Description of a Test Case: Trois-Villes

Saison - France

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1. Description of the Test-Case

Figure 1 and Figure 2 allow locating the HPP of Trois-Villes at different scales.

Figure 1: Location of the HPP of Trois-Villes at national and regional scale

Figure 2: Location of Trois-Villes at the scale of the river

1.1. Description of the water bodies related to the HPP

The HHP of Trois-Villes is included in waterbody 262. Waterbody 262 (Saison) is connected with 3 other water bodies: 2 upstream 261 (Saison) and 434 (Gave de St Engrâce) and one downstream 263 (Saison)

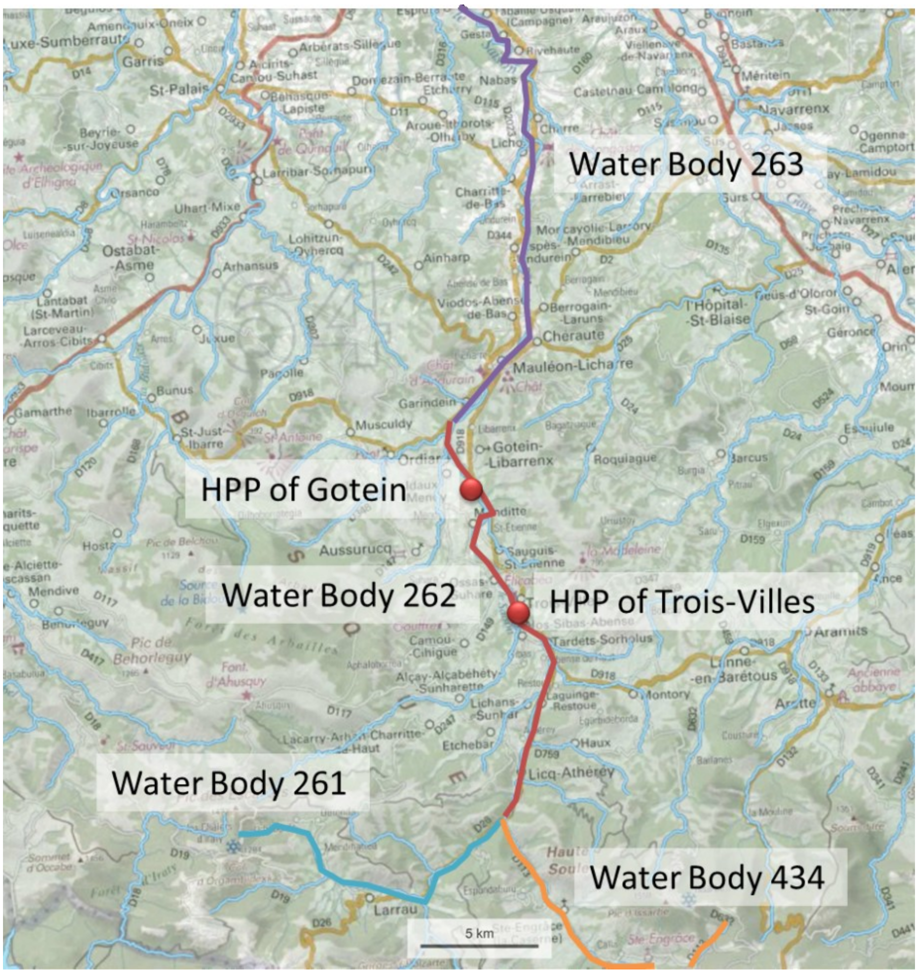

Figure 3: Water bodies related to the HPP of Trois-Villes

1.1.1. Hydrology of the Saison at Mauléon-Licharre

The hydrology of the Saison is characterized by sustained flows in winter, high water levels in spring due to snow melting and low water period from August to October.

At Trois-Villes the mean interannual discharge is estimated at 22.3 m^3/s.

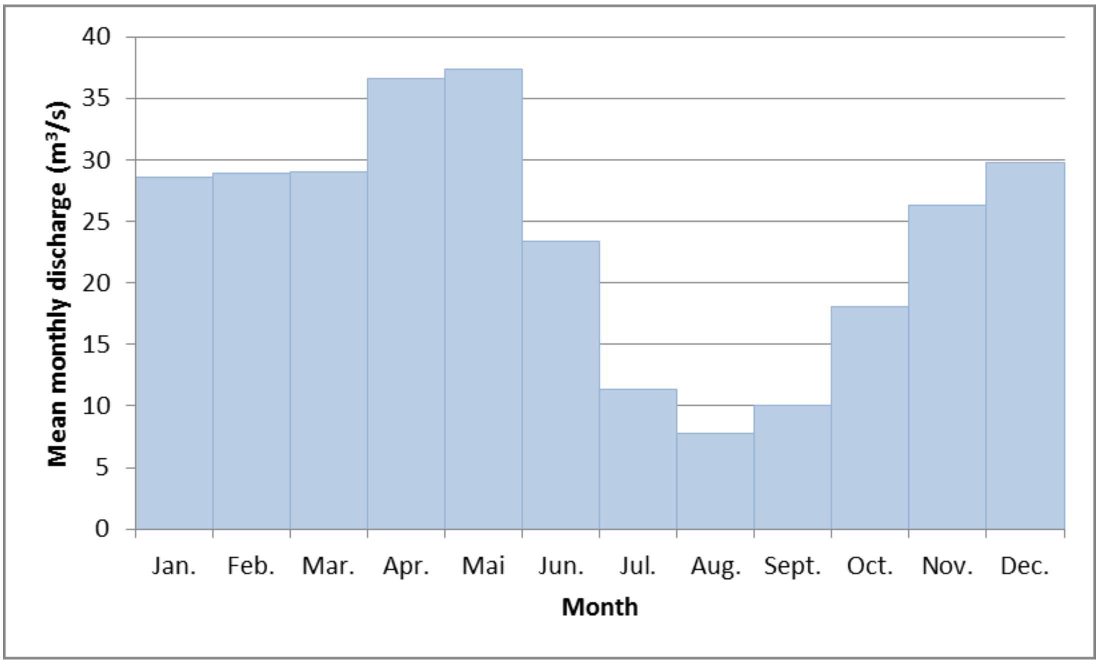

Figure 4: Mean monthly discharge of the Saison at Mauléon-Licharre (source: www.hydro.eaufrance.fr)

1.1.2. Main pressures

Several pressures are listed for the Saison near Trois-Villes:

Table 1: Main pressures on the Saison

Water treatment plant effluents	no significant
Spillover of Stormwater overflows	no significant
Nitrogen derived from agriculture	no significant
Pesticides	no significant
Water supply	no significant
Continuity	Moderate due to the 3 HPPs
Hydrology	high due to hydropeaking management upstream
Morphology	minimal

A SDAGE (Schéma Directeur d'Aménagement et de Gestion des Eaux) is like a River Basin Management Plan and describes measures to be implemented. All the measures are not related to hydropower pressures.

Table 2: Measures to be implemented at the river basin scale of the Saison

Flow change	legislation: instream flow in bypassed reach since 2014: 1/10 from minimum annual discharge
Fish migration measures	3 HPP: *Moulin Datto:* bar screen (bar clearance 2cm), fish ladder; *Bidondo's fish farming*: fish ladder; *Trois-Villes*: bar screen 2cm, fish ladder; *Gotein:* bar screen 2cm, fish ladder
Pollution control	implement a global study or a masterplan for reducing the pollution associated to industry, sanitation,

1.2. Fish fauna on the Saison

General data on fish fauna in the Saison

The fish fauna of the Saison is composed of amphibiotic and holobiotic species.

The **amphibiotic species** identified are:

- The atlantic salmon (upstream migration mainly from Mai to November);
- The sea trout (upstream migration mainly from Mai to November);
- The eel (upstream migration from April to October and mainly from June to September);
- The shad (upstream migration from April to July);
- The sea lamprey (upstream migration from April to July);

The **holobiotic species** identified are:

- *Salmonidae* : brown trout (upstream migration mainly autumnal for the trout);
- *Cyprinidae*: bleak, barbell, common bream, roach, chub, dace…
- *Cobitidae*: stone loach…

The study of the production capacity in juveniles of salmon was realized during the 1980s by the Scientific council of fishery based on flow facies of Malavoi (1989), (S.I.E.E. & GHAAPPE, 2002). The habitats taken into account for the calculation were: riffles, rapids, runs, with a weighting coefficient of 1/5 for runs.

On this basis, the Saison have a production surface of 45.79 ha which corresponds to 22 439 eq. smolts.

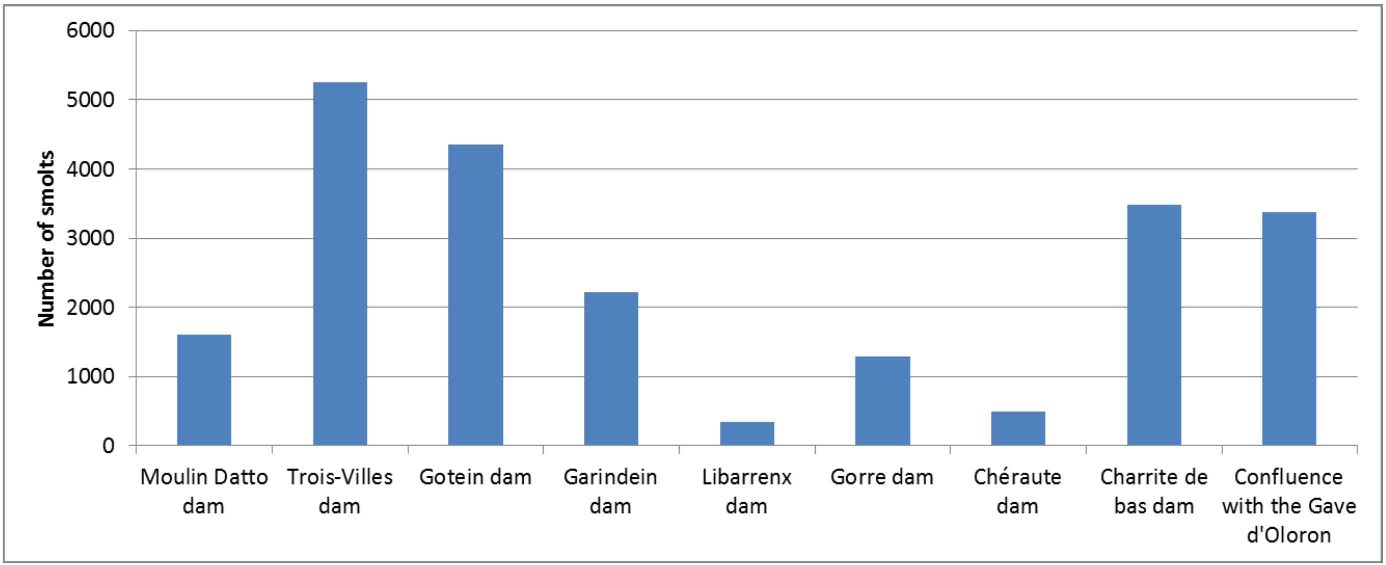

Figure 5: Potentialities between each facility (source : (S.I.E.E. & GHAAPPE, 2002))

2. In 2007, MIGRADOUR also published a study about potentiality of the Saison for the period 2002-2007. On its course, the Saison has a potential minimum production of 94 000 Atlantic salmons smolts and a potential maximum production of 135 000. These potential productions have been assessed thanks to a study on habitat availability.
3. In 2016, the mean production was around 60 150 Atlantic salmon smolts. The mean production is assessed thanks to control electrofishing on control station all along the river. These fishing allow calculating an abundance index per station; it corresponds to the number of smolts captured in 5 minutes. Then the density of smolts is calculated: the arithmetic average of the abundance index on the concerned station. Then the density is multiplied by the effective production area. This gives the production of smolts of a river stretch.

