LIVING NEAR DAMS
Extreme Rainfall Events

An informational booklet for policymakers, dam owners, and downstream communities.

This booklet was prepared by the Dam Owner Outreach Committee of the Association of State Dam Safety Officials.

FACT OR FICTION

Common Beliefs About Dams

FICTION	FACT
That dam has been here for years – it's not going anywhere. It can handle any storm.	Many manmade structures including dams, bridges, and buildings were not built to withstand the extreme rainfall events happening today. **Advancing age makes dams more susceptible to failure.** The average age of dams in the U.S. is more than 60 years old. As dams get older, deterioration increases, and construction costs rise. Some common problems of older dams are: ■ Deteriorating metal pipes and structural components—after 50 years, metal rusts and loses its structural integrity. ■ Subdivisions and businesses built upstream—roofs and paved streets and sidewalks increase the volume of runoff to the dam. Extreme rainfall events are by nature rare, and it's likely the dam hasn't seen the worst possible storm yet.
Dams are like roads. The government takes care of them.	**Most dams are privately owned. Dam owners are responsible for maintenance and upgrades.** Private dam owners are responsible for more than 65% of the nation's dams. Incidents and emergencies at the dam are handled by the dam owner and local emergency management officials.
The 100-year flood is the biggest storm that can happen, and it can only happen once every 100 years.	A 100-year flood has a 1% chance of occurring each year or a 26% chance of occurring during the life of a 30-year period. There are storms that occur in the U.S. every year that are many times larger than the 100-year storms.
Probable Maximum Precipitation (PMP) is an engineering calculation that is not real. It can never happen.	The PMP is possible and extreme rainfall events happen around the country almost every year. Extreme rainfall events have many labels. Storms now have names and probabilities: 100-year, Design Storm, Non-Exceedance Event, PMP, Worst Case Event.
There are only a few dams in my state.	There are more than 90,000 dams in the U.S. Most states are home to hundreds – or thousands – of dams of regulatory criteria. Most dams don't look like the Hoover Dam. They may be smaller and look less imposing. However, they also pose a risk to the public if they fail.
It never rains that much here.	Extreme rainfall events do occur. Storms happen every year, if not here then somewhere. There are normal storms and extreme storms such as 100-year storms and PMP events.

ASK YOURSELF THIS:

Can extreme storms happen?

The risks associated with dam failure and flooding in the U.S. continue to increase dramatically as a direct result of the occurrence of extreme rainfall events, local land development, and a failure to adequately maintain or upgrade existing infrastructure.

Extreme rainfall events happen almost every day somewhere—maybe not in your backyard or above a dam in your community, but around the country and the world. Sometimes we see them in the news on TV, and sometimes these extreme rainfall events get names like Katrina, Irene, Helene, and Sandy or are referenced by location, like Boulder, Colorado (2013), or Pensacola, Florida (2014), or Central, Texas (2025).

Climate experts put all the historical extreme rainfall events into a database to determine how often they happen, how big they can get, and what the threat is for individual communities. Experts consider hundreds of years of data at thousands of locations and have a broad understanding of the climate and the potential for extreme rainfall events. They know that extreme rainfall happens, may exceed the years of available data, and may be happening more often.

Dam engineers use this climate database to predict the extreme rainfall events they use in dam design. Mother Nature very often surprises us with the unexpected ferocity of her storms. Climate data helps engineers anticipate these surprises by allowing them to estimate the magnitude and frequency of extreme storm events.

This publication will help explain and justify the engineering principles involved with predicting extreme rainfall events and how they are used to design safe, functional, and economical dams. It will connect the concepts of rain, dams, failure, and flooding impacts downstream.

What Should Dam Owners Do?

- **Follow proper industry, state, and federal guidelines.**
- **Have your dam periodically inspected.**
- **Invest in routine maintenance and repair.**
- **Adhere to regulations (no shortcuts or exemptions).**
- **Don't let short-term band-aids become long-term fixes.**
- **Evaluate the consequences of significant flow from the dam or dam failures and have a plan for emergencies.**

What Should Policymakers Do?

- **Promote proactive dam safety programs that balance sound science and economics with risk reduction and public safety.**
- **Recognize that adequately funding dam safety programs is the most cost-effective hazard mitigation available for private and public dams.**
- **Recognize that public welfare and safety supersede individual hardships and ability to afford the proper level of protection for dam safety.**
- **Provide funding mechanisms. Storage of water is a personal responsibility but often requires public assistance due to the benefits realized by all.**

What Should Downstream Communities Do?

- **Know Your Neighborhood: Who is at risk?**
- **Ask: What level of flow could the dam release without failure?**
- **Ask: Is the dam upstream safe?**
- **Ask: Has it been inspected?**
- **Communicate: Inform the public of the dam and its purpose, benefit, operations, and risks.**
- **Know who your emergency manager is.**
- **Work cooperatively to minimize the risk to the public.**

1.

WHY SHOULD I CARE ABOUT EXTREME RAINFALL EVENTS?

