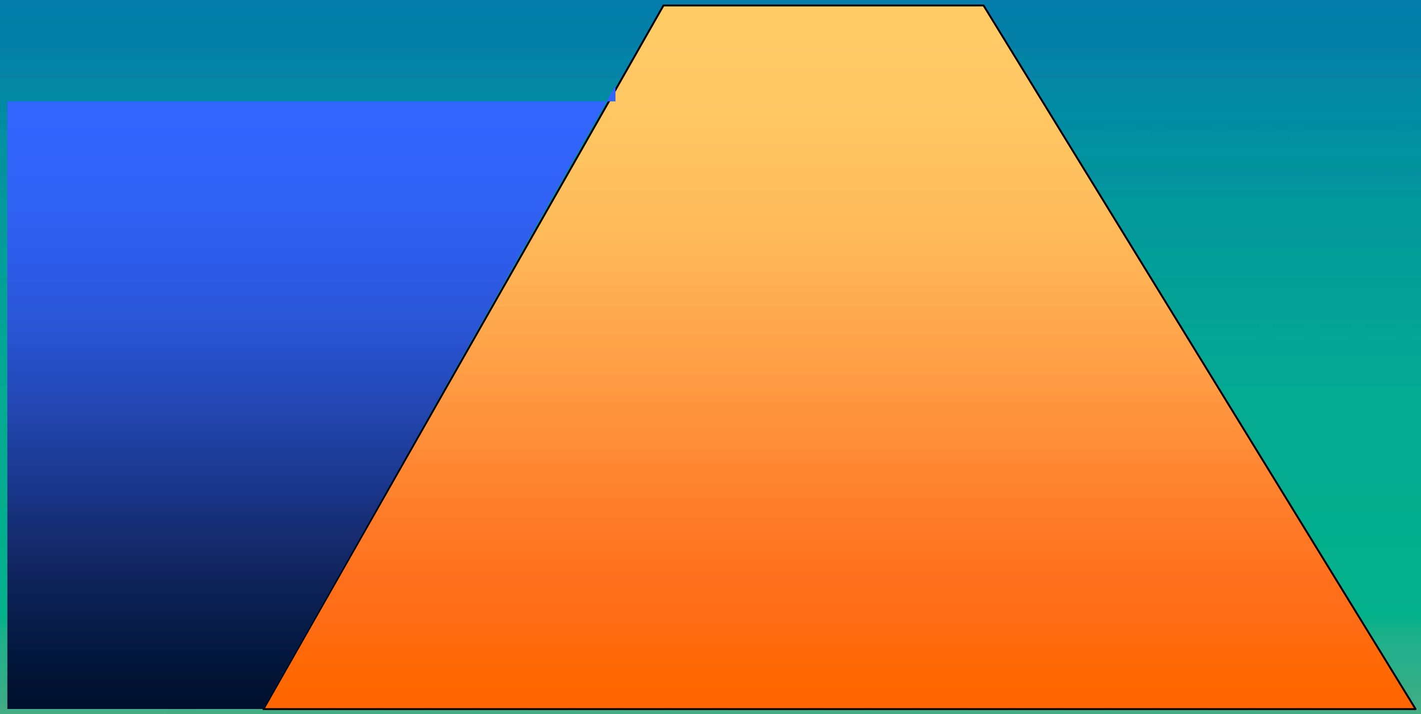
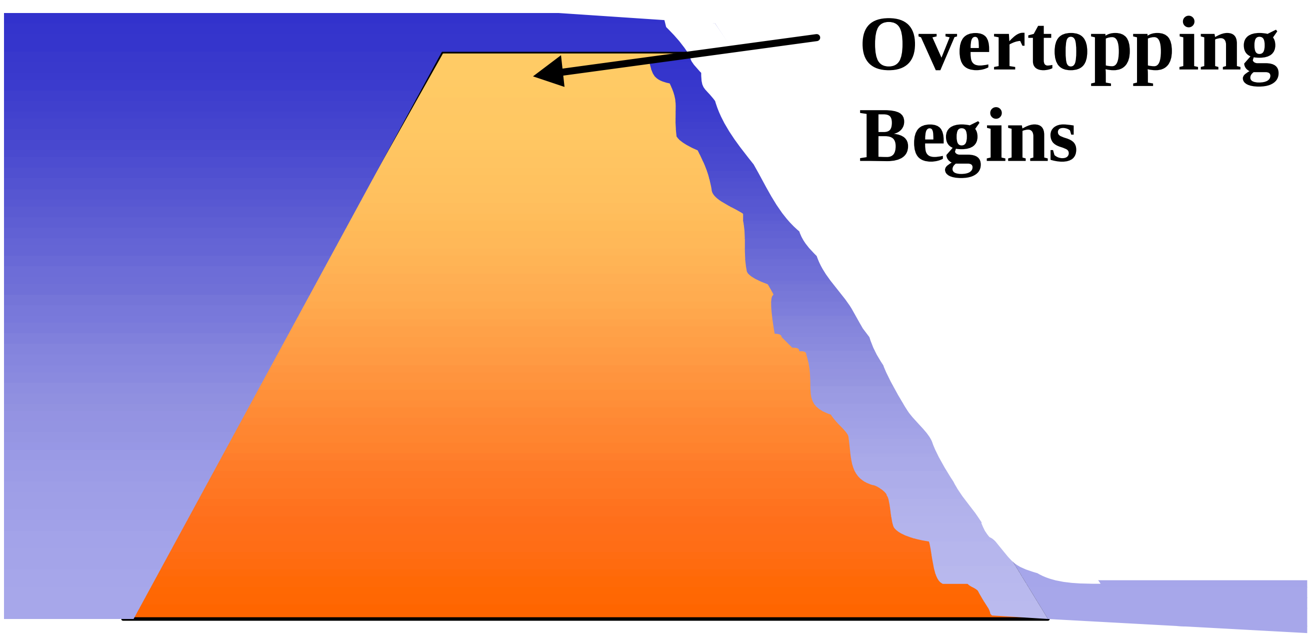

