RAC
Engineers & Economists

Briefing for MG Peabody

Wolf Creek Dam, KY

25 August 2009

US Army Corps of Engineers

Risk-based Evaluation of Operating Restrictions for Lake Cumberland

Wolf Creek Dam

Reference:
Loren R. Anderson. 2554. เอกสารประกอบการอบรม "การวิเคราะห์เพื่อออกแบบและประเมินความปลอดภัยเขื่อน", ระหว่างวันที่ 5,7 และ 8 เมษายน 2554, จัดโดย ศูนย์วิจัยและพัฒนาวิศวกรรมปฐพีและฐานราก มหาวิทยาลัยเกษตรศาสตร์ ร่วมกับ Thai Geotechnical Society (TGS), ณ โรงแรมมิราเคิล แกรนด์ คอนเวนชั่น, กรุงเทพฯ.

David S. Bowles and Loren R. Anderson

RAC Engineers & Economists and
Institute for Dam Safety Risk Management - Utah State University

Objective

To evaluate the strength of justification for maintaining or changing the Hold 680 operating restriction on Lake Cumberland following installation of the first grout curtain based on information available as of Nov 2007.

Including uncertainty analysis (OMB 2007)

Part 2 – Some Details of the Risk Analysis

1) Potential failure modes and event tree

Scope of Risk Assessment

- For Each Alternative Operating Restriction:
  1) PROBABILITY <u>of Failure</u> (/year)
     - Focused on Karst Foundation
     - Omitted Flood and Earthquake Failure Modes
  2) CONSEQUENCES <u>of Failure</u>
     - Economic ($)
     - Life loss
  3) Economic IMPACTS <u>of Operating Restriction</u> ($)
- Repeated for each stage of completion of the fix

Engineering Team

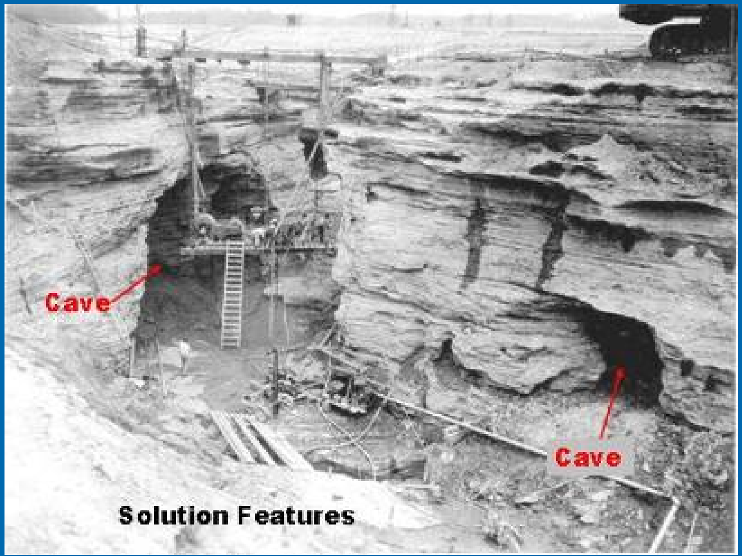
- Nashville District engineers
  - Michael Zoccola, Chief, Civil Design Branch
  - Tommy Haskins
  - Daphne Jackson
  - Tim McCleskey
  - Jody Stanton
  - James Gunnels
- ITR – participative role
  - John France
  - Francisco Silva
  - Dan Hurst
- RAC Engineers & Economists
  - Loren Anderson, Facilitator
  - David Bowles
  - Ignacio Escuder
- *DSAC 1 Expert Review Panel – not final estimates*
  - *Keith Ferguson*
  - *Jim Talbot*
  - *Don Bruce*

Potential Failure Modes Analysis

- Thorough review of drawings, performance history, etc.
- Detailed site visit
- Reviewed engineering analyses and USACE standards
- Reviewed design flood event
- Systematic evaluation of the potential failure modes for all dam components
- 7 failure modes identified but only 3 considered “credible” and “significant” for this IRRM study and these were combined into 2 for the Risk Analysis
- Other failure modes should be included in an IES or DSMS risk assessment

