RECEIVING WATER IMPACTS FROM WASTE WATER SYSTEMS

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1 INTRODUCTION

Acute pollution in rivers may be induced by wastewater systems, above all from combined sewer overflows (CSO). In view of the EU Water Framework Directive, the ambient water-quality based approach (“immission principle”) becomes part of a combined approach together with the well established precautionary principle (“emission principle”). The background is to design and operate wastewater systems such that good receiving water quality is not threatened by outlets. Since the link of emission characteristics to ecological receiving water quality still remains an unsolved problem, simulation efforts aiming at describing receiving water impacts typically apply compounds concentration after mixing, oxygen depletion or the extent of change in flow rate as indicators.

In the present study, long term simulation studies were carried out to identify characteristics of critical events with regard to TSS load, NH_3 toxicity and oxygen depletion. The simulation results were analysed with extreme value statistics and regression analysis methods to identify driving indicators.

2 APPROACH

2.1 Simulation

A coupled model system was set up on the SIMBA platform (ifak, 2005), including the sewer model SWMM 5.0 (EPA, 2006), the ASM1 wastewater treatment plant model (Henze *et al*., 2000), and a simplified version of the RWQM1 river water quality model (Reichert *et al*., 2001). Continuous long term simulations were carried out with the coupled model using rain information from gauges with 5-min resolution and covering a period of several years (10 and 7 years for the two case studies).

To achieve a realistic model, all roofs and streets were included with their correct area, connection point to the sewer, surface material and slope. The build-up and wash-off parameters for TSS were defined for the surface materials based on a literature review and on plausibility checks of the model (Dawood, 2012). For the sewage, a realistic daily pattern of flow, NH_4-N and TSS load was defined. The flow measurement period from 2005 to 2011 was used to estimate the 1-years peak runoff that would occur without influence of impervious areas ($HQ_{1,pnat}$, BWK, 2001).

NH_3 was calculated from the NH_4-N concentration as a function of temperature and pH in the water, which were estimated from the known air temperature.

2.2 Statistical evaluation

To carry out extreme value statistics the “Peak over Threshold” (POT) approach was applied (Ribatot, 2007) and analysed with the software R (R Development Core Team, 2009). The POT approach proved superior to the classical block maxima approach because of the limited data that could be analysed with the latter.

For further extremes evaluation with i) scatterplots, ii) correlation analysis, and iii) regression analysis (decision tree, MLR), Matlab (V2009b) with its statistics toolbox was used.

2.3 Indicators

As criterion for hydraulic impact, the relationship between the statistical one-year flood flow of a natural river basin ($HQ_{1,pnat}$) and the actual flow rate was used. According to the German protocol (BWK, 2001) this relationship should not exceed 1.1 to 1.3; in this study we estimated this factor as 1.2. As an indicator for pollution, the concentration of free ammonia (NH_3) was selected to assess acute toxicity based on the intensity-duration curve approach of the Swiss protocol (VSA, 2007). For oxygen depletion, the time period below a certain O_2 concentration as a function of the return period (see e.g. FWR, 1998) is considered decisive. As proxy for accumulative pollution, the emitted TSS load was chosen.

As potential causes for the calculated emissions and effects in the receiving water, the following indicators were evaluated (case 2): i) sum of precipitation, ii) mean rain intensity, iii) climatic water balance from start of simulation period and of the preceding 30 days, iv) number of preceding dry-weather days, v) rain duration, vi) composite parameters from the before mentioned.

2.4 Model catchments

Two cases formed the basis for the study.

1) The urban catchment of the first case (Schindler et al., 2010) is a part of the Dresden catchment, consists of an area of app. 2000 ha with 29% impervious surface area and its sewer system. The model of the real wastewater treatment plant of Dresden was downscaled to 1/5 of its capacity and thus tailored to the modelled catchment, namely to the number of connected inhabitants. A virtual receiving water was set up to be able to generate sensitive reactions. It has a constant low base flow and only moderate self-purification capacity, influenced by significant sediment oxygen demand. The simulation period for this case was 10 years.
2) A smaller sub-catchment of Dresden’s sewer system (Niedersedlitz) was selected for the second case. Here, two discharge points into the small running water Lockwitzbach are in the model sub-catchment: one CSO and one stormwater overflow. A WWTP was not included into the model. The receiving water runoff was represented by a hybrid of a hydrologic response duration model and a hydrodynamic approach for the river, which was calibrated according to the 7 years of measured flow data from 2005 to 2011.

3 RESULTS AND DISCUSSION

3.1 Extreme events analysis

Simulations showed that different events are decisive for relevant impacts in receiving waters with regard to ammonium peak and oxygen depletion. In Figure 1, simulation results of two events support this hypothesis inasmuch as the event shown on the left hand side is more critical for NH_4^+ and NH_3 impact, while the right event is more critical for oxygen depletion. Hence, the severity of the effects of an event is compound specific.

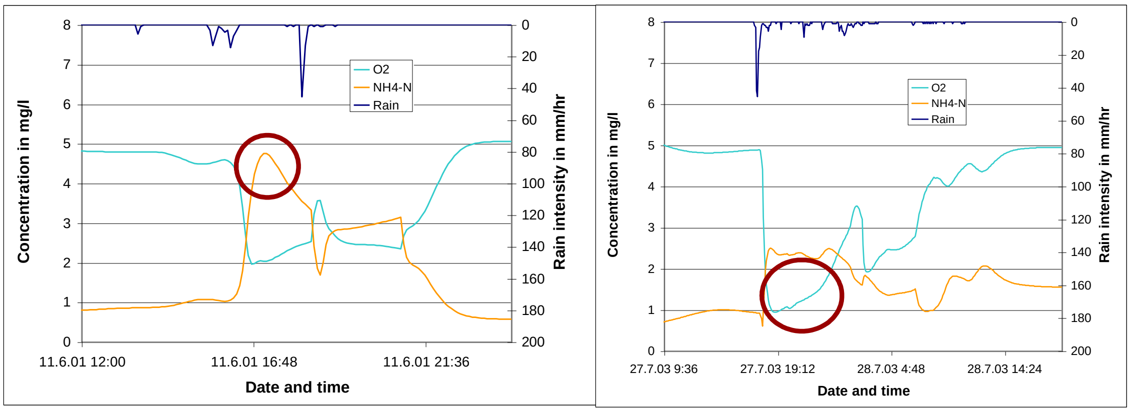
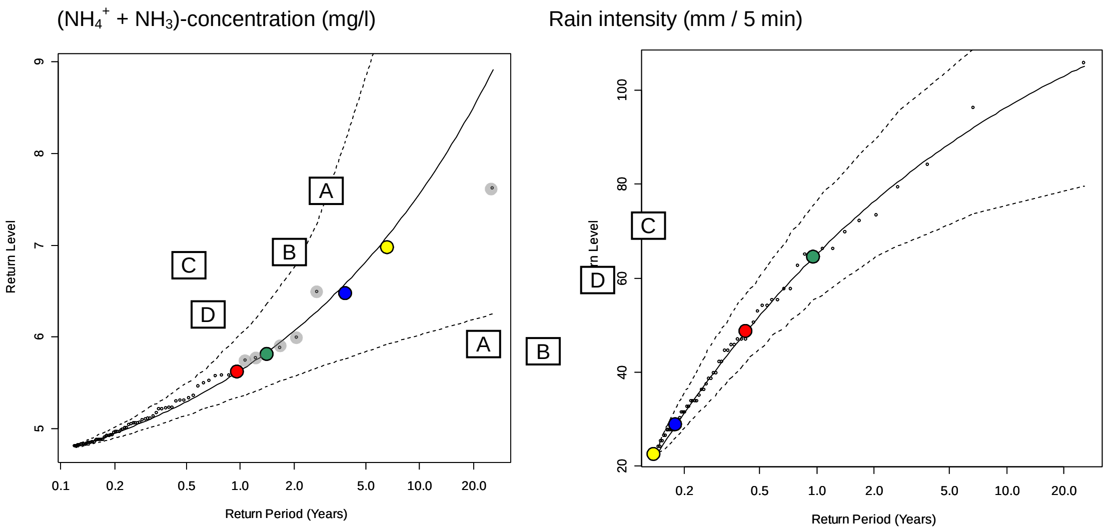


Figure 5: Two events simulations: the peak ($NH_4^+ + NH_3$)-concentration is higher in the left event while the oxygen depletion is more serious in the right event.

In Figure 2, extreme value analyses of ammonium (left) and rain intensity (right) are plotted, showing 5 min peaks of ($NH_4^+ + NH_3$) concentrations and of rain intensities. By identifying the rain events that cause extreme ammonium concentrations in the receiving water it can be stated that these may be caused by events that are relatively frequent. As an example, event A with a ($NH_4^+ + NH_3$) concentration of app. 7 mg/l has a return period of 7 years and is caused by a rain intensity with a frequency of app. 20 per year, while in event C a rain intensity with a return period of app. 1 year induces an ammonium peak with e return period app. 1.5 years (Krebs and Schindler, 2010).


($NH_4^+ + NH_3$)-concentration (mg/l)

Rain intensity (mm / 5 min)

Figure 2: Extreme value analysis for ($NH_4^+ + NH_3$) concentration (left) and rain intensities (right). The labelled dots represent the same events.

The extreme value approach offers the potential to analyse the simulation results such that frequency-duration curves can be compared with limits of guidelines, such as Lammersen (1997), FWR (1998), BWK M3 (2001), VSA (2007), and thus exhibits a strong link to practice.

3.2 Indicator analysis

Generally, scatter-plots, correlation and regression analyses show relatively weak relations to the impact indicators. Therefore, no simple systematic causes of relevant impacts can be identified. However, some statements are possible. Critical ammonia impact correlates strongest with rain intensity and duration, TSS-loads with rain height and intensity. The correlation becomes somewhat better by applying multi-linear regression analysis. For TSS loads, this applies for a combination of rain height, rain intensity and climatic water balance, while for ammonia peaks a combination of rain intensity and duration of preceding dry-weather period show improved correlation.

4 CONCLUSIONS

Acute receiving water impact is the consequence of a complex set of event and boundary conditions. A certain rain event may cause critical conditions for ammonia toxicity, while it is not critical for oxygen depletion and particulates load. Another event may induce a different impact pattern. Very similar events with similar boundary conditions may be harmless in the night hours while being severe through the day, since the compounds concentration in the sewage are much higher in the day hours. Hence, there are no unique major influences and no simple measures to improve the performance of the system to reduce acute receiving water impacts.

