Unlined Spillway Erosion Risk Assessment

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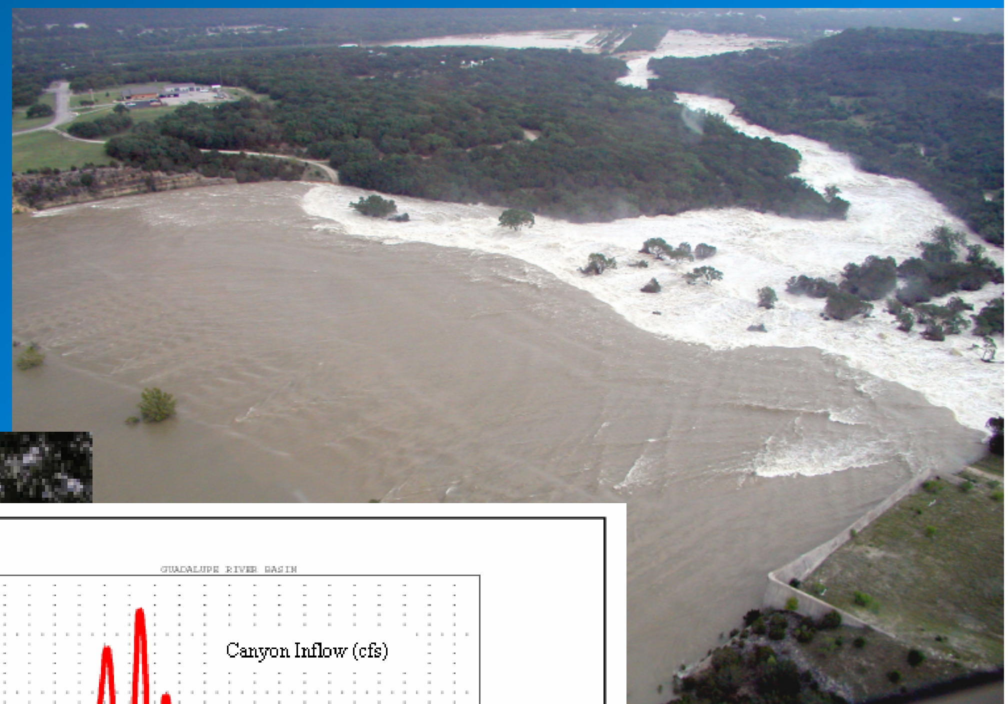
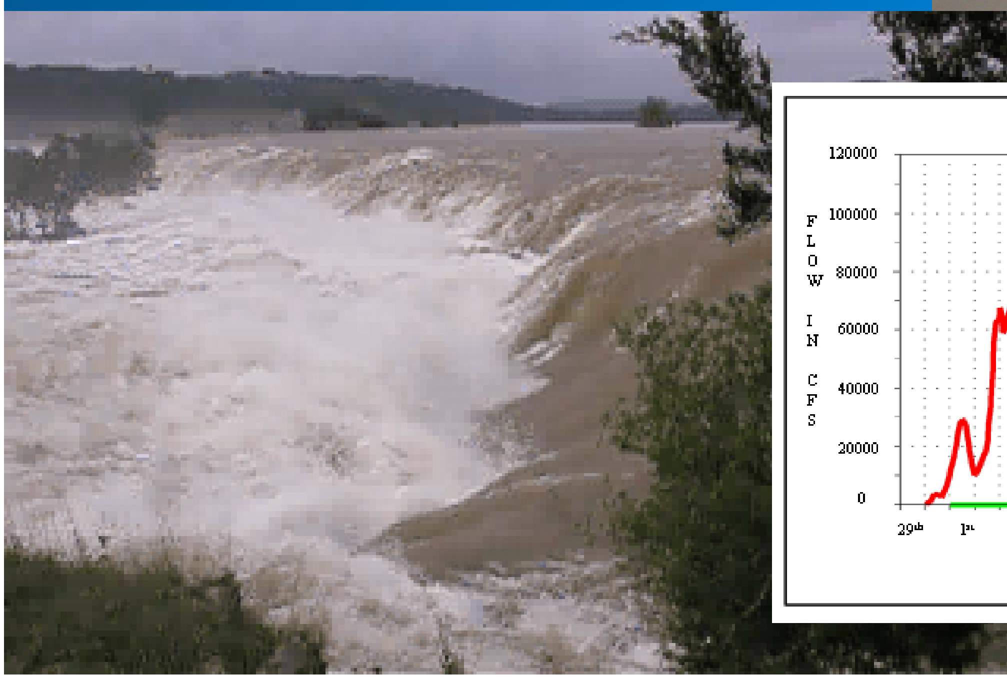
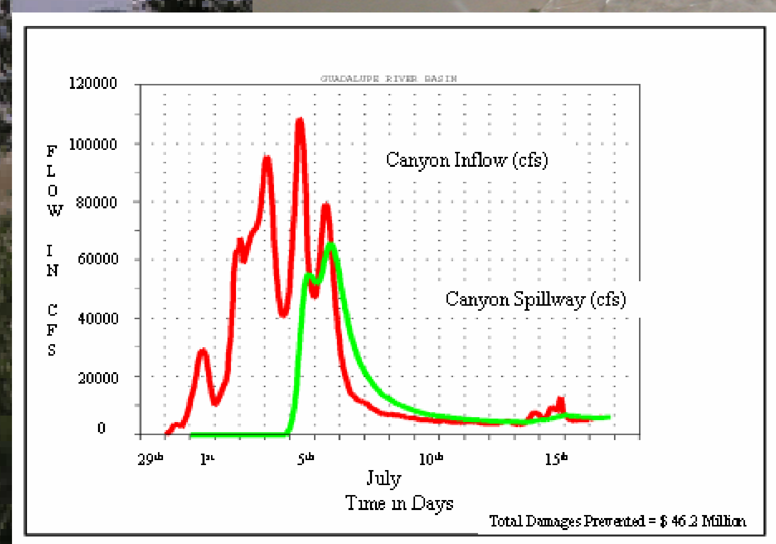
Introduction

