SAFETY OF DAMS:
A QUALITATIVE AND QUANTITATIVE RISK ANALYSIS

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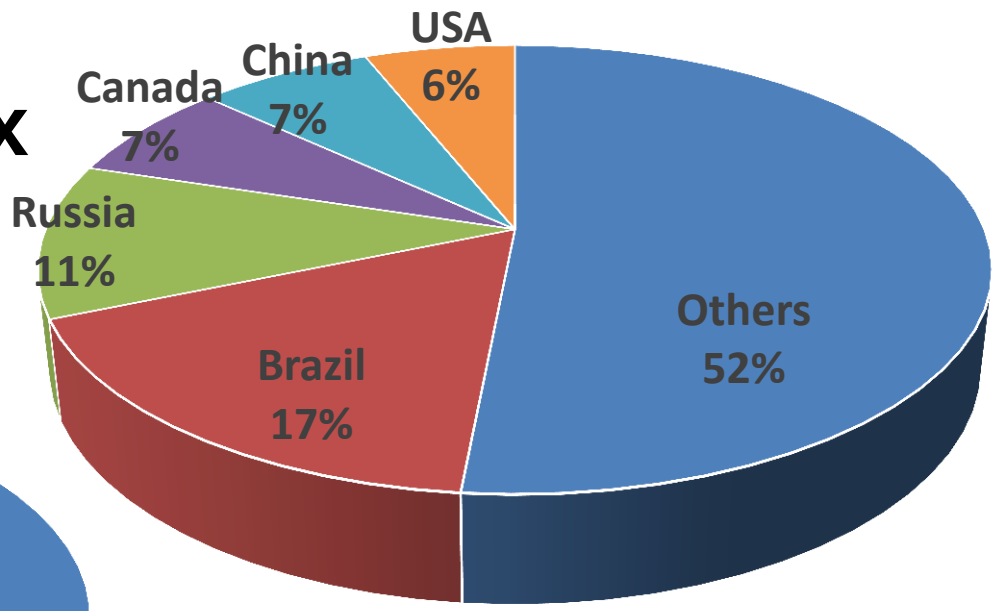
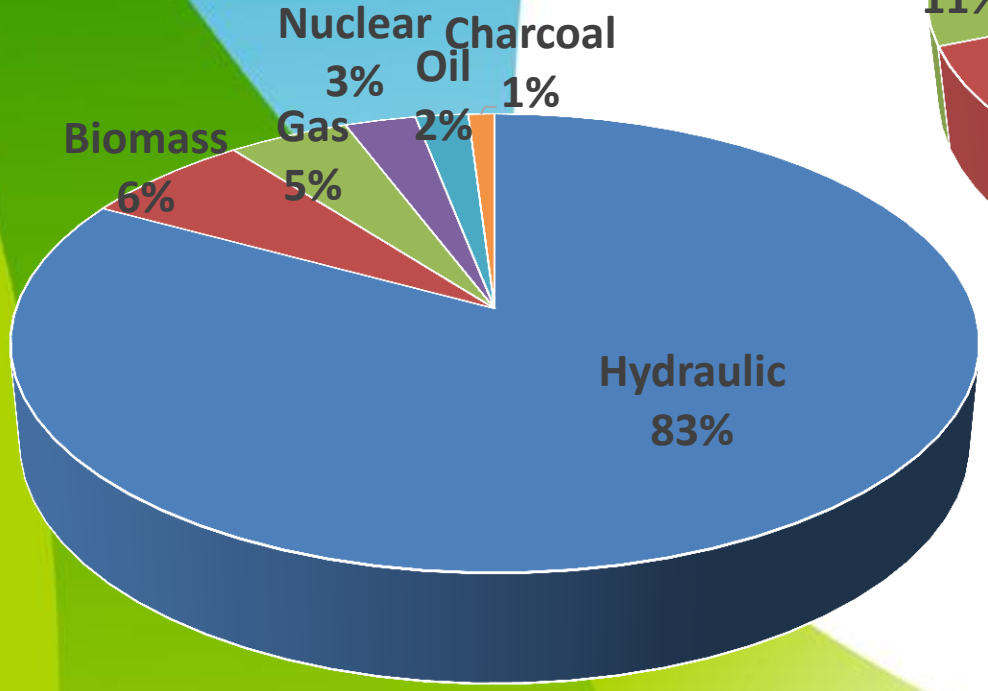
Global Distribution of Water