MARYLAND DAM SAFETY
Dam Break Analysis
&
Hazard Classifications
MDE

Types of Dam Failures



Embankment Dam Schematic

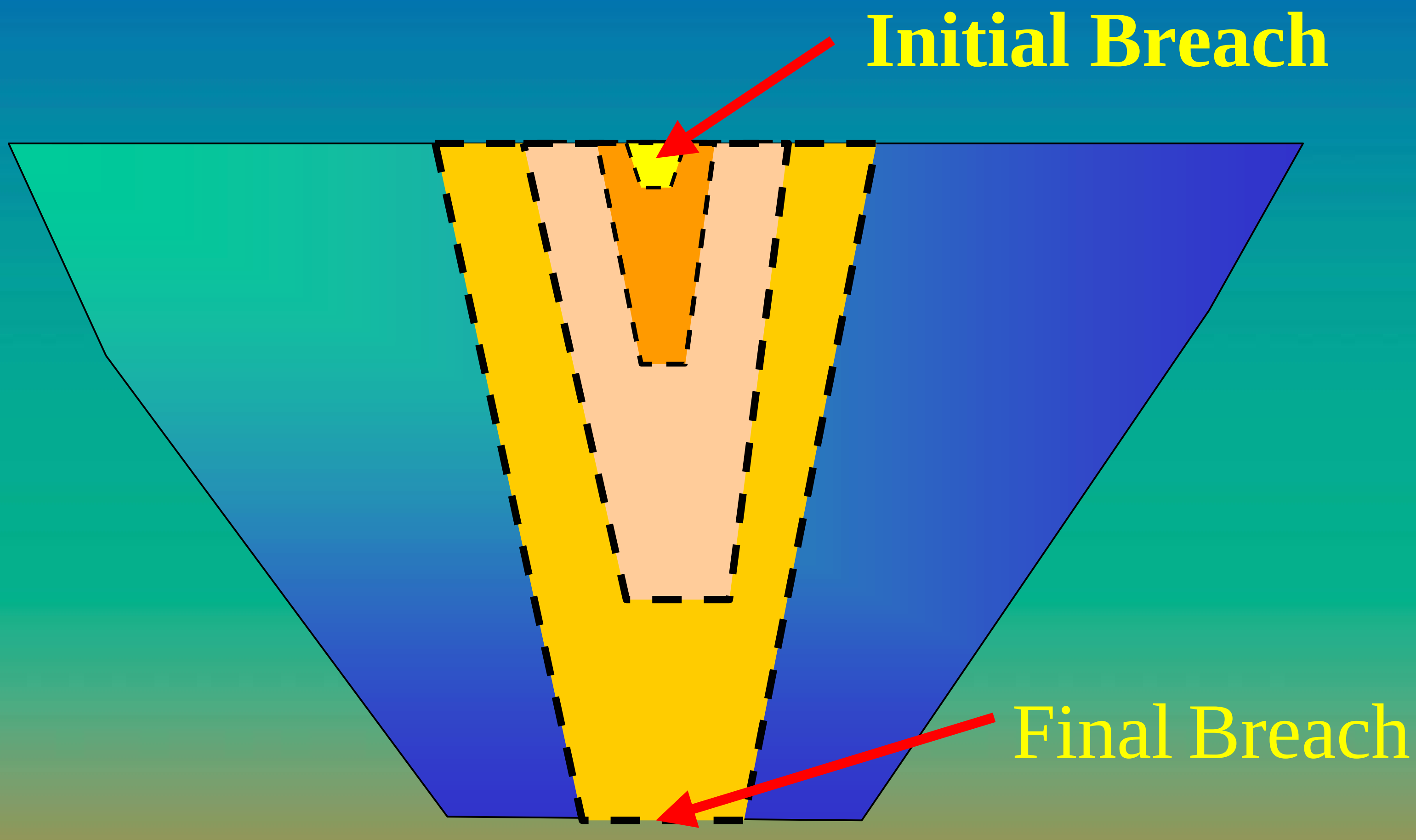
Overtopping Failure



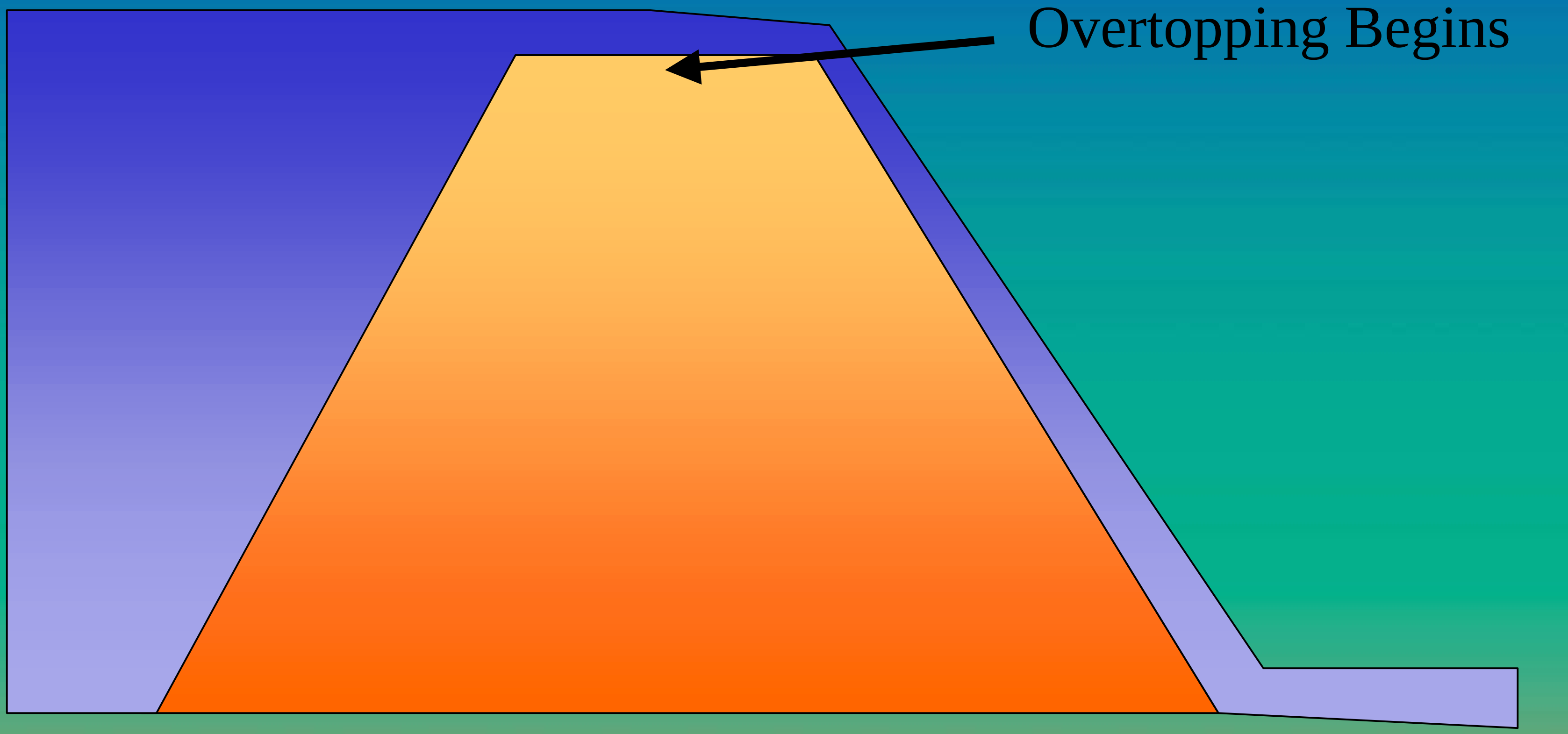
Dam Overtopping Photo 1

Dam Overtopping Photo 2

Overtopping Breach of Earth Dam



Overtopping Breach Stages for Earth Dam



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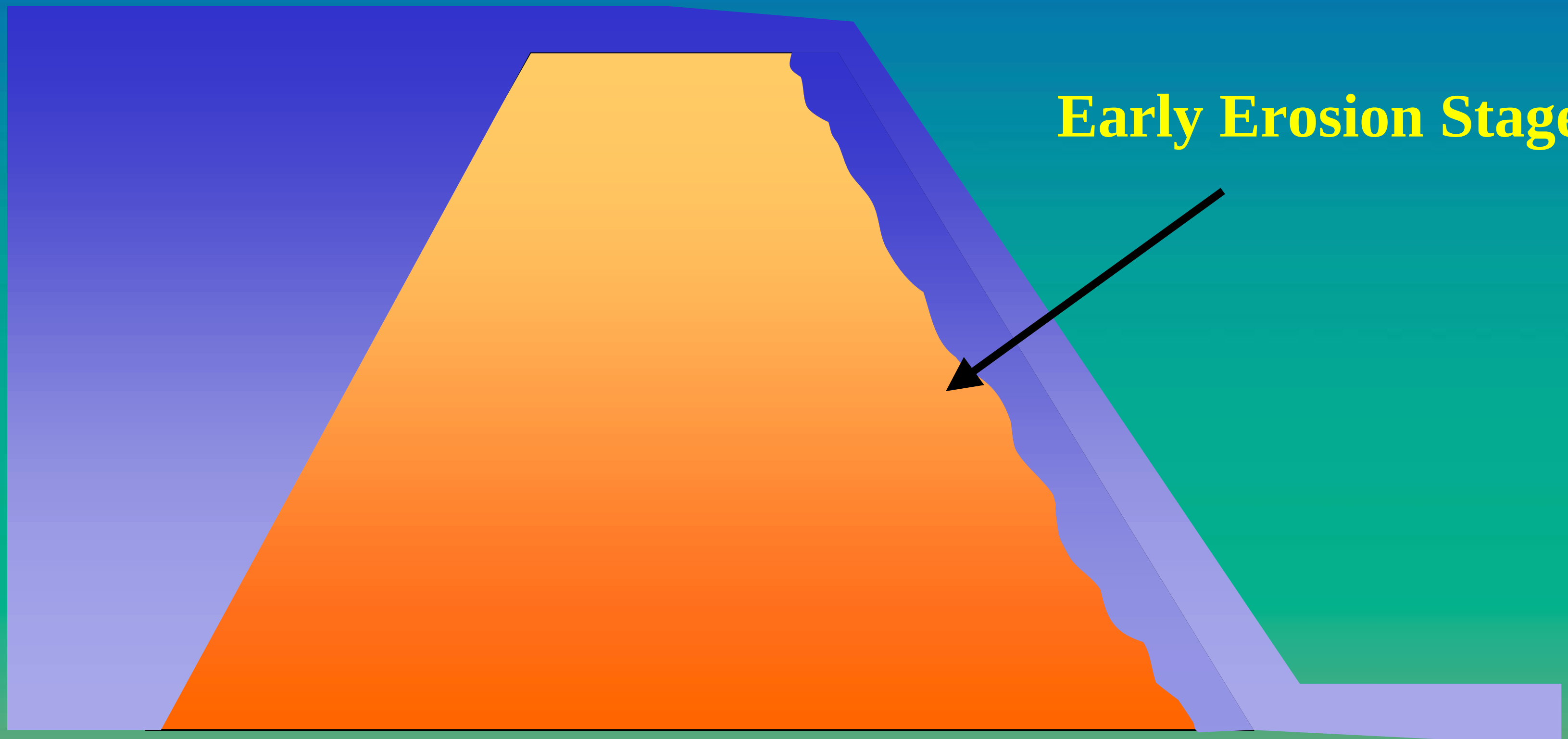
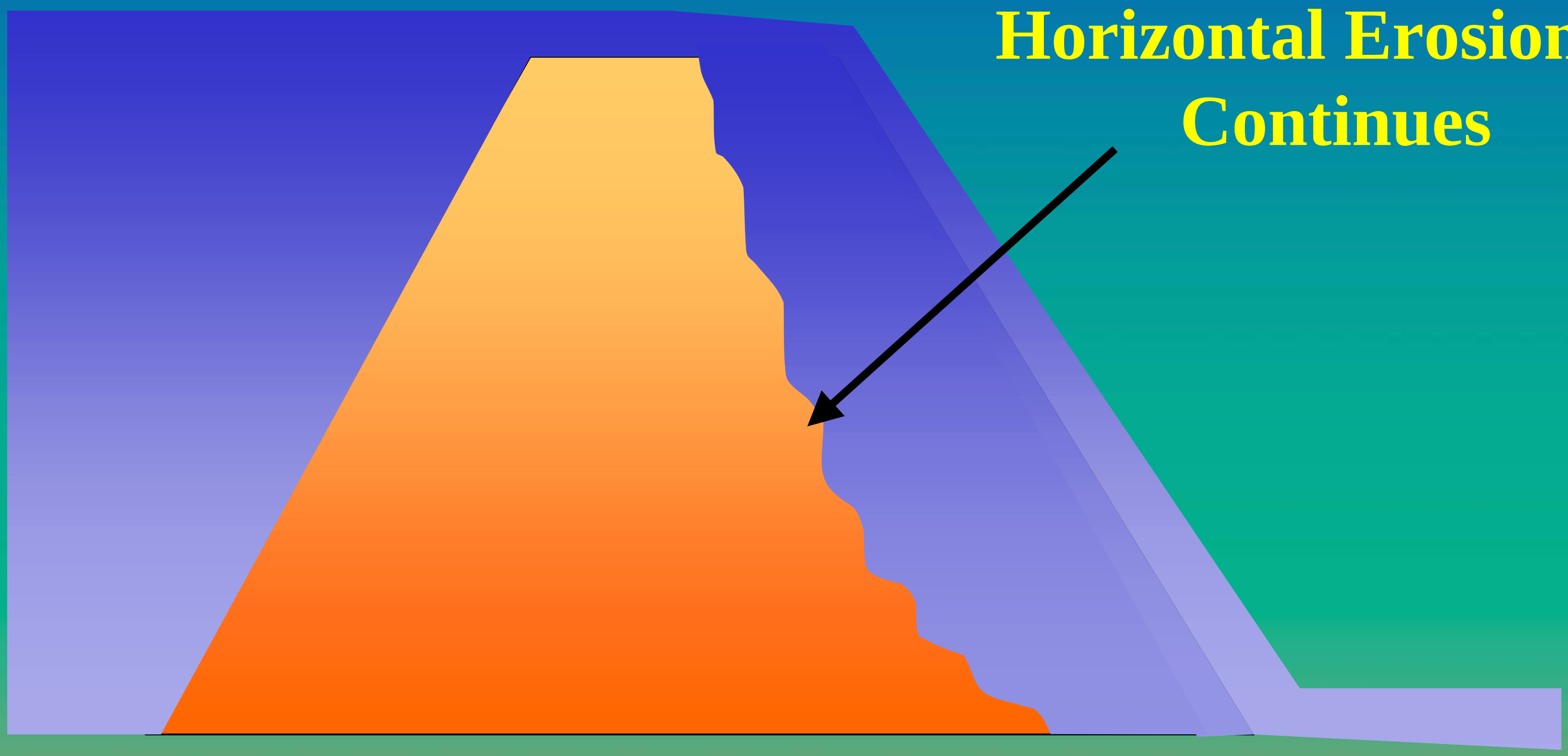
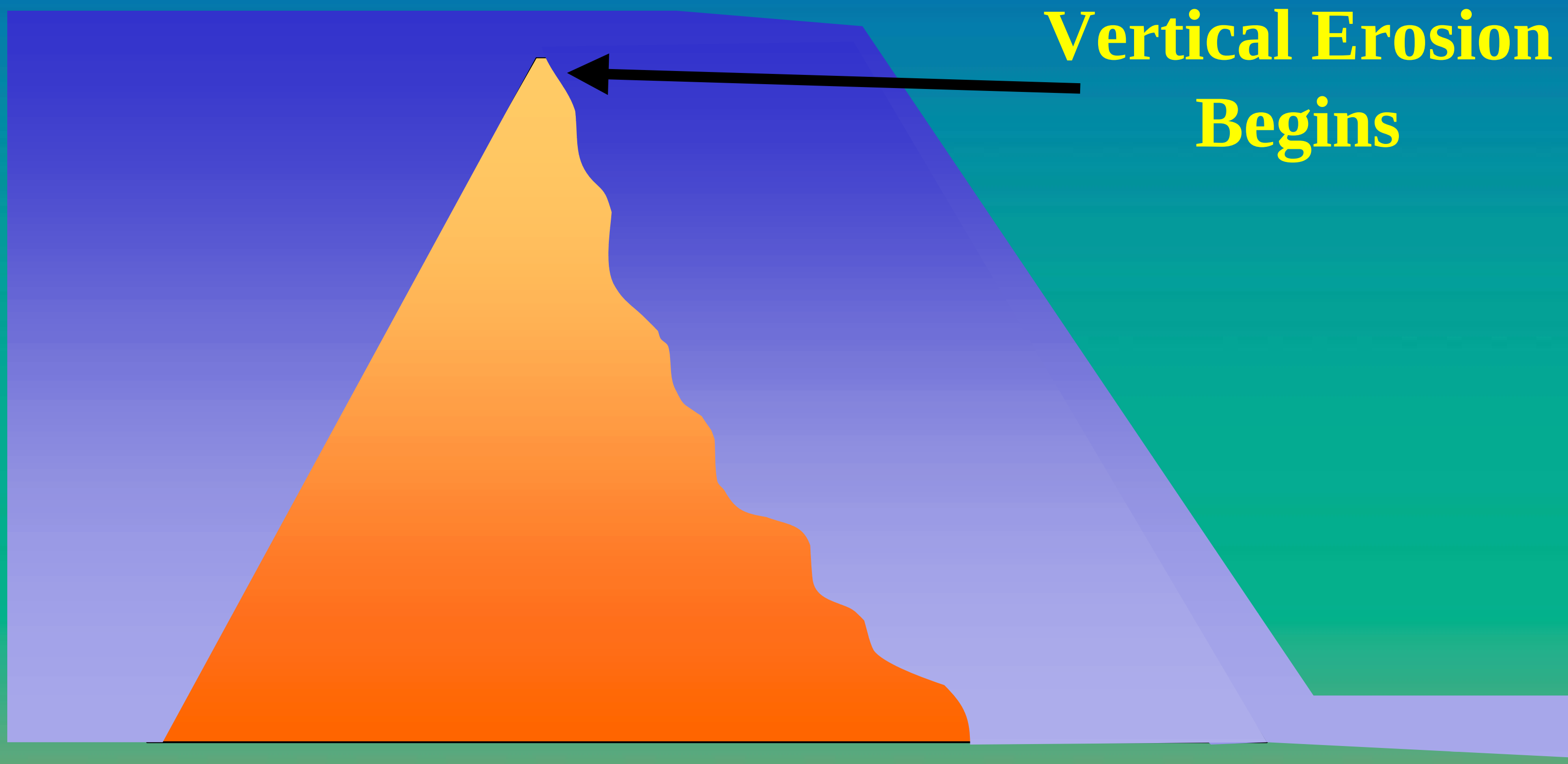


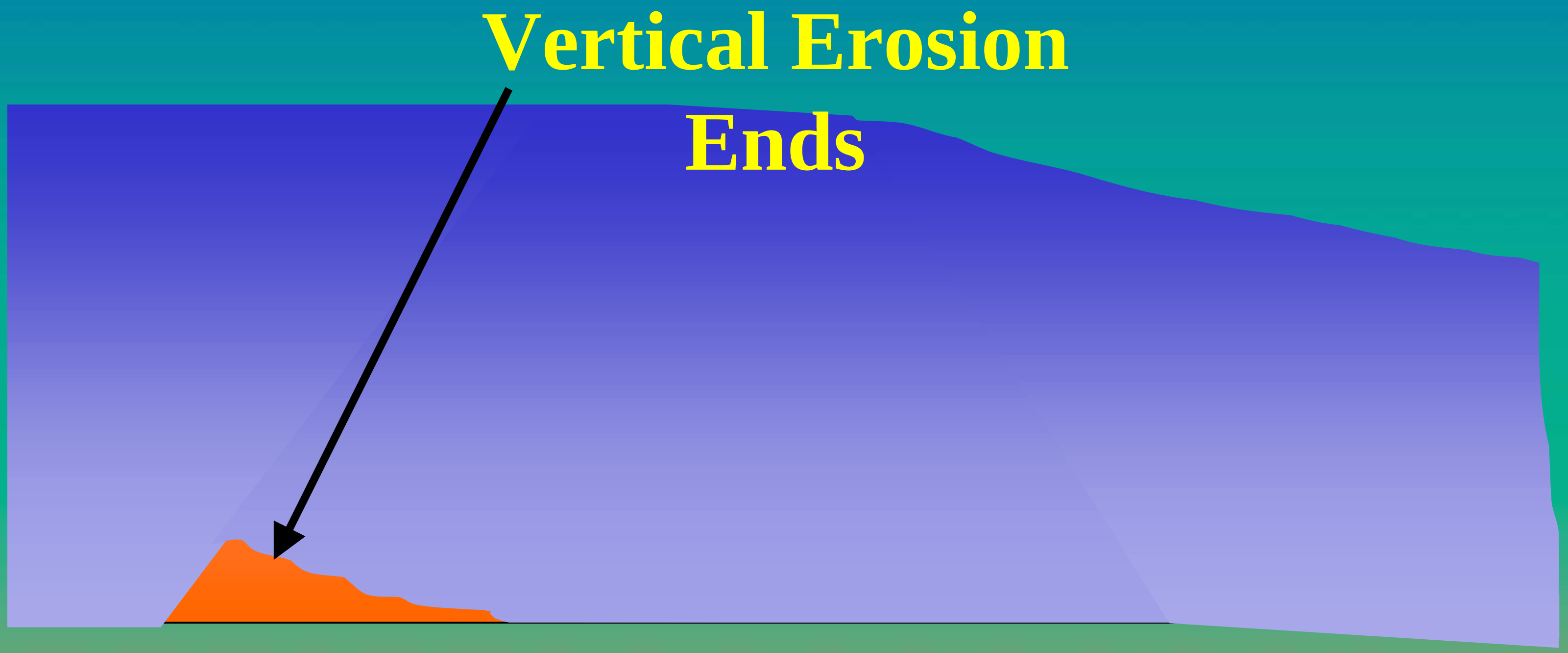
Overtopping Breach Stages for Earth Dam



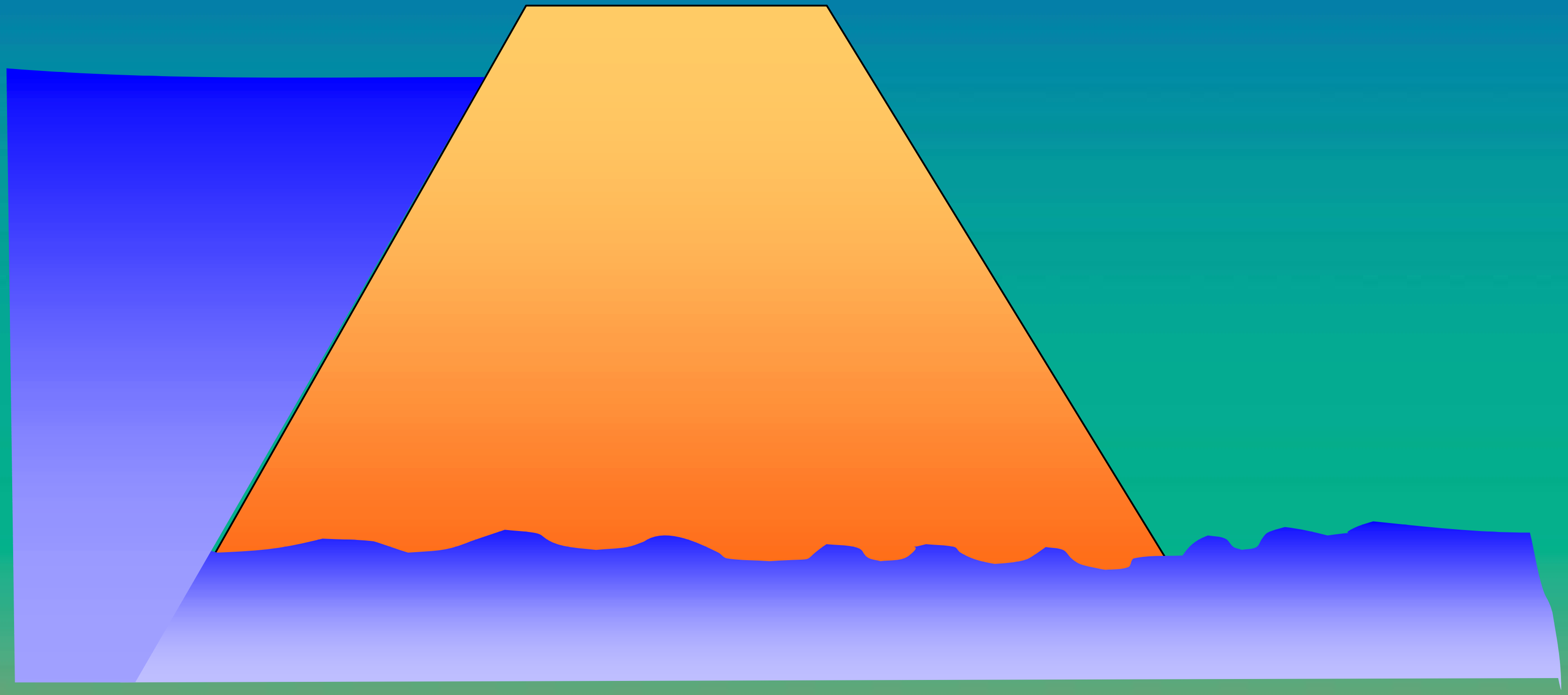
Overtopping Breach Stages for Earth Dam



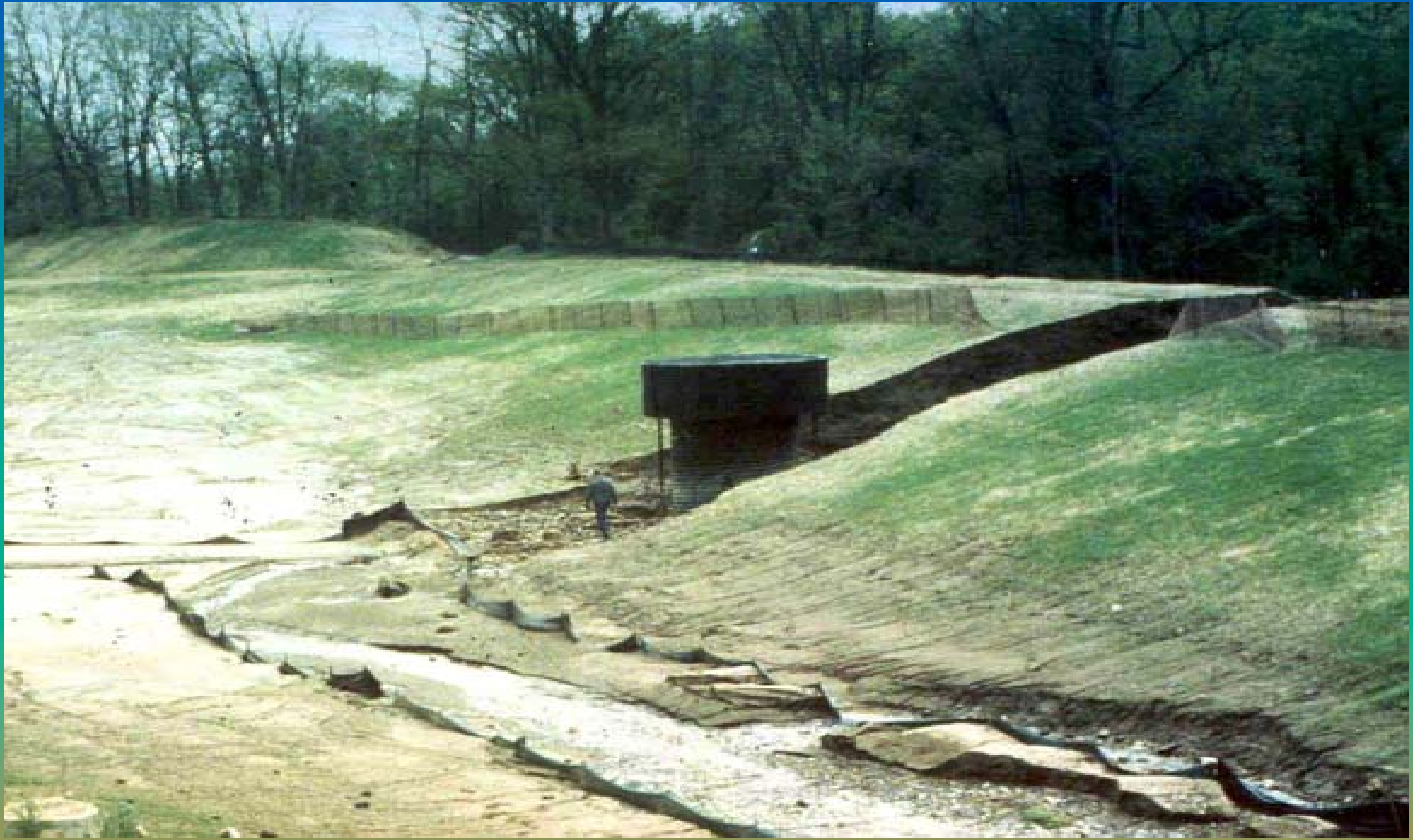
Overtopping Breach Stages for Earth Dam



Piping Failure for Earth Dam



Piping Failure at Loveton Dam (1989)



