Parsimonious hydrological modelling in urban areas: Towards integrated modelling

(S. Coutu, D. Del Giudice, L. Rossi, D. A. Barry)
Why another hydrological model?

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Position Paper

Ten iterative steps in development and evaluation of environmental models

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Step 1: Definition of the purposes for modelling
Micropollution: a Worldwide Growing Concern

- Micropollutants identified in many countries in the world, across all continents.

- Feminization of fish due explained by the occurrence of high concentration of hormones (Jobling et al., 1996, *Environmental Toxicology and Chemistry*)

- Decline of vulture population in Pakistan explain by ingestion of Diclofenac (Oaks et al., 2004, *Nature*)
Selection of model features

Flexibility

Sewage Network & Urban Rivers

Automatic Calibration

Support for further integrated modelling

Fast computation time
Limits of existing models

Popular existing model (e.g., MOUSE, SWMM, etc) are distributed

More variables --- Require quantities of data --- Computation time

Unfit to integrated modelling

Parsimonious modelling --- Tested rural environment

Ignore the complexity of drainage system
Map of the presentation

Conceptual description of the model

Calibration & Validation

Examples of Application for integrated modelling
Conceptual description of the model

Calibration & Validation

Examples of Application for integrated modelling
Lumped parsimonious approach is efficient for modeling both urban AND rural watershed
Precipitation/discharge model (Coutu et al., 2012)

\[ ET = A_p \cdot ET_{max} \cdot f(\theta) \]

\[ f(\theta) = \begin{cases} 
0 & \text{if } \theta < \theta_w \\
\frac{\theta - \theta_w}{\theta_r - \theta_w} & \text{if } \theta_w \leq \theta \leq \theta^* \\
1 & \text{if } \theta^* < \theta < n
\end{cases} \]

\[ S_u = Z \cdot \theta \cdot A_p \]

\[ j \cdot A_i \]

\[ S_s(t) = R(t) + A_i \cdot j(t) - Q_{sup}(t) \]

\[ R = A_p \cdot (j - I) \]

\[ I = A_p \cdot \text{Min}(j, K_{sat}(10 - 9 \cdot \frac{\theta}{n})) \]

\[ Q_{sup} = k_{sup} \cdot S_s \]

\[ J_c = A_p \cdot K_{sat} \left( \frac{\theta}{n} \right)^c \]

\[ Q_{sub} = k_{sub} \cdot S_g \]
Precipitation/discharge model (Coutu et al., 2012)

7 calibration parameters

Reduced to 2 after sensitivity analysis!
Statistical achievement of baseflow at WWTP

MONTHLY

DAILY

HOURLY

Big thanks to Jordan (2010), e-dric and Ville de Lausanne
Lumping all CSOs to a single representative one

- A single, representative flow delimiter models the effect of all CSOs of the system in a lumped fashion manner.

- This representative CSO is modeled using a diversion law that follows a linear threshold-limited function.

- It is possible for two reasons:
  (i) it is the first CSO to discharge water when rain occurs
  (ii) it is the last CSO before our flow measurement point.
Ignorance of the sewer network
Same framework for river and sewage network
CSOs lumped into a single representative one

Calibration & Validation

Examples of Application for integrated modelling
Ignorance of the sewer network
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Calibration & Validation

Examples of Application for integrated modelling
Presentation of a “two in one” case study

Vuachère River: -- 15 km²
-- 34% impervious.

Vidy WWTP: -- 37km²
-- 25% impervious
--200,000 inhabitants
Calibration & Validation results for the river

Performance criteria:
NS: 0.73 (optimal = 1)
NB: -0.0057 (optimal = 0)
Calibration & Validation results for the WWTP

Performance criteria:
NS: 0.72 (optimal = 1)
NB: 0.001 (optimal = 0)
Comparison with the distributed model

- Comparable performances
- 12 CSOs lumped into one
- Over 40 sub-basins lumped into one
- No information of pipe network
- Easier to calibrate
- Smaller computation time (20s vs 0s)

Black: our model
Grey: distributed model
Ignorance of the sewer network
Same framework for river and sewage network
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Good performance on:
1) River
2) Sewer flow

Examples of Application for integrated modelling
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Examples of Application for integrated modelling

Map of the presentation
Example of integrated modelling

Rain

Biocide concentration

Antibiotic concentration

Time
Example of integrated modelling

DARIO DEL GIUDICE, UDM 2012

Rain

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Time
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Good performance on:
1) River
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Support for integrated modelling of multiple sources of pollution with complex dynamics
Parsimonious hydrological modeling of urban sewer and river catchments

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The pipe network is replaced by underground impervious area

All CSOs are lumped into a representative one

Efficient for sewer system and urban rivers

Potential for further integrated water quality modelling

QUESTIONS?

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Multiple scientific concerns

What is the control point?
• WTP entrance for optimizing treatment strategy
• WTP outlet and CSOs for environmental impact
• Urban rivers

What are the source dynamics?
• Medical prescription
• Illicit drug habits
• Pesticides in agriculture

What are the transport dynamics?
• Dynamics of the sewer system
• Dynamics of an urban river
Multiple scientific concerns

What is the control points?
- Depends on the objective

What are the source dynamics?
- Depends on the substance

What are the transport dynamics?
- Dynamics of the sewer system
- Dynamics of an urban river
## Automatic calibration algorithm

<table>
<thead>
<tr>
<th>Criterion function</th>
<th>Expression</th>
<th>Optimal value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nash–Sutcliffe</td>
<td>( 1 - \frac{\sum_{i=1}^{n} [Z_{obs}(i) - Z_{sim}(i)]^2}{\sum_{i=1}^{n} [Z_{obs}(i) - \bar{Z}_{obs}]^2} )</td>
<td>1</td>
</tr>
<tr>
<td>Normalized Bias</td>
<td>( \frac{\sum_{i=1}^{n} [Z_{obs}(i) - Z_{sim}(i)]}{n \bar{Z}_{obs}} )</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Lower bound</th>
<th>Upper bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated conductivity</td>
<td>( K_{sat} \ (m \ s^{-1}) )</td>
<td>1.4 \times 10^{-6}</td>
<td>2.6 \times 10^{-5}</td>
</tr>
<tr>
<td>Wilting point</td>
<td>( \theta_w )</td>
<td>0.14</td>
<td>0.26</td>
</tr>
<tr>
<td>Clapp exponent</td>
<td>( c )</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>ET parameter</td>
<td>( a )</td>
<td>-4.8</td>
<td>-0.84</td>
</tr>
<tr>
<td>ET parameter</td>
<td>( b )</td>
<td>0.7</td>
<td>1.19</td>
</tr>
<tr>
<td>Subsurface discharge rate</td>
<td>( k_{sub} \ (s^{-1}) )</td>
<td>2.8 \times 10^{-8}</td>
<td>3.8 \times 10^{-7}</td>
</tr>
<tr>
<td>Surface discharge rate</td>
<td>( k_{sup} \ (s^{-1}) )</td>
<td>2.0 \times 10^{-5}</td>
<td>3.8 \times 10^{-4}</td>
</tr>
</tbody>
</table>

\[
\text{Min}\{ (1 - NS) + | NB | \}
\]