14. INFRASTRUCTURE FAILURE

14.1 HAZARD PROFILE

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

14.1.1 HAZARD DESCRIPTION

Infrastructure failure is a broad term that encompasses hazards created or intensified by the failure of an infrastructure element, whether due to natural incidents or human-caused events. These incidents include dam/hydrological failure, pre-building code engineering mishaps, interruption of operations, structural windborne debris, and transportation infrastructure failure. This section focuses on dam failure, while other types of infrastructure failure are addressed as cascading effects of other hazards within the risk assessment.

Overview

A dam is an artificial barrier allowing storage of water, wastewater, or liquid-borne materials for many reasons (flood control, human water supply, irrigation, livestock water supply, energy generation, recreation, or pollution control) (ASDSO 2023). In the City, most dams are used for irrigation and flood control (USACE 2025).

Constructed dams can be classified according to type of construction material used; methods applied in construction, slope, or cross-section of the dam; how a dam resists forces of water pressure behind it; means used to control seepage; and purpose of the dam. Dams are constructed with a variety of materials including earth, rock, tailings from mining or milling, concrete, masonry, steel, timber, miscellaneous materials, (such as plastic or rubber), and any combination of these materials. The dams on Oʻahu, like those throughout Hawaiʻi, are primarily earthen, meaning they are built from compacted soil; the Koʻolau Reservoir is constructed with earth and concrete materials (USACE 2025).

Dams and reservoirs in the City were predominantly developed for irrigation purposes by the agriculture industry in the early 20th 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, recreation, and other purposes. Most existing dams were built before regulatory construction standards were established. The dams on Oʻahu, like those throughout Hawaiʻi, are primarily earthen, meaning they are built from compacted soil.

Infrastructure Failure Causes and Types

Dam failures occur when the dam is damaged or destroyed, releasing water or other liquid stored behind the dam. 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. Structural failures generally refer to the collapse of dams, resulting in the rapid release of all the stored water.

As noted above, O‘ahu’s dams are primarily earthen dams. Earthen dams are unlikely to experience catastrophic failure under normal conditions, except in cases where significant earthquake activity occurs or where erosive forces compromise the integrity of the structure (ASDSO 2021). Earthen dam failures primarily occur due to three main categories: hydraulic failures (overtopping and erosion), seepage failures (internal erosion and piping), and structural failures (slopes and foundation issues) (ASDSO 2021):

- **Hydraulic failure due to overtopping or erosion**—When water levels due to floods exceed the crest of the dam, the uncontrolled flow of water over, around and adjacent to the dam, can erode the embankment and slopes, leading to failure.
- **Seepage failures**—All earthen dams leak to some extent, which is known as seepage. Seepage is the result of water moving slowly through the embankment and/or percolating slowly through the dam's foundation. This is normal and usually not a problem with most earthen dams if measures are taken to control movement of water through and under the dam. If uncontrolled, seepage can progressively erode soil from the embankment or its foundation, weaking the dam and eventually leading to failure.
- **Structural failure**—Structural failure involves issues with the dam’s structure itself, including slope failures (slips on the upstream or downstream sides), foundation issues (settlement or instability), and issues with construction or maintenance. Earthquakes can also contribute to structural failures by inducing cracks, settlement, shear slides, or liquefaction.

In addition to the above, dam failure can result from deliberate acts of sabotage. Dams are considered critical infrastructure and may be targets for attack due to their potential for causing widespread damage and casualties upon failure.

The threat of dam failure increases as existing dams get older or if they are located on smaller streams. Advancing age makes dams more susceptible to failure. As dams age, deterioration increases, and construction costs rise. More than 80 percent of Hawaii's dams were constructed before 1940 to support the sugarcane plantations making the majority of dams in the City over 85 years old (DLNR n.d.). Consequently, many of these dams require updates and maintenance to meet current safety standards and ensure their structural integrity.

Regulatory Oversight of Dams

The potential for catastrophic flooding caused by dam failures led to the enactment of the National Dam Safety Act (Public Law 92-367), which for 50 years has protected Americans from dam failures. The National Dam Safety Program is a partnership among states, federal agencies, and other stakeholders that encourages individual and community responsibility for dam safety. Under FEMA’s leadership, state assistance funds have allowed all participating states to improve their programs through increased inspections, emergency action planning, and purchases of needed equipment. FEMA has also expanded existing and initiated new training programs. Grant assistance from FEMA provides support for the improvement of dam safety programs that regulate most dams in the United States.

The U.S. Army Corps of Engineers (USACE) is responsible for safety inspections of some federal and non-federal dams in the United States that meet the size and storage limitations specified in the National Dam Safety Act. USACE has inventoried dams and surveyed each state and federal agency's capabilities, practices, and regulations regarding the design, construction, operation, and maintenance of the dams. USACE has also developed guidelines for the inspection and evaluation of dam safety.

At the state level, dams are regulated by the Hawai'i Dam Safety Program (DSP), which was created by statute under the State's Department of Land and Natural Resources (DLNR) in 1987 and further defined in 1989 with the development of the Hawai'i Administrative Rules for the program (Hawai'i Revised Statutes Chapter 179D [HRS] and the Hawaii Administrative Rules [HAR] Title 13, Subtitle 7, Chapter 190.1). The program aims to protect the health, safety, and welfare of the citizens of the State by reducing the risk of failure of the dams or reservoirs. Only dams that meet certain jurisdictional size criteria (height and volume) are regulated by the state's DSP. 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.

The DSP governs the design, construction, operation, maintenance, enlargement, alteration, repair, and removal of regulated dams, reservoirs, and their appurtenant works in the state. The DSP conducts safety inspections of all regulated dams and work with owners to develop remediation plans for deficiencies identified in the safety inspections. In addition, the DSP works with dam owners on planning for possible emergencies. State law requires owners of state-regulated high and significant hazard potential dams and reservoirs to establish an Emergency Action Plan (EAP) to assist the local community in effectively responding to a dam safety emergency. The EAP identifies incidents that can lead to potential emergency conditions at the dam, identifies the areas that could be affected in the event that the dam fails, and specifies pre-planned actions dam operators will follow during an unusual or emergency event at the dam, including detection and notification. Owners are also required to provide this EAP to the DLNR, State and County emergency management and first responder agencies. (HRS 179D-30)

DLNR was involved in the planning process for the LHMP development through participation in workshop meetings and events along with other agencies and stakeholders. DLNR provided dam-related data and information through the use of past studies, analysis modeling, and planning assessments.