(WCD-World Commission on Dams, 2016)



Brazilian Energy Matrix

(Ministry of Mines and Energy, 2017)



SOURCE	INSTALLED POWER
Hydroelectric	91.650 MW
Gas	14.116 MW
Biomass	13.336 MW
Oil	8.722 MW
Wind	7.633 MW
Charcoal	3.390 MW
Nuclear	1.990 MW
Solar	31 MW

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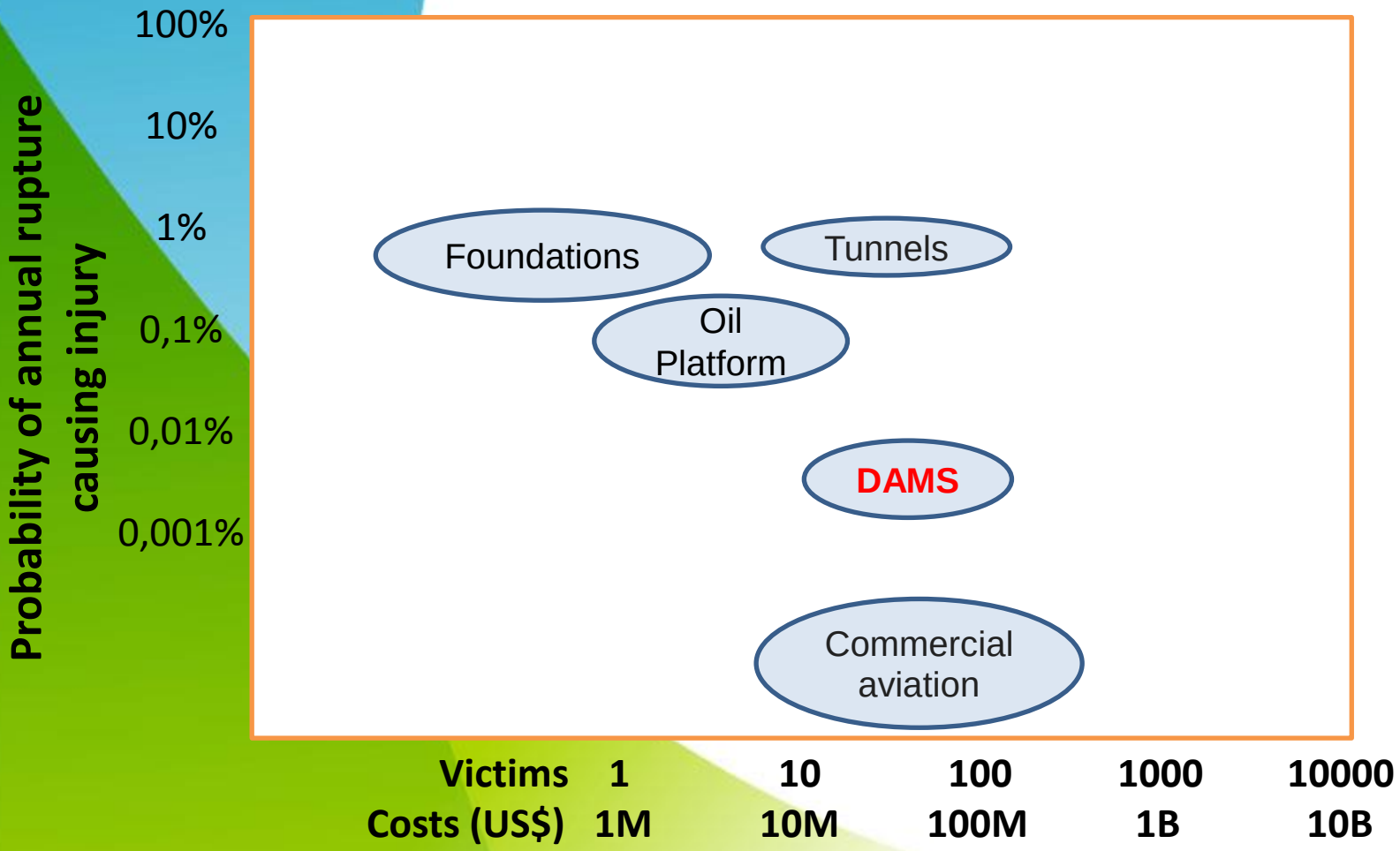
Risks associated with Engineering Works

