Presentation 18:
Inspection, Maintenance, and Monitoring of Service and Emergency Spillways

MWH

Inspection, Maintenance and Monitoring of Service and Emergency Spillways

Daniel L. Johnson
MWH Americas

Current Condition

- Change in Mentality
- Attention paid to safety of dams
- Understanding of design events
- Owners' awareness

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Levels of Experience
• Rarity of large flood events
• Denver snowstorm of 1913
• Big Thompson Flood of 1976
• South Platte Flood of 1965
• Events do occur and spillways are leading cause of failures
MWH


MWH

Personnel Issues

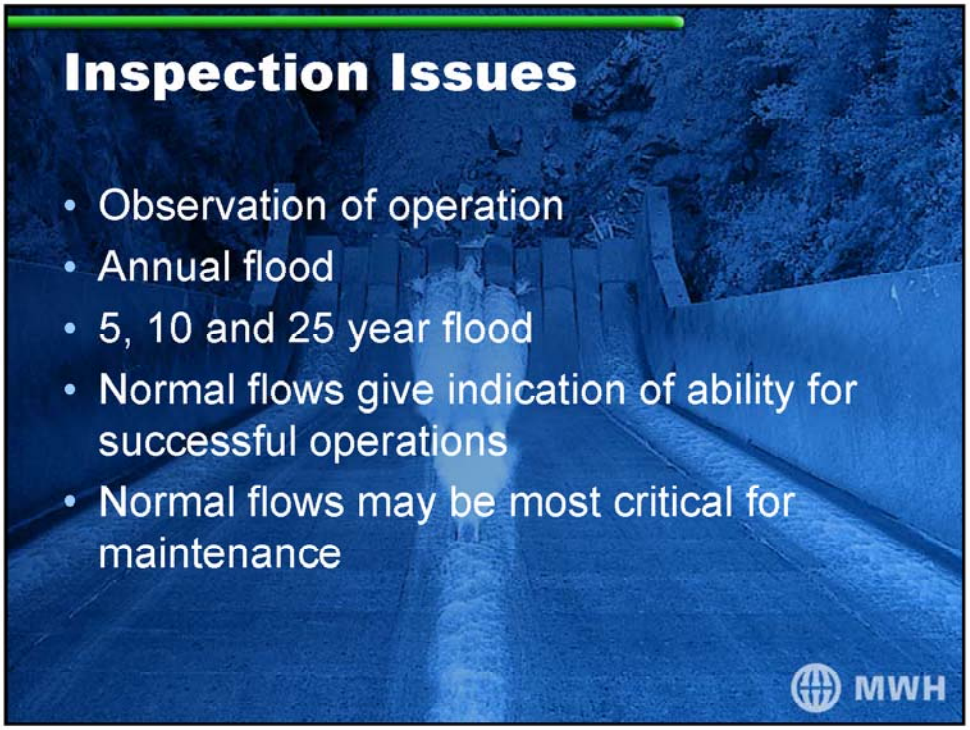
- Inspection Knowledge Needed
- Failure modes
- Service spillways see more use than emergency spillways
- Emergency spillway may have never been used

MWH

MWH

Inspection Issues

- Capability to meet design criteria
- Conditions and components for successful operation
  - Located on abutment
  - Located on dam
- Condition assessment
- Changes with time


Inspection Issues
Observation of operation
Annual flood
5, 10 and 25 year flood
Normal flows give indication of ability for successful operations
Normal flows may be most critical for maintenance
MWH


