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Turbidity and suspended sediment load in a vegetated channel

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Abstract
The objective of this work is to study the vegetation effect on sediment transport and the corresponding turbidity. First, we want to highlight the effect of vegetation and provide a database for future studies. In fact, laboratory experiments in two rectangular channels were carried out at the National Institute of Agronomy of Tunisia. A carpet of a flexible vegetation having a height of stems hp=40mm was placed on the channel central part, where different sand quantities were injected at the upstream of the vegetated environment for different flow rates. Then determination of the corresponding upstream and downstream turbidities and retained sand quantities by vegetation was considered. The results of this study have shown that the turbidities upstream and downstream of the vegetated environment decrease with time, following an exponential pace. It has also been noted that the downstream turbidity is lower than the upstream turbidity at the first time of the experiment, but after a while they merge into the same constant for the different flows, marking a state of stabilization.

1. Introduction
Traditional approaches to sediment transport in rivers consider the water and sediment system, but the presence of vegetation on the banks or the bottom of many rivers, makes it necessary to take into account this additional component [1-12]. Vegetation affects the water flow (velocity, turbulence…) [12-14]. In fact, vegetation tends to increase the flow resistance, and can create favorable conditions for the deposition of the fine sediments, and so slow the transport of coarse materials, and increase the cohesion of the banks and benches [14]. Couplings between vegetation and solid transport have both morphological and ecological consequences [7,17]. In fact, first they determine the morphological evolution of the watercourse (transition braiding/meandering for example); and second they generate a specific habitat characterized by local granulometry sediment, turbidity, turbulence and nutrient availability.
In this context, is considered this study, it aims to study the vegetation effect on sediment transport and water turbidity. To do so, experiments were conducted in laboratory fumes with a movable bed trapped in artificial vegetation. The experimental setup is first presented. The theoretical concepts are then introduced for turbidity measurement. The results are presented and discussed in the next section.

2. Theoretical background

In the field of water quality control, turbidity measurement is a convincing parameter in many applications. This is the case in the treatment of drinking water, and in the chemical sector [1]. Also, an important characteristic of the turbidity is its indication of the suspended particles quantities present in water. It is an optical characteristic of water, related to its ability to diffuse or absorb incident light. Turbidity is therefore one of the factors of the water color. It is due to the presence in water of mineral or organic suspended particles, living or detritic. Thus, the more water is loaded with phytoplankton, biomass, or sedimentary particles, the more turbid it is.

The consequences of turbidity concern the penetration of light and ultraviolet in water, and therefore effect the photosynthesis and the bacteria development. In addition, the water color affects its temperature and therefore its oxygen content, evaporation, and salinity [1].

Turbidity in surface water bodies is generally attributable to organic and inorganic matter.

Turbidity is measured in Nephalometric Turbidity Units (NTU) using a turbidimeter. This instrument sends a light ray through a water sample and measures the light quantity that passes through the water relative to the quantity of light that is reflected by the particles in the water.

Turbidity can range from less than 1 NTU to over 1000 NTU, at 5 NTU the water is visibly cloudy, and at 25 NTU it is blackish.

Tableau 1: Usual turbidity classes (NTU)

NTU <5	Clear water
5< NTU <30	Slightly cloudy water
NTU >50	Cloudy water
NTU >200	Most surface water in Africa reaches this level of turbidity

This key parameter can be used to study the sediment transport behavior in a vegetated environment.

It should be noted that the problem of excessive development of plants in rivers have a great importance because it deeply affects the normal water flow [3,9,10]. In fact, because of its rapid growth due to favorable conditions, the vegetation can change the flow speed and cause a disruption of the whole system operation [2,6,11]. It can create favorable conditions for the deposition of fine sediments, slow the transport of coarse materials, and modify the morphology of river beds, in particular reducing the cross section and increasing the flood risk. This is frequently observed, for example in the Medjerda wadi in Tunisia, causing a significant damage [15].

