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).

Concern about their safety and integrity grows as dams age, rendering oversight and regular inspection especially important. Despite efforts to provide sufficient structural integrity and to perform inspection and maintenance, problems can develop that cause dams to fail. Dam failures occur when a dam is damaged, destroyed, or otherwise overtopped, releasing the stored water or other liquid. According to the Association of State Dam Safety Officials (ASDO), the following are common causes of dam failures (ASDSO 2021):

- Overtopping caused by floods that exceed the capacity of the dam or levee (inadequate spillway capacity)
- Prolonged periods of rainfall and flooding
- Deliberate acts of sabotage (terrorism)
- Structural failure of materials used in dam construction
- Movement and/or failure of the foundation supporting the dam
- Settlement and cracking of concrete or embankment dams
- Piping and internal erosion of soil in embankment dams
- Inadequate or negligent operation, maintenance, and upkeep
- Failure of upstream dams on the same waterway
- Earthquake (liquefaction/landslides)

When dams fail or overtop, they can cause catastrophic impacts and lead to major flooding and impacts. Hundreds of dams have failed in the United States, causing property and environmental damage, injuries, and fatalities. While most dams have storage volumes small enough that failures would have little or no consequences, dams with large storage amounts can cause significant flooding downstream (FEMA 2013).

Dam incidents can occur suddenly, without warning, and may occur during normal operating conditions. This is referred to as a “sunny day” failure. Dam failures may also occur during a large storm event. Significant rainfall can quickly inundate an area and 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. New Jersey has seen significant property damage including damage or loss of dams, bridges, roads, and buildings as a result of storm events and dam failures (NJOEM 2019).

A dam failure may or may not leave enough time for evacuation of people and property, depending on its abruptness. 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 up to 100 mph. Dam failures due to the overtopping of a dam normally give sufficient lead time for evacuation (FEMA 2019).

6.1.2 Regulatory Oversight of Dams

National Dam Safety Program

The National Dam Safety Program (NDSP) is a partnership among states, federal agencies, and other stakeholders that encourages individual and community responsibility for dam safety. Grant assistance from FEMA provides support for improvement of dam safety programs that regulate most dams in the United States. These funds have allowed participating states to improve their dam safety programs through increased inspections, emergency action planning, and purchases of needed equipment. The NDSP also supports training programs (FEMA 2022).

U.S. Army Corps of Engineers Dam Safety Program

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 (Public Law 92-367). USACE has inventoried dams and has surveyed each state 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).

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).

New Jersey Department of Environmental Protection Dam Safety Program

New Jersey's Dam Safety program is administered by NJDEP's Bureau of Dam Safety, under the state's 1985 Dam Safety Standards (NJDEP 2023). Dams under state jurisdiction are any artificial barriers that raise the waters of a stream more than 5 feet above the usual mean low water height. Every regulated dam in the state is required to meet state dam safety standards. Dam safety laws provide the NJDEP with enforcement capabilities to achieve compliance with the standards. This includes issuing orders for compliance to dam owners and pursuing legal action if an owner does not comply (with possible fines levied on a per-day basis for violations) (NJDEP 2023).

The Bureau of Dam Safety reviews plans and specifications for the construction of new dams or for the alternation, repair, or removal of existing dams and must grant approval prior to construction (NJDEP 2023). Existing dams are periodically inspected to ensure that they are adequately maintained, and owners are directed to correct any deficiencies found. The regulations require owners to hire professional engineers to inspect their dams on a regular basis (NJDEP 2023).

Dam safety inspections are intended to identify conditions that may adversely affect the safety and functionality of a dam and its appurtenant structures; 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. Inspection guidelines are summarized in Table 6-1. NJDEP has set guidelines to meet the requirements of the National Inventory of Dams condition assessment of existing dams. Table 6-2 shows the definitions for each potential deficiency rating.

Table 6-1. New Jersey 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: NJDEP 2008

Table 6-2. New Jersey Dam Inspection 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. This rating 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 Bureau also coordinates with the Division of State Police and local and county emergency management officials in the preparation and approval of emergency action plans (EAPs). Since failure of a dam can take only hours or minutes, it is imperative to have a detailed emergency action plan ready for use (NJDEP 2023). All dams rated as high hazard or significant hazard must have NJDEP-approved EAPs in place. It is the responsibility of the dam owner to review and update the EAP on an annual basis.

