Risk
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Physics-Informed Stochastic Petri Nets for the Deterioration Modeling and Maintenance Assessment of Torrent Protection Structures

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BACKGROUND

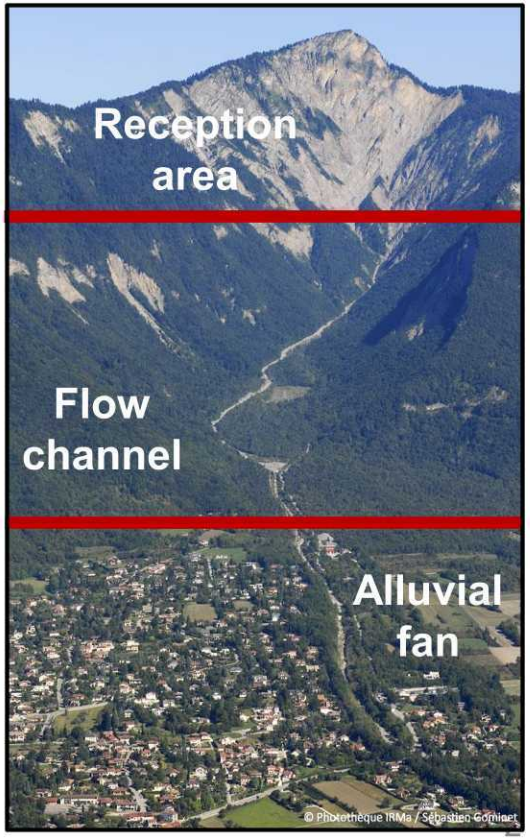
➢ Torrential watershed and natural risks

Floods

Debris flows

Landslides

Etc…



Manival torrent (FRANCE)

➢ Interdependent protection system

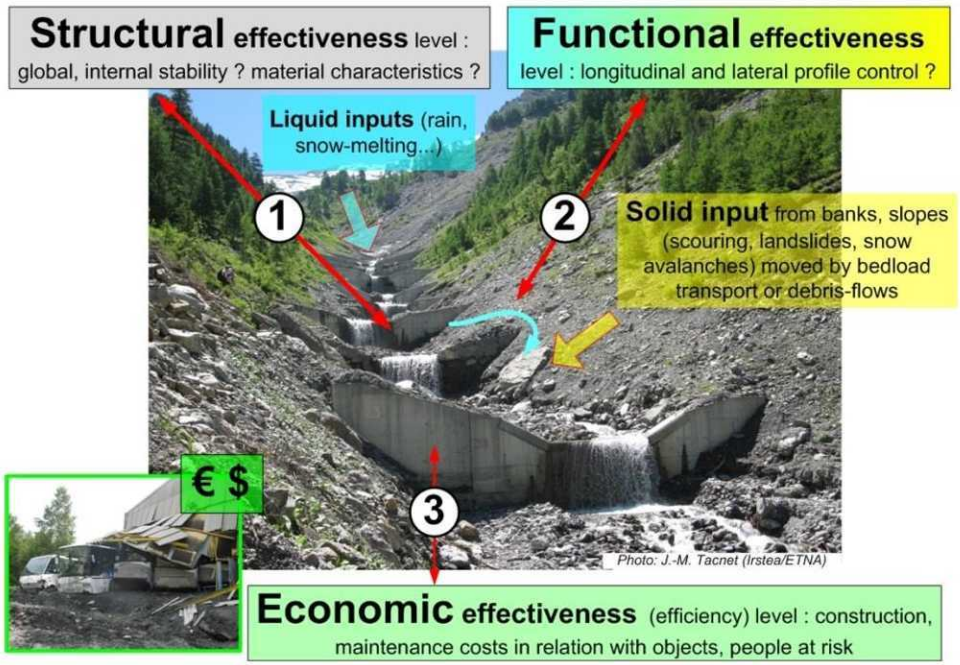
Check dams

Retention dam

Dykes/Levees

TECHNICAL AND SCIENTIFIC ISSUES

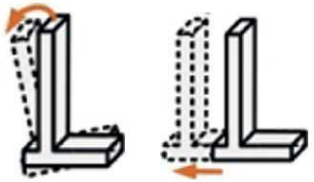
➢ Check dams' efficacy assessment



(Source J.-M. Tacnet)

Structural failures

cracks, corrosion, ...

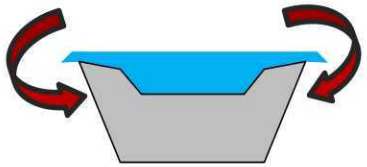


overturning, sliding, ...

