Simulation of sewer overflow volume in Flanders using a global sensitivity analysis

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Motivation & Objectives

Motivation:

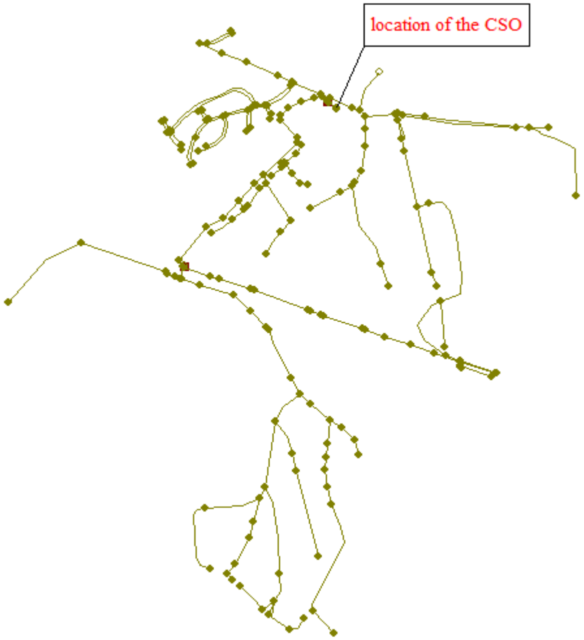
- Urban drainage models may be used to take decisions to manage sewer network infrastructure
- Any potential uncertainty in these models can affect the outcome of the decision making process
- We are trying to quantify the uncertainty in CSO volume to support decision making on the storage volume required for managing CSO spills under local regulations in Flanders, Belgium

Objectives:

- Identify the model input parameters which could potentially contribute most to the uncertainty in the combined sewer overflow volume
- Quantify uncertainty in the chosen input parameters
- Propagate the input parameter uncertainty through model simulations

Model & Data

- A drainage network of a small section of Herent catchment in Flanders, Belgium modelled in InfoWorks CS version 15.5
- Subsystem model has 179 nodes and 175 pipes
- The sewer system serves around 2100 inhabitants with a contributing area of about 87 hectares
- A single design composite storm event 'f7' to replicate the design guidelines by Flanders Environment Agency (VMM)



Input parameters	Unit	Minimum	Maximum
Colebrook-White roughness	mm	0.5	6.0
Initial loss value	mm	0.22	1.5
Fixed runoff coefficient - Impervious	-	0.6	1.0
Headloss coefficient	-	1	6.6
Primary Discharge Coefficient - Weir	-	0.2	3.0
Secondary Discharge Coefficient - Weir	-	0.5	1.5
Weir crest	m	35.25	35.45
Weir width	m	9.9	10.1

Sensitivity Analysis

- Morris Screening method was selected for Global Sensitivity Analysis (GSA)
- It is found to be computationally less expensive and gives comparable result to other popular GSA methods Extended-FAST and Standard Regression Coefficient (SRC) for a water quantity output[1]
- Morris sampling design divides the parameter space into p levels
- Random sampling is done from these levels to generate r elementary effects (EEs)
- If NF is the number of input parameters, the number of required simulations would be $r * (NF + 1)$

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[1] Vanrolleghem, P. A., Mannina, G., Cosenza, A., & Neumann, M. B. (2015). Global sensitivity analysis for urban water quality modelling: Terminology, convergence and comparison of different methods. Journal of Hydrology, 522(September), 339–352.

Sensitivity Analysis

Morris Screening Results

Convergence Analysis:

- A quantitative convergence analysis by analysing the variability in S_{SC} as we increase the number of simulations

S_{SC} can be given as $S_{SC} = \frac{\sum_{i=1}^{NF} SC_i}{NF}$

where SC_i is sensitivity index of input parameter i & NF is the number of input parameters

Variability y can be expressed as[1],

$$y = \left[\frac{\left(\sum_{i=1}^{NF} SC_i\right)_{n_{k-1}} - \left(\sum_{i=1}^{NF} SC_i\right)_{n_k}}{NF}\right]$$

