IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Global sensitivity analysis applied to riverine flood modelling

Vincent Rebour, Claire-Marie Duluc, Vito Bacchi, Lucie Pheulpin & Nathalie Bertrand
IRSN/SCAN

4th Annual Probabilistic Flood Hazard Assessment Workshop, april 29th – may 2nd 2019

La Garonne river, France
Picture taken during the 1981 flood event

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Presentation outline

I. Context

II. Uncertainty analysis (UA) and global sensitivity analysis (GSA)

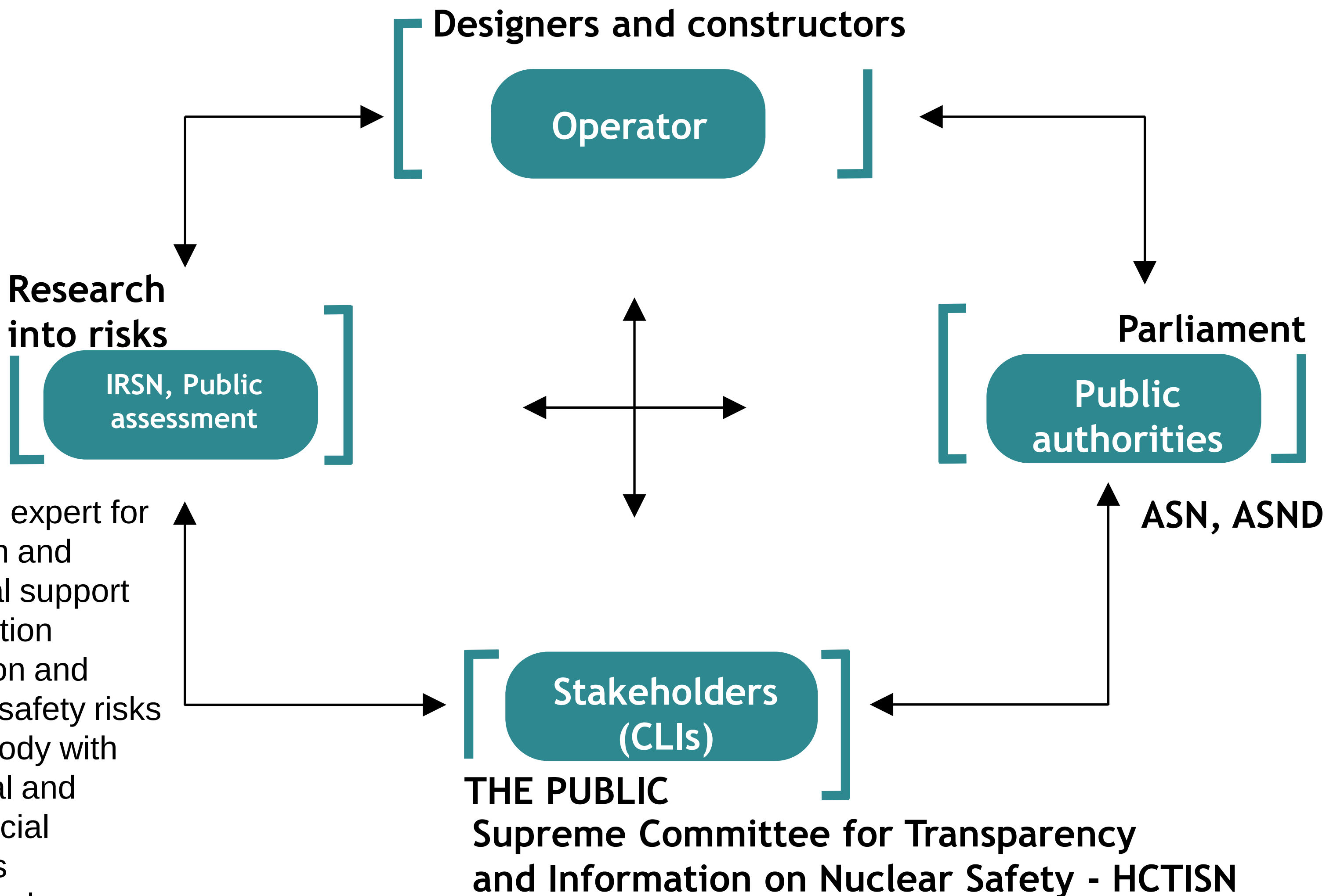
III. Preliminary studies applied to hydrodynamic models

IV. Levee breaches study on La Garonne river

V. Dependent inputs in hydraulic studies

VI. Conclusions and perspectives

Institutional environment

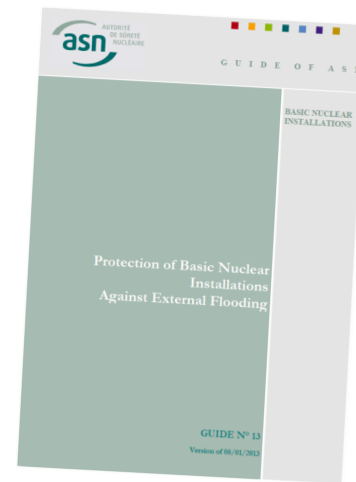


IRSN

- National expert for research and technical support on radiation protection and nuclear safety risks
- Public body with industrial and commercial activities
- 1700 employees

French ASN guide "Protection of Basic Nuclear Installations against External Flooding" (2013)

- ❑ Uncertainties taken into account through a robust, conservative and deterministic approach



- ❑ Upper bound of confidence interval, conservative assumptions defined for initial states...

