6. DAM FAILURE

6.1 HAZARD PROFILE

6.1.1 Hazard Description

A dam is a structure built across a river or stream to store water, wastewater, or liquid-borne materials for purposes such as flood control, human water supply, energy generation, recreation, or pollution control. Many dams fulfill a combination of these functions (ASDSO 2023).

A dam failure is any malfunction that adversely affects the primary function of the dam, releasing water or other liquid stored behind the dam (FEMA 2018). When dams fail or overtop, they can lead to major flooding and cause catastrophic impacts in downstream areas (ASDSO 2024). Throughout history, hundreds of dams have failed in the United States, causing property and environmental damage, injuries, and fatalities.

Dam failures are usually associated with intense rainfall and prolonged flood conditions. Significant rainfall can cause floodwaters to overwhelm a reservoir. If the spillway of the dam cannot safely pass the resulting flows, water will begin flowing in areas not designed for such flows, and a failure may occur. Dam breaks also may occur during dry periods as a result of progressive erosion of an embankment. This is referred to as a “sunny day” failure. Dam failures are most likely to for one or a combination of the following events (ASDSO 2024):

- Overtopping caused by water spilling over the top of a dam
- Foundation defects, including settlement and slope instability
- Cracking caused by movement
- Inadequate maintenance and upkeep
- Improperly seepage filtration that enables the formation of sinkholes in the dam

Dam failures may or may not leave enough time for evacuation of people and property, depending on their abruptness. Dam failures due to the overtopping of a dam normally give sufficient lead time for evacuation. Seepages in earth dams usually develop gradually, and if the embankment damage is detected early, downhill residents have at least a few hours or days to evacuate. Failures of concrete or masonry dams tend to occur suddenly, sending a wall of water and debris down the valley at more than 100 miles per hour. Dam failure events are frequently associated with other natural hazard events such as earthquakes, landslides, or severe weather, which limits their predictability and compounds the hazard.

6.1.2 Regulatory Oversight of Dams

National Dam Safety Program

The potential for catastrophic flooding caused by dam failures led to enactment of the National Dam Safety Act (Public Law 92-367), which for 30 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 the program, state assistance funds have allowed participating states to improve their programs through increased inspections, emergency action planning, and purchases of

needed equipment. Grant assistance from FEMA provides support for improvement of dam safety programs that regulate most dams in the United States (FEMA 2024).

New Jersey Department of Environmental Protection Dam Safety Section

The New Jersey Department of Environmental Protection (NJDEP) Dam Safety Section has responsibility for overseeing dam safety in the state. The primary goal of the oversight program is to ensure the safety and integrity of dams in New Jersey and thereby protect people and property from the consequences of dam failures. The Dam Safety Section reviews plans and specifications for the construction of new dams or for the alteration, repair, or removal of existing dams and must grant approval before the owner can proceed with construction. New Jersey's Safe Dam Act (NJSA 58:4) requires dams to meet state dam safety standards. NJDEP has enforcement capabilities to achieve compliance with the standards. This includes issuing orders for compliance to dam owners and pursuing legal action if the owner does not comply (with possible fines levied on a per-day basis for violations) (NJDEP 2024).

NJDEP assigns one of four hazard ratings to state-regulated dams in New Jersey (State of New Jersey 2017):

- Class I (High-Hazard Potential)—Failure of the dam may result in probable loss of life and/or extensive property damage.
- Class II (Significant-Hazard Potential)—Failure of the dam may result in significant property damage; however, loss of life is not envisioned.
- Class III (Low-Hazard Potential)—Failure of the dam is not expected to result in loss of life or significant property damage.
- Class IV (Zero-Hazard Potential)—Failure of the dam is not expected to result in loss of life or significant property damage.

Hazard potential is based on the consequences of dam failure and not the dam condition or the probability of failure occurring.

