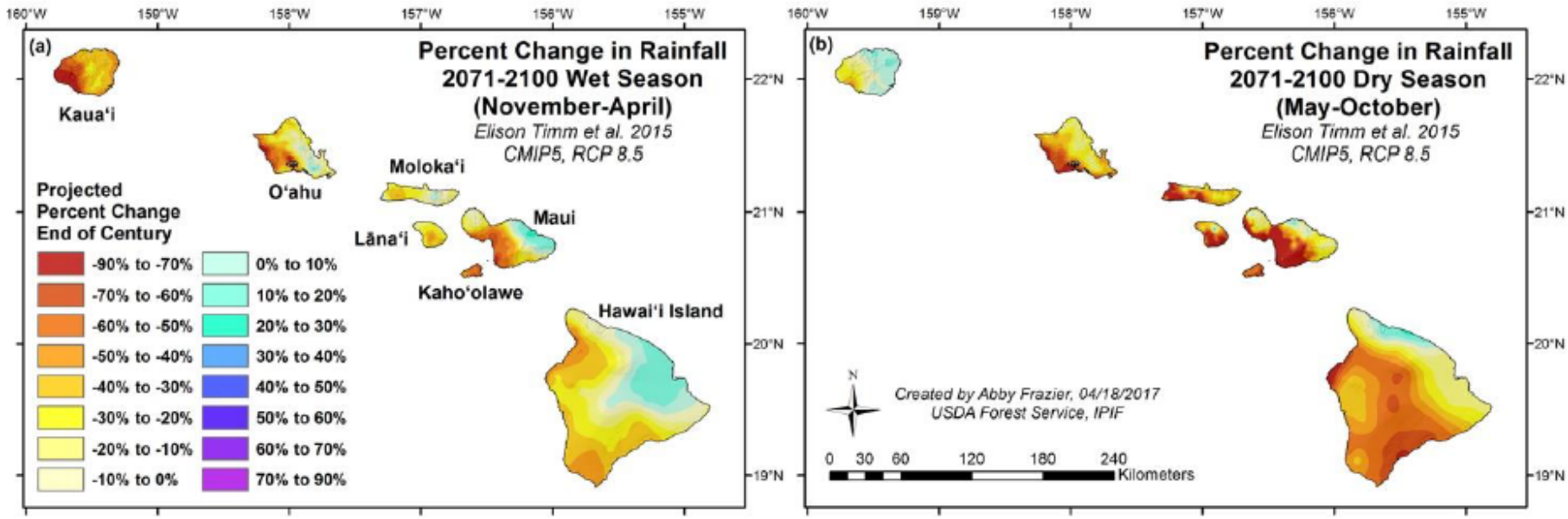
It is anticipated that climate change will increase the frequency of meteorological and agricultural droughts. This will increase the frequency of brief hydrological droughts, and the probability of a long hydrological drought. Figure 4.5-4 shows the potential for increased drought risk in the State of Hawai‘i based on historical drought and future projections of climate change. Figure 4.5-5 shows precipitation projections for the 2071 to 2100 wet and dry seasons in Hawai‘i based on statistical downscaling methods. It is important to note that there is inherent uncertainty in any global climate model that is downscaled to reflect the intricacies and microclimates of the Hawaiian Islands. These computer models continue to be refined and some downscaled Hawaii climate models have divergent results when compared with others.

Figure 4.5-4. Future Projections of Drought Based on Historical Data and Future Climate Projections



Source: State of Hawai'i Department of Land & Natural Resources Commission on Water Resource Management 2017

Figure 4.5-5. Percent Change in Rainfall



Source: State of Hawai'i Department of Land & Natural Resources Commission on Water Resource Management 2017

4.5.2 Vulnerability Assessment

The Hawai'i Drought Plan 2017 Update lists the different impacts of drought in the state, including: decimation of crops and livestock, the creating of dustbowls and erosion of landscapes, damage to terrestrial and aquatic wildlife habitats, enhanced wildfires, and economic damage. In addition to these impacts, the State of Hawai'i has other issues such as growing conflicts between agricultural uses of surface water and instream uses, surface and groundwater interrelationships, and the effects of growing water demands on traditional and cultural uses of water. Droughts have always been and will continue to be prevalent in the state. Droughts will continue to adversely affect the environment, economy, and the citizens of Hawai'i (State of Hawai'i Department of Land & Natural Resources Commission on Water Resource Management 2017).

