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Managing Water in the West

Dams Without Filters

and Responding to Seepage Incidents

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Presentation Overview

Do Dams Need Filters?

Evaluation using Potential Failure Modes

Seepage Incidents – Is it an Emergency?

Emergency Filters and Diffusers

Case Histories

Conclusions

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Do Dams Need Filters?

All modern embankment dams (including tailings dams) should have engineered filters and drains to prevent seepage-related failures.

Many embankment dams in the United States do not have properly designed filters.

The decision to add a toe drain, filter, etc. is risk based due to a need to prioritize limited funds. Often the decision is no action at this time (subject to monitoring, periodic inspection, and review).

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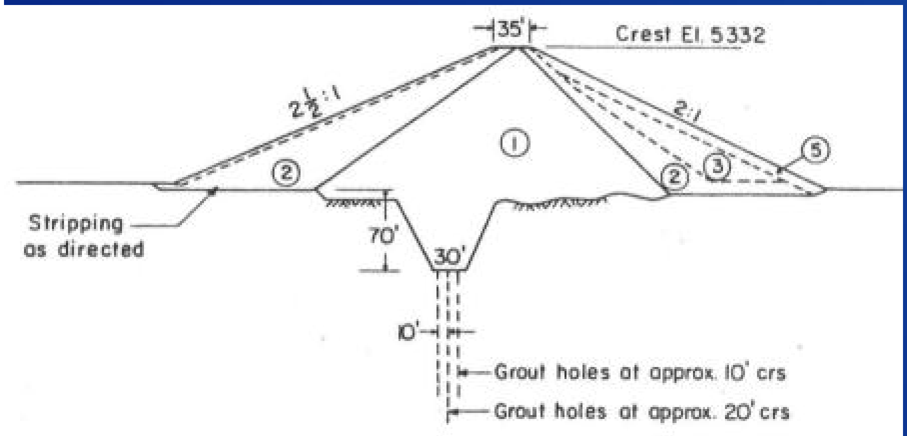
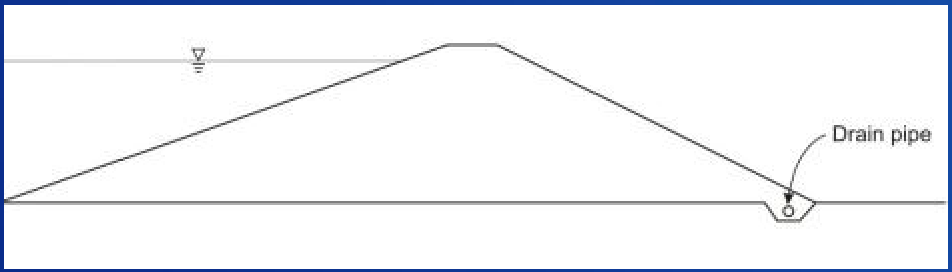
Teton Dam – Failed on first filling June 5, 1976.

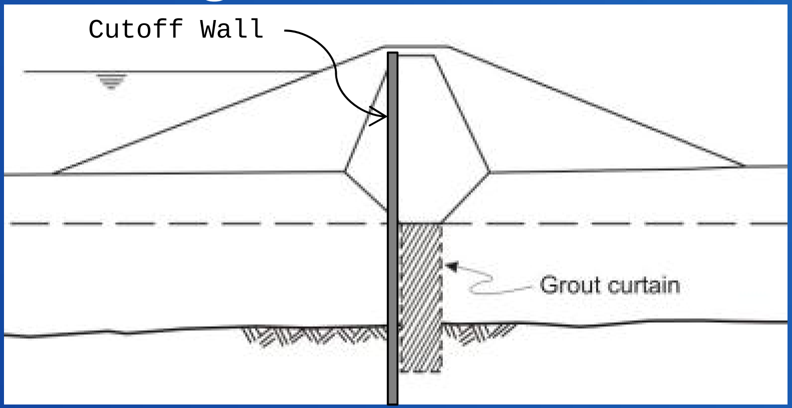
Dozing fill and riprap into the upstream whirlpool had no effect.



No Filter? - Reclamation Experience

Belle Fouche Dam, SD – No filters, clay dam, high foundation seepage in 1910 during first fill. Reclamation built its first toe drain, no additional incidents in 100+ years of monitoring.





Fontenelle Dam, WY – Outer filter zone (silt, sand, gravel) not designed. Silt core on open bedrock (some grouting). Near failure on first fill. More grouting, did not understand need for engineered filter & drain. Seepage incident in 1980 upon second fill, built a $55 million cutoff wall in 1985-87. No more incidents.

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Fontenelle Dam Wyoming

1965 Fontenelle Dam WY nearly failed during first fill due to seepage through cracks in the abutment rock causing the silty embankment soil to erode.

The reservoir was in flood stage with the spillway flowing when the muddy seepage started.