2.

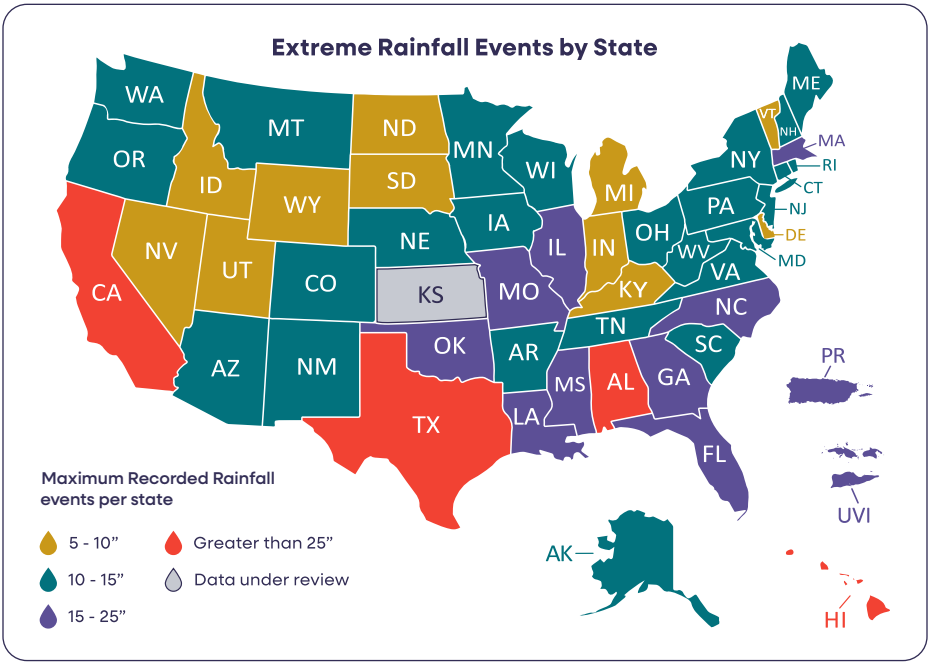
WHAT ARE THE RISKS INVOLVED?

3.

COULD A DAM FAIL AS A RESULT OF EXTREME RAINFALL EVENTS?

4.

HOW CAN ONE REDUCE THE CHANCES OF A DAM FAILING FROM AN EXTREME RAINFALL EVENT?



1. WHY SHOULD I CARE ABOUT EXTREME RAINFALL EVENTS?

Extreme rainfall events can severely damage dams and/or cause them to fail completely.

> **Even privately owned dams pose a public safety risk. Dam failures do not respect property, community, or state boundaries.**

There are more than 90,000 dams in the United States with various shapes, sizes, ages and uses. From Hoover and Grand Coulee Dams in the Western United States to the small New England stone and masonry dams, they all have potential to cause damage and loss of life. For that reason, it is imperative that they are properly designed and maintained.

Modern dams are built to withstand earthquakes and floods, seepage and slope instabilities. Many older dams were not designed to modern standards and are showing signs of deterioration. Earthquake and flood loading may exceed that for which the dam was designed.

Many need maintenance, upgrading, and repair. Dam engineering and hydrological science have improved over the past 50 years as has the understanding of the risk and liabilities associated with the storage

of water. Much of this science is intuitive, understandable, and accepted by dam owners. Some of it is not and is more mysterious, such as the size of potential extreme rainfall events and the resulting flooding that follows.

Often the combined effect of a series of storms repeatedly moving over the same area, dumping heavy rains over several days, can cause rainfall totals similar to a single extreme rainfall. Meteorologists refer to this as "storm training."

Critical infrastructure, such as dams, bridges, or nuclear power plants which pose a risk to human life are designed for extreme events because of the catastrophic impacts of a failure of the structure.

HAZARD POTENTIAL

The *Federal Guidelines for Dam Safety* designates a Hazard Potential Classification System for dams. This classification system identifies three qualitative hazard potential classes of dams. Hazard potential classification of a dam is determined by the impact a failure would have on the population and development located downstream. The size of the extreme rainfall event in an appropriate design typically increases as the impacts of failure increase.

The hazard classification is not related to the dam's size or condition. These hazard potential classifications are shown below.

HAZARD POTENTIAL CLASSIFICATIONS

1. HIGH-HAZARD POTENTIAL	Dams where failure or misoperation will cause probable loss of human life.
2. SIGNIFICANT-HAZARD POTENTIAL	Dams for which failure or misoperation results in no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or can impact other concerns.
3. LOW-HAZARD POTENTIAL	Dams for which failure or misoperation result in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the dam owner's property.

New development downstream of a dam in areas that would be impacted by failure may increase the hazard classification and owner responsibility due to the risk from a dam failure caused by extreme rainfall. This is known as hazard creep.

**Some states' regulatory definitions may vary slightly*

LEGAL LIABILITY

Dam owners are responsible for the upkeep of a dam and are liable, both legally and ethically, for all impacts that occur if the dam is not maintained, is improperly operated, or fails. Legal precedent shows that dam owners have been held liable for damages in past cases.

