Risk Exposure and Residual Risk Related to Dams

FEMA

Technical Advisory 2 – North and South Carolina DR-4285-NC and DR-4286-SC

Purpose and Intended Audience

The purpose of this Technical Advisory is to help all stakeholders better understand risk exposure, residual risk, and the potential contributing factors to risk related to living and working near a dam or within a dam inundation zone. The information is intended to help stakeholders improve emergency planning and community resilience based on informed decision making. The intended audience includes federal, state and local officials; tribal leaders; county and city planners and emergency managers; dam owners and operators; building and property owners near or potentially affected by a dam failure; and other interested stakeholders and the general public.

Introduction

Many people who live near a dam or who might be affected by a potential dam failure do not fully understand the risks that may be present. There are risks to the dam itself and there is resulting risk exposure to the nearby population and infrastructure due to proximity to the dam, including residual risk that remains even after risk reduction measures are enacted. This Technical Advisory describes these risks and the potential contributing factors to those risks. References and resources are provided for those interested in more information and additional details.

Understanding Risk Exposure and Residual Risk

A risk analysis is used to identify the risks associated with a dam. A risk analysis identifies the failure modes (USBR and USACE, 2015, p I-3-1) that are most likely to occur at the dam based on the site-specific characteristics. A risk analysis is used to determine risk exposure related to a potential dam failure and also used to make risk management decisions (refer also to Technical Advisory 1, *Risk Reduction Measures for Dams*). Risk analyses help dam owners prioritize mitigation and preparedness activities when not all risks can be removed. The results can be used by stakeholders to prepare a risk management plan. Risk management should include consideration of risk exposure, including residual risk.

Risk Exposure

There are many different sources of risk associated with dams. Risk exposure includes exposure to all the different types of dam-related risks, including those to population, infrastructure, or other assets and resources. The risk can be to the dam itself, it can be risk related to damage that occurs indirectly as a result of a dam failure, and it can be residual risk (see below).

Terminology

Risk Exposure: The population, infrastructure, and other assets and valued resources that would be adversely impacted by a dam failure. (USACE, 2014).

Residual Risk

In a general sense, residual risk the risk that remains after all mitigation actions and risk reductions actions have been completed. With respect to dams, FEMA defines residual risk as "risk remaining at any time" (FEMA, 2015, p A-2). It is

the risk that remains after decisions related to a specific dam safety issue are made and prudent actions have been taken to address the risk. It is the remote risk associated with a condition that was judged to not be a credible dam safety issue.

Other agencies involved with dam oversight defined residual risk as:

- The risk in the pool area and downstream of the dam at any point in time (i.e., prior to, during, or after implementation of risk reduction measures) is referred to as "residual risk," i.e., the risk that remains. Residual risk associated with a dam consists of two components: incremental risk and non-breach risk (USACE, 2014, p 2-7).
- Residual risk is the remaining level of risk at any time before, during, and after a program of risk mitigation measures has been taken (ICOLD, 2005).

Dam Hazard Potential Classification

One indication of potential risk exposure and residual risk is the hazard potential classification of the dam. Dams are classified by various regulating agencies according to potential consequences should the dam fail. Higher hazard classifications often trigger more stringent requirements, such as increased spillway capacity and/or reservoir storage volume, and more frequent inspections and Emergency Action Plan (EAP) updates. Hazard potential classification systems are numerous and vary within and between state and federal agencies.

Dam Hazard Potential Classification Systems

Federal Hazard Potential Classification: Published in FEMA P-333, *Federal Guidelines for Dam Safety Hazard Potential Classification System for Dams* (2004).

North Carolina Hazard Classification: Promulgated in the North Carolina Administrative Code, Title 15A - Environmental Quality, subchapter 2K – Dam Safety, as amended.

South Carolina Hazard Classification: Published in the Dams and Reservoirs Safety Act Regulations 72-1 thru 72-9, as amended.

Factors That May Contribute to Risk

This advisory briefly discusses many potential contributing factors to risk exposure and residual risk, including hazard creep, non-breach dam events, flawed design and construction, overdue maintenance and repair, earthquakes, uncertainties in forecasting models, extreme weather, and upstream dam events. It is important to note these are some of the contributing factors to risk, but certainly not all of them.