Functional failures

Local scouring

Lateral bypass



Technical efficacy → **Performance level** → **Risk level** ↑

TECHNICAL AND SCIENTIFIC ISSUES

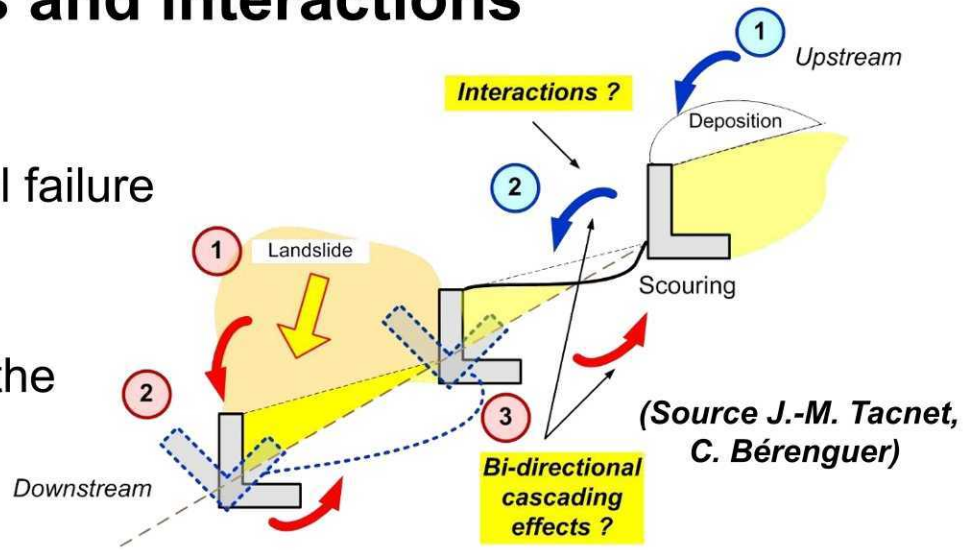
➢ Bi-directional dependencies and interactions

❑ **Dependencies between failures**

Functional failure **triggering** structural failure

❑ **Dependencies between structures**

Failure of one dam **triggering** the failure of consecutive dams



(Source J.-M. Tacnet, C. Bérenguer)

➢ Interventions' efficiencies and costs

❑ **Inspection**

Monitor, diagnose,…

When? How often?

❑ **Maintenance**

Preventive (repair), corrective (re-construct), …

When? What? How much?

OBJECTIVES

1

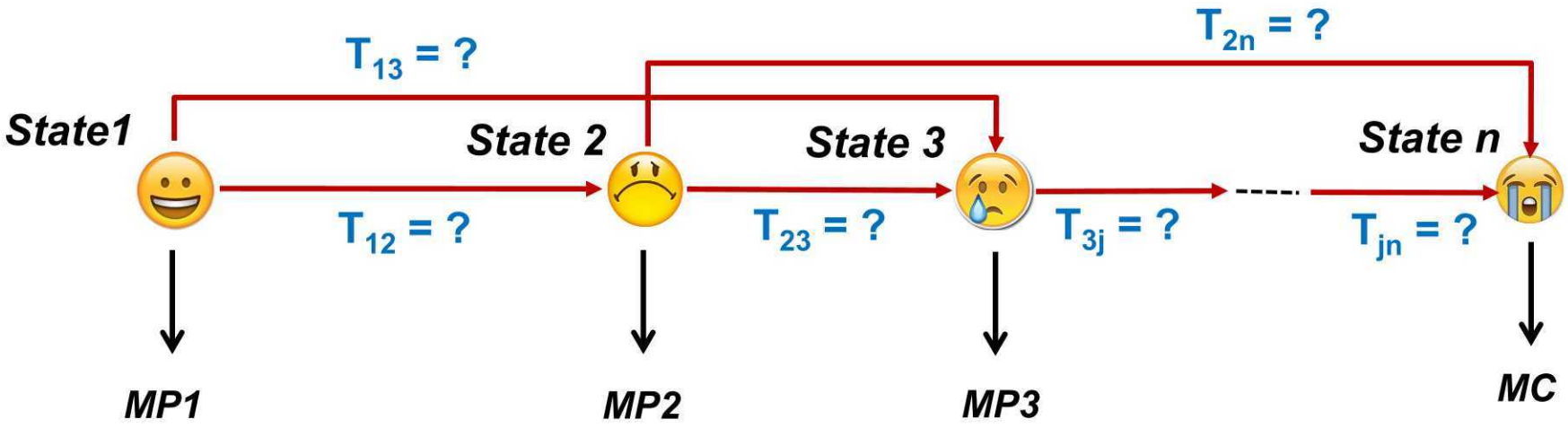
Model the **time-dependent state-evolution** of the dams when being subjected to torrential floods

2

Analyze the interactions between **scouring** and the **external stability** of the dams

3

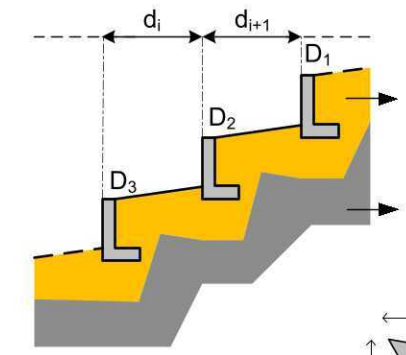
Support **maintenance decision-making** of the dams based on **multi-criteria**



