Lessons Learned from Embankment Dam Seepage Failures

Gannett Fleming

Maryland Department of the Environment

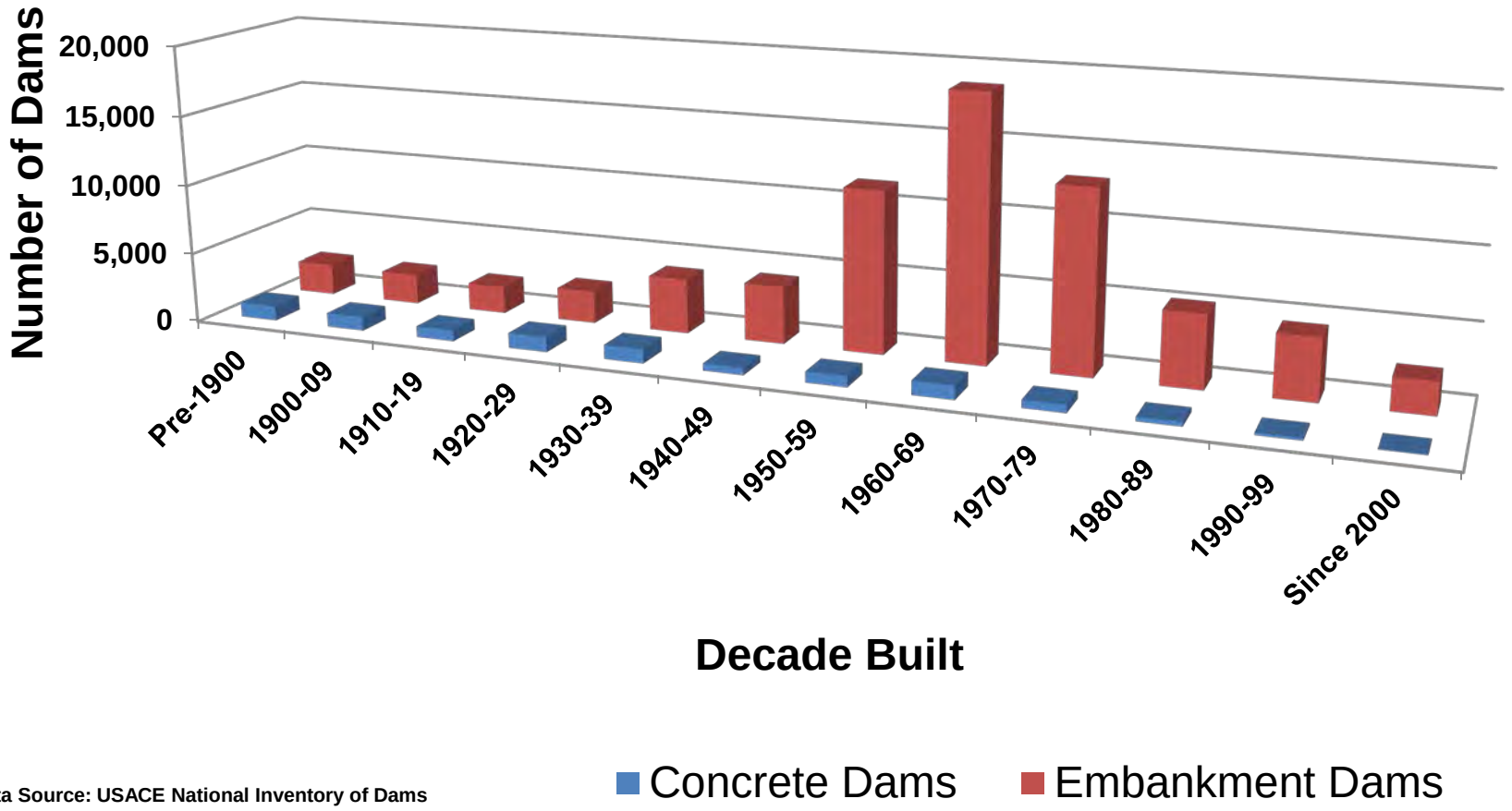
Dam Types

- Earth Embankment
- Rockfill
- Concrete
- Masonry
- Timber Crib
- Rubber/Inflatable
- Steel

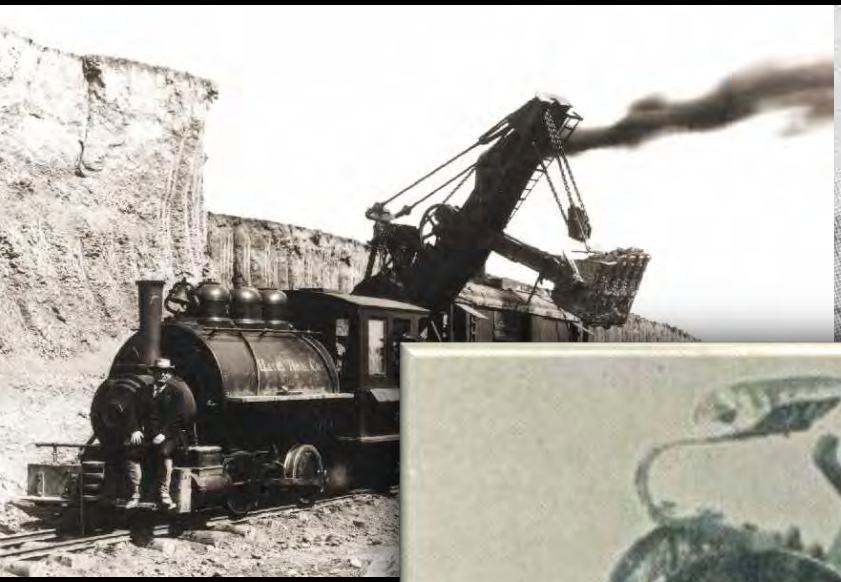
U.S. Dams by Type

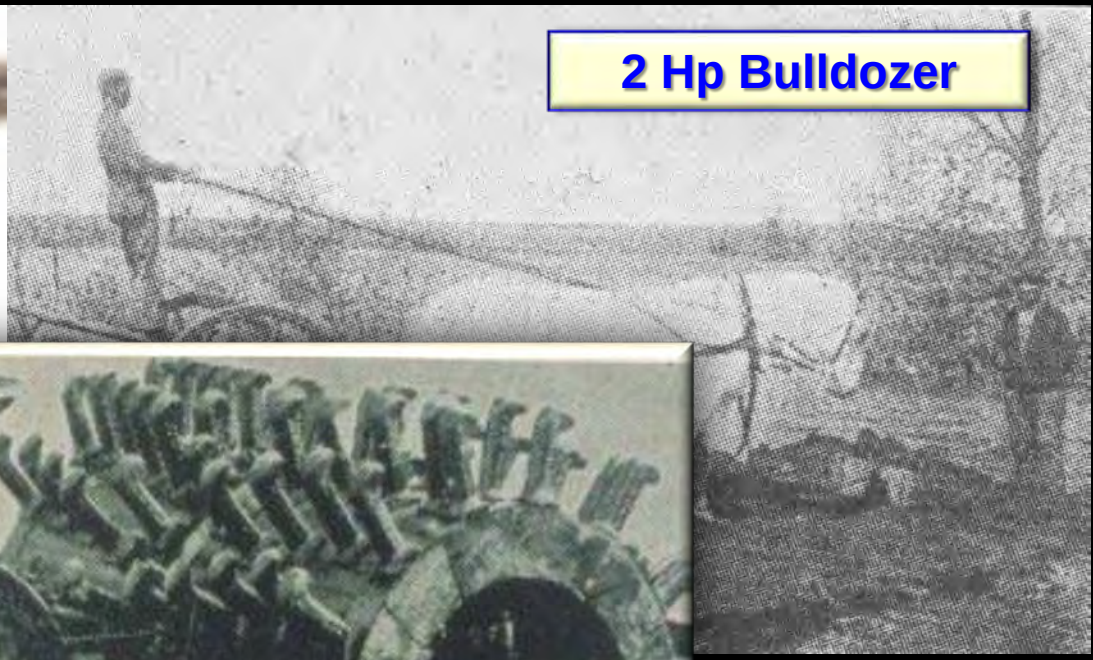
Data Source: USACE National Inventory of Dams

U.S. Dams by Decade Built

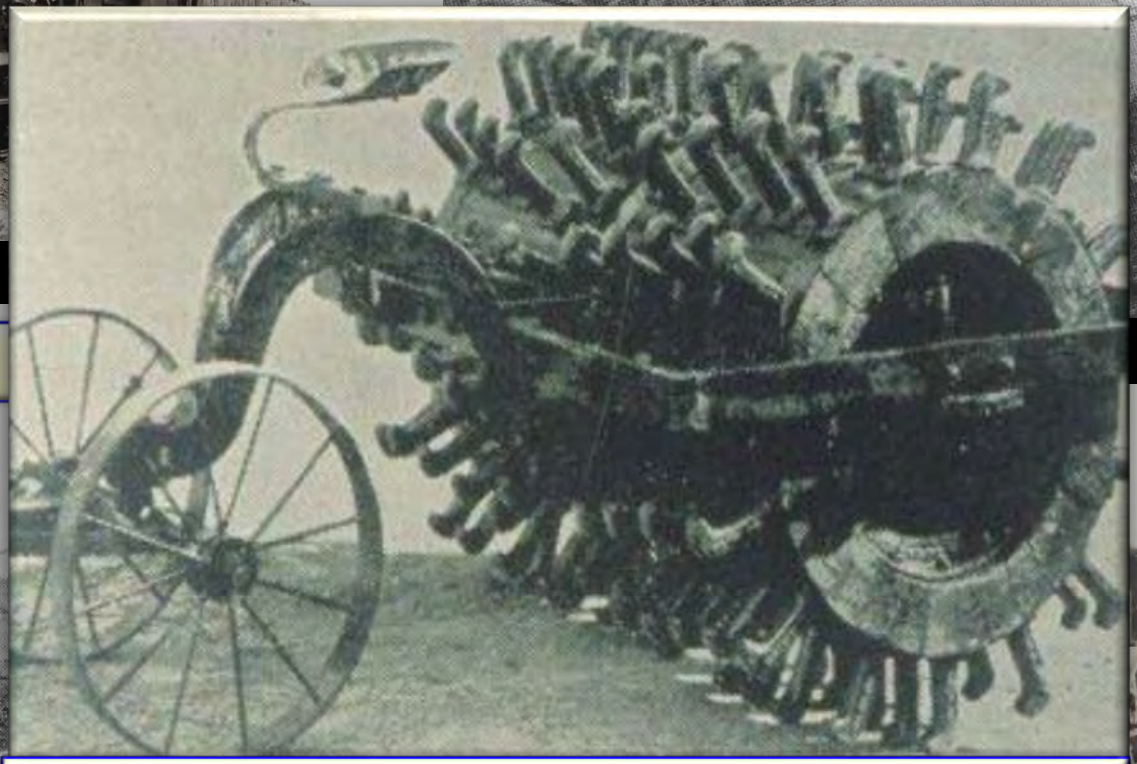


Data Source: USACE National Inventory of Dams

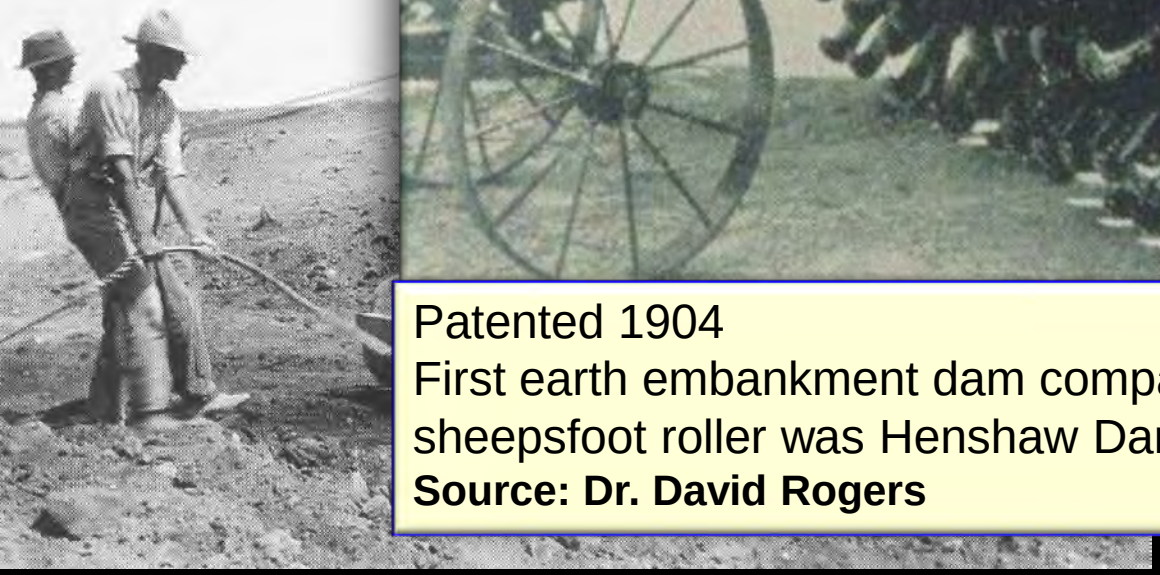




2 Hp Bulldozer



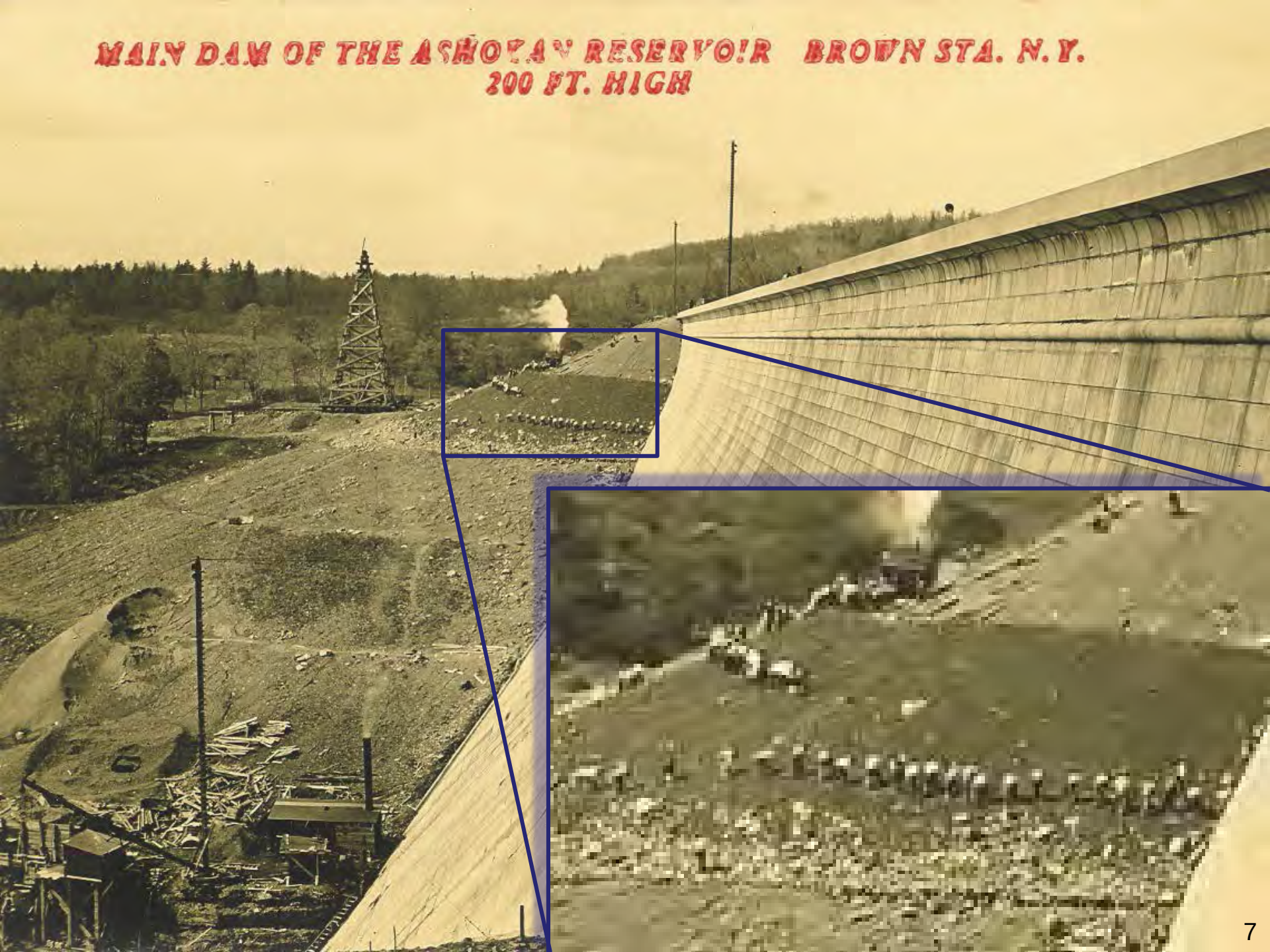
4 Hp Scraper



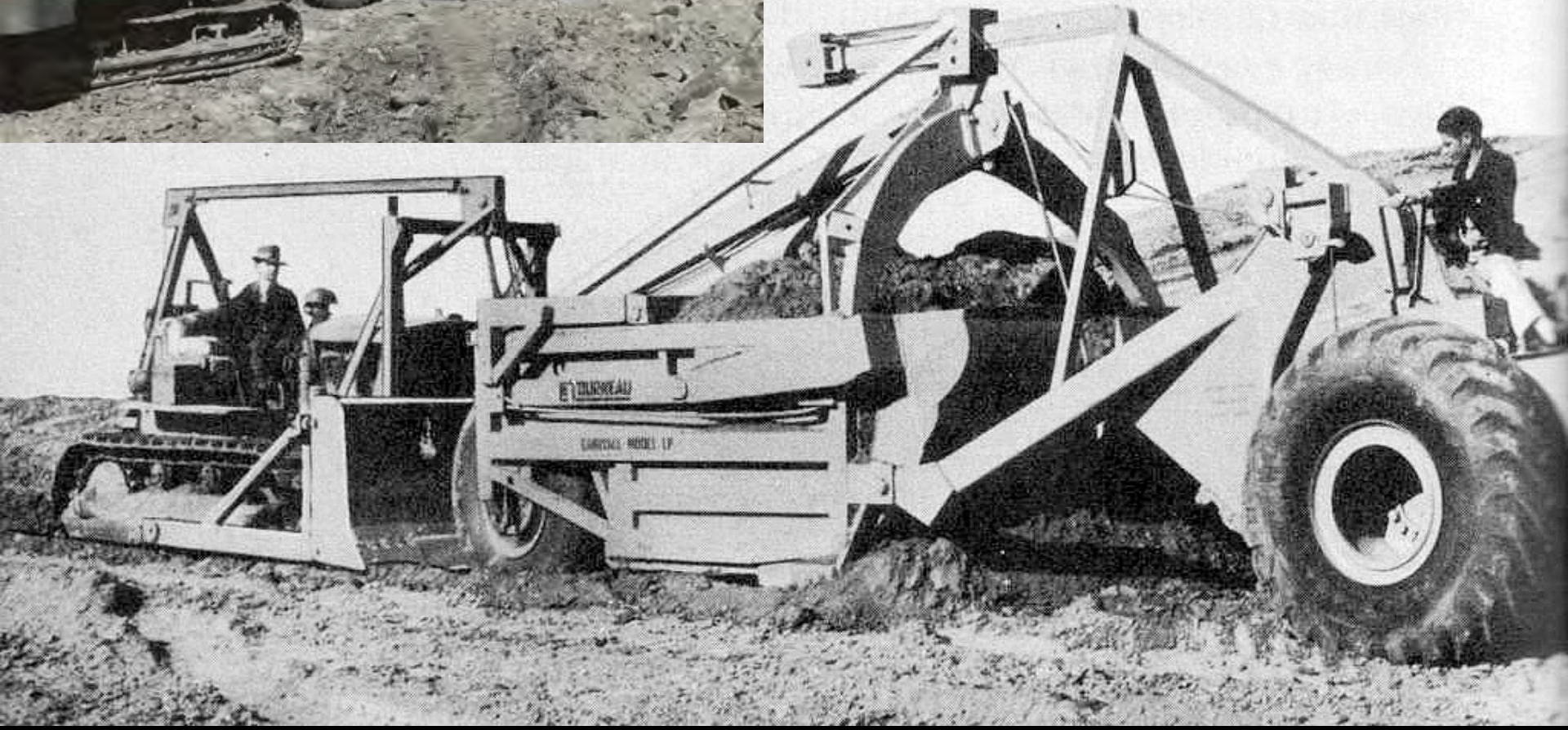
Steam Roller

Patented 1904
First earth embankment dam compacted with sheepsfoot roller was Henshaw Dam in 1920-23
Source: Dr. David Rogers