Canyon Dam Spillway, Texas
Date: July 6, 2002
Flow: 66,000 cfs, 250 yr flood
Duration: 12 days
Spillway Width: 1260 ft
Material: Limestone



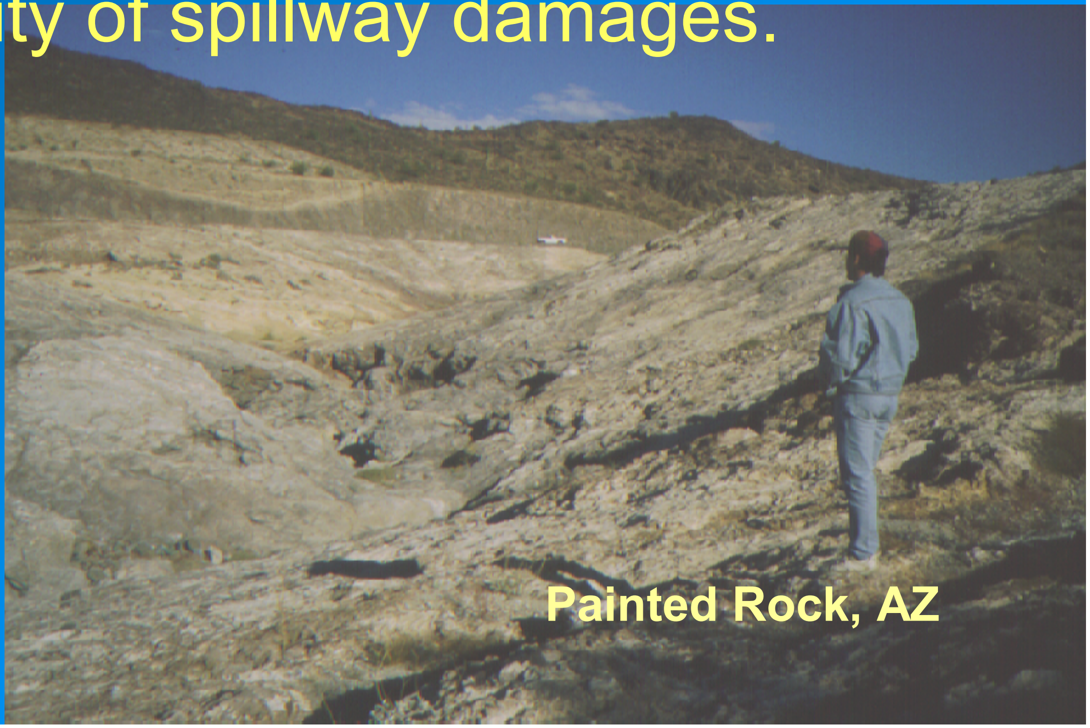




Introduction

Problem Statements:

- Spillway erosion analysis encounters variable nature of geometry, geologic material, and unpredictable flood events.
- Dam Safety Port Folio Analysis needs a tool to determine the probability of spillway damages.



