Session 3: Dam Failure Modes & Case Histories

1

What Will Be Covered in Session 3

- Principles of dam construction and operation
- How dams fail
- Circumstances that can make your dam fail
- Emergency actions by owners
- Examples of dam failures
- Conclusions and Lessions Learned

2

Why are Dam Failures of Concern?

- Loss of Life
- Property Damage
- Lifeline Loss
- Environmental Impact
- Loss of Use
- Repair Costs

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Potential Loss of Life

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Property Damage

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Loss of Reservoir Use

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"Dams 101"

- Principles of Dam Construction and Operation
- How Dams Fail
- Options for Repairs To Dams

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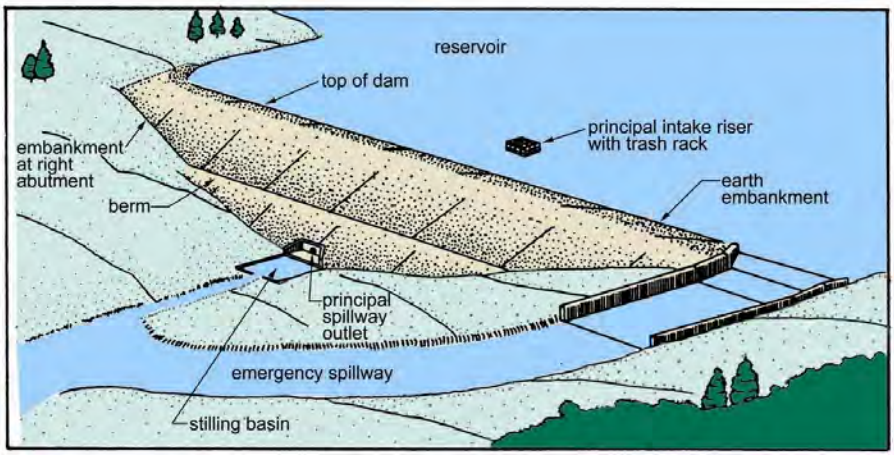
Dam Components



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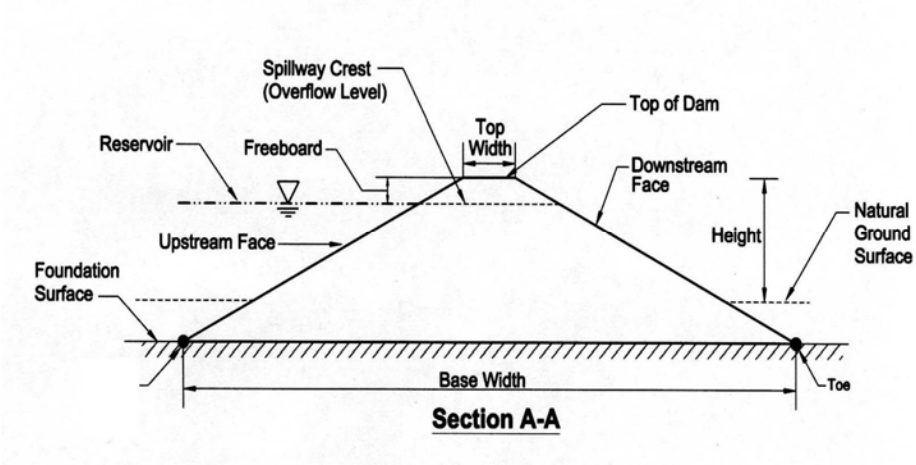
Nomenclature



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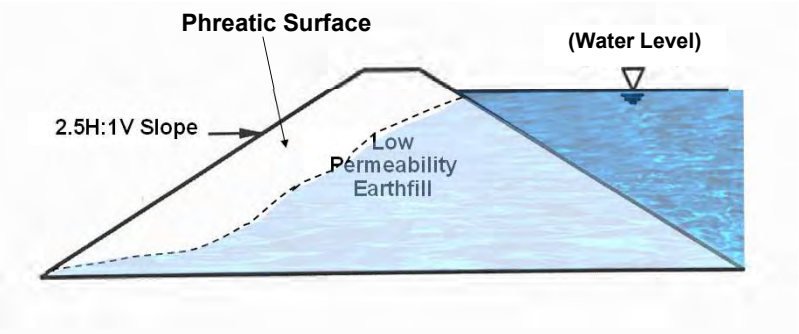
Earthfill Dam with Low Permeability Earthfill