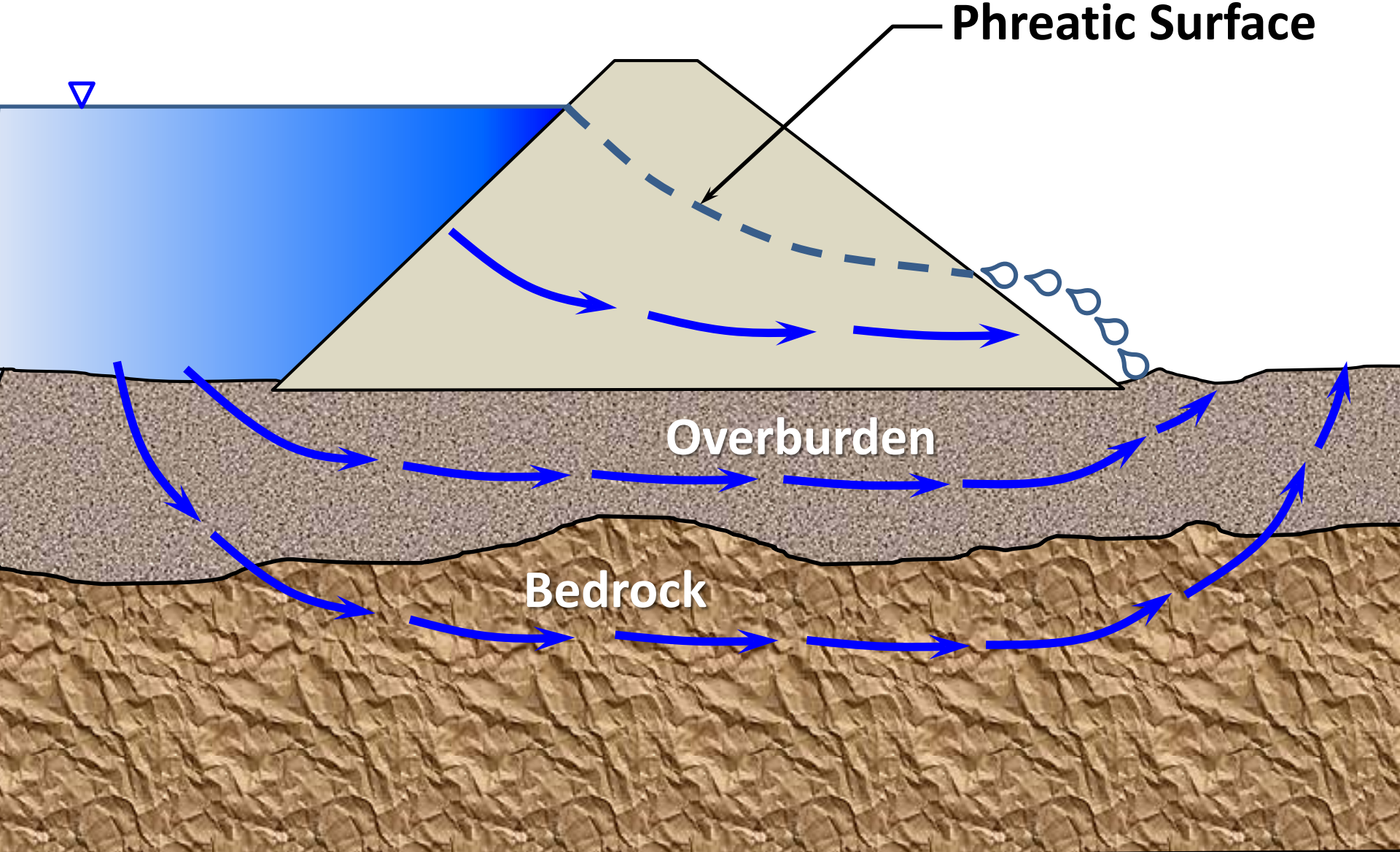
Earthmoving Equipment


MAIN DAM OF THE ASHOKAN RESERVOIR BROWN STA. N.Y.
200 FT. HIGH

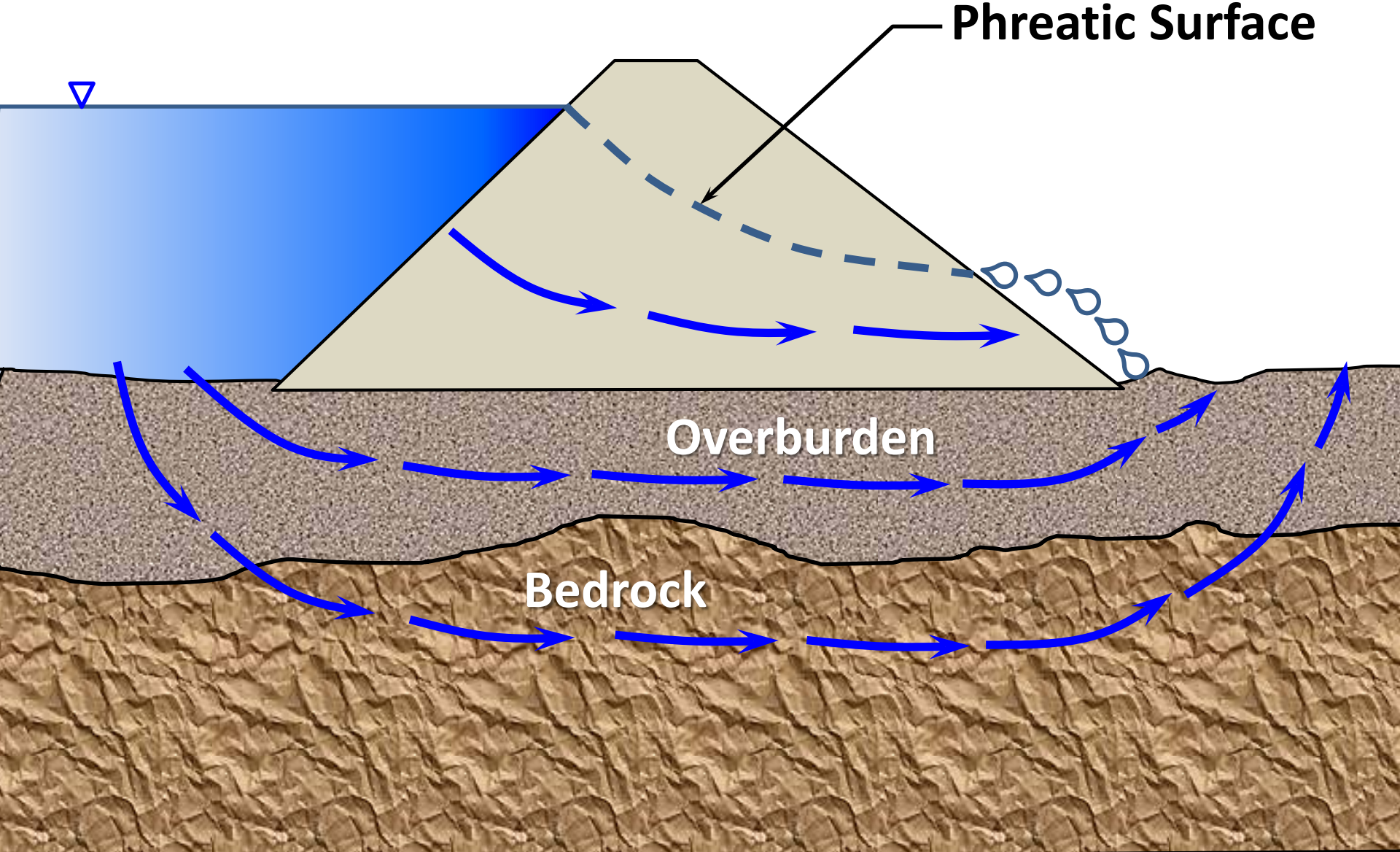
1940s-70s Earthmoving Equipment



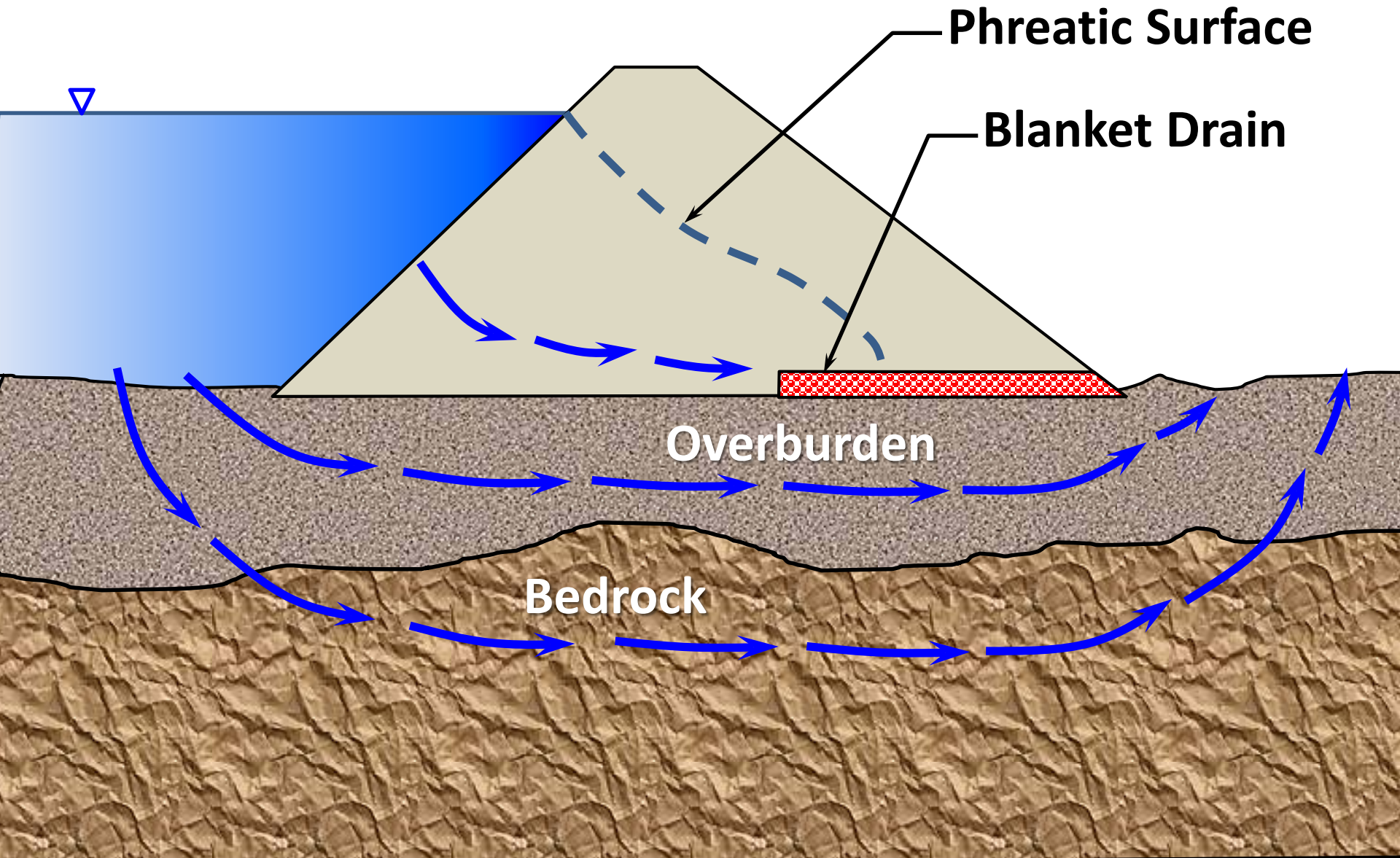
Homogeneous Dam



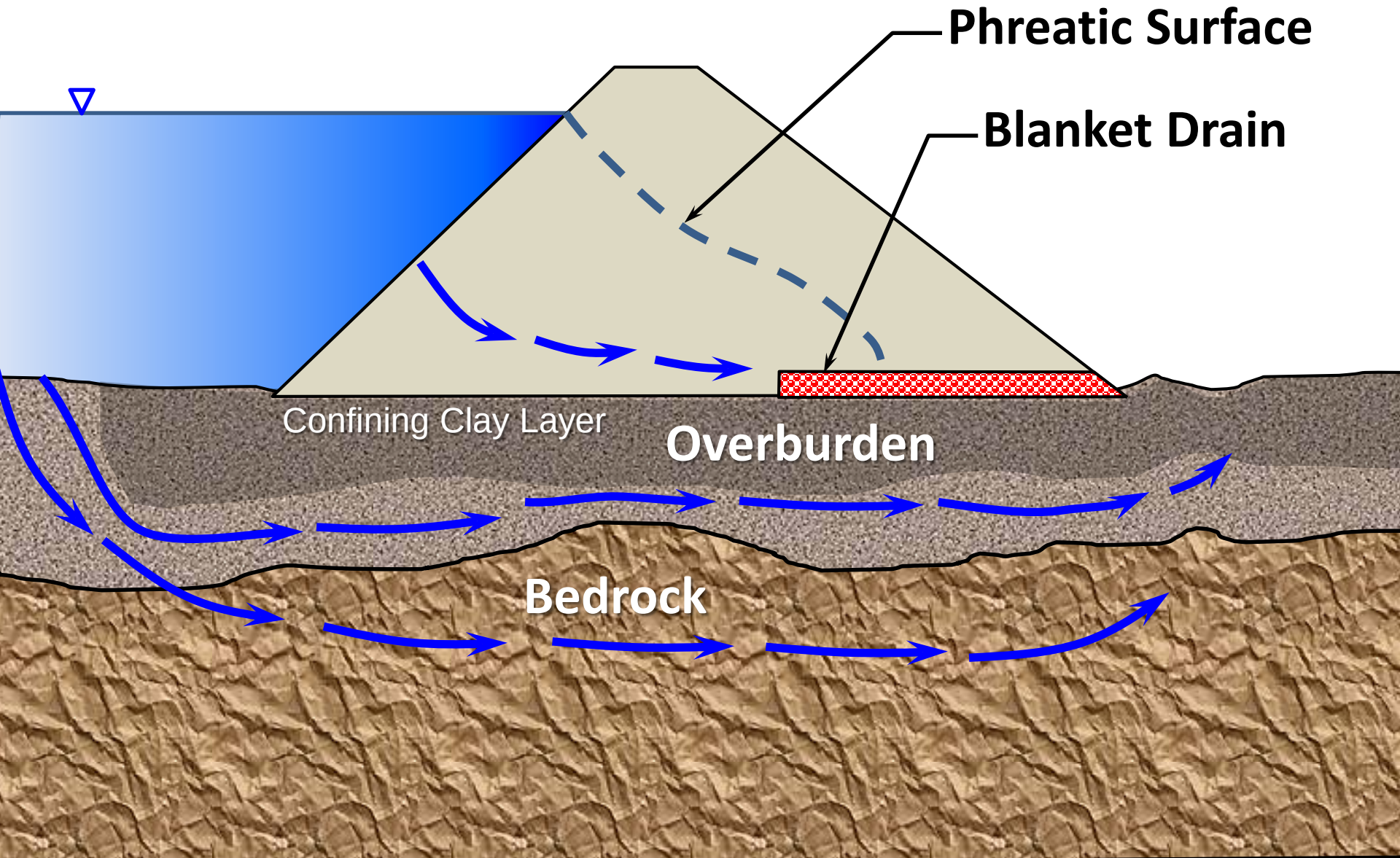
Homogeneous Dam



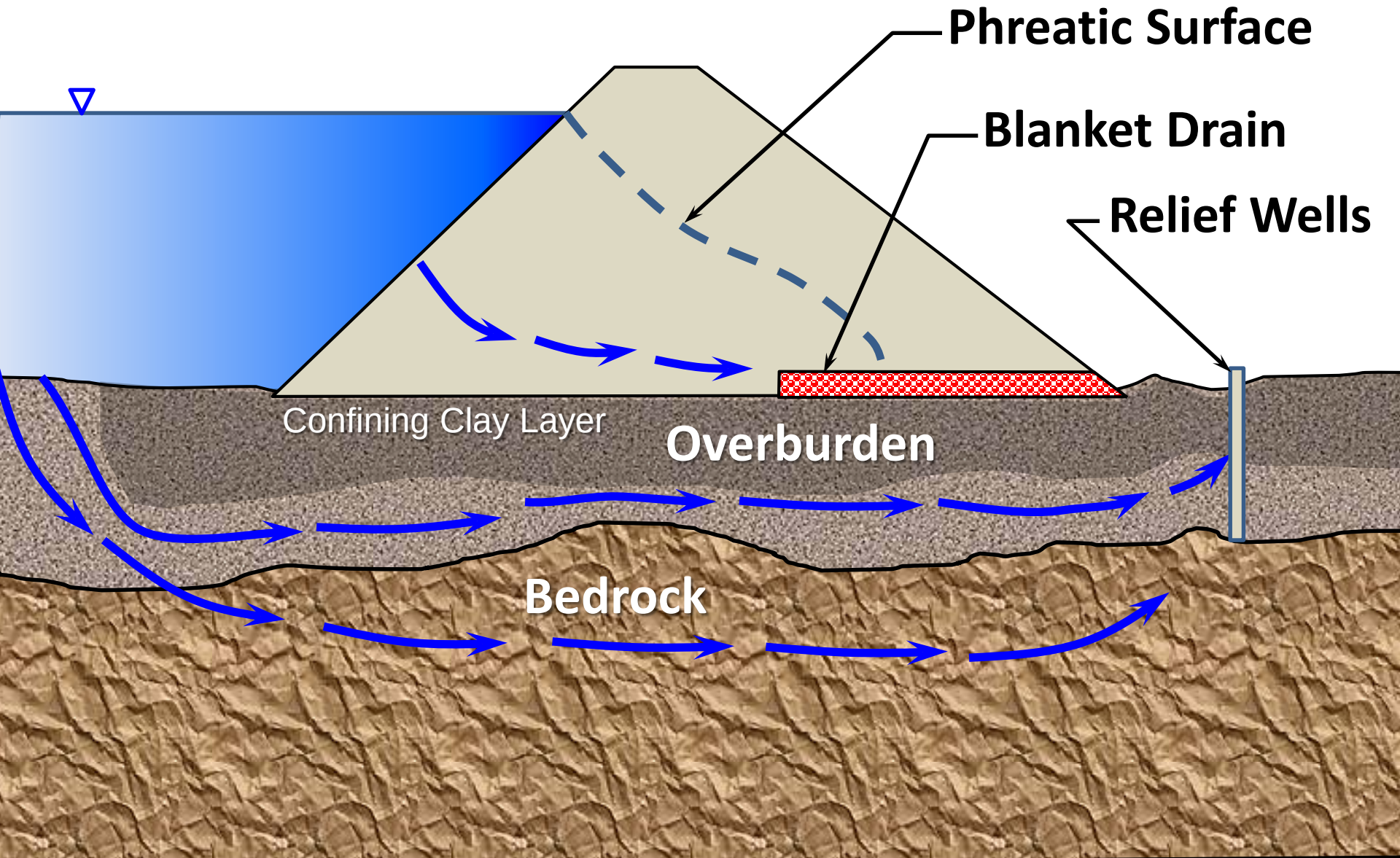
Homogeneous Dam



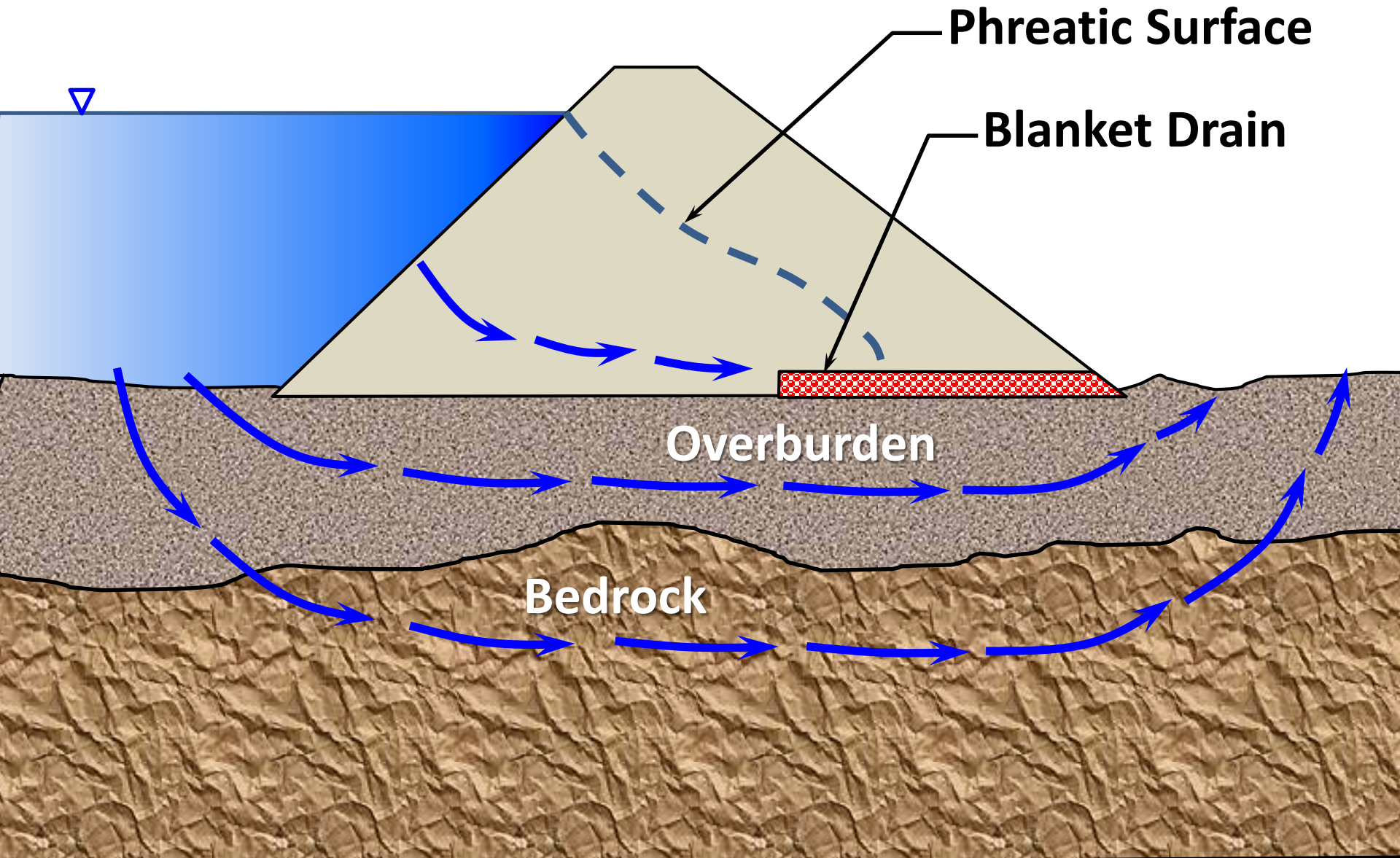
Homogeneous Dam



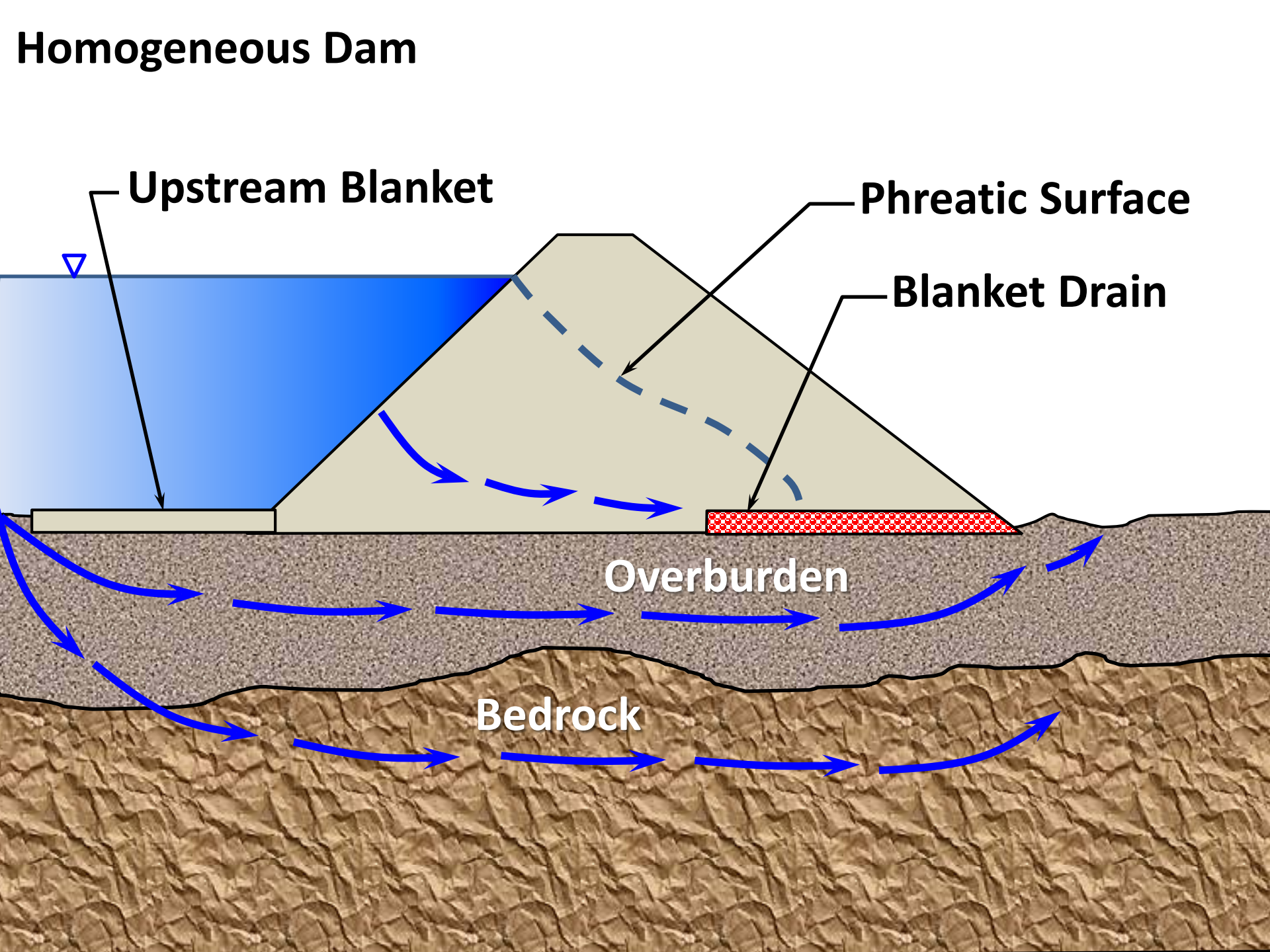
Homogeneous Dam



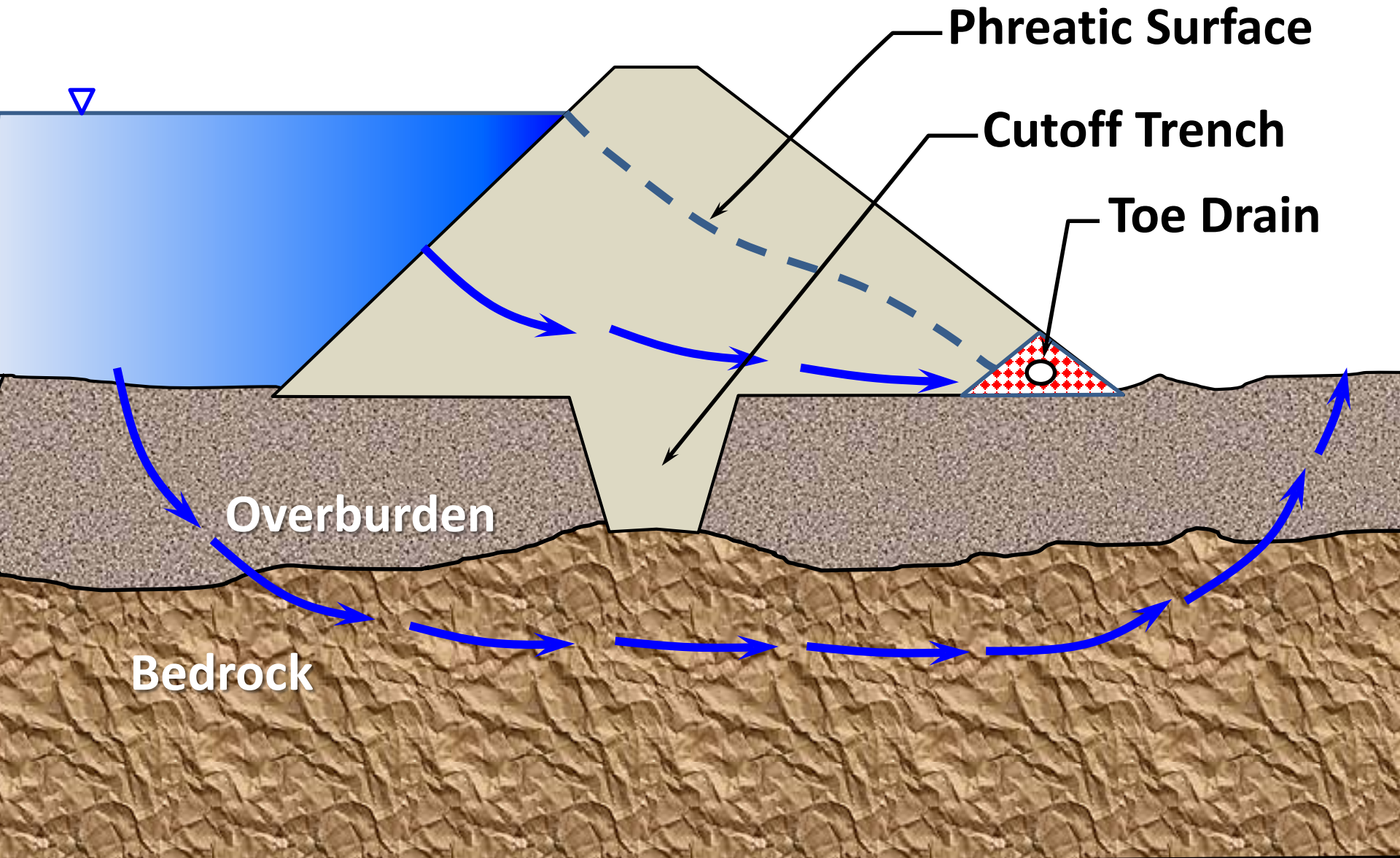
Homogeneous Dam



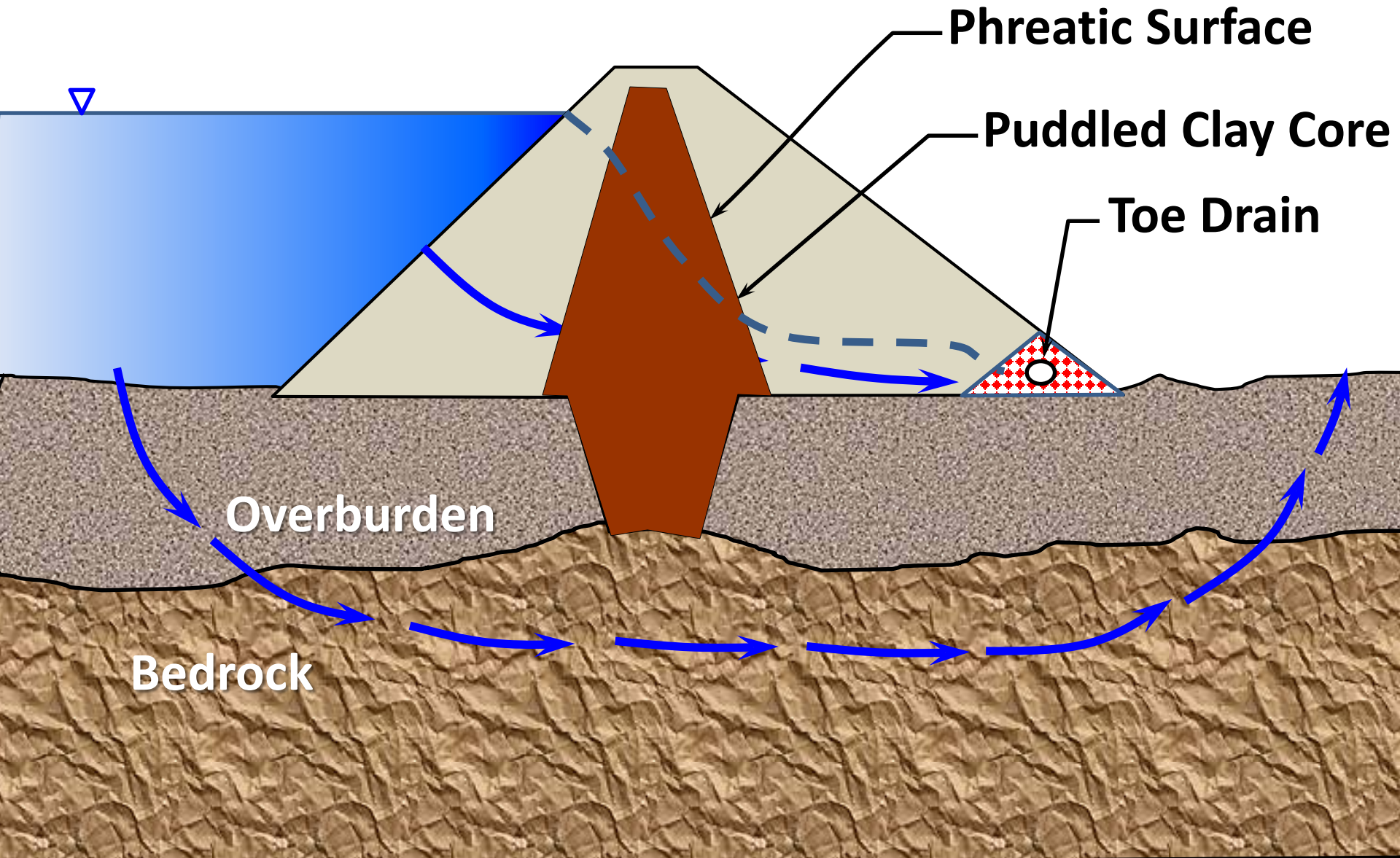
Homogeneous Dam



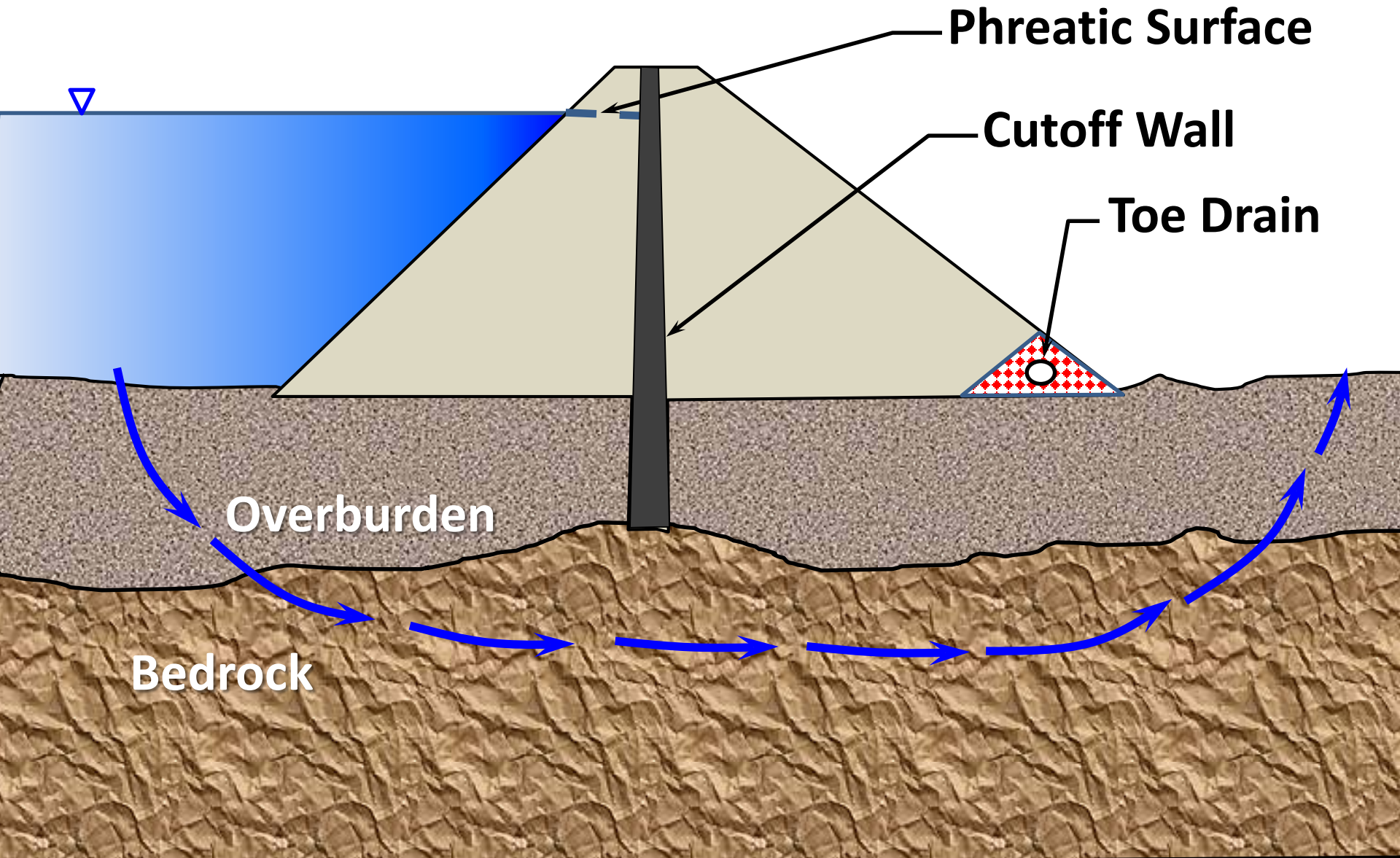
Homogeneous Dam



Puddled Clay Core Dam
1800s - ~1920



Homogeneous Dam With Cutoff Wall (~1860 – ~1930)



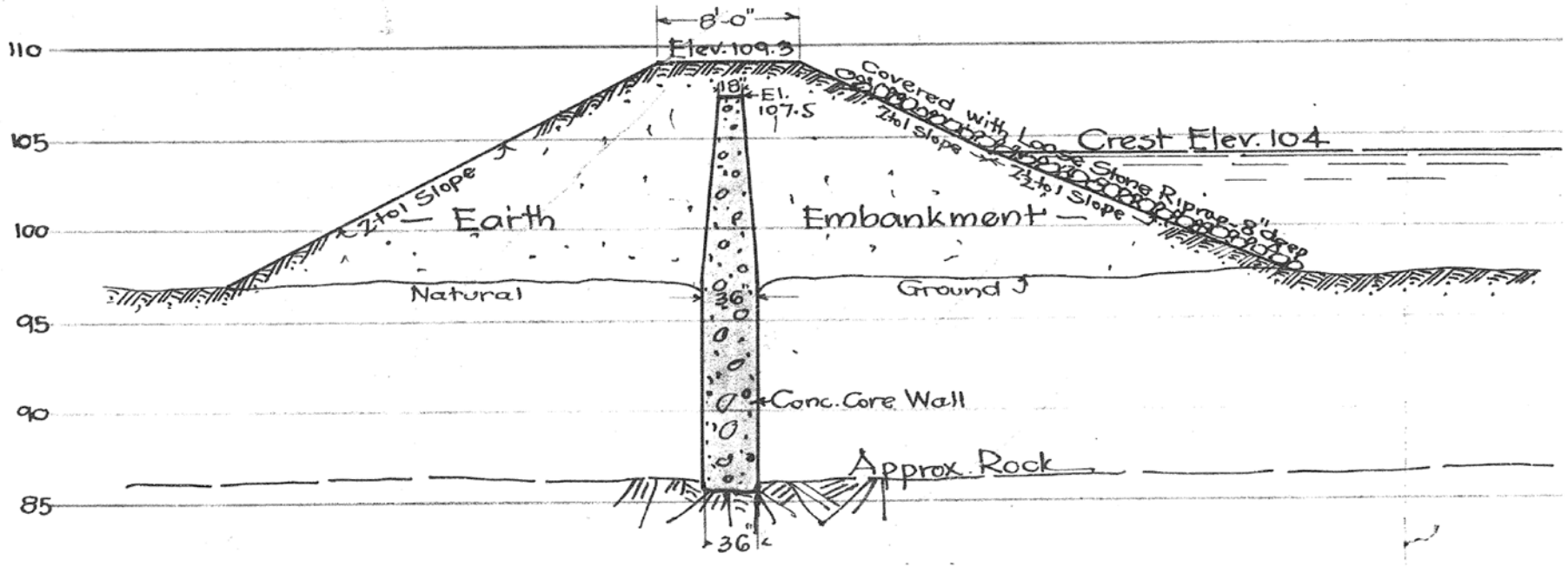
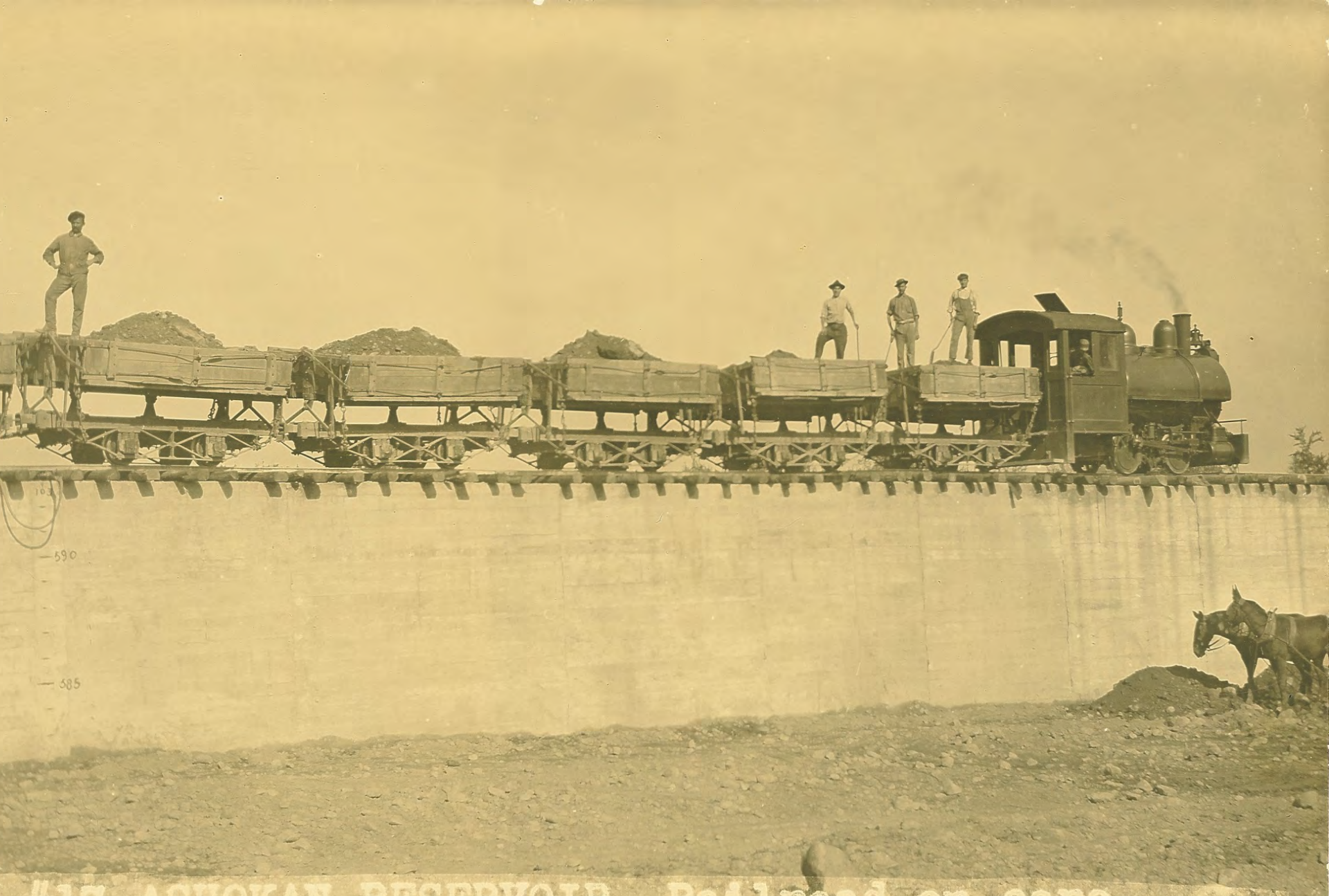


Figure 1-5

Typical cross section through left embankment.