Fontenelle Dam

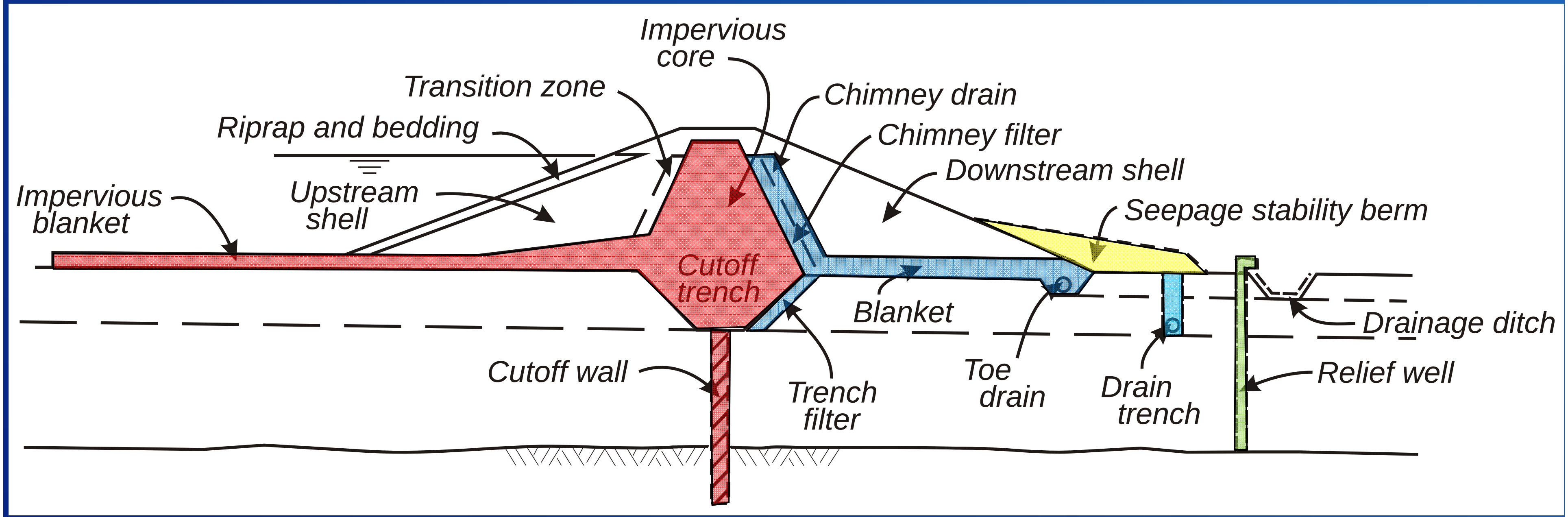
The dam was saved by:

1. **Riprap from the dam was thrown into the growing downstream cavern, this providing support so the dam crest did not collapse.**

2. **All outlets were opened full to quickly lower the reservoir.**

How do you decide what is needed?

Risk based evaluation of potential failure modes



Dam Components for Seepage Control

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How is it Accomplished?

- Step 1. Understand the dam geology, construction, and performance history. Review records, talk with operators, inspect the dam.
- Step 2. Brainstorm potential failure modes. Use critical thinking, do not just copy what others have done. Each dam is unique. Sketch the seepage pathways, write out detailed descriptions of the process.
- Step 3. Evaluate the potential failure modes and consequences. Use of event trees is helpful.
- Step 4. Get independent peer review and revise.
- Step 5. Make a decision based on potential for failure and risk.

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Potential Failure Modes

Are Related to Loadings:

- Seepage
- Earthquake
- Flood

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Some Seepage Related Potential Failure Modes

- Internal erosion along the outlet conduit.
- Internal erosion through the embankment.
- Internal erosion through the foundation.
- Flow erosion through a stress crack.
- Blowout of the toe due to high pressure flow through the foundation.
- Internal erosion into a flaw in the conduit.
- Internal erosion along the spillway wall.
- Internal erosion of embankment into foundation.
- Erosion due to water exiting a flaw in the conduit.

