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Diploma thesis

Field and laboratory experiments on settling process in stormwater storage tanks

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Declaration of Authorship

I hereby declare that the whole work of this diploma thesis is my own work, except where explicitly stated otherwise in the text or in the bibliography. This thesis has not been submitted in whole or in part for the award of any other academic degree.

Graz, 15. May 2007

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Signature

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Abstract

This work deals with settling process in stormwater storage tanks, and is based on field and laboratory experiments.
Settling velocity is a fundamental parameter for better conception, design, sizing, modelling and management for stormwater treatment facilities like storage tanks. Yet, a literature review has revealed that the settling velocity profiles obtained with some different methods (Chebbo, 1992, Michelbach and Wöhrle, 1993 and Tyack et al., 1993) are very different. Then the main objective of this work is to investigate, confirm and extend the measurement method of a French protocol called VICAS (VItesse de Chute en Assainissement). The procedure includes a field experiment (outside sampling and laboratory analyses) and the application of the Vicas protocol. Three measurement series have been obtained until July 2006, and the settling velocity measurement results obtained from the three series have been compared. Several investigations have been carried out by the application of the french protocol:
An experiment was done to evaluate the reproducibility of the settling velocity by the applied protocol, including a mass balance calculation; as a consequence the determination of losses of the protocol leads to important facts. The link between the evolution of the sample and its settling velocity evaluated by the protocol Vicas at different time has also been carried out. This knowledge will contribute to the management of storage tanks in future. The research on the influence of the sample's cooling time and of the fluids used will relieve the operational mode.

A geostatistical approach was implemented to estimate the settling velocity from well known location points into unknown points of the storage tank by interpolation and extrapolation respectively by cokriging (covariable: Pb). The analysis of their spatial distribution enables hydrodynamic tank modelling. An illustration of the measurement protocol's uncertainty and its bias is presented, and a further evaluation constitutes an interesting perspective view.

Résumé

Ce travail traite le processus de la vitesse de chute dans les bassins de stockage des eaux pluviales. Il est fondé sur les experiences de terrain et de laboratoire.
La vitesse de sédimentation est une donnée fondamentale pour la conception, le dimensionnement et la gestion des ouvrages de stockage d'eaux pluviales. Or la bibliographie révèle que les profils de vitesse de sédimentation diffèrent largement d'une méthode à l'autre (Chebbo, 1992, Michelbach and Wöhrle, 1993 and Tyack et al., 1993). L'objectif principal de ce travail est donc d'étudier, confirmer et élargir la méthode de mesure d'un protocole français, nommé VICAS (VItesse de Chute en ASsainessement). Cette procédure inclut une étude de terrain (une phase d'échantillonnage et des analyses en laboratoire) et l'application du protocole Vicas. Trois séries de mesures ont été réalisées jusqu'en juillet 2006 ; les résultats obtenus sur les mesures de vitesses de chute lors de ces trois séries ont été comparées. Différentes études ont été menées dans le cadre de l'application du protocole français :
Une expérience a étudié la reproductibilité de la vitesse de chute avec le protocole Vicas, ainsi que le calcul de bilans de masse ; la détermination des pertes occasionnées a conduit à souligner des faits importants. Le lien entre l'évolution de l'échantillon étudié et les vitesses de chute évaluées par le protocole Vicas à différents instants a également été étudié. La

connaissance de ces aspects est un atout pour la gestion future des bassins de stockage. L'étude de l'influence du temps de refroidissement de l'échantillon et du dispersant utilisé apporte également des informations d'un point de vue opérationnel.
Une approche géostatistique a été mise en œuvre pour estimer la vitesse de chute à certaines localisations du bassin à partir de points dont la vitesse de chute est connue, par interpolation et extrapolation (covariable : Pb). L'analyse de leur distribution spatiale permet une modélisation hydrodynamique du bassin. L'incertitude liée au protocole de mesure et son biais sont illustrés, et une évaluation plus approfondie constitue une perspective intéressante.

1. Introduction

Context of the research

Today, a combined sewer system is not able to transfer all part of its charge to the wastewater treatment plant, because of big rain events with large volumes of combined sewage (sanitary sewage and stormwater). Different relief structures (storage basin, retention basin, overflow structure, etc.) are accommodated in the sewer system to reduce the direct inlet of wastewater to the sewage treatment plant. This is necessary because of the limited capacity of a wastewater plant and the sewer system. A storage basin holds combined sewage when temporary storage is needed, typically when the flow rate from an event exceeds the carrying capacity of a pipe. A retention basin holds a part of the flood runoff and discharges it when the runoff subsides in the connecting sewer.

An overflow structure for combined sewage stores a part of the resulting discharge up to a certain sill, but then the flow runs over the structure into a receiving water (river, brook).

To avoid pollutant impact on receiving waters, it came to the consideration to construct stormwater retention-settling tanks. It is confirmed by different applications that a settling process is an efficient way of treatment. The harmful particles shall settle in this storage retention basins and the cleaned rain water passes to a natural infiltration basin.

Retention tanks are one of the most frequently used alternative techniques. Originally, they were constructed to control flooding risks. However, it is known that settling of suspended solids and associated particulate pollutants transported during storm events may reach a high removal efficiency within such tanks.
A stormwater tank named Django Reinhardt stormwater tank has been constructed in Chassieu – Grand Lyon, France. It is one of the experimental sites of the OTHU project (Field Observatory for Urban Water Management) with a volume equal to 32200m^3 and a bottom surface equal to 11300m^2.

Problem concerning the environmental context

The series of measurement campaigns on wet weather effluents have significant shown that in those discharges many pollutants are presented in particulate form in quantities. In fact, suspended solids concentrations in overflowing waters are much higher than in those of effluents of sewage treatment plants and they are known to be carriers of micro-pollutants which affect aquatic organism detrimentally.

Some observations lead to the conclusion that dead zones without settled solids indicate a wrong design of the Django Reinhardt stormwater tank.

Introduction

Objectives and overview

In order to optimize the Django Reinhardt tank, a modelling is to work out and the parameter of settling velocity is fundamental for better conception, design, sizing, modelling and the management of the Django Reinhardt tank.
A literature review has revealed that the settling velocity profiles obtained with some methods (Chebbo, 1992), (Michelbach and Wöhrle, 1993) and (Tyack et al., 1993) are very different. The main objective of this work is to investigate, confirm and extend the measurement method of one French protocol called VICAS (VItesse de Chute en ASsainessement). The procedure includes i) a field experiment; ii) the outside sampling and a laboratory analysis; iii) the application of the protocol Vicas. On twelve measurement points settlement traps were placed to analyse the settling behaviour of the received Total Suspended Solids (TSS) in the laboratory.
Settling velocity curves represent the cumulated percentage of solids and pollutants mass vs. settling velocity. The values measured and published by various authors vary greatly with storm events, experimental sites, and the diversity of used metrological equipments and protocols. These differences motivated to carry on research on this issue in order to answer the questions and to acquire a better knowledge about solids characteristics and about their variability.

This rapport presents successively:

- A literature review which contents:

  - the theoretical background
  - the origins and problems of pollutants in receiving waters
  - the results of measured settling velocities obtained by different protocols
  - the advantages and the disadvantages of each method

- The description of the experimental site

- The methodology and the following chapter of results include the description and analysis of the:

  - Experimental methods ((i)terrain, (ii)laboratory)
  - Comparison of settling velocities obtained out of different rain events by the application of the Vicas protocol
  - Rain data exploitation
  - Mass balance theory and as a consequence the determination of losses
  - Reproducibility of the French protocol
  - Uncertainty problem
  - Geostatistical interpolation
  - Time dependent physico-chemical evolution of a sedimentation sample concerning its settling velocity
  - Changing of a sample's settling velocity at different cooling times in the fridge.

The presentation of results and the corresponding analysis, as well as obtained perspectives, constitute the last chapters of this investigation.

2. Literature Review

2.1 Context

One of the principal causes of poor water quality in many urban rivers is combined sewage overflows (CSOs). Many pollutants found in combined sewage are attached to particles. Settleable particles, in particular, are of great importance for receiving water quality (Michelbach and Wöhrle, 1994). Poor water quality can be observed downstream from combined sewer outfalls and settleable solids in combined sewage are an important vector for pollutants found in receiving water sediments.

Also researches carried out in the early ninety's concluded that solids presented in big quantities in the effluents are the main vector of the pollution (Chebbo 1992; Bertrand-Krajewski, Chebbo and Gromaire-Mertz, 2003). These transported, suspended solids appear settleable in spite of their relative fine median diameter D50 between 30 and 40 µm (Chebbo, 1992). The following table shows the percentage of the pollution fixed on the solid particles, according to various authors quoted by Saget, 1994.

Pollutant	Pollution fixed on solid particles in %	Author
COD	83 – 91	Chebbo, 1992
BOD5	77 – 95	Chebbo, 1992
TKN	48 – 82	Chebbo, 1992
HC	82 – 99	Chebbo, 1992
Pb	79 – 100	Chebbo, 1992
PAH	90	Hermann *et al*., 1990
PCB	93	Marsalek, 1990

Table 1 Percentage of the pollutants attached to solid particles (Saget, 1994)

Suspended solids (SS) concentrations in overflowing waters are much higher than in those of effluents of sewage treatment plants. Further CSOs are major contributors for the pollution load discharged into receiving waters (Benoist and Lijklema, 1990).

The pollution of the receiving waters as a result of the discharge of SS includes the following effects (Benoist and Lijklema, 1990):

- Enhanced concentrations of SS lead to deterioration of light conditions, which may cause damage to the submerse flora.

- As a result of bio – degradation of the organic fraction of the SS (frequently > 50%) a depletion of the dissolved oxygen concentration is expected.

- Suspended Solids are known to be carriers of micro – pollutants such as heavy metals, which tend to accumulate in the sediment after settling. Aquatic organisms may be detrimentally affected, when exposed to too high concentration levels of these micro –pollutants.

Furthermore it is known that bacteria and viruses are attached to SS in CSO – water. It has been shown that especially the sediment near the outlet is more or less continuously contaminated with faecal coliforms due to their long survival times in the sediment (Benoist and Lijklema, 1990).

The treatment of highly polluted stormwater runoff from impervious urban surfaces did not begin at large scale before the mid-1970's. During the same period, the traditional management of stormwater by drainage systems was optimized and new techniques were developed to limit the downstream discharges and to control surface runoff as upstream as possible. They consist to collect, store temporarily and then evacuate stormwater to the ground or to a sewer (Azzout et al., 1994).

As a consequence, retention tanks became one of the most frequently used alternative techniques. Originally, they were constructed to control flooding risks. However, it is known that settling of suspended solids and associated particulate pollutants transported during storm events may reach a high removal efficiency within such tanks (Torres, Bertrand–Krajewski, 2006). This potentially high efficiency is mainly due to the fact that, in both separate and combined systems, many stormwater pollutants (COD, heavy metals, hydrocarbons, etc.) are attached to suspended solids (Schueler, 1987 ; Chebbo, 1992; Marsalek et al., 1992, 1997 ; Michelbach and Wöhrle, 1994 ; Matthews et al., 1997). Taking this into account, the formerly retention tanks became retention-settling tanks, and a new approach for stormwater management was developed.

The retention-settling tanks can present very good results according the pollutant removal of urban wet weather effluents. For example, Herremans et al. (1995) (mentioned by Lefebvre and Declercq (2002)), estimated the pollutant disposal obtained after a storage of a few hours in a simple settling tank.

Pollutant	Estimated pollutant disposal
Suspended Solis (SS)	80% à 85%
Organic Matter (OM)	60% à 70%
Heavy Metals (HM)	75% à 80%

Table 2 Pollutant removal estimated after a storage of a few hours, according to Herremans (1995)

Research groups confirm that a settling process is an efficient way of treatment (Chebbo 1992, Michelbach and Wöhrle 1993).
The process of settling is less site specific and more universal although a certain variation related to the composition of the pollutant load (particle size distribution, organic fraction, density of particles) must be expected. Hence experiences with settling at one site can be used to a certain extent for predictions elsewhere (Benoist and Lijklema, 1990).

To optimise the design and the management of sewer networks and settling tanks, the solid distribution into different settling velocity classes, called a settling velocity curve, is one of the reference parameters.

The importance of the determination of this parameter lies in the fact that sewage solids cannot be assigned a single representative value of specific gravity, which can be combined with particle size, in order to represent the influence of gravity on the transport characteristics of these particles (Hedges, Becker, Smisson; 1998), like in traditional settling velocity formula like the Stokes formula.

The settling velocity profiles are obtained by fractioning a suspension by classes of settling velocities in calm water in a settling column.

The resulting curves as shown in figure 1 have as an ordinate the percentage in mass of the pollutants those settling velocity is lower than the settling velocity given in the logarithmic abscise.

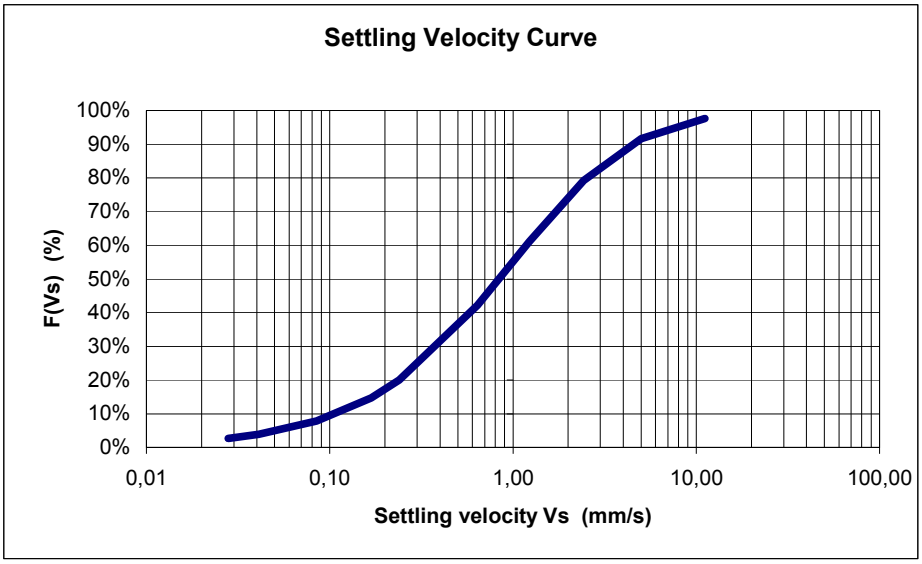


Figure 1 Settling Velocity Curve (example)

This information is used as an input data for the some models which simulate solid transport in networks or tanks.
The interest in the parameter of settling velocity lies also in the fact that it encompasses other parameters at the same time, like particle size, density and shape.

2.2 Settling Velocity V_s Measurement

2.2.1 Context

To split pollutants contained in urban effluents in settling velocity classes, various protocols were developed and used by several research teams since the beginning of the 1990s, (Benoist and Lijklema, 1990; Tyack et al., 1992; Michelbach and Wöhrle, 1993; Pisano, 1996; Lucas-Aiguier and et al., 1996; Chebbo, 1992; Bertrand-Krajewski, 2001; Gromaire-Mertz et al., 1998).

The objective of all protocols is to determine the curve S(t) (see explanation in chapter 4.2) and to transform it to get the curve $F(V_s)$ indicating the cumulated percentage F of the total mass of particles having a settling velocity lower than V_s. The measurement results are represented by a "settling velocity distribution curve" called $F(V_s)$ where the settling velocity V_s are given on the abscise in logarithmic scale with a base of 10 increasing towards the right - and the percentage of cumulated mass F of the particles having a settling velocity V_s lower than a given value is given on the ordinate in linear scale from 0 to 100% (Chebbo et al., 2003).

In general the measurement of the distribution of the pollutants by classes of settling velocities is executed in calm water in settling columns.

2.2.2 Mathematical approach to measure the settling velocity of particles in fluids – Stokes equation

Sedimentation by the effect of gravity is a widely applied process to separate a medium which comprises particles of different densities (Lafond, 1995). The settling velocity describes the vertical speed of a particle which sets off within the medium of a fluid.

In case of a purely gravitate sedimentation, it depends on:

- acceleration due to gravity,
- the density of the fluid/particle,
- the diameter and/or equivalent diameter of the particle,
- the viscosity of the fluid.

If these variables are well-known, it is possible to calculate the sedimentation velocity. Taking into account the value of the drag coefficient Cd which depends on the Reynolds number - Cd corresponds to 24/Re for slow velocities (Re<1) -, the settling velocity is calculable with the equation of Stokes. The settling velocity V_s of an ideal sphere is proportional to the square of the particle diameter and is given by:

$$V_c = \frac{\left(\frac{\rho_s}{\rho} - 1\right) g d_p^2}{18\nu}$$

where:

V_c is the particles settling velocity (m/s),
g is the acceleration due to gravity (m/s²),
ρ_p is the density of the particles (kg/m³), and
ρ_f is the density of the fluid (kg/m³),
v is the viscosity of the fluid (Pa*s)

The Stokes approach describes the settling characteristics of particulate materials in bodies of quiescent water.
For fast sedimentation (Re>1000), Cd corresponds to 1. In this case the sedimentation speed changes with the root of the particle radius. Between these two ranges there is no simple formula for Cd, but different empirical formulas were developed.

It is obvious that natural sedimentation does not take order to these abstract conditions very often.
This is why corrective factors were determined by certain authors (Boido, 1957) to take into account the shapes of particles (e.g. formula for a flat particle of small thickness or for a particle with the shape of a needle, where the ray is smaller than the length, which sediments in horizontal position).

In summary, various mathematical approaches were developed by different investigators but there is no one which is close enough to natural phenomena and therefore not enough reliable to describe the settling velocity of particles in fluids, especially particles in stormwater.

2.2.3 Principles: Homogeneous or inhomogeneous suspension

2.2.3.1 The principle of the floating layer

At the beginning of the measurement, the particles are accumulated in a thin layer on the surface of the fluid on the top of the settling column. Then particles settle and reach the bottom per decreasing order of settling velocity. The mass fraction Fi of particles which have settled at time t can be directly evaluated according to their settling velocity Vi=h/t.

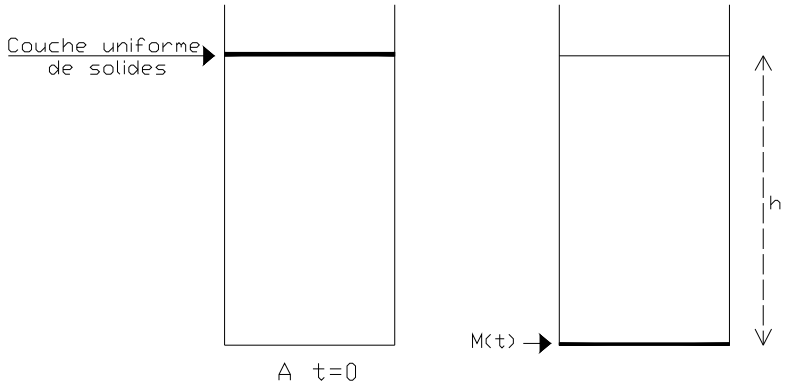


Figure 2 Principle of the floating layer (in French)

2.2.3.2 The principle of the homogeneous suspension

At the beginning of the measurement, the particles are distributed homogeneously over the height of the settling column.

To get the settling velocity distribution it is necessary to evaluate the mass which settles at the bottom of the column at different time intervals, or to calculate the concentration of the pollutants at one or more heights in the column.

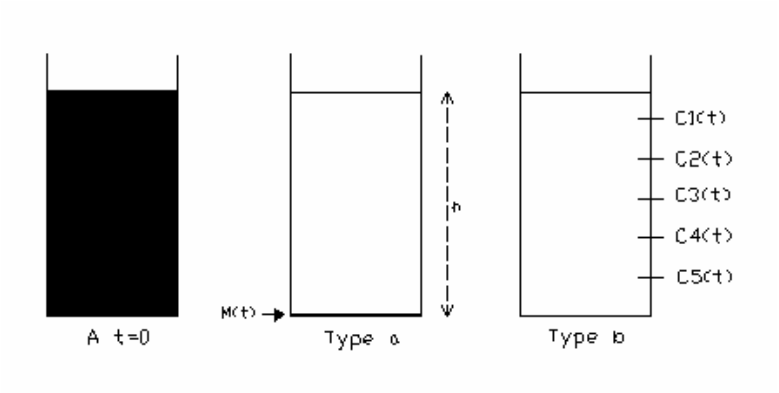


Figure 3 Principle of the homogeneous suspension

2.2.3.3 Conditions and difficulties

This part is taken from Chebbo (1992):
The method of the floating layer can have advantages during the process of sedimentation, each height level is occupied by particles of the same settling velocity. Then again, this method makes it possible (theoretically) to carry out the fractionation easily.

But it is not possible to eliminate all sources of errors:

- Not all particles leave exactly at the same level.
- It is difficult to deposit a layer of solids in a short time without generating disturbances.
- It is not possible to be sure of a good dispersion of the suspension during the sedimentation in the used liquid.

Therefore, the protocols of the floating layer require an important pretreatment of the sample to concentrate the particles which will be introduced at the top of the column. This pretreatment is to avoid significant modifications of particles (agglomeration in particular) and thus of their settling velocity.
These remarks let us think that the methods of the homogeneous suspension offer more guarantee to us.
Different devices and test methods for measuring the settling velocities of suspended solids have been developed by various French research groups. A first sophisticated device was invented by Chebbo (1992), within the scope of his thesis.
A second important step was activated during the year 1994 by the “Water Agency Seine – Normandy” when they contacted the “Center of Education and Research for the Management of Natural Resources and Environment (Cergrene)” in order to define a protocol to measure the distribution of pollutants by settling velocity classes which is adapted for solids in suspension of wet weather effluents and of dry weather effluents

2.2.4 Methods

2.2.4.1 Cergrene method

In the Cergrene method (Chebbo, 1992), the settling velocity measurements are carried out in two parts: in a settling column for the particles greater than 50 µm and in an Andreasen pipette for the particles smaller than 50 µm. The settling depth is 1,81 m for the Cergrene column and 0,20 m for the pipette. Their diameters are similar for the columns and the pipette (50 mm).
A pre-treatment is necessary. Particles are separated in two size fractions by wet sieving (mesh size: 50 µm). The mass of particles (greater than 50 µm) used in the settling column of Cergrene is around 1 g. For the particles smaller than 50 µm, a volumetric concentration of 0,2 – 0,5% is required in the pipette. Drinking water is used in the Cergrene method.

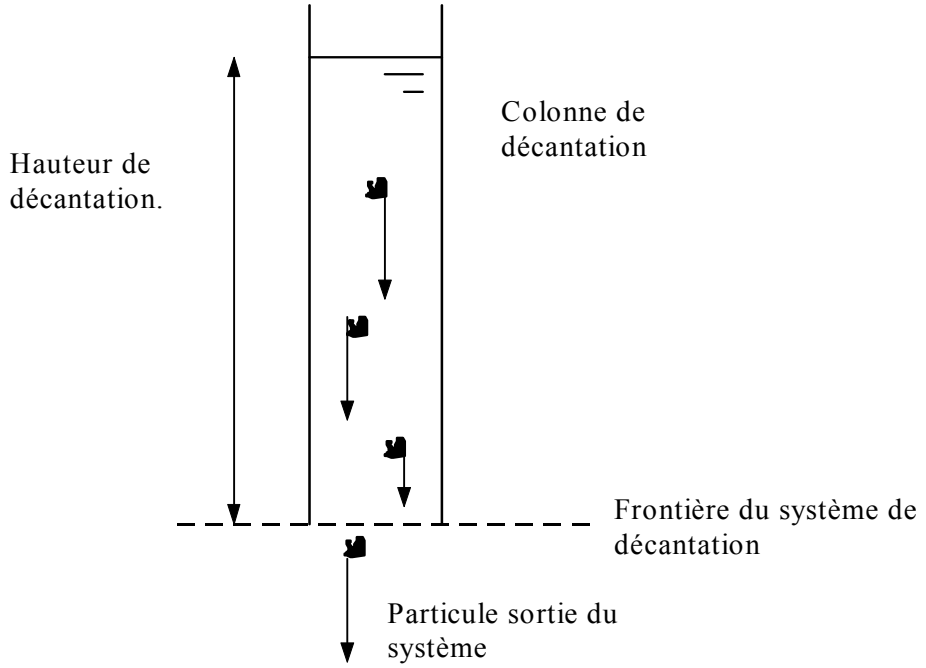


Figure 4 Principle of the Cergrene settling column (in French)

The particles are supposed to settle independently (no phenomena of aggregation or diffusion). The process can be described by the following equation:

$$M(t) = S(t) + t \times \frac{\partial M(t)}{\partial t}$$

where M(t) represents the cumulated mass of particulate pollutants collected at the moment t

S(t) represents the mass of particulate pollutants with a settling velocity higher than v = h/t where h is the height of decantation in the column

2.2.4.2 VICTOR method

The Victor method uses several columns (VItesse de Chute des pOlluants des Rejets urbains by Chebbo, Bertrand-Krajewski, Gromaire, Aires; 2003). According to the duration of the settling time, different concentrations C(t) are determined. The protocol Victor implements different columns from which the lower part is isolated by a valve from the upper part. Samples are taken at different times ti for each column i. It is necessary to measure the concentration Ci in the lower part at the end of settling time ti.
The settled particles in the lower part present all mass settled between t=0 and ti. The determined masses at various times ti corresponding to various columns i, make it possible to plot the settling curve.
The apparatus of fragmentation of the protocol Victor is made up of several elements, see Figure 10:

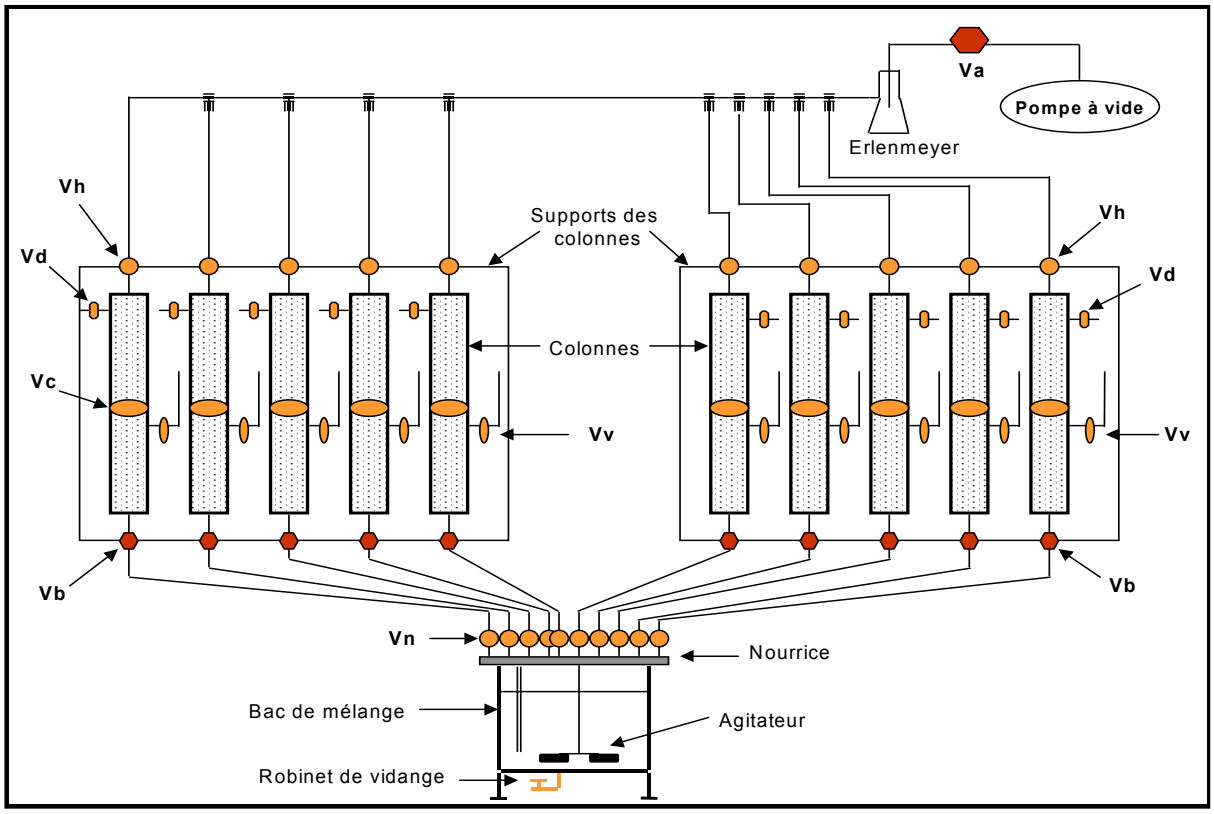


Figure 5 Principle of the protocol Victor (Chebbo et al., 2003)

Operation

Ten columns are provided with a central valve. Thus, at least 10 fractions can be carried out, but it is possible to use several times certain columns. The columns are practically identical (total=2,1l volume, drop height hi approximately 55cm). When the central valve will be closed at the time ti, all the particles which are in the upper part (a mass αM) have a settling velocity lower than hi/ti. The lower part contains the particles of the rough sample as well as the particles which have settled from the upper part between t=0 and ti.
This is because of a higher settling velocity of mass particles than hi/ti and because of the particles (1-α)*M whose settling velocity is lower than hi/ti but which have a lower distance hi to the horizontal plan of the central valve Vc.

The process needs at least 4 hours and can be carried out by only one person. A mixer stirres the sample throughout the filling of the columns. The columns are filled successively by aspiration of a vacuum pump from the vat.

With each column, a time of decantation ti is assigned and executed by closing the central valve Vc. The lower part is then isolated from the upper part.
Then it is possible to recover the volume of the lower part to measure various pollutant parameters (SS, SVS, COD, BDO5, TOC, Pb, Zn, Cu, Cd, etc).

To obtain a representative curve of settling velocity, it is necessary that this curve comprises at least 7 points. That implies the filling of 7 columns at least, and so the need for taking at least 15 L of sample. The vat of mixture has a capacity of 25l, which makes it possible to obtain 10 fractions corresponding to the 10 columns.
It is recommended to carry out the sample as soon as possible after the reception to reduce the time between the sampling and the analyses of pollutants on the fractions. The most suitable conservation is the refrigeration at 4°C for a lower duration than 24 hours. Too long times involve a biochemical evolution of the pollutants which makes difficult to compare and later to interpret the results.

Device	10 columns
Principle	Floating Layer
Decantation height (cm)	50
Diameter (mm)	50
Filling Mode	Vacuum pump
Volume Total (L)	25
Volume for each sampling (mL)	1000
Settling intervals	4 min, 8 min, 16 min, 32 min, 1 h, 2 h, 4 h, 24 h

Table 3 Principle characteristics protocol VICTOR Gromaire et al., 2003

2.2.4.3 Dutch method

Benoist and Lijklema (1990) split six samples from overflow units by using a protocol based on the principle of the homogeneous suspension.

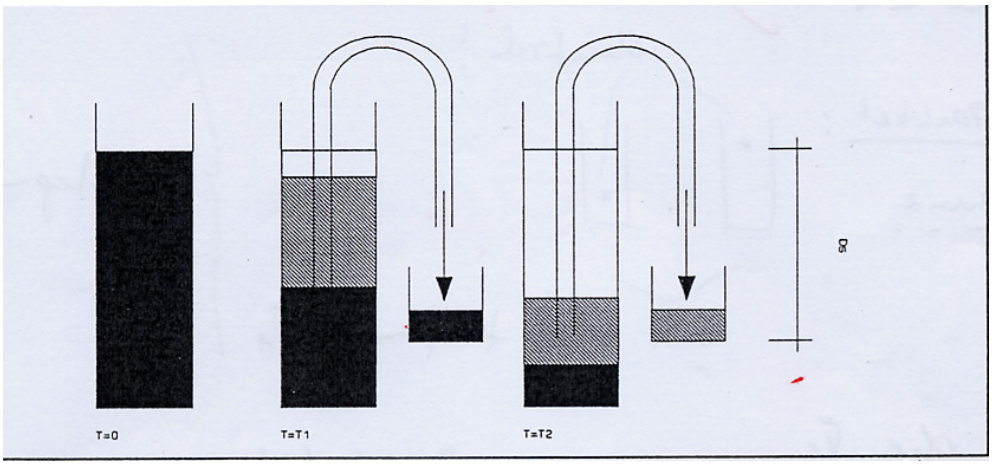


Figure 6 Principle of measuring the distribution of sedimentation rates using settling tubes (Benoist and Lijklema, 1990)

The majority of the samples were fragmented into five classes. Five columns were utilised for this protocol. Each column has a height of 40 cm and a diameter of D = 8cm, so a volume of 2 Liters. The filling of the columns is made by gravity. At time t=0, the columns are filled with the sample. At each time t=ti a sample of 100ml is extracted from column i for a decantation hi. On each fraction and on the initial sample, the concentrations are measured on SS, Cu, Pb, Zn and Cd. The distribution of the suspended solids (SS) concentrations and heavy metals is presented in form of histograms giving the percentage in mass for each fraction of settling velocity.

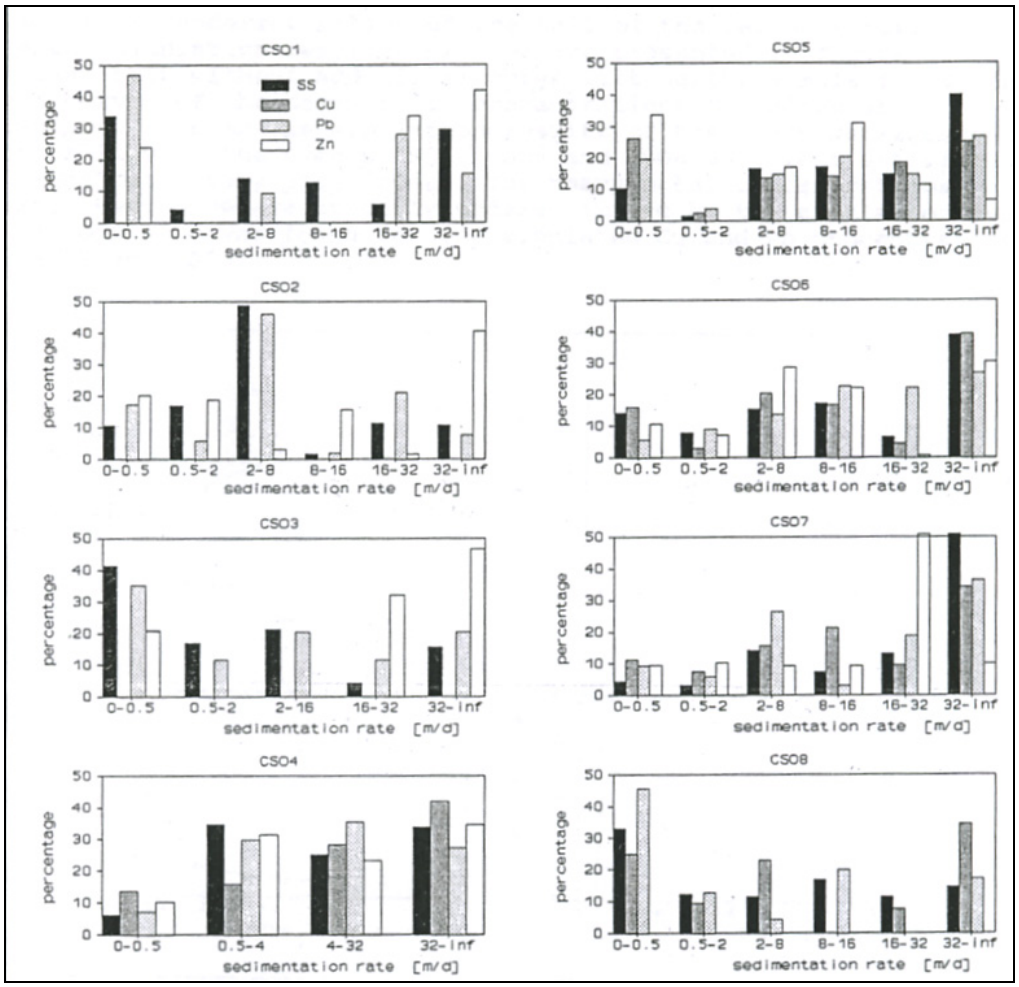


Figure 7 Normalized distributions of sedimentation rates of SS and associated heavy metals Cu, Pb and Zn (Benoist and Lijklema, 1990)

Strong points

This protocol is very interesting because it is possible to evaluate directly the percentage of the particles which have a settling velocity lower a given value. The measurement can be carried out quickly without preliminary treatment of the sample.

Weak points

We do not have sufficient details on the procedure to evaluate this protocol. In particular, Benoist and Lijklema (1990) do not give any indication on the methods utilised for the homogenisation of the initial sample, the filling of the various columns of decantation and for the sampling at times ti. The principal difficulties of this protocol would be on the one hand to ensure the homogeneity of the initial effluent between the various columns and on the other hand, to ensure a sampletaking of the fractions within a layer the most horizontal possible.

2.2.4.4 VICPOL method

There were very little details on the implementation of the protocol of Benoist and Lijklema. So that is why a device similar to this principle was chosen (Gromaire, Saad, Chebbo 2003).

The VICPOL method is a modification of the Dutch method. It rests on the principle of the homogeneous suspension of type B (Gromaire et al., 2003). Vicpol implements 5 columns of decantation, where each is provided with a device which makes it possible to take a horizontal water section at the end of a certain settling time ti. The horizontal water section is taken out of the column which has an average settlement height of 43 cm and a volume of 500 ml.

The percentage of particles which have a settling velocity lower than Vs is given directly by F(Vs) =100* Ci/Coi, where Ci is the measured concentration of the taken sample which is carried out in column i, at the end of the time of decantation ti, and Coi is the measured concentration of a sample taken during the filling of this same column i.

Device	Characteristics
Can	With broad opening, V = 40 L
Mixing vat	V = 25 L, approx. at 1 m above the ground and graduated every two liters between 21 and 25 L
Mixer	Provided with a blade with holes
5 columns	d = 9 cm ; h = 50 cm ; V = 3,2 L. At the end of the different times ti for each column, a horizontal water section is taken. The column has a settling height of 38 cm and volume of 500 mL
Vacuum pump	with a bottle, a plug and a battery of 12 V
Bottle	V = 2 L graduated every 400 mL
5 Bottles	V = 1 L, graduated every 800 mL and 900 mL
Jug	V = 5 L
5 stop watches	
Sieve of 2 mm	
d : diameter ; h : height ; L : length ; l : witdh ; Q : discharge ; V : volume	

Table 4 Device for VICPOL method (Muca, 2004)

The procedure of measuring is divided into 6 great phases, which arise in the following table.

Phases	Activities
Preparation of the sample and filling of the mixing vat	Install the mixing vat and the agitator. The bottom of the blade of the agitator must be located at approximately 1 cm of the bottom of the vat.
	Prepare a sample of 40 L
	Start the agitator
	Fill the vat with the jug of 5 L while filtering with a 2 mm sieve and while agitating
Preparation of the columns	Number the columns according to thé times of thé following fillings : 22 min ; 4 h ; 1 h ; 8 min ; >16 h

	Prepare the lid for the sample taking for each column (the bottom of the bored tube must be at 7 cm of the bottom when the lid is closed) and close the valve.
	Prepare the vacuum pump: connect the battery + pompe + bottle bottle plug + stopper rubber + receive the bottle for sample taking
	Place all on the ground
	Prepare the 2 L bottle for the initial sample
	Prepare the 1 L bottles for the sampling
Filling of the columns	Open the low valve and fill a jug of 5 L. Then give it into vat on the top (repeat 3 times before the filling of the first column and once before the filling of the others)
	It is necessary to take approximately 400 ml of the initial sample by the low valve of the mixing vat. Pour it into the bottle of 2 L to fill the column until a height of 50 cm.
	Pose the column on its site on the table
	Set up the lid of the sample tube and fix it
	Start the stop watch
	Note the exact height the water in the column
Sampling at the end of the decantation time	A few minutes before sample taking: (i) Connect the pipe to the lid of the column on the stopper rubber and to the vacuum pump; (II) Install the bottle of sample taking on the stopper rubber, maintain it quite vertical; (III) Check that the valve between the pump and the bottle is opened and that the two others are closed
	At the previewed decantation time: Start the vacuum pump
	5 seconds afterwards: Open the valve located between the sample taking bottle and the column
	Fill the bottle up to a volume of 800 or 900 mL
	Close the valve which ist situated between the bottle plug and the sample taking bottel
	Close the valve
	Deactivate the pump
	Recover the sample taking bottle
	Measure the exact volume contained in the bottle and note it on the laboratory sheet
	Note the time of decantation after sample taking
	Check and empty if necessary the bottle plug
	Put the bottle with the sample into the fridge
Fractionation intervals	Fill and set up successively the columns corresponding to 22min; 4h; 1hRemplir
	Wait the first 22min of the first column an take the sample
	Fill successive the columns at 8min and >16h
	Wait 8min for the column 4 and take the sample
	Begin the analyses while waiting for the sample taking of 1h and 4h
After the fractionation	Empty the columns as well as the sample tubes
	Wash the columns in soapy hot water with an aspergillum, to rinse with the water of the tap then with distilled water
	Clean the lids, the tubes and the pipes of sample taking (hot water in the tube, winnows open)

Table 5 Measurement procedure (Muca, 2004)

The percentage of the particles which have a settling velocity lower than Vs is calculated directly by the following equation(Muca, 2004):

$$F(V_s) = 100\frac{C_i}{C_{0i}}$$

C_i concentration measured at the end of ti in column i
C_{0i} concentration measured on the taken sample during the filling of column i

The Vicpol protocol makes it possible to get a sufficient volume to carry out the analyses of several pollutants such as , organic matter, mineral and organic micropollutants.

2.2.4.5 British method

Description of the method to measure the settling velocity distribution (Tyack, 1992):

A 10 L sample of sewage is taken from the inlet to the wastewater treatment works, returned to the laboratory and refrigerated overnight.
The following morning the sample is split into two using a specially designed riffle box. With reference to the figure below, the entire length of the settlement column, including the end cells, is filled with a well mixed sewage sample and is left in the vertical position, valves 2 and 3 open, for 3 hours. This results in the sinking fraction being collected in the bottom cell and the floating fraction in the top cell.
At the end of the settlement period the contents of the end cells are drained into separate containers.
With valves 2 and 3 closed, the sinking fraction is poured back into cell B, cell A is filled with clean water. The column is rotated so that cell B is uppermost, valves 2 and 3 are opened and the stop clock started.
At time intervals, valve 3 is closed and cell A emptied into a container. Cell A is refilled with clean water. 1 min after t_1, the column is rotated so that cell B is uppermost, valve 3 is opened and the test continues.
At the end of the test, the contents of cell B are drained into a container. Cell B is then filled with the retained floating fraction and the test repeated, but with cell B at the bottom of the column and cell A uppermost collecting the floating particles.
At the end of the test the contents of cell B and the central column are drained into separate containers.
The sub-samples are filtered to obtain the mass of suspended solids, from which a settling velocity distribution can be plotted.

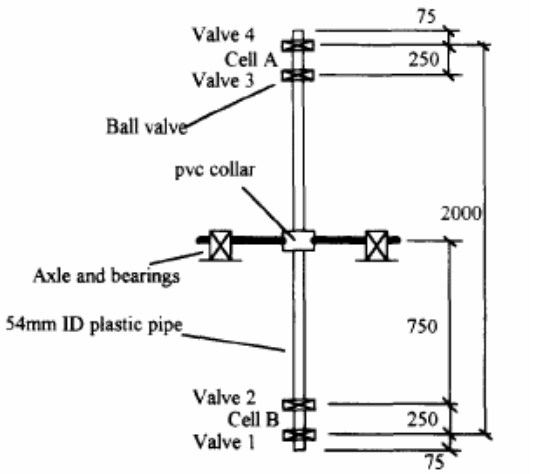


Figure 8 Construction of the settlement velocity measurement column (Tyack, 1992), (values in mm)

Advantages and drawbacks

The length of 1,5m of the column makes the column difficult to transport and unwieldy to use. Hence, the filling volume of 5 L means that the sample is more representative for the sampling and the fact having a larger mass of the fine slow settling fractions the mass of suspended solids was detectable on the balance. Another weak point constitutes a possible turbulence which cause some transfer of fine suspended solids because of the big volume of the column.

2.2.4.6 German method

The method was developed by the Umwelt- and Fluid- Technik, UFT (Brombach, 1990; Michelbach and Woehrle, 1993). First, the solids from a sample of ~1g settle for two hours in an Imhoff cone.

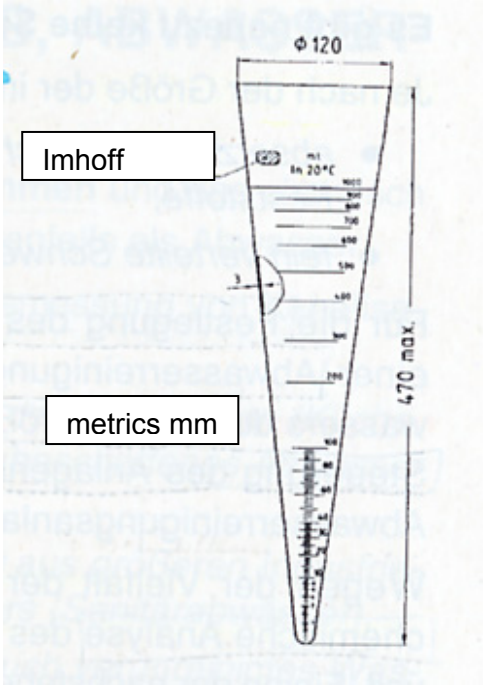


Figure 9 Imhoff cone (Brombach, 1990)

Next, the settled solids are placed in a vertical Perspex cylinder having a feeding mechanism at the top and a cone at the bottom.

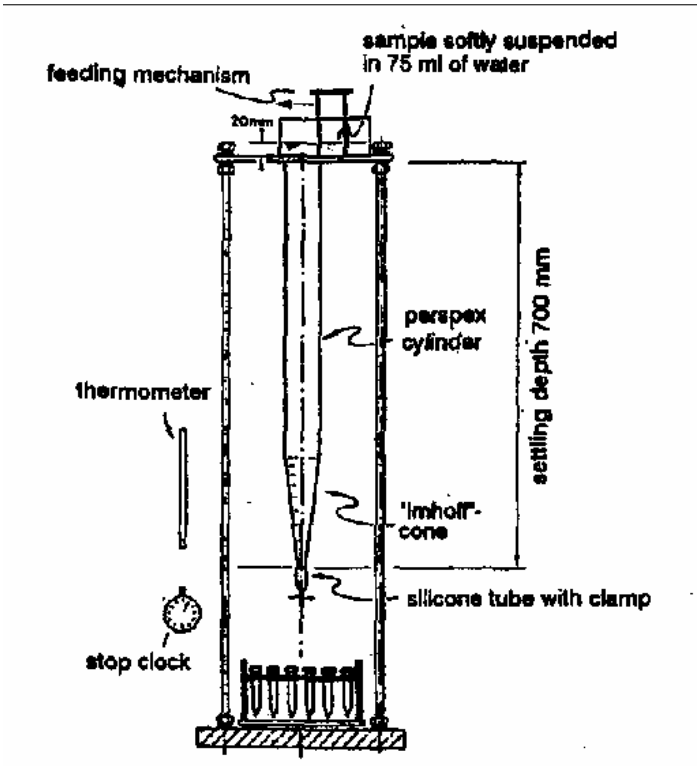


Figure 10 Settling apparatus german protocol (Bromabach, 1990)

Samples are withdrawn at logarithmic spaced intervals from the bottom of the Perspex tube.

Conclusion

The procedure is easy to handle and it is possible to carry out the experience quite fast. Otherwise, the residue in the Imhoff cone varies between 25% and 40% of the initial mass. Therefore the distribution curves of the German UFT method do not represent the full interval of settling velocity. Only the distribution of particles which settled 2 hours in an Imhoff cone and with a settling velocity greater than 0,01cm/s are represented.

2.2.4.7 American method

The American Environmental Protection Agency (EPA) considers the distribution of pollutants by settlement velocity classes as an essential parameter for dimensioning the overflow units of treatment works (Pisano with EPA, 1993; Gagné and Bordeleau, 1996).

Principle of measurement

The American method is based on the principle of the homogeneous suspension with several levels of sampling in settling column of approximately 2.6m height. In Canada, the protocol was adapted with five levels (60, 90, 120, 150, and 180cm initial height) at times 0, 1, 2, 4, 8, 15, 30, 60 and 120 minutes (Gagné and Bordeleau, 1996).

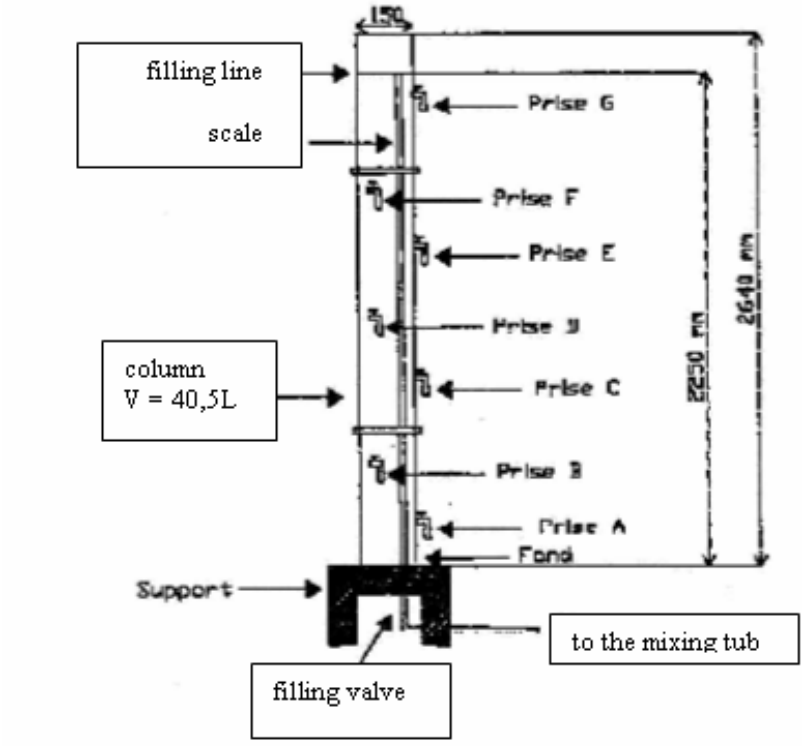


Figure 11 Scheme of the American column applied by Gagné and Bordelau (1996)

The column consists of a Plexiglass tube of 2.64 m height with a diameter of 15 cm. Over the height of this column five to seven portholes of 1cm diameter serve for sampling, at this points valves are fixed with a quarter turn to open to ensure a fast sampling of the fractions.

The column is linked by a flexible tube to a vat of mixture which is provided with an agitator. The filling of the column is made by pumping in the vat of mixture.

Operation

The procedure comprises several stages:
After the sample homogenisation in the vat of mixture the column is to fill. To mix the sample in the column for a few minutes a disk fixed-head on a stem is used and then three samples are taken to determine the initial concentrations of suspended solids. At the predetermined times, extraction is undertaken by the valves which are fixed along the column. After the last sampletaking, it is to recover and to evaluate the mass of the pollutants contained in the column, which makes it possible to calculate the balance of mass.

Strong points

The measurement can be carried out very quickly after the removal without pretreatment of the samples.

The necessary handling during measuring is simple and do not require a specific training.

The volumes of the fractions can be important because of big size of the column, which makes it possible to carry out the analysis of interesting pollutants (SS, organic matter, mineral and organic micropollutants).

Weak points

The American protocol uses a large column which requires a great volume of sample (45-50 liters). The protocol was tested and used by Gagné and Bordelau (1996) to characterize the particles in urban wet weather effluents. The results of the tests show a problem of heterogenity within the column with a variation of the initial concentration which can exceed 20% between the top and the bottom of the column.

The repeatability of fragmentation is poor for the sampling at t=1, 2 and 4 minutes (incertainty relative is always higher than 50%) but satisfactory (incertainty relative ranging between 10 and 25%) for the other sampling.

This protocol requires successive sampling in the same column which can induce hydraulic disturbances (water recirculation) at the time of each sampletaking likely to distort the continuation of measuring if the elementary sampling represents large volumes and if the hydrants are not distant enough from one to each other.

2.2.4.8 VICAS protocol

The need to define a common protocol to compare settling velocity grading distributions at an international level was responded by French research groups. A new protocol called VICAS (Settling Velocity in Urban Drainage) was developed (Chebbo, Gromaire, Bertrand-Krajewski, Lucas 2003).

Specifications:

- no pretreatment of the sample before measurement
- volume of necessary water should be low (a few liters of sample)
- no very expensive apparatus, simple to manufacture and simple to handle
- only one operator
- fast measurement (a few hours).

Principle of measurement:

The VICAS protocol (Gromaire et al., 2003a, b) is based on the principle of the homogeneous suspension, assuming that particles settle independently, without aggregation and diffusion. The measurement is carried out in the laboratory in a sedimentation column with still water. The solids settled during preset times t are collected at the bottom of the column, dried and then weighed. This allows determining the evolution of the cumulated mass of solids settled according to time, noted M(t). From this curve, one derives the curve F(Vs) indicating the cumulated fraction F of the total mass of particles having a settling velocity lower or equal to Vs, using the following equations:

$$F(V_s) = 100\left(1 - \frac{S(t)}{M_{dec} + M_{fin}}\right) \qquad S(t) = M(t) - t\frac{dM(t)}{dt} \qquad V_s = \frac{H}{t},$$

with Mdec the total mass settled in the column and Mfin the mass of solids remaining in the column at the end of protocol.

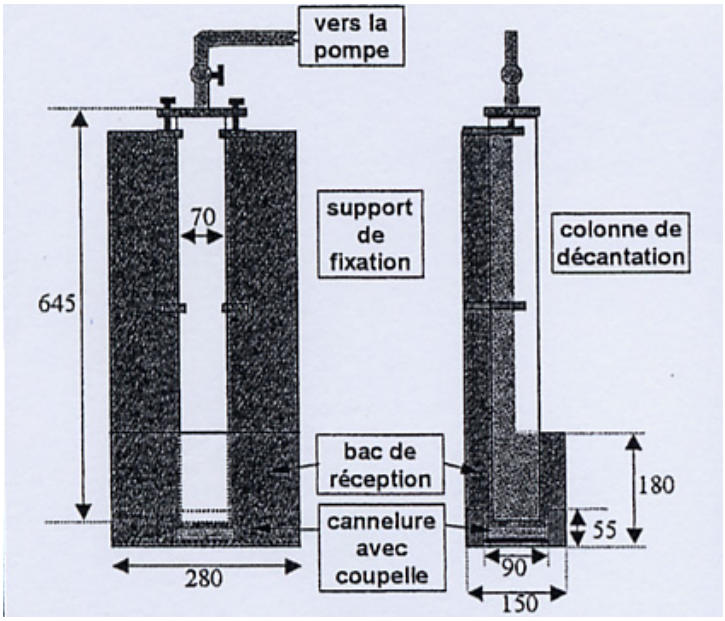


Figure 12 Scheme of the breadboard construction, details of the column, details of the mixing vat, details of the groove:

Device	Characteristics
Settlemant column	d = 70 mm ; h = 64 cm with indicator height and to screws on the top
Mixing vat	PVC rectangular. L = 28 cm ; w = 15 cm ; h = 18 cm groove: L = 27 cm ; w = 9 cm ; h = 5,5 cm on the bottom of the groove, opened plate : L = 26,7 cm ; w = 8,8 cm ; h = 1 cm
Vacuum pump	Q = 30 à 40 L/min
Spoons	In aluminium. d = 70 mm ; h = 18mm
Spoon carriyng device	PVC
Stop watch	
	Plastic (graduated). V = 5 L
Stopper	To seal the column base
Sieve of 2 mm	
d : diameter ; h : height ; L : length ; w = width ; Q : discharge ; V : volume	

Table 6 Device used for protocol VICAS (adapted from Gromaire and Chebbo, 2003)

2.2.4.9 Comparison of the methods

The following two tables show the various characteristics of some protocols.

CHARACTERISTICS	CERGRENE		UFT	ASTON	VICPOL
Method	FL, M(t)	HS, C(t)	FL, M(t)	FL, M(t)	HS, C(h,t)
Preparation	Sieve>50µm	Sieve<50µm	2h of decantation in the Imhoff cone	3h of decantation in the column	Sieve of 2mm
Sample (initial)	1g of SS>50µm	Cv=0,2-0,5% ; SS<50µm	1g of suspended solids	0,5 à 4g of SS	130 to 350 mg/l
Device	IFTS column	Pipette of Andréasen	Column with cone	Column	Column
Decantation height	1,8m	0,2m	0,7m	1,62m	0,43 m
Diameter	0,05m	0,1m	0,05m	0,05m	0,90m
Water origin	drinking	drinking	sewage	sewage	drinking
Range of Vc	0,0197 - 8cm/s	0,0014 to 0,41cm/s	0,01 - 17,5cm/s	0,018 - 2,7cm/s	0,002-3cm/s
FL : floating layer HS : homogenious suspension C(t) : Concentration in function of time M(t) : Settled mass in function of time C(h,t) : Concentration at different levels in function of time Cv : Concentration per volume					

Table 7 Methods to measure the settling velocity curves of solids (Lucas-Aiguier et al., 1998)

CHARACTERISTICS	VICAS	VICTOR	Pipette of Andréasen	American protocol	Dutch protocol
Method	HS, M(t)	HS, C(t,h)	HS, C(h,t)	HS, M(h,t)	HS, M(t)
Preparation	1 colonne	10 colonnes	Pipette	1 colonne	4 colonnes
Device	1 colonne	10 colonnes	Pipette	1 colonne	4 colonnes
Decantation height	0,65m	0,50m	0,50m	2,25m	0,40m
Diameter	70mm	50mm	50mm	150mm	80mm
Water origin	stormwater	drinking water	drinking water	sewage	drinking
Range of Vc	0,01 to 9,9mm/s	0,006 to 2,5mm/s	0,001 to 1,31cm/s	0,003 to 6,75cm/s	0,25 to 64m/d

Table 8 Methods to measure the settling velocity curves of solids (Torres, 2005)

The published results indicate quite different orders of magnitude concerning the obtained settlement velocities

Three nonexclusive principal causes can be proposed to explain these differences (Chebbo, Bertrand-Krajewski, Gromaire, Aires; 2003):

- The studied samples can have very variable characteristics, independently of the used protocols, because they were collected on quite different catchment zones: the differences observed would be only the reflection of this natural variability.

- The protocols, the devices and the fractionation procedures of the pollutants in settlement velocity classes are different and can lead to heterogeneous results for the same sample.

- Otherwise, the suggested methods are often difficult to implement and not always well adapted to the settling velocity ranges from the particles of wet weather effluents.

Gromaire et al., 2003 also described other principal factors which affect the determination of settling velocity distribution curves:

- Quality of the initial sample: the sample must be representative of the effluent and perfectly homogeneous. There are doubts when the filling is done by pumping.

- Errors due to analysis uncertainties of the pollutants: it is advisable to study the propagation of analysis uncertainties and to analyze the sensitivity of the measurement protocol.

- Modification of settlement conditions: settling velocities can be modified because of hydraulic disturbances.

In order to quantify the influence of the experimental procedure on the settling velocity grading curves, Lucas-Aiguier et al. 1996, compared three selected methods: (i) the method developed by the department of civil engineering of Royal Aston University (Tyack et al., 1992), (ii) the method of Cergrene (Chebbo, 1992 - 1994) (iii) the American method (Pisano, 1990) with (iv) the German method developed by UFT (Michelbach and Wöhrle, 1993). The results of the comparative tests indicate that the settling velocities are significantly higher with the UFT test procedure than the other methods. This is mainly explained by the fact that the first three protocols give the particle distribution in relation to the total mass of SS present in the initial suspension and the UFT method takes only settleable solids into account. The residue in the Imhoff cone varies between 25% and 40% of the initial mass. Therefore the distribution curves of the German UFT method does not represent the full interval of settling velocity. Only the distribution of particles which settled 2 hours in an Imhoff cone and with a settling velocity greater than 0,01 cm/s are represented.

2.2.5 Results described in the literature

To analyse the raw data of the UFT protocol, two methods were used:

- UFT calc-uft: the settling velocity curve only concerns the settleable solids whose settling velocity is greater than 0,01 cm/s (solids having settled in the Imhoff cone and in the column after two hours of settling).

- UFT calc Mt: The fraction of solids whose settling velocity is less than 0,01cm/s is the sum of two masses; the mass of solids remaining in the column after two hours of settling and the mass of solids in the residue in the Imhoff cone.

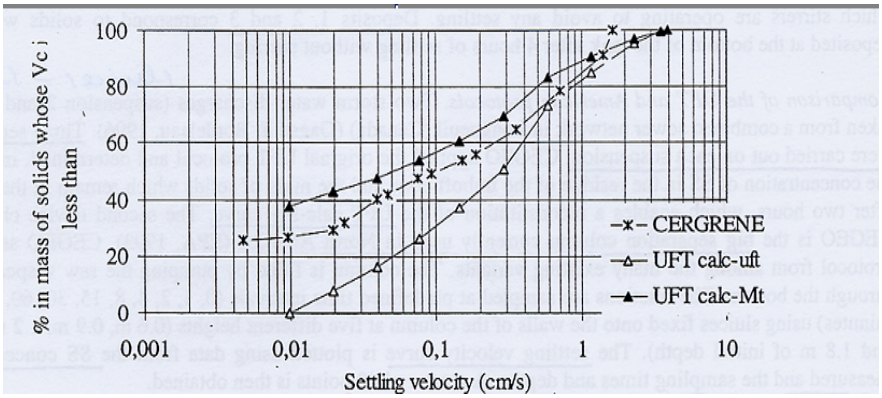


Figure 13 Settling velocity curves measured with UFT protocol and the Cergrene method (Chebbo, 1992)

The samples were taken during a rain storm at the entrance of a retention tank in a small waste water treatment plant. The two methods used for the UFT protocol [(i)calc uft; (ii)calc-Mt] and the obtained results out of these methods lead to the following conclusion: the higher the fraction of fine particles with low settling velocities in the sample, the greater the gap between the results of both methods. Cergrene method delivered settling velocity curve which is significant lower than the curve obtained with the general UFT method because Cergrene takes all solids into account.