DLNR participates in FEMA's High Hazard Potential Dam (HHPD) grant program, which provides grant funding for dam improvement projects. DLNR uses criteria such as overall condition, number and type of deficiencies, and failure impacts to prioritize applicant dams in the event grant applicant funding requests exceed available funding.

Potential Impacts

When a dam fails, a large volume of water, sediment, and debris is released downstream, potentially causing catastrophic flooding and damage. This sudden release of water can create powerful floodwaters which can destroy homes and infrastructure downstream of the dam. Particularly if the failure occurs without sufficient warning time to allow for evacuations, impacts can include injuries and loss of life. Dam failure can also cause

long-term environmental impacts, as the sudden surge of water, sediment, and debris can harm downstream habitats. Other potential cascading impacts include landslides around the reservoir's perimeter and bank erosion in nearby streams.

14.1.2 LOCATION

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

Dam failure can occur anywhere there is a dam. Figure 14-1 shows the location of regulated dams in the City. The communities downstream are at the greatest risk for dam failure. Flooding is the most common secondary effect of dam failure. If the dam failure is severe, a large amount of water will enter the downstream body of water and overflow the stream banks for miles.

DLNR maintains the online Dam Inventory System which includes detailed information and evacuation zones for each of the state-regulated dams in the City. On O‘ahu, there are 13 regulated dams, with 12 classified as high hazard, meaning their failure could result in significant consequences (DSP 2025). Twelve of these dams have Emergency Action Plans (EAPs), which include information on the dam’s inundation areas.

The inundation area is the area downstream of the dam that would be flooded in the event of a failure or uncontrolled release of water and is generally much larger than the area for a normal river or stream flood event. Within the City approximately 8 square miles are designated as high-hazard dam failure inundation hazard areas, representing 1.34 percent of the total area of the City (HI EMA 2023). The area was calculated based on the spatial layer provided by the Pacific Disaster Center, with data on high-hazard dam locations and inundation areas coordinated by DLNR.

An evacuation zone has been developed by the City for each dam, which in most cases includes the inundation area plus a buffer. In the event of a potential dam failure, everyone within the dam’s evacuation zone would be ordered to evacuate. Evacuation zones are available for the public to view at www.honolulu.gov/damevac.

Figure 14-2 shows the dam failure inundation hazard areas overlaid with the evacuation zone for each dam in the City.

Figure 14-1. Regulated Dams in the City

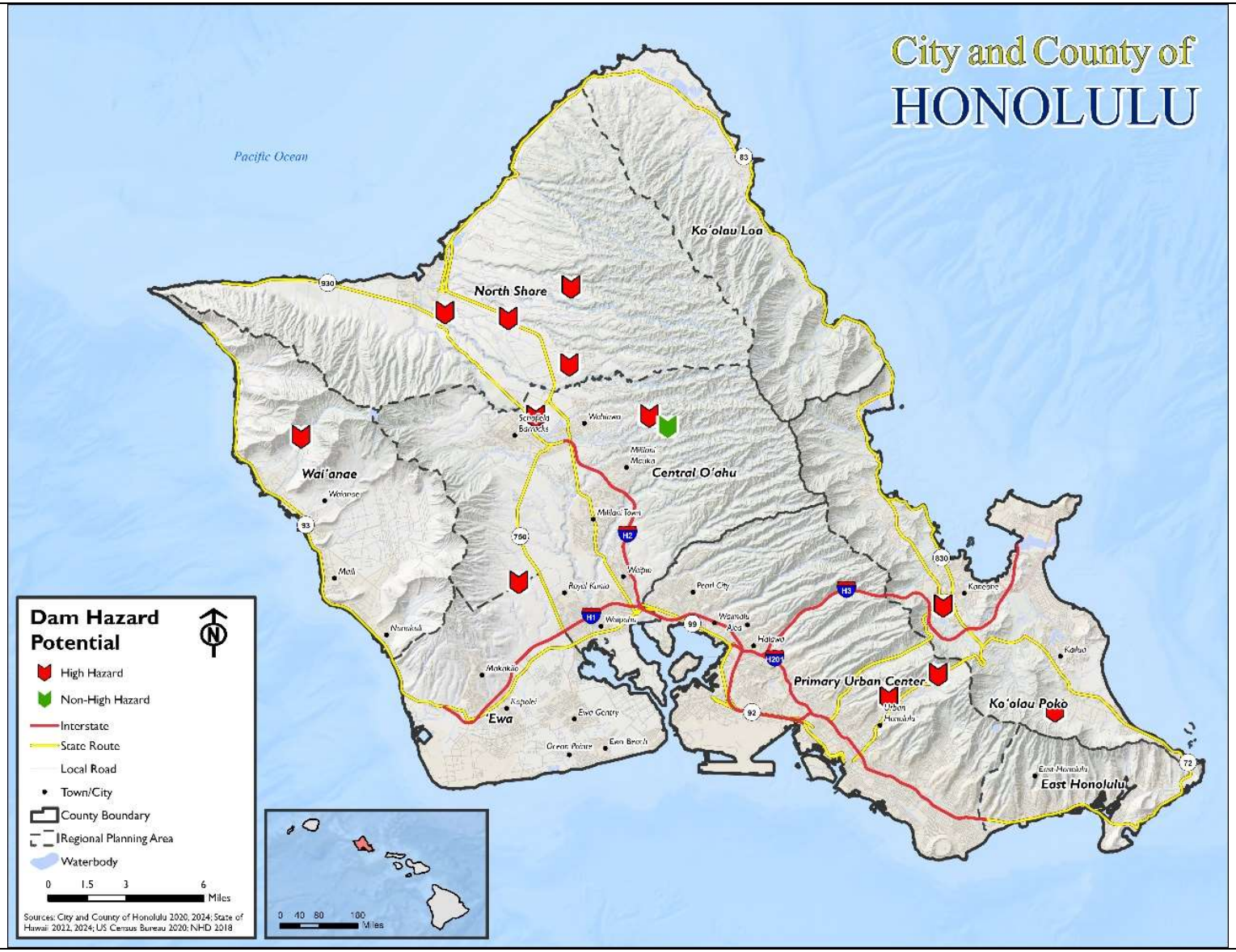
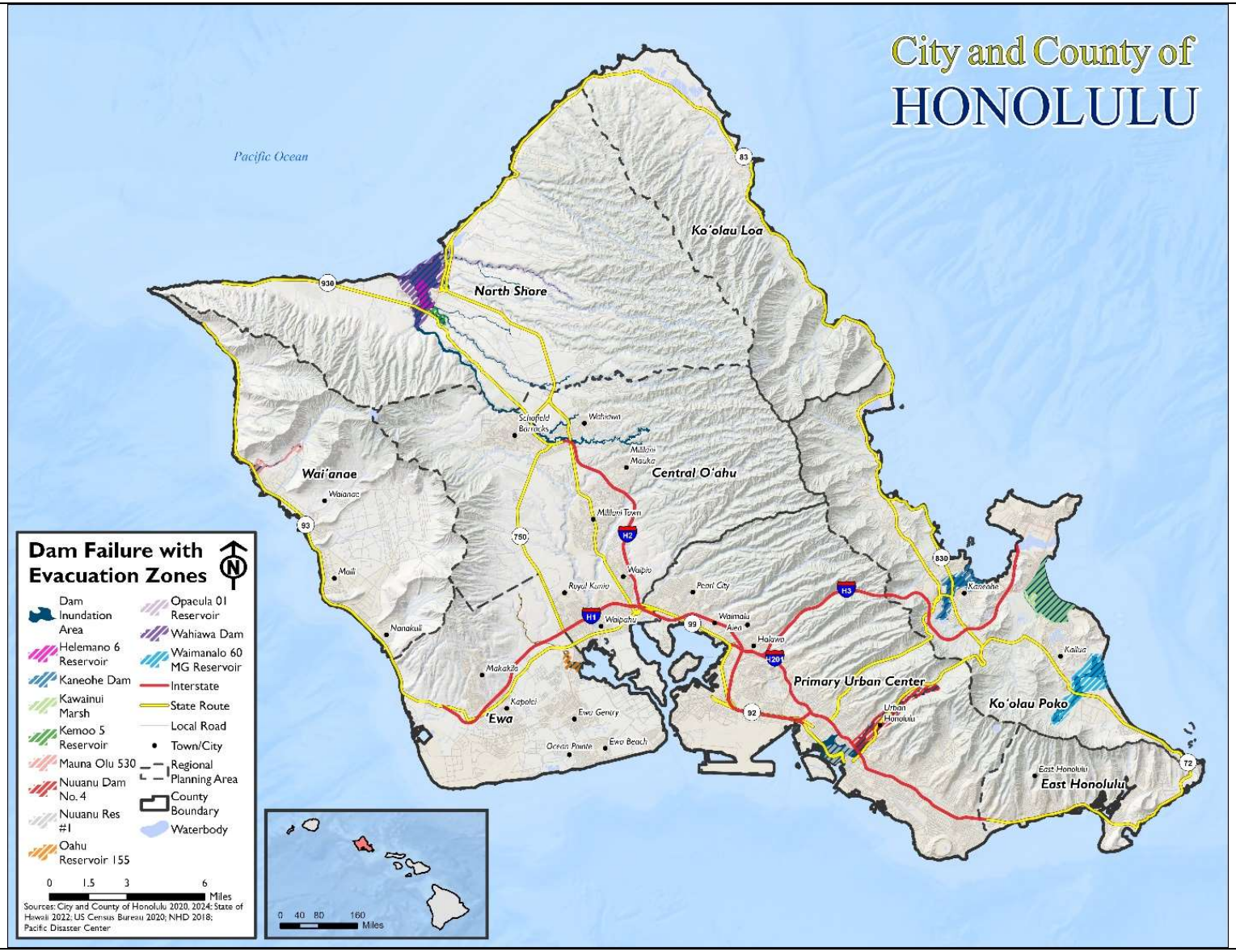