System Response Probability Estimation

- Review all available information
- Discuss all available information
- Make thorough descriptions of each event tree branch for each failure mode
- Identify factors making each event more likely or less likely to occur and duration of pool level influences
- Use probability estimation guidance table to make estimates of SRPs and minimum duration of pool exceedance
- Discuss differences in estimates and come to consensus



Branch number 2: Loss of alluvium or embankment material into a cavity

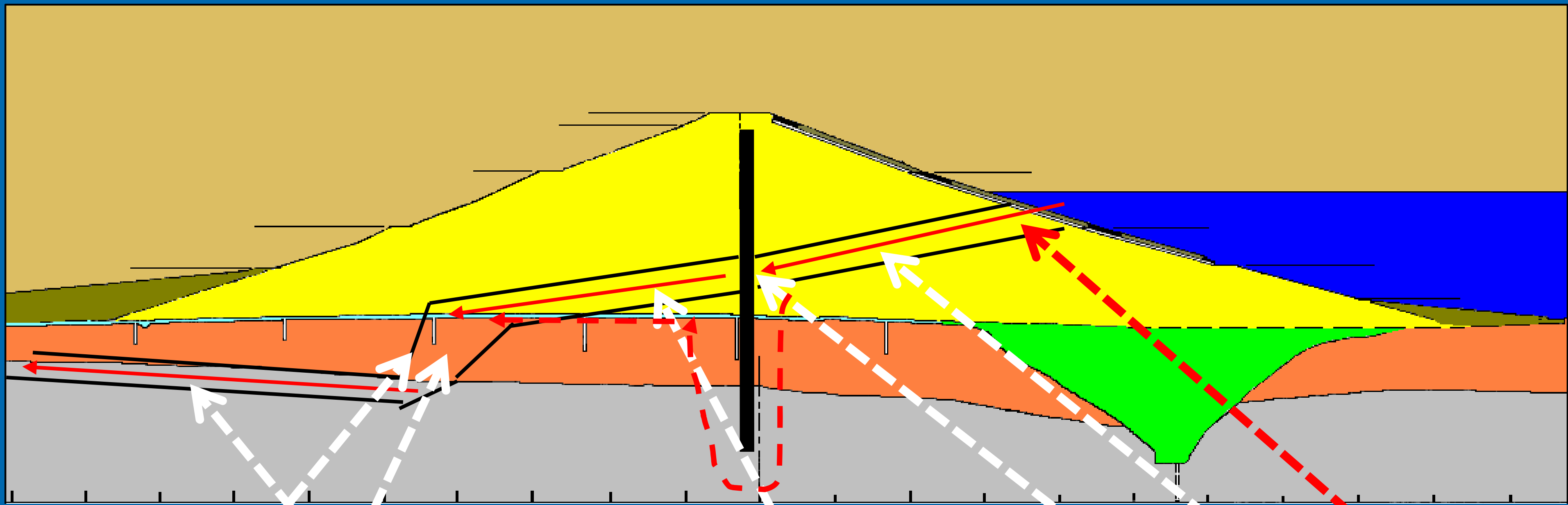
More Likely	Less Likely
Historical mechanism that occurred in 1968 at Wolf Creek and other places with similar geology	High water pressures are less in area downstream of the wall than occurred in 1968
Dimensions of cavities	Extensive grouting/cavity filling
Vertical joints and Karst orientation	Alluvium is cohesive
Embankment settlement	Trends in piezometric data
Water pressures in dam/alluvium that create a downward seepage gradient to transport material	Revised operations maintaining less reservoir fluctuations
Soft zones in the dam	
Trends in piezometric data	

Guidelines for judgment used in estimating system response probabilities

Event Descriptor	Assigned Probability
Certain	1.0
Virtually certain	0.999
Extremely likely	0.995
Very likely	0.99
Likely	0.9
Neutral	0.5
Unlikely	0.1
Very unlikely	0.01
Extremely unlikely	0.005
Virtually impossible	0.001
Impossible	0.0