Introduction

RESEARCH OBJECTIVES:

- Develop a tool to assess the probability of damages on unlined spillway erosion

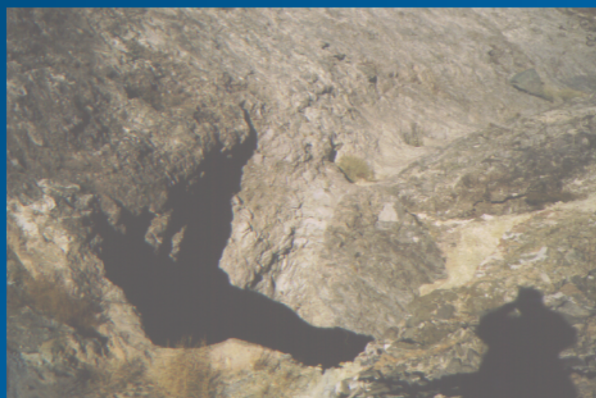
Risk Assessment

Process of Answering Three Questions:

1. What can go wrong?
2. What is the likelihood it will go wrong?
3. What are the consequences if it does go wrong?

Risk Assessment

1 What Can Go Wrong?



Local Scouring

Headcut Erosion

Spillway Breach

Dam Breach

Risk Assessment

2 What Is the Likelihood It Will Go Wrong?

- Uncertainty of Flood Event
- Uncertainty of Material Parameters
- Uncertainty of Performance of the Unlined Spillway

Risk Assessment

3 What Are the Consequences If It Does Go Wrong?

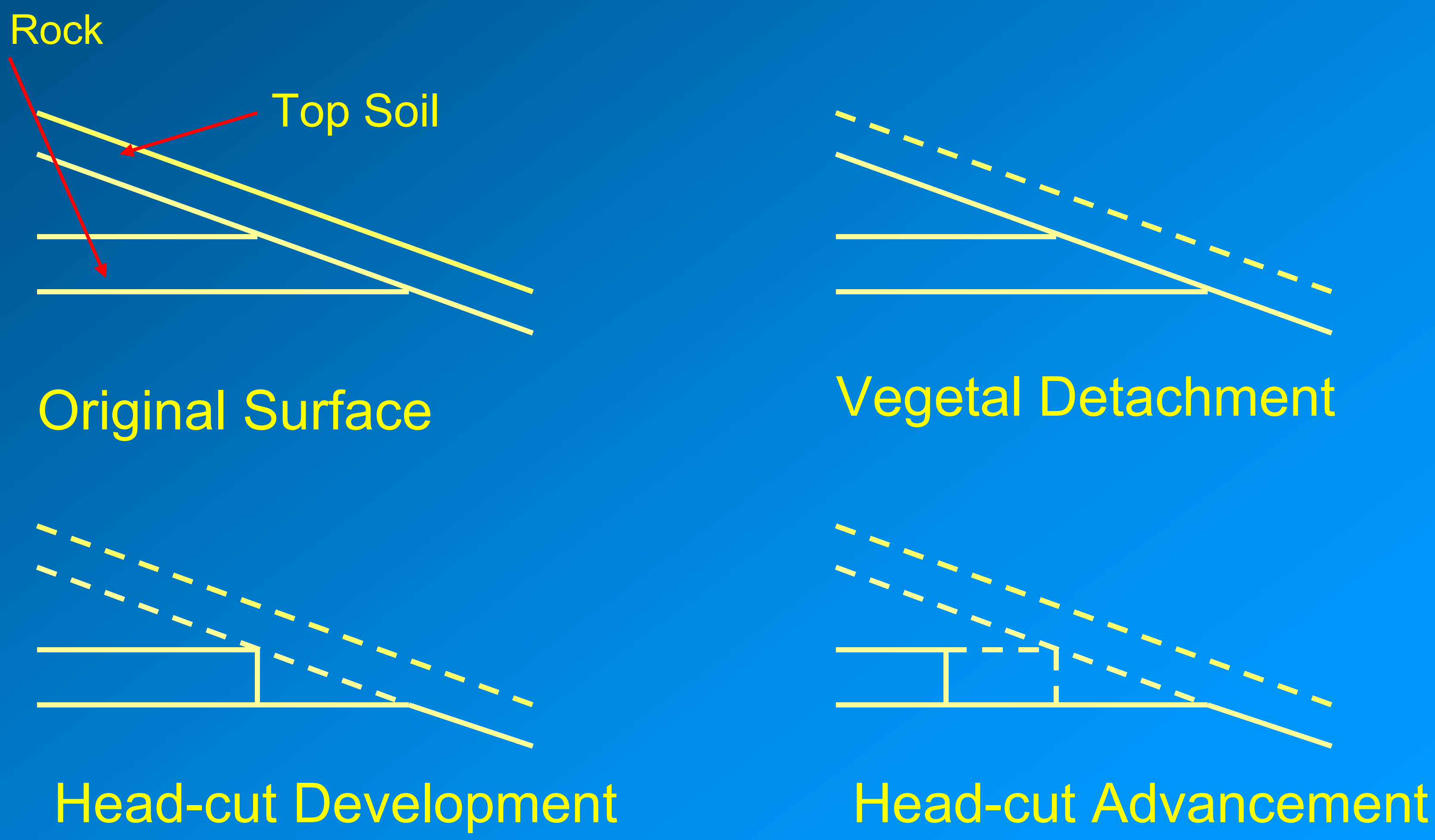
- Spillway Partial Damage
  - Lightly Damaged
  - Moderately Damaged
  - Severely Damaged
- Spillway Breach
  - Population at Risk
  - Loss of Economic Value

