Environmental effects of water level fluctuations in reservoirs:
What do we know?

Ingeborg Palm Helland
Leader WP4 HydroBalance
Outline

• Reminder of WP4 work plan
• Quick recap from 2016: simulations of temperature effects in future markets
• Known effects of water level fluctuations on fish
• Outlook
Outline

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WP4: Environmental impacts of new operational regimes

Task 4.1
Modelling ecological consequences along environmental gradients
→ Ecosystem effects (today's situation)

Task 4.2
Modelling hydro-dynamic changes introduced by new operational regimes.
→ Physical effects (future operations)

Task 4.3
Mitigating ecological effects of new operational regimes
→ Combine 4.1 and 4.2
WP4: Environmental impacts of new operational regimes

- Hydropeaking:
  More rapid and frequent changes in discharge and water level
WP4: Environmental impacts of new operational regimes
CEDREN EnviPeak: Method for determining the effects on fish in downstream rivers

- **Vulnerability:**
  - Effective population size
  - Recruitment limitations
  - Low water periods as bottlenecks
  - Habitat degradation
  - Reduced water temperature
  - Other effects
  - Proportion of affected river area

- **Impact:**
  - Rate of change
  - Dry area
  - Amplitude
  - Frequency
  - Distribution
  - Timing

### Påvirkning

<table>
<thead>
<tr>
<th>Slitasj</th>
<th>Hvøy 16-21</th>
<th>Stor 15-20</th>
<th>Moderat 10-14</th>
<th>Liten 4-9</th>
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<tr>
<td>Svært stor</td>
<td>21-32</td>
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www.cedren.no/Projects/HydroBalance

Centre for Environmental Design of Renewable Energy
HydroBalance WP4 focuses on reservoirs

- Most studies done in rivers
- >1000 reservoirs in Norway

Provide important ecological services and recreational areas
Importance of reservoirs in future market

- Avoid negative influence in rivers by only use hydropeaking between reservoirs?

- Any reason to believe that there are less negative impact in reservoirs?
Traditional vs future?
HydroBalance WP4 focuses on fish

Fish as top consumer – Bioindicator of ecosystem health
Deliverables HydroBalance WP4

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1) Natural variation in trout abundance
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Four manuscripts in preparation
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HydroBalance roadmap
Deliverables HydroBalance WP4

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Water level fluctuations in new markets
ProdRisk

Head of water (in meeters)

Hours in a year

Today
Future scenario
Hydrodynamic modelling
CE-QUAL-W2
Modelled temperature changes

(a) [Graph showing depth vs. date with temperature in °C]

(b) [Graph showing depth vs. date with temperature increase in °C]
We have developed a new method:
  - New link from international market to local environmental effects

Only tested in one case, but high potential for future studies

Makes us able to predict an unknown future

We can compare environmental effects of different hydropower operational regimes in advance
Outline

• Reminder of WP4 work plan
• Quick recap from 2016: simulations of temperature effects in future markets
• **Known effects of water level fluctuations on fish**
• Outlook
A reservoir is not a reservoir...
Role in power system
A reservoir is not a reservoir…
Shape and location

Amplitude
- Mean = 17 m
- Range = 0.5–140 m

Area
- Mean = 4.8 km²
- Range = 0.02–122 km²

Altitude
- Mean = 602 m a.s.l.
- Range = 19–1473 m a.s.l.

Data from 691 reservoirs
A reservoir is not a reservoir…

Water level fluctuations

**Espelandsvatnet**

- WLR:
  - Magnitude = 5.8 m
  - Frequency = 0.28
  - Duration = 0.16

**Olevatnet**

- WLR:
  - Magnitude = 13.2 m
  - Frequency = 0.13
  - Duration = 0.24
A reservoir is not a reservoir…
Shape and water level fluctuations
A reservoir is not a reservoir…
Shape and water level fluctuations
A reservoir is not a reservoir…

Climate variations
A reservoir is not a reservoir…

Fish community

Trout catches (ln CPUE)

Number of fish species present

(a) 160  56  50  12  5
A fish is not a fish…
Spawning and recruitment
A fish is not a fish…
Size and age classes

http://www.wildtrout.org/content/trout-lifecycle
A fish is not a fish…
Habitat use and niche
Water is not water…
Temperature zones
Water is not water…
Colour and turbidity
Separate hydropower from other (natural + anthropogenic) effects
Known impact: Impaired shoreline
Known impact:
Reduced food = reduced growth

Heavily regulated

Unregulated

Milbrink et al. 2011
Known impact:
Ice-cover and water temperature
Known impact:
Reduced access to spawning habitat

Waterfall and dry shoreline at low water

Spawning stream at high water
Still not easy to predict…
Still not easy to predict…

67 Norwegian reservoirs with brown trout as only fish
Review paper:
“Effects of water level regulation in alpine hydropower reservoirs: an ecosystem perspective with a special emphasis on fish”
Hirsch & Eloranta et al. (2017) Hydrobiologia

Table 1 Summary of identified WLR effects, the mechanisms through which the effects take place, and confounding factors that can mask, alter and/or interact with the WLR effects