Failure Mode

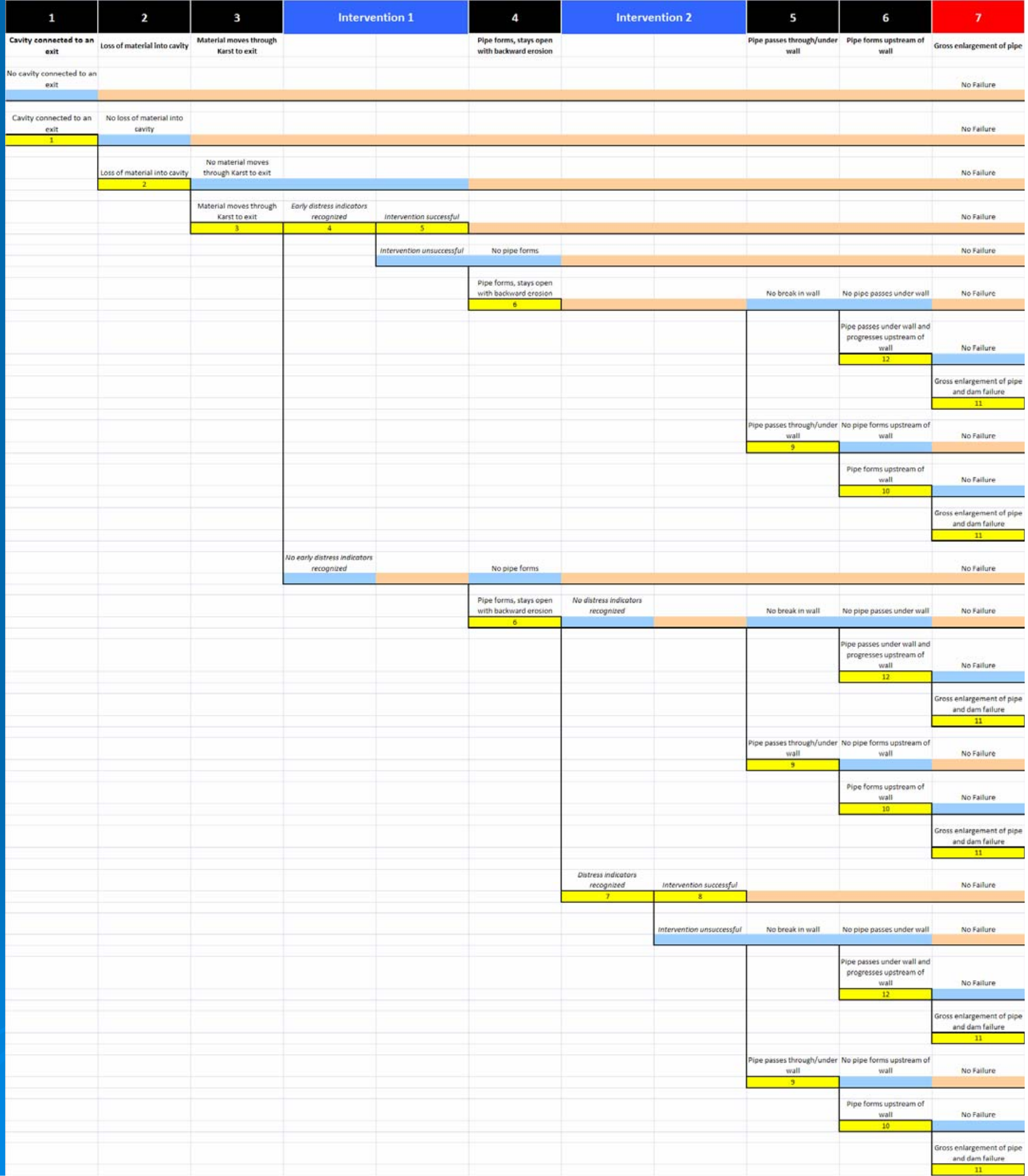
Loss of material into a collapsed cavity in the downstream Karst foundation followed by piping in the alluvium foundation or embankment back to the barrier wall and finally through an opening in the wall (or below the wall) followed by backward erosion through the embankment to the reservoir.