Hazard Creep

Hazard creep, also referred to as risk creep, is caused by changes in the watershed that may result in changes to a dam's hazard potential classification. New development constructed in the dam breach inundation zone downstream of a dam, or upstream development or deforestation that increases runoff from storms, can result in higher potential consequences if the dam were to release stored water in an uncontrolled manner or fail.

Hazard Creep Animation

To view the Association of State Dam Safety Officials' animation of hazard creep, please visit: https://www.youtube.com/watch?v=5CcVSVhAYvA.

Effect of hazard creep on dam classification. An increase in potential consequences may require a dam to be reclassified into a higher hazard category, even if there is no change in the condition of the dam. For example, a dam that was designed, constructed, and operated as having low- or significant-hazard potential can be reclassified as having a significant- or high-hazard potential due to downstream development in the inundation zone after the dam was already constructed. Once a dam is reclassified, it may not meet the design, inspection, and maintenance requirements for its new hazard potential classification for that state. If new regulatory requirements are triggered for that dam, its owner would need to bring the dam into compliance.

On the other hand, hazard creep does not necessarily result in a change in the dam's hazard potential classification. For example, a large increase in the Population at Risk (PAR) due to downstream development can result in the potential for much greater consequences without resulting in a change to the dam's classification. This can occur, for example, in

situations where the original presence of a single house close to the dam inundation area resulted in a dam being classified as a high-hazard dam (because of one PAR); subsequent new development in the inundation area of such a dam may not change its hazard classification, even if the post-development PAR escalated to 1,000,000 (thereby increasing the consequences should a dam failure occur).

Best Practices for Managing Hazard Creep

Monitoring hazard creep. It is a best practice to periodically re-evaluate the consequences of dam failure and the dam's hazard classification. This effort involves many individuals, including the dam owner, state and local emergency management professionals, state dam safety officials, local government officials, planning and zoning officials, and other stakeholders, as necessary. As a standard operating procedure, dam owners should review the EAP and inundation maps for each dam annually and update as needed. In addition, dam owners should coordinate with state and local emergency managers on any updates to inundation maps, Emergency Operations Plans (EOPs), evacuation plans, and any other emergency plans as necessary to include new homes or other occupied structures within the inundation area. Local government officials should complete hazard creep assessments and provide zoning or planning recommendations to minimize damage through prudent development. The state dam safety regulator should complete hazard creep analyses for dams and reclassify them as needed. Property owners and other stakeholders should be kept informed about a dam with the potential to impact their property due to spillway release, flood control storage release, or catastrophic failure and any changes of its hazard potential classification in order to make informed decisions. Design, inspection, and maintenance requirements should also be reviewed and updated as necessary.

Mitigating hazard creep. Sensible land use planning can help reduce or eliminate hazard creep. Zoning regulations, building codes, and floodplain management ordinances can be adapted to guide development away from inundation areas, elevate structures, wet or dry floodproof them, or implement other risk reduction measures for buildings and infrastructure. Relocating potential at-risk development away from inundation areas or developing property prudently, such as providing a park for public use, can reduce the risk.

Non-Breach Dam Events

A non-breach dam event is an event that will not, by itself, lead to a breach of the dam, but that requires investigation and notification of internal and/or external personnel. Non-breach events can still lead to flooding of upstream and downstream areas. Non-breach risks are one of the components of residual risk. For more information, see *Engineering and Design, Safety of Dams, Policy and Procedures* (USACE, 2014).

Upstream flooding. Improper operation, malfunction of a gate, flood events that exceed the design event, or other conditions can cause a higher than normal reservoir elevation and lead to upstream flooding, as illustrated in Figure 1. If an easement is not in place to prevent construction in the high pool area upstream of the dam, buildings may be flooded due to an increase in reservoir pool elevation. Appropriate land use planning can be used to reduce construction in the high pool area upstream of the dam if an easement is not in place.

