



4.3 HAZARDS OF CONCERN

The Sussex County hazards of concern are presented in Section 4.3 and outlined as follows:

- **Hazard Profile**
 - Location - geographic area most affected by the hazard
 - Extent – severity of each hazard
 - Previous Occurrences and Losses
 - Impacts of Climate Change
 - Probability of Future Hazard Events
- **Vulnerability Assessment**
 - Impact to Life, Health and Safety
 - Impact to the General Building Stock
 - Impact to Critical Facilities and Lifelines
 - Impact to the Economy
 - Impact to the Environment
 - Future Changes that may Impact Vulnerability
 - Change of Vulnerability Since the 2016 HMP

4.3.1 DAM FAILURE

The following section provides the hazard profile (hazard description, location, extent, previous occurrences and losses, probability of future occurrences, and impact of climate change) and vulnerability assessment for the dam failure hazard in Sussex County.

2021 HMP Changes

- All subsections have been updated using best available data.
- Previous occurrences were updated with events that occurred between 2015 and 2020.

Profile

Hazard Description

A dam or a levee is an artificial barrier that has the ability to impound water, wastewater, or any liquid-borne material for the purpose of storage or control of water (FEMA 2007). Dams are man-made structures built across a stream or river that impound water and reduce the flow downstream (FEMA 2003). They are built for the purpose of power production, agriculture, water supply, recreation, and flood protection. Dam failure is any malfunction or abnormality outside of the design that adversely affects a dam’s primary function of impounding water (FEMA 2007). Levees typically are earthen embankments constructed from a variety of materials ranging from cohesive to cohesionless soils. Dams and levees can fail for one or a combination of the following reasons:

- 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; or
- Earthquake (liquefaction / landslides) (FEMA 2018).

Regulatory Oversight of Dams

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 (NDSP) 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 improvement of dam safety programs that regulate most dams in the United States (FEMA 2016).

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. 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 2019).

Federal Energy Regulatory Commission Dam Safety Program

The Federal Energy Regulatory Commission (FERC) has the largest dam safety program in the United States. FERC cooperates with a large number of federal and state agencies to ensure and promote dam safety and, more recently, homeland security. A total of 3,036 dams are part of regulated hydroelectric projects and are included in the FERC program. Two-thirds of these dams are more than 50 years old. Concern about their safety and integrity grows as dams age, rendering oversight and regular inspection especially important (FERC 2017). FERC staff inspect hydroelectric projects on an unscheduled basis to investigate the following:

- 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 (FERC 2017).