In the study described in this paper we developed an approach to adequately comply with this complexity. Continuous long term simulations with coupled detailed models were carried out and extreme values of emission loads and receiving water concentrations were statistically analysed. Such a tool qualifies to improve the systems understanding and to carry out a water-quality based assessment of systems performance and so to evaluate options for system extension and for operation. The great advantage is that a high number of event patterns occurring in a period of several years is checked, while in conventional approaches typically a few events (which might not include unexpected critical configurations) serve to check the quality of extensions.

However, one must be aware that uncertainty is significant in integrated simulation and even difficult to quantify. The remaining drawback of the approach is that it still concentrates on loads (TSS), compounds concentrations in receiving water (NH_4^+ and NH_3) and direct consequences (O_2 depletion). There is still a missing link to ecological river water quality that opens up major research areas.

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Receiving water impacts from wastewater systems

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Karlsruher Flussgebietstage

KIT, 20 June 2013

The system

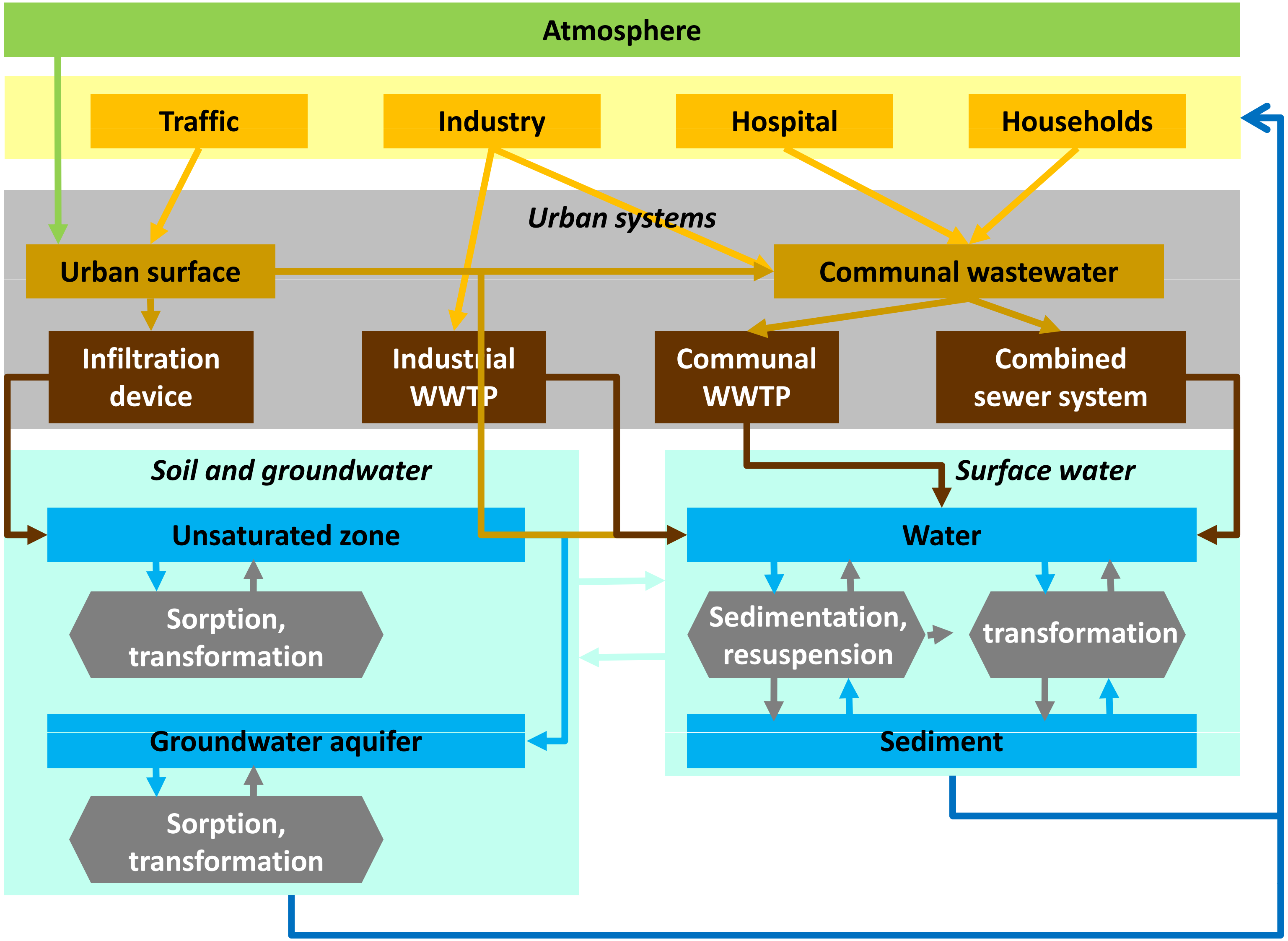
Particles loading

Flush from sewers

Extreme events analysis

Predictor analysis

Flux analysis on urban catchment scale



→ Water, compounds

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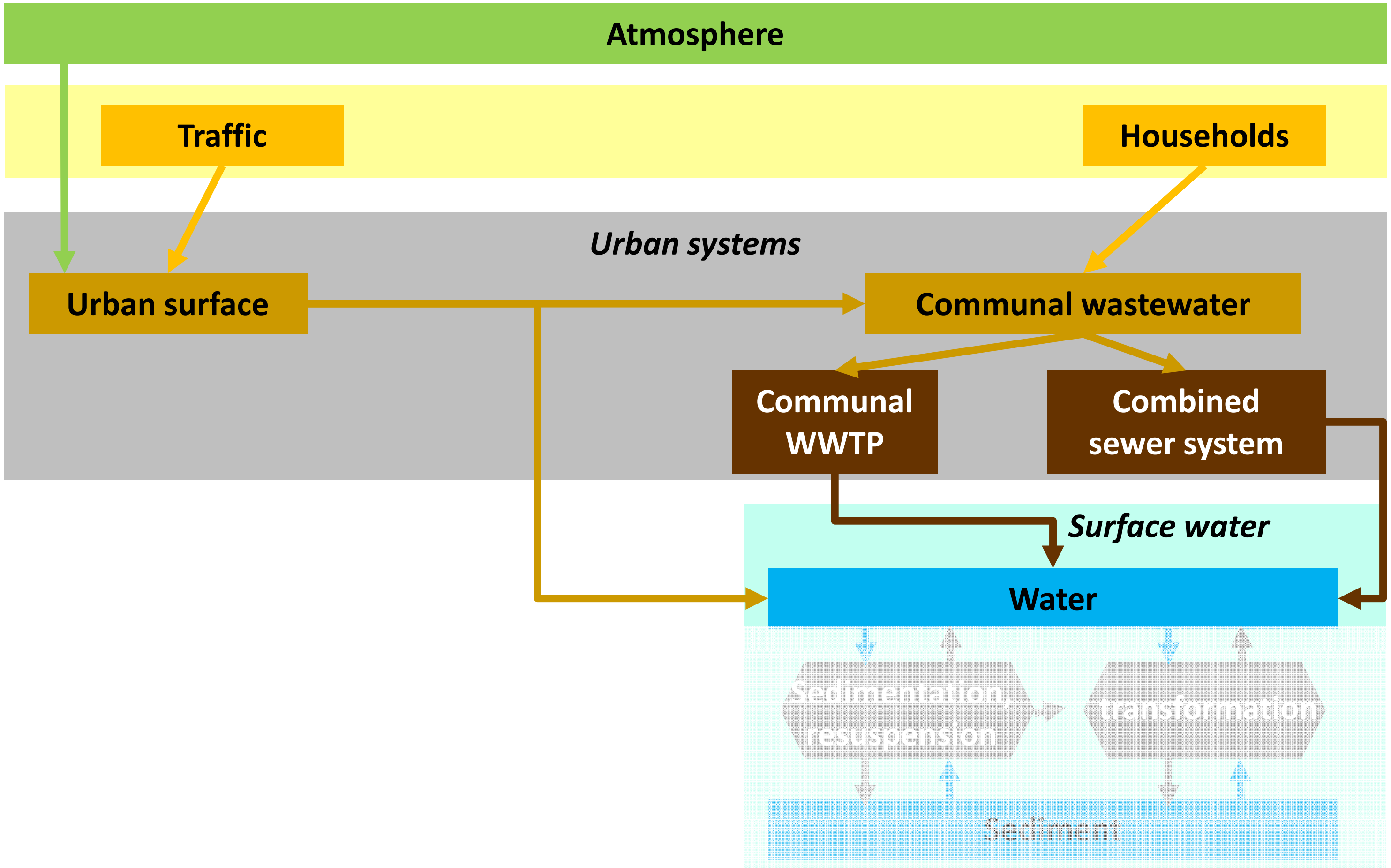
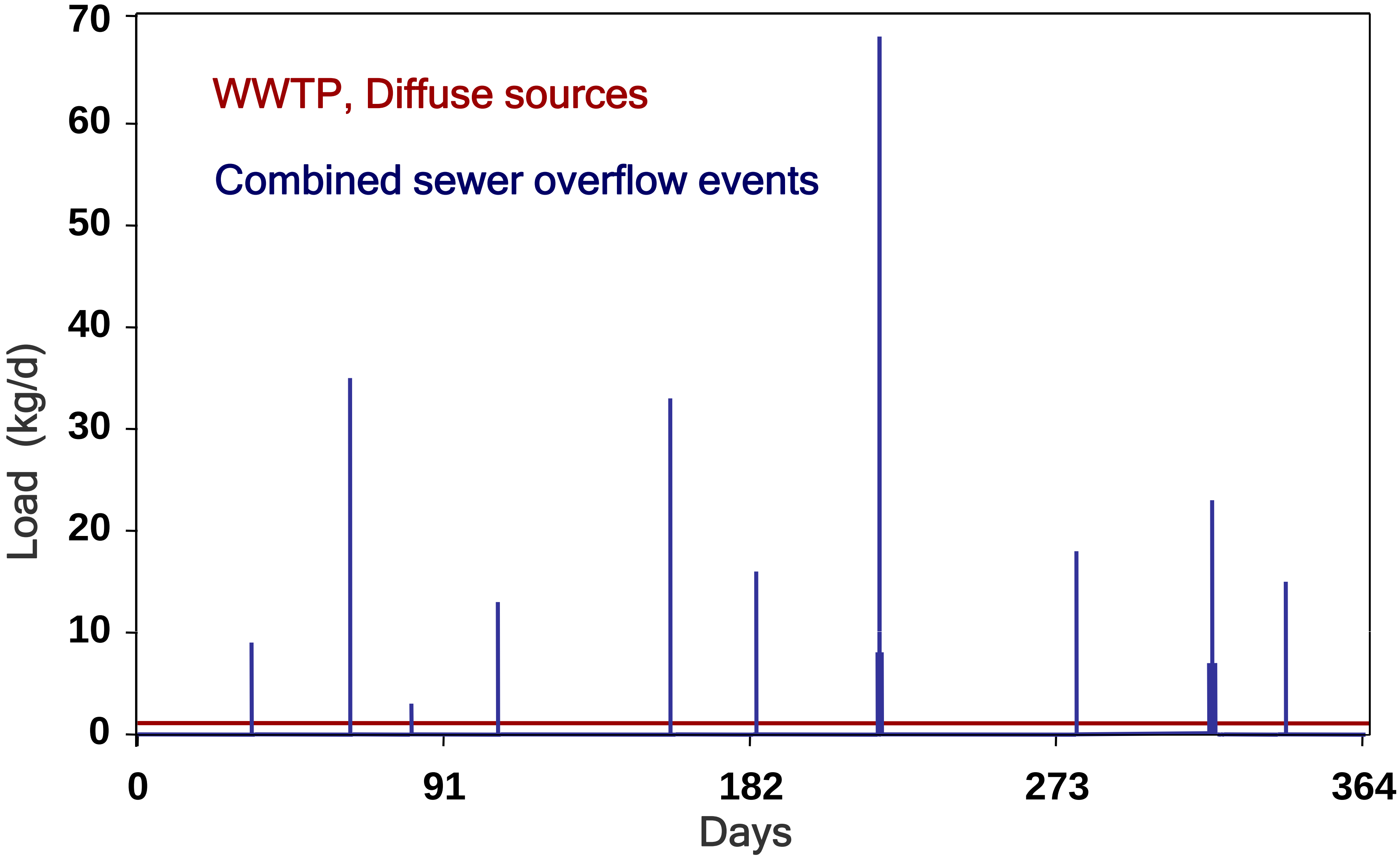
System of today's presentation