3. Materials and methods

3.1 Experimental protocol

The experiments were carried out into two flumes with different characteristics for the free-surface flows study at the INAT laboratory. The first flume is a rectangular open channel having a slope of 3%, a length L=10 m, and a section 0.80x0.60 m2, with variable slope and operating in a closed circuit (Fig. 1). The upstream of the channel is connected to a tank having a capacity of 3.6 m3. The flow divide at downstream of the channel into a tank having a capacity of 9 m3. The water level at the spill is controlled by a slide valve.

(a) (b)

Figure 1: Experimental device at the INAT laboratory: (a) The large channel, (b) The small channel

Four centrifugal pumps 10 l/s each, ensure the water flow from the downstream tank to the upstream tank by a single pipe. The supply line is equipped with an electromagnetic flowmeter for flow measurement. The bed was

covered with artificial flexible vegetation in the longitudinal direction of the flow spread over 4m in the channel central part, these stems had a height hp=40mm with a density m = 86000 stems/m².
The second flume is also a plexiglass rectangular open channel, having a slope of 3% and long enough to avoid flow disturbances, with a length L = 5m, a width B = 7.5cm, and a depth h = 15cm. The same vegetation cover was glued on the bottom of the flume central part over a distance of 3m.

Figure 2: The used artificial flexible vegetation

We realized two experiments series:

- Series 1: For the same flow rate, the upstream injected sediment quantity was varied

- Series 2: For the same upstream injected sand quantity, the flow rate was varied

Before each experiment, the downstream basin was covered with geotextile whose the dry mass is known to determine the output recovered sand quantity, at the end of each experiment.

3.1.1. Series 1: Constant flow rate for different upstream sediment injected quantities

For a given flow rate of 15 l / s, an initial sand quantity is poured at the input of the vegetation while agitating upstream, until the total disappearance of all the poured quantity. We repeat this experiment while keeping the same flow, but each time, we increase the injected sand quantity, and of course we consider, at each time the initial state corresponding to the trapped sand quantity during the previous experiment. At the end of this experiment, the trapped sand quantity in the geotextile for the same given flow rate is determined.
The evolution of the turbidity is also monitored over time by sampling upstream and downstream of the vegetation every 15 minutes.

3.1.2. Series 2: Same upstream injected sand quantity for different flow rates

For a given flow rate, and after the stabilization of the flow, a sand quantity of 2 kg is injected to the input of the vegetation (1800 g already exists from the previous experiments and 200 g injected again), while agitating upstream, until the total disappearance of the sand.
At the end of the experiment and after drying the geotextile, the recovered sand mass is weighed by measuring the difference between the geotextile mass containing the trapped and dried sand and the geotextile mass before the experiment. The trapped sand quantity is thus determined.
In the second step, the flow rate is varied, and for each new flow rate, the trapped sand quantity during the previous experiment is considered as an initial state, and a quantity giving 2 kg of sand (quantity chosen) is injected again, including that retained before in the vegetation. In the same way we follow the turbidity evolution over time, while taking samples upstream and downstream of the vegetation every 15 minutes.

3.2. Results and discussion

3.2.1. Series 1

The following table summarizes the details of the experiments performed with constant flow and with different upstream injected sediment quantities.

Tableau 2: Experiments carried out with a constant flow rate for the different upstream injected sediments quantities

Flow Q = 15 l/s				
Poured sand quantity (kg)	Initial geotextile mass (kg)	Final geotextile mass (kg)	Released sand quantity (kg)	Retained sand quantity (kg)
0.3	0.5	0.6	0.1	0.2
0.5	0.5	0.7	0.2	0.3
0.7	0.6	0.8	0.2	0.5
1	0.8	1	0.2	0.8

We noted that more we increase the upstream injected sand quantity, more the retained quantity in the vegetation will be large for the same flow rate 15 l / s. In addition, for an injected sand quantity of 300 g, only the 1/3 of this quantity came out of the vegetation environment; while for 1kg injected only the 1/5 that came out; this may explain the evolution of the turbidity in Figure 3: more the injected quantity increases more the turbidity decreases. Below is a comparison of upstream and downstream turbidities of the vegetation, for a constant flow and with the different upstream injected sediment quantity.

