

# HAZARD CLASSIFICATIONS & DANGER REACH STUDIES FOR DAMS

By

*Bruce W. Harrington, P.E.  
MD Dept. of The Environment  
Dam Safety Division*

To determine the hazard classification of a proposed dam<sup>1</sup> or reevaluate the hazard classification of an existing dam, an *incremental flood analysis* is required. The first step in an incremental flood analysis is to determine downstream flood depths and velocities without the dam failing to establish baseline flooding conditions. The second step is to determine the increased flood depths and velocities associated with dam failures during the same storm loading conditions. These loading conditions include several storm events that will or could occur during the lifespan of the dam. The storms to be examined include the following loading conditions: **1) normal pool, 2) 100-year flood, 3) brim-up flood, 4) 50% probable maximum flood (PMF) and 5) PMF.**

The normal pool or sunny day loading condition is the breach flow released from the dam during a normal pool failure. If there is no permanent pool, a sunny day failure would be assumed to occur at the first large opening in the principal spillway above the low flow outlet. The storm event that fills the reservoir up to the top of dam is the brim-up storm event. This storm event can be determined very quickly by selecting a few rainfall events larger than the design storm and routing them through the spillways. The PMF is the largest flood that is expected to occur on a watershed. The PMF is based on the most severe combination of meteorological and hydrological conditions that are reasonably possible.

In Maryland, ***all significant and high hazard dams require an emergency action plan*** to safeguard lives and reduce property damage in the event of a dam failure. In order develop an emergency action plan for an existing or proposed dam, a danger reach map must be completed. *If the hazard classification of an existing dam is well known, only a danger reach study is needed to define the downstream reach that would receive increased flooding if the dam were to fail.*

*The hazard classification of the dam is usually based on the increased flood depths and velocities against or over downstream structures.* These structures include houses, buildings, important utilities, roads and railroads. The U.S. Bureau of Reclamation Flood Danger Graphs<sup>2</sup> shown on pages 5, 6, and 7 of this document are used to determine if increased flood dangers will exists with a dam failure. If the depths and velocities with a dam failure increase from low to high danger as shown on the graphs, the dam would be classified as significant or a high hazard structure depending on the type of structure flooded and the probable loss of life. The definitions of low, significant & high hazard classifications for dams are defined on page 3.

<sup>1</sup>A dam also refers to an embankment pond or a road embankment used for stormwater management.

<sup>2</sup>"Downstream Hazard Classification Guidelines" ACER Technical Memorandum No. 11, USBR, 1988

After the hazard classification of the dam has been defined, the danger reach is typically determined by failing the dam during the normal pool and design storm loading conditions, and routing the dam failures downstream to a point where the increased flood depths are less than one foot. A low, significant, or high hazard dam is usually designed to safely pass the 100-year storm, 50% PMF, or PMF, respectively. The minimum freeboard above the design storm to the top of the dam is one foot but may be increased if there is no emergency spillway or if wave run-up is significant.

## **Dam Failure**

A dam failure hydrograph may be computed by the HEC-1 or National Weather Service (NWS) Dam-Break Models. For dams equal to or greater than 75 feet in height, the HECRAS or NWS Dam-Break Models are recommended for dam failure. For dams smaller than 75 feet high, the HEC-1, or NWS Dam-Break Models may be used to determine the breach hydrograph. Although the NWS Dam-Break Model is considered to be the most accurate model to determine dam failures, it is also very complex and temperamental, and requires considerable engineering expertise.

To determine the dam failure hydrograph, four parameters are needed to define the breach formation through the dam. These parameters include the breach bottom width, side slopes, time of failure, and the selected failure and breach bottom elevations. For earth embankment dams, the average breach width ranges from 1 to 5 times the height of water against the dam at failure; the breach side slopes range between 0 to 1 foot horizontal to 1 foot vertical; and the time of failure ranges from about 10 minutes for small dams to approximately 4 hours for very large dams. In 1987, Froelich developed breach predictor equations that estimate the average breach width and time of failure based on the height of water above the breach bottom and the corresponding storage volume. These equations, which were revised by Froelich in 1995, are included on page 12 of this document. Examples of input data for the HEC-1 and NWS Dam-Break Models can be obtained by contacting the Maryland Dam Safety Division.

## **Hydrology**

To determine the storms used for hazard classifications or danger reach delineations, the HEC-1, TR-20, or HydroCad Computer Models are required for drainage areas less than or equal to 10 square miles. For dams less than 10 square miles of drainage area, use a 24-hour duration rainfall for the 100-year and brim-up storm events; and a 6-hour duration rainfall for the 50% PMF and PMF. For drainage areas larger than 10 square miles, the HMR-52 Model is recommended to determine the rainfall amount and distribution. The rainfall hyetograph data from the HMR-52 Model is inputted into the HEC-1 Model for flow computations. The HMR-52 Model maximizes rainfall by generating elliptical rainfall bands over the watershed of the dam and the danger reach area. The HMR-52 model is free to download on our MDE Technical References Website. Go to [www.mde.state.md.us](http://www.mde.state.md.us) and search for technical references.

