5.4.1 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.

2016 Plan Update Changes

- The hazard profile has been significantly enhanced to include a detailed hazard description, location, extent, previous occurrences, probability of future occurrence, and potential change in climate and its impacts on the dam failure hazard is discussed. The dam failure hazard is now located in Section 5 of the plan update.
- New and updated figures from federal and state agencies are incorporated.
- Previous occurrences were updated with events that occurred between 2011 and 2015.
- A vulnerability assessment was conducted for the dam failure hazard and it now directly follows the hazard profile. The map illustrating the County's inventory of dams and specific dam failure scenario results were removed due to the sensitive nature of this information; only a qualitative assessment was completed.

5.4.1.1 Profile

Hazard Description

A dam is an artificial barrier that has the ability to store water, wastewater, or liquid-borne materials for many reasons (flood control, human water supply, irrigation, livestock water supply, energy generation, containment of mine tailings, recreation, or pollution control. Many dams fulfill a combination of the stated functions (Association of State Dam Safety Officials 2013). They are an important resource in the United States.

Man-made dams can be classified according to the type of construction material used, the methods used in construction, the slope or cross-section of the dam, the way the dam resists the forces of the water pressure behind it, the means used for controlling seepage, and, occasionally, according to the purpose of the dam. The materials used for construction of dams include earth, rock, tailings from mining or milling, concrete, masonry, steel, timber, miscellaneous materials (plastic or rubber), and any combination of these materials (Association of State Dam Safety Officials 2013).

More than a third of the country's dams are 50 or more years old. Approximately 14,000 of those dams pose a significant hazard to life and property if failure occurs. There are also about 2,000 unsafe dams in the United States, located in almost every state.

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. Complete failure occurs if internal erosion or overtopping results in a complete structural breach, releasing a high-velocity wall of debris-filled waters that rush downstream damaging and/or destroying anything in its path (FEMA 1996).

Dam failures can result from one or a combination of the following reasons:

- Overtopping caused by floods that exceed the capacity of the dam
- Deliberate acts of sabotage
- 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 maintenance and upkeep (FEMA 2013a)

Location

Dams provide a life-sustaining resource to people in all regions of the United States. They can provide water supply for domestic, agricultural, industrial, and community use; flood control; creation; and energy. The exact number of dams in the United States is unknown. According to the U.S. Army Corps of Engineers (USACE) National Inventory of Dams (NID), there are over 87,000 dams in the country; however, this inventory only covers dams that meet minimum height and impoundment requirements. In addition to those identified by the USACE, there are numerous small dams not identified. The NID reported 825 dams in the State of New Jersey, of which, 133 are located in Sussex County. However, this total differs from that provided by the NJDEP, which identifies 263 dams in the County. For the purpose of this HMP update, the New Jersey Department of Environmental Protection (NJDEP) data will be used. Table 5.4.1-1 summarizes the number of dams and their hazard classifications in Sussex County. According to the 2011 Sussex County HMP, there are high hazard dams in the following municipalities: Andover Township, Byram Township, Fredon Township, Green Township, Hampton Township, Hardyston Township, Montague Township, Newton, Ogdensburg Borough, Sandyston Township, Sparta Township, Stillwater Township, Sussex Borough, Vernon Township, and Wantage Township.

Table 5.4.1-1. Number of Dams in Sussex County

County	High Hazard	Significant Hazard	Low Hazard	Other	Total
Sussex	37	42	159	25	263

Source: NJDEP 2013

Extent

The extent or magnitude of a dam failure event can be measured in terms of the classification of the dam. Additionally, there are two factors that influence the potential severity of a full or partial dam failure are: (1) the amount of water impounded; and (2) the density, type, and value of development and infrastructure located downstream (City of Sacramento Development Service Department 2005). There are several classification tools used to identify the hazards of dam. FEMA, USACE and NJDEP all have a form of classifying hazards. For the purpose of this HMP Update, the NJDEP hazard classification will be explained in this section. Please refer to *Federal Guidelines for Dam Safety: Hazard Potential Classification System for Dams* (2004) and *Safety of Dams – Police and Procedures* (2014) for an explanation of the FEMA and USACE classifications.