Loveton Dam Failure (1989)

Loveton Failure Viewed from Downstream

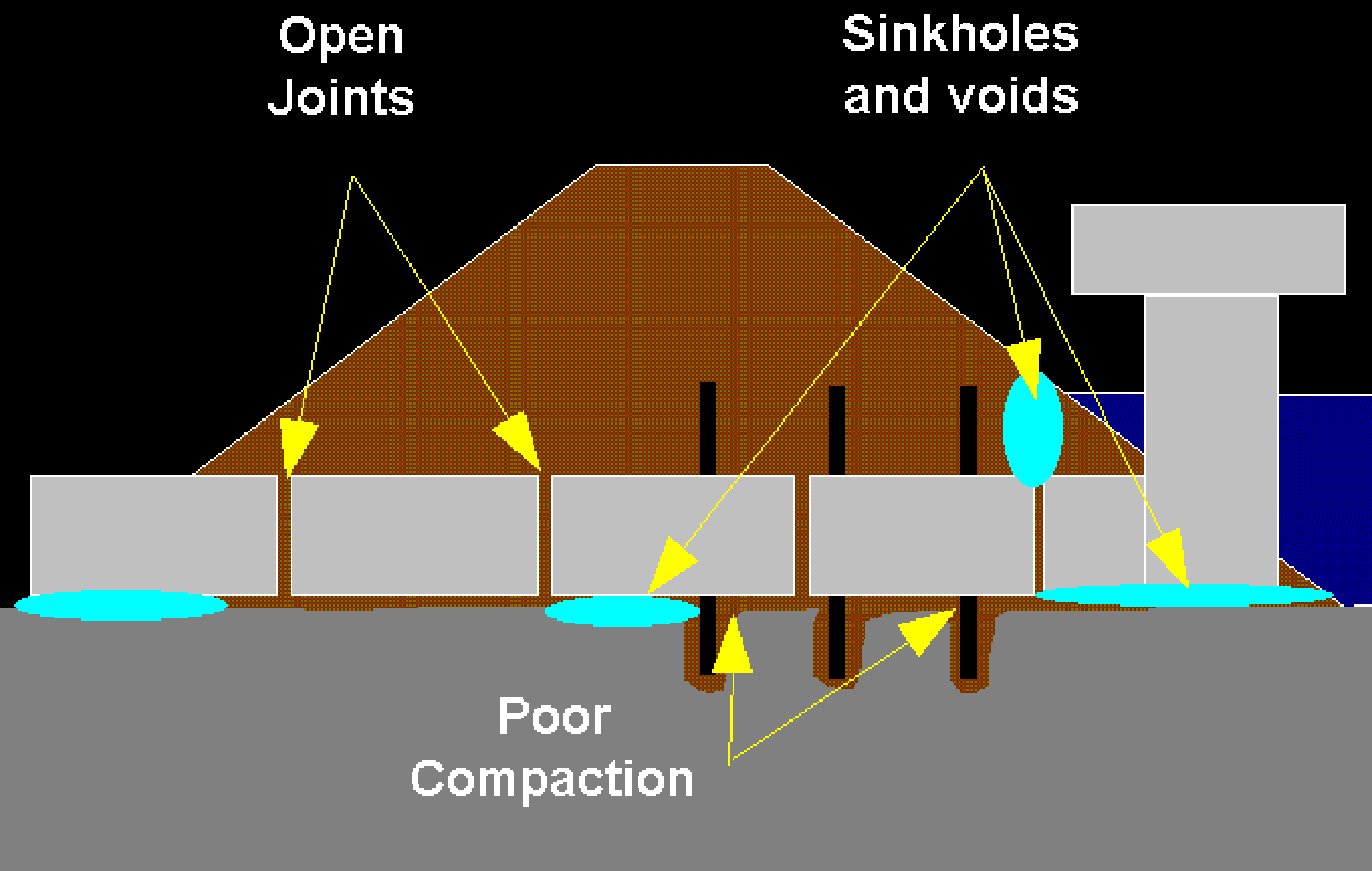
Medford Quarry Wash Pond Piping Failure

Piping Failure

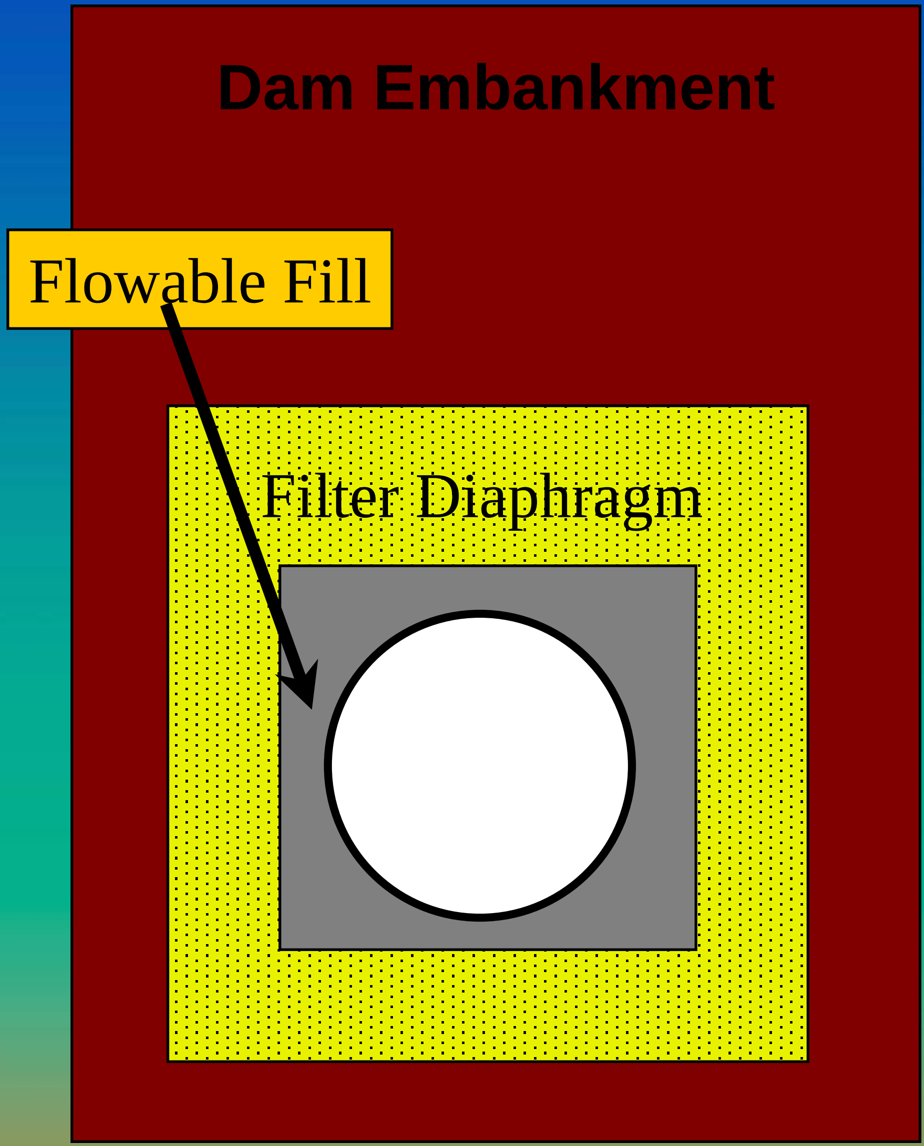
Annap. Mall Piping Failure

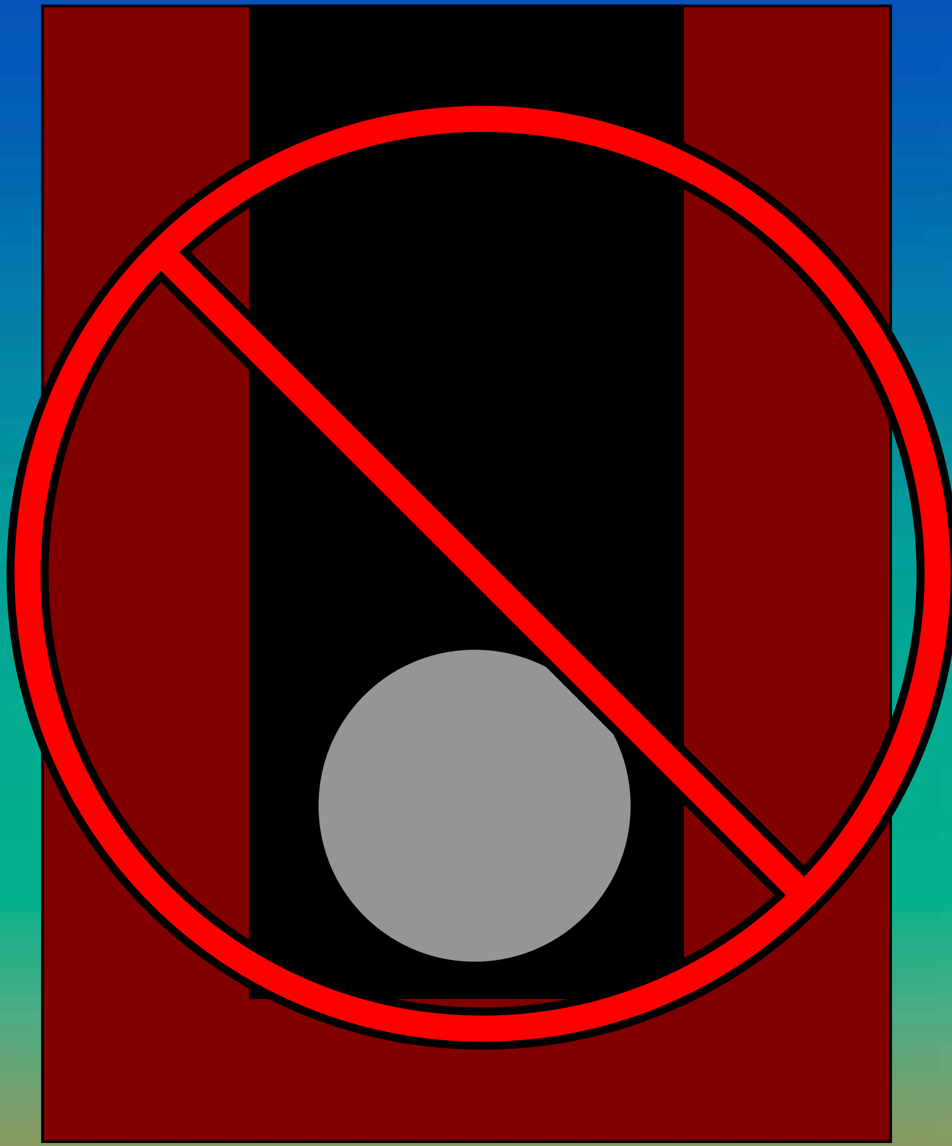
Sinkhole in Dam Crest

TYPICAL PROBLEMS

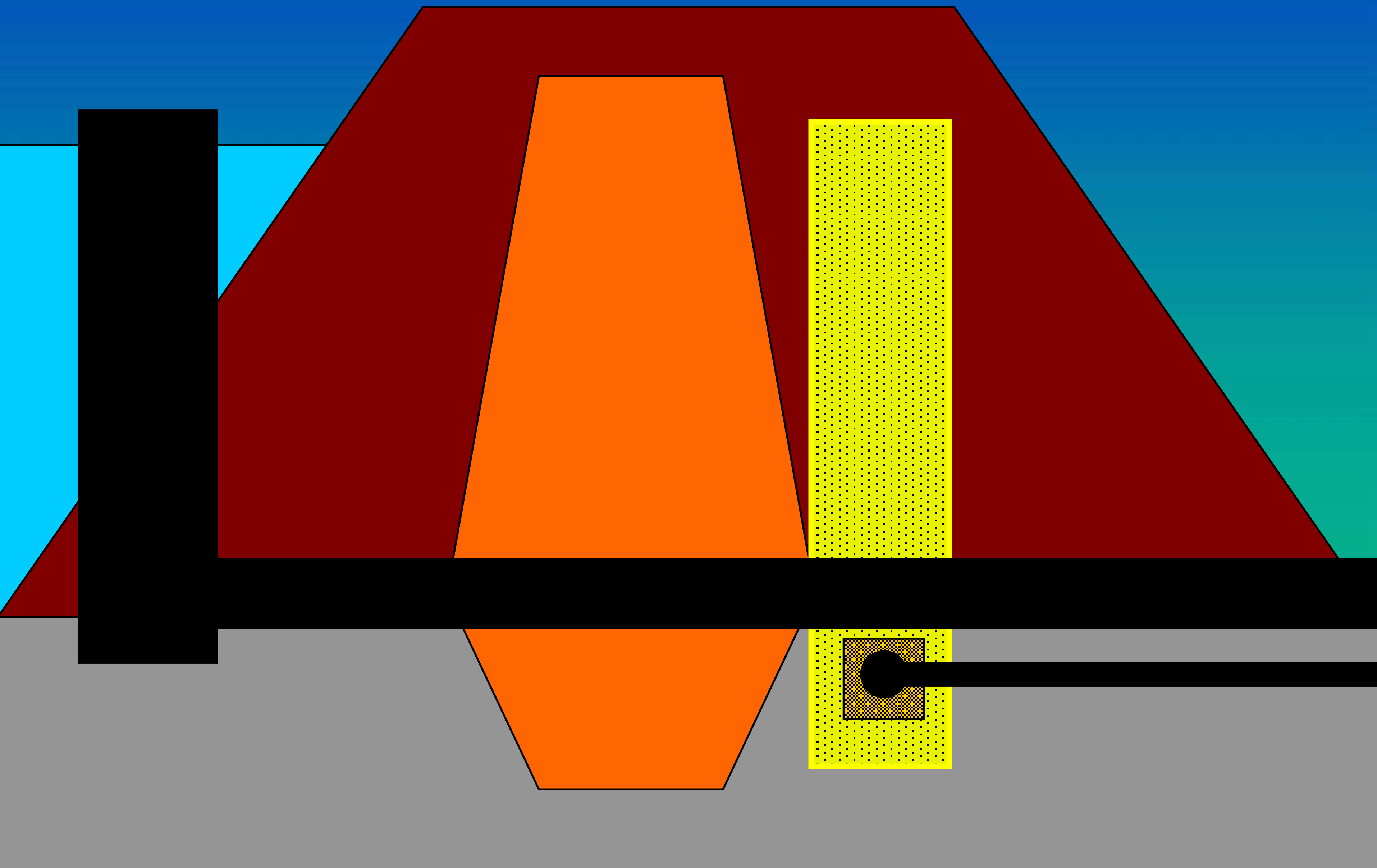


Pipe Installation in Dam

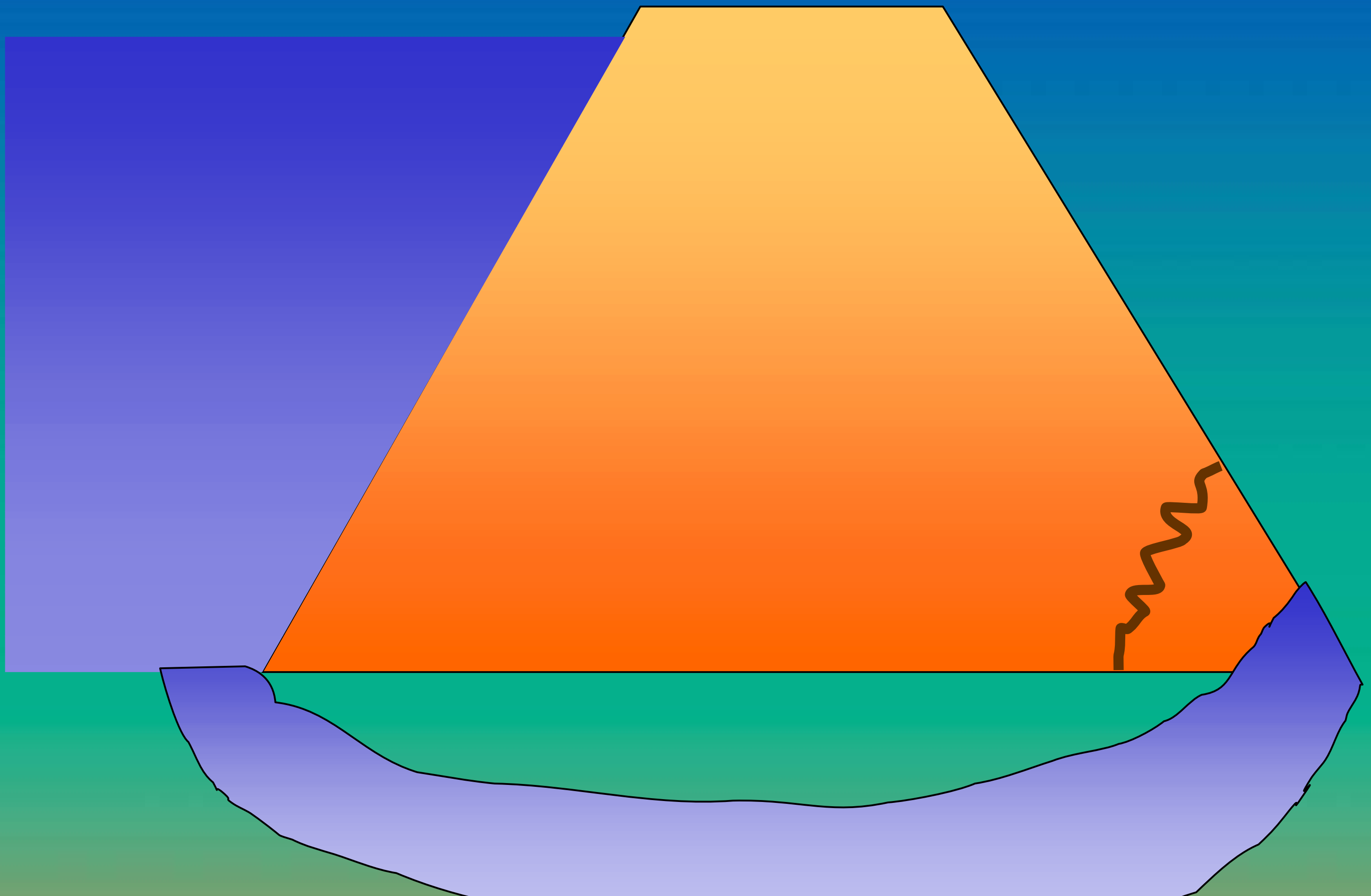




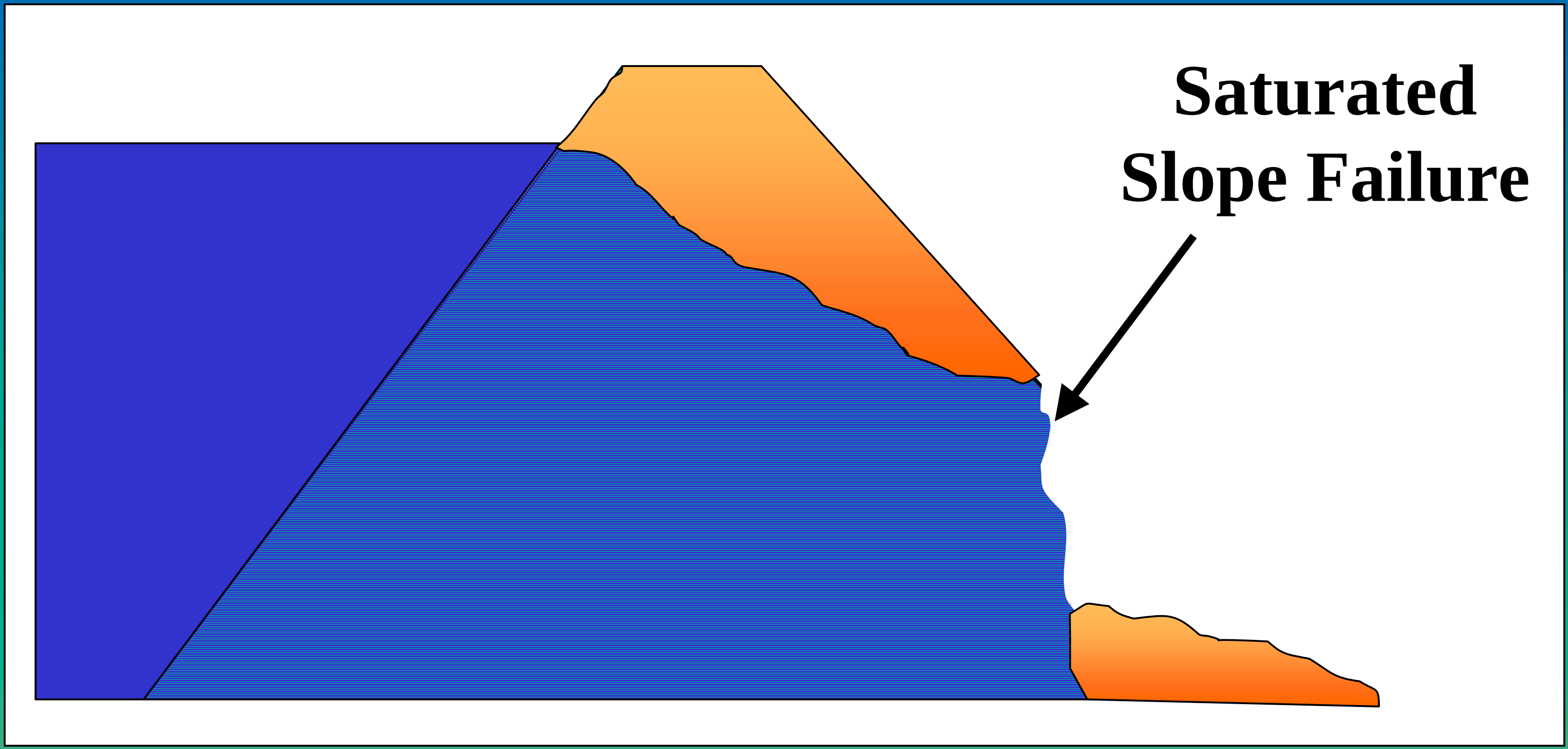
FILTER DIAPHRAGM



Foundation Failure

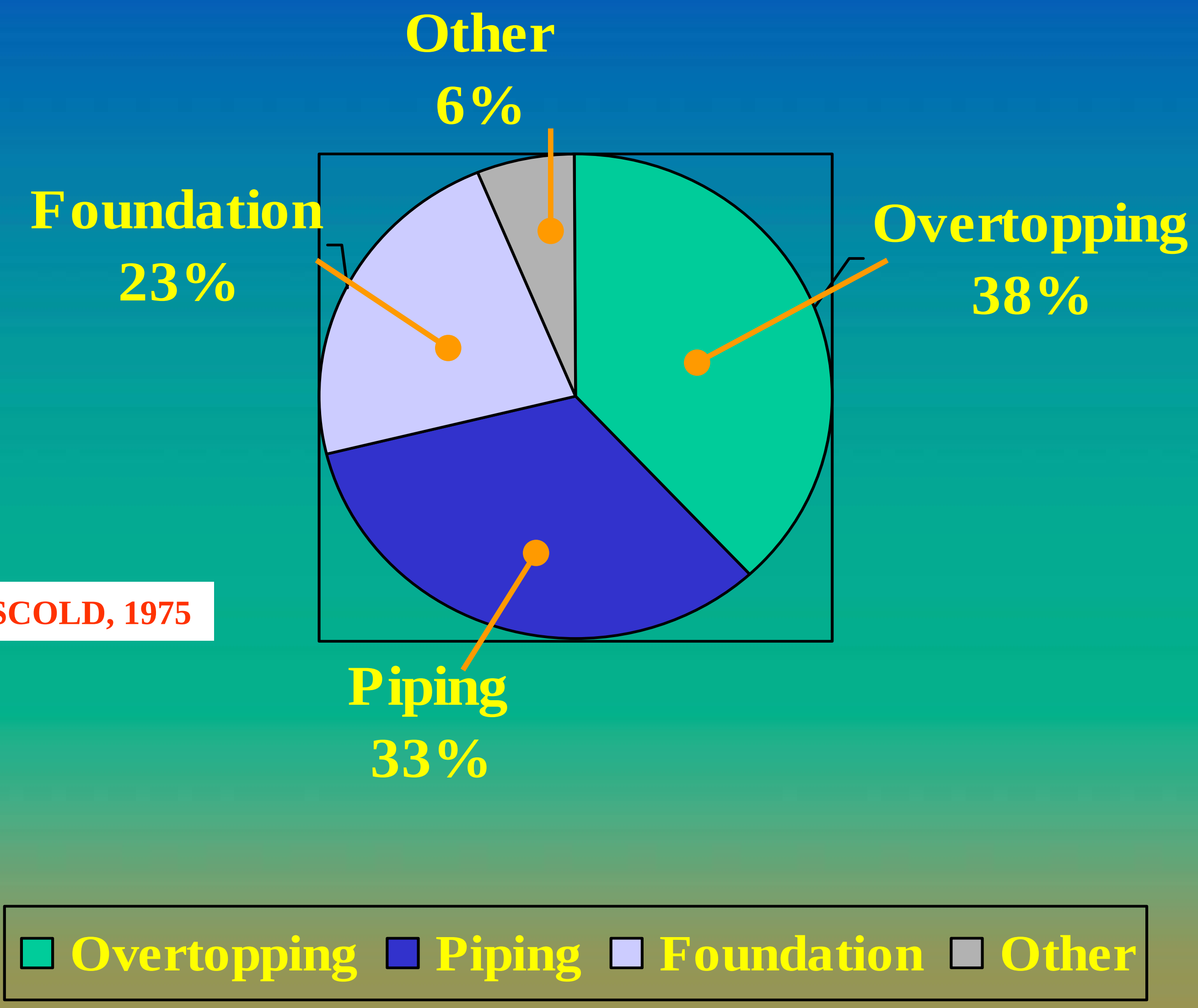


Slope Failure



Structural Failure

Types of Dam Failures



Source: ASCE/USCOLD, 1975