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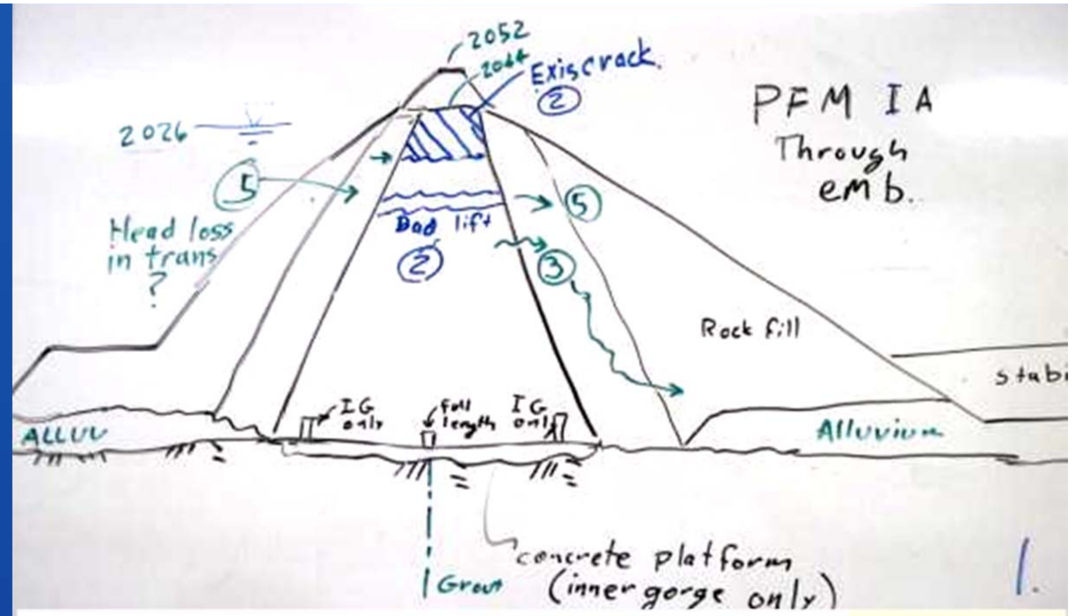
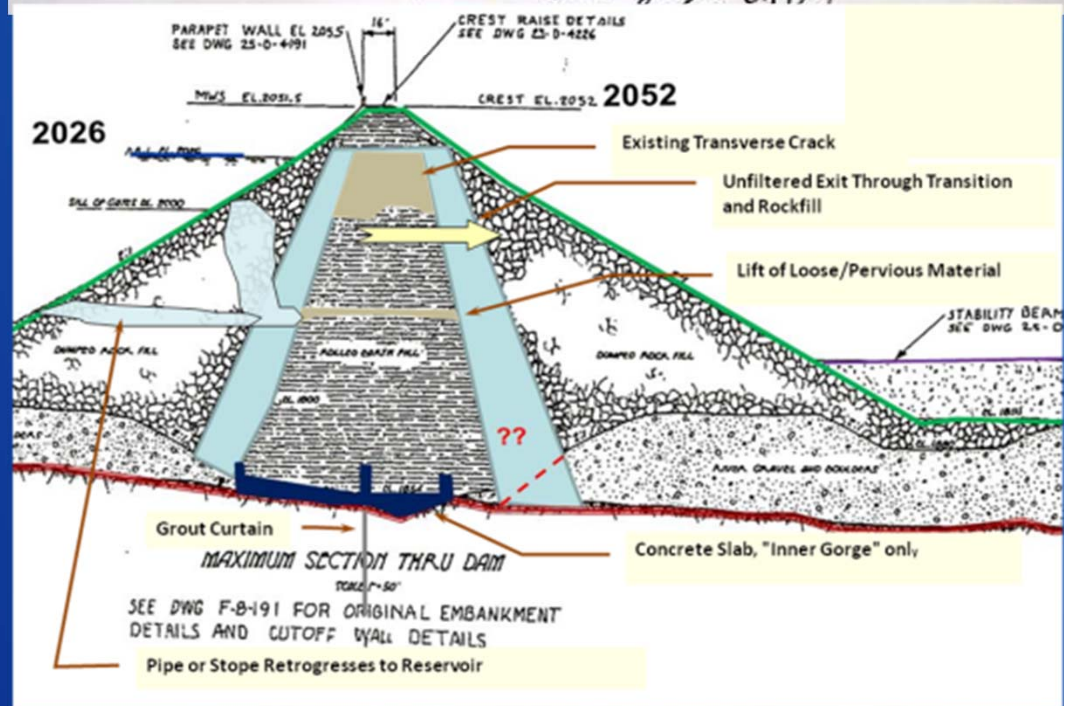
Component Events

- What loading makes failure start?
- How and where does it start?
- And then what happens?
- And then what?