Figure 14-2. Dam Failure Inundation Hazard Areas Overlaid with Dam Evacuation Zones



14.1.3 EXTENT

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

Hazard Classification

Dams are classified based on the downstream damage that would result if the dam were to fail. The hazard classification has no relationship to the condition of the dam, its structural integrity, operational status, or flood storage capability. In accordance with HAR 13-190.1, which is consistent with national dam safety practices such as USACE classifications, the State of Hawai'i classifies dams and reservoirs in a three-tier hazard rating system: low, significant, and high. The hazard potential classification system provides a means of categorizing the consequences of dam failure, used as a tool for prioritizing dam safety program activities, and identifying additional regulatory requirements or actions. Table 14-1 summarizes the hazard potential categories:

Table 14-1. Hazard Classification Definitions

Hazard Rating	Description
Low	Loss of life is not expected. Economic and environmental losses are low and generally limited to the owner's property
Significant	Loss of life is not expected, but major economic loss, environmental damage, disruption of lifeline facilities, or impacts of other concerns are possible.
High	Loss of life is probable, one or more expected. Economic and environmental losses are expected.

Source: (DLNR, Engineering Division 2024)

In addition to the classifications described above, USACE also developed a classification of hazard potentials of dam failures, based only on potential consequences of dam failure (see Table 14-2). This classification does not consider the probability of failure.

Table 14-2. USACE Dam Hazard Potential Classification

Hazard Category[a]	Direct Loss of Life[b]	Lifeline Losses[c]	Property Losses[d]	Environmental Losses[e]
Low	None (rural location, no permanent structures for human habitation)	No disruption of services (cosmetic or rapidly repairable damage)	Private agricultural lands, equipment, and isolated buildings	Minimal incremental damage
Significant	In rural locations, only transient or day-use facilities	Disruption of essential facilities and access	Major public and private facilities	Major mitigation required
High	Certain (one or more) extensive residential, commercial, or industrial development	Disruption of essential facilities and access	Extensive public and private facilities	Extensive mitigation cost or impossible to mitigate

Source: USACE 2023

a. Categories are assigned to overall projects, not individual structures at a project.
b. Loss-of-life potential is based on inundation mapping of the area downstream of the project. Analysis of loss-of-life potential should consider the population at risk, time of flood wave travel, and warning time.
c. Lifeline losses include indirect threats to life caused by the interruption of lifeline services from project failure or operational disruption; for example, loss of critical medical facilities or access to them.
d. Property losses include damage to project facilities and downstream property and indirect impact from the loss of project services, such as impact from the loss of a dam and navigation pool or impact from the loss of water or power supply.
e. Environmental impact downstream caused by the incremental flood wave produced by the project failure, beyond what would normally be expected for the magnitude flood event under which the failure occurs.

