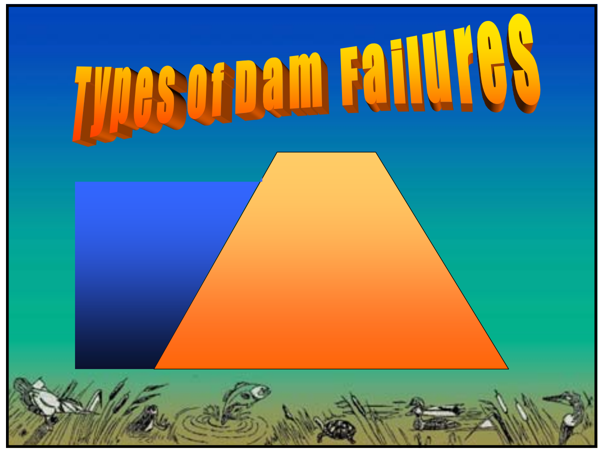
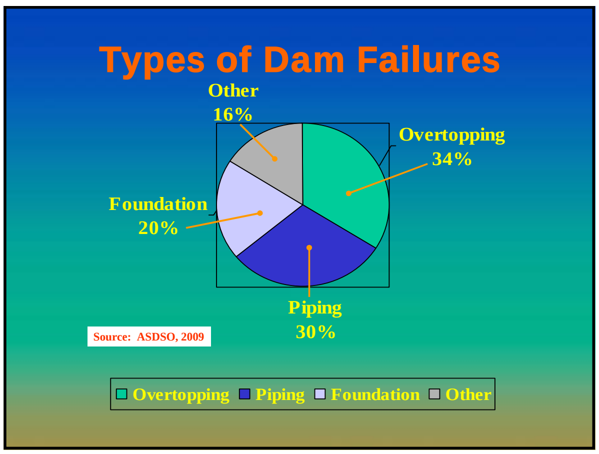
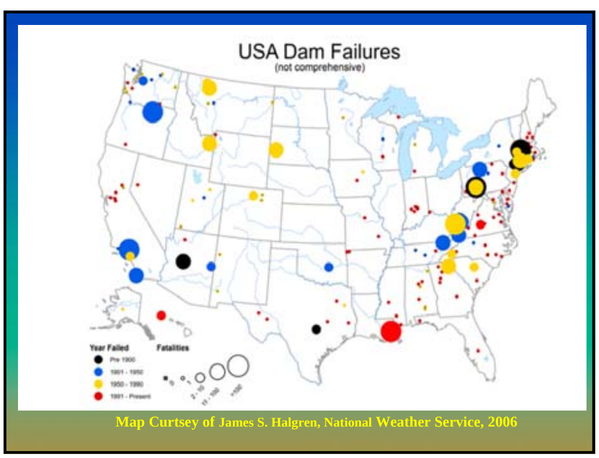
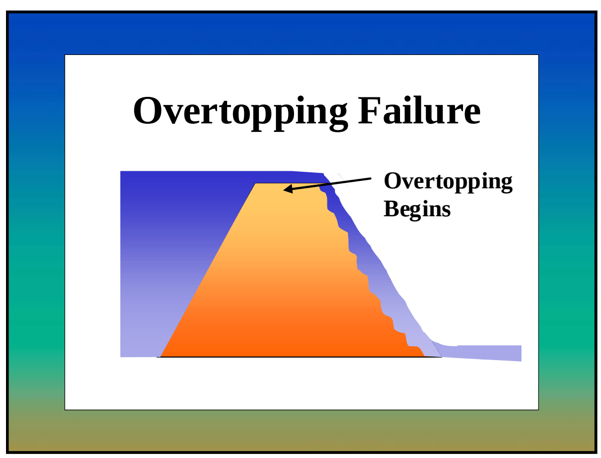


