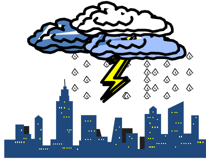
Urban Hydrology class: stochastic modelling approaches

Luca Rossi

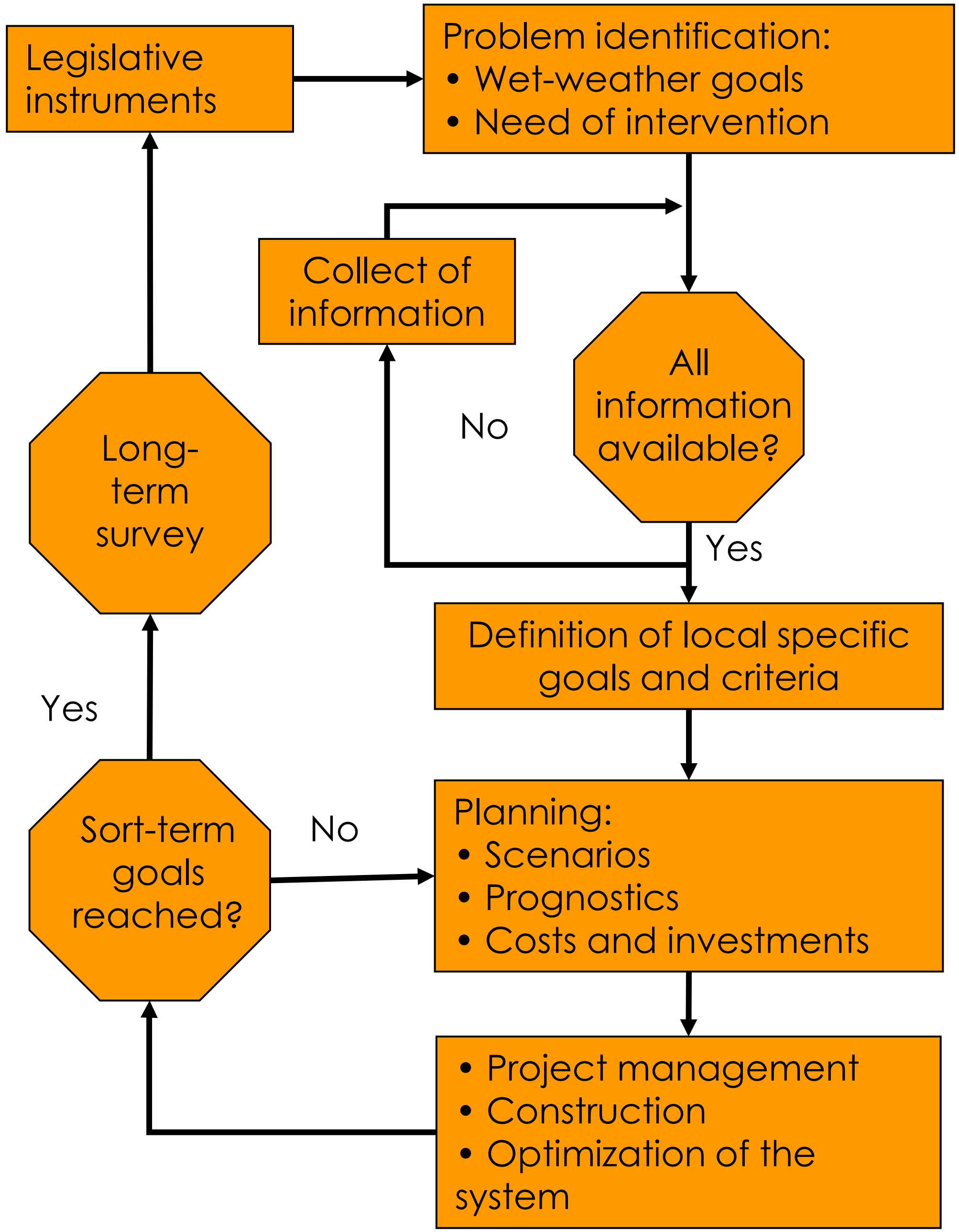
luca.rossi@epfl.ch



Date	Cours n°	Description	Exercices
20.02.2025	1	Introduction	Exercice 1
27.02.2025	2	Legislative aspects	Exercice 2
06.03.2025	3	Planning tools : PGEE	-
13.03.2025	4	Planning tools : PREE	Exercice 3
20.03.2025	5	Field trip (Lausanne wastewater system)	-
27.03.2025	6	Modeling tools	Exercice 4
03.04.2025	7	Deterministic modeling (Routing system 3)	Exercice 5
10.04.2025	8	Stochastic modeling (REBEKA)	Exercice 6
17.04.2025	9	Financial aspects	Exercice 7
24.04.2025		***Easter***	
01.05.2025	10	Technical solutions	-
08.05.2025	11	AG VSA Fribourg	-
15.05.2025	12	Field investigation (immission)	Exercice 8
22.05.2025	**13**	**Knowledge control (mandatory)**	
29.05.2025		***Ascension Day***	

Goals of the course

- To know how to model urban hydrological processes using a stochastic model
- Example of application: The REBEKA II Model



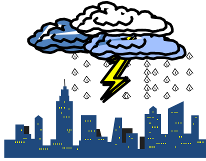
Immission strategy: the goal is to limit the impacts on the environment.

An integrated approach is therefore needed !

Table of content

- Do we have a problem ?
- Why a probabilistic approach ?
- How to analyse the results ?
- Sensitivity analysis
- Technical solutions
- Model validation
- Exercise with REBEKA

Do we have a problem?



Projet		Date de l'examen / base		*Matrice d'évaluation*
Cours d'eau		Section / site		

Hydrologie	Estimation (E)	Calcul (C)						
Surface BV (km^2)	Longueur de la section (km)	Largeur du cours d'eau (m)	Profondeur d'eau moy. (m)	Débit estimé (l/s)	Q347 (étiage) (l/s)	Altitude max.	Altitude min.	Pente moyenne (%)
Remarques								

Ecomorphologie	Classification moyenne	meilleure	pire	Variabilité en largeur (moy.)	Végétation riveraine	Déficit principal
Section considérée						
Section en amont						
Remarques						

Indications pour les déversements des eaux usées (installations)						
Désignation		Volume déversé (m^3/an)		Fréquence (nombre/an)		Durée (h/an)
Remarques						

Aspect général		*Hygiène*		*Physique*		*Chimie*				*Matières en suspension*				*Biologie*			
Matières grossières	Autres éléments	Baignade, jeux	Eau potable	Impacts hydraulique	Température	NH_3	Oxygène	Substances nutritives	Autres subs-tances, p.ex micropolluants	Colmatage	Turbidité	Sédiment toxique	Fond en anaérobiose	Diatomée	Couverture végétale	Invertébrés aquatiques	Poissons

Aspect général: trace de papiers, de déchets…

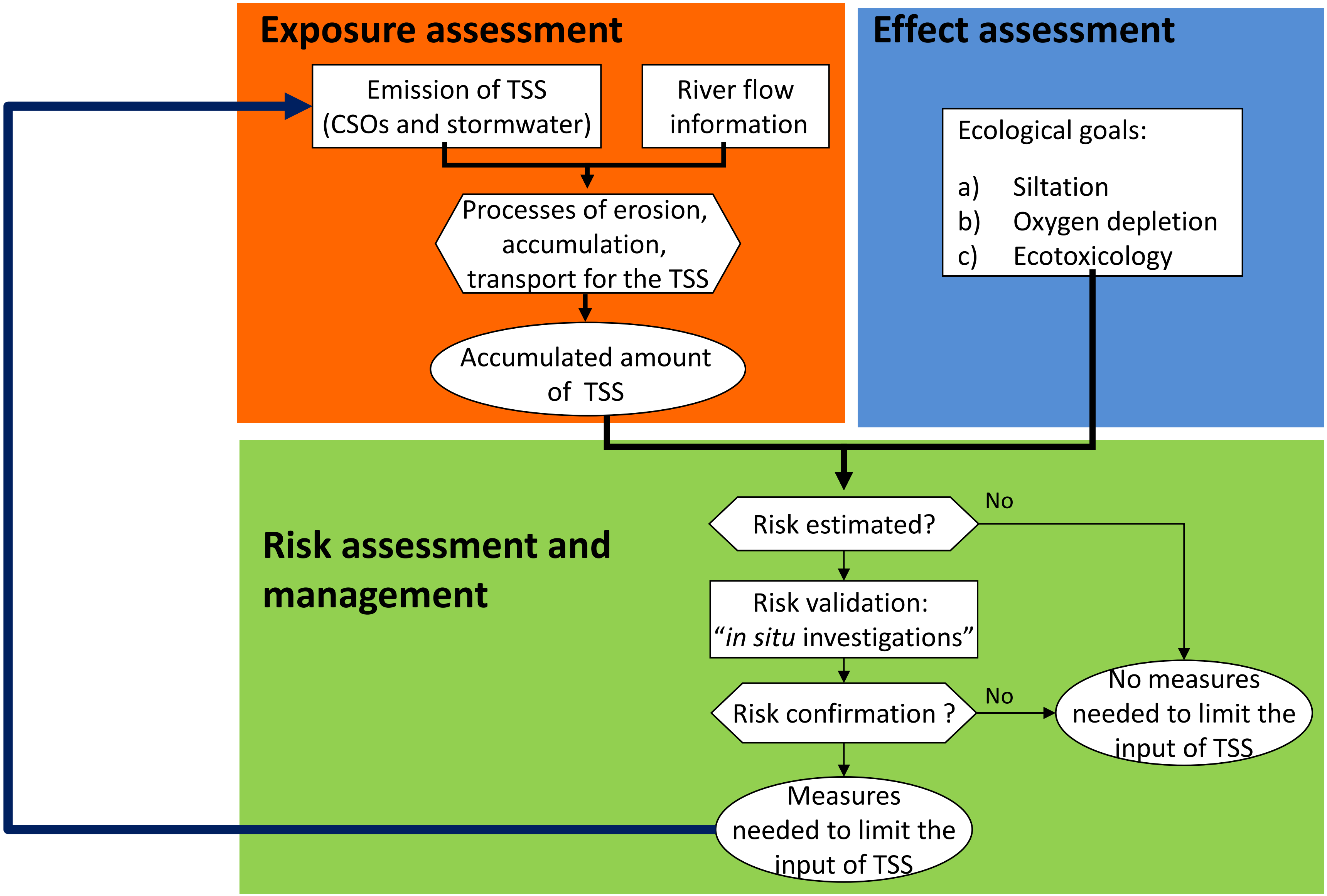
Physique: traces visibles d'érosion

Chimie:
sédiments contaminés ?

Remarques

Légende	Paramètre déterminant	oui	non		Problèmes avec →	Situation en temps de pluie	Fort	moyen	faible	aucun	Situation par temps sec	fort	moyen	faible	aucun

Do we have a problem?



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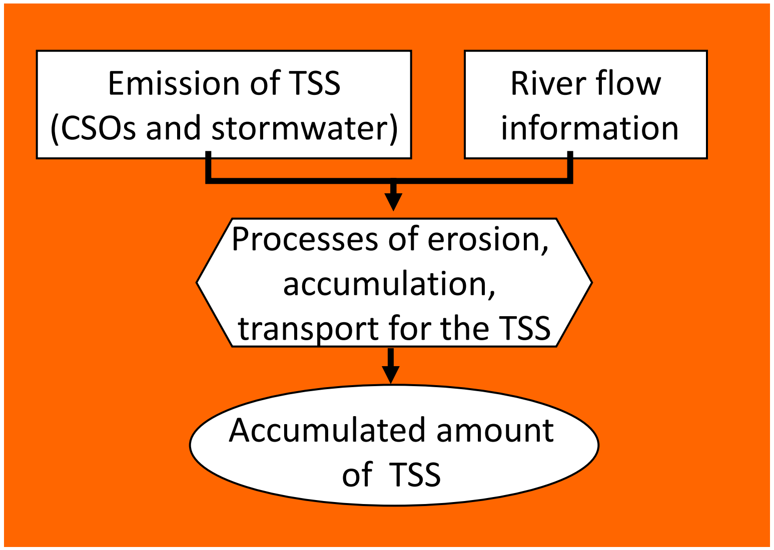
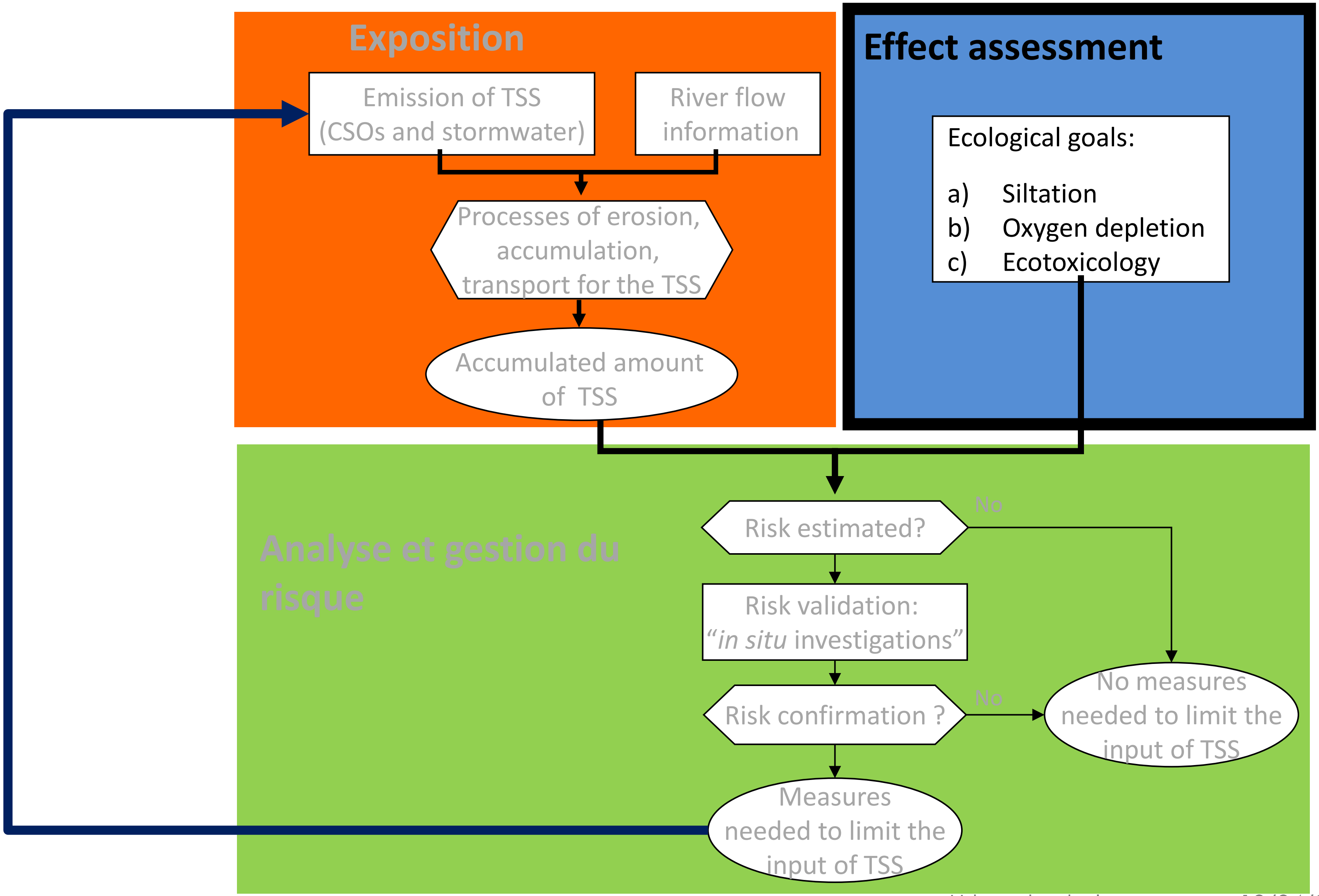


Modeling with REBEKA II software:

- Urban stormwater discharge
- Flow in the river
- Input of ammonium and TSS in receiving waters
- Deposition and erosion of sediments in the river
- pH and temperature fluctuation (ammonia toxicity)
- …

Legislation course

Do we have a problem?

