This Risk Assessment will be used to understand Kentucky’s dam-related risks and to help identify potential mitigation actions that may be implemented to reduce this risk.

2018 Kentucky Hazard Mitigation Plan Update – Dam Risk Assessment

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Executive Summary

As the Commonwealth of Kentucky's infrastructure ages, a quantifiable strategy is necessary to communicate the risks due to dam failure and identify mitigation opportunities and alternatives. Dam failure is one of the natural hazards encountered in the Commonwealth of Kentucky. The 2018 State Hazard Mitigation Plan (SHMP) update will serve the municipalities and unincorporated areas of the Commonwealth, dam owners, citizens, and the emergency community by conducting a comprehensive risk assessment for dams and outline mitigation strategies to identify and address Kentucky's dam-related needs. By conducting a holistic assessment of dam-related risks, within the context of the larger, flood risk assessment being conducted for the 2018 SHMP update, this risk assessment provides an opportunity to enhance and build upon the implementation of previous state and regional hazard mitigation plans.

Dams serve many functions throughout the Commonwealth including flood control, water supply, and recreation. The intended uses for dams may evolve over time dams which may pose significant hazards when risks are introduced via downstream development or as their components age. The assessment provides an opportunity to better understand the risks that dams pose and to identify mitigation options to better manage and reduce dam-related risks.

This risk assessment integrates methodologies from the scientific and emergency response and management community to gain a better understanding of the social and economic factors regarding dam failures. It is the hope that the efforts contained herein will encourage Commonwealth stakeholders, and subsequently, dam owners and communities to understand dam-related risks and identify mitigation actions that will be part of the solution to managing and reducing those risks.

Introduction

The purpose of a dam is to impound water, wastewater or other liquids for any of several reasons, e.g. flood control, human water supply, irrigation, livestock water supply, energy generation, or recreation or pollution control. Many dams fulfill a combination of the above functions.

Dams are 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. Materials used for construction of dams include earth, rock, tailings from mining or milling, concrete, masonry, steel, timber, or a combination of these materials.

Dams have many beneficial uses throughout the Commonwealth including flood control, water supply, hydroelectric power generation, and recreation. Often, dams are designed for an intended purpose that changes over time (e.g. when a dam designed for recreation becomes a community water supply). They are dynamic systems that require proper design, maintenance, and operation. Dams may pose risks both upstream and downstream of the water impounding structure. Often, large dam owners, such as the US Army Corps of Engineers identify areas upstream and downstream that must remain protected due to the potential of being inundated by floodwaters. However, most areas upstream and downstream of dams are often unrestricted to development, introducing considerable risks to dam owners, communities, and private citizens. Unchecked or unregulated development may occur downstream of dams, introducing risks either through deliberate or inadvertent actions. Additionally, dams may pose a significant risk when their components age or are not properly maintained. Consequently, catastrophic damage is possible should a dam failure occur. For these reasons, the Kentucky Division of Water (KDOW) has a dedicated Dam Safety program established by state statute (KRS 151).

KDOW Dam Safety Program

The Kentucky Dam Safety program, within the Energy and Environment (EEC) Cabinet, Department for Environmental Protection (DEP), Division of Water (DOW) is responsible for the following activities within the Commonwealth:

- Inspecting existing dams
- Assessing and ranking dams based on conditions and risks
- Issuing permits for dam construction/rehabilitation
- Managing dam-related risks to minimize hazard creep
- Preparing and reviewing Emergency Action Plans (EAPs)
- Communicating dam-related risks
- Managing the State Owned Dam Repair (SODR) program

A dam is defined by KRS 151 as any structure that is 25 feet in height, measured from the downstream toe to the crest of the dam, or has a maximum impounding capacity of 50 acre-feet or more at the top of the structure. Structures that fail to meet these criteria but have the potential to cause significant property damage or pose a threat to life in the downstream area are regulated in the same manner as dams. All water impounding structures meeting those requirements, except federal dams and those permitted by the Division of Mine Reclamation and Enforcement, fall under the purview of DOW. KRS 151 requires the Kentucky Energy and Environment Cabinet (EEC), Department for Environmental Protection (DEP), Division of Water (DOW) to identify, assess, and manage the Commonwealth's Dam Safety Program. The program was established in 1966, predating the establishment of the National Flood Insurance Program in 1968 and many other state dam-related programs. KRS 151.293 authorizes DOW to inspect existing structures that meet the definition of a dam. The Dam Safety program maintains a comprehensive inventory of all active and inactive dams throughout the Commonwealth. In determining the frequency of inspection of a particular dam, the division takes into consideration the size and type, topography, geology, soil condition, hydrology, climate, use of the reservoir, the expected inundation area downstream of the dam, the condition of the dam, and the hazard classification of the dam.

Dam Hazard Classifications

Hazard classifications are assigned to dams based on the anticipated impacts should a dam failure occur. Kentucky's dam hazard classifications align with the classifications outlined in federal dam safety guidance and consist of:

High Hazard (Class C) – Dam structures located such that failure may cause loss of life or serious damage to houses, industrial or commercial buildings, important public utilities, main highways or major railroads.

Moderate Hazard (Class B) – Dam structures located such that failure may cause significant damage to property and project operation, but loss of human life is not envisioned.

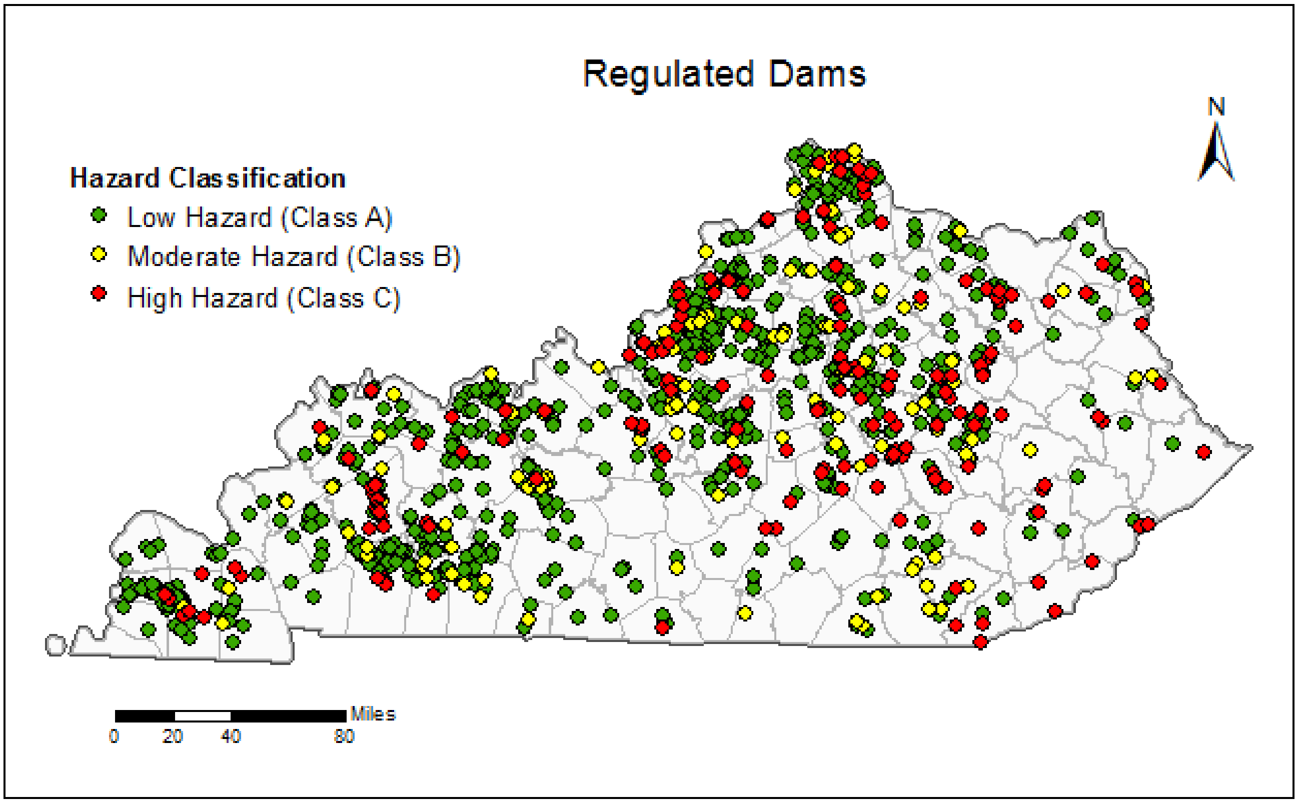
Low Hazard (Class A) – Dam structures located such that failure would cause loss of the structure itself but little or no additional damage to other property.