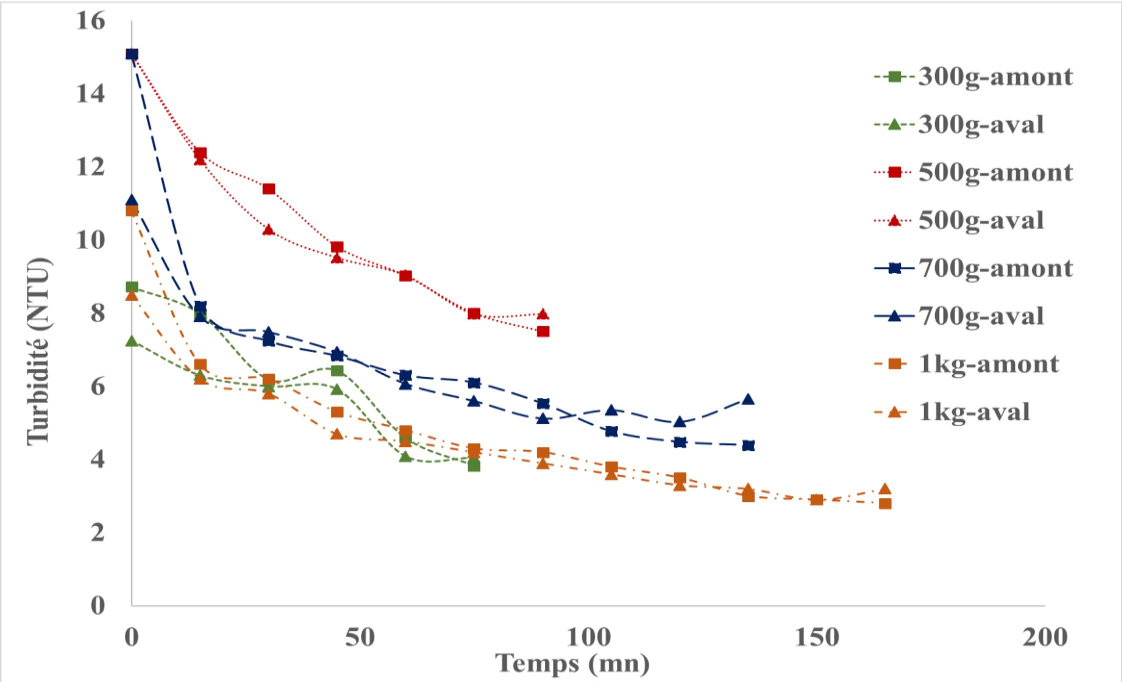

Figure 3: Comparison between upstream and downstream turbidities for the different sand injected quantities and for a flow of 15 l / s (experiments in the large channel)

The above figures show that the upstream and downstream turbidities decrease as a function of time in the same way, and tend towards a constant value, showing a state of stability of the environment. The downstream turbidity is lower than the upstream one at first, but after a while they merge. This is due to the fact that as soon as the sediment is injected, a quantity will come out at first, and the rest will be trapped at the center of the vegetation, and then will come out gradually. We noted that more the injected sand increase, more the trapped sediment in the downstream geotextile is tall, and therefore the turbidity will be greater, as well as the trapped sand quantity in the vegetation. At the end of all these experiments, we have retained about 2kg of sand (1800g) in the vegetation compared to 2.5 kg totally poured. These same results were also presented in a log-log curve, where it is noted that the upstream and downstream turbidities decrease exponentially as a function of time.

