MADCS Conference 2025

Low Level Outlet Forum

Your Forum Panelists

Moderator / Panelist

Benjamin J. (BJ) Cope, PE

- Bozeman
- 25 Years professional experience
- Dam safety, project management, spillways, rehab, hydroelectric plants
- Was the one person who volunteered to organize this panel

Your Forum Panelists

Panelist

Michael Browne, PE

- Helena
- 20 Years professional experience
- Dam safety, inspections, rehabilitation, geotechnical engineering
- *"Engineers don't cry over spilled water… unless it's coming through the dam."*

PIONEER TECHNICAL SERVICES

Your Forum Panelists

Panelist

Sam Johnson, PE

- Billings
- 30 Years professional experience \ 18 years with Dam Safety
- Consulting, construction, regulatory, community assistance
- Montana Dam Safety Act:
  - “The legislature finds that dams play a crucial role in maintaining the vitality of Montana’s economy”.
  - “The state therefore has a legitimate and compelling interest in encouraging the construction of dams..”
  - *The legislature understands the risk of dams to the public* “but finds that compliance with the Dam Safety Act reduces those risks to an acceptable level.”

Agenda

What Is a Low-level Outlet	30 Minutes
Low-level Outlet Failure Modes and Inspection	30 Minutes
Break	15 Minutes
Conduit Rehabilitation and Replacement	30 Minutes
Forum Discussion (Interactive)	~ 30 Minutes

What is a low-level outlet?

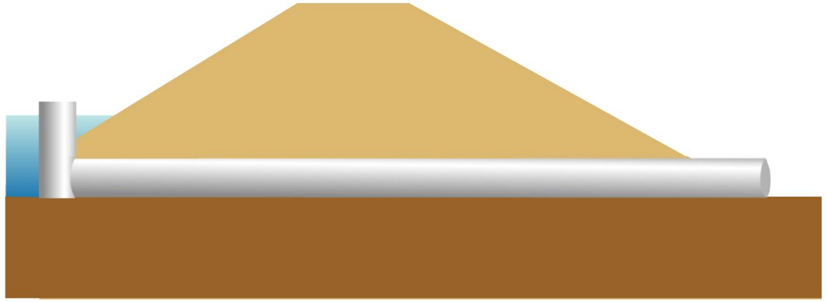
What is a low-level outlet - Topics

- Definition and function
- Configurations and components
- Conduit materials
- Hydraulic Design
- Embankment Considerations
- Intakes
- Outlets
- Accessibility / inspection
- Gates

Definition of a Low-Level Outlet

Technical definition:

A conduit that conveys water from a reservoir or body of water through, under, or around an embankment or dam in a controlled manner.



MADCS Practical definition:

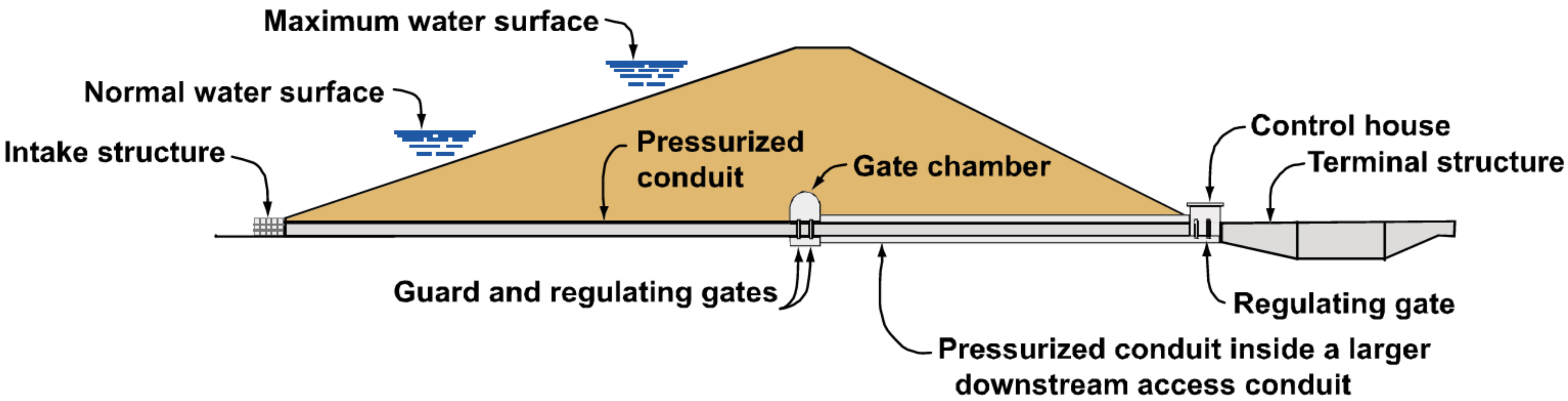
“This pipe/tunnel that carries water will be a real pain to fix if it ever has a problem”

Low-Level Outlet Purposes

- Releasing stored water
- Reservoir level regulation
- Flood control regulation
- Diverting flow to canals or pipelines
- Providing flow for power generation
- Emergency reservoir evacuation
- Stream diversion during construction
- Any combination of the above

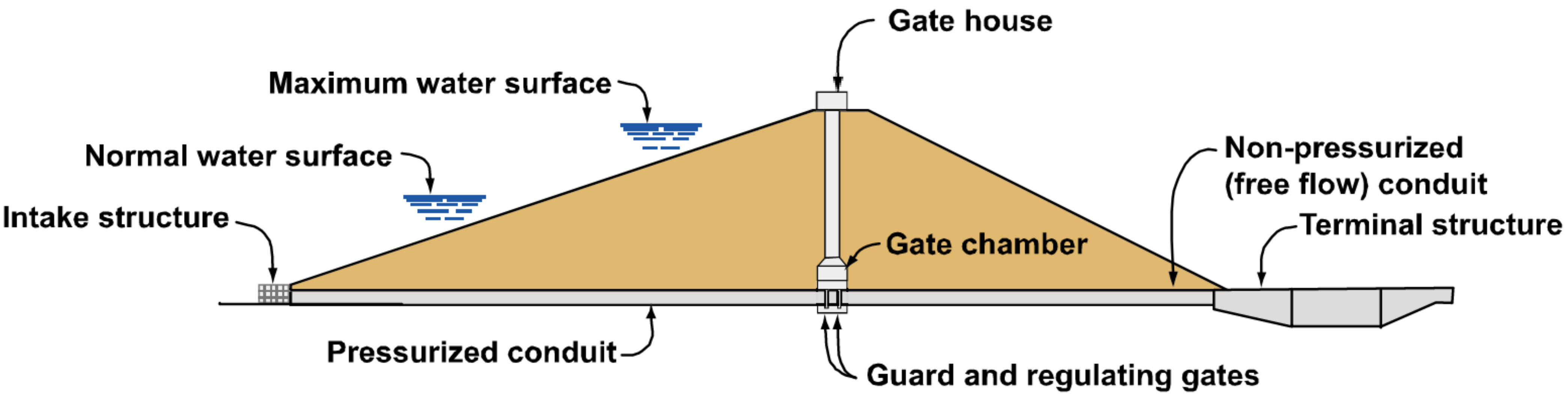
Some (not all) Low-level Outlet Configurations

1 – Intermediate Control, downstream access



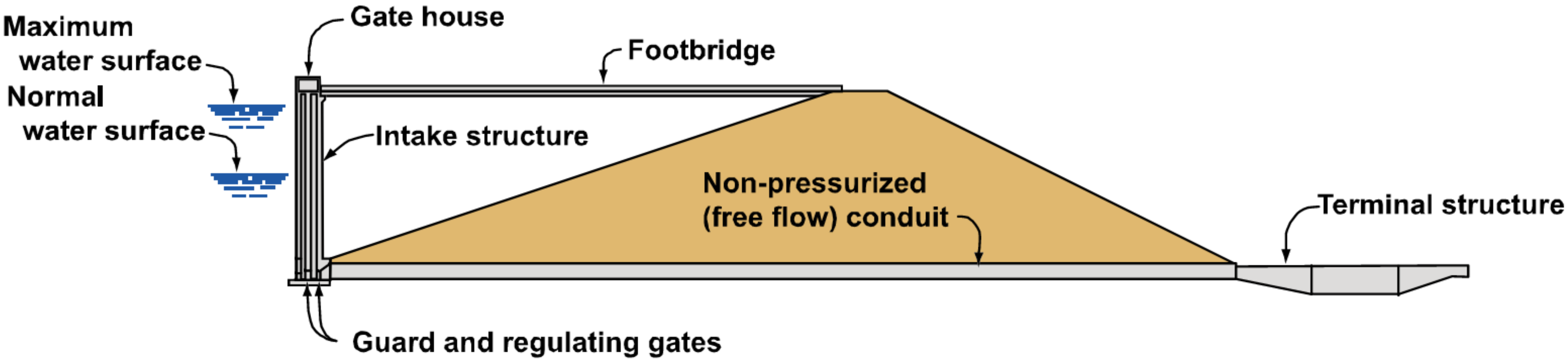
- Internal and external access for inspection of downstream portion
- Redundant and emergency closure provided by guard gate
- Pressurized conduit mitigated by hydrostatic pressure and access conduit

2 – Intermediate Control



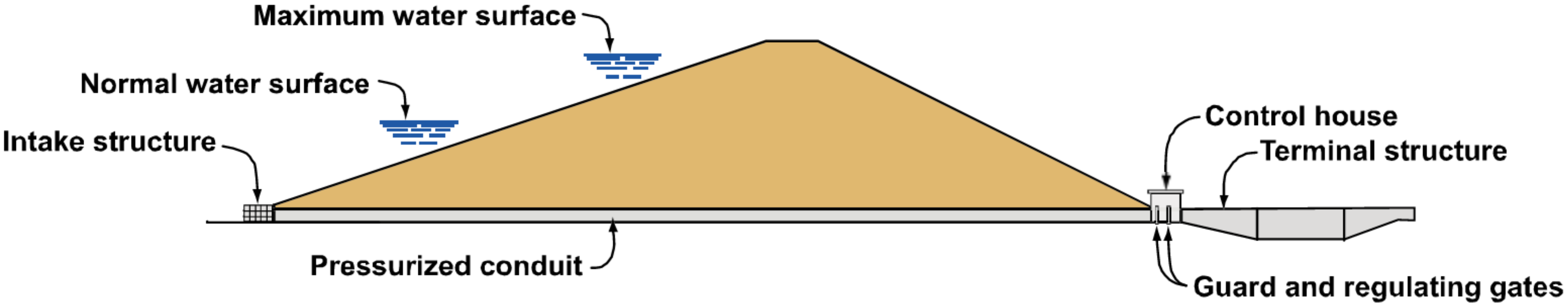
- Internal access to downstream half of conduit only
- Redundant and emergency closure provided by guard gate
- Pressurized conduit mitigated by hydrostatic in upstream embankment, non-pressurized in downstream embankment