Maintenance
Maintenance is typically not frequent
Emergency spillway may be forgotten
Repairs are necessary to maintain in as-designed condition
Concrete
– Movement, foundation erosion, toe and head erosion
Earth
– Slope protection, erosion of channel, abutments, toe, head
Deleterious materials
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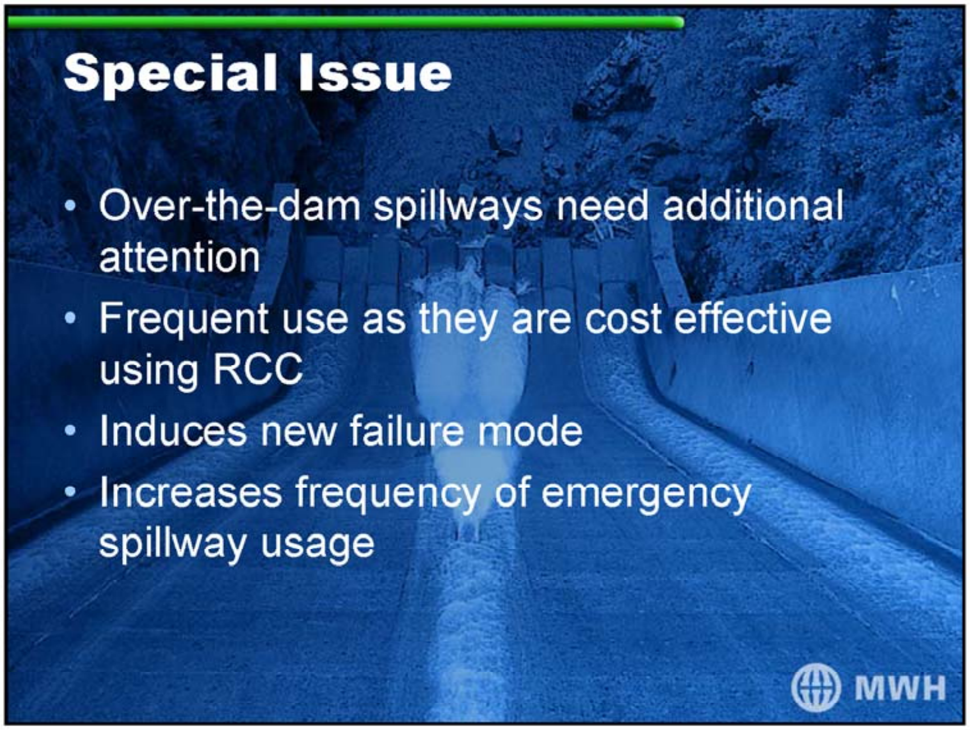
Special Issue
• Over-the-dam spillways need additional attention
• Frequent use as they are cost effective using RCC
• Induces new failure mode
• Increases frequency of emergency spillway usage
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Monitoring
• Monitoring is needed
– to estimate performance
– to set a maintenance/rehabilitation plan
• Measurements of
– movement, cracking, deterioration, aging issues
• Documentation of
– surveys, photos, checklists and notes
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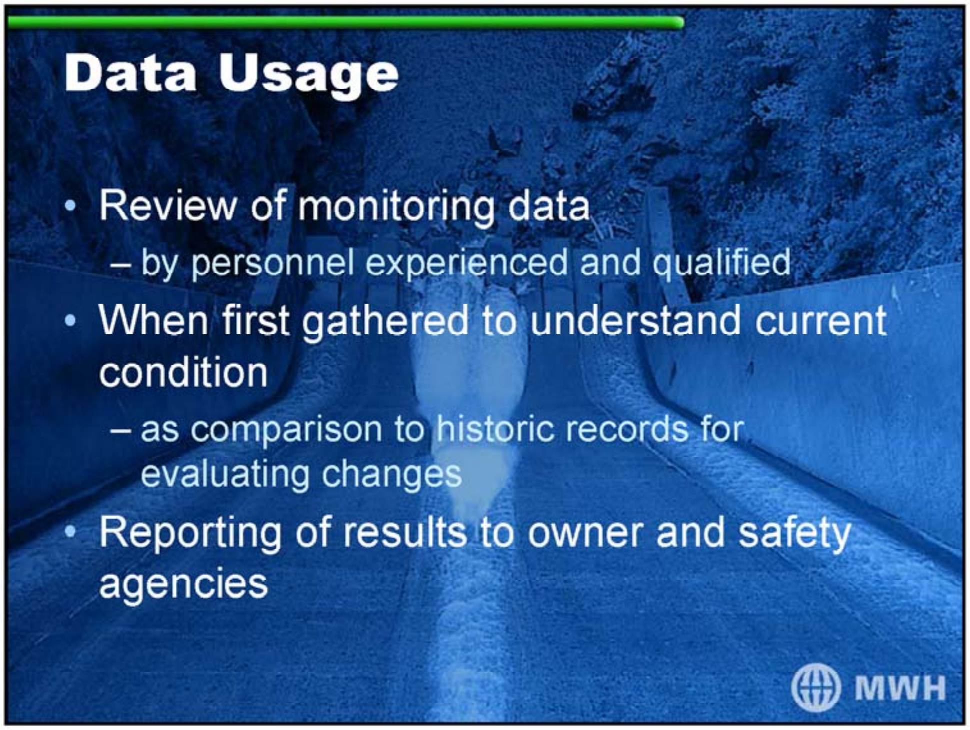
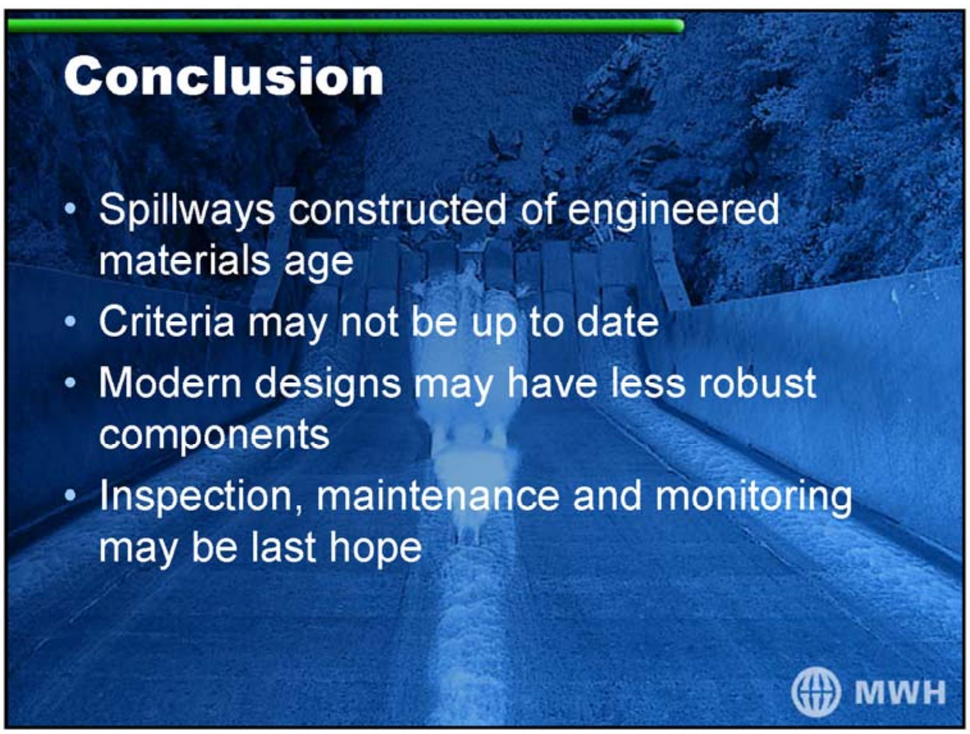

