Description of a Test Case:

Impact of an Archimedes screw hydropower plant on the local fish population

Shipping canal and ship lock complex of Ham (Kwaadmechelen) - Belgium

Picture: De Vlaamse Waterweg NV

Prepared by Ine Pauwels (INBO) and Jeffrey Tuthan (TUT)

Logo's ?

Table of Contents

Logo’s ?

List of Figures

List of Tables

1. Description of the Test-Case

1.1. Description of the water bodies related to the hydropower plant (HPP) and ship lock complex of Ham (Kwaadmechelen, Belgium).

The shipping lock complex and accompanying HPP studied here is located in the Albert Canal in the municipality of Ham (Kwaadmechelen, Belgium; Figure 1 and Figure 2). The Albert Canal is one of the most important shipping routes of Flanders as it connects the River Scheldt via the Port of Antwerp, with the River Meuse and the Juliana Canal. It is dug in the 1930's.

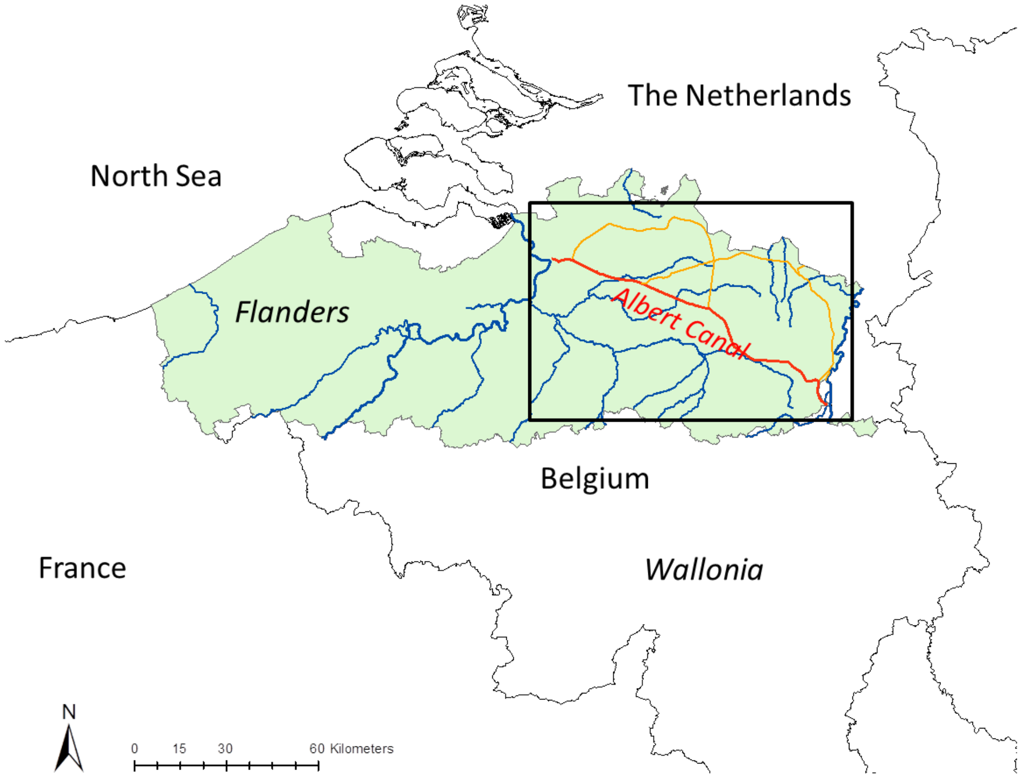
The canal bridges a 60 m height difference between the river Meuse(highest) and the river Scheldt (lowest; Figure 2). The 60 m head is covered by six ship lock complexes on the Albert canal, of which the ship lock complex of Ham (Kwaadmechelen) is one (Figure 1 and Figure 2). The ship lock complex of Ham is situated at 77,2 km of the river Meuse. The other ship lock complexes are located in Wijnegem (closest to Antwerp and 119,8 km of the river Meuse), Olen (95,9 km of the river Meuse), Hasselt (50,2 km of the river Meuse), Diepenbeek (45,7 km of the river Meuse) and Genk (41,5 km of the river Meuse; Figure 1 Figure 2). The ship lock complexes of Ham, Olen and Hasselt are by-passed by a small channel that runs through a hydropower station. The hydropower station contains the largest Archimedes screws in the world, which can not only pump, but also turbinate water (two operational modes for one and the same screw; see further details below). The construction of these by-pass channels and accompanying hydropower stations are as well planned for the three other ship lock complexes of Wijnegem, Diepenbeek and Genk.

The canal and its side-canals are almost entirely fed by water of the river Meuse, and are directly connected to it in the city of Liège (Wallonia, Belgium; Figure 1 Figure 2). The water in the Albert Canal is used for shipping, industry, drinking water supply, irrigation, and cooling of the nuclear power plant of Antwerp. The discharge of the Canal is regulated and depends on the discharge of the river Meuse. Back in 1995 The Netherlands and Belgium agreed upon the amount of water that can be directed to the Albert canal and its side-canals, versus the river Meuse and the Dutch canals, in function of the amount available in the River Meuse at periods of low water supply (Maas afvoerverdrag 17 januari 1995).