High- and moderate-hazard dams are inspected by DOW every two years. Low-hazard dams are inspected every five years. If the structure meets all the necessary requirements as outlined in Engineering Memorandum No. 5, a Certificate of Inspection is issued to the owner. Otherwise, the owner is notified of any deficiencies.

There are 954 active dams (177 high hazard – Class C; 132 moderate hazard – Class B; 645 low hazard – Class A) regulated by the Commonwealth as of May 2018. Additionally, approximately 70 dams remain in the DOW dam inventory but are no longer active due to being breached, drained or removed from the DOW dam inspection rotation. The Kentucky Dam Safety Program inspects approximately 300 dams per year. In determining the frequency of inspection of a particular dam, DOW takes into consideration the size and type, topography, geology, soil condition, hydrology, climate, use of the reservoir, the lands lying in the floodplain downstream and the hazard classification of the dam. High- and moderate-hazard dams are inspected every two years. Low-hazard dams are inspected every five years.

Recent efforts have highlighted the importance and need for developing Emergency Action Plans (EAPs) and conditions assessments for dams, particularly those classified as high hazard. Kentucky has a total of 133 high hazard dams with either full EAPs or simplified EAPs. The percentage of high hazard dams with EAPs or sEAPs in Kentucky is 75%. Kentucky is above the national average for EAPs for high hazard dams of 69%, based on the ASDSO Performance Report for Kentucky. Condition assessment ratings have been conducted on all high hazard dams. DOW has made a concerted effort to identify hydraulic, structural, geotechnical, and operational deficiencies in the inspection of dams. Inspection reports assess deficiencies and address a plan of action for dam owners. DOW conducts condition assessments on all dams as they are inspected.

Figure 1. Regulated dams in Kentucky.



Locations of DOW regulated dams by county and Area Development District (ADD) is included in Appendix D.1.

State Owned Dam Repair (SODR) Program

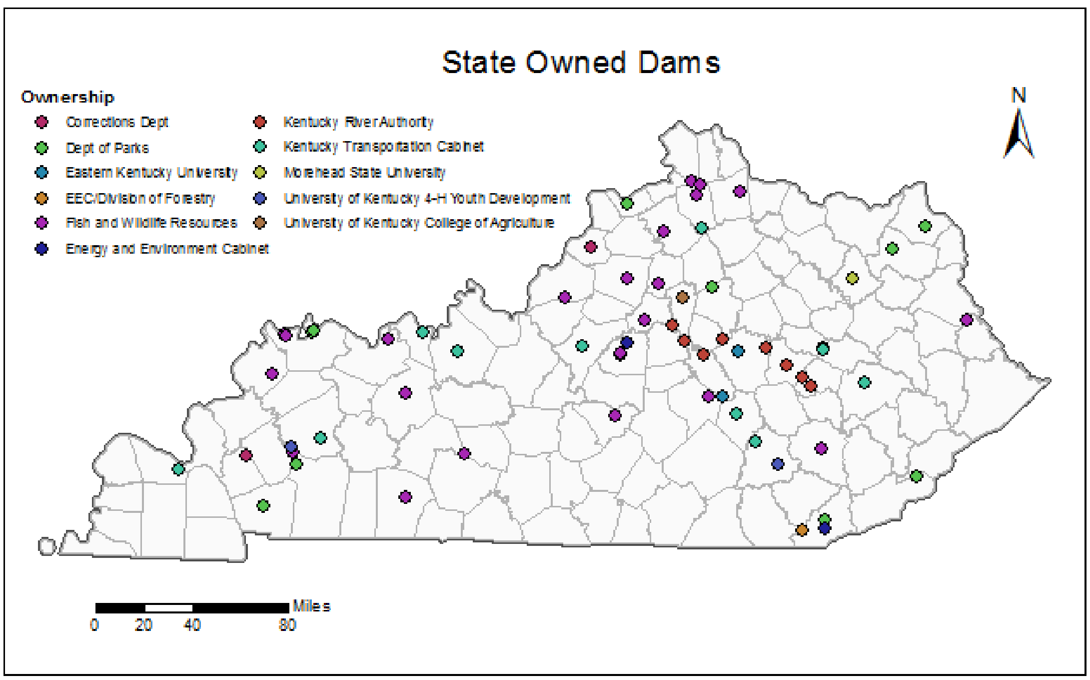
DOW manages the State Owned Dam Repair (SODR) program through statutory authority outlined in KRS 151.291. Ensures that dams owned by the Commonwealth are compliant with applicable regulatory standards in order to protect against loss of human life, and critical infrastructure due to dam failure. Through the SODR program, KDOW invests legislative appropriations for remediation of state-owned dams. Historically, the appropriations range from $1-2 million per state biennium. Through SODR, DOW has conducted capital construction projects, proactively acquired at-risk properties, collaborated with local communities to restrict development downstream of dams, saved millions of dollars that otherwise would have been spent on upgrading dam structures because of the change in risk class resulting from hazard creep.

The Commonwealth, through its various agencies, owns 73 dams; 23 high hazard (Class C), 17 moderate hazard (Class B), and 33 low hazard (Class A) structures. A breakdown of state owned dams by agency is as follows:

- KY Department of Fish and Wildlife – 26 dams
- KY Department of Parks – 13 dams
- KY Transportation Cabinet – 11 dams
- Kentucky River Authority – 10 dams
- Kentucky Universities – 8 dams
- KY Energy and Environment Cabinet – 3 dams
- KY Department of Corrections – 2 dams

Figure 2, below, indicates locations of state owned dams.

Figure 2. Locations of state owned dams.



Half of high (Class C) and moderate (Class B) state owned dams currently have a "Poor" conditions rating in the National Inventory of Dams (NID). This fact highlights the need of significant critical infrastructure in need of repair.

DOW's employs a risk-based approach to address deficiencies in state owned dams. Structural, hydraulic (capacity), and maintenance deficiencies are prioritized and multiple remediation options are considered including capital construction, property and easement acquisition downstream of dams, regulations in coordination with local municipalities, outreach, and a combination of options.

Often, a combination of mitigation options is identified as the most effective means to manage and mitigate dam-related risks.

National Dam Safety Program

The National Dam Safety Program (NDSP) is a partnership of the States, Federal agencies, and other stakeholders that encourages and promotes the establishment and maintenance of effective Federal and state dam safety programs to reduce the risks to human life, property, and the environment from dam related hazards. Additionally, the National Dam Safety Review Board (NDSRB) has been established to advise the FEMA Administrator in setting national dam safety priorities and considers the effects of national policy issues affecting dam safety. Review Board members include FEMA, the Chair of the Board and representatives from four federal agencies (U.S. Departments of Agriculture, Commerce, Homeland Security, and Interior), five state dam safety officials, and one member from the private sector. DOW is an active member of the NDSRB - https://www.fema.gov/national-dam-safety-review-board-members.

