

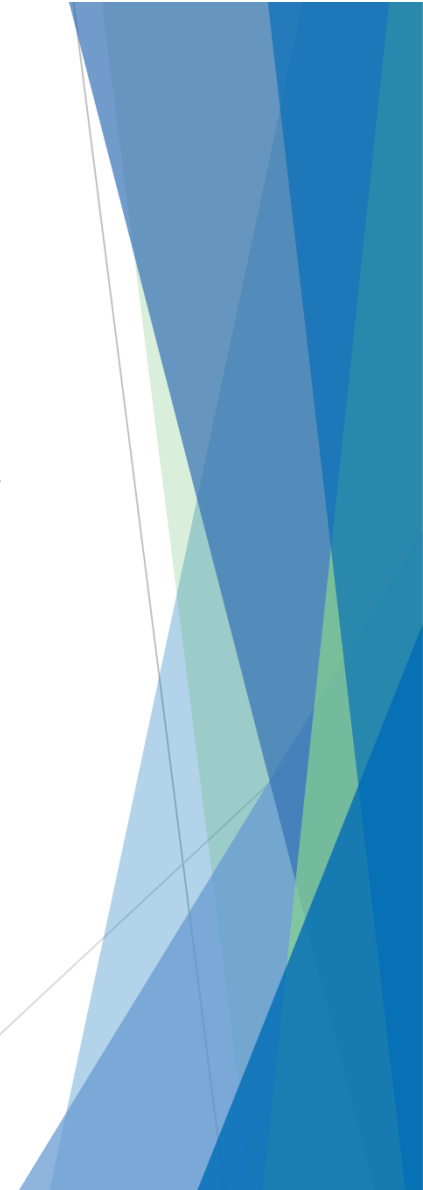
# Understanding Dams, Dam Failure and Dam Operational Hazards for Emergency Managers

IAEM National Conference, #IAEM18  
Grand Rapids, MI, October 22, 2018

Bill McCormick, P.E., P.G  
Association of State Dam Safety Officials  
Chief of Dam Safety, Colorado

# Goals of the Discussion

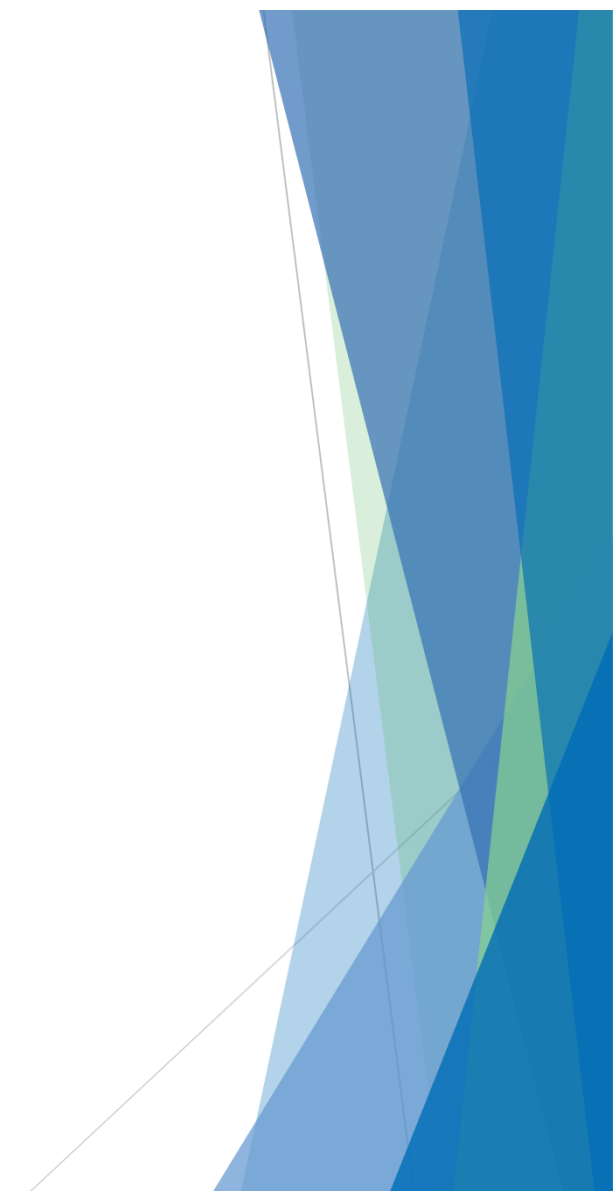
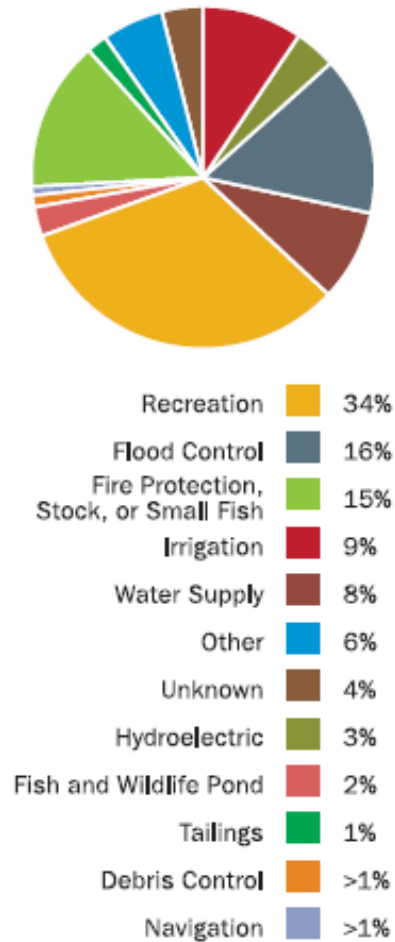
- ▶ Increase awareness of dam safety across the nation
- ▶ Create a forum dam safety and emergency management personnel
- ▶ Provide education on dam terminology, dam consequences and awareness of dams
- ▶ Reduce consequences (risk) of dam failure



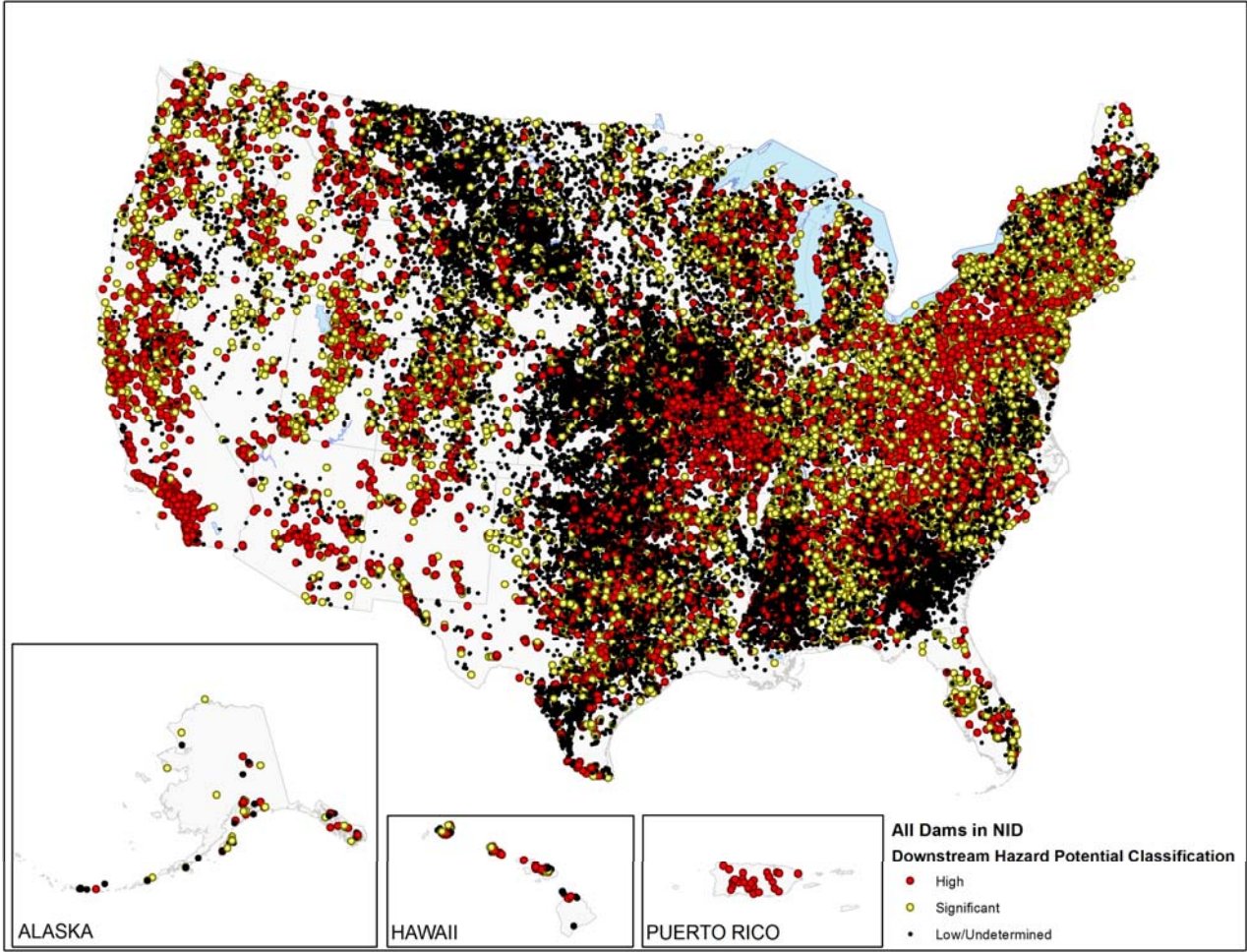
# Uses/Benefits of Dams

- ▶ Recreation
- ▶ Flood Control
- ▶ Irrigation
- ▶ Water Supply
- ▶ Hydropower

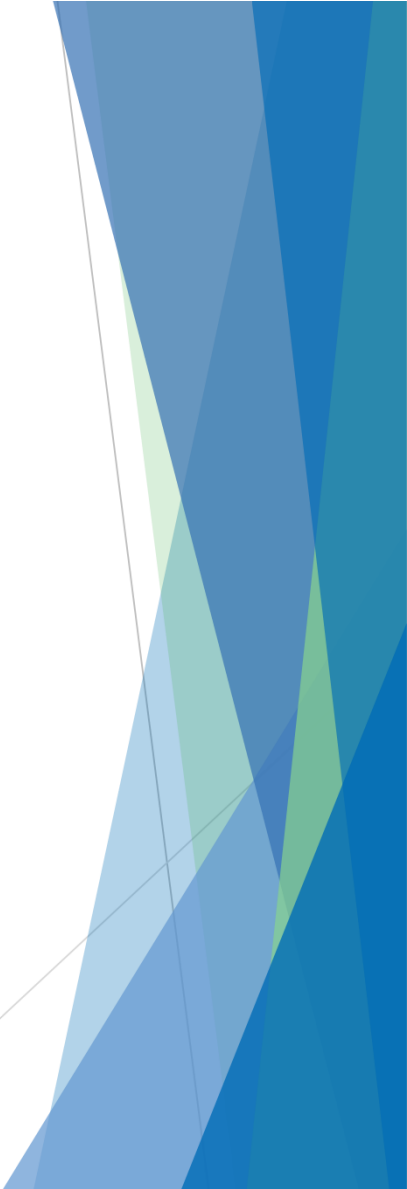
Dams by Primary Purpose



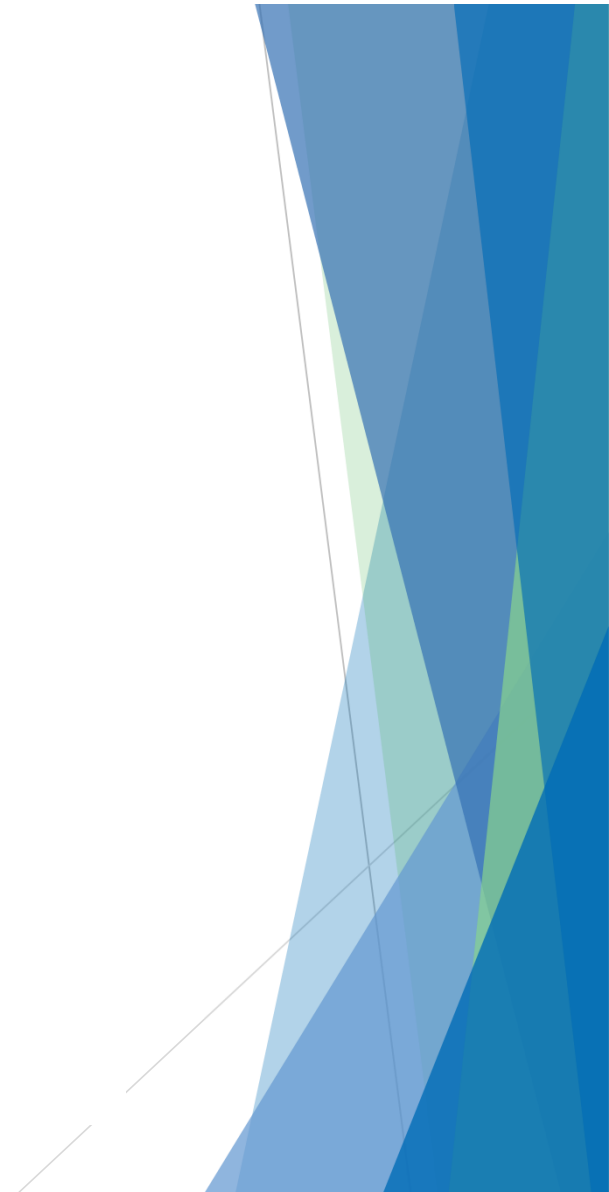
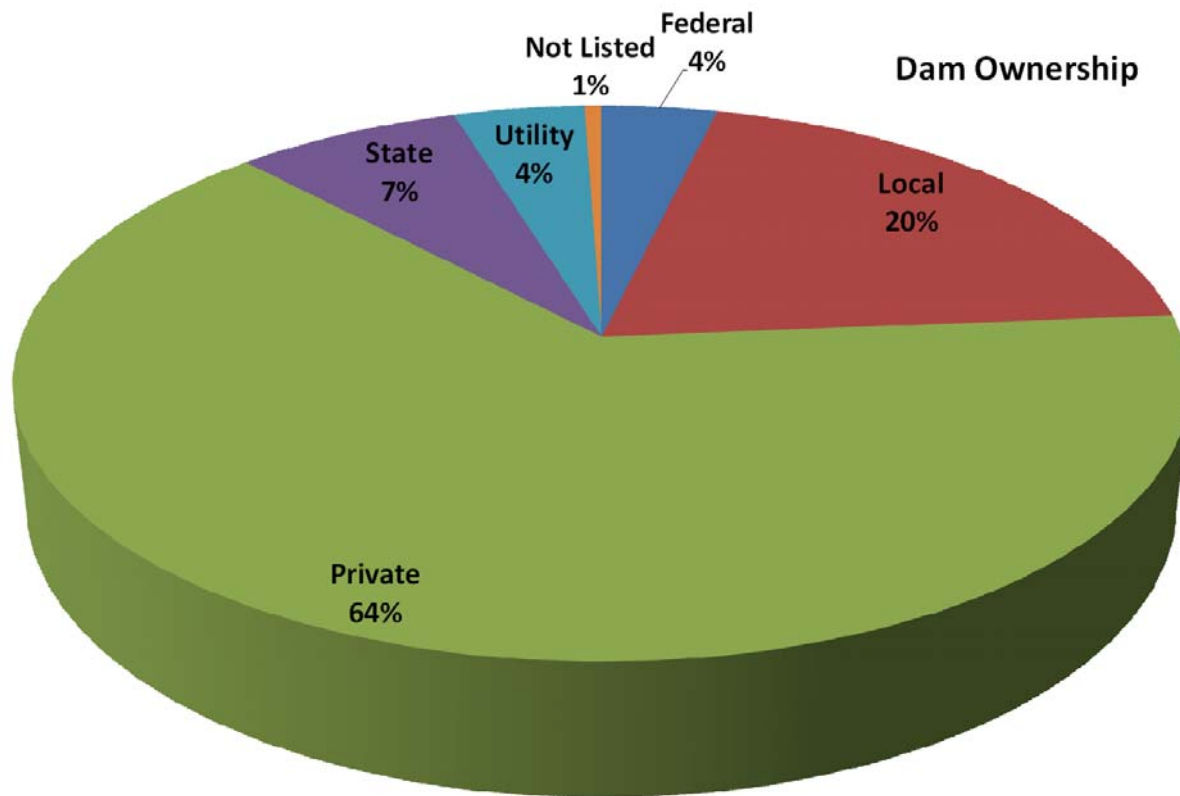
# 90,580 Dams in the United States



Source:  
2016, USACE NID

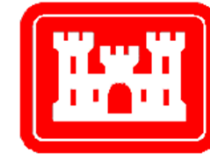


# Who Owns/Operates Dams



# Dam Safety in the U.S.

- ▶ State Dam Safety Programs
  - ▶ In 49 states (all except AL)
- ▶ Professional Organizations
  - ▶ ASDSO, USSD, ICOLD, others
- ▶ Government Organizations
  - ▶ FEMA, DHS, FERC, USBR, USACE, NRCS, TVA, others



US Army Corps  
of Engineers®



FEMA

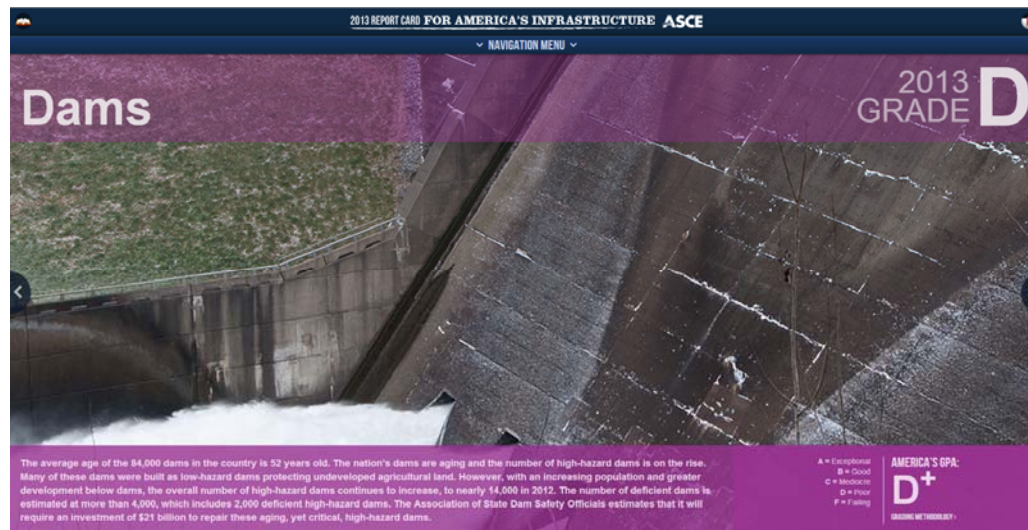


Association of State Dam Safety Officials

# Why Do We Care About Dam Safety?

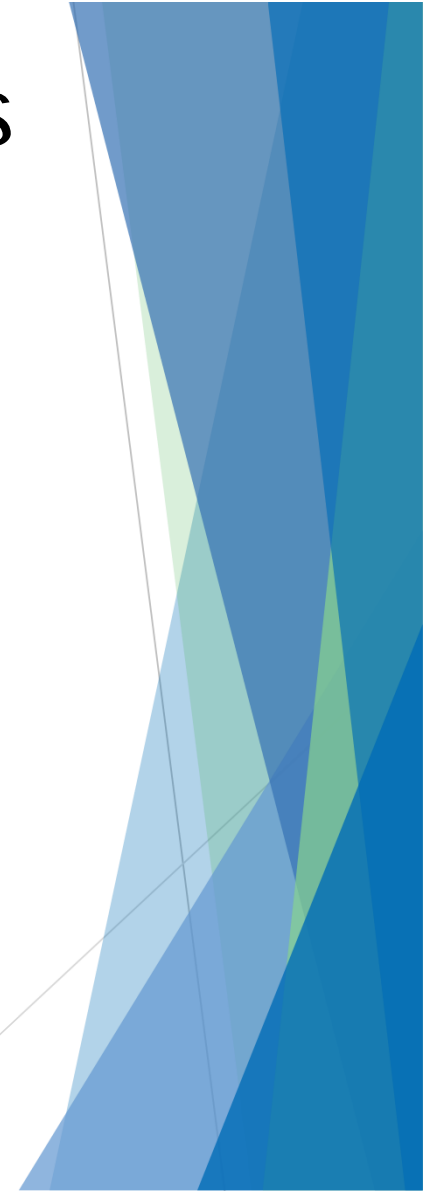
## Aging Infrastructure

- ▶ The average age of dams in the U.S. is more than 53-years old: deterioration increases, repair costs rise
- ▶ Advancing age makes dams more susceptible to failure
- ▶ Numerous dams in the nation are over 100 years old