The New Jersey Department of Environmental Protection (NJDEP) has four hazard classifications for dams located in New Jersey. The classifications relate to the potential of property damage and/or loss of life should a dam fail. The classifications are as follows:

- 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 and/or significant property damage.
- Class IV (Small-Dam Low-Hazard Potential) - Failure of the dam is not expected to result in loss of life or significant property damage. Dam must also meet the requirements of a Class IV dam above.

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 5.4.1-2 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 5.4.1-2. 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

As stated in the 2014 New Jersey State HMP Update, 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 (New Jersey HMP 2014).

According to the Association of State Dam Safety Officials, there have been no recorded events of dam incidents in Sussex County. However, the 2011 HMP indicates there have been four previous dam failures and 31 dam incidents in the County. Between 1954 and 2015, FEMA has not included the State of New Jersey in any dam/levee break-related major disasters (DR) or emergencies (EM). For this 2016 HMP update, dam failure events impacting Sussex County between 2008 and 2015 were researched, and no known events were reported. Please note that not all events that have occurred in Sussex County are included due to the extent of documentation and the fact that not all sources may have been identified or researched. Loss and impact information could vary depending on the source. Therefore, the accuracy of monetary figures discussed is based only on the available information identified during research for this HMP Update.

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 noted in the Previous Occurrences and Losses section, dam failures typically occur in New Jersey as a result of heavy rains or other precipitation. 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 (New Jersey State HMP 2014).

According to the 2011 County 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 the August 2000 severe storm. For the 2016 Plan 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. Therefore, for the purpose of this plan update, the most up-to-date data was collected to calculate the probability of future occurrence. 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 2015. 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 2016; NPDP 2016). Based on these statistics, there is an estimated 24.24% chance of a dam failure/incident occurring in any given year in Sussex County.

Table 5.4.1-3. Probability of Future Occurrences of 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	% Chance of occurrence in any given year
Dam Incident	16	0.25	4.13	0.24	24.24%

Source: NCDC 2016; NPDP 2016

In Section 5.3, 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 'Frequent' (likely to occur within 25 years, as presented in Table 5.3-3). The ranking of the dam failure hazard for individual municipalities is presented in Section 5.3 and 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 have significant effects on the hydrograph used for the design of a dam. 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 more readily to overtop the dam or create unintended loads. Such situations could lead to a dam failure.

The climate of New Jersey is already changing and will continue to change over the course of this century. Both northern and southern New Jersey have become wetter over the past century, and precipitation is expected to increase over the next several decades in the State. Since 1895, annual precipitation has increased at a rate of 4.1 inches per century. Northern New Jersey's 1971-2000 precipitation average was over five inches (12%) greater than the average from 1895-1970 (Sustainable Jersey Climate Change Adaptation Task Force [CATF] 2011). Average annual precipitation is projected to increase in the region by four to 11% by the 2050s and five to 13% by the 2080s. (New York City Panel on Climate Change [NPCC] 2015).

Heavy precipitation events have increased in the past 20 years and it is expected that this trend may continue (Rutgers Climate Institute 2013). Changes in climate may lead to higher intensity rainfall events. As a result, the failure probability of low, significant, and under-designed high hazard dams may increase.

5.4.1.2 Vulnerability Assessment

To understand risk, a community must evaluate what assets are exposed and vulnerable in the identified hazard area. For the dam failure hazard, dam failure inundation areas are identified as the hazard areas. The following text evaluates and estimates the potential impact of dam failures for Sussex County including:

- Overview of vulnerability
- Data and methodology used for the evaluation
- Impact on: (1) life, health and safety of residents, (2) general building stock, (3) critical facilities, (4) economy, and (5) future growth and development
- Effect of climate change on vulnerability
- Change of vulnerability as compared to that presented in the 2011 Sussex County Hazard Mitigation Plan
- Further data collections that will assist understanding this hazard over time

Overview of Vulnerability

As discussed above, dam failure events may occur suddenly, without warning, or during normal operating conditions. Additionally, events can occur as a result of a natural hazard event, including severe weather, earthquakes, landslides, and flooding. The direct and indirect losses associated with dam failures include injury and loss of life, damage to structures and infrastructure, agricultural losses, utility failure and stress on community resources. The warning time for a dam failure event is often limited, which contributes to the direct and indirect losses.