Although an extreme rainfall event may not have occurred at a given dam location, these events do occur, are quantifiable, and their likeliness is predictable. They are the basis of professional design practices for critical dam infrastructure where human lives are at risk. Extreme rainfall events are not random, unpredictable acts of God that surprise designers and owners with their ferocity.

The impoundment of water is a hazardous undertaking. Those who benefit from its storage are also responsible for its containment. Owners must diligently guard against the catastrophic release of this stored water. To do anything less, knowing the potential of extreme rainfall events and the dire impacts of failure, would be ethically irresponsible at best, and grossly negligent at worst. Ignorance is no excuse.

Elevators and major bridges are designed for a capacity and weight that should never be exceeded. We don't ever want that elevator or bridge to fail and we accept that design requirement. Dams are no different. Just as elevator cables and bridge structural members must support extreme weight, dams must safely withstand extreme rainfall events that, while difficult to imagine, do occur.

Failures are uncommon, but when they occur, the consequences can be devastating.

KEY LEGAL CONCEPTS

Negligence

A failure to use reasonable care, a careless mistake, or oversight causing harm.

Gross Negligence

A reckless departure from the standard of care that a reasonable person would use, demonstrating a conscious indifference to the safety or rights of others.

Reasonable Care

The degree of caution and attention to possible dangers that an ordinarily prudent and rational person would use in similar circumstances.

This **standard of duty** expected of a dam owner is one where the dam owner is to act as a reasonable person would act understanding the dangers/ threats associated with owning a dam and the impoundment of water. It is proportional to the downstream hazards involved – the potential consequences should the dam fail.

In generalized legal terms, negligence could be assigned to the dam owner for violation of a **'duty to act as a reasonable and prudent person'** would act.

To avoid negligence, a dam owner must:

1) **Determine whether the dam is safe and does not present a danger to downstream persons and property.**

2) **Eliminate unsafe conditions.**

ASK YOURSELF THIS:

- **Can an extreme rainfall event cause a dam failure?**
- **What are the consequences of a dam failure, and who is responsible?**
- **What steps can a local community and policymakers take to reduce the risks to life and property associated with extreme rainfall events and dams?**
- **How would a dam failure affect the local community?**

When policymakers lower regulatory standard, they increase the probability of failure.

2. WHAT ARE THE RISKS INVOLVED?

Most dams in the U.S. have spillway systems capable of safely passing rainfall events, oftentimes significant amounts of rainfall. But, when the rainfall event becomes an extreme event, the dam may experience extensive damage or even failure. The dam may not be capable of safely storing and/or passing these floodwaters.

While many communities follow minimum floodplain management practices, if a dam is above or upstream of a community, there is often still the potential risk for loss of human life. Dam failure floods from extreme rainfall events may also cause unprecedented damage to infrastructure including homes, schools, small businesses, industrial and commercial buildings, recreational areas, agricultural land, farm buildings, military facilities, public utilities, roads, power infrastructure, energy, and communication systems.

Dam failures caused by extreme events may also cause substantial long-term economic damage to downstream communities. Flooded homes and communities become stigmatized. Jobs are frequently lost when businesses, industrial, and commercial facilities are damaged, and operations are relocated. The property tax base can be dramatically reduced when structures and facilities are damaged. The loss of critical impounded water resources, or the flood reduction capability, may also stigmatize the community's continuity as public and private sector confidence in the community suffers.

A large majority of dams were not intended or designed to store enough flood water to provide significant flood protection to areas downstream. Flood waters must be allowed to safely pass through designed spillways or risk the water flowing over the vulnerable embankment, causing catastrophic failure. Therefore, unusual and substantial downstream flooding risks may exist for areas below a dam even if a dam does not fail during extreme rainfall events.

While primary spillways are passing their maximum amounts of flow, a dam's designed operation steps often include planned releases of substantial amounts of flood water through secondary / auxiliary spillway channels or gates. As these auxiliary spillway features are infrequently used and they are, in most instances, situated away from the main body of the dam, these planned release flood flows go to areas and elevations that are likely not subject to local floodplain zoning and development restrictions. These extreme rainfall events are not likely identified on flood insurance maps since insurance requirements are based on minimal flood design standards.

What are the risks from extreme rainfall events?

- **Loss of life and property.**
- **Impacts to community, schools, economy, transportation, infrastructure, etc.**
- **Small businesses and jobs can be affected.**
- **Loss of tax base.**
- **Loss of water resources and/or flood control protection.**
- **Loss of community confidence and continuity.**

CASE STUDIES

KA LOKO DAM

Hawaii – Failed on March 14, 2006. Killed 7 people with considerable property damage.

Privately owned dam on the Island of Kauai, Hawaii. Height 40 ft. Storage 1200-acre ft. The owner filled the auxiliary spillway with soil. There was a lack of maintenance, the crest was uneven, and there were trees on the dam which hid the erosion of the dam that had taken place. The reduced capacity of the spillway caused the dam to overtop and fail during a large rainstorm.