# ASDSO and State Dam Safety Missions

- ▶ A Future Where All Dams are Safe
- ▶ Prevent loss of life and property damage from dam failures
- ▶ Maximize *Safe* storage of water
- ▶ Technical liaison between dam owners and emergency managers

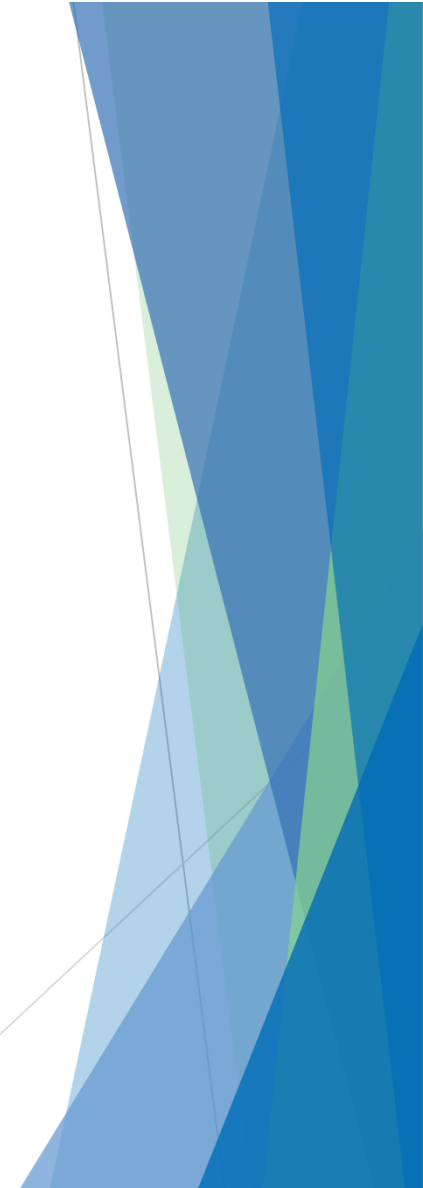




# Hazard Classification

- ▶ Based on an evaluation of consequences of dam failure, NOT condition of the dam
- ▶ Establishes standards for design and prioritization of inspection, monitoring and emergency preparedness

Hazard Classification	Description
HIGH	Loss of human life is expected in the event of a failure
SIGNIFICANT	Significant damage is expected, but no loss of human life
LOW	No significant damage and no loss of human life



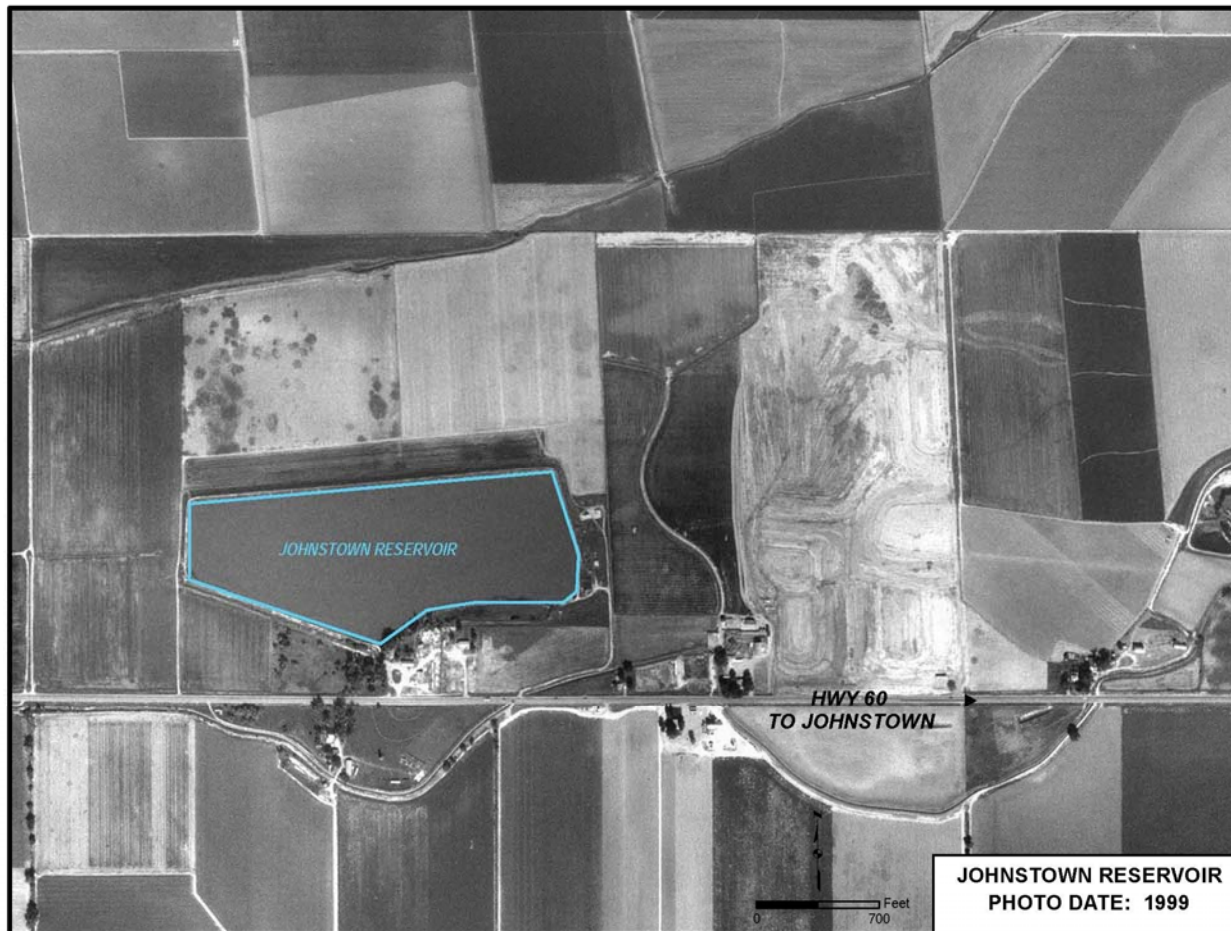
# Hazard Classifications - How Many

Hazard Classification					
	High	Significant	Low	Unknown	Total
All	15498	11882	60705	2495	90580
Federal	1192	320	1322		2834

Source - NID, 2016



# Hazard Classification - Is Not Static



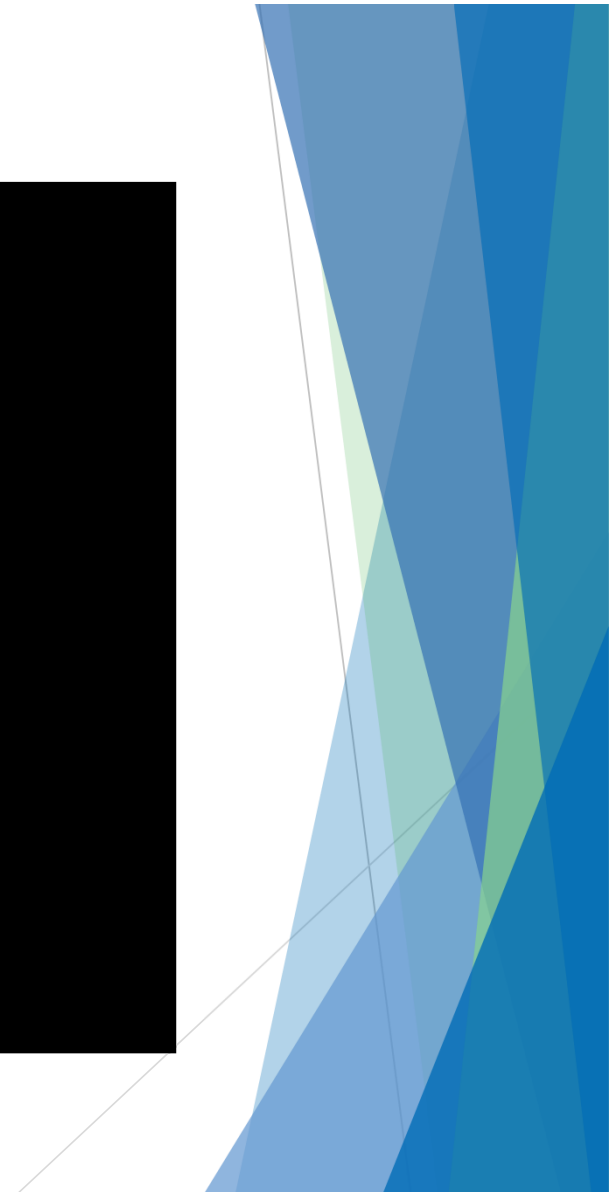
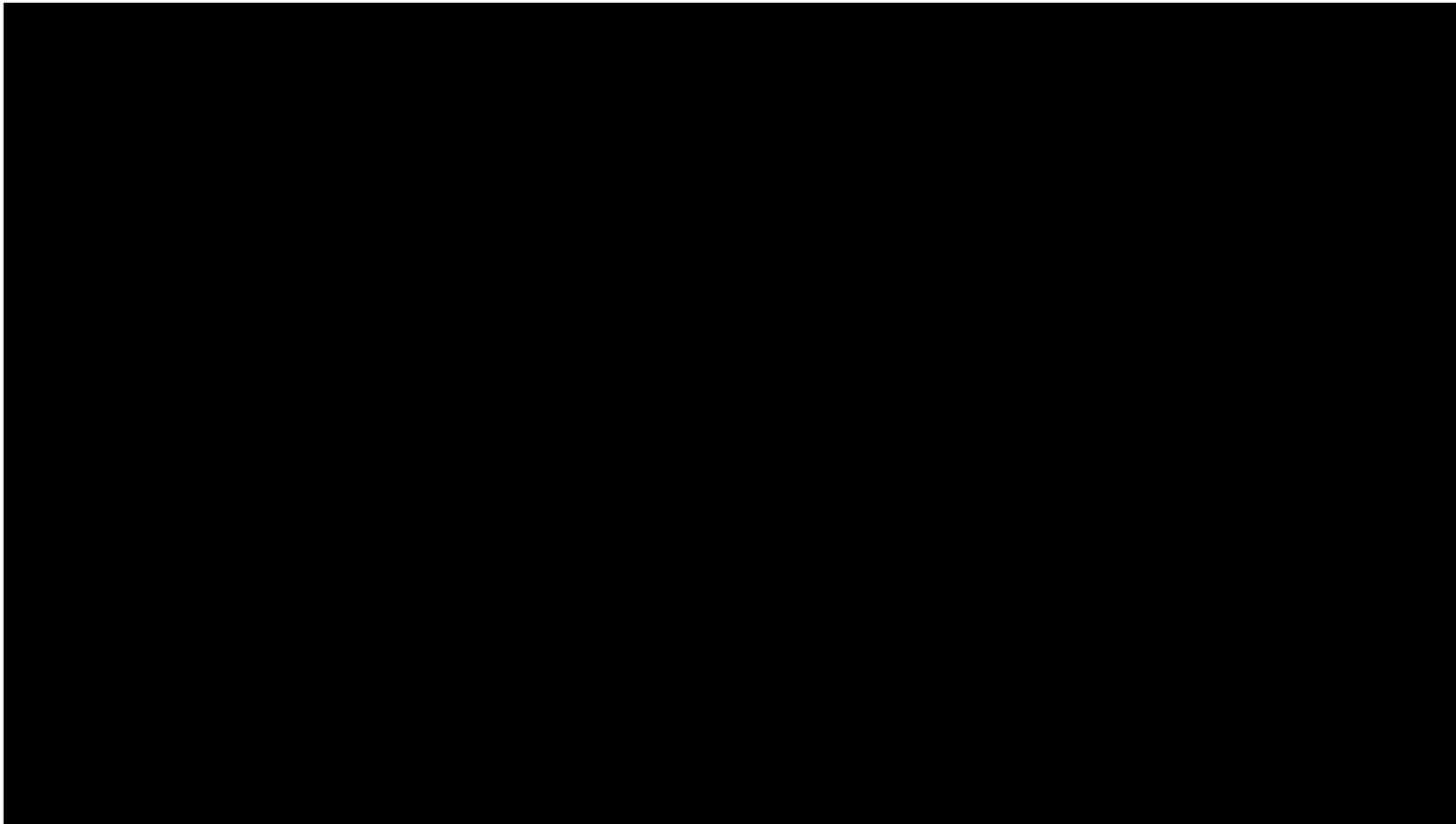
Hazard  
Creep

# Because Development is not Static



Hazard  
Creep

# Hazard Creep Animation



# Types of Dams

## ▶ Embankment Dams

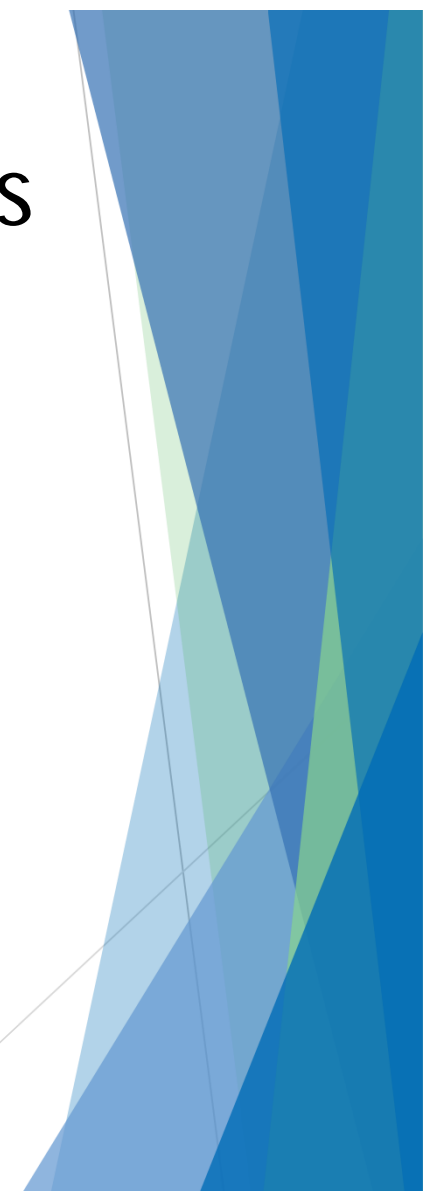
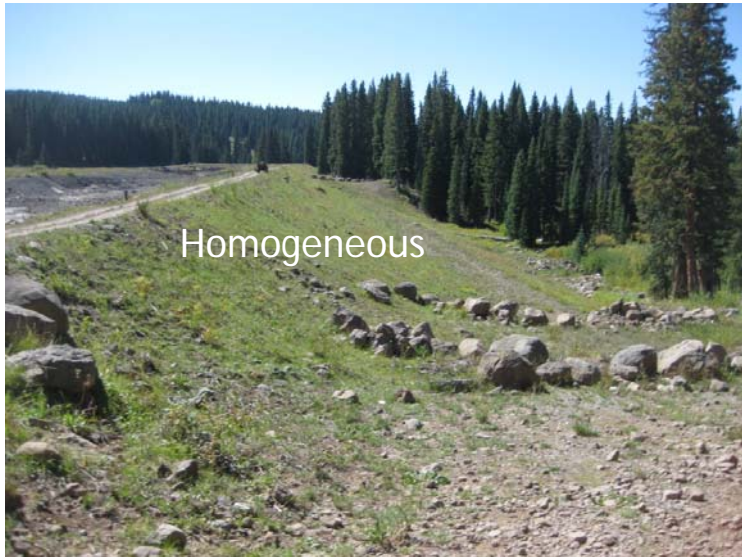
- constructed out of natural soil and/or rock materials as a compacted mass
- variable engineering properties

## ▶ Concrete Dams

- constructed of concrete, a rigid man-made structural material
- controlled engineering properties