<table>
<thead>
<tr>
<th>WLR effects</th>
<th>Mechanisms</th>
<th>Confounding factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abiotic conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Altered temperature and oxygen conditions</td>
<td>Increased mixing, loss of oxygenated water</td>
<td>Reservoir morphometry, location of turbine tunnels</td>
</tr>
<tr>
<td>Shorter ice-cover period</td>
<td>Weakened ice cover</td>
<td>Reservoir morphometry, location of turbine tunnels</td>
</tr>
<tr>
<td>Altered water quality</td>
<td>Resuspension and leaching of inorganic and organic matter</td>
<td>Reservoir morphometry, geology and succession, location of turbine tunnels</td>
</tr>
<tr>
<td>Lower trophic levels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decreased littoral production and diversity</td>
<td>Freezing, desiccation and physical alteration of shallow bottom areas</td>
<td>Reservoir succession, morphometry and geology</td>
</tr>
<tr>
<td>Altered pelagic production and diversity</td>
<td>Changes in abiotic conditions and fish predation pressure</td>
<td>Reservoir succession, morphometry and geology, fish community composition</td>
</tr>
<tr>
<td>Fish</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Successional change of fish abundance</td>
<td>Changes in lake productivity and food availability</td>
<td>Reservoir succession, fish community composition</td>
</tr>
<tr>
<td>Altered intra- and interspecific interactions</td>
<td>Changes in relative availability of littoral and pelagic resources</td>
<td>Reservoir morphometry, geology and succession, fish community composition</td>
</tr>
</tbody>
</table>

In all cases, the operational regime or how the water level is regulated for hydropower production (e.g. traditional vs. pump-storage operation, the amplitude, timing, frequency and rate of change of WLR) will strongly affect the abiotic and biotic conditions.

www.cedren.no/Projects/HydroBalance
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Common process

- Move to open water $\implies$ Larger risk of predation
- Smaller and more mobile prey $\implies$ Reduced growth
- More zooplankton in diet $\implies$ More parasites

Hirsch & Eloranta et al. 2017:
Eloranta et al. 2016:
Two lake comparison: Charr move away from shoreline (littoral)

Eloranta et al. 2016:

![Graph showing number of fish in regulated and unregulated lakes.](image-url)
Two lake comparison: Charr have reduced growth in open water

Eloranta et al. 2016:

(b) Fish biomass

<table>
<thead>
<tr>
<th></th>
<th>Cazajavri</th>
<th>Govdajavri</th>
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<tbody>
<tr>
<td>Unregulated</td>
<td></td>
<td>(a)</td>
</tr>
<tr>
<td>Regulated</td>
<td></td>
<td>(a)</td>
</tr>
</tbody>
</table>

CPUE (g 100 m² net 12 h⁻¹)
Two lake comparison: Charr eat different food in open water

Eloranta et al. 2016:
Ecological relevant measure of water level fluctuations in lakes?
Ecological relevant measure of water level fluctuations in lakes?
Olsjoen (567)

- Mean = -0.9 m
- Mean during open water season = -0.8 m
- Low WL threshold = -1.5
- SD = 0.6 m
- CV = 0.7 m
- Max weekly WL change = 2.7 m
- Min WL weeknr = 18
- Max WL weeknr = 27
- Max regulation amplitude = 3.3 m
- Proportion of low WL days = 0.16
- Area between curve and low WL th = 23

Vestredalsmagasinet (1499)

- Mean = -12.4 m
- Mean during open water season = -3.3 m
- Low WL threshold = -20.7
- SD = 8.3 m
- CV = 0.7 m
- Max weekly WL change = 7.2 m
- Min WL weeknr = 15
- Max WL weeknr = 28
- Max regulation amplitude = 21.9 m
- Proportion of low WL days = 0.20
- Area between curve and low WL th = 44
Selected measures
water level regulations (WLR)

• **Magnitude:**
  Maximum regulation amplitude

• **Frequency:**
  Relative proportion of weeks with a sudden rise or drop in water level

• **Duration:**
  Relative proportion of weeks with exceptionally low water levels
Comparison of 102 reservoirs with brown trout

- **Magnitude and frequency**
  - Influenced brown trout biomass, density and condition
  - The regulation effect varied with other environmental conditions