1.3. Presentation of the HPP

1.3.1. Main characteristics of the HPP of Trois-Villes

Table 3: Main characteristics of the HPP of Trois-Villes

Watercourse	Saison
Situation :	Commune de Trois-Villes
Inter-annual discharge	22.3 m^3/s
Instream flow in the bypassed reach:	2.5 m^3/s
Function of the dam :	Hydropower
Length of headrace canal :	550 m
Maximum turbine discharge:	4.1 m^3/s
Species concerned :	Salmon, sea trout, lamprey, eel, brown trout
Capacity of HPP	0.16 MW

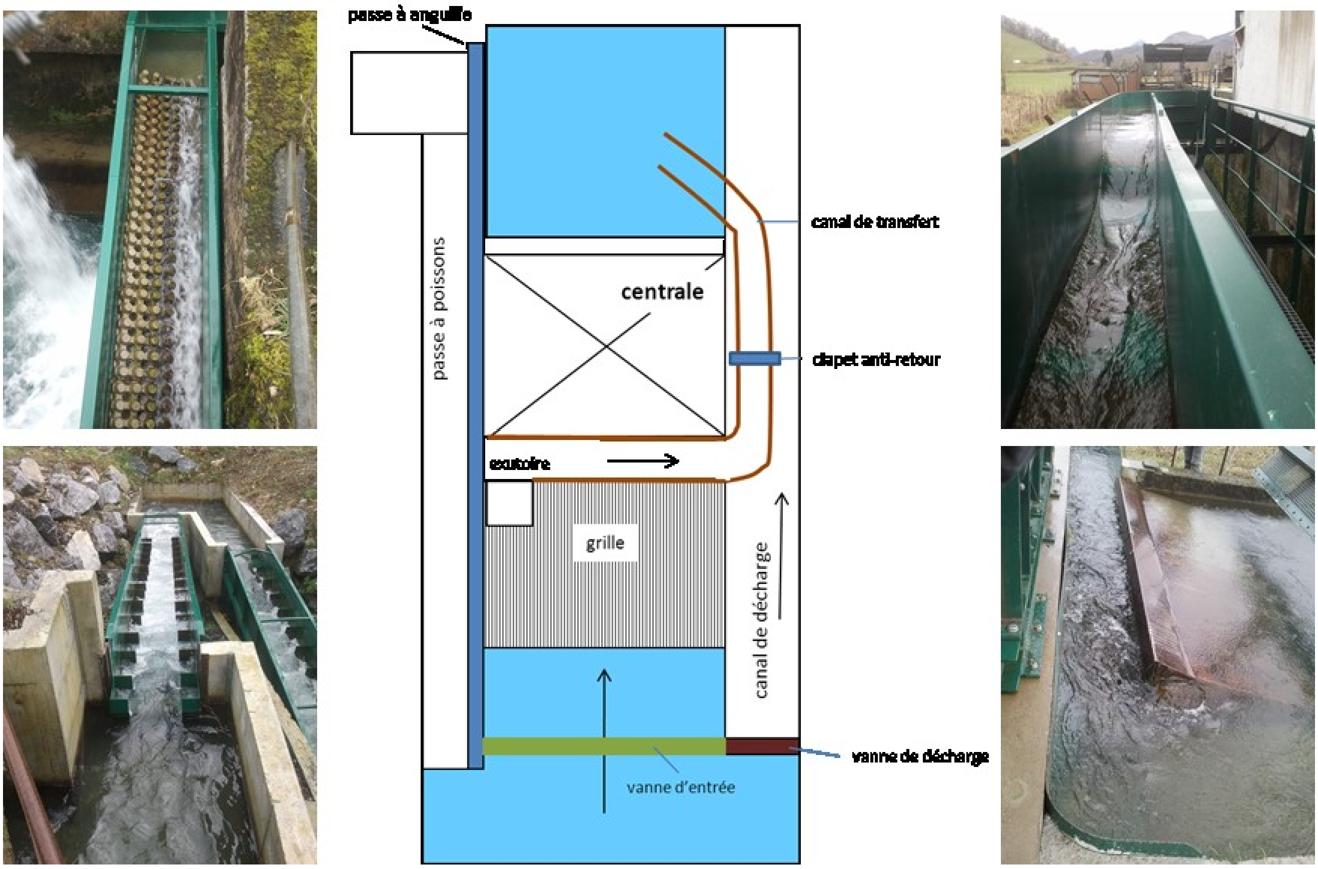

Figure 6: Devices for upstream and downstream migration at Trois-Villes

Equipment:

1 Kaplan turbine at the power plant:

- Maximum turbined flow: 4.1 m^3/s
- Rated head: 5 m
- Number of blades : 4
- Diameter of the wheel: 1.2 m
- Rotation speed: 330 rpm

1.3.1. E-flow

In France, the law of 2006 (LEMA) imposes an environmental flow that permanently guarantee the life, circulation and reproduction of the species that inhabit the waters, and also defines a minimum value of 1/10 of the mean inter-annual discharge. This should be implemented before 1rst January 2014 at the latest. The definition of the environmental flow in bypassed sections is normally based on a detailed study of hydrology (natural low flow), hydromophology and habitat. In 2014, if such study was available, its results were considered to define the environmental flow; otherwise it was mostly set to the minimum value (1/10 of the mean inter-annual discharge).

In Trois-Villes, the discharge value is 2.5 m^3/s, it's bigger than 1/10 of the mean interannual discharge and doesn't come from a biological study. It comes from a previous regulation (decree from January 1990) and wasn't change.

1.3.2. Downstream migration devices

- Former bar-screen in front of the HPP:
  - Width of the bar screen :
  - Clearance between the bars : 45 mm
  - 1 downstream migration outlet located at the top of the bar screen at the right bank
- Bar screen located at the hydropower plant (2014):
  - Width of bar screen: 6.36 m
  - Length of the bar screen : 6.57 m
  - Clearance between the bars : 20 mm
  - Inclination ß of 26°
  - 1 downstream migration outlets located at the top of the bar screen, dimensions of the outlet: L = 1 m and h = 0.50 m
  - Flow for the downstream migration : 201 l/s = 5.1% of the max turbined flow
  - Maximum velocity in front of the rack: 0.43 m/s

1.3.3. Previous study on the induced mortality by the hydropower facilities during downstream migration of atlantic salmon smolts (2002)

(S.I.E.E. & GHAAPPE, 2002)

The area of the study is 55 km long and includes 8 HPPs and 1 fish farm (Bidondo).

Hydrology between 1991 and 2000

The year 1992 was a really wet year; on the contrary 1993 was really dry. The hydrology has a big role on the distribution of production on the section.

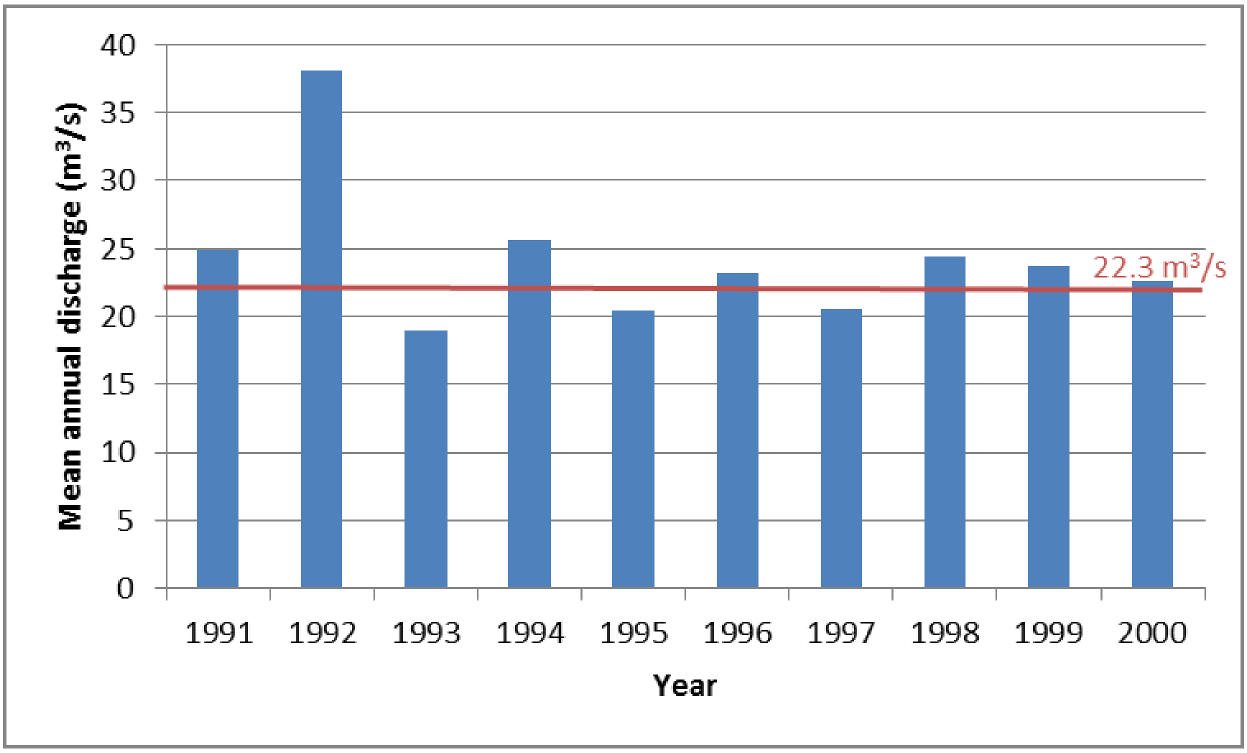

Figure 7: Mean annual discharges of the Saison between 1991 and 2001 at the station of Mauléon-Licharre (source: banque hydro France)

State of downstream migration facilities in 2002

According the characteristics of each facility the potential mortalities at each site are relatively high and bigger than 10%, except at Gorre HPP where the rate is about 8%.