Risk Components

The risk a dam poses to communities can be split into the following three components of the total risk (FEMA 2022):

- **Incremental Risk**—The risk (likelihood and consequences) to the pool area and downstream floodplain occupants that can be attributed to the presence of the dam should the dam breach prior or subsequent to overtopping, or undergo component malfunction or mis-operation, where the consequences considered are over and above those that would occur without dam breach. The consequences typically are due to downstream inundation, but the loss of the pool can result in significant consequences in the pool area upstream of the dam.
- **Non-Breach Risk**—The risk in the reservoir pool area and affected downstream floodplain due to normal operation of the dam (e.g., large spillway flows within the design capacity that exceeds channel capacity) or "overtopping of the dam without breaching" scenarios.
- **Residual Risk**—The risk that remains after all mitigation actions and risk reduction actions have been completed. With respect to dams, FEMA defines residual risk as "risk remaining at any time" (FEMA 2015). It is the risk that remains after decisions related to a specific dam safety issue are made, and prudent actions have been taken to address the risk. It is the remote risk associated with a condition that was judged to not be a credible dam safety issue.

Dam Condition

In addition to the classifications used to describe the hazard level posed by the dam, DSP also assigns regulated dams a classification based on an assessment of their overall condition, as defined in Table 14-3. The overall condition assessment classifications used in Hawai‘i are based on system adopted by the 2018 National Inventory of Dams.

Table 14-3. Dam Condition Definitions

Condition	Description
Satisfactory	No existing or potential dam safety deficiencies are recognized. Acceptable performance is expected under all loading conditions (static, hydrologic, seismic) in accordance with the applicable regulatory criteria or tolerable risk guidelines.
Fair	No existing dam safety deficiencies are recognized for normal loading conditions. Rare or extreme hydrologic and/or seismic events may result in a dam safety deficiency. Risk may be in the range to take further action.
Poor	A dam safety deficiency is recognized for loading conditions which may realistically occur. Remedial action is necessary. POOR may also be used when uncertainties exist as to critical analysis parameters which identify a potential dam safety deficiency. Further investigations and studies are necessary.
Unsatisfactory	A dam safety deficiency is recognized that requires immediate or emergency remedial action for problem resolution.

Rating of Dams on O‘ahu

Table 14-4 identifies dams located within the City and lists the dam name, dam owner, year constructed, date of last inspection, hazard potential classification, condition, and if there is an emergency action plan (EAP) available for the dam.

Table 14-4. Dam Classifications in the City

Dam Name	National Inventory of Dams ID No.	Dam Owner	Year Const.	Primary Purpose	Date of Last Inspection	USACE Hazard Potential Classification	Condition	EAP Approval Date	Population at Risk
Wahiawa Dam *Wahiawa discharges treated wastewater and R-1 into Lake Wilson which is associated with a dam.	HI00017	Dole Food Co. Hawaii, Sustainable Hawaii, Inc., Wahiawa Water Co., Inc.	1906	Irrigation	11/9/2023	High	Poor	11/19/23	2492
Waimanalo 60 Mg Reservoir	HI00129	State of Hawaii, Dept of Agriculture	1993	Irrigation	7/17/2024	High	Fair	10/25/2	1193
Maunaolu Reservoir	HI00149	Honolulu Board of Water Supply	1966	Irrigation	6/5/2024	High	Fair	8/20/22	1345
Upper Helemano Reservoir	HI00022	Dole Food Company Hawaii	1912	Irrigation	10/18/2022	High	Poor	11/29/23	318
Nuuanu Dam No. 4	HI00001	Honolulu Board of Water Supply	1910	Flood Control	4/3/2024	High	Fair	8/20/22	12947
Nuuanu Reservoir No. 1	HI00154	Honolulu Board of Water Supply	1905	Flood Control	4/3/2024	High	Poor	8/20/22	356
Kemoo 5 Reservoir	HI00021	Dole Food Company Hawaii	1920	Irrigation	9/9/2022	High	Poor	11/29/23	183
Helemano 6 Reservoir	HI00023	Dole Food Company Hawaii	1915	Irrigation	9/9/2022	High	Poor	11/29/23	78
Kaneohe Dam	HI00124	City and County of Honolulu Department of Facility Maintenance	1980	Flood Control	8/28/2024	High	Fair	8/18/22	4278

Dam Name	National Inventory of Dams ID No.	Dam Owner	Year Const.	Primary Purpose	Date of Last Inspection	USACE Hazard Potential Classification	Condition	EAP Approval Date	Population at Risk
O‘ahu Reservoir 155	HI00137	Agribusiness Development Corporation (ADC), Bayer U.S. Crop Science, Monsanto Company	1916	Irrigation	5/8/2024	High	Poor	5/5/23	146
Opaeula 01 Reservoir	HI00018	Kamehameha Schools	1910	Irrigation	3/15/2022	High	Fair	8/1/23	139
Ku Tree Reservoir	HI00025	Schofield Barracks	1925	Irrigation	6/22/2022	High	Unsatisfactory	8/19/22	107
Ko‘olau Reservoir	HI00156	Schofield Barracks	1919	Irrigation	6/22/2022	Low	Unsatisfactory	Not Required	0

Source: (USACE 2025)

Warning Time

The warning time for dam failure varies based on the cause. During extreme precipitation events, there may be enough time to order evacuations. However, in the case of structural failure due to an earthquake, warning time may be limited. The type of dam structure also impacts warning time. Earthen dams tend not to fail completely or instantaneously; once a breach begins, water erosion continues until either the reservoir water is depleted, or the breach resists further erosion. The time for breach formation can range from minutes to hours.

DSP has established three different warning levels for potential dam emergencies (see Table 14-5). Dam operators are required to make notifications to regulatory and/or first responder agencies based on the alert level. In the EAPs that the owners of high hazard dams are required to submit, owners must specify the conditions that would trigger each alert level. An imminent dam failure would also trigger the issuance of a flash flood warning by the National Weather Service and activation of emergency alert systems to alert the public.

Table 14-5. State Dam Safety Program (DSP) Dam Emergency Warning Levels

Level	Description
1	Non-Emergency, Non-Failure situation; Unusual Event, Slowly Developing
2	Emergency, Potential Dam Failure Situation
3	Urgent Emergency; Imminent or In-progress dam failure

14.1.4 PREVIOUS OCCURRENCES

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

Recent Events

Table 14-6 shows recent events for O‘ahu.

