Some aspects risk analysis

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10 + years - “mixed results”

- 1991 - 1993
  - Investigations and feasibility studies
- 1993 - 1997 - parallel paths
    - 1993 - 1997
      - 10 “Simplified” quantitative trial examples
    - 1995 - 1997
      - 2 limited “Detailed” quantitative trial examples
- 1997 -
  - Replace “simplified quantitative” with risk index
  - “Detailed quantitative informs difficult decisions

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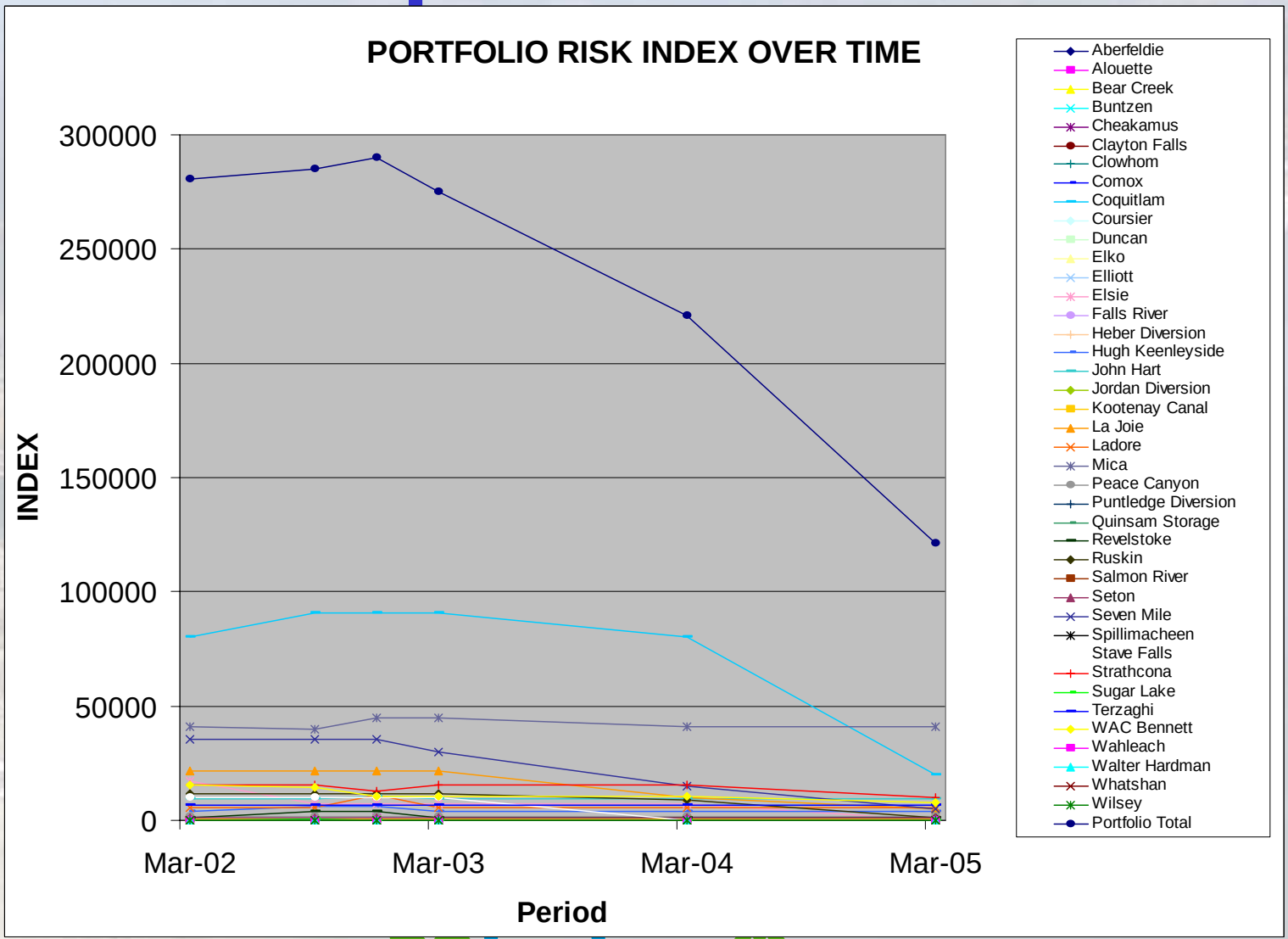
Now

- Dam Safety program based on risk management principles
  - Risk index used
    - to manage risks across portfolio
    - quarterly reports to the Board of Directors
    - annual reports to the Board and Regulator
- Risk index provides a “proxy” for probability of failure x consequences

Risk index profile



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The Risk Problem

Probability of failure

$$P_f = P[Z \le 0] = \int_{z \le 0} f_x(x)\,dx$$

$$P_f = \int_{z \le 0} f_x(x)dx = \int_{-\infty}^{\infty}\int_{-\infty}^{s \ge r} f_R(r)\, f_S(s)drds$$