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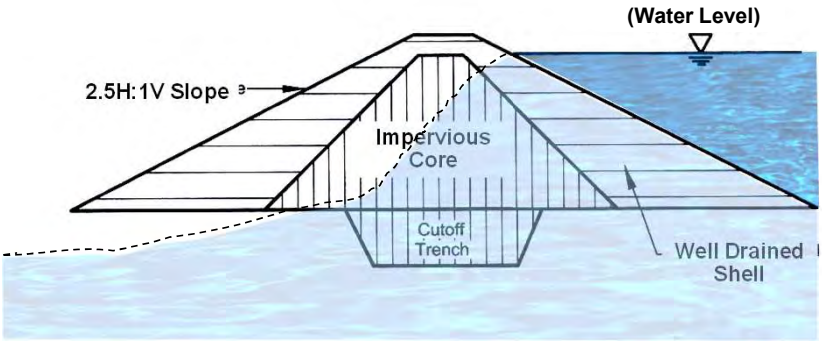
Earthfill Dam with Low Permeability Core



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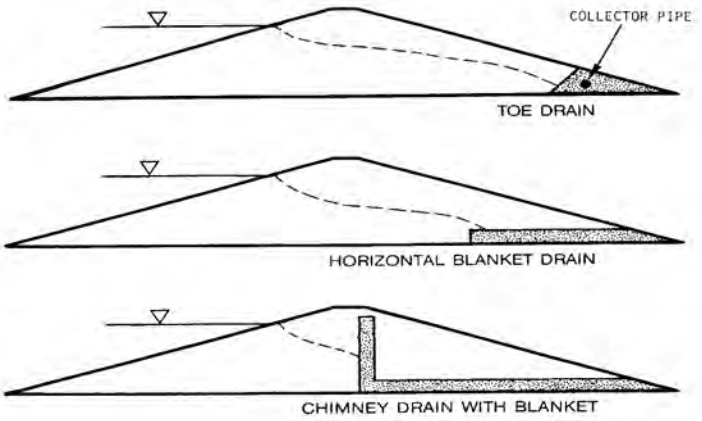
Drains Typical Configurations



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Earthfill Embankment

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Embankment

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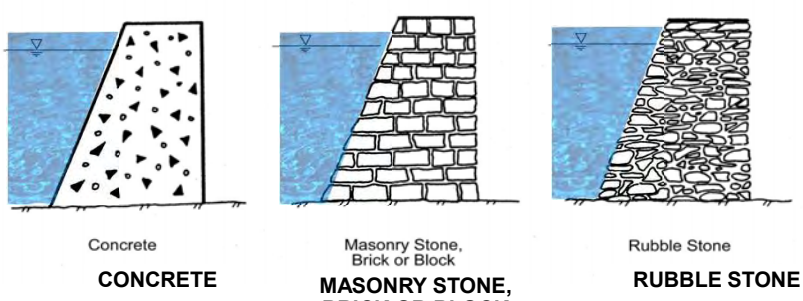
Concrete, Masonry and Rubble Gravity Dams



CONCRETE | **MASONRY STONE, BRICK OR BLOCK** | **RUBBLE STONE**

4-15

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Stone Masonry Gravity Dam

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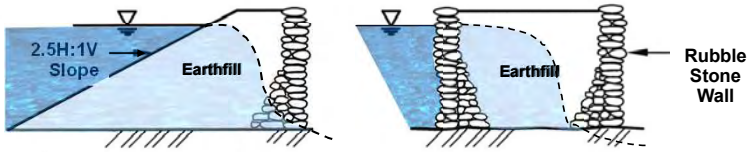
Masonry Wall / Earthfill Dams



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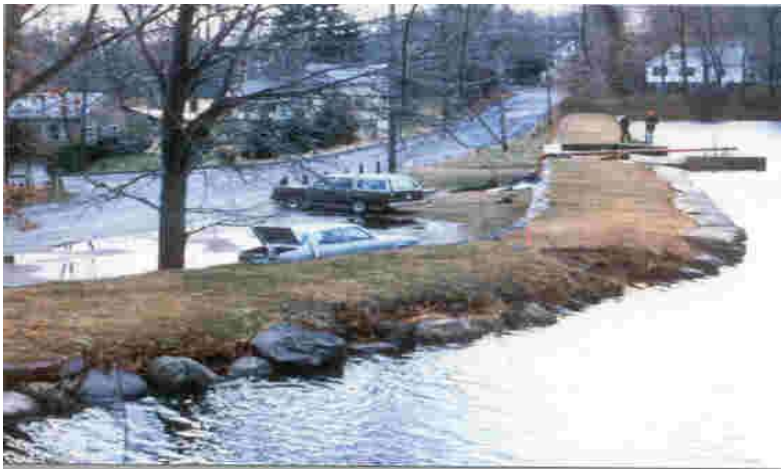
Masonry Wall / Earthfill Dam



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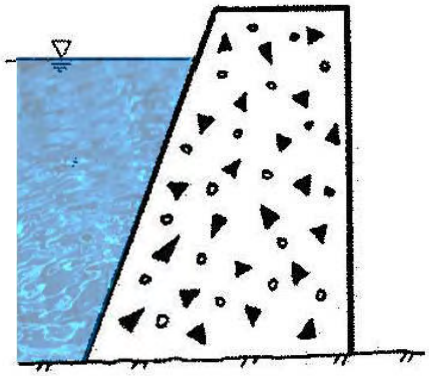
Concrete Gravity Dams



