TEST CASE:

GUMA AND VADOCONDES (DUERO RIVER, SPAIN)

SAVASA

SALTO DE VADOCONDES S.A.

Table of content

List of figures

List of tables

1. Description of the test case

The Guma-Vadocondes test case is located in the Duero River (Spain) (Figure 1). It belongs to the Iberian region defined by the FITHydro project. This test case affects 48 km of river length and includes two hydropower plants (HPPs), Guma HPP and Vadocondes HPP, both operated by Salto de Vadocondes S.A. (SAVASA).

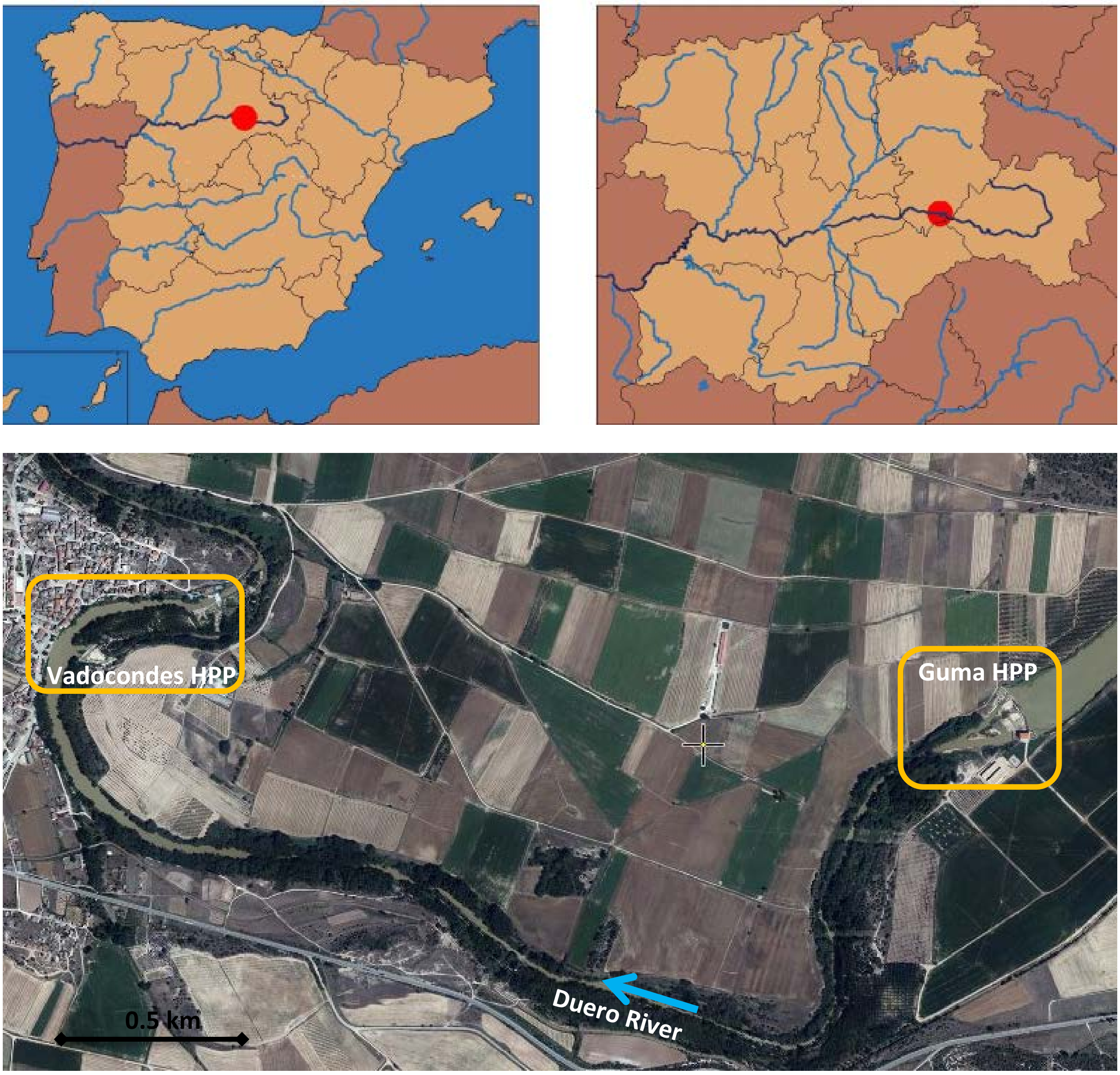


Figure 1: Plan view of the zone. Blue arrow indicates flow direction. Source: www.sigpac.es

1.1. Description of the water bodies related to the HPPs

The hydropower plants of Guma and Vadocondes are included in the Spanish water body code as: ES020365 (WFD code: ES020MSPF000000365) (Figure 2). This water body includes:

• 28 km of river length just upstream of Guma HPP.

• Guma HPP dam.

•The river section between Guma and Vadocondes HPPs, with 3.5 km length.

• Vadocondes HPP dam.

• The river reach downstream of Vadocondes, with 16 km.

[For more details, see annex 1 of WP4 “Additional information regarding status of implementation of EU WFD and other relevant directives”].

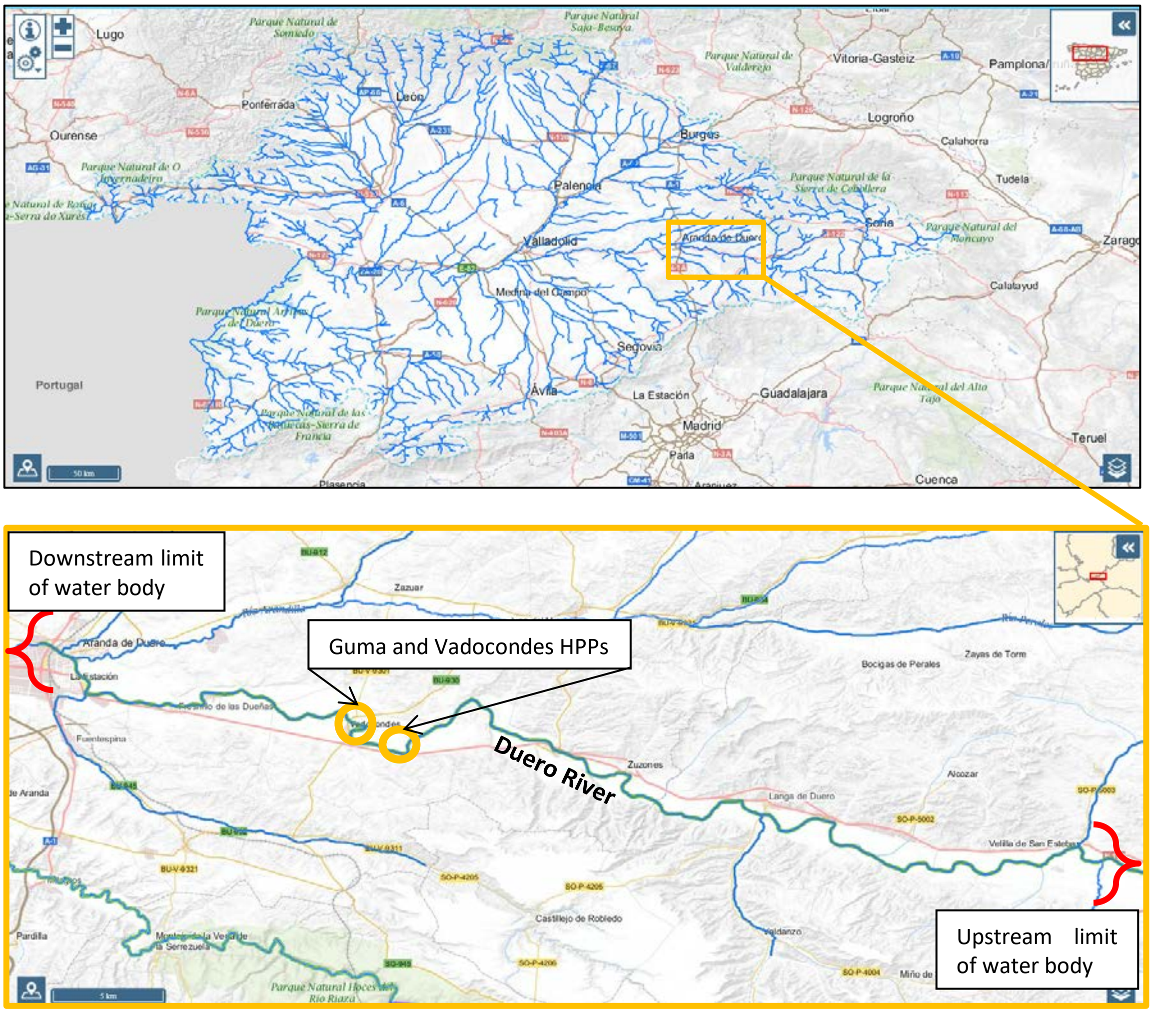


Figure 2: Water body of the Guma-Vadocondes test case . (Source: http://www.mirame.chduero.es/)

1.1.1. Hydrology of the Duero River at Guma-Vadocondes test case

In the study reach, the Duero River is regulated for irrigation, power generation and water supply. Its hydrology is characterized by low flows in summer (most of the flow is regulated for irrigation purposes through channels) and medium-high flows during winter and early spring, associated with rainy season and snow melting episodes.

At this location, the river drains a watershed of 7398 km^2 with a mean annual discharge of about 17.6 m^3/s (data from the gauging station 2522 at Vadocondes, www.saihduero.es) (Figure 3). This river reach belongs to the *Epipotamon zone* (Illies and Botoseanu, 1963) with an average altitude of around 810 m above sea level and corresponds to C6 category, i.e. a silt-clay bed stream of moderate sinuosity with a slope of 0.001-0.02 m/m (Rosgen and Silvey, 1996). The most abundant native fish species are potamodromous cyprinids, namely Iberian barbel (*Luciobarbus bocagei*) and northern straight-mouth nase (*Pseudochondrostoma duriense*).

The upstream migration period for native cyprinids is from April to June, with a mean monthly flow between 15 and 30 m^3/s approximately.

