DESCRIBING FISH PASSAGE IN A RIVER CONFLUENCE WITH TELEMETRY AND CFD

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The confluence between a hydropower tailrace and the old river bed in Stornorrfors in the river Umeälven in the northern part of Sweden has shown to be the largest obstacle for upstream migrating salmon and sea trout. Fish are attracted to the high flow rate from the tailrace and will not migrate upstream in the old river bed to the fishway leading past the hydropower dam. By using triangulation from eight antennas in the confluence, the tracks of radio tagged migrating fish can be determined. These tracks are then compared with three-dimensional Computational Fluid Dynamics (CFD) simulations of the confluence. By simulating the most common combinations of turbine flow and spill flow in the old river bed it is possible to find correlations between fish movements and the flow field. It was previously assumed that fish had trouble locating the old river bed, the results of the triangulation however shows that most fish find the old river bed within a few days but do not chose to migrate until several days or even weeks later. The main issue is therefore not how to attract the fish to the old river bed, but rather how to create favorable conditions in the old river bed so that migrating fish are more inclined to take that path upstream.

1 INTRODUCTION

Studies of tagged Atlantic salmon and sea trout in the unregulated river Vindelälven in northern Sweden during 1995-2005 have shown that only a third of the upstream migrating fish find their way to their natural spawning grounds [1]. The main reason for this is the Stornorrfors power plant located downstream the confluence between the rivers Vindelälven and Umeälven, the latter being a regulated river. A major issue at the power plant is that the fish are attracted into the tailrace channel from the turbines rather than migrating up through the 8 km long old river bed that offers a fishway around the turbines [2]. The flow rate from the turbines is typically 20 times larger than the flow rate from the old river bed and its entrance into the confluence is very wide. Hence fluid flow conditions for the old river bed to attract fish are limited. The fact that migrating fish are attracted to the tailrace of the turbines instead of the weaker current from the fishways is a common problem [3], [4].

Numerical models of river flow can be useful for many applications such as erosion studies, habitat modeling and hydraulic engineering. Depth averaged methods with simplified models for fluid flow can with the advancement of computer power be replaced by fully three-dimensional, turbulent fluid dynamics simulations. One of the first full scale river simulations was presented by Olsen and Stokseth [5] where the Sokna River in Norway was modelled with good correspondence with observed data. The SSIIM model developed by Olsen has been validated with LDV measurements in a meandering channel on a lab scale [6] where the model showed the ability to predict secondary currents. Simulations of river flow has also been applied to environmental flows to determine advantageous positions to construct fish ladders [7] and to investigate the possibility to build flow guidance devices to steer the near-surface flow and thus downstream migrating smolt past hydropower turbines [8].

By combining the knowledge of the fluid flow with fish preferences and movements it should be possible to find the limiting factors for fish migration and test different solutions to create an overall improved environment. One key factor is to find the connection between fish preference and flow parameters. This can be accomplished e g by comparing experimental results in a lab-scale [9] or combining field measurements of fish behavior with numerical models of the river flow [10].

2 METHOD

2.1 Numerical set-up

The bottom tracking feature of an Acoustic Doppler Current Profiler (ADCP) of the type RiverBoat RioGrande from RD Instruments was used to map the bathymetry of the river confluence. By combining the bottom-tracks with GPS data, a point cloud consisting of depths at specific satellite coordinates was obtained and converted to a solid surface. The geometry of the hydropower tailrace was omitted from this study since the focus was how the fish behaved in the confluence. The tailrace flow has been studied in more detail in earlier studies and the flow conditions from the outlet of those simulations were used as inlet boundary conditions for the confluence simulations.