MODELING APPROACH

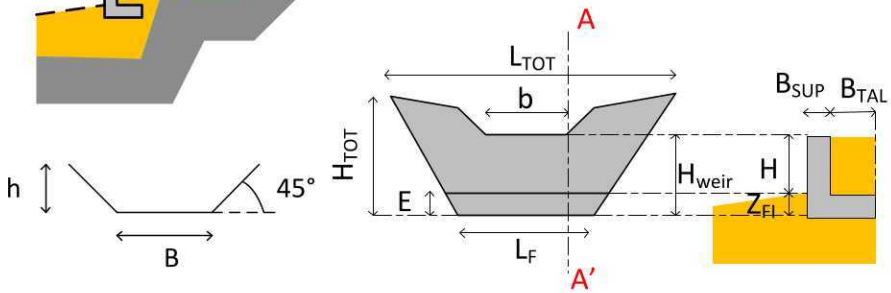
➢ Risk scenario definition

1. Data collection



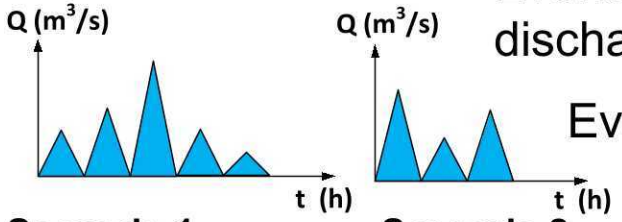
Erodible layer (grain size distribution, …)

substratum



2. Hazard scenarios

Torrential floods hydrographs

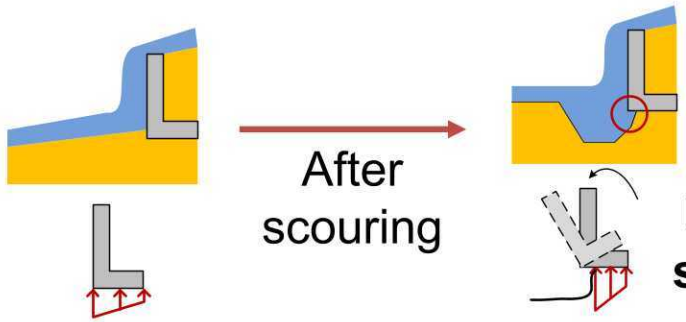


Events' maximum discharges?

Events' dates?

Scenario 1 **Scenario 2** **….. Scenario n**

3. Possible consequences

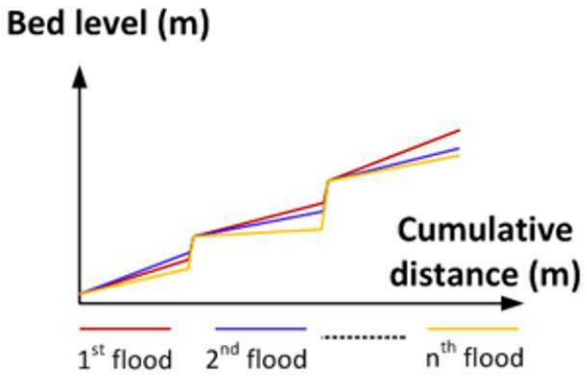


External stability?