CONCRETE

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Concrete Gravity Spillway

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Spillways

- Establishes normal water level
- Allows normal flows to pass safely
- Resistant to erosion
- Stilling basins or plunge pools
- Emergency spillways

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Spillway

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Intake/Outlet Structures (Drawdown Facilities)

- Control impoundment levels
- Typically valved piping systems
- May be incorporated into the principal spillway
- Located at low point
- Former stream channel

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Gate Operator Mechanism

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Low Level Outlet

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The Many Ways a Dam Can Fail

Primary causes of dam failures during an extreme event include:

- **Inadequate Spillway Capacity**
- **Spillway scour**
- **Internal erosion along conduits**
- **Structural Failure of Inlet or Outlet Works**
- **Increased Seepage Pressures**
- **Erosion from Uprooting of Trees and Woody Vegetation**
- **Wave Erosion**
- **Liquefaction**

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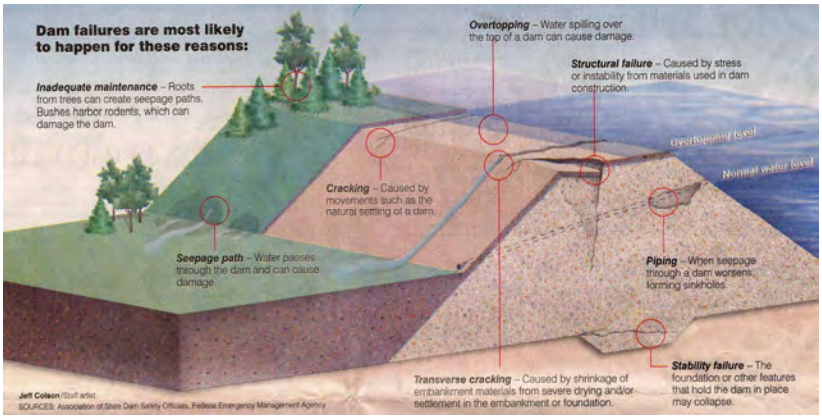
Anatomy of a Dam Failure

The most common causes of dam failures:



Circumstances That Can Cause Failure

Extreme Events

- **Rainfall Events**
- **Earthquakes**
- **Wind**

Rainfall Events

Hurricane Floyd off of East Coast

Erosion

- Erosion from Flood Flow
  - Overtopping Erosion
  - Foundation Undermining
  - Abutment Breach
- Internal Erosion
  - Embankment Seepage
  - Foundation Seepage
  - Preferential Seepage Paths

Causes of Flood Flow Erosion

- Inadequate Spillway Size
- Spillway Blocked with Debris
- Inadequate Freeboard
- Undermining of Spillway Toe
- Erosion of spillway material

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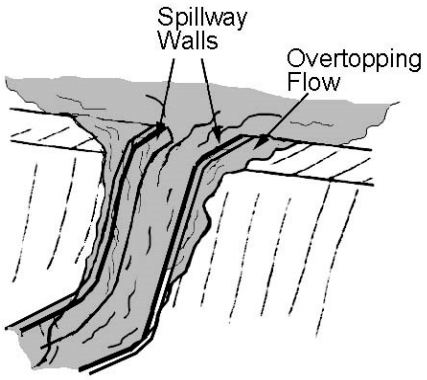
Inadequate Spillway Capacity



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Overtopping of an Embankment Dam

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Damage Caused by Embankment Overtopping

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Inadequate Spillway Capacity

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Weir Boards Blocking Spillway/Limiting Freeboard

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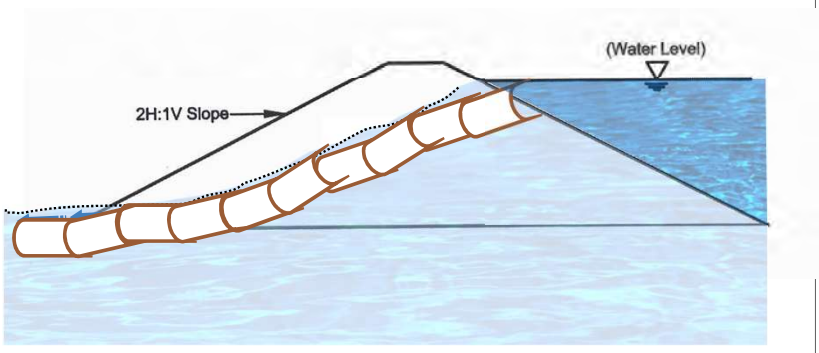
Undermining of Spillway Toe

Seepage/Piping

- What is Seepage/Piping?
  - Seepage
    - Water movement through the earth dam and its foundation
    - Seepage can be controlled and uncontrolled
    - Uncontrolled seepage can progressively erode soil
    - Uncontrolled flow can weaken soil and cause structural failure
  - Piping
    - Defined as movement of soil particles by percolating water leading to development of channels
    - This movement, or transport, of particles leads to voids within the embankment

