‘Anomalies’ in the Meuse/Moselle behaviour

Or how to model flood events
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Chair of the Netherlands Hydrological Society (NHV)
Anomaly?

Similar ‘anomaly’ in the Moselle/Mosel

Fig. 2. Comparison of observed and simulated hydrograph after Ashagrie et al. (2006). The observed discharge appears to be considerably overestimated in the central part of the observation period.
Anomaly in the rainfall-runoff behaviour of the Meuse catchment. Climate, land-use, or land-use management?

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Fig. 4. Schematic representation of the FLEX model.

Table 1. Interception threshold varies between $I_{\text{max}}$ and $I_{\text{min}}$.

<table>
<thead>
<tr>
<th>Land-use</th>
<th>$I_{\text{max}}$ (mm)</th>
<th>$I_{\text{min}}$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Pasture</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Agriculture</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Deciduous</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Coniferous</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Penman Monteith Equation

$$ E_P = \frac{1}{\lambda} \frac{s R_n + c_P \rho_a (e_d - e_a) / e_a}{s + \gamma (1 + \omega / r_o)} $$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_P$</td>
<td>Potential evaporation</td>
<td>m/s</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Latent heat coefficient</td>
<td>J/kg</td>
</tr>
<tr>
<td>$\rho_w$</td>
<td>Density of water</td>
<td>kg/m$^3$</td>
</tr>
<tr>
<td>$R_n$</td>
<td>Net radiation</td>
<td>W/m$^2$</td>
</tr>
<tr>
<td>$s$</td>
<td>Slope of the temperature-saturation vapour pressure curve</td>
<td>kPa/K</td>
</tr>
<tr>
<td>$c_P$</td>
<td>Specific heat of air at constant pressure</td>
<td>J/(kg K)</td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>Density of air</td>
<td>kg/m$^3$</td>
</tr>
<tr>
<td>$e_d$</td>
<td>Actual vapour pressure of the air</td>
<td>kPa</td>
</tr>
<tr>
<td>$e_a$</td>
<td>Saturation vapour pressure for the air temperature</td>
<td>kPa</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Psychrometric constant</td>
<td></td>
</tr>
<tr>
<td>$r_o$</td>
<td>Aerodynamic resistance</td>
<td>s/m</td>
</tr>
<tr>
<td>$r_c$</td>
<td>(Bulk) surface resistance</td>
<td>s/m</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Stomatal resistance coefficient</td>
<td></td>
</tr>
</tbody>
</table>
Anomaly disappeared by time-variable Lag Time and Evaporation conductivity factor

Real evaporation was substantially larger during industrial period of active forestry
Is this proof?

- No, it is an indication that land management is as important as land use in hydrology.
- It shows that forests and agriculture are key to the hydrology (and water quality) of the Meuse.
What about climate and land-use effects on Floods?

Do we understand flood generating processes sufficiently?
Threshold processes in Physics

- Heat transport driven by heating
  - molecular diffusion
  - convective transport
  - turbulent transport
  - boiling

Zehe & Sivapalan (2009) HESS

Threshold behaviour in hydrological systems as (human) geo-ecosystems: manifestations, controls, implications

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walk
trot
canter
gallop
Work per unit velocity vs Velocity

- Walk
- Trot
- Canter
- Gallop

Model
Knowledge questions

• We don’t fully understand the mechanisms
• We don’t know when a certain mechanism is dominant, or when the switches take place
• We don’t know the triggers for the switches
• We don’t know what happens when the entire system switches into “gallop”
Knowledge questions (2)

- Rainfall-runoff processes are complex: a multitude of processes,
- Heterogeneity, need for calibration
- Equifinality, undeterminable parameters
- Site specific combinations of processes and properties ('races')
A multitude of mechanisms

Fenicia et al. (2008)
Water Resources Research
Huewellerbach

- 2.7 km²
- Sand stone
- Vertical
- mainly
- Groundwater flow
Weierbach

• 0.5 km$^2$
• Schist
• Lateral
• Steep
• Rapid subsurface flow
Wollefsbach

- 4.5 km²
- Marls (eroded)
- Lateral
- Rapid subsurface flow / Hortonian overland flow
Topography as a driver

Renno et al. (2008)
Remote Sensing of Environment
Drainage direction: Lateral  Lateral  Vertical
Land use: Grass/wetland  Forest  Agriculture
Soil: Shallow  Variable  Deep
Dominant mechanism: Saturation overland flow  Rapid subsurface flow  Groundwater flow / Hortonian overland flow
## Three model classes

