Model-based assessment and mapping of water supply conditions of forest sites

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Sino-German-Symposium

The Role of Forests and Forest Management in the Water Cycle

November 27 - 30, 2006
Blockhaus Dresden
Water dynamics at forest sites

→ crucial component for sustainable forest planning and management of natural resources

- stand growth and stability
- societal benefits of forests
  → flood protection
  → groundwater recharge (quantity + quality)
- major site factor in forest land assessment
  (detailed forest site maps at scales 1:5,000 ... 1:25,000)

(Brechtel 1985)
Example: Forest Site Map 1:10,000 NE Germany
Display of “site units“

- Micro/meso climate
- Soil type
- Nutrient status
- Water status

- Selection and admixture of tree species
- Management concepts etc.
Empirical approach to determine “site water class“
Relative classification → G.A. Krauss (1936)

For terrestrial (freely draining) soils

- **Slope aspect**
  - S / SW: increasing inclination
  - "medium dry“ → "very dry“

- **Constant regional (meso) climate**
  - no relief (flat)
  - average (optimal)
  - „mäßig frisch bis „frisch“

- **Slope aspect**
  - N / NE: increasing inclination
  - "slightly wet“ → "very wet“

Potential natural vegetation (natural forest type)

→ Expert knowledge on interaction between relief/soil and (micro)climate
Empirical approach to determine “site water class“
Relative classification → G.A. Krauss (1936)

For hydromorphic soils (periodically or permanently waterlogged)

- soil profile information
- ground vegetation as indicator

Potential natural vegetation (natural forest type)
Empirical approach to determine “site water class“
Relative classification → G.A. Krauss (1936)

Disadvantages

subjective “Expert knowledge“

→ disequilibrium between soil morphology and actual water dynamics
→ based on lumped average climate numbers
→ transferability to other regions?
→ constant side conditions (notably climate)?
→ effects of forest management?

Urgent need for a novel approach
→ quantifying the variable water supply conditions!
The large potential of ecohydrological models

Input
- Meteorological data
- Soil physical properties
- Forest stand properties

Data situation
± critical !!!
→ point data
→ spatial data

Output
- Soil water dynamics
- Time series
- Plant-available water

Process-oriented Water Cycling Model
Forest site (plot scale)

Extremes:
- drought
- water-logging
  → occurrence
  → intensity
  → duration
Digital spatial information

Regionalization of model input parameters

Spatially distributed simulation of water dynamics

Spatially distributed model results

→ statistical analysis

→ physiol. relevance

Terrain morphology

Soil map

Forest inventory map

Meteorological data

e.g. radiation, temperature, precipitation

Soil physical parameters

e.g. water retention curve, hydraulic conductivity

Plant parameters

e.g. LAI, root distribution, stand density

BROOK 90+

GIS based modelling of water fluxes

Components of water balance

Ratio $E_{act} / E_{pot}$ (→ physiological stress)

$\Theta$, $\psi$ depth functions

Storage of plant available water

Components of water balance

• Components of water balance

• Ratio $E_{act} / E_{pot}$ (→ physiological stress)

• $\Theta$, $\psi$ depth functions

• Storage of plant available water
BROOK90: a sophisticated SVAT 1D-model for application on the plot (small watershed) scale

ETP:
→ Shuttleworth & Wallace

Soil water transport:
→ Richards equation
→ (macropore flow)

daily time-steps

→ http://users.rcn.com/compassbrook/brook90.htm
The testing area: Tharandt Forest (Saxony)
Stations of the IHM-Meteorology, TU Dresden

Tharandt Forest
Land-use from Landsat TM

Measurements
Climate and forest data since mid of the 19th century
continuous hydrological data since 1968 (4.6 km², spruce)
continuous flux measurements by EC

- since 1996 spruce
- since 2002 grass
- since 2004 crop rotation
- since 2005 beech

Elevation: 200 – 400 m asl
Precipitation: 840 mm yr⁻¹
Air temperature: 8.4 °C
Eddy covariance of energy, water and carbon fluxes

Leaf wetness sensors

Classical throughfall measurements accompanied by precipitation measurements at the tower and a clearing close by
## Measurements of water fluxes at different scales

<table>
<thead>
<tr>
<th>Spatial scale</th>
<th>Method</th>
<th>Temporal scale of balancing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single trees</td>
<td>Sap flow</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Field plots</td>
<td>TDR, tensiometers</td>
<td>daily</td>
</tr>
<tr>
<td>Forest Stand</td>
<td>eddy covariance</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Catchment</td>
<td>Water gauge</td>
<td>monthly</td>
</tr>
</tbody>
</table>
Point measurements: Cumulated rates of $\text{ETP}_{\text{act}}$ Tharandt Forest (spruce)