$$F_X(x) = P[X \le x] = \int_{-\infty}^{x} f_X(y)dy$$

$$P_f = P[R - S \le 0] = \int_{-\infty}^{\infty} F_R(y)\, f_S(y)dy$$

$$P_f = P[R - S \le 0] = \int_{-\infty}^{\infty} F_R(y)\{1 - F_S(y)\}dy$$

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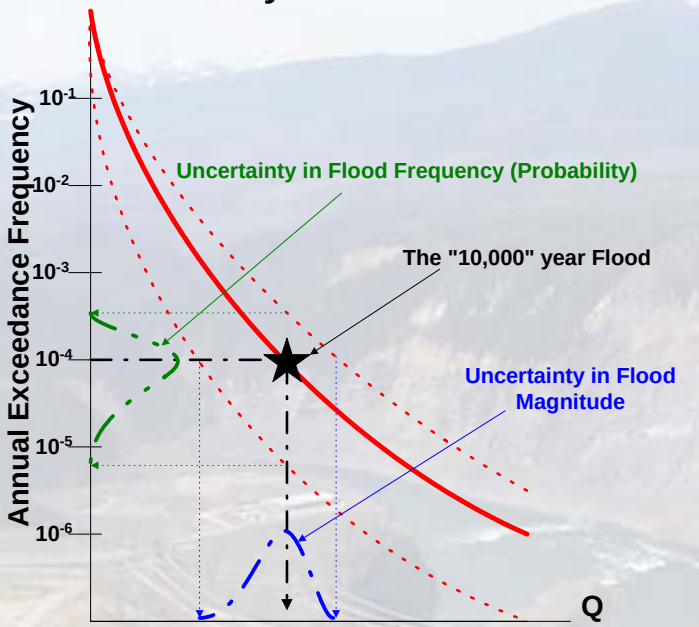
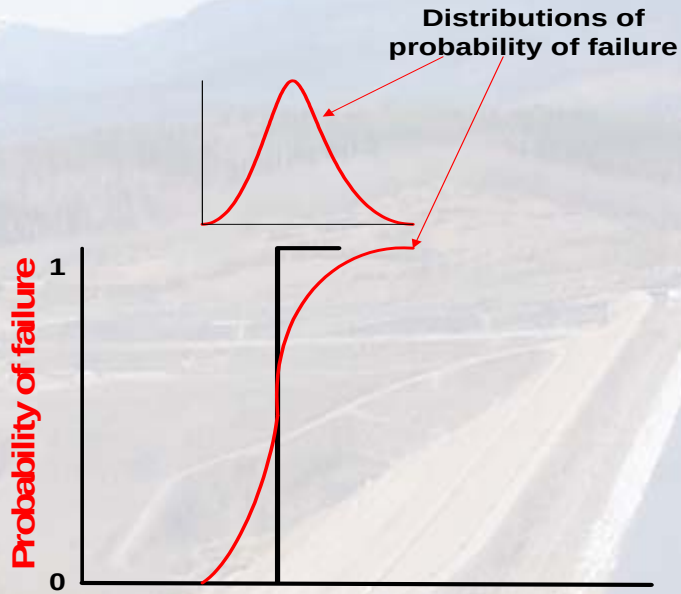
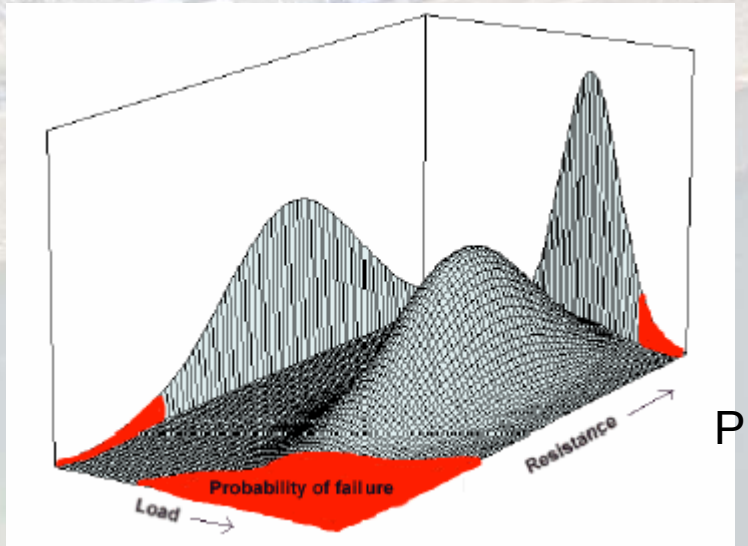
Probability of Hazard