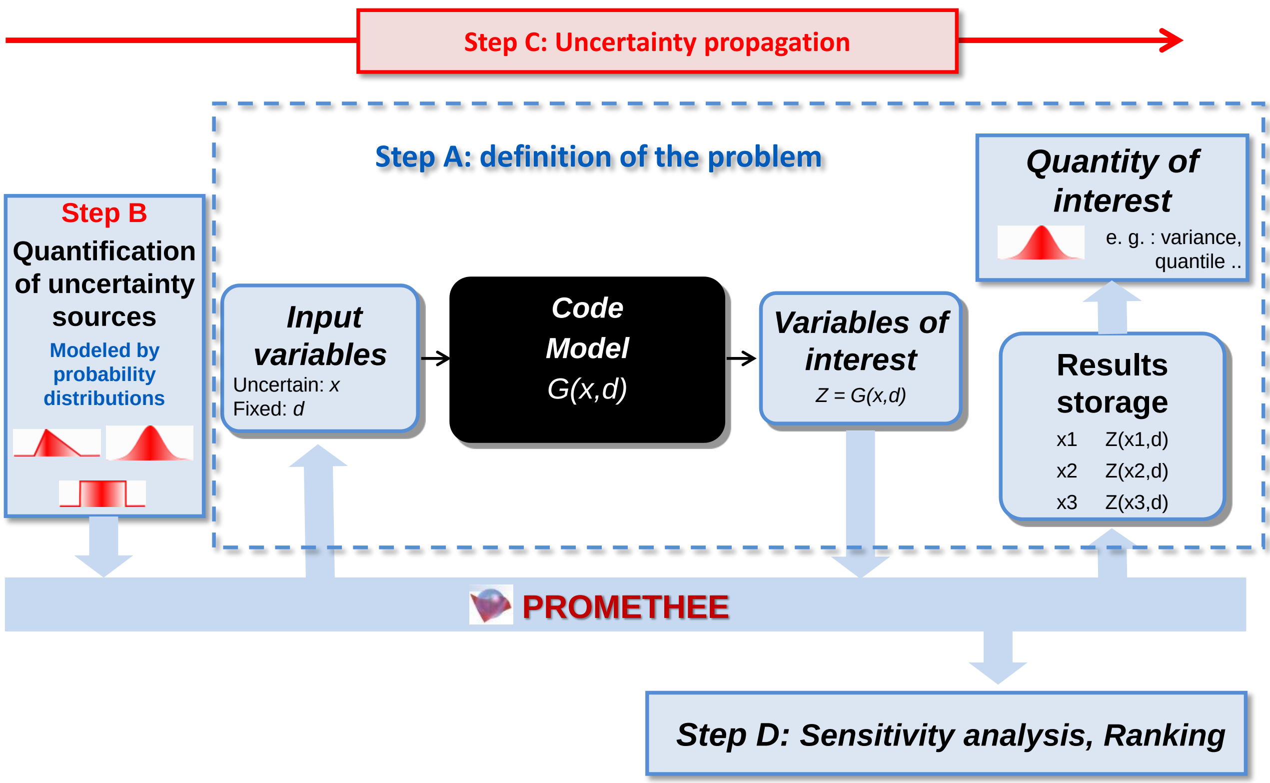
- ❑ Concerning the hydraulic modelling, penalization of the most influencing parameter

- ❑ Identifying the most influencing parameter and giving it a penalizing value is challenging and usually questionable…

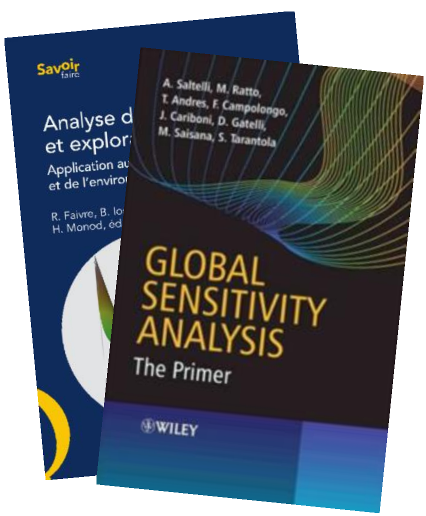
⇒ objective to develop a rigorous methodology to identify and penalize the most influencing parameter