Measured vs. BROOK90 simulation

→ difficulties of BROOK90 in sorting precipitation into snow or rain
→ overestimation of the (winter) interception storage capacity
→ uncertainties in recording evapotranspiration in winter month
Point measurements: Time series of soil moisture \( \Theta \)
Tharandt Forest (spruce) 1996 - 2006

Measured vs. BROOK90 simulation

Soil water content [Vol.-%]

- observed - topsoil
- predicted - topsoil

Soil water content [Vol.-%]

- observed - subsoil
- predicted - subsoil

Aug. 96  Aug. 98  Aug. 00  Jul. 02  Jul. 04  Jul. 06
Point measurements: Cumulative daily transpiration rates
Tharandt Forest (beech)
May 1 – Dec. 31, 2006
Measured vs. BROOK90 simulation

![Forest image]

<table>
<thead>
<tr>
<th>Date</th>
<th>Measured</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mai.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jul.06</td>
<td></td>
<td></td>
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<tr>
<td>Sep.06</td>
<td></td>
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</tbody>
</table>

b) Measured (blue) vs. Simulated (red)
Regionalization of meteorological input data

Solar radiation
GISRAD
(Goldberg & Häntzschel, 2002)

July 31, 2006

Precipitation
(Franke et al., 2006)
Transpiration during the growing season (May – Sept.) for two contrasting years

**1998 ‘wet’**
P: 420 mm  
CWB: -10 mm

**2003 ‘dry’**
P: 230 mm  
CWB: -230 mm

**Testing area: Buchhübel**

Range: 157 – 178 mm  
Range: 167 – 202 mm

CWB = Climatic Water Balance (P – ETP\text{pot})
Occurrence of “drought stress” during the growing season (May – Sept.) in the dry year 2003

Testing area: Buchhübel

“drought stress“: number of days with $\Theta_{act} < 30\%$ of $\text{PAW}_{RZ}$

$\text{PAW}_{RZ}$: plant available water in the rooting zone
Occurrence of “water stress” during the growing season (May – Sept.) in the wet year 1998

Testing area: Buchhübel

“water stress“: number of days with $\Theta_{\text{act}} > \Theta_{\text{act PAW}_{\text{RZ}}}$

$\Theta_{\text{act}}$: plant available water in the rooting zone
Work to do

- Statistical analysis
- Physiological relevance
- Scaling/Delineation of classes according to silvicultural needs

Follow-up Project
2008/09
Land-Use and groundwater recharge

Northern Upper Rhine Plain  650 mm annual precipitation

Groundwater recharge as % of precipitation

<table>
<thead>
<tr>
<th>Land-use</th>
<th>Sand</th>
<th>Loam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>Mixed pine forest</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Mixed Deciduous</td>
<td>22</td>
<td>17</td>
</tr>
<tr>
<td>Maize</td>
<td>42</td>
<td>33</td>
</tr>
</tbody>
</table>

Modelling results: BROOK90 (period 1975-2001)
Conclusions and Perspectives

• process-oriented ecohydrological models offer a large potential - however, there might be a considerable data problem

• inteligent regionalization concepts (→ “data mining“)

• uncertainties have to be addressed!

• (realistic) future scenarios have to be derived (climate change...)
  → show potential ranges and provide management options

• tools / findings have to be transfered to management & planning
  → bridging the gap
Bridging gaps …

Scientific understanding

- scales
- disciplines
- countries/cultures

molecule → aggregate → horizon → pedon → plot → stand → catchment → landscape → region
A Research Strategy for Sustainable Forest Management in Europe

Technical Report 5

Editors: Folke ANDERSSON, Per ANGELSTAM, Karl-Heinz FEGER, Hubert HASENAUER, Norbert KRÄUCHI, Anders MÅRELL, Giorgio MATTEUCCI, Uwe SCHNEIDER, and Paul TABBUSH
Forests and Water
(spatial-temporal variation)

Future?

Prognosis is difficult …
notably if it relates to the future!

Niels Bohr
Danish Physicist

Karl Valentin
Bavarian Humorist

Dresden University of Technology
Institute of Soil Science and Site Ecology
Institute of Hydrology and Meteorology
Measurements of water fluxes at different scales