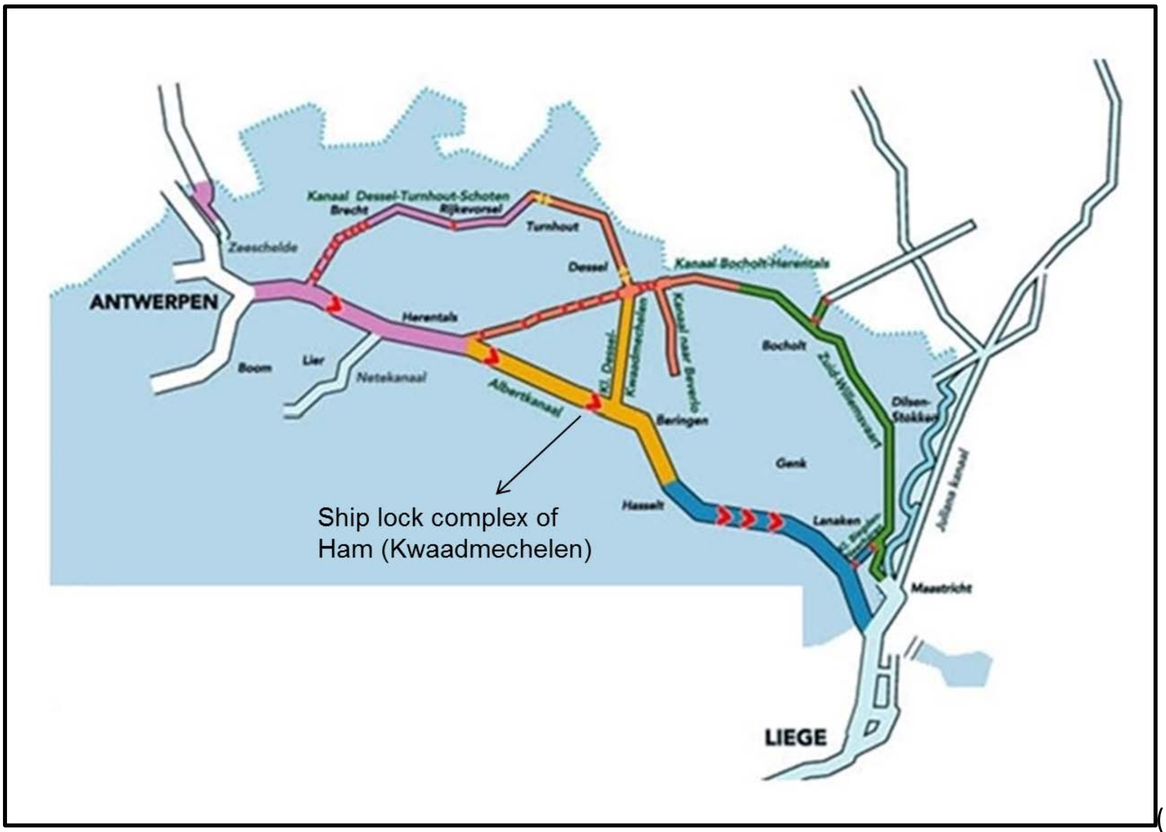
The river Meuse not only provides water for the Albert canal and its side-canals, but also for the Juliana canal going to the Netherlands (not indicated on the maps). The Meuse discharge is not constantly equally divided over all the canals and the Meuse itself. Depending on the water supply, more or less water is going to one or the other canal, or the river Meuse itself.

At the downstream side, the Albert canal meets the river Scheldt via the Port of Antwerp (Figure 1 and Figure 2). The canal is separated by the Port of Antwerp by a sluice that regulates the run off from the canal to the port (Figure 2). The river Scheldt itself is a tidal river with an open connection to the North Sea. At the location of the Port of Antwerp, the water is brackish. Unique to the Scheldt estuary is the freshwater tidal part between the city of Ghent and Antwerp. Although the Scheldt river is divided from the Albert canal through the Port of Antwerp and minimally one sluice, it is possible that fish migrate from the Scheldt river to the Albert canal. Therefore, it is possible that upstream migrating fish from the Scheldt river pass the Archimedes screws in pumping mode at specifically the most downstream ship lock complexes, and the one in Ham. Nevertheless, the probability of it is estimated to be low, and much lower than the probability that downstream migrating fish from the river Meuse pass the Archimedes screws in turbine mode.

In this respect, it is believed that the impact of the hydropower plant of Ham (Kwaadmechelen; and generally also the others in Olen and Hasselt) mainly affects the fish populations in the canal itself and its side-canals, as well as downstream migrating diadromous fish, going from the canal itself and the Meuse river to sea.



(a)



(b)

Figure 1: a) Related water bodies and location of the ship lock complex and hydropower plant of Ham (Kwaadmechelen) in Flanders (Belgium; thick blue lines: the river Scheldt (left) and the river Meuse (right), thin blue lines: other large rivers in Flanders, orange lines: the shipping canals connected to the Albert Canal and red line: the Albert Canal. b) Location of the ship lock complex and hydropower plant of Ham in the Albert Canal and indication of the 5 other ship lock complexes (red arrows; source of figure b: Logistiek Platform Limburg (POM)).

1.1.1. Ecological and biological status

Albert canal

(to be continued)

River Meuse

(to be continued)

1.1.2. Hydrology of the Albert canal and Meuse river

Meuse river

The river Meuse is a typical rain fed river that stretches from France through Belgium ending up in an embanked estuary in The Netherlands with a total fall of 409m. This 935km long river has a discharge area of 36.000km² and its mean discharge is 230m³, peaking up to tenfold after long and heavy rainfall. Besides the initial French part of the river and a stretch of 45km along the border between Belgium and The Netherlands, the river is highly regulated for navigation and therefor multiple sluices and calibration efforts were made. In total 45 barriers are present now of which 17 are equipped with hydropower turbines (http://www.meuse-maas.be/, retrieved 1st of December 2014). The total installed hydropower capacity downstream the city of Namur is around 75MW. The river also provides water to a number of canals that expanse the navigation network. This derived water is also used for irrigation, industrial processes and the production of drinking water. The Albert canal is one of these.

Albert canal

The hydrology of the Albert canal is entirely artificial and controlled by humans for shipping and other purposes. As indicated above, the canal is split in eight canal sections, divided by six ship lock complexes (with present or planned pumping/hydropower station) and one ship lock complex without pumping/hydropower station; Figure 2 Figure 3). The water level in each canal section depends on the water supply from the Meuse river, besides rainfall and the shipping/ship lock activity, the withdrawal of water for irrigation, drinking or cooling water, and the use of water for electricity production by the Archimedes screws in the pumping/hydropower station(s). Although the hydrology is highly artificial and water even sometimes flows from the Albert canal to the Meuse river, there mainly exists a net flow to the Port of Antwerp (Figure 1b).