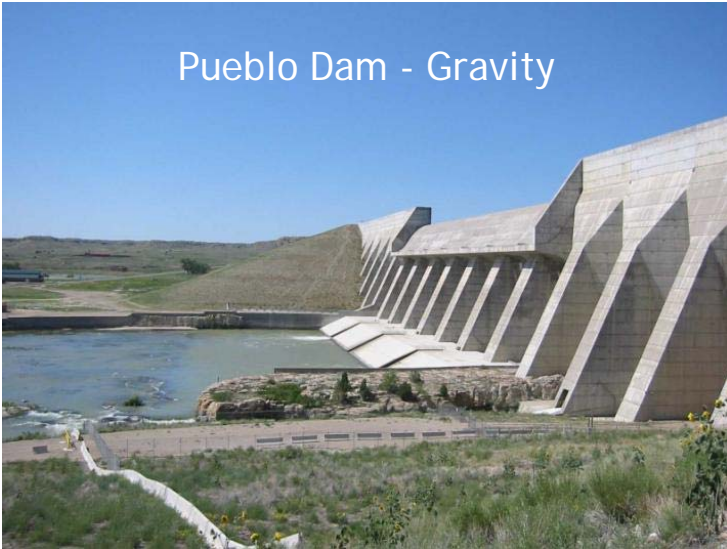


# Embankment Dams

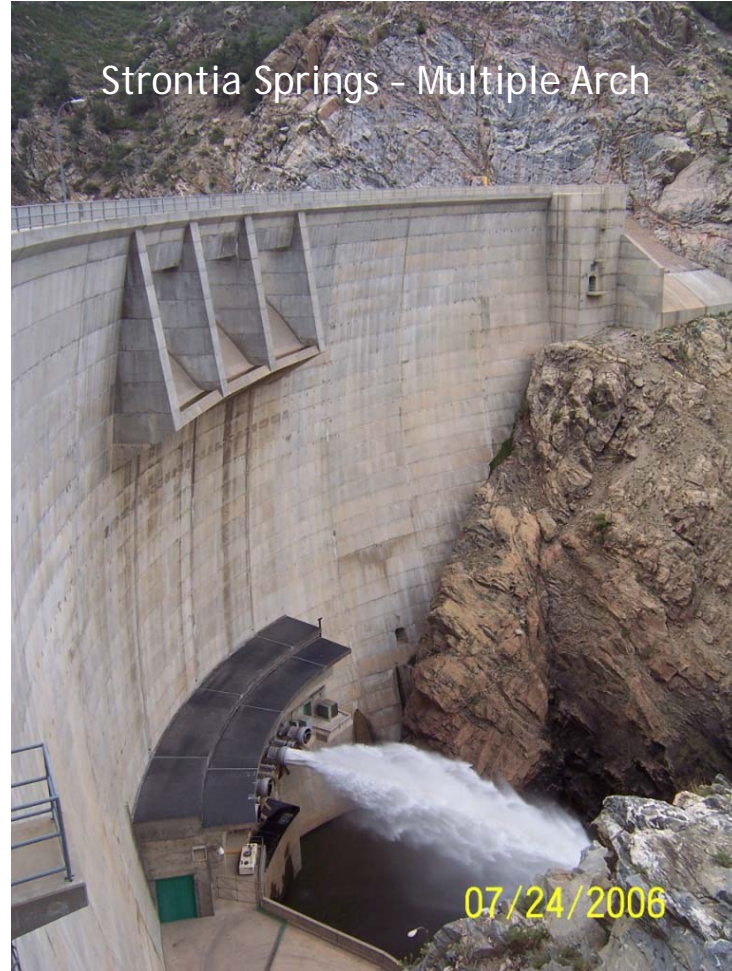


# Concrete Dams

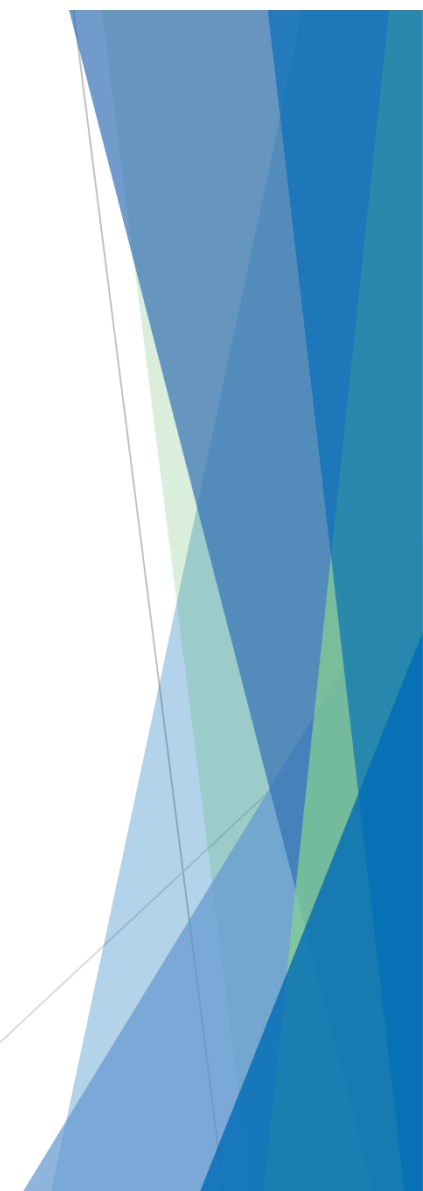
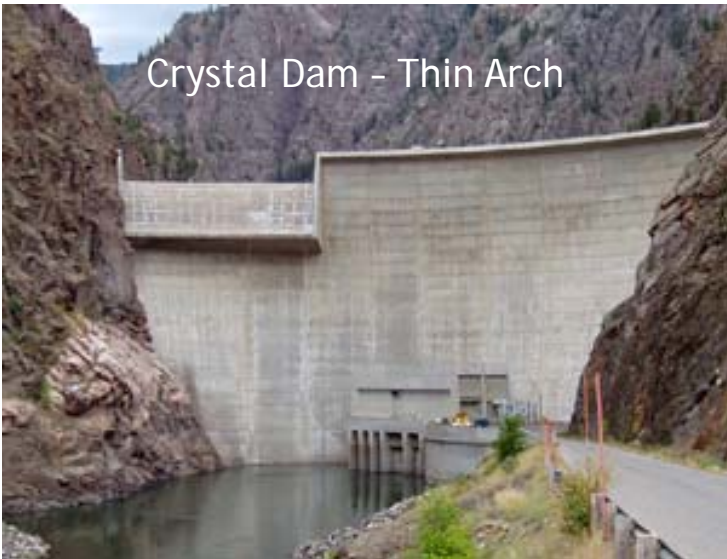
Pueblo Dam - Gravity



Strontia Springs - Multiple Arch

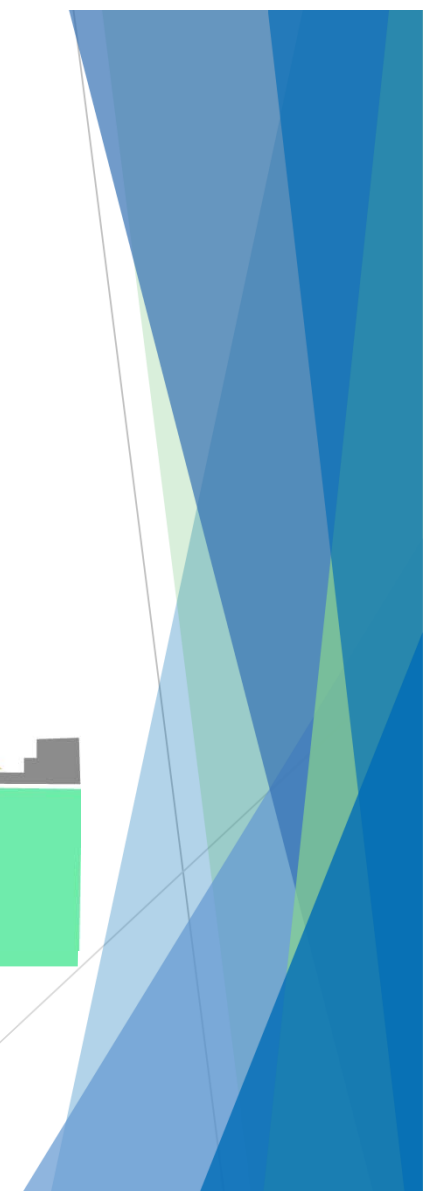
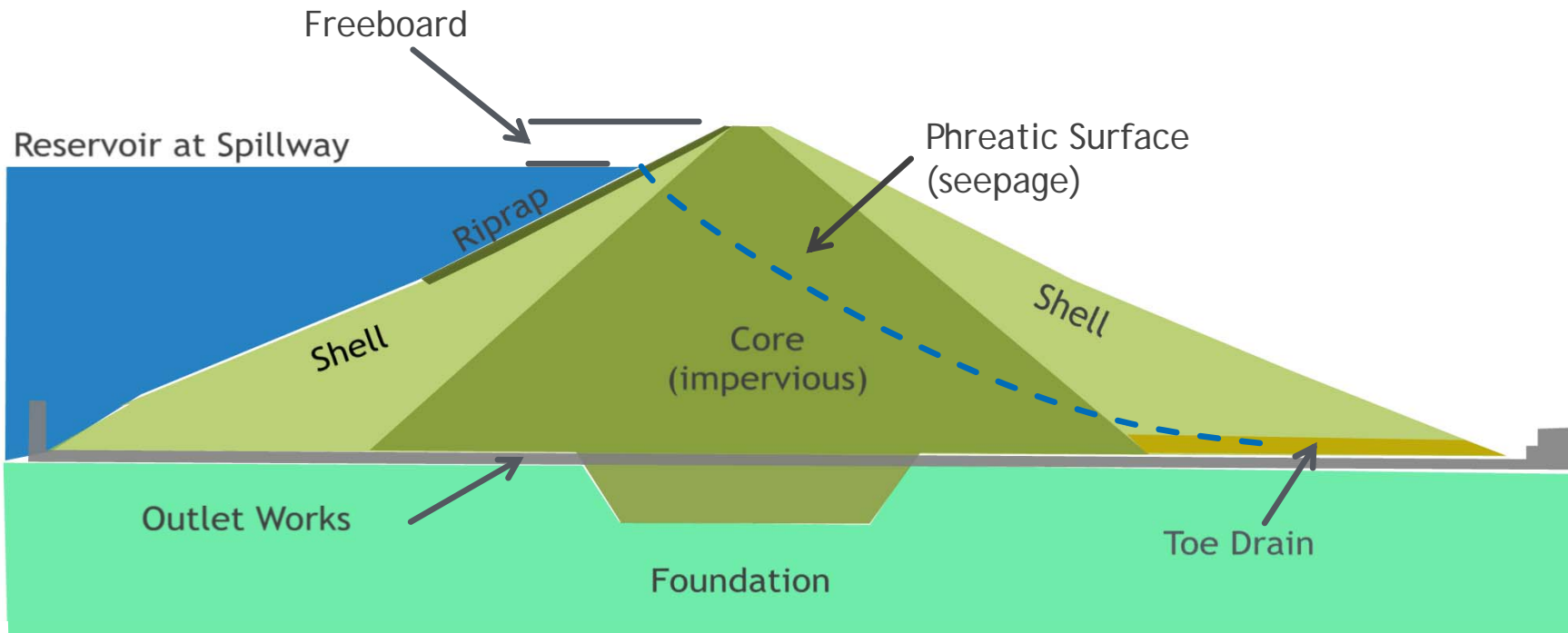


Crystal Dam - Thin Arch

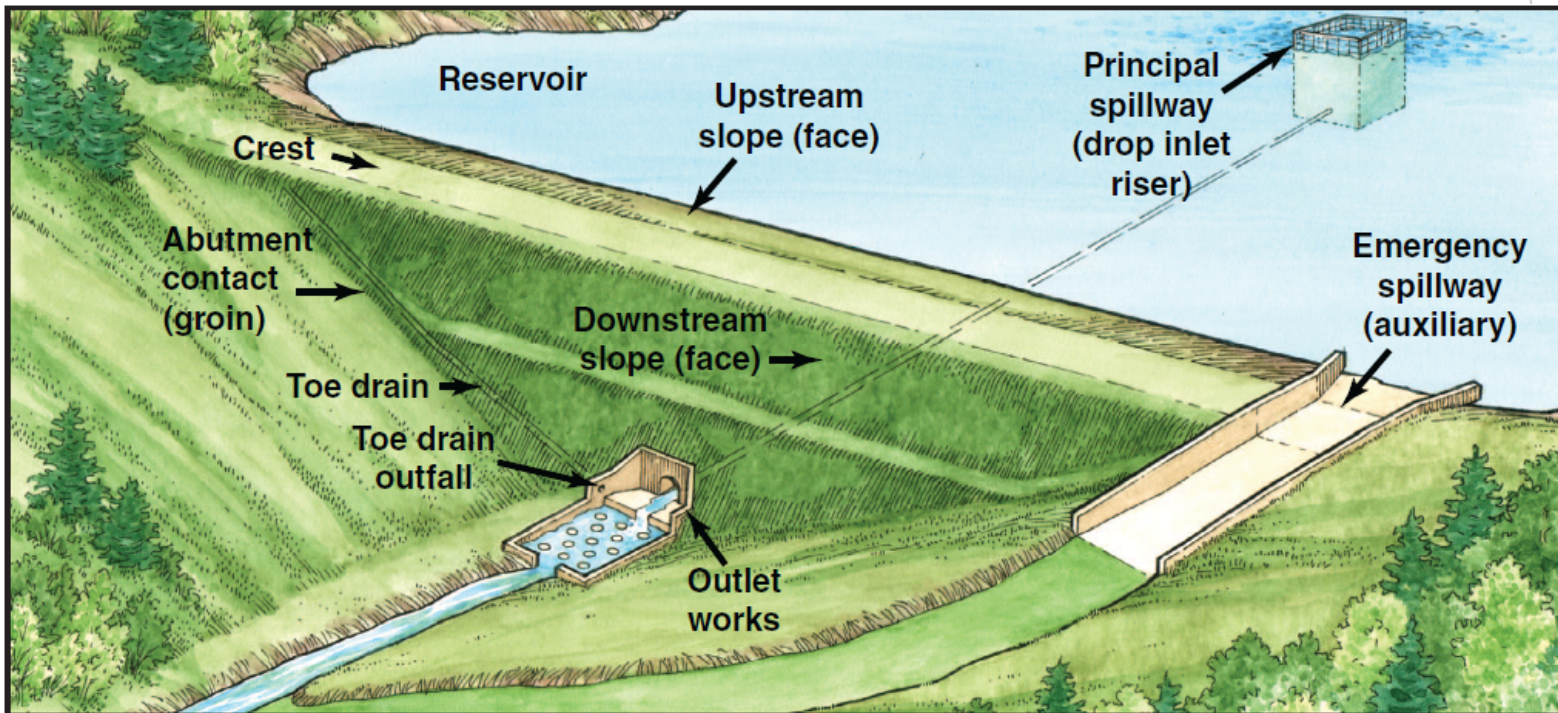




# Typical Earth Dam Section



# Typical Dam - Common Terms



Source: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center, 2012

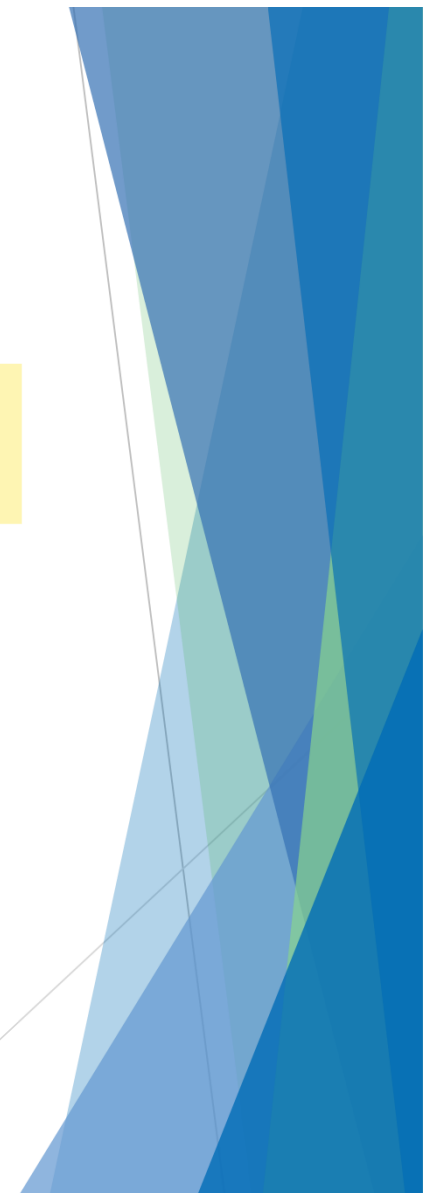
# Why Do Dams Fail?

▶ Water may pass from the reservoir to the downstream side by:

- Passing through the main spillway or outlet works
- Passing over an auxiliary spillway
- Overtopping the dam
- Seepage through the dam
- Seepage through the abutments
- Seepage under the dam

