Effect of Climate Change on Environmental Flow Indicators in the Narew Basin, Poland

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Outline

• Introduction: Background, motivation
• Tools and methods
  ➢ Hydrological models
  ➢ Climate change scenarios
  ➢ Approach of environmental flow indicators assessment
• Results
• Conclusions & Outlook
The Natural Flow Paradigm

- Poff et al. 1997 *Bioscience*
- Streamflow – a master variable
- Maintaining natural flow variability as a key measure of keeping ecological integrity of water-dependent ecosystems

Flow Regime
- Magnitude
- Frequency
- Duration
- Timing
- Rate of Change

Environmental Flows

- Water Quality
- Energy Sources
- Physical Habitat
- Biotic Interactions

Ecological Integrity

Poff et al. 1997
Background – SCENES project

• EU-FP6 IP SCENES „Water Scenarios for Europe and for Neighbouring States”

• Nov 2006 – Apr 2011
• 23 partners from 17 countries
• Similar methodology applied at three levels: pan-European, regional and local (pilot areas)
• Water for Nature indicators - impacts of climate change and socio-economic scenarios
- **Narew River Basin (NRB)**

**28,000 km²**
E-flows in the Narew context

- Adapted Building Block approach (Tharme & King 1997)
- Requirements of fish (pike & wels catfish) and floodplain vegetation (reed bed & sedge communities)

Objective

• To analyse the effect of climate change on environmental flow indicators in a semi-natural river basin using two different types of distributed models
  ➢ Global model – WaterGAP (CESR Kassel)
  ➢ Watershed model – SWAT
• CC impact: SRES-A2 GCMs: IPSL-CM4 & MIROC3.2 for 2050s
• Environmental flow indicators – IHA (Indicators of Hydrologic Alteration) approach
## Modelling approaches

<table>
<thead>
<tr>
<th>Aspect</th>
<th>SWAT</th>
<th>WaterGAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic unit</td>
<td>Hydrologic Response Unit</td>
<td>5' by 5' grid cell</td>
</tr>
<tr>
<td>Potential ET</td>
<td>Penman-Monteith</td>
<td>Priestley-Taylor</td>
</tr>
<tr>
<td>Actual ET</td>
<td>Evaporation from canopy &amp; soil + sublimation + plant water uptake</td>
<td>Evaporation from canopy &amp; vegetated soil + sublimation</td>
</tr>
<tr>
<td>Snowmelt</td>
<td></td>
<td>Degree-day method</td>
</tr>
<tr>
<td>Surface runoff</td>
<td>Modified SCS curve number method</td>
<td>HBV method</td>
</tr>
<tr>
<td>Redistribution in soil</td>
<td>Storage routing method between up to 10 soil layers</td>
<td>No redistribution, one soil layer</td>
</tr>
<tr>
<td>Soil water content</td>
<td>Variation between absolute zero and saturation</td>
<td>Variation between the wilting point and field capacity</td>
</tr>
<tr>
<td>Groundwater storage</td>
<td>Two groundwater storages (shallow unconfined and deep confined)</td>
<td>One groundwater storage</td>
</tr>
<tr>
<td>Baseflow</td>
<td>Recession constant method</td>
<td>Linear storage equation</td>
</tr>
<tr>
<td>Flood routing</td>
<td>Variable storage coefficient method</td>
<td>Linear storage equation</td>
</tr>
</tbody>
</table>
Modelling setup

**SWAT**: 151 sub-basins, 1131 HRUs
**WaterGAP**: 531 cells
SWAT – spatially distributed calibration

- Mean NSE for 11 calibration gauges:
  - Calibration period: 0.68
  - Validation period: 0.57
Baseline simulated & measured runoff

- Underestimation of mean runoff by 12-24% in WaterGAP
- Low runoff period lasts until Feb. in WaterGAP
- Overall – acceptable (WaterGAP calibrated for Europe not for Narew!)
GCM projections for 2050s – basin average