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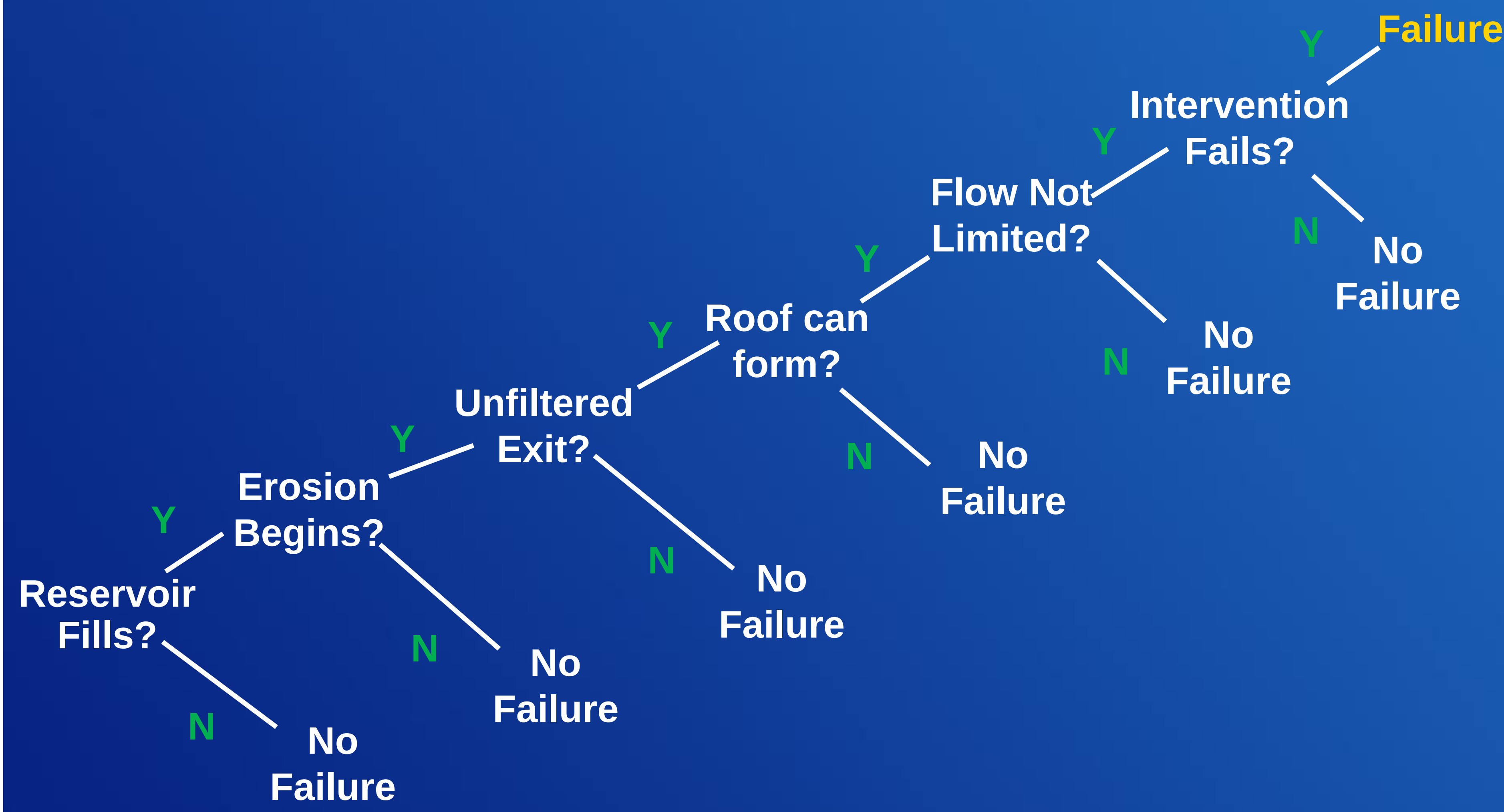
Event Tree for Internal Erosion



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Verbal Probability Scale

• Virtually Certain	• 0.999
• Very Likely	• 0.99
• Likely	• 0.9
• Neutral	• 0.5
• Unlikely	• 0.1
• Very Unlikely	• 0.01
• Virtually Impossible	• 0.001