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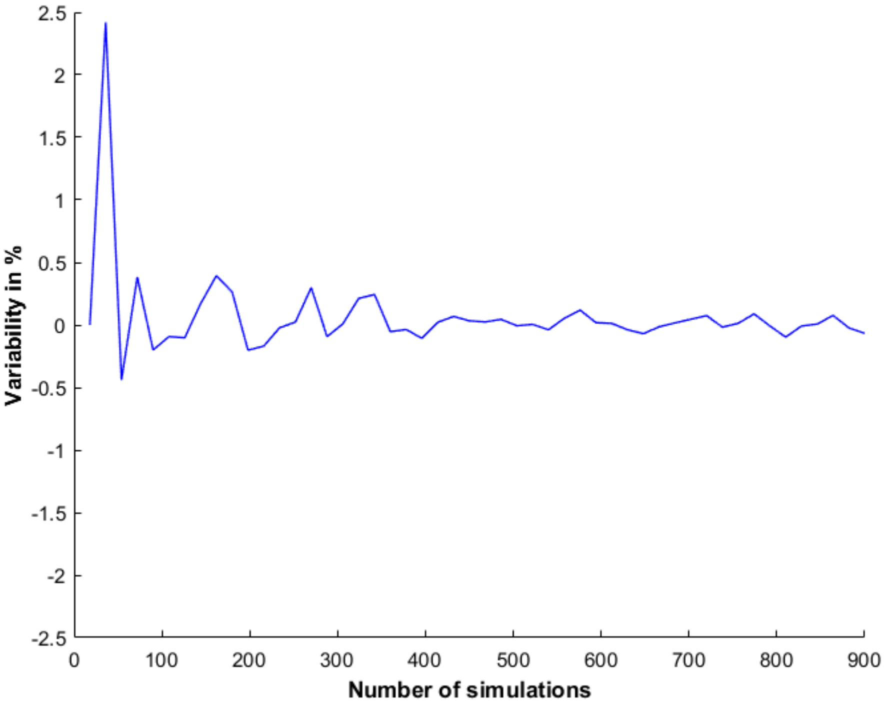
[1] Vanrolleghem, P. A., Mannina, G., Cosenza, A., & Neumann, M. B. (2015). Global sensitivity analysis for urban water quality modelling: Terminology, convergence and comparison of different methods. Journal of Hydrology, 522(September), 339–352.

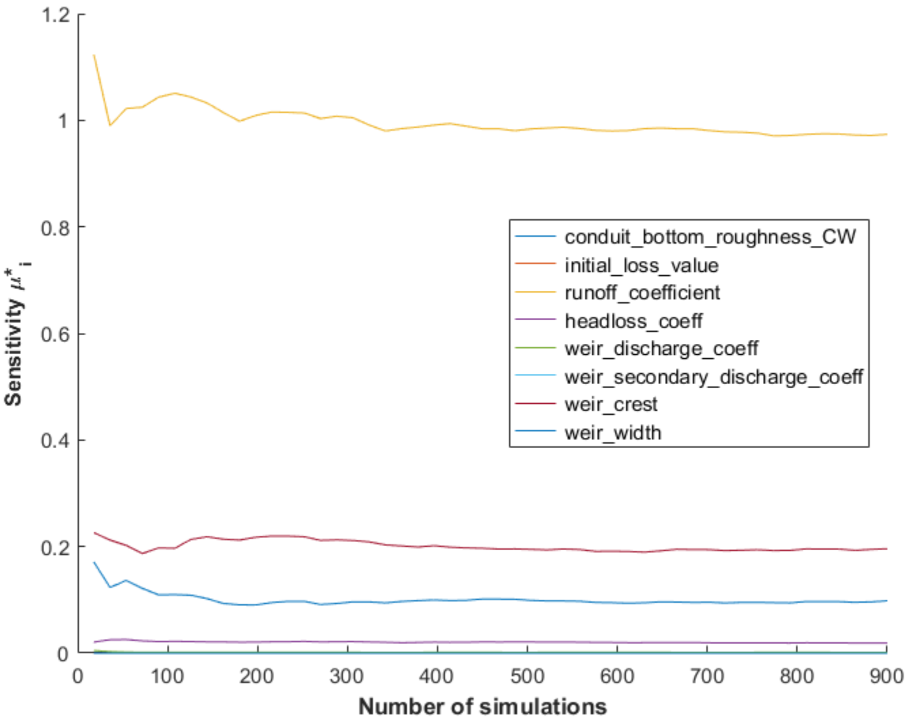
Sensitivity Analysis

Morris Screening Results:

Convergence Analysis results

- With as few as 900 model simulations, a stable convergence was achieved
- The variability converged within a precision threshold as low as 0.1%





Sensitivity Analysis

Morris screening results:

- Sensitivity measures: *absolute mean*[1] (μ^*) & *standard deviation* (σ)
- A cutoff threshold of 0.1 has been applied on μ^* to select important model inputs
- High value of μ^* → Model input has high effect on the model output
- High value of σ → suggests non linearity or interaction of the selected input with other model inputs

Parameters	**Absolute mean (μ^*)**	**Standard deviation (σ)**	**Rank**
Fixed Runoff Coefficient – Impervious surfaces	**0.974**	**0.055**	**1**
Weir Crest	**0.196**	**0.019**	**2**
Colebrook-White roughness	**0.098**	**0.048**	**3**
Headloss coefficient	0.019	0.008	4
Primary weir discharge coefficient	0.001	0.002	5
Weir Width	0	0	6
Initial loss value	0	0	7
Secondary weir discharge coefficient	0	0	8

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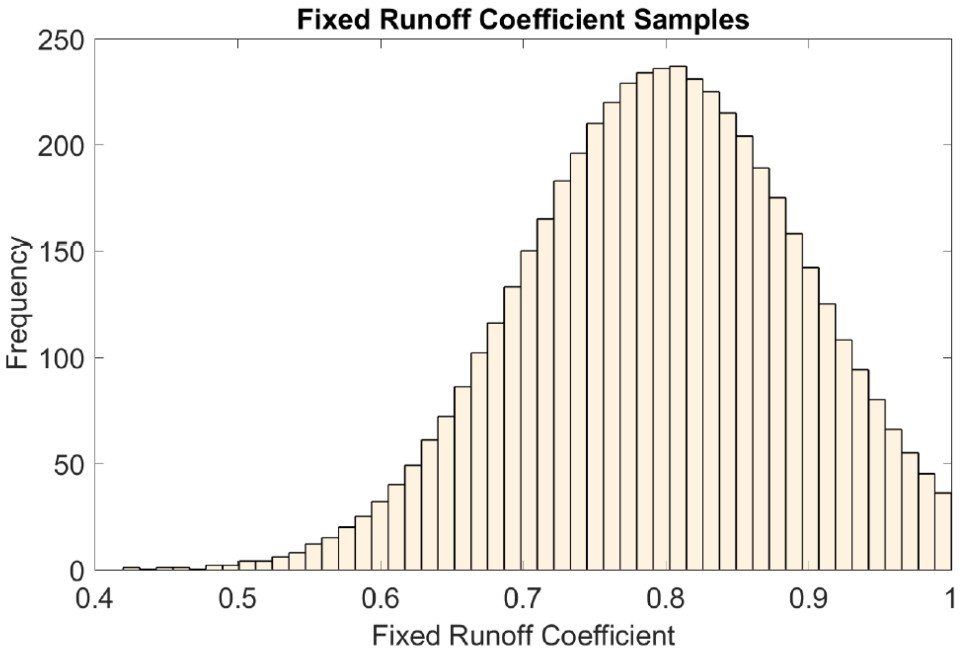
[1] Campolongo, F., Cariboni, J., & Saltelli, A. (2007). An effective screening design for sensitivity analysis of large models. *Environmental Modelling & Software*, *22*(10), 1509–1518.

Quantifying uncertainty in chosen input parameters

Fixed Runoff Coefficient – Impervious surfaces

- Assumed to follow a symmetrical normal distribution truncated at the upper limit of 1.
- Mean is set at 0.8 with a standard deviation of 0.1