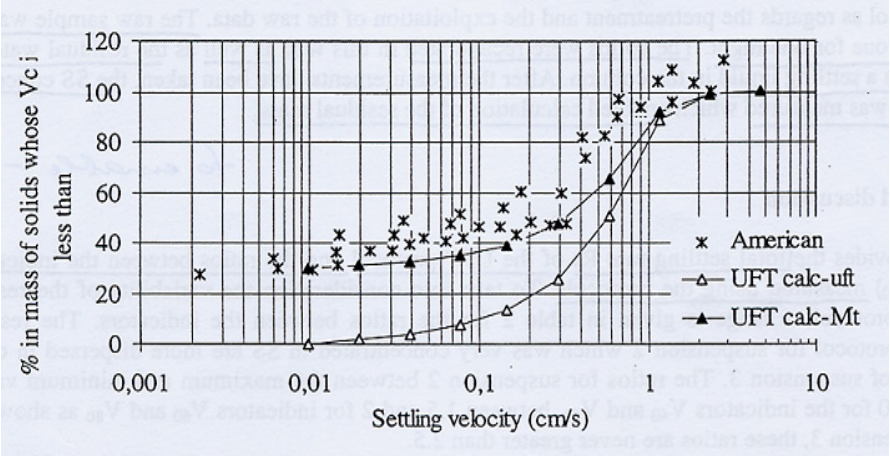


Figure 14 Settling velocity curves measured with UFT protocol and the American method (Chebbo, 1992)

Two stormwater discharges were taken from a combined sewer network. Also here it is obvious that the protocols produce different results for identical samples.

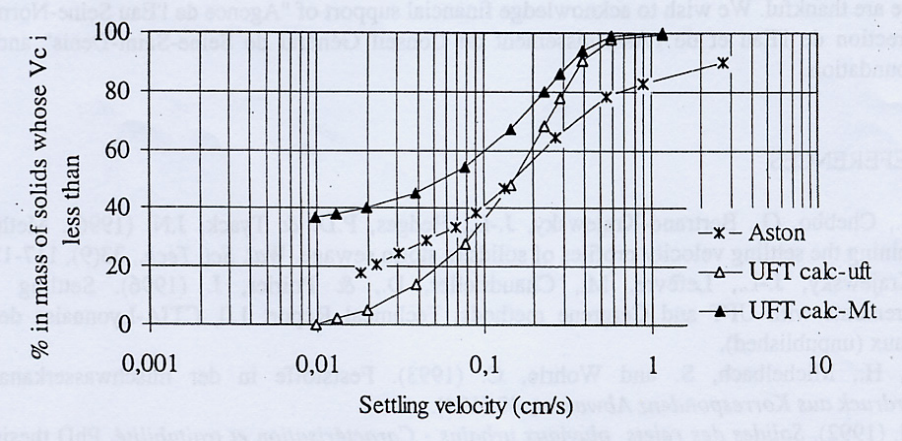


Figure 15 Settling velocity curves measured with UFT protocol and Aston method (Chebbo, 1992)

Four tests were carried out on a raw sewage from partially separated and separated sewer systems. The residue in the Aston column varies between 21 and 37%.

Regarding all three comparisons it is appearent that the inclusion in the UFT calculations of the residual masses in the Imhoff cone and in the column has a great influence on the resulting settling velocity curves. As a conclusion, it is to say that settling velocity curves produced by the original UFT protocol can not be used to evaluate the efficiency of settling tanks as it is recommended by the German guideline A 128. The fact that settling velocity distribution curves obtained by the UFT protocol do not include all settleable mass permits the statement that German stormwater tanks are quite high overdesigned, the efficiency was underestimated.

Michelbach and Wöhrle (1992), carried out experiments with the UFT laboratory on 350 samples to determine the settling velocities. They analysed settleable solids (mg/l), total solids (mg/l), and volatile loss. For each fraction they determined the median settling velocity for settleable solids and dry mass.

The results are shown in the following figure:

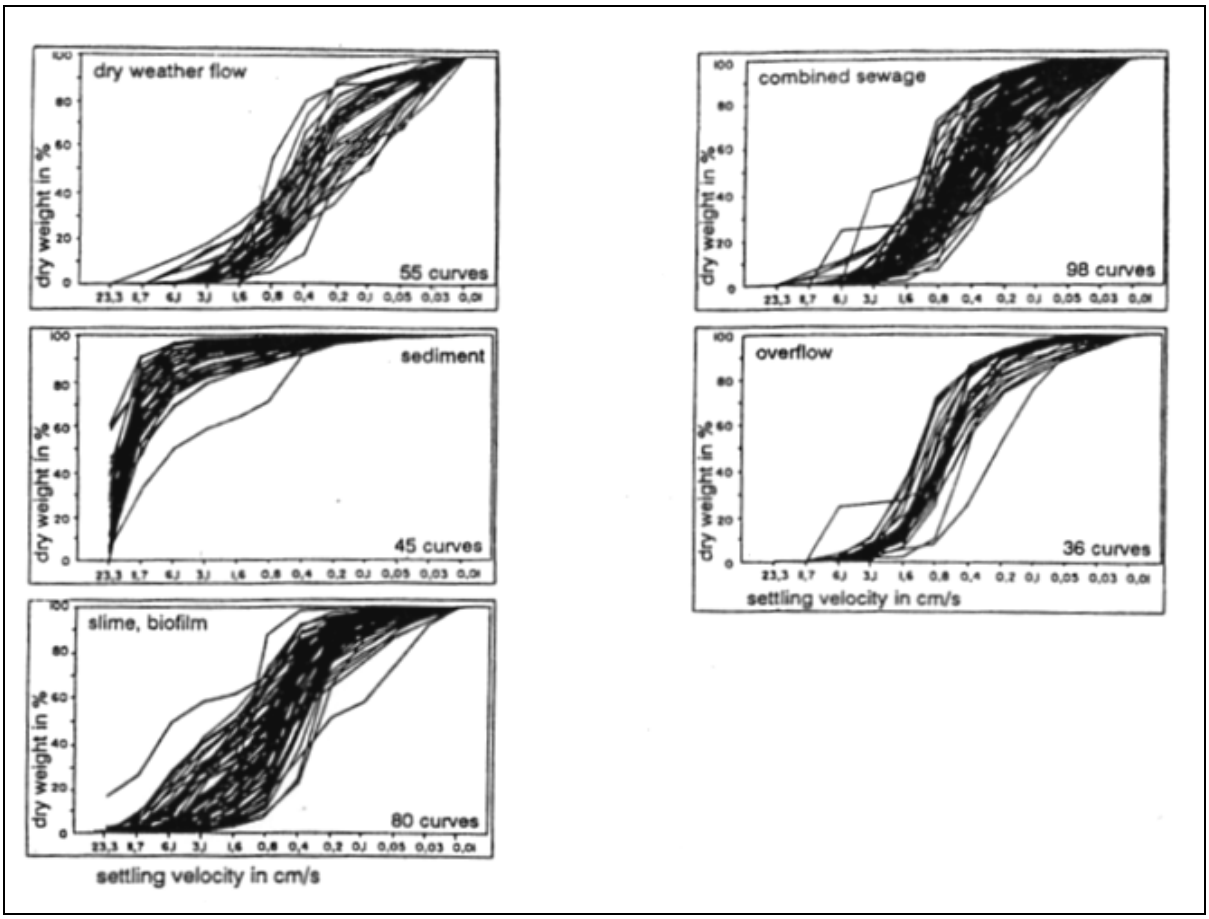


Figure 16 Settling velocity curves (Michelbach and Whörle, 1992)

Michelbach and Wöhrle found that the fastest settleable fractions with settling velocities between 3,1 and 0,8 cm/s had more organic mass than the slower settleable fractions. They also found that the COD was very well correlated with the organic mass, 70% were related to settleable solids with settling velocities higher than 0,28 cm/s, which accounts for 50% of the total COD. They found that the fractions with settling velocities between 0,8 and 0,4 cm/s had the highest load of heavy metals and organic micropollutants, and that the fractions with small heavy metal loads had also small organic loads in micropollutants, which shows a connection between these two pollutants. Moreover, Michelbach and Woehrle report that the settling velocity fraction of 0,4 cm/s is represented by mineral particle of 2,65 g/cm³ and of 0,069 mm size. They also found that a settling velocity of 0,28 cm/s, which corresponds a surface load of 10 m³/m²h, captures 68% of the settleable solids, 68% of the organic matter, 70% of the COD and 78% of the polluting load.

Hedges et al. (1998) investigated the distribution of chemicals within the settling velocity grading curve of suspended sewage solids. The pollutants investigated were COD, TKN, Phosphorus and a suite of 7 metals.
For COD, TKN and P the residue at the end of the tests contains the greatest pollutant load. For the sinkers (Vs > 0,18mm/s), the peak load occurs within the settling velocity of 0,90 to 2,71 mm/s. Regarding the overall distribution of these parameters, 7 to 15 % of the load is found in the floater fraction (< 0,18 mm/s), 31 to 33 % in the neutrally buoyant residue, with the sinkers carrying slightly over half: 54 to 59 %.
Catchment area size (large, medium and small) was not found to influence the distribution of COD, TKN or P within the grading curve.

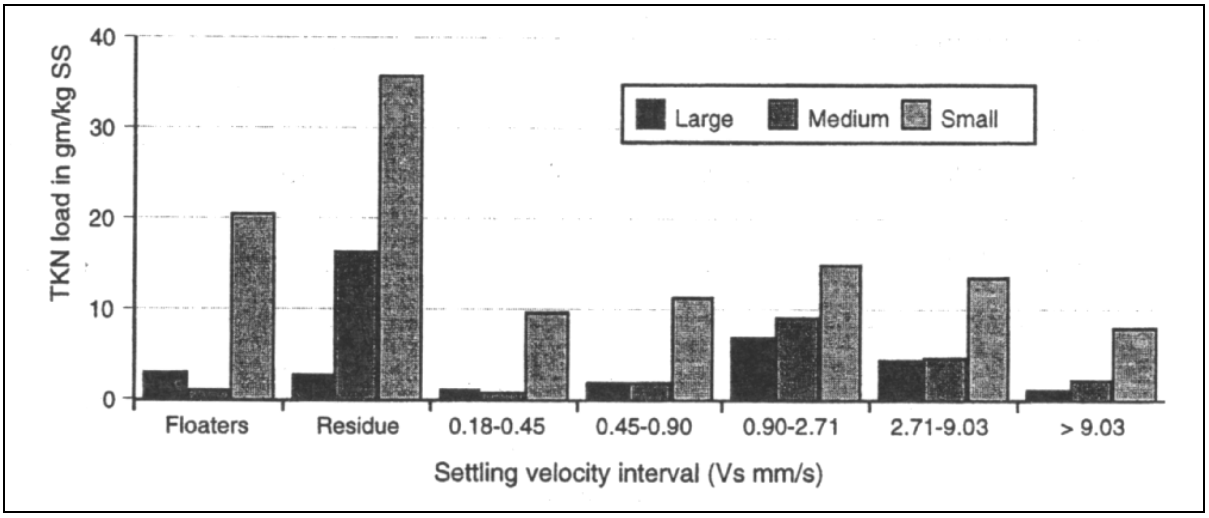


Figure 17 Comparison of TKN distribution for different catchment area sizes (Hedges et al., 1998)

Gromaire et al. (2003), evaluated the reproducibility and the exactitude of the measurement results by taking as protocol reference the protocol VICAS. In order to test the exactitude of the settling velocitiy distributions given by Victor and Vicpol, the results in terms of MES for the same sample were compared with those obtained by considering the Vicas protocol. Simultaneous measurements between Victor and Vicas were carried out for 5 units of rain samples, whose initial concentrations went from 157 to 337mg/l.

The results of Victor reveal systematical under estimated settling velocities compared with those mesured with the Vicas protocol. The differences between the two protocols vary according the studied sample. In addition, the distributions calculated from the upper part of the Victor method are in two cases out of three significantly different from those calculated of the other part of the columns, anyway the settling velocities of Victor remain lower than those of Vicas.

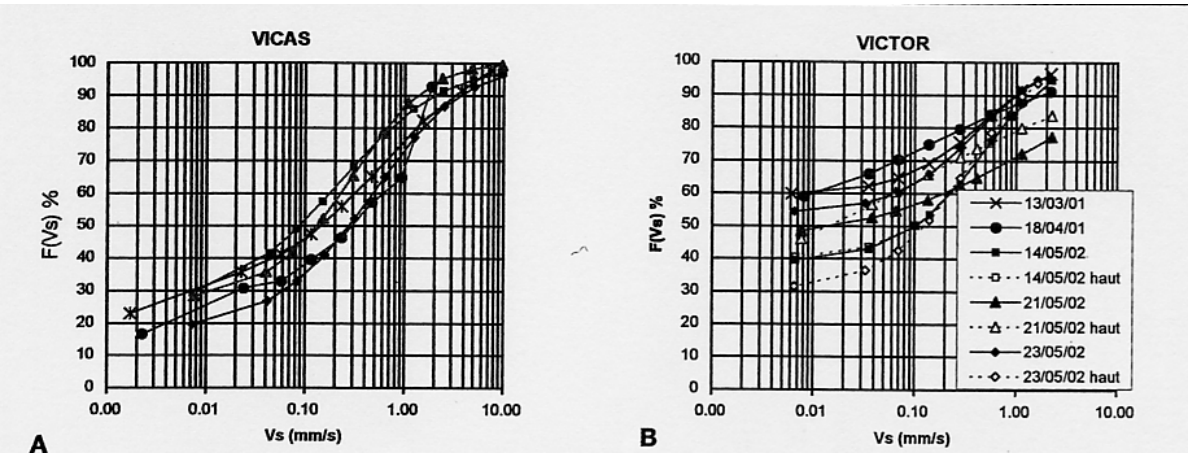


Figure 18 Settling velocity distribution curves of the same sample measured with protocols Victor and Vicas (Chebbo, 1990)

Tests were carried out in order to establish if the difference between Victor and Vicas could be imputed to the difference between the internal diameter of the columns of sedimentation: 50mm in the case of Victor and 70mm in the case of Vicas. In order to observe this phenomenon, settling velocity measurements were carried out in parallel with 2 Vicas columns with diameters 50 and 70. It was not possible to see differences between the two columns. This result confirms the informations given by Chebbo and Milisic (1989).

The tests carried out with the Victor method affirm the need to modify its mode of implementation in order to improve the reproducibility and to decrease its sensitivity to the initial homogeneity and the generated uncertainty. Uncertainty disappears on the other hand if the measurement of the initial concentrations is taken by the average value of the upper part and the lower part in the column.

Another conclusion was that protocol VICTOR has a bad reproducibility and that it underestimates the settling velocities. Reproducibility was evaluated by tests on the decantation of SS. The reproducibility of the settlement in the Victor columns was tested for the 4 following durations of decantation: 8min, 32min, 64min and 120min. For each one of these durations, fractioning was repeated 8 times on the same sample of rain water. The initial sample concentration of SS used for these tests varied between 153 and 417 mg/l. The settled mass was evaluated from the concentration in the lower part of the column, as recommended in the protocol. For the VICPOL protocol, fractionation was repeated 4 times on the same sample for the following times of decantation: 12min, 45min, 4h and 24h. The effluents utilised for these tests had initial concentrations in SS between 142 and 311mg/l.

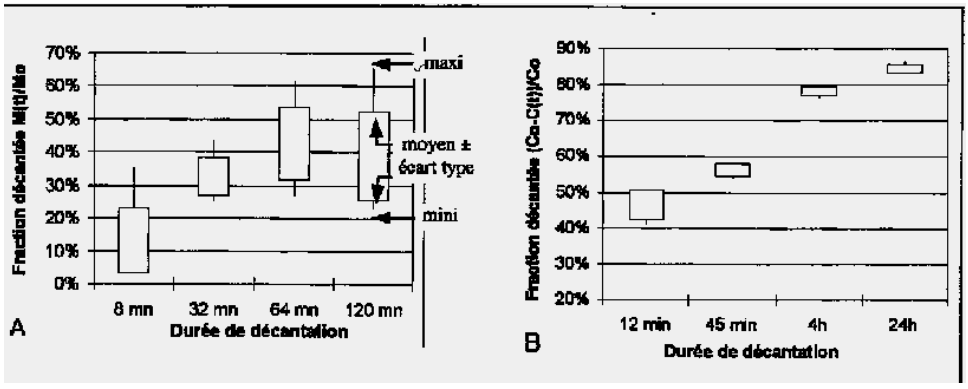


Figure 19 Reproducibility of protocol Victor (A, 8 repeats) and Vicpol (B, 4 repeats)

The reproducibility of the Victor method is insufficient when the calculation of the settled mass is carried out from the concentration of the lower part of the column. This bad repeatability can be partly imputed to the sensitivity of the protocol to the initial concentration. It is necessary to add uncertainties which depend on the initial homogeneity.

The results obtained with Vicpol reveal a good reproducibility of the settling curves for times 45min, 4h, 24h and in a less measurement for time 12min. Only four replica were carried out so it is possible that the values are a little bit underestimated.

The comparison between Vicas and Vicpol does not reveal a significant difference between the two settling velocity distributions.

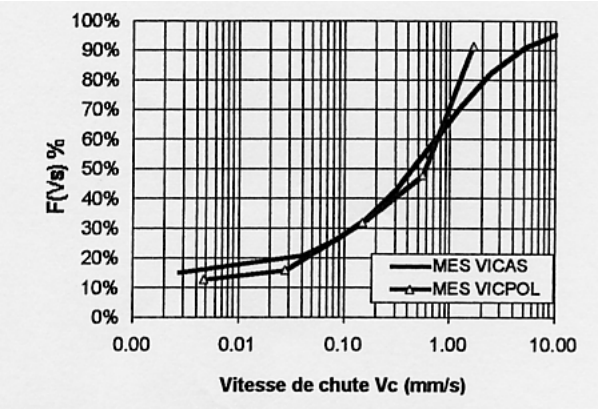


Figure 20 Comparison of settling velocity grading curves measeared with protocols Vicas and Vicpol

Three tests of reproducibility were carried out for the protocol Vicas (Chebbo, 1990). During these tests, 4 to 7 replicats of the settling velocity measurements were carried out by two different experimenters, on two different settlement columns. The settling curves obtained for the different replicats from the two tests are given in Figure 27:

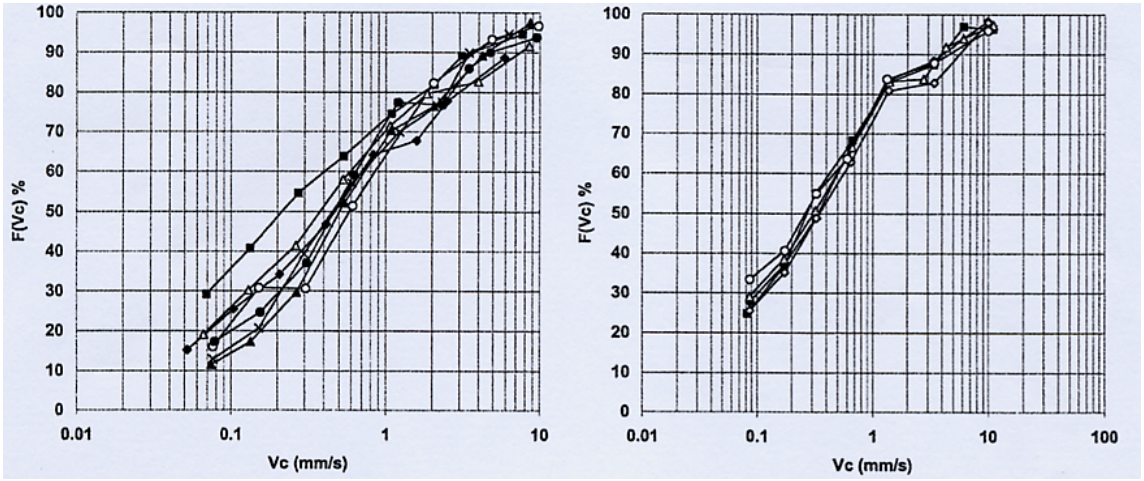


Figure 21 Comparison of settling velocity grading curves measeared with protocols Vicas and Vicpol

	Test 2		Test 3	
Nombre de réplicats	7		5	
Concentration initiale	121 mg/l ± 11 %		283 mg/l ± 3 %	
	σ /moy	E90	σ /moy	E90
V30	27,1 %	±53 %	11,5 %	± 24 %
V40	20,4 %	±40 %	10,6 %	± 23 %
V50	14,8 %	±29 %	12,4 %	± 26 %
V80	16,1 %	±31 %	5,7 %	± 12 %
% < 0,04 mm/s	29,5 %	±37 %	13 %	± 28 %
% < 0,4 mm/s	13,3 %	±18 %	4,4 %	± 9 %
% < 4 mm/s	3,6 %	±7 %	2,5 %	± 5 %

Figure 22 Reproducibility of protocol Vicas

Conclusion of the literature review:

All explained methods are quite different. The measurement principles are not the same ones and the utilised fragmentation apparatuses have different characteristics. Some methods make it possible to get sufficient volume to carry out the analyses of several pollutants such as SS, organic matter, mineral and organic micropolluants.
But they present a certain number of weak points, different from a protocol to another, which makes it very difficult to compare the results obtained.

However only two methods (Victor and that of Benoist and Lijklema) analyse various parameters because they function with a volume of 20 to 30 liters.
The implementation of the American method requires at least 45 to 50 liters to carry out the fragmentation, so its employment becomes more difficult.

It was confirmed by Chebbo et al. (2003), that the Vicas protocol constitutes a more simple and reliable protocol for the measurement of the settling velocity curve of SS. This is the protocol we used in our research work.

3. Description of the experimental site

3.1 OTHU Project

(Observatoire de Terrain en Hydrologie Urbaine) - Field Observatory for Urban Water Management

In all scientific fields, the precise observation of natural phenomena constitutes the basic element for the construction of knowledge. In urban hydrology, as in other disciplines, the teams of research are confronted with several specific difficulties: the environment can never be entirely controlled, systems of the biological and physical interactions are complex and the scales of studies are numerous. Measurement is thus subjected to the risks of nature and the in situ experimental difficulties, which often leads the researchers to privilege speculative steps.

The research described in this report was carried out within the OTHU project (Field Observatory for Urban Water Management). The scientific objectives of this observatory consist in improving knowledge on climatology, risks of flood and pollution by urban stormwater, volumes of water and masses of pollutants produced and discharged by the urban area, as well as their evolution in various devices (networks, tanks, infiltration devices), and in the natural systems (rivers, soils, groundwater, biocenosis).
See: http://www.graie.org/othu.

This outdoor laboratory is devoted to the acquisition of reliable urban hydrology data, in order to provide results, knowledge, and methodologies to assess the sustainability of the urban water system and to support operational decision making. The observatory is constituted of measuring units installed in the Lyon sewer system.
The research federation is composed out of seven universities and engineering schools, where French engineering school INSA - Lyon (Institut National des Sciences Appliques de Lyon) belongs. Further eleven research laboratories and approximately 45 researchers take part in the investigations.The Urban Community of Lyon, the Water Agency, Ministries of Equipment, Ecology and Research and Rhône-Alpes Regional Council assist also as operational partners.

A long term objective is a multidisciplinary approach on the following scientific fields:

- Climatology
- Hydrology
- Hydraulics
- Soil Science
- Chemistry
- Biology
- Hydrobiologie
- Social Science
- Economy

Experimental Site

The research actions concentrate on the following subjects:

- Rainfall distribution
- Hydraulic and pollutants loads in urban catchments during dry and wet weather periods
- Impact of discharges on soils, waterbodies and aquifers
- Interaction between urban and rural areas
- Development of strategies for sustainable urban water management.

The observations are provided based on long term by means of on-line monitoring sensors and samplers. With this, an objective is the global assessment of rainfall impact at five experimental catchments in Lyon agglomeration which are representative for :

- Urban and peri – urban areas
- Combined and separate sewer systems
- CSOs retention and infiltration tanks
- Impacts on small peri urban watercourses and aquifers.

3.1.1 Participation and interest of INSA

Urban hydrology can be defined as the scientific discipline focused on the water and its relationships to the various human activities in urban areas.

The pursued scientific goals are on the one hand the acquisition of knowledge on the physical phenomena, the construction and the validation of new models representing these phenomena and on the other hand the construction of methods for decision-making on processes like design, management and rehabilitation.

The principal research topics of the INSA laboratory are as follows:

- Knowledge of the rain on fine scale of time and space
- Hydrological behaviour of catchment areas in the course of urbanization
- Hydraulic operations of urbain drainage networks
- Behaviour of porous structures and roadways with structure tank
- Measuring and modelling the urban effluents during wet weather and to study their transformations in the facilities (pipe networks, retention tanks, infiltration tanks).

3.2 Django Reinhardt tank in Chassieu

The site Django Reinhardt is located in the industrial zone of the Chassieu municipoltiy, in the Eastern Suburbs of Lyon. This catchment area is equipped with a separative sewer system (sewage/rain water). The drained surface of the catchment area is 185 ha. The slope of the catchment area is average, approximately 4% in the East-West direction.

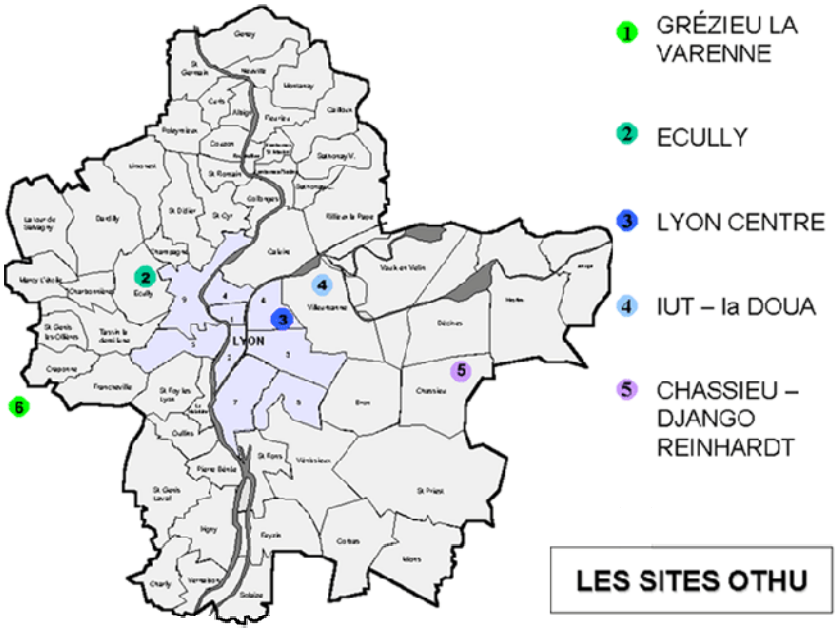


Figure 23 The experimental sites of OTHU project

This device was built in 1975 and was retrofitted in 1985, 2002 and 2004. It is composed of two sub-tanks connected by a 60 cm diameter pipe: a retention-settling compartment and an infiltration compartment. During dry weather periods, the tank receives a small flow of water from some industries that are authorized to discharge cooling waters to the stormwater network. Water enters the tank by two 1,6 m circular pipe.

Photograph of the experimental site

The bottom of the retention-settling tank has a bitumen layer and a gutter for dry weather flow with a depth of 20 cm and a width of 2 m. Its volume is about 32200 m^3 and its bottom surface of 11300 m^2 (Declercq and Lefebvre, 2002). The current stormwater outflow is in regularized to 700 L/s by an overflow and an emergency overflow also exists (Bardin and Barraud, 2004).

Photograph of the experimental site

After three years of operation, the infiltration compartment appears strongly colmatated. It was assumed that the settling was insufficient in the retention-settling tank (Bardin and Barraud, 2004). Following the recommendation of Bardin and Barraud (2004), the tank of retention-settling was modified. This modification consisted in the construction of a low separation wall in order to compartmentalize the tank.

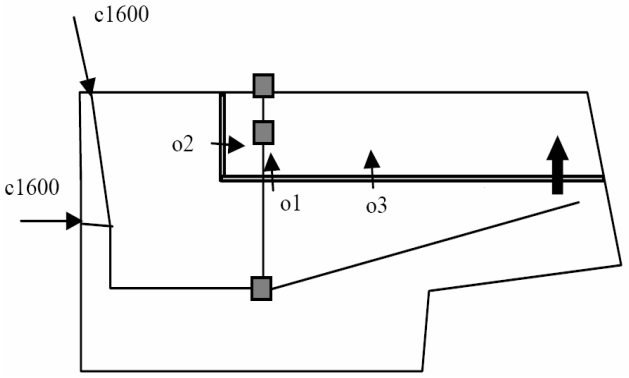


Figure 24 Schematic representation of the Django Reinhardt retention-settling tank after its retrofitting in 2004 (Bardin and Barraud, 2004)

Based on the topography of the settling tank done by Al Bitar (2002), a new topography including the low wall was constructed. This complete topography is the base for the hydraulic modeling now in progress.

4. Methodology

4.1 Description of the field experiment

Samples of settled solids were collected by means of 12 sediment traps -plastic boxes with internal honeycomb structure- installed in the tank which is given in Figure 26:

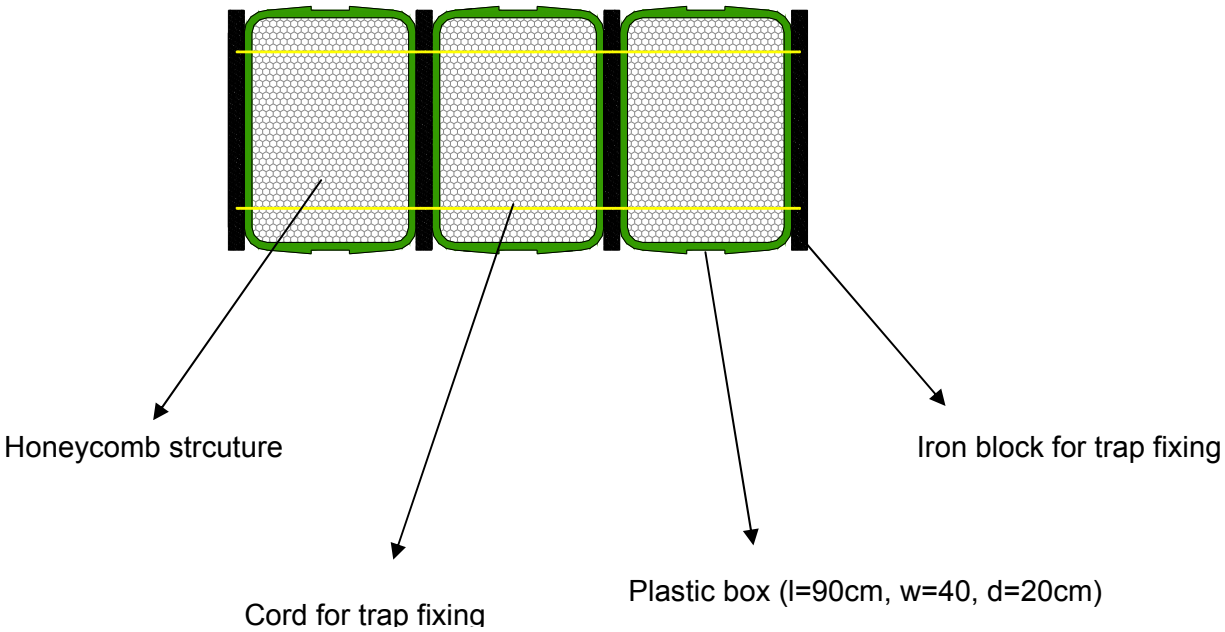


Figure 25 Plastic boxes with internal honeycomb structure

4.1.1 Settlement trap positioning

Their location (Figure 27) has been defined according to preliminary hydraulic modelling results, including recirculating zones, magnitude of flow velocities and real sediment accumulation zones observed in the tank.

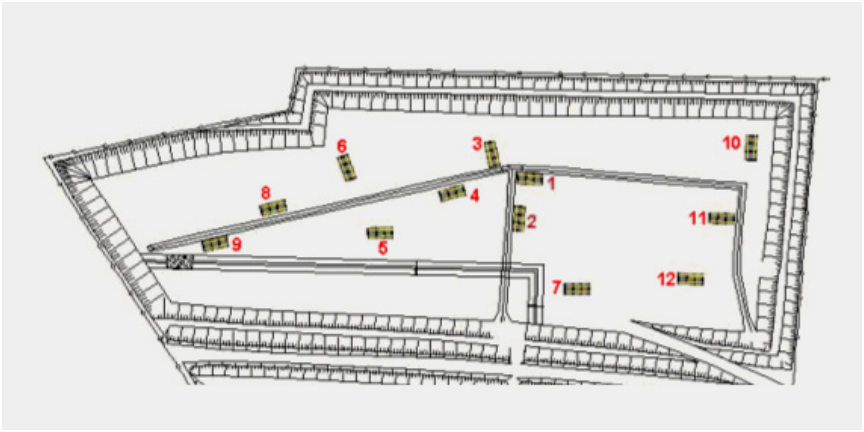


Figure 26 Plan with the 12 locations of settlement traps

4.1.2 Field operation

A constant observation of the weather and especially of possible rain events is very important before the setting of the sediment traps. The honeycomb structure is sensitive to sunlight therefore it is recommended to avoid sunlight which requires a weather dependend time planning.

Before the rain event:

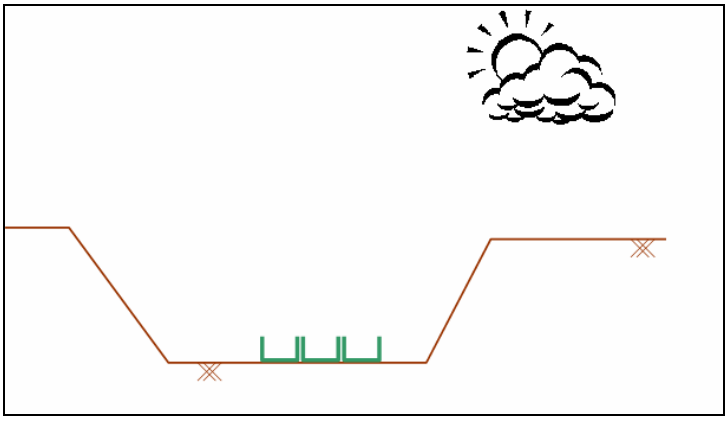


Figure 27 Scheme before the rain event

At each location it exists the possibility to set three settlement traps. The plastic boxes are located with their honeycomb structures where the suspended solids can settle calm and regularly. This structure avoids a resuspension of particles. The trap is fixed by an iron block at both sides and a rope is bound around the boxes (and the structure) linked and fasten with knots. This is necessary because of turbulences caused by heavy storms.

Figure 28 Fixed settlement traps (plastic boxes and honeycomb structure)

During the rain event:

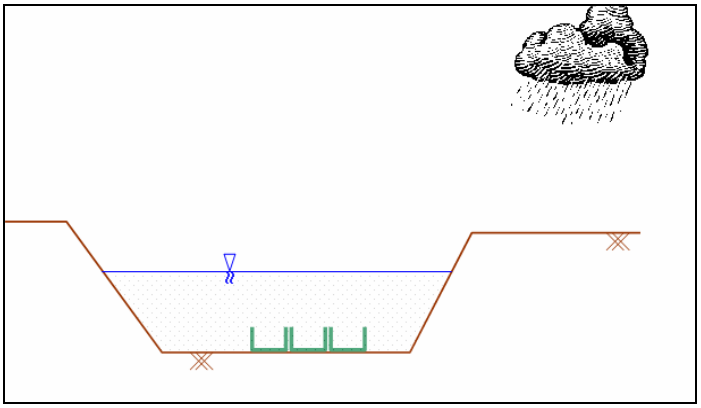


Figure 29 Scheme during the rain event

The storage / retention tank is filled and the sediments settle in the traps.

After the rain event:

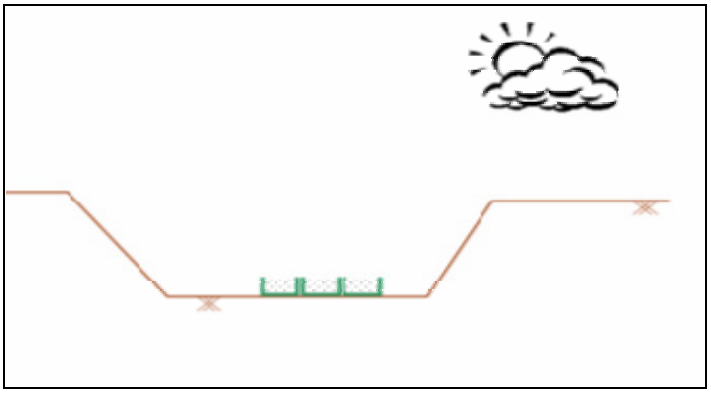


Figure 30 Scheme after the rain event

After the rain event the hollow spaces of the honeycomb structure in the plastic boxes are filled with settled particles. Now the collecting of the sample (mixture of stormwater and sediments) can be undertaken. Therefore it is necessary to take the honeycomb structure carefully out of the plastic boxes. The remaining mixture represents the sample. The laboratory experiment with the Vicas protocol needs a convenient concentration of the sample with a volume of 5 L. The content in the box will be mixed by hand and then a homogeneous (less heterogeneous as possible) content will be filled into plastic bottles (2 x 2 L and 1 x 1 L). Then the sample is brought to the laboratory for the determination of the settling velocity curve of these sediments.

Photographs of the experimental site at sampling:



4.2 Measurement principle of the laboratory experiment – VICAS protocol

The VICAS protocol (Gromaire et al., 2003a, b) is based on the principle of the homogeneous suspension, assuming that particles settle independently, without aggregation and diffusion.

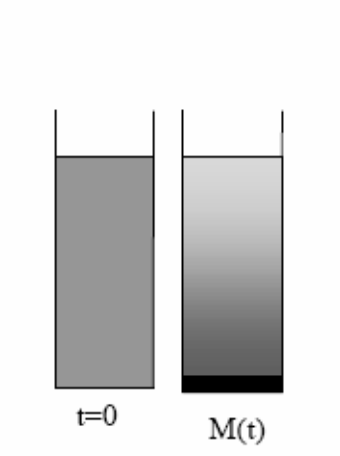


Figure 31 Principle of the homogeneous suspension

Protocol VICAS was conceived with the following objectives and conditions:

- Realization of measurement immediately after collection of the sample,
- No pretreatment of the sample before measurement
- Volume of necessary water should be low (a few liters of sample)
- Not very expensive apparatus, simple to manufacture and simple to handle
- Requires only one operator
- Fast measurement (a few hours).

Solids having settled during preset intervals of time are collected at the bottom of the sedimentation column. Their recovered mass is weighed and makes it possible to determine the evolution of the cumulated mass M(t) of the deposit according to time t (see Figure 33). In practice, the curve of the cumulated mass of suspended solids having settled consists of n points, generally between 7 and 12, corresponding to n sub – samples taken at different times t.

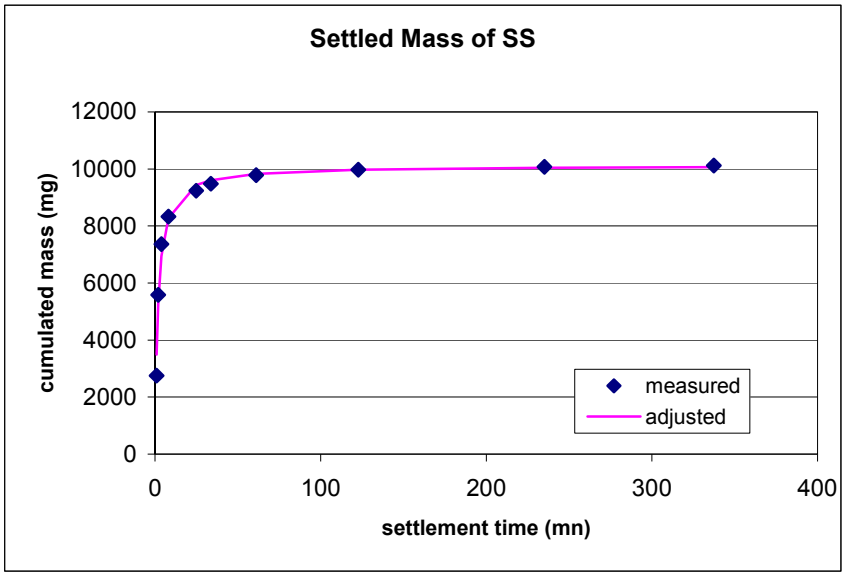


Figure 32 Curve of the mass cumulated of solids elutriated according to time

Particles being initially distributed in a homogeneous way on all the height of column, they all do not fall the same distance. So M(t) does not correspond with a homogeneous category of the particles.

A theoretical analysis (Chebbo, 1992; Chancellier et al., 1998) show that the curve M(t) can be written in the following form:

$$M(t) = S(t) + t\frac{dM(t)}{dt}$$

equation 1

where;

M(t): cumulated mass of particles settled at the column bottom until time t,

S (t): settled mass of particles at time t having a settling velocity higher than H/t, where H is the height of the water in the column,

tdM/dt: mass of particles settled at time t with a settling velocity lower than H/t (located initially at a distance d lower than H), where H is the maximum height of settling (height of water in the column)

The measurement objective is to determine the curve S(t) and to transform it into the curve F(Vs) indicating the cumulated percentage F(%) of the total mass of particles having a settling velocity lower than Vs (m/h) which is given in Figure 34:

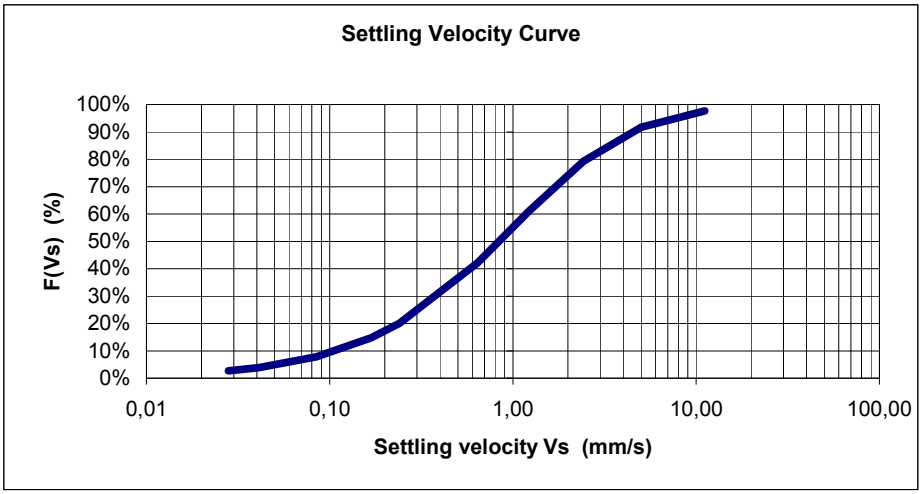


Figure 33 Example of a $F(V_s)$ curve

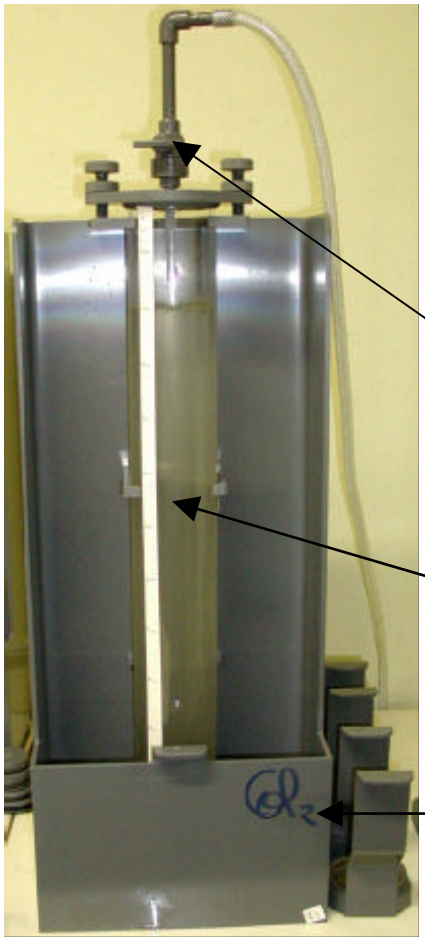
The settling velocity distribution curve F(Vs) represents:

- the settling velocities V_s in m/s are in x-coordinate on a basic logarithmic scale of 10 increasing towards the line.
- The percentage of the cumulated mass F of the particles having a settling velocity V_s lower than a given value is in ordinate on a linear scale from 0 to 100%.

4.2.1 Description of the fractionation device

The fractionation device of the VICAS protocol is composed of the following elements:

- Settling column



composed of a Plexiglass tube with an inner diameter of 70 mm and a height of 64 cm and provided with one scale graduated in cm indicating the distance from the bottom of the tube. The higher section of the column is connected to a rigid pipe provided with a valve allowing to seal the top of the column (Figure 35).

Figure 34 Device of fractionation

- Mixing vat

Rectangular mixing vat length is 28 cm, width 15 cm, height = 18 cm with a cannelure of 27 cm length, 9 cm width, 5.5 cm height. At the bottom of the cannelure there is a grid (plate in PVC pierced with holes) of L*b*h dimension = 26*88*10mm(Figure 36).

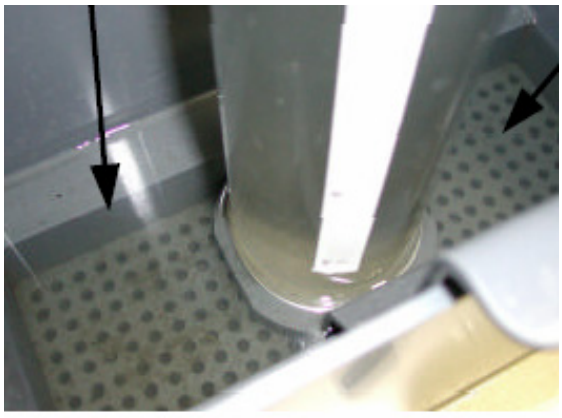


Figure 35 Interior of the mixing vat (cannelure and grid)

- A vacuum pump, with a capacity of 30 to 40 liters/minute, linked with a tube at the top of the column which draws and permits its filling

- A protection system for the pump against the backflow of the sample liquid

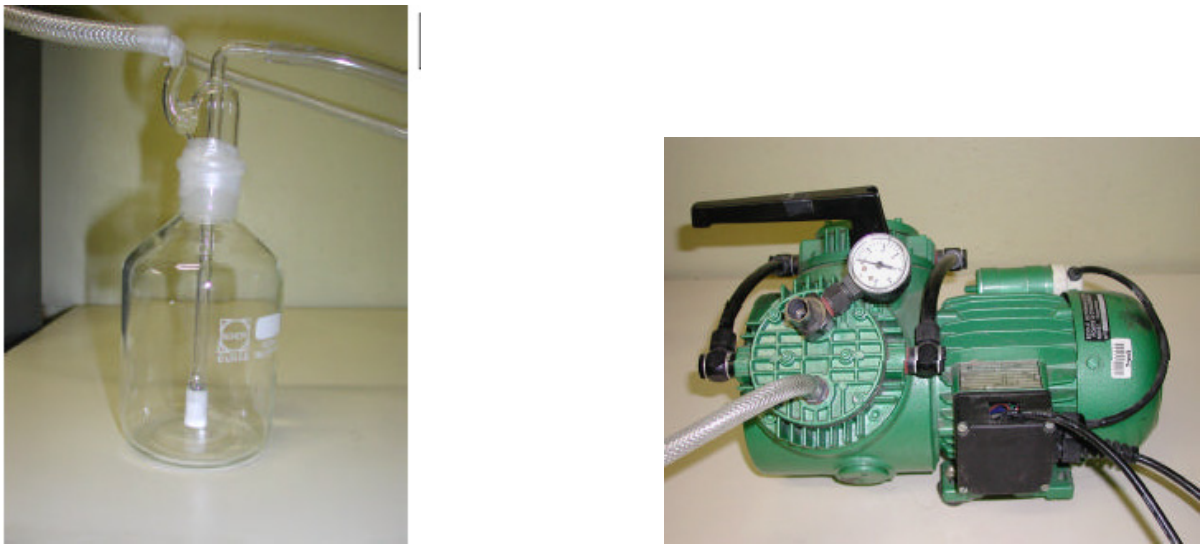


Figure 36 Vacuum pump (right) and protection device (left)

- Cup carrier made of PVC and cups of aluminium with a diameter of 70 mm, a height of 18mm, to collect the settled particles at the bottom of the column (Figure 38).

Figure 37 Aluminium cup and PVC cup carrier

- A stop watch

- A graduated pitcher of plastic with a content of 5 liters

- A cork which permits to close the end of the column

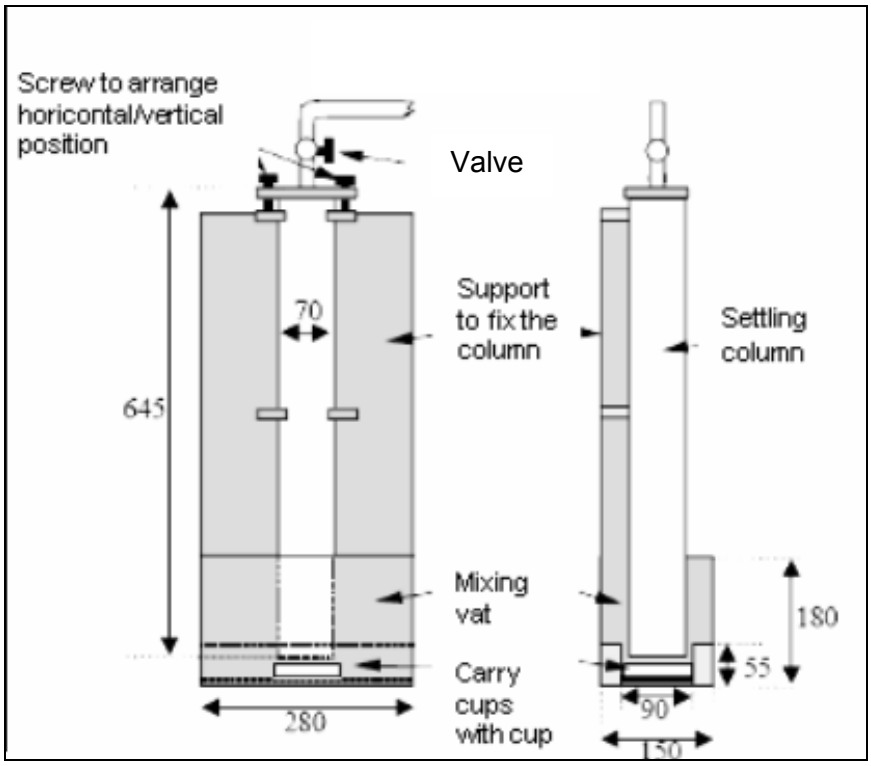


Figure 38 Device for the settlement measurement for the protocol Vicas

Figure 39 Experimental setup in the laboratory

4.2.2 Operation protocol

Preservation of the samples

The best adapted preservation, if it is not possible to avoid it, is refrigeration at 4°C for a duration lower than 24 hours in the fridge.

Preliminary Activities

- Check the position of the column above the vat.
  The distance between the bottom of the vat and the column bottom must be sufficient to move the cups under the column bottom. This can be adjusted by two screws which are located at the top of the column bottom.

- Check the verticality of the column by using a spirit level. If there is a need to modify the verticality, use the adjustment of the two screws on the top to find verticality.

- Prepare the first four cups being used for the first sub sampling at different time intervals (ti = 1 mn, 2 mn, 4 mn, 8 mn) which are carried out very close. The preparation consists to place the cups on their cup-carriers and to fill them with potable water.

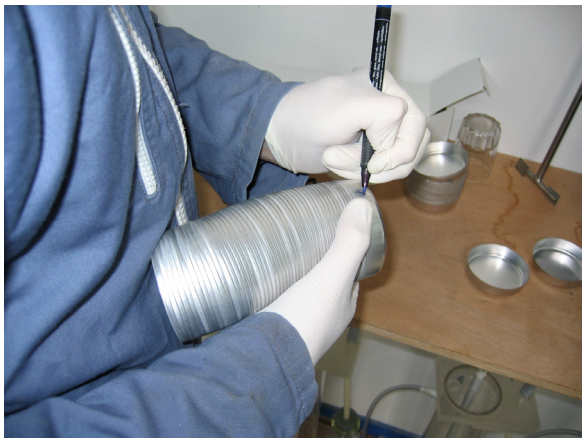


Figure 40 Marking of the cups with the time steps of the settling intervals

Preparation of the sample

- Homogenize the sample as much as possible without breaking particles
- Filter a sample volume of 4,5 L by using a 2mm fence
- Pour the sample into a graduated jug up to a volume of 4.5 L
- Homogenize the sample well by hand
- Take three sub samples in small bottles of 250 mL, from 100 to 150 mL each one. Determine on these three replicates the initial concentration of the sample. This step was led beside because of the uncertainty factor.

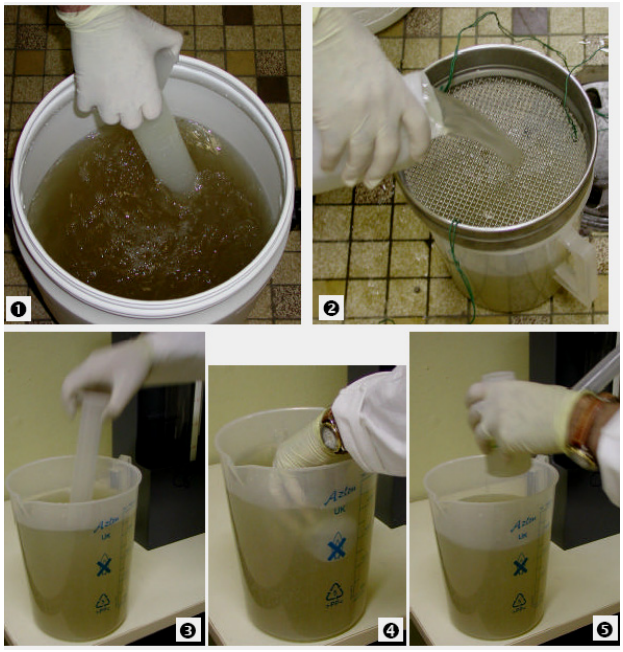


Figure 41 Preparation of the initial sample and sub-sampling

Filling of the column

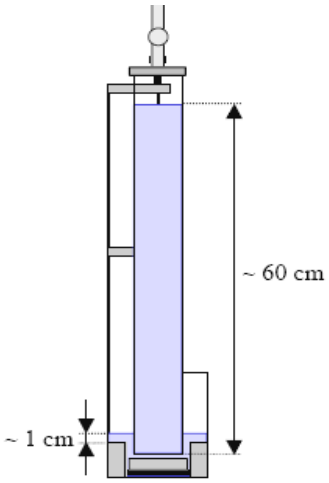


Figure 42 Filling of the column

- Open the valve with a quarter turn which is located at the top of the column.
- Bring into service the vacuum pump which is connected to the top of the column.
- Homogenize the sample well before pouring it in the vat of mixture. The liquid is then aspired in the column (this rise lasts from 2 to 5 seconds depending on the power of the pump).
- When the water level in the vat is just above the higher edges (inner edges of the mixing vat, see Figure 43) close the valve which is located at the top of the column.

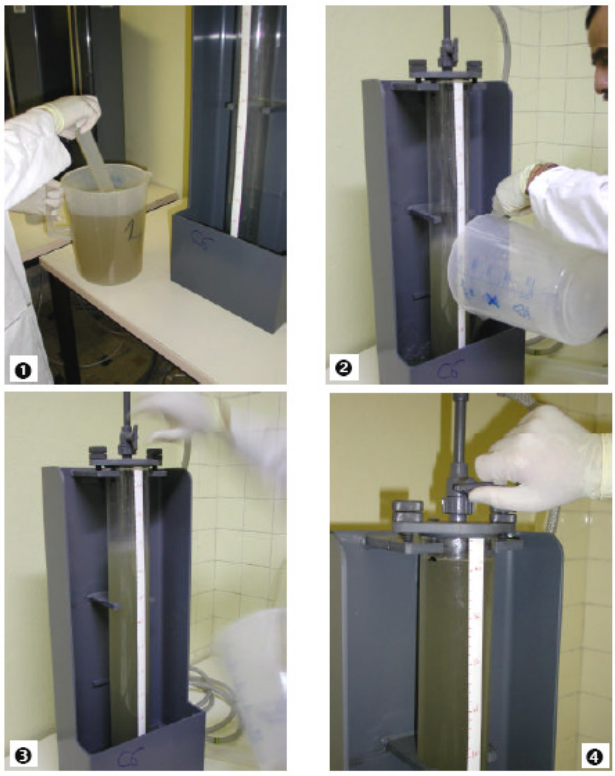


Figure 43 Mixing of the sample and filling of the column

Starting of the settling

- Place immediately and cautiously the cups in its cup-carriers in the cannelure, then let it slip to the column base and put it under the column
- Start the stop watch
- Stop the vacuum pump
- Note the waterlevel in the column

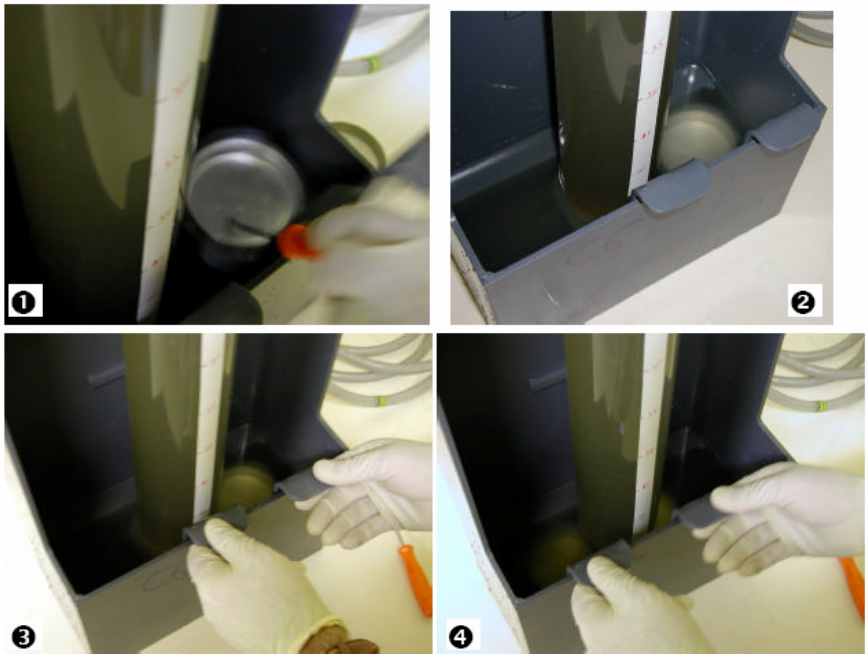


Figure 44 Placing and changing of the cups

Change of the cups

Change the cups at the end of times at 1 min, 2 min, 4 min, 8 min, 16 min, 32 min, 64 min, 2h, 4h and >12h.

Determination of the final concentration

- When the last sub-sampling is carried out, close the end of the column with a cork and withdraw the column of its support (see Figure 46)
- Pour the content of the column in a clean jug
- The sample of the jug will be filtered to determine exactly the final mass

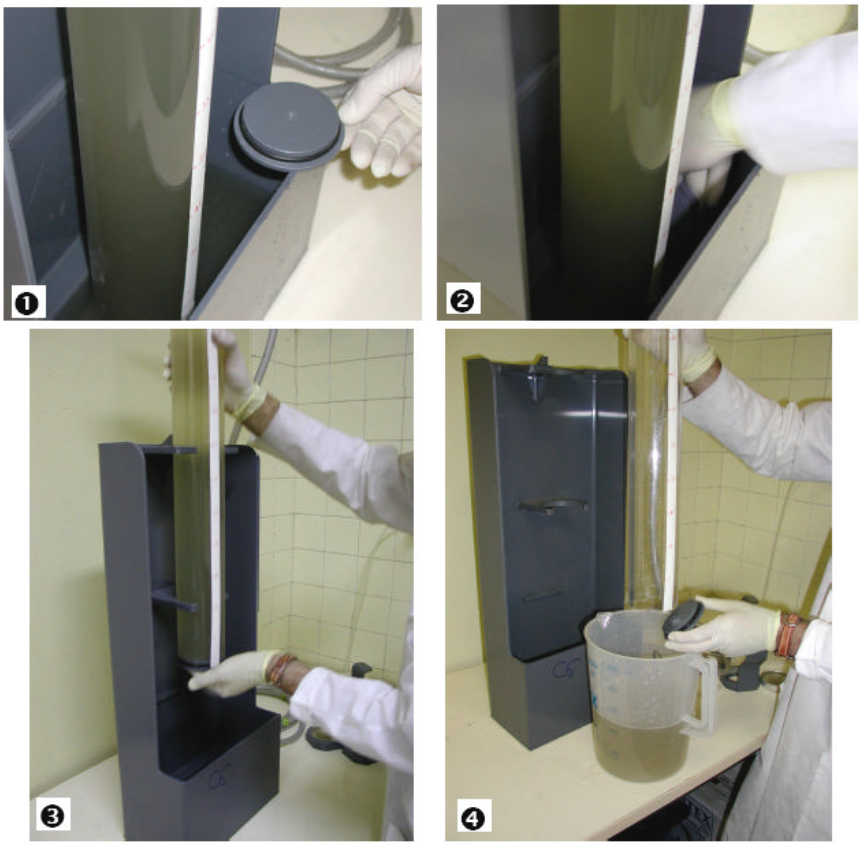


Figure 45 Collection of the last sample

4.2.3 Analytical Procedure

The initial and final concentrations as well as the masses collected in each cup are determined by vacuum filtration on a fiberglass membrane, dried at 105°C and then weighted after 24 h.

Pretreatment of the filters

The filters holding capacity is 0,7 µm. For each settling velocity, 16 filters are necessary. These filters must be prepared in advance, in order to have a sufficient number of them.

Pretreatment:

- Washing of the filter on the filtering device with approximately 50 to 100 mL of distilled water
- Drying of the filter at 105°C in a drying oven
- Cooling of the filter (15 to 30 min) in a desiccant
- Weighting of the filter on a balance with precision 0,1mg (determination of the mass m0, in mg) – value of the balance must be stable
- Storage of the filter in a numbered cup in the dessicant (to prepare one day before the experiment ~ netto weight of filters)

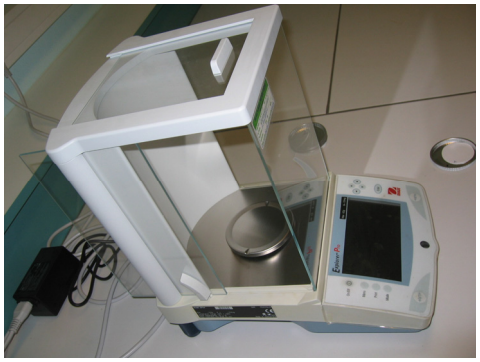


Figure 46 Weighting of the filters

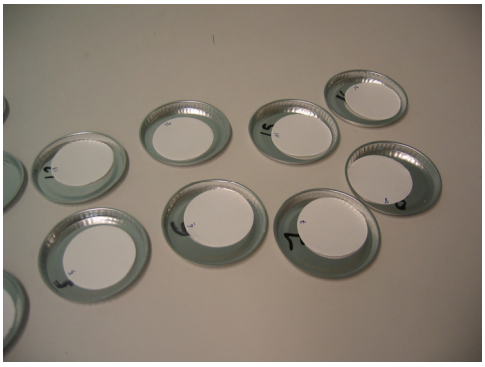


Figure 47 Filters on numbered cups

Initial and final concentration of the sample

The sub-sampling of the initial sample for the determination of the initial mass lead to very unprecise and varying results. So it was decided to led this procedure beside which does not constitute a problem because the initial mass is not used for a further exploitation regarding the settling velocity grading curves. Hence, the measurement of the final mass is important for the calculation of the protocol uncertainty interval.
The final mass determination was improved by filtering all content of the column after the last settlement interval. By this way it is possible to measure exactly the final mass in the column after the experience.