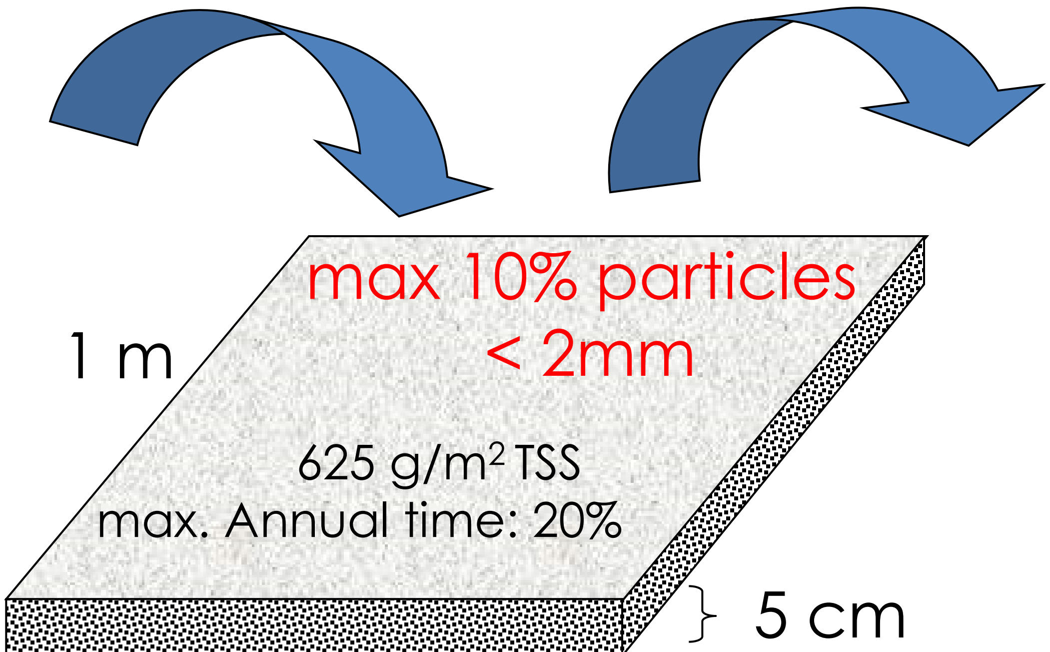


Do we have a problem?
Effect assessment for sediment

Siltation risk

Ecotoxicological risk

Anaerobic risk

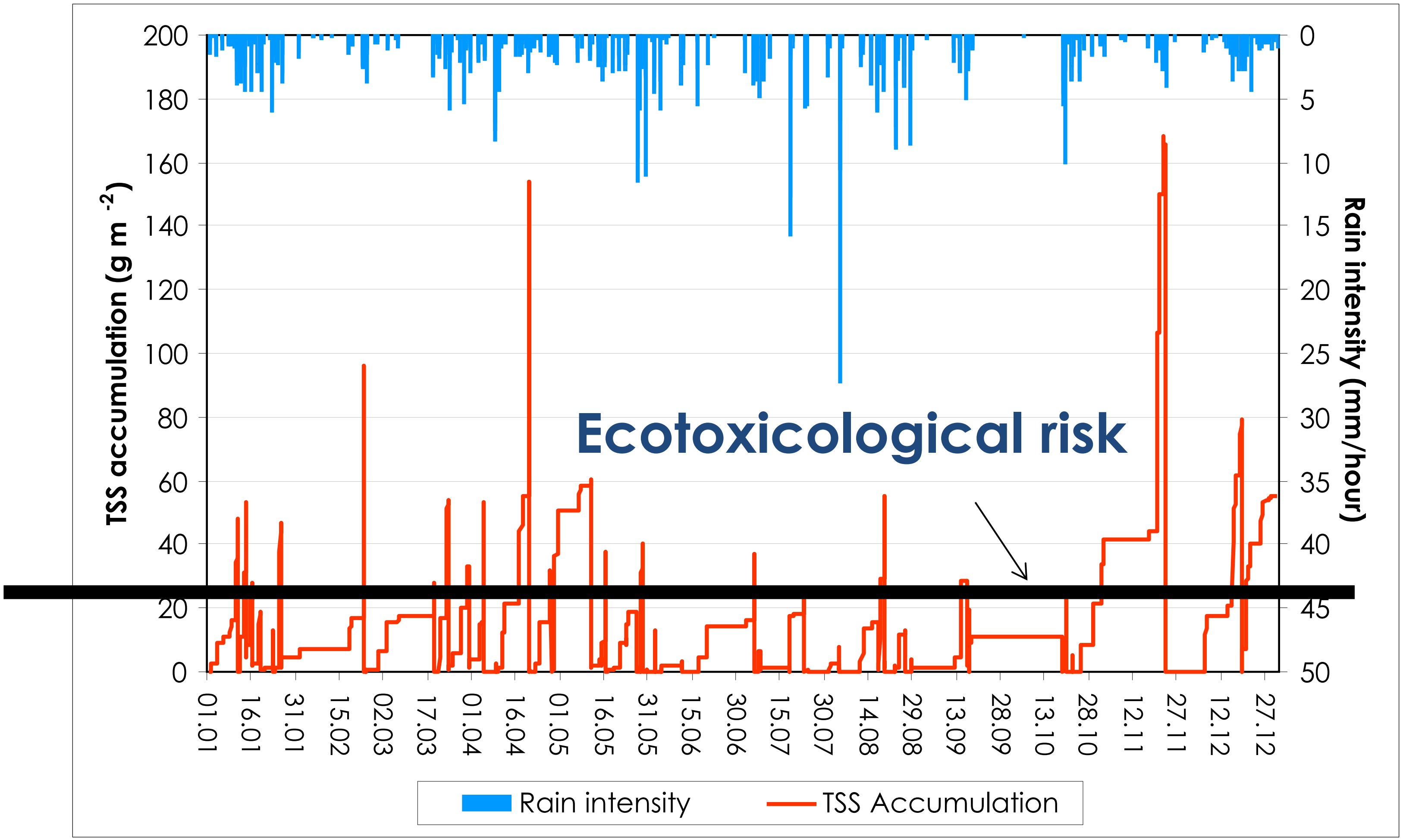


Criteria: f(mass of TSS, exposure time)

EIFAC: European Inland Fisheries Advisory Commission (1964)
Canadian Council of Ministers of the Environment, CCME (1995)

Do we have a problem?

Effect assessment for sediment



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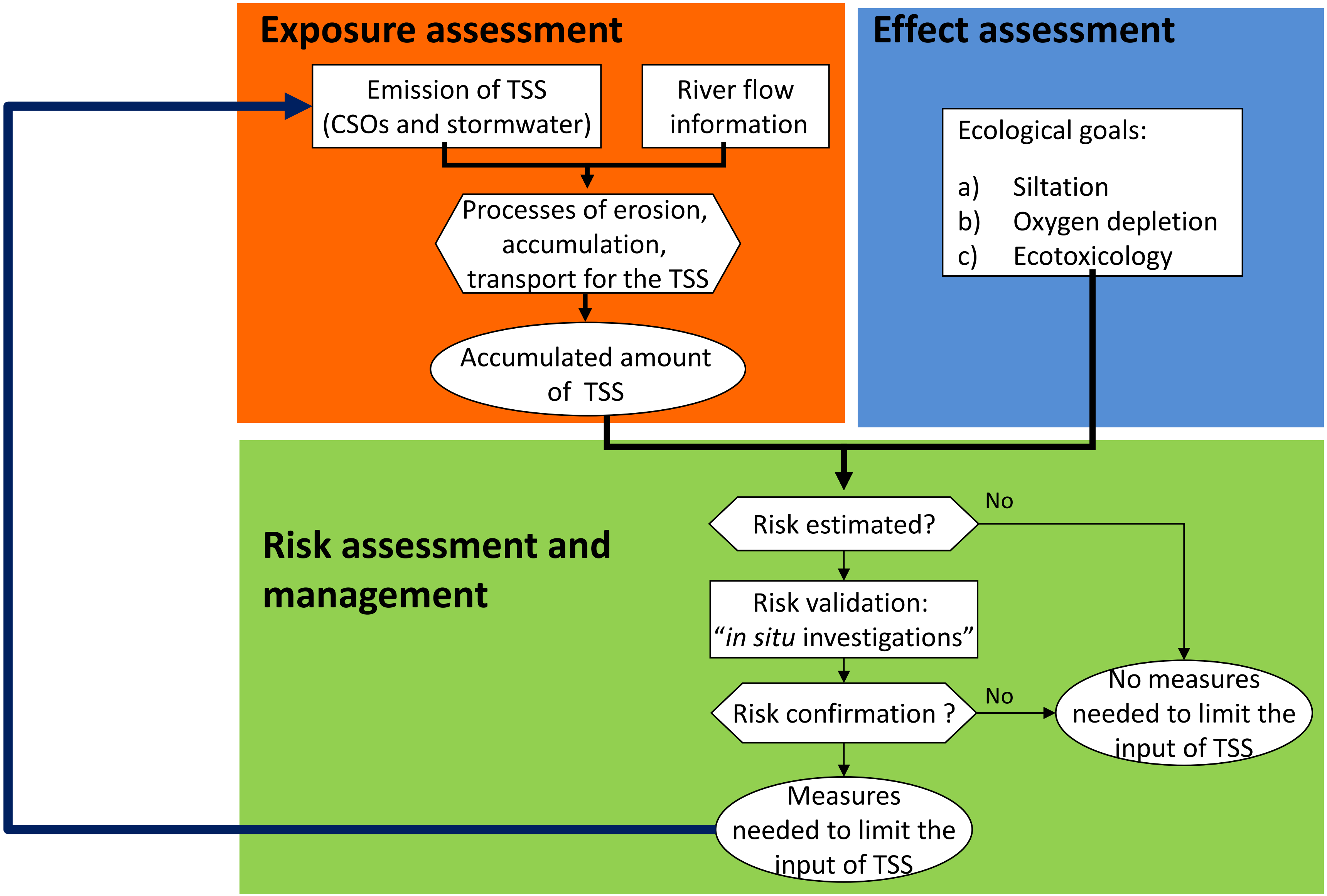
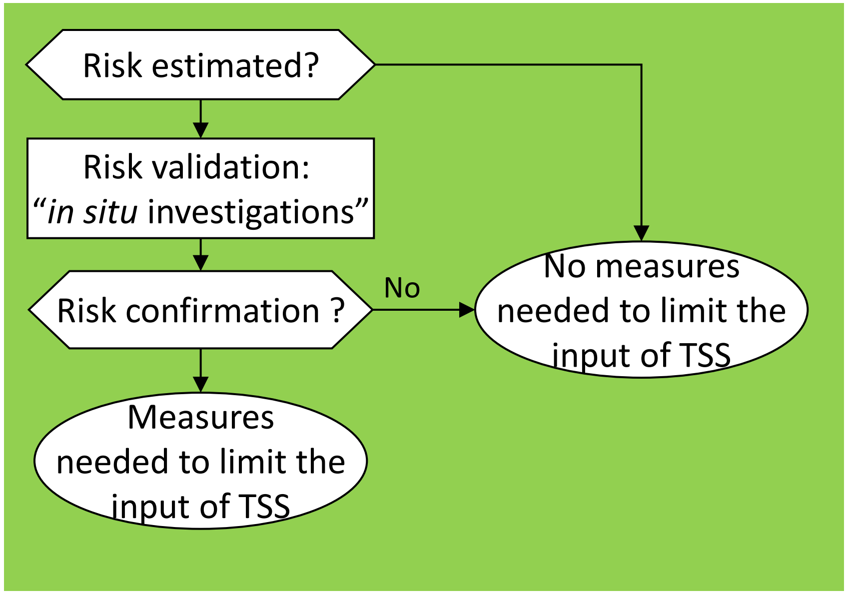


Do we have a problem?