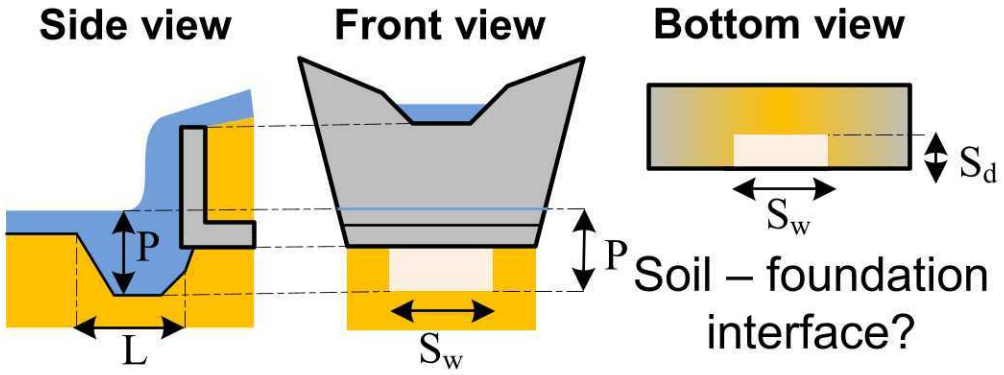
MODELING APPROACH

- **Physics-based model**

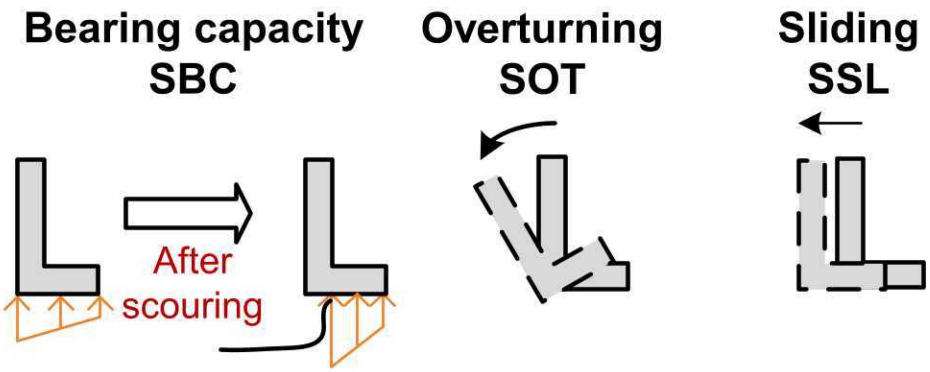
1. Bed evolution



2. Scouring estimation



3. External stability justification



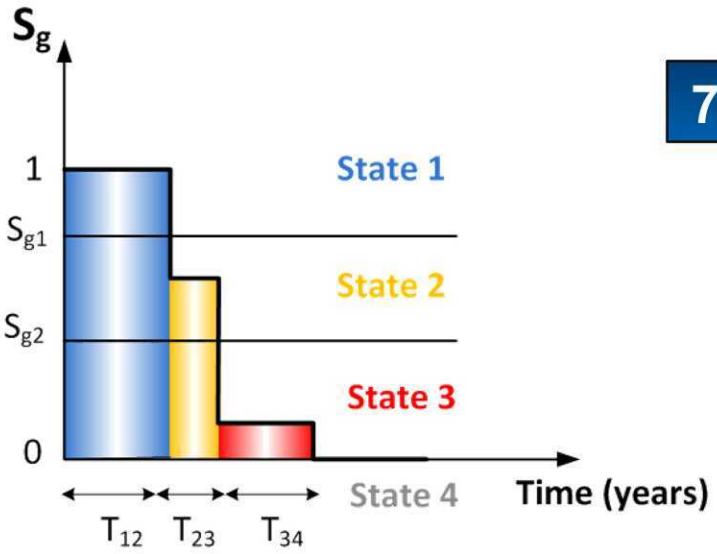
4. Global degradation indicator

$$Sg = \left(SBC^{\alpha} * SOT^{\beta} * SSL^{\gamma}\right)^{\wedge(1/(\alpha+\beta+\gamma))}$$