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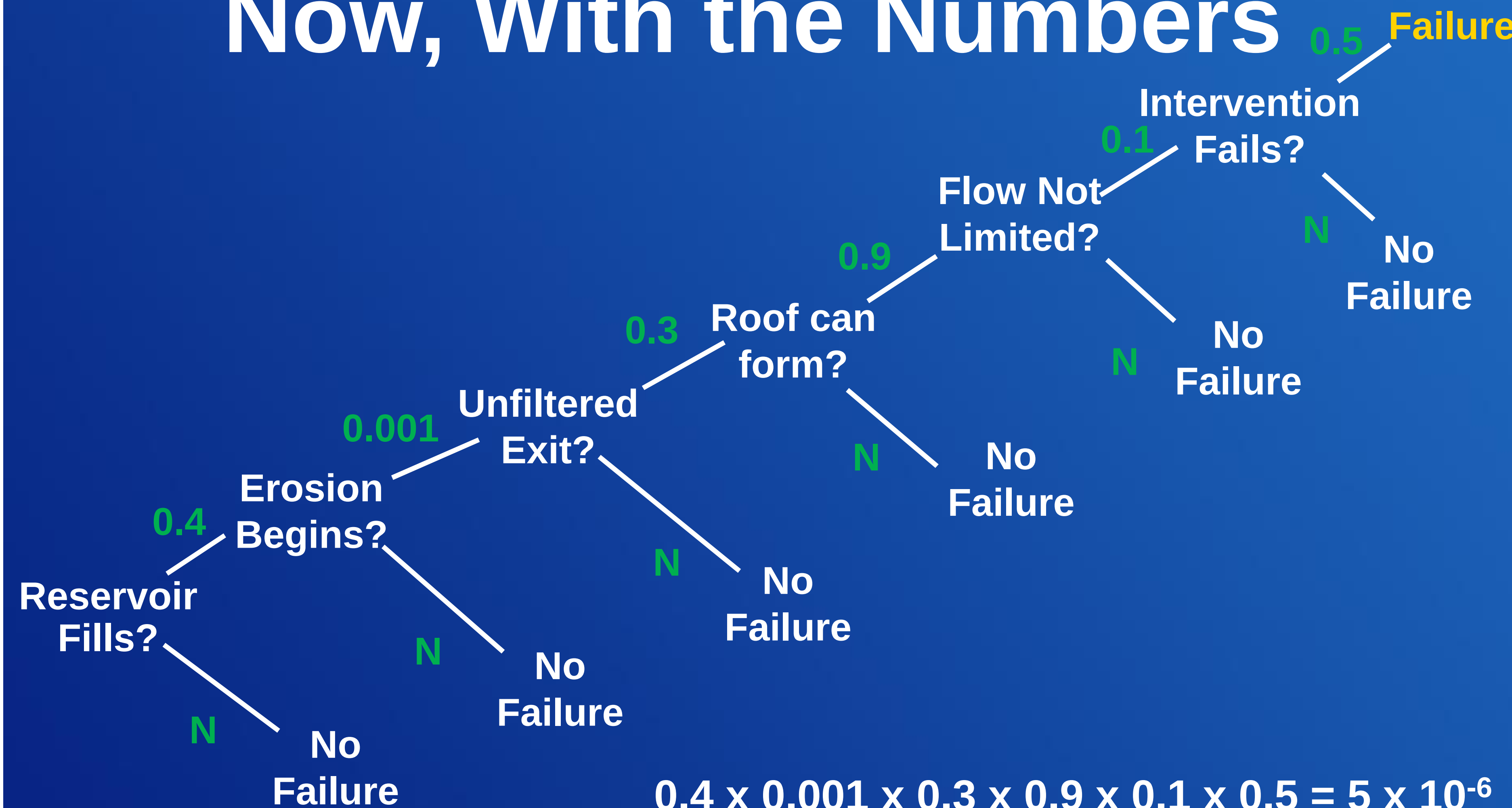
Now, With the Numbers



0.4 x 0.001 x 0.3 x 0.9 x 0.1 x 0.5 = 5×10^{-6}

(Therefore, below guideline level for APF.)

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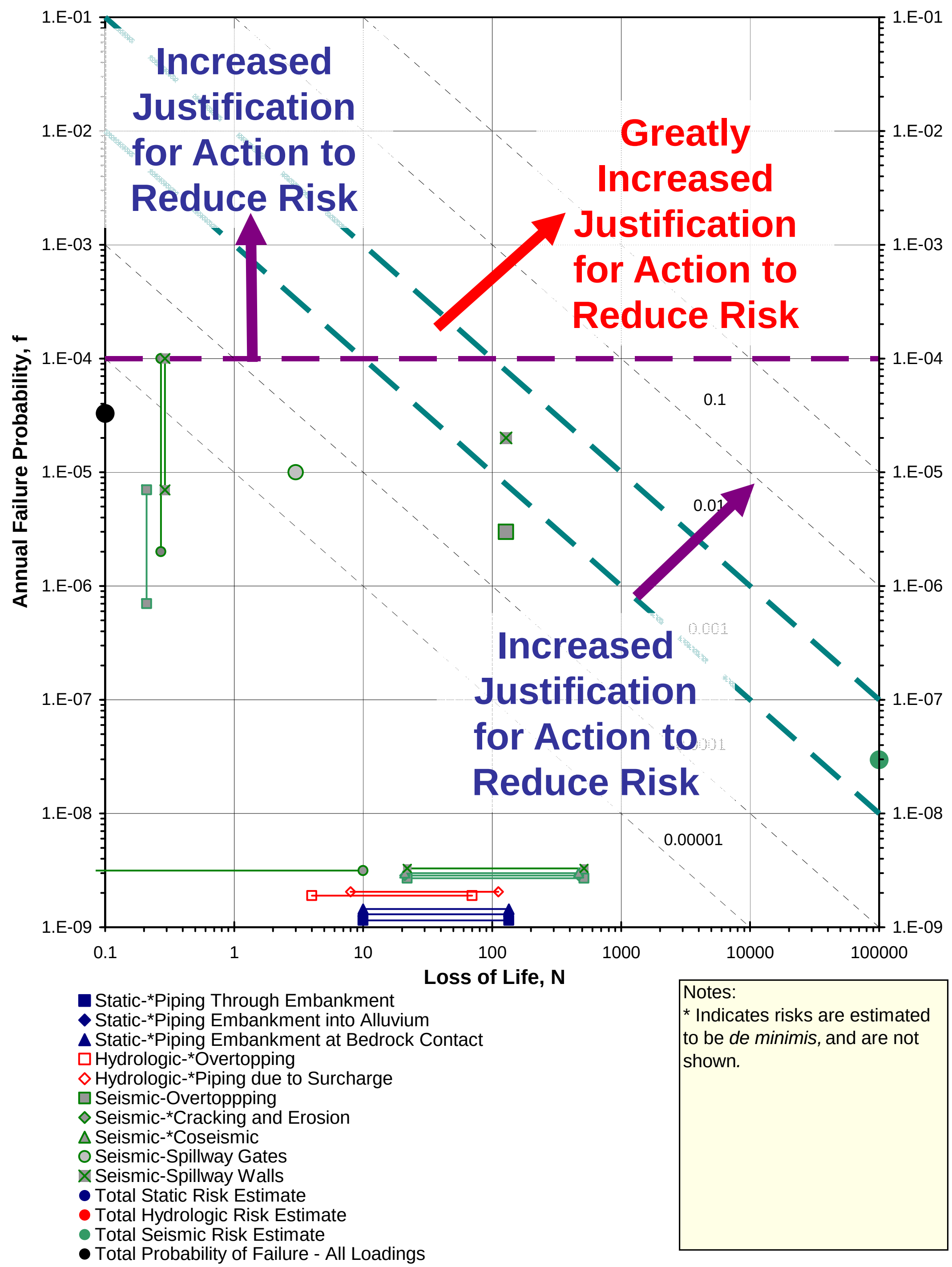
Proposed "Best Estimate" Values of Annual Probability of Initiation