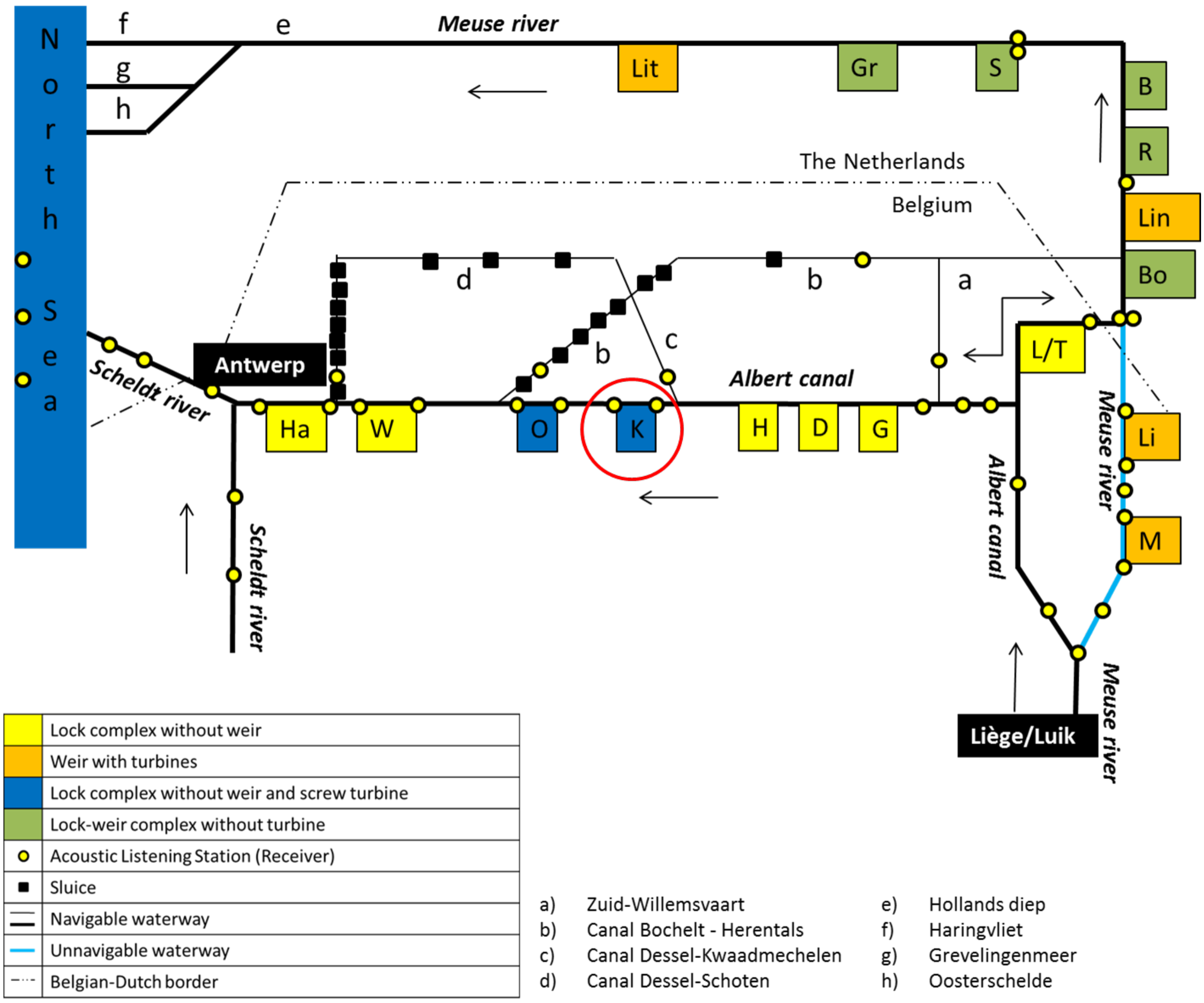


Figure 2: Schematic overview of Figure 2b, showing the Albert canal, the study site (red circle; ship lock complex with hydropower plant of Kwaadmechelen), its surrounding waterways and the location of ship lock complexes, weirs, sluices and hydropower stations. Additionally, the locations of the acoustic listening stations (ALSs or receivers) are indicated that are used to evaluate eel and salmon migration from the Meuse river to the North Sea. Arrows indicate flow direction (source: adapted from Raf Baeyens).

Figure 3: Lock complex in the Albert Canal (Ham) on the left and a weir complex with hydropower plant (Linne) on the right. (source: http://nts.flaris.be/ and http://www.microhydropower.net/)

Seen the highly artificial nature of the water flow and discharges in the canal sections, it is out of the question to deduce general discharges during migration periods for silver eel and salmon smolts. Figure 4 shows the discharges for the period of April-October 2014 at two locations in the Albert canal, and two locations in the Meuse river, close to their split.

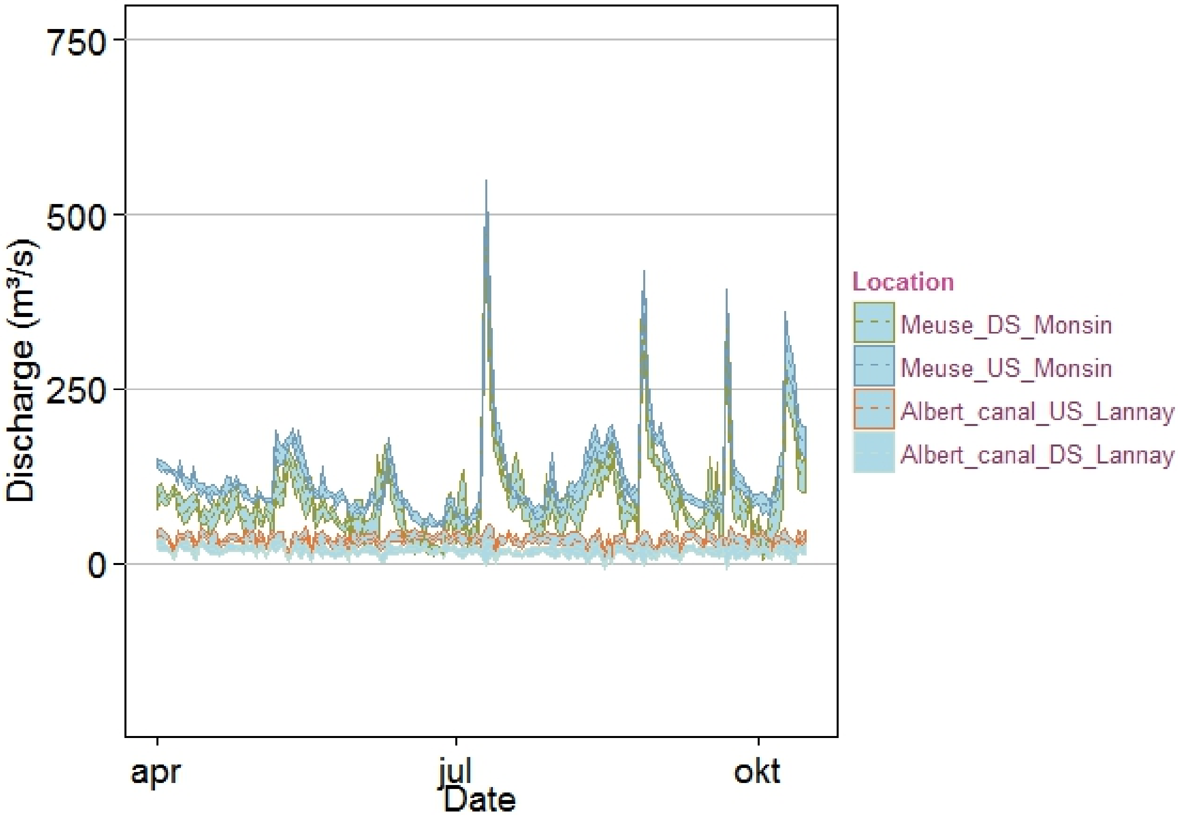


Figure 4: Mean discharge and 95% confidence interval, in the Meuse river upstream of the sluice complex in Monsin (Mo in Figure 2 ; Meuse_US_Monsin), downstream of Monsin (Meuse_DS_Monsin), and in the Albert Canal downstream of Monsin and upstream of the sluice complex in Lannay (La in Figure 2; Albert_canal_US_Lannay) and downstream of Lannay (Albert_canal_DS_Lannay) from April till October 2014 (source of the data: Service Publique de Wallonie, Direction générale opérationnelle de la Mobilité et des Voies hydrauliques, Département des Etudes et de l'Appui à la Gestion, Direction de la Gestion hydrologique intégrée, Namur).