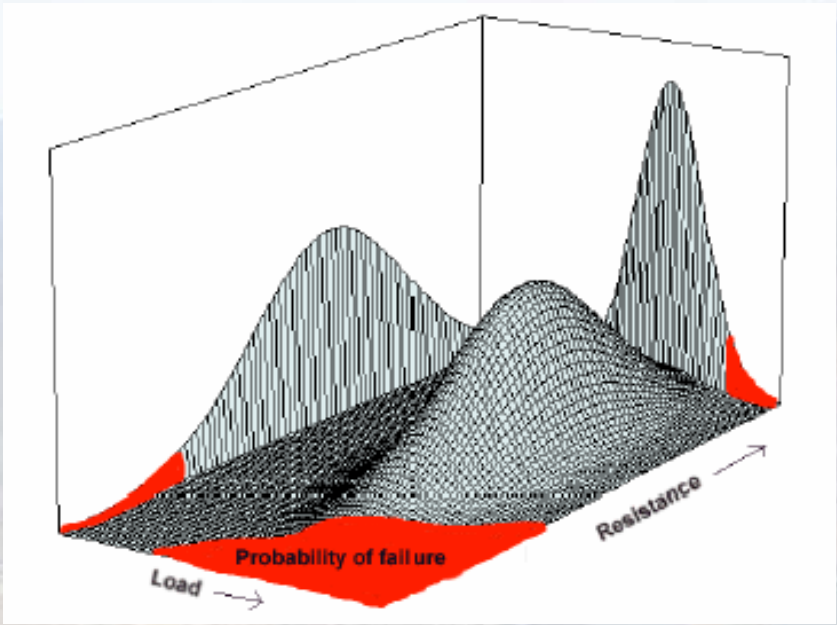


Probability of Failure given Hazard

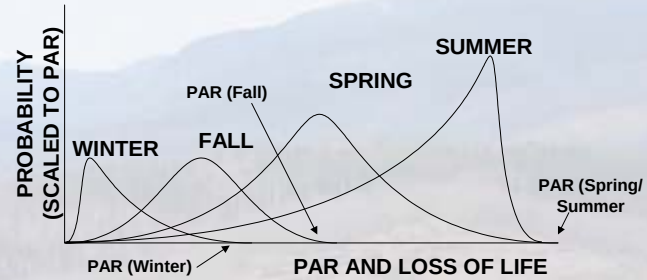




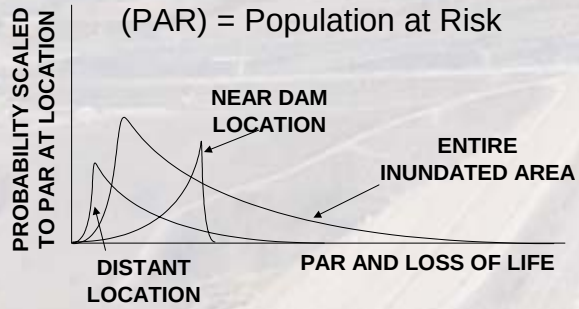
Probability of Failure



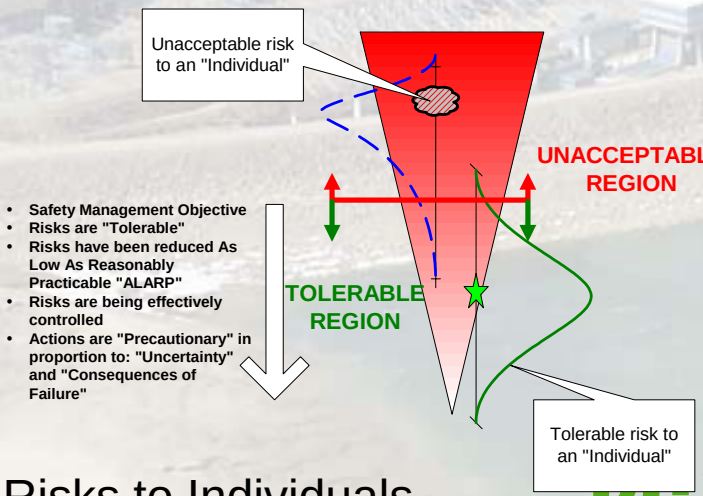
Probability of Failure



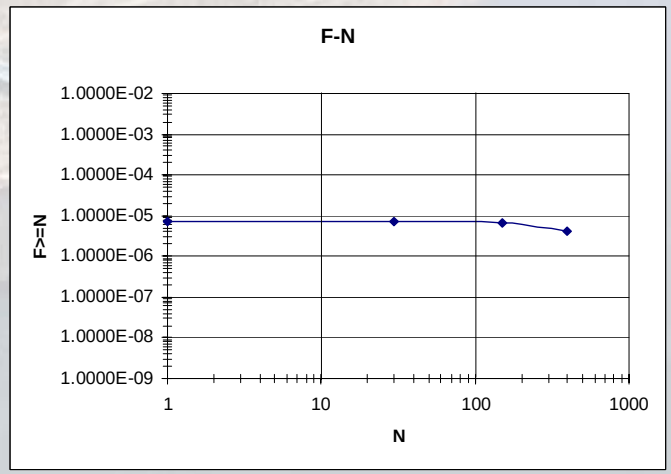
(PAR) = Population at Risk



Consequences of Failure



Risks to Individuals



Societal Risk

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All very fine - theoretically

- For details see
  - ***ICOLD Bulletin on Risk Assessment***
  - ***Risk and Uncertainty in Dam Safety***
- Too complex for day-to-day management
  - arguably not generally possible, at present.
- Need a simplified approach!
  - begin with a realistic representation of a complete risk model
    - introduce simplifications but retain the most essential characteristics

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Simplified Characterisation of Dam Safety Risks

