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Tests for evaluating damage to fish species migrating downstream during their transit through the VLH hydraulic turbine installed on the Tarn River in Millau.

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Report on tests run in May and June 2013.

View of the VLH, with injection tubes and the frame of the recovery net.

Author: T. Lagarrigue July 2013

(Translation of the French Language original report)

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Report on tests run in May and June 2013.

Several tests have been run for the downstream migration of smolts and silver eels as they pass through the VLH turbine at the Troussy (ECOGEA, 2007, 2008a and 2008b) and then after changing the VLH's hydraulic contour at the Frouard sur la Moselle (ECOGEA, 2011)[1] site. These tests were all performed with the VLH fully open and operating at full power.

Following some questions from ONEMA (Office National de l'Eau et des Milieux Aquatiques National French, the administration responsible for all aspects of water policy) on the downstream migration of fish through a partially open VLH, MJ2 Technologies decided to launch a new series of tests to assess the impacts to fish species transiting through a VLH operating in these conditions.

These tests were conducted from May 27 to June 7, 2013 on a VLH DN 5000, with spherical runner housing installed on the La Glacière site, which is located on the left bank of the Tarn River, immediately downstream of Millau.

This report presents the first results that were obtained in completion of these tests.

1. Site description

The average annual flow of the Tarn in Millau, downstream of the confluence with the Dourbie, is approximately 47 m^3/s, with a watershed of 2.170 km² (Hydro bank data - Station No. 03401010).

La Glacière site on the Tarn River downstream of Millau

La Glacière site is located on the left bank of the Tarn, immediately downstream of Millau.

Since 2013, the plant has been equipped with a DN 5000 VLH turbine with spherical runner housing and hub, which passes a flow of 23,5 m^3/s at 1.8 m of net head.

[1] These reports are available upon request from ECOGEA.

The Kaplan type runner has 8 blades with variable settings, measuring 5 m in diameter. During testing, the rotational speeds ranged from 27 to 30 rev/min.

La Glacière VLH operating at full capacity

La Glacière tailrace with VLH raised

2. Testing protocol

As in previous trials (ECOGEA 2007, 2008a, 2008b and 2011)[2], the test protocol was developed in consultation with ONEMA. (Office National de l'Eau et des Milieux Aquatiques)

2.1. Biological material

2.1.1. ***Species selection and size classes***

The focus here is on large salmonids (Atlantic salmon and sea trout) in two specific stages of their life cycle:

- adults at the "spent" stage: in post-breeding downstream migration,
- juveniles at the "downstream migrating smolt" stage: when descending the river to reach the ocean.

Since it was not possible to get salmon and sea trout for these tests, we used farmed rainbow trout (called FRT below).

We faced some difficulties with these fish:

- It was difficult to obtain large quantities (we used approximately 700 kg) of high quality large FRT (no trace or malformation, perfect health), which is why there was relatively few fish per batch,
- These fish are mostly iteroparous spawners, which are intensively bred to produce a maximum number of eggs. They are fragile and quite difficult to transport and handle, especially after a few days of containment.

[2] These reports are available upon request from ECOGEA.

	Large trout		Very large trout		Small trout	
	L (cm)	W (kg)	L (cm)	W (kg)	L (cm)	W (kg)
Average	48.2	1.6	68.9	5.1	23.2	131.8
Median	46.8	1.4	70.5	5.3	23.5	131.5
Minimum	42.5	1.1	64.0	4.5	20.0	96.0
Maximum	57.0	2.9	72.2	5.6	26.0	163.0

Main characteristics of FRT used for testing in Millau

Three size classes were used:

- Adult FRT, hereinafter referred to as “large trout”, between 43 and 57 cm long (1.1 to 2.9 kg), close to the size of large adult salmonids at the spent stage.
- Juvenile FRT, hereinafter referred to as “small trout”, between 20 and 26 cm long (96 to 163 g), close to the size of large salmonid smolts migrating downstream.
- In addition to this, a test was performed with some very large FRT adult specimens, herein after referred to as "very large trout", between 64 and 72 cm long (4.5 to 5.6 kg) to simulate the downstream migration of large spent salmonid specimens.

Large trout after injection


Very large trout after injection

Each fish was thoroughly inspected before injection and after recovery. Any visible external marks were photographed before the fish were injected to identify them easily during retrieval and be able to differentiate these from other possible injuries caused by the turbine or the recovery device.