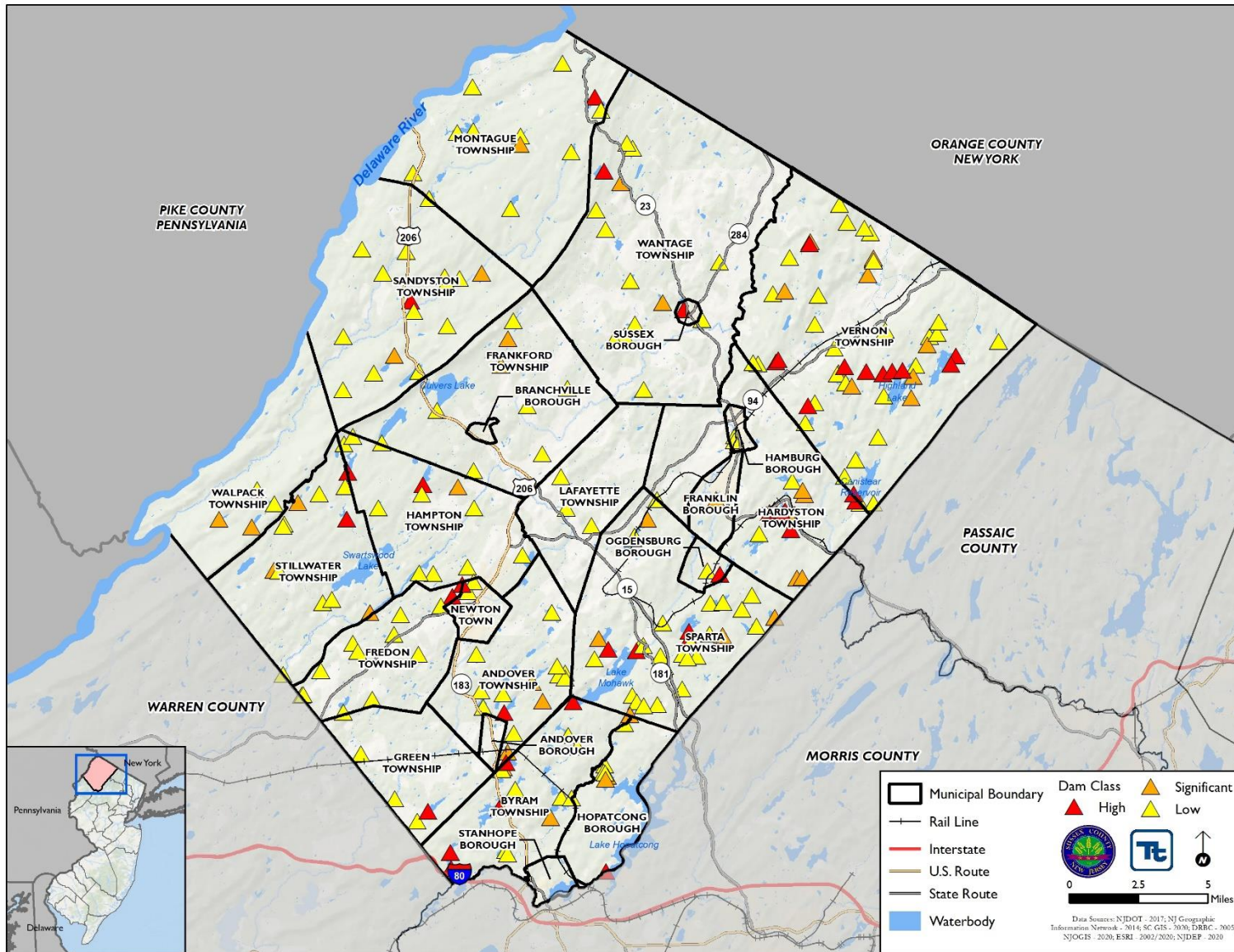
Every 5 years, an independent consulting engineer, approved by FERC, must inspect and evaluate projects with dams higher than 32.8 feet (10 meters) or with total storage capacity of more than 2,000 acre-feet (FERC 2017).

Location

According to NJDEP, Sussex County has 239 dams. Of these dams, 40 are considered high hazard, 41 are considered significant hazard, and 158 are considered low hazard. There are 41 dams classified as in a poor state of repair with one dam in an unsatisfactory state of repair. Figure 4.3.1-1 shows the dams by class throughout the County.



Figure 4.3.1-1. Dams by Class in Sussex County





Extent

The NJ DEP classifies dams according to their hazard potential using the following criteria:

- Class I - High Hazard Potential: This classification includes those dams, the failure of which may cause the probable loss of life or extensive property damage.
 - i. The existence of normally occupied homes in the area that are susceptible to significant damage in the event of a dam failure will be assumed to mean "probable loss of life".
 - ii. Extensive property damage means the destructive loss of industrial or commercial facilities, essential public utilities, main highways, railroads or bridges. A dam may be classified as having a high hazard potential based solely on high projected economic loss.
 - iii. Recreational facilities below a dam, such as a campground or recreation area, may be sufficient reason to classify a dam as having a high hazard potential.
- Class II - Significant Hazard Potential: This classification includes those dams, the failure of which may cause significant damage to property and project operation, but loss of human life is not envisioned. This classification applies to predominantly rural, agricultural areas, where dam failure may damage isolated homes, major highways or railroads or cause interruption of service of relatively important public utilities.
- Class III - Low Hazard Potential: This classification includes those dams, the failure of which would cause loss of the dam itself but little or no additional damage to other property. This classification applies to rural or agricultural areas where failure may damage farm buildings other than residences, agricultural lands or non-major roads.
- Class IV - Small Dams: This classification includes any project which impounds less than 15 acres/feet of water to the top of the dam, has less than 15 feet height-of-dam and which has a drainage area above the dam of 150 acres or less in extent. No dam may be included in Class IV if it meets the criteria for Class I or II. Any applicant may request consideration as a Class III dam upon submission of a positive report and demonstration proving low hazard.