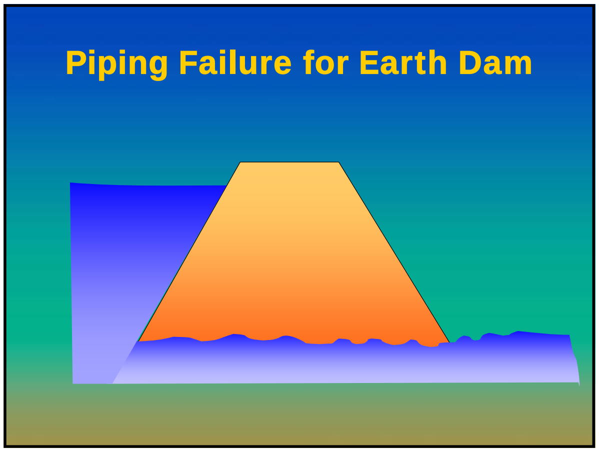


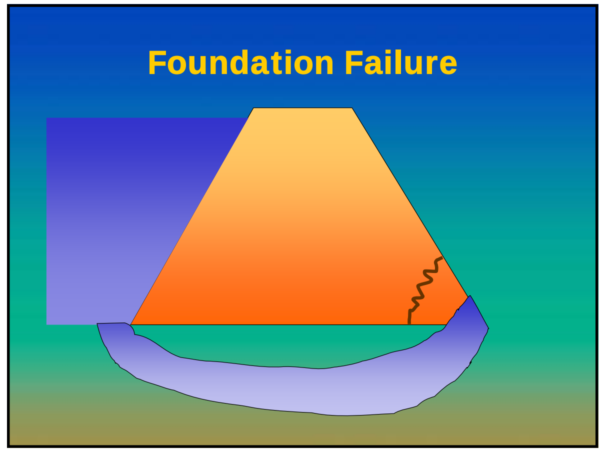
Other Causes of Dam Failures

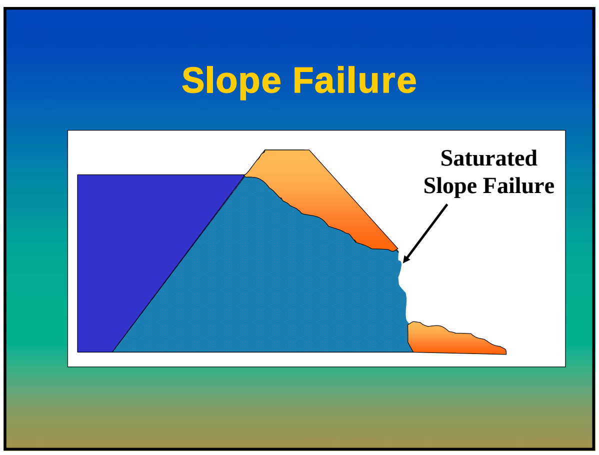
- Structural Failures
- Earthquake
- Trees
- Animal Burrows
- Poor Design
- Poor Construction
- Neglect / Lack of Maintenance
- Lightning