Determination of the final mass after the filtration of the remaining content in the column:

- Drying of the filter during 1h30 – 2h, at 105°C
- Cooling of the filter with the filtered mass in a dessicant
- Weighting of the filter on a balance with precision 0,1 Mg (determination of the mass m1, in mg) – value of the balance must be stable

Mass contained in each cup

- Carefully withdrawing of the cup from its carry-cup (any loss of liquid would involve a loss of particles and this imports a distorting of the measurement),
- Filtering the contents of the cup by using a pretreated filter,
- Carefully rinsing of the cup with distilled water to avoid any particles loss,
- Drying of the filter with the mass during 1h30 - 2h at 105°C,
- Cooling of the filter with its mass in the dessicant
- Weighting the filter with its mass on a balance with precision 0,1 mg (determination of the mass m1, in mg) – the value of the balance must be stable

Figure 48 Filtration of the cups content

Figure 49 Device of dessicant

4.2.4 Data Analysis

Principles of calculation

Mass balance
This mass balance rests on the comparison of the total initial mass presented in the column with the total settled mass and the final mass in the column at the end of the experience. A calculation of the mass balance is carried out in order to estimate the losses (or the profits) of solids with run of handling and thus to evaluate the quality of measurement:

Initial mass in the column (mg):

$$M_{ini} = \frac{C_{ini} H \pi R^2}{1000}$$

Final mass in the column (mg):

$$M_{fin} = \frac{C_{fin} H \pi R^2}{1000}$$

Cumulated settled mass (mg) :

$$M_{settl} = \sum_i m_i$$

Error (%) of the mass balance:

$$E = \frac{M_{ini} - M_{settl} - M_{fin}}{M_{ini}}$$

A careful handling makes it possible to reach errors on the mass balance lower than ±10 %. An error higher than ±15 % must invalidate the measurement.

Determination of the settling velocity distribution

This method implements a numerical fitting of a function M(t) on the measured values M(ti), then to solve equation 1 analytically. The function M(t) must accomplish the following criteria:

- Settled mass at time t=0, i.e. M(t=0) = 0 or limM(t) = 0 when t tends towards zero
- Settled mass increases according to time, dM(t) /dt > 0
- Curves inclination decreases according to time, $d^2M(t)/dt^2 < 0$
- Number of adjustment parameters should be lower or equal to 4 to preserve simple expressions and to allow a satisfying adjustment even with a limited number of points.

Methodology

The principle of this method was initially introduced by Saint Pierre *et al*. (1995), with the use of a function M(t) obtained by a regressive logarithmic curve. However the logarithmic function curve did not allow a sufficiently precise adjustment of the measured values mi. This method, and in particular the choice of the function M(t), was developed by Bertrand-Krajewski (2001). After having tested several tens of expressions for the curve M(t), Bertrand-Krajewski (2001) retained the following expression:

$$M(t) = \frac{b}{1 + \left(\frac{c}{t}\right)^d}$$

with b, c and d three numerical parameters where b > 0, c > 0 and d element of]0,1[.

Derivation S(t):

$$S(t) = M(t) - t\frac{dM(t)}{dt} = \frac{b\left(1 + (1-d)\left(\frac{c}{t}\right)^d\right)}{\left(1 + \left(\frac{c}{t}\right)^d\right)^2}$$

Finally:

$$F(V_s) = 100\left(1 - \frac{S(t)}{M_{dec} + M_{fin}}\right) \text{ with } V_s = \frac{H}{t}$$

An Excel Spreadsheet makes it possible to obtain the curve FVs) starting from equations written above which was developed by M.C. Gromaire and H. Chebbo (2001-2003).

4.3 Mass balance and determination of losses of the Vicas protocol

4.3.1 Introduction

Gromaire and Chebbo (2003) proposed to calculate a mass balance to judge the quality of results. This mass balance rests on the comparison of the total initial mass presented in the column with the total settled mass and the final mass in the column at the end of the experience. This method assumes and works with the hypothesis that systematical error comes only from the sample taking through using cup-carriers at the bottom of the column (Torres and Bertrand-Krajewski, 2006).
It was not possible to get a reliable mass balance because of the further necessity to use the initial mass during the protocol to determine the settling curves. For that purpose a spot check of three samples was carried out to determine the initial mass in the column by the initial concentration.

In fact, results of realized campaigns gave too different results of mass balances. Therefore, we decided to consider the results of the mass balance as an indicator value.

To precise the masse balance and to determine the losses, an experiment was carried out. To get a reliable value, it is necessary to predetermine the initial mass before the experiment is carried out. The idea was to produce three different loaded samples (high loaded sample, medium loaded sample and low loaded sample) where the initial mass is known and to look for the losses of the masses between them. To determine realistic different mass loads, we took into account the results obtained from previous experiments (from rain event 24/03/2006, campaign 02).

Mass balance of three different loaded samples:

Low loaded sample:

$$\% = \frac{(M_{ini,low} - (M_{dec,low} + M_{f,low}))}{M_{ini,low}}$$

Medium loaded sample:

$$\% = \frac{(M_{ini,med} - (M_{dec,med} + M_{f,med}))}{M_{ini,med}}$$

High loaded sample:

$$\% = \frac{(M_{ini,high} - (M_{dec,high} + M_{f,high}))}{M_{ini,high}}$$

4.3.2 Mass balance in the column

Ist) $M_{ini,\ col.} = M_{dec} + M_{fin} = 100\%$

2nd) $M_{ini,\ col.} - (M_{dec} + M_{fin}) = 0$

Mini……..initial mass in the column

Mdec..... settled mass of the column

Mfin, col..… final mass in the column

If there are no losses the second equation should be confirmed.

4.3.3 Experiment operation

4.3.3.1 Reflections before the validation was carried out

At the beginning of the experiment a predetermined initial mass was fixed. The homogeneous mixed suspension of the initial concentration was poured into a mixing pot by a bucket. A pump sucks the sample into the column. To the end of the experiment it was remarked, that greater parts of mass were remaining in the mixing tub.

4.3.3.2 Suppositions

1. It is highly probable that the homogeneous mixed sample was distributed unregular between the column and the mixing tub and that is why Mini was reduced in the column.

2. A non neglecting part of mass rests in the bucket which was used to pour the sample into the mixing tub.

3. The ´spoon´ which collects the settled mass of the column does not catch all settled mass Mdec of the column. A small part remains at the margin of this catching recipient.

4. A small part of the mass remains in the mixing tub because of the changing of the ´spoons´.

5. It is not clear that the balance is absolutly precise.

6. It is possible that the taken sample was not dry enough. The remaining humidity increases the initial mass at the time of the balancing but it decreases when it goes into suspension.

7. We did not use a ´desicateur´ to prevent a humidity taking of the air.

The experiment was carried out carfully and the points given above have been considered:

- The interior surface of the column was cleaned and its content was poured into the mixing tub.
- To homogenisize and to mix the sample before the experiment started, we used a mixing bar called homogeniziser.
- The remaining part of mass in the mixing tub was taken carefully after the experiment and weighten after infiltration.
- Also the bucket which was used to pour the sample into the mixing tub contained greater parts of mass which were weighten after infiltration of the remaining sample in the bucket.

4.3.3.3 Hypothesis of a systematic error

- During pouring the sample into the mixing tub parts of mass got lost or were poured beside.
- During the infiltration of the sample suspension smaller parts remained in the filling glas of the infiltration device.
- Parts of mass remained at the margin of the the catching recipient called ´coupelle´.

4.3.3.4 Mass balance taking into account all losses

Here, the initial mass is reduced with all its losses (mass in mixing tub, mass on homogenisizer, mass remaining in the bucket), with the remaining mass in the tube and the settled mass. By dividing this term through the initial mass the percentage of all losses is obtained:

$$\% = \frac{(M_{ini} - (M_{fin} + M_{settl.} + M_{mix.\text{-}tub} + M_{homog.} + M_{bucket}))}{M_{ini}}$$

4.3.3.5 Determination of the systematic loss

The initial mass consists of the following mass parts (including a systemati mass loss):

$M_{ini} = M_{fin} + M_{settl.} + M_{mix.\text{-}tub} + (M_{homog.} + M_{bucket})^{*1} + \Delta^{*2}$

*1 $M_{homog.}$ and M_{bucket} are considered as corrigible losses

*2 Δ = systematic loss of the experiment

The systematic mass loss is then:

$\Delta = M_{ini} - M_{settl.} - M_{fin} - M_{mix.tub} - M_{homog.} - M_{bucket}$

4.4 Measurement uncertainties associated to the Vicas protocol

The most commonly used protocol in France to measure the settling velocity curve is the protocol VICAS (Vitesse de Chute en ASsainissement), which is founded on the principle of the homogeneous suspension of type A. Despite VICAS protocol consists of various non-automatic stages to measure the distribution of settling velocity, no calculation formula for determining the uncertainty of obtained settlement curves exists until now.

Gromaire and Chebbo (2003) proposed to calculate a mass balance to judge the quality of results. This mass balance rests on the comparison of the total initial mass presented in the column with the total settled mass and the final mass in the column at the end of the experience. This method assumes and works with the hypothesis that the error comes only from the sample taking through using spoons at the bottom of the column.

A method was developed by Torres and Bertrand-Krajewski to calculate the uncertainty of settling velocity distribution for the VICAS protocol. Therefore a Matlab program application was developed. This program should estimate the uncertainties regarding the distribution of settling velocities.

The measurement uncertainty is a parameter associated to a measured result, which characterizes the dispersion of values which could be allotted to the measurande. This can be a standard deviation, a multiple of this, or the half-width of a given confidential interval.

The measurement uncertainty includes in general several components which can be evaluated from:

- statistical distribution of the measuring series results, characterized by experimental standard deviations.

- standard deviations, starting from the laws of probability, according to the gained experience or other information.

Standard uncertainty is the uncertainty of a measured result expressed in the form of a standard deviation.

4.4.1 Estimation of uncertainties on $F(V_s)$

To determine the uncertainty associated to the settling velocity curve of SS obtained by the protocol VICAS, it is necessary to treat uncertainties of the measurands F(s) and Vs independent from each other.

F(Vs) is not measured directly. It is determined by the values t, b, c, d, Msettl. and Mfin. with the following expression:

$$F(V_s) = f_F\left(t,b,c,d,M_{dec},M_{fin}\right) = 1 - \frac{b\left(1+(1-d)\left(\frac{c}{t}\right)^d\right)}{\left(1+\left(\frac{c}{t}\right)^d\right)^2\left(M_{dec}+M_{fin}\right)}$$

where,

t	:settling time
b, c, d	:parameters of the simulation curve in relation with the settled mass Msettl
Mfin	:final Mass in the column

Uncertainty associated with F(Vs) can be calculated with the equation:

$$u^2\left(F(V_s)\right) = \sum_{i=1}^{6}\left(\frac{\partial f_F}{\partial x_i}\right)^2 u^2\left(x_i\right) + 2\sum_{i=1}^{5}\sum_{j=i+1}^{6}\frac{\partial f_F}{\partial x_i}\frac{\partial f_F}{\partial x_j}u\left(x_i, x_j\right)$$

where,

$u\left(x_i\right)$: estimated incertainty of the variable x_i

$u\left(x_i, x_j\right)$: estimated covariance between x_i and x_j

with,

$x_1 = b$, $x_2 = c$, $x_3 = d$, $x_4 = t$, $x_5 = M_{settl}$, $x_6 = M_{fin}$

To evaluate the uncertainty u(F(Vs)) it is necessary to determine the parameters t, b, c, d, Msettl and Mfin and their respective uncertainties.

4.4.1.1 Evaluation of t and its uncertainty u(t)

Parameter t is measured directly. It is the time of settling, i.e. the moment when the operator recovers a certain mass of SS at the bottom of the column. The different times suggested by the protocol to recover each sample are 1 min, 2 min, 4 min, 8 min, 16 min, 32 min, 64 min, 2 h, 4 h and >12 h. So there are 10 different sampling times.

The uncertainty u(t) is the uncertainty associated with each time reading. An estimation cannot be done by observing a lot of experiment repeats and thus fix values are proposed a priori.

4.4.1.2 Evaluation of parameters b, c and d and their uncertainties u(b), u(c) and u(d).

b, c, and d are the parameters of the curve which are connected to the settled mass Msettl at a certain settling time ti.

$$M\left(t\right) = \frac{b}{1 + \left(\frac{c}{t}\right)^d}$$

Normally, these parameters are adjusted with the last squares method, and their uncertainties are not evaluable directly. To determine the parameters the Monte Carlo Simulation is applied.

4.4.2 Monte Carlo Simulation

Monte Carlo Simulation is a probability-weighted simulation to solve numerically complex processes. It is possible to simulate uncertainties and statistical behaviour on the basis of a random process. A random process designates equivalent and independent series of attempts. Although the result of each individual attempt is coincidential it is possible to perceive regularities by a high number of repetitions.

4.4.2.1 Operation

#	b	c	d
1 : : : : : 5000	; : : : : : ;	; : : : : : ;	; : : : : : ;
mean value	b(average)	c(average)	d(average)
σ	Δ(b)	Δ(c)	Δ(d)
uncertainty	u(b)	u(c)	u(d)

5000 sets of cumulated masses were simulated. For these sets of cumulated masses, the parameters, b, c and d were adjusted, so that b > 0, c > 0 and d element]0;1[.

For each attempt the following curve is calibrated:

$$M_k(t) = \frac{b_k}{1 + \left(\frac{c_k}{t}\right)^{d_k}}$$

by the method of the least squares, to find the parameters, b_k, c_k and d_k.
The procedure will be repeated from k=1 to n times. The obtained result is a triplet of parameters (b, c, d). From these triplets, it is possible to calculate the average value and the standard deviation of each parameter. The uncertainty-type of each parameter will be taken equal to the standard deviation of each parameter.

The following figures show successively the approach to find the uncertainties u(b), u(c) and u(d):

A. Measured values without simulation:

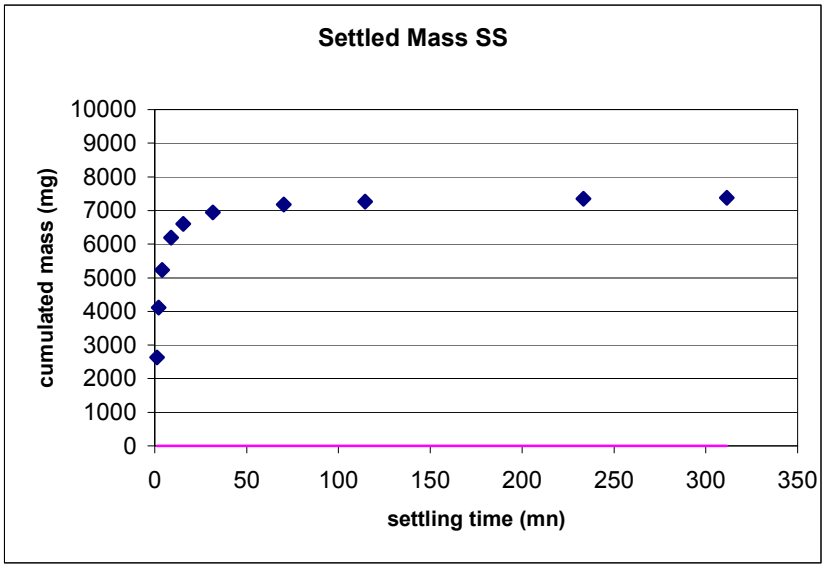


Figure 50 Measured values by protocol Vicas without calibration of the curve M(t)

B. Simulation of one curve where parameters b, c and d are exactly calibrated, u(b, c, d) = 0

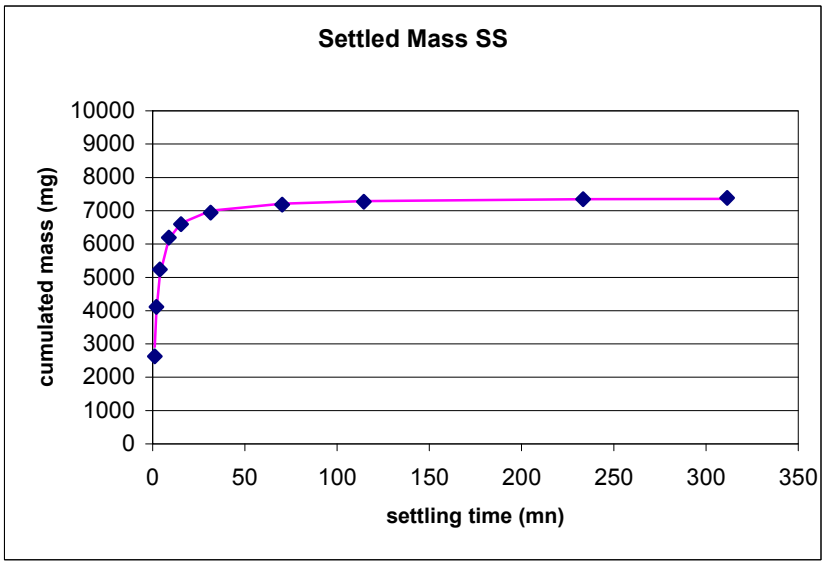


Figure 51 Measured values by protocol Vicas with exact calibration of b, c and d

C. Simulation of one curve where parameters b, c and d are not properly calibrated, so range of uncertainty is high

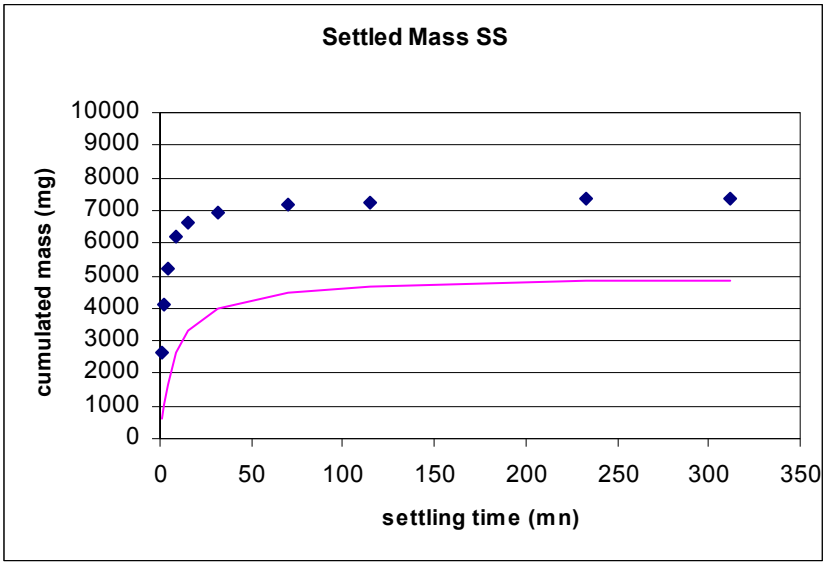


Figure 52 Measured values by protocol Vicas with imprecise calibration of b, c and d

D. Simulation of 5000 curves (x coordinate:time in sec – y coordinate:settled cumulated mass in mg)

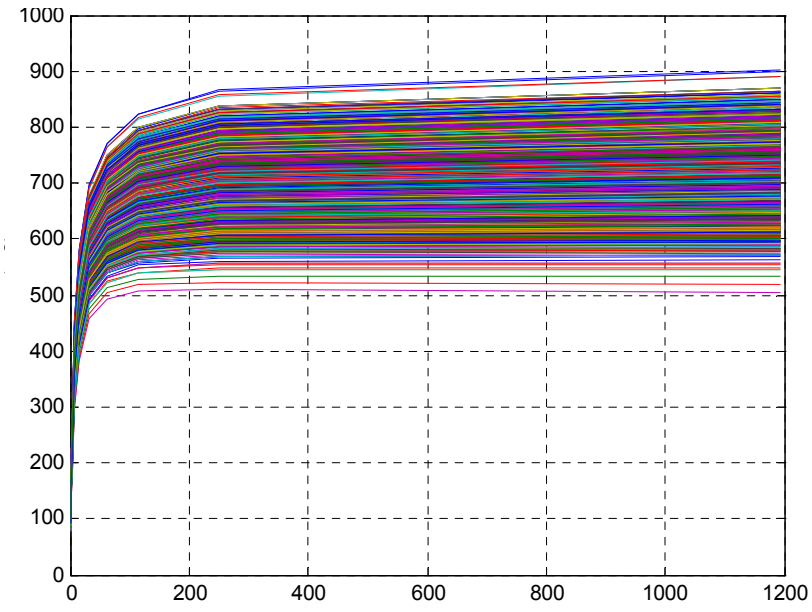


Figure 53 Simulation of 5000 curves

4.4.3 Estimation of uncertainties on V_s

Torres and Bertrand-Krajewski developed a program of propagation of uncertainty under MatLab. This program, called UVICAS, applies the Vicas protocol equations from page 57.

By the application of protocol VICAS there are several unknown variables (which are presented in Table 9) at the beginning of the experiment thats why they have to be fixed with values of standard uncertainties founded on the experiment of the applied protocol. The following table shows the values of uncertainties which will be applied to for all Vicas experiments:

Measurand	Uncertainty	Observations
$u(F(V_s))$	$u(t) = 0.0167$ min	Consideration that the values of times are noted with a margin of 2 s. Standard uncertainty is fixed at 1 s, independently of the concerned timestep.
$u(M_{settl})$	$u(m_{op}) = 0.5$ mg	The precision of the balance used is 1 mg.
	$u(m_{fp}) = 5.0$ mg	This value was chosen to take into account all the errors related to the handling from the positioning of the cup at the column base until the weighting of the settled mass.
$u(M_{fin})$	$u(H) = 0.05$ cm	The precision of the meter at the column is 1mm.
	$R = 3.493$ cm	Value obtained from 15 diameter measurings from each column
	$u(R) = 0.017$ cm	Value obtained from 15 diameter measurings from each column
$u(\overline{C_f})$	$u(V_{fg}) = 0.001$ L	The precision of the test-tube used is 2 mL.
	$u(m_{fi_g}) = 0.5$ mg	The precision of the balance used is 1 mg.
	$u(m_{ff_g}) = 5.0$ mg	This value was chosen to take into account all the errors related to the handling from the positioning of the cup at the column base until the weighting of the settled mass.
* if the confidence interval of a variable X is known, the interval has to be note in the form $X \pm 2u(X)$, with $u(X)$ as standard uncertainty and a factor of widening k=2 corresponding to a level of confidence from approximately 95%		

Table 9 Values of supposed uncertainties (Torres, 2005)

Then the matrices of correlation were calculated to estimate the uncertainty of the settling velocity curves.

Figure 54 shows an example with great range of uncertainties calculated with program UVICAS. Monte Carlo simulations were carried out for 800 curves.

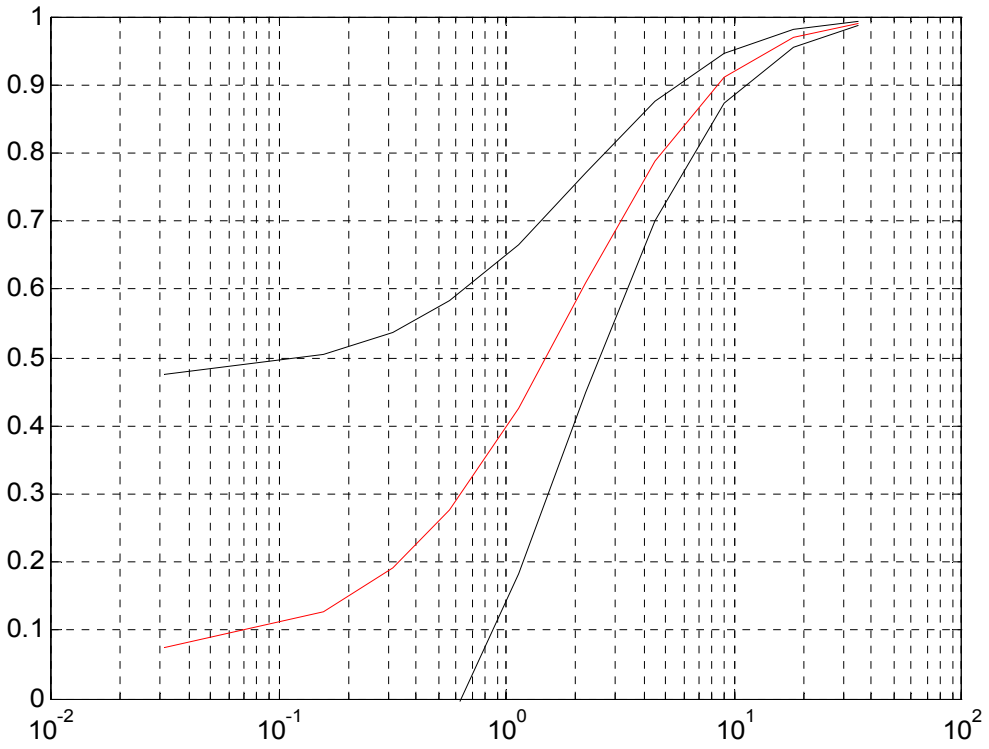


Figure 54 Example of uncertainty

Therefore it was necessary to change the following fixed values of uncertainty:

Concerning u(M_{settl}):

$u(m_{ffg}) = 0{,}5$ mg	This value was chosen to take into account all the errors related to the handling from the positioning of the cup at the column base until the weighting of the settled mass.

Concerning u(C_f):

$u(m_{fp}) = 0{,}5$ mg	This value was chosen to take into account all the errors related to the handling from the positioning of the cup at the column base until the weighting of the settled mass.

Figure 55 shows a settling velocity curve when the uncertainty is small:

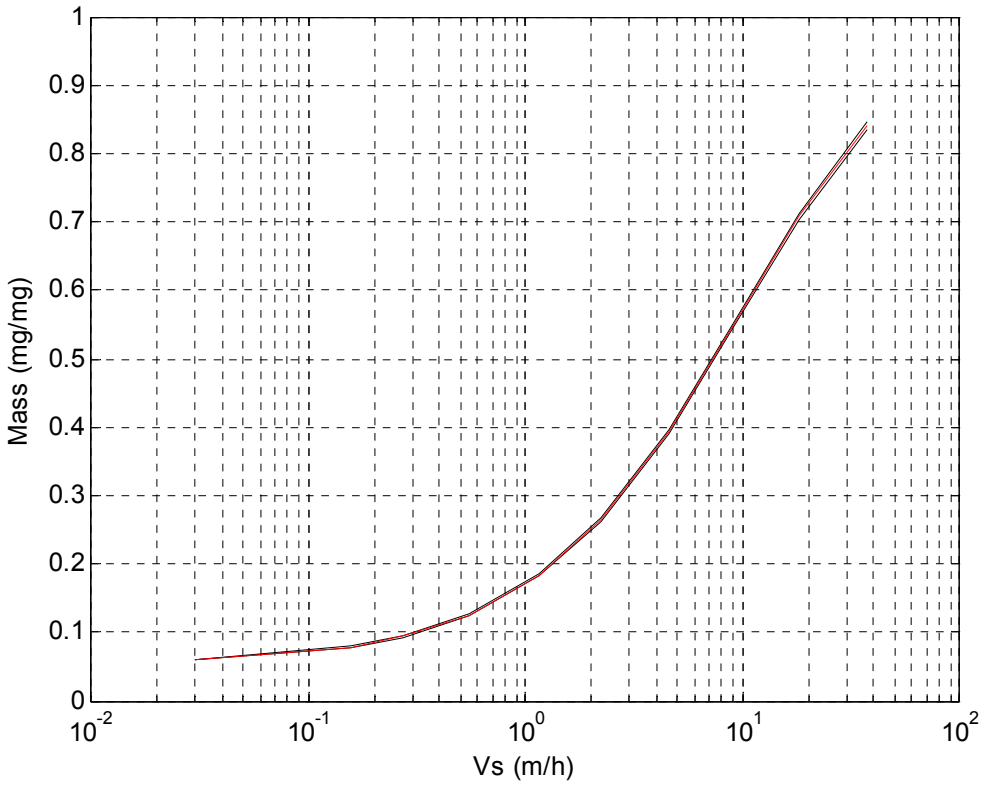


Figure 55 Example of uncertainty

The analysis of uncertainty was applied for the following measurement series:

- Preliminary tests
- Results of the three campaigns (measurement series) carried out in until june 2006
- Mass balance
- Physico-chemical evolution of a sample and its influence to settling velocity
- Reproducibility of the protocol Vicas
- Evolution of sample by different cooling times in the fridge

All measurement series delivered almost the same results as in Figure 56. For this reason all settling velocity tables are presented in the appendix.

4.5 Kriging – Interpolation

4.5.1 Introduction

The idea of the geostatistical interpolation called Kriging (Krige, 1950) is to measure settling velocities in some points of the stormwater storage tank and to interpolate the point data over the surface, to estimate the settling velocity values in other points where no measurements were carried out.

4.5.2 Variograph and Autocorrelation

The relation between the distance and the variable is described by a variograph. It indicates the differences between measured values in spatial dependence, this allows a spatial interpretation and an interpolation adapted to the data.
By correlating the variances of the measured values to its distance, it is possible to determine whether a distance-dependent autocorrelation of the measured values is present. At the same time the maximum range of the influence of close locations can be read from the variogramm.

Beyond this maximum distance no autocorrelation is present, the measured values are not taken into the following Kriging estimation. This method gets an optimal estimated result by the minimization of the estimated variance. Regions where information lacks can be identified with its high estimated variance.

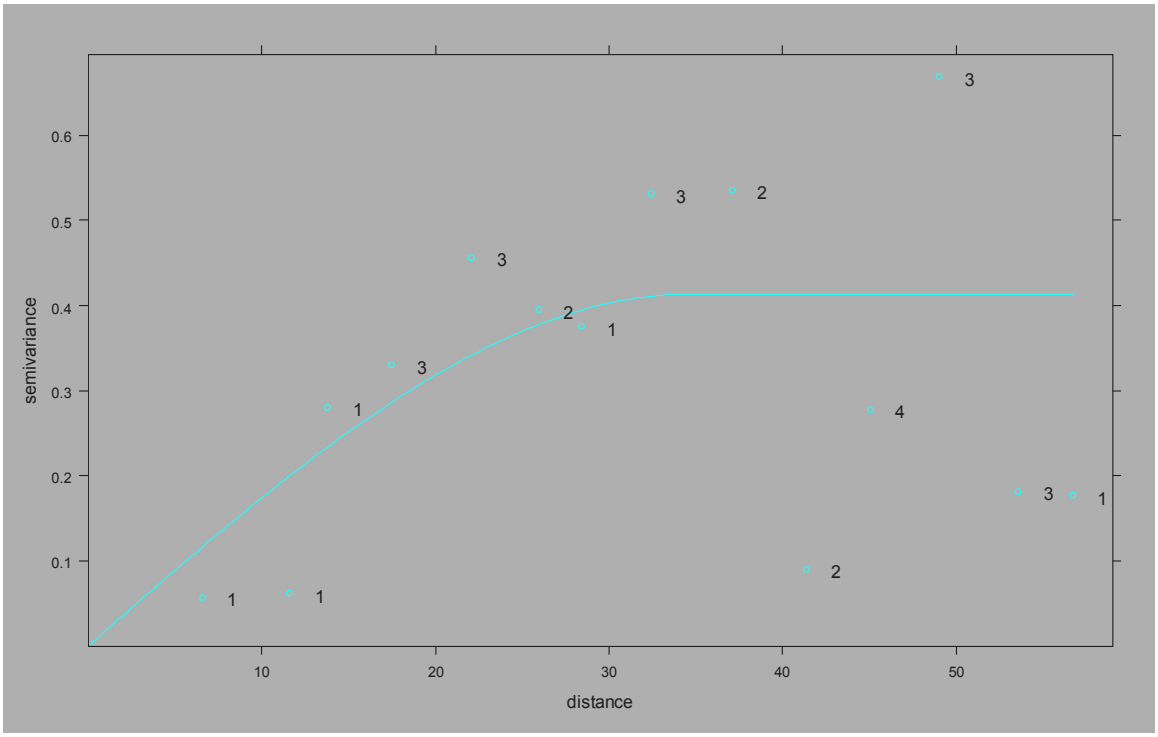


Figure 56 Variograph

Ordinate:	Semivariance of the sample values
Abscissa:	Distance intervals
Points:	Experimental Variograph
Line:	Theoretical Variograph

4.5.3 Presentation of results

The evaluation of the locally collected data by analyse of the variograph and by Kriging interpolation permits a quantifiable statement for the transferability of a point data into the surface.

For the exploitation of the measurement data a computer programm called Gstat was adapted. It permits geostatistical modelling, prediction and simulation which was applied to exploit three different measurment series.

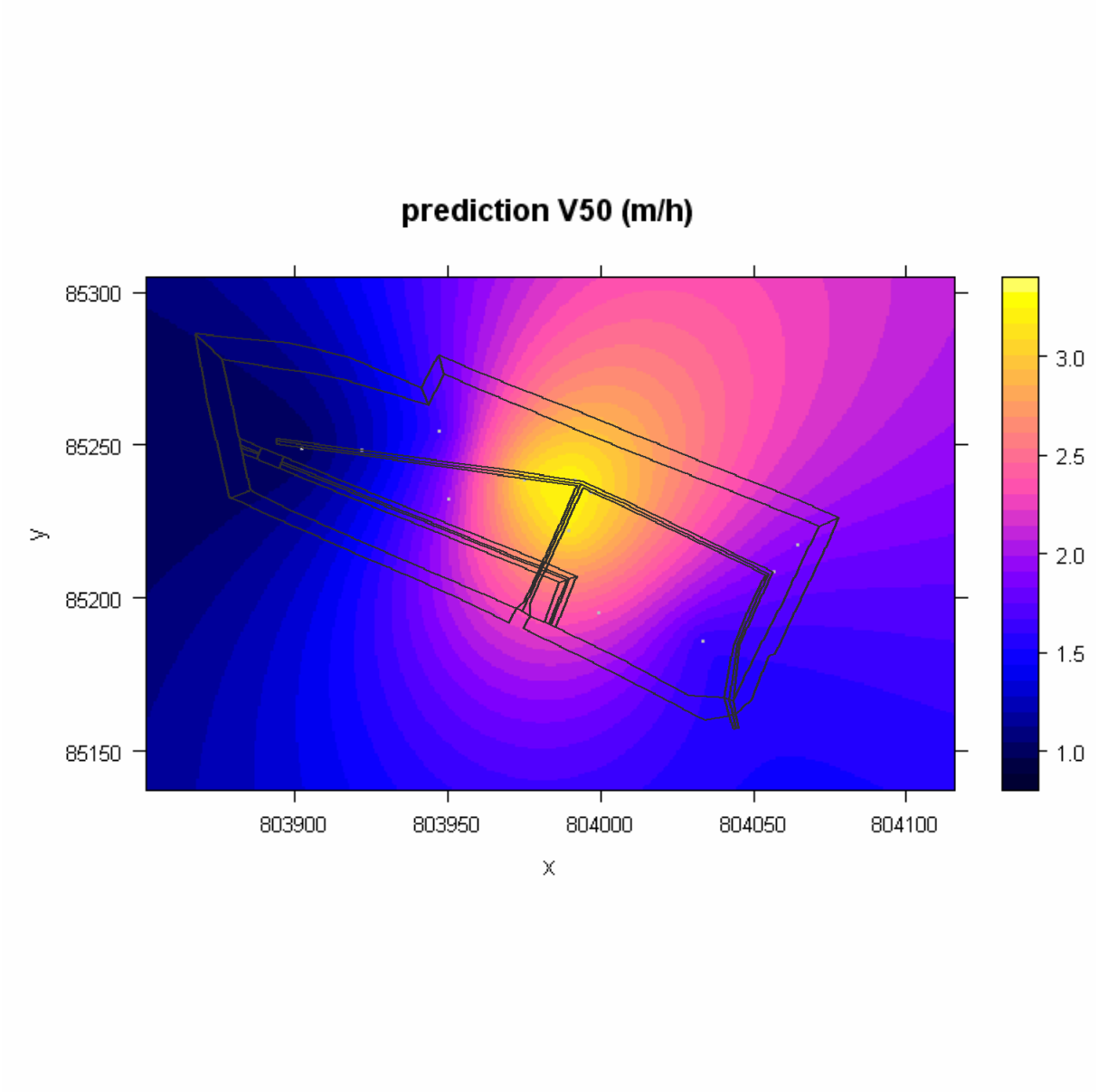


Figure 57 Example of a result obtained by Kriging Interpolation

Figure 54 shows the twelve settlement traps in the tank and permits to read the predicted settling velocities V50 (m/h) on the right ordinate. Settling velocity decreases from the outline to the center of the tank.

4.5.4 Kriging Interpolation and CO - Kriging by the Gstat programm for the third measurement campaign

The idea is to define a space structure for an objective variable V50 and to predict the settling velocity values (V50) between the 12 settlement trap positions. This procedure is called Ordinary Kriging (KO). A validation of the predicted values is undertaken too. The correlation between the predicted and the observed values of the objective variable demonstrates the quality of the model. This operation was done for the first two rain data series.

The third measurement serie permits another interesting application of the Gstat programm. Additional available raw data (hydrocarbons, heavy metals) obtained by a external research laboratory for water analyse represent covariables assumed to be related to the objective variable V50. Then it is necessary to apply a space structure modelling for a chosen covariable. This is called co-regionalization and it is an extension of the theory from only one regionalized variable used for the Ordinary Kriging (KO).

Initially the space structure of the objective variable has to be defined and after the same model is used for an interpolation by the Ordinary Kriging. This procedure is called CO - Kriging (KO - CO).

Table of covariables:

Positions	HT (mg/kgMS)	Cd (mg/kgMS)	Cu (mg/kgMS)	Pb (mg/kgMS)	Zn (mg/kgMS)
Trap1	26 868	14,1	260,4	371,0	1 160,8
Trap2	31 642	11,1	290,8	381,0	1 202,8
Trap3	30 578	10,6	277,2	363,0	1 165,7
Trap4	30 532	10,5	278,3	345,0	1 192,0
Trap5	27 287	7,6	234,1	270,0	1 014,0
Trap6	21 885	6,4	218,5	239,0	881,9
Trap7	24 075	10,1	221,3	369,0	990,1
Trap8	27 326	6,9	239,3	247,0	1 056,2
Trap9	26 585	6,7	240,1	246,0	983,2
Trap10	21 931	5,1	170,1	208,0	743,8
Trap11	24 088	6,8	194,5	235,0	836,4
Trap12	24 135	4,0	123,5	173,0	537,7

Table 10 Covariables for CO - Kriging

Table 10 shows the covariables which are used for the co-regionalisation as explained.
To choose the most correlated covariable the following aspects must be taken into account:

- - it must be correlated with the variable objective
- - it should appear stronger in the sample than other available co-variables
- - it must have a space covariance with the variable objective

4.5.5 Validation

To confirm the results it is to choose a grid and to leave aside one or more well known point/s of the precedent prediction. A second operation of the programm delivers another map of prediction and the points led beside can be read off the new predicted table and compared with the precedent result.

To evaluate the precision of the model it is also possible to make a cross validation. Each point is led aside and the prediction is made out of the remaining points beside the well known trap positions by using the variogramm. So it is possible to determine the errors of each point (which have been zero in the precedent prediction).

4.6 Physico-chemical evolution of a sedimentation sample

4.6.1 Investigation

$t_0 \Leftrightarrow t_1, t_2, t_3$

$t_1 \Leftrightarrow t_2, t_3$

$t_2 \Leftrightarrow t_3$

The interest is to investigate the possible settling velocity changes in relation of time dependent physico-chemical evolution of a sedimentation sample. Three significant traps, one of the center, another of the middle and a third at the margin of the storage tank were selected to study this phenomena. Therefore, the sample taking was carried out over a period of time.

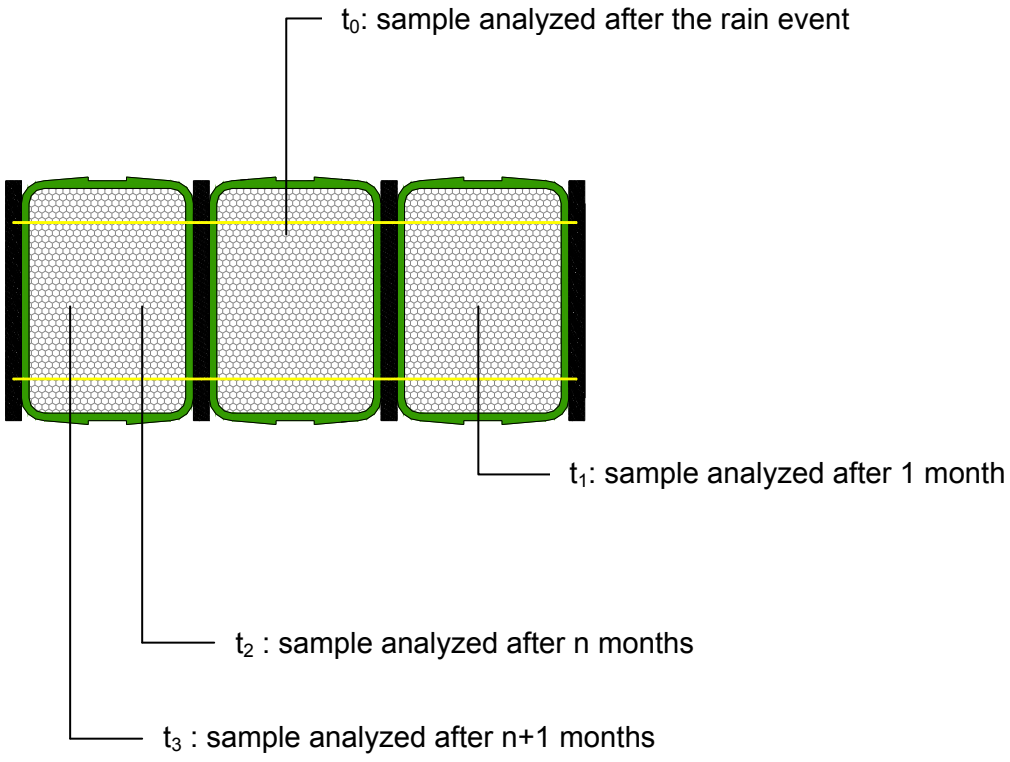


Figure 58 Samples analyzed at different times

At each time step the settling velocity is determined and the physico – chemical parameters are analysed in an external research laboratory.

4.6.2 Operation

i) First, at each position in the storage retention tank, a sample was taken just after a rain event and the two measurements (settling velocity grading curve by protocol Vicas / physico-chemical analyzes) have been carried out.

ii) A part of the sample from this initial rain event was conserved and led at the field site under natural conditions (rainy and sunny weather). See Figure 63:

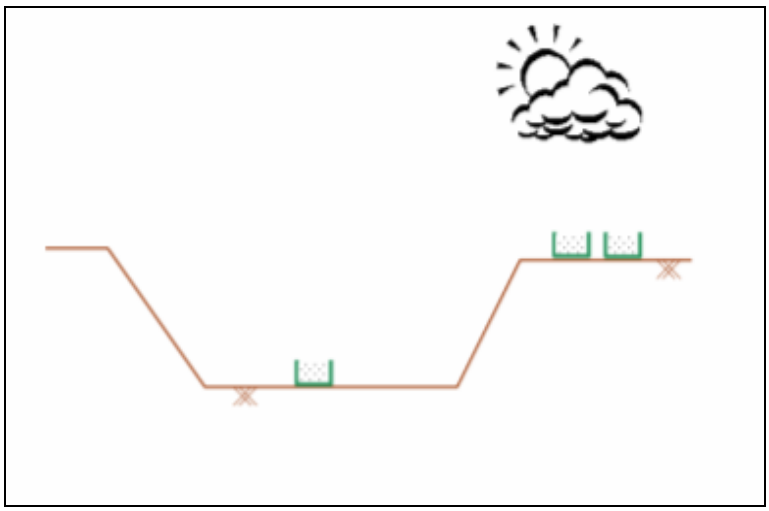


Figure 59 Process description

iii) After one month a new sampling was done with the conserved sample and the settling velocity curves have been determined at the laboratory.

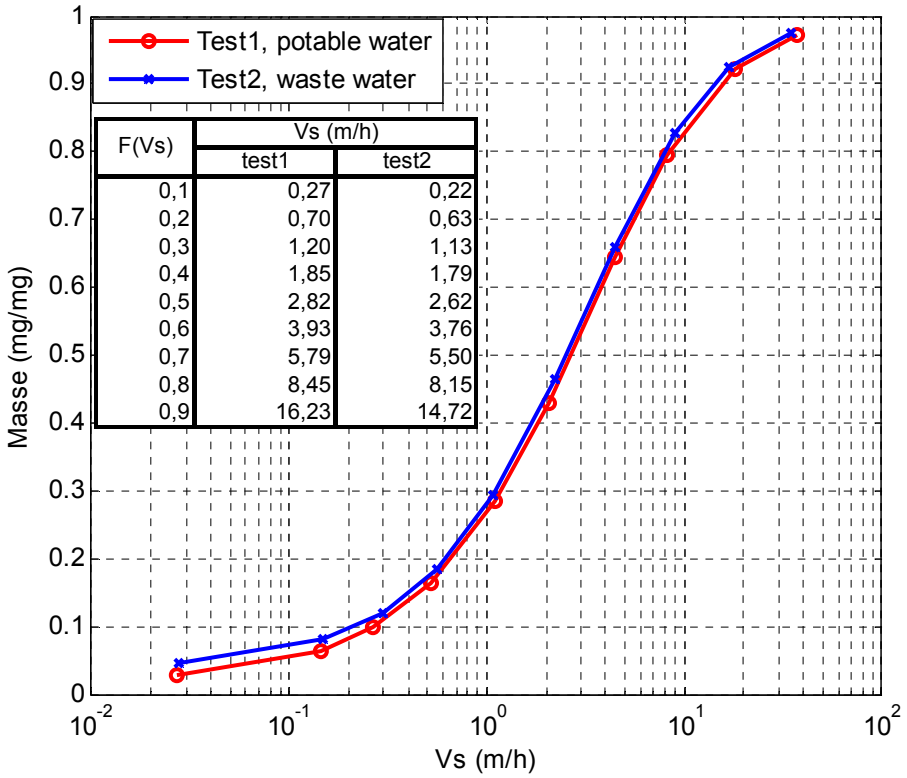
iv) The outside standing sample will be analyzed also after n months and then after n+1 months.

In our research, only for the third campaign a physico-chemical analyse has been carried out. The results are shown in the next chapter.

5. Results and Analysis

5.1 Results of the preliminary tests

Two preliminary tests have been carried out to experience the protocol Vicas and also to answer the questions how settling velocity distribution curves would change if different types of waters are used with the samples. The sample were collected in Chassieu during a fine weather period and were then mixed with potable water for the first test and with waste water for the second test in the laboratory.



F(Vs)	Vs (m/h)	
	test1	test2
0,1	0,27	0,22
0,2	0,70	0,63
0,3	1,20	1,13
0,4	1,85	1,79
0,5	2,82	2,62
0,6	3,93	3,76
0,7	5,79	5,50
0,8	8,45	8,15
0,9	16,23	14,72

Figure 60 Settling curves for Test1 and Test2

The result is shown in the upper graphic and the upper table. It is obvious that the two curves are very close and they have the same values. More tests should be undertaken to confirm this hypothesis in general.
We thought that it is more probable that waste water could influence the experiment and therefore potable water was used in all our experiments.

5.2 Evolution of settling velocity by sample keeping in fridge for different terms of time

The three samples had the same temperature at the starting of the experiment.

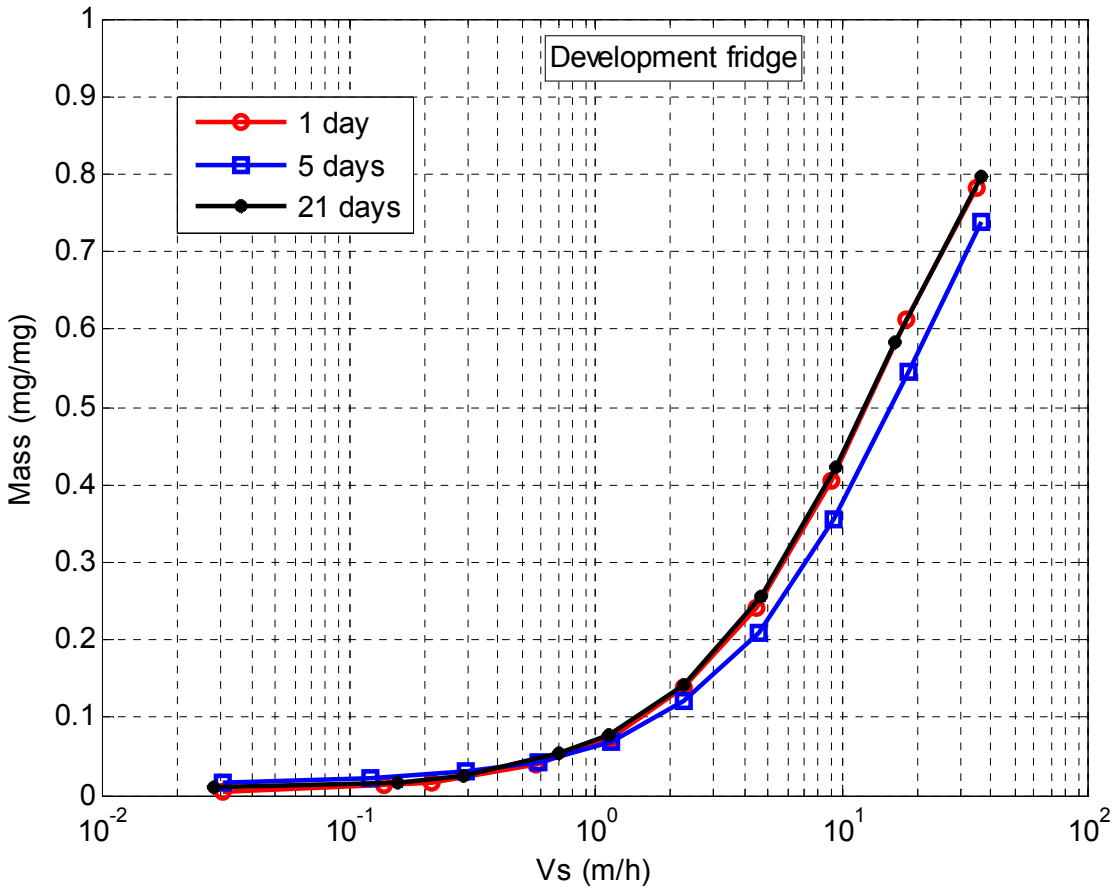


Figure 61 Settling velocity curves from samples after different keeping time in fridge

F(Vs)	settling velocity (m/h)		
	V1day	V5days	V21days
0,1	1,60	1,82	1,52
0,2	3,56	4,31	3,46
0,3	6,03	7,45	5,86
0,4	8,77	11,40	8,65
0,5	13,18	16,25	12,61
0,6	17,68	23,61	17,79
0,7	26,67	33,07	27,09
0,8	36,22	42,53	36,40
0,9	45,78	51,98	45,71

Table 11 Settling velocities after different keeping time in fridge

F(Vs)	settling velocity (m/h)			
	Vmin	Vmax	Vmean	σ
0,1	1,60	1,82	1,71	0,16
0,2	3,56	4,31	3,93	0,52
0,3	6,03	7,45	6,74	1,01
0,4	8,77	11,40	10,08	1,86
0,5	13,18	16,25	14,71	2,17
0,6	17,68	23,61	20,64	4,19
0,7	26,67	33,07	29,87	4,52
0,8	36,22	42,53	39,37	4,46
0,9	45,78	51,98	48,88	4,39

Table 12 Statistical exploitation of samples with different keeping time in fridge

The conclusion which can be drawn out of this experiment is that settling velocity does not change by different sample keeping durations in the fridge. This result will relieve the operational mode in future because it is not necessary to consider the time aspect of the sample's fridge keeping. It is not similar to previous conclusions obtained by prior investigations undertaken by Chebbo, 1990.

5.3 Reproducibility of the Vicas protocol

The reproducibility of the Vicas protocol was evaluated by testing the repeatability of TSS (total suspended solids) settling. The same sample was taken three times and tested under the same conditions with the protocol Vicas.

To present the result the mean settling velocity of each test was chosen and so the following graph was obtained:

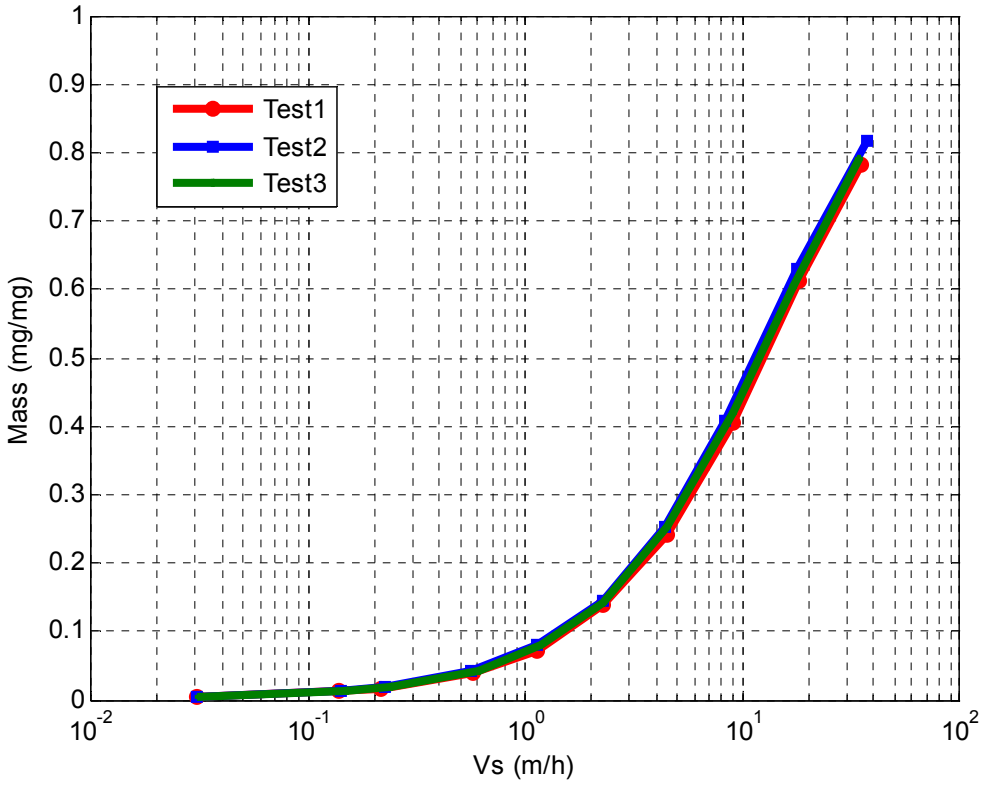


Figure 62 Reproducibility (Triplication) of one sample by protocol Vicas

F(Vs)	Settling Velocity (m/h)					
	Test 1	Test 2	Test 3	σ	range [Vmin; Vmax]	Vmean
0,10	1,60	1,47	1,54	0,09	[1,47; 1,60]	1,54
0,20	3,56	3,29	3,44	0,20	[3,29; 3,56]	3,43
0,30	6,03	5,52	5,80	0,36	[5,52; 6,03]	5,77
0,40	8,77	8,07	8,51	0,49	[8,07; 8,77]	8,42
0,50	13,18	12,24	12,55	0,66	[12,24; 13,18]	12,71
0,60	17,68	16,55	16,92	0,80	[16,55; 17,68]	17,11
0,70	26,67	25,05	26,01	1,14	[25,05; 26,67]	25,86
0,80	36,22	35,39	35,33	0,59	[35,39; 36,22]	35,81
0,90	45,78	45,73	44,65	0,04	[45,73; 45,78]	45,75

Table 13 Settling velocity values of reproducibility by protocol Vicas

It is obvious that the obtained curves of the triplication are very close and this is also confirmed by the statistical value of the standard deviation σ. The Vicas protocol is reliable regarding its reproducibility and another confirmation is given for the operational mode of the protocol under normal working conditions.

The sample used for the triplication was strong loaded and that is why the three curves plunges down at the beginning of the experience. It was not possible to measure the highest settling velocity in this case, therefore a very high column would be necessary. It is supposed and confirmed that particles settling velocity is higher at the beginning of the experience because of the faster settling of heavier particles. In general particles which are fixed by pollutants are found in the middle interval of the settling velocity grading curve (finer particles with bigger surface). This was tested by the exploitation of granulometry curves including the results in settling velocity distribution curves (Bertrand-Krajewski, 2000).

Another interesting aspect can be drawn out of the obtained result. The protocol Vicas contains losses of mass regarding the mass balance of the protocol. The equal obtained curves of the triplication experience confirm that the mass is always lost by the same way. Another chapter investigates this phenomenon.

Regarding the Victor method, a literature study has shown that reproducibility of protocol Vicas has achieved better results obtained by Bertrand-Krajewski 2001.

5.4 Results of the three campaigns

The results show a high spatial variability of the settling velocity curves, but if the different positions among the rain events are compared, they are strong similar.

5.4.1 Campaign 1 from rain event 14/06/2005

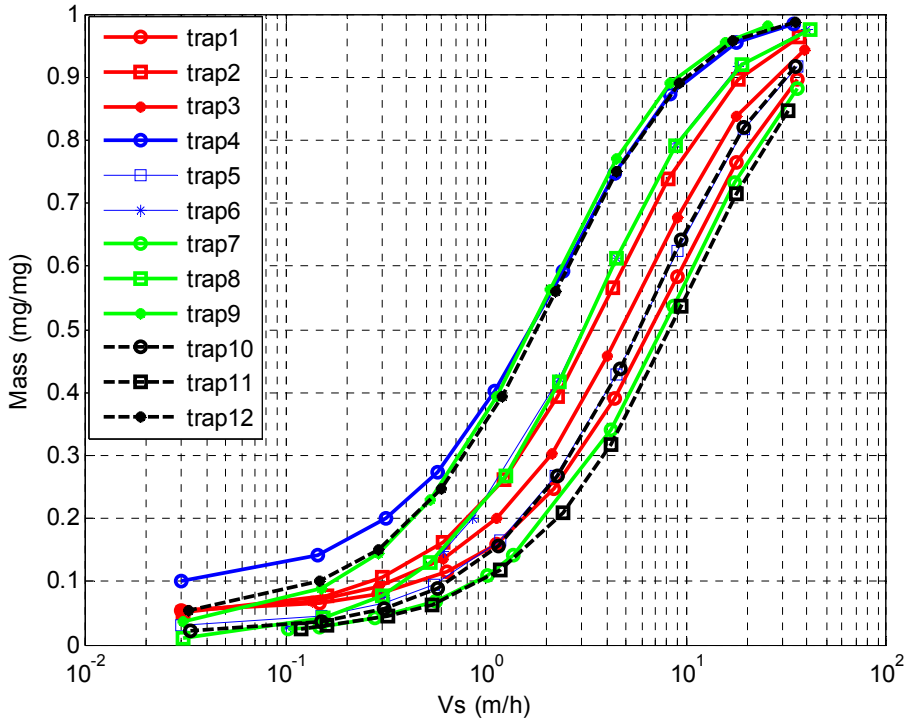


Figure 63 Results of Campaign 1

F(Vs)	Settling velocity (m/h)											
	Trap1	Trap2	Trap3	Trap4	Trap5	Trap6	Trap7	Trap8	Trap9	Trap10	Trap11	Trap12
0,1	0,49	0,27	0,35	0,03	0,59	0,40	0,90	0,40	0,17	0,65	0,97	0,15
0,2	1,61	0,84	1,13	0,32	1,54	0,86	2,21	0,89	0,44	1,59	2,28	0,45
0,3	3,01	1,52	2,08	0,68	2,70	1,51	3,64	1,47	0,78	2,74	3,89	0,81
0,4	4,65	2,34	3,34	1,11	4,09	2,16	5,57	2,18	1,16	4,13	6,17	1,23
0,5	7,05	3,51	5,03	1,77	6,12	3,18	7,85	3,24	1,72	6,12	8,59	1,85
0,6	9,89	5,03	7,27	2,49	8,40	4,29	11,52	4,36	2,49	8,49	12,43	2,68
0,7	14,76	7,23	10,25	3,78	13,03	6,54	15,99	6,63	3,64	12,70	17,09	3,86
0,8	22,81	11,94	15,74	6,03	18,35	9,30	25,70	9,48	5,38	18,23	26,81	6,10
0,9	36,38	18,97	30,37	11,44	32,87	16,78	38,08	17,31	9,36	32,27	37,47	10,26

Table 14 Results of settling velocity parameters from Campaign 1 for all positions

F(Vs)	Settling velocity (m/h)			
	Vmin	Vmax	Vmean	σ
0,1	0,27	0,49	0,38	0,15
0,2	0,84	1,61	1,23	0,55
0,3	1,52	3,01	2,27	1,05
0,4	2,34	4,65	3,49	1,63
0,5	3,51	7,05	5,28	2,51
0,6	5,03	9,89	7,46	3,44
0,7	7,23	14,76	10,99	5,33
0,8	11,94	22,81	17,37	7,69
0,9	18,97	36,38	27,67	12,31

Chebbo received similar results in 1992 at the Marais catchment: V10=0,36; V50=7,16; V90=49,17.