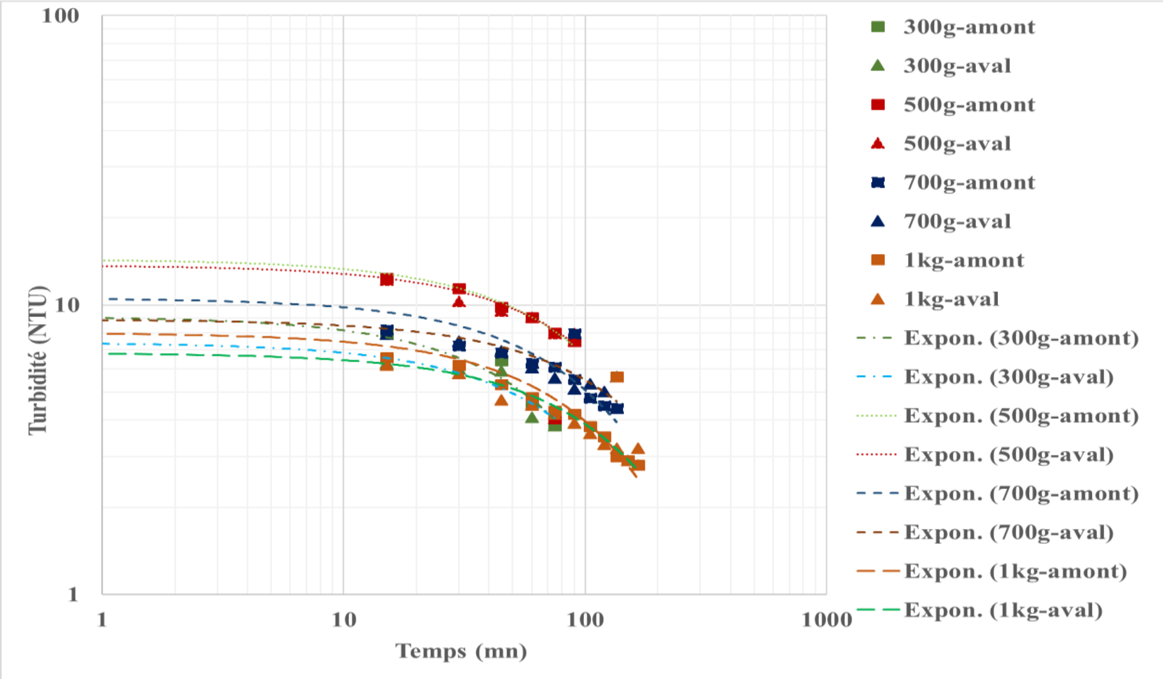

Figure 4: Log-log curve of the upstream and downstream turbidities variation as a function of time for the different injected sand quantities and for a flow of 15 l / s (experiments in the large channel)

3.2.2. Series 2

The following table summarizes the details relating to the experiments carried out with an upstream injected sediment quantity and with different flow rates.

Tableau 3: Experiments carried out with a given upstream injected sediments quantity and with different flow rates

Flow Q (l/s)	Poured sand quantity (kg)	Initial geotextile mass (kg)	Final geotextile mass (kg)	Released sand quantity (kg)	Retained sand quantity (kg)
15	2	1	1.2	0.2	1.8
20	2	0.5	0.8	0.3	1.7
25	2	1	1.5	0.5	1.5
30	2	1	1.5	0.5	1.5

We noted that more we increase the flow; more the retained sand quantity in the vegetation decreases, and more the output sediment quantity increases. Below is a comparison between the turbidities upstream and downstream of the vegetation, for the same upstream injected sand quantity, 2 kg, and for different flow rates.

For this measurement's series, we also note the same interpretations considered previously. In fact, upstream and downstream turbidities decrease as a function of time in the same way, and tend towards a constant value, showing a state of stability of the environment. The downstream turbidity is lower than the upstream turbidity at first, but after a while, they merge. This is due to the fact that as soon as the sediment is injected, a sand quantity will come out at first, and then the rest will be trapped at the center of the vegetation, and after will come out gradually.

