Understanding hyporheic interactions under hydropeaking: an experimental approach

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1.Introduction

Sudden flow changes caused by hydropeaking are likely to become more frequent with increasing demand for renewable energy (Hallerarker *et al.* 1999). Short regulation regimes can significantly influence hyporheic exchange flows (Hancock, 2002). Particularly these sudden fluctuations result in big differences in water head, which govern the exchange of water between stream and hyporheic zone (Wondzell & Swanson, 1999) and have the potential to alter surface water-groundwater interactions (Sawyer et al, 2009).

The hyporheos plays an important role in freshwater ecology. Hyporheic exchange is fundamental to vertical connectivity, transporting mass and energy between the sediment and the water column, resulting in mixing chemistry that can support unique communities of benthic organisms (Boulton, 2001), contribute to the energy and nutrient cycles (Malard *et al.*, 2002), and serve as spawning grounds for fish (Power *et al.* 1999).

The hyporheic zone in hydropeaked rivers become even more significant for ecology given its potential for example to act as refugia for benthic organisms such macroinvertebrates (Bruno, 2009) and fish (Saltveit *et al.* 2001), and its influence for embryo survival (Malcolm *et al.* 2004, 2008). Only a few studies have examined hyporheic alterations due to hydropeaking (Nyberg *et al.*, 2008; Maier & Howard, 2011) and many questions regarding the extent of the environmental impact of successive events remain.

This study aims to investigate the detailed processes occurring in the hyporheic zone during hydropeaking with a particular focus on the dewatering events in winter, a specially critical period for survival of benthic organisms due to their reduced mobility and lack of food availability; moreover hydropeaking adds the danger of freezing low flow habitats during prolonged dry periods. The present work is being conducted in conjunction with a study on salmon embryo survival from the egg to the hatching stage.

2. Objectives

Specific objectives for the presented work are as follows:

1. **To characterize the dewatering and watering processes through hydrological parameters at several locations of the gravel bar.**
2. **To assess the surface vs subsurface water dominance during both dewatering and watering events.**
3. **To understand the interactions between changes in physical conditions and ecological processes in the dried out area.**

2. Study site: Lundesokna river

The Lundesokna is a regulated tributary to the Gaula river, one of the most important salmon rivers in Norway (figure 1a). Its hydropower system comprises the whole Lundesokna catchment and parts of another two with a total catchment area of **395 km²** an average annual runoff of 381 Mm³/y.

Tronder Energi owns the whole system consisting of **3 regulated reservoirs, 3 interbasin transfers** and **3 power plants** with a total installed capacity of 61MW and an average annual production of 278 GWh.

The study site consist in a coarse gravel dominating gravel bar of 150m length by 15-20m width. It is located some 2km downstream the lower power plant outlet and it is subject to regular hydropeaking operations (figure 1d) , with flow variations from ***0.4 to 20 m³/s in 1 h 10 min***, and ***20 to 0.4 m³/s in 20 min*** (fig 2).

Both macroinvertebrates and fish densities in the river Lundesokna are very low compared to the unregulated Gaula. It remains to be investigated whether observed abrupt changes in discharges could be a potential cause explaining such affectation.