Table 15 Statistical exploitation of results from Campaign 1

5.4.2 Campaign 2 from rain event 24/03/2006

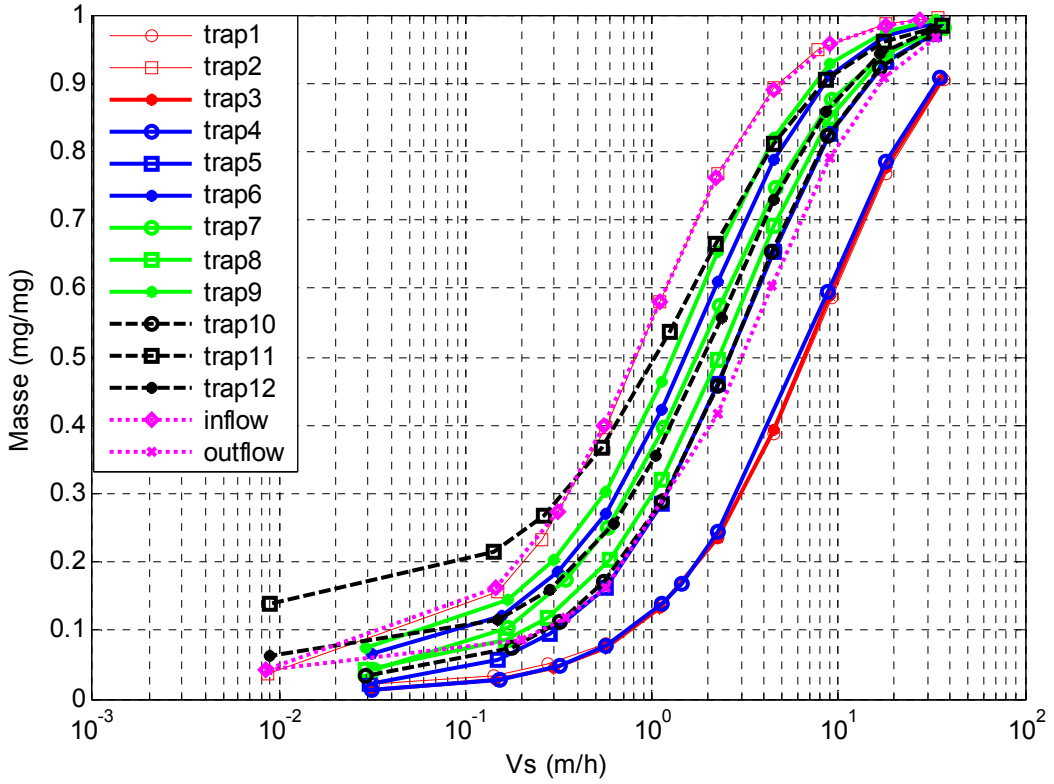


Figure 64 Results of Campaign 2

F(Vs)	Settling velocity (m/h)											
	Trap1	Trap2	Trap3	Trap4	Trap5	Trap6	Trap7	Trap8	Trap9	Trap10	Trap11	Trap12
0,1	0,07	0,75	0,08	0,81	0,78	0,31	0,11	0,16	0,21	0,08	0,27	0,06
0,2	0,20	1,84	0,21	1,86	1,78	0,73	0,36	0,43	0,58	0,29	0,69	0,12
0,3	0,36	3,20	0,38	3,17	3,32	1,23	0,67	0,78	1,03	0,55	1,19	0,35
0,4	0,56	4,78	0,57	4,67	5,18	1,88	1,04	1,19	1,62	0,90	1,85	0,68
0,5	0,86	7,12	0,87	6,95	7,04	2,72	1,59	1,84	2,28	1,34	2,71	1,10
0,6	1,21	9,79	1,23	9,48	9,05	3,84	2,18	2,66	3,42	1,93	3,84	1,71
0,7	1,83	14,62	1,85	14,28	13,86	5,64	3,38	3,98	4,72	2,87	5,64	2,73
0,8	2,87	22,37	2,84	21,21	20,00	8,25	4,92	6,50	7,54	4,20	8,24	4,29
0,9	5,07	36,58	4,92	35,38	34,38	15,26	8,65	12,13	13,80	7,83	14,97	8,39

Table 16 Results of settling velocity parameters from Campaign 2 for all positions

F(Vs)	Settling velocity (m/h)			
	Vmin	Vmax	Vmean	σ
0,1	0,07	0,75	0,41	0,48
0,2	0,20	1,84	1,02	1,16
0,3	0,36	3,20	1,78	2,01
0,4	0,56	4,78	2,67	2,99
0,5	0,86	7,12	3,99	4,43
0,6	1,21	9,79	5,50	6,06
0,7	1,83	14,62	8,22	9,04
0,8	2,87	22,37	12,62	13,79
0,9	5,07	36,58	20,82	22,28

Table 17 Statistical exploitation of results from Campaign 2

5.4.3 Campaign 3 from rain event 09 - 10/04/2006

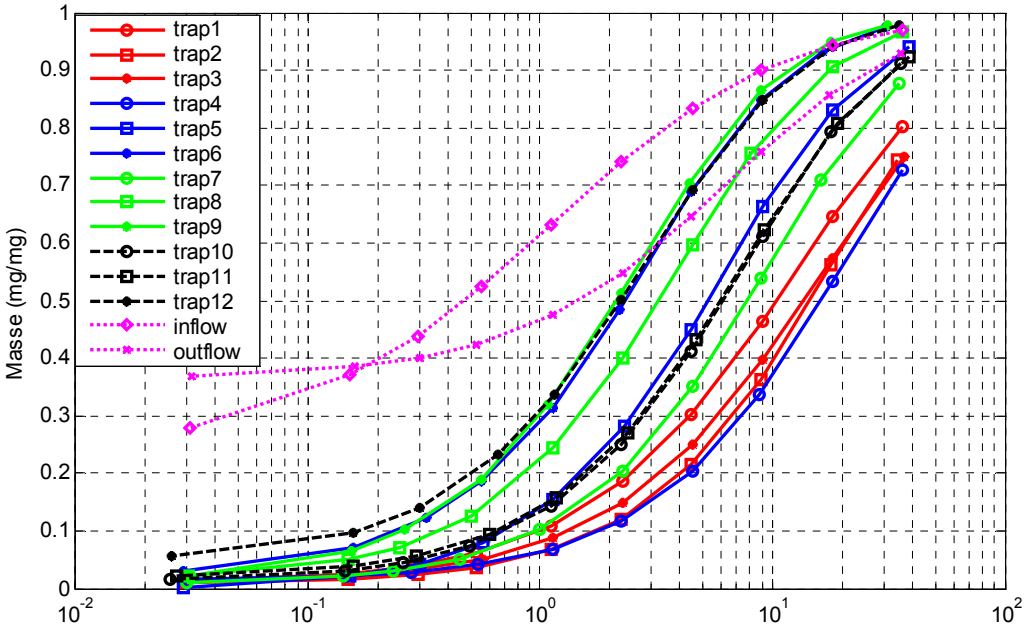


Figure 65 Results of Campaign 2

F(Vs)	Settling velocity (m/h)											
	Trap1	Trap2	Trap3	Trap4	Trap5	Trap6	Trap7	Trap8	Trap9	Trap10	Trap11	Trap12
0,1	-0,21	1,02	1,79	1,36	1,86	0,71	0,25	0,97	0,38	0,26	0,73	0,66
0,2	-0,07	2,54	4,08	3,42	4,40	1,54	0,62	2,18	0,90	0,59	1,71	1,63
0,3	0,06	4,44	6,96	6,11	7,60	2,52	1,06	3,72	1,54	1,00	2,93	2,80
0,4	0,21	7,20	10,54	9,31	11,79	3,78	1,66	5,66	2,26	1,56	4,31	4,23
0,5	0,48	10,76	15,13	14,43	16,58	5,51	2,36	7,99	3,41	2,16	6,47	6,27
0,6	0,95	15,74	21,49	21,02	24,35	7,73	3,48	11,49	4,60	3,20	8,74	8,62
0,7	1,81	24,29	30,58	31,76	33,58	11,09	4,79	15,75	6,84	4,32	13,35	13,24
0,8	3,65	35,78	39,68	42,50	42,81	16,41	7,58	26,39	11,02	7,11	18,95	18,52
0,9	8,82	47,28	48,78	53,25	52,05	31,17	13,41	37,76	17,57	12,70	33,92	34,85

Table 18 Results of settling velocity parameters from Campaign 3 for all positions

F(Vs)	Settling velocity (m/h)			
	Vmin	Vmax	Vmean	σ
0,1	0,00	1,02	0,40	0,86
0,2	0,00	2,54	1,23	1,85
0,3	0,06	4,44	2,25	3,10
0,4	0,21	7,20	3,71	4,94
0,5	0,48	10,76	5,62	7,26
0,6	0,95	15,74	8,35	10,46
0,7	1,81	24,29	13,05	15,89
0,8	3,65	35,78	19,72	22,72
0,9	8,82	47,28	28,05	27,19

Table 19 Statistical exploitation of results from Campaign 3

5.5 Comparison among rain events

An analysis of the three rain events (associated to the mentioned campaigns in chapter 5.4) between a certain time period of some months in spring 2006 lead to the consideration to compare the events among each other. Some parameters which affect the settling velocity distribution were taken into account. These parameters were obtained by turbidity measurements at the inflow of the storage retention tank in Chassieu.

The hypothesis that settling velocity changes along with the variation of some parameters is expressed by the following equation:

$Vs = f(Qmax, Vtot, \Delta t_{dry}, \Delta t_{rain,} Turb.)$

where

Vs :settling velocity

f :function()

Qmax :maximum stormwater runoff discharge measured at the inflow of the stormwater tank during the rain event

Vtot :total inflow volume entering the stormwater tank for the whole rain event

Δt_{dry} :dry weather interval between the last rain event and the investigated rain event

Δt_{rain} :rain interval of the investigated rain event

$Turb._{max}$:max. value Turbidity

If the variation of a certain parameter influences the settling velocity it is interesting to analyse in which way it does.
For example:

It is supposed that an increase of the total stormwater volume would lead to an increase of the settling velocity (Vtot ↑ => V50 ↑). These and other assumptions shall be explained by the application of the R – Project for Statistical Computing which is used for the analysis of the rain data.

5.5.1 Rain Event 14/06/05

The following Figures contain parameters like the maximum stormwater runoff discharge, the total inflow volume, the dry weather interval, the rain interval and the maximum turbidity.

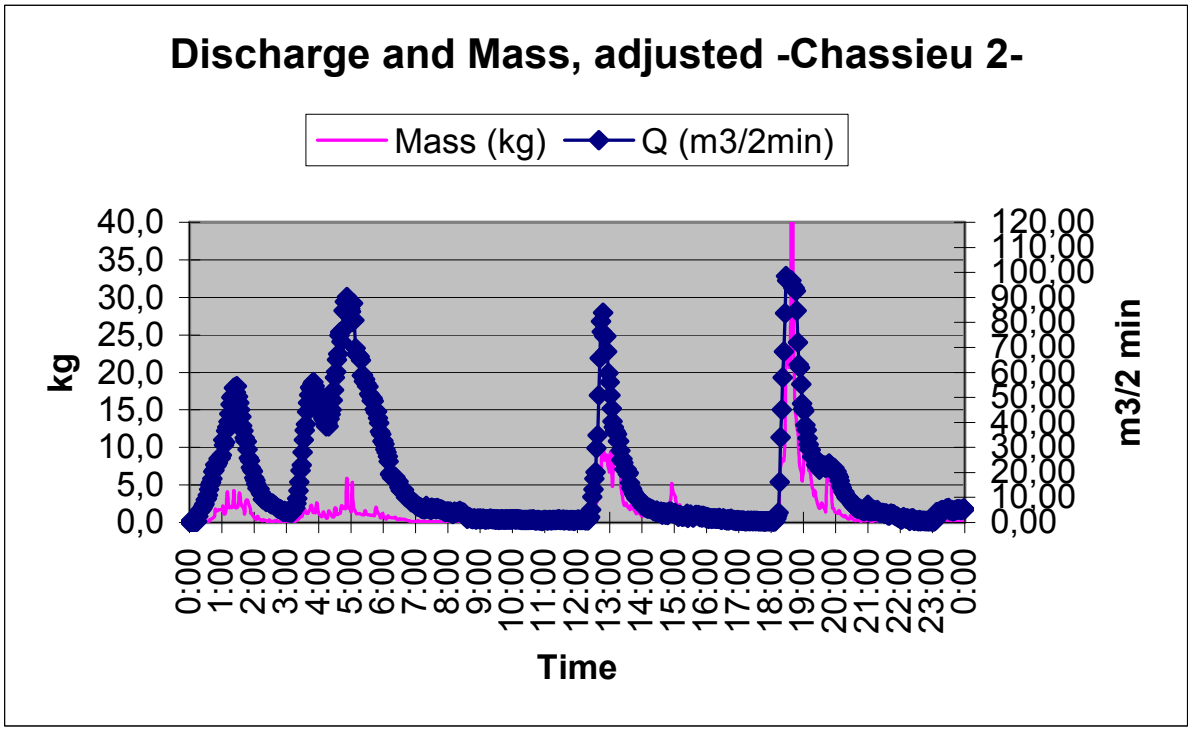


Figure 66 Rain data of Campaign 1

Qmax = 0,85 m^3/s

Vtot = 11803,96 m^3

Δt_{dry} = 3h (from 21h00 13/06/05 to 00h00 14/06/05)

Δt_{rain} = 24h (from 00h00 to 24h00 on 14/06/05)

$Turb._{max}$ = 1174 NTU (Nephelometric Turbidity Unit)

5.5.2 Rain Event 24/03/06

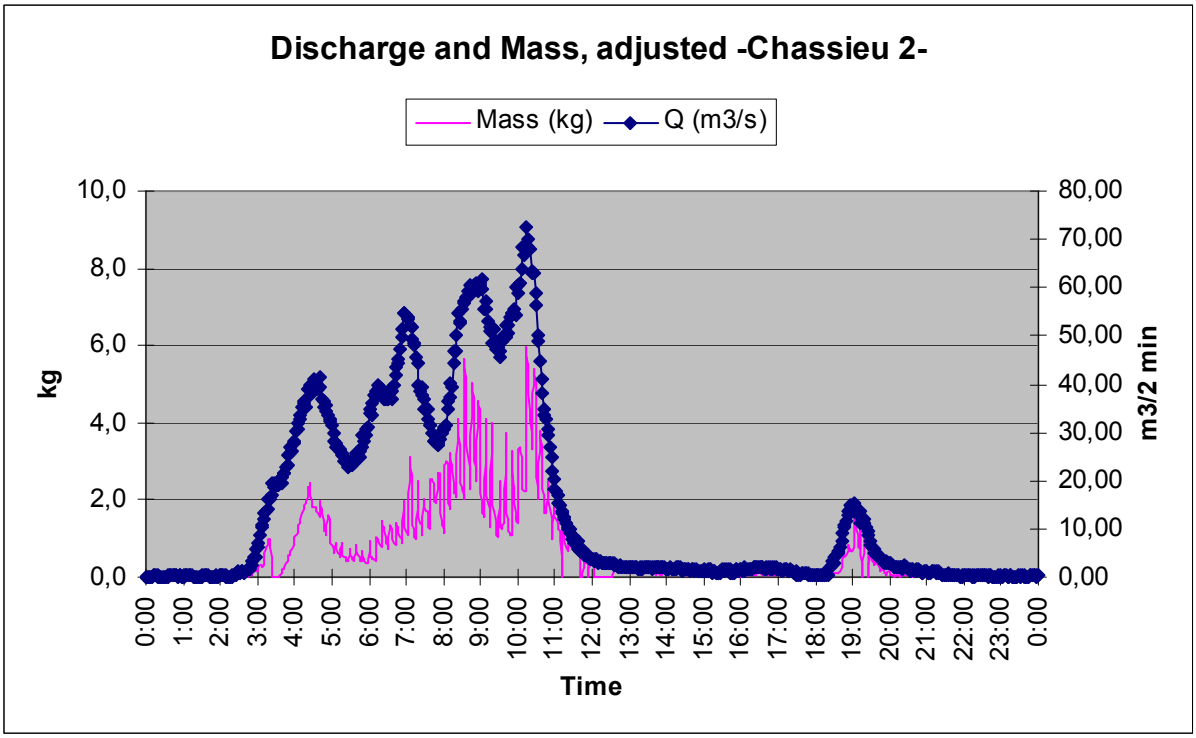


Figure 67 Rain data of Campaign 2

Qmax = 0,60 m^3/s

Vtot = 10490 m^3

Δt_{dry} = 32h (from 17h00 22/03/06 to 02h00 24/03/06)

Δt_{rain} = 20h (from 02h00 to 22h00 on 24/03/06)

$Turb._{max}$ = 106 NTU (Nephelometric Turbidity Unit)

5.5.3 Rain Event 09 - 10/04/06

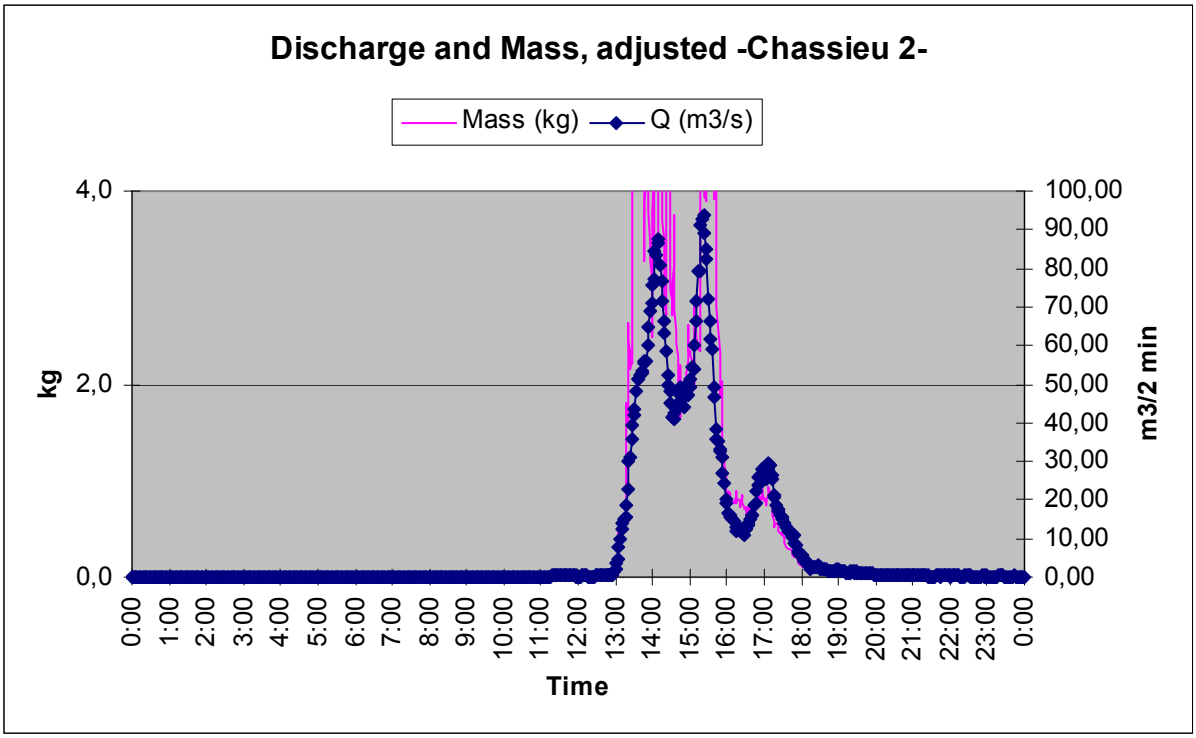


Figure 68 Rain data of Campaign 3, first day of rain event

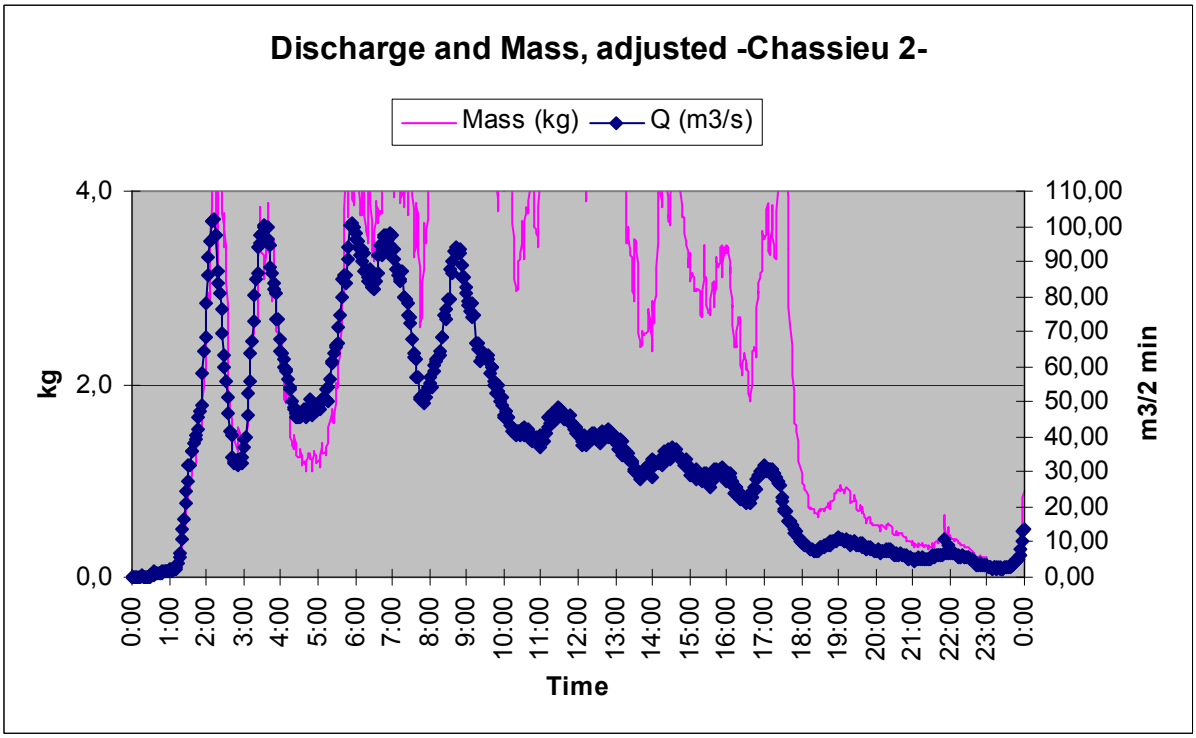


Figure 69 Rain data of Campaign 3, second day of rain event

Qmax = 0,85 m^3/s

Vtot = 5747,13 m^3 + 27013,65 m^3 = 32760,78 m^3

Δt_{dry} = 95h (from 12h00 05/04/06 to 11h00 09/04/06)

Δt_{rain} = 37h (from 11h00 on 09/04/06 to 24h00 on 10/04/06)

$Turb._{max}$ = 216 NTU (Nephelometric Turbidity Unit)

The results delivered by the application of the R Project for Statistical Computing are shown in the following table.

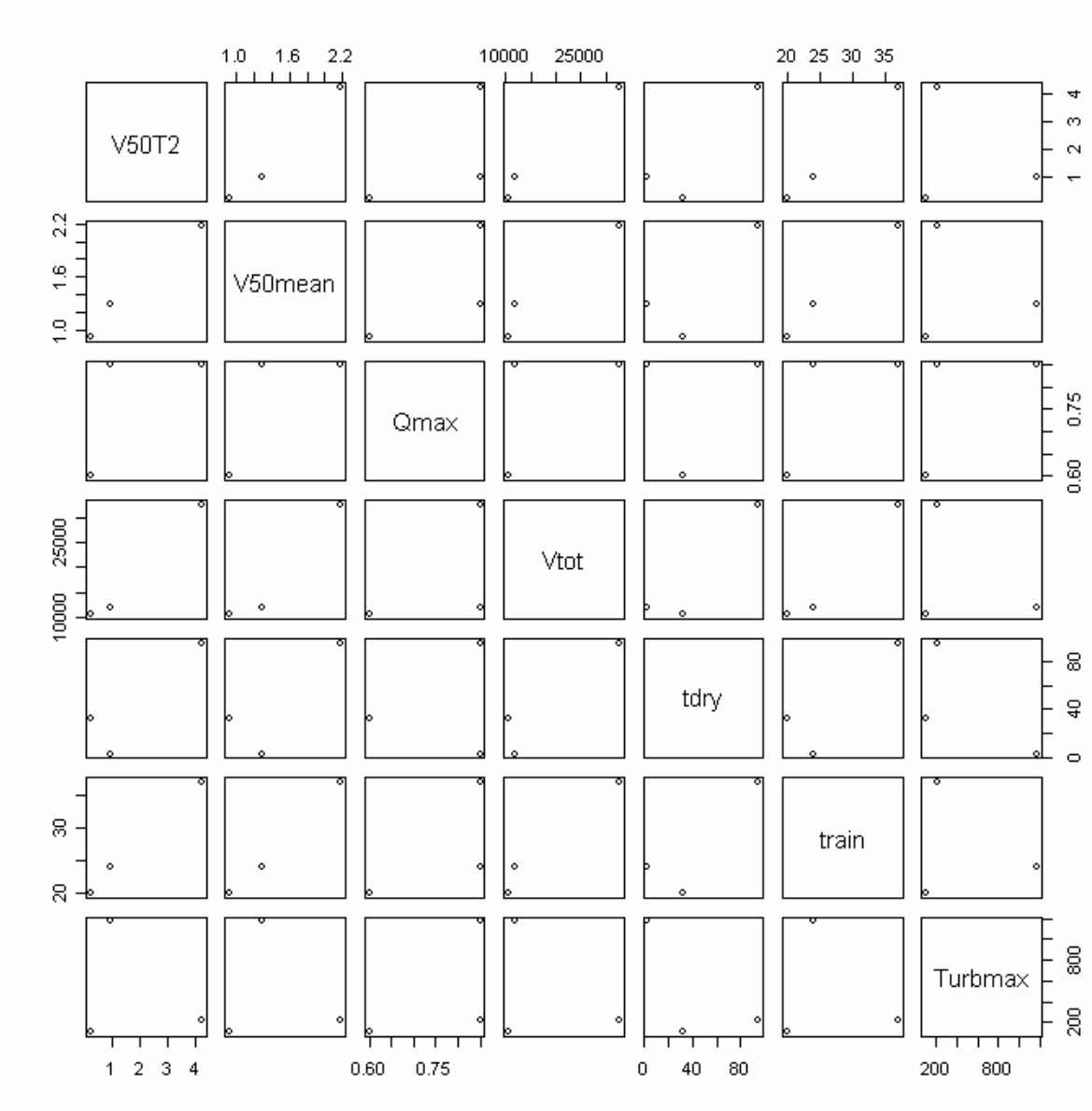


Figure 70 Correlation of rain parameters and V50 delivered by R-Project Interpolation

The correlation regarding the two parameters V50T2 (settling velocity V50 of Trap 2) and V50mean (mean value of settling velocity V50) are shown in the first two lines of Table 19. The result confirms the hypothesis that settling velocity increases with the value of the total inflow volume. The correlation of the settling velocity and the rain time period confirmed. Weak relation was carried out for the Turbidity and the settling velocity. The following table shows the mathematical expression of the upper graphic in values of correlation:

V50T2	0,99	0,64	0,99	0,88	1,00	-0,25
0,99	V50mean	0,73	0,97	0,82	1,00	-0,14
0,64	0,73	Qmax	0,54	0,21	0,68	0,58
0,99	0,97	0,54	Vtot	0,93	0,98	-0,37
0,88	0,82	0,21	0,93	tdry	0,86	-0,68
1,00	1,00	0,68	0,98	0,86	train	-0,20
-0,25	-0,14	0,58	-0,37	-0,68	-0,20	Turbmax.

Table 20 Correlation of results (r^2)

5.6 Comparison of results between the settlement traps

As an obvious result it is remarkable that the curves of the campaign 1 from rain event 14/06/05 and also the curves of the campaign 2 from rain event 09 – 10/04/06 are very close, they are almost identical. The hydrological data analyse makes clear that these two rain events, both, have been quite strong. In the majority of cases, these curves has a higher settling velocity than curves out of weak rain events (curve of campaign 2).

5.6.1 Trap 1 – Settling Velocities of three Campaigns

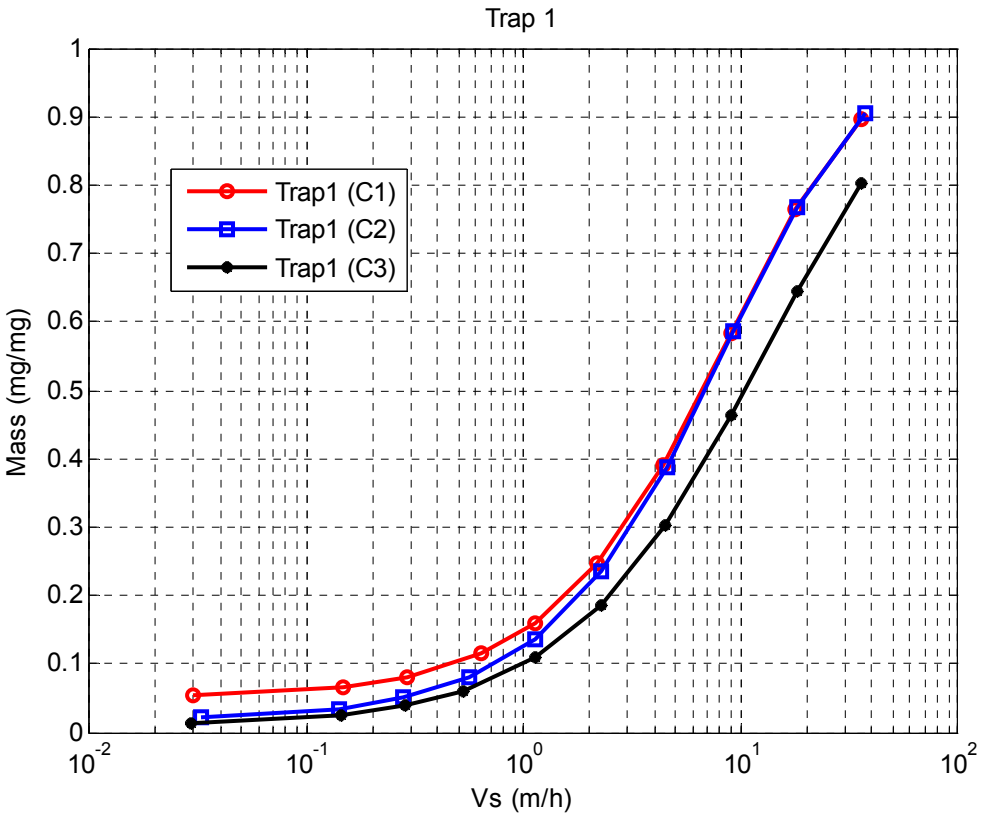


Figure 71 Trap 1 (C1, C2, C3)

F(Vs)	Vs (C1) (m/h)	Vs (C2) (m/h)	Vs (C3) (m/h)	Vmin (m/h)	Vmean (m/h)	Vmax (m/h)	σ (m/h)
0,10	0,49	0,75	1,02	0,49	0,62	0,75	0,19
0,20	1,61	1,84	2,54	1,61	1,73	1,84	0,16
0,30	3,01	3,20	4,44	3,01	3,11	3,20	0,14
0,40	4,65	4,78	7,20	4,65	4,72	4,78	0,09
0,50	7,05	7,12	10,76	7,05	7,09	7,12	0,05
0,60	9,89	9,79	15,74	9,79	9,84	9,89	0,07
0,70	14,76	14,62	24,29	14,62	14,69	14,76	0,10
0,80	22,81	22,37	35,78	22,37	22,59	22,81	0,31
0,90	36,38	36,58	47,28	36,38	36,48	36,58	0,14

Table 21 Settling velocity comparison for trap 1, from campaign 1 (C1), campaign 2 (C2) and campaign 3 (C3)

5.6.2 Trap 2 – Settling Velocities of three Campaigns

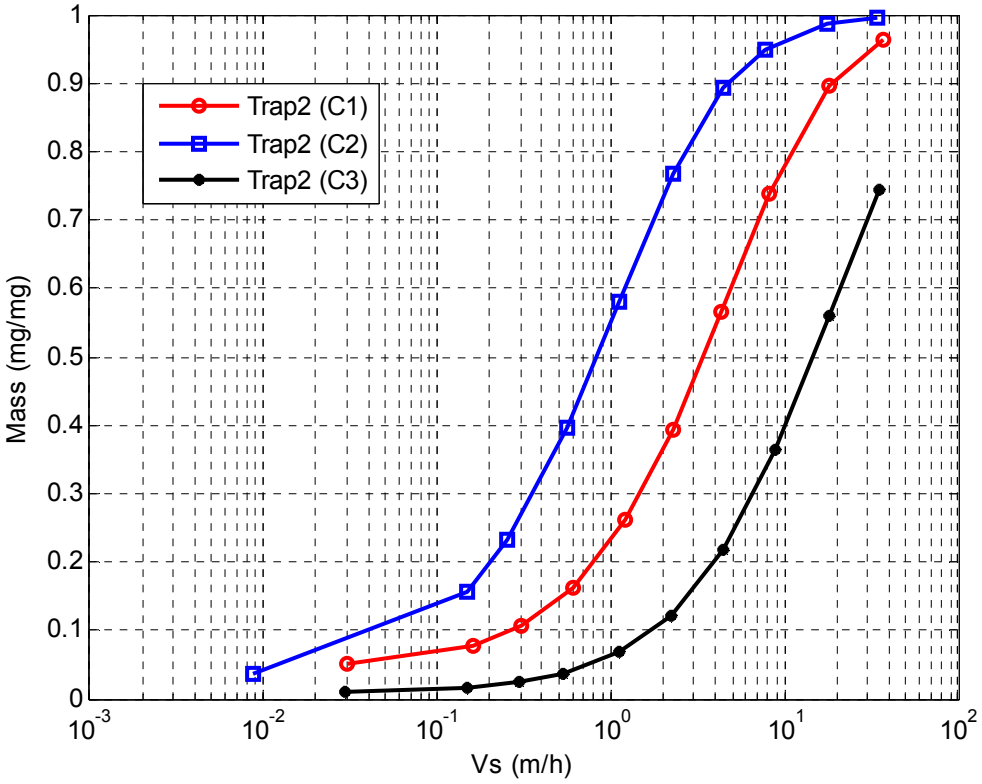


Figure 72 Trap 2 (C1, C2, C3)

F(Vs)	Vs (C1) (m/h)	Vs (C2) (m/h)	Vs (C3) (m/h)	Vmin (m/h)	Vmean (m/h)	Vmax (m/h)	σ (m/h)
0,10	0,27	0,08	1,79	0,08	0,18	0,27	0,13
0,20	0,84	0,21	4,08	0,21	0,52	0,84	0,44
0,30	1,52	0,38	6,96	0,38	0,95	1,52	0,81
0,40	2,34	0,57	10,54	0,57	1,45	2,34	1,25
0,50	3,51	0,87	15,13	0,87	2,19	3,51	1,87
0,60	5,03	1,23	21,49	1,23	3,13	5,03	2,69
0,70	7,23	1,85	30,58	1,85	4,54	7,23	3,81
0,80	11,94	2,84	39,68	2,84	7,39	11,94	6,43
0,90	18,97	4,92	48,78	4,92	11,94	18,97	9,93

Table 22 Settling velocity comparison for trap 2, from campaign 1 (C1), campaign 2 (C2) and campaign 3 (C3)

5.6.3 Trap 3 – Settling Velocities of three Campaigns

Another conclusion can be drawn out of the settlement behaviour of the first four traps which are situated more in the center of the tank than the other traps. These traps show a different behaviour regarding their settling velocity. Except for the trap 1, the curves in the center vary quite strong.

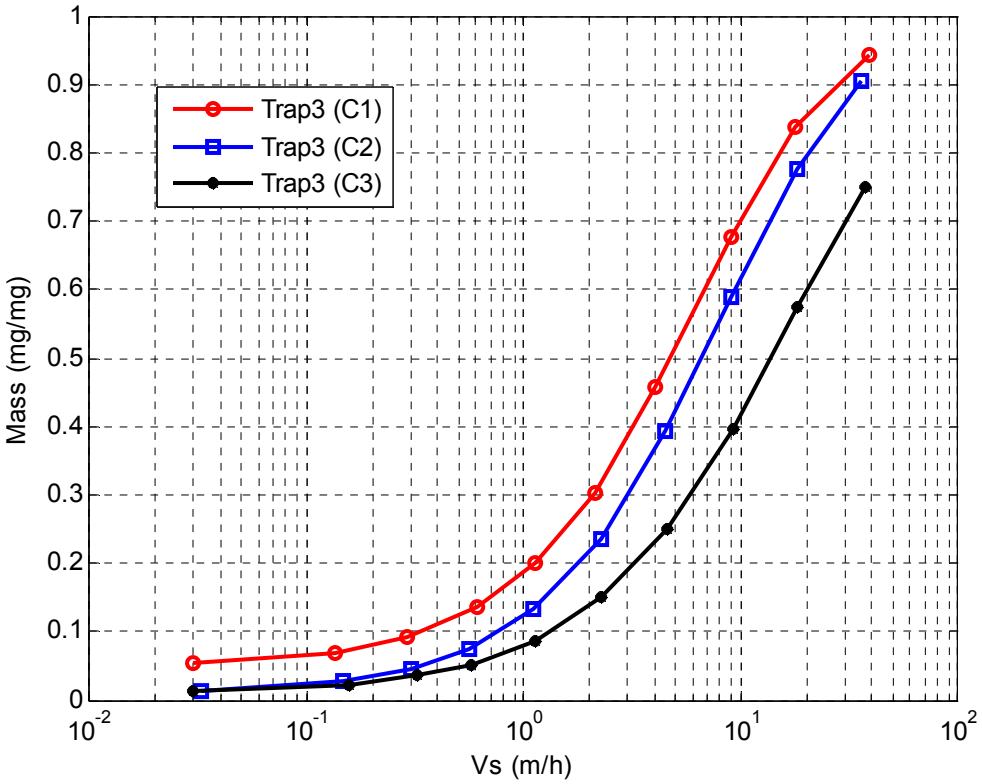


Figure 73 Trap 3 (C1, C2, C3)

F(Vs)	Vs (C1) (m/h)	Vs (C2) (m/h)	Vs (C3) (m/h)	Vmin (m/h)	Vmean (m/h)	Vmax (m/h)	σ (m/h)
0,10	0,35	0,81	1,36	0,35	0,81	0,58	0,32
0,20	1,13	1,86	3,42	1,13	1,86	1,49	0,51
0,30	2,08	3,17	6,11	2,08	3,17	2,63	0,77
0,40	3,34	4,67	9,31	3,34	4,67	4,00	0,94
0,50	5,03	6,95	14,43	5,03	6,95	5,99	1,36
0,60	7,27	9,48	21,02	7,27	9,48	8,38	1,56
0,70	10,25	14,28	31,76	10,25	14,28	12,27	2,85
0,80	15,74	21,21	42,50	15,74	21,21	18,48	3,87
0,90	30,37	35,38	53,25	30,37	35,38	32,88	3,54

Table 23 Settling velocity comparison for trap 3, from campaign 1 (C1), campaign 2 (C2) and campaign 3 (C3)

5.6.4 Trap 4 – Settling Velocities of three Campaigns

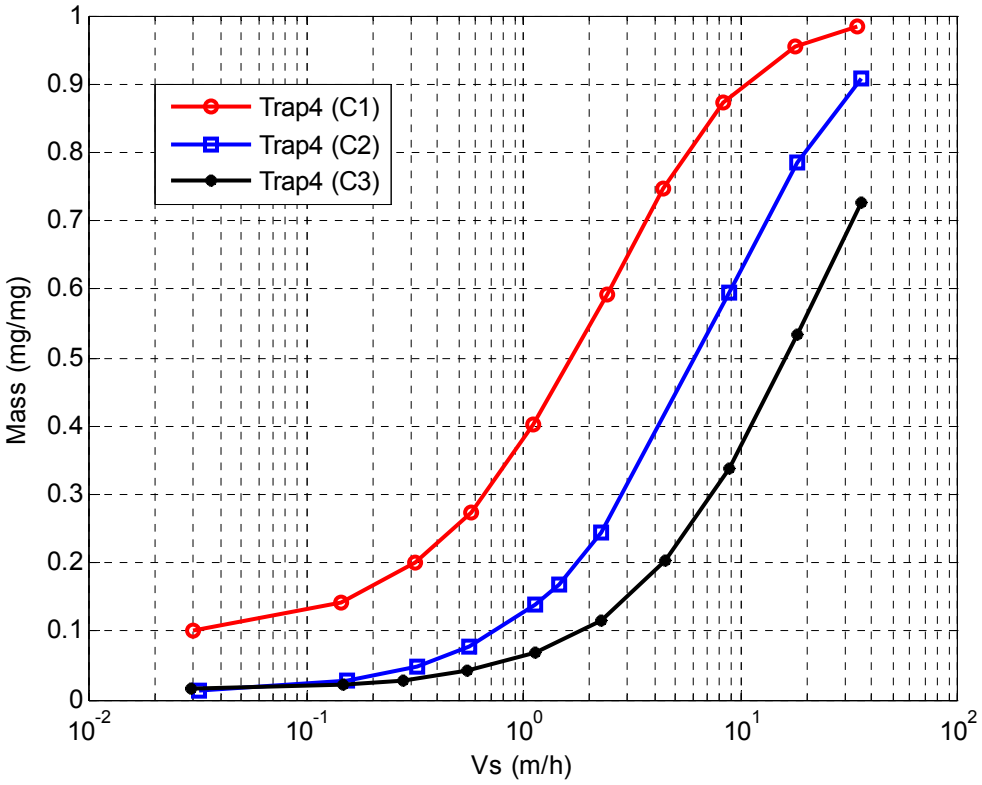


Figure 74 Trap 4 (C1, C2, C3)

F(Vs)	Vs (C1) (m/h)	Vs (C2) (m/h)	Vs (C3) (m/h)	Vmin (m/h)	Vmean (m/h)	Vmax (m/h)	σ (m/h)
0,10	0,03	0,78	1,86	0,03	0,40	0,78	0,53
0,20	0,32	1,78	4,40	0,32	1,05	1,78	1,03
0,30	0,68	3,32	7,60	0,68	2,00	3,32	1,86
0,40	1,11	5,18	11,79	1,11	3,14	5,18	2,88
0,50	1,77	7,04	16,58	1,77	4,41	7,04	3,73
0,60	2,49	9,05	24,35	2,49	5,77	9,05	4,64
0,70	3,78	13,86	33,58	3,78	8,82	13,86	7,13
0,80	6,03	20,00	42,81	6,03	13,01	20,00	9,88
0,90	11,44	34,38	52,05	11,44	22,91	34,38	16,22

Table 24 Settling velocity comparison for trap 4, from campaign 1 (C1), campaign 2 (C2) and campaign 3 (C3)

5.6.5 Trap 5 – Settling Velocities of three Campaigns

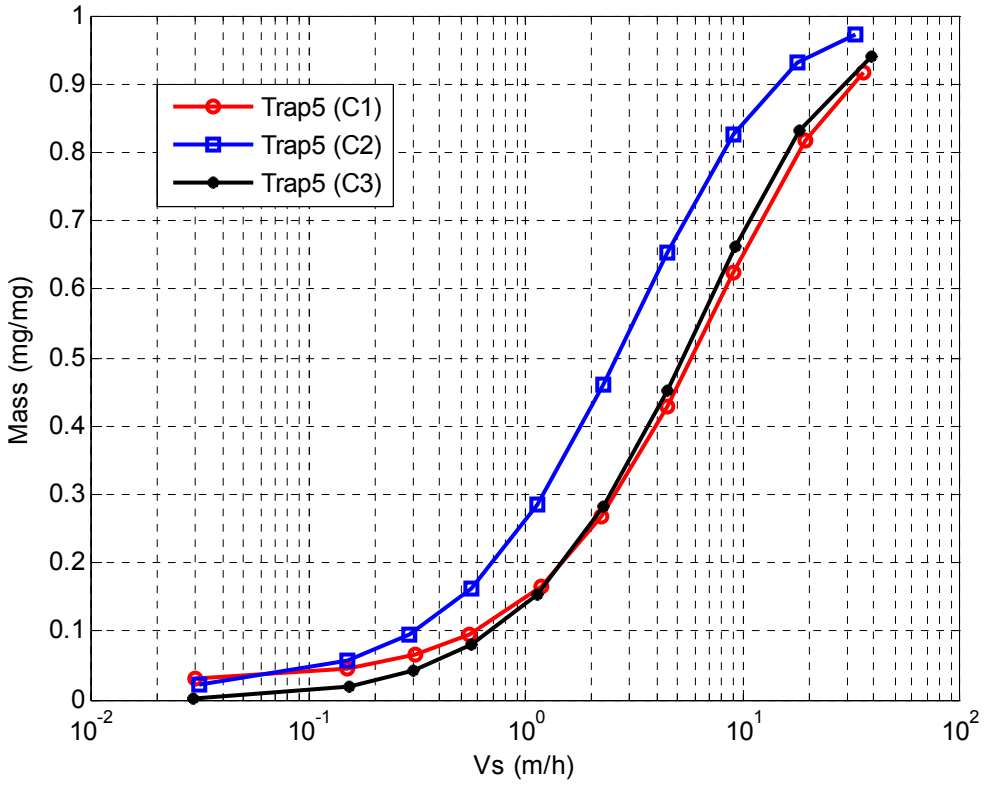


Figure 75 Trap 5 (C1, C2, C3)

F(Vs)	Vs (C1) (m/h)	Vs (C2) (m/h)	Vs (C3) (m/h)	Vmin (m/h)	Vmean (m/h)	Vmax (m/h)	σ (m/h)
0,10	0,59	0,31	0,71	0,31	0,45	0,59	0,20
0,20	1,54	0,73	1,54	0,73	1,14	1,54	0,57
0,30	2,70	1,23	2,52	1,23	1,97	2,70	1,04
0,40	4,09	1,88	3,78	1,88	2,99	4,09	1,57
0,50	6,12	2,72	5,51	2,72	4,42	6,12	2,40
0,60	8,40	3,84	7,73	3,84	6,12	8,40	3,22
0,70	13,03	5,64	11,09	5,64	9,34	13,03	5,22
0,80	18,35	8,25	16,41	8,25	13,30	18,35	7,14
0,90	32,87	15,26	31,17	15,26	24,06	32,87	12,46

Table 25 Settling velocity comparison for trap 5, from campaign 1 (C1), campaign 2 (C2) and campaign 3 (C3)

5.6.6 Trap 6 – Settling Velocities of three Campaigns

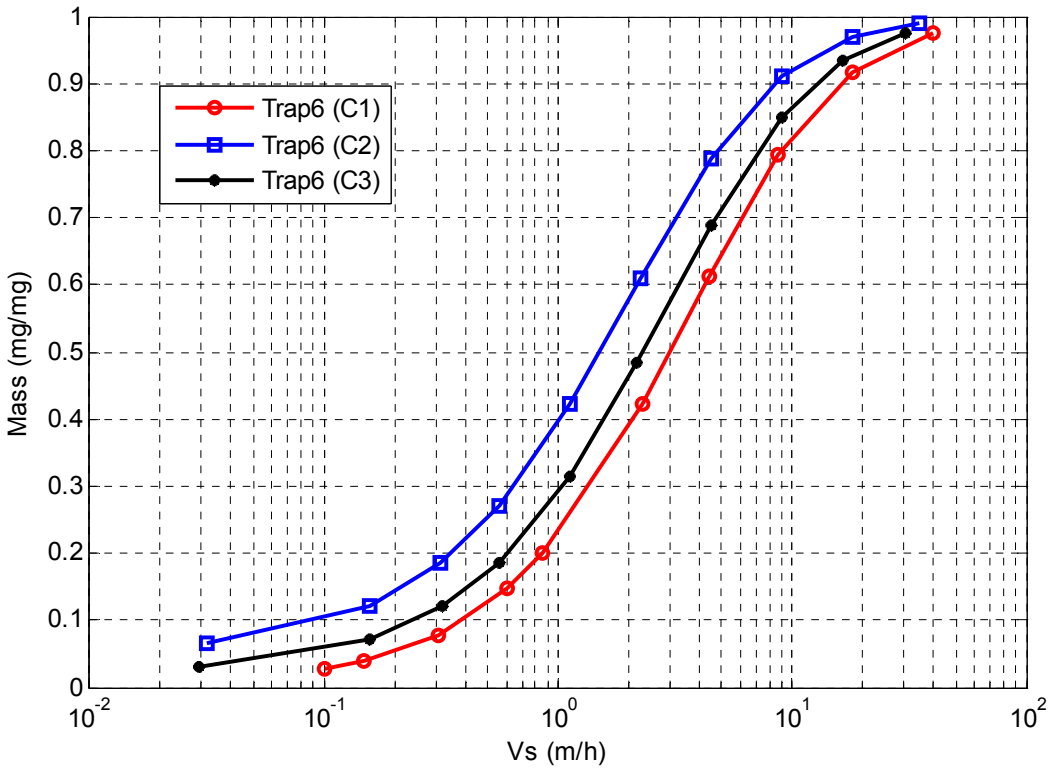


Figure 76 Trap 6 (C1, C2, C3)

F(Vs)	Vs (C1) (m/h)	Vs (C2) (m/h)	Vs (C3) (m/h)	Vmin (m/h)	Vmean (m/h)	Vmax (m/h)	σ (m/h)
0,10	0,40	0,11	0,25	0,11	0,25	0,40	0,21
0,20	0,86	0,36	0,62	0,36	0,61	0,86	0,36
0,30	1,51	0,67	1,06	0,67	1,09	1,51	0,60
0,40	2,16	1,04	1,66	1,04	1,60	2,16	0,79
0,50	3,18	1,59	2,36	1,59	2,38	3,18	1,12
0,60	4,29	2,18	3,48	2,18	3,24	4,29	1,49
0,70	6,54	3,38	4,79	3,38	4,96	6,54	2,24
0,80	9,30	4,92	7,58	4,92	7,11	9,30	3,09
0,90	16,78	8,65	13,41	8,65	12,72	16,78	5,75

Table 26 Settling velocity comparison for trap 6, from campaign 1 (C1), campaign 2 (C2) and campaign 3 (C3)

5.6.7 Trap 7 – Settling Velocities of three Campaigns

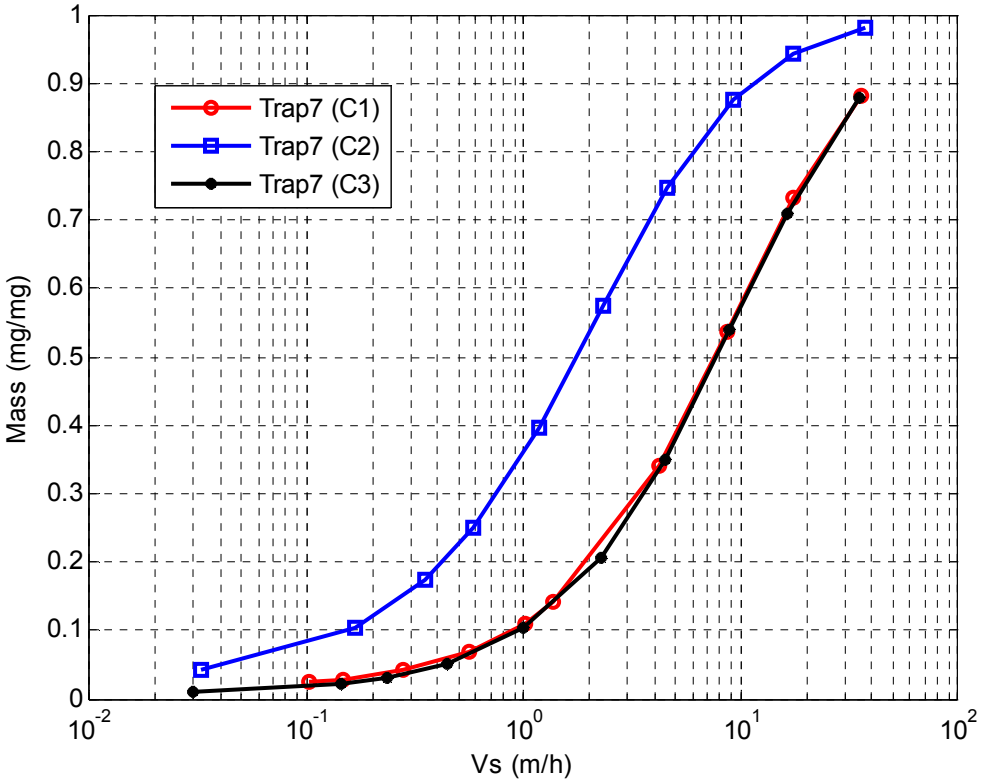


Figure 77 Trap 7 (C1, C2, C3)

F(Vs)	Vs (C1) (m/h)	Vs (C2) (m/h)	Vs (C3) (m/h)	Vmin (m/h)	Vmean (m/h)	Vmax (m/h)	σ (m/h)
0,10	0,90	0,16	0,97	0,16	0,53	0,90	0,52
0,20	2,21	0,43	2,18	0,43	1,32	2,21	1,26
0,30	3,64	0,78	3,72	0,78	2,21	3,64	2,02
0,40	5,57	1,19	5,66	1,19	3,38	5,57	3,10
0,50	7,85	1,84	7,99	1,84	4,85	7,85	4,25
0,60	11,52	2,66	11,49	2,66	7,09	11,52	6,27
0,70	15,99	3,98	15,75	3,98	9,99	15,99	8,50
0,80	25,70	6,50	26,39	6,50	16,10	25,70	13,57
0,90	38,08	12,13	37,76	12,13	25,11	38,08	18,35

Table 27 Settling velocity comparison for trap 7, from campaign 1 (C1), campaign 2 (C2) and campaign 3 (C3)

5.6.8 Trap 8 – Settling Velocities of three Campaigns

There are also a few positions where a quite similar settling velocity behaviour for all three curves are notable: trap1, trap6, trap8, trap9 and trap12.

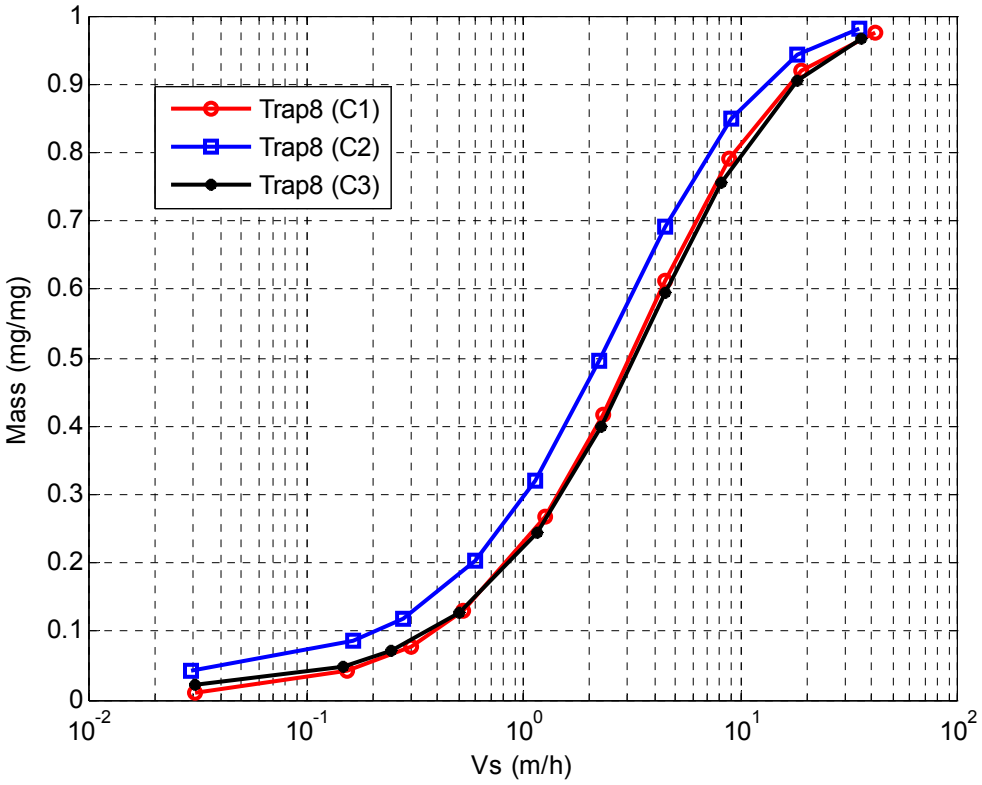


Figure 78 Trap 8 (C1, C2, C3)

F(Vs)	Vs (C1) (m/h)	Vs (C2) (m/h)	Vs (C3) (m/h)	Vmin (m/h)	Vmean (m/h)	Vmax (m/h)	σ (m/h)
0,10	0,40	0,21	0,38	0,21	0,30	0,40	0,13
0,20	0,89	0,58	0,90	0,58	0,74	0,89	0,23
0,30	1,47	1,03	1,54	1,03	1,25	1,47	0,32
0,40	2,18	1,62	2,26	1,62	1,90	2,18	0,39
0,50	3,24	2,28	3,41	2,28	2,76	3,24	0,68
0,60	4,36	3,42	4,60	3,42	3,89	4,36	0,67
0,70	6,63	4,72	6,84	4,72	5,68	6,63	1,35
0,80	9,48	7,54	11,02	7,54	8,51	9,48	1,37
0,90	17,31	13,80	17,57	13,80	15,56	17,31	2,48

Table 28 Settling velocity comparison for trap 8, from campaign 1 (C1), campaign 2 (C2) and campaign 3 (C3)

5.6.9 Trap 9 – Settling Velocities of three Campaigns

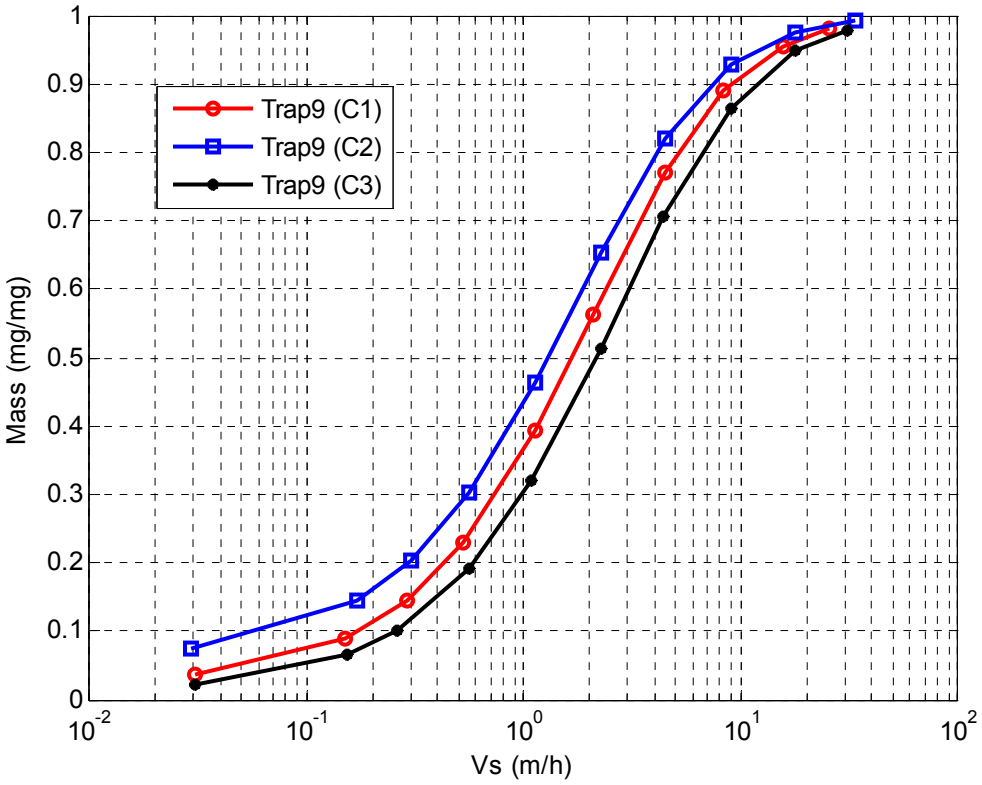


Figure 79 Trap 9 (C1, C2, C3)

F(Vs)	Vs (C1) (m/h)	Vs (C2) (m/h)	Vs (C3) (m/h)	Vmin (m/h)	Vmean (m/h)	Vmax (m/h)	σ (m/h)
0,10	0,17	0,08	0,26	0,08	0,13	0,17	0,07
0,20	0,44	0,29	0,59	0,29	0,37	0,44	0,11
0,30	0,78	0,55	1,00	0,55	0,67	0,78	0,16
0,40	1,16	0,90	1,56	0,90	1,03	1,16	0,18
0,50	1,72	1,34	2,16	1,34	1,53	1,72	0,27
0,60	2,49	1,93	3,20	1,93	2,21	2,49	0,40
0,70	3,64	2,87	4,32	2,87	3,25	3,64	0,55
0,80	5,38	4,20	7,11	4,20	4,79	5,38	0,84
0,90	9,36	7,83	12,70	7,83	8,59	9,36	1,08

Table 29 Settling velocity comparison for trap 9, from campaign 1 (C1), campaign 2 (C2) and campaign 3 (C3)

5.6.10 Trap 10 – Settling Velocities of three Campaigns

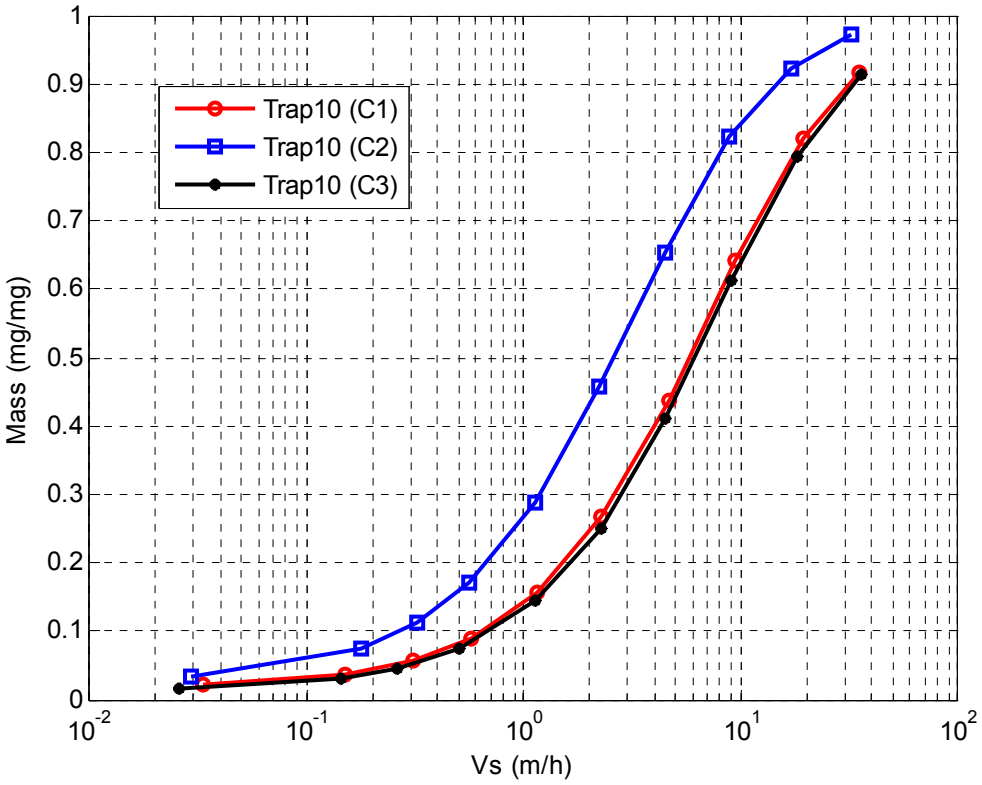


Figure 80 Trap 10 (C1, C2, C3)

F(Vs)	Vs (C1) (m/h)	Vs (C2) (m/h)	Vs (C3) (m/h)	Vmin (m/h)	Vmean (m/h)	Vmax (m/h)	σ (m/h)
0,10	0,65	0,27	0,73	0,27	0,46	0,65	0,27
0,20	1,59	0,69	1,71	0,69	1,14	1,59	0,64
0,30	2,74	1,19	2,93	1,19	1,97	2,74	1,09
0,40	4,13	1,85	4,31	1,85	2,99	4,13	1,61
0,50	6,12	2,71	6,47	2,71	4,42	6,12	2,42
0,60	8,49	3,84	8,74	3,84	6,16	8,49	3,29
0,70	12,70	5,64	13,35	5,64	9,17	12,70	4,99
0,80	18,23	8,24	18,95	8,24	13,23	18,23	7,07
0,90	32,27	14,97	33,92	14,97	23,62	32,27	12,24

Table 30 Settling velocity comparison for trap 10, from campaign 1 (C1), campaign 2 (C2) and campaign 3 (C3)

5.6.11 Trap 11 – Settling Velocities of three Campaigns

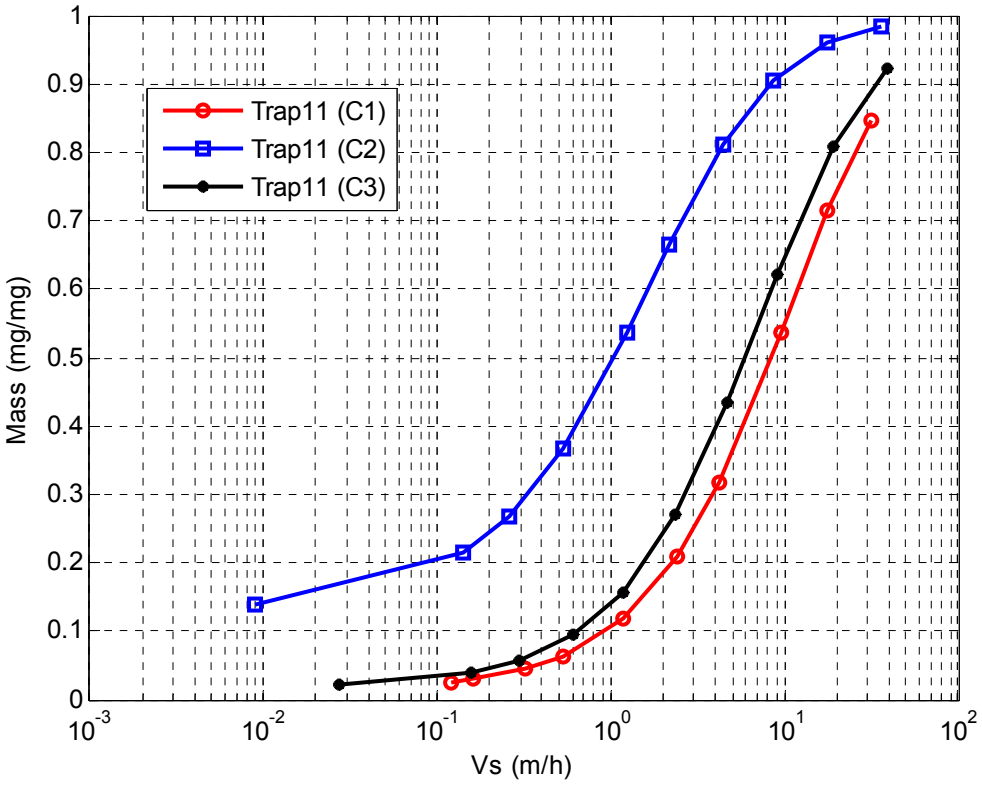


Figure 81 Trap 11 (C1, C2, C3)

F(Vs)	Vs (C1) (m/h)	Vs (C2) (m/h)	Vs (C3) (m/h)	Vmin (m/h)	Vmean (m/h)	Vmax (m/h)	σ (m/h)
0,10	0,97	-0,06	0,66	0,06	0,45	0,97	0,73
0,20	2,28	0,12	1,63	0,12	1,20	2,28	1,53
0,30	3,89	0,35	2,80	0,35	2,12	3,89	2,50
0,40	6,17	0,68	4,23	0,68	3,42	6,17	3,88
0,50	8,59	1,10	6,27	1,10	4,84	8,59	5,30
0,60	12,43	1,71	8,62	1,71	7,07	12,43	7,58
0,70	17,09	2,73	13,24	2,73	9,91	17,09	10,15
0,80	26,81	4,29	18,52	4,29	15,55	26,81	15,92
0,90	37,47	8,39	34,85	8,39	22,93	37,47	20,56

Table 31 Settling velocity comparison for trap 11, from campaign 1 (C1), campaign 2 (C2) and campaign 3 (C3)

5.6.12 Trap 12 – Settling Velocities of three Campaigns

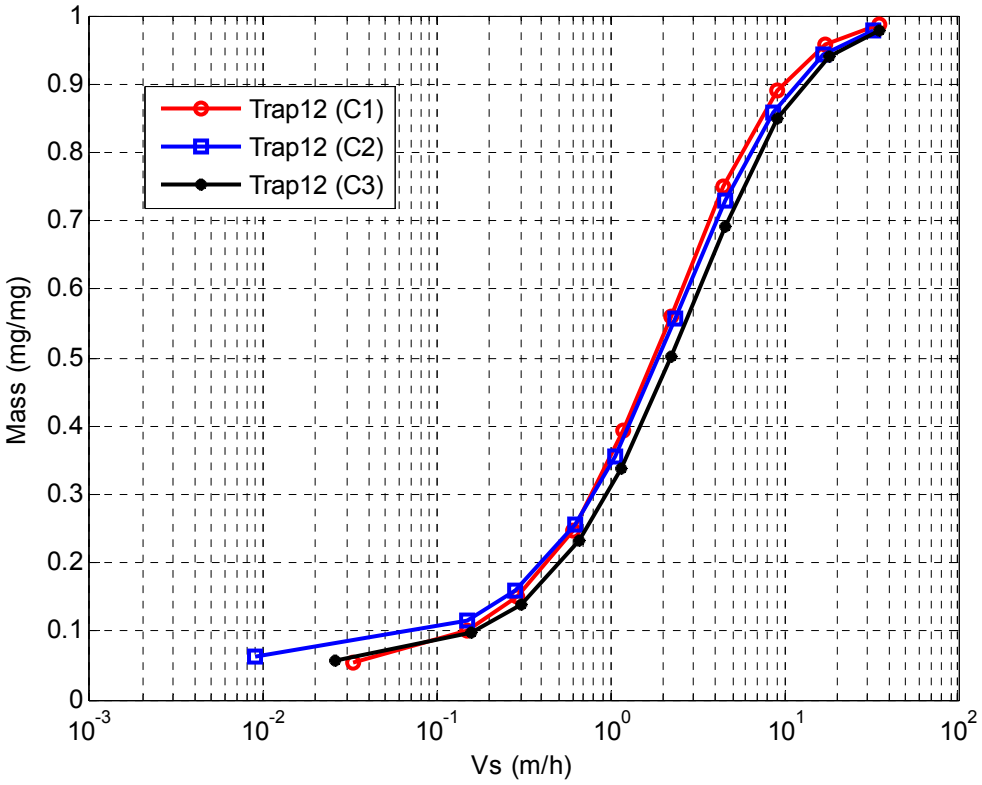


Figure 82 Trap 12 (C1, C2, C3)

F(Vs)	Vs (C1) (m/h)	Vs (C2) (m/h)	Vs (C3) (m/h)	Vmin (m/h)	Vmean (m/h)	Vmax (m/h)	σ (m/h)
0,10	0,15	0,11	0,16	0,11	0,13	0,15	0,03
0,20	0,45	0,42	0,53	0,42	0,43	0,45	0,01
0,30	0,81	0,81	0,98	0,81	0,81	0,81	0,00
0,40	1,23	1,34	1,57	1,23	1,29	1,34	0,08
0,50	1,85	1,99	2,23	1,85	1,92	1,99	0,11
0,60	2,68	2,90	3,40	2,68	2,79	2,90	0,16
0,70	3,86	4,17	4,71	3,86	4,02	4,17	0,22
0,80	6,10	6,72	7,59	6,10	6,41	6,72	0,44
0,90	10,26	12,58	14,10	10,26	11,42	12,58	1,64

Table 32 Settling velocity comparison for trap 12, from campaign 1 (C1), campaign 2 (C2) and campaign 3 (C3)

5.7 Correlations between Rain Data and Turbidity Measurements

The analysis of measured parameters (rain data like flow rates, turbidity, waterlevel in the stormwatertank etc. and settling velocity) at the inlet and the outlet of the storage retention tank are subject of this section. The settling velocity measurement of inlet and outlet of the storage retention tank in Chassieu represent the highest (inlet) and the lowest (outlet) settling velocity values. This was confirmed by turbidity measurements with the device “Edress – Hauser” for two measurement series (campaign2 and campaign3). Within this range of the highest and the lowest values it is supposed to find the settling velocities measured at different points in the storage retention tank.

