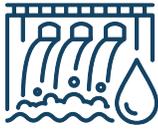




## **Section 4.10 Infrastructure Failure**



# Infrastructure Failure

Infrastructure failure is a broad term that encompasses the hazards that are created or exacerbated when incidents, both human-caused and natural, cause the failure of an infrastructure element. The statistics below focus on the high hazard dam inundation area.

### CHANGES SINCE 2018

+ 0

Declared Disasters

+ 0

Events

### COUNTIES MOST VULNERABLE



Kaua'i Honolulu Maui Hawai'i

### SOCIALLY VULNERABLE POPULATION

0.9%

Of Total Population

12,510

Persons

### CLIMATE PROJECTIONS



Increased drought and heavy rain events will cause an increase in flash flooding, infrastructure damage, runoff, and sedimentation



Increased rainfall from El Niño may lead to an increased risk of dam failure



Spillway overflow events may increase due to an increase in flooding potential

### HAZARD RANKING



Low Medium High

### COMMUNITY LIFELINES

21

Total



Greatest

197

State Buildings



9

Environmental Resources



2

Hawaiian Home Lands



3

Cultural Resources



26

Miles of State Road

SQUARE MILES





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<sup>1</sup> Section Cover Photo: Remainder of the Morita Reservoir wall and a road, downstream of the 400+ million-gallon flow from the Ka Loko dam failure in 2006. Photo courtesy of Kaua’i Emergency Management Agency



# SECTION 4. RISK ASSESSMENT

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## 4.10 INFRASTRUCTURE FAILURE

### 2023 SHMP Update Changes

- ❖ The infrastructure failure profile is new for the 2023 update; however, it primarily focuses on dam failure, which was previously a stand-alone section.
- ❖ Dam failure events that occurred in the State of Hawai'i from January 1, 2018, through December 31, 2022, were researched for this 2023 SHMP Update.
- ❖ New and updated figures from federal, state, and local agencies were incorporated.
- ❖ This section now includes a discussion of how infrastructure failure impacts socially vulnerable populations and community lifelines.
- ❖ Six types of cultural resources (archaeology, burial sensitivity area, historic building, historic district, historic object, and historic structure) were added to the vulnerability assessment.
- ❖ This section now includes an analysis of the exposure of state and county assets to high hazard dam inundation areas.

#### 4.10.1 HAZARD PROFILE

Infrastructure failure is a broad term that encompasses the hazards that are created or exacerbated when incidents, both human-caused and natural, cause the failure of an infrastructure element. These incidents include disasters like dam/hydrological failure, pre-building code engineering mishaps, interruption of operations, and structural windborne debris and transportation infrastructure failure at the harbor or airport (State of Hawai'i Emergency Management Agency 2022). This section focuses on dam failure, while other types of infrastructure failure are addressed as cascading effects of other hazards within Section 4 Risk Assessment.

Dams and reservoirs in the State of Hawai'i were predominantly developed for irrigation purposes by the agriculture industry in the early 20<sup>th</sup> century. More than 100 years later, 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 statutes were passed by the legislature and was followed up in 1989 with the Hawai'i Administrative Rules that were set up by the Department of Land and Natural Resources (DLNR). Most existing dams were built before regulatory construction standards were established.





## 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 2016).
- **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.

Only dams that meet 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 4.6 (Flood), event-based flooding is discussed in Section 4.6 (Flood), and storm surge is discussed in Section 4.9 (Hurricane).

## 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 2016). A dam impounds water in the upstream area or reservoir. The amount of water impounded, or stored, is measured in acre-feet, referring to the volume of water that covers an acre of land to a depth of one foot (USGS 1995).