3 – Upstream Control



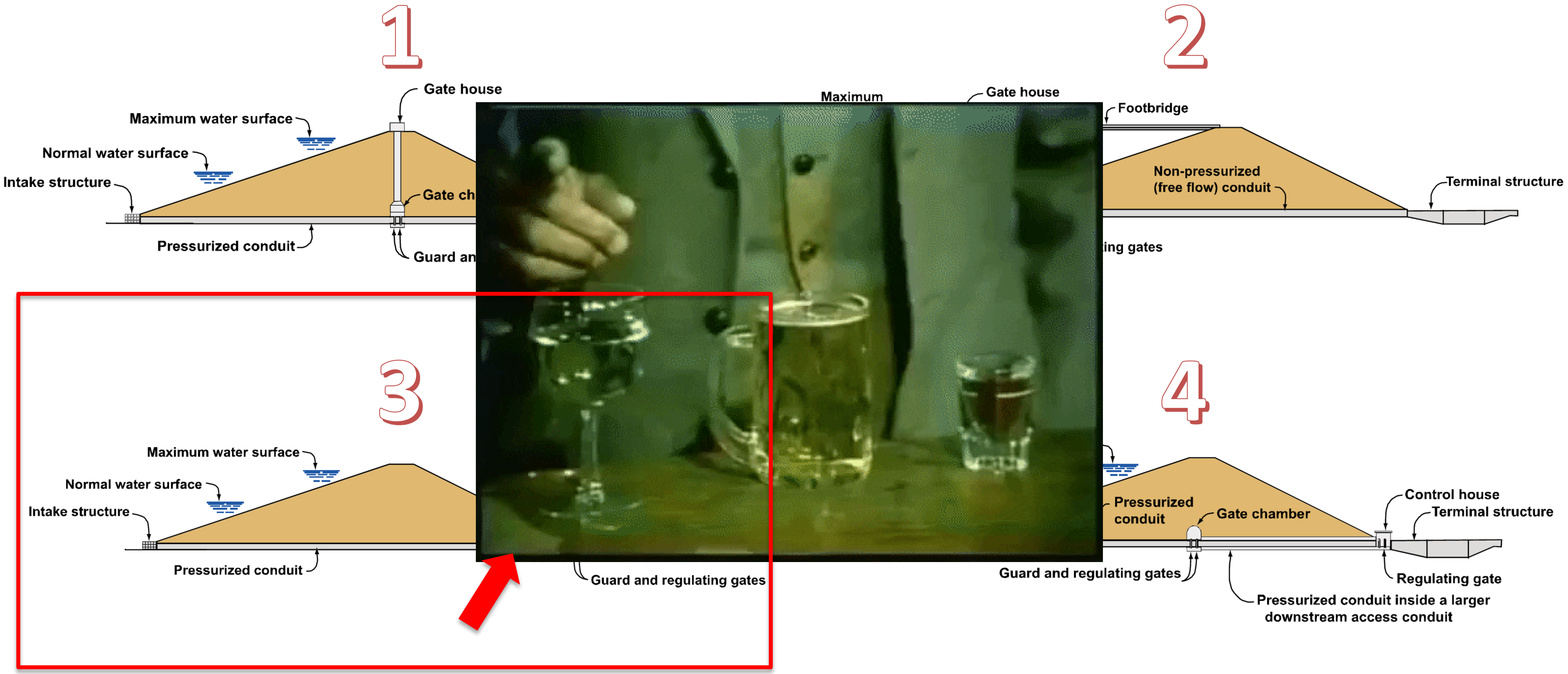
- Internal access to entire length of conduit
- Redundant and emergency closure provided by guard gate
- Non-pressurized conduit for entire length

4 – Downstream Control



- No access to conduit
- No emergency closure or conduit dewatering possible
- Pressurized conduit for entire length

Which is the Highest-Risk?



Conduit Materials - Steel

The old guard. Widely use for more than a century for all sizes and configurations of outlets. Alloys and methodologies have evolved from rivets to robot-welded. High pressure capability for penstocks.

Pros:

- Elastic and Ductile
- High strength / weight
- Wide size range (plates, spiral-weld, etc.)
- Possible to repair in place

Cons:

- Thermal expansion / contraction effects
- Requires corrosion mitigation & maintenance
- Service life and inspection compromised when buried

Conduit Materials – CMP

Very common in low-hazard dams due to low cost and simple installation. Only really suitable for storm drainage culverts under low-traffic roads. NOT suitable for high-hazard dams.

Pros:

- Low cost
- Corrugations result in high strength / weight
- Wide size range

Cons:

- Service life often overstated
- Highly vulnerable to corrosion even when galvanized
- Successful compaction of embankment/backfill difficult
- Deterioration can lead to multiple failure modes

Conduit Materials – Ductile Iron

Not common in dams and irrigation but still in use for municipal utilities.

Pros:

- High strength / better ductility than cast iron.
- Available in large sizes
- Wide range of options for joints and fittings
- Proven corrosion-resistant coatings and mitigation

Cons:

- High weight makes installation more difficult
- Less ductile than steel (more brittle)
- Vulnerable to corrosion without mitigation

Conduit Materials – Precast Concrete

More common in storm drainage applications but in smaller sizes or with appropriate engineering and design considerations can be good solution for outlets.

Pros:

- Available up to 96" diameter
- Corrosion resistant
- High strength and durability
- Maintain and repair in-place

Cons:

- High weight makes installation more difficult
- Risk of differential settlement and joint deflection w/o additional construction considerations
- Joints can leak w/o addition treatment

Conduit Materials – Cast-in-place Concrete

Infinitely customizable but requiring structural design and specialized construction. More common for very large outlets with linings

Pros:

- Infinite options of size and configuration.
- Corrosion-proof, strong and durable
- Maintain and repair in place
- Completely water-tight if designed and installed correctly

Cons:

- Requires detailed engineering for mix, reinforcing, joints, etc.
- Requires internal lining, external forming
- Limitation of transport and placing fresh conc.

Conduit Materials – Plastic

For good or ill lasts forever. Big advances in recent decades in materials, sizes, jointing, installation. High hazard applications require addl. considerations

Pros:
- Best hydraulic performance
- Large range of sizes available up to 9' or greater
- Will not corrode or deteriorate.
- Light weight and flexible
- Material and jointing options

Cons:
- Addl. considerations necessary to achieve adequate compaction around pipe
- Some formulations vulnerable to UV degradation.

Conduit Materials – Wood Stave

Natural materials and widely adaptable.
Common a century ago but obsolete now.

Pros:

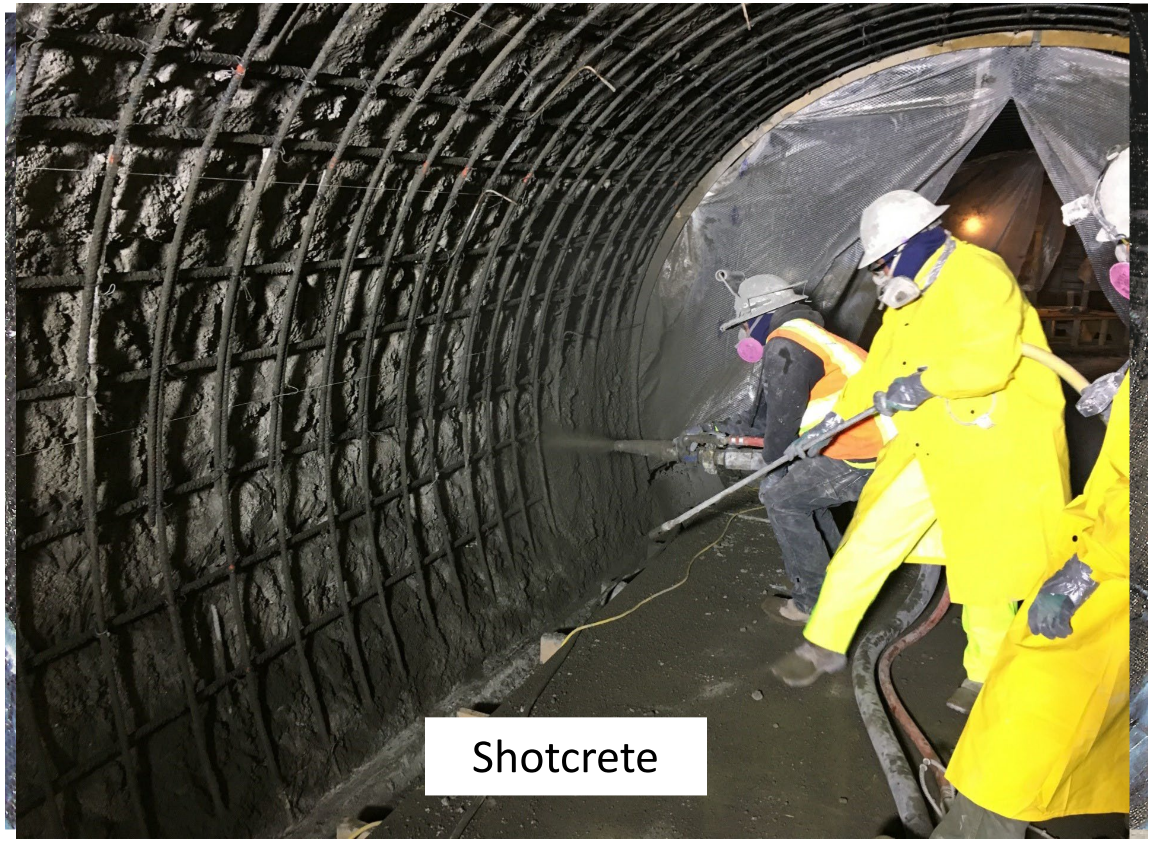
- Good hydraulic performance
- Resistant to deterioration when continuously submerged

Cons:

- Steel banding required for strength
- Not very durable
- Required skilled craftsman to construct

Conduit Materials – Linings / Rehabilitation

Various materials and methodology to extend the life of existing in-place conduit.



