A DIRECT METHOD TO DELIMIT WEIR POOLS

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ABSTRACT:
Weir pools are one of the most widespread artificial aquatic environments in Europe. In recent years, they draw the attention of scientists and managers, who try to understand how they work and put in place strategies to manage them. However, these studies confront with the difficulty of delimiting the spatial extension of weir pools: to solve this problem, we created a direct technique that permits to identify their perimeter through the measure of the raising of the waterline and the slowing down of the flow generated by weirs. To verify its validity and efficiency we tested it in two weir pools located in France to check whether it can find them. In both cases, the results obtained are convincing and they demonstrate how this methodology can be used to study and manage the spaces that form upstream weirs.

Key-words: *Weir, Weir pool, Run-of-river dam, Weir pool perimeter.*

1. INTRODUCTION

A weir pool is the space where occurs the raising of the water line and the slowing of the flow caused by weir, a hydraulic structure generally of small dimensions, overflows and transverses to the river bed of a stream (Degoutte, 2012). Over time, this kind of environment became very common in European rivers, especially in countries where industrialization developed in previous times, such as in France, where several thousands of weir pools have been built, mostly to operate water mills (Barraud et al., 2013; Rivals, 2000).

From an ecological point of view, the main characteristic of a weir pool is the flow velocity gradient which develops from upstream to downstream and whose intensity varies according to the time of year, determining the typical hybrid operation of this kind of environment, which cross lotic and lentic features (Donati, 2021; Donati et al., 2019; Donati et al., 2020 a; Donati et al., 2020 b). That can create some environmental impacts, such as the retention of sediments transported by the waters or the formation of thermal stratifications and the consequent warming of the waters downstream of the weirs. For this reason, especially after the promulgation of the Water Framework Directive and the diffusion of the concept of Ecological Continuity, everywhere in Europe weir pools draw the attention of scientists and managers, who try to understand how their work and put in place strategies to manage them (e.g. Malavoi, 2003; Rickard et al., 2003; Anderson et al., 2015).

However, any study about weir pools must be confronted with some practical constraints that they pose: one of these is the delimitation of their spatial extent. Indeed, their perimeter is not immediately recognizable, because weirs do not cause the overflow of the watercourse that they

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obstruct, unlike other structures which create real waterbodies, for example the dams or the pond's dykes. To overcome this issue, in the scientific literature it is possible to find indirect methods, which are based on geometric calculations made from the height of the structure, the slope of the water line or that of the bed. (*e.g.* Csiki & Rhoads, 2010; Maniere, 2013; Pearson & Pizzuto, 2015). They have several advantages such as being cheap and less time-consuming, but our experience taught us that they can also be inaccurate and not always reliable. So, we created a direct method that permits to limits a weir pools thanks field measurements and that we consider very efficient. The purpose of this article is to illustrate it, so that scientists can use it in their research and managers as decision support for their action about weir pools.

2. STUDY AREA

To verify the reliability and efficiency of our methodology we tested it in two study area located in Metropolitan France.

2.1. The Saint-Hilaire weir pool

The first site we tested is the Saint-Hilaire weir pool, located in central France, in the Loiret department, to the west of Orléans. It is supplied by the Mauves, a watercourse of approximately 40 km, with an average flow of 1,075 m^3/s (Banque Hydro data). It is created by the weir of the homonymous water mill, which is 0,5 meters tall and which is surmounted by a gate.

The peculiarity of this weir pool is that we know its spatial extent. Indeed, in previous times its water level was regulated at a precise height, registered in a local law, in order not to interfere with the operation of the Pantin water mill, which is located upstream. This height is still respected today by the site manager and for this reason we know that the weir pool extends throughout all the space that separates these two ancient factories. Therefore, this study area is ideal for testing the reliability of our methodology, observing whether the results reflect the reality.

2.2. The Baerenthal weir pool

The second site we tested is the Baerenthal weir pool, located in the North-East of France, in the Moselle department, to the South-East of Bitche. It is supplied by the Zinsel du Nord, a river of approximately 40 km with an average flow of 0,596 m^3/s (Regional Natural Park of Vosges du Nord data). More precisely, it is supplied by the confluence of this river and an artificial canal that comes from a pond. This study area is characterized by a concrete weir, which is 1 m tall and which is devoid of any moving element.