Dam failures can occur with little to no warning. Dam failures are most likely to occur for one of five reasons, including:

- Overtopping caused by water spilling over the top of a dam
- Foundational defects, including settlement and slope instability, cause about 30% of all dam failures
- Cracking caused by movements like the natural settling of a dam
- Inadequate maintenance and upkeep
- Piping is when seepage through a dam is not properly filtered, and soil particles continue to progress and form sinkholes in the dam
- (Association fo State Dam Safety Officials 2022)

## LOCATION

DLNR maintains the online *Dam Inventory System* which includes detailed information and evacuation zones for each of the 126 state-regulated dams. As of December 31, 2021, 118 of the 126 state-regulated dams have a classification of "high hazard" (Association of State Dam Safety Officials 2021). A detailed inventory of dams, by county, is listed in Appendix F (State Profile and Risk Assessment Supplement). Table 4.10-1 summarizes the total number of dams in each county. A majority of the dams (55 total) are located in the County of Maui, followed by the County of Kaua'i with 48 dams. Table 4.10-2 summarizes the total square miles of high hazard dam inundation area by county. The Counties of Kaua'i and Maui have the greatest inundation area, followed by the City and County of Honolulu.





**Table 4.10-1. Total Number of Dams and Reservoirs in Each County**

County	Total Number of Dams and Reservoirs
County of Kaua'i	48
City and County of Honolulu	13
County of Maui	55
County of Hawai'i	10
<b>Total</b>	<b>126</b>

Source: DLNR n.d.

**Table 4.10-2. Total Square Miles of High Hazard Dam 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	624.29	16.5	2.64%
City and County of Honolulu	598.57	8	1.34%
County of Maui	1176.28	30.1	2.56%
County of Hawai'i	4039.64	10.3	0.25%
<b>Total</b>	<b>6,438.78</b>	<b>64.9</b>	<b>1.01%</b>

Source: Department of Land and Natural Resources 2022; Pacific Disaster Center 2022

Note:

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

High hazard dams throughout the state are indicated in Figure 4.10-1. Inundation area mapping for high hazard dams can be found in Appendix D (Map Atlas). DLNR, with coordination from the Pacific Disaster Center, provided the data for the high hazard dam locations and inundation areas represented in this SHMP Update.

### **Obstacles and Challenges**

DLNR continues to address obstacles and challenges for overall dam safety in the state by maintaining updated data on the following website: [Engineering Division, Dam Safety \(hawaii.gov\)](https://www.hawaii.gov/engineering/division-dam-safety/). The information and interactive mapping increases understanding of the dam failure risk in Hawai'i. Both state and federal sources are used to fund the DLNR State Dam Safety Program. Continued access to funding is critical to keep information up to date as climate conditions, including extreme precipitation events, change in the state.

### **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 the downstream areas from the dam. The State of Hawai'i classifies dams and reservoirs in a three-tier hazard rating system based on the probable loss of human life and impacts on the economy and environment. The hazard potential categories are listed below and summarized in Table 4.10-3.