(Source: 1923 Construction Drawings)

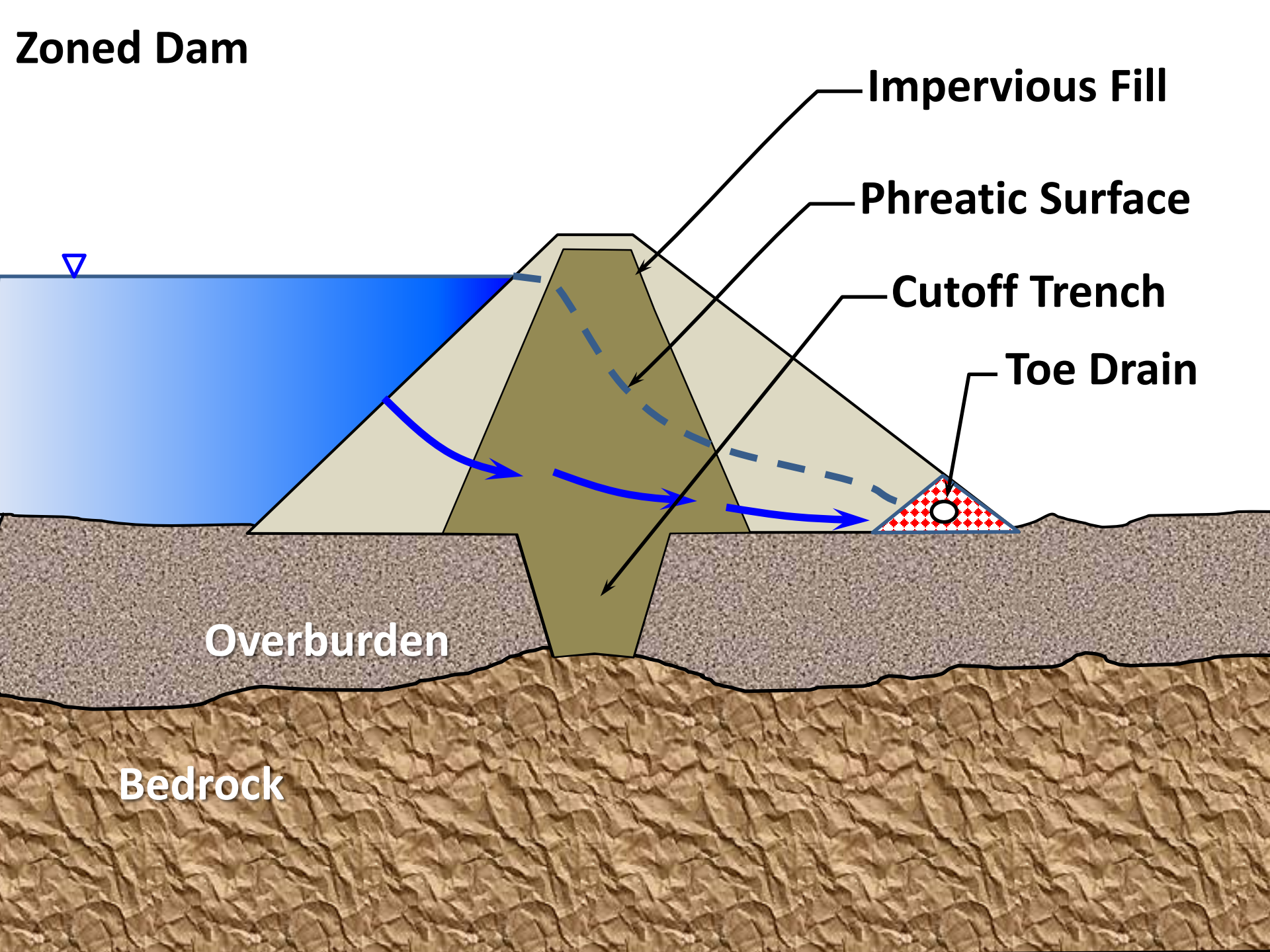

ACC HDO.R. 101
CONTRACT 3, NOV. 19. 09.

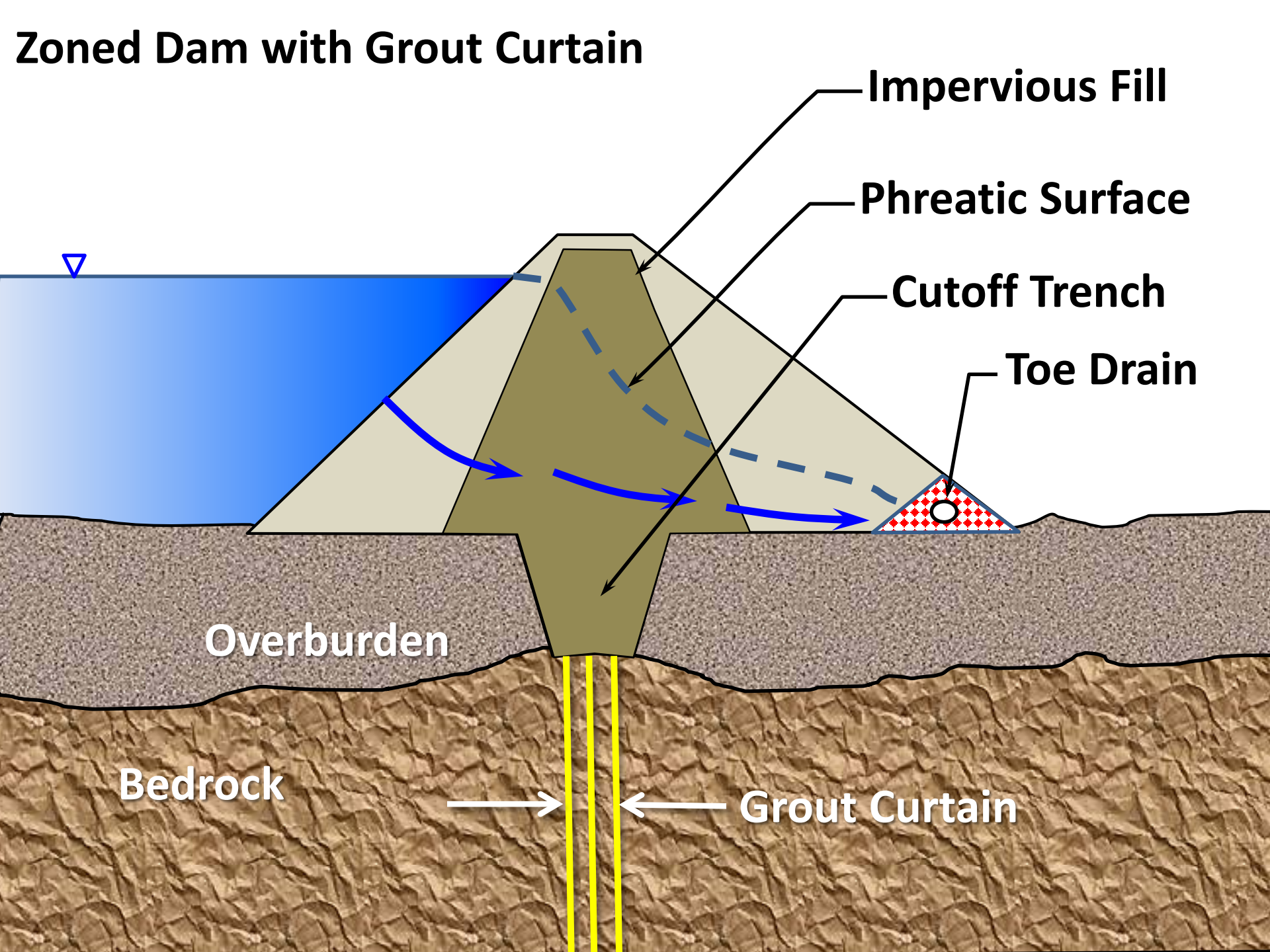


#17 ASHOKAN RESERVOIR. Railroad on core wall, East dyke. Sep. 30th. 1909.


UNLOADING DIRT AT SOUTH WING OF MAIN DAM
BROWN'S STATION N. Y.

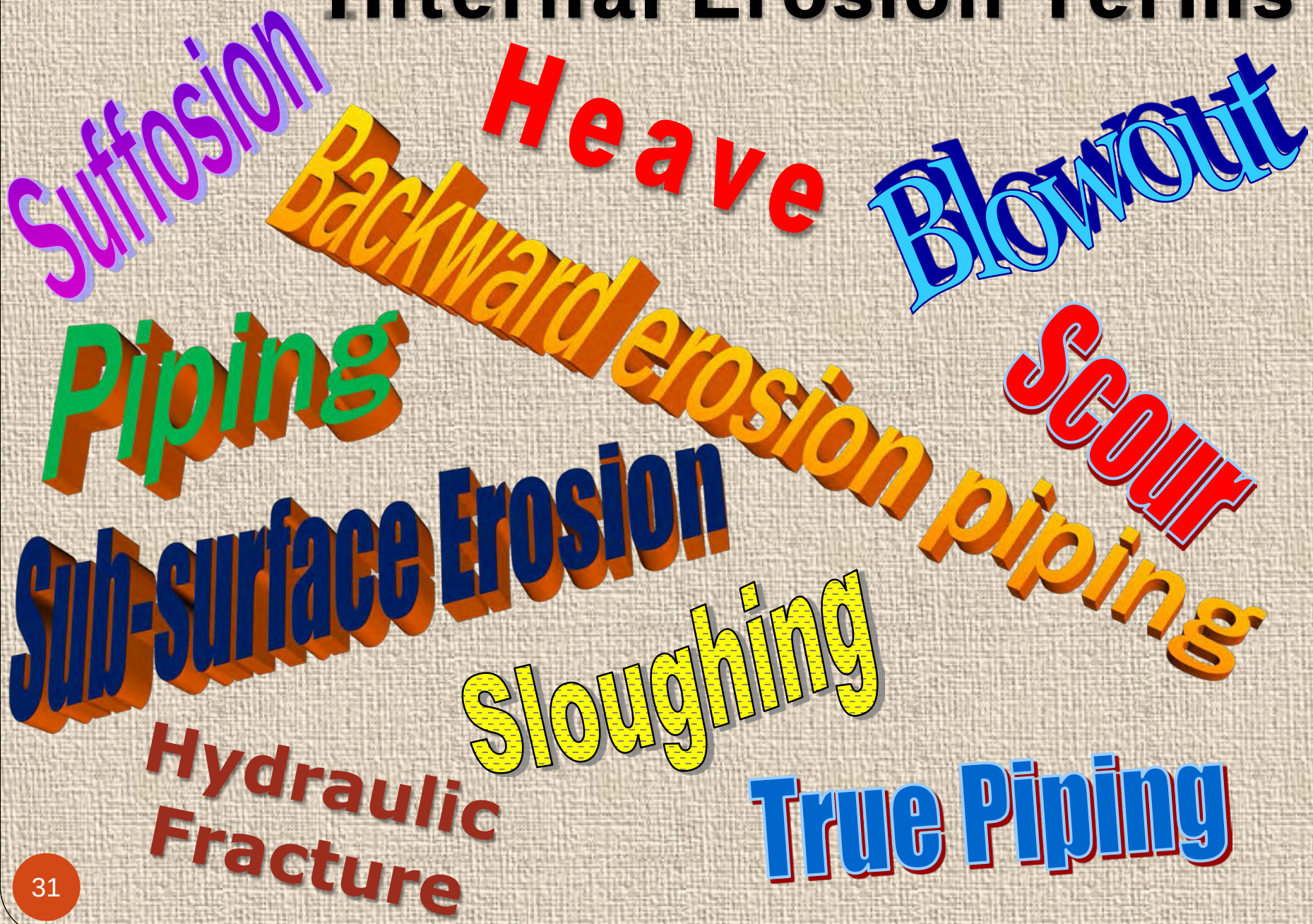

ACC HDQ,
CONTRACT 60


Zoned Dam
Impervious Fill
Phreatic Surface
Cutoff Trench
Toe Drain
Overburden
Bedrock


Zoned Dam with Grout Curtain
Impervious Fill
Phreatic Surface
Cutoff Trench
Toe Drain
Overburden
Bedrock
Grout Curtain

Failure By Internal Erosion

Internal Erosion Terms



ASDSO Dam Piping Failure Video

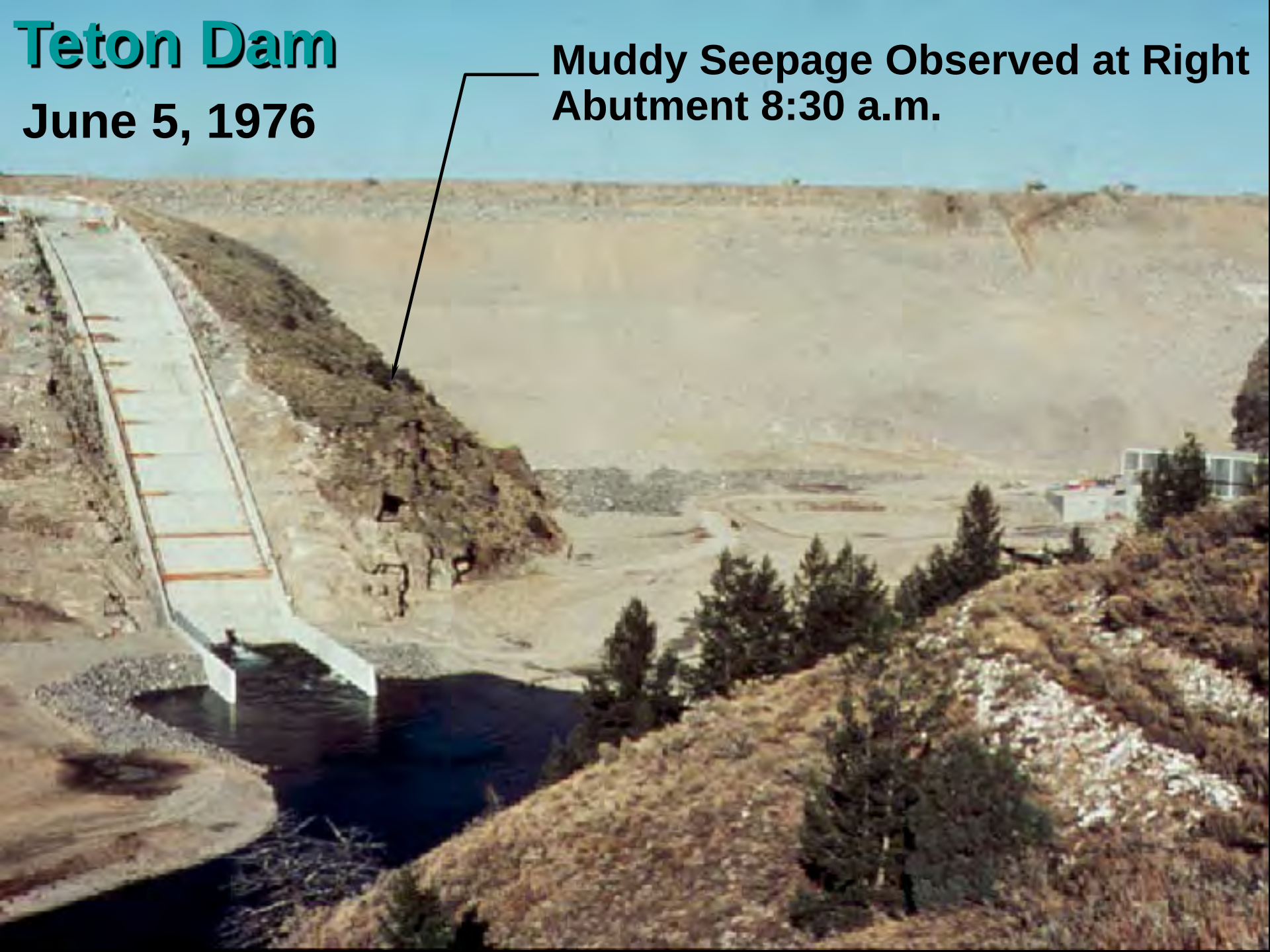
Teton Dam

June

Clear Water Springs from Joints

Teton Dam

June 5, 1976



Two Dozers Sent to Fill Hole, 10:30 a.m.

AFTER VAINLY TRYING TO FILL BRE
IN EMBANKMENT OF TETON DAM,
"CAT" OPERATORS BACK TOWARD
SAFETY AS THEIR BULLDOZERS SLID
INTO THE WIDENING GAP


June 5, 1976
10:45 a.m.

11:20 a.m. Large Vortex Observed In Reservoir


Dam Crest Breaching, 11:55 a.m.


Early Afternoon

.... 14 Lives Lost

.... Over 1 Billion in Property Damage

A sign expressing feelings concerning the Teton Dam was posted next to wrecked homes in Rexburg during cleanup efforts.

Post Register file photo

Case History: Tongue River Dam, Montana

- Constructed 1937-1939
- 1,300 feet long, 91 feet high
- 65,000 AF Storage

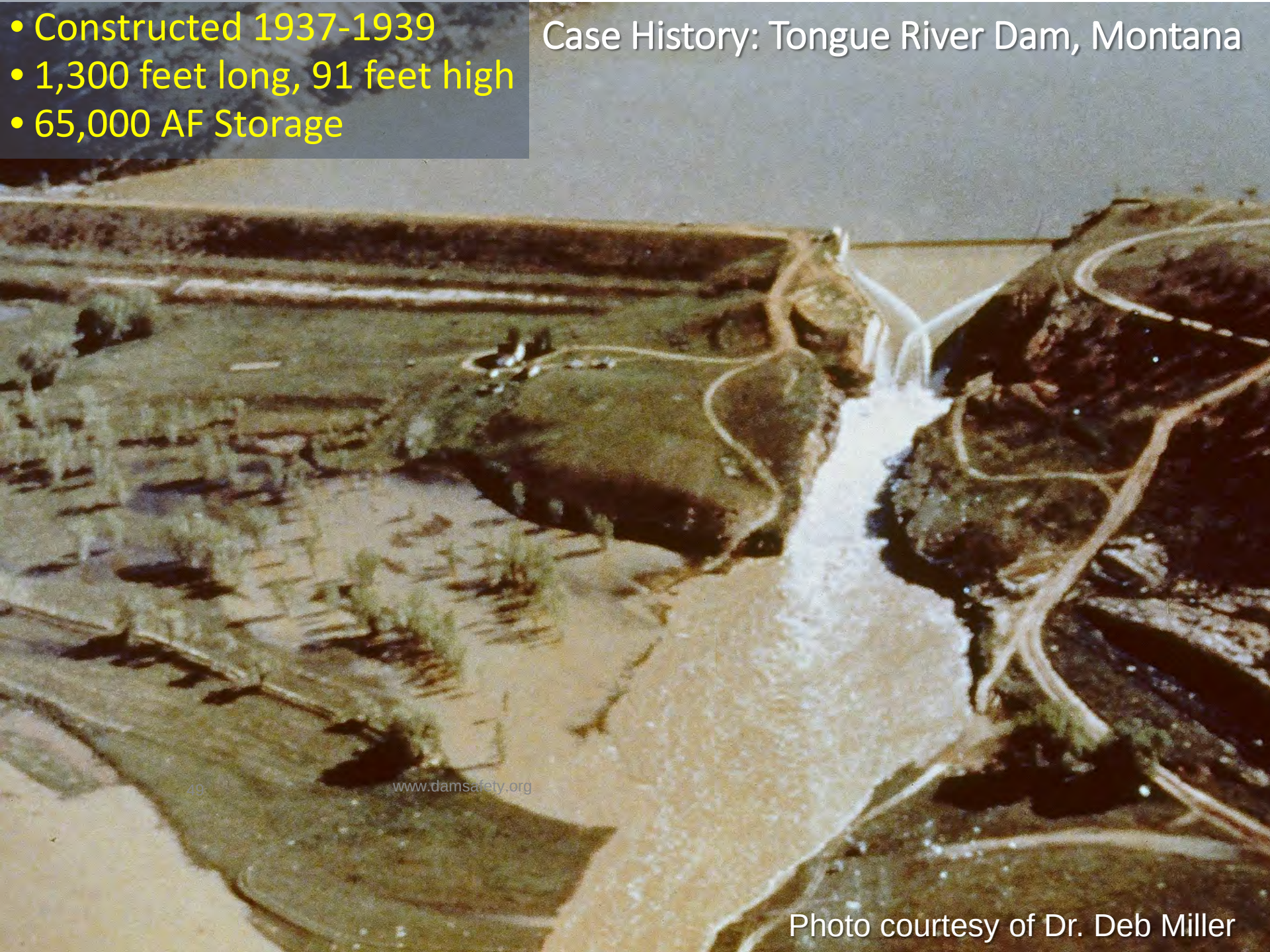


Photo courtesy of Dr. Deb Miller

Tongue River Dam, Montana

Photo courtesy of Dr. Deb Miller

Tongue River Dam, Montana

Photo courtesy of Dr. Deb Miller

Tongue River Dam, Montana

Photo courtesy of Dr. Deb Miller

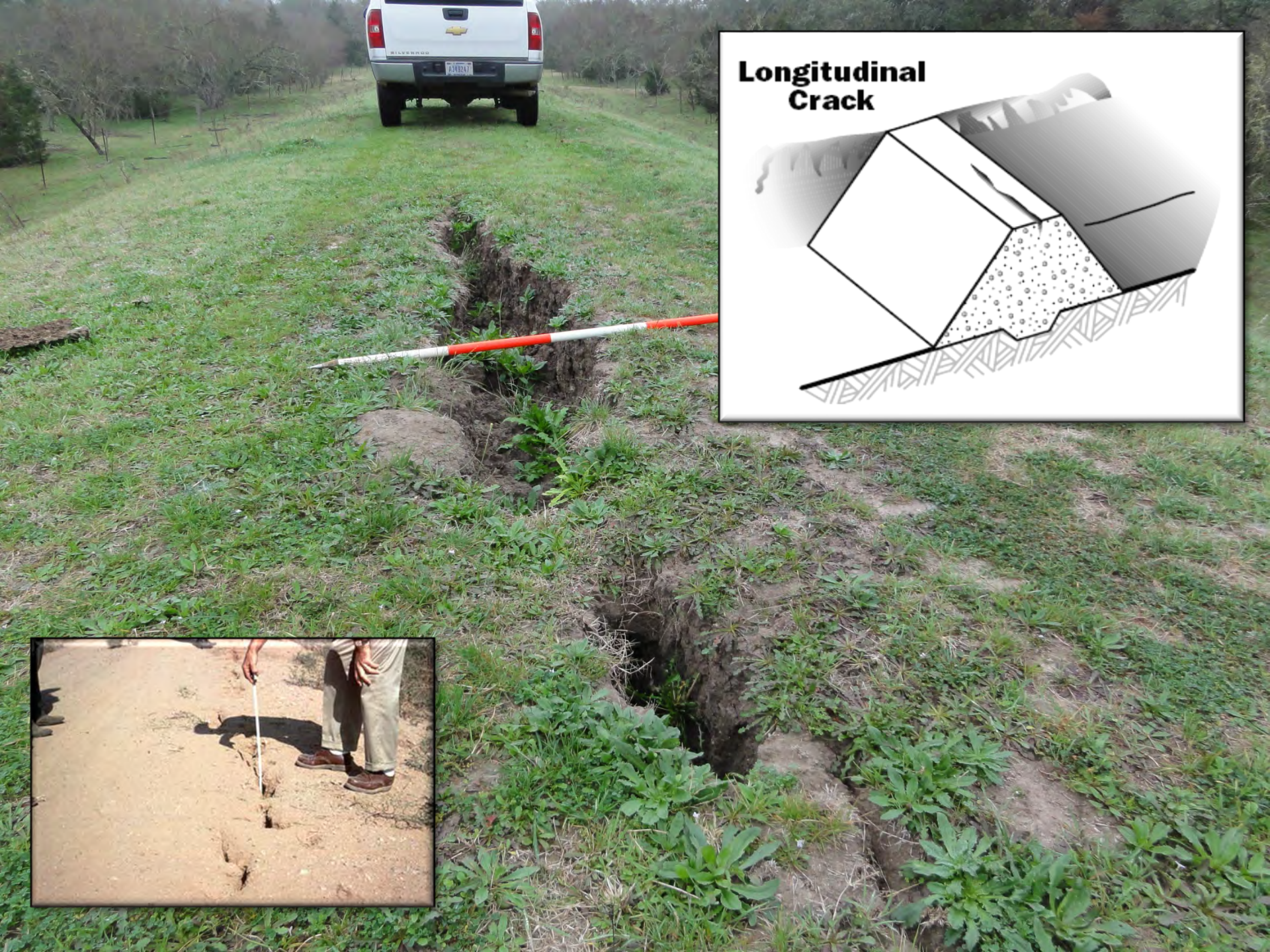
Tongue River Dam, Montana

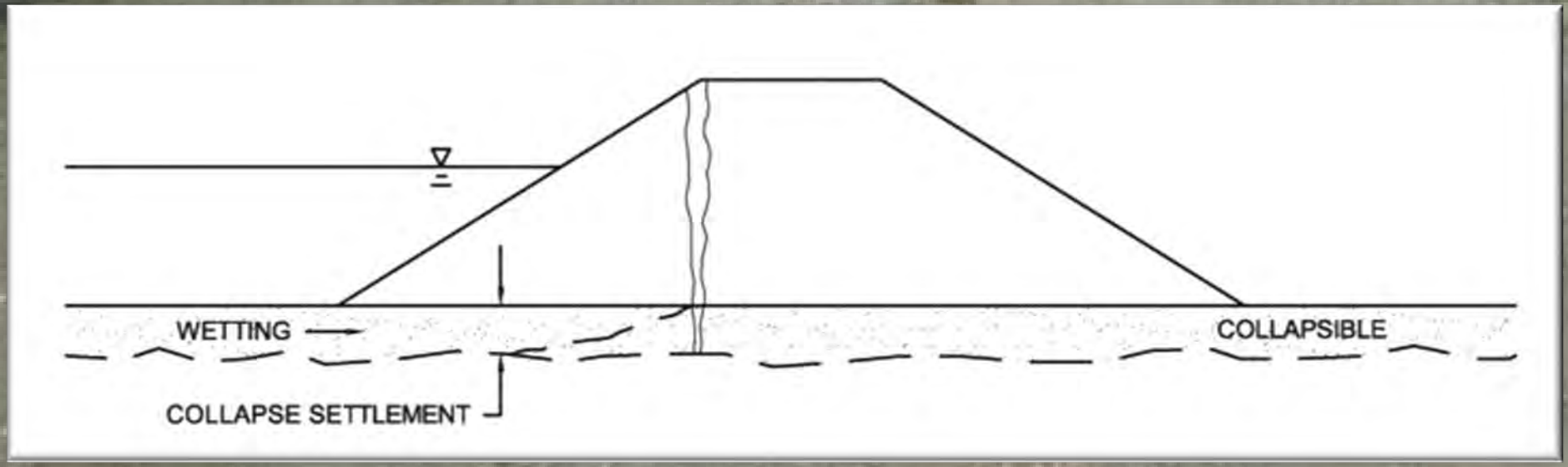
Photo courtesy of Dr. Deb Miller

Embankment Cracking

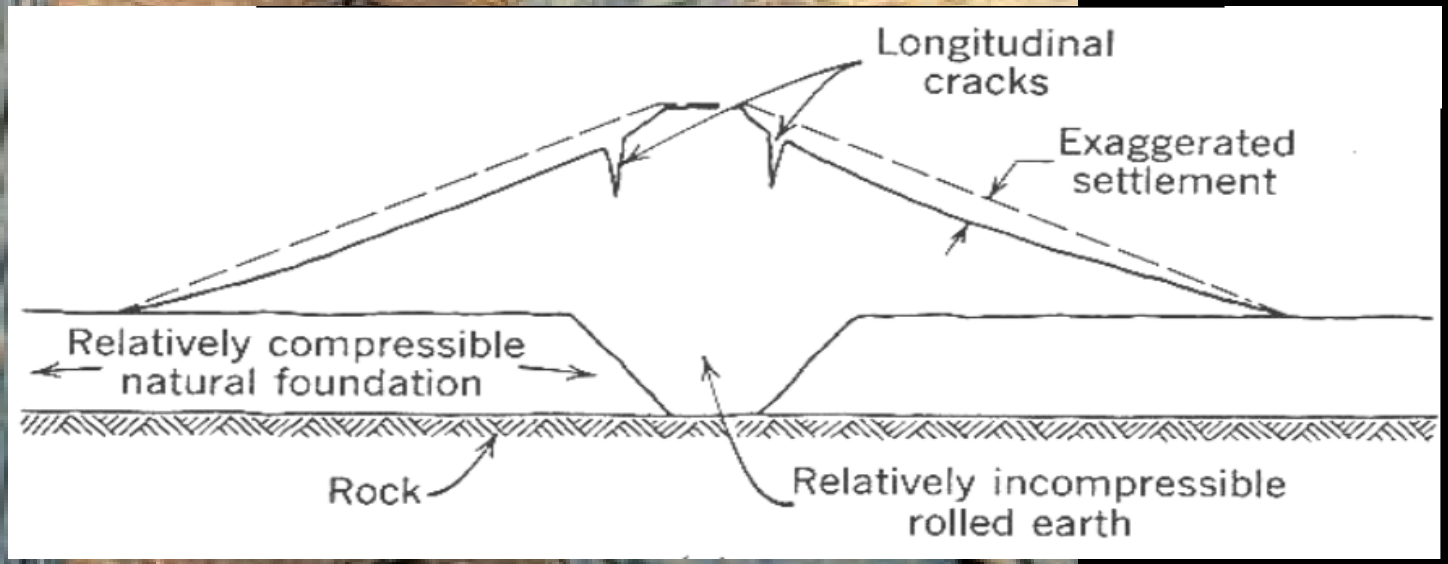
Casagrande (circa 1950)