It is recommended that the watershed hydrology parameters (drainage area, curve numbers, times of concentration) be determined using the GISHydro2000 Model developed by the University of Maryland. This GIS Model is free on the internet at the following website: [www.gishydro.umd.edu/](http://www.gishydro.umd.edu/). The model will load electronic soil maps, digital elevation and landuse data for Maryland, as well as many other GIS datasets & shape files. It will compute watershed areas, hydrologic soil groups, landuse curve numbers, times of concentration, and generate a TR-20 Hydrology Model. It will also determine USGS Regression flow rates up to the 500-year storm. The times of concentration should be verified using the standard velocity segment method outlined in TR-55 Publication.

**I. Compute Storm Events and Breach Flows in the Danger Reach Area below the Dam**

- A. Calculate runoff, flows, and hydrographs (hydrology) on the watershed above the dam and the danger reach area below the dam for the 100-year, brim-up, 50% PMF, and 100% PMF storm events. (**GISHydro2000, HEC-1, HydroCad, TR-20, & HMR-52 Models**).
- B. Route storms as well as sunny day failure through dam and downstream floodplain with & without dam failure. *If the hazard classification of the dam is known, only the sunny day and design storm (PMF for High Hazard Dams) are necessary to define the danger reach limits. The danger reach must extend downstream to a point where the increased flood levels are less than one foot.*

**Hydraulics**

Compute the existing and proposed water surface elevations for the selected storm events. The HEC-1, HECRAS, or National Weather Service Dam-Break Models are used to determine the flood depths. For drainage areas less than 10 square miles, the HECRAS Models is recommended because it is easy to learn and apply, and will result in reasonably accurate water surface elevations.

For danger reaches that impact only downstream roads and a few buildings, the HEC-1 Model may be used for both hydrology and hydraulic calculations. The HEC-1 Model is not as accurate in calculating the depth of flooding because the floodplain cross sections are not detailed and the water surface slopes are approximated. To use only the HEC-1 Model for hydrologic and hydraulic computations, discuss the dam failure study with the Dam Safety Division for approval.

**I. Calculate the Water Surface Profiles both With and Without Dam Failure in The Danger Reach**

- A. Input flow values, stream cross-sections, Manning's roughness values, and dam & road structure data into the water surface profile models.
- B. Determine increased flood risks to houses, buildings, and roads by using the enclosed USBR Hazard Graphs.

**II. Determine Hazard Classification of Dam**

- A. Classify or reclassify dam as a low, significant, or high hazard structure.
  - 1. Low Hazard - Unlikely loss of life; minor increases to existing flood levels at roads and buildings.
  - 2. Significant Hazard - Possible loss of life, significant increased flood risks to roads and buildings with no more than 2 houses or 6 lives in jeopardy.

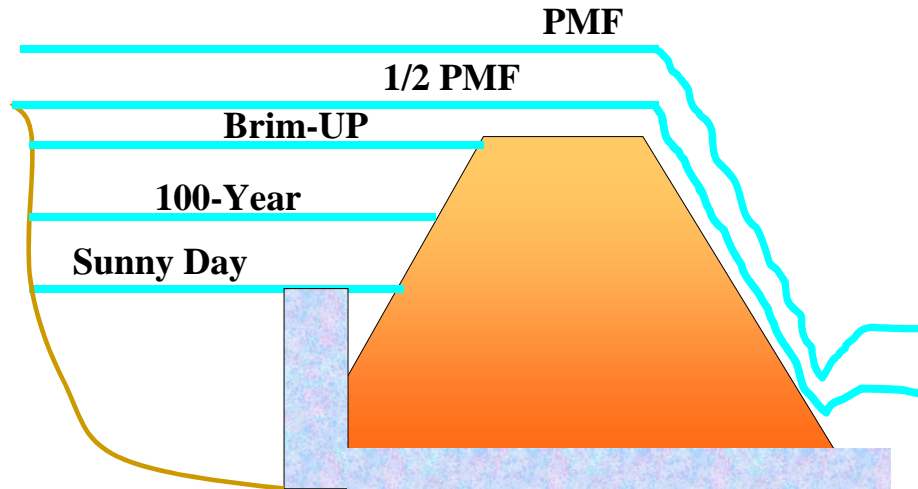
3. High Hazard -

Probable loss of life; major increases to existing flood levels at houses, buildings, major interstates and state roads with more than 6 lives in jeopardy.

