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1st year Master's degree internship report

Investigating organic matter retention and hydromorphic complexity in streams. The application of particle release experiments and their ecological significance.

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Abstract

Natural rivers have dynamic geomorphic features creating flow diversity and habitats. Hydromorphic complexity is partly responsible for the Coarse Particulate Organic Matter (CPOM) retention capacity of streams. Therefore quantifying hydraulic complexity and retention capacity of reaches is very important for the understanding of river processes.

This internship report presents the analysis of two experiments that aims to quantify the processes described previously undertaken on the Allan Water Catchment (Scotland).

The first experiment investigates the temporal and spatial parameters of 3 types of release particle released into a river. Experiments were found to have a good repeatability. From these results, the golf balls and the bamboo sticks used, reflect the morphological diversity. The alder leaves, reflect the hydraulic diversity. The hydromorphic complexity is changing in the same way that the complexity of the retention pattern of the particles within the bed, but opposite to the percentage of retention by the banks.

The second experiment released small-squares of paper across a riffle to investigate links between retention of drifting particles and macroinvertebrate community diversity. It turns out that the location of retention areas of particulate matter affect the amount of organic matter and the macroinvertebrates communities. These areas depend on the depth.

Keywords: hydromorphic complexity, hydraulic complexity, retention capacity, particle release experiment, macroinvertrebrate community, riffle experiments.

Résumé

Les rivières naturelles ont une dynamique géomorphologique propre qui crée une diversité des écoulements et des habitats. La complexité hydromorphologique est en partie responsable de la capacité de rétention de grosses particules de matière en suspension dans les cours d’eau. La quantification de la complexité hydraulique et de la capacité de rétention de tronçons de rivières est donc importante dans la compréhension des processus fluviaux.

Ce rapport de stage présente 2 expérimentations menées dans le bassin versant de l’Allan Water (Ecosse) qui visent à quantifier les processus décrit précédemment.

La première consiste à suivre des paramètres temporels et spatiaux de 3 types de particules libérées dans un cours d’eau. Les expériences se sont avérées avoir une bonne répétitivité. D’après ces résultats, les balles de golf et les battons de bambou utilisés reflètent la diversité morphologique. Les feuilles d’aulne reflètent la diversité hydraulique. La complexité hydromorphologique évolue de paire avec la complexité du modèle de rétention des particules au sein du lit, et de manière opposée à celle du pourcentage de rétention par les berges.

La seconde consiste à libérer des petits carrés de papier au sein d’un radier pour expliquer les relations entre la rétention des particules dérivantes et les communautés de macroinvertébrés. Il s'avère que la localisation des zones de rétention de la matière particulaire a des conséquences sur la quantité de matière organique présente et sur les communautés de macroinvertébrés. Ces zones, dépendant de la profondeur.

Mots clés : complexité morphologique, complexité hydraulique, capacité de rétention, expériences de libération de particules, communautés de macroinvertébrés, étude de radiers.

Introduction

Hydromorphic complexity is due to morphological, hydrological and ecological processes. These are assessed in the science of ecohydromorphology (Milner, 2010).

These features are responsible for the retention characteristics of the stream system and the retention of allochthonous organic matter inputs including Coarse Particulate Organic Matter (CPOM) which overlaps leaves, woody debris and aquatic vegetation (James and Henderson, 2005). It is important for stream functioning and for aquatic communities, providing a food source, habitat and act as biodiversity "hotspots" for macroinvertebrate communities (James and Henderson, 2005; Milner, 2010; Muota and Laasonen, 2002).

Therefore, study of hydromorphic complexity is important for management and for implementation of stream restoration projects. Actual indicators of stream features are mainly focused on specific indicators like geometry, velocity, roughness, stream bed, biological indices. Few approaches combined hydraulic and retention traits of physical biotopes at the reach scale. However, Milner (2010), studie the time it takes for particles to pass through a river reach and features providing retention capacity. For this, they conducted golf ball release experiments in different stream types.

The present study has being conducted at the Centre for River Ecosystem Science (CRESS), a research centre of the University of Stirling. It explores the monitoring of several hydromorphological parameters with particle type (practice golf balls, bamboo sticks, alder leaves), reach size, distance and the retaining structure. It was conducted in 2 headwater streams of the Allan Water catchment (Scotland) with differences in hydromorphological complexity.

To complete the retention study, one other experiment has been undertaken in the present study. This first approach was intended to examine the relationships between areas of particle retention, macroinvertebrate community and amount of organic matter in a riffle. It was conducted by releasing small squares of paper followed by sampling the substrate.

This study aims to respond to the following questions:

- Which indices are most appropriate for summarising data from particle release experiments?
- Are particle release experiments sensitive to differences in hydraulic diversity?
- Is there a link between macroinvertebrate community structure, organic matter retention and the variability in retention across a riffle environment?

This report is structured as follows: firstly, the retention process and the study area are briefly described. Then the experimental method and rational choice are discussed. Finally, the results and analysis are presented.

I. Ecohydromorphology and retention process

Reach type and biological communities within river systems are due to biotic and abiotic variables. Some are common to both with hydrology, hydraulic, external geography, vegetation, channel environment. Some others are specific with evolutionary events for morphology and water quality and health/competition for biological communities (Appendix1).

Ecohydromorphology is a science focused on the study of interconnection between geomorphology, hydrology and ecology (Milner, 2010; Figure 1). In rivers geomorphology and hydrology are more or less complex and influence aquatic communities differently; this is the hydromorphic complexity.

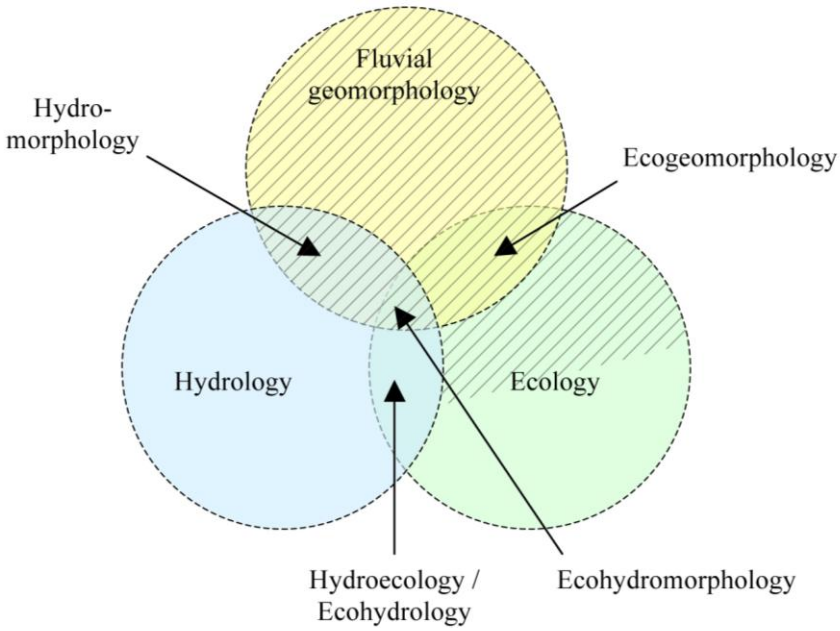

Figure 1: interconnections between different disciplines according to the conceptual Venn diagram (Milner, 2010).

Retention characteristics depend on previous parameters. Autochthonous organic matter inputs are included within stream system and called Coarse Particulate Organic Matter (CPOM). It combined leaves, woody debris (large woody debris, branches, twigs) and aquatic vegetation (James and Henderson, 2005). In all hydromorphological stream types, more or less CPOM enters a reach. They may arrive directly from fallen trees, branches or leaves of the riparian forest or from macrophyte debris or can be transported by the river from upstream.

CPOM retention affects stream functioning (Cummins et al., 1983 *in* James and Henderson, 2005) and is important for aquatic communities. Indeed, CPOM accumulation provides a food source, a habitat (Death, 2000 *in* Milner, 2010, James and Henderson, 2005, Muota and Laasonen, 2002) and may also act as biodiversity "hotspots" for macroinvertebrate communities (Milner, 2010).

CPOM is colonised by aquatic fungi, bacteria and macroinvertebrates (Cummins et al., 1989 *in* James and Henderson, 2005). Physical and chemical characteristics of species are responsible of the relative rate at which leaves are transformed (Iron et al., 1988; Webster and Benfield, 1986 *in* Coleen et al, 2004). Generally, coniferous needles provide a poorer food resource for leaf processing biota than deciduous leaves and have slower processing rates with a slower rate of decomposition (Collen et al, 2004). This rate is also related to stream chemistry and water temperature (Kaushik and Hynes, 1971 *in* Coleen et al, 2004). The implication is, that retention processes will be affected by changes to riparian zone features (density, age, species). The majority quantity of leaves enter streams in autumn. This process is followed by "the more important growth of many detrivorous invertebrates in winter when there are the peak availability of well-conditioned leaf detritus" (the 'shredder response model' of Cummins et al, 1989).

CPOM is transported downstream and can be retained by a trap (and then be integrated to food webs). The distance required to retain particles, the type of trap responsible and the time of a particle pass through a reach are 3 important characteristics of particle retention. The amount of benthic organic matter will depend of the capacity of a stream to retain terrestrial inputs (Cummins et al, 1989 *in* James and Henderson, 2005).

Stream modifications by humans probably influence this important process, by changing hydromorphic complexity. Therefore, it appears that the study of hydromorphic complexity is important for management and stream restoration.

II. Study area

II.1. Location

Preliminary studies were conducted on 3 headwater streams of the region of Argyle, near Loch Awe in order to define the method. These rivers were: The Allt Ghlinne, the Allt Mòr and the Allt Criche. Further works is planned by CRESS at these locations.

Trialling was conducted on 2 headwater streams of the Allan Water catchment (210km^2) near Stirling (Figure 2). This catchment has been chosen because it is a possible location for a large restoration project CRESS is involved with. If results are conclusive and the project completed, this trialling will permit to study the influence of restoration on hydromorphic complexity.

The first reach is located on the Allan Water, 200m at the upstream on the bridge of the A822 near Greenloaning. The second reach is located on the the Muckle Burn, 500m at the west of the bridge of the B8033 near Craighead, between Braco and Dunblane. The following part of this presentation will only cover the main study reaches.

II.2. Physical features

Geology of reaches of Allan Water (60 km^2) and the Muckle Burn (14km^2) and their watershed are present on sandstone, respectively of the Dunblane formation (Armstrong et al, 1974) and the Teith formation (Armstrong et al, 1974), which have a moderate permeability (90%; NERC). The catchment is subject to a maritime temperate climate, mean annual precipitation on the catchment from 1 100 to 2 000mm (1961 to 1990; NERC) and altitude ranging from 100m to 530m (NERC). This catchment can be qualified of a "flashy catchment" because flows can change very quickly (Figure 3).

During the experiments, flows rates were below the annual average flow (7.6m^3/s; SEPA) at the hydrological station of Kinbuck (Table 1) with a flow rate that decreased from 3.3 to 1.3m^3/s.

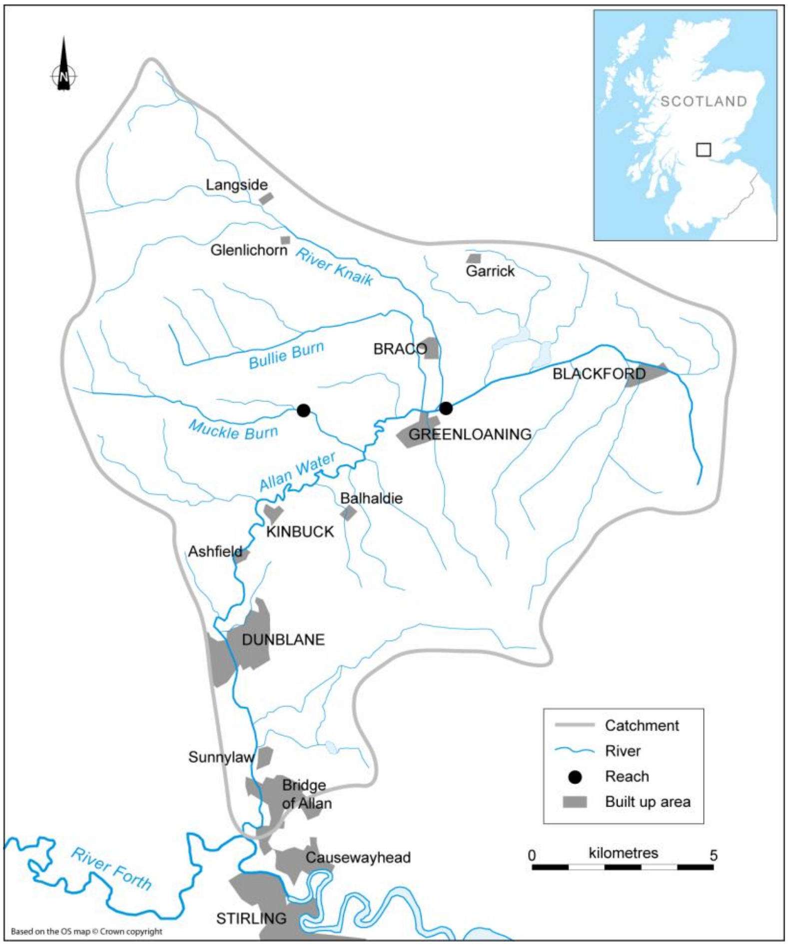

Figure 2 : Map of the Allan Water catchment and of the 2 reaches (Based on the OS map of EDINA)

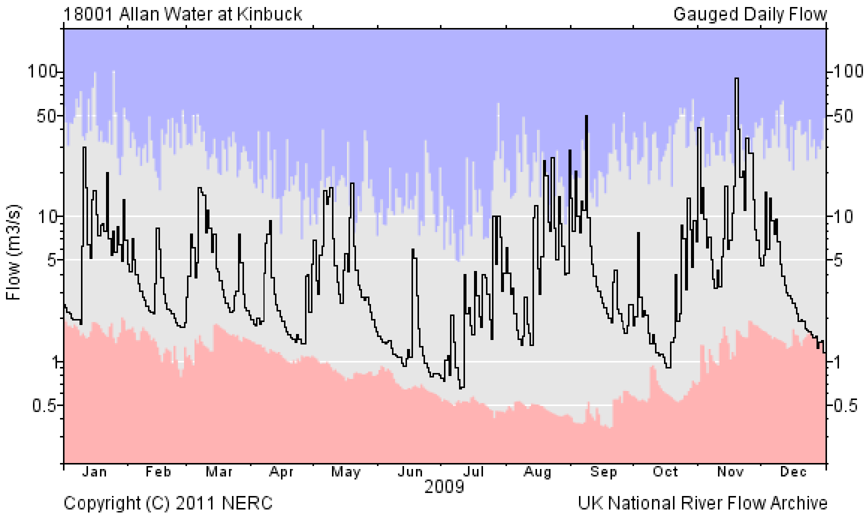

Figure 3: Hydrograph of the Allan Water at Kinbuck in 2009 and flow record between 1957 and 2009 (NERC)

Table 1: Daily flow at Kinbuck from June 28 to July 5, 2011 (Courtesy of SEPA)

Date	Q (m^3/s)	Date	Q (m^3/s)
28/06/2011	3,32	02/07/2011	1,64
29/06/2011	2,41	03/07/2011	1,50
30/06/2011	2,03	04/07/2011	1,37
01/07/2011	1,81	05/07/2011	1,28

II.3. Reach features

The land cover at the upstream end of the first reach is mainly grassland and arable or horticultural land. This lowland straightened reach (Appendix 2) corresponds to a plane-riffle according to SEPA (Scottish Environment Protection Agency) typology (2006, Appendix 3). Bed substrates consists of sand and pebble with sand and silt accumulation in the lea of the aquatic vegetation (*Phalaris, Myriophyllum,* family of *characeae)*. The riparian vegetation is herbaceous.