Figure 4.10-1. High Hazard Dams Statewide

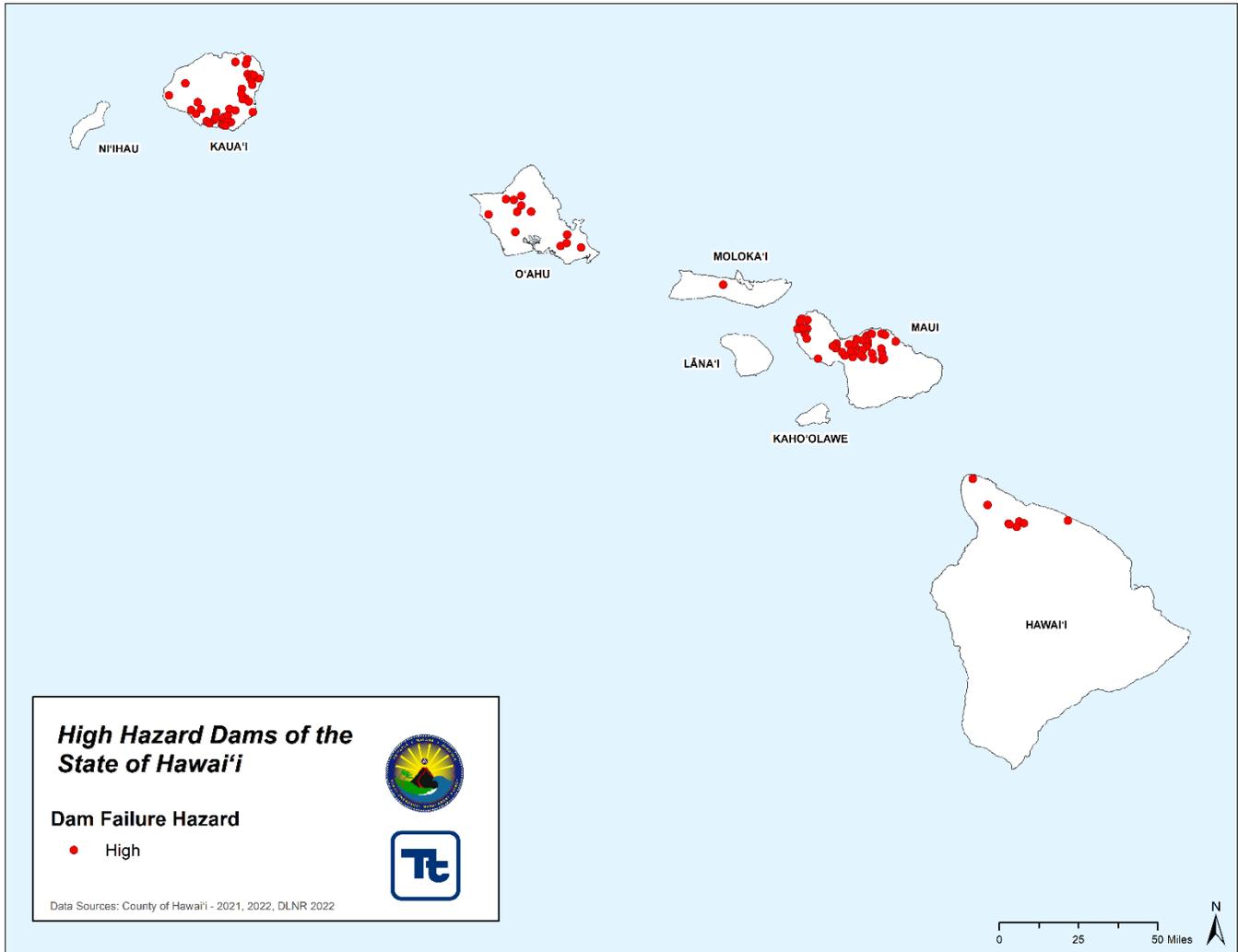


Table 4.10-3. Dam Hazard Potential Classification

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 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, evacuations can be planned with sufficient time. In the event of a structural failure because of an 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 (Association of State Dam Safety Officials 2021). 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 (Veale and Davison 2013).

High and significant hazard dam owners are required to prepare and maintain an Emergency Action Plan (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 their adopted emergency operations plans. These protocols are tied to the EAPs created by the dam owners. These documents are customarily maintained as confidential information, although copies are required to be provided to DLNR. DLNR has an EAP for every regulated dam in the State of Hawai'i (DLNR 2022).

## PREVIOUS OCCURRENCES AND LOSSES

### *Event History*

The 2018 SHMP discussed specific dam failure events that occurred in the State of Hawai'i through 2017. For this 2023 SHMP Update, dam failure events were summarized between January 1, 2018, and December 31, 2022. For events prior to 2018, please refer to Appendix E (Hazard Profile Supplement). Between 2018 and 2022, no dam failure incidents occurred in the State of Hawai'i; however, following heavy rains in March 2021, the Kaupakalua Dam crested, causing evacuations of homeowners. This event led to discussions of the dam being slated for removal (DLNR 2021).