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Risk Index

Numerical Index

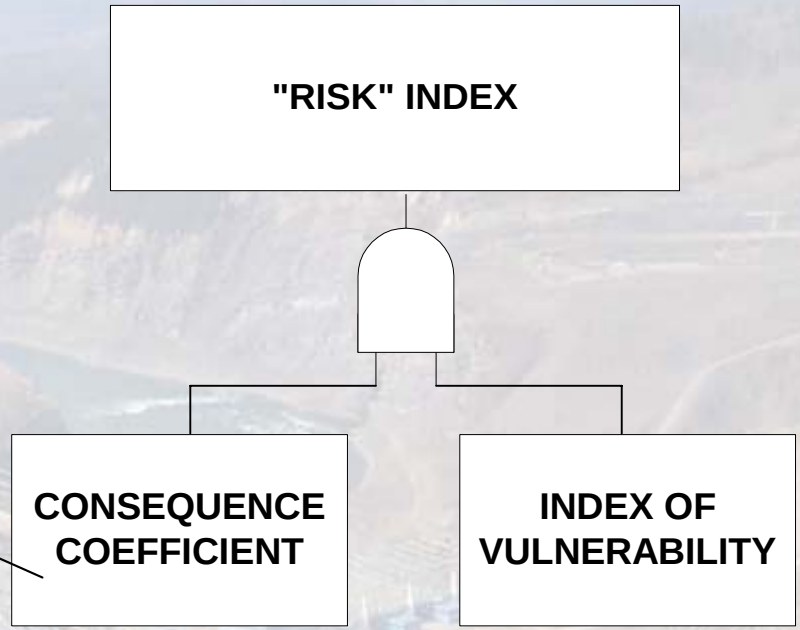
Extreme = 4

Very High = 3

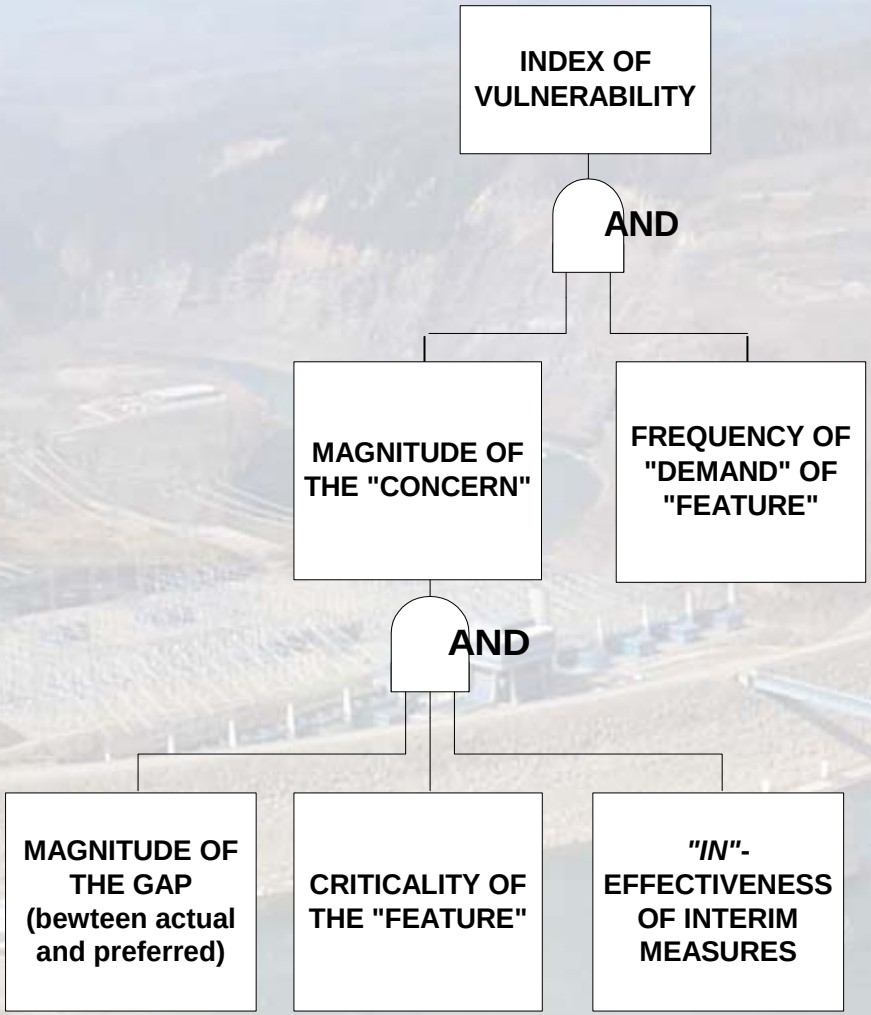
High = 2

Low = 1

Very Low = 0



Index of Vulnerability



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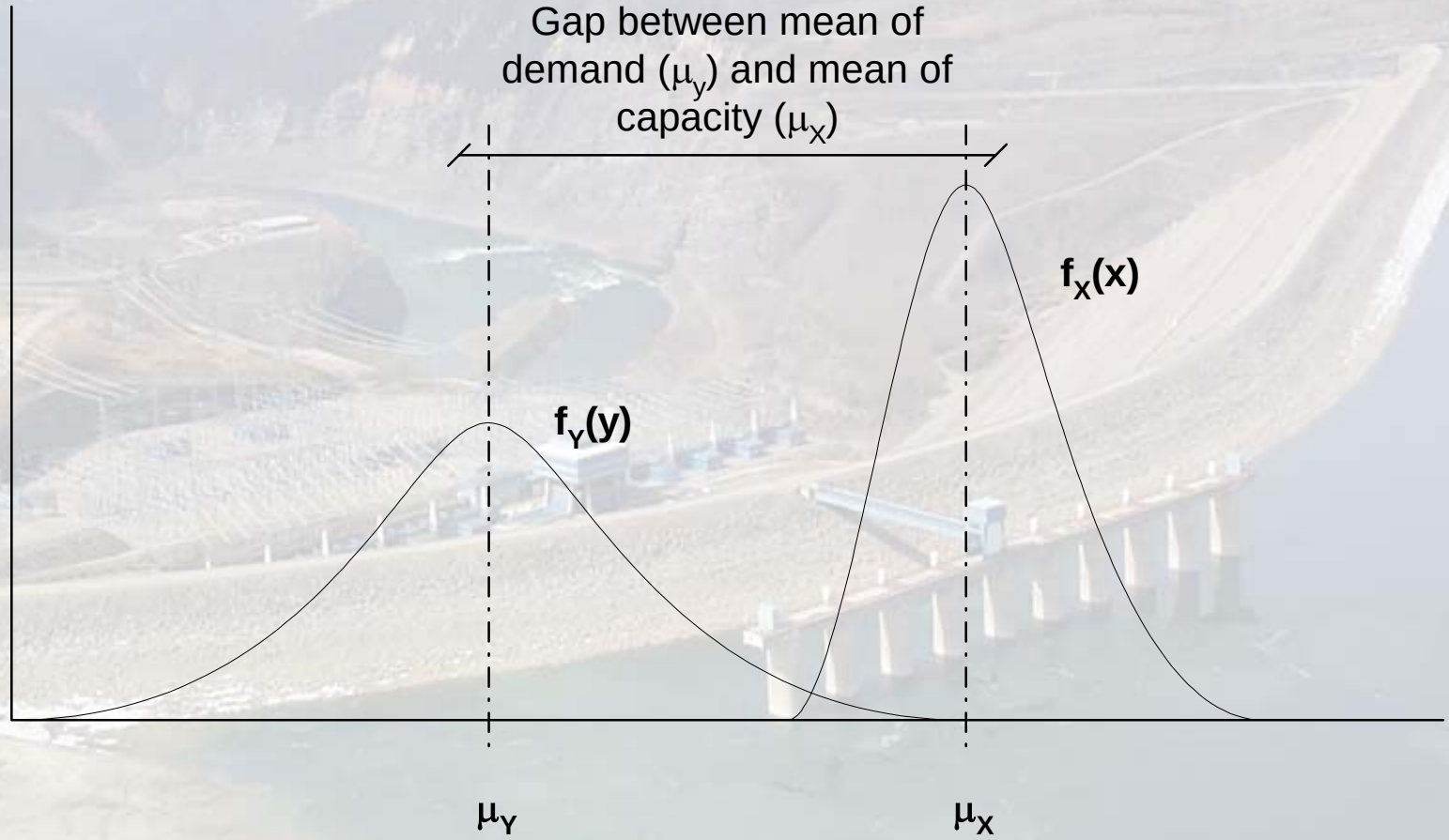
Magnitude of “the Gap”