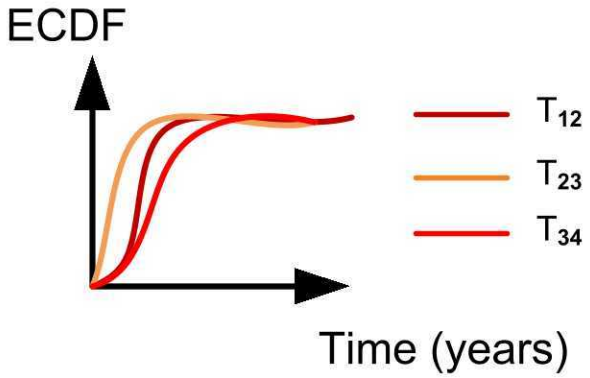
MODELING APPROACH

- **Physics-based model**

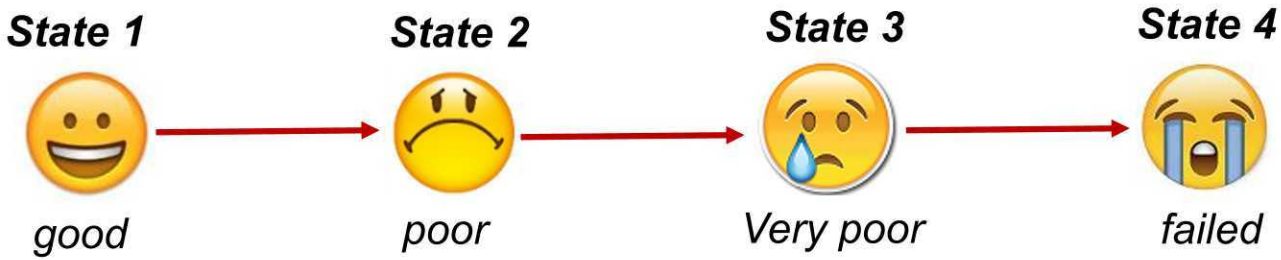
5. S_g time-dependent evolution



7. Transition times' laws estimation



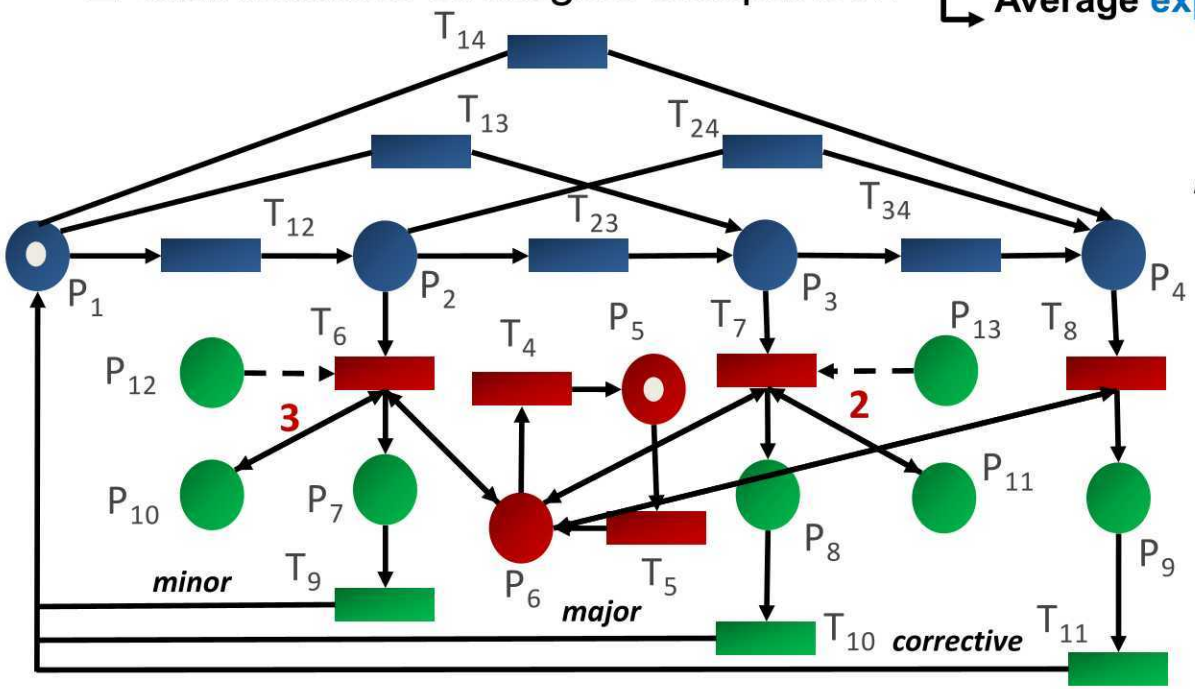
6. Check dam's states definition

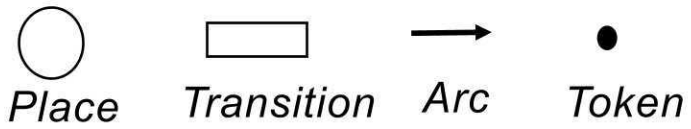


MODELING APPROACH

➢ Reliability-based model (Stochastic Petri Nets SPN)

- ❑ SPN model construction
- ❑ Maintenance strategies definition
  - **Strategy 1: all** operations are **allowed**
  - **Strategy 2: inhibit minor** operations
  - **Strategy 3: inhibit major** operations
  - **Strategy 4: only corrective** operations are allowed
- ❑ Monte-Carlo simulations
- ❑ Maintenance strategies comparison
  - **Mean sojourn time** in each state
  - **Average expected cost** of maintenance strategies



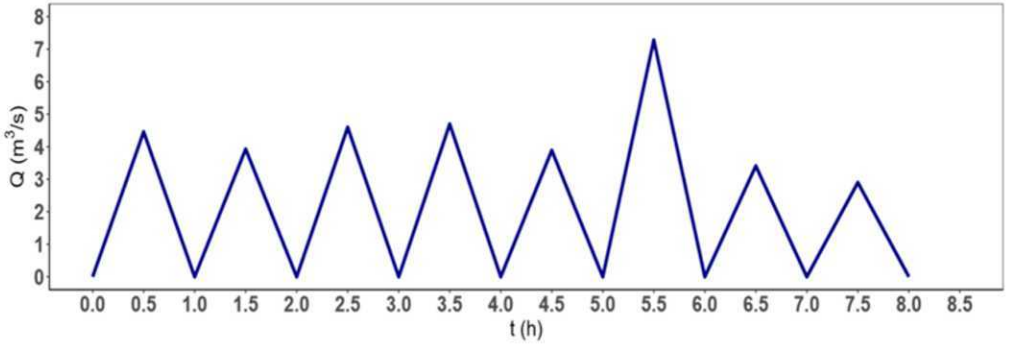


- Degradation process
- Inspection process
- Maintenance process

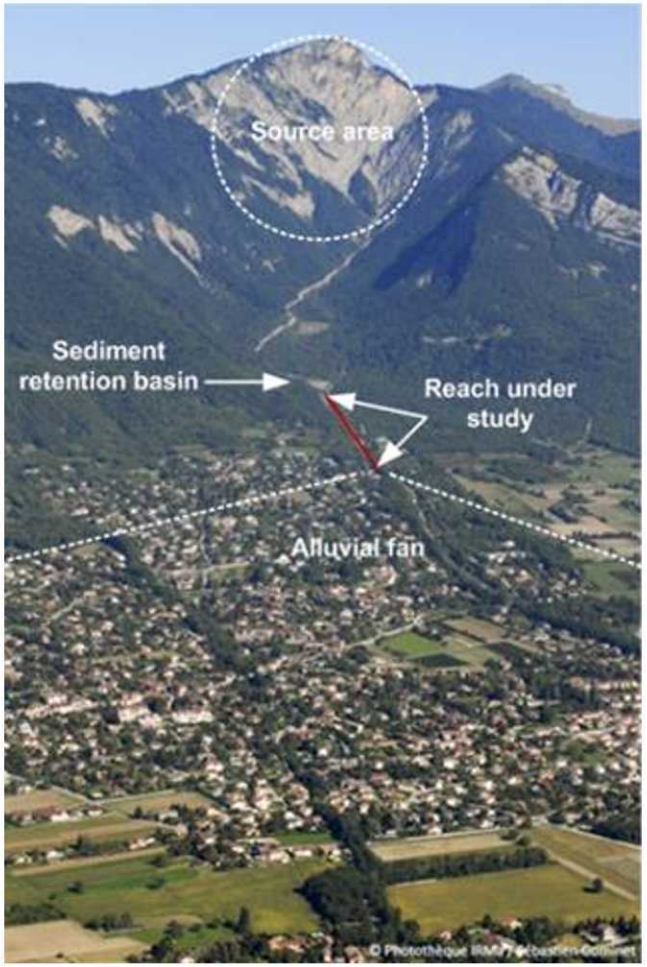
CASE STUDY: DESCRIPTION & INPUT DATA

- **Data collection (ONF – RTM database)** *(Chahrour et al. RESS 2021)*
  - Longitudinal & transverse profiles
  - Grain size distribution
  - Geotechnical data
  - Check dams' dimensions

- **Flood scenario definition**
  - Random generation of 50 scenarios
  - Clear water flood events
  - Floods with return period of 10 years
  - Period considered (100 years)



Hydrograph showing a series of flood events – scenario 1.

