Cost-effective solutions for river water quality improvement in Eindhoven supported by sewer-WWTP-river integrated modeling

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⁵ Witteveen+Bos, PO Box 233, NL-7400 AE Deventer, Netherlands
⁶ Waterschap De Dommel, 5280 Boxtel, Netherlands
– The Kallisto project
– System definition
– Project approach
– Selection of measures
– Scenario analysis
– Conclusions
Together

Smart

Clean
Clean: Improving the receiving surface water quality to comply with the national legislation and the EU Water Framework Directive

Smart: Controlling storm water and wastewater flows by cost-effective control, buffering and treatment measures in the Integrated Urban Water System
Together: Involving different stakeholders in the water chain across the boundaries of responsibilities including municipalities, the waterboard, knowledge institutes and STOWA (dissemination)
The Eindhoven system

Complex combined wastewater system

Large area with severe impact on vulnerable surface water

10 municipalities

750,000 PE WWTP

>200 CSOs
The Eindhoven WWTP
The Dommel River: ecological quality
Storm weather

Inflow Works

Supply system North
Supply system City
Supply System South

Sewer system municipality

Primary Sedimentation tank

Storm water buffertank

Biological treatment + post sedimentation

Effluent
Storm weather + overflow

Inflow Works

Primary Sedimentation tank

Biological treatment + post sedimentation

Storm water buffertank

Effluent

Sewer system municipality

Supply system North
Supply system City
Supply system South
Water Quality Policy / WFD

- Inflow Works
- Primary Sedimentation tank
- Biological treatment + post sedimentation
- Storm water buffertank
- Sewer system municipality

Physical: Q, T
Chemical: O₂, NH₄

Ecology
Storage / treatment

Physical: Q, T
Chemical: O₂, NH₄ N, P

Ecology

Supply system North
Supply system City
Supply system South

Sewer system municipality

Inflow Works

Primary Sedimentation tank

Biological treatment + post sedimentation

Post treatment

Storm water buffertank

€ XX mln.

€ XX mln.

Influent

Post treatment

Filter

Effluent

Water Quality Policy / WFD
Modeling (after monitoring)

1. model development

- sewer model (InfoWorks)
- WWTP model (WEST)
- river model (Duflow)

integrated model (WEST)

cost model
• One single model:
  • Mass and information flows (impact on receiving water, RTC)
• Speed:
  • Many scenarios
  • Long-term simulation (10y in 2h)
  • Monte Carlo for UA/SA
Integrated model results:
DO at river section DS of WWTP
1. model development

- sewer model (InfoWorks)
- WWTP model (WEST)
- river model (Duflow)

integrated model (WEST)

cost model

2. model analysis

- global sensitivity analysis
GSA: operational parameters ranking
1. Model Development

- Sewer model (InfoWorks)
- WWTP model (WEST)
- River model (Duflow)
- Integrated model (WEST)
- Cost model

2. Model Analysis

- Global sensitivity analysis

3. Model Application

- Current infrastructure (RTC)
- Additional measures (including RTC)
- Robustness check
<table>
<thead>
<tr>
<th>Measure</th>
<th>Field of application/objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTC in the sewer system</td>
<td>Minimisation of DO dips and/or NH$_4$ peaks in river with available system capacity</td>
</tr>
<tr>
<td>DAF, fine screens, lamella settler, fuzzy filter</td>
<td>Pre-treatment of wastewater during DWF Treatment of WWF</td>
</tr>
<tr>
<td>CSO storage</td>
<td>Reduction of CSO emissions</td>
</tr>
<tr>
<td>Dry buffers at WWTP inlet</td>
<td>Peak load shaving to reduce NH$_4$ concentration peaks in effluent</td>
</tr>
<tr>
<td>River aeration</td>
<td>Reduce DO dips in river</td>
</tr>
<tr>
<td>Effluent aeration</td>
<td>Reduce DO dips in river due to WWTP effluent</td>
</tr>
<tr>
<td>WWTP: additional aeration capacity, increase of MLSS and of aeration volume</td>
<td>Enhance nitrification process to reduce NH$_4$ peak concentrations in river</td>
</tr>
<tr>
<td>Equalisation pond/wetland</td>
<td>Equalisation of WWTP effluent to reduce NH$_4$ peak concentrations to the river</td>
</tr>
<tr>
<td>Increase interceptor/pumping capacities</td>
<td>Reduce DO dips in river</td>
</tr>
<tr>
<td>Increase hydraulic capacity of biological treatment at WWTP</td>
<td>reduce NH$_4$ peak concentrations and DO dips in river</td>
</tr>
<tr>
<td>Sand filter for treatment of WWTP effluent</td>
<td>Reduce N$<em>{\text{total}}$ and P$</em>{\text{total}}$ in effluent</td>
</tr>
</tbody>
</table>
Scenario analysis

- **10-year dynamic** simulations
- Approx. **40** different scenarios tested

**Evaluation**

- Ecological framework based on **concentration-duration-frequency** curves for sensitive species
- Focus on **DO** and **NH₄**
- Costs (**CAPEX** and **OPEX**)
## Scenario analysis: costs