As noted earlier, there are 37 high hazard dams located in Sussex County: Andover Township, Byram Township, Fredon Township, Green Township, Hampton Township, Hardyston Township, Montague Township, Newton, Ogdensburg Borough, Sandyston Township, Sparta Township, Stillwater Township, Sussex Borough, Vernon Township, and Wantage Township (Sussex County, 2011).

The 2011 Sussex County HMP included analyses on three high hazard dam sites: Morris Lake Dam, Lake Wallenpaupack in Wilsonville, Pennsylvania, and Mongaup River complex in Sullivan County, New York. The results of these analyses are summarized below.

- The Morris Lake Dam is owned and operated by the Town of Newton. The scenario evaluated was a probable maximum precipitation flood with a breach (representing a worse-case scenario, as documented in the EAP). This dam breach scenario is estimated to impact areas of Sparta Township, Ogdensburg Borough and Franklin Borough.
- The Wallenpaupack hydroelectric station in Wilsonville, Pennsylvania is owned and operated by PPL Generation, LLC. To evaluate a dam breach event, the probable maximum precipitation flood with a breach as included in the EAP was used (representing the worse-case scenario). This dam breach scenario is estimated to impact areas of Montague Township, Sandyston Township and Walpack Township.
- The Mongaup River Hydro System consists of Swinging Bridge, Mongaup, and Rio dam systems; is owned and operated by AER-NY Gen, LLC. The dam breach scenario evaluated was a flood breach, representing the worse-case scenario as included in the EAP. This dam breach scenario is estimated to impact areas of Montague Township, Sandyston Township and Walpack Township (Sussex County, 2011).

Data and Methodology

Dam failure inundation maps and delineated downstream hazard areas are considered sensitive information and were not available to conduct a quantitative risk assessment. Inundation mapping of select high hazard dams may be available upon request of the New Jersey Bureau of Dam Safety & Flood Control. The following section discusses the County's vulnerability to the hazard in a qualitative nature.

Impact on Life, Health and Safety

The entire population residing within a dam failure inundation zone is considered exposed and vulnerable to an event. The potential for loss of life is affected by the capacity and number of evacuation routes available to populations living within these areas. Those most at risk include the economically disadvantaged, the population over the age of 65, and non-English speakers. 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 dam failure event and other difficulties in evacuating.

Impact on General Building Stock, Critical Facilities and Economy

All buildings and infrastructure located in the dam failure inundation zone are considered exposed and 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.

Effect of Climate Change on Vulnerability

As discussed above, climate change can have great impacts upon the functionality of dams in the County. Dams are constructed based on assumptions about a river's flow, which is expressed as a hydrograph. Changes in precipitation will alter surface and groundwater flow, which will directly affect riverine flow. Climate change could cause these dams to become obsolete.

Change of Vulnerability

Overall, the County's vulnerability has not changed and the entire County will continue to be exposed and vulnerable to dam failure events, especially those located within or near flood hazard areas (i.e., downstream dam-failure inundation areas such as those delineated in EAPs). However, for the 2016 HMP update, the County's inventory of dams was removed due to their sensitive nature.

Future Growth and Development

As discussed in Sections 4 and 9, areas targeted for future growth and development have been identified across the County. Any areas of growth could be potentially impacted by the dam failure hazard if located within an inundation area. Please refer to the specific areas of development indicated in tabular form and/or on the hazard maps included in the jurisdictional annexes in Volume II, Section 9 of this plan.

Additional Data and Next Steps

Because of the sensitive nature of the dam failure inundation zones, potential losses have not been quantified and presented in this plan. To estimate potential losses to population, buildings, critical facilities and infrastructure, dam inundation areas and depths of flooding may be used to generate depth grids. HAZUS-MH may be used to estimate potential losses for the County and participating municipalities.