Modelling WW influent aspects: flows, loads, and variability

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International Water Association

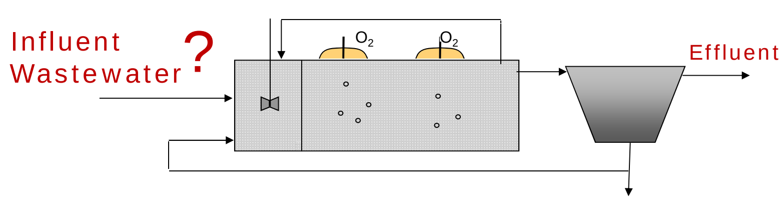
4th IWA/WEF Wastewater Treatment Modelling Seminar
Spa, Belgium, March 30th – April 2nd 2014

Water Environment Federation

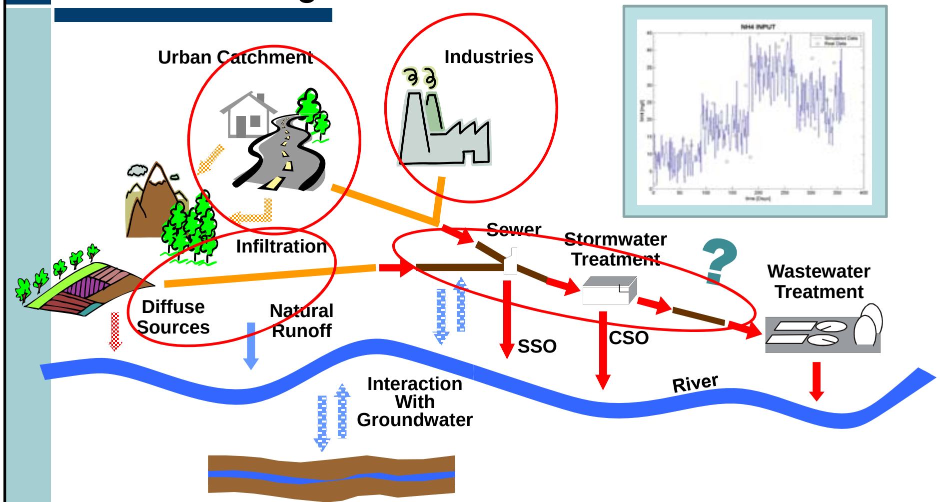
Problem Statement – WWTP Influent data

The influent wastewater is related to…

- Different types of population (urban – rural areas)
- Possible industrial discharges
- Different climatologic conditions (mediterranean, continental, etc.)
- The occurrence of Wet-Weather (WW) episodes??



Catchment area and the relationship with the wastewater generation



Modelling WW influent aspects: flows and loads (Martin and Vanrolleghem, 2014)

Solutions of Influent Generators

A. From the information available at the WWTP pumping station
   - Solutions based on dataset analysis
   - Solutions based on the use of harmonic functions

B. From the information about the catchment area
   - Analising the very source generation points: phenomenological models

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Dry Weather Conditions (I)

Databases – Emission-based approach

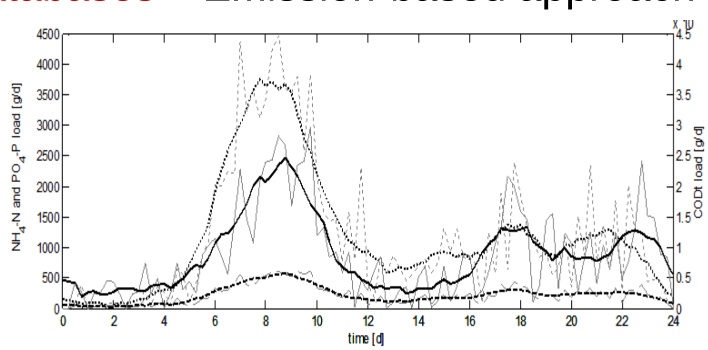
- Micro-pollutants release in urban areas
- Emission sources on daily, weekly and yearly basis
- The generator is linked to benchmark simulation model for dry weather flow generation
- It provides profiles of priority pollutants, generic pollutants and wastewater flow rates

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.

WWTmod 2014
Modelling WW influent aspects: flows and loads (Martin and Vanrolleghem, 2014)

Dry Weather Conditions (I)

Databases – Emission-based approach



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.

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Dry Weather Conditions (II)

Use of harmonic functions

- Diurnal variations of wastewater flow and conc.