6.1.3 Location

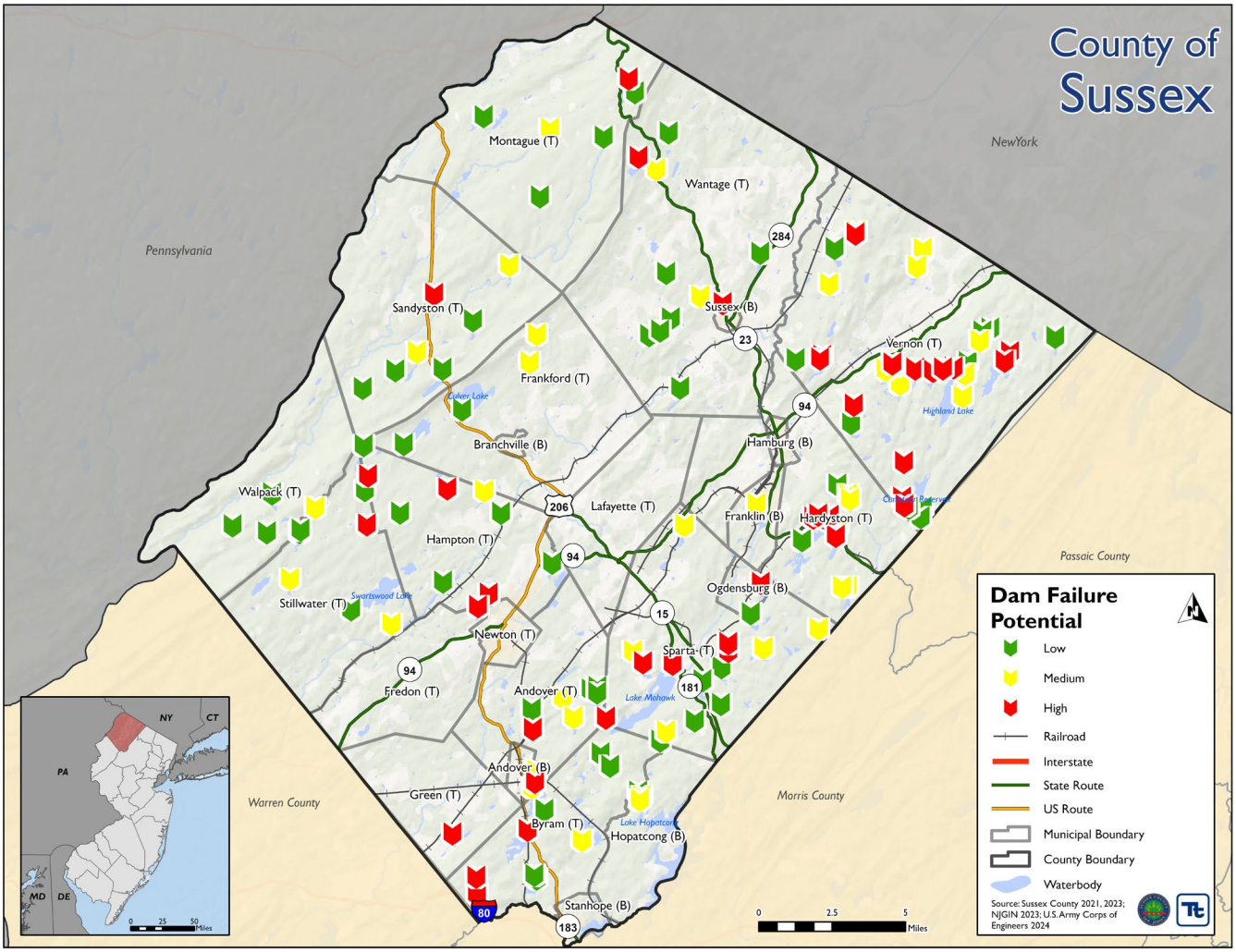
According to the USACE National Inventory of Dams, Sussex County has 139 dams. Of these dams, 40 are considered high hazard, 39 are considered significant hazard, and 60 are considered low hazard. There are 26 dams classified as in a poor state of repair; five of these are high hazard dams. Figure 6-1 shows the dams by class throughout the County. Table 6-3 lists the high hazard dams.

