Lessons Learned from Spillway Failures

Gannett Fleming

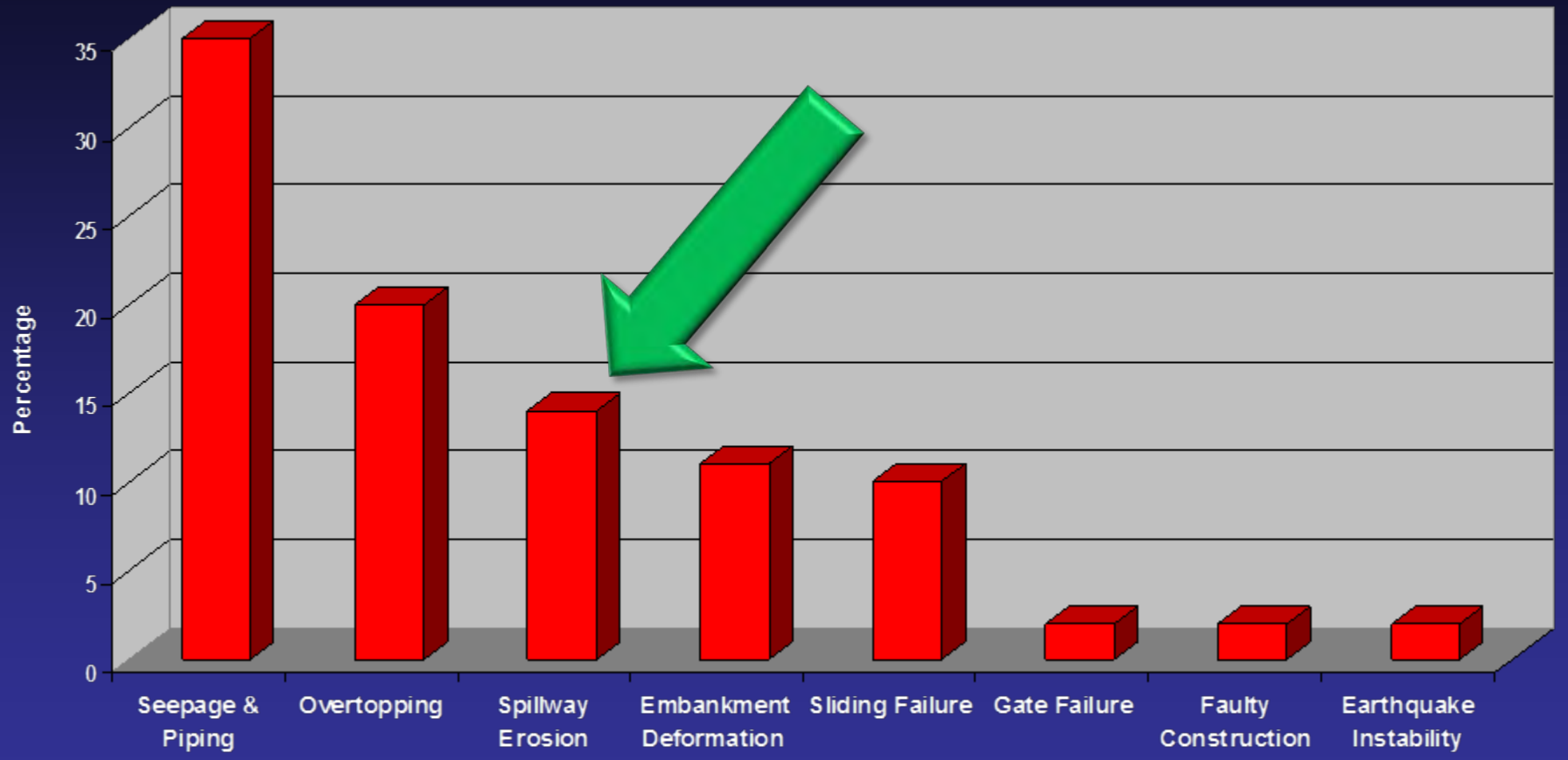
Maryland
Department of
the Environment

Causes of Dam Incidents

Fundamental Causes	Percentage
Sabotage	0
Earthquake Instability	1
Faulty Construction	2
Gate Failure	2
Sliding	10
Deformation	11
Spillway Erosion/Breach	14
Overtopping	25
Seepage/Piping	35

Source: NRC, Safety of Existing Dams, 1983

Failure Incident Types



Source: NRC, Safety of Existing Dams, 1983

US Deaths From Dam Failures

Dam Failure	Lives Lost
South Fork, PA (1889)	2,209
Austin, PA (1911)	80
Laurel Run, PA (1977)	40
Kelly Barnes, GA (1977)	39
Canyon Lake, SD (1972)	33
Teton, ID (1976)	14
Swift, MT (1964)	19
Ka Loko, HI (2006)	8

No known deaths attributed to a spillway breach

Categories of Spillway Incidents

- Inadequate Spillway Capacity
- Failure of Flow Surfaces
  - Erosion
  - Abrasion
  - Cavitation
- Structural Failure from Uplift
  - Seepage
  - Stagnation Pressures
- Structural Failure from Dynamic Loadings
- Failure of Operating Provisions
  - Hoists, Gates …
  - Controls


1997, Flow~160,000 cfs

00:00 - 02:03
CC
FOX 40

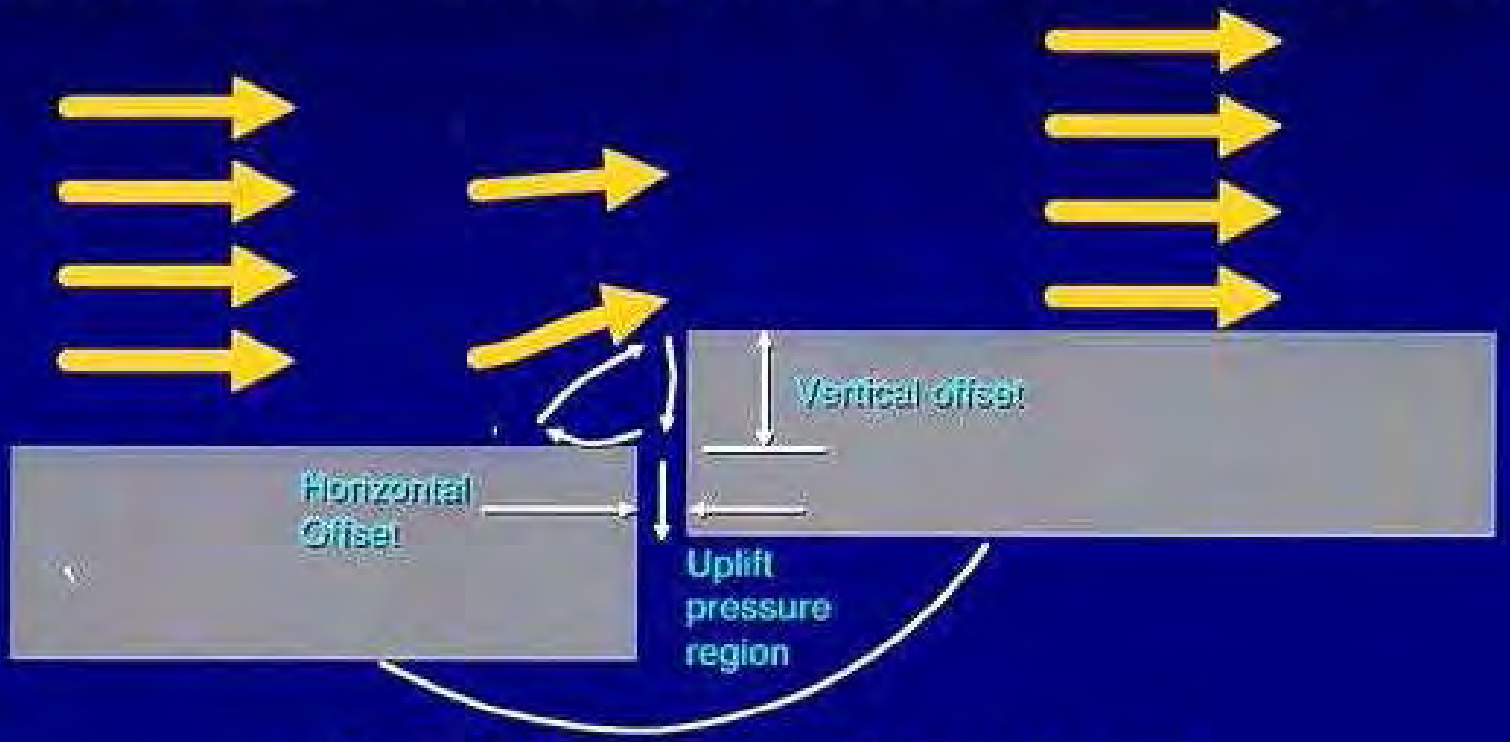

1997, Flow~160,000 cfs

Preliminary Factors Potentially Contributing to Failure

- Lack of waterstops in slab joints
- Concrete cracking and surface deterioration
- Plugging and collapse of underdrain pipes (roots)
- Unfiltered drains
- Soil-like erodible foundation in places
- Drought impacts on foundation materials
- Insufficient anchorage
- Large variations in slab thickness
- Limited slab reinforcement and joint restraint
- Cavitation?

Stagnation Pressure

- Significant damage has occurred on several Reclamation spillways



Flow Pattern Over Displacement

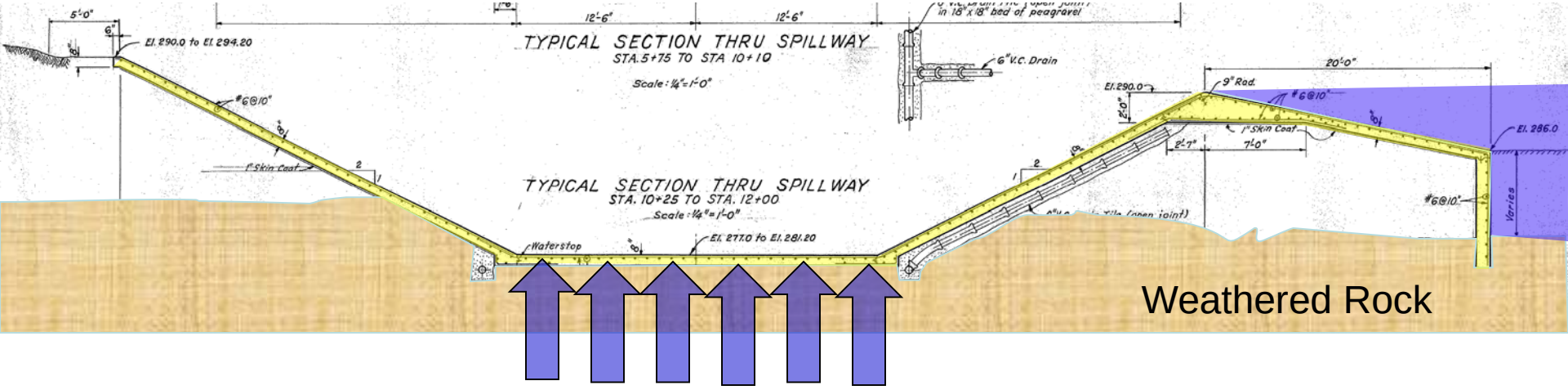

09.19.2011


09.19.2011


05.01.2013


05.29.2013


ZONK



Water Head Needed to Lift 8" Concrete Slab:

$$= \frac{8" \times 150 \text{ pcf}}{62.6 \text{ pcf}} = 19.2" = \textbf{1.6 Feet}$$

2009, 20-25 gpm


CNOLNY
2009


2009


07/21/2009


Mount Carmel Dam, ND


Mount Carmel Dam, ND

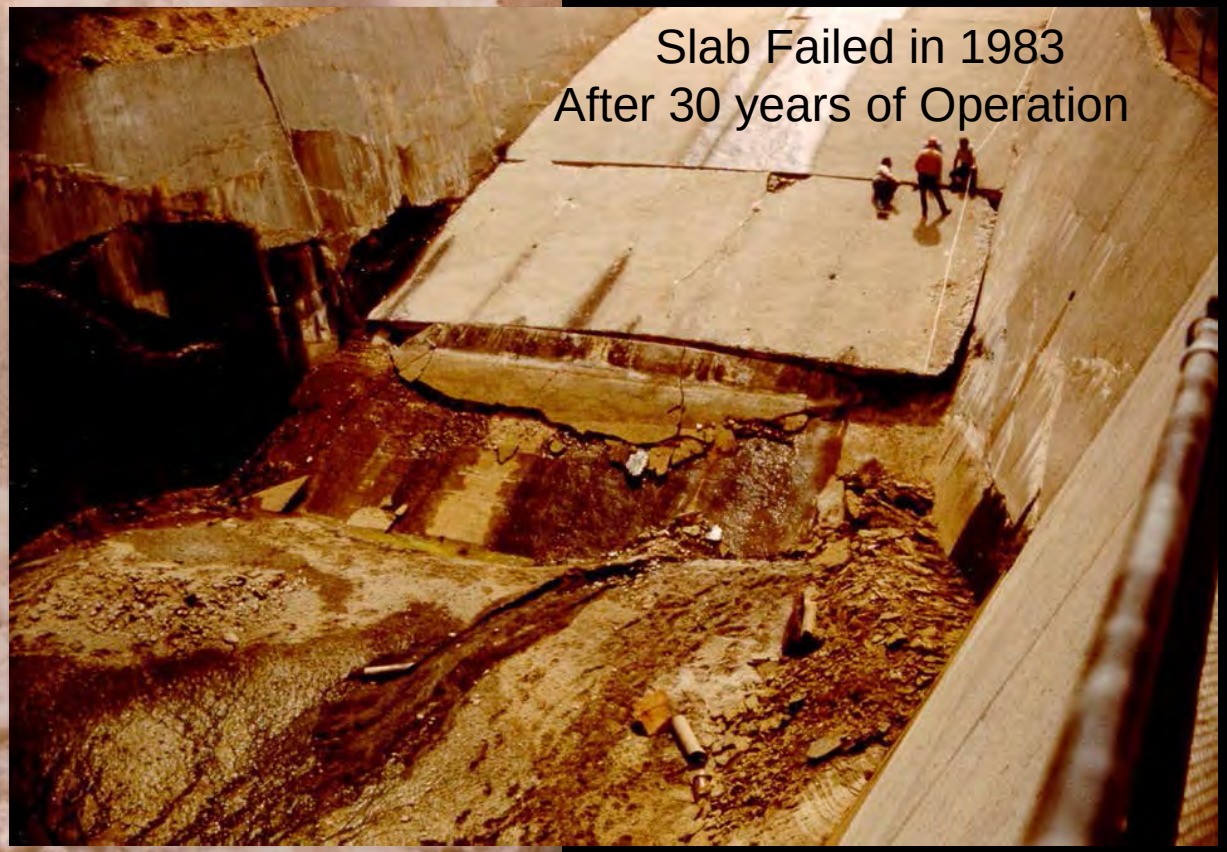

BA12 - Auxillary Spillway - Soil Cement - July 1974


BA12 - August 20, 2007
Bad Axe Dam, Wisconsin

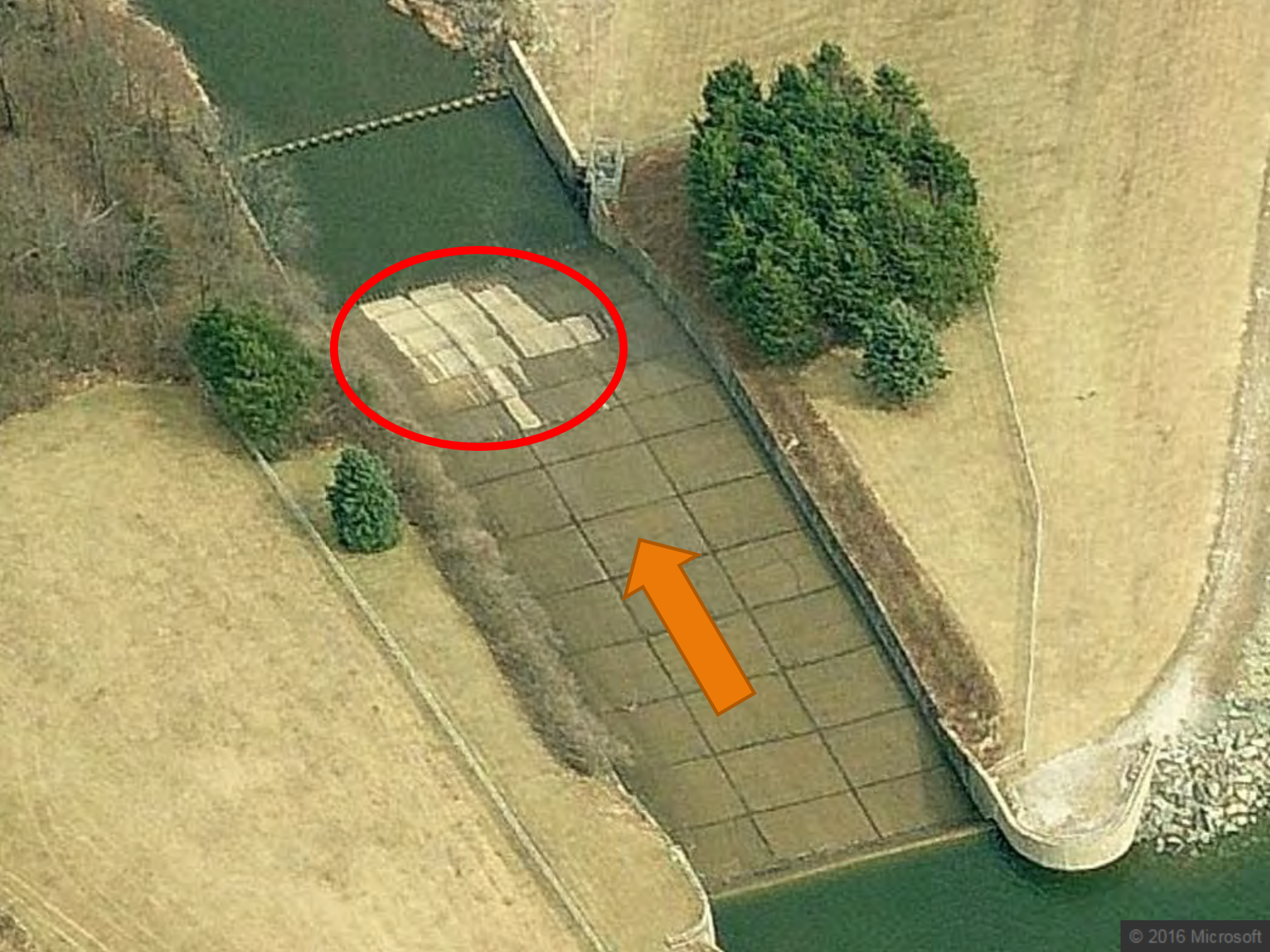

2007/08/20
Bad Axe Dam, Wisconsin


2007/08/20
Bad Axe Dam, Wisconsin

Big Sandy Spillway, WY
Stagnation Pressure Failure



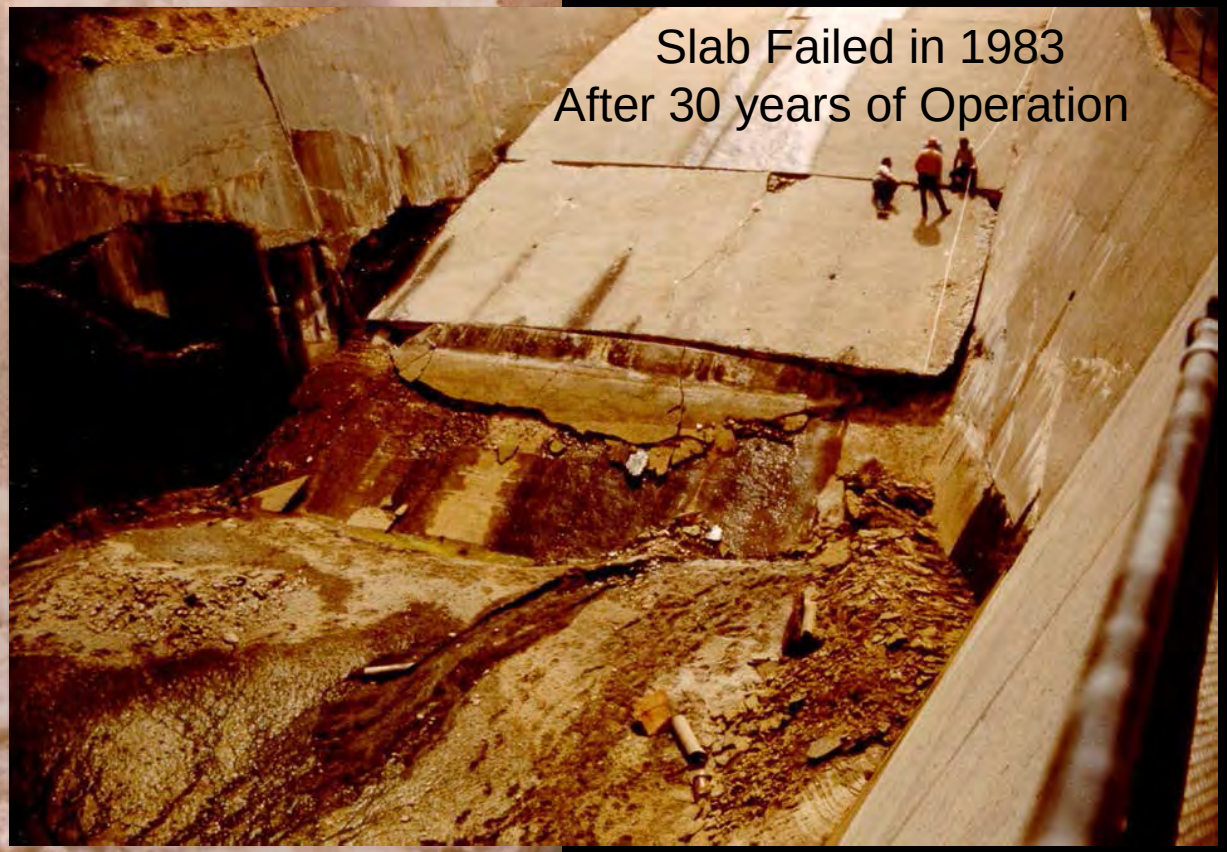

Dye Injected
Dye Observed
Exiting


© 2016 Microsoft

Hope Mills Dam , NC (2010)