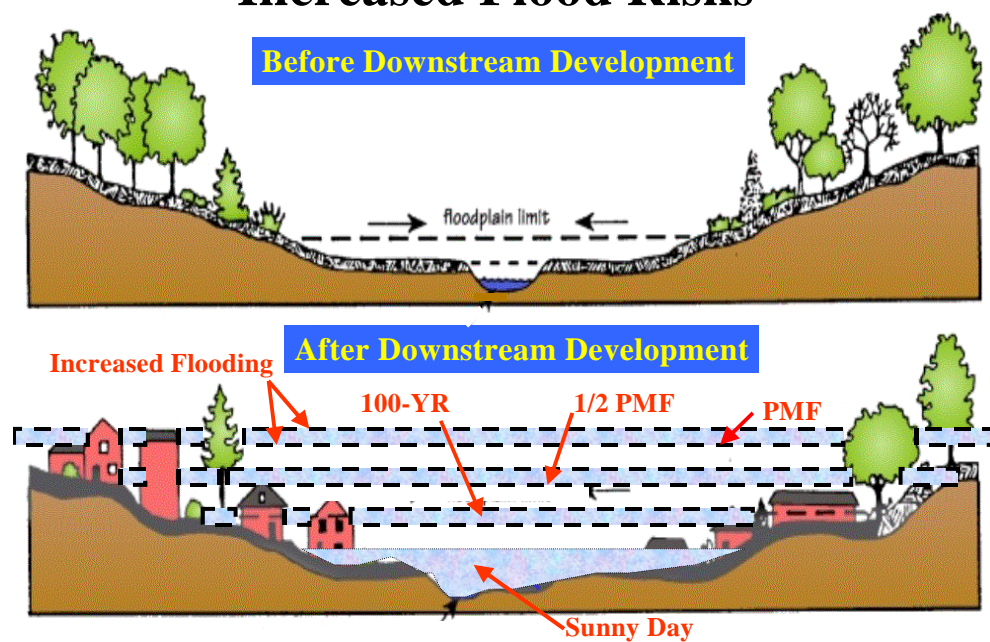
**III. Develop Danger Reach Maps**

- A Plot the flood boundaries for the sunny day and design storm dam failures on topographic maps. The map must clearly show downstream roads, buildings, and houses within the danger reach, and the recommended evacuations routes. The danger reach maps are to be included in the Emergency Action Plan for the dam and should be no larger than 11" x 17" per panel.

