BIOMATH
Department of Applied Mathematics, Biometrics and Process Control

Past, present and future of Integrated Urban Wastewater Systems management

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Outline

- Introduction
- Past – a few words
- Present – several examples
- Future – new developments and challenges

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Water

Water

The **usable** freshwater for ecosystems and humans is only **0.01%** of all the water on Earth.

Freshwater, although a renewable resource, is **finite** and is very **vulnerable**.

Freshwater is collected and “stored” in **river basins**.

EU Water Framework Directive (2000)

Approach for water management:

- by river basin, the **natural** geographical and hydrological unit
- not according to **administrative** boundaries.

Ecological and **chemical** protection.

Combined approach:

- **emission** limits (emission-based)
- **water quality** standards (immission-based)

EU Water Framework Directive (2000)

River basin **management** plan: what, when and how.

Public participation:

- balancing interests of various groups
- **transparency** ➔ enforceability

Water **pricing**:

- true cost
- incentive for sustainable use

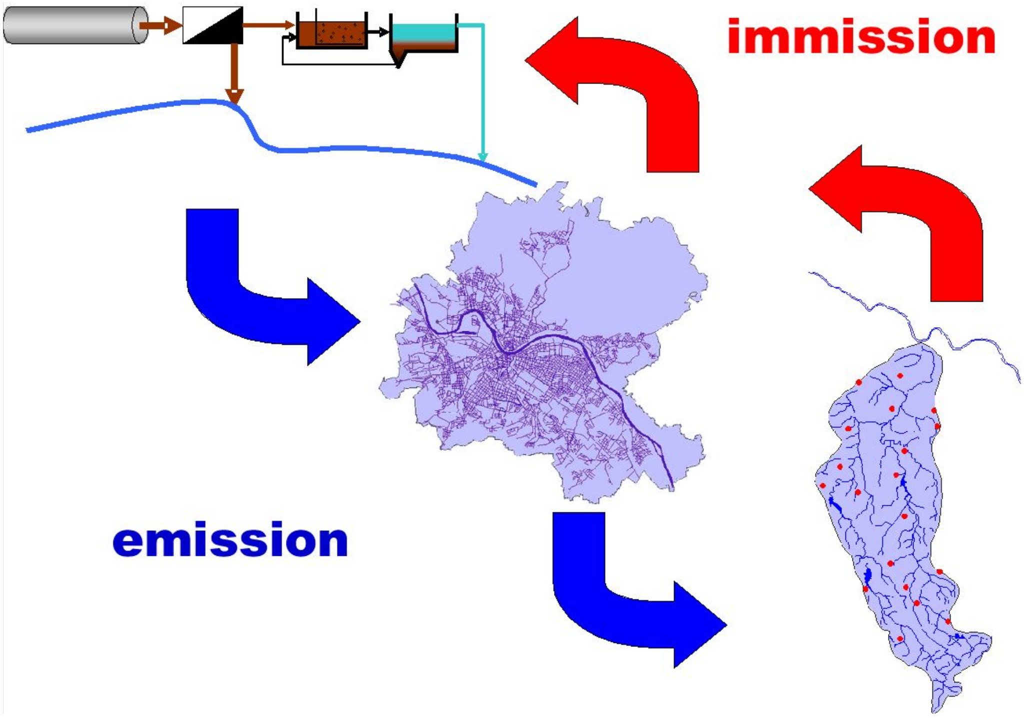
Urban wastewater system

Urban environments are **not** the **major** sources of **pollution** in a river basin in developed countries.

Why are they interesting?

- represent a "**control handle**" in river basin governance
- increased **urbanisation** on the world.

Waste water system optimisation



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Long history…

- **From 3.000 BC**: Mesopotamia, China, Romans, Arabs
- Until 19th century: complex structures but **no** conceptual advances
- Until 20th century: large (**utopian**) projects for quantity management, man governing nature
- 1920s to 1970s: multipurpose planning, **dams** ("not one drop of water should reach the sea"), but also pollution concern and river basin organisations
- 1970s to 1990s: **pollution**, point-source treatment, no unified basin management, centralised decisions

1990s - to date

- **Ecological** state and services
- **Recreational** use
- Increased **complexity**, expert knowledge not sufficient
- **Decentralisation**, democratisation, stakeholder involvement, subsidiarity

Modern urban wastewater systems

- **Sewer** systems: recent (100-200ys)
- **WWTPs**: more recent (<100ys)
- **Rivers**: natural ➔ open sewers ➔ polluted
- Not considered as a **whole**:
  - emission limits
  - different governing bodies/offices
  - local optima ➔ global optimum

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Examples – CD4WC

- Water Framework Directive
  - **Holistic** approach
  - « **good** » chemical and ecological status of natural waters: **Immission criteria**

River water quality evaluates the performance of the urban wastewater system

- www.cd4wc.org

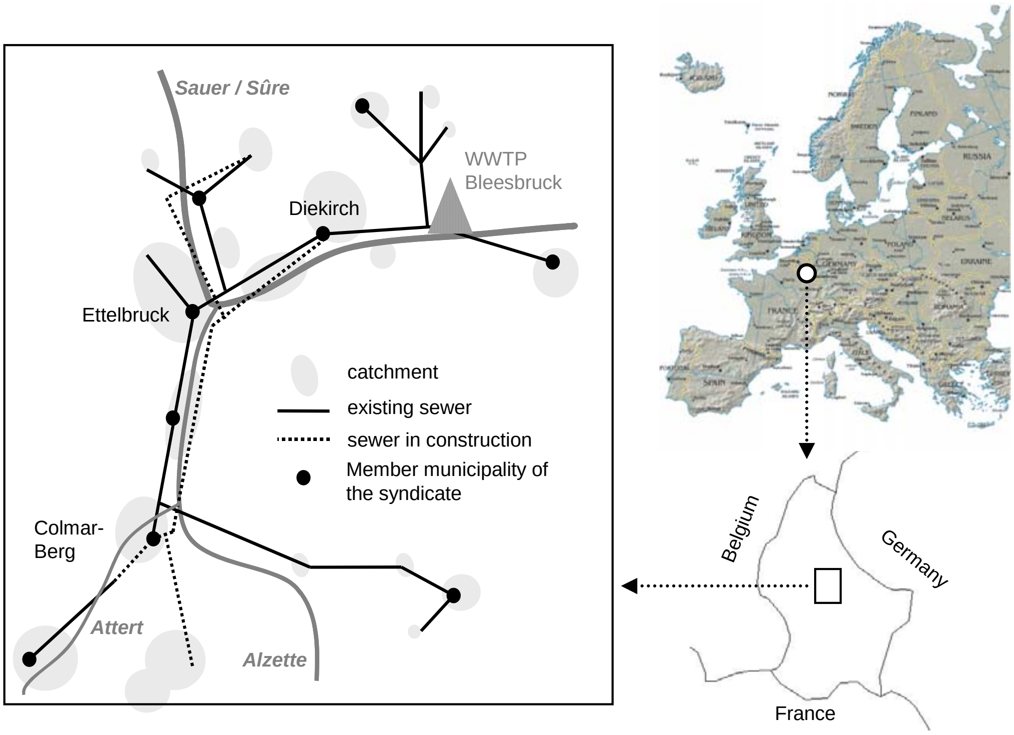
Cost-effective development of
urban wastewater systems for
Water Framework Directive compliance

River Drau (Austria)

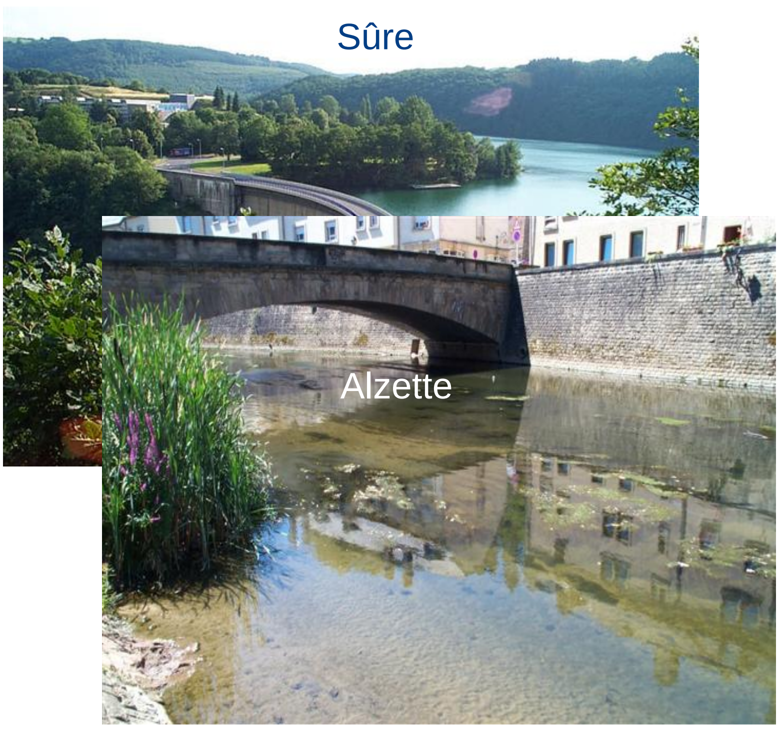
- Alpine river (steep, cold, high oxygen)
- WWTP: insufficient **nitrification** in winter
- **Irrelevant** for discharge into clean and cold water
- **Legislative** problem

- IUWS: potential economic benefit

Case-study in Luxembourg



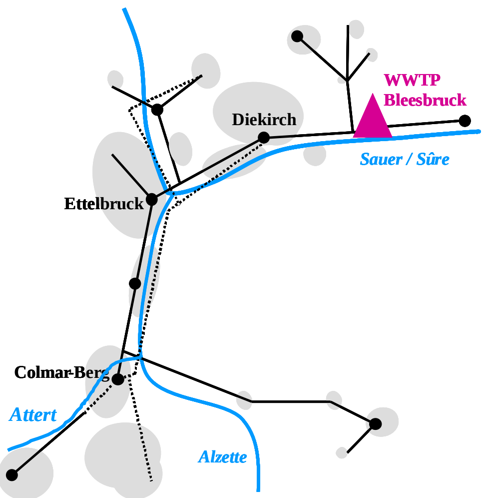
Case-study in Luxembourg



3 river stretches

Length: ± 20 km

Base Flows: 3-15 m3/s



Case-study in Luxembourg – problems

Problems in the river:

- during summer low **DO**: < 5 mg/l
- high ammonium: **NH_4**: > 3 mg/l
- high phosphate: **PO_4**: ~ 0.5 mg/l
- localised high **algae** concentration

Case-study in Luxembourg – pressures

Pressures to the river:

Upstream: Alzette carrying wastewater from populated and industrial South of Luxembourg, agriculture,…

WWTP: No denitrification.