Costs of measures to reduce **DO** depletion and achieve basic DO levels

<table>
<thead>
<tr>
<th>Measure</th>
<th>Investment</th>
<th>CAPEX</th>
<th>OPEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional storage</td>
<td>€ 79,800,000</td>
<td>€ 3,830,000</td>
<td>€ 79,500</td>
</tr>
<tr>
<td>River aeration</td>
<td>€ 1,040,000</td>
<td>€ 96,700</td>
<td>€ 117,000</td>
</tr>
</tbody>
</table>
Scenario analysis: costs

**Reference scenario:**

- conventional methods of solving water quality issues (**uncoupling** of paved area, building sewer **storage** facilities at CSOs)

- yearly cost (CAPEX+OPEX) approximately € 15 million
## Scenario analysis: costs

<table>
<thead>
<tr>
<th>Scenario</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Measure in all scenarios</strong></td>
<td>River aeration + effluent aeration</td>
<td>Sand filter for effluent filtration</td>
<td>RTC aiming at reducing NH$_4$ concentration peaks</td>
</tr>
<tr>
<td><strong>Measures</strong></td>
<td>dry storage</td>
<td>wetland</td>
<td>DAF pre-treatment</td>
</tr>
<tr>
<td><strong>Investment</strong></td>
<td>€ 160,140,000</td>
<td>€ 90,410,000</td>
<td>€ 36,780,000</td>
</tr>
<tr>
<td><strong>CAPEX</strong></td>
<td>€ 11,295,000/year</td>
<td>€ 8,328,000/year</td>
<td>€ 3,052,000/year</td>
</tr>
<tr>
<td><strong>OPEX</strong></td>
<td>€ 3,670,000/year</td>
<td>€ 3,194,000/year</td>
<td>€ 4,641,000/year</td>
</tr>
<tr>
<td><strong>Total annual costs (CAPEX + OPEX)</strong></td>
<td>€ 14,965,000/year</td>
<td>€ 11,522,000/year</td>
<td>€ 7,693,000/year</td>
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</tbody>
</table>
### Scenario analysis: water quality

**NH\textsubscript{4}**

<table>
<thead>
<tr>
<th>Duration of the event</th>
<th>S066</th>
<th>S000</th>
<th>S017</th>
<th>S010</th>
<th>S008</th>
<th>S031</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tolerated</strong></td>
<td>12</td>
<td>1.5</td>
<td>0.7</td>
<td>0.3</td>
<td>12</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>frequency per year</strong></td>
<td>4</td>
<td>0.2</td>
<td>0.5</td>
<td>1</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>0.2</strong></td>
<td>1</td>
<td>6.1</td>
<td>2.8</td>
<td>1</td>
<td>0.6</td>
<td>1.6</td>
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</table>

**DO critical**

<table>
<thead>
<tr>
<th>Duration of the event</th>
<th>S066</th>
<th>S000</th>
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<th>S031</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tolerated</strong></td>
<td>12</td>
<td>5.5</td>
<td>6</td>
<td>7</td>
<td>12</td>
<td>5.5</td>
</tr>
<tr>
<td><strong>frequency per year</strong></td>
<td>4</td>
<td>0.3</td>
<td>0.5</td>
<td>1</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>0.2</strong></td>
<td>1</td>
<td>4.0</td>
<td>2.0</td>
<td>3</td>
<td>1</td>
<td>4.0</td>
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</tbody>
</table>

**DO basic**

<table>
<thead>
<tr>
<th>Duration of the event</th>
<th>S066</th>
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<tbody>
<tr>
<td><strong>Tolerated</strong></td>
<td>12</td>
<td>3</td>
<td>3.5</td>
<td>4</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td><strong>frequency per year</strong></td>
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<td>2.5</td>
<td>3</td>
<td>4</td>
<td>2</td>
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<tr>
<td><strong>0.2</strong></td>
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<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

**Duration of the event**

- WWTP current situation
- Frequency per year
- DO critical
- DO basic
# Scenario analysis: water quality

## scenario C

(RTC + riv.aer. + DAF)

### Scenario C

<table>
<thead>
<tr>
<th>NH₄</th>
<th>Duration of the event</th>
<th>S066</th>
<th>S000</th>
<th>S017</th>
<th>S010</th>
<th>S008</th>
<th>S031</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 - 5 h</td>
<td>6 - 24 h</td>
<td>&gt; 24 h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tolerated frequency</td>
<td>12</td>
<td>1.5</td>
<td>0.7</td>
<td>0.3</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>per year</td>
<td>4</td>
<td>2</td>
<td>1.2</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2.5</td>
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<td>2</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>4.5</td>
<td>3</td>
<td>1.5</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
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</table>

### DO critical

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<td>per year</td>
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<td></td>
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<td>3</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
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<td>2</td>
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### DO basic

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<td>3</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>1</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Conclusions

**Integrated model** used to describe the **dynamics** of the whole urban wastewater system and evaluate **cost-effective** upgrade scenarios to comply with specific **water quality regulation**

Several upgrade options are available to achieve the desired water quality in terms of **DO** and **NH₄**

There are **substantial cost differences** between scenarios, with clear advantages in using **in-stream aeration** for **DO** depletion and WWTP **DAF** pre-treatment for **NH₄** peaks

The integrated model proved to be a very powerful tool to quickly investigate **interactions, synergies and conflicts** in the system
Perspectives

Next 2 years implementation:

• Sewer RTC
• WWTP higher inflow + RTC upgrade
• DAF demo 1500 m$^3$/h
• River aeration one station upstream WWTP
THANK YOU !!!

more details on RTC Wed 10:30 session 87

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