**PLANNED RELEASES**

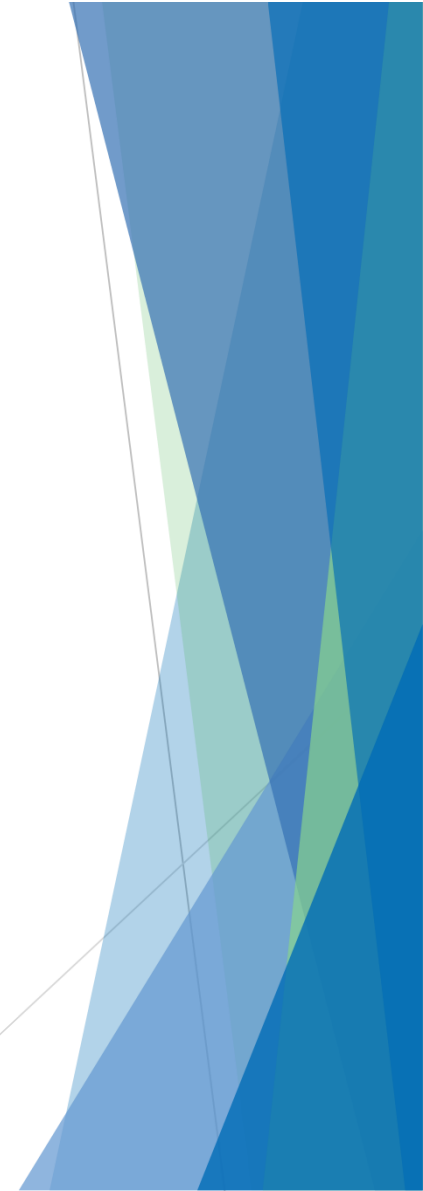
**UNPLANNED**



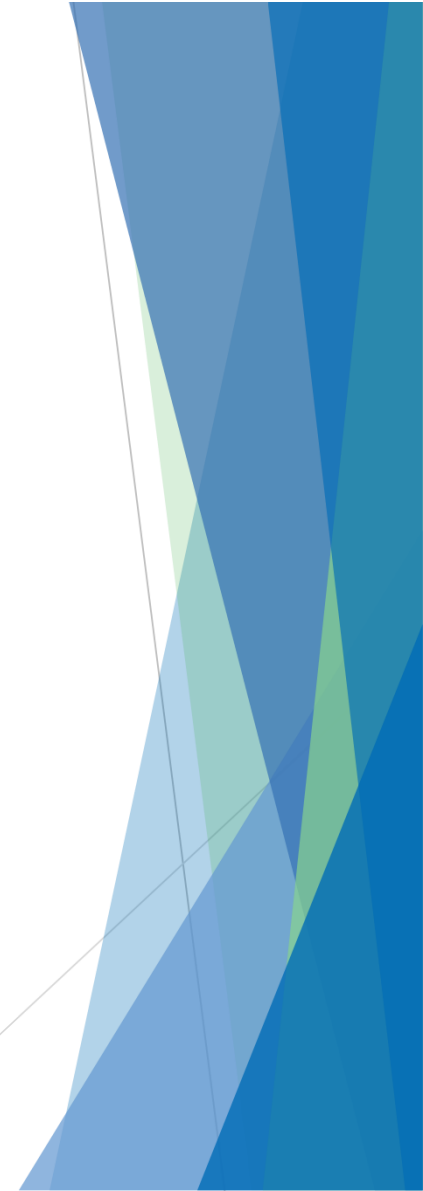
# Why Do Dams Fail? - Failure Modes

## Earth Dams

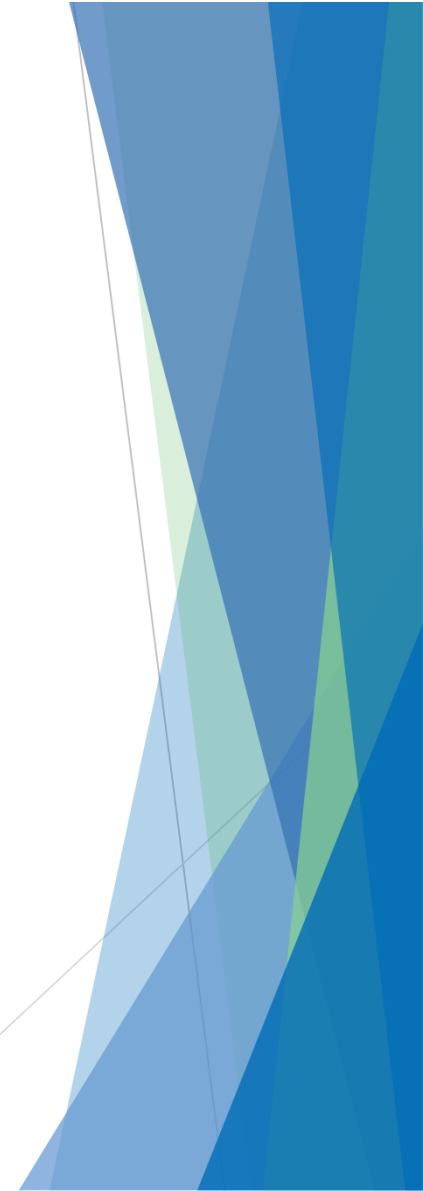
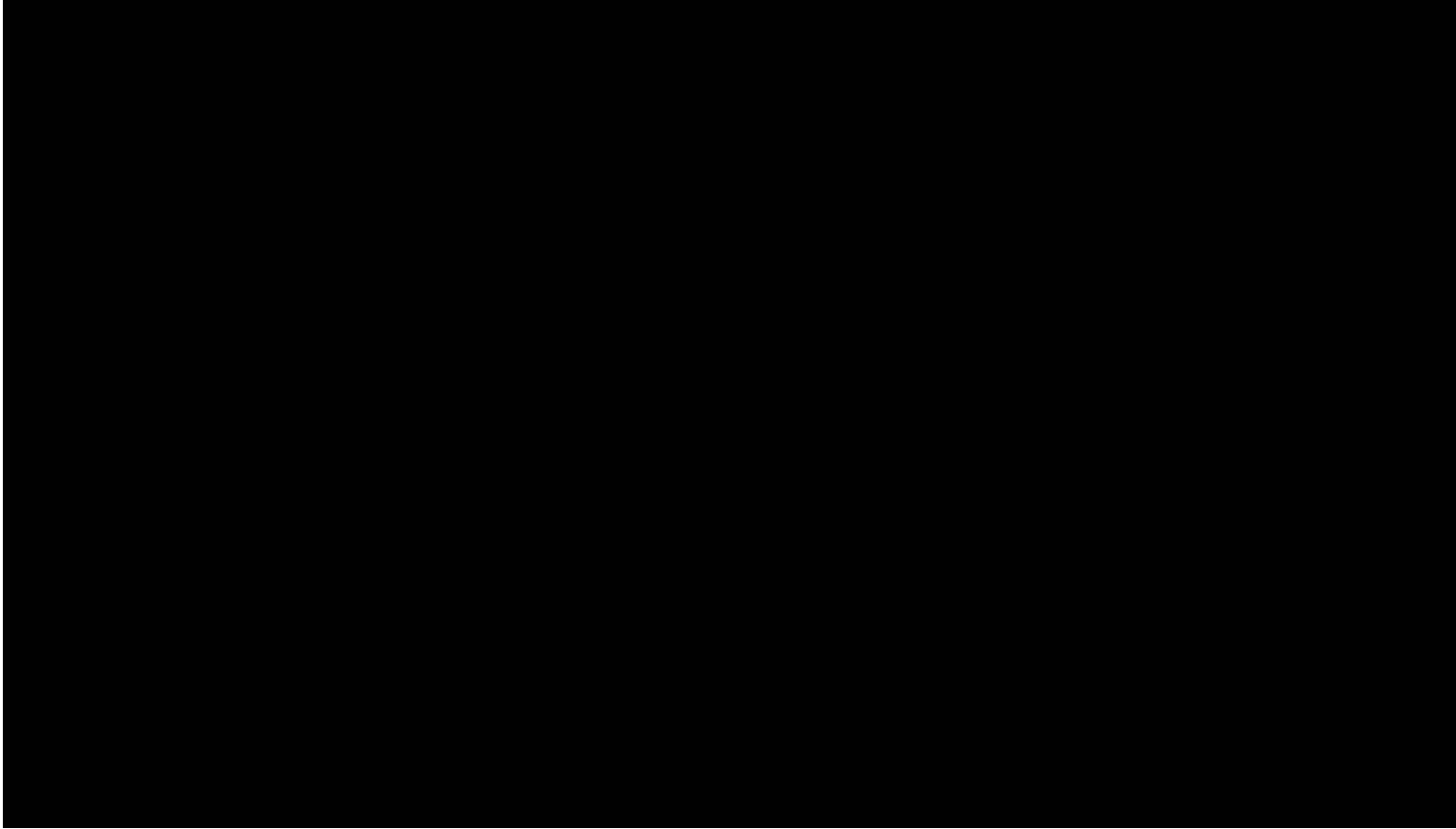
- ▶ Overtopping (48%)
- ▶ Piping/Internal Erosion (46%)
- ▶ Foundation (4%)
- ▶ Seismic (2%)



# *Dam Overtopping*



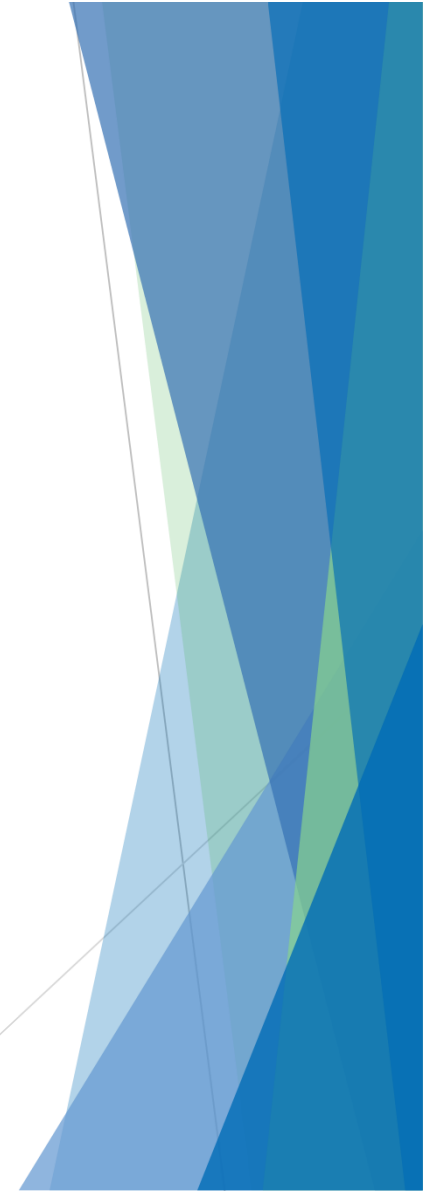
# ASDSO Overtopping Animation



# Dam Overtopping Failure



Meadow Dam, 7:30 am 9/12/13



# Piping/Internal Erosion

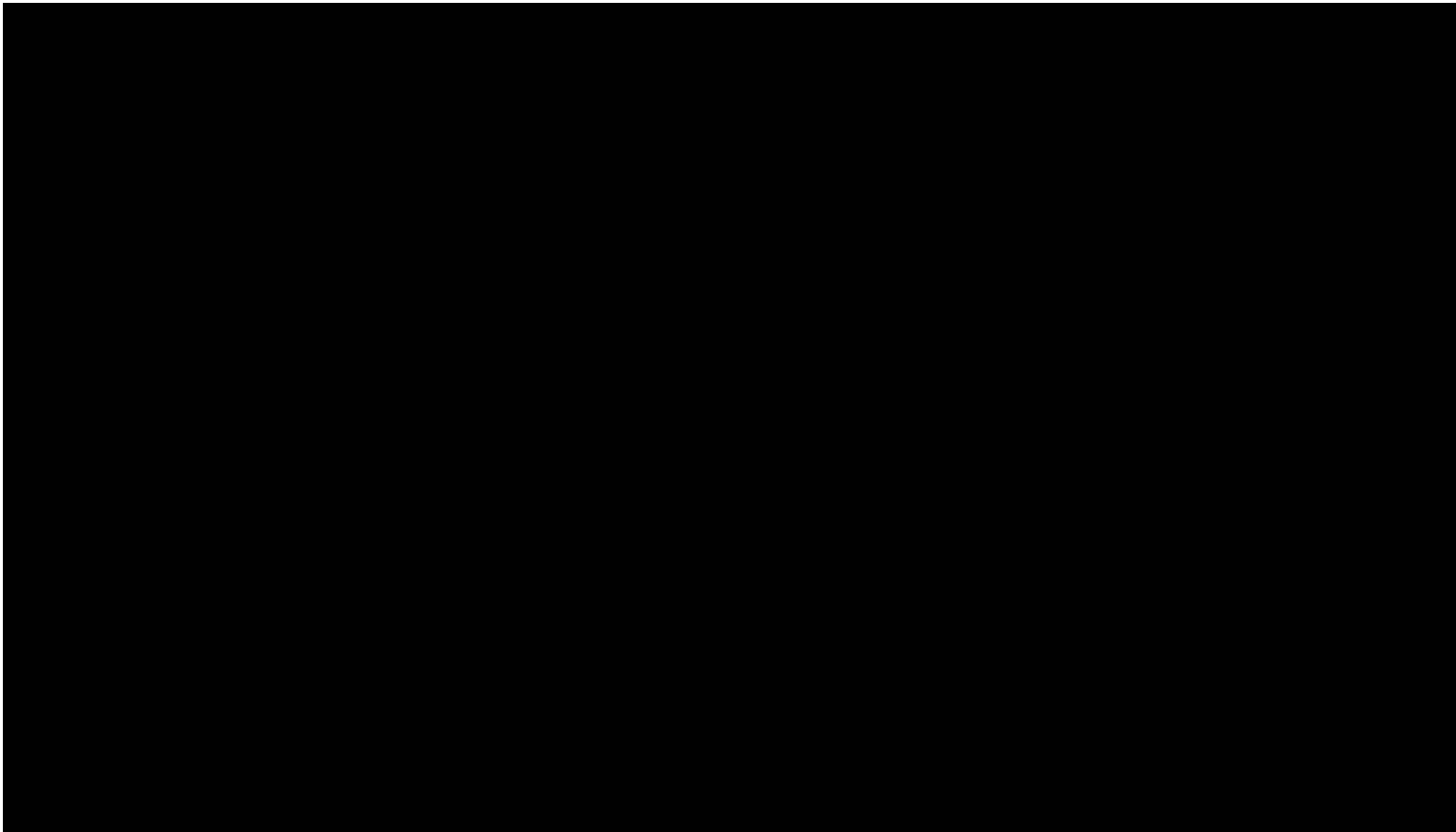


Internal erosion is the process where water that seeps through the dam carries soil particles away from the embankment, foundation or abutments of the dam.

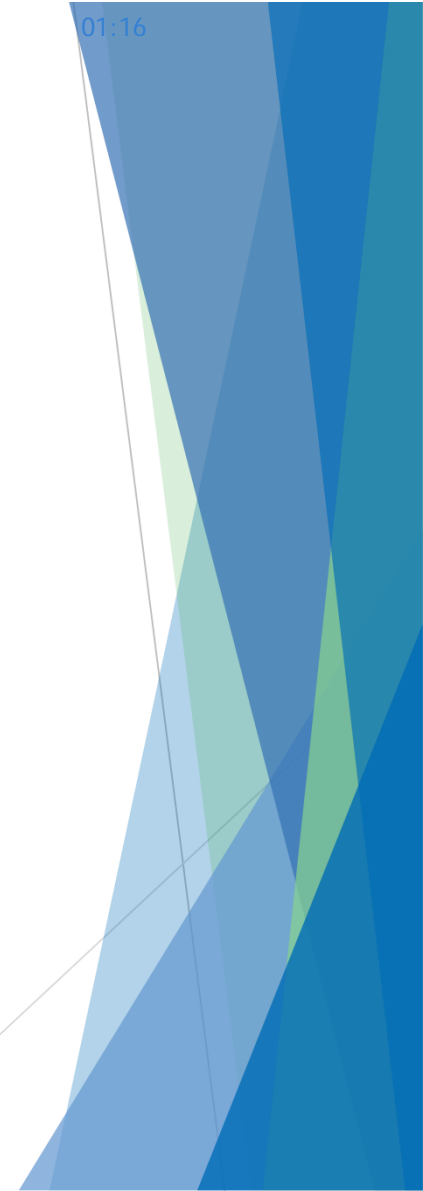




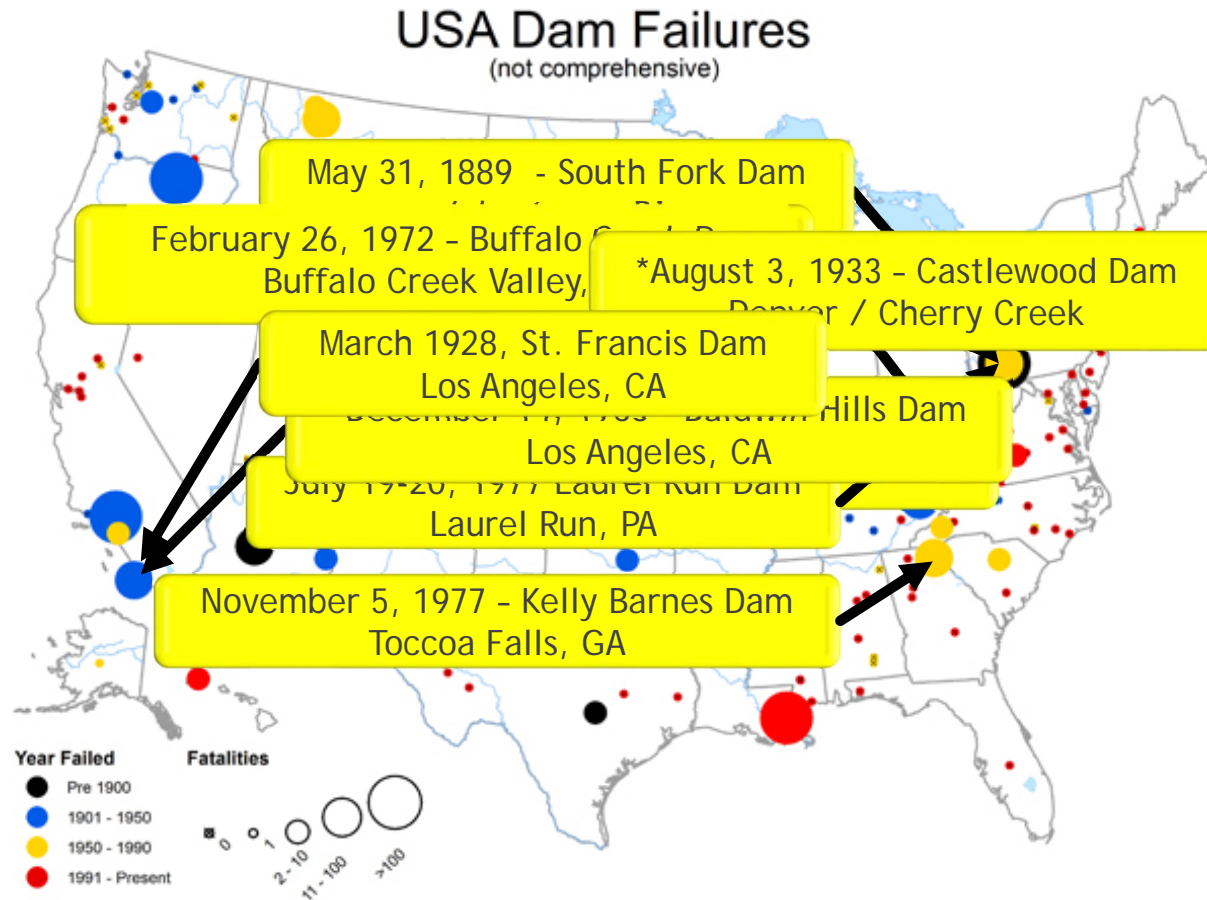
# ASDSO Piping Animation



01:16

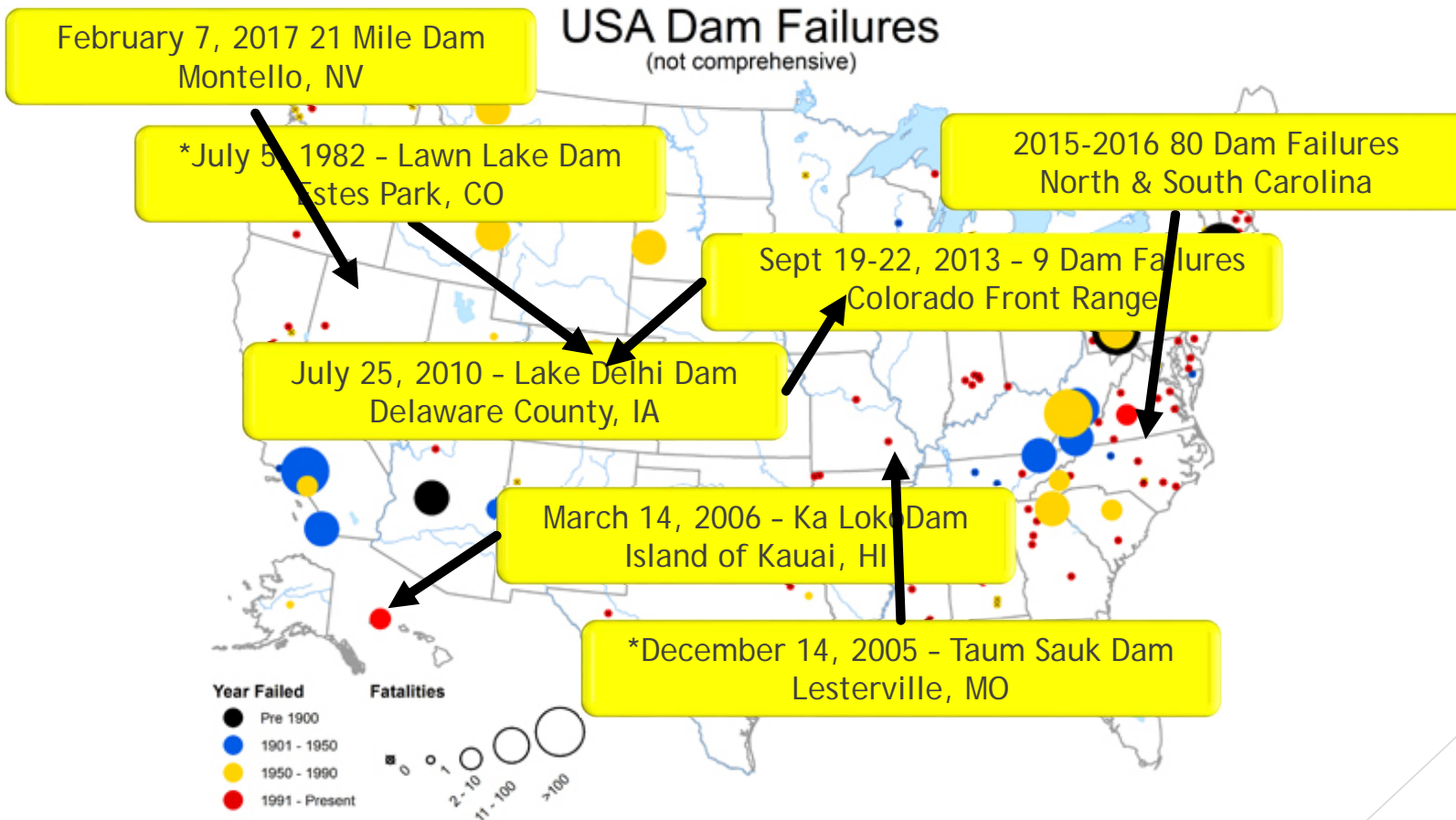


# Historically Significant Dam Failures



Map courtesy of James S. Halgren, Office of Hydrologic Development, National Weather Service, National Oceanic and Atmospheric Administration

# Recent Dam Failures



Map courtesy of James S. Halgren, Office of Hydrologic Development, National Weather Service, National Oceanic and Atmospheric Administration

# Notable U.S. Dam Failures

- ▶ South Fork Dam, PA 1889
- ▶ Teton Dam, ID 1976
- ▶ Ka Loko Dam, HI 2006
- ▶ 21 Mile Dam, NV 2017



