Global Sensitivity Analysis and Multi-Objective Optimisation

for Estimation of Combined Sewer Overflows

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Introduction

Frame

- 7th EU framework project SUDPLAN (Sustainable Urban Development Planner for climate change Adaption)
  - Web based decision support platform in urban infrastructure for extreme events due to climate change effects
- Pilot study Linz
  - Evaluate impact of climate change scenarios on combined sewer overflows
- Assessment according to Austrian requirements
  - Meet defined CSO efficiency rate; long term simulations
- Project and results: WCE Dublin and WWC Busan

Introduction

Today's presentation

Model preparation, analysis and calibration

- Results from Master thesis (Wendner 2011)

Aim

- Apply readily available methods to real-world example
- Sound model basis for SUDPLAN project & evaluation of climate change scenarios

Methods

- Data evaluation
- Global sensitivity analysis (GSA) - Morris Screening
- Multi-objective calibration - Optimiser based on evolution strategies

Introduction
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- Model preparation, analysis and calibration
  - Results from Master thesis (Wendner 2011)
- Aim
  - Apply readily available methods to real-world example
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- Methods
  - Data evaluation
  - **Global sensitivity analysis (GSA) - Morris Screening**
  - **Multi-objective calibration - Optimiser based on evolution strategies**

Introduction

Linz Pilot Catchment

Linz: 3rd Austrian city

~ 1000 km upstream Belgrade

Google Maps, 2012

Introduction

Linz Pilot Catchment

Linz AG

- **Downtown Linz and 39 neighbour communes**
  - Total area ~ 900 km²
  - 950 000 PE
- **Combined & separate system**
- **Several CSO tanks, pumps and specials structures**

Introduction
Linz Pilot Catchment

Linz AG

- **Limited knowledge about system**
  - **especially for neighbour communes**
- **Partly real time controlled since 2005**
  - **“Semi-automatic” (manual) operation**
- **Calibration pre-2005 status**
  - **3 in-sewer water level measurements**
  - **1 rain gauge**

Methods

Austrian requirements

Efficiency rate η

- Percentage of stormwater runoff routed to WWTP on annual average
- For dissolved (η_d) and particulate pollutants (η_p)

Required efficiency rates

- Defined in Austrian RB19 guideline

Actual efficiency rate

- Calculated by simulation model in long-term simulations
- sedimentation efficiency in storage units for particulate pollutants

Methods
Sewer Model

Aggregated model in SWMM 5

- Basic model set up:
  Innsbruck University
- Model evaluation: Wendner (2011)

All relevant structures included

- 43 combined sewer overflows
- Pumps and storage units

Computational demand

- One year simulation = 20 minutes simulation time

Gamerith et al. (2011)

Methodology

Investigated model parameters

parameter	unit	short description
MAN	$s/m^{1/3}$	Manning's n
IMP1	%	Imperviousness neighbour communes
IMP2	%	Imperviousness downtown Linz
IMP3	%	Imperviousness creek area
P2	%	Max. pump rate
STS	%	Sedimentation efficiency
SV	%	Storage volume

- **7 parameters derived from available base data**
- **Three zones for imperviousness**
- **Except MAN: percentage range from prior catchment data evaluation (Wendner)**
- **Uniform distribution**

Methods

GSA and Optimisation

- **GSA: Evaluate parameter sensitivities for long-term efficiency rates as defined in Austrian requirements**
- **Determine parameters that are**
  - important in model calibration (factor fixing) or
  - would profit of a better prior evaluation (factor prioritisation)
- **Optimiser: Calibrate the model based on GSA results**
  - Try to best calibrate parameters sensitive for effeciency rate with available data
  - Multi-objective calibration on several events
- **Both methods: coupling with SWMM via BlueM.OPT**

Methods

Global Sensitivity Analysis – Morris Screening

Why Morris Screening?

- Computational demand low compared to other methods
- Ranking and identification of interaction / non-linearity
- Settings: 7 parameters with 20 repetitions
  160 simulation runs (approx. 55 hours)