Risk assessment and management

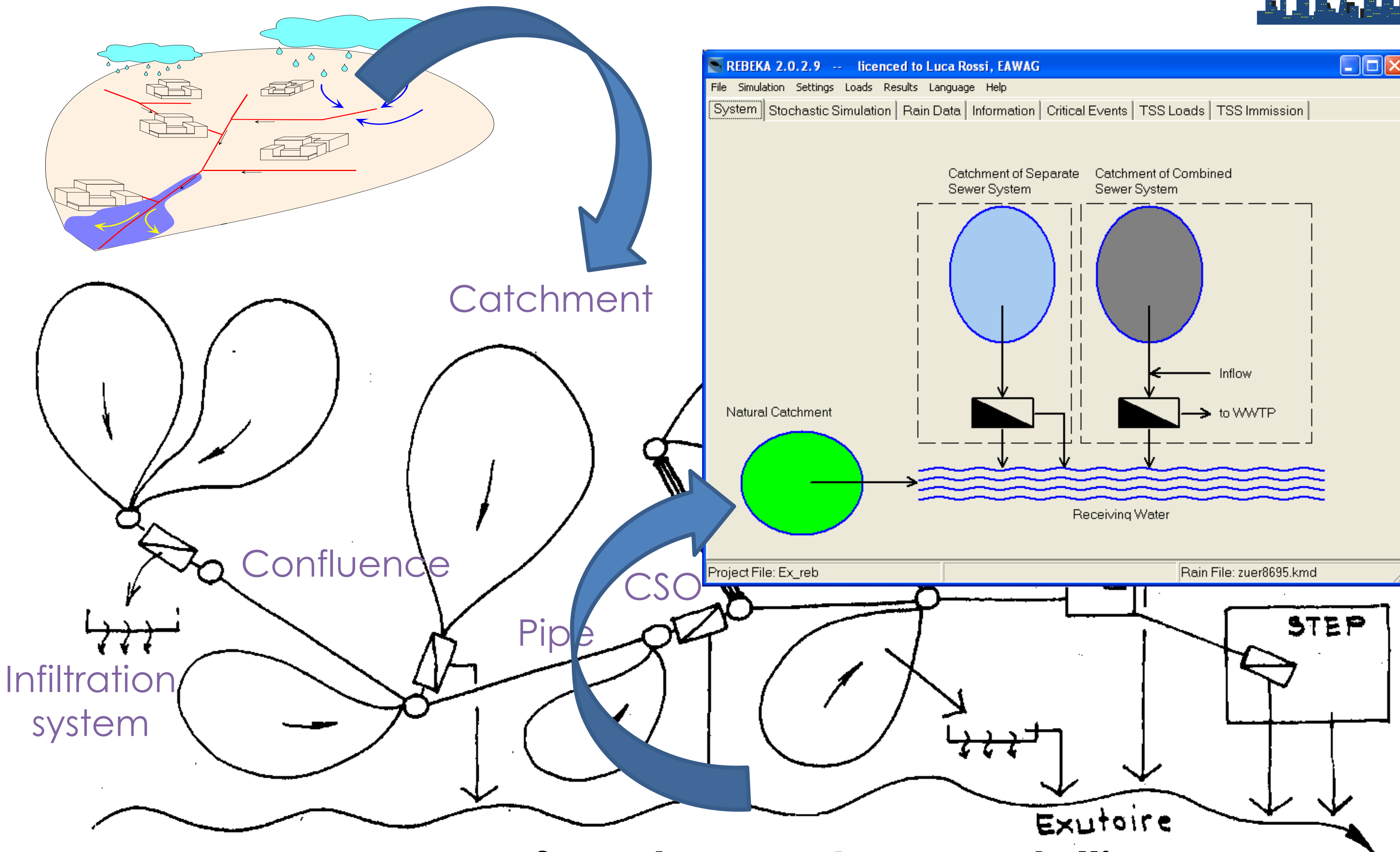


Sampling of sediments

- Chemical analysis
- Exotoxicological analysis

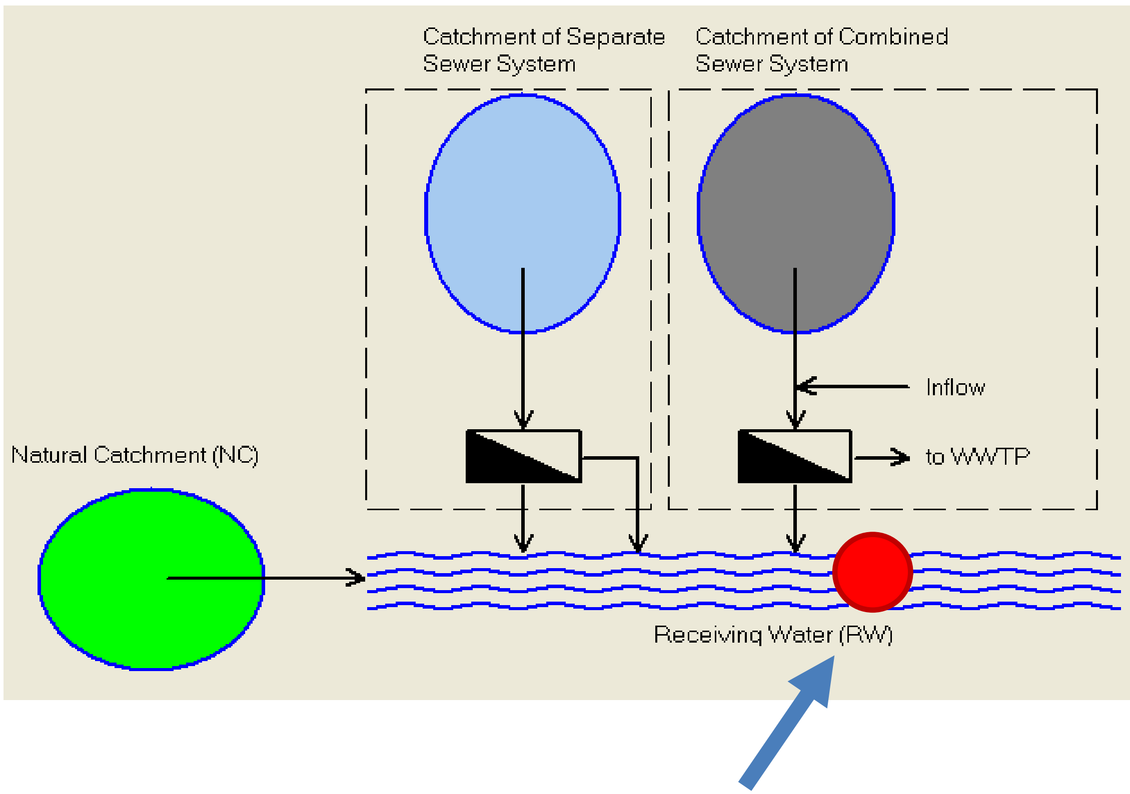
Biological survey

Conceptualization of the model



Key for urban system modelling = discretization of the system in single units

Conceptualization of the model

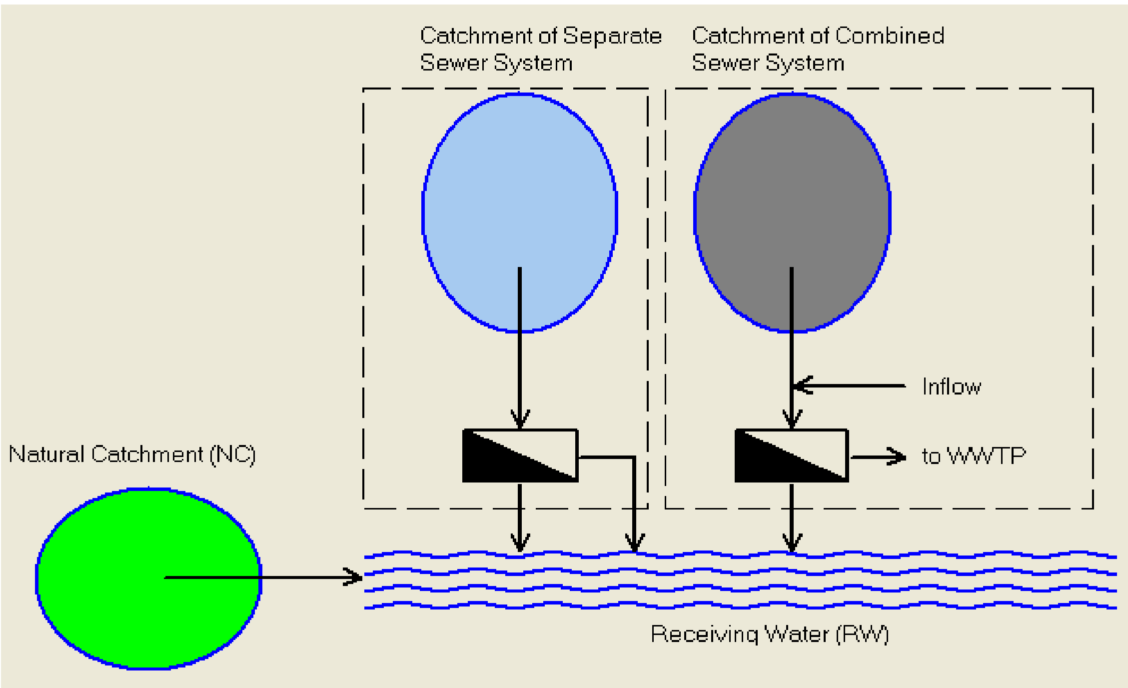


www.rebeka.ch

Goal: to estimate a ***probability of impacts*** in the receiving waters

Data needed for the model

Ca. 40 parameters, 15 « standard values »



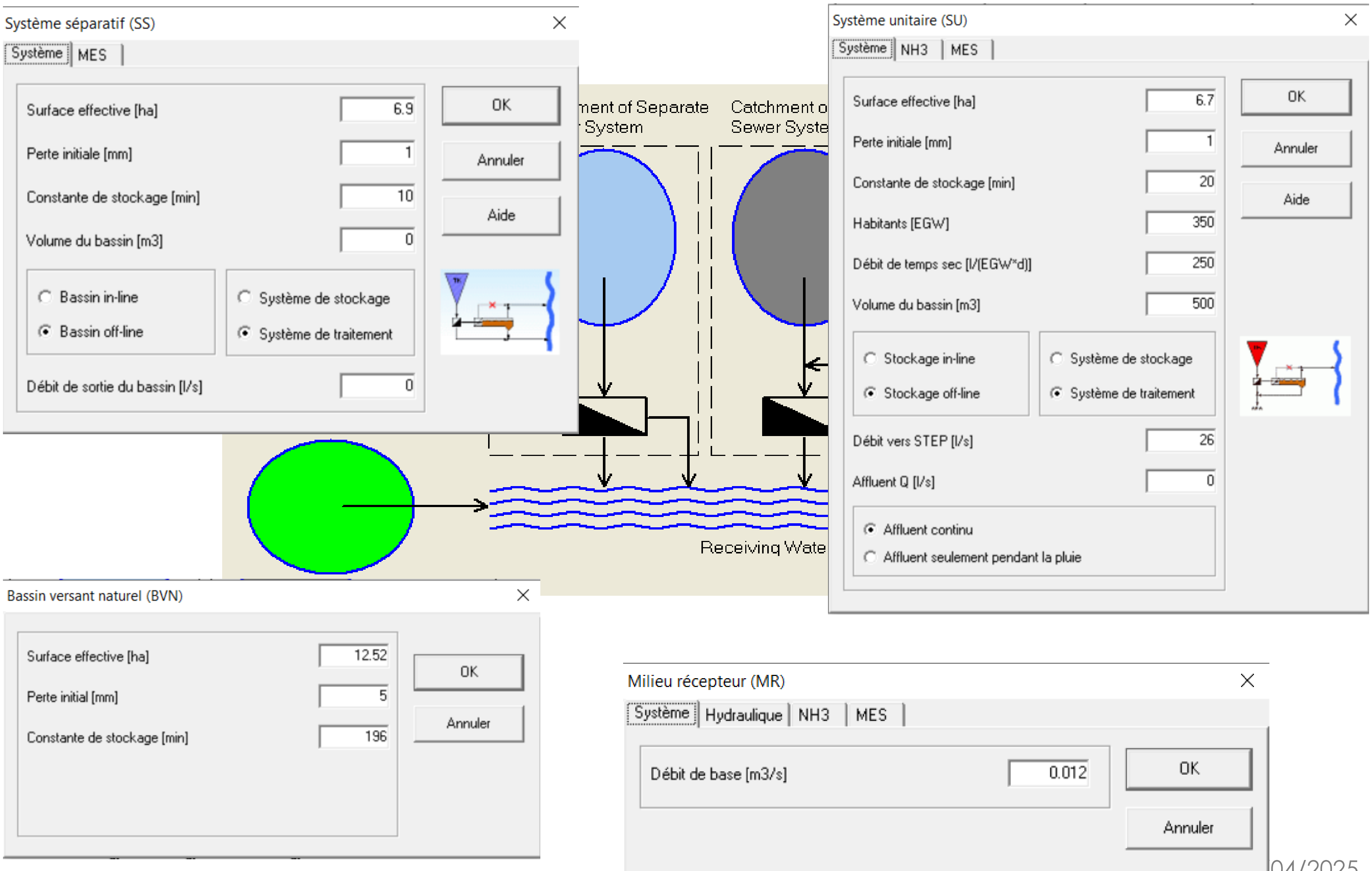
Natural Catchment (NC)
Contributing Area [ha]
Initial Loss [mm]
Reservoir Time Constant [min]

Separate Sewer System (SSS)
Contributing Area [ha]
Initial Loss [mm]
Reservoir Time Constant [min]
Stormwater Tank Volume [m^3]
Outflow [l/s]
First Flush Coefficient b [-]
Efficiency Factor [-]
TSS Conc. in Rainw. [mg/l]

Combined Sewer System (CSS)
Contributing Area [ha]
Initial Loss [mm]
Reservoir Time Constant [min]
Inhabitants [PE]
*Dry Weather Flow [l/(PE*d)]*
Outflow to WWTP [l/s]
CSO Tank Volume [m^3]
NH4-N in Rainwater [mg/l]
pH in Wastewater [-]
*NH4-N Load [g/(PE*d)]*
Alkalinity in Wastew. [mmol/l]
TSS Conc. in Wastewater [mg/l]
First Flush Coefficient b [-]
Sediment Fraction [-]
CSO Efficiency Factor [-]

Receiving Water (RW)
Baseflow Q347 [m^3/s]
Channel Slope [-]
Channel Width [m]
Side Slope x:1 (H:V) [-]
Strickler Coefficient [$m^{(1/3)}$/s]
Average Grain Size [m]
90% Grain Size [m]
NH4-N Concentration [mg/l]
pH Value [-]
Alkalinity [mmol/l]
Min. Temp. (February) [°C]
Max. Temp. (August) [°C]
TSS Settling Velocity [cm/s]
Erosion Coefficient [g/m^2/s]
Degradation Rate of org. Matter [1/d]
Critical Shear Stress [N/m^2]
gO2/gTSS from combined system [-]
gO2/gTSS from separate system [-]

Data needed for the model



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- **Why a probabilistic approach ?**
- How to analyse the results ?
- Sensitivity analysis
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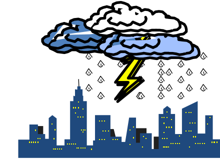
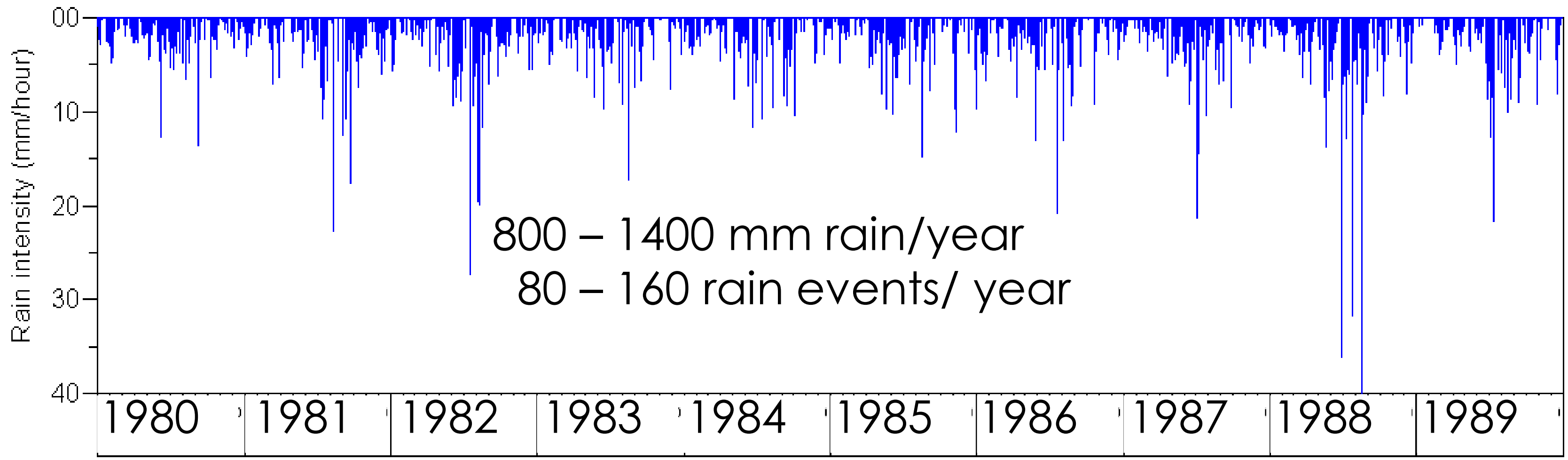
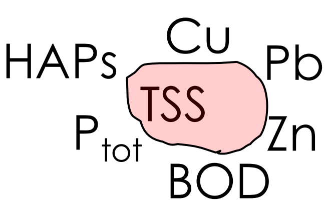
- Exercise with REBEKA : Dr R. Fankhauser

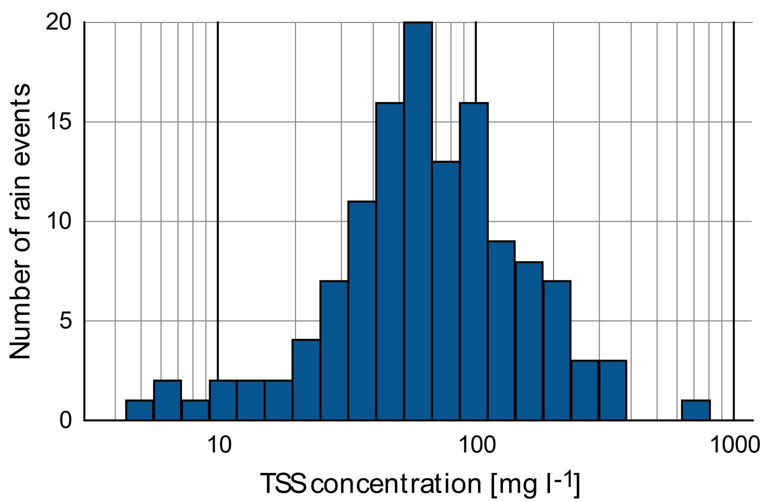
Why a *probabilistic* risk assessment ?