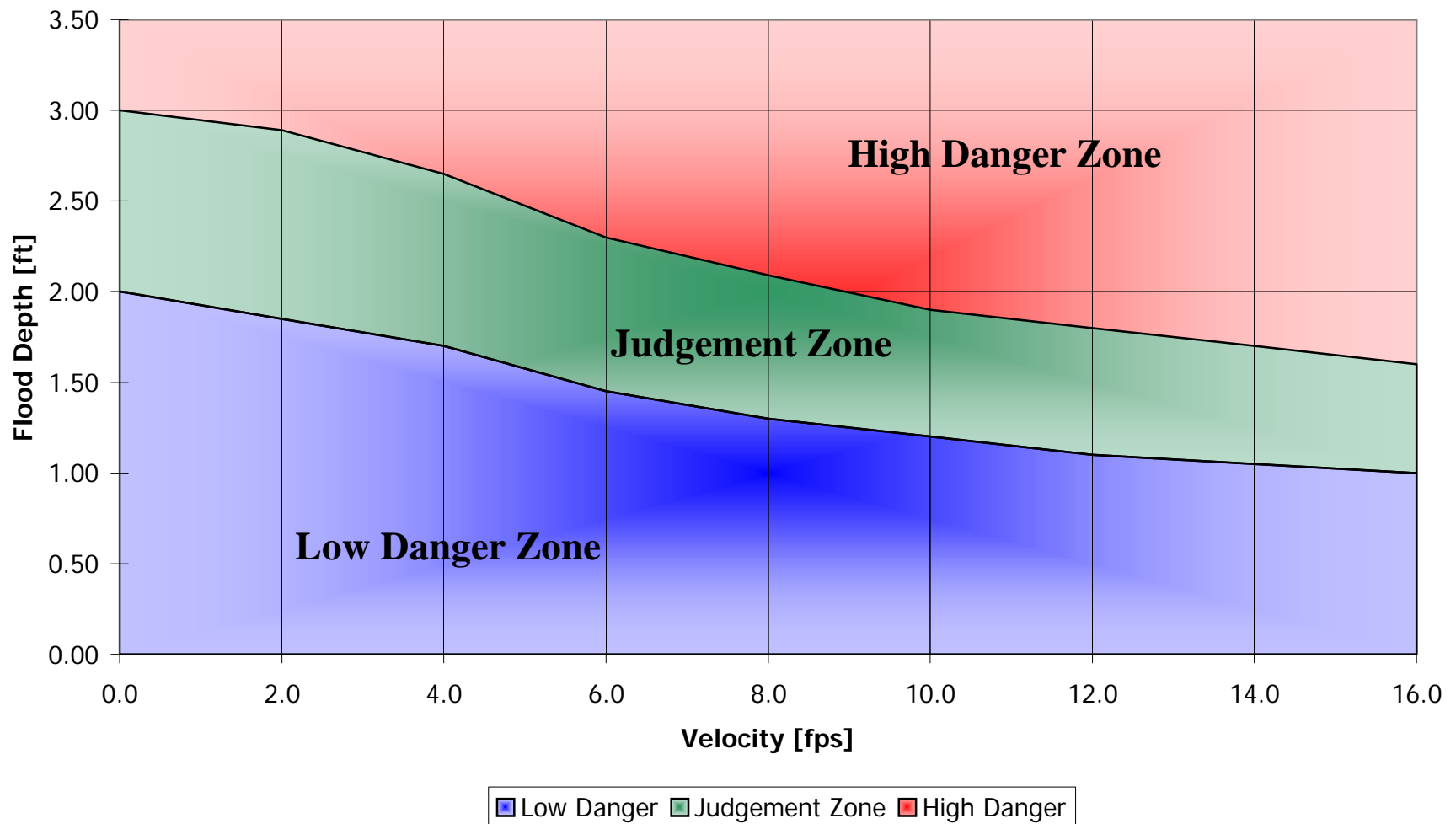
## Failure Storms to Analyze



## Increased Flood Risks

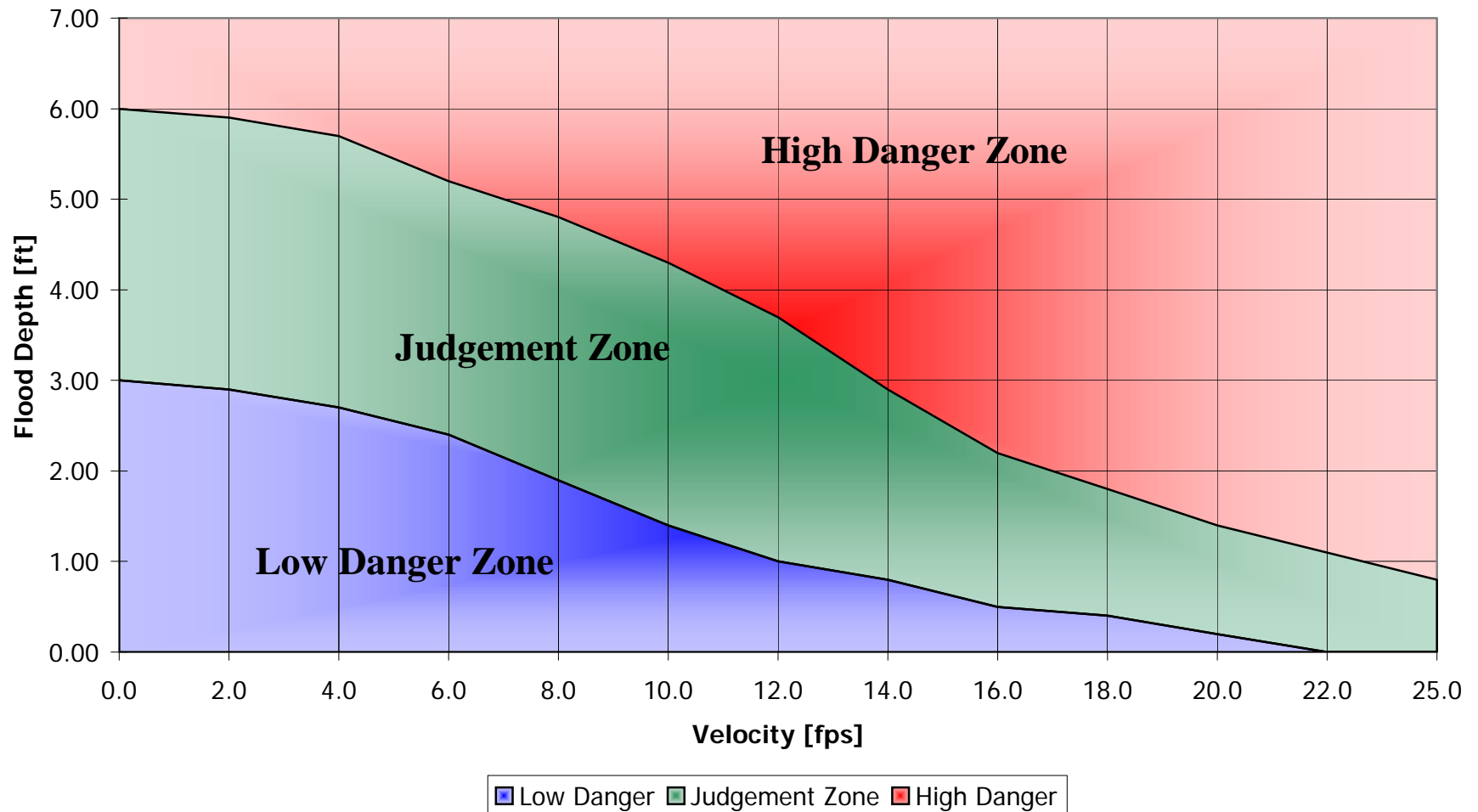


# Flood Danger for Cars



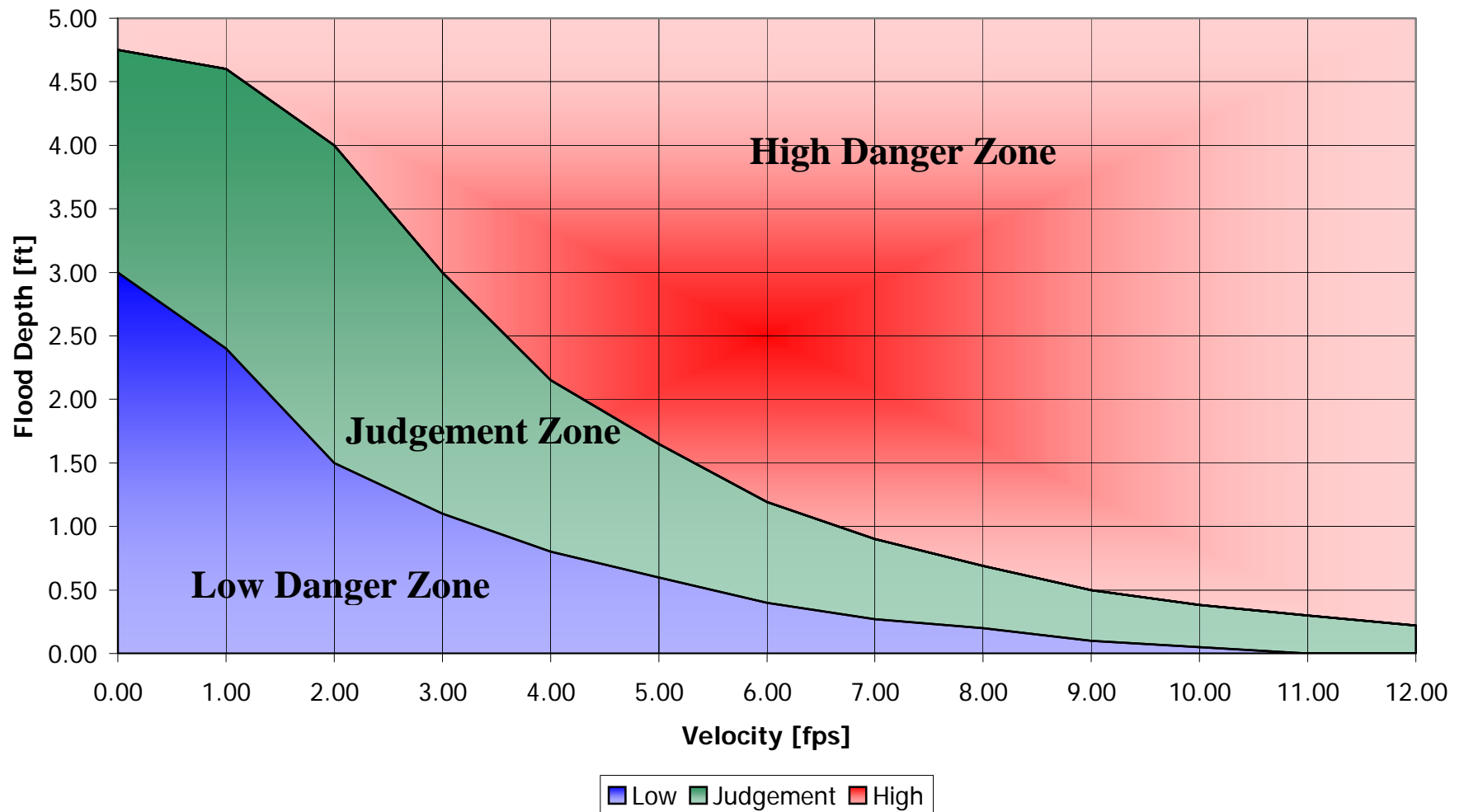
Source: ACER Technical Memorandum No. 11, "Downstream Hazard Classification Guidelines", USBR, 1988

# Flood Danger for Houses



Source: ACER Technical Memorandum No. 11, "Downstream Hazard Classification Guidelines", USBR, 1988