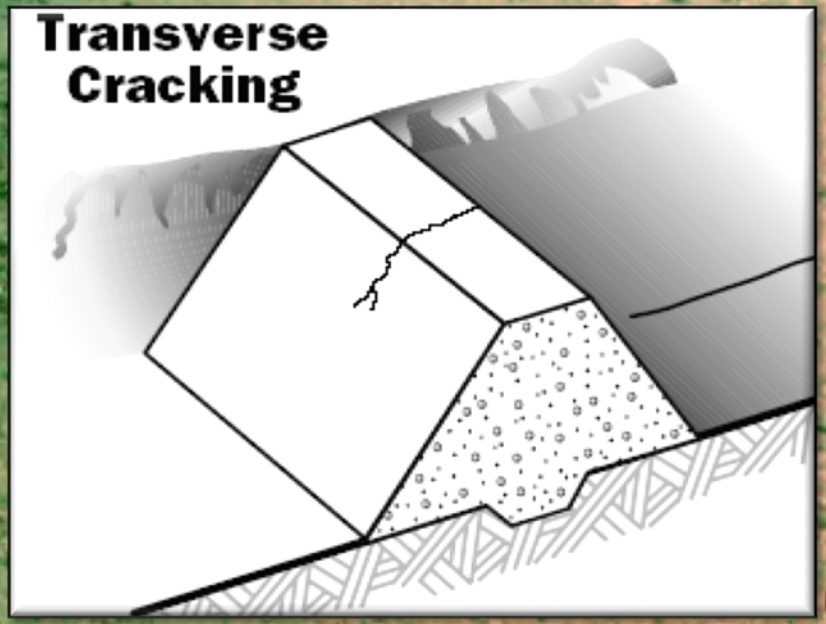
Cracks are likely to occur in most embankment dams, not only in poorly constructed ones, or where topographic conditions are especially unfavorable

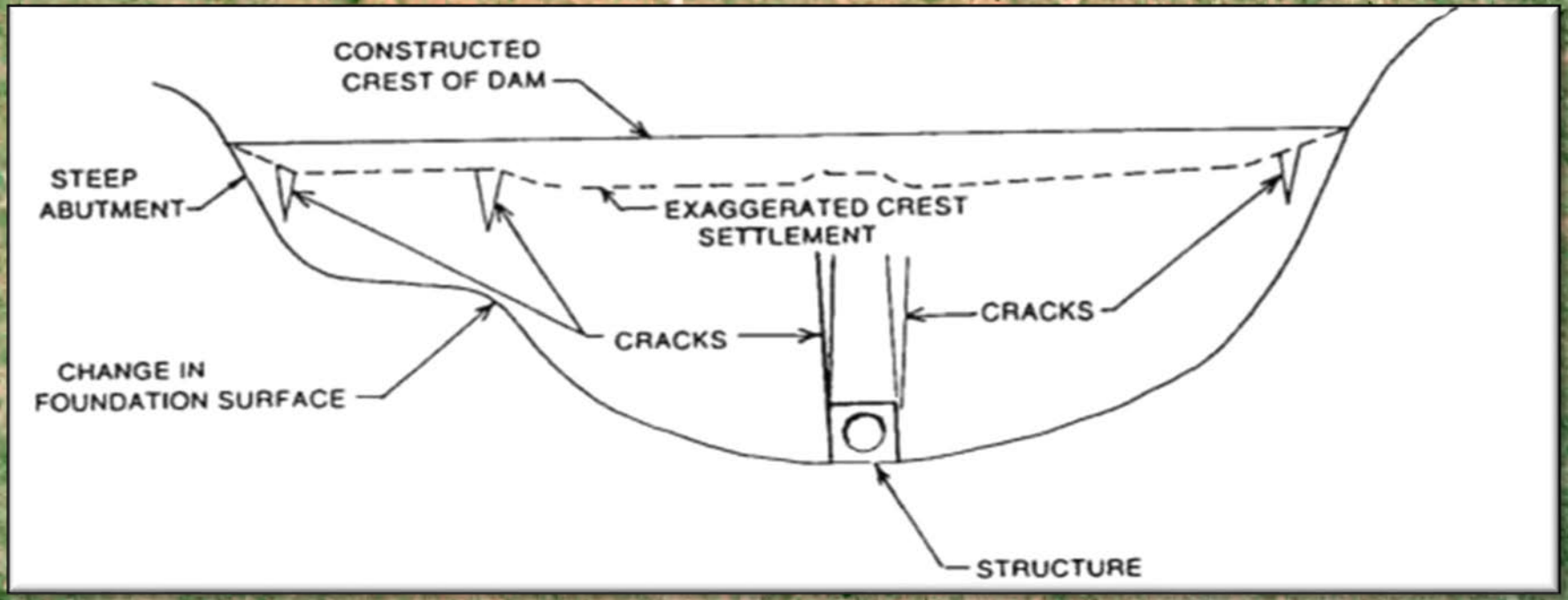

Longitudinal
Crack

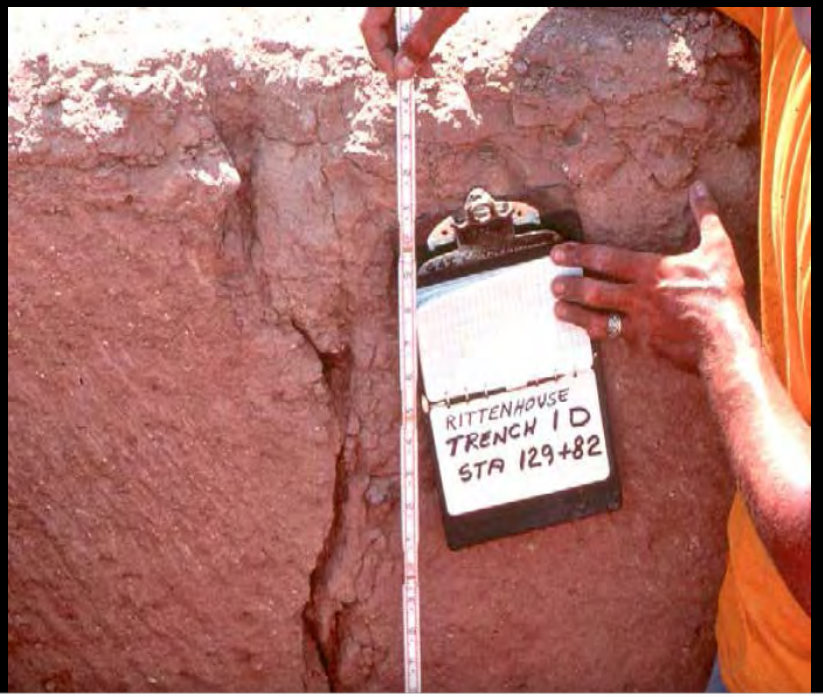

WETTING
COLLAPSIBLE
COLLAPSE SETTLEMENT

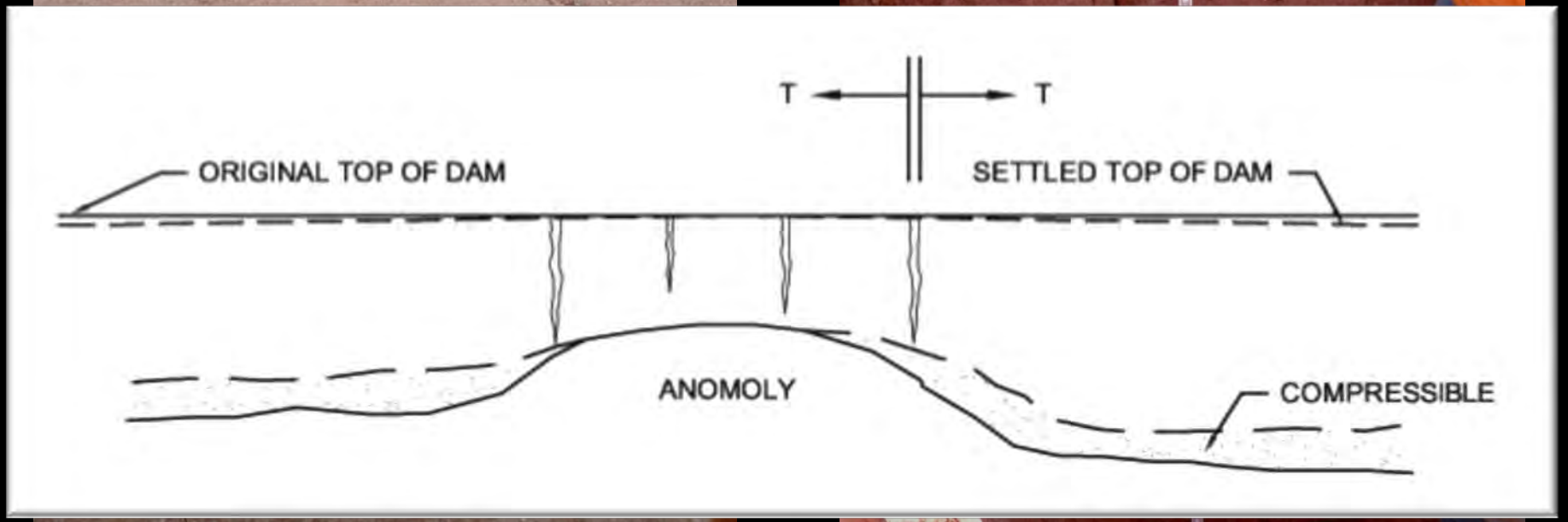
2008 Wenchuan Earthquake
Sichuan, China

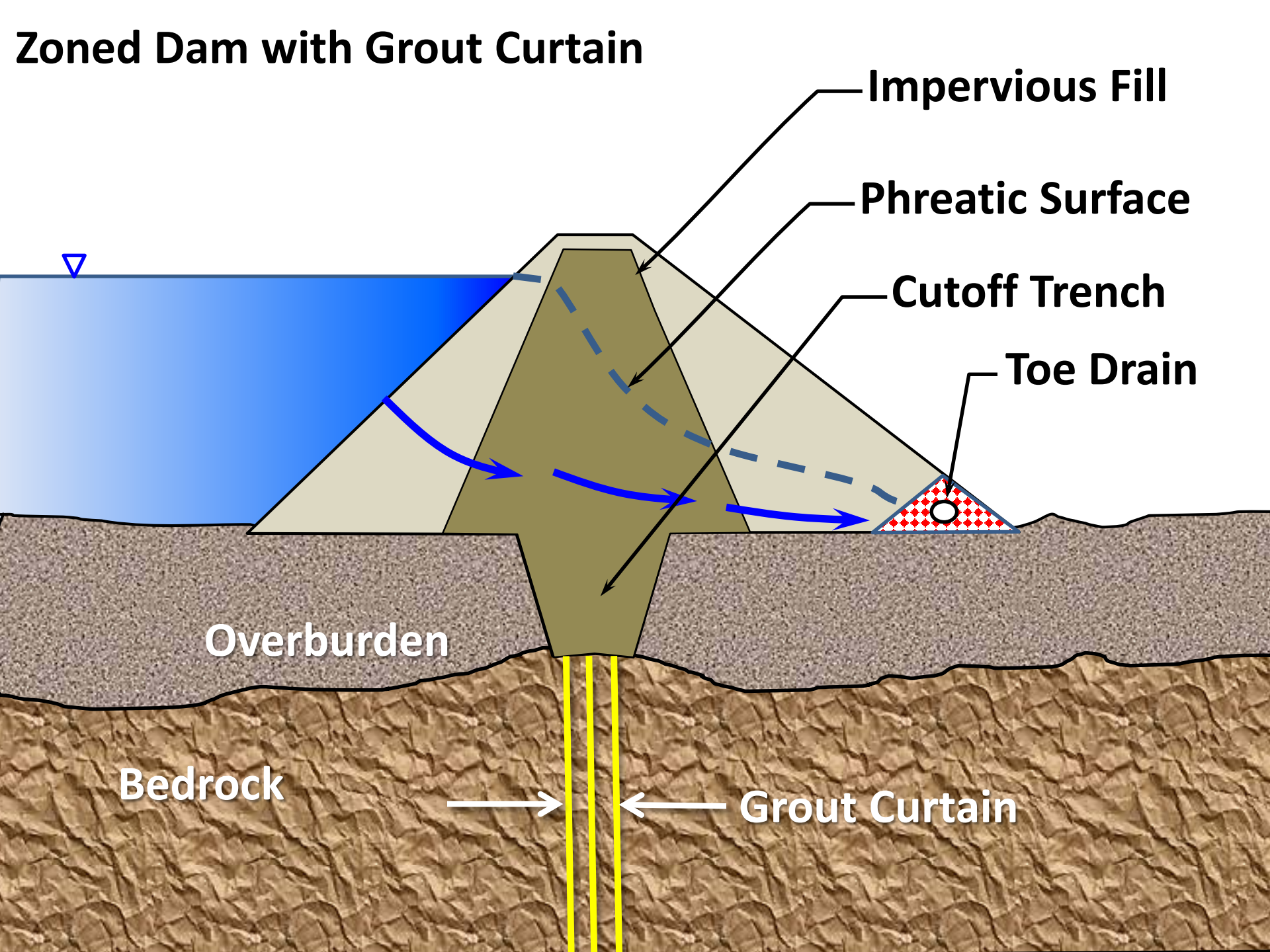


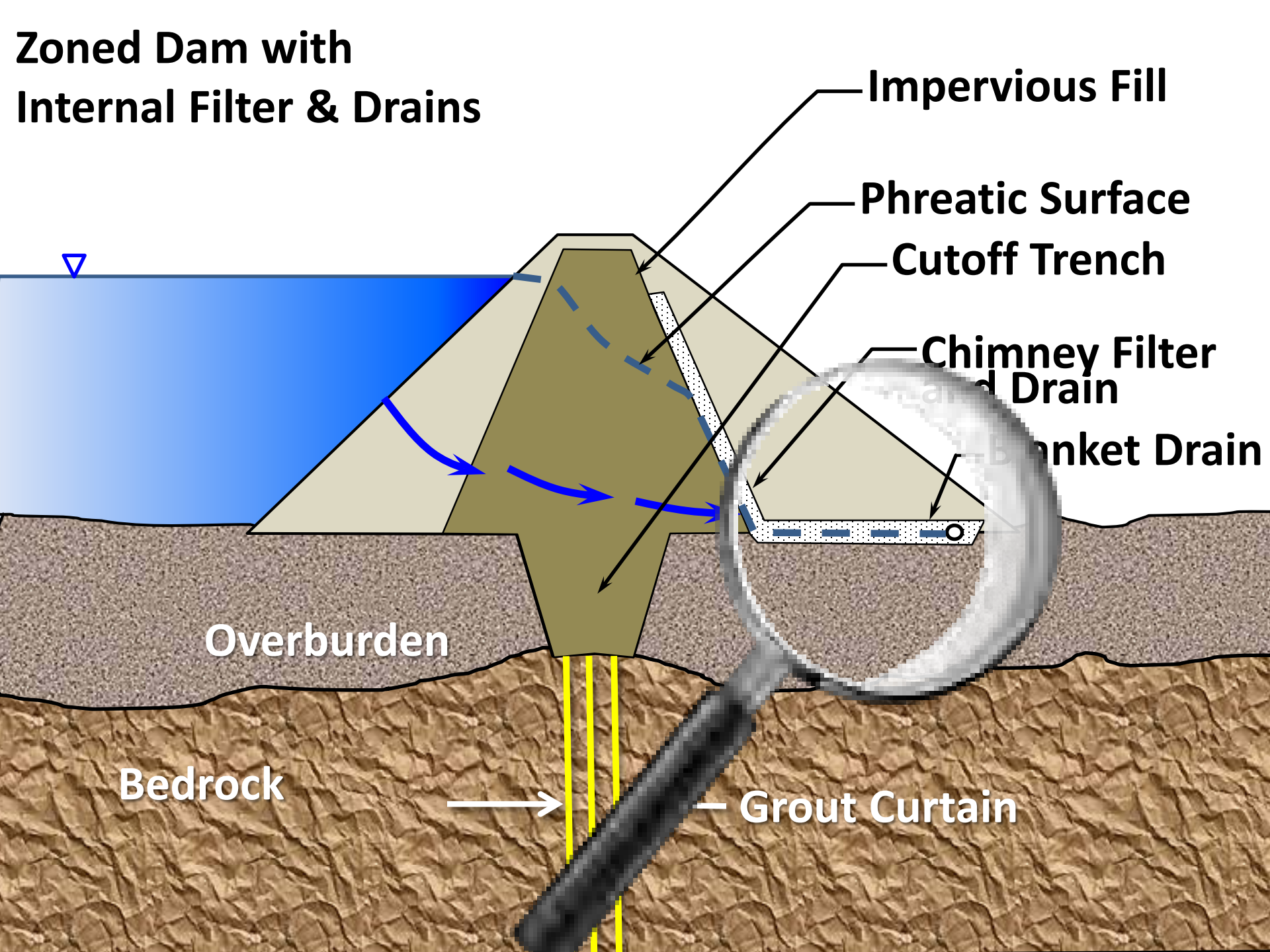

Transverse
Cracking

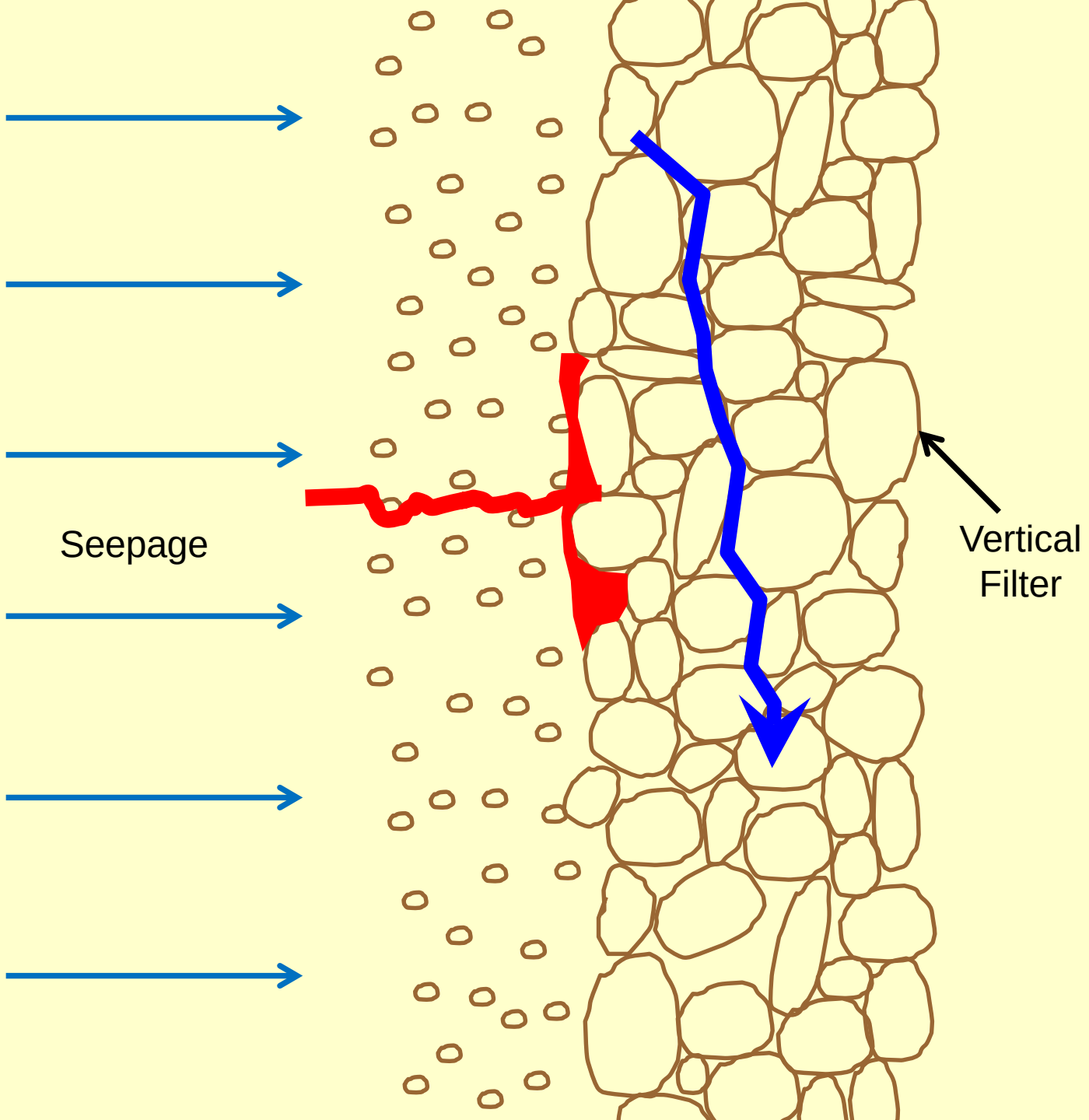

CONSTRUCTED
CREST OF DAM
STEEP
ABUTMENT
EXAGGERATED CREST
SETTLEMENT
CRACKS
CRACKS
CHANGE IN
FOUNDATION SURFACE
STRUCTURE

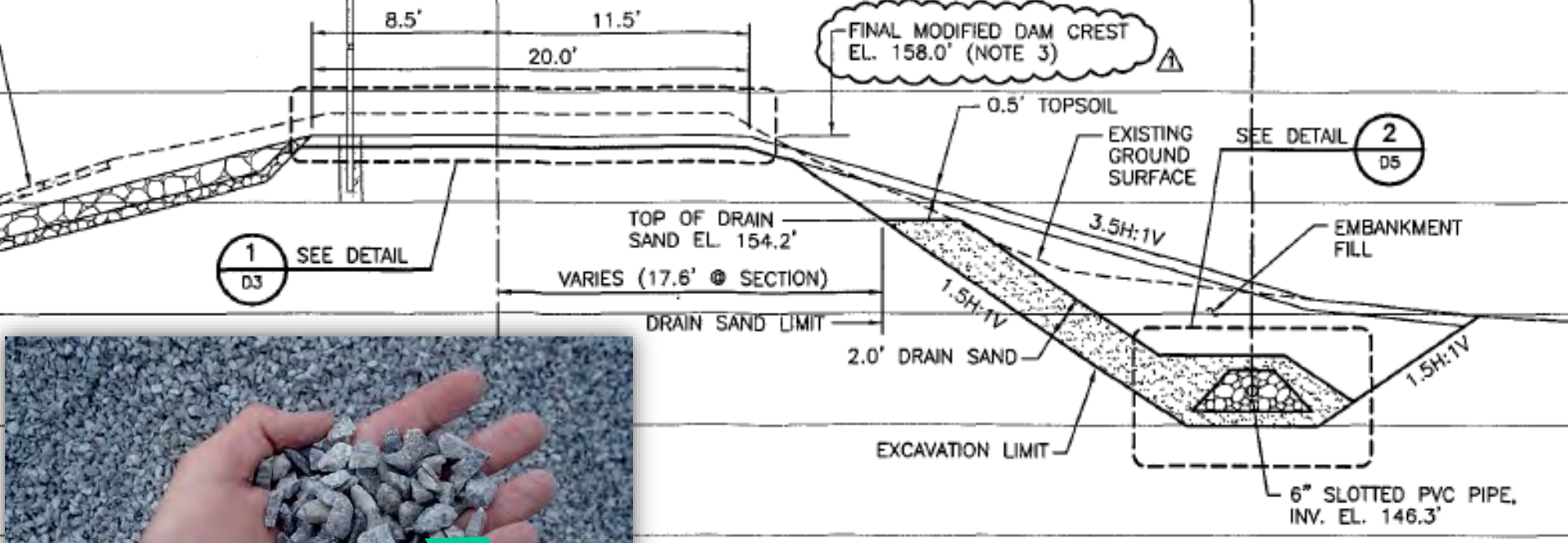

RITTENHOUSE
TRENCH 1D
STA 129+82


T
T
ORIGINAL TOP OF DAM
SETTLED TOP OF DAM
ANOMOLY
COMPRESSIBLE


Zoned Dam with Grout Curtain
Impervious Fill
Phreatic Surface
Cutoff Trench
Toe Drain
Overburden
Bedrock
Grout Curtain

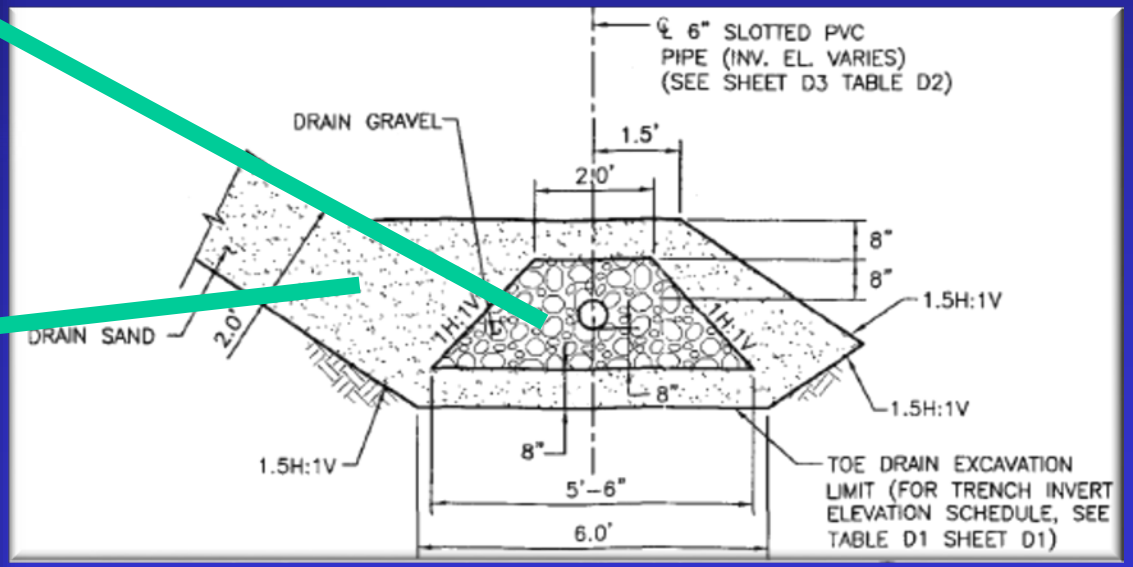

Zoned Dam with
Internal Filter & Drains
Impervious Fill
Phreatic Surface
Cutoff Trench
Chimney Filter
Drain
nket Drain
Overburden
Bedrock
Grout Curtain

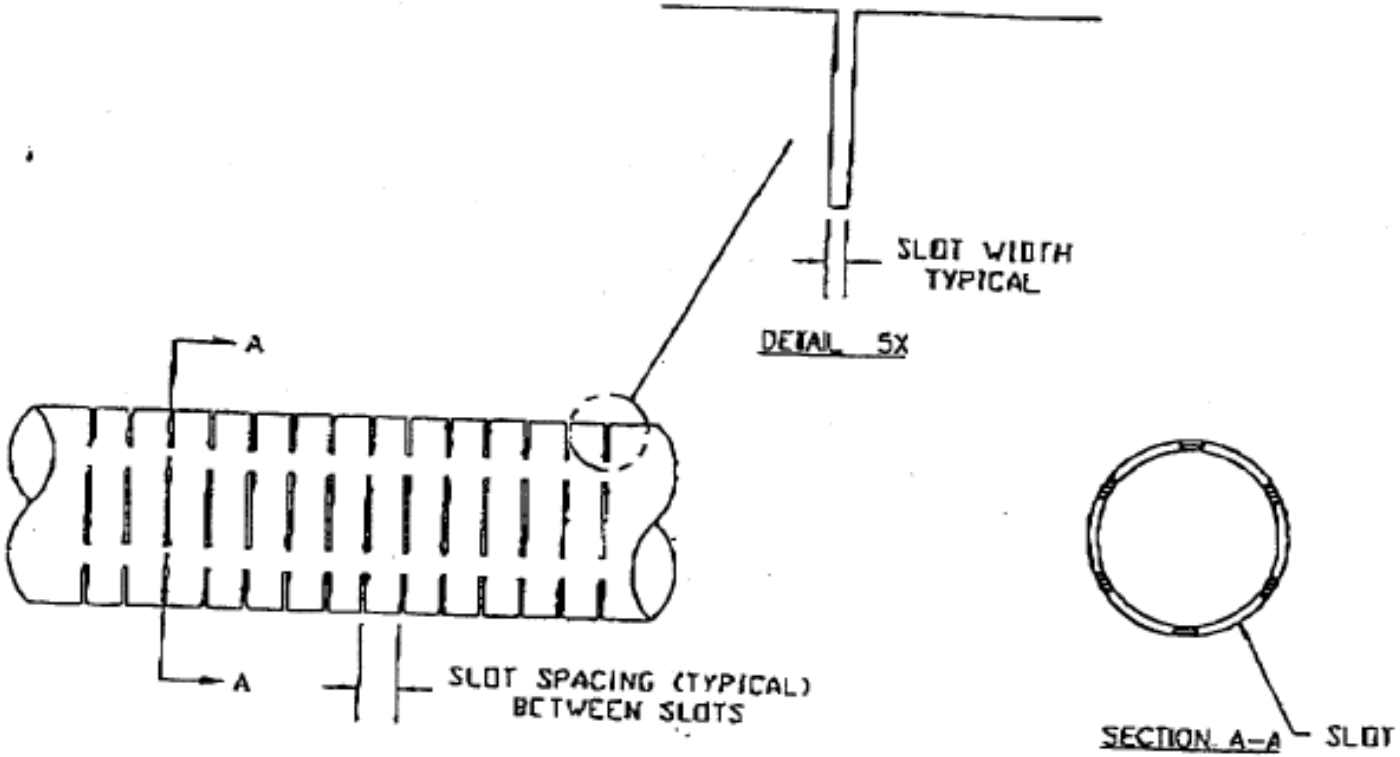

Seepage
Vertical
Filter


8.5'
11.5'
20.0'
FINAL MODIFIED DAM CREST
EL. 158.0' (NOTE 3)
0.5' TOPSOIL
EXISTING
GROUND
SURFACE
SEE DETAIL 2
D5
1
D3
SEE DETAIL
TOP OF DRAIN
SAND EL. 154.2'
VARIES (17.6' @ SECTION)
DRAIN SAND LIMIT
3.5H:1V
EMBANKMENT
FILL
1.5H:1V
2.0' DRAIN SAND
1.5H:1V
EXCAVATION LIMIT
6" SLOTTED PVC PIPE,
INV. EL. 146.3'

Drain Gravel


Drain Sand


℄ 6" SLOTTED PVC
PIPE (INV. EL. VARIES)
(SEE SHEET D3 TABLE D2)
DRAIN GRAVEL
1.5'
2.0'
8"
8"
1.5H:1V
1H:1V
1H:1V
DRAIN SAND
2.0'
8"
1.5H:1V
8"
1.5H:1V
TOE DRAIN EXCAVATION
LIMIT (FOR TRENCH INVERT
ELEVATION SCHEDULE, SEE
TABLE D1 SHEET D1)
5'-6"
6.0'



SLOT SPECIFICATIONS

NOMINAL PIPE SIZE: 6"

SCHEDULE: SDR 35

NOMINAL O.D.: _____ I.D.: _____

NOMINAL WALL THICKNESS: _____

SLOT WIDTH: .020 X slot Length 1.3"

SPACING BETWEEN SLOTS: .250

NUMBER OF ROWS: 8

ENDS: BELL X GASKET
13' lgths.