Dam failures cause serious downstream flooding either because of partial or complete dam collapse. Failures are usually associated with intense rainfall and prolonged flood conditions; however, dam breaks may occur during dry periods as a result of progressive erosion of an embankment. The greatest threat from a dam break is to areas immediately downstream. Dam failures may or may not leave enough time for evacuation of people and property, depending on their 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 more than 100 mph. Survival would be a matter of having the good fortune not to be in the flood path at the time of the break. Dam failures due to the overtopping of a dam normally give sufficient lead time for evacuation.

The environmental impacts of a dam or levee failure can include significant water-quality and debris-disposal issues. 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 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. In addition, severe erosion is likely; such erosion can negatively impact local ecosystems.

It is required by the State of New Jersey that all High Hazard and Significant Hazard dams must have NJDEP-approved Emergency Action Plans (EAP) in place. It is the responsibility of the dam owner to review and update the EAP on an annual basis. New Jersey Dam Safety Standards also require that are periodically inspected to identify conditions that may adversely affect the safety and functionality a dam 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, as identified in the State Hazard Mitigation Plan, are reproduced in Table 4.3.1-1 in brief. Complete inspection and operating requirements for dams can be found in the New Jersey Dam Safety Standards (N.J.A.C 7:20-1.11).

Table 4.3.1-1. 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

In New Jersey, every dam in the State as defined in the Safe Dam Act, N.J.S.A. 58:4 is required to meet State dam safety standards. Dam Safety Laws provide the NJDEP with enforcement capabilities to achieve statewide compliance with dam safety standards. This includes issuing orders for compliance to dam owners and pursuing legal action if the owner does not comply (with the goal of compliance and possible fines levied on a per-day basis for violations).

Previous Occurrences and Losses

FEMA Major Disasters and Emergency Declarations

Between 1954 and 2019, no disasters (DR) or emergencies (EM) were declared for dam failure in the State of New Jersey.

U.S. Department of Agriculture Disaster Declarations

The Secretary of Agriculture from the U.S. Department of Agriculture (USDA) is authorized to designate counties as disaster areas to make emergency loans to producers suffering losses in those counties and in counties that are contiguous to a designated county. Between 2015 and 2019, Sussex County was not included in any USDA declaration involving dam failure.

Dam Failure Events

For the 2021 HMP update, known dam failure events that have impacted Sussex County between 2015 and 2019 were researched. No events were found to have occurred (NOAA NCEI 2020, FEMA 2020, NPDP 2020). For events prior to 2015, refer to Appendix E (Risk Assessment Supplement).

Probability of Future Occurrences

Dam failure events are infrequent and usually coincide with events that cause them, such as earthquakes, landslides, and excessive rainfall and snowmelt. As stated in the 2019 New Jersey State HMP, dam failures 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).

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).

According to the 2011 HMP, 2016 HMP, and 2019 State HMP, there were at least 31 dam failures identified based on information queried from the National Performance of Dams Program (NPDP) database; however, details regarding every incident in the County were not included. Eighteen of these dam failures were associated with a severe storm in August 2000 where more than 14 inches of rain fell over a 4-day period. For the 2021 HMP update, however, a query of the NPDP database was conducted and it identified 16 dam incidents in Sussex County, with 15 occurring during the August 2000 severe storm event. Information from the Stanford University’s NPDP database and the NOAA-NCDC storm events database were both used to identify the number of failures/incidents that occurred between 1950 and 2020. Using both sources ensures the most accurate probability estimates possible. The table below shows these statistics, as well as the annual average number of events and the estimated percent chance of an incident occurring in a given year (NOAA-NCDC 2020; NPDP 2020). Based on these statistics, there is an estimated 24.5% chance of a dam failure/incident occurring in any given year in Sussex County.

Table 4.3.1-2. Probability of Future Dam Damage and Failure Events

Hazard Type	Number of Occurrences Between 1950 and 2015	Rate of Occurrence or Annual Number of Events (average)	Recurrence Interval (in years) (# Years/Number of Events)	Probability of Event in any given year	Percent Chance of occurrence in any given year
Dam Incident	16*	0.23	4.44	0.23	24.5%

Source: NOAA NCEI 2020; NPDP 2020

*15 events were associated with the August 2000 storm event which occurred over a 4-day period. The recurrence interval of this storm event is not known; therefore, the dam failure event probability is likely over-estimated.