- “Natural” variability in rain intensity and volume
- Uncertainties and variability in the data
- Uncertainties in describing processes





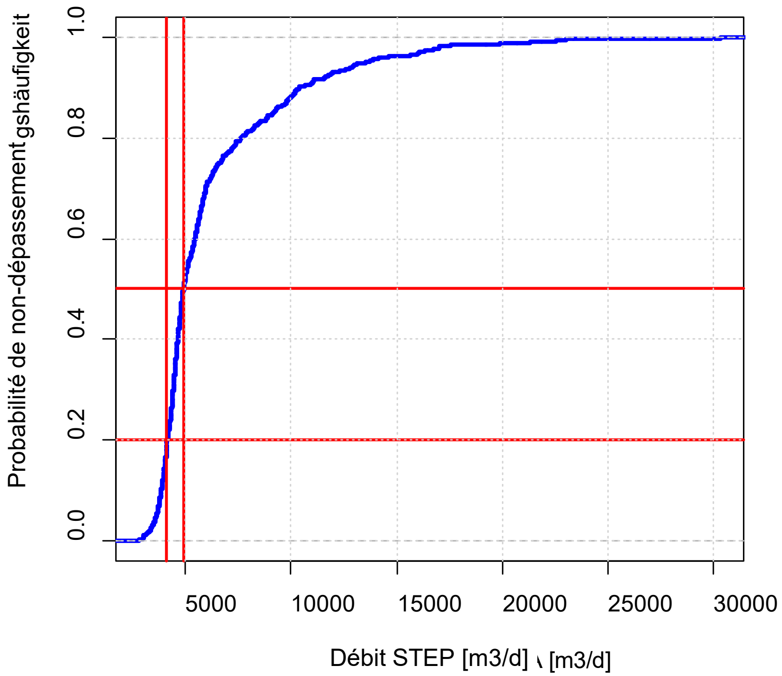


Probabilistic risk assessment

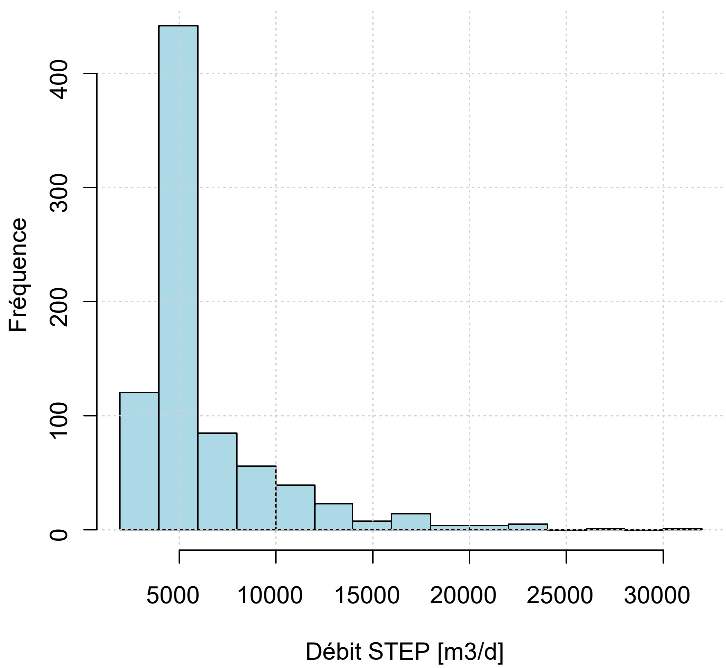
Representation of frequency or probability distributions

- WWTP example: representation of average daily flows

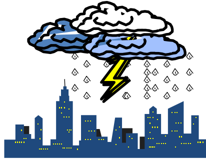
Probability of no-exceedance



Histogram

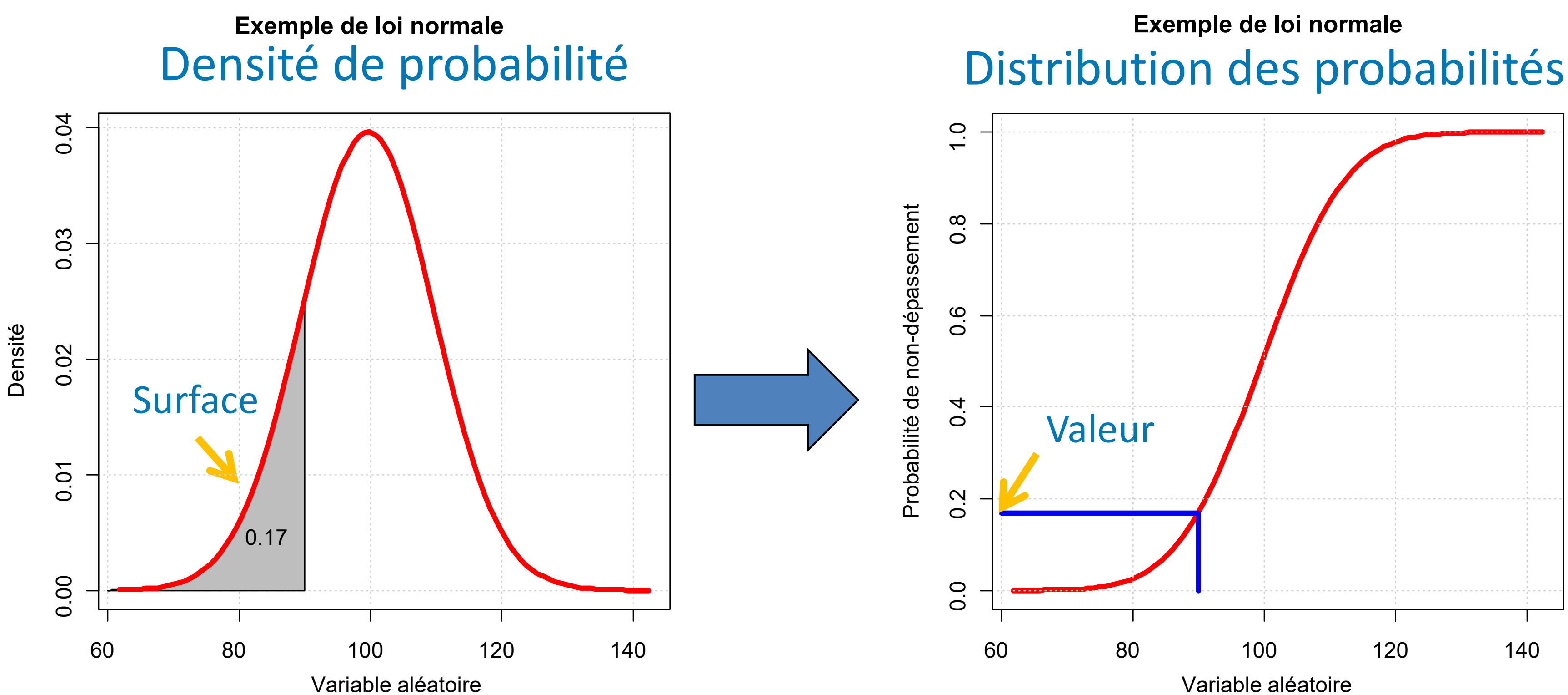


Probabilistic risk assessment



Probability distribution

- Integration on probability density
- Probability that a data is below a certain value → probability of no-exceedance – resp. probability

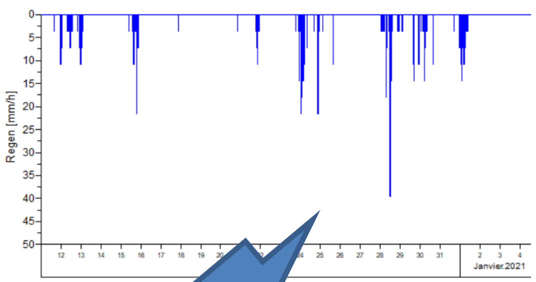


probabilité de non dépassement = Probabilité de respecter un critère spécifique

Probabilistic risk assessment

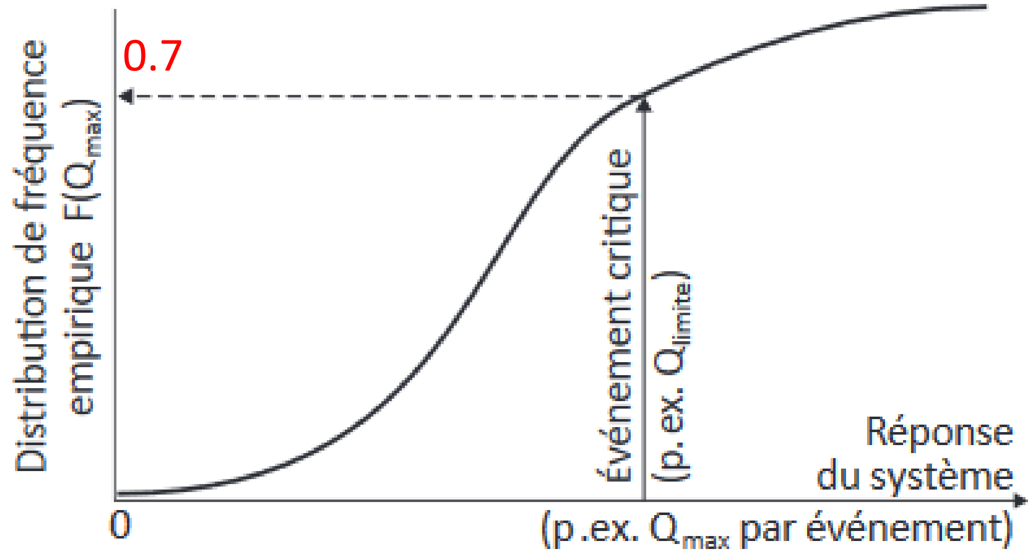
Example 1: Ideal "perfect" model

Stress factor (i.e. precipitations)



Système réel

Fig. S7



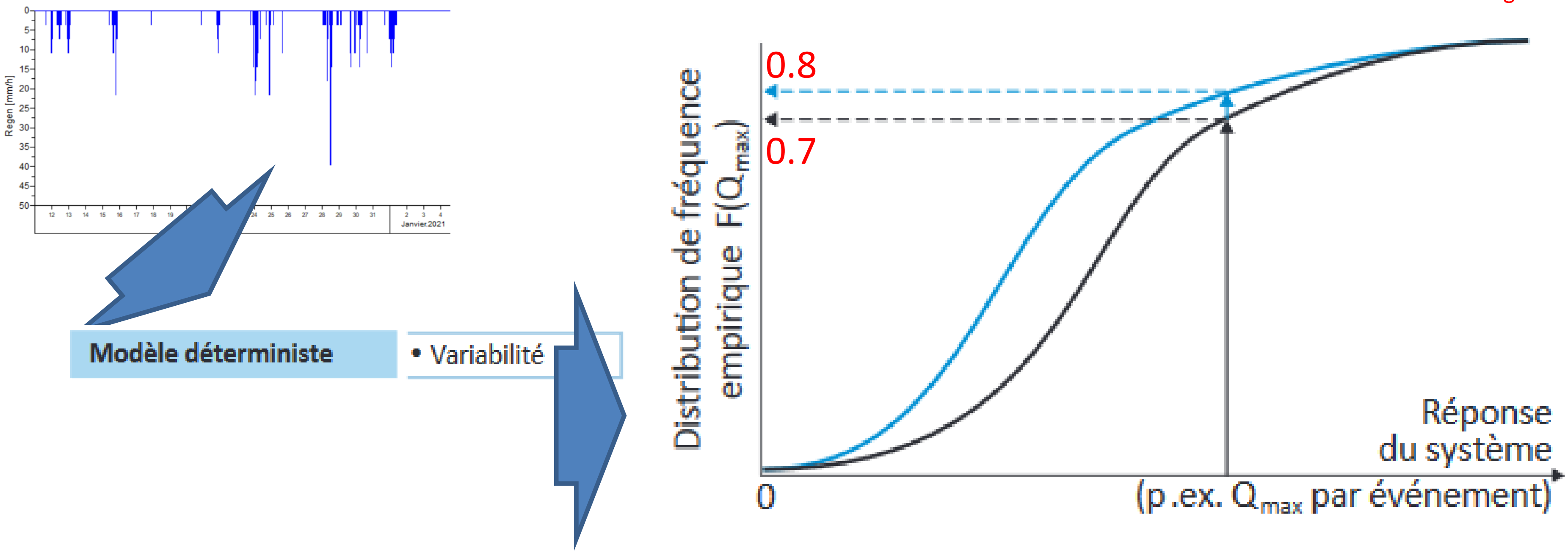
Frequency of critical events = 1 – 0.7 = 0.3

Probabilistic risk assessment

Example 2: deterministic modelling

Stress factor (i.e. precipitations)

Fig. S7



Fréquence des événements critiques = 1 – 0.8 = 0.2

Probabilistic risk assessment

Example 3: Stochastic-probabilistic model (with variability and uncertainties)

Stress factor (i.e. precipitations)

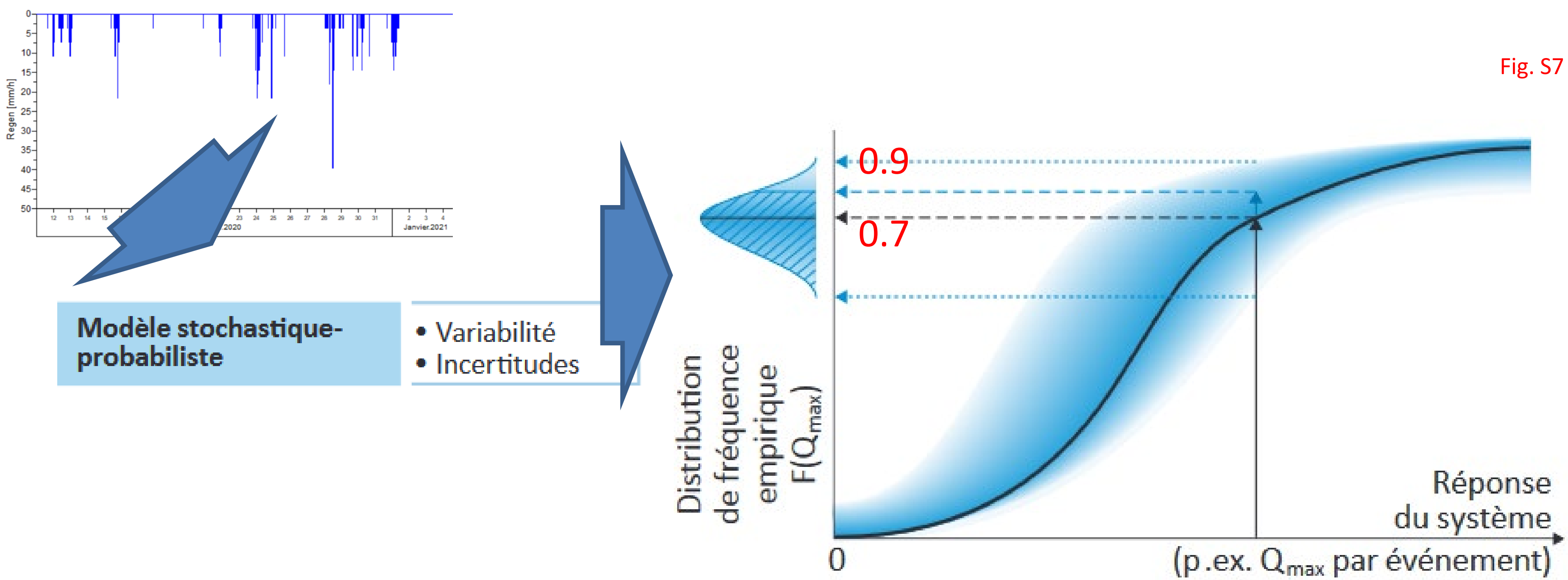
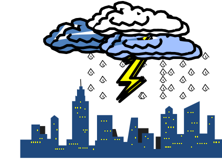
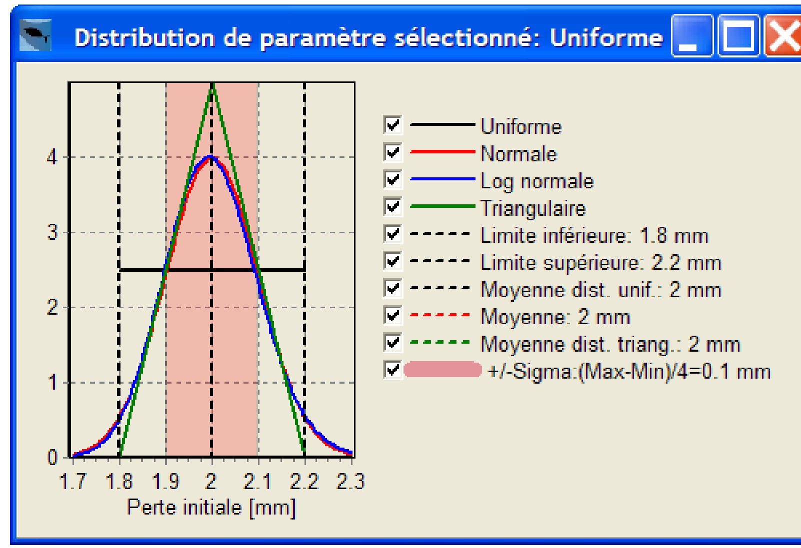


Fig. S7

Definition of uncertainties in the parameters

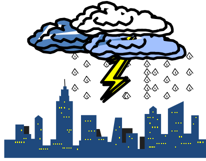


- Average value = value considered in the deterministic simulation
- Uncertainty: defined by minimal, maximal, average value and distribution (uniform, normal, log-normal, triangle...)