The second reach is in a V shape valley (mountain stream, high slope), type bedrock or pool riffle (Appendix 2) according to SEPA typology. The substrate is mainly boulder and the bed has some large woody debris. The riparian vegetation is continuous woodland.

III. Objectives and hypotheses

III.1. Trial n°1: particle release experiments at the reach scale

As already presented in the introduction, although hydromorphic complexity is important for stream health, few studies have combined the study of hydraulics and of retention features in rivers. However, Milner (2010) describes this type of experiments, with golf ball release experiments in different stream types. In it, they study the time it takes for particles to pass through a river reach and features with retention capacity.

The protocol implemented and which will be described later, is focused on the study of several important hydromorphic parameters: the hydraulic complexity, the morphological complexity, the retention features and the impact of the discharge.

The hypotheses to be assessed by the experiments are as follow:

- The following metrics (as mentioned in section I) will best summarise the retention characteristics of the reaches:
    - travel time: the travel time and the height of the peak of particles,
    - retention distance: the coefficient of retention,
    - retention structures: the diversity of structure involved.
- It is expected that the experiments have a high repeatability when there is little hydromorphological complexity, but that an increase in the complexity will reduce repeatability.
- Significant differences in the parameters studied are expected to be observed among the types of particles tested, due to their different physical properties. Results from golf balls are expected to be more precise, because these particles are more visible during the experiments.
- The reduction in stream discharge should result in an increase in retention and travel times, due to greater contact with the substrate. This follows the finding of Pretty and Dobson (2004), Riis and Sand-Jensen (2006).

III.2. Trial n°2: particle release experiments at the mesohabitat scale

Particle and plant release experiments have already been carried out to study retention properties in streams or to study hydromorphic complexity as has been developed in the previous section. However, less focus has been placed on the links between locations of traps and macroinvertebrate communities, and therefore also with the quantity of organic matter, and physical conditions. This second experiment will therefore attempt to study the relationships between these parameters in a riffle of the Muckle Burn the July 20, 2011.

The hypotheses made in the study of these relationships are:

- Retention of coarse particulate organic matter occurs by trapping of particles and therefore in areas where the depth and the velocity are more complex than in the other parts of the riffle. These features are mainly at the top of the riffle.
- The trapping of the paper in particule release experiments should correspond to areas where the organic matter is retained.
- Taxonomic richness of places of the riffle (the number of taxa) differs according to the type of habitat and therefore on the physical characteristics, the presence of species depends of meso-habitat characteristics of the environment. The taxa needs a food resource, richness depends on the particles and the organic matter.
- The abundance (number of individuals) is mainly governed by the amount of organic matter for the same reasons.

IV. Methods

IV.1. Trial n°1: particle release experiment in streams reaches

For the implementation of particle release experiments different items were used. The selection of the parameters studied was made following preliminary tests. These and protocols defined are discussed bellow.

IV.1.1. Particles used

As discussed above, several types of elements enter waterways. Different studies have already been made to study particle release including leaves (Pretty and Dobson, 2004), dowels (Millington and Sear, 2007), plastic strips (Muotka and Laasonen, 2002). They had different objectives, but they were not interested in their implementation to study the hydraulic complexity. In the present study 3 types of particle, with different shape, size and density have been use in order to characterize the overall retention of particles in reaches and to bring out hydraulic complexity. Practice golf balls, leaves and bamboo sticks were used. Their features are summarised table 2.

Table 2: Features of the particles release for the first experiment

Particle	Features
Practice golf balls 	Diameter: 4 (±0.2) cm Weight: 4.5 (±0.2) g Density: 0.4
Deciduous leaves 	Species: Common alder (*Alnus glutinosa* (L.) Gaertn.) Size: 7.5 (±1.5); 7 (±2) cm Weight: 0,8 (±0.5) g Density: 0.98
Bamboo sticks 	Length: 15 (±2) cm Diameter: 0.8 (±0.6) cm Weight: 6.6 (±3.6) g Density: 0.8

100 items of each of these 3 main types of particle were use in each experiment.

IV.1.2. Delineation of parameters and preliminary data analysis

Preliminary field work was conducted in 3 reaches of the region of Argyle to define the followed method. These reaches were chosen for their different features, such as their substrate (silt to boulder), width (less than 1m to more than 3m), the bed slope, the banks slope and the presence or absence of moss. Their description appears in appendix 4.

In the preliminary fieldwork, 100 items of each particle have been released across the width of the channel at the upstream end of reaches of 100m. The time it takes for each particle to pass through the reach is recorded until all the particles seem to have gone. Distance of particle traps from the upstream end, and the type of trap were then recorded.

Main results of this work have shown:

- The use of 100 items of each particle appears suitable for fieldwork, this approach is reliable, functional and obtains usable results.
- Trialling carried out with all the particle types at the same time or with a small time interval revealed through field observations, some interactions between particles which affect the determination of hydromorphic complexity. Therefore, for the other experiments release experiments will be made individually.
- Channel width strongly influences the retention of particles. In the reach of Allt Ghlinne (width less than 1m), particles found were retain at less than 40m upstream. Therefore, it appears that when the stream is too small, the approach prevents the demonstration of the hydromorphic features by this experiment. This element has led to develop of the other experiments in bigger reaches. The reaches studied have been selected to have a width similar (about 6m) with a depth sufficient to make flow measurements.
- The preliminary fieldwork has shown that it was not necessary to paint particle to see them. Particles loss was due to the fact that they were not visible, hidden by the traps. However, experiments on the reach of the Allan water catchment, bigger than reaches of Argyle area, have shown the need to paint the bamboo sticks whose colour made them difficult to see, as has been done with other particles, laboratory tests made by Pretty and Dobson (2004) have shown paint particle does not affect the behaviour of particles. Therefore, this change was made.
- In carrying out the experiments, the search for trapped particles turned out to be long and difficult. Despite being meticulous, particles were lost and some are found later in the searches of the following experiments. Due to the use of golf balls, both plastic and more expensive, they have been released in first in order to increase probability of finding them. Furthermore, for more reliable data in case of repeatability of experiments with golf balls, it is clear than the use of golf balls of different colour is useful. It is the same for the colour of bamboo sticks, although this was not done because it requires more time and equipment.
- Characterization of particle traps during the fieldwork (Appendix 5) is made to be too complex (waste of time, subjective) and has been simplified to a more comprehensive characterisation of them.

IV.1.3. Method defined:

Taking into account the observations mentioned above, the following method was implemented during the fieldwork: practice golf balls are release at the same time at the top of the reach across the whole width of the channel. Time taken for each golf ball to pass through 3 reach lengths (80, 120 and 240m) is recorded (Appendix 2) in a time interval of 5s until all the particles seems to have gone at the end of the bigger reach (240m) or have been trapped golf ball were then collected. The distance from the top where particle have been retained and the type of trap (bankside habitat, bed, boulder, eddy, embayment, vegetation, large woody debris) are then recorded. Experiments are subsequently made in the same way with bamboo sticks (paint when it was useful) and alder leaves. Subsequent experiments were as far as possible made with other colour of golf ball.

The implementation of these experiments required 3 to 4 people. They were carried out on the two reaches described in section II.3. on 28th and 30 th June and July 4 th, 2011 on the Allan Water reach and June 30 th and July 4 th, 2011 on the Muckle Burn reach. For reproducibility, experiments were repeated the same day with the same particle at least once per reach. On the Allan water the more important replicates were conducted 3 times with each particle the June, 28 th and the June, 30 th for the Muckle burn with golf balls and bamboo sticks.

Depth and velocity were measured in cross and longitudinal sections twice on each reach to characterize hydraulic complexity and study the influence of discharge. On the cross section, characteristics were measured every 0.5 cm on the Allan Water and 0.3 cm on the Muckle Burn to have about 15-20 measurements. On the longitudinal section, they were measured approximately every 2 m in the middle of the channel along the 240m reach. Velocity of each location was measured at 60% of the depth.

IV.1.4. Data treatment

IV.1.4.1. <u>Physical features</u>

Discharge was calculated with data from the most homogeneous cross sections.

To summarize hydraulic complexity, descriptive variables were calculated for the depth and the velocity (minimum, average, maximum, standard deviation) per day and reach for each section. The means of each of the variables were calculated for each day and for each cross section. The two profile types (longitudinal and lateral) were compared. The sum of squared differences (the summation of the squared differences between consecutives point along the profile) adapted form Bartley and Rutherfurd (2005) will also be calculated for the longitudinal profile. In order to compare these values between different stream types and with a different number of data points, this metric will be multiplied by 100 and divided by the number of measurements and by the average value; the new coefficient will be named "coefficient of squared differences".

IV.1.4.2. <u>Release experiments</u>

Variables for the quantitative assessment of particle release experiments were defined for each experiment.

<u>Study of the distribution of the travel time:</u>

Variables were used to determine the time it takes for each particle to pass through the reach. The purpose of these is to study the repeatability of the experiments, the influences on the particles and the differences between the reach lengths.

The descriptive parameters used are:

- the number of particles reaching the end of each of the three reach lengths,
- the height of the peak, i.e. the maximum number of particles reaching end of the reach within a single time interval of 5s,
- the travel time (transit time) of the first particle, the peak and the last particle,
- the peak to transit time ratio : the ratio of the difference between the height of the peak and the difference in travel time between the last and the first particle,
- graphs of the cumulative number of particles passing through the reach depending on the time were made for each experiment to highlight the changes.

Study of the retention distance:

Variables were used to describe the retention distance of the particle, i.e. the distance between the release point and the place of retention. The level of retention corresponding to the number of particles trapped, the distance of the first particle and the last trapped particle found were presented.

Graphs of the cumulative number of particles retained in relation to the distance traveled were made for each experiment.

To quantify dispersal pattern of the retention distance, shown by the previous graph, the slope of the linear trendline of the rate of retention and the correlation coefficient were calculated with a y axis origin at 100 particles.

Moreover, Riis and Sand-Jensen (2006) have used a retention coefficient (k, m^{-1}) and have showed that the retention of plant fragments is constant per unit length downstream from the point to release. The number (or the percentage) of particles retained (N_x) decline exponentially with downstream distance (x) (Riis and Sand-Jensen, 2006). For a particle release number of N_o (or 100 with the percentage data) this decline can be defined according to:

$$Nx = N_o\, E^{-kx}$$ (Riis and Sand-Jensen, 2006).

Study of the retention structures

The number of particles retained by the retention structures, described in section IV.1.3. was calculated to study the difference of retention between particle types, reaches and days.

IV.2. Trial n°2: particle release experiments at the mesohabitat scale

IV.2.1. Methods

IV.2.1.1. Experimentation

The dispersal properties of square of papers (25mm^2; 80g/m^2) were investigated on a “test” riffle to determine the number of squares needed for this study. 25 000 square of papers were released across the width at the top of a riffle. A Surber sampler (30*30cm, mesh 0,25mm, Appendix 2) was then used to collected 20 samples of substrate (with benthic macroinvertebrates and organic mater) uniformly distributed over 4 transects with 5 points (Figures 4 and 5) for 60s each. These samples were then preserved in 70% industrial Methylated Spirits and stored at 4°C prior to laboratory work. At each sampling point, depth and average velocity (at 60% of the depth) measurement were made.

Figure 4: Picture of the squares of paper release operation

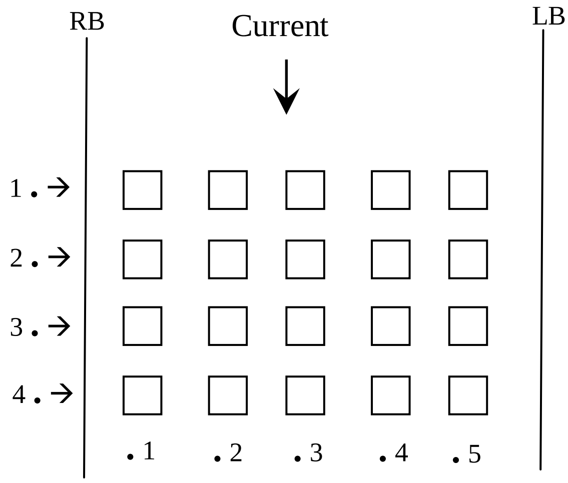

Figure 5: Location schema of sampling point in the riffle

IV.2.1.2. <u>Laboratory work</u>

In the laboratory, the paper squares and any macroinvertebrates were removed from the samples. Loss on ignition was used as an indicator of the energy value of the remaining organic matter. This was calculated by subtracting the ashing weight (500°C) from the dry weight (105°C). Benthic macroinvertebrates were indentified to species level where possible (where features permit and when identification keys were available). However, for 2 families of Diptera (Chironomideae and Simulideae) and the class of arachnide was identified only up to family because their identification is difficult, requiring lot of time relative to the information provided and the 2 Dipteran families are numerous. For the other species, identification were conducted with the following books: Edington and Hildrew (1995), Elliott and Mann (1979), Elliott and Humpesch (2010), Friday (1988), Hynes (1977), Nilsson (1982), Nilsson (1996), Smith (1989), Tachet (2006), Wallace et al. (2003).