	Small tench		Small common carp		Large tench		Large common carp	
	L (cm)	W (g)	L (cm)	W (g)	L (cm)	W (g)	L (cm)	W (g)
Average	23.1	170	19.9	154	43.1	953	48.2	1414
Median	23.5	161	18.7	116	43.5	933	46.0	1308
Minimum	17.4	63	14.0	40	36.8	606	38.9	528
Maximum	30.5	358	25.6	316	47.5	1335	66.1	3120

Main characteristics of tench and common carp used for testing in Millau

Finally, at the request of the German Government, some additional tests were performed on common carp and tench, between 14 and 66 cm long (40 g to 3.120 kg).

Small tench after injection

Large carp after injection

2.1.2. Origin and number of specimens

Rainbow trout came from Charles Murgat's Les Fontaines salmon farm, located in Beaufort (Alps, France). Approximately 350 large trout, 10 very large trout, and 550 small trout were supplied for testing, for a total of nearly 700 kg of FRT.

Common carp and tench came from Sylvain Labat's En Férié fish farm, located in Thil (Toulouse Area, France). Approximately 100 large and 200 small common carp and tench were supplied for testing, for a total of nearly 150 kg of these cyprinids.

2.2. Storage conditions

Given the substantial biomass to be stored, the fish were contained in two locations:

- In 12 floating fish boxes (of about 1 m^3 each) installed directly on the Tarn River in a quiet area downstream of and close to the La Glacière VLH site, or

Fish boxes to store fish, installed on another site

- In 8 circular tanks (600 liters capacity) with surface overflows, installed near the VLH site and continuously supplied with water from the Tarn River by two high capacity submersible pumps.

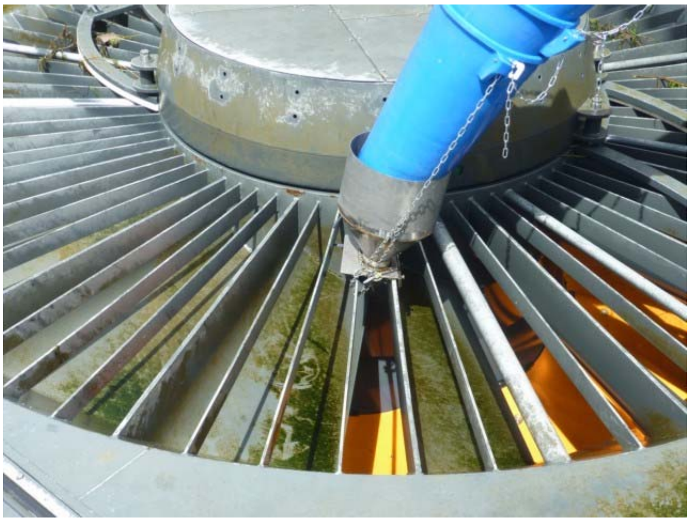
Circular storage tanks with overflows in Millau

2.3. Injection device

Stacked components of the injection tube

Injection tubes installed at mid-blade and at the runner periphery

The fish are injected through a PVC tube with a very smooth inside surface, including the various adjustable elements and couplings (male to female). This prevents any rough areas in the tube and allows the tube to be bent to some degree depending on the position of the injection point. However, the disadvantage of these tubes is that the connections between different components are not sealed, which can substantially reduce the vacuum that gets generated by the turbine in the injection tube.



Injection tube exit between the trash-rack bars - at the hub

Injection tubes exit between the trash-rack bars - at mid-blade and at the runner periphery

The plastic components of the injection tube lead into a metallic cone, which creates a smaller outlet diameter to guide the fish through the bars of the VLH trash rack. Particular attention was given to make sure the metal cone's inner surface was perfectly smooth.

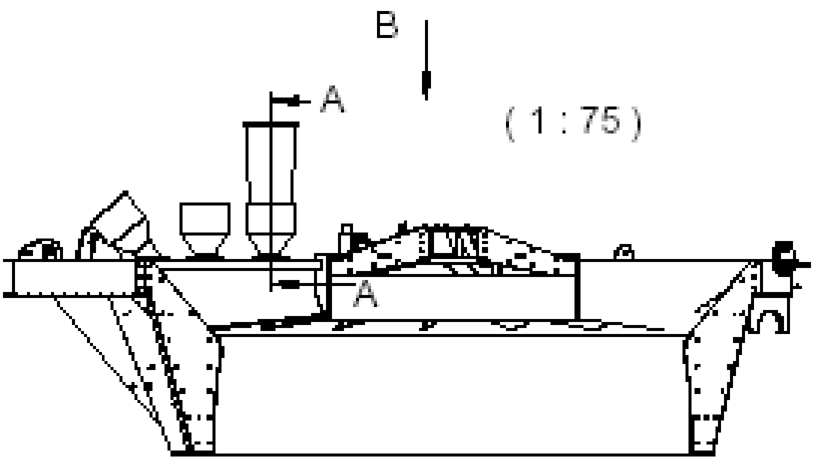
2.4. Injection points

To obtain an estimated rate of mortality that is as accurately representative as possible, three injection points between the hub and the runner periphery were tested, so that it can be considered as the whole runner area. The mortality rate is then obtained by calculating an arithmetic average of observed mortality rates at each injection point.