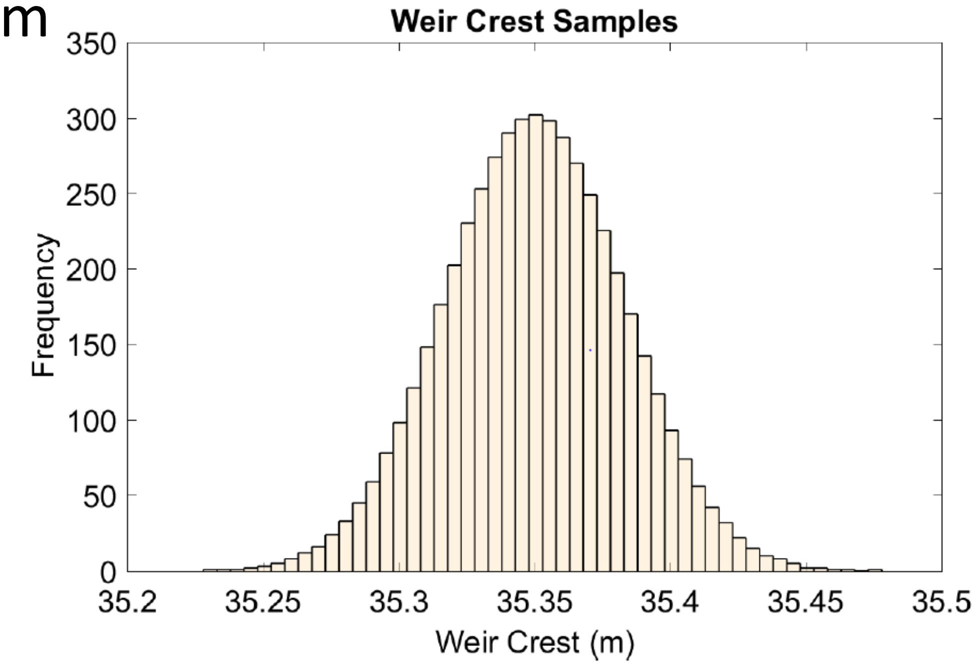


Quantifying uncertainty in chosen input parameters

Weir Crest

- Random physical measurement
- Assumed to follow a symmetrical normal distribution
- Mean is set at 35.35m
- A range of 10cm is chosen such that

3 x Standard deviation = 10 cm



Quantifying uncertainty in chosen input parameters

Colebrook-White Roughness k_s

- The Colebrook-White equation is used

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left[\frac{k_s}{14.83R} + \frac{2.52}{R_e\sqrt{f}}\right]$$

where, f = Darcy resistance constant; k_s = Colebrook-White roughness (m); R = Hydraulic radius (m); R_e = Reynolds number

$$f = \frac{8SRg}{V^2} \quad \& \; R_e = \frac{4VR}{\boldsymbol{\nu}}$$

where S = slope of the pipe (used here as hydraulic gradient),

$\boldsymbol{\nu}$ = Kinematic viscosity of water (m^2/s) at 15°C,

g = acceleration due to gravity (m/s^2)

Quantifying uncertainty in chosen input parameters

Colebrook-White Roughness k_s

- Flow survey data consists of flow measurements at 10 locations in Herent, Belgium
- Water depth and flow velocity were used in calculating roughness
- Since Colebrook-White equation is applicable only for uniform flow conditions, only 3 Out of these 10 locations were found suitable
- For these 3 locations, Dry Weather periods are filtered based on average daily flow.

Quantifying uncertainty in chosen input parameters

Colebrook-White Roughness k_s

Distribution fitting

- Multiple probability distribution families have been tried to find the best fit to calculated roughness values
- *Bayesian information criterion* (BIC) is used to find the best fit because it penalises distributions with greater number of parameters
- Two parameter *Log logistic distribution* comes out as the best fit closely followed by *Lognormal distribution*
- *Maximum Likelihood Estimation* is used as the fitting method

Quantifying uncertainty in chosen input parameters

Colebrook-White Roughness k_s

Distribution fitting

- Probability density function of two parameter Log logistic distribution

$$f(x;\alpha,\beta)=\frac{\left(\frac{\beta}{\alpha}\right)\left(\frac{x}{\alpha}\right)^{\beta-1}}{\left(1+\left(\frac{x}{\alpha}\right)^{\beta}\right)^{2}}$$