At Trois-Villes, according the bar spacing and the low downstream migration discharge, the efficiency of the downstream migration device (bar-rack) is estimated at 40%.

The global mortalities were simulated for the years 1991 to 2000 at each site, see Table 4. The mean total mortality for the Saison until the confluence with the Gave d'Oloron is about 18.6% and varies from 10% to 25.9 %. The more important global mortalities are calculated for the HPP of Moulin Datto and Mauléon. The HPP of Trois-Villes induces a global mortality of 6.3% in average. These mortalities are theoretical and are calculated on a basis of 100 potential individuals going downstream at each HPP.

It's important to take into account the real number of fishes going downstream to evaluate the real impact of each facility. So, if we care about the percentage of dead fishes for one facility regarding the total number of fishes dead on the entire section, the HPPs of Mauléon, Gotein and Charitte de Bas are responsible of 65.3% of the total losses on the axis, see Table 5.

The HPP of Trois-Villes induces 10.9 % of the total losses of the axis, which corresponds to 455 individuals among 4175.

Table 4: global mortalities at each facility taking into account the spill at the dam (source: (S.I.E.E. & GHAAPPE, 2002))

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Average
Moulin Datto	7.5%	6.3%	15.3%	5.7%	15.3%	15.3%	15.3%	11.0%	8.2%	11.3%	11.1%
Trois Villes	**5.6%**	**6.6%**	**6.6%**	**4.6%**	**6.6%**	**6.6%**	**6.6%**	**6.6%**	**6.6%**	**6.6%**	**6.3%**
Gotein	4.3%	3.0%	9.4%	2.9%	9.4%	9.4%	9.4%	9.4%	4.4%	9.4%	7.1%
Mauléon	7.1%	5.6%	16.2%	5.4%	16.2%	16.2%	16.2%	10.5%	7.9%	10.6%	11.2%
Libarrenx	4.0%	2.8%	8.5%	2.7%	8.5%	8.5%	8.5%	8.5%	5.2%	8.5%	6.6%
Gorre	0.6%	0.9%	1.4%	0.5%	2.6%	19.0%	3.8%	1.8%	1.2%	1.2%	3.3%
Chéraute	1.2%	2.1%	2.7%	1.1%	5.9%	4.7%	6.2%	4.2%	2.8%	2.7%	3.4%
Charitte de bas	2.4%	2.8%	4.7%	2.1%	6.8%	6.2%	7.4%	5.3%	3.9%	4.0%	4.6%

Table 5: distribution of losses due to each facility (source : (S.I.E.E. & GHAAPPE, 2002)

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Average
Moulin Datto	4.3%	3.8%	5.1%	4.1%	4.4%	4.7%	4.2%	3.7%	3.8%	4.2%	4.2%
Trois Villes	**13.6%**	**16.6%**	**9.1%**	**14.0%**	**7.8%**	**8.3%**	**7.5%**	**9.3%**	**12.6%**	**10.2%**	**10.9%**
Gotein	16.7%	11.9%	20.5%	14.2%	17.7%	18.7%	16.9%	20.8%	13.2%	22.9%	17.4%
Mauléon	31.8%	26.3%	39.8%	30.6%	34.2%	36.1%	32.8%	26.2%	27.8%	29.1%	31.5%
Libarrenx	10.6%	9.0%	0.6%	10.7%	0.5%	0.6%	0.5%	8.0%	9.9%	8.7%	5.9%
Gorre	2.6%	4.4%	3.3%	3.0%	5.4%	4.0%	7.5%	4.5%	4.5%	3.2%	4.2%
Chéraute	5.7%	10.5%	6.7%	7.1%	12.3%	10.5%	12.4%	10.7%	10.3%	7.5%	9.4%
Charitte de bas	14.7%	17.6%	14.8%	16.3%	17.6%	17.2%	18.2%	16.8%	17.9%	14.1%	16.5%

Simulations of the mortality on the section were also led with improvement of the downstream migration devices. Two hypothesis of efficiency of downstream migration devices were chosen: 50% and 70%.

Simulation of efficiency improvement to 50%

With an improvement of the efficiency of all downstream migration devices to 50%, the global mortality on the axis falls to 12.6% in average. The HPP of Mauléon is the more damaging, see Table 7.

The global mortality of Trois-Villes is 5.3% which represents 13.5% of the global losses on the axis.

Table 6: global mortalities at each facility taking into account the spill at the dam for an improve efficiency of 50% for all downstream devices (source: (S.I.E.E. & GHAAPPE, 2002))

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Average
Moulin Datto	3.7%	3.1%	7.7%	2.9%	7.7%	7.7%	7.7%	5.5%	4.1%	5.6%	5.6%
Trois Villes	**4.7%**	**5.5%**	**5.5%**	**3.9%**	**5.5%**	**5.5%**	**5.5%**	**5.5%**	**5.5%**	**5.5%**	**5.3%**
Gotein	2.5%	1.8%	5.5%	1.7%	5.5%	5.5%	5.5%	5.5%	2.6%	5.5%	4.2%
Mauléon	3.9%	3.1%	9.0%	3.0%	9.0%	9.0%	9.0%	5.8%	4.4%	5.9%	6.2%
Libarrenx	4.0%	2.8%	8.5%	2.7%	8.5%	8.5%	8.5%	8.5%	5.2%	8.5%	6.6%
Gorre	0.6%	0.9%	1.4%	0.5%	2.6%	1.9%	3.8%	1.8%	1.2%	1.2%	1.6%
Chéraute	0.8%	1.5%	1.9%	0.8%	4.2%	3.4%	4.5%	3.0%	2.0%	1.9%	2.4%
Charitte de bas	1.4%	1.6%	2.8%	1.2%	4.0%	3.6%	4.3%	3.1%	2.3%	2.3%	2.7%

Table 7: distribution of losses due to each facility with an improvement of the efficiency of downstream migration devices up to 50% (source: (S.I.E.E. & GHAAPPE, 2002))

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Average
Moulin Datto	3.2%	2.7%	4.0%	3.0%	3.3%	3.5%	3.1%	2.7%	2.7%	3.1%	3.1%
Trois Villes	**16.7%**	**19.9%**	**11.9%**	**17.1%**	**9.9%**	**10.6%**	**9.3%**	**11.3%**	**15.2%**	**12.6%**	**13.5%**
Gotein	14.5%	10.1%	18.9%	12.2%	15.7%	16.9%	14.9%	17.9%	11.2%	19.9%	15.2%
Mauléon	26.4%	21.3%	35.7%	25.2%	29.7%	31.9%	28.0%	21.9%	22.7%	24.7%	26.8%
Libarrenx	15.8%	13.0%	0.9%	15.9%	0.8%	0.8%	0.7%	12.0%	14.5%	13.2%	8.8%
Gorre	4.0%	6.6%	5.8%	4.5%	9.0%	6.8%	12.3%	7.0%	6.8%	5.1%	6.8%
Chéraute	6.2%	11.1%	8.2%	7.6%	14.6%	12.6%	14.4%	11.9%	11.1%	8.5%	10.6%
Charitte de bas	13.2%	15.3%	14.6%	14.4%	17.0%	16.8%	17.2%	15.3%	15.8%	13.0%	15.3%

Simulation of efficiency improvement to 70%

With an improvement of the efficiency of all downstream migration devices to 50%, the global mortality on the axis falls to 7.9% in average. The HPP of Mauléon is the more damaging, see Table 9 and Table 7.

The global mortality of Trois-Villes is 3.2% which represents 13.2 % of the global losses on the axis (232 dead individuals at Trois-Villes among 1760 dead overall the entire section.

Table 8: global mortalities at each facility taking into account the spill at the dam for an improve efficiency of 70% for all downstream devices (source: (S.I.E.E. & GHAAPPE, 2002))

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Average
Moulin Datto	2.2%	1.9%	4.6%	1.7%	4.6%	4.6%	4.6%	3.3%	2.5%	3.4%	3.3%
Trois Villes	**2.8%**	**3.3%**	**3.3%**	**2.3%**	**3.3%**	**3.3%**	**3.3%**	**3.3%**	**3.3%**	**3.3%**	**3.2%**
Gotein	1.5%	1.1%	3.3%	1.0%	3.3%	3.3%	3.3%	3.3%	1.5%	3.3%	2.5%
Mauléon	2.4%	1.9%	5.4%	1.8%	5.4%	5.4%	5.4%	3.5%	2.6%	3.5%	3.7%
Libarrenx	2.4%	1.7%	5.1%	1.6%	5.1%	5.1%	5.1%	5.1%	3.1%	5.1%	3.9%
Gorre	0.3%	0.5%	0.8%	0.3%	1.6%	1.1%	2.3%	1.1%	0.7%	0.7%	0.9%
Chéraute	0.5%	0.9%	1.2%	0.5%	2.5%	2.0%	2.7%	1.8%	1.2%	1.1%	1.4%
Charitte de bas	0.9%	1.0%	1.7%	0.7%	2.4%	2.2%	2.6%	1.9%	1.4%	1.4%	1.6%

Table 9: distribution of losses due to each facility with an improvement of the efficiency of downstream migration devices up to 70% (source: (S.I.E.E. & GHAAPPE, 2002))

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Average
Moulin Datto	3.1%	2.6%	3.8%	3.0%	3.2%	3.4%	3.0%	2.6%	2.6%	3.0%	3.0%
Trois Villes	**16.5%**	**19.6%**	**11.6%**	**16.9%**	**9.6%**	**10.3%**	**9.0%**	**10.9%**	**14.9%**	**12.2%**	**13.2%**
Gotein	14.4%	10.0%	18.6%	12.2%	15.4%	16.5%	14.5%	17.5%	11.1%	19.6%	15.0%
Mauléon	26.5%	21.2%	35.6%	25.2%	29.4%	31.7%	27.7%	21.8%	22.6%	24.7%	26.6%
Libarrenx	15.8%	13.0%	0.9%	15.9%	0.8%	0.8%	0.7%	12.0%	14.5%	13.1%	8.8%
Gorre	4.1%	6.7%	5.9%	4.6%	9.2%	7.0%	12.5%	7.2%	6.9%	5.3%	6.9%
Chéraute	6.4%	11.3%	8.5%	7.8%	15.0%	13.0%	14.9%	12.3%	11.3%	8.8%	10.9%
Charitte de bas	13.4%	15.5%	15.0%	14.6%	17.5%	17.3%	17.8%	15.7%	16.1%	13.3%	15.6%

Conclusion

The Saison got a good potential of production: 22 439 eq. smolts. The cumulative mortalities depend on the hydrology and vary between 10% and 25.9%. The more damageable facilities are Mauléon, Gotein and Charitte de bas. It appears to be essential to operate some changes at these HPP in order to decrease the total mortality on the section.