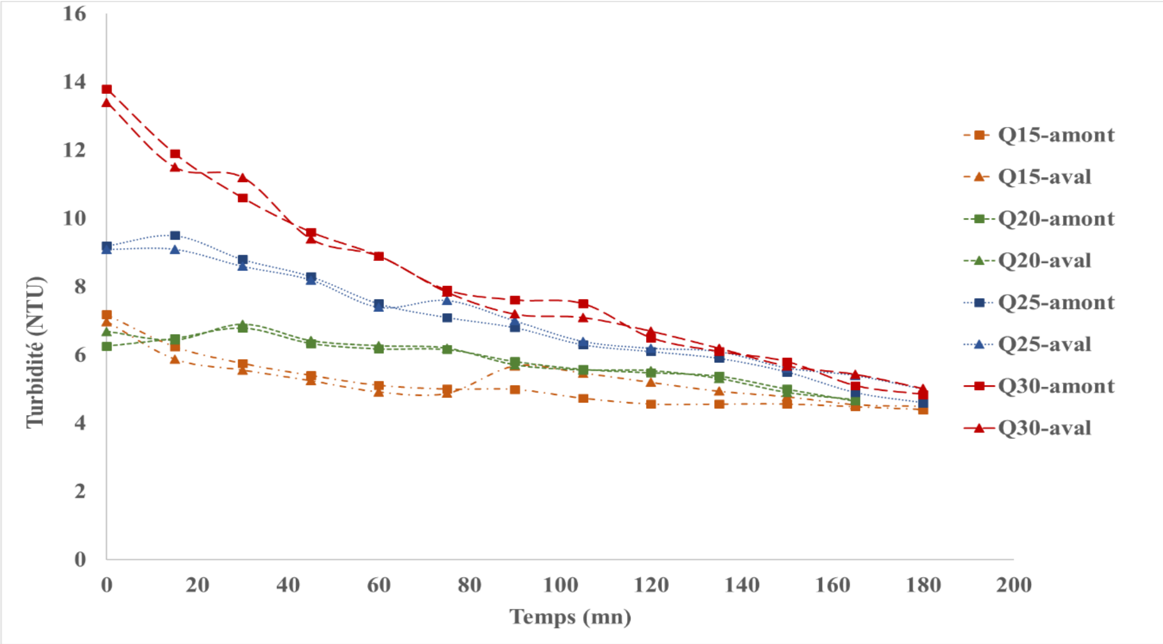

Figure 5: Comparison between upstream and downstream turbidities for the different flow rates and for an injected sand quantity of 2 kg (experiments in the large channel)

The following figure shows a log-log curve of the upstream and downstream turbidities variation as a function of time for the different flow rates and the same injected sand quantity, 2 kg.