Seepage/Piping



Common Causes of Seepage/ Piping

- Poor Construction
  - Unspecified materials used to construct the dam
  - Inadequate compaction
  - Insufficient existing information gathered prior to construction
- Rodent Activity
- Tree Roots

Uncontrolled Seepage

- Erosion of Embankment Material

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Progressive Piping Problem

- 300 ft High Teton Dam, Idaho - 1967

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Progressive Piping Problem

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Seepage from an Embankment

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Seepage/Piping Problem

Leakage Around Outlet Pipe

Internal Erosion Along Conduits

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Internal Erosion Along Pipes

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Water Exiting as a Boil

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Whirlpool in Reservoir

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Earthquake

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Above photo taken within 6 hours of the Nisqually Earthquake – drainage channel normal

Right photo taken 24 hours later illustrating delayed occurrence of liquefaction

Circumstances That Can Cause Failure

- **Inadequate Design**
- **Poor Operation or Maintenance**
- **Vandalism**

Primary Causes of Dam Failures Due to Inadequate Design

- Spillway Size
- Seepage
- Stability

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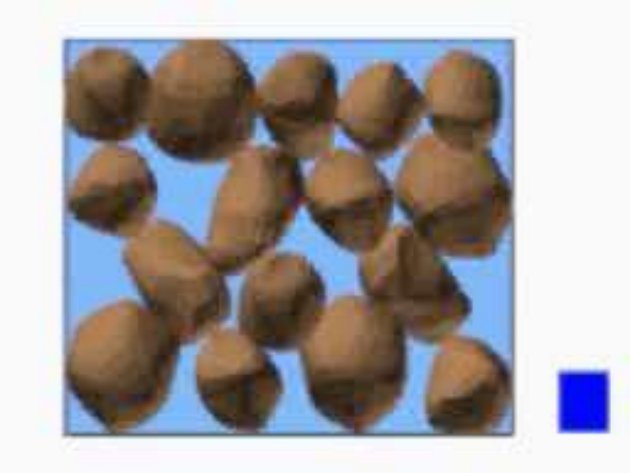
Liquefaction



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Unstable Slopes

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Spillway Scour

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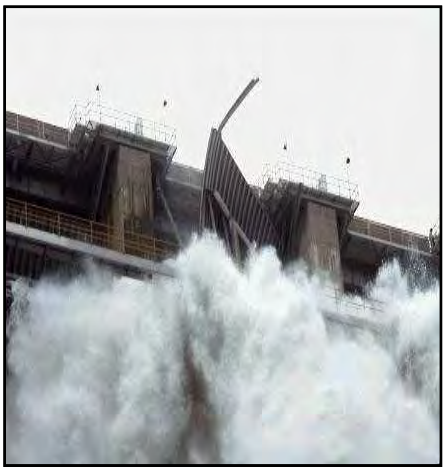
Poor Operation or Maintenance

Primary causes of dam failures due to poor operation and maintenance include:

- **Inoperable gates unusable in emergency**
- **Poor maintenance of embankment surfaces cause erosion or uprooting of trees**
- **Blocked spillways**
- **Plugged drains**

Poor Maintenance



Deteriorated Gate Stem

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Poor Design/Poor Maintenance

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Plugged Drains

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Blocked Inlet

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Sharp Crested Spillway

Scour and Undermining of Downstream Foundation

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Inadequate Vegetation Control

Inadequate Vegetation Control Leads to Animal Borrows, Root Development and Poor Inspection all of Which Could Lead to Dam Deterioration and Failure

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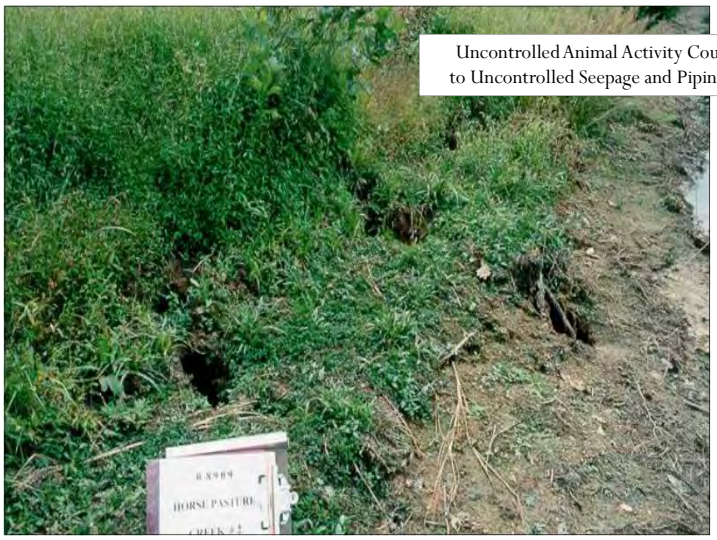
Animal Activity