National Inventory of Dams

Congress first authorized the U.S. Army Corps of Engineers (USACE) to inventory dams in the United States with the National Dam Inspection Act of 1972. The NID was first published in 1975, with a few updates as resources permitted over the next ten years. The Water Resources Development Act of 1986 (P.L. 99-662) authorized the Corps to maintain and periodically publish an updated NID, with re-authorization and a dedicated funding source provided under the Water Resources Development Act of 1996. USACE also began close collaboration with the Federal Emergency Management Agency (FEMA) and state regulatory offices to obtain more accurate and complete information. The National Dam Safety and Security Act of 2002 and the Dam Safety Act of 2006 reauthorized the National Dam Safety Program and included the maintenance and update of the NID by USACE. Most recently, the NID was reauthorized as part of the Water Resources Reform and Development Act of 2014. The NID is published every two years. (http://nid.usace.army.mil/)

The NID consists of dams meeting at least one of the following criteria:

1) High hazard potential classification - loss of human life is likely if the dam fails,
2) Significant hazard potential classification - no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or impact other concerns,
3) Equal or exceed 25 feet in height and exceed 15 acre-feet in storage,
4) Equal or exceed 50 acre-feet storage and exceed 6 feet in height.

Dam Conditions Assessments

During each dam inspection a Condition Assessment is performed that assesses the physical characteristics of the dam. Dams are assigned as one of the following four conditions: Satisfactory, Fair, Poor, and Unsatisfactory. See Appendix D.2 for Conditions Assessments of Kentucky regulated dams.

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The following guidelines have been established for Kentucky to meet the requirement of assigning appropriate condition assessments to existing dam structures. These criteria reflect how the Commonwealth regulates dams in accordance with applicable statutes and regulations.

Satisfactory

- Dam has no deficiencies beyond minor maintenance items such as minor brush growth or saplings, small eroded/bare areas, small areas of non-structural deterioration to concrete, metal or timber components, debris in the outlets, or similar.
- Dam has no known structural issues.
- Dam may have seepage/leakage issues, provided that they are longstanding, previously evaluated and deemed to be static or not presenting a stability issue.
- Dam meets design storm event standard for its classification.

Fair

- Dam has maintenance deficiencies beyond the minor ones allowable for "Satisfactory" dams, but these deficiencies are non-structural and do not affect the safe operation of the dam.
- Dam has no known structural issues.
- Dam may have seepage/leakage issues that, though not deemed an immediate threat to the stability of the dam, have not been adequately investigated, evaluated or addressed.
- Dam meets at least 90% of its design storm event standard for its classification.

Poor

- Dam has multiple maintenance deficiencies that can affect the safe operation of the dam, some of which may be structural or need further evaluation by a qualified engineer.
- Dam may have structural issues.
- Dam may have significant seepage/leakage issues that need to be addressed.
- Conditions are not bad enough to warrant a lowering of the reservoir.

Unsatisfactory

- Dam is unsafe. A dam safety deficiency exists that requires prompt remedial action for problem resolution. Reservoir restrictions may be necessary.

Not Rated

- No condition assessment of the dam has been completed.
- Inadequate information exists to make a condition assessment determination.
- Additional information concerning the condition of the dam is forthcoming from the dam owner.

Types of Dams

Embankment Dams: Embankment dams are the most common type of dam in use today. Materials used for embankment dams include natural soil or rock, or waste materials obtained from mining or milling operations. An embankment dam is termed an "earthfill" or "rockfill" dam depending on whether it is comprised of compacted earth or mostly compacted or dumped rock. The ability of an embankment dam to resist the reservoir water pressure is primarily a result of the mass weight, type and strength of the materials from which the dam is made.

Concrete Dams: Concrete dams are categorized according to the design used to resist the stress due to reservoir water pressure. Three common types of concrete dams are: **gravity, buttress** and **arch**.

Gravity: Concrete gravity dams are the most common form of concrete dam. The mass weight of concrete and friction resist the reservoir water pressure. Gravity dams are constructed of vertical blocks of concrete with flexible seals in the joints between the blocks.

Buttress: A buttress dam is a specific type of gravity dam in which the large mass of concrete is reduced, and the forces are diverted to the dam foundation through vertical or sloping buttresses.

Arch: Concrete arch dams are typically rather thin in cross-section. The reservoir water forces acting on an arch dam are carried laterally into the dam abutments. The shape of the arch may resemble a segment of a circle or an ellipse, and the arch may be curved in the vertical plane as well. Such dams are usually constructed of a series of thin vertical blocks that are keyed together; barriers to stop water from flowing are provided between blocks.

https://damsafety.org/different-types-dams

Dam Failures

Hundreds of dam failures have occurred throughout U.S. history. These failures have caused immense property and environmental damages and have taken thousands of lives. As the nation's dams age and population increases, the potential for deadly dam failures grows. No one knows precisely how many dam failures have occurred in the U.S., but they have been documented in every state. From Jan. 1, 2005 through June 2013, state dam safety programs reported 173 dam failures and 587 "incidents" - episodes that, without intervention, would likely have resulted in dam failure (https://damsafety.org/dam-failures). Unfortunately, many dam-related incidents go unreported due to several factors, including the rural nature of many dams.

Several factors influence loss of life from dam failures including the population at risk (PAR), the velocity and depth of the flood wave, the time of day or year the dam failure occurs, ease of evacuation from the inundated areas, and the timeliness of warning about the dam failure. Tools have been developed, such as Emergency Action Plans (EAPs) to communicate to dam owners, emergency management personnel, communities, and citizens the risks of dam failure and what actions must be undertaken to protect life and property.

Types of Dam Failures

Dam failures are most likely to happen for several reasons:

1) Overtopping caused by water spilling over the top of a dam. Overtopping of a dam is often a precursor of dam failure.

2) Foundation defects and slope instability (e.g. sinkholes or steep slopes)

3) Cracking caused by natural settling of the dam

4) Inadequate maintenance and operation of the dam

5) Piping. Piping occurs by internal erosion caused by seepage. Seepage often occurs around hydraulic structures, such as pipes and spillways; through animal burrows; around roots of woody vegetation; and through cracks in dams, dam appurtenances, and dam foundations.

https://damsafety.org/what-are-causes-dam-failures

Most dam failures occur due to flooding events that cause overtopping of the dam. Other factors that may cause a dam to fail include foundation defects, internal erosion caused by seepage (piping), and inadequate maintenance. Regardless of the manner in which a dam failure may occur, communities and dam owners must be prepared to deal with the consequences.

Signs of Potential Dam Failure

- Seepage. The appearance of seepage on the downstream slope, abutments, or downstream area may indicate or be the precursor to a dam failure. If the water is muddy and is coming from a well-defined hole, material is probably being eroded from inside the embankment and a potentially dangerous situation can develop.
- Erosion. Erosion on the dam and spillway is one of the most evident signs of danger.
- Cracks. Cracks are of two types: traverse and longitudinal. Traverse cracks appear perpendicular to the axis of the dam and indicate settlement of the dam. Longitudinal cracks run parallel to the axis of the dam and may be the signal for a slide, or slump, on either face of the dam.
- Slides and Slumps. A slide on the face of a dam may cause catastrophic failure of the dam. Slides may occur for many reasons.
- Subsidence. Subsidence is the vertical movement of the foundation materials. The rate of subsidence may be so slow that it can go unnoticed without proper inspection. Foundation settlement is the result of placing the dam and reservoir on an area lacking suitable strength, or over unsuitable foundation materials such as sinkholes or mines.
- Vegetation. A prominent danger signal is the appearance of "wet environment" types of vegetation such as cattails, reeds, mosses and other wet area vegetation. These types of vegetation can be a sign of seepage.
- Boils. Boils indicate seepage water exiting under some pressure and typically occur in areas at the toe or downstream of the dam.
- Animal Burrows. Animal burrows present a potential risk since such activity can undermine the structural integrity of dams.
- Debris. Debris on dams and spillways can reduce the function of spillways, damage structures and valves, and destroy appropriate vegetative cover.