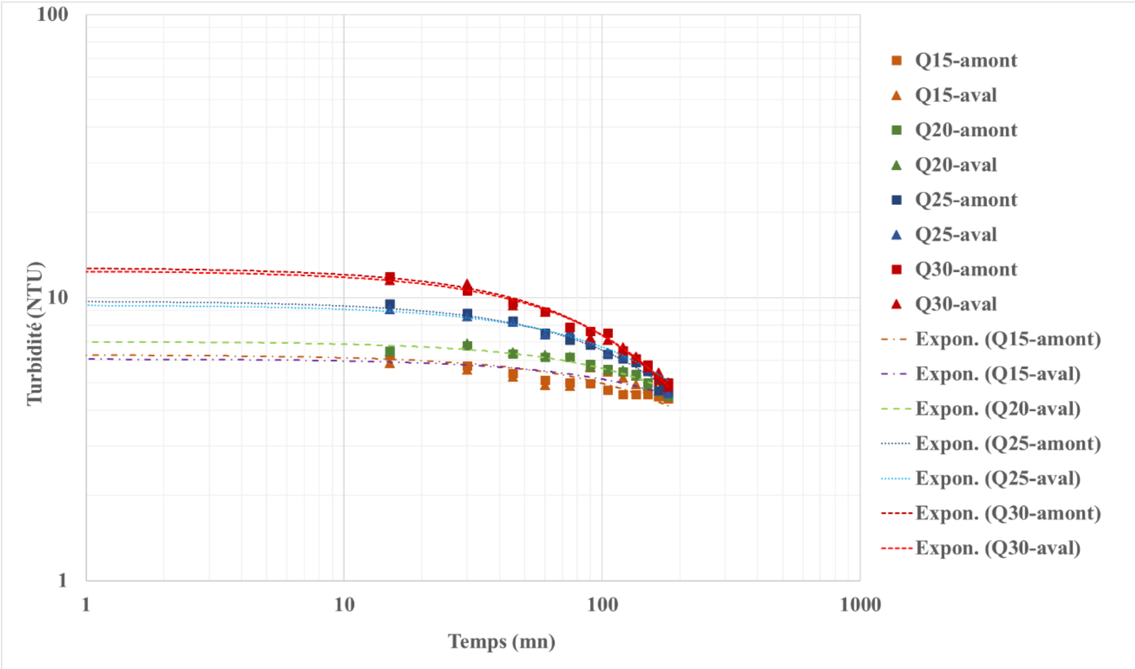

Figure 6: Log-log curve of the upstream and downstream turbidities variation as a function of time for the different flow rates and an injected sand quantity of 2 kg (experiments in the large channel)

The following figure shows that upstream and downstream turbidity increases with flow. In fact, more the flow is increased, more the environment becomes turbid and more the trapped sediments in vegetation come out of the environment. On the other hand, for each flow, the turbidity decreases with time, following an exponential pace. It is also noted that upstream and downstream turbidities tend towards the same constant value, of 5 NTU order, for the different flow rates, this is the stabilization state. The same experiments were carried out on the small channel of INAT. In these experiments, we worked with the same upstream injected sand quantity which is 200g (the chosen quantity), and the flow rate was varied.

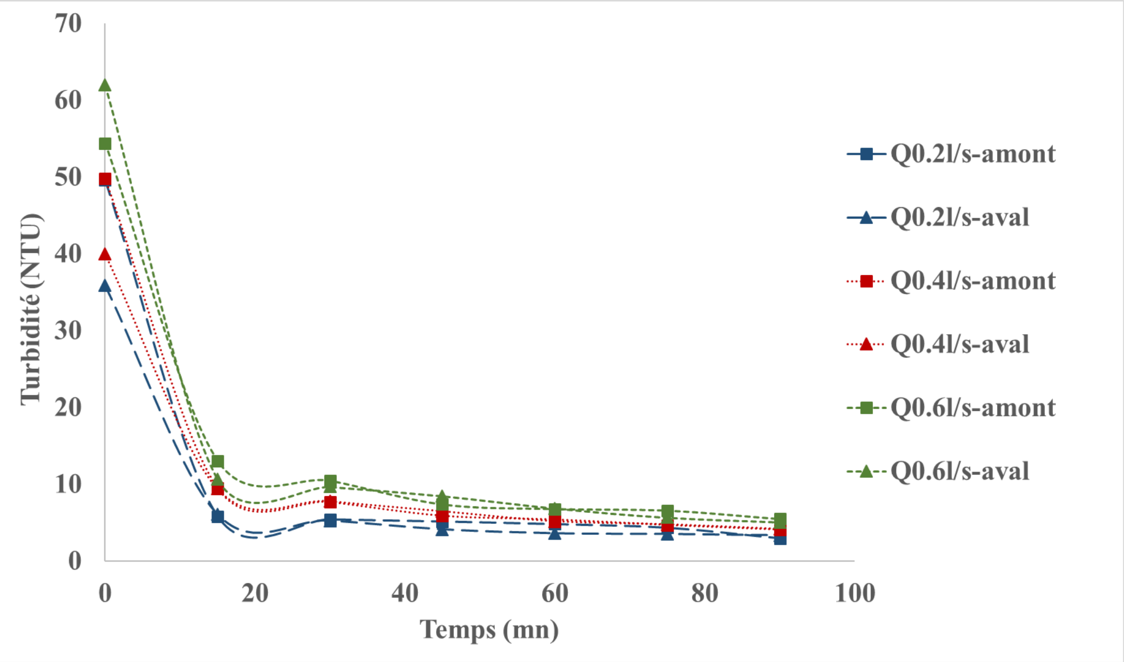

Figure 7: Comparison between upstream and downstream turbidities for different flow rates and an injected sand quantity of 200 g (experiments in the small channel)

