Present and future environmental impacts of hydropower on Norwegian lakes

*HydroBalance project*

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1. CEDREN HydroBalance: Facts

- **CEDREN project**
- **2013-2017**
- **24,864 MNOK (about 2.7 mill. EUR)**
- **Research partners (11)**
  - SINTEF Energy Research,
  - NTNU: Norwegian university of Science and Technology,
  - NINA: Norwegian Institute for Nature Research,
  - UiO: University of Oslo,
  - UiT: University of Tromsø,
  - NIVA: Norwegian Institute for Water Research
  - ECN: Energy Research Centre of the Netherlands,
  - University of Waterloo,
  - University of Exeter,
  - University of Aachen & E.ON
  - EdF: Electricité de France

- **Funding:**
  - Research Council of Norway
  - Statnett,
  - Sira Kvina kraftselskap,
  - Statkraft,
  - EnergiNorge,
  - Agder Energi,
  - BKK,
  - Listerrådet,
  - EdF: Electricité de France,
  - NVE (Norwegian Water Resources and Energy Directorate)
  - E.ON,
  - ECN: Energy Research Centre of the Netherlands,
Feasibility of large scale development of energy balancing and storage from Norwegian hydropower in the future European electricity market with respect to the power system, environmental aspects, economic viability and social acceptance.

WP 1
Roadmaps for balancing from Norwegian hydropower

WP 2
Demand for energy balancing storage

WP 3
Analyses to develop relevant business models

WP 4
Environmental impact of operation schemes for balancing

WP 5
Social acceptance and regulatory framework
1. Future energy demand and water level fluctuations

- Integration of **renewable** from **intermittent** sources

- Future energy demand: more **flexibility**, more **storage**

- New operational regimes
  - More rapid, intense and frequent **water level fluctuations** (WLF)
  - **Pump-storage**
1. WP4 focuses on HP reservoirs

- Environmental impacts of new operational regimes in reservoirs
- Most of studies in rivers
- > 900 reservoirs (lakes) in Norway
  Also used as recreational area
1. Potential impacts of water level fluctuations in reservoirs

- **Abiotic consequences**
  - Water temperature
  - Stratification period/duration/intensity
  - Ice cover thickness/period/duration...
  - Water quality

- **Biotic consequences**
  - Biological productivity
  - Species composition
  - Fish diet
  - Growth and reproduction...
1. HydroBalance WP4: Environmental impacts of new operational regimes

**Task 4.1**
Modelling *ecological* consequences of WLF along environmental gradients

→ Biotic effects (*current situation*)

**Task 4.2**
Modelling lake *physical properties* changes introduced by new operational regimes

→ Abiotic effects (*future operational regimes*)

**Task 4.3**

→ Combined results to **predict** how future operational regimes can impacts lakes ecosystems

→ Define **mitigation** measures to reduce potential negative impacts
2. Biotic impacts of new operational regimes
2. Focus on fish

Fish as **top predator**: bio-indicator for **ecological status**
2. Natural variation due to climate

... which impacts lakes ecological status
2. Natural variation in drainage basin

... which impacts lakes ecological status
2. Natural variation in morphology

... which impacts lakes ecological status

**Area**

- Mean = 4.51 km²
- Range = 0.018–122 km²

**Altitude**

- Mean = 584 m a.s.l.
- Range = 19–1477 m a.s.l.

**Shape**

\[ Shape = \frac{L}{2\sqrt{\pi A}} \]

- Mean = 2.5
- Range = 1.1–10.5
2. Natural variations in fish growth
How to separate effects from **hydropower** from **natural** variation?
2. Data collection

Large dataset from previous field campaign + Field work in 2014

- Compare natural lakes and regulated lakes (reservoirs)
- Understand large-scale trend along environmental variations
2. Data about fish population

- Fish communities: Density, Growth, reproduction, diet
- Understand the structure and the function of food chain
  - Stable isotopes analyses
2. Statistical analysis and modelling of interactions

...for separating impacts from hydropower and natural variations
2. Some results: 

*Fish abundance along environmental gradients*

- Lower trout abundance in regulated lakes
- ...but also when:
  1) Competitive & predatory fishes are present
  2) Littoral zone is small and dominated by other fishes

- Trout abundance higher in lakes with productive catchments
  → but only when competitors are absent
2. Some results:

**WLF impacts on Arctic charr niche**

- More turbid water and limited littoral production has resulted to:
  1. Decreased use of littoral food and habitat resources
  2. Increased infections by zooplankton-transmitted parasites