Uncontrolled Animal Activity Could Lead to Uncontrolled Seepage and Piping Failure

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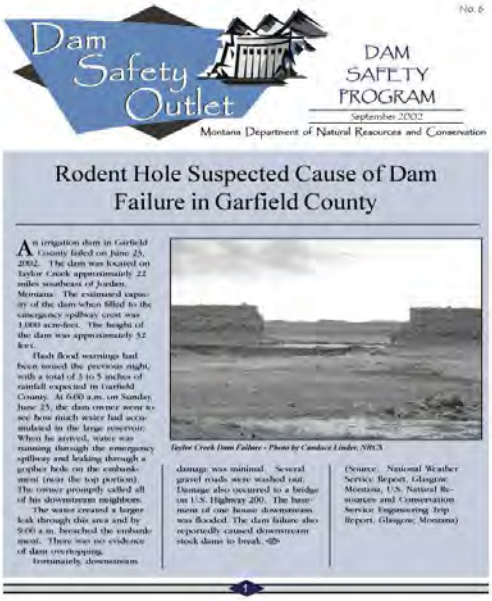
Animal Burrows



Dam Safety Outlet

DAM SAFETY PROGRAM

September 2002

Montana Department of Natural Resources and Conservation

No. 6

Rodent Hole Suspected Cause of Dam Failure in Garfield County

An irrigation dam in Garfield County failed on June 23, 2002. The dam was located on Taylor Creek approximately 22 miles southeast of Jordan, Montana. The estimated capacity of the dam when filled to the emergency spillway crest was 1,000 acre-feet. The height of the dam was approximately 32 feet.

Flash flood warnings had been issued the previous night, with a total of 3 to 5 inches of rainfall expected in Garfield County. At 6:00 a.m. on Sunday, June 23, the dam owner went to see how much water had accumulated in the large reservoir. When he arrived, water was running through the emergency spillway and leaking through a gopher hole on the embankment (near the top portion). The owner promptly called all of his downstream neighbors.

The water created a larger leak through this area and by 9:00 a.m. breached the embankment. There was no evidence of dam overtopping.

Fortunately, downstream damage was minimal. Several gravel roads were washed out. Damage also occurred to a bridge on U.S. Highway 200. The basement of one house downstream was flooded. The dam failure also reportedly caused downstream stock dams to break.

Taylor Creek Dam Failure - Photo by Candace Linder, NRCS

(Source: National Weather Service Report, Glasgow, Montana, U.S. Natural Resources and Conservation Service Engineering Trip Report, Glasgow, Montana)

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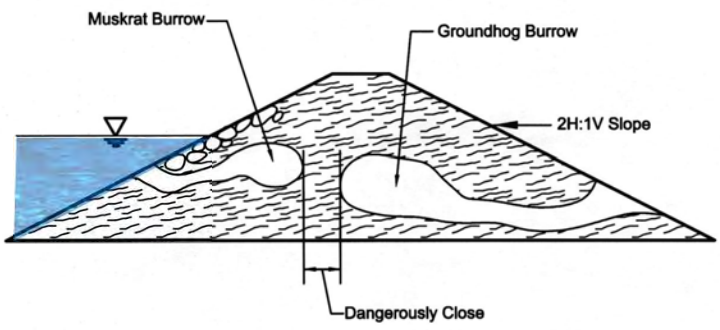
Problem Animal Species

- **Muskrat**
  - burrow on the u/s slopes
- **Beaver**
  - burrow - Dens 6' dia., 2' high
- **Woodchuck**
  - burrow on d/s slopes 12" dia.,
  - 5' deep, 8-60' long

How do dams fail?

- **Rodent Activity**



Sinkhole

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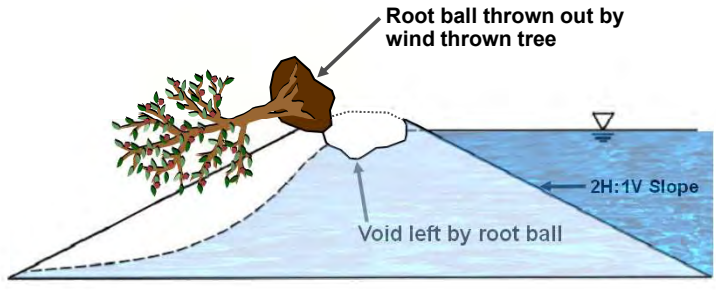
Uprooted Trees on Dams

- **Trees/Brush**



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Uprooted Trees on Dams

Tree Roots

Spalled Concrete

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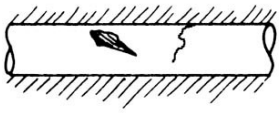
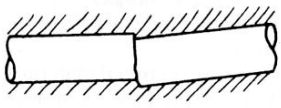
Structural Problem

