



## SECTION 4. RISK ASSESSMENT

### 4.4 Dam Failure

#### 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).
- ❖ The total number of dams and reservoirs differ from the 2013 State HMP. Updated data (Department of Land and Natural Resources' [DLNR] Dam Inventory System) was used to determine the total number of dams and reservoirs in each county.
- ❖ Dam failure 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, state and local agencies are incorporated.
- ❖ Analyzed state asset exposure to statewide dam inundation areas. Assessed local vulnerability utilizing three dam inundation areas per county.

#### 4.4.1 Hazard Profile

Dams and reservoirs in the State of Hawai'i were predominately developed by the agriculture industry in the early 1900s. Today, dams and reservoirs continue to be used by the agriculture industry, in addition to providing storage for drinking water, flood control, hydropower, recreation and other purposes. The Hawai'i Dam Safety Program was started in 1987 when the statues were passed by the legislature and was followed up in 1989 with the Hawai'i Administrative Rules that were set up by DLNR. Most existing dams were built by private plantation owners in the early 1900s for irrigation and not for flood control; there were no regulatory construction standards at that time.

Only dams that meet a certain jurisdictional size criteria (height and volume) are regulated by the State's Dam and Reservoir Safety Program. Regulated dams are identified as having artificial barriers which are 25 feet or more in height or have an impounding capacity of 50 acre-feet (approximately 17 million gallons) or more.

This section provides general information on the dam failure hazard. Flooding caused by chronic coastal flooding is discussed in Section 4.2 (Chronic Coastal Flood), event based flooding is discussed in Section 4.6 (Event-Based Flood), and storm surge is discussed in Section 4.10 (Hurricane).

#### Key Terms

**Dam** - An artificial barrier that has the ability to impound water, wastewater, or any liquid-borne material, for the purpose of storage or water control (FEMA 2014).

**State-Regulated Dam** - Any artificial barrier that can or does impound or divert water and is 25 feet or more in height or impounds 50 acre-feet or more (Hawai'i Administrative Rules, Chapter 190.1.)

**Dam Failure** - An uncontrolled release of impounded water.



## HAZARD DESCRIPTION

A dam is an artificial barrier that has the ability to impound water, wastewater, or any liquid-borne material, for the purpose of storage or water control (FEMA 2014). A dam impounds water in the upstream area, or reservoir. The amount of water impounded is measured in acre-feet referring to the volume of water that covers an acre of land to a depth of one foot (FEMA 1997). In the State of Hawai'i, there are three types of dams:

- **Detention** dams are constructed to retard and minimize the effects of flood runoff. These types of dams are used to store all or a portion of an anticipated flood runoff. The floodwater stored by the dam is released at a rate that does not exceed the carrying capacity of the channel downstream.
- **Storage** dams are constructed to impound water during periods of surplus supply for use during periods of drought. This water is for crop irrigation, livestock watering, and municipal and industrial water supply. Lake Wilson and Nu'uuanu Reservoir on the island of O'ahu are examples of local dams constructed for storage.
- **Diversion** dams are constructed to provide hydraulic head for diverting water from streams and rivers into ditches, canals, or other water conveyance, and are typically very small (Hawai'i State HMP 2013).

Dam failures can result from natural events, human-induced events, or a combination of the two. Dam failures typically occur when spillway capacity is inadequate and excess flow overtops the dam, or when internal erosion (piping) through the dam or foundation occurs. Complete failure occurs if internal erosion or overtopping results in a complete structural breach, releasing a high-velocity wall of debris-filled waters that rush downstream damaging or destroying anything in its path (FEMA 1997). Dam failures can result from one or a combination of the following reasons:

- Overtopping caused by floods that exceed the capacity of the dam
- Deliberate acts of sabotage
- Structural failure of materials used in dam construction
- Movement and/or failure of the foundation supporting the dam
- Settlement and cracking of concrete or embankment dams
- Piping and internal erosion of soil in embankment dams
- Inadequate maintenance and upkeep (FEMA 2017b)

## LOCATION

The State of Hawai'i has a total of 132 dams and reservoirs, of which 123 have a classification of 'high hazard'. An inventory of dams, by county, is listed in Appendix X. Table 4.4-1 summarizes the number of dams in each county. A majority of the dams and reservoirs (56 total) are located in the County of Maui, followed by the County of Kaua'i with 53 dams and reservoirs. Table 4.4-2 summarizes the total square miles of dam failure inundation area statewide by county. The Counties of Maui and Kaua'i have the greatest inundation area, followed by the City and County of Honolulu.



