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INVESTIGATING THE IMPACT OF FEED RATE AND GRAIN SIZE DISTRIBUTION ON PHYSICAL MODEL OF A SEMI ALLUVIAL URBAN RIVER

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I would particularly like to thank Dr. Sarah Peirce, with whom I worked on all experiments. She helped me beyond measure with understanding semi-alluvial river systems, flume research, experiment design, and report writing and was a pleasant person to work with.

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Introduction

[The experiments and results shown in this report are in line with the work being done by the River Hydraulics research group of the University of Waterloo. It describes the events that occurred during an engineering student internship for a duration of 12 weeks but has been written and submitted before the end of this period. The lack of complete results at the moment of its redaction doesn't allow for an optimal data treatment and therefore all assumptions and conclusions are strictly hypothetical and need to be verified through further experimentation.]

Semi-alluvial rivers are often considered as rivers presenting a partial or discontinuous alluvial cover laying on top of a bedrock or glacial till plan. If it is admitted that the study of alluvial cover in rivers is a fundamental step to reach an efficient management plan in aquatic environments, this assertion is even more true in the case of semi-alluvial rivers.

Indeed the characteristics of the alluvial cover (stability, spatial distribution, thickness and position in the channel) are parameters capable of determining the erosion intensity at which the non-alluvial plan will be exposed (Hodge R.A, Hoey T.B, 2016) as well as the availability of the substratum to the channel fauna (Hodge R.A, Hoey T.B, 2016). In addition, as alluvial cover stability (both spatially and temporally) is essential for determining local sediment abundance, bed roughness and shear force, semi-alluvial channels may behave differently than purely alluvial ones (Hodge R.A, Hoey T.B, Sklar L.S, 2011).

Knowing that frictions and impacts of sediments on the bed of a watercourse are an important mechanism in erosion and incision processes (Sklar L.S, Dietrich W.E, 2004), the understanding and ability to anticipate evolutionary trends in alluvial cover are great tools in the management and restoration of semi-alluvial river systems (Hodge R.A, Hoey T.B, 2016) and surrounding structures.

This report aims to describe the work done on alluvial cover in semi-alluvial rivers, continuing the work of Welber et al. (in press). The work aims to optimize the experimental technical parameters as well as elaborate a procedure to be followed by the next research team, as well as study of the effects of sediment input on the stability of sediment cover in an irregular meandering river using a small-scale physical model of a reach of a real river (The Wilket Creek). In that way, these methods create a bridge between field surveys and analytic predictions realized in similar contexts.

Each experiment was run at the same constant water discharge, and was characterized by a specific constant sediment input rate. The experiments are divided into intervals (runs), at the end of which a photographic survey was done then treated in order to obtain data on cover and elevation.

In addition to the main investigation on sediment input rates, a secondary experiment inspired by the work of MacKenzie and Eaton (MacKenzie L.G, Eaton B.C, 2017) was developed. Its objective was to investigate the reaction of the sediment cover and the transport dynamics in the channel when having to face an increased D_{90} due to the introduction of additional coarse grains. The objective was to learn more on the importance of big grain size classes and fixed channel banks on these parameters.

The host structure

This internship was completed at the River Hydraulics research group from the Department of Civil and Environmental Engineering of the University of Waterloo.

Professor Bruce MacVicar is the supervisor of this research group in which he and 10 other PhD, Masters and co-op students work on themes related to hydraulic engineering and fluvial geomorphology.

The River Hydraulics group's ongoing research includes field research, numerical modeling, and physical modeling looking at sediment transport in urban rivers.

Materials and Methods

Semi-alluvial rivers and previous research

The semi-alluvial rivers

Semi-alluvial rivers are rivers with a relatively thin layer of alluvium on a substratum considered as non-alluvial or weakly erodible (Ashmore P., University of Western Ontario) in which the alluvial elements are largely set in motion during flood events. The moving elements in these streams play a key role in their morphological stability, as the bulky elements contribute to stabilizing the stream during periods of low water and are responsible for the erosion of the channel when they are put into movement during floods (Sklar L.S, Dietrich W.E, 2004). Sediment cover stability, in both their temporal and spatial dimensions, plays a role in local sediment supply, bed roughness, and shear stress, indicating that semi-alluvial rivers may behave differently than fully alluvial rivers (Hodge R.A, Hoey T.B, Sklar L.S, 2011) and the mechanisms at work are not yet fully understood.
Also, given that the saltation and impact mechanisms of solid particles in the watercourse are dominant in the erosion of the bedrock and the incision of the channel (Sklar L.S, Dietrich W.E, 2004), it becomes essential to anticipate alluvial cover behavior in order to achieve effective management objectives for these types of rivers.

In this context, many management issues are raised. Particularly in the case of heavily modified streams in highly anthropogenic environments. In these circumstances, the flood peaks have a higher intensity in heavily impervious watersheds capable of moving larger solid elements into the stream, increasing its erosive capacity and reducing the stability of the channel.

In addition, a reduction in the recruitment of solid elements into urban watercourse due to bank hardening and stabilization processes in man-made environments, further reduces the course's capacity to compensate for the increased erosion. Furthermore, the impact of future climatic variations that seem to tend towards an intensification of rainstorms and winter storms, may result in even more erosion in urban semi-alluvial streams. In response to increased storm intensity, the river may incise and erode the banks in search of available materials.

These deep changes in the channel have a definite impact on the stream habitats and therefore on the biotic diversity present. In the case where the stream exists in spaces occupied by human structures or activities and when this erosive phenomenon presents risks for those, the problems of managing the morphology to protect infrastructure are added to these biological issues.

Previous research and objectives

In semi-alluvial rivers sediment cover area and volume are mainly controlled by two parameters: sediment input and bed topography. However, the work of Hodge and Hoey (2016) suggests that bed morphology is the dominant factor in determining all alluvial cover characteristics, by acting through the control of local flows and sediment inputs.

To date, the majority of research on semi-alluvial rivers has been based on field work or small-scale physical models based on bedrock rivers. In addition, the existing works concentrated on the semi-alluvial till rivers are most often concentrated in the study of a reduced surface and relatively simple geometries (Welber et al., In press). Thus the relationships between alluvial cover and morphology of the channels with weakly or non-erodible banks are not well understood.

Alluvial cover is important in semi-alluvial rivers for several reasons. First, in terms of physical processes, cover can act as a protective agent for the substratum against erosion. In other cases, when sediment input in the channel is high, the increase in the number of transportable solids in the stream leads to an increase in the impacts of the latter on the bed and tends to increase erosion. These two

actions are known as the cover and tool effect and are described by Sklar and Dietrich (REF) and are known as the cover and tool effects, respectively. As a result, the volume of mobile sediment in the channel appears to play a role in the stability of the channel. In addition, erosion of the bedrock of a semi-alluvial river can have serious consequences for surrounding infrastructure.

In order to identify the role of the sediment feed rate on the extent of alluvial cover in urban semi-alluvial rivers, Welber et al., (In press) have used a physical model of a sinusoidal geometry urban river with simple geometry (Figure 1). In these experiments the channel was fed with sediment at constant rates of 2, 4, 6 or 8 g/s until a sediment equilibrium state was reached (sediment input = output). Since each experiment initially presented a bare bed, it was possible to compare both the topography of the bed obtained for each feed rate but also the development of the bars over time. These experiments showed that the bars formed simultaneously and extended at a similar rate along the length of the channel and that the size of the bars increased as the feed rate increased. It is important to note that these observations were made in a channel with a simple geometry almost absent from natural rivers.

Finally it seems that the stability of the bed is affected by the local grain size distribution. MacKenzie and Eaton (2017) have shown in their research on an erodible bed flume that a small change in the coarse tail of the grain size distribution resulted in bar stabilization and reduced erosion (MacKenzie L.G, Eaton B.C, 2017).

Thus research in this area suggests that alluvial cover is the result of the combination of morphology, feed rate and grain size distribution. However, there is currently very little research on these relationships in the semi-alluvial rivers complex. The objective of this work is therefore to study the role of each of these parameters in order to identify their importance on sediment transport and bed stability. To do this, the work carried out during this internship is a continuation of previous research by Welber et al., (in press), applied to a complex geometry and attempting to answer the following questions:

1. How does a complex channel geometry impact bar formation, stability, and sediment equilibrium in semi-alluvial rivers?
2. How does sediment feed rate impact bar formation, stability, and sediment equilibrium in semi-alluvial rivers?
3. How does grain size distribution impact bar formation, stability, and sediment equilibrium in semi-alluvial rivers?

Figure 1: Welber et al.'s simple geometry flume (Source : Welber et al., in press)

To answer these questions experiments will be carried out at a constant flow rate of 1.93 l/s for sediment contributions of 2, 4, 6 and 8 g/s on a meandering channel with complex geometry. In these experiments, it was assumed that the equilibrium state was reached when the Output / Input ration was equal to 100% (+/- 5%) for at least 2 consecutive hours.

By using an existing river as a model and replicating it on a small scale, this research can be used directly for the management of this river. Finally, the use of small-scale physical models makes it possible to create a bridge between field studies and predictions of analytical and computer models.

The Wilket Creek

The experiments carried out during this research are carried out in an artificial channel whose morphology is based on a semi-alluvial stream of the City of Toronto, in Southern Ontario (Figure 2). The Wilket Creek is a tributary of the West Don River and crosses the heavily urbanized spaces of the City of Toronto.

Figure 2: The Wilket Creek in the Wilket Creek park (source : Peirce S.)

Today it is estimated that the entire 15.5 km^2 of its watershed is urbanized (Toronto and Region Conservation Authority (TRCA)). Its northern portion south of York Mills Road was channelized into a network of pipes during the 1940s and 1950s. Its southern portion is a 4.5 km open channel up to its confluence with the West Don River. Of all the tributaries of the West Don River still having an open channel today, it is estimated that Wilket Creek is among those with the longest and deepest hydrologic changes as a result of the urbanization of southern Ontario.
Wilket Creek is supplied by runoff from rain events, drainage and rainwater collection systems, and partly by groundwater. The poor management of rainwater in the watershed, driven by the density and advanced age of the networks in the upstream part of the watercourse, leads to extremely fast flash floods in the watercourse.

The official destabilizations cited by the Ontario Ministry of the Environment and retained by the Toronto and Region Conservation Authority (TRCA) as present in Wilket Creek are:

- increased cross sectional area of the channel
- down-cutting into the channel bed
- increased sediment loads due to the erosion
- changes to typical channel characteristics such as meandering patterns

- decreased quality and quantity of habitat
- degraded water quality
- loss of riparian vegetation (Ministry of Environment, Ontario (MOE), 2003)

In light of these destabilizations, a number of erosion control measures responding to "traditional" engineering methods were put in place (bed and bank concreting, rip rap, gabions), but the latter proved to be ineffective and have significant impacts on habitats for aquatic and riparian species (Figure 3).

Figure 3: Damaged bridge on Wilket Creek post 2005 Storm. (Source : TRCA, 2005)

After the 2005 storm the City of Toronto asked the TRCA in 2007 to manage, develop, and implement a large-scale watercourse restoration project in the reach located in Edwards Garden. Shortly after the completion of this work a 2008 storm damaged three of the ten recently restored sites. As a result of these events, a new project including a need for a thorough understanding of the mechanisms at work was developed to meet the security and management needs of Wilket Creek.

Materials

The flume

The experiments were performed on a river modelling flume at the University of Waterloo. It consists of a 13.3 meters long and 2 meters wide plateau whose slope can be adjusted to create a slope for the stream. The channel was carved out of roofing foam, approximating the plan geometry of a segment of the Wilket Creek (Figure 4). Roughness was created on the bed and the banks of the channel by sticking sand (0.7 - 1 mm) to the foam. Larger roughness was added on the rectangular parts upstream and downstream of the main study area in order to mitigate supercritical flow through the straight reaches.

Figure 4: The empty flume and the channel construction

The result is a reproduction of the Wilket Creek on a 1:40 scale made from a field survey from the riverbanks (Appendix I) and whose geometry is repeated twice on the physical model (Figure 5). The banks have a slope of 30 degrees for a height of 7 cm.

Figure 5: Orthophoto of the bare channel (flowing from right to left)

The slope of the physical model was set to a value of 1.1% in order to reproduce the experimental conditions of Welber et al. (in press) then was later modified to 1.5% in order to take into account the winding character of the channel.