Dam Hazard Classifications

• Low Hazard	=	Class "a"
• Significant Hazard	=	Class "b"
• High Hazard	=	Class "c"

MDE Dam Hazard Classifications

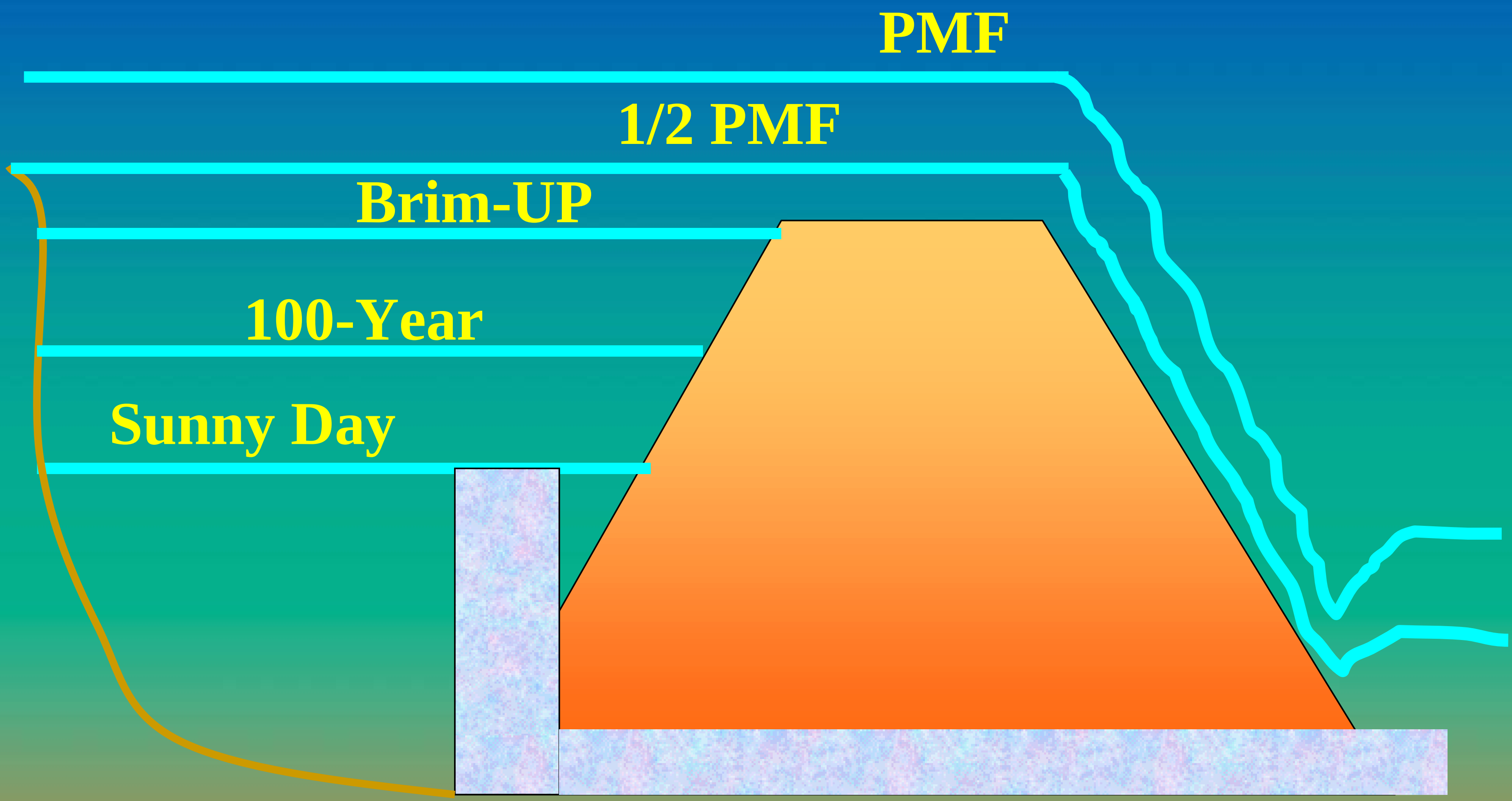
- Low Hazard - **Potential loss of life is very** unlikely **due to low danger flood depths.**

- Significant Hazard - **Potential loss of life is** possible **with no more than 6 lives in jeopardy and flooding to no more than two isolated houses and downstream roads.**

- High Hazard - **Potential loss of life is** very likely **with more than 6 lives in jeopardy, and serious damage to residential, commercial, or industrial buildings, and downstream roads.**