**Table 4.4-1. Total Number of Dams and Reservoirs in each County**

County	Total Number of Dams and Reservoirs
County of Kaua'i	53
City and County of Honolulu	13
County of Maui	56
County of Hawai'i	10
<b>Total</b>	<b>132</b>

Source: State of Hawai'i DLNR Engineering Division – Dam Safety 2018

**Table 4.4-2. Total Square Miles of Dam Failure Inundation Area in each County**

County	Total County Area (square miles)	Total Square Miles of Dam Failure Inundation Area	Percent (%) of Total Area
County of Kaua'i	630.3	13.8	2.2%
City and County of Honolulu	600.2	7.8	1.3%
County of Maui	1,174.6	24.1	2.1%
County of Hawai'i	4,027.8	7.5	0.2
<b>Total</b>	<b>6,432.9</b>	<b>53.2</b>	<b>0.8%</b>

Source: PDC 2018

Note: Area was calculated based upon the spatial layer provided by PDC. All dam failure inundation areas were merged for each county to remove overlap.

**EXTENT**

It is common practice among federal and state dam safety offices to classify a dam according to the potential impact a dam failure (breach) or misoperation (unscheduled release) would have on upstream and/or downstream areas or at locations remote from the dam. The hazard potential classification system categorizes dams based on the probable loss of human life and the impacts on economic, environmental, and lifeline interests. Improbable loss of life exists where persons are only temporarily in the potential inundation area.

The State of Hawai'i classifies dams and reservoirs in a three-tier hazard rating system based on two factors: the amount of water impounded and the density, type, and value of development and infrastructure located downstream. The hazard potential classification system categorizes dams based on the probable loss of human life and the impacts on economic, environmental, and lifeline interests. Improbable loss of life exists where persons are only temporarily in the potential inundation area. The hazard potential categories are listed below and summarized in Table 4.4-3.

**Table 4.4-3. Dam Hazard Potential Classification**

Category	Loss of Life	Property Damage	Hazard Description
Low	None expected	Low and generally limited to owner property	Dams assigned the low hazard potential classification are those where failure or misoperation results in no probable loss of human life and in low economic and/or environmental losses. Losses are principally limited to the owner's property.
Significant	None expected	Yes	Dams assigned the significant hazard potential classification are those dams where failure or misoperation results in no probable loss



Category	Loss of Life	Property Damage	Hazard Description
			of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or can impact other concerns. Significant hazard potential classification dams are often located in the predominantly rural or agricultural areas but could be located in areas with population and significant infrastructure.
High	Probable, one or more expected	Yes (but not necessary for this classification)	Dams assigned the high hazard potential are those where failure or misoperation will probably cause loss of human life.

Source: DLNR 2017

### Warning Time

Warning time for dam failure varies depending on the cause of the failure. In events of extreme precipitation or massive snowmelt, evacuations can be planned with sufficient time. In the event of a structural failure because of earthquake, there may be no warning time. A dam’s structural type also affects warning time. Earthen dams do not tend to fail completely or instantaneously. Once a breach is initiated, discharging water erodes the breach until either the reservoir water is depleted or the breach resists further erosion. Concrete gravity dams also tend to have a partial breach as one or more monolith sections are forced apart by escaping water. The time of breach formation ranges from a few minutes to a few hours (U.S. Army Corps of Engineers [USACE] 1997).

High and significant hazard dam owners are required to prepare and maintain an Emergency Action Plans (EAP). The EAP is to be used in the event of a potential dam failure or uncontrolled release of stored water. Owners are also required to have established protocols for flood warning and response to imminent dam failure in the flood warning portion of its adopted emergency operations plan. These protocols are tied to the EAPs also created by the dam owners. These documents are customarily maintained as confidential information, although copies are required to be provided to DLNR. The DLNR has an EAP for every regulated dam in the State of Hawai'i (DLNR 2017).

### PREVIOUS OCCURRENCES AND LOSSES

The 2013 HMP discussed specific dam failure events that occurred in the State of Hawai'i through 2012. For this 2018 HMP Update, dam failure events were summarized between January 1, 2012, and December 31, 2017. For events prior to 2012, please refer to Appendix X. Between 2012 and 2017, no dam failure incidents occurred in the State of Hawai'i.

### FEMA Disaster Declarations

Between 1954 and 2017, the State of Hawai'i was not included in any dam failure-related federal disasters (DR) or emergencies (EM) by FEMA (FEMA 2017).

### PROBABILITY OF FUTURE HAZARD EVENTS

Causes for dam failure can be controlled through proper design, proper construction, regular inspections by qualified personnel, and a commitment to strong enforcement in order to correct identified deficiencies. The risk to downstream life and property can also be substantially reduced with effort to limit some types of development adjacent to streams and rivers. As these water control structures continue to age, the likelihood or probability of failure increases.