1.1.3. Main pressures

The main pressures and measures described below (Table 1 Table 2), focus on the Albert canal itself, specifically on the hydropower plant and ship locks and their effect on fish of the canal itself and of the neighboring, connected water bodies. Hence, it does not include the pressures and measures on the neighboring water bodies an sich.

Table 1: Main pressures on the fish of the Albert canal and surrounding, upstream water bodies

Fish damage	It is investigated in this case study how harmfull the hydropower plant (and pumping station) with this type of Archimedes screws is to fish passing the station, and what the impact is on the total fish population. Apart from the (potential) damage caused by the hydropower plant, parallel ongoing research hypothesizes a potential harm of the ship lock complex as well in terms of fish damage.
Migration delay	A study of the migration behaviour of eel and salmon in the canal indicates serious downstream migration delays caused by the artificial hydrology of the canal, as well as the ship locks. Eventually and potentially preventing fish to successfully survive and reproduce.
Pollution (non-significant)	The water in the Albert canal is not of good quality, however, the water quality is a rather insignificant pressure on the local or passing fish, compared to the (potential, is being investigated here) detrimental effect of the hydropower plant, the artificial/controlled and highly unnatural hydrology, and the potential detrimental effects of the ship lock complexes on fish by delaying their migration as well as harming them during passage.
Morphology (high)	The Albert canal is an artificial water body. It is constructed for economic purposes and the question is if measures exist that can : 1) prevent the water body from harmfull effects on neighbouring nature (fish coming from semi-natural water bodies that are connected to it), and 2) be used (spatially) as “extra” local habitats for plants, fish, macroinvertebrates, or as a safe-enough corridor between the river Scheldt and the river Meuse.

Table 2: Potential measures to prevent fish damage by hydropower

Fish migration measures	Bar screens or other fish guidance structures or methods (e.g. strobe light fish deterrence) that prevent fish from entering either the hydropower plant, either the by-pass channel leading to the hydropower plant.
Technical measures	Adaptations to the Archimedes screws to increase the fish-friendliness of the screw. E.g. closed screw that can

	serve as turbine, preventing fish from being squeezed between the blades and the housing. Other potentials are to be investigated, and are investigated through the experiments with the barotrauma detection sensors (BDS sensors) in this case study.
Operational measures	As long as fish damage by the screws is substantial, prevent high hydropower activity during downstream migration season of fish (specifically Silver eel and salmon/trout smolts). If there is a relation between the turbinated discharge and fish damage, then one or the other operational scenario (e.g. lower discharge for longer period, or higher discharge over shorter period) could be more fish friendly and should be taken into account. The research on the relation between discharge and fish damage is one of the major goals of this case study and is ongoing at the time writing.

The technical and operational measures might have an effect on the hydropower production. Fish deterrence structures or methods at the entrance of the by-pass channel are not expect to have an effect on the hydropower production.

1.2. Presentation of the HPP

1.2.1. Rationale

As indicated in section 1.1, the Albert canal is almost entirely fed by the river Meuse, and in periods of low water supply, The Netherlands and Belgium decide how much (how less) water can flow to the Albert Canal.

The prevalence of dry periods is predicted by scientists to occur more frequently in future. Hence, this poses a threat to economy, as low water levels restrict the shipping capacity by restricting ship lock complex activity and lowering the vessel draft in the canal. To lift a ship in a ship lock from a lower to a higher canal section, a large amount of water is needed from the higher canal section, and is transported to the lower canal section. Consequently, to prevent economic loss following from a diminished shipping activity in dry periods, six pumping stations are to be built on the Albert canal. These pumping stations will enable to pump water from the lower to the higher canal section at each of the six ship lock complexes. The stations exist of three open Archimedes screws with a head of 10 m (see section 1.2.3 for further details), and in Ham as well one closed Archimedes screw that can only serve as pump and is supposed to be fish-friendly. To regain part of the energy cost of the pumping activity, the Archimedes screws are developed so that they can turbinate besides pumping, gaining electricity. So, the pumping stations serve as hydropower stations in periods of a high enough water supply (discharge).

To date (June 2018), three pumping/hydropower stations have been built and are in use. This case study investigates the impact of the pumping/hydropower station in Ham (Kwaadmechelen), which was the first of these three and the first hydropower plant in Flanders (Belgium). The hydropower station in Ham is the only of three that has one closed Archimedes screw. This screw has his housing attached to the blades, preventing fish from being squeezed between the blades and the housing. This screw, which is supposed to be fish-friendly, can only pump water and cannot serve as turbine. The other two pumping/hydropower station were built in the cities of Olen and Hasselt (Figure 1). None of the pumping/hydropower stations in the Albert canal have Kaplan turbines, they only have Archimedes screws.

1.2.2. Location

The hydropower station, which also serves as pumping station, is located in a by-pass channel (380 x 6 meters) bridging the ship lock complex of Ham (Kwaadmechelen, Belgium; Figure 5). The location of the ship lock complex is indicated in the previous section and Figure 1 Figure 2.

Fish can freely swim from the Albert canal to the by-pass channel. Only during the time of this case study, the hydropower plant is disconnected for fish from the Albert canal at its' outlet by a large fish cage (Figure 5). The cage is used to catch studied fish that passed through the turbines, either naturally or by forced experiments, to evaluate fish mortality and injury caused by the screws of the pumping/hydropower station.