ΔH

Big Sandy Spillway, WY
Stagnation Pressure Failure

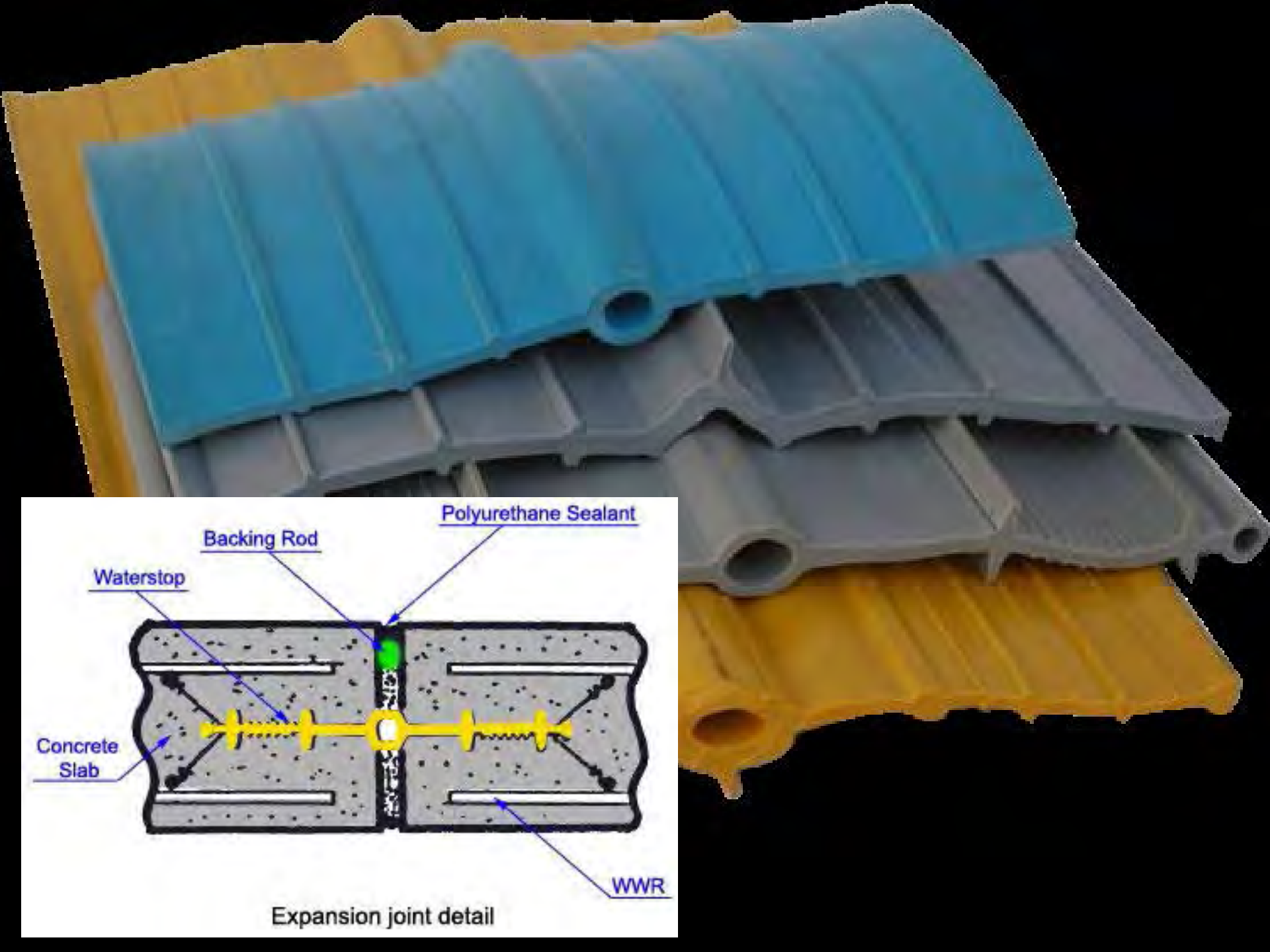



Dutch Fork Lake, Washington County, PA

Fellows Lake Dam, Greene County MO (Photos courtesy of Glenn Lloyd)


Old sealant between concrete expansion joints needs to be removed and replaced.


7 28 '01



Expansion joint detail


KOBELCO

12 27 01


Rounded Top of Joint Filled with
Flexible Sealant and ¾" Offset
Smooth Dowels
Waterstop
Concrete Key
Continuous Bottom Reinforcement
Leveling Concrete on Bedrock


Woodlake Dam (Moore County), Post Hurricane Matthew (2016)

Silver Lake Dam Failure, Michigan

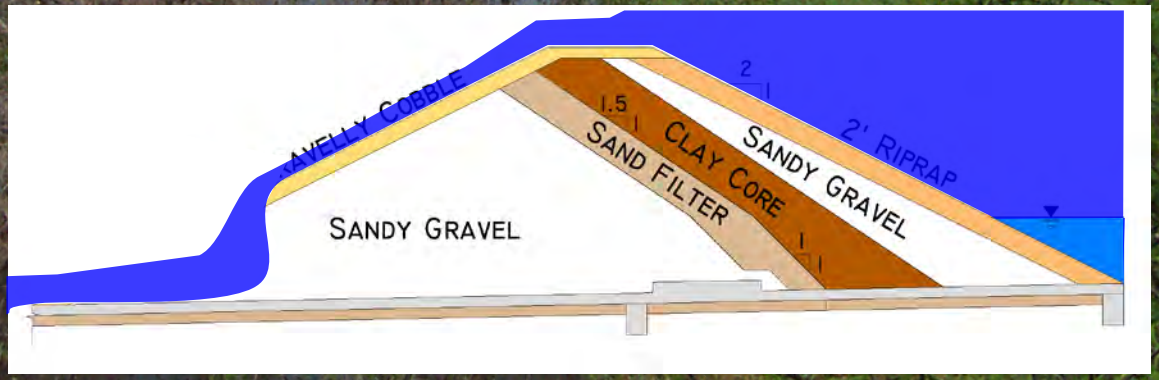
Silver Lake Dam, Mi

- Constructed 1896, rebuilt 1912 & 1945
- 30.5’ high, 1,500’ long embankment, 23.6 mi^2
- Four earth saddle dikes
- Upgrades Completed 2002
- Increase spillway capacity (PMF)
- **Fuse plug** emergency spillway (Dike 2)
- Also raised dam crest
- **Un-manned site**

Source: FERC Root Cause Report, October 6, 2003


1.5' GRAVELLY COBBLE
2
1
SANDY GRAVEL
1.5
CLAY CORE
SAND FILTER
1
1
2
2' RIPRAP
SANDY GRAVEL


2
1
1.5' GRAVELLY COBBLE
2
1
SANDY GRAVEL
1.5
1
CLAY CORE
SAND FILTER
1
1
SANDY GRAVEL
2
1
2' RIPRAP


GRAVELLY COBBLE
SANDY GRAVEL
1.5
CLAY CORE
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2' RIPRAP


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SANDY GRAVEL
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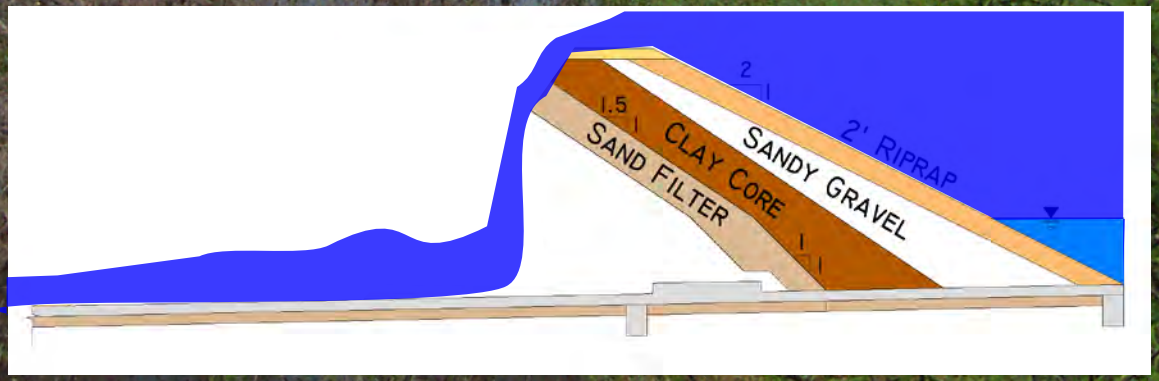
GRAVEL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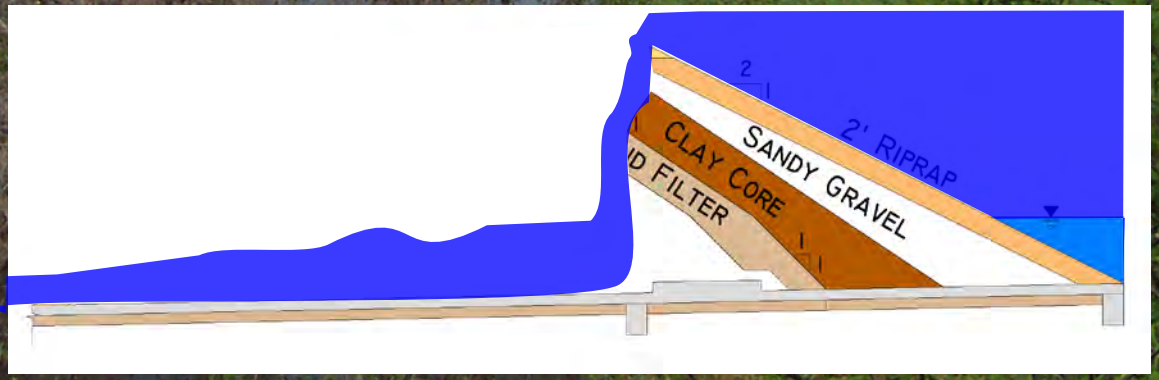
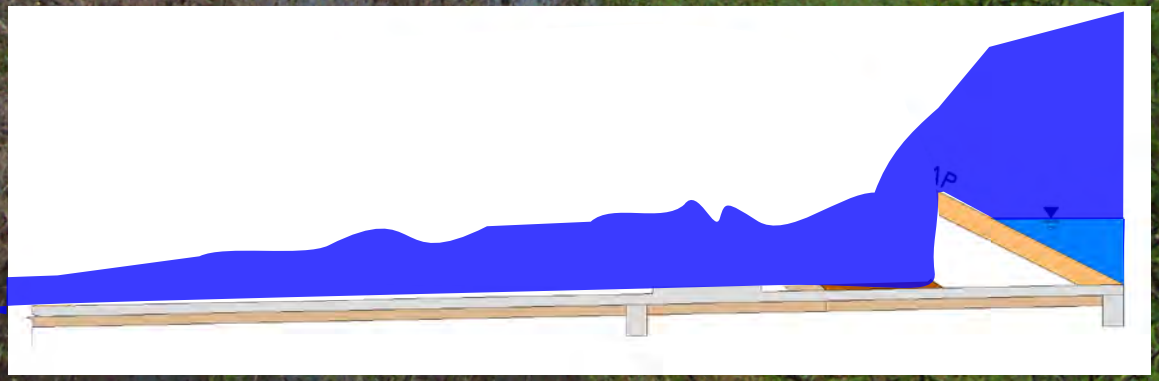
2' RIPRAP
SANDY GRAVEL
CLAY CORE
SAND FILTER


2
2' RIPRAP
SANDY GRAVEL
CLAY CORE
D FILTER


2' RIPRAP
SANDY GRAVEL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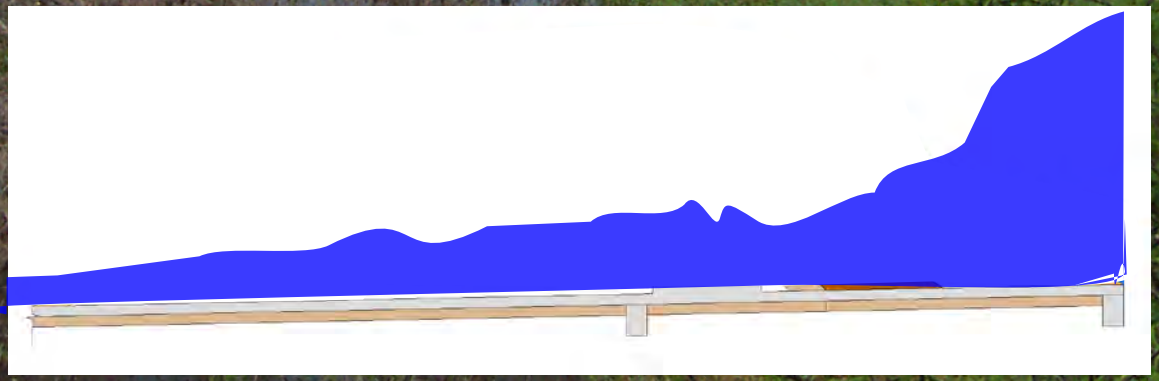
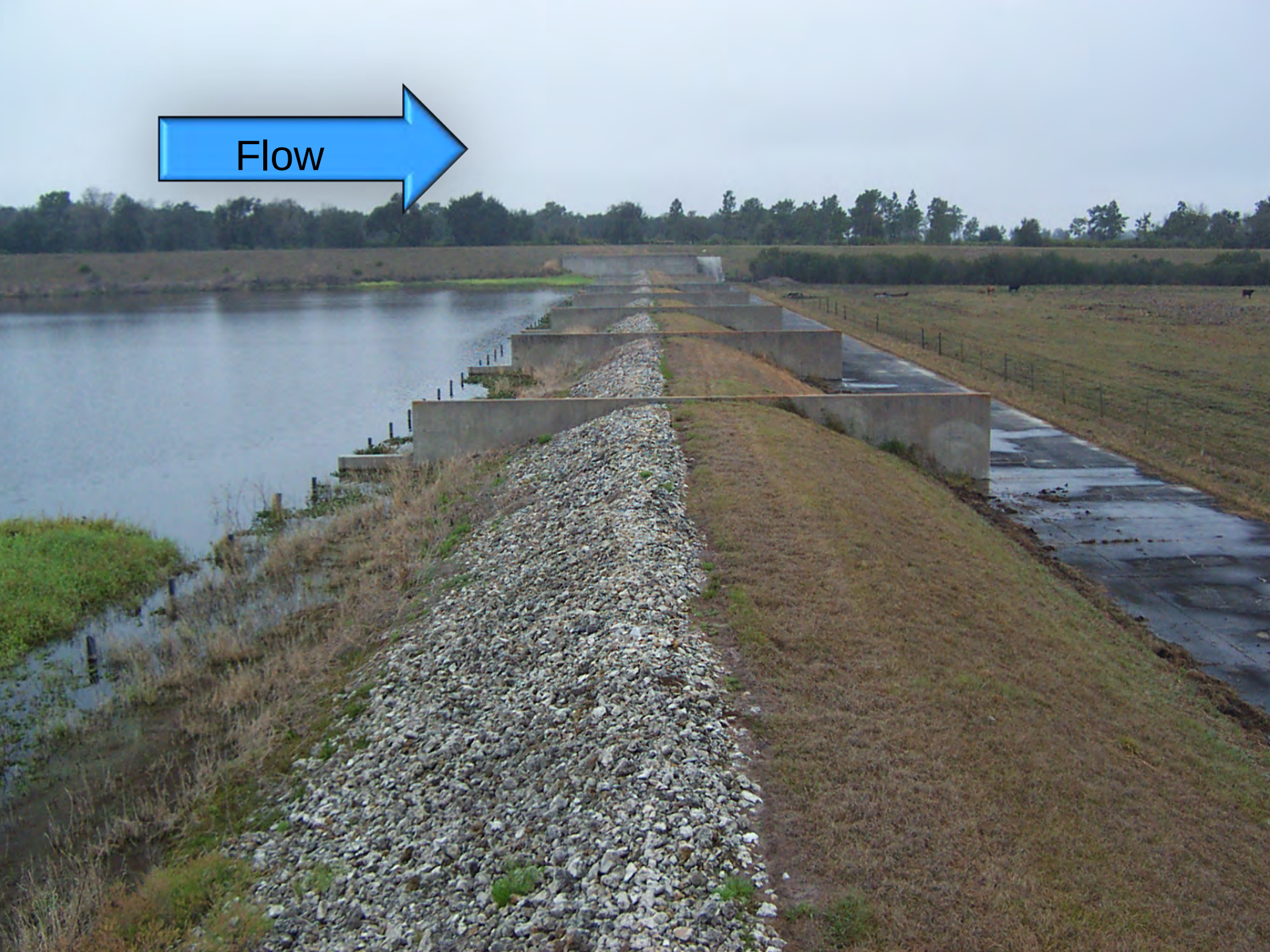
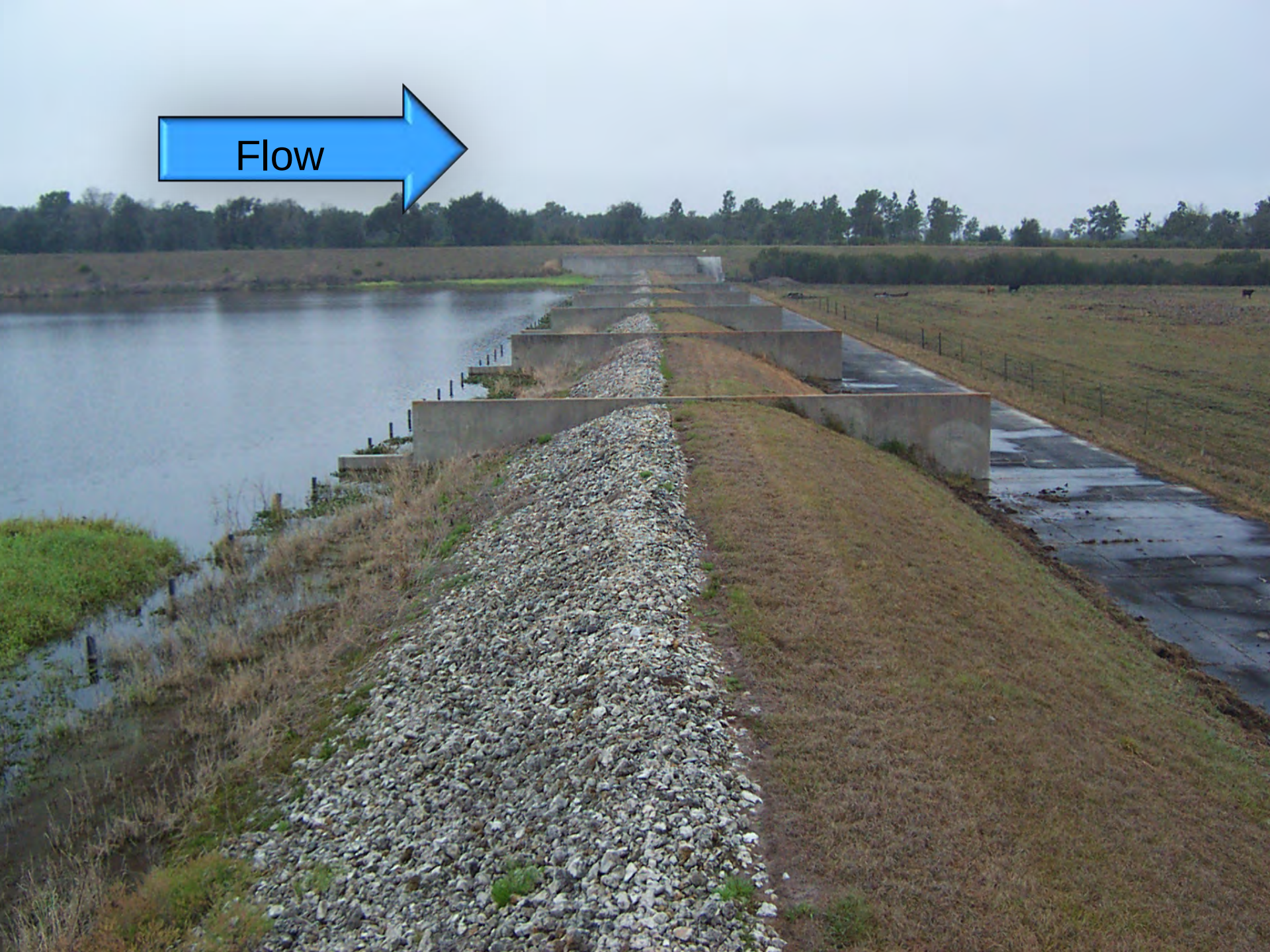
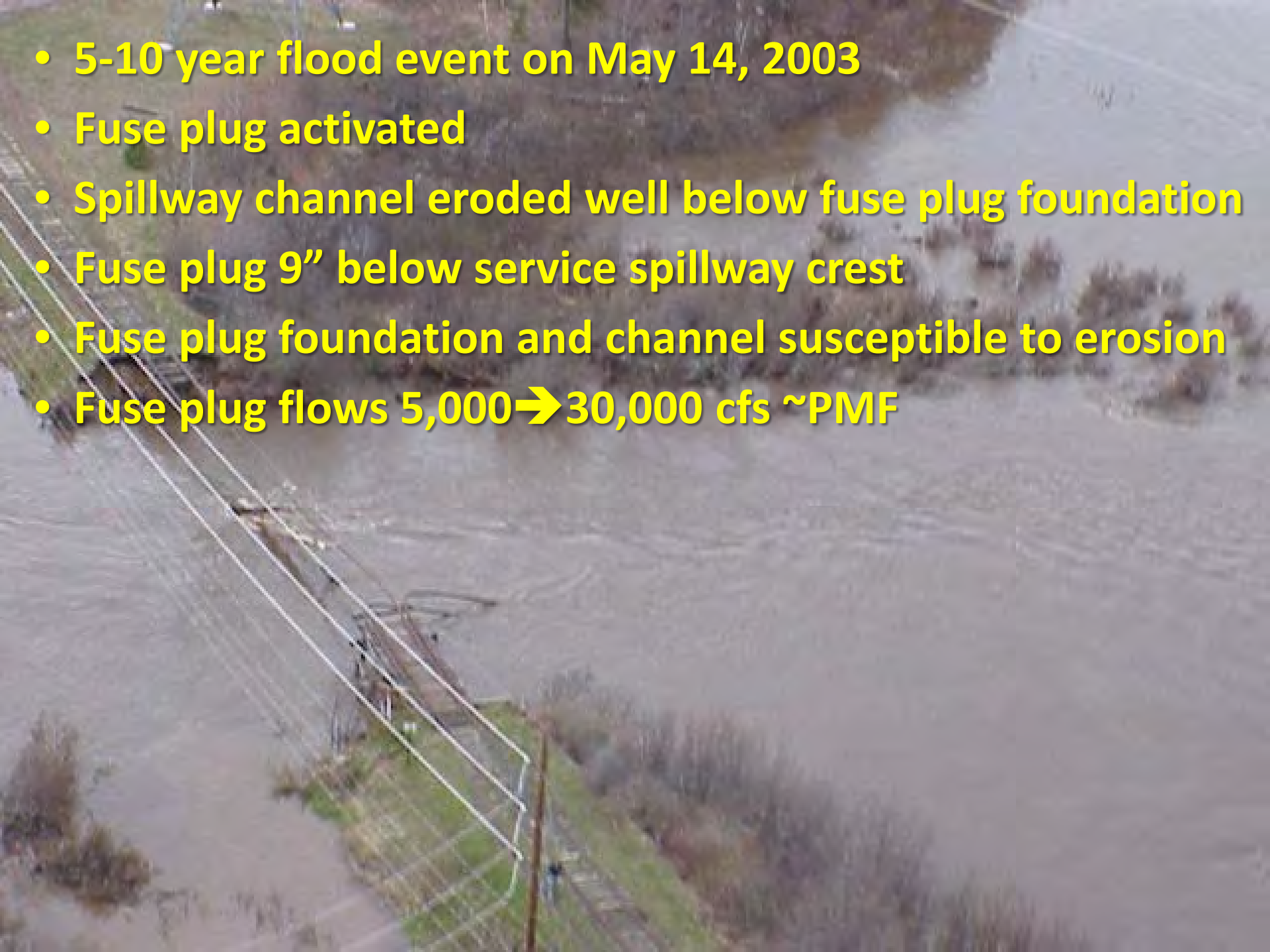