→ Water, compounds

Continuous and acute loading



The system

Particles loading

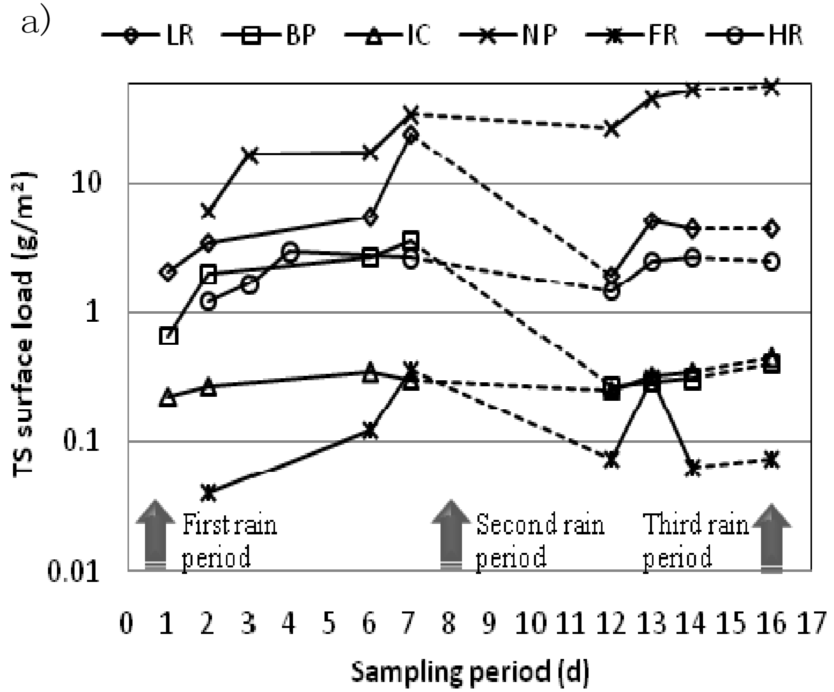
Flush from sewers

Extreme events analysis

Predictor analysis

Surface accumulation of particles and organic matter

TSS



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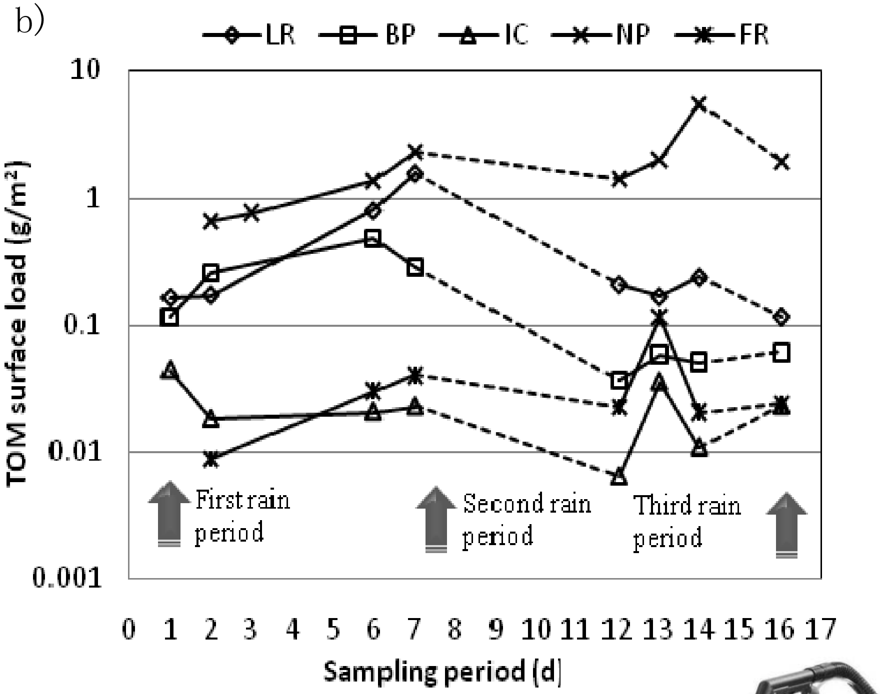
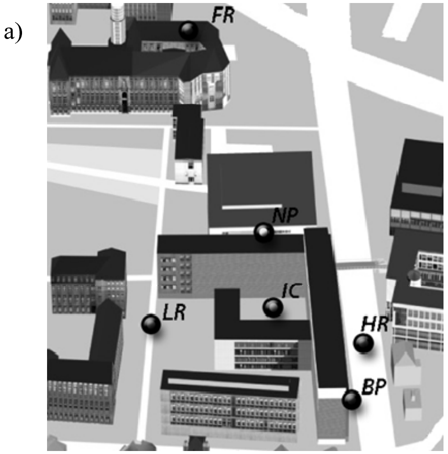
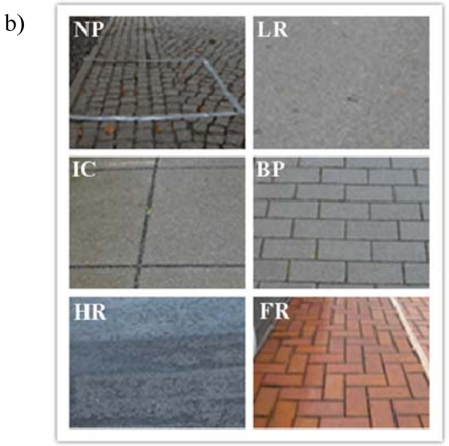






Zhang *et al*. (2013a)

Sampling sites

Site		Road class	Pavement quality	ADWP[a]	Average daily traffic[b]	Heavy traffic	“land use”
				Days	Vehicle/day	%	
Walpurgisstr.	W	Main road	Good	1, 8	12600	3 - 4	Commercial centre
Albertplatz (Glacisstr.)	A	Secondary road	Average	1, 8	800	2	Residential area
Bannewitz	B	Federal highway	Average	1, 8	15900	5	Petrol and bus station
Südhöhe	S	Main road	Good	1, 8	6800	3	Bus station
Industrial area (Hermann-Mende-Str.)	I	Secondary road	Average	1, 8	1100	14	Industrial area
Rural area (Nöthnitz)	R	Secondary road	Good	1, 8	50	< 1	Residential area

[a] ADWP: Antecedent dry weather period

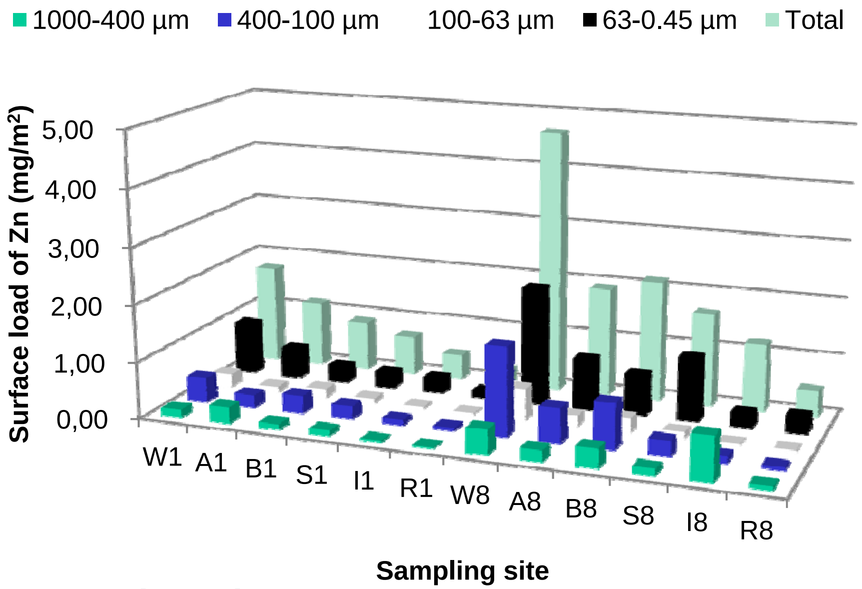
[b] The traffic loads were determined in one flow direction (Straßen- und Tiefbauamt Dresden).