Pros:
- Can be less intensive than total replacement
- Often requires special materials / skilled installers

Cons:
- Access can be challenging
- Limited size applications and base materials
- Doesn't address external pipe concerns
- Usually reduced diameter and hydraulic capacity

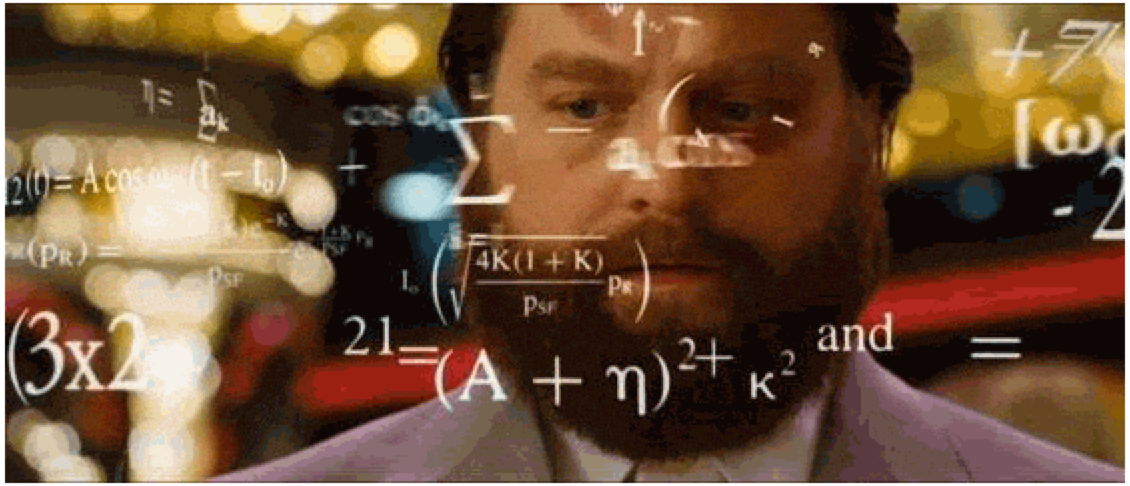
Conduit Hydraulic Design

Design Parameters

- Reservoir size
- Flood flow
- Normal flow
- Conduit Size
- Conduit material / condition
- Elevation head
- Intake depth
- Entrance conditions
- Exit conditions
- Tailwater hydraulics
- Auxiliary spillway capacity
- Equipment / turbine size

Design Goals

- Flow Rate
- Head (pressure)
- Reservoir / canal evacuation
- Longevity
- Minimize erosion
- Sluice capability
- Target discharge temperature / dissolved O_2



Conduit Hydraulic Design

<u>Larger Conduit</u> VS <u>Smaller Conduit</u>

Capacity
Conduit Cost
Installation Cost
Sedimentation
Cavitation
Access / Inspection
Debris

Advantages

Embankment Considerations

Main Goals:

1. Prevent differential settlement
2. Protect against internal erosion
3. Provide redundancies to mitigate failure modes

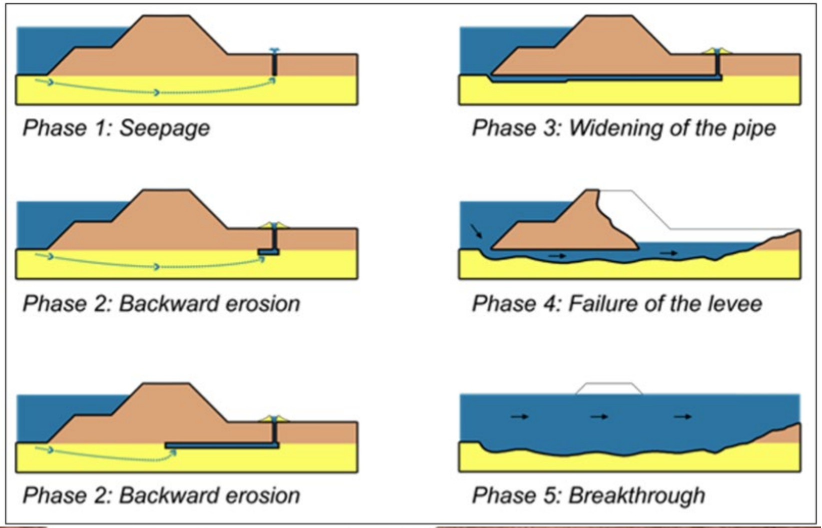
Embankment – Prevent Differential Settlement

- Use Geotechnical Engineer
- Strive for homogenous and well-
  materials
- Address compaction under pipe
- Consider concrete encasement
- Flatten excavation slopes /Cons
  benching
  - Safer construction
  - Better integration with backfi
  - Less likely to form cracks
- Use hand compaction around conduits & structures
- Avoid oversaturation and freezing
- Test compaction

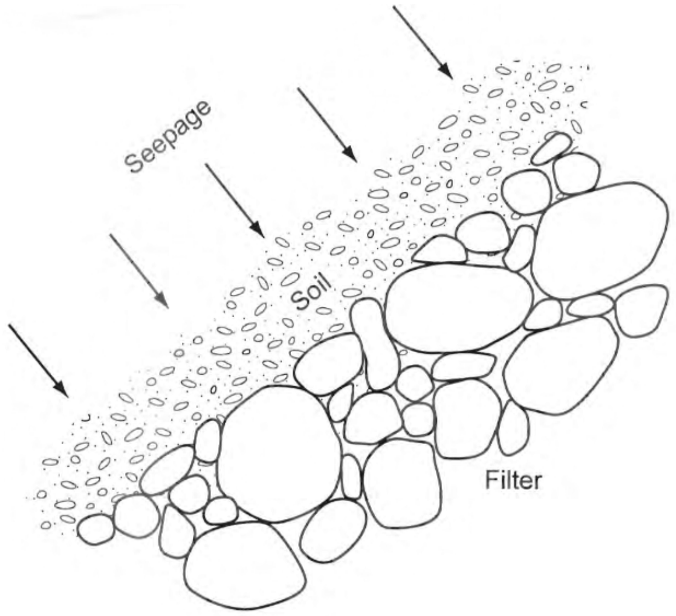
Embankment Considerations - Internal Erosion

- Cracks / defect / penetration (conduit?) / high gradient in embankment creates leak.
- Leakage and gradient erodes finer-grained materials first
- Erosion progresses in upstream direction
- Forms a “pipe”
- Progresses to failure

- Seepage collars are bad news
  - Make compaction more difficult
  - Don’t address the source of the problem
  - Many instances of failure

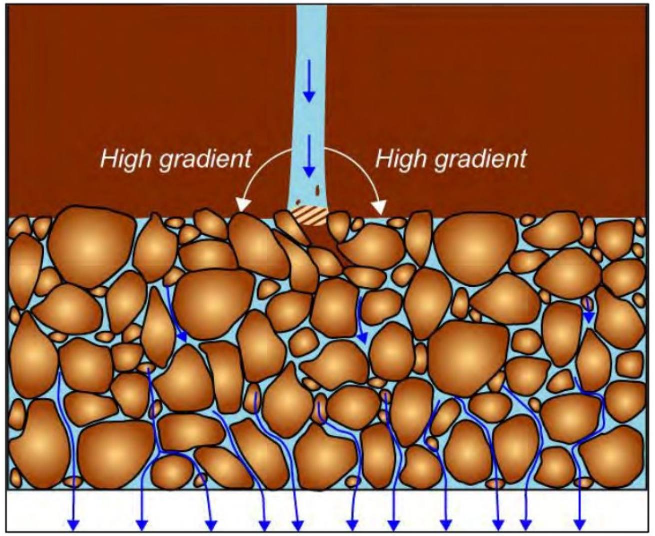


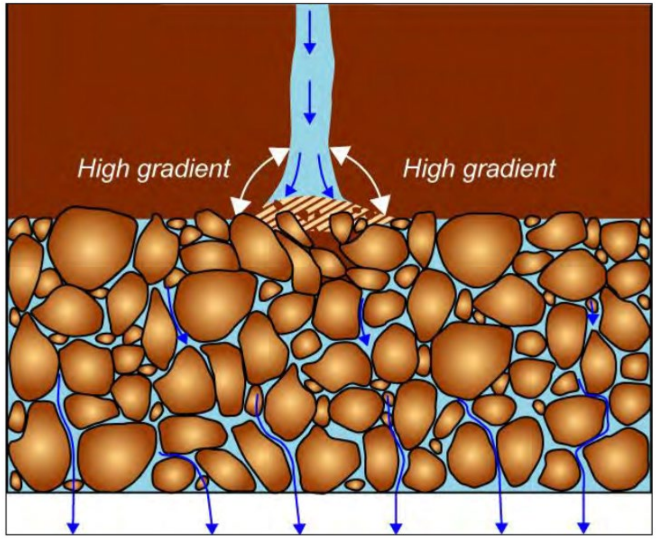
Embankment Considerations - Filters

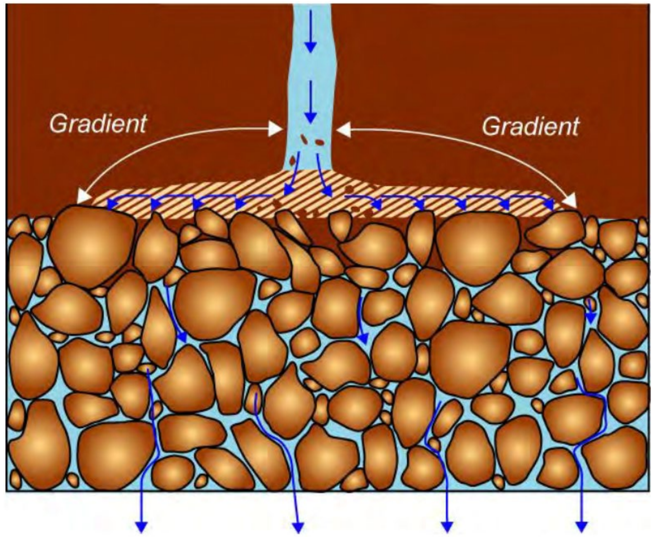


Sand layer expressly designed to pass inevitable seepage but stop internal erosion of fine-grained soils.