Impacts of Dam Failures

Dam failures may cause flooding that is much more impactful than riverine or coastal flooding. Floodwaters from a dam failure may arrive before warning or evacuation can occur and the resulting environmental impacts can be devastating. Additionally, dams serve as critical infrastructure to many communities via water supply or power generation. The loss of these means have the potential to be even more pervasive than the inundation of floodwaters. Often dams serve as a direct or indirect economic driver for many communities. The loss of recreation, in addition to the other benefits dams serve, impact the overall social, economic, and environmental resilience of communities across the Commonwealth and the nation.

Emergency Planning

EAP Development

Emergency Action Planning involves a team of individuals with specific responsibilities related to developing, reviewing, updating, and implementing the plan. A stakeholder group should be formed as soon as possible to complete the EAP. The EAP will describe roles and responsibilities in detail.

In the event that the plan is implemented and damage or loss of the dam and/or downstream facilities occur, the community will need to address recovery.

DOW has developed EAPs for many state owned dams and have provided EAP template forms with basic dam and community information pre-populated for many municipally owned dams. Although statewide data sources are excellence starting points, community information unique to the dam is critical. Upon receipt of this EAP, dam owners should verify the information populated in the EAP. This process can either be done individually or with the support of an EAP community stakeholder group.

Dam owners should determine the individuals responsible for implementing the EAP and complete the contact information for each responsible individual in the three emergency level call-down lists and the Emergency Services Contacts table. A back-up contact should be identified for each primary contact in order to be prepared in the event that a primary contact is unable to perform their duties. Please note that the roles listed in the notification call-down lists in the EAP template are generic and should be revised as appropriate to accurately reflect the local community. Dam owners should also identify local resources that can be utilized in the event of an emergency. These resources include equipment and materials that may be needed for emergency remedial actions during an emergency event.

In addition to the EAP text, an Evacuation Map, as well as inundation maps, are provided showing the results of the dam study. These data identify potential inundation areas should the dam overtop. Based on the inundation area, an Evacuation Map indicates areas to be considered for evacuation in addition to routes that may be overtopped and some critical facilities such as hospitals, schools, and treatment plants within the community. The evacuation area has been divided into areas and currently unpopulated zones have been identified based on a review of aerial imagery. By designated unpopulated areas, responders can focus on areas with greater potential for loss of life. These areas should be reevaluated at least once a year for any changes in development.

The data should be reviewed by stakeholder groups and modified to include additional areas within the inundation area where people may be present that had not been identified, such as parks, campgrounds, or other recreational facilities. Dam owners should also identify locations that will require additional time and complexity for evacuation, such as hospitals, nursing homes, hotels, schools, and community utilities. The Dam Operator should coordinate with property owners or managers to determine if evacuation plans already exist for these facilities.

Dam owners should develop evacuation plans that include the following, at a minimum: how residents and businesses within the inundation and/or evacuation areas will be notified; locations of emergency shelters; which roads should be closed and how this will be accomplished; how residents without access to vehicles will be transported to emergency shelters; and how food, water, and other supplies will be provided to evacuees at the emergency shelters. 4-6

Upon finalizing EAPs, dam owners should deliver copies of the EAP to individuals responsible for implementing the EAP. Dam owners should invite responsible individuals to an onsite review of the dam to ensure each individual is familiar with the dam and its features. Dam owners are responsible for maintaining and exercising the EAP. Dam owners should review EAPs at least once each year and update the document as needed. This annual review should include contacting and verifying the phone numbers for each of the contacts listed in the EAP.

Long-Term Recovery Plans

Dam owners, community leaders, and state and federal representatives involved in the long-term recovery of a dam after a partial or total dam failure should carefully coordinate and prepare long-term recovery plans to facilitate the recovery of critical community functions (drinking water supply, flood control, recreation, etc.) lost as a result of a dam failure. Long-term recovery plans may be a valuable resource used in conjunction with EAPs and associated dam failure inundation analyses. The long-term recovery plans support dam owners in gaining an understanding of risks, mitigation alternatives, and coordination efforts of post-disaster activities related to the repair or reconstruction of a failed dam. These activities are intended to help transition the community from emergency response to disaster recovery after implementation of Emergency Support Function (ESF) #14 – Community Recovery and other applicable emergency response procedures.

Considerations and approach methods for populating and enhancing long-term recovery plans should help set the stage for successful, comprehensive plan development.

Since dams are generally considered critical for the needs of the community, a plan should be in place to restore essential functions provided by the facility in the event of a dam failure. If it is determined that a dam does not serve a critical need for the region, consideration must be given to the feasibility of dam reconstruction, including short- and long-term alternative needs, as well as potential future risks associated with reconstruction.

The long-term recovery plans are not intended to address emergency response activities in the event of a dam failure, or in the event of a perceived or imminent threat of dam failure. These emergency response measures are implemented through the Emergency Action Plan (EAP), which is coordinated by the dam owner, local emergency management officer, Kentucky Dam Safety, and/or Kentucky

Emergency Management. Long-term recovery plans are designed to synergize with EAPs to help transition from emergency response to recovery. EAPs contain a multitude of information that should be reviewed and fully understood in order to successfully transition into short-term and eventually long-term recovery. EAP information relevant to the long-term recovery may include critical community contacts, immediate response procedures, the number and type of properties potentially affected, critical infrastructure impacted, inundation maps, anticipated degree of impacts affecting downstream properties, and other necessary information.

Long-term recovery plans do not address recovery of all community infrastructure that could be affected by a dam failure, such as roads, bridges, buildings, power substations, telecommunication systems, medical facilities, water and wastewater services, and other structures necessary for normal community function. The plans should also not be considered as a stand-alone document, and must be implemented in coordination with other, in-effect, local, regional, state and federal master plans and disaster management response procedures. Plan implementation must consider all appropriate federal, state, and local standards and regulations.

In support of developing long-term recovery plans, information and data may be retrieved from a variety of sources including Kentucky's Dam Safety Database, the dam's EAP, inundation zone maps, and other related local, state, and federal mitigation planning and emergency data sources. When desired information is not available, dam owners may choose to complete new analyses as part of a commitment to preparedness and to optimize the recovery from a dam failure.

For the most part, the risks due to dam failure are difficult to quantify and understand due to the relative low probability and high consequences related to dam failures. However, when dams fail the consequences are often catastrophic. Many outreach and education materials are available from a variety of sources such as FEMA, DOW, and the Association of State Dam Safety Officials (ASDSO). Long-term recovery plans are intended to be used as a planning tool that may proactively assist dam owners to meet challenges should a catastrophic event occur.

Table 1. Dam incidents in Kentucky.

Dam Name	Incident Date	Incident Type	Dam Type	URR*
Slaughters Lake Dam	2/25/2018	Hydrologic Event	Earth	Yes
Hematite Lake Dam	6/11/1998	Not Known; Seepage-Piping	Earth	Yes
Guist Creek Lake Dam	3/1/1997	Inflow Flood - Hydrologic Event	Earth	No
Kincaid Creek Dam	3/1/1997	Inflow Flood - Hydrologic Event	Earth	No
Mud River MPS 6A	3/1/1997	Inflow Flood - Hydrologic Event	Earth	No
Indian Lake Dam	1/1/1983	Piping	Earth	Yes
Camp Ernst Dam	9/15/1978	Embankment Slide	Earth	Yes
Caulk Lake Dam	12/16/1973	Seepage	Earth	Yes

*URR = Uncontrolled Release of the Reservoir
http://npdp.stanford.edu/dam_incidents
Kentucky Dam Safety Program

The dam risk assessment addresses the Commonwealth's inventory of regulated dams and has developed a model for 1) expanding the Commonwealth's capability to address flood and seismic risks associated with dams 2) effectively assess, communicate, and mitigate the risks associated with dams, and 3) develop strategies to mitigate identified risks that can be incorporated in the both the state and local hazard mitigation planning process.