IV.2.1.3. <u>Data treatments</u>

The number of paper squares, the richness, the abundance, the amount of organic matter, the depth and the velocity data are summarized in a table and compared in graphs. A linear regression model was fitted to the data to assess the relationship between variables to determine which affect the distribution of another. Some data have been transformed using log base 10 to normalize the data. The level of significance used $p<0.1$.

V. <u>Results</u>

V.1. Trial n°1: particle release experiments at the reach scale

V.1.1. Physical features

The discharges calculated for the 2 reaches during the experiments were:

- $1.41 m^3/s$ the June 28 and $0.94 m^3/s$ the July, 4 on the Allan Water reach,
- $0.12\ m^3/s$ the June 30 and $0.08\ m^3/s$ the July, 5 on the Muckle Burn reach.

These changes are consistent with the data of the hydrologic station of Kinburk which also shows a decrease in the discharge. Therefore, the discharge of June 30 on the Allan Water reach can be considered between the 2 other measures.

V.1.1.1. <u>Bathymetry</u>

Data on depth was collected and averages are presented for the two days of measurement for each reach and profile types (Table 3). The depths are found to be greatest in the middle of the bed with average depths of the cross-sections lower than in the longitudinal section. In addition, it appears that the depths have more irregular changes in the centre of the channel than in the lateral profile (higher standard deviation). The results show that the average depth of the Muckle Burn (0.25m in the centre) is lower than that of Allan Water reach (0.5m in the centre), but the maximum water level is the same for the two study reaches (1m). Although standard deviation indicates slightly greater relative depth variations for the Allan Water reach compare to the Muckle Burn reach in the longitudinal and cross-section (factor of 1.1 and 1.5 respectively), the coefficient of square differences indicate an opposite trend and a greater variation for the longitudinal section (factor of 4.1).

V.1.1.2. <u>Hydraulic</u>

According to the data collected (Table 3), there are a small decreases in the average and the maximum velocity on the 2 profiles types of the Allan Water reachand on the cross sections of the Muckle Burn reach. However, there is a small increase of the maximum velocity of the Muckle Burn in the longitudinal profile. Velocity is higher in the Allan Water reach(average of 0.45m/s in the longitudinal profile) than in the Muckle Burn reach (0.3m/s). The standard deviation decrease slightly between the days and are bigger in the Muckle Burn, mainly for the longitudinal profile. The coefficient of squared differences shows the same thing but in proportions 10 times higher.

Table 3: Bathymetric and hydraulics features of the Allan Water and the Muckle Burn reaches

	River	Allan water		Muckle Burn		Allan water		Muckle Burn	
	Parameter	Depth (m)				Velocity (m^3/s)			
	Date	28/06/2011	04/07/2011	30/06/2011	05/07/2011	28/06/2011	04/07/2011	30/06/2011	05/07/2011
Longitudinal section	Minimum	0,12	0,10	0,04	0,00	0,16	-0,02	-0,10	-0,06
	Average (X)	0,55	0,50	0,22	0,26	0,50	0,38	0,32	0,30
	Maximum	1,03	0,96	0,81	1,10	0,91	0,74	1,06	1,14
	Standard Deviation (SD)	0,16	0,16	0,11	0,17	0,14	0,14	0,28	0,25
	Number of values (N)	106	110	128	141	106	111	129	142
	Sum of squared differences (∑dx2)	0,75	0,99	1,79	7,31	1,45	0,90	16,25	15,06
	Coefficient of squared differences 100*(∑dx2)/N*X	1,28	1,77	6,44	19,81	2,72	2,10	40,16	35,69
Cross section	Number of sections	5,00	4,00	2,00	5,00	5,00	4,00	2,00	5,00
	Minimum	0,142	0,128	0,01	0,026	0,02	0,01	0	-0,01
	Average	0,38	0,33	0,08	0,11	0,42	0,38	0,24	0,14
	Maximum	0,52	0,48	0,24	0,23	0,646	0,573	0,685	0,402
	Standard Deviation (SD)	0,10	0,09	0,06	0,07	0,19	0,16	0,20	0,14
	Number of values (N)	17	19	21,5	16,8	17	19	21,5	16,8
	Channel width	7,14	8,9	6,75	5,04	7,14	8,9	6,75	5,04

V.1.2. Distribution of travel time

During the experiments, more or less particles were retained, reducing the number of particle reaching the end of the reaches. The higher number of particles presented on the results at the upstream of a reach size can be explained by a temporal retention of them or, by stop the counting of particles too early during fieldwork due to technical reasons (not enough people).

V.1.2.1. <u>Allan Water reach</u>

On the Allan Water reach few particles were retained (12% on 240m, Table 4). On this reach, more golf balls reached 80m than sticks and leaves and at 160 and 240m it appears that leaves were the most retained particle (13% at 160m, 22% at 240m).

Repeatability of the experiments

The number of particles travelling the reach is not consistent between repeats of the experiment (around 20 particles over 240m), although 2 of the 3 experiments were very similar (a difference of 5 particles). Regarding the travel time of the first particle and of the peak of particles (Table 4, Appendices 6 and 7) there are no differences between repeats of the experiment (less than 25s difference). Regarding the travel time of the last particle, the differences are greater (maximum of 200s difference at 240m). The number of particles reaching the end of the reach is one parameter that varies a lot (up to a factor of 2). Because of these differences, the height of the peak and the time between the first and the last particle, it is not surprising to find differences in the peak to transit time ratio of this two parameters (up to a factor of 3).

Particles influence

There is only 20s difference in transit time of the first particle and of the height of the peak of particles of the 3 particle types. There are few differences in the number of golf balls and sticks retain (less than 5 particles) and the number at their peak. However, there are more leaves retained (20 particles more) and the height of the peak is therefore smaller reducing (3 to 5). The most important differences concern the time of the last particles which generally increasing with the reach length. These differences are lowest among the golf balls and the sticks that differ in the repeat experiments by 3% at 80m, 30% at 160m and 40% at 240m. Gaps with leaves are greatest with 30% difference at 80m, 75% at 160m and 70% at 240m.

Temporal differences

The experiments of different days do not show differences in the number of particle counted when taking into account the repeatability of experiments presented previously. However, the arrival time at the 3 reach sizes for the first particle, the peak and the last particle with golf balls and leaves increased during the visit days. At the opposite, the height of the peak decrease or do not change during the visit days. The ratio described previously decreases with the visit days for all the experiments. Furthermore, the ratio decreases with increasing reach length. The transit time for successive reach lengths remains constant for most particles with only the last few particles experiencing an increased delay. The differences described above are greatest between the second and the third visits and the peak of particles lowest.

V.1.2.2. <u>Muckle Burn Reach</u>

On the Muckle Burn reach more particles are retained with in average 6.8 particles reaching 80m and 0.4 reaching 240m reach. On this reach, 18% of golf balls and 2% of bamboo sticks travel 80m and 1.3% of golf balls, 160m. All the leaves were retained within the first 80m and bamboo sticks before 160m.

Table 4: Summary of the travel time of particles released on 80, 160 and 240m long reaches of the Allan Water and the Muckle Burn.

River	Allan Water																				
particle	Golf Ball																				
Date	28/06/2011									30/06/2011									04/07/2011		
	1			2			3			1			2			3			1		
Distance (m)	80	160	240	80	160	240	80	160	240	80	160	240	80	160	240	80	160	240	80	160	240
Code	AW/GB/28,06/80/1	AW/GB/28,06/160/1	AW/GB/28,06/240/1	AW/GB/28,06/80/2	AW/GB/28,06/160/2	AW/GB/28,06/240/2	AW/GB/28,06/80/3	AW/GB/28,06/160/3	AW/GB/28,06/240/3	AW/GB/30,06/80/1	AW/GB/30,06/160/1	AW/GB/30,06/240/1	AW/GB/30,06/80/2	AW/GB/30,06/160/2	AW/GB/30,06/240/2	AW/GB/30,06/80/3	AW/GB/30,06/160/3	AW/GB/30,06/240/3	AW/GB/4,7/80	AW/GB/4,7/160	AW/GB/4,7/240
Number of particle count	94	72	88	100	100	98	100	98	98	100	98	82	100	99	95	100	100	98	99	72	82
Time of the 1st particle (s)	115	265	410	115	255	405	120	270	430	130	305	465	135	235	470	120	290	460	140	325	515
Time of the peak (s)	125	290; 310	425	125	285	430	130	285; 295	455; 460	145	340	520; 540	135	330	530	125	315	525	150	340	550
Time of the last particle (s)	155	355	735	155	320	630	165	355	725	205	445	675	245	400	740	170	375	565	245	615	2375
Height of peak	30	12	20	22	14	21	23	15	12	28	12	7	22	18	9	20	16	12	17	6	6
Time between 1st and last particle	40	90	325	40	65	225	45	85	295	75	140	210	110	165	270	50	85	105	105	290	1860
Ratio Height of peak/time between 1st and last particle	0,75	0,13	0,06	0,55	0,22	0,09	0,51	0,18	0,04	0,37	0,09	0,03	0,20	0,11	0,03	0,40	0,19	0,11	0,16	0,02	0,00

River	Allan Water																																				
particle	Bamboo sticks															leaves												
Date	28/06/2011									30/06/2011			04/07/2011			28/06/2011									30/06/2011		
	1			2			3			1			1			1			2			3			1		
Distance (m)	80	160	240	80	160	240	80	160	240	80	160	240	80	160	240	80	160	240	80	160	240	80	160	240	80	160	240
Code	AW/BS/28,06/80/1	AW/BS/28,06/160/1	AW/BS/28,06/240/1	AW/BS/28,06/80/2	AW/BS/28,06/160/2	AW/BS/28,06/240/2	AW/BS/28,06/80/3	AW/BS/28,06/160/3	AW/BS/28,06/240/3	AW/BS/30,06/80/1	AW/BS/30,06/160/1	AW/BS/30,06/240/1	AW/BS/4,7/80/1	AW/BS/4,7/160/1	AW/BS/4,7/240/1	AW/L/28,06/80/1	AW/L/28,06/160/1	AW/L/28,06/240/1	AW/L/28,06/80/2	AW/L/28,06/160/2	AW/L/28,06/240/2	AW/L/28,06/80/3	AW/L/28,06/160/3	AW/L/28,06/240/3	AW/L/4,7/80/1	AW/L/4,7/160/1	AW/L/4,7/240/1
Number of particle count	86	98	80	86	94	93	55	93	100	100	98	92	100	77	89	79	79	65	100	100	88	96	88	90	92	82	70
Time of the 1st particle (s)	110	255	415	115	260	425	120	270	430	130	105	470	130	305	510	115	260	425	105	295	420	120	275	430	140	330	535
Time of the peak (s)	120	275	445	125; 130	300	440	135	295	470; 475	145	325	530	135	335	560; 570; 590	120	275; 285; 295	470	120; 130	325	465	130	310	485	150	365	565
Time of the last particle (s)	160	325	545	165	355	540	140	355	535	205	390	595	250	850	1395	200	435	735	280	520	570	205	440	770	225	1345	1785
Height of peak	33	15	18	17	12	11	18	16	11	21	16	14	14	12	6	15	7	7	18	14	12	20	13	9	18	12	8
Time between 1st and last particle	50	70	130	50	95	115	20	85	105	75	285	125	120	545	885	85	175	310	175	225	150	85	165	340	85	1015	1250
Ratio Height of peak/time between 1st and last particle	0,66	0,21	0,14	0,34	0,13	0,10	0,90	0,19	0,10	0,28	0,06	0,11	0,12	0,02	0,01	0,18	0,04	0,02	0,10	0,06	0,08	0,24	0,08	0,03	0,21	0,01	0,01

River	Muckle Burn																										
particle	Golf Ball												Bamboo sticks												leaves		
Date	30/06/2011									05/07/2011			30/06/2011									05/07/2011			05/07/2011		
	1			2			3			1			1			2			3			1			1		
Distance (m)	80	160	240	80	160	240	80	160	240	80	160	240	80	160	240	80	160	240	80	160	240	80	160	240	80	160	240
Code	AW/GB/30,06/80/1	AW/GB/30,06/160/1	AW/GB/30,06/240/1	AW/GB/30,06/80/2	AW/GB/30,06/160/2	AW/GB/30,06/240/2	AW/GB/30,06/80/3	AW/GB/30,06/160/3	AW/GB/30,06/240/3	AW/GB/5,7/80/1	AW/GB/5,7/160/1	AW/GB/5,7/240/1	AW/BS/30,06/80/1	AW/BS/30,06/160/1	AW/BS/30,06/240/1	AW/BS/30,06/80/2	AW/BS/30,06/160/2	AW/BS/30,06/240/2	AW/BS/30,06/80/3	AW/BS/30,06/160/3	AW/BS/30,06/240/3	AW/BS/5,7/80/1	AW/BS/5,7/160/1	AW/BS/5,7/240/1	AW/L/5,7/80/1	AW/L/5,7/160/1	AW/L/5,7/240/1
Number of particle count	21	1	1	13	2	2	29	2	2	10	0	0	2	0	0	2	0	0	3	0	0	1	0	0	0	0	0
Time of the 1st particle (s)	205	1250	1455	200	520	725	210	545	740	330			215			275			255			525					
Time of the peak (s)	205						240			440																	
Time of the last particle (s)	2260			595	690	985	1500	1700	770	440			235			965			330								
Height of peak	2			1	1	1	3	1	1	2			1			1			1								
Time between 1st and last particle	2055			395	170	260	1290	1155	30	110			20			690			75								
Ratio Height of peak/time between 1st and last particle	0,00						0,00			0,00																	

Label code: Stream name / particle type / date / distance (m) / number of the experiment
AW= Allan Water; MB= Muckle Burn; GB= golf ball; BS= bamboo stick; L= leaves

V.1.3. Retention distance

V.1.3.1. Level of retention

As just presented, few particles were retained on the Allan Water reach and particles were retained in only 3 of 9 experiments (Table 5, Appendix 8). The average retention was 16 particles (11 to 22) and relates to the 3 particle types.