⇒ objective to develop a probabilistic flood hazard assessment method

Main steps of uncertainty analysis and global sensitivity analysis



IRSN computational environment PROMETHEE



A : definition of the problem

B : definition of the input affected by uncertainty

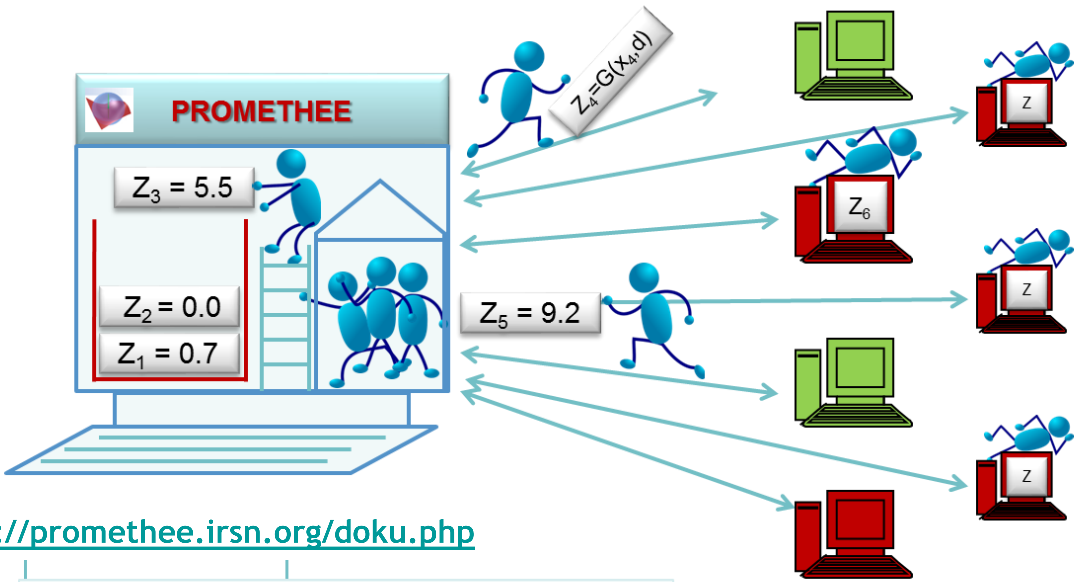
C : uncertainty propagation

D : sensitivity analysis ranking

IRSN

The key role of Promethee in performing UA and GSA

- Promethee environment coupled to different numerical models
  - *Allows the parameterization of any numerical code to carry out a huge number of simulations*
  - *Graphical user interface*
  - *Takes advantage of [R] algorithms to perform uncertainties propagation, sensitivity analysis, …*
  - *Deploys computational resources (e.g. work stations, servers, clusters)*



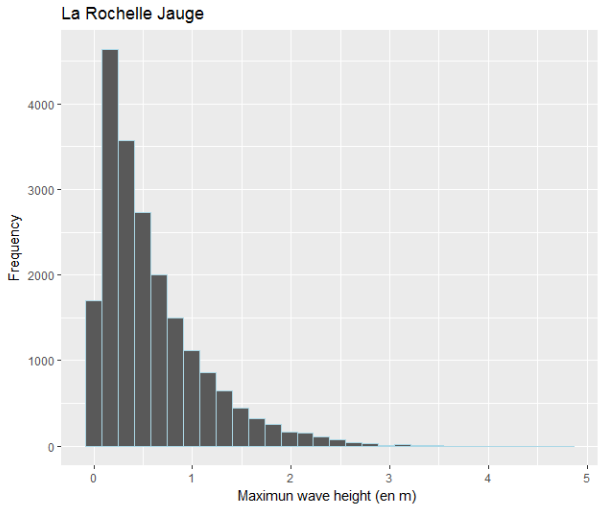
http://promethee.irsn.org/doku.php

Steps C : Monte-Carlo sampling for UA

Sample of size N-inputs

Hydrodynamic numerical model

N-outputs



- Law of response : statistic estimation

Mean

$$E[Y] = \mu_Y = \frac{1}{N}\sum_{i=1}^{N} G(x^i)$$

Variance

$$Var(Y) = \frac{1}{N-1}\sum_{i=1}^{N}\left[G(x^i) - \mu_Y\right]^2$$

St. deviation

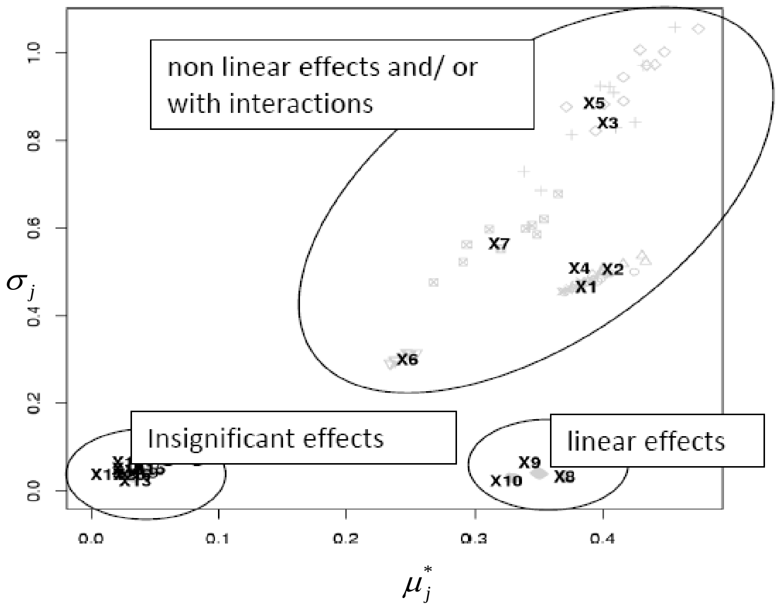
$$\sigma_Y = \sqrt{Var(Y)}$$

Convergence speed

$$o\left(\frac{1}{\sqrt{N}}\right)$$

Step D: sensitivity analysis

- D.1) Morris screening-method (One-at-a-time) – Morris, 1991



μ_j^* is a measure of influence of the *j-th* input on the output
σ_j is a measure of non-linear and/or interaction effects of the *j-th* input

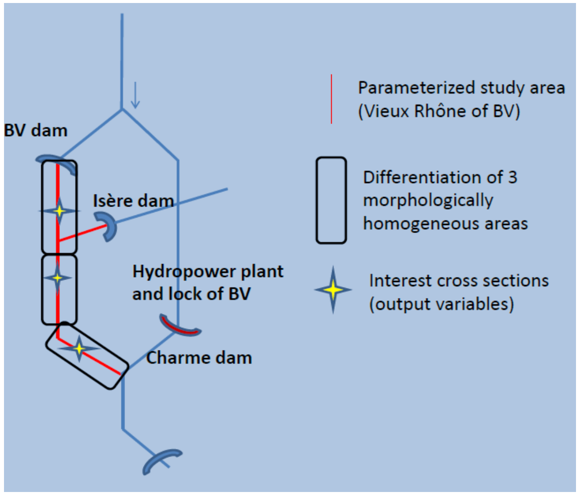
- D.2) Sobol' index computation

$$S_i = \frac{D_i(Y)}{Var(Y)}, \quad S_{ij} = \frac{D_{ij}(Y)}{Var(Y)}, \quad \ldots$$