Additionally, the risk assessment characterizes dam safety and the synergies with FEMA and the Commonwealth's Risk MAP program, which serves as the nation's flood hazard mapping program. Risk MAP (Mapping, Assessment, and Planning) carries a dam safety component with it; many of the products created as part of this plan are complementary to the flood risk datasets and products present in Risk MAP. The results of this risk assessment will be used to prioritize future dam improvements and mitigation measures.

The outcomes of this risk assessment will serve to:

1) Provide a means to quantify, communicate, mitigate current and avoid future risk associated with dams.
2) Provide a framework in which the public's awareness of the risks associated with living within the risk area of a dam failure will result in effective mitigation of current and future risk.
3) Develop processes for effectively conducting routine dam risk assessments and measuring reductions in risk.
4) Create partnerships that successfully leverages Kentucky Emergency Management and Dam Safety programs with FEMA's Mitigation and Dam Safety programs.
5) Integrate project outcomes into Kentucky's hazard mitigation plan and to use project results to effectively implement mitigation action and eliminate future risks.
6) Assist the Commonwealth of Kentucky in preparing standardized best practices for dam-related risk assessments, emergency action planning, catastrophic long-term recovery planning, and risk communication.
7) Educate local and state entities on the risks associated with living downstream of a dam.

Risk Assessment

In order to effectively characterize dam failure risks in the 2018 State Hazard Mitigation Plan update for Kentucky, several methodologies were applied to create a holistic dam-related risk assessment. Dam inundation maps and HAZUS risk assessments were conducted on a subset of state and municipally owned dams. The HAZUS analyses were used to provide information on the expected damage to the built environment. Additional tools developed by the Natural Resource Conservation Service (NRCS) and US Bureau of Reclamation (USBR) were utilized to assess the risk of dams based on their physical characteristics. Information on the risk assessment methodologies may be found below.

Inundation Mapping

Inundation mapping uses predictive models to identify downstream flooding from a dam failure. Two failure modes, piping and overtopping, are calculated and the resultant inundation areas are identified. These data provide a characterization of the risk posed by dam failure to downstream structures and infrastructure. The models use dam-related information to calculate the breach parameters. These data may be edited to reflect more accurate and precise information or account for future conditions, such as increased rainfall or other hydrologic and hydraulic parameters. The models allow users to specify heights at each modeled cross section to determine how long the floodwaters will be above the specified height. This is especially important in determining inundation time and duration for bridges or other structures that are located downstream of the dam. The outputs provide results on maximum elevation, depth, depth time, and flow for each cross section in the analysis. These results are then used to create inundation maps within Geographic Information Systems (GIS). The results of the inundation mapping may be found in Appendix D.3.

HAZUS

HAZUS is a nationally applicable standardized methodology developed by FEMA that contains models for estimating potential losses from earthquakes, floods, and hurricanes. HAZUS uses GIS technology to estimate physical, economic, and social impacts of disasters. It graphically illustrates the limits of identified high-risk locations so users can then visualize the spatial relationships between populations and other more permanently fixed geographic assets or resources for the specific hazard being modeled, a crucial function in the pre-disaster planning process. HAZUS analyses were also conducted for each county leveraging depth grids generated from the National Flood Hazard Layer (NFHL) as part of the flood risk assessment.

Dam failure depth grids were utilized in HAZUS to create a user defined flood risk for each dam assessed that provides a more granular analysis than is present in the automated flood depth generation routines currently present in HAZUS. The analyses provided an estimate of damage and losses using data provided with the HAZUS software for overtopping scenarios.

HAZUS results may be characterized in many different ways based on the user's needs. For this risk assessment, the flood loss estimation analysis for each dam is reported in tabular and spatial formats in Appendix D.4. The tabular loss reports characterize the direct economic losses for agricultural products, direct economic losses for buildings, a shelter summary, direct economic losses for utilities, and direct economic losses for vehicles. The spatial loss format is reported for each dam based on the total economic loss for buildings at a census block level. Losses were classified using the Natural Breaks (Jenks) method and depict the census blocks with low, moderate, significant, and high damage potential.

HAZUS outputs are very useful in assessing the potential damages from a potential dam failure. There are a multitude of ways to characterize the analysis based on the needs of a particular agency or individual. The results were based on an overtopping event and illustrate the census blocks affected by each dam inundation zone. Losses were classified using the Natural Breaks (Jenks) method and depict the census blocks with low, moderate, significant, and high damage potential. These products are enormously useful for use in community development plans, local mitigation plans, and for infrastructure development. Additionally, local data may be utilized to replace the native results compiled as part of this plan to supplement the risk assessment further. At any rate, the HAZUS outputs provide a building block for more refined risk assessments in the future.

NRCS Risk Assessment Spreadsheet Tool

The Natural Resources Conservation Service (NRCS) has created a spreadsheet tool that is based on the U.S. Bureau of Reclamation's (USBR) Risk Based Profile System (RBPS) developed for dam safety prioritization. This spreadsheet provides an overall "Total Failure Index" and "Total Risk Index" that are based on the potential for failure and the consequences of a failure. These values can be used to rank and compare the dam with other dams to prioritize funding and future studies. The risk assessment allows for overall dam-related risk prioritization.

The NRCS risk assessment spreadsheet consists of a series of questions that are answered by the user based on available information for each dam assessed. The spreadsheet tool then calculates a "Total Failure Index" based on the condition of the dam and its likelihood of failure and a "Total Risk Index" based on the consequences of a failure and the likelihood of failure. The process is relatively objective, which is important in order to be able to compare the dams to one another.

The spreadsheet contains five tabs: static, hydrologic, seismic, risk and consequences. The "static" tab considers the risk of a "sunny-day" failure due to the condition of the dam including the condition of the principal spillway, past reservoir filling history, seepage and deformation, foundation geology, and the design, construction and monitoring of the embankment. Dam-specific information such as the last inspection report and as-built drawings, as well as publicly available data such as geologic quadrangle maps and soil surveys are assessed. The results are summed to determine the "Static Failure Index."

The "hydrologic" tab considers the risk of a failure during a storm event based on the hydrologic capacity of the dam, and the geometric configuration of the spillways. Users enter values for each field based on available data, including previous hydrologic & hydraulic analyses, and an overall "Hydrologic Failure Index" is computed.

The "seismic" tab considers the proximity of the dam to seismic zones and the potential for liquefaction of the dam foundation. Users enter values based on as-built drawings or publicly available datasets such as seismic zones and geologic quadrangle maps. For this tab a "Seismic Failure Index" is computed.

The "risk" tab calculates the "Total Failure Index" and the "Total Risk Index." The "Total Failure Index" is the sum of the three failure indices (static, hydrologic, and seismic). The maximum amount of points for both the static and hydrologic failure indices is 300. The maximum for the "Seismic Failure Index" is 100. Therefore, the maximum "Total Failure Index" that can be calculated is 700. A higher risk index number corresponds with a higher risk of failure. For the "Total Risk Index" the user enters the estimated population at risk and a "fatality rate" based on warning time, the community's understanding of evacuation procedures, and the depth and velocity of a potential dam breach. The failure index for each scenario (static, hydrologic, and seismic) is multiplied by the fatality rate and the population at risk to come up with a risk index. These risk indices are summed to compute the "Total Risk Index." Because the failure index is multiplied by the population at risk to compute the risk index, there is no maximum value for the "Total Risk Index."

The final tab is a "consequences" tab which summarizes the risk indices and gives an overview of the dam being considered. Most of the data on this tab is not considered in the computation of the risk indices, but can be used to compare the different failure impacts of two dams with similar risk indices. This information can help the end user determine which dam is more of a priority in terms of funding or further analysis.