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Failure Modes Analysis

Functional model

- Create a model of how the dam is designed to function
  - Define failure modes in terms of *"failure to function as designed"*
- Transform the functional model into a "failure to function" model
  - Identify Potential Failure Modes
    - Define "Magnitude of Gap" in terms of the difference between "actual capacity" and "desired capacity"

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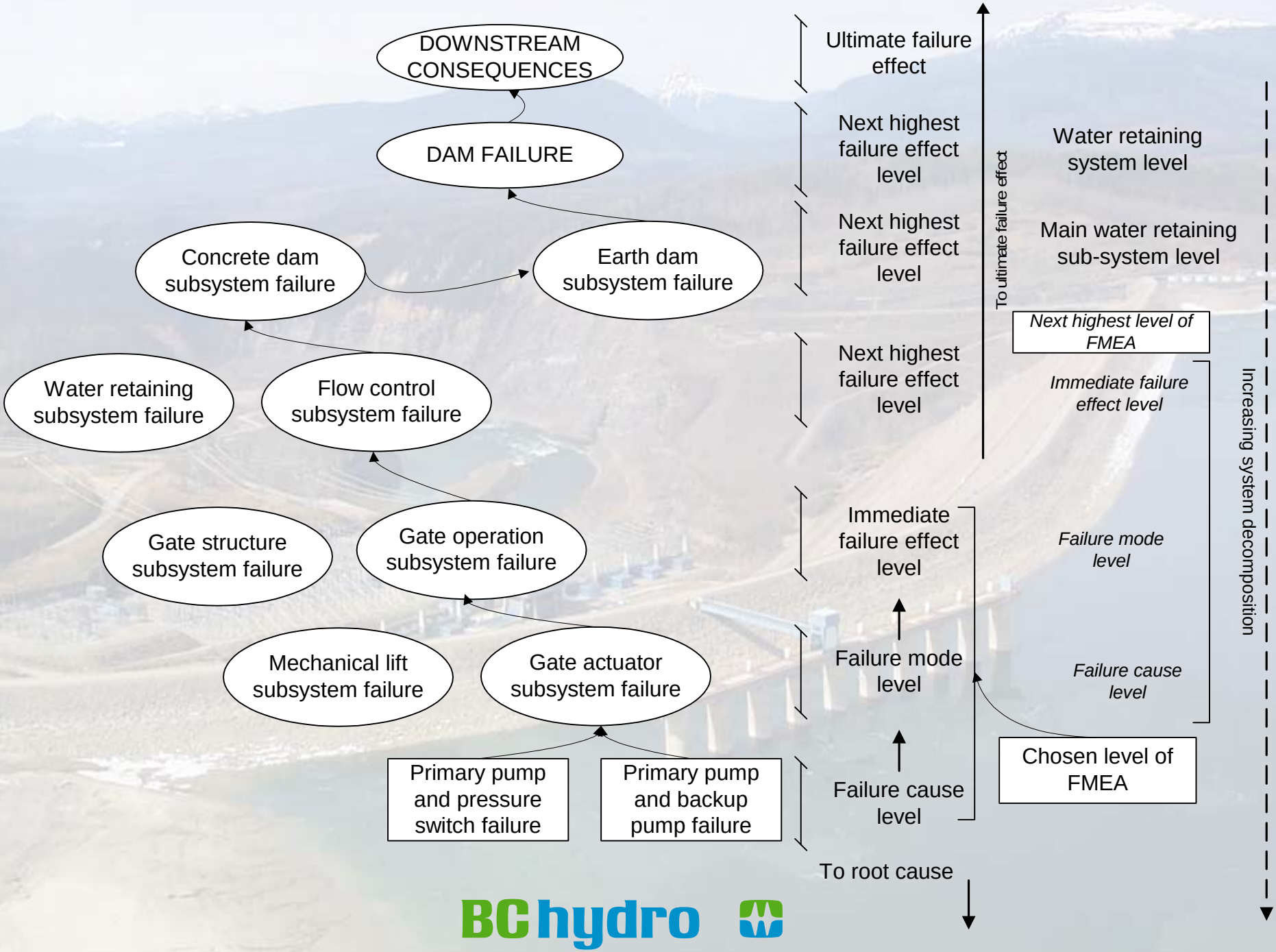
DOWNSTREAM CONSEQUENCES
DAM FAILURE
Concrete dam subsystem failure
Earth dam subsystem failure
Water retaining subsystem failure
Flow control subsystem failure
Gate structure subsystem failure
Gate operation subsystem failure
Mechanical lift subsystem failure
Gate actuator subsystem failure
Primary pump and pressure switch failure
Primary pump and backup pump failure
Ultimate failure effect
Next highest failure effect level
Next highest failure effect level
Next highest failure effect level
Immediate failure effect level
Failure mode level
Failure cause level
To root cause
To ultimate failure effect
Water retaining system level
Main water retaining sub-system level
Next highest level of FMEA
Immediate failure effect level
Failure mode level
Failure cause level
Chosen level of FMEA
Increasing system decomposition

Failure Modes & Hazards Matrix

GLOBAL FAILURE MODES		FUNCTIONAL FAILURE CHARACTERISTICS	EXTERNAL HAZARDS			INTERNAL HAZARDS (Design, Construction, Maintenance, Operation			
			Seismic	Meteorological	Human Attack	Water Barrier	Hydraulic Struct.	Mech/Elec	Human Actions
DAM OVERTOPPING	All water barriers	Hydraulic adequacy (discharge capacity)							
		Discharge reliability (e.g. Failure to open)							
		Operational adequacy (e.g rules/followed)							
		Facility performance (e.g. debris & other fns.)							
		Overtopping waves (landslides, u/s dams)							
		Management systems (hydraulic operations)							
DAM COLLAPSE (INTERNAL STRUCTURAL WEAKENING AND AGEING)	Fills and foundations	Management systems (for dam performance)							
		Internal erosion (dam/abutments./foundns)							
		Deformations (deprssions/mass mvmnt)							
		Liquefaction (static/seismic)							
	Concrete and steel	Structural weakening (AAR/strength loss)							
		Structural anchors (relaxation/strength loss)							
		Water stops/interfaces (unintended ingress)							
		Mech/elec stability (uplift pressure control)							