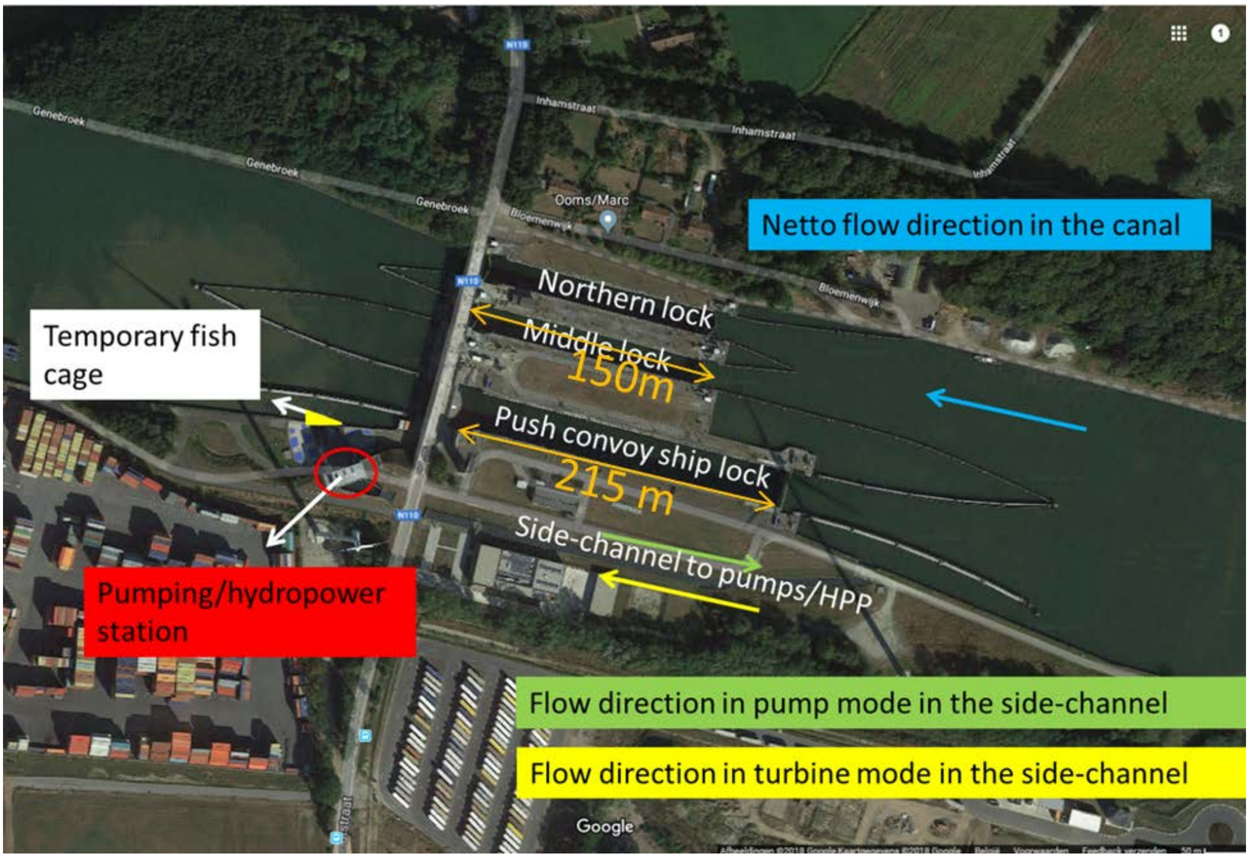


Figure 5: Aerial view on the ship lock complex of Ham (Kwaadmechelen, Belgium) and the location of the pumping/hydropower station.

1.2.3. Main characteristics

Albert canal

As indicated earlier hydropower is generated in the Albert canal by means of Archimedes screws that work efficient in situations with a low water head (height of dam/weir) and a high flow. Besides generating electricity, these facilities can also pump up water in times of water scarcity. These screws have a length of 22 m, a diameter of 4,3 m, an inclination angle of 38° and a weight of 85 tons. Each screw facility has a combined maximum output power of 1,2 MW. Installation and maintenance costs of a screw turbine are lower compared with propeller types and they are believed to be more fish friendly (Figure 6, Figure 7, Figure 8, and Table 3). The highly efficient Archimedean screw is able to generate electricity 24 hours a day, whilst maintaining the natural flow of a river (Elbatran et al., 2015). At the time writing three of six sluice complexes are provided with an Archimedes screw facility. The sluice complex and its screw facility in Ham is used to look after the possible impact on eel migration.

Figure 6: The pictures on the left apply on the Albert canal and visualize the pumping/hydropower station of Ham (top left), and one of the screws during its construction phase (bottom left). In contrast, the pictures on the right visualize the hydropower station of Lixhe on the Meuse river (top right) and its type of propeller (a propeller from a Straflo turbine; bottom right; sources: INBO, http://edfluminus.edf.com/ & http://www.dvo.be/)

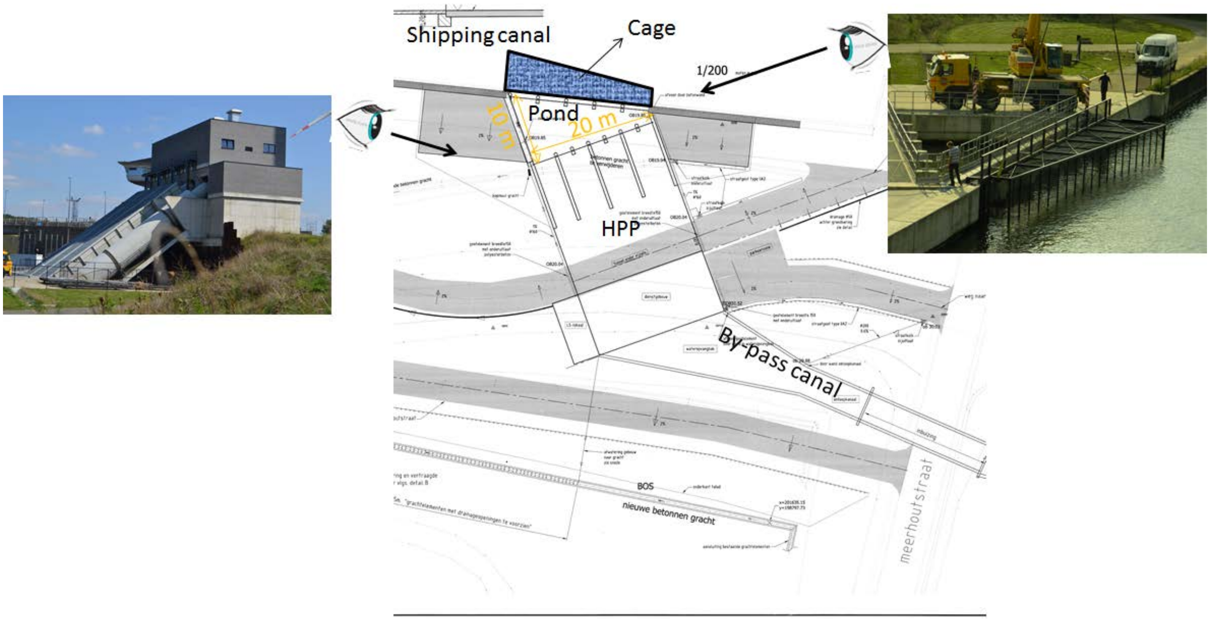


Figure 7: Map of the hydropower plant (HPP, picture on the left) and its location along the shipping canal, indicating the fish cage (picture on the right).