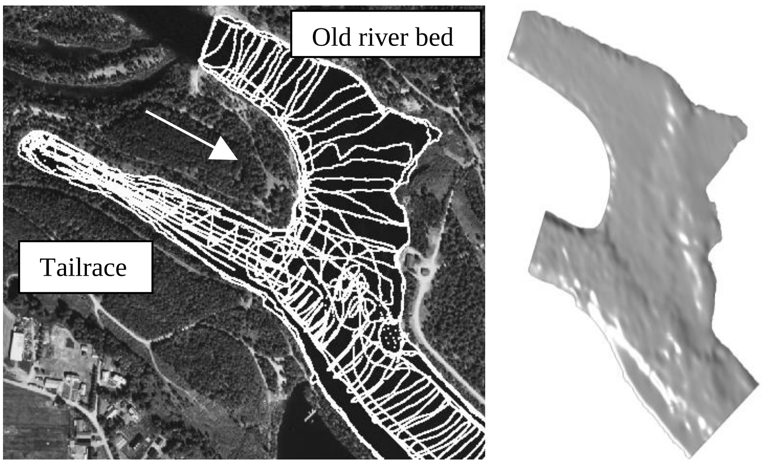

Figure 1. Measured depth data for geometry creation and the simulation domain

The numerical domain was discretized by an unstructured mesh with 4.1M nodes (21.5M elements). Different combinations of spill flow and flow from the turbines were chosen according to the most common flow combinations during the migrating season. The inlet from the old river bed was simplified with constant velocity in the flow direction. The bottom surface was given a roughness of 0.2 m. The water surface was modelled as a rigid lid with zero friction. The variations in water level for the different flow combinations was not considered in the numerical model, instead all simulations were run at the same water depth. All simulations were performed with the commercial software Ansys CFX15 using the standard k-ε turbulence model.

2.2 Triangulation

In 2013, 148 Atlantic salmon (*Salmo salar*, L.) were captured in fyke nets at the river mouth of the River Umeälven and each individual was provided with a radio transmitter tag of 30 MHz by means of gastric tagging. When the tagged salmon passed the confluence area the signals from the transmitters was recorded on archival loggers attached to eight antennas placed along the shore at the confluence area as in figure 2. There were one underwater antenna and seven air antennas. The underwater antenna picked up signals from up to about 20 m, while the air antennas picked up signals from the entire area. The positioning of the recorded signal strengths were made by selecting the best least square fit to a reference data set of 27854 recordings that was created by dragging active radio transmitters after a boat that was maneuvered to cover as much as possible of the confluence area, see Figure 2. To reduce the amount of noise as much as possible a moving average filter with window size 11 was applied. This window size was set by reconstructing the boat tracks by using the reference data. From this validation the precision in the positioning could be calculated to ± 30 m with 95 % probability. Although this is a considerable uncertainty, it allows the positioning of the salmon to the areas of interest in the confluence since the width of the main river is about 135 m. The positioning of the salmon was then linked to the prevailing flow conditions. To have a measure of how large fraction of the salmon that were at the entrance to the old river bed, the number of tagged salmon that were north of a line running from antennae 2 to the edge of the cape south of antennae 1 was divided by the total number of recorded salmon in the area.

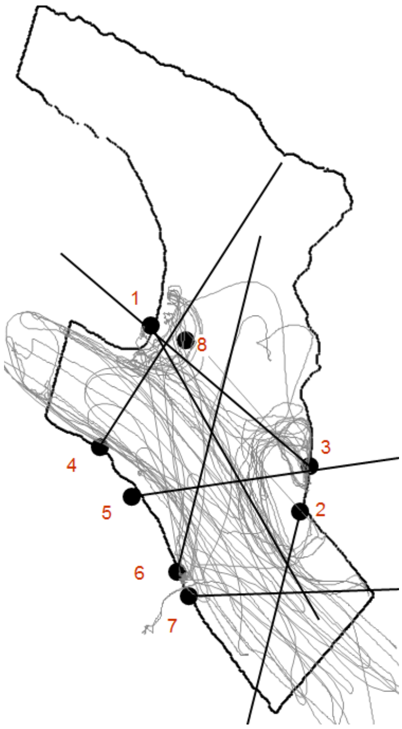

Figure 2. Antenna positions (black dots) and directions (black lines), and reference transmitter track (gray lines). Numbering corresponds to ID of air antennas, 1-7; and underwater antenna, 8.

3 RESULTS

The velocity field is similar for all tested flow combinations. A large area of still flow will be formed at the cape that separates the tailrace and the old river bed. A large wake is also formed behind the largest of shallow areas located furthest upstream as seen in Figure 3. The vorticity (rotation around the vertical axis) of the flow is also similar for the flow configurations and streaks of high vorticity can be seen originating from the tailrace propagating downstream and also from the downstream intersection between the old river bed and tailrace, see Figure 4.