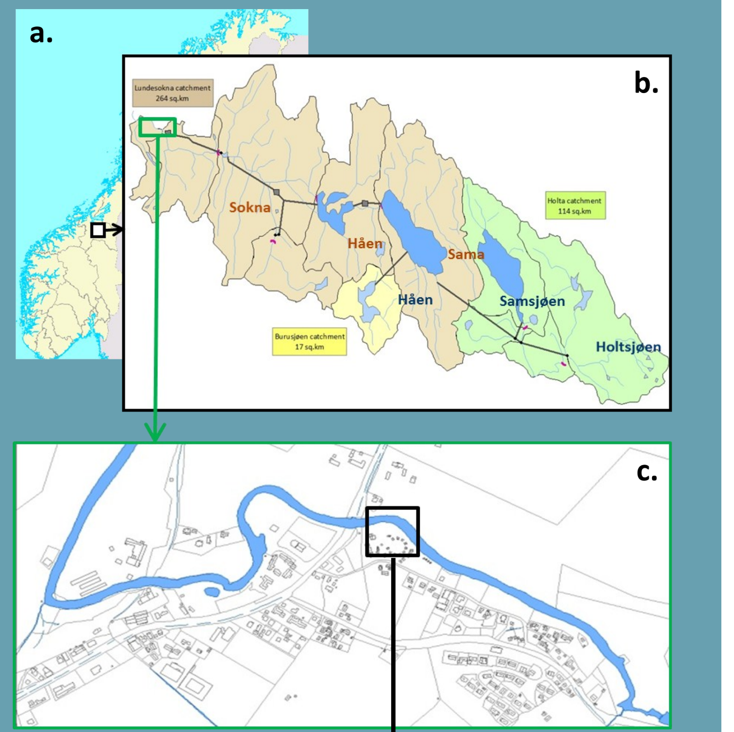

Figure 1. Study site: The Lundesokna river

4. Methodology

A. Data collection

- Site geomorphology with Laser-scan and dGPS (fig 3)
- Discharge and water levels data with ADCP and dGPS
- Continuous data data at 14 locations
  - Water levels / Temperature / Conductivity

B. Experimental set-up

Starting in December 2011, a total of **14 pipes** were installed (fig 4 & 5) at several depths (from 20 to 70 cm) across and along a 5 x 20 m side bar subject to regular hydropeaking.

Water pressure sensors were placed in the pipes to monitor the hyporheic water level and flow with **1-2 minutes time resolution**. In addition, **temperature, conductivity** and dissolved oxygen are collected at the same site.

Data will be collected until mid-May 2012, the whole sampling period coinciding with the early stages of salmon egg development in this catchment.