- Applies only to Reclamation embankments
- Values serve only as "starting points" – each dam is unique and must be evaluated separately, looking at site specific features/vulnerabilities

Type of Internal Erosion	Range of Initiation Probability (Best Estimate)
Embankment only	$3x10^{-4}$ to $1x10^{-3}$
Foundation only	$2x10^{-3}$ to $1x10^{-2}$
Embankment into foundation	$3x10^{-4}$ to $7x10^{-4}$
Into/along conduit	$4x10^{-4}$ to $1x10^{-3}$
Into drain	$1x10^{-4}$ to $1x10^{-3}$

Reporting the Results

f-N Chart



We do not always have time to do an evaluation!

Most calls come in on a Friday mid-day to late afternoon or before a holiday weekend.

Why: They may have known about it for a few days but are afraid to let it go unaddressed over the weekend.

If they call it in it becomes someone else's responsibility, they are off the hook. (or so they think)

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The Call

The call can be from anyone, usually it's the dam operator

A. V. Watkins Dam – Rancher noticed water in his field.

Red Willow - A person from the inspection team fell into a sinkhole.

All American Canal – My boss called me at home 9 days after the earthquake, need to go look at some seepage.

Weber Siphon – Construction Inspector - we have a flood, is it a problem?

Box Butte – Dam Tender noted seepage changes on the inspection checklist.

McKay Dam – Dam Tender noticed piles of gravel in toe drain.

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Key Questions

- Where is it?
- Is the water cloudy or muddy?
- Are piles of sediment forming?
- Is the water flow increasing?
- Are the seepage areas expanding in extent?
- What is the Reservoir level and recent history?
- What's the weather forecast?

Caution: soil erosion is sometimes imperceptible

Common Factors in Many Incidents

- Erodible embankment/foundation soils.   Low PI silts, lean clays, fine sands, dispersive soils, collapsing soils
- Backward erosion piping mechanism is common.
- Often along a penetrating structure such as outlet works conduit, spillway wall, or floor slab.
- Internal erosion can initiate under low hydraulic gradients (less than 0.08)

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Actions to Consider

- Measure flow rate
- Determine aerial extent (changing with time)
- Measure for sediment transport
- Increased inspections (up to 24hr)
- Bring in equipment and filter materials
- Build a filter
- Lower the reservoir
- Maybe inform authorities

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Filters

Consist of a filter material, a drain, and a cover

Filter – Its function is to stop the loss of soil particles (silt, clay, fine sand size material) but allow seepage flow to continue. If you block the seepage it will find a new route to take or may build up and cause slope instability.

Drain – Its function is to quickly remove the filtered water so the seepage does not cause a rise in the ground water levels inside the embankment. Can also be a cover.

Cover – Function is to protect the filter and drain from the elements and to provide weight so a surge in seepage flow will not displace the filter. (Washakie Dam)

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When the flow is too swift

If the leak is so great that it just pushes the filter sand aside when applied then you need to take other actions to slow the seepage and allow a filter to be placed.

Diffuser – Gravel or riprap used to spread out (diffuse) the flow and provide weight to support the remaining embankment.