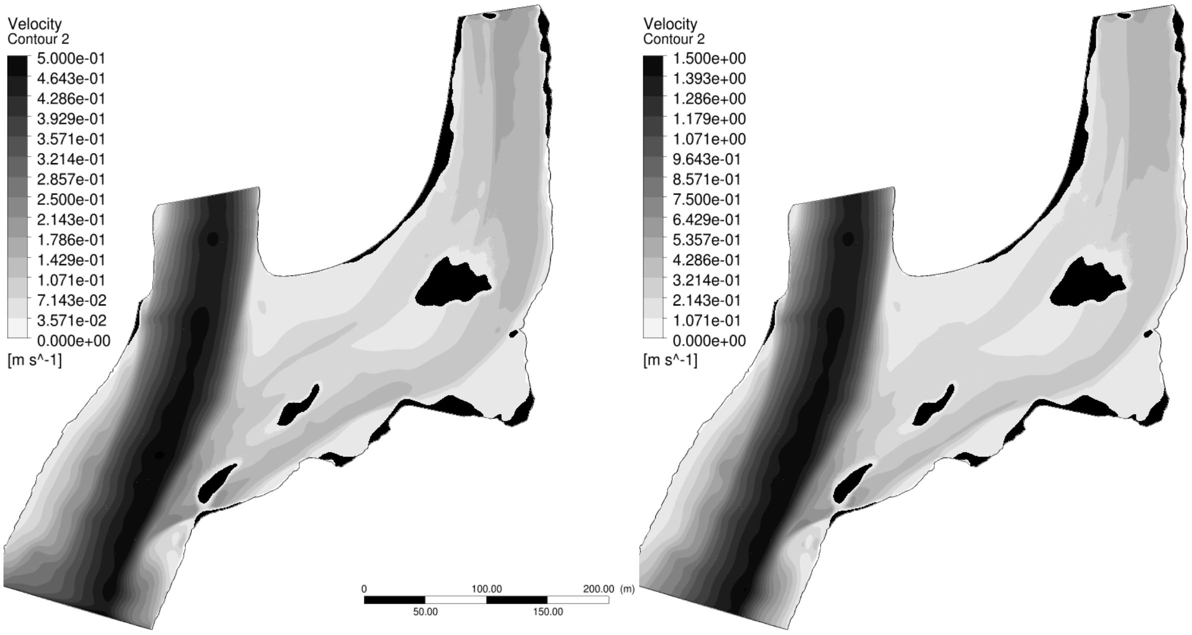

Figure 3. Velocity contours at 1 m depth for 200 m^3/s, 20 m^3/s spill (left) and 600 m^3/s, 50 m^3/s spill (right). Areas with depth < 1 m are marked with black color.