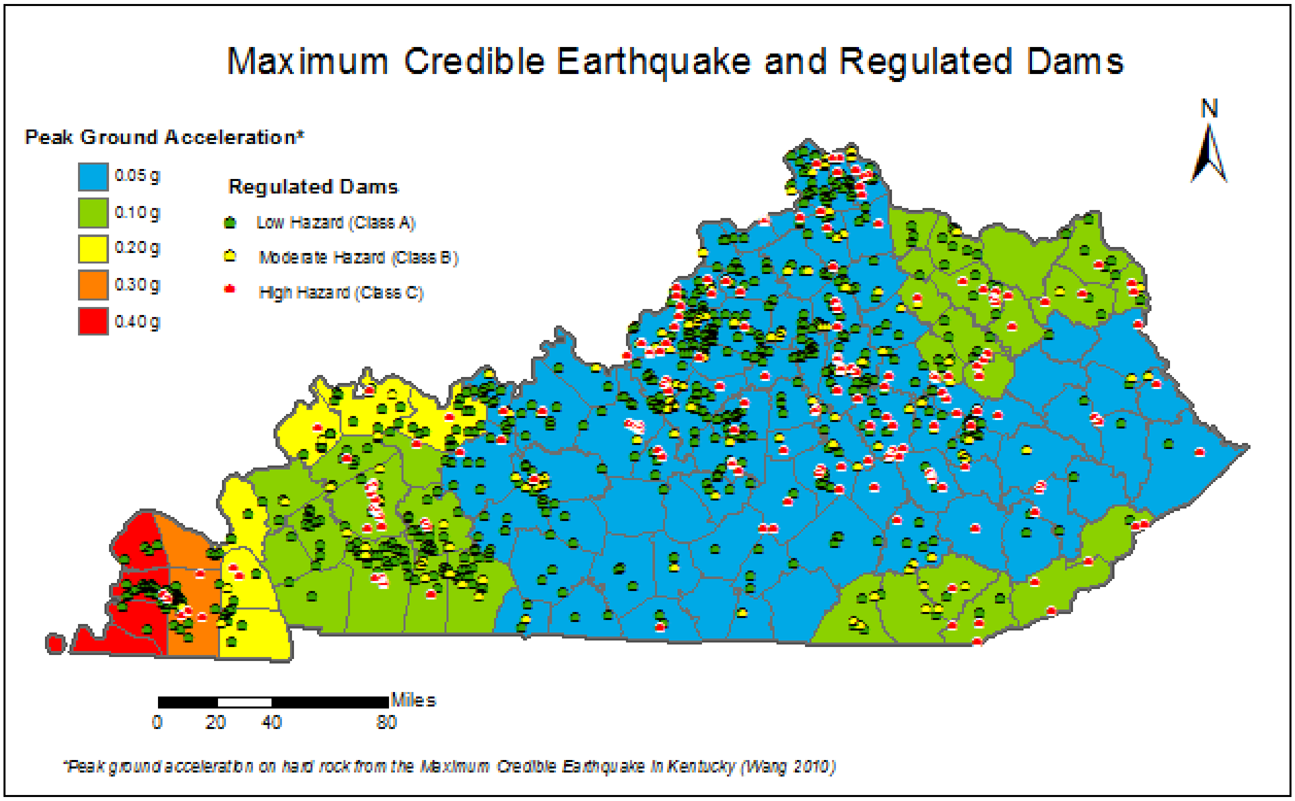
The output of the spreadsheet consists of two indices, a "Total Failure Index" (based on the condition of the dam and its likelihood of failure) and a "Total Risk Index" (based on the consequences of a failure combined with the likelihood of failure). These numbers can be computed for all of the dams and used to rank the dams. This ranking can be used for risk prioritization to determine which of the priority dams are in most need of further analysis or potential mitigation measures. Tables 2.2 and 2.2 depict the "Total Failure Index" and "Total Risk Index" for each of the assessed dam. The results of the Risk Assessment Spreadsheet Tool are located in Appendix D.5.

Seismic Risk Assessment

One component of risk related to dams is the probability of failure and the consequences (economic and non-economic) resulting from an earthquake. There are four active seismic zones in Kentucky, each containing dams of all hazard categories (high – Class C, moderate, Class B, and low – Class A). Thirty-three dams are in western Kentucky, closer to the New Madrid and Wabash Valley seismic zones, and seven dams are in southeastern Kentucky, closer to the East Tennessee seismic zone. An area of northeastern Kentucky is also of interest for seismic loading. Table 2 presents a selection of dams in areas of higher seismic risk in Kentucky.

Seismic information was based on Kentucky Geological Survey (KGS) publications instead of USGS publications, which are typically used in the NRCS risk assessment methodology discussed above. KGS specializes in Kentucky-specific geologic hazards; this provides a thorough understanding of state-specific seismic information that was leveraged for the risk assessment. The NRCS spreadsheet instructs the user to use USGS mapping to obtain the peak ground acceleration (PGA) on rock for an earthquake having a 2 percent probability of exceedance in 50 years (2,475-year return period). The risk assessment utilizes the PGA on hard rock for the Maximum Credible Earthquake (MCE), as derived by KGS for each county in Kentucky (Wang 2010). Figure 3 presents a map of Kentucky with the MCE PGA values and the locations of all state regulated dams.

Figure 3. Regulated dams in Kentucky with seismic zones defined by county by the PGA from the MCE.



The probability of dam failure due to an earthquake is controlled primarily by the anticipated PGA, represented by the seismic load factor. The limited geotechnical information regarding foundation and embankment materials makes it difficult to identify dams that may have seismic vulnerabilities, represented by the seismic response factor. Thus, the dams with higher seismic failure indices are found in close proximity to the New Madrid seismic zone (extreme west Kentucky) and the Wabash Valley seismic zone (western Kentucky counties along the Ohio River adjacent to southwestern Indiana). Moderate seismic failure indices are found in areas slightly farther from the New Madrid and Wabash zones (i.e., the remainder of western Kentucky) and in areas near small source zones (northeastern and extreme southeastern Kentucky). The remainder of the state has low seismicity and as a result, dams in these regions have the lowest seismic failure indices (for PGA less than 0.1 g, the seismic load factor is zero, meaning the seismic failure index is also zero).

Seismic Failure Index Methods

The Seismic Failure Index is comprised of two components: the seismic load factor and the seismic response factor. The load factor is based solely on peak ground acceleration on rock, typically taken from published seismic hazard mapping. The method is not designed to account for local site effects, such as amplification or deamplification that results from soils at a particular site. The response factor is based on geometric and material properties, with respect to foundation liquefaction, embankment freeboard, and embankment cracking.

NRCS SFI

The maximum (worst) possible seismic failure index (100 points) is scaled relative to the static (300 points maximum) and hydrologic (300 points maximum) failure indices. Due to the relatively low probability of occurrence of large earthquakes, the seismic failure index is the smallest contributor to the total failure index, which is the sum of the three modes. The total NRCS risk index is the product of the total failure index, PAR, and fatality rate.

Available data for the KDOW portfolio of regulated dams is often quite limited, particularly with respect to site-specific embankment and foundation materials. In almost all cases, foundation materials were assumed based on USDA soil survey maps. Embankment materials were assumed based on the date of construction and a general assumption about changes over time in the state of practice for filter design. It should be noted that concrete dams have unique failure modes that cannot fully be represented by a screening tool designed for earth dams. A separate attempt to rate concrete dams using a more appropriate tool is discussed below.

Modified USBR Method

In addition to applying the NRCS screening tool, KDOW also attempted to apply a modified version of the seismic component of the USBR RBPS tool. The goal was to reevaluate the high seismic dams using a method that accounts for additional seismic load and response criteria, and then to compare the results against those from the NRCS tool. While the USBR seismic component is very similar to the NRCS version, it includes an additional factor for potential embankment liquefaction. The seismic load factor was assessed for two earthquakes; the MCE (using KGS published PGA values, identical to the NRCS method discussed above) and a smaller earthquake that KGS has designated the "Probable Earthquake" (PE) (Wang et al 2012). KGS defines the PE as "the earthquake that could be expected to occur in the next 250 years." The 250-year return period corresponds to a 26 percent probability of exceedance in 75 years. Although the specific return period of the PE is not critical for this application, the event is used to represent a more frequent earthquake that could cause a seismically-induced dam failure.