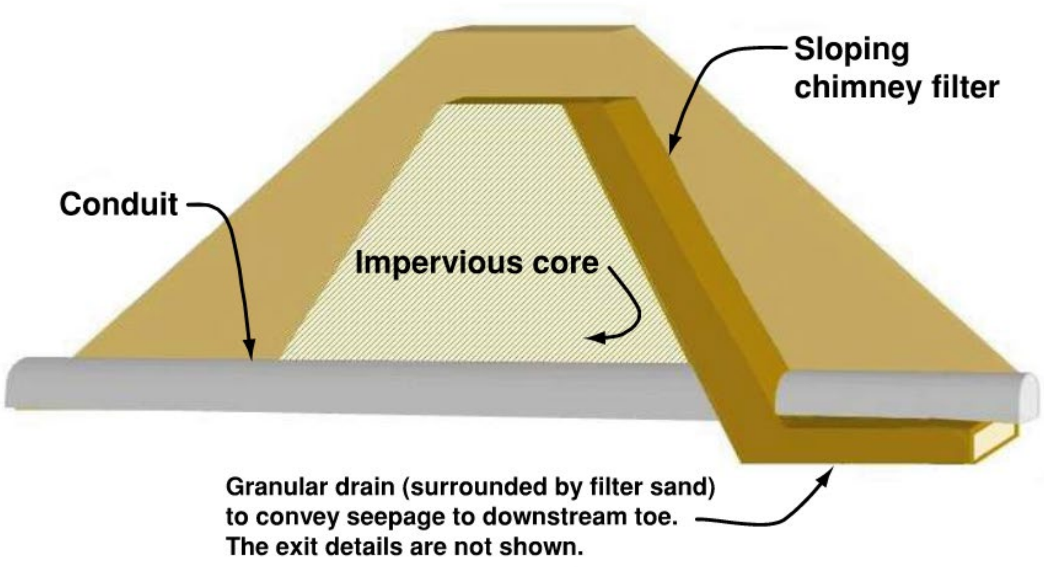
- Couple with downstream drainage to reduce gradient
- Seepage monitoring provides early detection
- Vastly superior to filter fabric for high gradients

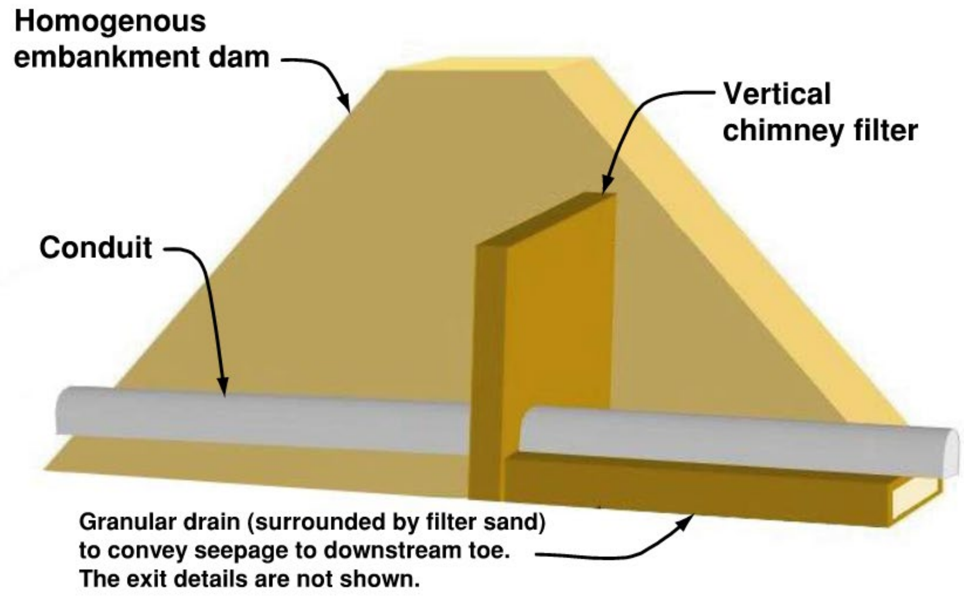






Embankment Considerations - Filters





Intake Structures

- Controlled water intake
- Prevent erosion to embankment / foundation
- House gates
- Protect conduit and gates from debris
  - Grate
  - Trash screen
  - Trash rake
- Depth considerations
  - Head
  - Debris (type, size, floats/sinks)
  - Temperature
  - Dissolved O2

Outlet Structures

- Dissipate Energy
- Prevent erosion at toe of dam
- House gates / bulkheads (pressurized conduit)

- Design Considerations
  - Avoid cavitation velocities
  - Consider tailwater / potential submergence effects on hydraulics
  - Erosion will happen, plan for it
  - Consider scour / sidecutting /undercutting

Accessibility

- Provide access for inspection
- Internal inspection vs external inspection
- Mid-point, downstream, upstream
- Large enough for entry?
- Camera / ROV?
- Confined space issues (2024 MADCS)

Some words on gates

For low-level outlets gates provide:
- Flow control
- Flow isolation / redundancy
- Inspection access
- Maintenance access

Adequate gate maintenance can pay big dividends on the rare occasion you really need it.

<u>Provide air vent downstream of gate to prevent negative pressure failure.</u>

Failure Modes, Inspection, & Intervention

Mike Browne, PE
Pioneer Technical Services, Inc.
mbrowne@pioneer-technical.com

Internal erosion (piping) is a process that occurs inside the dam whenever 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.

'I believe the failure was caused by piping resulting from seepage passing under the east sloping wing wall…'

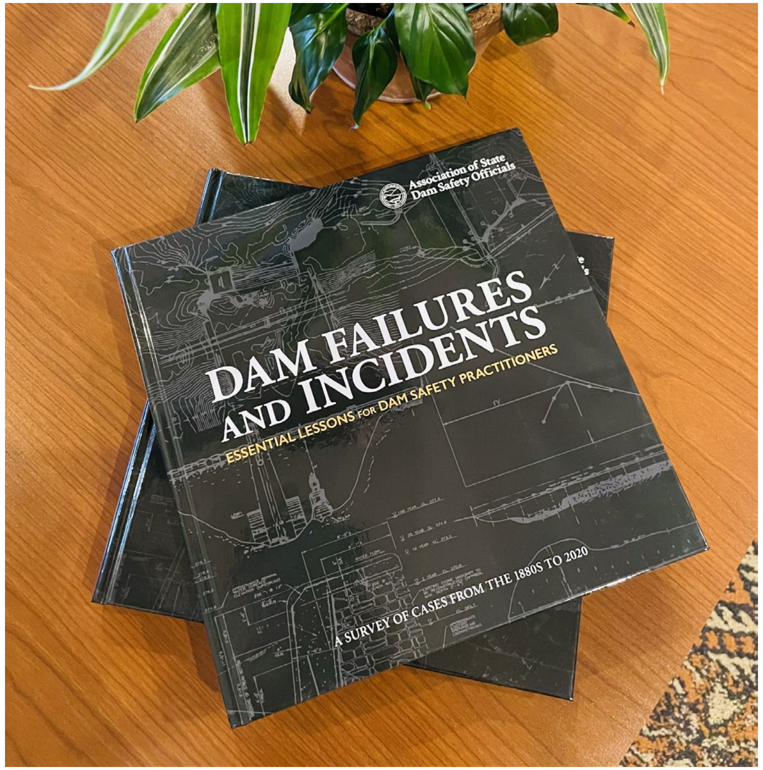
Excerpt from State Water Conservation Board
Investigation Letter

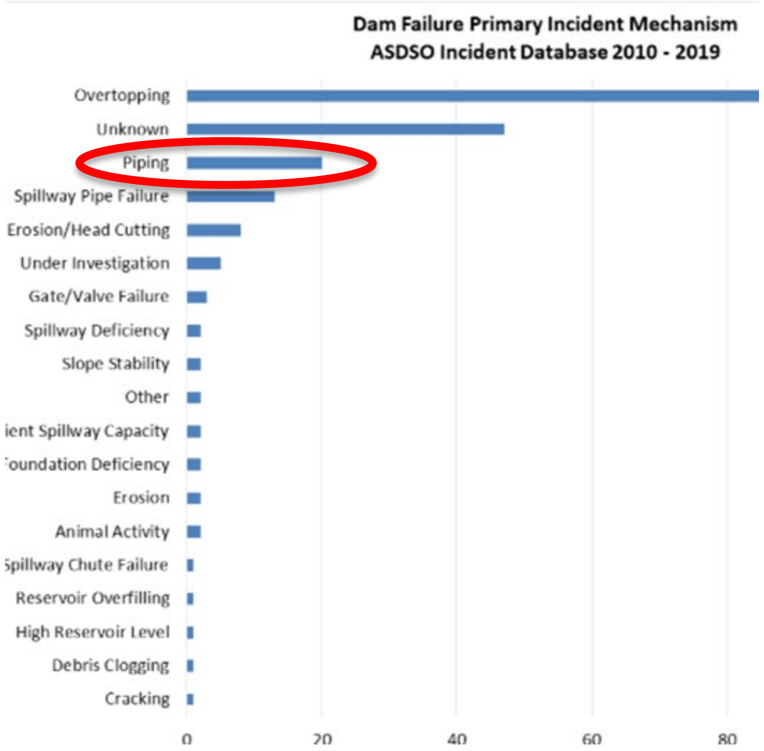
Frenchman Dam 1952
Phillips County, MT

Lessons Learned

Historically internal erosion (piping) is one of the primary causes of dam failures

Identified four primary Potential Failure Modes (PFM) associated with internal errosion





Cause
Earthquake Instability
Faulty Construction
Gate Failure
Slope Failure
Spillway Erosion
Overtopping
Seepage/Piping

Potential Failure Mode (PFM): Internal Erosion (Piping)

Chain of events

- Initiation – Conditions that trigger erosion (e.g. hydraulic gradient, soil erodibility)
- Progression – Erosion channels enlarge, forming pipes or tunnels
- Breach – Structural failure

Factors

- Conduit Condition
  - Joints
  - Corrosion/cracks
- Soil type/gradation
- Differential head
- Filter
- Soil compaction
- Anti-seep collars
- Dispersive clay

Negative thinking encouraged…

- What could lead to failure?
- Design features?
- Visual indicators
  - Wet spots
  - Cloudy seepage
  - Sinkholes
  - Increased flow from drains
- **Understanding PFMs is important first step in improving dam safety.**