Table 5: Summary of the retention distances of particles released on 240m long reach of the Allan Water and the Muckle Burn reaches.

River	Allan Water																
Particle	Golf Ball							Bamboo sticks					leaves				
Date	28/06/2011			30/06/2011			04/07/2011	28/06/2011			30/06/2011	04/07/2011	28/06/2011			30/06/2011	
Experimentation n°	1	2	3	1	2	3	1	1	2	3	1	1	1	2	3	1	1
Number of particle trap fined	0	0	1	0	0	0	16	1	0	0	0	22	0	0	0	0	11
Distance of the 1st particle (m)			143				30	140				90					90
Distance of the last particle (m)							230					230					190

River	Muckle Burn									
Particle	Golf Ball				Bamboo sticks				leaves
Date	30/06/2011			05/07/2011	30/06/2011			05/07/2011	05/07/2011
Experimentation n°	1	2	3	1	1	2	3	1	1
Number of particle trap fined	54	88	68	96	97	97	89	100	80
Distance of the 1st particle (m)	1	3	1	1	1	0,5	0,2	1,9	1,4
Distance of the last particle (m)	215	215	240	155	118	138	94	130	60,2

Retention capacity on the Muckle Burn reach was higher, with 82 particles retained on average (41 to 100). It shows that the retention was relatively high with, on average, a distance for the last particle found of 152m (60 to 240) and only 78 particles counted out of a total of 900 at 80m (less than 10%) and 5 particles at 160 and 240m.

V.1.3.2. Retention distance

On the Allan Water reach, the overall trend of retention distance was more or less linear with a correlation coefficient of 0.91 (Table 5, Appendix 8). All the particle types followed approximately the same pattern of retention (Figure 6) with a retention coefficient of 0.008 although the correlation coefficient of the exponential trendline (0.67) is lower than for the linear trendline.

On the Muckle Burn reach, the retention distance has an exponential decrease with an average correlation coefficient of 0.93 (Table 6). However, there are some differences between the particle types. Golf balls are retained less than the other particles with a retention coefficient (0.02) smaller than that of the bamboo sticks (0.05) and the both are smaller than that of the leaves (0.08).

Furthermore, the retention data of the golf balls and the bamboo sticks are more dispersed than the leaves with retention curve diverse. It also appears that the retention coefficients of the golf balls and of the bamboo sticks are higher the July 5, 2011 that the June 20, 2011 (golf balls 0.018 then 0.025, bamboo sticks 0.049 then 0.031).

The retention coefficients observed for particles on the Allan Water reachare smaller than those observed on the Muckle Burn reach.

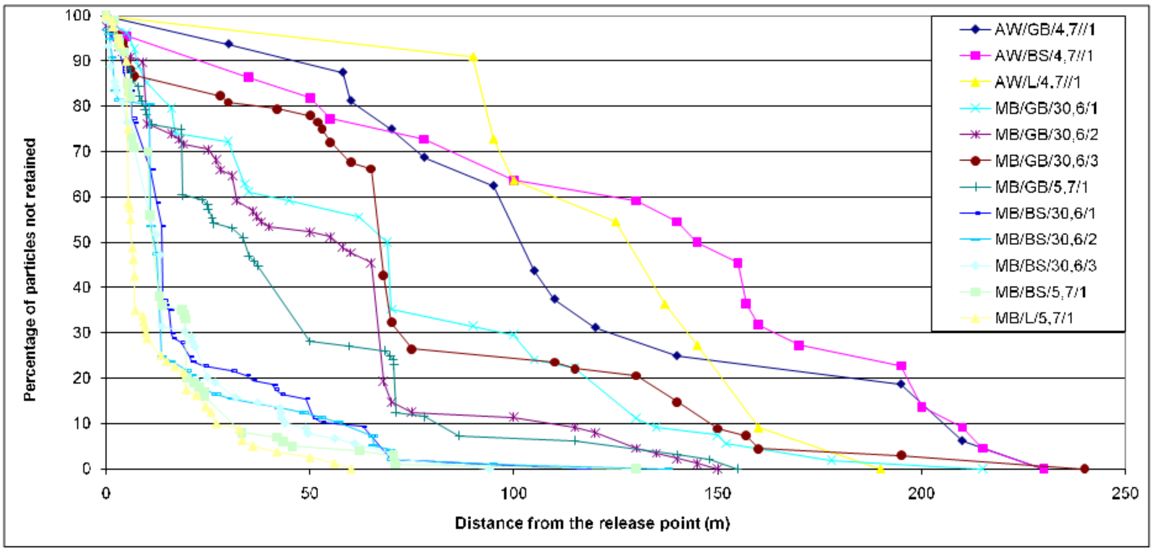

Figure 6: Distribution graph of the spatial retention on 240m of 3 particle types release on the Muckle Burn and the Allan Water reaches under different experiments made the June 30, 2011, 4 and 5 July 2011

Label code: Stream name / particle type / date / distance (m) / number of the experiment
AW= Allan Water; MB= Muckle Burn; GB= golf ball; BS= bamboo stick; L= leaves

Table 6: Feature of the retentive distance of particle during the release experiments on 240m reach of the Allan Water and the Muckle Burn

Trendline / Code	Linear trendline		Exponential trendline	
	Slope	Correlation coefficient (R2)	Retention coefficient	Correlation coefficient (R2)
AW/GB/4,7//1	-0,4538	0,969	0,009	0,807
AW/BS/4,7//1	-0,405	0,9626	0,008	0,6933
AW/L/4,7//1	-0,4543	0,791	0,008	0,5107
MB/GB/30,6/1	-0,6696	0,9197	0,017	0,913
MB/GB/30,6/2	-0,8332	0,8205	0,023	0,9016
MB/GB/30,6/3	-0,6079	0,9099	0,015	0,8883
MB/GB/5,7/1	-0,9687	0,7127	0,025	0,9721
MB/BS/30,6/1	-1,9271	0,5261	0,046	0,9032
MB/BS/30,6/2	-1,6056	0,3472	0,049	0,9125
MB/BS/30,6/3	-1,9348	0,5749	0,051	0,9767
MB/BS/5,7/1	-2,0448	0,5109	0,061	0,9494
MB/L/5,7/1	-2,8837	0,1383	0,082	0,9545

V.1.4. Retentive structures

On the Allan Water reach 4 types of structure have retained particles (Table 7, Appendix 9), but the bankside habitats were the most important trap retaining 73% of particles. 16% and 11% retention were recorded for the embayment and the in-channel structure type, respectively. No major differences in the level of retention, between particle types are evident in the date except that bankside habitat have retained a more important proportion of the bamboo sticks and, that leaves was the alone particle retain by the bed. Real differences may have been obscured by the low number of observations collected.

On the Muckle Burn reach, 7 structure types have retained particles, but more than 99% of them have been retained by 5 trap types and 70% by 3 types: the bed (30%), the boulder (20%), the large woody debris (20%), the eddy (10%) and the embayment (10%). Bankside habitats and in-channel vegetation have retained few particles. Traps have retained different proportions of the 3 particle types, 94% of golf balls have been retained by 3 traps (bed, boulder and large woody debris), 88% of leaves by 2 traps (bed, boulder) and about 20% of bamboo sticks have been retain by each of the 5 trap types. The proportion of particles retained by each of the trap type is not consistent between repeats of the experiment, but their values broadly respect the proportions described previously.

River	Allan Water			Muckle Burn		
Particle	Golf ball	Bamboo sticks	Leaves	Golf ball	Bamboo sticks	Leaves
Bankside habitat	62	86	40		0,5	
Bed			20	39,1	22,3	56,3
Boulder (and mossy boulder)				27,2	16,6	32,5
Eddy				0,6	21	
Embayment	25	9	20	5	20,3	2,4
In-channel vegetation	13	5	20	0,3		
Large Woody debris				27,8	19,3	8,8

Table 7: Average percentage of golf ball, bamboo sticks and leaves trapped by the different structures types during the particle release experiments made on the Allan Water and the Muckle Burn reaches.

V.2. Trial n°2: particle release experiments at the mesohabitat scale

V.2.1. Presentation of data

The average depth of the riffle at the sampling point (Table 8) is about 0.1m with minimum and maximum values varying by a factor of 5 (0.04 to 0.2m). The average velocity is 0.39m/s and has much larger variations than the depth with minimum and maximum values varying by a factor of 30 (0.03 and 0.88m/s).

The ecological parameters measured also have significant variability. Among the 42 taxa present (Table 8, Appendix 10), there are on average, 13 taxa per plot with a maximum of 20 taxa. The average abundance of samples is about 100 individuals with a wide variation in this number from 4 to 377 individuals, but this difference is accentuated by the two stations that have more than 200 individuals.

The amount of organic matter present is about 0.2g (dry weight) per sampling area and varies widely with a range of values from 0 to 1.6g. However, the station with the highest quantity of organic matter could be considered an extreme value, the second largest amount being four times lower than it (0.55g).

On average 10 paper squares were retained at sampling points (0 to 54 paper squares) but the majority of the sampling points have retained less than 10. Indeed, half the total number of paper squares recovered was from just 2 sample plots and 70% recovered from 4 plots.

Number of the sample	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5
Depth (m)	0,16	0,14	0,09	0,17	0,07	0,12	0,14	0,18	0,8	0,4	0,15	0,07	0,16	0,09	0,2	0,1	0,12	0,05	0,1	0,09
Velocity (m/s)	0,61	0,15	0,29	0,09	0,17	0,88	0,21	0,48	0,37	0,03	0,42	0,43	0,68	0,21	0,75	0,27	0,72	0,36	0,22	0,38
Number of taxas	19	16	4	19	18	4	16	9	14	7	17	3	13	11	20	11	13	13	19	18
Number of individuals	92	79	12	156	105	71	97	23	32	29	290	4	172	46	377	89	24	32	170	103
Number of papers	54	5	2	7	0	4	1	1	1	1	52	1	12	1	26	18	12	2	4	3
Quantity of organic matter (g)	0,428	0,223	0	0,159	0,305	0,015	0,015	0,059	0,057	0,249	1,632	0,185	0,139	0,066	0,066	0,267	0,009	0,03	0,011	0,554

Table 8: Summary of the variables measured for each sample point during the experiments of release of squares of paper

V.2.2. *Correlation of the parameters*

The results obtained allow the confirmation of assumptions made earlier (section III.2.) at the level of significance of $p<0.1$ (Table 9). They seem to indicate that the areas of retention of particles affect directly or indirectly the amount of organic matter ($p=0.13$, $R^2=8.3$), the abundance ($p=0.004$, $R^2=40.6$) and the richness ($p=0.033$, $R^2=25.5$) of macroinvertebrates. They also show that the depth is the main factor responsible of the retention of particulates ($p=0.013$, $R^2=31.2$) and influences the abundance of the macroinvertebrates. A summary of the clearest relationships is presented in figure 7. The velocity also influences the taxonomic abundance and the amount of organic matter.

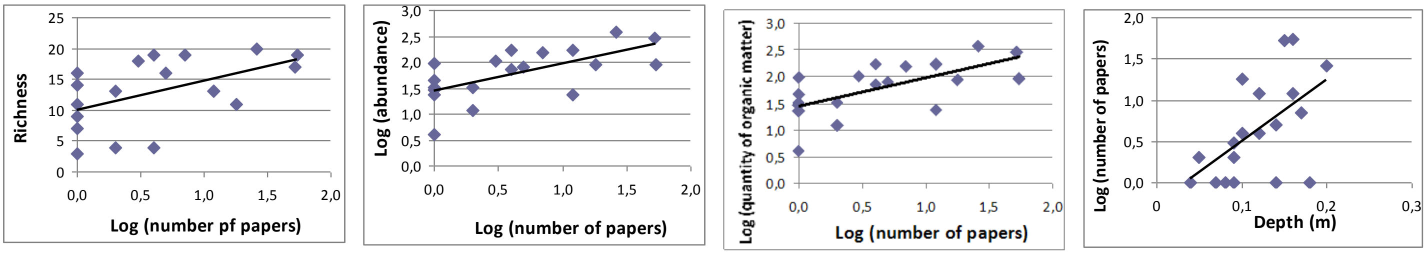

Figure 7: Correlation between key variables of the second experiment (richness, log (abundance), log (quantity of organic matter) as a function of the log (number of paper); log (number of paper) as a function of depth)

Parameter	Predictors		
Number of taxas	log (number of paper)	P-value	0,033
		R^2 (%)	25,51
	log (number of paper) velocity	P-value	0,008 0,083
		R^2 (%)	31,35
	log (number of paper) velocity depth	P-value	0,021
		F	4,36
		R^2 (%)	38,13
Log (abundance)	log (number of paper)	P-value	0,004
		F	11,75
		R^2 (%)	40,65
Log (number of papers)	depth	P-value	0,013
		F	7,73
		R^2 (%)	31,25
Log (quantity of organic matter)	log (number of paper)	P-value	0,13
		R^2 (%)	8,32
	log (number of paper) velocity	P-value	0,062
		F	3,36
		R^2 (%)	21,73

Table 9: Summary results for the regression of the parameters studied.

VI. <u>Discussion</u>

VI.1. Trial n°1: particle release experiments at the reach scale

VI.1.1. *Hydromorphic complexity in the context of retention*

VI.1.1.1. <u>Bathymetry</u>

Relatively homogeneous bathymetry data in the repeat experiments shows the relative reliability of the results. Bathymetric diversity proves to be more pronounced in the longitudinal profile that the lateral profile for the reaches, exhibiting a greater standard deviation. The discharge reduction is accompanied by an increase in variations of the bathymetric profile and therefore of the hydromorphic complexity. The difference is more evident using the coefficient of squared difference than using the standard deviation, for both reaches. This coefficient also shows that the Muckle Burn reach has a greater hydromorphic complexity than the Allan Water reach with a more diverse bathymetry, confirming field observations. This difference was not highlighted by the standard deviation.

VI.1.1.2. Hydraulic

The reduction of the discharge between site visits is in a general way demonstrated by the changes in average and maximum velocity. The Muckle Burn reach has a greater hydraulic complexity than the Allan Water reach with an average coefficient of squared differences 15 times higher (28/2.4).