Data Usage
• Review of monitoring data
– by personnel experienced and qualified
• When first gathered to understand current condition
– as comparison to historic records for evaluating changes
• Reporting of results to owner and safety agencies
MWH


Conclusion
• Spillways constructed of engineered materials age
• Criteria may not be up to date
• Modern designs may have less robust components
• Inspection, maintenance and monitoring may be last hope
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Presentation 19:
Unlined Spillway Erosion Risk Assessment

Unlined Spillway Erosion Risk Assessment

Johannes Wibowo
Evelyn Villanueva
Don Yule
Darrel Temple

Unlined Spillway Erosion Risk Assessment

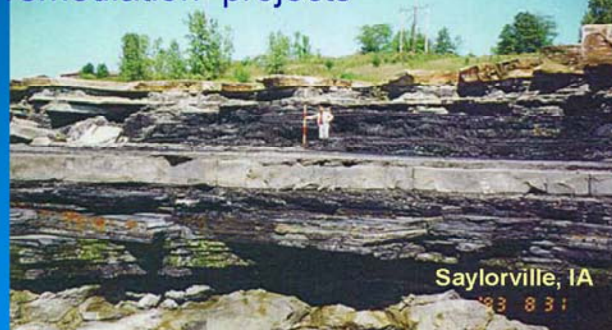
Problem Statements:

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

Unlined Spillway Erosion Risk Assessment

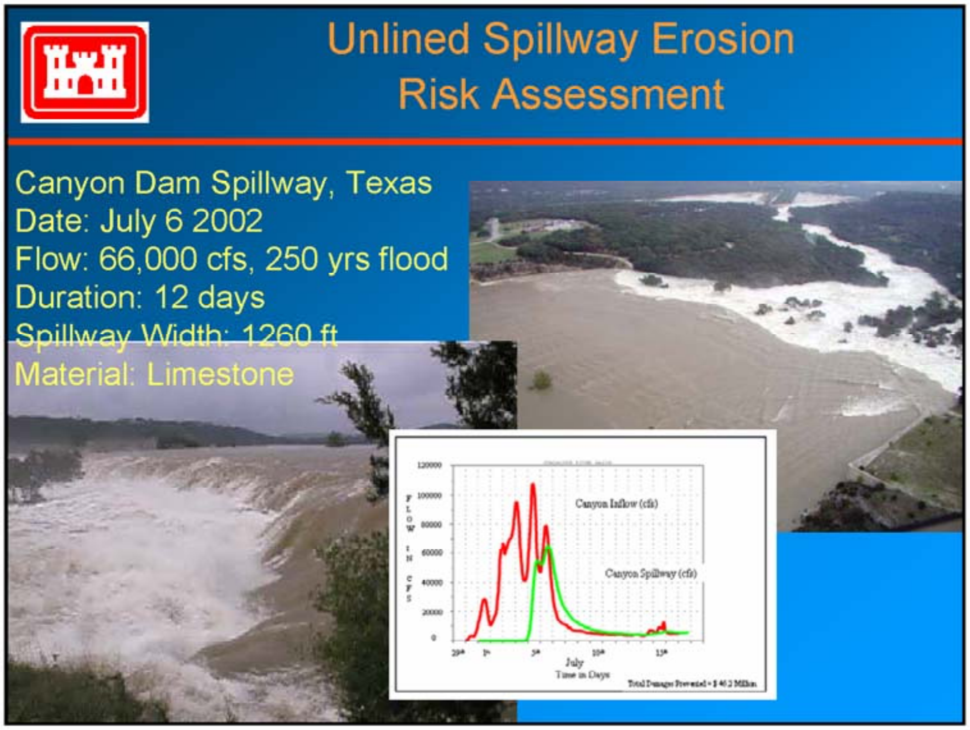
RESEARCH OBJECTIVES:

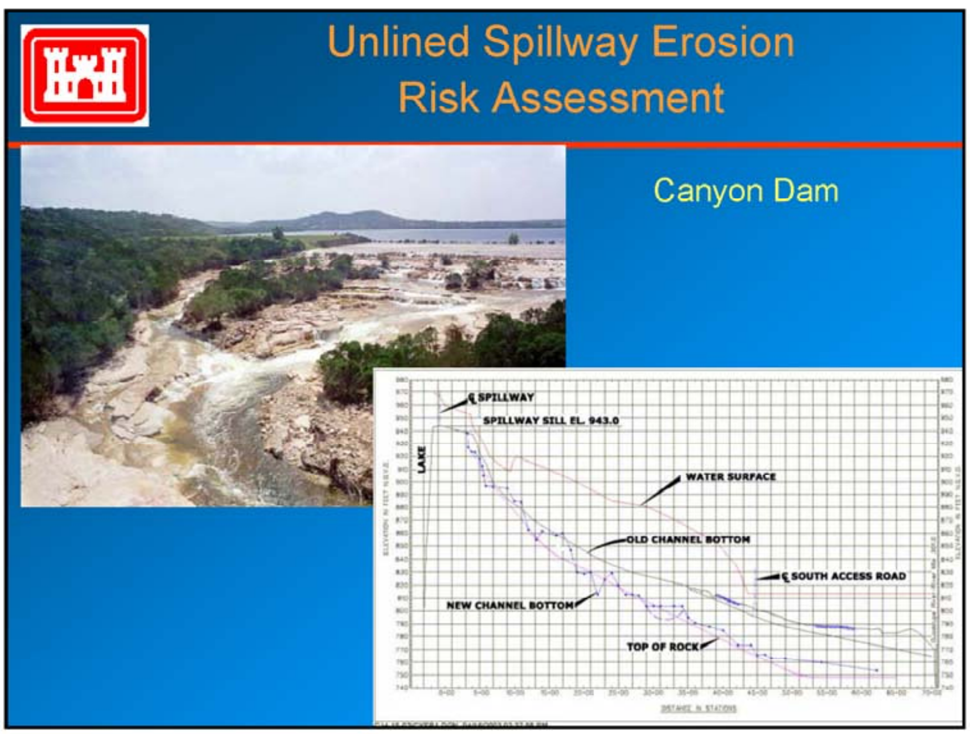
- Develop a tool to assess the probability of damage on unlined spillway erosion
- Develop a tool to prioritize unlined spillway/channel remediation projects



Unlined Spillway Erosion Risk Assessment

DMAD spillway shortly after failure (1982)


Unlined Spillway Erosion
Risk Assessment
Canyon Dam Spillway, Texas
Date: July 6 2002
Flow: 66,000 cfs, 250 yrs flood
Duration: 12 days
Spillway Width: 1260 ft
Material: Limestone
Canyon Inflow (cfs)
Canyon Spillway (cfs)
FLOW IN CFS
120000
100000
80000
60000
40000
20000
0
July
Time in Days
Total Damages Prevented = $ 46.2 Million


Unlined Spillway Erosion
Risk Assessment
Canyon Dam
SPILLWAY
SPILLWAY SILL EL. 943.0
LAKE
WATER SURFACE
OLD CHANNEL BOTTOM
SOUTH ACCESS ROAD
NEW CHANNEL BOTTOM
TOP OF ROCK

Unlined Spillway Erosion Risk Assessment

Risk Assessment

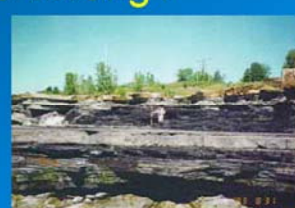
Process of Answering Three Questions:

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

Unlined Spillway Erosion Risk Assessment

1 What Can Go Wrong?

Local Scouring



Headcut Erosion

Spillway Breach

Dam Breach

Unlined Spillway Erosion 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

Unlined Spillway Erosion 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

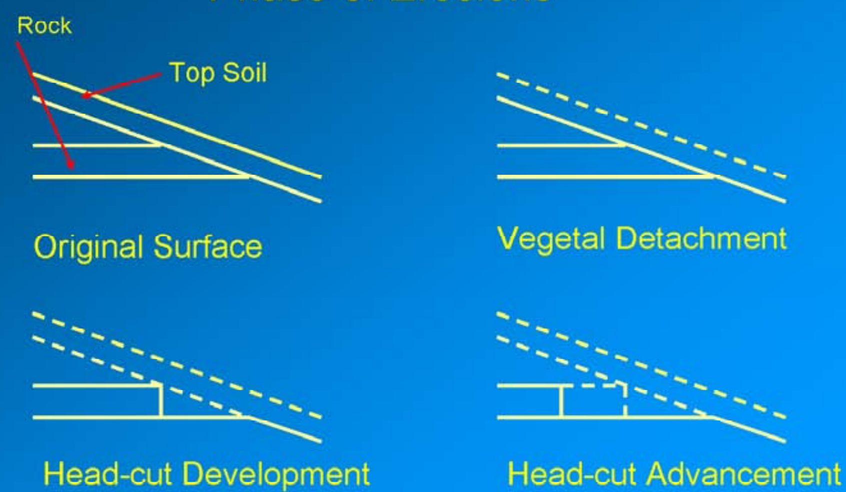
Unlined Spillway Erosion Risk Assessment

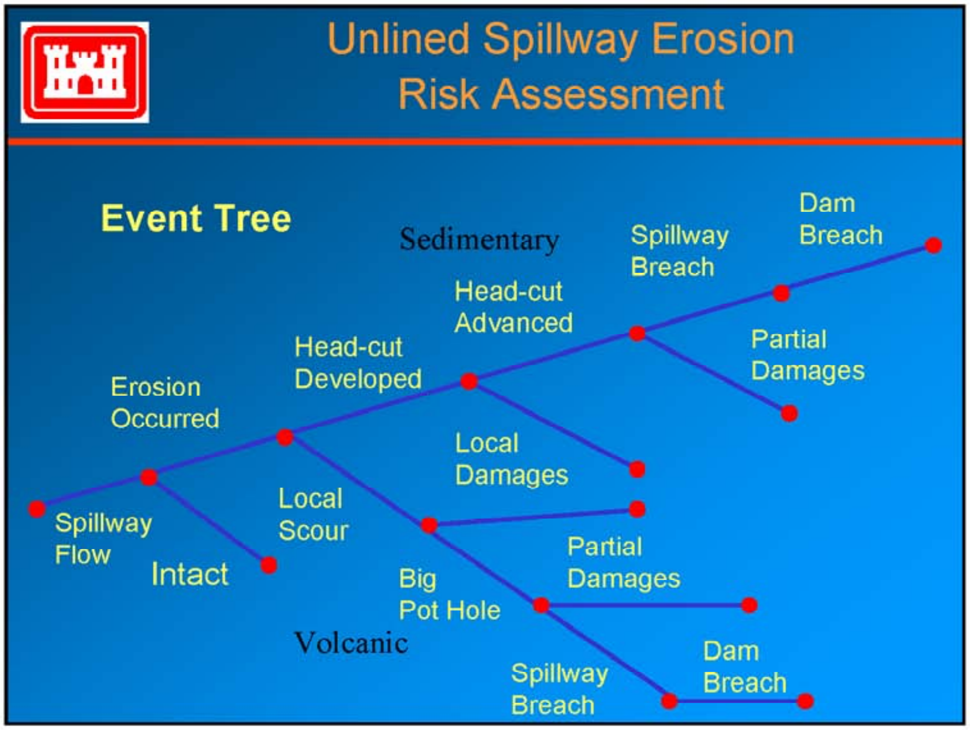
Spillway Erosion Models

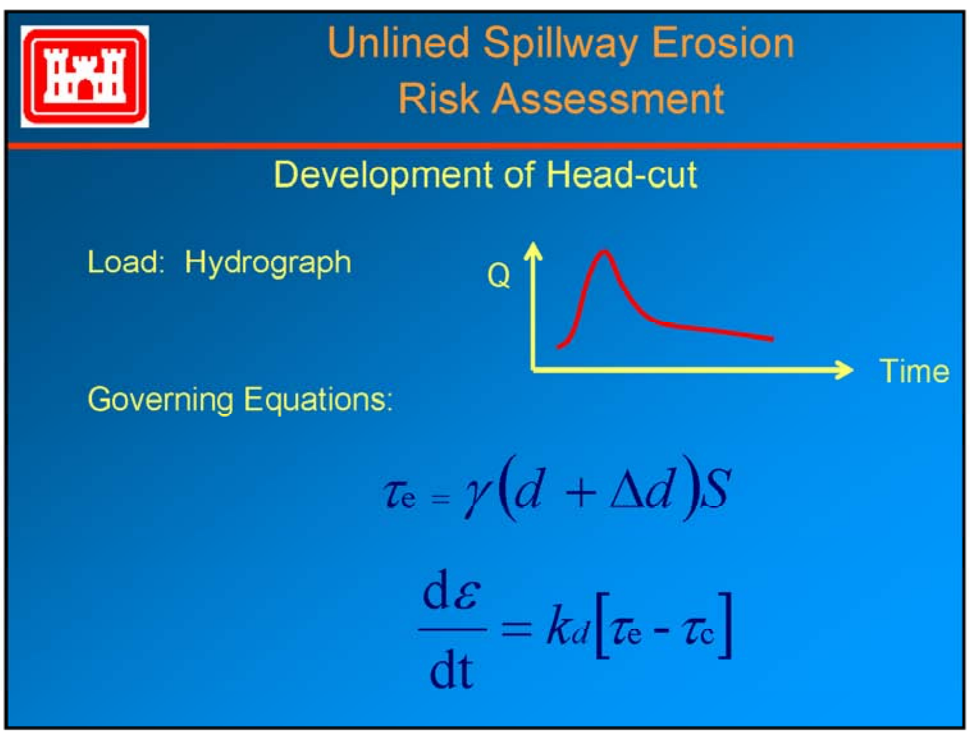
- USDA (Temple et al., 1994)
- Modified USDA (KCD,1995; ERDC, 2002)
- Annandale (1995)
- REMR (WES, 1998)