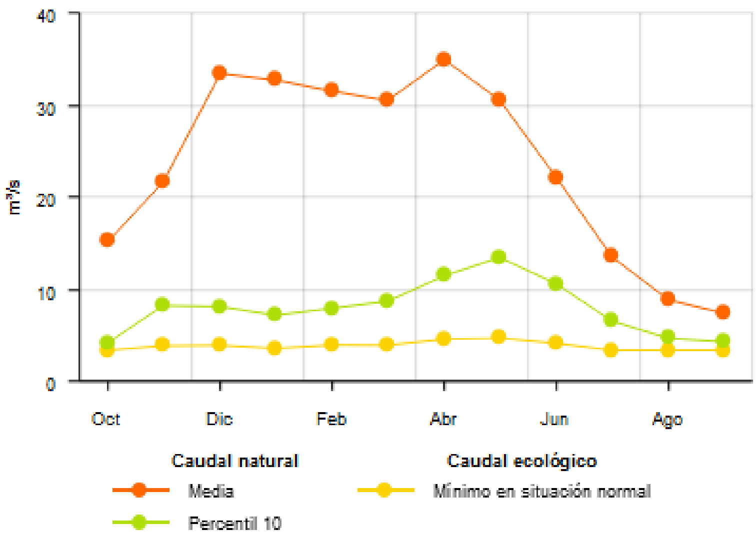


Figure 3: Mean monthly flow in the Guma-Vadocondes test case. In orange: natural mean flow. In green: 10th percentile. In yellow: environmental flow in normal situation (Source: http://www.mirame.chduero.es)

1.1.2. Main pressures

Several pressures (Table 1) and potential improving measures (Table 2) have been identified in the water body of the Guma-Vadocondes test case

Table 1:Main pressures on the Duero river in the location of the Guma-Vadocondes test case.

ASPECT	LEVEL	PRESSURE
Continuity	SIGNIFICANT	Several dams upstream and downstream (different purposes) which impose difficulties to fish migration
Hydrology	MODERATE	Flow highly regulated for irrigation and hydropower uses. A lot of artificial lentic habitats due to the presence of dams
Pollution	MINIMAL	All physico-chemical indexes show adequate values in the last years
Agriculture	HIGH	Most of the agricultural uses in the area, with significant use of agrotoxics
Morphology	MODERATE	Several dams blocking sediment transport (there are no laws to force its improving).
Fish population	HIGH	Native species in decline and several alien species rising or appearing

Table 2: Measures to be implemented at the Duero River basin

ASPECT	MEASURE	DESCRIPTION
Hydrology	Environmental flow	Marked by law (2015-2021 Hydrological Plan) based on hydrological studies
Continuity	Fish migration measures	Ecohydraulic assessment of fishways associated with hydropower plants and some gauging stations, with the obligation of corrective measures in case of deficient performance.
Morphology	Sediment control	There are no planned measures for its implementation.
Pollution	Pollution control	New water treatment plants.

1.2. Presentation of the HPPs

1.2.1. Location of the HPPs

Both HPPs are located in Burgos province (Central-North of Spain), one between Guma and Vadocondes village (Guma HPP) and the other one in Vadocondes village (Vadocondes HPP). They are consecutive, i.e., Guma dam is close to the end of Vadocondes reservoir, and the distance between both is about 3.5 km (Figure 1 and Figure 4). They are operated coordinately (flow and time period) by the same company, SAVASA (Table 3). In Table 4 and Table 5, the characteristics of the HPP are shown.

Operator

Table 3: Operator information

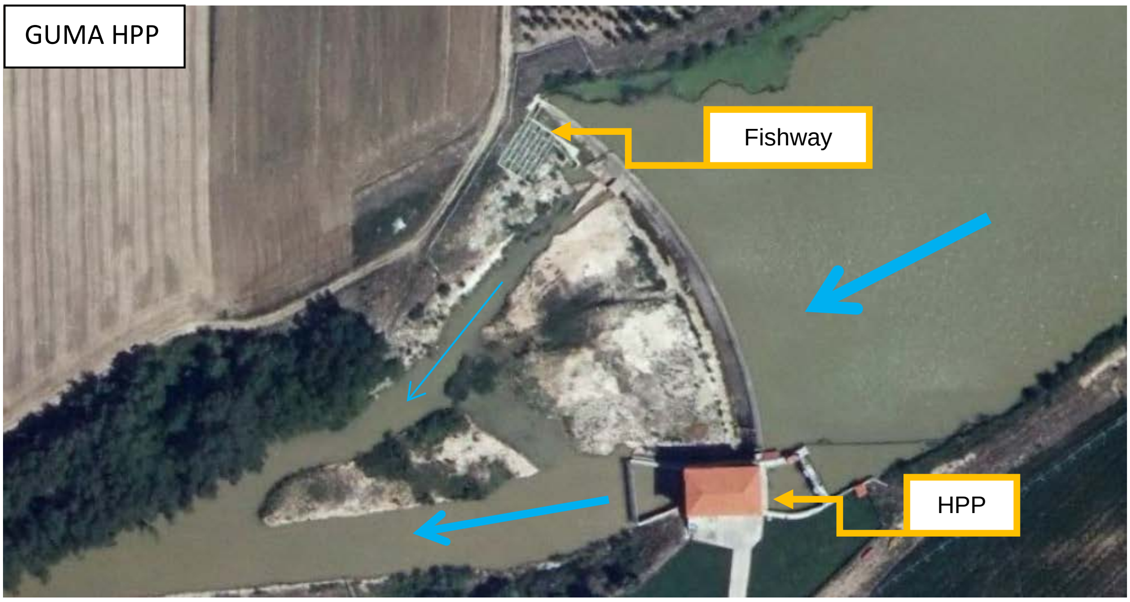
Company	Salto de Vadocondes S.A. (SAVASA)
VAT number	ES-A09045105
Head manager	Juan Carlos Romeral de la Puente
Adress	C/ Burgo de Osma 1, 1º G, 09400. Aranda de Duero (Burgos, Spain)

HPPs features

Table 4: Main characteristics of the hydropower plants

	GUMA	VADOCONDES
Watercourse	Duero	
Location	Guma village	Vadocondes village
Mean annual discharge	17.6 m^3/s	
Minimum annual discharge	6.0 m^3/s	

Maximum annual discharge	48.9 m^3/s	
Purpose	Power generation	
HPP type	Run-of-river	
Length of headrace channel	0 (HPP over the dam)	
Length of tailrace channel	~ 150 m	~160 m
Maximum turbine discharge	35 m^3/s	28 m^3/s
Dam height	8.85 m	3.75 m
Power	2250 kW	1000 kW
Turbines	2 Kaplan (10 and 25 m^3/s)	2 Kaplan (14 m^3/s)
Target fish species	Iberian barbel (*Luciobarbus bocagei*) and Northern straight-mouth nase (*Pseudochondrostoma duriense*)	



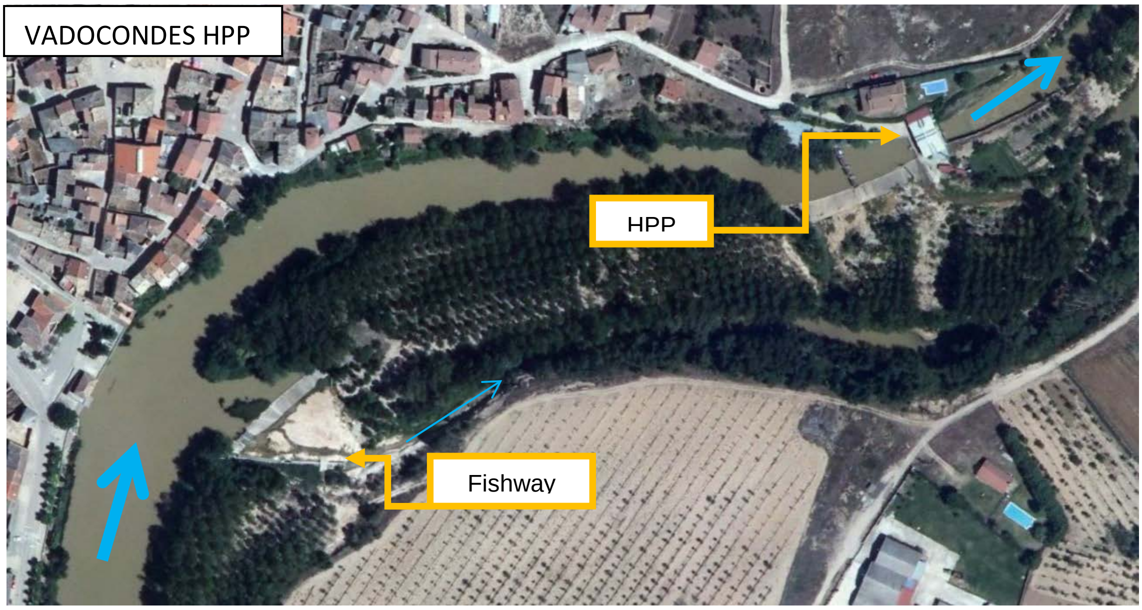


Figure 4: Plan view of Guma (up) and Vadocondes (down). Source: www.sigpac.es

Equipment:

Table 5: Turbine description

Guma: 2 Kaplan (10 and 25 m^3/s) Vadocondes: 2 Kaplan (14 m^3/s)	Kaplan 10 m3/s: Ø 1.54 m; 144 rpm Kaplan 14 m3/s: Ø 1.45 m; 250 rpm Kaplan 25 m3/s: Ø 1.08 m ; 250 rpm

1.2.2. Eflow

Due to the hydropower plant type (over the dam and run-of-river type), there is no legal requirement for environmental flow (Eflow). Nonetheless, fishways must always have enough flow for operating and, therefore, the downstream by-pass of the river always maintains a minimum flow of 0.25-0.50 m^3/s.

1.2.3. Downstream migration devices

Both HPPs have trash racks with 90 mm clearance between bars. However, currently there are no other additional special fish protection measures for downstream migration.

1.2.4. Upstream migration devices

The main facilities for upstream migration in both HPPs are the pool type fishways (Figures 4 and 5 and Table 6). Both have supplementary attraction flow into the fishway entrance and have a gate for controlling the flow entering the fishway.

Table 6: Geometrical characteristics and design operating values of the fishways

	VADOCONDES	GUMA
Fishway type	Vertical slot	Submerged Notch with Bottom Orifice
Trial height	3.75 m	8.85 m
Volumetric Power Dissipation	122 ± 7 W/m^3	121± 10 W/m^3
Slope	6.52%	8.77%
Pool dimension (length x width)	2.10 m x 1.60 m	2.60 m x 1.60 m
Width of the notches/slots	0.20 m	0.30 m
Bottom orifice size	-	0.20 m x 0.20 m
Flow discharge	0.25 ± 0.01 m^3/s	0.27 ± 0.01 m^3/s
Water depth	0.92 m	1.32 m
Water drop between pools	0.15 m	0.15 m
Water velocity at the notches/slots	1.48 ± 0.08 m/s	1.29 ± 0.07 m/s
Water velocity at the orifices	-	1.94 ± 0.09 m/s

Figure 5: Test case fishways (at closed gate). Left: vertical slot fishway at Vadocondes HPP dam. Right: Submerged notch with bottom orifice fishway at Guma HPP dam

2. Objectives for this test case

The main goals of this test case are:

- To increase the knowledge concerning fish upstream and downstream migration, as well as spawning areas.
- To improve fishway attraction.
- To maximize the relationship between flow attraction and hydropower production.
- To study fish passage and survival through turbines.
- To transmit the sustainability in hydropower production plants to River, Energy and Environmental Authorities and NGOs, following protection and environmental criteria.

