# Description of a Test Case:

# Anundsjoe

Mo - Sweden

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# 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 km². 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, Anunssjön



**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 m³/s and in the area were the HPP is located it is 10,2 m³/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 m³ of volume available to regulate. A larger reservoir of 24.5 Mm³ 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 m³/s |
| Low-water flow | 2,21 m³/s |
| Instream flow | 0,25 m³/s |
| Function of the dam | Hydropower |
| Length of bypassed reach | 4 km |
| Maximum turbine discharge | 10 m³/s |
| Species concerned | Salmon, see trout, pike, perch, grayling, brown trout, crayfish |
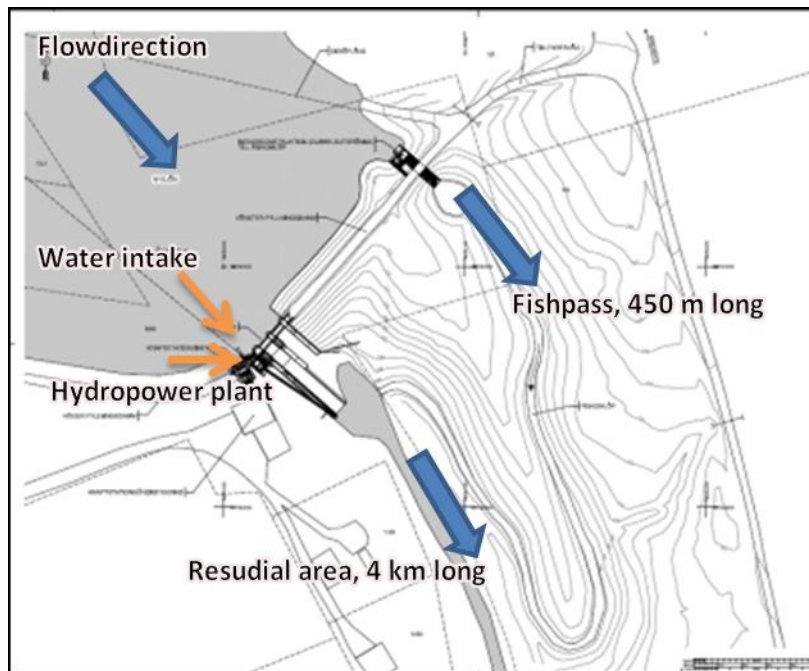
**Figure 3: Map of the water intake, the outlet is located 4 km downstream and not visible on this map**

Equipment:

1 Francis turbine (1954)

- Maximum turbine flow: 10 m³/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 m³/s in the fishway between the 15th of July and the 5th of October and 0.25 m³/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 m³/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 m³/s between the 15th of July and the 5th of October; 0.25 m³/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 arereleased 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, which is using the very well fitting structure and sediment distribution in the residual flow reach as well as the sufficient low water depth there.
- Bypassed reach: Some measurements will be undertaken to evaluate if the bypass reach offers sufficient sediment availability to be defined as habitat. Hence we can make sure if in case the migration activity would be reestablished this area could work as a potential habitat.
- 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 tubine 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 meet the bypassed reach of the river to assess passability and the attractionof 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 in 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 | Geometry | See 5 | 3.1 |

| | | | | | |
|---|---|---|---|---|---|
| | | flow (c) | | | |
| 7 | ADV | Residual Flow Reach (d) | Velocity | Potential use for further development of the DAM | 3.2 |
| 8 | SfM | Residual Flow Reach (d) | Geometry | Potential use for further development of the DAM | 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 modeled 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 modeling. 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 were 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 deep 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 certain 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

First results are available as a very basic geometry for a certain area of the residual flow reach (Figure 10). The work will continue in 2019.



**Figure 10: First results from the SfM measurements in the residual flow reach**

### 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 are 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 11) that affects the water velocity, this was considered for the measurements.

**Figure 11: Barrier guiding towards the fishway entrance approx. in the middle of the lake (red line)**

On the shoreline at the southern and southeastern 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.
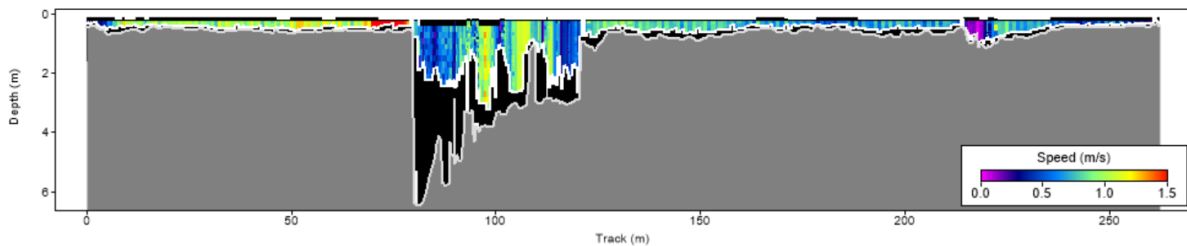


**Figure 12 : Flow velocity in front of the turbine with very shallow areas in most parts (less than 1 m) and the deep areas of the intake**

### 3.3.3  Results

# 4. References

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