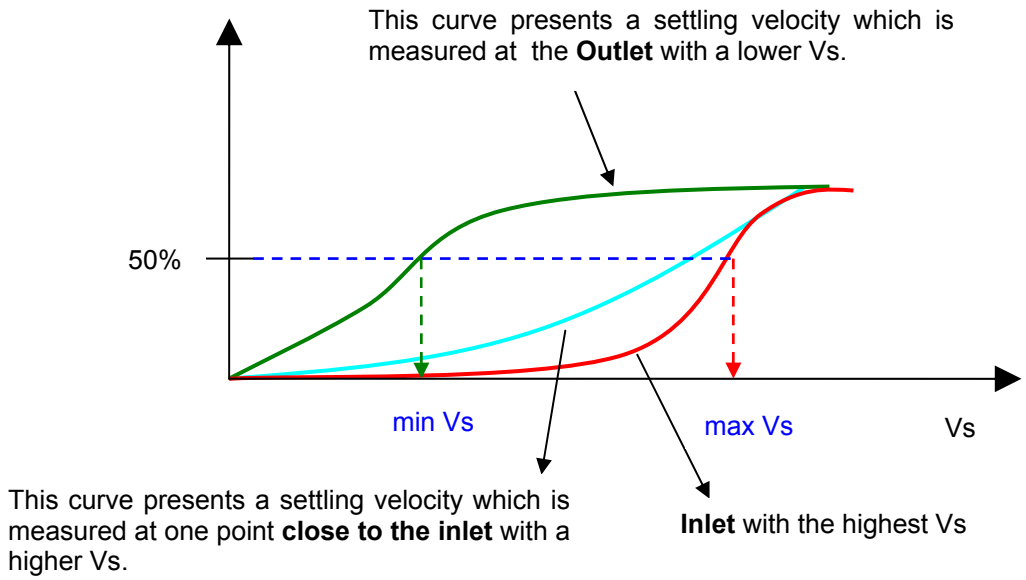
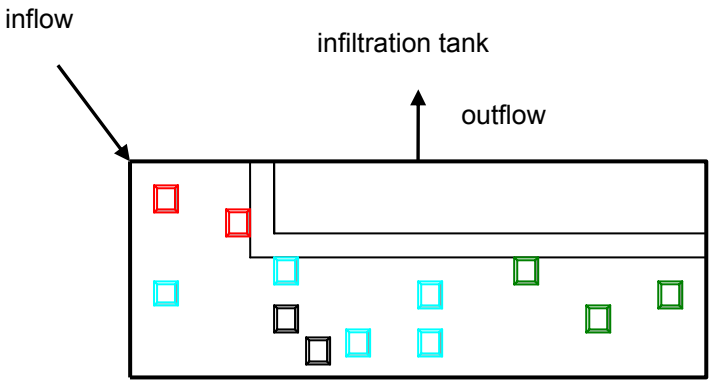


Figure 83 Settling velocities according to different positions in the stormwater tank

Clarification of the upper graphic:



By the analysis of the rain data like flow rates, turbidity, waterlevel in the stormwatertank etc. it should be possible to relate different rain parameters with the settling velocity grading curves. To draw conclusions out of rain events it is necessary to have more data. A long time monitoring of different rain events could be very interesting. Also the influence of dry weather periods on settling velocity grading curves play an important role. The absence of runoff leads to an accumulation of pollutants in the catchment area. So it is supposed that different dry weather periods deliver different settling velocity distribution curves. The rain data for the inflow and outlow parameters of the three measurement series are shown in the appendix.

5.8 Mass balance

Determination of the systematical loss

The initial mass consists of the following mass parts (including a systemati mass loss):

Mini = Mfin + Msettl. + Mmix.-tub + (Mhomog. + Mbucket)*1 + Δ*2

*1 Mhomog. and Mbucket are considered as corrigible losses

*2 Δ = systematical loss of the experiment

The systematic mass loss is then:

Δ = Mini – Msettl. – Mfin – Mmix.tub – Mhomog. – Mbucket

Parts of Mass	High Mass	Medium Mass	Low Mass
Mini (mg)	10894,00	7367,00	344,40
Mfin (mg)	87,00	73,00	9,00
Msettl. (mg)	3481,20	1663,90	83,50
Mmix.-tub (mg)	6606,80	3952,30	202,00
Mhomog. (mg)	7,30	6,30	0,30
Mbucket (mg)	353,10	1325,10	36,50
Δ, systematical mass lost (mg)	358,60	346,40	13,10
Δ, systematical mass balance (%)	3,29	4,70	3,80

Table 33 Calculation table for determining of systematical losses

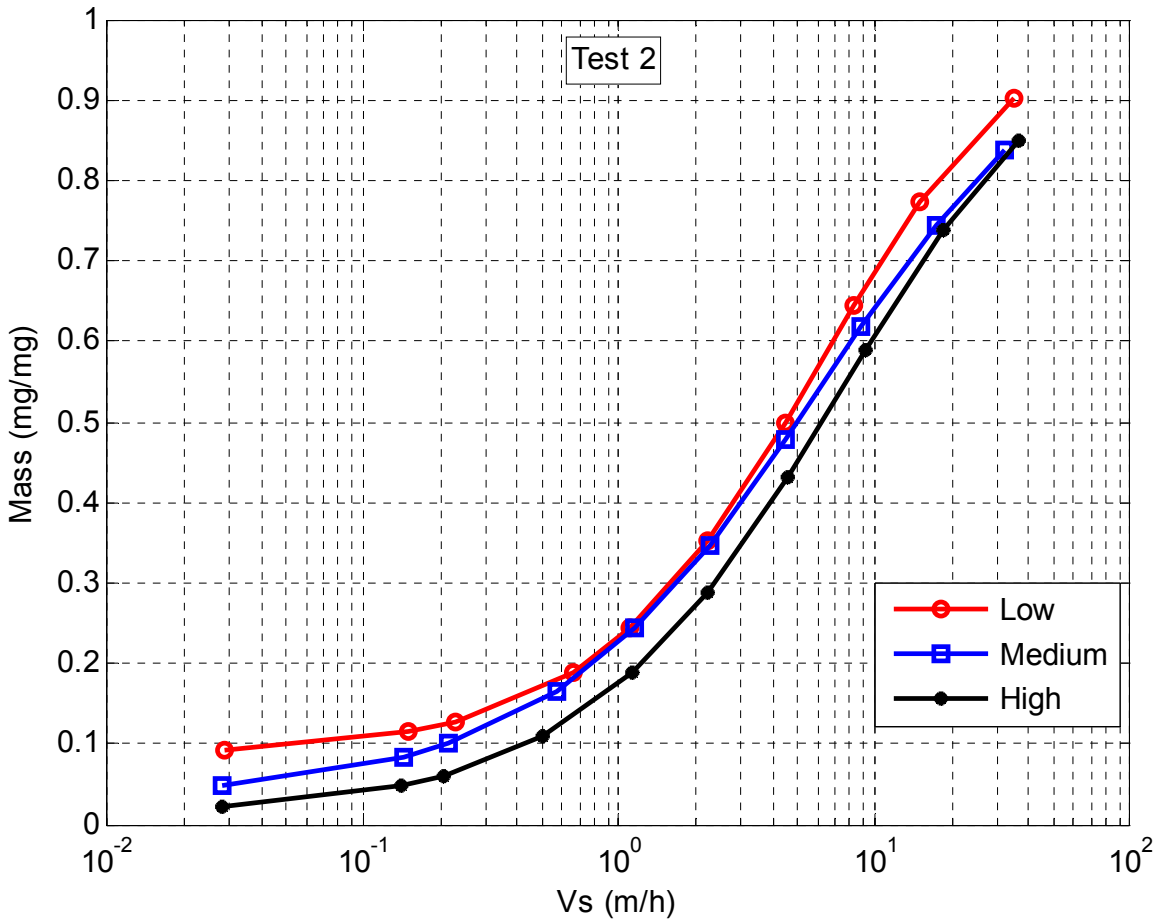


Figure 84 Result of mass balance verification

This experiment showed that settling velocity of the settled mass is determined for only one third of the initial mass because almost two third of the mass are remaining in the mixing tub. It is supposed that the mass in the mixing tub has another settling velocity than the settled mass in the column.
The results for the three different loaded samples deliver much smaller percentage values of the mass balance. The mass balance delivered a result of 3,29% for the high loaded mass, 4,70% for the medium loaded mass and 3,80% for the low loaded mass.

5.9 Settling velocity development in relation of time dependent physico-chemical evolution of a sedimentation sample

Figure 85 contains settling velocity curves of samples taken from three different points in the stormwater settling tank at different times (T2, T7 and T11 after the rain event and T2evolution, T7evolution and T11evolution taken one month after the rain event).

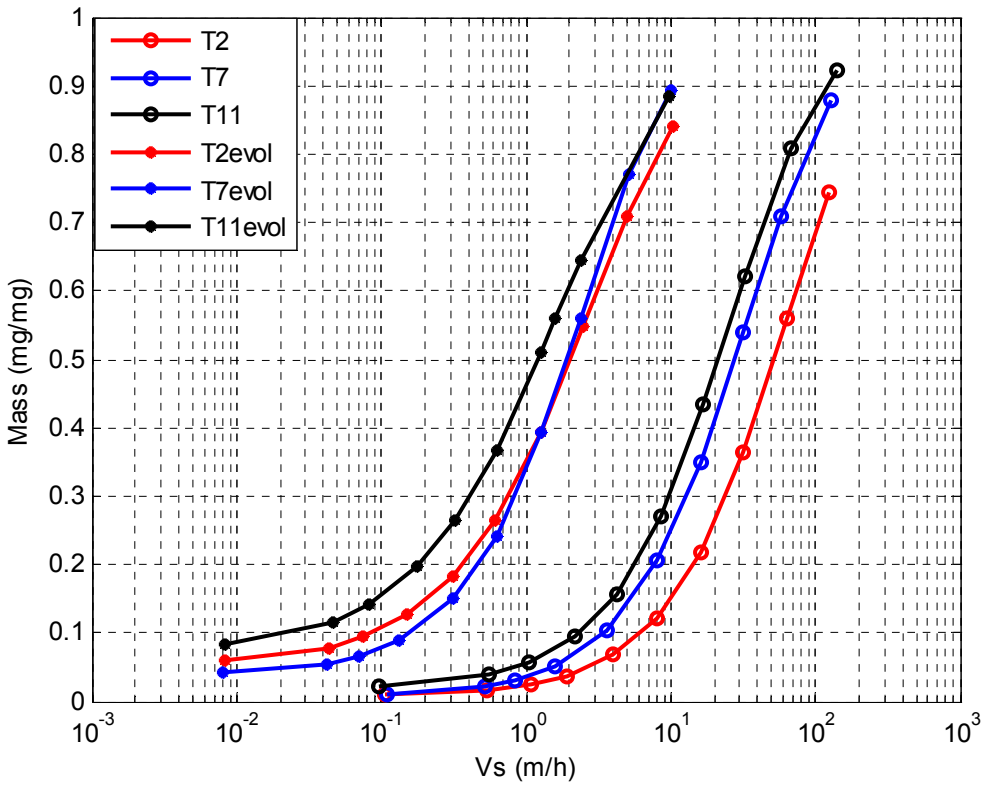


Figure 85 Settling velocity curves at the time of the rain event and one month after

This result shows that the settling velocity decreased within one month. The settling velocity at the time of the rain event was much higher than after one month.

A splitting of the curves makes clear the evolution and a table of values is given below the figure.

5.9.1 Evolution Trap 2

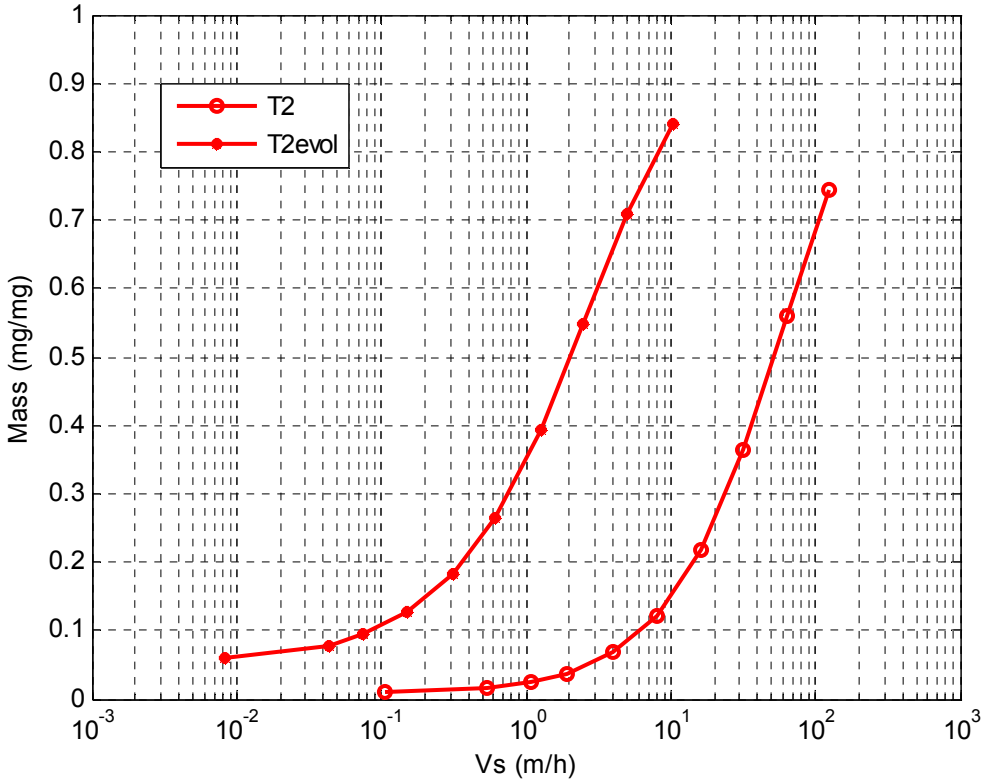


Figure 86 Settling velocity curves of trap 2 at the time of the rain event and one month after

F(Vs)	V (m/h)	
	Trap2 init.	Trap2 evol.
0,1	6,46	0,09
0,2	14,69	0,38
0,3	25,06	0,78
0,4	37,93	1,30
0,5	54,48	2,11
0,6	77,35	3,33
0,7	110,10	4,92
0,8	142,86	8,79
0,9	175,61	12,86

Table 34 Settling velocity values of trap 2

F(Vs)	Trap2 settling velocity (m/h)			
	Vmin	Vmax	Vmean	σ
0,1	0,09	6,46	3,28	4,50
0,2	0,38	14,69	7,53	10,12
0,3	0,78	25,06	12,92	17,17
0,4	1,30	37,93	19,62	25,90
0,5	2,11	54,48	28,30	37,03
0,6	3,33	77,35	40,34	52,34
0,7	4,92	110,10	57,51	74,38
0,8	8,79	142,86	75,82	94,80
0,9	12,86	175,61	94,23	115,08

Table 35 Settling velocity values of trap 2 – statistical exploitation

5.9.2 Evolution Trap 7

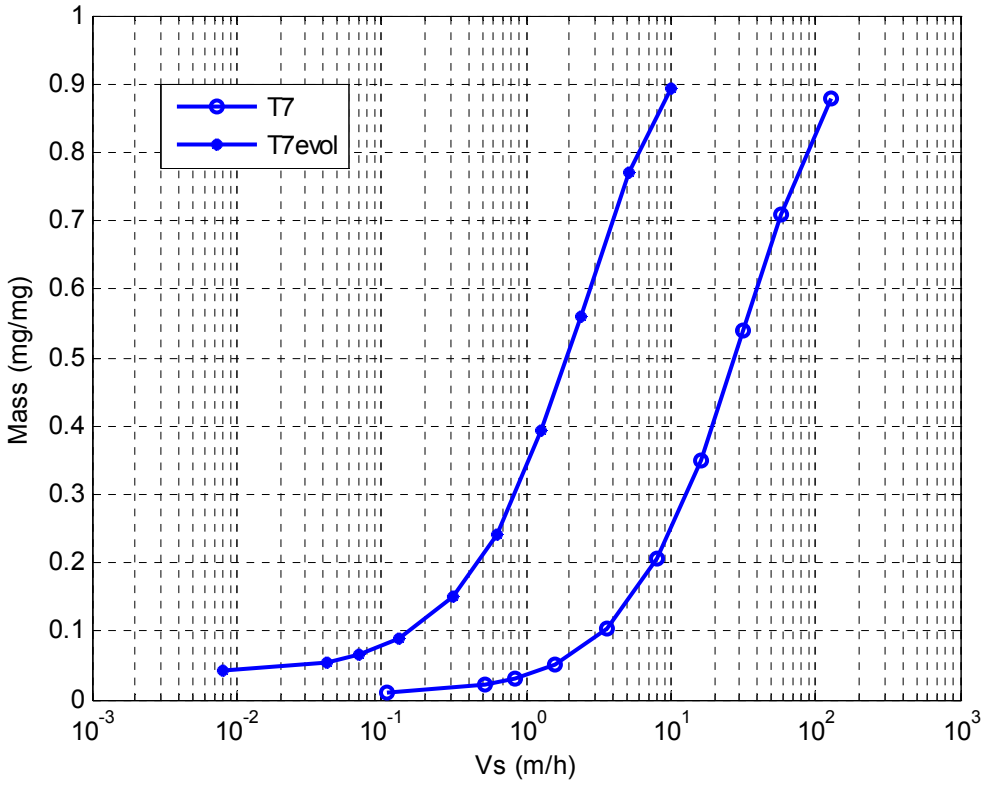


Figure 87 Settling velocity curves of trap 7 at the time of the rain event and one month after

F(Vs)	V (m/h)	
	Trap2 init.	Trap2 evol.
0,1	3,49	0,17
0,2	7,86	0,49
0,3	13,39	0,88
0,4	20,37	1,34
0,5	28,76	1,99
0,6	41,38	2,92
0,7	56,70	4,28
0,8	95,00	6,38
0,9	135,92	10,27

Table 36 Settling velocity values of trap 7

F(Vs)	Trap2 settling velocity (m/h)			
	Vmin	Vmax	Vmean	σ
0,1	0,17	3,49	1,83	2,35
0,2	0,49	7,86	4,17	5,22
0,3	0,88	13,39	7,14	8,85
0,4	1,34	20,37	10,85	13,46
0,5	1,99	28,76	15,38	18,92
0,6	2,92	41,38	22,15	27,19
0,7	4,28	56,70	30,49	37,07
0,8	6,38	95,00	50,69	62,66
0,9	10,27	135,92	73,10	88,85

Table 37 Settling velocity values of trap 7 – statistical exploitation

5.9.3 Evolution Trap 11

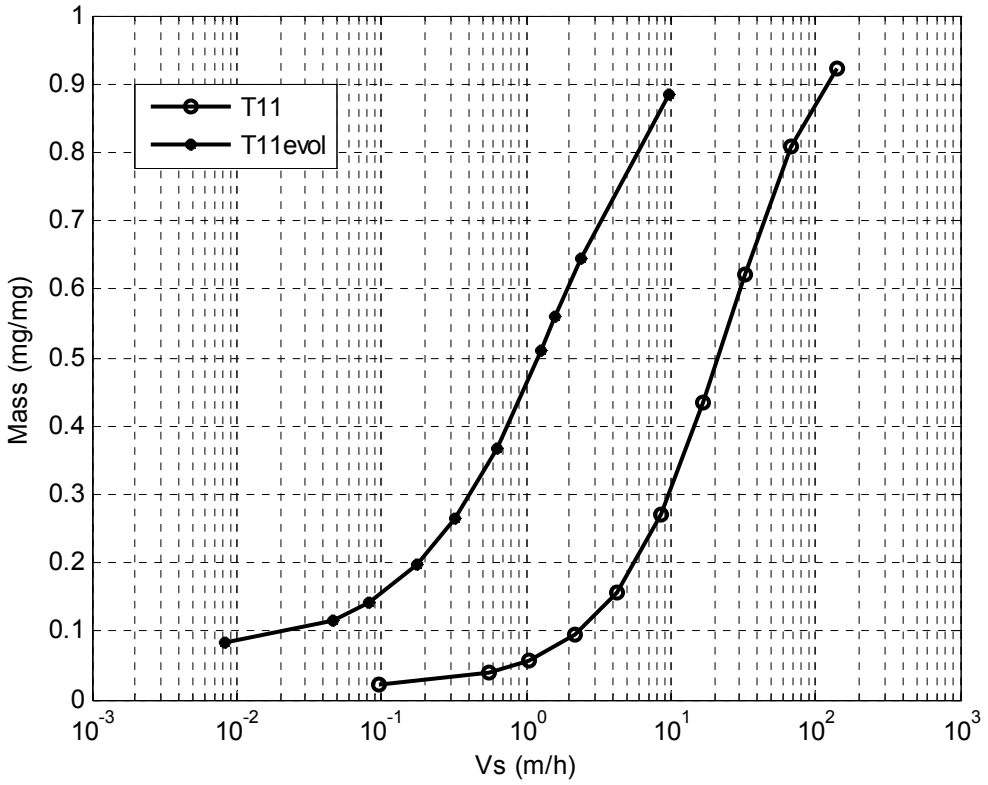


Figure 88 Settling velocity curves of trap 11 at the time of the rain event and one month after

F(Vs)	V (m/h)	
	Trap2 init.	Trap2 evol.
0,1	2,37	0,03
0,2	5,86	0,18
0,3	10,08	0,43
0,4	15,22	0,78
0,5	22,58	1,23
0,6	31,03	1,96
0,7	47,65	4,07
0,8	66,67	7,19
0,9	125,45	10,31

Table 38 Settling velocity values of trap 11

F(Vs)	Trap2 settling velocity (m/h)			
	Vmin	Vmax	Vmean	σ
0,1	0,03	2,37	1,20	1,66
0,2	0,18	5,86	3,02	4,01
0,3	0,43	10,08	5,25	6,82
0,4	0,78	15,22	8,00	10,22
0,5	1,23	22,58	11,91	15,10
0,6	1,96	31,03	16,50	20,56
0,7	4,07	47,65	25,86	30,81
0,8	7,19	66,67	36,93	42,06
0,9	10,31	125,45	67,88	81,41

Table 39 Settling velocity values of trap 11 – statistical exploitation

If the result will be confirmed by future experiments consequences regarding the management of the storage tank could be expected (storage tank maintenance practices, depollution strategies, designe of the storage tank).

6. Conclusions and Perspectives

This work presents an investigation on settling velocity distribution in a storage retention tank measured with the French protocol Vicas (VItesse de Chute en ASsainissement). The main objective was to investigate, confirm and extend the laboratory measurement method. Hence, an intensive literature research constitutes the theorical background of the research.

The field experiments were executed for three rain events and in succession various tests have been realized with the French device to evaluate the exactitude of the protocol and the influence of the experimental procedure on the settling velocity distribution. Therefore it is important to have a profound knowledge about its operational mode, including advantages and drawbacks.

The reproducibility of the protocol Vicas has been confirmed by good results of three corresponding curves.

An experiment carried out to analyse the mass balance lead to satisfying results concerning the systematic errors and the knowledge of the losses' distribution within the experimental modus. An astonishing cognition is that only one third of the initial mass was found in the settling column and two thirds were remaining in the mixing vat. A quite positive aspect is that some recommendations can be given to improve the operational mode. A careful sample pouring into the mixing vat of the Vicas device reduces obviously mass loss. The determination of the final mass by filtration of all remaining content in the settling column after the procedure leads to reliable values.

The uncertainty of settling velocity distribution for the VICAS protocol was determined by the application of a Matlab program. A perspective out of this two tests is to adjust the settling velocity curve by taking into account the systematic errors obtained by the mass balance experiment.

A comparison of settling velocity measurement results obtained for the 3 series are given, as well as an analysis of their spatial distribution in the tank carried out with the GSTAT software. A geostatistic Ordinary Kriging and Kriging with more covariables interpolation to transfer a point data into the surface to estimate the settling velocity values in other points was done The results show a high spatial variability of the settling velocity curves. It is necessary to carry out further measurements and to complete and compare these with the existing measurement series. At the moment only one campaign was investigated by Kriging with more than one covariable because of little available variables. It is supposed that the spatial variability improves if a better covariable could be found.

The analysis of the rain data like flow rates, turbidity, waterlevel in the stormwater tank etc. showed an implication of different rain parameters in the settling velocity distribution. Also the influence of dry weather periods on settling velocity grading curves play an important role. The absence of runoff leads to an accumulation of pollutants in the catchment area. So it is to suppose that different dry weather periods deliver different settling velocity distribution curves. A long time monitoring of different rain events constitutes a very interesting futural project. It could be confirmed that settling velocity changes along with the variation of some rain related parameters (Qmax, Vtot, Δt_{dry}, $\Delta t_{rain,}$ Turb.). More raw data must be collected to draw conclusions out of rain events in future.

Another perspective is the study of grain size distribution and its relationship to the settling velocity. Further raw data like granulometry curves of settled sediments should be used for this investigation.

The time dependent, physico-chemical evolution of a sedimentation sample has been studied concerning its influence on settling velocity. The time period for the carried out experiment was one month and further experiments in the mid and long term will be done. We observed a settling velocity slow down by the progression of time. If the result will be confirmed by future experiments, consequences regarding the management of the storage tank could be expected (storage tank maintenance practices, depollution strategies, designe of the storage tank).

Finally it is to declare that settling velocity distribution curves measured by the French Vicas protocol respond an international level and it is recommended to carry out settling velocity measurements by the application of this protocol. It delivers qualified results as shown, no pretreatment of the sample is necessary, the protocol measurement by itself is a fast measurement method, the device is not very expensive and handy. The procedure can be undertaken by only one operator in large part.

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APPENDIX A : DATA PROTOCOL VICAS

Rain Data of the three measurement series

Campaign 1

Trap 1

Informations échantillon — **Informations colonne**

Référence	Pluie du 14/06/2005, piège 1
Date prélèvement	20/06/2005
Conservation	frigo
Date d'analyse	20/06/2005

Hauteur de chute (cm)	59,5
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)	m2 (mg)
Echantillon 1	41	89,4	126,5	
Echantillon 2	32	92,4	117,4	
Echantillon 3	43	91,3	126,8	

Etat final	Volume (ml)	m0 (mg)	m1 (mg)	m2 (mg)
Echantillon 1	191	94,1	104,2	
Echantillon 2	158	92,9	101,4	
Echantillon 3	167	93,6	103	

Décantation	Temps (min)			
1	1	91,9	909,5	
2	2	90,6	621,4	
4	3,95	91,8	563,1	
8	8,116666667	93,6	433,7	
16	16,43333333	92,6	309,3	
32	32,01666667	94,8	206	
1h	56,76666667	90,1	157,3	
2h	123	90,4	145,3	
4h	244,55	93,2	141,9	
+12h	1203,683333	89	117,5	

Trap 2

Informations échantillon — **Informations colonne**

Référence	Pluie du 14/06/2005, piège 2
Date prélèvement	20/06/2005
Conservation	frigo
Date d'analyse	20/06/2005

Hauteur de chute (cm)	60,2
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	44	90,2	113,8
Echantillon 2	45	92,2	117,8
Echantillon 3	44	90	113,8

Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	105	91,4	95,6
Echantillon 2	116	90,9	95,4
Echantillon 3	99	90,9	94,9

Décantation	Temps (min)		
1	0,983333333	88,4	281,2
2	2	90,5	361,5
4	4,466666667	89,3	467
8	8,45	90,9	345,8
16	16	91,9	268,2
32	29,55	90,8	188,1
1h	59,48333333	94,3	160,3
2h	118,7666667	93,4	134
4h	227,25	89,5	115,3
+12h	1188,15	91,1	113,6

Trap 3

Informations échantillon — **Informations colonne**

Référence	Pluie du 14/06/2005, piège 3
Date prélèvement	20/06/2005
Conservation	frigo
Date d'analyse	21/06/2005

Hauteur de chute (cm)	59,6
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1			
Echantillon 2			
Echantillon 3			

Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	132	119,3	126,7
Echantillon 2	155	125,2	133,8
Echantillon 3	159	114,8	123,8

Décantation	Temps (min)		
1	0,916666667	92,8	595,9
2	2,016666667	91,3	510,4
4	3,966666667	94,2	529,3
8	8,816666667	90,5	479,16
16	16,91666667	89,8	292,9
32	31,7	90,4	220,4
1h	59,1	91,8	165,9
2h	124,95	94,1	155,1
4h	267,6833333	90,5	117,3
+12h	1206,416667	90,2	108,5

Trap 4

Informations échantillon — **Informations colonne**

Référence	Pluie du 14/06/2005, piège 4
Date prélèvement	20/06/2005
Conservation	frigo
Date d'analyse	21/06/2005

Hauteur de chute (cm)	59,5
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1			
Echantillon 2			
Echantillon 3			

Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	95	109,4	112,3
Echantillon 2	104	101,1	104,6
Echantillon 3	139	96,1	100,9

Décantation	Temps (min)		
1	1,05	91,3	189,7
2	2,033333333	89,8	157,2
4	4,316666667	90,3	174,6
8	8,15	91,6	219,2
16	14,93333333	93,2	203,2
32	32,11666667	89,2	187,2
1h	63,26666667	90,8	146,7
2h	114,45	92,7	126,9
4h	249,3	90,1	113,7
+12h	1193,266667	90,5	106,9

Trap 5

Informations échantillon

Référence	Pluie du 14/06/2005, piège 5
Date prélèvement	16/06/2005
Conservation	frigo
Date d'analyse	16/06/2005

Informations colonne

Hauteur de chute (cm)	59,5
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	74	94,2	568,2
Echantillon 2	40	91,6	329,1
Echantillon 3	36	92	305,7

Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	152	92,4	99,2
Echantillon 2	178	90,4	98,6
Echantillon 3	193	90,8	99,7

Décantation	Temps (min)		
	1	91,7	3809,4
	1,85	90,4	3313,8
	4	91,3	3934,4
	7,933333333	91,7	1368,4
	15,95	91,6	1054,1
	30,55	92	1400,7
	64,76666667	93,1	728
	116,3	93,8	519,2
	237,7833333	91,5	429,3
	1193,616667	92	408,3

Trap 6

Informations échantillon

Référence	Pluie du 14/06/2005, piège 6
Date prélèvement	16/06/2005
Conservation	frigo
Date d'analyse	17/06/2005

Informations colonne

Hauteur de chute (cm)	59,1
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	52	93,9	173,3
Echantillon 2	41	94	153,4
Echantillon 3	56	89	153,6

Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	134	92,2	97,6
Echantillon 2	200	91,9	99,5
Echantillon 3	206	92,2	100,4

Décantation	Temps (min)		
1	0,883333333	90,6	451,6
2	1,966666667	93,5	645,5
4	4,05	89,2	1075,2
8	8,016666667	92,8	924,3
16	15,4	91,3	556,5
32	41,15	90,8	468,9
1h	58,56666667	94	224,9
2h	116,2666667	93,6	213,2
4h	240,6	91	176,1
+12h	352,75	94,2	122,8

Trap 7

Informations échantillon

Référence	Pluie du 14/06/2005, piège 7
Date prélèvement	16/06/2005
Conservation	frigo
Date d'analyse	17/06/2005

Informations colonne

Hauteur de chute (cm)	56,9
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	36	92,5	231,4
Echantillon 2	42	91,4	245,8
Echantillon 3	36	92,4	231

Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	204	94,1	106,6
Echantillon 2	160	92	101,9
Echantillon 3	145	92,2	101,5

Décantation	Temps (min)		
1	0,95	89,7	2846,8
2	1,95	94,3	2924,7
4	3,933333333	93,9	1872,8
8	8,066666667	93,9	1056,2
16	24,91666667	90,8	998,4
32	33,68333333	90,4	336,8
1h	61,16666667	91	392,5
2h	122,7	91,7	284,5
4h	235,0166667	92,4	188
+12h	337,4166667	92,3	137,1

Trap 8

Informations échantillon

Référence	Pluie du 14/06/2005, piège 8
Date prélèvement	16/06/2005
Conservation	frigo
Date d'analyse	16/06/2005

Informations colonne

Hauteur de chute (cm)	60,4
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	48	93,9	137,8
Echantillon 2	40	93,4	128,3
Echantillon 3	46	91,4	132,7

Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	148	92,3	94,4
Echantillon 2	166	92,4	95,3
Echantillon 3	210	90,1	93,7

Décantation	Temps (min)		
	0,883333333	92	316,1
	1,916666667	92,5	417,3
	4,083333333	90,4	759
	8,033333333	92,4	577,3
	15,83333333	92,4	375,7
	29	92,8	271,3
	68,88333333	91,2	269,1
	121,3166667	94,2	158,1
	237,1166667	94,1	137,2
	1177,9	92,2	134,8

Trap 9

Informations échantillon

Référence	Pluie du 14/06/2005, piège 9
Date prélèvement	16/06/2005
Conservation	frigo
Date d'analyse	16/06/2005

Informations colonne

Hauteur de chute (cm)	59,5
Rayon (cm)	3,5

Etat initial

	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	68	92,3	121
Echantillon 2	72	92,5	121,9
Echantillon 3	66	90,6	115,9

Etat final

	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	191	91,9	94,1
Echantillon 2	217	93,5	97,4
Echantillon 3	175	92,1	94,5

Décantation

Temps (min)		
1,416666667	93,4	218,6
2,3	93,3	172,6
4,3	91,2	185,5
8	91,6	301,2
17,23333333	92,2	263,3
31,65	91,1	203,7
68,36666667	92	180,2
124,35	92	133,5
237,3666667	93	128,2
1161,833333	93,8	121,9

Trap 10

Informations échantillon

Référence	Pluie du 14/06/2005, piège 10
Date prélèvement	15/06/2005
Conservation	frigo
Date d'analyse	15/06/2005

Informations colonne

Hauteur de chute (cm)	60,8
Rayon (cm)	3,5

Etat initial

	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	90	94,2	181,2
Echantillon 2	94	93,2	193,9
Echantillon 3	114	94	247,5

Etat final

	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	202	93,7	97,5
Echantillon 2	204	94	97,7
Echantillon 3	200	93	96,3

Décantation

Temps (min)		
1,05	93,3	763
1,883333333	93,5	471
3,85	92,4	546,6
7,85	93,6	449,5
16,05	93,3	335,9
31,91666667	93	232,1
64,28333333	93,5	184
118,7833333	93,2	148,5
246,0333333	93,8	125,7
1099,566667	94,1	114,8

Trap 11

Informations échantillon

Référence	Pluie du 14/06/2005, piège 11
Date prélèvement	16/06/2005
Conservation	frigo
Date d'analyse	17/06/2005

Informations colonne

Hauteur de chute (cm)	61,9
Rayon (cm)	3,5

Etat initial

	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	31	92,1	156,2
Echantillon 2	29	92,6	148,7
Echantillon 3	33	91,5	166,8

Etat final

	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	210	91	103,3
Echantillon 2	155	92,4	100,4
Echantillon 3	145	92,8	100,4

Décantation

	Temps (min)		
1	1,166666667	92,4	2721,6
2	2,083333333	91,8	1578,4
4	3,916666667	90,9	1206,6
8	8,9	91,4	1050,9
16	15,45	92,2	500
32	31,55	90,2	436,7
1h	70,16666667	92,8	325,9
2h	114,5666667	91,2	181,5
4h	233,4333333	91,7	171,8
+12h	311,4	92,4	122

Trap 12

Informations échantillon

Référence	Pluie du 14/06/2005, piège 12
Date prélèvement	15/06/2005
Conservation	frigo
Date d'analyse	15/06/2005

Informations colonne

Hauteur de chute (cm)	58,9
Rayon (cm)	3,5

Etat initial

	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	160	94,9	146,8
Echantillon 2	180	92,4	149,2
Echantillon 3	154	93,6	154

Etat final

	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	224	92,5	94,6
Echantillon 2	216	93,8	96,7
Echantillon 3	212	91,9	95

Décantation

Temps (min)		
1	93,9	163,9
2,066666667	94,5	158,5
3,883333333	95	178,6
7,916666667	93,6	215,3
15,96666667	93,9	203,1
29,76666667	91,1	160,3
58,96666667	92	150,2
122,5833333	91,9	125,2
239,7	91,3	112,8
1081,183333	92,7	114,9

Campaign 2

inflow

Informations échantillon

Référence	echantillon d'entree
Date prélèvement	24/03/2006
Conservation	Frigo
Date d'analyse	25/03/2006

Informations colonne

Hauteur de chute (cm)	59,6
Rayon (cm)	3,5

Etat initial

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	130	92,9	154,3
Echantillon 2	150	93,3	154,8
Echantillon 3	130	93,9	154,1

OPTION 1

Etat final

m0 (mg)	m1 (mg)
92,6	103,5
91,2	101,5
92,1	104,1
93,4	94,1

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1,316666667	92,3	160
2	93,2	135,2
4	93,1	159,8
7,983333333	92,2	182,8
16,08333333	93,1	246
32,5	91,8	250,4
64,8	91,1	197,8
114,4333333	93,6	156
246,85	93	153
4170,483333	93,4	151,2

Trap 1

Informations échantillon

Référence	echantillon piège01
Date prélèvement	24/03/2006
Conservation	Frigo
Date d'analyse	25/03/2006

Informations colonne

Hauteur de chute (cm)	59,8
Rayon (cm)	3,5

Etat initial

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	130	89,5	255,1
Echantillon 2			
Echantillon 3			

OPTION 1

Etat final

m0 (mg)	m1 (mg)
90,5	95,9
92,4	97,3
92	96,5
90,6	96,4
90,6	104,8
91,7	97,3
92,4	96,9
92	96,4
91	103,1

Décantation

Temps (min)	m0 (mg)	m1 (mg)
0,966666667	90	996,3
2	90,3	824,4
3,916666667	91,1	663,8
7,95	92,1	541,7
16	89,8	334,3
32,03333333	91,6	258,3
64,05	91,7	200,5
129,9	92,2	155,9
255,7666667	89,9	129,8
1116,416667	90,7	115,7

Trap 2

Informations échantillon

Référence	echantillon piège02
Date prélèvement	24/03/2006
Conservation	Frigo
Date d'analyse	25/03/2006

Informations colonne

Hauteur de chute (cm)	59,8
Rayon (cm)	3,5

Etat initial

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	112	93,8	295,5
Echantillon 2	76	93,1	219
Echantillon 3	94	91,7	314,2

OPTION 1

Etat final

m0 (mg)	m1 (mg)
92,5	95,7
91,5	96,1
90,8	102,8
91,4	94,7

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1,05	92,3	160
2,016666667	93,2	135,2
4,633333333	93,1	159,8
8,033333333	92,2	182,8
15,86666667	93,1	246
32,38333333	91,8	250,4
64,2	91,1	197,8
140,45	93,6	156
240	93	153
4132,416667	93,4	151,2

Trap 3

Informations échantillon

Référence	echantillon piège03
Date prélèvement	24/03/2006
Conservation	Frigo
Date d'analyse	25/03/2006

Informations colonne

Hauteur de chute (cm)	60
Rayon (cm)	3,5

Etat initial

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	130	91,9	198,8
Echantillon 2			
Echantillon 3			

OPTION 1

Etat final

m0 (mg)	m1 (mg)
90,4	106
91,7	99,5
91,5	98,9
91,9	96,3
91	95,5
91,3	98,6

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1	91,2	935,8
2	90,4	526
4	91,6	512,2
8	89,9	495,2
15,98333333	91,5	380,4
32,41666667	92	219,6
63,93333333	90,1	175,5
120,0666667	90,1	124,9
245,5	91,9	107,1
1107,783333	89,9	100,1

Trap 4

Informations échantillon

Référence	echantillon piege04
Date prélèvement	24/03/2006
Conservation	Frigo
Date d'analyse	25/03/2006

Informations colonne

Hauteur de chute (cm)	60
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	130	92,7	217,4
Echantillon 2			
Echantillon 3			

Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	180	92,2	96,8
Echantillon 2	128	92,2	94,3
Echantillon 3	127	91,6	94,3

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1,016666667	91,2	951,7
2	90,5	673
4,083333333	90	735,2
16	91,5	753,2
25	91,7	203,5
32,05	89,8	147
64,06666667	91,6	175,8
111,3333333	92,1	141
236,6666667	91,6	126,1
1140	90,2	108

Trap 5

Informations échantillon

Référence	echantillon piege5
Date prélèvement	24/03/2006
Conservation	Frigo
Date d'analyse	25/03/2006

Informations colonne

Hauteur de chute (cm)	59,6
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	130	89,2	134,7
Echantillon 2			
Echantillon 3			

OPTION 2

Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	130	92,2	93,6
Echantillon 2	140	92,2	93,7
Echantillon 3	130	92,8	94,3

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1,1	91,2	186,3
2	91,3	179,7
4	91,9	213,5
8,033333333	90,8	213
15,76666667	90,2	228,8
31,78333333	91,9	162,4
64,01666667	92,1	128,7
125	91	112,5
241	90,8	101
1159,133333	90,4	99,2

Trap 6

Informations échantillon

Référence	echantillon piege06
Date prélèvement	24/03/2006
Conservation	Frigo
Date d'analyse	25/03/2006

Informations colonne

Hauteur de chute (cm)	60,2
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	136	90,8	107,1
Echantillon 2			
Echantillon 3			

OPTION 2

Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	130	90,8	91,7
Echantillon 2	130	91	92,3
Echantillon 3	130	91,6	92,7

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1,033333333	92,2	111,1
2	90,7	108,2
4	91,7	118,4
8,066666667	92,5	135,3
16,16666667	91,9	137,9
32,11666667	90,3	123
64,11666667	89,7	105,8
115	89	98,4
232	89,7	95
1150,616667	91,8	95,8

Trap 7

Informations échantillon

Référence	echantillon piege7
Date prélèvement	24/03/2006
Conservation	Frigo
Date d'analyse	25/03/2006

Informations colonne

Hauteur de chute (cm)	62
Rayon (cm)	3,5

Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	140	92,1	92,9
Echantillon 2	130	92	92,6
Echantillon 3	140	91,8	92,3

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1	90,6	128,5
2,133333333	90,3	116,7
4,033333333	89,3	119,5
8,1	88,9	130,1
16,03333333	91,7	142
32	91,1	133,4
64,03333333	90,9	109,4
106,9333333	90,7	105,9
223,2833333	90,3	101,4
1142,15	92,3	100,2

Trap 8

Informations échantillon

Référence	echantillon piege8
Date prélèvement	24/03/2006
Conservation	Frigo
Date d'analyse	25/03/2006

Informations colonne

Hauteur de chute (cm)	59,8
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	144	91,5	114
Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	140	91,9	93,2
Echantillon 2	130	91,9	93,1
Echantillon 3	140	92,4	93,5

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1,016666667	91,3	138,5
2	91,5	134,1
4	91,4	152
8,05	92,2	167,3
16,06666667	91,7	168,3
32,06666667	92,1	129,5
60,75	91,1	115,9
129,8833333	91,1	102
219	91,6	97,4
1239,15	92,4	102,7

Trap 9

Informations échantillon

Référence	echantillon piege9
Date prélèvement	24/03/2006
Conservation	Frigo
Date d'analyse	25/03/2006

Informations colonne

Hauteur de chute (cm)	59,8
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	168	92	109
Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	130	91,2	92,3
Echantillon 2	130	91,5	92,8
Echantillon 3	130	91,3	92,3

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1,066666667	91,5	113,5
2,016666667	91,9	107,8
4	92,9	117,9
8	92	128,1
16,01666667	92,3	135
32	91,5	127,1
64,03333333	91,5	117,5
120,2166667	91,1	102
211	90,4	97,7
1231,133333	92,5	97,8

Trap 10

Informations échantillon

Référence	echantillon piege10
Date prélèvement	24/03/2006
Conservation	Frigo
Date d'analyse	25/03/2006

Informations colonne

Hauteur de chute (cm)	59,5
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	150	91,9	113,5
Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	130	92,4	93,1
Echantillon 2	130	90,1	90,9
Echantillon 3	130	90,2	91

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1,1	92,2	153,6
2,116666667	91,8	134
4,033333333	92,4	143
8,033333333	92,4	161,4
15,98333333	90,9	149,6
31,95	92,2	127,3
64,35	91,3	117,4
111,4666667	92	103,9
202,8833333	92,2	99,2
1222,55	91,1	97,1

Trap 11

Informations échantillon

Référence	echantillon piege11
Date prélèvement	24/03/2006
Conservation	Frigo
Date d'analyse	25/03/2006

Informations colonne

Hauteur de chute (cm)	59,7
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	178	92,3	102,7
Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	mesuree toute la masse	88,4	96,2
Echantillon 2		89	99,5
Echantillon 3			

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1	89	100,3
2,033333333	88	99,3
4,166666667	88,4	104,5
8	87,6	102,5
16,38333333	90	112,2
28,6	88,9	101,5
67,33333333	88,2	103,4
136,8	90,6	99,2
252,4666667	90,7	94,9
3994,766667	92,5	99,7

Trap 12

Informations échantillon

Référence	echantillon piege12
Date prélèvement	24/03/2006
Conservation	Frigo
Date d'analyse	25/03/2006

Informations colonne

Hauteur de chute (cm)	59,6
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	212	90,6	109

Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	mesuree toute la masse	89,6	95,9
Echantillon 2		88,5	95,3
Echantillon 3			

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1,116666667	88,4	117,2
2,133333333	90,1	115,7
4,183333333	89,9	119,8
7,883333333	92	123,5
15,06666667	91,3	126,7
34,1	89	118
57,65	88,5	104,4
127,0333333	89	98
242,7	91,1	99,3
3989,05	91,2	98,4

outflow

Informations échantillon

Référence	echantillon de sortie
Date prélèvement	24/03/2006
Conservation	Frigo
Date d'analyse	25/03/2006

Informations colonne

Hauteur de chute (cm)	59,7
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	130	92,9	161,9
Echantillon 2	135	92,3	164,9
Echantillon 3	130	92,9	156,3

OPTION 1

Etat final	m0 (mg)	m1 (mg)
	90	98,4
	93	104,2
	93,2	105,5
	92,5	100,7

OPTION 2

Etat final	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1			
Echantillon 2			
Echantillon 3			

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1,066666667	93,3	170
2,033333333	91,9	338
4	93	204,2
8,166666667	92,4	323,8
16	93,7	232,4
63,85	92,2	164,8
102,6333333	92,7	128,6
178	92	117,2
4162,416667	93,1	122,9

Campaign 3

inflow

Informations échantillon

Référence	echantillon d'entree
Date prélèvement	09/04/2006
Conservation	Frigo
Date d'analyse	12/04/2006

Informations colonne

Hauteur de chute (cm)	59,9
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	150	88,5	98,7
Echantillon 2	150	89,6	98,1
Echantillon 3	150	87,6	96,2

OPTION 1

Etat final	m0 (mg)	m1 (mg)
	90,8	95,2
	90,1	94,8
	89,2	94,6
	88,7	95

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1	92,7	106,7
2	88	97,2
4,033333333	89,4	101,9
8	89,9	103,4
16,01666667	90,5	104,7
32,08333333	91,5	108,4
64,16666667	88,9	102,6
121,3333333	88,1	97,3
236,2833333	90,4	97,8
1154,283333	90,4	98,7

Trap 1

Informations échantillon

Référence	echantillon piège01
Date prélèvement	09/04/2006
Conservation	Frigo
Date d'analyse	19/04/2006

Informations colonne

Hauteur de chute (cm)	60
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	150	91,1	324,7
Echantillon 2	150	91	382
Echantillon 3	150	91,4	340,8

OPTION 1

Etat final	m0 (mg)	m1 (mg)
	90,4	107
	90,9	109,8
	88,6	109,8

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1	88,4	1831,5
2	89,9	742,6
4	90,3	659,8
8,016666667	91	545,2
15,96666667	91,1	381,8
32,15	89,9	287,9
68,1	91,5	186,4
126	88,2	136,7
250,1166667	89,9	111,7
1229,866667	90,2	111,2

Trap 2

Informations échantillon

Référence	echantillon piège02
Date prélèvement	09/04/2006
Conservation	Frigo
Date d'analyse	19/04/2006

Informations colonne

Hauteur de chute (cm)	59,8
Rayon (cm)	3,5

Etat initial

	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	150	91,5	502,4
Echantillon 2	150	92,4	256,5
Echantillon 3	150	91,9	562,2

OPTION 1

Etat final

m0 (mg)	m1 (mg)
89,1	110
87,5	107,8
92,2	128

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1,033333333	93,3	3687,9
2	91,3	1339,4
4,05	89,2	1052,2
8,033333333	91	783,8
16,08333333	92,5	410,7
32,01666667	91,8	250,4
67,28333333	92,5	232,9
120,65	90,1	134,4
240,9666667	92,2	119,9
1222,85	87,8	109,2

Trap 3

Informations échantillon

Référence	echantillon piège03
Date prélèvement	09/04/2006
Conservation	Frigo
Date d'analyse	19/04/2006

Informations colonne

Hauteur de chute (cm)	60,7
Rayon (cm)	3,5

Etat initial

	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	150	92,5	521,8
Echantillon 2	150	92,6	467,5
Echantillon 3	150	92,1	395,2

OPTION 1

Etat final

m0 (mg)	m1 (mg)
92,4	130,4
92,9	114,4
92,8	110

Décantation

Temps (min)	m0 (mg)	m1 (mg)
0,983333333	91,9	3346,7
2	91,6	1101,6
4	91,2	1031,8
8,016666667	90,3	708,3
16,05	92,2	448,4
32,16666667	90,3	330
64,55	91,4	245,6
112,8333333	91,9	146,2
234,1166667	91,8	126,5
1221,916667	88,9	127,1

Trap 4

Informations échantillon

Référence	echantillon piège04
Date prélèvement	09/04/2006
Conservation	Frigo
Date d'analyse	20/04/2006

Informations colonne

Hauteur de chute (cm)	60
Rayon (cm)	3,5

Etat initial

	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	150	91,1	375
Echantillon 2	150	90,5	255,6
Echantillon 3	150	88,4	407,1

OPTION 1

Etat final

m0 (mg)	m1 (mg)
90,8	112,9
93,4	116,5
90,9	116,7

Décantation

Temps (min)	m0 (mg)	m1 (mg)
1	94,4	2601,8
1,983333333	94,4	931,9
4,083333333	90,8	728,4
8	91,3	440,4
16,05	91,4	303,5
32,01666667	91,9	213,4
66,6	90,9	173,8
128,7166667	91,5	138,4
246	91,6	106,7
1244,9	91,5	103,9

Trap 5

Informations échantillon

Référence	echantillon piège05
Date prélèvement	09/04/2006
Conservation	Frigo
Date d'analyse	20/04/2006

Informations colonne

Hauteur de chute (cm)	60,1
Rayon (cm)	3,5

Etat initial

	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	150	92,5	171,8
Echantillon 2	150	92	144,6
Echantillon 3	150	91,9	178,1

OPTION 1

Etat final

m0 (mg)	m1 (mg)
90,3	98,1
91,1	99,8
91,5	101,6

Décantation

Temps (min)	m0 (mg)	m1 (mg)
0,933333333	91,7	364,3
2	92	364,4
3,95	92,4	338,5
8,15	92,4	289,6
15,78333333	91,4	303,5
32,03333333	91,9	149
64,06666667	91,9	117,9
119,9833333	94,8	107,3
237,9166667	94,6	101,2
1236,65	91	99,1

Trap 6

Informations échantillon

Référence	echantillon piège06
Date prélèvement	09/04/2006
Conservation	Frigo
Date d'analyse	20/04/2006

Informations colonne

Hauteur de chute (cm)	59,8
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	150	91,7	126,7
Echantillon 2	150	91,7	117,9
Echantillon 3	150	91,4	120,5

OPTION 1

Etat final	m0 (mg)	m1 (mg)
	91,6	97,7
	93,1	100
	91,5	98,7

Décantation	Temps (min)	m0 (mg)	m1 (mg)
	1,166666667	91,5	155,8
	2,2	95,1	144,7
	4	91,4	158,1
	8,033333333	94,4	203,1
	16,41666667	91,4	180,3
	31,78333333	92,8	141,5
	64	94	117,9
	111,0333333	94,8	107,3
	230	94,7	103,3
	1228,216667	91,5	103,9

Trap 7

Informations échantillon

Référence	echantillon piège07
Date prélèvement	09/04/2006
Conservation	Frigo
Date d'analyse	21/04/2006

Informations colonne

Hauteur de chute (cm)	59,8
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	150	91	184,6
Echantillon 2	150	92,7	177,2
Echantillon 3	150	92,4	213,5

OPTION 1

Etat final	m0 (mg)	m1 (mg)
	95,1	107,4
	93,3	104
	89,6	101,6

Décantation	Temps (min)	m0 (mg)	m1 (mg)
	1,016666667	90,9	750,9
	2,216666667	91,7	485,3
	4,033333333	92,9	413,2
	7,966666667	91,5	381,1
	15,96666667	95,3	245,3
	35,93333333	91,2	175,6
	80,4	92	132
	155	91,9	109
	251,9	95,1	103,8
	1192,2	92,2	99

Trap 8

Informations échantillon

Référence	echantillon piège08
Date prélèvement	09/04/2006
Conservation	Frigo
Date d'analyse	21/04/2006

Informations colonne

Hauteur de chute (cm)	59,9
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	150	92,4	145,4
Echantillon 2	150	92,9	145,5
Echantillon 3	150	92,2	139,4

OPTION 1

Etat final	m0 (mg)	m1 (mg)
	91,9	100,3
	90	96,9
	92	101,3

Décantation	Temps (min)	m0 (mg)	m1 (mg)
	1	92,2	204,7
	2	91,3	190,7
	4,45	94,5	258,6
	7,966666667	90,3	218,6
	15,95	91,4	202
	31,6	94,4	155,2
	71,36666667	92,2	126,2
	145,9333333	91,8	111,1
	242,8666667	91,6	99,6
	1184,033333	95,4	102,8

Trap 9

Informations échantillon

Référence	echantillon piège09
Date prélèvement	09/04/2006
Conservation	Frigo
Date d'analyse	21/04/2006