Outlet Pipe Damage

Hole, Crack



Joint Offset



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Leak in Low Level Outlet

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Leakage from Conduit

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Unapproved Modification

Road Access Added Over Crest of Dam Resulted in Lowering of Crest in that Area that Could Lead to Overtopping

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Unapproved Modifications

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Vandalism

- **Vandalism/Terrorism**

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Statistics on Dam Failures

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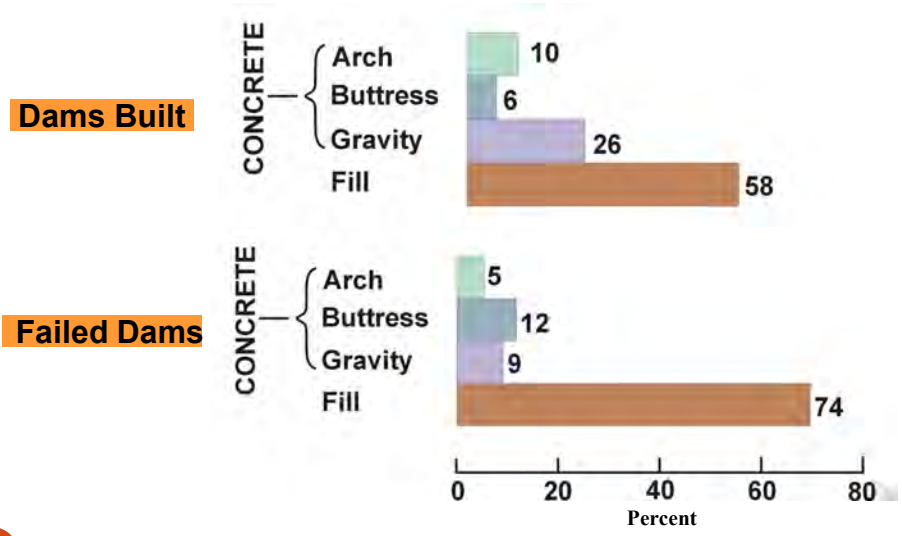
Dam Built vs. Dam Failures



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Excluding failures during construction and acts of war

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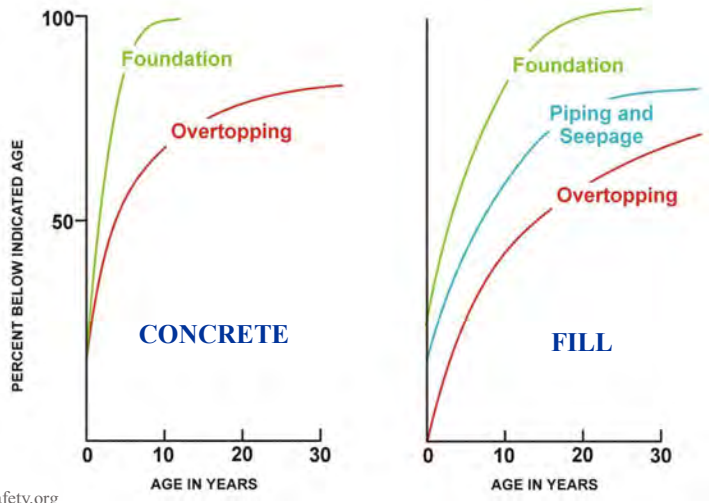
Dam Failures by Age of Dam

Over 15 m height



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Excluding failures during construction and acts of war

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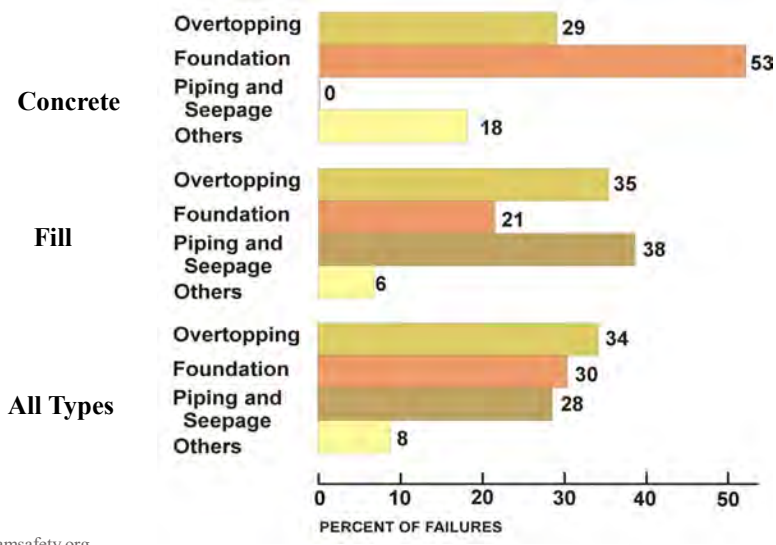
Dam Failures by Type of Dam