Assessment of State Vulnerability and Potential Losses

This section discusses statewide vulnerability of exposed state assets (state-owned or state-leased buildings), state roads and critical facilities to droughts.

State Assets

Drought does not directly affect structures, so no state buildings are considered vulnerable to drought. However, there are secondary impacts that state buildings would be vulnerable to as a result of drought: wildfires and expansive soil effects on concrete and structure foundations.

Drought conditions may make structures more vulnerable to wildfires, which are more likely during a prolonged drought. Risk to life and property is greatest in areas where forested areas adjoin urbanized areas known as the wildland urban interface (WUI). Therefore, all state buildings and critical facilities (discussed below) in and adjacent to the WUI zone and located in high wildfire risk areas are considered vulnerable to wildfire. Section 4.15 describes the State's vulnerability to the wildfire hazard.

State buildings could be affected by the shrink-swell cycle that occurs as soils swell during wet periods and shrink during drought periods can cause damages to concrete components and structure foundations. Bridges and roads are especially vulnerable to damages as a result of the shrink-swell cycle. The Hawai'i Department of Transportation (HDOT) monitors this type of damage and is responsible for the repairs of those roads and bridges that are state-owned/maintained.

Critical Facility

As stated previously, drought does not directly impact structures. However, water-dependent critical facilities may be impacted. Under extreme drought conditions, where local water supplies are depleted and water utilities are unable to supply adequate water pressure, fire stations and healthcare facilities could be impacted. Healthcare facilities, including hospitals, clinics and nursing homes, rely on water for heating, cooling and ventilation systems, as well as for equipment sterilization, sanitation, water-based patient treatments, fire suppression and hazmat-decontamination.

Critical facility elements such as landscaping may not be maintained due to limited resources, but the risk to the critical facilities inventory will be largely aesthetic. For example, when water conservation measures are in place, landscaped areas will not be watered and may die. These aesthetic impacts are not considered significant.

Secondary impacts from drought include an increased risk of wildfires which could threaten critical facilities and to the concrete components and structure foundations from the shrink-swell cycle of expansive soils, as discussed above.

Assessment of Local Vulnerability and Potential Losses

Drought impacts cross jurisdictional boundaries and primarily impact the population's water supply and the agricultural/aquacultural industry. The state is vulnerable to drought, both statewide and county-specific because it has limited groundwater resources and is isolated. Buildings are not anticipated to be directly affected by a drought, and all are expected to be operational during a drought event. As discussed above, droughts can create conditions conducive to wildfires, and therefore local populations and buildings in and adjacent to the wildfire hazard areas are considered vulnerable to wildfire.

It is important to note that the unique terrain and orography of the Hawaiian Islands produce extremely variable microclimates and drought may impact limited geographical areas or affect large portions of an island. Where some areas on an island may be experiencing drought, other areas may be free of drought conditions. Drought conditions and impacts in Hawaii may vary greatly both temporally and spatially and this is an important factor to consider when planning for drought mitigation and preparedness.

Drought events impact the economy, including loss of business function and damage and loss of inventory. Industries that rely on water for business may be impacted the hardest (e.g., agriculture/aquaculture). Even though a majority of businesses will still be operational, they may be impacted aesthetically. These aesthetic impacts are most significant to the recreation and tourism industry which is an important part of each county's economy. In 2017, tourist expenditures in the State of Hawaii increased $980.7 million or 6.2 percent from the previous year.

Economic impacts may include:

- Losses from crop, livestock, timber, and aquaculture production and associated businesses.
- Losses from recreation providers and associated businesses.
- Losses related to the increased costs resulting from increased energy demand and from shortages caused by reduced hydroelectric generation capacity.
- Revenue losses for federal, state, and local governments from a reduced tax base and for financial institutions from defaults and postponed payments.
- Long-term loss of economic growth and development.

The size of the agriculture industry varies from county to county. A prolonged drought event could have significant impacts to the state's economy, particularly in counties that have large amounts of agricultural lands. Additionally, damaged and dead crops are also vulnerable to wildfires which can spread easily during periods of drought. Additional information about the potential exposure areas to drought in each county are discussed further below.