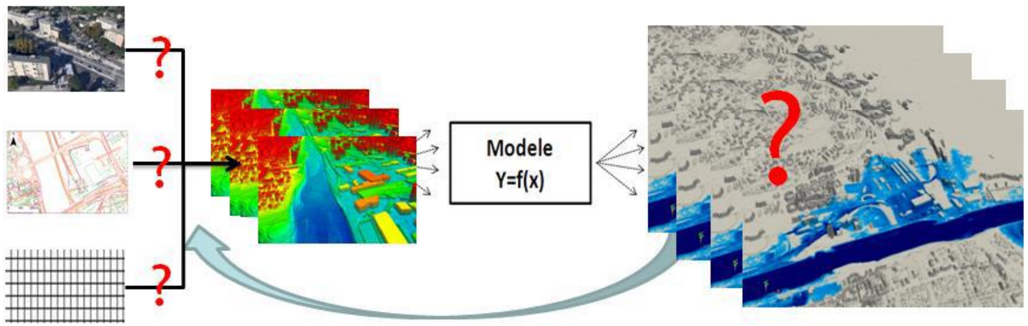
$$S_{Ti} = S_i + \sum_{i<j} S_{ij} + \sum_{j \neq i, k \neq i, j<k} S_{ijk} + \ldots = \sum_{l \in \neq i} S_l$$

- Results of ANOVA (ANanlysis Of VAriance) decomposition
- Quantify the contribution of each input parameter on the output variance
- Independent input parameters

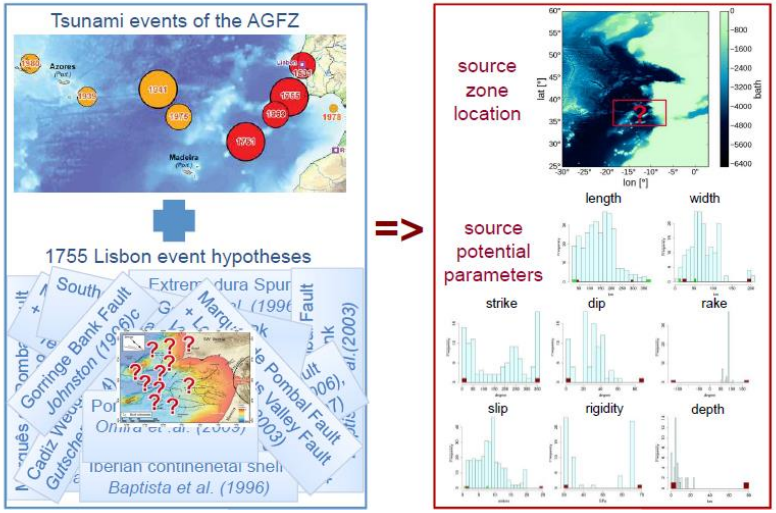
1D hydraulic model of the Rhône river [2011-2014]



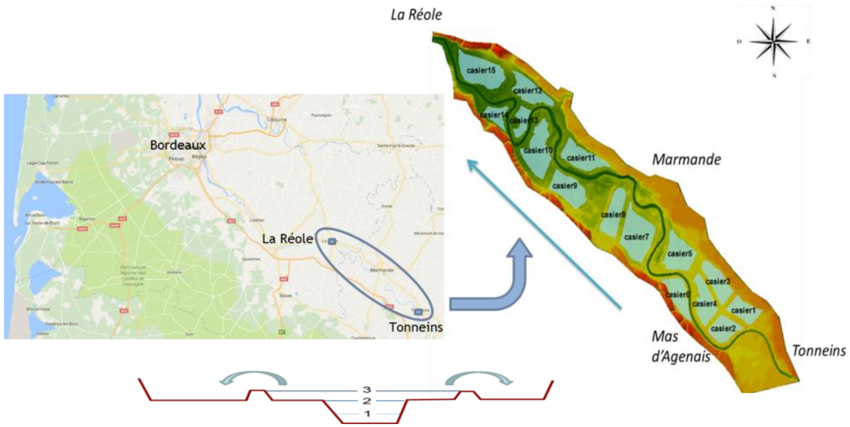
Topography with a 2D model [2013-2016]



2D Tsunamigenic potential of the AGFZ [2014-2017]



Flooding and levee breaches study on La Garonne river [2015-2019]



