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Individual internship report

4th year

Fragmentation of rivers by barriers: Impacts of small natural and artificial barriers

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Glossary

Artificial barrier: Man-made structures on rivers constructed to control the flow, raise the water level or increase flood defenses. These barriers include flumes, sluices, weirs, dams, culverts, barrages and river crossings and can obstruct all or part of the minor bed of a watercourse (weir) or extend beyond the minor bed(dam).

Ammonium (NH_4^+): NH_4^+ is the reduced form of azote, it comes from the decomposition of natural proteins contained in organisms. It also arises from urban effluents or agricultural and industrial runoff. According to the cycle scheme of azote of Fort.M & Fustec.E (2000), NH_4^+ is available for plants after the process of nitrification but is otherwise subject to denitrification, where the ion is transformed in N_2 and returned to the atmosphere.

Conductivity (µS/cm): The capacity of water to conduct electricity, dependant on the ionic concentration and temperature. Conductivity increases with the augmentation of dissolved solids. This measurement is used to determine the degree of mineralization (Government of Quebec, 2018).

Dissolved oxygen: the ratio expressed as a percentage between the immediate oxygen content and the maximum solubile in water at the temperature and the pressure given during the sampling (SANDRE, 2017).

Hydrogen potential (pH): Represents the equilibria between acid and bases, it's a measurement of the concentration of hydrogen ion. Values are reported on a scale between 0 and 14. A value under 7 correspond at acid condition, a value of 7 corresponds to neutral, higher values correspond to alkaline conditions. pH influences the toxicity of numerous elements and depends on water origin, geology and human activities.

Natural barrier: A barrier occurs naturally and hinders the ecological and sedimentary circulation, they are often related to geological processes. They can be represented by the cascades, waterfalls and rapids (Rachel, 2007).

Paving: partial fixation of the bed by a selection of larger materials, which are removed only by exceptional floods. The bottom of the bed is fixed by pebbles that the river can no longer transport, but the banks remain mobile. The process is accentuated by the lack of materials retained by the barriers notably the sands and gravels. A consequence is a decrease of the capacity of self-purification of the watercourse and an impoverishment of the diversity of the habitats.

1. Introduction

Rivers have been used by humans more than other types of ecosystem (Jungwirth, 1998), as a result, the majority of rivers are fragmented by different barriers and a very few water courses maintain their original integrity (Jungwirth, 1998; Jager et al., 2001). The goal of the barriers is to alter the flow regime for different uses like the production of energy, industry or flood defense.

Many studies have assessed the effects of large dams and showed consequences on river connectivity like the discharge change or the blocking fishes migration (Larinier,2000). Nevertheless, few studies have examined the effects of small obstacles and natural barriers (Alexrandre & Almeida, 2009). However, the majority of barriers are not dams or big and could be natural like waterfalls. It does not mean these small barriers have non-impacts, indeed some local impacts or a cumulative effect could appear. Moreover Rahel (2007) showed that geographical barriers like rapids and waterfall are a potential barrier for aquatic organisms and could cause a decrease of habitat connectivity.

River flow regimes are the primary driving force of the river ecosystem (Poff et al., 1997; Yang et al., 2012). The integrity and stability of river ecosystems is largely dependent on the natural dynamic change characteristics of the streamflow (Poff et al., 1997). Nevertheless, the development of barriers to manage water resources has altered the natural flow of river. Moreover, barriers could modify the sediment transport and affect the repartition of the sediment in river by trapping them (Mccully,1996).

Among the principal's physicochemical factors which condition life in aquatic environment it's possible to quote the temperature, dissolved oxygen and the hydrogen potential (pH) (Secondat, 1952). These different parameters follow cycles with daily variations and are interrelated. Indeed, concentration of dissolved oxygen depend of temperature, decomposition of organic matter and photosynthesis. Temperature and pH are very important for the development of organisms in river, then these organisms will modify the quantity of dissolved oxygen. For example, the seasonal variation of phytoplanktonic biomass impact the concentration of dissolved oxygen and pH in water (Charles,1999). The decomposition/respiration will decrease the quantity of dissolved oxygen while photosynthesis will increase the concentration. Conductivity is also important and reflect the concentration of minerals in water which can impact the autotroph organism development. Moreover, the ammonium (NH_4^+) informs about the incomplete degradation of the organic matter which can prove the presence of an organic pollution. Impounding a structure in a river can decrease the water quality (decreased circulation), cause a pollutant accumulative, an oxygen depletion or an augmentation of temperature as shown in the figure 1.

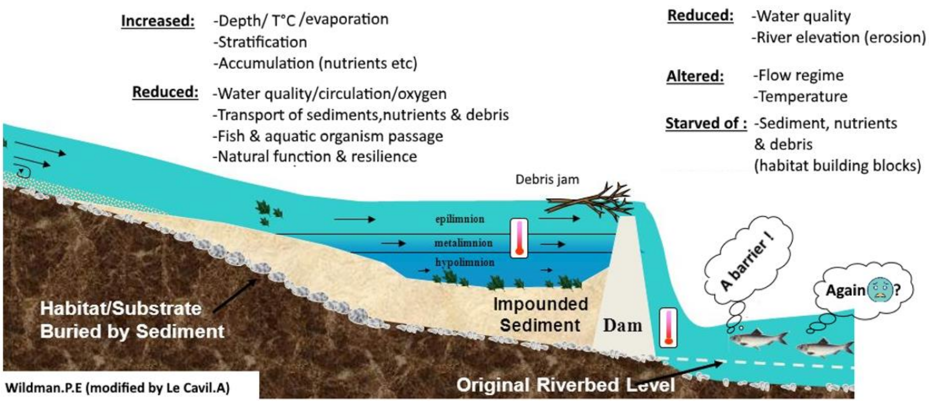


Figure 1 : Impacts of the presence of barriers in a stream. Source: Laura Wilman Princeton, modified by Le Cavil.A,2018

The decomposition of organic matter is in direct connection with the biotic and physico-chemical conditions of location and may reflect the presence of environmental conditions. Terrestrial leaf litter is an important organic input to many streams. This leaf litter is processed by initial rapid leaching of soluble compounds, abiotic fragmentation, microbial decomposition, and invertebrate feeding (Kaushik & Hynes 1968; Petersen & Cummins 1974). The part decomposed by microbes is important for making leaf material palatable to stream invertebrates (Sedell et al., 1975). This degradation occurs at different rates in different species and under different environmental conditions (Petersen & Cummins 1974; Anderson & Sedell 1979) so measuring the dynamic of decomposition could inform on the presence of a barriers.

Another biotic parameters, the biofilm, which respond to local hydraulic conditions (Warner et al., 2007) is used in this project as biological indicators. Biofilms are structured aggregates of bacterial cells that are embedded in self-produced extracellular polymeric substances (EPS), (Lemming et al., 2010). They can grow on natural or artificial surfaces. Biofilm is the result of a complex process which include the transport and adsorption of organic and inorganic particles on a wet surface. Then there is the production of EPS implied in the fixation process (Das et al., 2013). Assemblage and structure of Biofilm varies with this process which is influenced by the environmental conditions like the nutriments, oxygen, surface, environmental stress, temperature, flow etc. Development of biofilm is divided in several steps and explain in appendix n° 1

Biotic, abiotic and physicochemical parameters will be measured at each barrier, upstream and downstream in order to test the discontinuity with different null hypothesis:

- H1: There is no difference between upstream and downstream of natural or artificial barriers.
- H2: There is no difference between natural and artificial barriers

There are few rivers unimpacted by barriers. Therefore, experimental conditions were reproduced in artificial channels. A set of biotic, abiotic and physicochemical measurements were studied in artificial channels where the only variable parameter is the presence of a barrier. The null hypothesis tested is:

- H3: There is no difference between channels with and without barriers.

The mains goals of this work are to try to better understand the impacts caused by small natural and artificial barriers on a local scale. This study also tries to detect the fragmentation without knowledge of barrier presence so that it allows to look for those impacts rather than the barriers themselves.

Firstly, the report will present the study locations followed by the description of methods used to realize each measurement. Secondly results will be presented and analyses conducted by hypothesis order. The last part will present the discussion and conclusion of findings.

2. Presentation of the host structure

Swansea University is a research-led university that has been making a difference since 1920 (Swansea University, 2011). This is the third biggest university of Wales in term of student number. The university is divide in two campuses; Singleton campus and Bay campus. The university of Swansea have eight academic colleges divide themselves in different department host different research group.

The internship take place in the College of Sciences, in the Biosciences department in the Centre for Sustainable Aquatic Research. This group was founded in 2003 with support from the European Union, Welsh Government, and Swansea University.

CSAR group at to it disposal modern equipment which allow to apply research on a diverse range of aquatic organisms, from temperate to tropical and marine to freshwater environments (Swansea University, 1011). The area of expertise includes general themes like food and fuel security or climate change and many other themes. The CSAR team provides information and advice to industry and governments, such as developing the aquaculture section of the Wales Fisheries Strategy. This group is research active across the United Kingdom and Europe. The CSAR group deliver research, development and technical assistance within industrial and academic consortia. This group also have a role of education and training activities include hosting research studentship programmer, supervising Undergraduate and Master research projects and assure vocational training for students to personal institutes.

The project I worked on and which is one project of the CSAR group is the AMBER project, that stands for Adaptive Management of Barriers in European Rivers. AMBER is a €6.2 million research and innovation European project included 20 partners from 11 countries (AMBER, 2017). Partners form the AMBER consortium and they includes large hydropower business rivers authorities, non-governmental organizations, universities and the European Joint Research Centre. This project also involves authorities and the public in data collection and dissemination (AMBER, 2017).

Many of technical means are involved to study different themes like the fragmentation of rivers and it's impacts, improvement of knowledges on dams and provide innovative solution to the fragmentation of rivers in Europe. The main goal of the project is seeking to apply adaptative management to the operation of dams and barriers in European rivers to achieve a more efficient restauration of connectivity, and address impacts caused by river fragmentation.

3. Materials and methods

3.1. Introduction of the study location

3.1.1. Presentation of the Afan catchment

3.1.1.1. Location and hydrology

This case study takes place on the Afan catchment which is a watershed of 119 km^2 situated in Wales and more precisely in the county of Port Talbot. The river Afan extends on 18 km (Rossall, 2013) from the village of Cymmer at the confluence of the river Cymmer and Gwynfi to Port Talbot, where the river discharge into the Swansea Bay.

The River Afan is joined by five major tributaries shown in appendix n°2. First the Afon Corrwg, approximately 11 km long, the Afon Gwynfi which joins the Corrwg at Cimer after a flow on 8 km. The Nant Cregan, small tributary joins the Afan river at Abercregan while the river Pelenna meets the Afan at Pontrhydyfen. To finish, the Afon Ffrwdwyllt, the most downstream of the catchment which represents a section of less than 8 km discharge in the river near Port Talbot. According to the National River Flow Archive, the mean flow of the river at the station "Marcroft Weir" (situated at 3.5 km from the mouth and drained through a watershed of 87.8km^2) is 5.168 m^3/s (data from 1978 to 2014) and the annual rainfall is 2036 mm (data from 1961 to 1990).

3.1.1.2. Morphological and topographical features

The geology of the Afan catchment is dominated by Middle and Upper Coal Measures and Carboniferous Limestone (National Rivers Authority Welsh Region, 1995). The mean altitude of the catchment is 302 m with a maximum near 600 m. The mean slope is around 20% with the maximum slopes near waterways especially the Afan river, the topography is shown on the appendix n°2.

3.1.1.3. Watershed activities

An important part of the Afan catchment is used for coniferous forestry and the breeding of sheep and cattle in the headwaters (Natural Resources Wales, 2015). The mid and upper reaches of the Afan catchment were marked by coal mining combined with metal smelting in the early 19th Century (Natural Resources Wales, 2015). In the same period lot of artificial barriers were built in the Afan catchment to control the flow or raise the level of water or to increase the flood defense. Indeed around 150 barriers are counted on the Afan catchment (Environment Agency Wales, 2010).

These barriers have possible consequences for different parameters like the discharge, water velocity, temperature, dissolved oxygen, river bed movement, siltation and suspended solids (Crisp & Trevor, 1993). These modifications impact also life in the stream. Indeed, the fisheries of the Afan catchment composed by Atlantic salmon (*Salmo salar*), Brown trout and Sea trout (*Salmo trutta*), European bullhead (*Cottus gobio*), European eel (*Anguilla anguilla*) and the Flounder have experienced a decline in the past. In recent year the quality of salmon and sea trout fishery had augmented due to numerous factor like there stocking, the improvement of water quality and alleviation of several man-made barriers. Nevertheless, the majority of Afan water bodies student are currently failing the WFD objective for fish and stock remain instable due to the different activities on the Afan catchment and it history.

According to the Naturales Resources of Wales, the main causes as to why water bodies are failing to meet the required standard are the physical modifications like the presence of man-made weirs (survey realized on 6 catchments including the Afan catchment) followed by diffuse source.

3.1.1.4. Management of the catchment

The Afan catchment is managed by the Natural Resources Wales, which is the largest Government Sponsored body in Wales. The principal's goals to this organization are to understand how the issues in the catchment are affecting the current local benefits and future uses of water. Different objectives are targeted like the prevention of the deterioration in status water, achievement of objectives for protected area and achieve good overall status for surface and ground waters. Among these objectives some measurements are taken like removal and modification of barriers and reduction impacts from flood defenses.

3.1.2. Selected stations

Across the Wales there are more than 5500 barriers with a median height drop of 2.07m (Environment Agency, 2010). While in the Afan catchment the major part of the barriers has a head drop inferior at 0.5m although database is not complete. The Afan catchment contains 150 barriers, 63 % are artificial, 24% are a type unknown and the last 13% are natural barriers as shown on the figure 2, map A.

The barriers studied are located in the head of the watershed and have a head drop between 0.21 m and 0.92 m, naturals barriers have an average head drop of 0.53m against 0.63 m for artificial barriers which correspond to the mean class size to the barriers head drop of the Afan catchment. These barriers are described in Appendix 4 to 9.

Moreover, they were chosen because they are accessible and in the same location to have similar environmental conditions. Figure 2 map B shows the location of each station. One barrier is located on the River Afan and the others are situated on the Corrwg which is a tributary of the river Afan. The stations 1 and 6 are spacing of around 5 km and the stations 3 to 6 are located on a distance of 1 km.

A set of measurement on biotic (biofilm and leaf decomposition), abiotic (sediment, depth, flow) and physicochemical parameters (T°C, pH, conductivity, dissolved oxygen NH_4^+,) were applied in each station in order to study the fragmentation due to this barrier. The study is on a local scale due to the size of the barriers it is supposed that impacts are local.

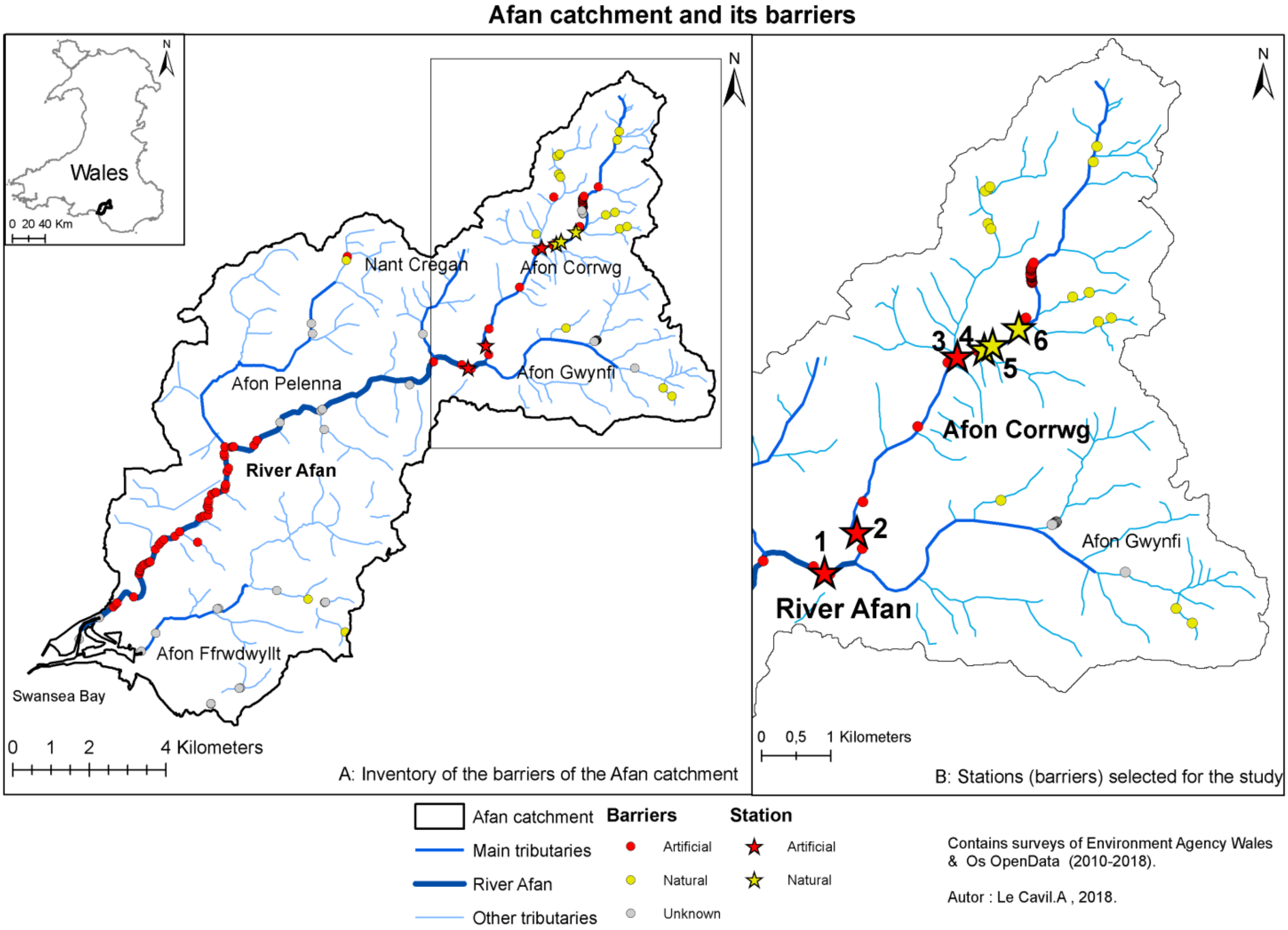


Figure 2 : Presentation of study sites.
Source : Os OpenData 2018 & Environment Agency Wales 2010.Autor: Le Cavil. A, 2018

3.2. Introduction of the experimentation

It was chosen to apply an experimental method to reproduce conditions in a river using artificial channels. The conditions on the channels are controlled and the only parameter which change between channels is the presence of artificial barriers or not. This difference between channels allow to test the discontinuity by measuring biotic, abiotic and physiochemical parameters.

It was chosen to have three channels with barriers and three others without barriers in order to have replicates. Choice of placements of the barriers or not were determined by estimating the sun position through a day, so channels could have the same insolation. For this experimentation two plastic troughs of 2,06-meters-long were used and divided into three channels. Three channels had a succession of three barriers of 5cm height made of plastic while the three other channels didn't have barriers. The parameters of channels are shown in appendix n°10. The plastic troughs were on a closed circuit where water was supplied to the channels by opening valves. This closed circuit is composed of pipes connecting to a pump which allow to circulate the water stocked in a tank. Twice a week new water is added in the tank to compensate the loss of water induced by evaporation and leaks of water.