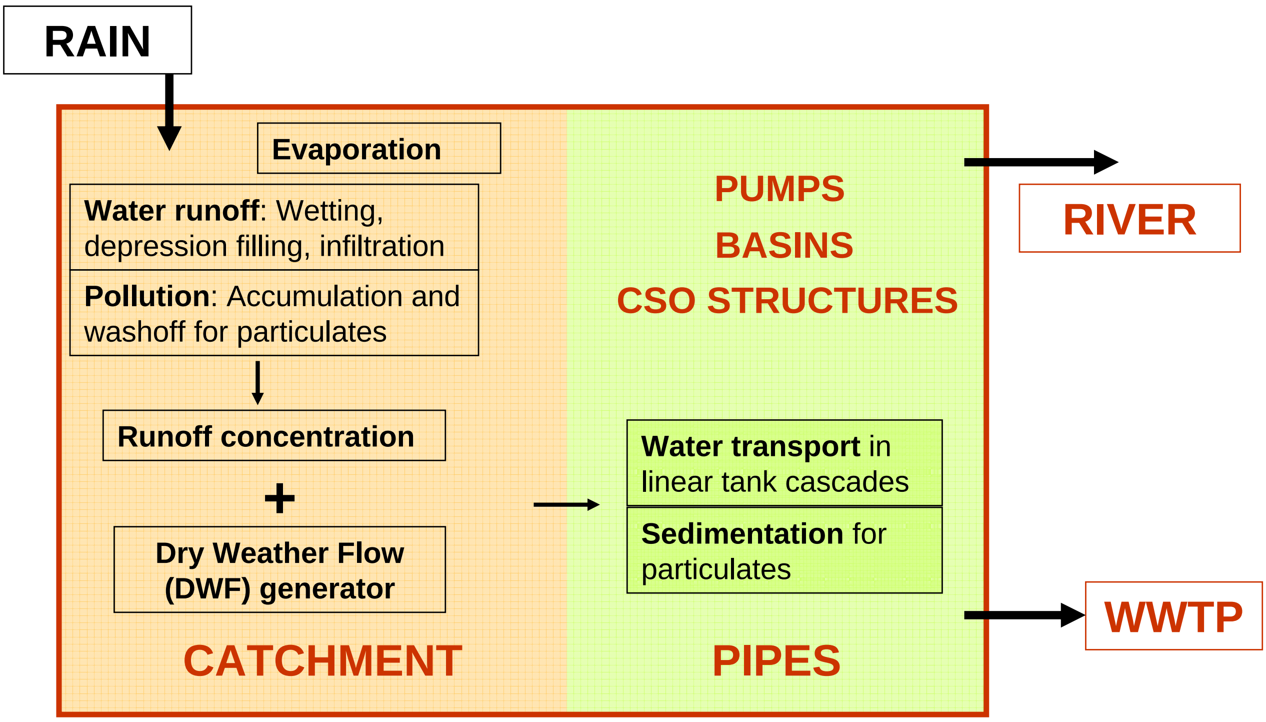
Sewer: No storage volume until now, infiltration, river water intrusion during high flows in winter, not much control potential so far,…

Case-study in Luxembourg – our plan

- **Measurement campaign** on the river and the WWTP
- **Data collection** and deficit analysis
- **Model** building and calibration

Develop scenarios to improve quality of the eutrophied river and test them using simulations of the integrated system.

Case-study in Luxembourg – modelling



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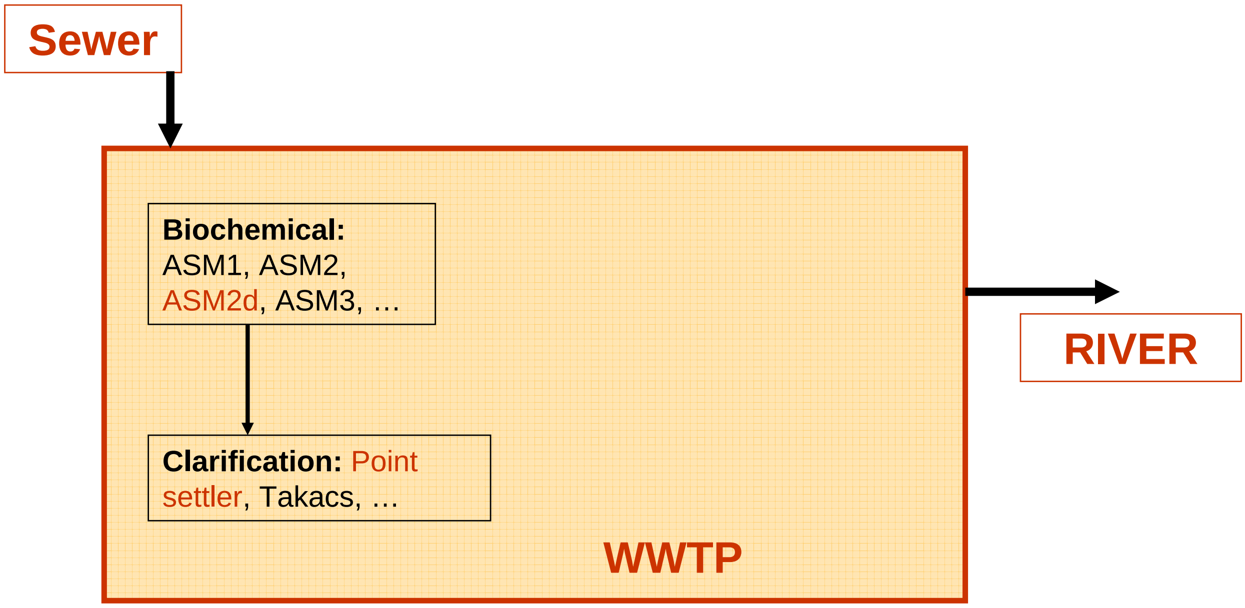

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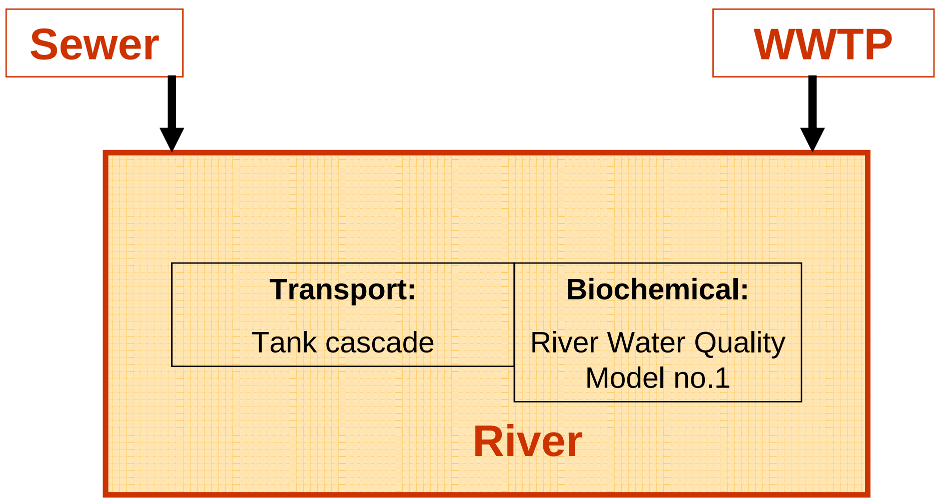

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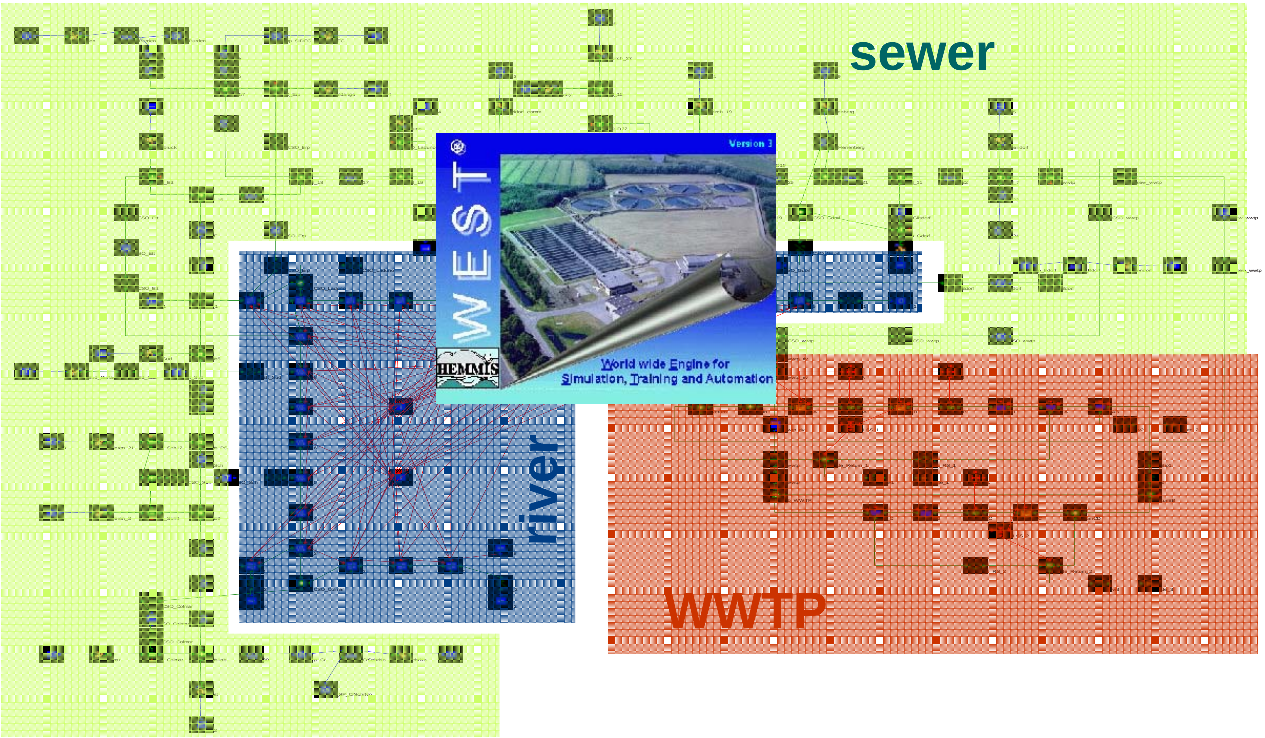