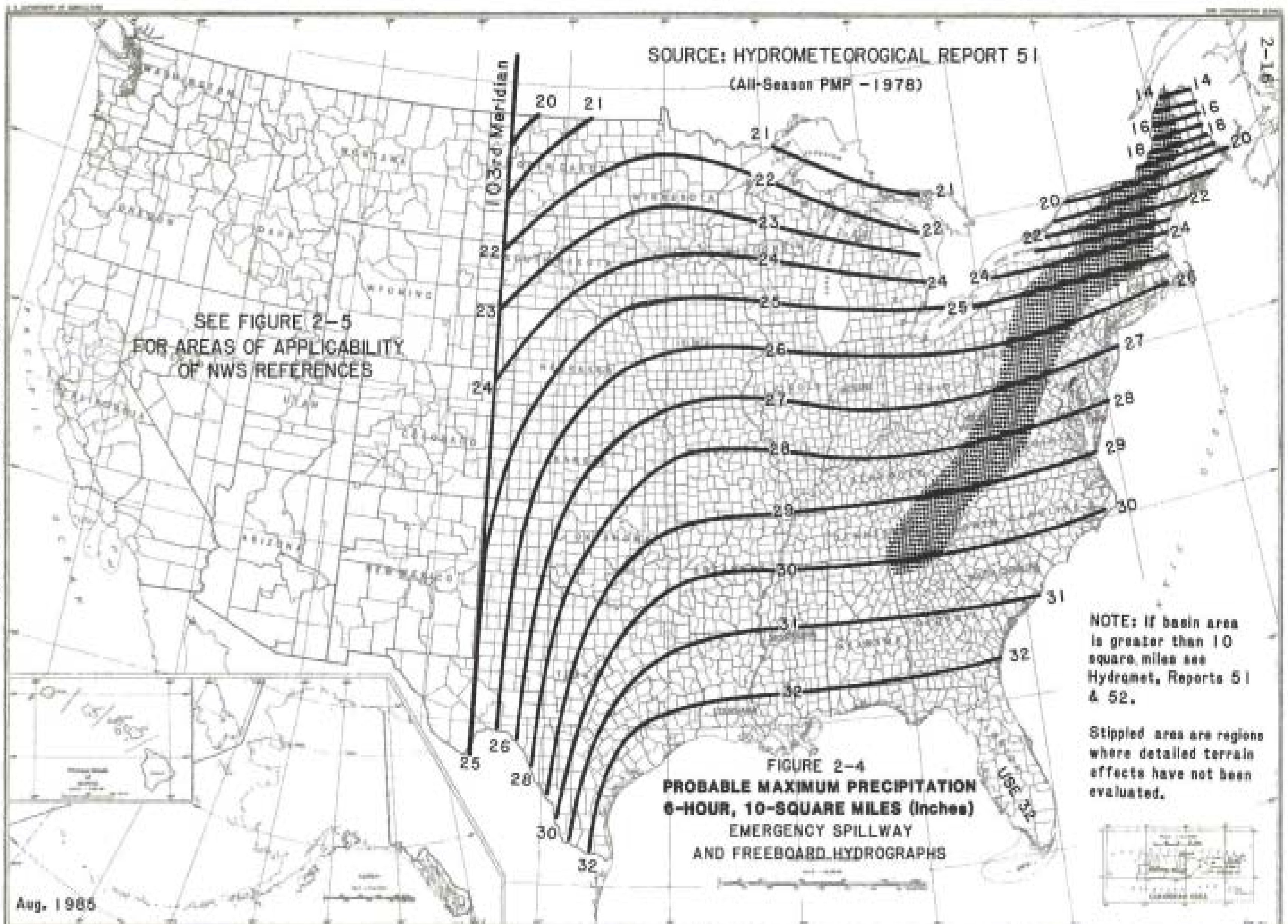
Dam Break Analysis

Failure Storms to Analyze



Probable Maximum Flood (PMF)

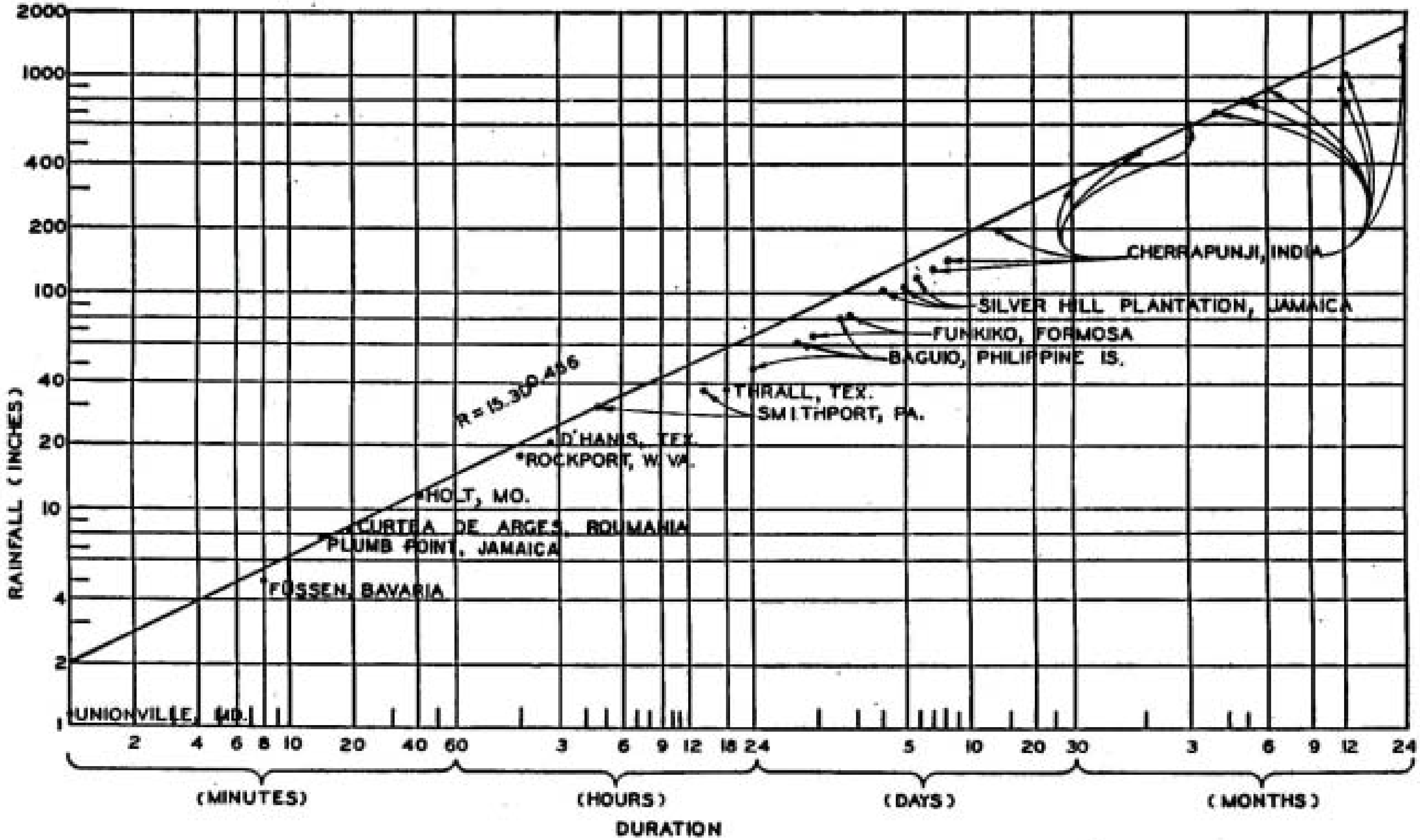
PMF - the largest flood considered possible based on the most severe combination of meteorological and hydrologic conditions that are reasonably possible.



SOURCE: HYDROMETEOROLOGICAL REPORT 51
(All-Season PMP - 1978)
2-16
(210-VI-TR60, OCT. 1985)
103rd Meridian
SEE FIGURE 2-5
FOR AREAS OF APPLICABILITY
OF NWS REFERENCES
NOTE: If basin area is greater than 10 square miles see Hydromet. Reports 51 & 52.
Stippled areas are regions where detailed terrain effects have not been evaluated.
USE 32
FIGURE 2-4
PROBABLE MAXIMUM PRECIPITATION
6-HOUR, 10-SQUARE MILES (Inches)
EMERGENCY SPILLWAY
AND FREEBOARD HYDROGRAPHS
Aug. 1985

WORLD RECORD RAINFALL AMOUNTS

SOURCE: JENNINGS, A. H. WORLD'S GREATEST OBSERVED POINT RAINFALL. MONTHLY WEATHER REV., VOL 78, 1950



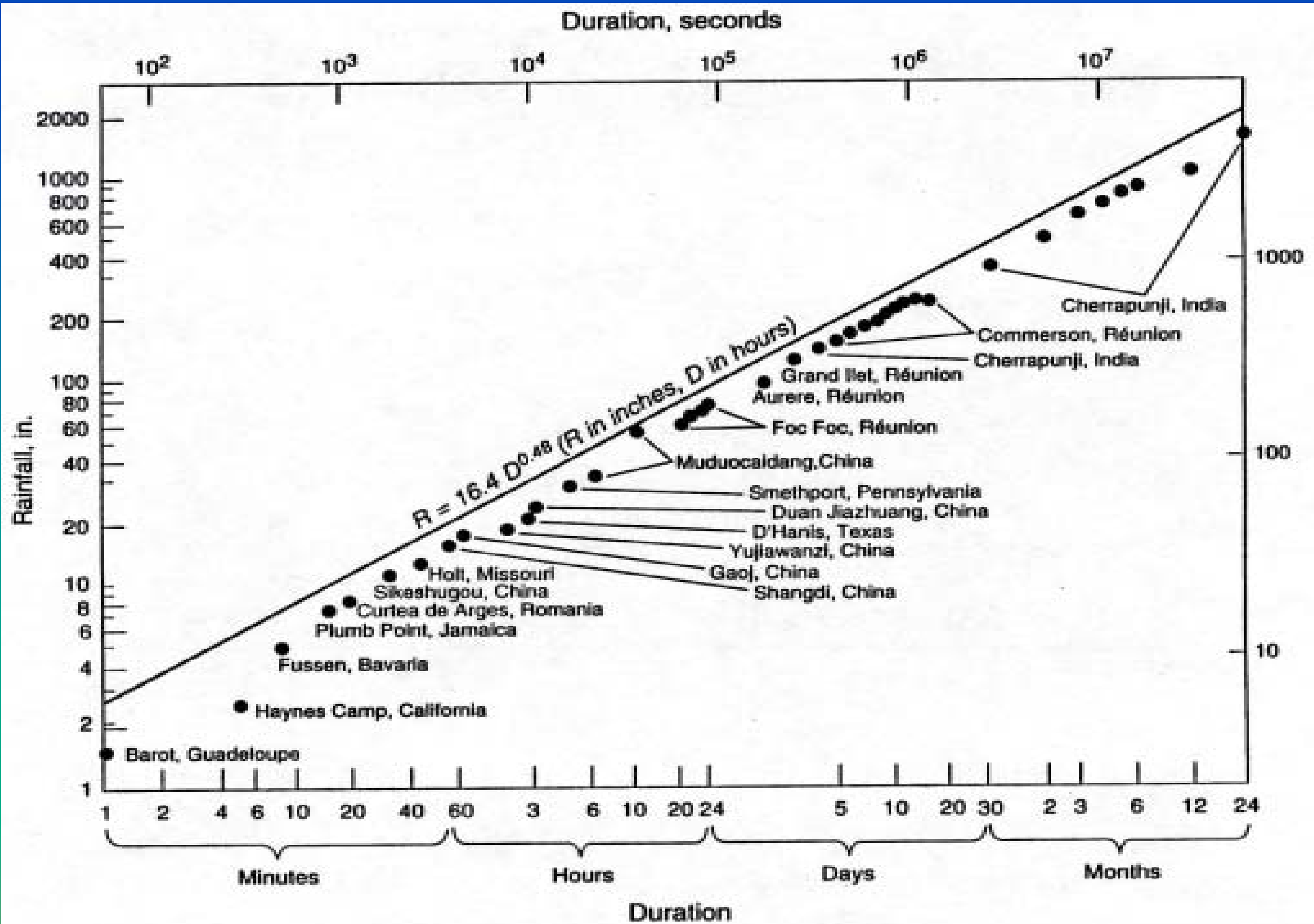
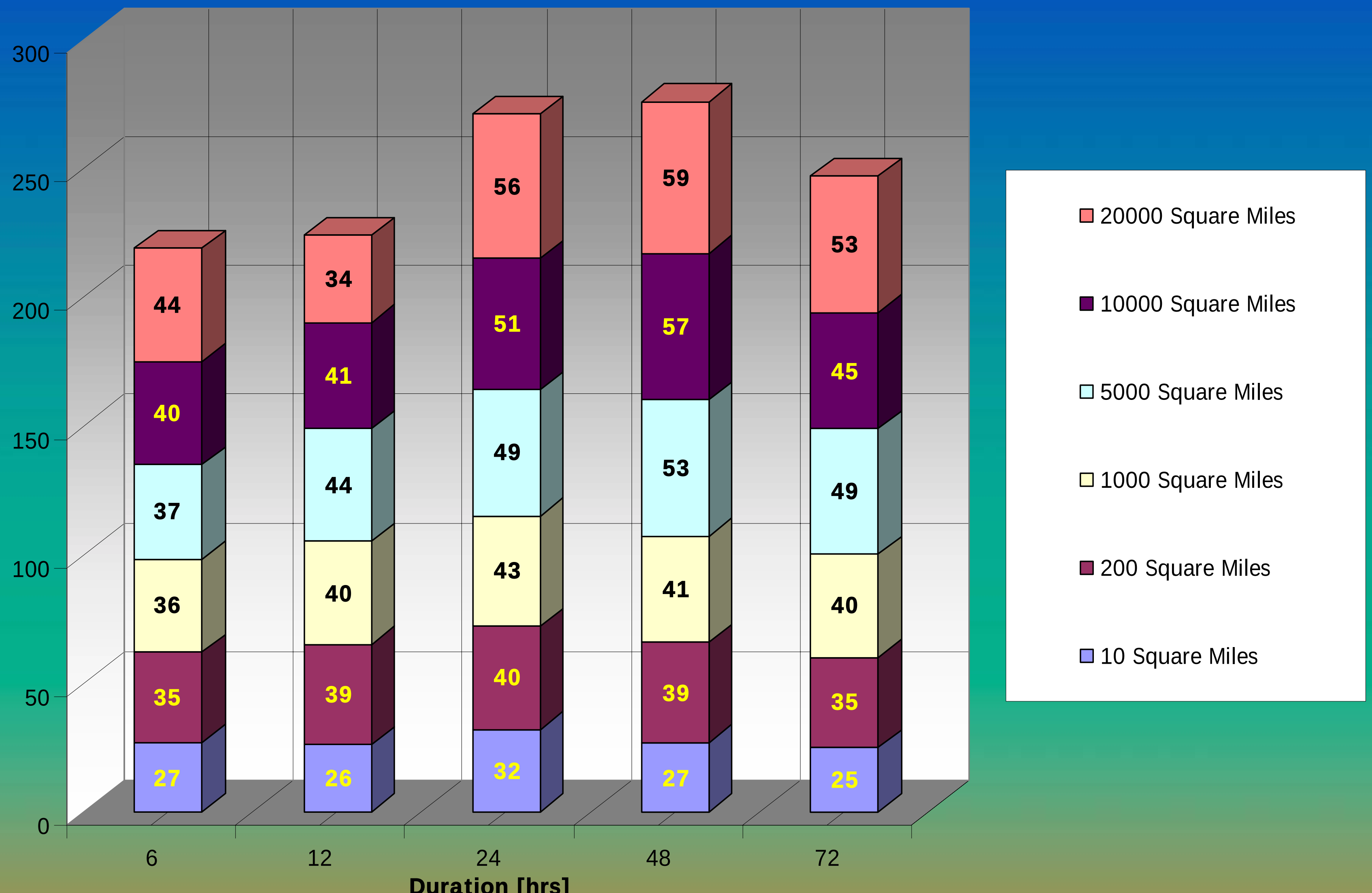


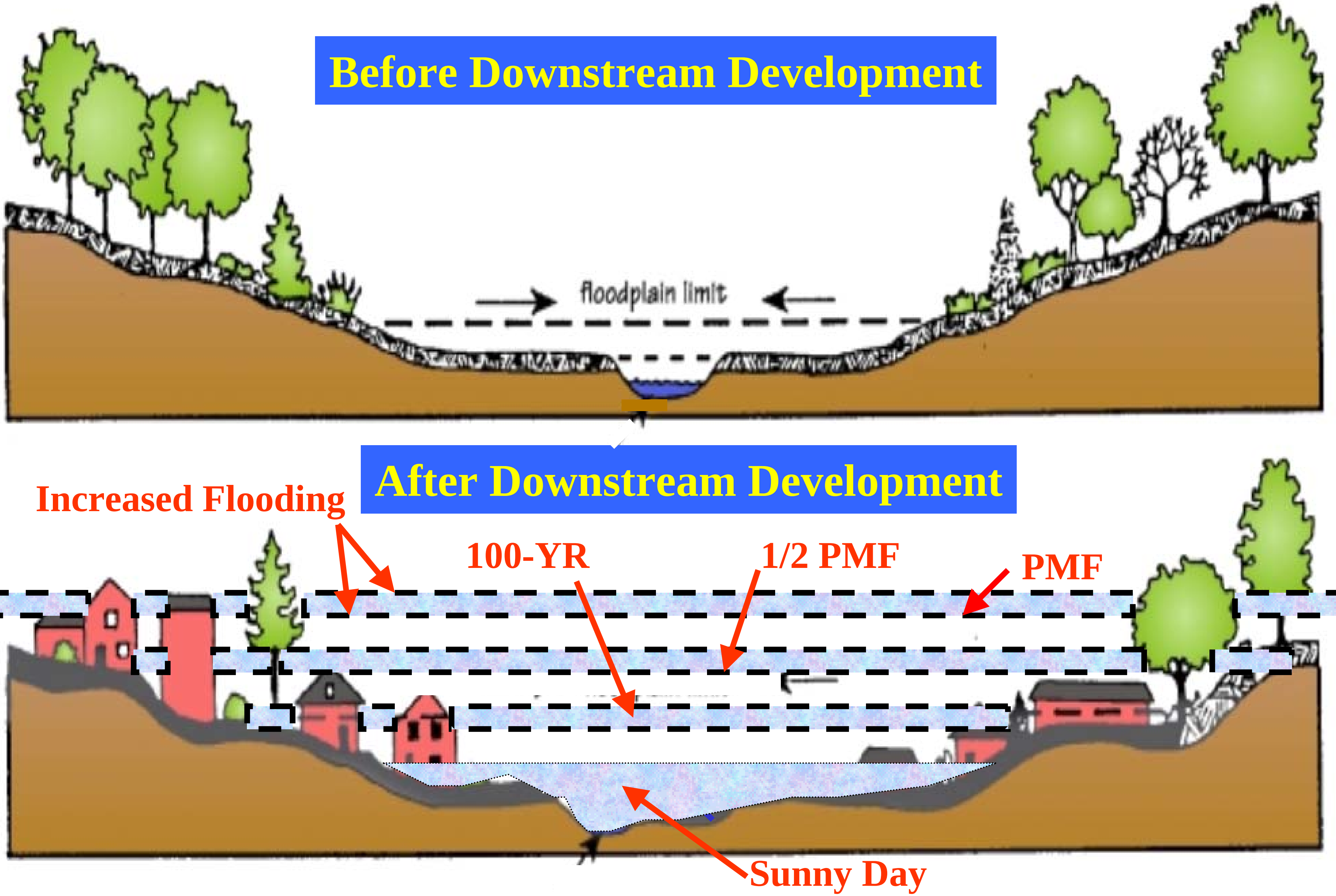
FIGURE 1 Maximum observed point rainfalls as a function of duration. (Courtesy of John Vogel, National Weather Service.), 1986.