Evaluation of sensitivities for CSO efficiency rates

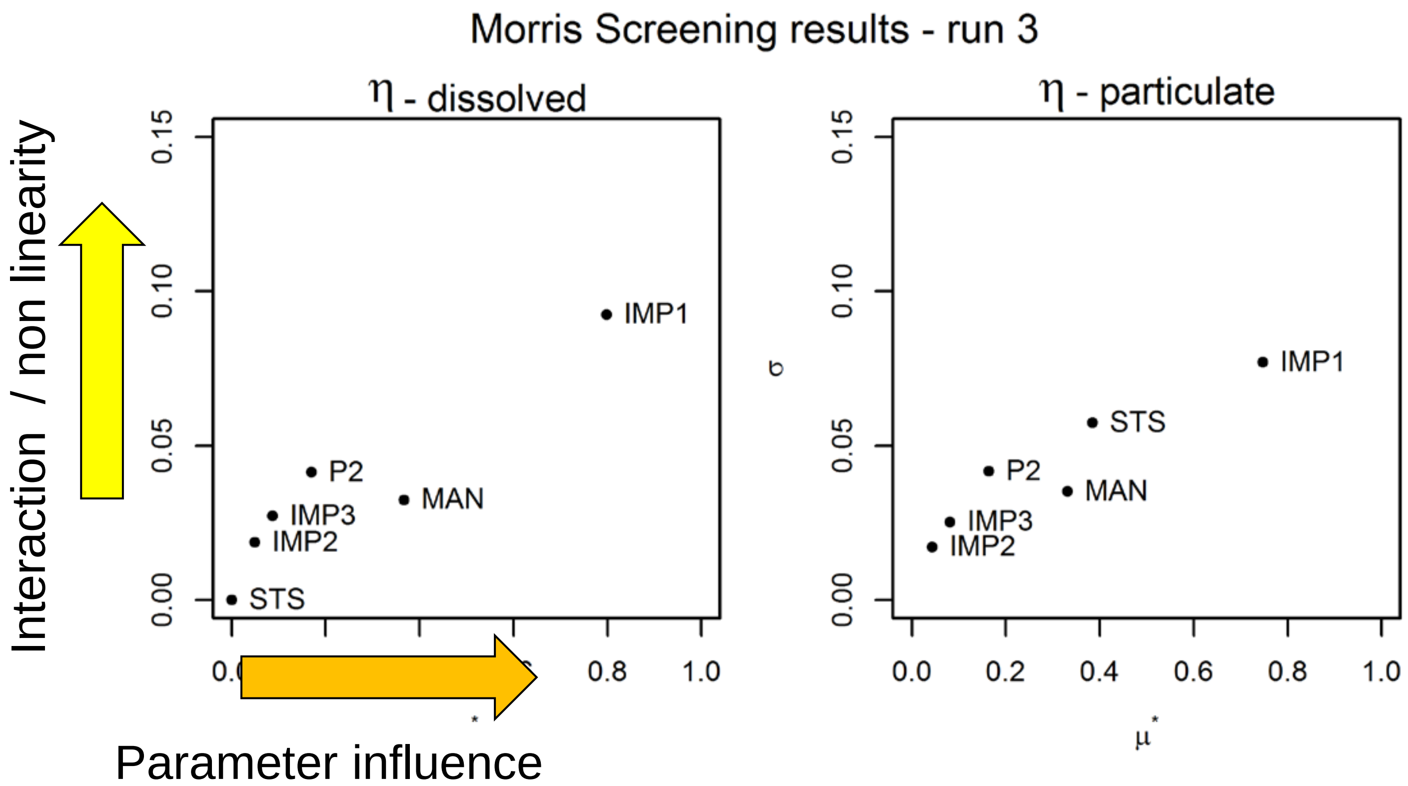
- independent from reference measurement data

Morris Screening runs with different parameter limits

- Explore impact of parameter range assumption
- Parameter ranges chosen arbitrarily and adapted in 7 consecutive Morris Screening runs

