Description of a Test Case:

Anundsjö

Mo - Sweden

Table of contents

List of figures

1. Description of test-case

1.1. Description of water bodies related to the HPP

The test-case is located in a small river in the northern part of Sweden and the catchment area is 810 km^2. Anundsjö dam created a small reservoir in the River Mo. Water is diverted from 4 km of the river directly downstream the dam. Further upstream areas are known to be spawning grounds and potentially good rearing habitats A few hundred meters downstream the outlet of the power plant, River Mo meets a smaller tributary and flows further into the biggest lake in the system, Anundsjön.

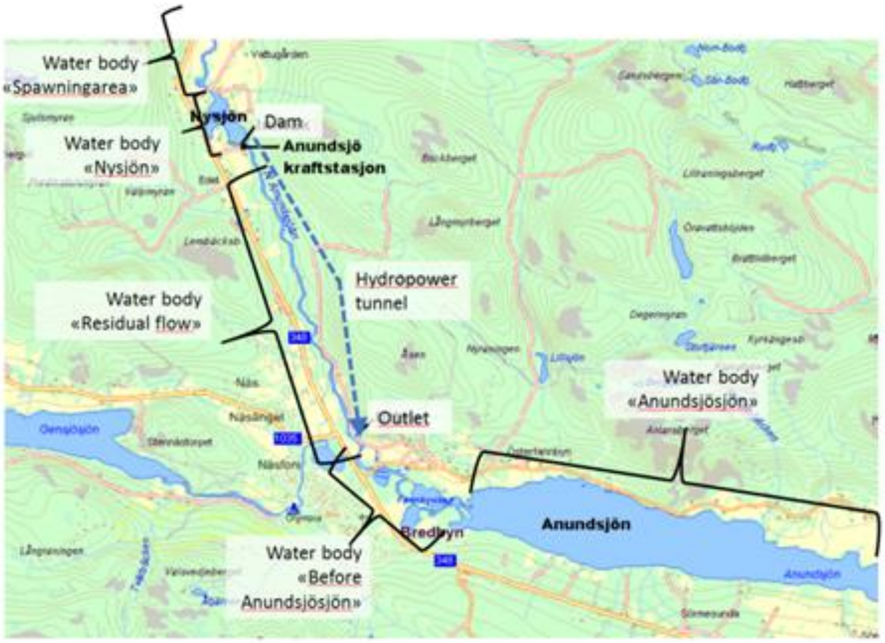


Figure 1: Water bodies related to HPP of Anundsjoe

1.1.1 Hydrology of the River Mo

The hydrology in River Mo is typical for the northern part of Sweden, often a lot of snow and low flow in wintertime, a spring flood when the snow melts, less flow during summer and often an autumn rainwater flood before the winter settles. Mean precipitation for the whole catchment area per year is approx. 727 mm, mean flow at the outlet in the Baltic sea is 27.9 m^3/s and in the area were the HPP is located it is 10,2 m^3/s. The small reservoir directly upstream has an area of 0.5 ha and the license of the HPP allows a regulation of 0.5 m which means 0.26 Mill m^3 of volume available to regulate. A larger reservoir of 24.5 Mm^3 is located further upstream and provides the HPP with water during the winter.

1.1.2 Main pressures

Continuity (moderate)	Two dams downstream whit unknown passage efficiency
Hydrology (moderate) and morphology (moderate)	In most of rapids of the river, modifications to ease timber floating were carried out long time ago. Some of these rapids are restored. The flow directly downstream the outlet of the HPP is affected by short-time regulation. The water level of the small reservoir varies within 0.5 m.
Pollution (moderate)	Mercury imbedded in the ground is released due to forestry activities, a general problem in the majority of Sweden.

1.2. Presentation of the HPP

1.2.1. Location of the HPP

Figure 2: Location of the HPP

The HPP is impounding a small reservoir and further releasing the water through the turbines and a tunnel back into the river (fig.1). As a result of this design the bypass reach is only fed by the discharge through the fishway (see 1.2.2). Only during high flow events additional discharge is released over the weir into the bypassed reach.