Why are we planning this on this Test case?

The test case site is near the working place of GEA-ecohidráulica research group. This hydropower plant type (run-of-river) is quite common on the main Spanish river basins. ITAGRA-GEA directly designed both fishways and did some fish ascent trials, having information about fish population at this site, as well as ascent performance of both fishways. Also, all turbines of the two hydropower plants are manufactured by VOITH, a member of the FIThydro consortium, thus allowing to serve as another possible data source or trial location.

Last but not least, relationships with the Operator and his willingness to collaborate are really good and he is very concerned with ecology and riverine problems.

What are we expecting?

We expect to improve the knowledge of this hydropower plant type and their impacts on fish migration, and the location of ascent paths. In addition, we would like to try different flow configurations through turbines and fishway-attraction flow, seeking to maximize the relationship between fish upstream movement and hydropower production. Also, fish passage through turbines and their survival using different turbine configurations will be an important result about HPP management and impact.

Relevance in FIThydro?

This test case serves as an example of a common situation in Mediterranean environments, but quite different from other European cases, improving the overview of hydropower and their effect on European fisheries.

One of the aims of this test case is to maximize the relationship between fish movement and hydropower production and, therefore, in a clear alignment with FIThydro objectives.

3. Presentation and results of activities in FIThydro

3.1. Population and habitat analysis

An assessment in terms of fish species and population structure of the river section affected by both HPPs will be done to provide reliable information of the fish population status. The study will focus mainly on cyprinid fishes, which are the dominant group in the study reach, and also in endemic species.

3.1.1. Methodology

The information will be collected from literature as well as on site by:

- The review of previous studies and data in historic, national and regional databases.
- Fish samples in the vicinity and in the two fishways. Fish samples have been done from May 2018 to date with electrofishing equipment (Hans-Grassl ELT60II backpack equipment) in the 60 m river length downstream of both fishways (Figure 6) with a sampling frequency of twice a month. In addition, fish sampling with nets have been carried out in the fishways, closing the upstream gate and taking out all the fish inside. All fish were put in holding tanks with oxygen supply until they were identified and measured (species, fork length, weight, sex and others). To manipulate fish, eugenol was used as anaesthetic agent (variable dose depending on the species and water temperature). After fish recovery, they were released in their capture zones. Those species declared by the Spanish law as alien species were killed following the law and ethical guidelines about research with animals.

Figure 6: Electrofishing sample downstream of Guma fishway

3.1.2. Results

A brief summary of the main preliminary results on population analysis are presented in Tables 7, 8 and 9.

Table 7: Fish species of the study area (based on literature and previous studies review as well as during the fish samples).

Family	Scientific name	Status
Aguillidae	*Anguilla anguilla*[2]	Extinct native
Centrarchidae	*Lepomis gibbosus*	Invasive exotic
Centrarchidae	*Micropterus salmoides*	Invasive exotic
Cyprinidae	*Achondrostoma arcasii*[1]	Native*
Cyprinidae	*Alburnus alburnus*[1]	Invasive exotic
Cyprinidae	*Carassius auratus*[1]	Exotic
Cyprinidae	*Cyprinus carpio*	Invasive exotic
Cyprinidae	*Gobio lozanoi*[1]	Exotic
Cyprinidae	*Luciobarbus bocagei*[1,2]	Native
Cyprinidae	*Phoxinus bigerri*	Exotic
Cyprinidae	*Pseudochondrostoma duriense*[1,2]	Native*
Cyprinidae	*Squalius carolitertii*[1]	Native
Cyprinidae	*Tinca tinca*[1]	Exotic
Percidae	*Sander lucioperca*[1]	Invasive exotic
Poeciliidae	*Gambusia holbrooki*	Invasive exotic
Salmonidae	*Salmo trutta*[1,2]	Native

*Iberian endemism, cited at the Annex II of Habitat Directive 92/43/EEC (IUCN Vulnerable).

[1]Presence confirmed by the field samples.

[2]Abundant in 1846 (Madoz, 1846).

Table 8: Preliminary results of the number of individuals captured during the samples from May to September 2018, by species and sampling point

Species	GUMA		VADOCONDES		TOTAL
	Fishway	River	Fishway	River	
Achondrostoma arcasii	1	1	2	2	6
Alburnus alburnus	4762	1040	1753	863	8418
Carassius auratus	-	1	-	-	1
Gobio lozanoi	144	146	58	1158	1506
Luciobarbus bocagei	589	48	160	251	1079
Pseudochondrostoma duriense	4	-	2	4	10
Salmo trutta	5	-	1	11	17
Squalius carolitertii	-	-	-	8	8
Tinca tinca	1	1	-	-	2
TOTAL	5506	1237	1976	2297	11047

Table 9: Preliminary results of the length distribution of fish by species and sampling point: median (first and third quartiles) in mm

Fork length (mm)	GUMA		VADOCONDES	
	Fishway	River	Fishway	River
Achondrostoma arcasii	94	102	88 (84 – 92)	71 (52 – 90)
Alburnus alburnus	92 (88 – 98)	77 (58 – 85)	88 (57 – 116)	75 (66 – 120)
Carassius auratus	-	77	-	-
Gobio lozanoi	78 (36 – 110)	70 (42 – 80)	72 (50 – 90)	64 (39 – 108)
Luciobarbus bocagei	130 (113 – 173)	92 (42 – 116)	117 (98 – 140)	113 (75 – 155)
Pseudochondrostoma duriense	106 (94 – 111)	-	67 (66 – 68)	58 (55 – 61)
Salmo trutta	180 (175 – 206)	-	95	70 (65 – 75)
Squalius carolitertii	-	-	-	132 (120 – 142)
Tinca tinca	-	119	-	-

Despite crayfish were not defined as target species at the beginning of the samples, due to their continuous presence, they were taken into account but noting them only qualitatively. *Pacifastacus leniusculus* and *Procambarus clarkii* (both declared as alien species) were found in Guma fishway during all samples. *Procambarus clarkii* had a peak of abundance at the end of July and *Pacifastacus leniusculus* at the end of August.

Apart from these preliminary results other analysis will be done with the data from this experiment. Frequency, length and condition factor distribution analysis will be carried out between sample points and along the time, as indices of peak migration movements, fishway use and general state of fish population.

3.1.3. Conclusion

Luciobarbus bocagei and *Gobio lozanoi* are the most abundant non-invasive species in the study reach, being the remainder species in decline. Throughout all sampling months both species have been present. *L. bocagei* was more frequently found in Guma fishway whereas *G. lozanoi* was more frequently captured in the downstream vicinity of Vadocondes fishway. Length distribution for *L. bocagei* has shown a wide range (between 30 and 425 mm of fork length) although large individuals were not found (it has been possible to visually verify their existence in close sections). Previous studies focused on this species have shown a decrease in the migration movements of the larger individuals (Bravo-Córdoba et al 2017). The historical references include *Anguilla anguilla* as a species with a remarkable presence in this area (Madoz, 1846). However, nowadays it has completely disappeared in this river reach. The brown trout (*Salmo trout*) also had a greater distribution in the past (Madoz, 1846), with occasional appearances at present. *Pseudochondrostoma duriense* deserves a special mention since it was abundant a few years ago but has been suffering an important decline (own data and personal communications of river policy, fishermen and inhabitants) in these last years.

Current fish assemblage is mainly characterized by the presence of exotic and alien species, probably due to the dominance of lentic sections as a consequence of the presence of the HPP dams. In this regard, *Alburnus alburnus* has shown a great abundance. Its continuous presence suggests that the fishways and their river vicinity could be an acceptable habitat and/or movement path for this species. In the Spanish law, this species is declared as alien species (R.D. 630/2013), with a potential risk for native cyprinids due to the competition for the habitat and the food, egg predation, and hybridization risk (SIBIC, 2014).

Regarding crayfish, both species (*P. leniusculus* and *P. clarkii*) are declared as alien species by the Spanish law (R.D. 630/2013) with a high negative impact on native crayfish (*Austropotamobius pallipes*), amphibians and fish species. This threat is mainly due to their feeding habits (depredation risk on eggs and larvae), digging behavior (changes in sediment balance) and disease transmission (the *afanomicosis* is a lethal disease for native crayfish) (GEIB, 2011). Its temporal abundance distribution is an indicative of the use of the fishway as a migration route by these crayfish species and may be related to pre-reproductive movements (spawning period for *P. leniusculus* in autumn; Salvador, 2015). This fact makes fishways as hotspots for another alien species, the American mink (*Neovison vison)* which depredates on the crayfish (numerous excrements have been found close to the fishways).

3.2. Analysis of the conceptual solutions and facilities for fish migration

In order to assess the current solutions and facilities for upstream fish migrations, an evaluation of the upstream fish passage is carried out based on fish monitoring data for different seasons and different hydraulic conditions.

3.2.1. Methodology

A processing of previous collected data on fish ascent in the two fishways (submerged notch with bottom orifice fishway at Guma HPP and vertical slot fishway at Vadocondes HPP) related to hydrodynamics features, was done. In addition, the characterization of the swimming performance of the main native cyprinids species in the river reach was carried out in order to define their swimming abilities and limitations. Both experiments were done by telemetry. The behavior of fish was modelled through survival analysis methods. These statistical tools are really suitable to analyse this kind of data due to their particularities: events along the time, individuals without events, repeated events along the time, competing risk events and events dependent on time-varying covariates (for more details see full publications below).

3.2.2. Results and conclusions

Two scientific papers have been published in indexed journals (JCR): Ruiz-Legazpi, J., Sanz-Ronda, F. J., Bravo-Córdoba, F. J., Fuentes-Pérez, J. F., & Castro-Santos, T. (2018). Influence of environmental and biometric factors on the swimming capacity of the Iberian barbel (*Luciobarbus bocagei* Steindachner, 1864), an endemic potamodromous cyprinid of the Iberian Peninsula. *Limnetica*, *37*(2), 251-265. DOI: 10.23818/limn.37.21. [In Spanish].

Abstract: This paper analyses the volitional swimming capacity of the Iberian barbel (*Luciobarbus bocagei* Steindachner, 1864) in an open flume during its migration period, in relation to environmental and biometric factors. Water temperature, flow velocity and fish length were the most important factors which affected the swimming speed of barbels and their fatigue time. Within the range of values studied, the Iberian barbel was able to maintain sprint swim speeds (> 15 BL/s) for 3-10 s, and 17-117 s in prolonged swim mode (7-15 BL/s). The results can be used as a tool for the management of barbel populations, mainly in the design of fishways.

Bravo-Córdoba, F. J., Sanz-Ronda, F. J., Ruiz-Legazpi, J., Valbuena-Castro, J., & Makrakis, S. (2018). Vertical slot versus submerged notch with bottom orifice: Looking for the best technical fishway type for Mediterranean barbels. *Ecological Engineering, 122*, 120-125. DOI: 10.1016/j.ecoleng.2018.07.019.