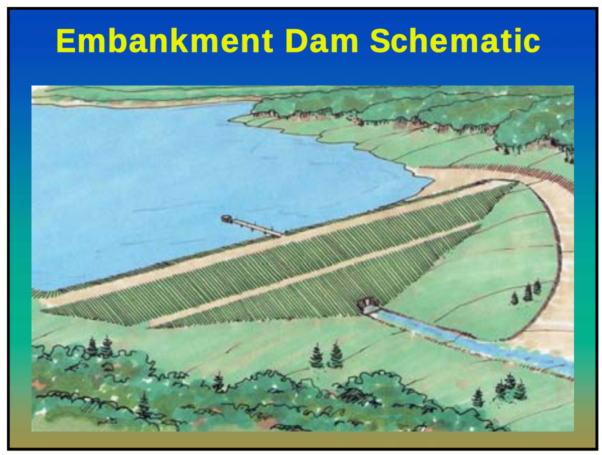




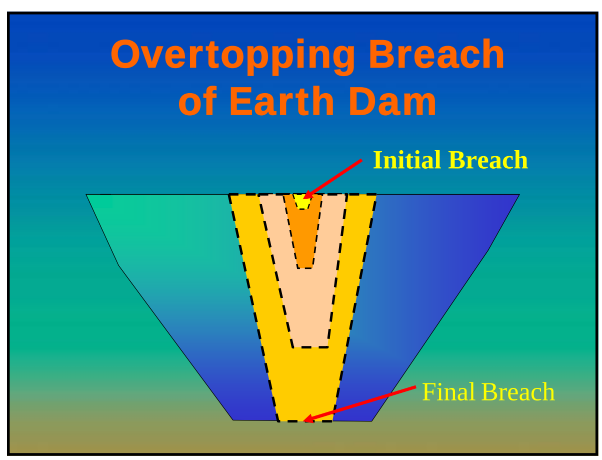

Piping Failure for Earth Dam

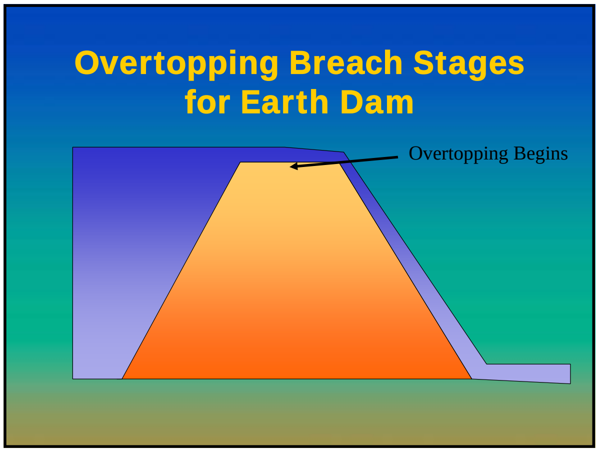

Foundation Failure

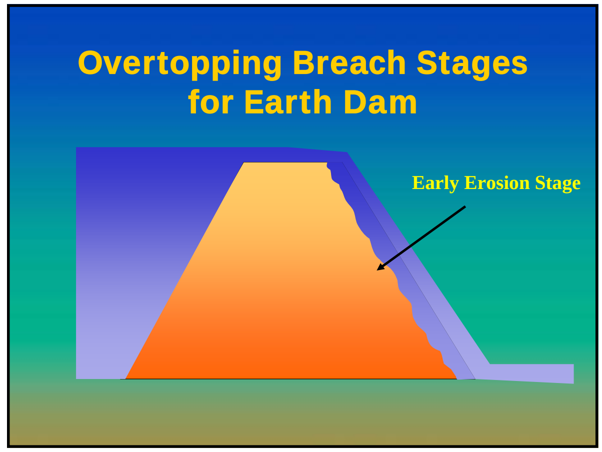

Slope Failure
Saturated
Slope Failure

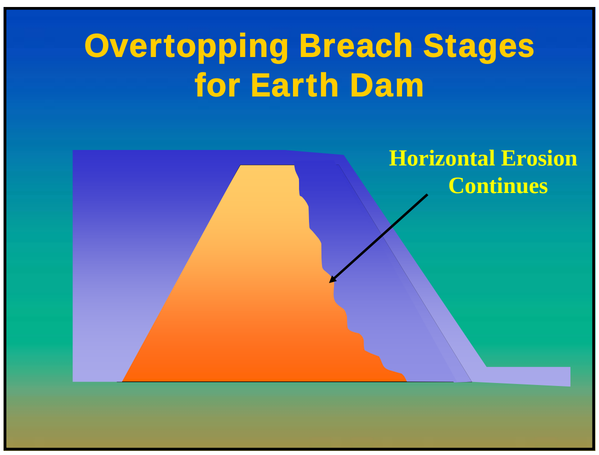

Embankment Dam Schematic

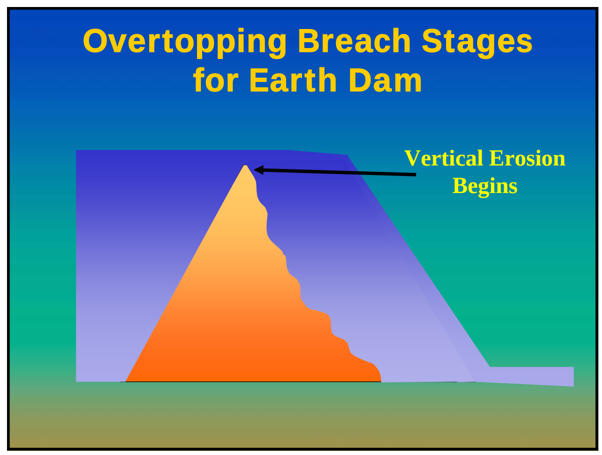

Dam Overtopping Photo

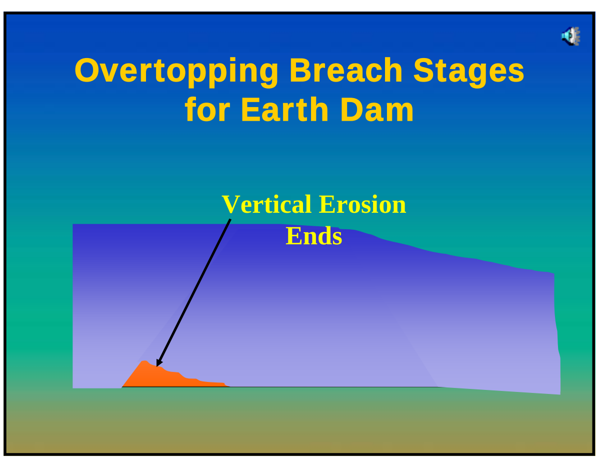

Overtopping Breach
of Earth Dam
Initial Breach
Final Breach

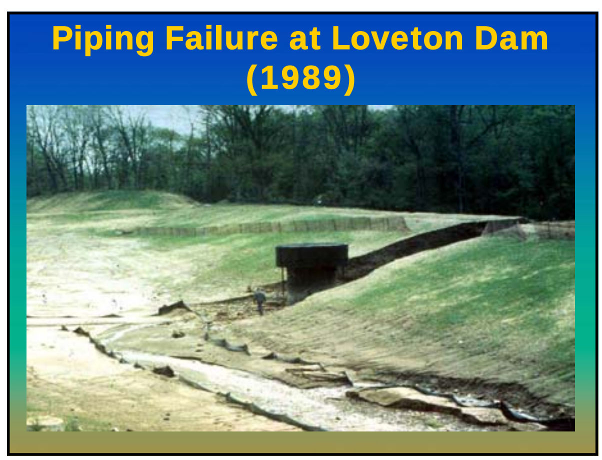

Overtopping Breach Stages
for Earth Dam
Overtopping Begins


Overtopping Breach Stages
for Earth Dam
Early Erosion Stage


Overtopping Breach Stages
for Earth Dam
Horizontal Erosion
Continues


Overtopping Breach Stages
for Earth Dam
Vertical Erosion
Begins

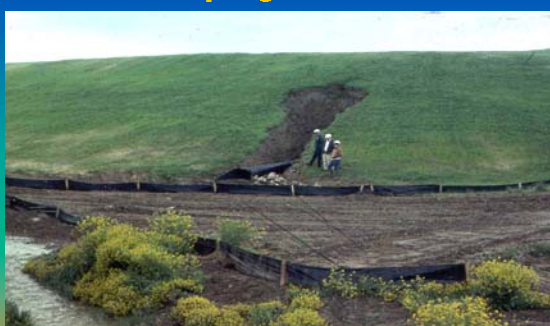

Overtopping Breach Stages