Flow

Little Grassy Dam, Crab Orchard NWR, Illinois (1994)

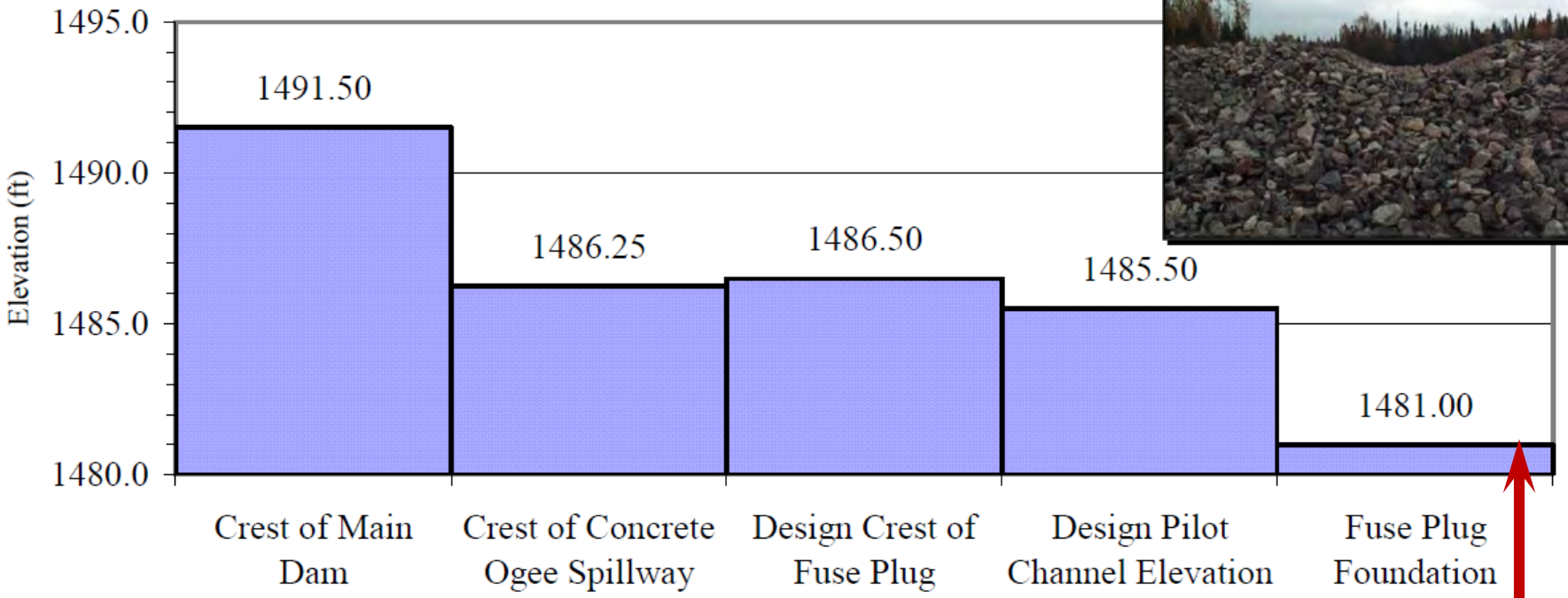
Little Grassy Dam, Crab Orchard NWR, Illinois (2012)


Flow



- 5-10 year flood event on May 14, 2003
- Fuse plug activated
- Spillway channel eroded well below fuse plug foundation
- Fuse plug 9” below service spillway crest
- Fuse plug foundation and channel susceptible to erosion
- Fuse plug flows 5,000➔30,000 cfs ~PMF

Summary of Project Structure Elevations



25'

Final Eroded Fuse Plug Breach

Source: FERC Root Cause Report, October 6, 2003


Tourist Park Dam
• Flooding caused >$100 million damages
• 1,700 people evacuated
• Several bridges damaged or washed out
• Tourist Park Dam overtopped and failed
• Power plant flooded and shut down
• No loss of life or personal injuries (EAP)

Flooding caused over $100 million in damages, but no fatalities

Failure By Spillway Erosion

> 27,000 Earth-cut Emergency Spillways In the U.S.

Niagara Falls

1842-1905 Average Rate of Erosion =
3.8 feet per year (240 feet in 63 years)

Federally Owned or Regulated Dams

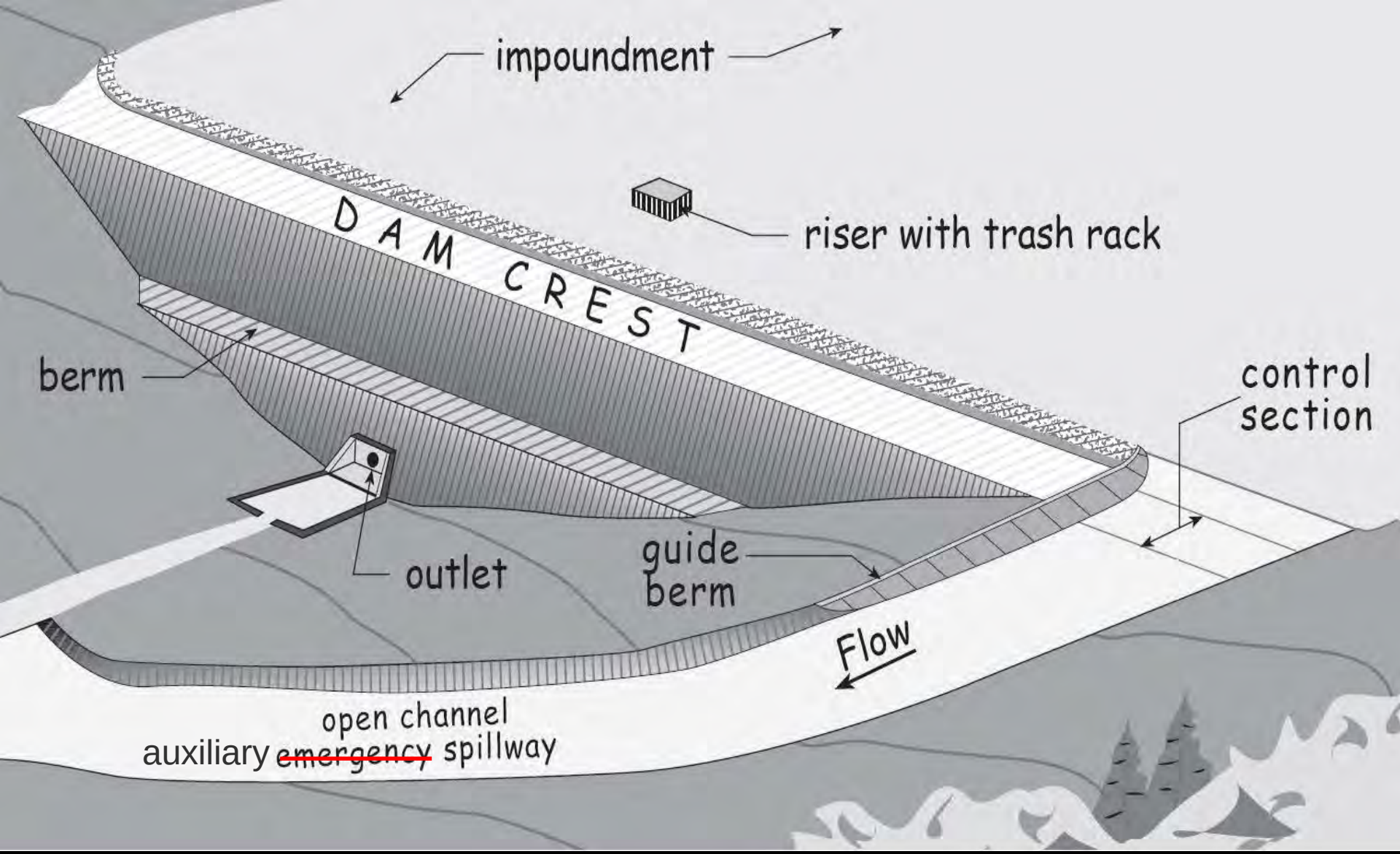
United States Department of Agriculture NRCS Natural Resources Conservation Service — **27,252 Dams**

U.S. Department of the Interior — 2,700 Dams

Federal Energy Regulatory Commission — 2,524 Dams

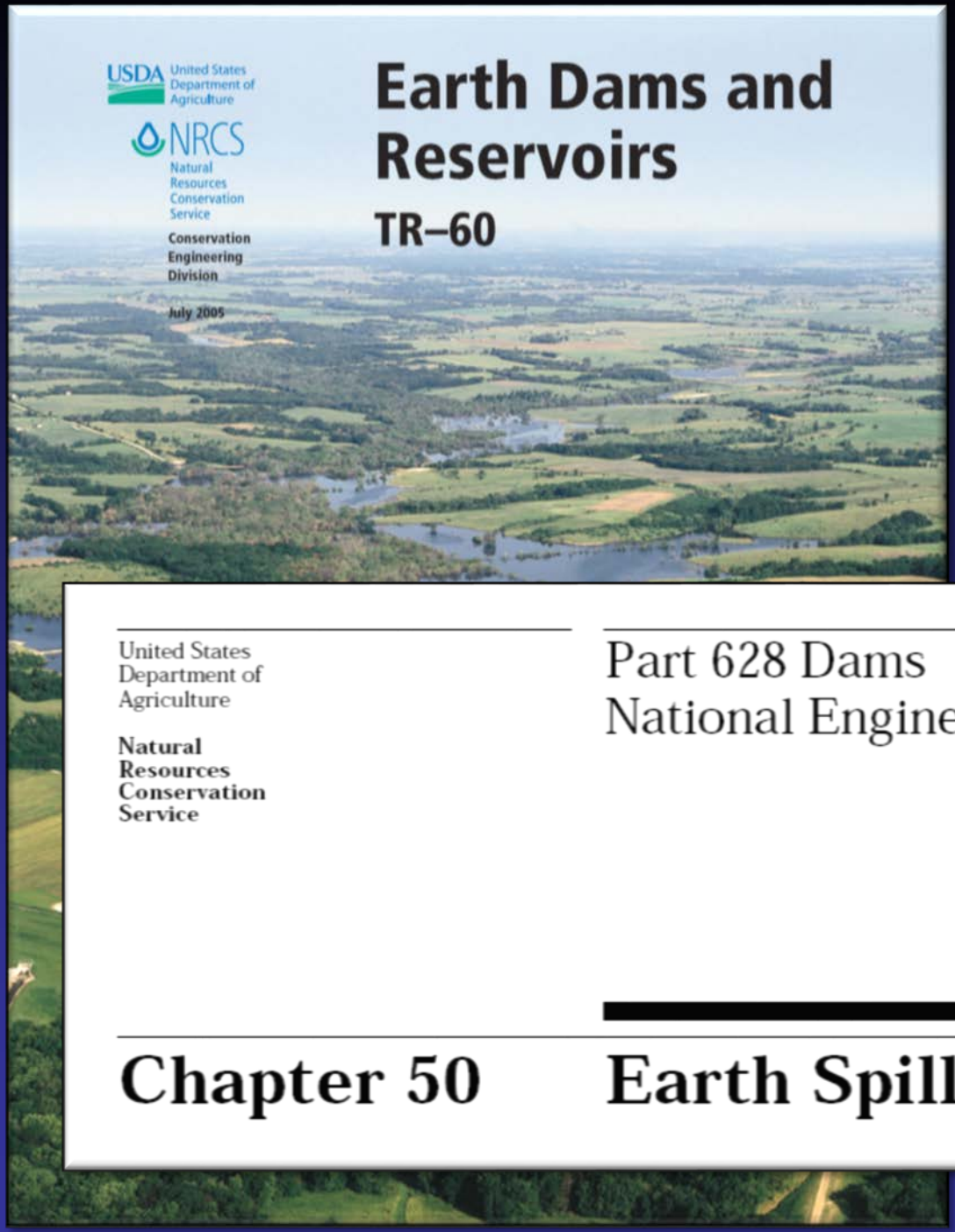
669 Dams

TVA — 49 Dams



Earth Cut Auxiliary Spillway


Auxiliary
Spillway
United States Department of Agriculture
NRCS
Natural
Resources
Conservation
Service



United States Department of Agriculture

Natural Resources Conservation Service

Part 628 Dams
National Engineering Handbook

Chapter 50 Earth Spillway Design


United States Department of Agriculture
NRCS
Natural Resources Conservation Service
Top of Dam
Auxiliary Spillway Crest
100-Year Flood Storage
Normal Pool
Pohick No. 4, VA

Pohick No. 4, Fairfax VA


Pohick No. 4, Fairfax VA

Earthen spillway scour/erosion

Earthen spillway scour/erosion

VEGETAL EROSION PROTECTION

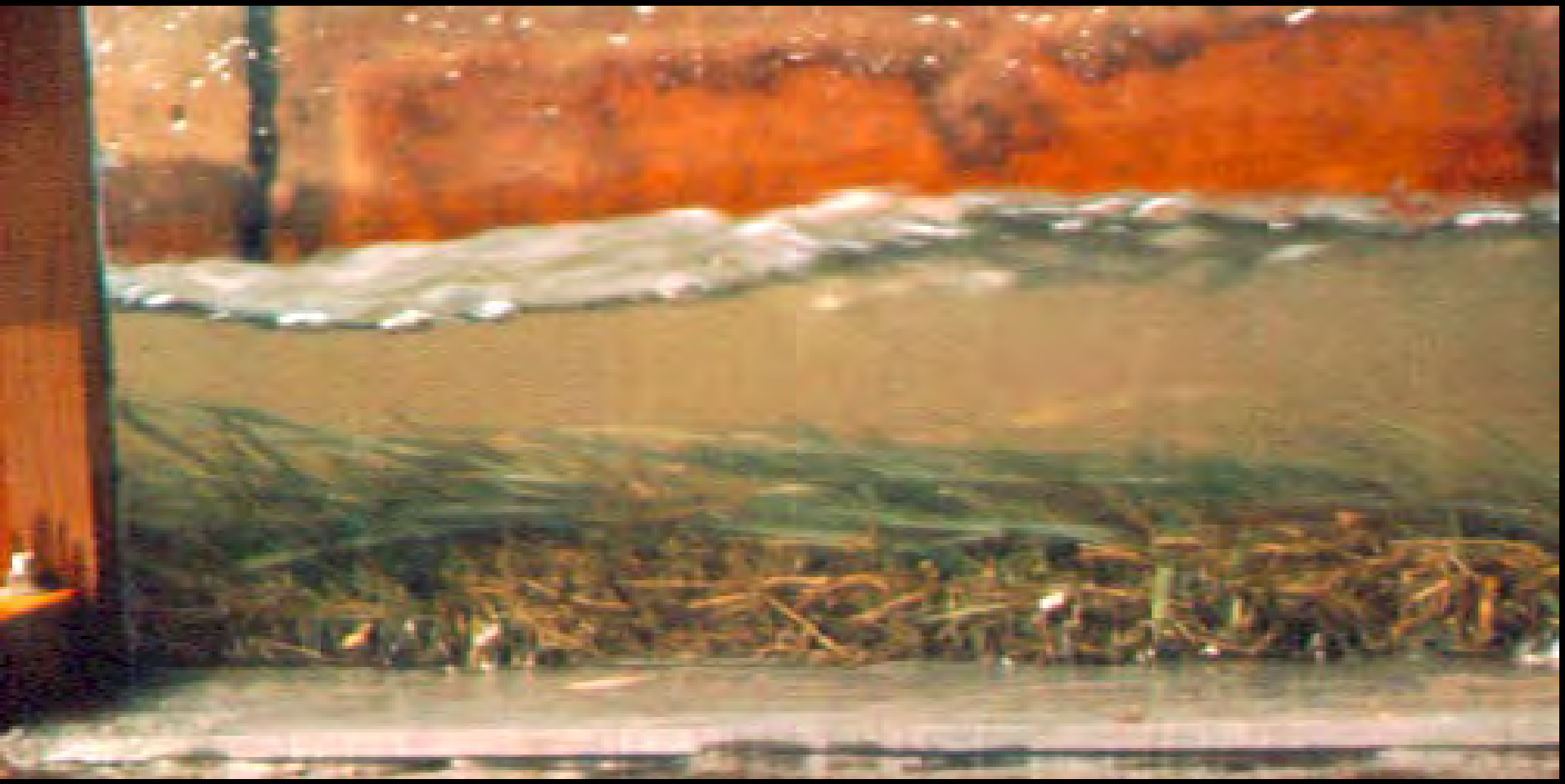
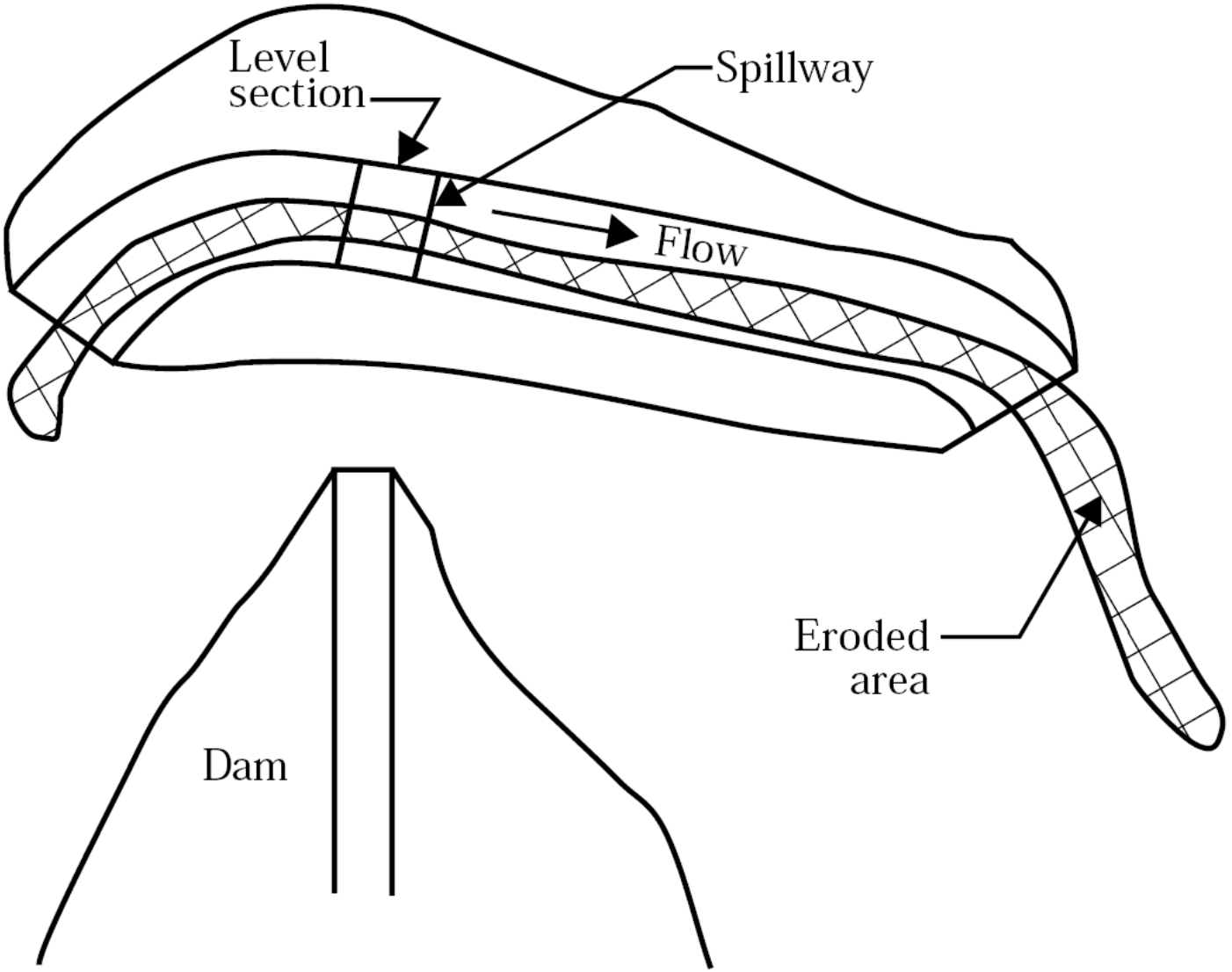