Sand and gravels were added on the same proportions in each channel, then different samples were added in each channel. To study sediment transport, at the end of each channel a platform which holds filters is placed to collect the sediments which pass through each channel and prevent them from returning to the system.

Samples of leaves were placed the channels in order to study the decomposition of matter. Tiles were depolocationd to observed the development of biofilm. Moreover, a set of measurements were realized to determine the water level, the flow and the physicochemical parameters. It possible to consult the installation and the placing of different samples on the figure 3.

Figure 3 : Channels experimentation. Source : Le Cavil. A,2018.

3.3. Measurements of abiotic parameters

This part will focus on the method employed to measure the different abiotic parameters on the fieldwork and on the experimental channels. A set of abiotic parameters were measured in order to test the different hypotheses. Moreover, these parameters could be analyzed with the biotic parameters, to study their interaction.

3.3.1. Measurements of the flow and the depth

3.3.1.1. Fieldwork measurements

To measure the discharge a Digital Water Velocity Meter is used. This tool is made of a moving part which correspond to a propeller, a fixed axis on which the propeller turns. The axis is relayed to an impulse counter which receives an electrical signal from the propeller, amplifies the signal, and converts the reading to meters per second. The large LCD screen displays average, minimum, and maximum water velocity readings. The range of measurement is between 0.1 et 0.4 m/s with an accuracy of 0.03m/s, under 0.03 m/s nothing appears, the default value 0.0.1m/s was chosen.

The stream width is measured with a measuring tape, then the stream is divided into sections perpendicular to the streamflow. Velocity and depth were measured with the water flow measurement meter in each section. Sections are divided in subsection extends laterally from half the distance from the proceeding observation vertical to half the distance to the next. The width of each subsection corresponds to the subtraction of the distance to the previous vertical from the distance to the next vertical divided by two (the measures are taken in this subsections). The width of subsections can be variable and the number of measurement point taken depend on the width of the stream. According to the von Kármán constant, the mean velocity is situated at 0.4 d from the bottom of the river (Therefore, the measurement of the velocity is taken at this depth. In deeper streams (>0.6m) the velocity is take at 0.2 and 0.8 d from the bottom, then an average is realized to get the mean velocity in the section. The figure 4 details the manipulation.

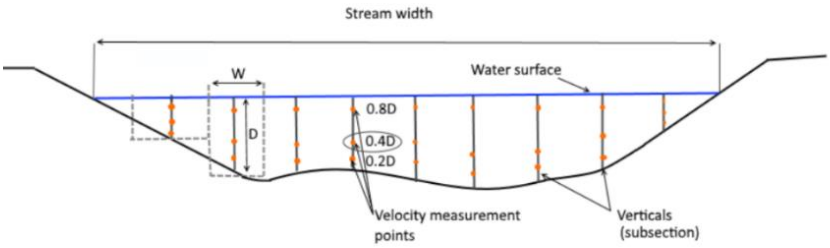


Figure 4: Scheme of the manipulation to measure the flow with a swoffer meter.
Source: Le Cavil.A, 2018 .

The discharge Q (m^3/s) is calculated with this formula: $\boldsymbol{Qt\ (m^3/s) = \sum Wn \times Dn \times Vn}$
Where: **Qt**: total flow (m^3/s), **D:** Depth of the vertical (m), **W**: median width of the section (m),

After the flow measurement another transect (T2) spacing of 10 meters from the first transect (T1) is realized to measure the wet width and depth in order to observe or not a physical difference between the two transects.

3.3.1.2. Experimental channels

Flow is measured once at the beginning of each channel of each plastic trough in order to know the initial flow. The method applied is the bucket method which is adapted to small flow. This method consists to measure the filling time of a tank. The result is determined using the formula below:

$$\boldsymbol{Q = \frac{V}{T}}$$

Q: flow (L/s) V: volume (L) of water flowing into the tank T: time of filling (s)

In a second time the flow is measured by the float method. This method consists to put a floating object in the channel and measure the time of displacement of it over a known distance and depth with the formula below:

Q = V x S

Q: flow (L/s) V: velocity (m/s); V = distance (m) /time (s) S: area (m^2); Length (m) x mean depth (m)

The depth in channels is taken in four transects for each channel; downstream and upstream each barrier (at the middle distance between barriers), the same distance is applied for the channels without barriers. Measurements are realized with a ruler and three measurements are taken by transect due to the small width of channels (9cm).

3.3.2. Measurements of the sediments

3.3.2.1. Fieldwork measurements

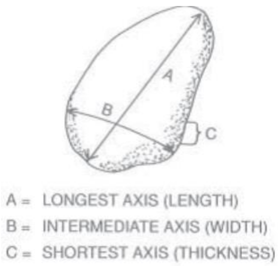


Figure 5 : Pebble axis.
Source: a: Dynamic Aqua-Supply Ltd.

This method allows to determines the size of material on a bed of a stream. It based upon an analysis of the relative area covered by particles of given sizes (Wolman, 1954). The method could be applied on rivers which flow on coarse material. The operator choses a transect where there are pool and riffles at the same proportion. After that the operator walks across the section and take at each step the particles which touch their big toe without regarding it. When the particle is picked, the b-axis (figure 5) is measured with a ruler. The particles measured are classed among size classes determined by Wolman, classes begin at Sand (<2m) and finish at the very large boulder (2048 - 4096 mm). For embedded pebbles or those that are too large to move the shortest axis visible is measured.

If the stream reach is <2 m the method could be modify by walking upstream in a zig zag pattern instead of perpendicular to the flow. The sampling is repeated until a minimum of 100 measurements are made in order to accurately quantify pebble distribution. To finish data are collected, data is plotted by size class (log2 scale or log10) and frequency to determine distribution (Wolman, 1954).

It is also possible to determine the coefficient of uniformity which provide information on the repartition of the granulometry. The coefficient of uniformity is calculated by the formula below:

$\mathbf{C_u = D_{60}/D_{10}}$ (Guettouche,2016).

$C_u < 2$: granulometry is qualified as uniform
$C_u > 2$: granulometry is qualified as spread/varied
D_{10}: 10% of the particles are inferior to this value
D_{60}: 60 % of the particles are inferior to this value

After the application of the Wolman method a visual analysis is realized to determinate the flow facies according the classification of Malavoi and Souchon (2001). This analysis is realized upstream and downstream for three flow facies (pool, lentic-lotic flats and fast stream), in the same time sediment size presence is determined for each flow facies. Only the size class of the dominant sediment is noted and the accessory which is the less represented.

3.3.2.2. Experimental channels

In this case the quantity of sediment which passes the totality of the system is measured. Filters of 50µm are placed at the end of each channel to catch sediment. By determining the weight of sediment which pass through the channel it is possible to study difference between channel with barriers and without barriers. These filters are removed and cleaned at the end of the experimentation. The content of the filters is put in aluminum boxes where a hand sorting is realized to isolated sediment from organic debris. Then sediments are dried in an oven at 100°C for 24hours (Fournier et al., 2012). Then sediments are sieved with 4 mesh sieves ([0; 251 µm [- [251; 500 µm [- [500; 1,7 x 10^4 µm - [[1,7 x 10^4 µm; x [). To finish, sediments are weighed to the nearest gram. In order to study the movement of sediment photo are taken at the beginning of the experiment, at the middle of the experiment and at the end to compare the sediment formation/transport by a visual analysis.

3.4. Measurements of physicochemical parameters

3.4.1. Temperature,pH,dissolved oxygen, conductivity,$NH_4^{\pm}$

3.4.1.1. Fieldwork measurements

To measure physicochemical parameters a YSI Professional Plus handheld multiparameter is used. This tool is composed by four cables which hold sensor for temperature/conductivity, dissolved oxygen, and any two sensors among ammonia, nitrate or chloride. Cables are related to a box with a screen which allow to read data and save them.

Dissolved oxygen, temperature, conductivity, pH and ammonium were measured on the same transect as the flow measurement (transect upstream and downstream with a spacing of five meters from the barrier). Measurements were taken at one meter from each bank and at the middle of the river. These 3 measurements points were taken three times in a row from the left to the right bank.

3.4.1.2. Experimental channels

These measurements were taken upstream and downstream barriers for channels with barriers and at the end of the channels. Concerning the channels without only one measurement were realized at the end of the channel due to the lower water level. Measurements were also realized in the plastic tank where the water is stocked.

3.4.2. Continuous measurements of temperature

3.4.2.1. Fieldwork measurements

Some parameters are subject to daily variation and it's more representative to get continual data on a period as just on a specific time. With the material available (two thermo button temperature data logger) continual temperature was saved. These two iButtons were placed; downstream of the barrier most downstream (station 1) and upstream of the barrier most upstream (station 6). The thermo buttons temperature data logger were placed in the same place where other samples were deposed, part 3). These data provide useful information that it will possible to correlate with other parameters like the decomposition of matter or development of biofilm.

The Thermo button temperature data logger are pieces of computer (integrate in a stainless-steel box with a diameter of 17 mm) that record the temperature continuously. These iButtons have an accuracy of ±1°C from 30°C to +70°C. To parameterize the thermo button temperature data logger and extract data it's necessary to plug them on a receptor connected to a USB port that must be connected to the computer. Then the manipulation take place on the computer under a software (1-Wire). Thermo buttons temperature data logger was parametrized to save temperature each thirty minute from the 05/28/2018 to the 06/11/2018.

3.5. Measurements of biotic parameters

3.5.1. Decomposition of willow leaves

3.5.1.1. Fieldwork measurements

The rate of degradation is determined by biotic (bacteria, invertebrates), abiotic (depth, temperature, pH) and physicochemical factors. Knowing barriers impacts these parameters, a potential relationship between the barriers and the dynamic of degradation could be realized.

In this method willow leaves (*Salix sp.*) were used, this species is frequent in the riparian zone of the river and used in several similar studies (Collier & Winterbourn,1986). In this case fives samples will be deposit upstream, and fives downstream for each barrier which make a total of 60 samples. Leaves are collected on a willow and dried in an oven at 40°C during 48 hours (Bouraada & Essafi, 2016) as shown on the figure 6, n° 1. In the same time bags are construct (10cmx10cm, made of nylon mesh 0.5mm) in order to host the leaves (figure 6, n°2). These bags allow the retention of leaves against the flow velocity. To allow the decomposition by invertebrates 24 holes of 5 mm (5mm; ±2 mm) are made in each bag.

When leaves were dried, they were weighed with a balance HR120 (Repeatability/Std. Dev.0.0001g) and the total weight were divided by the number of samples in order to know the approximate weight to put in each bag. Another weighting was realized before putting leaves in the nylon bags to know the exact weight selected. Then bags are closed with staples and the bag are agitated to remove leaves fragments which are smallest than the holes bags. To finish a third and last weighting was realized while subtract weigh of staples in order to know the exact weight at the end of the preparation, the mean is 1.084g per bag and the standard deviation is 0.078 (figure 6, n°3). To finish the bags were enclosed in little yellow boxes (plastic mesh 0.7mm) themselves locked by a zip cable tile. These yellow boxes protect the samples and facilitate locating and fixing the sample in the river (figure 6, n° 4). Before the fieldwork leaves are placed in a hermetic bag in order to conserve them (figure 6, n°5). Samples are deposed upstream and downstream each barrier (5 to 15 meters from the barriers maximum) in a shallow area (10-30cm) with a small flow and they are attached with a rope to cobbles in order to secure it (figure 6, n°6).

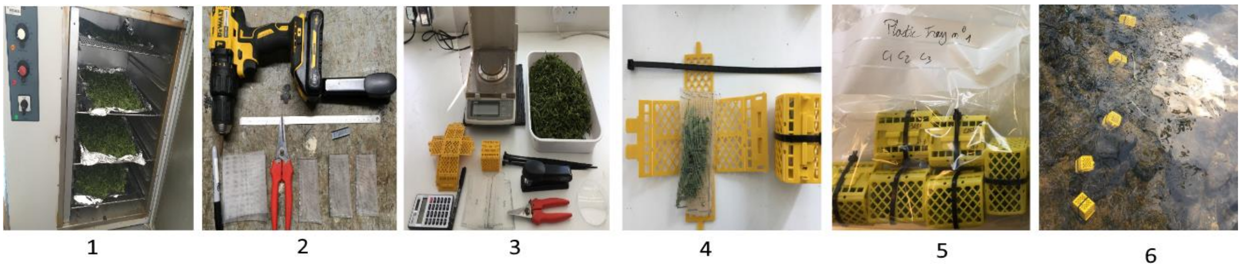


Figure 6 : Steps of preparation of the leaf samples. Source: Le Cavil. A,2018.

After (20-21-22 days) the samples were collected and cleaned in the lab in order to separate leaves to debris or invertebrates. Then each sample were put in an aluminum boxes previously weighed empty. Boxes are placed in the oven to dry the leaves with the same conditions that preparation of samples. After drying the boxes were weighing, then a difference was realized between the weight of boxes after drying and it initial weight (before drying and without leaves) to know the weight of dry leaves remaining after the days in the river.

A comparison of weight at t0 and after tx (x = days in river) could be realized in order to know the weight loss or initial weight remaining (Petersen, 1974). Moreover, a decay coefficient (per days) for leaves is calculated using the weight lost divided by number of days in the river.

3.5.1.2. Experimental channels

The same principles as the leaf decomposition on fieldwork were used for the channels experimentation with some differences in the preparation of samples. Indeed, the weight measured was the wet weight. Moreover, no bags were used to lock the leaves, only the yellow boxes because there is not enough velocity to take them away. Some shingles are put in the yellows boxes in order to fix them on the ground.

Samples are placed downstream each barrier at the median distance between two barrier/end or begin of the channels, which correspond to a total of 4 samples for each channel with barriers. Concerning channel without barrier, samples are placed at the end in order to benefit of a maximum water level because all samples are totally (or 90%) covered by water. Figure 7 shown the placing of each samples.

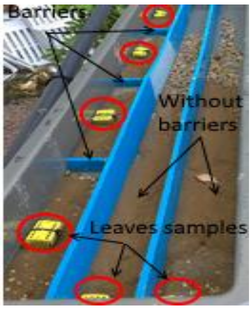


Figure 7 : Placinf of Leaves samples. Source: Le Cavil.A, 2018.

After 28 days leaves are removed from channels and a weighting was realized (wet weight) in order to know the weight and process to the analysis already see in the method for leaves decomposition on fieldwork.

3.5.2. Biofilm

3.5.2.1. Fieldwork measurements

Two tiles were depolocationd per barrier, one downstream and one upstream the barrier. Tiles of 15x15 cm were the support for the biofilm. These tiles are not smooth and coated with varnish because the extent of microbial colonization appears to increase as the surface roughness increase (Characklis et al., 1990). The tiles were performed in each side to attach them in order to secure the samples.

During the fieldwork tiles were deposed in a sector with a low flow. Indeed, higher the shear stress is, the longer it takes for micro-organisms to acclimatize to environmental conditions (Qi et al., 2008). Moreover, the sticking efficiency decrease with the augmentation of shear stress (Lecuyer et al., 2011). There is an exponential decrease of the number of adhesion bacteria with the shear rate.

Moreover, tiles were deposed in a zone of water level (<20cm) to be sure they will not too subject to excessive water level and flow variations. Tiles were dropped on the bottom of the river and attached with string to cobbles to secure them. The conditions of deposit of samples and method of fixation is the same as the leaves, that's why leaves and tiles where attach between them and deposit in the same zone of the river. The figure below shows a tile and it fixation in the river with other samples.

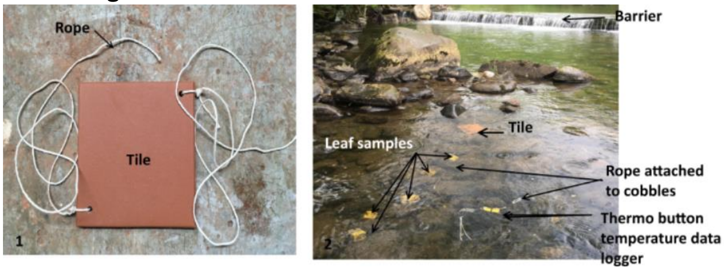


Figure 8 : Tile used for the study of biofilm development (1) and it fixation in the river with the other samples (2).

After 20,21 and 22 days (due to a deposit on different days) the tiles were recovered in order to study them. A photo of each tiles was taken after it exit from the water. Photos were analyzed with the software Mesurium to determine the percentage of recovery. This software allows to determine the area colonized by the biofilm by different methods. Methods chosen consist to select zones which have a specific color (color of the biofilm in this case), the software recognize all the similar color and give their area. This percentage will give information on the condition of development in the location.

3.5.2.2. Experimental channels

The same method is used for the experimental channel however tiles had a smaller dimension (5cm x 5cm). Tiles were put upstream and downstream barriers ahead the samples of leaves (yellow boxes) which were placed at the middle distance between the barrier or the end/beginning of the channel. Concerning the channels without barriers only one tile was placed at the end of the channel in order to get the maximum water level. The placing of the samples respects the same as leaves.

3.6. Data processing

3.6.1. Fieldwork data

The results will be treated in two different sections, first the difference by types of barriers (natural or artificial) within location (upstream vs upstream or downstream vs downstream) and across location (upstream vs downstream). Then a comparison between natural and artificial barriers by analyzing differences upstream minus downstream of each type of barriers. This plan is followed for depth and width due to the measurements of two transects per location. Concerning sediment and biotic parameters only one measurement per location was carried out. Therefore, there is no comparison within location but only across location (upstream vs downstream) and type of barriers.

3.6.1.1. Comparison within and across location for natural and artificial barriers

The analysis is a comparison of many observables positions on dependent samples. Indeed, the samples (upstream/downstream) are dependent because there is an interaction between them and between the stations. Indeed, five stations on six are located on the same river, the last is in another river but it is connected with the tributary where are the five other stations and the maximum distance between the station one and six is around five kilometers.
There is a chose between on parametric test (repeated measures ANOVA using mixed models) or a nonparametric test (Friedman). The conditions to realize the parametric test is to check that the differences between series follow a normal distribution with a normality test (Shapiro-Wilk) with the risk of error α =0.05, the hypotheses are:

H0: The variable from which the sample comes has a normal distribution.

Ha: The variable from which the sample comes does not follow a normal distribution.

If the p-value is superior to 0.05, the null hypothesis is accepted, and the parametric test is realized otherwise the non-parametric test is chose. Nevertheless, before testing normality the number of individuals per samples should be taken in consideration. The number of individuals is very important in the choice of the test. The practical importance of the normal law comes mainly from the fact that the average of a sample extracted from any population has a practically normal distribution when the size of this sample is sufficiently large in practice as soon as the number reaches 30 (Huguier et.al, 2000). Moreover, the test of variance is not enough powerful on small sample size (Peru,2003).

In the majority of the case the samples contain less than 30 measurements, so the normality could not be tested and give a significant result. When the samples are very small (N=6), the only possibility is the use of a nonparametric test (Le Guelte et al., 1983). The nonparametric tests are more robust than parametric tests, they can be used in a larger number of situations (XLSTAT, 2016). Nevertheless, they are less powerful than parametric test and are less sensitive to small variations (StatSoft, 2013). The hypotheses for the parametric and nonparametric are:

H0: The samples are not significantly different

Ha: The samples are significantly different

In this case H0 means there are no differences between natural upstream and natural downstream and the same thing for artificial upstream and artificial downstream. Analysis will be focused on the results by types of barriers.