Table 14-6. Infrastructure Failure Events in the City (2020 to 2024)

Event Date	Disaster Declaration/ Proclamation			Description
	Federal	State	Mayoral	
March 9, 2021	No	Yes	No	The Governor issued an emergency proclamation for potential dam failure due to heavy rainfall. Five emergency proclamations were issued related to heavy rains.

Source: (State Procurement Office n.d.)

Federal Disaster Declarations

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

State and Local Emergency Proclamations

State law authorizes the Governor to issue emergency proclamations if an emergency or disaster has occurred, or there is imminent danger or threat of an emergency or disaster in any portion of the state. County Mayors have the authority to issue local emergency proclamations when such conditions exist within any part of their respective jurisdictions. Table 14-6 indicates recent events for which state or local emergency proclamations were issued.

14.1.5 PROBABILITY OF FUTURE OCCURRENCES

There have been no significant dam failure events reported in the City. However, the area is still at risk due to the presence of regulated dams. These dams, mostly constructed before modern standards, could potentially fail during heavy or prolonged rainfall.

There have been previous instances where interventions were necessary to prevent dam failures. During Tropical Storm Olivia in September 2018, Nuuanu Reservoir Dam No. 1, constructed in 1905 with a capacity of 21 million gallons, required intervention by the Honolulu Fire Department and BWS. This precautionary measure was taken to prevent overtopping its spillway. Heavy rainfall from the storm resulted in 7.3 inches (18 centimeters) of precipitation in the area, causing water levels in the dam to rise by 4 to 5 feet (approximately 1.5 meters) overnight. By midday on September 13, 2018, the water level had reached 5 feet below the top of the dam and was just 18 inches (45 centimeters) below the spillway (City and County of Honolulu 2020). The BWS was able to drain the reservoir level sufficiently to reduce the risk of a dam failure.

Causes for dam failure can be mitigated through proper design and construction, regular inspections by qualified personnel, and a commitment to strong enforcement to correct identified deficiencies. As water control structures continue to age, the likelihood or probability of failure increases. Risks to downstream life and property can be substantially reduced with the effort to limit some development adjacent to streams and rivers. However, if dams are located on streams not mapped as floodplains existing development downstream may be at greater risk.

Information on previous infrastructure failure occurrences in the City was used to calculate the probability of future occurrence of such events. Based on these records, the probability of the occurrence of infrastructure failure in the City is considered “low.” However, there is a potential for dam failure to occur during or after extreme rainfall events, earthquakes, or landslides.

14.2 VULNERABILITY AND IMPACT ASSESSMENT

To understand risk, a community must evaluate what assets are exposed and vulnerable in the identified hazard area. To estimate vulnerability to the infrastructure failure hazard event, specifically for dam failure, the dam failure inundation boundary from the Pacific Disaster Center/DLNR was overlaid on updated maps of assets (population, building stock, critical facilities, and new development). Centroids within the boundary were totaled to estimate the building replacement cost value and population vulnerable to the hazard.

14.2.1 LIFE, HEALTH, AND SAFETY

Overall Population

The impact of dam failure on life, health, and safety depends on several factors such as the class of the dam, the area being protected, the location, and the proximity of structures, infrastructure, and critical facilities to the dam. A dam failure can result in flooding that threatens public health and safety through exposure to unsafe food, contaminated drinking and washing water, mosquitoes, animals, mold, and mildew.

The population living in or near the inundation areas is considered exposed to the hazard, along with people traveling in those areas at the time of a dam failure or whose access to emergency services is compromised by such failures. The population adversely affected by a dam failure may also include those beyond the disaster area who rely on the dam for providing potable water.

The entire population residing within a dam failure inundation hazard area is considered exposed and vulnerable to an event. The potential for loss of life is affected by warning time, which contributes to the capacity and number of evacuation routes available to populations living within these areas. As shown in Table 14 7, the Koʻolau Poko regional planning areas is at the greatest risk, with 6,542 people residing in a dam failure inundation hazard area within the regional planning area.

There are 56,747 persons living in the combined dam failure inundation hazard area and the dam evacuation zones; the regional planning area, Koʻolau Poko has the greatest population of 30,862 persons, or 25.6 percent, in the dam failure inundation hazard area and evacuation zones. Koʻolau Poko regional planning areas contains the Kaneohe Dam and Waimanalo 60 Mg Reservoir.

Table 14-7 shows the total population within the dam failure inundation hazard areas for each dam located in the City. Please note that for some dams, their inundation areas extend into more than one regional planning area.

Table 14-7. Population in Dam Failure Inundation Hazard Areas for Regulated Dams

Dam Within Each Regional Planning Area	Population in the Dam Failure Inundation Hazard Area	
	Number of Persons	% of Total Population in the Dam Failure Inundation Hazard Area
Central O'ahu	**41**	**<0.1%**
Ku Tree Reservoir	41	<0.1%
Upper Helemano Reservoir	0	0.0%
Wahiawa Dam	0	0.0%
'Ewa	**127**	**<0.1%**
O'ahu Reservoir 155	127	<0.1%
Ko'olau Poko	**6,542**	**5.5%**
Kaneohe Dam	5,504	4.6%
Waimanalo 60 Mg Reservoir	1,038	0.9%
North Shore	**2,730**	**15.0%**
Helemano 6 Reservoir	54	0.3%
Kemoo 5 Reservoir	143	0.8%
Opaeula 01 Reservoir	147	0.8%
Upper Helemano Reservoir	88	0.5%
Wahiawa Dam	2,298	12.6%
Primary Urban Center	**9,118**	**2.0%**
Nuuanu Dam No. 4	6,478	1.4%
Nuuanu Reservoir No. 1	2,640	0.6%
Wai'anae	**1,343**	**2.6%**
Maunaolu Reservoir	1,343	2.6%

Source: U.S. Census Bureau ACS 2022; Pacific Disaster Center; City and County of Honolulu 2024

Note: As population values are rounded down, the total exposed population per planning area may differ slightly in comparison to the combined dam failure inundation tables. This is due to the fact that the population values are rounded down by each individual dam first and then aggregated by planning area, rather than rounding down by the total exposed for all inundation areas combined.