for Earth Dam
Vertical Erosion
Ends


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

Structural Failure

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.**

Loss of Life from Dam Failure Varies with Warning Time

Warning time < 15”,	Loss of Life = .5(PAR)
Warning time 15” to 90”,	Loss of Life = $PAR^{.6}$
Warning time > 90”,	Loss of Life = .0002(PAR)

Source: **“A Procedure for Estimating Loss of Life Caused by Dam Failure”, USBR, Wayne Graham, 1999**

Dam Break Analysis

Incremental Flood Analysis

Flood Conditions without & with Dam Failure

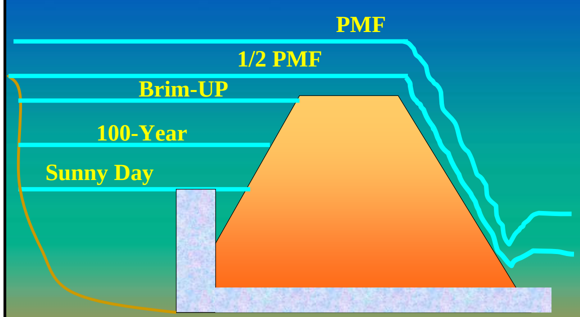
Storms to Evaluate

- **Sunny Day (Normal Pool)**
- **100-Year Storm**
- **Brim-up Storm (fill reservoir to top of dam)**
- **1/2 of Probable Maximum Flood**
- **Full Probable Maximum Flood**

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.