Positioning at the inside (hub) point

Position at the median point (mid-blade) on the left and external (at the runner periphery) on the right

While the injection is done perpendicular to the machine at the hub and mid-blade points, it is tangential to the runner housing at the runner periphery, which prevents the injected fish from hitting the metal cone when they exit the injection pipe.



Positioning of the 3 injection points, perpendicular to the VLH for the hub and mid-blade points, and tangential to the runner housing at the runner periphery.

2.5. VLH operating conditions

To consider partial blade openings, three blade opening settings were tested:

- A first test with a 100% opening, to validate the absence of mortality at full opening, which is supposed to be the least detrimental to the fish when they pass through,
- A second intermediate test with a 75% opening, and
- A third test with a 50% opening, which is supposed to be the most detrimental to the fish when they pass through.

These three blade settings cover the vast majority of situations encountered under normal VLH operating conditions (there is almost no turbine operation at opening <50%).

As far as the supplementary test on common carp and tench is concerned, only two blade openings were tested (50% and 100%).

2.6. Number of specimens per batch

The batches are made up of 30 large FRT and 50 small FRT. The low number of fish per batch means that **for every single dead fish at an injection point at a given blade setting, the mortality rate is 3.3% (1/30) for large FRT and 2% (1/50) for small FRT.**

2.7. Number of test batches

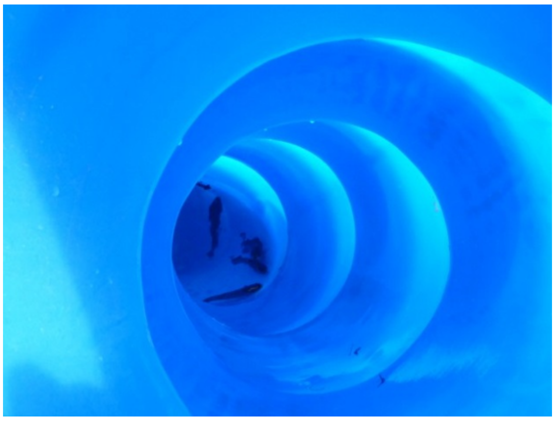
For each FRT size class (large and small), 10 test batches were established:

- One control batch: this batch, made up of 30 large or 50 small FRT, was subjected to the same handling as the other test batches, except that the fish were not made to pass through the turbine (control batch fish were injected immediately downstream of the turbine, directly in the net). This batch then allowed us to assess the impact of the testing method (transport, handling, and holding conditions), as well as of the injection and recovery equipment, separate from that of the turbine.
- Nine test batches (three injection points X 3 blade openings), made up of 30 large or 50 small FRT each.

Each batch was kept for at least 48 hours after passing through the VLH to assess the potential deferred mortality, which could be due to internal injuries that were not visible during the eye examination and/or to non-immediate lethal injuries.

2.8. Adjustments made to improve recapture rates

The recapture rates of the first two batches of trout that were tested were poor as they barely reached 20%. The connections between the various injection tube plastic components were not tight and allowed water and/or air to enter the tube. Therefore, the suction caused by the turbine was low in the tube and even lower with reduced blade openings.



Trout settling on the inside surface of the injection tube

We also observed that some fish settled in the injection tube.

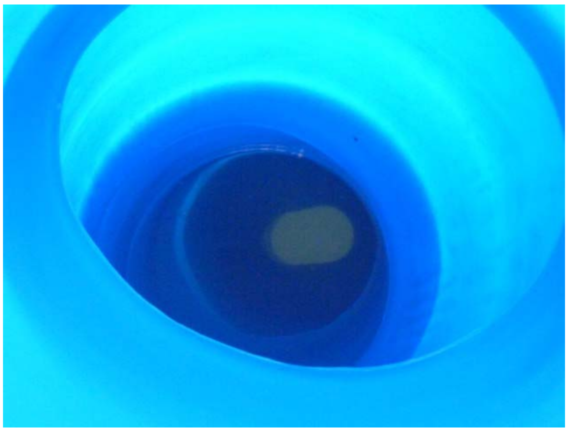
Although no mortalities were observed in these two recaptured batches, it was decided that the test was to be redone with a light anaesthetic given to the fish. This significantly improved recapture rates and all the trout batches injected at the hub (three batches of large and three batches of small trout) were lightly anaesthetized.