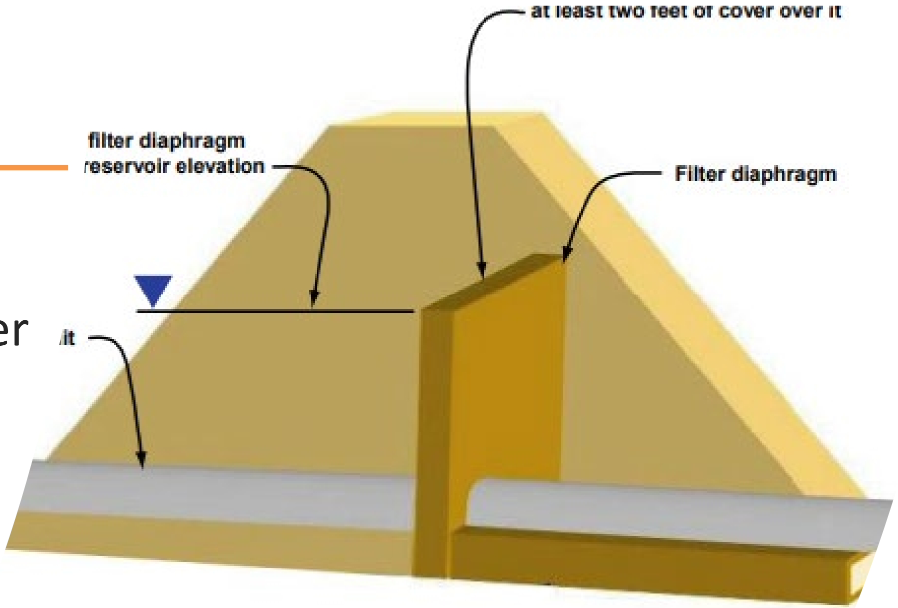
Anti-Seep Collars

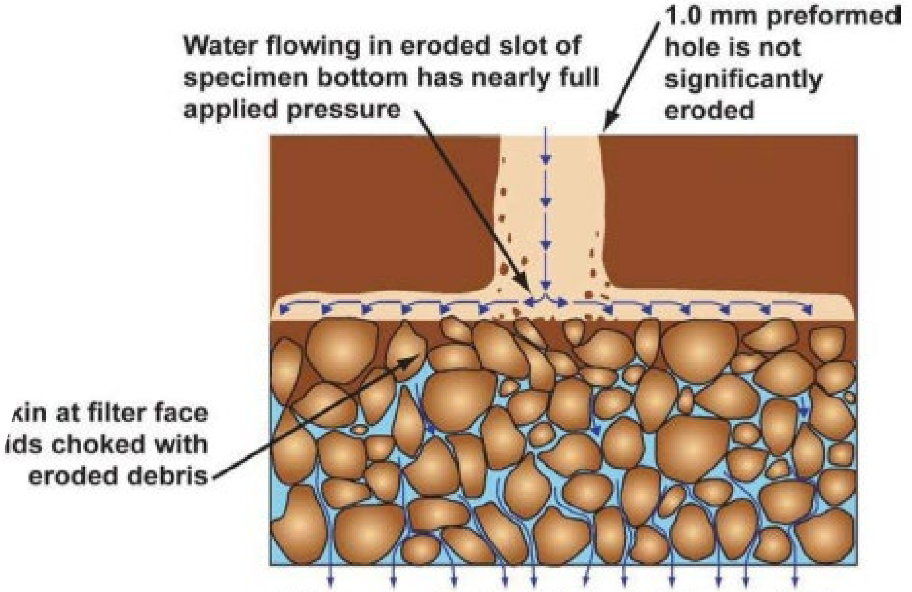
- Impermeable diaphragm constructed at intervals along the conduit that passes through an embankment dam.
- Theory: forcing water to take a longer flow path along the conduit would dissipate hydraulic forces and prevent piping at the downstream toe.
- Lessons Learned:
  - Impeded proper compaction.
  - Low density zones => increased risk of hydraulic fracture and piping.
  - Root cause for many piping failures.
- State of Practice: use filter instead of anti-seep collars.

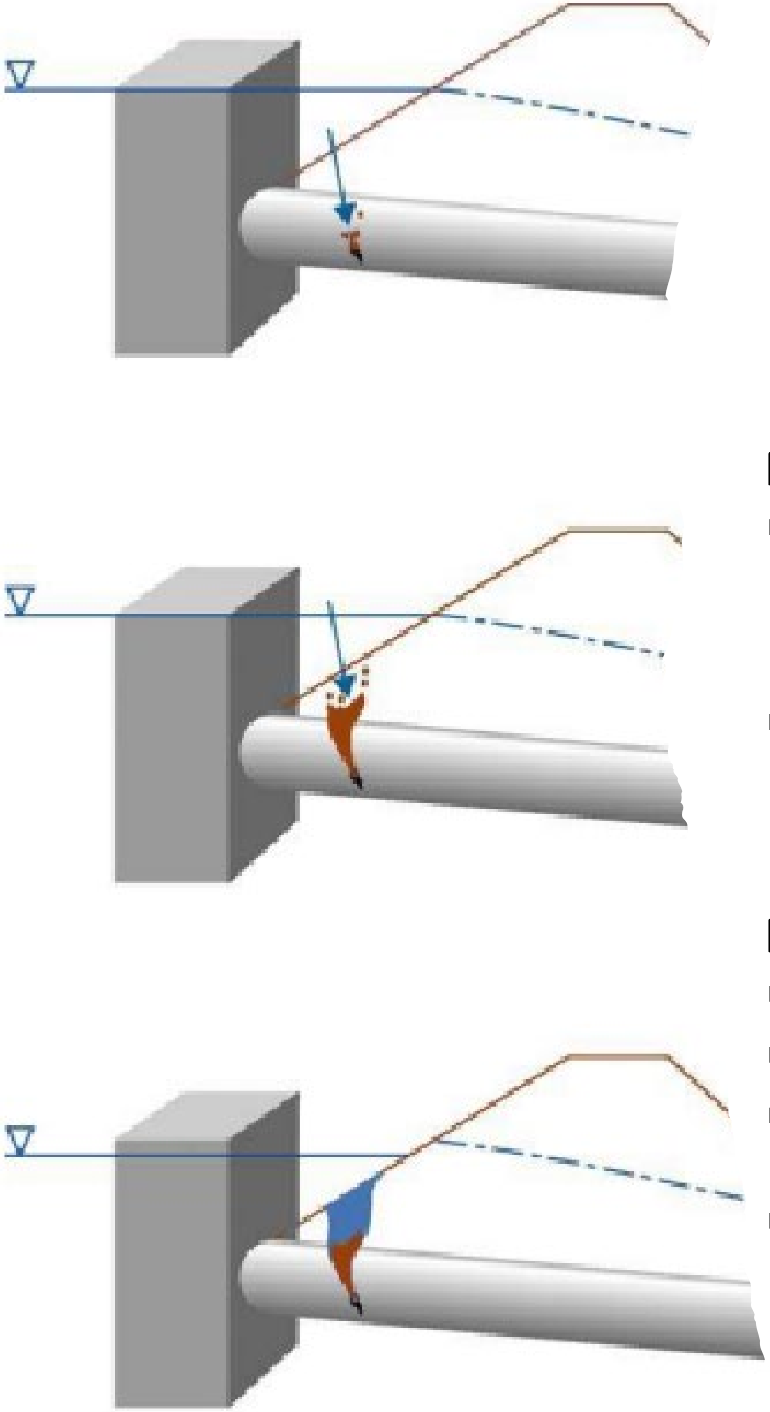
Filters in Embankment Dams

Zones of specially designed material (sand and/or gravel) placed within dams, especially around conduits, to prevent soil erosion caused by uncontrolled seepage.

Function is to intercept and block the movement of soil particles while allowing water to pass through, thus preventing internal erosion (piping) and embankment failure.







PFM 1: Internal Erosion of Soils into a Nonpressurized Conduit

Mechanism:

- Soil particles are eroded into the conduit through joints, cracks, or defects when the conduit is not under pressure.
- Progressive erosion can lead to voids, settlement, and ultimately dam failure.

Risk Factors:

- Poor joint sealing
- Lack of filters
- Inadequate compaction around the conduit.
- Conduit Corrosion

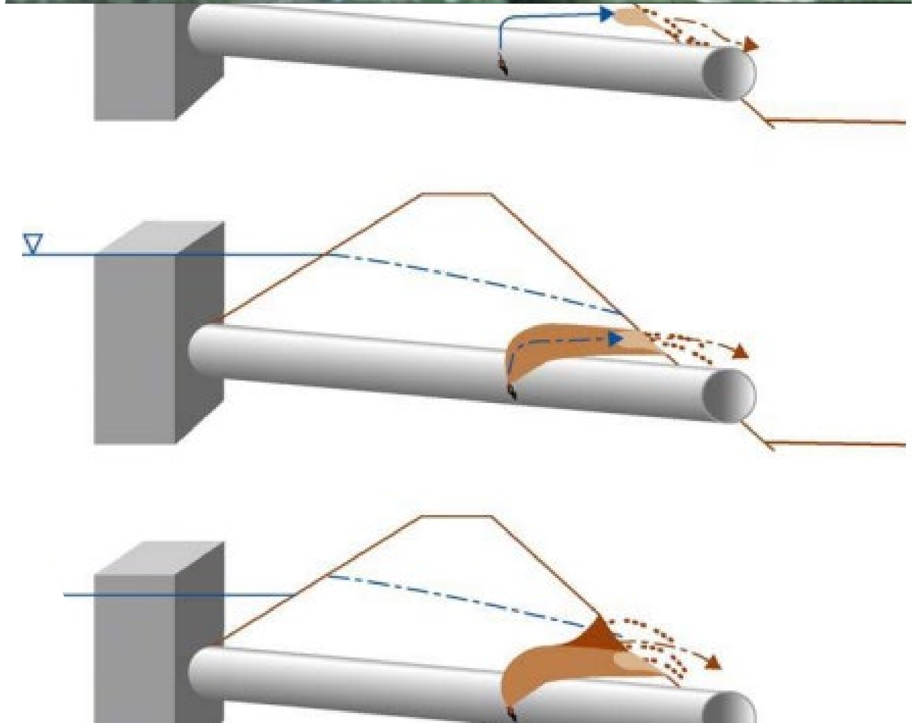
PFM 2: Backward Erosion from a Pressurized Conduit

Mechanism:

- Pressurized water escapes through a conduit defect into the embankment
- Seepage forces can detach soil particles
- Backward erosion piping can occur, forming a tunnel
- Can lead to a breach of the embankment dam

Risk Factors:

- Cracked or leaking pressurized pipes, especially in older or poorly maintained systems
- No filters



Lawn Lake Dam Failure, CO, 1982

"… the failure occurred due to leakage under high pressure from the leaded connection of the outlet pipe and valve, causing progressive piping of the dam embankment in the vicinity of the outlet pipe during periods of high reservoir levels and gate closure and sudden collapse of the embankment allowing rapid evacuation of the reservoir."