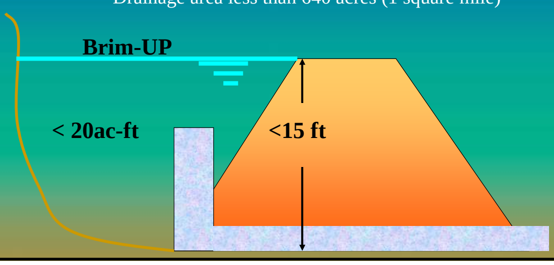
Failure Storms to Analyze



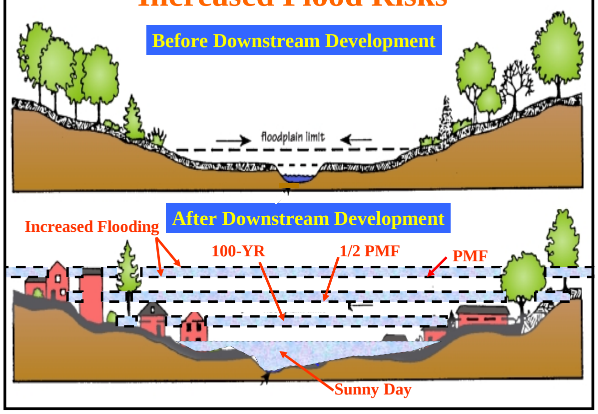
Small Dam or Pond

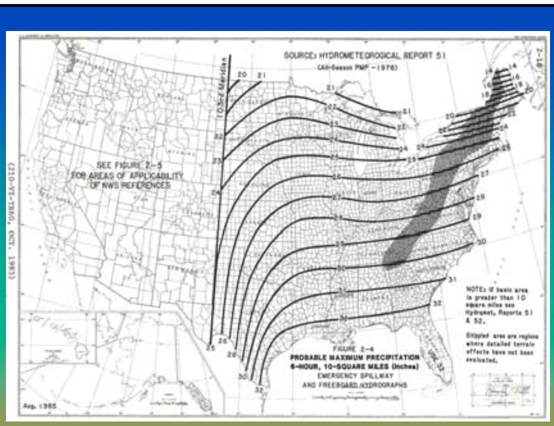
Use NWS Dam Break Equation

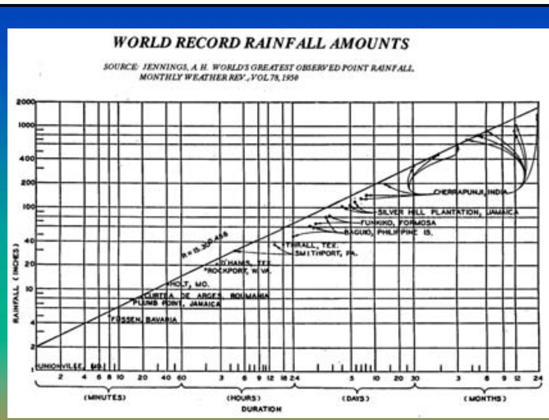
- 15 ft or less in height,
- Storage volume less than 20 acre-feet
- Drainage area less than 640 acres (1 square mile)



Increased Flood Risks







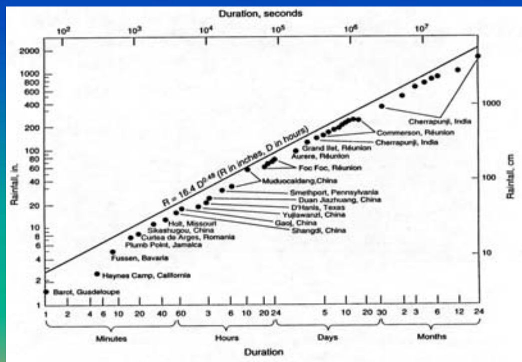
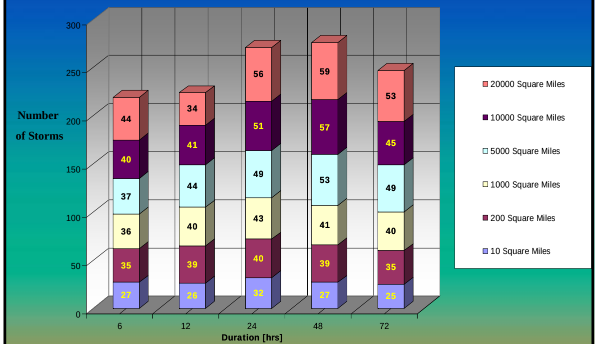


FIGURE 1 Maximum observed point rainfalls as a function of duration. (Courtesy of John Vogel, National Weather Service.). 1986.

Rainfall Greater than 50% PMP



Source: NWS, HMR 51, 1978

Hydrology for Dams

- **GISHydro2000 Model > 400 acres**
- **TR-20 Models**
- **HEC-1 Model**
- **HydroCad Model (new dam break added)**

Web Sites:

www.gishydro.umd.edu

www.hydrocad.net

Dam Break Models

- **HEC-1 Computer Model**
- **HECRAS Computer**
- **NWS DAMBRK or FLDWAV**
- **NWS Simple DAMBRK Equation**
- **HEC-HMS (New HEC-1 but not recommended)**

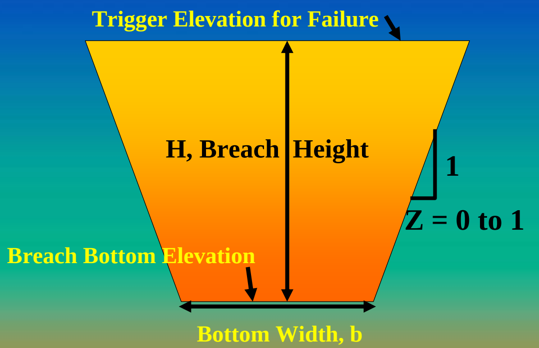
Learn HEC1 Model

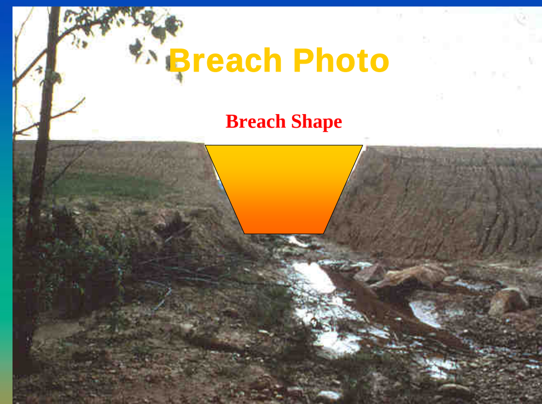
```
* ALL DATA IS ENTERED IN FIELDS OF 8 WITH TEN COLUMNS MAXIMUM UNLESS YOU
USE FREE FORMAT
* THE NEXT CARD ALLOWS YOU TO USE A FREE FORMAT WHERE YOU DON'T HAVE TO
WORRY ABOUT COLUMN LOCATIONS.  You place a comma between data entries.
*FREE
* THE NEXT CARD TELLS THE COMPUTER TO PRINOUT A TREE DIAGRAM OF THE
WATERSHED
*DIAGRAM
* THE NEXT THREE CARDS ARE PROJECT DESCRIPTION CARDS, USE ONE OR MORE OF
THESE CARDS
ID Your Dam Name, File Name (*.dat)
ID 100 YEAR ROUTING WITH & WITHOUT DAM FAILURE (DESCRIPTION)
ID HYDROLOGIC DATA OBTAINED FROM 11/79 SCS (USE AS MANY OR ONLY ONE ID
CARD
* Next card is the time computing ordinates 6 minutes interval and 300
ordinates
IT     6                      300
* The next card tells the computer how much to print out, recommend
minimum = 5
IO     5
* The next card says that there are 2 jobs (without failure & with
failure)
JP     2
```