a

b

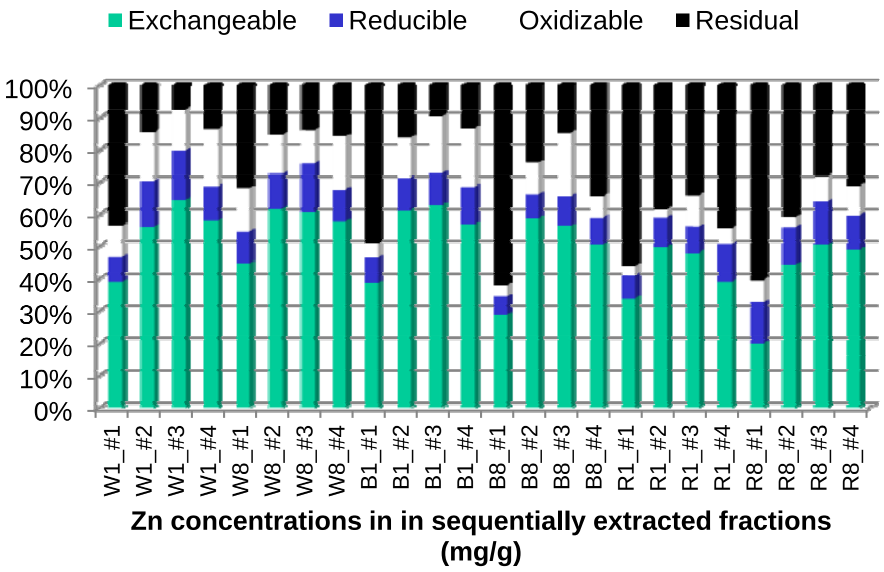
Zhang *et al*. (2013b)

Heavy metal surface loading



Step[a]	Fraction	Reagent
1	Exchangeable	CH_3COOH
2	Reduciable	$NH_2OH \cdot HCl$
3	Oxidisable	H_2O_2, NH_4OAc
4	Residual	H_2O_2, HNO_3

[a] Three-step sequential extraction and total digestion protocols

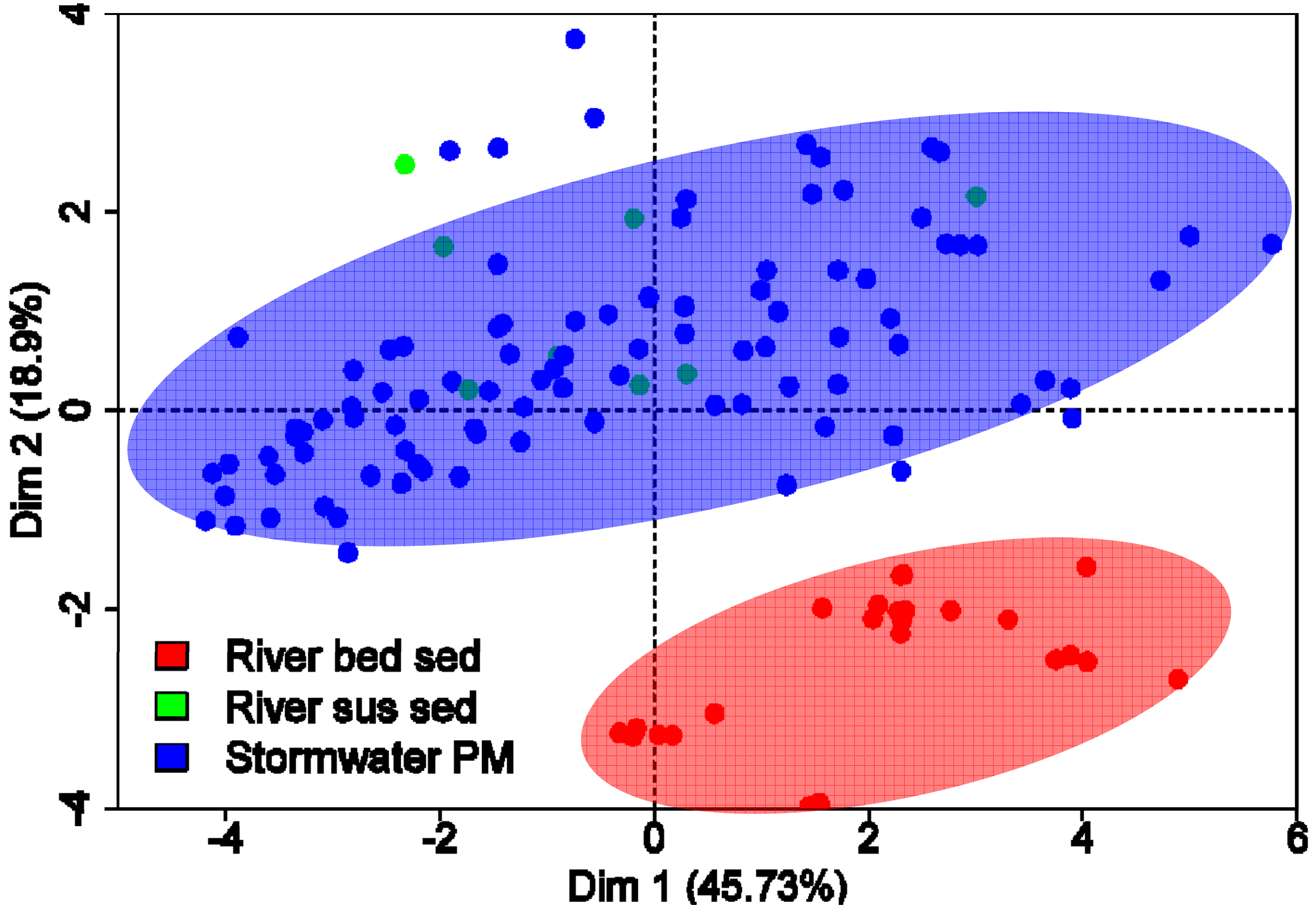


Zn (zinc)

- Tire ruber (potential source)
  - •1.2 % of ZnO for car tires (min 0.4 %, max 2.9 %);
  - •2.1 % (min 1.2 %, max 4.3 %) for truck tires
- Brake pad (potential source)

Zhang *et al*. (2013c)

Particle loading pattern → fingerprinting



PCA on particle-associated compounds concentrations

after angular transformation

River bed sediments

Suspended sediments in river

Stormwater particulate matter PM

Separation in PCA explained by particulate N, Cu and ZN

David *et al*. (2013)