Informations colonne

Hauteur de chute (cm)	59,6
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	150	92,5	151,5
Echantillon 2	150	92,2	147,2
Echantillon 3	150	92,6	154,8

OPTION 1

Etat final	m0 (mg)	m1 (mg)
	91,5	101,8
	93,2	104,5
	88,2	98,1

Décantation	Temps (min)	m0 (mg)	m1 (mg)
	1,15	91,9	184,2
	2	92,2	160,5
	3,983333333	92,1	237,7
	8,183333333	90,5	295,8
	15,95	91	245,5
	33,13333333	94,1	188,2
	64,55	90,8	134,7
	136,9	91,3	125,2
	233,8666667	91,8	107,7
	1175,616667	96,1	110,3

Trap 10

Informations échantillon

Référence	echantillon piège10
Date prélèvement	09/04/2006
Conservation	Frigo
Date d'analyse	19/04/2006

Informations colonne

Hauteur de chute (cm)	59,8
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	150	91,6	144
Echantillon 2	150	90,5	135,5
Echantillon 3	150	91,8	133,1

OPTION 1

Etat final	m0 (mg)	m1 (mg)
	92,5	98,8
	91,9	99,3
	91,8	99,3

Décantation	Temps (min)	m0 (mg)	m1 (mg)
	1	92,8	302,5
	2	92,8	256,6
	3,983333333	91,3	255,4
	8	92,4	220,5
	16	93,4	166,9
	32	92,6	131,2
	71,81666667	92,1	115,9
	139,4166667	93	101,9
	247,7	92	96,1
	1403,983333	92,2	98,6

Trap 11

Informations échantillon

Référence	echantillon piège11
Date prélèvement	09/04/2006
Conservation	Frigo
Date d'analyse	19/04/2006

Informations colonne

Hauteur de chute (cm)	62,8
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	150	92,6	146,2
Echantillon 2	150	92,4	146,7
Echantillon 3			

OPTION 1

Etat final	m0 (mg)	m1 (mg)
	90,2	97,3
	91,6	96,5
	93,5	100,7

Décantation	Temps (min)	m0 (mg)	m1 (mg)
	0,966666667	91	335
	1,983333333	90,5	242,9
	4,116666667	93,1	243,5
	8,016666667	91,3	215
	15,93333333	91,2	189,7
	32,06666667	90,7	146,3
	62,43333333	91,2	120,9
	128	92	108,3
	241,0166667	92,2	98,9
	1393,133333	91,4	99,5

Trap 12

Informations échantillon

Référence	echantillon piège12
Date prélèvement	09/04/2006
Conservation	Frigo
Date d'analyse	19/04/2006

Informations colonne

Hauteur de chute (cm)	59,9
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	150	92,3	115,7
Echantillon 2	150	92,3	114,8
Echantillon 3			

OPTION 1

Etat final	m0 (mg)	m1 (mg)
	92,9	99,1
	90,6	97,8
	92,1	97,3

Décantation	Temps (min)	m0 (mg)	m1 (mg)
	1,033333333	91,9	140,3
	1,983333333	92,6	128,4
	4	92,1	138,5
	8	91,1	147,3
	16,05	91,1	144,6
	31,05	93,2	132,8
	54,41666667	92	108,9
	119,4	91,5	111
	231,9666667	91,5	98,5
	1386	92,2	99,4

outflow

Informations échantillon

Référence	echantillon sortie
Date prélèvement	09/04/2006
Conservation	Frigo
Date d'analyse	12/04/2006

Informations colonne

Hauteur de chute (cm)	60,1
Rayon (cm)	3,5

Etat initial	Volume (ml)	m0 (mg)	m1 (mg)
Echantillon 1	150	90,5	93,2
Echantillon 2	150	92,2	95
Echantillon 3	150	91,4	94,4

OPTION 1

Etat final	m0 (mg)	m1 (mg)
	90,7	93,9
	89,3	92,8
	90	94,4
	91,8	96,6

Décantation	Temps (min)	m0 (mg)	m1 (mg)
	1,016666667	90,9	98,6
	2,066666667	91,8	97,4
	4,066666667	92,5	96,6
	8,083333333	93,2	97,1
	16	90,4	93,1
	32,11666667	92,4	93,5
	68,03333333	90,6	92
	120,1666667	90,8	92,2
	227,1666667	88	88,5
	1145,483333	88,9	89,7

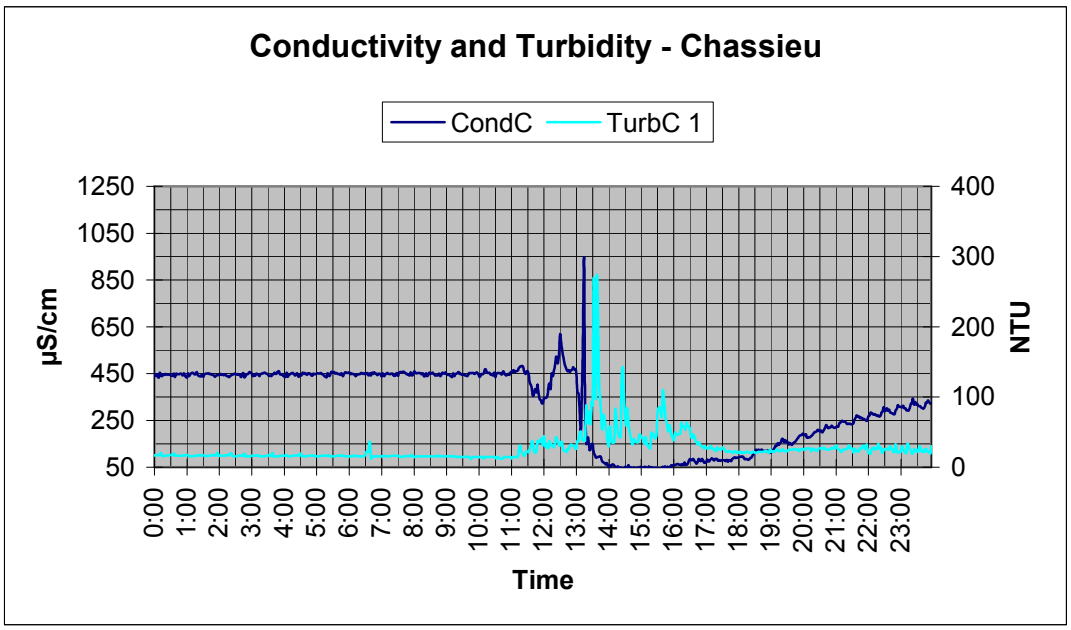
APPENDIX B : RAIN DATA

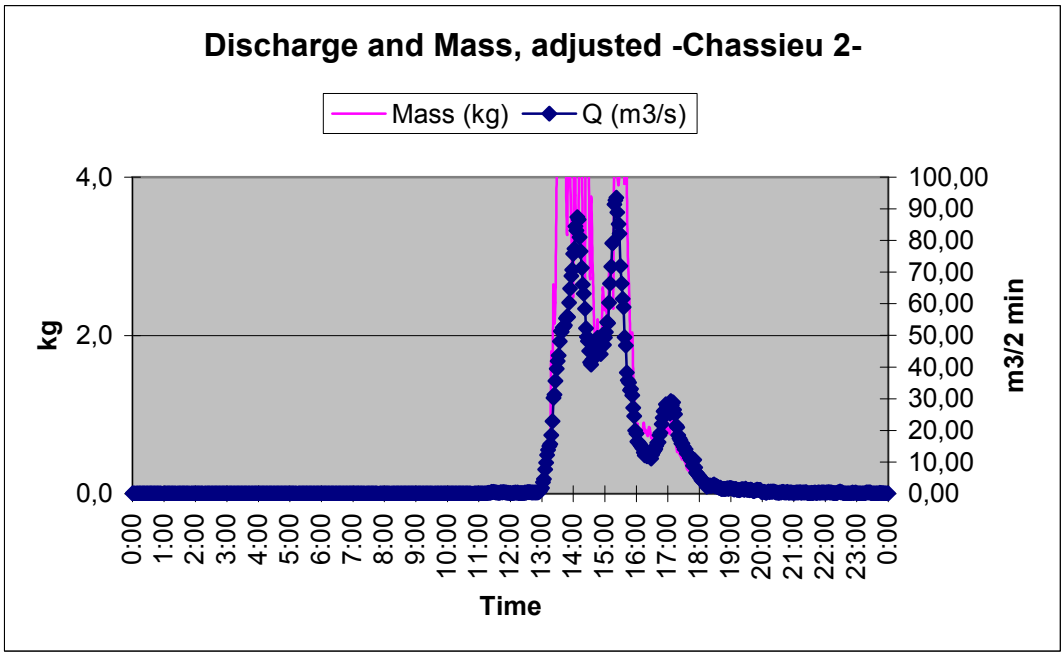
Rain Data of the three measurement series

Inflow parameters

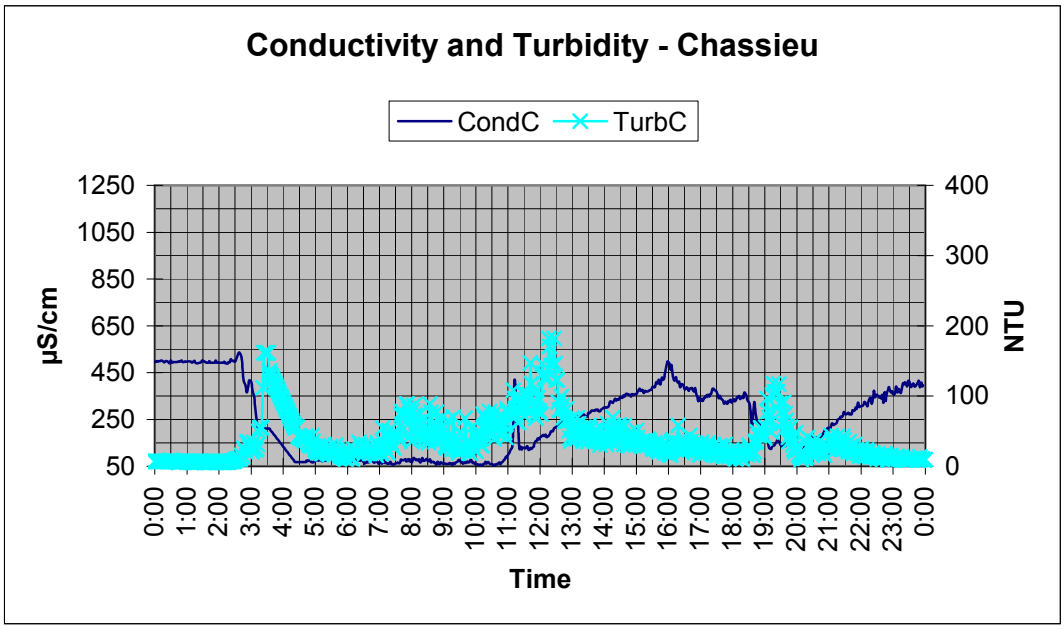
Rain event 09 – 10/04/05 Inflow

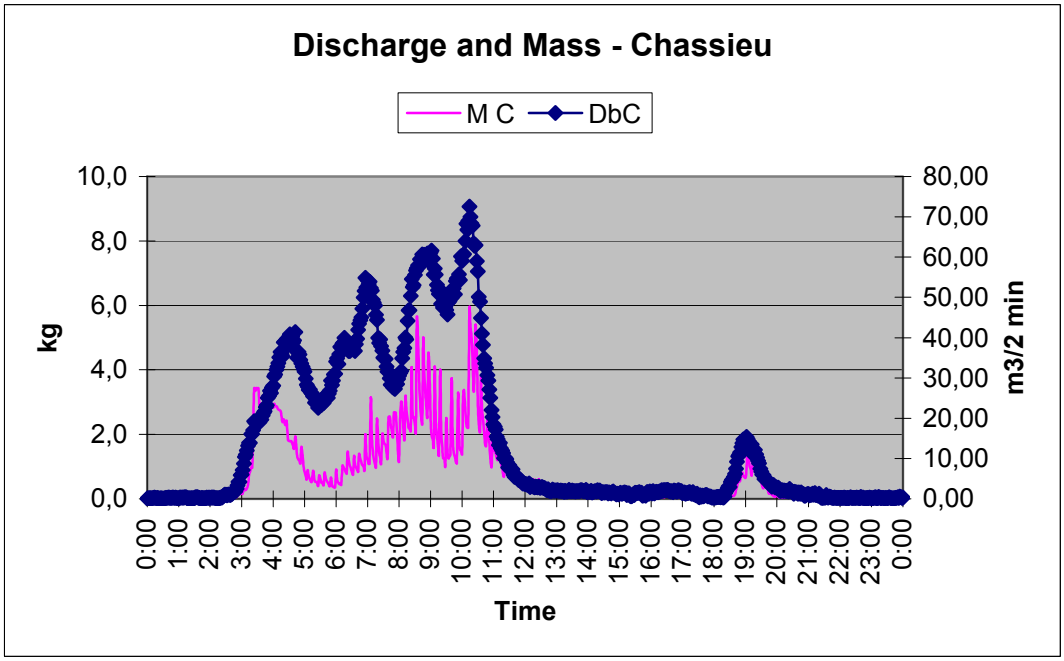
09/04/05



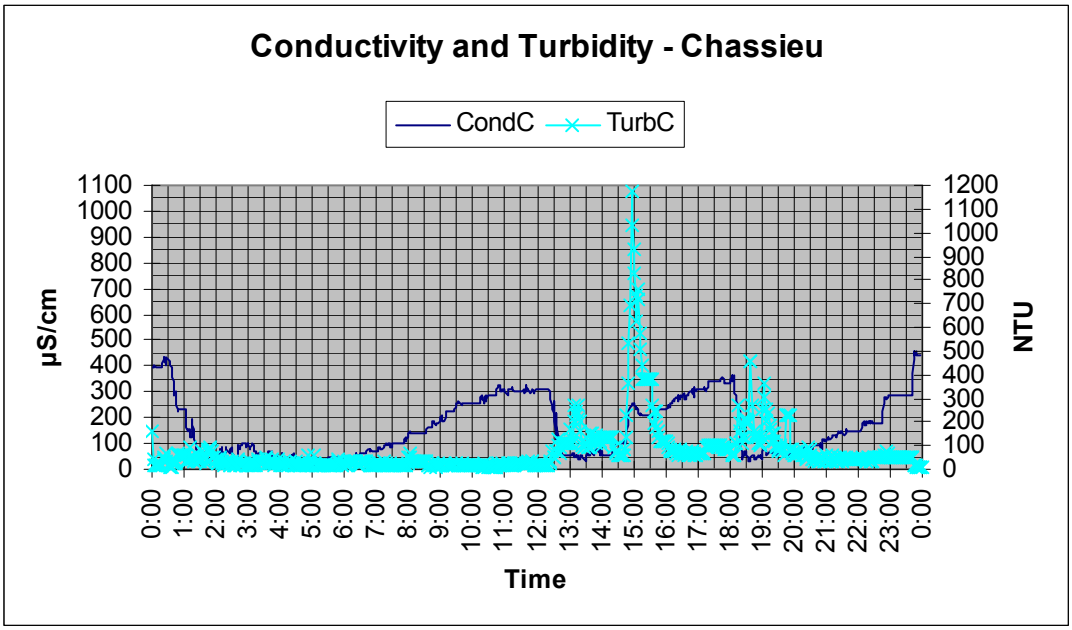


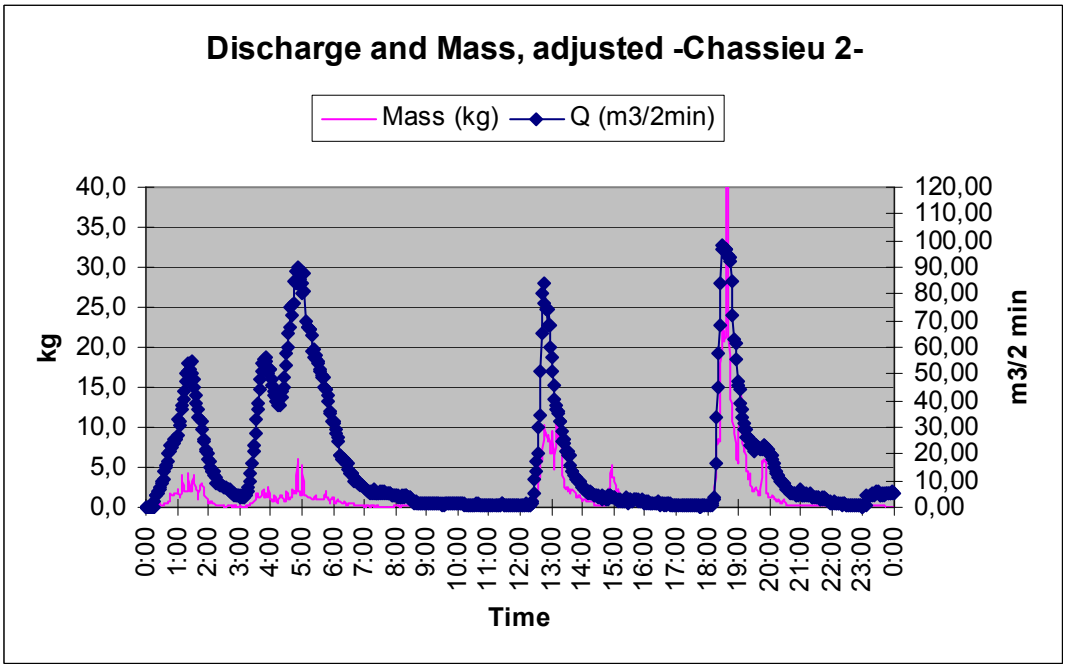
Rain event 24/03/06 Inflow



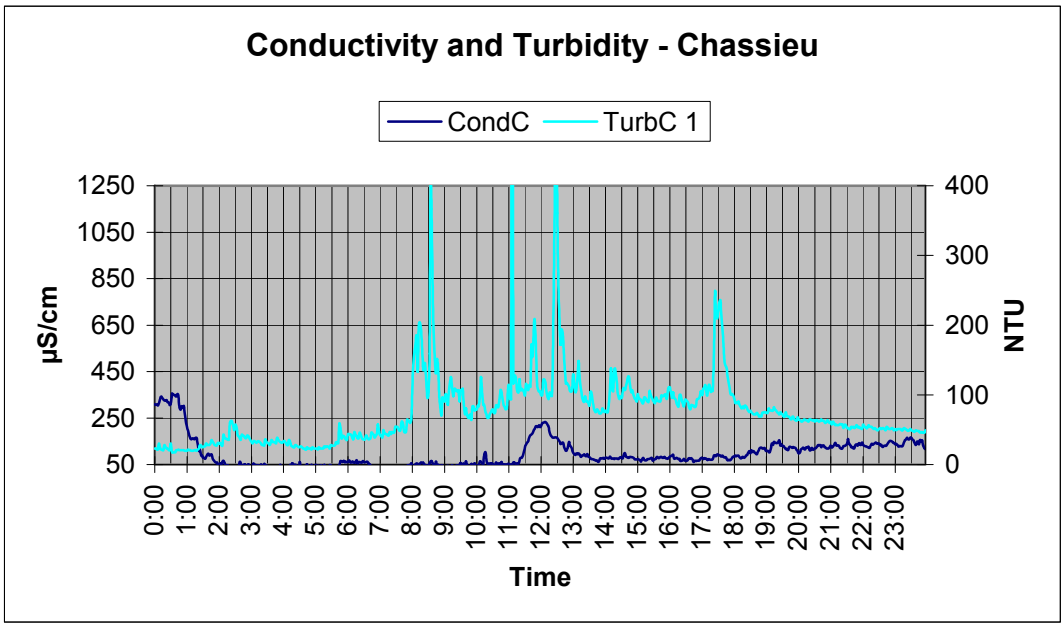


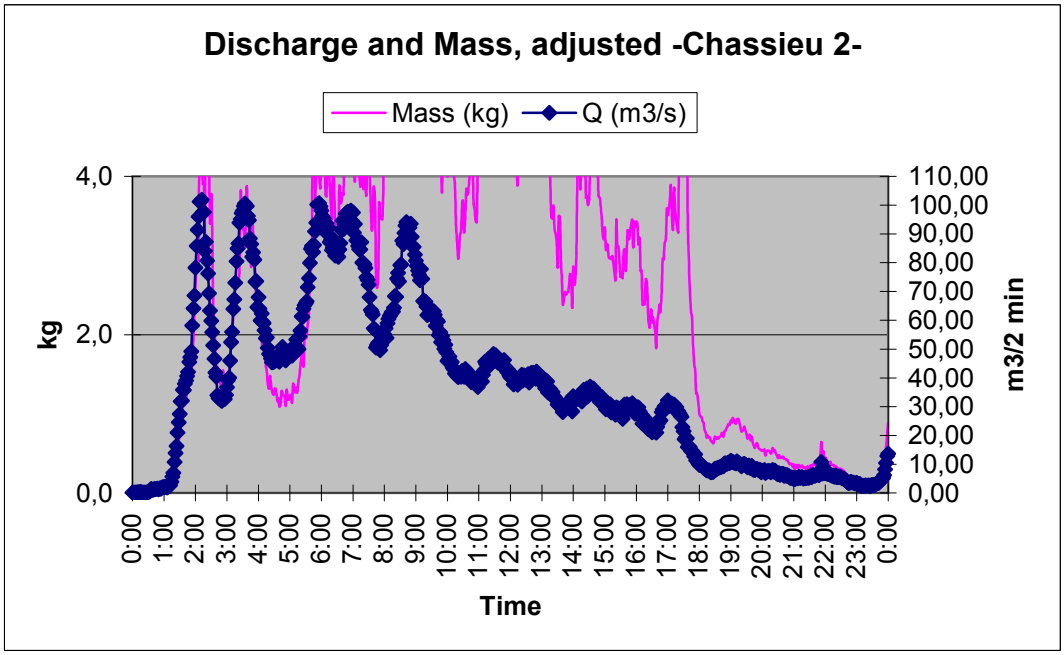
Rain event 14/06/06 Inflow





10/04/05

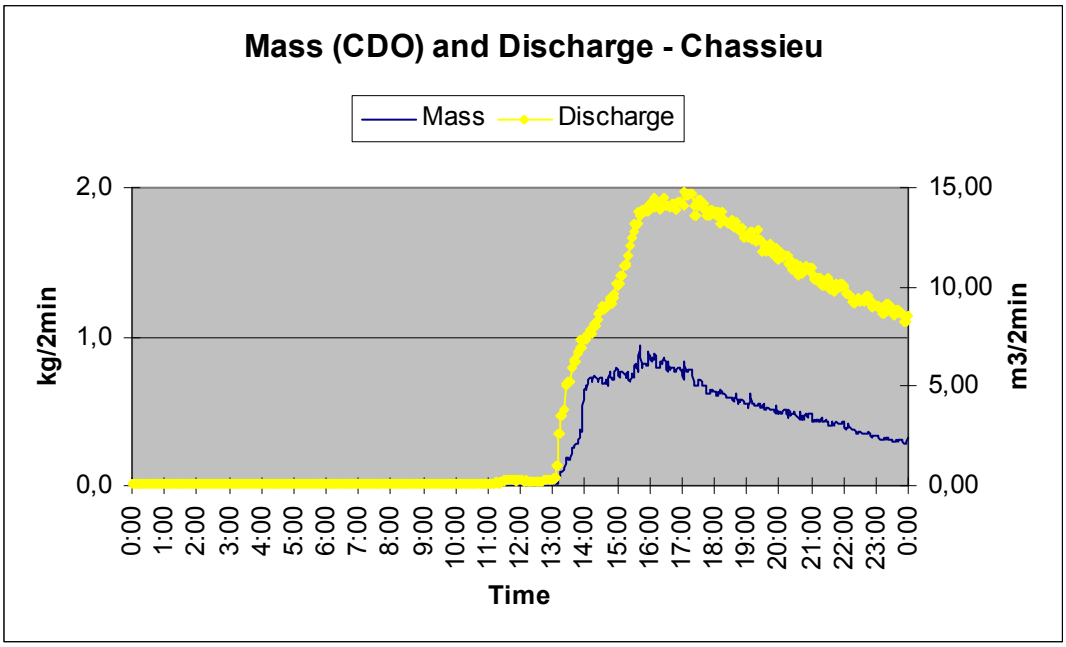

Conductivity and Turbidity - Chassieu
CondC
TurbC 1
1250
1050
850
650
450
250
50
µS/cm
400
300
200
100
0
NTU
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time

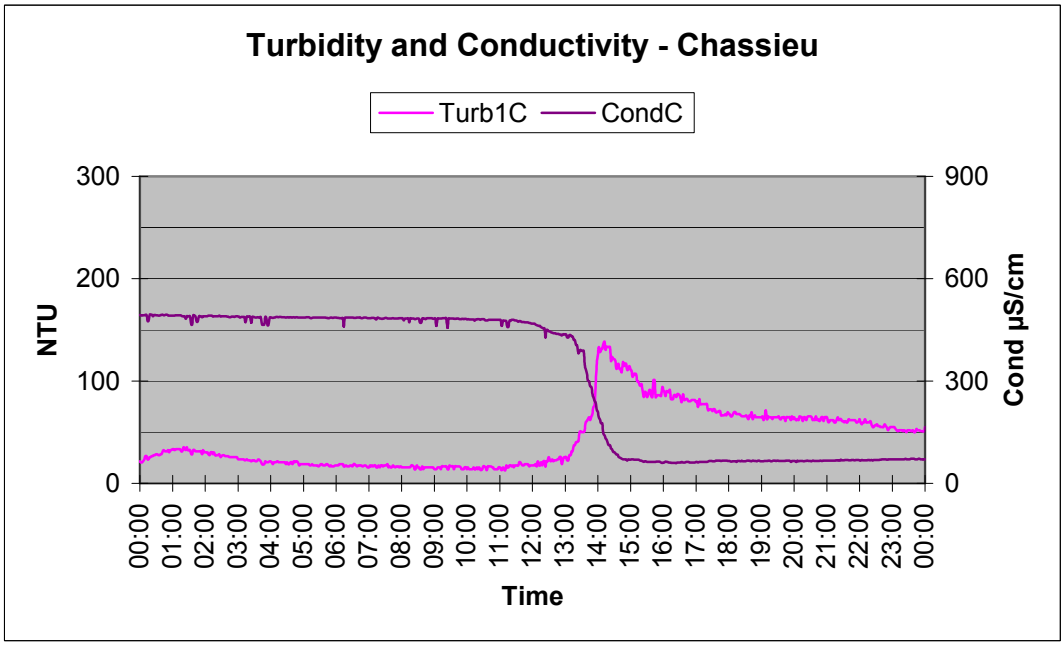

Discharge and Mass, adjusted -Chassieu 2-
Mass (kg)
Q (m3/s)
4,0
2,0
0,0
kg
110,00
100,00
90,00
80,00
70,00
60,00
50,00
40,00
30,00
20,00
10,00
0,00
m3/2 min
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
Time

Outflow parameters

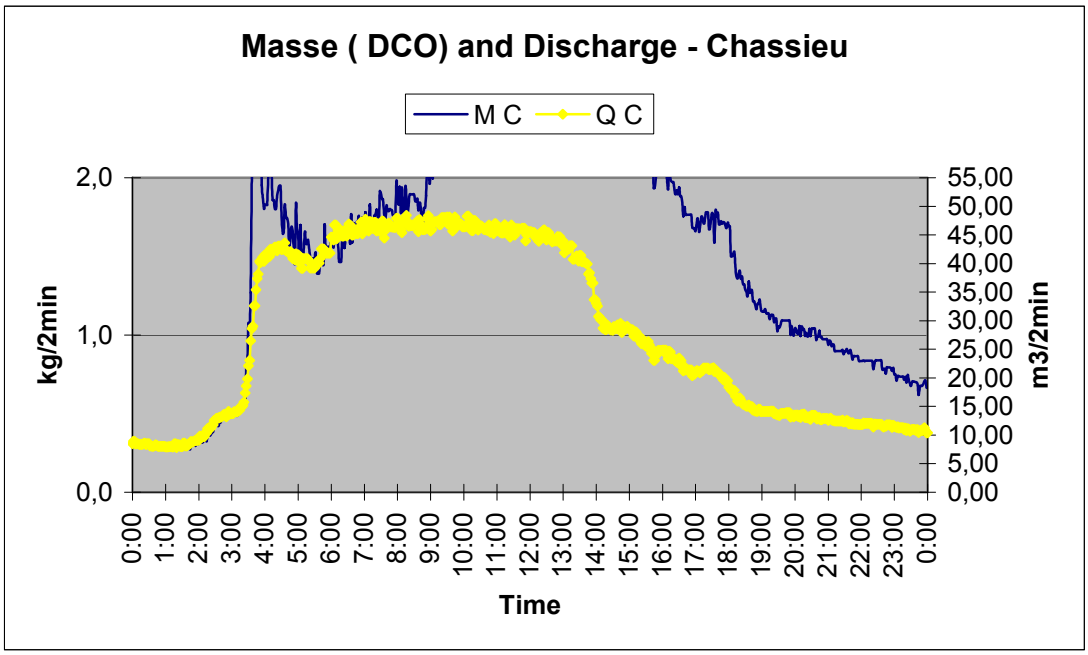
Rain event09 – 10/04/05 Outflow

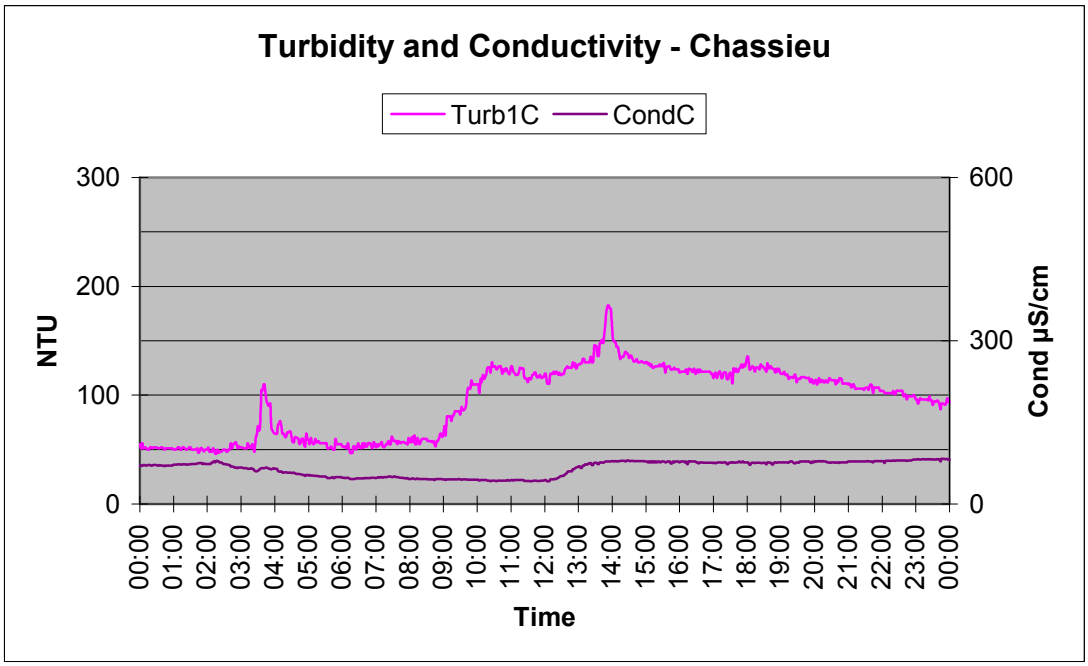
09/04/05



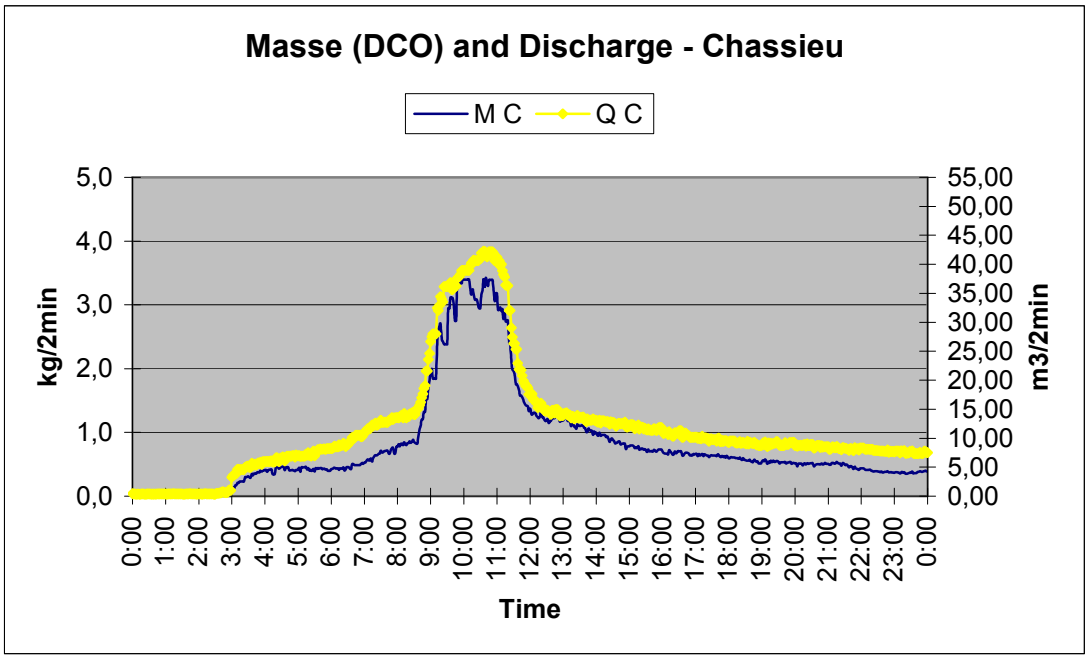


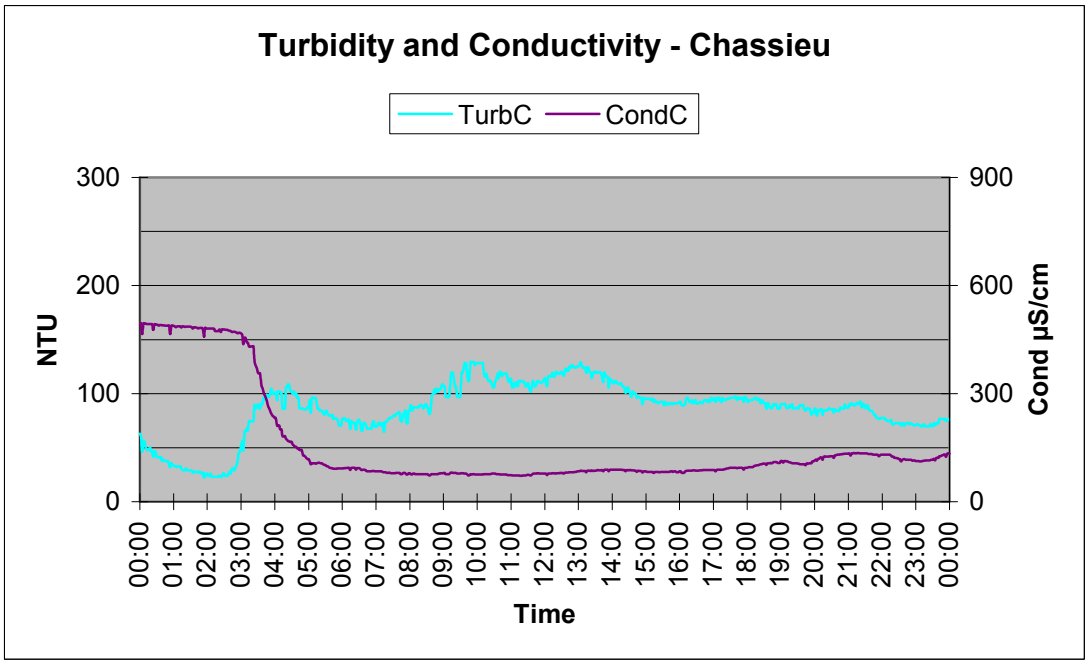
10/04/05


Masse (DCO) and Discharge - Chassieu
M C
Q C
kg/2min
m3/2min
2,0
1,0
0,0
55,00
50,00
45,00
40,00
35,00
30,00
25,00
20,00
15,00
10,00
5,00
0,00
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
Time

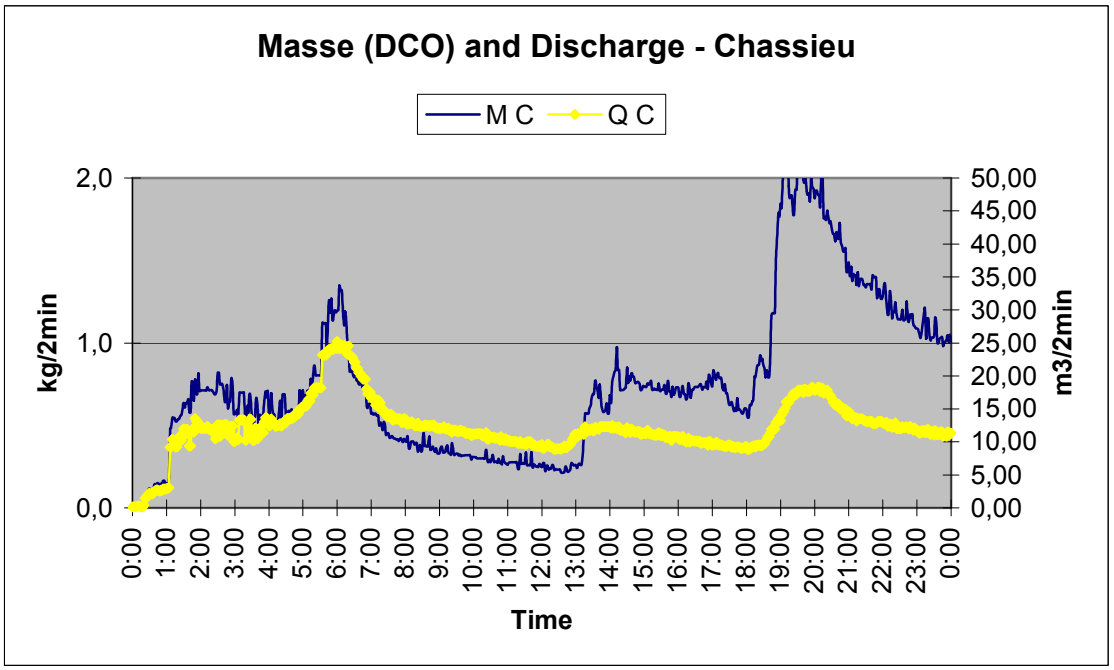

Turbidity and Conductivity - Chassieu
Turb1C
CondC
NTU
Cond µS/cm
300
200
100
0
600
300
0
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
00:00
Time

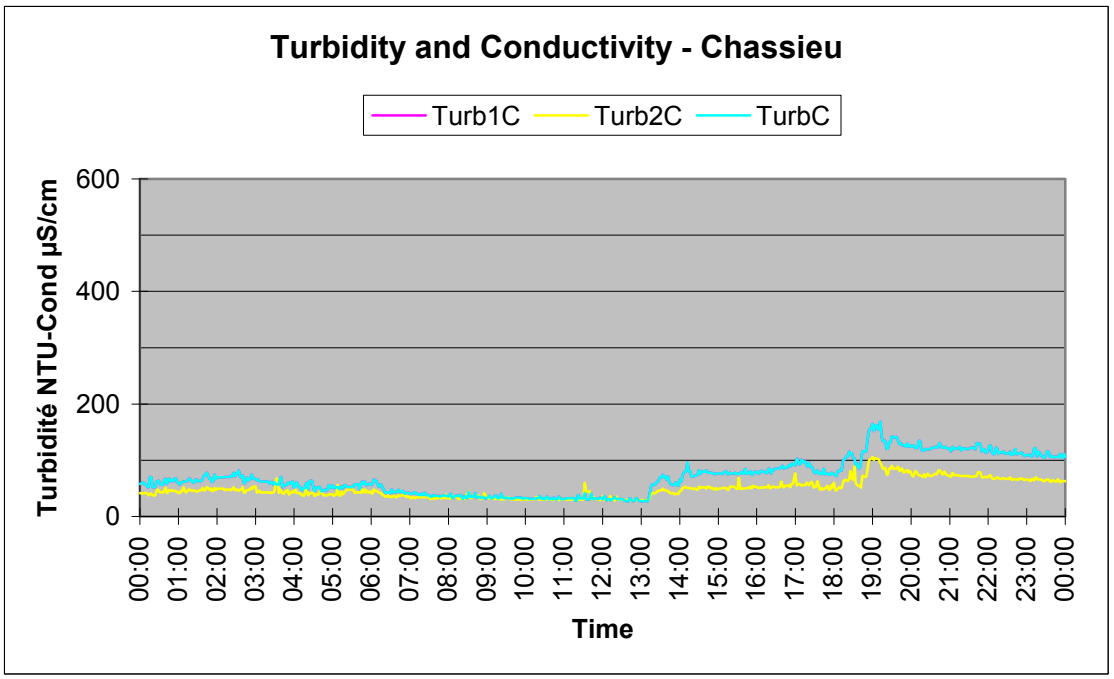
Rain event 24/03/06 – Outflow





Rain event 14/06/06 Outflow

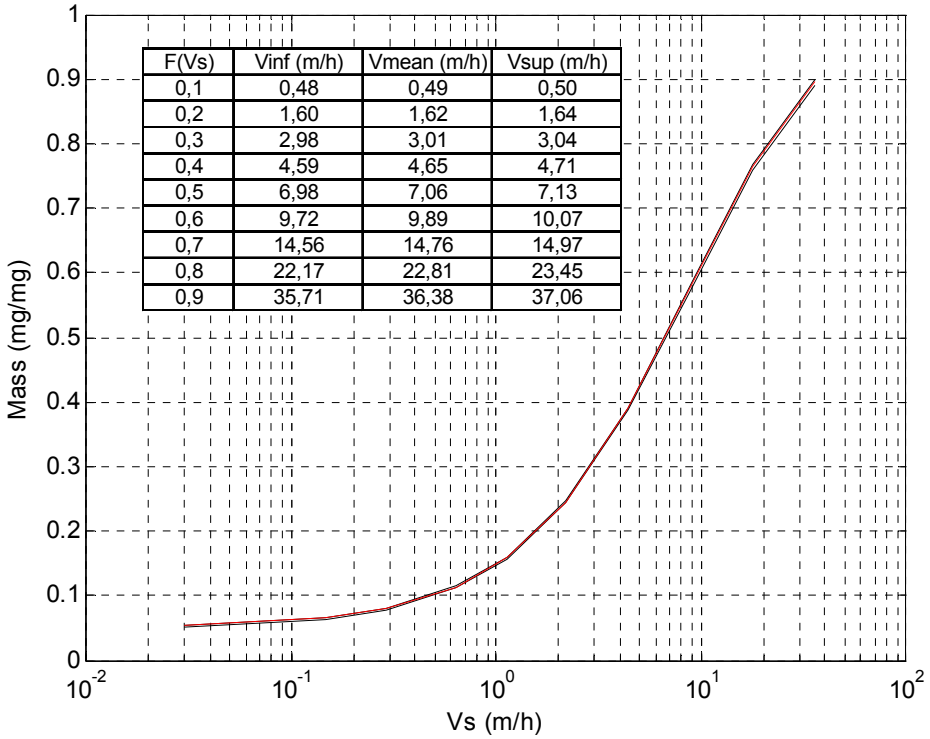




APPENDIX C : UNCERTAINTY RESULTS

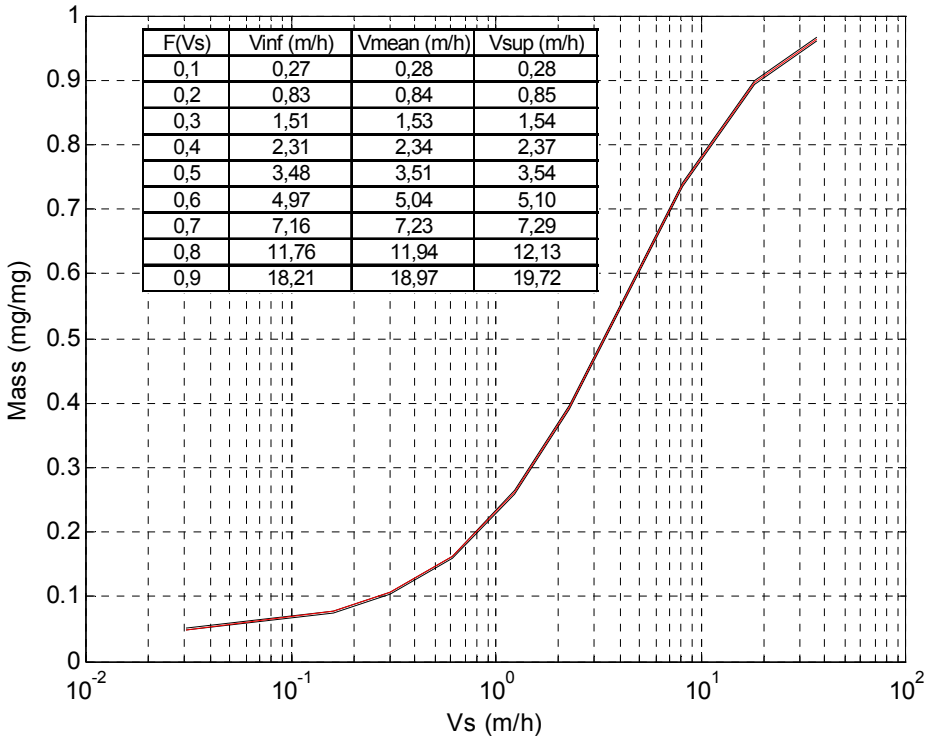
Campaign 1

Trap 1 (C1)



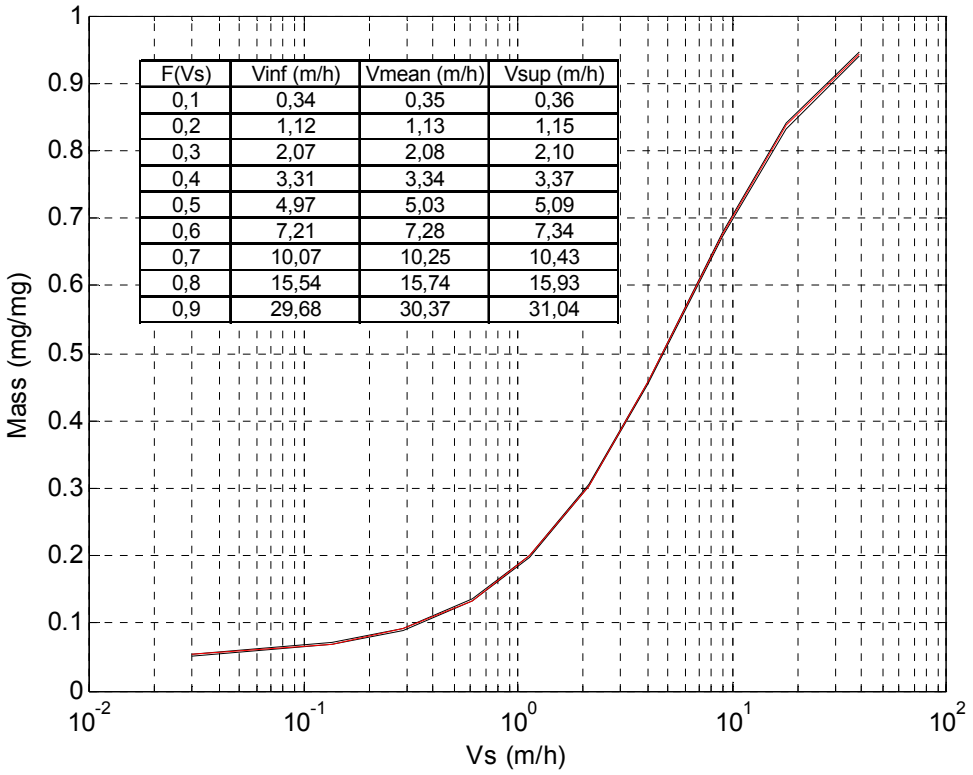
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,48	0,49	0,50
0,2	1,60	1,62	1,64
0,3	2,98	3,01	3,04
0,4	4,59	4,65	4,71
0,5	6,98	7,06	7,13
0,6	9,72	9,89	10,07
0,7	14,56	14,76	14,97
0,8	22,17	22,81	23,45
0,9	35,71	36,38	37,06

Trap 2 (C1)



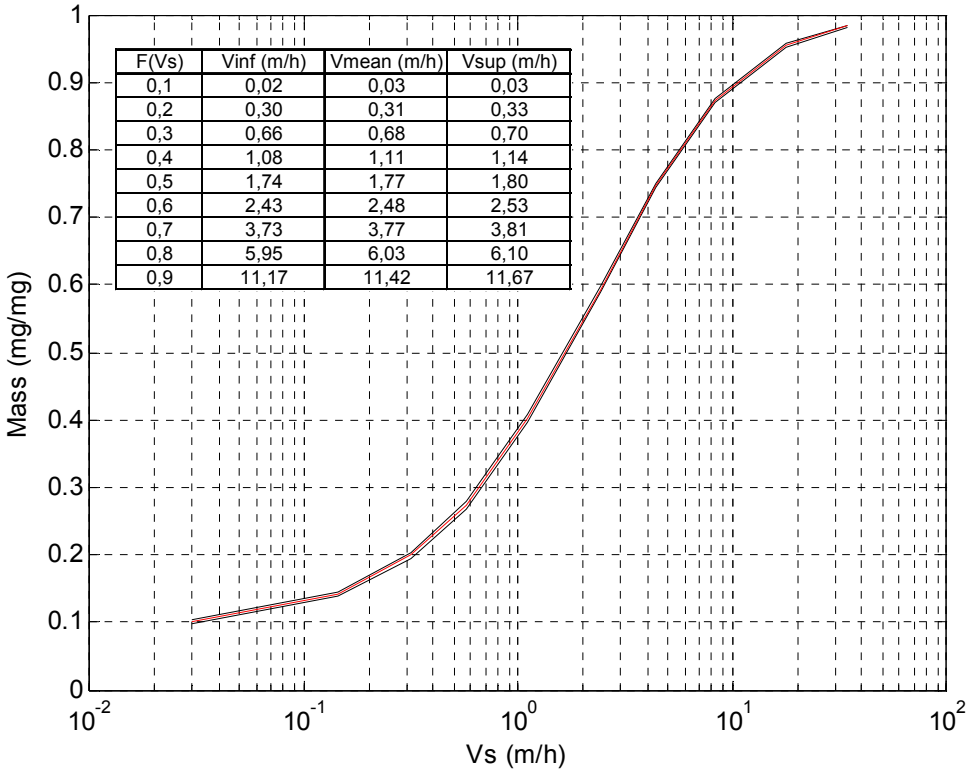
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,27	0,28	0,28
0,2	0,83	0,84	0,85
0,3	1,51	1,53	1,54
0,4	2,31	2,34	2,37
0,5	3,48	3,51	3,54
0,6	4,97	5,04	5,10
0,7	7,16	7,23	7,29
0,8	11,76	11,94	12,13
0,9	18,21	18,97	19,72

Trap3 (C1)



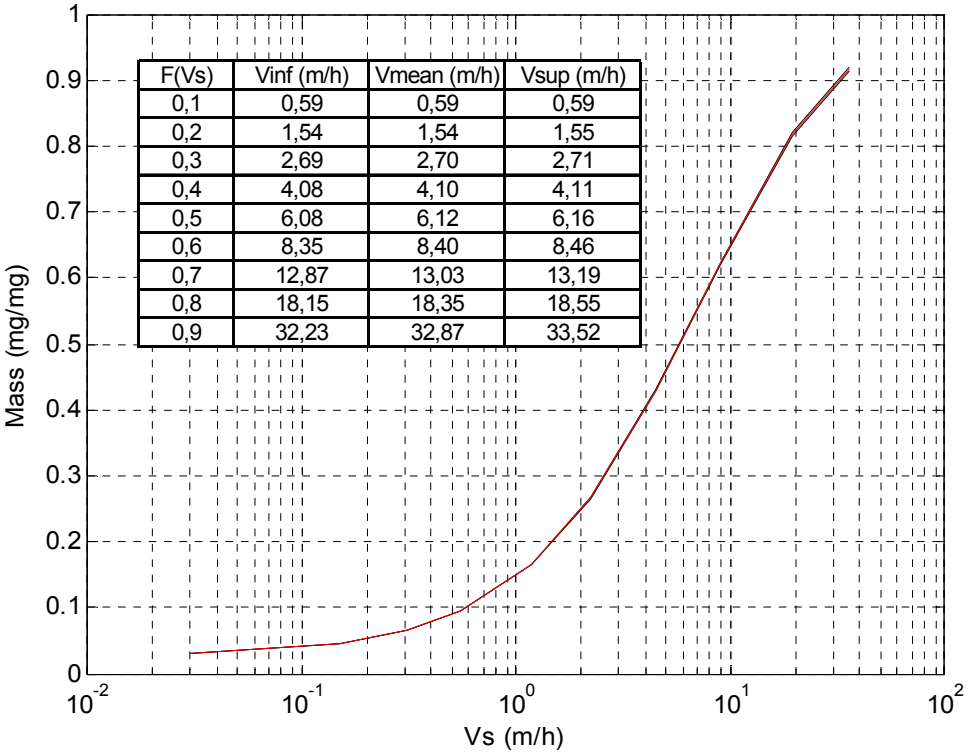
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,34	0,35	0,36
0,2	1,12	1,13	1,15
0,3	2,07	2,08	2,10
0,4	3,31	3,34	3,37
0,5	4,97	5,03	5,09
0,6	7,21	7,28	7,34
0,7	10,07	10,25	10,43
0,8	15,54	15,74	15,93
0,9	29,68	30,37	31,04

Trap 4 (C1)



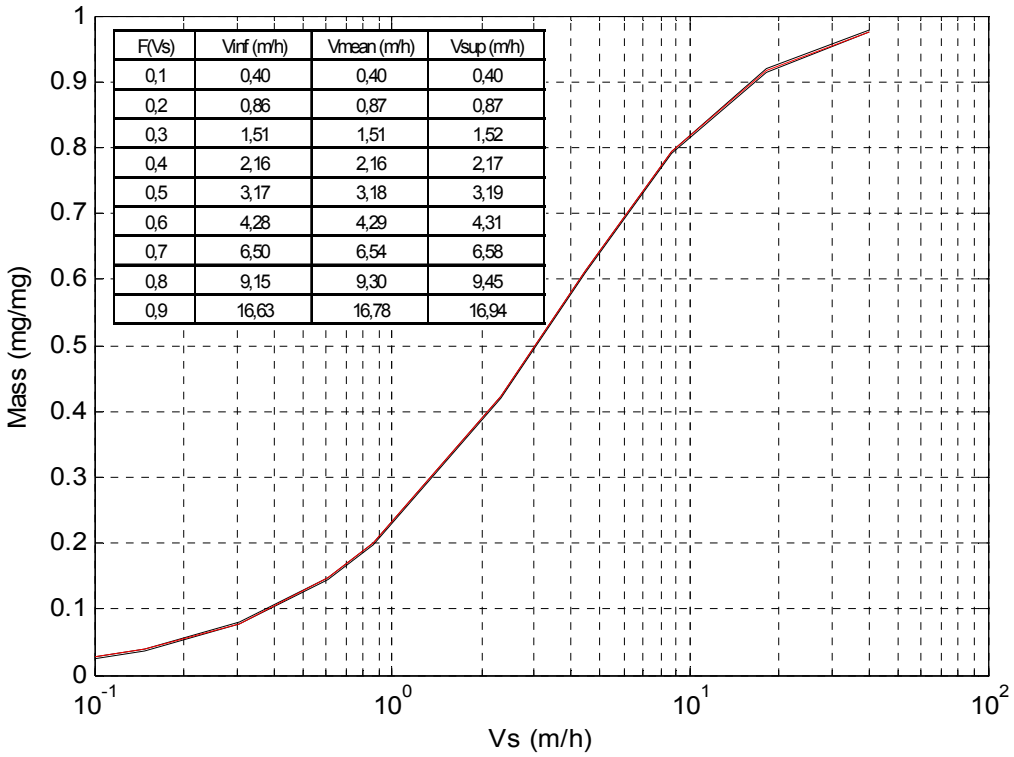
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,02	0,03	0,03
0,2	0,30	0,31	0,33
0,3	0,66	0,68	0,70
0,4	1,08	1,11	1,14
0,5	1,74	1,77	1,80
0,6	2,43	2,48	2,53
0,7	3,73	3,77	3,81
0,8	5,95	6,03	6,10
0,9	11,17	11,42	11,67

Trap 5 (C1)



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,59	0,59	0,59
0,2	1,54	1,54	1,55
0,3	2,69	2,70	2,71
0,4	4,08	4,10	4,11
0,5	6,08	6,12	6,16
0,6	8,35	8,40	8,46
0,7	12,87	13,03	13,19
0,8	18,15	18,35	18,55
0,9	32,23	32,87	33,52

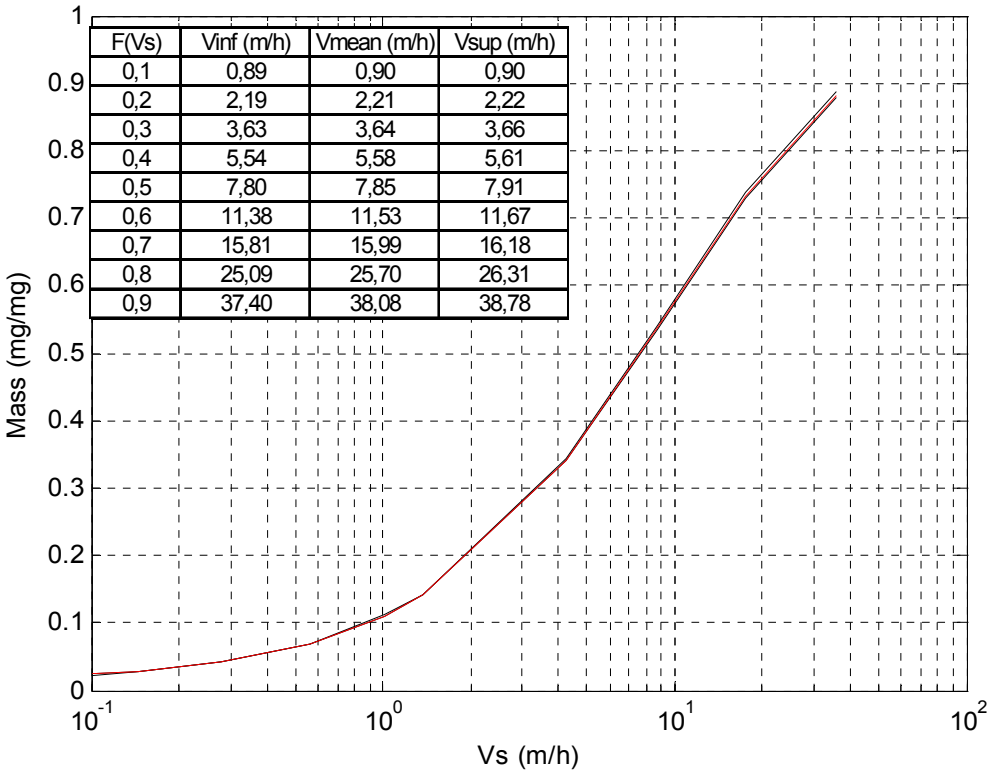
Trap 6 (C1)



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,40	0,40	0,40
0,2	0,86	0,87	0,87
0,3	1,51	1,51	1,52
0,4	2,16	2,16	2,17
0,5	3,17	3,18	3,19
0,6	4,28	4,29	4,31
0,7	6,50	6,54	6,58
0,8	9,15	9,30	9,45
0,9	16,63	16,78	16,94

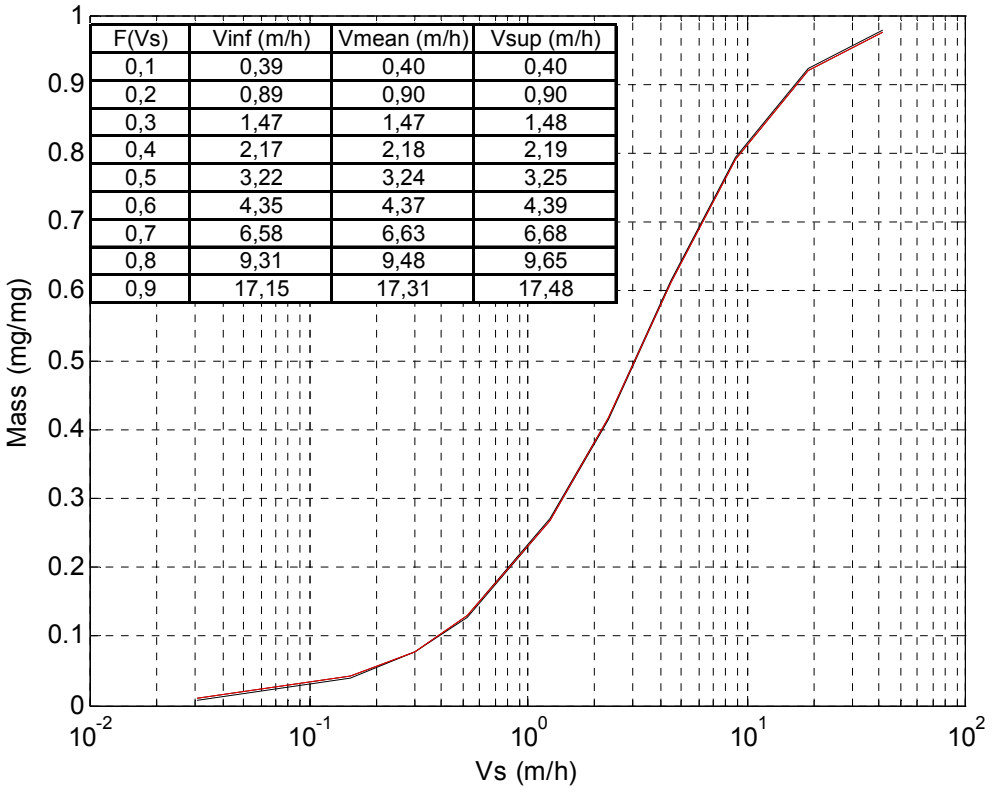
Trap 7 (C1)

F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,89	0,90	0,90
0,2	2,19	2,21	2,22
0,3	3,63	3,64	3,66
0,4	5,54	5,58	5,61
0,5	7,80	7,85	7,91
0,6	11,38	11,53	11,67
0,7	15,81	15,99	16,18
0,8	25,09	25,70	26,31
0,9	37,40	38,08	38,78