Breach Parameters for HEC-1 Model

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

Breach Parameters





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

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

$$T_f = 0.59 (V_s^{0.47}) / H^{0.91}$$

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

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

Dam Break Models

NWS Simple Dam Break Equation

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

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)

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 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

Recommended Dam Failure Methods for Small Dams 15 feet or less in height

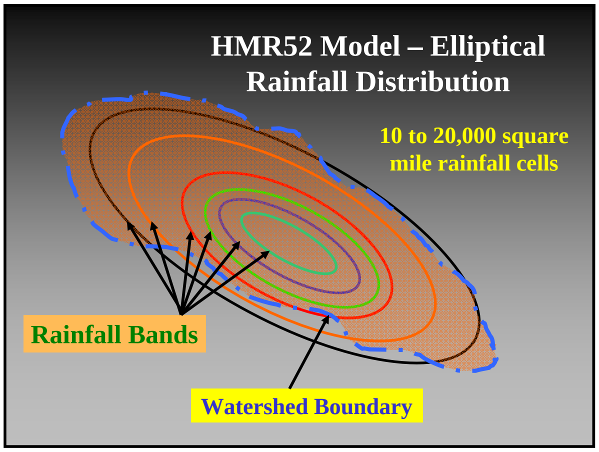
- Use NWS SMPDBK Equation to determine Breach Flows
- Use HECRAS Model to determine Downstream Flood Depths
- Stop Danger Reach when roads flood < 1.5 feet, and Flooding to Houses & Buildings < 6 inches

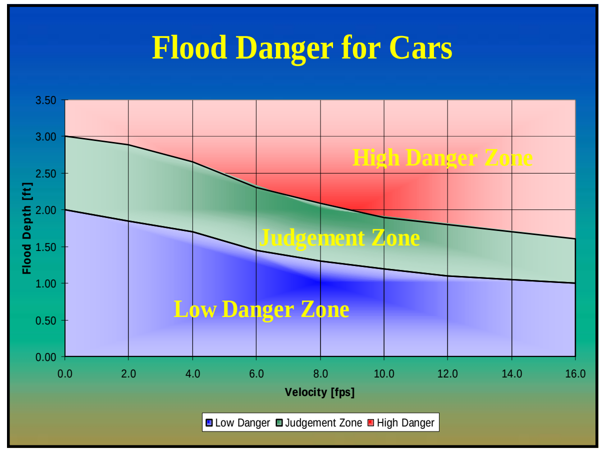
Recommended Dam Failure Methods for Dams > 15 & < 75 feet high

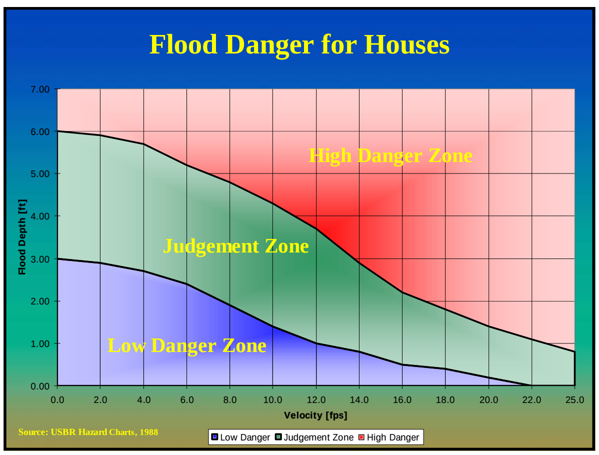
- Use Hec-1 Model for Breach Flows
- Use HECRAS Model to determine Downstream Flood Depths & USBR Hazard Charts to determine Flood Dangers
- Stop Danger Reach when Increased Flooding < 1 foot or no structures flooded

