Evaluation of Model Calibration and Uncertainty Analysis with Incorporation of Watershed General Information

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Outline

- Overview
- Calibration of Watershed Models
- Manual and Auto-Calibration
- Constrained Optimization for Watershed Model Calibration
- Case Study & Results
- Discussion & Conclusion
Overview

- Advanced technology in computer science
  - Complex watershed simulation models
  - Distributed in space & process-based
  - Long term simulations with large amount of data

- Development of complex watershed models
  - Evaluate impact from climate changing, various human activities on issues such as:
    - Availability of water resources
    - Water quality
    - Watershed management
Calibration of Watershed Models

- **Why and how do we calibrate?**
  - Model parameters can be case sensitive
  - Before conducting model simulation for various scenarios
    - To ensure model responses are close to natural responses
    - To minimize the “differences” between observed/simulated data by adjusting values of model parameters
  - “Differences” can be calculated as?
    - Error statistics (ex. RMSE, PBIAS, 1-NS)
Calibration Techniques (1/3)

- Manual Calibration
  - Manual tuning model parameters
  - Easier to get familiar with the watershed system
  - IT IS SLOW!!!
    - Time consuming
    - Extremely difficult to apply for multi-site, multi-variable problems
Auto-Calibration

- Calibration implementing mathematical/statistical theorems
- IT IS Fast!!! (automated optimization process)
- Full understanding of the model is required
  - Selection of the objective function
  - Parameter ranges (upper/lower bounds) must be assigned carefully
Calibration Techniques (3/3)

- Objective function of automated optimization process
  - Mathematical equation to be minimized
    \[ RMSE: OF = \sum_{m=1}^{M} \sqrt{\frac{1}{N_m} \sum_{n=1}^{N} [y_{n,\text{sim}}^m - y_{n,\text{obs}}^m]^2} \]

- Behavior definition
  - Statistical thresholds in evaluating model performance
  - To ensure calibrated results satisfy many statistics

<table>
<thead>
<tr>
<th>Performance Rating</th>
<th>Nash-Sutcliffe Coefficient</th>
<th>PBIAS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Streamflow</td>
</tr>
<tr>
<td>Very Good</td>
<td>0.75 &lt; NSE ≤ 1.00</td>
<td>PBIAS &lt; ±10</td>
</tr>
<tr>
<td>Good</td>
<td>0.65 &lt; NSE ≤ 0.75</td>
<td>±10 ≤ PBIAS &lt; ±15</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>0.50 &lt; NSE ≤ 0.65</td>
<td>±15 ≤ PBIAS &lt; ±25</td>
</tr>
<tr>
<td>Unsatisfactory</td>
<td>NSE ≤ 0.50</td>
<td>PBIAS ≥ ±25</td>
</tr>
</tbody>
</table>

General Performance Ratings, Moriasi et al. (2007)
Constrained Optimization (1/2)

- Intra-watershed responses
  - (X) Time varying responses
    - Hydrograph, water quality in time series
  - (O) A general system response (intra-watershed responses) in terms of summative quantities
    - Ex. Crop yield, accumulated mass of biodegeneration, amount of nutrient leaching
- Calibration without considering intra-watershed responses
  - Actual watershed behavior could be violated
  - Excellent but useless statistics
  - Results are “precisely wrong”
  - Calibrated model parameters are not applicable
Examples of intra-watershed responses (Midwest region of the United States)

- Annual denitrification (DENI)
  - From 0 to 50 kg/ha/yr (David et al., 2009)
- Ratio that NO₃ loadings to streams from subsurface flow (SSQ Ratio) versus all NO₃ loadings
  - No less than 60% (Schilling, 2002)
Case Study Area

- Eagle Creek watershed
  - Central Indiana, USA
  - 248km²
- Available data
  - 1997~2003
  - Streamflow (1 site)
  - NOX (4 sites)
Case Study Settings (1/2)

- Basic settings
  - Daily streamflow + Monthly Total Nitrate (28 parameters)
  - Objective function (Ahmadi et al., 2012)
- Simulation length
- Sampling technique of auto-calibration
  - Dynamically Dimensioned Search (Tolson and Shoemaker, 2007)
## Case Study Settings (2/2)

