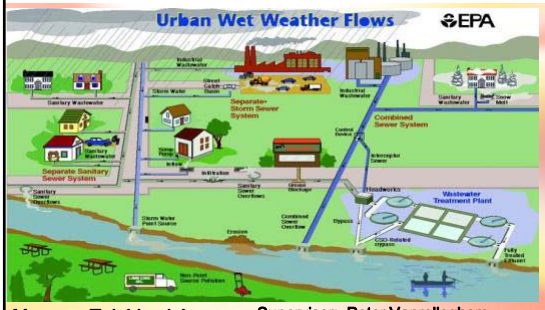
A Stochastic Input Disturbance Model for Probabilistic Design of Wastewater Treatment Plants



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Statistics and Control Meeting

Queen's University
Kingston, Ontario

27 May 2013

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Outline

- Introduction
- Objectives
- Methodology
- Results
- Conclusion and next steps

Introduction

- WWTP's main objective

  Treatment of wastewater under a set of constraints (e.g. cost, effluent standards, environmental impact, etc).

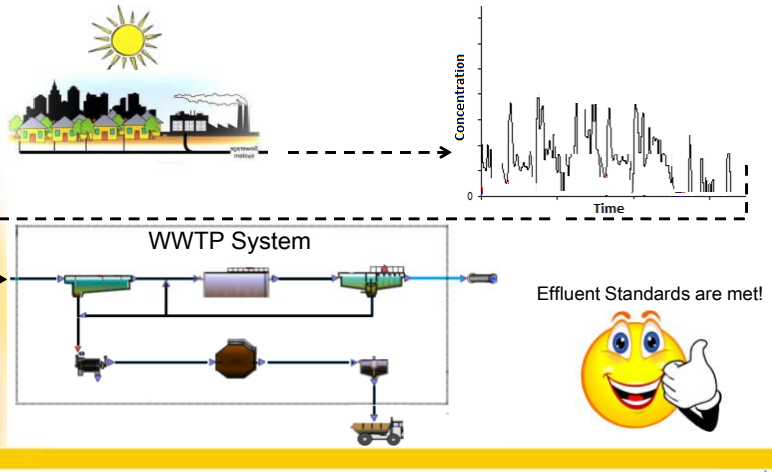
  Many of the design inputs are uncertain

Introduction

- How to tackle the uncertainty in design?

Applying safety factors *VS* Explicit characterization of uncertainty and estimating the Probability of non-compliance

Introduction



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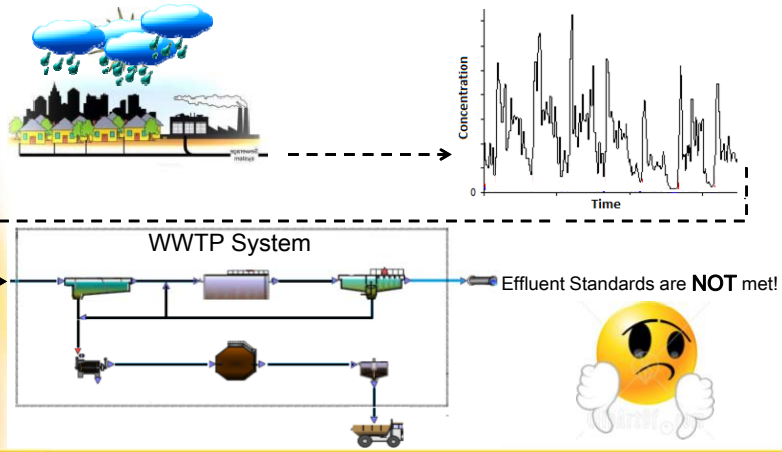
Introduction



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6

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Objectives

- Development of a dynamic influent generator that:
  - ✓ Generates time series of flow and pollution with a fine temporal resolution (15-minute)
  - ✓ Respects the statistical properties of a real influent (e.g. mean, variance, autocorrelation, and cross-correlation among rainfall, flow and pollution)
  - ✓ Needs only basic information regarding sewage system
  - ✓ Is not computationally-expensive