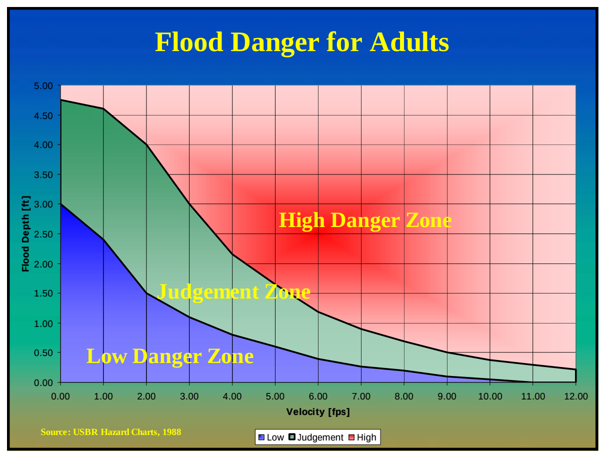
Recommended Dam Failure Methods for Dams > or = 75 feet high

- Use HMR-52 & HEC-1 Model for Hydrology
- Use HECRAS Model for Breach Flow
- Use the Unsteady HECRAS Model if feasible
- May also use DAMBRK , or FLDWAV Models for Breach Flow

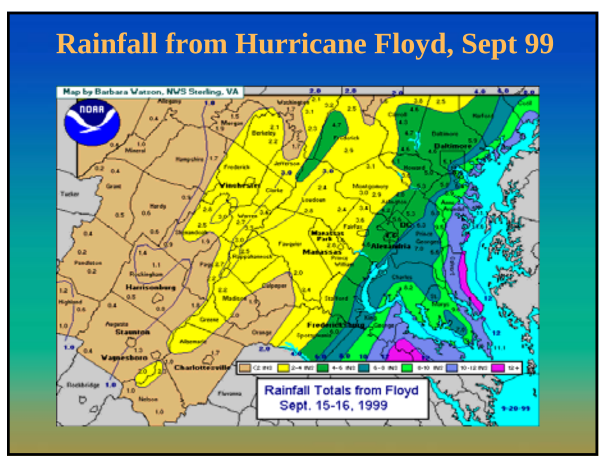

HMR52 Model – Elliptical Rainfall Distribution
10 to 20,000 square mile rainfall cells
Rainfall Bands
Watershed Boundary


Flood Danger for Cars
High Danger Zone
Judgement Zone
Low Danger Zone
Flood Depth [ft]
Velocity [fps]
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
Low Danger
Judgement Zone
High Danger

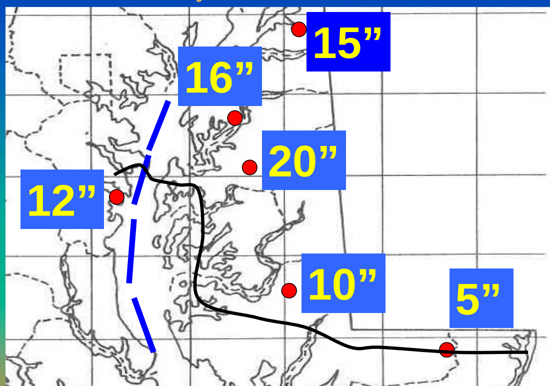

Flood Danger for Houses
High Danger Zone
Judgement Zone
Low Danger Zone
Flood Depth [ft]
Velocity [fps]
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
25.0
Source: USBR Hazard Charts, 1988
Low Danger
Judgement Zone
High Danger


Flood Danger for Adults
High Danger Zone
Judgement Zone
Low Danger Zone
Flood Depth [ft]
Velocity [fps]
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
12.00
Source: USBR Hazard Charts, 1988
Low
Judgement
High


Hurricane Floyd
September 15-16, 1999


Rainfall from Hurricane Floyd, Sept 99
Map by Barbara Watson, NWS Sterling, VA
NOAA
Rainfall Totals from Floyd
Sept. 15-16, 1999

