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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Introduction
Linz Pilot Catchment

Linz: 3rd Austrian city
~ 1000 km upstream Belgrade

Google Maps, 2012
Introduction
Linz Pilot Catchment

- 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

- 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 $\eta$
- Percentage of stormwater runoff routed to WWTP on annual average
- For dissolved ($\eta_d$) and particulate pollutants ($\eta_p$)

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
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

<table>
<thead>
<tr>
<th>parameter</th>
<th>unit</th>
<th>short description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAN</td>
<td>s/m$^{1/3}$</td>
<td>Manning’s n</td>
</tr>
<tr>
<td>IMP1</td>
<td>%</td>
<td>Imperviousness neighbour communes</td>
</tr>
<tr>
<td>IMP2</td>
<td>%</td>
<td>Imperviousness downtown Linz</td>
</tr>
<tr>
<td>IMP3</td>
<td>%</td>
<td>Imperviousness creek area</td>
</tr>
<tr>
<td>P2</td>
<td>%</td>
<td>Max. pump rate</td>
</tr>
<tr>
<td>STS</td>
<td>%</td>
<td>Sedimentation efficiency</td>
</tr>
<tr>
<td>SV</td>
<td>%</td>
<td>Storage volume</td>
</tr>
</tbody>
</table>

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

Morris Screening results - run 3

Parameter influence

Interaction / non linearity

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Influence</th>
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</thead>
<tbody>
<tr>
<td>MAN</td>
<td>0.015</td>
</tr>
<tr>
<td>IMP1</td>
<td>±50</td>
</tr>
<tr>
<td>IMP2</td>
<td>±10</td>
</tr>
<tr>
<td>IMP3</td>
<td>±80</td>
</tr>
<tr>
<td>P2</td>
<td>±20</td>
</tr>
<tr>
<td>STS</td>
<td>±50</td>
</tr>
<tr>
<td>SV</td>
<td>-</td>
</tr>
</tbody>
</table>
## Results

### Morris Screening

#### Morris Screening results - run 7

**η** - dissolved

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAN</td>
<td>0.015</td>
</tr>
<tr>
<td>IMP1</td>
<td>±20</td>
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<td>±10</td>
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<td>±80</td>
</tr>
<tr>
<td>P2</td>
<td>±20</td>
</tr>
<tr>
<td>STS</td>
<td>±20</td>
</tr>
<tr>
<td>SV</td>
<td>±60</td>
</tr>
</tbody>
</table>

Overall behaviour similar with different parameter settings

- IMP1, MAN, (P2) sensitive, STS for $\eta_p$
- 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