However, once the hub tests were done, anaesthetics were no longer used, but rather a submersible pump was installed to continuously feed water from the Tarn River into the injection tube at each of the different injection spots (moved from the hub to the mid-span and to the runner periphery).

Running water continuously into the injection tube

Using this method, the recapture rate improved significantly and the majority of the rates were better than those for the anaesthetized fish. The use of anaesthetics was stopped altogether at this time. All batches tested at mid-blade and at the runner periphery did not receive anaesthetics, nor did any of the batches of carp and tench.

When injecting at the runner periphery, we were able to see the bottom of the injection tube and the blades of the VLH since the injection tube was not curved.



Injection tube exit and blades at the runner periphery

This enabled us to observe the fish gradually swimming in the tube until they were drawn down to the end of the tube by the turbine suction and to verify that no fish were settling in the tube. However, even with this method, the recapture rate was still not consistently 100%, concluding the only possibility for trout to escape was to:

- Either stay in the eddies downstream of the turbine (very rough and very aerated flows between the VLH exit and the recovery net entry).
- Find holes in the net, which is a less likely scenario, especially for large trout, given that the net was systematically inspected several times onshore.

3. Key results

3.1. Recapture rates

3.1.1. Large and very large trout

Batch #	Injection point	Opening %	Size	Anaesthetic	# Injected	# Recaptured	Recapture rate
1	Hub	100	Large	Yes	19	14	73.7%
2	Hub	75	Large	Yes	30	21	70.0%
3	Hub	50	Large	Yes	30	24	80.0%
4	Hub	100	Very large	No	10	8	80.0%
5	Periphery	100	Large	No	30	21	70.0%
6	Periphery	75	Large	No	30	24	80.0%
7	Periphery	50	Large	No	30	24	80.0%
8	Mid-blade	100	Large	No	30	22	73.3%
9	Mid-blade	75	Large	No	30	24	80.0%
10	Mid-blade	50	Large	No	30	23	76.7%
11	Periphery (dead)	100	Large	Dead	30	30	100.0%
12	Control Group		Large	No	30	30	100.0%

Recapture rates for large and very large trout

The average recapture rate for large trout was 76% on test batches #1 to #10. It varied from 70% to 80%, depending on the batch.

The recapture rate for very large trout (Batch #4) was 80%.

The recapture rate of the large trout Control Group (Batch #12) was 100%.

Batch # 11: large dead trout

Because recapture rates were not 100% on the test batches, a batch made up of 30 large dead trout was prepared, which was injected at the runner periphery, with a 100% opening. For this batch of large dead trout (Batch #11), a recapture rate of 100% was achieved, which allows us to assume that **non-recaptured fish from the test batches are living fish,** able to swim actively downstream of the VLH, upstream of the net and/or to find a hole in the net to escape.

3.1.2. *Small trout*

Batch #	Injection point	Opening %	Size	Anaesthetic	Number injected	Number recaptured	Recapture rate
1	Hub	100	Small	Yes	50	46	92.0%
2	Hub	75	Small	Yes	50	38	76.0%
3	Hub	50	Small	Yes	49	40	81.60%
4	Periphery	100	Small	No	50	45	90.0%
5	Periphery	75	Small	No	50	43	86.0%
6	Periphery	50	Small	No	50	42	84.0%
6	Mid-blade	100	Small	No	50	41	82.0%
8	Mid-blade	75	Small	No	50	38	76.0%
9	Mid-blade	50	Small	No	50	36	72.0%
10	Periphery (dead)	100	Small	Dead	40	36	90.0%
11	Control Group		Small	No	50	50	100.0%

Recapture rates for small trout

Of the test batches (Batch #1 to #9, the average recapture rate for small trout was 82%. It varied from 72% to 92%, depending on the batch.

The recapture rate of the small trout Control Group (Batch #11) was 100%.

The fact that recapture rates are higher for small trout than for large trout reinforces the hypothesis that lost fish probably settled between the area downstream of the VLH and the recovery net entry (large trout with better swimming capabilities than small trout) compared to the other hypothesis that there are holes in the net (small trout more able to escape through potential holes in the net).