Since the 2006 breach of the Ka Loko Dam, the State of Hawai'i has increased their monitoring procedures and the probability of a dam failure has been significantly reduced statewide. A major dam failure event is considered rare; however, there is the potential for a dam failure to occur during or after extreme rainfall events, earthquakes, or landslides. Additionally, there is a risk of a dam failure should an event occur beyond those that the dam was designed to withstand. Overall, the probability of any type of dam failure is low due to dam safety regulations and oversight.

### **Potential Impacts of Climate Change on Probability of Future Events**

Small changes in rainfall and runoff may have significant impacts for water resource systems, such as dams. Dams are designed partly based on assumptions about a stream's flow behavior, expressed as hydrographs. Changes in weather patterns can have significant effects on the hydrograph used for the design of a dam. If the hydrograph changes, it is conceivable that the dam can lose some or its entire designed margin of safety, also known as freeboard. Loss of designed margin of safety may cause floodwaters to more readily overtop the dam or create unintended loads. However, the probable maximum flood used to design each dam may be able to accommodate changes in climate.

Additionally, dams are constructed with safety features known as "spillways," which provide a safety measure in the event of the reservoir filling too quickly. Spillway overflow events result in increased discharges downstream and increased flooding potential. Although climate change will not increase the probability of catastrophic dam failure, it may increase the probability of spillway flows.

It is projected that the State will experience increased drought and heavy rain events causing an increasing flash flooding, infrastructure damage, runoff, and sedimentation (University of Hawai'i at Mānoa Sea Grant College Program 2014). In addition to a warming climate, the State of Hawai'i has experienced the impacts of El Niño and La Niña. El Niño leads to increase rainfall, flooding, and sediment runoff, which may lead to an increase risk of a dam failure as some dams may not be designed to withstand an increase in rain totals (NOAA 2018). For specific details regarding climate change, refer to Section 4.1 (Climate Change and Sea Level Rise).

### **4.4.2 Vulnerability Assessment**

A DNLR-led study was conducted on 140 dams in the State and reported potential impacts of each dam's failure. This study was not available for the vulnerability assessment. For the 2018 HMP Update, the total number of state assets located in all spatially-delineated dam failure inundation areas was examined. However, it is important to note that it is highly unlikely that all dams would fail at the same time.

To assess local vulnerability, both the local HMPs were consulted and the HI-EMA Mitigation Section asked each County to select three dams they would like included in the risk assessment. The dam failure inundation areas for these 12 dams were provided by the PDC. Due to the limited number of dams evaluated to assess local vulnerability, the assessment below does not fully represent each county's total exposure nor vulnerability. The areas exposed to flooding from a dam failure would only experience serious flooding or flood damage if there was a dam failure.

The 12 dams selected to assess local vulnerability are listed below. Table 4.4-1. inundation area for these 12 dams. Refer to Appendix X which display the dam failure inundation areas.



- County of Kaua'i – Waita Reservoir (HI00099), Huinawai Reservoir (HI00104), Kapaia Reservoir (HI00012)
- City and County of Honolulu – Wahiawa Dam (HI00017), Kaneohe Dam (HI00124), Nuuanu Dam No. 4 (HI00001)
- County of Maui – Horner Reservoir (HI00054), Kualapuu Reservoir (HI00041), Wailuku Water Reservoir 6 (HI00150)
- County of Hawai'i – Waikoloa Reservoir No. 1 (National ID HI00040), Waikoloa Reservoir No. 2 (HI00122), Waikoloa Reservoir No. 3 (HI00136)

**Table 4.4-4. Dam Failure Inundation Area for the 12 Selected Dams by County**

County	Area		
	Total Area (square miles)	Dam Failure Inundation Area (square miles)	Percent (%) of Total Area
County of Kaua'i	4,027.8	3.9	0.6%
City and County of Honolulu	600.2	0.6	0.1%
County of Maui	630.3	8.5	0.7%
County of Hawai'i	1,174.6	5.3	0.1%
<b>Total</b>	<b>6,432.9</b>	<b>18.3</b>	<b>0.3%</b>

Source: Pacific Disaster Center 2017

Note: These results do not represent the total dam failure inundation area statewide; and only reflect the 12 dams analyzed. There are overlapping dam failure inundation areas in the Counties of Kaua'i and Hawai'i.

## ASSESSMENT OF STATE VULNERABILITY AND POTENTIAL LOSSES

This section discusses statewide vulnerability of exposed state assets (state buildings and state roads) and critical facilities to the dam failure hazard.

### State Assets

For the purposes of this risk assessment, an asset is considered potentially vulnerable if it is in an identified hazard area. To assess the vulnerability of the state buildings, GIS software was used to overlay the statewide dam inundation hazard area with the buildings. Table 4.4-5 and Table 4.4-6 summarize the state buildings located in the statewide dam failure inundation area per county and state agency, respectively. The spatial analysis indicates that there are 232 state buildings (3.8%) vulnerable to dam failure statewide. Of these, the greatest number are in the City and County of Honolulu (102 buildings with a replacement cost value of \$673 million. The majority of these buildings are occupied by the Department of Education and Department of Transportation.