If a high value of this coefficient (or the standard deviation) is taken to indicate higher hydraulic complexity, the results suggest that the discharge reduction is accompanied by a decrease of the hydraulic complexity. However, this result is contrary to results obtained by other studies (Riis and Sand-jensen, 2006).

These surprising results therefore lead us to caution the use of standard deviation and of the coefficient of squared differences. It must be assumed that differences are only when the variations between two values differ at least by a factor of 2 or possibly higher.

VI.1.2. Repeatability of the experiments and evaluation of the results and method

VI.1.2.1. Evaluation of the results and method

Some experiments were repeated several times under the same conditions (same day, same particle). Differences between the repeat runs of the experiment may show the fragility of the experiment or be interpreted as an indicator of the complexity of the reach. The parameters collected (time, distance, trap) do not necessarily reveal the same information. Indeed, it is such that all particles retained are not found during the search. It also appears that determining the number of particles retained can be done accurately from the results of the transit times for the particles. However, this monitoring requires more people than the monitoring of the retention features, when it is conducted at different distances. Inaccuracies in the counting of particles (like observed in some experiments, bamboo sticks the June, 28 for instance) were due to the shortage of fieldworkers. A solution would have been to use more people or reduce the number of reach lengths studied.

During the experiments, the variability in the number of particles retained also affects the accuracy of the results. Indeed, the data collected when more particles are retained, allows more information to be extracted on the retention distances and the retention structures. However, the information about the travel time will be less detailed and more difficult to use. The reverse is also true. Therefore, it happens sometimes that there is no useable information for only one of the parameters. This is particularly the case for the retention features on the Allan Water reach and the travel time on the Muckle Burn reach.

The accuracy of the results is also affected by the use of the same particle types during successive experiments or when conducted for several days on the same reach. Indeed, when all the particles are not found, they are sometimes, found later, and it is not possible to determine the which release they originate from. This is, for example, demonstrated by the results carried out with the bamboo sticks on July 4, where the number of sticks found (22 particles) was higher than the theoretical maximum number to find (11) according to the number of sticks counted at the end of the reach (89). This discovery highlights the value of the suggestion made that sticks are painted of different colours or that different colours of golf balls are used.

VI.1.2.2. Repeatability of the experiments

Distribution of the travel time:

In the case of the experiments conducted on the Allan Water reach, there is a good repeatatibility of the measurements of the travel time of the first particle and of the peak of particles.

This repeatability can be due to the low hydraulic complexity shown by the results of the velocity (section V.1.1.2) and thus confirming the hypotheses. However, there are some differences in the repeatability of the travel time of the last particle and of the height of the peak of particle which can show the presence of one hydraulic complexity in this reach.

On the Muckle Burn reach, where few data are present, it appears with the golf balls at 80m that they are a repeatability of travel time of the first particle but not of the other parameters.

Therefore, we can suggest that the evaluation of the repeatability of the travel time concern the study of the travel time of the first particle. The other parameters reflect the complexity.

Retention features:

On the Allan Water reach only the number of particles retained can be compared to study the repeatability of the retention process. According to the data of the travel time, it appears that there are some differences of this number (up to 20 at 240m) which can show a diversity of the morphology.

On Muckle Burn reach, more data are available because of the higher level of retention. The retention coefficient demonstrates the good reproducibility of the data when the reach presents a high hydromorphic complexity. The percentage of particles retained per trap type is not consistent and reflect the hydromorphologic complexity.

Regarding to the results it is difficult to conclude with certainly in the repeatability of the experiments. Indeed, although the results seem to indicate that some parameters reflect this repeatability; results of each variables studied during repeat experiments are only available for one reach type. It is possible that the good repeatability of some results correspond to a specific type of hydromorphic feature. Therefore, it is suggested that the experiments are continued on other stream types.

VI.1.2.3. Particle influence

Distribution of the travel time:

In the Allan Water reach, the travel times of the first particle and of the peak of particles are consistent between particles type and can therefore be considered like characteristics of a reach under the same hydraulic condition. The number of particle reaching the end of a reach is one characteristic of difference between particle types. This number is similar for the golf balls and bamboo sticks demonstrated a similar behaviour of this 2 particles, which differt for the leaves.

Data for the travel time of the first particle on the Muckle Burn reach seems also show that the golf balls and the bamboo sticks have similar behaviour. However, the lowest retention property of golf balls is evident aver longer reach. Indeed the leaves are more retained that the bamboo sticks which are more retain that the golf balls.

Retention features:

The retention coefficient and the decrease slope of the 3 particle types are most similar on Allan Water reach. It can show a low hydromorphic complexity. There are broadly the same differences of the percentage of the retention structure according to the particle types. However it would seem that the leaves are less retained by the banks and can be trapped by the bed contrary to the other particle. Furthermore, it would seem that the bamboo sticks is the particle the most retain, in proportion, by the banks.

The retention coefficients of the particle types are most similar in the Muckle Burn reach, but it appears that the coefficient of the leaves is slightly higher of the sticks and slightly higher of the golf balls. It confirms the observations made at 240m in the Allan Water reach showing that the leaves have a greater retention than the sticks and than the golf balls. Furthermore, the spatial retention of the golf balls and the bamboo sticks is more irregular that the leaves, showing the hydromorphic complexity. Particles are retain by the same trap type but in different proportions. The bamboo sticks are retaining in the same proportion by the trap type. The leaves are mainly retained by the bed and the boulder although the leaves are more retained by the bed probably because of their size and their flexibility. It appears that the golf ball are the more retained by the large woody debris. However, it is likely more leaves and bamboo sticks have been trap by the large woody debris and have not been found because of their shape and the difficulty to catch them.

VI.1.2.4. Discharge influence

According to the velocity and depth measurements and the discharge records provided by SEPA, the discharge decreased with the visit days. The comparison of the values of the variables between the days can therefore permit to study the influence of the discharge decrease.

Distribution of the travel time:

In the Allan Water reach, the travel time of the particles have increased with the decrease of the discharge, showing a higher hydraulic complexity. This decrease was accompanied by a decrease of the height of the peak showing also the higher hydraulic complexity. These two changes are responsible for the decrease in the peak to transit time ratio of the particles.

On the Muckle Burn reach, the travel time of the first particle has also increased with the decrease in the discharge therefore also showing that the decrease in the discharge is responsible of a higher hydraulic complexity.

Retention features:

In the Allan Water reach, it seems that the retention of particles increases with the flow, but, because of the variability of the experiences, this influence can not be demonstrated.

On the Muckle Burn, this influence is slightly more pronounced with fewer particles of golf balls and bamboo sticks counted at 80m. However, the retention coefficient allows to show that the retention of the particles increases with the decrease in the discharge. There is no influence of discharge on the proportion of retention by the each structure, shown in the results.

The analysis of the distribution of the travel time and the retention distance confirm the hypothesis that retention increases with a decrease in the discharge.

VI.1.2.5. Hydromorphic complexity

The retention curves of golf balls and bamboo sticks have several inflections on the Muckle Burn data which highlight the importance for retention, of the bed. Therefore, they can allow the local hydromorphology of the reach to be characterized and therefore the hydromorphic complexity. The retention curve of the leaves is more regular and can therefore be associated to the general hydraulic complexity of the reach. These inflections are also present on the retention curve of the Allan Water reach but in a smaller quantity. In this reach, they can be associated with the morphologic diversity of the banks, the location of the most retention.

The retention coefficient of this curve of the Muckle Burn reach is always greater by a factor of 20, than the Allan Water reach showing that the Muckle Burn reach has a higher hydromorphic complexity. Furthermore, the retention data confirm that the Muckle Burn reach retains more particles that the Allan Water reach. This higher retention can be associated to a higher hydromorphologic complexity of its bed.

The structure type can also show the hydromorphic complexity. Indeed, on the Allan Water reach, particles have been mainly retained by the bankside habitat contrary to the more complex Muckle Burn reach, where particles have been retained more by in-channel structures with the bed and the boulders for the leaves and the bed, the boulder and the large woody debris for the golf balls. The diversity of the retention structures and of the increase of the in-channel structures can therefore be associated to the hydraulic complexity. These differences confirmed and provide detail about the hypothesis mentioned in the previous section (Section III.1), that the presence of obstacles, a high travel time and the diversity of flows increase contact time between the particle and the bed structures and therefore the cumulative roughness. This explains why the retention increases with a decrease of the flow. Moreover, this results show the importance of large woody debris on retention processes and in the hydromorphic complexity that, despite their low percentage of recovery are responsible for an important part of retention.

The results show that a higher hydomorphic complexity results in an increase of the level of retention of the coarse particulate organic matter (CPOM). Therefore, it permits to increase the exchanges of nutrients with the riparian vegetation. This reduction in the rate of downstream migration is integrated to the nutrient spiralling concept. Furthermore, the increase of the CPOM retention must be favourable for the detritivorous invertebrates according to the shredder response model exposed section I (Cummins et al, 1989).

VI.1.2.6. Reach length

The increase in reach length leads to a decrease in the height of the peak of particles and an increase of the difference in travel time between the first and the last particle. Longer reach lengths therefore, highlight differences in hydromorphic complexity more clearly between 2 similar reaches. However, as demonstrated by the Muckle Burn reach retention data, reaches with high hydromorphic complexity and high retention have lost a lot of information about the travel time, when studied over longer reach lenghts. In this case, the golf balls can be considered the better particle to use for the study of the travel time.

VI.2. Trial n°2: particle release experiments at the mesohabitat scale

VI.2.1. Physicals parameters:

The high variance of physical parameters measured allows the relationship between several factors to be studied. The results show the influence of the depth and the velocity on the ecological processes that have been investigated. The increase of the depth promotes the retention of particles. The velocity influences the quantity of organic matter retained probably by promoting its transport. It also influences the taxonomic richness; taxa have ecological requirements related to their physical abilities. Because of the importance of depth it is possible that changes in stream discharge will also affect the ecological parameters studied. To investigate this further the experiment should be repeated under different discharges.

It is likely that additional physical parameters will also be influence the ecological processes because natural processes are governed by an interaction of factors. These parameters are for instance the roughness of the bed and the granulometric diversity. Moreover due to changes in the parameters studied within the sample plots, it is recommended that smaller surfaces areas are sampled in order to more precisely characterize the habitat.

VI.2.2. Correlation between retention and macroinvertebrate community

The protocol used correlates the areas of particle retention to the following three ecological parameters, the quantity of organic matter retained, the richness and the taxonomic abundance of macroinvertebrates. This result confirms the hypothesis that the retention of particulates affects the amount of organic matter and the macroinvertebrate communities. Because the relationships discussed are weakly significant, it is planned to repeat the experiment later by researchers at CRESS in order to obtain more significant results.

Furthermore, the results show the importance of the retention processes for macroinvertebrate communities. Therefore, the restoration of these natural processes, including replanting riparian vegetation in a degraded ecosystem will potentially contribute to improved biological condition.

Conclusion

The release experiments conducted on 2 reaches of streams have satisfactory results. Indeed some parameters of the first experiment studied, show good repeatability and permit the hydromorphological complexity of reaches to be characterized. Measuring the average of the travel time of the first particle, of the peak of particles, the retention coefficient and the retention structures provide this information. It turns out, for instance, that the monitoring of the retention distance of the golf balls and the bamboo sticks used reflect the morphological diversity. The alder leaves, reflect the hydraulic diversity.

It appears that the diversity of the retention structures and the bed morphology are important for the hydromorphological complexity and that the large woody debris, although present in a small area of the wet bed, are some key retention structures.

These parameters depend of the discharge, which when reduced is accompanied by the increase of the retention. According to the experiment conducted in a riffle, the impact of the discharge is mainly due to changing in water level. This, in a broader context highlights the importance of the channel morphology for natural processes and the value of these experiments in monitoring of restoration works.

This experiment can demonstrate that the retention of coarse particulate organic matter has consequences for the macroinvertebrates communities and for the quantity of organic matter, indicating, the importance of the retention process for the aquatic ecosystems.

These conclusions show the value of the leaf release experiments. Indeed, they permit the study of both ecological and the hydromorphological processes. However, the results obtained punctual can not yet be generalised, because they have been conducted an insufficient number of times under not enough different discharges and on not enough reach types and need to be further researched. It is possible that these conclusions do not apply to all stream types.