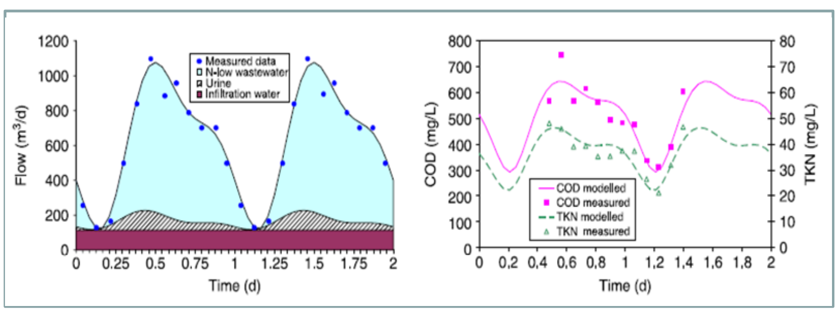
Data:
Daily influent dry weather flow
Daily mean concentrations of COD, TKN and TP
Flow and concentrations of infiltration water and urine

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.
- Mannina, G., Cosenza, A., Vanrolleghem, P.A., Viviani, G., 2011. A practical protocol for calibration of nutrient removal wastewater treatment models. *J. Hydroinform.*, **13**, 575-595

Dry Weather Conditions (II)

Use of harmonic functions



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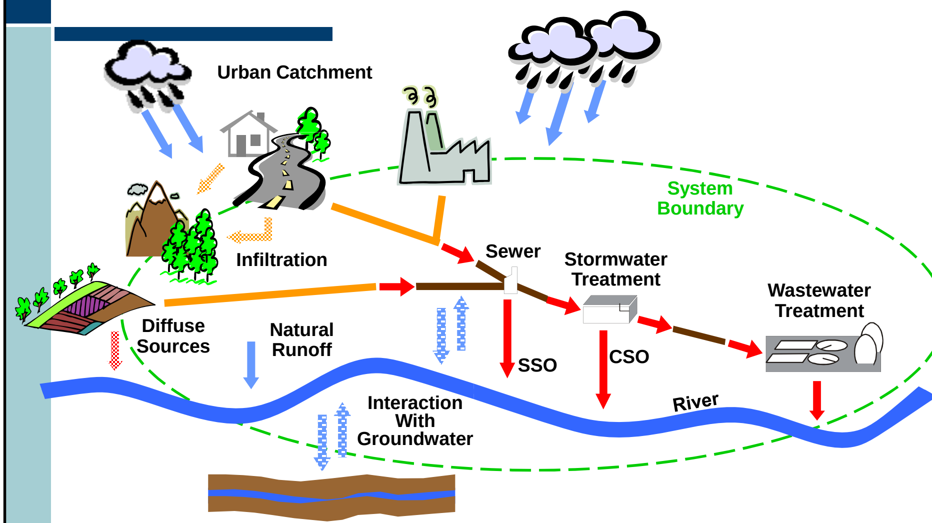
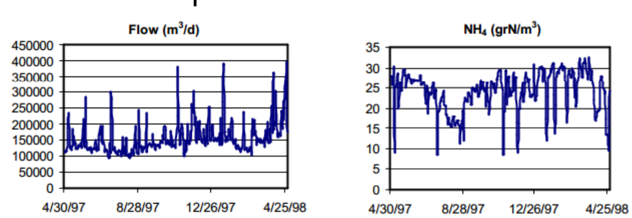
What happens if it rains?



Wet-Weather vs. Dry-Weather

- Highly variable flows and loads
- Low predictability of the WWTP behaviour
  - Difficult to model the transport in the sewer (first-flush effect)
  - Difficult to predict the income to the WWTP

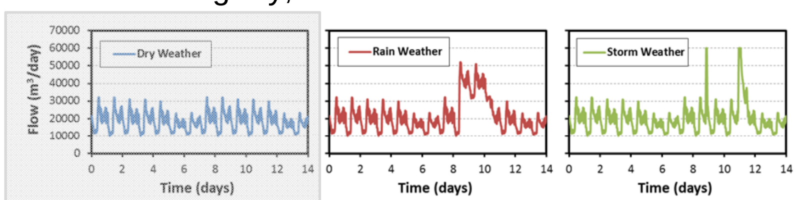


Galindo WWTP Influent Characteristics

Benchmark Influent Data

Straightforward solution for engineers…

- Influent profiles for a WWTP of 100,000 PE are available at http://www.benchmarkwwtp.org/ including dry, rain and storm weather conditions.