Table 6-3. High Hazard Dams in Sussex County

Municipality	Dam Name	Water Body
Andover Township	Forest Lake Dam	Pequest River-TR
Andover Township	Lake Lenape Dam	Tar Hill Brook
Byram Township	Reservoir Lake Dam	Watchu Pond
Byram Township	Cranberry Lake Dam	Lubbers Run
Byram Township	Frenches Pond Dam	Musconetcong River-TR
Franklin Borough	Lake Gerard Dam	Franklin Pond Creek
Franklin Borough	Lake Gerard Dam A	Franklin Pond Creek
Franklin Borough	Lake Gerard Dike C	Franklin Pond Creek
Franklin Borough	Lake Gerard Dike B	Franklin Pond Creek
Green Township	Lake Tranquility Dam	Trout Brook
Hampton Township	Crandon Lake Dam	Black Brook
Hampton Township	Kemah Lake Dam	Paulkinskill River-TR
Hardyston Township	Diversion Dam	Pequannock River
Hardyston Township	Lake Tamarack Dam	Franklin Pond Creek-TR
Hardyston Township	Canistear Reservoir #1 Dam	Pacock Brook
Montague Township	Steenykill Lake Dam	Steent Brook
Ogdensburg Borough	Heaters Pond Dam	Sawmill Brook
Sandyston Township	Robert Rooke Dam	Branch of Big Flat Brook
Sparta Township	West Shore Trail Dam	Wallkill River
Sparta Township	Morris Lake Dam	Wallkill River-TR
Sparta Township	Lake Mohawk Dam	Wallkill River
Sparta Township	Glen Lake Dam	Wallkill River
Sparta Township	Upper Mohawk Lake Dam	Paulinskill River-TR
Stillwater Township	Willow Crest Dam	Black Brook
Sussex Borough	Clove River Dam	Clove Brook
Sussex Borough	Paulinskill Water Shed #2 Dam	Moores Brook
Town of Newton	Paulins Kill Site 4 Dam	Moore's Brook-TR
Vernon Township	Lake Panorama Dike	Wallkill River-TR
Vernon Township	Great Gorge Dam	Black River-TR
Vernon Township	East Cove Dam	Wallkill River-TR
Vernon Township	Wawayanda Lake Dam	Wawayanda Creek-TR
Vernon Township	Mountain Creek Lake Dam	Black Creek-TR
Vernon Township	Upper West Highland Lake Dam	Highland Lake
Vernon Township	Highland Lakes Dam	Double Kill River
Vernon Township	Upper Highland Lake Dam	Highland Lakes-TR
Vernon Township	Hidden Valley Lake Dam	Pachuck Creek-TR
Vernon Township	Canistear Reservoir #2 Dam	Pacock Brook
Vernon Township	Stump Pond Dam	Black Creek-TR
Vernon Township	Pleasant Valley Lake Dam	Black Creek-TR
Wantage Township	Lake Rutherford Dam	Clove Brook-TR

Source: USACE 2023

Figure 6-1. Dams by Class in Sussex County



The County may also be impacted by inundation from failure of high-hazard dams in surrounding counties. The inundation zone is the area downstream of a dam that would be flooded in the event of a failure or uncontrolled release of water. This zone is generally much larger than the area of a normal river or stream flood event. Downstream development increases the potential consequences of a dam's failure. Any dam has the potential to adversely affect downstream areas and lives. Many dams, should they fail, can also affect the delivery of essential utilities or flood control (FEMA 2013). Passaic County in New Jersey has 49 high-hazard dams, Morris County in New Jersey has 42 high-hazard dams, Warren County in New Jersey has 15 high-hazard dams, Orange County in New York has 33 high-hazard dams, and Pike County in Pennsylvania has 46 high-hazard dams (USACE 2023).

6.1.4 Extent

Several state and federal agencies assign ratings to dams based on the potential consequences of the dam's failure. These ratings represent the hazard extent for dam failure. Two such rating systems are described in the sections below. Both of these classification systems are based on the consequences of dam failure, not the likelihood of failure occurring.