Hawaii AG's Office

BOULDER, COLORADO

Flash floods of 2013.

More than 200 dams were identified as having been exposed to rainfall with return frequencies from the 50-year to over the 1000-year event. Nearly all of those dams withstood the event because they were held to high standards.

Mirror Lake Dam – Photo by Dana Miller

LAKE DELHI DAM

Delaware County, Iowa – July 2010

Lake Delhi Dam experienced what is believed to be a record inflow of water, with 48-hour rainfall totals of up to 13".

The flood overtopped the dam by about 1 foot, and exposed long dormant design deficiencies and unrepaired maintenance problems. A 150-ft-long breach formed when heavy rains swelled the 448-acre lake to 9,920 acre-ft, or 3.2 billion gallons, from its normal 3,790 acre-ft, or 1.2 billion gallons of water.

The breach resulted in extensive damages to property on the reservoir above the dam and in the communities downstream of the dam. More than 1,100 homes flooded, but there was no loss of life.


Iowa Department of Natural Resources


Iowa Department of Natural Resources

SPENCER DAM

Niobrara River, Nebraska – March 2019

The Spencer Dam failed from overtopping during a major ice run on the river. The homeowner could not be located after the event. His home and the other structures were swept downstream by the dam failure. The owner was later declared dead by drowning.


Nebraska Department of Natural Resources


Nebraska Department of Natural Resources

EDENVILLE & SANFORD DAMS

Michigan – May 19, 2020

On May 19, 2020, following several days of rain, failure occurred at both Edenville and Sanford Dams, located in central Michigan (United States), with resulting downstream flooding that caused extensive property and environmental damage. Two other dams failed in a cascading effect. Fortunately, there was no loss of life because a cautious decision was made to evacuate about 10,000 people starting about 18 hours before it was clear that either dam was going to fail. Environmental and property damage totaled more than $120 million. The price tag for rebuilding the four dams is over $215 million. Several lawsuits ensued and homeowners around the drained lakes have seen property values decrease.

EGLE Water Resources Division

Florida, 2013: A radar estimated that approximately 20 inches of rain fell in the area in just 24 hours, with rates in Pensacola at one point on Tuesday night reaching an incredible 6 inches in one hour.

What is an acceptable level of risk?

The public faces many risks on a daily basis. How much risk they are willing to accept seems to vary greatly depending upon the circumstances.

The public is fairly accepting of high levels of risk when it is:

- **Consistent and shared evenly by all,**
- **Not caused by human actions or negligence, and**
- **Controllable, real or imagined – such as everyday driving.**

The public is less accepting of risk when it is caused by human actions or negligence such as:

- **An accident caused by a drunk driver, or**
- **An accident caused by poorly cleared roads.**

The public is even less accepting of risk when preemptive action could have been taken to avoid or reduce the risk such as:

- **When damages resulting from a dam failure could have been prevented by proper operation and maintenance or completion of a rehabilitation project.**


Photo Credit: Iowa Civil Air Patrol

3. COULD A DAM FAIL AS A RESULT OF EXTREME RAINFALL EVENTS?

YES.

Failure of a dam from an extreme rainfall event is similar to the failure of a bridge or an elevator whose weight/capacity is exceeded.

The extreme rainfall event will cause increased stream flows, resulting in the water level in the reservoir rising to heights that the dam may have never previously experienced. And, if the dam and spillway system are not equipped to safely pass an extreme rainfall event, the reservoir level will rise and water will go over the dam itself. This is called "overtopping." Most dams are not designed to withstand *overtopping*. Extreme rainfall events, therefore, have the potential to cause a dam to fail from erosive forces of overtopping flows.

In addition, as reservoir pool levels rise from the increased stream flows of an extreme rainfall event, the structural and hydraulic stresses that the weight of the additional water in the reservoir creates will likely exceed any levels previously experienced in the history of the dam. These stresses may cause potential instability of the dam, leading to its failure.

ASK YOURSELF THIS

- **What are the most likely failure modes?**
- **What else can fail a dam?**
- **How much damage would be done?**
- **Could there be loss of life?**

Overtopping

Earthfill dams and many concrete dams are not typically designed to withstand the erosive forces of overtopping flows. As an extreme rainfall event exceeds the capacity of a dam's spillways, water begins to flow across the top and then down the downstream slope of the earthen embankment dam or cascades down the face of a concrete dam. As the flow continues to the downstream toe, velocities become so great that erosion begins to cut away the earthen embankment dam or erodes the foundation material of the concrete dam. This erosive process progressively works its way in an upstream direction through the earthen embankment dam or under the concrete dam and can lead to a gradual partial failure of the dam or, more catastrophically, to a sudden complete breaching or collapse of the dam with the release of the entire reservoir to impact downstream inhabited areas.

Phreatic Surface Within Earth Embankments

The phreatic surface is the line between relatively dry soils and saturated soils in the dam.