Figure 50–4 Spillway gully resulting in breach of spillway



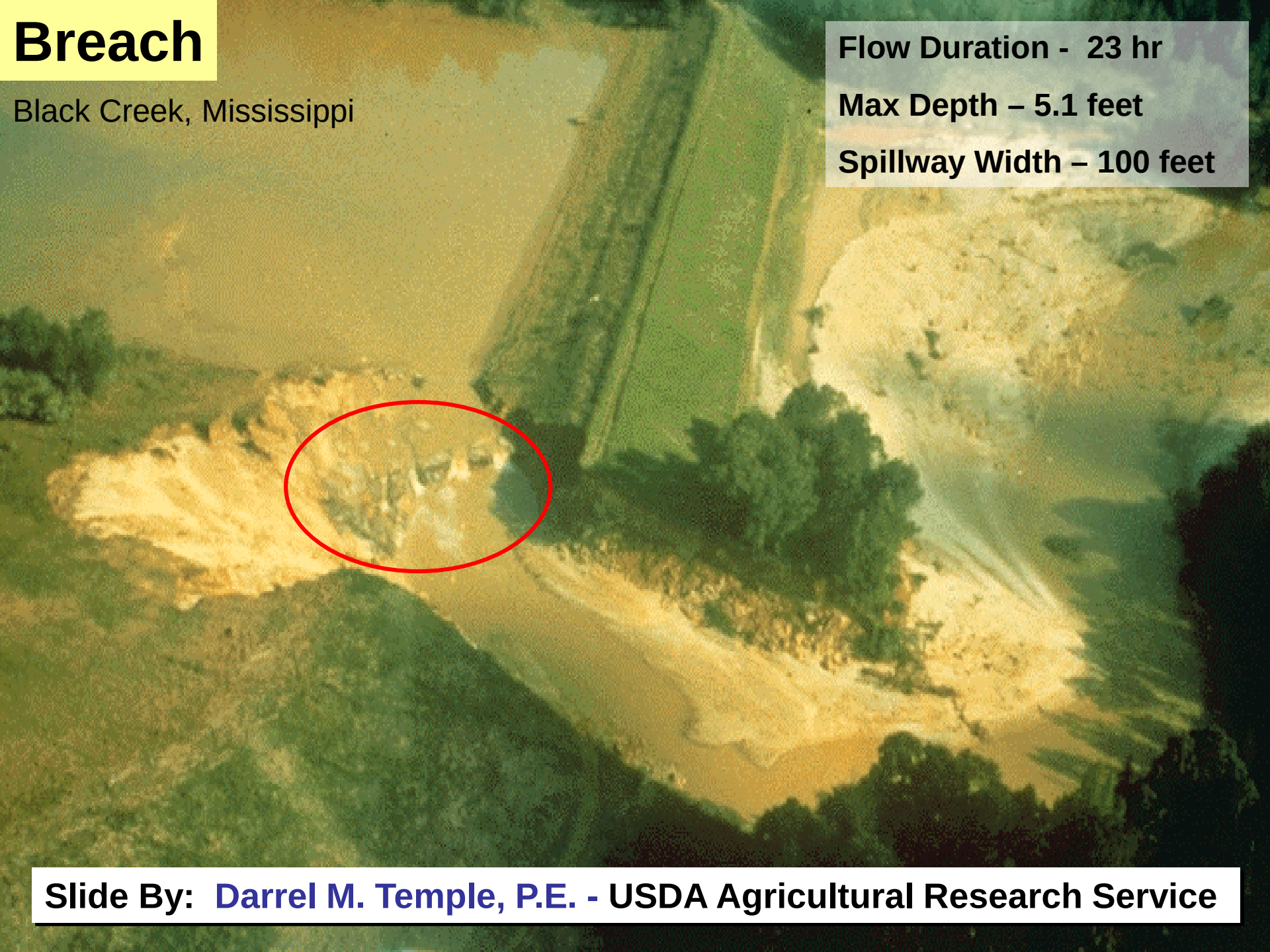
Old Timbers Dam, Big Oaks NWR, Indiana

28. Erosion gully in downstream channel of emergency spillway, looking upstream.

Old Timbers Dam, Big Oaks NWR, Indiana

Breach

Black Creek, Mississippi



Flow Duration - 23 hr

Max Depth – 5.1 feet

Spillway Width – 100 feet

Slide By: Darrel M. Temple, P.E. - USDA Agricultural Research Service

Three Phase Approach

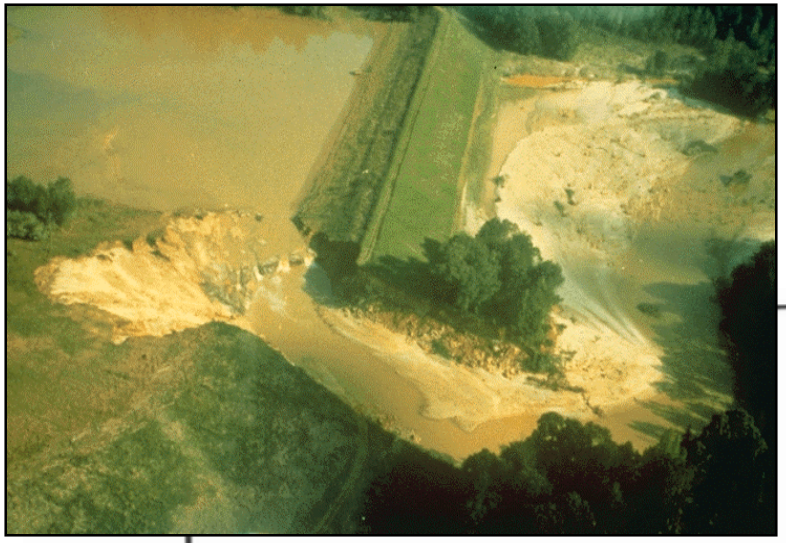
Photos courtesy of Darrell Temple


PM
JUN. 29 1989

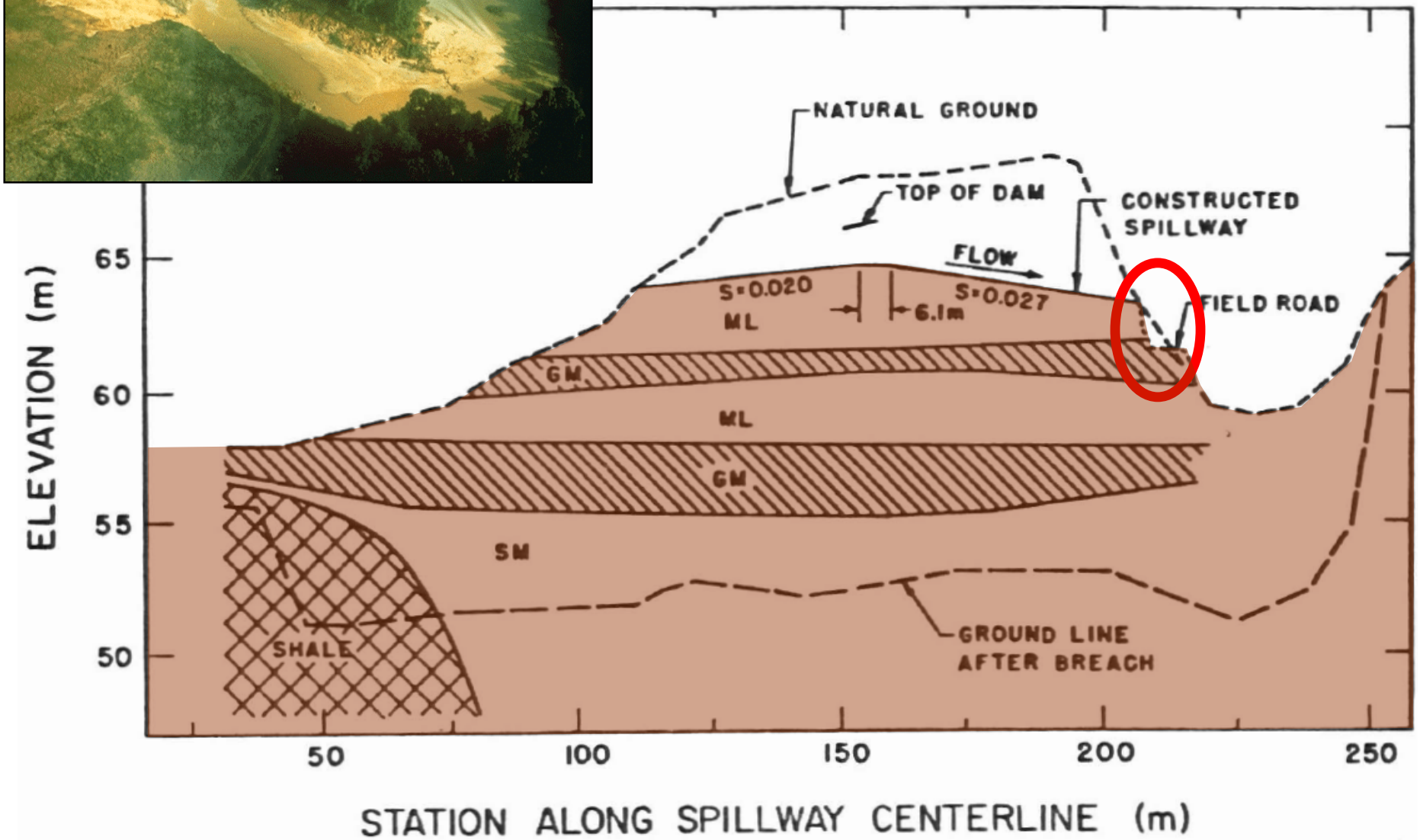
Black Creek Dam, Mississippi

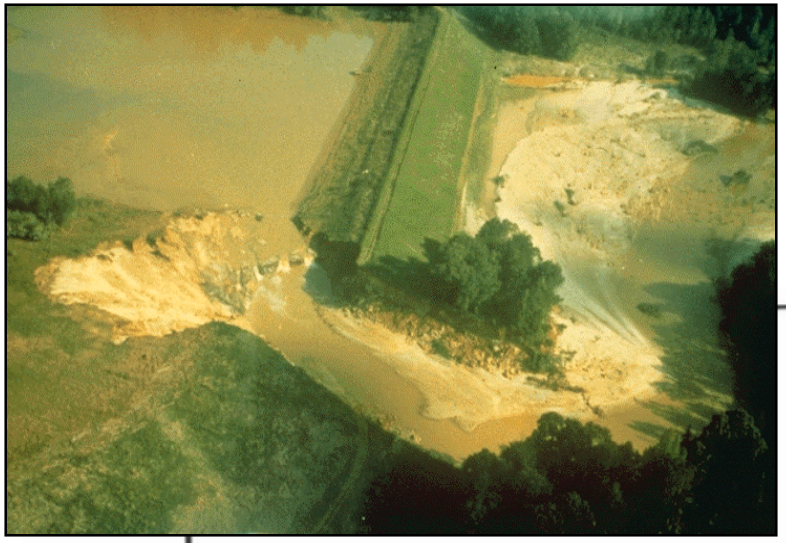
Flow Duration - 23 hr
Max Depth – 5.1 feet
Spillway Width – 100 feet
~190,000 CY Eroded

Slide By: Darrel M. Temple, P.E. - USDA Agricultural Research Service

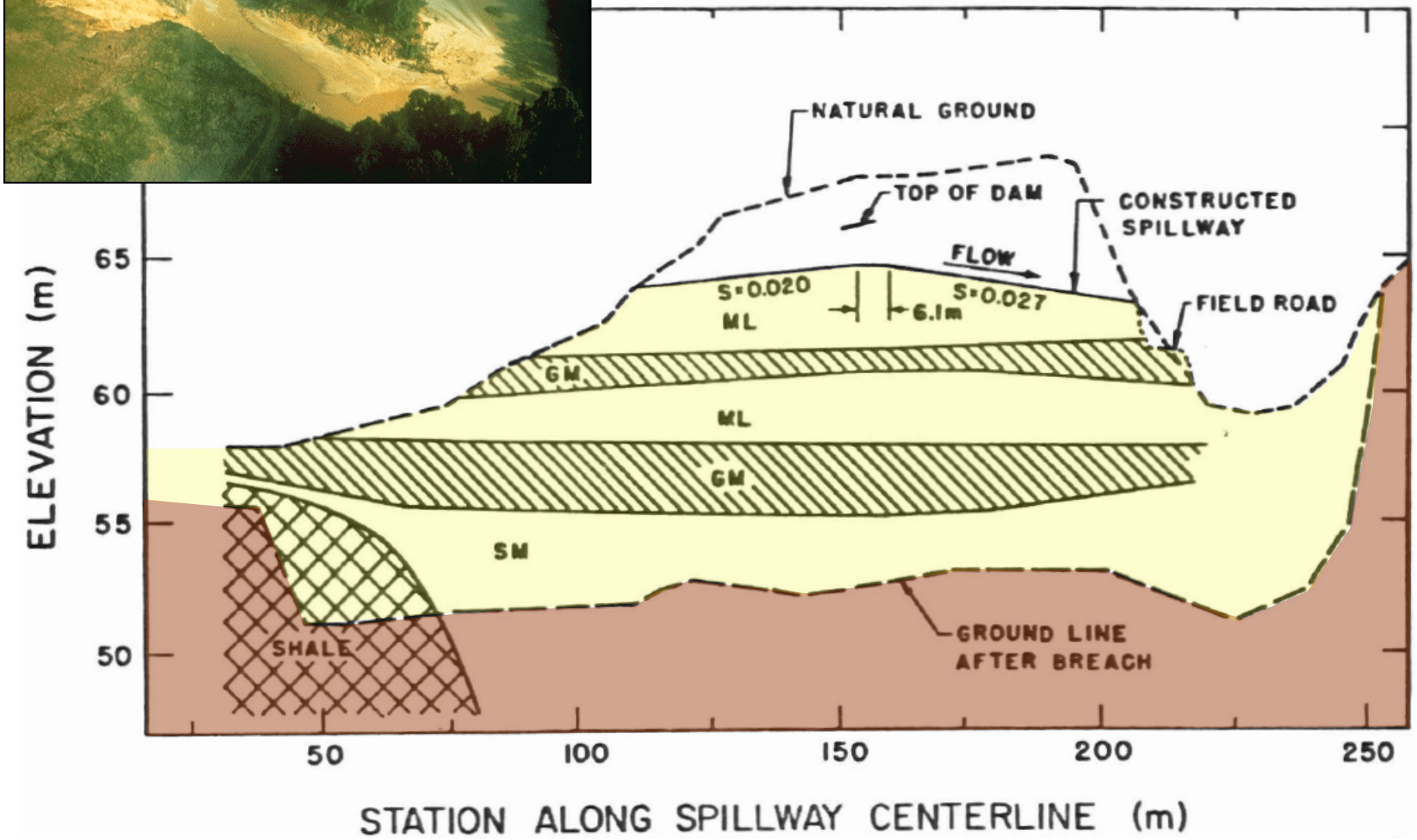


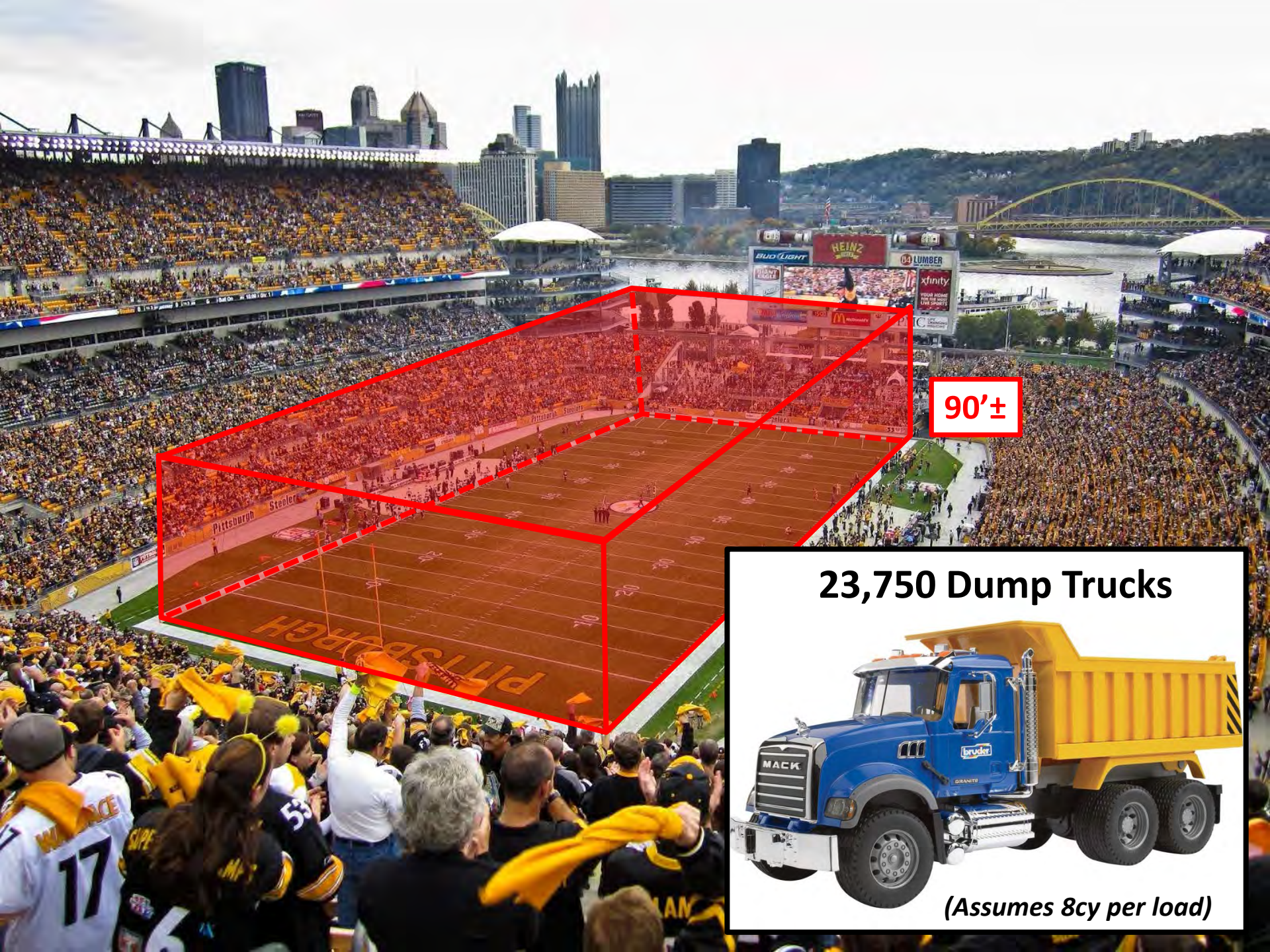
~190,000 CY Eroded





~190,000 CY Eroded




90'±
23,750 Dump Trucks
(Assumes 8cy per load)


LaMoure Dam, ND
(2009 Flood)
e, ND
e: N 46° 17.75' / Longitude: W 098° 15.50'
Dam


FEMA


CAT
330C

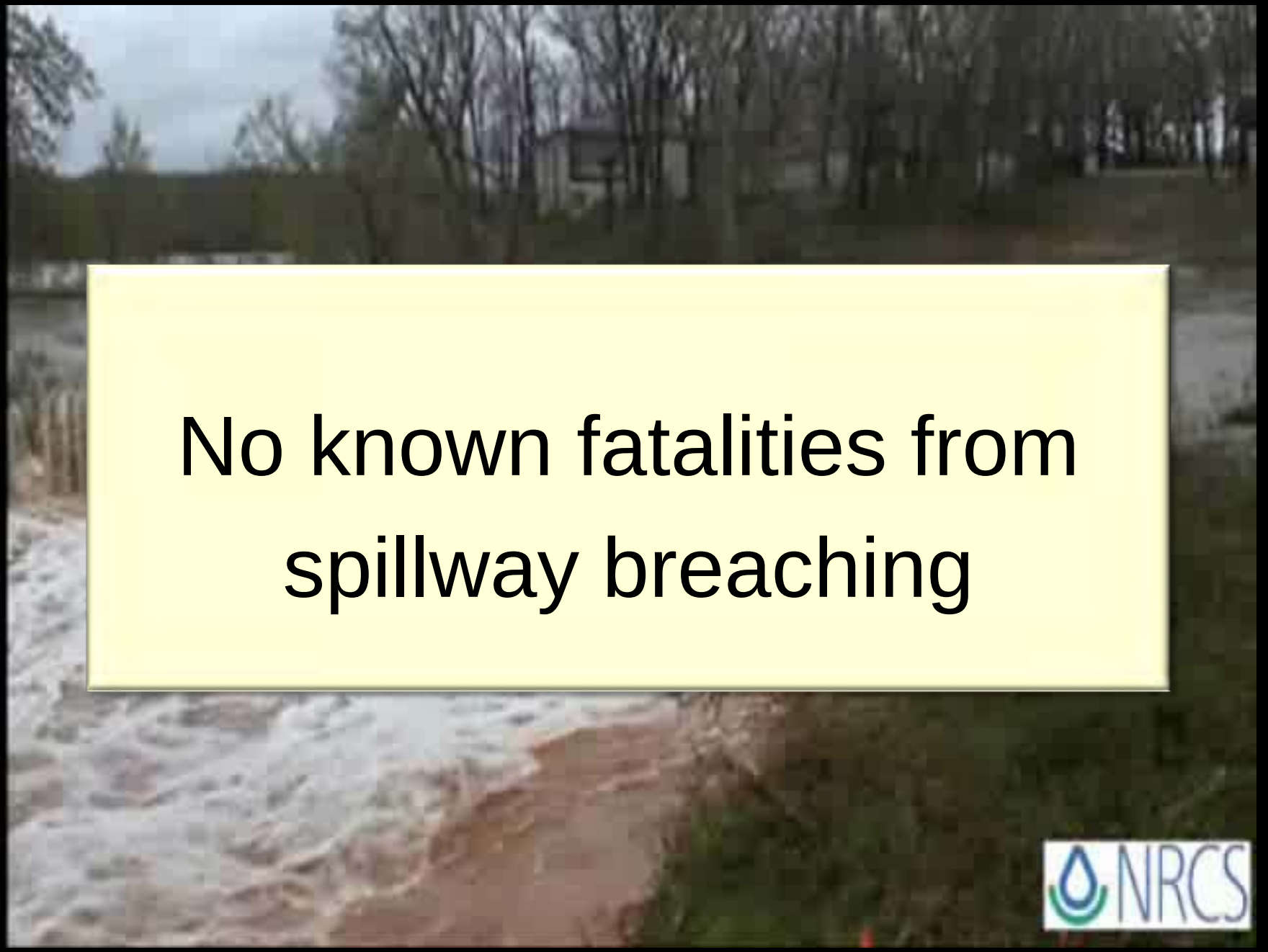
The Washington Post

Dam failure drains Fairfax County lake, kills wildlife

By Derek Kravitz
Tuesday, October 5, 2010; 11:38 PM

During the heavy rains that drenched the Washington region Thursday, Kingstowne Park dam in Fairfax County's Alexandria section failed. It was a quick and quiet death.