### *Disaster and Emergency Declarations*

Between 1955 and December 2022, the State of Hawai'i experienced one federal disaster associated with a dam failure, Kaloko Dam (DR-1640), in March 2006. This is described further in Appendix E (Hazard Profile Supplement).

## PROBABILITY OF FUTURE HAZARD EVENTS

### *Overall Probability*

Causes for dam failure can be mitigated through proper design, proper construction, regular inspections by qualified personnel, and a commitment to strong enforcement in order to correct identified deficiencies. Risks to downstream life and property can be substantially reduced with effort to limit some development adjacent to streams and rivers. As 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 its 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 presumed to be low due to dam safety regulations and oversight.

### *Climate Change Impacts*

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. Since dams throughout the state were primarily built for irrigation purposes before regulatory construction standards were established and long before the anticipated impacts of climate change, the frequency and duration of extreme precipitation events directly corresponds to the frequency and duration of potential dam failure incidents. 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 may 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 increase in flash flooding, infrastructure damage, runoff, and sedimentation (State of Hawai’i 2022). 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 increased risk of dam failure as some dams may not be designed to withstand an increase in rain totals (NOAA 2015). For specific details regarding climate change, refer to Section 4.2 (Climate Change and Sea Level Rise).

## 4.10.2 VULNERABILITY ASSESSMENT

For the 2023 SHMP Update, the total number of state assets located in all high hazard dam failure inundation areas were examined. However, it is highly unlikely that all high hazard dams would fail at the same time.

### ASSESSMENT OF STATE VULNERABILITY AND POTENTIAL LOSSES

This section discusses statewide vulnerability of state assets (state buildings and roads) and critical facilities exposed 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 4.10-4 and Table 4.10-5 summarize the state buildings located in the statewide dam failure inundation area per county and state agency, respectively.





**Table 4.10-4. State Buildings Exposure to Statewide High Hazard Dam Inundation Areas by County**

County	Total Number of State Buildings	Total Replacement Cost Value (structure and contents)	Number of State Buildings in the Hazard Area	Percent (%) of Total Buildings	Total Value of State Buildings in the Hazard Area (structure and contents)	Percent (%) of Total Value
County of Kaua'i	531	\$990,850,824	18	3.39%	\$13,195,343	1.33%
City and County of Honolulu	3,472	\$17,393,945,915	108	3.11%	\$694,271,214	3.99%
County of Maui	831	\$3,097,491,689	38	4.57%	\$98,035,539	3.16%
County of Hawai'i	1,261	\$4,638,567,141	33	2.62%	\$412,057,638	8.88%
<b>Total</b>	<b>6,095</b>	<b>\$26,120,855,568</b>	<b>197</b>	<b>3.23%</b>	<b>\$1,217,559,734</b>	<b>4.66%</b>

Source: Department of Land and Natural Resources 2022; Pacific Disaster Center 2022; State of Hawai'i Risk Management Office 2017