Conclusions of preliminary studies

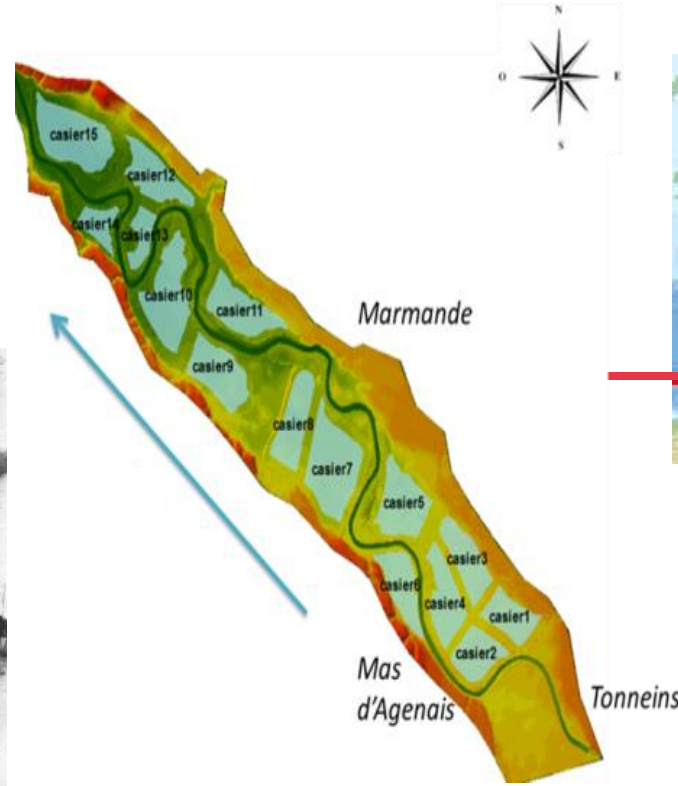
Interest for flood hazard assessment:

- In the context of nuclear safety UA and GSA allow to *identify the influencing parameters in a rigorous way*
- Identify *some rare combinations* of critical flooding situation that would have not been identified with an expert opinion
- Can be a *complementary approach* to the current state of practices concerning uncertainties on flooding hazard assessment

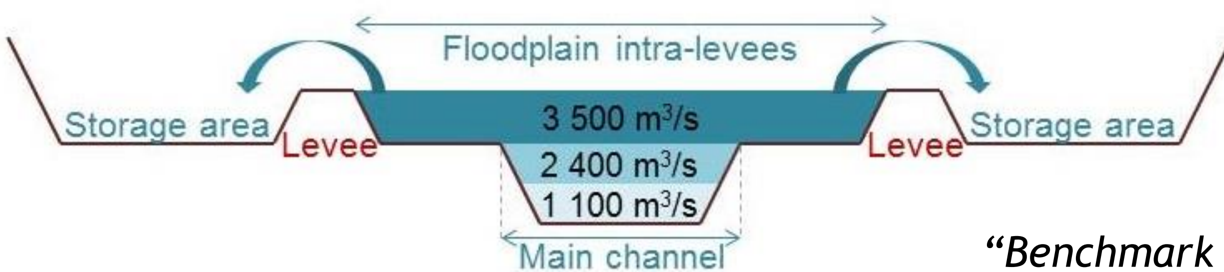
Main challenges:

- Time consuming calculations (interest of meta-model approaches…)
- Dealing with *dependent input parameters*

Case study on La Garonne river

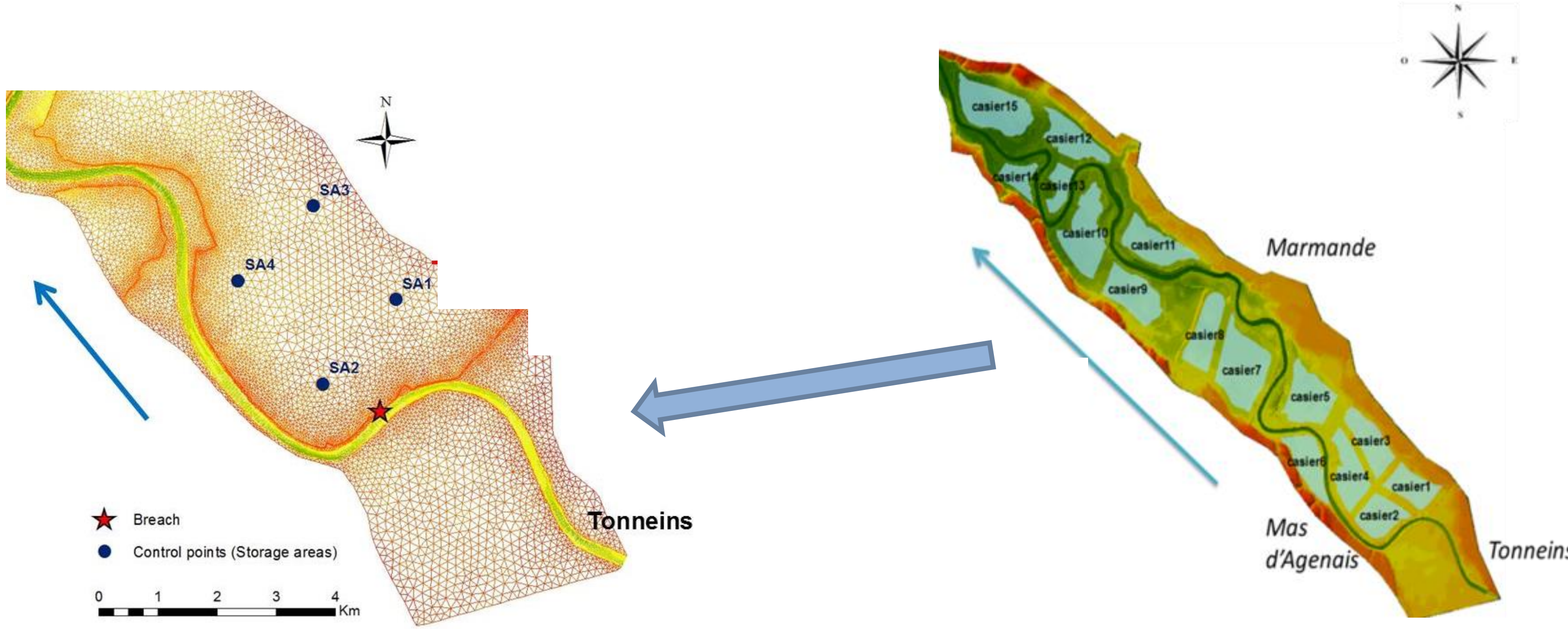


Picture taken during the 1981 flood event
(Sudouest.fr, Photo Archives G.L.)