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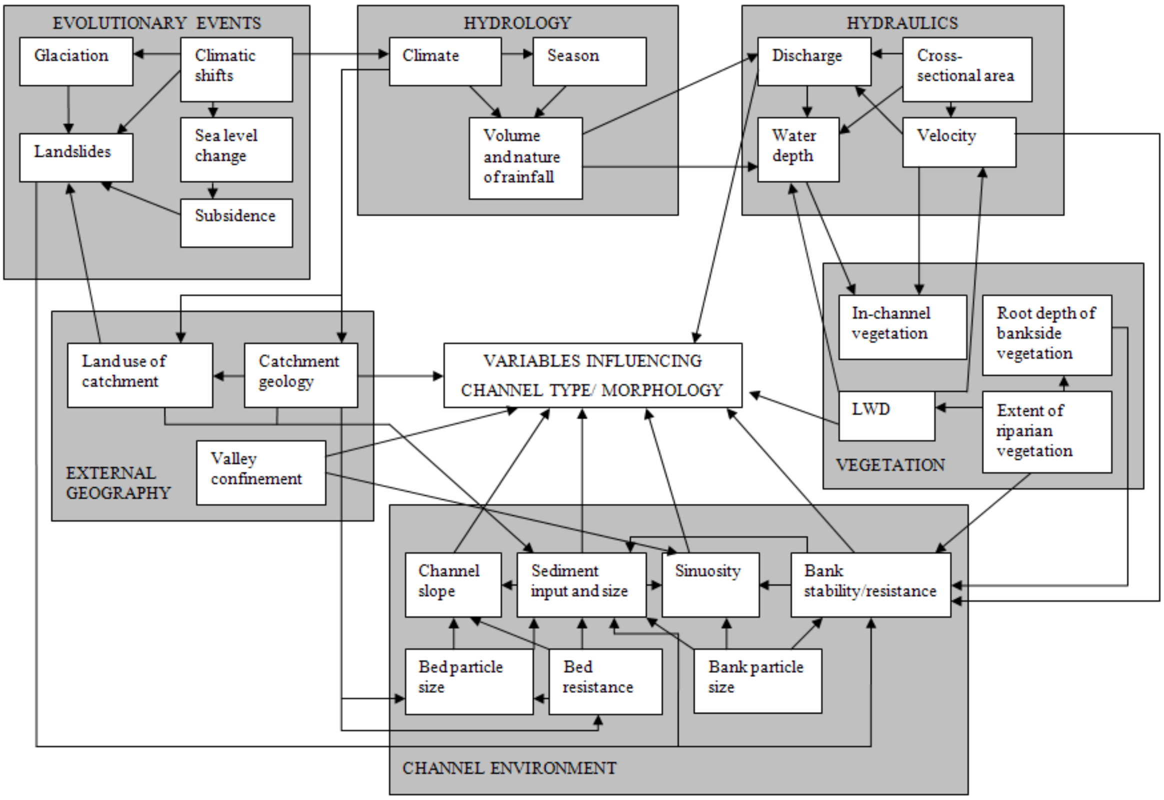
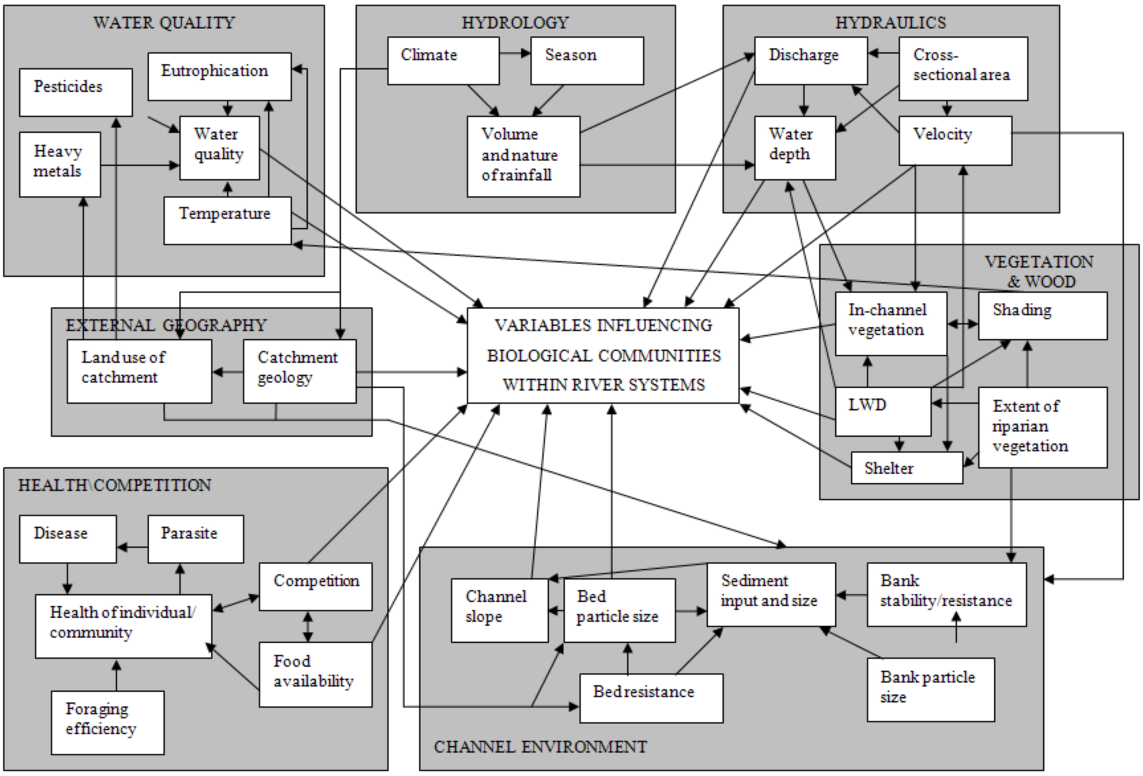
APPENDIX 1: Links between fluvial geomorphology, hydrology and ecology (Milner, 2010).



A conceptual model of the abiotic variables affecting channel morphology.



A conceptual model of the abiotic and biotic variables influencing biological communities within river systems.

APPENDIX 2: Picture library.

Allan Water Reach (picture 1)

Allan Water Reach (picture 2)

Muckle Burn Reach (picture 1)

Muckle Burn Reach (picture 2)

Surber sampler

Measurement of the travel time and particles removal

APPENDIX 3: Geomorphic summary of channel types in the SEPA typology (modified from Greig *et al.* 2006).

Channel type	Geomorphic Description
Bedrock channels	Most commonly found in upland areas, and are dominated by a bedrock substrate. Generally contain little, if any, bed sediment and have limited hydraulic connection with the riparian zone. Channel gradients tend to be high, resulting in a high transport capacity but limited sediment supply.
Cascades	Are restricted to upland areas with steep slopes and are characterised by disorganised bed material typically consisting of cobbles and boulders constrained by confining valley walls. The riparian zone is usually extremely small in extent. The large size of bed material, high levels of energy dissipation due to the bed roughness, dictate that the bed only becomes mobile in extreme floods (ca. >25 year return interval). Bedrock outcrops are common, and small pools may be present among the boulders.
Step-pool channels	Step-pool channels have a steep gradient and consist of large boulder clasts which form discrete sediment accumulations across the channel, forming a series of “steps” which are separated by intervening pools containing finer sediment. The stepped channel morphology results in zones of turbulence interspersed by more tranquil flows. High channel roughness and large bed material results in stable channels that respond only to very large flood events. The stream is generally confined by the valley sides.
Plane-bed channels	Generally moderate gradient streams with relatively featureless gravel/cobble beds, but include units ranging from glides, riffles and rapids. Sediment size and channel gradients are smaller than step-pool channels and deeper pool sections tend to be lacking. The river bed is generally armoured and, thus, mobilized in larger floods. Although channels are typically stable, they are more prone to channel change than any of the preceding channel types. Thus, with relatively more frequent bedload movement, they represent transitional channels between the more stable types listed above and the following more dynamic types of channel. Channels are generally straight and may be confined or unconfined by the valley sides.
Pool-riffle channels	Meandering and unconfined channels that are characterised by lateral oscillating sequences of bars, pools and riffles during low flow, resulting from oscillations in hydraulic conditions from convergent (erosive) to divergent (depositional) flow environments. The gradient of such channels is low-moderate and the width depth ratio high. The bed is predominantly gravel, with occasional patches of cobbles and sand. Accumulation of sediments in gravel bars indicates increasingly transport-limited conditions, though most large floods will produce some bedload movement on an annual basis, thus reducing the stability of the channel The banks are typically resistant to erosion, and lateral migration of the channel is limited, resulting in relatively narrow and intermittently deep channels.
Plane-riffle channels	Plane-riffle channels form an intermediate channel form between plane-bed and pool-riffle channels. They retain many of the attributes of pool-riffle channels, however, they generally have less defined pools, coarser (armoured) substrate and less extensive bar features.
Braided channels	Braided reaches are characterised by relatively high gradients (but ones that are less than upstream reaches) and/or abundant bedload. Sediment transport is usually limited under most conditions and the channel splits into a number of threads around instream bars. Poor bank strength renders them highly dynamic and channels will generally change even in relatively small flood events.
Wandering channel	These reaches exhibit characteristics of braided and meandering channels simultaneously, or if studies over a number of years, display a switching between divided and undivided channel types. Wandering channels may also be susceptible to channel avulsions during high flow events, where the channel switches to a historical planform. Wandering channels typically occur where a reduction of bed material size and channel slope is combined with a widening of the valley floor.
Low gradient actively meandering	Are unconfined low-gradient meandering channels with a bedload dominated by sand and fine gravel. Hence, the channel bed has marked fine sediment accumulations that are mobile in most flood events. These occur in higher order (i.e. typically lowland settings). The fine bed sediment erodible banks and unconfined settings means that such channels are dynamic and prone to change, they also often have extensive riparian zones and floodplains which are linked to the channel. Bars and pools may be present, and are associated with bends and crossing of the meander pattern.
Groundwater dominated channels	Groundwater-dominated rivers are low gradient channels, which are characterised by a stable flow regime; although limestone rivers with cave systems may display hydrological characteristics similar to freshet rivers. This stable regime is a product of the pervious catchment geology, and consequent reduction in overland flow that characterises groundwater-dominated streams. Bed movement is infrequent and sediments are predominantly transported in suspension. As bed disturbance is infrequent, deposited sediments may remain in the gravel for extended periods, promoting the accumulation of large quantities of fine sediment. Substrate generally comprises gravels, pebbles and sands, and glides and runs are the dominant flow types.
Low gradient passively meandering	These channels are typically found at lower extremities of the channel system. Generally they flow through resistant alluvium. They are typically ‘fixed’ in there planform geometry, which is sinuous. These channels are often incised and display low width depth ratios. The beds typically comprise fine sedimentary materials, although pockets of gravel can be present. These channels are typically deep and flows are dominated by glides, although runs may be associated with meander bends.

APPENDIX 4: Features of the reaches of the preliminary study and of the study

River	Alt Ghlinne	Alllt Mòr	Allt Criche	Allan Water	Muckle Burn
Location	South west of near Inverinan	South of Eredine	Between Ford and Dalavich	200m at the upstream on the bridge of the A822 near Greenloaning	500m at the west of the Bridge of the B8033
Stream size	100m	100m	100m	240m	240m
Dominant strate of the riparian forest	herbaceous	herbaceous	herbaceous	herbaceous	arboreous
Dominant substrate	silt to pebble	pebble to boulder	pebble to boulder	sand to gravel	pebble to boulder
Wetted width	1,8m	3m	0,7-0,8mm	6-11m	5-7m
Presence of woody debris	yes	yes	yes	no	yes
Some rock outcrop	yes	no	yes	no	yes
Aquatic vegetation	few	bryophytes and algae	few	macrophytes	few

APPENDIX 5: Table of the particles trapped on 3 reaches of the Argyle area.

River	Alt Ghlinne					Allt Mòr			Allt Criche		
Date	14/06/2011					15/06/2011			16/06/2011		
Trap type / Particle	Golf ball	bamboo sticks	leaves	Golf ball	bamboo sticks	Golf ball	bamboo sticks	leaves	Golf ball	bamboo sticks	leaves
bank	3	2	2	4	1	1	2	1	1	2	1
bank + riparian vegetation					11						
bank + roots		17									
bank embayment							3	5			
bank riffle				3							
debris behind bank slump	5										
eddy	1						8		1		
embayment		2				2	2	1			
embayment + riparian vegetation	5	25									
floating		5	1	4	3	2		5		1	
gravel bar	23					2				3	1
gravel bar (submerged)			10	19	7						
gravel bar + woody debris									3		
instream woody debris small						1					
marginal boulder								4			
marginal pool	2				1						
marginal pool macrophyte	1										
marginal pool riparian vegetation	1										
marginal rock riffle pool									7		
mossy rock						21	25	20			
mossy rock embayment						4					
riffle	9	9	28	5	6			5	7	15	10
riffle boulder trap							11				
riffle crest									2	2	2
riffle marginal									14		8
riffle marginal (pool)										38	
riffle middle	4										10
riffle rock			1								
riffle stone									1		
riffle type stream bed				13							
riffle woody debris											3
riparian vegetation	12	16	35	21	43	3		1		1	2
river bed		1		2	1		2	1			6
river bed riffle		2	4	1	2						
river bed roote		1									
river bed stone											1
rock	3	2	2	2	4	17	17	8	2	2	20
rock embayment							3				
rock on bed						2			9	1	
rock pool						3	1				
rock pool embayment								6			
rock riffle									3	1	10
rock riffle pool marginal										3	
roots		2	5	5	7		2				
steep boulder riffle						9					
stone bank	2										
woody debris	7	6	7	6	14				32	10	12
woody debris (riffle)										4	2
woody debris marginal						7	8		5		3

APPENDIX 6: Travel time of particles released over 80, 160 and 240m long reaches of the Allan Water reach and the Muckle Burn reach.

Golf balls on the Allan Water reach.

River	Allan Water																	
particle	Golf Ball																	
Date	28/06/2011						28/06/2011						28/06/2011					
Number of the experimentation	1		1		1		2		2		2		3		3		3	
Distance	80m		160m		240m		80m		160m		240m		80m		160m		240m	
Code used in the graphs	AW/GB/28,06/80/1		AW/GB/28,06/160/1		AW/GB/28,06/240/1		AW/GB/28,06/80/2		AW/GB/28,06/160/2		AW/GB/28,06/240/2		AW/GB/28,06/80/3		AW/GB/28,06/160/3		AW/GB/28,06/240/3	
	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n
	115	8	265	7	410	3	115	19	255	6	405	1	120	12	270	2	430	2
	120	20	270	10	415	9	120	11	260	15	410	6	125	21	275	4	435	4
	125	30	275	2	420	12	125	22	265	8	415	2	130	23	280	14	440	4
	130	15	280	7	425	20	130	15	270	9	420	3	135	16	285	15	445	6
	135	7	285	11	430	10	135	12	275	10	425	18	140	13	290	4	450	9
	140	6	290	12	435	5	140	13	280	10	430	21	145	8	295	15	455	12
	145	3	295	8	440	7	145	5	285	14	435	8	150	3	300	13	460	12
	150	2	300	10	445	8	150	2	290	12	440	6	155	2	305	9	465	9
	155	3	305	5	450	9	155	1	295	10	445	11	160	1	310	6	470	5
			310	12	455	7			300	2	455	5	165	1	315	5	475	8
			315	4	480	2			310	2	460	4			320	5	480	3
			335	1	485	1			315	1	465	3			325	1	485	7
			345	1	505	1			320	1	470	3			335	3	490	5
			355	1	520	1					475	2			350	1	495	5
					525	1					480	1			355	1	500	3
					730	1					495	2					505	
					735	1					510	1					515	
											630	1					550	
																	725	