Spillway Erosion Models

- REMR (WES, 1998)
- USDA (Temple et al., 1994)
- Annandale (1995)
- Bollaert (2002)

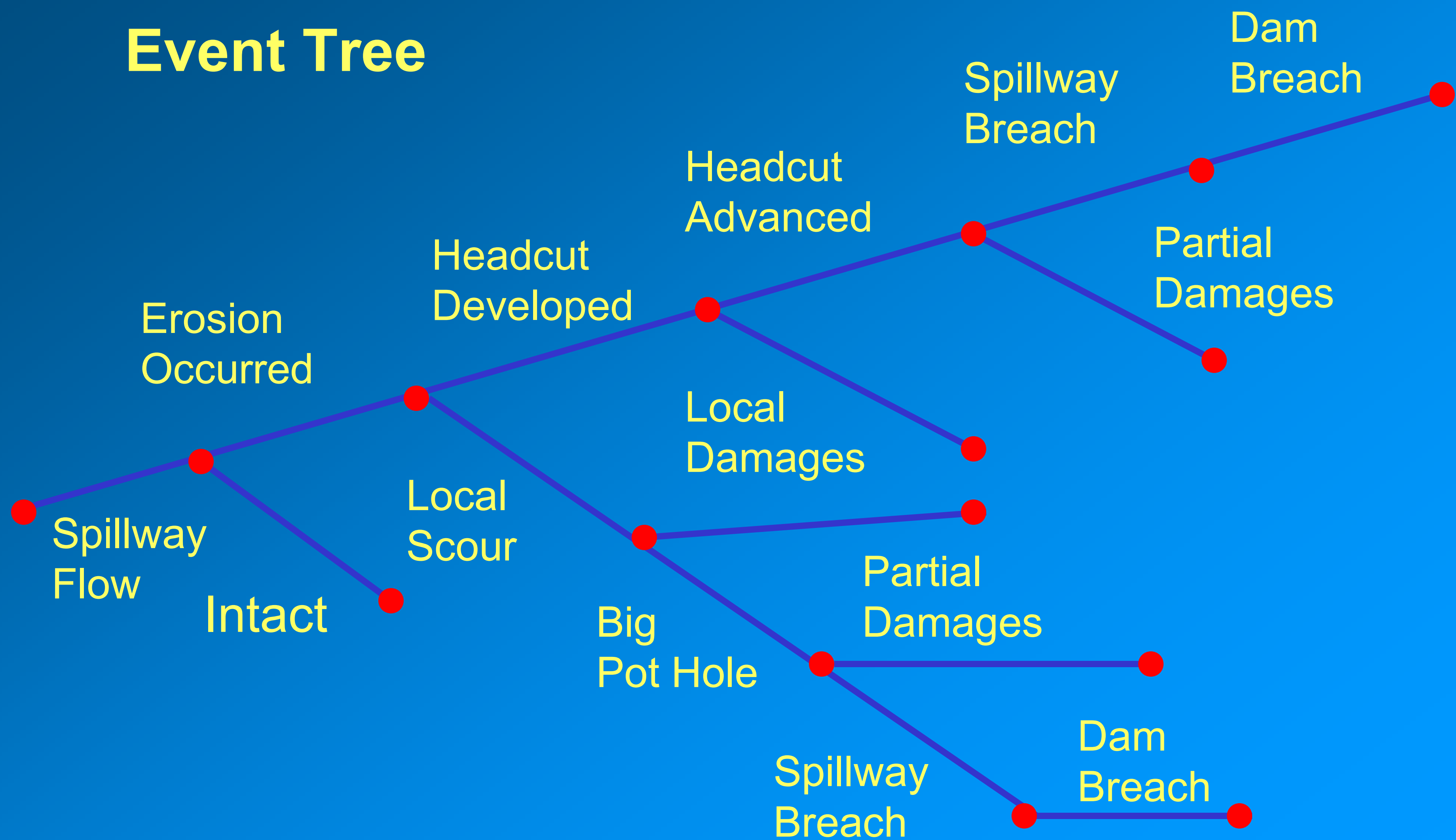
Spillway Erosion Models

Phases of Erosion



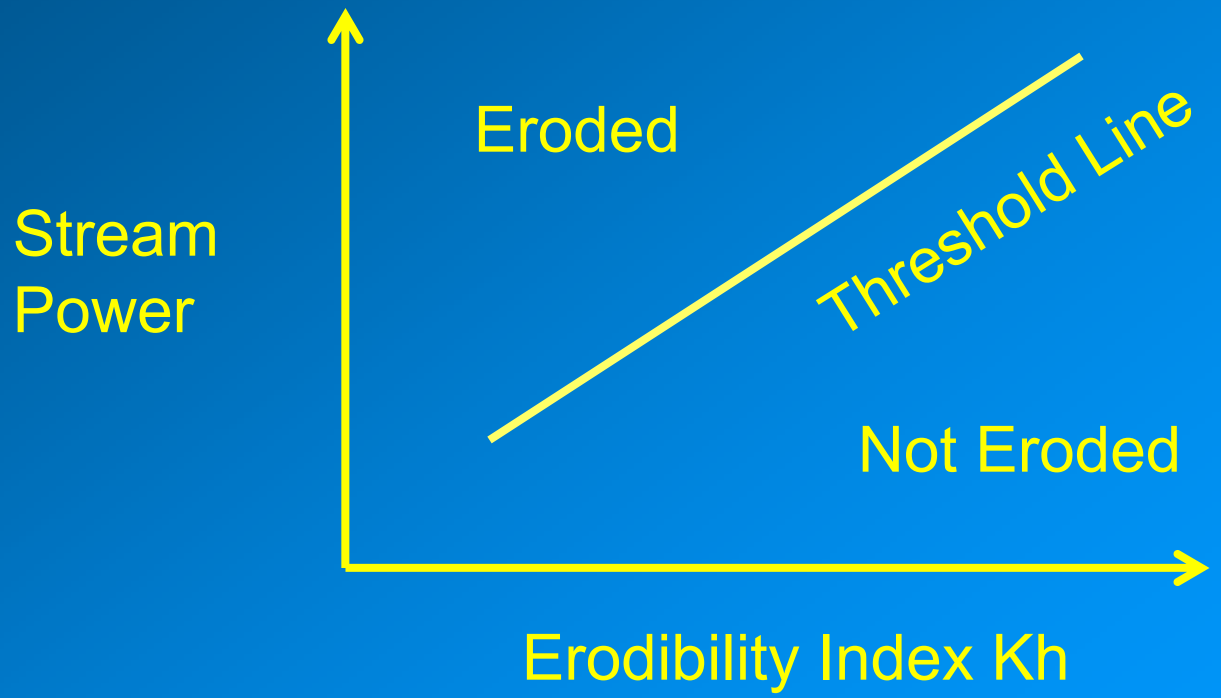
Erosion Process

Event Tree



Erosion Model - Threshold Line

Erosion Model - Threshold Line



Erosion Model - Threshold Line

Erodibility Index (K_h)

$$K_h = M_s * K_b * K_d * J_s$$

M_s = Material Strength Number

K_b = Block Size Number

K_d = Joint Shear Strength Number

J_s = Joint Orientation Number

Erosion Model - Threshold Line

Stream Power

$$P = \gamma * q * S_f$$

P = Stream Power

γ = Unit weight of water

q = Unit discharge

S_f = Energy Slope

Logistic Regression

- Regression for Binary Outcomes
  - Occurrence (Erosion)
  - Non-Occurrence (No Erosion)
- User of Logistic Regression Method
  - Medical
  - Business
- Probabilistic Liquefaction Analysis (Liao et al, 1988)