Abstract: When engineers and ecologists face a fishway design, many issues need to be considered, the type of fishway being the first and foremost. It is an especially complex issue in areas with species whose migratory and swimming behavior are as yet poorly known as Mediterranean barbels. The present study focuses on the fish passage of two of the most common types of technical fishways: Vertical Slot (VS), and Submerged Notch with Bottom Orifice (SNBO). Both types were studied and compared in terms of ascent ability (as the success rate and transit time) and motivation (as the proportion of attempts and attempt rate). Ascent ability in VS and SNBO were similar: more than 90% of fish did it successfully and the median transit time to ascend 2.25 m in height was lower than 23 minutes. Fish length had an effect on ascent time, being faster the biggest ones. Motivation was greater for VS, although not seeming to have a relevant influence in passage performance. These results provide new data of fishways performance and may help ecologists and engineers with their decision making, mainly in Mediterranean areas with similar habitats and species.

3.3. Assessment and improvement of fish mortality in the turbines

This task will focus on the technical issues of turbines and possible adaptive solutions of operation modes (more fish-friendly operation modes). Spanish test case will serve as a field test for other FIThydro partners (VOITH, TUT, TUM), being SAVASA and ITAGRA-GEA collaborators on field work and data analysis. Voith is working on CFD/BioPA calculations and TUT will do the BDS (Barotrauma Detection System) tests. Furthermore, Voith will use the same models and focus on different operating modes to evaluate the possibility of adapting the operation for certain time period. Finally, the results from TUT and VOITH will be provided to TUM for fish turbine mortality assessment.

3.3.1. Methodology

Currently, we are collaborating and following the instructions of the leader partners in this subtask. Turbine data from the two HPPs (a total of four VOITH turbines in the range of 10 to 25 m^3/s) and the HPP facilities could be used for field trials (e.g. barotrauma and lateral line probe experiments and/or changes in operation modes). Leader partners think that Guma larger turbine is the most interesting for tests.

Experiments with the barotrauma detection sensors will be conducted during full load. The objective will be to collect 30 time series data sets of the pressure, linear acceleration, rotation rate and orientation during turbine passage. An injection system consisting of vertical tubes which can be flushed using water flow will be constructed. The system will allow the BDS to be injected at locations corresponding to the bottom blade tip, the bulb centre and the blade top. If the weather allows it, additional load scenarios may also be feasible. Based on previous field experiments, one day for testing the deployment, injection system and sensory recovery will be required. Each load scenario will also require one full day of field work. The data will be provided to FITHydro project partners as comma delimited text files for assessment in the BioPA model by VOITH.

In May 2018 one pre-test was done in Vadocondes HPP together with TUT staff, in order to know the behaviour of barotrauma sensors (BDS) into these facilities and for training in the recovery of these sensors in the river. Two different sensor types and some fake probes (Figure 7) were used. The sensors were thrown just upstream the turbines while several persons distributed in the outlet channel were waiting with capture devices at the riverbanks and on a boat to recover them.

3.3.2. Results

At present, we are waiting for adequate flow conditions in the Duero River and combining agendas of involved partners (scheduled for completion in December 2019).

Regarding the pre-test carried out in Vadocondes HPP, all devices (sensors and fake probes) were recovered in the outlet channel between 3 and 5 minutes after the release. An example of sensor output data capture can be seen in figure 7.

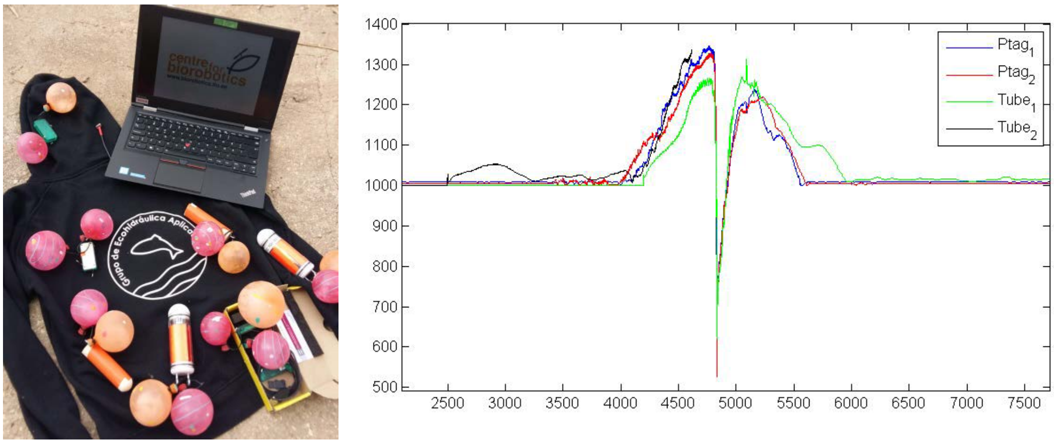


Figure 7: Left: Barotrauma sensors and fake probes with floating devices after the recovery used in the pre-test in Vadocondes HPP. Right: an example of output data of pressure (Y axis) along the time (X axis) registered by the sensors

3.4. Spawning areas and hydro-morphology to attain self-sustainable populations

Spawning areas are affected by the HPP infrastructures (reservoir area) and the operational management (sediment dynamics). On this subtask, these effects want to be briefly assessed.

3.4.1. Methodology

The study stretch was considered from Vadocondes HPP (downstream limit) up to a dam located in Guma village, upstream of Guma HPP (upstream limit) (Figure 9). The Guma village dam does not have a fishway, and it blocks the upstream fish migration.

First, visual recognitions of the study stretch were carried out, looking for the potential spawning areas during pre-spawning period (riffles with shallow water and gravel bed, during April and May 2018) for the main species of interest (native cyprinids – benthic spawners above gravel substrates).

After that, the potential spawning areas were mapped and visited several days looking for signs of spawning (fish groups, fights between fish, sign of nests, etc.).

Finally, larvae sampling was performed to confirm the spawning. These samples were done in August and September 2018 with a cone net with a mesh of 0.5 mm, doing *zig-zag* transects by foot in the river, from downstream to upstream in fast movements.

Figure 8: Potential area for spawning and cone net for trapping fish larvae

3.4.2. Results

Table 9 shows the potential spawning areas within the study reach. The percentage of areas with enough conditions to serve as spawning sites was quite small, not exceeding 2% in all the study stretch (Table 10).

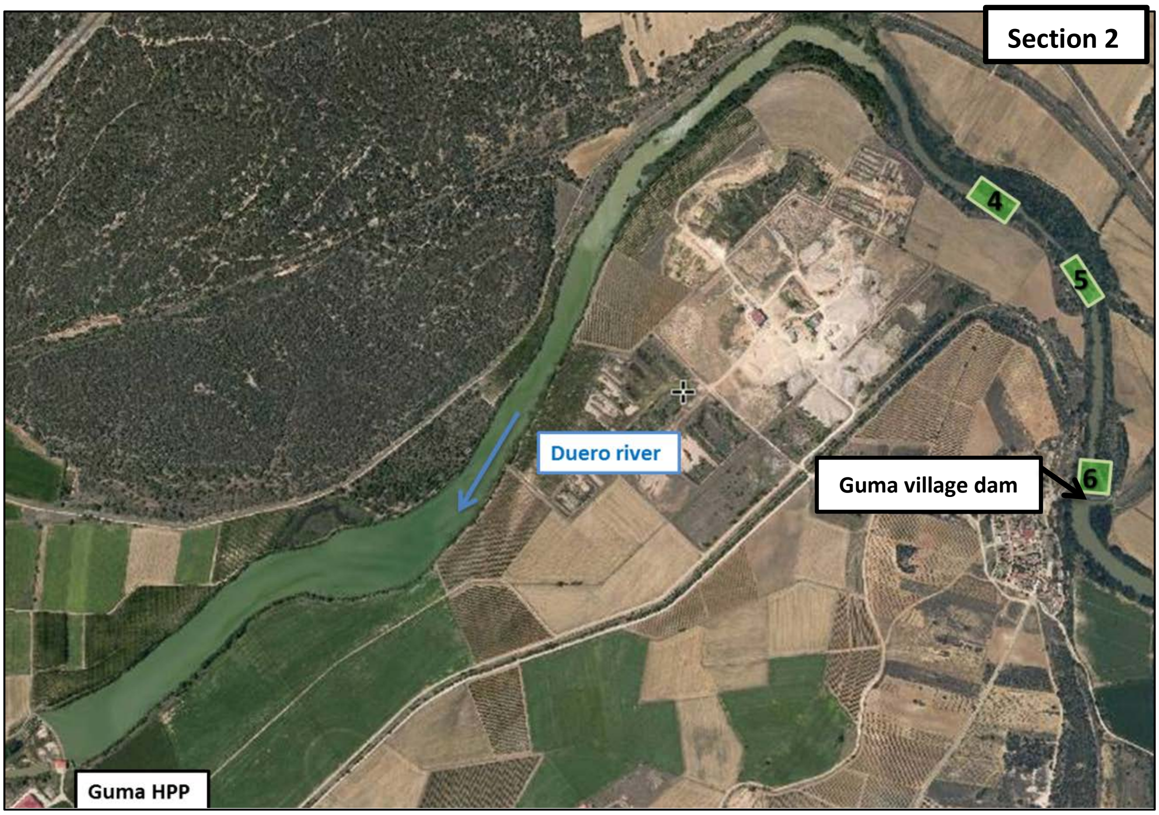


Figure 9: Potential spawning areas in the study reach. The downstream limit is Vadocondes HPP (section 1) and the upstream limit is the dam in Guma Village (section 2). Potential spawning areas are numerated from downstream to upstream (see table 10)

Table 10: Potential spawning areas between Vadocondes HPP and Guma village dam (see figure 9).

	Section 1	Section 2
Spawning subareas	1 = 1200 m^2 2 = 700 m^2 3 = 350 m^2	4 = 900 m^2 5 = 750 m^2 6 = 1900 m^2
Subtotal spawning areas	2250 m^2	3550 m^2
Subtotal river area	129000 m^2	283000 m^2
% spawning vs river area	1.74%	1.25%

Due to the unusual high flow conditions during the spawning period of 2018, it was not possible a visual confirmation. Water level and turbidity were too high from April to July 2018, being impossible to see any evidence of spawning. In the previous spring (2017), it was possible to visually confirm the presence of some *L. bocagei* in the subarea number 2 with spawning behavior.

Larvae sampling confirmed the presence of fish of the year (0^+) of different species but not in all the defined spawning areas (table 11).