Paramètres	Moyenne	Limite inférieure	Limite supérieure	relative	Distribution
Système unitaire (SU)					
Surface effective [ha]	20	18	22	☐	Normale
Perte initiale [mm]	2	1.8	2.2	☐	Uniforme
Constante de stockage [min]	20	15	25	☐	Constant
Habitants [EGW]	1.1E4	9900	12100	☐	Uniforme
Débit de temps sec [l/(EGW*d)]	250	225	275	☐	Uniforme
Débit vers STEP [l/s]	100	90	110	☐	Uniforme

Definition of uncertainties in the parameters: stochastic approach

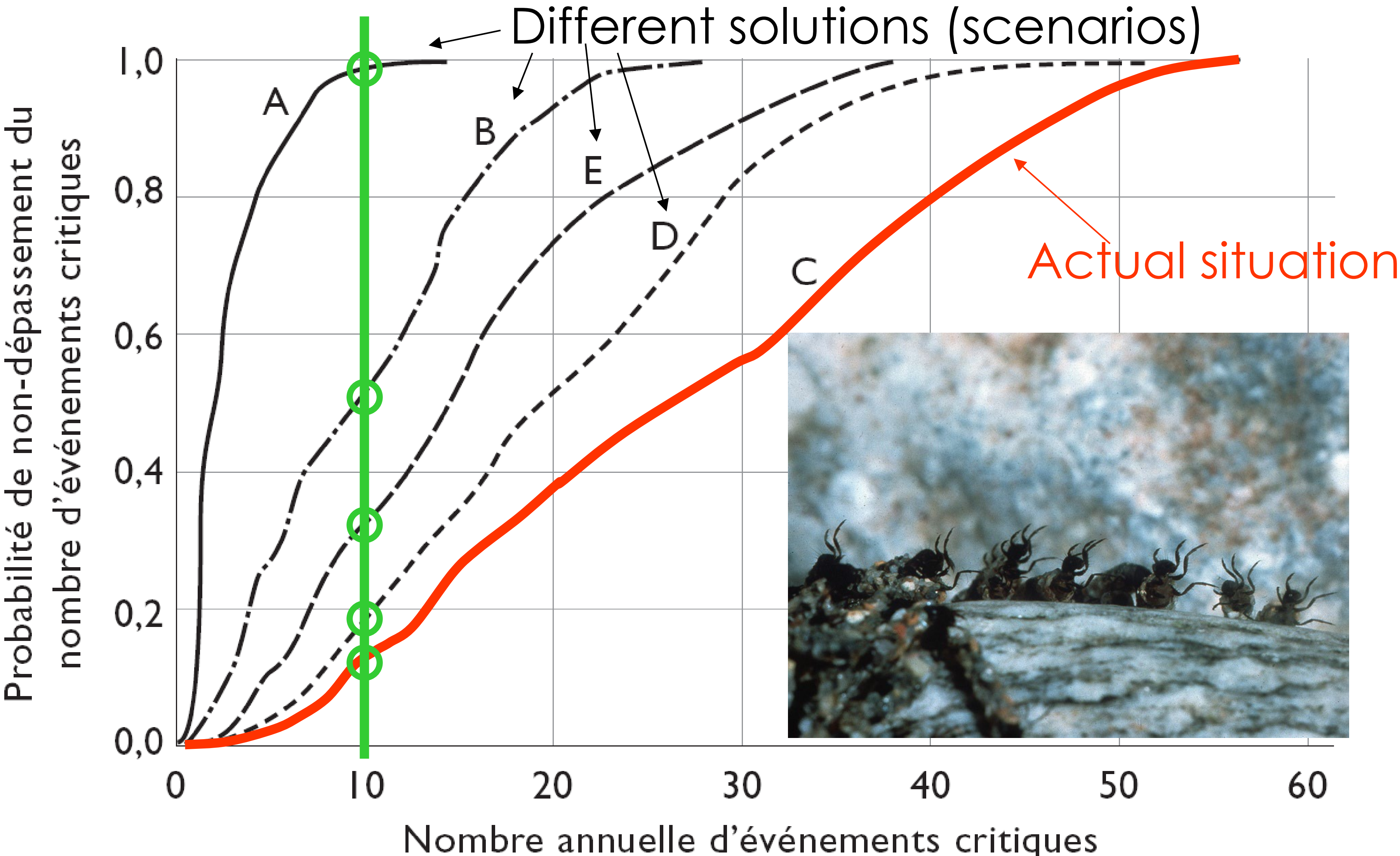


Definition of the number of iteration → Monte-Carlo simulation → Results in terms of cumulative probabilities

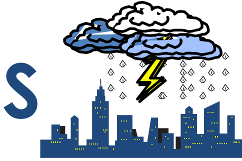
For each iteration:

- Random selection of values for the parameters (in function of the defined domain and the distribution)
- Deterministic simulation with these values
- Storage of the results
- Iteration n+1

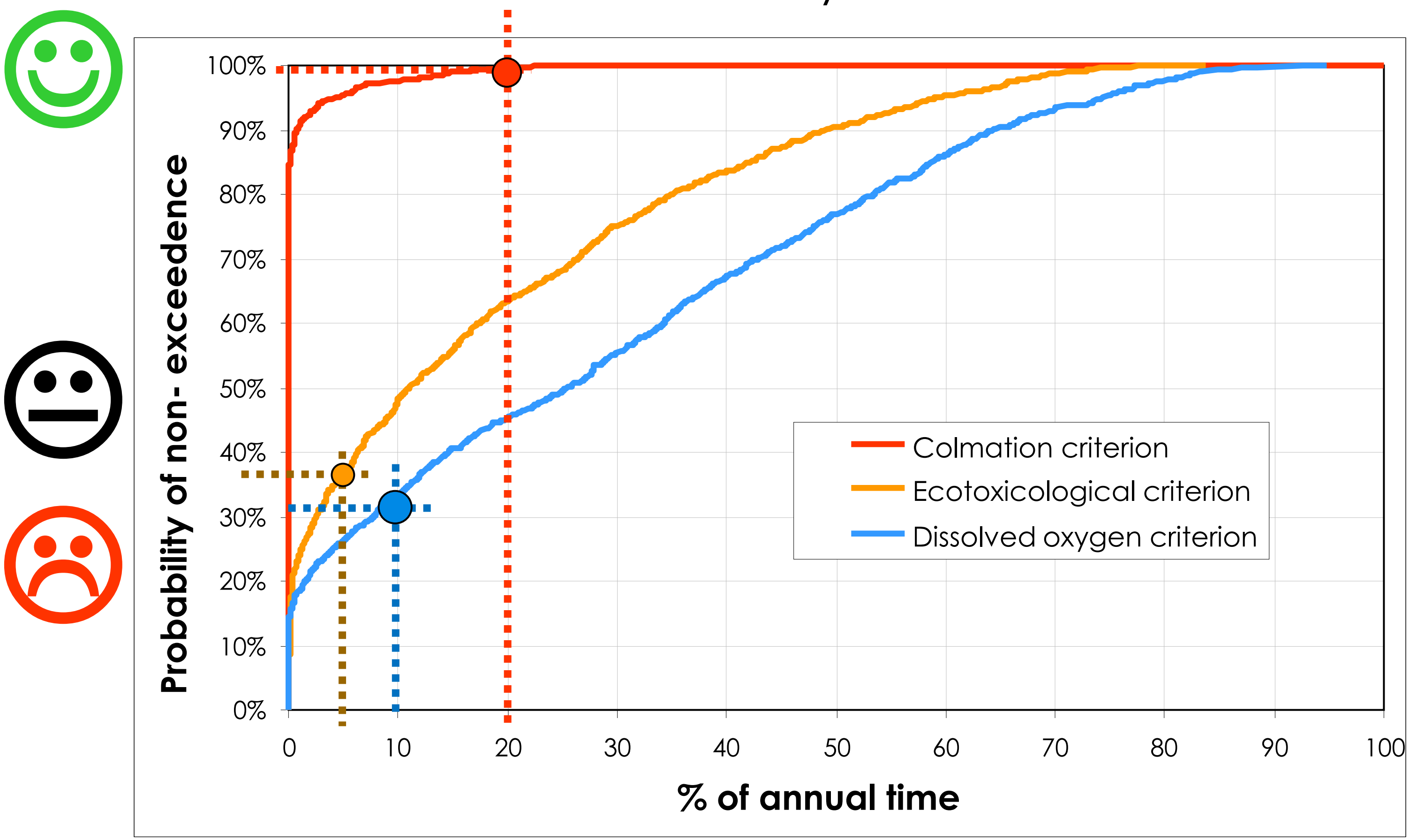
Stochastic approach: example of results for hydraulic stress and for different scenarios



Stochastic approach: example of results for TSS accumulation in sediments on the riverbed



500 itérations, each on a 10 years rain information



Who will define an acceptable probability ?

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- **Sensitivity analysis**
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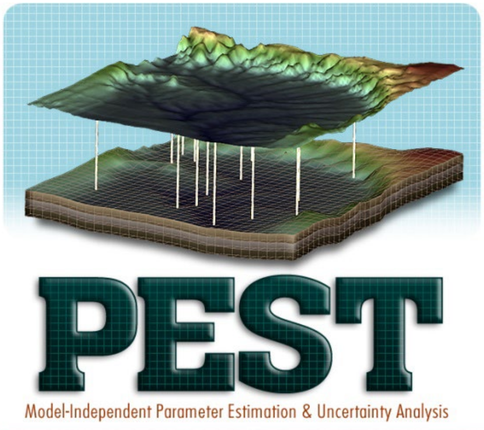
- Model validation
- Exercise with REBEKA : Dr R. Fankhauser

Sensitivity analysis

- Model with « only » 40 parameters → the most important one must be identified !
- Local sensitivity analysis around the average value of the parameters
- 1 parameter will vary, all the others will stay constant
- From 3 to 11 calculation points within the variation domain are determined
- Number of iterations = Number of parameters *number of calculation points
- Analysis needed for **ALL** numerical models !

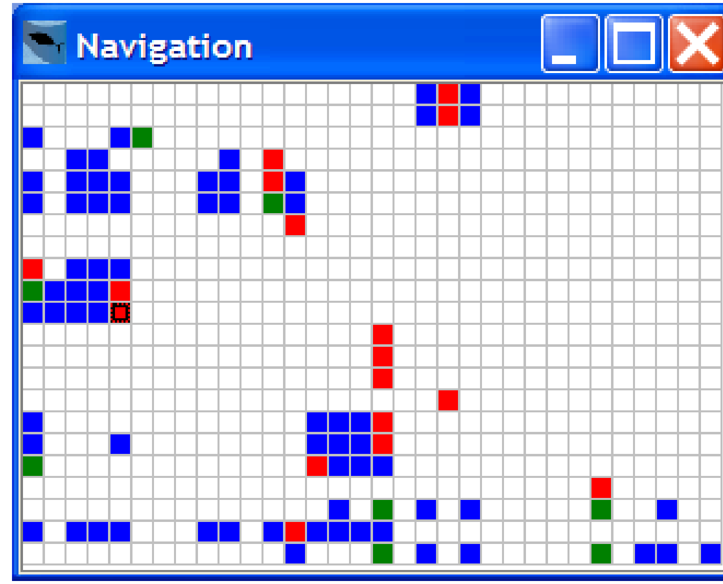
www.pesthomepage.org/

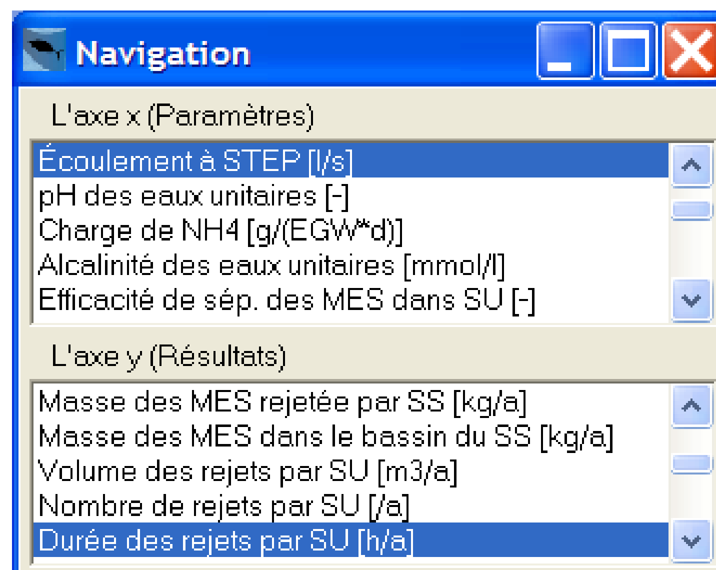


Sensitivity analysis in REBEKA software

- Matrix of graphs XY
- In each graph:
  - Axis x: one parameter of the model (≈ 40 parameters)
  - Axis y: one result for one value (22 values)

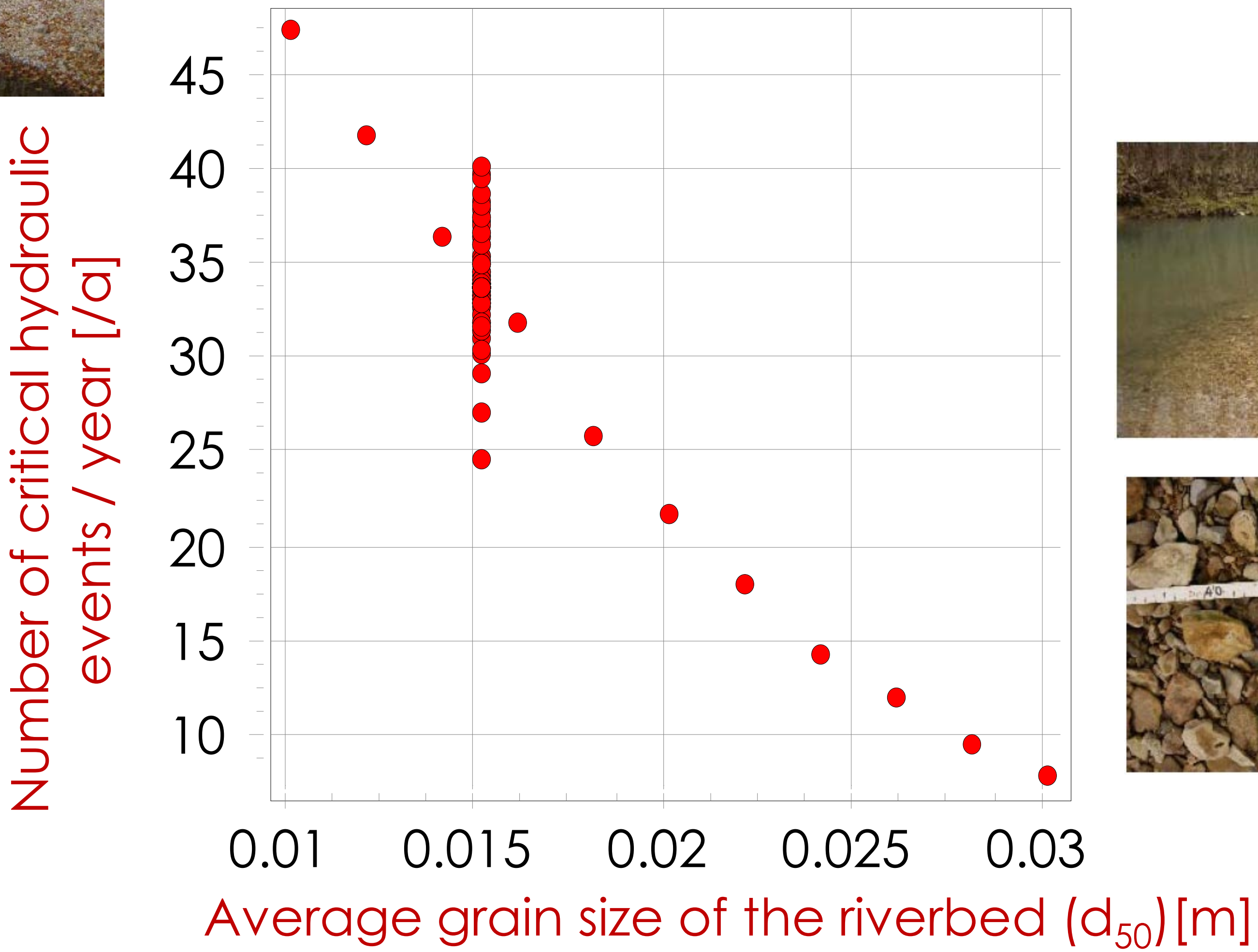
  → 40 x 22 graphs !!
- Navigator:
  - Abstract of the graph's matrix
  - Navigation tools to simplify the identification of the most important parameters