The authors of the report (S.I.E.E. & GHAAPPE, 2002) recommended to improve the efficiency of the downstream migration by adding another bypass at the top of the trash rack. It should improve the efficiency to 70%. In that case, the downstream migration channel must be resized because of the increase of discharge.

1.3.4. Upstream migration devices

At the dam, the fishes can use a pre-barrage fish pass to go upstream (2014).

- Flow in the fish pass: 1 m^3/s;
- 3 pools of 44, 49 and 62 m^2.

Table 10: Dimension of the pools of the pre-barrage fish pass at the water intake dam (source: (Atesyn, 2014)

	Pool 1		Pool 2		Pool 3		Downstream	
	Notch	weir/wall	Notch	weir/wall	Notch	weir/wall	Notch	weir/wall
	1.00	8.33		4.00		4.00		
Upstream	206.61	207.67		207.67		207.67		
			1.00	9.28				
Pool 1 (44 m^2)			206.33	207.45				
					1.00	13.38		
Pool 2 (49 m^2)					206.01	207.22		
							1.00	15.30
Pool 3 (62 m^2)							205.68	206.98

Figure 8: Location of the fish pass at the water intake dam

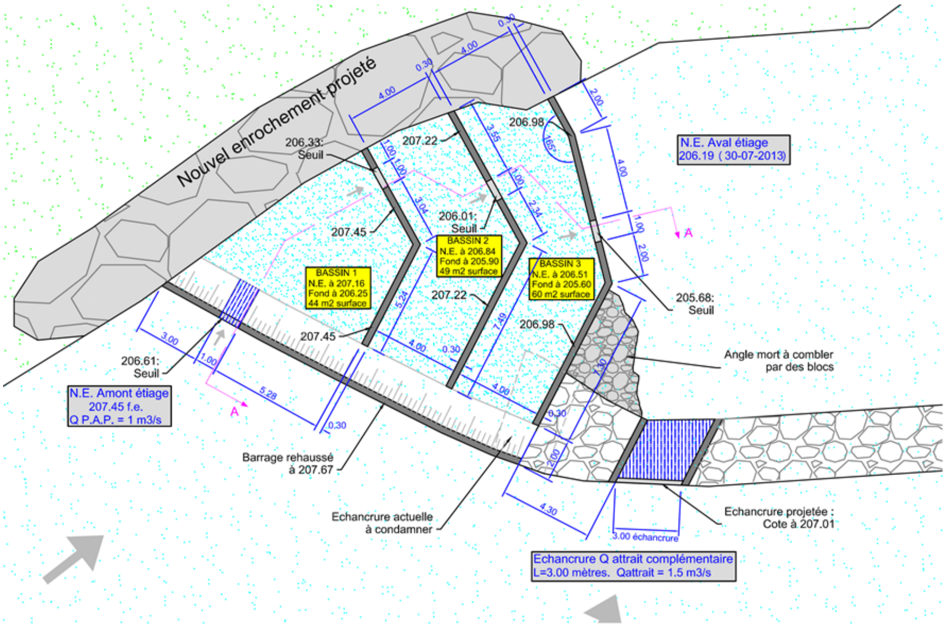

Figure 9: drawing of the pre-barrage fish pass at the dam (source : (Atesyn, 2014))

The dissipated energy in the pools is between 72 W/m^3 in low flow water periods and 196 W/m^3 when the discharge is 2 times the mean interannual discharge (≈44 m^3/s).

At the powerplant

Baffle fish pass (2014):

- 16% slope
- 4 portions 0.5*7.5 m + one portion 0.5*7 m connected with pools 3.0*2.0*1.0 m
- Flow in the fish pass : 150 l/s

Figure 10: upstream view of the baffle fishway

Eelpass (2014):

- 2 portions of 3 to 9 m long;
- 25-30% slope;
- Resting pools 1.5*1.0*0.5 m;
- Flow in the pass: a few l/s.

Figure 11: View of the eel pass and of the baffle fishway at Trois-Villes

2. Objectives on this Test Case

What we are planning?

In Trois-Villes different activities are planned:

- Assessment of the efficiency of the fish friendly water intake for smolts;
- Hydraulic modelling of the of the fish friendly water intake in order to characterize the attractiveness of the bypass;

Why are we planning this on this Test case?

The test case site of Trois-Villes is a small HPP with a fish friendly water intake. Most of actual design recommendations are respected on this test case.

What are we expecting?

We expect from this test case to consolidate the design recommendation for fish friendly water intake.

Relevance in FIThydro?

We will respond to some objectives of the project and WP2 like applying the existing SMTDs on a test case, have feedback on their use and application range.

3. Presentation and results of activities in FIThydro

3.3. Efficiency of downstream migration devices

3.3.1. Methodology

In 2016, a study was led by the French Agency for Biodiversity (AFB) in order to assess the efficiency of Trois-Villes' downstream migration device for Atlantic salmon smolts (Tomanova, et al., 2018).

3.3.1.1. Technology

The fishes are tracked with the PIT-Tag technology and detected with RFID antennas.

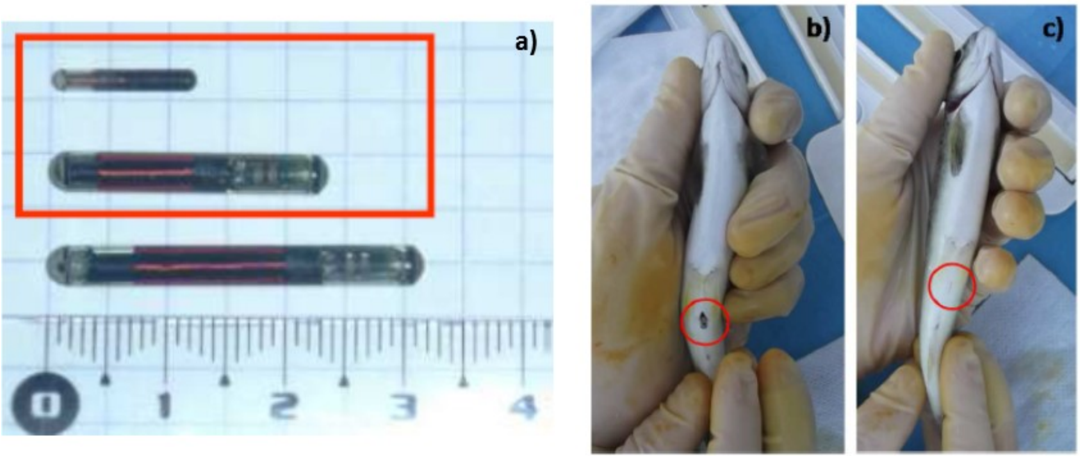

Figure 12: Tagging of fishes a) mark of 23 mm used b) and c) surgical insertion of the mark in the fish (source: (Tomanova, et al., 2018))

The fishes were marked between the 29th and the 30th of March 2016 at the fish farm of Castels. The fishes were anaesthetized with eugenol for the surgery. The 11th of April they were moved to Trois-Ville and stabled in a pool with non-stop water renewing.

6 batches of 50 fishes were released between 18h30 and 00h30 100m upstream the power plant, in the headrace channel, see Table 11.

Table 11: Number of fishes and their size for each batch, date and time of release on Trois-Villes' site (source : (Tomanova, et al., 2018))

Batches	Number of fishes	Date of release	Time of release		Size (mm)			
					Average	Standard deviation	Min	Max
TV_L1	50	12/04/2016	18:28	evening	187.7	10	166	205
TV_L2	50	12/04/2016	22:20	night	186.9	9.3	162	210
TV_L3	50	13/04/2016	00:12	night	185.8	8.3	165	205
TV_L4	50	13/04/2016	18:07	evening	186.3	9.4	161	211
TV_L5	50	13/04/2016	22:07	night	187.2	10.6	165	221
TV_L6	50	13/04/2016	23:34	night	185.7	10.6	159	204

3.3.1.2. Set of detection antennas

Two antennas were installed in the downstream migration channel (metal) downstream the control weir and one upstream, another antenna in the resting pool of the fish pass, one last was installed in the dump channel, see Figure 13. The dump channel is fed in water automatically when the discharge in the headrace channel is bigger than the max turbined discharge (a valve opens). The eel-pass was screened in order to avoid the smolts to enter it. If the fish is detected by an antenna in the downstream migration channel it means that it took this way of passage. The efficiency of the antennas in the channel was tested. 20 fishes were released one by one in the channel, than two groups of 5 fishes were released in the channel.

Table 12: Detection efficiency (%) of the antennas in the downstream migration channel (source: (Tomanova, et al., 2018))

	test ind20	test gr5-1	test gr5-2
EXU1	95	60	20
EXU2	90	20	0
EXU3	100	40	60
EXU1+2+3	100	80	60
EXU2+3	100	40	60

The efficiency decreases when several fishes go through the channel at the same time because of the collision between marks but the feedbacks on the other sites prove that in most case passage of smolts in the channel are more spaced. We supposed that every fish going through the channel will be detected by the antennas.

The detection by EXU1 doesn't allow confirming passage through the downstream migration channel because the antenna is before the control weir and the fishes can turn back.