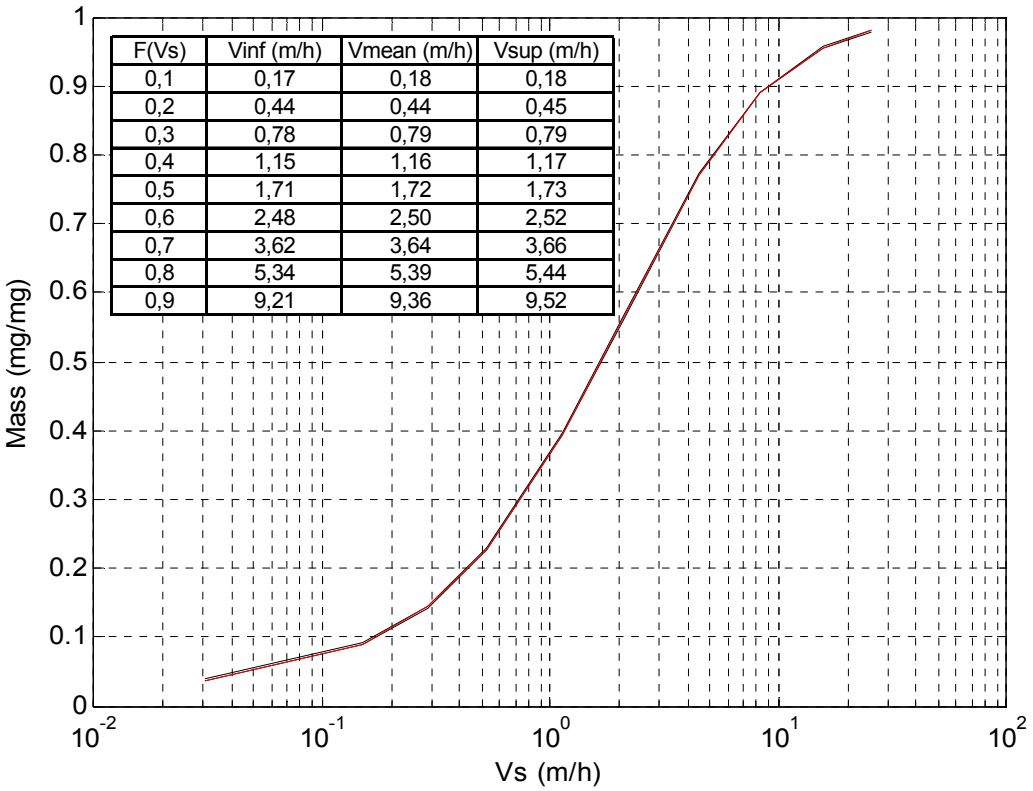


Trap 8 (C1)

F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,39	0,40	0,40
0,2	0,89	0,90	0,90
0,3	1,47	1,47	1,48
0,4	2,17	2,18	2,19
0,5	3,22	3,24	3,25
0,6	4,35	4,37	4,39
0,7	6,58	6,63	6,68
0,8	9,31	9,48	9,65
0,9	17,15	17,31	17,48

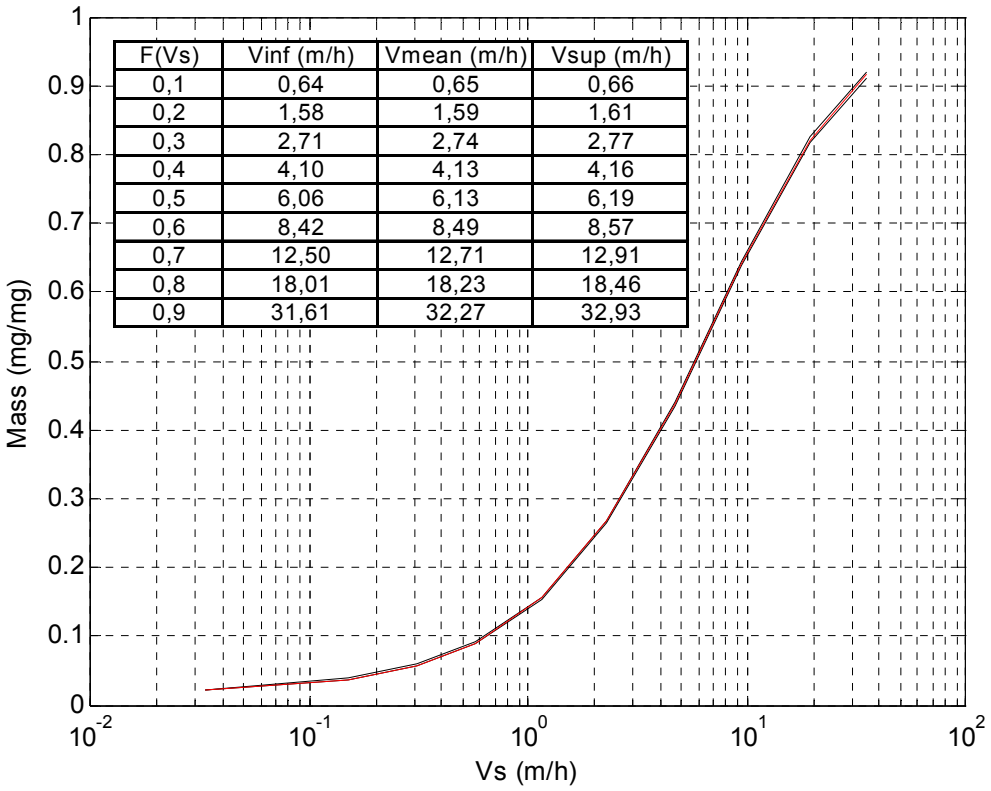


Trap 9 (C1)



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,17	0,18	0,18
0,2	0,44	0,44	0,45
0,3	0,78	0,79	0,79
0,4	1,15	1,16	1,17
0,5	1,71	1,72	1,73
0,6	2,48	2,50	2,52
0,7	3,62	3,64	3,66
0,8	5,34	5,39	5,44
0,9	9,21	9,36	9,52

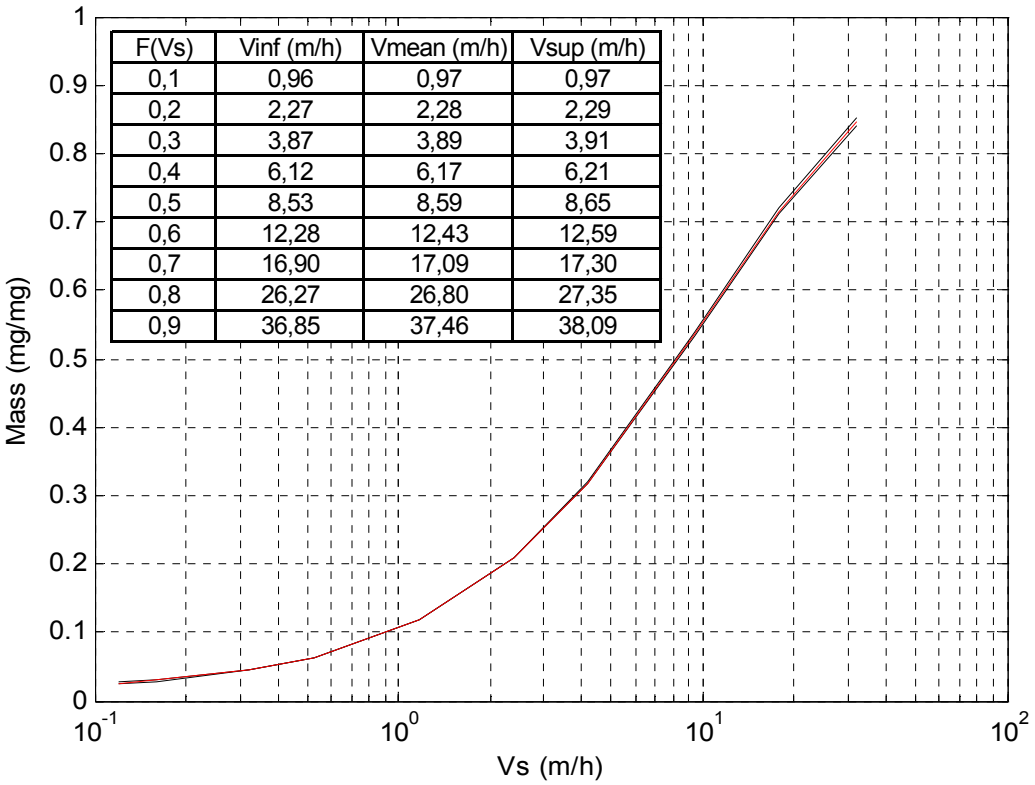
Trap 10 (C1)



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,64	0,65	0,66
0,2	1,58	1,59	1,61
0,3	2,71	2,74	2,77
0,4	4,10	4,13	4,16
0,5	6,06	6,13	6,19
0,6	8,42	8,49	8,57
0,7	12,50	12,71	12,91
0,8	18,01	18,23	18,46
0,9	31,61	32,27	32,93

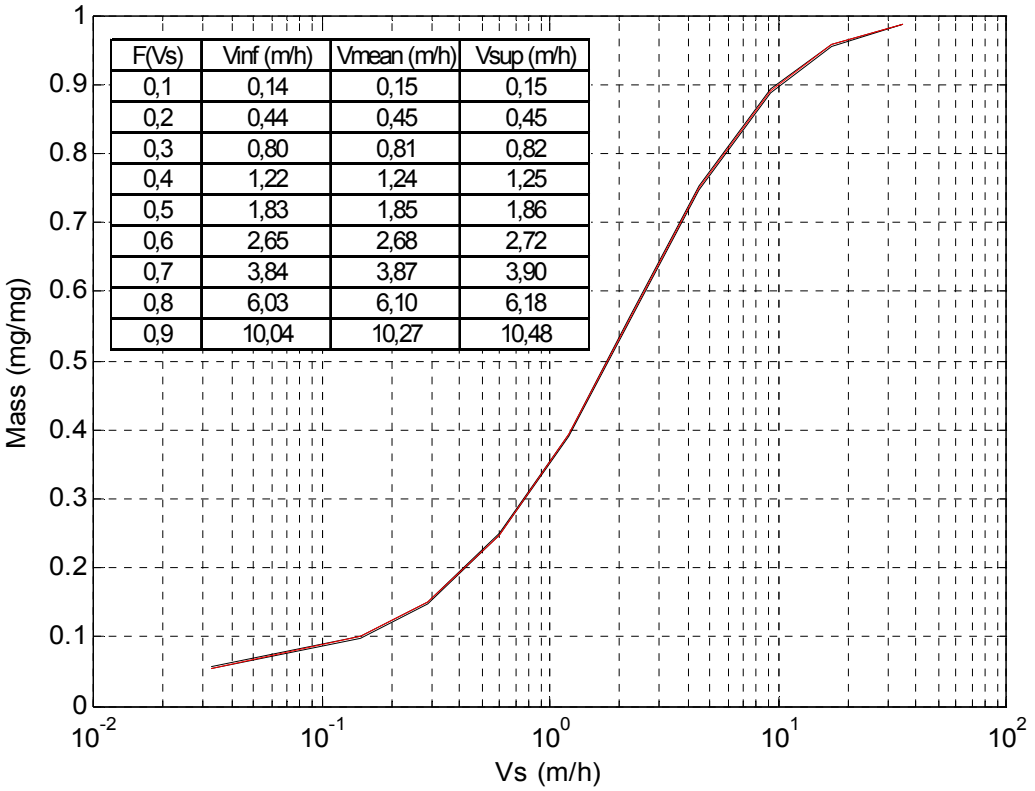
Trap 11 (C1)

F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,96	0,97	0,97
0,2	2,27	2,28	2,29
0,3	3,87	3,89	3,91
0,4	6,12	6,17	6,21
0,5	8,53	8,59	8,65
0,6	12,28	12,43	12,59
0,7	16,90	17,09	17,30
0,8	26,27	26,80	27,35
0,9	36,85	37,46	38,09



Trap 12 (C1)

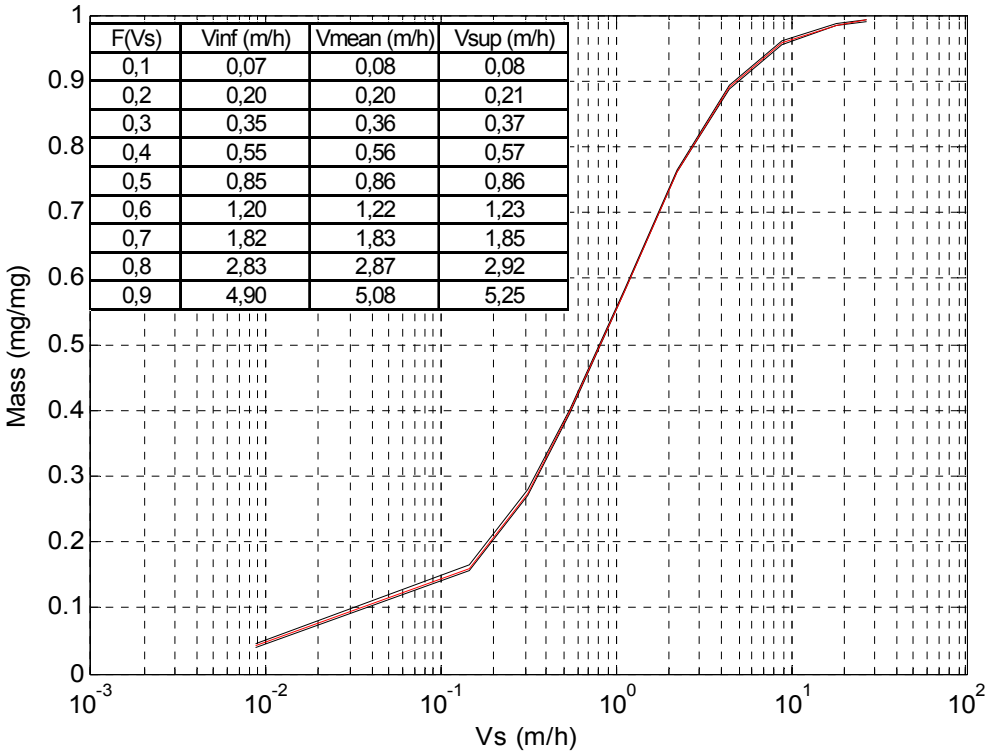
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,14	0,15	0,15
0,2	0,44	0,45	0,45
0,3	0,80	0,81	0,82
0,4	1,22	1,24	1,25
0,5	1,83	1,85	1,86
0,6	2,65	2,68	2,72
0,7	3,84	3,87	3,90
0,8	6,03	6,10	6,18
0,9	10,04	10,27	10,48



Campaign 2

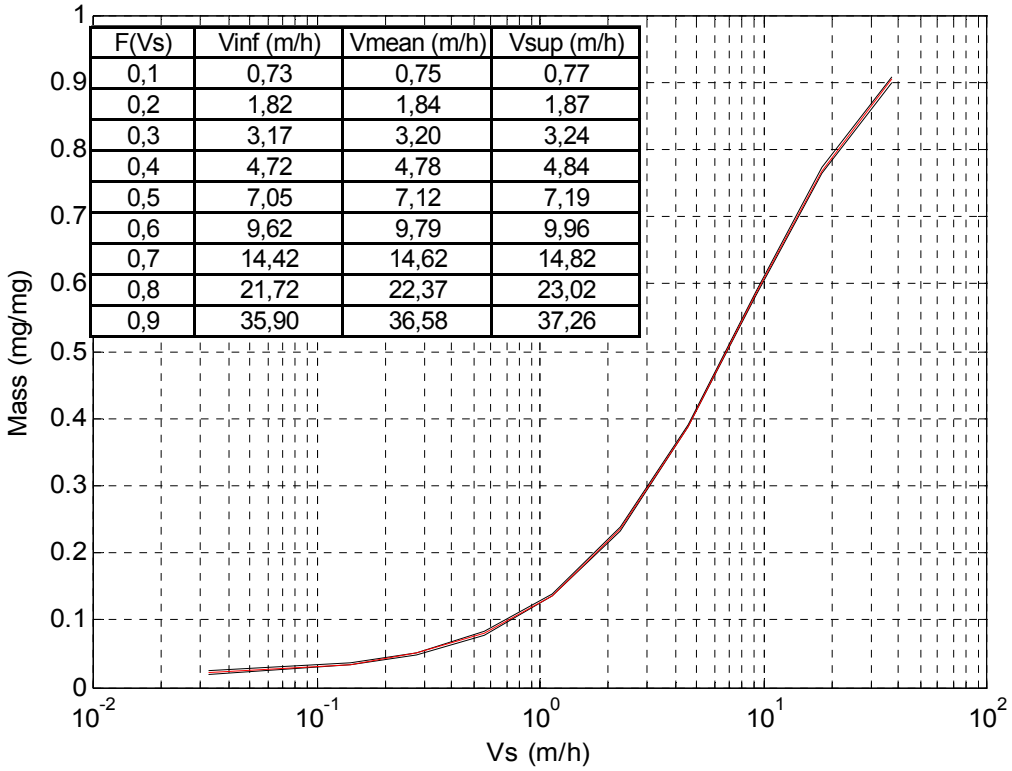
Inflow (C2)

F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,07	0,08	0,08
0,2	0,20	0,20	0,21
0,3	0,35	0,36	0,37
0,4	0,55	0,56	0,57
0,5	0,85	0,86	0,86
0,6	1,20	1,22	1,23
0,7	1,82	1,83	1,85
0,8	2,83	2,87	2,92
0,9	4,90	5,08	5,25

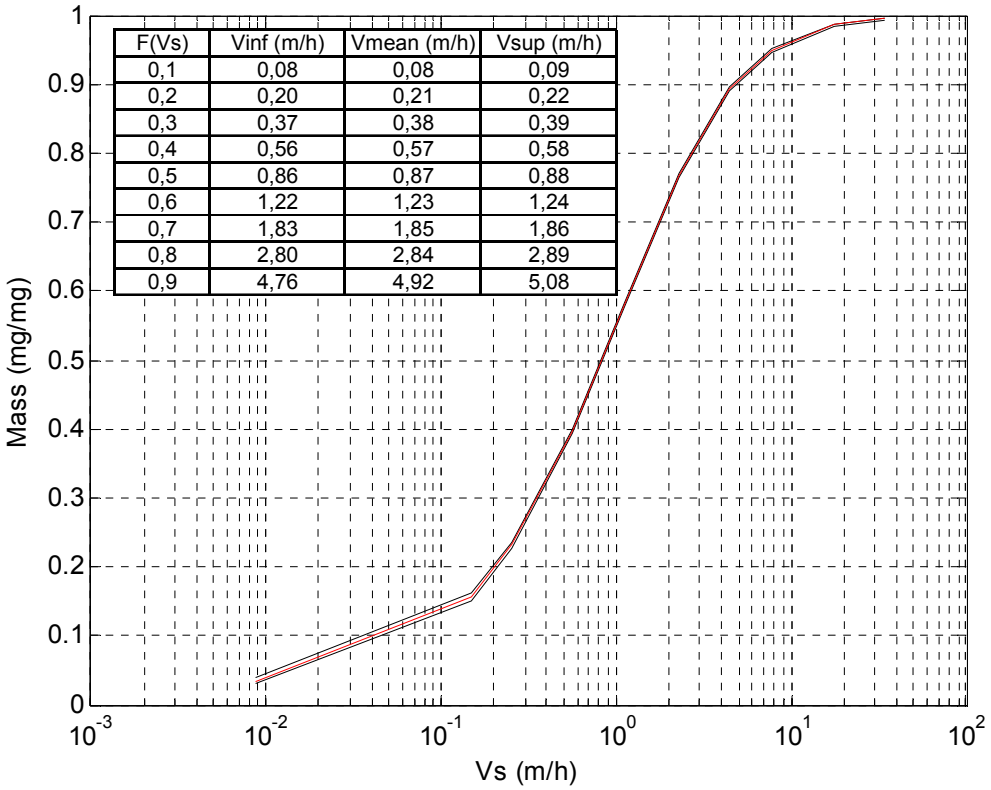


Trap 1 (C2)

F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,73	0,75	0,77
0,2	1,82	1,84	1,87
0,3	3,17	3,20	3,24
0,4	4,72	4,78	4,84
0,5	7,05	7,12	7,19
0,6	9,62	9,79	9,96
0,7	14,42	14,62	14,82
0,8	21,72	22,37	23,02
0,9	35,90	36,58	37,26

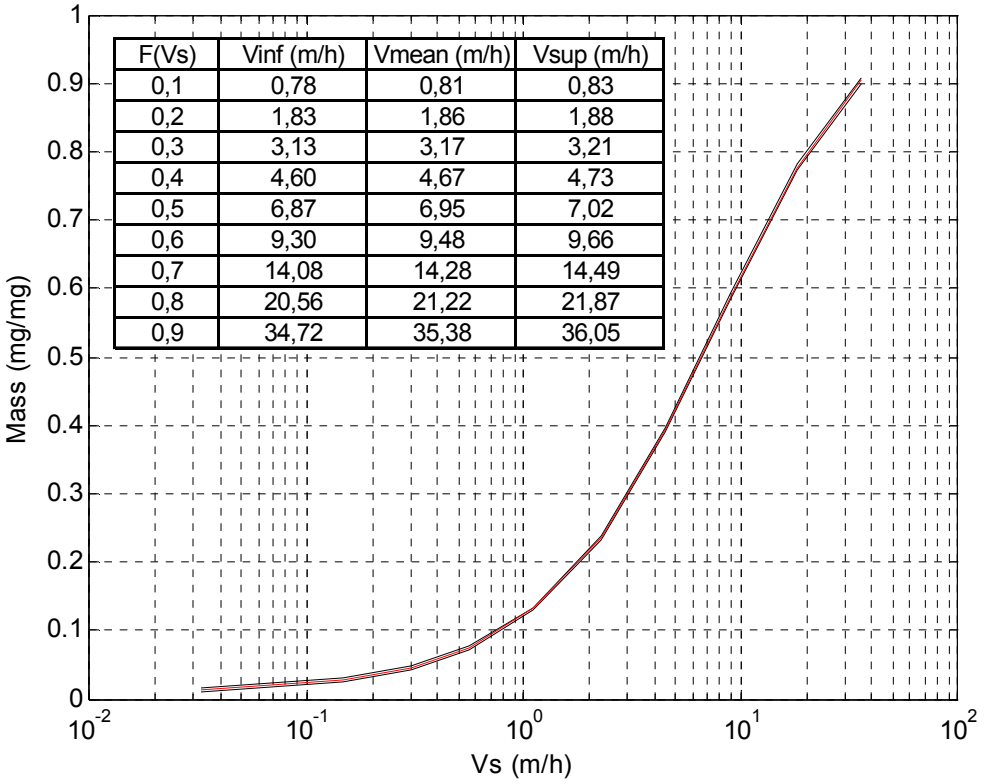


Trap 2 (C2)



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,08	0,08	0,09
0,2	0,20	0,21	0,22
0,3	0,37	0,38	0,39
0,4	0,56	0,57	0,58
0,5	0,86	0,87	0,88
0,6	1,22	1,23	1,24
0,7	1,83	1,85	1,86
0,8	2,80	2,84	2,89
0,9	4,76	4,92	5,08

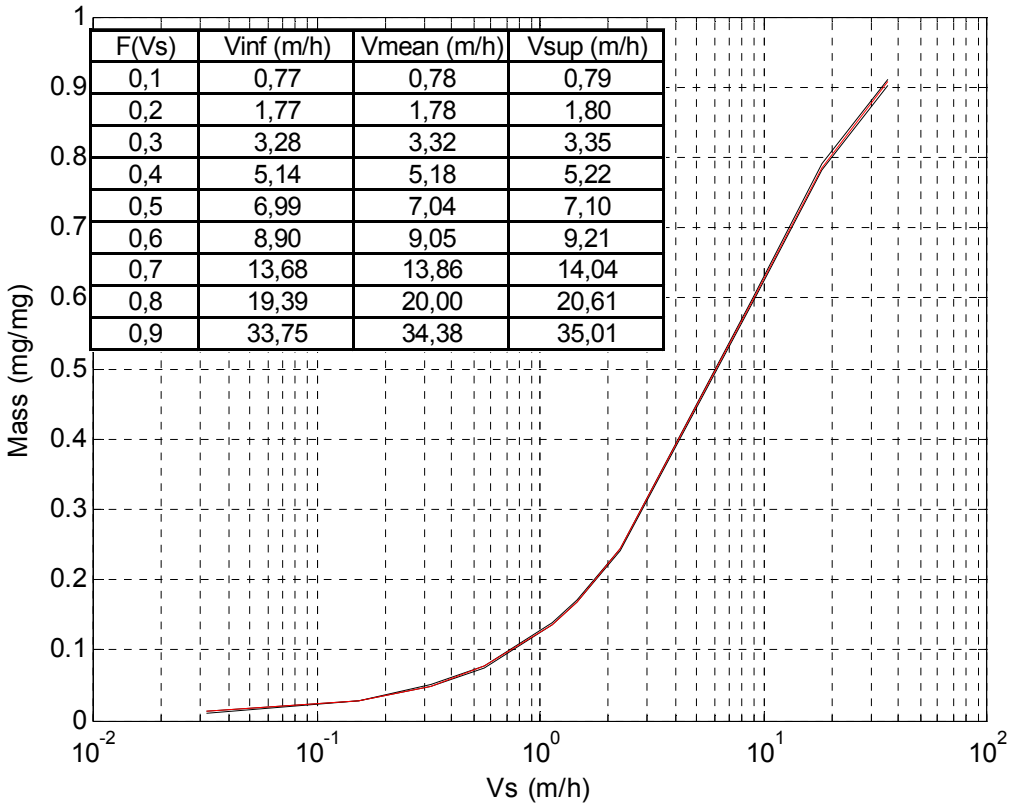
Trap 3 (C2)



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,78	0,81	0,83
0,2	1,83	1,86	1,88
0,3	3,13	3,17	3,21
0,4	4,60	4,67	4,73
0,5	6,87	6,95	7,02
0,6	9,30	9,48	9,66
0,7	14,08	14,28	14,49
0,8	20,56	21,22	21,87
0,9	34,72	35,38	36,05

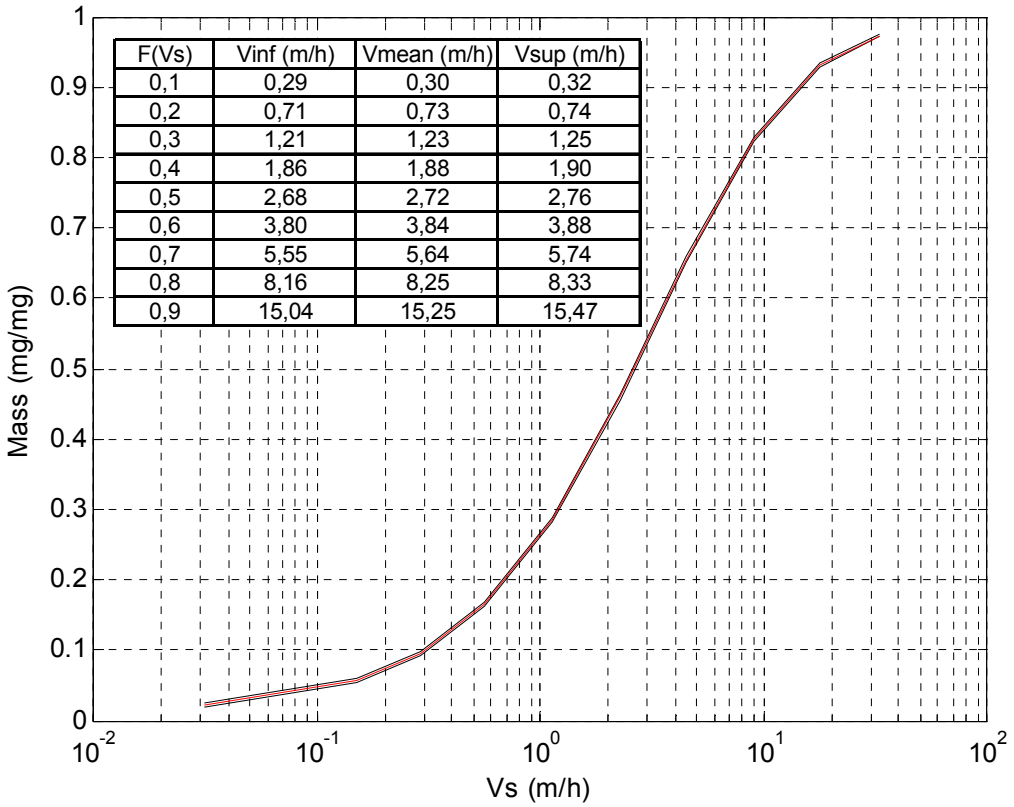
Trap 4 (C2)

F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,77	0,78	0,79
0,2	1,77	1,78	1,80
0,3	3,28	3,32	3,35
0,4	5,14	5,18	5,22
0,5	6,99	7,04	7,10
0,6	8,90	9,05	9,21
0,7	13,68	13,86	14,04
0,8	19,39	20,00	20,61
0,9	33,75	34,38	35,01

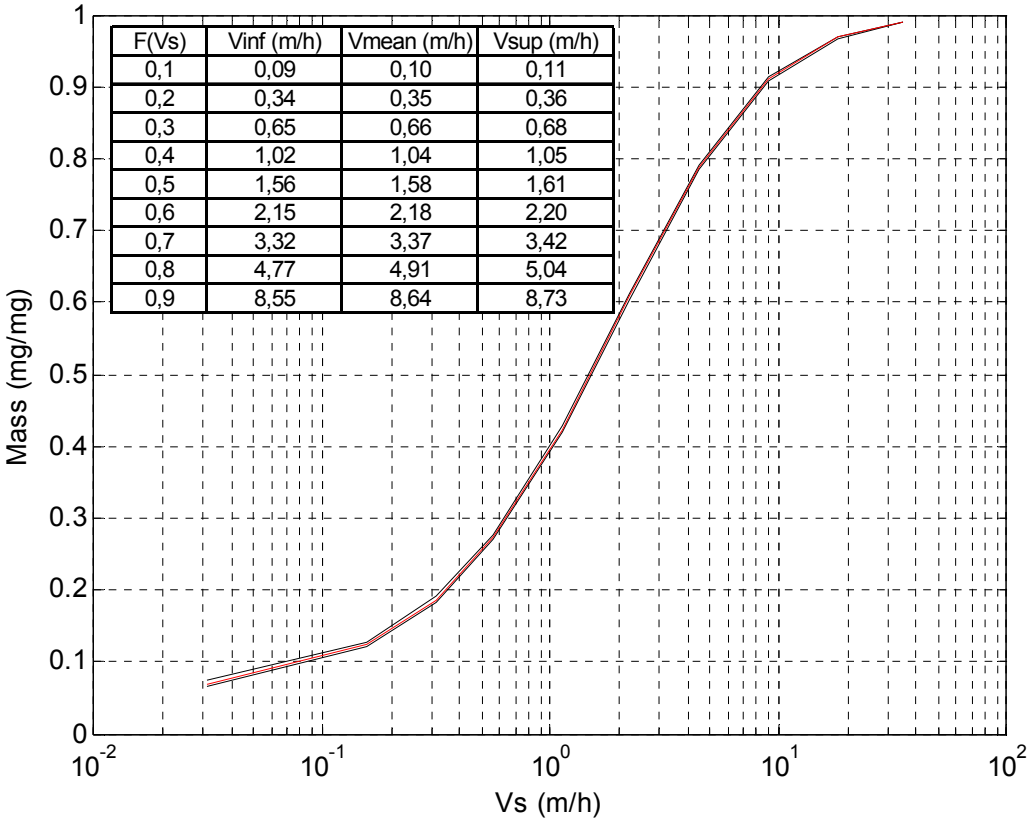


Trap 5 (C2)

F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,29	0,30	0,32
0,2	0,71	0,73	0,74
0,3	1,21	1,23	1,25
0,4	1,86	1,88	1,90
0,5	2,68	2,72	2,76
0,6	3,80	3,84	3,88
0,7	5,55	5,64	5,74
0,8	8,16	8,25	8,33
0,9	15,04	15,25	15,47

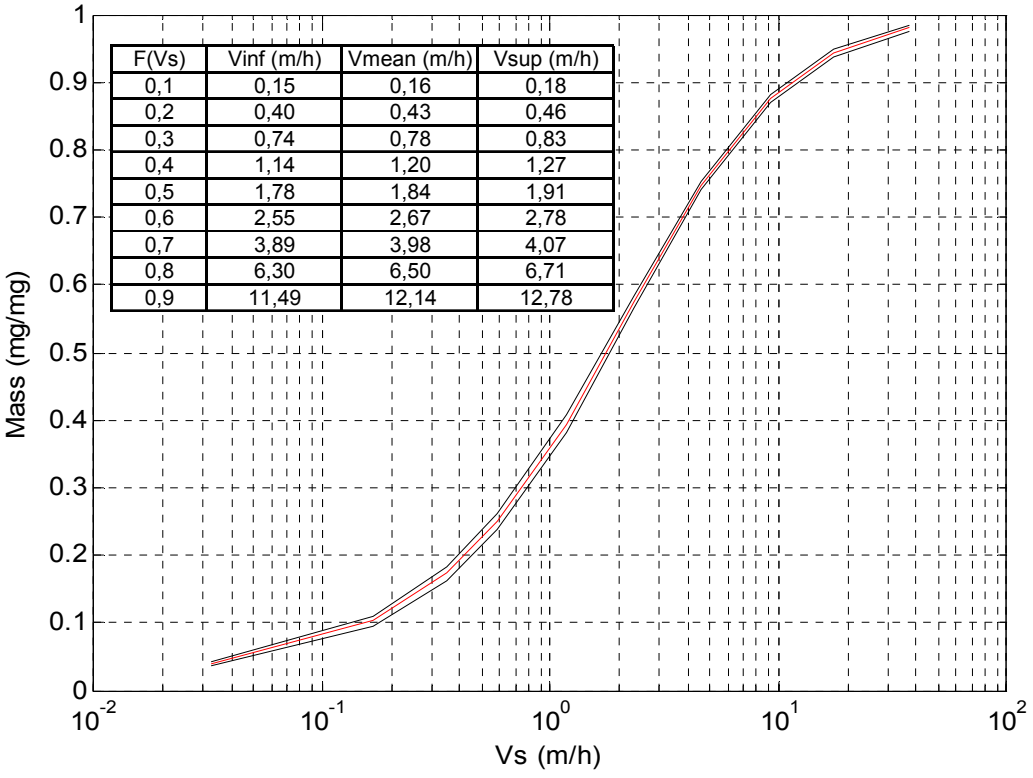


Trap 6 (C2)



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,09	0,10	0,11
0,2	0,34	0,35	0,36
0,3	0,65	0,66	0,68
0,4	1,02	1,04	1,05
0,5	1,56	1,58	1,61
0,6	2,15	2,18	2,20
0,7	3,32	3,37	3,42
0,8	4,77	4,91	5,04
0,9	8,55	8,64	8,73

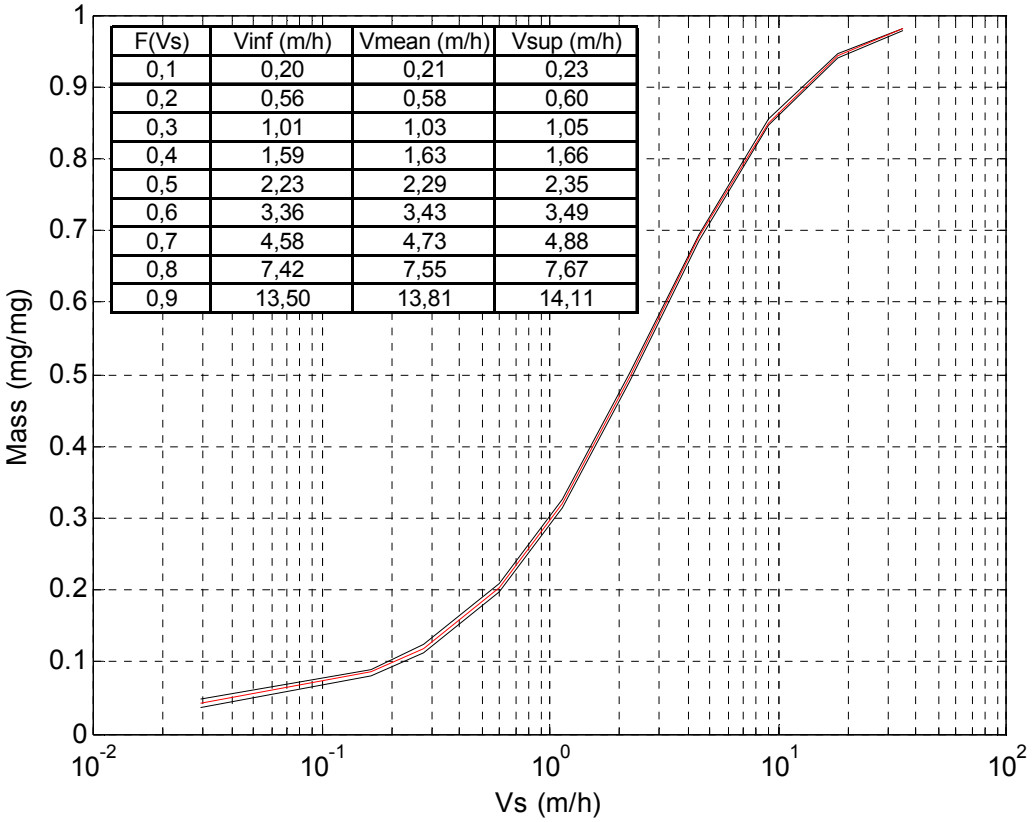
Trap 7 (C2)



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,15	0,16	0,18
0,2	0,40	0,43	0,46
0,3	0,74	0,78	0,83
0,4	1,14	1,20	1,27
0,5	1,78	1,84	1,91
0,6	2,55	2,67	2,78
0,7	3,89	3,98	4,07
0,8	6,30	6,50	6,71
0,9	11,49	12,14	12,78

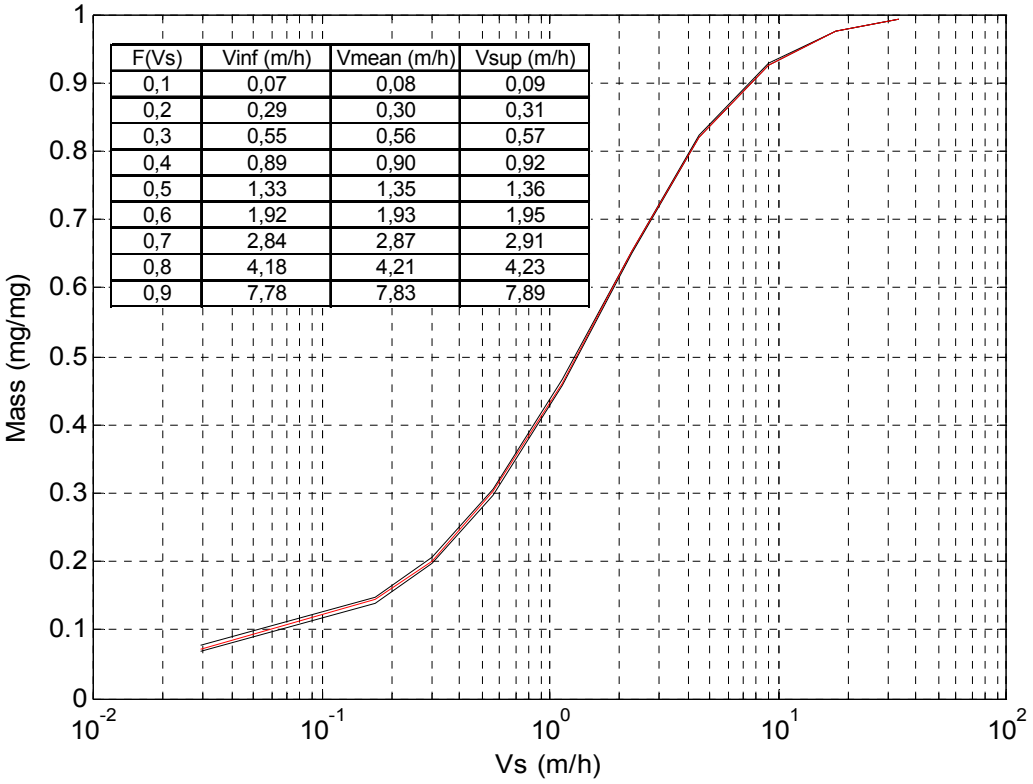
Trap8 (C2)

F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,20	0,21	0,23
0,2	0,56	0,58	0,60
0,3	1,01	1,03	1,05
0,4	1,59	1,63	1,66
0,5	2,23	2,29	2,35
0,6	3,36	3,43	3,49
0,7	4,58	4,73	4,88
0,8	7,42	7,55	7,67
0,9	13,50	13,81	14,11

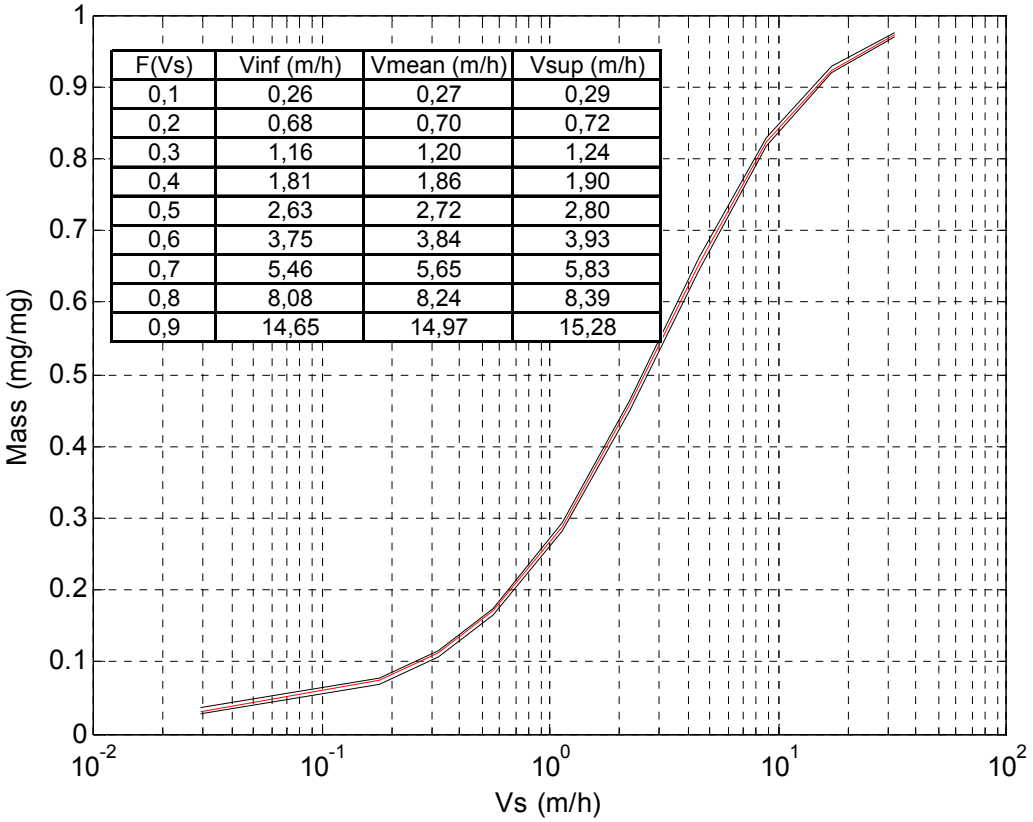


Trap 9 (C2)

F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,07	0,08	0,09
0,2	0,29	0,30	0,31
0,3	0,55	0,56	0,57
0,4	0,89	0,90	0,92
0,5	1,33	1,35	1,36
0,6	1,92	1,93	1,95
0,7	2,84	2,87	2,91
0,8	4,18	4,21	4,23
0,9	7,78	7,83	7,89

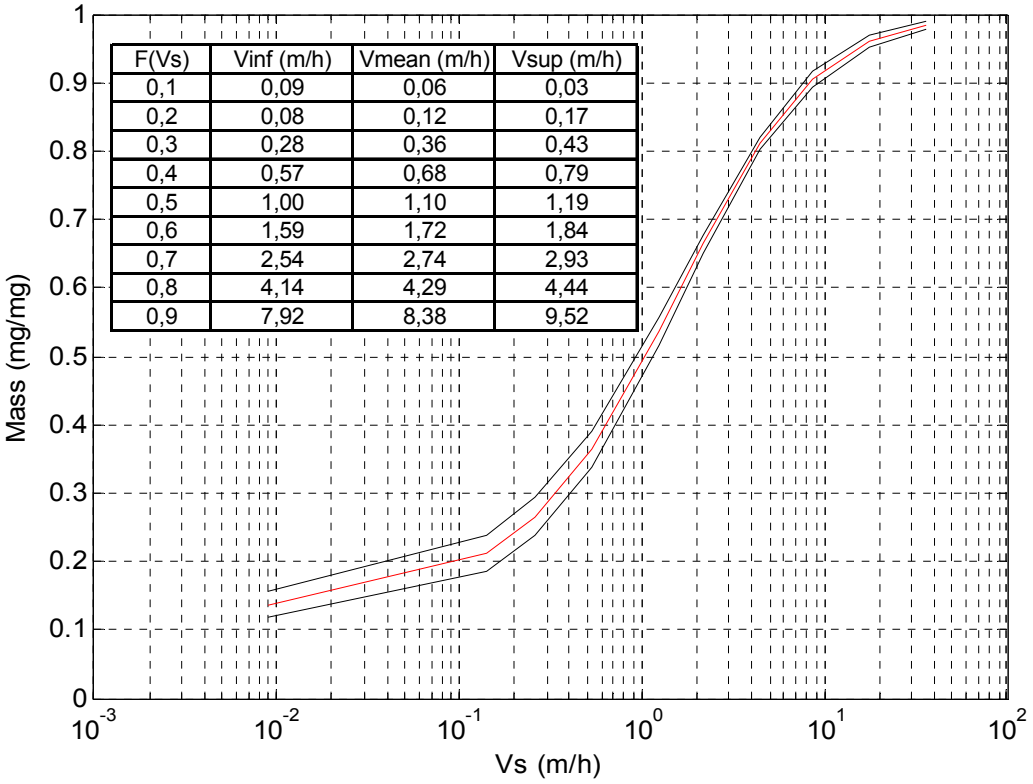


Trap 10 (C2)



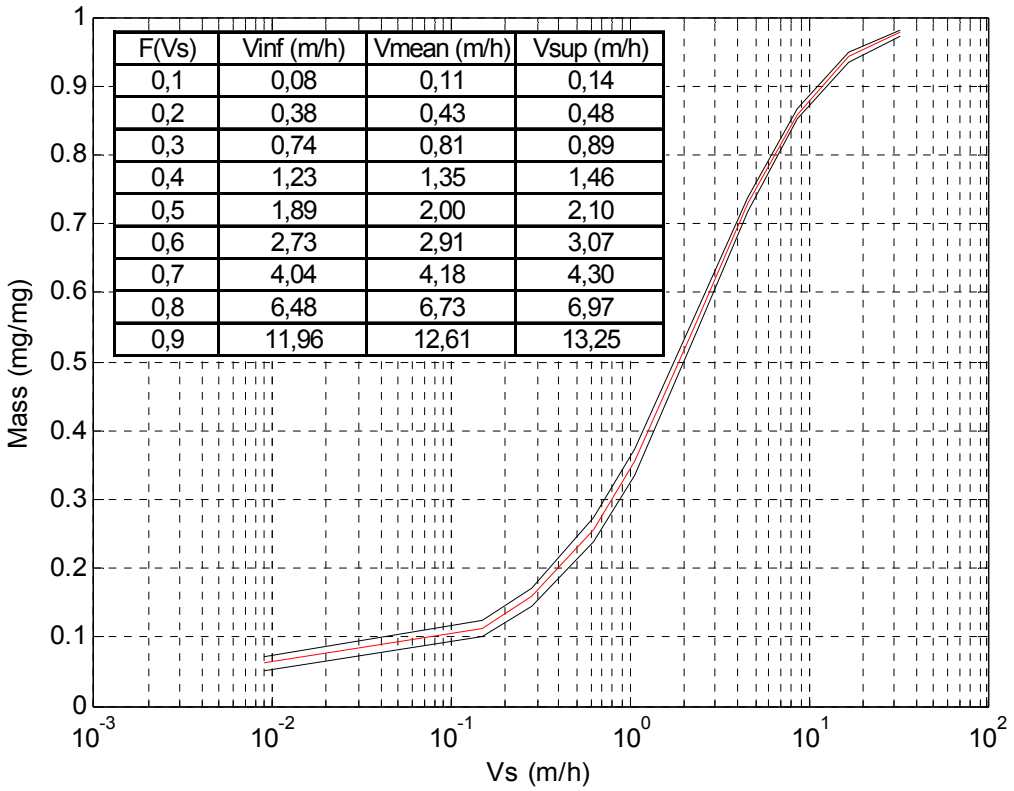
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,26	0,27	0,29
0,2	0,68	0,70	0,72
0,3	1,16	1,20	1,24
0,4	1,81	1,86	1,90
0,5	2,63	2,72	2,80
0,6	3,75	3,84	3,93
0,7	5,46	5,65	5,83
0,8	8,08	8,24	8,39
0,9	14,65	14,97	15,28

Trap 11 (C2)



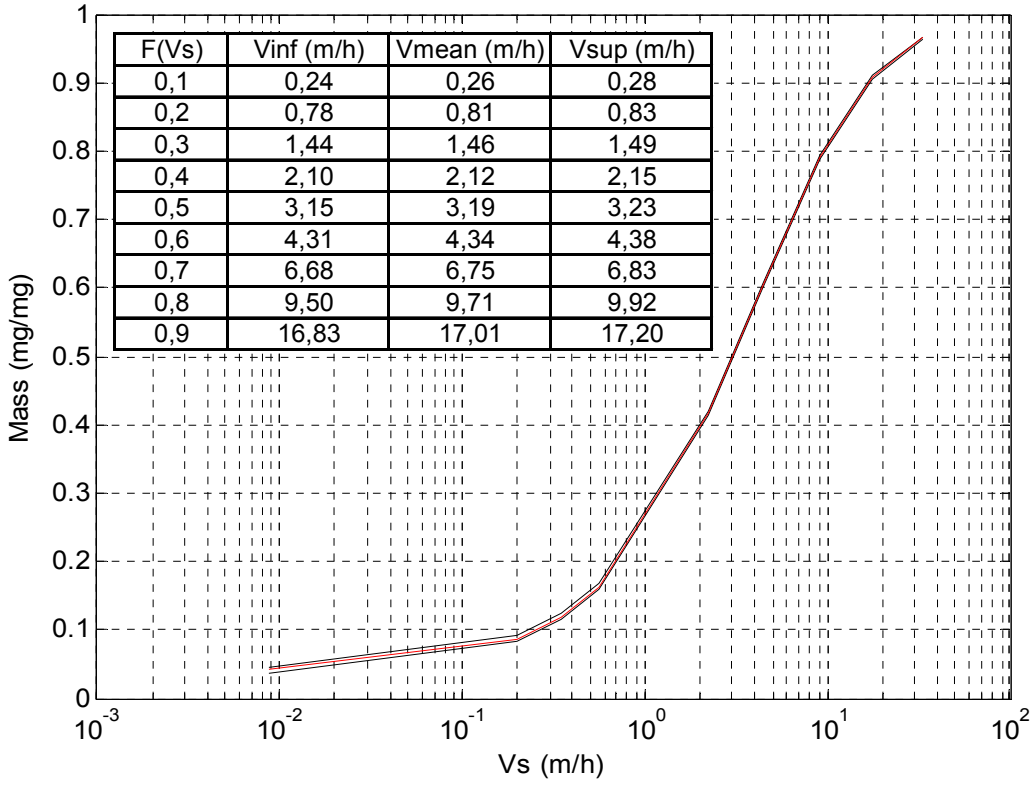
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,09	0,06	0,03
0,2	0,08	0,12	0,17
0,3	0,28	0,36	0,43
0,4	0,57	0,68	0,79
0,5	1,00	1,10	1,19
0,6	1,59	1,72	1,84
0,7	2,54	2,74	2,93
0,8	4,14	4,29	4,44
0,9	7,92	8,38	9,52

Trap 12 (C2)



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,08	0,11	0,14
0,2	0,38	0,43	0,48
0,3	0,74	0,81	0,89
0,4	1,23	1,35	1,46
0,5	1,89	2,00	2,10
0,6	2,73	2,91	3,07
0,7	4,04	4,18	4,30
0,8	6,48	6,73	6,97
0,9	11,96	12,61	13,25

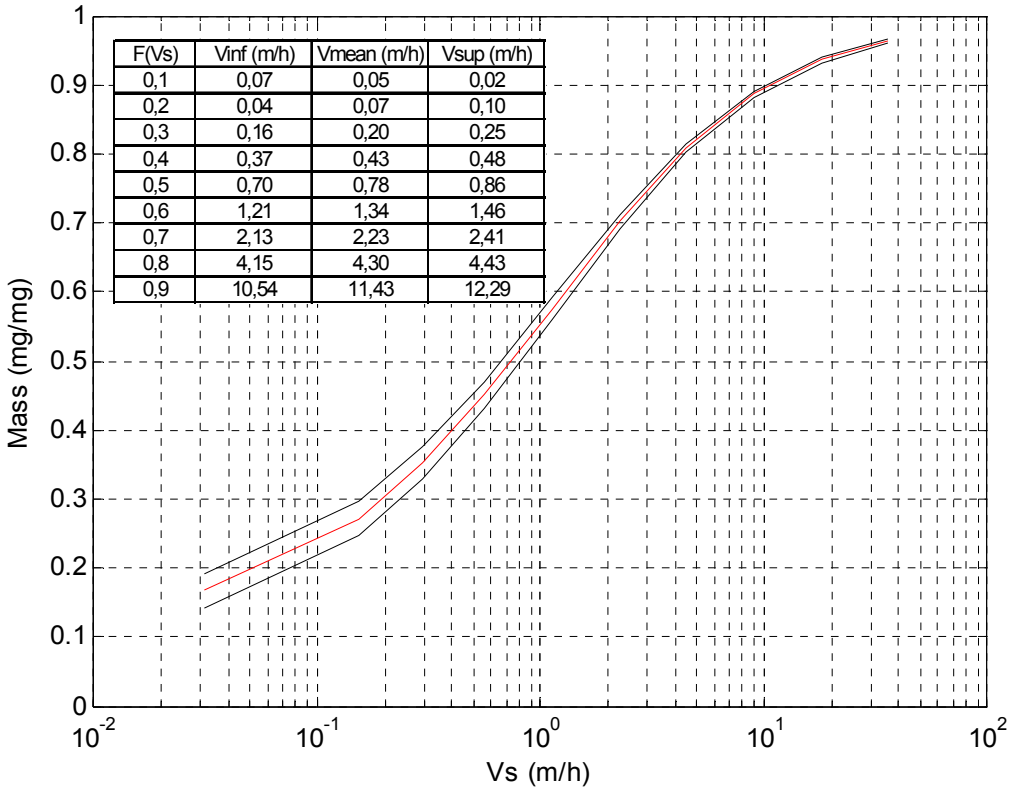
Outflow (C2)



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,24	0,26	0,28
0,2	0,78	0,81	0,83
0,3	1,44	1,46	1,49
0,4	2,10	2,12	2,15
0,5	3,15	3,19	3,23
0,6	4,31	4,34	4,38
0,7	6,68	6,75	6,83
0,8	9,50	9,71	9,92
0,9	16,83	17,01	17,20

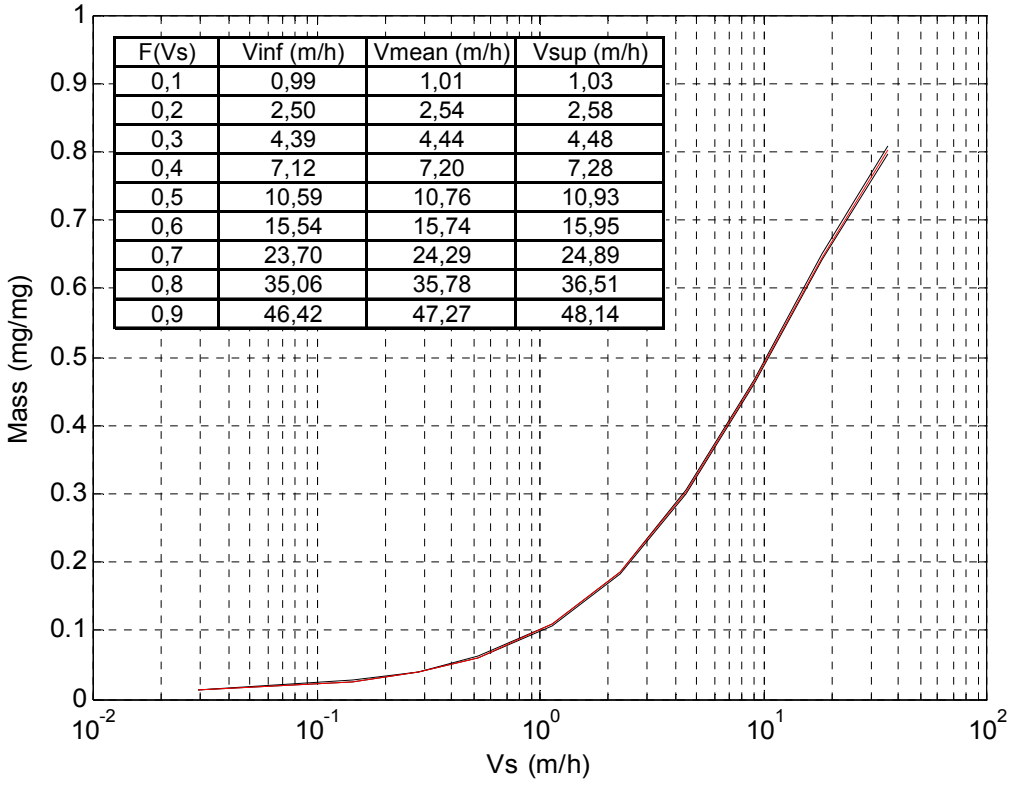
Campaign 3

Inflow (C3)



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,07	0,05	0,02
0,2	0,04	0,07	0,10
0,3	0,16	0,20	0,25
0,4	0,37	0,43	0,48
0,5	0,70	0,78	0,86
0,6	1,21	1,34	1,46
0,7	2,13	2,23	2,41
0,8	4,15	4,30	4,43
0,9	10,54	11,43	12,29

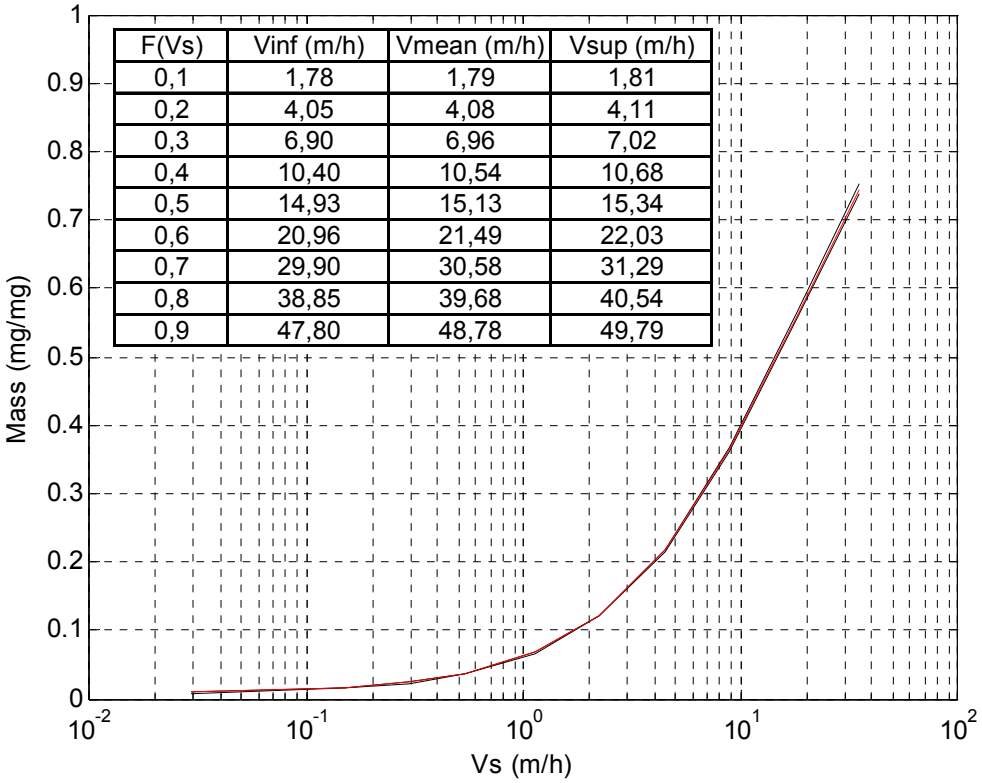
Trap 1 (C3)



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,99	1,01	1,03
0,2	2,50	2,54	2,58
0,3	4,39	4,44	4,48
0,4	7,12	7,20	7,28
0,5	10,59	10,76	10,93
0,6	15,54	15,74	15,95
0,7	23,70	24,29	24,89
0,8	35,06	35,78	36,51
0,9	46,42	47,27	48,14

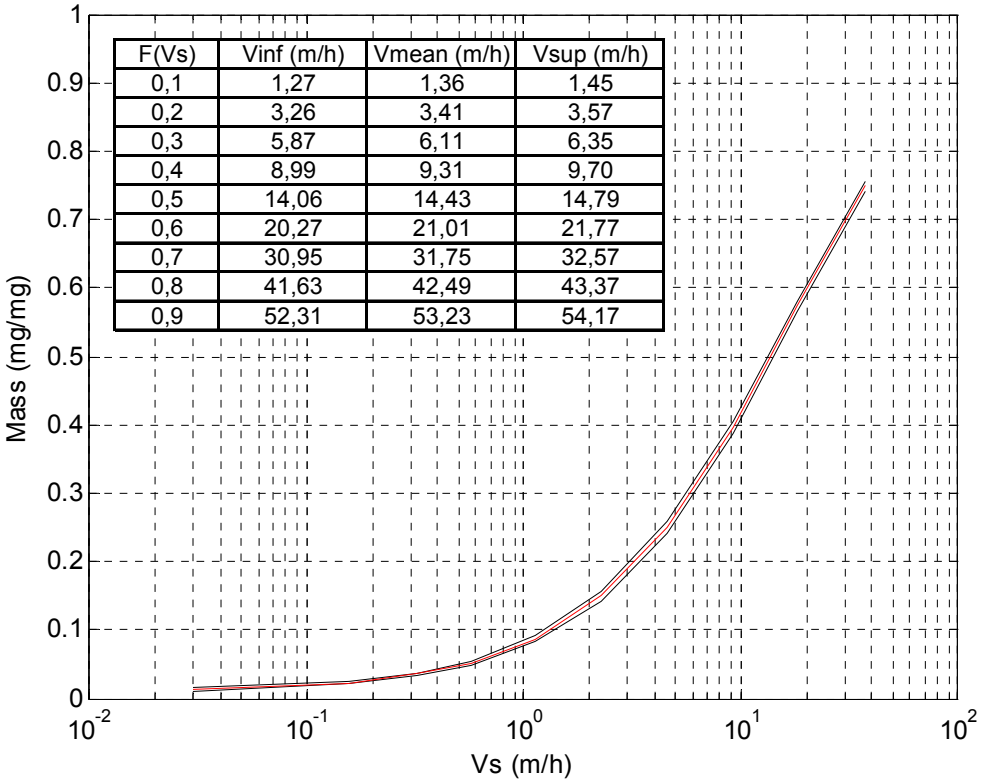
Trap 2 (C3)