The flow rate used for these experiments was 1.93 l / s, as this flow rate is at the same time similar to the experiments of Welber et al. (in press), and approximately corresponds to the flow of a 2-year return period flood on the actual site (AECOM). The water supply is made from a reservoir upstream of the channel from which water escapes through a V-shaped overflow weir (Figure 6) allowing to control the flow in the channel by modifying the height of water in the reservoir.

Figure 6: The V-shaped overflow

The sediment supply was carried out upstream of the channel on a rectangular section just before the first curves of the channel. Sediment was brought to the channel through the use of a calibrated auger style sediment feeder (Figure 7) and a dispersion system consisting of a trough with and a nail at its end. Styrofoam walls were added near the lower part of the trough to avoid any loss due to bouncing particles on the nail.

The sediments used during the experiment are a mixture of sand and gravels seeking to respect the natural characteristics of the watercourse while reproducing the experiences of Welber et al. (in press) (Appendix III) characterized by a D_{10} of 0.3 mm, D_{50} of 1.6 mm, and D_{90} of 3.5 mm. Sediments are collected at the downstream end of the channel in baskets and weighed after 2 minutes at the end of each run.

Figure 7: The sediment feeder and weighting station

Each run follows the same procedure. First the water was turned on and then when the initial wave reaches the downstream end of the channel, the sediment feeder was started. The runs last either 20

minutes (at the beginning of the experiment) or 60 minutes (after catching the first coarse grains in the downstream baskets). During the 60-minute runs, the downstream sediment baskets were still exchanged and weighed every 20 minutes. At the end of each run the water was cut off and the sediments captured during the last 20 minutes are labeled and kept for analysis.

It was then necessary to wait for the complete drying of the channel before proceeding to the photographic survey.

The delay in channel drying and data acquisition greatly slowed down the process so that about three runs could can be done per day. Added to this was the time required for the cleaning of the channel between each experiment and the painting work to be done on the areas that have suffered damage or had started to rust.

During the experiments it was observed that special attention should be given to the feeder systems of the channel. Indeed, the water supply valve and the feeder adjustment dial are extremely sensitive and require special monitoring between and during each run. These adjustments can be source of uncertainty if not monitored.

The photographic survey

At the end of each run, a photographic survey of the channel was made to be processed using the software package Agisoft Photoscan 1.4 and the ArcGIS suite.

A set of targets was distributed over the surface of the flume. These targets are identified by the Agisoft Photoscan software and are used to reference the location of each photograph taken. Allowing the software to assemble them and create an orthophotograph and a Digital Elevation Model (DEM) of the entire flume.

To acquire the photographs from a high enough point and with enough angle, two Canon T5I SLR cameras are attached to a movable cage (Figure 8) above the surface of the bed. One photograph per camera is taken every 40 cm along the flume to obtain the most effective coverage and overlapping between photographs.

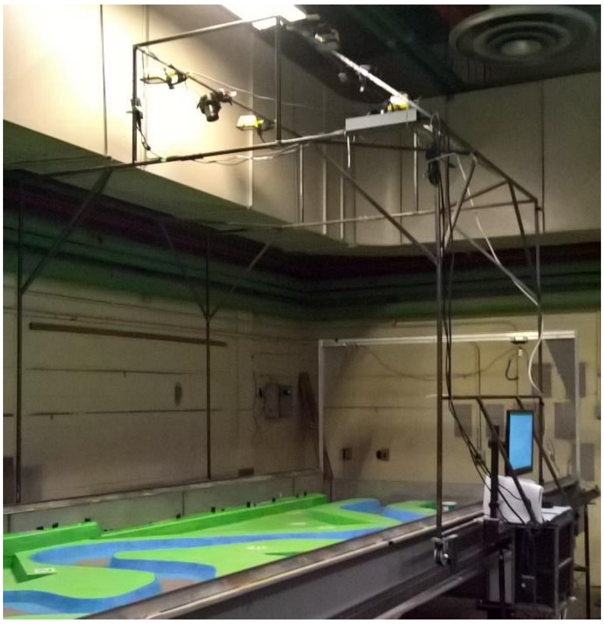

Figure 8: The movable trolley and camera set up

The Agisoft Photoscan software searches common points between pictures and matches them as well as finds the position of the cameras. It then builds a dense point cloud based on the estimated camera positions and pictures and reconstructs a 3D polygonal mesh of the flume using the recorded altitude of the targets (Agisoft LLC, 2018).
The creation of a DEMs allows for the creation of DEMs of Difference (DoDs) so that the volume of sediments stored in the channel can be

calculated, although this analysis was not completed for this report.

It is important to notice that in this report all the orthophotographs are showing the flume flowing from the right of the image to its left.

In addition to these relief data, the orthophotographs produced by Agisoft are used to produce alluvial cover maps using the supervised classification of ArcMap where each pixel of the image is classified into different classes based on the spectral signatures devired from user-defined training samples (ESRI).

Each processed run is accompanied with a Agisoft report stating the precision of the data acquisition and quality of the image and DEM produced. This led to numerous issues that are still being worked on currently and delayed data production. Multiple camera positions, as well as target and lighting configurations were tested and are still being tested to date. Much time is still spent improving the method of data acquisition to get the lowest error possible, with the overall goal of achieving sub-millimeter vertical error.

Results and discussion

Experiment C4b

The first experiment is C4b, it was carried out under the following conditions:

- 1.1 % flume slope
- 1.93 l/s discharge
- 4g/s sediment supply rate

During the first runs, sediments begin to accumulate under the sediment feeder as well as in the first meander where storage is important. After three hours of experiments, it was clear that most of the sediments were being stored in the upper half of the canal and that few grains were reaching the downstream parts of the flume, as can be seen in Figure 9. This massive sediment storage was realized again in the first meander of the downstream part of the flume (repetition of the first meander).

Figure 9: C4b Orthophotograph, T+03h00

After three days (3 hours of experimental runs) where no significant output was measured, the decision was made to change the duration of the runs from 20 minutes to 1 hour. At this stage some coarse grains were found in the downstream basket and some isolated coarse grains were present at the locations of the most downstream bars. These criteria were reused in the following experiments to decide when to go from 20-minute runs to 1-hour runs.

Two hours later, after 5 hours of experiments, levees had to be added on the upstream part of the first meander to cope with the increase in water level caused by sediment accumulation. These levees were extended later in the experiment on almost all the upstream of the channel in order to face this problem whose extent was only increasing.

After 16 hours of experimental runs, it was found that the value of the feeder system was different from that required to provide 4g / s of sediment. Faced with this observation in addition to the fact that sediments continued to accumulate massively over the entire flume and more particularly on its upstream part (Figure 10), it is decided to put an end to the experiment.

Figure 10:C4b Orthophotograph, T+16h00

This first experiment revealed several things. Firstly, sediments are massively stored in the flume and 7 hours of experiments were needed to obtain a significant output (Figure 11).

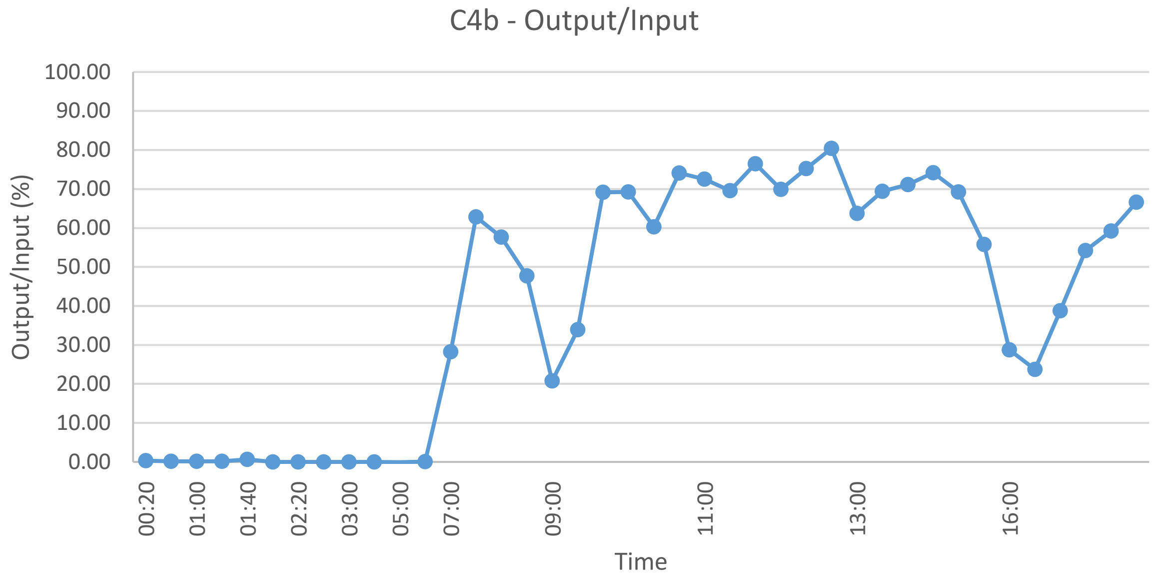

Figure 11: C4b sediment Output/Input ratio according to time

The ratio of sediment output/input, even if it seems to increase over time, fell more or less abruptly in a fairly regular manner and does not exceed 80% percent. The dip observed around 16h00 may also be related to the disregulation of the sediment feeder adjustment knob.

Thus, the flume continued to store more and more materials and continued to store sediments when it was decided to put an end to the experiment (Figure 12).

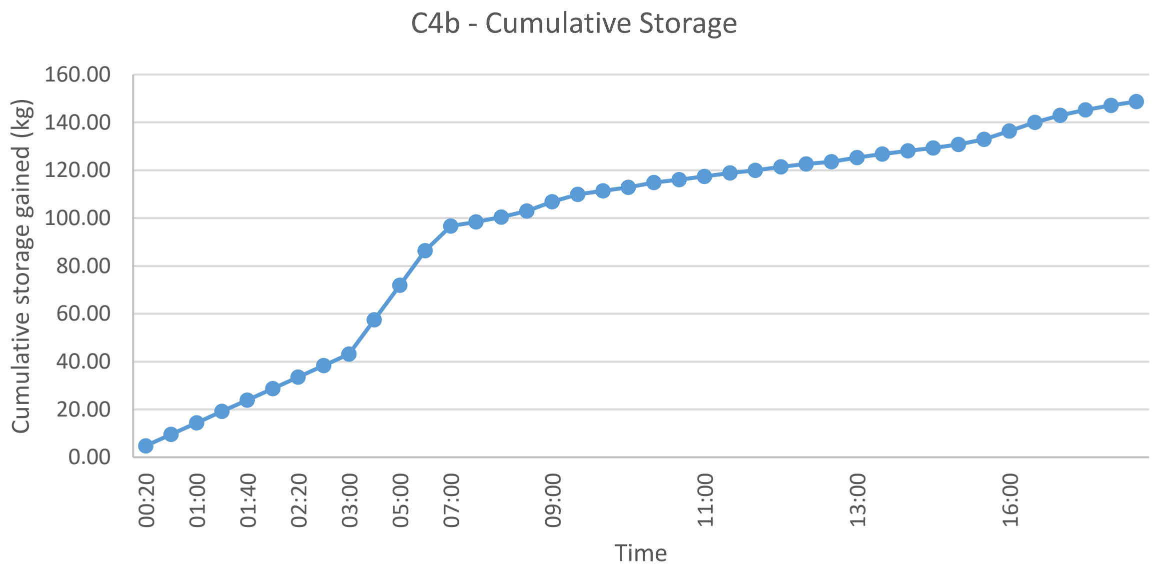

Figure 12:C4b Cumulative storage gained according to time

Although the uncertainty introduced by the change in sediment flow between hours 12 and 16 does not allow us to draw certain conclusions about the end of the experiment, there were several observations.

First of all, the sediment bars exhibit a behavior different from that described by the work of Welber et al. (in press) performed under conditions of similar solid and liquid flow on a regular geometry. In these works the bars are described as forming simultaneously and growing at a similar rate over the

entire length of the flume. Conversely, we find here that the bars form sequentially, where coarse grains form the base of the first bar in the upstream-downstream direction and the next bar will begin to form only when the previous one reaches a certain level of stability. In this respect, the first significant mass measurements downstream of the channel revealed that the first wave of sediment to arrive en masse at the end of the flume was mostly coarse grains.
It was also possible to see that the flume stored a lot of sediment almost causing an overflow event. It was found that this accumulation was more important upstream of the channel than downstream. After verification of the Wilket Creek field data, it was found that the recorded slope of 1.1% was consistent with the direct slope not taking into account the sinuosity of the channel. After calculation, it was determined that a valley slope of 1.5% would achieve the desired cover slope of 1.1% taking into account the geometry of the channel.