**Table 4.10-5. State Buildings Exposure to Statewide High Hazard Dam Inundation Areas by Agency**

Agency	Total Number of State Buildings	Total Replacement Cost Value (structure and contents)	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	\$953,963,738	2	3.03%	\$12,312,612	1.29%
Dept of Agriculture	70	\$147,607,399	7	10.00%	\$15,101,709	10.23%
Dept of Attorney General	15	\$108,425,480	1	6.67%	\$1,288,081	1.19%
Dept of Budget & Finance	16	\$28,968,679	1	6.25%	\$4,806,631	16.59%
Dept of Business, Economic Development & Tourism	25	\$645,480,379	0	0.00%	\$0	0.00%
Dept of Commerce & Consumer Affairs	2	\$40,197,360	0	0.00%	\$0	0.00%
Dept of Defense	69	\$267,352,836	2	2.90%	\$8,951,140	3.35%
Dept of Education	4,090	\$10,598,205,739	95	2.32%	\$506,980,435	4.78%
Dept of Hawaiian Home Lands	12	\$110,427,352	0	0.00%	\$0	0.00%
Dept of Health	44	\$387,068,440	1	2.27%	\$642,741	0.17%
Dept of Human Resources Development	1	\$5,973,872	0	0.00%	\$0	0.00%
Dept of Human Services	130	\$480,212,294	9	6.92%	\$21,728,493	4.52%
Dept of Labor & Industrial Relations	22	\$90,076,209	0	0.00%	\$0	0.00%
Dept of Land & Natural Resources	90	\$101,441,821	4	4.44%	\$3,377,505	3.33%
Dept of Public Safety	154	\$440,774,415	0	0.00%	\$0	0.00%
Dept of Taxation	1	\$7,174,162	0	0.00%	\$0	0.00%
Dept of Transportation	68	\$2,935,208,214	9	13.24%	\$44,441,751	1.51%
Hawai'i State Ethics Commission	1	\$984,533	0	0.00%	\$0	0.00%
Hawai'i Health Systems Corporation	106	\$1,230,852,871	2	1.89%	\$3,086,734	0.25%
Hawai'i Housing Finance & Development Corporation	86	\$360,851,671	0	0.00%	\$0	0.00%
Hawai'i Public Housing Authority	273	\$982,981,701	29	10.62%	\$139,214,142	14.16%
Hawai'i State Legislature	2	\$48,555,381	0	0.00%	\$0	0.00%





Agency	Total Number of State Buildings	Total Replacement Cost Value (structure and contents)	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	9.43%	\$22,596,333	4.30%
Judiciary	41	\$534,877,354	0	0.00%	\$0	0.00%
Legislative Reference Bureau	1	\$2,996,162	0	0.00%	\$0	0.00%
Office of Hawaiian Affairs	11	\$54,125,645	2	18.18%	\$26,025,298	48.08%
Office of the Auditor	2	\$1,921,180	0	0.00%	\$0	0.00%
Office of the Governor	1	\$2,996,162	0	0.00%	\$0	0.00%
Office of the Lieutenant Governor	2	\$4,588,849	0	0.00%	\$0	0.00%
Office of the Ombudsman	1	\$1,818,060	0	0.00%	\$0	0.00%
Research Corporation of the University of Hawai'i	3	\$4,189,026	0	0.00%	\$0	0.00%
University of Hawai'i	637	\$5,014,974,503	28	4.40%	\$407,006,130	8.12%
<b>Total</b>	<b>6,095</b>	<b>\$26,120,855,568</b>	<b>197</b>	<b>3.23%</b>	<b>\$1,217,559,734</b>	<b>4.66%</b>

Source: Department of Land and Natural Resources 2022; Pacific Disaster Center 2022; State of Hawai'i Risk Management Office 2017

The spatial analysis indicates that there are 197 state buildings (3.2%) vulnerable to dam failure statewide. Of these, the greatest number are in the City and County of Honolulu (108 buildings with a replacement cost value of \$694 million. The majority of these buildings are occupied by the Department of Education (95) and Hawai'i Public Housing Authority (29).

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 4.10-6 shows the length of state roads in the dam inundation areas by county. Maui County has the greatest length of state road (13.3 miles) exposed to the dam inundation areas that were analyzed. A complete list of state roads is included in Appendix F (State Profile and Risk Assessment Supplement).

**Table 4.10-6. State Road Exposure to Statewide High Hazard Dam 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	103.7	2.7	2.60%
City and County of Honolulu	374.9	9.2	2.45%
County of Maui	245.9	13.3	5.41%
County of Hawai'i	379.2	0.4	0.11%
<b>Total</b>	<b>1,103.70</b>	<b>25.6</b>	<b>2.32%</b>

Source: State of Hawai'i Dept. of Transportation 2022; Department of Land and Natural Resources 2022; Pacific Disaster Center 2022

### Community Lifelines and 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 4.10-7 summarizes the total number of community lifelines and critical facilities by category located in the dam failure inundation areas statewide by county. The City and County of Honolulu has the greatest number of critical facilities (41) within the analyzed dam inundation areas, with the majority of the facilities being categorized as Energy. Table 4.10-8 summarizes the number and percentage of exposed community lifelines and critical facilities by category. Energy facilities have 16.85% of their facilities within the analyzed dam inundation areas.