<table>
<thead>
<tr>
<th>Case Scenarios</th>
<th>Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario I</td>
<td>Calibration without any constraints</td>
</tr>
<tr>
<td>Scenario II</td>
<td>Calibration + Constraint (DENI, unit: kg/ha) → 0 ≤ DENI ≤ 50</td>
</tr>
<tr>
<td>Scenario III</td>
<td>Calibration + Constraint (SSQ Ratio) → 0.60 ≤ SSQ Ratio ≤ 1.00</td>
</tr>
</tbody>
</table>
| Scenario IV    | Constraints (Both) → \[ \begin{align*} &0 \leq DENI \leq 50 \\
&0.60 \leq SSQ Ratio \leq 1.00 \end{align*} \] |
Results (1/6)

- Objective function values

![Graph showing objective function values for different scenarios over the number of model evaluations.](image)
Results (2/6)

- Percentage of parameter samples that satisfy the behavior definition

<table>
<thead>
<tr>
<th>Case Scenarios</th>
<th>Behavior Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Satisfactory</td>
</tr>
<tr>
<td>Scenario I</td>
<td>78.73</td>
</tr>
<tr>
<td>Scenario II</td>
<td>64.40</td>
</tr>
<tr>
<td>Scenario III</td>
<td>1.91</td>
</tr>
<tr>
<td>Scenario IV</td>
<td>60.78</td>
</tr>
</tbody>
</table>
## Results (3/6)

- Best results with corresponding DENI & SSQ Ratio

<table>
<thead>
<tr>
<th>Period</th>
<th>Scenario</th>
<th>Nash-Sutcliffe Efficiency Coefficient (NSE)</th>
<th>DENI (kg/ha/yr)</th>
<th>SSQ Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>35  (STR)</td>
<td>32  (NOX)</td>
<td>27  (NOX)</td>
</tr>
<tr>
<td>Calibration</td>
<td>Scenario I</td>
<td>0.91</td>
<td>0.95</td>
<td>0.91</td>
</tr>
<tr>
<td>1997~2000</td>
<td>Scenario II</td>
<td>0.87</td>
<td>0.82</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>Scenario III</td>
<td>0.89</td>
<td>0.89</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>Scenario IV</td>
<td>0.87</td>
<td>0.72</td>
<td>0.88</td>
</tr>
<tr>
<td>Validation</td>
<td>Scenario I</td>
<td>0.77</td>
<td>0.10</td>
<td>0.13</td>
</tr>
<tr>
<td>2001~2003</td>
<td>Scenario II</td>
<td>0.61</td>
<td>0.23</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>Scenario III</td>
<td>0.70</td>
<td>0.20</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>Scenario IV</td>
<td>0.60</td>
<td>0.43</td>
<td>0.58</td>
</tr>
</tbody>
</table>
## Results (4/6)

- Percentage of parameter samples penalized for each scenario (%)

<table>
<thead>
<tr>
<th>Case Scenarios</th>
<th>Rate of Penalty</th>
<th>DENI Constraint</th>
<th>SSQ Ratio Constraint</th>
<th>At least one constraint violated</th>
<th>Both constraints violated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario I</td>
<td>0.00</td>
<td>99.83</td>
<td>99.59</td>
<td>99.96</td>
<td>99.46</td>
</tr>
<tr>
<td>Scenario II</td>
<td>24.50</td>
<td>24.50</td>
<td>7.60</td>
<td>26.71</td>
<td>5.39</td>
</tr>
<tr>
<td>Scenario III</td>
<td>48.48</td>
<td>92.99</td>
<td>48.48</td>
<td>93.11</td>
<td>48.34</td>
</tr>
<tr>
<td>Scenario IV</td>
<td>59.24</td>
<td>56.08</td>
<td>22.69</td>
<td>59.24</td>
<td>19.55</td>
</tr>
</tbody>
</table>

- You don’t want to use results from Scenario I at all!
- DENI constraint has influence on SSQ Ratio constraint.
Results (5/6)

- Cumulative distribution functions of constraints

![Cumulative distribution functions of constraints](image)
Results (6/6)

- Cumulative distribution functions of sensitive parameters

- Sensitive to denitrification

- Sensitive to SSQ ratio
Discussion and Conclusion

- It is important to include additional constraints that represent intra-watershed responses
  - Statistically well performed parameter samples are giving wrong outputs in real world applications
  - Watershed characteristics could be violated
  - Especially for watershed which little knowledge is available on parameter ranges

- Interactions between constraints
  - Denitrification constraint has shown great influence over results
  - Automatically regulates SSQ Ratio
Thanks for your attention!

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