Based on past information, during a long-term drought (several months to years) drought first affects unirrigated agriculture and pasture operations. As the drought continues, surface water supplied water systems are impacted due to lowered stream flows, there is an increase in wildland fire occurrence, and residences that rely on rainwater catchment may need to purchase drinking water from water delivery companies (water haulers). If the drought

continues, ground water supplies and drinking water utilities may be affected due to decreases in aquifer recharge, which is replenished by rainfall during normal conditions.

Population

Directly or indirectly, the entire population of the State of Hawai'i is vulnerable to drought events. Drought can affect people's health and safety, as well as other impacts. Health problems related to low water flows, poor water quality, or dust could arise. Additional possible impacts include recreational risks; air quality reduction; diminished living conditions related to compromised, local hydroelectric power sources; compromised food and nutrition; and increased incidence of illness and disease. How and to what degree drought affects the State's population does vary. However, there are primarily three sectors affected by drought which can affect the State as well as the individual counties populations to different degrees.

Overall, there are primarily three drought impact sectors that are critical to the health and welfare of the State's population in terms of social, economic, and environmental aspects. These impacts include: the Water Supply Sector, the Agriculture and Commerce Sector, and the Environment, Public Health, and Safety Sector. These sectors are not mutually exclusive and, as such, impacts in one sector may result in secondary or cumulative impacts in other sectors. The following describes these sectors:

Water Supply Sector

The water supply sector includes public and private urban and rural drinking water systems, agriculture water systems, and rainwater catchment systems. Since the availability of freshwater is crucial to human survival in both direct and indirect ways, minimizing the impact of drought to the State's freshwater is a significant priority. In the State of Hawai'i, most public water systems (PWS) are supplied by groundwater sources, but there are seven water systems and four catchment water systems that are considered PWS by the DOH (Hawaii Drought Plan 2017).

Agricultural and Commerce Sector

The Agriculture and Commerce Sector experiences severe negative drought impacts due to dependence upon both surface water and rainfall. Rainfall shortage-induced impacts are often exacerbated by the limits placed on ground water pumping during drought periods. A persistent shortage of rainfall and the resultant lack of soil moisture can result in reduced ground cover and lower agricultural yields. Reduced ground cover and pasture can result in the reduction of livestock herd sizes and is also associated with an increased rate of erosion. Drought impacts to the agriculture sector are highly dependent on whether or not the crops are irrigated since un-irrigated pasture, orchards, or other fields are most vulnerable to droughts. Irrigated agricultural areas become more vulnerable when water supplies become more threatened. Commerce sectors such as tourism will also experience negative drought impacts since tourism directly depends on healthy, thriving Hawaiian ecosystems (Hawai'i Drought Plan 2017).

Environment, Public Health, and Safety Sector

The Environment, Public Health, and Safety Sector mainly focuses on the increased incidence of wildfires due to drought conditions. Wildfires are described in Section 4.15 (Wildfire). However, there are environmental impacts of drought conditions that are also an important component of this sector. Stressed water supplies exacerbate already vulnerable island ecosystems and can result in impacts to wildlife habitats, water quality, land quality, biodiversity, and can contribute to erosion (Hawai'i Drought Plan 2017).

General Building Stock and Economy

As stated previously, drought does not directly impact structures, including the general building stock. The general building stock, as defined for this plan would continue to be functional during a drought. The only secondary impacts from drought would be an increased risk of wildfires which could threaten buildings located close to WUI areas, and to the concrete components and structure foundations from the shrink-swell cycle of expansive soils, as discussed previously.

Drought causes the most significant economic impacts on industries that use water or depend on water for their business, most notably in the State of Hawai‘i, agriculture and aquaculture, as well as 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.

According to the 2017 USDA Agriculture Overview for the State of Hawai‘i, statewide there are 1,120,000 acres in agricultural use (USDA 2017). However, each county varies in the acreage of agricultural land and the overlapping risk from drought. Table 4.5-8 shows the USDA Census of the State of Hawai’i and the total value of agricultural products sold totaled $661 million that are exposed to drought conditions.