3.6.1.2. Comparison of natural barriers versus artificial barriers

A comparison of two observed position on two groups is realized: natural versus artificial. Before that a subtraction of upstream minus downstream for each type is realized to compare only the differences. The samples are paired as said in the previous part. There is a choice between the paired t-test (parametric) and the Wilcoxon test (non-parametric). The condition to apply the parametric test is to check that the differences between series follow a normal distribution. If there are more than 30 individuals per samples the normality is tested otherwise the nonparametric test is automatically applied. The hypotheses for the tests are:

H0: The distribution of the two samples follows the same distribution

Ha: The distribution of the two samples follow a different distribution

In other word H0 mean there are no differences between natural and artificial barriers. A detailed example is realized on transect depth in appendix n° 11, it is strongly recommended to read this appendix to understand the full calculations.

- **Sediment distribution**

This analysis corresponds to test the association between two qualitative variables (natural upstream vs natural downstream etc.) measured on different sediment classes. The Hypotheses are:

H0: the two qualitative variables are independent.

Ha: the two qualitative variables depend on one another

In this case that mean the type and position of barriers affect or not the repartition of sediment. To validate the hypothesis, a comparison of the calculated χ^2 to the theoretical χ^2 obtain with the degrees of freedom is realized. If χ^2 theoretical > χ^2 calculated the null hypothesis is accepted. The Chi-square test is based on the computation of a chi-square statistic which reflects the distance between the real data and theoretical data if the null hypothesis were true (XLSTAT,2017), the Chi-square also calculate the theoretical frequencies.

If there are expected values lower than one, the test should not be used (categories should be combined to avoid this problem) and no more than 20% of the expected values should be less than five (Calvin, 2011) otherwise it is better to use the Fisher's exact test (XLSTAT,2017). To avoid the values lower than one and more than 20% of expected values less than 5, the classes [4:6[mm and [6:8[mm are merged and the classes [1024-2048[to [2048-4096[too.

The Fisher exact test computes the probability of having the observed data as well as the probabilities of getting all of the more extreme possible datasets under the null hypothesis. The Fisher's test could also be used to analyzed exact difference by classes in details.

3.6.2. Channels data

For all the analysis a comparison between two observed position is realized except for the sediment which is a comparison of observed distribution. The comparison is realized between two samples, channels with barriers and without barriers composed each one of three channels (3 replicates or individuals) within which a number of different measures have been carried out (number of measurements/observations). The samples are independent because channels with and without barriers are isolated and the values of one sample doesn't influence the values of the other.

There is a choice between one parametric test (t-test) and one non-parametric test (Mann-Whitney). To apply the parametric test, the data needs to respect four conditions (XLSTAT,2016);

(1) Independent, unbiased samples (2) Data normally distributed (3) Equal variance

(4) At least 20 individuals per sample, or normality of populations of each sample assumed* *(At) least 30 concerning AnaStats.fr).

The conditions 1 is also validated concerning all the case as explain before. The normality is tested for each sample with the test of Shapiro-Wilk only if there are more than 30 individuals per samples (ref part 3.5.1), otherwise a non-parametric test is used. If there is more than 30 individuals and the normality of each samples is verified, the equality of variance of the two samples is tested using the Fisher test, hypotheses are:

H0: The ratio between the variances is equal to 1.

Ha: The ratio between the variances is different to 1.

If the null hypothesis is accepted the parametric test is used. Nevertheless, in the majority of case there are less than 30 individuals, conditions 2 and 3 are not verified and the nonparametric test is used. In all the case the hypotheses are:

H0: There are no differences of position between channels with and without barriers

Ha: There are differences of position between channels with and without barriers

- **Sediment**

Concerning the sediments this is a comparison of the distribution by classes between channels with and without barriers. The test which exactly fit with this analysis is the Kolmogorov-Smirnov test which do not require specific assumptions (XLSTAT,2016). The hypotheses are:

H0: The data from channels with and without barriers follow the same distribution

Ha: The data from channels with and without barriers do not follow the same distribution.

The results of the test calculate also the Statistic D of the Kolmogorov-Smirnov test which corresponds to the highest difference between the frequency cumulative curves for the classes studied. The higher the difference, the lower the associated p-value, and the more the two distributions will be significantly different.

4. Results

4.1. Fieldwork results

4.1.1. Abiotic parameters

4.1.1.1. Flow facies

These measurements were realized for each station and an average was realized, the results are shown on the table below:

flow categories	Pool (%)	Lentic/lotic flat (%)	Fast stream (%)	total effective (%)
upstream artificial	16,7	60,0	23,3	100,0
down artificial	20,0	10,0	70,0	100,0
upstream natural	26,7	10,0	63,3	100,0
down natural	50,0	10,0	40,0	100,0

Table 1 : Flow facies

Concerning upstream artificial barriers, the flow facies seems more heterogenous than downstream the barriers with a majority of flats. Some pools were observed and localized just downstream the artificial barriers created by the head drop of the barriers. Then the depth decrease and the fast stream appear and become dominant with 70% of presence. For natural barriers the fast stream is dominant upstream the barriers follow by pools while downstream the pools are dominant with the fast stream.

Generally, the pools are more present downstream barriers followed by the fast stream for the two types of barriers. The proportion of fast stream is inversed between downstream artificial and upstream natural and flat are almost exclusively present upstream artificial barriers.

4.1.1.2. Wet width of the river

- **<u>Comparison within and across location for natural and artificial barriers</u>**

The table of results (appendix n°12) record only two differences for different type of barriers. Nevertheless, this part is focused on the differences in the same type of barriers. Therefore, there is <u>no significant</u> difference upstream-downstream natural or artificial barriers for the wet width (p-value from 0.113 to 1). However, the boxplot in figure 9 shows striking differences but it's between type of barriers, change within type of barriers is similar.

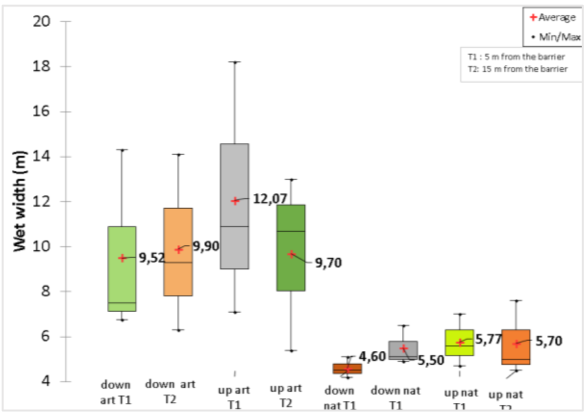


Figure 9 : box plot of wet width for the different transects

- **<u>Comparison of differences within and across location for natural and artificial barriers</u>**

The results of the Friedman test are p-value between 0.709 and 1 that mean there is <u>no difference</u> of wet width whatever the comparison (appendix n°13). The figure 10 show that the average of difference is close except for two box plots but it's not the same type of barrier.

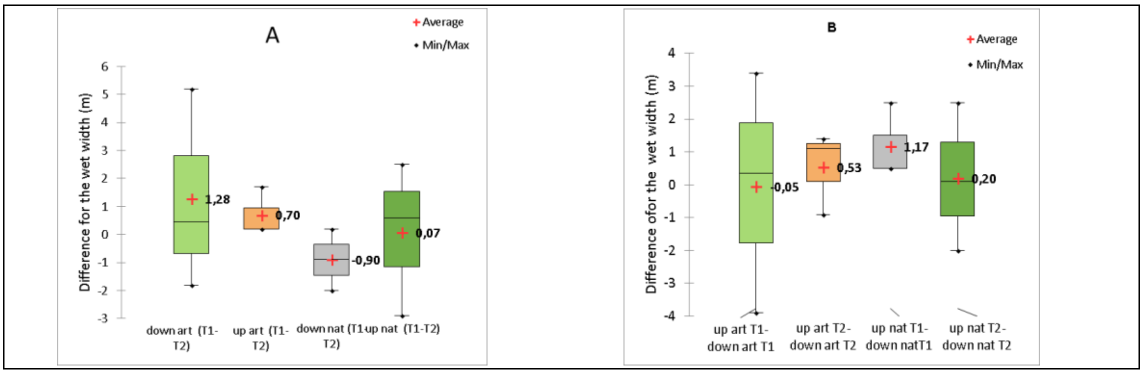


Figure 10 : Box plot of difference for the wet width within the location (A) and across the location (B)

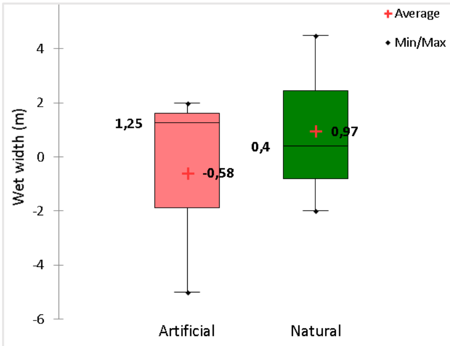


Figure 11 : Box plot of the difference between natural and artificial barriers based on difference within site

➢ **<u>Natural versus artificial</u>**

This is a comparison of change between two dependent groups, the p-value is 0.5, <u>there is no difference</u> in wet width change between natural and artificial barriers. Indeed, according the figure 11, there is 1.6m of difference between the change of transect 1 and 2 in the same location for natural and artificial barriers based on two differences (T1-T2 within the section for upstream and downstream and after upstream – downstream).

4.1.1.3. <u>Depth</u>

➢ **<u>Comparison within and across location for natural and artificial barriers</u>**

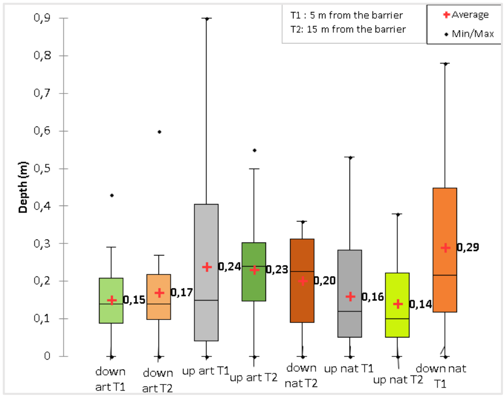


Figure 12 : box plot of depth transects for the 8 different groups

The normality was tested for the difference of variable nevertheless for at least one series the normality is not assumed so the test of Friedmann was utilized. The result show only one p-value inferior to 0.05 for upstream natural T2 and downstream natural T1. So, there <u>is only one significant</u> difference for natural barriers on six combinations and no significant difference for artificial barriers whatever the combination (appendix n°14). According to the figure 12 the group up art T1(upstream artificial, transect n°1) and down nat T1 have the more higher variation and the most important difference is between up nat T2 and down nat T1 as prove with the p-value. Nevertheless, there is also some difference for down art T1 and down art T2 with up art T but it's not significantly different.

➢ **<u>Comparison of differences within and across location for natural and artificial barriers</u>**

All the p-value for comparison within and across location are superior to 0.05, so there <u>is no significant</u> difference between differences within location upstream or downstream. Nevertheless, there two significant differences for two comparisons between natural and artificial barriers as shown on appendix n°15. The figure 13 prove that the differences are close within (A) and across the location (B).

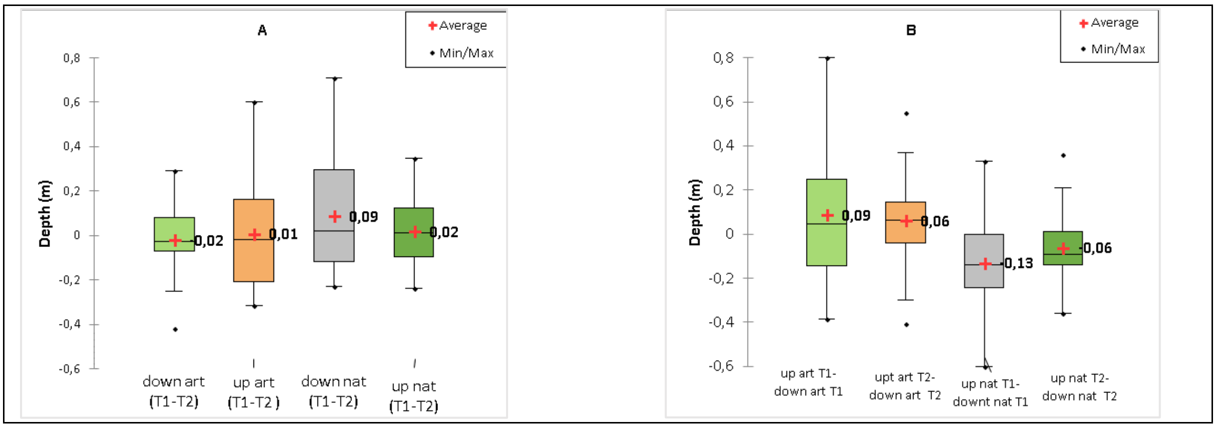


Figure 13 : Box plot of difference in depth transects within the location (A) and across the location (B)

- **<u>Natural versus artificial</u>**

The p-value calculated is equal to 0.405, therefore <u>there is no significant</u> difference between natural and artificial barriers concerning the transect depth. The figure 14 could confirm that the difference between natural and artificial barriers (based on the difference between change on transect T1 and T2 within section subtracted after by upstream minus downstream) is very similar.

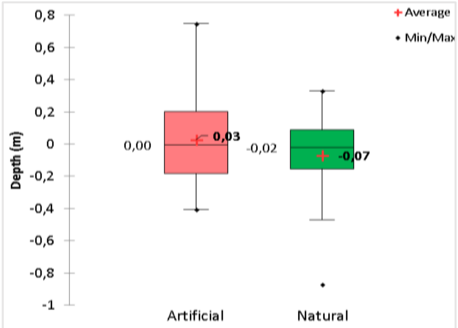


Figure 14 : Differences on depth transects based on difference within site and location.

4.1.1.4. <u>Sediment</u>

- **<u>Comparison upstream and downstream natural barriers</u>**

The repartition of sediment upstream natural barriers follows a trimodal distribution with three modes located at the size class, [8:11[mm, [64:90[mm and [180:256[mm while downstream the distribution is polymodal as shown on the figure 15.

The location upstream the barrier has a greater frequency than the location downstream for the size classes from [8:11[mm to [64;90[mm. Then, downstream the barrier has a higher frequency from the size class [90:128[to [1024:2048[mm. Upstream barriers is the only location which contain sediment in the size class [2048;4096[nevertheless downstream have more big particles and the station 4 presented an important presence of bedrock without sediments. Average is 126 mm for upstream against 131 for downstream.

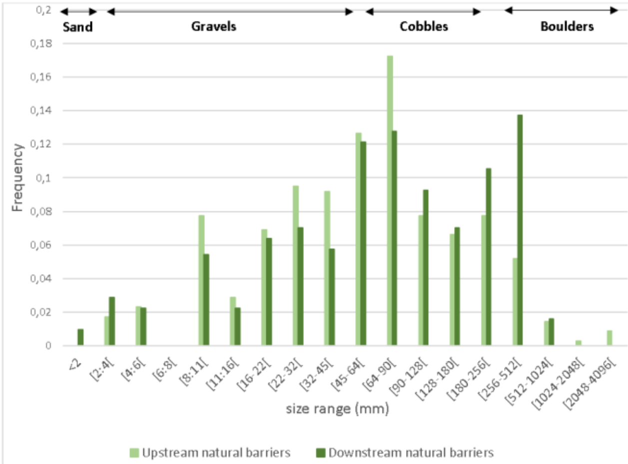


Figure 15 : Frequency of sediment for upstream and downstream natural barriers.

It is also possible to analyses the cumulative effective (%) according to the size to improve the analyses of the sediment distribution, the curves are shown in appendix n°16. The shape of the two curves are stretch that mean the repartition of sediment is heterometric. This aspect is validated with

Class	Sand	Small boulders	Very large boulders
Size range (mm)	<2	[256-512[	[1024-4096[
natural upstream	<	<	>
natural downstream	>	>	<
The values displayed in red are significant at the alpha threshold = 0.05			

Table 2 : Result of the exact test of Fisher

the coefficient of uniformity (upstream=7.7 and downstream = 10.8). The D50 is respectively 59 mm and 73.8 mm. The differences between the curve is due to the higher frequencies until the size class [64:90[mm for upstream the barrier. The p-value of the Khi^2 is 0.009, so the type and position of barriers significantly affect the repartition of sediments. This is especially true for three classes as shown on the table 2 according the results of the fisher exact test.

- **Comparison upstream and downstream artificial barriers**

The distribution of sediment upstream the artificial barriers follow a trimodal distribution (as upstream natural) while downstream the distribution is bimodal (figure 16). The most important frequency for upstream and downstream is located for the size classes [16-128[mm. However upstream the barriers has a higher frequency than downstream for the size classes [16:90[mm. Nevertheless, after these classes the trend is reversed and the average upstream is 109 mm against 139 for downstream.

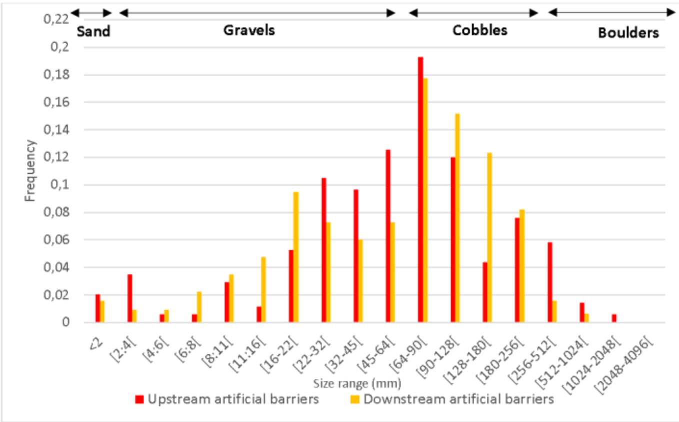


Figure 16 : Frequency for upstream and downstream artificial barriers.

According the cumulative curves (appendix n°17) the distribution of sediment is heterometric which is validated with the coefficient of uniformity (upstream= 6.3; downstream= 6.5) that mean the sediment are spread distributed. The D50 is 65.3mm for upstream against 100.8mm for downstream. The p-value of the χ^2 test is <0.0001. The type and position of barriers significantly affect the repartition of sediment. The Fisher exact Test (table 3) prove there is at least one significant differences for 6 size classes of sediments and 4 significant differences for the both (very coarse gravels to large cobbles).

Class	Sand	Very coarse gravels	Small cobbles	Medium cobbles	Large cobbles	Very large cobbles
Size range (mm)	<2	[45-64[	[64-90[	[90-128[	[128-180[	[180-256[
Artificial up	>	>	>	<	<	<
Artificial down	<	<	<	>	>	>
The values displayed in red are significant at the alpha threshold = 0.05						

Table 3 : Results of the Fisher exact Test for upstream and downstream artificial barriers

- **Comparison natural and artificial barriers**

If we compare natural and artificial barriers the figure 17 showed that the major frequency is between [16-22[mm and [256-512[with a maximum for [64-90[mm size class followed by the [90-128[mm size class. Distribution between [16-512[seem similar for natural and artificial barriers with small difference except for [8-11mm [and [90-128 [mm for artificial barriers which have a frequency difference ranged between 0.04 and 0.06. Sediments under [8-11[mm are not well represented especially for natural barriers and it the same for sediment superior to the size class [512-1024[mm. Nevertheless the natural barriers have more sediment in the size classes after [256-512[mm.