Photo Credit ASDSO website

PFM 3: Erosion Along the Outside of the Conduit

Mechanism:

- Water seeps along the conduit's exterior, especially if the conduit is not well bonded to surrounding fill.
- Preferential flow paths result in backward erosion piping.
- Breaching failure

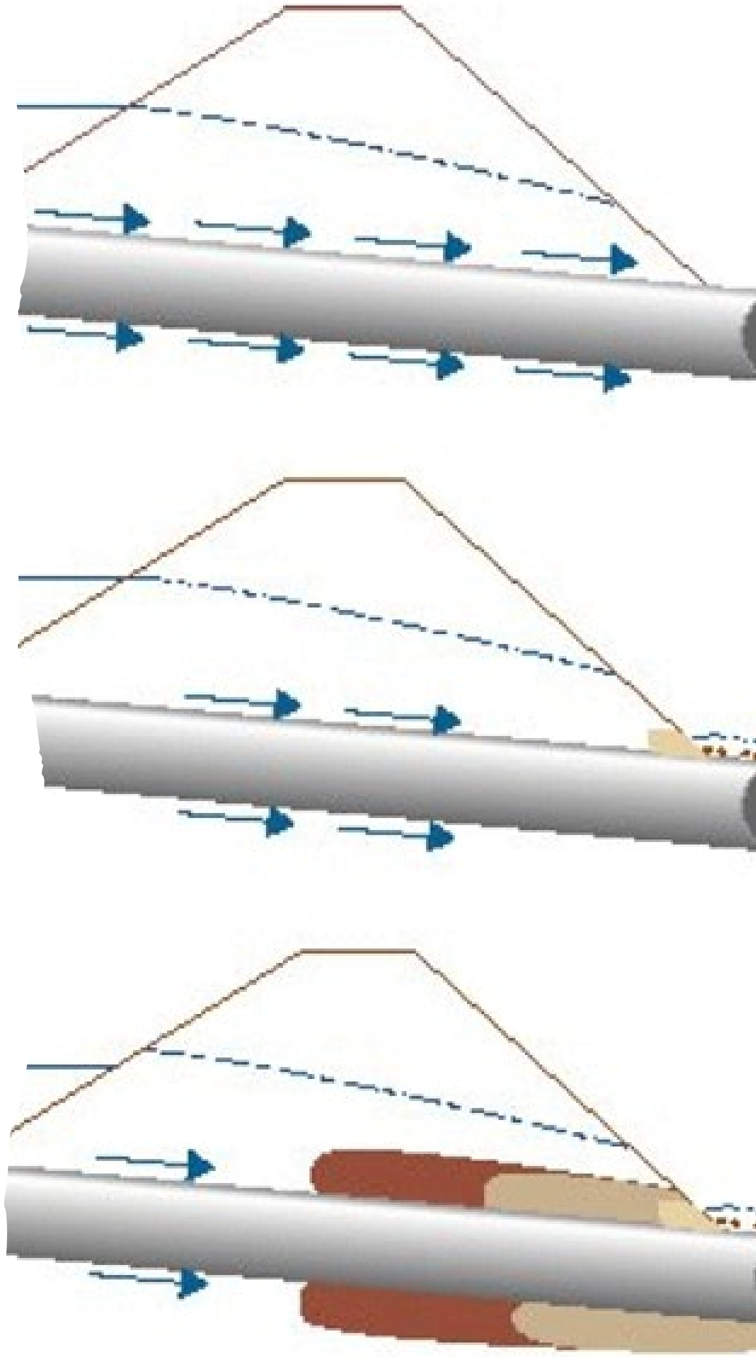
Risk Factors:

- Poor compaction,
- Anti-seep collars
- No filter diaphragms or collars
- Differential settlement.

Anita Dam Failure, MT, 1997

- Hydraulic fracturing & poor compaction around the conduit & anti-seep collars.
- Dispersive lean clay
- Flowable backfill instead of concrete cradle
- Lack of filter and drain systems
- Frozen lenses in the backfill which thawed and allowed concentrated leakage.

Photo Credit ASDSO website



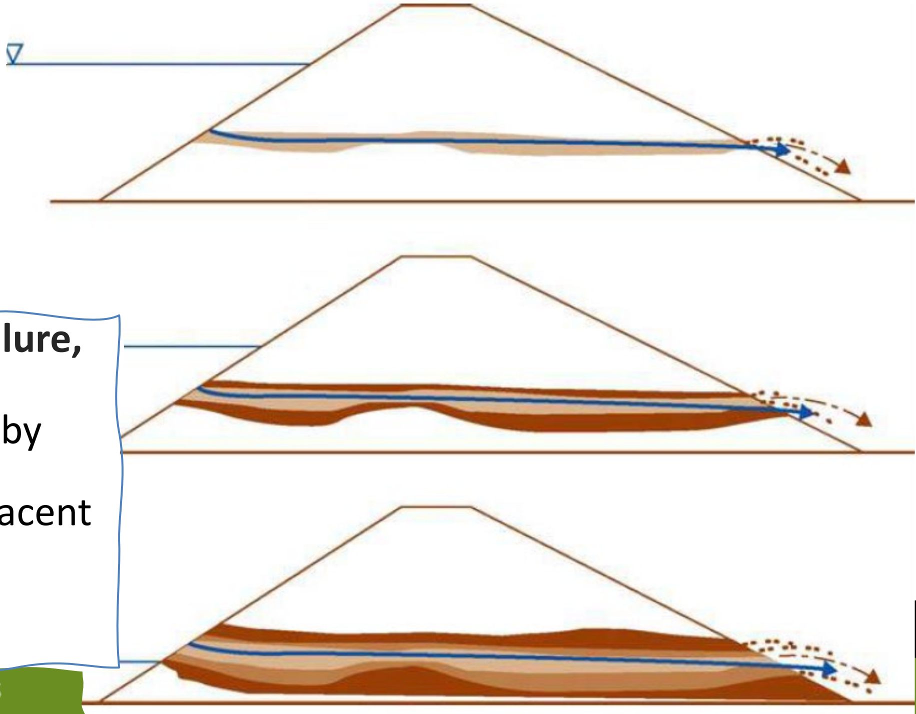
PFM 4: Hydraulic Fracture Cracks in the Earthfill Above, Below, or Adjacent to the Conduit

Mechanism:

- Cracks form in the embankment due to hydraulic fracturing, and water flow enlarges these cracks by eroding the soil.
- Backward erosion occurs. Water discharging at downstream face of embankment is muddy and vortex may form at entry point.
- Erosion tunnel enlarges, reservoir empties/breaches.

Risk Factors:

- Most frequent during first filling
- Dispersive clay
- No filter diaphragms or collars
- Low compaction
- Excess pore pressure



Upper Red Rock Site 20 Dam Failure, OK, 1973

‘Failure of an embankment dam by internal erosion resulting from hydraulic fracture of earthfill adjacent to the flood control conduit’

Photo Credit ASDSO website

Potential Failure Mode Identified… what next?

Filter Diaphragms

Context: Embankment dams equipped with properly designed filter diaphragms around conduits have successfully prevented internal erosion.

Design Feature: These diaphragms intercepted seepage and filtered out soil particles, maintaining embankment integrity even under high reservoir levels.

Slip Lining Conduits

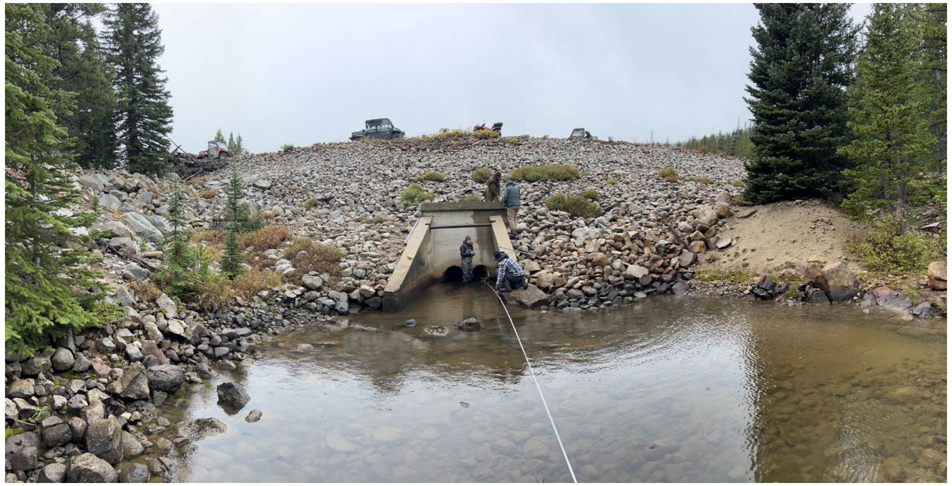
Context: In older dams where conduits had deteriorated, slip lining with HDPE or steel liners restored structural integrity and watertightness.

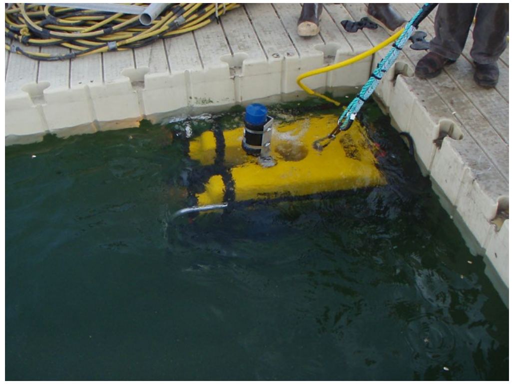
Outcome: These retrofits extended the service life of the conduits and prevented failures without requiring full replacement.

Upstream Control

Context: Dams with upstream control gates were able to isolate flow during emergencies, reducing the risk of pressurized conduit failures.

Benefit: This design allowed for safer inspection and maintenance access.





Inspections

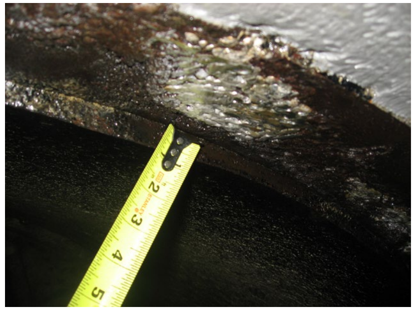
Early detection of problems is critical to prevent failures.

Regular, thorough inspections are essential (both interior and exterior) .

Use of modern technology (CCTV, ROVs, sonar, etc.) improves inspection quality, especially for inaccessible conduits.