Spanjers H., Vanrolleghem P.A., Nguyen K., Vanhooren H. and Patry G.G. (1998) Towards a simulation-benchmark for evaluating respirometry-based control strategies. Wat. Sci. Tech., **37**(12), 219-226

Database approach…

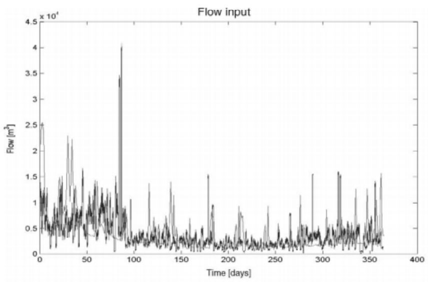
Data from more than 100 WWTPs in Flanders

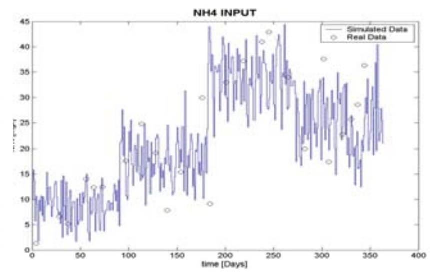
- Corrective factors to represent Weekends and First Flush effect
- Flow rate daily mean values
  - Classified into dry and wet days
  - Serve to identify daily patterns
- Quality data are aggregated in seasonal averages and redistributed
  - Day-to-day basis using a Normal distribution

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.

Database approach…

Data from more than 100 WWTPs in Flanders





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Phenomenological model (Gernaey et al. 2011)

Disturbance scenario for the BSM2 model (Gernaey et al. 2011)

- 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 (Gernaey et al. 2011)

Disturbance scenario for the BSM2 model (Gernaey et al. 2011)

- ...t flow rate
- ...files
- Poll...

ASM1, ASM2d or ASM3

It provides influent wastewater influent profiles considering **all the elements of the catchment area**

It achieves influent profiles ...

- diurnal phenomena
- seasonal phenomena
- rain events
- weeken...
- holiday periods

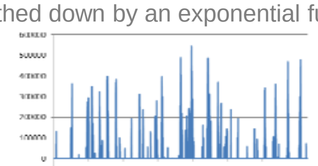
Gernaey K.V., Flores-Alsina X., Rosen C., Benedetti L. and Jeppsson U. (2011). Dynamic influent pollutant disturbance scenario generation using a phenomenological modelling approach. *Environmental Modelling & Software,* **26** (2011), 1255-1267.

Modelling WW influent aspects: flows and loads (Martin and Vanrolleghem, 2014)

Phenomenological model modules (I)

- Rainfall generation:

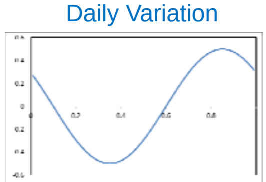
  Transforms a random number into a rain event, the peak value of which is smoothed down by an exponential function until the next rain event occurs



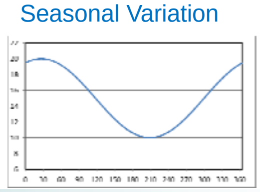
- Temperature representation:

  Daily and yearly temperature variations are defined by two sinusoidal functions

Daily Variation



Seasonal Variation



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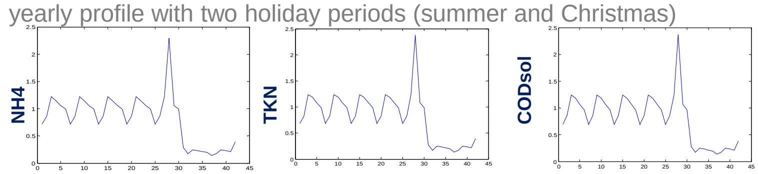
Phenomenological model modules (II)

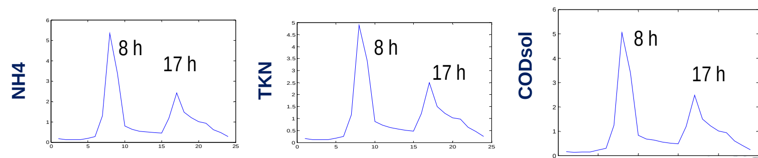
- Industrial discharges generation:

  The wastewater flow presents a weekly profile (lower at the weekend) and yearly profile with two holiday periods (summer and Christmas)



- Household wastewater generation:

  Average load rates (COD, NH4, TKN, etc.) multiplied by the number of PE. It assumes a fixed daily pattern with two peaks at 8 and 17 hours



Phenomenological model modules (III)

- Soil model module

  Represented by a **variable volume tank model.** The flow entering the tank is composed of a fraction of the rainfall that falls in permeable areas, and the outflow represents the flow to the sewer system and the aquifers

$$\frac{dh1}{dt} = \frac{1}{A_1}(Q_{in1} + Q_{in2} - Q_{out1} - Q_{out2})$$

→ infiltration Q_{in1}

→ rainfall Q_{in2}

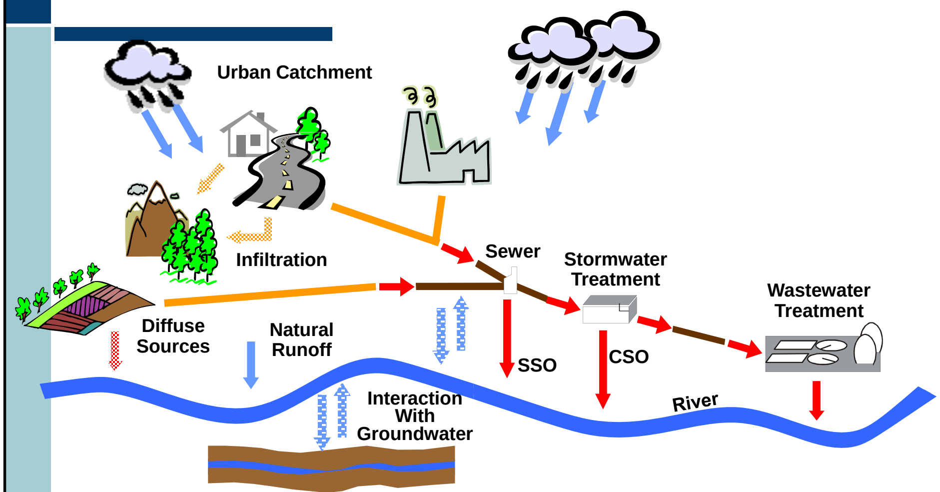
→ sewer $Q_{out1} = K_{inf} \cdot \sqrt{H_{inf}}$

→ aquifers $Q_{out2} = K_{down} \cdot h_1$

- Sewer model module

  The sewer system is defined by connecting a different number of subcatchments (one to eight) to represent more or less complex sewer systems. Each subcatchment is modelled by a tank-in-series approach using variable volume reactors.

How can we move forward?



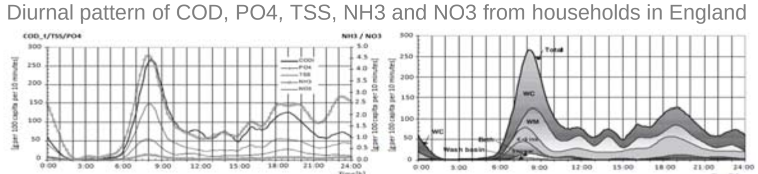
Martin, C., Vanrolleghem P. A., 2014. Analysing, completing, and generating influent data for WWTP modelling: A critical review. *Env. Model. Soft.*, *Submitted*.

Modelling WW influent aspects: flows and loads (Martin and Vanrolleghem, 2014)

Phenomenological model – Moving forward

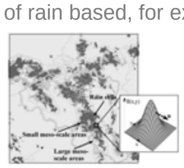
- Household wastewater generation:

  Diurnal pattern of COD, PO4, TSS, NH3 and NO3 from households in England



- Rain generation:

  Spatial stochastic generation of rain based, for example, in the definition of cells with different scales



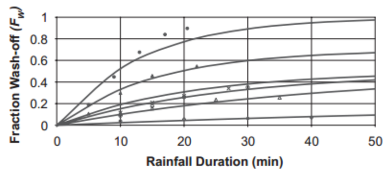
Almeida, M.C., Butler, D., Friedler, E., 1999. At-source domestic wastewater quality. *Urb. Water*, **1**, 49-55.
Willems, P., 2001. A spatial rainfall generator for small spatial scales. *J. Hydrol.*, **252**, 126-144