Logistic Regression

- Odds ratio $$\frac{p}{1 - p}$$
- Logit transformation

$$Ln\left[\frac{p}{1-p}\right] = b_0 + b_1 x$$

$$p = \frac{1}{1 + \exp\left[-\left(b_0 + b_1 x\right)\right]}$$

p = probability of occurrence

b_0, b_1 = regression parameters

x = independent variable

Logistic Regression

Multiple Logistic Regression

$$p = \frac{1}{1 + \exp\left[-\left(b_0 + b_1 x_1 + b_2 x_2 + .. + b_n x_n\right)\right]}$$

p = probability of occurrence

b_0, b_1, b_2, .., b_n = regression parameters

x_1, x_2, .., x_n, = independent variables

Logistic Regression

Multiple Logistic Regression for Spillway Erosion

$$p = \frac{1}{1 + \exp\left[-\left(b_0 + b_1 K_h + b_2 qH\right)\right]}$$

K_h = Erosion Index, Material Resistance

qH = Hydraulic Attack

Logistic Regression

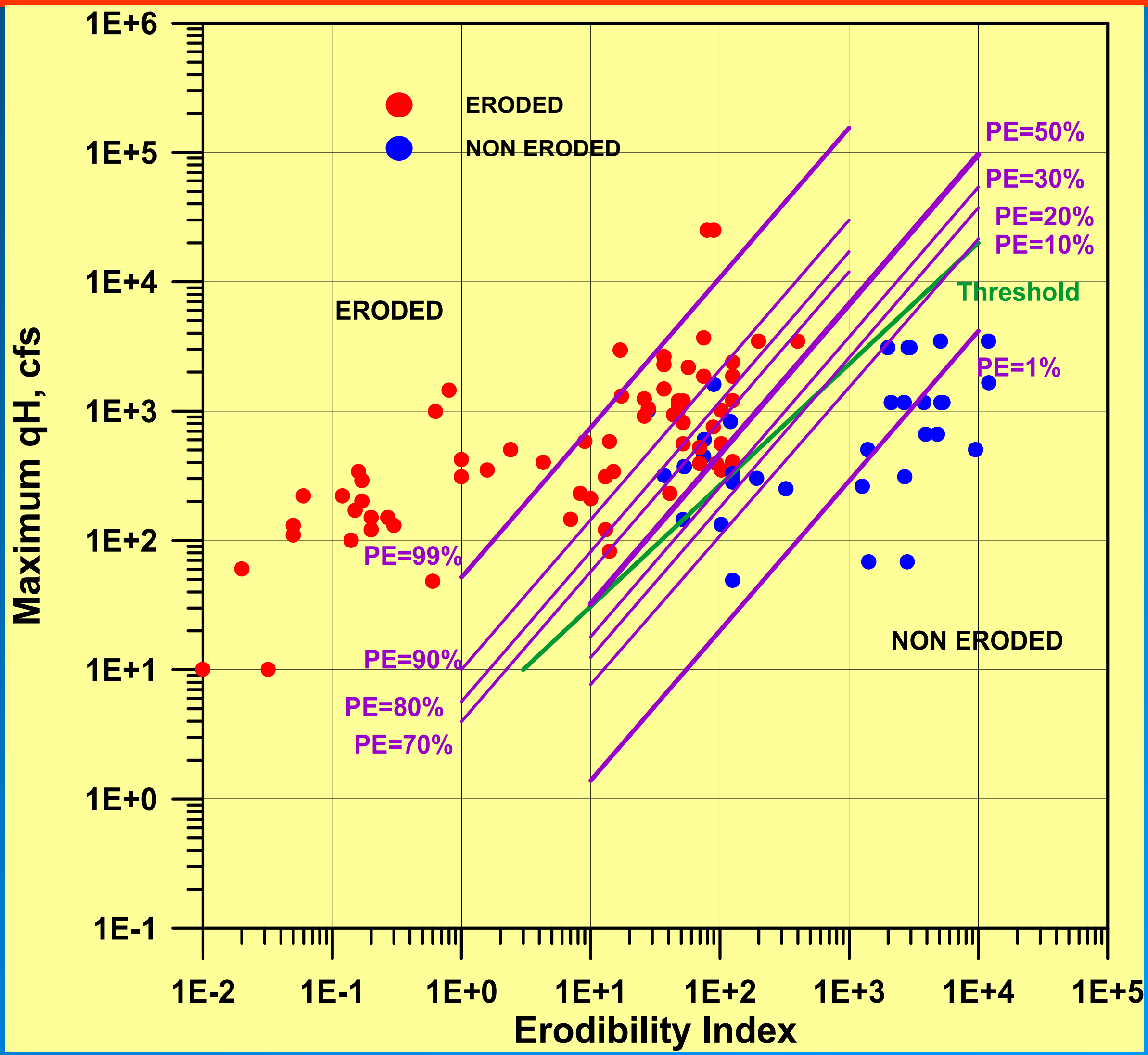
