PORE WATER EXCHANGE IN GRAVEL BED RIVERS DURING HYDROPOWER PEAKING EVENTS

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A recent publication (Spiller, Rüther, & Friedrich, 2014) states significant lift force fluctuations on the riverbed during unsteady flow. The present study discusses how such lift force fluctuations might affect the vertical head gradient in the hyporheic zone and sets it into perspective with current literature on the processes of up- and downwelling.

1 Introduction

1.1 The hyporheic zone

The hyporheic zone is the area beneath the streambed surface in a river where surface water and ground water are interacting and mixing (Arntzen, Geist, & Dresel, 2006; Maier & Howard, 2011; Sawyer, Cardenas, Bomar, & Mackey, 2009). River regulation alters the hydrological processes in the hyporheic zone (Maier & Howard, 2011; Sawyer et al., 2009). During unsteady flow, surface water is observed to infiltrate deeper into the subsurface. Thus, the development of the hyporheic zone adjacent to the streambed is not comparable to steady-state flow situations (Maier & Howard, 2011). Surface water infiltration or exfiltration to and from the hyporheic zone, provides particular physical and chemical conditions (oxygen and nutrients) that can support unique hyporheic communities. Oxygen rich hyporheic water can provide shelter from benthic invertebrates or juvenile fishes during extreme low flow events. However, such processes can also transport sediments and pollutants into the hyporheic zone, affecting the hyporheos. Suspended load can lead to clogging of the riverbed, infiltrating pollutants can be stored for a long time and gradually contaminate the river for years. How unsteady flow is affecting such pore water exchanges is still a matter of current research.

The stage difference in ground water and surface water influences the hyporheic zone and causes upwelling or downwelling (Maier & Howard, 2011). A positive head gradient indicates upwelling, which implies a higher pressure below the streambed than above it, so that pore water from the hyporheic zone enters the surface water. It occurs usually after a decrease in flow depth when, due to a certain dampening effect of the granular bed material, stream stage and ground water stage do not act synchronous, but with a time delay. During this process the ground water stage remains high, whilst the stream stage decreases. Downwelling denotes the opposite effect.

1.2 Lift force during unsteady flow

Physical experiments in the hydraulic laboratory of the University of Auckland have shown that strong lift force oscillations at a patch of an artificial armor layer occur during increasing flow, such as a hydropower peaking scenario (Spiller et al., 2014). Figure 1 shows an example of the observed effect. The water level (thick solid line) for this particular experiment was increased from about 4 cm to 12 cm in approximately 30 s. From a quasi-steady perspective, the lift force was expected to linearly drift from its initial steady level to its final steady level (dashed line). In fact, the measured lift force (thin solid line) showed three significant "peaks" or deviations from the quasi-steady reference line at about 132 s, 134 s and 142 s of the experimental time. These three peaks were recognizable for almost the entire spectrum of 190 experiments, including different ramping rates and initial water levels. In general, higher ramping rates, higher differences in final and initial discharge as well as a higher initial water level increased the magnitude of the lift force peaks.