Rainfall Greater than 50% PMP



Source: NWS, HMR 51, 1983 (?)

Increased Flood Risks



Dam Break Models

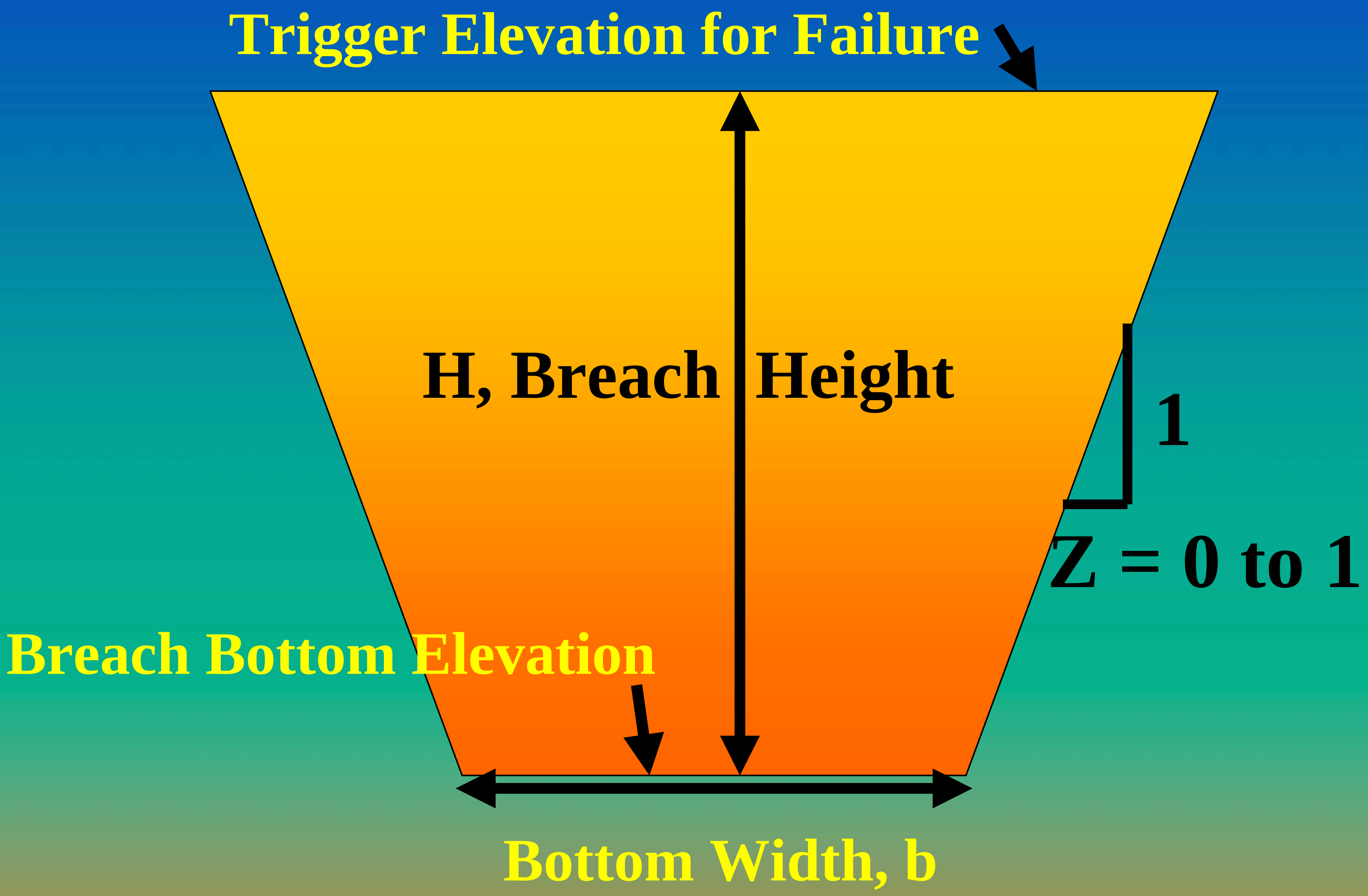
- HEC-1 Computer Model
  - Develop & Route Hydrographs
  - Fail Dam with NWS Dam Break Method
  - Route Breach Hydrograph Downstream
  - Route Through & Over Downstream Roads or Dams

Breach Parameters for HEC-1 Model

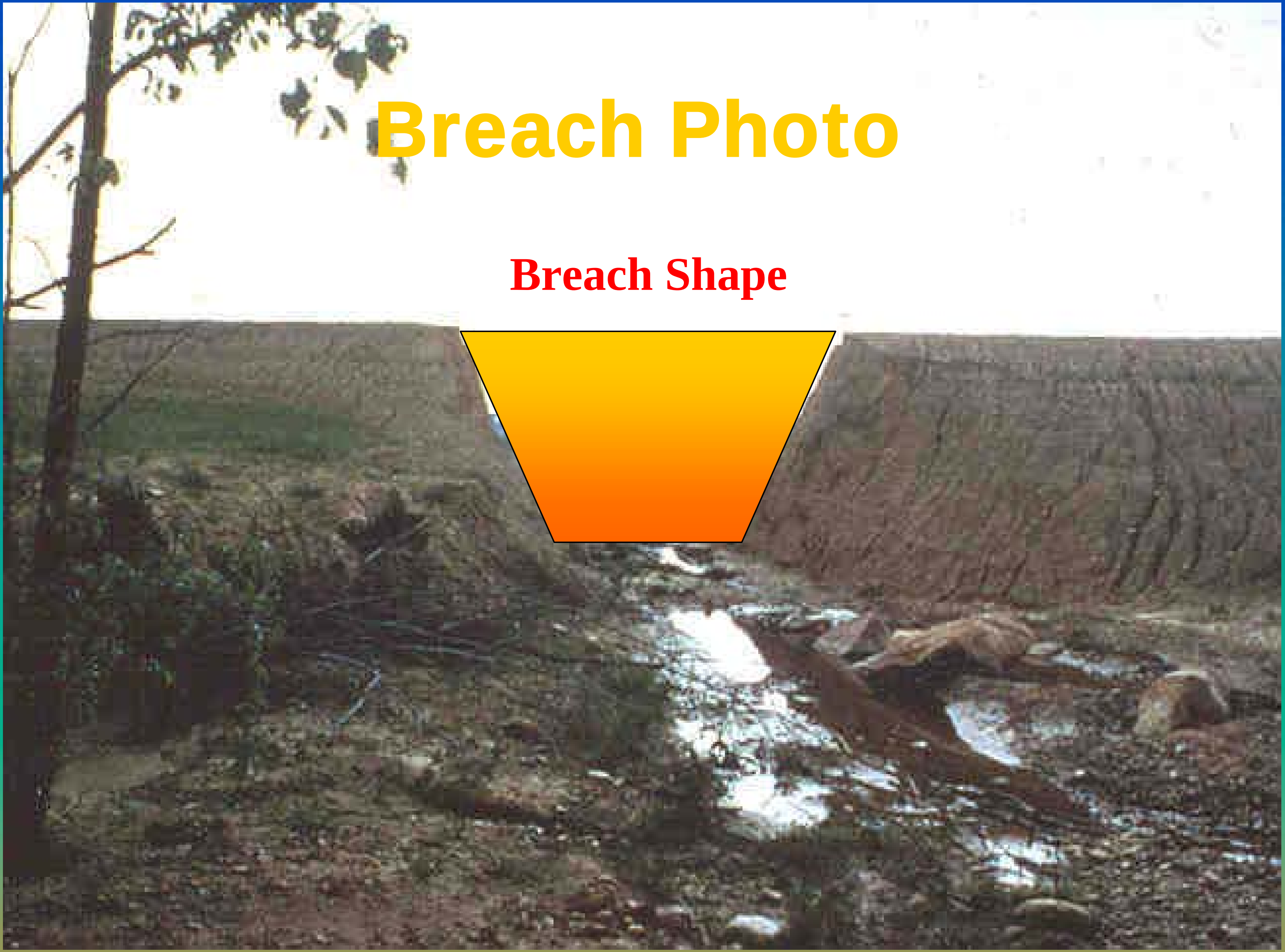
- Breach Bottom Elevation
- Breach Top Elevation (Trigger Elevation)
- Bottom Breach Width
- Breach Side Slope
- Time of Failure

- HEC-HMS – New Windows Model

Breach Parameters



Breach Photo



Suggested Breach Parameters for Earth Dams

Source	Average Breach Width (ft)	Breach Side Slope (1V:ZH)	Breach Failure Time (hrs)
NWS (1988)	1H to 5H	Z = 0 to 1	0.1 to 2.0
COE (1980)	0.5H to 4H	Z = 0 to 1	0.5 to 4
FERC (1991)	1H to 5H	Z = 0 to 1	0.1 to 1.0
USBR (1982)	3H	N/A	0.00333b
Boss Dambrk (1988)	0.5 to 4H	Z= 0 to 1	0.5 to 4
Harrington (1999)	1H to 8H	Z= 0 to 1	H/120 to H/180

Froelich Breach Predictor Equations

$$b = 9.5 K_0 (V_s H)^{0.25}$$

$$\tau = 0.59 (V_s^{0.47}) H^{0.91}$$

b = Average Breach Width (ft),

= Time of Failure (hrs)

K_0 = 0.7 for Piping & 1.0 for Overtopping Failure

Vs = Storage Volume (ac-ft)

H = Selected Failure Depth (ft) above Breach Bottom

τ **= Time of Failure (hrs, ~H/120 or Minimum of 10 Min)**

Dam Break Models

NWS Simple Dam Break Equation

$$Q_b = Q_0 + 3.1 B_r \left(C / \left(T_f + C/\sqrt{H}\right)\right)^3$$

Q_b = Breach + Non-Breach Flow (cfs)

Q_o = Non-Breach Flow (cfs)

B_r = Final Average Breach Width (ft, ~ 1H to 5H)

C = 23.4 As/Br

A_s = Reservoir Surface Area (ac) at Failure Elevation

H = Selected Failure Depth (ft) above Final Breach Elevation

T_f = Time of Failure (hrs, ~H/120 or Minimum of 10 Min)

NWS Simple DAMBRK Equation

100-Year Failure for Your Dam

BREACH FLOW EQUATION:

$$Q_b = Qo + 3.1\ Br(C/Tf + C/H^{1/2})^3,$$

WHERE,

Q_b = BREACH FLOW + NON-BREACH FLOW (cfs)
Qo = NON-BREACH FLOW (cfs)
Br = FINAL AVERAGE BREACH WIDTH (ft, APPROX. 1H TO 5H)
C = 23.4*As/Br
As = RESERVOIR SURFACE AREA (ac) AT MAXIMUM POOL LEVEL
H = SELECTED FAILURE DEPTH (ft) ABOVE FINAL BREACH ELEVATION
Tf = TIME TO FAILURE (hrs, USE H/120 OR A MINIMUM OF 10 MIN)

INPUT VARIABLES:

Qo =	0	cfs
As =	5.00	ac
H =	20.0	ft

OUTPUT VARIABLES:

SELECTED BREACH WIDTHS Br, [ft]		TIME OF FAILURE T_f, [hrs]	COMPUTED C VALUE	MAXIMUM BREACH FLOW Q_b,[cfs]	
20.0	[H]	0.17	5.85	3844	
30.0	[1.5H]	0.17	3.90	4875	
40.0	[2H]	0.17	2.93	5545	
50.0	[2.5H]	0.17	2.34	5961	
60.0	[3H]	0.17	1.95	6196	
70.0	[3.5H]	0.17	1.67	6303	
80.0	[4.0H]	0.17	1.46	6318	
100.0	[5.0H]	0.17	1.17	6175	
35.4	Froelich	0.22	3.31	4508	<SELECTED FLOW
35.4	Froelich	0.17	----	2847	= Vs/T_f

DEVELOPED BY BRUCE HARRINGTON, 9/92

BREACH PREDICTOR EQUATIONS

Recently some statistically derived predictors for average breach width (b) and time of failure (Tf) have been developed by MacDonald and Langridge-Monopolis (1984) and Froelich (1987,1995). From Froelich's work in which he used the properties of 63 breaches of dams ranging in height from 12 to 285 feet, with 6 dams greater than 100 feet, the following predictor equations were obtained:

$$b = 9.5Ko(VsH)^{0.25}$$

$$T_f = 0.59(Vs^{.47})/(H^{.91})$$

where,

b = average breach width (ft),
T_f = time of failure (hrs),
Ko = 0.7 for piping and 1.0 for overtopping failure
Vs = storage volume (ac-ft), and
H = height (ft) of water over breach bottom

BREACH WIDTH & TIME OF FAILURE FOR

NWS Simple DAMBRK Equation
100-Year Failure for Your Dam

INPUT VARIABLES:		OUTPUT PARAMETERS:	
H =	20.0 ft	b =	35.4 ft
Vs =	40.0 ac-ft	T_f =	0.22 hrs
Ko =	0.7		

DEVELOPED BY BRUCE HARRINGTON, 9/92, REVISED 10/96

Dam Break Models

- SCS (NRCS) Breach Formula

$$Q_b = 3.2H^{5/2}$$

  - Usually Conservative Estimate of Breach Flow but not Always
  - Storage Volume not included in Formula
  - Similar to a V-Notch Weir Formula

COMPARISON OF DAM BREACH EQUATIONS

NWS SIMPLE DAMBRK vs NRCS BREACH EQUATIONS

NWS SIMPLE DAMBRK EQUATION:

$$Q_{NWS} = 3.1 B_r (C/T_f + C/\sqrt{H})^3$$

NRCS MD-378 EQUATION:

$$Q_{NRCS} = 3.2 H^{2.5}$$

Br = 3H (Breach Width, ft)
H = Height of Water at failure, ft
C = 23.4As/Br = 7.8As/H
As = Surface Area at Failure (acres)
T_f = H/120 (Failure Time, hrs)
= Minimum Time of 10 min = 0.17 hrs

H [ft]	As [ac]	T_f [hrs]	C	Q_{NWS} [cfs]	Q_{NRCS} [cfs]
5.0	0.3	0.17	0.47	88	179
5.0	1.0	0.17	1.56	270	179
5.0	5.0	0.17	7.80	451	179
10.0	0.3	0.17	0.23	79	1012
10.0	1.0	0.17	0.78	610	1012
10.0	5.0	0.17	3.90	1996	1012
15.0	0.5	0.17	0.26	184	2789
15.0	1.0	0.17	0.52	696	2789
15.0	5.0	0.17	2.60	4117	2789
20.0	1.0	0.17	0.39	648	5724
20.0	3.0	0.17	1.17	3705	5724
20.0	10.0	0.17	3.90	9750	5724
40.0	10.0	0.33	1.95	10605	32382
40.0	20.0	0.33	3.90	26012	32382
40.0	40.0	0.33	7.80	46207	32382

Dam Break Models

- NWS Simple Dam Break Equation
  - Developed from NWS Full Dam Break Model
  - Based on Falling Head Weir Flow
  - Input Non-Breach Flow, Surface Area, Selected Failure Depth, & Time of Failure

Dam Break Models

- NWS Simple Dam Break Model
  - Easy to Use
  - Uses NWS Simple Dam Break Equation for Breach Flow
  - Uses Dynamic Routing of Flood Wave
  - Input Downstream Cross Sections
  - Will Not Route through Downstream Structures

Dam Break Models

- NWS Full Dam Break Model (DAMBRK)
  - Very Difficult to Learn & Temperamental
  - Uses Unsteady State Dynamic Routing by a Finite Difference Technique
  - Includes Pressure & Acceleration Effects
  - A Hydrograph must be Inputted
  - Has Been Replaced by NWS Flood Wave Model (FLDWAV), Free Download at: http://hsp.nws.noaa.gov/oh/hrl/rvrmech/rvrmain.htm