In Section 4.4, the identified hazards of concern for Sussex County were ranked. The probability of occurrence, or likelihood of the event, is one parameter used for hazard rankings. Based on historical records and input from the Planning Committee, the probability of occurrence for dam failure in the county is considered ‘rare’ (between 1 and 10 percent annual probability of a hazard event occurring, as presented in Table 4.4-1). The ranking of the dam failure hazard for individual municipalities is presented in the jurisdictional annexes.

Climate Change Impacts

Dams are designed partly based on assumptions about a river’s flow behavior, expressed as hydrographs. Changes in weather patterns can significantly affect the hydrograph used for the design of a dam. If the hydrograph changes, the dam conceivably could lose some or all of its designed margin of safety, also known as freeboard. Loss of designed margin of safety increases the possibility that floodwaters would overtop the dam or create unintended loads, which could lead to a dam failure.

Due to the increase in greenhouse gas concentrations since the end of the 1890s, New Jersey has experienced a 3.5° F (1.9° C) increase in the State’s average temperature (Office of the New Jersey State Climatologist 2020), which is faster than the rest of the Northeast region (2° F [1.1° C]) (Melillo et al. 2014) and the world (1.5° F [0.8° C]) (IPCC 2014). This warming trend is expected to continue. As temperatures increase, Earth’s atmosphere can hold more water vapor which leads to a greater potential for precipitation. Currently, New Jersey





receives an average of 46 inches of precipitation each year (Office of the New Jersey State Climatologist 2020). Since the end of the twentieth century, New Jersey has experienced slight increases in the amount of precipitation it receives each year, and over the last 10 years there has been a 7.9% increase. By 2050, annual precipitation in New Jersey could increase by 4% to 11% (Horton et al. 2015). By the end of this century, heavy precipitation events are projected to occur two to five times more often (Walsh et al. 2014) and with more intensity (Huang et al. 2017) than in the last century. New Jersey will experience more intense rain events, less snow, and more rainfalls (Fan et al. 2014, Demaria et al. 2016, Runkle et al. 2017). Also, small decreases in the amount of precipitation may occur in the summer months, resulting in greater potential for more frequent and prolonged droughts (Trenberth 2011). New Jersey could also experience an increase in the number of flood events (Broccoli et al. 2020).

A warmer atmosphere means storms have the potential to be more intense (Guilbert et al. 2015) and occur more often (Coumou and Rahmstorf 2012, Marquardt Collow et al. 2016, Broccoli et al. 2020). In New Jersey, extreme storms typically include coastal nor'easters, snowstorms, spring and summer thunderstorms, tropical storms, and on rare occasions hurricanes. Most of these events occur in the warmer months between April and October, with nor'easters occurring between September and April. Over the last 50 years, in New Jersey, storms that resulted in extreme rain increased by 71% (Walsh et al. 2014) which is a faster rate than anywhere else in the United States (Huang et al. 2017). As temperatures increase so will the energy in a storm system, increasing the potential for more intense tropical storms (Huang et al. 2017), especially those of Category 4 and 5 (Melillo et al. 2014).

Vulnerability Assessment

Dam failure inundation maps and downstream hazard areas are considered sensitive information and were not available for use in this risk assessment. To assess Sussex County's risk to dam failure, a qualitative review was conducted.

Impact on 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. According to the State HMP, the level of impact that a failure would have can be predicted based upon the hazard potential classification as rated by the United States Army Corps of Engineers (State of NJ 2019). Table 4.3.1-3 outlines the recommended hazard classifications.

Table 4.3.1-3. United States Army Corps of Engineers 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	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

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.