The system

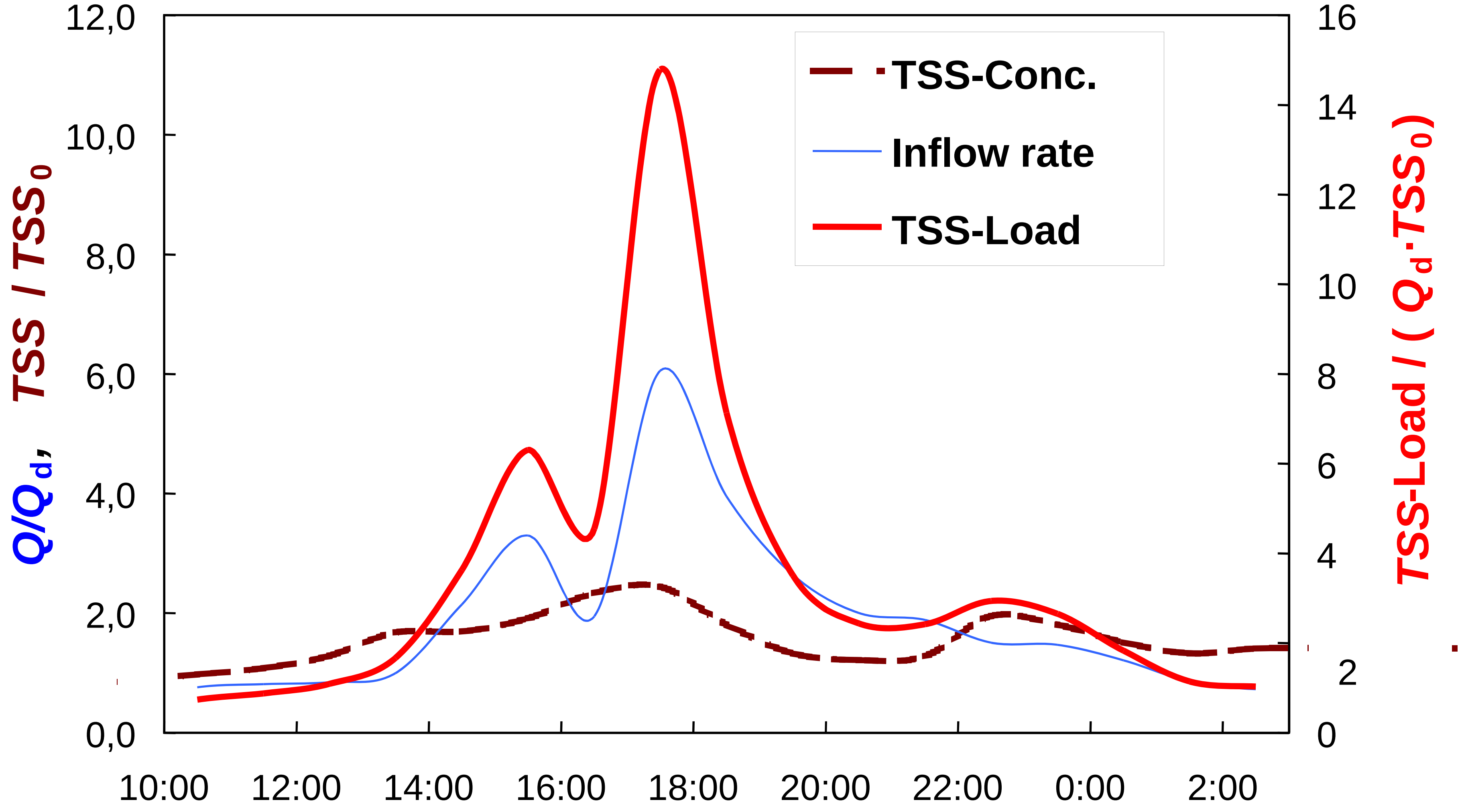
Particles loading

Flush from sewers

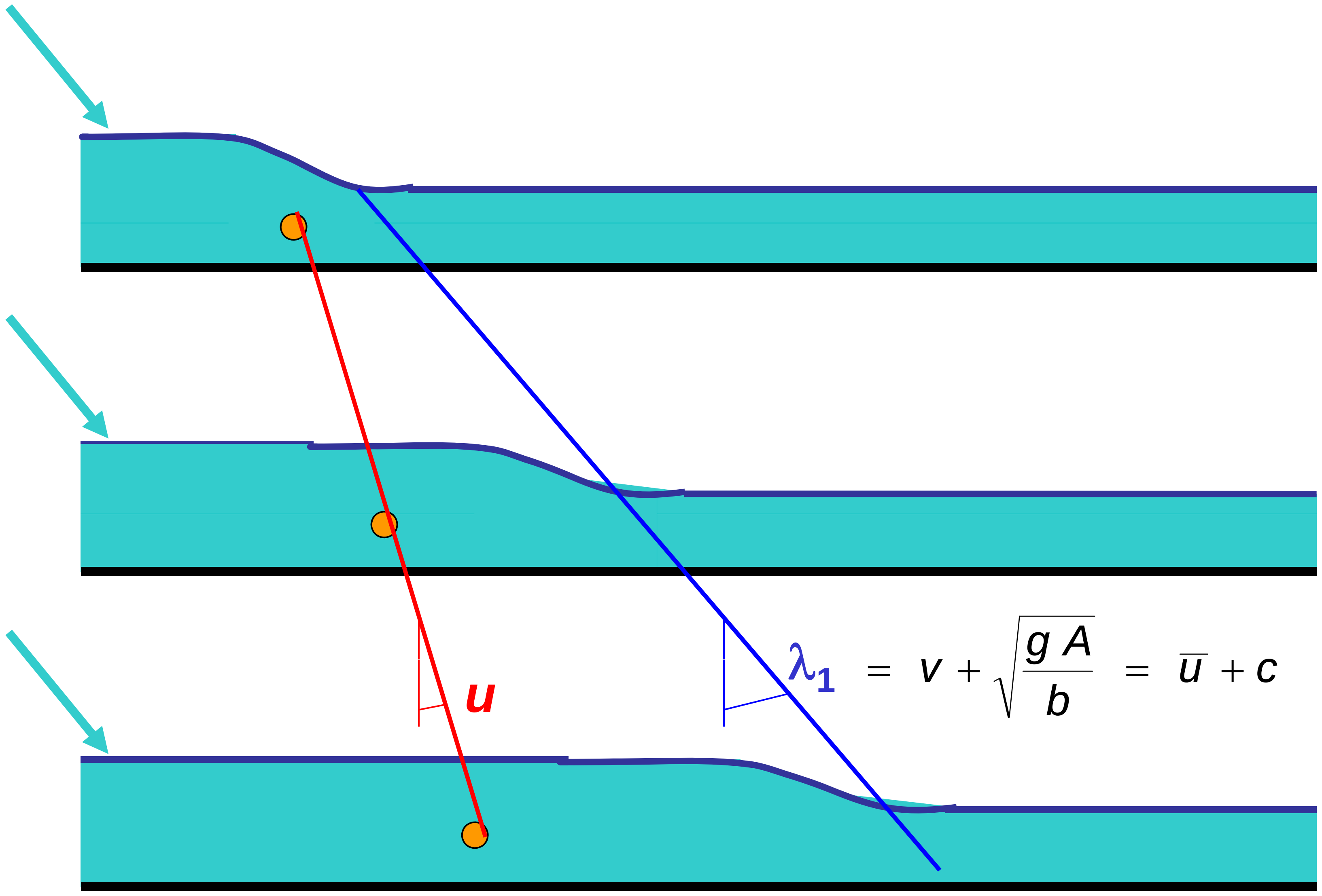
Extreme events analysis

Predictor analysis

First flush of particles



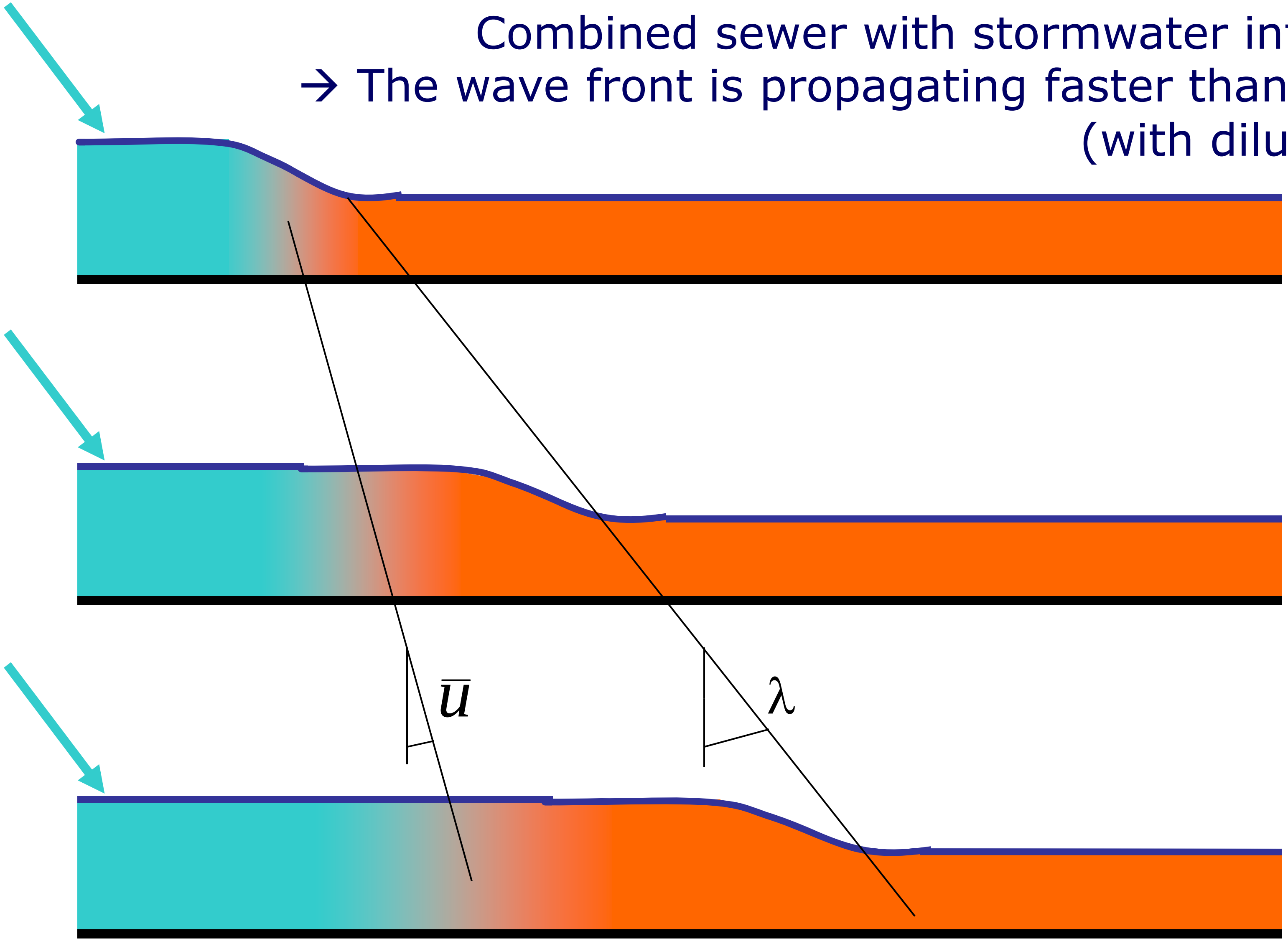
Wave propagation and flow



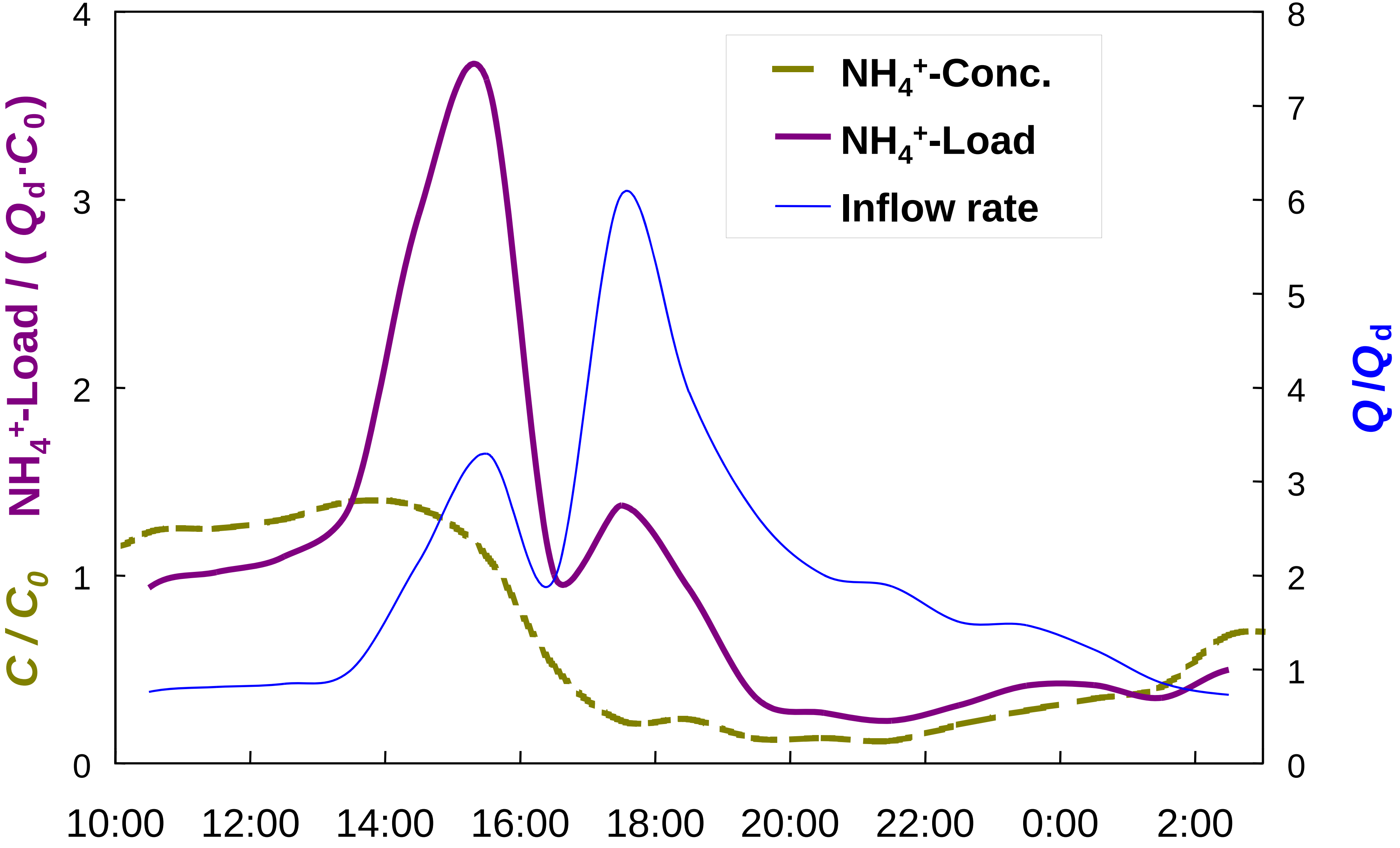
$$\lambda_1 = v + \sqrt{\frac{g\,A}{b}} = \overline{u} + c$$