The Fairfax County Park Authority and the Board of Supervisors acquired the Kingstowne Lakes in 2002 from the original developer, said James W. Patteson, Fairfax's director of public works and environmental services, and planned to conserve the area

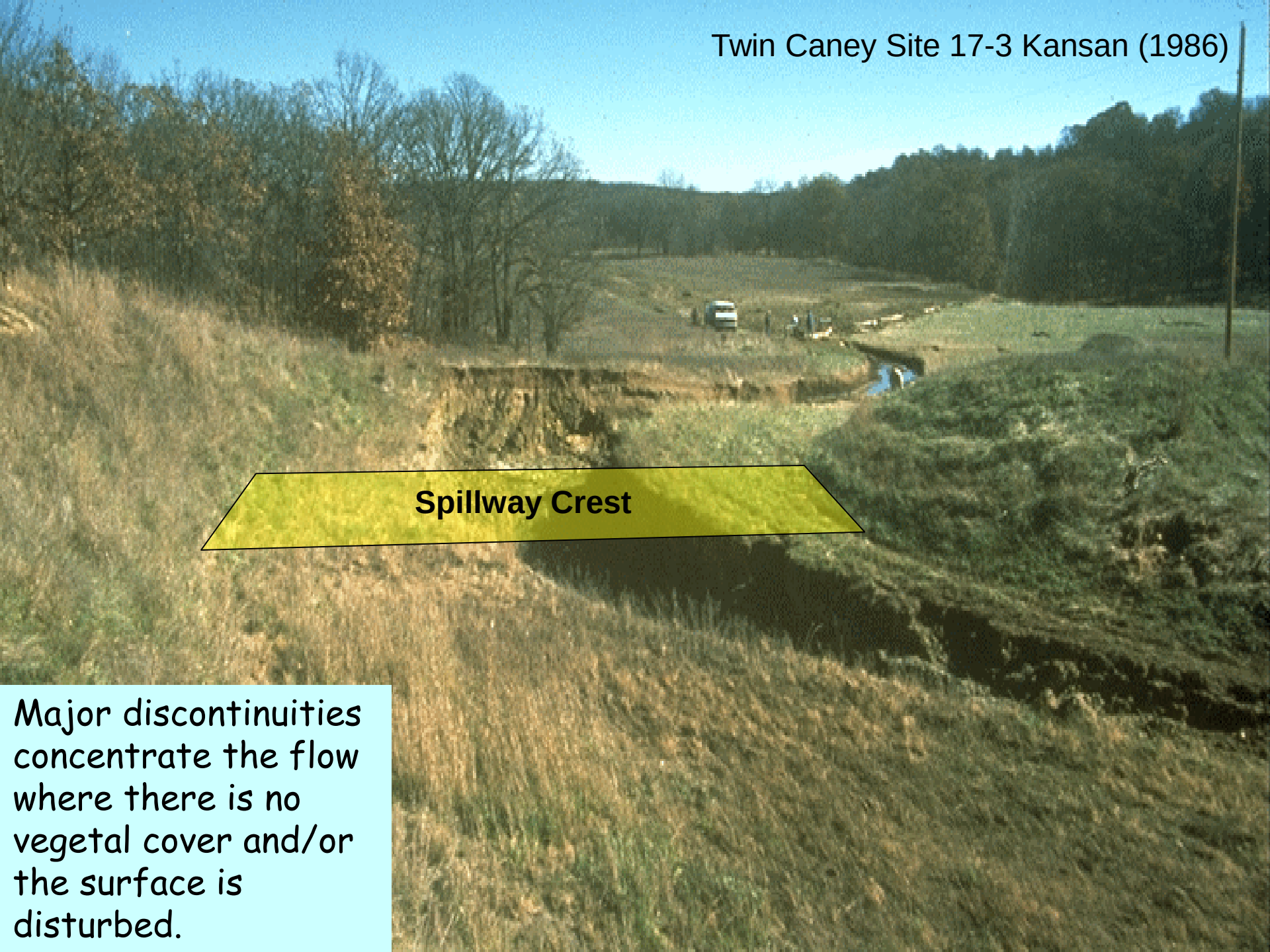

No known fatalities from spillway breaching
NRCS


Sugar Creek Dam L-44, Caddo County Oklahoma
Tropical Depression Erin (Aug. 18-19, 2007)
>8” in less than 12 hours

Photo Courtesy of
Ed Fiegle

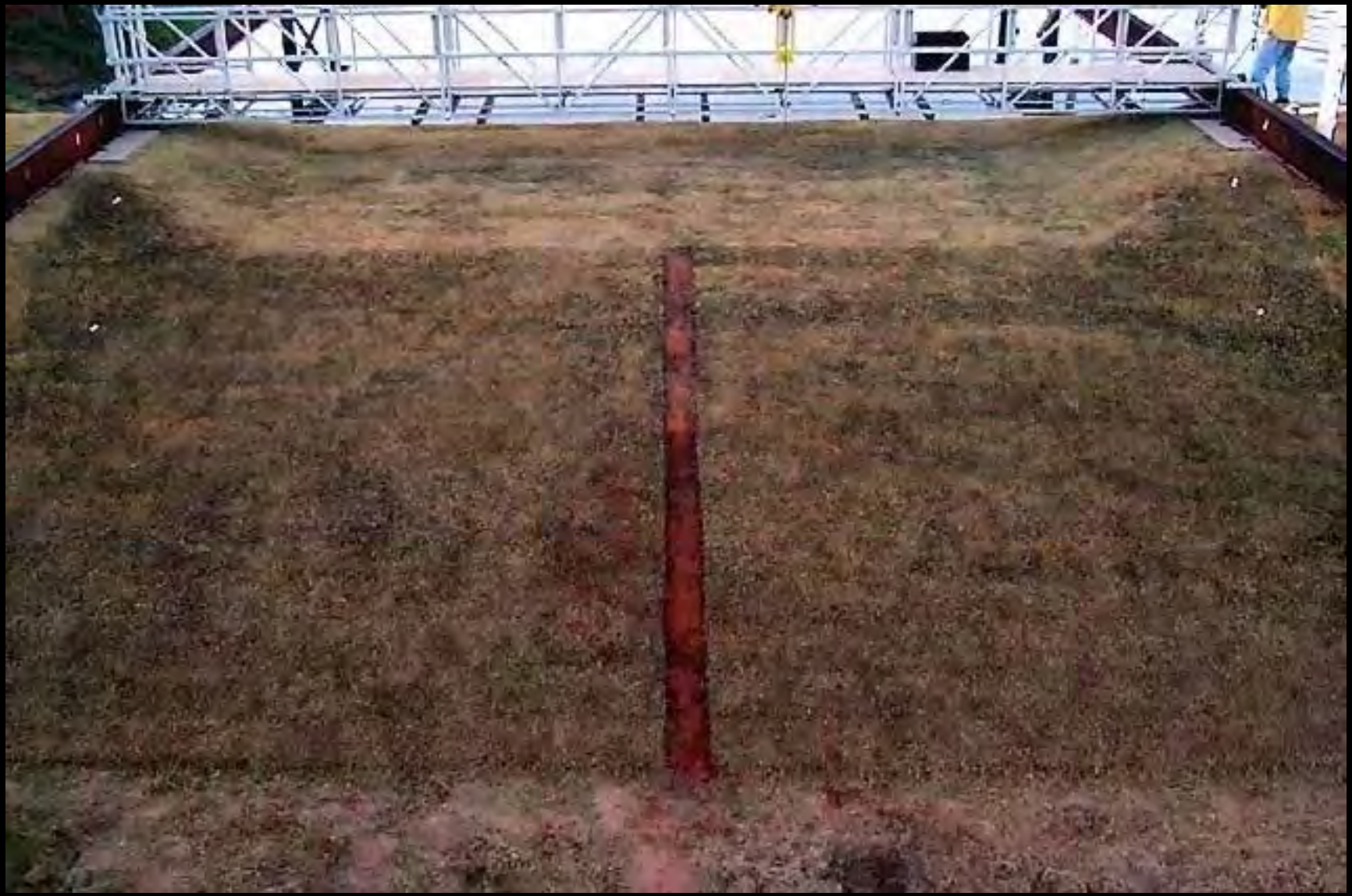

Flow
Photo Courtesy of
Darrel Temple


Mills Creek Dam, VA

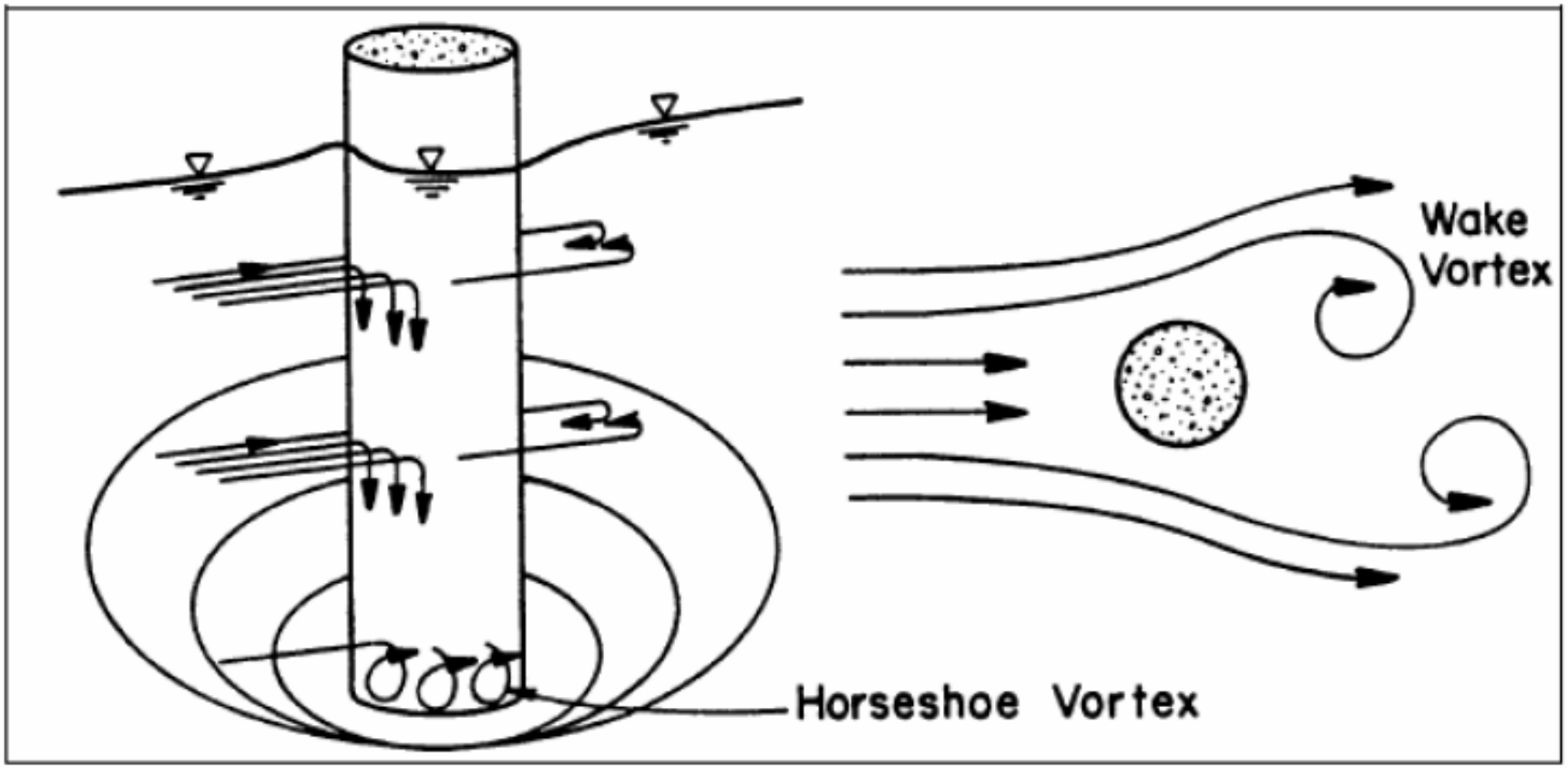


Major discontinuities concentrate the flow where there is no vegetal cover and/or the surface is disturbed.

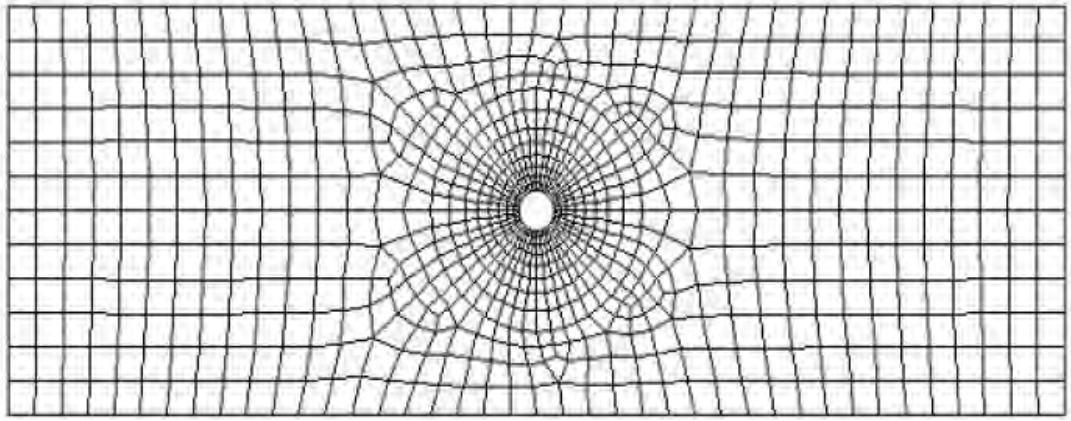

OCT.17.2001
AM 8:31



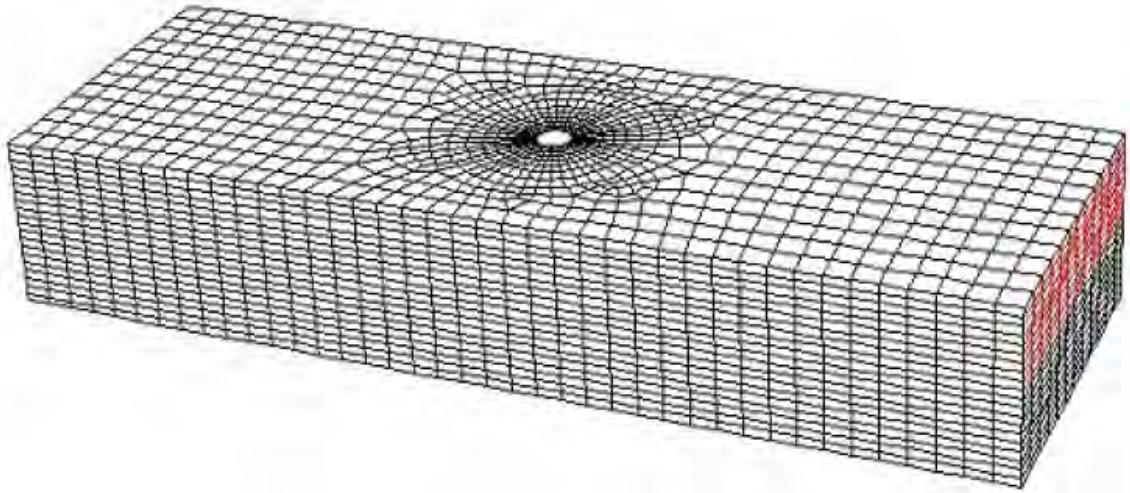
Local Scour



igure 1.2 Schematic Representation of Local Scour at a Cylindrical Pier (Richardson et al., 2001)