Table 11: Spawning areas (figure 9) and confirmation of fish larvae presence by species (X) for benthic spawners

Spawning areas	1	2	3	4	5	6
Achondrostoma arcasii						
Alburnus alburnus	x	x	x		x	x

Gobio lozanoi	x			x
Luciobarbus bocagei	x			x
Pseudochondrostoma duriense		x	x	x
Salmo trutta				
Squalius carolitertii				

3.4.3. Conclusion

The optimal potential spawning areas for native cyprinids was very small, clearly influenced by the flood storage area of Guma and Vadocondes HPP reservoirs. Also, the bed of the six potential spawning areas showed some problems of silting. Despite this, the presence of fish of the year of several species was confirmed both by larvae sampling and by periodical samples in the fishways (see table 9; minimum fork length of several species probably indicates fish of 0^+ age). In September 2018, with low flow conditions, it was possible to make an electrofishing sampling point just downstream of Guma village dam (that corresponds to the potential spawning area number 6. Figure 9). Although the fish were not fork length measured, the presence of fish of the year for *Luciobarbus bocagei, Pseudochondrostoma duriense, Gobio lozanoi* and *Alburnus alburnus* was confirmed, finding some big schools in the vicinity of the dam. Due to this impassable dam, the presence of these schools cannot be only attributed to a good recruitment of this point but also as a bottleneck point for fish dispersion.

Regarding the used methods for larvae sampling, for some species this is probably not the most effective way to detect their presence. With adequate flow conditions and having identified the potential areas, light larvae traps could be a good tool to confirm it, especially for post-hatching stages (see an example on figure 10).

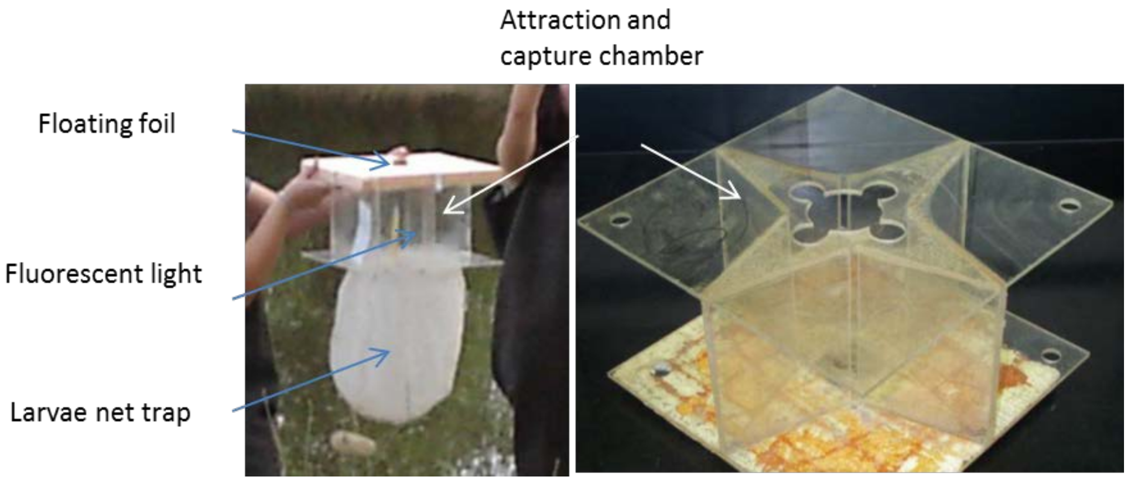


Figure 10: Fish larvae light trap. Right: bottom view of the trap without the net and the light. (modified from Pérez et al 2009)

3.5. Migration facilities and attraction flow

Fish passage will be analysed based on fish monitoring data and related to hydraulic variables (river and attraction devices). In particular, the attractiveness of fishway and the relationship with the river flow and operational management of HPP will be evaluated.

3.5.1. Methodology

Fish of direct sampling (subsection 3.1.) were marked with Visible Implant Elastomer (NMT®), that helps for recognize recaptures and previous location in subsequent samples (Figure 11).

Fish from Guma were marked with yellow elastomer and fish from Vadocondes samples with red elastomer. In addition, fish from the fishways were marked in the dorsal fin and fish from the downstream section of the fishways were marked near the caudal fin. First mark in a fish was done in its left side and, if a recapture happened, it was marked again but in the right side. All fish were anesthetized before the marking procedure with eugenol.

Figure 11: Marking procedure with Visible Implant Elastomer. Left: yellow elastomer in the dorsal fin (fish from Guma fishway). Right: red elastomer near the anal fin (fish from downstream of Vadocondes fishway).

From May to October 2018, at least twice per month, native fish species (*Luciobarbus bocagei*, *Pseudochondrostoma duriense* and *Squalius carolitertii*) were PIT tagged. They were captured in different places downstream and upstream of the fishways and they were also released in different places downstream and upstream and in both river side banks. Passive integrated transponder (PIT) tags of 12 and 23 mm length and 0.1 and 0.6 g of weight (freevision®) were used not exceeding a maximum weight of the tag equal to 2% of the fish weight. All fish were anaesthetized (solution of eugenol), measured (mass and fork length) and PIT-tagged intraperitoneally by an incision posterior to the left pectoral fin (Figure 12).

Figure 12: Passive Integrated Transponder Tagging.

A pass-through antenna system was used to study fish movements in Guma fishway. Four antennas were placed in the notches and orifices. Each antenna was connected to a dedicated reader (ORFID® Half Duplex multiplexer reader), programmed to query the antennas at 14 Hz (3.5 Hz or 0.29 s per antenna) (Figure 13). Antennas system worked with solar power (40 W solar panel and charge controller) and two batteries (Pb-acid of 12 V and 60 Ah each one, connected in parallel) since mid of May until mid of September 2018. Then, due to the decrease of solar radiation/insolation, the equipment has been connected to the electrical network (Alternating Current) through an electronic battery charger and the batteries (Direct Current).

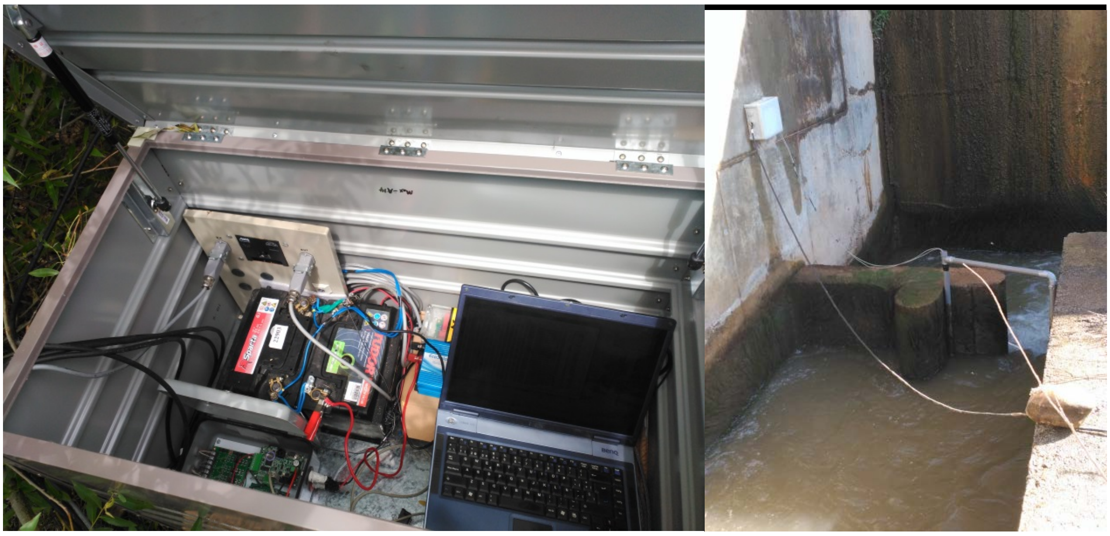


Figure 13: PIT tag antennas system (Oregon RFID® reader). Left: multiplexer reader with batteries and charge controller. Laptop is connected through an inverter. Right: hand-made RFID antenna with four loops of coil (2.5 mm2) enclosed in PVC pipe

Variations of Duero River natural flow and changes in flow discharge through Guma turbines have been recorded for future fish attraction models, as well as water temperature (data provided by Hydrologic Automatic System of Duero River basin authority).

Eleven individuals of *Luciobarbus bocagei* were tagged with radio transmitters. They were caught in different dates and places (upstream and downstream Guma fishway) and released both upstream and downstream the fishway. Radio transmitter (model TXC007I of Scubla S.R.L®) has an internal coil antenna with a dimension of 19x10 mm (length x diameter) and weight of 2.9 g, with a theoretical life of about 4 months and 40 pulses per minute (frequency between 151.000 and 151.500 MHz). They were implanted in the intraperitoneal cavity through an incision of about 1.5 cm. The wound was closed with three absorbable stitches and liquid cutaneous suture. All the surgery process was done in a portable fish surgery box, where barbels could stay without movements, with the gills submerged in the water and with continuous water oxygenation with maintenance doses of anaesthetic (eugenol) (Figure 14). After the surgery, recovery of fish was confirmed carefully, by looking for the usual swimming activity and good equilibrium of the individuals. From July to October 2018 radiotracking was done once a week in the river reach between Vadocondes HPP and Guma village dam, with a three-fold element Yagi antenna and a VHF portable receiver (Telenax® R-1000 receiver).

Figure 14: Left: table with field surgery equipment for radio tagging. Right: Detail of *Luciobarbus bocagei* anesthetized and sutured, with the gills submerged into the water with supply oxygen and the body of the fish secured (position and humidity) with the foam

The schedule for 2019 includes:

- A fishcounter will be installed in Guma HPP fishway for evaluating the location and entrance of fish with this tool and comparing with the used ones.

- PIT antenna system will still be worked continuously.

- The influence of turbine operation and attraction flows in fishway location will be modelled using Survival Analysis methods.

3.5.2. Results

Results of marking and recapturing with elastomers:

Regarding visible elastomer implants, 1718 individuals of 8 species were marked, from which, 198 were recaptured (tables 12 and 13). Only *L. bocagei* and *G. lozanoi* were recaptured (they were also the most tagged species), mainly in the same sample place where they were marked for the first time, except for *L. bocagei* in Vadocondes, where a remarkable proportion were first tagged in the fishway and recaptured then in the river. Only one recapture of *L. bocagei* in Guma fishway was previously marked in Vadocondes fishway.

About the body marking location, although dorsal fin is generally recommended for other species, with small size cyprinids, we have observed that it is not the best place. In this case, the subcutaneous injection is quite difficult (very thin skin) and the visibility of the elastomer some time later was not good enough. However, based on our experience, near the caudal fin (the bottom of the fish) is a really good body part, being the marking procedure comfortable and it has good visibility in subsequent recaptures.

Table 12: Number of marked fish with Visible Implant Elastomer from May to September 2018, by species and sampling point.

Number of marked	GUMA		VADOCONDES		TOTAL
	Fishway	River	Fishway	River	
Achondrostoma arcasii	1	1	2	2	6
Carassius auratus		1			1
Gobio lozanoi	120	146	58	378	702
Luciobarbus bocagei	567	42	160	216	985
Pseudochondrostoma duriense	4		2	4	10
Salmo trutta	3		1	1	5
Squalius carolitertii				8	8
Tinca tinca		1			1
TOTAL	695	191	223	609	1718

Table 13: Number of recaptured fish with Visible Implant Elastomer from May to September 2018, by species and sampling point. (In brackets: first number indicates the number of fish marked in the same sampling point in which it has been recaptured / second number indicates fish marked in different sampling points).