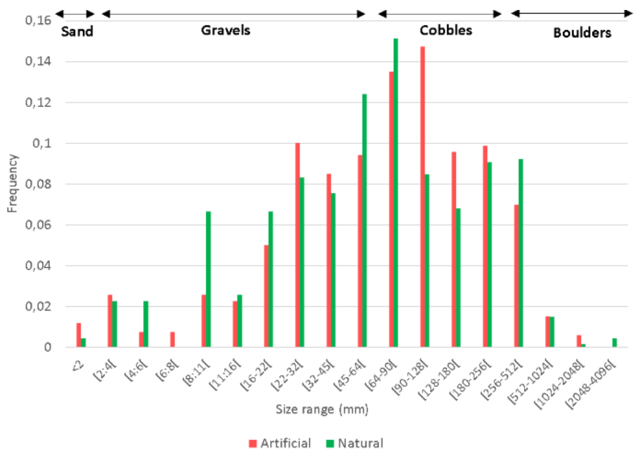


Figure 17 : Frequency distribution of sediment for natural and artificial barriers

The cumulative curves (appendix n°18) show that the two type of barriers follows an heterometric distribution with a majority of frequency between the classes [8:11[mm and [256:512[mm that inform the granulometry is composed in majority by gravel and cobbles. The D50 is around 75 and the average is 123 mm for artificial barriers and 128 for natural. The test inform that the type and position of barriers affect the repartition of sediment. The table n°4 proves that there is only significant difference for medium gravels and medium cobbles.

Class	Medium gravels	Medium cobbles
Size range (mm)	[8:11[	[90-128[
artificial	<	>
natural	>	<

Table 4 : Results of the Fisher exact Test for upstream and downstream artificial barriers

4.1.2. Physicochemical parameters

4.1.2.1. Continuous temperature data

The figure 18 show that there is a variation of maximum and minimum temperature. The maximum temperature appears at the same time for each location and is located between 1:52 pm and 9:52 pm, generally this period has a duration of 3 or 4 hours. The minimum temperature is located between 3:52 and 9:52 am and the location upstream has a decrease more important in temperature than downstream due to a wider valley that allow a longer sunshine. Moreover, there is a greater volume that explain the water is less impacted by temperature changes.

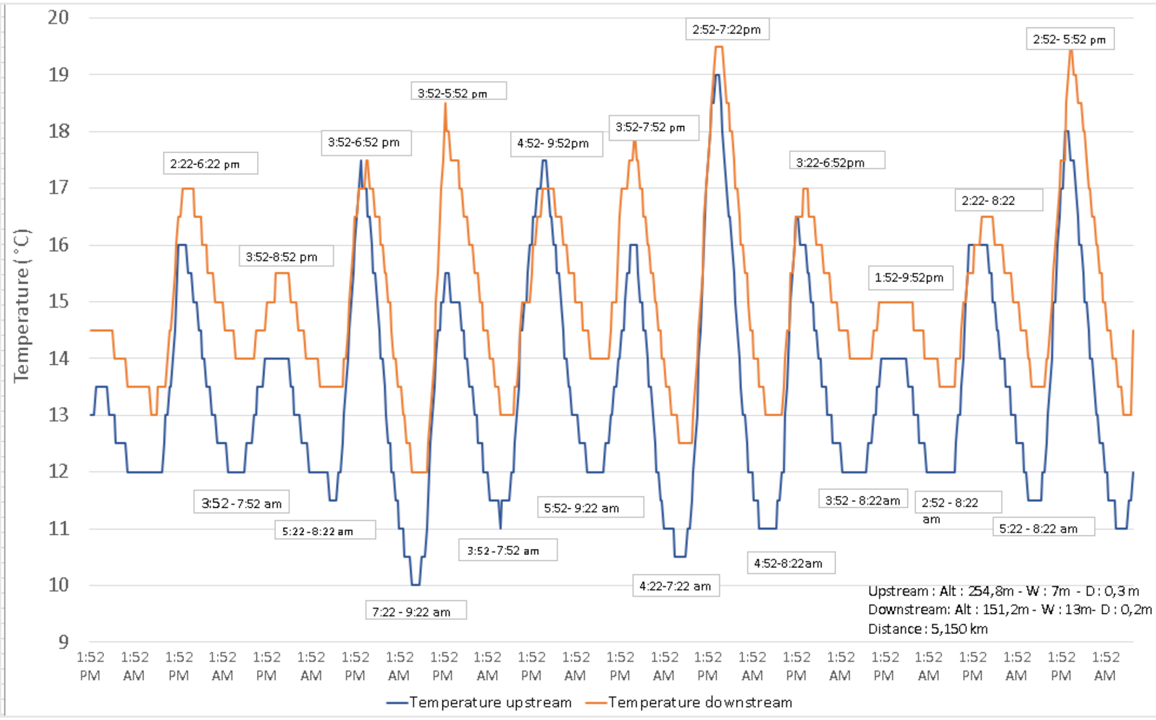


Figure 18 : Continual temperature. (W: wet width, D : depth)

The test there is a significative difference for the temperature between the location upstream and the location downstream. Indeed, the figure 19 show there is an average of 15.01 °C downstream against 13.41°C upstream.

All the other physicochemical parameters are not analyzed because the data are only one point in time and they are not taken at the same time; these data are only used to describe the stations.

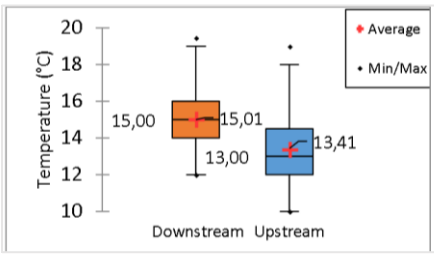


Figure 19 : Box plot of temperature for station 1 and station 6

4.1.3. Biotic parameters

4.1.3.1. Leaf decomposition

➢ **Comparison upstream and downstream for natural and artificial barriers**

The initial weight remaining seem very close for all the station (figure 20), the average variation is around 15% and the most important gap seems between downstream natural and upstream natural. Then the decay per days (g) is analyzed with the Friedman test. The p-value for upstream versus downstream natural is 0.942 and 0.198 for upstream versus downstream artificial.

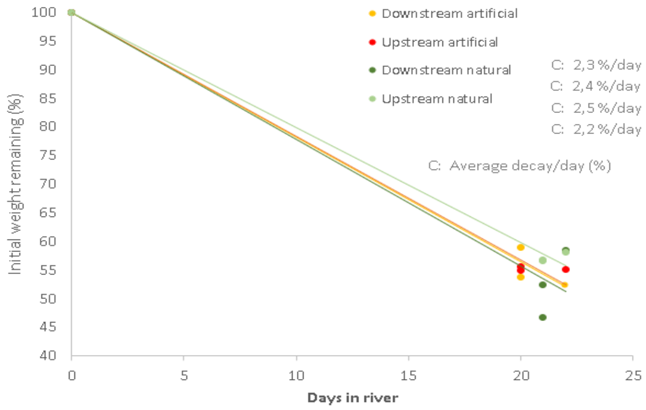


Figure 20 : Initial weight remaining

There is no significant difference on the decay of leaf per days on the both groups for upstream and downstream. Moreover, the test compares all the other combination (example downstream artificial and downstream natural), all the p-value demonstrate there is no difference whatever the combination. Indeed, according the box plot of the weight decay per day (figure 21) the average and the median are all include between 0.022 g/day and 0.025g/day.

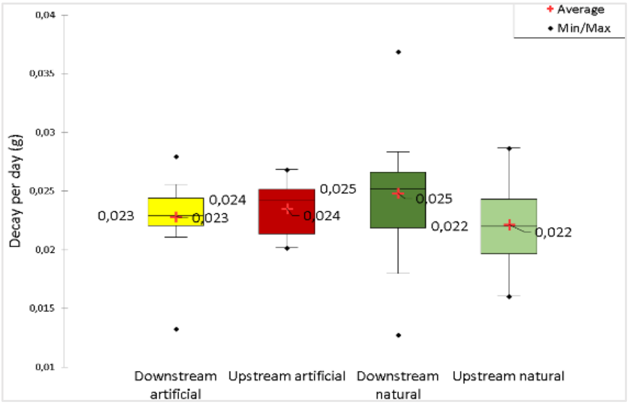


Figure 21 : Box plot of weight decay per day

➢ **Comparison between natural and artificial barriers**

After realizing the subtraction upstream minus downstream for each type, the Wilcoxon test is realized. The p-value is equal to 0.118, the null hypothesis is accepted, there is no significant difference between natural and artificial barriers for the decays per day. The figure 22 proves that trend with an average and a median very close for the two groups.

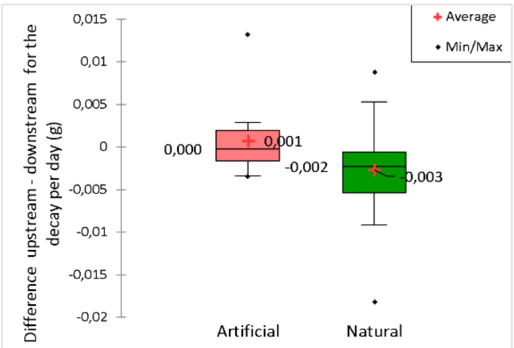


Figure 22 : Box plot of differences (upstream-downstream) for each group concerning the decay per day (g)

➢ **Comparison of station 1 and 6**

Knowing there is a significant difference in temperature between the station 1 and 6 (results of part 4.1.1.1) the leaf decomposition at these stations is compared to know if there is a difference. The result of the Wilcoxon test proves that there is no significant difference for leaf decomposition between station 1 ad 6 (p-value = 0.557). The decay per day is 0.22g for the station 6 and 0.023 for the station 1.

4.1.3.2. Biofilm

➢ **Comparison upstream and downstream for natural and artificial barriers**

The percentage of recovery by biofilm for the majority of stations is located between 30% and 50 % (figure 23) nevertheless some stations have very high or low values. The recovery per day (%) is close within type and different position, the maximum difference is between upstream natural and upstream artificial.

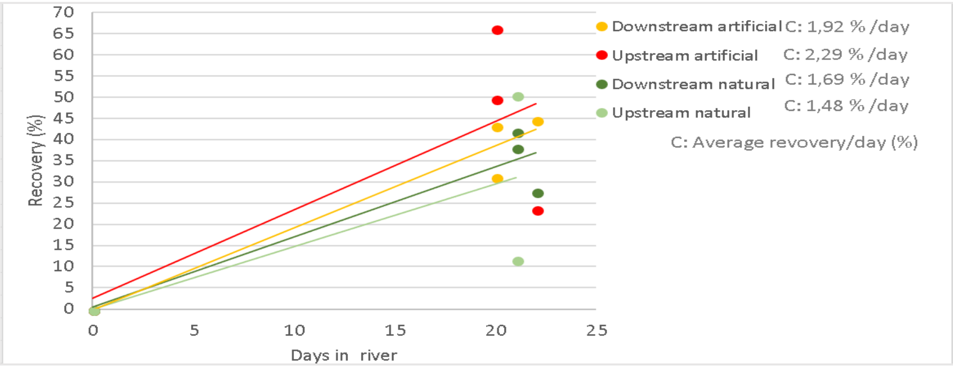


Figure 23 : Recovery of tiles by biofilm in river

The tiles have the same area and were remained between 22 and 20 days in the river so the area colonized per day (cm^2) is compared to compare a similar measurement.

According to the Friedman test, there is no significant difference between upstream artificial and downstream artificial (p-value = 0.410), it is the same result between upstream natural and downstream natural (p-value = 1). The analysis of all the different combinations does not prove any differences too. Nevertheless, according to the figure 24 there are small variations between upstream and downstream for the mean and the standard deviation which is always greater for the location upstream (upstream artificial = 2.74; upstream natural = 2.071) than downstream (downstream artificial =0.578; downstream natural =0.706).

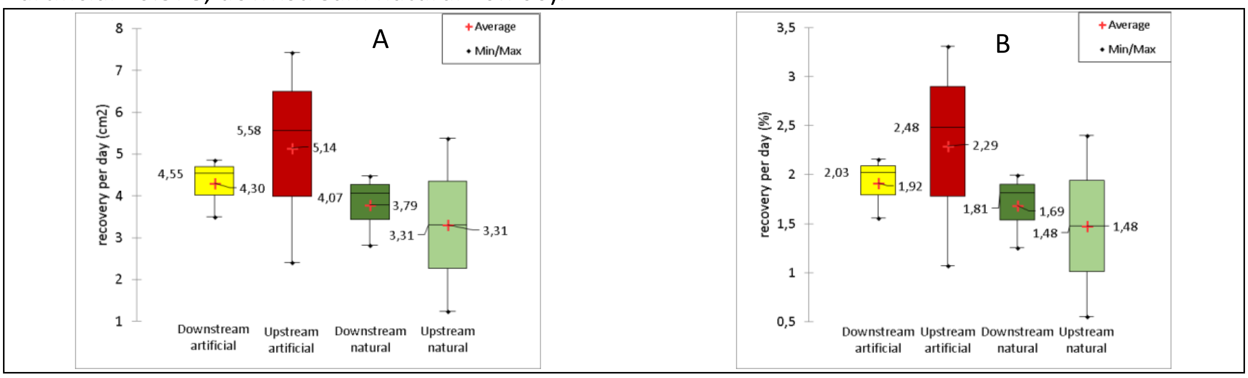


Figure 24 : Box plot of biofilm on fieldwork. a: area in cm2 b: percentage

➢ **Comparison natural and artificial barrier**

The p-value is equal to 1, there is no significant difference between natural and artificial barriers for the development of biofilm and according to the boxplot of difference there is a gap of $2cm^2$ in the average.

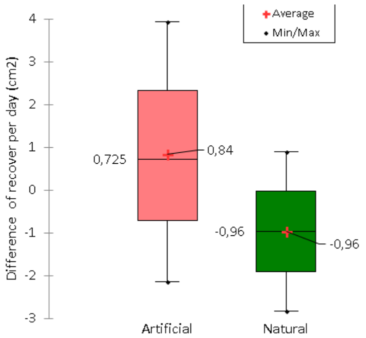


Figure 25 : box plot of natural versus artificial

4.2. Artificial channels with or without barriers

4.2.1. Abiotic parameters

4.2.1.1. Flow discharge

In this section the flow discharge at the beginning of each channels is tested to verify if each channel undergoes the same parameters. The result of the Mann-Whitney test is a p-value equal to 0.825 with the risk at 82.48% to reject the H0 while it is true. The null hypothesis is accepted, there is no difference of positions between channels with and without barriers. That mean the experiment is based on the same hydraulic condition that is important to realize comparison for the other parameters and rely difference to barriers. The figure 26 shown that the average is very close and the standard deviation is 0.77 for channels with barriers against 0.41 for channels without barriers.

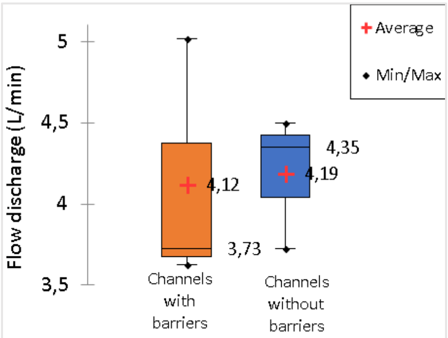


Figure 26 : initial flow discharge in channels

4.2.1.2. Velocity

The p-value calculated is 0,0004, this is inferior to α (0.05), the null hypothesis is rejected and the alternative hypothesis (Ha) is accepted. There is a significant difference of positions between channels with and without barriers. According the figure 27 the average is 0.05 m/s for channels with barriers against 0.017 m/s for channels without.

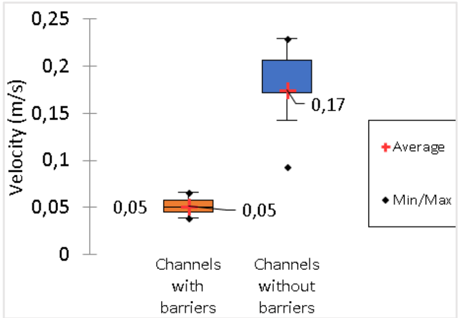


Figure 27 : Box plot of channels velocity

4.2.1.3. Depth

Twelves measurements per channels on four transects were realized for a total of 36 measurements per samples (N>30), the conditions to apply a parametric need to be checked in this case. According to the shapiro test only the data from channels without barriers follows a normal distribution, so the conditions is not validated and the variance doesn't need to be check, the test Mann-whitney is also used.The p-value is inferior to 0.05, so there there is a significant difference of positions between channels with and without barriers. The figure 28 confirms this trend with an average of 0.5 cm from channels without barriers against 3.2 cm for channels with barriers.

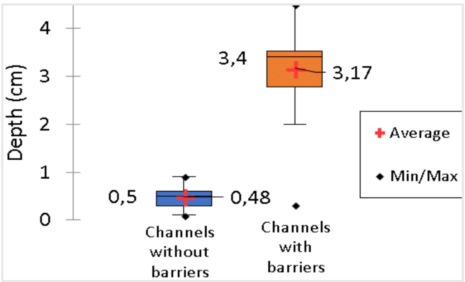


Figure 28 : Box plot of depth in channels

4.2.1.4. Sediment transport

- **Photo interpretation**

At the beginning of the experimentation a rapid movement of sediment appear for every channels corresponding at the step of stabilization of the transport. Three zones are formed (appendix n°19) for channels without barriers (red square), one corresponding at a sector or all the sediment were removed (1) another to a sector with a mixt of sand and gravel with active movement (2) and the last a zone where nothing happen.

Concerning channels with barriers (green square) the sector with all the sediment removed is smaller than channels without barriers (1) and an accumulation of sediment appear upstream the barriers (2 & 2*). There is also a zone without sediment downstream the barriers (3) due to the energy created by the head drop of the barriers which remove them. After this local erosion there is a local but important deposit of the sediment removed (4) follow by a gradual deposit due to the presence of another barrier (2*). The last sector (5) correspond to a small quantity of sediment due to important water movement before the water pass in the plastic tank and the absence of barrier.

Concerning channels without barriers the sector 1 increase with the days (day 14). The sector 2 is divided in two other sectors. Indeed, the sector 2 is reduced to give place to a zone (2) with just gravel (paving) and with gravel and sand with a process of erosion (3). The old sector 3 is now record as sector4 and correspond to a sector of deposit. After 28 days for channels without barriers, the sector 1 have increase in length, the sector 2 too but the sector 3 become limited. The sector 4 had decrease in length but increase his height due to accumulation of sediment.

The formations for the channels with barriers were very fast (between day 0 and 7) it seems to strengthen slightly but tend to stabilize while channels without barriers showed a continual evolution.