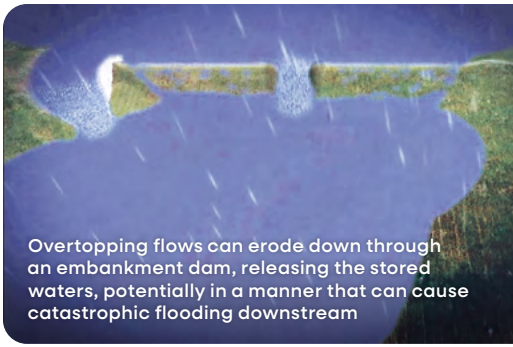
The reservoir upstream of an earthfill dam seeps through the embankment materials in a downstream direction on a continuous basis.

The rate of water movement through the earthfill dam is dependent on the properties of the embankment soils and the compaction effort that was utilized when the dam was built. A well compacted earthfill dam built with proper soils is relatively resistant to the flow of water.

- **Extreme rainfall events can cause overtopping.**
- **Overtopping of earthen dams can often cause them to fail catastrophically and completely unless they are designed to overtop.**
- **Failure by overtopping is one of the most common forms of dam failure.**

Overtopping can fail an earthen dam

Complete loss of reservoir and catastrophic failure at a dam in New Jersey



Overtopping flows can erode down through an embankment dam, releasing the stored waters, potentially in a manner that can cause catastrophic flooding downstream

Slope Failure

Slope instability can be caused by extreme rainfall events. During the time of elevated reservoir pool levels caused by runoff from extreme rainfall events, this phreatic surface will become elevated, possibly to levels never before experienced by the dam. If this phreatic surface begins to approach the surface of the downstream slope, the dam may experience a structural slope failure, which could, under the right conditions, cause a total catastrophic failure of the dam and release of the entire reservoir of stored water.

General Seepage

All dams leak to some extent. This leakage, commonly referred to as seepage in the engineering community, may or may not be evident to the casual observer on a day-to-day basis. Seepage may develop through the soil particles of an earthfill dam, may travel along the outside perimeter of outlet pipes passing through earthfill dams, or may travel through the naturally occurring materials of the foundation under any dam.

Seepage can be evident on the downstream slope or near the downstream toe of earthfill dams. In some dams that were possibly built from less than ideal soils, not compacted sufficiently, built with overly steep downstream slopes or any combination of these factors, the phreatic surface may intercept the downstream slope of the dam. When this happens, seepage will be evident on the downstream slope or near the toe of the dam and this can become so concentrated at certain locations that an uncontrolled seepage path is created directly from the reservoir to the downstream toe.

Piping Failure

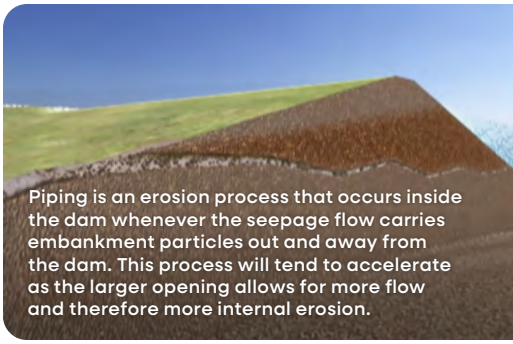
Piping failures can be caused by extreme rainfall events. Again, during the time of elevated reservoir pool levels caused by runoff from extreme rainfall events, the phreatic surface will become elevated within the embankment, possibly to levels never before experienced by a dam. The added pressure that the elevated reservoir level creates on an existing seepage path may become so strong that soil particles begin to be displaced out of the dam embankment in an accelerating fashion, eventually developing into a seepage pathway through the soil, progressing from the downstream toe in an upstream direction toward the reservoir.

Eventually, water from the reservoir flowing along this path through the dam erodes what is known as an internal erosion failure of the dam, releasing the entire reservoir of stored water.

Seepage Along or Around Pipes Within Embankment Dams

Outlet pipes through earthfill dams provide a potential seepage path of water through earthfill dams. It is difficult to adequately compact earthfill around the entire perimeter of pipes through the dam. Additional pipe within the earthfill may develop stresses allowing cracking of the earthfill. Depending upon the age of the dam and the design of the pipe penetration, this may be an issue. Modern design includes construction details that provide a continuous concrete footing under the entire length of the pipe. In addition, depending upon the age of a dam, it may not have provisions for collection of seepage flowing along or in the vicinity of the pipe and for the safe discharge of this seepage downstream without removing soil particles of the dam.

Animations showing how piping and overtopping cause complete breach and failure of the dam are available at ASDSO's YouTube™ channel.



Piping is an erosion process that occurs inside the dam whenever the seepage flow carries embankment particles out and away from the dam. This process will tend to accelerate as the larger opening allows for more flow and therefore more internal erosion.