## Flood Danger for Adults

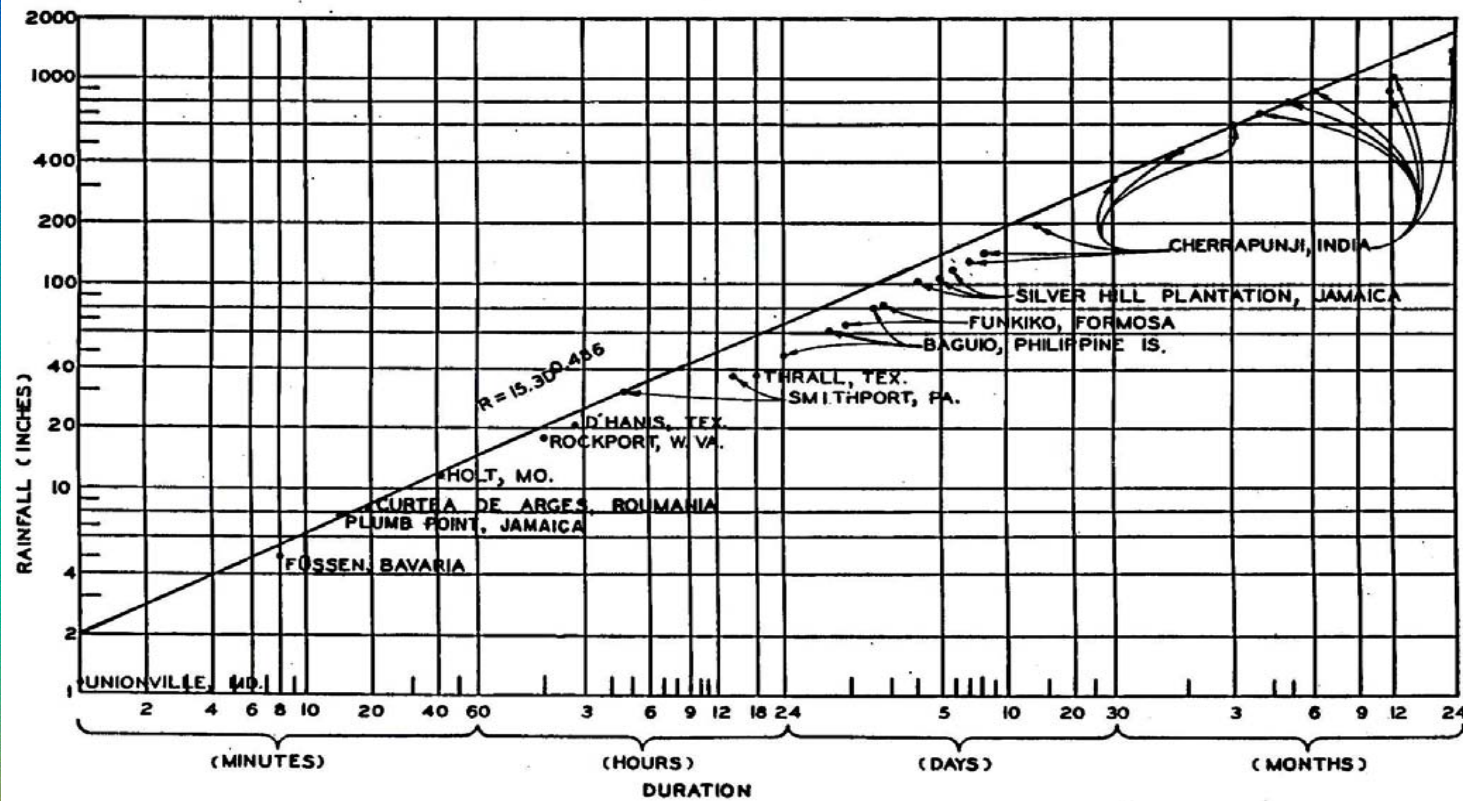


Source: ACER Technical Memorandum No. 11, "Downstream Hazard Classification Guidelines", USBR, 1988