**Table 4.10-7. Community Lifelines and Critical Facilities Exposure to Statewide High Hazard Dam Inundation Areas, by County**

County	Community Lifeline Categories							Total in the Hazard Area	Additional Critical Facilities
	Communications	Energy	Food, Water, Shelter	Hazardous Material	Health & Medical	Safety & Security	Transportation		
County of Kaua'i	0	0	0	0	0	2	0	2	1
City and County of Honolulu	7	13	6	0	3	12	0	41	0
County of Maui	4	2	12	0	3	7	8	36	3
County of Hawai'i	1	0	3	0	1	0	0	5	1
<b>Total</b>	<b>12</b>	<b>15</b>	<b>21</b>	<b>0</b>	<b>7</b>	<b>21</b>	<b>8</b>	<b>84</b>	<b>5</b>

Source: Department of Land and Natural Resources 2022; Pacific Disaster Center 2022; Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020

**Table 4.10-8. Community Lifeline and Critical Facility Exposure to Statewide High Hazard Dam Inundation Areas, by Category**

Category	Total Number of Facilities	Total Replacement Cost Value	Number of Facilities in Hazard Area	Percent (%) of Total Facilities	Value in the Hazard Area	Percent (%) of Total Value
Communications	188	\$776,797,683	12	6.38%	\$47,000,315	6.05%
Energy	89	\$3,093,949,530	15	16.85%	\$557,941,340	18.03%
Food, Water, Shelter	345	\$11,847,189,588	21	6.09%	\$740,398,300	6.25%
Hazardous Material	12	\$436,474,800	0	0.00%	\$0	0.00%
Health and Medical	193	\$4,606,713,364	7	3.63%	\$95,885,988	2.08%
Safety and Security	486	\$38,164,188,232	21	4.32%	\$3,036,032,806	7.96%
Transportation	56	\$2,039,091,600	8	14.29%	\$290,352,000	14.24%
Additional Critical Facilities	106	\$447,698,794	5	4.72%	\$86,491,270	19.32%
<b>Total</b>	<b>1,475</b>	<b>\$61,412,103,591</b>	<b>89</b>	<b>6.03%</b>	<b>\$4,854,102,018</b>	<b>7.90%</b>

Source: Department of Land and Natural Resources 2022; Pacific Disaster Center 2022; Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020





## ASSESSMENT OF LOCAL VULNERABILITY AND POTENTIAL LOSSES

The local HMPs were reviewed to integrate risk assessment results into the 2023 SHMP 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 2020).
- **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 Nu'uuanu Reservoir dam and the Kāne'ohe Dam (City and County of Honolulu 2020).
- **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 Kualapu'u on Moloka'i. These dams were selected because they represent the largest, non-overlapping exposure areas on each island (County of Maui 2020).
- **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 2020).

### *Socially Vulnerable and Total Population*

Vulnerable populations are all populations downstream from dam failures that are unable to escape the area within the necessary time. This includes the elderly, the young, individuals with disabilities, and individuals with access or functional needs who may be unable to get out of the inundation area. The vulnerable population also includes those who may lack broadband or cell access and would not have adequate warning from the emergency warning system (e.g., television or radio); this includes residents and visitors. 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 4.6 (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 high hazard dam failure is summarized in Table 4.10-9. The City and County of Honolulu has the greatest population (23,842) and the greatest number of the high vulnerability population (8,588) located in the dam failure inundation hazard area; however, the County of Maui has the highest population percentage (4.31%) and highest vulnerable population percentage (2.25%) exposed. 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 4.10-9. 2020 U.S. Census Population Located in the High Hazard Dam Inundation Areas by County**