Dynamic transport of dissolved compounds

Combined sewer with stormwater inflow:
→ The wave front is propagating faster than flow (with dilution)



Wash-out of dissolved compounds



The system

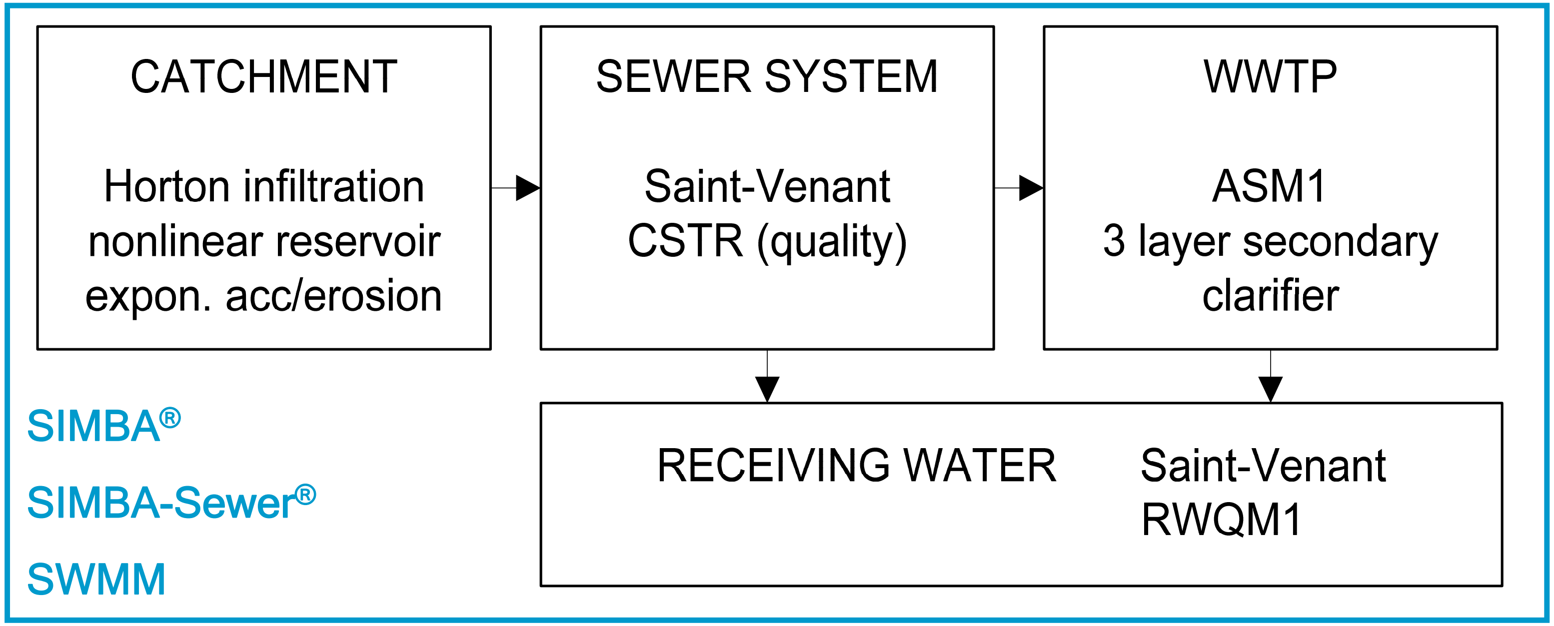
Particles loading

Flush from sewers

Extreme events analysis

Predictor analysis

Model set-up



CATCHMENT

Horton infiltration
nonlinear reservoir
expon. acc/erosion

SEWER SYSTEM

Saint-Venant
CSTR (quality)

WWTP

ASM1
3 layer secondary clarifier

RECEIVING WATER

Saint-Venant
RWQM1

SIMBA®

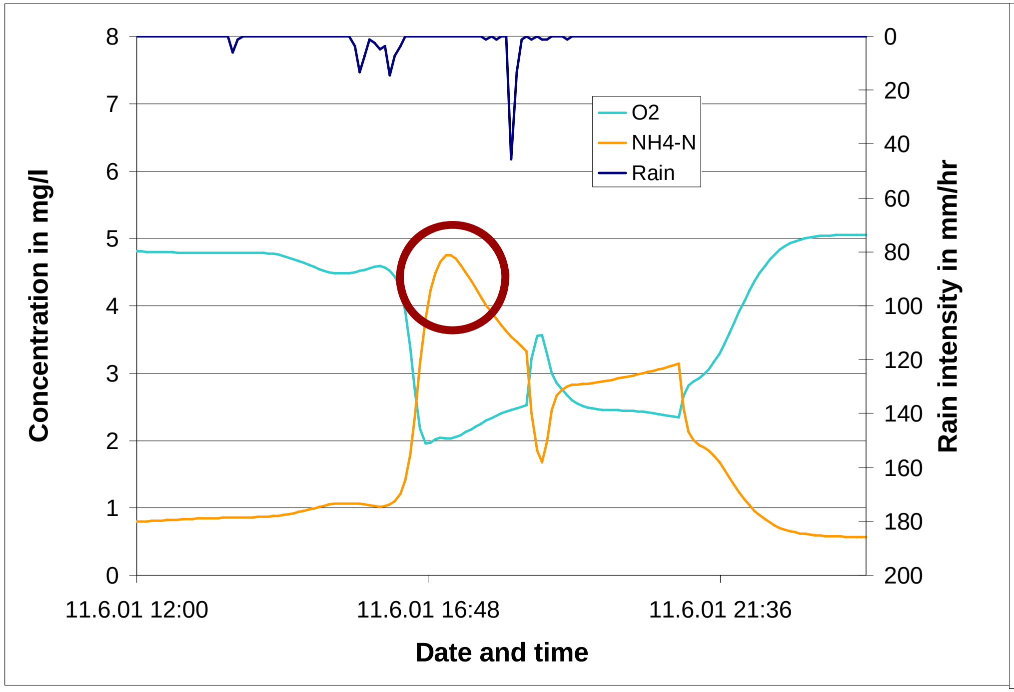
SIMBA-Sewer®

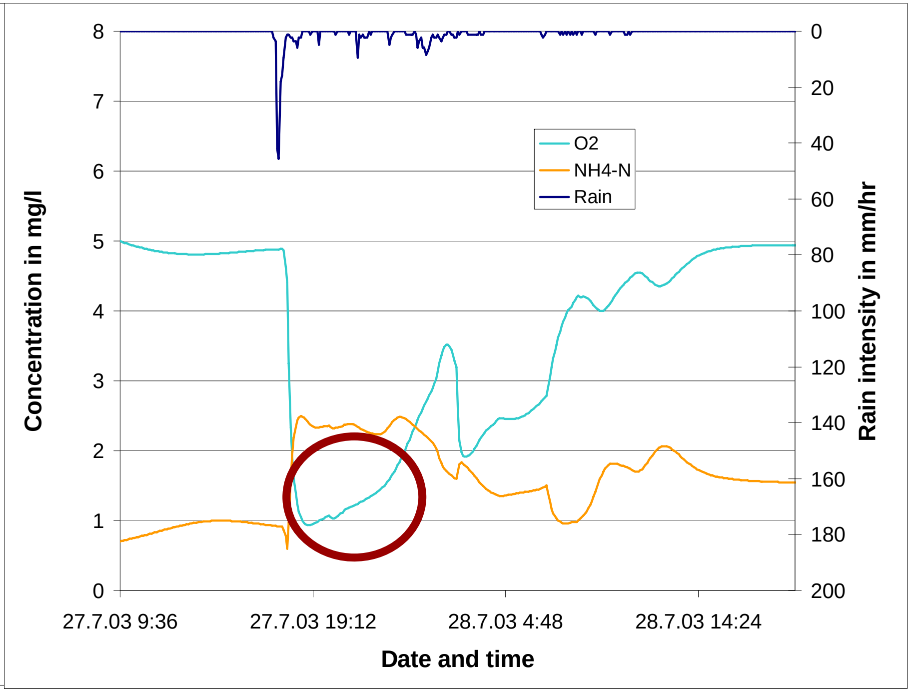
SWMM

- 2000 ha urban catchment (part of real catchment and sewer system)
- scaled WWTP
- virtual receiving water with moderate self-purification capacity
- COD (O_2) and TKN (NH_4^+-N)
- Rain input: 10 years data with 5 minutes resolution