The peculiarityy of this weir pool is that the slowing down of flow caused by the weir forming it cause the deposition of a large quantity of sediment over its bottom. Therefore, this study area is ideal to test the effectiveness of our methodology in a real study, verifying if it permits to bring a better understanding of the phenomena which characterize this type of environment. In this specific case we are observing if the limits that it permits to fix intercept the sectors that are silted up.

3. DATA AND METHODS

The methodology that we created to delimit weir pools is based on the direct observation of the two main effects generated by weirs, that are the raising of the water line and the slowing of the flow. More specifically, it makes possible to set the upstream limit of a weir pool, the downstream one coinciding with the weir.

To do this, first of all it is necessary to select a homogeneous section of river, between the weir that forms the studied weir pools and another hydraulic structure, a confluence, a sudden change in the stream hydromorphology, etc. Second of all, in this sector, from downstream, we position fifteen equidistant transects which will serve as a measuring station, by lining the last one up with the weir. This number of transects was established from other protocols used for rivers study, according to which fifteen measurement stations are sufficient to be able to assess the features of a river section. (*e.g.* the French protocol CARHYCE, see Onema, 2010). Furthermore, this same number of transects was found to be effective in other studies whose purpose was to study the characteristics of the spaces located upstream of weirs (Bellot, 2014; Donati et al., 2020). In Saint-Hilaire, a transect was placed every 37 meters, between the two water mills that delimit this study area; In Baerenthal, a transect was placed every 24 meters, between the weir and a confluence located a few hundred meters upstream.

On the fifteen transects, the average speed of the flow (m/s) is measured using a current meter. The kind of instrument that is used is established by the conformation of the study area: if from one hand it is possible to prospect it by foot it is possible to use a conventional current meter (helices or doppler), on the other hand if the depth is too great it is possible to use a floating profiler. In this study we used a doppler current meter, the "FlowTracker 2". With this instrument, on each transect of the two-study area, the speed was measured in three verticals: two beside the banks and one in the center of the river. The number and depth of the measurement points were automatically calculated by the current meter, as the average speed of each transect.

On the fifteen transects, the average water depth (m) is also measured. Indeed, at the raising of the water line generated by the weir corresponds a progressive increase in the thickness of the water column, an effect that in Hydraulics we associate to a back water curve designated with the acronym "M1" (Chanson, 2004; Dingman, 2009; Martin, 2013). To measure this, there are several solutions: it is possible to use a graduated staff, the bar of the current meter or the average depth value that the profilers usually give after each measurement. In the first two cases, it is necessary to measure the velocity depth in several verticals and then calculate the average depth for each measuring station.

Finally, we enter the data collected in a Cartesian graph with an abscise axis for the transects and a double ordinate axis for the speed and the average depth of the flow. The intersection between the two curves materializes the upstream limit of the weir pool as the point where these two phenomena begin.

From a temporal point of view, this methodology should be applied during low flows, when the velocity gradient that characterizes the weir pool is stronger and better visible. Rather, it shouldn't be applied during high flows, when the energy gradient is lower, especially during floods when the hydrological effects of the weir can be completely canceled.

4. RESULTS AND DISCUSSIONS

In the two fields of study that we studied/tested, the application of this methodology gave the following results

4.1. The results in Saint-Hilaire weir pool

Regarding the Saint-Hilaire study area, the data that we collected show that the raising of the water line and the slowing of the flow begin at the beginning of the reach upstream the old water mill (**Fig. 1**). More precisely, the curves of these two hydrological parameters intersect at the level of transect number 2, where we fix the upstream limit of weir pool (**Fig. 2**). It has an area of about 0,5 ha, an average width of 8 m and an average depth of 0,54 m. This perimeter corresponds to the information that the manager gave us on this study area before the application of our methodology, that is the weir pool is spread over the entire length of the reach that divide the Saint Hilaire and Pantin water mill.