Table 4.5-7. State of Hawai’i State Agriculture Market Value

Agricultural Products Sold	Market Value
Value of crops, including nursery and greenhouse	$538,873,000
Value of livestock, poultry, and their products	$122,474,000
Total value of agricultural products sold	**$661,347,000**

Source: USDA Census 2012

According to the 2017 USDA Agriculture Overview for the State of Hawai‘i, statewide there are 144,000 cattle (including calves) and 5,000 hogs (USDA 2017). The total value of livestock in 2012 was $122,474,000 (USDA 2018). Some of the best available current data to determine losses due to drought in the agricultural sector can be taken from records of the United States Drought Monitor which indicates severe impacts on livestock as well as crops. Lack of rainfall reduces the availability of forage plants for cattle grazing. During a severe drought, the herd may be culled to ensure that the remaining cattle stock survives during the drought. Once the drought is over, the plants take time to recover and this leads to a lag time in recovery to livestock herds. During a drought year, breeding cows decrease by 20% and calving decreases by 10%. Following the drought, it takes about 2.5 years to recover from the impacts to the herds (HMP 2013).

Estimates indicate a 50% reduction in production for cattle ranches, which approximate a decrease in revenue for ranches in the State of Hawai‘i of about $4 million annually through the drought, and subsequently for 2.5 years following the drought while herds are reestablished. Not only are cattle affected by the lack of water, but by the lack of nutritional forage, which results in decreased weights of cattle and declines in reproduction. In October 2011, the FSA reported that various areas of the Island of Hawai‘i have experienced a 30% to 100% loss of forage plants for livestock. Indirect costs from being unable to replace equipment, such as vehicles, during drought years compound the direct revenue losses and can extend recovery periods by three or four more years.

Environmental Resources and Cultural Assets

Environmental losses from drought are associated with damage to plants, animals, wildlife habitat, and air and water quality; forest and range fires; degradation of landscape quality; loss of biodiversity; and soil erosion. Some of the effects are short-term and conditions quickly return to normal following the end of the drought. Other environmental effects linger for some time or may even become permanent.

Watersheds are critical to replenishing Hawaii’s groundwater aquifers, which supply most of the state’s drinking water. Healthy watersheds also reduce polluted runoff into our nearshore waters and support healthy stream ecosystems. Watersheds impacted by drought-induced ecosystem damage or wildfires result in decreased ground and surface water supplies and damage to nearshore waters and reef ecosystems.

Wildlife habitat, for example, may be degraded through the loss of wetlands, lakes and vegetation. However, many species will eventually recover from this temporary condition. The degradation of landscape quality, including increased soil erosion, may lead to a more permanent loss of biological productivity. The impacts to vegetation and wildlife can include death from dehydration and the spread of invasive species or disease because of stressed conditions. Invasive species pose problems for the ecosystems in which they are introduced. Like many hazards that affect the State of Hawaii's environment, invasive species have both direct and indirect impacts.

When groundwater is not replenished over a period of time, aquifer and well water levels diminish making irrigation and drinking water difficult to obtain. In addition, contamination of surface water sources can occur during drought conditions. Surface water reservoirs (although there are few in Hawai‘i) may experience increased pollutant levels and lower levels of oxygen, contributing to higher concentrations of illness-causing bacteria and protozoa as well as toxic blue-green algae blooms.

Growing public awareness and concern for environmental quality has required that public officials focus greater attention and resources on these effects. Since the tourism industry accounts for a significant portion of the State’s economy, adverse effects on the natural environment could have serious effects on this important sector (DLNR 2017).

The primary impacts on cultural assets from drought would be an increased risk of wildfires which could threaten these assets, and to structure foundations from the shrink-swell cycle of expansive soils.

Droughts may impact Native Hawaiian traditional and customary practices which rely on healthy terrestrial and marine ecosystems. These practices may include the collection of plants, animals and minerals and other practices. As discussed above, drought and its secondary impacts can damage watersheds and nearshore waters may impair, diminish, or impede the exercise of traditional and customary practices.

Future Changes that May Impact State Vulnerability

Understanding future changes 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.

As the resident and visitor populations in the State of Hawai‘i continue to increase, the stresses on the State's water sources will increase as more resources will be needed for human use and consumption and these resources are further taxed by changing climate conditions. 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. In addition, newly developed land or expansion into upland forested areas may reduce groundwater recharge as more land in the State becomes impermeable.

Native Hawaiian cultural practices are closely tied to the natural environment. Together, drought, wildfire, and invasive species threaten many of Hawaii's iconic plants and animals. When coupled with land use change and the spread of diseases facilitated by warming temperatures, impacts to native species and their habitat may incur (USGS 2018).