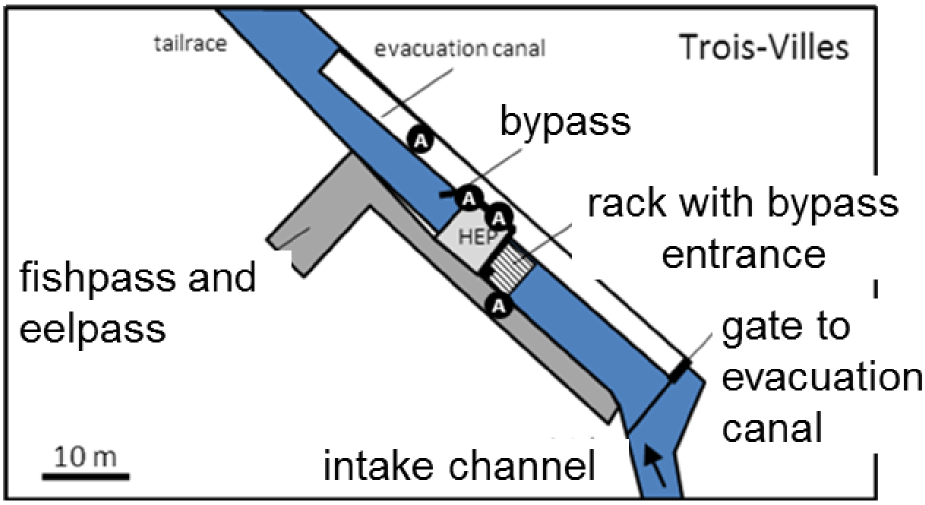

Figure 13: Pictures of the HPP and location of the antennas (source: (Tomanova, et al., 2018))

It is not possible to detect the fishes going through and the rack and therefor through the turbine. We will consider that non-detected fishes went through the turbine.

3.3.1.3. Hydrology of the Saison during the study

During the 5 days after the first release the discharge varied between 29 and 46 m^3/s. Most of fishes went downstream during this period. Trois-Villes HPP worked stable, the discharge in the headrace channel is controlled at the dam. An ADCP measurement the 19th of Mai revealed a discharge of 3.9 m^3/s in the headrace channel and 0.22 m^3/s in the downstream migration channel.

3.3.2. Results

30.7% of fishes went through the dump channel when the valve opens.

In average 61% of the fishes went through the downstream migration device and 0.7% used the fish pass, see Table 13.

When we exclude the fishes taking the dump channel, 87.5 % of fishes went through the downstream migration device and 1% through the fish pass.

Table 13: number and distribution of detected fishes or not in the different ways at Trois-Villes (in blue: batches released in the evening) a) with b) without fishes detected in the dump channel (source: (Tomanova, et al., 2018))

a)

Batch	Total of released fishes	Number of non-detected fishes	Number of fishes detected in			Percentage of fishes detected in			Total percentage of fishes gone
			bypasses	fish pass	dump channel	bypasses	fish pass	dump channel	
TV_L1	50	4	37	1	8	74	2	16	92
TV_L2	50	6	24		20	48	0	40	88
TV_L3	50	3	25	1	21	50	2	42	94
TV_L4	50	2	38		10	76	0	20	96
TV_L5	50	1	33		16	66	0	32	98
TV_L6	50	7	26		17	52	0	34	86

Mean efficiency	61	0.7	30.7	92.3
Standard deviation	12.6	1	10.6	4.6

b)

Batch	Total of released fishes	Number of non-detected fishes	Number of fishes detected in			Percentage of fishes detected in			Total percentage of fishes gone
			bypasses	fish pass	dump channel	bypasses	fish pass	dump channel	
TV_L1	42	4	37	1		88.1	2.4		90.5
TV_L2	30	6	24			80.0	0		80.0
TV_L3	29	3	25	1		86.2	3.4		89.7
TV_L4	40	2	38			95	0		95
TV_L5	34	1	33			97.1	0		97.1
TV_L6	33	7	26			78.8	0		78.8

Mean efficiency	87.5	1		88.5
Standard deviation	7.5	1.5		7.6

A Student test was run in order to detect an eventual difference of size between fishes taking the downstream migration device or non-detected. The mean size of fishes taking the downstream migration device (186.5 mm) is bigger than the one non-detected (183.4 mm). The student test revealed that this difference is not significant, see Figure 14.

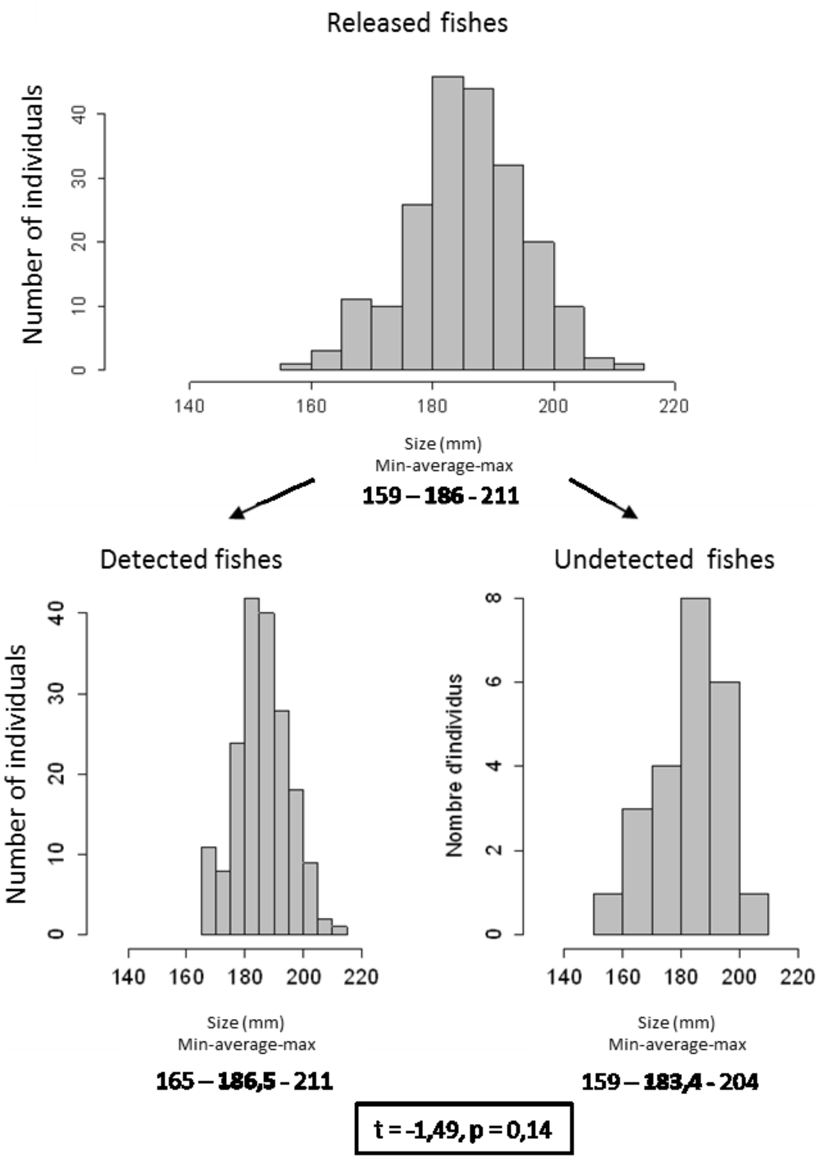

Figure 14: Distribution of released fishes' size, non-detected fishes' size and detected in the downstream migration channel fishes' size (source: (Tomanova, et al., 2018))

The timing was also studied. For all batches the first detections happened between 4 and 12 minutes after release. 50% of fishes take less than 1 hour to circumvent the power plant through the downstream migration device, 75 % need less than 3h15, see Table 14. The timing passage is longer for the fishes released in the evening than at night.

Table 14: Timing of passage of smolts for the different batches, in grey the batches released in the evening (source: (Tomanova, et al., 2018))

Exutoire et canal de transfert

	Nb d'ind.	min	Q25	mediane	Q75	max
LOT1	37	1:08:10	3:21:13	4:24:06	7:00:07	9:45:10
LOT2	24	0:12:11	0:21:43	0:54:07	1:42:09	4:06:33
LOT3	25	0:07:12	0:11:23	0:28:17	1:21:26	5:00:13
LOT4	39	0:06:41	0:46:15	1:11:41	3:49:30	40:58:52
LOT5	33	0:04:25	0:17:55	0:24:41	0:49:04	3:08:22
LOT6	27	0:08:55	0:18:03	0:37:32	1:06:16	16:35:00
Total	185	**0:04:25**	0:24:41	**1:02:01**	**3:15:39**	40:58:52

Canal de décharge

	Nb d'ind.	min	Q25	mediane	Q75	max
LOT1	8	2:45:05	3:11:58	3:33:18	4:21:07	6:49:54
LOT2	20	0:09:30	0:11:05	0:15:27	0:18:04	7:15:55
LOT3	21	0:03:27	0:05:49	0:10:20	0:18:12	1:23:00
LOT4	10	0:12:41	3:40:36	6:13:02	7:08:14	27:42:28
LOT5	16	0:07:39	0:22:30	0:33:22	1:32:47	23:12:45
LOT6	17	0:04:50	0:11:09	0:13:04	0:21:51	46:34:01
Total	92	**0:03:27**	0:11:06	**0:19:12**	**2:36:16**	46:34:01

3.3.3. Conclusion

The configuration of Trois-Villes is quite specific because of the presence of the dump channel. Its entrance is located in a calm area upstream the trash rack where the fishes stable. The dump valve opened regularly during the study, in short duration and suddenly. This area seems to be more used during night.

Some detections revealed that some fishes were detected by the first antenna in the downstream migration channel but then were detected in the dump channel. This shows a reluctance of fishes to go through the downstream migration device. However these reluctances don't question reaching a good efficiency.

Table 15: Summary of the distribution of fishes among the different ways, passage rate through turbines (this study) and their mortality rates (according (Voegtlé, 2010)), and global passage efficiency taking into account passage over the spillway, the downstream migration device and survival after passage through turbines (Tomanova, et al., 2018)

Dam		Power plant			
Proportion (%) of fish passing over the spillway of the dam	Proportion (%) of fish led to headrace channel	Proportion (%) of fish passing through the turbine	Mortality through the turbine (%)	Proportion (%) of fish assumed dead due to passage through the turbine	**Total survival rate at Trois-Villes**
8.4	91.6	7.02	11	0.77	**99.23**

3.4. Hydraulic modelling

In spring 2016, the AFB team made some measurements in order to assess the discharge assign to downstream migration.