Modelling WW influent aspects: flows and loads (Martin and Vanrolleghem, 2014)

Phenomenological model – Moving forward

- First flush model:

  Description of Build up and Wash off of pollutants in urban areas

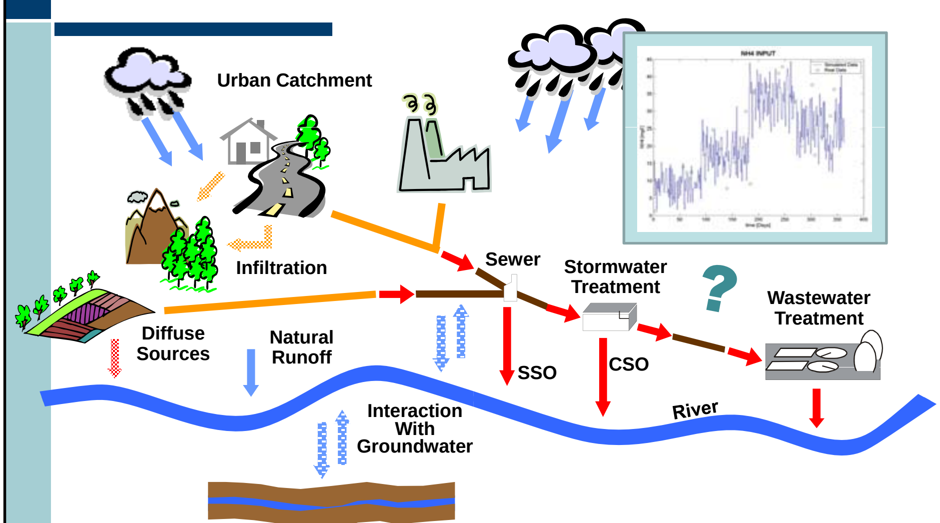


- Soil Model:

  The description of the vertical infiltration in terms of the soil properties: specific moisture capacity, capillarity head, effective hydraulic conductivity, etc.

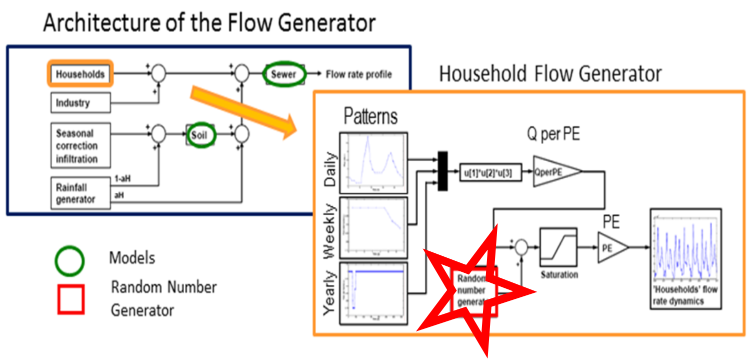
- Egodawatta, P., Thomas, E., Goonetilleke, A., 2007. Mathematical interpretation of pollutant wash-off from urban road surfaces using simulated rainfall. *Wat. Res.*, **41**, 3025-3031.
- Corradini, C., Flammini, A., Morbidelli, R., Govindaraju, R.S., 2011. A conceptual model for infiltration in two-layered soils with a more permeable upper layer: From local to field scale. *J. Hydrol.*, **410**, 62-72

How can we describe the uncertainty?



Generating uncertainty over each component

In the phenomenological model of Gernaey et al. 2011:



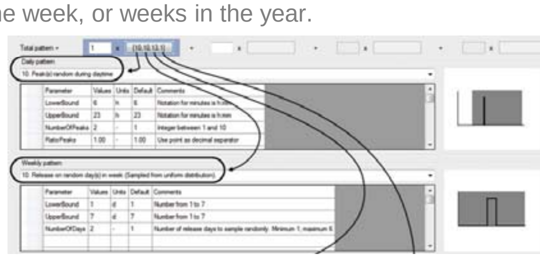
Modelling WW influent aspects: flows and loads (Martin and Vanrolleghem, 2014)

Generating uncertainty over each component

In the *emission-based* model of De Keyser et al. 2010

- Adding white noise to the obtained time series
- Allowing pattern parameters to be randomly sampled

The modeler defines uniform distributions to randomly determine, for example, when an emission peak occurs: at which hour of the day, day of the week, or weeks in the year.