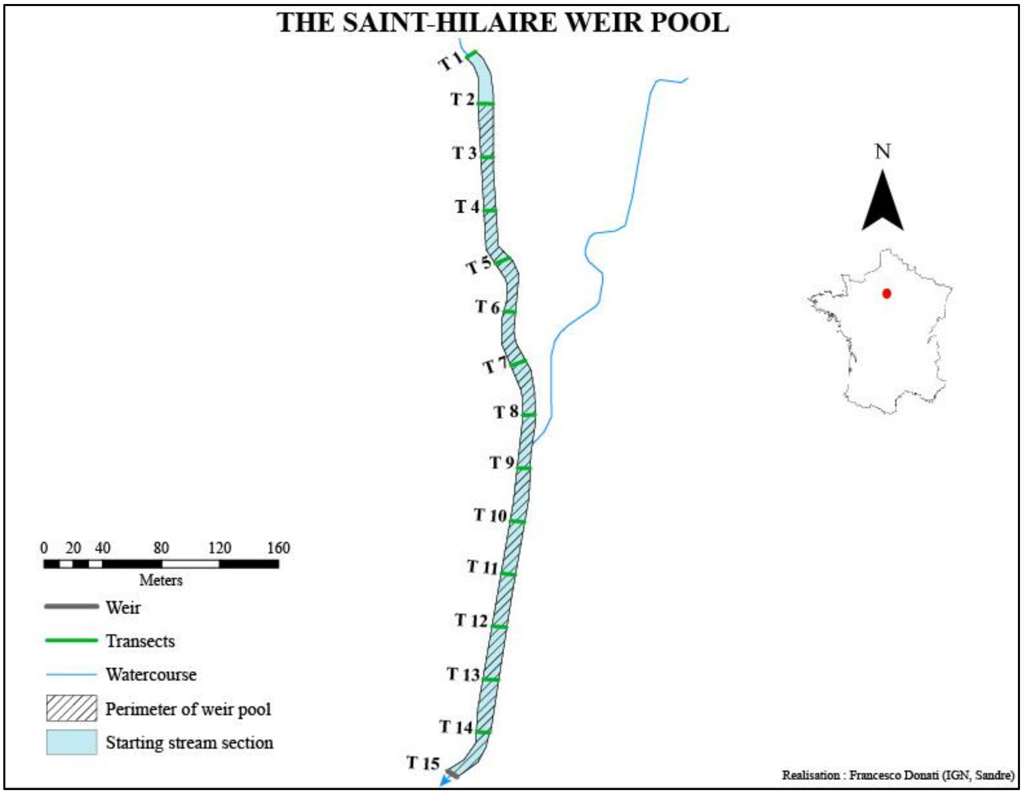

Fig. 1. The extension of Saint-Hilaire weir pool (*Realization: Francesco Donati*).

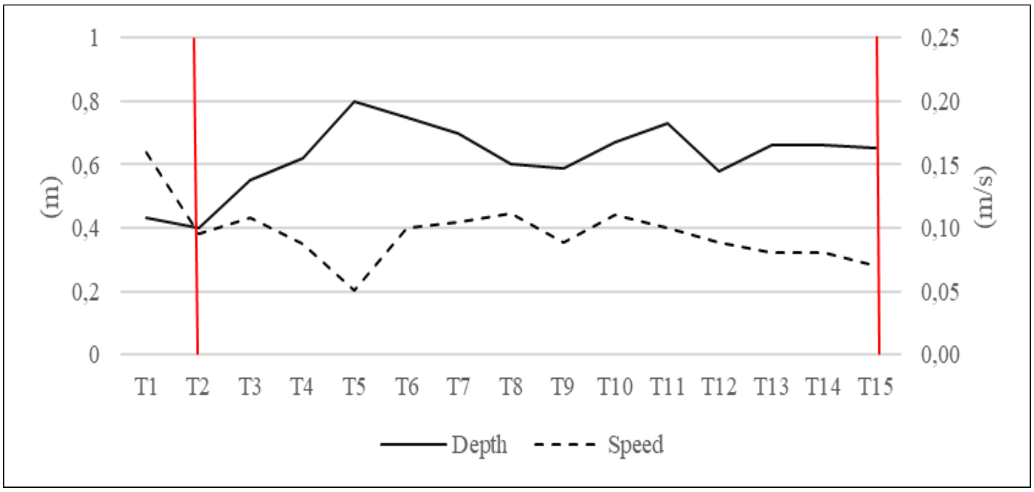

Fig. 2. The evolution of the depth and the speed of the flow in the Saint-Hilaire weir pool; the red bars show the extension of weir pool (*Realization: Francesco Donati*).