2. On-going work

Understand link between WLF and ecological status

- Establish parameters for WLF and not only HRWL-LRWL
- Link WL timeseries to fish caught date
- Renforce/Establish relationships between large-scale variations by including more data-points
3. Abiotic consequences of new operational regimes
3. Modelling hydro-dynamics consequences from new operational regimes

1. 2D Hydro-Dynamic modelling of a regulated reservoir and calibration
   - water temperature and stratification characteristics
   - Ice cover period-thickness-duration
3. Modelling hydro-dynamics consequences from new operational regimes

1. 2D modelling of a regulated reservoir and calibration

2. Extension of the existing case to additional cases

   Reservoirs types:
   - Regulated amplitude
   - Area
   - Mean depth
   - Climate region
### 3. Modelling hydro-dynamics consequences from new operational regimes

<table>
<thead>
<tr>
<th>Climate Type</th>
<th>ΔH</th>
<th>Mean Depth (m)</th>
<th>Area</th>
<th>0.75 – 2 km²</th>
<th>20 km²</th>
<th>&gt; 45 km²</th>
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</thead>
<tbody>
<tr>
<td>Warm</td>
<td>2-5 m</td>
<td>WH-1a</td>
<td>8-15</td>
<td>25</td>
<td>&gt; 85</td>
<td>WH-2a</td>
</tr>
<tr>
<td></td>
<td>20 m</td>
<td>WM-1a</td>
<td>8-15</td>
<td>25</td>
<td>&gt; 85</td>
<td>WM-2a</td>
</tr>
<tr>
<td></td>
<td>&gt; 40 m</td>
<td>WH-1a</td>
<td>8-15</td>
<td>25</td>
<td>&gt; 85</td>
<td>WH-2a</td>
</tr>
<tr>
<td>Mild</td>
<td>2-5 m</td>
<td>MH-1a</td>
<td>8-15</td>
<td>25</td>
<td>&gt; 85</td>
<td>MH-2a</td>
</tr>
<tr>
<td></td>
<td>20 m</td>
<td>MM-1a</td>
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<td>MM-2a</td>
</tr>
<tr>
<td></td>
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<td>MH-1a</td>
<td>8-15</td>
<td>25</td>
<td>&gt; 85</td>
<td>MH-2a</td>
</tr>
<tr>
<td>Cold</td>
<td>2-5 m</td>
<td>CH-1a</td>
<td>8-15</td>
<td>25</td>
<td>&gt; 85</td>
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<td>20 m</td>
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<tr>
<td></td>
<td>&gt; 40 m</td>
<td>CH-1a</td>
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<td>CH-2a</td>
</tr>
</tbody>
</table>

**Reservoir types:**

**Climate region**

**Regulated amplitude**

**Mean depth**

**Area**

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[www.cedren.no/Projects/HydroBalance](http://www.cedren.no/Projects/HydroBalance)

Centre for Environmental Design of Renewable Energy
3. Modelling hydro-dynamics consequences from new operational regimes

1. 2D modelling of a regulated reservoir and calibration

2. Extension of the existing case to additional cases

3. Run simulations of future operational regimes
   - (present regime)
   - Big Storage
   - Niche Storage
Key messages

- Integration of **renewable** from **intermittent** sources → new operational regimes

- Within **HydroBalance** project: environmental impacts of future operational regimes
  - Biological impacts: field work and statistical analysis of present regimes
    → **Predict** ecological impacts for future operational regimes
  - Physical impacts: 2D modelling of new regulation regimes
    → Define **mitigation measures** to reduce potential negative impacts in the future
Thank you for your attention!

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www.cedren.no/Projects/HydroBalance
Habitat use

Littoral

Pelagic

Phytoplankton

Zooplankton

Benthic algae

Profundal

Compensation depth (1 % PAR)

Zoobenthos

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Food chain
Publications

Community structure influences species’ abundance along environmental gradients
AP Eloranta, IP Helland, OT Sandlund, T Hesthagen, O Ugedal, AG Finstad
Journal of Animal Ecology

Water level regulation affects niche use of a lake top predator
AP Eloranta, J Sánchez-Hernández, IP Helland, PA Amundsen, S Skoglund, J Brush, M Power
Manuscript to Freshwater Biology submitted

Effects of anthropogenic water level fluctuations in hydropower reservoirs – an ecosystem approach with a special emphasis on fish
Manuscript to Ambio submitted