PRETTYBOY DAM DANGER REACH

A COMPARISON OF NWS DAMBRK & HEC-1 MODELS

Template Cross Sections

Miles Below Dam	**** Discharge **** NWS [cfs]	HEC-1 [cfs]	**** Elevation **** NWS [NGVD]	HEC-1 [NGVD]	Elev. Change [feet]
Dam	509947	508554	538.1	538.1	----
1.49	474643	477837	426.3	416.4	9.9
5.37	414066	405271	390.3	388.2	2.1
9.70	385871	364986	353.4	352.0	1.4
14.20	349989	334765	326.0	310.5	15.5
18.18	335059	299656	310.7	311.1	-0.4

Recommended Dam Failure Methods for Small Dams < 15 feet High

- Use NWS SMPDBK and SCS Breach Equation to determine Breach Flows
- Use HECRAS Model to determine Downstream Flood Depths
- Stop Danger Reach when roads flood < 1.5 feet, and Flooding to Houses & Buildings < 6 inches

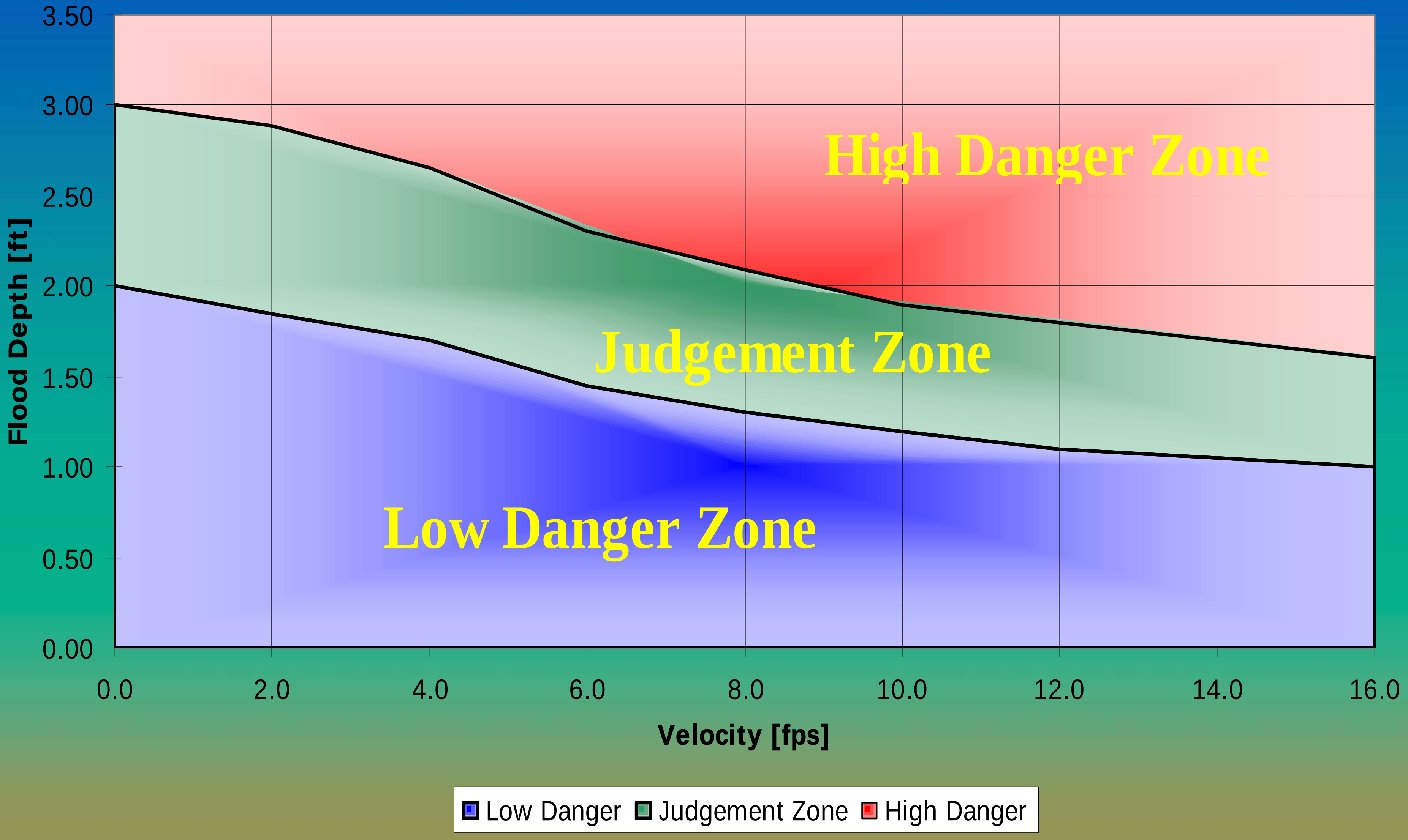
Recommended Dam Failure Methods for Dams > 15 & < 75 feet high

- Use Hec-1 Model for Breach Flows
- Use HECRAS Model to determine Downstream Flood Depths & USBR Hazard Charts to determine Flood Dangers
- Stop Danger Reach when Increased Flooding < 1 foot or no structures flooded

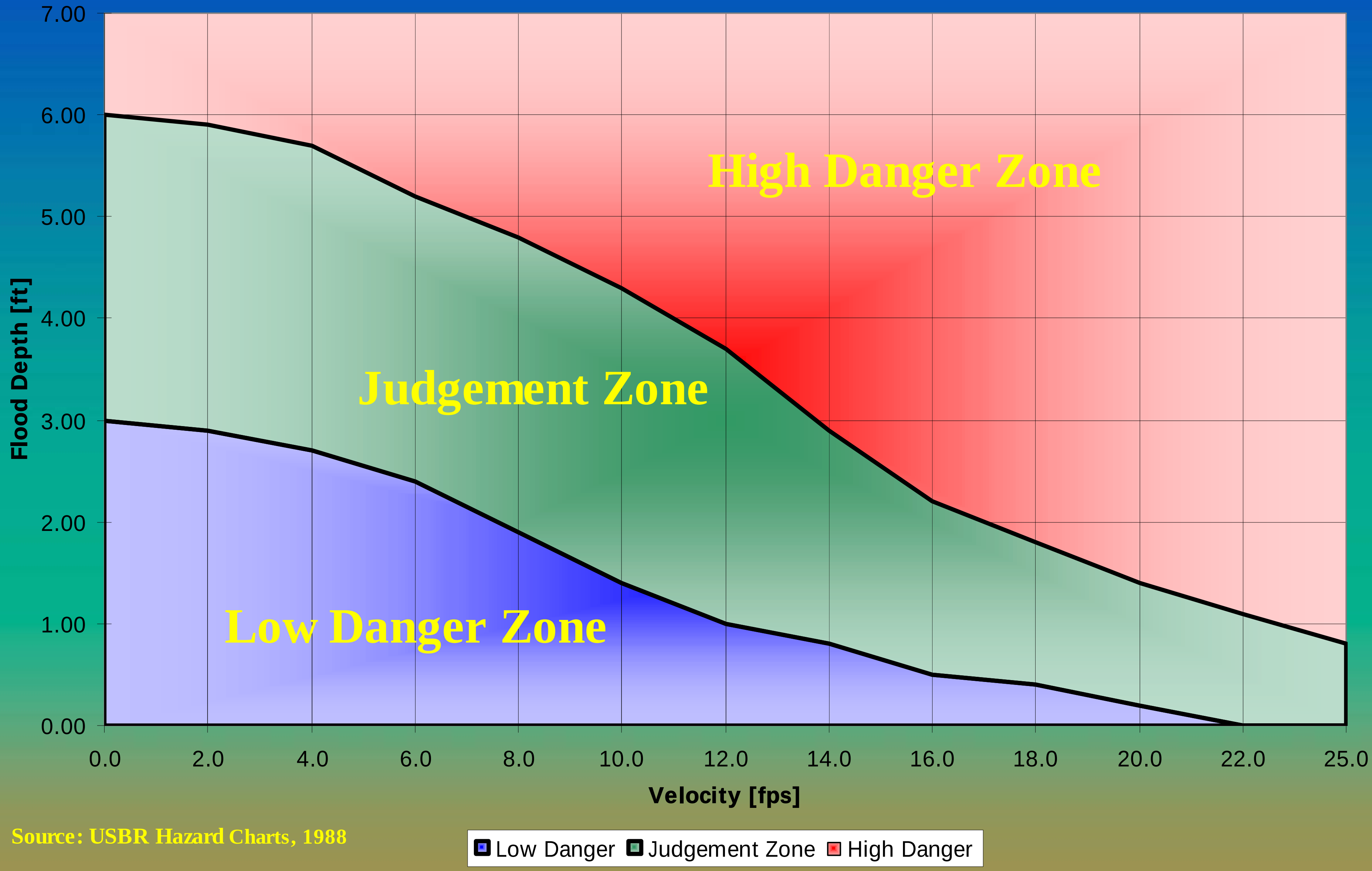
Recommended Dam Failure Methods for Dams > or = 75 feet high

- Use HMR-52 & HEC-1 Model for Hydrology
- Use DAMBRK or FLDWAV Model for Breach Flow
- Suggest Checking DAMBRK and FLDWAV Results with HECRAS Model