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

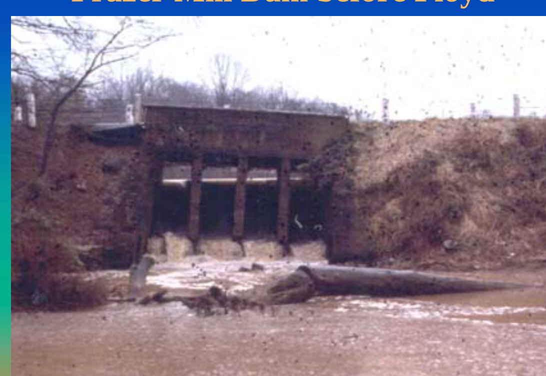
Foreman Branch Dam after Floyd

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



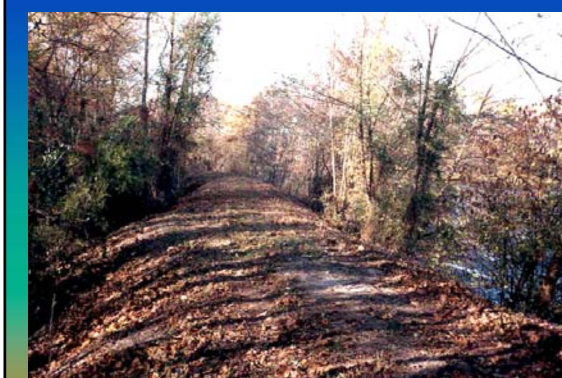
Frazer Mill Dam after Floyd

Frazer Mill Dam after Floyd

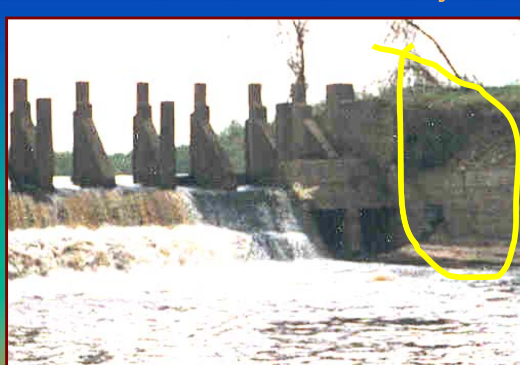
Frazer Dam Breach Statistics

Overtopping Failure
Breach Width = 120 ft = 6H
Side Slope Z = 0.6
Time of Failure Unknown

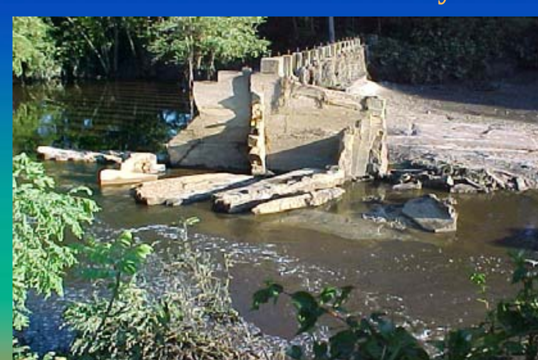
Jones Lake Dam before Floyd



Jones Lake Dam before Floyd



Jones Lake Dam after Floyd



Jones Lake Dam Breach Statistics

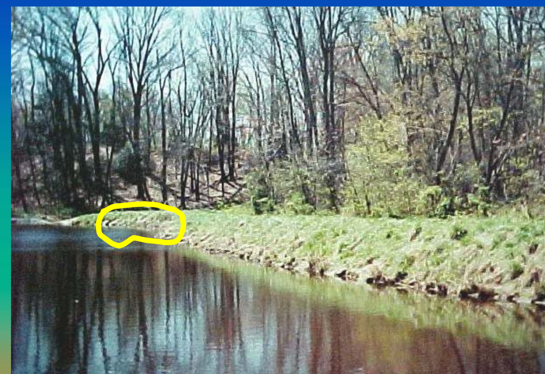
Piping Failure

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

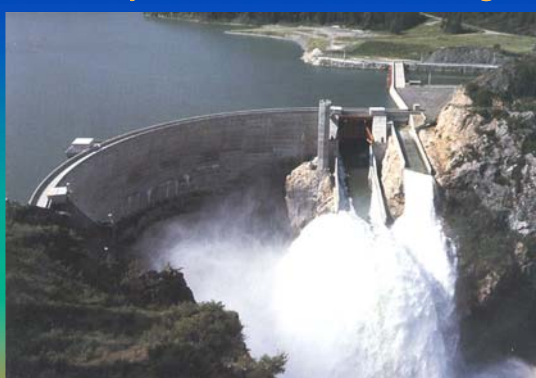
Piping Failure
Breach Width = 30 ft = 2.5H
Side Slope Z = 0.2
Failure Time Unknown

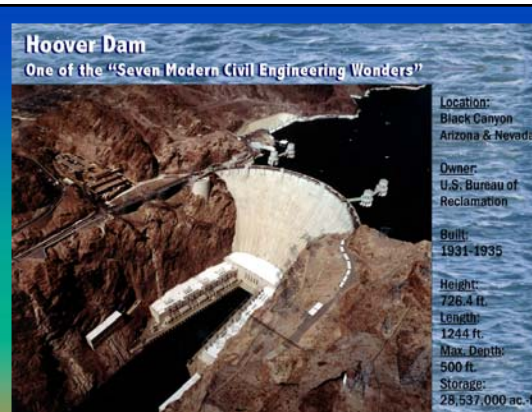
Tuckahoe Dam after Floyd

Tuckahoe Breach below Spillway

St Pauls Emergency Spillway during Floyd

Boundary Dam Near Seattle Washington





MDE Dam Break Web Site

Go to **www.mde.state.md.us** & Search for **technical references**

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, 410-713-3687