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Methodology

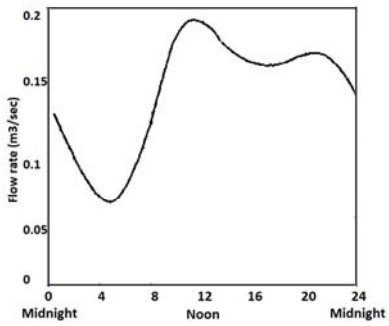
- Two different conditions must be considered:

1. Dry weather flow (DWF)

2. Wet weather flow

Methodology

- Wastewater variation in DWF conditions
- Easier to model compared to WWF conditions
- Periodic behavior
  - Daily variation
  - Seasonal variation
  - Industrial variation



Methodology

- Simulating the time series of wastewater in DWF conditions is easier than the one in WWF conditions

- Univariate ARMA model (Martin et al., 2007)
  - Main shortcomings:
    1. Wastewater time series have different seasonal variations
    2. The cross-correlation between different wastewater constituents is not respected

Methodology

- Our Approach:
  - Modelling the periodicity of the time series using a Fourier series approximation
  - Fitting a multivariate auto-regressive time series model to the residuals
  - Random generation of time series for different wastewater constituents

Methodology

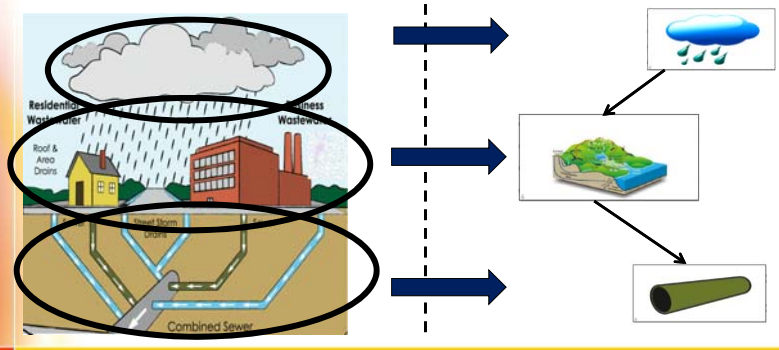
- Wastewater time series in WWF conditions
  - Difficult to simulate
  - Rainfall plays an important role
  - Different processes are involved
  - Scarce availability of data during WWF
  - Pure statistical models may not be feasible

Solution?

  - A conceptual model with stochastic inputs and uncertainty propagation

Methodology

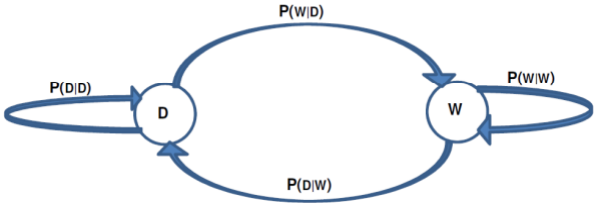
System Components | Model Components



Methodology

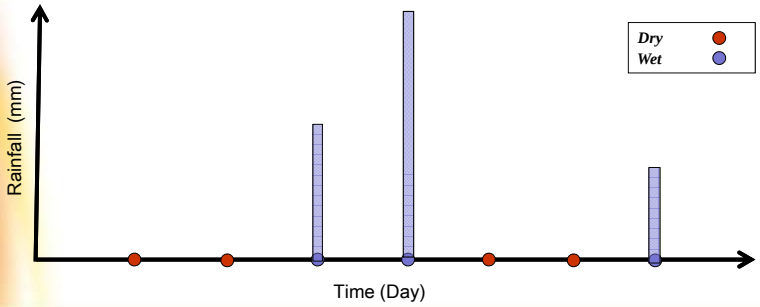
- Markov-Exponential model

  - A two state Markov-Chain for the generation of dry and wet days (Richardson 1981).