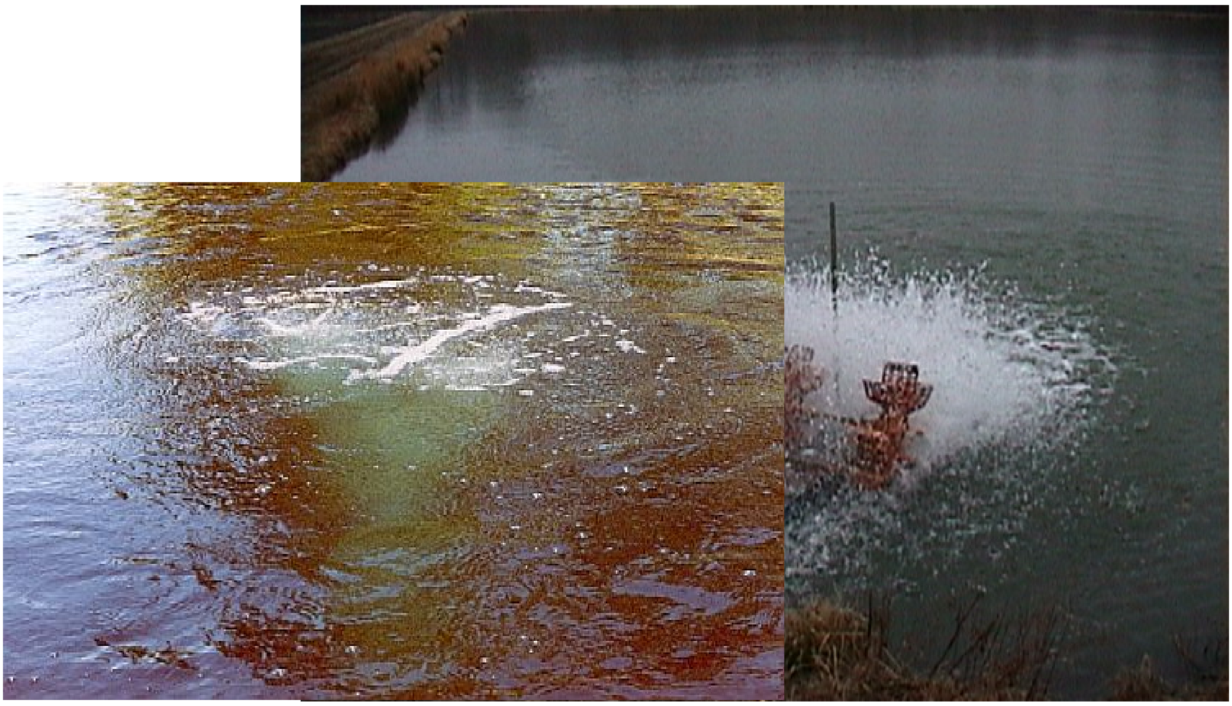
Case-study in Luxembourg – scenarios

Tested scenarios

- **Source control**:
  - Ammonia decoupling — FlatNH3
  - DWF flattening through basins at housing level — FlatDWF
  - Impervious surface reduction — RedImp
- **System rehabilitation**
  - Sewer infiltration reduction — RedInf
  - Retention basins — RetBas
  - Buffer tank for incoming sludges — Buffer
  - Nitrification volume increase — NitVol
- **Operation strategies**
  - Increase in WWTP loading — OvLo
  - Improved nitrogen control — ImprN
  - Improved phosphorus control — ImprP
- **River measures**
  - Shading — Sha
  - Reaeration — Reae

Case-study in Luxembourg – aeration

Case-study in Luxembourg – aeration



Case-study in Luxembourg – shading

Case-study in Luxembourg – criteria

Evaluation criteria

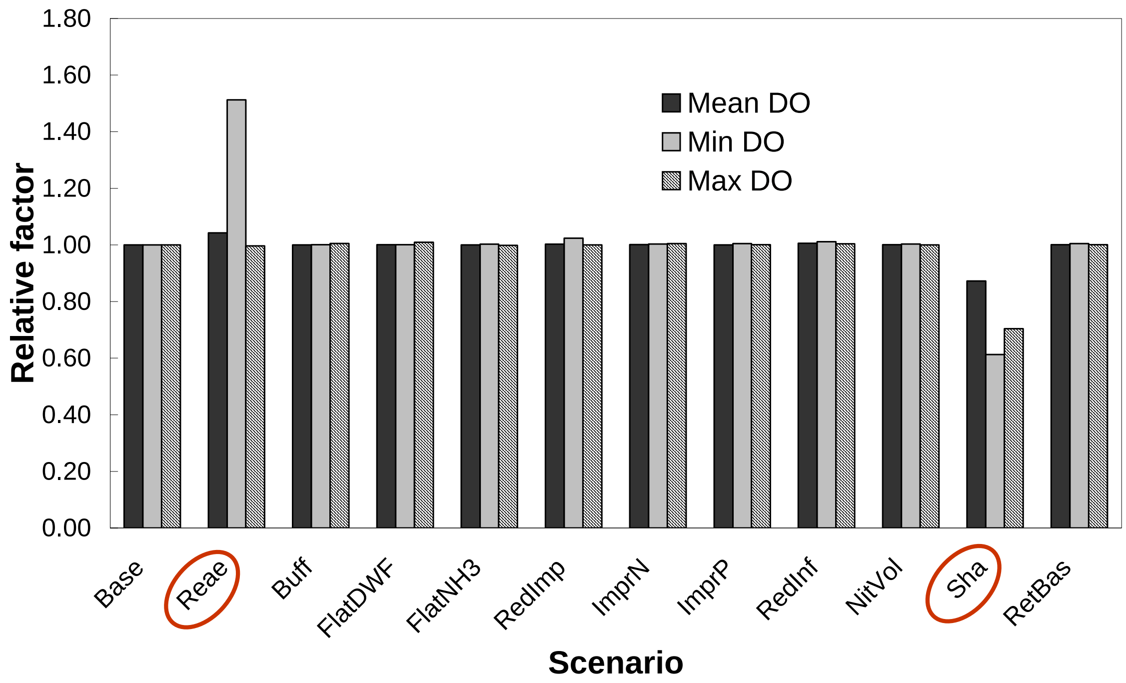
Immission and Emission

Exceedance = period when a certain concentration threshold is exceeded

- Exceedance lengths
- Number of exceedances
- Means
- Maxima
- Minima
- Total loads