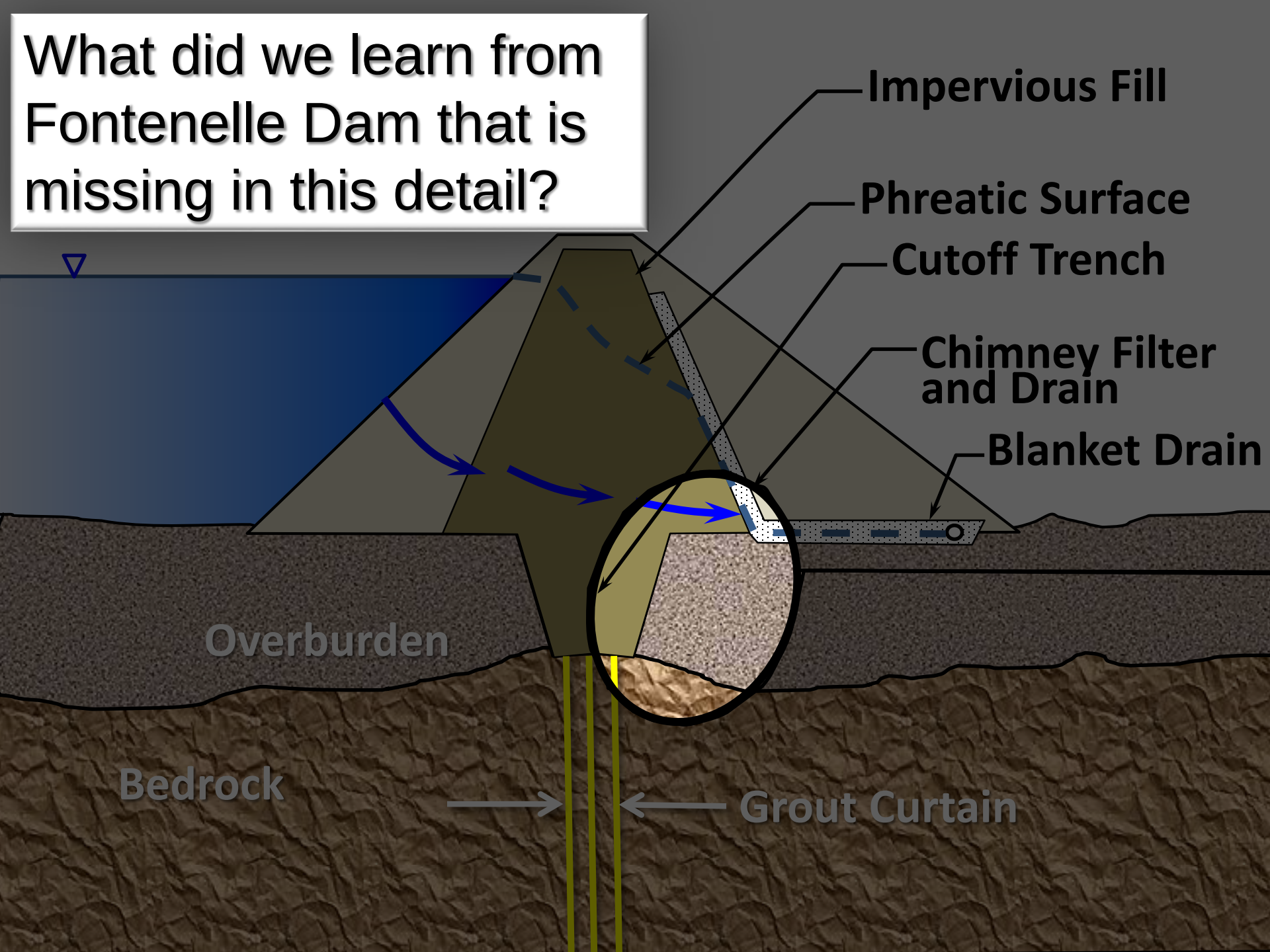

10

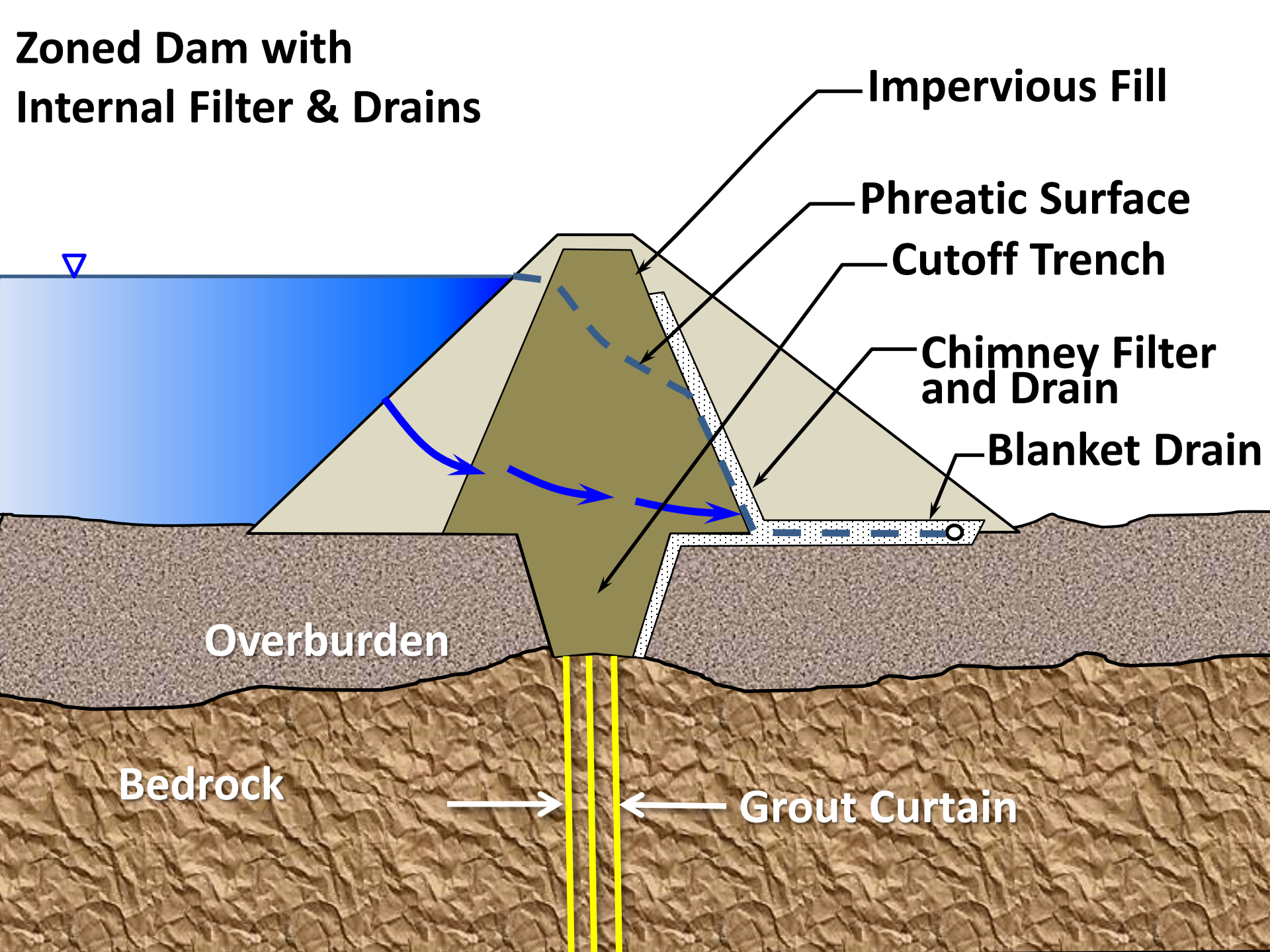

11

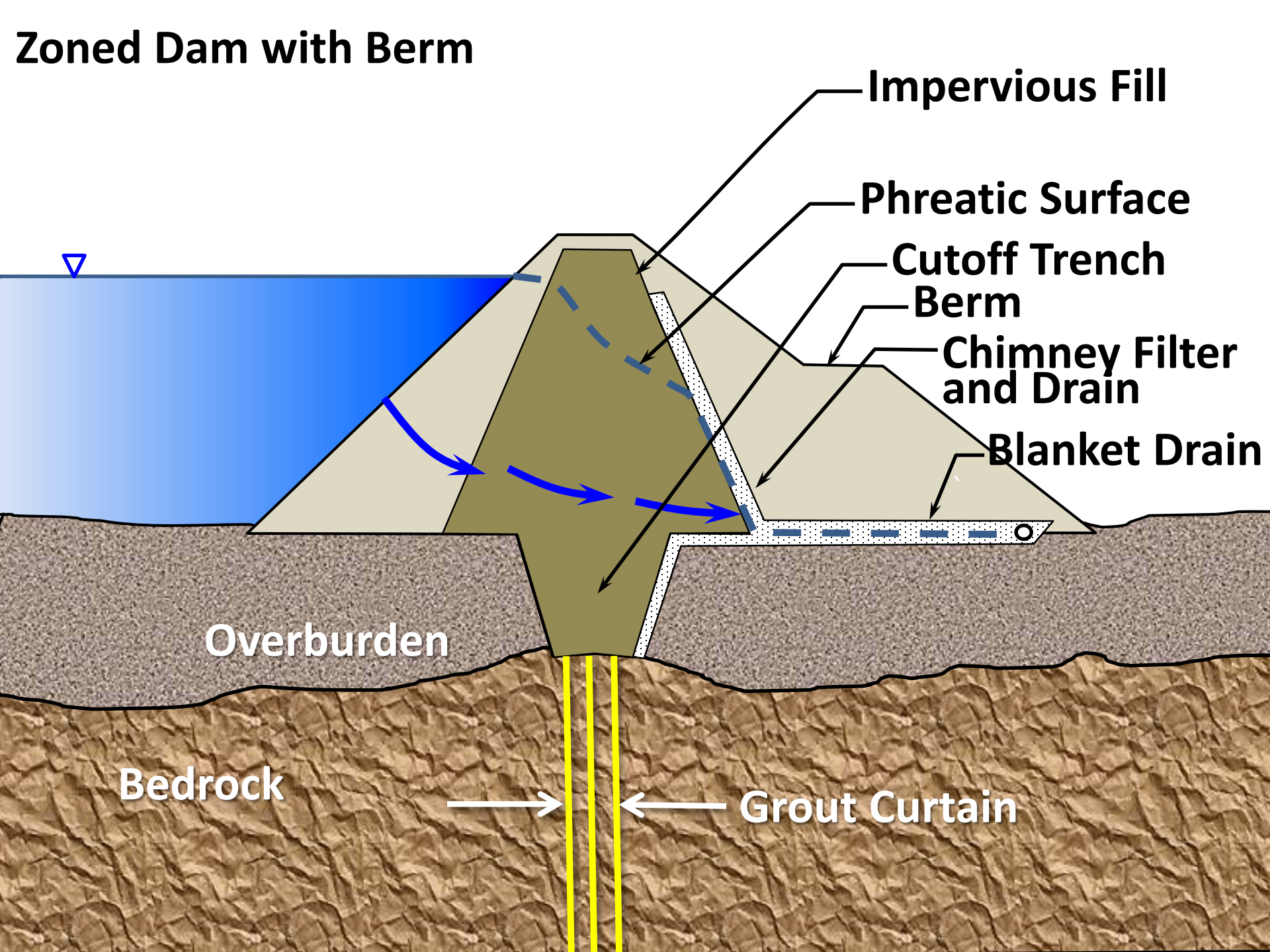

Fontenelle Dam, WY

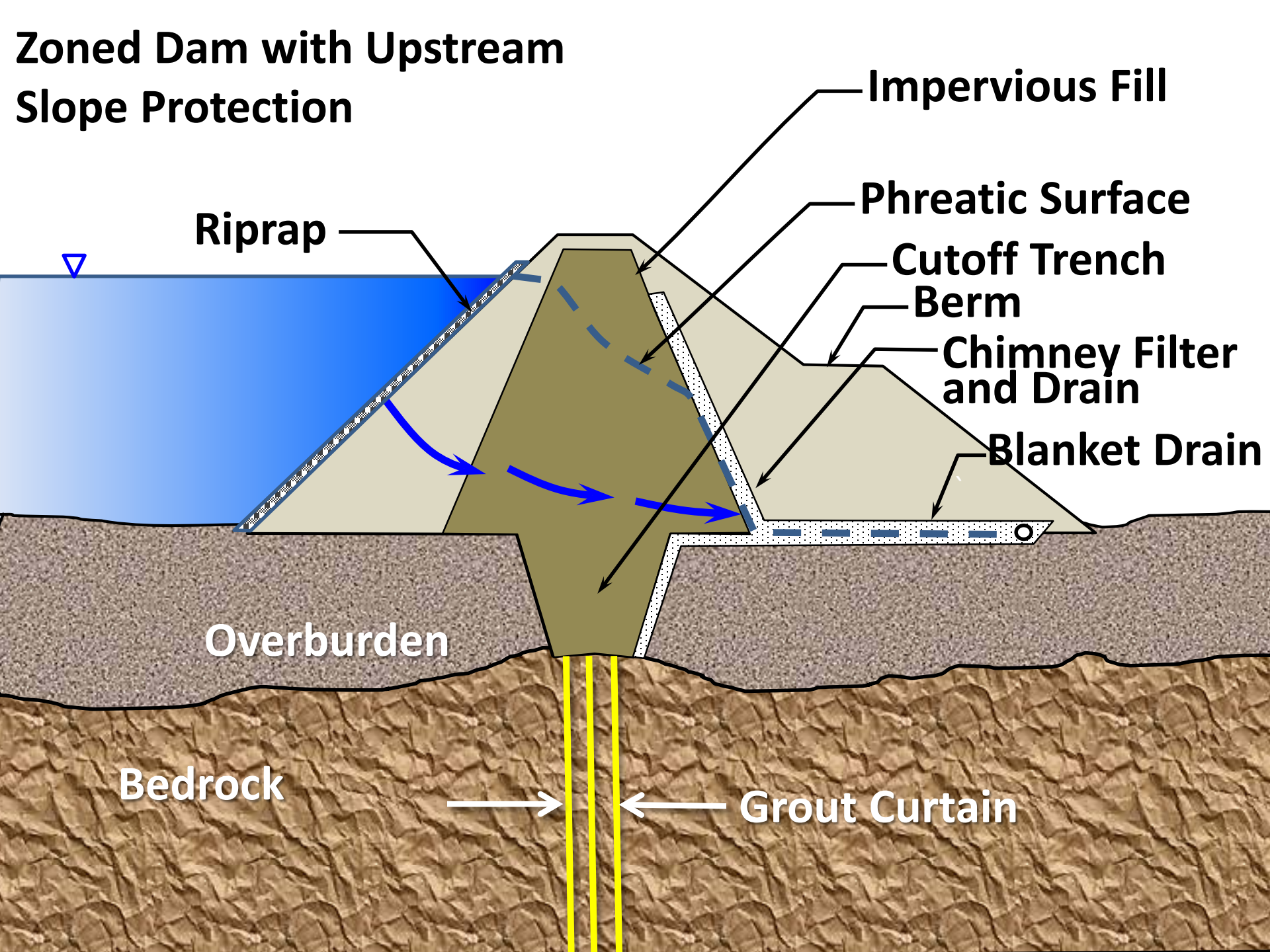

Fontenelle Dam, WY

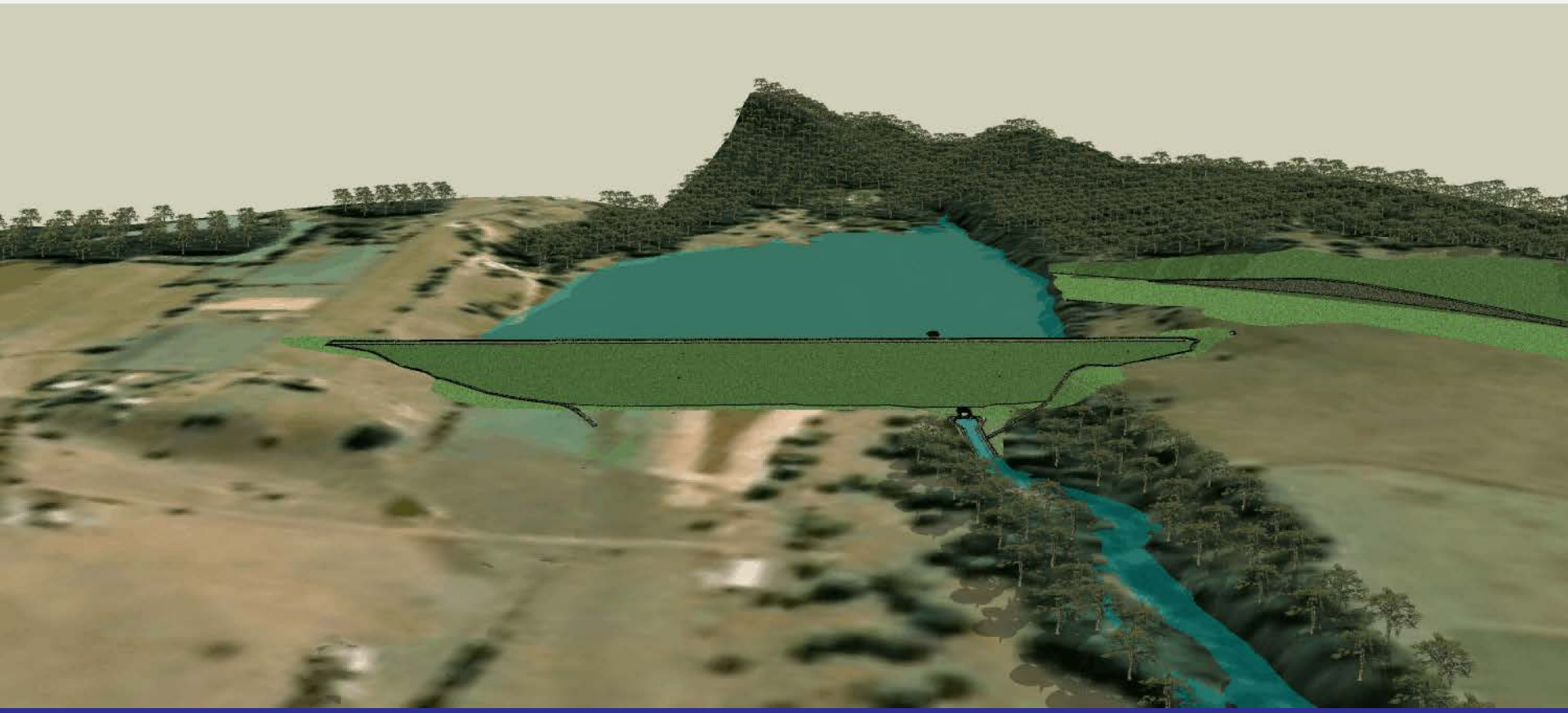
What did we learn from Fontenelle Dam that is missing in this detail?




Zoned Dam with
Internal Filter & Drains
Impervious Fill
Phreatic Surface
Cutoff Trench
Chimney Filter
and Drain
Blanket Drain
Overburden
Bedrock
Grout Curtain


Zoned Dam with Berm
Impervious Fill
Phreatic Surface
Cutoff Trench
Berm
Chimney Filter and Drain
Blanket Drain
Overburden
Bedrock
Grout Curtain

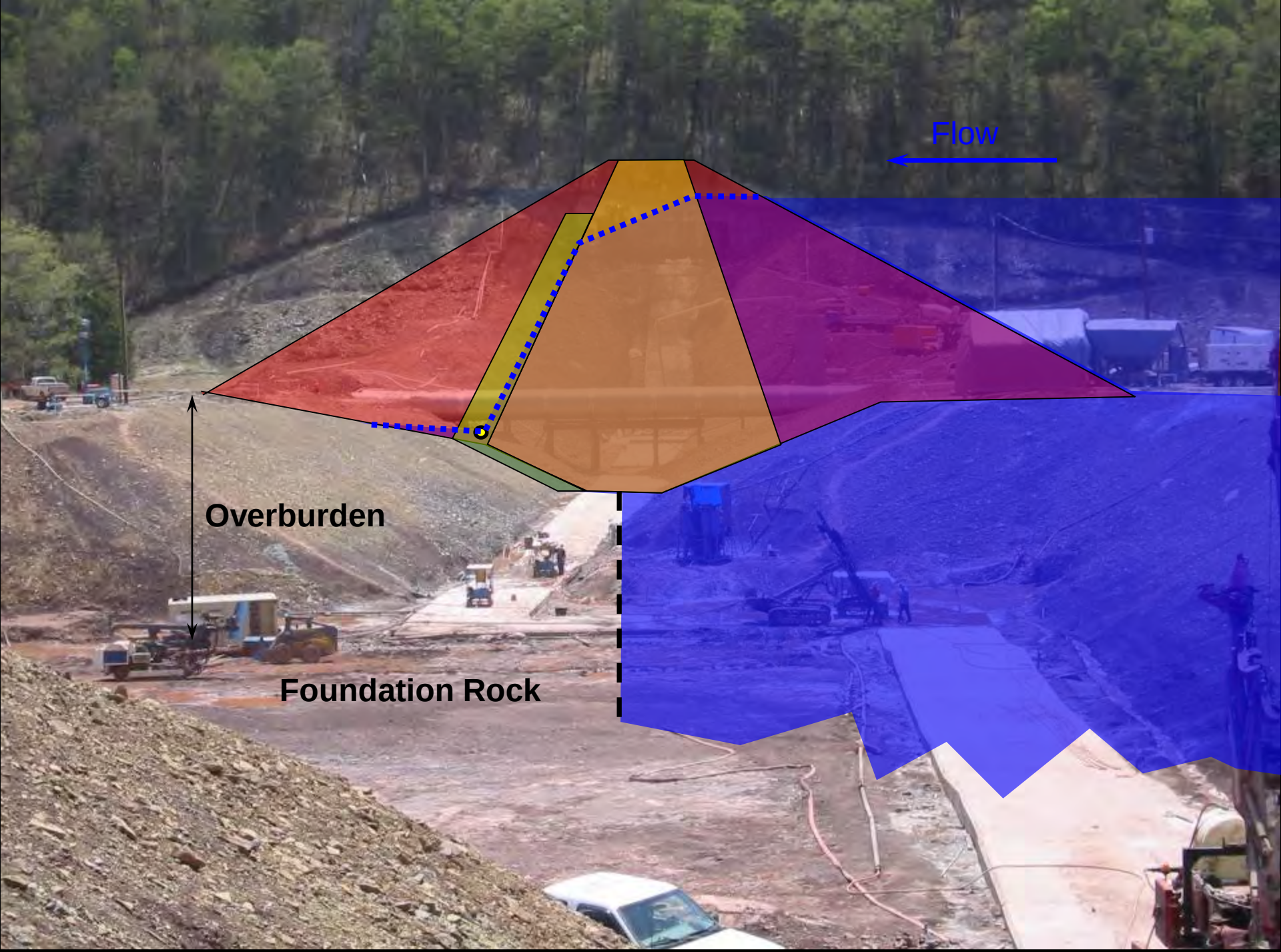

Zoned Dam with Upstream Slope Protection
Impervious Fill
Phreatic Surface
Riprap
Cutoff Trench
Berm
Chimney Filter and Drain
Blanket Drain
Overburden
Bedrock
Grout Curtain



Video Clip of Modern Earth Dam Embankment

United States Department of Agriculture
NRCS Natural Resources Conservation Service