(Salmon & Hartford, 1995)



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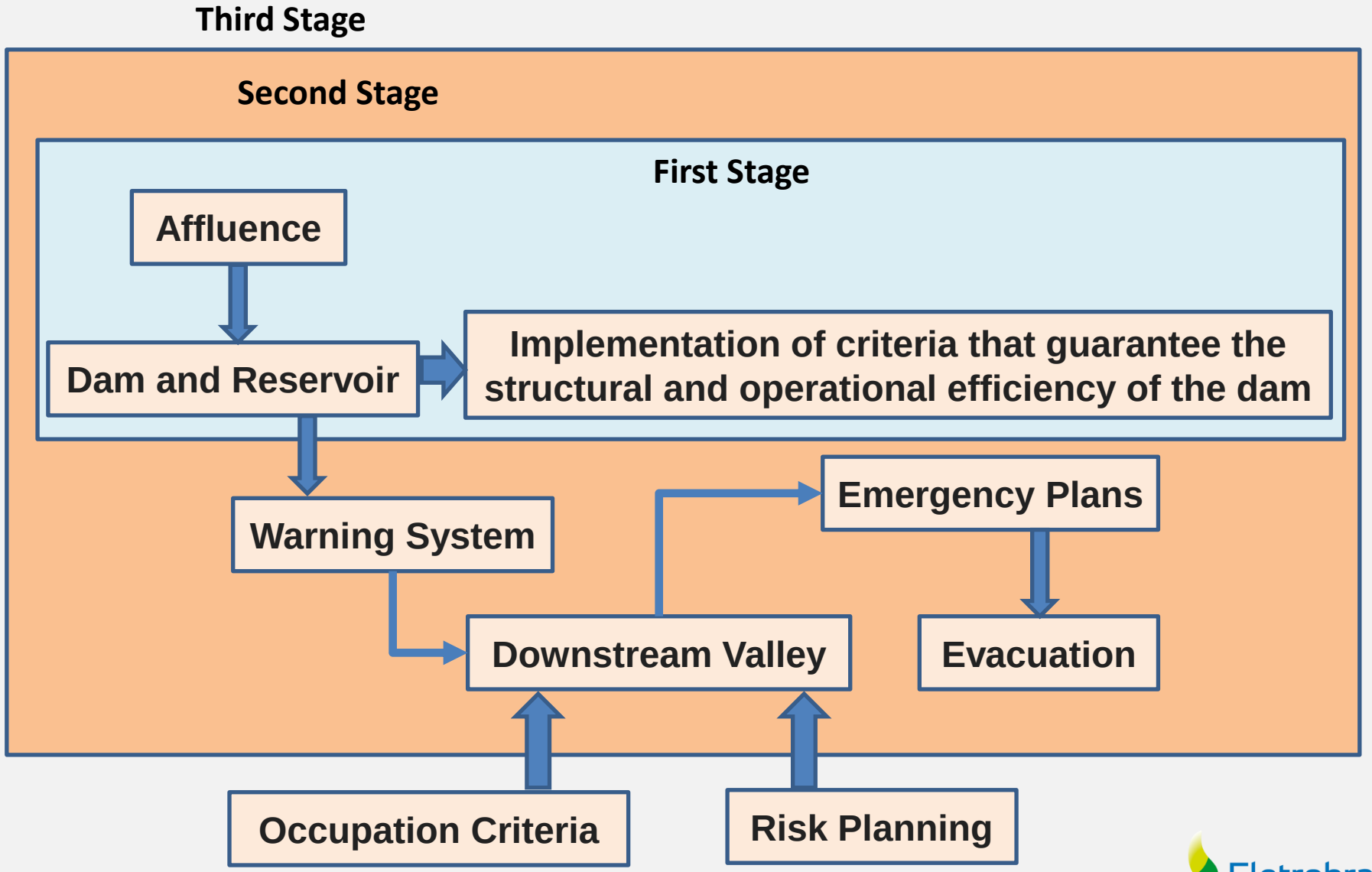
Approaches to Dam Safety