Batch #10: small dead trout

Because recapture rates were not 100%, we prepared a batch with 40 small dead trout that we injected at the runner periphery, with a 100% opening. For this batch of small dead trout (Batch #10), the recapture rate was high but not complete (90%).

3.1.3. *Small and large carp/tench*

Batch #	Injection point	Opening %	Species	Size	# Injected	# Recaptured	Recapture rate
1	Hub	100	Carp	Large	15	15	100.0%
2	Hub	50	Carp	Large	15	15	100.0%
3	Periphery	100	Carp	Large	10	10	100.0%
4	Periphery	100	Tench	Large	10	10	100.0%
5	Periphery	50	Carp	Large	15	15	100.0%
6	Mid-blade	100	Carp	Large	15	15	100.0%

7	Mid-blade	50	Carp	Large	15	15	100.0%

Recapture rates for large carp/tench

The recapture rate for large carp/tench was 100% for 7 test batches.

Batch #	Injection point	Opening %	Species	Size	# Injected	# Recaptured	Recapture rate
8	Hub	100	Tench	Small	25	24	96%
9	Hub	50	Carp	Small	31	31	100%
10	Periphery	100	Tench	Small	25	23	92%
11	Periphery	50	Tench	Small	29	29	100%
12	Mid-blade	100	Tench	Small	30	27	90%
13	Mid-blade	50	Tench	Small	30	28	93%

Recapture rates for small carp/tench

The average recapture rate for small carp/tench was 95%. It varied from 90% to 100% depending on the batch.

The fact that recapture rates were almost 100% and, therefore, significantly higher for carp/tench than for trout, also strengthens the hypothesis that lost trout probably settled between the area downstream of the VLH and the recovery net entry (trout swimming capabilities are far superior to those of carp/tench, especially in 12 °C water).

3.2. Immediate mortality rate and after 48 hours of observation

3.2.1. Large and very large trout

Batch #	Injection point	Opening %	Size	Anaesthetic	# Injected	# Re-captured	Mortalities				Mortality rate
							Immediate	After 24hr	After 48hr	Total	
1	Hub	100	Large	Yes	19	14	0	0	0	0	0.0%
2	Hub	75	Large	Yes	30	21	0	0	0	0	0.0%
3	Hub	50	Large	Yes	30	24	1	1	0	2	6.7%
4	Hub	100	Very large	No	10	8	0	0	0	0	0.0%
5	Periphery	100	Large	No	30	21	0	0	0	1	3.3%
6	Periphery	75	Large	No	30	24	0	1	0	1	3.3%
7	Periphery	50	Large	No	30	24	1	1	0	2	6.7%
8	Mid-blade	100	Large	No	30	22	0	0	0	0	0.0%
9	Mid-blade	75	Large	No	30	24	0	0	0	0	0.0%
10	Mid-blade	50	Large	No	30	23	0	0	0	0	0.0%

11	Periphery (dead)	100	Large	Dead	30	30					
12	Control Group		Large	No	30	30	0	0	0	0	0.0%

Mortality rates for large and very large trout

Calculation method:

No mortalities were observed in the Control Group (Batch #12). Based upon the established hypothesis that all lost (not-recaptured) fish can be considered alive (total recapture rate for the batch of large dead trout) for each batch, the mortality rates were calculated by dividing the total number of fish in the batch that were dead after 48 hours of observation by the total number of fish in the batch that were injected into the VLH.

For large trout, out of 9 batches injected, there were mortalities in 4 of them:

- Batch #3 – Injected at the hub, 50% opening, 1 dead trout in the recovery net and one trout died after 24 hours of observation.
- Batch #5 – Injection at the runner periphery, 100% opening, 1 dead trout in the recovery net.
- Batch #6 – Injection at the runner periphery, 75% opening, 1 dead trout after 24 hours of observation.
- Batch #7 – Injection at the runner periphery, 50% opening, 1 dead trout in the recovery net and one dead trout after 24 hours of observation.

Mortality rates were 3.3% (1 fish) for Batches 5 and 6, and 6.7% (2 fish) for Batches #3 and #7. They were zero on all other batches, including the Control Group (Batch #12).

For very large trout, no immediate mortalities or deferred mortalities after 48 hours of observation were observed when the injection was at the runner periphery, with a 100% opening. However, because we only had a small number of fish of this size at our disposal, we were not able to test other injection points and/or other blade openings.