(a) Change in temperature

Mean annual change:
IPSL-CM4: 3.5 °C
MIROC3.2: 3.2 °C

(b) Change in precipitation

Mean annual change:
IPSL-CM4: 1%
MIROC3.2: 11%
Indicators of Hydrological Alteration approach

- Comparison of natural & altered flow regime
- Calculation of 16 indicators (Richter statistics) representing the average and variability
- Threshold for difference in indicators (scenario vs. baseline) set to 30%
- Aggregation of differences into a colour-coding system
  - Number of different Richter stats:
    - 0
    - 1-5
    - 6-10
    - 11-16
Environmental flow indicators (Richter statistics)

<table>
<thead>
<tr>
<th>Regime characteristic</th>
<th>Parameter monthly (one value per year)</th>
<th>Indicator (one value per record)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flood Magnitude &amp; Frequency</strong></td>
<td>Number of times that monthly flow exceeds threshold (all-data naturalised Q5 from the baseline period)</td>
<td>Median (P1) 25(^{th})-75(^{th}) percentile span (P2)</td>
</tr>
<tr>
<td><strong>Flood Timing</strong></td>
<td>Month (as number Jan=1, Dec=12) of maximum flow</td>
<td>Mode of month (P3)</td>
</tr>
<tr>
<td><strong>Seasonal Flow</strong></td>
<td>January flow (mm runoff)</td>
<td>Median (P4) 25(^{th})-75(^{th}) percentile span (P5)</td>
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<td>April flow (mm runoff)</td>
<td>Median (P6) 25(^{th})-75(^{th}) percentile span (P7)</td>
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<td>July flow (mm runoff)</td>
<td>Median (P8) 25(^{th})-75(^{th}) percentile span (P9)</td>
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<td></td>
<td>October flow (mm runoff)</td>
<td>Median (P10) 25(^{th})-75(^{th}) percentile span (P11)</td>
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<tr>
<td><strong>Low Flow Magnitude &amp; Frequency</strong></td>
<td>Number of months that flow is less than threshold (thresholds = all-data naturalised Q95 from the baseline period)</td>
<td>Median (P12) 25(^{th})-75(^{th}) percentile span (P13)</td>
</tr>
<tr>
<td><strong>Minimum Flow Timing</strong></td>
<td>Month (as number Jan=1, Dec=12) of minimum flow</td>
<td>Mode of month (P14)</td>
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<tr>
<td><strong>Low Flow Duration</strong></td>
<td>Number of times that two consecutive months are less than threshold (all-data naturalised Q95 from the baseline period)</td>
<td>Median (P15) 25(^{th})-75(^{th}) percentile span (P16)</td>
</tr>
</tbody>
</table>
Approach - technically

• Generate monthly flow time series for the baseline period
  ➢ SWAT 1976-2000
  ➢ WaterGAP 1961-90

• Generate flow time series for the CC scenarios

• Read generated time series (baseline & scenarios) for selected locations into a programme calculating the impacts

• Visualize (i.e. colour coding) & analyze outputs
Results – composite e-flow index
Case 1: joint baseline period 1976-1990
Results – composite e-flow index
Case 2: separate baseline periods
Results – individual indicators

- For a given indicator (P1 – P16), what percentage of locations on river network has consistent colour coding?
Results – groups of indicators

- Flood Seasonal Low flows

Group of statistics

- Percent of consistent pairs
- Median Mode Variability

Group of statistics

- IPSL-CM4 MIROC3.2
Results – spatial variability of consistent impacts

For a given location on river network, what percentage of indicators showed consistent impacts?
Conclusions & Outlook

- Projected impacts on environmental flows:
  - Spatially variable (from green to red)
  - Larger for IPSL-CM4 (esp. in WaterGAP)
  - Larger for joint (shorter) baseline period

- Not bad news for decision makers:
  - 66-69 % of locations with consistent colour codes
  - No location with a green colour for one model and red colour for another model
  - Good agreement for low flow indicators, worse for floods

- Future work:
  - Link with ecological data – fish & floodplain wetlands (daily time scale?)
  - Using more climate models
Thank you!