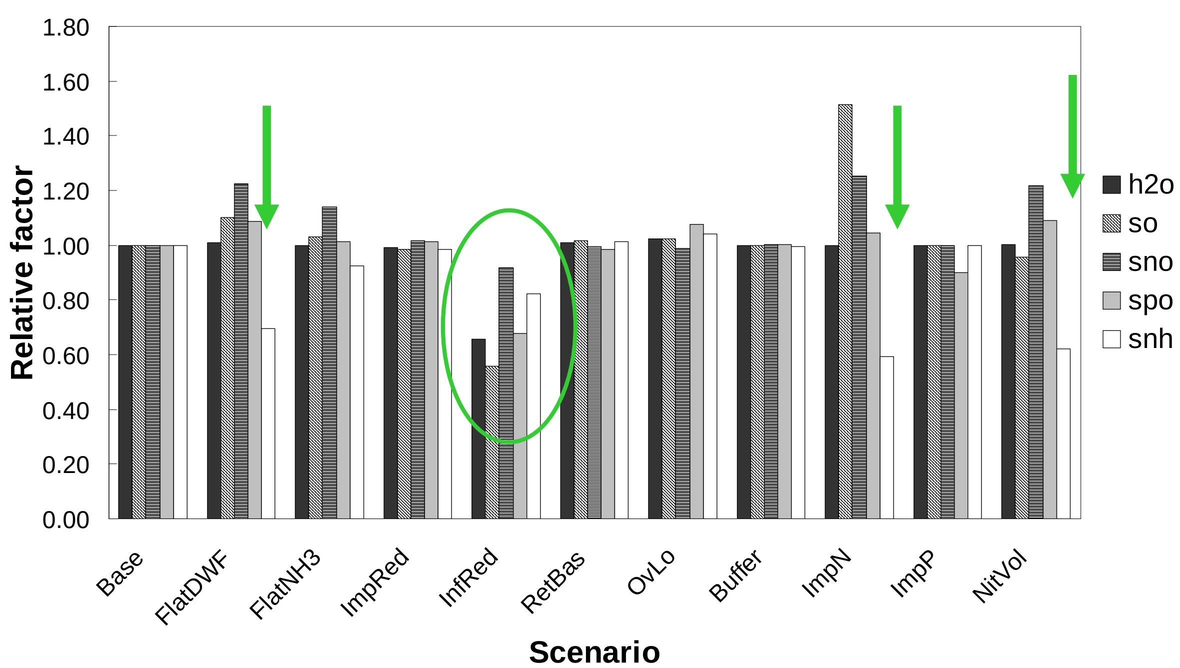
Case-study in Luxembourg – results

Immission: Dissolved Oxygen

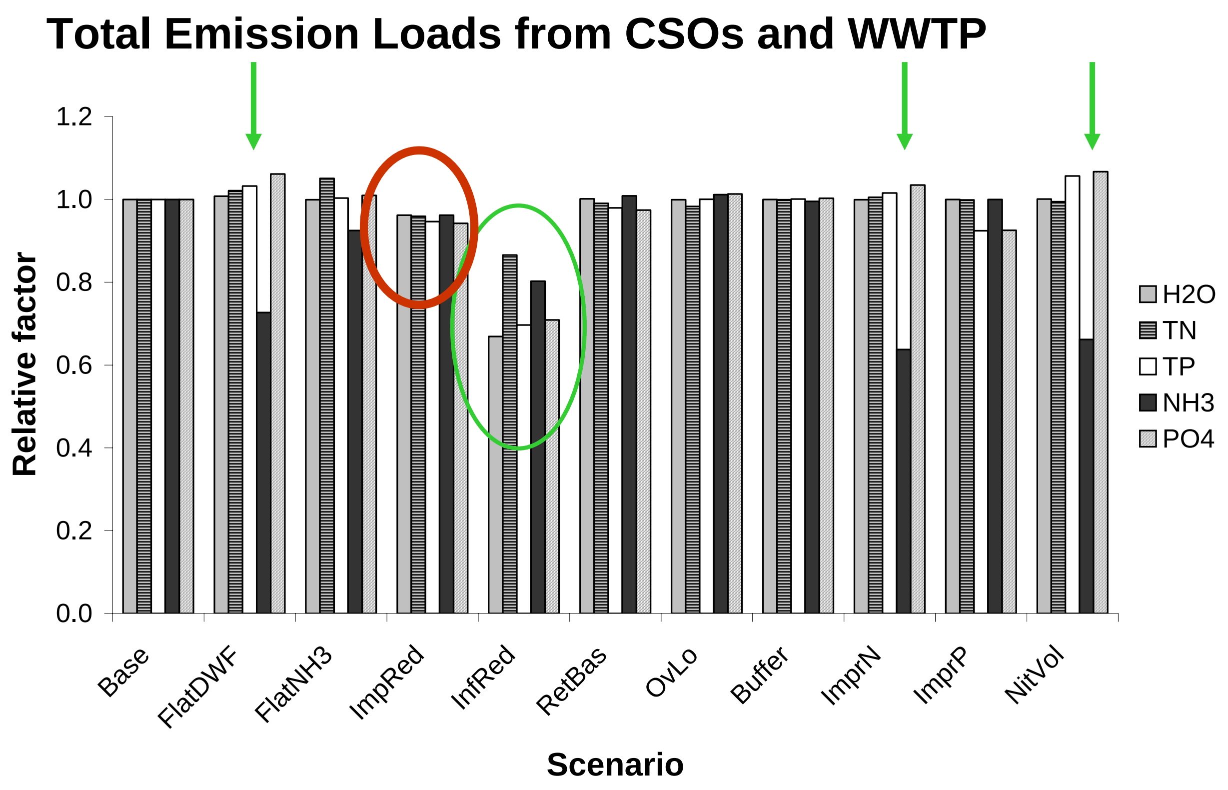


Case-study in Luxembourg – results

Emission Loads from WWTP



Case-study in Luxembourg – results



Case-study in Luxembourg – conclusions

- **Shading** not an option here
- **Reaeration** helps to improve DO concentrations, but is expensive
- **Background pollution** large compared to impact of catchment, therefore measures within the catchment seem to have little impact
- Measures are often expensive, **N-control** and **P-control** cheap to implement bringing about good changes
- **Infiltration reduction** reduces loads significantly
- **Imperviousness reduction** shows beneficial impact (keep impervious surface to a minimum during planning processes)

Case-study in Luxembourg – conclusions

Benefits of **IUWS**:

- Possibility to **compare** effectiveness on **receiving water quality** of measures in the **whole** system (catchment, sewer, WWTP, river)
- Useful to prioritise **investments**

Developed methodology – methodology + practice

Systems analysis

- Substance Flow Analysis
- Indicators

"WHERE ?"

Systems design (WWTP)

- Influent
- Modelling
- Probabilistic analysis
- Emission-based evaluation
- Immission-based evaluation

"HOW ?"

Outline

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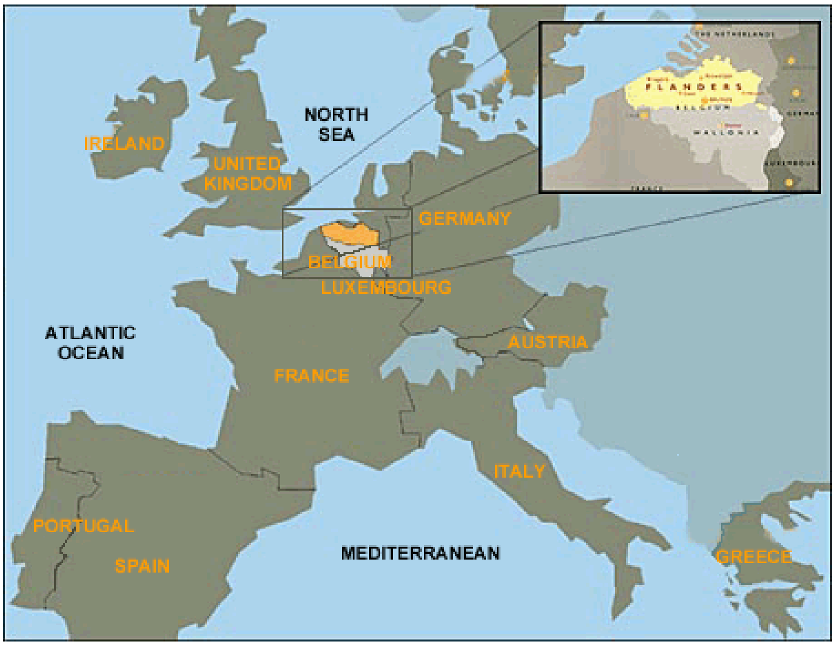
Case study for systems analysis

The **Nete** river basin



Substance Flow Analysis

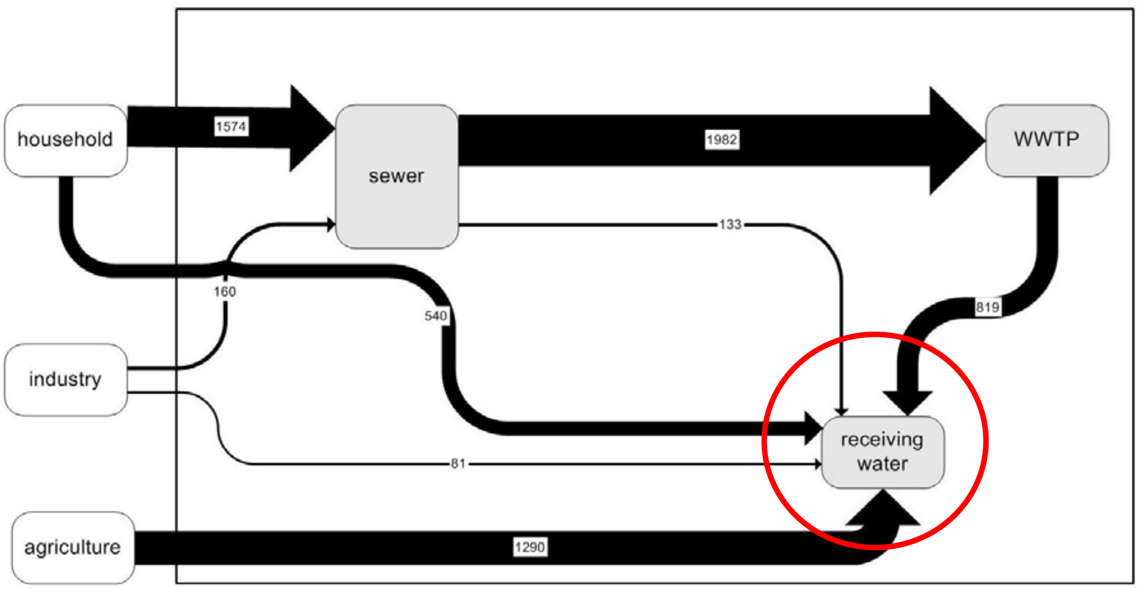
Substance Flow Analysis:

- accounting for the flows of a substance
- to, through and from a system
- over a determined time period

Studied substances:

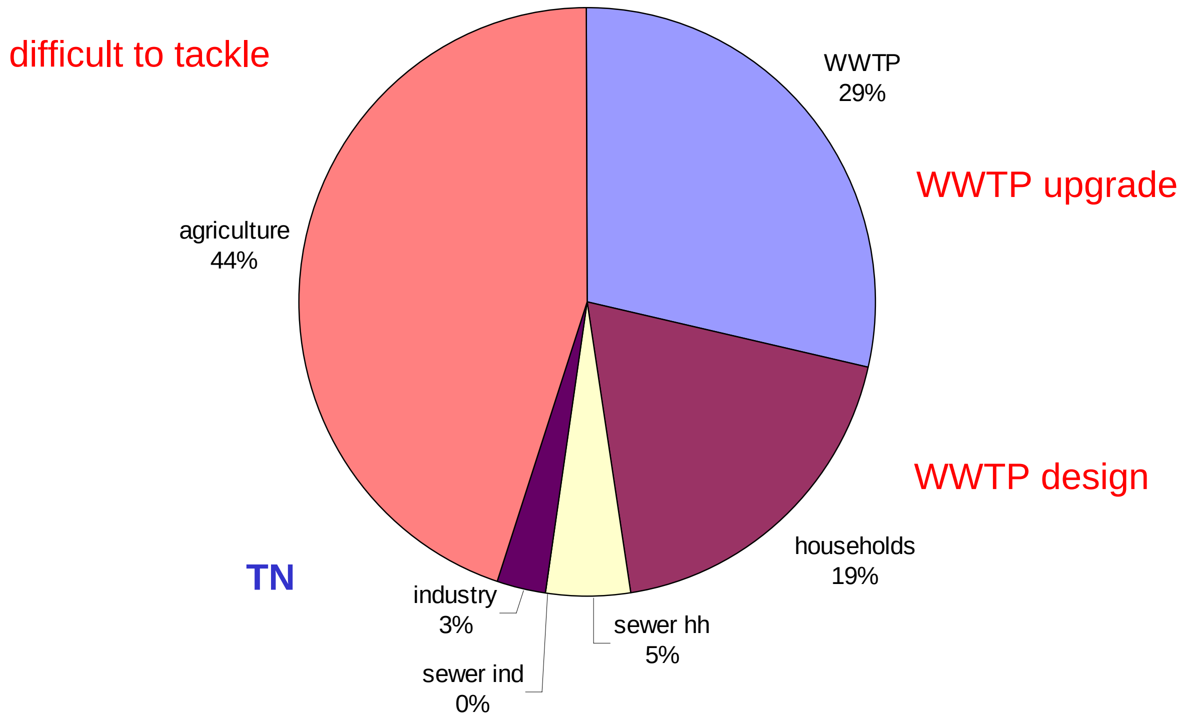
- water
- BOD
- COD
- Total Nitrogen
- Total Phosphorous
- Zinc

Substance Flow Analysis – Sankey diagram



Total Nitrogen [ton/y]

Substance Flow Analysis – pressures on RW



Systems analysis – conclusions – SFA

SFA of the IUWS allows to identify the **pollution paths** and the **pressures** on the receiving water.

Stressors in the Nete basin (for all substances):

- unconnected households
- WWTPs
- agriculture (limited to nutrient emissions)

Outline

Systems analysis

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Systems design – “HOW ?”

Case of WWTP

Aim at **general** advice:

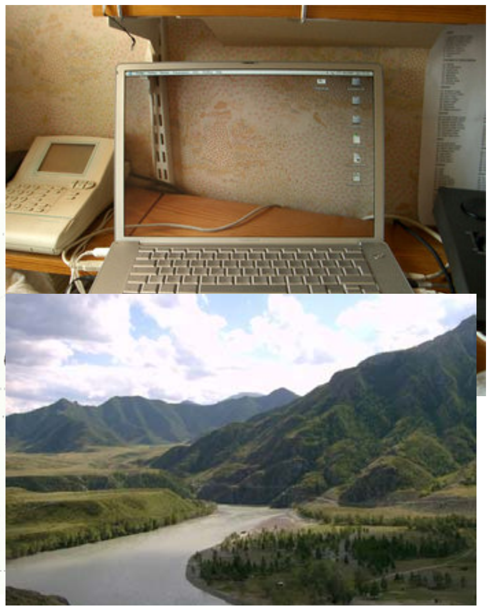
- 4 climate types
- 3 plant sizes
- 10 plant configurations

More information, **transparency**
➔ uncertainty analysis

Data **overload** ➔ descriptors

Combined approach:

- emission-based evaluation
- immission-based evaluation



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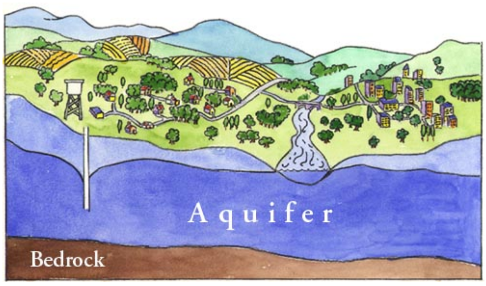
Modelling the WWTP influent

Use of **long term dynamic influent** data: seasonal effects, variability of disturbances

Simple model of the draining catchment:

- number of **inhabitants**
- presence of **industry**
- **loads** *per capita* of households and industry
- **size** of the catchment
- length of the **sewer** system
- **rainfall** data
- interactions with **groundwater**.



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- **Probabilistic analysis**
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Uncertainty

Lack of sureness about something.

From a falling **short of certainty** to an almost **complete lack of knowledge**.

It is seen as **negative**.

It is usually **disregarded**.

It must be made **explicit**.

Probabilistic analysis – uncertainty

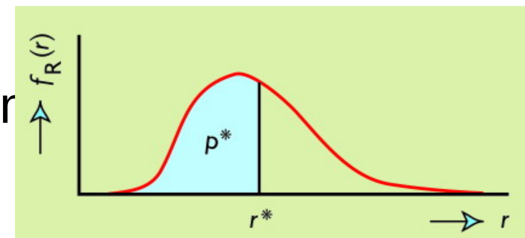
Models are **imperfect**:

- inputs
- parameters
- equations

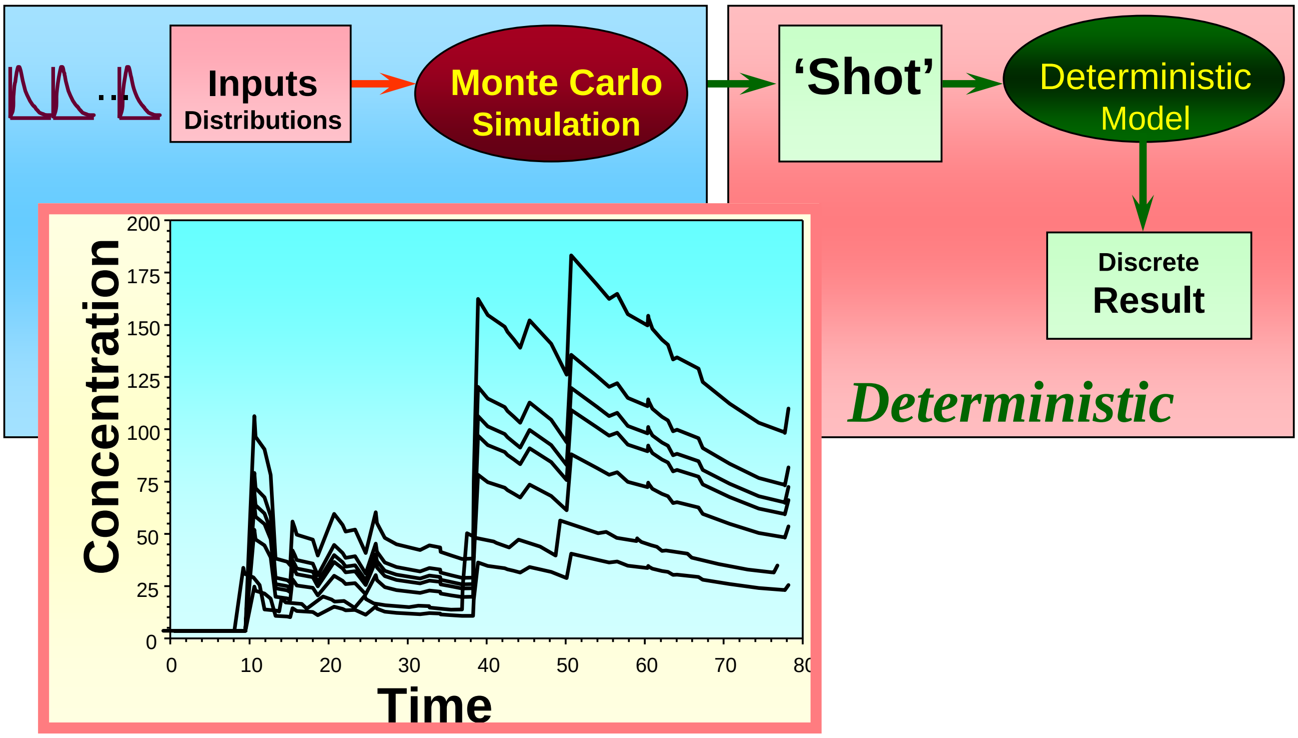
Information is available on uncertainties:

- probability distributions

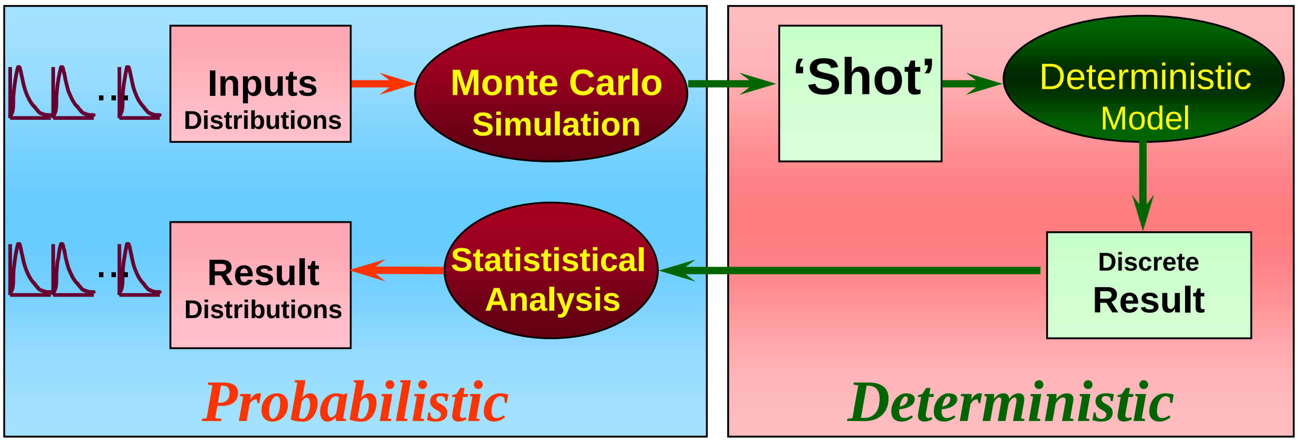
Uncertainty is propagated to r
(Monte Carlo simulations)