Main characteristics:

Watercourse	River Mo
Situation	Municipality of Örnsköldsvik
Mean annual discharge	10,2 m^3/s
Low-water flow	2,21 m^3/s
Instream flow	0,25 m^3/s
Function of the dam	Hydropower
Length of bypassed reach	4 km
Maximum turbine discharge	10 m^3/s
Species concerned	Salmon, see trout, pike, perch, grayling, brown trout, crayfish

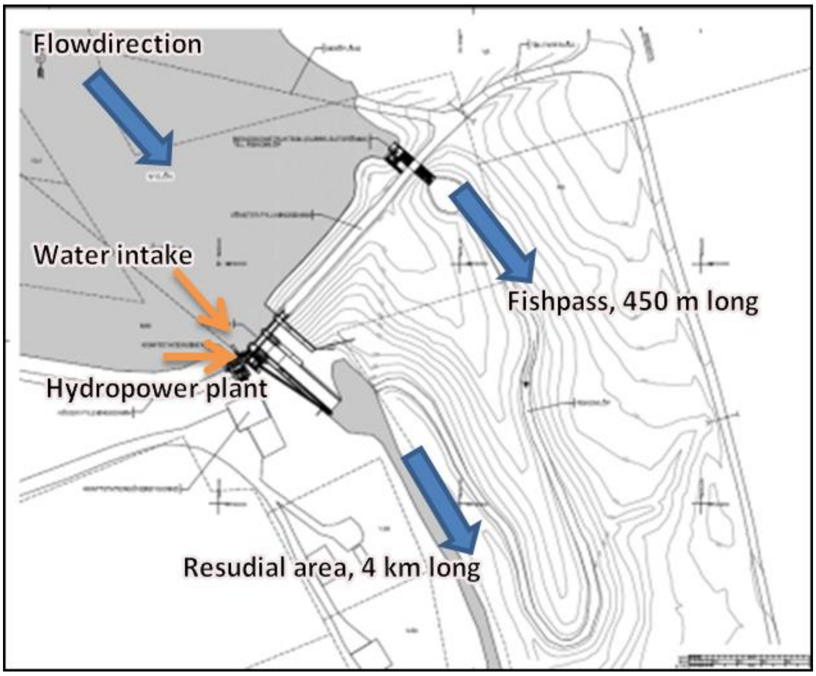


Figure 3: Map of the water intake, the outlet is located 4 km downstream and not visible on this map

Equipment:

1 Francis turbine (1954)

- Maximum turbine flow: 10 m^3/s
- Rated head: 61 m
- Number of blades: 24
- Diameter of the wheel: 1.2 m
- Rotation speed: 375 rpm

1.2.2. E-flow

In the new license from 2012 the requirements are to release 0.8 m^3/s in the fishway between the 15th of July and the 5th of October and 0.25 m^3/s the rest of the year. During the summer period one hour every Tuesday and Thursday the power plant must shut down and release the discharge through the gates in order to attract salmon into the bypassed reach.

1.2.3. Downstream migration device

The downstream migration device includes a floating guidance structure, installed right next to the intake, leading the fish into a smolt trap which then leads the smolt further to the downstream side of the dam. The license states that this device shall be installed before 1st May every year and water released in the smolt trap shall be 0.25 m^3/s. This solution was evaluated together with the authorities after the first year, 2016, and the conclusion was that it did not work as intended. A new solution was tested in 2017, with fishing nets, leading the smolts to the fishway instead. The water initially released to the smolt trap is released through the fish way now instead to ensure a sufficient discharge guiding the fidh there and the date for installing the device is moved to a flexible time due to when ice is gone from the reservoir. See Figure 4.