# South Fork Dam (Johnstown Flood)

- ▶ Pennsylvania,
  - ▶ May 31, 1889
  - ▶ (Memorial Day)
- ▶ aka Johnstown Flood
- ▶ Dam Characteristics:
  - ▶ Dam type: Earthfill
  - ▶ Dam height: 72 feet
  - ▶ Crest length: 918 ft
  - ▶ Reservoir volume:  
11,500 acre-feet



South Fork Dam failure photos courtesy of Johnstown Flood Museum (<http://www.jaha.org>)

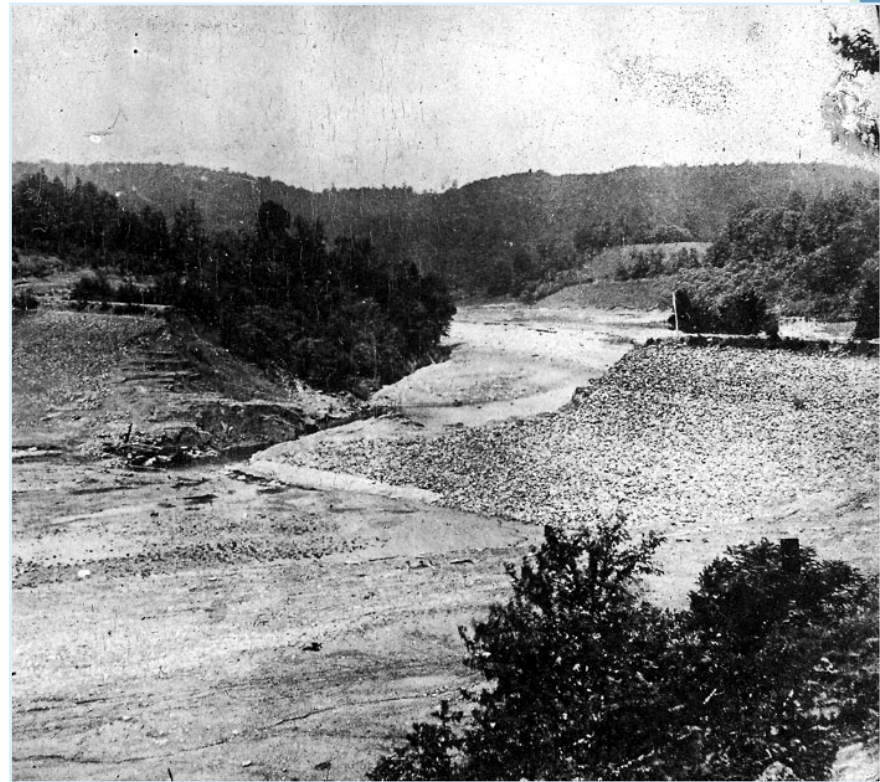
# South Fork Dam (Johnstown Flood)

- ▶ Incident:
  - ▶ Heavy rains for several days
  - ▶ Spillway partially blocked by fish screen to prevent fish loss from recreational lake
  - ▶ Crest lowered to accommodate 2-way carriage access
  - ▶ Overtopping failure due to spillway inadequacy.
  - ▶ 2,209 fatalities.
  - ▶ Mass destruction in Johnstown, PA



# South Fork Dam (Johnstown Flood)

Cause: Inability of dam to pass incoming flood event.



# South Fork Dam (Johnstown Flood)

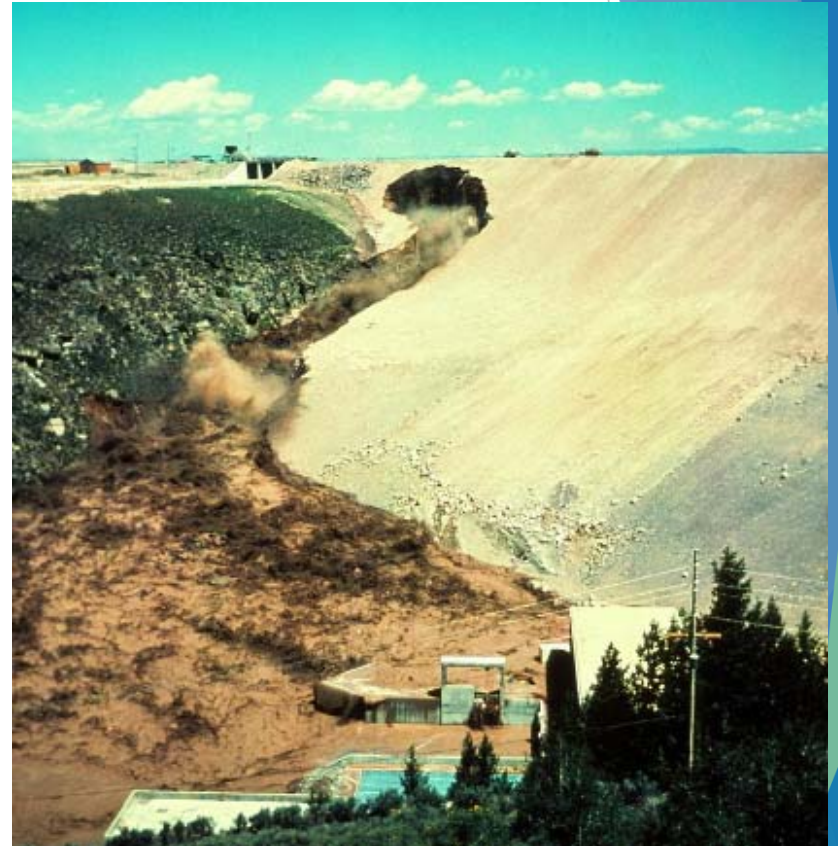
- ▶ Lessons learned:
  - ▶ Lack of engineering in repair and operation of dam
  - ▶ Lack of failure detection and downstream warning.
  - ▶ Lack of knowledge of hazard potential





# Teton Dam

- ▶ Idaho
  - ▶ Sat., June 5, 1976
- ▶ Dam Characteristics:
  - ▶ Dam type: Earthfill
  - ▶ Dam height: 305 feet
  - ▶ Dam crest length: 3,100 ft
  - ▶ Reservoir volume:  
300,000 acre-feet
  - ▶ Spillway: Reservoir water never reached spillway crest



Teton failure slides courtesy of John France, AECOM

# Teton Dam

## ▶ Incident:

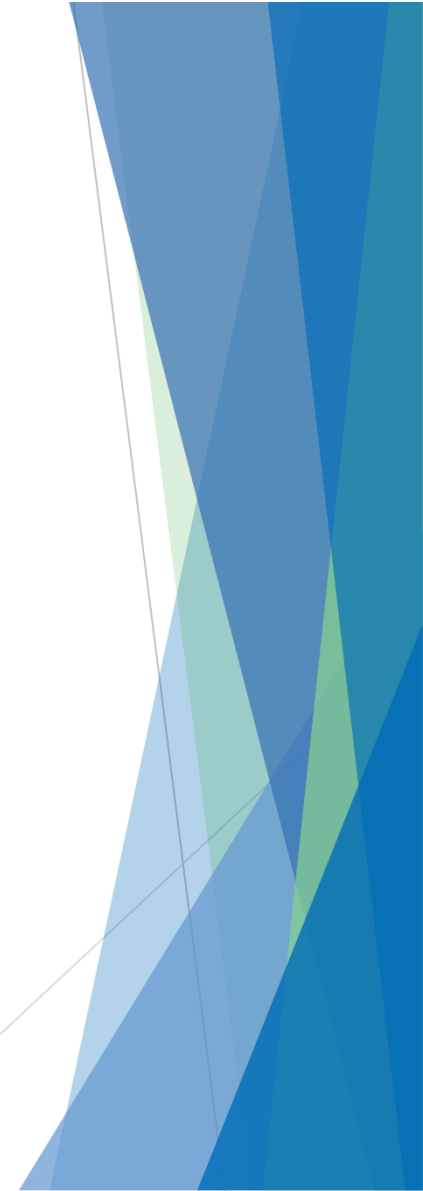
- ▶ Seepage and internal erosion leading to catastrophic failure
- ▶ 11-14 fatalities.
- ▶ Mass destruction in Rexburg and Sugar City, ID
- ▶ Over half billion dollars in damage



# Teton Dam



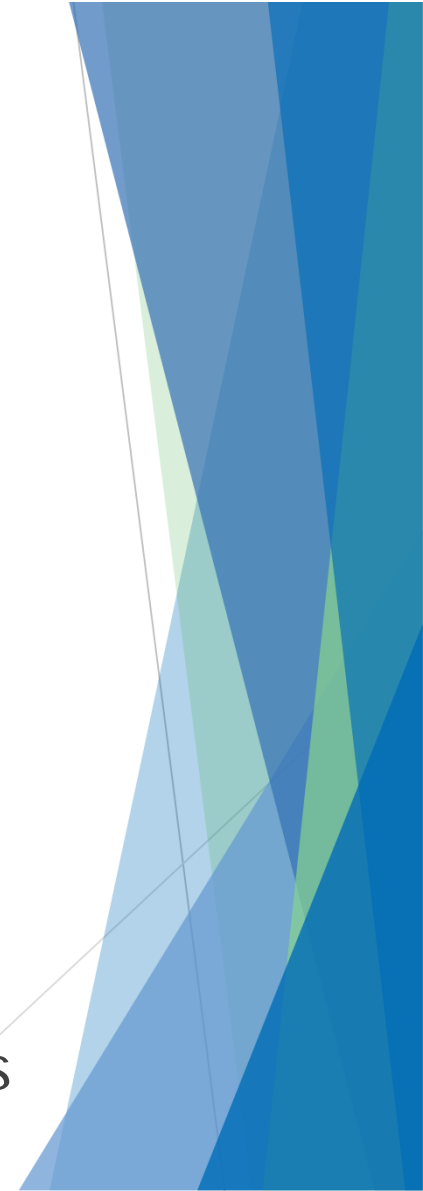
8:30 am - Muddy flow observed from right downstream toe, estimated 20 to 30 cfs.



# Teton Dam

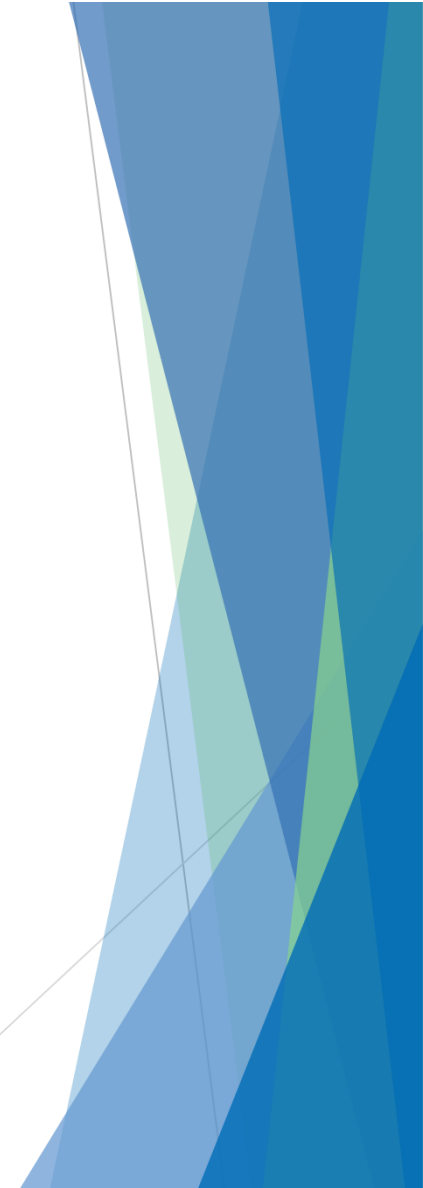
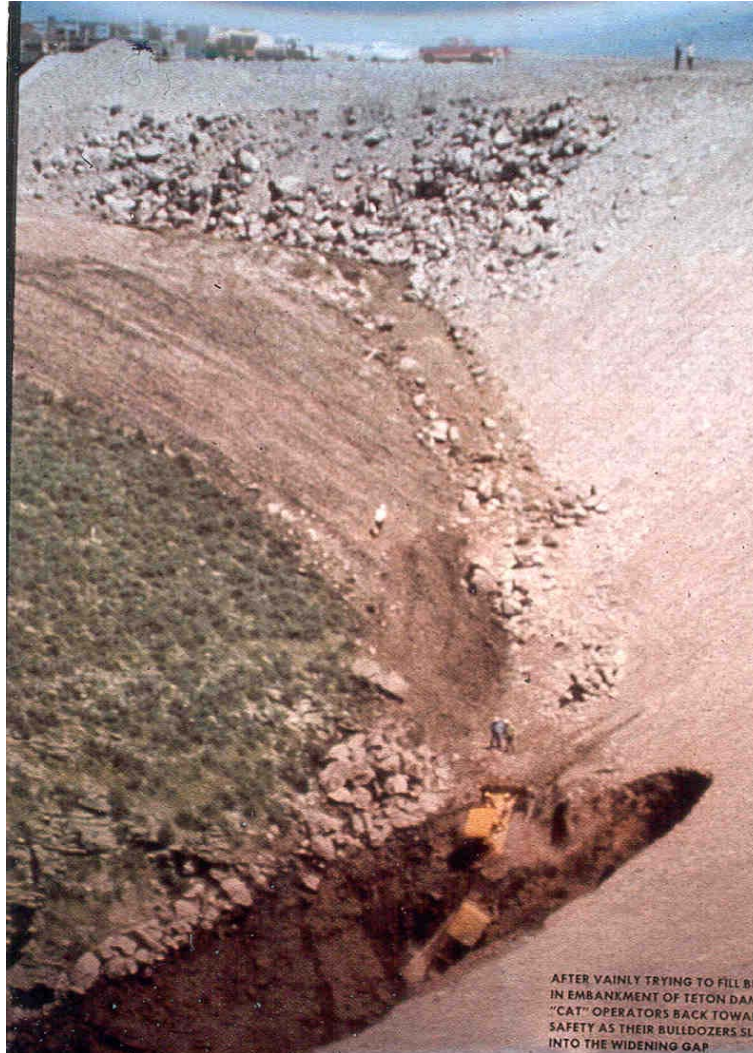


10:40 am - Flow increasing, two bull dozers sent to fill quickly expanding hole



# Teton Dam

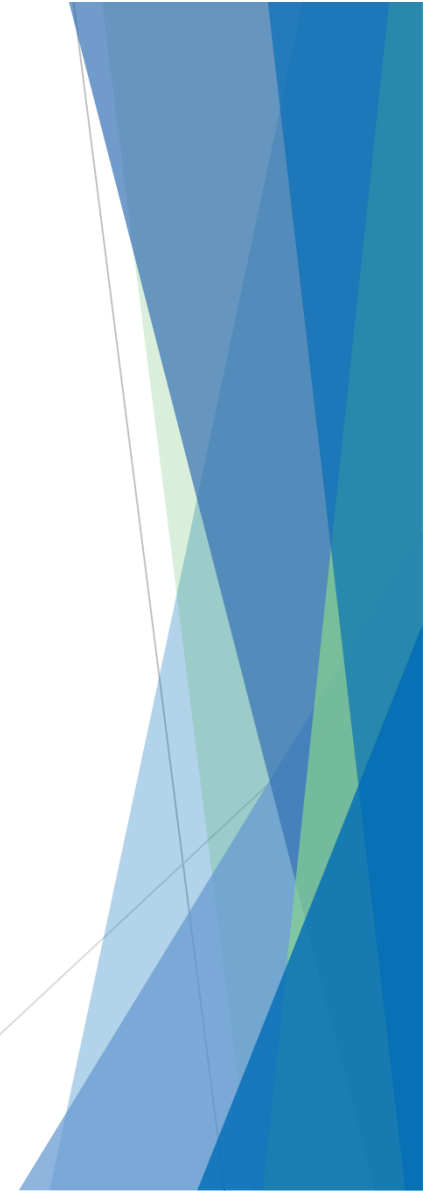
11:20 am - Bull dozers slide into sinkhole, operators escape



# Teton Dam



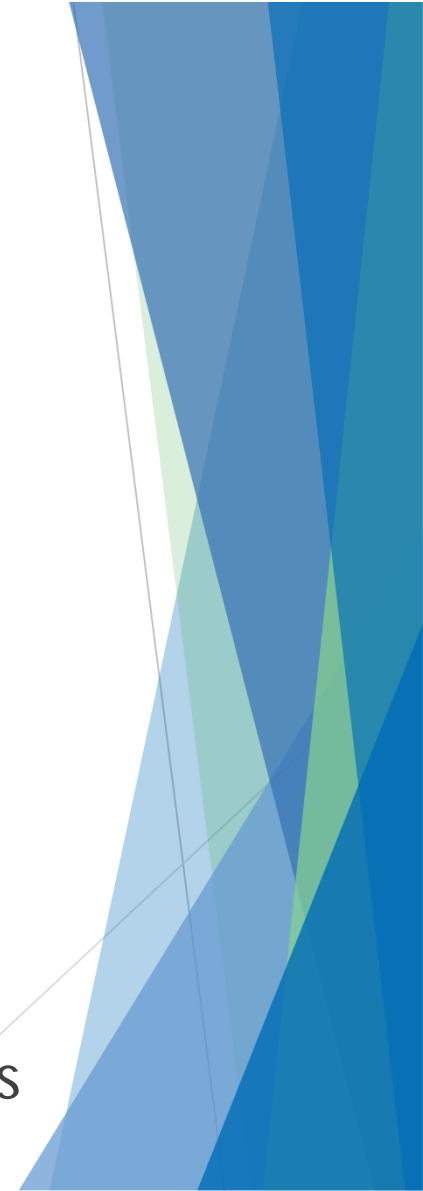
11:25 am - sinkhole expands up the downstream face



# Teton Dam



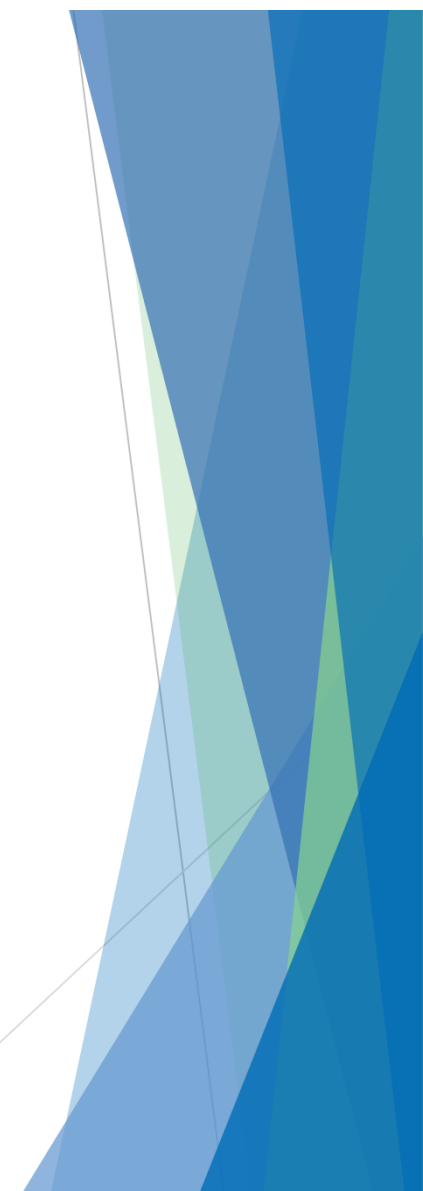
Approximately 11:30 am - sinkhole continues  
up toward dam crest