Seismic load factors for the MCE and PE were scored using identical methods, and then the two factors were added to produce a combined seismic load factor. The result is that dams will have higher load factors if they are located in proximity to source zones that produce significant earthquakes for both the MCE and PE. Based on the risk assessment, dams located in western and northeastern Kentucky scored higher than those in southeastern Kentucky, all other things equal. This is due to the PE for southeastern Kentucky having a seismic load factor of zero (PGA less than 0.1 g), while the PE for western and northeastern Kentucky has a seismic load factor greater than zero.

Seismic Failure Index Results

Computing the seismic failure index required relatively little site-specific information. The input for seismic loading was readily available from published KGS seismic hazard mapping. Freeboard parameters could be calculated based on site-specific information in KDOW files (height of dam, crest elevation, pool elevation). However, in 75 percent of the cases, site-specific information was not available to understand the potential for foundation liquefaction, based solely on soil type or the potential for embankment cracking, based on presence or absence of self-healing filter zones. Soil types were based on county soil survey maps, which cannot account for potentially localized variations in soil type and/or removal/replacement of soils during dam construction. The presence or absence of filter zones was assumed based on when the dam was constructed, in relation to the general state of practice regarding inclusion of self-healing filter zones in embankment dams.

NRCS SFI

The NRCS method was applied to the high seismic dams and results are included in the Table below. The maximum possible seismic failure index is 100, compared to a maximum of 300 for both the static and hydrologic failure indices.

The results ranged from 0 to 30, and were strongly correlated with the PGA, which is the basis for the seismic load factor. Only one dam (KY0288, Lake Washburn, located in Ohio County) scored zero, because the PGA for the MCE was below 0.1g. Five dams scored 30, and were located in counties (Union, Daviess, McCracken, and Henderson) closest to the New Madrid or Wabash Valley seismic zones. Four concrete gravity dams within the high seismic portfolio each scored 2, indicating a low probability of failure. This was due in part to the assumption that they are each founded on rock, thus no foundation liquefaction. This is a reasonable assumption based on available project records and the general geologic setting. With regard to embankment cracking, the concrete dams were scored favorably, assuming that even if the concrete were to crack, it would not erode and widen to allow a catastrophic loss of pool, as could occur for a cracked earth dam without a self-healing filter zone.

Modified USBR Method

The modified USBR method for earth dams (considering both MCE and PE) indicates a maximum possible seismic failure index of 600. The USBR results ranged from 0 to 60, with trends generally mirroring those of the NRCS method. It should be noted that the USBR numerical score cannot be directly compared against scores from the NRCS method. Again, Lake Washburn scored zero because the PGA for the MCE and PE was below 0.1g. One dam scored 60 (KY0402, Priester Dam, located in McCracken County), as it has the highest PGA of any dam in the portfolio. Eleven dams scored 22.5 or greater, and were located in counties (Union, Daviess, McCracken, Henderson, and Crittenden) closest to the New Madrid or Wabash Valley seismic zones, except for two in northeastern Kentucky (Rowan and Greenup Counties. The four concrete gravity dams within the high seismic portfolio each scored 1.5, indicating a low probability of failure. This was due in part to the assumptions that they are each founded on rock (thus no foundation liquefaction) and each could crack without catastrophic loss of the lake upstream of the dam.

Table 2. Seismic Failure Indices for dams in high seismic areas.

KDOW No.	Dam	Dam Type	County	NRCS SFI	Modified USBR SFI (Earth Dam Method)	Modified USBR SFI (Concrete Dam Method)
0001	Des Islet Dam	Earth	Union	30	45	-
0004	N Fork Little River MPS No 4A	Earth	Christian	8	7.5	-
0012	Scenic Lake Dam	Earth	Henderson	30	45	-
0015	Kingfisher Lake Dam	Earth	Daviess	30	30	-
0016	Carpenter Lake Dam	Earth	Daviess	15	15	-
0029	Clements Lake Dam	Earth	Rowan	15	30	-
0037	Smokey Valley Dam	Earth	Carter	8	15	-
0039	Greenbo Lake Dam	Earth	Greenup	15	30	-
0042	Fishpond Lake Dam	Rockfill	Letcher	15	15	-
0044	Beshear Lake	Earth	Caldwell	8	7.5	-
0075	Whitesburg Impoundment Dam	Gravity	Letcher	2	1.5	18
0083	Chenoa Lake Dam	Earth	Bell	8	7.5	-
0113	Elkhorn Lake Dam	Gravity	Letcher	2	1.5	21
0114	Olive Hill Reservoir Dam	Earth	Carter	8	15	-
0118	Pine Mountain State Park Lake Dam	Gravity	Bell	2	1.5	18
0132	Marion City Lake (Old) Dam	Earth	Crittenden	8	15	-
0133	Marion City Dam	Earth	Crittenden	15	30	-
0142	Madisonville Reservoir Dam No 1 (North)	Earth	Hopkins	15	15	-
0143	Madisonville Reservoir Dam No 2	Earth	Hopkins	2	1.5	-
0144	Madisonville Reservoir Dam No 3 (South)	Earth	Hopkins	8	7.5	-

KDOW No.	Dam	Dam Type	County	NRCS SFI	Modified USBR SFI (Earth Dam Method)	Modified USBR SFI (Concrete Dam Method)
0145	Lake Peewee Dam	Earth	Hopkins	8	7.5	-
0148	Loch Mary Reservoir Dam	Earth	Hopkins	15	15	-
0156	Mortons Gap Reservoir Dam	Earth	Hopkins	8	7.5	-
0157	Nortonville Lake Dam	Earth	Hopkins	8	7.5	-
0171	Skinframe Creek Impoundment	Earth	Lyon	2	1.5	-
0173	Pennyrile Lake	Gravity	Christian	2	1.5	18
0176	NF Little River MPS 4B	Earth	Christian	8	7.5	-
0185	University Of Kentucky Youth Camp Dam	Earth	Hopkins	8	7.5	-
0189	Crofton Lake Dam	Earth	Christian	8	7.5	-
0192	Providence City Dam (Old)	Earth	Webster	15	15	-
0193	Providence City Dam (New)	Earth	Webster	15	15	-
0196	N Fork Little River MPS No 3	Earth	Christian	8	7.5	-
0212	N Fork Little River MPS No 5	Earth	Christian	8	7.5	-
0275	Cannon Creek Dam	Earth & Rockfill	Bell	15	15	-
0287	Dixon City Lake Dam	Earth	Webster	8	7.5	-
0288	Lake Washburn	Earth	Ohio	0	0	-
0324	Morganfield City Lake Dam	Earth	Union	30	45	-
0402	Priester Lake Dam	Earth	McCracken	30	60	-
0578	Kingdom Come State Park Dam	Earth	Harlan	15	15	-
0657	Boots Randolph Golf Course Dam	Earth	Trigg	8	7.5	-
0836	Audubon State Park Wildlife Lake Dam	Earth	Henderson	15	22.5	-

KDOW No.	Dam	Dam Type	County	NRCS SFI	Modified USBR SFI (Earth Dam Method)	Modified USBR SFI (Concrete Dam Method)
1132	Daviess County Landfill Sed Pond	Earth	Daviess	3	3	-
1147	Sloughs Wildlife Area (Cavanaugh Tract)	Earth	Henderson	15	22.5	-
1164	Moist Soil Unit	Earth	Henderson	15	22.5	-

While the seismic failure index is driven by proximity to seismic source zones, the risk is also a function of the potential loss of life and economic consequences. Further, risk should not be focused on a single failure mode (e.g., seismic) but should consider all viable failure modes and their relative probabilities.

Results of Dam Risk Assessment

The dam risk assessment was conducted using nationally accepted methodology and using data that is much more granular than other state or regionally based mitigation plans. This comprehensive assessment will allow the Commonwealth to make informed decisions based on sound information. Additionally, the risk assessment serves as an initial baseline for future state and local dam-related risk assessments. The combination of economic and social factors used in this risk assessment is extremely valuable when considering potential mitigation options with limited funding.