- **<u>Analyze of the contains of the filters</u>**

The frequency of different sediment size classes founded in the filter at the end of the channels were similar (figure 29, graphic A) with a majority of the size class [251; 500[µm. Concerning the average weight for the three channels with and without barriers (figure 32, graphic B) there is much more sediment for channels without barriers in each size class. Indeed, the average weight for the group channels without barriers was 4.3 and 5.7 times higher for the differents classes for a total of 5.06 grams collected for channels with barriers against 27.1 grams for channels without barriers.

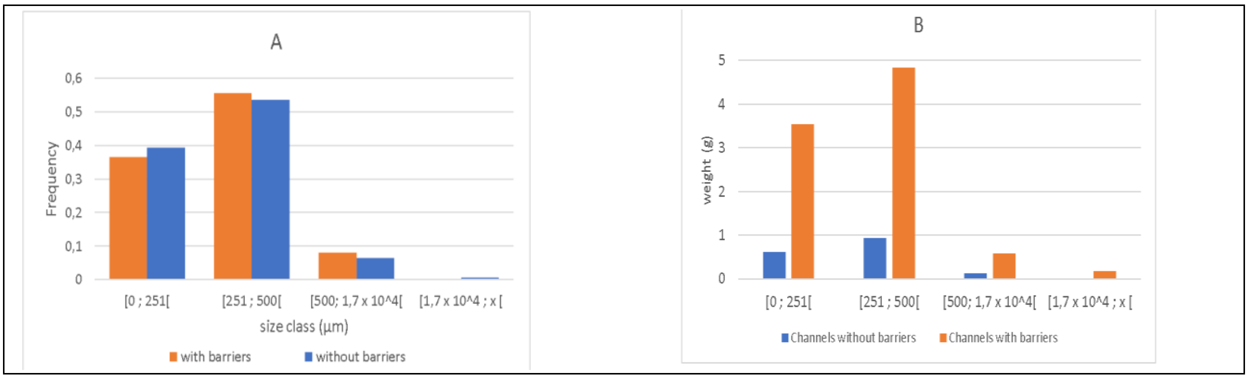


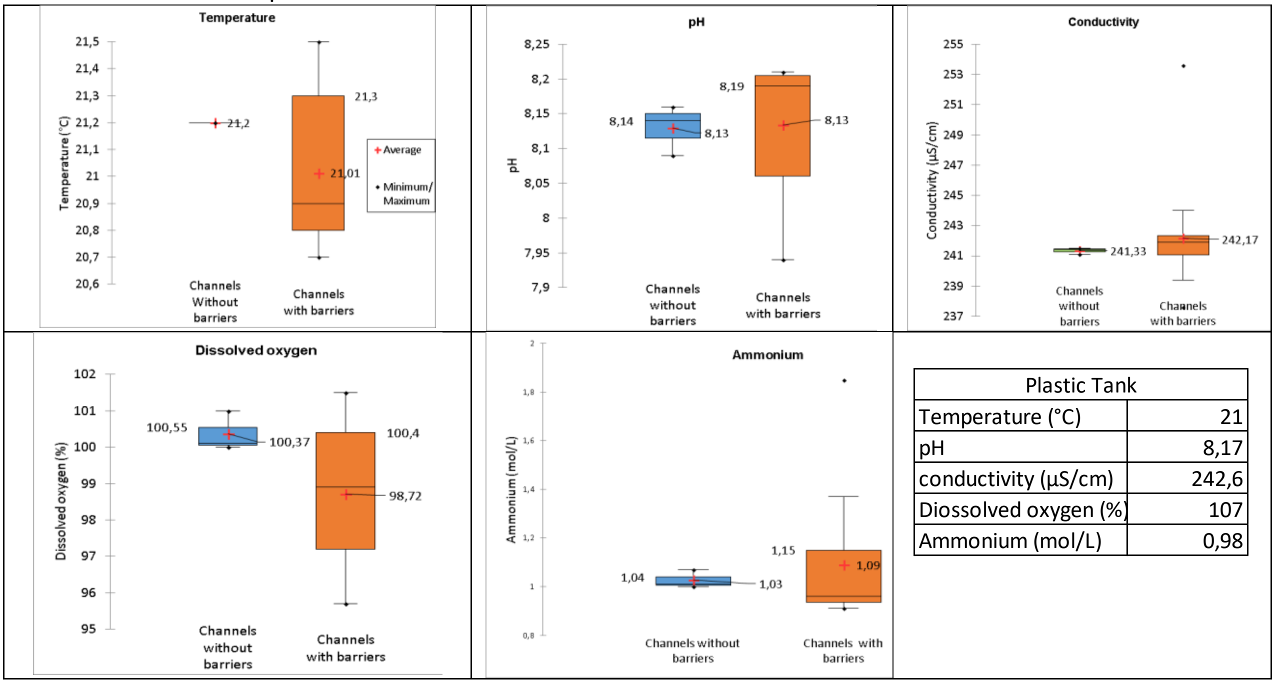
Figure 29 : Analyze of average frequency (graphic A) and average weight per channels (graphic B)

First the relative abundance of each class between the three channels with and without barriers is realized, results are shown on the appendix n°20. All the p-value are superior to α, H0 is accepted. The data from channels with and without barriers follow <u>the same distribution.</u> For three class the D is low that mean the result of the p-value is significative. Then the weight of each class between the six channels is analyzed. The results are shown on the appendix 21. The results inform that in all the case the p value is superior to 0.05 (0.1) so the null hypothesis is accepted. The data from channels with and without barriers follow <u>the same distribution, so there is no significant difference</u>. Nevertheless, for the first three size classes the <u>D is very</u> high that mean <u>there are differences</u> between the frequency cumulative curves but it <u>is the limit</u> to pass the p-value under 0.05 and get a significative difference.

4.2.2. Physicochemical parameters

4.2.2.1. Temperature, pH, dissolved oxygen, conductivity, NH_4^+

All the measurements are very close between channels with and without barriers (figure 30). The repartition of data in the channels with barriers is explain by more measurements realized than channels without barriers. Indeed, only one measurement was possible for channels without barriers due to the very low water level, concerning the channels with barriers, measurements were taken upstream and downstream barriers (4 per channels). The extreme value is explicated in majority by manipulation errors. The results are also close to the water in the plastic tank where come from the water except for dissolved oxygen which is higher in the tank due to the fall create by the denivelation between channel and plastic tank which allow a movement of water.



Plastic Tank	
Temperature (°C)	21
pH	8,17
conductivity (µS/cm)	242,6
Diossolved oxygen (%)	107
Ammonium (mol/L)	0,98

Figure 30:Analysis of water in the channels the 06/06/201

4.2.3. Biotic parameters

4.2.3.1. Decomposition of leaf

As show on the figure 31, graph A the initial weight remaining (%) after 28 days of experiment seems very similar between channels with and without barriers because there is only 3% of differences. If the initial weight remaining is similar, that's mean the decays per day is similar too. Indeed, the figure 31, graph B prove that the average decays per day is only different of 0.01 g between the groups.

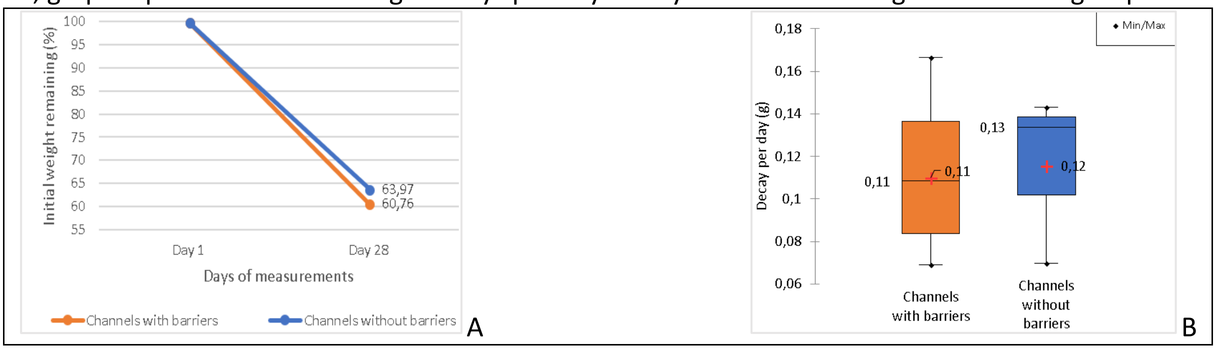


Figure 31 : Analysis of average initial weight remaining (A) and the average decay per day (B)

According to the Mann-Whitney test there is no significant difference of positions between channels with and without barriers concerning the decays per days (p-value =0.942).

4.2.3.2. Biofilm

A comparison of the covered surface (cm^2) by the biofilm is realized. The p-value is equal to 0.348, the null hypothesis is accepted, there is no significant difference of positions between channels with and without barriers. The figure 32 show only 7% of differences between the 2 groups.

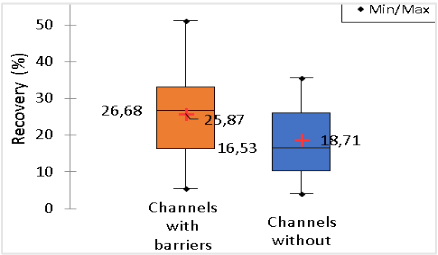


Figure 32 : Box plot of recovery (%) per the biofilm

5. Discussion

5.1. Fieldwork results

5.1.1. Abiotic parameters

Analysis of flow facies revealed differences between upstream and downstream barriers, with a major presence of pools downstream the barriers due to the dissipation of energy induced by the head drop and lentic/lotic flat, especially in upstream artificial barriers. These results seem to correspond to the observations of Malavoi (2003) who proved that weirs aggravate the natural "deficit" in shallow lotic facies.

Generally, depth was more important downstream natural barriers and upstream artificial barriers, one significant difference was detected for the depth upstream natural T2 and downstream natural T1. These findings could be explained by the morphology of the barriers. Indeed, artificial barriers are more uniforms than natural barriers, which means the water is distributed over the entire width with an augmentation of depth upstream (Vazquez,2010) and an erosion downstream on all the width. Therefore, for natural barriers the flow is concentrated on one point that creates an acceleration and an important process of erosion downstream (augmentation of depth) on the length rather the width.

Concerning the depth within and across section or between natural and artificial barrier, no others significant differences were observed. These results do not seem to match those of other studies which already shown depth changes induced by hydraulic structures (Vazquez,2010; Delaunay,2008). The same results for the width are found due to a change at the location of the barrier followed by a progressive change of width on the distance and not locally. The flow discharge and velocity were not measured continuously, which prevented the use of statistical analyses. Some studies on dams show that flow discharge impacts observed flows at monthly and daily scales (Assani,2007). However, the barriers studied are smaller than a dam and in all the cases the amount of water stored during a hydrological year is fully released (Assani,2007). This shows that it is difficult to prove an effect on the flow discharge especially when there is no storage of water. nevertheless, modification of velocity was observed with flow facies and differences were already proves.

Concerning sediment, the stations upstream natural and artificial barriers contain more sediment from medium gravel class to small cobble class than downstream, which present a higher frequency for bigger sediment class from medium cobbles to large boulders and the average size is greater downstream than upstream especially for artificial barriers. In all cases, the repartition was heterometric with a coefficient of uniformity, no embeddedness was detected. The χ^2 test proved significant differences (appendix n°22) for upstream natural barrier which contain less sand and small boulders while downstream the trend is inverted with a significant augmentation of small boulders and an absence of very large boulders. For artificial barriers more, size classes are significantly impacted with more sediment from [45:90[mm upstream and less sediment from [90:256[mm. Final differences between natural and artificial barriers concern only two size classes being significantly different and average sediment size being very similar between the two kinds of barriers.These observations are explained by the fact that upstream the weirs the augmentation of depth

(Vazquez,2010) and the diminution of velocity (Delaunay,2008*)* cause a reduction and deposition of the coarse load early upstream the weir that could create a paving(Bacchi.2011) while there is an accumulation of fine particles near the barriers. This process decreases the sediment input for downstream the barrier, which causes a deficit of coarse load downstream and erodes the minor bed with an augmentation of size substrate (and also create a paving). Another similar process which increases the erosion is an augmentation of depth from upstream to downstream and a change in flow regimes on a short distance (Vazquez,2010) that cause a hydraulic jump downstream. The head drop creates a turbulent zone (hydraulic jump) which erodes the bottom and removes the sediments (Bacchi, 2011). This was observed during fieldwork, especially for natural barrier with the presence of bed rock without other sediment after the head drop (figure 33).

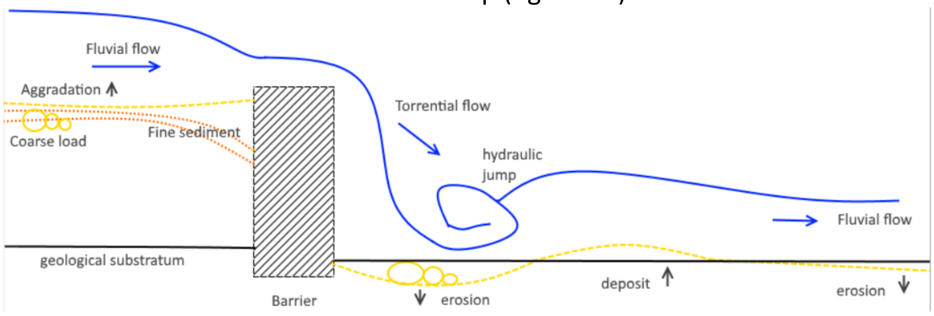


Figure 33 : Impacts of a barrier (weir) on the longitudinal profile. Source: Le Cavil. Inspired by Degoutte,2006.

5.1.1.1. Limits and recommendations

To get comparable data measurement of flow discharge, stations should be placed upstream and downstream the barriers but differences are difficult to prove without water storage (Assani,2007), it's more relevant to study velocity.Concerning the wet width, changes could be detected due to the fact that transects were taken close to the barriers and the section changes gradually. For depth, the first 5 meters after the barriers downstream was not measured due to the protocol and the fact that deep was important. For natural barriers, after 5-meter downstream the effect of head drop was still visible and measured (the end of the pool) due to the configuration of barriers. Nevertheless, that was not the case for artificial barriers. So, it should be interesting to measure the direct impact of the head drop on the bottom of the river by using one transect stick to the barrier.

It was difficult to find significant differences for the depth although it was already proved that depth is higher upstream a barrier (Mueller et.al,2011). The work was to merge data by location due to the independence of stations to study differences by location and type of barriers (it's also allow to compare just by location but is has not been realized to the extent of the given time). Nevertheless, in this case the change of depth and the width are supposed to be small and/or local and measurement were not taken the same days. Moreover, the stations are spaces at a total of 5km and one of the barrier is on the principal river. This means that merging the data could cause a loss of information and change who are cause by other parameters than barriers. Therefore, it's should be better to use a paired test rather than combine data. For example, using a paired test for station 1 (artificial up vs down for T1) a significant difference was found while none was found for locations upstream versus downstream artificial for the transect 1 with the Friedman test. The same remarks could be made for differences between artificial and natural barriers.

Concerning the sediment, the major limit was realizing a representative sampling downstream the barriers. Indeed, the depth just after the head drop did not allow sampling in this zone. Only the sector between transects 1 and 2 could be sampled. That could explain the low presence of small particles although the stations are located at the head of the watershed and the river has a coarse load. Moreover, the trapping of sediment is more important for slow river slope (Malavoi.2003) that is not the case here.

5.1.2. Physicochemical parameters

Physicochemical parameters were not analysed (except continuous temperature) due to only one measurement performed on one day and not at the same time. Nevertheless, the modification of biotic parameters (depth, velocity) impacts physicochemical processes. Indeed, studies showed that the water temperature increased upstream of barriers especially during low water levels that induce a decrease of dissolved oxygen (Malavoi, 2003). Moreover, variation in dissolved oxygen between free-flowing water and the interstitial zone are higher upstream a weir than downstream (Mueller et al.,2011). It was also showed a gradient in temperature which is higher upstream (0.3) than downstream and the pH being a little bit higher downstream (0.1). Nevertheless, no differences were detected for the conductance.

For continuous temperature a significant difference was found between the stations 1 and 6 but it is impossible to rely that with the presence of barriers due to the distance and difference of elevation between the two measurements locations.

Concerning nutrients, the barriers could cause a modification of the kinetics of water purification (Malavoi & Salgues 2011) and an accumulation of them especially in sediment (Nogaro et al., 2017). Artificial barriers seem beneficial for denitrification (upstream) on a small extent and the removal of a weir could have an indirect effect of increasing eutrophication impact by exporting Nitrogen (N) downstream (Cisowska & Hutchins, 2015). Barriers seem to have a positive effect by increasing the nutrient stockage and degradation upstream (Power et al,.2005). That avoids a dispersion downstream but that means there is a difference in nutrient concentration between upstream and downstream that can impact aquatic life and water quality.

5.1.2.1. Limits and recommendations

The method used didn’t allow to carry out analysis, to improve this point continual measurements could be taken upstream and downstream of barriers. Another solution is to realize measurements in different points at the same time (to have same weather condition) upstream and downstream on more transects.

5.1.3. Biotic parameters

To study the decomposition of leaf decomposition a number of factors must be considered, such as water temperature, dissolved nutrient concentrations, stream topography, and discharge. Indeed, these parameters could affect leaf breakdown rates (Reice 1974; Davis & Winterbourn 1977). Nevertheless, in this case, in absence of data, the assumption was made that similar conditions were present between station 2 to 4 (verified by visual analyses of punctual data) due to the small length between them (1km). If the distance increases difference could appear. Indeed, continuous data was significantly different but between station 1 and 6 but it did not induce significant difference in leaf decomposition between station 1 and 6. The same observations are done for all the other comparisons.

No differences were found for leaf decomposition, nevertheless, artificial barriers like dams, decrease water exchange and organic matter could accumulate upstream with low dissolved oxygen concentration (Brierley & Fryirs,2008). That mean the decomposition of matter is less rapid upstream than downstream.

Moreover, the degradation of leaves depends on physical fragmentation induced by invertebrates or by the water velocity, depth, turbulence and sediment transport (Hear et.al,1999; Chauvet et al.,1993). The degradation of leaves is more rapid when the velocity is high because of a higher mechanical abrasion (Hear et.al,1999). Leaf decomposition also depends on the seasons due to the depth variation and the macroinvertebrates assemblages (Serra et.al, 2015). For example, invertebrate biomass is higher in deeper areas with a positive correlation of leaf breakdown in autumn-winter, while in spring the breakdown rate is less important (Martinez et.al,2016). Nevertheless, all the studies didn't find the same results in community invertebrates assemblages. Some found more biomass in current-shallow reaches (Ferreira et al, 2006; Brooks et al.,2005). In this case no correlation or supposition could be due to, the absence of information on invertebrates, the absence of significant results and the different finding between studies.

No significant differences were found for biofilm development, nevertheless some small differences appear with a higher recovery percentage per days for artificial barriers than natural barriers. Generally, the development of pools allows the retainment of nutrients (Stanley et.al, 2002) which could explain more important developments of biofilm, but differences are very small in this case. Mueller and Pander (2011) found the invert results for artificial barrier, indeed a higher species richness and cell number per cm^2 for stations downstream weirs was found but a beta diversity similar. The same trend was present in the change in biofilm mass (Warner et al.,2007) this pattern is correlated with an increased frequency and longer duration of low-flow conditions downstream and it is consistent with other studies relating biofilm mass and flow regime (Clausen and Biggs, 1997). Warner and Ryder (2007) found the same trend with higher number of cell periphyton downstream in shallow and fast-flowing zones than upstream and this difference is stronger in calm and deep rivers. Differences found for biofilm recovery in this study are too small to show a trend.