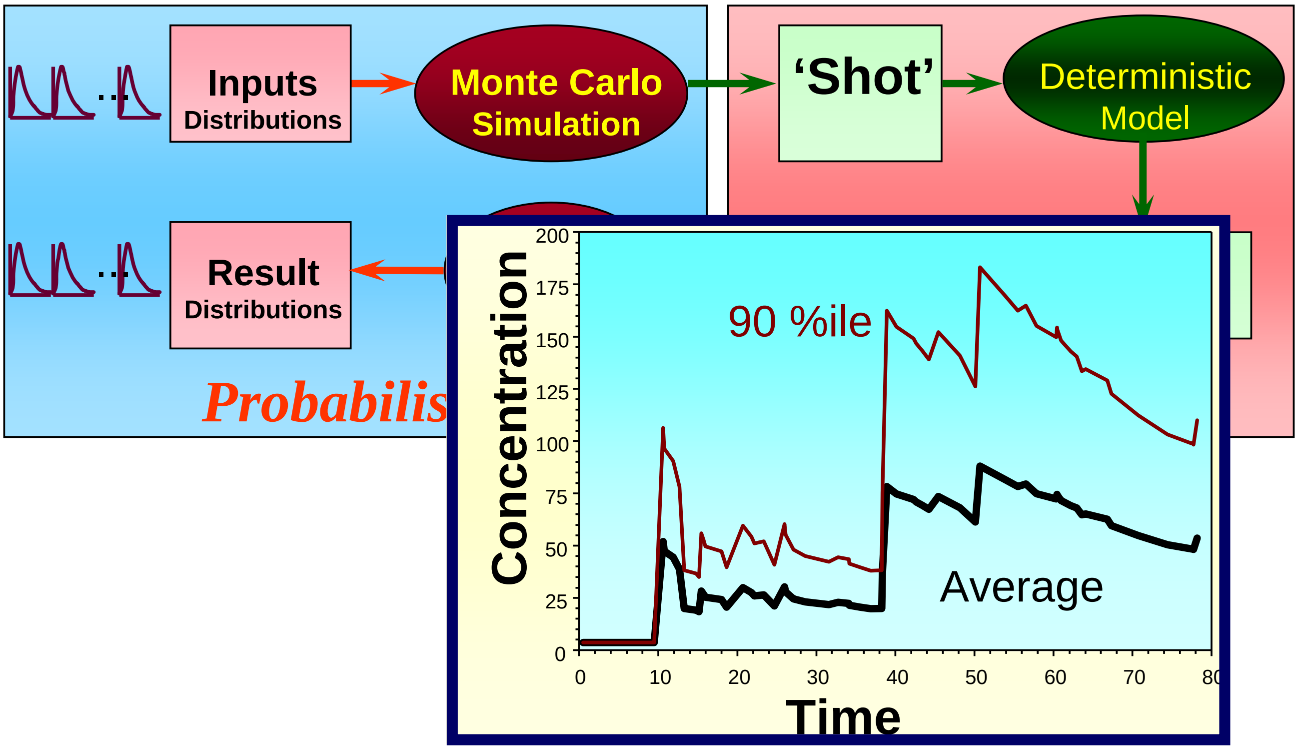
Probabilistic analysis – uncertainty



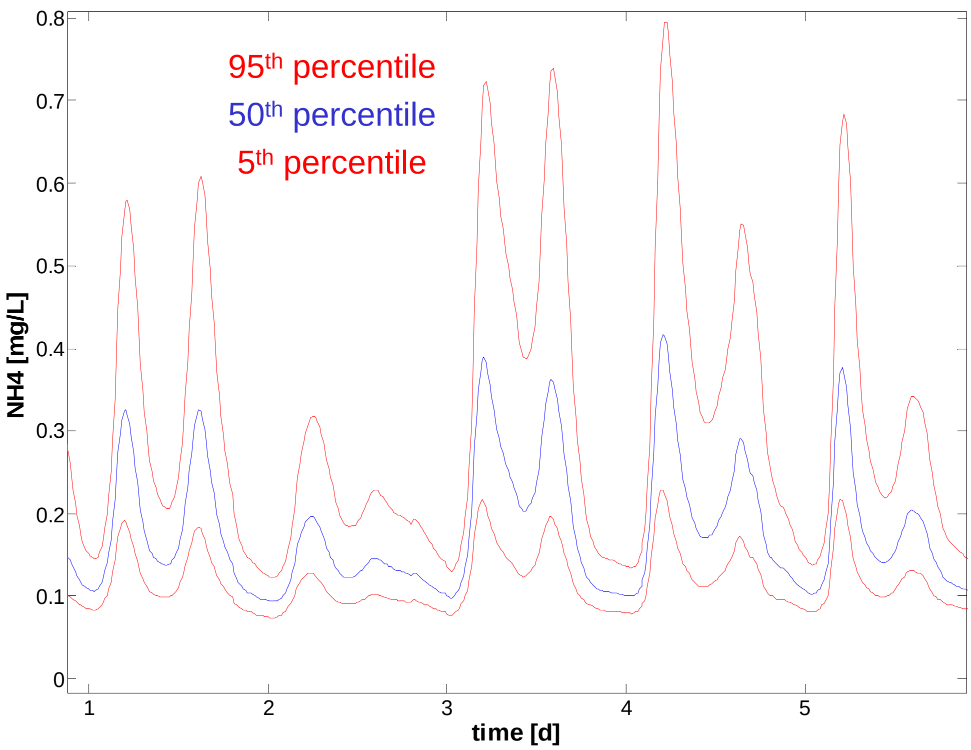
Probabilistic analysis – uncertainty



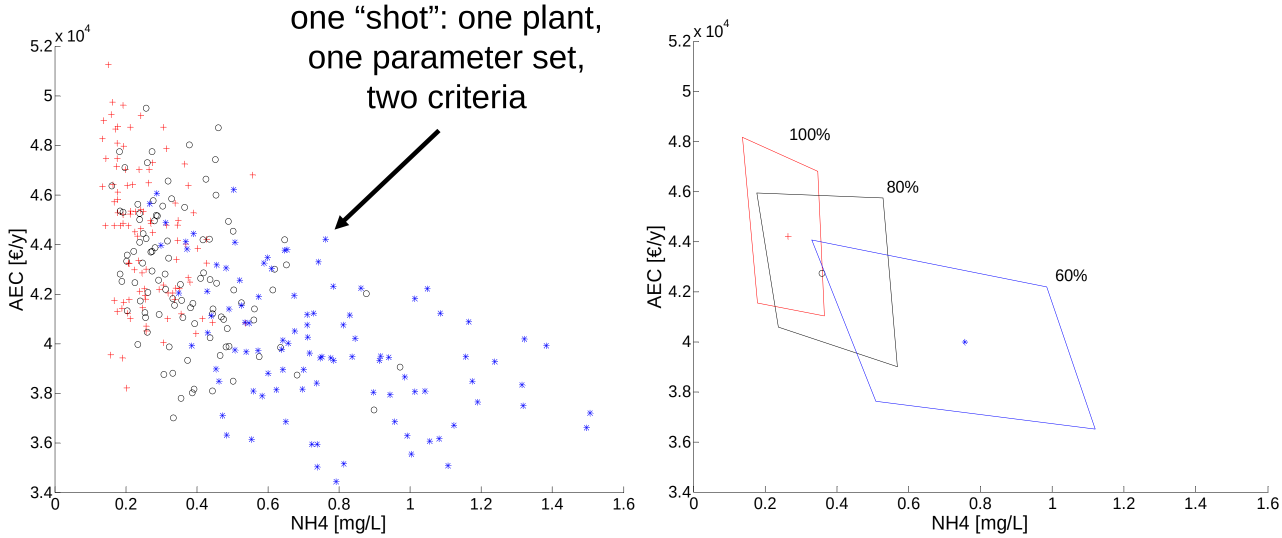
Probabilistic analysis – uncertainty



Probabilistic analysis – time series



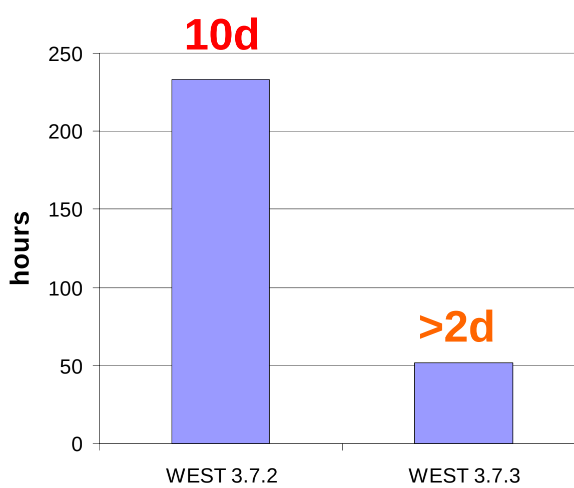
Probabilistic analysis – percentile polygons



Yearly averages for ammonia effluent and aeration costs: cloud (L) and 5th-95th percentile polygons (R).