River	Allan Water																	
particle	Golf Ball																	
Date	30/06/2011						30/06/2011						30/06/2011					
Number of the experimentation	1		1		1		2		2		2		3		3		3	
Distance	80m		160m		240m		80m		160m		240m		80m		160m		240m	
Code used in the graphs	AW/GB/30,06/80/1		AW/GB/30,06/160/1		AW/GB/30,06/240/1		AW/GB/30,06/80/2		AW/GB/30,06/160/2		AW/GB/30,06/240/2		AW/GB/30,06/80/3		AW/GB/30,06/160/3		AW/GB/30,06/240/3	
	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n
	130	4	305	3	465	1	135	22	295	2	470	1	120	1	290	5	460	5
	135	10	310	6	480	2	140	16	300	5	475	2	120	1	290	5	460	5
	140	12	315	8	485	6	145	18	305	3	480	2	125	20	295	13	465	5
	145	28	320	6	495	3	150	18	310	6	485	3	130	15	300	7	470	2
	150	15	325	5	500	3	155	11	315	6	490	5	135	15	305	5	475	6
	155	8	330	10	510	6	160	3	320	13	495	5	140	22	310	13	480	4
	160	5	335	9	515	4	165	3	325	12	500	7	145	15	315	16	485	7
	165	4	340	12	520	7	170	4	330	18	505	4	150	4	320	11	490	5
	170	2	345	7	525	2	180	1	335	9	510	8	155	1	325	6	495	5
	175	1	350	3	530	4	185	1	340	8	515	6	155	1	330	8	500	4
	180	1	355	5	535	3	190	1	345	1	520	4	160	2	335	7	505	7
	185	3	360	7	540	7	200	1	350	1	525	7	165	2	340	2	510	9
	190	3	365	1	545	8	245	1	355	1	530	9	170	2	345	2	515	7
	195	1	370	5	550	2			360	1	535	5			350	3	520	1
	200	1	375	1	555	5			365	3	540	5			360	1	525	12
	205	2	380	1	560	2			370	2	545	5			375	1	530	6
			385	1	570	4			375	1	550	2					535	4
			395	1	575	1			380	4	555	3					545	2
			410	1	580	2			385	1	560	1					550	2
			415	1	585	1			400	2	565	2					555	1
			420	1	590	1					570	1					560	3
			425	2	600	3					580	1					565	1
			430	1	610	2					595	1						
			445	1	615	1					610	1						
					645	1					625	1						
					675	1					675	2						
											735	1						
											740	1						

River	Allan Water					
particle	Golf Ball					
Date	04/07/2011					
Number of the experimentation	1		2		3	
Distance	80m		160m		240m	
Code used in the graphs	AW/GB/4,7/80/1		AW/GB/4,7/160/1		AW/GB/4,7/240/1	
	t	n	t	n	t	n
	140	7	325	5	515	1
	145	7	330	3	520	3
	150	17	335	2	540	3
	155	15	340	6	545	2
	160	15	345	2	550	6
	165	3	350	4	560	2
	170	1	355	3	565	7
	175	1	365	1	570	2
	180	3	370	2	575	2
	185	10	375	1	585	3
	190	6	380	3	590	5
	195	3	385	1	595	1
	200	1	390	2	600	2
	205	4	395	3	605	1
	210	1	400	5	610	4
	215	1	405	4	615	2
	220	1	410	1	620	3
	225	1	420	1	635	3
	245	3	430	1	640	2
			435	3	650	4
			440	2	655	2
			445	1	660	1
			450	1	665	2
			455	2	680	1
			460	1	685	2
			465	1	690	2
			475	3	710	1
			485	1	720	1
			495	1	725	1
			505	1	735	1
			515	1	760	1
			530	1	775	2
			535	1	795	1
			610	1	820	1
			615	1	1195	1
					1415	1
					1780	1
					2330	1
					2375	1

t times
n number of particle
N cumulatif number of particle

Bamboo sticks and leaves on the Allan Water reach.

Allan Water

Bamboo sticks

28/06/2011																			30/06/2011						04/07/2011					
1		1		1		2		2			2		3		3		3		1		1		1		1		1		1	
80m		160m		240m		80m		160m			240m		80m		160m		240m		80m		160m		240m		80m		160m		240m	
AW/B/28,06/80/1		AW/B/28,06/160/1		AW/B/28,06/240/1		AW/B/28,06/80/2		AW/B/28,06/160/2			AW/B/28,06/240/2		AW/B/28,06/80/3		AW/B/28,06/160/3		AW/B/28,06/240/3		AW/B/30,06/80/1		AW/B/30,06/160/1		AW/B/30,06/240/1		AW/B/4,7/80/1		AW/B/4,7/160/1		AW/B/4,7/240/1	
t	n	t	n	t	n	t	n	t	n		t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n
110	1	255	1	415	3	115	10	260	3	3	425	2	120	7	270	3	430	1	130	3	305	1	470	1	130	1	305	1	310	1
115	4	260	3	435	16	120	10	265	5	8	430	5	125	13	275	9	435	4	135	8	310	2	480	1	135	14	320	3	315	1
120	33	265	6	445	18	125	17	270	9	17	435	10	135	18	280	8	440	3	140	20	315	5	500	4	140	2	325	2	320	3
125	24	270	14	455	5	130	17	275	10	27	440	11	140	17	285	8	445	10	145	21	320	9	505	2	145	9	330	9	330	4
130	11	275	15	465	14	135	13	280	7	34	445	10			290	9	450	3	150	20	325	16	510	7	150	3	335	12	335	2
135	7	280	7	475	5	140	2	285	9	43	450	9			295	16	455	7	155	7	330	13	515	7	155	12	340	8	340	2
140	1	285	7	485	5	145	13	290	10	53	455	4			300	13	460	7	160	4	335	12	520	4	160	4	345	2	345	5
145	2	290	13	490	4	150	1	295	7	60	460	4			305	6	465	7	165	3	340	1	525	1	165	6	350	1	350	4
150	2	295	3	495	1	155	1	300	12	72	465	2			310	3	470	11	170	7	345	9	530	14	170	5	355	2	355	5
160	1	300	4	500	2	165	2	305	8	80	465	1			315	3	475	11	175	4	350	9	535	9	180	2	360	2	360	6
		305	4	505	1			310	2	82	465	1			320	3	480	1	190	1	355	5	540	11	185	6	365	5	365	3
		310	9	510	2			315	3	85	465	1			325	6	485	2	195	1	360	2	545	2	195	1	370	2	370	6
		315	1	530	1			325	3	88	465	1			330	2	490	8	205	1	365	5	550	4	210	7	375	4	375	5
		320	1	535	1			330	3	91	465	1			335	2	495	6			370	2	555	3	215	1	385	2	380	3
		325	7	540	1			340	2	93	470	3			340	1	500	5			375	3	560	1	225	8	395	2	385	5
				545	1			355	1	94	475	4			355	1	505	1			380	2	565	5	230	1	400	2	390	6
											480	3					510	4			390	2	570	6	235	9	415	4	395	4
											485	5					515	6					575	3	250	1	425	2	605	2
											490	3					535	3					580	3			435	1	615	2
											495	2											585	1			445	1	620	1
											500	2											590	1			450	2	630	1
											505	1											595	2			455	1	635	2
											510	3															460	1	640	1
											515																475	1	650	3
											520																650	1	665	1
											525																655	3	675	1
											535																890	1	700	1
											540																		705	1
																													715	1
																													735	1
																													815	1
																													840	1
																													870	1
																													1060	1
																													1305	1
																													1695	1

leaves

28/06/2011																		30/06/2011					
1		1		1		2		2		2		3		3		3		1		1		1	
80m		160m		240m		80m		160m		240m		80m		160m		240m		80m		160m		240m	
AW/L/28,06/80/1		AW/L/28,06/160/1		AW/L/28,06/240/1		AW/L/28,06/80/2		AW/L/28,06/160/2		AW/L/28,06/240/2		AW/L/28,06/80/3		AW/L/28,06/160/3		AW/L/28,06/240/3		AW/L/4,7/80/1		AW/L/4,7/160/1		AW/L/4,7/240/1	
t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n
115	7	260	2	425	3	105	1	295	1	420	1	120	3	275	5	430	2	140	8	325	3	530	3
120	15	265	2	430	2	115	2	300	1	425	1	125	19	280	2	435	3	145	16	330	1	535	2
125	14	270	4	435	5	120	18	305	1	430	2	130	20	285	4	440	1	150	18	340	7	545	2
130	5	275	7	440	4	125	23	310	11	435	1	135	12	290	8	450	3	155	16	345	5	550	2
135	3	280	5	445	3	130	18	315	1	440	3	140	9	295	7	455	3	160	6	350	2	555	2
140	7	285	5	450	1	135	12	320	13	445	8	145	15	300	4	460	4	165	10	355	4	560	4
145	5	290	7	455	4	140	6	325	14	450	4	150	6	305	11	465	5	170	4	360	9	565	8
150	2	295	7	460	4	145	3	330	12	455	5	155	1	310	13	470	5	175	4	365	12	570	4
155	6	300	3	465	2	150	6	335	8	460	7	160	2	315	4	475	5	180	1	370	8	575	2
160	5	305	6	470	7	155	4	340	9	465	12	165	5	320	6	480	8	185	2	375	3	580	1
165	2	310	4	475	2	160	1	345	5	470	8	170	1	325	5	485	9	190	2	380	2	585	3
170	3	315	1	480	2	165	1	350	9	475	7	175	1	330	4	490	8	200	1	395	1	590	1
175	1	320	2	485	6	170	1	355	2	480	6	185	1	335	1	495	5	205	1	400	1	595	2
180	1	325	3	490	2	180	1	360	3	485	3	205	1	340	3	500	2	215	2	405	3	605	4
185	1	330	1	495	1	190	1	365	4	490	4			345	3	505	2	225	1	410	1	610	2
195	1	335	3	505	1	230	1	370	1	495	1			350	2	510	4			420	1	615	2
200	1	340	3	510	1	280	1	375	1	500	2			360	1	515	1			425	4	620	3
		345	2	515	2			385	2	505	1			375	1	520	1			445	1	625	3
		355	3	525	1			390	1	510	5			390	1	525	1			450	1	630	2
		360	1	525	1			520	1	520	1			410		530	3			475	1	635	1
		365	1	530	1					525	1			425	1	535	3			485	1	660	2
		370	2	535	1					530	1			440	1	540	1			505	1	665	1
		375	1	540	1					535	1					565	1			510	1	670	1
		380	1	545	1					540	2					570	2			515	1	695	1
		385	1	565	1					570	1					600	1			520	1	705	1
		405	1	570	1											605	2			540	1	710	1
		435	1	590	1											630	1			550	1	725	1
				615	1											645	1			570	1	735	2
				625	1											655	2			575	2	760	1
				630	1											770	1			1280	1	790	1
				735	1															1345	1	870	1
																						1085	1
																						1405	1
																						1550	1
																						1785	1

Golf ball, bamboo sticks and leaves on the Muckle Burn reach.

Muckle Burn

Golf Ball																							
30/06/2011																		05/07/2011					
1						2						3						1					
80m		160m		240m		80m		160m		240m		80m		160m		240m		80m		160m		240m	
MB/GB/30,06/80/1		MB/GB/30,06/160/1		MB/GB/30,06/240/1		MB/GB/30,06/80/2		MB/GB/30,06/160/2		MB/GB/30,06/240/2		MB/GB/30,06/80/3		MB/GB/30,06/160/3		MB/GB/30,06/240/3		MB/GB/5,7/80/1		MB/GB/5,7/160/1		MB/GB/5,7/240/1	
t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n
205	2	1250	1	1455	1	200	1	520	1	725	1	210	1	545	1	740	1	330	1		0		0
215	1					205	1	690	1	985	1	225	2	1700	1	770	1	350	1				
220	1					220	1					230	2					350	1				
225	2					225	1					235	1					355	1				
230	1					235	1					240	3					360	1				
240	1					240	1					250	2					370	1				
255	1					305	2					255	2					400	1				
270	1					315	1					260	1					415	1				
275	2					325	1					270	1					440	2				
280	1					375	1					275	1										
285	2					480	1					285	1										
300	1					595	1					290	2										
305	2											300	1										
310	1											320	1										
330	2											405	1										
345	1											435	1										
395	1											440	1										
470	1											525	1										
475	1											630	1										
2260	1											660	1										
												1200	1										
												1500	1										

Bamboo sticks																							
30/06/2011																		05/07/2011					
1						2						3						1					
80m		160m		240m		80m		160m		240m		80m		160m		240m		80m		160m		240m	
MB/BS/30,06/80/1		MB/BS/30,06/160/1		MB/BS/30,06/240/1		MB/BS/30,06/80/2		MB/BS/30,06/160/2		MB/BS/30,06/240/2		MB/BS/30,06/80/3		MB/BS/30,06/160/3		MB/BS/30,06/240/3		MB/BS/5,7/80/1		MB/BS/5,7/160/1		MB/BS/5,7/240/1	
t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n	t	n
215	1		0		0	275	1		0		0	255	1		0		0	525	1		0	0	0
235	1					965	1					300	1										
												330	1										

leaves					
05/07/2011					
1					
80m		160m		240m	
MB/L/5,7/80/1		MB/L/5,7/160/1		MB/L/5,7/240/1	
t	n	t	n	t	n
	0		0		0

Label code: Stream name / particle type / date / distance (m) / number of the experiment

AW= Allan Water; MB= Muckle Burn; GB= golf ball; BS= bamboo stick; L= leaves

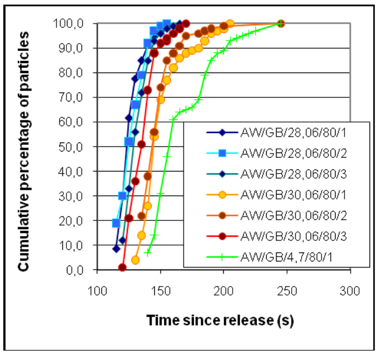
APPENDIX 7: Graphs comparing travel time of 3 particle types on 2 reaches.