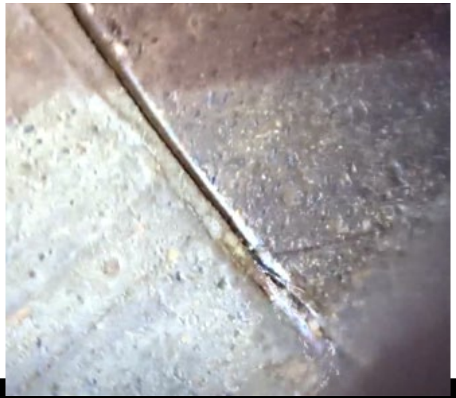
Good recordkeeping and trend analysis help in proactive dam safety management.

- Quantitative measurements: joint displacement, ultrasonic thickness
- Measured seepage/cloudy water



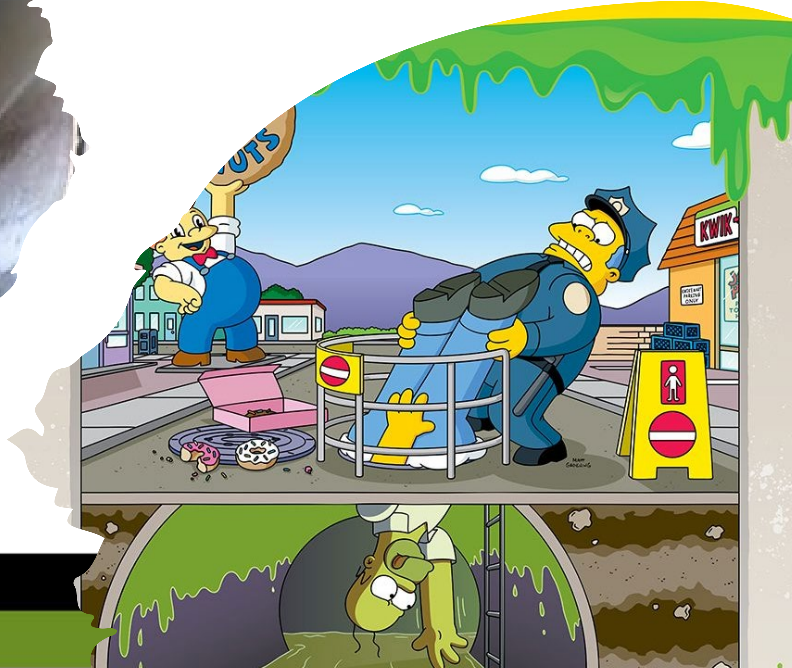
An outlet conduit inspection is required. Experience has repeatedly shown DNRC that inspecting the outlet conduit at least once every five years is prudent. If your outlet is inaccessible due to the presence of a downstream gate or valve, please discuss the situation with your local DNRC Dam Safety Engineer in advance.

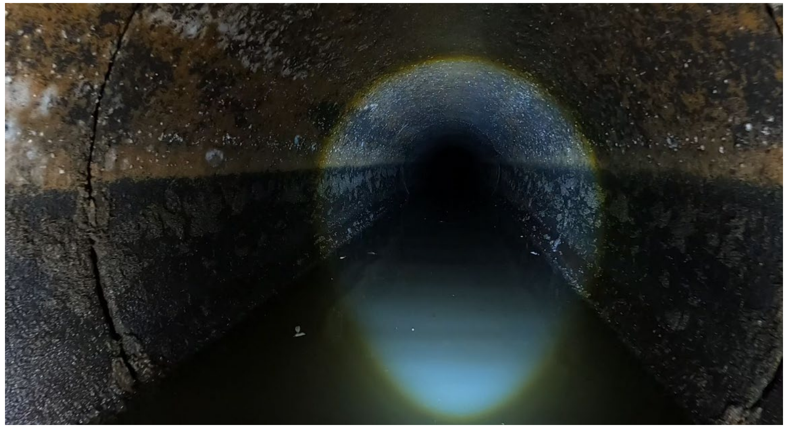
Physical Inspections



Safety Moment - Confined Space

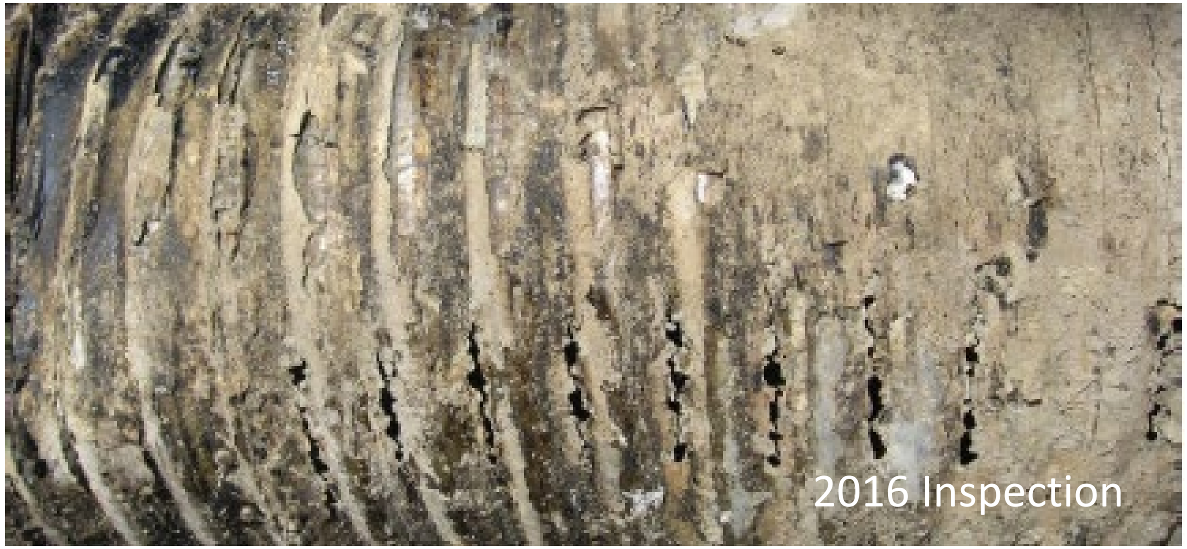
- A confined space is a space that workers enter to conduct maintenance/inspections but as a limited or restricted means for entry and exit and is not designed for continuous occupancy.
- i.e. outlet pipes, gate towers, tunnels
- Hazards: ventilation, hazardous gases, restricted entry, entrapment, structural condition, falls.
- Six fatalities in MT (2011-2018). With toxic gases, often results in fatalities for rescuers too.
- Have a plan: preparation, assess area for hazards, test the air, use personal protection equipment, ventilation system, rescue equipment/team, communication
- DNRC dam safety has some equipment available for dam safety use. Requires planning.
- Ask for help.
- Resources: [Confined Space Entry - ASDSO Dam Safety Toolbox (damtoolbox.org)]