Flood Danger for Cars

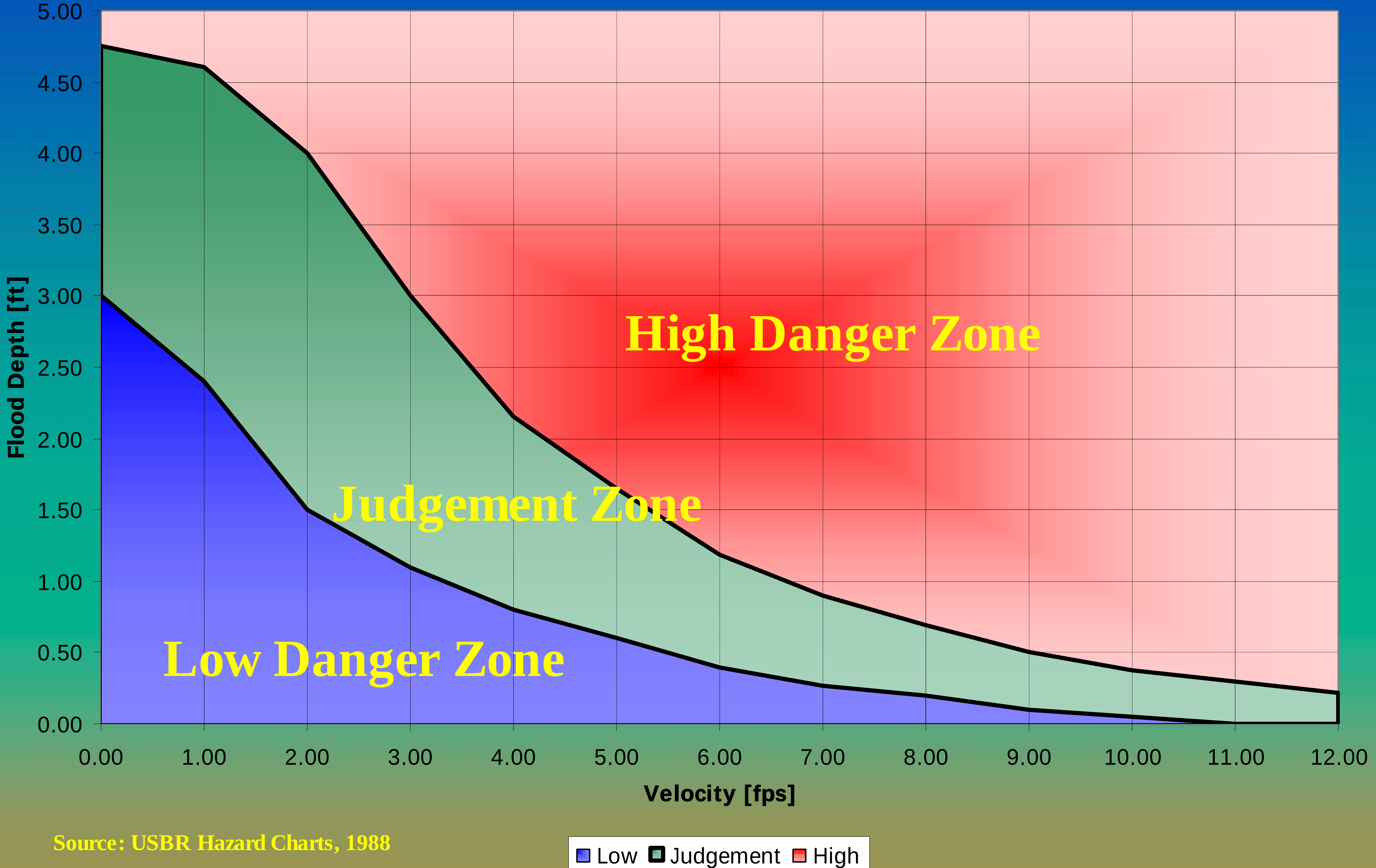


Flood Danger for Houses



Source: USBR Hazard Charts, 1988

Flood Danger for Adults

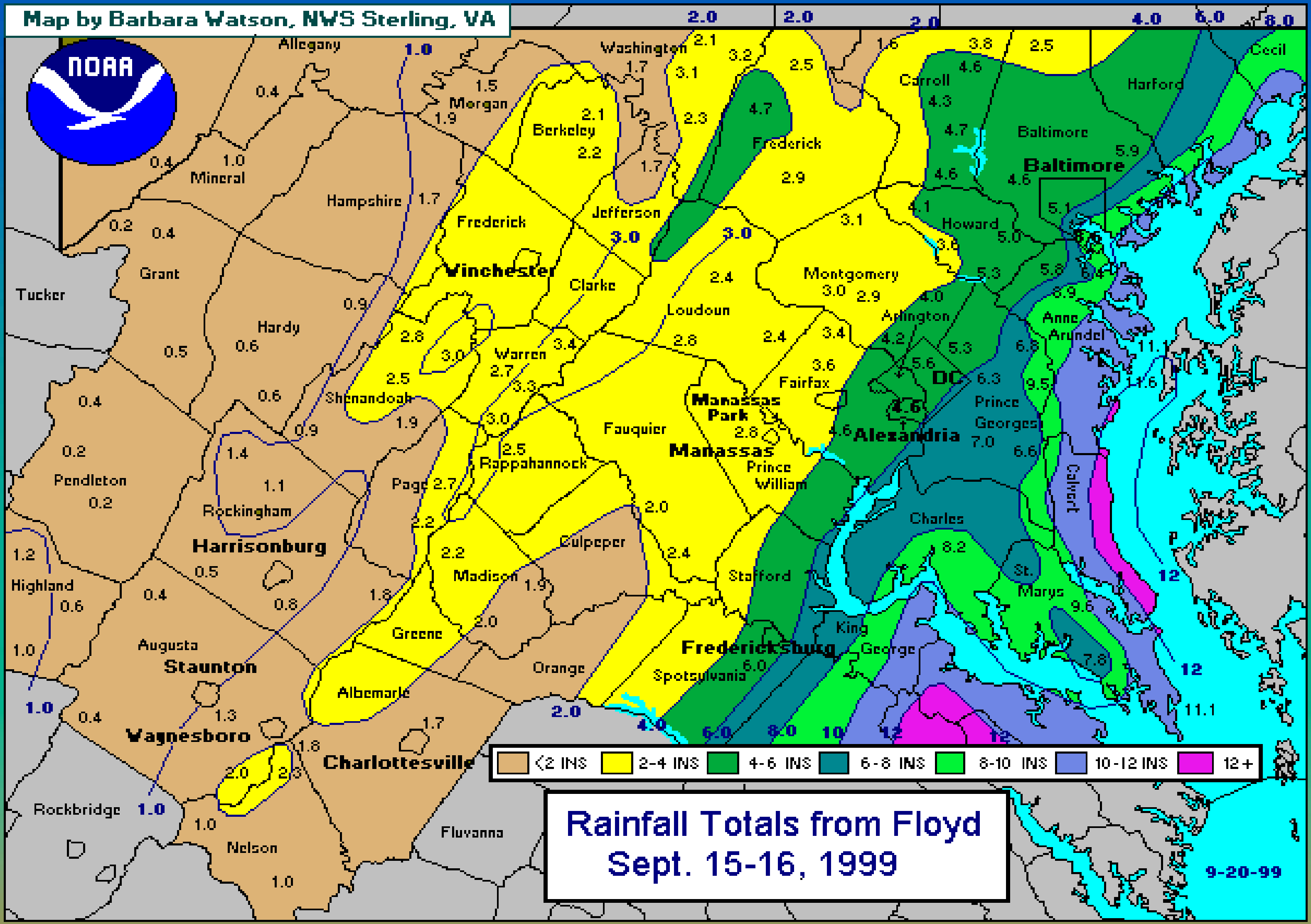


Source: USBR Hazard Charts, 1988

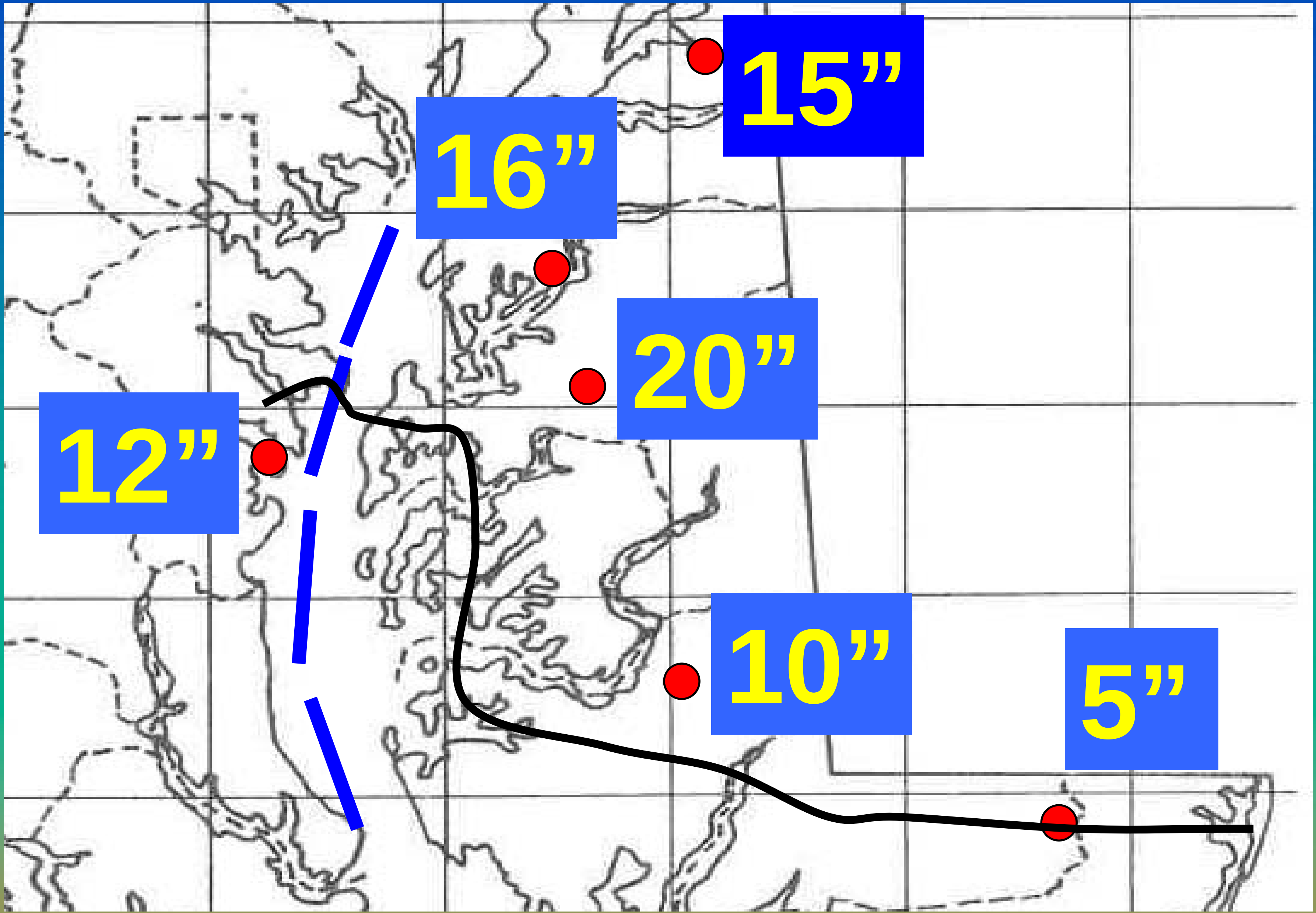
Hurricane Floyd

September 15-16, 1999

Rainfall from Hurricane Floyd, Sept 99



Hurricane Floyd Rainfall on Eastern Shore



Nagel Mill Dam before Floyd

Nagel Mill Dam after Floyd

Nagel Mill Dam after Floyd

Nagel Mill Dam after Repair

Nagels Breach Statistics

Piping Failure

Breach Width = 60 ft = 4H

Side Slope Z = 0.4

Time of Failure <20 min

Foreman Branch Dam before Floyd

Foreman Branch Dam after Floyd

Foreman Branch Dam after Floyd

Foreman Branch Dam after Repair

Foreman Dam Breach Statistics

Overtopping Failure

Breach Width = 85 ft = 8H

Side Slope Z = 0.5

Time of Failure <30 min

Frazer Mill Dam before Floyd

Frazer Mill Dam after Floyd

Frazer Mill Dam after Floyd

Frazer Dam Breach Statistics

Overtopping Failure

Breach Width = 120 ft = 6H

Side Slope Z = 0.6

Time of Failure Unknown

Jones Lake Dam before Floyd

Jones Lake Dam before Floyd

Jones Lake Dam after Floyd

Jones Lake Dam Breach Statistics

Piping Failure

Breach Width = 103 ft = 6H

Side Slope Z = 0.6

Failure Time Unknown

Sassafras Dam before Floyd

Sassafras Dam after Floyd

Sassafras Dam During Floyd

Sassafras Dam after Repair

Sassafras Dam During Repair

Sassafras Dam Breach Statistics

Overtopping Failure

Breach Width = 47 ft = 4H

Side Slope Z = 0.2

Failure Time = 15 Min

Stubbs Dam after Floyd

Stubbs Dam after Floyd

Stubbs Dam after Repair

Stubbs Dam Breach Statistics

Piping Failure

Breach Width = 30 ft = 2.5H

Side Slope Z = 0.2

Failure Time Unknown

Tuckahoe Dam after Floyd

Tuckahoe Breach below Spillway

St Pauls Emergency Spillway during Floyd

Boundary Dam Near Seattle Washington

Hoover Dam

One of the "Seven Modern Civil Engineering Wonders"

Location:
Black Canyon
Arizona & Nevada

Owner:
U.S. Bureau of Reclamation

Built:
1931-1935

Height:
726.4 ft.
Length:
1244 ft.
Max. Depth:
500 ft.
Storage:
28,537,000 ac.-ft.

Emergency Action Plan

Introduction

1) **Purpose**. The purpose of the Emergency Action Plan (EAP) is to safeguard lives and secondarily to reduce property damage in the event that ***(your dam)*** would fail. To carry out this mission, the EAP contains: 1) procedures to monitor ***(your dam)*** periodically and during flood warnings issued by the National Weather Service; 2) notify ***(County)*** Emergency Operation Center of a potential dam failure; and 3) warn and evacuate the isolated residences at risk. These procedures are to supplement and be used in conjunction with ***(your County's Emergency Operation Plan)***.

2) **Flood Description**. Failure of the dam could cause significant damage to ***(all roads and isolated residences downstream of your dam within the danger reach)*** located ___ miles downstream of ***(your dam)***.

OPERATING PROCEDURE

I. The dam will be inspected periodically each year for maintenance and distress signals.

II. The dam observer will inspect the dam when the National Weather Service issues a Flood Warning for the area and complete the following tasks.

1. The dam observer will note & record water levels in reservoir and the rate at which the pool is rising.
2. If the dam shows signs of internal piping (muddy seepage exiting the downstream embankment), erosion, slope failures, blocked spillways, or other ominous distress signs, the dam observer wil call the County Emergency Operation Center to send out police to roadblock downstream roads and warn any isolated residences in the danger reach. The dam observer may contact the Md Dam Safety Division or his designated engineer to provide assistance.
3. If the pool level rises too within one foot (or other levels accepted by MDE) of the dam crest, the dam observer will contact the County Emergency Operations Center to dispatch police to roadblock downstream roads and warn any isolated residences in the danger reach.

Emergency Action Plan

DAM NAME

Signatures of Persons Involved in Emergency Action Plan

)am Owner By ______________________ Date ___________

Typed Name: _________________
Title: _________________
Phone: (day) _________________
(night) _________________

:ounty Department of By ______________________ Date ___________
:mergency Operations

Typed Name: _________________
Title: _________________
Phone: (day) _________________
(night) _________________

.ocal or State Police By ______________________ Date ___________
;arracks "?"

Typed Name: _________________
Title _________________
Phone: (day) _________________
(night) _________________

/ID Department of the Environment By ______________________ Date ___________
)am Safety Division

Typed Name: Brad Iarossi
Title: Chief
Phone: 410-631-3538

)wner's Engineer By ______________________ Date ___________

PREVENTATIVE ACTIONS

If time allows, contact your engineer (__________________) and the Maryland Dam Safety Division for advice on preventative actions. Listed below are potential emergency actions which may prevent or delay the failure of the dam. They should be considered based on site-specific conditions, as well as the risk of failure and risk to employees.

Possible Actions To Be Taken In The Event Of:

Imminent Overtopping by Flood Waters:

1) Open drain or flood gates to maximum capacity.
2) Place sand bags along the dam crest to increase freeboard.
3) Place riprap or sandbags in damaged areas of dam.
4) Provide erosion protection on downstream slope by placing riprap or other appropriate materials.
5) Divert flood waters around dam if possible (such as emergency spillway)

Erosion of Dam by Seepage Through the Embankment, Foundation, or Abutments:

1) Plug the seepage with appropriate material such as (riprap, hay bales, bentonite, sandbags, soil, or plastic sheeting if the leak is on upstream face of dam).
2) Lower the reservoir level until the flow decreases to a non-erosive velocity or stops leaking.
3) Place a sand and gravel filter over the seepage exit area to minimize loss of embankment soils.
4) Continue lowering the reservoir level until the seepage stops or is controlled. Refill reservoir to normal levels only after seepage is repaired.

Slide or Slope Failure on Upstream or Downstream Slope of Embankment:

1) Lower the reservoir water level at a rate, and to an elevation that is considered safe. Contact your engineer or the Dam Safety

Emergency Action Plan

SUPPLIES AND RESOURCES

In an emergency situation, equipment and supplies may be needed on short notice. The following supplies and resources may be needed during an emergency: earthmoving equipment, sand and gravel, sandbags, riprap, pumps, pipe, laborers.

List of Contractors

It will be the responsibility of the owner to maintain the list of contractors that may be contacted during an emergency condition f equipments, materials, and repairs.

For each contractor on the list, the following information is needed:

- Contractor name
- Contact person.
- Address.
- Phone number.
- Equipment & repair supplies available.
- Arrival time to dam

1. Contractor: ______________________________
   Contact person: ______________ Phone No: ______________
   Address: ______________________________
   Services contracted for: ______________________________

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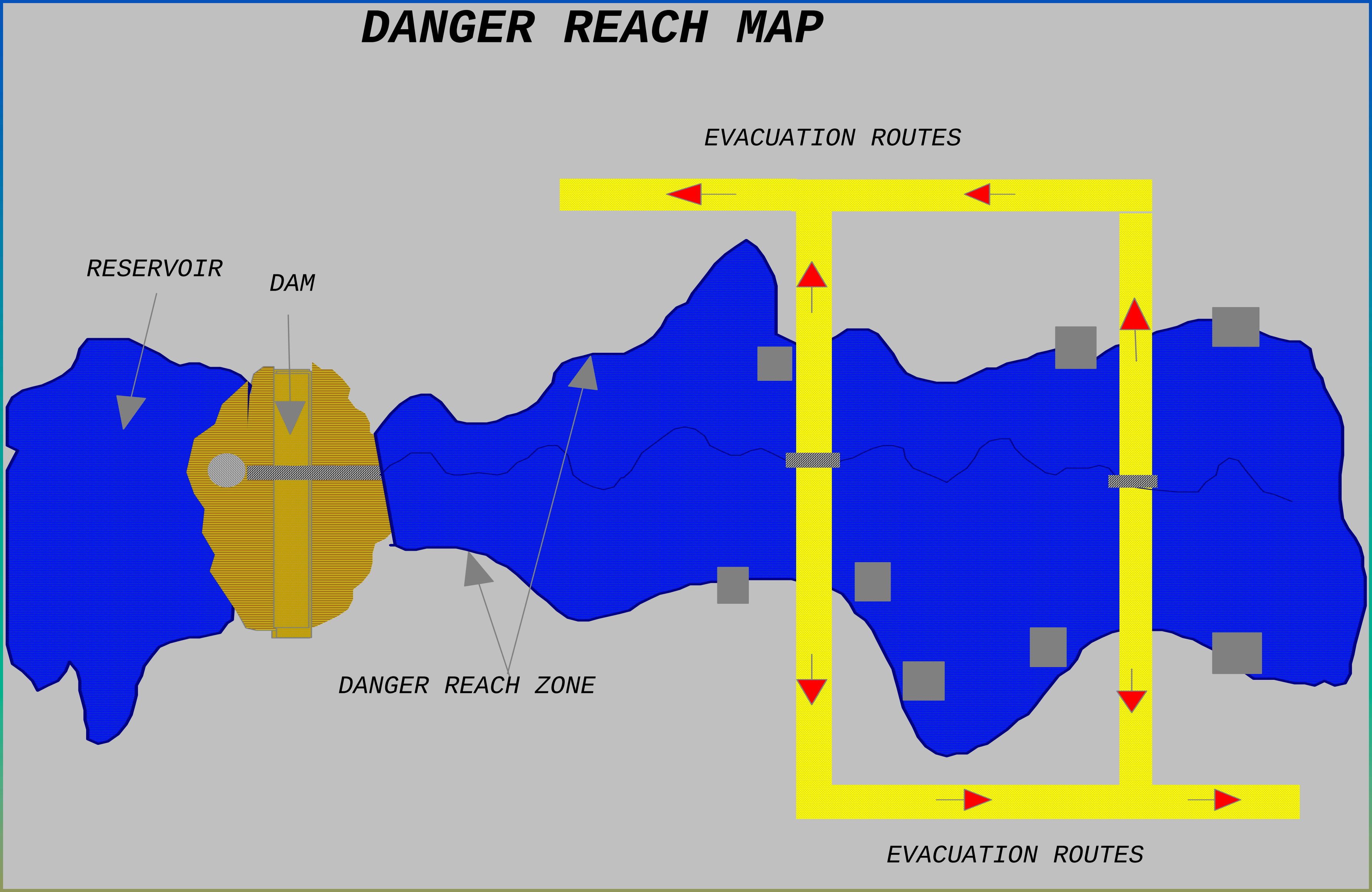
2. Contractor: ______________________________
   Contact person: ______________ Phone No: ______________
   Address: ______________________________

Emergency Action Plan



MDE Dam Break Web Site

ftp://ftp.mde.state.md.us/outgoing/Dam_Safety/

Microsoft Word Documents

- Hazard Guidelines
- Model Emergency Action Plans

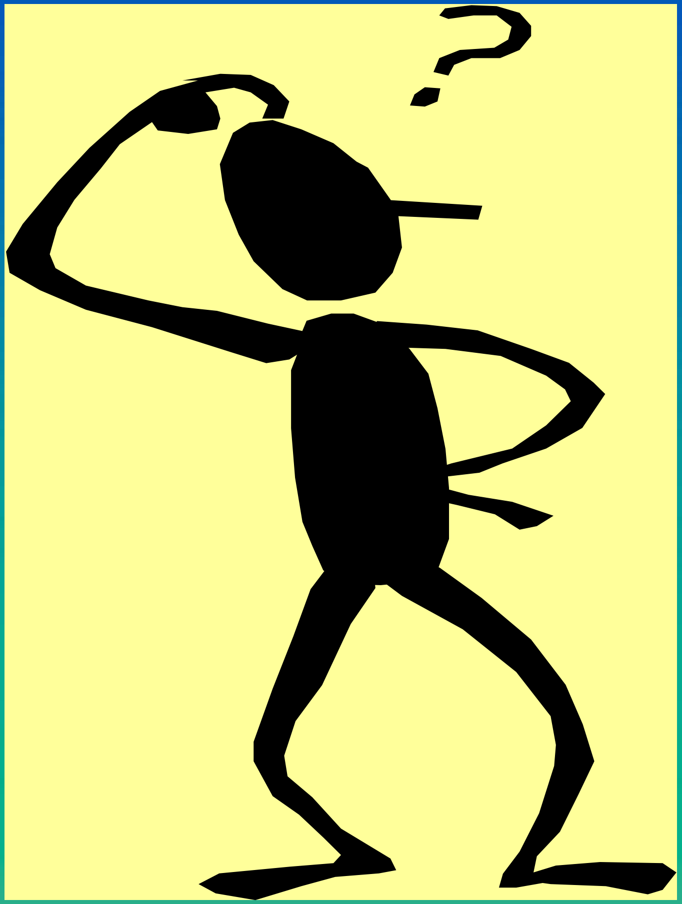
Microsoft Excel Spreadsheets

- NWS Dam Break Equation
- USBR Hazard Graphs
- Hydrology Spreadsheets
- Hydraulic Spreadsheets

Executable Programs

- HEC-1 Program
- NWS Simple Dam Break Program
- Sample Data for HEC-1 & NWS Simple Dam Break

Any Questions?



Bruce Harrington, MD Dam Safety, 410-334-3411