FutureHydro Workshop

Julian Sauterleute, SINTEF Energy Research

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Impacts of flexible hydropower

Julian Sauterleute\textsuperscript{1}, Atle Harby\textsuperscript{1}, Ånund Killingtveit\textsuperscript{2}, Eivind Solvang\textsuperscript{1}, Julie Charmasson\textsuperscript{1}

\textsuperscript{1}SINTEF Energy Research
\textsuperscript{2}Norwegian University of Science and Technology
Hydropeaking = ?

= Rapid changes in power production by hydro-electric facilities as a consequence of varying electricity generation and demand on the electricity market.

Impact on ecosystems of water bodies downstream of the power plant outlets.

- Outlet into river → Rapid fluctuations of stream flow and water level
- Outlet into a reservoir → Rapid fluctuations of reservoir water level
Rapid flow fluctuations in rivers

May appear as follows:

Flow time series from Nidelv, Trondheim
Analysis river Nidelv

- Event identification by river/data-specific threshold
- Parameter calculation
- 15-minutes interval
- Years 1994-1996
## Selected parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td></td>
</tr>
<tr>
<td>Stage</td>
<td></td>
</tr>
<tr>
<td>Flow maximum/minimum of a rapid increase</td>
<td></td>
</tr>
<tr>
<td>Flow maximum/minimum of a rapid decrease</td>
<td></td>
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<tr>
<td>Stage maximum/minimum of a rapid increase</td>
<td></td>
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<tr>
<td>Stage maximum/minimum of a rapid decrease</td>
<td></td>
</tr>
<tr>
<td>Flow ratio of a rapid increase/decrease</td>
<td>$Q_{\text{max}}/Q_{\text{min}}$</td>
</tr>
</tbody>
</table>
## Selected parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scale of time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean rate of flow increase/decrease</td>
<td></td>
</tr>
<tr>
<td>Mean rate of stage increase/decrease</td>
<td></td>
</tr>
<tr>
<td>Maximal rate of flow increase/decrease</td>
<td></td>
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<tr>
<td>Maximal rate of stage increase/decrease</td>
<td></td>
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<tr>
<td>Time of the start/end of a rapid increase</td>
<td></td>
</tr>
<tr>
<td>Time of the start/end of a rapid decrease</td>
<td></td>
</tr>
<tr>
<td>Duration between a rapid increase and decrease</td>
<td></td>
</tr>
<tr>
<td>Duration between a rapid decrease and increase</td>
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</table>

### Frequency

<table>
<thead>
<tr>
<th>Frequency</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Count of rapid increases/decreases per year</td>
<td></td>
</tr>
<tr>
<td>Portion of days with certain number of rapid increases/decreases per day</td>
<td></td>
</tr>
<tr>
<td>Portion of rapid increases/decreases during daylight/twilight/darkness</td>
<td></td>
</tr>
</tbody>
</table>
Results river Nidelv

Flow ratio ($Q_{\text{max}}/Q_{\text{min}}$)

- Magnitude in general low
- 2 to > 50 in Swiss and Austrian rivers \textit{(VAW & LCH, 2006)}
- Extreme values up to 510 in USA/Canada/Finland/France \textit{(Bain, 2007)}

Percentage of days with rapid fluctuations: on average 29 %
Results river Nidelv

Rates of stage increase/decrease

- Relatively low rates of change; Up to 240 cm/h in Swiss rivers (*Baumann & Klaus, 2003*)
- Critical: 10 cm/h to 18 cm/h (*Halleraker et al., 2003; Saltveit et al., 2001*)

<table>
<thead>
<tr>
<th>Mean rate cm/h</th>
<th>Maximal rate cm/h</th>
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<tbody>
<tr>
<td>Median</td>
<td>P90</td>
</tr>
<tr>
<td>19.9</td>
<td>26.2</td>
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<tr>
<td>19.4</td>
<td>26.6</td>
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</tbody>
</table>
Results river Nidelv

Distribution on time of day

(a) Rapid increases

(b) Rapid decreases
Results river Nidelv

Light conditions

(a) Rapid increases

(b) Rapid decreases
Environmental impacts

- Temperature variations
- Fish growth
- Invertebrates
- Sediment transport, erosion
- Ice conditions
Modelling water level fluctuations in reservoirs

- Reservoir pairs in Southern Norway
- Balancing power capacity in addition to installed capacity
- Operation of existing power station remains unchanged
- Balancing power operation within current reservoir regulations
- Input data
  - Simulated wind power time series from North Sea
  - Observed reservoir water level and volume
    - Current operational regime
    - Natural inflow
- Time step: 1 day
Background

Increasing balance power capacity in Norwegian hydroelectric power stations – A preliminary study of specific cases in Southern Norway

Solvang et al., 2011, SINTEF TR A7195

- **20.000 MW possible by 2030**
- Hydro storage + pumped storage
- Existing dams and reservoirs
- Outlet into reservoir or fjord/sea
Example case

Holen (Urarvatn–Bossvatn)

- Volume upper reservoir: 253 mill. m³
- Volume lower reservoir: 296 mill. m³
- Installed capacity: 1400 MW
Balancing power needs

Daily wind power generation and 7-days moving average

10^4 MW

- Daily average
- Moving average - 7 days

Generation

Pumping
Water level fluctuations

- Strong increase in rates of change in water level
- Shorter periods with high WL
- Longer periods with low WL

- Strong increase in rates of change in water level
- Longer periods with higher WL
Number of changes in stage

Holen

Current vs. balancing power operation

<table>
<thead>
<tr>
<th>Percentage of days</th>
<th>Urarvatn (upper reservoir)</th>
<th>Botsvatn (lower reservoir)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
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<tr>
<td>15</td>
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<tr>
<td>20</td>
<td></td>
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<tr>
<td>25</td>
<td></td>
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<tr>
<td>30</td>
<td></td>
<td></td>
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<tr>
<td>35</td>
<td></td>
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<tr>
<td>40</td>
<td></td>
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<tr>
<td>45</td>
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</tbody>
</table>

- **Urarvatn (upper reservoir)**
- **Botsvatn (lower reservoir)**

**Current**

**Simulated**
Necessity for seasonal regulations?

Monthly mean rate of change in WL – Holen

**Upper reservoir**

- Current Rate of Change
- Simulated rate of change

Monthly mean rate of change in WL – Holen

**Lower reservoir**

- Current rate of change
- Simulated rate of change
Environmental impacts

- Hydrodynamics
- Circulation
- Mixing
- Temperature

Temperature stratification in Vassbygdvatn, Aurland
Environmental impacts

► Erosion
Environmental impacts

- Ice
- Recreation
Environmental impacts

► Biodiversity
Conclusions

- Identification and quantification of water level fluctuations

- Basis for assessment of environmental impacts

- (Re-)licencing of hydropower stations