Figure 4: Location of downstream migration device

1.2.4. Upstream migration device

The upstream migrating fish encounter the outlet, located 4 km downstream the fishway, see Figure 3 and Figure 5. The attraction flow is represented by the minimum flow, 0.8 m^3/s between the 15th of July and the 5th of October; 0.25 m^3/s the rest of the year. At the end of the 4 km long residual area the upstream migration must continue in the fishway, see figure 3. The last part of the fishway hrough the dam is a vertical slot fish ladder made in concrete, see figure 6.

Figure 5: Reach of residual area, 4 km long between intake and outlet

Figure 6: Upstream migration device inlet structure (vertical slot pass with entrance gate)

2. Objectives on this Test Case

The overall question at the HPP Anundsjø is how different mitigation measures around the HPP can improve the situation for fish, mainly salmon, in the river Mo. The current situation shows a huge population decrease for salmon. A clear reason is not known so far but there are some assumptions for the decline. To get more detailed information on the situation for the smolt, which are mainly arriving at the HPP since some years smolts are released in the upstream area. Since these activities are running, no further information about their survival or swimming paths are known, neither at the HPP nor in the upstream or downstream areas. Also the situation for juvenile fish of different species as well as the passability of the HPP in Anundsjø is an open question, further no information are available on the effect of the HPP further downstream of the HPP Anundsjø and the river reach and lakes to the Baltic sea for salmon on the way to spawn and back. Hence, the research questions to be answered as part of the FIThydro project are manifold. The most pressing ones are:

- The reservoir: Smolt affected by the current in the reservoir and at the turbine- inlet (CNRS / SWECO / NTNU)
- The fishway and the residual flow reach: Flow and turbulent structures (NTNU)
- Bypassed reach: Flow, sediment management and resulting habitat availability (NTNU / SWECO)
- Fishway and bypassed reach entrance attraction: Passability and attraction at the downstream fishway entrance as well as the upstream entrance, and also past the turbine outlet (TUM / SWECO / NTNU)

Based on the given research questions above the following activities are planned for the HPP Anundsjø:

- The reservoir: The numerical simulation should lead to a more detailed view on the flow situation leading the smolts and the question if the flow structure guiding them towards the fish way functions properly.
- The residual flow reach and the fishway: In this area NTNU will develop the double averaging method further.
- Fishway and bypassed reach entrance attraction: as the main flow goes through the turbine and only a small portion flows through the bypass the flow conditions at the junction need to be evaluated with a focus on the attraction flow for possible upstream migrating salmon. The numerical simulation shall give a deeper insight into the flow structures in this area indicating if the attraction towards the bypass would be sufficient for migratory salmon.

The answers to these questions are of relevance in FIThydro as this is the only test case with a) such a high head not allowing survival for smolts during turbine passage and b) offering as well a very long residual flow reach with all the advantages such as potential for new habitat but also disadvantages such as long reaction times for discharge changes etc. Further it is the only test case dealing with salmons in different life stages.

3. Presentation and results of activities in FIThydro

At this test case the FIThydro partners NTNU, SWECO, CNRS and TUM work together on the tasks mentioned in section 2. In general, NTNU is responsible for the sediment and habitat evaluations including adaption of the Double Averaging Method (DAM) to field use. NTNU supports SWECO in ADCP measurements to collect information about velocity and bathymetry (see also Table 1). These datasets on hydraulics and geometry are the input data for CNRS and TUM, both conducting numerical simulations. CNRS is evaluating the flow structure in the reservoir and its effects on smolt migration., TUM will run numerical simulations where the outlet of the turbines meets the bypassed reach of the river to assess the passability and the attraction of fish.

During the first year of field studies, various measurements were conducted by NTNU and SWECO to prepare the relevant data sets to work on the objectives as described above.