Almeida, A.B., Ramos, C.M., Santos, M.A. & Viseu, T. (2003)



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Stages of Dam Safety Assessment

1. Classification of the dam (High, Medium, Low Risk)
2. Site Inspection
3. Critical analysis of design and construction
4. Critical analysis of the operation
5. Critical review of maintenance
6. Inspection and monitoring of dam performance
7. Preparation of the Emergency Action Plan
8. Establishment of compatibility with previous evaluations
9. Preparation of the Dam Safety Report

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Risk Analysis for Dam Safety

- ✓ **Two Scales:**
  - ✓ **1. Structural and Inspection Risks**
    - ✓ **PH-Potential Hazard**
    - ✓ **PV-Potential Vulnerability**
  - ✓ **2. Downstream Risks**
    - ✓ **PI-Potential Impact**

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Risk Analysis for Dam Safety

- ✓ Potential Hazard (PH): Measures structural aspects
  - ✓ Project Flow; Height and Length of the Reservoir; Type of Dam; Type of Foundation
- ✓ Potential Vulnerability (PV): Measures the construction
  - ✓ Age of the Dam; Technical Qualification; Dam Safety Report; Existence of Project; Stability of slopes; Percolation; Deformations; Reliability of the Spillway; Evaluation of Dam-Behavior; Equipment Conditions
- ✓ Potential Impact (PI): Measures the social, economic and environmental impact downstream
  - ✓ Volume of the Reservoir; Economic, Social and Environmental Impact downstream; Cost of the Dam; Generation Capacity; Warning and Alert Systems

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Risk Analysis for Dam Safety

The scale PH+PV (Potential Hazard and Vulnerability) is divided in 3 classes:

CLASS	PH+PV	MEANING
A (Immediate Inspection)	≥ 47	There may be structural problems
B (Short Term Inspection)	30 to 46	There may be some points to improve
C (Normality)	≤ 29	Routine inspection

The scale PI (Potential Impact) is divided in 3 classes:

CLASS	PI	MEANING
A (In case of a dam break, damage downstream can be high)	≥ 37	Semiannual or monthly inspections
B (Moderate damage and risk)	23 to 36	Annual inspections
C (Damage and risk low)	≤ 22	Biannual inspections

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Risk Analysis for Dam Safety

Hydroelectric Plant	PH	PV	PI	RP	PH+PV	PI
Itumbiara	12	13	46	1150	C	A
Foz do Chapecó	10	19	37	1073	C	A
Furnas	12	10	46	1012	C	A
Porto Colômbia	12	10	44	968	C	A
Santo Antônio	13	10	41	943	C	A
Serra da Me	10	13	41	943	C	A
Serra da Mesa	12	11	41	943	C	A
Funil	11	13	39	936	C	A
Marimbondo	15	10	36	900	C	B
Simplício	12	13	36	900	C	B
Retiro Baixo	12	13	34	850	C	B
Peixe Angical	11	11	36	792	C	B
Mascarenhas de Moraes	11	13	33	792	C	B
Baguari	9	12	34	714	C	B
Manso	14	11	23	575	C	B
Serra do Facão	10	10	25	500	C	B
Corumbá	11	11	22	484	C	C
Batalha	13	13	12	312	C	C