Number of recaptured	GUMA		VADOCONDES		TOTAL
	Fishway	**River**	**Fishway**	**River**	
Achondrostoma arcasii	-	-	-	-	0
Carassius auratus		-			0
Gobio lozanoi	-	1 (1/-)	-	5 (5/-)	6
Luciobarbus bocagei	126 (125/1)	1 (-/1)	53 (50/3)	12 (8/4)	192
Pseudochondrostoma duriense	-		-	-	0
Salmo trutta	-		-	-	0
Squalius carolitertii				-	0
Tinca tinca		-			0
TOTAL	126	2	53	17	198

Results of PIT tagging:

As preliminary results, a selection of data has been done focused only on *L. bocagei* (barbels) that were released downstream of Guma fishway, about 200 m from the entrance of the fishway, where both branches (fishway entrance channel and turbine outlet channel) join. Sample characteristics of marked fish with PIT tag can be seen in table 14.

Table 14: Characteristics of fish sample (Luciobarbus bocagei) tagged with PIT tag for the analysis of upstream migration. There are three different sources of fish (all of them upstream the release place). [median (first quartile – third quartile)]

Source	Guma fishway	Guma village	San Esteban fishway*
N	164	43	60
Fork length (mm)	136 (113-175)	125 (112-145)	139 (119-193)
Weigth (g)	37 (21-78)	28 (20-42)	35 (22-95)
Condition Factor	1.42 (1.36-1.50)	1.40 (1.35-1.46)	1.35 (1.29-1.41)

* Fishway located 31 km upstream Guma village dam.

There were 149 of 267 barbels that located the fishway (56%), of which 79 had success in the ascent of the fishway (53%). Both fishway location and passage success were influenced by the source (origin) of the fish. About fishway location, Guma village origin had the lower location rate (19%), being similar in fish from San Esteban and Guma fishway origins (62% and 63% respectively). For the success in the ascent, the better rate was for San Esteban origin (81%), followed by Guma fishway (44%) and Guma village (38%) origins.

If dates of release are analysed, a decrease in the proportion of fish which locate the fishway along the migration season can be seen (figure 15).

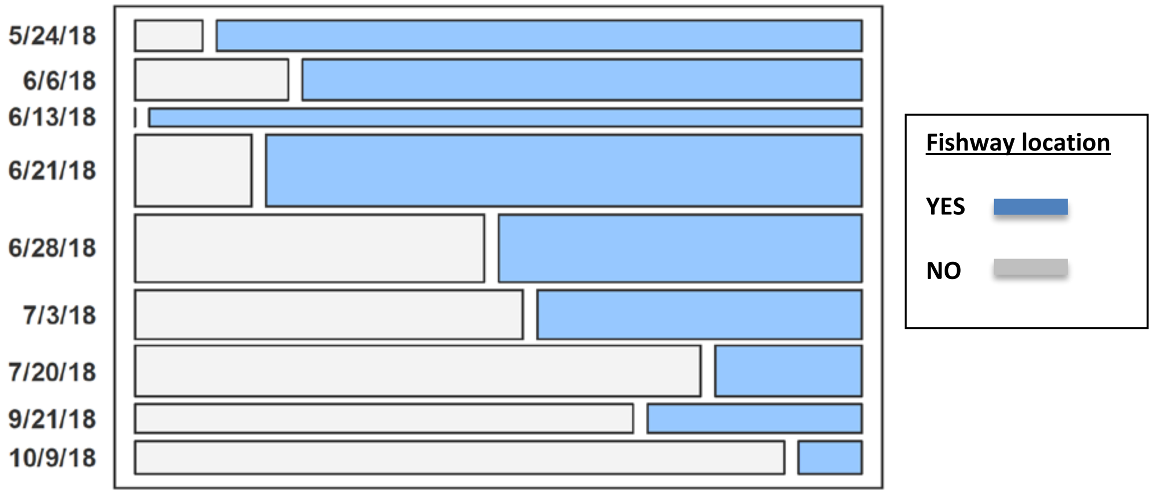


Figure 15: Proportion of barbels that located the fishway as a function of release date (month/day/year).

Regarding fish length, there were differences in the rate of fishway location. Median length of barbels which did not locate the fishway was 121 mm vs barbels that located the fishway = 154 mm; (Mann-Whitney test of median comparison; $p<0.001$). There were no differences in the ascent success due to the fish length.

Regarding Condition Factor ($K = 100*weight/length^3$), there were differences among condition factors of the different fish origin sources (San Esteban < Guma village < Guma fishway). For the Guma fishway origin, there were more fish with higher Condition Factor that located the fishway. Anyway, these results are preliminary, i.e. not conclusive, due to the need to assess the cross effect of other variables as for example the release date.

Fishway location and ascent success could be related with some environmental variables, for example the total river discharge, discharge through the turbines or over the dam, and water temperature. These parameters have been represented in figure 12 to try to find some relationships. It can be seen a period of peak movement mainly during the second half of June and first days of July, according with changes in the river discharge and water temperature.

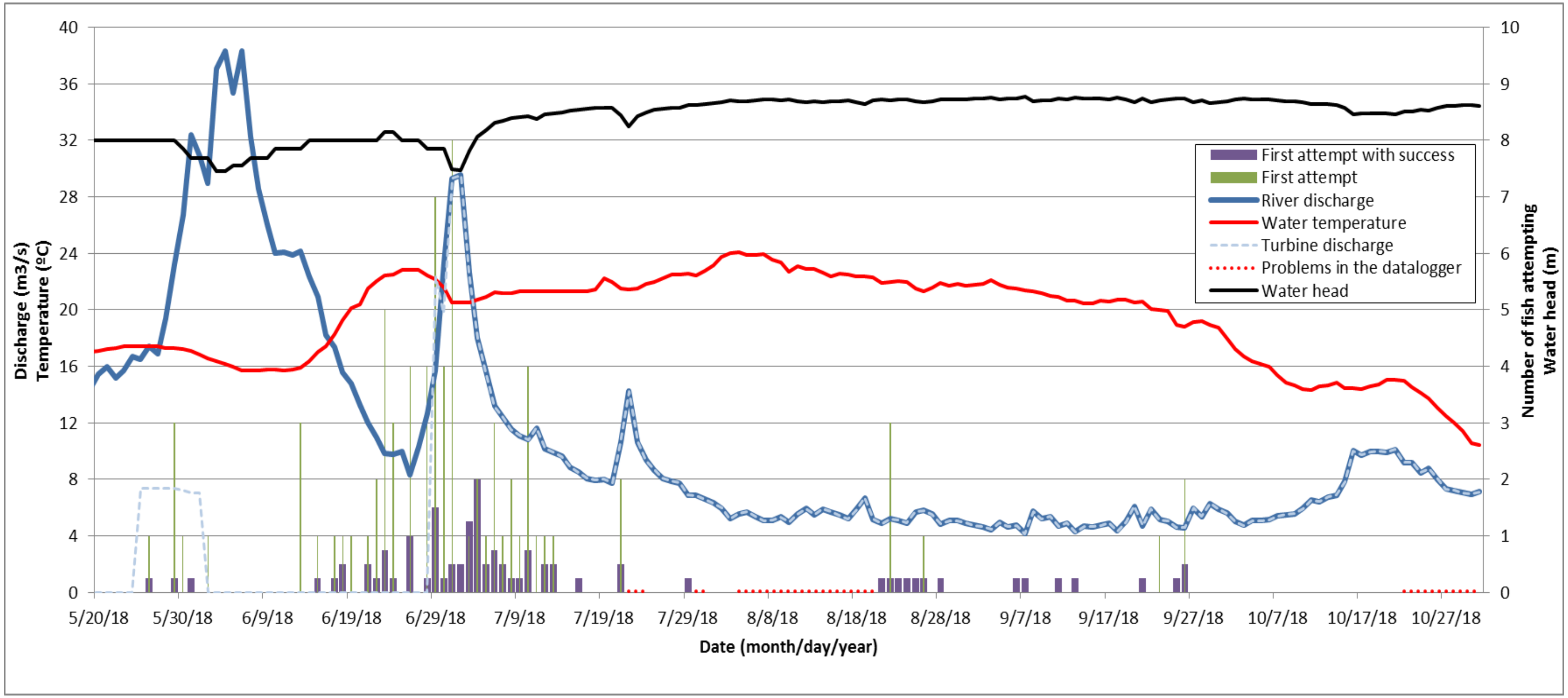


Figure 16: Fishway location and ascent success of Guma fishway, related to flow discharge and water temperature. Turbine discharge was affected by operational problems until 29th June. Water head refers to the difference between water level upstream and downstream

.

Another important result is the ascent time or transit time. In this case, it is possible to know the time that takes to a fish to ascent between the entrance of the fishway (antenna 1) and the exit (antenna 4). It corresponds to an approximately total water head of 8 m (31 pools with water drops of 0.25 m between each one). In table 15 the summary of the main ascent time results is shown. Global median time for ascending the fishway is about 3.5 hours, although quite variable according to the fish source. Of the data collected by the antennas, it is possible to see differences in ascent behavior between fish source, with a higher motivation for the ascent of fish from upstream origins. However, fish that were caught in the fishway showed another kind of movements, probably more related to refuge and/or food search.

Table 15: Summary of the ascent time of Luciobarbus bocagei in Guma fishway, as a function of the source of the fish, in hours. Time is obtained between antenna 1 and antenna 4, corresponding to a total water head of 8 m (31 pools with mean water drops of 0.25 m

Fish source	Guma fishway	Guma village	San Esteban fishway	Total
N	36	4	29	69
Median ascent time	9.3	2.3	1.9	3.4
First quartile	2.4	1.4	1.3	1.5
Third quartile	45.7	2.9	4.2	12.0

We expect to obtain more results from data about upstream migration and also downstream movement since we have tagged another 254 fish which were released upstream of Guma fishway. Of these fish, 132 were released in the right riverbank and 122 in the left riverbank, in different dates (summer and autumn) looking for results about fishway location in downstream movement. Until the 1st October 2018, at least 49 barbels released in the right riverbank and 13 of the left bank located the fishway, most of them moving downstream through the fishway and few of them seeming to move through the turbines (provisional data that need to be confirmed).

<u>Results of radiotracking</u>

Eleven barbels were radio tagged and also pit tagged to know exactly the moment of passing Guma fishway. In the beginning, ten fish were tagged but one of them died in August 2018 (number 1, Table 16) and we could recover the tag and reuse it in a new fish (number 11). Fish numbers one to five were captured some kilometers upstream of Guma fishway and released 250 m downstream of the fishway. Fish numbers 6 to 11 were captured in Vadocondes fishway and released approximately 600 m upstream of Guma fishway.