Existing dams are periodically inspected to ensure that they are adequately maintained, and owners are directed to correct any deficiencies found. The owners or operators of all dams that raise the waters of any stream more than 70 feet above its usual mean low-water height or that impound more than 10,000 acre-feet of water must have a regular inspection performed annually and formal inspections performed every three years by a state-licensed professional engineer. These inspections must be attended by a professional engineer assigned from the NJDEP (State of New Jersey 2024). Inspection guidelines are summarized in Table 6-1.

Table 6-1. Dam Inspection Requirements

Dam Size/Type	Regular Inspection	Formal Inspection
Class I (High Hazard) Large Dam	Annually	Once every 3 years
Class I (High Hazard) Dam	Once every 2 years	Once every 6 years
Class II (Significant Hazard) Dam	Once every 2 years	Once every 10 years
Class III (Low Hazard) Dam	Once every 4 years	Only as required
Class IV (Zero Hazard) Dam	Once every 4 years	Only as required

Source: State of New Jersey 2017

Based on the inspection, owners are required to note the extent of deterioration as a basis for long term planning, periodic maintenance, or immediate repair; to evaluate conformity with current design and construction practices; and to determine the appropriateness of the existing hazard classification. NJDEP has guidelines to meet the requirements of the National Inventory of Dams condition assessment of existing dams. Table 6-2 summarizes the definitions for each potential deficiency rating.

Table 6-2. Dam Deficiency Ratings

Rating	Definition
Satisfactory	No existing or potential dam safety deficiencies are recognized. Acceptable performance is expected under all applicable loading conditions (static, hydrologic, seismic) in accordance with the applicable regulatory criteria. Minor maintenance items may be required.
Fair	Acceptable performance is expected under all required loading conditions (static, hydrologic, seismic) in accordance with the applicable dam safety regulatory criteria. Minor deficiencies may exist that require remedial action and/or secondary studies or investigations.
Poor	A dam safety deficiency is recognized for any required loading condition (static, hydrologic, seismic) in accordance with the applicable dam safety regulatory criteria. Remedial action is necessary. Poor also applies when further critical studies or investigations are needed to identify any potential dam safety deficiencies.
Unsatisfactory	Considered unsafe. A dam safety deficiency is recognized that requires immediate or emergency remedial action for problem resolution. Reservoir restrictions may be necessary.

Source: NJDEP 2017

The Dam Safety Section also coordinates with the Division of State Police and local and county emergency management officials in the preparations and approval of emergency action plans (EAPs). The state requires all high hazard and significant hazard dams to have NJDEP-approved EAPs in place. It is the responsibility of the dam owner to review and update the EAP on an annual basis.

U.S. Army Corps of Engineers Dam Safety Program

The U.S. Army Corps of Engineers (USACE) is responsible for safety inspections of 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 has surveyed each state's and federal agency's capabilities, practices, and regulations regarding design, construction, operation, and maintenance of the dams. USACE has also developed guidelines for inspection and evaluation of dam safety (USACE 2014).

Table 6-3 lists USACE-developed ratings of hazard potentials of dams, based on potential consequences of a dam failure. According to New Jersey's State HMP, the level of impact that a failure would have can be predicted based upon the USACE hazard rating.

Table 6-3. USACE Dam Hazard Ratings

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	Rural location, only transient or day-use facilities	Disruption of essential facilities and access	Major public and private facilities	Major mitigation required

Hazard Category[a]	Direct Loss of Life[b]	Lifeline Losses[c]	Property Losses[d]	Environmental Losses[e]
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 2014

a. Categories are assigned to overall projects, not individual structures at a project.

b. Loss-of-life potential is based on inundation mapping of area downstream of the project. Analyses of loss-of-life potential should take into account 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 loss of project services, such as impact from loss of a dam and navigation pool, or impact from 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.

Federal Energy Regulatory Commission Dam Safety Program

The Federal Energy Regulatory Commission (FERC) cooperates with a large number of federal and state agencies to ensure and promote dam safety and, more recently, homeland security. Nationally, over 3,000 dams are part of regulated hydroelectric projects and are included in the FERC Dam Safety Program. Two-thirds of these dams are more than 50 years old. FERC staff inspect hydroelectric projects on an unscheduled basis to investigate the following (FERC 2020):

- Potential dam safety problems
- Complaints about constructing and operating a project
- Safety concerns related to natural disasters
- Issues concerning compliance with terms and conditions of a license.