Finally, this experience provided an opportunity to work on and improve sediment and water supply systems, as well as photography and data acquisition methods.

Experiment C4d

The second experiment C4d was carried out under the same conditions as C4b from the point of view of discharge (1.93 l/s) and sediment flow (4 g/s). However, the slope of the flume was changed to 1.5% so that the actual slope of the channel reached the 1.1% target. In addition, a nail was added on the lower part of the trough distributing the sediments in the flume to increase their dispersion. To prevent sediment from being diverted out of the channel after striking the nail, two walls were added along the banks to force them into the channel.

During this experiment the sediments are more easily carried away by the current benefiting from the adjusted slope. Thus, the first meanders of the flume stored much less sediment and the bars formed had a smaller shape and spread. The first meander that stored a large part of the sediment brought into the was less high and less large than in C4b, no longer risking overflow.

From the beginning of the experiment it was possible to observe that bars developed mainly in inside bends where the formation of sediment bars. After 1h20 of experiments, stable bars were formed in the whole of the upstream part of the channel and with the first bars appearing in the downstream part as well (Figure 13). The general rate of progression of the bars from upstream to downstream was then slowed down by the filling of the large meander present at the beginning of the downstream section (Appendix IV).

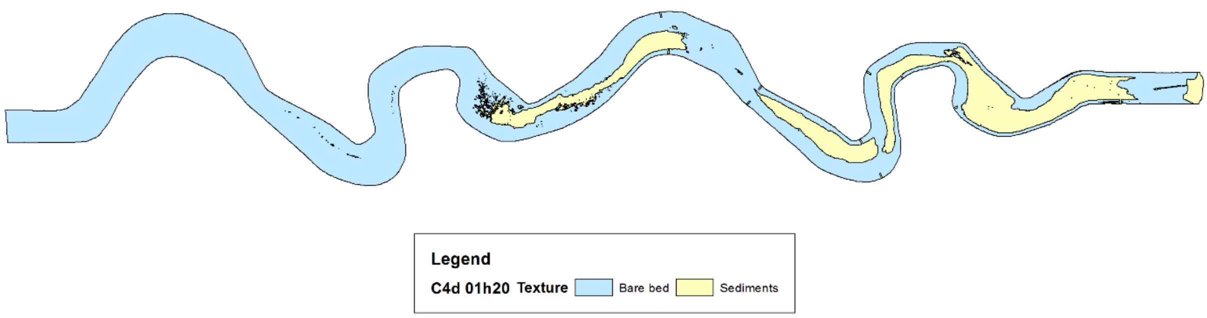

Figure 13:C4d sediment cover (Image classification from orthophotograph data), T+01h20

In the same way as the C4b experiment, it was decided to increase the run time from 20 minutes to 1 hour after 3 hours of experiments, since bars were formed on the whole channel and the first coarse grains were captured in the collecting baskets.
After 7 hours of experiments, the channel displayed well developed and stable bars throughout its length as visible in Figure 14.

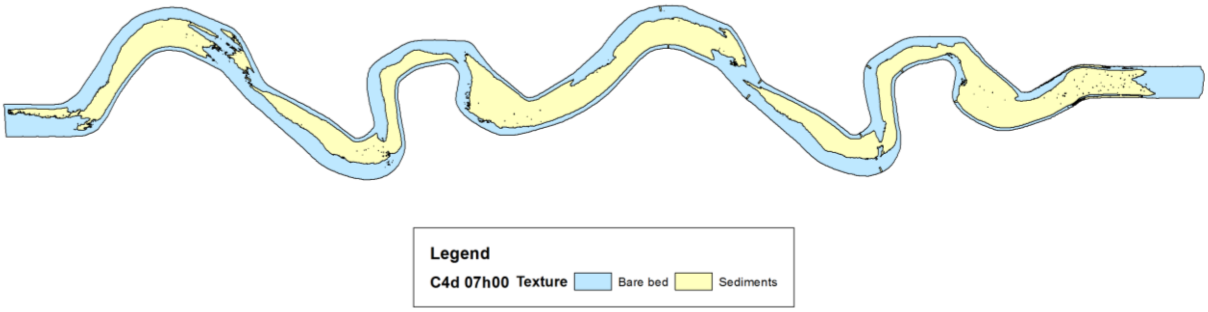

Figure 14:C4d sédiment cover (Image classification from orthophotograph data), T+07h00

The experiment was stopped 4 hours later, 11 hours after starting. As the photographic data collected have not yet been processed, no orthophotograph or image classification of the experiment after 7 hours is available at this time. However, a sediment cover survey at T + 7:00 indicates that approximately 50% of the channel surface is occupied by sediments at this time.

The study of the evolution of the sediment output/input ratio during this experiment indicates that there was a period of building during which the flume stored all the given materials for 3 hours. The first significant measurement of sediment output mass happened as soon as the 3 hours point was reached (Figure 15).

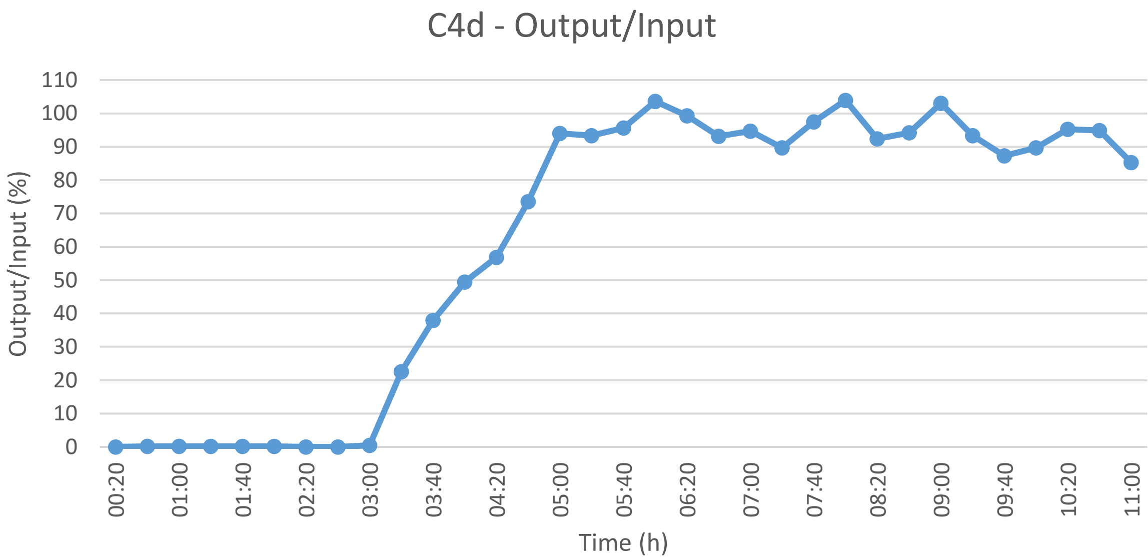

Figure 15: C4d sediment Output/Input ratio according to time

This peak corresponds to the moment when the last bar is formed in the flume after 3 hours of experimental time (evolution between T+02h00 and T+04h00 visible in

Appendix IV) and once again the first significant mass measurements were mostly composed of coarse grains before evolving to a more representative mixture of input sediments.

However, the construction of the most downward bars does not stop instantly and the observation of the cumulative storage (Figure 16) illustrates that the sediment storage rate gradually decreases over time before reaching a plateau after 5 hours of experiments.

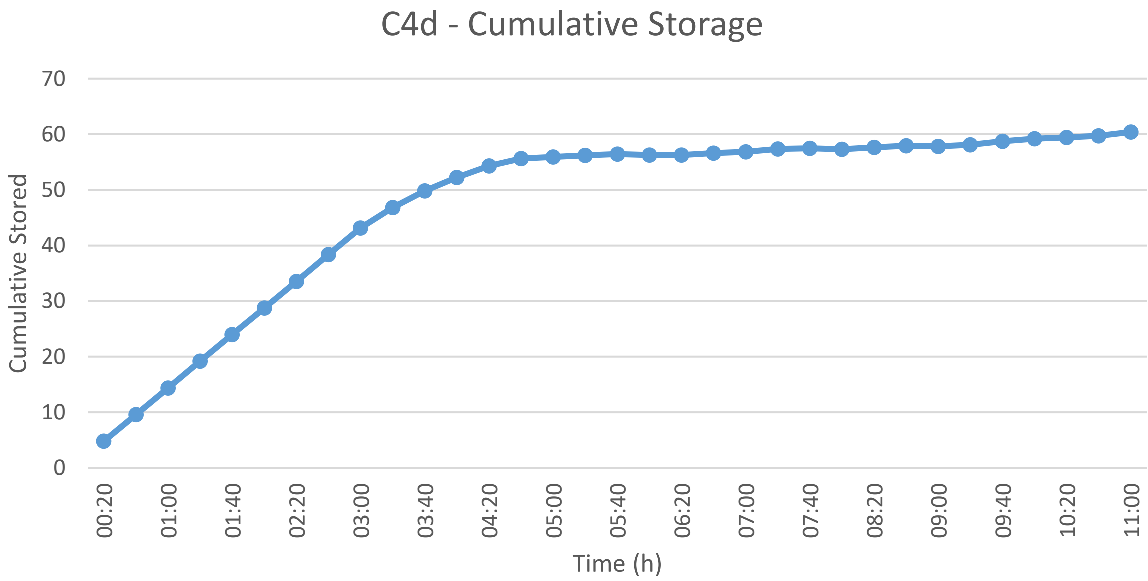

Figure 16: C4d Cumulative storage gained according to time

This state is also viewable on Figure 15 which shows that the output / input ratio tends to stabilize in a value range between 87 and 105%. It was determined in the experiments of Welber et al. (in press) that the system was in equilibrium when the output / input ration was equal to 100 (+/- 5). However, in the experiment conducted here, this stability was never really achieved and the stable level reached presents an oscillatory dynamic that was absent in the work of Welber et al.(in press). It is assumed that this variation was the result of the geometry of the channel used, which was more complex than that of the work of Welber et al. (in press).
Although the oscillation of the measured values does not allow us to reach the objective of targeted stability, averages realized over 2 consecutive hours over the period T+05h00 to T+11h00 indicate values around 95%. Thus, it was decided that this value would be retained to validate the equilibrium state of the system at this moment, obtained after 5 hours of experiments.

This experiment was also the opportunity to observe again the sequential character of formation of bars in the channel. Even if some coarse grains managed to pass the most upstream bar, the latter was formed and reached a sufficiently stable state before the immediate downstream bar really begins to form. This seems to be a key driver for the initially slow progression of the output / input ratio, followed by a rapid increase in this value once the last bar is formed.

The computer processing of the photographic data collected will help to push the interpretation of the mechanisms at work. Moreover this experiment realized with a sediment feed rate of 4g/s will be completed by similar experiments at feed rates of 2, 6 and 8 g/s and flow of 1.93 l/s, thus offering possibilities of comparison in order to identify the role of the flow of sediment in the formation and stability of the bars.

Experiment C2Pa

The latest experiment was inspired by the work of MacKenzie and Eaton (2017) whose objective was to study the importance of the highest classes of grain size distribution on erosion resistance. To do this, two flume experiments were planned under almost identical conditions. The only difference was the value of the D_{90} was increased from 3.7 to 3.9 mm, while maintaining an identical D_{50} (1.6mm) (MacKenzie L.G, Eaton B.C, 2017). Experience had shown that this modification led to profound changes in the erosive dynamics of the studied flume since the coarse immobile grains were responsible for a doubling of erosion resistance.

The aim here was to test whether the same conclusions can be obtained on a non erodible meandering channel with complex geometry, and whether these variations have an impact on the parameters usually studied during the current experiments. This experiment was therefore performed at a discharge of 1.93 l/s and a feed rate of 2 g/s for a slope of 1.5% while maintaining the methods and techniques used during the C4d experiment.

In the experiment carried out here, a mixture of sediment was created in order to reproduce the experimental conditions of MacKenzie and Eaton (2017). A new class of grains was introduced (6.73mm - 8mm) in order to move the value of the D_{90} while limiting the modifications made to the D_{50}. This new blend had the characteristics presented in Table 1.