"Benchmark Garonne" project by EDF

TELEMAC 2D model



<u>TELEMAC 2D:</u>

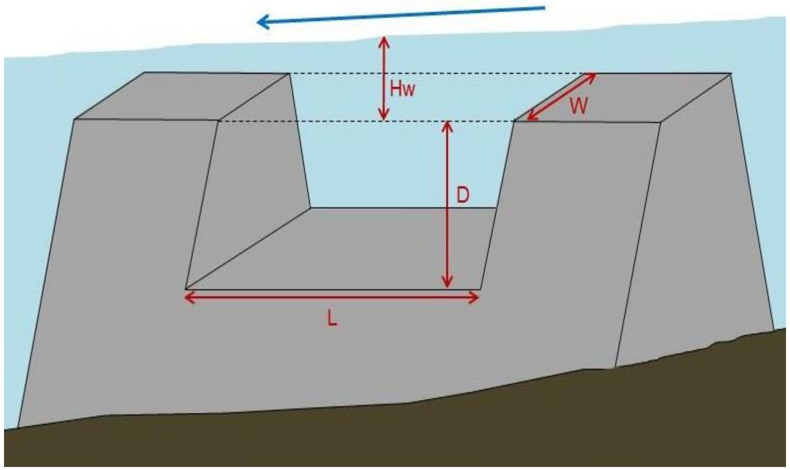
- 82,116 cells with different length varying from 10 to 300 m
- Upstream boundary condition: triangular hydrograph with a flow peak of 3,081 m^3/s
- The peak discharge is achieved after 18 hours and the simulation ends after 5 days

Levee breaches study

- **TELEMAC** breaching process : when the water level above the dyke reaches a given value "Hw"

- Uncertain parameters :
  - Overflow **Hw** : from 50 cm below levee crest to 10 cm above

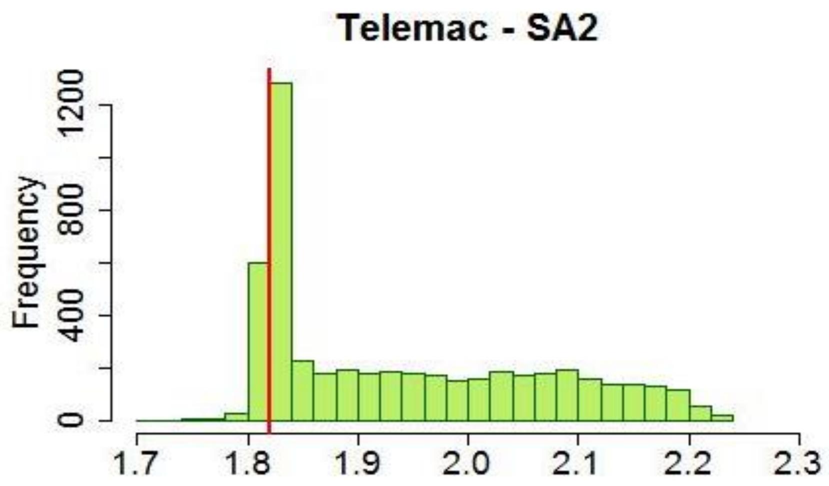
  + 2 geometrical parameters :
  - Depth **D** : from 0 to 100% of the levee height
  - Length **L** : between 40 and 200 m



Levee breach diagram.
The parameters are the length (L), the depth (D), the width (W) and the water level above the crest, that means the overflow (Hw).

- 200 simulations performed => raised to 5,000 with kriging meta-model (validated as a good emulator for reproducing the TELEMAC-2D code behavior)

Uncertainty propagation and GSA



Frequency distributions of the maximum water levels in four storage areas

SA Sobol' indices for the 3 uncertain parameters

⇒ Large variation of water height compared to the simulation without breach (red lines), influence of Depth…

⇒ No dependency taken into account between Overflow, Length nor Depth

⇒ See *SimHydro 2019, Pheulpin & al - Comparison between uncertainty propagations and sensitivity analyses from two hydraulic models (1D and 2D) of the Garonne River: Application to levee breach parameters*

Dependant inputs taken into account in a simplified case : 1D equations of Saint-Venant, with uniform and constant flowrate and large rectangular sections

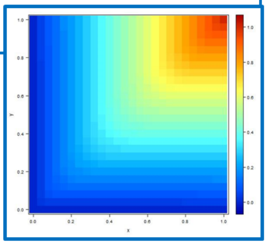
Step B: Uncertainty sources quantification

For all parameters, definition of:

- Parameter bounds
- Parameter distribution laws

For dependent parameters:

- Groups of parameters identification
- Copula selection (*e.g.* normal copula) adapted to each group of parameter and definition of the correlation coefficients (*r*)
- Construction of multivariate distributions



Example of a normal copula cumulative distribution function

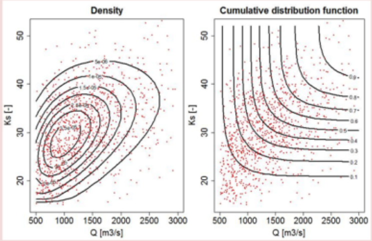
Uncertainty sources quantification

Inputs	Symbols	Units	PDF
Maximal annual flow rate	Q	m^3/s	Truncated Gumbel
Strickler coefficient	K_s	-	Truncated Normal
River downstream level	Z_v	m	Triangle
River upstream level	Z_m	m	Triangle
Levee height	H_d	m	Uniform
Bank level	C_b	m	Triangle
Length of the river stretch	L	m	Triangle
River width	B	m	Triangle