Every five years, an independent consulting engineer, approved by FERC, must inspect and evaluate projects with dams higher than 32.8 feet (10 meters) or with total storage capacity of more than 2,000 acre-feet (FERC 2020). FERC staff visit dams and licensed projects during and after floods, assess extents of damage, and direct any studies or remedial measures the licensee must undertake.

FERC requires licensees to prepare EAPs and conducts training sessions on developing and testing these plans. The plans outline an early warning system in the event of an actual or potential sudden release of water from a dam failure. The plans include operational procedures that may be implemented during regulatory measures, such as reducing reservoir levels and downstream flows, as well as procedures for notifying affected residents and agencies responsible for emergency management. These plans are frequently updated and tested to ensure that all applicable parties are informed of the proper procedures in emergencies (FERC 2020).

6.1.3 Location

Passaic County considers the locations of dams to be sensitive information. A map is not included, and municipal-level statistics are not listed in the plan due to these sensitivities. NJDEP has identified and classified 134 dams in Passaic County (NJOEM 2024).

6.1.4 Extent

The extent of a dam failure event is defined by the damage associated with a dam's NJDEP or USACE hazard rating. Passaic County contains 134 dams. Of these, 50 structures are rated as high hazard potential dams, as shown in Table 6-4. The failure of these dams could cause loss of life or property damage.

Table 6-4. Dams by Hazard Classification in Passaic County

Hazard Ranking	Number of Dams
High	50
Significant	22
Low	62
Total	134

Source: (NJOEM 2024)

Additionally, there are two factors that influence the potential severity of a full or partial dam failure: the amount of water impounded; and the density, type, and value of development and infrastructure located downstream (FEMA 2018).

6.1.5 Previous Occurrences

FEMA Major Disaster and Emergency Declarations

Passaic County has not been included in any major disaster (DR) or emergency (EM) declarations for dam failure-related events (FEMA 2023).

USDA Declarations

The U.S. Secretary of Agriculture is authorized to designate counties as disaster areas to make emergency loans from the U.S. Department of Agriculture (USDA) to producers suffering losses in those counties and in contiguous counties. Since the previous HMP, Passaic County has not been included in any USDA dam failure-related agricultural disaster declarations (USDA 2024).

Previous Events

No known dam failure events impacted Passaic County since the previous HMP (NJDEP 2024, NOAA-NCEI 2024, FEMA 2024). Refer to the 2020 Passaic County HMP for any earlier events. According to the New Jersey Bureau of Dam Safety, five dams in Passaic County were damaged by the remnants of Hurricane Floyd in 1999 once it reached New Jersey; but none of these dams experienced a failure.

6.1.6 Probability of Future Occurrences

Probability Based on Previous Occurrences

Dam failures are infrequent and usually coincide with events that cause them, such as earthquakes, landslides, excessive rainfall and snowmelt. Based on NJDEP, FEMA, and NOAA-NCEI records, no dam failure events have occurred or affected Passaic County (NJDEP 2024, NOAA-NCEI 2024, FEMA 2024). Based on historical records

and input from the Steering Committee, the probability of occurrence for dam failure in the County is considered "rare."

There are many regulatory bodies and mitigation measures in place to protect communities from the impacts of dam failures. Even with these safeguards, dams experience "residual risk," which refers to the risk of more severe events than those that the facility was designed to withstand. Still, the probability of any type of dam failure is low given New Jersey's dam safety regulatory and oversight environment. However, failure risks increase if dams age and are not maintained properly. The construction of new dam structures also could increase failure risks in the future.

Effect of Climate Change on Future Probability

Climate change can impact stored water systems as increased rainfall accumulations can cause reservoirs to overtop. Dams are designed using a hydrograph to evaluate dam safety issues for situations where the reservoir inflow peak discharge is greater than the maximum spillway capacity, the reservoir has large surcharge storage, or the reservoir has dedicated flood control space. Increased precipitation due to climate change may result in overtopping, as the hydrographs are based on historical events (FEMA 2013).