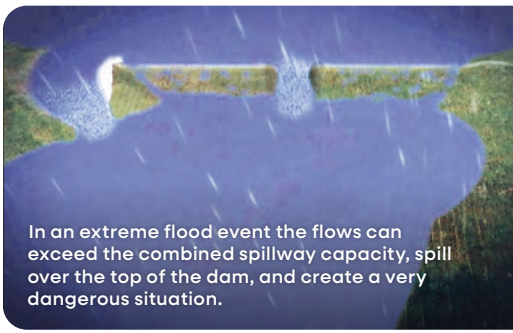
Seepage Through Dam Foundation

The reservoir upstream of any dam may seep continually through the naturally occurring materials of the dam's foundation in a downstream direction. The occurrence and rate of water movement through a dam's foundation is dependent on the properties of the naturally occurring materials. The foundation may consist of sound durable bedrock with little or no fractures and seepage may be non-existent. However, the foundation may consist of fractured bedrock or bedrock may be so deep that the dam is built on the soil above the bedrock with potentially pervious properties. Depending on the age of the dam and the sophistication of its design, a cutoff may not exist through any fractured rock or pervious foundation materials. Regardless of the design, foundation seepage may exist to some extent under a dam.

During elevated reservoir pool levels caused by extreme rainfall events, the added pressure on the seepage path around pipe penetrations or through foundation materials may become so strong that soil particles begin to be displaced out of the dam. Water flowing along either of these seepage paths can create an internal erosion failure of the dam.

When storage has reached an appropriate limit, spillways are designed to pass the excess flood-waters, initially through a primary spillway.

Many dams are equipped with an emergency spillway to help pass very large floods which exceed the capacity of the primary spillway.



In an extreme flood event the flows can exceed the combined spillway capacity, spill over the top of the dam, and create a very dangerous situation.


Jamestown, Colorado, September 15, 2013

4. HOW CAN ONE REDUCE THE CHANCES OF A DAM FAILING FROM AN EXTREME RAINFALL EVENT?

Inspections are critical but, alone, are not enough.

A Dam Owner Needs To...

- Design to industry, state, and federal guidelines.
- Recognize responsibility.
- Observe and record changes at your dam or outside factors that affect its safety/performance and be prepared to respond accordingly.
- Practice situational awareness and preparedness.
- Have your dam inspected routinely.
- Ensure proper design, construction, maintenance, and operation.
- Adhere to regulations; no short cuts or random exemptions.
- Avoid short-term band-aids (drawdown, etc.).
- Invest in repair and routine maintenance.
- Be in contact with your state dam safety office.
- Have an up-to-date emergency action plan, inundation maps.

What's next for an owner?

It is imperative to understand that all dams will deteriorate with age, loading conditions may change, downstream risk may increase, and it is impossible to guarantee that a dam will never fail. However, dam owners can take steps to reduce and minimize the risk of their dam failing.

Dam owners must recognize their responsibilities and be vigilant in addressing any dam deficiencies. One of the most important measures owners can take to reduce the possibility of dam failure would be to establish an effective dam safety program in accordance with their state or federal dam safety requirements. Such a program will help to ensure that potentially dangerous conditions are recognized, accounted for, and addressed. The dam safety program will also help meet current regulations and standards of care.

KEY ELEMENTS OF AN OWNER'S DAM SAFETY PROGRAM WOULD INCLUDE THE FOLLOWING:

1. Regular and thorough inspections

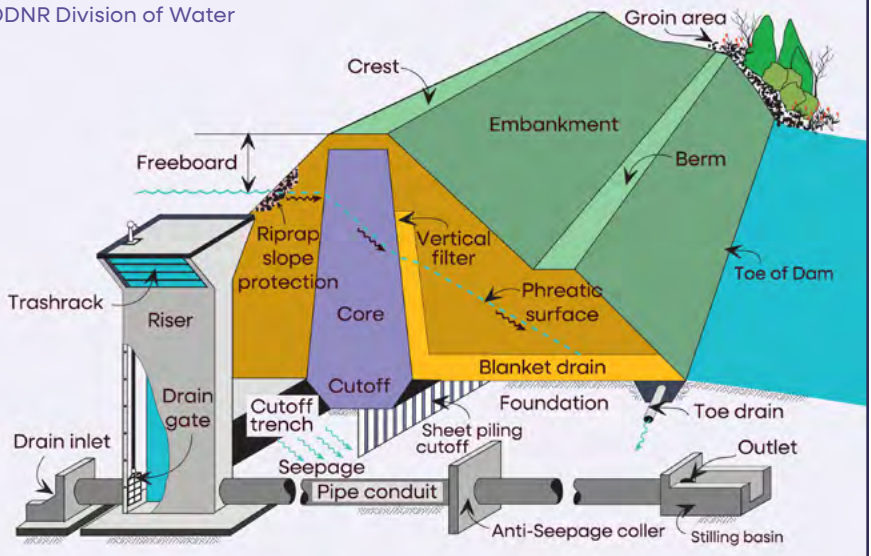
Periodic Safety Inspections

Formal and systematic visual inspections by owner/operator or representative to review all components of the dam including equipment. The inspection report should be written and include photos and any other available records. Frequency of inspections should be based on size, condition, and dam hazard classification. Inspections should be conducted at a minimum of once per year.