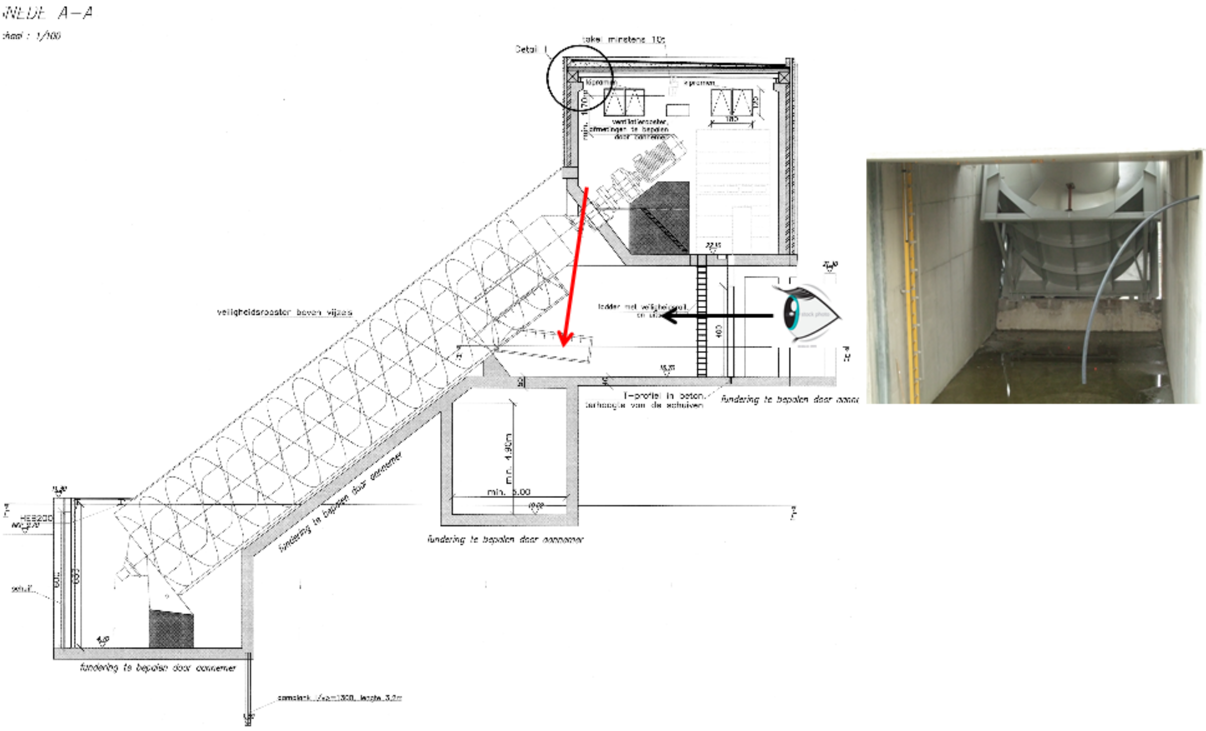


Figure 8: Side view on the hydropower plant and one of its open Archimedes screws. Red arrow indicating the injection tube through which fish is injected into the turbine for experimental tests on their impact on fish. Black arrow indicates the point of view of the picture on the right, of a closed turbine valve.

Table 3: Main characteristics of the HPP of Ham (Kwaadmechelen)

Watercourse	Albert canal
Situation :	Village of Ham (part of the municipality of Kwaadmechelen)(address: Meerhoutstraat 44A, Ham, Belgium)
Operator	De Vlaamse Waterweg (former NV De Scheepvaart)
Capacity of HPP	1,2 MW at maximal turbine discharge
Capacity of one Archimedes screw/turbine	8000 W
Maximum turbine discharge:	15 m^3/s with three screws (5 m^3/s per screw)
Minimum turbine discharge	3 m^3/s (3 m^3/s per screw)
Head of one screw	10 m
Length screw/blades	22 m
Length screw/blades plus central axis	28 m
Diameter of one Archimedes screw	4,3 m
Weight of one Archimedes screw	85 ton
Inclination of the screws	38°
Length of bypassed reach/bypass channel leading to the HPP:	~350 m
Width of bypassed reach/bypass channel leading to the HPP:	~47 m
Species concerned :	European eel, Atlantic salmon/Trout, Bream, Roach and all other fish species present in the canal
Species studied (impact HPP)	European eel, Trout, Bream, Roach
Species studied (downstream migration by acoustic telemetry)	European eel (yellow and silver eels), Atlantic salmon (salmon smolts)

Principles of the Archimedes screw as pump/turbine

When the screw turns, water is taken up or down in portions in between the blades. The portions of water go up when the screw is pumping and are going down when turbining. The water flows out either at the top and the bottom of the screw, respectively. Pumping requires an opposite turning direction of the screw.

When water is pumped, the screw is driven by an engine, and the rotation speed of the blades corresponds to a certain amount of water to be taken upwards (the pumped discharge).

When water is turbinated, the water pushes the screw to turn. The amount of water that flows into the screw is controlled by the controlled opening of a valve at the top of the screw. To prevent the screws from ‘running’ (acceleration of the rotation speed), the screw rotation has to be slowed down. This is done by the engine that serves as a generator, producing the energy.

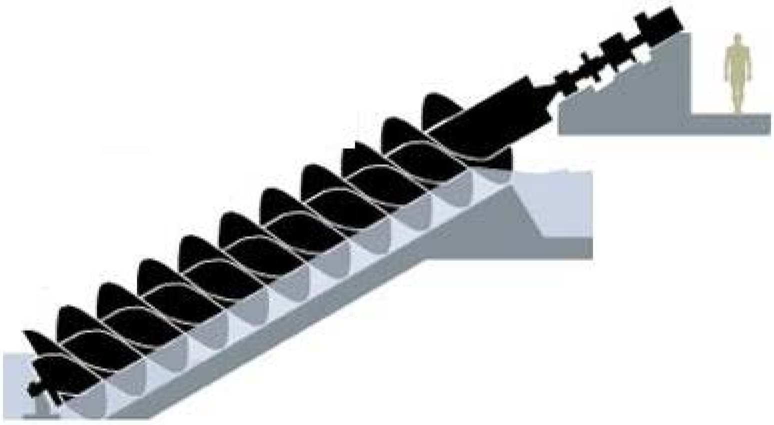


Figure 9: Schematic side view on an Archimedes pump/turbine screw.

Meuse river

This short paragraph on the hydropower on the Meuse river is just to contrast the Archimedes screw type hydropower stations with Straflo turbine propeller type, and Kaplan type hydropower stations, as the ones located on the Meuse river.

Three of four turbines downstream of the city of Liège in the River Meuse are Kaplan type turbines (two horizontal bulb types and one vertical one). The fourth one is of the Straflo type, a Kaplan-based turbine-concept where the flow also passes in horizontal direction (Figure 6). They all have blades with a diameter ranging between 3,55 and 5,6 m and their rotation speed ranges from 65 to 120 rpm. The power output ranges from 11,5 to 20 MW. All these propeller turbines are ideal in riverine situations that are characterized by a low water head (height of dam/weir) and a high discharge, but efficiency drops quickly when flows are less than provided (Okot, 2013).