Hazard Category(a)	Direct Loss of Life (b)	Lifeline Losses (c)	Property Losses (d)	Environmental Losses (e)
<p>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.</p> <p>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.</p> <p>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.</p>				

Source: State of NJ 2019

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 warning time provided, and capacity and number of evacuation routes available to populations living within these areas. Those most at risk include the economically disadvantaged and the population over the age of 65. The 2018 American Community Survey population estimates indicate there were 22,889 persons over 65 years old and 7,191 living below the poverty level in Sussex County. These populations are more at risk during a dam failure event because economically disadvantaged populations are likely to evaluate their risk and make the decision to evacuate based upon the net economic impact to their family, while elderly populations are likely to seek or need medical attention. The availability of medical attention may be limited due to isolation during a flood event and other difficulties in evacuating. There is often limited warning time for a dam failure event. Populations without adequate warning of the event are highly vulnerable.

Dam failure can cause persons to become displaced if flooding of structures occurs. Dam failure may mimic flood events, depending on the size of the dam reservoir and breach. Understanding potential outcomes of flooding for each dam in Sussex County would require intensive hydraulic modeling.

Impact on General Building Stock

All buildings and infrastructure located in the dam failure inundation zone are considered exposed and potentially vulnerable. Property located closest to the dam inundation area has the greatest potential to experience the largest, most destructive surge of water. All transportation infrastructure in the dam failure inundation zone is vulnerable to damage and potentially cutting off 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.

Dam failure can cause severe downstream flooding and may transport large volumes of sediment and debris, depending on the magnitude of the event. Widespread damage to buildings and infrastructure affected by an event would result in large costs to repair these locations. In addition to physical damage costs, businesses can be closed while flood waters retreat and utilities are returned to a functioning state.

Impact on Critical Facilities and Lifelines

Dam failures may also impact critical facilities and infrastructure located in the downstream inundation zone. Consequentially, dam failure can cut evacuation routes, limit emergency access, and/or create isolation issues. Widespread damage to buildings and infrastructure affected by an event would result in large costs to repair these locations. In addition to physical damage costs, businesses can be closed while flood waters retreat and utilities are returned to a functioning state. Further, 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.



Impact on the Economy

Severe flooding that follows an event like a dam failure can cause extensive structural damage and withhold essential services. The cost to recover from flood damages after a surge will vary depending on the hazard risk of each dam. The State HMP discusses damages from dam failures ranging from \$7 million to \$25 million as a result of previous events in the State. This cost likely varies because of the density of structures and businesses that surround the dam protected area.

Severe flooding that follows an event like a dam failure can cause extensive damage to public utilities and disruptions to delivery of services. Loss of power and communications may occur and drinking water and wastewater treatment facilities can become temporarily out of operation. Debris from surrounding buildings can accumulate should the dam mimic major flood events, such as the 1-percent annual chance flood event that is discussed in Section 4.3.5 (Flood).

Impact on the Environment

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 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.

Future Changes That May Impact Vulnerability

Understanding future changes that affect vulnerability can assist in planning for future development and ensure establishment of appropriate mitigation, planning, and preparedness measures. Several factors are examined in this section to assess hazard vulnerability.

Projected Development

As discussed and illustrated in Section 3 (County Profile), areas targeted for future growth and development have been identified across the County. Any areas of growth could be potentially impacted by a dam or levee failure event if the structures are located within the flood protection 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.

Projected Changes in Population

Sussex County has experienced a population decline since 2010. According to the U.S. Census Bureau, the County's population has decreased 4.7-percent between 2010 and 2018 (U.S. Census Bureau 2020). The population is expected to continue to decrease as residents move away from the suburbs and towards urban centers (Stirling 2018). Even though the population has decreased, any changes in the density of population can impact the number of persons exposed to the probable maximum flood inundation hazard areas. 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. Refer to Section 3 (County Profile) for more information about population trends in the County.



Climate Change

As discussed above, most studies project that the State of New Jersey will see an increase in average annual precipitation. Annual precipitation amounts in the region are projected to increase, primarily in the form of heavy rainfalls, which have the potential to increase the risk to dam failures. Increases in precipitation may stress the dam wall.

Further, existing dams 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.

Vulnerability Change Since 2016 HMP

For the 2021 HMP update, risks to the County's population, building stock, and critical facilities were assessed. Overall, Sussex County remains potentially vulnerable to the dam failure hazard. To estimate losses to these elements 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 for Sussex County. In addition, inspections of dams may also inform the status of each and maintenance and mitigation measure that may be needed.

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