Lost River Site 16, WV


Flow
Overburden
Foundation Rock

Three Conduit Failure Modes

- Seepage along conduit
- Seepage into the conduit
- Seepage out of conduit

Three Conduit Failure Modes

- Seepage along conduit
- Seepage into the conduit
- Seepage out of conduit


21 4'08


08/09/2008

Lake Wendy, Colorado

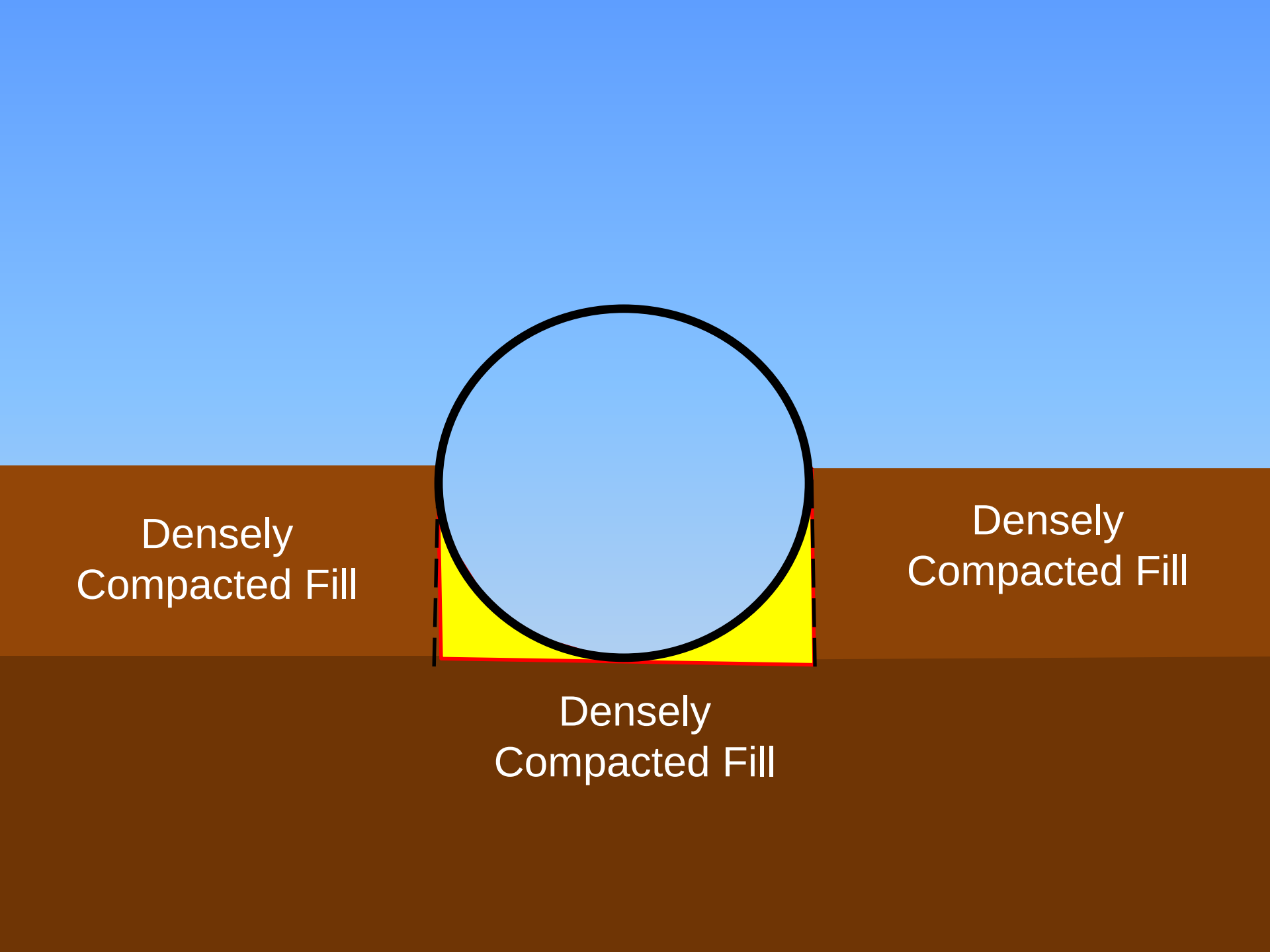
Sheep Creek Dam


Dr. Erwyn Freeman 01-003
Yazoo Co.
AUG 4 2004

Photo Courtesy of Jill Butler


Anti-seepage Collar

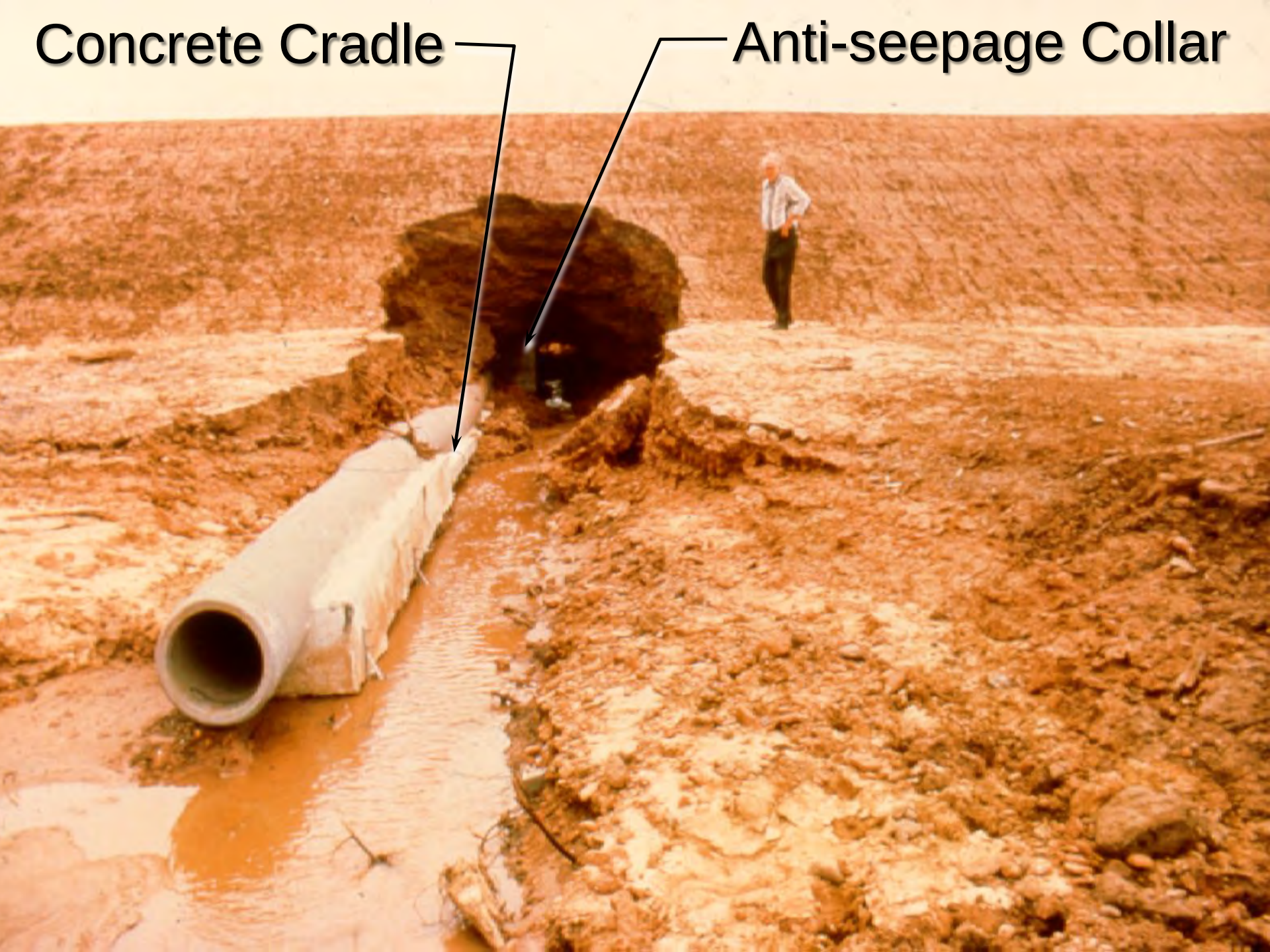
Photo Courtesy of Jill Butler


Densely
Compacted Fill
Densely
Compacted Fill
Densely
Compacted Fill

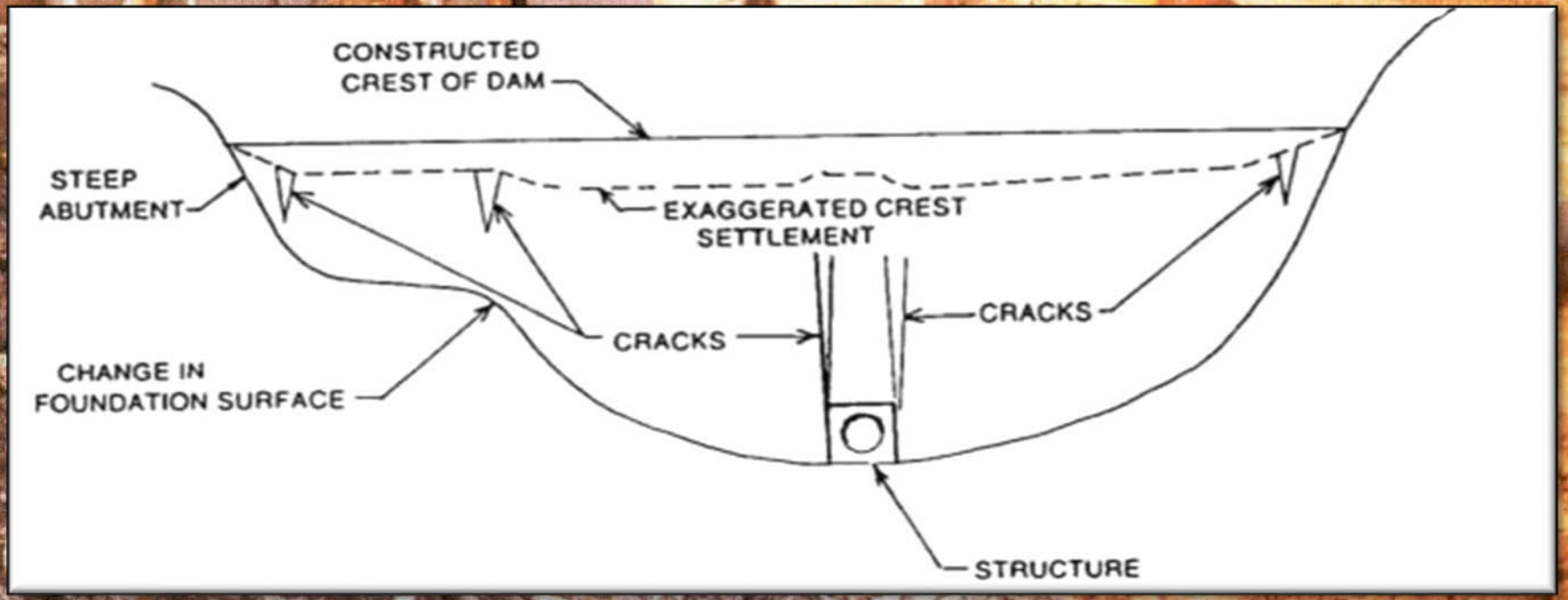

10 27 95


WACKER


Anti-seepage Collar
No Concrete Cradle


Concrete Cradle
Anti-seepage Collar

What's the Problem?



Use of seepage cutoff collars:

Corps of Engineers (1974)

"In future designs, cutoff collars for seepage control are not to be provided for conduits through earth and rockfill dams."

NRCS (1985) for dams

"Use a filter and drainage diaphragm around any structure that extends through the embankment...." (Do not use cutoff collars.)

NRCS (1985) for ponds

"Seepage along pipes extending through the embankment shall be controlled by use of a filter and drainage diaphragm, unless it is determined that anti-seep collars will adequately serve the purpose."

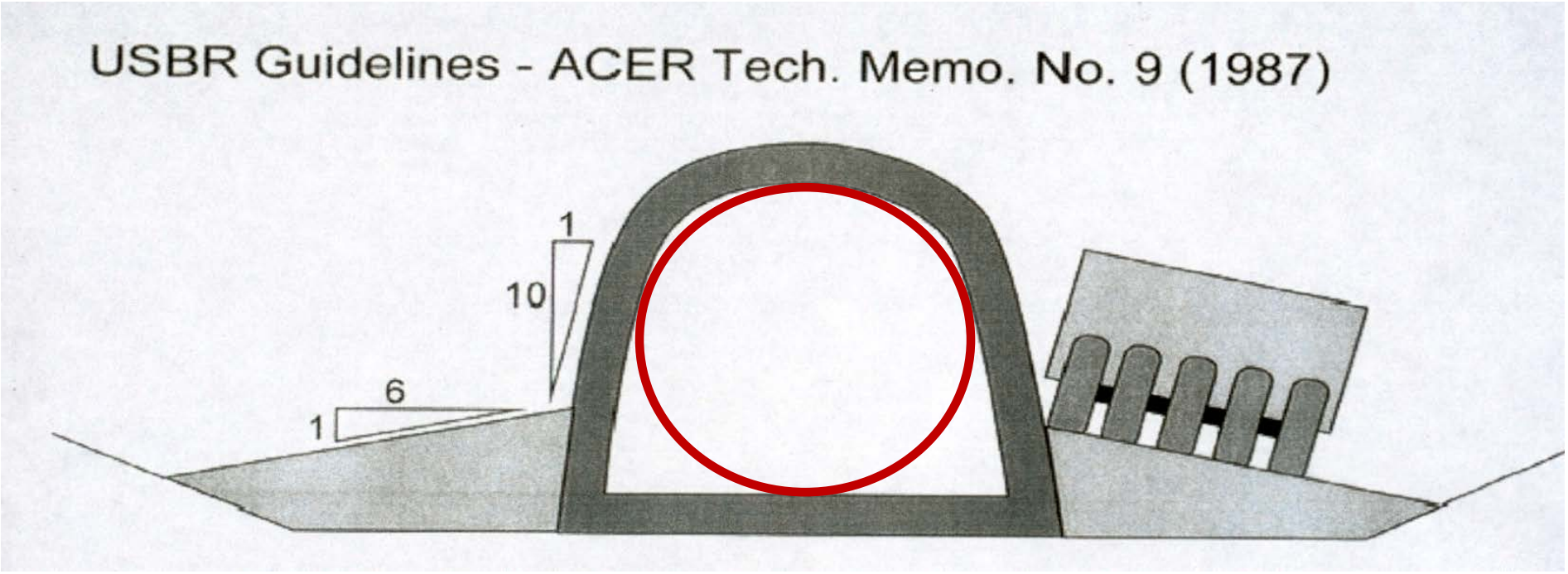
USBR (1987)

"When a conduit is selected for a waterway through an earth or a rockfill embankment, cutoff collars will not be selected as the seepage control measure."

Filter Diaphragm Around Outlet Conduit

ASTM C-33 FINE AGGREGATE (SAND) GRADATION FOR FILTER DIAPHRAGM	
SIEVE SIZE	PERCENT PASSING
⅜ INCHES	100
NO. 4	95-100
NO. 10	74-94
NO. 20	35-75
NO. 30	25-60
NO. 50	10-30
NO. 100	2-10

USBR Guidelines - ACER Tech. Memo. No. 9 (1987)



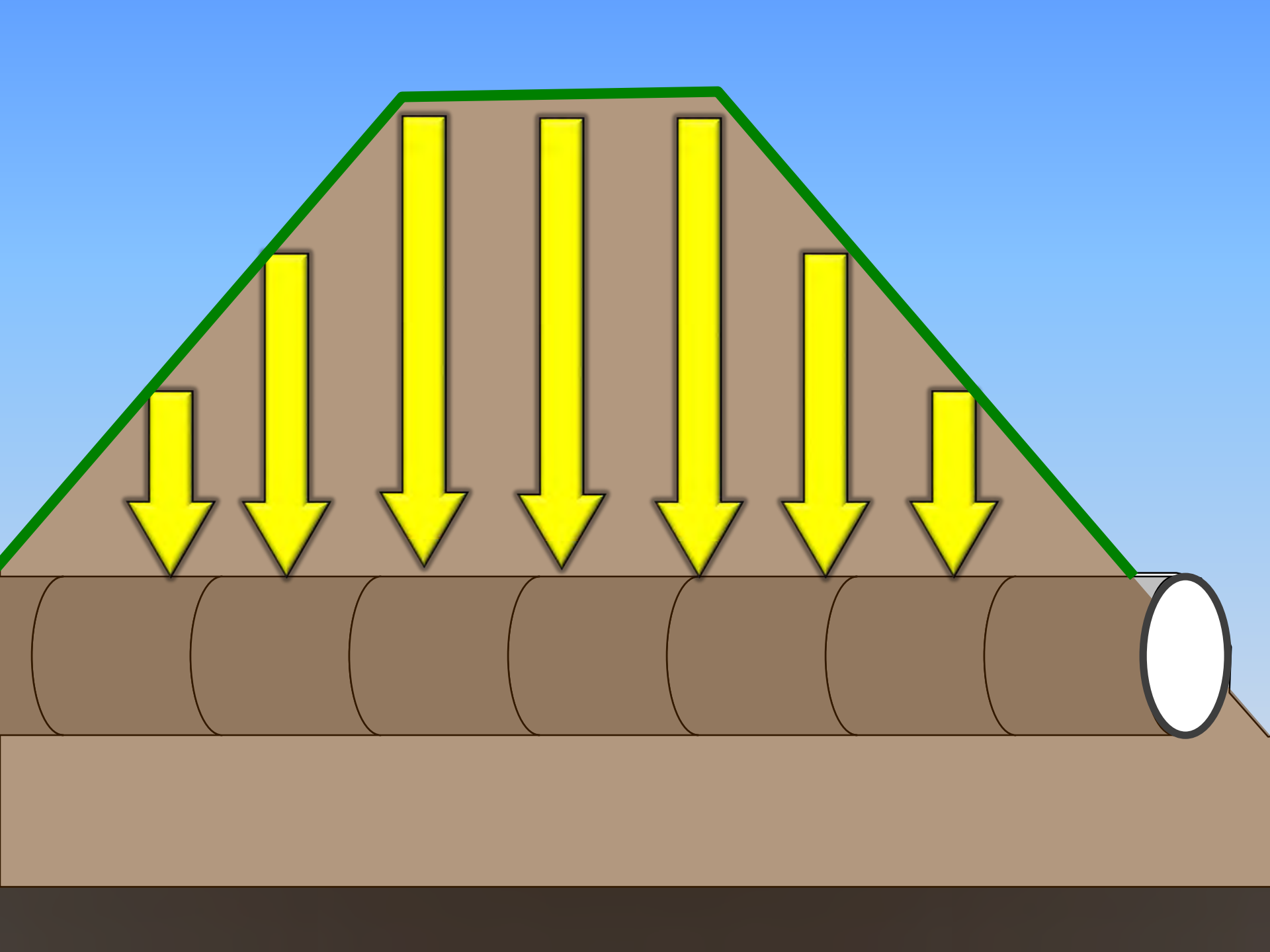
- **Wide trench to allow for equipment**
- **Provide intimate contact with foundation**
- **Articulated design if settlement a concern**
- **Use a robust material for conduit (No CMP!!)**
- **Use ‘Battered’ sides (1:10)**
- **Use rounded top**
- **Use sloped fill (6:1) for direct compaction against sides**
- **Keep fill same level on both sides**
- **NO SEEPAGE COLLARS**
- **FILTER DIAPHRAGM**

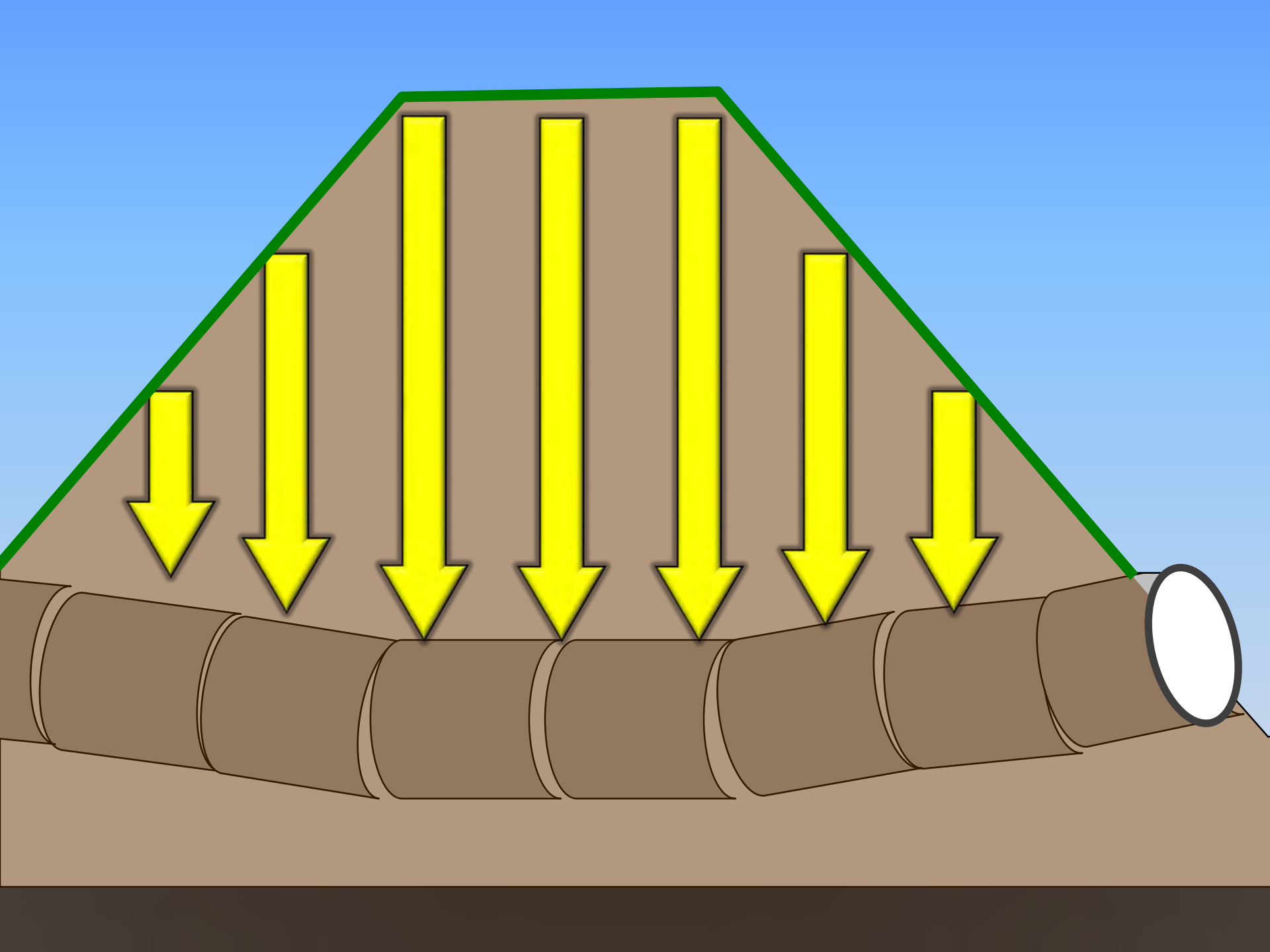

What is wrong?