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Excluding failures during construction and acts of war

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Options for Dealing with Unsafe Dams

- **Repair the Dam**
- **Permanent Lowering of Impoundment**
- **Removal of Dam**

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Options for Repairing Dams

- Increase Spillway Capacity
  - Lower permanent pool
  - Increase spillway size
  - Design to overtop safely
  - Justify smaller SDF
- Intercept/Control Seepage/Leakage
- Tree/Stump/Root Removal
- Concrete Repair/Reconstruction
- Repair Low Level Outlets

Options for Removing Dams

- Complete Removal
- Full Height Breach
- Partial Height Breach

Responsibility of Owner

- **Proposed Dam Safety Regulations Will Require:**
  - **Inspect dam - frequent basis**
  - **Inspect during/after major floods**
  - **Take emergency action to protect dam**
  - **Report major damage and changes in condition**
  - **Maintain structure and operate dam safely**

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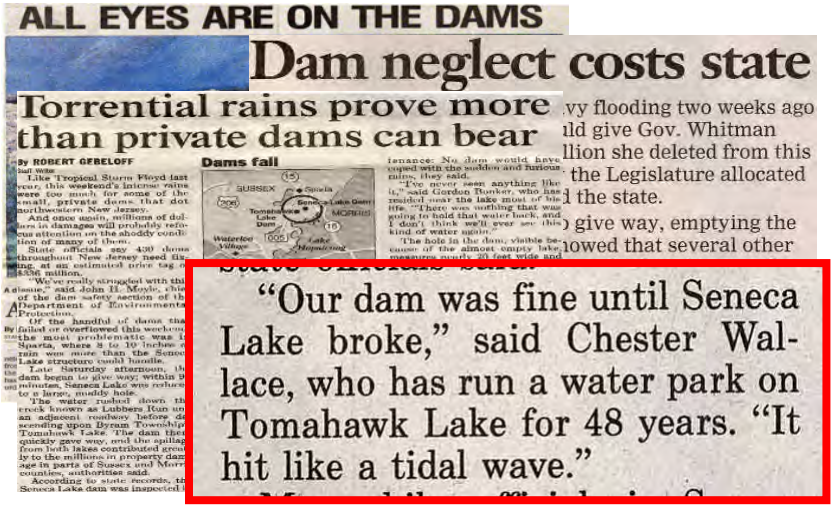
It Can Happen to You!



ALL EYES ARE ON THE DAMS

Dam neglect costs state

Torrential rains prove more than private dams can bear

By ROBERT GEBELOFF

Dams fail

"Our dam was fine until Seneca Lake broke," said Chester Wallace, who has run a water park on Tomahawk Lake for 48 years. "It hit like a tidal wave."

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How do dams fail?

- Multiple Causes
  - Embankment Sloughing
  - Overtopping

Dam Failures in Vermont

- But dams in Vermont never fail!!
  - Vermont has been fortunate, so far, there has been no loss of life & few cases of major property damage from dam failures.
  - Dam failures in Vermont are fairly common and potential exists for loss of life/significant economic losses.
  - ~70 dam failures in Vermont documented since 1900.
  - 2011 Tropical Storm Irene, numerous small dams failed.

Tropical Storm Irene, August 2011

- 11 inches of rain in some areas of Vermont
- Caused ~$733 Million in Damages
- ~2,400 roads, 800 homes and businesses, 300 bridges and 6 railroad lines were destroyed or damaged, according to the NOAA
- Numerous small dams failed. No large or SIGNFICANT/HIGH hazard dams failed.

Dam Failures in Vermont (Cont.)

- 1984 failure of Wards Pond Dam in Morrisville: Significant property damage but fortunately no loss of life.
- 1947 failure of East Pittsford Dam: Devastated Rutland resulted in no loss of life because there was enough warning time for evacuation.
- 1927 flood: over sixty dams failed which contributed to property damage and possibly loss of life.
- 1852 failure of Lake Paran Dam in Bennington: major destruction along Paran Creek and the loss of one life, warning time for evacuation

Earth Embankment Inspection 2008

Sloughing of Downstream Slope Observed

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Earth Embankment Failure 2011

Downstream Slope Internal Erosion Failure

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Mill Pond Dam
2006

Hazard Classification Downgraded

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Mill Pond Dam Failure
2011

Complete
Erosive Failure

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Examples of Dam Failures: Meadow Pond Dam Failure, Alton, New Hampshire March 1996

- Loss of One Life
- ~$8 Million in Property Damage
- 45-acre pond, ~280-acre-foot capacity
- Earth Dam 465 feet long, 36 feet high
- Significant Hazard
- Privately owned

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It Can Happen to You!