6.1.7 Cascading Impacts on Other Hazards

Dam failure can cause severe downstream flooding, depending on the magnitude of the failure. Floods caused by dam failures have caused loss of life and property damage (FEMA 2013). Other potential secondary hazards of dam failure are landslides around the reservoir perimeter, bank erosion on the rivers, and destruction of downstream habitat. Seismic activity is another concern, as earthquakes can damage dams, particularly those not designed to withstand seismic forces.

6.2 VULNERABILITY AND IMPACT ASSESSMENT

The dam failure hazard is of significance to Passaic County because 134 dams are present across the County, 50 of which are identified as high hazard (USACE 2023). Dam failure inundation maps and downstream hazard areas are considered sensitive information and were not available for use in this risk assessment. To assess Passaic County's risk to dam failure, a qualitative review was conducted.

6.2.1 Life, Health, and Safety

Overall Population

The impact of dam failure on life, health, and safety is dependent on factors such as the class of dam, the area that the dam is protecting, the location of the dam, and the proximity of structures, infrastructure, and critical facilities to the dam structure.

The entire population residing within a dam failure inundation zone is considered vulnerable to a dam failure event. The potential for loss of life is affected by the warming time provided, and capacity and number of evacuation routes available to populations living within these areas. Dam failure can cause persons to become displaced if flooding of structures occurs.

Socially Vulnerable Population

People living below the poverty level are more at risk during a dam failure event because they may be unable to evacuate based upon the net economic impact to their family. Elderly populations are more likely than the general population to need medical attention, and the availability of medical services may be limited due to isolation during a dam failure event. This population also faces difficulties in evacuating. There is often limited warning time for a dam failure event. Populations without adequate warning of the event are highly vulnerable.

Without a quantitative assessment of potential impacts of a dam failure on socially vulnerable populations, the Planning Partners can best assess mitigation options through an understanding of the general numbers and locations of such populations across Passaic County. Section 3.6.3 provides detailed data on socially vulnerable populations within the planning area. Table 6-5 summarizes highlights of this information. For planning purposes, it is reasonable to assume that percentages and distribution of socially vulnerable populations affected by a dam failure will be similar to the countywide numbers.

Table 6-5. Distribution of Socially Vulnerable Populations by Municipality

	Countywide Total		Municipality Highest in Category		Municipality Lowest in Category	
Category	Number	Percent	Number	Percent	Number	Percent
			Paterson	North Haledon	Prospect Park	Passaic
Population Over 65	**78,440**	**15.1%**	**18,141**	**24.6%**	**625**	**9.0%**
			Paterson	Passaic, Prospect Park	Bloomingdale	Bloomingdale
Population Under 5	**33,502**	**6.4%**	**12,442**	**8.3%**	**247**	**3.2%**
Non-English-Speaking Population	**68,953**	**13.3%**	Paterson **34,885**	Passaic **22.4%**	Bloomingdale, Ringwood **104**	Ringwood **0.9%**
Population With Disability	**46,707**	**9.0%**	Paterson **12,756**	Prospect Park **14.3%**	Bloomingdale **588**	Pompton Lakes **7.2%**
Population Below Poverty Level	**68,995**	**13.3%**	Paterson **37,143**	Paterson **23.5%**	Ringwood **262**	Ringwood **2.2%**
Households Below ALICE Threshold	**62,752**	**35%**	Paterson **33,284**	Paterson **67%**	North Haledon **745**	Ringwood **22%**

6.2.2 General Building Stock

All buildings located in the dam failure inundation zone are considered vulnerable to the hazard. Property closest to the dam inundation area has the greatest potential to experience the most destructive surge of water. Dam failure can transport large volumes of sediment and debris, depending on the magnitude of the event, which can cause widespread damage to buildings, resulting in large repair costs. In addition to physical damage costs, businesses can be closed while flood waters retreat and utilities are returned to a functioning state. Debris from damaged buildings can accumulate.