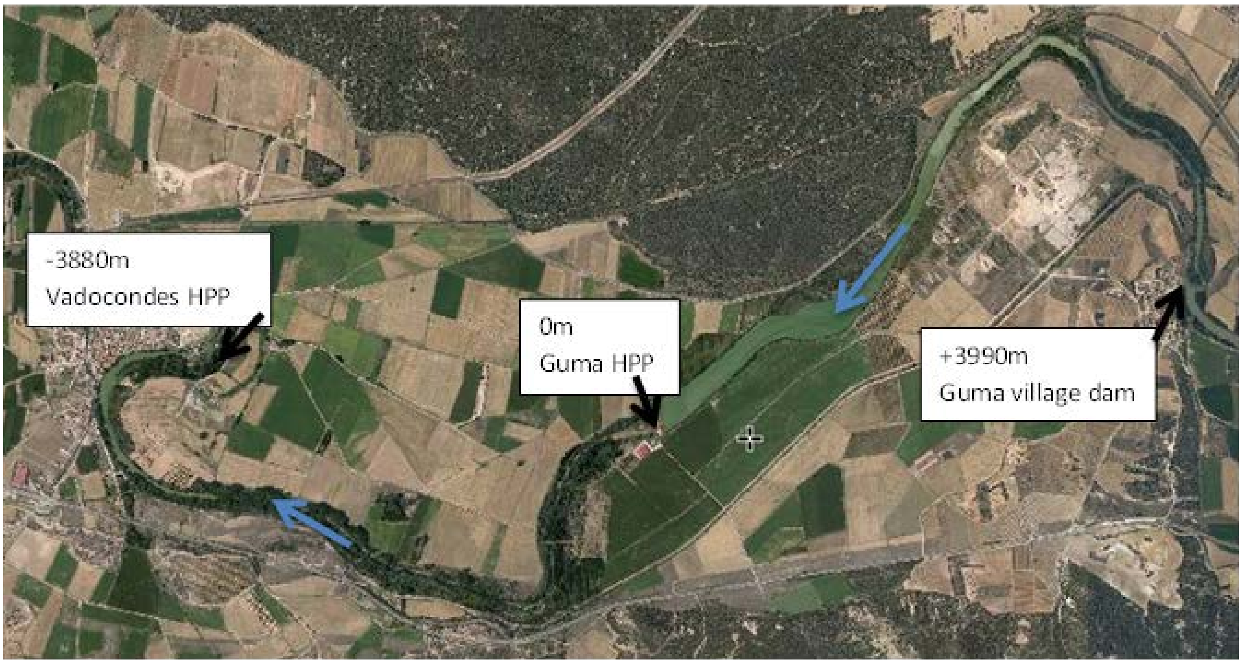
Table 16: Barbels (Luciobarbus bocagei) that were radiotagged (see figure 13 for details of their movements)

Barbel number	Length (mm)	Weight (g)	Sex	Condition Factor	Source	Release	Release date
1	250	213	Male	1.36	Upstream	Downstream	6/28/2018
2	205	115	Male	1.33	Upstream	Downstream	6/28/2018
3	213	121	Unknown	1.25	Upstream	Downstream	6/28/2018
4	210	128	Male	1.38	Upstream	Downstream	6/28/2018
5	200	105	Unknown	1.31	Upstream	Downstream	6/28/2018
6	224	149	Unknown	1.33	Downstream	Upstream	7/11/2018
7	185	76	Unknown	1.20	Downstream	Upstream	7/11/2018

8	255	210	Male	1.27	Downstream	Upstream	7/16/2018
9	200	110	Unknown	1.38	Downstream	Upstream	7/16/2018
10	255	200	Male	1.21	Downstream	Upstream	7/16/2018
11	233	164	Unknown	1.30	Downstream	Upstream	9/6/2018

The details of movements performed by barbels are shown in figure 16. As a summary, about the fish released downstream, three of them ascended Guma fishway (between 11 and 13 of July). Another descended more than 2 km, and then ascended till near the entrance of the fishway and finally it was found dead near there. The other one descended more than 2 km and stayed there until batteries ran out. In relation to the six fish released upstream, four of them went upstream until they got the dam of Guma village (which has no fish passage), with three of these four fish staying there until the batteries ran out. The other one after arriving to Guma village descended till near Guma HPP dam. Another two fish (8 and 9) were impossible to locate after they were released.

It seems that only one fish descended Guma HPP during the life of the radiotag batteries, but we cannot know the way (the fishway or the turbines) because PIT antenna reader had some problems in the middle of its descent movement (fish 2).



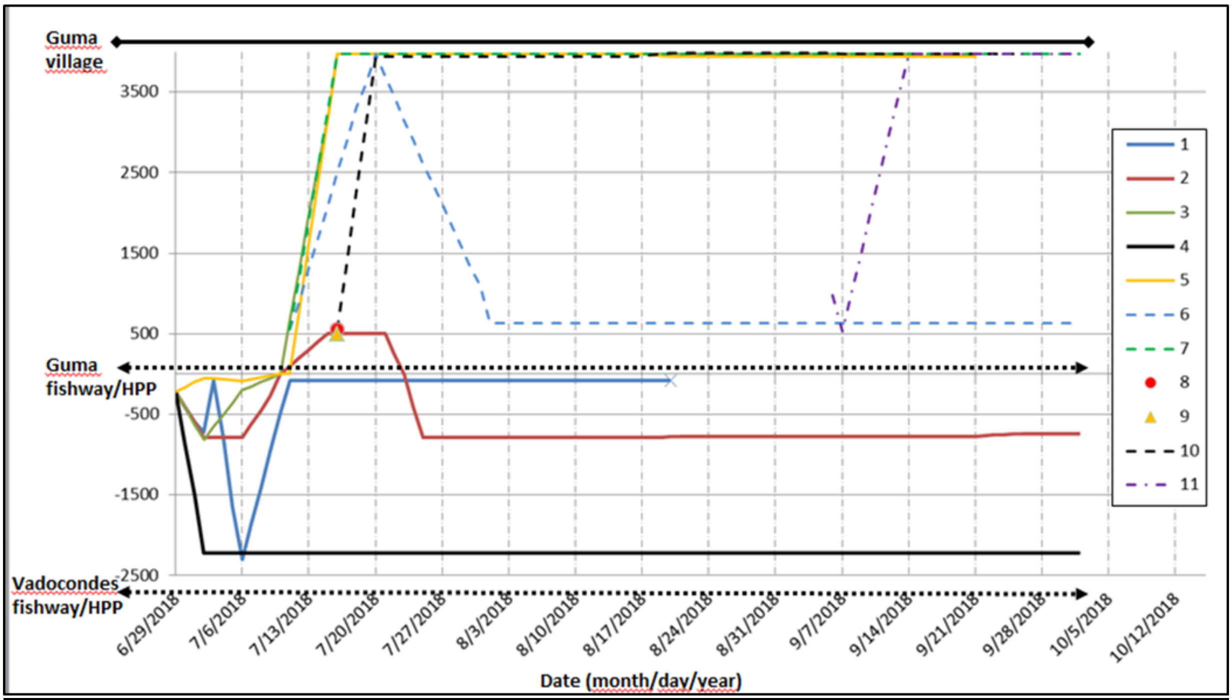


Figure 17: Scheme of movement for barbels with radiotag. Above: map of the section under study where radiotracking was done once a week since July to October 2018. Below: graph of fish movements along the time (X axis) as a function of the distance from Guma HPP

3.6. Hydraulic modelling of the fishway and its attractiveness

The aim of this subtask is modelling the fishway and the downstream section of Guma HPP to analyse and improve its hydrodynamics by correlating it with fish behaviour. Mainly, we would like to improve the knowledge about the fishway hydrodynamics, its attractiveness, and the influence of the attraction flow on fish movements s.

Fishway hydrodynamics will be analysed under different flow regimes and operational constraints (like an orifice or notch clogging), using 3D numerical modelling.

To analyse the fishway attractiveness considering the competing turbined flow, different scenarios will be analysed using 2D and 3D modelling to try to find the scenarios that maximize fish upstream movement and hydropower production to try to establish more fish-friendly operation rules.

ITAGRA-GEA is responsible for data collection and IST is implementing the hydraulic model. Later, comparisons between these models and fish behaviour models will be done.

3.6.1. Methodology

With the 2D plans of the fishway facility of Guma HPP the 3D geometry of the fishway was created using Autocad. The geometry of the fishway was simplified, (22 pools were modelled instead of 31 pools) to allow for lower run times. This geometry was imported to the 3D model as stereolithography (STL) files. The computational domain was discretized using multi-block grids to optimize the mesh according to the simulated geometry. The flow field numerical modelling was performed using FLOW-3D®, a CFD commercial software that solves the governing equations of fluid motion in a Cartesian staggered grid using finite volumes method.

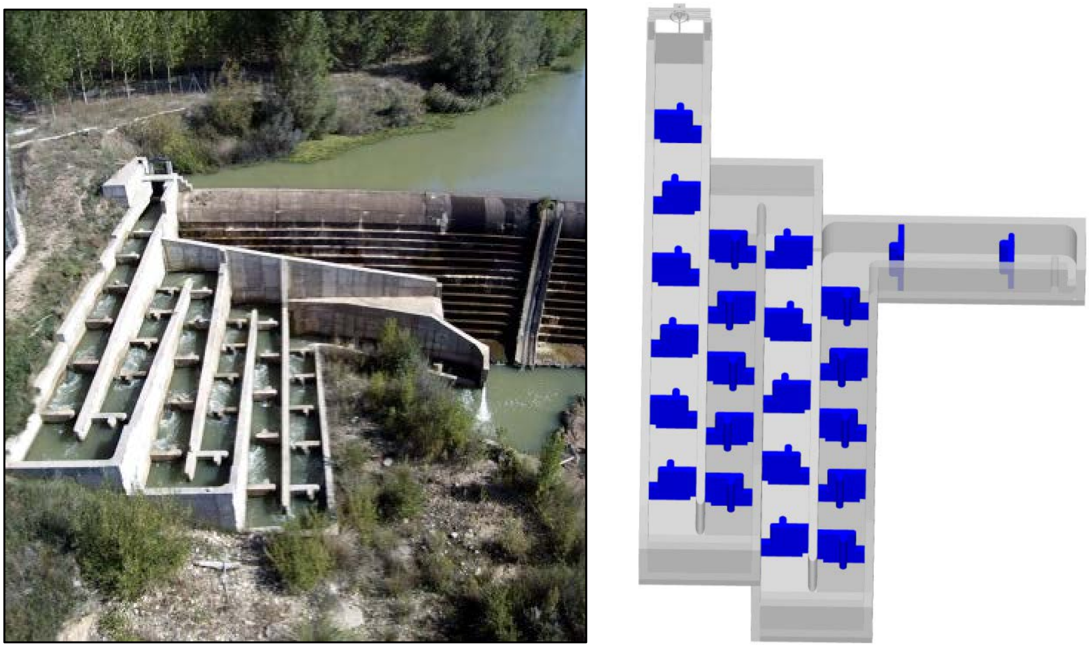


Figure 18: Left: Guma HPP fishway. Right: Guma HPP modelled fishway geometry

The 2D and 3D numerical modelling of the downstream river reach is being performed with HEC-RAS and FLOW-3D® software. To build these numerical models several tasks were carried out:

- Hydraulic characterization of the downstream section (about 300 m) of Guma HPP with Doppler bathymetry ADCP, current meter and topographic equipment, under different flow conditions (Figure 19).