# Teton Dam



11:32 am - Second sinkhole appears

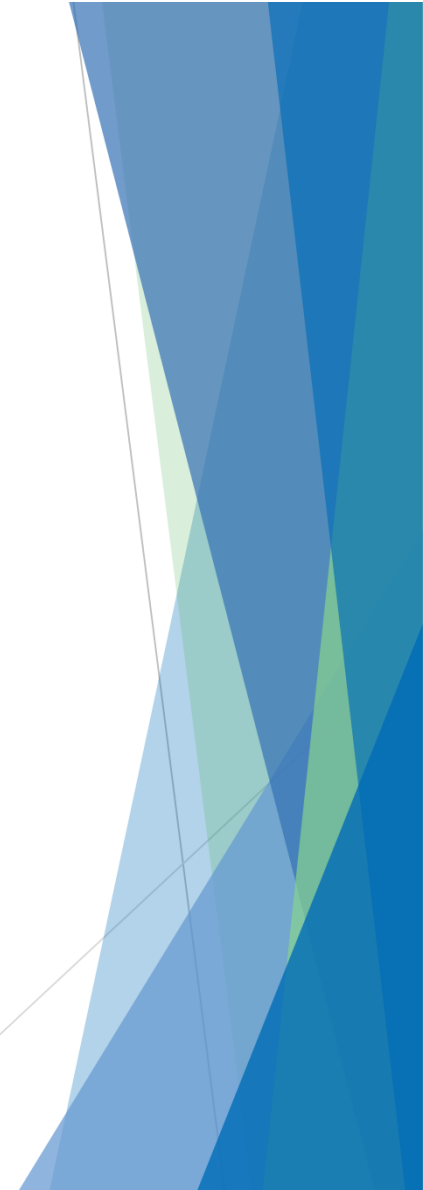




# Teton Dam



11:50 am - Large masses of embankment caving into sinkhole



# Teton Dam

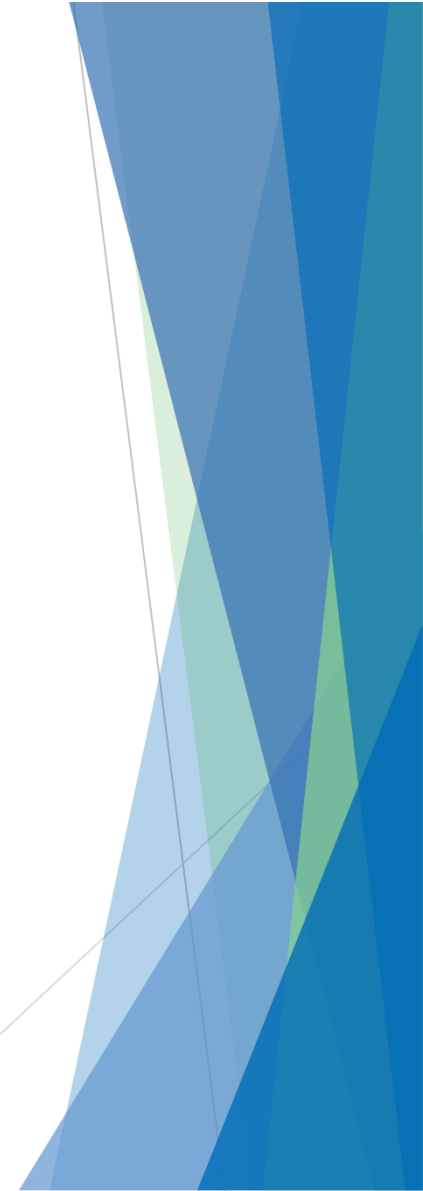


11:55 am - Dam crest collapses into breach

# Teton Dam



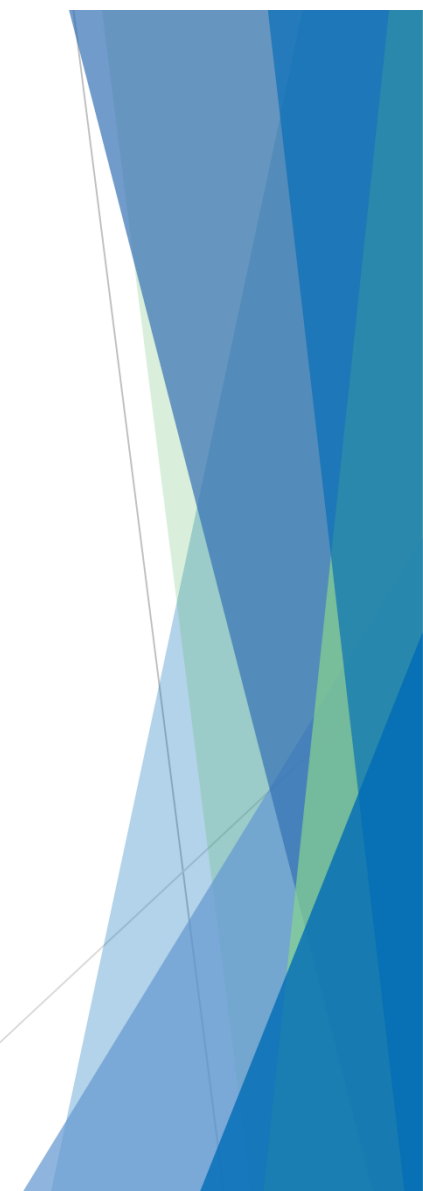
11:55 am - Reservoir breaches through dam crest (3 hrs 25 min)



# Teton Dam



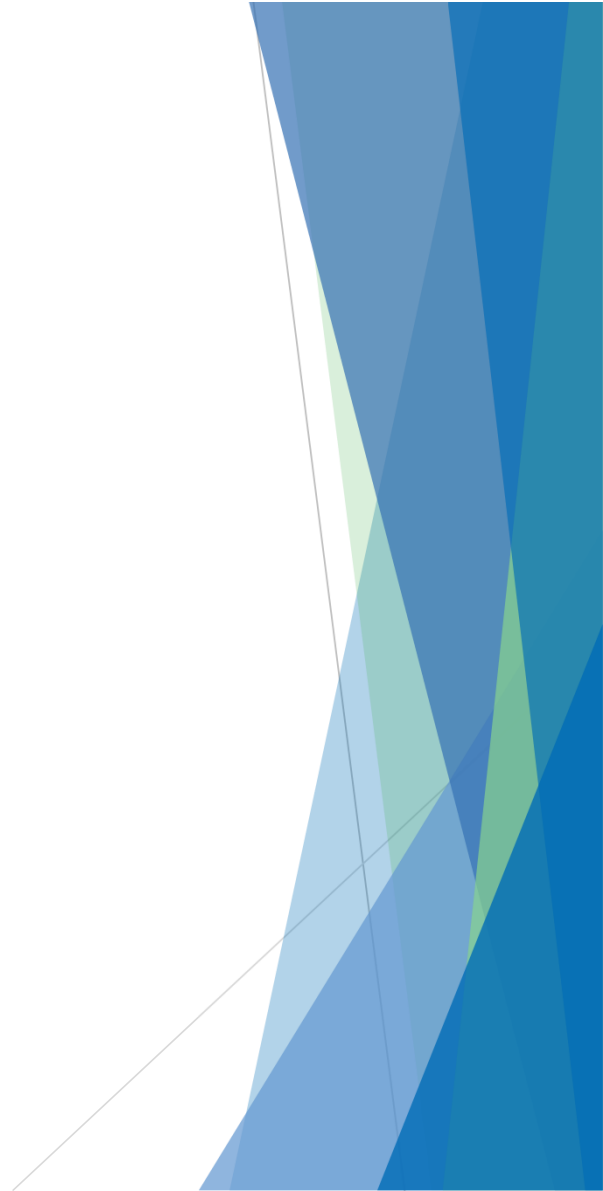
Breach widens as reservoir is uncontrollably released



# Teton Dam



Rexburg, Idaho



# Teton Dam

- ▶ Lessons learned:
  - ▶ Change in engineering design
  - ▶ Importance of seepage control
  - ▶ Importance of geology
  - ▶ Example of first-fill failure
  - ▶ Hallmark event for national dam safety



# Ka Loko Dam

- ▶ Hawaii
  - ▶ 2:30 am, March 14, 2006
- ▶ Dam Characteristics:
  - ▶ Dam type: Earthfill, 1890
  - ▶ Dam height: 44 feet, enlarged 1911
  - ▶ Reservoir volume: 1,500 acre-feet (approx.)



Ka Loko failure slides courtesy of Wayne Graham, USBR, retired

# Ka Loko Dam

## ▶ Incident

- ▶ Overtopping failure due to heavy rain
- ▶ Spillway filled in to increase storage
- ▶ Release of 1,400 acre-feet
- ▶ 7 fatalities, including a toddler and pregnant woman
- ▶ Significant property damage





# Ka Loko Dam

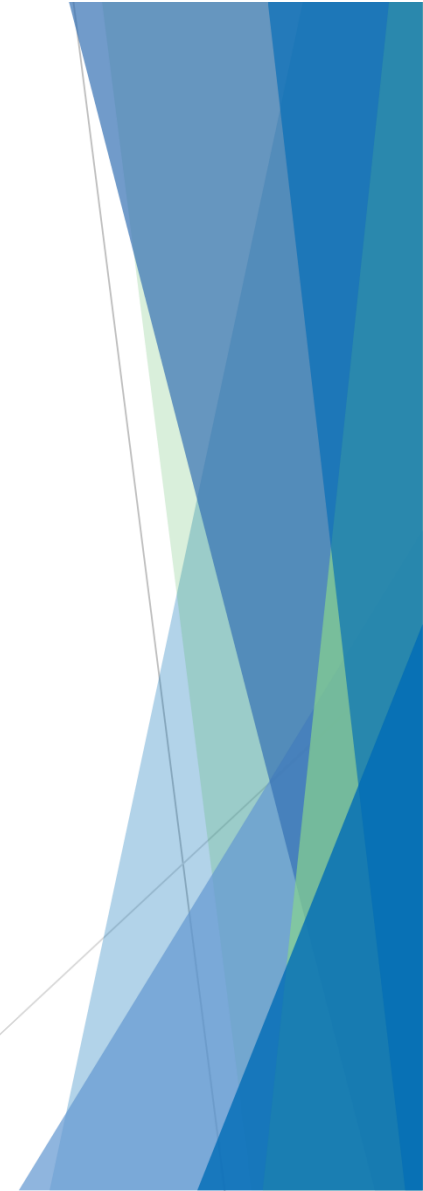
Destruction between  
dam and ocean  
along steep channel



# Ka Loko Dam



Discharge into ocean



# Ka Loko Dam

- ▶ Lessons Learned
  - ▶ Low Hazard Classification at time of failure
  - ▶ Minimal State dam safety program at time of failure
  - ▶ Several pending civil lawsuits
  - ▶ Independent investigations
  - ▶ Criminal investigation

Report of the Independent Civil Investigation  
of the  
March 14, 2006, Breach of Ka Loko Dam

Robert Carson Godbey  
*Special Deputy Attorney General*

January 2007

**Volume 1**

# Ka Loko Dam



**Dam Safety Program**  
Department of Land and Natural Resources  
State of Hawaii

- Program Overview
- Objectives
- Dam Inventory
- Regulations
- Forms/Applications
- Hazard Classification
- References

**Program Overview**  
The [Hawaii Dam and Reservoir Safety Act of 2007](#) mandates the Board provide for the inspection and regulation of construction, enlargement, operation, and removal of dams or reservoirs to protect the health, safety, and welfare of the State by reducing the risk of failure of the dams or reservoirs.

## ▶ Lessons Learned

- ▶ Creation of Hawaii State Dam Safety Program
- ▶ Owner accused of filling in spillway to create building lots

**PACIFIC BUSINESS NEWS**

From the Pacific Business News:

[http://www.bizjournals.com/pacific/blog/morning\\_call/2012/01/06/ka-loko-dam-accused-of-filling-in-spillway-to-create-building-lots-for.html](http://www.bizjournals.com/pacific/blog/morning_call/2012/01/06/ka-loko-dam-accused-of-filling-in-spillway-to-create-building-lots-for.html)

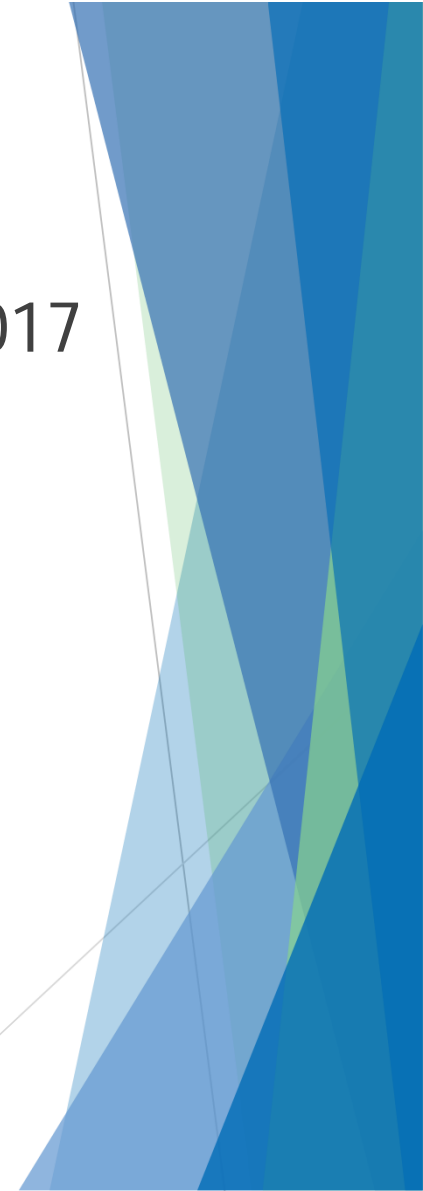
## Attorneys agree on October for Pflueger manslaughter trial

Pacific Business News

Date: Friday, January 6, 2012, 7:25am HST

# 21 Mile Dam, NV

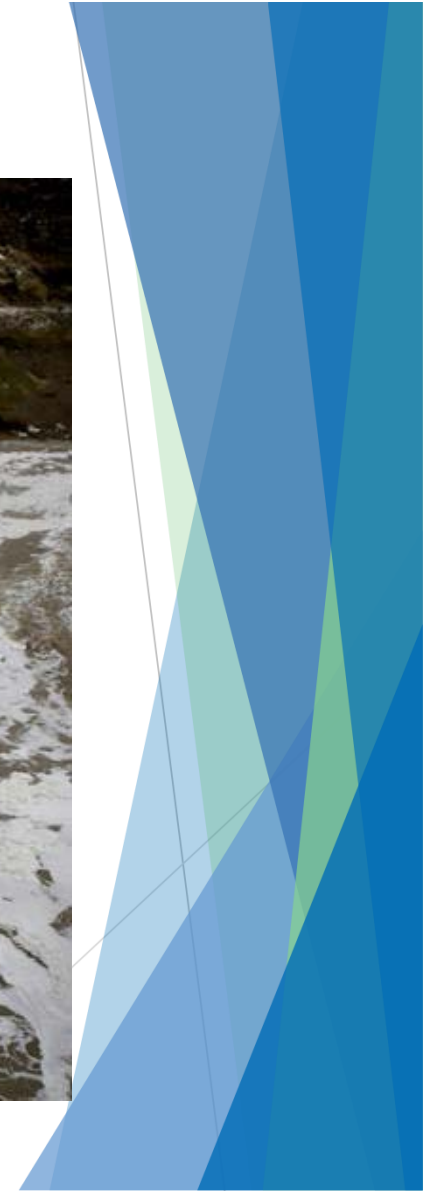
- ▶ Embankment dam overtopped on February 7, 2017
- ▶ Dam failure flows flooded about 30 homes in Montello, NV
- ▶ 10 miles of Nevada State Route 233 was closed
- ▶ 65 miles of Highway 93 was closed
- ▶ Union Pacific railroad trains were stopped or rerouted



# 21 Mile Dam, NV

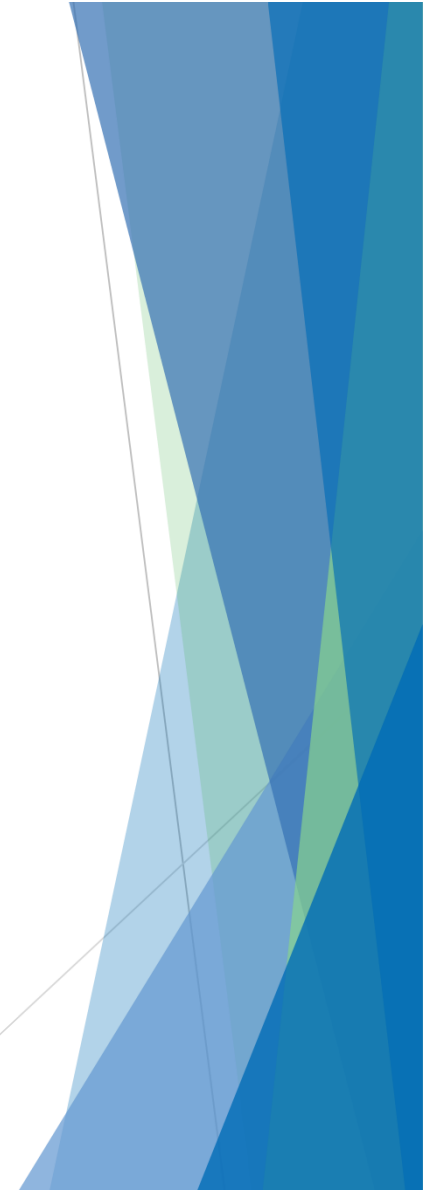


- ▶ Lessons Learned:
  - ▶ Effective NWS warnings saved lives



# Why Study Dam Failures?

- ▶ Dams are man-made structures and do fail
- ▶ False sense of complacency can lead to catastrophic consequences
- ▶ Build upon past experiences
- ▶ Strengthening of Dam Safety awareness, engineering design and emergency preparedness

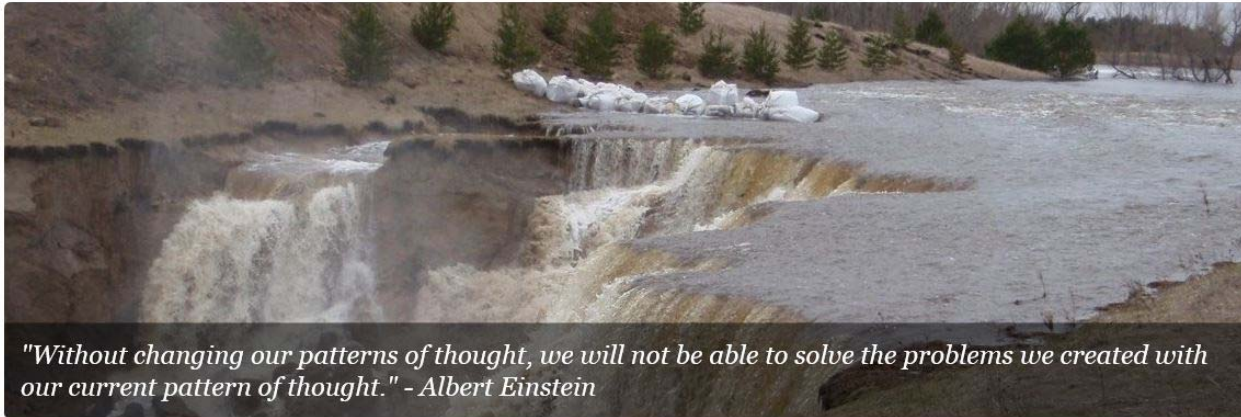




## Lessons Learned

From Dam Incidents and Failures

[Home](#) [Lessons Learned](#) [Case Studies](#) [Resources](#) [About](#)



*"Without changing our patterns of thought, we will not be able to solve the problems we created with our current pattern of thought." - Albert Einstein*



### Lessons Learned

See the lessons learned from dam incidents and failures.