2. Objectives on this Test Case

The objectives of this test case (what are we planning?)

The aim of this test case is to apply BDS sensors on the largest Archimedes screws in the world serving as turbines. On the one hand, these BDS sensors are further developed and improved based on the application. On the other hand, the BDS sensors are used to define the impact of the Archimedes screws on downstream migrating fish (eel, bream, roach and trout). The research results are further interpreted with tests on life fish in another project, commissioned by the hydropower operator, "De Vlaamse Waterweg NV", which aims to investigate:

1. The impact of the hydropower station (3 open Archimedes screws as turbines) on fish that pass the screws, by evaluation of mortality and injury of fish that passed the screws in turbination mode (and pumping mode, beyond the scope of this test case but tested in a parallel study).
2. The impact of the hydropower station on fish by evaluation of several pressure-related parameters by BDS sensor tests that pass the screws.
3. The impact of the hydropower plant on the local fish population and downstream migrating eel and salmon, by evaluation of the (relative) number of acoustically tracked eel and salmon that pass the sluice complex in the downstream direction by the by-pass channel and hydropower station (instead of taking the 'route' of the ship locks in the canal).

Here, further info is given on these three research objectives and the results of the tests performed will as well be mentioned in the Fithydro project in a later stage. However, the focus of the research in this test case as part of Fithydro is on the application and development of the BDS sensors.

Why are we planning this on this Test case?

The pumping/hydropower station of Ham (Kwaadmechelen, Belgium) has (the largest) Archimedes screws (in the world) that serve as pump and turbine. This makes this site specifically interesting to investigate. Moreover, studies on the harmfulness of these types of screws are rare. Additionally, the pumping/hydropower station has a closed screw (used for pumping only), which is designed to prevent fish from being squeezed in between the blades of the screw and its housing. In a parallel study, the expected fish friendliness of this design is evaluated. The study is not part of the test case for FIThydro, because it focuses on pumping instead of hydropower. However, might be interesting for hydropower operators as well, specifically if they design pumps that can as well generate power in times of high water supply.

What are we expecting?

It is expected that the Archimedes screws are more fish-friendly than other turbine types, such as Kaplan turbines or propellers of the Safro-turbine type. However, it is as well expected that the impact on fish is still > 0%. Consequently, research on the precise reasons of the impact is needed, to further improve the design of the screws to screws with the lowest fish-damage possible. Furthermore, it is believed that the results of the fish tracking will further indicate the potential impact on the (local) fish population, and might help in finding successful measures to minimalize this impact.

Relevance in FIThydro?

This research gives insight into the fish-friendliness of this type of turbine, which is relevant information for hydropower operators who need to install new hydropower plants.

The study partly gives insight into the mechanisms of fish harm in these screws, which is relevant info for Archimedes screw turbine developers/producers.

3. Presentation and results of activities in FIThydro

3.1. Study of survival through Archimedes screws

To investigate the impact of the hydropower station on fish that pass the screws:

(1) forced fish pass experiments are performed in which four species (in three repetitive groups of each 100 individuals (so, a total of 300 individuals per species) are inserted at the top of one of the three screws, to pass it.

(2) BDS

The species investigated are European eel, Roach, Bream and Trout. The experiments are performed for all three possible turbine-operation modes, namely turbination at a discharge of 3, 4 and 5 m^3/s, respectively. Hence, in total 900 individuals of each species are forced into the screws to pass it, and evaluated on mortality, injury and potential delayed mortality. Second, (delayed) mortality and injury on individual fish that naturally passed the turbines is evaluated. Those fish are not forced into the turbines, but naturally passed it on their way down in the canal/by-pass channel. Those individuals can be of any species that is present in the canal. This measurement is performed on all fish that passed the turbines during one 24h cycle of hydropower generation with three screws on 5 m^3/s. The natural-pass experiments are repeated 10 times (ten 24h cycles, so a total of 240h of hydropower generation), and are spread over one year, so that both periods of more and less fish migration activity are monitored.

As life fish experiments are part of an other project, the methodology and the results are not included yet at this stage of the report. It should be included later after the “De Vlaamse Waterweg NV” project is finished.

The evaluation of the impact of the hydropower station by pressure related parameters is performed by the passage of BDS sensors developed at the Tallinn University of Technology (TUT). For further details on the methodology see Figure 10 A.

3.1.1. Methodology

The objective of the fieldwork with the barotrauma sensors was to record 30 data sets per operational mode (3, 4 and 5 m^3/s). The sensors were deployed in the identical manner as the live fish in the forced fish-pass experiments (Figure 10 C), and are recaptured downstream with a hand-held fish net (Figure 10 D). Balloon tags were attached to each sensor and were set to inflate 1 minute after deployment in the Archimedes screw tail water. Metadata for each deployment were recorded including the time of deployment, passage duration, noticeable scratches, dents or if the sensor was crushed. The BDS collect the time series at 100 Hz including the total pressure, linear acceleration, rotation rate, magnetic field as well as the absolute orientation of the sensors during their passage through the screws.

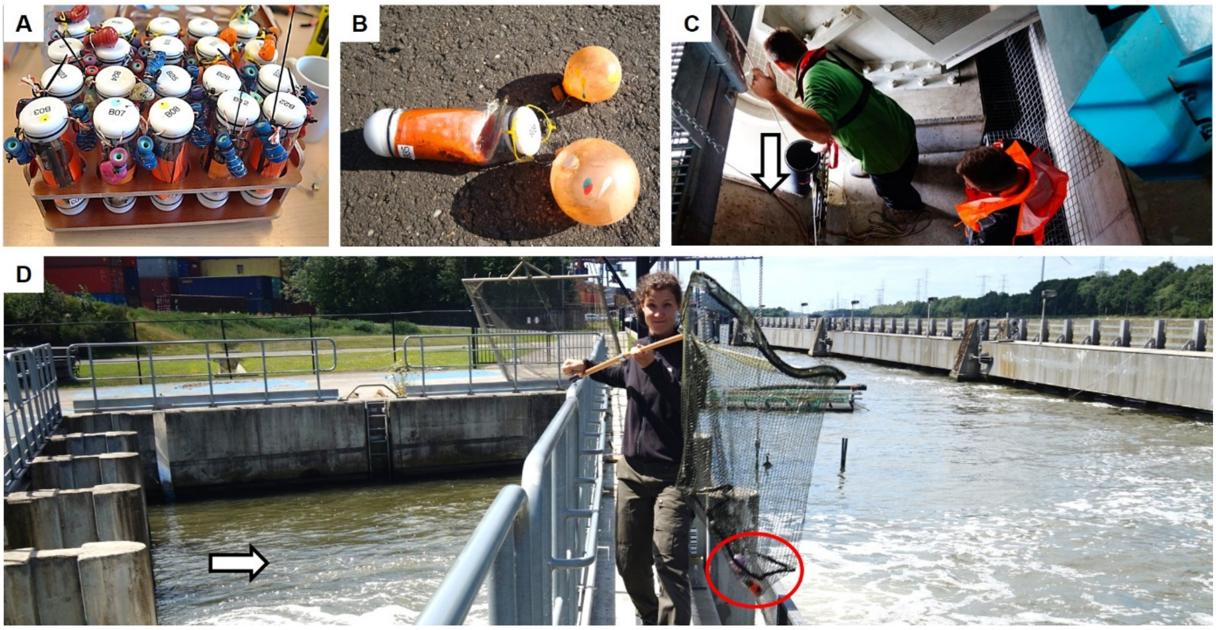


Figure 10: BDS deployment at Ham from 20-22.06.2018. A) Sensors outfitted with balloon tags ready for deployment. B) Sensor destroyed by crush event. C) Deployment of BDS into the Archimedes screw. D) Recovery downstream via balloon tags in a hand net.