Methodology

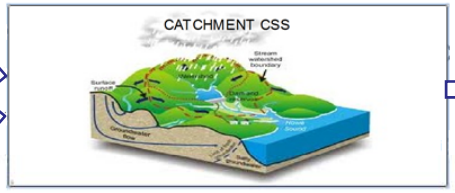
- Daily rainfall time series
  - An exponential distribution for the generation of the amount of rainfall



Methodology

- Catchment block

Rainfall
(Markov chain exponential model)



WWF

DWF
(Multivariate AR model)

Methodology

- No model can provide accurate results
  - Deficiency in model structure
  - Uncertainty in parameters
  - Measurement error
- Models need to be calibrated
  - Calibrated parameters may not be unique
  - Parameters could compensate for each other

Methodology

- How to take into account the uncertainty in model's outputs?
  - Assigning an initial distribution to uncertain model parameters (Prior distribution)
  - Updating the prior distribution using a Bayesian framework
  - Monte Carlo simulation for the propagation of total uncertainty into the model's outputs

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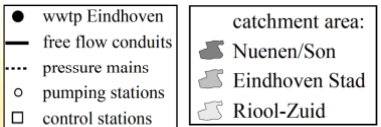
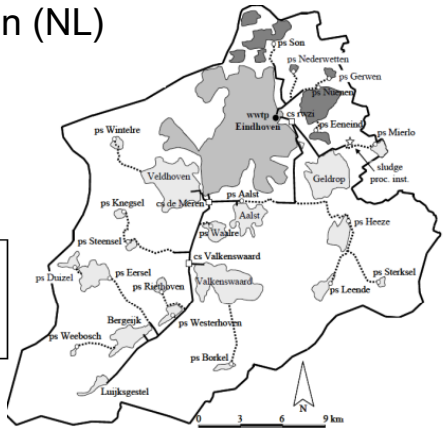
Results

- Case study: Eindhoven (NL)

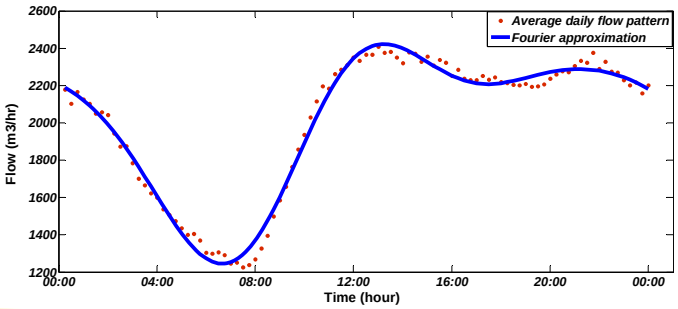
Main components of the Eindhoven area wastewater system (750,000 inhabitants)





Results: DWF

- Capturing daily periodicity



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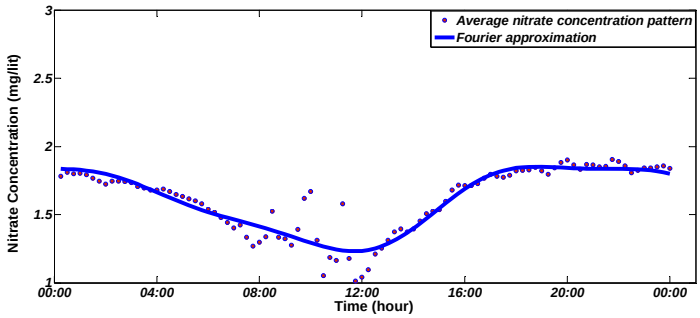
Results: DWF