Table 1: Original and modified grain size distributions

	Original Distribution	Increased D90 Distribution
D95	4.18	4.81
D90	3.62	3.76
D84	3.10	3.26
D75	2.38	2.50
D65	1.78	1.82
D50	1.14	1.13
D35	0.77	0.72
D16	0.42	0.39
D10	0.32	0.30

Among the sediments used for this experiment, those falling in the size classes 4 - 5.6 , 5.6 - 6.73 and 6.73 - 8 mm were painted in green, purple and orange, respectively (Figure 17) in order to visualize their behavior during the experiment, study their position on the bars, and visually identify the impact of each class on the sediment dynamics of the experiment. The objective here was also to determine if it is possible to bring a similar method to the management of natural rivers in order to limit erosion by bringing coarse materials without modifying the average values of the grain size distribution and thus limit the disturbances brought to the habitats offered by the sediments. In order to arrive at usable results, this experiment will be compared with the results of a future experiment obtained by using the original sediment mix at a similar feed rate and discharge.

Figure 17: Painted grains according to their class size

During this experiment it was noted that the general behavior of the sediments was similar to what was observed previously, where the coarse grains form a first upstream bar that will develop and stabilize globally before coarse grains form the next bar which will follow the same evolution resulting in a sequential formation from upstream to downstream of the channel bars (Figure 18).

However, during this experiment the speed at which the bars form and stabilize was much smaller than in the previous experiment. After 1h20 of experiments, only 11% of the channel had sediment cover where the C4d experiment had 22% of the channel surface occupied by sediments over the same amount of time.

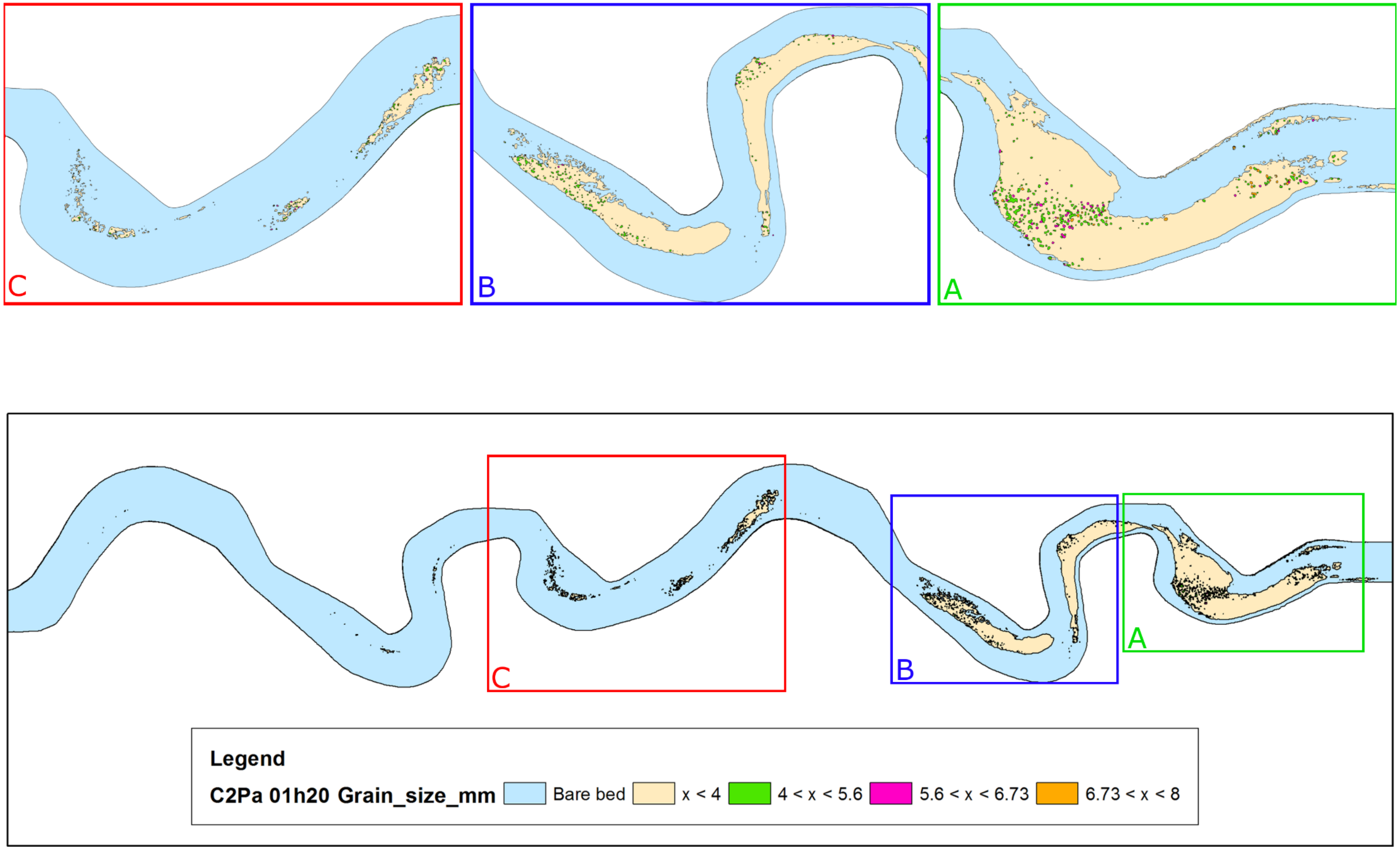

Figure 18:C2Pa sediment cover (Image classification from orthophotograph data) on three zoomed sectors, T+01h20

The sediment output weight data obtained at the time of submission covers 4 hours of experiments. These results indicate that the equilibrium state was not yet reached (where 3 hours were necessary to reach a balance during the previous experiment) and that the flume continued to store all sediments brought in at a steady rate (Figure 19). This evolution seems very similar to the sediment storage period encountered in previous experiments during which it was necessary to achieve that all the bars of the channel were constructed before obtaining a significant output.

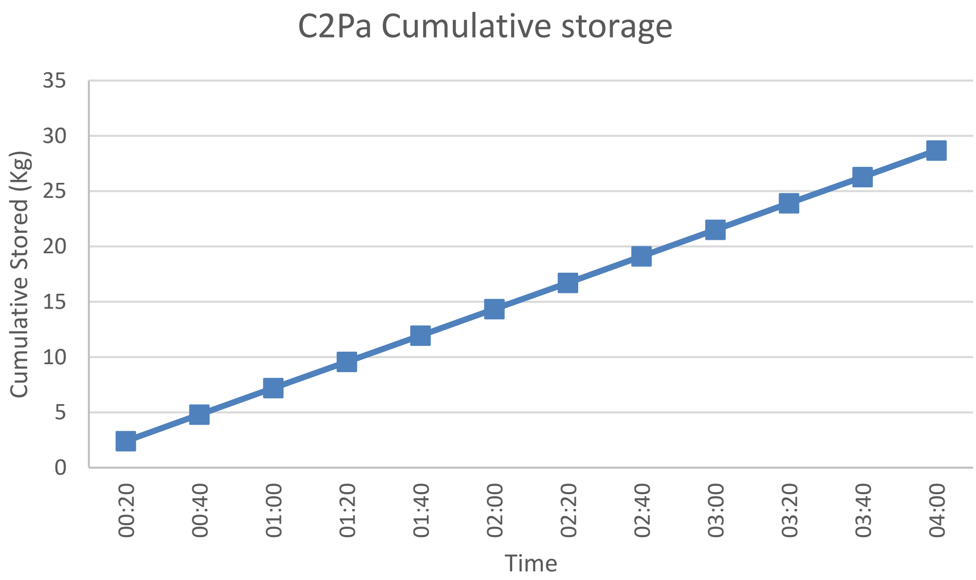

Figure 19: C2Pa Cumulative storage gained according to time

The progressive construction of sediment bars over time can be seen on the sediments cover maps created from orthophotograph data on Figure 20 and Appendix VI. These data only exist for the runs realized from the beginning of the experiment to T+01h20.

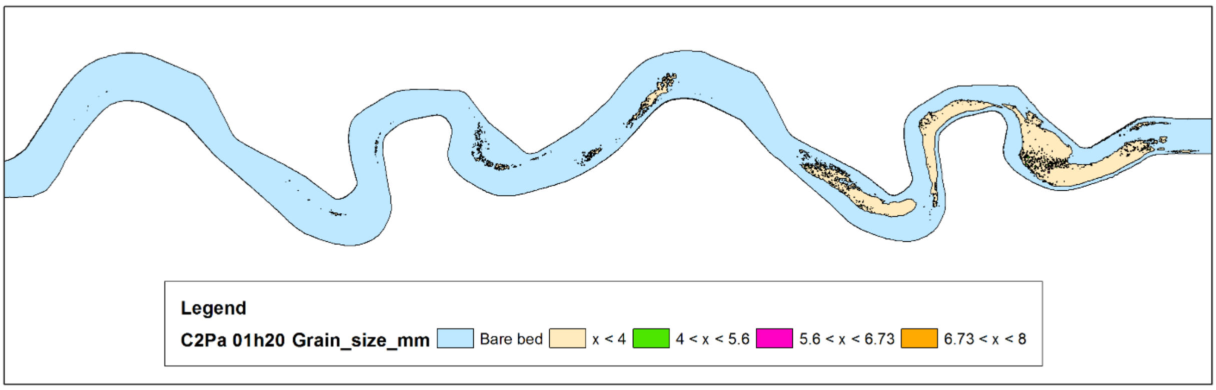

Figure 20:C2Pa sediment cover (Image classification from orthophotograph data), T+01h20

These sediment cover maps also make it possible to visualize the location of coarse painted sediments and to provide more data on their involvement in the formation of sediment bars in the channel. The data created by the image classification of orthophotograph of the channel seem to indicate that partially covered grains are also spotted by this method, but that some of the colors of the original photograph are sometimes interpreted as grains of a class to which they do not belong. In general, the result obtained gives an idea of the behavior and overall location of the size classes studied (Figure 21).

Figure 21: C2Pa Comparison between orthophotograph and sediment cover map, T+01h20

Using this kind of image it becomes possible to locate preferential flow areas where fine sediments are washed away and coarser left behind, as well as potential areas of accumulation of coarse materials leading to the development of sediment bars in the channel (Appendix VII) while individually identifying the grain size classes in question. It is currently unclear whether the slower rate of bar formation and equilibrium is the simple product of sediment flow reduction or if the addition of a size class enter into equation, future experiments carried out at 2 g/s with the original sediment mix should resolve this question.

Conclusion

Experimental conclusion

Several observations could be made from the experiments carried out during this internship. The first of these is common to all three experiments, and that is the sequential character of bar formation, a trait not observed in the works of Welber et al. (in press). It was observed each time that the bars begin to form on a few coarse grains once the bar that precedes them has reached a relatively stable state. Moreover, the first significant output mass measurements were mostly composed of coarse grains and intervened once the last downstream bars appeared in the flume, before returning to an average more similar to the sediment input.

The study of the evolution of the output/input ratio over time (Figure 22) indicates that the first hours of experiment saw the majority of sediments trapped and stored in the flume (resulting in the formation of bars sequentially) before seeing these values increase rapidly to reach a state of oscillation more or less marked depending of the experiment. As far as C2Pa is concerned, the experiment was not advanced enough to be able to observe these changes in its output/input ratio.