Socially Vulnerable Population

Some populations may be more susceptible to the adverse impacts of a dam failure. This population includes older adults, children, individuals with disabilities, access, or functional needs, economically disadvantaged individuals, and individuals with limited access to transportation—all of whom may be unable to get themselves out of the inundation area or may require additional time and resources to recover. The vulnerable population also includes individuals who would not have adequate warning from the emergency warning system (e.g., television or radio) either due to limited access to technology or limited English proficiency.

Table 14-8 presents the estimated socially vulnerable populations located in the dam failure inundation hazard areas for each regional planning area. Please note that for some dams, their inundation areas extend into more than one regional planning area.

The Primary Urban Center regional planning area has the highest number of socially vulnerable populations that live within the dam failure inundation hazard areas. The Primary Urban Center regional planning area contains the Nuuanu Dam No. 4 and Nuuanu Reservoir No. 1.

Table 14-8. Vulnerable Persons Located in the Combined Dam Failure Inundation Hazard Area

Dam Within Each Regional Planning Area (RPA)	Vulnerable Persons Located in the Dam Failure Inundation Hazard Area									
	Persons Over 65		Persons Under 5		Non-English Speaking Persons		Persons with a Disability		Persons in Poverty	
	Number	% of Total in RPA	Number	% of Total in RPA	Number	% of Total in RPA	Number	% of Total in RPA	Number	% of Total in RPA
Central Oʻahu	**6**	**<0.1%**	**2**	**<0.1%**	**1**	**<0.1%**	**4**	**<0.1%**	**3**	**<0.1%**
Ku Tree Reservoir	6	<0.1%	2	<0.1%	1	<0.1%	4	<0.1%	3	<0.1%
Upper Helemano	0	0	0	0	0	0.0%	0	0.0%	0	0.0%
Wahiawa Dam	0	0	0	0	0	0.0%	0	0.0%	0	0.0%
ʻEwa	**14**	**<0.1%**	**9**	**<0.1%**	**2**	**<0.1%**	**12**	**<0.1%**	**8**	**<0.1%**
Oʻahu Reservoir 155	14	<0.1%	9	<0.1%	2	<0.1%	12	<0.1%	8	<0.1%
Koʻolau Poko	**1,280**	**5.5%**	**404**	**5.5%**	**75**	**5.4%**	**655**	**19.0%**	**369**	**5.3%**
Kaneohe Dam	1,077	4.6%	340	4.6%	63	4.5%	551	4.6%	311	4.5%
Waimanalo 60 Mg Reservoir	203	0.9%	64	0.9%	12	0.9%	104	0.9%	58	0.8%
North Shore	**518**	**15.0%**	**206**	**14.9%**	**64**	**14.6%**	**327**	**14.9%**	**276**	**14.9%**
Helemano 6 Reservoir	10	0.3%	4	0.3%	1	0.2%	6	0.3%	5	0.3%
Kemoo 5 Reservoir	27	0.8%	10	0.7%	3	0.7%	17	0.8%	14	0.8%
Opaeula 01 Reservoir	28	0.8%	11	0.8%	3	0.7%	17	0.8%	15	0.8%
Upper Helemano	16	0.5%	6	0.4%	2	0.5%	10	0.5%	9	0.5%
Wahiawa Dam	437	12.6%	175	12.6%	55	12.6%	277	12.6%	233	12.6%

Dam Within Each Regional Planning Area (RPA)	Vulnerable Persons Located in the Dam Failure Inundation Hazard Area									
	Persons Over 65		Persons Under 5		Non-English Speaking Persons		Persons with a Disability		Persons in Poverty	
	Number	% of Total in RPA	Number	% of Total in RPA	Number	% of Total in RPA	Number	% of Total in RPA	Number	% of Total in RPA
Primary Urban Center	**1,903**	**2.0%**	**456**	**2.0%**	**979**	**2.0%**	**1,048**	**2.0%**	**874**	**2.0%**
Nuuanu Dam No. 4	1,352	1.4%	324	1.4%	696	1.4%	745	1.4%	621	1.4%
Nuuanu Reservoir No. 1	551	0.6%	132	0.6%	283	0.6%	303	0.6%	253	0.6%
Wai‘anae	**174**	**2.6%**	**116**	**2.6%**	**22**	**2.6%**	**181**	**2.6%**	**245**	**2.6%**
Maunaolu Reservoir	174	2.6%	116	2.6%	22	2.6%	181	2.6%	245	2.6%

Source: U.S. Census Bureau ACS 2022; Pacific Disaster Center; City and County of Honolulu 2024

Note: As population values are rounded down, the total exposed population per planning area may differ slightly in comparison to the combined dam failure inundation tables. This is due to the fact that the population values are rounded down by each individual dam first and then aggregated by planning area, rather than rounding down by the total exposed for all inundation areas combined.

14.2.2 ECONOMY AND GENERAL BUILDING STOCK

Dam failures can significantly impact the economy. Potential losses include damage to buildings and infrastructure, agricultural losses, business interruption, and impacts on the tax base. Combined, these impacts may lead to extended business closures or transportation inconveniences, like closed roads, which may discourage tourism or individuals looking to move to or do business in the area. In addition to physical damage costs, businesses can be closed while flood waters retreat, and utilities are returned to a functioning state.

Buildings located downstream of a dam are at risk of being damaged should there be a failure. Properties located closest to the dam failure inundation hazard area have the greatest potential to experience the largest, most destructive surge of water. The overall impact of flooding damage caused by dam failure will vary depending on the depth of flooding and velocity of the surge. Table 14-9 provides the estimated number of buildings within the dam failure inundation hazard areas. The Primary Urban Center regional planning area is estimated to have the highest number of buildings within the dam failure inundation hazard areas, with 1,913 buildings. The estimated replacement cost value for buildings in the Primary Urban Center is $5,892,433,263.

Table 14-10 presents the buildings categorized by general occupancy class within the dam failure inundation hazard areas. The Koʻolau Poko regional planning area has the highest number of residential buildings (1,455), while the Primary Urban Center regional planning areas has the greatest number of commercial, industrial, and government, religion, agricultural, and education buildings.