RP=RISK POTENTIAL

RP = (PH+PV) x PI

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Risk Analysis for Dam Safety

Location-Cause-Indicator

Location	Cause	Indicator	I	P	C	SI	CI	RI
Mass of the dam, foundation and shoulders	Stress	Cracks, fissures in the dam and attached structures	5	1	1	5	5	35254
		Damage to the dam interfaces, attached structures, shoulders	1	1	1	1	1	7051
		Percolation, infiltration	2	1	2	2	4	28203
		Internal Erosion	5	1	1	5	5	35254
		Free edge reduction	1	1	1	1	1	7051
		Overflow, Dam Break	5	1	1	5	5	35254
	Instability	Deformations, cracks	4	3	2	12	24	169218
		Free edge reduction	1	1	1	1	1	7051
		Overflow	5	1	1	5	5	35254
	Internal Erosion	Wet areas, excessive vegetation growth	1	2	1	2	2	14102
		Piping	5	1	1	5	5	35254
		Slope instability, overlap	5	1	1	5	5	35254
	External Erosion	Overlapping of the dam's foot	2	1	2	2	4	28203
		Deterioration of upright slope	1	2	2	2	4	28203
		Downstream slope erosion	1	1	1	1	1	7051
		Overflow	5	1	1	5	5	35254