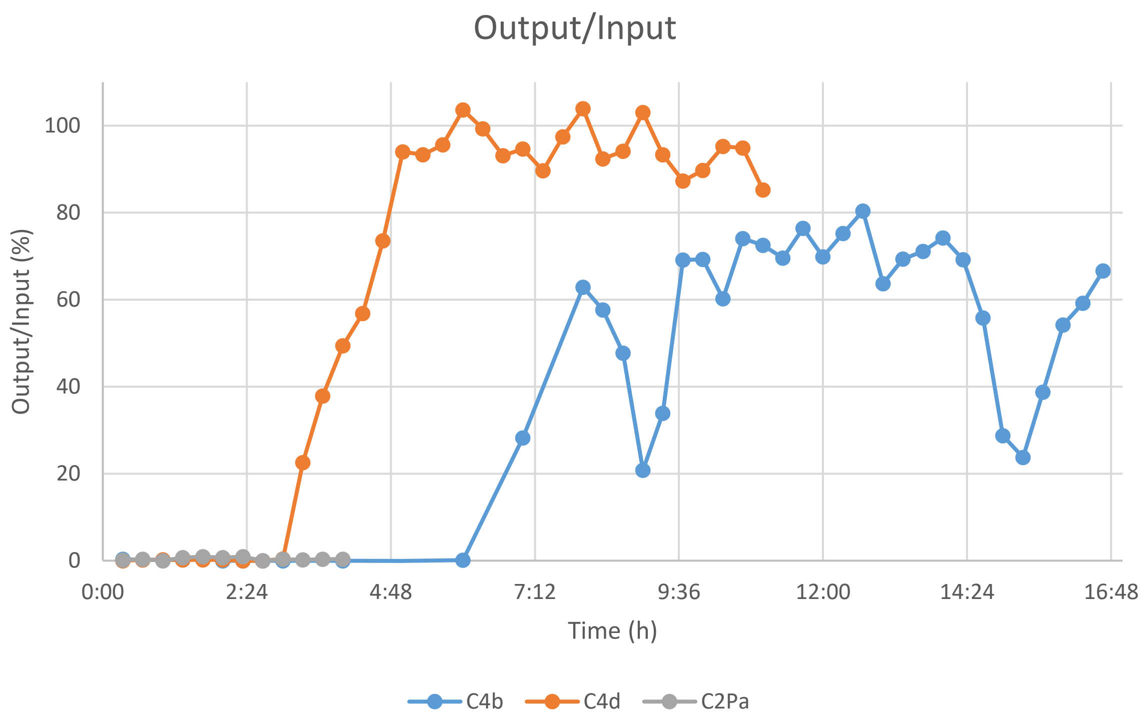

Figure 22: Comparative Output/Input ratio according to time

If we exclude C4b because of the slope error during the experiment, it is possible to observe that the maximum output/input values of C4d (feed rate = 4 g/s of original grain distribution mix) oscillate over a range between 86 and 105%. This oscillation was not observed in the work of Welber et al. (in press) performed under identical conditions of discharge and feed rate using the same sediment mix. Thus, the parameter capable of explaining these output variations seems to be the complex geometry of the channel.

Continuing the C2Pa experiment (feed rate = 2 g/s of modified distribution mix) and experimenting with 2, 6 and 8 g/s of original sediment mix should provide more information on this topic.

The study of the evolution of the sedimentary cover also brought some interesting elements through comparison between the C4d and C2Pa experiments.

During experiment C2Pa (feed rate = 2g/s of modified mix) it was noted that bar evolution and sediment bed occupancy was much slower than in the C4d experiment (feed rate = 4g/s of original mix). However, it was noticed that the shift seemed to follow the order of magnitude imposed by the difference between feed rate. Since for a feed rate divided by 2 it was observed that for the same experimental period, the area covered by C2Pa sediments was 2 times lower than the area covered by C4d (Table 2).

Table 2: Comparison of the sediment cover of two experiments at two identical times

Time	% Sediment Cover C2Pa (2g/s)	% Sediment Cover C4d (4 g/s)	Ratio C4d/C2Pa
00:40	6.43	12.6	2.0
01:20	11.69	22.44	1.9

The spatial study of the cover in question reveals however that no major difference exists between the two experiments and that the bars seem to develop in a globally identical manner (
Figure 23). The difference in sediment cover between the two experiments is then mainly due to the longitudinal progression of C4d whose formed sedimentary bars are present far further downstream (Appendix VIII).

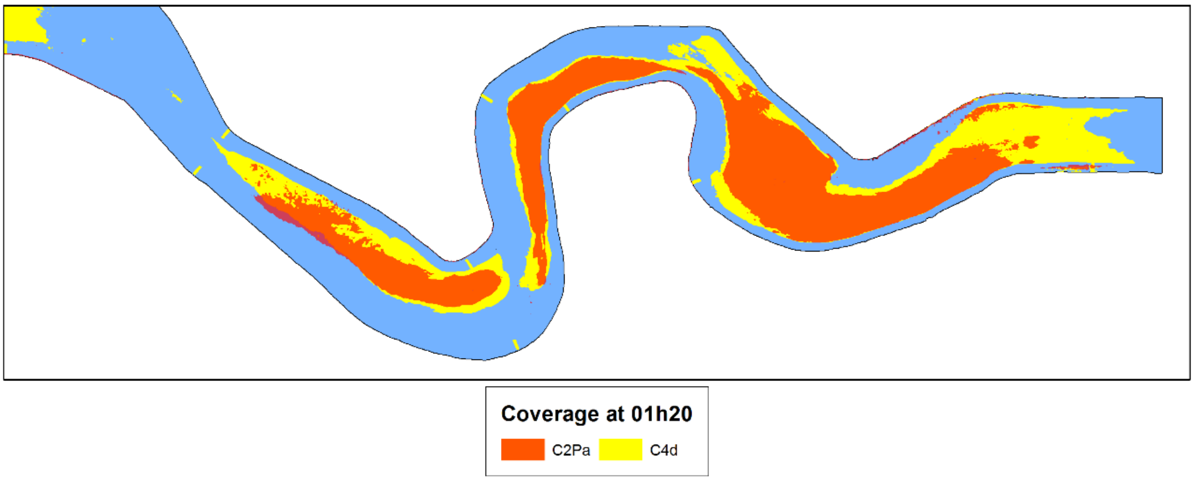

Figure 23: Comparison of the spatial distribution of sediment cover of experiment C4d and C2Pa on the upstream part of the flume at T+01h20

Finally, if we compare the experiments C4d and C2Pa not at the same moment but at the same values of cumulative sediment stored (Table 3) it is possible to see that the sediment cover value is identical for the same mass stored for the two experiments.

Table 3:Comparison of the sediment cover of two experiments at two identical sediment storage

Experiment	Time	Cumulative sediment storage (kg)	% Sediment Cover
C2Pa (2g/s)	01:20	9.6	11.7
C4d (4g/s)	00:40	9.6	12.6

The data from the C2Pa / C4d comparison seems to indicate that the change in grain size distribution and / or the variation of the feed rate does not lead to a change in the sediment storage and the extent occupied by the latter but rather on the speed at which the bars are formed. Here again the dominant parameter in the regulation of the extent of the bars seems to be the morphology of the watercourse, by its importance in local variations of current.
Continuing the C2Pa experiment will provide insight into these assumptions and replicate an experience at a feed rate of 2 g / s with an original mix will help identify the impact of the grain size change.

To conclude, it appears that experiments carried out during this internship show the potential importance of the morphology of the channel in the sedimentary dynamics of a semi-alluvial river in an urban environment. The tested parameters of the feed rate and the grain size distribution do not seem to influence this dynamic as much as the morphology.
However, the aforementioned assumptions should be interpreted as ideas for reflection to be tested with future experiments (Table 4) in an attempt to bring them complete answers backed with enough data.

Table 4: Planned experiments

Upcoming experiment	Discharge (l/s)	feed rate (g/s)	Variable tested		
			Complex geometry	Feed rate	Grain size distribution
C2	1.93	2	✓	✓	✓
C6	1.93	6	✓	✓	
C8	1.93	8	✓	✓	

Personal conclusion

This internship was for me the opportunity to discover the world of research that I had never the occasion to experience and in which I wanted to do an internship experience during my studies. Unfortunately, the writing of this report happened at the two-thirds of this experience and I regret not being able to provide more detailed results.

I was able to learn how to work with new tools such as the flume and all of its ancillary tools. I also discovered semi-alluvial rivers and learned a lot about them both in terms of management and restoration in natural and urban environment.

This internship was an opportunity to work on my professional skills such as developing an experimental method during the C2Pa experiment or even improving parts of the flume. Each experiment performed on the flume was also an opportunity to learn how to perform experiments using a physical model, experiments requiring to be carried out with precision and rigor. Finally, I was able to improve my skills in analyzing results when processing photographic data, statistics or visual information during experiments and during data processing. Also, I noticed that the daily teamwork necessary to carry out these experiments is a great way to improve my interpersonal skills.

This experience allowed me to improve my social skills by immersing myself in a professional environment speaking a foreign language and in which I had to learn how to interact, work, and live. In addition, a good knowledge of the English language was a prerequisite for the practice of a professional scientific activity and this experience is an explicit example.

Finally, this discovery of the world of research has left me an excellent impression and confirms the possibility of seeing me apply in this kind of environment during my future professional research.

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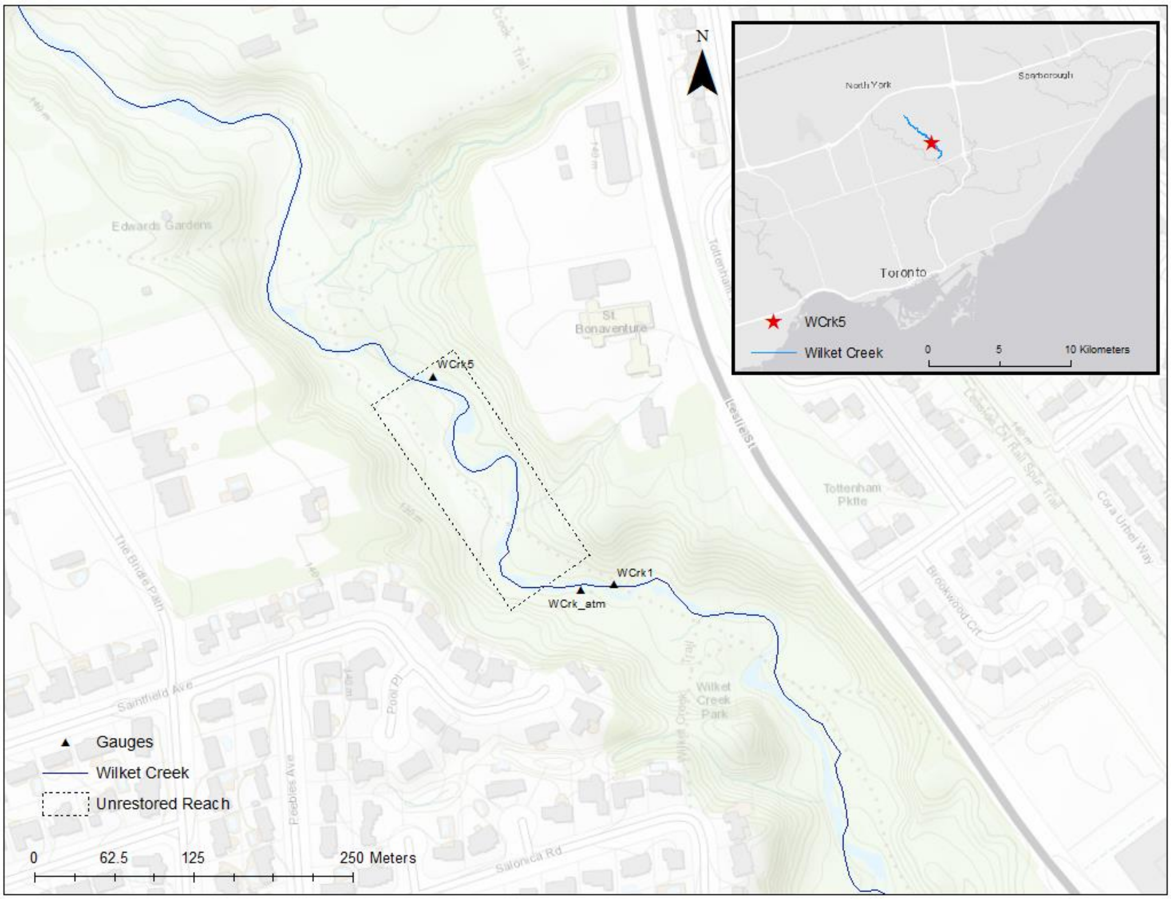
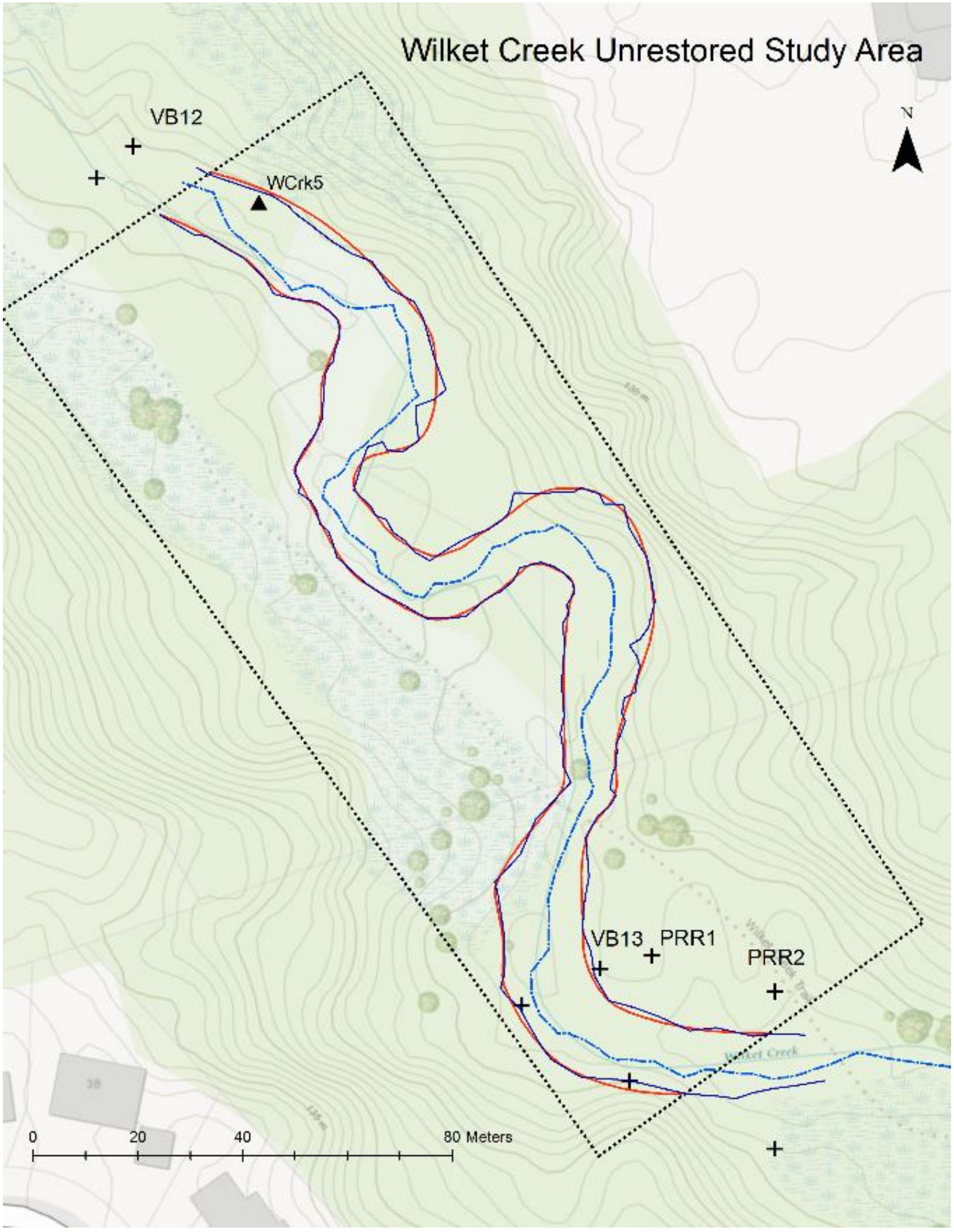
Appendices