→ **Generating data: 10 years long-term simulation with 5 min time steps**

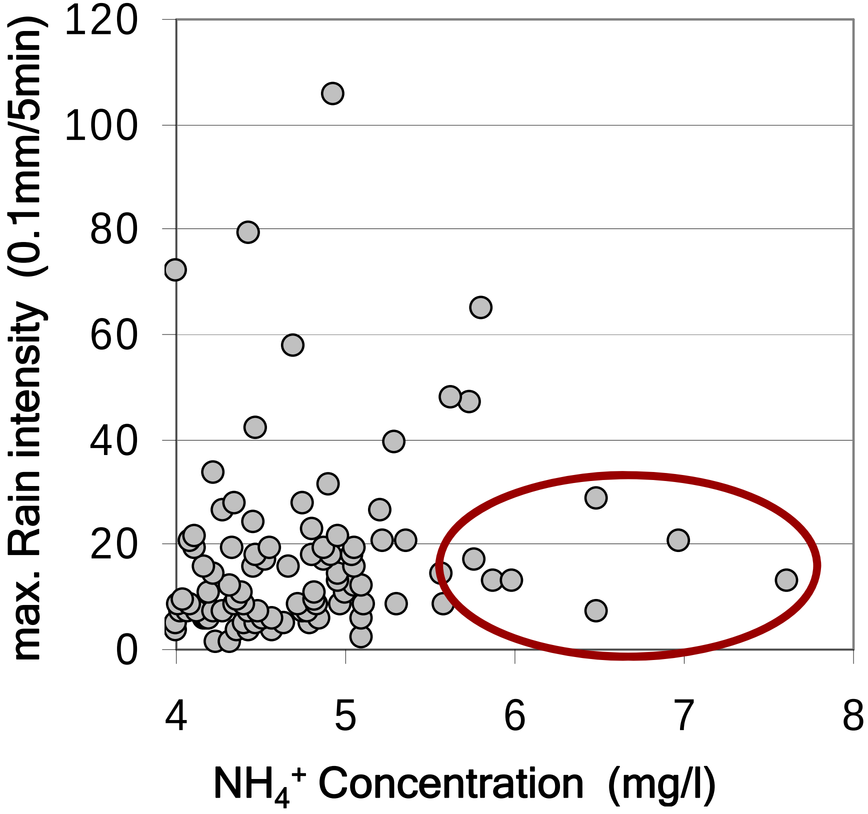
Analysis of peak impacts

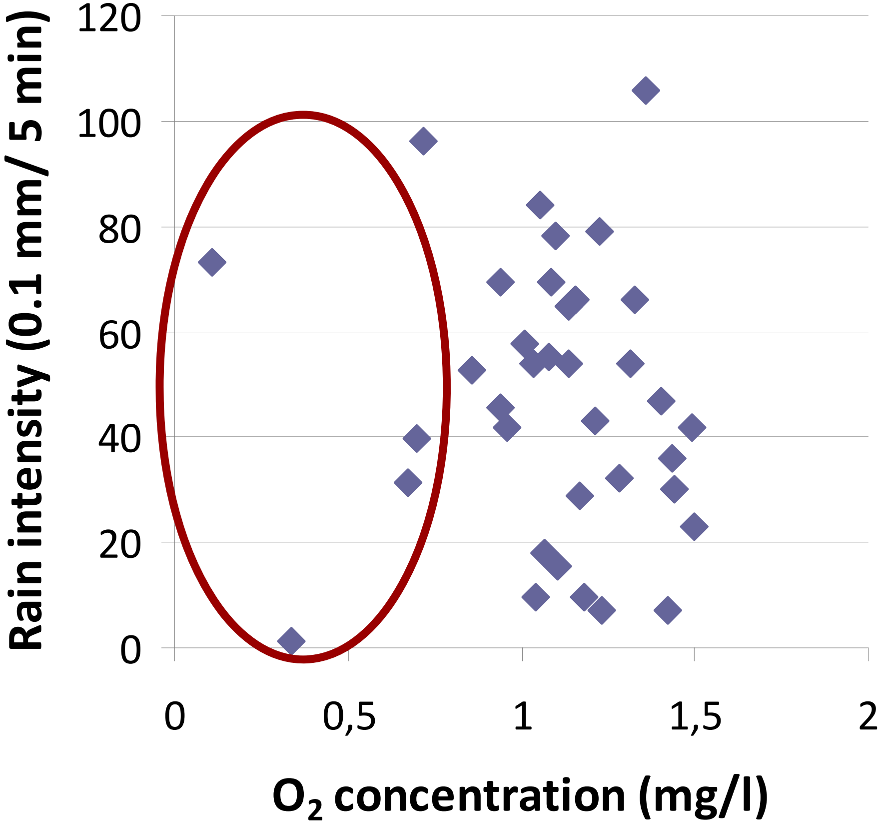




→ Different events induce critical NH_3 and Oxygen concentrations

Scatter plots: rain vs. concentrations

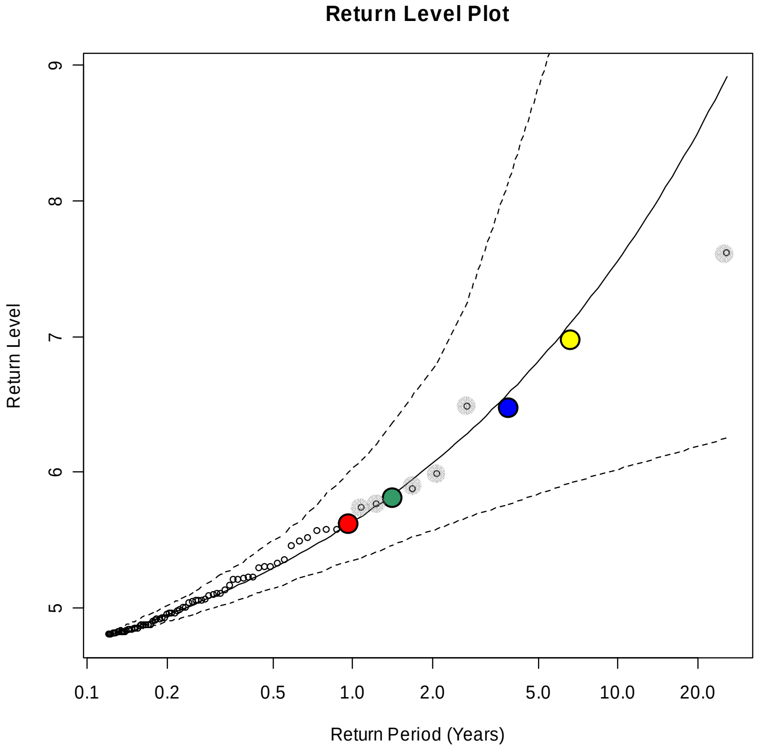




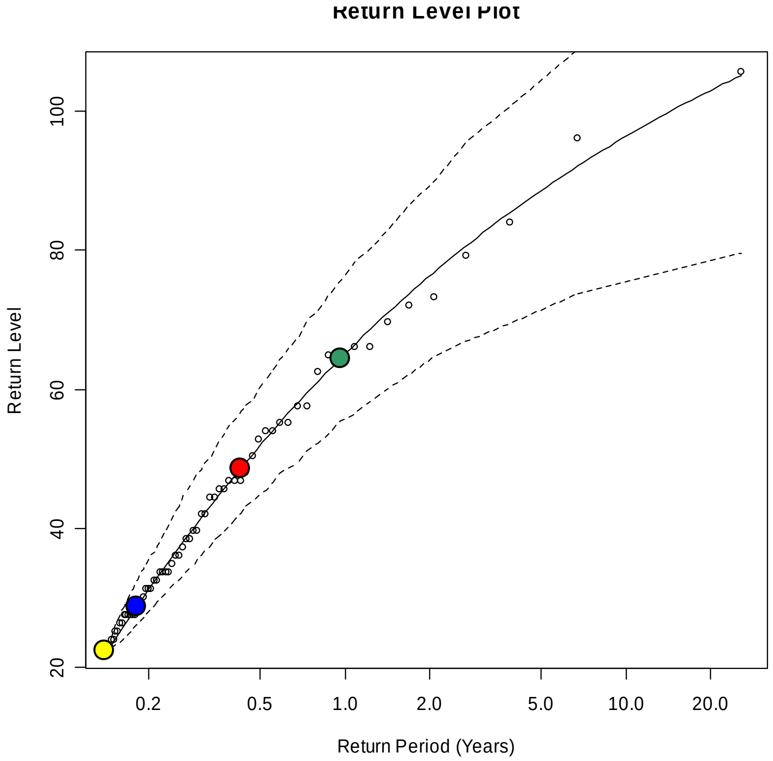
From Schindler *et al*. (2010)

Extreme value statistics: analysis of NH_4^+ and rain

NH_4^+ – concentration (mg/l)



Rain (0.1 mm / 5 min)



→ Extreme rain events ≠ extreme concentrations in river

From Schindler *et al*. (2010)

The system

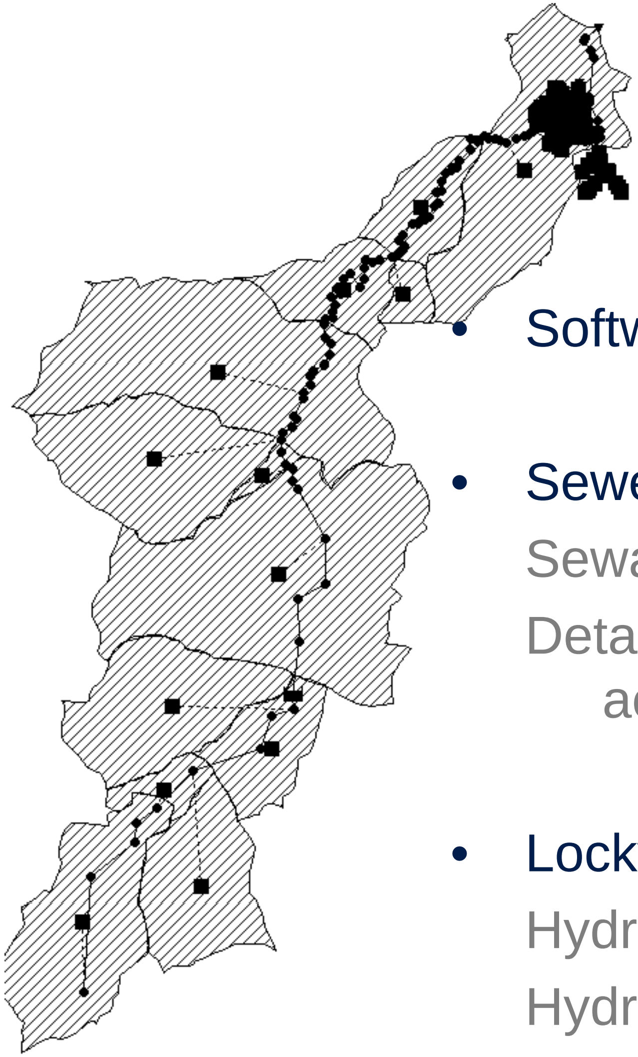
Particles loading

Flush from sewers

Extreme events analysis

Predictor analysis

Model setup



- Software: EPA-SWMM 5.0

- Sewer:

  Sewage as daily pattern

  Detailed spatial analysis of land use types with different accumulation characteristics

- Lockwitzbach:

  Hydrologic model for rainfall-runoff

  Hydrodynamic flow for river bed

→ Combined simulation in one model (2005 – 2011)

→ Statistical analysis of results

Tränckner *et al*. (2013)