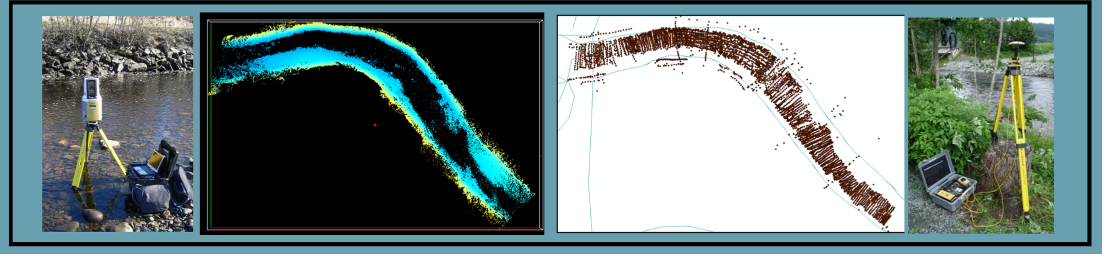

Figure 3. Obtention of the study site geometry by combining Laser Scan and dGPS

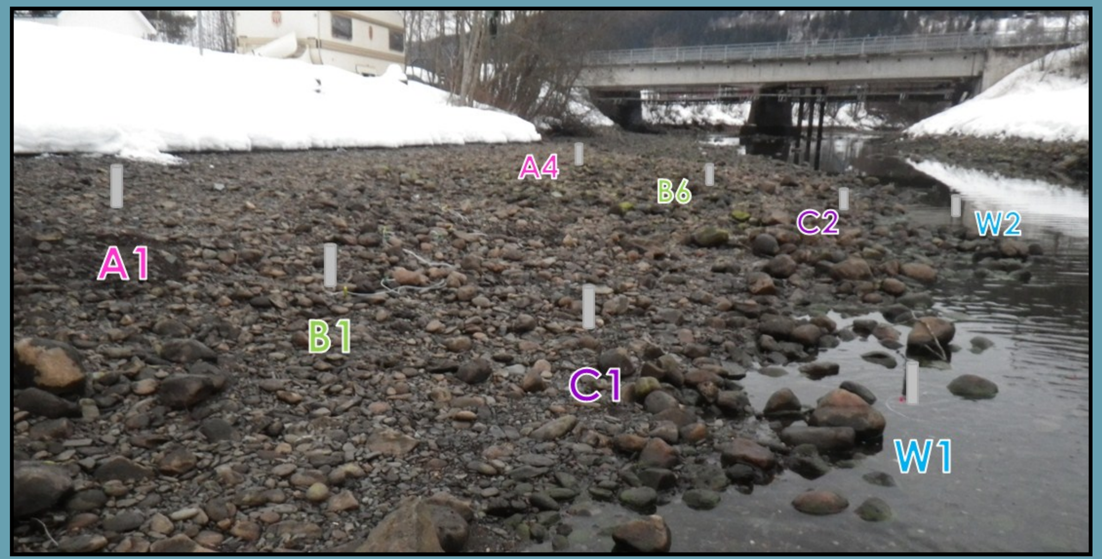

Figure 4. Experimental set-up with the location of some of the pipes (photo looking downstream)

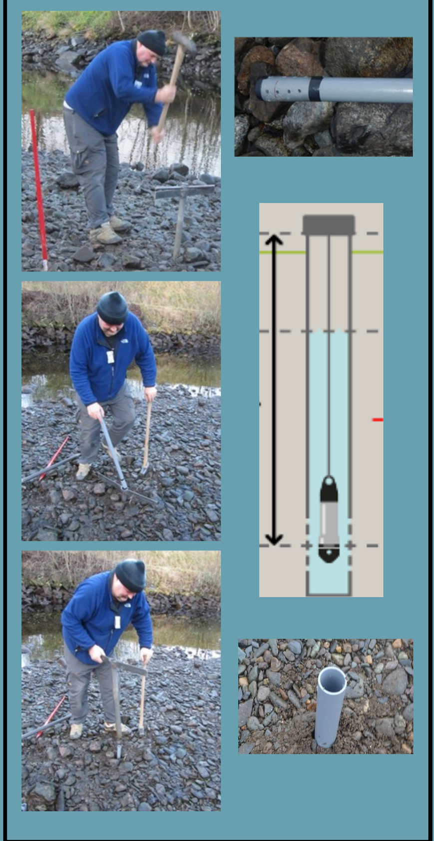

Figure 5. Field installation of pipes and water pressure sensors

C. Data Analysis

Two dewatering events were selected for analysis:

- **Long duration**

Data at the upstream transect of the site was selected for its analysis (fig 6)

- **Short duration**

Data at the downstream transect of the site was selecte for its analysis (fig. 6)

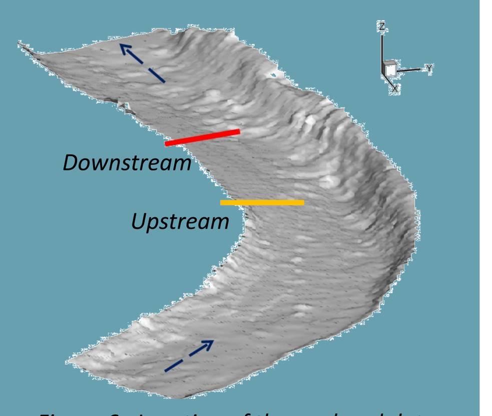

Figure 6. Location of the analysed data along the site

Both *Topcon Scan Master* (v.2.5.0) and *ArGis 10* software were utilised for processing and analysis of geometric data. For the analysis of pressure, conductivity and temperature data, *R* (v.2.14.0) was selected.

All resulting graphs were produced with *SigmaPlot* (v.12).