Table 1 :Measurements conducted by NTNU and SWECO during the first and second field campaign in 2018 (see Figure 7 for location of sites that are described by a-e in the table)

#	Type of measurement	Location	Type of data	Further use of data	Reference chapter 3
1	ADCP	Reservoir (a)	Bathymetry / velocimetry	Numerical simulation of the flow structure in the lake	3.3
2	SfM	Fishway (b)	Geometry	Potential use for further development of the DAM	3.2
3	Salt	Fishway (b)	Discharge	See 2	3.2
4	GPS	Fishway (b)	Geometry	See 2	3.2
5	ADCP	Junction tunnel outlet / residual flow (c)	Bathymetry / velocimetry	Numerical simulation of the flow structure and the possible attraction of fish into the residual flow in this area	3.1
6	GPS	Junction tunnel outlet / residual flow (c)	Geometry	See 5	3.1
7	ADV	Residual Flow Reach (d)	Velocity	Potential use for development of the DAM further	3.2
8	SfM	Residual Flow Reach (d)	Geometry	Potential use for development of the DAM further	3.2
9	GPS	Residual Flow Reach (d)	Geometry	See 8	3.2
10	ADCP	Junction downstream area (e)	Bathymetry / velocimetry	See 5	3.1
11	GPS	Junction downstream area (e)	Geometry	See 5	3.1

Figure 7 : Map (tilted, North is left) of Anundsjø showing the different areas according to tab. 1

3.1. Passability and attraction at the fishway entrance

3.1.1. Data

The passability and attraction at the fishway entrance and at the downstream end of the bypassed reach will be evaluated by running numerical simulations by TUM. As basis for the model simulations, NTNU and SWECO collected flow and bathymetry data in the respective area.

The data sets were collected upstream and downstream of the junction of the bypassed reach and tunnel outlet (Figure 7, c), towards the tunnel outlet and more downstream towards the lake-like river widenings (Figure 7, e).

3.1.2. Methodology

The **hydraulic measurements** were mainly conducted with two Acoustic Doppler Current Profilers (ADCP) from Sontek M9 (Figure 8).

Figure 8 : The Sontek M9, one mounted on a kayak (left) and an autonomous boat (right)

Cross sections in the relevant areas were measured using these two devices. These cross sections were complemented by additional loops in between which do not contribute to the velocity information. As the two devices were mounted on different types of boats (a kayak and a boat operated by remote control) it was possible to conduct very efficient and detailed measurements even in shallow areas. The water level was measured also with a GPS to ensure a sufficient calibration and accuracy.

The area around the confluence of the bypassed reach and the outlet of the power plant will be modelled and simulated. In order to perform hydrodynamic simulation, and flow field (specifically velocity field) calculations in this domain, two different scenarios are defined. Since the power plant must shut down and release the discharge through the gates during the specific hours, in the first scenario, the hydrodynamic simulation will be performed without operating the hydropower plant. In the second scenario, the presence of the operating hydropower plant will be considered in simulation. To achieve this aim, the TELEMAC-MASCARET system has been proposed for the hydrodynamic modelling. All modules of the system are based on unstructured grids and finite-element or finite volume algorithms. The model system includes 2D and 3D hydrodynamic modules (TELEMAC-2D and -3D), and a spectral wave propagation model (TOMAWA). TELEMAC-2D module solves the shallow water equations with several options for the horizontal dispersion terms (e.g. depth-averaged k–ε model, Elder model, and constant eddy viscosity models) and source terms (e.g. atmospheric pressure gradients, Coriolis force, etc.). The numerical discretization includes a choice of classical methods for the advection terms. The use of implicit schemes enables relaxation of the limitation on time steps (typically, values of a CFL-numbers up to 10 or 50 are acceptable). Recently, ideas stemming from finite volume techniques have been coupled with these implicit schemes to ensure monotonicity of depth and sediment concentrations, as well as mass conservation at machine accuracy. TELEMAC-3D solves the Reynolds-Averaged Navier-Stokes (RANS) equations in unstructured meshes obtained by a super-imposition of 2D meshes of triangles. The 3D model can be applied to capture the effect of vertical recirculation cells as well as stratification effects, assuming a hydrostatic or non-hydrostatic pressure distribution. As this study is focusing mainly on the hydrodynamic simulation in the fish path, it is recommended to apply TELEMAC-3D which provides information in vertical direction.