## WORLD RECORD RAINFALL AMOUNTS

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



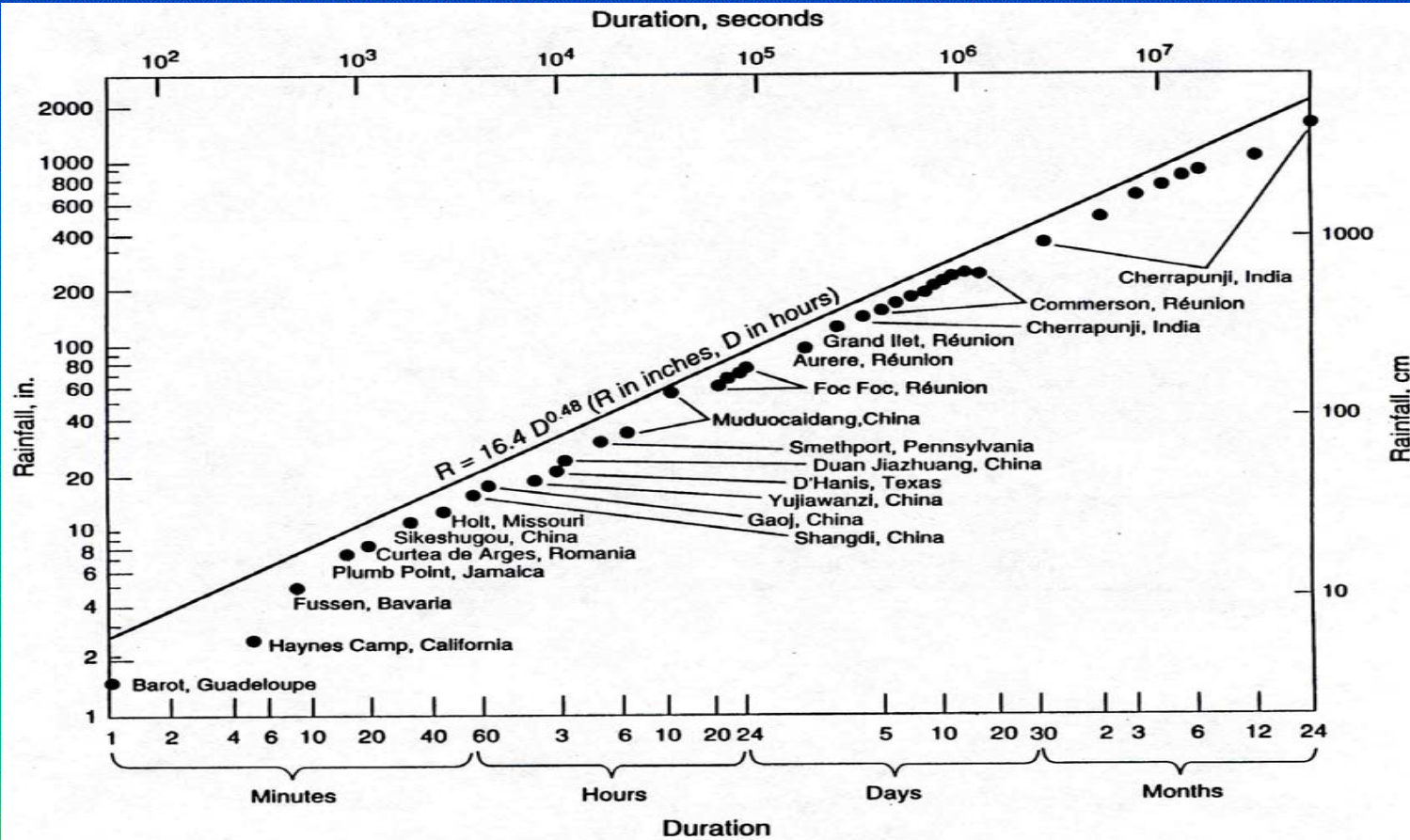
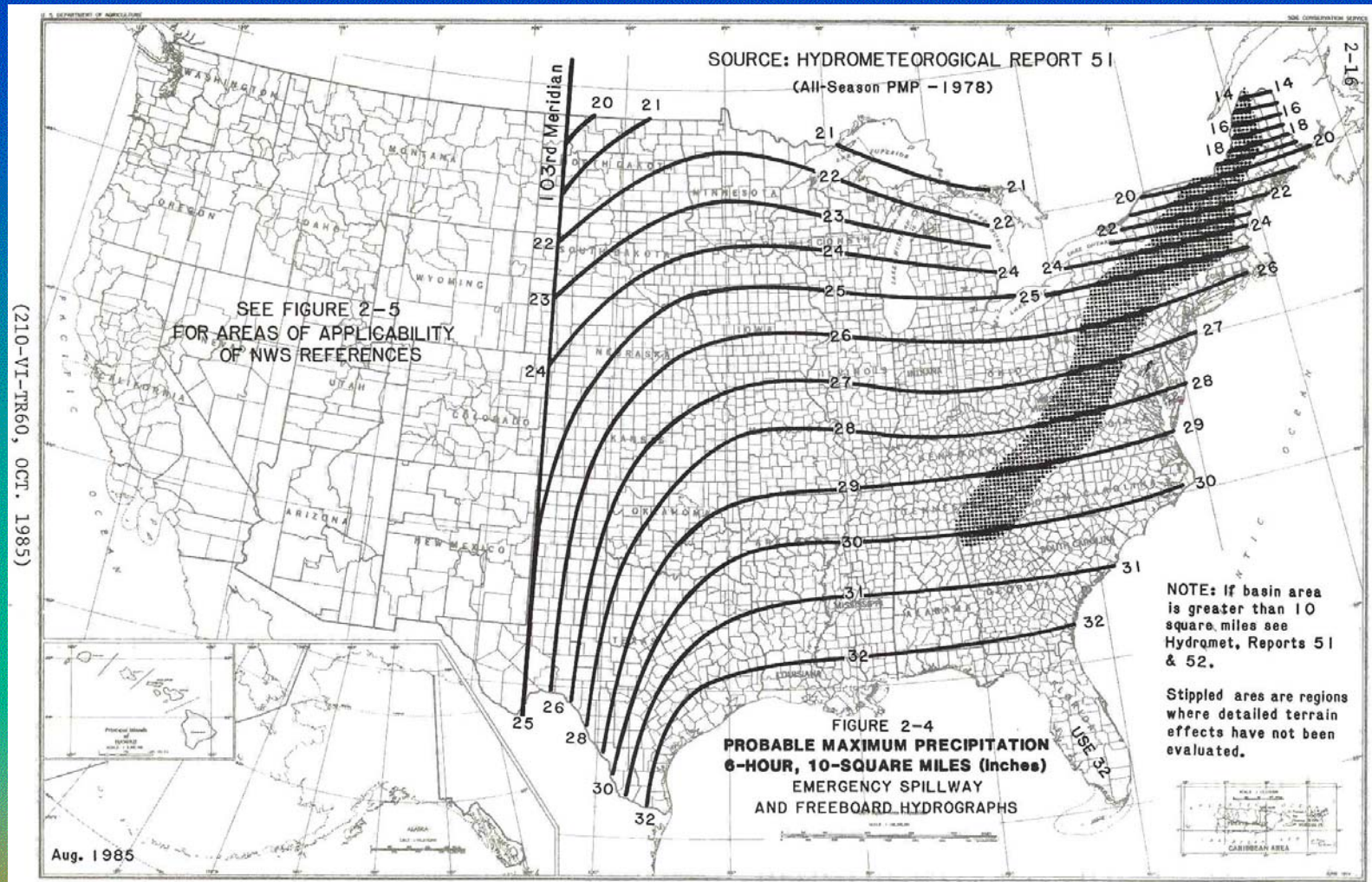


FIGURE 1 Maximum observed point rainfalls as a function of duration. (Courtesy of John Vogel, National Weather Service.), 1986.





## 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

Note: H = Height of water against dam above breach bottom elevation in feet.