Probabilistic analysis – feasibility

Computational **burden** ➔ **distributed** simulations (Typhoon)



100 simulations of LLAS model (50d in steady state and 415d dynamic) with input and output data every 15 minutes

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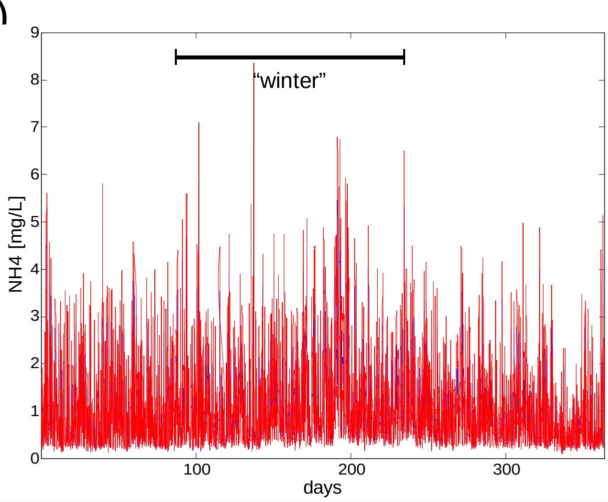
- Immission-based evaluation

Emission-based evaluation of alternatives

Environmental performance:

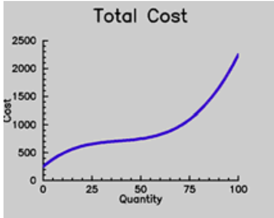
- effluent TSS, BOD_5, COD, TN and TP concentrations
- **Effluent Quality Index** (EQI)
- period of **effluent violations**

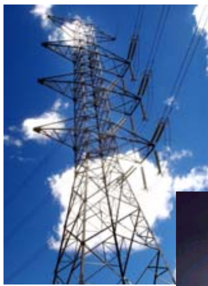


Emission-based evaluation of alternatives

Economic performance:

- use of cost **functions**
- depending on the **country/region**
- rough estimates for process options **screening**
- **sludge** production
- **energy** and **chemicals** consumption
- **data** from Aquafin and Ruhrverband



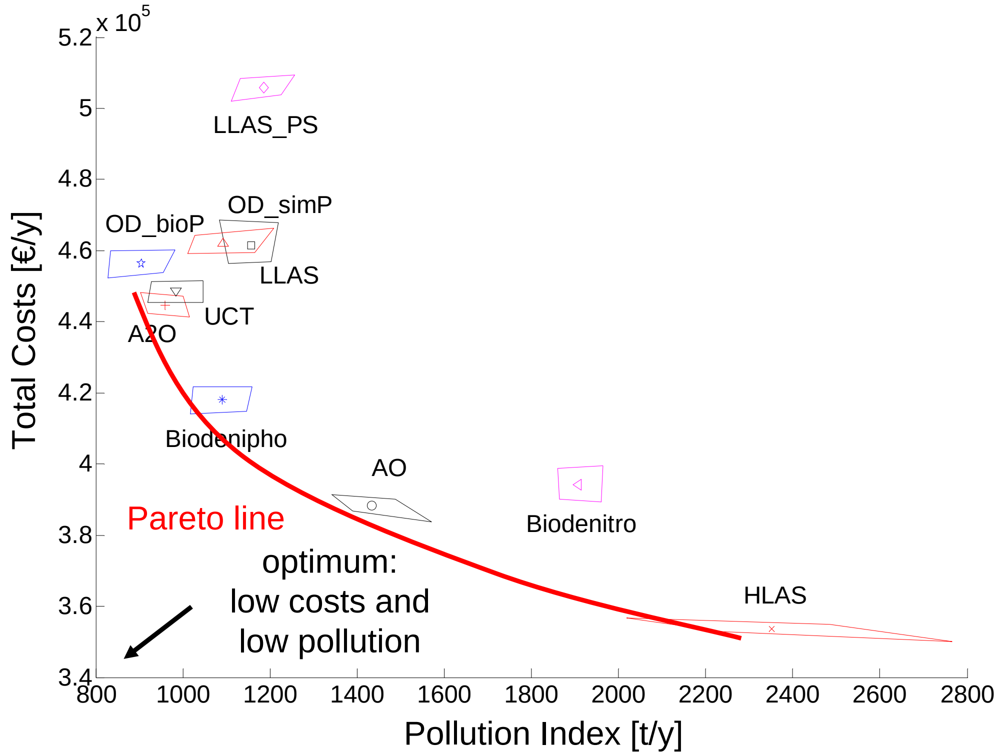


Modelling WWTP alternatives

Ten process configurations for **design** for 30.000PE in Oceanic climate:

anaerobic-anoxic-oxic (A2O)
anaerobic-oxic (AO)
Biodenipho
Biodenitro
high loaded activated sludge (HLAS)
low loaded activated sludge with bio-P removal (LLAS)
LLAS with primary settler (PS)
oxidation ditch with bio-P removal (OD_bioP)
oxidation ditch with chemical P removal (OD_simP)
University of Cape Town process (UCT)

Emission-based evaluation – design – EQI/TC



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  - **Immission-based evaluation**

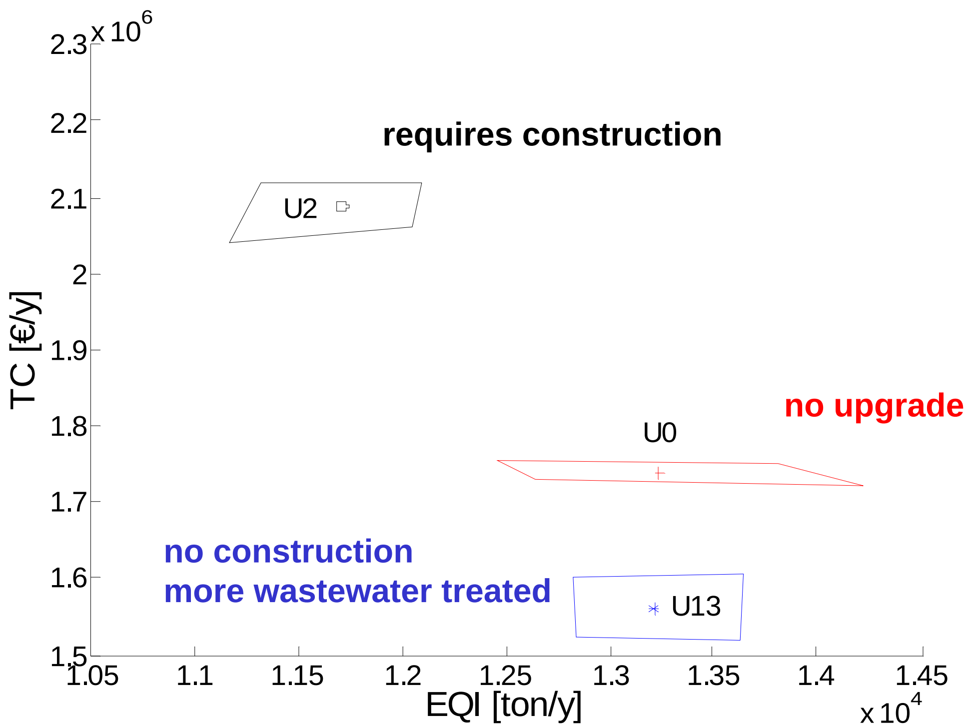
Immission-based evaluation – upgrade

Low loaded system 300,000PE Continental climate

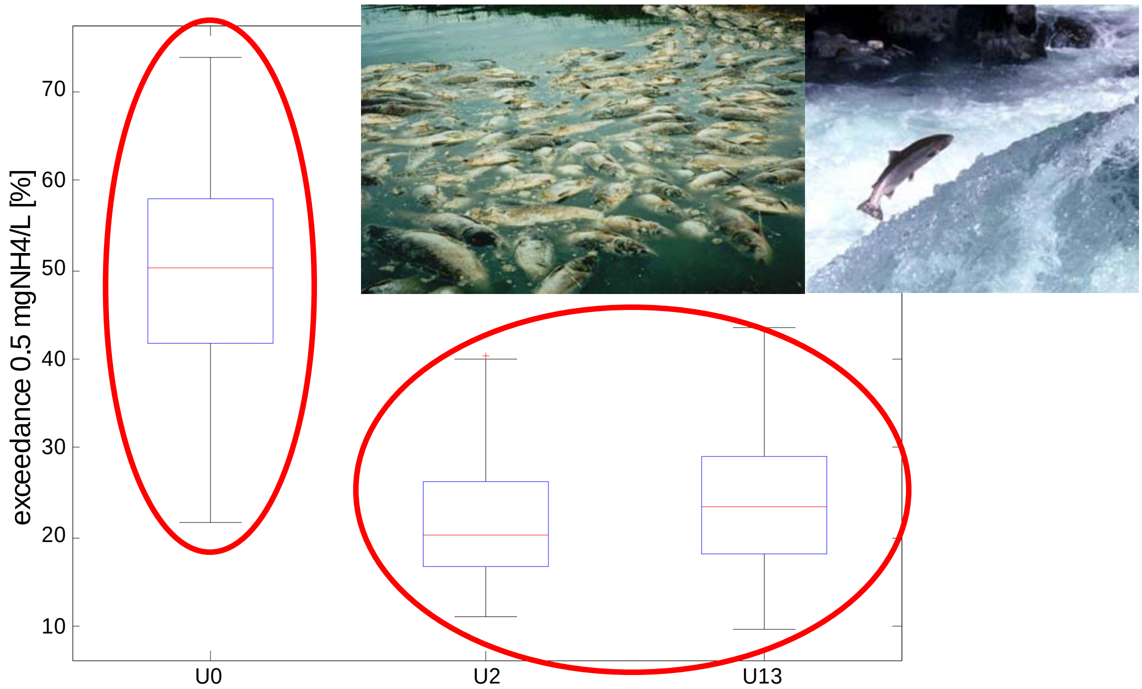
➔ 3 different activated sludge **upgrades**:

(out of 12 evaluated)

Immission-based evaluation – EQI/TC of effluent



Immission-based evaluation – NH_4 in the river



Systems design – conclusions

Immission-based evaluation:

- “more wastewater” shows bad performance for WWTP effluent **BUT**
- “more wastewater” is much cheaper than “construction”
- “more wastewater” performs as well as “construction” for receiving water quality

Conclusions

Uncertainty is made explicit.