8’ Diameter RCP & Outlet Structure. View Looking Upstream

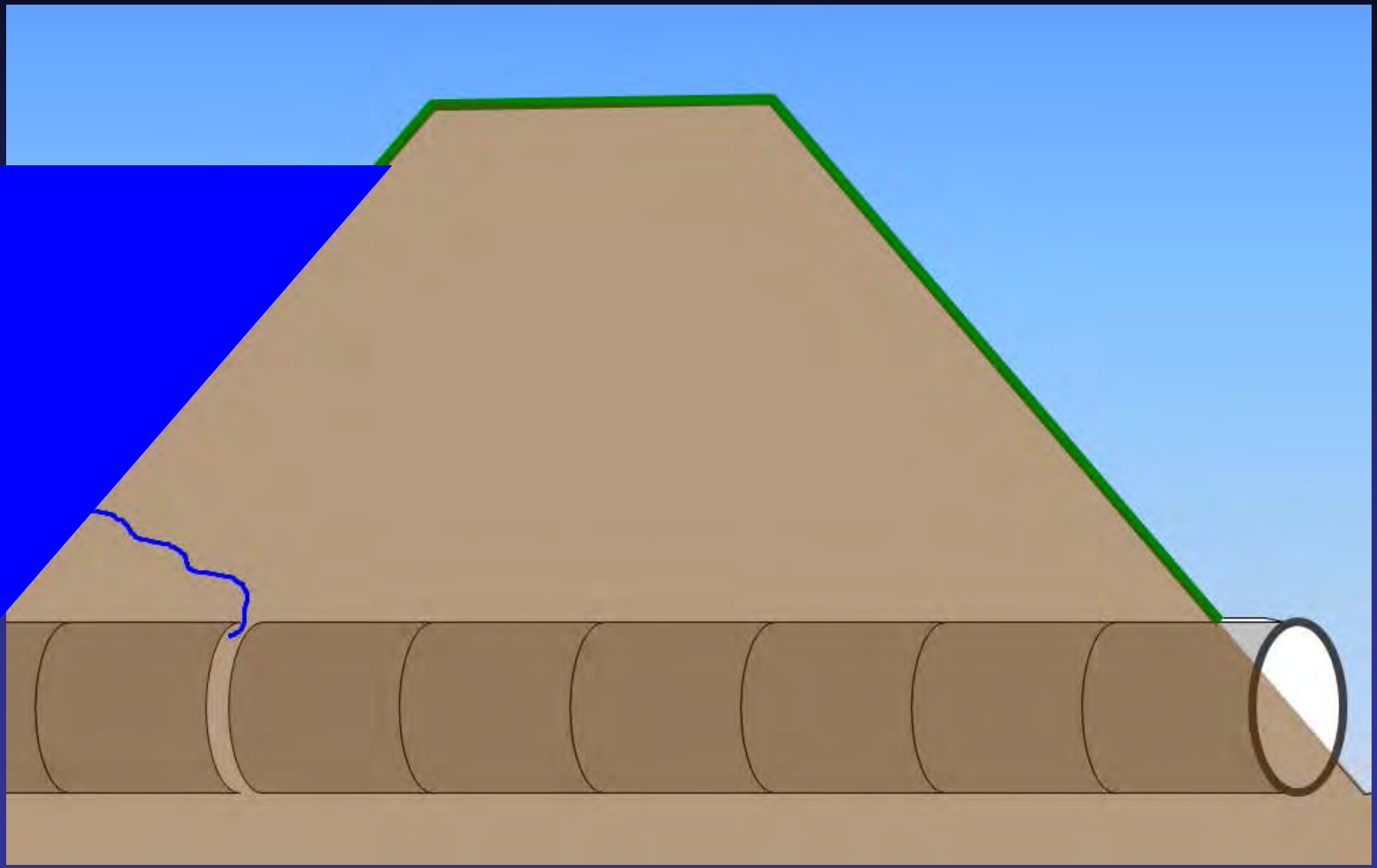
Three Conduit Failure Modes

- Seepage along conduit
- Seepage into the conduit
- Seepage out of conduit

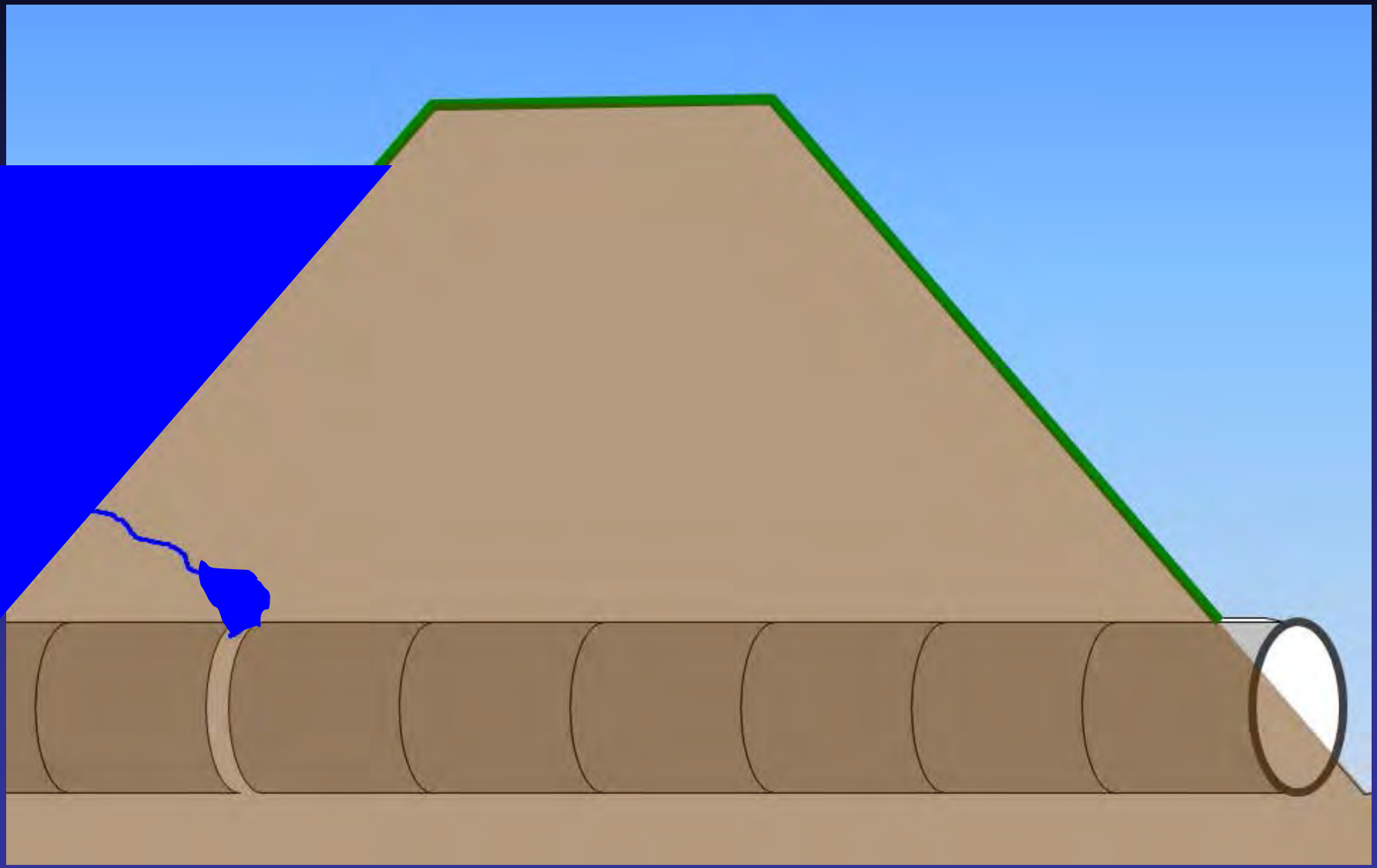




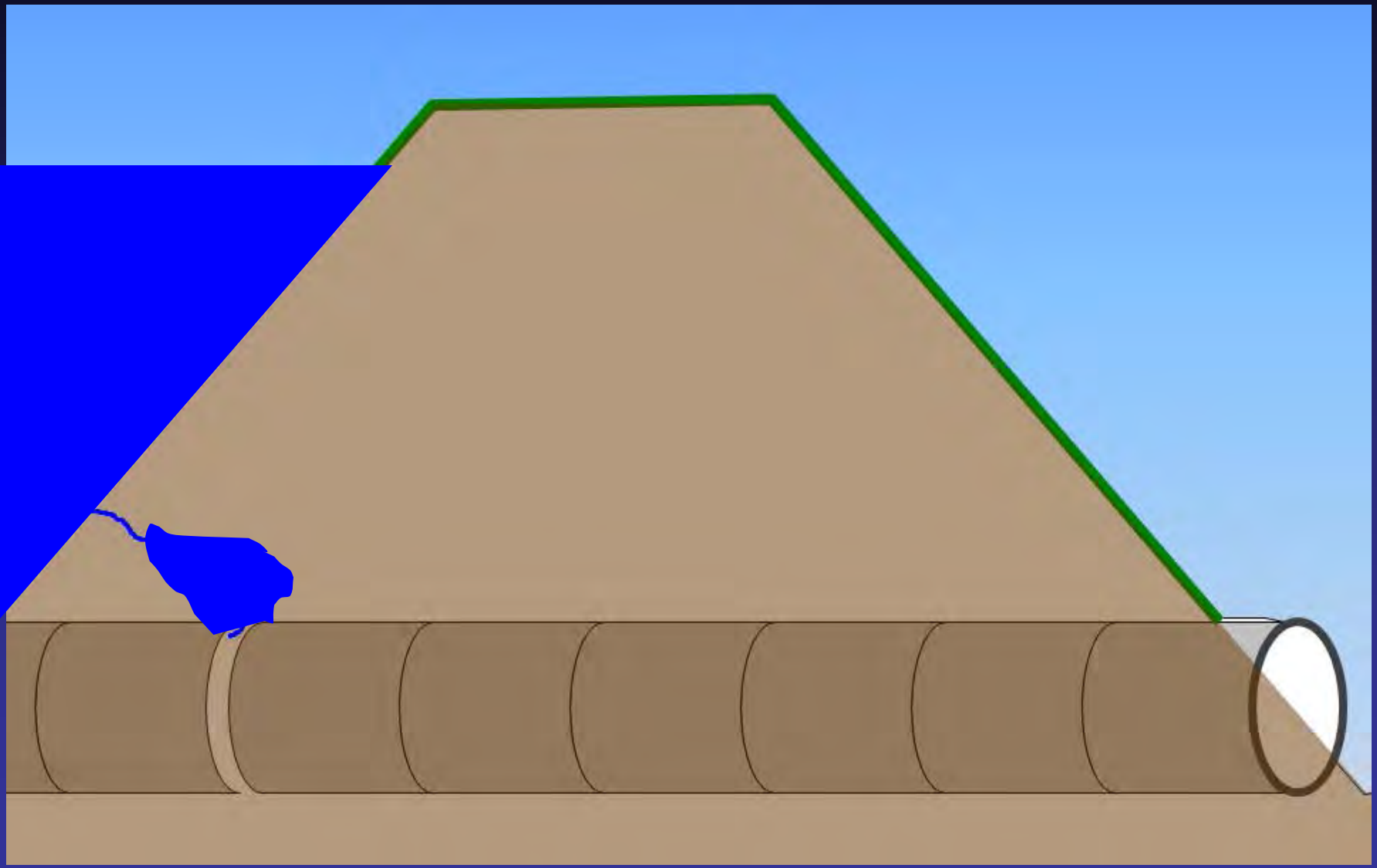
Seepage Into a Conduit



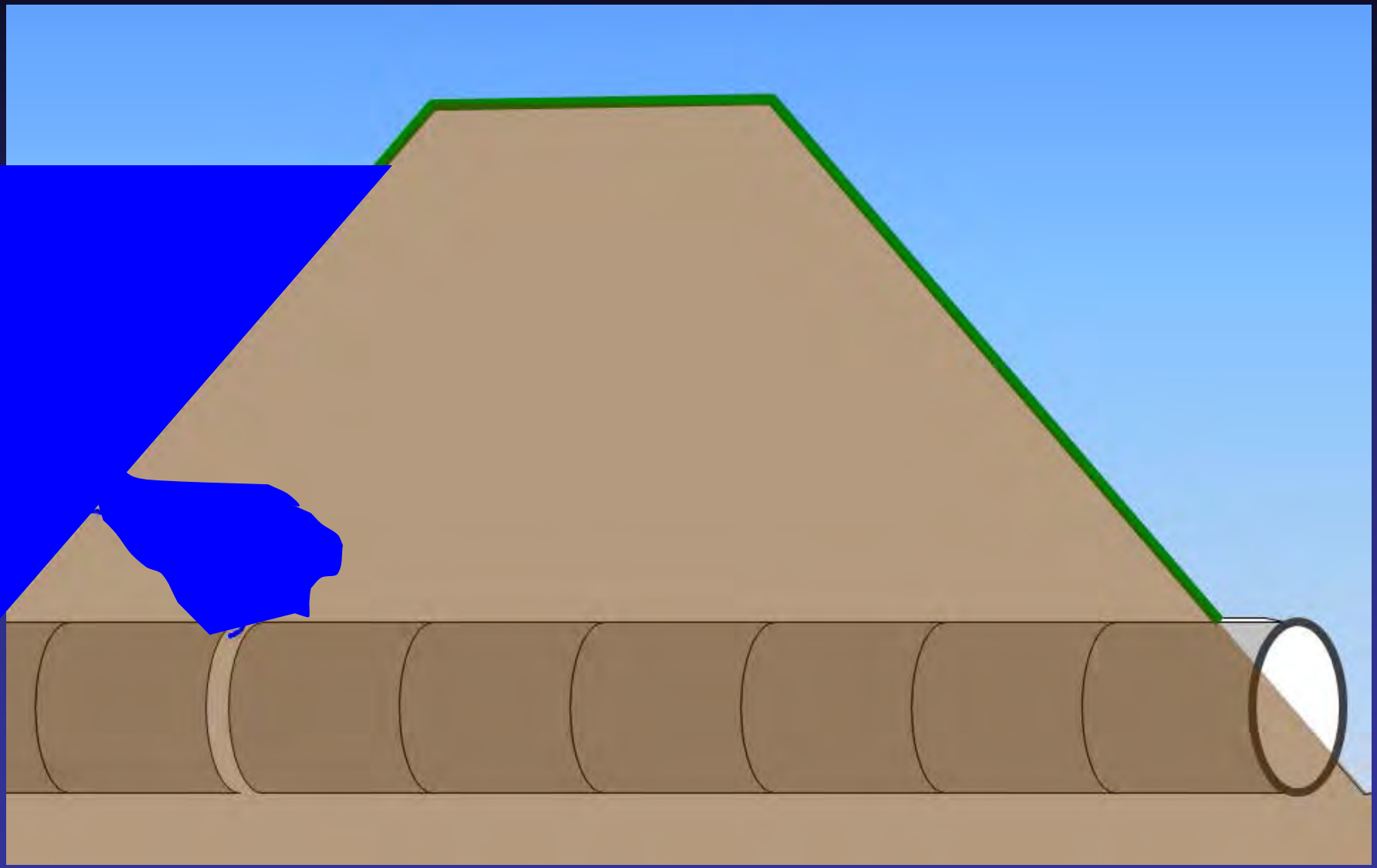
Seepage Into a Conduit



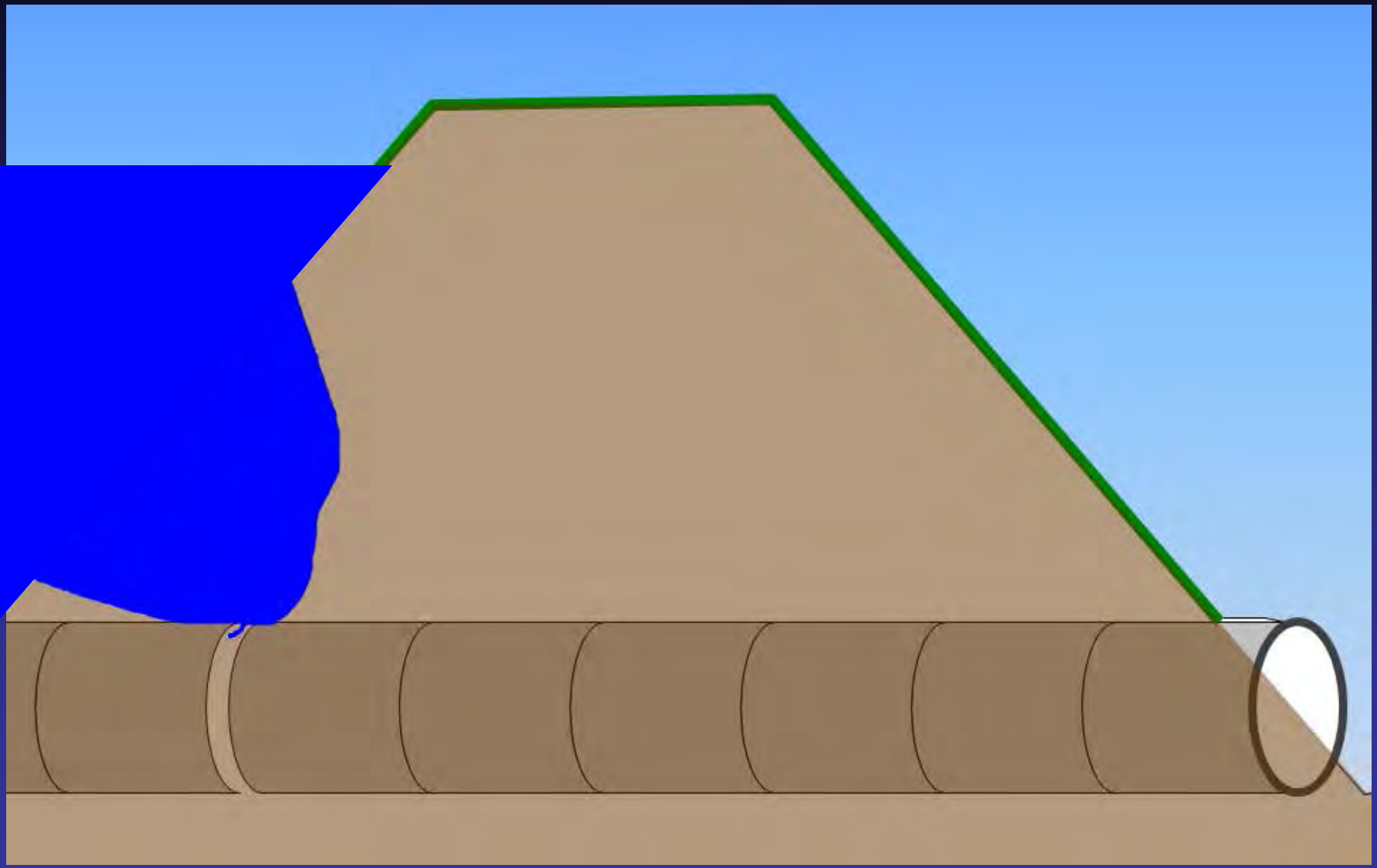
Seepage Into a Conduit



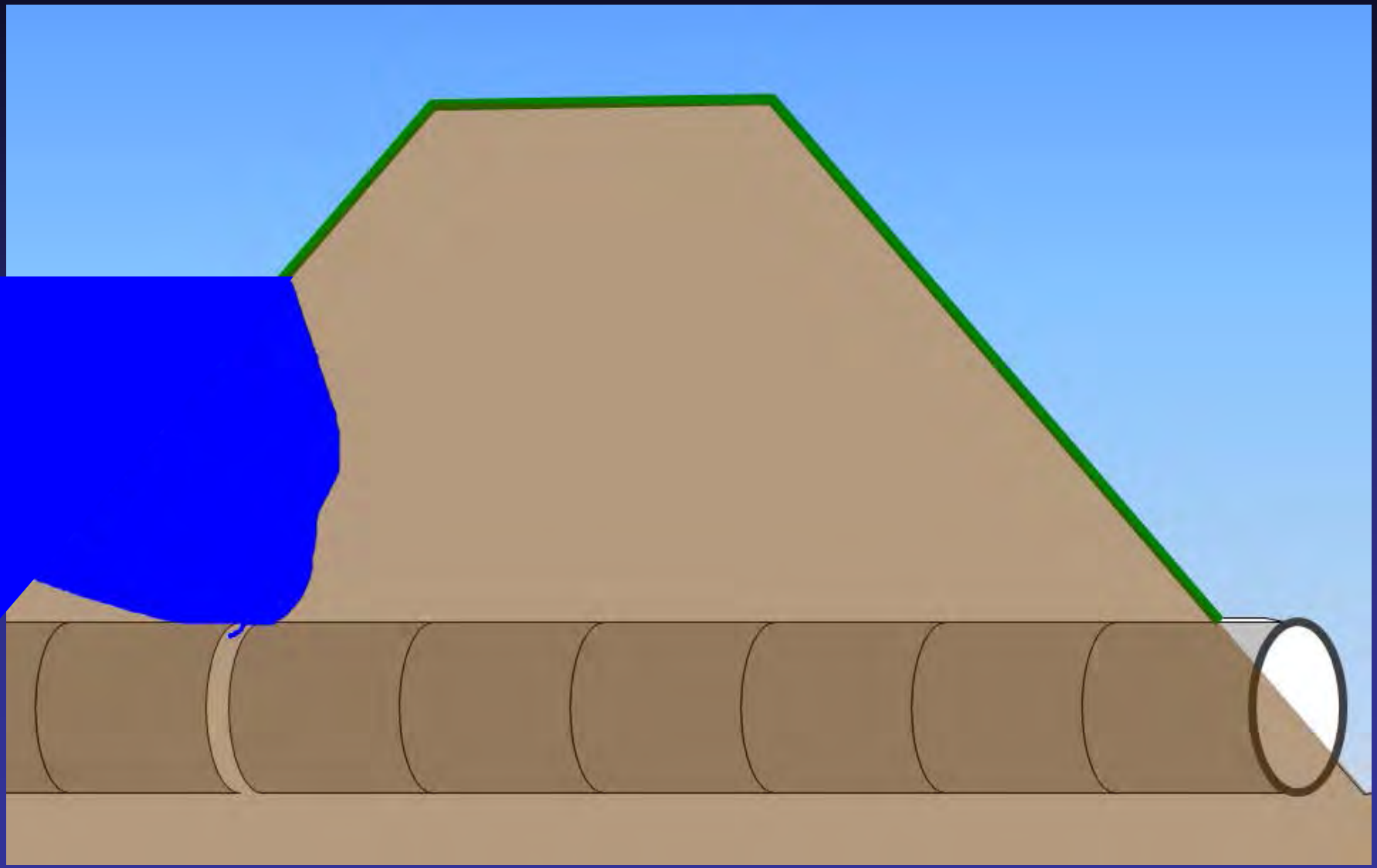
Seepage Into a Conduit



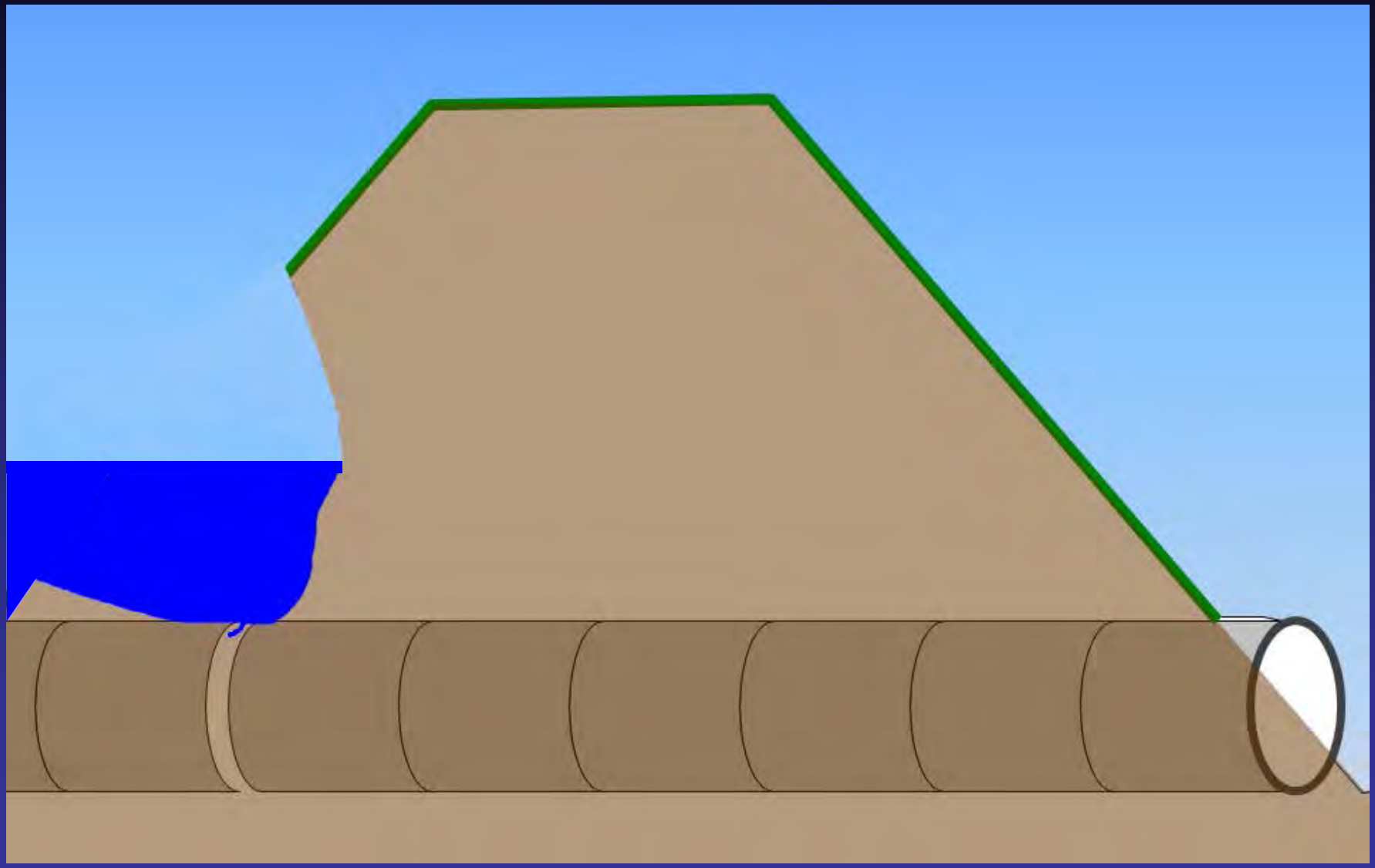
Seepage Into a Conduit



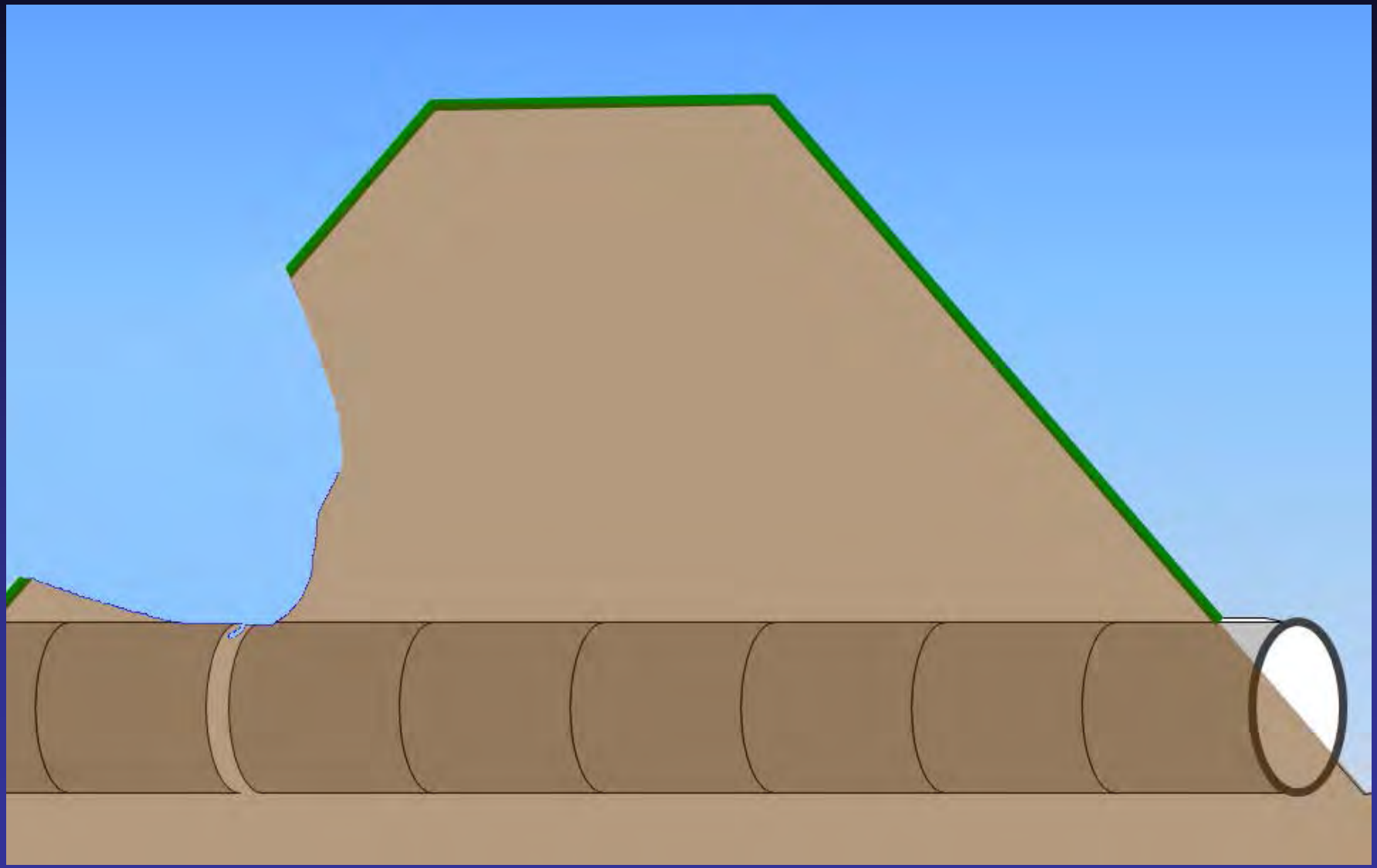
Seepage Into a Conduit



Seepage Into a Conduit



Seepage Into a Conduit




30 6'96


Nelson Perch Pond, ND


Nelson Perch Pond, ND


Nelson Perch Pond, ND


Nelson Perch Pond, ND


Nelson Perch Pond, ND


Nelson Perch Pond, ND


Nelson Perch Pond, ND
Nelson Perch Pond, ND


Nelson Perch Pond, ND

Nelson Perch Pond, ND


King No. 1 Dam Wyoming, WY
07.21.2014 11:20


King No. 1 Dam Wyoming, WY
07.21.2014 11:32

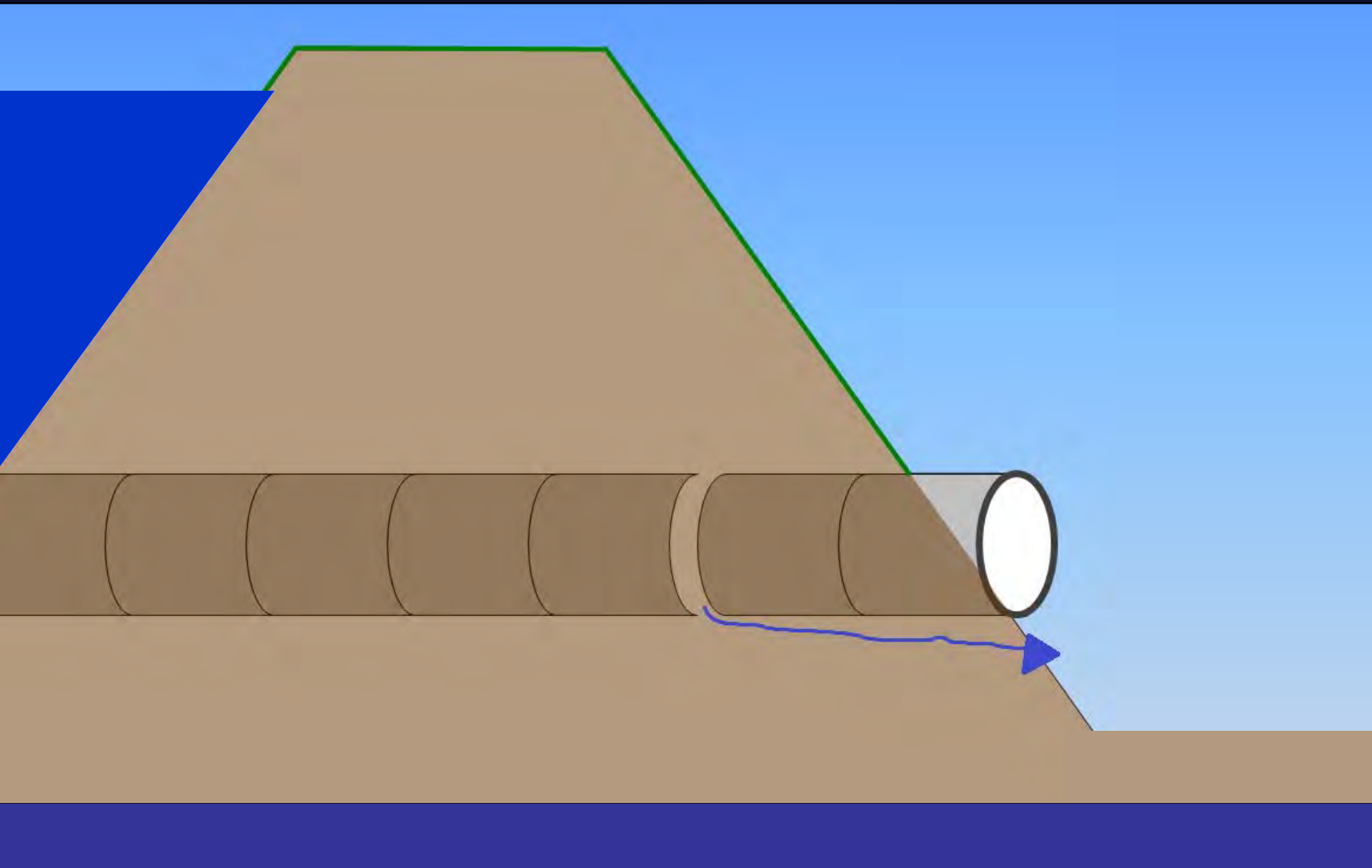
King No. 1 Dam Wyoming, WY

21.2014 11:32

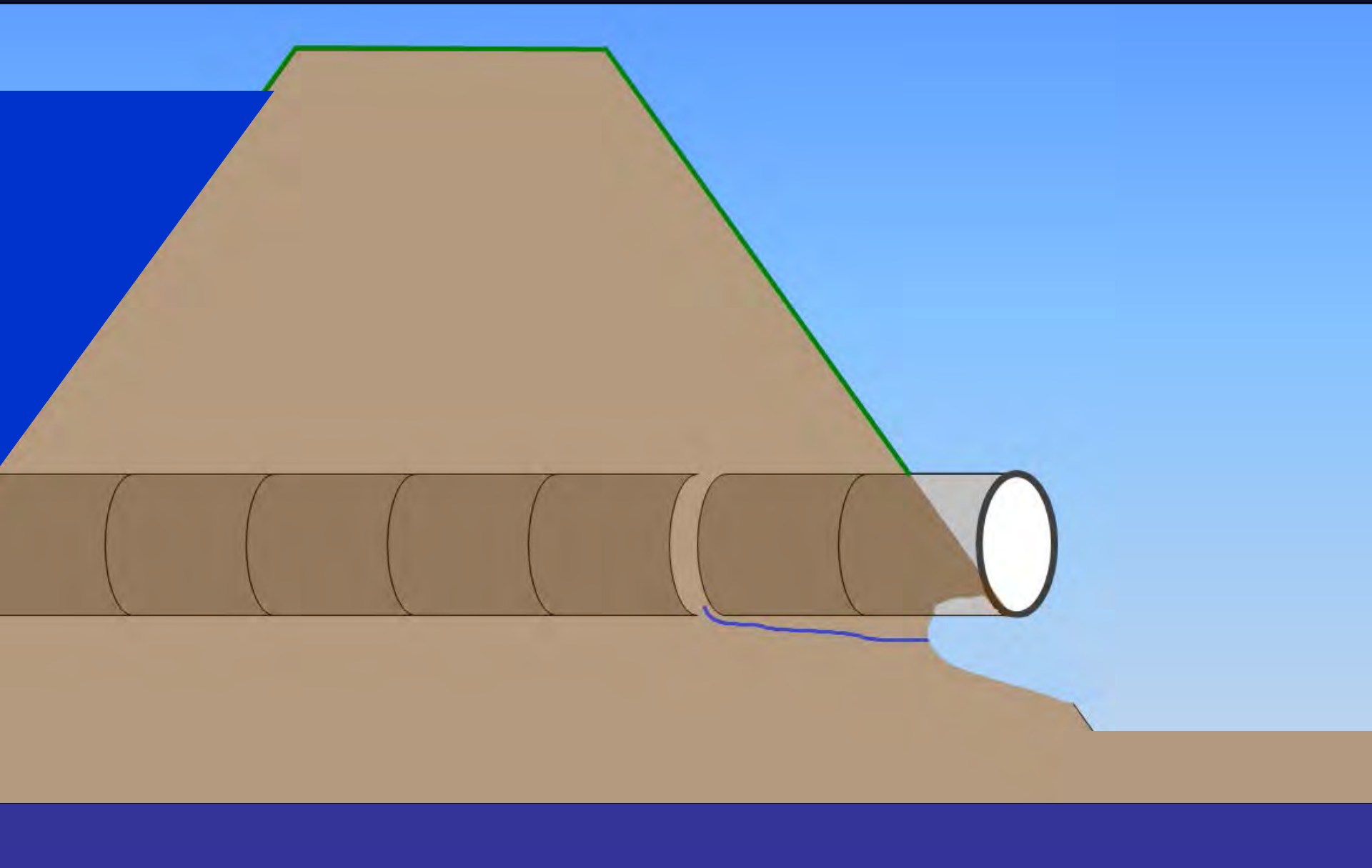
Three Conduit Failure Modes

- Seepage along conduit
- Seepage into the conduit
- Seepage out of conduit

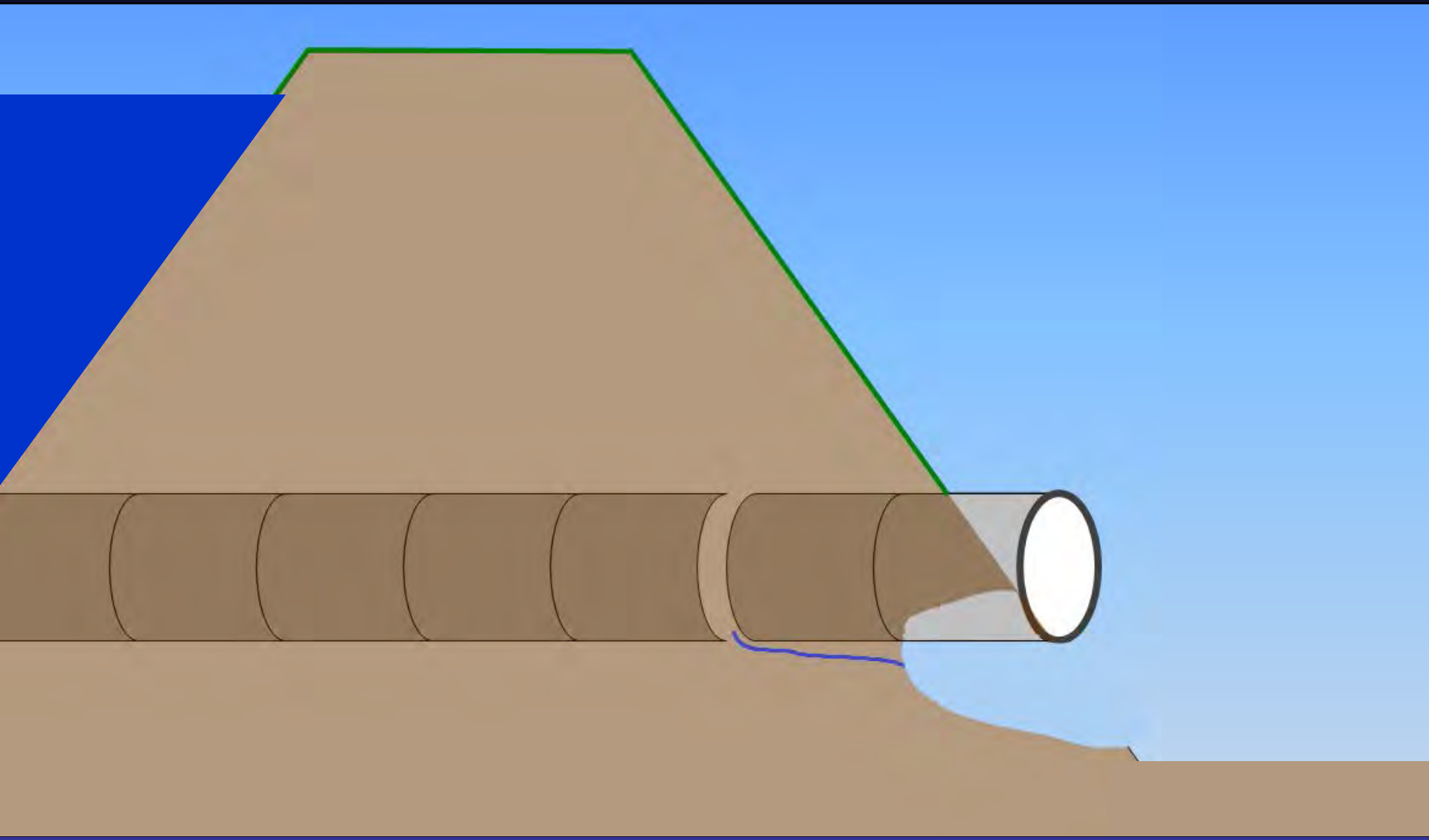
Seepage Out of a Conduit



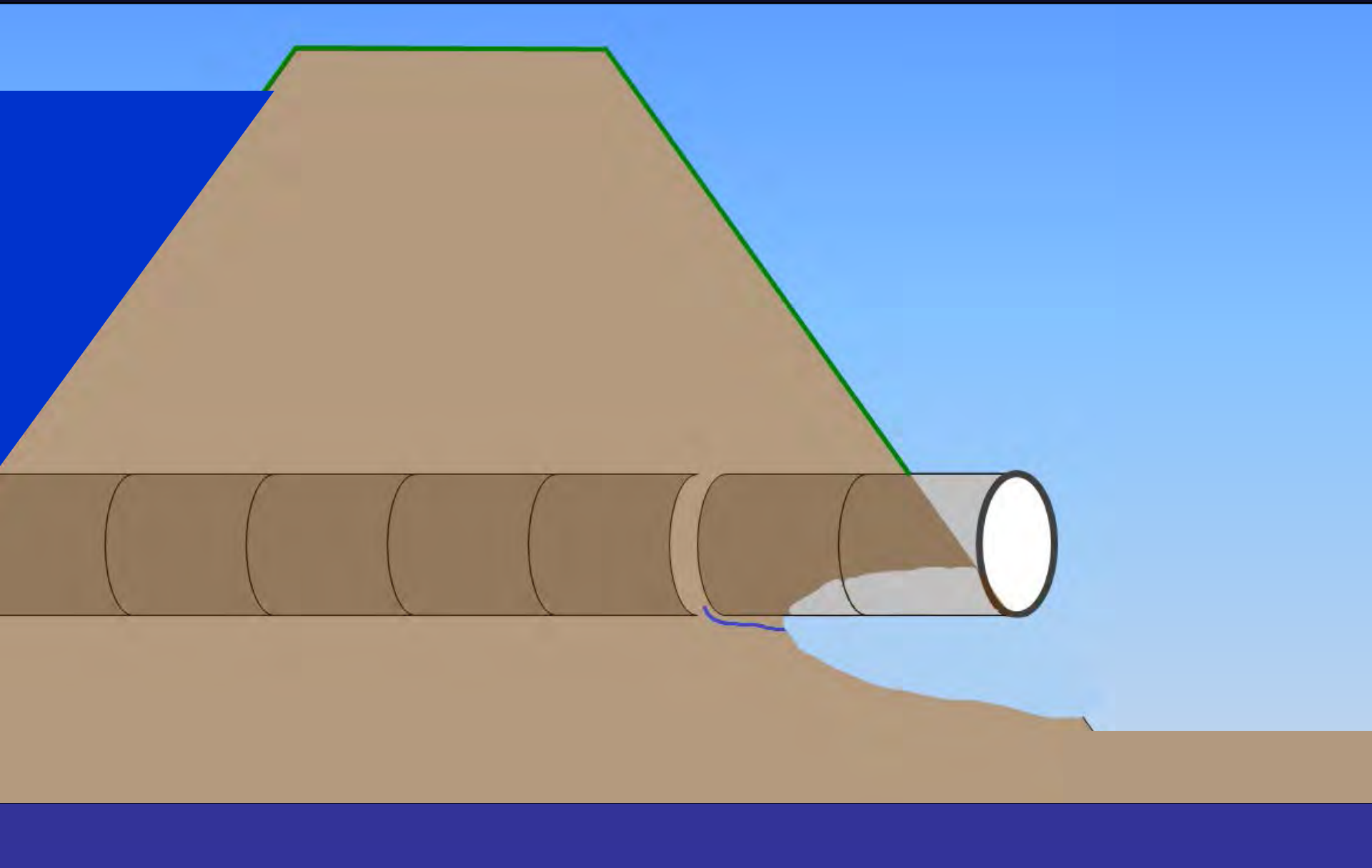
Seepage Out of a Conduit



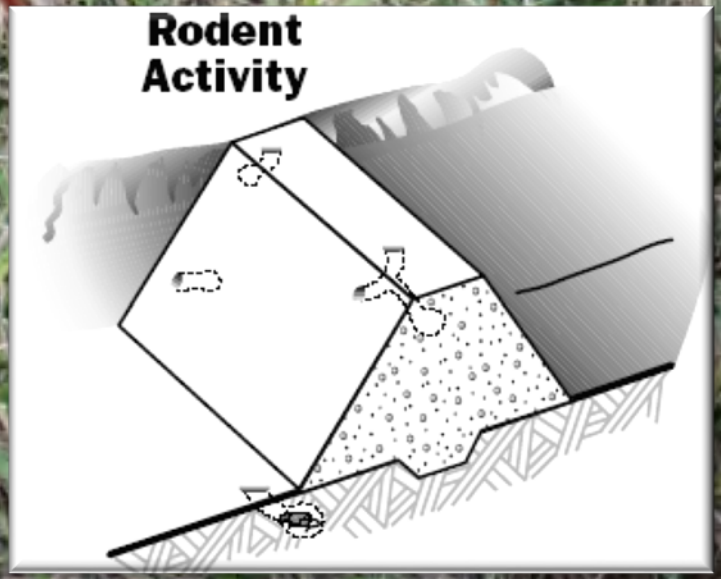
Seepage Out of a Conduit

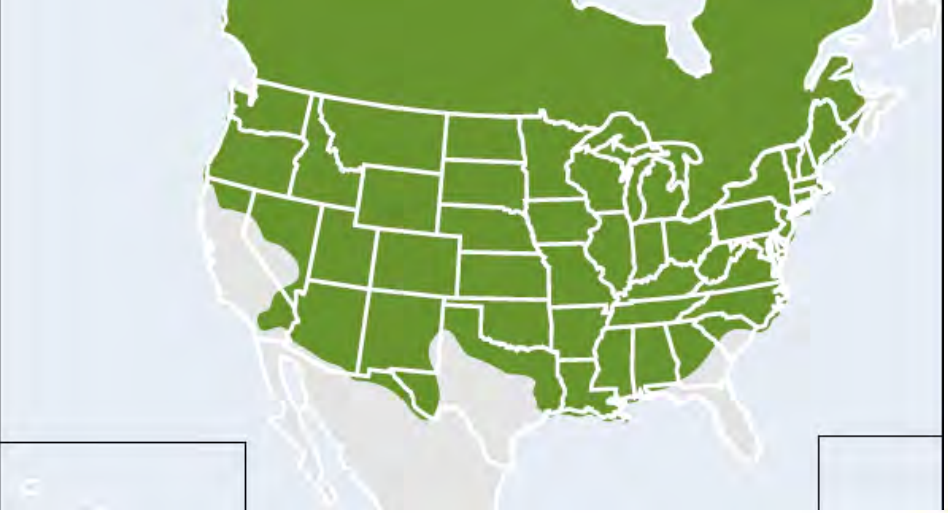


Seepage Out of a Conduit

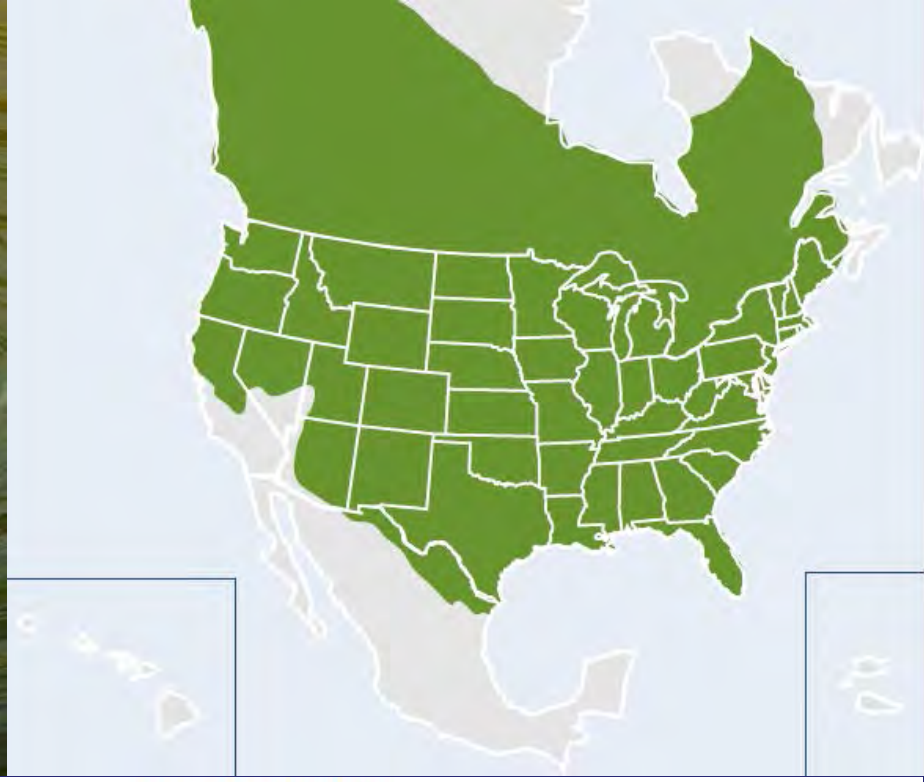


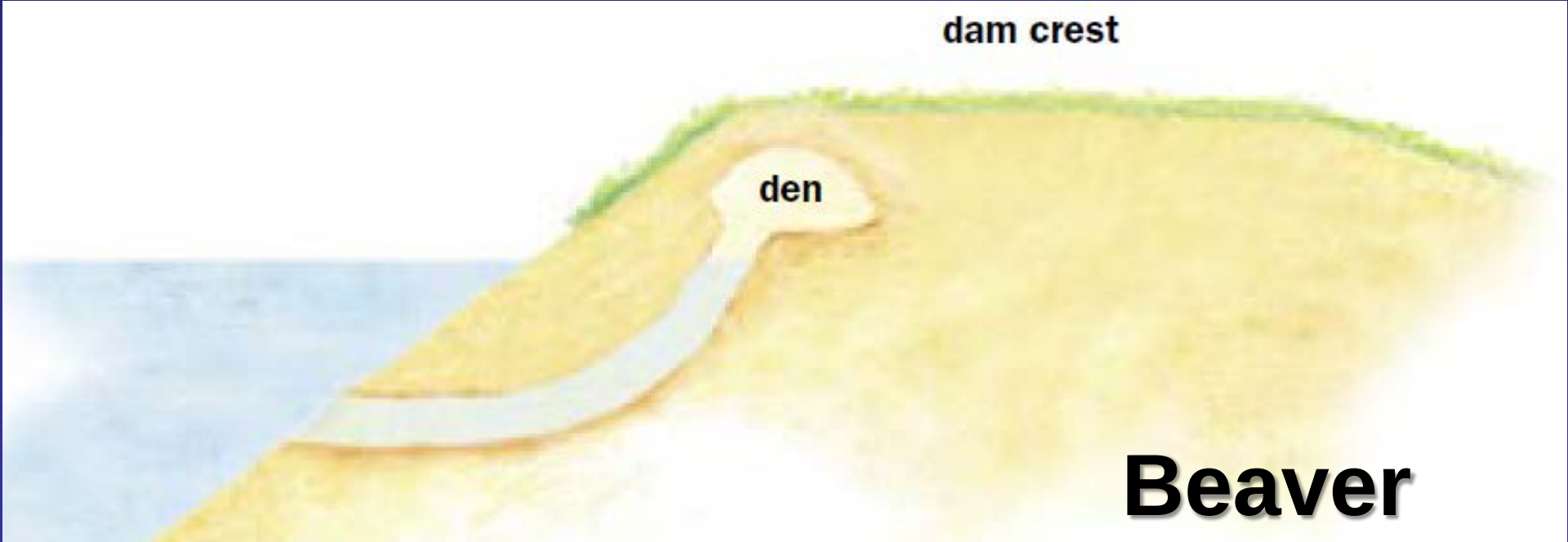
Animal Burrows/Piping


Rodent
Activity



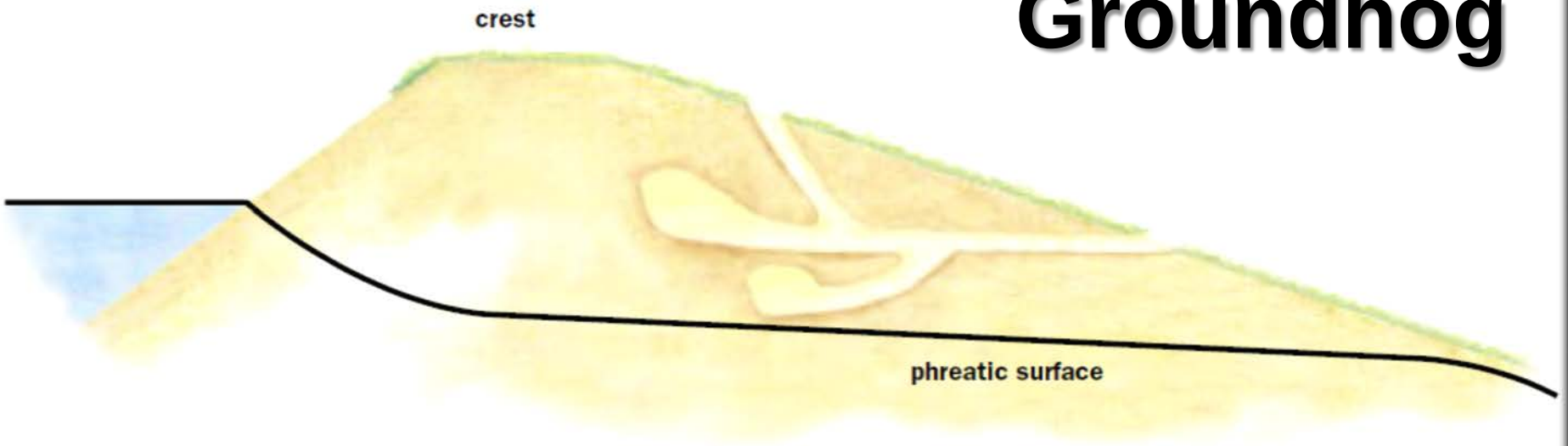
Muskrat





Beaver

Groundhog



~30-Foot Long Groundhog Tunnel at Spruce Run Dam

Used Smoke Bomb and Probe to Locate Tunnel

Photo Courtesy of Marc Brooks, NJWSA

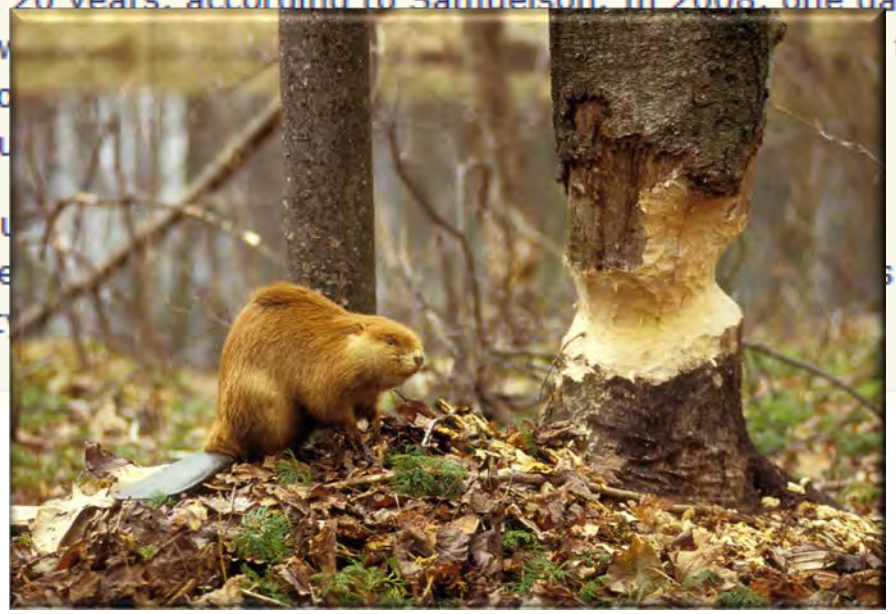
Burrowing Beaver Contributes to Dam Collapse

The northeast Texas community of Edgewood received rain for a few days leading up to Thursday, March 12, 2009. That morning, rain fell again on the already damp town, and by 12:45 p.m. an earthen dam on the 25-acre private lake south of town had failed. A beaver had tunneled into the 14-foot-high earthen dam, contributing to the dam's collapse.