3.4.1. ADCP measurements

These measures aim to assess the efficiency of the flow upstream the bar rack installed at Trois-Villes hydropowerplant.

The mapping of each component of the velocity results from the processing of these measures.

They allow validating, after computation of the tangential and normal velocities, the fish friendly criteria of the rack.

3.4.1.1. The technology used

The currentology measures upstream the bar rack have been made with an Acoustic Doppler Current Profiler (ADCP) StreamPro Teledyne RDI (Figure 15). The probe is equipped with 4 sensors which issuance-reception beams are inclined of 20° to the axis of the probe. The width of a beam is 3°. The probe is vertically settled and slightly immersed (a few cm). The device measures the water depth, and the 3 components of flow velocity within 20 measurements cells uniformly distributed along the water column. The division of the cells is continuous during the measures and defined according maximal depth provided by the operator. The frequency of measure acquisition is 1 Hz.

Figure 15: Pictures of the ADCP StreamPro assembled on its trimaran and the probe with a closer view of the 4 sensors

The data analysis is made by a software Teledyne Winriver II. Trois-Villes was the French first test case where the ADCP was tested. The protocol was not optimized. The choice was made to acquire the data continuously when the ADCP was moving along the section. The measure has uncertainties due to this acquisition mode: the ADCP is installed on a catamaran and is handled with a pole.

In Trois-Villes, four measurement sections have been made, see Figure 16.

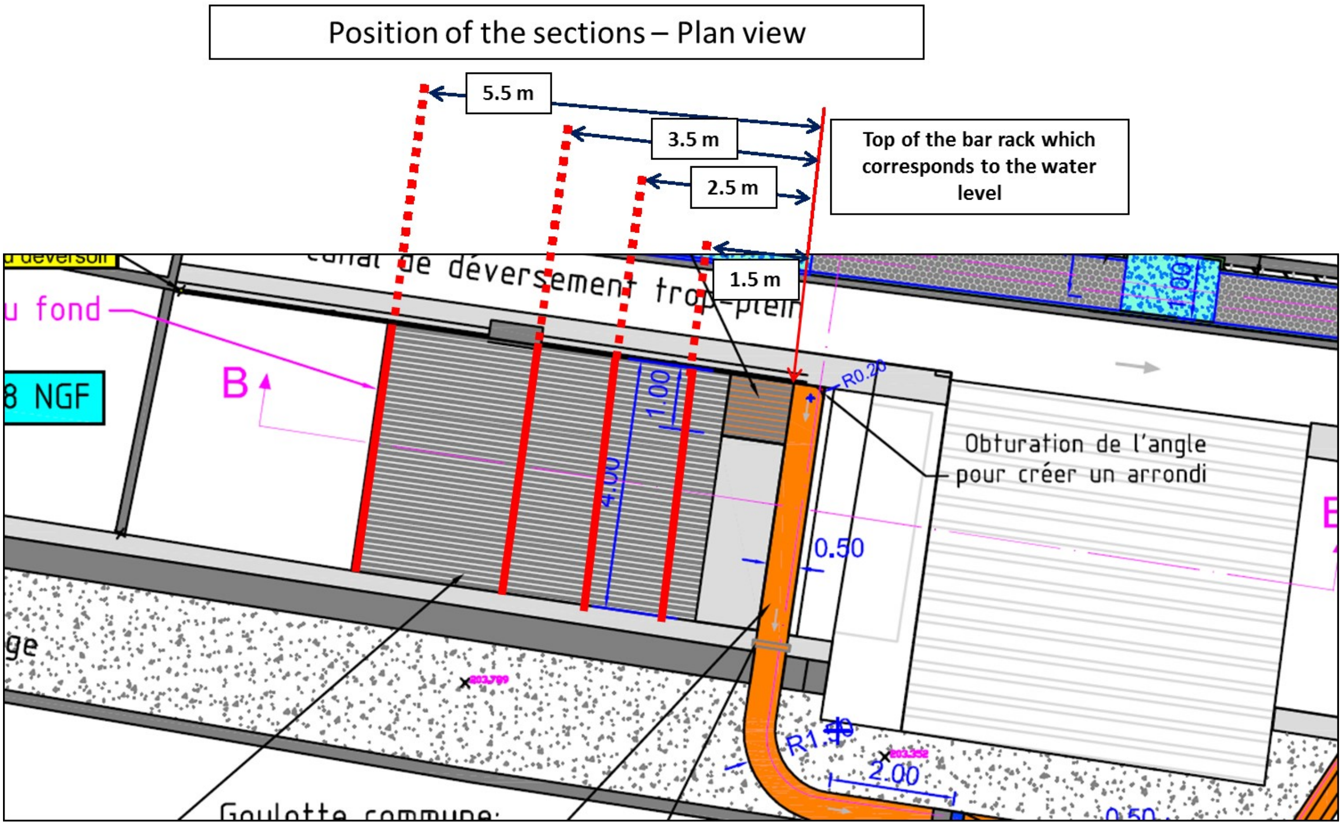

Figure 16: Positioning of the four sections upstream the bar rack in Trois-Villes

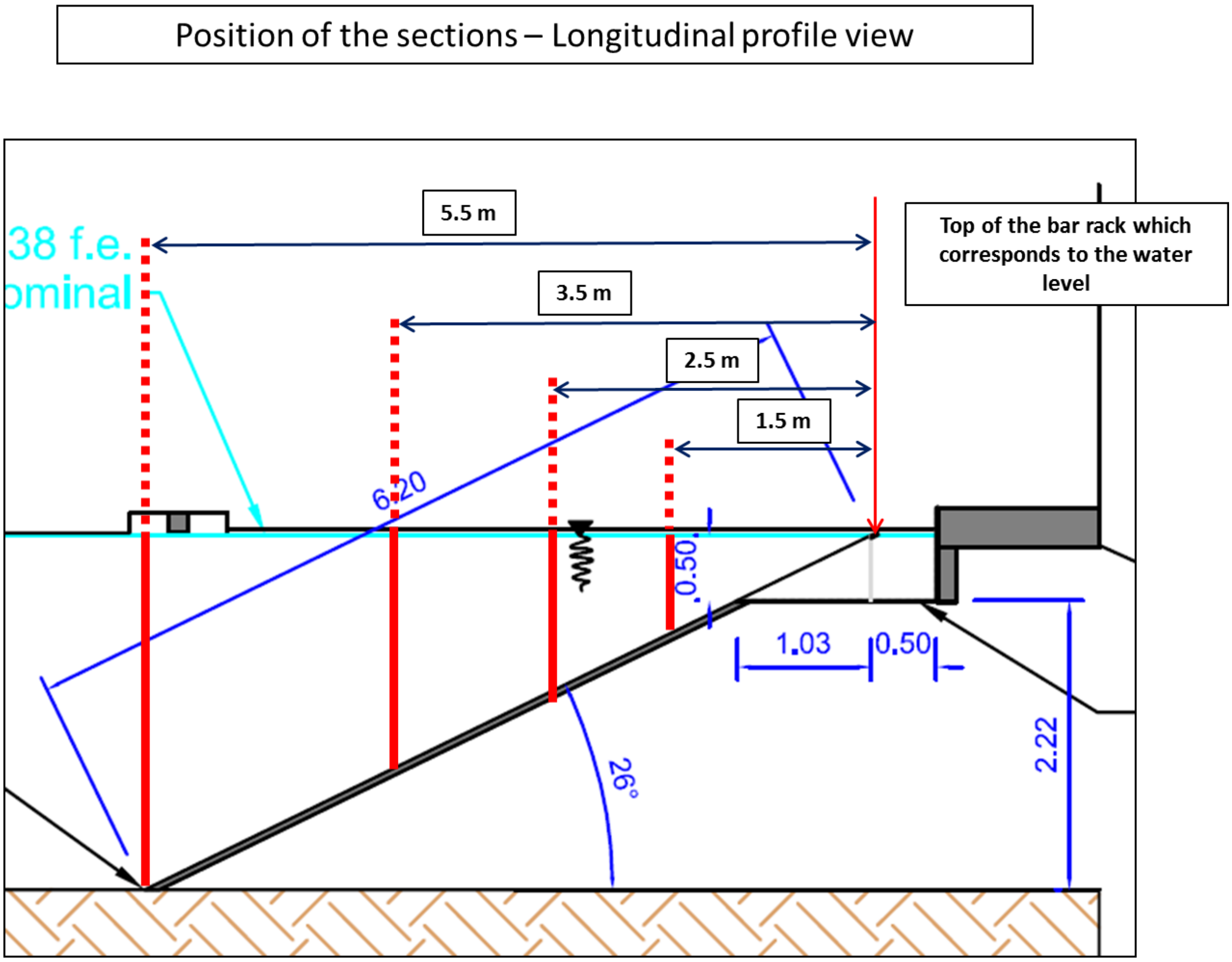

Figure 17: Positioning of the different sections

The North, East and Earth Up velocities are extracted, as well as the coordinates. These data are projected under Vx, Vy and Vz velocities. Then the outliers and empty values are delated. Finally, an average is made every 0.1 m.

The maps are made with the Tecplot software from these mean values by interpolation of the point according to the direction of Y and Z axes, see Figure 18 and Figure 19.