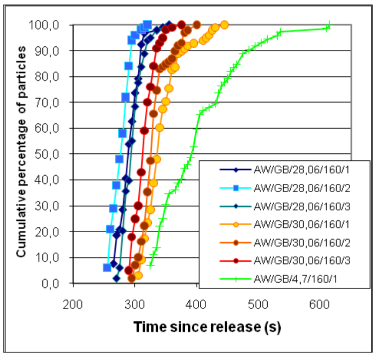
3 reach lenght on the Allan Water reach on 28th and 30 th June and 4 th July, 2011
80m of the Muckle Burn reach on 30 th June and 5 th July, 2011

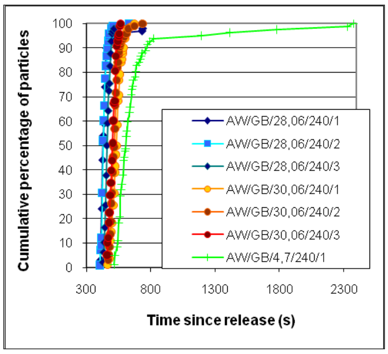
(*Label code:* Stream name / particle type / date / distance (m) / number of the experiment
AW= Allan Water; MB= Muckle Burn; GB= golf ball; BS= bamboo stick; L= leaves)

Allan water

Golf ball

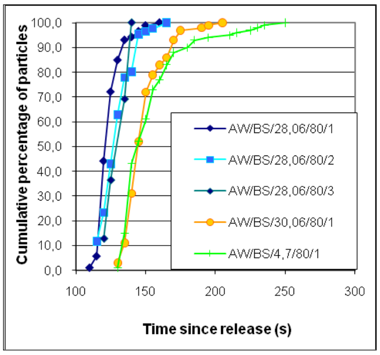


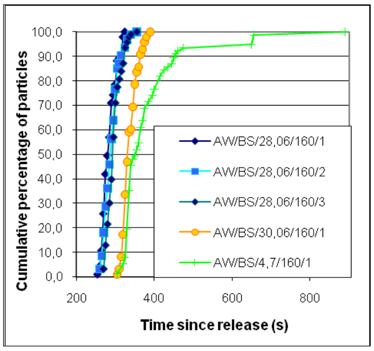


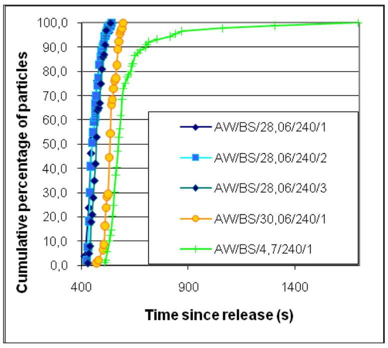


Allan water

Bamboo sticks

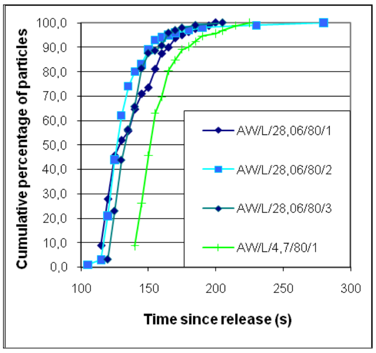


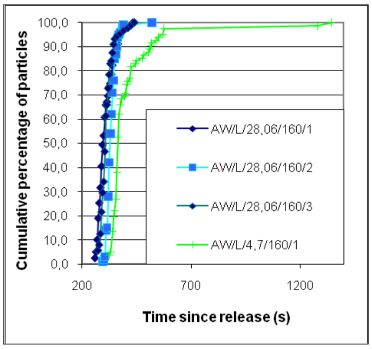


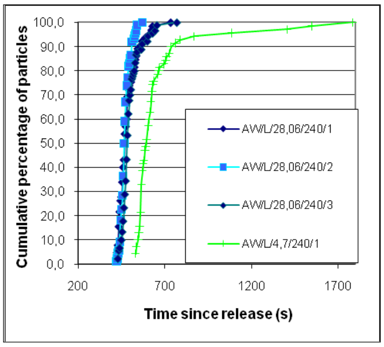


Allan water

Leaves

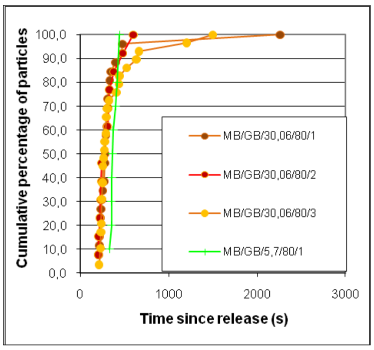






Muckle Burn

Golf ball



80m *160m* *240m*

APPENDIX 8: Retention distances of particles released on 240m long reaches of the Allan Water and the Muckle Burn.

River	Muckle Burn																	
Particle	Golf Ball								Bamboo sticks								Leaves	
Date	30/06/2011						05/07/2011		30/06/2011						05/07/2011		05/07/2011	
Experimentation n°	1		2		3		1		1		2		3		1		1	
Code	MB/GB/30,6/1		MB/GB/30,6/2		MB/GB/30,6/3		MB/GB/5,7/1		MB/BS/30,6/1		MB/BS/30,6/2		MB/BS/30,6/3		MB/BS/5,7/1		MB/L/5,7/1	
Distance (d) or number (n)	d	n	d	n	d	n	d	n	d	n	d	n	d	n	d	n	d	n
	0		0		0		0		0		0		0		0		0	
	1	1	3	2	1	2	1	1	1	3	0,5	3	0,2	1	1,9	1	1,4	1
	5	2	4	6	3	3	1,2	2	1,4	5	0,8	4	0,5	6	3	5	1,5	2
	7	4	6	7	4	4	2,4	4	2,4	6	1	5	1	10	3,1	6	2,8	4
	8	6	9	8	4,5	5	3,3	5	2,9	7	1,5	9	2	13	3,3	7	3,5	5
	10	8	10	9	5	7	5,5	11	4,2	11	2,2	16	2,2	14	4,3	8	4,9	8
	16	11	16	21	6	8	6	12	4,3	12	3,1	18	2,4	15	5,3	15	5,3	20
	17	14	18	23	7	9	6,4	14	5	14	10,7	19	3,8	17	5,5	17	5,4	33
	30	15	19	24	28	12	8	15	6	16	11	45	5	21	6,1	18	5,7	34
	34	20	25	25	30	13	8,2	17	6,5	22	12,5	51	6,2	23	6,3	27	5,9	36
	35	21	27	26	42	14	8,9	18	7	23	13,7	73	11	40	6,9	29	6,4	41
	45	22	28	28	50	15	9,6	20	11	33	16	74	12,1	43	10,3	30	6,6	43
	62	24	31	30	52	16	10	21	12,3	40	20	76	13,2	47	10,7	44	6,9	46
	69	27	32	31	53	17	11,3	23	13,5	45	21	77	13,6	61	13	62	7,1	52
	70	35	36	36	55	19	18,5	24	14	61	22	78	19,2	62	13,7	64	8,9	53
	90	37	37	38	60	22	18,7	38	14,5	62	24	80	20,8	63	18,7	65	9,1	54
	100	38	38	39	65	23	23,5	39	15,5	63	27	81	21	64	19,2	66	9,5	55
	105	41	40	40	68	39	24,9	40	15,9	68	31	82	21,7	65	19,5	67	9,7	56
	115	42	50	41	70	46	25	41	16,2	69	42,6	84	24,7	71	19,8	80	10	57
	130	48	55	42	75	50	26	43	18,5	70	48,5	85	26,7	72	21,6	81	13,4	60
	135	49	58	43	110	52	26,4	44	20,5	73	53	86	31,8	75	22,8	82	14,8	61
	150	50	60	45	115	53	31	45	21	74	57	87	37,1	76	24	83	16,9	62
	152	51	65	46	130	54	33,7	47	24	75	65,5	90	42,6	77	24,2	84	18,9	63
	178	53	68	48	140	58	35	51	31	76	65,6	92	42,8	78	33,3	92	19,6	66
	215	54	70	71	150	62	36,3	52	34,5	77	69,8	93	42,9	79	41,9	93	22,1	67
			75	75	157	63	37,3	53	36	78	69,9	94	43,8	80	43,4	94	24,4	69
			100	77	160	65	50	69	41	79	70	95	48,9	81	45,7	95	25,7	70
			115	78	195	66	59,6	70	41,5	80	95	96	49,4	82	62,1	96	27	72
			120	80	240	68	68,4	71	43	81	138	97	56	83	70,5	97	32,7	73
			130	81			69,7	72	49	82			60,9	84	71	99	33,3	75
			135	84			70,4	73	51	86			70	86	130	100	36	76
			140	85			70,6	74	53	87			70,3	87			41,9	77
			145	86			71	84	63	88			94	89			50	78
			150	87			78	85	65	90							56	79
			215	88			86,7	89	70	95							60,2	80
							115	90	118	97								
							140	93										
							148	94										
							155	96										

River	Allan water					
Particle	Golf Ball		Bamboo stick		Leaves	
Date	04/07/2011		04/07/2011		30/06/2011	
Experimentation n°	1		1		1	
Code	AW/GB/4,7/1		AW/BS/4,7/1		AW/L/4,7/1	
Distance (d) or number (n)	d	n	d	n	d	n
	0		0		0	
	30	1	5	1	90	1
	58	2	35	3	95	3
	60	3	50	4	100	4
	70	4	55	5	125	5
	78	5	78	6	137	7
	95	6	100	8	145	8
	105	9	130	9	160	10
	110	10	140	10	190	11
	120	11	145	11		
	140	12	155	12		
	195	13	157	14		
	210	15	160	15		
	230	16	170	16		
			195	17		
			200	19		
			210	20		
			215	21		
			230	22		

Label code: Stream name / particle type / date / distance (m) / number of the experiment
AW= Allan Water; MB= Muckle Burn; GB= golf ball; BS= bamboo stick; L= leaves

APPENDIX 9: Table of the particles trapped on the Allan Water reach and the Muckle Burn reach.

River	Allan Water																
Particle	Golf Ball							Bamboo sticks					Leaves				
Date	28/06/2011			30/06/2011			04/07/2011	28/06/2011			30/06/2011	04/07/2011	28/06/2011			30/06/2011	
Experimentation n°	1	2	3	1	2	3	1	1	2	3	1	1	1	2	3	1	1
Number of particle fined	0	0	1	0	0	0	16	1	0	0	0	22	0	0	0	0	5
Bankside habitat			1				10	1				19					2
Bed																	1
Boulder (and mossy boulder)																	
Eddy																	
Embayment							4					2					1
In-channel vegetation							2					1					1
Large Woody debris																	

River	Muckle Burn								
Particle	Golf Ball				Bamboo sticks				Leaves
Date	30/06/2011			05/07/2011	30/06/2011			05/07/2011	05/07/2011
Experimentation n°	1	2	3	1	1	2	3	1	1
Number of particle fined	41	85	55	92	97	97	86	100	80
Bankside habitat						2			
Bed	11	29	28	41	17	10	23	35	45
Boulder (and mossy boulder)	22	9	9	26	32	18	9	5	26
Eddy				2	15	29	22	14	
Embayment	3	6	2	2	15	27	15	21	2
In-channel vegetation				1					
Large Woody debris	5	41	16	20	18	13	18	25	7

APPENDIX 10: Macroinvertebrate taxa present in the sampling plots of the second experiment

Classification					Sample																			
Class	Order	Family	Genrus	Species	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5
Arachnide	Hydracharia				1	3		1													1	1	1	2
Insect	Coleoptera	dytiscidae	*Oreodytes*	*sanmakii*				3	9			1											4	
		elmidae	*Elmis*	*aenea*	6	2		1	4				1		1			1	14	1	3	1	3	9
		elmidae	*Esolus*	*parallelepidus*	7	21	2	38	11		1	1	2			1	8		3	4		3	23	2
		elmidae	*Limnius*	*volkmari*	1	1		1	1		3		1		5		1		4	1			6	10
		Helophoridae	*Helophorus*	*brevipalpis*															1					
		hydraenidae	*Hydraeca*	*gracilis*	1						3				2				2		1		3	
		Hydrophilidae	*Hydrophilus*	*sp.*															1					
		Scirtadae	*Elodes*	*sp.*	1												6		1					
		Scirtadae	*Scirtus*	*sp.*		1		1	1		2				3			1	5				2	1
	Crustacea	Gammaridae	*Gammarus*	*pulex*		2			2										1					
	Diptera	Chironomidae			11	16	6	40	28	4	19		7	5	47		28	13	49	13	4	5	65	37
		Empididae	*Hermerdromia*	*sp.*	1			2					1		3		1				1			
		Pediciidae	*Dicranota*	*sp.*		1			1						1					1			19	
		simulidae			3	1		1		3	4	10			78		7	4	109	11	1	2	5	4
	Ephemeroptera	Baetidae	*Baetis*	*muticus*	2			1			4		1	1			2	1	9		2	1	1	2
		Baetidae	*Baetis*	*rhodani*	28	2	3	54	12	63	39	6	7	5	110	2	96	20	95	49	2	7	15	16
		Caenidae	*Coenis*	*rivulorum*	3	2		2	1		7	1	2	2	5		5		1	1		2	2	2
		Ephemerellidae	*Serratella*	*ignita*	1			2	7		5	1					2	1	62	6	3	2	5	7
		Heptageniidae	*Ecdyonurus*	*torrentis*				2										1				2		
		Heptageniidae	*Ecdyonurus*	*venosus*	1				4		4		2										1	
		Heptageniidae	*Ecdyonurus*	*sp.*		7					2	1						1						
	Heteroptera	Veliidae													1				1					
		Corixidae					1																	
	Oligocheta								3															
	Plecoptera	Chloroperlodae	*Chloroperla*	*tripunctata*	12	1			3															
		Leuctridae	*Leutra*	*fusca*		1		2					3						2		3		4	
		Leuctridae	*Leutra*	*sp.*																		4		2
		Leuctridae	*Leutra*	*hippopus*	5			2				1		8			3							
		Leuctridae	*Leutra*	*inermis*		15							1	7		1	9							
		Leuctridae	*Leutra*	*sp.*					13						5									
		Nemouridae	*Protonemusa*	*meyeri*				1													1			1
		pedicidae	*Dicronas*	*cephalotes*	3								1		4			1	4					2
		perlidae	*Perla*	*bipuncata*	3	3		1	1	1	1	1		1	4		4		1		1	1	6	3
		Perlodidae	*Isoperla*	*grammatica*																1				
	Tricoptera	goeridae	*Sillo*	*pallipes*							1												4	
		hydropsychidae	*Hydropsyche*	*siltalai*							1		2		11			2	6	1	1		1	
		Limnephilidae	*Drusus*	*annalatus*					1															
		Odontoceridae	*Odontocerum*	*albicorne*					3				1											1
		Polycentropodidae	*Polycentropus*	*flavomaculus*																				1
		Psychomyiidae	*Psychomyia*	*pusilla*											8									1
		Rhyacophilidae	*Rhyacophilla*	*dorsalis*	2						1				2				6			1		

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