**Table 4.4-5. State Buildings Exposure to Statewide Dam Failure Inundation Areas by County**

County	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings in the Hazard Area	Percent (%) of Total Buildings	Total Value of State Buildings in the Hazard Area	Percent (%) of Total Value
County of Kaua'i	531	\$957,679,537	18	3.4%	\$13,195,343	1.4%
City and County of Honolulu	3,472	\$16,750,785,426	102	2.9%	\$673,908,023	4.0%
County of Maui	831	\$2,862,316,819	79	9.5%	\$127,452,761	4.5%



County	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings in the Hazard Area	Percent (%) of Total Buildings	Total Value of State Buildings in the Hazard Area	Percent (%) of Total Value
County of Hawai'i	1,261	\$4,209,774,236	33	2.6%	\$34,772,378	8.3%
<b>Total</b>	<b>6,095</b>	<b>\$24,780,556,017</b>	<b>232</b>	<b>3.8%</b>	<b>\$1,162,328,505</b>	<b>4.7%</b>

Note: Total Value = Replacement cost value of the structure and contents  
 Source: Hawai'i State Risk Management Office 2017; Pacific Disaster Center 2017

**Table 4.4-6. State Buildings Exposure to Statewide Dam Failure Inundation Areas by Agency**

Agency	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings in the Hazard Area	Percent (%) of Total Buildings	Value in the Hazard Area	Percent (%) of Total Value
Dept of Accounting & General Services	66	\$946,504,656	2	3.0%	\$11,709,702	1.2%
Dept of Agriculture	70	\$133,065,375	7	10.0%	\$13,966,868	10.5%
Dept of Attorney General	15	\$95,151,863	1	6.7%	\$1,133,204	1.2%
Dept of Budget & Finance	16	\$26,624,294	1	6.3%	\$4,210,917	15.8%
Dept of Business, Economic Development & Tourism	25	\$612,574,032	0	0.0%	\$0	0.0%
Dept of Commerce & Consumer Affairs	2	\$35,611,360	0	0.0%	\$0	0.0%
Dept of Defense	69	\$246,099,477	2	2.9%	\$7,745,320	3.1%
Dept of Education	4,090	\$9,604,111,443	130	3.2%	\$468,961,028	4.9%
Dept of Hawaiian Home Lands	12	\$100,471,477	0	0.0%	\$0	0.0%
Dept of Health	44	\$387,068,440	0	0.0%	\$0	0.0%
Dept of Human Resources Development	1	\$5,523,320	0	0.0%	\$0	0.0%
Dept of Human Services	130	\$420,004,555	9	6.9%	\$18,603,114	4.4%
Dept of Labor & Industrial Relations	22	\$79,322,626	0	0.0%	\$0	0.0%
Dept of Land & Natural Resources	90	\$98,666,185	4	4.4%	\$2,939,792	3.0%
Dept of Public Safety	154	\$427,884,909	0	0.0%	\$0	0.0%
Dept of Taxation	1	\$6,864,408	0	0.0%	\$0	0.0%
Dept of Transportation	68	\$2,912,510,888	10	14.7%	\$55,065,292	1.9%
Hawai'i State Ethics Commission	1	\$1,223,962,810	0	0.0%	\$0	0.0%
Hawai'i Health Systems Corporation	106	\$333,526,064	2	1.9%	\$2,979,553	0.2%
Hawai'i Housing Finance & Development Corporation	86	\$933,255,767	0	0.0%	\$0	0.0%
Hawai'i Public Housing Authority	273	\$891,212	28	10.3%	\$120,813,608	12.9%
Hawai'i State Legislature	2	\$43,024,855	0	0.0%	\$0	0.0%



Agency	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings in the Hazard Area	Percent (%) of Total Buildings	Value in the Hazard Area	Percent (%) of Total Value
Hawai'i State Public Library System	53	\$525,584,082	5	9.4%	\$22,596,333	4.3%
Judiciary	41	\$511,093,204	1	2.4%	\$2,265,282	0.4%
Legislative Reference Bureau	1	\$2,686,408	0	0.0%	\$0	0.0%
Office of Hawaiian Affairs	11	\$53,991,251	2	18.2%	\$25,998,989	48.2%
Office of the Auditor	2	\$1,789,788	0	0.0%	\$0	0.0%
Office of the Governor	1	\$2,686,408	0	0.0%	\$0	0.0%
Office of the Lieutenant Governor	2	\$3,977,640	0	0.0%	\$0	0.0%
Office of the Ombudsman	1	\$1,620,944	0	0.0%	\$0	0.0%
Research Corporation of the University of Hawai'i	3	\$3,713,497	0	0.0%	\$0	0.0%
University of Hawai'i	637	\$5,000,692,783	28	4.4%	\$403,339,505	8.1%
<b>Total</b>	<b>6,095</b>	<b>\$24,780,556,017</b>	<b>232</b>	<b>3.8%</b>	<b>\$1,162,328,505</b>	<b>4.7%</b>