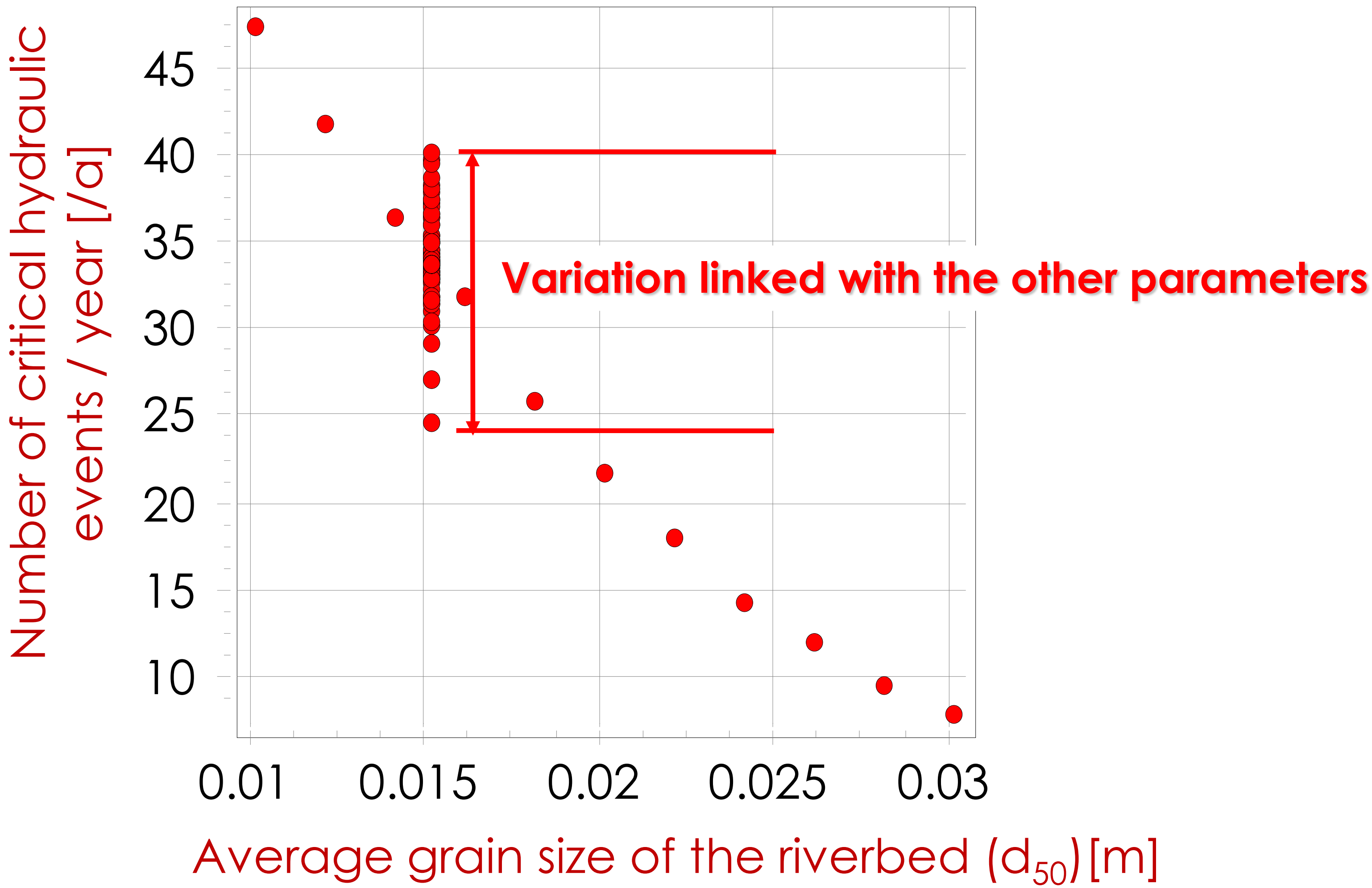


Right click on the mouse to switch between the illustrations

Sensitivity analysis in REBEKA software



Sensitivity analysis in REBEKA software



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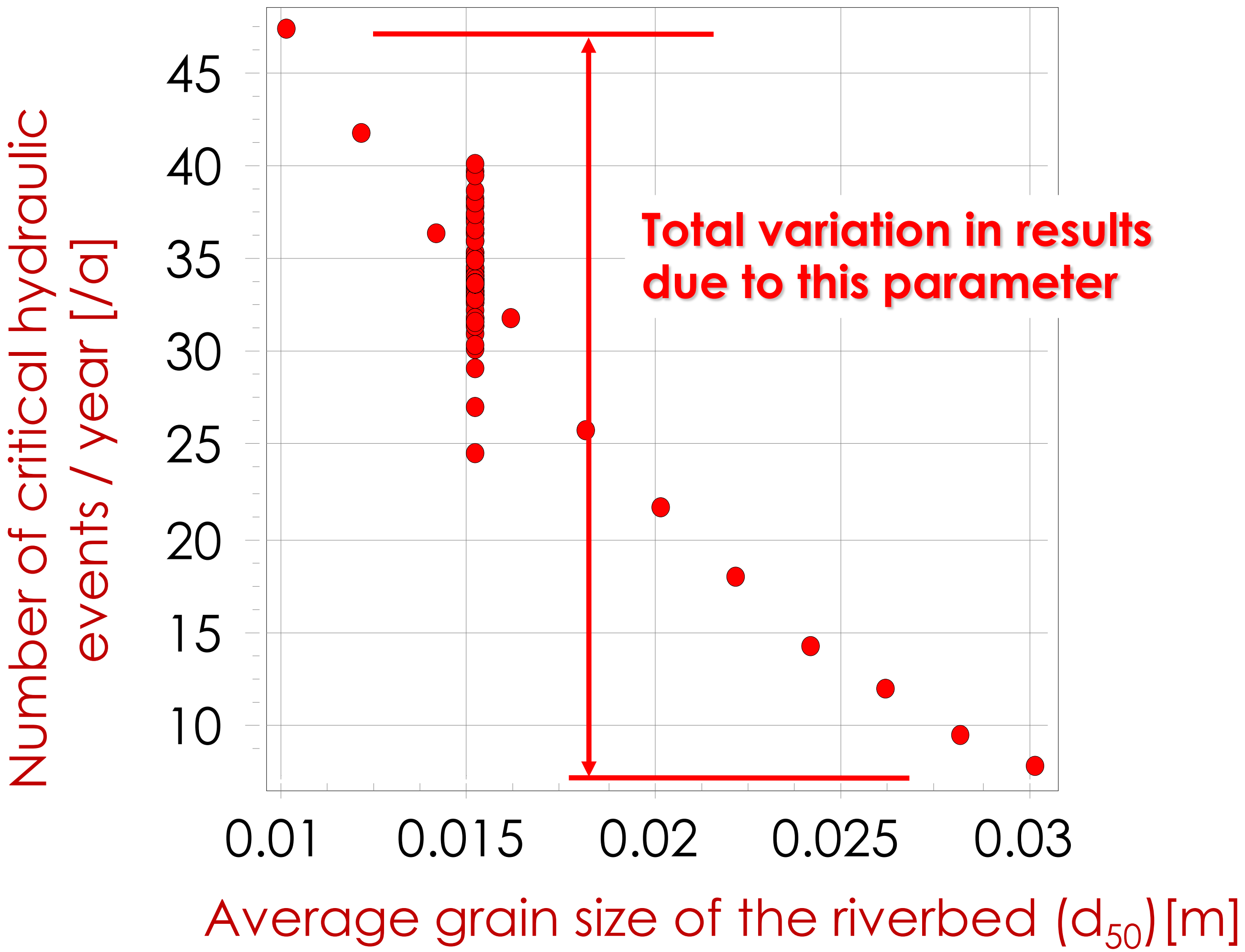
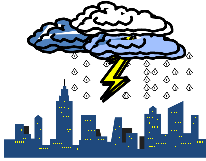
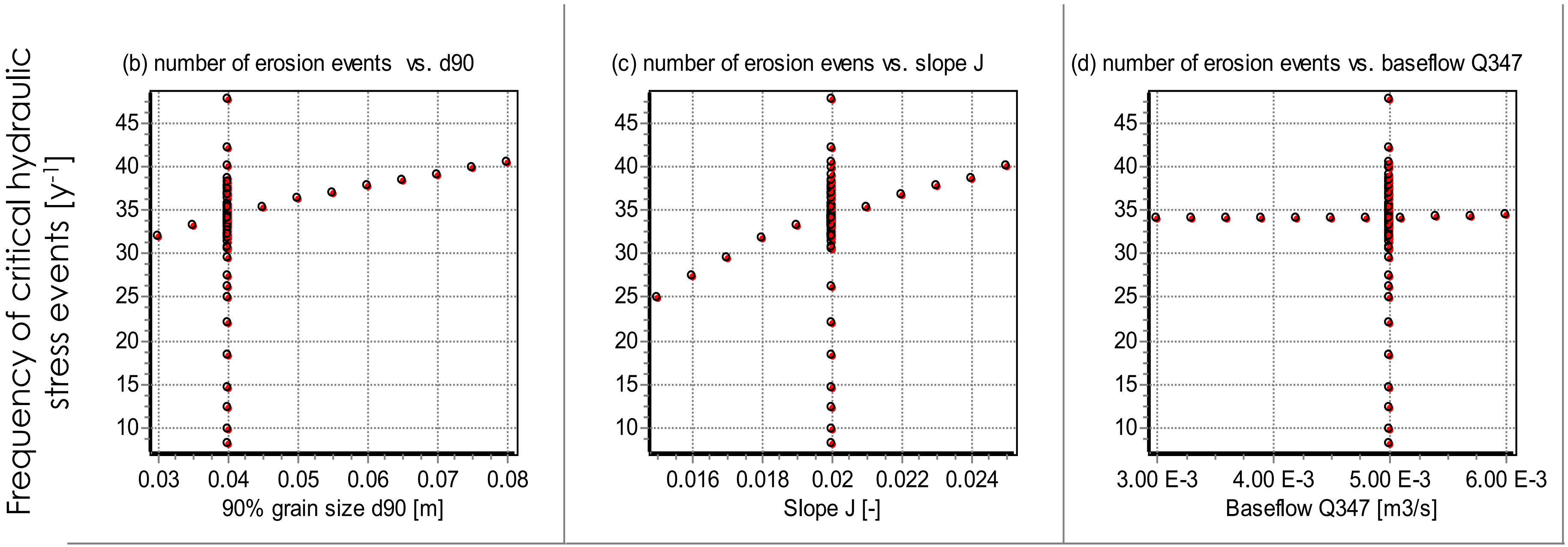




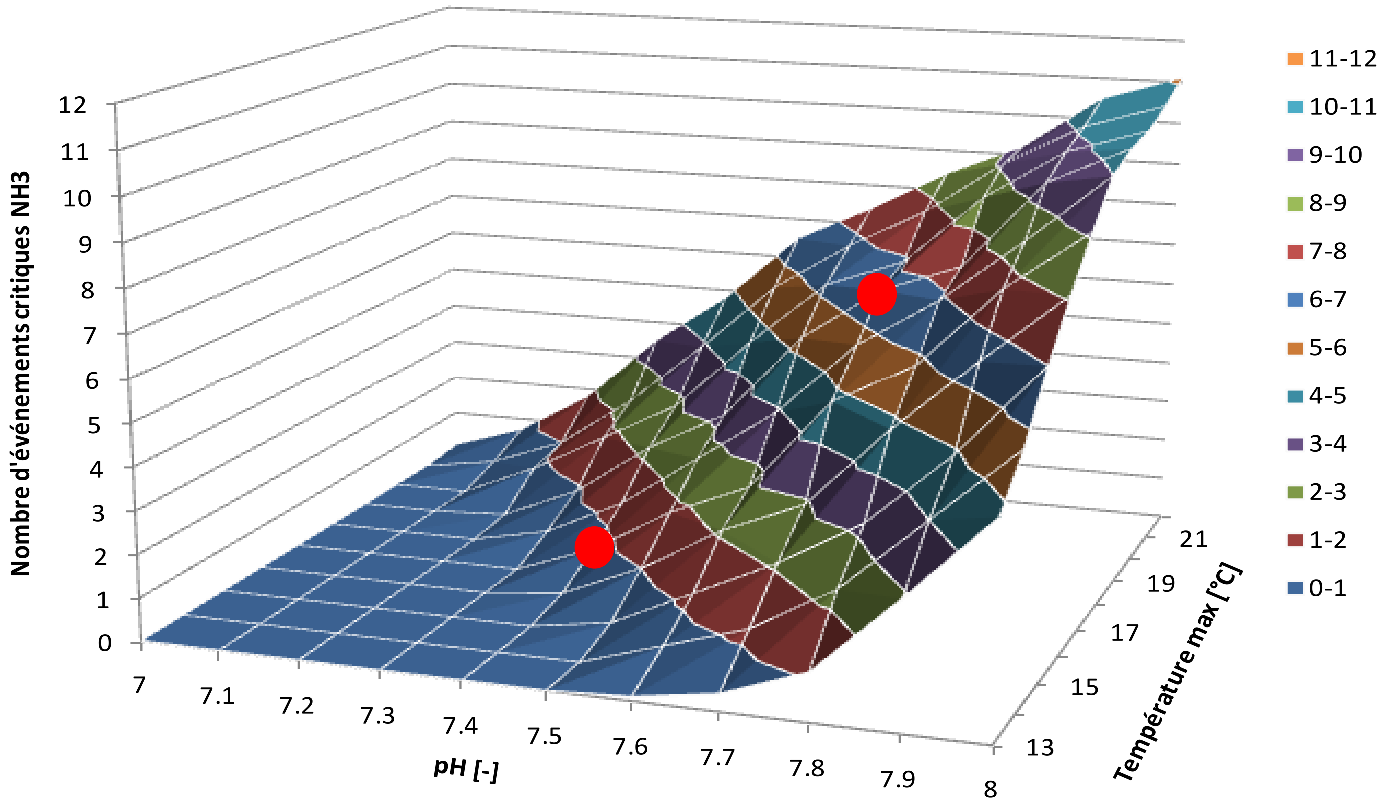
Sensitivity analysis in REBEKA software



- Identification of the most sensitive parameters for a given situation
- Important help in the data acquisition process

Sensitivity analysis in REBEKA software

[Margot, 2008]



Delta pH :0.3

Delta t° : 2°C

Example ammonia toxicity:

→ very high influence of river temperature and pH !

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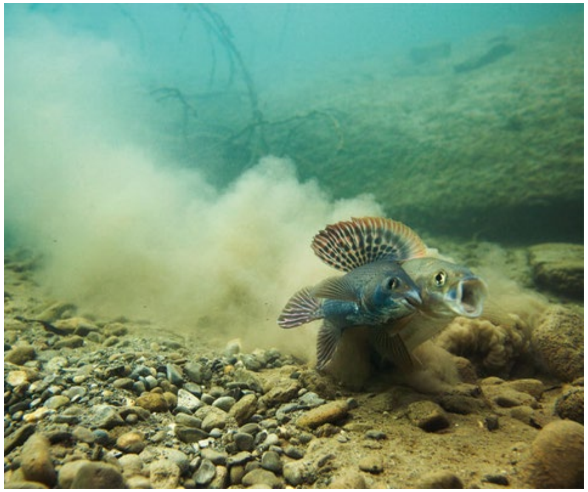
Technical solutions (in REBEKA)

STORM

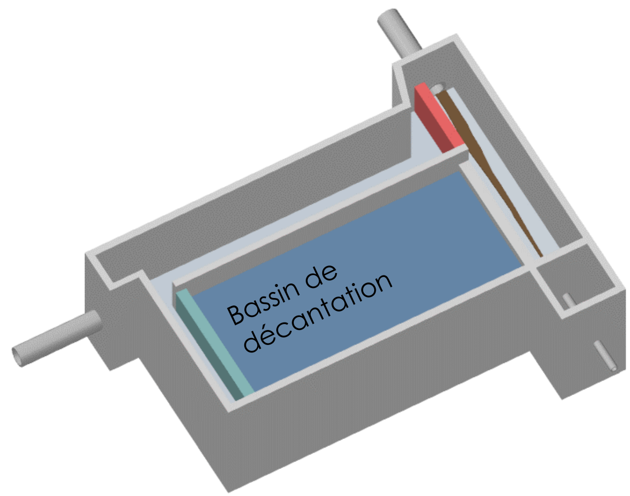


Results of the STORM conceptual approach

Example:
To reach the TSS immission objectives with a probability of 50%, (p=0.5), the emissions of TSS should be reduced by 65 % (equivalent to a TSS mass reduction of 1000 to 1500 kg y^{-1})