4.2. The results in Baerenthal weir pool

Regarding the Baerenthal study area, the data that we collected show that the raising of the water line and the slowing of the flow appear shortly after half of the reach created by the weir (**Fig. 3**). More precisely, the curves of these two hydrological parameters intersect at the level of transect number 9, where fix the upstream limit of weir pool (**Fig. 4**).

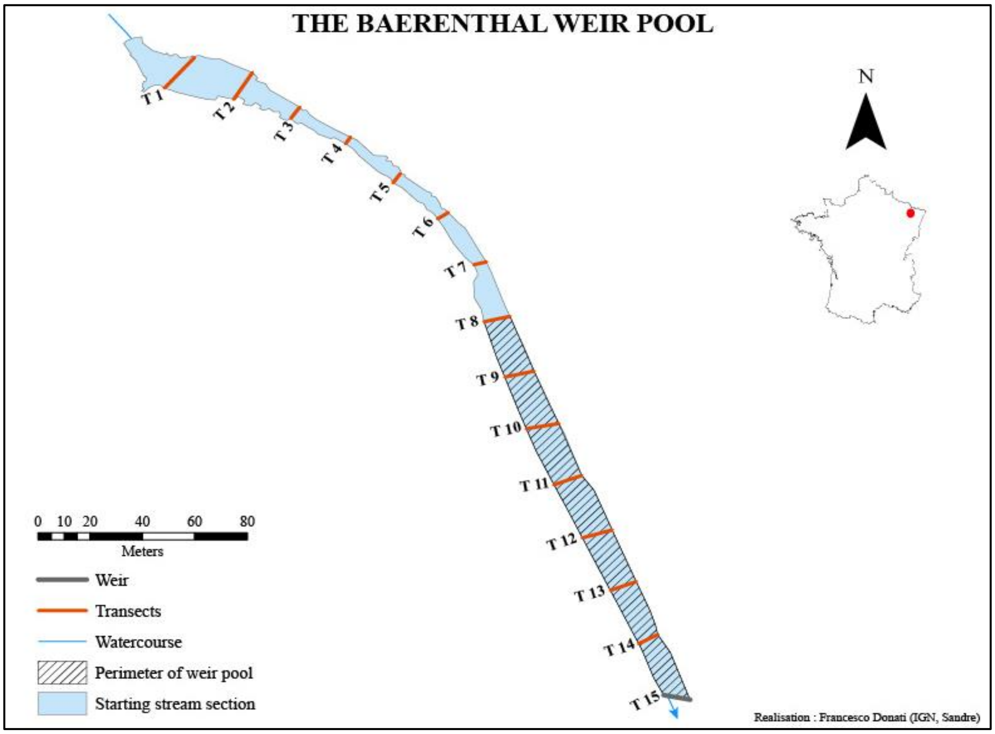

Fig. 3. The extension of Baerenthal weir pool (*Realization: Francesco Donati*).

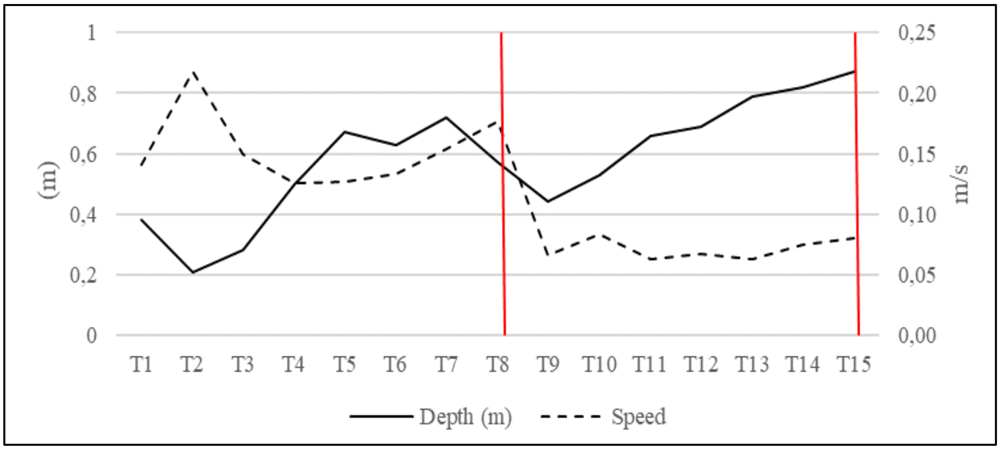

Fig. 4. The evolution of the depth and the speed of the flow in the Baerenthal weir pool; the red bars show the extension of weir pool (*Realization: Francesco Donati*).