Back Pressure – A berm or coffer dam placed to create a pond of water at the exit point of the seepage to put some hydraulic back pressure on the seepage.

Plug – Material placed in the upstream side of a seepage path to block the flow. Sand, riprap, etc.

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Filters

Prefer C-33 Sand with not more than 5% fines (minus no. 200 sieve size material) This will filter most soils (does not filter a highly dispersive soil)

Sand from wind deposited dunes or weathering of sandstone is usually too fine to be an effective filter.

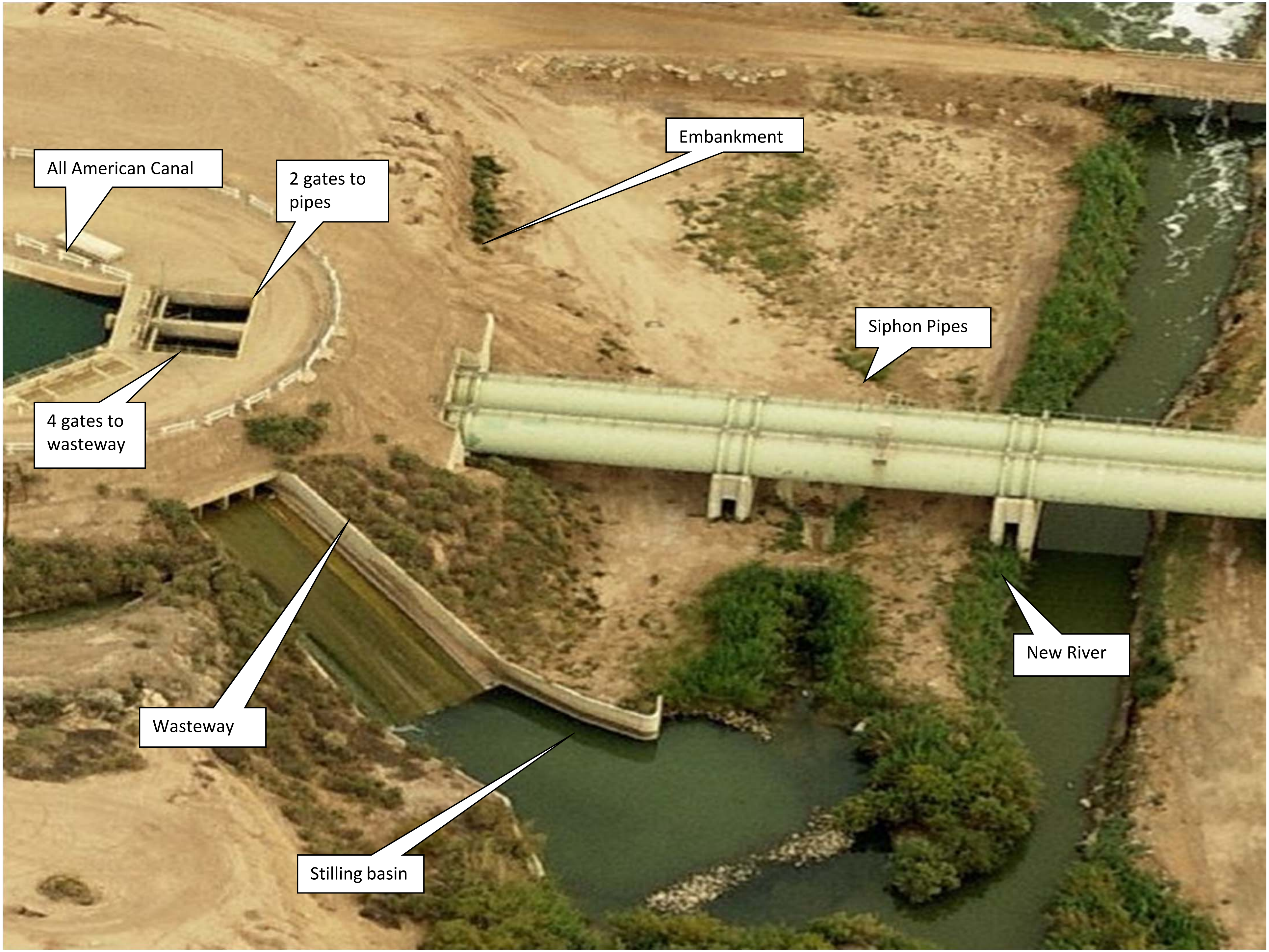
A non-woven geotextile filter cloth covered with gravel may also work in an emergency, but the C-33 sand works better.

Stockpiles at a Colorado Dam

Case History – All American Canal

The New River crossing supplies 1,800 ft^3/s of irrigation water to 250 square miles of fruit & vegetable crops.