Development Level No.	1	2	3	Intervention 1		4	Intervention 2		5	6	7
Branch No.	i	ii	iii	iv	v	vi	vii	viii	ix	x	xi
	Cavity connected to an exit	Loss of material into cavity	Material moves through Karst to exit			Pipe forms, stays open with backward erosion			Pipe passes through/under wall	Pipe forms upstream of wall	Gross enlargement of pipe

Failure Mode Event Tree

- Left with Barrier Wall
- Right without Barrier Wall

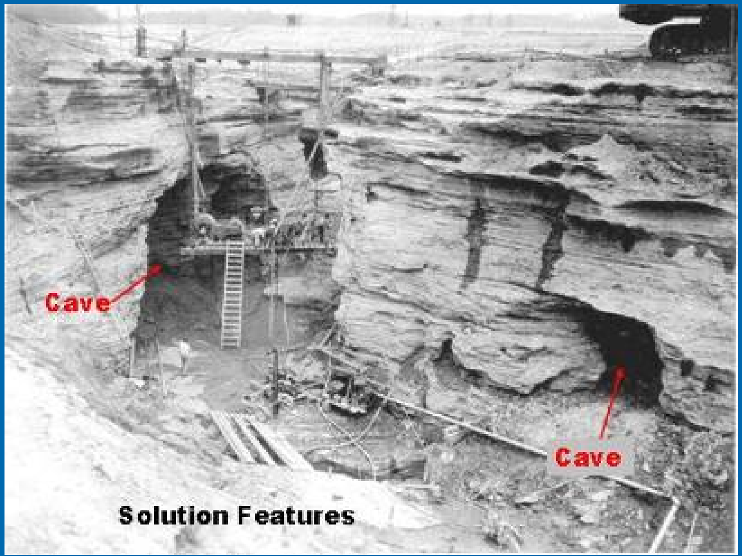


Part 2 – Some Details of the Risk Analysis

2) Probability estimation

System Response Probability Estimation

- Review all available information
- Discuss all available information
- Make thorough descriptions of each event tree branch for each failure mode
- Identify factors making each event more likely or less likely to occur and duration of pool level influences
- Use probability estimation guidance table to make estimates of SRPs and minimum duration of pool exceedance
- Discuss differences in estimates and come to consensus