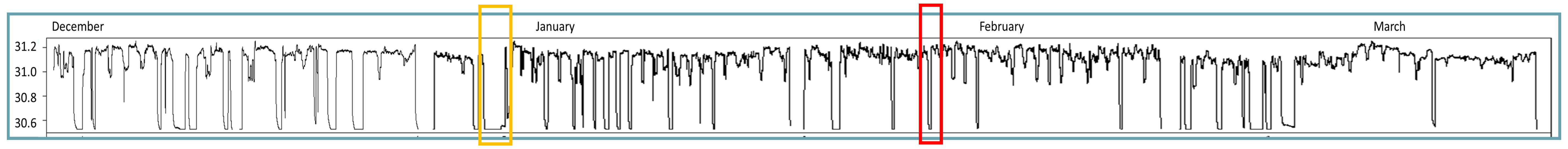

Figure 2. Water level variations due to hydropeaking operations at Lundesokna river, for the period December '11— March '12

5. Preliminary Results

I. Hydraulic processes occurring at the upstream area of the studied gravel bar during a long dewatering event (fig 7 above)

Hydraulic processes differ between flow decrease (fig 8 & 11) and increase (fig 9 & 12) in the gravel bar.

- Water level increase is higher and much faster than the decrease (tbl 2 & 4).
- During decrease, whilst some locations are able to hold the water level quite high, some others can be dried out up to a depth of 25 cm (tbl 1 & 3).

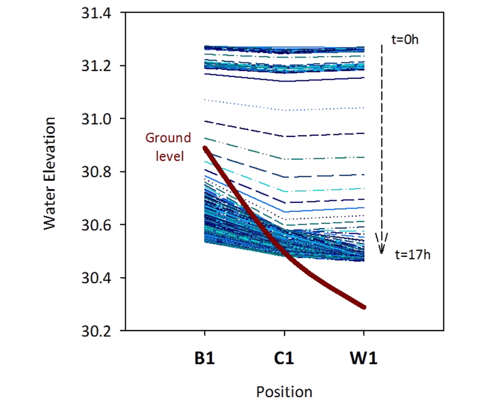

Figure 8. Illustration of the water levels variations across the upstream transect in relation to the ground level during ***17 h flow decrease****.*

Table 1. Maximum decrease flow & habitat charact.

	B1	C1	W1
Max WL (m)	31.22	31.20	31.21
Min WL (m)	30.66	30.55	30.48
WL decrease (cm)	55.10	64.20	73.10
Duration (h)	1.47	1.47	1.47
Rate (cm/h)	37.57	43.77	49.84
Ground level (m)	30.89	30.49	30.29
Max habitat loss (m)	**0.23**	**-0.06**	**-0.19**

Total event duration	48 hours
Maximum water level	31.37 m
Maximum flow	22.97 m³/s
Minimum water level	30.46 m
Minimum flow	1.21 m³/s

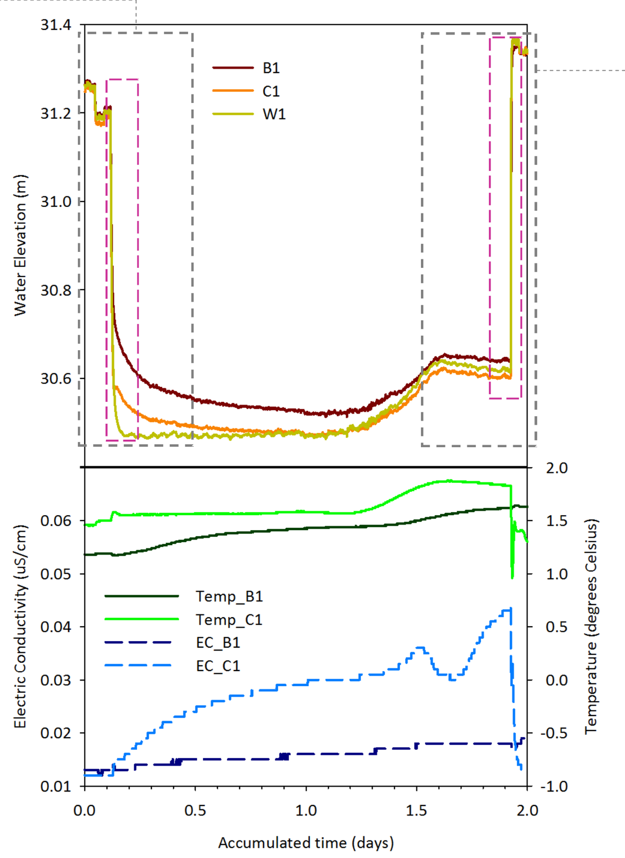

Figure 7. Variations in water level (3 positions), conductivity and temperature (2 positions) at the upstream transect during a long dewatering event, from ***time 0 to 2 (days).***