Result of Multiple Logistic Regression

$$p_e = \frac{1}{1 + \exp\left[-\left(1.171 - 3.9K_h + 3.364\,qH\right)\right]}$$

Nagelkerke's $R^2 = 0.763$

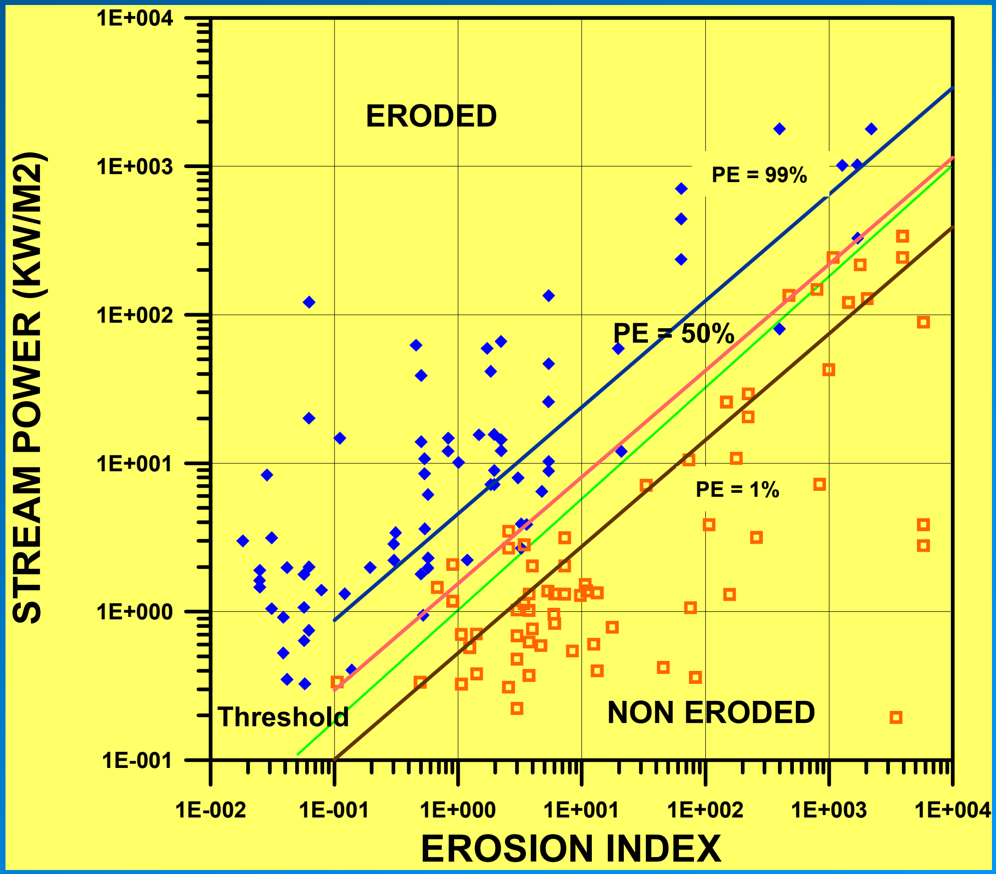
p_e = probability of erosion
K_h = Erosion Index, Material Resistance
qH = Maximum qH, Hydraulic Attack

Logistic Regression



Logistic Regression for ERDC Threshold

Logistic Regression



Logistic Regression for Annandale Threshold

Ordinal Logistic Regression

Independent Variables

- Hydrograph
  - Peak unit discharges (cfs/ft)
  - Flood durations (hrs)
- Spillway Geometry
  - Lengths (ft)
  - Slopes (degrees)
- Material Index
  - Erosion Indexes

Ordinal Logistic Regression

Sj = F (Material, Peak Discharge, Duration, Average_Slope, and Length)

Data: Case Histories (USDA and COE)