A magnitude 7.2 earthquake occurred on Easter Sunday, April 4, 2010, southeast of Mexicali, Mexico


All American Canal
2 gates to pipes
Embankment
Siphon Pipes
4 gates to wasteway
New River
Wasteway
Stilling basin

Earthquakes can cause seepage

Seepage flow monitoring

Sand Bags for Back Pressure

Equipment stuck in mud, had to rebuild road access

First Load Gravel Arrives

Digging out the spot at last 2:15 am

One final measurement
“Pipe” moved back 2 feet

Gravel and sand partly in place

Putting in a second panel

Finally under control 6:19 am

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Conclusions

- Seepage forces never stop acting as long as a reservoir is present. Horizontal flow gradients as low as 0.08 can erode fine soils.

- Dams lacking engineered cutoffs, filters, and drains should be considered safety deficient.

- Acceleration of seepage flow and/or material removal is a dangerous sign, you need to act now.

- Regular Inspection and seepage monitoring are essential requirements for safe dam operations.

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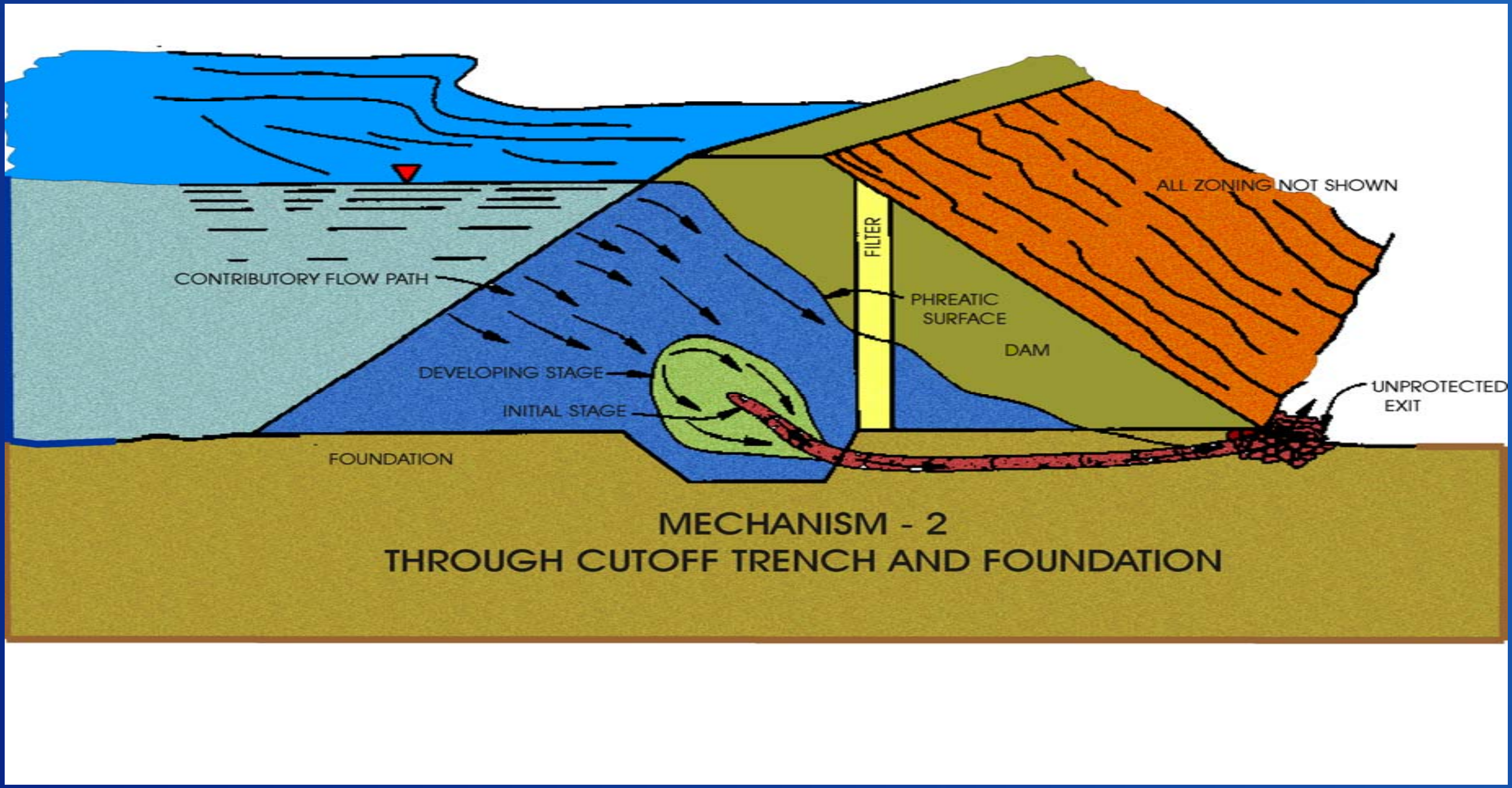
Questions ?

FEMA Manual



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