Unlined Spillway Erosion Risk Assessment

Phase of Erosions




Unlined Spillway Erosion
Risk Assessment
Event Tree
Sedimentary
Spillway Breach
Dam Breach
Head-cut Advanced
Partial Damages
Head-cut Developed
Erosion Occurred
Local Damages
Local Scour
Spillway Flow
Intact
Partial Damages
Big Pot Hole
Volcanic
Dam Breach
Spillway Breach


Unlined Spillway Erosion
Risk Assessment
Development of Head-cut
Load: Hydrograph
Q
Time
Governing Equations:
$\tau_e = \gamma(d + \Delta d)S$
$\frac{d\varepsilon}{dt} = k_d[\tau_e - \tau_c]$

Unlined Spillway Erosion Risk Assessment

Parameters

τ_e = effective stress

γ = unit weight of water

d = normal depth of flow

S = surface slope

$d\varepsilon/dt$ = erosion rate

k_d = detachment rate coefficient

τ_c = threshold stress

Unlined Spillway Erosion Risk Assessment

Head-cut Advance

Load: Hydrograph

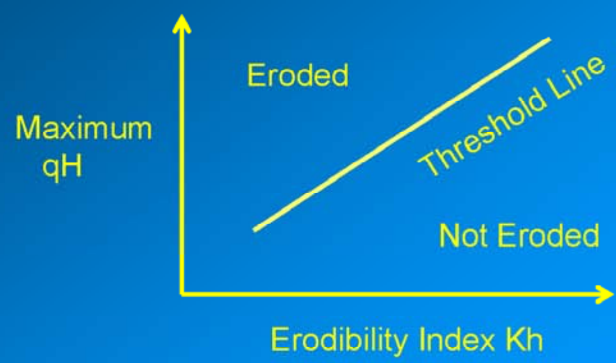
Governing Equations:

$$\frac{dx}{dt} = \begin{cases} C(A - A_0) & (A - A_0) > 0 \\ 0 & (A - A_0) \le 0 \end{cases}$$

dx/dt = Rate of headcut advance
C = Empirical parameter
A = Hydraulic attack
A_0 = Threshold level

Unlined Spillway Erosion Risk Assessment

Erosion Model - Threshold Line



Unlined Spillway Erosion Risk Assessment

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

Unlined Spillway Erosion Risk Assessment

Maximum Hydraulic Attack

E = ☎ * q * H

E = Maximum Hydraulic Attack
☎ = Unit weight of water
q = Unit discharge
H = Energy line drop