- Capturing daily periodicity



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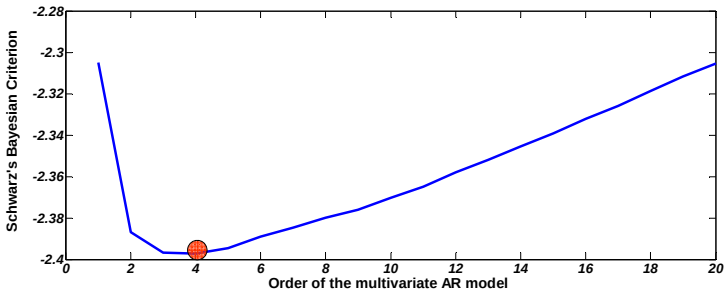
Results: DWF

- Determining the order of model using Schwarz's Bayesian Criterion



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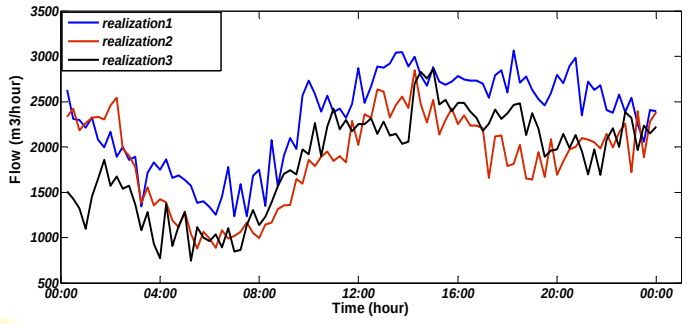
Results: DWF

- Daily flow time series



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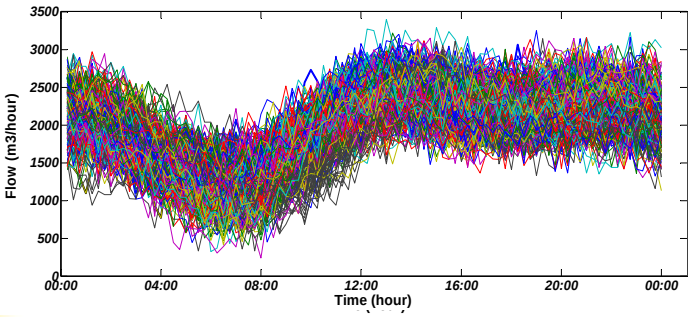
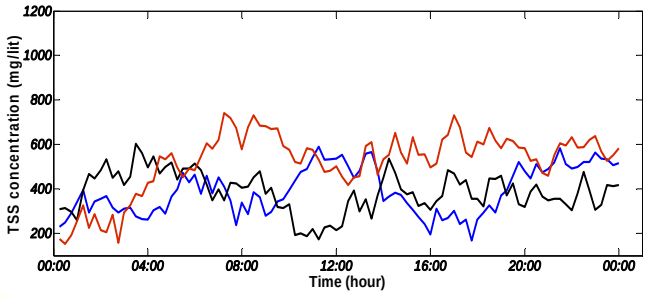
Results: DWF