3.1.3. Results

The turbines were shut-off during the field campaign and hence the flow situation was not representative for normal operation. Therefore, the ADCP measurements showed very low water velocities. This cannot be seen as representative and therefore needs to be used only for calibration and validation of the model.

The bathymetry data showed relatively shallow areas in the bypassed reach and deep areas just at the tunnel outlet. In addition, a lot of driftwood was present in the downstream areas.

3.2. Bypassed reach and fishway: Flow

3.2.1. Data

The residual flow reach will be used to develop the Double Averaging Method (DAM) (Nikora et al 2007 a, b; Navaratnam et al 2018) further. Currently this method is developed and only tested under lab conditions. At the test site in Anundsjø, we will adapt this method to field conditions. Further measurements, mainly of the geometry were taken in the fishway. However, the tests showed that the residual flow corresponds better to the requirements for comparing the DAM field results with the lab results due to its broader variety of currents.

3.2.2. Methodology

For this method first Acoustic Doppler Velocimeter (ADV) tests were run in the bypassed reach. Therefore, a cross section was chosen with a mix of shallow and deeper water zones. Three ADV vectrino probes from Nortek were used to collect point measurements at three different spots at the same time (Figure 9) following a predefined raster.

Figure 9 : ADV measurements in the bypassed reach

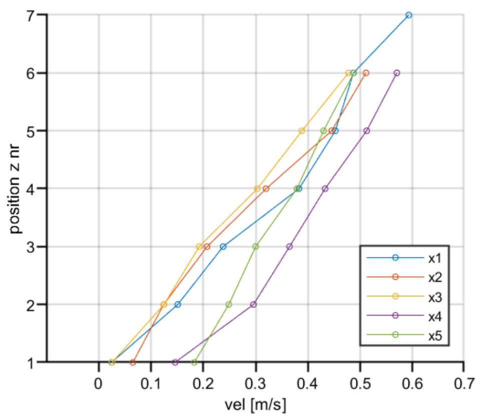
Based on ongoing investigations and tests in the lab these measurements will be evaluated, repeated, and used to develop the DAM for field use.

Geometry data were mapped using the "Structure from motion" technique (SfM) with an UVA Phantom 4. These measurements are used to predefine specific spots in the residual flow reach where tests on the habitat availability will be conducted in 2019. The method is described in more detail in section 3. This will be done by the use of the Finstad method for shelter mapping (Finstad et al 2007), as also conducted in the test site in Schiffmühle in Switzerland. The data sets are tested for further use to collect information about the sediment distribution. This depends highly on the quality of the results which can be achieved with SfM and is still in the evaluation process. In addition, four cross sections were measured in the field with the UVA, to be able to evaluate the drone data with a sufficient accuracy of detected coordinates. These data are linked to the SfM results via the use of targets.

3.2.3. Results

The ADV measurements were conducted at two different spots at different water levels, which offers the possibility for one spot to get flow velocity data as well as high quality roughness information gained with SfM (fig. 10). This is essential for the application of the DAM and one of the hindering factors for the application of the method in the field. The second spot was set in the area of general submergence.

Figure 10: SfM measurements in the residual flow reach to evaluate the roughness of the gravel areas



The results of the ADV measurement show clearly the large effects of coarse sediments on the current including strong recirculation effects. Hence the application of the DAM in these areas is quite challenging. The DAM can be applied from within the water-bed-interface up to the water surface. In the residual flow the macro roughness elements directly reach the water surface, which means that a clear and well-established layer between the roughness elements and the water surface is missing (fig. 11). Further, it might appear that the quasi-linear trend of the intrinsic averaged velocity only below zc =0.15 h doesn`t apply here, but can be seen for approx. z = h as the depth to roughness ratio is smaller than in previous studies. Figure 11: Velocity results for different cross sections in different water depths

The results achieved are quite promising and currently compared to results achieved in laboratory studies using the DAM. This also shows the restrictions of the method in the field highlighted for specific relevant points, such as the number of measured points is less, the general accuracy of positioning and stability appears to be a bit lower as mounting and technical set up of the experiment cannot be as perfect as in the laboratory, the water level cannot be kept stable hence the ration between water depth and roughness element height can change.