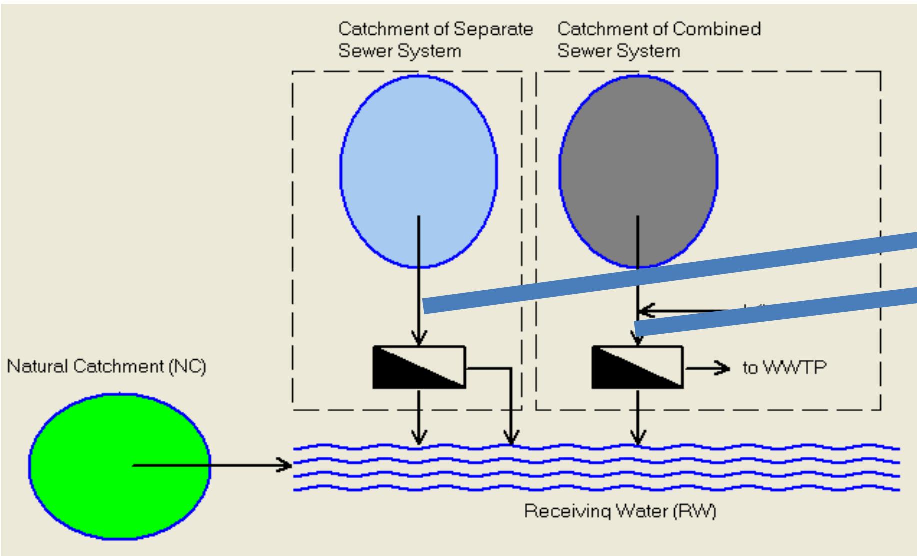
Transposition in a technical solution

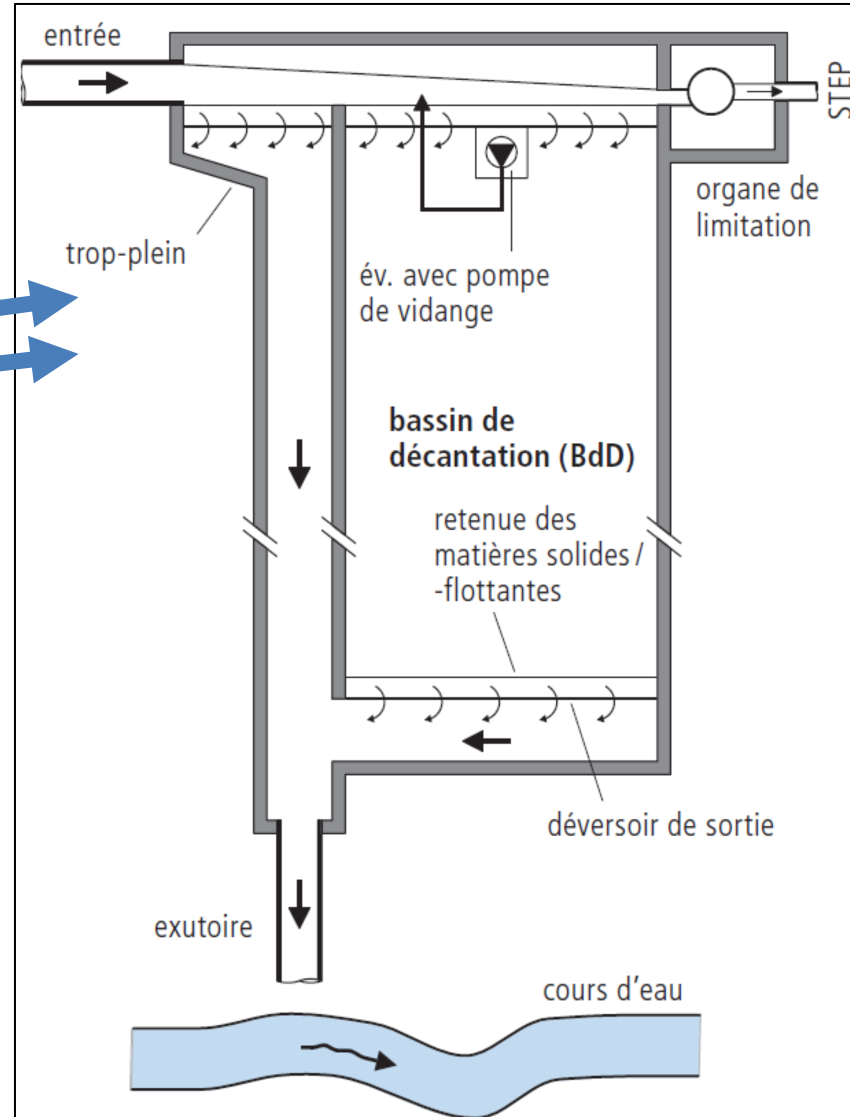
For example:
Detention pond with settling of TSS
Size of the settling zone:
L=20 m / B = 6m / H = 2.5 m



Source: Cécile Züst, Bachelorarbeit GEP Vorderthal, ZHAW Zürich, 2013

Technical solutions (in REBEKA)





Catalogue of solutions !

In the field of this exercice:
Detention pond

Technical solutions (in REBEKA)

$$EFF = 1.0 - \left[1.0 + \frac{V_s}{n \cdot (Q/A)} \right]^{-n}$$

EFF: Yield / efficiency
Vs: Settling velocity of particles ($m \cdot s^{-1}$)
Q : Max. flowrate to the pond ($m^3 \cdot s^{-1}$)
A : Effective settling surface(m^2)
n : Turbulence and short-circuit factor (-)

Goals:
To evaluate the performance of detention basins in terms of TSS elimination

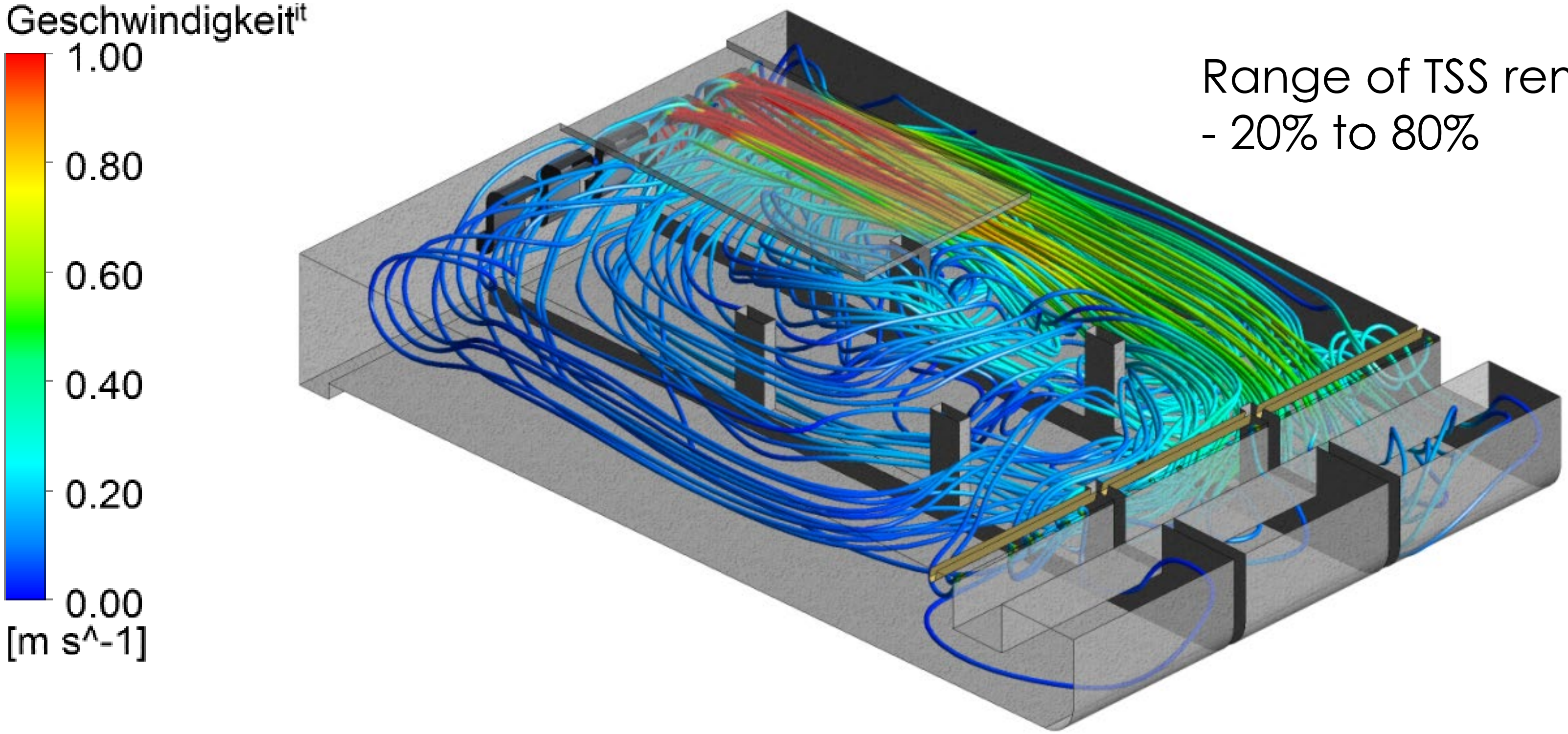
Processes:
Efficiency based on 1 equation:
Full mixing, dilution of contaminants.
Different types of detention basins

Results:
Average amount of pollutants (TSS and NH4) retained in the detention basin

Study of sedimentation processes in detention ponds [Torres A, INSA Lyon, 2007]

Technical solutions (in REBEKA)

Yield of detention ponds: very sensitive to small hydraulic changes !

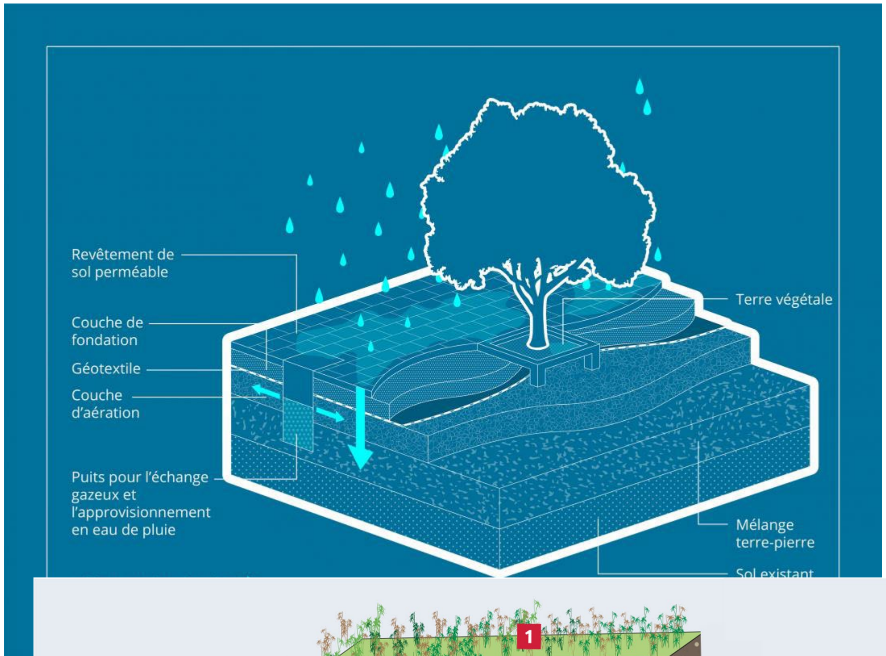


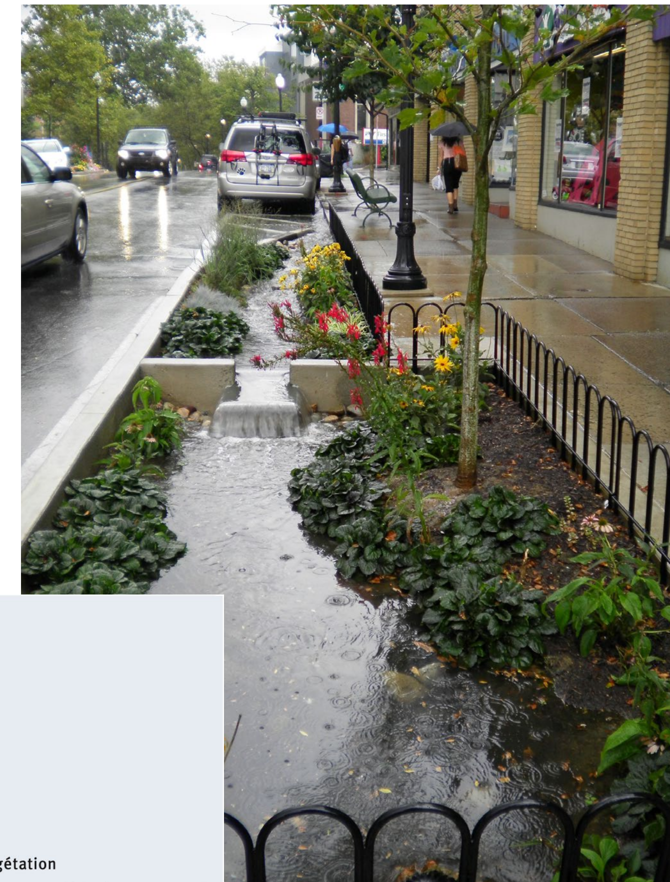
Range of TSS removal:
- 20% to 80%

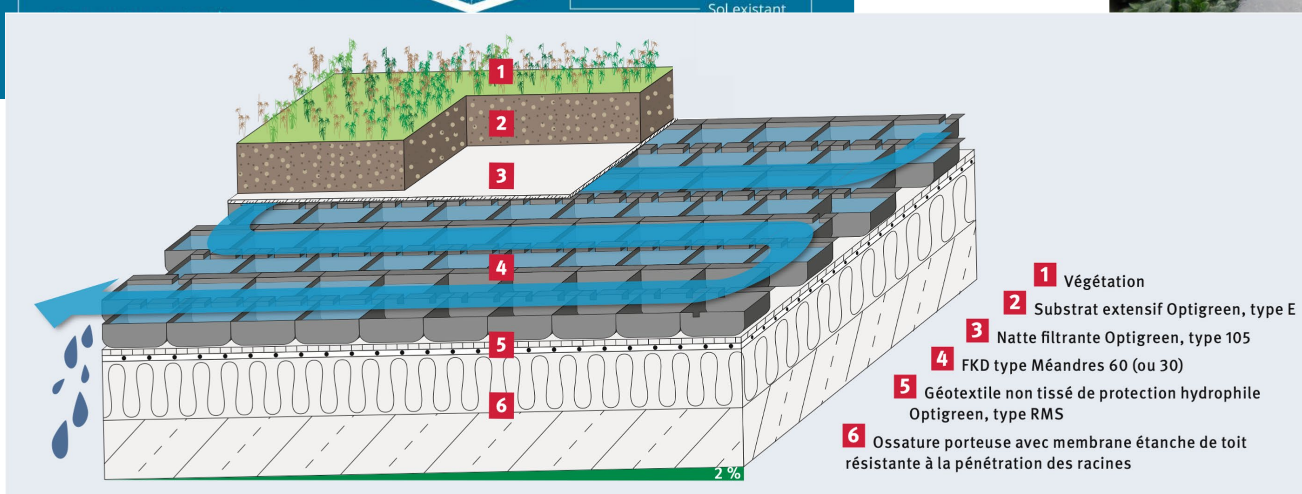
Illustration des cheminements de l'eau dans un bassin
Source: P. Staufer, Canton Soleure

Technical solutions (in REBEKA)

Sponge city solutions: increase initial loss values (up to 10-20 mm for example…)







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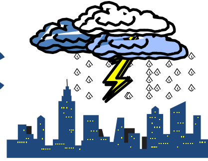
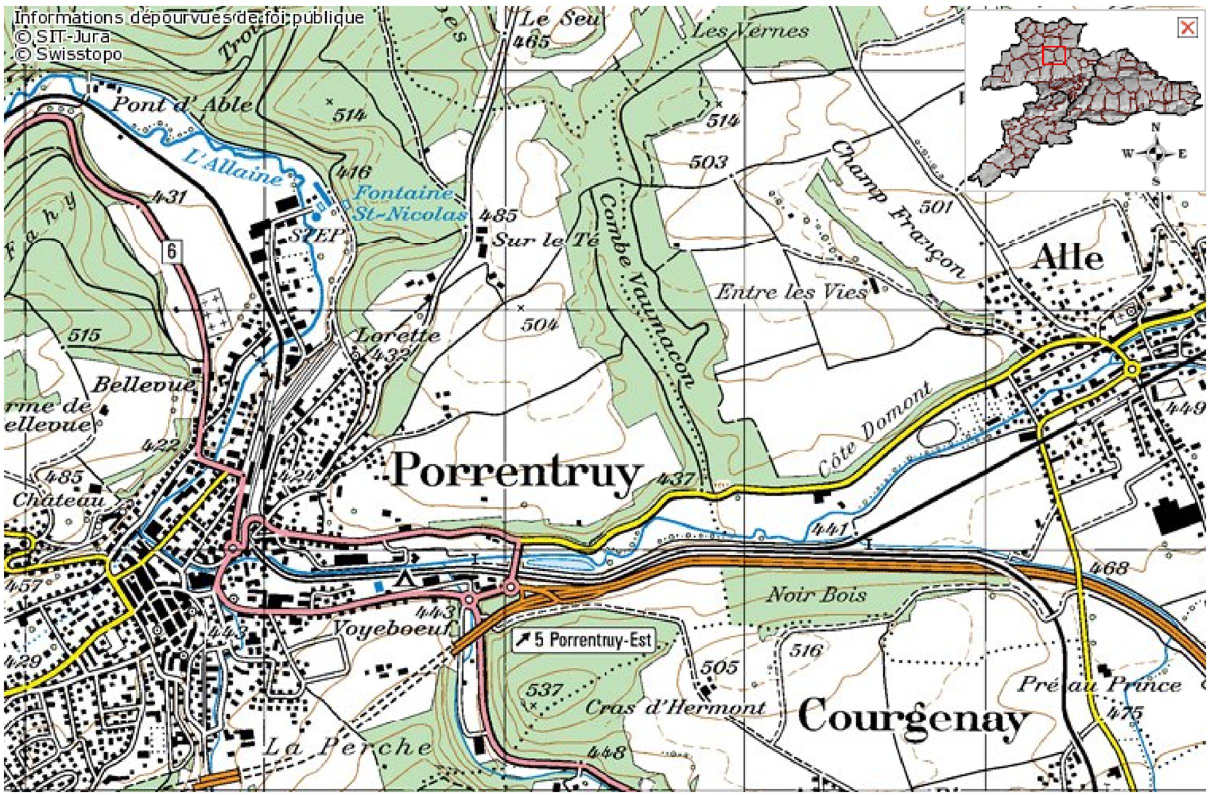
Validation of a probabilistic-stochastic software ?