Unlined Spillway Erosion Risk Assessment

Logistic Regression

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

Unlined Spillway Erosion Risk Assessment

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

Unlined Spillway Erosion Risk Assessment

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

Unlined Spillway Erosion Risk Assessment

Multiple Logistic Regression for Spillway Erosion

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

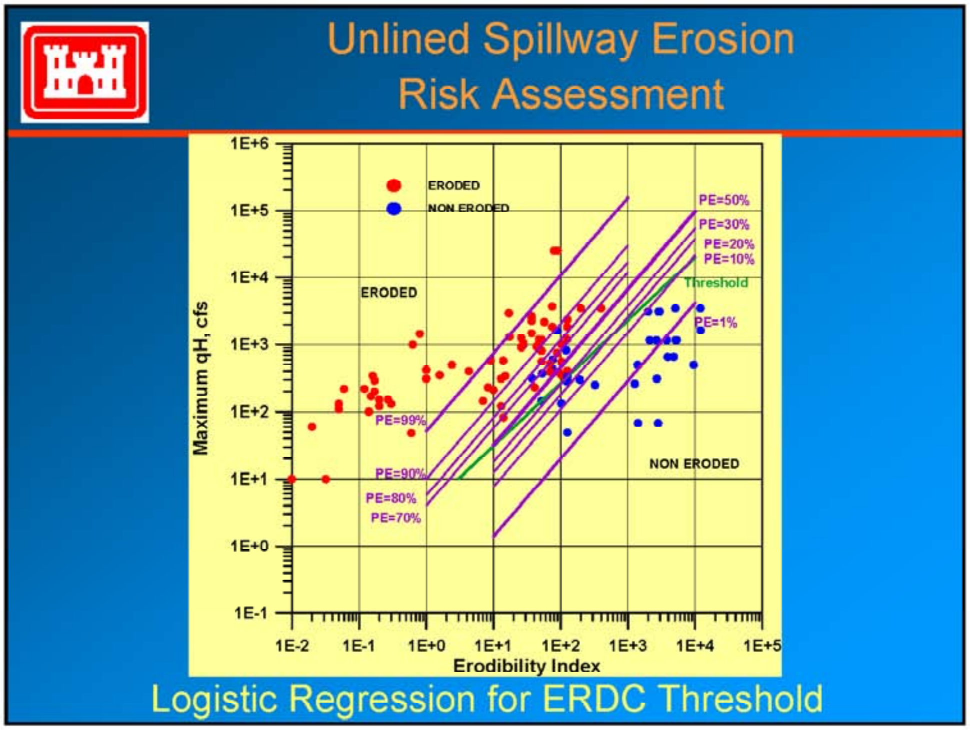
K_h = Erosion Index, Material Resistance
qH = Maximum qH, Hydraulic Attack

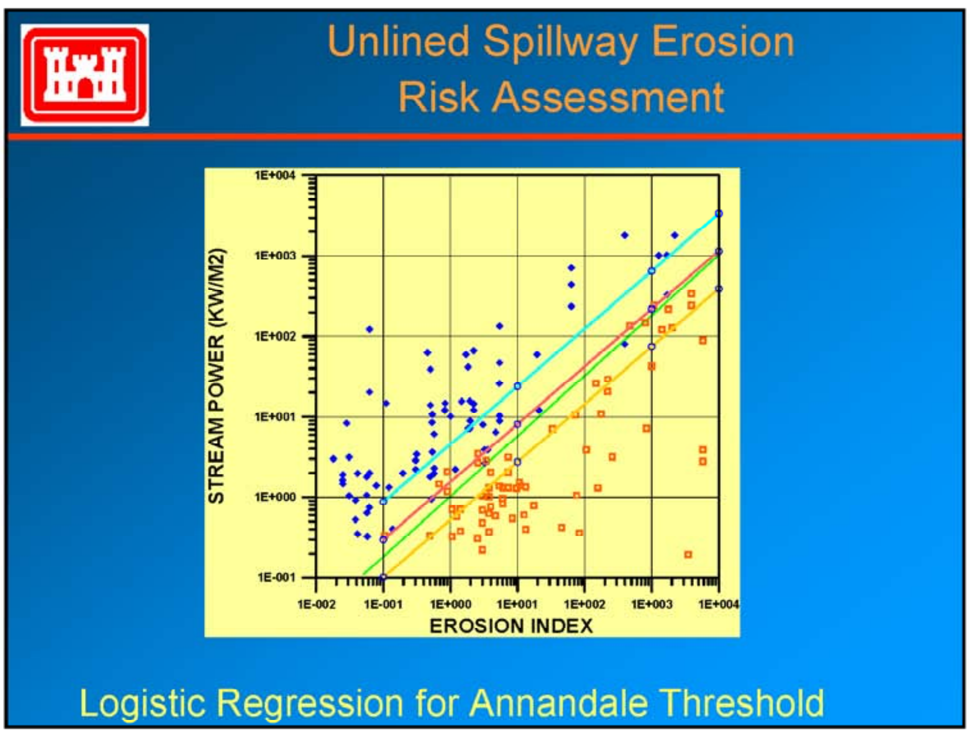
Unlined Spillway Erosion Risk Assessment

Result of Multiple Logistic Regression

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

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


Unlined Spillway Erosion
Risk Assessment
ERODED
NON ERODED
ERODED
NON ERODED
PE=50%
PE=30%
PE=20%
PE=10%
Threshold
PE=1%
PE=99%
PE=90%
PE=80%
PE=70%
Maximum qH, cfs
1E+6
1E+5
1E+4
1E+3
1E+2
1E+1
1E+0
1E-1
1E-2
1E-1
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
Erodibility Index
Logistic Regression for ERDC Threshold


Unlined Spillway Erosion
Risk Assessment
STREAM POWER (KW/M2)
1E+004
1E+003
1E+002
1E+001
1E+000
1E-001
1E-002
1E-001
1E+000
1E+001
1E+002
1E+003
1E+004
EROSION INDEX
Logistic Regression for Annandale Threshold

Unlined Spillway Erosion Risk Assessment

Independent Variables

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

Unlined Spillway Erosion Risk Assessment

Ordinal Logistic Regression

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

Data: Case Histories (USDA and COE)