UQ for independent and dependent parameters

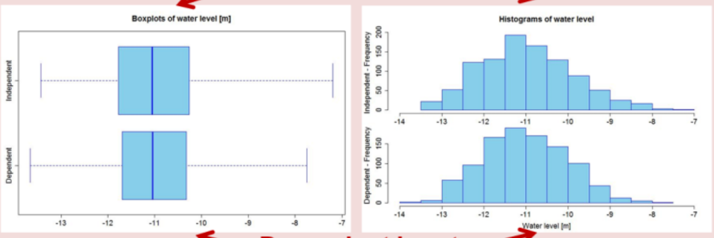
Dependent inputs → 3 normal copulas: Q/K_s (r = 0.5) ; Z_v/Z_m (r = 0.3) ; L/B (r = 0.3)

Normal copula Q/K_s



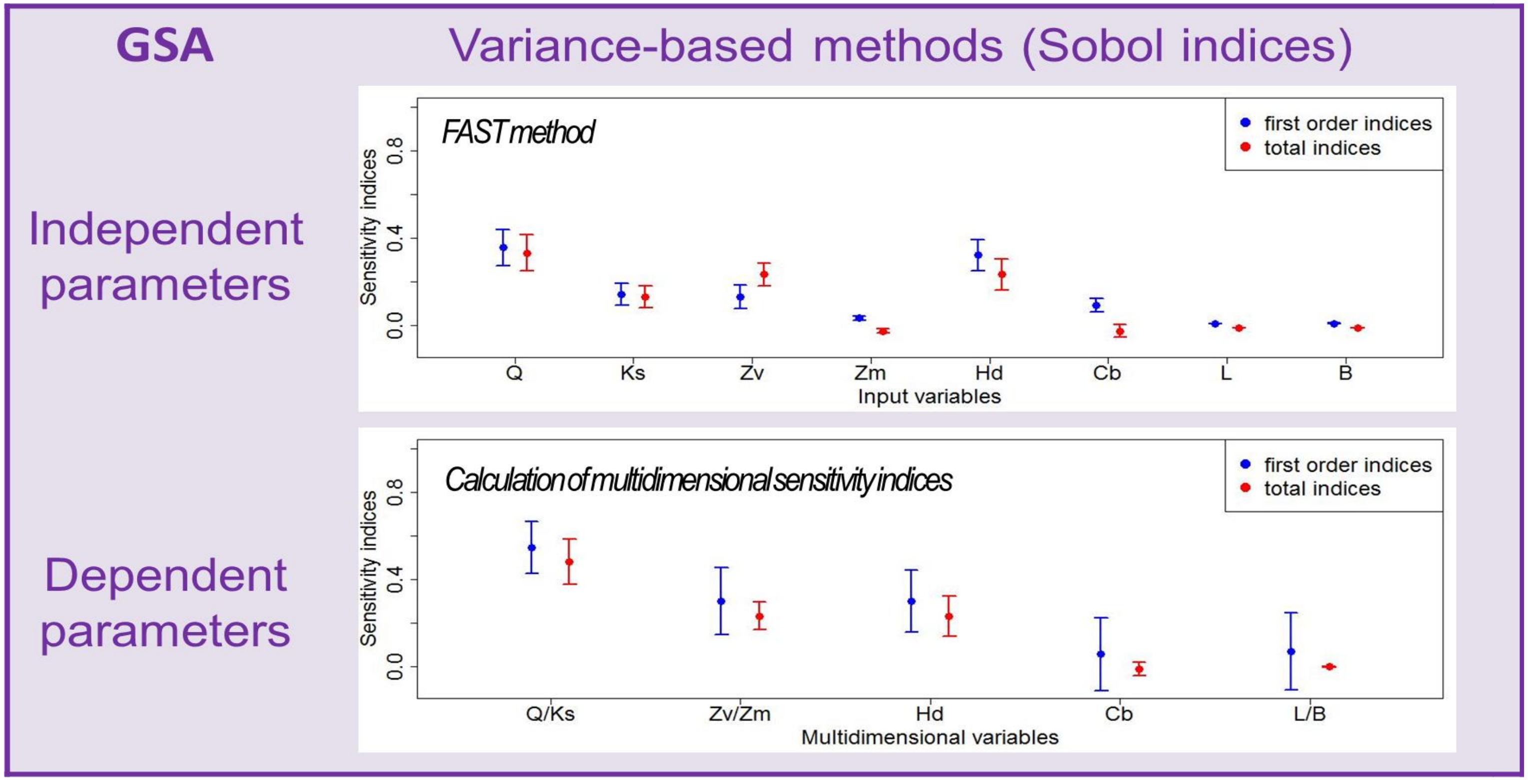
Outputs Distribution

Independent inputs



Dependent inputs

Simplified case: global sensitivity analysis



- In this example, the choice of the copula has very few impact on the outputs
- Some parameters (e.g. Zm) can have more influence once included in a group than considered independent

⇒ More information : see *IRSN EGU 2019 poster (Pheulpin & al)*

Application to a real case study (perspective)

Step A: Problem specification

Input parameters:
- **Fixed**: Time step, grid resolution, *etc.*
- **Uncertain**:
  - Hydraulic parameters: hydrograph parameters, Strickler coefficient, *etc.*
  - Breach parameters: length, depth, time formation, *etc.*