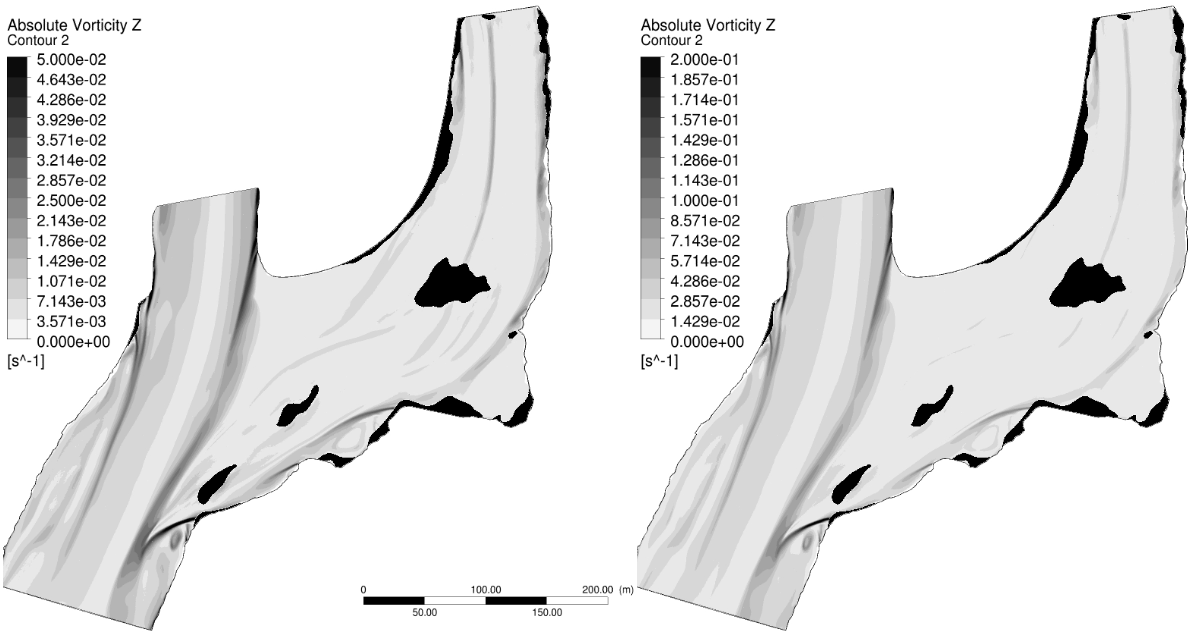

Figure 4. Absolute vorticity at 1 m depth for 200 m^3/s, 20 m^3/s spill (left) and 600 m^3/s, 50 m^3/s spill (right). Areas with depth < 1 m are marked with black color.

Most salmon tracks from the telemetry study were logical in the sense that they started with a low signal on the downstream antennas, followed by an increasing signal strength and were then recorded on the upstream antennas. Data for positioning was required to have recordings on at least three antennas for each transmitter ping. There were $1.2*10^6$ pings with in total $5.9*10^6$ signal recordings that could be used for positioning of the salmon. On average there were 9700 pings per salmon, ranging from 132 to 51000. The swimming activity of the salmon was lowest during night. It increased towards on average 0.8 m/s between 1 and 4 am and decreased slowly from 15 pm to midnight (Figure 5). The lower speed during night was a consequence of that more individuals were resting compared to during daytime.

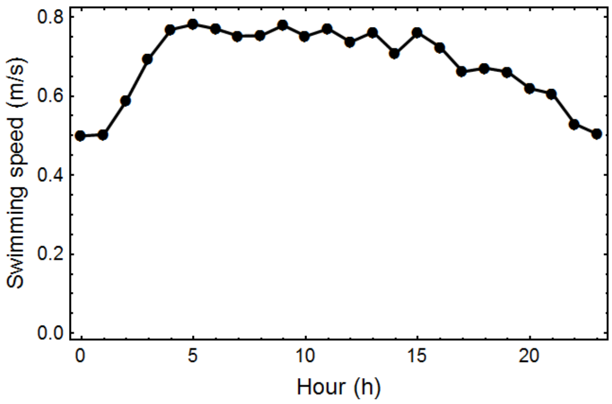

Figure 5. The swimming average swimming speed of the tagged salmon was somewhat lower during nighttime compared to daytime.

The antennas 2, 3, 6 and 7 had a majority of registrations, 60 %, and the underwater antennae had c. 8 % of the registrations despite much shorter range than the air antennas. The proportion of salmon just upstream the border to the old riverbed peaked two times per day, one wide peak during the morning around 4 to 6 pm (c. 23 – 24 %) and a smaller peak around 8 am (c. 20 %) (Figure 6). The peak in the morning coincides with the peak in proportion of spill flow of the total flow (Figure 7). However, the increased number of salmon in that area during the evening was not related to any increased influence of the spill flow. The density plots on the positioning of the salmon show somewhat more concentrations towards the cape during the period 5 - 10 pm when compared to during the evening (8 pm to 4 am) (Figure 8). On the average each salmon spent c. 17 ±8 (±1 SD, n = 119) % of the recorded time just upstream the border towards the old riverbed. 98 % of all individuals were recorded upstream the border to the old river bed at one or more occasions and the average estimated distance upstream the border was 87 m. From that point on, they have another 290 m to the area where the water velocity increases, and especially so when a spill of 20 m^3/s or lower is applied in the old riverbed.

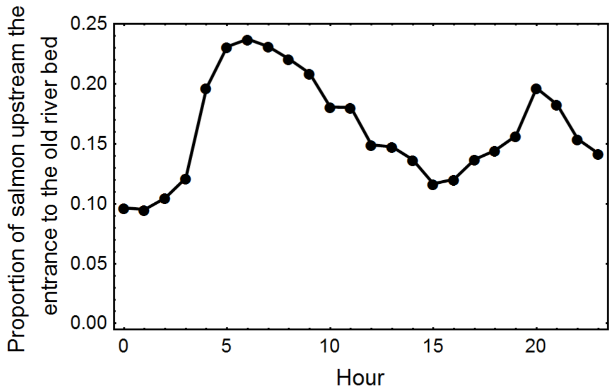

Figure 6. There were two daily activity peaks with salmon moving around just upstream the entrance to the old river bed, now acting as a bypass channel towards the fish ladder 8 km upstream the confluence.

