State of the art in WWTP Influent Generation

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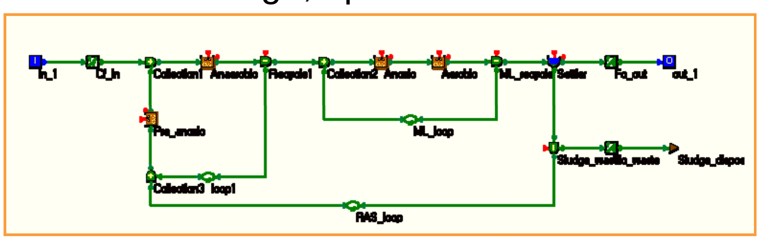
Water Environment Federation

Problem Statement

Simulation of WWTPs

- ✓ Reliable models have been developed
- ✓ They have become a standard for: WWTP design, operation and control

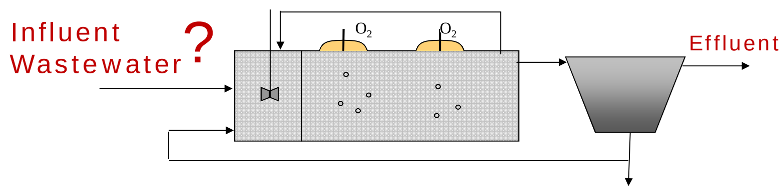


Problem Statement

Simulation of WWTPs

✗ Scarce Influent Data – Difficulty to explore the behaviours of a WWTP under:

- Different climatologic conditions
- Different types of population (urban – rural; big - small)
- Under incidents or non-controlled spills



Three different situations

Depending on the available information:

A Modeller has a little dataset. He has some ideas about how the influent should be. He might also have some data about the catchment area

B Modeller has information enough to estimate the WWTP influent data

C Modeller has a complete dataset. It is only a single realisation of the problem. He would like to generate other similar influent conditions

Three Situations – Different Solutions

A Modeller has a little dataset

1. Building Datasets
2. Building models based on harmonic functions
3. Building a Phenomenological Model

Three increasing complexity solutions

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WWTmod 2012

Three Situations – Different Solutions

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WWTmod 2012

Building Databases

Devisscher et al. (2006)

- Corrective factors: Weekend/First Flush effect
- Available quality data are aggregated in seasonal averages and redistributed
  - Day-to-day basis using a Normal distribution
- Daily pattern: flow rate mean values
  - If necessary, mean flow rate values are generated from a Poisson distribution

Devisscher M., Ciacci G., Fé L., Benedetti L., Bixio D., Thoeye C., De Gueldre G., Marsili-Libelli S. and Vanrolleghem P.A. (2006). Estimating costs and benefits of advanced control for wastewater treatment plants – the MAgIC methodology. *Water Science & Technology*, **53** (4-5), 215-223.

Building Databases

De Keyser et al. (2010)

- Micro-pollutants release in urban areas
- Database with a structure and quantitative description of emission sources and their patters on a typical daily, weekly and yearly basis
- Generator is able to provide profiles of priority pollutants, generic pollutants, and wastewater flow rates

De Keyser W., Gevaert V., Verdonck F., De Baets B., Benedetti L. (2010). An emission time series generator for pollutant release modelling in urban areas. *Environmental Modelling & Software*, **25** (2010), 554-561.

Three Situations – Different Solutions

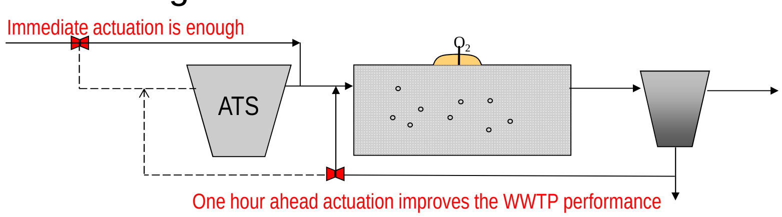
A Modeller has a little dataset

1. Building Data Basis
2. Building models based on harmonic functions
3. Building a Phenomenological Model

Using Fourier models

Carstensen et al. (1998)

- Was able to predict the hydraulic load entering a WWTP one hour ahead



Carstensen J., Nielsen M.K. and Strandbaek H. (1998). Prediction of hydraulic load for urban storm control of a municipal WWT plant. *Water Science & Technology*, **37** (12), 363-370.