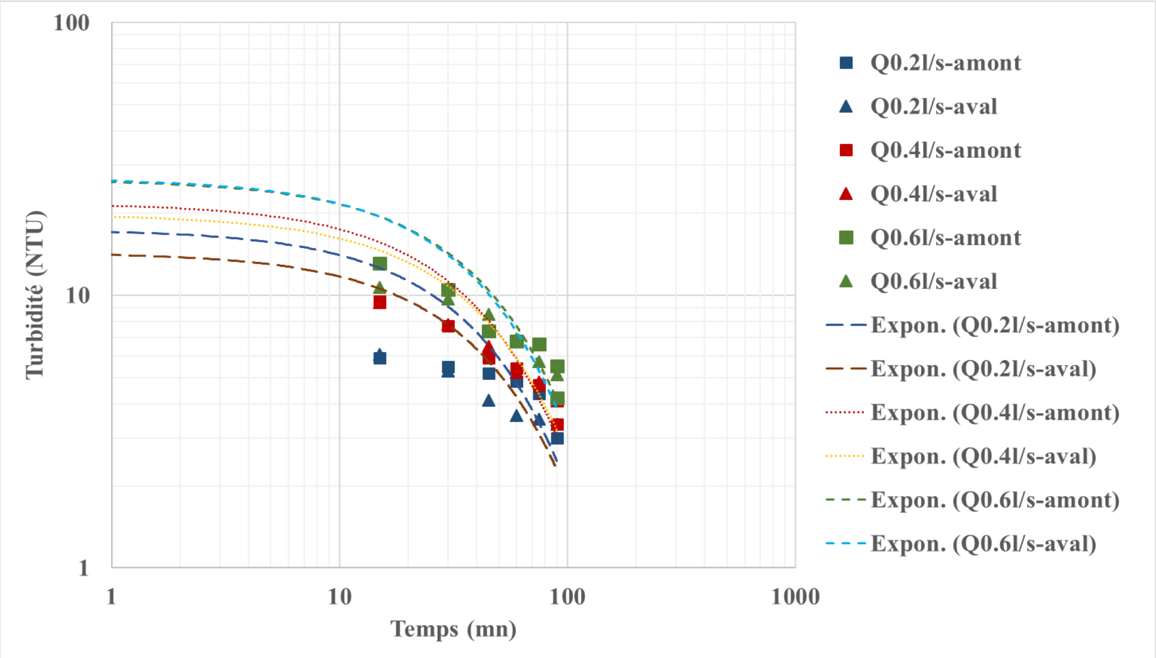

Figure 8: Log-log curve of the upstream and downstream turbidities variation as a function of time for the different flow rates and an injected sand quantity of 200 g (experiments in the small channel)

The same interpretations observed in the large channel were recorded here, confirming the vegetation's behavior with respect to sediment transport and subsequent turbidity.

4. Conclusion

In a vegetated environment, turbidity is an important indicator of sediments transport.

In our experiments, it has been noted that the upstream and downstream turbidities in the vegetated system decrease with time, following an exponential pace. It has also been shown that the downstream turbidity is lower than the upstream turbidity at the first time of the experiments, but after a while they merge into the same constant for the different flow rates, this is the stabilization state.

It has been deduced that dense vegetation greatly favors local sediments depositions and therefore contributes to the reduction of beds cross sections, and subsequently could increase the flooding risk. To cope with these constraints, different maintenance techniques are essential in order to reduce these risks, such as cleaning, leveling and clearing vegetated islands.

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