FACTORS INFLUENCING THE LIKELIHOOD THAT INTERVENTION FAILS FOR INTERNAL EROSION				DATE: JULY 2012
Factor	**Influence on Likelihood (see notes)**			**Comments**
	Less Likely	**Neutral**	**More Likely**	
Detection Factors				
Signs of internal erosion are detectable and recognizable	Adequate monitoring system with a plan specifically developed to address internal erosion potential failure modes. Well-trained dam operations, maintenance and monitoring staff.	Ability to detect may vary seasonally, depending on weather (snow, rain), vegetation (thick grass, tall vegetative cover), etc.	Little or no monitoring system. No trained staff. Evidence of eroded materials masked by rockfill zone, or eroded away by seepage flows.	
Evaluation of instrumentation data	Piezometric and seepage weir flow data is regularly evaluated; long-term trends are reviewed; look for changes in behavior.		Piezometric and seepage weir flow data is not collected or evaluated.	
Opportunity to observe signs of internal erosion ("eyes on the dam")	On site dam tender; frequent site visits; specific observations focused on areas where internal erosion could develop (d/s of conduits, walls; groin areas; d/s toe area, etc.).	Ability to observe, may vary seasonally, depending on season (summer vs. winter recreationists) weather, and other factors (park ranger patrols, etc.).	Infrequent site visits.	
Rate of erosion pathway development	Erosion expected to occur slowly; slow enlargement of the erosion pathway. Erosion resistant materials (e.g. dense, plastic materials).		Erosion expected to occur rapidly; rapid enlargement of the erosion pathway. Erosive materials (e.g. loose silt, sandy silt, granular materials with non-plastic fines).	Slower developing erosion pathways are more likely to be detected.
Physical Intervention Actions				The question is: Can physical intervention actions be taken in time to stop or slow the failure process to the point where dam breach does not occur?
Reservoir drawdown	Significant and effective emergency release capability (compared to the expected rate of development of the failure mode). Decisions made to release in a timely manner, despite potential adverse downstream consequences.		Small emergency release capability (compared to the expected rate of development of the failure mode). Potential failure mode is related to the outlet works and its use could worsen the situation. Decisions not made to release in a timely manner.	In some cases, the entrance point for a potential failure mode may be associated with a particular defect (e.g. a high permeability lift) and drawdown to just below the elevation of that defect could be very effective intervention.
Material erodibility	Erosion pathway is through rock; erodible soils not involved.	Erosion pathway is mostly through erosion resistant materials, therefore allowing greater time for intervention efforts	Erosion pathway is mostly through erosive materials, therefore allowing little time for intervention efforts	
Erosion mechanism	Small sinkholes on the crest or downstream face caused by suffusion or	Large sinkholes on the crest caused by suffusion or internal migration. Scour of	Large sinkhole on upstream face; backwards eroding pipe	

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Factor	**Influence on Likelihood (see notes)**			**Comments**
	Less Likely	**Neutral**	**More Likely**	
	internal migration	erosion pathway through crack.		
Accessibility of downstream exit point	Easily accessible for construction equipment.	Difficult access for construction equipment; additional time and effort would be needed to construct access.	Difficult access for construction equipment; soft/wet areas, poor roads; crest width; bridge restrictions across dam crest.	
Adequate filter and drain material available	Large stockpile of filter compatible materials available on site. Large embankment freeboard could allow for "cannibalization" of the upper parts of the embankment.		No nearby source of appropriate filter and drain materials. Little or no freeboard to allow for "cannibalization" of the upper parts of the embankment.	The farther along the internal erosion process that a failure mode has progressed, the larger the volume of materials that are needed to effectively intervene.
Ability to quickly mobilize equipment and materials	Equipment and materials readily available on site.	Equipment and materials readily available from the local water district, a nearby contractor, or a nearby sand and gravel supplier and can be mobilized with minimal delay. Pre-established agreements with local contractors to supply equipment and materials.	Equipment and materials not readily available; difficulties envisioned with procurement and mobilization to the site.	
Accessibility of upstream sinkhole or entrance point	Sinkhole or entrance point easily reached from the dam crest.	Location of potential sinkhole or entrance point could be anywhere on the upstream face of the dam.	Sinkhole or entrance point not likely to be within reach of the dam crest.	
Availability of large material to plug the sinkhole or entrance point	Appropriately sized materials are stockpiled on site.	Materials are available nearby and can be mobilized with minimal delay.	No nearby source of appropriate materials.	
Capability of intentional breach	A benign breach area exists (smaller low hazard dike location, reservoir rim area, etc.) that would allow a lesser uncontrolled release of the reservoir. Flooding would not impact a populated area.		No benign breach area exists.	

Notes on use of Table:

1. Table is intended to provide guidance on the probability that intervention fails for internal erosion. Intervention includes both detection and physical intervention components. Although the probability that intervention fails is evaluated just before breach, it is understood that intervention efforts could occur at any time.

2. Unlike the "initiation" tables, there are no historical average base rates to compare relative probabilities. The more likely and less likely factors can be considered qualitatively, and can be considered along with verbal descriptors for a quantitative estimate. The neutral factors listed in the table are factors that have a small influence on the likelihood, or factors that could equally increase or decrease the likelihood of unsuccessful intervention. Neutral factors do not automatically imply a 50% probability.

References:

Draft Risk Analysis Methodology Appendix E (2000), Estimating Risk of Internal Erosion and Material Transport Failure Modes for Embankment Dams, version 2.4, Bureau of Reclamation, Technical Service Center, Denver, CO. August 18, 2000. (This document was never finalized; it was superseded in 2008 by Dam Safety Risk Analysis Best Practices Training Manual, Chapter 24.)

Fell, R., C.F. Wan, and M. Foster (2004), "Progress Report on Methods for Estimating the Probability of Failure of Embankment Dams by Internal Erosion and Piping," University of New South Wales, Sydney, Australia. UNICIV Report 428. 2004.

Bureau of Reclamation (2011), Dam Safety Risk Analysis Best Practices Training Manual.