Water rushed through the southern parts of Edgewood, rising in lawns. The Edgewood Volunteer Fire Department reacted quickly, closing flooded FM 859. School buses were re-routed. Later, as the floodwaters receded, people were relieved to discover that no one was hurt and there was no significant property damage. The community was fortunate despite the dam's failure.

"We were scheduled to do an inspection there the following week," says Warren Samuelson, manager of the TCEQ's Dam Safety Program. "The dam's owner had seen water flowing through the dam but didn't completely understand the nature of the problem."

Texas has experienced dam failures in the past 20 years, according to Samuelson. In 2008, one dam fa to th fo o tu W cu in tre s of li rt



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)

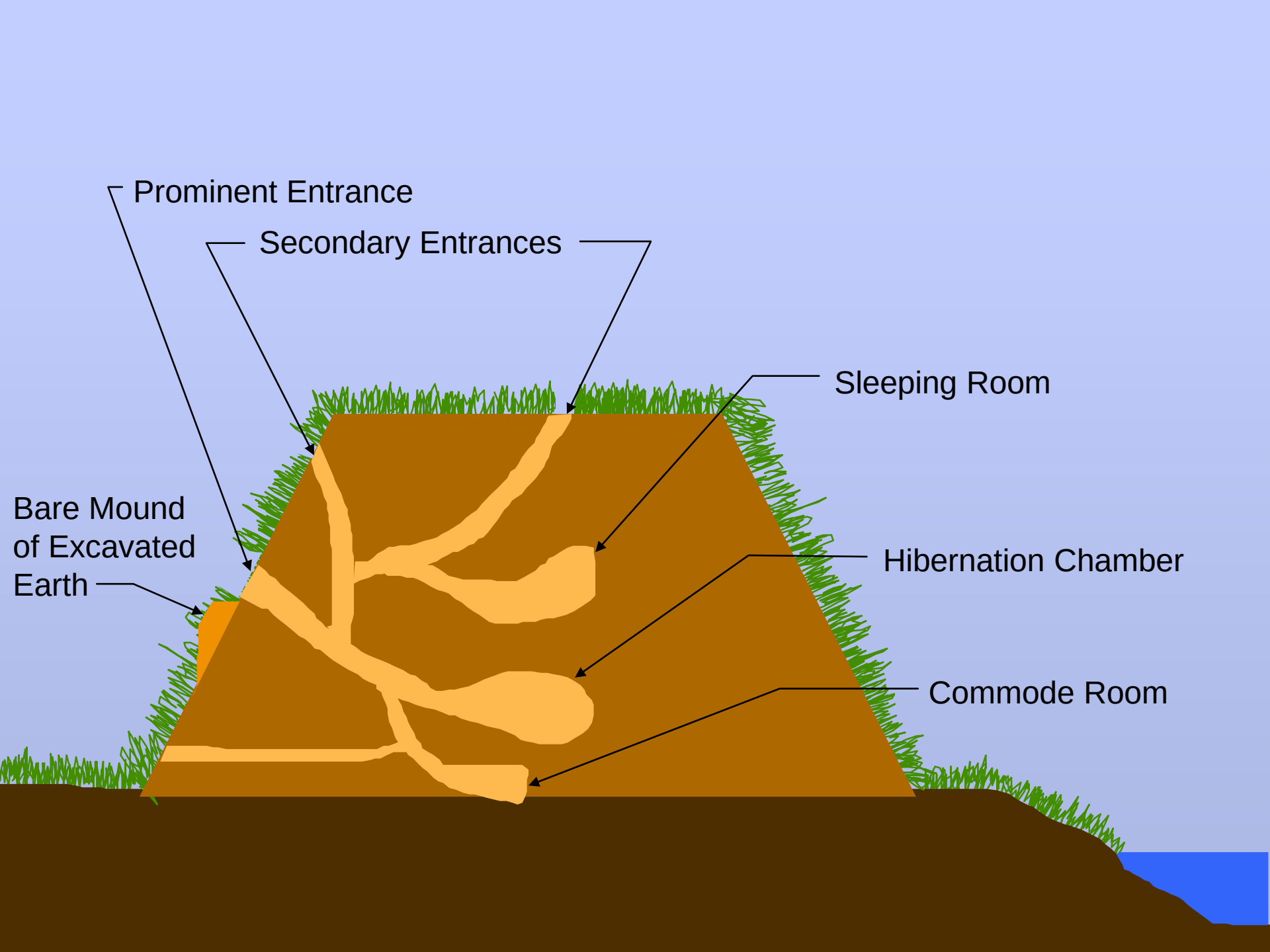
Edgewood Old City Lake Dam, TX
Partial failure in 1988, failed in 2009 – both due to animal burrows
Owner had removed 20-30 beaver in past few years

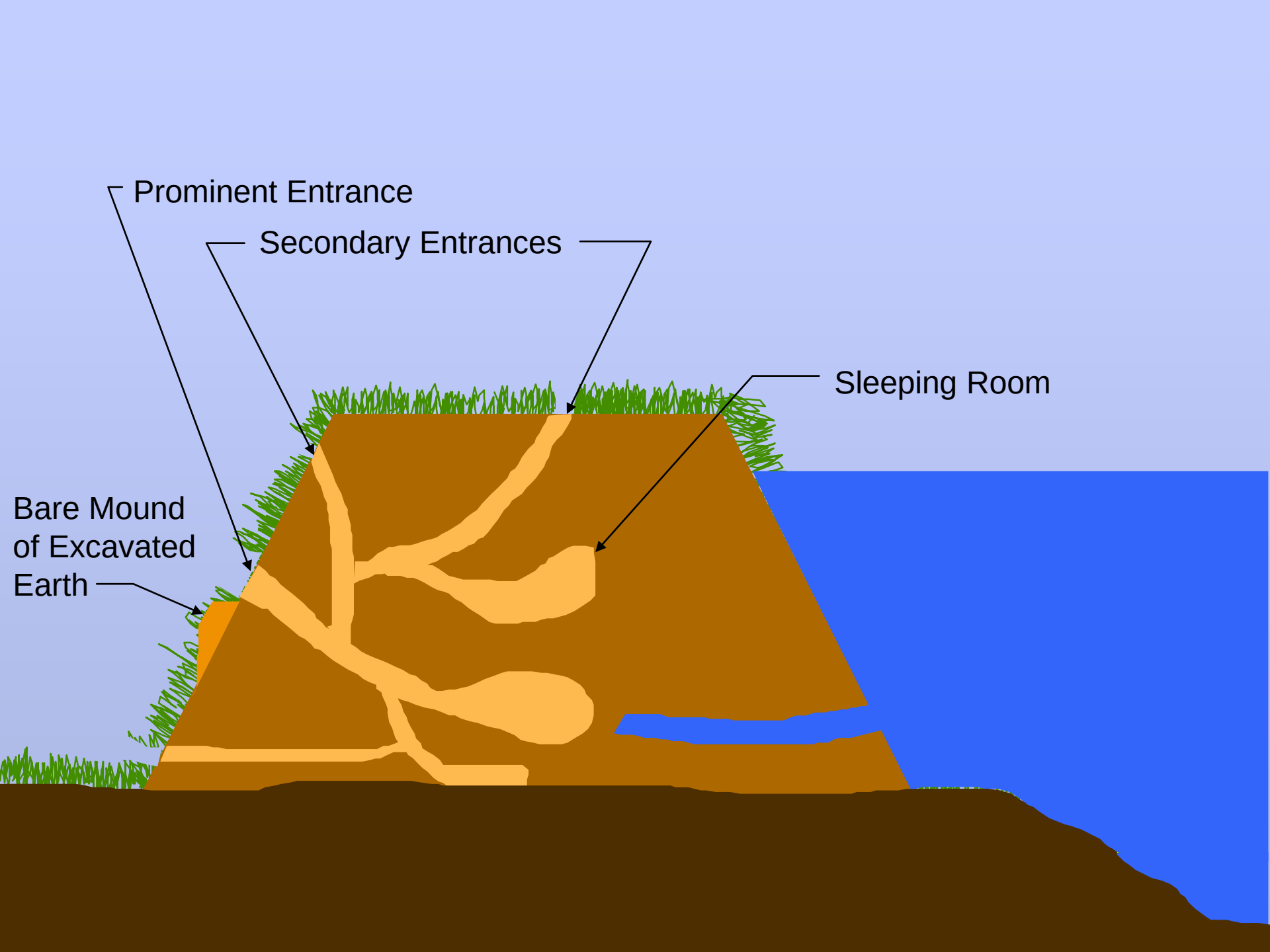
Troublesome muskrat causes levee to fail in Missouri town

Anthony Souffle/AP Photo. Enlarge photo.

Water pours though a break in the Pin Oak levee Friday in Winfield, Mo. A new defense is in the works: a quickly constructed 4-foot-tall sandbag levee to protect 100 homes in the floodwater's path.

Failure From Deterioration & Animal Damage


Prominent Entrance
Secondary Entrances
Sleeping Room
Bare Mound
of Excavated
Earth
Hibernation Chamber
Commode Room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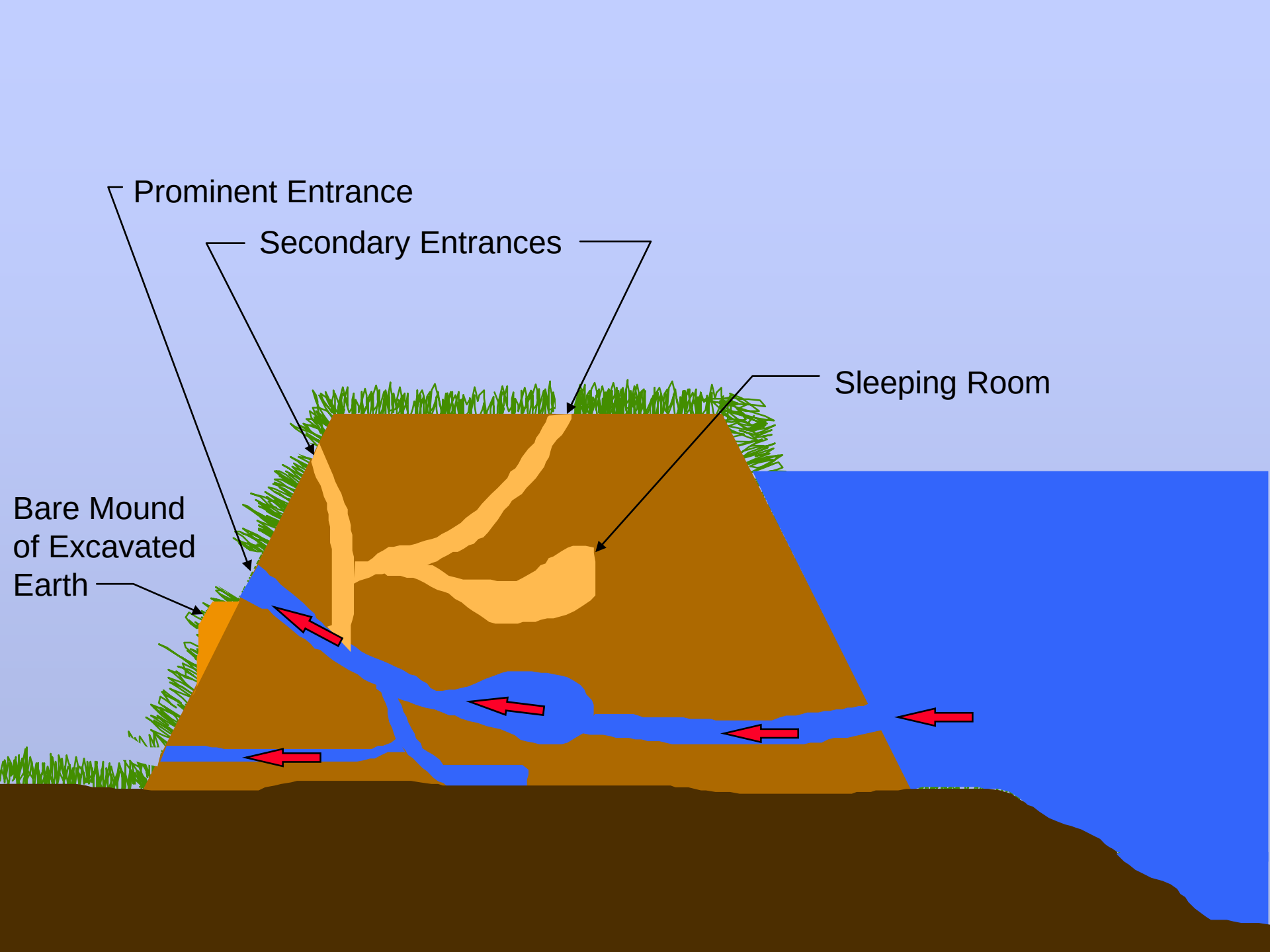
Prominent Entrance
Secondary Entrances
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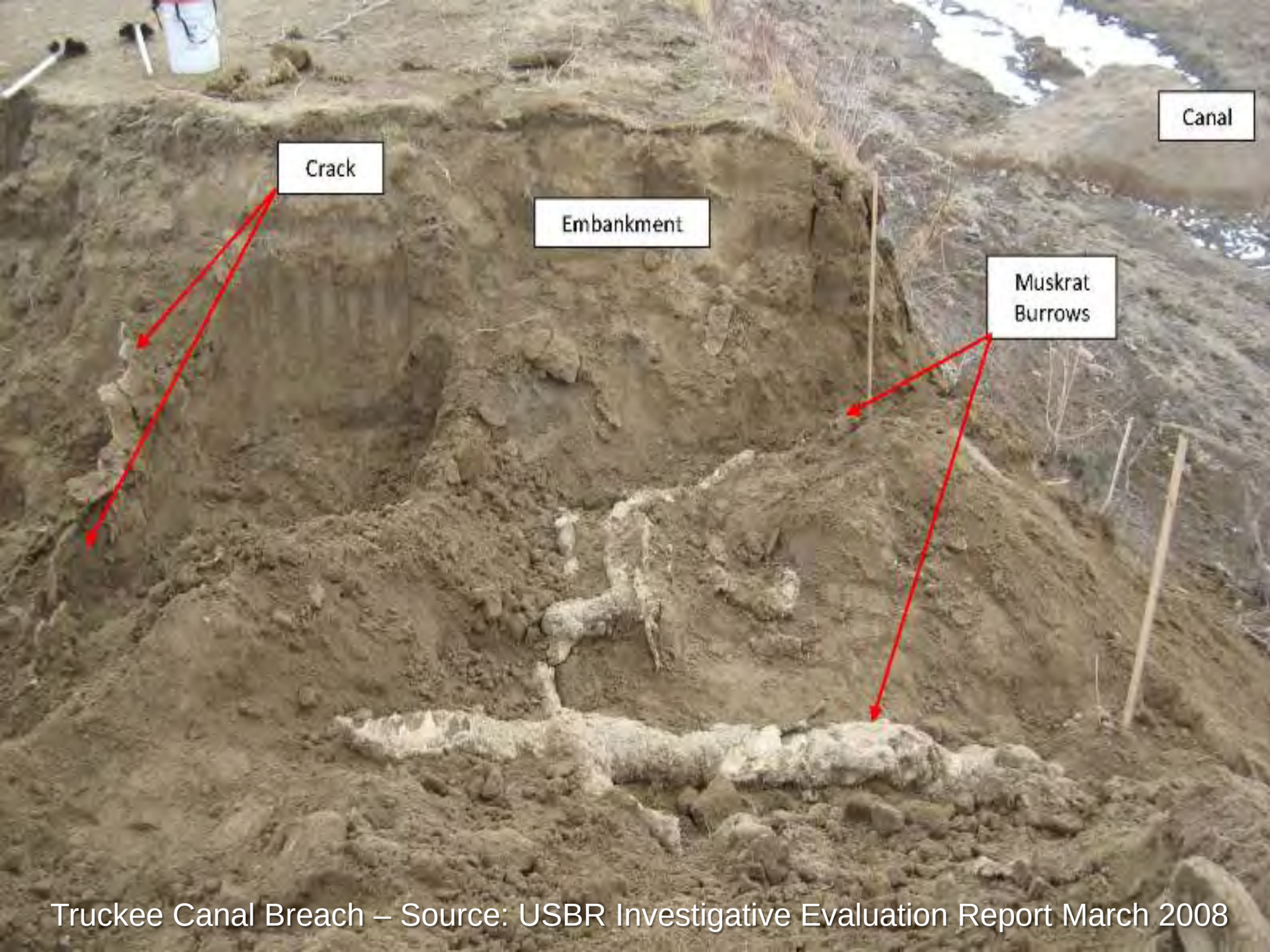
of Excavated
Earth

Posted March 21, 2008 - 10:00pm

Truckee Canal at Fernley Nevada

Rodent burrows blamed in canal failure

Damages estimated to be ~$50,000,000



Truckee Canal Breach – Source: USBR Investigative Evaluation Report March 2008

Truckee Canal Breach – Source: USBR Investigative Evaluation Report

Truckee Canal Breach – Source: USBR Investigative Evaluation Report


Santa Clara Dam Failure, Santa Clar
Sept. 11, 2012

Santa Clara Dam Failure, Santa Clara Utah, Sept. 11, 2012

15 Minute Break

Lessons Learned from Embankment Dam Seepage Failures

Gannett Fleming

Maryland Department of the Environment