Camera Inspections

Outlet Deterioration



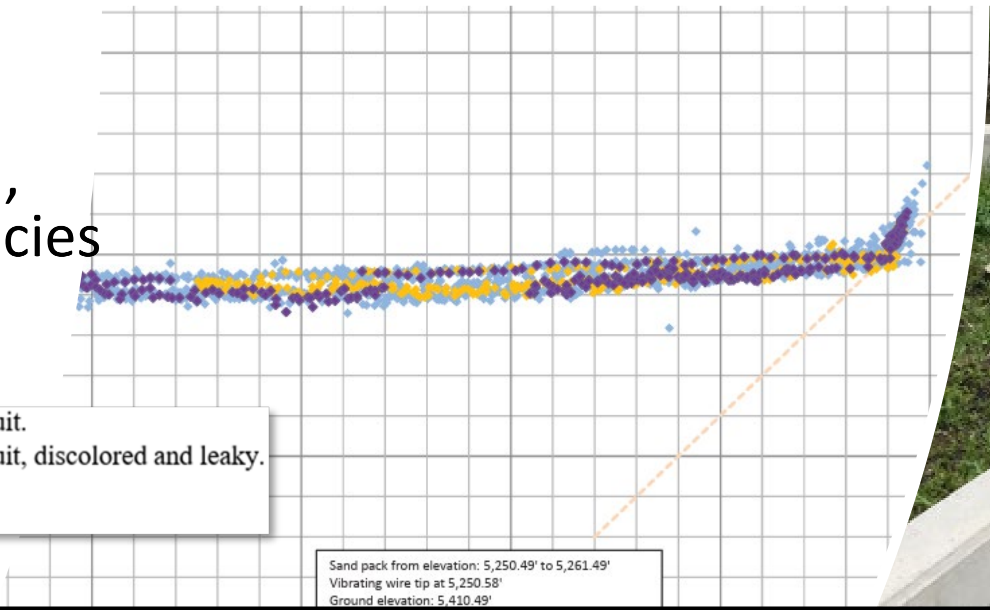
Photos curtesy of DNRC Dam Safety

Outlet Deterioration

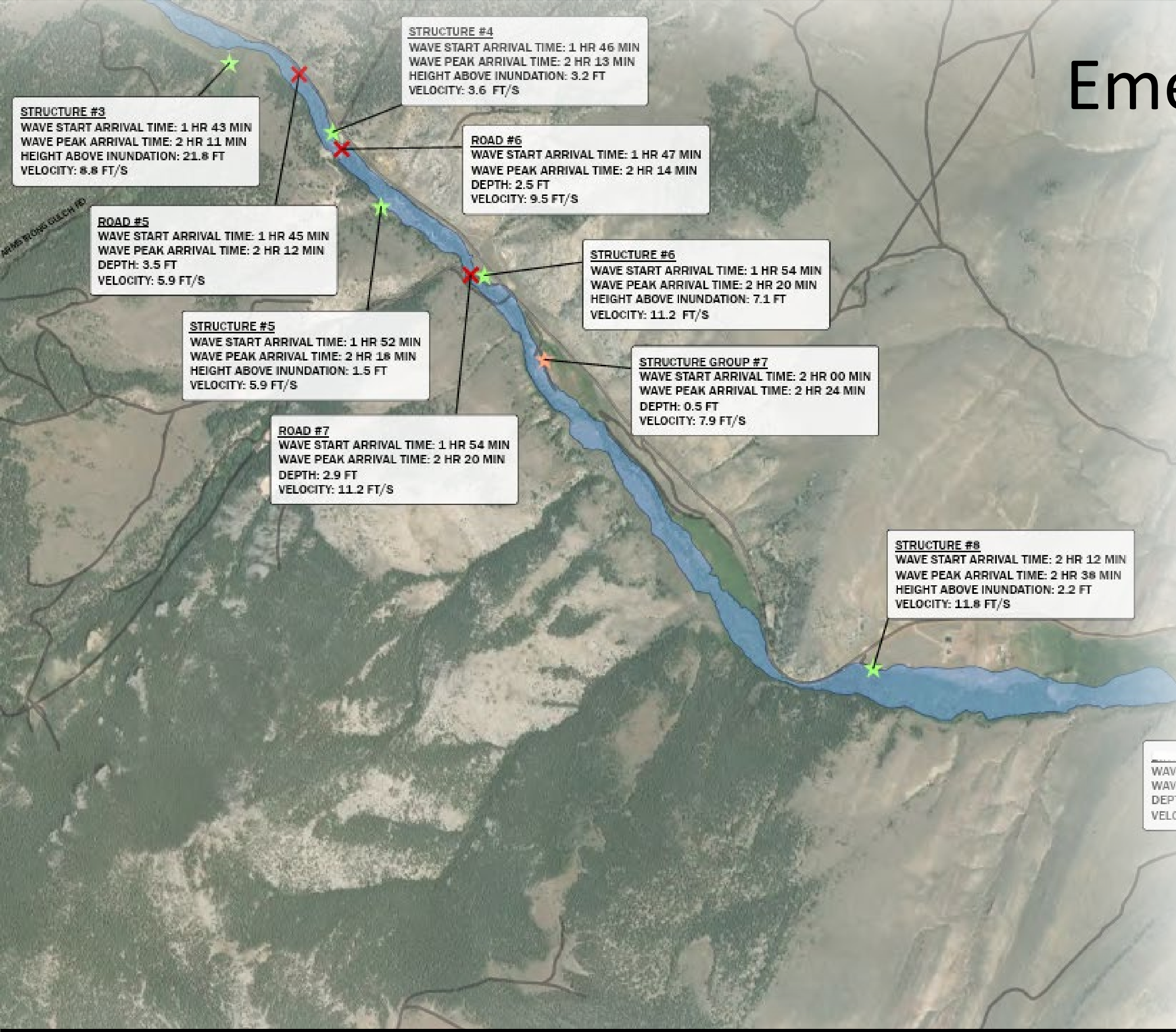
Photos curtesy of DNRC Dam Safety

Instrumentation

- Piezometers, settlement markers, flumes, and other instruments to monitor water pressures, seepage, and structural movement.
- Regular readings and documentation are critical, especially during emergencies or after repairs.



65-feet: Large crack on the North side of the conduit.
80-feet: Large crack on the North side of the conduit, discolored and leaky.
97.5-feet: Leaky joint.
110-feet: Leaky joint.



Emergency Action Plan (EAP) & Intervention Plan

EAP that identifies dam characteristics, roles/responsibilities, event detection, notification, inundation maps, and other preplanned actions to be followed to attempt to prevent a dam failure and to possibly minimize downstream property damage and potential loss of life.

The **Emergency Intervention Plan** provides information for identifying, addressing, and responding to specific emergency situations (i.e. internal erosion) should they occur. Companion document to the EAP.

'Intervention can stop or minimize consequences of a dam failure. Warning signs should not be ignored'.
ASDSO

Intervention

Observation: Piping is occurring…cloudy seepage exiting the dam and sinkhole observed on upstream slope…now what.

Next Steps:

1) Activate Emergency Action Plan. This is an emergency event. Notify parties identified in EAP.
2) Potential Intervention Steps
   - Lower the reservoir
   - Construct ring dike around the seepage discharge
   - Install a filter blanket
   - Plug sinkhole

References/Resources

Dam Owner Emergency Intervention Toolbox, Gannett Fleming, 2016.

Technical Manual: Conduits through Embankment Dams, FEMA 484, 2005

Association of State Dam Safety Officials (ASDSO)

damsafety.org
damfailures.org
damtoolbox.org

Montana Department of Natural Resources & Conservation, Dam Safety Program

FEMA

Association of State Dam Safety Officials®

MONTANA DNRC

Conduit Rehabilitation & Replacement

1. Two Case Studies
2. Discussion on Conduit Inspections

Recent Dam Construction Permitting Projects

New Dams	1
Spillway Rehabilitations	3
Conduits: Repairs, Rehab, or Replacement	14
Seepage/drainage mitigation	5
Concrete Dam Rehabilitation	1

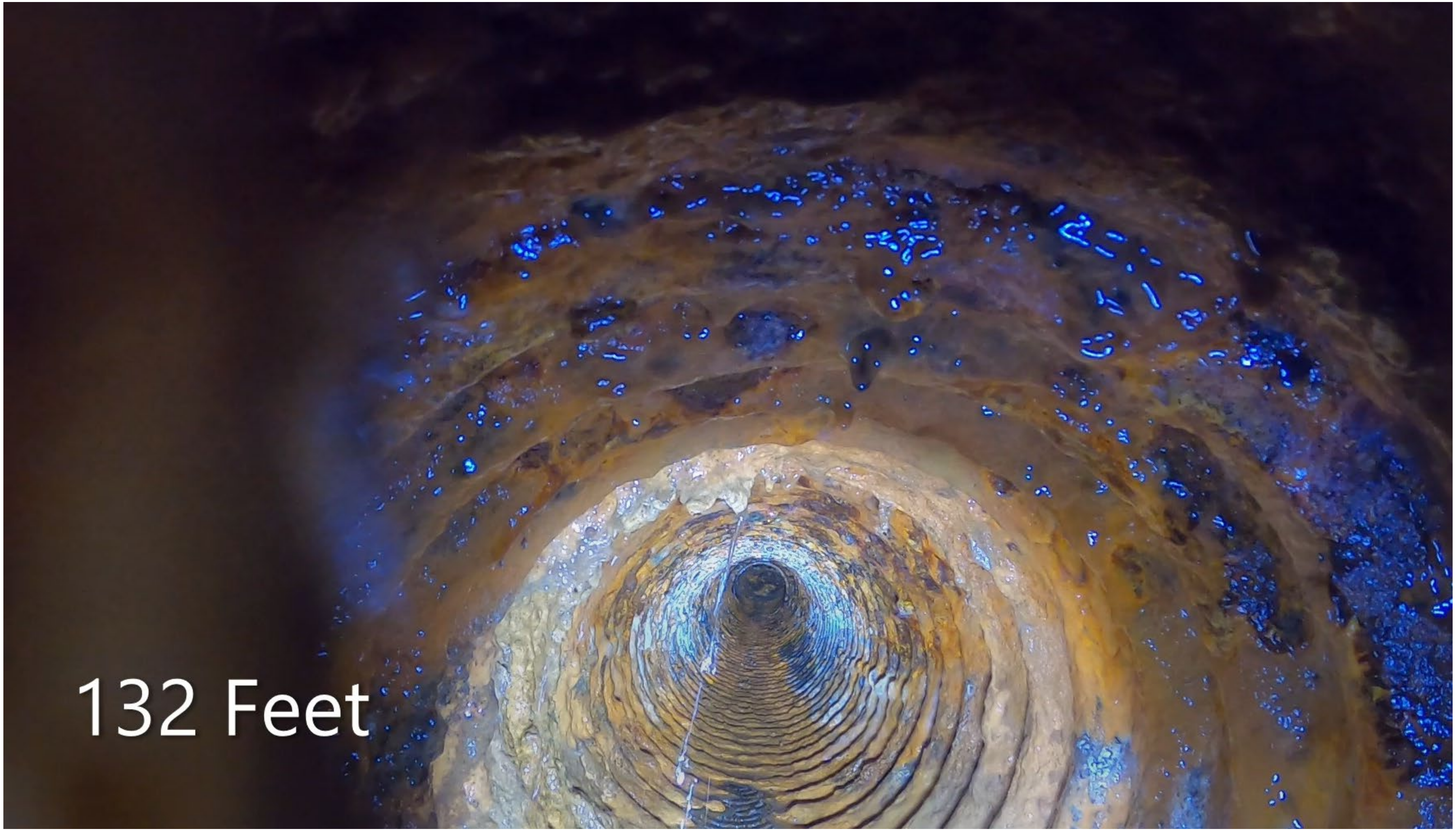
Case Study 1

Beautiful setting,
but the low-level conduit was beyond its design life.
~Uncertain of the age but could be as old as 80 years.

USE: Recreation and late summer/fall irrigation.

The inclined slide gate was also drifting in with sediment, making it unreliable to open and close.

Draw down capability is important due to limited access.


132 Feet


VOLVO
VOLVO

Replacement

1. 14” HDPE Pipe encased in lean concrete.
2. Slip-lining not preferred
3. ~~Excavate and replace the existing conduit.~~
4. Change order: Abandon the existing conduit in-place and construct over the top of it. (Reduced the amount and cost of excavating the original pipe.)

4. Inlet structure with vertical drop keeps the inlet pipe clear of the sediment and other bottom debris.


CAT

Flowable fill emerging at the downstream end.

Removed 30-ft of the downstream end of original conduit.

Case Study 2

Terrific recreation and irrigation resource for a large, private subdivision. But the low-level conduit was beyond its design life. ~Built in the 1960's.

The inclined slide gate was seized in a closed position. Probably because low-level releases were never made.

Lawn irrigation for subdivision residents is pumped from the reservoir.

Outlet end of the conduit
had completely failed.

Coating is gone and joints are in
terrible corroded condition.
Conduit appears to show ovality.

Replacement

1. Abandon the existing conduit in-place, using flowable fill.
2. High-level weir & drop-inlet structure for reservoir elevation control.
3. High-level inlet structure includes a slide gate at the bottom of the structure for emergency drawdown.
   ~ capable of 5-feet of drawdown
   ~ provides enough drawdown until irrigation and additional pumps can assist further, if necessary.
4. New conduit was positioned over the old to reduce excavation costs.

Outlet conduit to be buried minimally under the embankment slope.

Ready to be encased in CLSM.

Case Study 2

Cas

Filter diaphragm with embankment fill constructed in simultaneous lifts to prevent contaminating the filter with embankment materials.

Outlet structure with conduit knockout for the conduit.

Cas

No mink were harmed during the making of this presentation.

No mink were harmed during the making of this presentation.

Forum Discussion

- Questions
- Additional information
- Suggestions for audience
- Suggestions for an existing project / concern
- This one time I …
- Dam jokes….but we’ve probably heard them

And thank you to

MONTANA DNRC

for your support!