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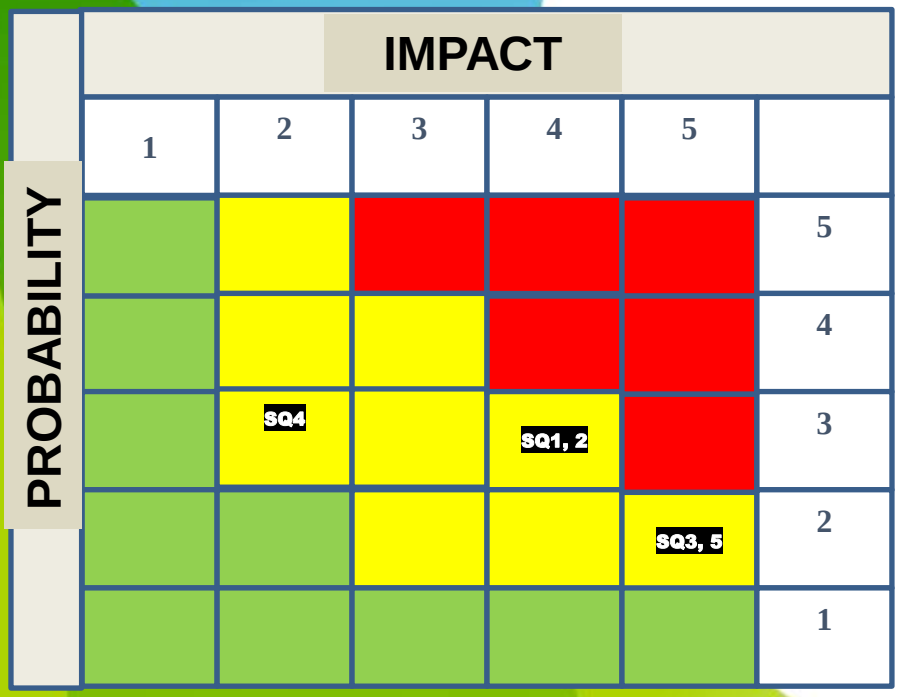
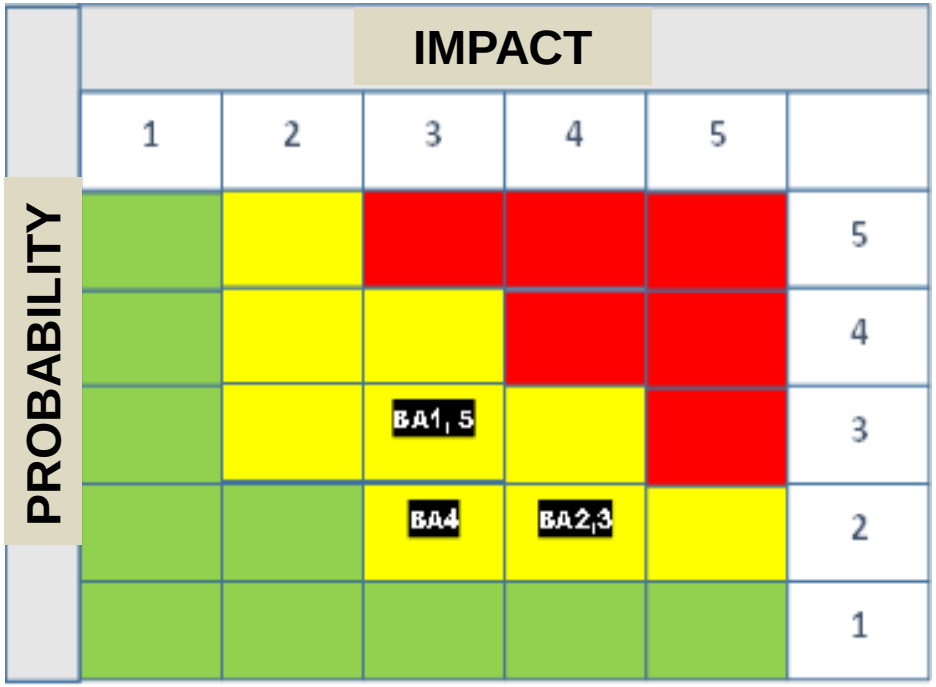
Risk Analysis for Dam Safety
Risk Matrix of LCI Method





HIGH MEDIUM LOW

HIGH MEDIUM LOW

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Risk Analysis for Dam Safety

FMECA (Failure Mode, Effect and Criticality Analysis)

FUNCTION	FAILURE MODE	CAUSE	EFFECT	P	I	I_{CR}	DETECTION MODE (DM), PREVENTION (PR)	D	RPN
1.CONCRETE DAM									
CONTAIN RESERVOIR	1(1) OVERFLOW (HYDRAULIC FAULTS)	Exceptional water levels	External erosion with dam break	2	20	40	Reservoir lowering (PR) Level monitoring by telemetry system (DM)	2	80
	1(2) SLOPE SLIP	Exceptional uploads	Global instability with uncontrolled water release	1	20	20	Reservoir lowering (PR) Visual inspection and instrumentation (DM)	3	60
		Inadequate material properties		1	5	5	Geological mapping (PR) Instrumentation (DM) Consolidation Injection (DM), Installation of drains (PR)	2	10
		Inadequate foundation properties		2	8	16	Technological control (PR), Instrumentation (DM), Construction of stabilizer bats (DM), Compression (DM)	1	16

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CONCLUSIONS

- ✓ EACH OBJECTIVE HAS A RISK METHOD
- ✓ THERE IS NO METHOD THAT WORKS FOR EVERYTHING
- ✓ TO STUDY RISKS FOR DAMS, WE SUGGEST:
- ✓ 1. USE A METHOD THAT CAN PRIORITIZE THE PORTFOLIO OF DAMS
- ✓ 2. FOR CRITICAL DAMS, USE LCI AND FMECA METHODS, TO VERIFY WHAT IS HAPPENING WITH DAM COMPONENTS

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THANK YOU !

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