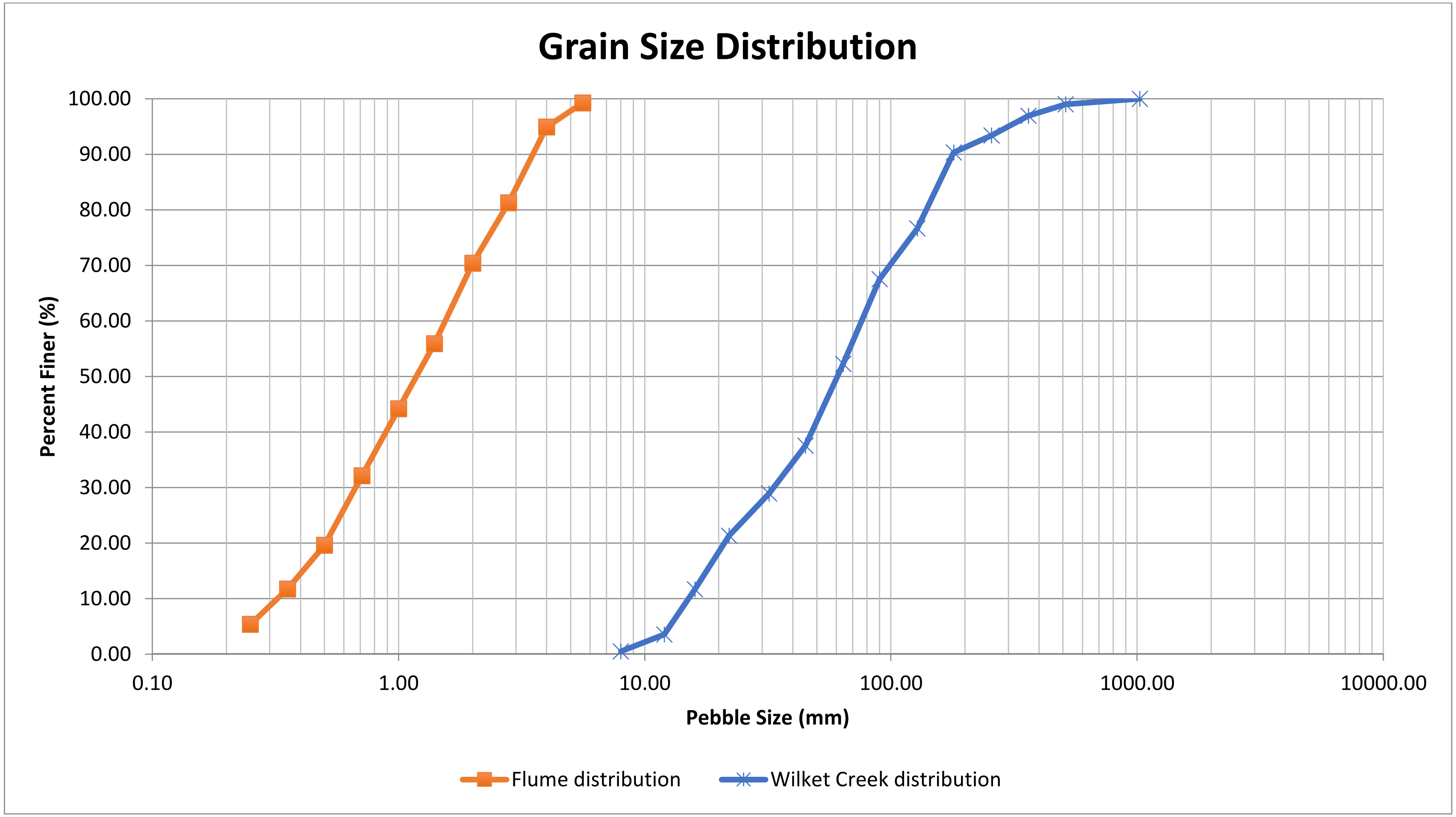
Appendix I:The Wilket Creek and the studied reach (source : Peirce S.)



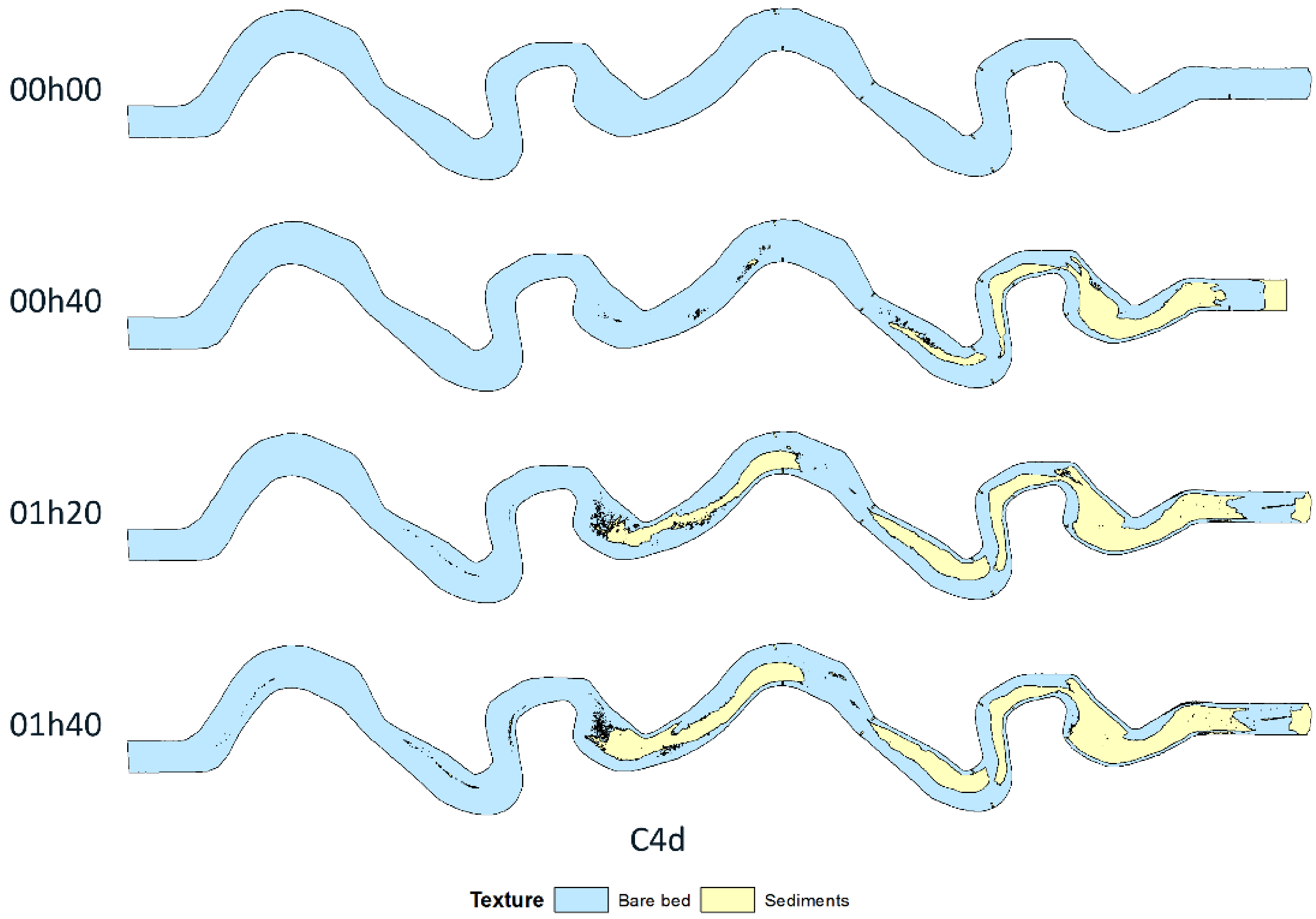
Appendix II:The studied reach (source : Peirce S.)