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Representing uncertainty over a data series

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

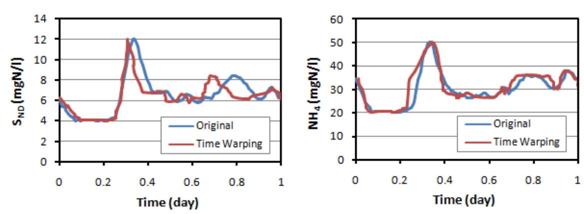
Carstensen J., Nielsen M.K. and Strandbaek H. (1998). Prediction of hydraulic load for urban storm control of a municipal WWT plant. *Water Science & Technology,* **37** (12), 363-370.

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).

Representing uncertainty over a data series

Time Warping Approach

Profiles are disrupted by introducing the uncertainty of their timings



Villez, K., Steppe, K., De Pauw, D.J.W., 2009. Use of Unfold PCA for on-line plant stress monitoring and sensor failure detection. Biosystems Engineering **103**, 23-34.

Gins, G., Espinosa, J., Smets, I. Y., Van Brempt, W., Van Impe, J. F. M., 2006. Data alignment via dynamic time warping as a prerequisite for batch-end quality prediction. Lecture Notes in Artificial Intelligence, **4065**, 506–510.

Using Bayesian estimation of the parameters

Bechmann et al. (1999)

- A grey box model to estimate the pollutant mass flow entering a WWTP
  - UV absorption & Turbidity → COD and SS
- Different realisations of the same process are achieved by estimating the likelihood function of the parameters

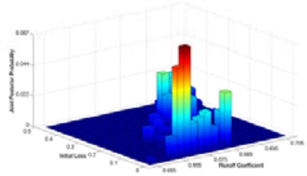
$$y(t) = a_0 + \underbrace{\sum_{k=1}^{n} (a_k \cdot sin(2\pi k) + b_k \cdot cos(2\pi k))}_{\text{Static part based on Fourier expression}} - \underbrace{\frac{dx}{dt}}_{\text{Dynamic}} + \underbrace{\epsilon(t)}_{\text{Stochastic Component}}$$

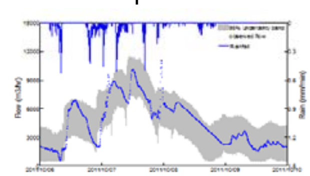
Bechmann H., Nielsen M.K., Madsen H. and Poulsen N.K. (1999). Grey-box modelling of pollutant loads from a sewer system. *Urban Water,* **1**, 71-78.

Using Bayesian estimation of the parameters

Talebizadeh et al. (2014)

- Proposes a *new* influent generator with a detailed description of sewershed characteristics.
  - It uses CITYDRAIN drainage model for the stochastic generation of water quantity and quality profiles under WW conditions.
- Different realisations of the process are achieved by estimating the likelihood function of the parameters





Talebizadeh, M., Belia, E., Vanrolleghem, P.A., 2014. Influent generator for probabilistic design of nutrient removal wastewater treatment plants. WWTmod2014.

Conclusions (I)

- Solutions for influent generation under wet weather conditions
  - Benchmark Influent profiles (Spanjers et al., 1998)
  - Generators based on databases (Devisscher et al., 2006)
  - Phenomenological model of BSM2 (Gernaey et al., 2011)

The most comprehensive approach is the phenomenological model (Gernaey et al., 2011)

  - It includes a mechanistic description of each of the elements in the catchment area
  - It allows improvements in the definition of the different elements using a flexible open source code.

Conclusions (II)

- How could we move forward the mechanistic description of the wastewater generation?
  - Including spatial stochastic generation of the rain events
    - More phenomenological catchment model
    - Better weather generator
  - Including more detailed description of the household wastewater generation
  - Including soil properties: specific moisture capacity, capillarity head, effective hydraulic conductivity, etc.

Conclusions (III)

- How can we include the uncertainty description?
  - Including random variables in the models of the catchment area (Gernaey et al., 2011)
  - Including random variables in the selection of the patterns of given databases (De Keyser et al., 2010)
  - Using Time Series models or Time Warping approach over a given data profile (Martin et al., 2007; Villez et al., 2009)
  - Adopting Bayesian estimation techniques for the parameter estimation (Bechmann et al., 1999; Talebizadeh et al., 2014)

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WWTmod 2014

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Water Environment Federation — Preserving & Enhancing the Global Water Environment