[Learn More](#)



### Case Studies

Learn more about historic dam incident and failure case studies.

[Explore](#)



### About

Find out more about this website and how you can contribute.

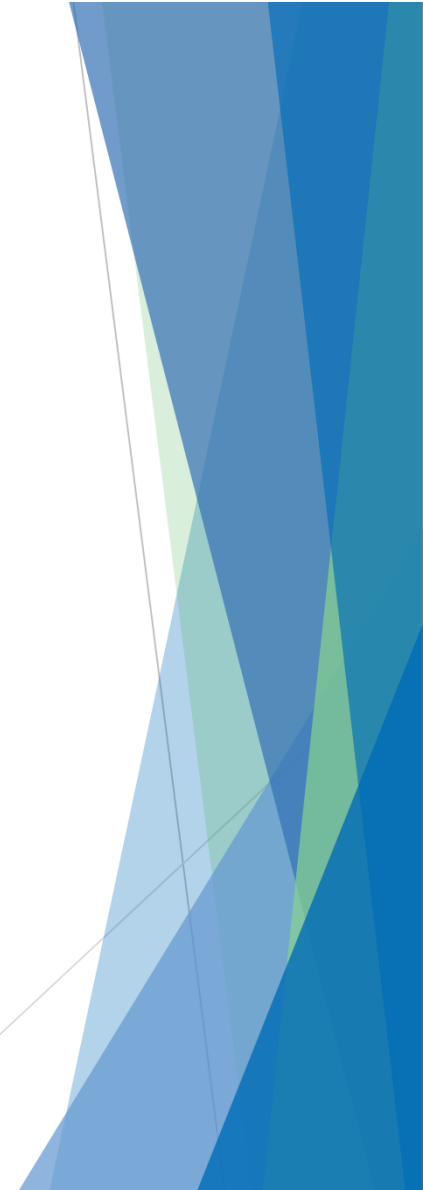
[About this Site](#)

# DamFailures.org

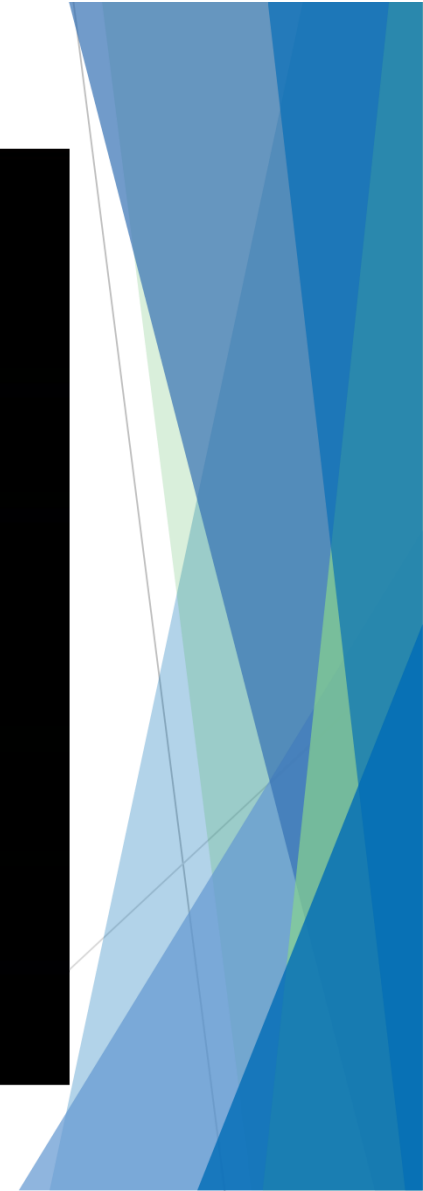


# Operational Releases

- ▶ Colorado in 2013, 2015
- ▶ NC, SC 2015 & 2016
- ▶ Oroville and Houston in 2017
- ▶ Other
- ▶ Events Show dams operating as designed but still cause dangerous flooding downstream



# *Flood Operation Releases - September 2013*

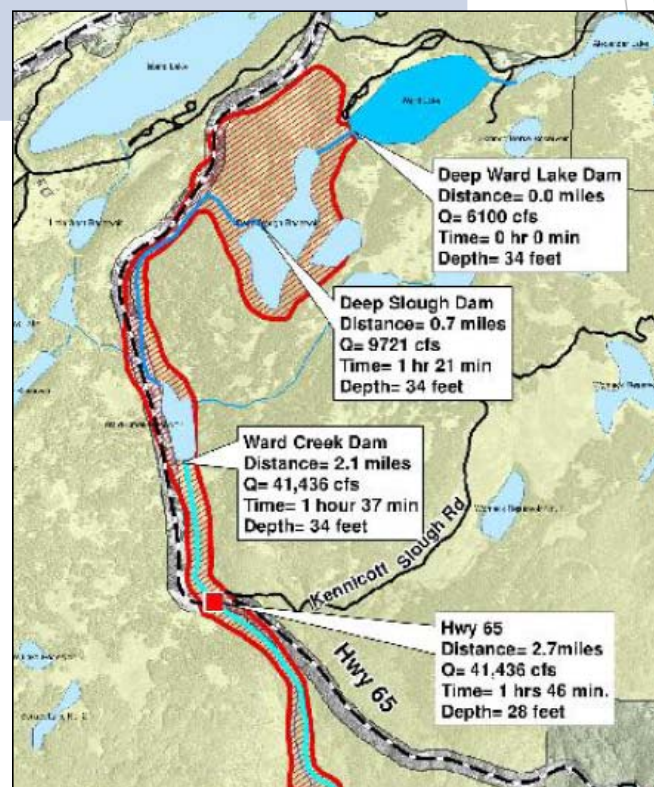


# Inundation Mapping Primer

Location	100-year Peak Flow	Routed Dam Failure Peak Flow
Ward Creek at 11.5 miles below Ward Lake dam	1,010 cfs (USGS)	33,709 cfs

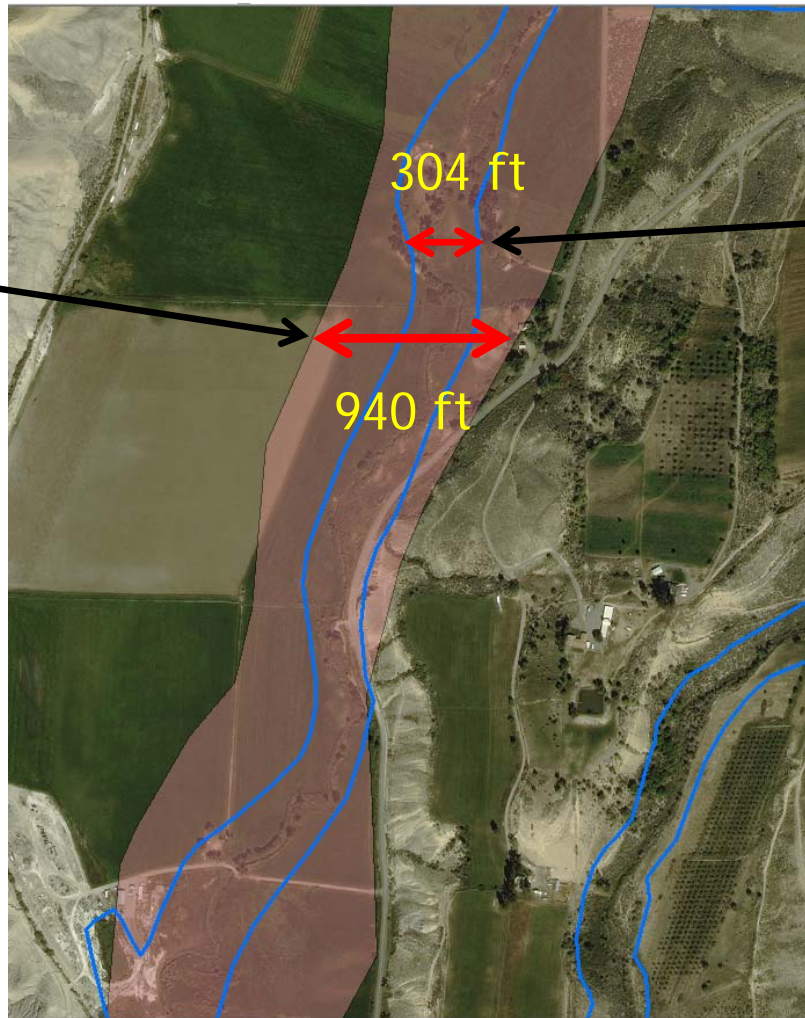
## *Why so large?*

- ▶ Dam is fully breached in one-hour or less.
- ▶ Assumes dams below Ward Lake fail due to overtopping; cascading and cumulative flows

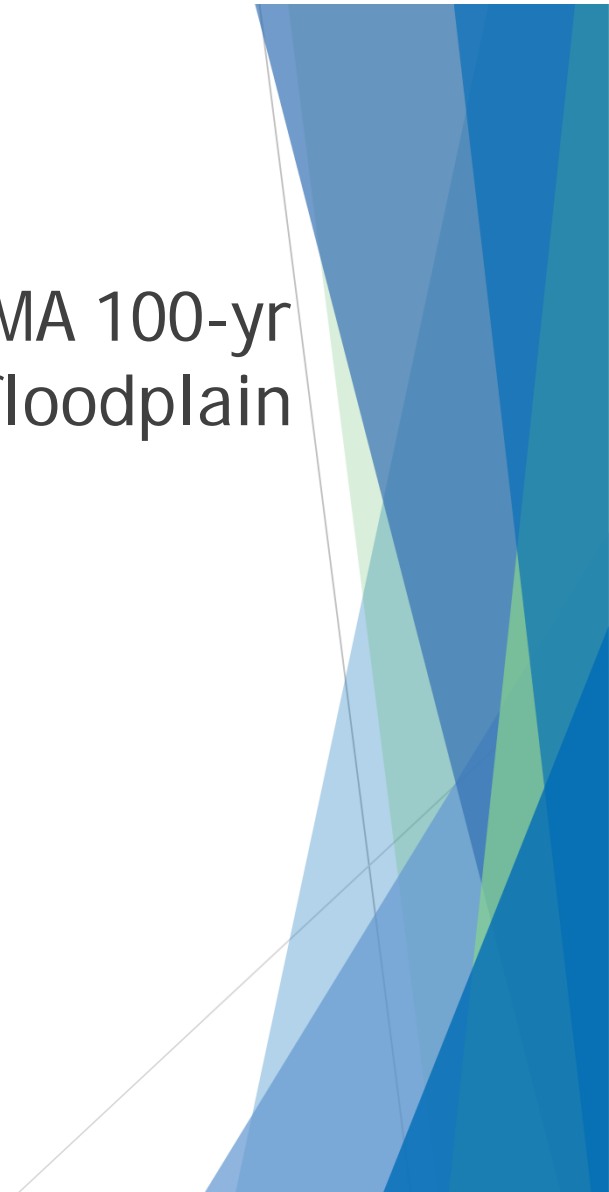


# Inundation Mapping Primer

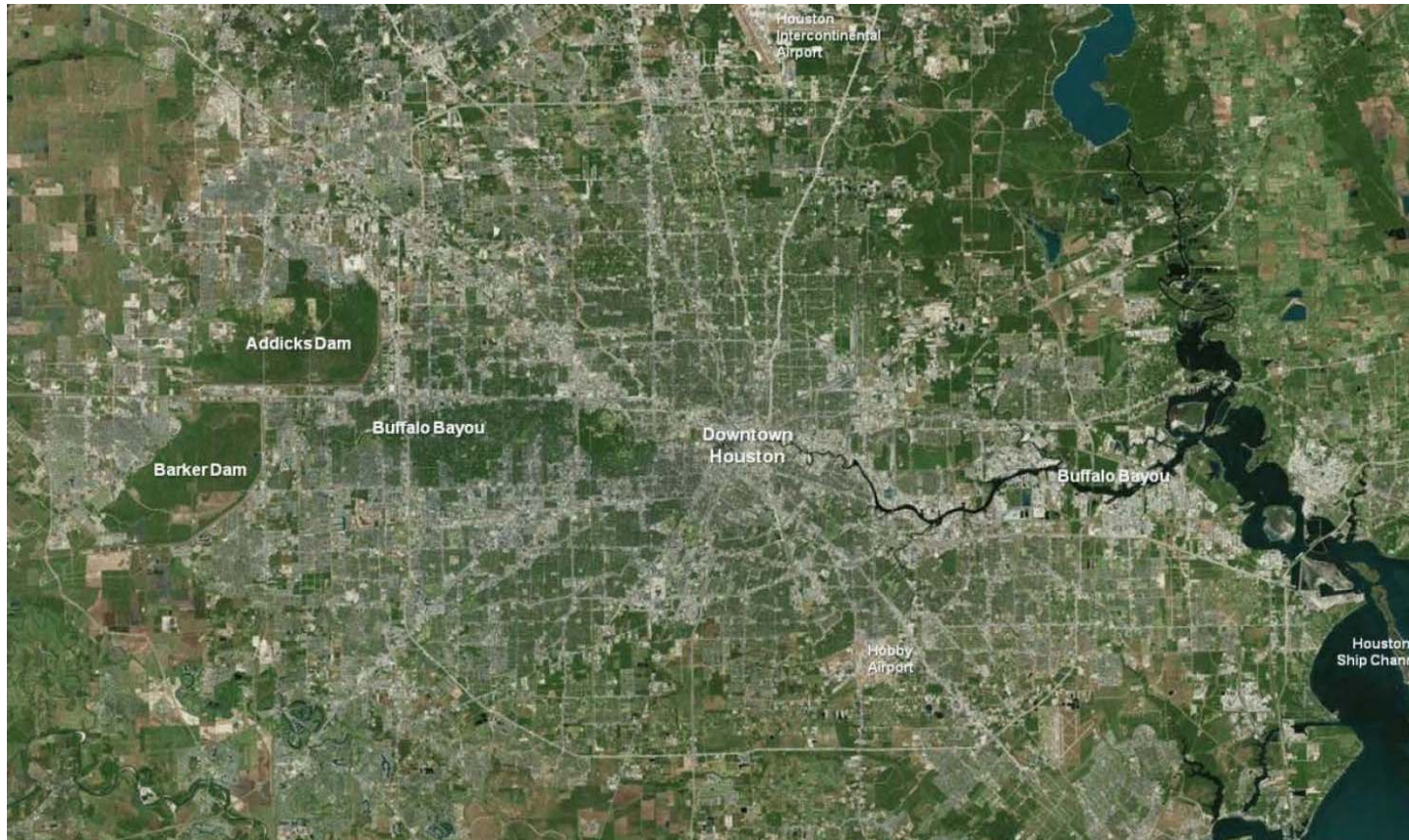
Ward Lake  
Inundation  
Mapping



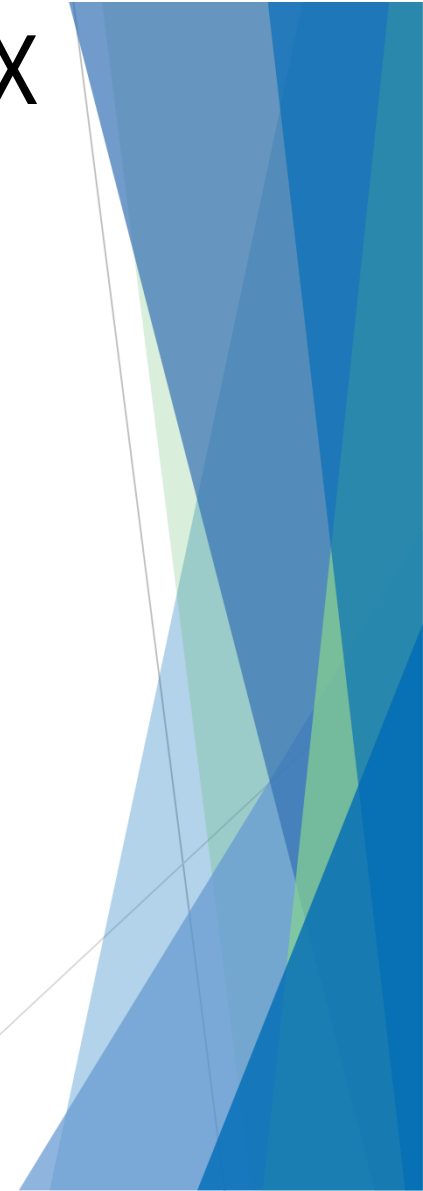
FEMA 100-yr  
floodplain



# Barker and Addicks Dams - Houston, TX

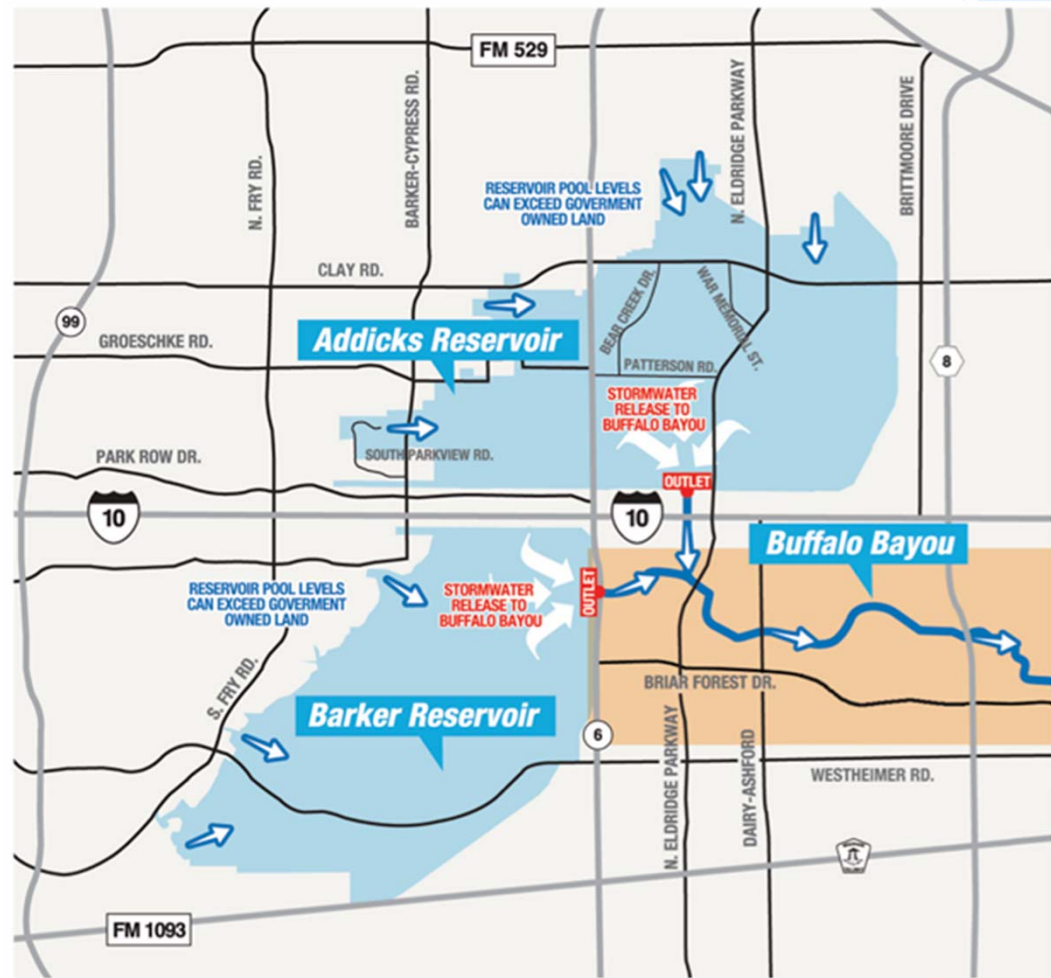


Flood control dams built in 1940



# Barker and Addicks Dams - 2017

- ▶ Hurricane Harvey
- ▶ Water surface in reservoir rising at ½ ft per hour
- ▶ Record high elevation
- ▶ Outlets opened, releasing 4,000 cfs each