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Examples of Dam Failures
New Hampshire, Ashuelot Paper Mill Dam
October 2005

- Low Hazard Dam
- Run of the river
- Record rainfall
- No significant incremental damage downstream due to failure

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Notable Recent Failures
Nationwide

- Spencer Dam (NE) 2019
- Oroville Dam (CA) 2017
- South Carolina 2015
- Hawaii 2006
- New England 2005
- Missouri 2005
- New Jersey 2000 & 2004
- Michigan 2003
- Mississippi 2004

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Taum Sauk Failure

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Taum Sauk Dam, Missouri

- December 14, 2005
- 4,300 ac-ft of storage released
- Severely damaged a state park
- Swept away the caretakers house leaving 3 children critically injured.

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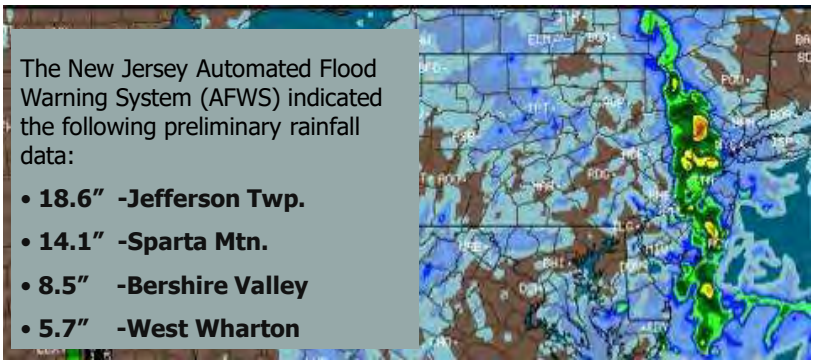
Examples of Dam Failures

New Jersey - August 2000



The New Jersey Automated Flood Warning System (AFWS) indicated the following preliminary rainfall data:

- **18.6″ -Jefferson Twp.**
- **14.1″ -Sparta Mtn.**
- **8.5″ -Bershire Valley**
- **5.7″ -West Wharton**

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Examples of Dam Failures

New Jersey - August 2000

On August 12, 2000, parts of northern NJ experienced unusually heavy rainfall.
4 dam failures, 26 dams damaged

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Southern New England 2005 Floods

- Wettest October since 1905
- Oct. 7,8 – Hurricane Remnants
  - 12 inches in western MA & CT
  - 6 inches in central areas MA & CT
- Light to Moderate Rain thru Week
- Oct. 14, 15 – Low Pressure System
  - 6 to 8 inches in:
    - Northeastern & Northcentral CT
    - Southcentral MA
- Oct. 7 – 15
  - 12 to 16 inches fell

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South Central Massachusetts

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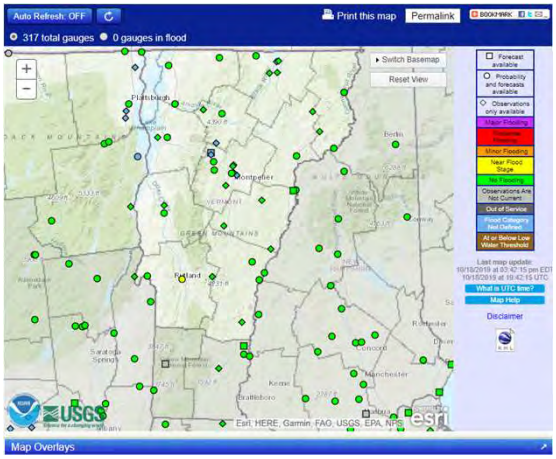
Conclusions

- Not If, But When Flooding will Occur
- Dams That Typically Fair Well:
  - Well Designed
  - Well Maintained
  - Operated Properly
  - Protected During Floods
- Owners Minimize Liability by:
  - Making sure their dams meet all of the above
  - Proper Communication
  - Complying with Regulatory Requirements

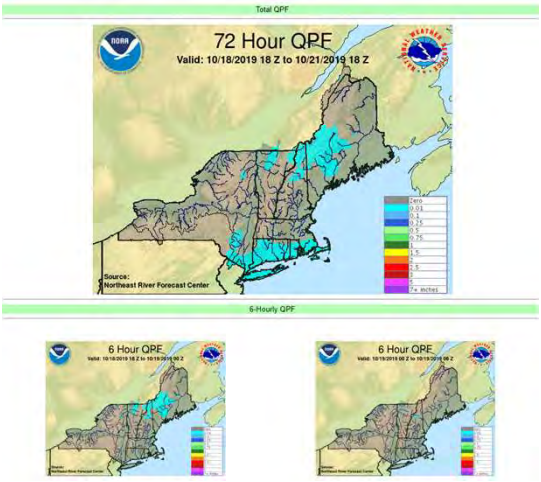
Flood Forecast Internet Resource

- https://water.weather.gov/ahps2/index.php?wfo=btv



Flood Forecast Internet Resource

- https://www.weather.gov/nerfc/ForecastPrecipitation



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Dam Failure Case Histories

Dams Do Not Have To Be Large Structures to Cause Loss of Life During Failure!!

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