5.1.3.1. Limits and recommandations

The time scale of the experiment for leaf decomposition is limited and the degradation is not advanced. In the majority of studies leaves are left in the river at least one month. Indeed, leaves show an initial period of rapid weight loss followed by a period of much slower leaf breakdown (Collier & Winterbourn,1986). Half-life of leaves in this study was between 40 and 61 days. Moreover, the method used reduce the mechanical abrasion because bags protect the samples and restrict access by abrading particles. To improve this point sediments could be added in the yellows boxes (Heard,1999).

Another limit is that only one measurement at the end of the experiment was realized while in other method (Maggi & Gessner,2002; Collier & Winterbourne, 1986) different measurements in time are realized, it allows to have very precise measurements in time and significative breakdown rate. To complete the method using, the biomass of bacteria, fungi and invert should be determined to know the proportion of each in the decomposition process (Petersen& Cummins, 1974).

The method applied for the biofilm only allow to study the percentage of recovery which does not fully inform the development of the biofilm. Indeed, methods generally propose to count the number of cells on an area by preparing the samples with the Utermohl method (Utermohl, 1931). In the same idea the number of taxa could be determined to inform of the richness species. The thickness is also an important parameter to know because it is related to the rate of growth of the biofilm. Nevertheless, it need to be measured by light microscopy (Bakkle et al., 2001) that is not possible if the samples are too big for a microscope analysis. However other methods (Warner et.al,2007) propose to analyses the dry mass of the biofilm collected on the river. In lot of the studies case sampling are directly realized in the river on the substratum on repeating point (Warner et.al,2007; Mueller et.al,2011).

A common limit is the very low quantity of barriers studied and samples per locations which not allow to have significant data and use quite powerful statistical tests. A solution to get significant data and improve the robustness of the analysis is to multiply the number of barriers, samples and increase the number of measurement of them as explain to get a complete analysis.

5.2. Channels experimentations

5.2.1. Abiotic parameters

The initial flow discharge of the experiment between channels with and without barriers is verified equal. Nevertheless, the velocity of the channels with barrier is lower than channels without barriers (appendix n°23) that correspond to the observation found on river which confirm that barriers alter the flow regime and the velocity (Environment Agency,2010).

The depth was also significantly different between the types of channels with an average depth 6.6 times greater for channels with barriers that confirm barriers increase the water level. The modification of depth could also explain the differences for velocity and flow. Indeed, the channel flow is non-uniform if the hydraulic depth and velocity change from channel section to channel (Graf,2000). It is especially the case between the two types of channels because the same flow discharge and volume of water pass in two different section (different depth). That cause an adjustment of velocity and flow according to the law of flow and the formula of Manning-Strickler, the relation is demonstrate in appendix n° 24. There is an augmentation of velocity with the diminution of the depth. The presence of the hydraulic jump was very visible during the experimentation as its effect on sediments.

Indeed, according the visual analysis of the sediment transport, the process followed by channels with barriers was the same as explained in the part 5.1.1, figure 33. Nevertheless, a continuous deposit after the important local deposit due to the sediments removal by the head drop is observed due to the presence of another barrier downstream. Without another barrier a progressive erosion should be observed. Concerning channels without barriers the sediment transport was very dynamic with many evolutions over time. On the contrary, the sediment transport (and sedimentary formation) in channels with barriers were very fast but quickly stabilized.

The frequency distribution size of sediment found in the filter were similar, that could be explain by the fact that there is the same flow discharge in each channel. Nevertheless, for the average weight per class the differences are obvious. However, the statistical test proves a p-value of 0.1 for the first three size classes. In this case results are considered almost significantly different due to the p-value close to 0.05 and the differences on the descriptive statistics.

5.2.1.1. Limits and recommandations

A limit of this experiment was its scale size and the number of measurement repetitions. Indeed, the depth and flow discharge were very small that complicate the measurements of depth and make it almost impossible to accurately measure velocity and flow discharge. To resolve this, the experimentation can be done at a bigger scale with a higher flow discharge could be realized.

Moreover, the visual analysis of sediment transport was complicate because of the low quantity of sediments and size classes (in agreement with the flow discharge used). Some studies proposed to use many different size classes and color sediments to make the analysis easier (Bacchi,2011). Nevertheless, the principal limit was to use only one input of sediment which do not allow to reflect the reality with continual sediment input due to erosion process. A way to better imitate the natural sediment transport is to use an installation who constantly bring sediment with a treadmill system (Bacchi, 2011; Leduc,2015).

5.2.2. Physicochemical parameters

All the physicochemical parameters were found similar between channels and very close to the results of the water plastic tank. This is explained by the presence of only one closed circuit and one plastic tank. The same water pass in all the channels and return in the plastic tank before being sent back to the system. That mean if a change was induced by the barriers it was impossible to measure it. Moreover, it was difficult to hope some differences on this small scale (2.05 meter of length) and measurements were only possible at the end of channel because of the low water height.

5.2.2.1. Limits and recommendations

The study of Ferreira et al. (2006) used the same flume system to study leaf decomposition caused by different invertebrate's assemblages and flow velocity by having similar physicochemical parameters. Nevertheless, in this study the changes in physicochemical parameters due to the barriers presence want to be studied. Therefore, differents closed circuits should be used at least for channels without barriers and with barriers. That allow to separate water and realize individual measurements. Concerning water measurements, they could be carried out at the beginning and the end of channels by using repeated measurement or continuous measurement with special tools like ESI sensors (pH, dissolved oxygen) or thermo button temperature data logger.

5.2.3. Biotic parameters

The results of the leaf decomposition between the two groups were very close (difference of 0.01 g lost per day) and the same trend was recorded for biofilm. The biotic parameters are closely linked to biotic and physicochemical parameters. Nevertheless, the physicochemical parameters are similar that may explain these results. The velocity is different (with barriers = 0.05 m/s and without = 0.17m/s) that could create differences in the leaf breakdown rate due to a different mechanical abrasion. Nevertheless, a similar study has shown that under 20m/s physical fragmentation is considered unimportant in decomposition rate (Ferreira et al.,2006).

Added to that is the fact that there was no sudden change in flow discharge which did not allow a different response of the parameters due to the barriers presence. For example, the species' richness composing the biofilm is greater when there is less flooding frequency and less modifications in the flow (Bondar-Kunze et.,al 2016; Clausen and Biggs 1997). Moreover the increase of velocity due to hydropeaking decrease the biomass of biofilm (Bondar-Kunze et.,al 2016).If this type of event would have appeared, biofilm would have remained more present in the channels with barriers due to a decrease of flow velocity and homogenization of conditions .With the actual conditions we should have observed more biofilm in channels without barrier due to presence of a more important shallow zone (Warner et al.,2007) nevertheless difference seems not on an adapted scale to produce significant differences.

5.2.3.1. Limits and recommendations

The major part of the limits are already quote but another seems to be very important to note. Indeed, the number of replicates and measurements used are very small. First, it should be better to increase the number of replicates (channels). Indeed, If the size of the samples is too small, the experiment will not be enough precise to answer the questions reliably (Stat Soft ,2013). Then the number of measurements (or samples) should be increased and the same number between the channels need to be carried out. Respecting these conditions could allow to get comparable and significant data to apply parametric test more powerful.

6. Conclusion

Of all the parameters measured during the fieldwork, only the depth and the sediment seem significantly different for the first hypothesis and only sediment for hypothesis 2. Only one combination of transect depth comparison was significantly different. Nevertheless, sediment seems seriously more impacted. Concerning the flow facies (category), they seem different but any statistical test as applied.

Average sediment size is generally greater downstream when compared to upstream and the presence of bedrock downstream for some natural barriers explained the process of the hydraulic jump and the sediment trapping. Moreover, the question of this impact downstream was raised between natural and artificial barriers due to the different morphology of the barriers. Nevertheless, this difference could not be detected by measures that were not well suited to this. The type of barrier the most impacted for the hypothesis 1 is the artificial barrier with 6 size classes being significantly different against two different for natural barriers. These differences decrease with the merging by type of barriers and only two significant differences for sediment size class were observed for natural and artificial barriers.

The other parameters did not get the results attempt regarding similar study case on barriers. Indeed, several studies have shown the effect of artificial barriers on flow discharges (Environmental Agency,2010), depth, velocity (Delaunay,2008), fish migration (Larinier,2000) and benthic biota (Clausen and Biggs, 1997). The impacts of the barriers are due to their nature, size, height and the cumulative number (Souchon & Nicolas,2011). That does not mean there are no impact of small barriers. For example, it was proven that small natural barriers can also be crucial in structuring fish fauna and play a key role in the segregation of fish assemblages (Silva et al., 2016). That point indicates the limits of the method applied. More barriers should be studied with more measurements (including continuous measurement) at different scales distance to get significant data in order to apply powerful statistical tests. Other studies showed significant differences by applying 15 measurements points upstream and downstream distributed on three tracks on a length of 15 times the width of the river (Silva et al., 2015) or makes comparison with locations without barriers (Warner et al.,2007). The method applied do not allow to detect the impact due to barriers without detect their presence.

Concerning the experimental channels, the results were different on testing the discontinuity and impact due to the presence of barriers. the results prove a significant difference for depth, velocity and a difference for sediment transport. Therefore, hypothesis 3 was invalided for depth, velocity and almost invalided for sediment transport. This result is possibly easier to show because a reference location is compared with an impacted location. This is not the case for hypothesis 1 and 2. Hypothesis 3 was validated for physicochemical and biotic parameters. The differences that appeared for physicochemical parameters are due to the use of one closed circuit for all the channels and a small-scale experiment. The biofilm and decomposition of mater is in part reliant on the physicochemical parameters. This explains the absence of difference even if abiotic parameters are different.

Using experimental channels is another way to study the effect of barriers on river considering that there are only a few rivers unimpacted by barriers, it also allows more precise control of experimental parameters. Therefore, this method could be repeated taking in account the various remarks mentioned before.

The method applied in this study demonstrated the difficulty to prove impacts induced by small artificial and natural barriers. The importance to use a robust method to collect significative data was also underlined, especially when the effects are not very strong. The use of an experimental method was proved to be an interesting way to get a reference location and strengthen the analysis of fieldwork.

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Fragmentation of rivers by barriers

Impacts of small natural and artificial barriers

Summary: Hydraulic structures such as dams, hydroelectric power stations but also weirs resulting from industrial or agricultural uses have been built in the majority of rivers in the world. These structures have contributed to the fragmentation of rivers although physical barriers are naturally present in the environments. Many scientists have studied the impact of large structures and have shown disruptions of aquatic ecosystems. Few studies have focused on the impact of small artificial and natural barriers. The mains goals of this study are to demonstrate river fragmentation by analyzing impacts induced by small artificial and natural barriers. This study was conducted on a set of abiotic, physicochemical and biotic parameters determined as indicators of the environment quality. These results were compared for upstream and downstream from a barrier, as well as between artificial and natural barriers. In addition, a second experiment was carried out on artificial channels to test the discontinuity induced by the presence of barriers. Few differences were found for the fieldwork measurements except for the sediment transport which is very impacted whatever the comparison followed by depth different between two transects for natural barriers. On the contrary many more abiotic parameters were significantly different for the artificial channels but physicochemical and biotic parameters haven't reveal differences. The study raised the difficulty to show differences on indicators parameters for small natural and artificial. Moreover, it was revealed that the experimental channels are a complementary method to improve fieldwork analysis. By exploring how small natural and artificial barriers impacts rivers, it could improve knowledges in river fragmentation induced by all type of barriers. Moreover, that could allow to develop a method to detect the barriers presences by only measuring certain key parameter without knowing their presence.

Résumé : Des structures hydrauliques telles que des barrages, des centrales hydroélectriques mais aussi des seuils, issus d'utilisations industrielles ou agricoles, ont été construites dans la plupart des cours d'eau du monde. Ces structures ont contribué à la fragmentation des rivières bien que des barrières physiques soient naturellement présentes dans les milieux. De nombreux scientifiques ont étudié l'impact des grands ouvrages et ont montré des perturbations des écosystèmes aquatiques en raison de leur présence. Peu d'études ont porté sur l'impact des petites barrières artificielles et naturelles. Les principaux objectifs de cette étude sont de démontrer la fragmentation des rivières en analysant les impacts induits par de petites barrières artificielles et naturelles. Cette étude a été menée sur un ensemble de paramètres abiotiques, physico-chimiques et biotiques déterminés comme indicateurs de l'environnement pour mettre en évidence des impacts potentiels. Les résultats ont été comparés en amont et en aval d'une barrière, ainsi qu'entre les barrières artificielles et naturelles. De plus, une deuxième expérience a été réalisée sur des canaux artificiels pour tester la discontinuité causée par la présence de barrières. Peu de différences ont été trouvées pour les mesures de terrain, sauf pour le transport sédimentaire qui est très impacté quelle que soit la comparaison, et pour la profondeur, différente entre deux transects pour les barrières naturelles. Au contraire, beaucoup plus de paramètres abiotiques sont significativement différents pour les canaux artificiels, mais les paramètres physico-chimiques et biotiques n'ont révélé aucune différence. L'étude a soulevé la difficulté de montrer des différences pour des petites barrières naturelles ou artificielles. De plus, il a été révélé que les canaux expérimentaux sont une méthode complémentaire pour améliorer l'analyse de terrain. En explorant la façon dont les petites barrières naturelles et artificielles affectent les rivières, cela pourrait améliorer les connaissances sur la fragmentation des rivières induites par tout type de barrières ce qui permettra d'avoir une vue d'ensemble. De plus, cela pourrait permettre de développer une méthode pour détecter la présence des barrières en ne mesurant que certains paramètres clés.

Key words: natural and artificial barriers, discontinuity, impacts, abiotic/biotic/physicochemical parameters, artificial channels

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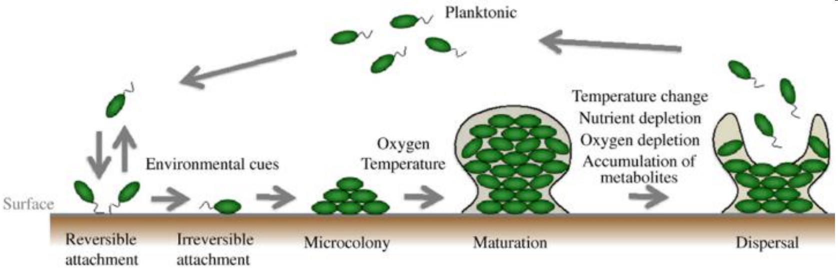
Appendix

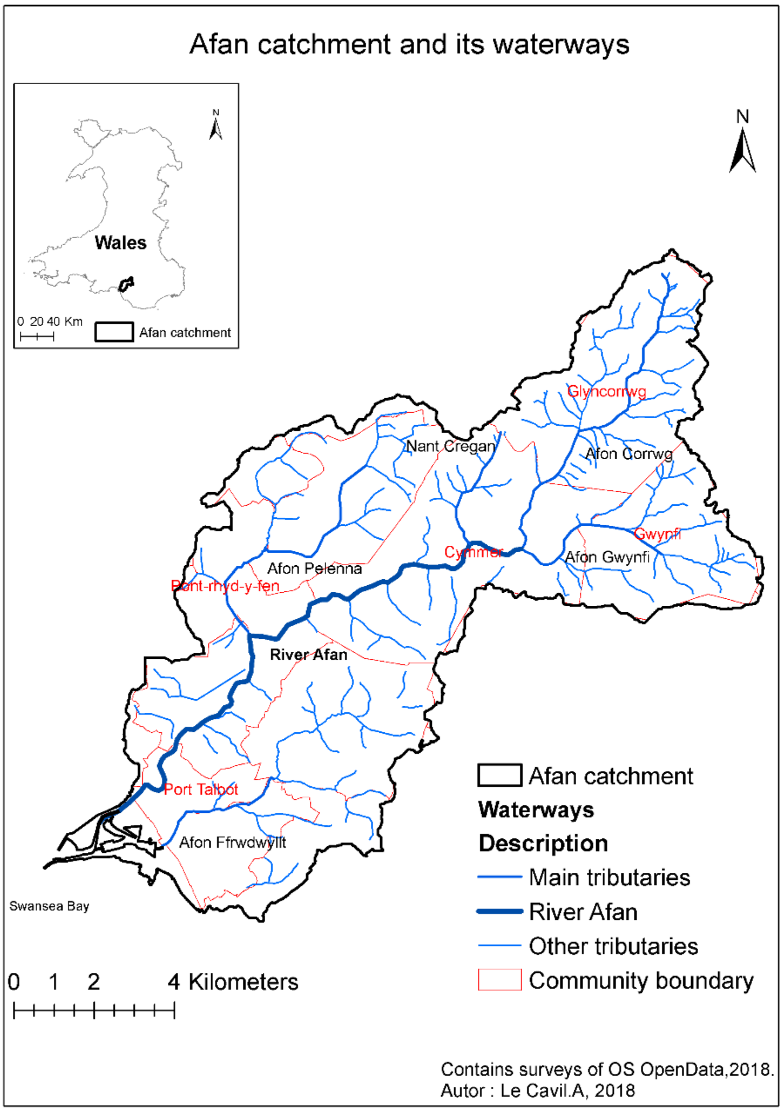
Appendix 1 : Steps of formation of the biofilm



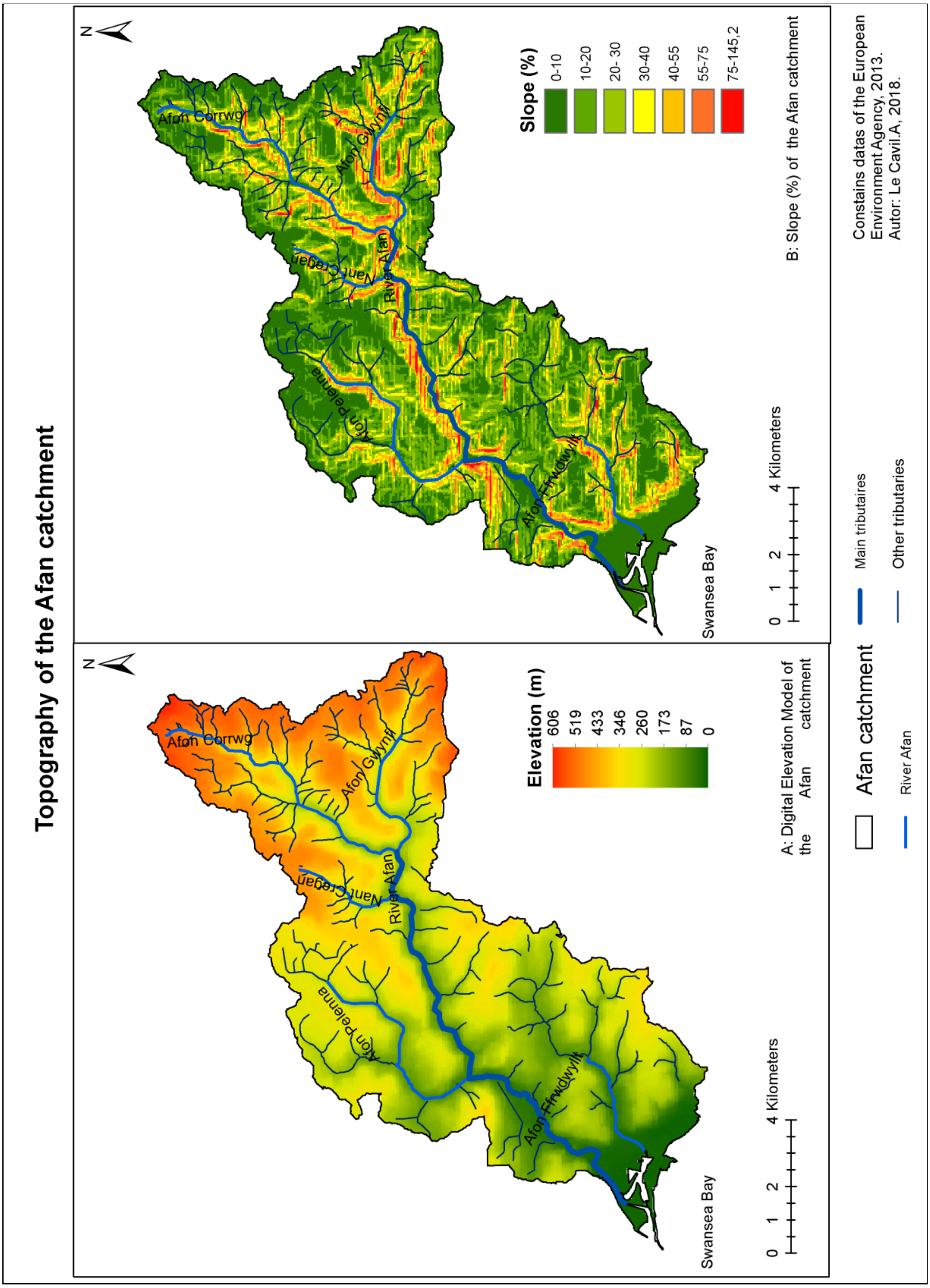
Steps of formations of the biofilm. Source: Masanori T, Tomohiro I & al., 2016

-The planktonic steps correspond to the moment of transport and reversible fixation
-Fixation of cells to a surface and creation of EPS correspond to the irreversible attachment
-Microbial growth and evolution of the shape with formation of primary micro-colonies
-Maturation and development of the colonies
-Detachment of colonies caused by the hydrodynamics conditions

Appendix 2 : Presentation of the Afan catchment.
Source : OS openData,2018. Autor: Le Cavil.A, 2018.