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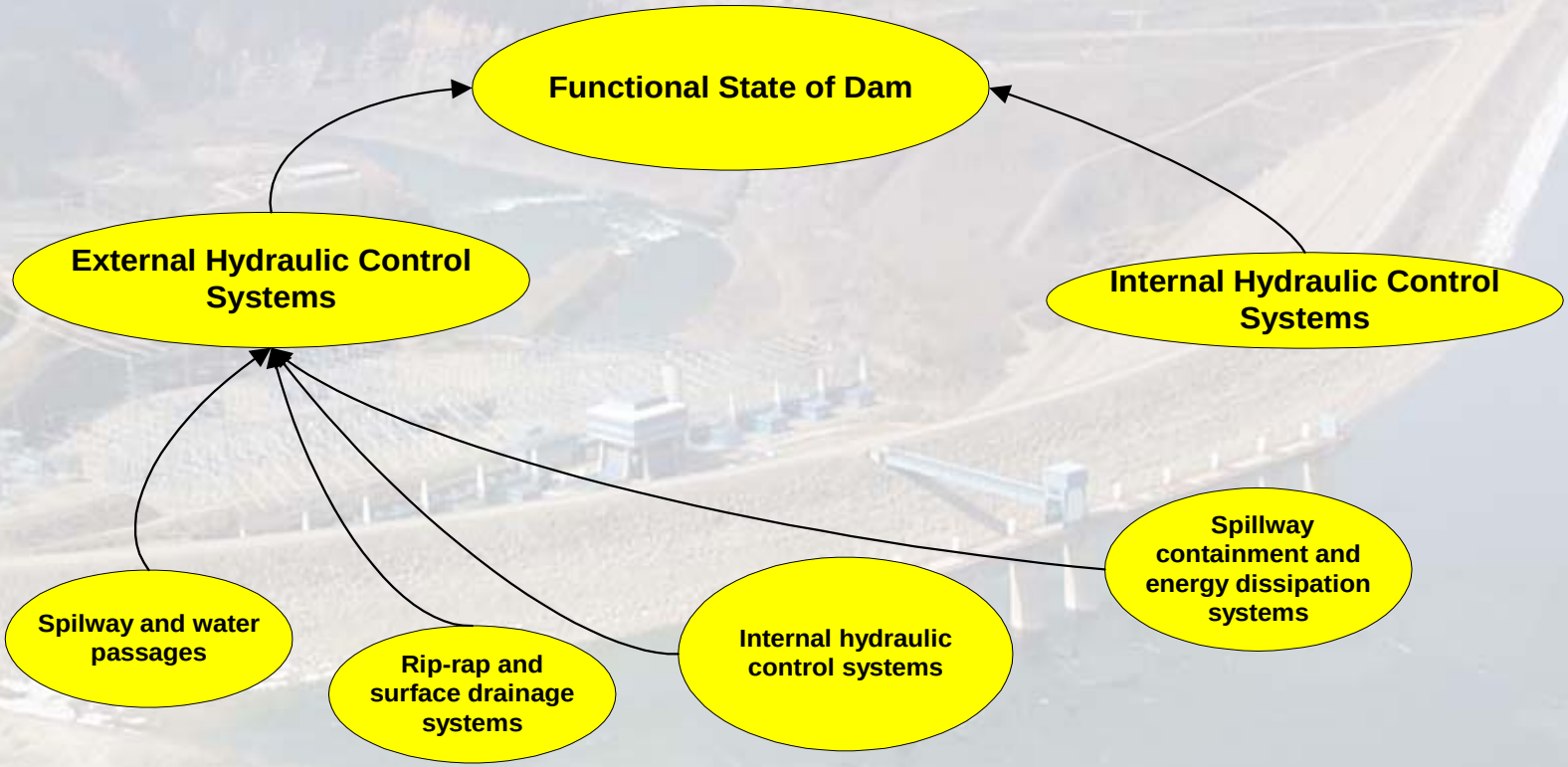
Decomposition of Functional model



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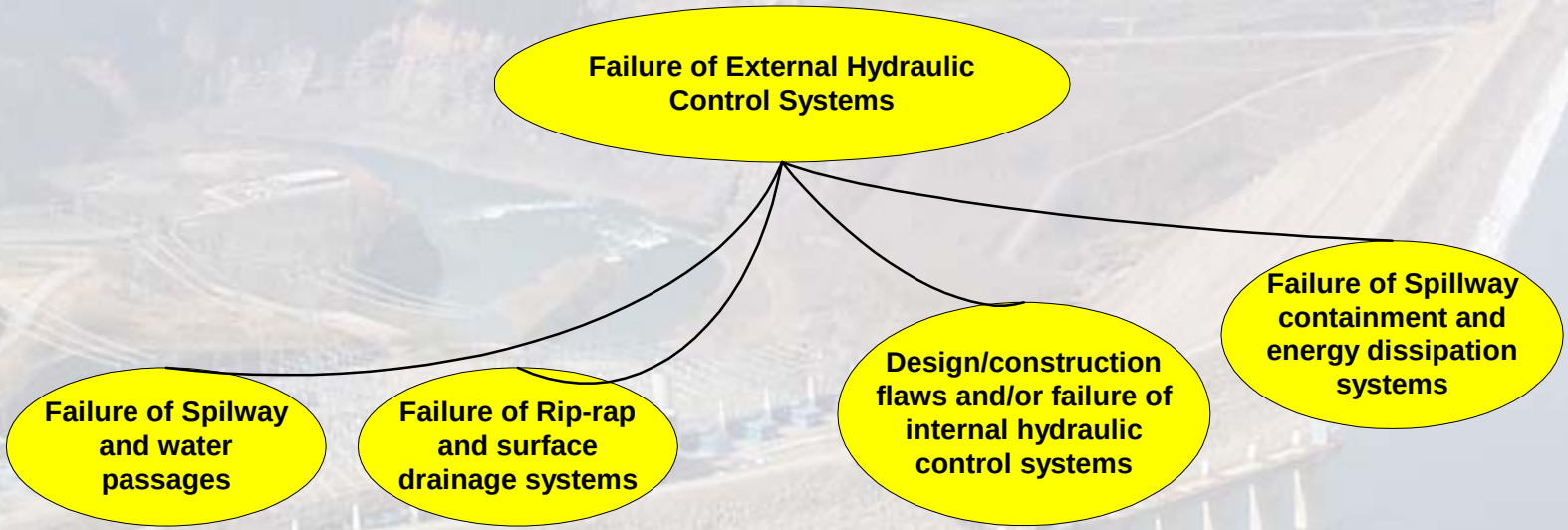
Functional failure of external hydraulic control systems