Dam Construction Cutaway

Typical features of an embankment dam

ODNR Division of Water



Technical Inspections

These inspections are performed by a qualified professional engineer, and may include the detailed investigations of identified problems, stability and hydrologic analyses, and review for compliance with current state dam safety regulations.

Frequency of technical inspections may be dictated by state regulation and dam hazard classification.

Monitoring Inspections

These inspections are informal on-site visits to visually check for any warning signs of structural distress or spillway problems. The frequency of monitoring inspections could be as often as daily. At a minimum, they should be conducted weekly.

Monitoring inspections are critical before, during, and after extreme rainfall events.

2. Proper operation and maintenance

An efficient maintenance program will help protect a dam against deterioration and prolong its safe operational life. A properly maintained dam minimizes the likelihood of failure. Subsequently, maintenance is a task which should never be neglected. The financial costs associated with a proper maintenance program are relatively small compared to the significant cost of major repairs or even the disastrous consequences of a dam failure. This is the “pay me now or pay me later” concept. Therefore, a dam owner should develop a basic maintenance program based primarily on regular and thorough inspections.

Development of an operation program helps ensure the safe operation of a dam. This includes normal operations and special routines necessary during emergencies. Prescribed reservoir operation guidelines should be developed to address operation during extreme rainfall events. The operation program may also include equipment operation instructions, periodic and systematic testing of equipment, and increased monitoring of instrumentation and gages during extreme rainfall events.

3. Timely correction of dam safety deficiencies

When dam safety deficiencies are identified, it is important that corrective actions are carried out in a well-planned and timely fashion to reduce the potential of a dam failure. The need for corrective actions to address deficiencies may be established by state regulation or be recommended as a result of owner or operator inspection findings.

Reasons for recommending corrective actions may include but are not limited to structural deficiencies, damaged or inoperable equipment, changes in engineering guidelines or regulatory requirements such as revised spillway capacity requirements, and revisions in hazard classification.

Owner and community vigilance is critical.

4. Extreme incident planning including emergency action procedures

Dams do fail! Often these failures will cause extensive property damage, personal injuries, and in some situations, loss of life. To minimize the consequences of a dam failure, it is imperative that a dam owner prepare an emergency action plan (EAP) for their dam.

An EAP is a formal document that identifies emergency conditions at a dam and the areas that would be inundated if the dam were to fail. It specifies preplanned actions to be followed to moderate or alleviate problems at the dam and to provide adequate downstream warning of failure. In the case of a dam failure, the EAP may help to minimize the consequences of the failure. EAPs are required by most state dam safety regulatory programs for high-hazard potential dams.

KEY COMPONENTS OF AN EAP WOULD INCLUDE:

- **Inundation maps indicating areas that will be impacted by the dam failure flood wave.**
- **Notification flowcharts for warning of inhabitants in inundation areas by emergency management authorities.**
- **Monitoring – Emergency detection, evaluation and responsibility protocol.**
- **Preventative Action – Effective response actions to prevent failure.**

5. A dam owner's obligation – meeting current standards

Spillway Design Criteria

The spillway capacity of any dam should, at a minimum, comply with the current state guidelines for the dam's spillway design capacity. Most all of these state guidelines relate directly to extreme rainfall events and to hazard potential classification of the dam. Historically, standards for dam spillway design floods have varied from state to state but typically have been specified as a flood resulting from some significant percentage of an extreme rainfall event known as the probable maximum precipitation (PMP).

Published national guidelines for selecting and accommodating inflow design floods (IDF) for dam structures (FEMA P-94/August 2013) recommends more rigorous analyses such as an incremental dam breach consequence analysis, a risk based hydrologic hazard analysis, or site-specific PMP

The use of one of these recommended site-specific approaches may result in a more cost-effective rehabilitation project for the dam under review than using just a prescriptive approach to spillway design floods.

Extreme Storm Events as Existing Standard of Care

Regardless of the dam's size, when the costs of conducting one of these detailed analyses is prohibitive for the owner, the recommended design storm for high-hazard potential dams is the flood event resulting from the probable maximum flood (PMF). The current recommended standard of care for dam spillway design to protect the safety of individuals inhabiting areas downstream of dams is summarized in the table below (FEMA P-94).

Lawmakers may believe that owners are right when they say their state is making them follow some arbitrary design standard that doesn't relate to their situation. However, in reality these requirements are not created in a vacuum nor are they developed arbitrarily.

The worst case of these extreme rainfall events has been determined by the National Weather Service (NWS) to be the probable maximum precipitation (PMP) in the USA. These PMP events are defined by the NWS as, "the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographic location during a certain time of year." Combining these storm events with the most severe hydrologic conditions that are reasonably possible in a given drainage basin is the basis of determining the probable maximum flood (PMF) that is the national industry standard for high-hazard potential dam design.