Damage Levels:

No Damage	0 - 0.05%
Lightly Damage	0.06 – 15%
Moderately Damage	16 – 40%
Severely Damage	41 – 75%
Breach	76 – 100%

Unlined Spillway Erosion Risk Assessment

Ordinal Logistic Regression

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

Probability Formulation:

No Damage	= 1/(1+ exp(Sj-k1))
Lightly Damage	= 1/(1+ exp(Sj-k2)) - 1/(1+ exp(Sj-k1))
Moderately Damage	= 1/(1+ exp(Sj-k3)) - 1/(1+ exp(Sj-k2))
Severely 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

Unlined Spillway Erosion Risk Assessment

Input	Tuttle Cr., KS Ls-Sh G/J	Painted Rock, AZ		Saylorville, IA Ss-Sh, 91	Buck_Doe, MO
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
Lightly	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

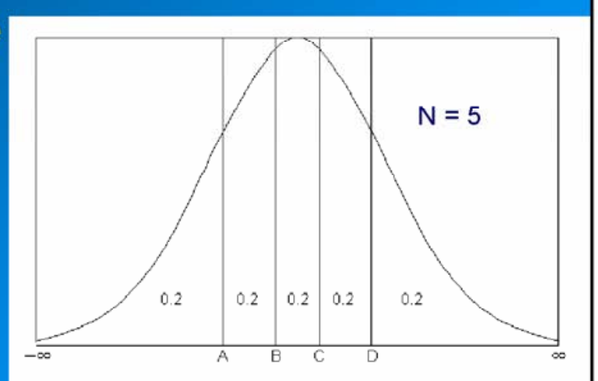
Unlined Spillway Erosion Risk Assessment

	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

Simulation Using USDA Model

- Monte Carlo
- Latin Hyper-Cube



Unlined Spillway Erosion Risk Assessment

LHC Simulation

Variables:

Materials
Hydrographs

Damage Levels:

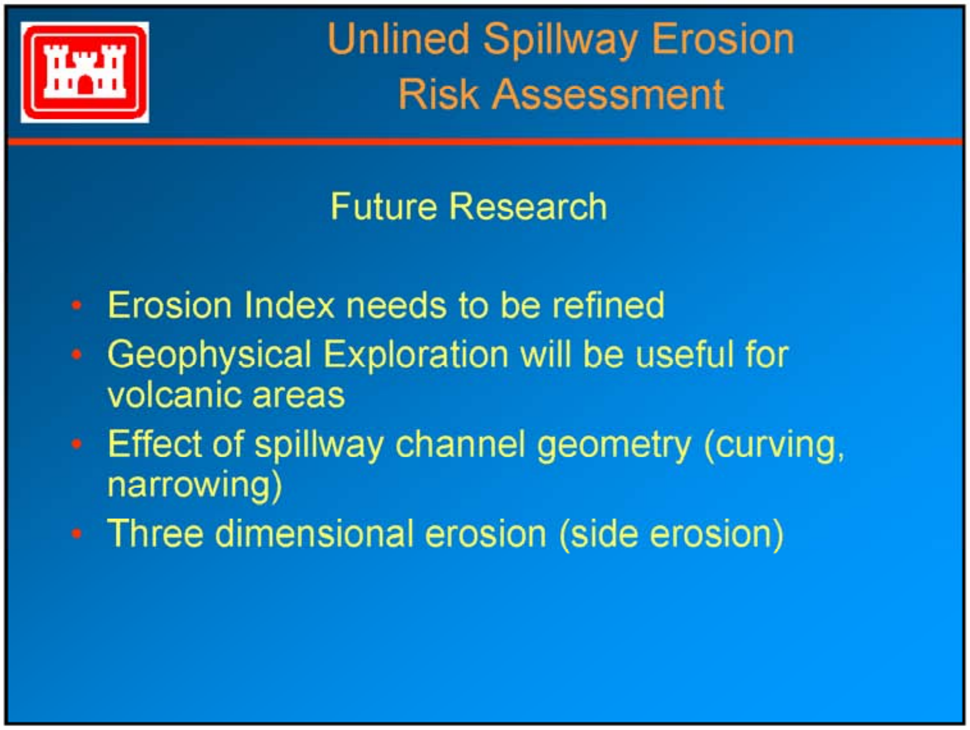
No Damage	0 - 0.05%
Lightly Damage	0.06 – 15%
Moderately Damage	16 – 40%
Severely Damage	41 – 75%
Breach	76 – 100%

Unlined Spillway Erosion Risk Assessment

Prioritizing Process

Ranking the outcome:

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


Unlined Spillway Erosion
Risk Assessment
Future Research
• Erosion Index needs to be refined
• Geophysical Exploration will be useful for volcanic areas
• Effect of spillway channel geometry (curving, narrowing)
• Three dimensional erosion (side erosion)