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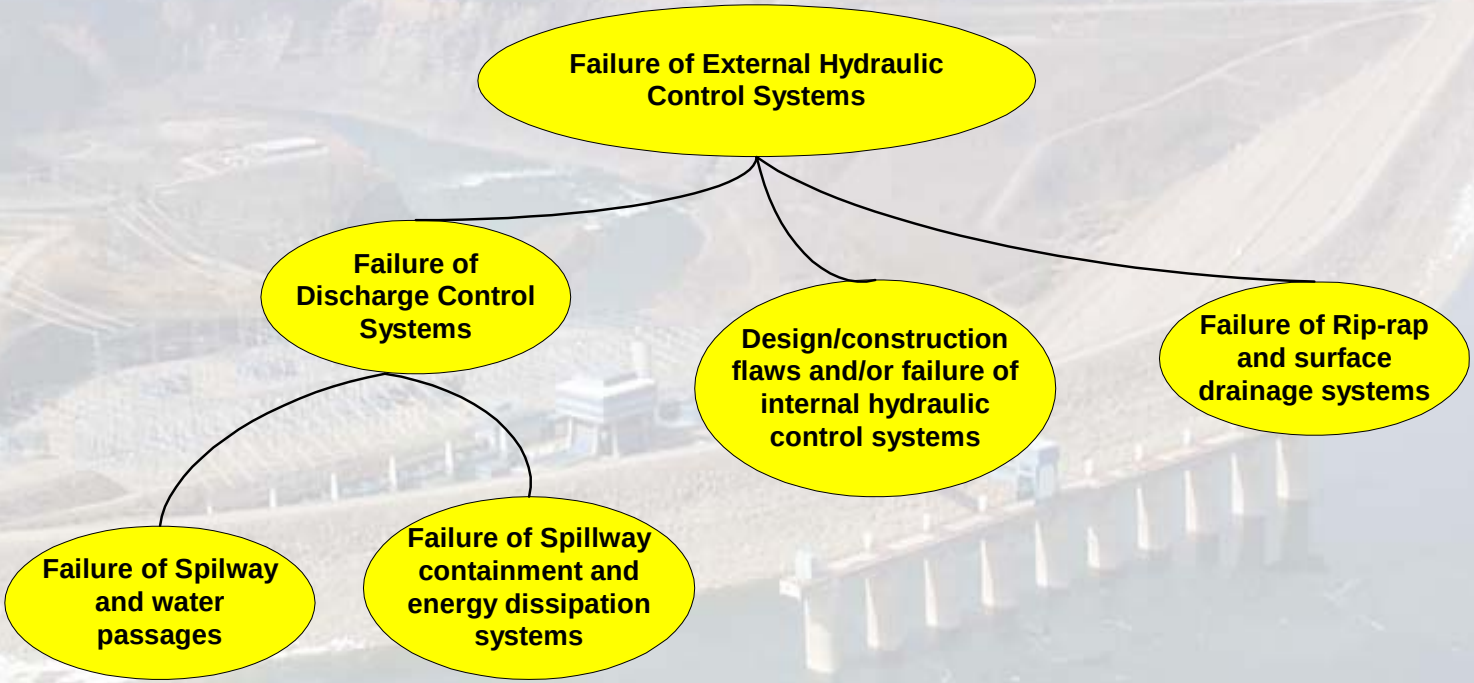
Alternative functional failure model