County	Population				
	Total Population	Population in the Hazard Area	Population Exposed as % of Total Population	Socially Vulnerable Population in the Hazard Area	Socially Vulnerable Population Exposed as % of Total Population
County of Kaua'i	71,949	2,369	3.29%	130	0.18%
City and County of Honolulu	979,682	23,842	2.43%	8,588	0.88%
County of Maui	167,093	7,201	4.31%	3,756	2.25%
County of Hawai'i	201,350	912	0.45%	36	0.02%
<b>Total</b>	<b>1,420,074</b>	<b>34,324</b>	<b>2.42%</b>	<b>12,510</b>	<b>0.88%</b>

Source: U.S. Census Bureau 2020; Centers for Disease Control and Prevention 2018; Department of Land and Natural Resources 2022; Pacific Disaster Center 2022

### Land Use Districts

Table 4.10-10 shows the total area of each state land use district in the dam inundation hazard areas that were analyzed; refer to Appendix F (State and Risk Assessment Supplement) for results by county. Of those dams chosen for analysis, Agricultural District Lands comprise the greatest area in the inundation areas. 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. 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 2023 SHMP Update. As local hazard mitigation plans are updated, the full extent of this hazard in each county should be further analyzed.

**Table 4.10-10. State Land Use Districts Located in the High Hazard Dam Inundation Areas**

Land Use District	Total (square miles)	Square Miles in Dam Inundation Area	Percent (%) of Total Area
<b>Agricultural</b>	2,973.6	30.7	1.03%
<b>Conservation</b>	3,202.9	3.4	0.11%
<b>Rural</b>	16.3	0.13	0.80%
<b>Urban</b>	319.1	9.5	2.98%
<b>Total</b>	<b>6,511.95</b>	<b>43.73</b>	<b>0.67%</b>

Source: Department of Land and Natural Resources 2022; Pacific Disaster Center 2022; State Land Use Commission, Hawai'i Statewide GIS Program 2021; Honolulu County GIS 2022

### General Building Stock

The economic impact of dam failures depends on 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 in relation to the high hazard dam inundation areas. The general building stock in the inundation area is considered exposed to a dam failure. Structures closest to the inundation area 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 4.10-11 summarizes the building replacement cost value located in the high hazard dam inundation areas.





**Table 4.10-11. General Building Stock Exposure to the High Hazard Dam Inundation Areas**

County	Total Replacement Cost Value (structure and contents)	Value Located in Dam Inundation Area	Percent (%) of Total Value
County of Kaua'i	\$24,246,497,228	\$1,415,139,425	5.84%
City and County of Honolulu	\$239,152,051,766	\$6,939,077,118	2.90%
County of Maui	\$50,796,693,140	\$4,848,480,535	9.54%
County of Hawai'i	\$58,395,349,136	\$1,080,164,946	1.85%
<b>Total</b>	<b>\$372,590,591,270</b>	<b>\$14,282,862,024</b>	<b>3.83%</b>

Source: NIYAM IT 2022; U.S. Army Corps of Engineers 2022

Approximately \$14 billion, which represents 38.3% of the total building stock replacement cost value in the state, is located in the high hazard dam inundation area. The County of Maui has the largest percent (9.54%) of their building stock located in the high wildfire risk hazard area, while the City and County of Honolulu has the highest dollar amount exposure with over \$6.9 billion. The replacement cost value of buildings exposed is provided as an estimate for total loss.

### 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 4.10-12.

**Table 4.10-12. Environmental Resources Located in the High Hazard Dam 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>	951	0	0.04%
Wetlands	3,637	6	0.17%
Parks and Reserves	2,778	2	0.09%
Reefs <sup>b</sup>	55	0	0.04%
<b>Total <sup>c</sup></b>	<b>7,420</b>	<b>9</b>	<b>0.12%</b>

Source: PDC 2018; U.S. Fish and Wildlife Service 2017; 2017; State Office of Planning 2017; Department of Land and Natural Resources 2015; Hawai'i Division of Aquatic Resources 2005; NOAA 2002

Notes:

- 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 includes environmental assets within 3 nautical miles of each county and may be over reported as some environmental asset areas may overlap.