Table 14-9. Buildings in the Dam Failure Inundation Hazard Areas in the City

Dam Name Within Each Regional Planning Area	Buildings in the Dam Failure Inundation Hazard Area			
	Number of Buildings		Replacement Cost Value	
	Count	% of Regional Planning Area Total	Value	% of Regional Planning Area Total
Central O'ahu	**13**	**<0.1%**	**$34,890,018**	**0.1%**
Ku Tree Reservoir	12	<0.1%	$30,713,998	0.1%
Upper Helemano, Central O'ahu	0	0	$0	0.0%
Wahiawa Dam, Central O'ahu	1	<0.1%	$4,176,020	<0.1%
'Ewa	**23**	**0.2%**	**$41,314,792**	**0.3%**
O'ahu Reservoir 155	23	0.2%	$41,314,792	0.3%
Ko'olau Poko	**1,541**	**5.3%**	**$953,673,358**	**3.9%**
Kaneohe Dam	1,272	4.4%	$682,248,407	2.8%
Waimanalo 60 Mg Reservoir	269	0.9%	$271,424,951	1.1%
North Shore	**725**	**15.4%**	**$522,035,267**	**13.7%**
Helemano 6 Reservoir	13	0.3%	$6,883,805	0.2%
Kemoo 5 Reservoir	36	0.8%	$16,133,106	0.4%
Opaeula 01 Reservoir	56	1.2%	$64,758,525	1.7%
Upper Helemano, North Shore	31	0.7%	$18,429,140	0.5%
Wahiawa Dam, North Shore	589	12.5%	$415,830,691	10.9%
Primary Urban Center	**1,913**	**2.7%**	**$5,892,433,263**	**4.3%**
Nuuanu Dam No. 4	1,365	1.9%	$3,900,110,481	2.8%
Nuuanu Reservoir No. 1	548	0.8%	$1,992,322,782	1.4%
Wai'anae	**257**	**2.5%**	**$81,686,263**	**1.1%**
Maunaolu Reservoir	257	2.5%	$81,686,263	1.1%

Source: U.S. Army Corps of Engineers 2022; Pacific Disaster Center; City and County of Honolulu 2024; RSMeans 2024

Table 14-10. Buildings in the Combined Dam Failure Inundation Hazard Area by General Occupancy Class

Dam Name Within Each Regional Planning Area	Buildings in the Dam Failure Inundation Hazard Area by General Occupancy Class			
	Residential	Commercial	Industrial	Other[a]
Central O'ahu	**7**	**5**	**1**	**0**
Ku Tree Reservoir	7	5	0	0
Upper Helemano, Central O'ahu	0	0	0	0
Wahiawa Dam, Central O'ahu	0	0	1	0
'Ewa	**22**	**1**	**0**	**0**
O'ahu Reservoir 155	22	1	0	0
Ko'olau Poko	**1,455**	**65**	**11**	**10**
Kaneohe Dam	1,224	37	6	5
Waimanalo 60 Mg Reservoir	231	28	5	5
North Shore	**647**	**66**	**5**	**7**
Helemano 6 Reservoir	13	0	0	0
Kemoo 5 Reservoir	34	2	0	0
Opaeula 01 Reservoir	35	20	1	0
Upper Helemano, North Shore	21	7	1	2
Wahiawa Dam, North Shore	544	37	3	5
Primary Urban Center	**1,195**	**513**	**130**	**75**
Nuuanu Dam No. 4	849	369	91	56
Nuuanu Reservoir No. 1	346	144	39	19
Wai'anae	**255**	**2**	**0**	**0**
Maunaolu Reservoir	255	2	0	0

Source: U.S. Army Corps of Engineers 2022; Pacific Disaster Center; City and County of Honolulu 2024

a. Other = Government, Religion, Agricultural, and Education

14.2.3 COMMUNITY LIFELINES AND OTHER CRITICAL FACILITIES

A dam failure may impact downstream critical facilities and community lifelines. It can cut evacuation routes and limit emergency access. Dam failure floodwaters may transport large volumes of sediment and debris. A failure can cause extensive damage to public utilities and disrupt the delivery of services. Loss of power and communications may occur and drinking water and wastewater treatment facilities may be temporarily out of operation. Damage to infrastructure could result in large repair costs. Utilities such as overhead power lines and phone lines could also be vulnerable. Table 14-11 summarizes the number of critical facilities in the dam failure inundation hazard areas by type for each regional planning area. The Primary Urban Center regional planning area has the greatest number of community lifelines exposed to the dam failure inundation hazard.

Table 14-11. Critical Facilities in the Combined Dam Failure Inundation Hazard Area, by Lifeline Category

Dam Name Within Each Regional Planning Area	Critical Facilities in Each Dam Failure Inundation Hazard Area, by Lifeline Category									Total Facilities in Hazard Area	
	Communications	Energy	Food, Hydration, Shelter	Hazardous Materials	Health & Medical	Safety & Security	Transportation	Water Systems	Other Critical Facilities	Count	% of Regional Planning Area Total
Central O'ahu	**0**	**0**	**0**	**0**	**0**	**1**	**3**	**0**	**0**	**4**	**1.4%**
Ku Tree Reservoir	0	0	0	0	0	0	2	0	0	2	0.7%
Upper Helemano	0	0	0	0	0	0	0	0	0	0	0.0%
Wahiawa Dam	0	0	0	0	0	1	1	0	0	2	0.7%
'Ewa	**0**	**0**	**0**	**0**	**1**	**0**	**5**	**0**	**0**	**6**	**2.4%**
O'ahu Reservoir 155	0	0	0	0	1	0	5	0	0	6	2.4%
Ko'olau Poko	**1**	**1**	**2**	**2**	**1**	**6**	**4**	**3**	**1**	**21**	**6.9%**
Kaneohe Dam	1	0	1	1	1	5	3	2	1	15	4.9%
Waimanalo 60 Mg Reservoir	0	1	1	1	0	1	1	1	0	6	2.0%
North Shore	**1**	**1**	**2**	**0**	**1**	**6**	**9**	**0**	**0**	**20**	**23.0%**
Helemano 6 Reservoir	0	0	0	0	0	1	1	0	0	2	2.3%
Kemoo 5 Reservoir	1	0	0	0	0	1	1	0	0	3	3.4%
Opaeula 01 Reservoir	0	1	0	0	0	1	2	0	0	4	4.6%
Upper Helemano	0	0	0	0	0	1	1	0	0	2	2.3%
Wahiawa Dam	0	0	2	0	1	2	4	0	0	9	10.3%