Source: Hawai'i State Risk Management Office 2017; Pacific Disaster Center 2017

Notes: Dept Department

There are portions of state roads that are exposed to flood waters should a dam failure occur. Flood waters can undermine or fully submerge roads for a period of time resulting in closures and cutting off critical access to communities. In addition, the flood waters can degrade the integrity of the roads. Sometimes the damage is apparent – a road that washes away, a sinkhole that appears, a bridge that crumbles, but often the damage is less obvious on the surface. Table 4.4-7 shows the length of state road in the dam inundation areas by county. Maui County has the greatest length of state road (5.4 miles) exposed to the dam inundation areas that were analyzed. A complete list of state roads is included in Appendix X.

**Table 4.4-7. State Road Exposure to Statewide Dam Failure Inundation Areas by County**

County	Length (in miles)		
	Total Length	Length of Road in the Hazard Area	Percentage (%) of Total Length
County of Kaua'i	104.0	3.1	2.9%
City and County of Honolulu	375.3	10.7	2.9%
County of Maui	238.6	15.6	6.5%
County of Hawai'i	378.7	0.6	0.2%
<b>Total</b>	<b>1,096.5</b>	<b>30.0</b>	<b>2.7%</b>

Source: State of Hawai'i SDOT State Routes GIS layer 2017; Pacific Disaster Center 2017

Note: Due to the limited number of dams evaluated, the tabular results do not fully represent the statewide exposure nor vulnerability.

### Critical Facilities

Transportation routes are vulnerable to dam inundation and have the potential to be wiped out, creating isolation issues. This includes all roads and bridges in the path of the dam inundation. Those that are most vulnerable are those that are already in poor condition and would not be able to withstand a large water surge. Utility



infrastructure is also vulnerable; interruption of services may not only impact vulnerable populations but may also impact facilities that need to be in operation during a disaster.

Table 4.4-8 summarizes the total number of critical facilities by core category located in the dam failure inundation areas statewide by county. City and County of Honolulu has the greatest number of critical facilities (43) within the analyzed dam inundation areas with the majority of the facilities being categorized as Energy. Table 4.4-9 summarizes the number and percentage of exposed critical facilities by core category. Commercial facilities have 34.2% of their facilities within the analyzed dam inundation areas.

**Table 4.4-8. Critical Facilities Exposure to Statewide Dam Failure Inundation Areas by County**

County	Category of Critical Facilities										Total in the Hazard Area
	Commercial Facilities	Communications	Emergency Services	Energy	Food and Agriculture	Government Facilities	Healthcare and Public Health	Mass Care Support Services	Transportation Services	Water, Waste, and Wastewater Systems	
County of Kaua'i	0	0	2	0	0	0	0	1	0	0	3
City and County of Honolulu	2	6	5	13	0	3	3	5	0	6	43
County of Maui	2	4	2	3	0	4	2	5	8	9	39
County of Hawai'i	1	0	0	0	2	0	1	1	0	1	6
<b>Total</b>	<b>5</b>	<b>10</b>	<b>9</b>	<b>16</b>	<b>2</b>	<b>7</b>	<b>6</b>	<b>12</b>	<b>8</b>	<b>16</b>	<b>91</b>

Source: Pacific Disaster Center 2017; Makani Pahili 2017 Emergency Power Prioritization Workshop Series final report; Hazus v4.2

Notes: Hazus Hazards-U.S.

**Table 4.4-9. Critical Facilities Exposure to Statewide Dam Failure Inundation Areas by Core Category**

Core Category	Total Number of Critical Facilities	Total Replacement Cost Value	Number of Critical Facilities in Hazard Area	Percent (%) of Total Facilities	Value in the Hazard Area	Percent (%) of Total Value
Commercial Facilities	60	\$206,894,206	5	8.33%	\$70,681,201	34.2%
Communications	130	\$523,848,060	10	7.69%	\$35,770,200	6.8%
Emergency Services	149	\$1,017,628,710	9	6.04%	\$59,703,090	5.8%
Energy	90	\$2,591,975,628	16	17.78%	\$475,256,573	18.3%
Food & Agriculture	39	\$829,869,410	2	5.13%	\$63,264,080	7.6%
Government Facilities	100	\$399,781,575	7	7.00%	\$27,409,085	6.9%
Healthcare & Public Health	193	\$3,399,521,375	6	3.11%	\$41,400,713	1.2%
Mass Care Support Services	353	\$11,497,547,155	12	3.40%	\$398,512,675	3.5%
Transportation Services	56	\$1,739,256,960	8	14.29%	\$247,664,640	14.2%
Water, Waste, & Wastewater Systems	305	\$9,481,445,760	16	5.25%	\$496,930,560	5.2%
<b>Total</b>	<b>1,475</b>	<b>\$31,687,768,838</b>	<b>91</b>	<b>6.17%</b>	<b>\$1,916,592,816</b>	<b>6.1%</b>

Source: Pacific Disaster Center 2017; Makani Pahili 2017 Emergency Power Prioritization Workshop Series final report; Hazus v4.2

Notes: Hazus Hazards-U.S.