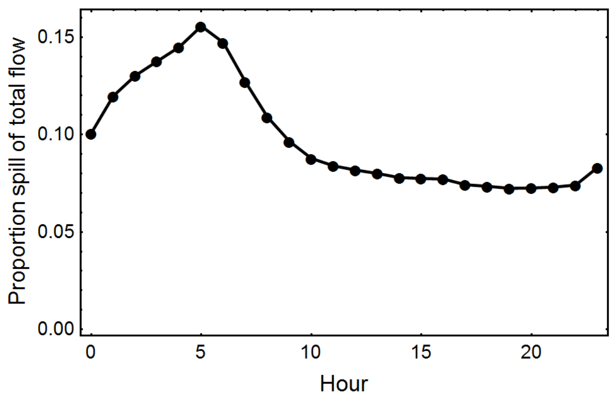

Figure 7. The average daily pattern of spill in relation to total flow displayed a peak around 5 am and remained low from 10 am to 10 pm.

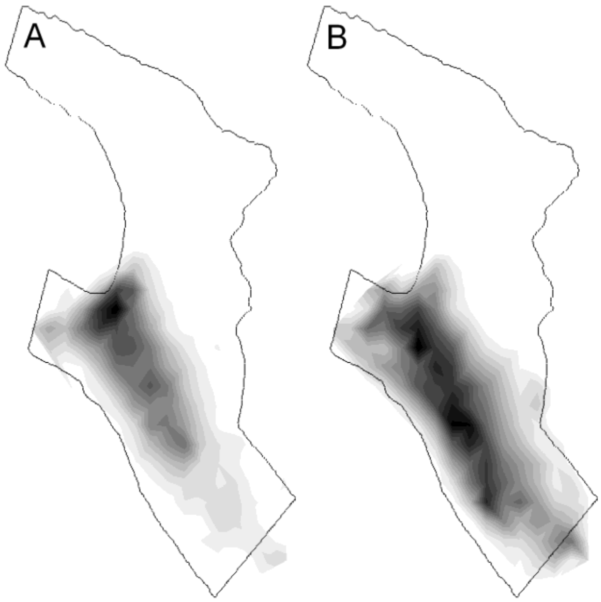

Figure 8. The salmon were concentrated near the cape during the morning 5-10 am (A), but more towards the southern side during the evening and night (8 pm to 4 am). Darkest tone corresponds to ~ 370 registrations**.**

The reason for why salmon spend time in area just upstream the border to the old riverbed is probably that they seek shelter in the wake of the cape and are resting in the area. Another explanation could be that they sense the smell of salmon that already passed upstream in the old riverbed. However, most salmon in the mainstem continue upstream towards the tailrace, from which they return later on [1]. Many salmon return repeatedly to the tailrace, which delay the upstream migration via the old river bed. During the evening period there are also some registrations of fish entering the old river bed at the downstream end of the confluence. They could be attracted to this area from the velocity increase from the shallow area seen in Figure 3 or the vortical structures originating from this area seen in Figure 4.

There has been suggestions to build a construction that creates a jet to attract the salmon from the main stem to the old riverbed [7]. However, the results presented here indicate that the salmon find the entrance to the old riverbed, but they seem to lack motivation to continue upstream. That lack of motivation is most likely due to improper flow conditions just upstream the entrance to the old river bed rather than lack of attraction from the mainstem to the entrance. Mitigations to increase the water velocity just upstream the entrance to the old riverbed should therefore be prioritized.

4 CONCLUSIONS

The main conclusion from this study is that the primary problem for migrating salmon is poor hydraulic conditions (no attraction flow) in the wide entrance to the old riverbed at the cape rather than the absence of a jet to attract salmon from the mainstem.

Future studies could include time-resolved simulations with more advanced turbulence models, simulations considering both air and water phases and measurements of fish movements with higher spatial accuracy. While the results presented here gives a good overview of the fish behavior and flow field in the area, the uncertainty in the positioning of the telemetry results was too high (±30 m) to compare individual fish tracks to the detailed flow parameters from the hydraulic results derived with CFD-modelling. This telemetry study was performed in 2013 and since then the technical development and price changes has made it possible to use acoustic transmitters with depth sensors to allow much higher accuracy and precision in the positioning. This technique will also provide information at which depth the fishes are swimming, information that was not possible to derive in the positioning based on the active radio transmitters.

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