## 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)

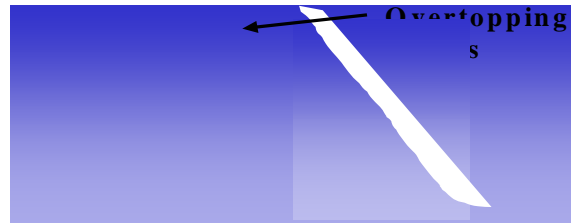
**K<sub>0</sub>** = 0.7 for Piping & 1.0 for Overtopping Failure

**V<sub>s</sub>** = Storage Volume (ac-ft)

**H** = Selected Failure Depth (ft) above Breach  
Bottom

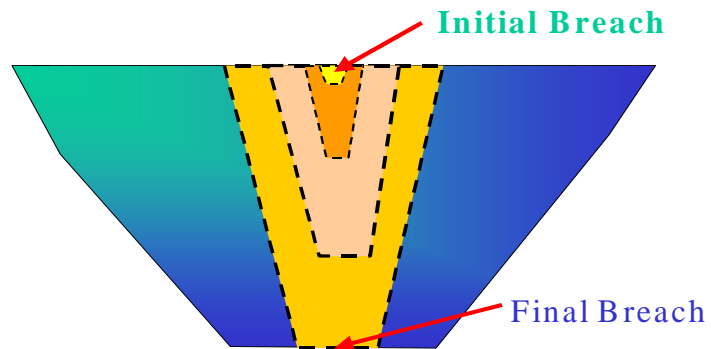
**τ** = Time of Failure (hrs)

## Overtopping Failure



## Profile View

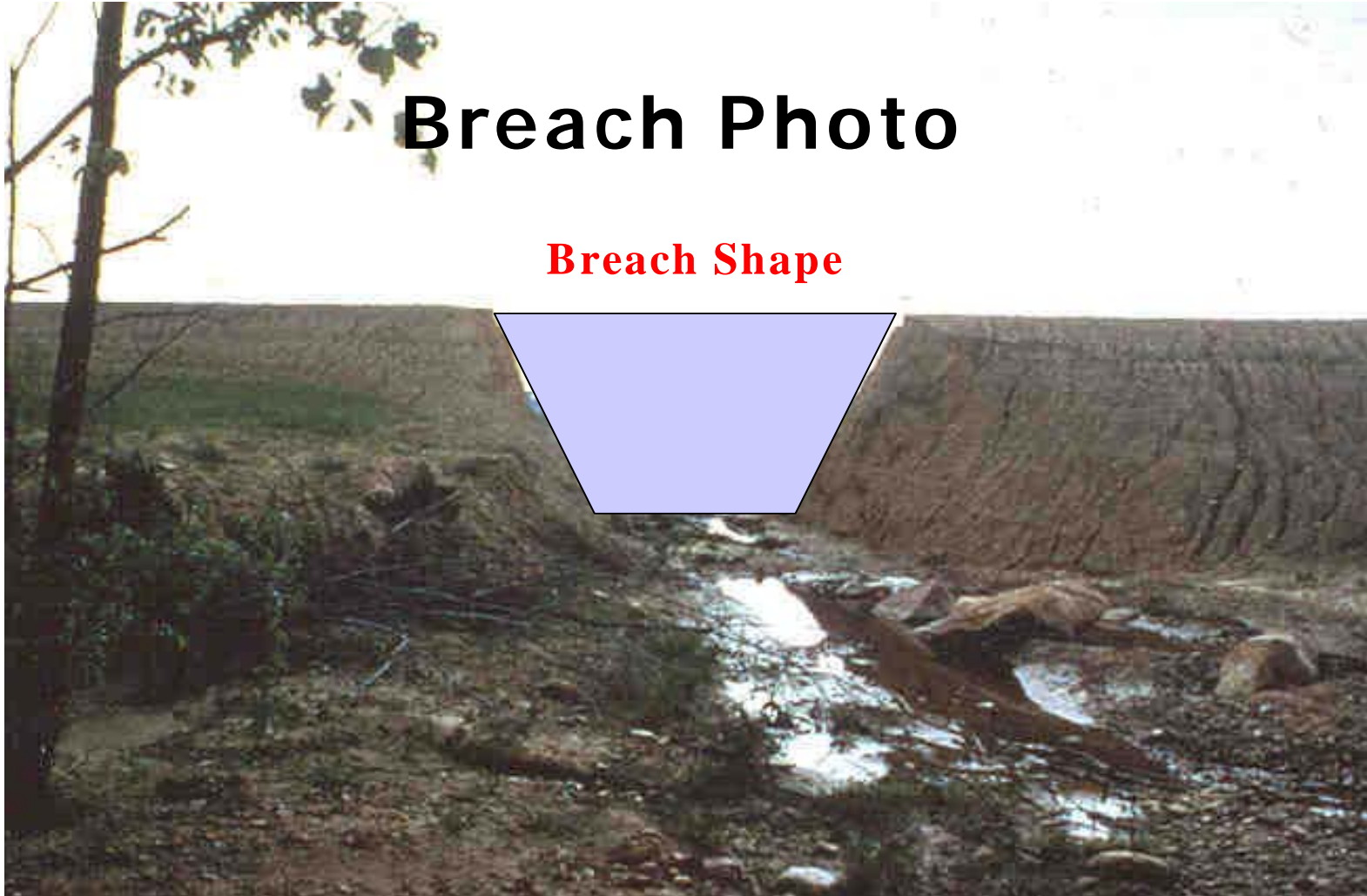
## Overtopping Breach of Earth Dam



## Cross Section View

# Breach Photo

**Breach Shape**





## Breach Parameters