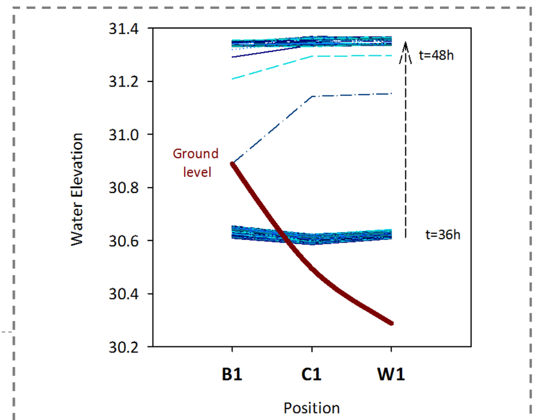

Figure 9. Illustration of the water levels variations across the upstream transect in relation to the ground level during ***12 h flow increase****.*

Table 2. Maximum increase flow characteristics

	B1	C1	W1
Max WL (m)	31.32	31.35	31.35
Min WL (m)	30.64	30.60	30.61
WL decrease (cm)	68.20	75.00	73.90
Duration (h)	0.43	0.43	0.43
Rate (cm/h)	157.38	173.08	170.54

Changes in temperature and conductivity present similar trends but much clearer for the long (fig 7 below) than the short event (fig 10 below).

In both events, the changes in conductivity and temperature with flow are more obvious at the site further away from the main channel (C1 and B1), indicating a greater groundwater influence .

II. Hydraulic processes occuring at the downstream area of the studied gravel bar during a short dewatering event (fig 10 above)

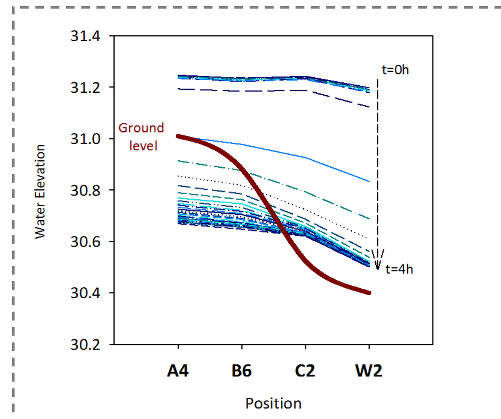

Figure 11. Illustration of the water levels variations across the downstream transect in relation to the ground level during ***4 h flow decrease****.*

Table 3. Maximum decrease flow characteristics

	A4	B6	C2	W2
Max WL (m)	31.24	31.22	31.23	31.25
Min WL (m)	30.76	30.73	30.65	30.56
WL increase (cm)	47.70	49.00	57.90	69.3
Duration (h)	0.06	0.06	0.06	0.058
Rate (cm/h)	817.71	840.00	992.57	1188
Ground level (m)	31.01	30.88	30.52	30.4
Max habitat loss (m)	0.25	0.15	-0.13	-0.16

Conductivity clearly reduces as the water increases and viceversa, indicating groundwater dominance in the gravel (upwelling) as the water level goes down.

Temperature also increases with water level decrease, which would be expected in groundwater dominating streams in winter. conditions during upwelling.