3.1.2. Barotrauma sensors

The BDS time series data from this test case (I) to determine statistical properties of the passage conditions at the Archimedes screw under three different operational conditions operations, (II) to advance in understanding of the effect of screw operation on fish passage, (III) to evaluate fish passage through the screw (as an operational measure for downstream fish passage), and (IV) to create recommendations for fish friendly passage at large Archimedes screws.

3.1.3. Results

The preliminary results of the sensor data are provided in the form of summary statistics in the following tables. Data post-processing and comparison with biological data and literature on Archimedes screws is currently ongoing. A peer-reviewed journal publication from the Ham BDS and live fish data set is under preparation and will be submitted in 2019.

The results of the BDS are a statistical analysis of the time series data for each of the sensor modes (e.g. pressure, acceleration, etc.). The following parameters are calculated for each individual measurement: min, max, mean, median, standard deviation, Q1, Q3 and the number of blade strikes. These statistical parameters are then aggregated according to flow scenario (full or half-load) and injection location (low, mid, high) into ensembles representing the distributions of each parameter. In this way, each hydropower plant can be compared using a set of reproducible, statistically-derived parameters. For example, if the number of blade strikes differs between flow scenarios but only significantly between two different injection heights, it is possible to “drill down” into the data by comparing the ensemble statistics to gain insight into the physical environment during passage and suggest corrective measures such as installing fish avoidance targeted at a particular location. The preliminary results from the BDS investigation at Ham are provided in the following tables and figures.

Table 4: Ensemble statistics of BDS deployment at Ham (n = 30), Q = 3 m³/s.

	PL (hPa)	PC (hPa)	PR (hPa)	Euler X (deg)	Euler Y (deg)	Euler Z (deg)	Acc X (m/s²)	Acc Y (m/s²)	Acc Z (m/s²)	Rot X (deg/s)	Rot Y (deg/s)	Rot Z (deg/s)
Min	983	989	985	0	-86	-181	-30	-33	-29	-959	-1717	-1009
Max	1229	1229	1227	362	87	182	31	30	30	1044	1723	979
Mean	1069	1068	1067	186	-1	79	0	-6	-2	15	-4	-3
Median	1047	1045	1045	191	-2	103	0	-8	-3	9	-1	-1
STD	58	58	58	104	26	78	4	5	5	137	185	138
Q1	1025	1024	1024	95	-16	60	-2	-9	-5	-38	-51	-53
Q3	1100	1098	1099	276	13	125	2	-4	0	67	48	50

Table 5: Ensemble statistics of BDS deployment at Ham (n = 28), Q = 4 m³/s.

	PL (hPa)	PC (hPa)	PR (hPa)	Euler X (deg)	Euler Y (deg)	Euler Z (deg)	Acc X (m/s²)	Acc Y (m/s²)	Acc Z (m/s²)	Rot X (deg/s)	Rot Y (deg/s)	Rot Z (deg/s)
Min	972	979	978	0	-86	-181	-32	-34	-34	-1099	-1786	-1017
Max	1227	1228	1226	360	86	182	33	27	32	1108	1748	984
Mean	1069	1069	1069	181	0	74	0	-6	-3	18	-1	-1
Median	1053	1053	1052	183	0	101	0	-8	-3	13	1	2
STD	56	56	56	104	30	89	5	5	5	169	220	162
Q1	1023	1024	1023	94	-19	55	-3	-9	-6	-52	-64	-68
Q3	1100	1100	1099	268	19	130	3	-4	0	88	67	69

Table 6: Ensemble statistics of BDS deployment at Ham (n = 33), Q = 5 m³/s.

	PL (hPa)	PC (hPa)	PR (hPa)	Euler X (deg)	Euler Y (deg)	Euler Z (deg)	Acc X (m/s²)	Acc Y (m/s²)	Acc Z (m/s²)	Rot X (deg/s)	Rot Y (deg/s)	Rot Z (deg/s)
Min	980	983	978	0	-87	-181	-31	-34	-34	-1012	-1750	-1010
Max	1191	1193	1192	361	85	182	32	28	31	1028	1681	1076
Mean	1052	1053	1052	185	-1	73	0	-7	-3	22	0	2
Median	1033	1034	1033	188	-2	92	0	-8	-3	18	3	3
STD	47	48	48	106	31	82	5	5	5	170	231	173

Q1	1016	1016	1015	97	-22	50	-3	-9	-6	-58	-70	-75
Q3	1081	1082	1081	274	19	126	3	-4	0	104	76	80

3.2. Fish tracking by acoustic telemetry

The impact of the hydropower plant on the local fish population and downstream migrating eel and salmon is investigated by acoustic telemetry on downstream migrating European eel and salmon smolts in the Albert canal. The tagged eels and salmons are released upstream of the sluice complex of Ham and their downstream migration route (passing the sluice complex through the ship locks, or passing it through the by-pass channel and the hydropower station) is evaluated by acoustic listening stations (ALSs or receivers) in the entire shipping canal, and the ship locks and by-pass channel of Ham). This evaluation should give a general estimation of the proportion of fish that take the route of the hydropower station, and is thus potentially harmed by the Archimedes screws. The results of this part of the study may also give further insight into potentially successful mitigation measures.

As fish tracking by acoustic telemetry is part of an other project, the methodology and the results are not included yet at this stage of the report. It should be included later after the “De Vlaamse Waterweg NV” project is finished.

4. References

Elbatran, A. H., Yaakob, O. B., Ahmed, Y. M. & Shabara, H. M. (2015). Operation, performance and economic analysis of low head micro-hydropower turbines for rural and remote areas: A review. *Renewable and Sustainable Energy Reviews, 43*, 40-50. http://dx.doi.org/10.1016/j.rser.2014.11.045

Okot, D. K. (2013). Review of small hydropower technology. *Renewable and Sustainable Energy Reviews, 26*, 515-520.