New Jersey Department of Environmental Protection

The NJDEP assigns the following hazard classifications to state-regulated dams in New Jersey (NJAC 7:20-1.8):

- Class I (High-Hazard Potential)—Failure of the dam may result in probable loss of life 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)—This classification includes any dam that impounds less than 15 acre-feet of water to the top of the dam, has less than 15 feet height-of-dam and has a drainage area above the dam of 150 acres or less. No dam may be included in Class IV if it meets the criteria for Class I or II.

The 40 high-hazard (Class I) dams in Sussex County establish the extent of the dam failure hazard as including possible loss of life and extensive property damage.

U.S. Army Corps of Engineers

Table 6-4 lists USACE-developed classifications of hazard potentials of dam failures, based on potential consequences of a dam failure.

Table 6-4. USACE Dam Hazard Classifications

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
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.

6.1.5 Previous Occurrences

FEMA Major Disaster and Emergency Declarations

There are two types of federal disaster declarations that can be issued by the U.S. president: emergency (EM) declarations and major disaster (DR) declarations. Both declaration types authorize the president to provide supplemental federal disaster assistance. Sussex County has not been included in any federal declarations for dam failure-related events (FEMA 2024).

U.S. Department of Agriculture 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 Sussex County HMP, the County has not been included in any USDA declarations issued for dam failure-related events (USDA 2024).

Previous Events

There have been no known dam failure-related events that impacted Sussex County between January 2020 and June 2024.

6.1.6 Probability of Future Occurrences

Probability Based on Previous Occurrences

Information on previous dam failure occurrences in the County was used to calculate the probability of future occurrence of such events, as summarized in Table 6-5. Based on historical records and input from the Steering Committee, the probability of occurrence for dam failure in the County is considered “occasional.”

There is a “residual risk” associated with dams. Residual risk is the risk that remains after safeguards have been implemented. For dams, the residual risk is associated with events beyond those that the facility was designed to withstand. However, the probability of any type of dam failure is low in today’s dam safety regulatory and oversight environment (NJOEM 2019).

Effect of Climate Change on Future Probability

Projections of climate change for New Jersey predict more intense rainfall events and increases in total annual precipitation (see Section 3.3.4). 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, and/or the reservoir has dedicated flood control space. Increased precipitation may result in overtopping, as the hydrographs are based on historical events (USBR 2003).

Table 6-5. Probability of Future Dam Failure Events in Sussex County

Hazard Type	Number of Occurrences Between 1996 and 2024	Percent Chance of Occurring in Any Given Year
Dam Incident	20	71%

Source: Association of State Dam Safety Officials 2021; FEMA 2023; NJOEM 2019; Stanford University 2018; FEMA 2011; County of Sussex 2021

6.1.7 Cascading Impacts on Other Hazards

Dam failure can cause severe downstream flooding. Other potential secondary hazards of dam failure are landslides around the reservoir perimeter, bank erosion on the rivers, and destruction of downstream habitat (FEMA 2013).

6.2 VULNERABILITY AND IMPACT ASSESSMENT

The dam failure hazard is of significance to Sussex County because 139 dams are present across the County, 40 of which are identified as high hazard (refer to Figure 6-1) (USACE 2023). 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. Dam failure inundation maps and downstream hazard areas are considered sensitive information and were not available for use in this risk assessment. Therefore, to assess Sussex County's risk from dam failure, a qualitative review was conducted.

6.2.1 Life, Health, and Safety

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

Overall Population

The entire population residing within a dam failure inundation zone is considered exposed and potentially vulnerable to a dam failure event. The potential for loss of life is affected by the warming time provided and the 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. Understanding potential outcomes of flooding for each dam in Sussex County would require hydraulic modeling of the likely areas of inundation.

Socially Vulnerable Population

People living below the poverty level in Sussex County 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 Sussex County. Section 3.5.3 provides detailed data on socially vulnerable populations within the planning area. Table 6-6 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.

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.