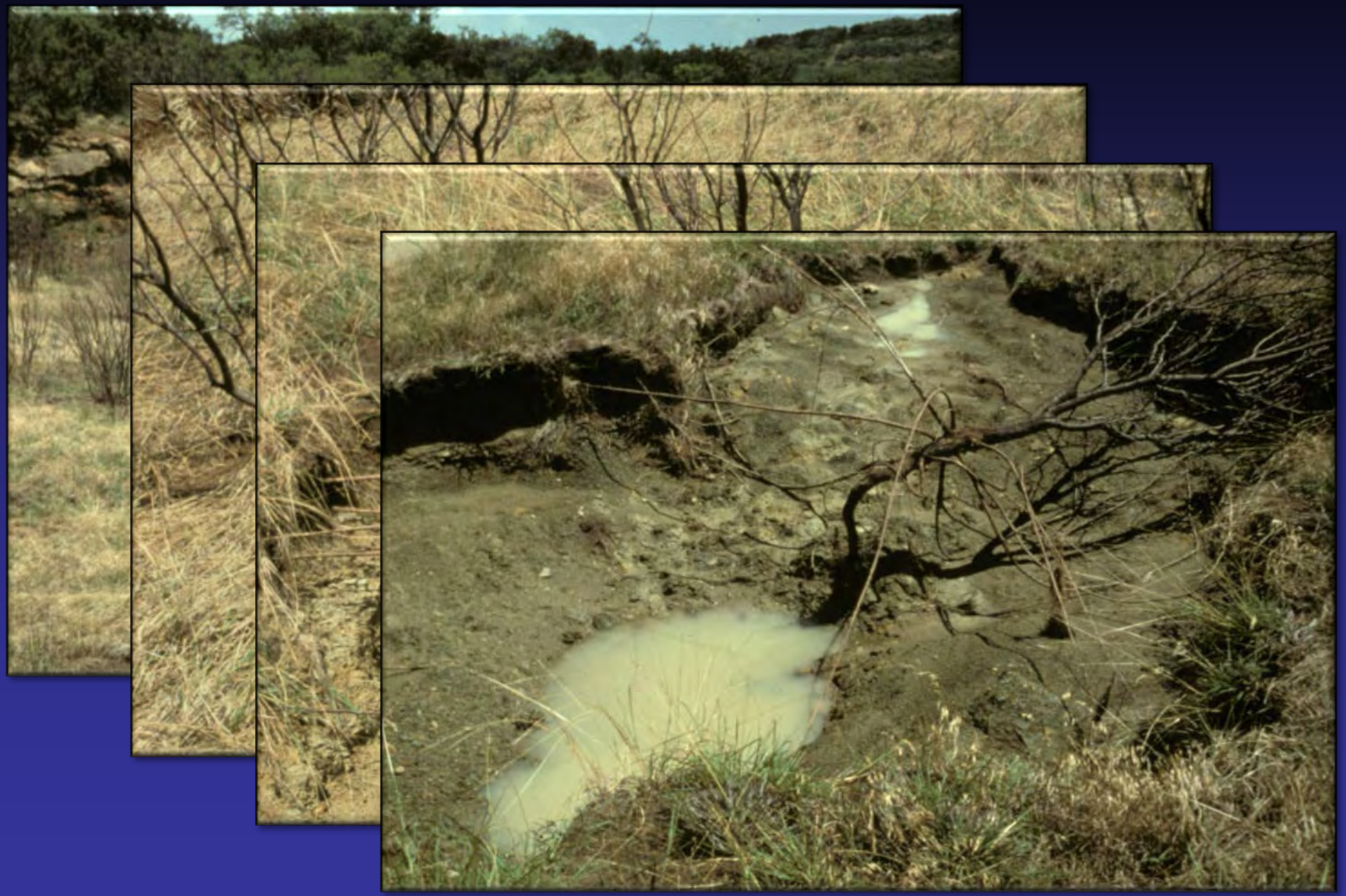


(a) Top View



(b) 3-D View

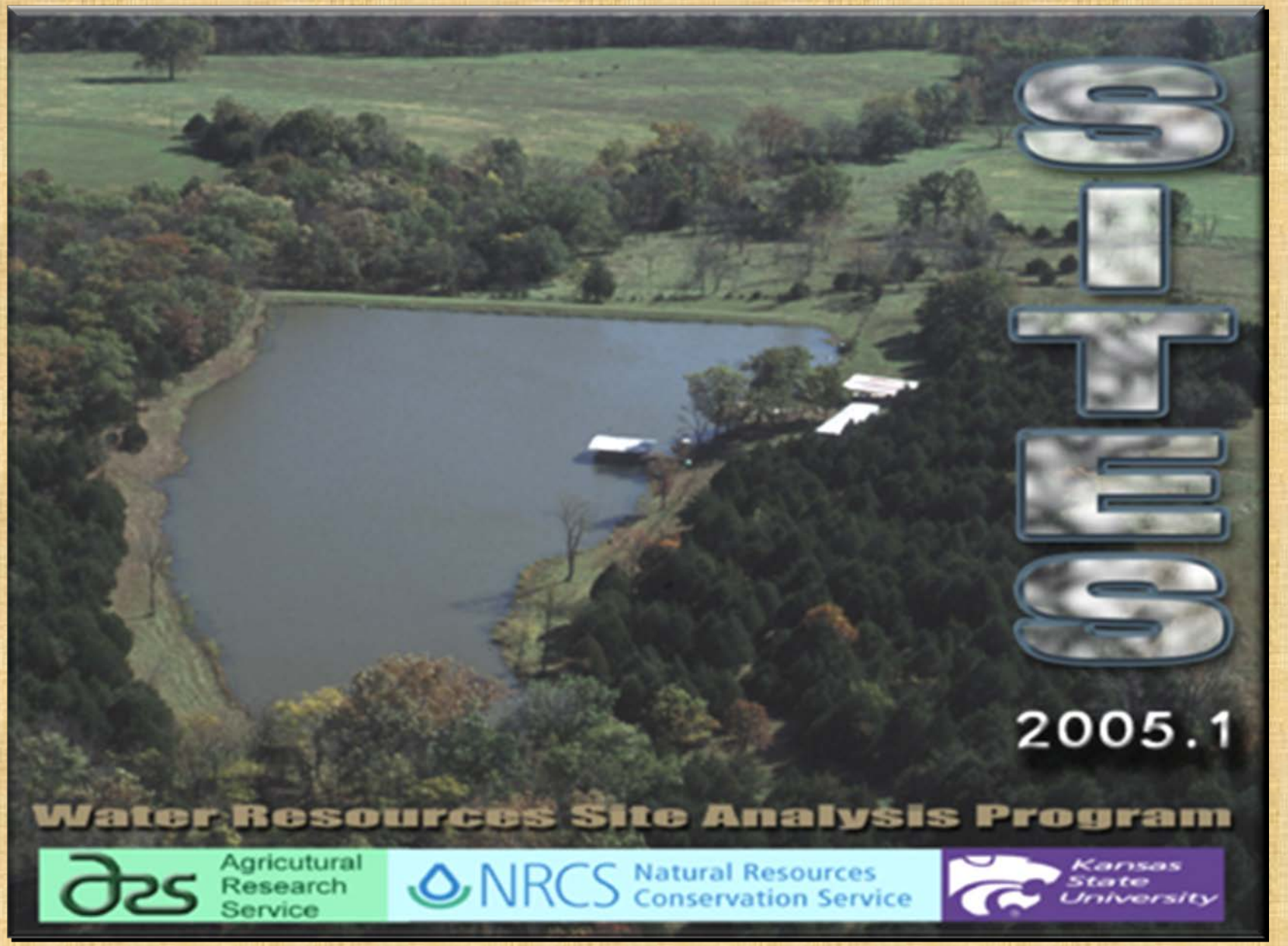
SURFACE DISCONTINUITIES




Slide Courtesy of Gregg Huddock, Golder Associates

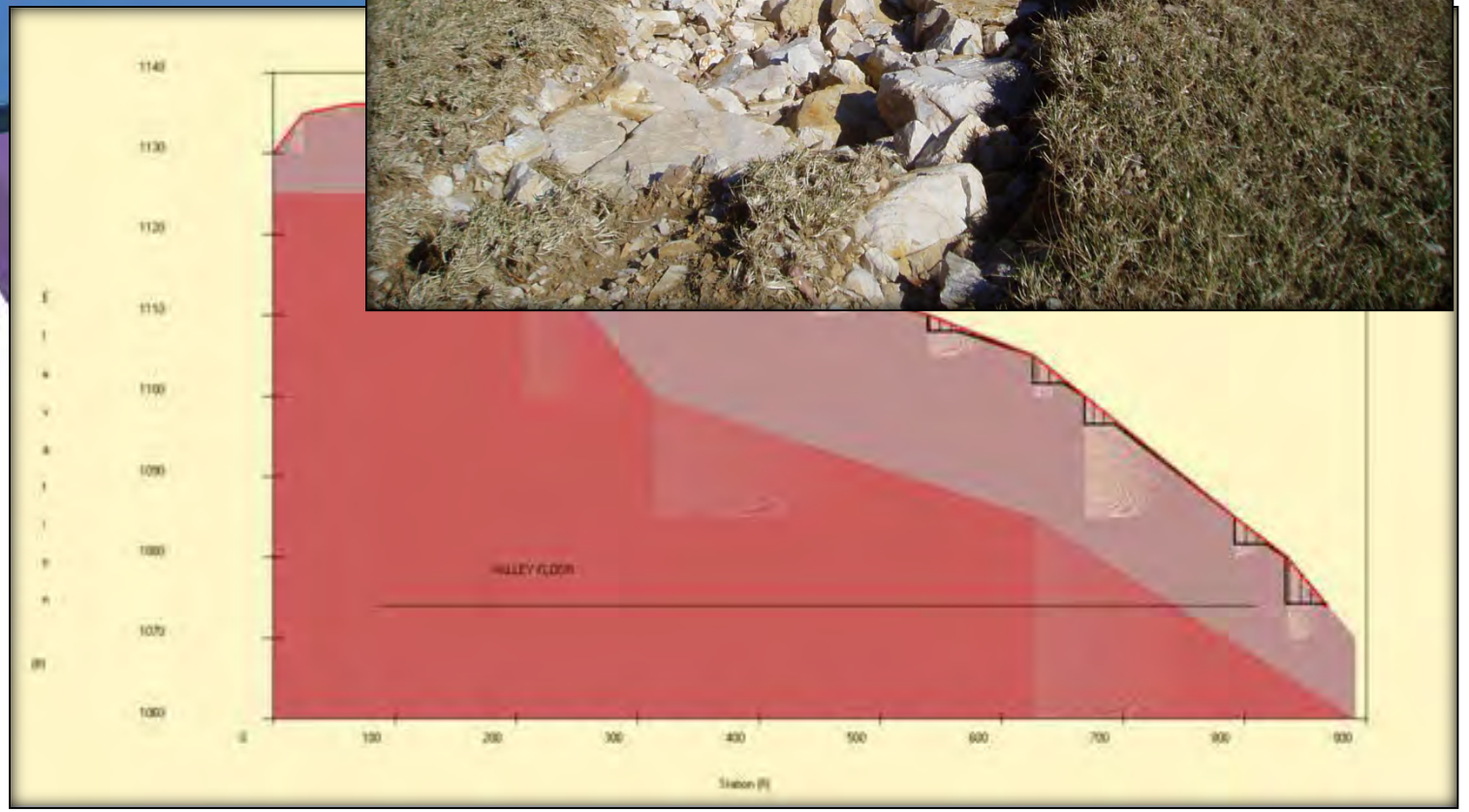


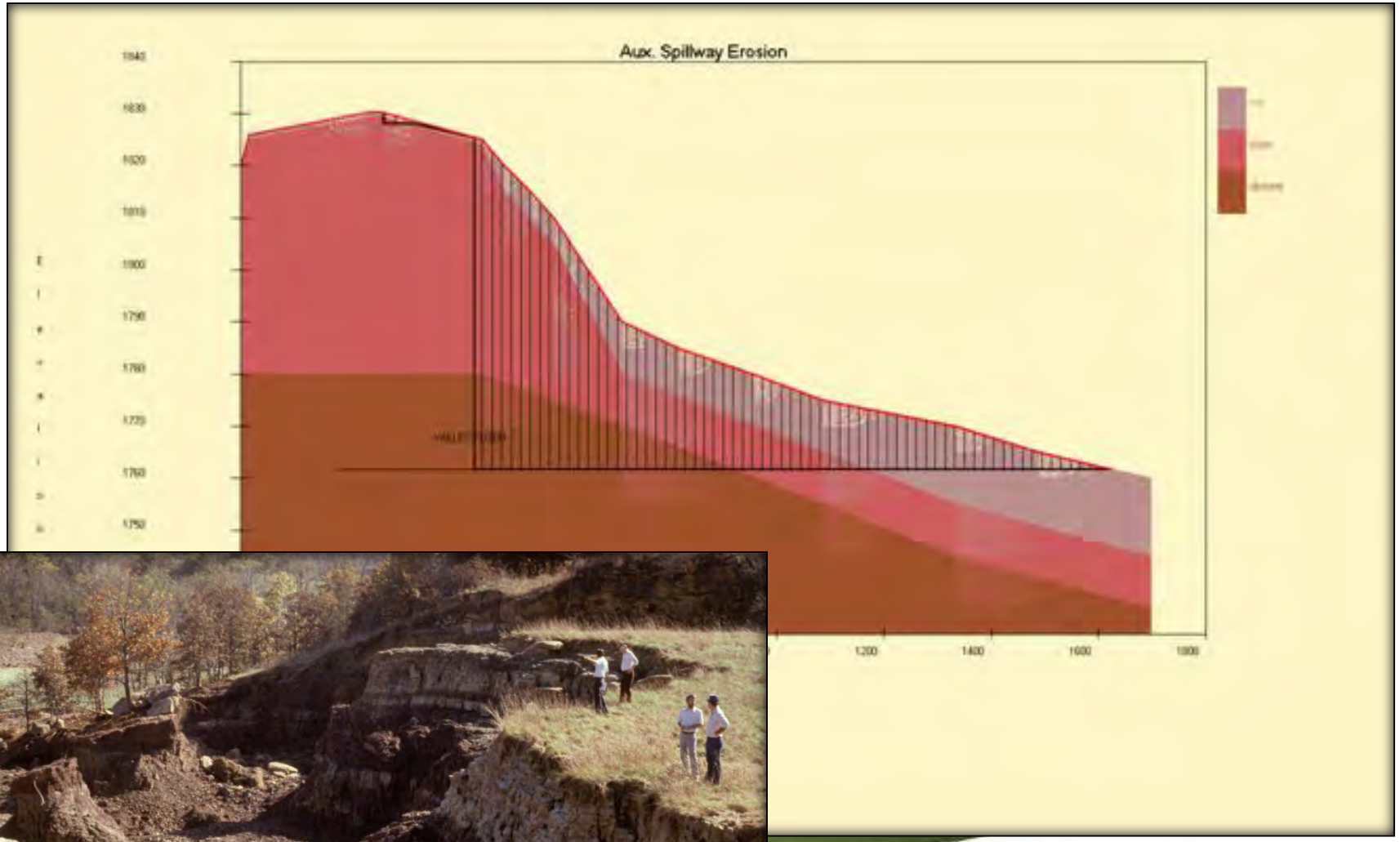

Spillway Erosion Assessment



Spillway Breached (27%)

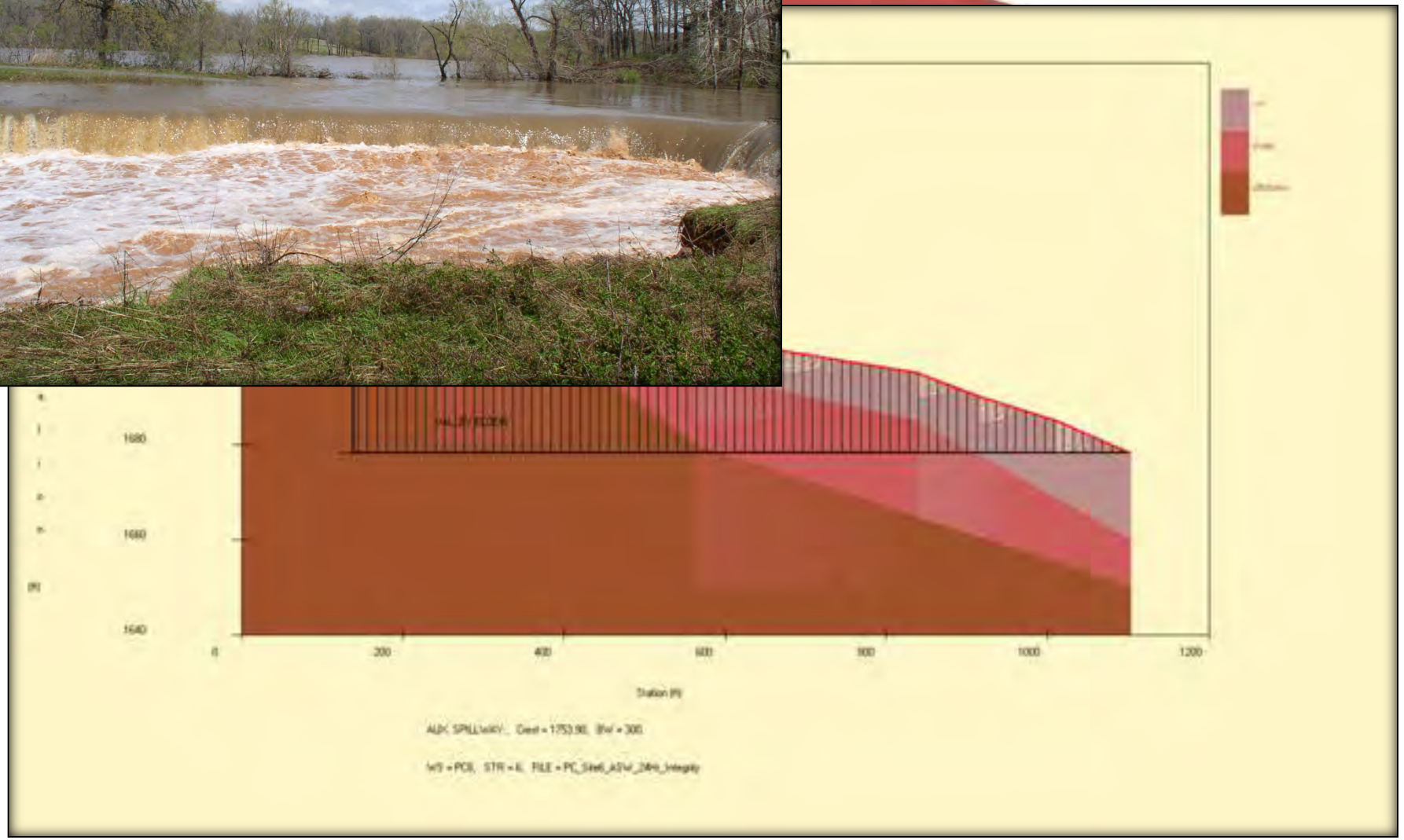
Minor Damage 5%



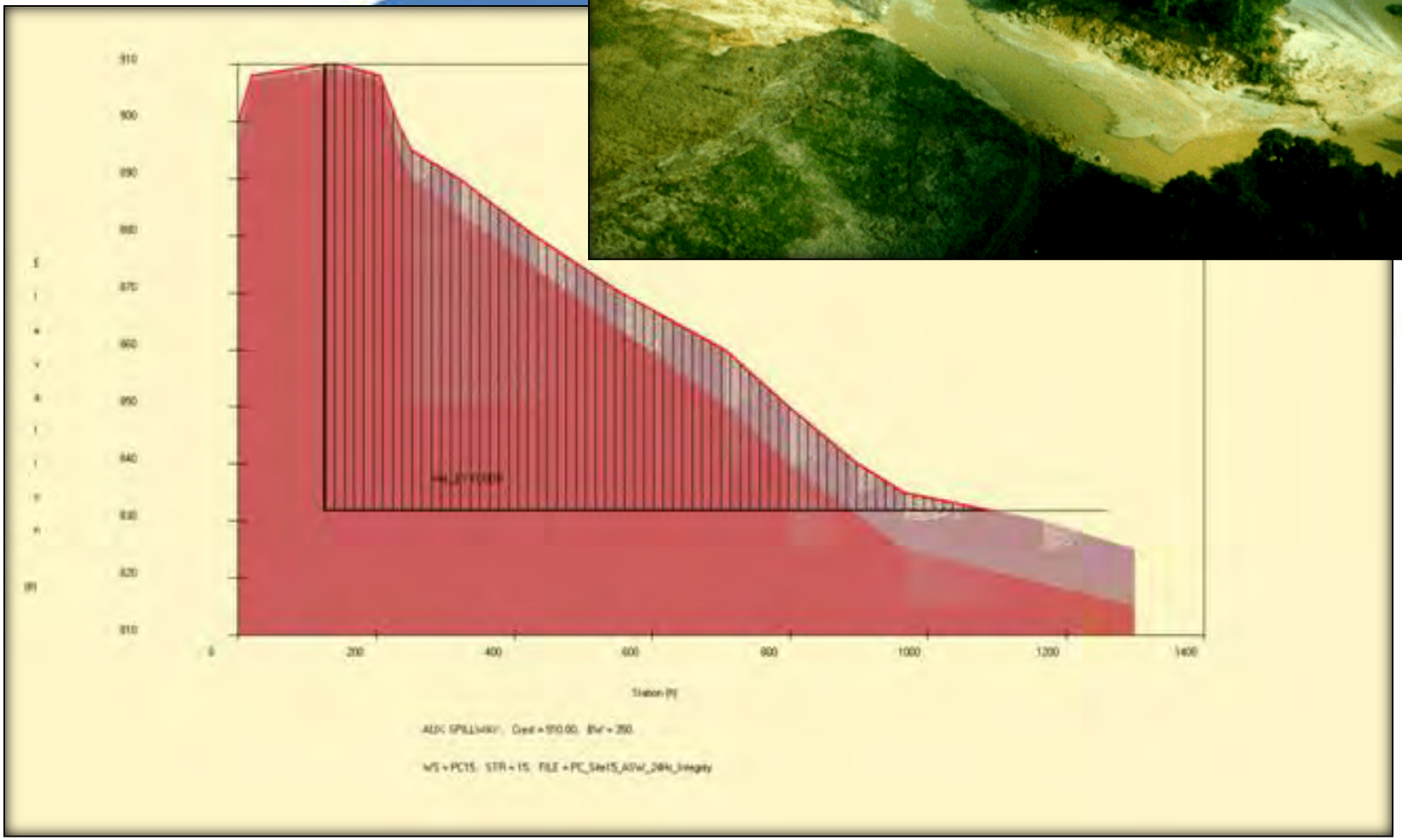


Significant Damage (39%)

Spillway Almost Breached (29%)



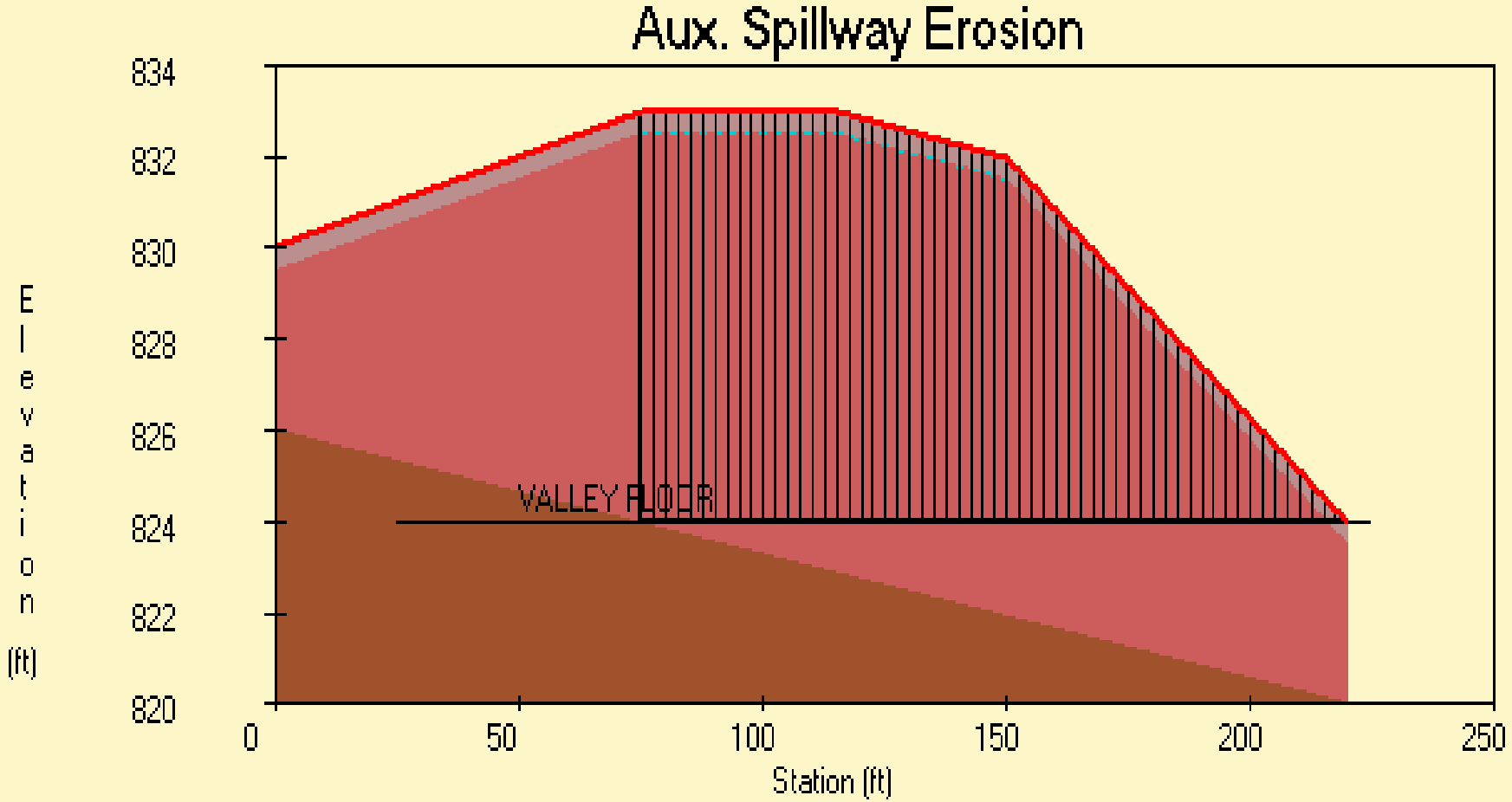
Spillway Breached (27%)