3.2.2. Small trout

							Mortalities				Mortality rate
Batch #	Injection point	Opening %	Size	Anaesthetic	# Injected	# Re-captured	Immediate	After 24hr	After 48hr	Total	
1	Hub	100	Small	Yes	50	46	0	0	0	0	0.0%
2	Hub	75	Small	Yes	50	38	0	0	0	0	0.0%
3	Hub	50	Small	Yes	49	40	0	0	0	0	0.0%
4	Periphery	100	Small	No	50	45	0	0	0	0	0.0%
5	Periphery	75	Small	No	50	43	0	0	0	0	0.0%
6	Periphery	50	Small	No	50	42	0	0	0	0	0.0%
7	Mid-blade	100	Small	No	50	41	0	0	0	0	0.0%

8	Mid-blade	75	Small	No	50	38	0	0	0	0	0.0%
9	Mid-blade	50	Small	No	50	36	0	0	0	0	0.0%
10	Periphery (dead)	100	Small	Dead	40	36					
11	Control Group		Small	No	50	30	0	0	0	0	0.0%

Mortality rate for small trout

No immediate or deferred (after 48 hours) mortalities were observed for small trout, in any of the nine batches tested or in the Control Group (Batch #11). Mortality rates are therefore zero for this size class (20 to 26 cm, 96 to 163 g).

3.2.3. Small and large carp / tench

Batch #	Injection point	Opening %	Species	Size	# Injected	# Re-captured	Mortalities				Mortality rate
							Immediate	After 24hr	After 48hr	Total	
1	Hub	100	Carp	Large	15	15	0	0	0	0	0.0%
2	Hub	50	Carp	Large	15	15	0	0	0	0	0.0%
3	Periphery	100	Carp	Large	10	10	0	0	0	0	0.0%
4	Periphery	100	Tench	Large	10	10	0	0	0	0	0.0%
5	Periphery	50	Carp	Large	15	15	0	0	0	0	0.0%
6	Mid-blade	100	Carp	Large	15	15	0	0	0	0	0.0%
7	Mid-blade	50	Carp	Large	15	15	0	0	0	0	0.0%

Recapture rates for large carp/tench

No immediate mortalities or deferred mortalities (after 48 hours) were observed in any of the seven large carp/tench batches tested. Mortality rates are therefore zero for this size class (37 to 66 cm, 528 g to 3.120 kg).

Batch #	Injection point	Opening %	Species	Size	# Injected	# Re-captured	Mortalities				Mortality rate
							Immediate	After 24hr	After 48hr	Total	
8	Hub	100	Tench	Small	25	24	0	0	0	0	0.0%
9	Hub	50	Carp	Small	31	31	0	0	0	0	0.0%
10	Periphery	100	Tench	Small	25	23	0	0	0	0	0.0%
11	Periphery	50	Tench	Small	29	29	0	1	0	1	3.45%
12	Mid-blade	100	Tench	Small	30	27	0	0	0	0	0.0%
13	Mid-blade	50	Tench	Small	30	28	0	0	0	0	0.0%

Recapture rates for small carp/tench

Of the small carp/tench batches, only one small tench was found dead after 24 hours of observation (Batch #11 - Injection at the runner periphery, 50% opening), resulting in a mortality rate of 3.5% for this batch.

No immediate or deferred mortalities (after 48 hours) were observed in any of the other 5 batches. Therefore, mortality rates are zero for the 5 batches of carp/tench sized 14 to 31 cm, weighing between 40 and 358 g.

3.3. *Causes of deaths and injuries*

3.3.1. ***Trout***

Of the trout only large fish were impacted, as there were no immediate or deferred mortalities (after 48 hours of observation) in the small trout batches.

3.3.1.1. *Large trout mortality*

Observed large trout mortalities occurred mainly when the injection point was at the runner periphery, where the blade speed is the highest, and when the blade opening was the lowest (50%), which is when the space between the blades is the smallest.

Out of the six large trout mortalities during the different tests, the following was observed:

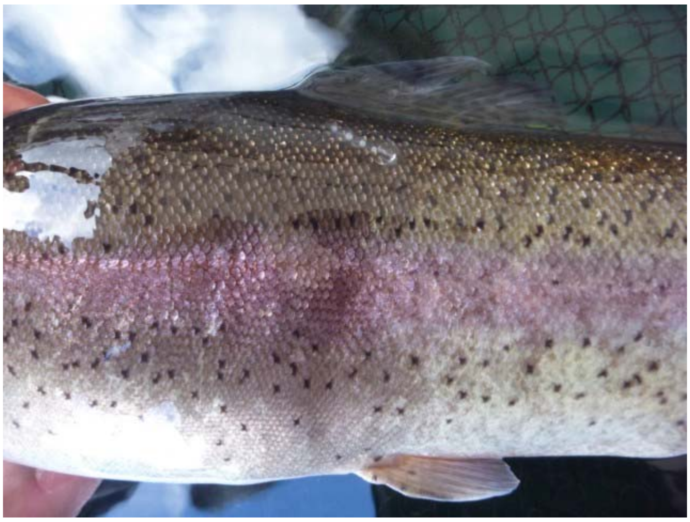
- 3 mortalities with a clear bruise of a lateral blow on the body:

Trout #1: outline of the bruise on the side

Close-up of the bruise on the side, with discoloration across the bruise

Trout #2: outline of the bruise on the side

Close-up of the bruise on the side, with discoloration across the blow

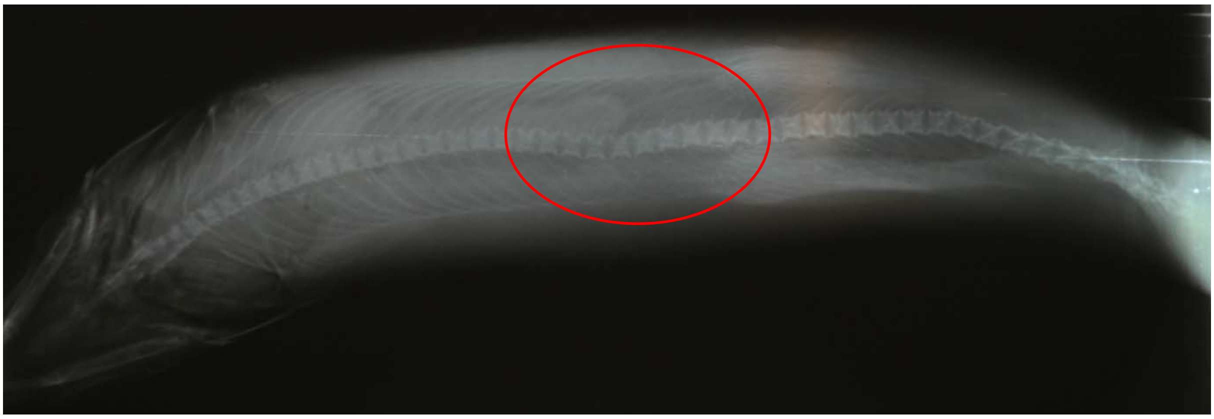


Trout 3: Outline of the bruise, with depression of the rib cage

Visible caving of the ribcage in this view from the top

The three trout were subsequently X-rayed. X-rays of Trout #1 and #2 showed no spinal injuries. However, in an autopsy done by a veterinarian (Dr. F. Moyroud) on Trout #1, found "a contusion of the left lumbar muscles and a large hematoma. Within this injury, 5 bones were fractured and the liver had a traumatic injury - capsule tear with hematoma of the left lobe - these injuries are the cause of death for the fish" (summary quote from the autopsy report).

X-rays of Trout #3 did not reveal any fracture of the spine.



Trout #3 : X-ray from the top showing spine curvature

Nonetheless, the curvature of the spine can clearly be seen, which coincides with the depression of the ribcage, from the assumed blade impact, the probable cause of the fish death.

Given these results, it is assumed that these three large trout were probably struck by the turbine blades.

- 3 Large dead trout, but without any visible bruises. In the case of these 3 fish, it could not be determined with certainty what exactly caused their death and to link it with certainty to the impact of the turbine or test conditions.

3.3.1.2. *Other injuries*

Hematoma on the back

Close-up of the hematoma on the back

Apart from these six trout mortalities, a large trout from Batch #6 (Injection at the runner periphery, with a 75% opening) had an externally visible bruise on its back, which did not seem to disrupt its swimming ability or behaviour. This injury did not appear to be lethal, and an autopsy was therefore not performed on the trout.

Aside from some minor isolated scaling, which is most likely due to the fish recovery equipment, no other injuries were found on the other large trout, or on any of the small trout. No other abnormal behaviour was observed when the fish were settling in the containers after testing.

As for the very large trout, the results obtained from a single batch appears to indicate that, under the conditions used for the tests (at the runner periphery with a 100% blade opening), large fish of this size (between 64 cm and 72 cm and 4.5 kg to 5.6 kg) can pass through a VLH DN5000 without apparent injury.

3.3.2. Carp / Tench

For the large carp/tench, no mortalities (immediate or after 48 hours) were observed in any of the seven batches that were tested.