Branch number 2: Loss of alluvium or embankment material into a cavity

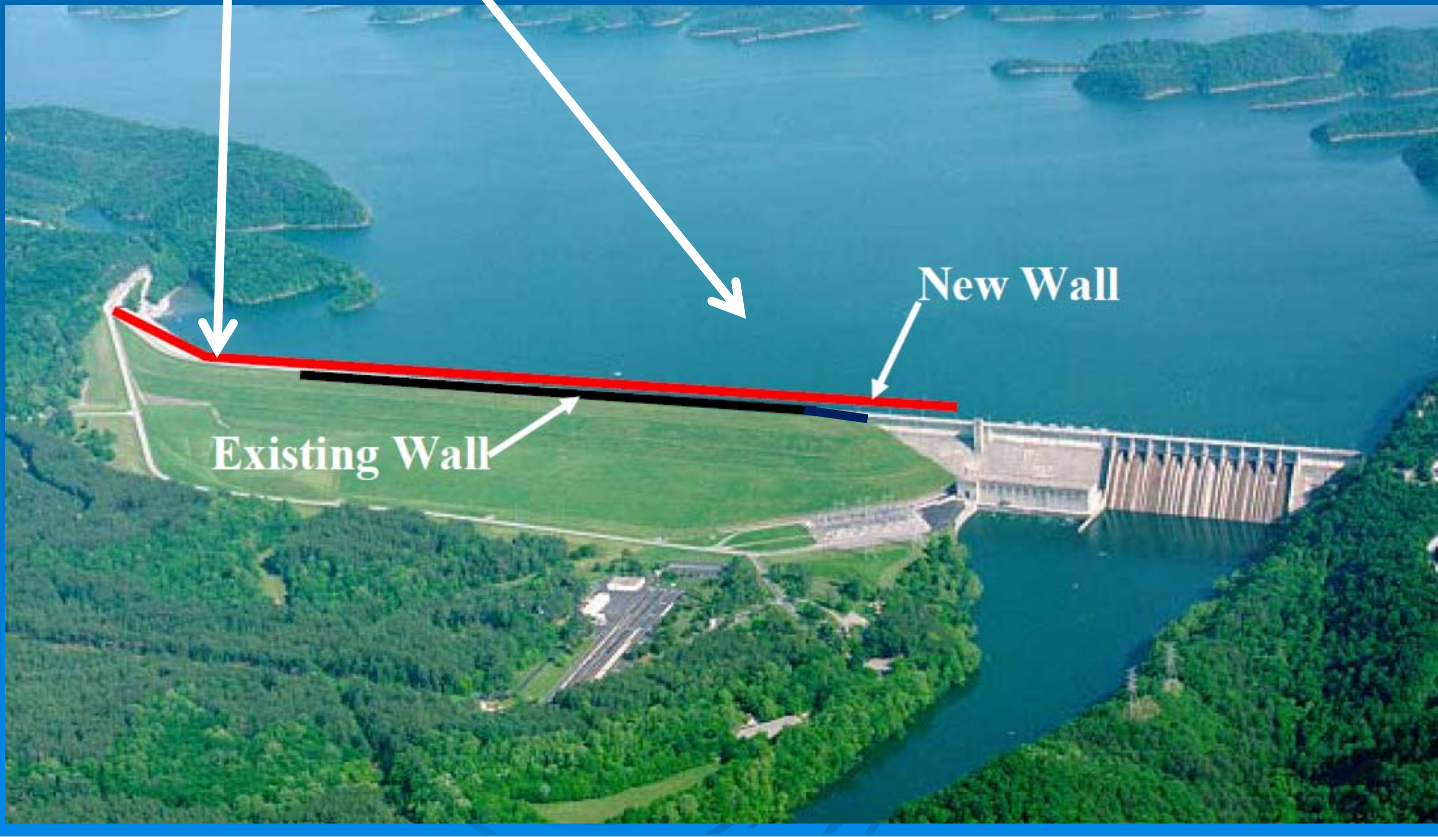
More Likely	Less Likely
Historical mechanism that occurred in 1968 at Wolf Creek and other places with similar geology	High water pressures are less in area downstream of the wall than occurred in 1968
Dimensions of cavities	Extensive grouting/cavity filling
Vertical joints and Karst orientation	Alluvium is cohesive
Embankment settlement	Trends in piezometric data
Water pressures in dam/alluvium that create a downward seepage gradient to transport material	Revised operations maintaining less reservoir fluctuations
Soft zones in the dam	
Trends in piezometric data	

Guidelines for judgment used in estimating system response probabilities

Event Descriptor	Assigned Probability
Certain	1.0
Virtually certain	0.999
Extremely likely	0.995
Very likely	0.99
Likely	0.9
Neutral	0.5
Unlikely	0.1
Very unlikely	0.01
Extremely unlikely	0.005
Virtually impossible	0.001
Impossible	0.0