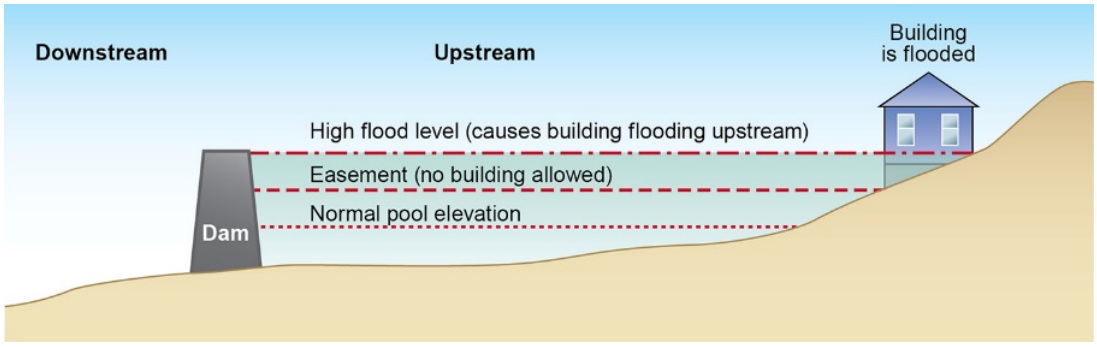

Figure 1: Upstream flooding increases pool elevations beyond easements

Large reservoir releases. Short, intense storms can create conditions that require the release of reservoir storage to reduce the risk of overtopping or catastrophic dam failure. These large releases are intended to prevent a breach of the

dam but may result in downstream flooding conditions. It is important for the dam owner to communicate about pending large releases with the local emergency managers or others, as indicated in the EAP for the dam, or as coordinated in advance with the state and local governments. It is also important to note that large releases can often impact multiple jurisdictions. Having release inundation maps (see text box) will help state and local agencies develop or integrate release inundation information into their EOPs, evacuation maps, land development plans, and zoning plans and develop consequence assessments or other efforts. Having access to the maps and information about pending large releases also helps make communities more resilient by reducing risk to the PAR and nearby structures.

Best Practice

Often, regulations require inundation maps be provided only for a dam failure, not for a large reservoir release; however, it is a best practice for owners of dams with the potential for large reservoir releases to coordinate with the appropriate state and/or local government agencies and provide them with inundation maps or information about potential large water release outflows.

Controlled/partial breaches. The dam owner, in coordination with an engineer, local emergency managers, and others, may implement a controlled or partial breach of the dam to reduce the risk of catastrophic dam failure. A partial or controlled breach could result in a large release of reservoir storage and flood parts of the inundation zone. The dam owner may choose to release a certain amount of water so the dam will remain stable, but these releases can pose risks to those downstream of the dam. Dam owners should provide advance notice or communicate the schedule of controlled and partial breaches to state and/or local emergency managers or others, as indicated in the EAP for the dam.

Dam Design, Construction, and Repair

Design and construction. Risk exposure can be increased by flaws in the original design or construction of a dam. Human error, such as miscalculations or misapplication of dam engineering methods in the design, can result in a higher risk of failure, as can faulty construction.

Earthquake hazard design. Depending on where a dam is located, risk exposure from a dam can increase due to earthquake hazards. For example, parts of South Carolina are located in a high-risk seismic zone. Dams can be designed to resist some amount of seismic movement, but there is still generally increased risk exposure when a dam is located in a high-risk seismic zone. Furthermore, geologists are constantly learning of new faults or revising their understanding of seismic risks and hazards on already existing faults. In either situation, risk exposure can escalate for dam owners and affected stakeholders when new or increased seismic risk data become available. The increased potential future loads imposed on the dam if a seismic event were to occur might result in overloading the existing dam's design or construction or fall below designed factors of safety. To view the U.S. Geological Survey United States National Seismic Hazard Maps, see https://earthquake.usgs.gov/hazards. For guidelines on the basic framework for the earthquake design and evaluation of dams, see FEMA P-65, *Federal Guidelines for Dam Safety: Earthquake Analyses and Design of Dams* (2005). FEMA P-65 also discusses liquefaction potential of foundation and embankment soils and other stability issues related to earthquake hazards.

Lack of needed repair. Risk exposure can increase if dam repairs have not been adequately carried out due to lack of funding or for other reasons. If the element is critical either to the function of the dam or for minimizing risk to it, such as gates, valves, bottom drains, or conduits, the lack of repairs can result in a drastic increase of the risk exposure.