- Daily flow time series



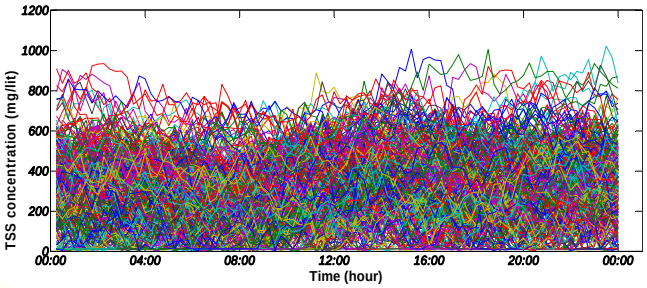
Results: DWF

- Daily TSS concentration time series



Results: DWF

- Daily TSS concentration time series



Results: DWF

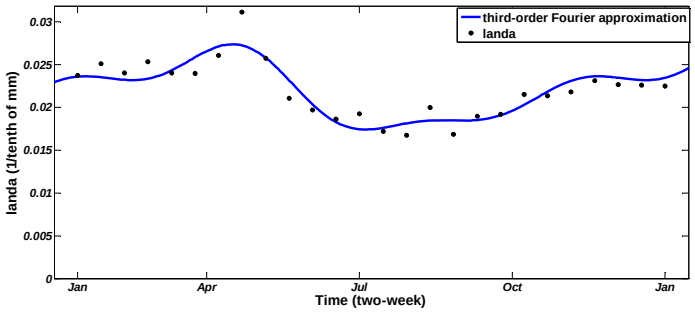
- Correlation matrices

	Observed Time Series				
	Flow	COD_S	COD_TOT	TSS	NO3
Flow	1.00				
COD_S	0.17	1.00			
COD_TOT	0.09	0.59	1.00		
TSS	0.03	-0.10	0.71	1.00	
NO3	-0.07	0.16	-0.18	-0.39	1.00

	Generated Time Series				
	Flow	COD_S	COD_TOT	TSS	NO3
Flow	1.00				
COD_S	0.13	1.00			
COD_TOT	0.06	0.55	1.00		
TSS	0.03	-0.10	0.74	1.00	
NO3	-0.06	0.17	-0.19	-0.42	1.00

Results: Rainfall generation

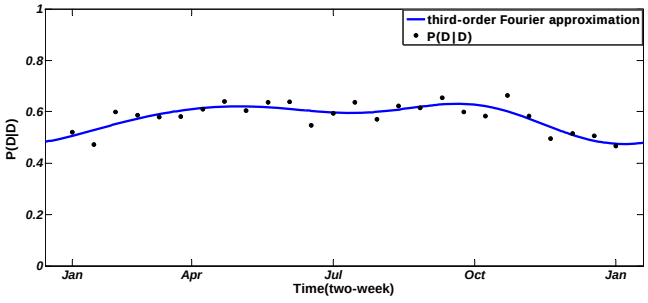
- Removing seasonal variations using Fourier series



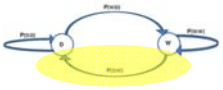
Results: Rainfall generation

- Removing seasonal variations using Fourier series

$$\begin{pmatrix} P(W|W) & P(D|W) \\ P(W|D) & P(D|D) \end{pmatrix}$$



Results: Rainfall generation



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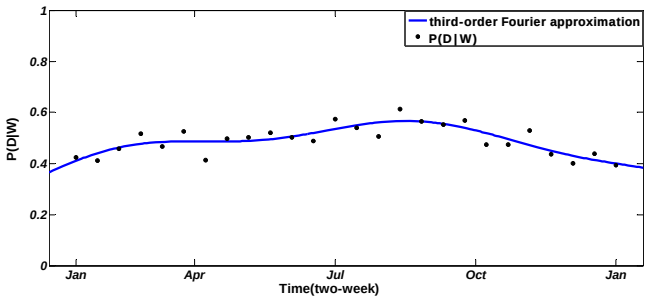
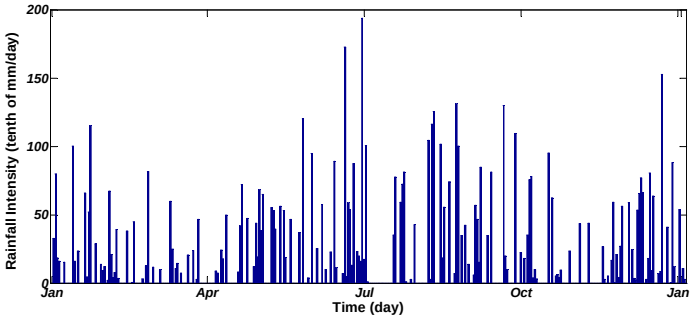