Souhegan 15

Souhegan 15, NH

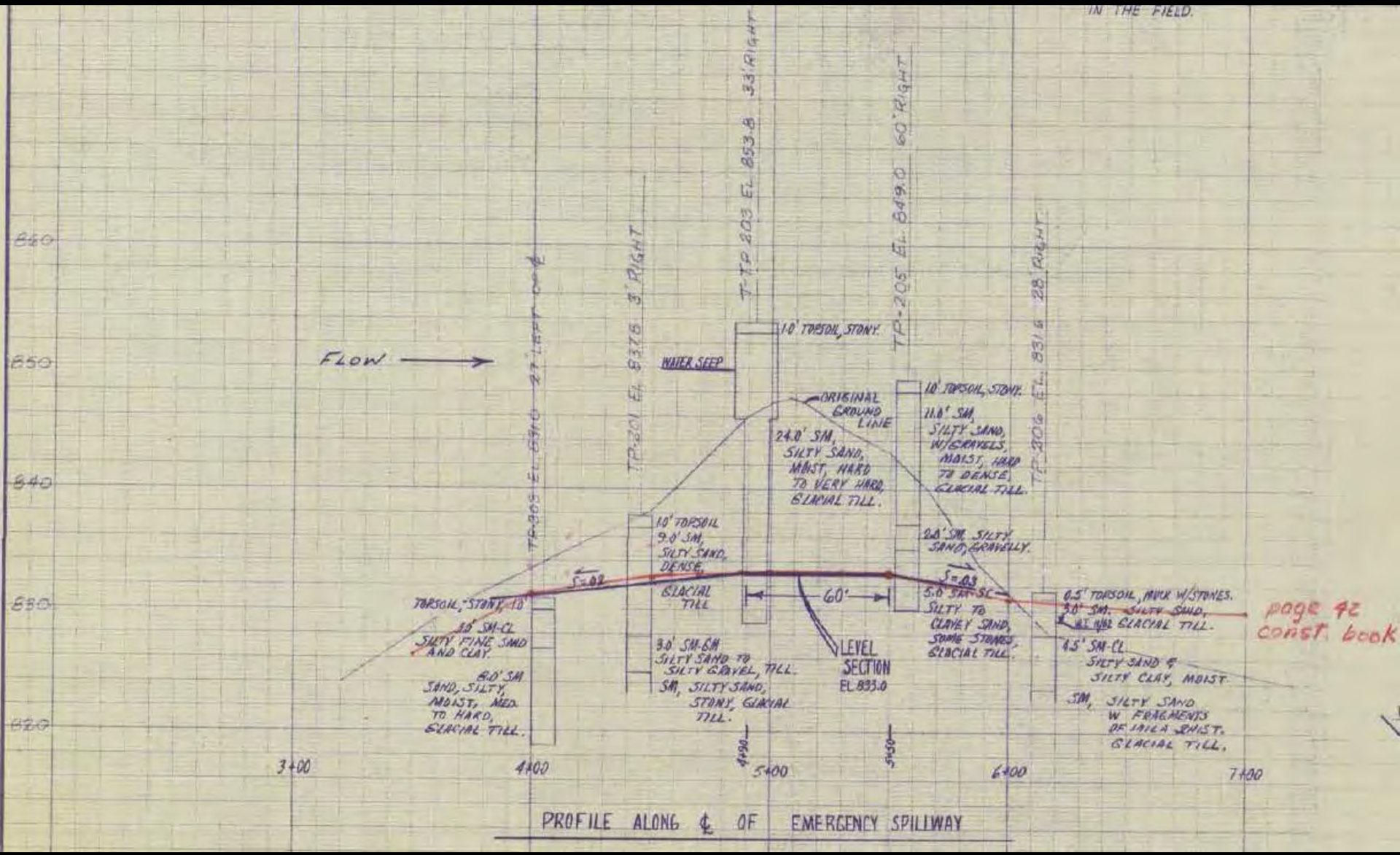

08/19/2015



Material Description	Detach. Rate (ft/h)/(lb/sq ft)	Dry Density (lbs/cu ft)	Headcut Index (Kh)	Percent Clay	Plasticity Index	Rep. Diameter (in)
Topsoil	--	100.	0.28	15.0	5.	0.00200
SM	--	115.	0.08	10.0	5.	0.04700
SM & CL	--	110.	0.07	20.0	15.	0.00400


TBM ELEV. 835.56
TBM
WASTE AREA
STILLING BASIN SEE SHEET 6 FOR DETAILS
CONTROL SECTION
TOP OF DAM ELEV. 837.0
10' BERM ELEV. 830.5
PRINCIPAL SPILLWAY STA. 2+00 = STA. 6+50 ℄ OF DAM
APPROX. ℄ OF INLET CHANNEL
℄ OF DAM
TOP WIDTH 12.0'
ELEV. 837.0
GRAVELLED SLOPES
V-DITCH
℄ OF FIBER RIPE & BERM
TP 304
TP 303
TP 201

IN THE FIELD.



page 42 const. book

PROFILE ALONG ℄ OF EMERGENCY SPILLWAY

Form SCS 376 B

The two remaining test pits were at the foot of the slope and showed 4.-5.' of silty sand underlain by 5.' of horizontal interbeded layers. An additional 2.' of silty sand was found below the interbeded SM-CL in one of the pits. No bedrock or unconsolidated materials were found in any of the test pits. The bottom of the spillway excavation will be in compact silty sand material.

Alternate Emergency Spillway

Alternate Emergency Spillway

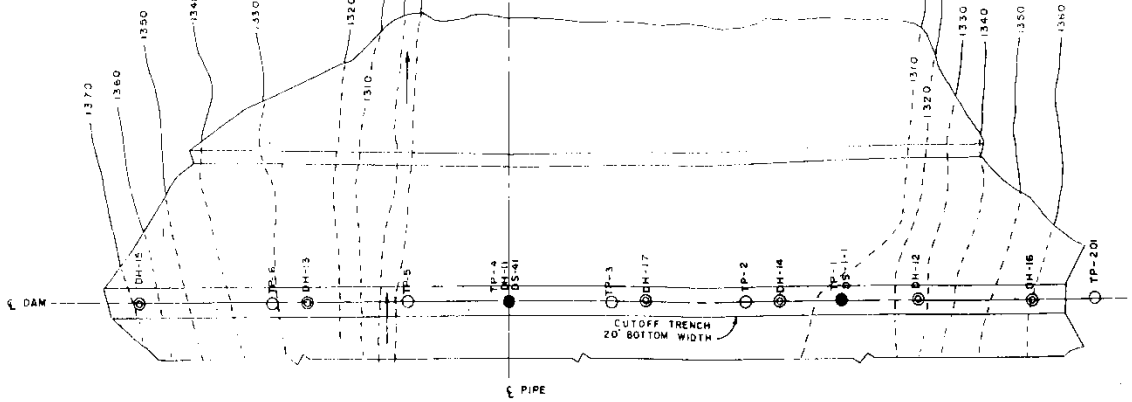
Three holes were used to investigate the Alternate Emergency Spillway which is located in the vicinity of the left abutment.

All three holes show 1.5-3.0' of relatively coarse silty sand underlain by weathered gneiss or schist which becomes sound bedrock at about 2.0'.

The watertable along the centerline of the proposed outlet structure was about 2.0' below ground level. Recharge is estimated to be medium.

The pocket penetometer reading for the centerline portion of the interbedded SM and CL was about 3 tons per square foot. The SM materials are firm to dens

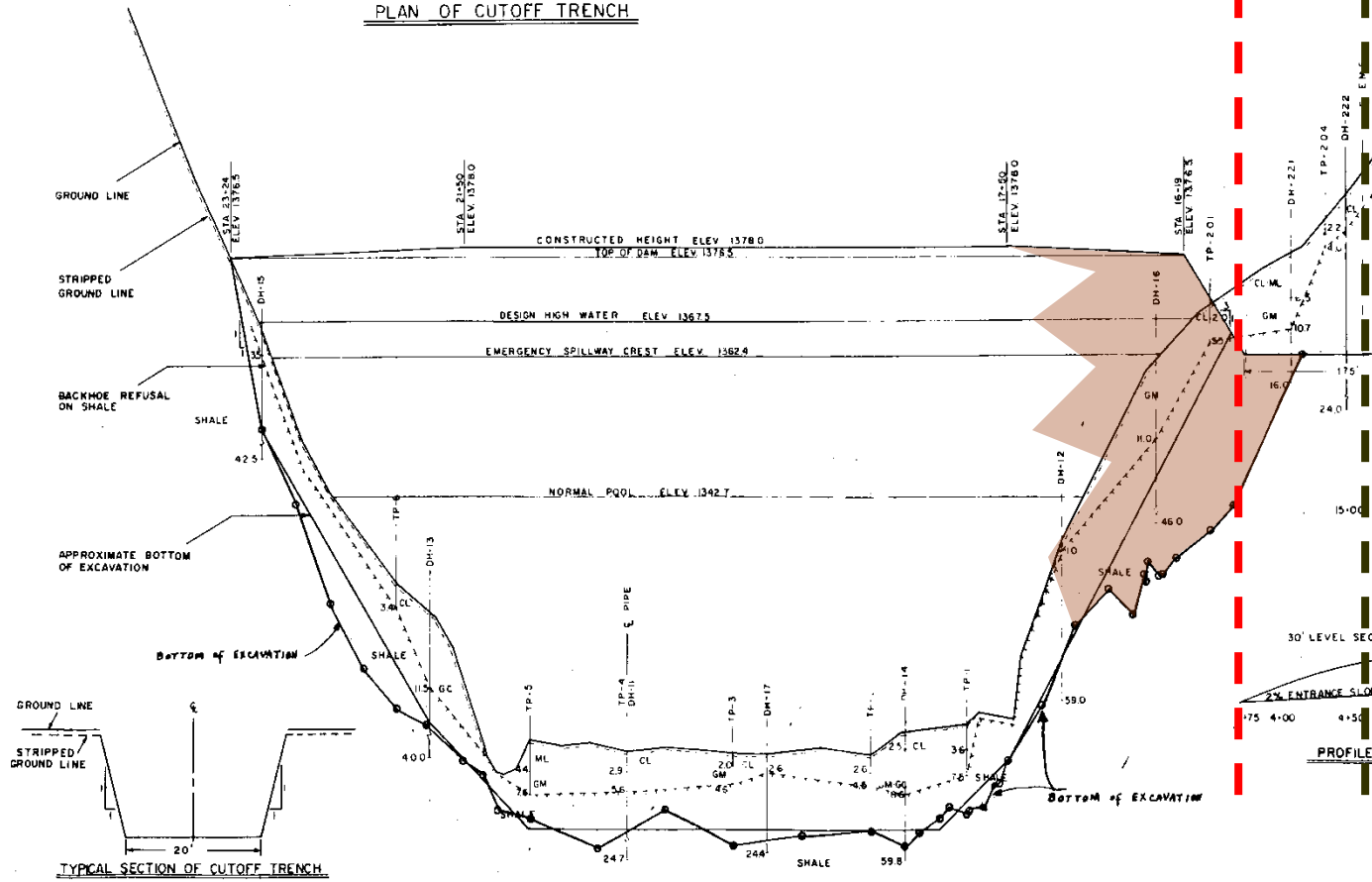
REFERENCE:	U.S.DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE	DRAWING NO. SHEET 4 OF ____ DATE ____

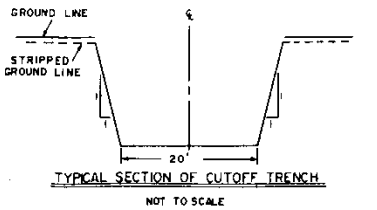


PLAN OF CUTOFF TRENCH

CONSTRUCTION DETAILS

1. THE EXCAVATION LIMITS ARE APPROXIMATE AND WILL BE ADJUSTED IN ACCORDANCE WITH CONDITIONS ENCOUNTERED.
2. ROCK EXPOSED IN THE BOTTOM OF THE CUTOFF TRENCH SHALL BE THOROUGHLY CLEANED AND SHALL BE INSPECTED BY THE ENGINEER PRIOR TO THE PLACEMENT OF COMPACTED FILL MATERIAL.



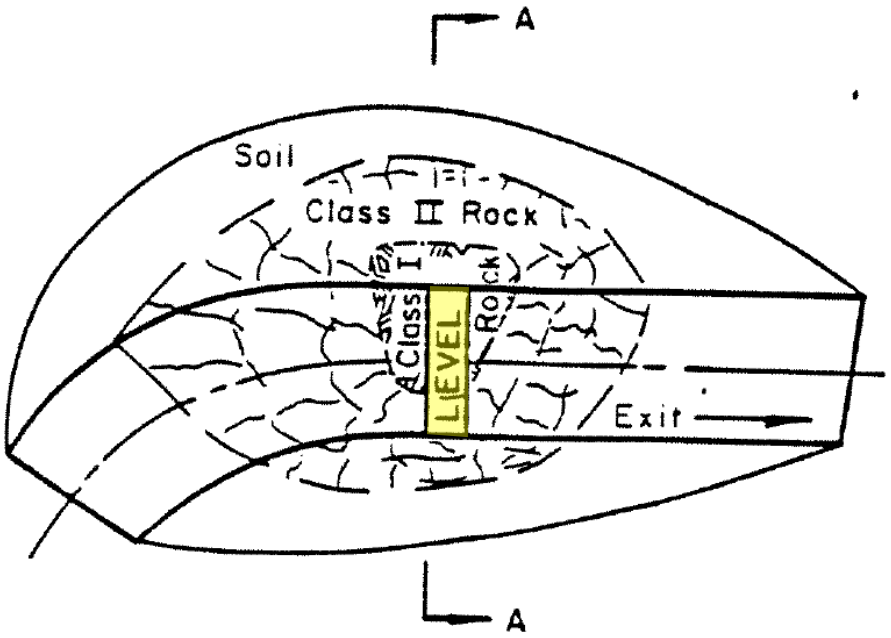


TYPICAL SECTION OF CUTOFF TRENCH
NOT TO SCALE

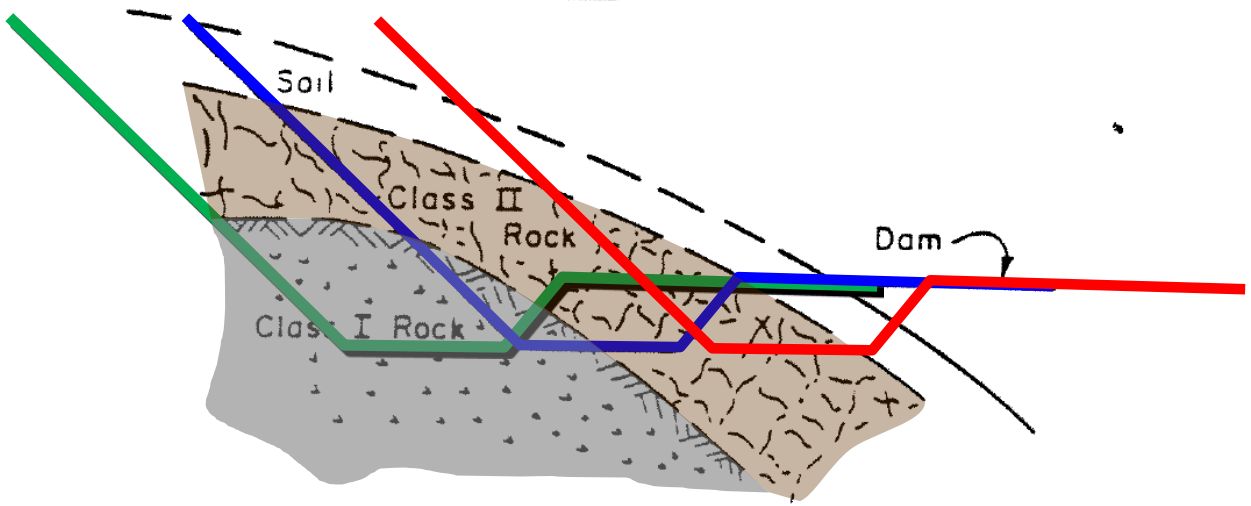
STONY CREEK SITE No. 9
STONY CREEK WATERSHED
SHENANDOAH COUNTY, VA.
DETAILS OF CUTOFF TRENCH
DEC 21 1971

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

N.W.WILSON Date
Designed R.E.CURTISS 2/71
Drawn J.F.BLODGETT 2/71
Traced
Checked
Approved by
File
Title
Scale S
Drawing No. VA-588-P