6.2.3 Community Lifelines and Other Critical Facilities

Dam failures may impact critical facilities and infrastructure located in the downstream inundation zone. All transportation infrastructure in the dam failure inundation zone is vulnerable to damage and cut-off of evacuation routes, limiting emergency access and creating isolation issues. Utilities such as overhead power lines, cable and

phone lines could also be vulnerable. Loss of these utilities could create additional isolation issues for the inundation areas. Loss of power and communications may cause drinking water and wastewater treatment facilities to become temporarily out of operation. Widespread damage to facilities and infrastructure would result in large repair costs.

6.2.4 Economy

Flooding from a dam failure can cause extensive structural damage to private property and public utilities, cutting off essential services. Debris from damaged buildings can accumulate, adding to the costs of removal. The inability to access shopping centers or workplaces further amplifies the economic strain by halting business operations, reducing revenue, impacting employment, disrupting supply chains, and decreasing consumer spending, all of which hinder the local economy's stability and recovery.

6.2.5 Natural, Historic and Cultural Resources

Natural

The environmental impacts of a dam failure can include significant water-quality and debris-disposal issues or severe erosion that can impact local ecosystems. Floodwaters 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. The destruction of local ecosystems is a significant concern because they are essential for maintaining biodiversity, supporting wildlife, and providing critical services such as clean water, air, and soil health.

Historic

Historic structures, sites, monuments, districts, and documents may become damaged or destroyed in the flood waters following a dam failure.

Cultural

Cultural resources include artifacts, statuary, artwork, and important documents housed in libraries, museums, archives, historical repositories, or historic properties. All of these can be damaged or destroyed by flood waters following a dam failure.

6.3 FUTURE CHANGES THAT MAY AFFECT RISK

6.3.1 Potential or Planned Development

Any areas of growth could be impacted by a dam failure event if the structures are located within the downstream inundation area and mitigation measures are not considered. Therefore, it is the intention of the County and all participating municipalities to discourage development in vulnerable areas or to encourage higher regulatory standards at the local level. Due to the sensitive nature of dam locations and downstream inundation zones, an assessment to determine the proximity of these new development sites to potential dam inundation cannot be performed at this time.

6.3.2 Projected Changes in Population

Any changes in the density of population can impact the number of persons exposed to the dam failure hazard. Higher density can not only create issues for local residents during evacuation of a dam failure event but can also have an effect on commuters that travel into and out of the County for work.

The New Jersey Department of Labor and Workforce Development produced population projections by County for 2029 and 2034. According to these projections, Passaic County is projected to have an increase in population in the upcoming years. These projections include a population of 536,100 by 2029 and 542,500 by 2034 (State of New Jersey 2017).

6.3.3 Climate Change

Most studies indicate that the State of New Jersey will experience a rise in average annual precipitation, primarily in the form of heavy rainfalls, which could elevate the risk of dam failures. Increased precipitation may place additional stress on dam structures. Existing flood control systems might struggle to manage the higher water flow from more frequent, intense rainfall events. This could lead to more frequent overtopping of dams and flooding of county assets in adjacent inundation areas. However, the probable maximum flood used in dam design may still accommodate these climate changes.

Projections suggest that annual precipitation in the State of New Jersey could increase by 4 percent to 11 percent, potentially affecting the hydrographs of many dammed rivers. This rise in precipitation could reduce the designed margin of safety for dams. A decrease in margin of safety may result in floodwaters overtopping the dam or creating unintended loads, potentially leading to dam failure (NJOEM 2024).

6.3.4 Other Identified Conditions

Aging infrastructure is a significant risk factor, as many dams may not meet current safety standards and are more susceptible to failure due to wear and tear. Design and construction flaws can become critical over time, especially under changing environmental conditions. Inadequate maintenance and delayed repairs further increase the risk of dam failure (FEMA 2018). Issues with upstream dams can impact downstream dams, potentially leading to cascading failures. Additionally, cybersecurity attacks and other security threats can alter dam operations and pose significant risks (CRS Report 2023).