- **Duration:**
  - No effect seen

<table>
<thead>
<tr>
<th>Parameter</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
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<tr>
<td><strong>Response</strong></td>
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<tr>
<td>Biomass (g 100m$^{-2}$ night$^{-1}$)</td>
<td>102</td>
<td>1168</td>
<td>761</td>
<td>168</td>
<td>3706</td>
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<tr>
<td>Density (n 100m$^{-2}$ night$^{-1}$)</td>
<td>102</td>
<td>10</td>
<td>9</td>
<td>1</td>
<td>42</td>
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<tr>
<td>Mean weight (g)</td>
<td>102</td>
<td>144</td>
<td>86</td>
<td>50</td>
<td>727</td>
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<tr>
<td>Mean condition</td>
<td>90</td>
<td>1.02</td>
<td>0.08</td>
<td>0.88</td>
<td>1.22</td>
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<tr>
<td>Mean maturity length (mm)</td>
<td>43</td>
<td>289</td>
<td>35</td>
<td>220</td>
<td>367</td>
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<tr>
<td><strong>Predictor</strong></td>
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<td></td>
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<tr>
<td>Surface area (km$^2$)</td>
<td>102</td>
<td>8</td>
<td>16</td>
<td>0.2</td>
<td>122</td>
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<tr>
<td>Terrain slope (%)</td>
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<td>9.7</td>
<td>4.2</td>
<td>3.1</td>
<td>26.9</td>
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<tr>
<td>Shoreline development</td>
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<td>-0.04</td>
<td>0.27</td>
<td>-0.54</td>
<td>0.75</td>
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<tr>
<td>NDVI</td>
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<td>113</td>
<td>9</td>
<td>99</td>
<td>134</td>
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<tr>
<td>Mean July air temperature ($^\circ$C)</td>
<td>102</td>
<td>8.7</td>
<td>2.7</td>
<td>3.5</td>
<td>14.6</td>
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<td>WLR magnitude</td>
<td>102</td>
<td>18</td>
<td>15</td>
<td>1</td>
<td>76</td>
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<tr>
<td>WLR frequency</td>
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<td>0.18</td>
<td>0.07</td>
<td>0.04</td>
<td>0.31</td>
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<tr>
<td>WLR duration</td>
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<td>0.18</td>
<td>0.06</td>
<td>0.01</td>
<td>0.29</td>
</tr>
</tbody>
</table>
Some results

- **Eloranta et al. in prep.**

![Graphs showing correlations between WLR magnitude and density, and between WLR frequency and population response.](image-url)
Deliverables **HydroBalance WP4**

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5) **Review paper of environmental impacts in reservoirs**
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**HydroBalance roadmap**

- **Fundamental research on fish in lakes and reservoirs**
- **Effects of present-day water level regulations on fish in reservoirs**
- **Predicting future impact in hydropower reservoirs**
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Charr move away from shoreline into open water:
- Reduced growth
- More parasites

Summary of known effects in literature
Outlook for future studies

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Charr move away from shoreline into open water:
- Reduced growth
- More parasites
- More trout in large and complex-shaped reservoirs, hosting no other fish species
- Increasing WLR frequency gives more trout, but of poorer condition

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- Summary of known effects in literature
- Outlook for future studies
- New method for future studies
Outline

• Reminder of WP4 work plan
• Quick recap from 2016: simulations of temperature effects in future markets
• Known effects of water level fluctuations on fish
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Diagnosis + design solution

Håndbok for miljødesign i regulerte laksevassdrag

Redaktione:
Torbjørn Forseth ogAlle Harby

DATAINNSAMLING OG VERKTØY
- Kartlegging av elveklasse, substrat og skjul
- Kartlegging av forskomst og spredning av gytehabitat
- Sammenheng mellom vanndekt areal og vannføring
- Hydrologisk variasjonsanalyse
- Temperaturdata eller modellering
- Innsamling av bestandsdata
- Beskrivelse av kraftproduksjonsystemet og reguleringseffekter

SYSTEMATISERING OG KLASSEFISERING
- Laksebestanden
- Kraftproduksjon

DIAGNOSE
- Habitatflaskehåler
  - Skjul
  - Gyteområder
- Hydrologiske flaskehåler
  - Vannføring
    - sommer- og vintervannføring
    - gytevannstand
    - smoltvannføring
    - 0+ habitat
    - homogenisering av elvelep
    - habitatforringelse
- Vanntemperatur:
  - 0+ vekst
  - smoltalder

DESIGNLØSNINGER OG TILTAKSMETODIKK
- Habitatløsninger
  - Skjul
  - rensing av grusbanker
  - etablering av skjul
  - terskelfjerning og annen restaurering
  - "elv i elv"
- Gytehabitat
  - rensing
  - utlegging av gytegrus
  - Vannbruk
  - Vanntemperatur
  - feksible tapplosninger
  - vannmengder i nøkkelperioder
  - ulike vannveier
  - Vannføring
  - økt minstevannføring
  - omfordeling
  - gytevannføring
  - situasjonsavhengige slipp
  - utvidelser

HJELPEVERKTØY
- Byggeommetodene
- Vannbank
- Varighetstyper for vannføring
- Prioriteringstabell
- Vannforhandlinger
- Effektimestorer for vannbruk
- Effektimestorer for habitatløsninger
Environmental design for trout in reservoirs?

- We first need **diagnosis tools**
  - Systematizing and properly testing

- Understand **bottlenecks**
  - What are the main bottlenecks where and when?
What do we need in future studies?

Habitat and hydrological properties

- Depth maps, temperature loggers, hydrodynamic modelling
- Understand relevant measures of water level fluctuations
- Habitat mapping: spawning, feeding, shelter
What do we need in future studies?

Fish ecology

- Move from aggregated population data to individual life-history