3.3 Reservoir

3.3.1 Data

In the reservoir the behavior and swimming paths of smolts are of high interest. As the smolts hardly can be detected in the VAKI fish counter at the entrance to the fishway, no information is available. To allow a first rough idea about possible paths based on the flows and currents in the reservoir, a numerical simulation of this area at the turbine inlet will be conducted by CNRS with OPENFOAM. First the model of the reservoir with the entrance of the turbine will be calibrated with the same inlet conditions recorded in the second field campaign. Then, guiding walls will be tested at different location to provide an optimal solution for guiding the fish to the fishway. SWECO and NTNU collected velocity and bathymetry data in the reservoir. For information about the devices please see chapter 3.1.

3.3.2 Methodology

The ADCP measurements were conducted in lines and loops in a pattern which ensured a detailed description of the bathymetry in the reservoir, comparable to chapter 3.1. As the reservoir is divided by a temporal floating guidance structure (Figure 111) that affects the water velocity, this was considered for the measurements.

Figure 111: Barrier guiding towards the fishway entrance approx. in the middle of the lake (red line)

On the shoreline at the southern and south-eastern part of the reservoir, a lot of water plants and shallow depths hindered the measurements (Figure 12). As mentioned in 3.1, the turbine was shut off, therefore also these velocity results can only be used for calibration and validation.

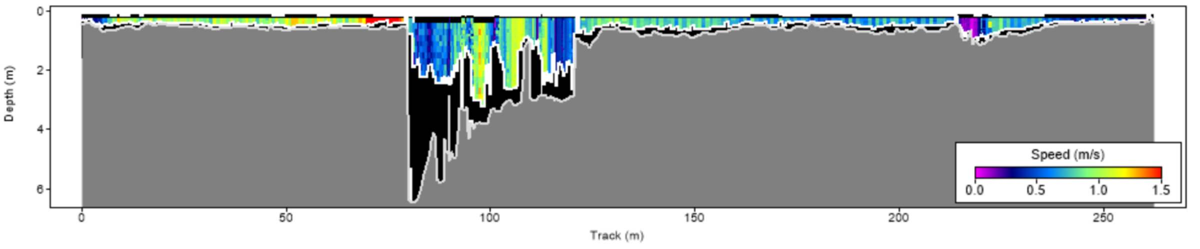


Figure 12 : Flow velocity in front of the turbine with very shallow areas in most parts (less than 1 m) and the deep areas of the intake

3.3.3 Results

3.4 Telemetry study of smolts

4. References

Finstad, A.G., Einum, S., Forseth, T., Ugedal, O., 2007. Shelter availability affects behaviour, size-dependent and mean growth of juvenile Atlantic salmon. Freshwater Biology 52, 1710–1718. https://doi.org/10.1111/j.1365-2427.2007.01799.x

Navaratnam, C.U., Aberle, J., Qin, J., Henry, P.-Y., 2018. An experimental investigation on the flow resistance over a porous gravel-bed surface and its non-porous counterpart. E3S Web of Conferences 40, 05073. https://doi.org/10.1051/e3sconf/20184005073

Nikora, V., McEwan, I., McLean, S., Coleman, S., Pokrajac, D., Walters, R., 2007a. Double-Averaging Concept for Rough-Bed Open-Channel and Overland Flows: Theoretical Background. Journal of Hydraulic Engineering 133, 873–883. https://doi.org/10.1061/(ASCE)0733-9429(2007)133:8(873)

Nikora, V., McLean, S., Coleman, S., Pokrajac, D., McEwan, I., Campbell, L., Aberle, J., Clunie, D., Koll, K., 2007b. Double-averaging concept for rough-bed open-channel and overland flows: Applications. JOURNAL OF HYDRAULIC ENGINEERING-ASCE 133, 884–895. https://doi.org/10.1061/(ASCE)0733-9429(2007)133:8(884)