Using Fourier models

Langergraber et al. (2008)

- Describe diurnal variations of wastewater flow and concentrations by using a Fourier model

Data
Daily influent dry weather flow
Daily mean concentrations of COD, TKN and TP
Flow and concentrations of infiltration water and urine

Eqs.
$Q_{inf}(t) = Q_{inf} = const$
$Q_u(t) = Q_u + a_1 \sin(wt) + a_2 \cos(wt) + a_3 \sin(2wt) + a_4 \cos(2wt)$
$Q_d(t) = Q_d + b_1 \sin(wt) + b_2 \cos(wt) + b_3 \sin(2wt) + b_4 \cos(2wt)$

Langergraber G., Alex J., Weissenbacher N., Woerner D., Ahnert M., Frehmann T., Halft N., Hobus I., Plattes M., Spering V. and Winkler S. (2008). Generation of diurnal variation for influent data for dynamic simulation. *Water Science & Technology*, **57** (9), 1483-1486.

Langergraber model applications

Spering et al. (2008)

- Dynamic simulations for design of new plants where no dynamic data are available
- Simulation results in agreement with those of stationary design rules

Alex et al. (2009)

- Simulation studies for control and operation of WWTPs.

Spering V., Alex J., Langergraber G., Ahnert, M., Halft N., Hobus I., Weissenbacher N., Winker S. and Yücesoy, E. (2008). Using dynamic simulation for design of activated sludge plants. In: *Proceedings of the International Symposium on Sanitary and Environmental Engineering-SIDISA08*, 24-27 June 2008, Florence, Italy.

Alex J., Hetschel M. and Ogurek M. (2009). Simulation study with minimised additional data requirements to analyse control and operation of WWTP Dorsten, Germany. *Water Science & Technology*, **60** (6), 1371-1377.

Three Situations – Different Solutions

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Phenomenological model: Gernaey et al. 2011

Disturbance scenario for the BSM2 model

- Influent flow rate
- Temperature profiles
- Pollutant concentrations

ASM1, ASM2d or ASM3

It achieves influent profiles that feature:

- diurnal phenomena
- seasonal phenomena
- rain events
- weekends effect
- holiday periods

Gernaey K.V., Flores-Alsina X., Rosen C., Benedetti L. and Jeppsson U. (2011). Dynamic influent pollutant disturbance scenario generation using a phenomenological modelling approach. *Environmental Modelling & Software*, **26** (2011), 1255-1267.

Phenomenological Model - GSA

Flores-Alsina et al. 2011

- The analysis is focussed on the influent flow rate
- RESULTS

Dry Weather	Rain Event
Catchment Size	Probability of occurring a rain event
Production of wastewater per person	Catchment Size
	Quantity of rain falling in permeable areas

Flores-Alsina X., Gernaey K.V. and Jeppsson U. (2011). Global Sensitivity Analysis of the BSM2 Dynamic Influent Disturbance Scenario Generator. In: *Proceedings of 8th IWA Symposium on Systems Analysis and Integrated Assessment, Watermatex2011, San Sebastián (Spain), 20-22 June, 2012.*

Applications of Phenom. Model

Lindblom et al. (2006)

- In a new model to describe the fate and transport of two xenobiotic compounds
- Bispherol A and pyrene concentration profiles were added to the ASM1 variables

Lindblom E., Gernaey K.V., Henze M. and Mikkelsen P.S. (2006). Integrated modelling of two xenobiotic organic compounds. *Water Science & Technology*, **54** (6-7), 213-221.

Applications of Phenom. Model

Ráduly et al. (2007)

- Artificial neural network (ANN) to rapidly check a WWTP performance
  - Influence disturbance model is used to generate 4 months of synthetic data
- The ANN is trained on the results of the mechanistic model
  - The success of the tool is related with the inclusion of: rain events, holiday effects; industrial discharges, etc.

Ráduly B., Gernaey K.V., Capodaglio A.G., Mikkelsen P.S. and Henze M. (2007). Artificial neural networks for rapid WWTP performance evaluation: Methodology and case study. *Environmental Modelling & Software*, **22** (2007), 1208-1216.