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

	Sussex County Total		Municipality Highest in Category		Municipality Lowest in Category	
Category	Number	Percent	Number	Percent	Number	Percent
			Vernon (Twp)	Walpack (Twp)	Walpack (Twp)	Sparta (Twp)
Population Over 65	**25,451**	**17.65%**	**3,687**	**100.00%**	**7**	**13.38%**
			Sparta (Twp)	Lafayette (Twp)	Walpack (Twp)	Walpack (Twp)
Population Under 5	**6,500**	**4.51%**	**1,160**	**7.21%**	**0**	**0.00%**
Non-English-Speaking Population	**1,922**	**1.33%**	Hopatcong (B) **339**	Hamburg (B) **10.17%**	Andover, Frankford, Sandyston, Stanhope, Stillwater, Walpack **0**	Andover, Frankford, Sandyston, Stanhope, Stillwater, Walpack **0.00%**
Population With Disability	**15,697**	**10.88%**	Vernon (Twp) **2,318**	Franklin (B) **17.32%**	Walpack (Twp) **0**	Walpack (Twp) **0.00%**
Population Below Poverty Level	**7,320**	**5.08%**	Vernon (Twp) **877**	Sussex (B) **18.03%**	Walpack (Twp) **0**	Walpack (Twp) **0.00%**
Households Below ALICE Threshold	**14,428**	**21%**	Vernon (Twp) 1,833	Sussex (B0 **48%**	Branchville (B) 90	Green (Twp) **14%**

Note: B = Borough; Twp = Township

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

Inundation from a dam failure can cause extensive structural damage and interfere with essential services. The 2019 State HMP discusses damage from previous dam failures in the state ranging from $7 million to $25 million. Costs vary with the density of structures and businesses in the area downstream of the dam..

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. Flood waters can back up sanitary sewer systems and inundate wastewater treatment plants, causing raw sewage to contaminate the flooded waterway. The contents of unsecured containers of oil, fertilizers, pesticides, and other chemicals may get added to flood waters and distributed widely across the area of inundation. After the flood waters subside, contaminated and flood-damaged building materials and contents must be properly disposed of (EPA 2024).

Historic

Historic buildings, structures, sites, monuments, districts, and documents may be damaged or destroyed by 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 CHANGE OF VULNERABILITY SINCE 2021 HMP

Overall, the County's vulnerability to the dam failure hazard has not changed, and the entire County will continue to be vulnerable to this hazard. Any change in vulnerability since the previous HMP would be attributed to changes in population density and new development. This updated HMP used updated building stock and critical asset inventories to assess the County's risk to these assets. The building inventory was updated using RSMeans 2022 values, which are more current and reflect replacement cost rather than the building stock improvement values reported in the 2021 HMP. Further, the 2021 5-year population estimates from the American Community Survey were used to evaluate the population exposed to the hazard areas.

6.4 FUTURE CHANGES THAT MAY AFFECT RISK

Understanding future changes that affect vulnerability can assist in planning for future development and ensure establishment of appropriate mitigation, planning, and preparedness measures. To estimate losses in the future, dam inundation areas and depths of flooding may be used to analyze exposure and generate depth grids. Hazus could be implemented to estimate potential losses. In addition, inspections may inform the status of each dam, as well as maintenance and mitigation measures that may be needed. The following sections examine potential conditions that may affect hazard vulnerability.

6.4.1 Potential or Planned Development

Any areas of growth could be impacted by a dam failure if the structures are within the downstream inundation area and mitigation measures are not implemented. 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.

6.4.2 Projected Changes in Population

Changes in the density of population can impact the number of persons exposed to dam failure inundation hazard areas. Higher density could create issues for local residents during evacuation of a dam failure event and for commuters who travel into and out of the County for work.

The New Jersey Department of Labor and Workforce Development produced population projections by County from 2014 to 2019, 2024, 2029, and 2034. Sussex County is projected to have a decrease in population in the upcoming years. These projections estimate a population of 140,400 by 2024, 137,300 by 2029, and 136,600 by 2034 (State of New Jersey 2017).

6.4.3 Climate Change

Most studies project that the State of New Jersey will see an increase in average annual precipitation, primarily in the form of heavy rainfalls, which have the potential to increase the risk of dam failures by increasing loading on dam structures. Existing flood control structures may not be able to retain and manage increases in water flow from more frequent, heavy rainfall events. Heavy rainfalls may result in more frequent overtopping of these dams and flooding of the County's assets in adjacent inundation areas. However, the probable maximum flood used to design each dam may be able to accommodate changes in climate.