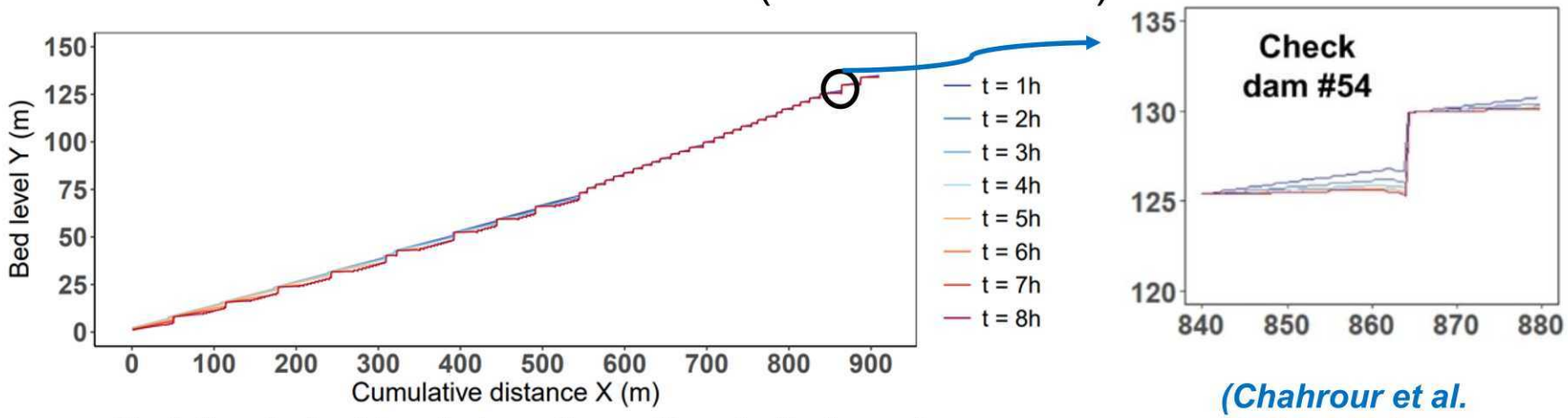


Manival torrent (FRANCE)

CASE STUDY: RESULTS & DISCUSSIONS

➢ Physics-based modeling by LOGICHAR (e.g. scenario 1)

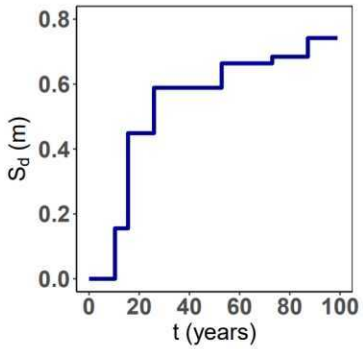
Reach down stream retention dam (39 check dams)



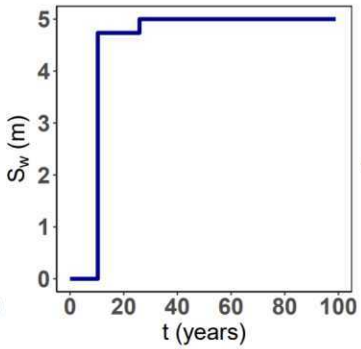
Variation in bed level along the entire studied reach

(Chahrour et al. RESS 2021)

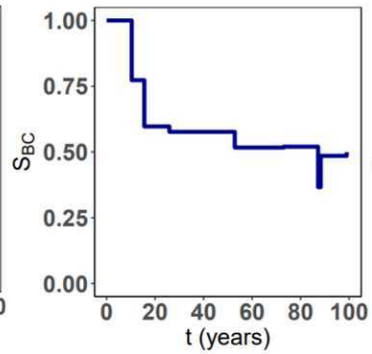
Time-based evolution of **degradation indicators** related to check dam #54