Duration of a dewatering event is also a differenciated characteristic between both events (tbl 1 & 3):

- Total event duration varies between 10 (short) and 48 hours (long)
- Total time with minimum flows results in 4 (short) and 19 hours (long)

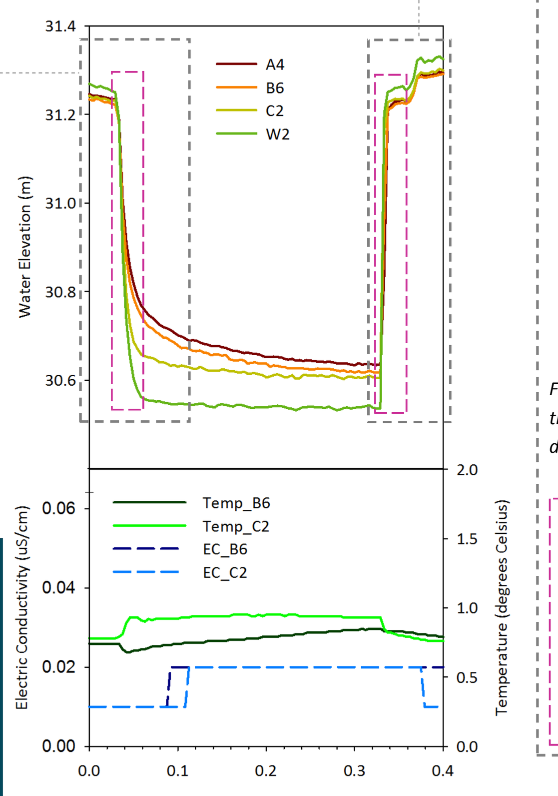

Figure 10. Variations in water level (4 positions), conductivity and temperature (2 positions) at the downstream transect during a short dewatering event, from ***time 0 to 0.4(days).***

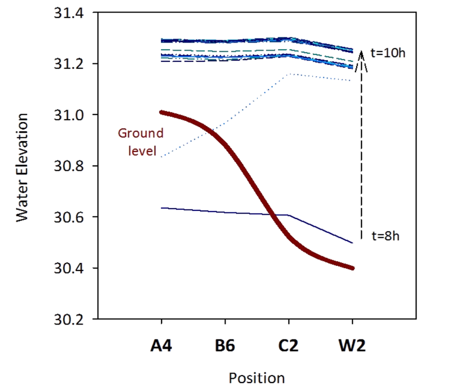

Figure 12. Illustration of the water levels variations across the downstream transect in relation to the ground level during ***2 h flow increase****.*

Table 4. Maximum increase flow characteristics

	A4	B6	C2	W2
Max WL (m)	31.21	31.21	31.23	31.25
Min WL (m)	30.64	30.62	30.61	30.54
WL increase (cm)	57.30	59.40	62.20	71.5
Duration (h)	0.20	0.20	0.20	0.2
Rate (cm/h)	286.50	297.00	311.00	357.5

Total event duration	10 hours
Maximum water level	31.33 m
Maximum flow	21.58 m³/s
Minimum water level	30.53 m
Minimum flow	1.99 m³/s

6. Preliminary Conclusions and Further Work

The role of hyporheos during dewatering

Dewatering events due to hydropeaking, although less abrupt than flow increase, can have detrimental effects on local ecosystems. Results show that potential groundwater fluxes can help maintain survival conditions in the hypoheic in certain locations in Lundesokna river, showing some areas where the flow in the ground is kept at a level potentially utilized by organisms.

This is supported by data obtained from the ongoing embryo survival experiment at the same location, showing high survival rates on certain locations in the stranded area (fig 12 above)

Figure 12. Embryo survival experiments in Lundesokna

Duration

However, in some areas the flow in the ground can drop up to 25cm after some time. Duration of an individual dewatering event plays an important role, influencing the length of time where survival conditions can be maintained. This is particularly important during winter conditions, since potential frost exposure during long periods can prevent survival (fig 12 below).

Bed Geometry

Along a transect, sites closer to the permanent wet area are more likely to hold the water levels for longer due to generally lower ground elevations. However, incoming groundwater flows can vary within individual locations, resulting in very differentiated water levels between close locations.

Longitudinally, watering and dewatering responses will smooth down from upstream to downstream a river. At this stage, no significant differences have been found between the two studied transects.

Further work is planned in the close future and includes the following:

- Continuation of data collection until May '12
- Computation of fluxes and flow rates
- Investigation of more episodes to identify potential flow patterns
- Further analysis on collected water quality
- Data links to key ecological variables such salmon embryo survival

7. References

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