



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 fact sheet describes these risks and the potential contributing factors to those risks.

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. 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. *A comprehensive risk assessment should, at a minimum, assess **both** public safety considerations and potent damage to the dam infrastructure.*

Residual Risk

In a general sense, residual risk is 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.

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.

Factors That May Contribute to Risk

This fact sheet briefly discusses many potential contributing factors to risk exposure and residual risk, including hazard creep, non-breach dam events (e.g., earthquakes), 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.

Effect of Hazard Creep on Dam Classification

An increase in potential consequences may require a dam to be reclassified into a higher hazard potential 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.

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

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.

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.

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.

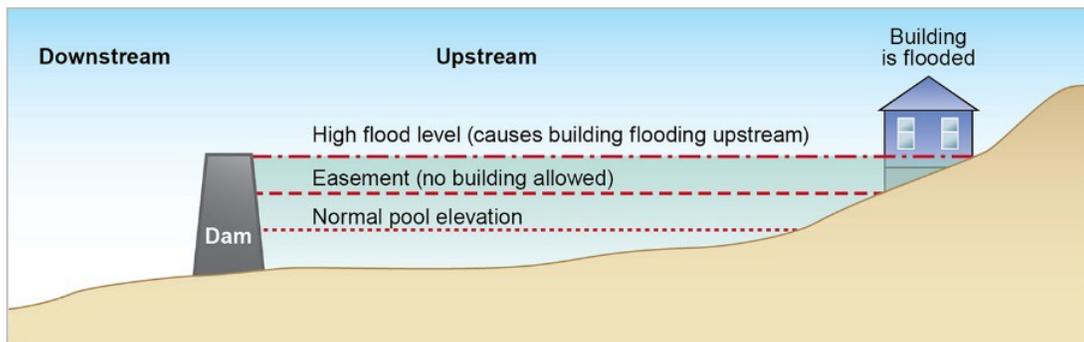


Figure 1: Upstream flooding increases pool elevations beyond easements

Large Reservoir Releases

Short, intense storms can create conditions that require the release of reservoir storage through the principal spillway or the auxiliary spillway 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. Dam owners should map the area inundated by spillway releases and incorporate this information in the EAP. It is important for the dam owner to communicate 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 important to note that large releases can often impact multiple jurisdictions. Sharing inundation maps with emergency management officials across geographic and jurisdictional boundaries may help state and local agencies develop or integrate release inundation information into their emergency operations plan (EOP), 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.

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 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. Dams can be designed to resist some amount of seismic movement, but there is still generally increased risk exposure when a dam is in a high-risk seismic zone. 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 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 of 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 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, mis-operation, 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 mis-operation; 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.