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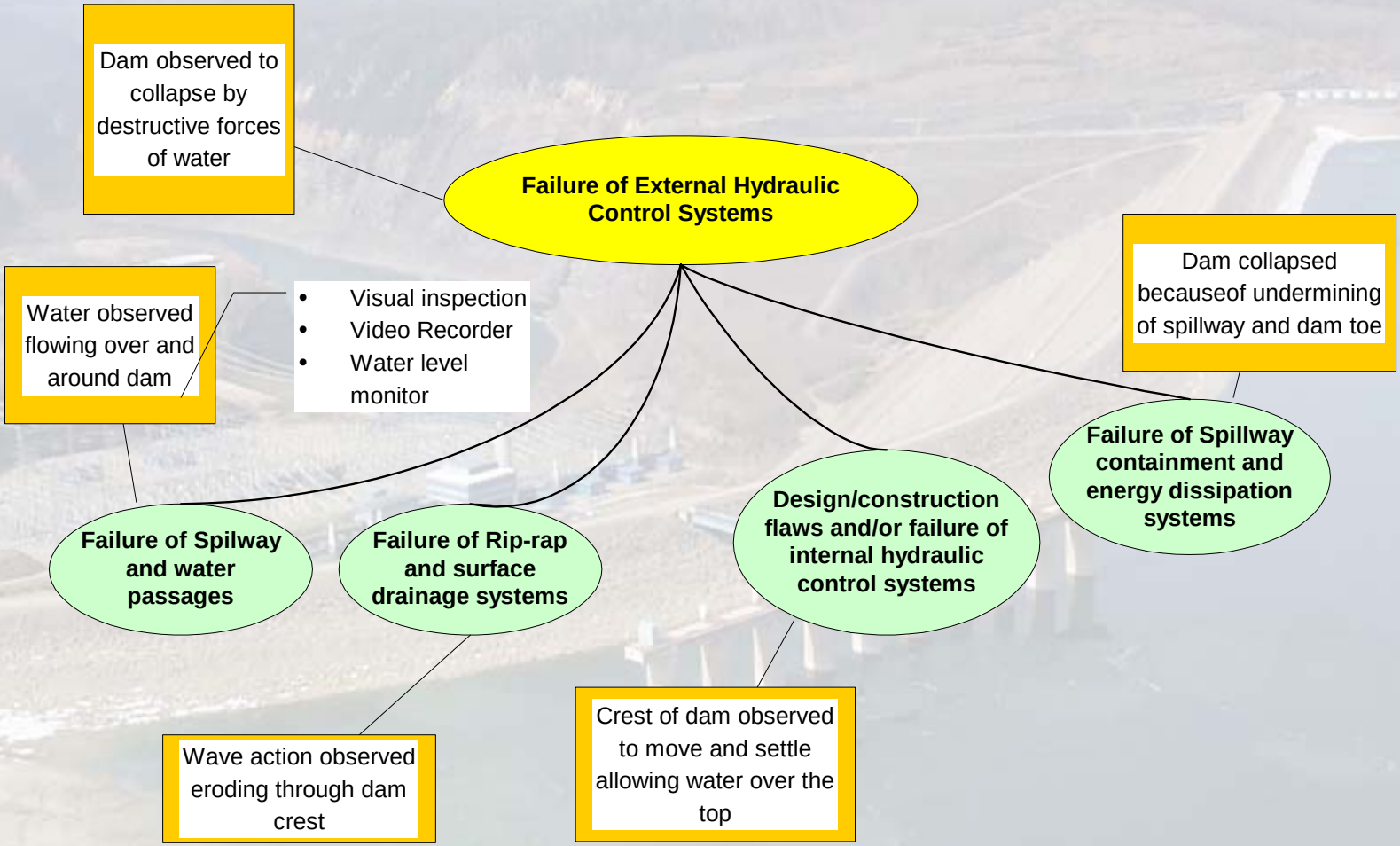
Failure mode description and means of identification



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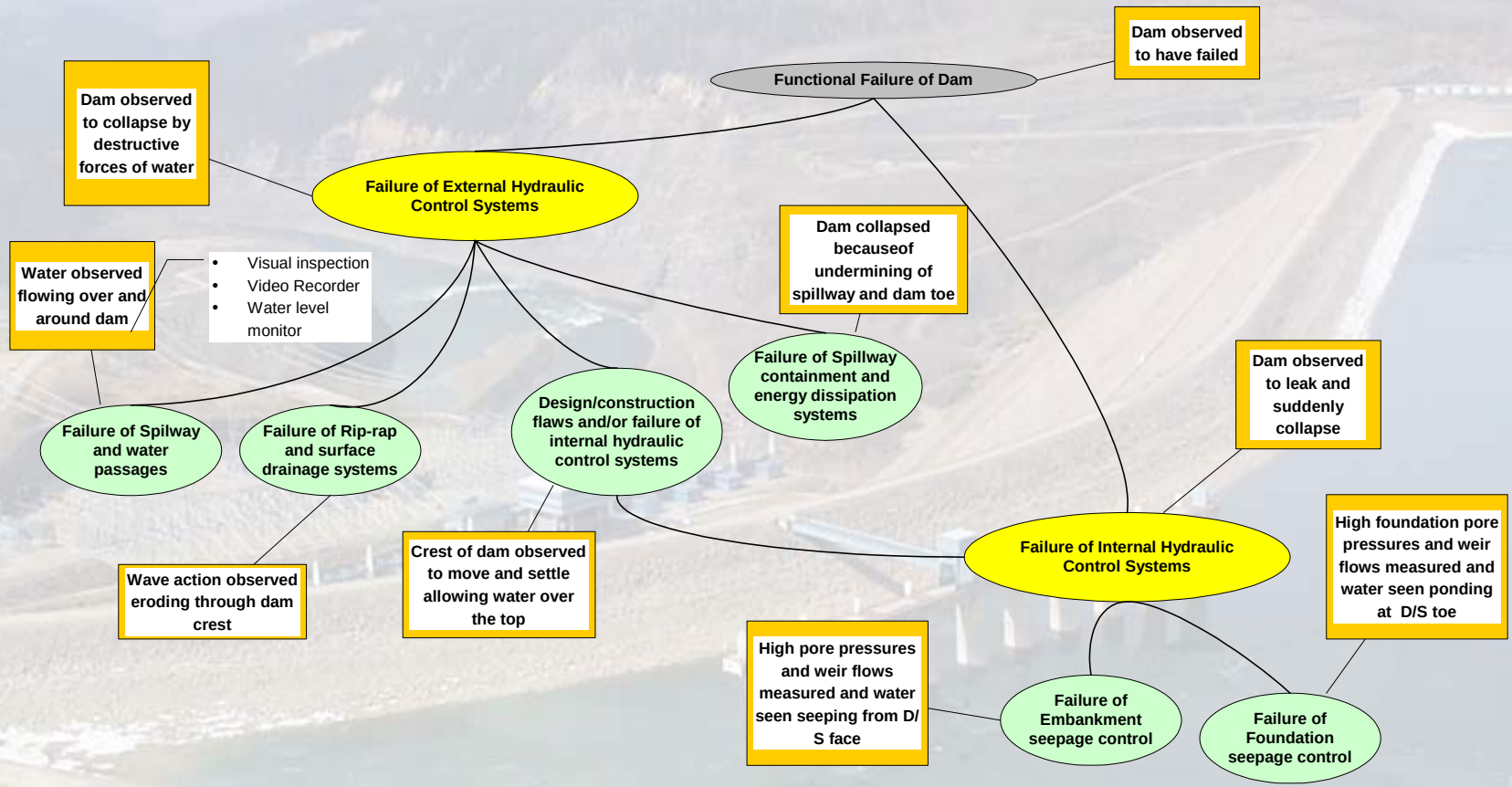
Influence Diagram for the "decomposed" system



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