Mitigation Action Identification

One of the primary goals outlined in the State Hazard Mitigation Plan is to identify actions to mitigate current risks and avoid future risks associated with dams. The risk assessment allowed for the rankings based on failure risks, population at risk, and future risks due to potential "hazard creep" to identify mitigation options that include the following:

- Dam Improvements (capital improvements)
- Easements to disallow the introduction of future risk ("hazard creep")
- Structure Buy Outs and Relocations
- Flood Protection (berm/floodwall and/or floodproofing)
- Conveyance and Storage
- Warning Systems and Emergency Action Plans (EAPs)

The mitigation screening incorporated the population at risk calculations, HAZUS inventory, and observations from DOW's dam inventory database. The data were used to identify densely populated residential areas, high density structures (such as hospitals, schools, hotels, etc.), mobile homes, campgrounds, sole access roads, commercial/industrial districts, and critical facilities.

Each category was populated with either a "yes" or "no" to provide a characterization of the inundation area, and based on the assumptions shown in Table 3.

Table 3. Sources of characterization.

Characteristic of Inundation Area	Source
Residential Area (> 15 homes)[1]	PAR Calculation – Number of homes
High Density Structure	HAZUS and Field Observations – identification of school, hospital, or hotel
Mobile Homes/ Campgrounds	PAR Calculation and Field Observations – Number of campgrounds
Sole Access Roads[2]	Map review – location of sole access related to a critical facility
Commercial/ Industrial Districts	PAR Calculation – number of businesses
Critical Facility	HAZUS and Field Observations – identification of emergency facility, treatment plant, school

*PAR – Population at Risk
[1]It was assumed that if an area had more than 15 homes, there would likely be a high Benefit/Cost if improvements were made upstream as opposed to through buy outs.
[2]Sole access roads were identified as it related to critical facilities. It was assumed that residences with an inundated sole access road would be included in an evacuation in the case of an emergency.

The screening provides an assessment of which mitigation options may provide benefit for the downstream risks. Table 4 below describes the assumptions for each classification based on the mitigation option, as well as examples of what each level represents for the option. Level 1 indicates that there is high potential benefit or reducing risks for a mitigation option. Level 2 indicates that the mitigation option will likely provide a risk reduction; however, it may not be the priority mitigation measure. Level 3 indicates that the preliminary screening shows that the mitigation option will likely not provide desired benefits to the area inundated by the dam failure.

Table 4. Level of potential for mitigation options.

Mitigation Option	Level 1	Level 2	Level 3
<u>Dam Improvements</u> – Improvements to the dam to meet H&H requirements.	Does not meet the H&H design criteria. Inundation area is densely populated.	Does not meet the H&H design criteria. Inundation area is not densely populated.	Dam meets the H&H design criteria.

Mitigation Option	Level 1	Level 2	Level 3
Easements – Protection of undeveloped areas to reduce future risks.	The inundation area is not considered densely populated.	The inundation area is considered densely populated, however, pockets of open space were observed during a map review.	The inundation area is considered densely populated.
Buy Outs/ Relocations – Removing the risks from the inundation area in less densely populated areas.	The inundation area is less densely populated.	The inundation area is considered densely populated.	No residential structures were located within the inundation area.
Flood Protection Berm/ Floodproofing – Providing physical protection along critical infrastructure, commercial, or industrial property to reduce damage.	Treatment plant located in or adjacent to inundation area that may benefit from a berm.	Nonresidential structure is located in inundation area that may benefit from floodproofing.	
Conveyance/ Storage – Modification of hydraulic structures could attenuate or convey flow to modify inundation area.		Road crossings are located along downstream reach and map review shows varying stages of development.	Treatment plants or Commercial/ Industrial districts were not identified within the inundation area.
Warning System/ Advanced EAP – Provide more advanced warning or evacuation system for densely populated areas.	Inundation area includes densely populated residential area, high density structures.		Inundation area does not represent a densely populated residential development or structures.

It should be noted that some items in Table 4 do not have three levels of benefits. For example, buy outs/ relocations will remove risks from the inundation area and will always provide a benefit. However, in heavily populated areas, it may be more economical to upgrade a dam as opposed to buying out numerous structures.

The reviewed mitigation options are not necessarily independent of one another. It was assumed that mitigation options may work in conjunction with one another. For example, Clements Lake Dam was identified as benefiting from dam improvements, however, due to the population downstream, a warning system could benefit the community and a berm around the water treatment plant in Morehead, KY may provide the desired protection to the critical facility.

Risk MAP-related watershed based maps may provide additional insight to the risks associated with dams. These products provide a generalized depth for the inundation zone of the dam, arrival times of the flood wave after a dam failure, and specific call-outs where potential mitigation actions have been identified. These data are extremely useful in communicating the areas of particular risk to government officials and the general public.

The intent of the mitigation analysis was to provide direction on options best suited for the characteristics of dams with a goal to serve as a communication tool for communities to understand dam-related risks and options for reducing those risks. These rankings were based on the adjusted total failure index of the dam and probability of loss of life; the dams were assessed based on a combination of the two rankings. Excerpts of the mitigation screening are located in Appendix D.6.

Floodplain management is an important and effective tool that may be used as a mitigation alternative to preclude dam-related hazard creep (e.g. reclassification of lower risk dams to higher risk dams). A floodplain management plan that includes the following components should be considered for at-risk areas associated with dams:

1) Potential measures, practices, and policies to reduce the loss of life, damage to property, public expenditures, and other impacts (such as water supply, economic ramifications, etc.) in areas proximal to dams;
2) Plans for evacuation and flood fighting should a dam failure occur; and
3) Public education and awareness of dam-related risks.

These components are discussed in greater detail in the Emergency Planning section of this document. Additionally, should communities choose to develop floodplain management plans in areas impacted by dams, flood insurance premium reductions via the Community Rating System (CRS) and the overall resilience of communities may be enhanced.

Given the magnitude of the analyses performed and their applicability to better characterize and understand the risks of dam failures, this risk assessment provides a suite of products and results that may be shared with all levels of government, dam owners and the general public. Additionally, these products may be used to collaborate with dam owners and local governments to achieve cost effective mitigation options, promote the purchase of flood insurance, and increase the awareness of the risks inherent to dam-related risks.

References and Resources

Federal Emergency Management Agency. Emergency Action Planning for State Regulated High-Hazard Potential Dams: Findings, Recommendations, and Strategies, FEMA 608, March 2, 2012, 40 pp.

Federal Emergency Management Agency. *Federal Guidelines for Dam Safety: Emergency Action Planning for Dam Owners,* FEMA 64, 1998, 36 pp.

Federal Emergency Management Agency. *Federal Guidelines for Dam Safety: Hazard Potential Classification Systems for Dams,* FEMA 333, 1998, 90 pp.

Fread, Danny L. *DAMBRK – Revision 4, National Weather Service, 1998* (manual only), or Fread, Danny L. and Lewis, J.M. *FLDWAV, National Weather Service,* 1996 (manual only).

Graham, Wayne. *A Procedure for Estimating Loss of Life Due to Dam Failure*, 1997 ASDSO Annual Conference, pp. 629-640.

U.S. Bureau of Reclamation. *Safety Evaluation of Existing Dams (SEED Manual)*, 1992. 178 pp.

U.S. Bureau of Reclamation. *Training Aids for Dam Safety,* Denver, 1988.

Wang, Z. (2010). "Ground Motion for the Maximum Credible Earthquake in Kentucky." Report of Investigations 22, Series XII, prepared for the Kentucky Geological Survey.

Wang, Z., Harik, I. E., Woolery, E. W., Shi, B., and Peiris A. (2012). "Seismic Hazard Maps and Time Histories for the Commonwealth of Kentucky." Report No. KTC-07-07/SPR246-02-6F, prepared for the Kentucky Transportation Center.