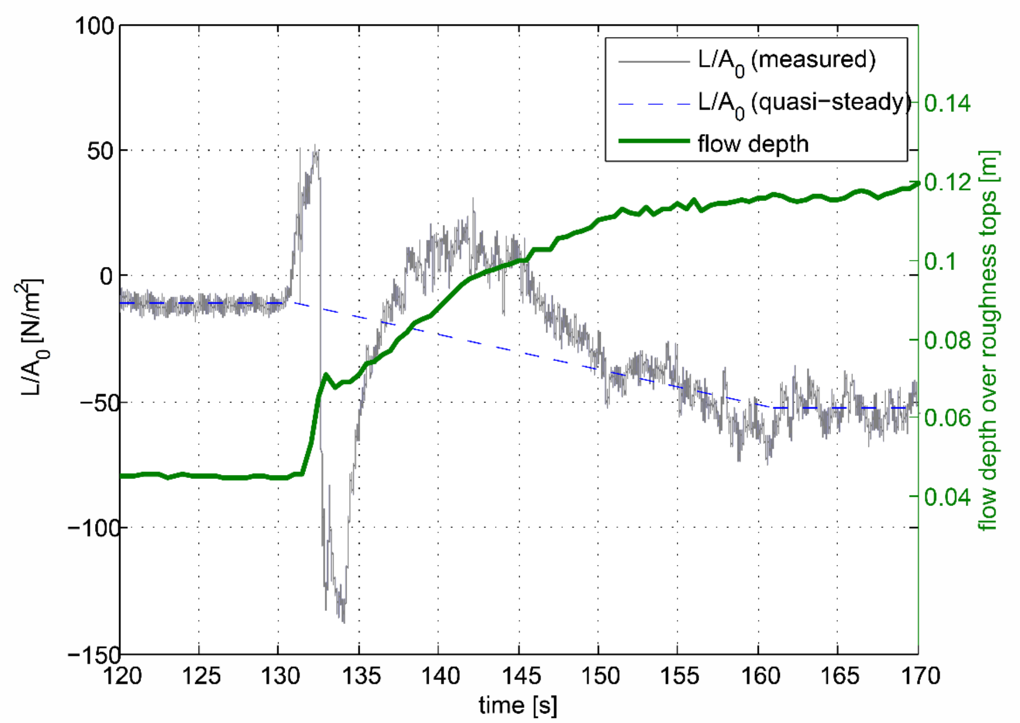

Figure 1 Lift force and water level during an experimental flow increase in a laboratory flume. *Thick solid line and right axis*: Flow depth over time. *Dashed line and left axis*: Expected lift force over time if quasi-steady assumptions would apply. *Thin solid line and left axis*: Measured lift force during the experiment.

2 Discussion

2.1 Quasi-steady and unsteady effects

The flow in a river during hydropower peaking is unsteady, with water discharge, flow depth and flow velocity increasing or decreasing over time. It is well known that a higher flow depth causes a higher bed shear stress. This alone is not an unsteady effect, as it can be explained by steady assumptions. Even during a flow increase, from a quasi-steady perspective, the shear stress should gradually increase with the flow depth. The same applies to the lift force. For the rest of this paper, these effects will be addressed as "quasi-steady".

In addition to the quasi-steady effects, "unsteady effects" occur during the actual flow increase or decrease. These are still a matter of research. The significant lift force deviation from the quasi-steady reference line, observed by Spiller et al. (2014), represent such an effect, as they were not explainable from a steady or quasi-steady point of view.

In general, quasi-steady effects are only dependent on the amount of flow increase, while unsteady effects are affected by the unsteadiness of the hydrograph, i.e. the ramping rate.

2.2 How does unsteady flow affect the hyporheic zone?

The pore water exchange in the hyporheic zone is driven by vertical head gradients. This is a quasi-steady effect, where a higher head gradient implies more pore water exchange. In addition, the lift force variations, described earlier, are associated with a pressure difference between the water in the hyporheic zone below the bed surface and the stream stage above. This unsteady effect should be expected to add to the quasi-steady head gradient.

In case of a clogged bed (Schälchli, 1992), such a vertical head gradient might be able to lift fines and increase the bed porosity.

2.3 Importance of unsteady effects in a hydropower peaking scenario.

The main question is whether the observed unsteady effect in form of lift force variations, that is expected to add to the quasi-steady head gradient, plays a significant role on the development of the hyporheic zone. A wide range of experiments in Spiller et al. (2014) showed lift forces that would certainly have a significant effect on the vertical head gradient. However, the unsteadiness of hydrographs in real hydropower peaking scenarios is more comparable to the lower end of the experimental range (Spiller et al., 2014), where only minor lift force deviations were recorded.

3 Conclusion

Two processes affect the pore water exchange in the hyporheic zone during hydropower peaking. 1.) Quasi-steady effects like up- and downwelling cause pore water, including oxygen, nutrients, sediments and pollutants, to infiltrate the hyporheic zone. 2.) Unsteady effects like lift force variations during flow increases enhance upwelling. To which degree process 2 contributes to the pore water exchange depends on the unsteadiness of the peaking hydrograph, i.e. mainly the ramping rate.

The ramping rates used in hydropower peaking might often seem very high from an ecological perspective. They are, however, mostly too low to cause strong lift force variations, as experienced in the laboratory experiment. Even though unsteady effects, like the lift force variations, should be measurable in real hydropeaking scenarios and might even be significant for some events, they have most likely a minor effect on the hyporheic zone compared to the quasi-steady effects due to the flow in- or decrease.

Acknowledgements

This research was supported by the Centre for Environmental Design of Renewable Energy (CEDREN) in Norway.

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