Appendix 3 : Elevation and slope of the Afan catchment.
Source : European Environment Agency, 2013. Autor : Le Cavil.A,2018.

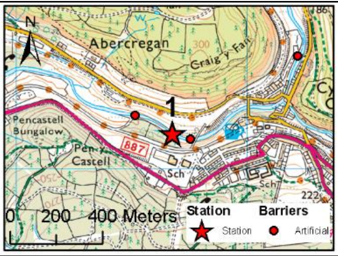


Appendix 4 : Presentation of the station 1. Source: Le Cavil. A, 2018.

Station 1

Location

County boroughs	Neath Port Talbot
River	Afan
Tributary of	Afan River
Longitude	-3.65395
Latitude	51.65252
Date	21/05/2018



Source : Environment Agency Wales,2010. Autor :

Main characteristics of the station

Elevation (m)	151.2
Distance to the source (km)	0.47
Watershed area (km2)	119
length of the station (m)	30
Dimension of the barrier (m)	Head drop: 0.65 width: 24.1
Type of barrier (nature and feature)	Artificial-Weir
Hydrology	Low water level

Downstream the barrier	Upstream the barrier

Flow (m3/s)	0.827	Flow (m3/s)	0.561
Depth of Transect 1 (m) :5m from the barrier	0.197	Average depth of Transect 1 (m) :5m from the barrier	0.399
Wet width of transect 1 (m)	18.2	Wet width of transect 1 (m)	14.3
Depth of T2 (m): 15 m from the barrier	0.184	Depth of T2 (m): 15 m from the barrier	0.325
Wet width of transect 2 (m)	13	Wet width of transect 2 (m)	14.21
Temperature (°C)	14.86	Temperature (°C)	14.52
pH	7.57	pH	7.63
Conductivity (µS/cm)	182.69	Conductivity (µS/cm)	190.99
Dissolved oxygen (%)	108.16	Dissolved oxygen (%)	105.4
Ammonium (mol/L)	0.85	Ammonium (mol/L)	0.70

Downstream the barrier

Flow facies	Importance (%)	Granulometry (mm)		
		Dominant	Accessory	Embeddedness
Pool	20	> 256	64 ; 256	Fine sediment
Lentic - lotic flat	10	4; 64	2 ; 4	/
Fast stream	30	64; 256	4 ; 64	/

Upstream the barrier

Flow facies	Importance (%)	Granulometry		
		Dominant	Accessory	Embeddedness
Pool	0	> 256	64-256	/
Lentic- lotic flat	10	4 ; 64	2 ; 4	/
Fast stream	30	64 ; 256	4 ; 64	/

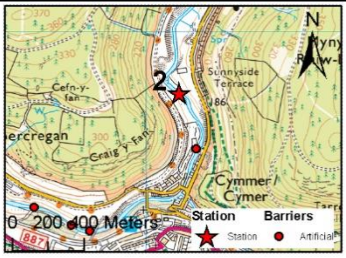
Note:

Appendix 5 : Presentation of the station 2. Source: Le Cavil.A, 2018.

Station 2

Location

County boroughs	Neath Port Talbot
River	Afon Corrwg
Tributary of	Afan River
Longitude	51.65781
Latitude	-3.64737
Date	23/05/2018



Source : Environment Agency Wales,2010. Autor :

Main characteristics of the station

Elevation (m)	166.7
Distance to the source (km)	8.314
Watershed area (km2)	119
length of the station (m)	30
Dimension of the barrier (m)	Head drop: 0.56 width: 17.4
Type of barrier (nature and feature)	Artificial-Weir
Hydrology	Low water level

Downstream the barrier		Upstream the barrier	
			
Flow (m3/s)	0.424	Flow (m3/s)	0.350
Depth of Transect 1 (m) :5m from the barrier	0.113	Average depth of Transect 1 (m) :5m from the barrier	0.179
Wet width of transect 1 (m)	9.03	Wet width of transect 1 (m)	10.9
Depth of T2 (m): 15 m from the barrier	0.179	Depth of T2 (m): 15 m from the barrier	0.187
Wet width of transect 2 (m)	9.3	Wet width of transect 2 (m)	10.7
Temperature (°C)	13.92	Temperature (°C)	15.21
pH	7.82	pH	8.37
Conductivity (µS/cm)	189.02	Conductivity (µS/cm)	188.18
Dissolved oxygen (%)	109.7	Dissolved oxygen (%)	109.89
Ammonium (mol/L)	0.67	Ammonium (mol/L)	0.61

Downstream the barrier

Flow facies	**Importance (%)**	**Granulometry (mm)**		
		Dominant	Accessory	Embeddedness
Pool	20	> 256	64-256	Fine sediment
Lentic - lotic flat	/	/	/	/
Fast stream	30	64; 256	> 256	/

Upstream the barrier

Flow facies	**Importance (%)**	**Granulometry**		
		Dominant	Accessory	Embeddedness
Pool	0	/	/	/
Lentic- lotic flat	100	64; 256	4; 64	/
Fast stream	0	/	/	/

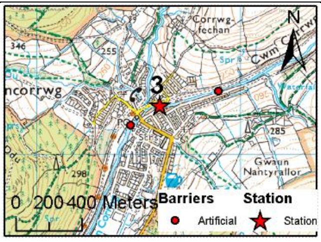
Note:

Appendix 6 : Presentation of the station 3. Source: Le Cavil. A, 2018.

Station 3

Location

County boroughs	Neath Port Talbot
River	Afon Corrwg
Tributary of	Afan River
Longitude	51.68062
Latitude	-3.62684
Date	23/05/2018



Source : Environment Agency Wales,2010. Autor :

Main characteristics of the station

Elevation (m)	211.5
Distance to the source (km)	5.174
Watershed area (km2)	119
length of the station (m)	30
Dimension of the barrier (m)	Head drop: 0.68 width: 11.2
Type of barrier (nature and feature)	Artificial-Ramp-bed sill
Hydrology	Low water level

Downstream the barrier		Upstream the barrier	
			
Flow (m3/s)	0.246	Flow (m3/s)	0.213
Depth of Transect 1 (m) :5m from the barrier	0.113	Depth of Transect 1 (m) :5m from the barrier	0.233
Wet width of transect 1 (m)	6.75	Wet width of transect 1 (m)	7.1
Depth of T2 (m): 15 m from the barrier	0.179	Depth of T2 (m): 15 m from the barrier	0.151
Wet width of transect 2 (m)	6.3	Wet width of transect 2 (m)	5.4
Temperature (°C)	15.58	Temperature (°C)	16.41
pH	9.64	pH	9.58
Conductivity (µS/cm)	194.3	Conductivity (µS/cm)	180.29
Dissolved oxygen (%)	115.56	Dissolved oxygen (%)	113.23
Ammonium (mol/L)	0.91	Ammonium (mol/L)	0.71

Downstream the barrier

Flow facies	Importance (%)	Granulometry (mm)		
		Dominant	Accessory	Embeddedness
Pool	0	/	/	/
Lentic - lotic flat	80	4; 64	2; 4/	/
Fast stream	20	4; 64	64; 256	/

Upstream the barrier

Flow facies	Importance (%)	Granulometry		
		Dominant	Accessory	Embeddedness
Pool	50	> 256	> >256	/
Lentic- lotic flat	/	/	/	/
Fast stream	50	64 ; 256	4 ; 64	/

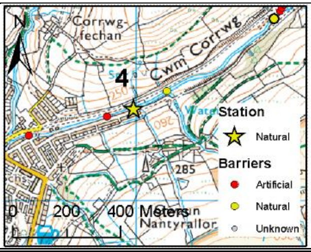
Note: Presence of green algae, biofilm and organic pellicle on the substrate.
A part of the sector is in the shade under the bridge where flow and pH, T°C were taken

Appendix 7 : Presantation of the station 4 . Source: Le Cavil. A, 2018

Station 4

Location

County boroughs	Neath Port Talbot
River	Afon Corrwg
Tributary of	Afan River
Longitude	51.68169
Latitude	-3.62131
Date	21/05/2018



Source : Environment Agency Wales,2010. Autor :

Main characteristics of the station

Elevation (m)	237.5
Distance to the source (km)	4.766
Watershed area (km2)	119
length of the station (m)	30
Dimension of the barrier (m)	Head drop: 0.92 width: 6.4
Type of barrier (nature and feature)	Natural - Waterfall
Hydrology	Low water level

Downstream the barrier		Upstream the barrier	
			
Flow (m3/s)	0.156	Flow (m3/s)	0.213
Depth of Transect 1 (m)	0.113	Depth of Transect 1 (m)	0.233
Wet width of transect 1 (m)	4.2	Wet width of transect 1 (m)	5.1
Depth of T2 (m): 15 m from the barrier	0.223	Depth of T2 (m): 15 m from the barrier	0.097
Wet width of transect 2 (m)	4.7	Wet width of transect 2 (m)	7.6
Temperature (°C)	16.68	Temperature (°C)	16.83
pH	6.39	pH	7.51
Conductivity (µS/cm)	211.72	Conductivity (µS/cm)	180.29
Dissolved oxygen (%)	109.8	Dissolved oxygen (%)	106.0
Ammonium (mol/L)	1.04	Ammonium (mol/L)	0.74

Downstream the barrier

Flow facies	**Importance (%)**	**Granulometry (mm)**		
		Dominant	Accessory	Embeddedness
Pool	80	Bedrock	64; 256	/
Lentic - lotic flat	20	64; 256	4; 64	/
Fast stream	/	/	/	/

Upstream the barrier

Flow facies	**Importance (%)**	**Granulometry**		
		Dominant	Accessory	Embeddedness
Pool	20	64; 256	4; 64	/
Lentic- lotic flat	10	4; 64	/	/
Fast stream	70	4; 64	64; 256	/

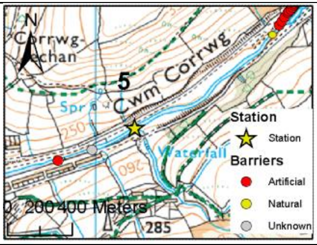
Note: Presence of a tributary between the junction upstream and downstream the barrier. Downstream the tributary there is lot of green algae which are not present upstream the tributary. Downstream the barrier there is an important pool 1;1.5m. In this pool there is only big sediment (> 256mm and the bedrock.

Appendix 8 : Presentation of the station 5. Source: Le Cavil. A, 2018

Station 5

Location

County boroughs	Neath Port Talbot
River	Afon Corrwg
Tributary of	Afan River
Longitude	51.68213
Latitude	-3.61995
Date	21/05/2018



Source : Environment Agency Wales,2010. Autor :

Main characteristics of the station

Elevation (m)	237.9
Distance to the source (km)	4.610
Watershed area (km2)	119
length of the station (m)	30
Dimension of the barrier (m)	Head drop: 0.21 width: 4.1
Type of barrier (nature and feature)	Natural - Waterfall
Hydrology	Low water level

Downstream the barrier		Upstream the barrier	
			
Flow (m3/s)	0.216	Flow (m3/s)	0.275
Depth of Transect 1 (m) :5m from the barrier	0.185	Depth of Transect 1 (m) :5m from the barrier	0.086
Wet width of transect 1 (m)	5.1	Wet width of transect 1 (m)	5.6
Depth of T2 (m): 15 m from the barrier	0.272	Depth of T2 (m): 15 m from the barrier	0.125
Wet width of transect 2 (m)	4.7	Wet width of transect 2 (m)	5.6
Temperature (°C)	14.82	Temperature (°C)	15.05
pH	7.53	pH	7.45
Conductivity (µS/cm)	215.5	Conductivity (µS/cm)	218.63
Dissolved oxygen (%)	108.69	Dissolved oxygen (%)	106.6
Ammonium (mol/L)	1.13	Ammonium (mol/L)	1.01

Downstream the barrier

Flow facies	**Importance (%)**	**Granulometry (mm)**		
		Dominant	Accessory	Embeddedness
Pool	20	>256	4; 64	/
Lentic - lotic flat	0	/	/	/
Fast stream	80	>256	64; 256	/

Upstream the barrier

Flow facies	**Importance (%)**	**Granulometry**		
		Dominant	Accessory	Embeddedness
Pool	0	/	/	/
Lentic- lotic flat	0	/	/	/
Fast stream	100	64; 256	>256	/

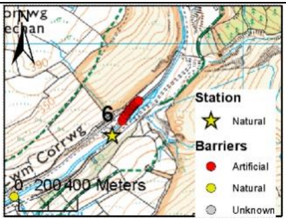
Note: Presence of a tributary and an installation to deflect water upstream the location.

Appendix 9 Presentation of the station 6. Source: Le Cavil. A, 2018

Station 6

Location

County boroughs	Neath Port Talbot
River	Afon Corrwg
Tributary of	Afan River
Longitude	51.68478
Latitude	-3.61403
Date	22/05/2018



Source : Environment Agency Wales,2010. Autor :

Main characteristics of the station

Elevation (m)	254.9
Distance to the source (km)	4.148
Watershed area (km2)	119
length of the station (m)	30
Dimension of the barrier (m)	Head drop: 0.46 width: 6.2
Type of barrier (nature and feature)	Semi natural- old blocks of rocks
Hydrology	Low water level

Downstream the barrier		Upstream the barrier	
			
Flow (m3/s)	0.128	Flow (m3/s)	0.211
Depth of Transect 1 (m) :5m from the barrier	0.508	Depth of Transect 1 (m) :5m from the barrier	0.297
Wet width of transect 1 (m)	4.5	Wet width of transect 1 (m)	7
Depth of T2 (m): 15 m from the barrier	0.104	Depth of T2 (m): 15 m from the barrier	0.193
Wet width of transect 2 (m)	3.5	Wet width of transect 2 (m)	4.5
Temperature (°C)	13.61	Temperature (°C)	13.88
pH	6.63	pH	7.43
Conductivity (µS/cm)	229.86	Conductivity (µS/cm)	231.28
Dissolved oxygen (%)	105.27	Dissolved oxygen (%)	105.16
Ammonium (mol/L)	1.14	Ammonium (mol/L)	0.95

Downstream the barrier

Flow facies	**Importance (%)**	**Granulometry (mm)**		
		Dominant	Accessory	Embeddedness
Pool	50	64; 256	>256	/
Lentic - lotic flat	10	4; 64	2; 4	/
Fast stream	40	64; 256	4; 64	/

Upstream the barrier

Flow facies	**Importance (%)**	**Granulometry**		
		Dominant	Accessory	Embeddedness
Pool	60	4; 64	64; 256	/
Lentic- lotic flat	20	4; 64	2; 4	/
Fast stream	10	64; 256	4; 64	/

Note: Station located downstream treatment basins of water. Important presence of green algae, biofilm and pellicle of organic matter. There is also numerous ramp-bell sill upstream this barrier.

Appendix 10 : Characteristic of the experimental channels. Source: Le Cavil. A, 2018.

Main characteristics of the trough						
Slope (‰)	29.27					
Length of channel (cm)	205					
Width of channel (cm)	11.5 ± 1					
Dimension of the channel exit (cm); Height, width, distance from the bottom	9-6-3					
Tank capacity (L)	160					
Barrier height (cm)	5					
Barrier width (cm)	Width of the channel					
Main characteristics of the channels						
	C1*	C2	C3	C4	C5*	C6*
Q initial (L/s) 24/05/2018	0.060	0.074	0.062	0.072	0.084	0.062
Gravel quantity (g)	520	520	520	520	520	520
Gravel quantity (g)	3280	3280	3280	3280	3280	3280
Number of leaf samples	4	1	1	1	4	4
Number of tile samples	4	1	1	1	4	4
Note: Samples are placed upstream and downstream barrier for the channels with barriers and at the end of the channel for the channels without barriers. Initial flow was measured at the exit of the tap. The average of the initial flow for channel with barrier is 0.067 L/s and 0.70 for channels without barriers. The maximum difference is 0.024 L/s between C1* and C5* * Channel with barriers						

Before carrying out the tests, it is important to know how organize the data according to what needs to be demonstrated. The explanation will be applied on width and depth because it is the most complicated case but the principle is the same for biotic parameters. Concerning the sediment another method is used that why a special part is dedicated to the sediment.

- **Comparison within and across location for natural and artificial barriers**

At total there are six barriers divided in three natural and three artificial barriers. This natural and artificial barrier are sub divided in upstream and downstream for a total of four groups if only one measurement location is realized (upstream artificial, downstream artificial, upstream natural, downstream natural). Nevertheless, for depth and width two transect (T1 & T2) were measured so the number of groups is doubled, there are eight different groups as shown on the table below:

Observations	up art T1	down art T1	up art T2	down art T2	up nat T1	down nat T1	up nat T2	down nat T
1	18,20	14,30	13,00	14,10	4,70	4,20	7,60	5,10
2	10,90	7,50	10,70	9,30	5,60	5,10	5,00	4,90
3	7,10	6,75	5,40	6,30	7,00	4,50	4,50	6,50

Each group will include <u>all</u> the measurements realized on it subdivision (upstream or downstream) regardless the station number because the samples are paired.