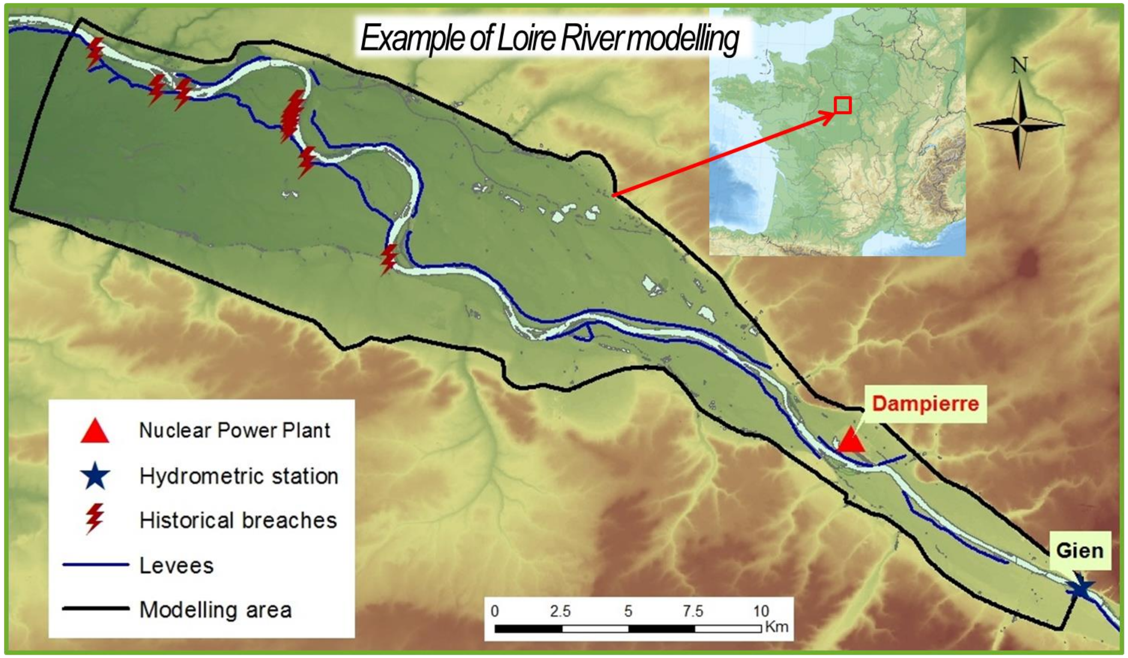
↓

Independent parameters or not?

Hydraulic and levee breach modelling: Example for the Loire River
- 50 km-long reach modelling, between Gien and Orléans
- 2D modelling with Telemac-2D
- Numerous levees along this reach with known historical breaches

Variables of interest
- Water levels at certain location in the flood plain (*e.g.* near the breaches)

Quantities of interest
- Probability, variance, *etc.*



Conclusion of recent and on going studies on riverine flood modelling

- Uncertainty quantification related to levee behavior during an inundation event can be a very difficult (but essential) task

- Additional uncertainty associated to the chosen numerical model representing the breach process (1D vs 2D…)

- Theoretical framework available to take into account dependencies, data needed to characterize dependencies

- Interest of meta-models and inversion approach to control calculation time

Probabilistic Flood Hazard Assessment (perspectives…)

Riverine flood

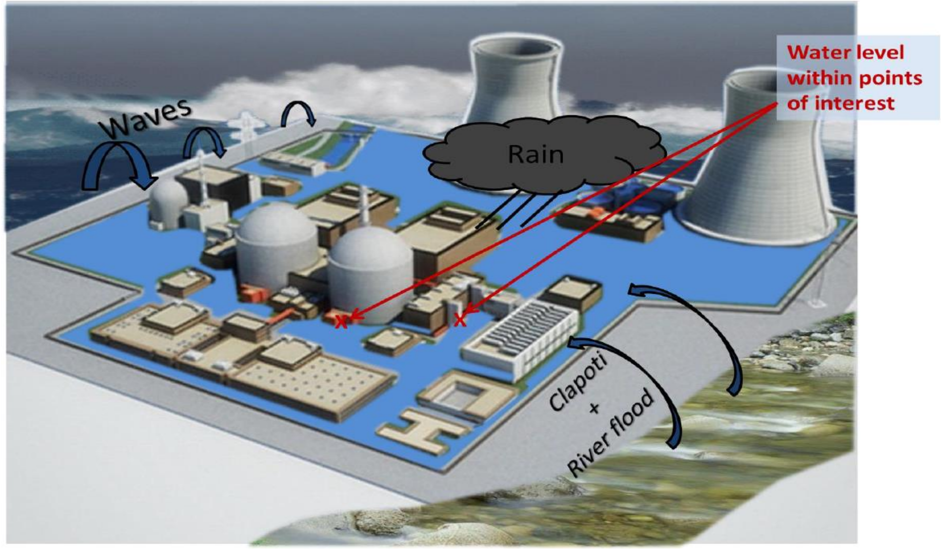
- objective of including a probabilistic assessment through uncertain input parameters (e.g. peak flow rate distribution and duration of flood…)
- propagate uncertainties or use inversions methods to define the probability of some outputs safety criteria

⇒ *See Bacchi & al, CMWR conference in June 2018*

Combining hazards

- on going PhD

⇒ see *Ben Daoued & al “Modeling coincidence and dependence of flood hazard phenomena in a Probabilistic Flood Hazard Assessment (PFHA)* » *(under revision)*



IRSN

Thank you for your attention