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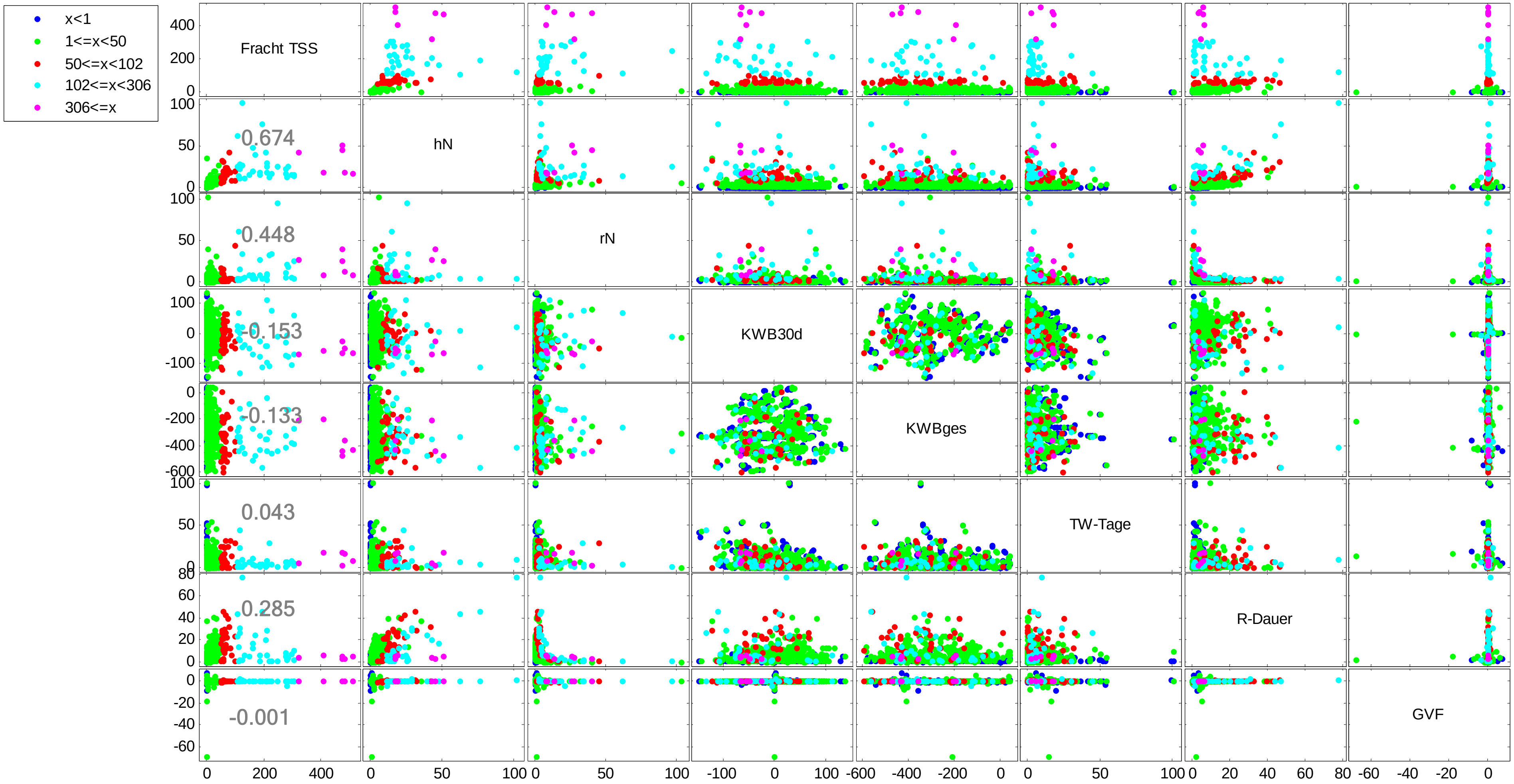
Potentially influencing parameters

“Predictors”

- Rain event:
  - Rain height
  - Rain duration
  - Mean Rain intensity
- Preceding period
  - Days with dry weather
  - Climate water balance since start of simulation
  - Climate water balance of the last 30 days
  - GVF Wetting index = ΣETA/KWB 30d (-1…+1)

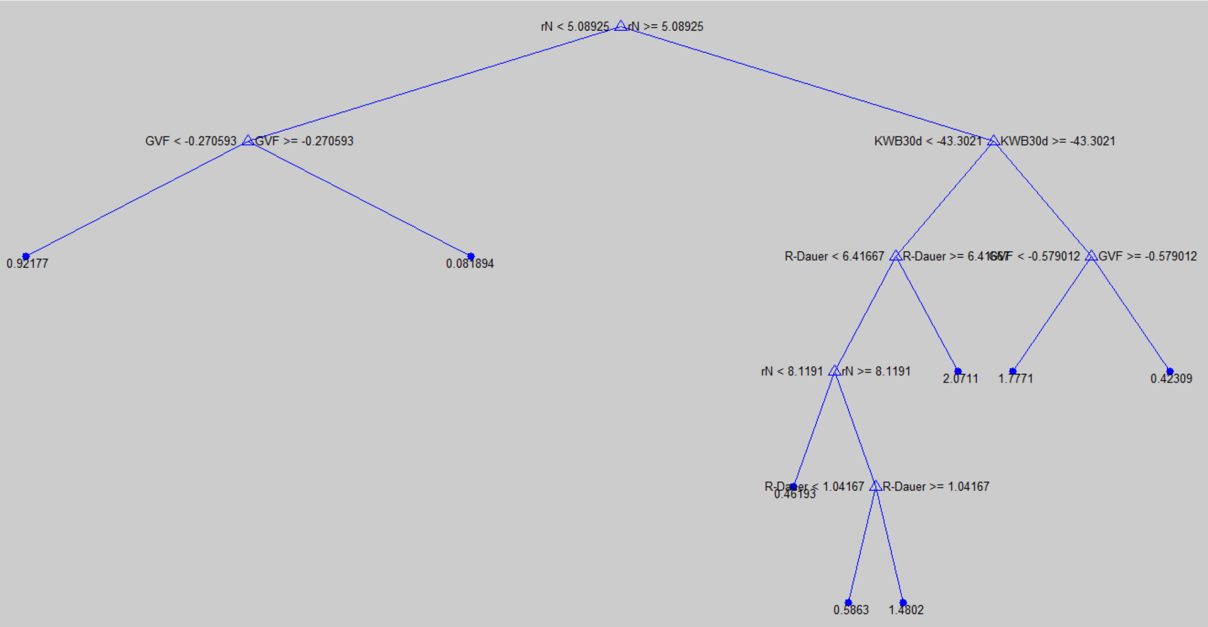
Correlation: emitted TS load – predictors



Tränckner *et al*. (2013)

Regression trees

- Partition of data into homogeneous subsets
- Binary splitting of predictor variables with respect to response variable



Critical events:

- TSS-load:
  intense + long rain events
  (Less intense events + dry period before)

- Critical NH_4^+ concentration:
  Short intense events
  Less intense events + preceding dry period
  (plus temperature for NH_3)
  Clock time

Tränckner *et al*. (2013)

Conclusions

Distinguish between continuous and acute pollution

Polycyclic aromatic hydrocarbons (PAHs) and heavy metals from surface particles and sewer sediments

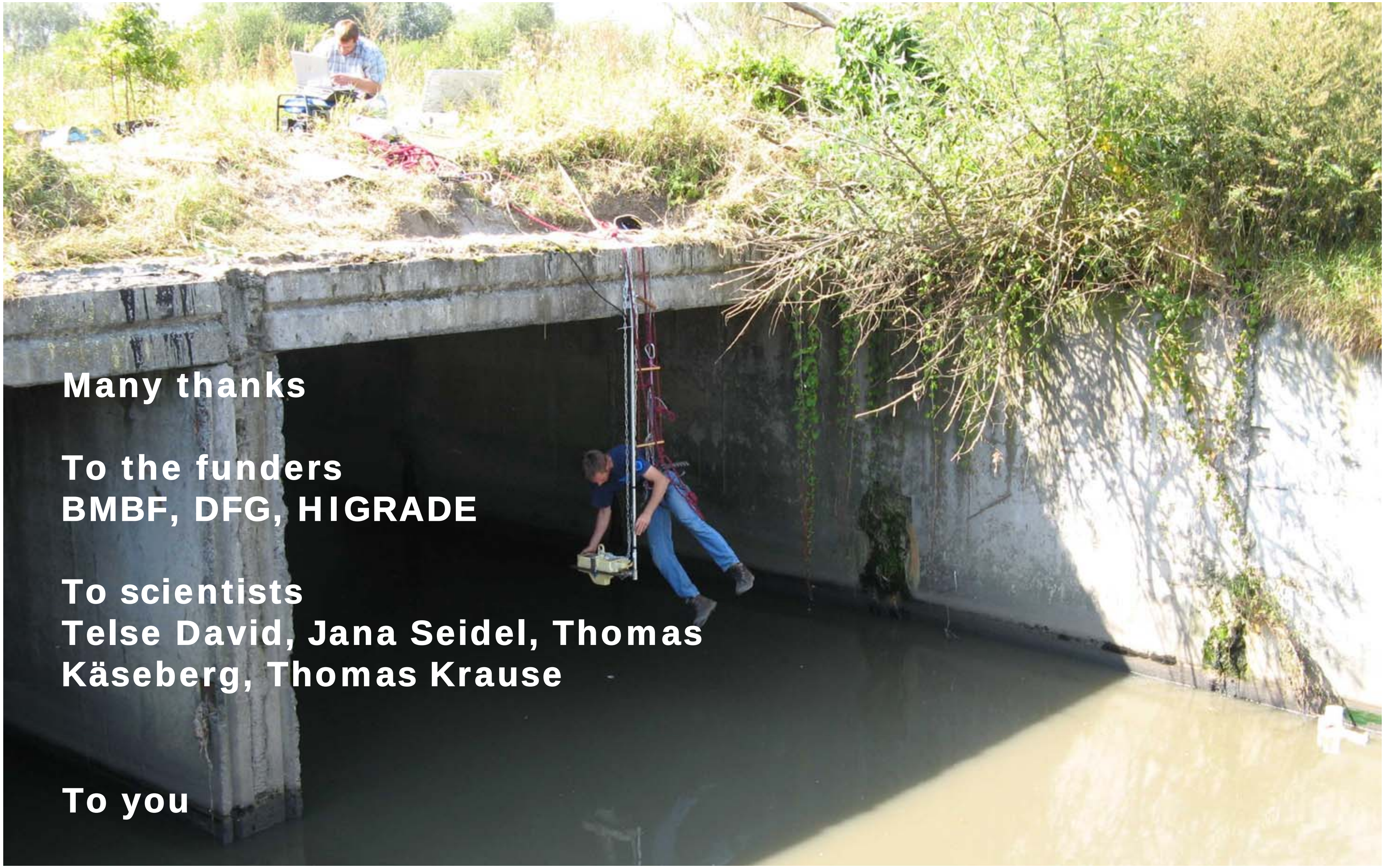
COD and nutrients from sewage

Integrated modelling and statistical analysis to identify impacts

Complex pattern of relevant predictors is to be identified

Missing link between chemical parameters and ecological status

… do not only model!



Many thanks

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To scientists
Telse David, Jana Seidel, Thomas Käseberg, Thomas Krause

To you