# Neighborhoods Up and Downstream



# What Did We Learn?

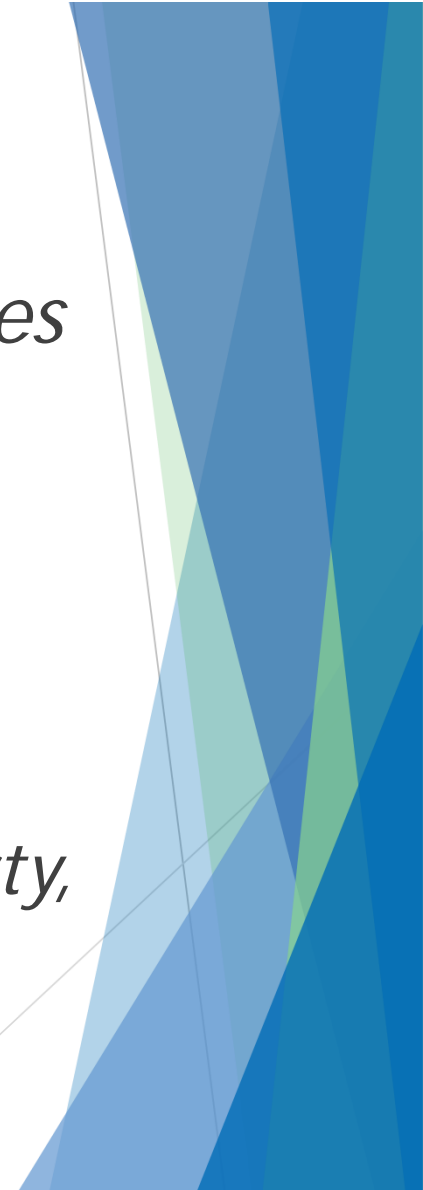
- ▶ Colorado in 2013 and 2015, Oroville and Houston in 2017 show dams operating as designed can still cause dangerous flooding downstream
- ▶ Dam Emergency Action Plans have maps for dam failure inundation - of no use in operational release flooding scenarios
- ▶ Coordination needed between Flood Plain Managers, Dam Operators, Dam Regulators and Emergency Managers. Share information and knowledge
- ▶ Hazard Mitigation Plans - Flooding





# Risk In Dam Safety

- ▶ *Risk = Probability of Failure x Consequences*
- ▶ *Probability of Failure*
  - ▶ *pipng, overtopping, sliding, operations*
- ▶ *Consequences*
  - ▶ *Population at Risk (PAR), Loss of Life, property, public anxiety*



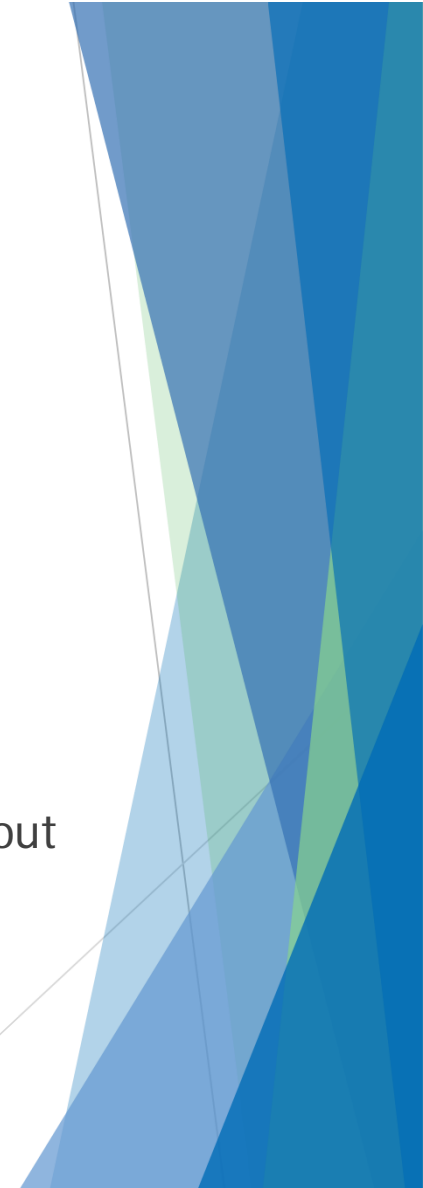
# Risk Reduction Techniques

## ▶ Reduce Probability of Failure

- ▶ Structural changes to the dam based on most likely “Failure Modes”
- ▶ Focused Inspections, Monitoring and Surveillance
- ▶ Educate/Train dam owners to identify issues early

## ▶ Reduce Consequences of Failure/Incidents

- ▶ Update and Exercise Emergency Action Plans to prepare to get people out of harms way
- ▶ Coordinate with Emergency Management Community
- ▶ Train, Empower and mobilize an “Emergency Response Team”



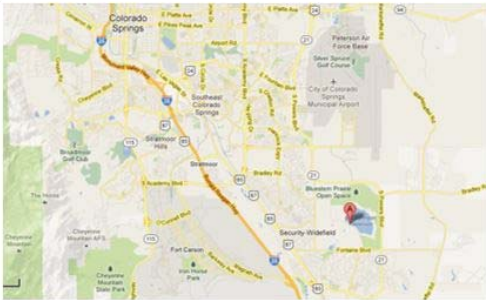
# Emergency Action Plans

## EMERGENCY ACTION PLAN (EAP)

*Notifications and Essential Information*

\_\_\_\_\_ DAM  
 \_\_\_\_\_ County, Colorado  
 HAZARD CLASSIFICATION: \_\_\_\_\_  
 State of Colorado DAMID: \_\_\_\_\_

Location Map:



Vicinity Map:



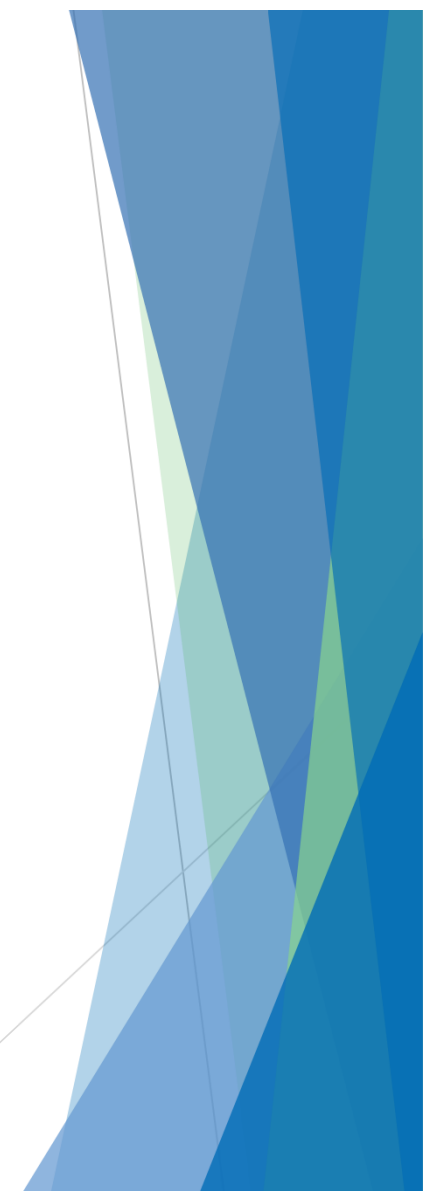
EAP Date: MMDDYYYY

Dam, DAMID: \_\_\_\_\_

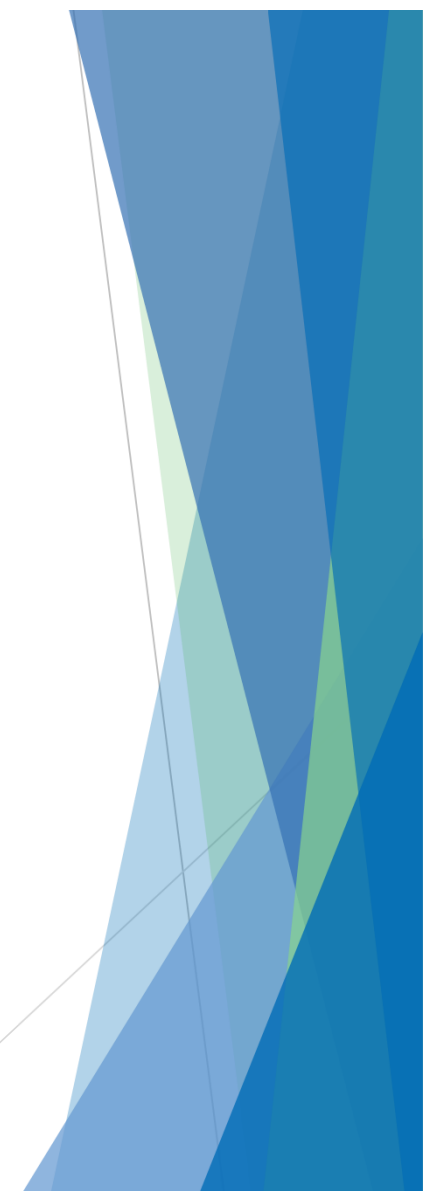
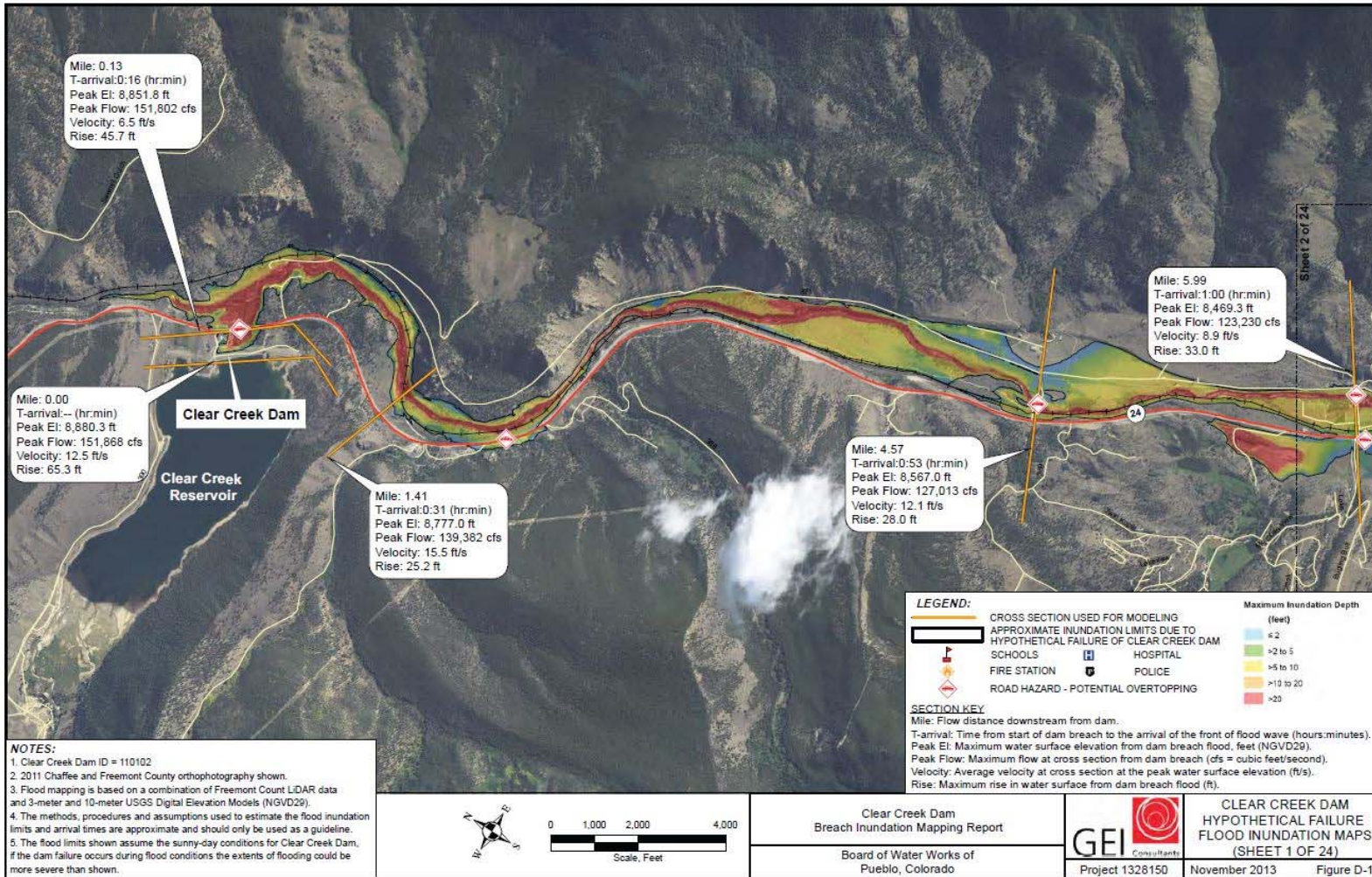
EAP Date: MMDDYYYY

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# Inundation Mapping



# Emergency Response Team

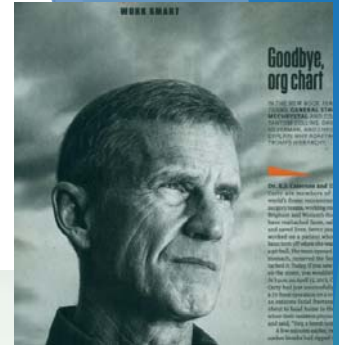
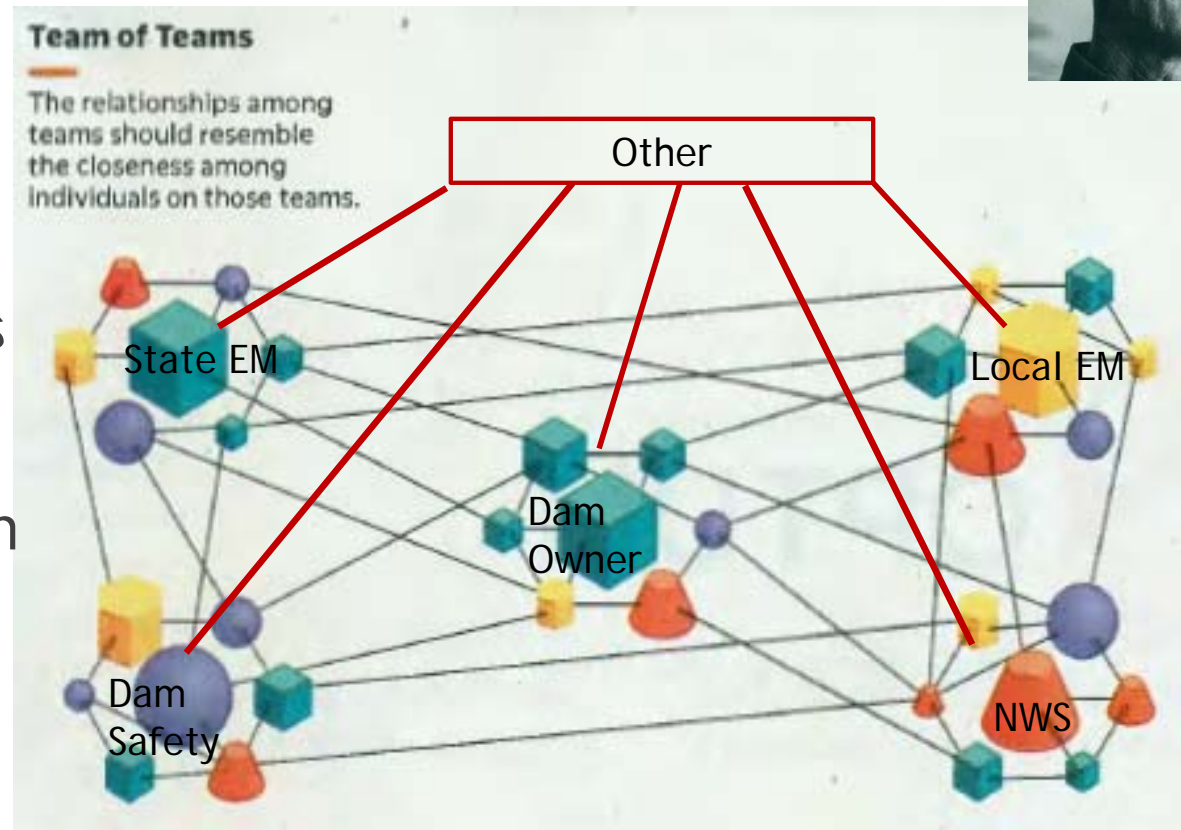
- ▶ Dam Owner
- ▶ Dam Owners Engineer
- ▶ Dam Regulator
- ▶ Local Emergency Manager
- ▶ State Emergency Manager
- ▶ National Weather Service
- ▶ Local Resources
- ▶ Other

## Emergency Notifications List

<i>Emergency Notifications List - Contact to be made with an individual with each organization</i>				
<u>Agency/Organization</u>	<u>Contact Name</u>	<u>Email Address</u>	<u>Primary #</u>	<u>Alternate #</u>
<b>Dam Owner</b>				
Primary				
Secondary				
<b>Local Communications Dispatch Center</b>				
County Sheriff's Office	Dispatch		911 (if emergency)	
<b>Local Emergency Managers</b>				
County EM Director				
County EM Deputy				
<b>State Department of Homeland Security and Emergency Management (DHSEM)</b>				
Primary - RFM				
Secondary - Duty Officer				
Alternate - Plan Coordinator				
CDOT - Region __				
CO State Patrol - Region __				
<b>Division of Water Resources - Dam Safety</b>				
Primary - DSE				
Secondary - Chief				
Alternate - Water Commissioner				
<b>National Weather Service (NWS) Regional Office</b>				
Warning Meteorologist				
Warning Hydrologist				
<b>Other</b>				

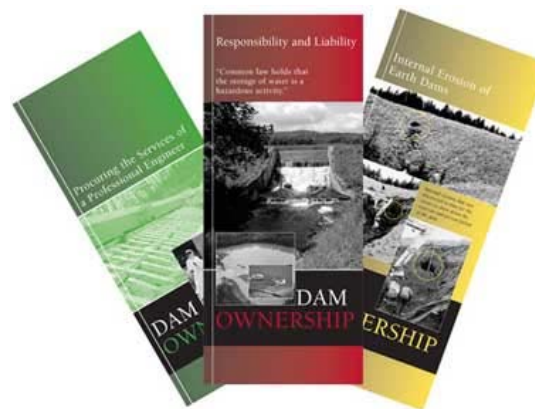
# Coordination = Trust Teams = Resources

- ▶ Information
- ▶ Communication
- ▶ Situational Awareness
- ▶ Shared Consciousness
- ▶ Empowered Execution



# What Can ASDSO and your State Dam Safety Program Do For You?

- ▶ Public awareness
- ▶ Education and training for emergency managers, engineers and dam owners
- ▶ Provide Information on dams in all states
- ▶ Performance data collection
- ▶ State program peer reviews
- ▶ Legislative advocacy
- ▶ Student outreach
- ▶ Publications
- ▶ Partnerships and national coordination



Visit: [DamSafety.org](http://DamSafety.org)



Thank You!

Questions?