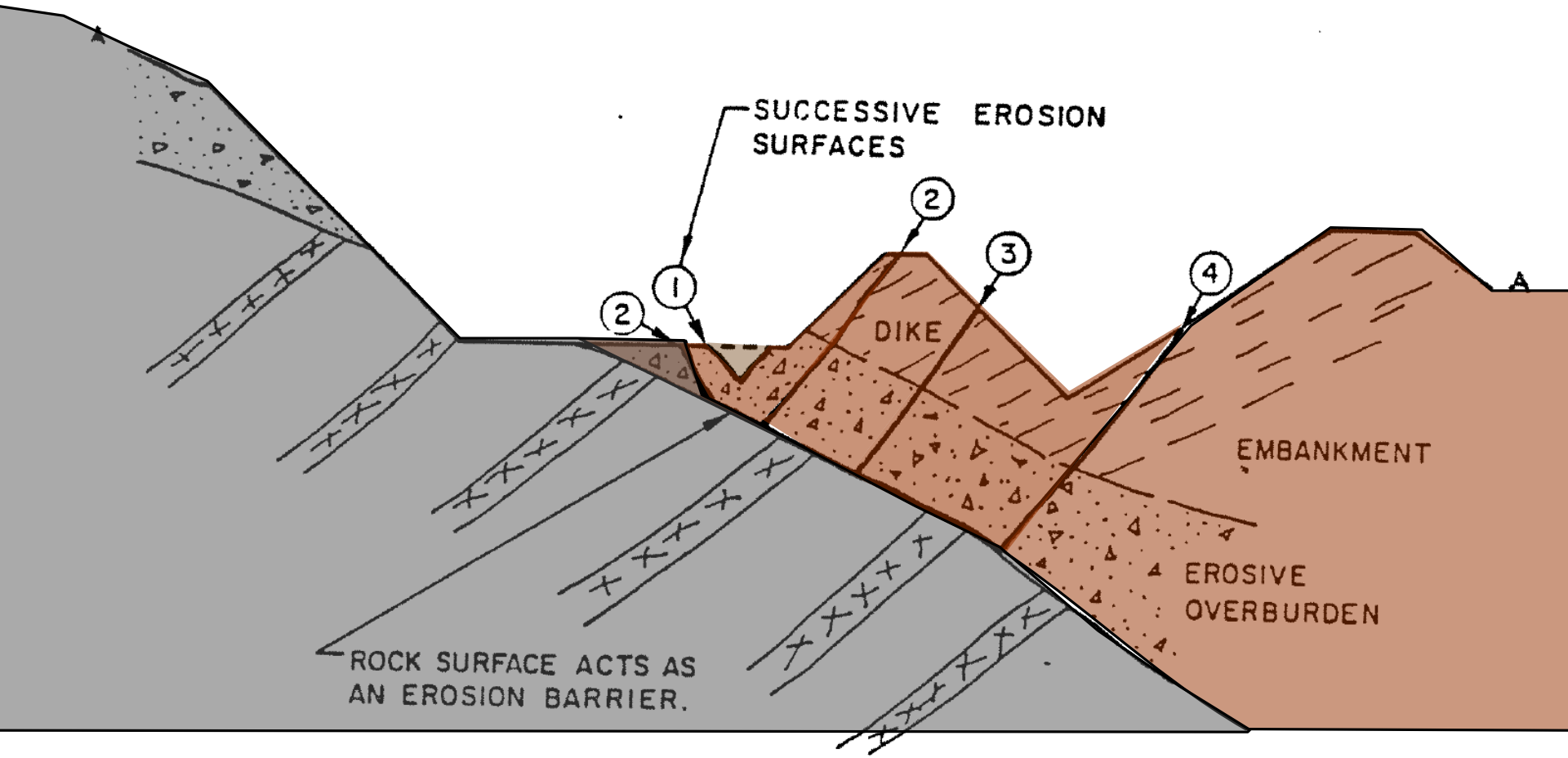


PLAN



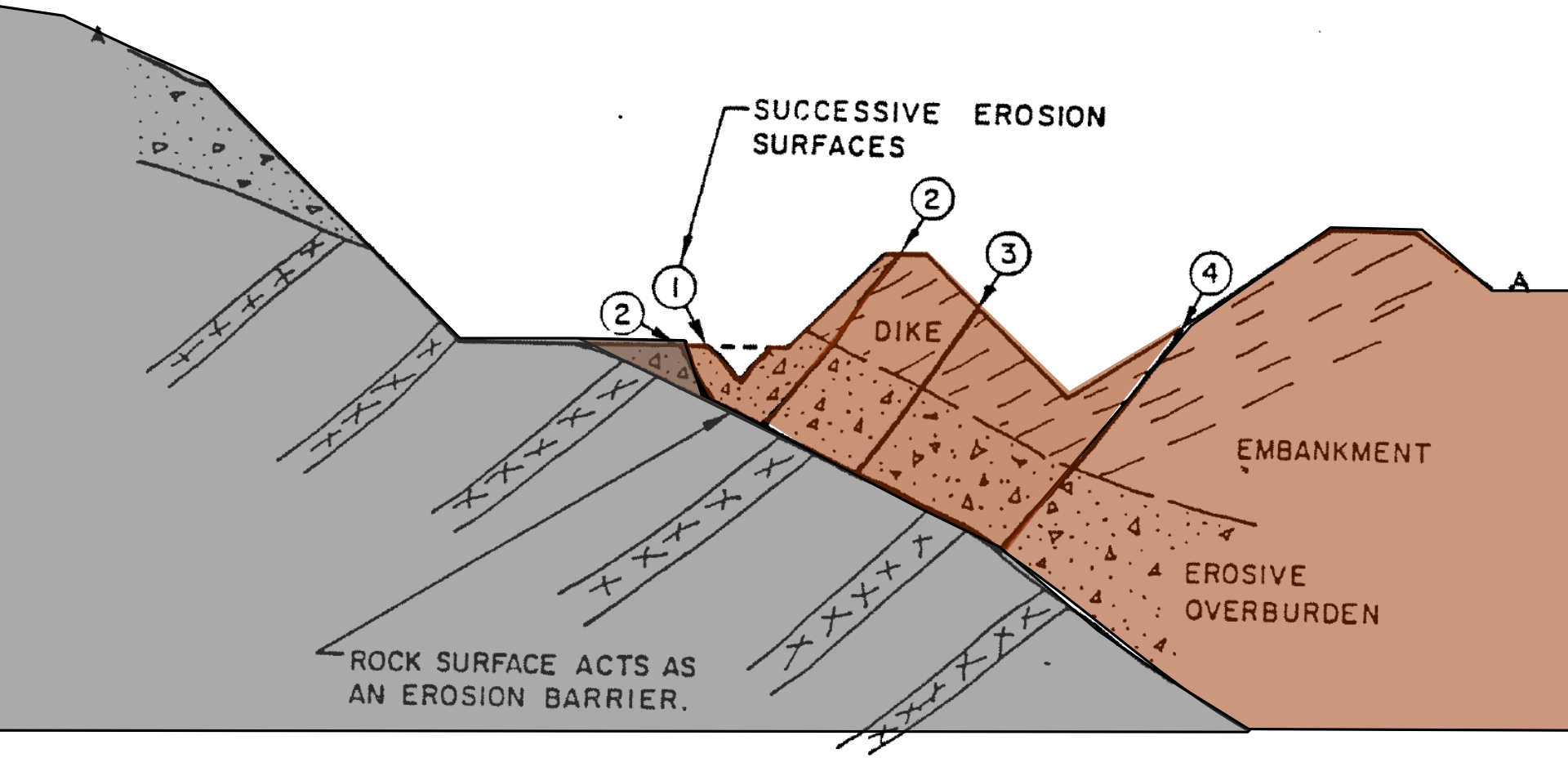
SECTION A-A

TYPICAL SPILLWAY CONSTRUCTED IN CLASS II ROCK



SECTION A - A

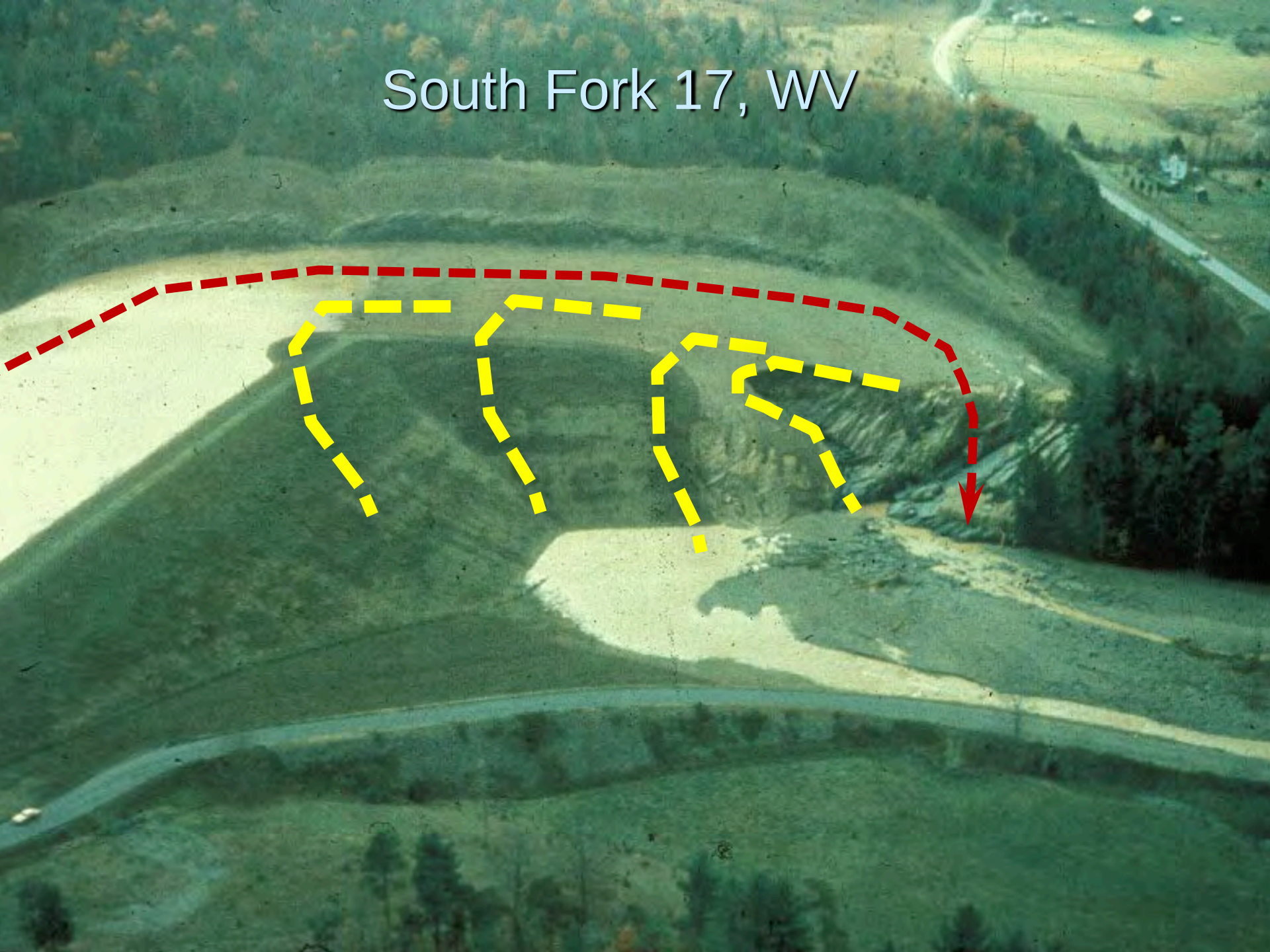
ROCK SURFACE DIRECTS GULLYING OF OVERBURDEN TOWARD EMBANKMENT TOE



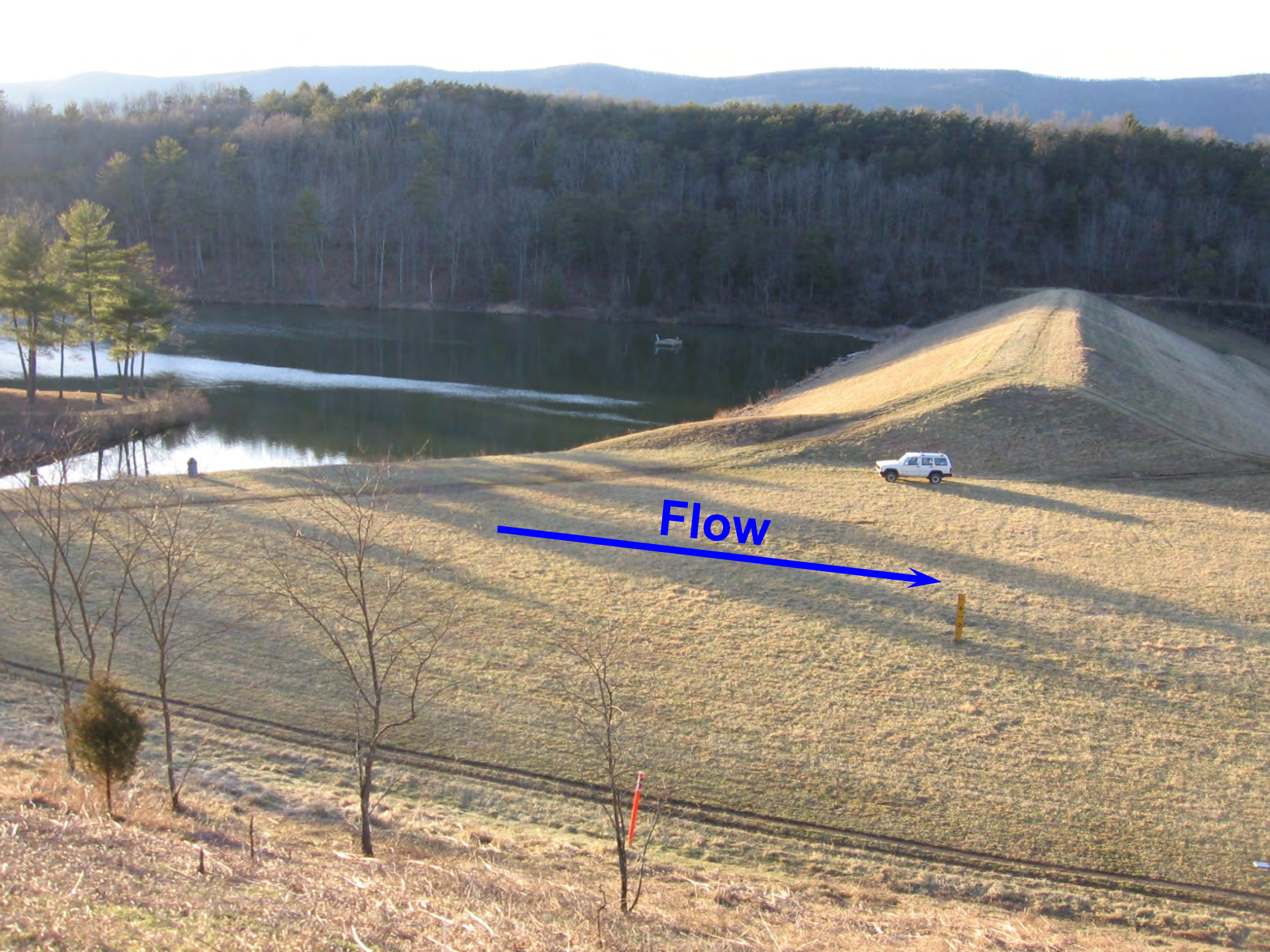
SECTION A - A

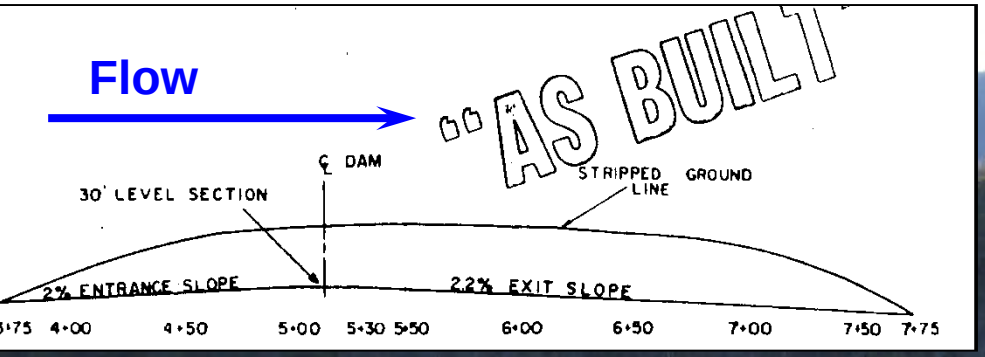
ROCK SURFACE DIRECTS GULLYING OF OVERBURDEN TOWARD EMBANKMENT TOE

South Fork 17, WV

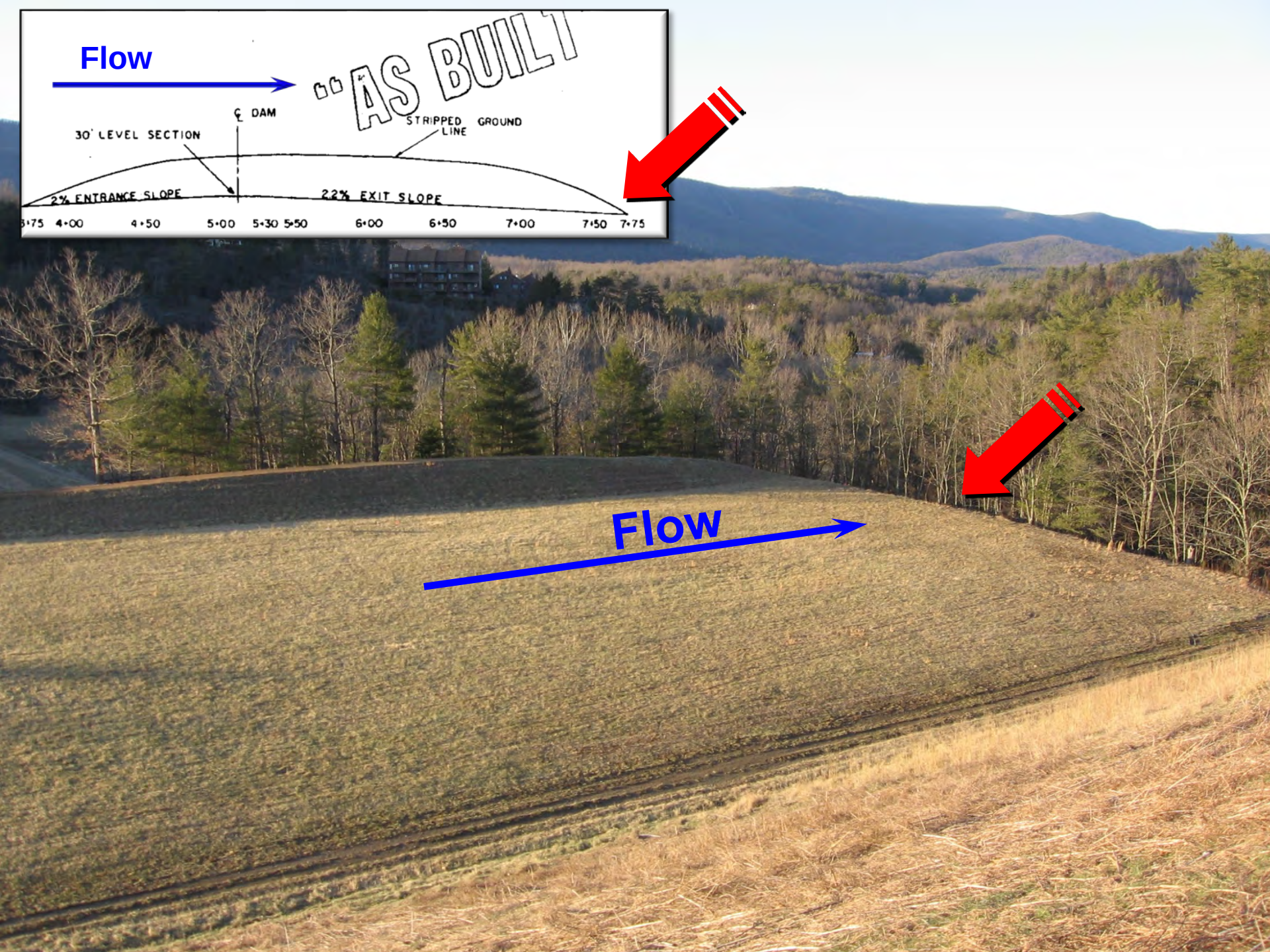


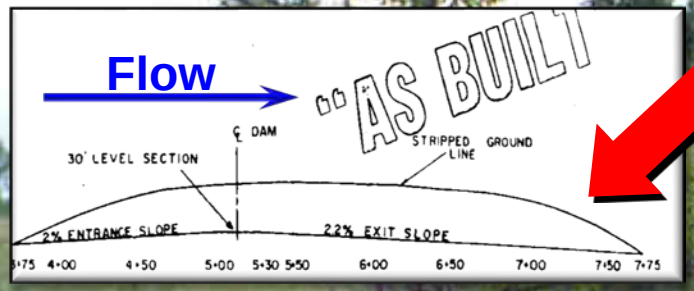

South Branch Potomac 17
Bedrock Dipping
Towards Dam

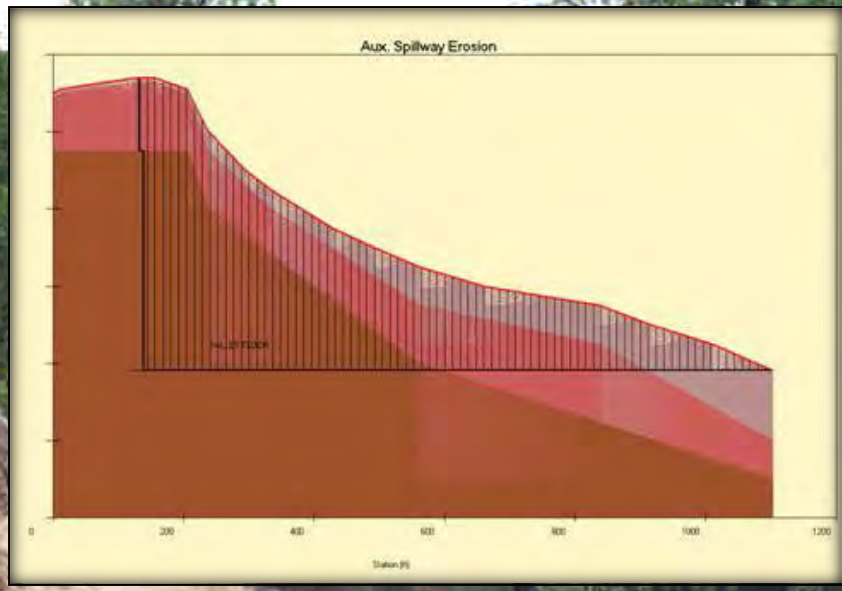

Flow


Flow
"AS BUILT"
℄ DAM
30' LEVEL SECTION
STRIPPED GROUND LINE
2% ENTRANCE SLOPE
2.2% EXIT SLOPE
3+75 4+00 4+50 5+00 5+30 5+50 6+00 6+50 7+00 7+50 7+75

Flow


Flow
"AS BUILT"
℄ DAM
30' LEVEL SECTION
STRIPPED GROUND LINE
2% ENTRANCE SLOPE
2.2% EXIT SLOPE
3+75 4+00 4+50 5+00 5+30 5+50 6+00 6+50 7+00 7+50 7+75
Flow


Flow
"AS BUILT"
℄ DAM
30' LEVEL SECTION
STRIPPED GROUND LINE
2% ENTRANCE SLOPE
22% EXIT SLOPE
3+75 4+00 4+50 5+00 5+30 5+50 6+00 6+50 7+00 7+50 7+75


Aux. Spillway Erosion
0
200
400
600
800
1000
1200

6 13 '00

White Oak Dam

Location: Madison County, VA
Dam Height: 63 Feet
Spillway Width: 75 Feet

Date: June 27, 1995
Event: 24” Rain in 18 Hrs
Maximum Head: 10 Feet
Max. Discharge: 7,000 cfs


White Oak Dam
Eroded: 10,500 C.Y.
Headcut Depth: 40 Feet
Headcut Length: 400 Feet


10 16'97

Photo Courtesy of Thomas I Roberts, VADCR


Auxiliary Spillway Discharge Channel
After Activation of Spillway
Before
Photo Courtesy of Thomas I Roberts, VADCR

Sugar Creek Dam L-44, Caddo County Oklahoma

Tropical Depression Erin (Aug. 18-19, 2007)

>8” in less than 12 hours

Photo Courtesy of
Ed Fiegle


Flow
Photo Courtesy of
Darrel Temple


El Guapo Dam, Venezuela
Failed December 16, 1999


El Guapo Dam, Venezuela
Failed December 16, 1999


El Guapo Dam, Venezuela
Failed December 16, 1999


El Guapo Dam, Venezuela
Failed December 16, 1999


El Guapo Dam, Venezuela
Failed December 16, 1999


LOOKS TO ME LIKE IT'S THE MOTHERBOARD...
THAT'S ENOUGH. NOW GO OUTSIDE AND GET SOME FRESH AIR!

Break

Lessons Learned from Spillway Erosion Failures

Gannett Fleming

Maryland
Department of
the Environment