Figure 19: Hydraulic data acquisition on Guma HPP. Left: Doppler bathymetry in the turbine tailrace. Right: topographic survey of bathymetry sections

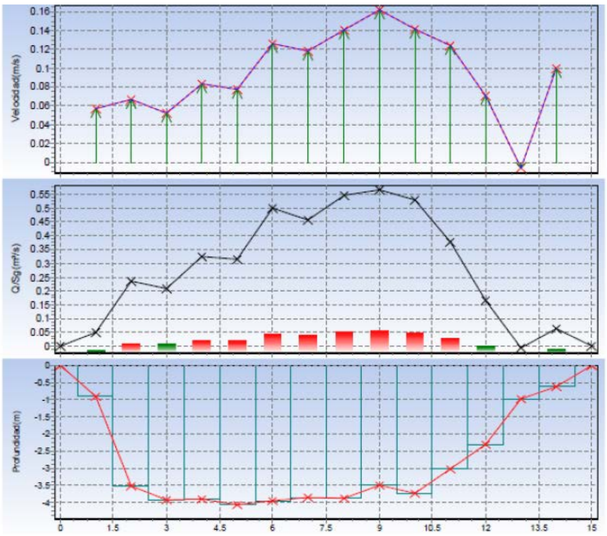
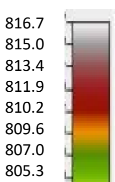


Figure 20: Example of bathymetry results of one section in Guma downstream reach. Up: current velocity; Middle: flow discharge; Down: water depth

- Characterization of the river stretch under study through aerial photography (drone flight).

Figure 21: Photos from drone flight over Guma HPP

These data is being used to build (Figure 22), calibrate and validate the 2D and 3D numerical models.



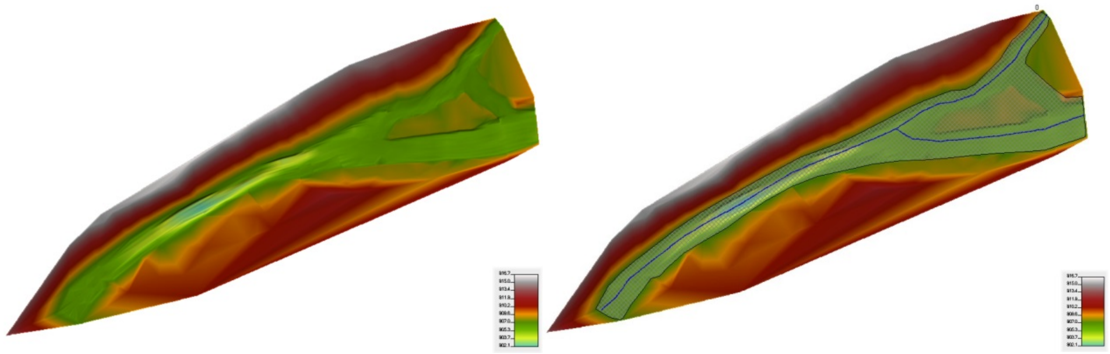
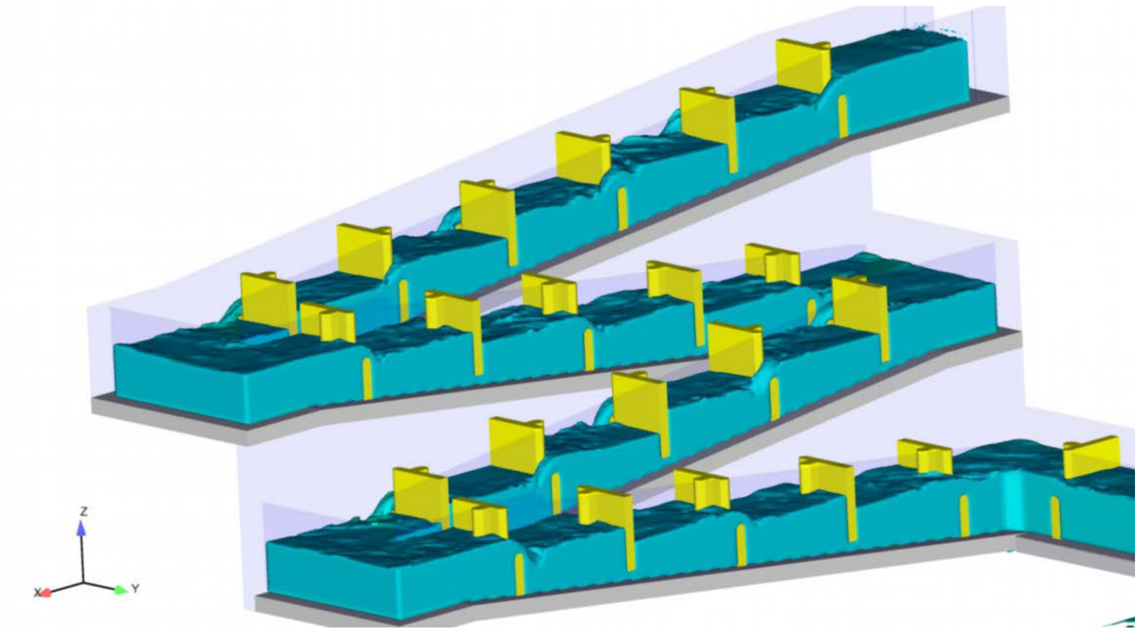


Figure 22: Downstream river stretch under study. Left: terrain elevation. Right: HEC-RAS 2D model area

3.6.2. Results

The 2D and 3D modelling of the downstream river stretch and of the 3D modelling of the fishway is being carried out. The verification and validation procedure of the 3D fishway modelling is being performed to obtain valid accurate results. Some preliminary results are shown in figure 23.



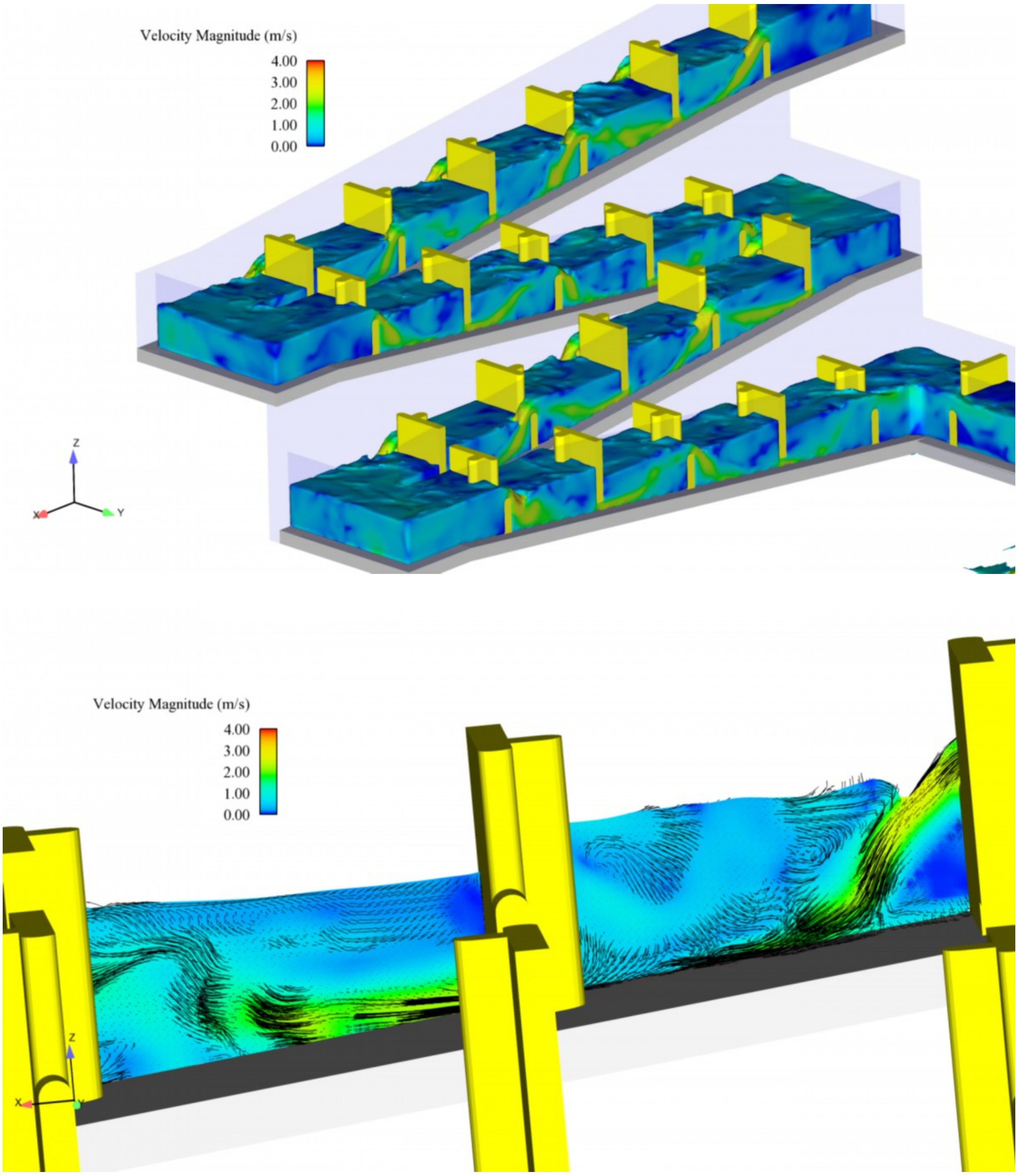


Figure 23: 3D fishway model preliminary results. Top: 3D flow and water surface configuration. Middle: 3D flow coloured by velocity magnitude. Bottom: Velocity magnitude and streamlines in two regular pools at y = 0.15 m (right located notch axis)

The model results will be analysed to characterize the flow hydrodynamics and turbulence patterns to try to correlate with the observed fish behaviour. The different pools (regular and turning pools) hydrodynamics will be fully characterized to understand differences and possible trapping zones. The hydrodynamics of non-uniform flow regimes caused by the river hydrological variability and/or operational constraints (like an orifice or notch clogging) will also be assessed.

The attractiveness of the fishway will be analysed by the characterization of the downstream river reach hydrodynamics, considering the competing turbined flow in order to investigate possible operational management options to enhance attractiveness and thus upstream migration.

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