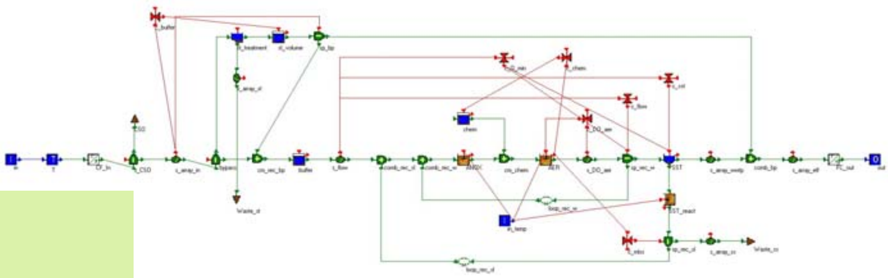
Robustness of configurations against process disturbances.

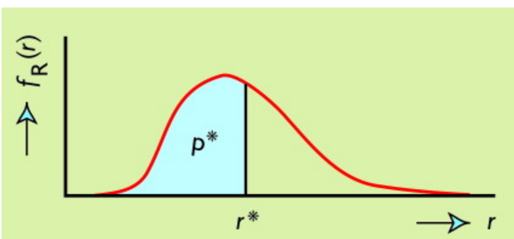
Water quality based regulation ➔ effluent quality is not sufficient to take appropriate and informed decisions ➔ substantial **savings** can be achieved with **IUWS management**.

CD4WC general conclusions

The actual availability of well-accepted

- **models**
- **risk assessment** techniques
- sufficient **computational power**





CD4WC general conclusions

The actual availability of well-accepted

- **models**
- **risk assessment** techniques
- sufficient **computational power**

should move the design practice and planning process

- from the use of **conservative** and **not flexible** rules
- to more **advanced**, **transparent** and **cost-effective** procedures.

Industrial districts

Protocol for the quantitative assessment of industrial effluents for discharge permitting

Funded by the Water Research Commission of South Africa

- University of KwaZulu-Natal (Prof. Chris Buckley)
- eThekwini Water and Sanitation
- University of Cape Town (Prof. George Ekama)
- Sasol
- BIOMATH

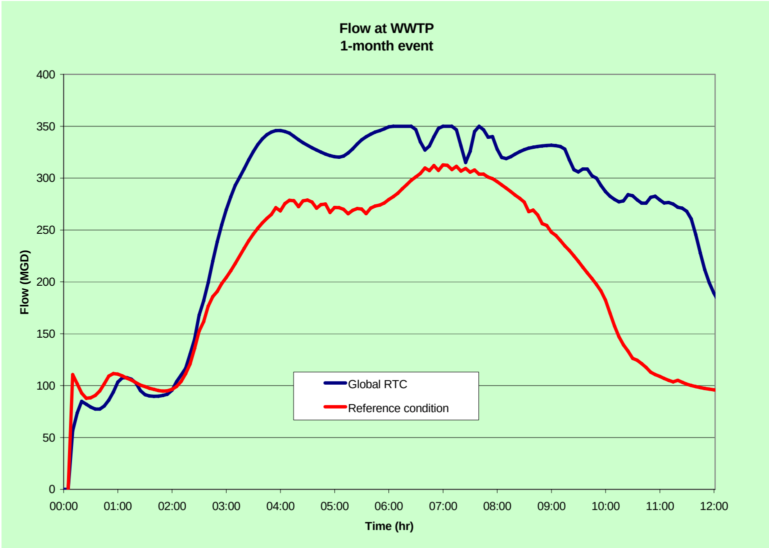
Case-study – Umbilo WWTP


Industrial districts

- Study the effect of **textile effluents** to WWTPs
- Study the **removal** processes for colour, conductivity and heavy metals in WWTPs
- **Model** the industrial catchment and the WWTP to evaluate **joined effects** on treatment capacity
- Set fair and scientifically sound discharge **permits** ➔ legally **enforceable**
- Provide **guidance** to the whole South Africa

Global Real Time Control for CSO reduction

Maximize inflows to WWTP

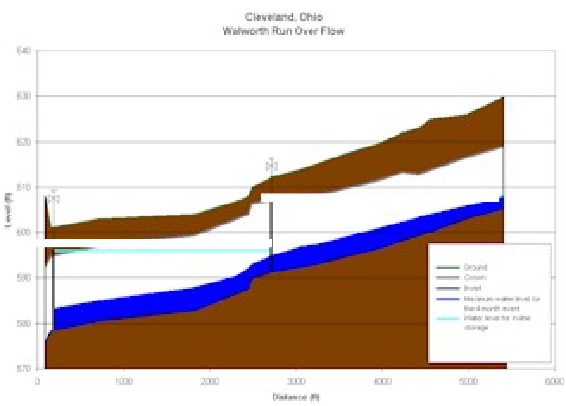


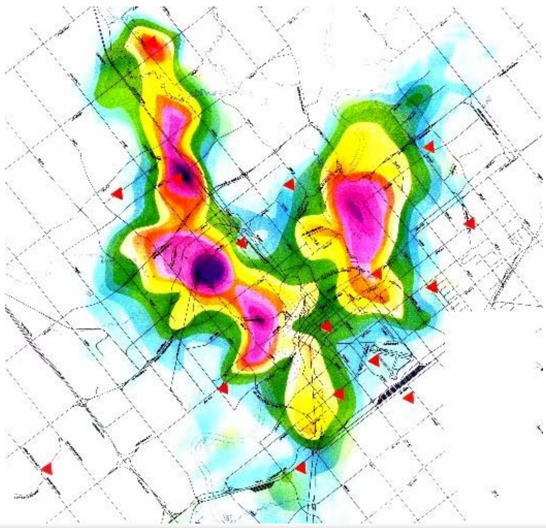
Global Real Time Control for CSO reduction

Maximize inflows to WWTP

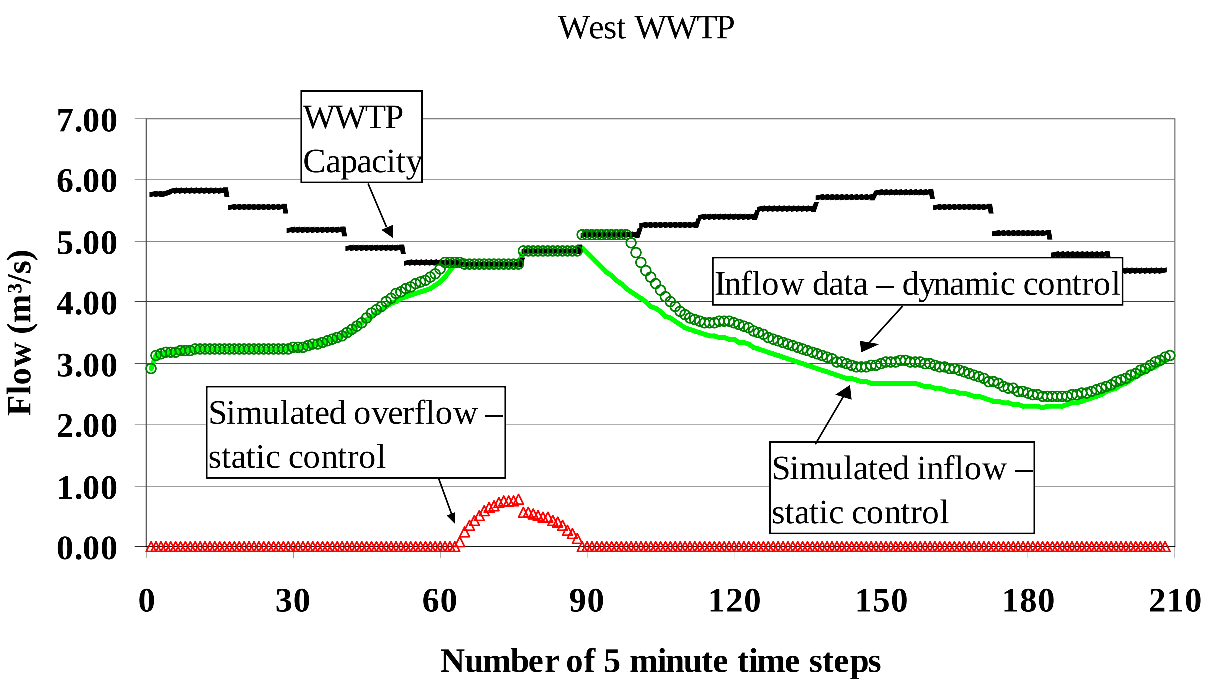
Use in-line storage capacity

Control flows according to rain distribution





Interactions WWTP-sewer



Québec City project

Québec City project

- 550 square kilometres - Population of 470 000
- 2 distinct district and 2 WWTP
- 135 kilometres of interceptors - 50 CSOs
- CSO control plan :
  - 2 - 4 overflow per year
  - $US 220 million prior to RTC
  - $US 140 million with RTC

Savings

	Without RTC	With RTC	Savings
Louisville, KY	$ 200 – 250 M	$ 80 M	$ 120 - 170 M
Quebec, Qc	**$ 220 M**	**$ 140 M**	**$ 80 M**
Ile-de-France	$ 3 000 M	$ 2 200 M	$ 800 M
Wilmington, DE	$ 110 M	$ 25 M	$ 85 M

- Savings 30% to 70% on Capital Improvements
- Same environmental objective

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Developments

More and more integration (also in modelling):

- technical and environmental dimension (WWTP, sewer, river, catchment, industry)
- economic dimension
- social dimension

Challenges

After Water Framework Directive:

- bathing water
- groundwater
- priority pollutants

Climate change:

- temperature
- rainfall dynamics
- migrations

Conclusions

Modelling the integrated system takes some extra efforts but it largely **pays back**.

Great tool to prioritise **investments**.


Thank you for your attention !