Automatic calibration of a 3D morphodynamic numerical model of a 180° channel bend

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https://www.europeanbackdoors.com
Introduction & Background

- The quality of numerical modelling outputs depends on how well the physical processes can be mathematically described through
  - governing equations
  - discretization schemes
  - boundary conditions
  - empirical formulas
  - input parameters (numerical & physical)

- The relationship between data, such as direct observations and recorded measurements, and numerical models is very complicated in the ‘water domain’.
  - uncertain input variables which cannot be measured directly
  - limitation in measured data for model calibration (certain locations over a finite duration)
The model accuracy and its prediction reliability strongly depend on the calibration procedure by adjustment of the uncertain input parameters.

**Introduction & Background**

- **Manual**
  - trial-and-error adjustment of input values
  - complex, subjective, time-consuming

- **Automated**
  - using **optimization algorithms**

  - **Gradient-based (Local) algorithms**
    - computationally efficient
    - can be trapped in a local minimum

  - **Population-evolution-based (Global) algorithms**
    - computationally demanding
    - robust in finding the global minimum
Methods

- Experimental Data (Yen & Lee 1995)

- 20 cm non-uniform sand $d_{50} = 1.0$ mm
- standard deviation of the particle size distribution $\sigma = 2.5$
- initial bed slope $S_0 = 0.002$
- base flow discharge $Q_0 = 0.02$ m$^3$/s and depth $h_0 = 5.44$ cm
- unsteady inflow with two different hydrographs

- **Run#1**: $T = 180$ min
  $Q_{\text{peak}} = 0.0750$ m$^3$/s
- **Run#3**: $T = 240$ min
  $Q_{\text{peak}} = 0.0613$ m$^3$/s
Methods

Numerical Model (SSIIM2)

Grid

- adaptive 3-D, non-orthogonal grid
- wetting and drying algorithm
- finite-volume approach for the spatial discretization
- grid size: $225 \times 20 \times 5$ cells

Hydrodynamics

- RANS equations
  - Reynolds stress term $\rightarrow$ k-ε turbulence model
  - pressure term $\rightarrow$ semi-implicit method (SIMPLE)
  - convective term $\rightarrow$ second-order upwind (SOU) scheme
- implicit scheme for the temporal discretization

Sediment Transport

- 8 grain size classes
- bedload transport calculation by using the formulas of
  - van Rijn
  - Engelund/Hansen
  - Einstein
  - Wu
Methods

➢ Calibration

• PEST (Parameter ESTimation) ➔ a model-independent, non-linear inverse modeling code
  • optimization algorithm: Gauss-Marquardt-Levenberg (GML)
  • objective function: sum of the squared residuals
    \[ \Phi = \sum_{i=1}^{m} (w_i(s_i - o_i))^2 \]
  • inverse problem solver: singular value decomposition (SVD)

• Investigated parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Initial value</th>
<th>Lower bound</th>
<th>Upper bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughness height ( (k_s) )</td>
<td>( d_{90} )</td>
<td>( d_{50} )</td>
<td>( 10d_{90} )</td>
</tr>
<tr>
<td>Active layer thickness ( (ALT) )</td>
<td>( d_{\text{max}} )</td>
<td>( d_{50} )</td>
<td>( 5d_{\text{max}} )</td>
</tr>
<tr>
<td>Volume fraction of sediments/water content ( (VFS) )</td>
<td>50%</td>
<td>40%</td>
<td>60%</td>
</tr>
</tbody>
</table>

\( d_{50} = 0.1 \, \text{cm} \)
\( d_{90} = 0.32 \, \text{cm} \)
\( d_{\text{max}} = 0.85 \, \text{cm} \)
The sediment packing volume in comparison to the water content remains almost constant around 50%, independent of the discharge alteration. → exception: van Rijn

The thickness of the active layer and the roughness height rise by the increase of the flow discharge.
Results

- Bed levels of the bend along 3 longitudinal-sections

Run#1

10 cm from the inner wall

10 cm from the outer wall

Central radius
Results

• Bed levels of the bend along 3 longitudinal-sections

Run#3

10 cm from the inner wall

Central radius

10 cm from the outer wall
**Results**

- Statistical performance of the calibrated models

<table>
<thead>
<tr>
<th>Goodness of Fit</th>
<th>Sediment Transport Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>van Rijn</td>
</tr>
<tr>
<td>Run#1</td>
<td>Run#3</td>
</tr>
<tr>
<td>$R^2(-)$</td>
<td>0.90</td>
</tr>
<tr>
<td>RMSE (cm)</td>
<td>1.57</td>
</tr>
<tr>
<td>Initial bed level</td>
<td></td>
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</tbody>
</table>
Conclusion

• PEST can considerably expedite and facilitate the model calibration procedure by reducing the user-intervention.

• PEST is a gradient-based method; consequently its prediction credibility is dependent on the parameter starting value. Therefore, the calibration routine can be reassessed using different criteria for parameters.

• Based on the coefficient of determination, and the root mean squared error the calibrated model outputs obtained by Wu’s formula have the best agreement with the experimental data.

• The formula by van Rijn using the hiding-exposure approach of Wu also provides reasonably acceptable results.

"No man ever steps in the same river twice, for it is not the same river and he is not the same man"

Heraclitus
Thank you

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The reliability of results depends on

- initial guess of parameters
- meaningful upgrade boundaries