Assessing the impact of land management changes on nutrient loads with the Reliability Ensemble Averaging (REA) method

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1. Scenario analysis in hydro-biogeochemical modelling

Classical approach:
- Calibration and prediction by a single model
- Alteration of relevant boundary conditions
- Re-run and study of difference between original and new prediction

But...
… how reliable is an extensively calibrated model under changed boundary conditions?
… would a multi-model ensemble predict the same changes?

2. Ensemble modelling
- Pools different predictions of the same system
- Aims at balancing strengths and weaknesses between members
- Widely used in climate sciences
- Averaging methods usually provide more reliable predictions than single models
- State-of-the-art method to circumnavigate structural uncertainty issues

3. Ellen Brook River
- Located in south-west Western Australia
- Mediterranean climate with cool and wet winters, dry and hot summers
- Contributes 6% and 10% to total annual stream flow and N loads entering the Swan Canning estuary
- High frequency N monitoring
- Inorganic N represents about 10% of TN

Due to frequent algal disturbances, the Swan River Trust [1] set a reduction of N loads by 50% over next years.

3. REA method

Philosophy [2]:
- Model reliability under current conditions
- Convergence with other ensemble members
- Model weights in the averaging scheme

Put in a mathematical way, each model $i$ of the ensemble is assigned a weight $w$ computed such as

$$w_i = \left( R_{i,m} \cdot C_i \right)^{1/(m+n)}$$

where $R_i$ and $C_i$ are the reliability and convergence criteria of model $i$, respectively. Coefficients $m$ and $n$ are used to give more importance to either the reliability or the convergence criterion.

4. Ensemble setup
- Four model structures: LASCAM, CHIMP, SWAT and HBV-N-D
- Calibration to simulate daily runoff and TN fluxes between 01/01/1989 and 31/12/1997
- Scenarios of reduction in N fertiliser application set between 01/01/1998 and 31/12/2006
- REA using the inverse of the RMSE during calibration as reliability criterion and the inverse of the absolute difference between model as convergence criterion.

5. Calibration results

<table>
<thead>
<tr>
<th>Model</th>
<th>RMSE [g N / (ha d)]</th>
<th>TN export [t N / yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Calibration Validation</td>
<td>Calibration Validation</td>
</tr>
<tr>
<td>LASCAM</td>
<td>5.4 7.1</td>
<td>83.0 59.7</td>
</tr>
<tr>
<td>CHIMP</td>
<td>10.8 9.9</td>
<td>84.9 69.0</td>
</tr>
<tr>
<td>SWAT</td>
<td>18.4 26.2</td>
<td>131.1 117.7</td>
</tr>
<tr>
<td>HBV-N-D</td>
<td>14.3 10.4</td>
<td>34.3 31.3</td>
</tr>
</tbody>
</table>

6. Scenario results and discussion

Results of the different scenarios for the different models and some averaging techniques are summarised in Figure 3.

![Figure 3 Scenario results for single models and ensembles](image)

Although they predict very different absolute TN fluxes predictions, all models except CHIMP have a similar absolute response to the same scenario. If we only use a simple average or a weighted mean based on calibration results ($n=0$), the outlying position and calibration performances of CHIMP ($2nd$ best) pull the ensemble towards higher response to fertilisation rate reduction. By integrating the convergence criterion ($n=1$), the REA provides a more reliable scenario result without totally disqualifying any of the models.

This method has a great potential in the hydro-biogeochemical modelling context.

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References