Results

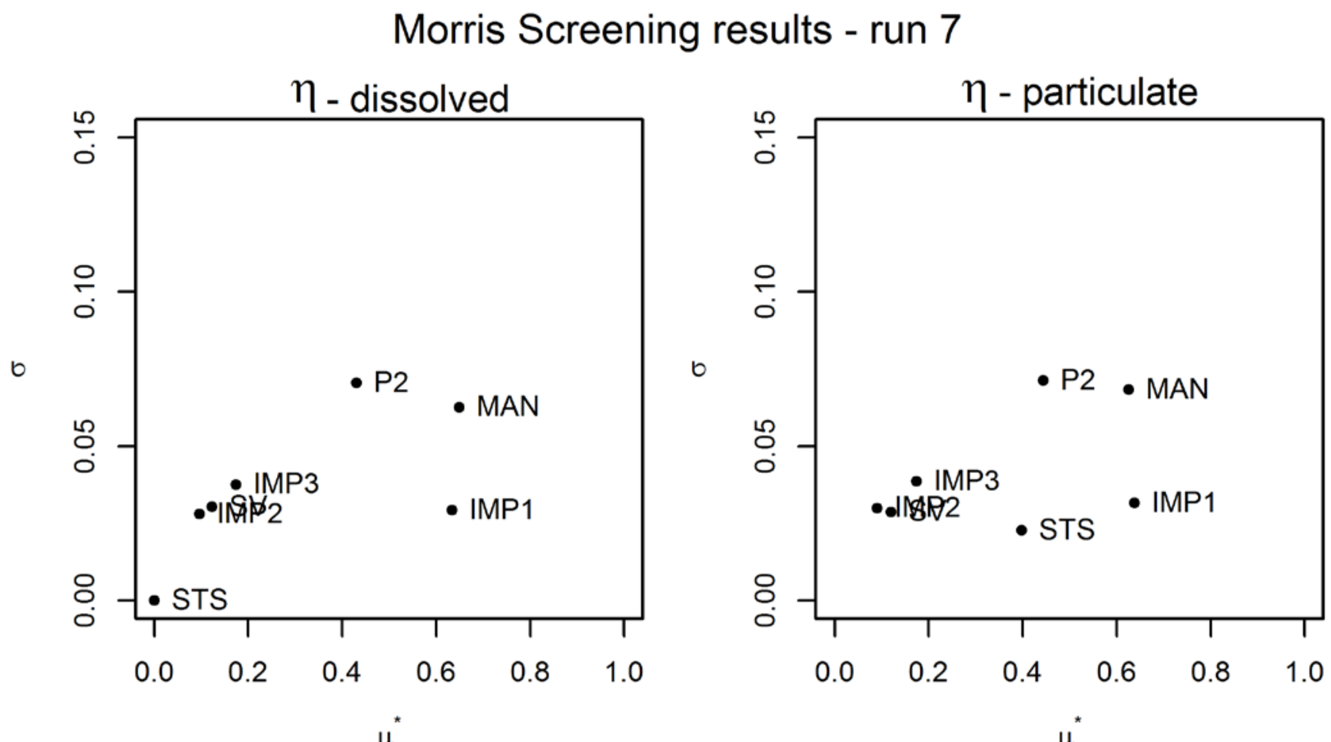
Morris Screening



MAN	0.015 0.020
IMP1	±50
IMP2	±10
IMP3	±80
P2	±20
STS	±50
SV	-

Results

Morris Screening



MAN	0.015 0.020
IMP1	±20
IMP2	±10
IMP3	±80
P2	±20
STS	±20
SV	±60

- Overall behaviour similar with different parameter settings
- IMP1, MAN, (P2) sensitive, STS for η_p
- IMP2, IMP3, SV low sensitivity
  - IMP3 with large variation range

Methodology

Optimisation – Evolution Strategies

Multi – Objective optimisation

- Optimiser based on evolution strategies
- Simultaneously for 3 water level measurements
- Objective function: Nash-Sutcliffe efficiency *E*
- Evaluation of percentage bias as informative criterion

Calibration parameters

- MAN, IMP1, IMP2, IMP3 and P2

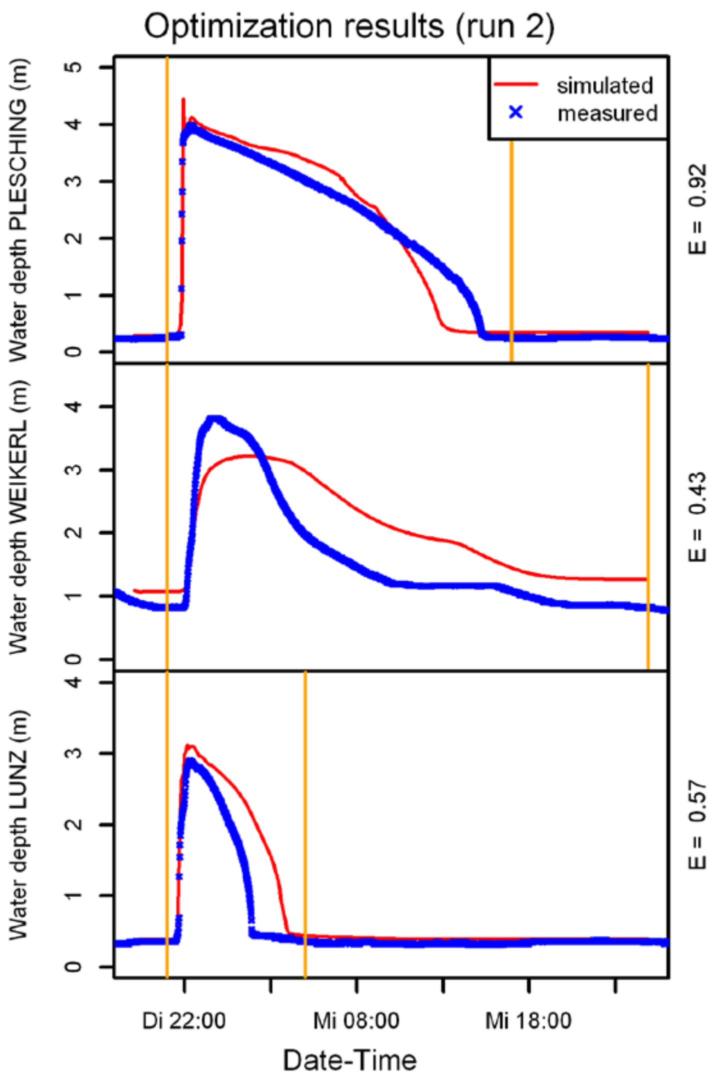
5 independent, single rainfall events

Final parameter set

- weighted parameters based on E (arbitrary)