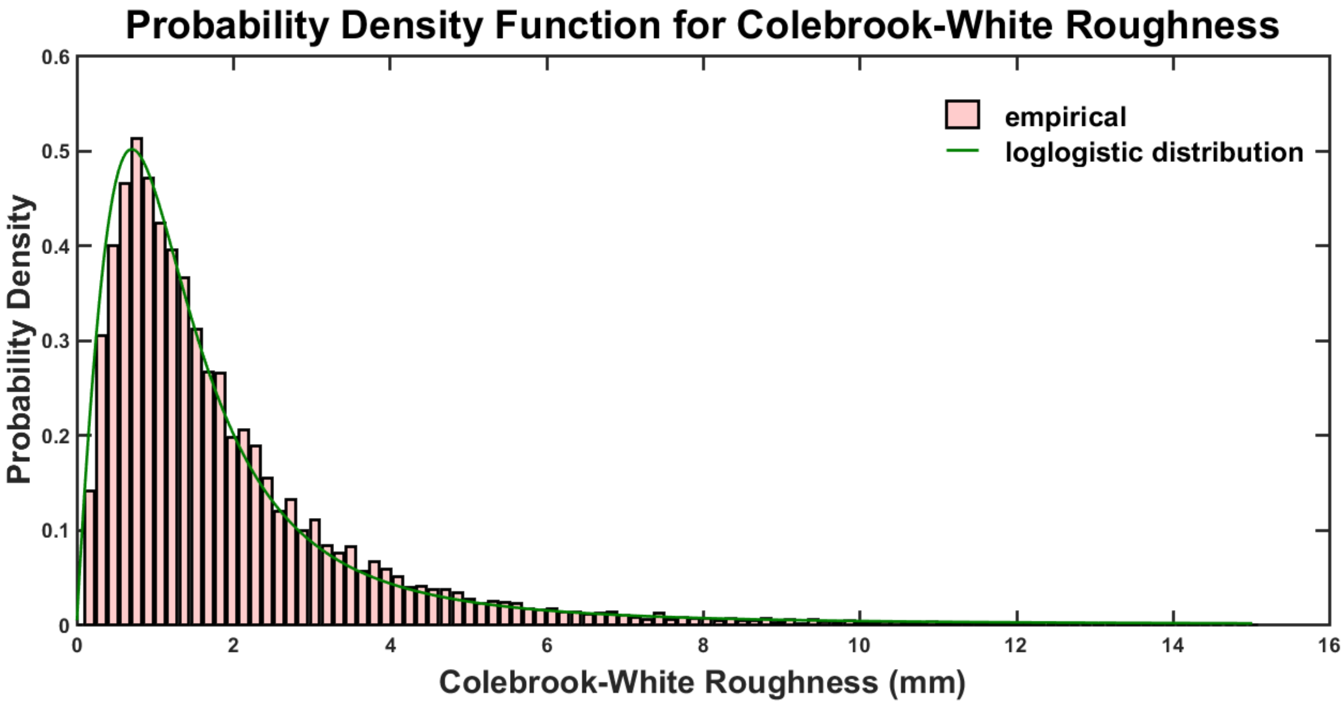
Where $\alpha > 0$ is scale parameter and $\beta > 0$ is shape parameter

- Log logistic distribution parameters for the 3 locations:

Location	**α (mm)**	**β**
M3	0.218	1.002
M5	1.276	1.928
M109	0.464	0.999

Quantifying uncertainty in chosen input parameters

- Distribution of roughness values at one of the locations



- To obtain a single probability distribution of Colebrook-White roughness, average values of the distribution parameters have been used