For the small carp/tench, only one small tench was found dead after 24 hours of observation (Batch #11 – Injection at the runner periphery, with 50% blade opening). It had an abnormal swelling of the swim bladder. However, given the characteristics of the VLH, which does not have a significant pressure change moving through the runner, unlike other types of turbines; it is unlikely that the swim bladder problem is related to the fish passing through the turbine.

Furthermore, 36 large carp/tench were selected at random from the seven test batches and 39 small carp/tench were randomly selected from the six test batches and X-rayed by the same veterinarian (Dr. F. Moyroud). After examining the 21 X-rays (several fish on one plate), it was determined that there were no skeletal lesions on any of the fish that were X-rayed (no fractures or dislocations of the spine detected). This diagnosis was subsequently confirmed by Dr. Köhler from the German Administration who examined copies of these X-rays as well.

Slight scaling on a small tench

Bleeding eye in a large carp

Only a few isolated cases of slight scaling were observed, and a bleeding eye in a large carp. However, these two types of injuries could not be linked with certainty to the fish passing through the turbine or to the test methods (recovery net, holding containers, etc.).

3.4. Overall mortality rate with the VLH

Without the knowledge of what point fish migrating naturally downstream are likely to enter the turbine, the tests aimed to be as inclusive as possible with injections at three points: near the hub, at mid-blade and at the runner periphery.

First, the total surface area was divided into three equal circular areas. The three injection points were then positioned at the center of each of these three circular areas. The overall mortality rate was thus determined by calculating the average mortality observed at the three points, for a given blade opening and a given size class of fish.

3.4.1. Large trout

Opening %	Periphery	Mid-blade	Hub	**VLH 3 points combined**
100	3.3%	0.0%	0.0%	**1.1%**
75	3.3%	0.0%	0.0%	**1.1%**
50	6.7%	0.0%	6.7%	**4.4%**

Overall mortality rate for large trout with the VLH

For large trout ranging from 43 cm to 57 cm and with weights of 1.1 kg to 2.9 kg, the overall mortality rate with the VLH was 1.1% at 100% and at 75% opening, and 4.4% at 50% blade opening.

3.4.2. Small trout

Opening %	Periphery	Mid-blade	Hub	**VLH 3 points combined**
100	0.0%	0.0%	0.0%	**0.0%**
75	0.0%	0.0%	0.0%	**0.0%**
50	0.0%	0.0%	0.0%	**0.0%**

Overall mortality rate for small trout with the VLH

For small trout ranging from 20 cm to 26 cm and with weights of 96 g to 163 g, the overall mortality rate with the VLH was zero, regardless of the blade opening.

3.4.3. Large carp / tench

Opening %	Periphery	Mid-blade	Hub	**VLH 3 points combined**
100	0.0%	0.0%	0.0%	**0.0%**
75	0.0%	0.0%	0.0%	**0.0%**
50	0.0%	0.0%	0.0%	**0.0%**

Overall mortality rate for large carp/tench with the VLH

For large carp/tench ranging between 37 cm and 66 cm and with weights of 528 g to 3.120 kg, the overall mortality rate with the VLH was zero, regardless of the blade opening.

3.4.4. Small carp / tench

Opening %	Periphery	Mid-blade	Hub	**VLH 3 points**

				combined
100	0.0%	0.0%	0.0%	**0.0%**
75	0.0%	0.0%	0.0%	**0.0%**
50	3.4%	0.0%	0.0%	**1.1%**

Overall mortality rate for small carp/tench with the VLH

For small carp/tench ranging between 14 cm to 31 cm and with weights of 40 g to 358 g, the overall mortality rate with the VLH was zero at 100% and at 75% blade opening, and 1.1% at 50% opening.

4. Conclusion

	VLH 3 points combined mortality rate			
Opening %	Large FRT	Small FRT	Large carp/tench	Small carp/tench
100	1.1%	0.0%	0.0%	0.0%
75	1.1%	0.0%	0.0%	0.0%
50	4.4%	0.0%	0.0%	1.1%

Mortality rates of fish tested on the VLH DN5000 with a spherical runner housing installed on the Tarn River at La Glacière:

- Varied from 1.1% to 4.4% depending on the blade opening, for large rainbow trout that were similar in size and weight to large migratory salmonids at the spent stage,
- Were zero, regardless of the blade opening for small rainbow trout that are similar in size and weight to smolts migrating downstream
- Were zero, regardless of the blade opening for large carp/tench,
- Varied from 0% to 1.1% for small carp/tench depending on the blade opening.