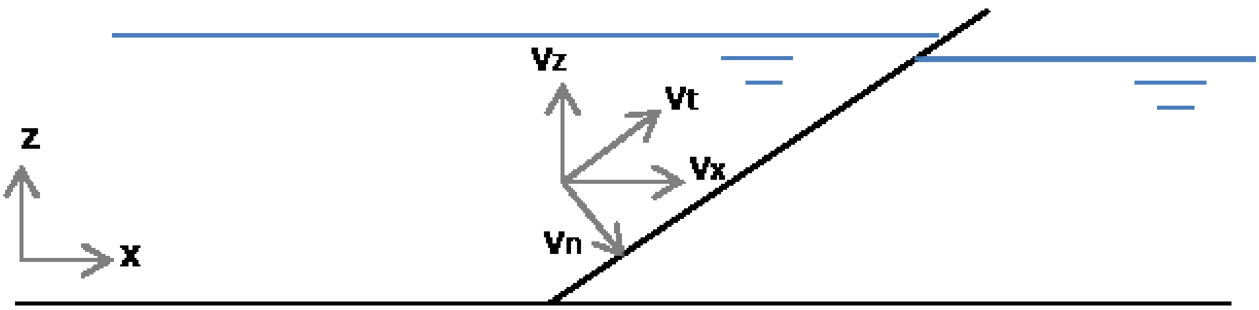

Figure 18: longitudinal section of a water intake and representation of the different components of the velocity

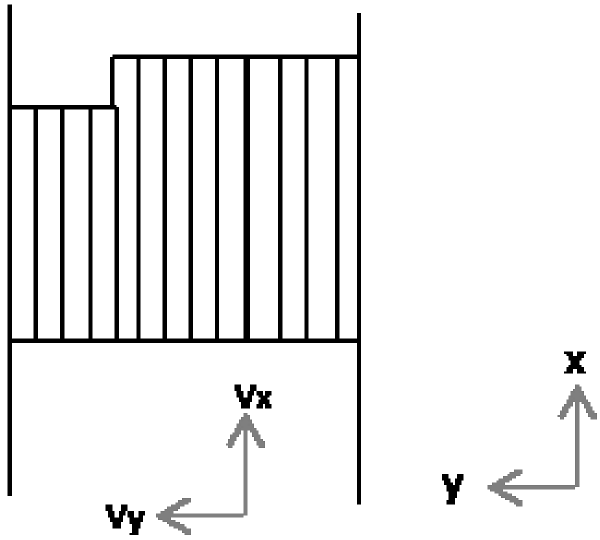

Figure 19: Plan view of a water intake and representation of the different components of the velocity

3.4.1.2. Conditions during the measurements

During the measurements the mean discharge in the Saison was 18 m^3/s.

3.4.1.3. Results

Figure 20 presents the cartography of components $\mathbf{V_X}$ and $\mathbf{V_Z}$ of the dimensionless velocity at the 3 transects. The bar rack is viewed from upstream. At the 2 transects located at 5.5 m and 3.5 m upstream the top of the bar rack the components $\mathbf{V_X}$ vary between 0.5 V_0 and 1.5 V_0.

Figure 21**Erreur ! Source du renvoi introuvable.** presents the cartography of tangential components $\mathbf{V_t}$ and normal $\mathbf{V_n}$ of the dimensionless velocity to the bar rack at the 3 transects. At the 2 transects located at 5.5 m and 3.5 m upstream to top of bar rack, the tangential components $\mathbf{V_t}$ present values between 0.5 and 1.5 time V_0. At the transect located 1.5 m upstream the top of the grid, the components $\mathbf{V_t}$ decrease significantly between -0.5 to 0.5 V_0 in front of the outlet. The normal components of the velocity $\mathbf{V_n}$ to the bar rack vary according the transects but are, in any case, lower than 50 cm/s.

Figure 22 presents the cartography of the ratio between tangential and normal velocities $\mathbf{V_t/V_n}$. The ratio $\mathbf{V_t/V_n}$ between 1 and 3.

Figure 23 presents the cartography of components $\mathbf{V_Y}$ of the dimensionless velocity at the 3 transects. The bar rack is viewed from upstream. The value of $\mathbf{V_Y}$ vary between -0.5 and 0.5 V_0.

Figure 24 presents the cartography of components $\mathbf{V_Y}$ of the dimensionless velocity of the transect located at 1.5 m upstream the rack. The value of $\mathbf{V_Y}$ vary between -0.5 and 0.75 V_0. The lateral attractiveness of the outlet seems good since the flow is directed to the outlet bypass.

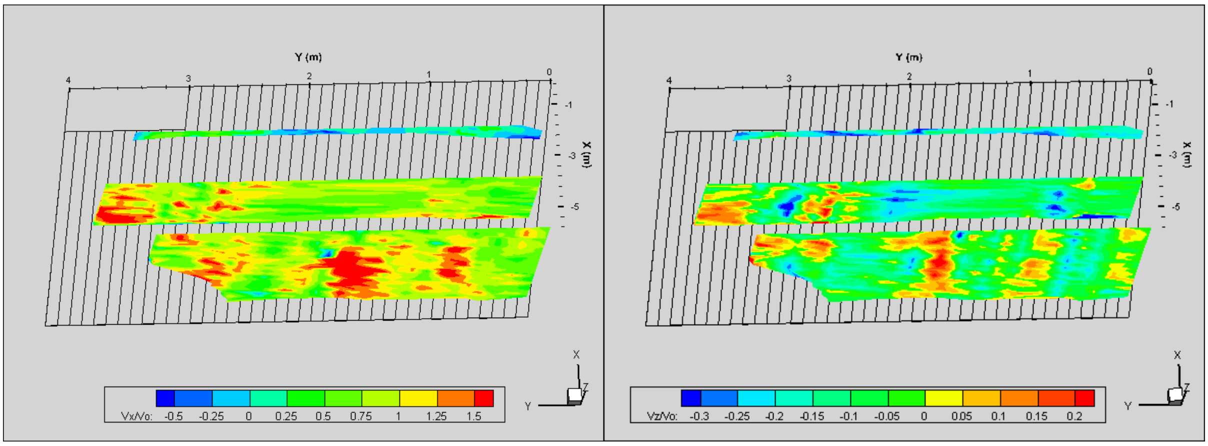

Figure 20: Cartographies of the normalised measured velocities Vx/Vo and Vz/Vo with Vo=0.43m/s

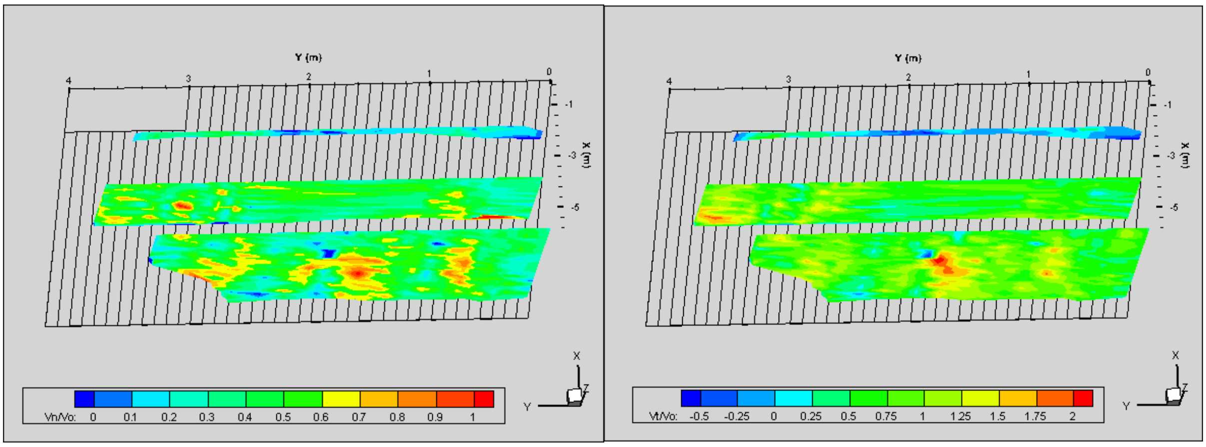

Figure 21: Cartographies of the normalised measured velocities Vn/Vo and Vt/Vo with Vo=0.43m/s

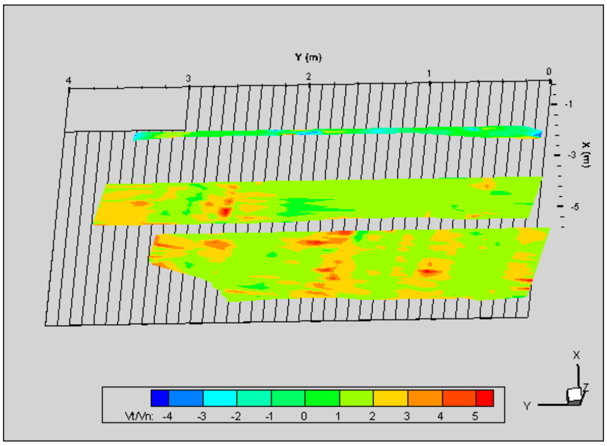

Figure 22: Cartographies of the ratio between normal and tangential velocities Vt /Vn

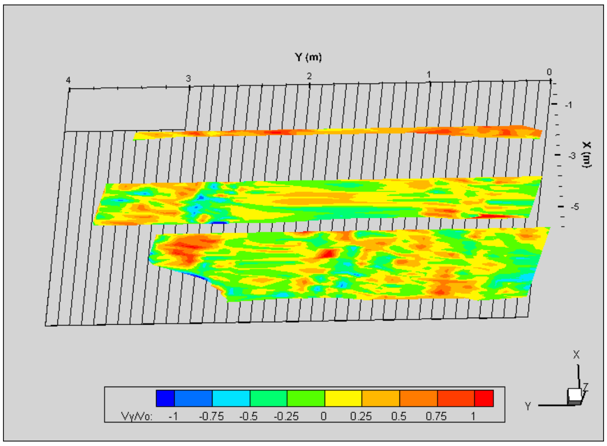

Figure 23: Cartographies of the normalised measured velocity Vy/Vo with Vo=0.43m/s

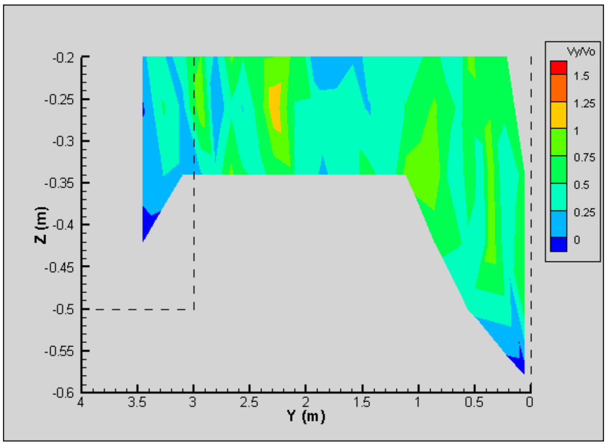

Figure 24: Cartographies of the normalised measured velocity Vy/Vo at x=1.5m with Vo=0.43m/s

3.4.2. Discharge measurements

They made ADCP measurements in the headrace channel 20 meters upstream the bar rack.

The data processing gives a global discharge in the headrace channel of 4.24 m^3/s.