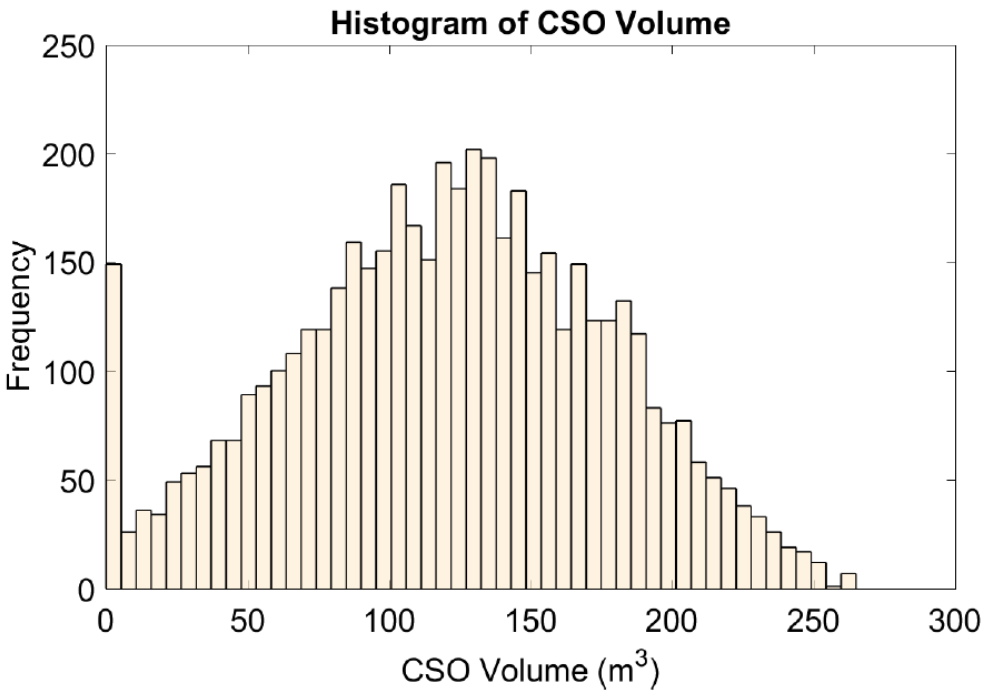
Quantifying uncertainty in CSO volume

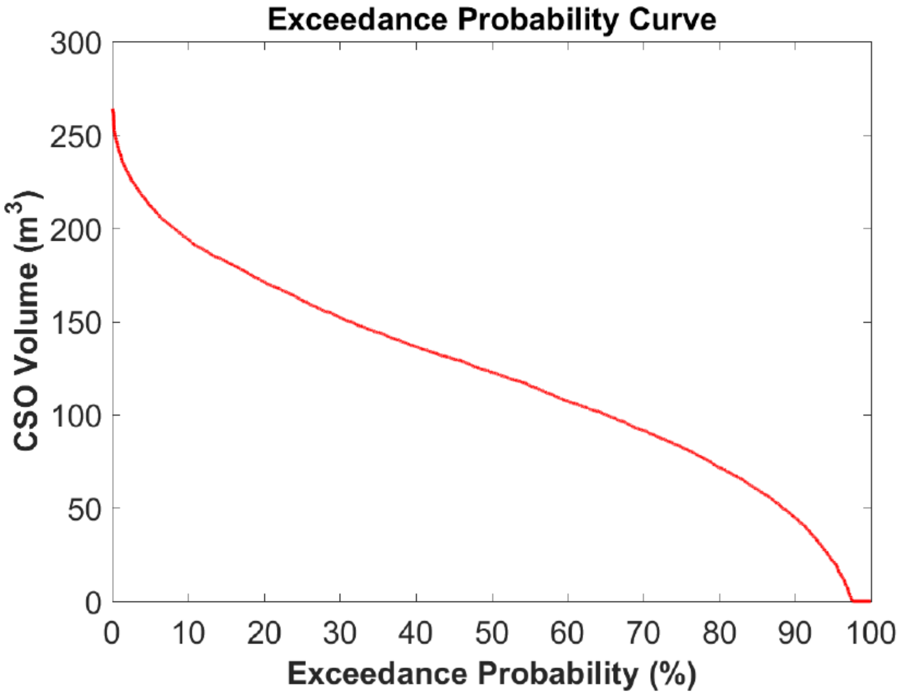
Method:

- Direct Monte Carlo simulations were run for 5000 parameter samples
- Latin hypercube sampling (LHS) was used instead of random sampling to draw samples from the parameter space (*R* package: ‘lhs’)
- The three input parameters were assumed to be not correlated to each other

Quantifying uncertainty in CSO Volume

Result:





Comments

- The catchment model used in this study is a flat, gravity driven urban catchment representative of a typical urban system.
- Runoff coefficient has a very high dominating effect on the CSO volume and the uncertainty in its estimation. Extra care should be given while quantifying the uncertainty in such parameters.
- Runoff Coefficient and Colebrook-White roughness were found to be not independent or have a non-linear relationship with CSO volume
- Is requiring no spills for a set design storm a sensible way to regulate CSOs?
- How can we use the information about the uncertainty in CSO volume to select optimal storage volume?