Can Complexity Simplify Modeling?

Hydrologic Flowpaths
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My Thoughts

• First, I don’t like calibration, but it is often necessary
  • Calibration tells us what we don’t know or can’t figure out about the system
• Goal: to provide actionable info about *intra*-watershed processes to inform management
• My Rules:
  • Use as much ‘real’ data as is available
  • Determine parameter values *a priori* if possible
  • Constrain parameters to realistic ranges
  • Be wary of purely fitting parameters or parameters we don’t understand the function of or what they do
Outline

- Context: Hydrologic complexity as an example
  - Variable Source Area Hydrology and Soil Physics
  - Snowmelt/Accumulation
- Summary
Can we use Hydrologic Complexity to Constrain Models?

- There are a number of aspects of the hydrologic response that can be used as the underlying linkages to constrain a calibration
  - Storage versus Discharge relationships
  - Storage versus Saturated Area relationships
  - Water Balance, a universal concept that is also scalable
  - Terrain Attributes
  - Probability distribution of Soil Depths, Infiltration Capacity
  - Heterogeneity
- Goal: represent complex processes/landscapes without over parameterization or inducing model instability
Variable Source Areas

Most Watershed Models were not intended to capture this complexity

• Soil and Water Assessment Tool (SWAT)
• General Watershed Loading Function (GWLF)
• Agricultural Nonpoint Source Pollution Model (AGNPS)
• Hydrologic Simulation Program Fortran (HSPF)
The Curve Number as an example

“Runoff” = \( P_e^2 / (P_e + S) \)

\[ S = 25400 / \text{CN} - 254 \]

Tables link CN to land use and soil drainage class. CN is then calibrated.
Parameter Estimation

\[ Q = \frac{P_e^2}{(P_e + S)} \]

\[ A_f = \frac{\partial Q}{\partial P_e} \]

\[ A_f = 1 - \frac{S^2}{(P_e + S)^2} \]

\[ A_s = 1 - \frac{S^2}{(\sigma_e + S)^2} \]

\[ \sigma_e = S\sqrt{\frac{1}{1 - A_s}} - 1 \]

\[ A_f, A_s, \sigma_e = f(S, P) \]
We know how much area is contributing...

\[ A_f = f(S, P_e) \]

...but from where in the landscape?
\[
\ln \left( \frac{a}{\tan \beta} \right)
= \ln \left( \frac{1}{1 - A_s} \right) - 1
\]

\[s_i = \text{local storage}\]

\[\lambda_i \quad \sigma_{10} \quad \sigma_9 \quad \sigma_8 \quad \sigma_7 \quad \sigma_6 \quad \sigma_5 \quad \sigma_4 \quad \sigma_3 \quad \sigma_2 \quad \sigma_1\]

Wetness Index Classes

Easton et al., 2008. *J. Hydrol*
Easton et al., 2011. *Hydrol. Proc*
\[ \sigma_8 = f(\lambda_8) \]
\[ \sigma_{10} = f(\lambda_{10}) \]
\[ \sigma_1 = f(\lambda_1) \]
\[ \sigma_6 = f(\lambda_6) \]
\[ \sigma_4 = f(\lambda_4) \]

\[ \sigma_e = S(\sqrt{1/(1-A_s)}) - 1 \]

\[ \sigma_i = q_{B,i}/q_{E,i} \]

\[ \Sigma_B = Q_B/Q_E \]
“Calibration”

TI and Hydrograph Decomposition

E = 0.69
S = 16.4

Full Auto Calibration

E = 0.68
CN = 76
$R^2 = 0.79$

$R^2 = 0.57$

Demo
Snow Melt/Accumulation

• Many watershed models use a temperature index to ‘model’ snowmelt and snow accumulation
  
  • \( M = \text{MF} \times (T_a - T_{\text{base}}) \)

• Simple, but requires calibration and cannot be applied outside the range of conditions for which they were calibrated
  
  • e.g., Assessing Landuse or Climate Change
## Temperature Index

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snowfall temperature [C]</td>
<td>-1.27</td>
<td>2.62</td>
<td>-2.06</td>
</tr>
<tr>
<td>Snow melt base temperature [C]</td>
<td>0.02</td>
<td>3.62</td>
<td>181.00</td>
</tr>
<tr>
<td>Melt factor on June 21 [mm H$_2$O/C-day]</td>
<td>-1.62</td>
<td>2.67</td>
<td>-1.65</td>
</tr>
<tr>
<td>Melt factor on December 21 [mm H$_2$O/C-day]</td>
<td>-0.27</td>
<td>3.41</td>
<td>-12.63</td>
</tr>
<tr>
<td>Snow pack temperature lag factor</td>
<td>0.15</td>
<td>3.13</td>
<td>20.87</td>
</tr>
</tbody>
</table>

Can this be used to predict anything?
Surface Radiation Budget

\[ \Delta SWE = \frac{(S + L_a - L_t + H + E + G + P - SWE(C \Delta T_s))}{\lambda} \]

- \( \Delta SWE \): change snow water equivalent
- \( S \): net incident solar radiation
- \( L_a \): atmospheric long wave radiation
- \( L_t \): terrestrial long wave radiation
- \( H \): sensible heat exchange
- \( G \): ground heat conduction
- \( P \): heat added by rainfall
- \( E \): energy flux latent heat, vaporization & condensation
- \( SWE(C \Delta T_s) \): change of snowpack heat storage
- \( \lambda \): latent heat of fusion
Complexity actually helps with calibration issues...

![Graph showing SNOTEL, PB, and Temp Index over years 2001 to 2008.](image)
Summary

- Be careful with un/loosely constrained calibration
- Constrained calibration can improve process representation reducing computational needs and represent the correct physical processes
- Difference between initial model estimates and calibrated model tells us what we don’t know about the system
- Improve landscape management by ensuring watershed info is translatable to the landscape level
  - Where should we focus efforts/money?