Breach Scenarios

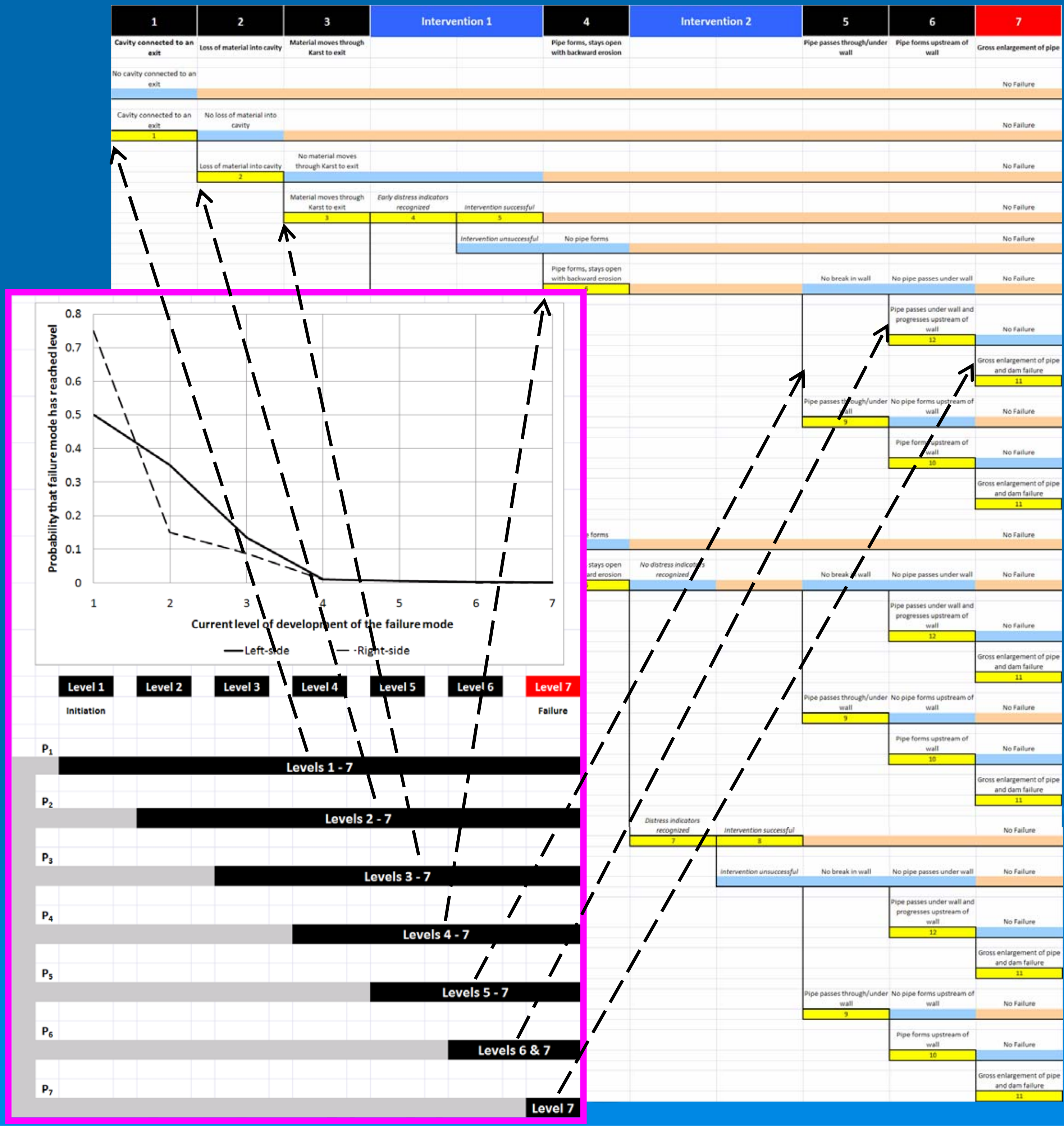
- 8 Breach Cases
  - 6 cases on left (with existing barrier wall) – 200 ft and 600 ft wide – Pool El. 640, 680 and 723
  - 2 cases on right (no barrier wall) – Pool El. 680 and 723



Part 2 – Some Details of the Risk Analysis

3) Risk model incorporating uncertainty analysis

Knowledge uncertainty in current level of development for the piping failure mode



Risk Reduction Measures for Piping – Participant Discussion