## ASSESSMENT OF LOCAL VULNERABILITY AND POTENTIAL LOSSES

The local HMPs were reviewed to integrate risk assessment results into the 2018 HMP Update; a summary of information available is below.

- **County of Kaua'i** – The County HMP included dam risk assessment maps in an appendix. Exposure and potential loss estimates were not available in the main plan (County of Kaua'i 2015).
- **City and County of Honolulu** - The two dams for which failure is considered to have the greatest impact, due to their high populations downstream of the dams, are the Nuuanu Reservoir dam and the Kaneohe Dam (City and County of Honolulu 2012).
- **County of Maui** - The Maui County HMP conducted an exposure analysis using dam failure evacuation area mapping for all state-regulated dams. The building exposure (in dollars) for each evacuation area was analyzed by overlaying each evacuation area on the general building stock inventory used. Exposure estimates for each evacuation area are listed by dam. In total, there is over \$25 billion in building value (structure and contents) exposed to the dam failure hazard in Maui County. Three dams were chosen for a more in-depth exposure and vulnerability analysis: Horner Reservoir and Wailuku Water 6 on Maui and Kualapuu on Molokai. These dams were selected because they represent the largest, non-overlapping exposure areas on each island (Maui County 2015).
- **County of Hawai'i** - Dam failure scenarios were modeled for all registered dams in the county and impacts to population, transportation, building infrastructure and critical facilities were considered. These results are not reported in the public plan, and are for official use only (County of Hawai'i 2015).

Because not all local HMPs quantified dam failure impacts, the HI-EMA Mitigation Section asked each County to identify three dams they would like included in the 2018 HMP Update. This section provides a summary of vulnerability and potential losses to population, general building stock, environmental assets and cultural resources by county for the 12 dams selected for analysis. Similar to the analysis for state assets, a spatial exposure analysis was conducted and the results are summarized below.

### Population

Vulnerable populations are all populations downstream from dam failures that are incapable of escaping the area within the allowable time frame. This population includes the elderly, young and individuals with disabilities, access or functional needs who may be unable to get themselves out of the inundation area. The vulnerable population also includes who would not have adequate warning from the emergency warning system (e.g., television or radio); this would include residents and visitors/tourists. The population adversely affected by a dam failure may also include those beyond the disaster area that rely on the dam for providing potable water.

Floods created from a dam failure and their aftermath present numerous threats to public health and safety including exposure to unsafe food, contaminated drinking and washing water, mosquitoes, animals, mold and mildew. For more detailed descriptions of these and additional threats to public health and safety, refer to Section 4.7 (Event-Based Flood). Current loss estimation models such as Hazus are not equipped to measure public health impacts such as these. The best preparation for these effects includes awareness that they can occur, education of the public on prevention, and planning to deal with them during responses to dam failure events.



The population exposed to a dam failure for the 12 dams chosen for further analysis is summarized in Table 4.4-10. Maui County has the greatest number of people located in the dam failure inundation hazard area assessed. This analysis does not include all dams statewide, and does not include the number of tourists and visitors in the State; therefore, this estimate may be underestimating exposure and vulnerability.

**Table 4.4-10. 2010 U.S. Census Population Located in the 12 Dam Failure Inundation Areas by County**

County	Total Population	Population in Hazard Area	Population Exposed as Percent (%) of Total	Population Over 65 in Hazard Area	Population Over 65 Exposed as Percent (%) of Total Population	Population with Income <\$30K/year in Hazard Area	Population with Income <\$30K/year as Percent (%) of Total
County of Kaua'i	67,091	1,818	2.7%	382	0.6%	387	0.6%
City and County of Honolulu	953,207	4,685	0.5%	876	0.1%	795	0.1%
County of Maui	154,924	5,263	3.4%	890	0.6%	1,317	0.9%
County of Hawai'i	185,079	3,096	1.7%	341	0.2%	549	0.3%
<b>Total</b>	<b>1,360,301</b>	<b>14,862</b>	<b>1.1%</b>	<b>2,489</b>	<b>0.2%</b>	<b>3,048</b>	<b>0.2%</b>

Source: U.S. Census 2010; Pacific Disaster Center 2017

Due to the limited number of dams evaluated, the tabular results do not fully represent the statewide exposure nor vulnerability.