Hazard Potential	Definition of Hazard Potential Classification	Inflow Design Flood
High	Probable loss of life due to dam failure or misoperation (economic loss, environmental damage, or disruption of lifeline facilities may also be probable, but are not necessary for this classification)	PMF
Significant	No probable loss of human life but can cause economic loss, environmental damage, or disruption of lifeline facilities due to dam failure or misoperation	0.1% (1,000 - year) Annual Chance Exceedance Flood
Low	No probable loss of human life and minimal economic and/or environmental losses due to dam failure or misoperation	1% Annual Chance Exceedance Flood (100-year Flood) or a smaller flood justified by rationale


Just because you haven't experienced a flood in the past, doesn't mean you won't in the future.
www.fema.gov/flood-insurance

What is the 100-Year Flood?

The 100-year flood is a flood event that has a 1% chance of occurring in any given year. The 100-year floodplain is mapped on FEMA's Flood Insurance Rate Maps which is intended for insurance, floodplain management, and planning purposes and is not intended to be a safety standard.

In your community, you have a 26% chance of experiencing a 100-year flood magnitude during the life of a 30-year mortgage. You have a 4% chance of experiencing a fire during the same period of time. Dam operation or failure flood inundation areas may far exceed the 1% flood zones (100-year flood) mapped by FEMA. Floods greater than a 100-year flood can and do happen, as seen in the Midwest, which received two 500-year floods in a 15-year period (1993 and 2008). Dam failure floods are almost always more violent than the normal stream, river, or coastal flood.

RESOURCES

For More Information

Association of State Dam Safety Officials:
https://damsafety.org

National Dam Safety Program:
https://www.fema.gov/grants/mitigation/learn/dam-safety

National Inventory of Dams:
https://nid.sec.usace.army.mil

American Society of Civil Engineers Infrastructure Report Card–Dams:
https://infrastructurereportcard.org

FEMA FloodSmart:
https://www.floodsmart.gov

Ready.Gov:
https://www.ready.gov/floods

USDA Natural Resources Conservation Service Watershed Rehabilitation Information:
https://www.nrcs.usda.gov

National Weather Service:
https://www.weather.gov

The National Emergency Management Association:
https://nemaweb.org

The International Association of Emergency Managers:
https://www.iaem.org

Find out more about the maps used to determine flood risk:

In addition, you can order maps online or by emailing or phoning the FEMA Flood Map Service Center.

FEMA Mapping and Insurance eXchange:
https://floodmaps.fema.gov/fhm/fmx_main.html

(877) 336-2627

Email Address: FEMA-FMIX@fema.dhs.gov

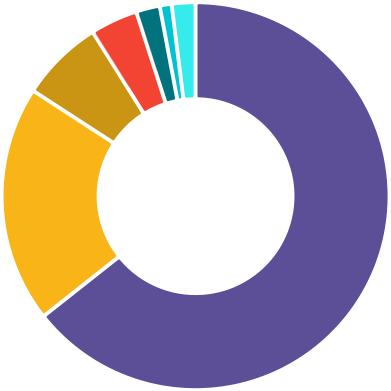
Contacting FEMA: For a comprehensive list of contact information, please see the FEMA website: www.fema.gov

FEMA publishes maps indicating a community's flood hazard areas and the degree of risk in those areas. Flood insurance maps usually are on file in a local repository in the community, such as the planning and zoning or engineering offices in the town hall or the county building.

Dam Ownership & Purpose

*Based on data from the National Inventory of Dams (NID)

DAMS BY OWNER TYPE



Primary Owner Type	Percentage
Private	65%
Local Govt	20%
State	7%
Federal	4%
Public Utility	2%
Tribal Govt	0%
Not Listed	2%

DAMS BY PRIMARY PURPOSE

Primary Purpose	Percentage
Tailings	1%
Irrigation	8%
Navigation	0%
Fish & Wildlife Pond	3%
Recreation	33%
Hydroelectric	2%
Debris Control	1%
Water Supply	6%
Flood Risk Reduction	16%
Fire Protection, Stock, or Small Fish	13%
Grade Stabilization	1%
Other	8%
Unknown	6%

KNOW THIS

- **Can an extreme rainfall event cause a dam failure?**
- **What are the consequences of a dam failure, and who is responsible?**
- **What steps can a local community and policymakers take to reduce the risks to life and property associated with extreme rainfall events and dams?**
- **How would a dam failure affect the local community?**

How can dam owners, dam safety officials, lawmakers, and concerned citizens reduce the chance and risk of dams failing from extreme rainfall events?

1. Promote proactive dam safety programs that balance sound science and economics with risk reduction and public safety.
2. Recognize that public safety and welfare supersede individual hardship and the ability to afford the proper level of protection for dam safety.
3. Recognize that adequately funding dam safety and rehabilitation programs are the most cost-effective hazard mitigation measures available for private and public dams.

LIVING NEAR DAMS

www.livingneardams.org

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damsafety.org