## Cultural Assets

Portions of the Hawaiian Home Lands are located in high hazard dam inundation hazards areas; land is vulnerable in the Counties of Hawai'i and Maui (see Table 4.10-13). The County of Maui has the greatest number of square miles (1.12) and the highest percentage (1.09%) of Hawaiian Home Lands located in dam inundation hazard areas.

**Table 4.10-13. Hawaiian Home Lands Located in High Hazard Dam Inundation Areas**

County	Area		
	Total Area (square miles)	Dam Failure Inundation Area (square miles)	Percent (%) of Total Area
County of Kaua'i	32.09	0.17	0.53%
City and County of Honolulu	10.61	0.02	0.15%
County of Maui	102.59	1.12	1.09%
County of Hawai'i	191.46	0.56	0.29%
<b>Total</b>	<b>336.75</b>	<b>1.87</b>	<b>0.55%</b>

Source: Hawai'i State Department of Hawaiian Homelands 2021; Department of Land and Natural Resources 2022; Pacific Disaster Center 2022

Table 4.10-14 discusses the cultural resources in dam inundation hazard areas. The cultural resource type with the largest total area and largest area in the hazard area is the Historic District; however, the district with the largest percentage of area in the dam inundation hazard area is the Burial Sensitivity Area.

**Table 4.10-14. Cultural Resources Located in the High Hazard Dam Inundation Areas**

Cultural Resource Site Type	Area (in square miles)		
	Total Square Miles of Asset	Total Square Miles in Hazard Area	Percent (%) of Total Asset Area
Archaeology	90.9	1.2	1.4%
Burial Sensitivity Area	2.1	0.1	2.9%
Historic Building	2.7	0.1	2.4%
Historic District	849.4	1.7	0.2%
Historic Object	9.6	0.0	0.0%
Historic Structure	20.7	0.1	0.3%
<b>Total</b>	<b>975.4</b>	<b>3.2</b>	<b>0.3%</b>

Source: Department of Land and Natural Resources, Hawai'i State Historic Preservation Division 2022; Department of Land and Natural Resources 2022; Pacific Disaster Center 2022

## 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 4.10-15 below; refer to Section 3 for more information on projected development areas). There are 9.94 square miles exposed to dam inundation areas in the County of Kaua’i, 11.11 square miles exposed in the City and County of Honolulu, roughly 47 square miles in the County of Maui, and 2.3 square miles in the County of Hawai’i. 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.

**Table 4.10-15. HCDA Community Development Districts, Maui Development Projects, and Enterprise Zones Located in High Hazard 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	0	0	0.0%	0	0	0.0%	251.0	9.94	4.0%
City and County of Honolulu	7.4	0	0.0%	0	0	0.0%	297.3	4.7	1.6%
County of Maui	0	0	0.0%	27.62	0.8	2.9%	1,059.8	19.7	1.9%
County of Hawai’i	0	0	0.0%	0	0	0.0%	1,274.9	2.3	0.2%
<b>Total</b>	<b>7.4</b>	<b>0</b>	<b>0.0%</b>	<b>27.62</b>	<b>0.8</b>	<b>2.9%</b>	<b>2,883</b>	<b>36.64</b>	<b>1.3%</b>

Source: Maui County Planning Department 2016; Hawai’i Community Development Authority 2021; Community Economic Development Program, Department of Business, Economic Development & Tourism, County Planning Departments 2021; Department of Land and Natural Resources 2022; Pacific Disaster Center 2022

### 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 are 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. High hazard dam inundation areas were overlain on areas that may experience significant changes in development or redevelopment in future years (see Table 4.10-15 below and Section 3 (State Profile) for more information on projected development areas). The results of this exercise indicate that the Enterprise Areas in the County of Hawai'i make up roughly half (1,274.9) of the total area located in high hazard dam inundation areas.