The poverty threshold for the State is \$24,000/year (Federal Register 2017). Utilizing the demographic layer in Hazus, the total households with an income of \$30,000 or less was calculated. Per the U.S. Census Bureau QuickFacts, the average number of persons per household (2012-2016) is 3.03 for the State of Hawai'i. To convert households to residents, three people per household was used.

### Land Use Districts

Table 4.4-11 shows the total area of each State Land Use District in the dam inundation hazard areas that were analyzed; refer to Appendix X for results by county. Of those dams chosen for analysis, Urban District Lands comprise the greatest area in the inundation areas. The high degree of exposure for these Urban District lands may have contributed to the counties' selection of these dams for analysis. Conservation District lands account for only a small amount of the dam inundation areas analyzed, likely due to the selection of particularly high impact dams. It is Conservation District Lands contain valuable environmental resources. Additional discussion of exposure and vulnerability of these resource areas can be found in the subsection below. An assessment of the combined inundation areas and the relative exposure of the State Land Use Districts was not conducted for this 2018 HMP Update. As local hazard mitigation plans are updated, the full extent of this hazard in each county should be further analyzed.



**Table 4.4-11. State Land Use Districts Located in the 12 Dam Failure Inundation Areas**

Land Use District	Total (square miles)	Square Miles in Dam Inundation Area	Percent (%) of Total Area
Agricultural	2,942.8	5.3	0.2%
Conservation	3,156.3	0.6	0.0%
Rural	16.1	3.9	0.2%
Urban	319.7	8.5	1.7%
<b>Total</b>	<b>6,434.9</b>	<b>18.4</b>	<b>0.2%</b>

Source: Pacific Disaster Center, 2017; State Land Use Commission, 2016

Notes: Total area calculated from the State of Hawai'i State Land Use District GIS layer

Hazard area clipped to coastline downloaded from State of Hawai'i GIS Program Geospatial Data Portal

Total area may differ slightly between this and other calculations due to slight differences in the shoreline geography.

Due to the limited number of dams evaluated, the tabular results do not fully represent the statewide exposure nor vulnerability.

### General Building Stock

The economic impact of dam failures varies depending upon the location and severity of the failure. Potential economic impacts include agriculture, business, tourism and the loss of buildings and tax-base. To further assess what is at risk, each county's general building stock's exposure was examined for the dams chose for further analysis. The general building stock in the inundation area is considered exposed to a dam failure. The structures closest to the dam failure inundation area are considered vulnerable because they would experience the largest, most destructive surge of water. Damages to buildings can displace people from their homes, threaten life safety and impact a community's economy and tax base. Table 4.4-12 summarizes the building replacement cost value located in the 12 dam failure inundation areas assessed.

**Table 4.4-12. General Building Stock Exposure to the 12 Dam Failure Inundation Areas**

County	Total Replacement Cost Value	Value Located in Dam Inundation Area	Percent (%) of Total Value
County of Kaua'i	\$13,287,882,000	\$585,507,000	4.4%
City and County of Honolulu	\$164,787,212,000	\$731,088,000	0.4%
County of Maui	\$31,320,693,000	\$1,132,904,000	3.6%
County of Hawai'i	\$33,326,392,000	\$638,880,000	1.9%
<b>Total</b>	<b>\$242,722,179,000</b>	<b>\$3,088,379,000</b>	<b>1.3%</b>

Source: Hazus v4.2, State of Hawai'i GIS layer Trust Land, State of Hawai'i GIS Program Geospatial Data Portal, 2017

Notes: Hazus Hazards-U.S.

RCV = replacement cost value structure and contents

Due to the limited number of dams evaluated, the tabular results do not fully represent the statewide exposure nor vulnerability.

### Environmental Resources

The environment is vulnerable to a number of risks in the event of a dam failure. Water releases from dams usually contain very little suspended sediment; this can lead to scouring of river beds and banks. The inundation may introduce foreign elements into local waterways, resulting in destruction of downstream habitat and impacting many animal and plant species, especially endangered species and coral ecosystems. Environmental resources, including critical habitat (or habitats that are known to be essential for an endangered or threatened



species), wetlands, parks and reserves, and reefs located in dam inundation areas evaluated are summarized by county in Table 4.4-13.