Results

Optimisation / Model Calibration

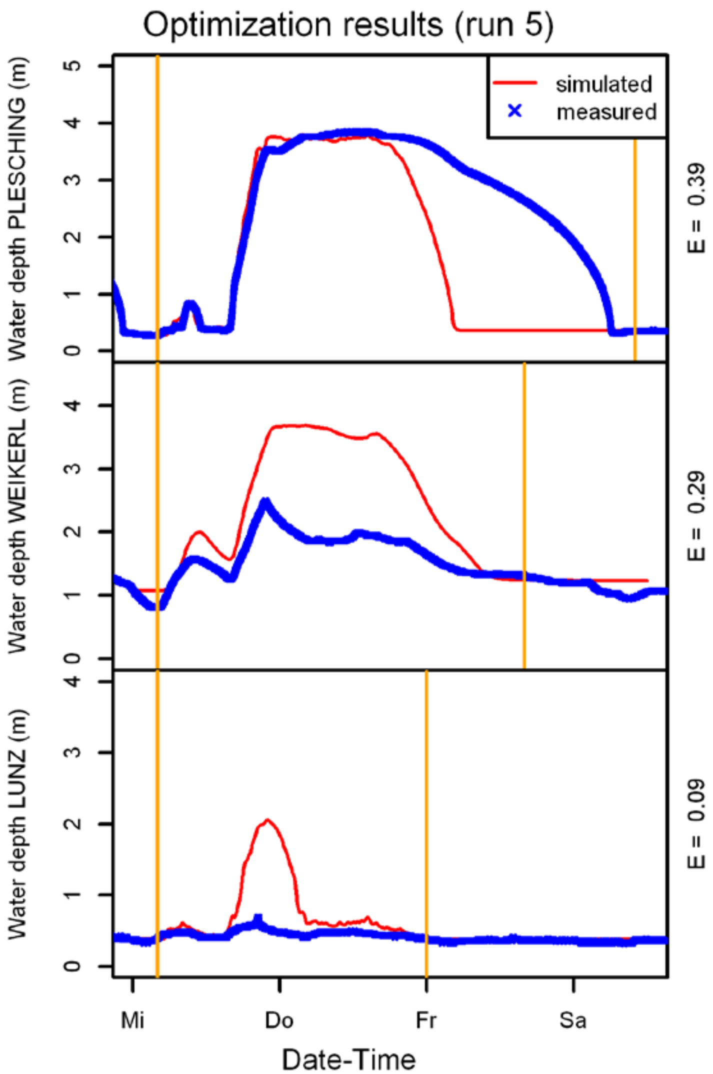


- **Best fit**
- *E* from 0.43 to 0.92
- Timing and peak well fit.
- Percentage bias

  +1% (PLESCHING)
  -23% (WEIKERL)
  -36% (LUNZ).

Results

Optimisation / Model Calibration



- **Worst fit**
- *E* from 0.09 to 0.4
- Start time and peak fit for PLESCHING
- Percentage bias

  +32% (PLESCHING)
  -50% (WEIKERL)
  -71% (LUNZ)
- uniform rainfall distribution for large catchment

Results

Model Calibration – Summary parameters

- **MAN** sensitive, calibration results in narrow range (+- 0.001 $s/m^{1/3}$)
- **Imperviousness** generally decreased.
  - **IMP1** sensitive & high variability in the optimised values.
  - **IMP2** is stable with a reduction to ~ 90% in all optimisation runs.
  - **IMP3** reduced to 20 to 45%. Low sensitivity reduces identifiably
- **Pump rate** generally decreased
- **Validation** of the model with weighted parameter set was done on one event (*E* values of 0.5 to 0.6)

Conclusions

GSA & Optimisation

GSA allowed identifying and ranking parameters

- Different parameter limits impact on importance ranking

For the investigated model

- Prioritise neighbour communes
- IMP3 (creek catchment): a lot of effort put in prior evaluation for small influence on results

Optimisation & Calibration

- Parameter sensitivity prerequisite for parameter calibration
- Different calibration quality for different events
- Use of spatially distributed rainfall

Conclusions
& Outlook

- **GSA and optimisation methods applied on** (computational heavy) **SWMM model**
  - Real-world application
  - Methods readily available
  - Complexity of methods manageable

- **Better knowledge on parameters and model behaviour**

- **Promote use of methods**

  …also in engineering practice