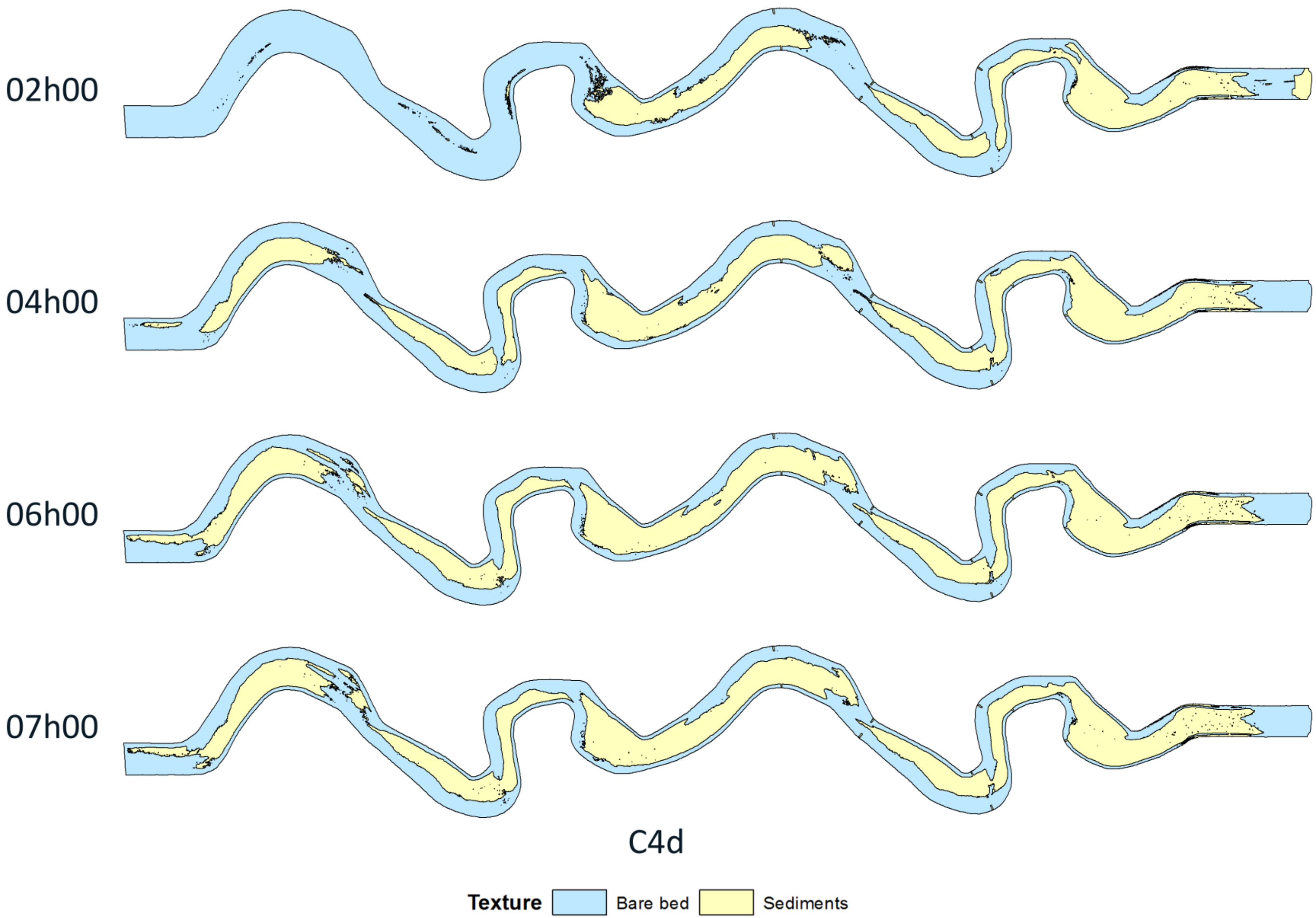


Appendix III:Experimental grain size distribution

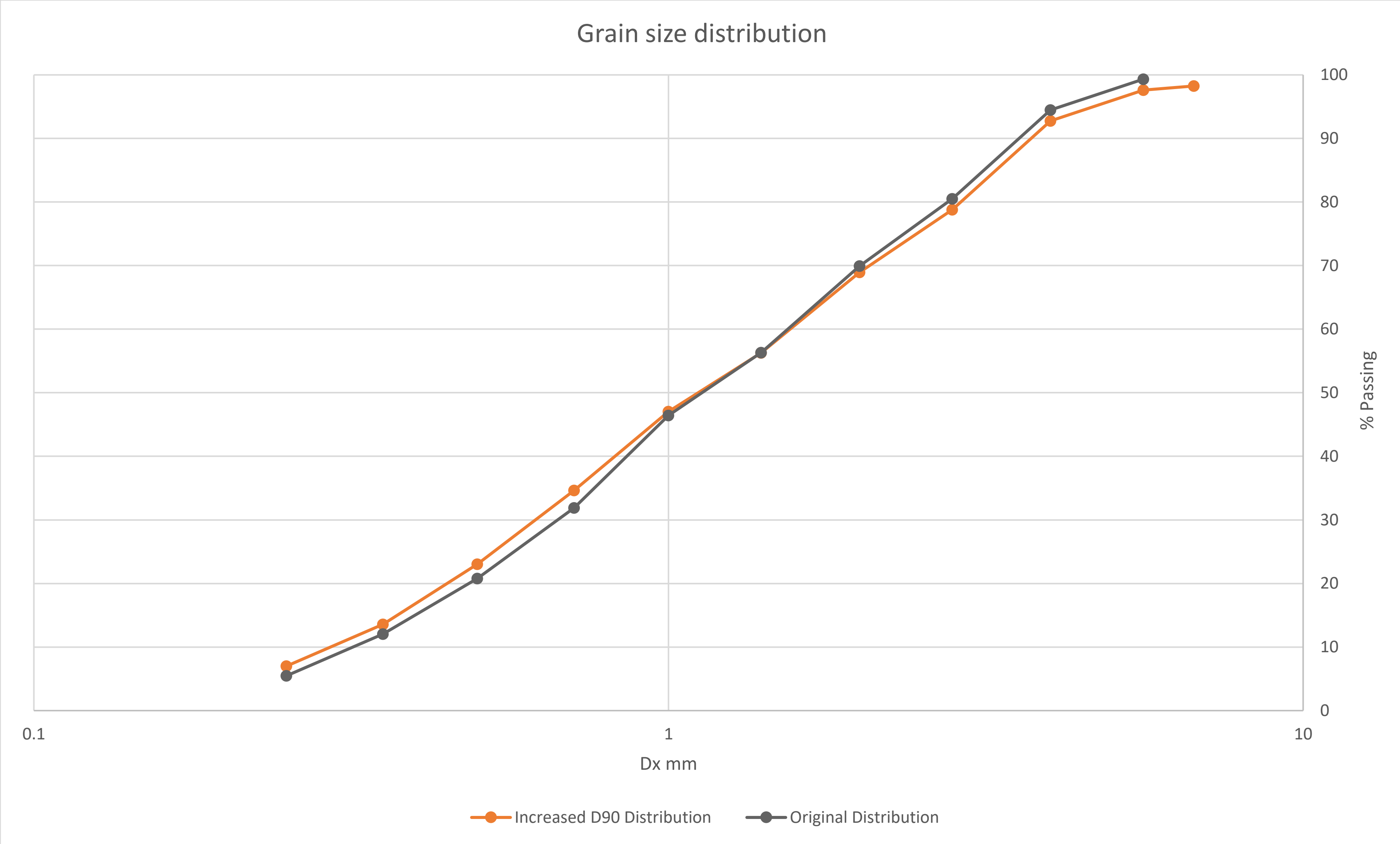


Appendix IV: C4d, sediment cover (Image classification from orthophotograph data)