Applications of Phenom. Model

Benedetti et al. (2008)

- Methodology to design correction measures for urban wastewater systems
- Different WWTP configurations are assessed in terms of effluent quality index and total cost
  - Generating realistic influent data profiles
  - Presenting an uncertainty framework (MC simulations)
  - Presenting probabilistic descriptors in order to make sense of the results

Benedetti L., Bixio D., Claeys F. and Vanrolleghem P.A. (2008). Tools to support a model-based methodology for emission/immission and benefit/cost/risk analysis of wastewater systems that considers uncertainty. *Environmental Modelling & Software*, **23** (8), 1082-1091.

Three Situations – Different Solutions

B Modeler has information enough to estimate the WWTP influent data

- The problem becomes an estimation problem

Y = F(x),
Having data of Y we wonder about the values of x

Influent solved as: Estimation Problem

Bechmann et al. (1999)

- A grey box model to estimate the pollutant mass flow entering a WWTP
  - UV absorption & Turbidity → COD and SS
- Model includes a stochastic component
  - Model residuals and Model parameters are defined by probability distributions (likelihood estimator)

$$y(t) = a_0 + \sum_{k=1}^{n} (a_k \cdot sin(2\pi k) + b_k \cdot cos(2\pi k)) - \frac{dx}{dt} + \epsilon(t)$$

Static part based on Fourier expression | Dynamic | Stochastic Component

Bechmann H., Nielsen M.K., Madsen H. and Poulsen N.K. (1999). Grey-box modelling of pollutant loads from a sewer system. *Urban Water 1*, (1999), 71-78.

Influent solved as: Estimation Problem

Kern et al. (2012)

Influent, x → WWTP model $y = J(x)$ → Effluent, y

- $y = J(x)$ → Particle Swarm Optimization (PSO) algorithm changes x till getting y close to data $y_{Meas.}$
- The mechanistic model is substituted by a surrogate model, $y = J'(x)$

Kern P., Ebel A., Wolf C., McLoone S. and Bongards M. (2012). Simulation based feed stream estimation of wastewater treatment plants using a surrogate model. *WWTmod2012, Mont-Sainte-Anne, Québec*, 26-28 February 2012.

Three Situations – Different Solutions

C Modeller has a complete dataset. He would like to build other similar influent conditions

Time Series Models

Carstensen et al. (1998)

- Used an AR(1) to generate some noise over a model based on 2nd order Fourier Series

Martin et al. (2007)

- Proposed ARMA models to generate other time series data similar to a given one

Carstensen J., Nielsen M.K. and Strandbaek H. (1998). Prediction of hydraulic load for urban storm control of a municipal WWT plant. *Water Science & Technology*, **37** (12), 363-370.

Martin C.M, Eguinoa I., McIntyre N.R., Garcia-Sanz M. and Ayesa E. (2007). ARMA models for uncertainty assessment of time series data: Application to Galindo-Bilbao WWTP. *In: Proceedings of Watermatex2007*. Washington (USA), May 7-9 (2007).

Stochastic Models

Bechmann et al. (1999)

- Different realisations of the same process are achieved by estimating the likelihood function of the parameters

Rosen et al. (2008)

- Markov Chain is used to add some realism to the measurements given by a perfect (modelled) sensor or actuator

Bechmann H., Nielsen M.K., Madsen H. and Poulsen N.K. (1999). Grey-box modelling of pollutant loads from a sewer system. *Urban Water 1*, (1999), 71-78.

Rosen C., Rieger L., Jeppsson U. and Vanrolleghem P.A. (2008). Adding realism to simulated sensors and actuators. *Water Science & Technology*, **57** (3), 337-344.

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Conclusions I

Little information available about WWTP infl.

- Database approaches
  - They are home made recipes
  - Provide good results on a minimum modelling effort
- Fourier based models
  - Provide daily and weekly patterns
  - Do not allow extrapolation to other situations: population increases, other city, other climate…
- Phenomenological models
  - Acquire knowledge about the catchment
  - Provide dry and wet weather profiles

Conclusions II

There is information enough to estimate the WWTP influent

- The problem becomes a general estimation problem
- If numerically solved, it may need the simulation of the mechanistic model hundreds of times
  - Surrogate models

An interesting proposal is going to be presented in this conference!

Conclusions III

Generating some variability over some given influent data – Adding realism

- ARMA models
  - May not respect the diurnal or weekly patterns
  - They can add: White or Color noise
- Model parameters defined by a likelihood function
  - Provides a stochastic model to generate the data
  - Different realisations can be obtained!
- Markov Chains
  - Useful to generate faults – Different from adding noise!

Any questions?

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