It has an area of about 0,2 ha, an average width of 11 m and an average depth of 0,78 m. As it is possible to see from figure 4, the depth and speed curves also intersect before the transect number 9: this is not due to the effect of the weir, but to the morphology of the site. In fact, between transects 1 and 4, the speed of the water before increases because of the confluence of the two streams that supply this this study area, after it decrease due to the widening of the riverbed. On the other hand, between transects 4 and 8, the riverbed suddenly narrows, causing the increase of water depth, while the energy of the flow remains constant.

As we explained above, this study area was selected to verify whether this methodology makes possible to delimit some aspects of the functioning of the weir pool, in this specific case the silting up of the bottom. To study this phenomenon, we collected additional data, using a technique commonly deployed upstream of any type of reservoir (Carlini, 2006; Donati et al., 2020; Maleval & Alain, 2002; Maleval & Pitois, 2017). On each transect used to study the hydrological parameters, the depth of the water and the substrate were measured using a graduated staff, in three verticals.

First of all, we measured the water depth, after which we measured the depth of the substrate: the difference between these two data gives the thickness of the layer of sediment covering the bottom. When we cross these data with those used to determine the extent of the sill reservoir, we observe that the area silted up are included almost perfectly within the perimeter of the weir pool that we identified and they coincide with the sudden change in flow velocity and the consequent decrease in its sediment competence (**Fig. 5**).

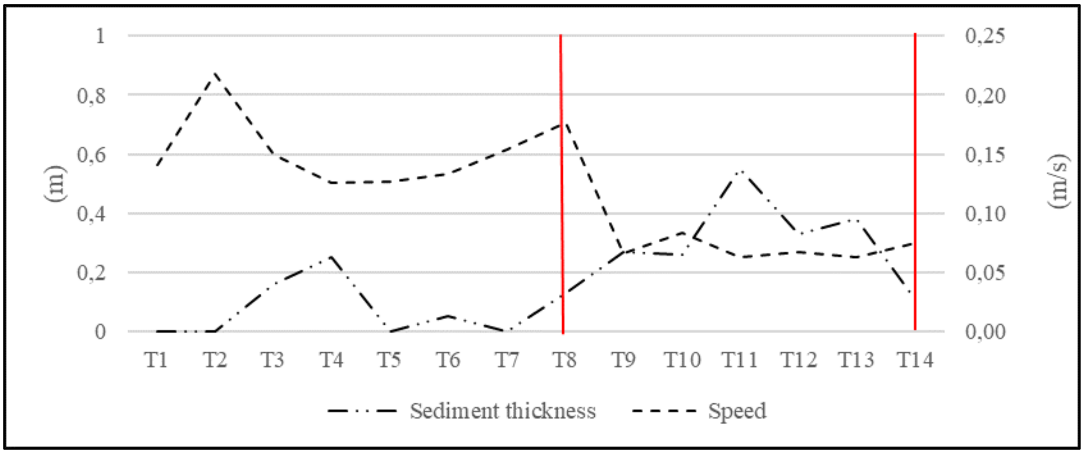

Fig. 5. The evolution of the thickness of sediments and the speed of the flow in the Baerenthal weir pool; the red bars show the extension of weir pool (*Realization: Francesco Donati*).

6. CONCLUSIONS

These results that we obtained seems to demonstrate the reliability of the methodology that we created to delimit weir pools. Indeed, the perimeters that we identified thanks to it reflect the informations we had about the two-study area before its application. So, this technique looks like a valid tool for researchers and technicians, for example during studies about the operation of this kind of environments or projects of river restauration. Of course, compared to indirect methodologies, it requires the use of instruments that can be expensive or the deployment of several people to realize the measurements. However, it allows to avoid generalizations that may be wrong and to better consider the environmental context of each weir pool.

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