**Table 4.4-13. Environmental Resources Located in the 12 Dam Failure Inundation Areas**

Environmental Asset	Total Area (square miles)	Area in the Dam Failure Inundation Area (square miles)	Percent (%) of Total Area
Critical Habitat <sup>a</sup>	915.2	0.3	0.03%
Wetlands	260.0	1.9	0.7%
Parks and Reserves	54.7	0.3	0.01%
Reefs <sup>b</sup>	3,837.6	0.0	0.0%
<b>Total<sup>c</sup></b>	<b>915.2</b>	<b>2.6</b>	<b>0.1%</b>

Source: State of Hawai'i GIS Program Geospatial Data Portal; HWMO 2013

a. Critical area mileage includes the combined area of coverage of individual critical habitat areas

b. Reefs include artificial and coral reefs

c. Total square miles may be over reported as some environmental asset areas may overlap.

Sq. Mi. = Square miles.

Due to the limited number of dams evaluated, the tabular results do not fully represent the statewide exposure nor vulnerability.

### Cultural Assets

Portions of the Hawaiian Home Lands are located in dam inundation hazards areas for the 12 dams assessed; land is vulnerable in the Counties of Hawai'i and Maui (see Table 4.4-14).

**Table 4.4-14. Hawaiian Home Lands Located in Dam Failure Inundation Areas**

County	Area		
	Total Area (square miles)	Dam Failure Inundation Area (square miles)	Percent (%) of Total Area
County of Kaua'i	32.0	0.0	0.0%
City and County of Honolulu	10.9	0.0	0.0%
County of Maui	92.6	3.0	3.2%
County of Hawai'i	190.3	0.2	0.1%
<b>Total</b>	<b>325.8</b>	<b>3.2</b>	<b>1.0%</b>

Source: State of Hawai'i GIS layer Trust Land, State of Hawai'i GIS Program Geospatial Data Portal

Notes: GIS Geographic Information System

Due to the limited number of dams evaluated, the tabular results do not fully represent the statewide exposure nor vulnerability.

### FUTURE CHANGES THAT MAY IMPACT STATE VULNERABILITY

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

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



## Potential or Projected Development

Dam failure inundation areas were overlain on areas that may experience significant changes in development or redevelopment in future years (see Table 4.4-15 below; refer to Section 3 for more information on projected development areas). None of the dam inundation areas selected for analysis intersect with the potential or projected development areas in the County of Kaua'i or the City and County of Honolulu. Almost 4 square miles and more than 8 square miles are located in dam inundation areas in the County of Maui and the County of Hawai'i, respectively. It should be noted that this analysis does not include all dam failure risk within the State because only a subset of dam inundation areas was analyzed. It is likely that there are other dams whose failures would impact these areas. While existing floodplain development regulations in place at the county level may offer some protection for new development located in these areas, such protections would likely not be sufficient in many instances in the event of a catastrophic dam failure. This results from a number of factors such as, the extent of the dam inundation areas may be larger than the regulated floodplain and water depths and velocities may be stronger and higher than the 1% annual chance flood event.

## Projected Changes in Population

As population in the State continues to increase there is the potential that more people will reside or work within dam inundation areas. Increased density and development is most likely to occur in Urban District lands, so careful attention should be paid to ensuring local zoning codes consider these risks. Additionally, as the population in the State ages (more than 23% of the population is projected to be 65 years of age or older by 2040) more residents may face challenges quickly evacuating an area in the event of an impending failure.

## Other Factors of Change

The impacts of climate change in the state have the potential to increase the probability of future dam failure events as discussed in the Probability of Future Hazard Events section above; however, the direct impacts of a dam failure would not be likely to change.



**Table 4.4-15. HCDA Community Development Districts, Maui Development Projects, and Enterprise Zones Located in Dam Inundation Areas**

County	Area (in square miles)								
	HCDA Community Development Districts	Total Area Exposed to Hazard	Hazard Area as % of Total Area	Maui Development Projects (Total Area)	Total Area Exposed to Hazard	Hazard Area as % of Total Area	Enterprise Zones (Total Area)	Total Area Exposed to Hazard	Hazard Area as % of Total Area
County of Kaua'i	-	-	-	-	-	-	1,286.6	0.0	0.0%
City and County of Honolulu	7.4	0.0	0.0%	-	-	-	288.3	0.0	0.0%
County of Maui	-	-	-	27.6	0.3	1.2%	252.3	3.9	1.5%
County of Hawai'i	-	-	-	-	-	-	1,016.7	8.4	0.8%
<b>Total</b>	<b>7.47</b>	<b>0.0</b>	<b>0.0%</b>	<b>28</b>	<b>0.3</b>	<b>1.2%</b>	<b>2,844</b>	<b>3.9</b>	<b>1.5%</b>

Total area calculated from: (1) HCDA Community Development District GIS layer from Hawai'i Community Development Authority (2) Maui Development Projects GIS layer from Maui County Planning Department (3) Enterprise Zones from Community Economic Development Program, DBEDT

Hazard area clipped to coastline downloaded from State of Hawai'i GIS Program Geospatial Data Portal

Due to the limited number of dams evaluated, the tabular results do not fully represent the statewide exposure nor vulnerability.