In this case one measurement of the wet width were taken for each group but there are three natural barriers corresponding to three measurements (upstream) and three downstream (observations) so there are three observations. The result of the test is a combination of the number of column raised to square, result is a combination of sixty-four possibilities as shown on the table below.

	up art T1	down art 1	up art T2	down art T2	up nat T1	down nat T1	up nat T2	down nat T2
up art T1	1	0,974	0,807	0,885	0,598	0,046	0,113	0,200
down art 1	0,974	1	1,000	1,000	0,991	0,429	0,654	0,807
up art T2	0,807	1,000	1	1,000	1,000	0,760	0,916	0,974
down art T2	0,885	1,000	1,000	1	1,000	0,654	0,849	0,941
up nat T1	0,598	0,991	1,000	1,000	1	0,916	0,984	0,998
down nat T1	0,046	0,429	0,760	0,654	0,916	1	1,000	0,999
up nat T2	0,113	0,654	0,916	0,849	0,984	1,000	1	1,000
down nat T2	0,200	0,807	0,974	0,941	0,998	0,999	1,000	1

results of the statistical test (p-value)

Nevertheless, in this case the analysis will **be focused on the results by type of barriers** (table above, green and yellow), by paired within the location (downstream vs downstream or upstream vs upstream) or across the location (upstream vs downstream) as shown on the value in red, at total six combination for each type of barriers is analyzed, other results will be report in appendix.

- **Comparison of differences within and across location for natural and artificial barriers**

Then the difference between transect upstream minus downstream is realized in order to analyzed the <u>change</u> with the same statistical test as shown on the table below. Nevertheless, analysis of difference between transect 1 and transect 2 was not realized across the location.

	Across the location				**Within the location**			
observations	up art T1-down art T1	up nat T1 - down nat T1	up art T2 - down art T2	up nat T2 - down nat T2	up art (T1-T2)	down art (T1-T2)	up nat (T1-T2) nat	down nat (T1-T2)
1	-3,90	0,50	1,10	2,50	0,20	5,20	-2,90	-0,90
2	3,40	0,50	1,40	0,10	0,20	-1,80	0,60	0,20
3	0,35	2,50	-0,90	-2,00	1,70	0,45	2,50	-2,00

➢ Natural versus artificial

To finish, the change calculated at the step before is used to realize another subtraction to analyzed the difference change between natural and artificial as show on the table A. The calculation is based on the result within the station and a subtraction upstream minus downstream is realized up art (T1-T2)- down art (T1-T2).

Within the location			
up art (T1-T2)	down art (T1-T2)	up nat (T1-T2) nat	down nat (T1-T2)
0,20	5,20	-2,90	-0,90
0,20	-1,80	0,60	0,20
1,70	0,45	2,50	-2,00

A

up art (T1-T2) - down art (T1-T2)	up nat (T1-T2) - down nat (T1-T2)
Artificial	**Natural**
-5	-2
2	0,4
1,25	4,5

B

The same method is follow for the depth but the transect are analyzed (based on twelves verticals) for each transect so a total of 36 per groups.

Concerning the leaf and the biofilm the data treatment is more much easier because samples were deposit on one location (not 2 transects). That means only four groups are formed, the number of combination is much less important and two tests rather three are used (upstream vs downstream and natural versus artificial)

Appendix 12 : Results upstream versus downstream for wet width

	art upT1	art downT1	art upT2	art downT2	nat upT1	natdownT1	nat upT2	nat down T2
art upT1	1	0,974	0,807	0,885	0,598	0,046	0,113	0,200
art downT1	0,974	1	1,000	1,000	0,991	0,429	0,654	0,807
art upT2	0,807	1,000	1	1,000	1,000	0,760	0,916	0,974
art downT2	0,885	1,000	1,000	1	1,000	0,654	0,849	0,941
nat upT1	0,598	0,991	1,000	1,000	1	0,916	0,984	0,998
natdownT1	0,046	0,429	0,760	0,654	0,916	1	1,000	0,999
nat upT2	0,113	0,654	0,916	0,849	0,984	1,000	1	1,000
nat down T2	0,200	0,807	0,974	0,941	0,998	0,999	1,000	1

Appendix 13 : Results for difference upstream versus downstream for wet width within and across section

	up art T1- down art T1	up nat T1 - down nat T1	up art T2 - down art T2	up nat T2 - down nat T2	up art (T1-T2)	down art (T1-T2)	up nat (T1-T2) na	down nat (T1-T2)
upT1 art - downT1 art	1	0,995	1,000	1,000	1,000	1,000	1,000	0,984
upT1 nat - downT 1nat	0,995	1	1,000	0,941	0,999	0,999	1,000	0,709
upT2 art - downT2 art	1,000	1,000	1	0,984	1,000	1,000	1,000	0,849
upT2 nat- downT2 nat	1,000	0,941	0,984	1	0,999	0,999	0,991	1,000
up (T1-T2) art	1,000	0,999	1,000	0,999	1	1,000	1,000	0,960
down (T1-T2) art	1,000	0,999	1,000	0,999	1,000	1	1,000	0,960
up (T1-T2) nat	1,000	1,000	1,000	0,991	1,000	1,000	1	0,885
down (T1-T2) nat	0,984	0,709	0,849	1,000	0,960	0,960	0,885	1

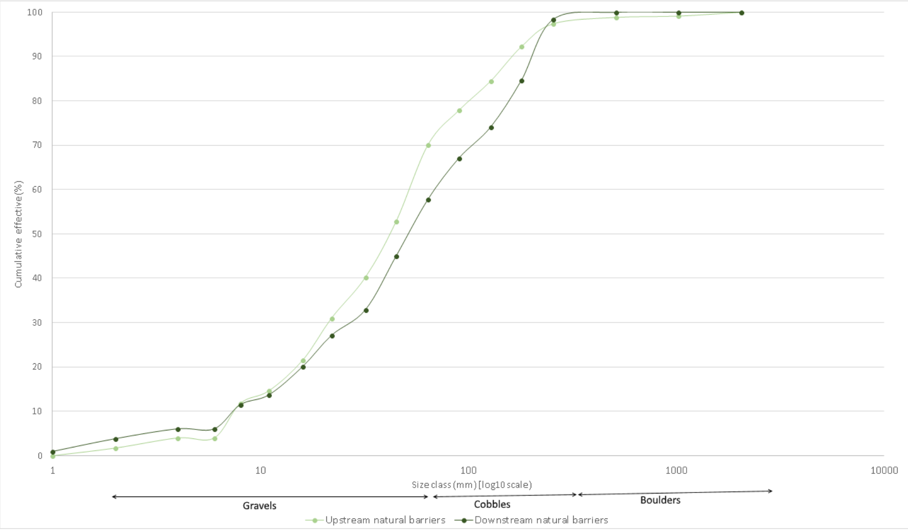
Appendix 14 : Results upstream versus downstream for depth

	up art T1	**down art T1**	**up art T2**	**down art T2**	**up nat T1**	**down nat T1**	**up nat T2**	**down nat T2**
up art T1	1	0,869	0,999	0,931	0,937	0,836	0,422	1,000
down art T1	0,869	1	0,503	1,000	1,000	0,096	0,996	0,682
up art T2	0,999	0,503	1	0,618	0,634	0,990	0,129	1,000
down art T2	0,931	1,000	0,618	1	1,000	0,145	0,987	0,785
up nat T1	0,937	1,000	0,634	1,000	1	0,153	0,985	0,799
down nat T1	0,836	0,096	0,990	0,145	0,153	1	**0,011**	0,955
up nat T2	0,422	0,996	0,129	0,987	0,985	**0,011**	1	0,232
down nat T2	1,000	0,682	1,000	0,785	0,799	0,955	0,232	1

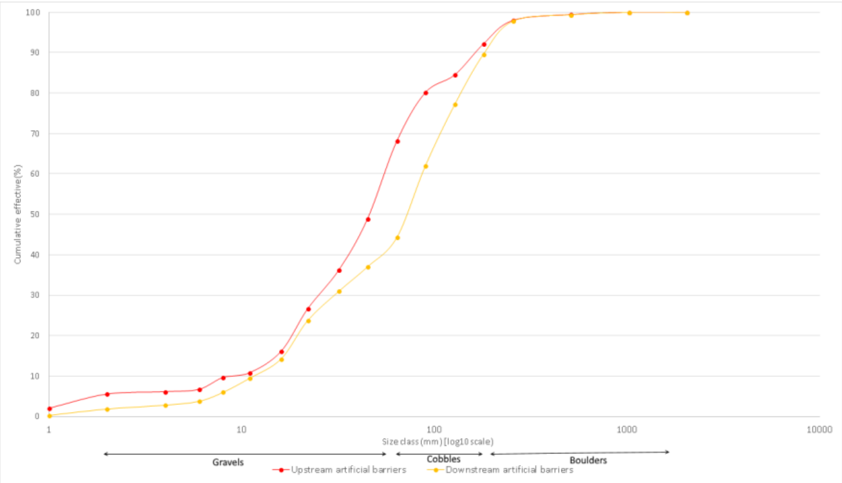
Appendix 15 : Results upstream versus downstream for transect depth within and across location

	up art T1- down art T1	up nat T1 - down nat T1	up art T2 - down art T2	up nat T2 - down nat T2	up art (T1-T2)	down art (T1-T2)	up nat (T1-T2) nat	down nat (T1-T2)
up art T1- down art T1	1	**0,002**	1,000	**0,020**	0,362	0,454	0,973	0,973
up nat T1 - down nat T1	**0,002**	1	**0,006**	0,997	0,568	0,470	0,050	0,050
up art T2 - down art T2	1,000	**0,006**	1	0,058	0,601	0,698	0,998	0,998
up nat T2 - down nat T2	**0,020**	0,997	0,058	1	0,937	0,889	0,267	0,267
up art (T1-T2)	0,362	0,568	0,601	0,937	1	1,000	0,937	0,937
down art (T1-T2)	0,454	0,470	0,698	0,889	1,000	1	0,969	0,969
up nat (T1-T2) nat	0,973	0,050	0,998	0,267	0,937	0,969	1	1,000
down nat (T1-T2)	0,973	0,050	0,998	0,267	0,937	0,969	1,000	1

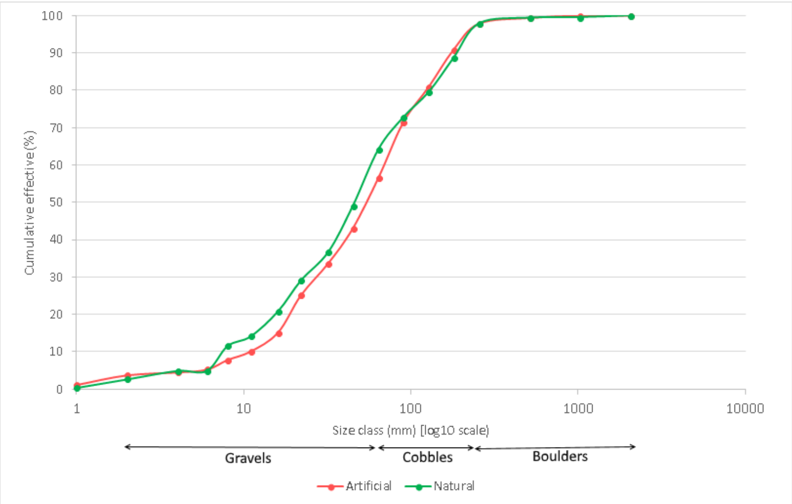
Appendix 16 : Cumulative effective curves for sediment upstream and downstream natural barriers



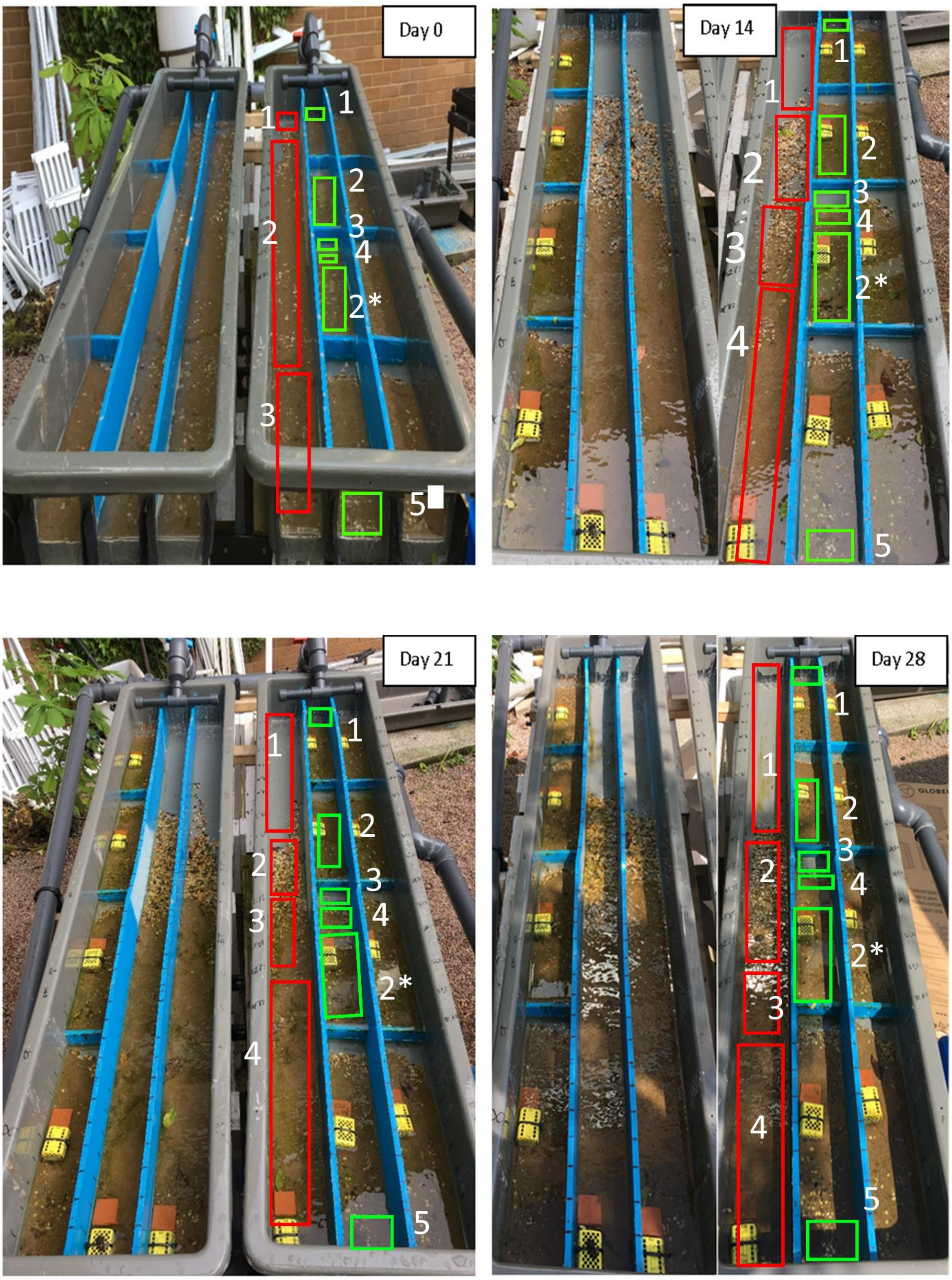
Appendix 17 : Cumulative effective curves for sediment upstream and downstream artificial barriers



Appendix 18 : Cumulative effective curves for sediment for artificial and natural barriers



Appendix 19 : Photo interpretation of channels



Appendix 20 : Results of kolmogorow-smirnow test for the abundance

Class	p-value	D
[0 ; 251[	0,996	0,333
[251 ; 500[	0,996	0,333
[500; 1,7 x 10^4	0,518	0,667
[1,7 x 10^4 ; x [	0,996	0,333

Appendix 21 : Results of kolmogorow-smirnow test for the weight

Class	p-value	D
[0 ; 251[	0,1	1
[251 ; 500[	0,1	1
[500; 1,7 x 10^4[	0,1	1
[1,7 x 10^4 ; x [	1	0,333

Type of parameters	Measurements		Hypothesis 1: upstream vs downstream for natural barriers			Hypothesis 1: upstream vs downstream for artificial barriers			Hypothesis 2: Natural vs artificial		
			p-value	Effect upstream	Effect downstream	p-value	Effect upstream	Effect downstream	p-value	Natural barriers	Artificial barriers
Abiotic parameters	**Wet width**	Initial data	0,885 to 1			0,113 to 1					
		≠ within location	0,885			0,960 to 1			0,5		
		≠ across location	0,94 to 0,99			1					
	Depth	Initial data	0,01 to 0,98	- : 1/6 comparisons	+ : 1/6 comparisons	0,503 to 1					
		≠ within location	1			0,36 to 0,57			0,405		
		≠ acrros location	0,99 to 1			1					
	Sediment	Distribution by classes	0,009	- <2 ; [256:512[	+ [256:512[- [1024:4096[		+ [45:90[; [64:90[- [90:128[; [128: 190[; [180:256[	+ [90:128[; [128:180[- <2 ; [45:64[; [64:90[		+ [90:128[- [8:11[	+ [8:11[- [90:128[
Biotic parameters	**Leaf decomposition**		0,942			0,198			0,118		
	Biofilm		1			0,41			1		

Legend

Effect

No effect

Effect

Not measured

Type of effect

" + " : Increase

" - " : Decrease

Appendix 23 : Summary of the channel experimentation results

Type of parameters	Measurements		Hypothesis 3 Channels with barriers vs chanels without barriers	
			p-alue	**Effect of barrier**
Abiotic parameters	**Depth**		< 0,0001	+
	Velocity		0,0004	-
	Sediment	Frequency	0,518 to 0,996	
		Distribution by classes	0,1 to 1	-
Physicochemical parameters	**pH**		*	
	T°C		*	
	Dissolved oxygen		*	
	Conductivity		*	
	NH4+		*	
Biotic parameters	**Leaf decomposition**		0,942	
	Biofilm		0,348	

Legend

* : descriptive statistics

Effect	Type of effect
No effect	" + " : Increase
Almost	" - " : Decrease
Effect	
Not measured	

Appendix 24 : Demonstration of change in flow velocity

The formula of Manning-Strickler is used to calculate the flow of a surface flow free standing uniform according to the characteristics geometrical of the canal, here it's use to prove the relation between velocity and the section. The different parameters of the equations are:

Ks : roughness coefficient   Rh : hydraulic radius (m)   I : slope (m/m)

Q : flow discharge (m3/s)   V : velocity (m/s)   S : wet section (m2) (rectangle : length x depth)

$$V = Ks \times R_h^{\left(\frac{2}{3}\right)} \times I^{\left(\frac{1}{2}\right)}$$

$$Q = Ks \times R_h^{\left(\frac{2}{3}\right)} \times I^{\left(\frac{1}{2}\right)} \times s$$ and the relation between velocity and flow is: $Q = S \times V$

Therefore V = Q/S. In this case Q is constant (verified) but the wet section which is calculate by length multiplied per depth change because the depth increases with the presence of barriers. So, if the wet section increases the velocity decrease. Example:

$$\swarrow V = \frac{Q =}{S \nearrow}$$

1 : Q = 3 ; S= 5 V = 15m/s   2 : Q=3 ; S = 3 V = 9m/s :