Thanks to the law of spillways and the DEVER tool, developed by the AFB, the discharge over the control weir was calculated:

Table 16 : Calculation of the discharge over the weir

Water level upstream the control weir (under the gate)	0.670	m
Floor level upstream the control weir	0.150	m
Width of downstream migration channel	0.490	m
Width of control weir	0.490	m
Water height upstream the control weir (under the	0.520	m
Flow cross-section upstream the control weir (under	0.255	m²
Level of the control weir	0.300	m
Head on the weir	0.370	m
Discharge calculated by the DEVER tool	**0.224**	**m^3/s**
Flow velocity upstream	0.879	m/s

The calculated discharge is of 0.224 m^3/s, it is close to the targeted value of 200 L/s.

3.4.3. 3D Flow modelling

Methodology:

Numerical simulations have been performed using the multi-physics open-source library OpenFOAM (OpenField Operation And Manipulation), which provides solvers, meshing utilities and post-processing tools for various physics and mathematics problems. The code is written in C++ and solves partial differential equations (PDE) problems using the finite volume method. OpenFOAM is fully customizable and can address a number of fluid mechanics problems such as compressible and incompressible flows, multiphase flows, heat transfer, combustion, etc.

Free surface flow simulations of the laboratory bar-racks have been carried out using the interFOAM unsteady incompressible multiphase solver which solves the Navier-Stokes Equations (NSE) using the merged PISO-SIMPLE (PIMPLE) algorithm, and the phase concentrations using the VOF (Volume Of Fluid) method. The VOF method can be used to track free surfaces and fluid interfaces by considering the volume fractions of multiple fluids that are advected in the computational domain.

The full-scale simulations of the test-case HPP intakes have been conducted using the steady incompressible single phase simpleFoam solver, which solves the NSE using the SIMPLE algorithm.

Turbulence can be modelled using various approaches, and in particular the steady and Unsteady Reynolds-Averaged NSE (RANS and URANS) used in this study with the k-epsilon turbulence model.

Meshing

For all simulations, channels have initially been defined as cartesian blocks with base cell size set to 1 cm. Bar racks and bypass structures have been modelled as CAD elements which have then been subtracted for the initial blocks using mesh castellation and local surface adaptation. The openFOAM utilities blockMesh and snappyHexMesh have been used to perform these pre-processing operations.

Results

Single-phase numerical simulations have been carried out at full scale for the test-case HPP of Las Rives. The intake channel is 4 m wide with a water depth of 2.72 m. The 4 m wide bar rack is vertically inclined at 26° with respect to the river bed, comprising 8 mm thick bars with hydrodynamic profile, 20 mm free spacing between bars, and horizontal spacers. The total inflow is nominally set at 4.67 m^3/s, from which 0.224 m^3/s discharges through the bypass on the right bank of the intake channel.

The numerical simulations of the free surface are represented as a fixed horizontal boundary with the slip condition at the nominal water height. Figures 25 to 28 show the bar rack with its supporting elements, terminated by the entrance bypass channel.

The resulting average approach velocities at 3 stations along the rack are represented in Figures 25 (longitudinal and vertical velocity components), 26 transverse velocity component and 27 (tangential and normal velocities). The tangential-to-normal velocity ratio is presented in Figure 28. The velocities are in agreement with the fish friendly criteria and the measurement campaign.

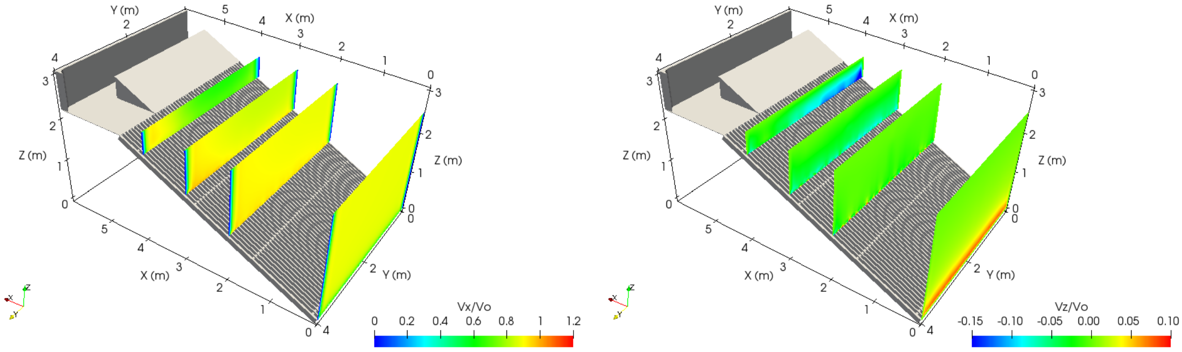

Figure 25:Cartographies of the normalised numerical velocities Vx/Vo and Vz/Vo with Vo=0.43m/s

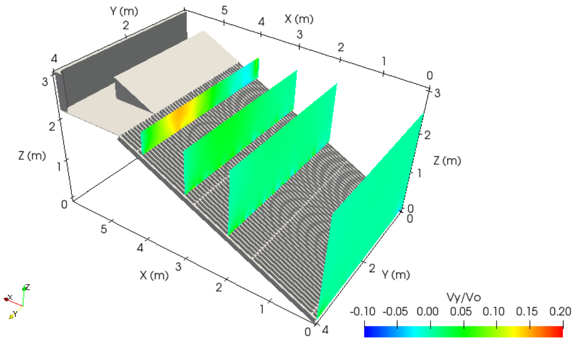

Figure 26: Cartographies of the normalised numerical velocity Vy/Vo with Vo=0.43m/s

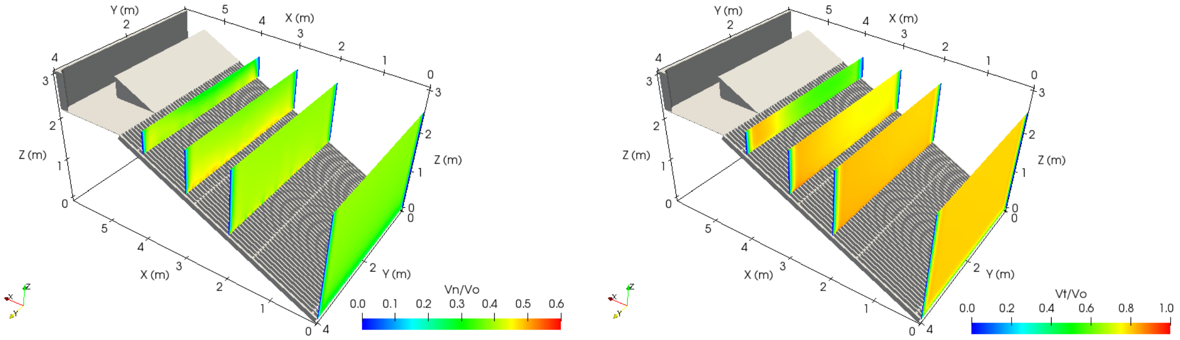

Figure 27: Cartographies of the normalised numerical velocities Vn/Vo and Vt/Vo with Vo=0.43m/s

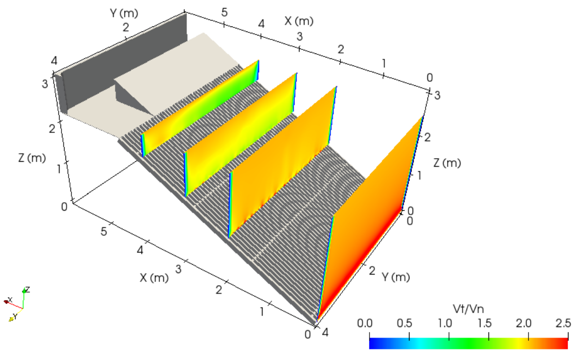

Figure 28: Cartographies of the ratio between normal and tangential velocities Vt /Vn

Figure 29 shows the velocity distribution and streamlines at free-surface level upstream of and across the bypass channel. The curvature of the streamlines shows the attractiveness of the bypass entrance with a velocity Vx between 1 to 1.25 Vo at the bypass entrance and a recirculation zone near the deflector. The velocity Vx tend to diminish in the downstream migration channel since the direction is changed laterally.

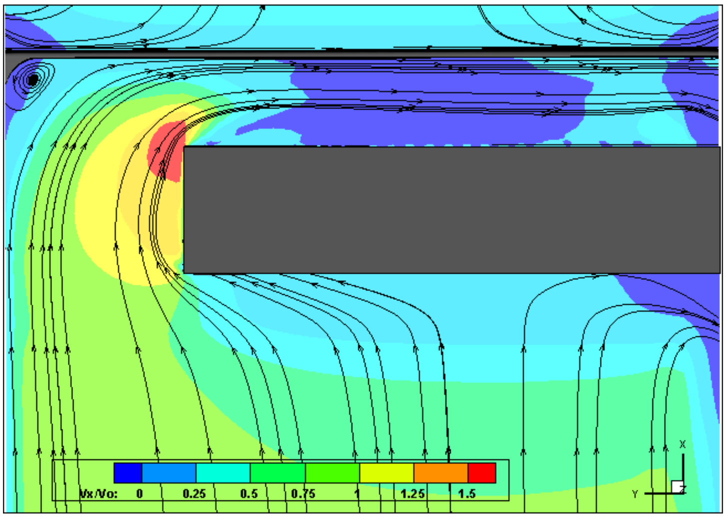

Figure 29: Top view of the slice at z=2.37m of the normalised axial velocity Vx/Vo with Vo=0.43m/s and the streamlines of the flow.

4. Conclusion of the activities

The Trois-Villes test case consists in a small HPP with a fish friendly water intake. Most of the current design recommendations are respected on this test case for both upstream and downstream migration. The configuration of Trois-Villes is quite specific because of the presence of the dump channel. Its entrance is located in a calm area upstream of the trash rack, in which the fishes stable. The dump valve regularly opened during the study, suddenly and for short durations. This test case is used for evaluating the efficiency of an inclined low bar spacing trashrack and for validating the discharge calculated using 3D modelling inside the bypasses as well as the tangential and normal components of the upstream velocity. ADCP measurements have been used to monitor the discharge of the HPP. The tangential and normal components of the velocity have been measured with ADCP and are in good agreement with the 3D numerical modelling. Pit-tag measurements have been carried out on six batches of 50 smolts over days during which the discharge varied. Fishes were released in the headrace channel and used different paths ways to migrate downstream. 30.7% of the fishes went through the dump channel when the valve opened. In average, 61% of the fishes went through the downstream migration device and 0.7% used the fish pass. The total survival rate is 99.23%.

5. References

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