Dam Name Within Each Regional Planning Area	Critical Facilities in Each Dam Failure Inundation Hazard Area, by Lifeline Category									Total Facilities in Hazard Area	
	Communications	Energy	Food, Hydration, Shelter	Hazardous Materials	Health & Medical	Safety & Security	Transportation	Water Systems	Other Critical Facilities	Count	% of Regional Planning Area Total
Primary Urban Center	**1**	**11**	**6**	**17**	**2**	**11**	**29**	**2**	**0**	**79**	**6.8%**
Nuuanu Dam No. 4	1	10	5	9	2	8	14	1	0	50	4.3%
Nuuanu Reservoir No. 1	0	1	1	8	0	3	15	1	0	29	2.5%
Waiʻanae	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**2**	**1.6%**
Maunaolu Reservoir	0	0	0	0	0	0	2	0	0	2	1.6%

Source: City and County of Honolulu 2023, 2024; State of Hawai'i 2017, 2021, 2022, 2023, 2024; US Energy Atlas 2024; Pacific Disaster Center; City and County of Honolulu 2024

14.2.4 NATURAL, HISTORIC, AND CULTURAL RESOURCES

Natural Resources

The environmental impacts of dam failure can include significant water quality and debris-disposal issues or severe erosion that can impact local ecosystems. Flood waters can back up sanitary sewer systems and inundate wastewater treatment plants, causing raw sewage to contaminate residential and commercial buildings and the flooded waterway. The contents of unsecured containers of oil, fertilizers, pesticides, and other chemicals may get added to flood waters. Hazardous materials may be released and distributed widely across the floodplain. Water supply and wastewater treatment facilities could be offline for weeks. After the flood waters subside, contaminated and flood-damaged building materials and contents must be properly disposed of. Contaminated sediment must be removed from buildings, yards, and properties (EPA 2024).

Historic and Cultural Resources

Dam failures can significantly affect cultural and historic resources due to the resulting floodwaters. Cultural resources include “moveable heritage,” such as collections of artifacts, statuary, artwork, and important documents or repositories. These resources are housed in libraries, museums, archives, historical repositories, or historic properties. Flood waters following a dam failure create the largest risk to these resources.

Historic buildings, structures, sites, monuments, districts, and documents are often irreplaceable; therefore, they may incur damage or be destroyed in the aftermath of a dam failure. The loss of these resources can be particularly distressing, as community members often rely on them to strengthen their connections with neighbors and the broader community and to find solace in the wake of a disaster.

Table 14-12 highlights the number of historic sites in the City located within the dam failure inundation hazard areas. The majority of these sites, 22 in total, are situated in the Primary Urban Center planning area.

Table 14-12. Historic Sites in the Combined Dam Failure Inundation Hazard Area

Dam Name Within Each Regional Planning Area	Historic Sites in the Dam Failure Inundation Hazard Area	
	Count	% of Regional Planning Area Total
Central O'ahu	**0**	**0.0%**
Ku Tree Reservoir	0	0.0%
Upper Helemano	0	0.0%
Wahiawa Dam	0	0.0%
'Ewa	**1**	**50.0%**
O'ahu Reservoir 155	1	50.0%
Ko'olau Poko	**0**	**0.0%**
Kaneohe Dam	0	0.0%
Waimanalo 60 Mg Reservoir	0	0.0%
North Shore	**4**	**50.0%**
Helemano 6 Reservoir	0	0.0%
Kemoo 5 Reservoir	0	0.0%
Opaeula 01 Reservoir	0	0.0%
Upper Helemano	0	0.0%
Wahiawa Dam	4	50.0%
Primary Urban Center	**22**	**4.9%**
Nuuanu Dam No. 4	15	3.3%
Nuuanu Reservoir No. 1	7	1.6%
Wai'anae	**0**	**0.0%**
Maunaolu Reservoir	0	0.0%

Source: Pacific Disaster Center; City and County of Honolulu 2024

14.2.5 FUTURE CHANGES THAT MAY AFFECT RISK

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

Potential or Planned Development

Understanding future changes that affect vulnerability can assist in planning for future development and ensure the establishment of appropriate mitigation, planning, and preparedness measures. Any increases in development in the City taking place within dam failure inundation hazard areas would increase the overall risk from the dam failure hazard. Table 14-13 displays the number of new developments in the combined dam failure inundation hazard area for the City.

Table 14-13. New Development in Regulated Dam Failure Inundation Hazards Areas in the City

Dam Name Within Each Regional Planning Area	New Development in the Dam Failure Inundation Hazard Area	
	Count	% of Regional Planning Area Total
Central O‘ahu	**0**	**0.0%**
Ku Tree Reservoir	0	0.0%
Upper Helemano	0	0.0%
Wahiawa Dam	0	0.0%
‘Ewa	**0**	**0.0%**
O‘ahu Reservoir 155	0	0.0%
Ko‘olau Poko	**10**	**3.6%**
Kaneohe Dam	9	3.2%
Waimanalo 60 Mg Reservoir	1	0.4%
North Shore	**13**	**22.0%**
Helemano 6 Reservoir	0	0.0%
Kemoo 5 Reservoir	0	0.0%
Opaeula 01 Reservoir	2	3.4%
Upper Helemano	0	0.0%
Wahiawa Dam	11	18.6%
Primary Urban Center	**9**	**1.2%**
Nuuanu Dam No. 4	5	0.6%
Nuuanu Reservoir No. 1	4	0.5%
Wai‘anae	**3**	**2.6%**
Maunaolu Reservoir	3	2.6%

Source: Pacific Disaster Center; City and County of Honolulu 2024

Projected Changes in Population

Projected population growth in the City, estimated at an annual rate of 0.2 percent from 2020 to 2040, could increase the risk of infrastructure failure (DBEDT 2024). This heightened demand can intensify wear and tear, potentially leading to more frequent maintenance issues and failures. Additionally, increased population density in areas downstream of dams could elevate the consequences of any infrastructure failure, as more people and properties would be at risk. Therefore, it is crucial to consider these projections in future infrastructure planning and maintenance to mitigate potential risks effectively.

Climate Change

Future climate changes may significantly impact the risk of infrastructure failure, particularly for dams. Changes in rainfall and runoff patterns can alter the hydrographs (assumptions regarding a stream's flow behavior) used in dam design, potentially reducing the designed margin of safety and increasing the risk of overtopping or unintended loads. Many dams, built before modern regulatory standards and the anticipated impacts of climate change, may face higher failure risks due to more frequent and intense precipitation events.

If the hygrograph 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 correspond to the frequency and duration of potential dam failure incidents. 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.