Lack of rehabilitation. Although it may be prudent for a dam owner to rehabilitate a dam, regulations might not specifically require it. In these situations, risk exposure can increase if the dam is not rehabilitated due to lack of funding or for other reasons. As in the case of the seismic example provided above, if a hazard increases and an analysis to determine how to address the resulting changes in the risk profile of the dam is not conducted promptly or the required remedy is not implemented, the dam will remain vulnerable to a hazard event until it is rehabilitated or interim risk reduction measures are employed, such as restricting the reservoir elevation.

Older design or no design for original construction. Older dams may not have been designed to a standard, or may have been designed to federal, state, or other specific design standards that are no longer the current dam engineering state of practice. For example, an older dam may have an unknown inflow design flood that does not meet current requirements for a spillway design (existing regulations may specify the 100-year flood all the way up to the Probable Maximum Flood, depending on hazard and size), but is not required by regulations to do so. Such a scenario would increase the risk of that dam and affected stakeholders by increasing the chances of the dam being overtopped.

State regulatory requirements. State regulatory requirements can significantly differ from each other and from guidelines and requirements used by federal agencies for their own dam design. State-determined design parameters such as Probable Maximum Precipitation parameters or flood recurrence intervals have associated differences in risk exposure. Requirements that are less stringent will generally result in higher risk exposure for stakeholders.

Uncertainties in Inundation and Forecasting Models

The accuracy of topographic maps, new development, or improper modeling of bridges or other structures can drastically affect the accuracy of inundation models. Uncertainties in inundation and forecasting models can lead to increased risk exposure for dam stakeholders. Flooding that is greater than a dam's design conditions can and does occur. These conditions can cause flows beyond the designed spillway capacity. If forecasts do not provide adequate time to react, or models significantly underestimate precipitation, area impacted, intensity, duration, antecedent soil conditions, or other parameters, the dam owner may not be able to draw down reservoir levels sufficiently to handle an incoming storm. Multiple consecutive storm events can also lead to conditions that exceed design capacities. Older designs, mentioned above, may not have sufficient spillway capacity, further increasing the risks to the dam and affected stakeholders.

Conditions Beyond the Dam

Flooding conditions resulting from obstructions unrelated to the dam can also generate risks. For example, flooding caused by nearby obstructions such as bridges or culverts creating backwater conditions can undermine the dam structure or appurtenances. Excessive floodwater can undercut the downstream slope or decrease outflow capacity.

Best Practice

Dam owners who identify hazard conditions beyond the dam, but who cannot mitigate them, can work with federal, state, and local authorities, as needed, to determine potential options for correcting these problems.

Upstream Dam Events

Events upstream of a given dam may pose risks to that dam. Stakeholders can incur risk as a result of the condition, misoperation, or failure of an upstream dam, or partial or full release of an upstream reservoir.

Dam Operation and Maintenance Issues

Some examples of common operation and maintenance issues include misoperation; inadequate maintenance; broken or blocked gates; debris obstructing trash racks, inlet/outlet works, and spillways; damage to earthen embankments caused by plant and animal penetrations; and many others. For more information about dam operation and maintenance, see FEMA, DR-4241-SC *Dam Maintenance Technical Advisory for Dams in South Carolina*, FEMA P-473 (FEMA, 2005), , and FEMA P-534 (FEMA, 2005),.

References and Resources

References

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Resources

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Laws and Regulations

North Carolina Administrative Code:

http://reports.oah.state.nc.us/ncac/title%2015a%20-%20environmental%20quality/chapter%2002%20-%20environmental%20management/subchapter%20k/subchapter%20k%20rules.pdf.

South Carolina Department of Health and Environmental Control Dams and Safety Act Regulations: http://www.scdhec.gov/Environment/docs/r72-1.pdf .

Website

- Association of State Dam Safety Officials: https://damsafety.org/
- South Carolina Dam Safety: http://www.scdhec.gov/environment/WaterQuality/DamsReservoirs/
- North Carolina Dam Safety: https://deq.nc.gov/about/divisions/energy-mineral-land-resources/energy-mineral-land-permits/dam-safety

Other Technical Advisories in this series:

- Technical Advisory 1: Risk Reduction Measures for Dams
- Technical Advisory 3: Dam Awareness

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