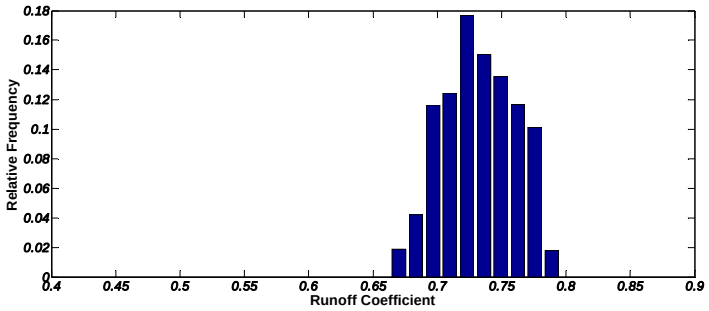
Results: Rainfall generation

- Daily rainfall series



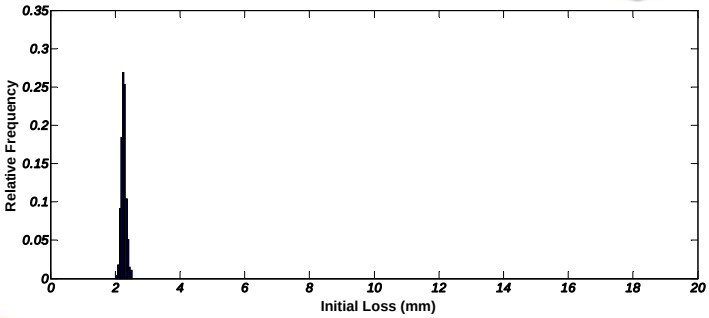
Results: WWF

- Marginal Posterior distribution



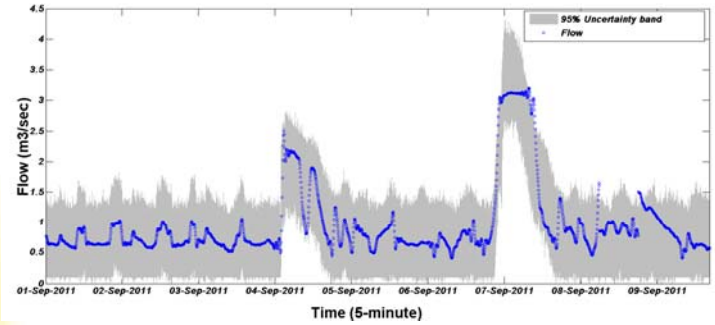
Results: WWF

- Marginal Posterior distribution



Results: WWF

- Uncertainty propagation



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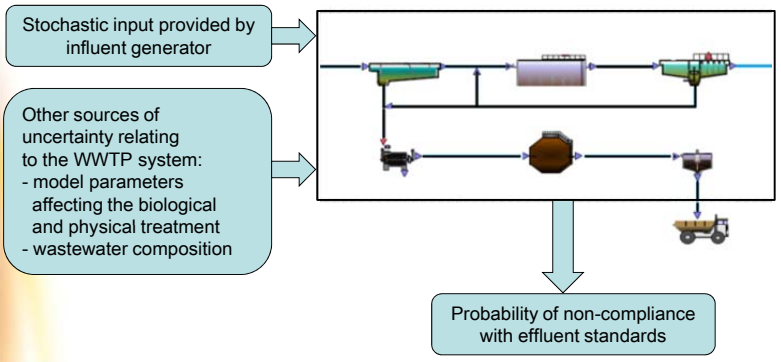
Conclusion and next steps

- Development of a set of statistical and conceptual models for synthetic generation of influent time series
  - ✓ Mathematically sound techniques for rainfall time series generation
  - ✓ Successful application of a multivariate time series for DWF simulation
  - ✓ Application of a conceptual model with stochastic inputs and uncertainty propagation to estimate the range of output variables

Conclusion and next steps

- Probability of meeting effluent standards



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