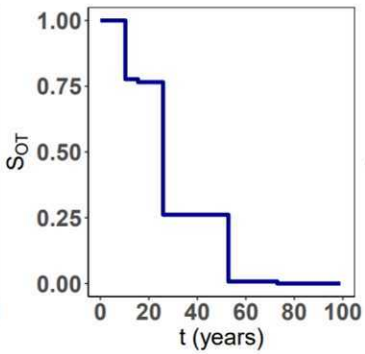
Local scouring depth



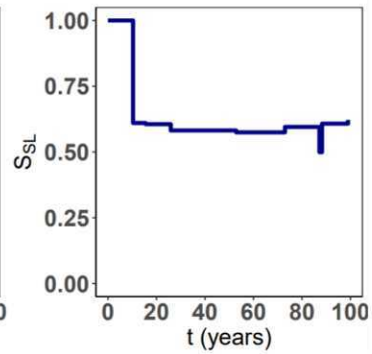
Local scouring width



Bearing capacity stability ratio



Overturning stability ratio

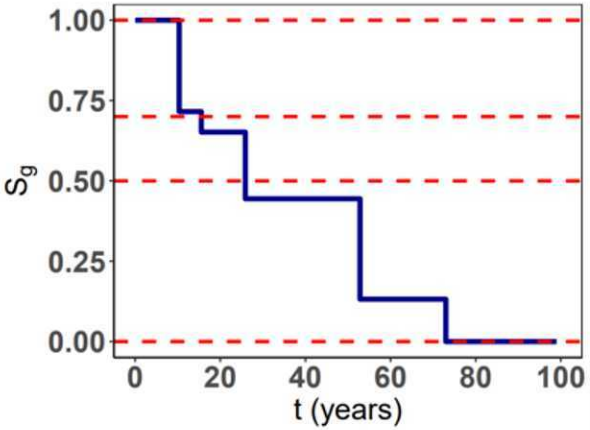


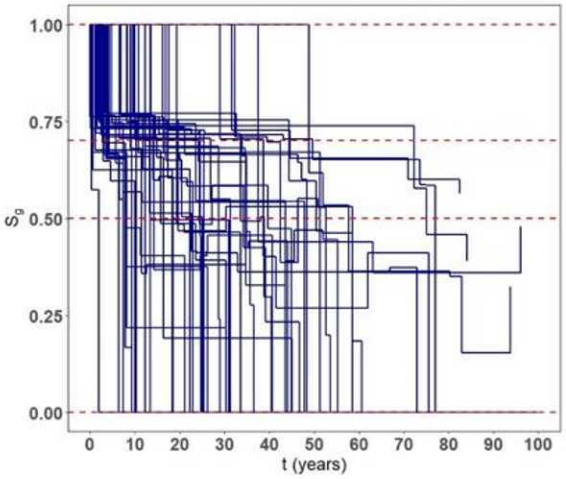
Sliding stability ratio

CASE STUDY: RESULTS & DISCUSSIONS

Time-based evolution of the **global stability index Sg** related to check dam #54

Sg corresponding to scenario 1





Sg corresponding to the 50 generated scenarios

(Chahrour et al. RESS 2021)

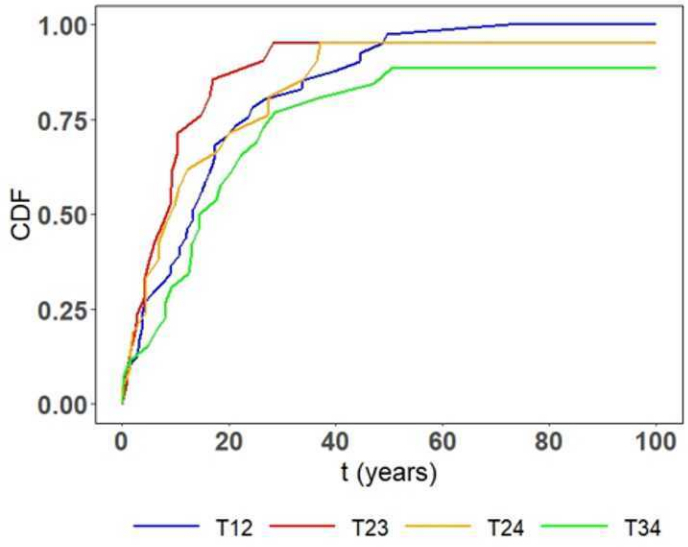
Fitting **probability distributions** for stochastic **transitions**

T12 (41 values)
T23 (20 values)
T24 (20 values)
T34 (23 values)

Empirical CDF using Kaplan Meier Estimator

T13 (6 values)
T14 (3 values)

Log normal distribution (μ, σ)

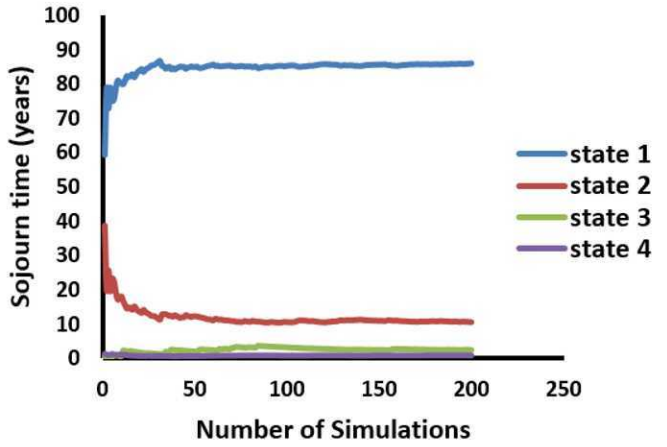


CASE STUDY: RESULTS & DISCUSSIONS

➢ Reliability-based modeling by SPN (check dam #54)