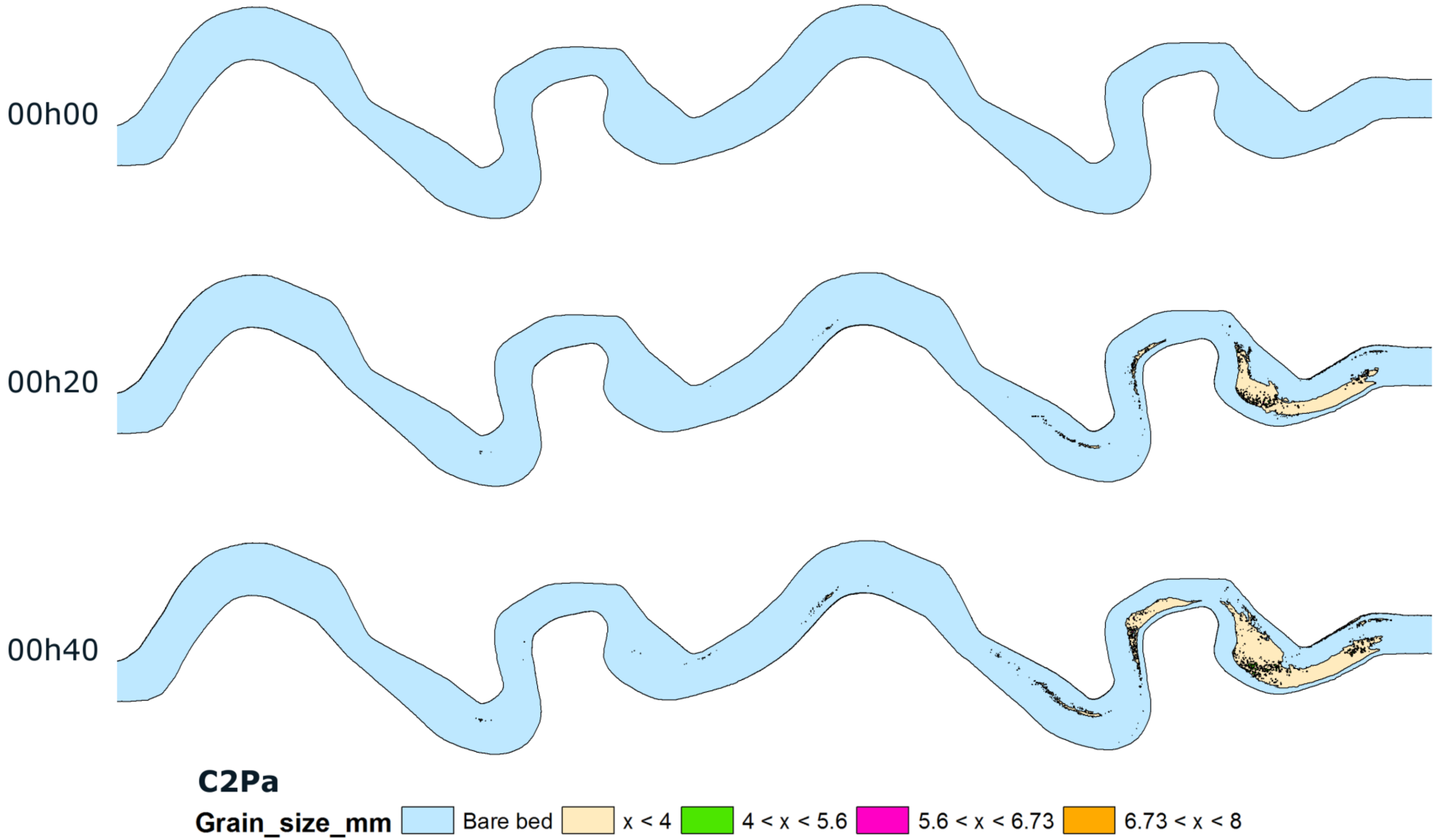


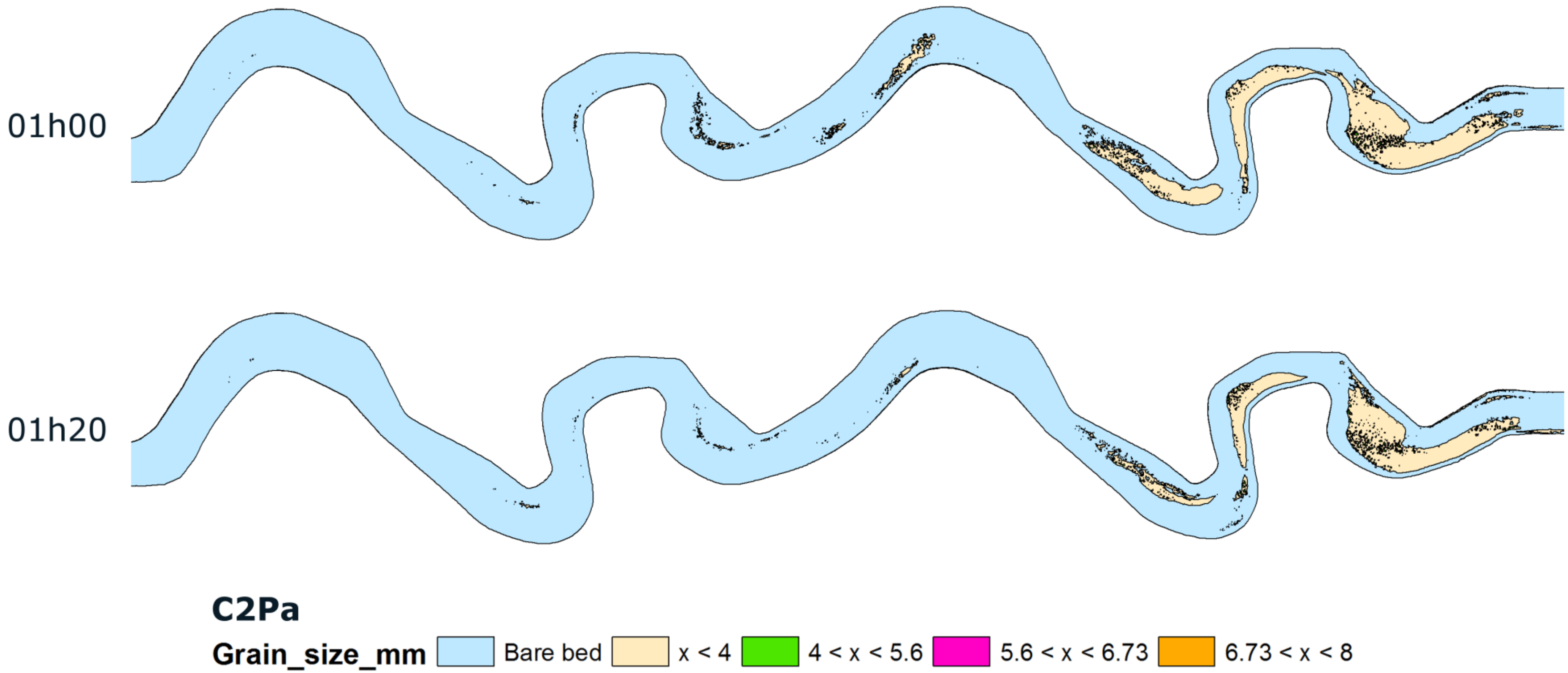

02h00
04h00
06h00
07h00
C4d
Texture
Bare bed
Sediments

Appendix V: Usual and experimental sediment mix granulometric curve

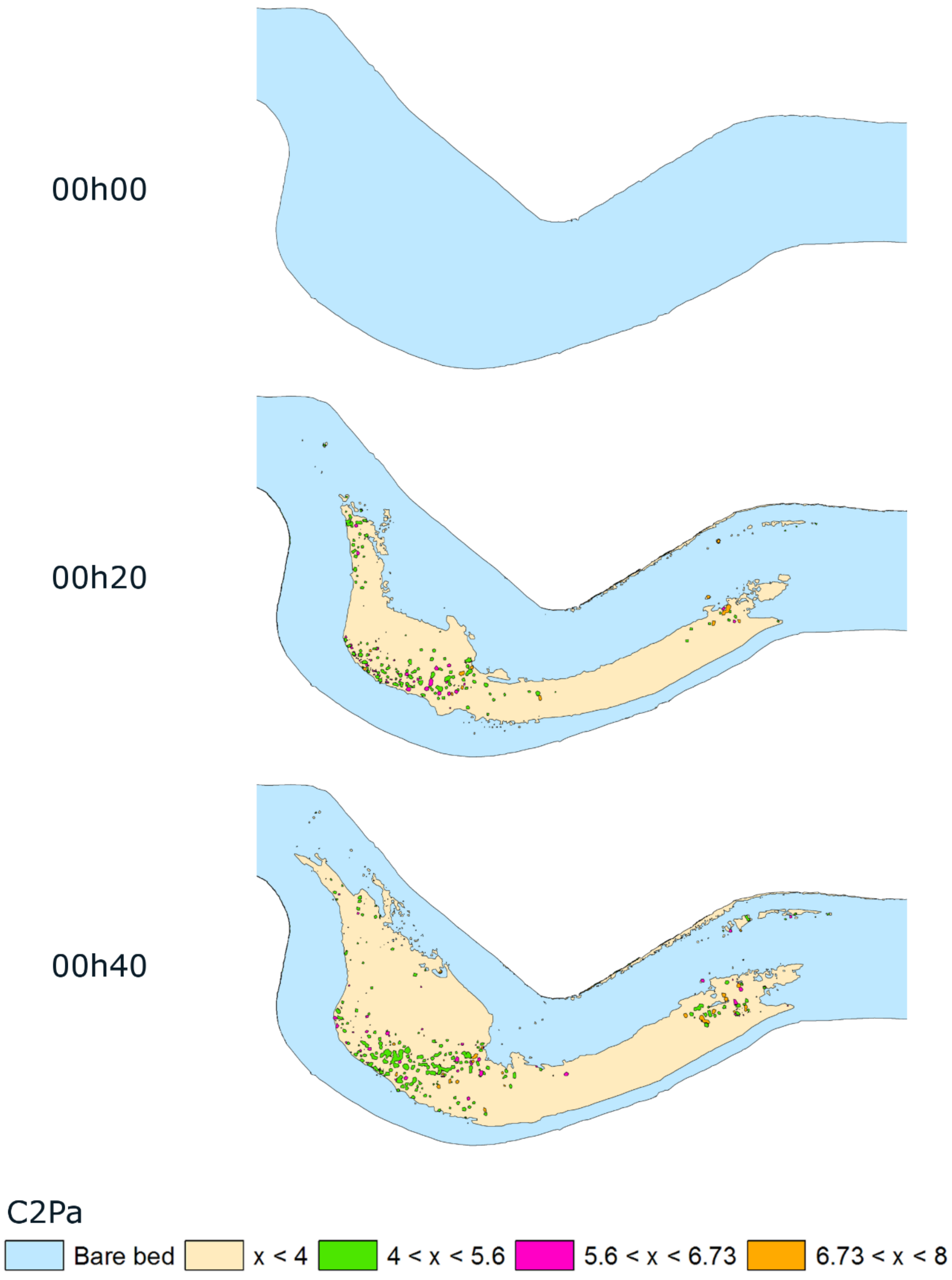


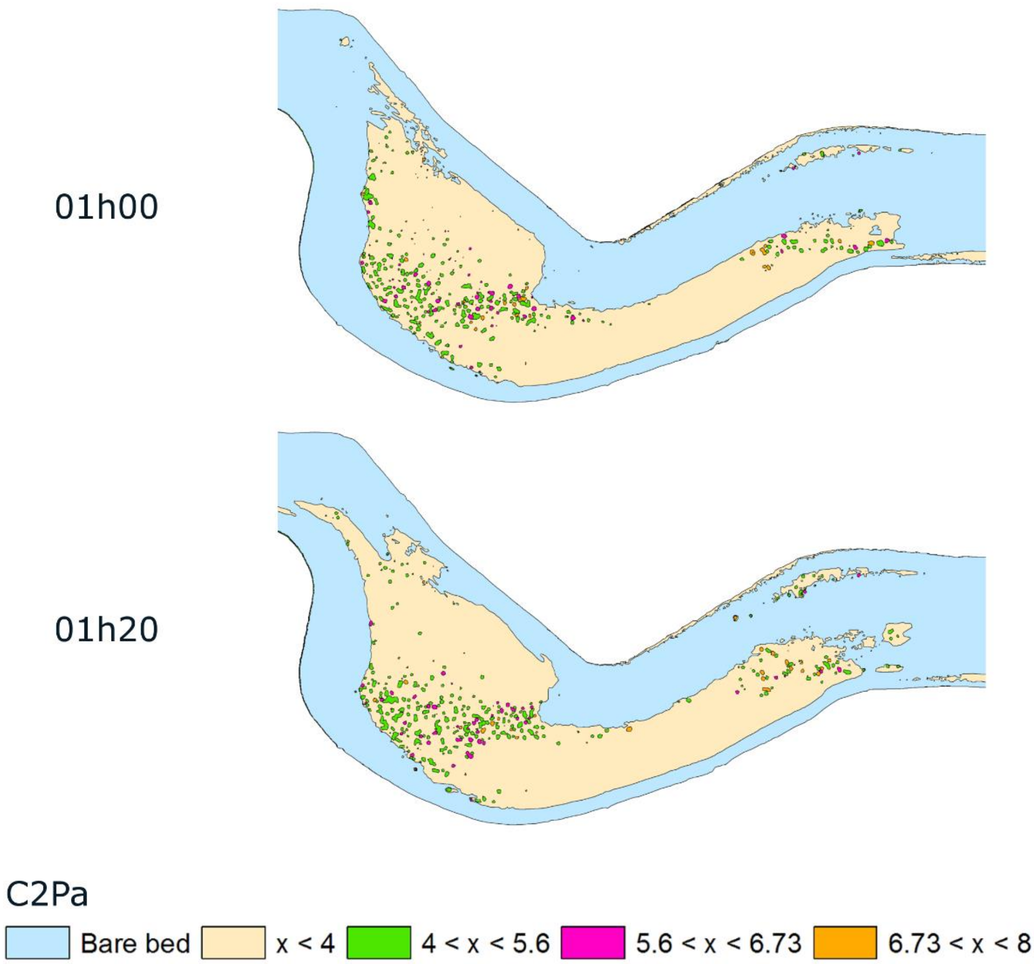
Appendix VI: C2Pa, sediment cover (Image classification from orthophotograph data)



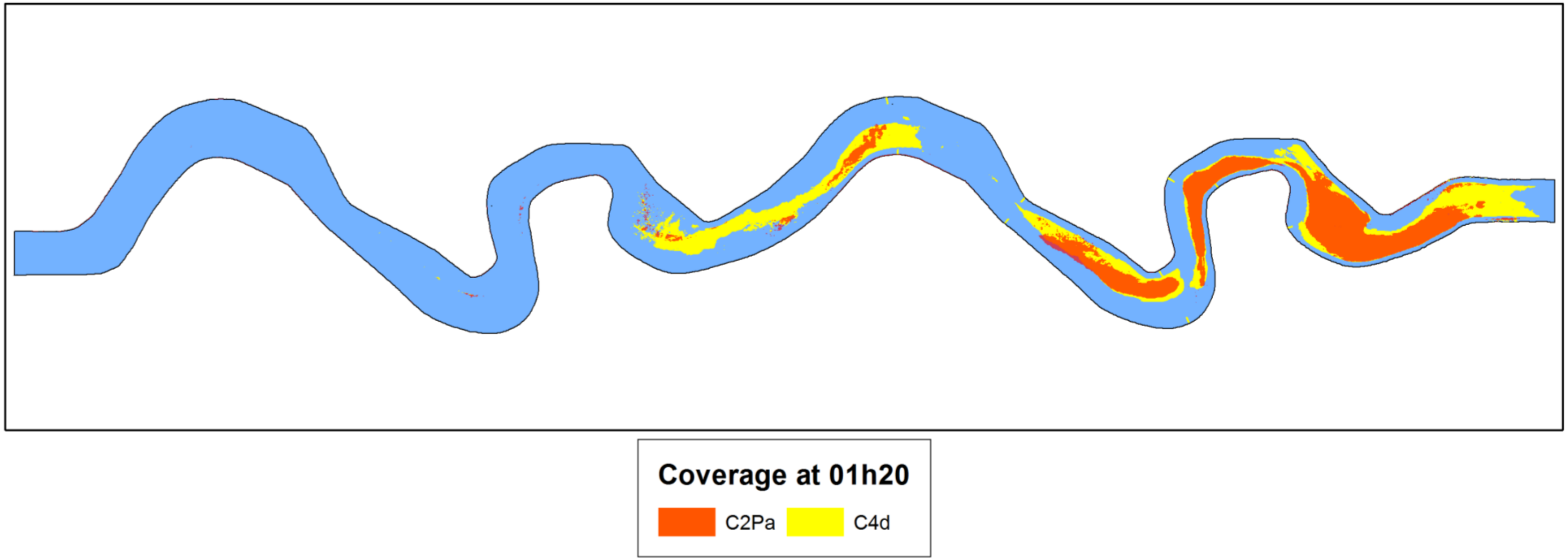

01h00
01h20
C2Pa
Grain_size_mm
Bare bed
x < 4
4 < x < 5.6
5.6 < x < 6.73
6.73 < x < 8

Appendix VII: C2Pa sediment cover (Image classification from orthophotograph data) of the first upstream meander, T+01h20




01h00
01h20
C2Pa
Bare bed
x < 4
4 < x < 5.6
5.6 < x < 6.73
6.73 < x < 8

Appendix VIII: Comparison of the spatial distribution of sediment cover of experiment C4d and C2Pa at T+01h20



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Investigating the impact of feed rate and grain size distribution on physical model of a semi alluvial urban river

Résumé : This report aims to describe the work done on the subject of alluvial cover in semi-alluvial rivers on a physical model by studying the effects of sediment input on the stability of sediment cover in an fixed irregular meandering river reproducing at small scale a reach of a real river (The Wilket Creek).

Mots Clés : Flume, Hydrogeomorphology, Semi-alluvial rivers, Sediment transport

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