<table>
<thead>
<tr>
<th>Classes:</th>
<th>Wetland</th>
<th>Hill slope</th>
<th>Plateau</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topography</td>
<td>flat</td>
<td>steep</td>
<td>undulating</td>
</tr>
<tr>
<td>Land use</td>
<td>pasture, wetland</td>
<td>forest, nature</td>
<td>agriculture, pasture</td>
</tr>
<tr>
<td>Soils</td>
<td>shallow</td>
<td>shallow</td>
<td>deep</td>
</tr>
<tr>
<td>Dominant mechanism</td>
<td>saturation overland flow</td>
<td>storage excess sub-surface flow</td>
<td>groundwater flow</td>
</tr>
<tr>
<td>drainage</td>
<td>not well-drained</td>
<td>well-drained</td>
<td>not well-drained</td>
</tr>
<tr>
<td>drainage direction</td>
<td>lateral</td>
<td>lateral</td>
<td>vertical</td>
</tr>
<tr>
<td>time scale</td>
<td>very fast</td>
<td>fast</td>
<td>very slow</td>
</tr>
<tr>
<td>Supporting mechanism</td>
<td>groundwater flow</td>
<td>groundwater flow</td>
<td>infiltration excess sub-surface flow (during high intensity rainfall)</td>
</tr>
<tr>
<td>drainage</td>
<td>not well-drained</td>
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<td>slow</td>
<td>fast</td>
</tr>
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</table>
Wetland

4 parameters:
- $D_w$
- $S_{w,max}$
- $K_w$
- $\beta_w$

$P_e = \max (P - D_w, 0)$

$E_w \approx E_0$

$c_w = 1 - \left(1 - \frac{S_w}{S_{w,max}}\right)^{\beta_w}$

$Q_{w, sof} = c_w \cdot P_e$

$Q_{w, gw} = \frac{S_w}{K_w}$
Hillslope

6 parameters:
- $D_h$
- $S_{h,max}$
- $K_h$
- $\beta_h$
- $a$
- $S_{wp}$

$P_e = \max(P - D_h, 0)$

$c_h = 1 - \left(1 - \frac{S_h}{S_{h,max}}\right)^{\beta_h}$

$Q_{h,gw} = \frac{S_{h,gw}}{K_h}$
Plateau

\[ P_e = \max(P - D_p, 0) \]

\[ E_i = E_{i,0} \cdot \max\left(\frac{1}{P} S_u - S_{wp}, 0\right) \]

\[ F = \min(P_e, F_{max}) \]

\[ Q_{p,ieo} = \frac{S_{p,gw}}{K_p} \]
## Characteristics of sub-models

<table>
<thead>
<tr>
<th>Model:</th>
<th>Wetland</th>
<th>Hillslope</th>
<th>Plateau</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dominant mechanism</strong></td>
<td>saturation overland flow</td>
<td>rapid sub-surface flow</td>
<td>groundwater flow</td>
</tr>
<tr>
<td><strong>parameters</strong></td>
<td>$D_w$ [L/T], cc</td>
<td>$D_h$ [L/T], cc</td>
<td>$D_p$ [L/T], est</td>
</tr>
<tr>
<td></td>
<td>$S_{w,\text{max}}$ [L], fc</td>
<td>$S_{h,\text{max}}$ [L], fc</td>
<td>$S_{u,\text{max}}$ [L], est</td>
</tr>
<tr>
<td></td>
<td>$\beta_w$ [-], fc</td>
<td>$\beta_h$ [-], fc</td>
<td>$S_{\text{wp}}$ [L], est</td>
</tr>
<tr>
<td></td>
<td>$a$ [-], fc</td>
<td>$p$ [-], est</td>
<td>$p$ [-], est</td>
</tr>
<tr>
<td></td>
<td>$T_h$ [T], fc</td>
<td>$T_h$ [T], fc</td>
<td>$K_p$ [T], est</td>
</tr>
<tr>
<td><strong>Supporting mechanism</strong></td>
<td>groundwater flow</td>
<td>groundwater flow</td>
<td>infiltration excess flow (during high intensity rainfall)</td>
</tr>
<tr>
<td><strong>parameters</strong></td>
<td>$K_w$ [T], est</td>
<td>$K_h$ [T], est</td>
<td>$F_{\text{max}}$ [L/T], est</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$T_p$ [T], est</td>
</tr>
</tbody>
</table>
Ways forward

• Classification of catchments into sub-systems based on topography, geology, ecology, landuse
• Developing simple lumped conceptual sub-system models (as simple as possible)
• Combining these in parallel (or possibly in series)
• Feed these sub-models with spatially distributed rainfall
• ‘Space for Time’ exchange
Conclusion

• There is a definite need for more knowledge on how the system behaves, both under normal and under extreme conditions

• There is a need to cooperate in the development of adequate tools

• There is a need to share operational knowledge, information and experiences