- Plausibility of results ?
- Comparison with discharged flowrate from other models already validated
- Field investigations !!!

Validation of a probabilistic-stochastic software

- Allaine river in Jura



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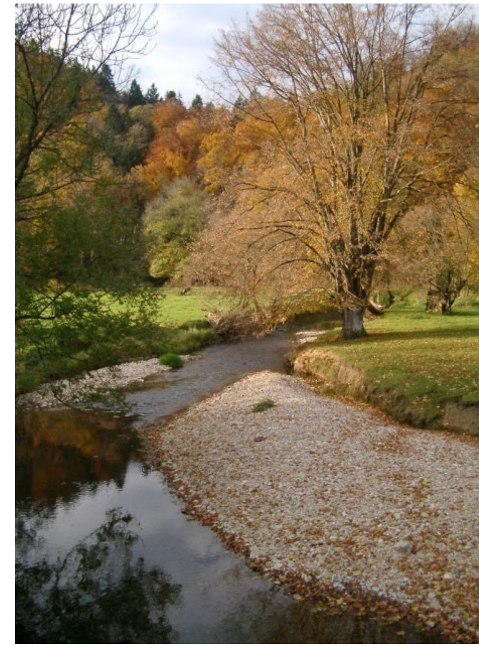
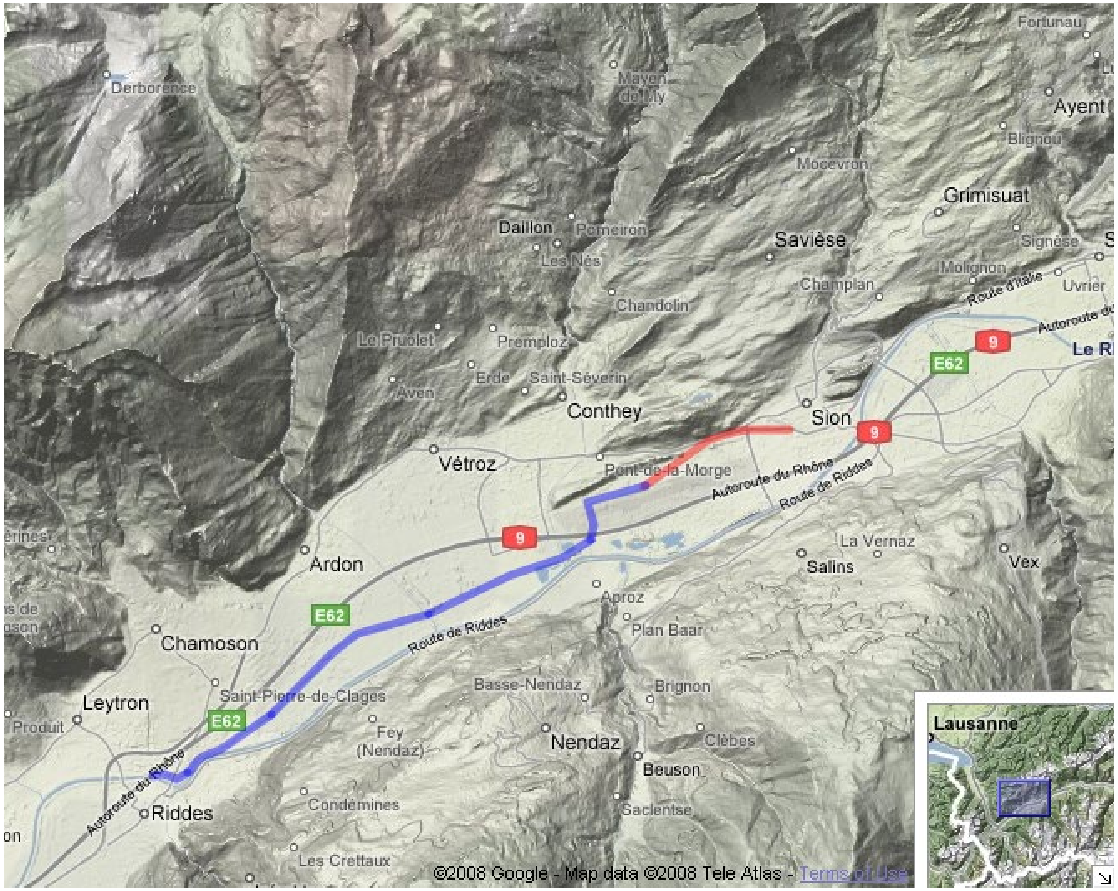


Validation of a probabilistic-stochastic software

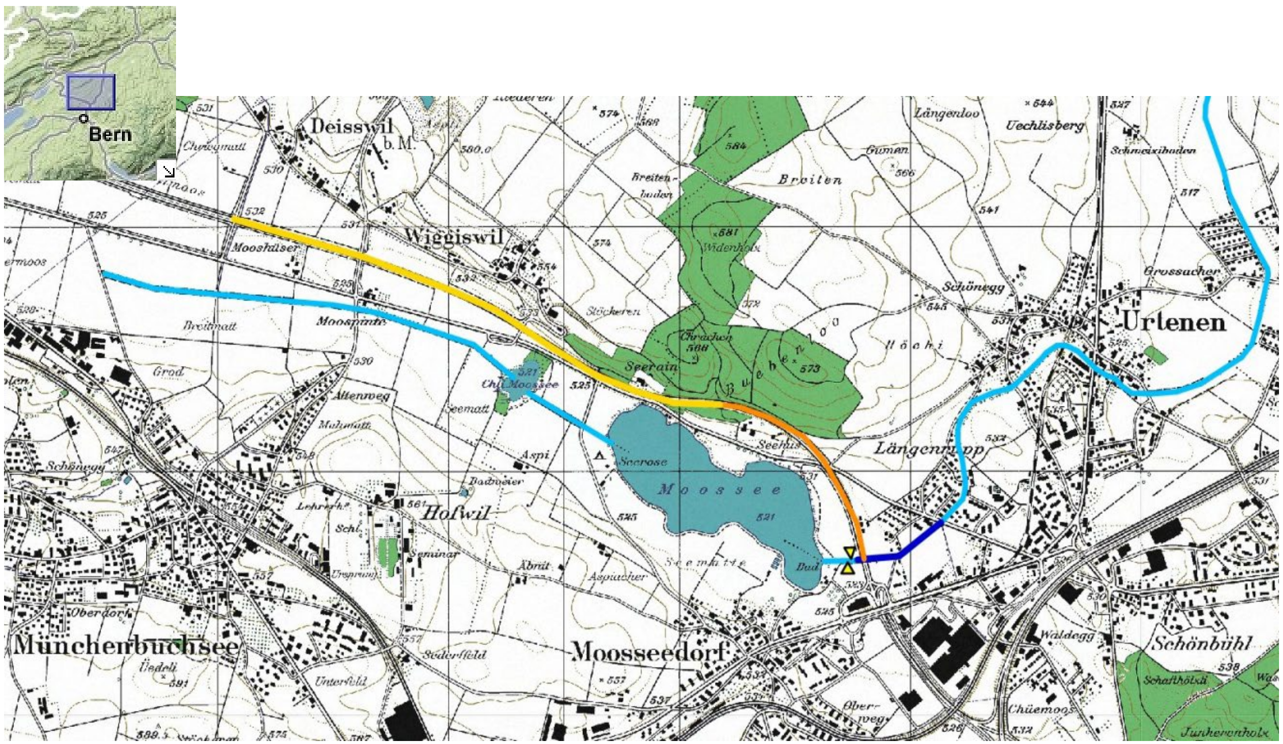
- Sion-Riddes channel in Valais



http://maps.google.com/

Validation of a probabilistic-stochastic software

- Urtenen river in Bern



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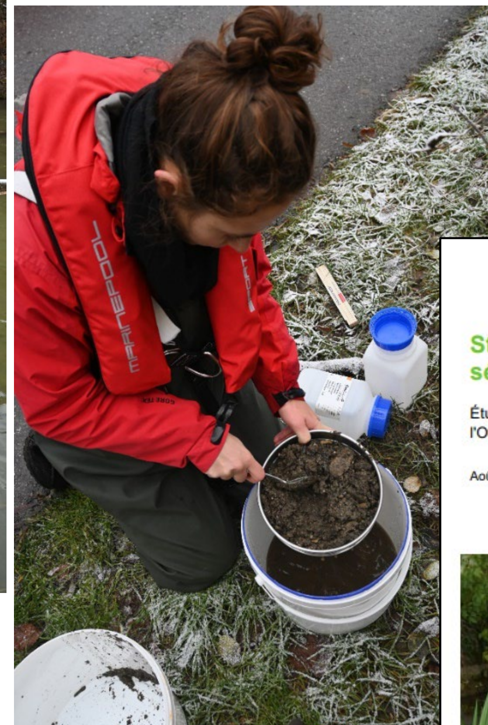
Validation of a probabilistic-stochastic software : field investigations

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Stratégie d'évaluation de la qualité des sédiments en Suisse

Étude élaboré sur mandat de
l'Office fédéral de l'environnement

Août 2021

+ Infos Module G !

Nouveau document pour l'analyse des sédiments !

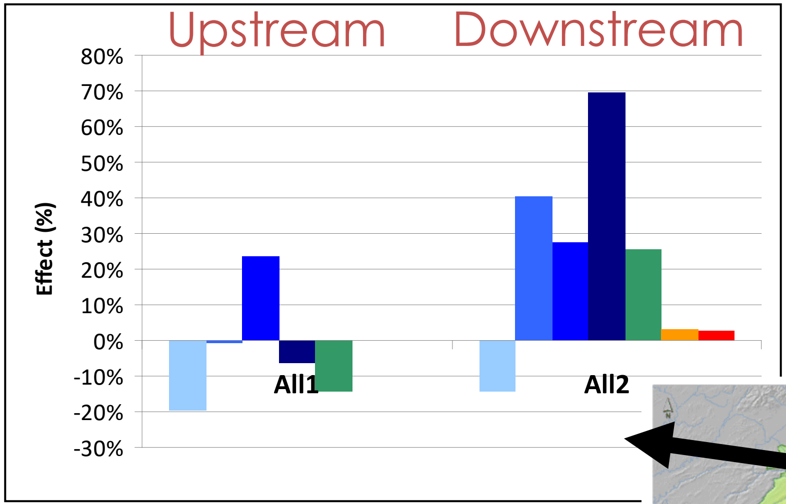
Lien download Centre Ecotox

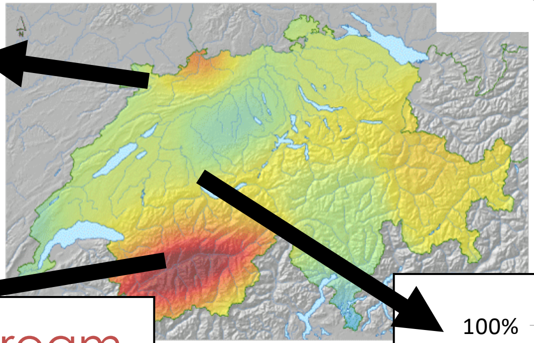
www.centreecotox.ch/news-publications/actualites/rapport-d-expert-strategie-d-evaluation-de-la-qualite-des-sediments-en-suisse/

Validation of probabilistic-stochastic software

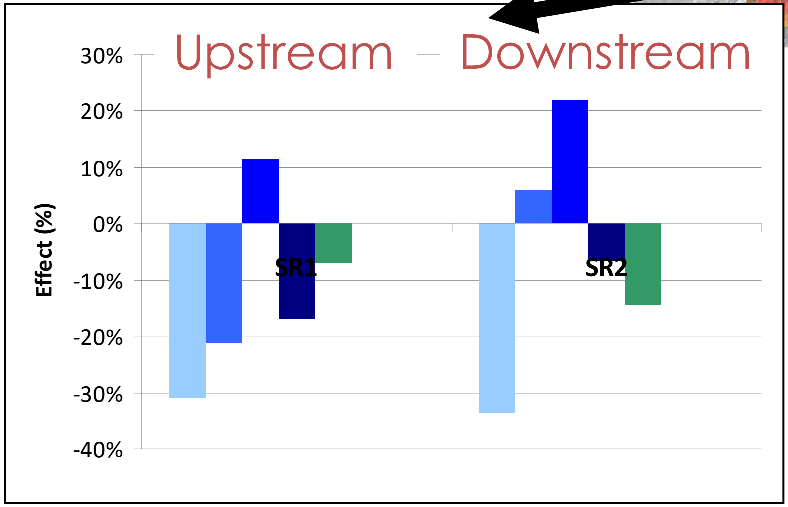
Microtox - Pore water
Microtox - Elutriate
Microtox - Solvent extract
Microtox - Solid phase test
Rotifer - Pore water
Daphnia - Pore water
Daphnia - Solvent extract

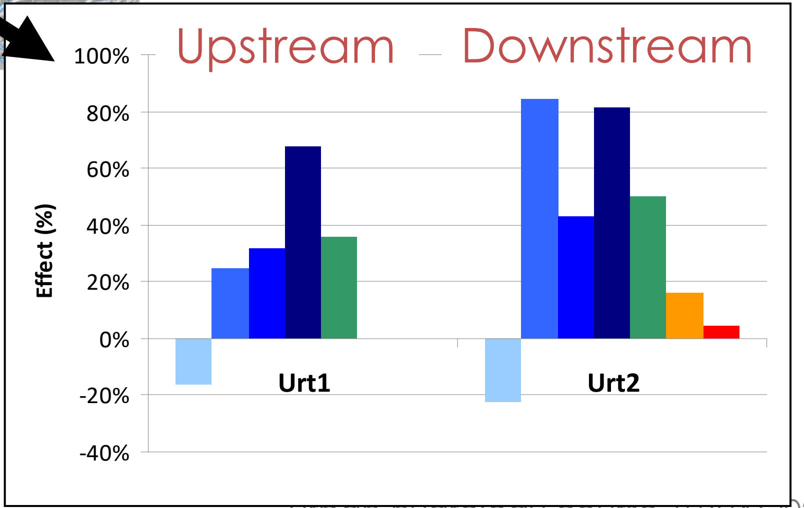




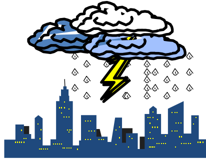


[Margot J. 2008]





Some conclusions on the use of stochastic approaches



Simplified approach, realistic results, limit of complexity for engineers

Processes: numerous simplifications, be aware of limitations (for example: hydrological urban model OK, natural watershed: ?)

Uncertainties and variability : Better illustration of the reality ?

Nuances in the interpretation of results:

- Is it better to select a cheaper solution, but with less probability of success?
- Or is it better to select a more expensive solution, with a higher probability of success?
- Should we invest money in the data acquisition process, to reduce the uncertainties?
- Or is it better to invest money in technical realizations ?

Who will define the probability of success / problem ?