Damage Levels	Percent of Erosion
No Damage	0 - 0.05%
Light Damage	0.06 – 15%
Moderate Damage	16 – 40%
Severe Damage	41 – 75%
Breach	76 – 100%

Ordinal Logistic Regression

Sj = -1.515 Log_Kh + 8.635 Log_q – 1.581Log_Dura + 0.807 Slope_av + 3.975 Log_Length

Nagelkerke's $R^2 = 0.727$

Probability Formulation:

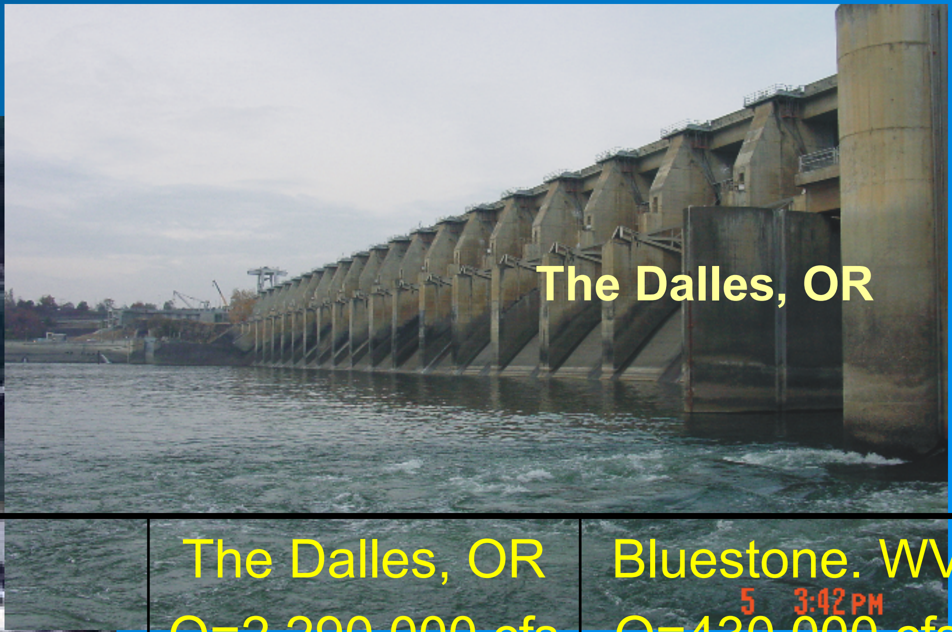
No Damage	= 1/(1+ exp(Sj-k1))
Light Damage	= 1/(1+ exp(Sj-k2)) - 1/(1+ exp(Sj-k1))
Moderate Damage	= 1/(1+ exp(Sj-k3)) - 1/(1+ exp(Sj-k2))
Severe Damage	= 1/(1+ exp(Sj-k4)) - 1/(1+ exp(Sj-k3))
Breach	= 1 – 1/(1+ exp(Sj-k4))

k1,k2, k3, and k4 = boundary parameters from regression

Ordinal Logistic Regression

Input	Tuttle Creek KS Ls-Sh	Painted Rock AZ Felsite	Painted Rock AZ Tuff	Saylorville IA Ss-Sh	Buck_Doe MO Clay
Unit Disch. (cfs/ft)	112.1	41.8		104.4	163.5
Duration (hours)	120	576		216	3
Erosion Index, K_h	17	5340	28	103	0.01
Ave. Slope (deg)	1.4	1.32	14.04	1	7.2
Length (ft)	2200	520	230	1340	155
Probability Output					
No Damage	0.001	0.990	0.000	0.029	0.000
Light	0.019	0.009	0.002	0.275	0.000
Moderate	0.305	0.001	0.047	0.609	0.000
Severe	0.629	0.000	0.639	0.085	0.003
Breach	0.046	0.000	0.312	0.002	0.997

Logistic Regression



	The Dalles, OR Q=2,290,000 cfs	Bluestone. WV Q=430,000 cfs
Erosion Index (Kh)	1960	2734
Stream Power (Kw/m2)	125.4	22.3
Probability of Erosion	0.012	0.000

Unlined Spillway Erosion Risk Assessment

Prioritizing Process

Ranking the outcome:

$$Risk = P_{occurrence} * P_{failure} * Consequences$$

Summary

- Two Risk Assessment tools were developed for Port Folio analysis:
  - Logistic Regression Formulation for calculating the probability of erosion
  - Ordinal Logistic Regression for calculating the probability of erosion of different levels of damages
- These tools will be useful for prioritizing the maintenance of earth and rock surface unlined spillway