Mean sojourn time spent in each state

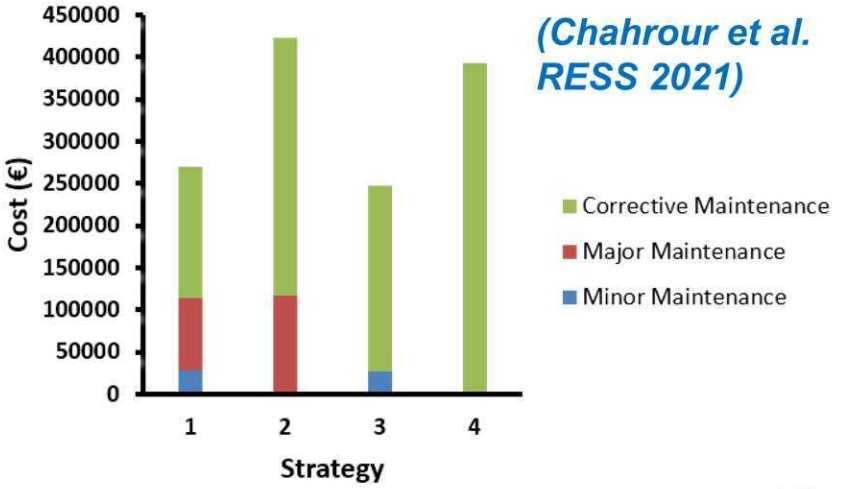
	State 1	State 2	State 3	State 4
strategy 1	86.01	10.49	2.55	0.87
strategy 2	56.62	37.27	4.20	1.77
strategy 3	73.04	6.73	19.02	1.21
strategy 4	44.43	25.89	27.45	2.23



Time spent by the dam in each state - strategy 1.

Average number of maintenance operations applied on the dam over a **period of 100 years**

	Minor operation	Major operation	Corrective operation
strategy 1	3.85	1.13	1.04
strategy 2	0.00	1.57	2.04
strategy 3	3.49	0.00	1.48
strategy 4	0.00	0.00	2.62



(Chahrour et al. RESS 2021)

Average expected cost of each maintenance strategy.

CONCLUSION

- A **multidisciplinary approach** that combines several fields:

Natural hazards

Torrential hydraulics

Civil engineering

Reliability engineering

Applied Mathematics

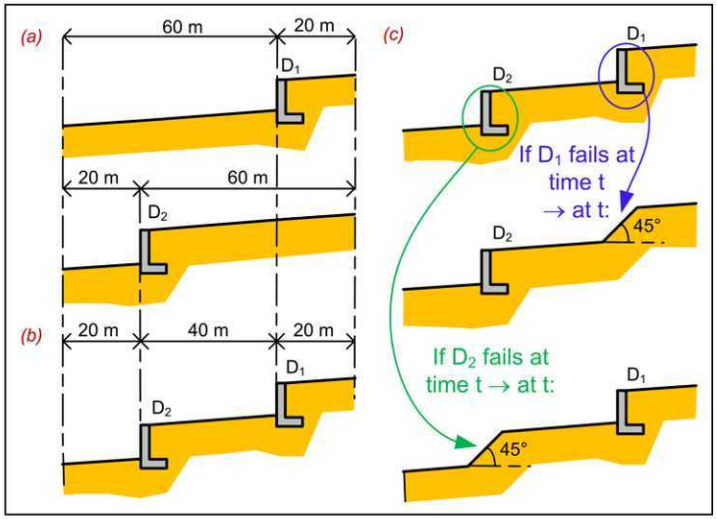
Decision support

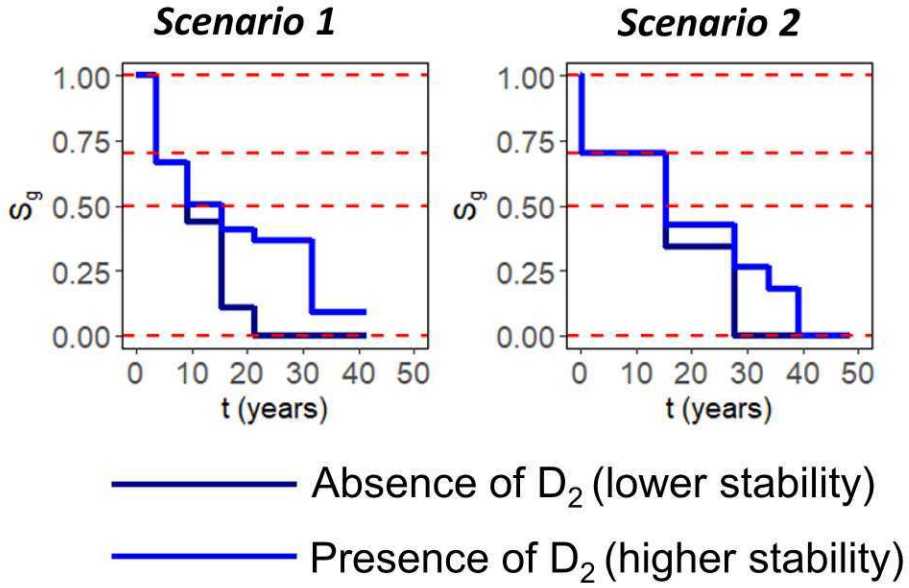
- **Coupling two approaches** for modeling the time-dependent behavior of a check dam
  - (1) Physics-based modeling (hydraulic and mechanical)
  - (2) Stochastic modeling (SPN, CM and Monte-Carlo)
- A **new decision-support approach** (dynamic, over their lifetime) to support check dams' decision-making
- A completely **generic approach** (applicable to any type of civil engineering structure, whatever the type of phenomenon, etc.)

PERSPECTIVES

- Analysis of a **multi-component system**: bi-directional dependencies between dams

(Chahrour et al. RAMS 2021)





- Considering other **failure modes** (e.g. internal stability of the dam)

- Sensitivity analysis: effect of **imperfect information** on the final risk management decision

THANK YOU

QUESTIONS

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