F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	1,78	1,79	1,81
0,2	4,05	4,08	4,11
0,3	6,90	6,96	7,02
0,4	10,40	10,54	10,68
0,5	14,93	15,13	15,34
0,6	20,96	21,49	22,03
0,7	29,90	30,58	31,29
0,8	38,85	39,68	40,54
0,9	47,80	48,78	49,79

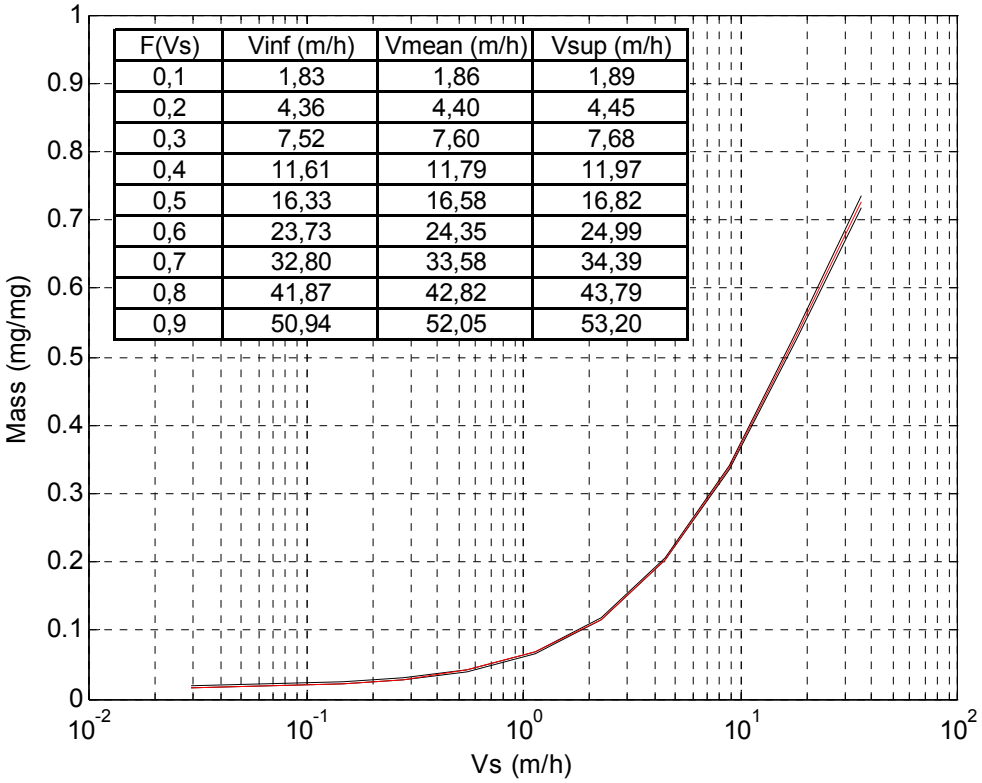


Trap 3 (C3)

F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	1,27	1,36	1,45
0,2	3,26	3,41	3,57
0,3	5,87	6,11	6,35
0,4	8,99	9,31	9,70
0,5	14,06	14,43	14,79
0,6	20,27	21,01	21,77
0,7	30,95	31,75	32,57
0,8	41,63	42,49	43,37
0,9	52,31	53,23	54,17

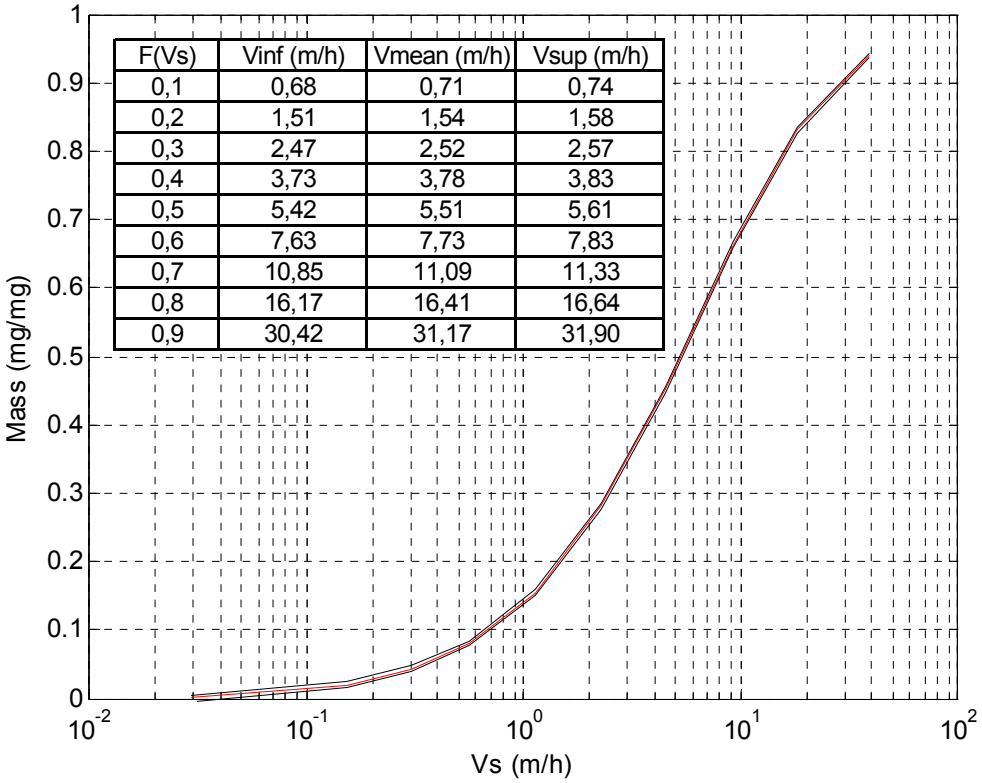


Trap 4 (C3)



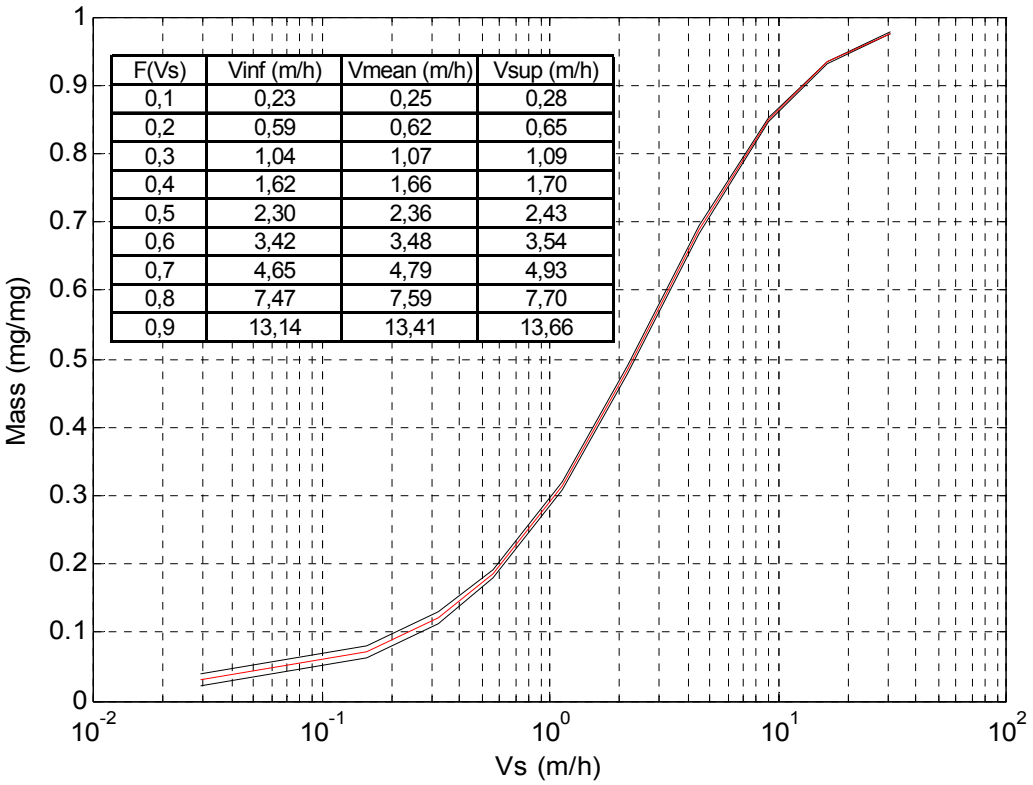
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	1,83	1,86	1,89
0,2	4,36	4,40	4,45
0,3	7,52	7,60	7,68
0,4	11,61	11,79	11,97
0,5	16,33	16,58	16,82
0,6	23,73	24,35	24,99
0,7	32,80	33,58	34,39
0,8	41,87	42,82	43,79
0,9	50,94	52,05	53,20

Trap 5 (C3)



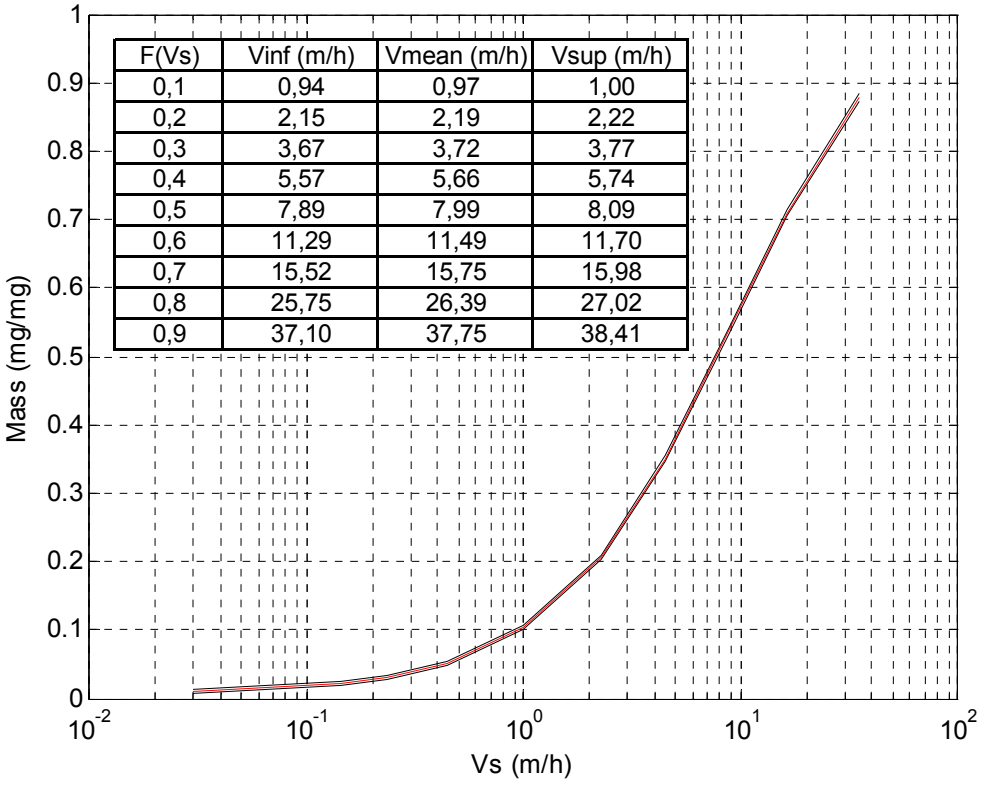
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,68	0,71	0,74
0,2	1,51	1,54	1,58
0,3	2,47	2,52	2,57
0,4	3,73	3,78	3,83
0,5	5,42	5,51	5,61
0,6	7,63	7,73	7,83
0,7	10,85	11,09	11,33
0,8	16,17	16,41	16,64
0,9	30,42	31,17	31,90

Trap 6 (C3)



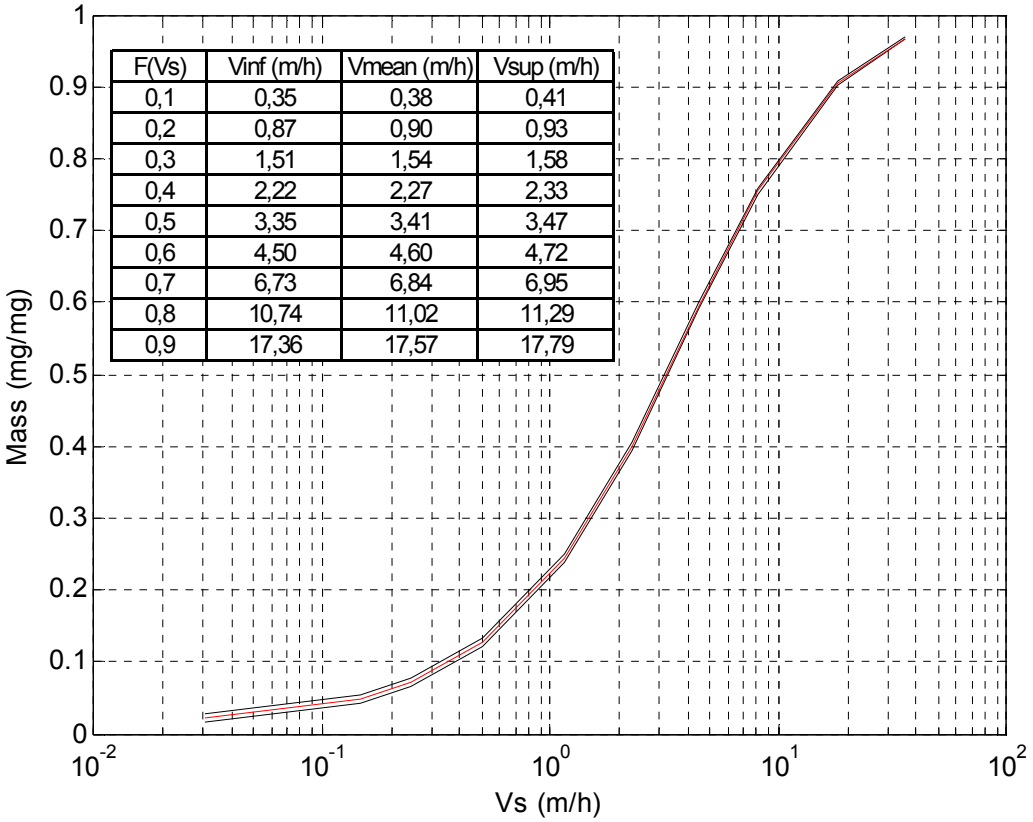
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,23	0,25	0,28
0,2	0,59	0,62	0,65
0,3	1,04	1,07	1,09
0,4	1,62	1,66	1,70
0,5	2,30	2,36	2,43
0,6	3,42	3,48	3,54
0,7	4,65	4,79	4,93
0,8	7,47	7,59	7,70
0,9	13,14	13,41	13,66

Trap 7 (C3)



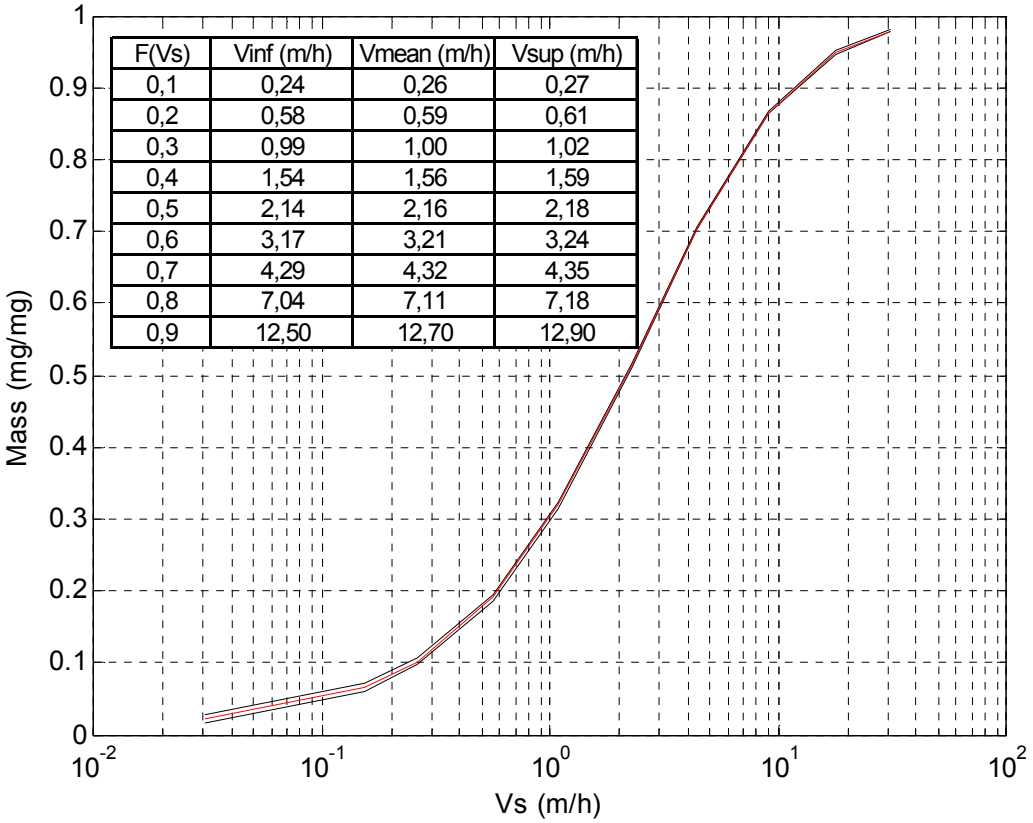
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,94	0,97	1,00
0,2	2,15	2,19	2,22
0,3	3,67	3,72	3,77
0,4	5,57	5,66	5,74
0,5	7,89	7,99	8,09
0,6	11,29	11,49	11,70
0,7	15,52	15,75	15,98
0,8	25,75	26,39	27,02
0,9	37,10	37,75	38,41

Trap 8 (C3)



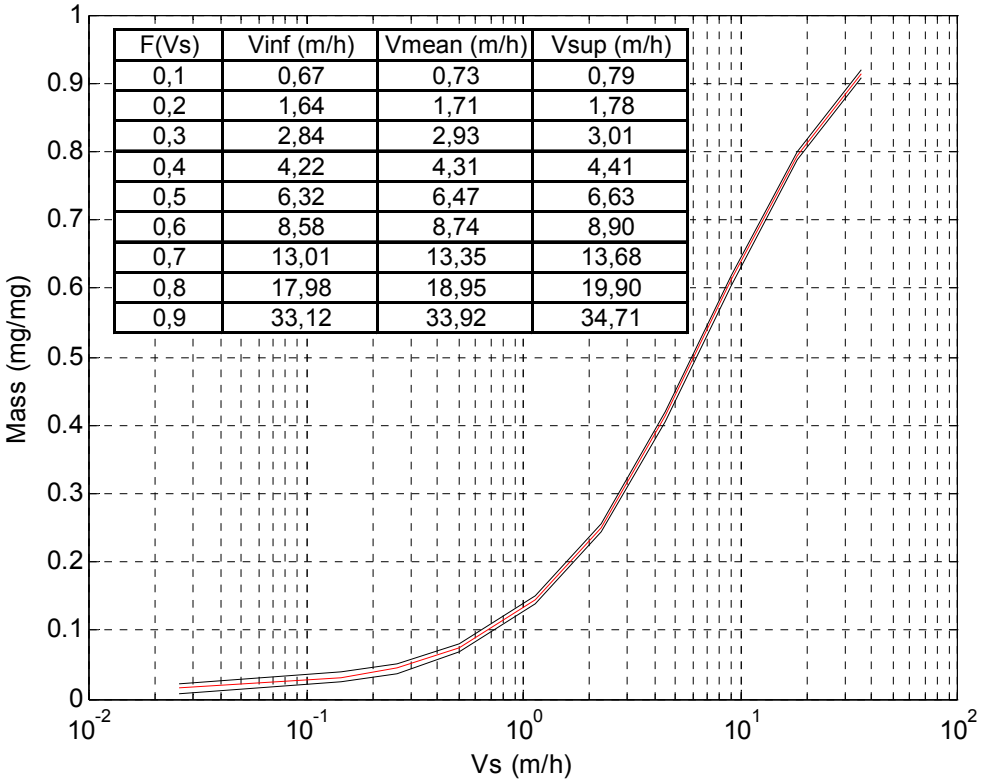
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,35	0,38	0,41
0,2	0,87	0,90	0,93
0,3	1,51	1,54	1,58
0,4	2,22	2,27	2,33
0,5	3,35	3,41	3,47
0,6	4,50	4,60	4,72
0,7	6,73	6,84	6,95
0,8	10,74	11,02	11,29
0,9	17,36	17,57	17,79

Trap 9 (C3)



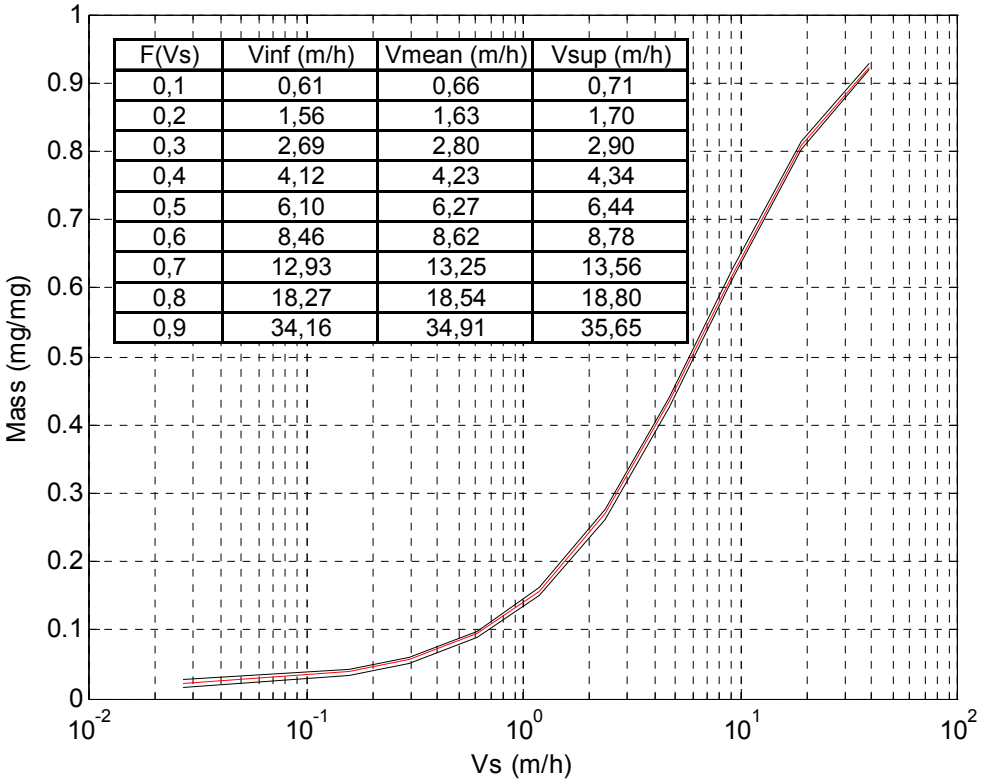
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,24	0,26	0,27
0,2	0,58	0,59	0,61
0,3	0,99	1,00	1,02
0,4	1,54	1,56	1,59
0,5	2,14	2,16	2,18
0,6	3,17	3,21	3,24
0,7	4,29	4,32	4,35
0,8	7,04	7,11	7,18
0,9	12,50	12,70	12,90

Trap 10 (C3)



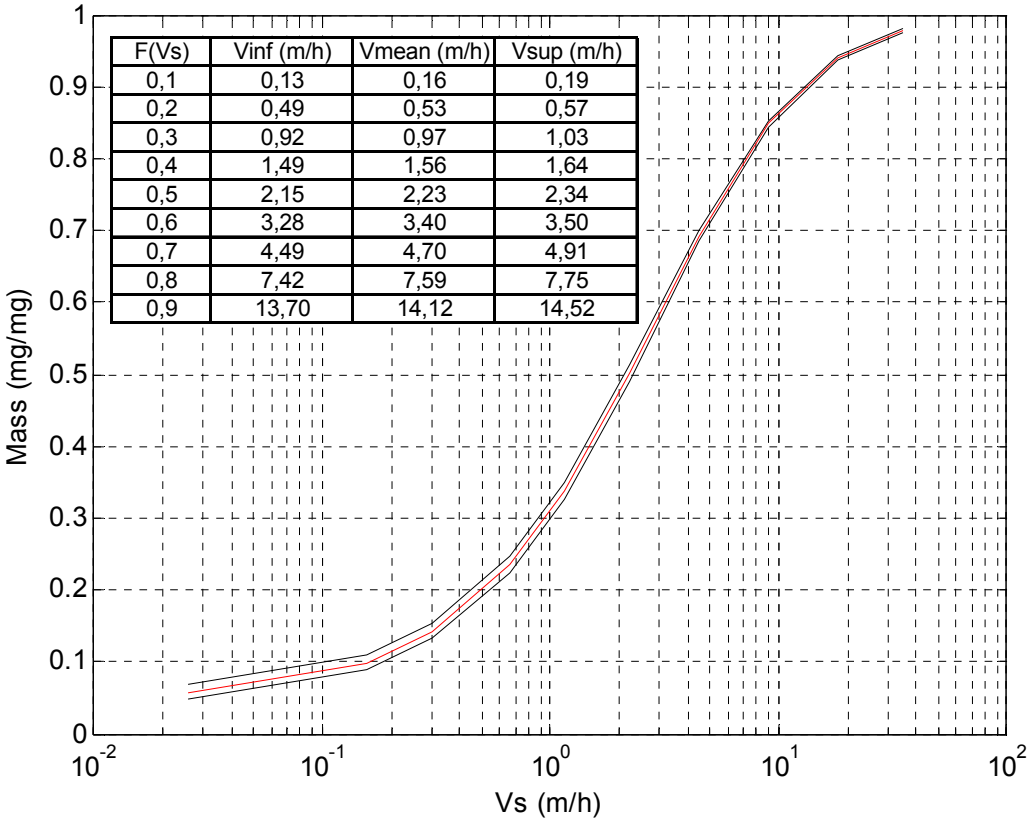
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,67	0,73	0,79
0,2	1,64	1,71	1,78
0,3	2,84	2,93	3,01
0,4	4,22	4,31	4,41
0,5	6,32	6,47	6,63
0,6	8,58	8,74	8,90
0,7	13,01	13,35	13,68
0,8	17,98	18,95	19,90
0,9	33,12	33,92	34,71

Trap 11 (C3)



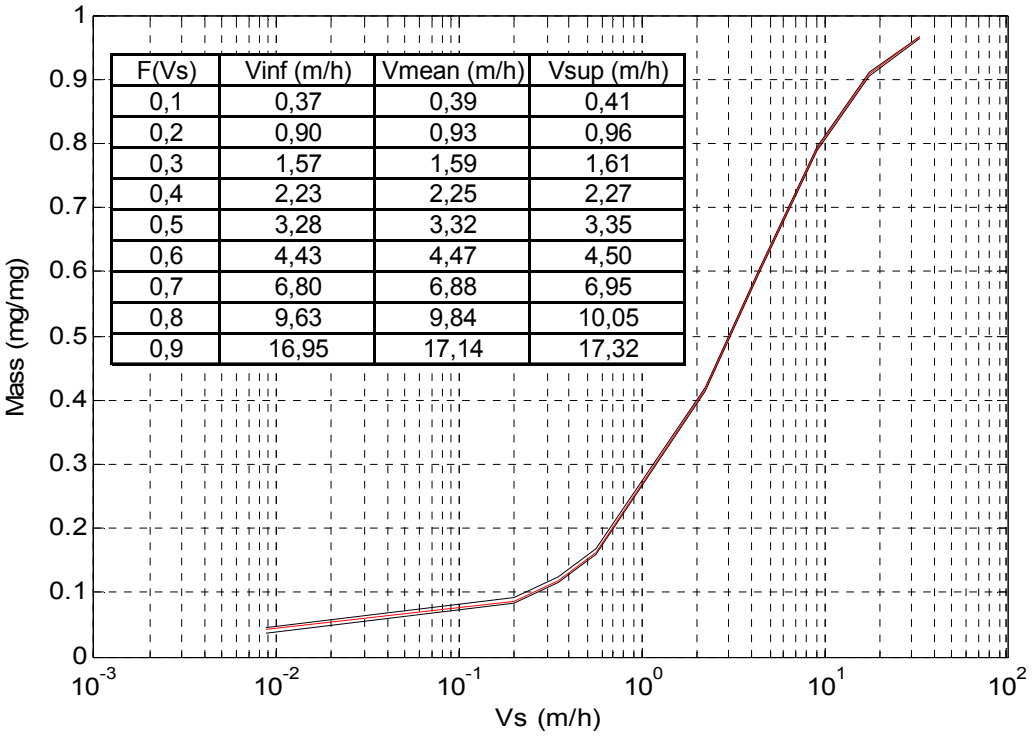
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,61	0,66	0,71
0,2	1,56	1,63	1,70
0,3	2,69	2,80	2,90
0,4	4,12	4,23	4,34
0,5	6,10	6,27	6,44
0,6	8,46	8,62	8,78
0,7	12,93	13,25	13,56
0,8	18,27	18,54	18,80
0,9	34,16	34,91	35,65

Trap 12 (C3)



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,13	0,16	0,19
0,2	0,49	0,53	0,57
0,3	0,92	0,97	1,03
0,4	1,49	1,56	1,64
0,5	2,15	2,23	2,34
0,6	3,28	3,40	3,50
0,7	4,49	4,70	4,91
0,8	7,42	7,59	7,75
0,9	13,70	14,12	14,52

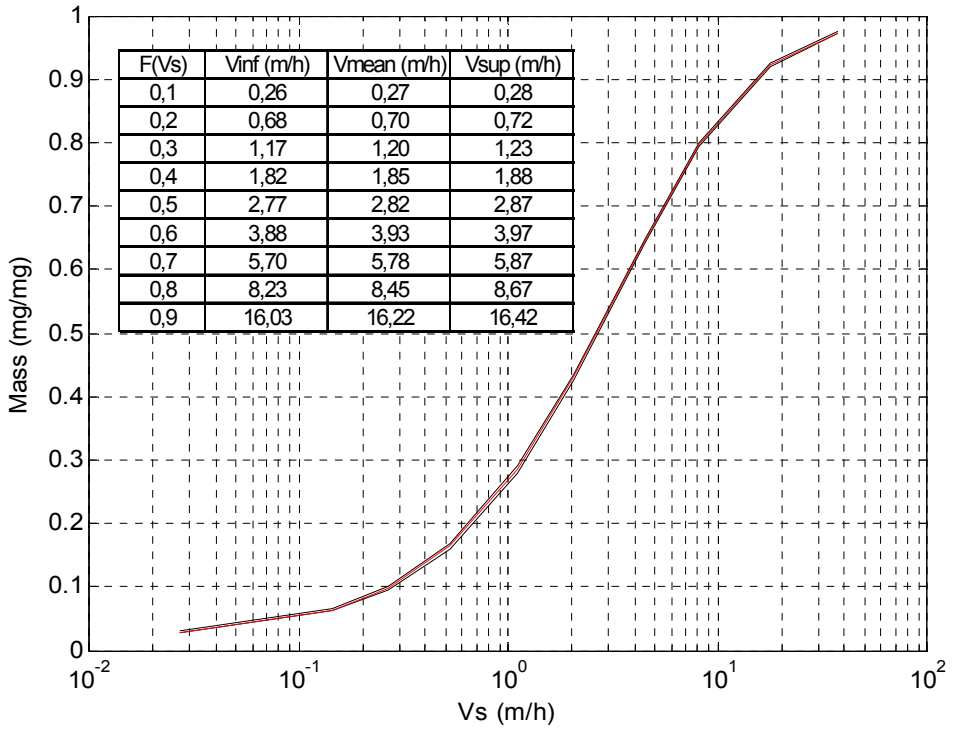
Outflow (C3)



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,37	0,39	0,41
0,2	0,90	0,93	0,96
0,3	1,57	1,59	1,61
0,4	2,23	2,25	2,27
0,5	3,28	3,32	3,35
0,6	4,43	4,47	4,50
0,7	6,80	6,88	6,95
0,8	9,63	9,84	10,05
0,9	16,95	17,14	17,32

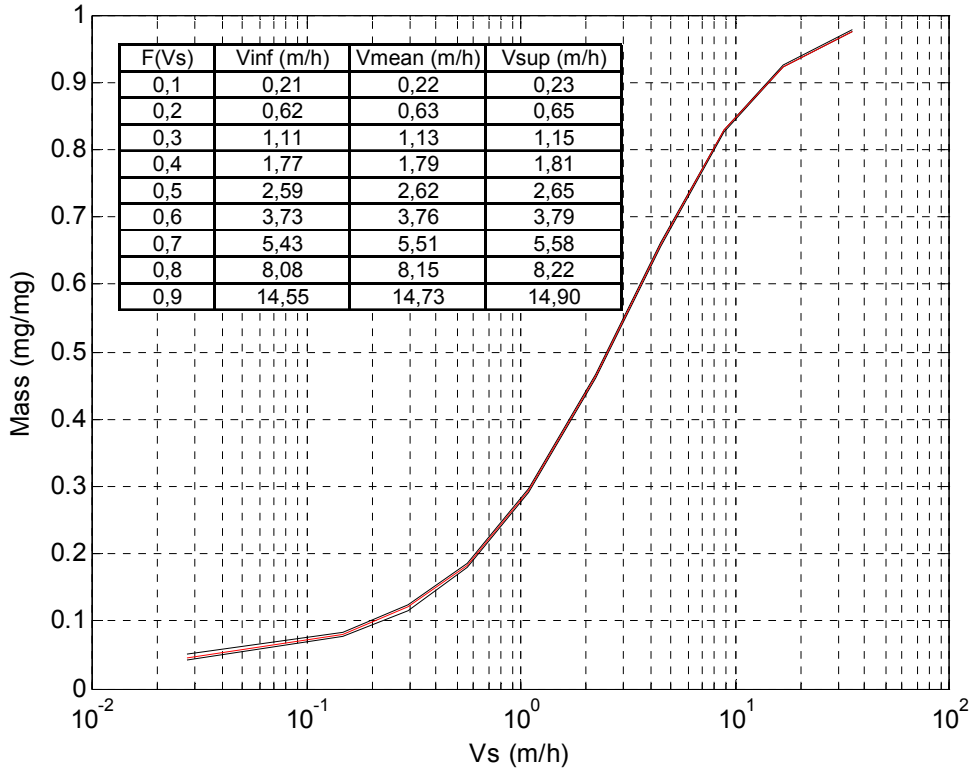
Preliminary tests

Test 1, potable water



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,26	0,27	0,28
0,2	0,68	0,70	0,72
0,3	1,17	1,20	1,23
0,4	1,82	1,85	1,88
0,5	2,77	2,82	2,87
0,6	3,88	3,93	3,97
0,7	5,70	5,78	5,87
0,8	8,23	8,45	8,67
0,9	16,03	16,22	16,42

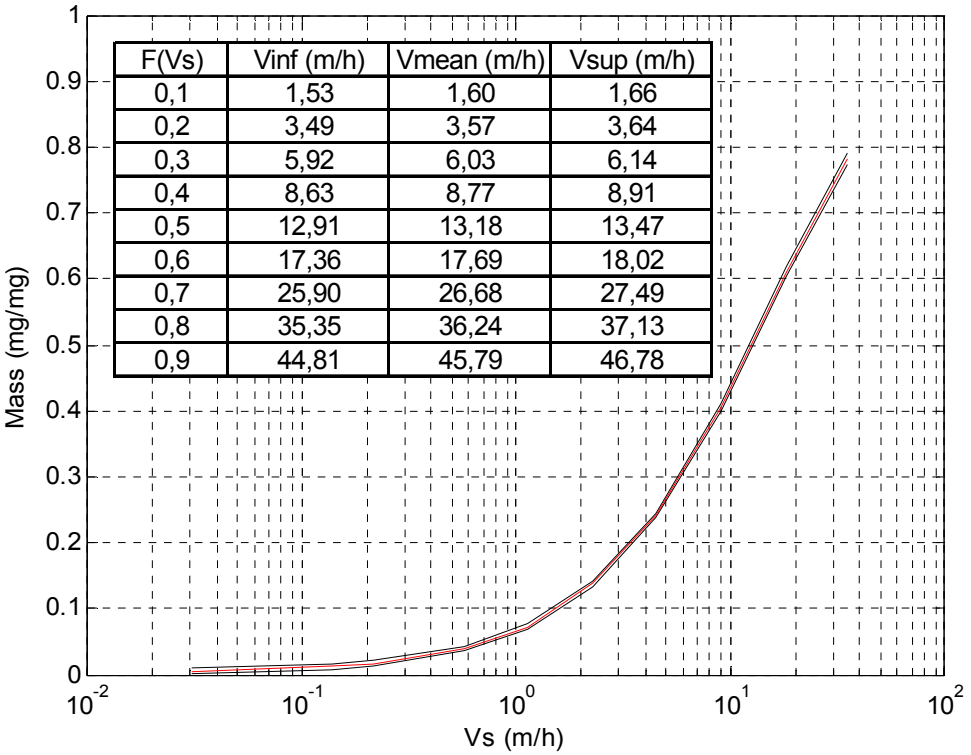
Test 2, waste water



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,21	0,22	0,23
0,2	0,62	0,63	0,65
0,3	1,11	1,13	1,15
0,4	1,77	1,79	1,81
0,5	2,59	2,62	2,65
0,6	3,73	3,76	3,79
0,7	5,43	5,51	5,58
0,8	8,08	8,15	8,22
0,9	14,55	14,73	14,90

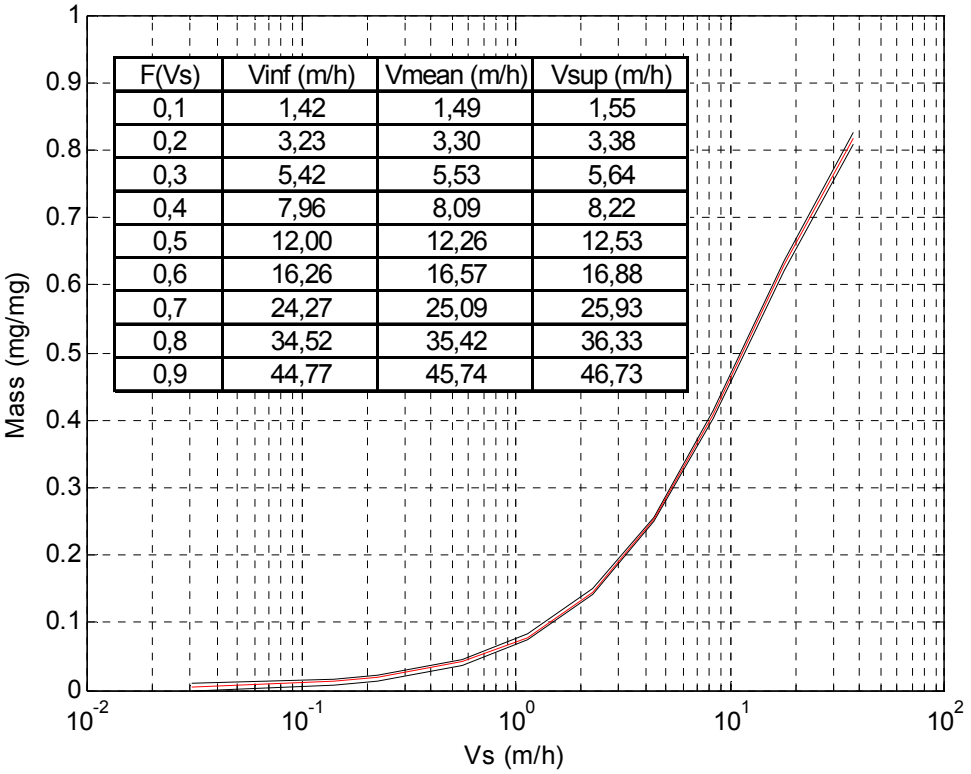
Reproducibility (Triple)

Test 1



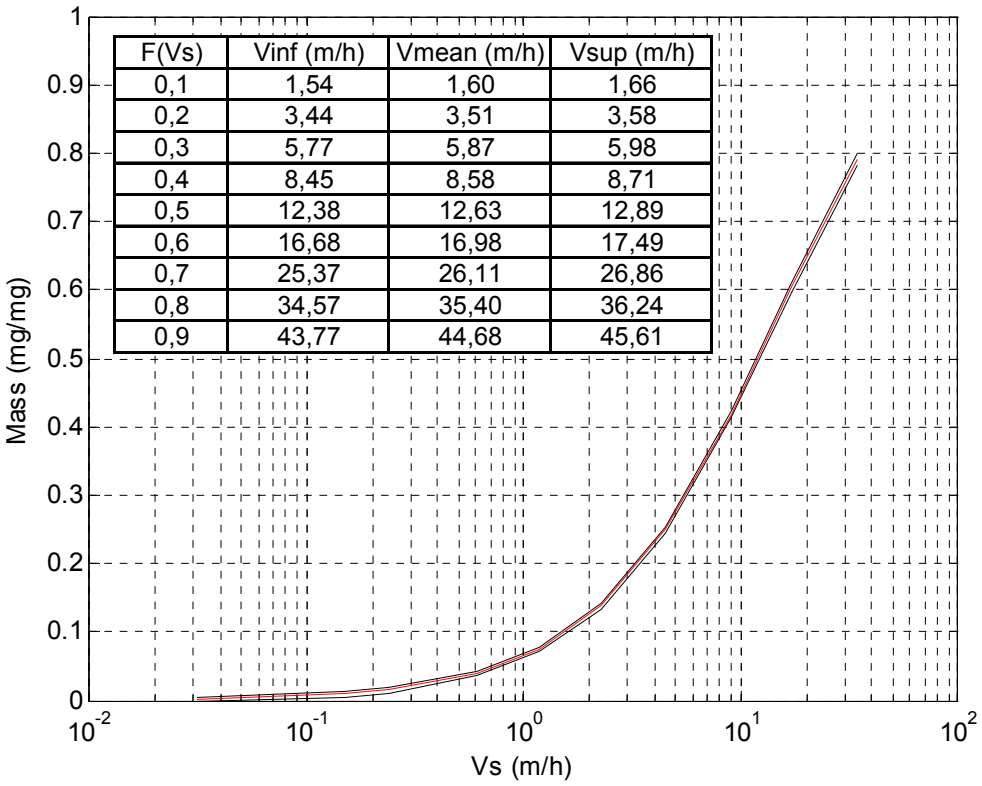
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	1,53	1,60	1,66
0,2	3,49	3,57	3,64
0,3	5,92	6,03	6,14
0,4	8,63	8,77	8,91
0,5	12,91	13,18	13,47
0,6	17,36	17,69	18,02
0,7	25,90	26,68	27,49
0,8	35,35	36,24	37,13
0,9	44,81	45,79	46,78

Test 2



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	1,42	1,49	1,55
0,2	3,23	3,30	3,38
0,3	5,42	5,53	5,64
0,4	7,96	8,09	8,22
0,5	12,00	12,26	12,53
0,6	16,26	16,57	16,88
0,7	24,27	25,09	25,93
0,8	34,52	35,42	36,33
0,9	44,77	45,74	46,73

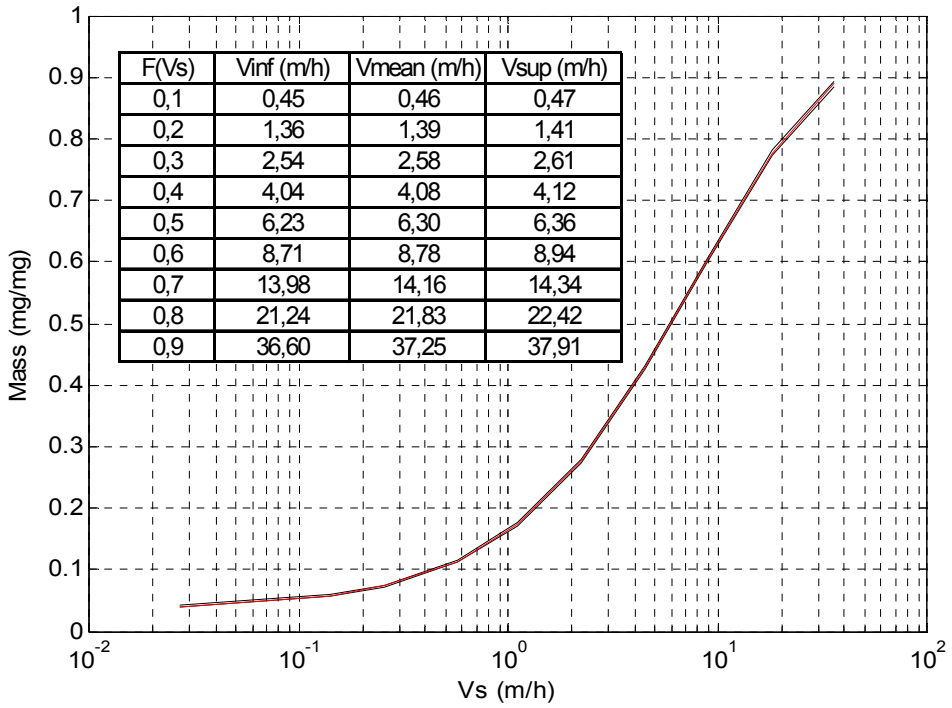
Test 3



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	1,54	1,60	1,66
0,2	3,44	3,51	3,58
0,3	5,77	5,87	5,98
0,4	8,45	8,58	8,71
0,5	12,38	12,63	12,89
0,6	16,68	16,98	17,49
0,7	25,37	26,11	26,86
0,8	34,57	35,40	36,24
0,9	43,77	44,68	45,61

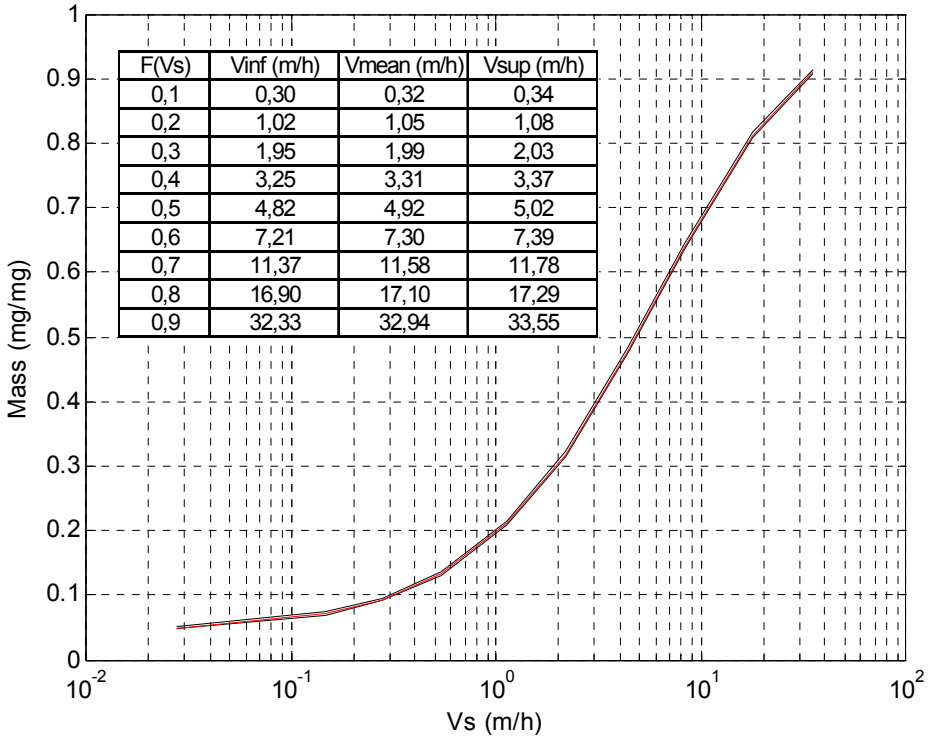
Mass balance verification

High loaded sample



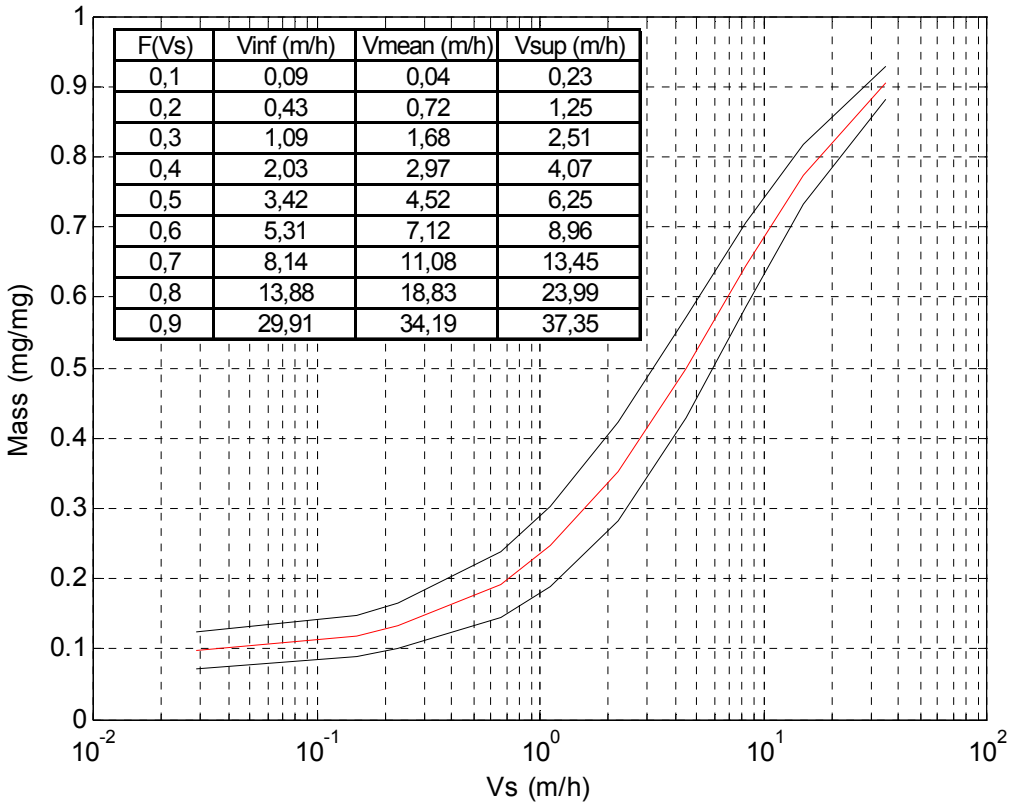
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,45	0,46	0,47
0,2	1,36	1,39	1,41
0,3	2,54	2,58	2,61
0,4	4,04	4,08	4,12
0,5	6,23	6,30	6,36
0,6	8,71	8,78	8,94
0,7	13,98	14,16	14,34
0,8	21,24	21,83	22,42
0,9	36,60	37,25	37,91

Medium loaded sample



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,30	0,32	0,34
0,2	1,02	1,05	1,08
0,3	1,95	1,99	2,03
0,4	3,25	3,31	3,37
0,5	4,82	4,92	5,02
0,6	7,21	7,30	7,39
0,7	11,37	11,58	11,78
0,8	16,90	17,10	17,29
0,9	32,33	32,94	33,55

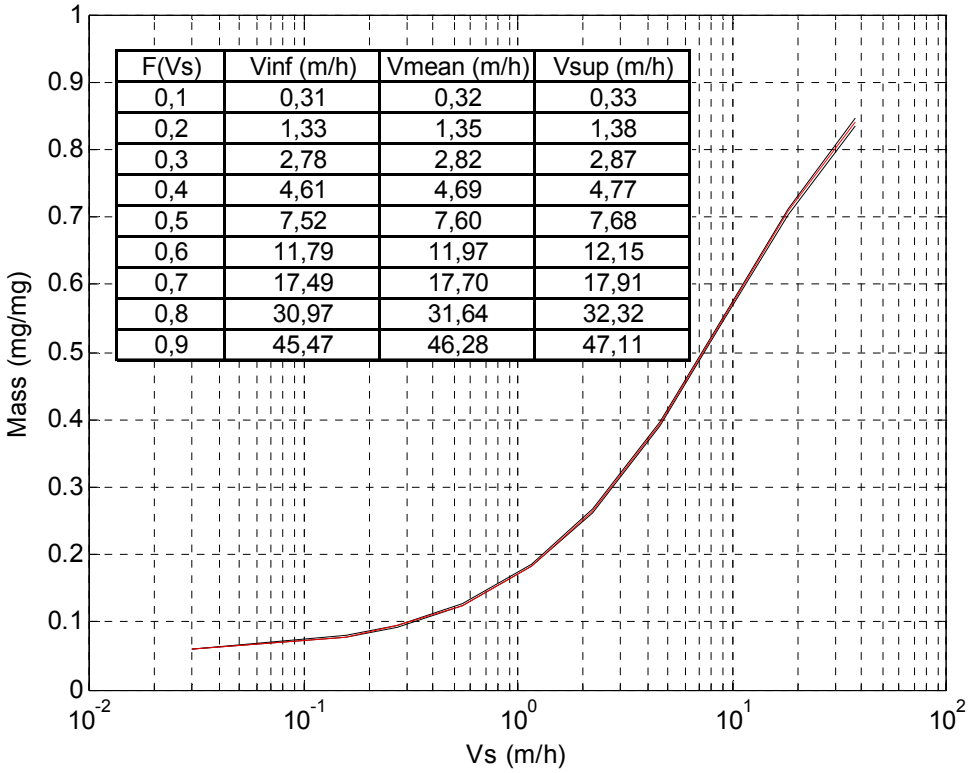
Low loaded sample



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,09	0,04	0,23
0,2	0,43	0,72	1,25
0,3	1,09	1,68	2,51
0,4	2,03	2,97	4,07
0,5	3,42	4,52	6,25
0,6	5,31	7,12	8,96
0,7	8,14	11,08	13,45
0,8	13,88	18,83	23,99
0,9	29,91	34,19	37,35

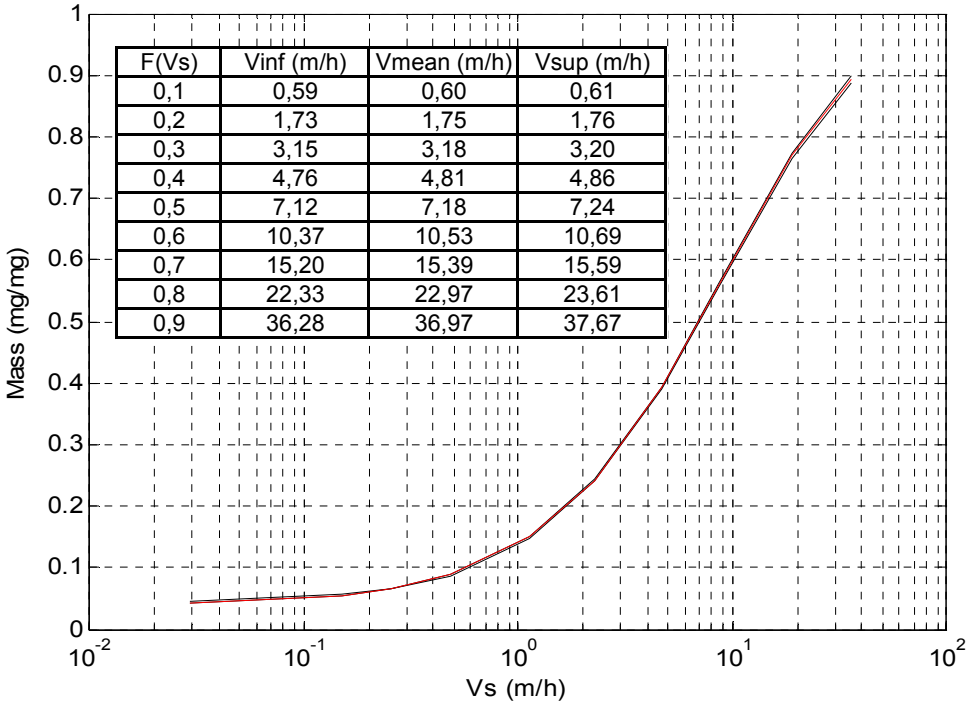
Time related evolution of particles settling velocity after one month of the rain event

Trap2



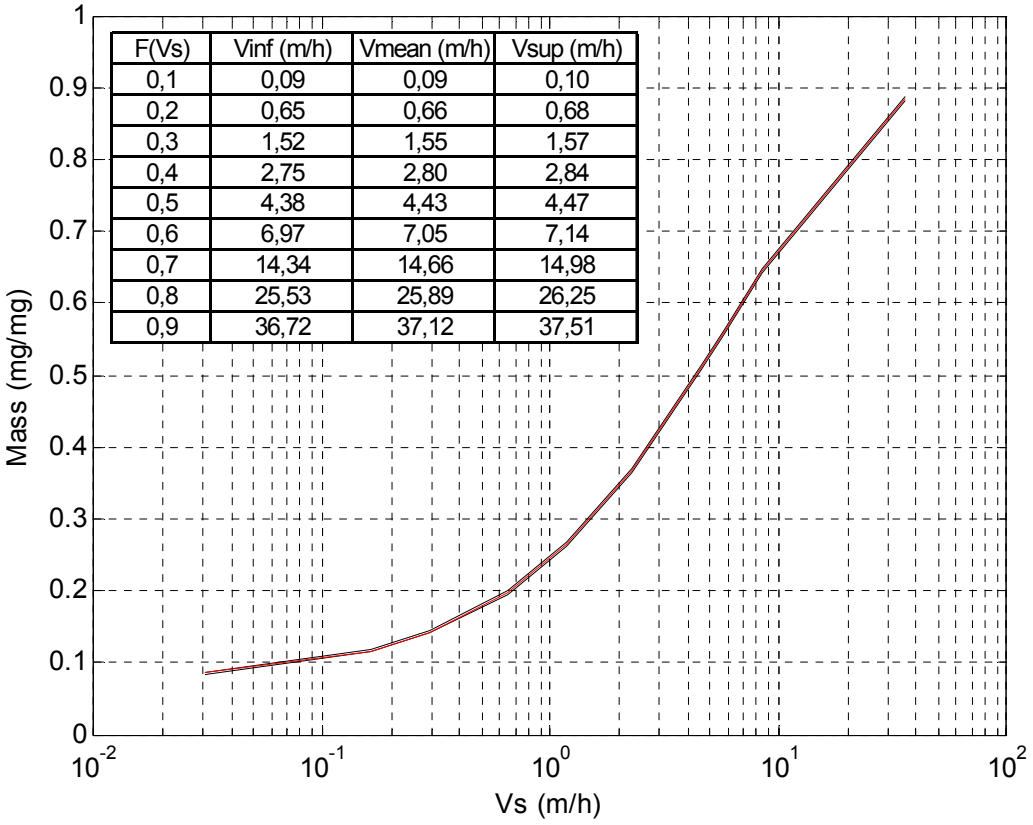
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,31	0,32	0,33
0,2	1,33	1,35	1,38
0,3	2,78	2,82	2,87
0,4	4,61	4,69	4,77
0,5	7,52	7,60	7,68
0,6	11,79	11,97	12,15
0,7	17,49	17,70	17,91
0,8	30,97	31,64	32,32
0,9	45,47	46,28	47,11

Trap 7



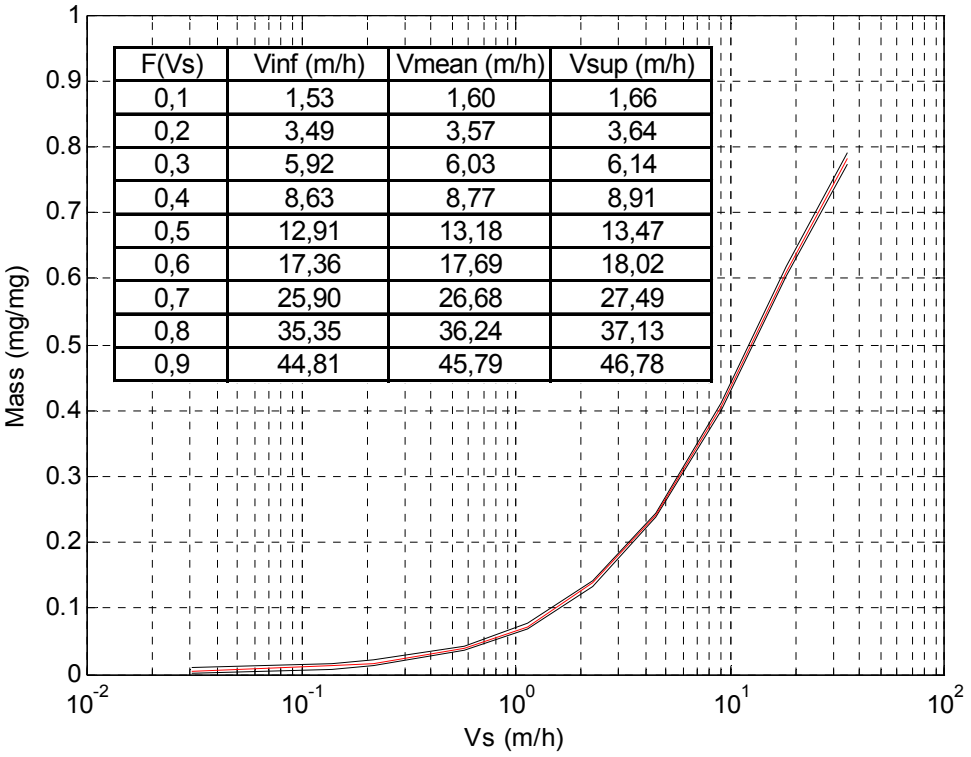
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	0,59	0,60	0,61
0,2	1,73	1,75	1,76
0,3	3,15	3,18	3,20
0,4	4,76	4,81	4,86
0,5	7,12	7,18	7,24
0,6	10,37	10,53	10,69
0,7	15,20	15,39	15,59
0,8	22,33	22,97	23,61
0,9	36,28	36,97	37,67

Trap 11


F(Vs) | Vinf (m/h) | Vmean (m/h) | Vsup (m/h)
0,1 | 0,09 | 0,09 | 0,10
0,2 | 0,65 | 0,66 | 0,68
0,3 | 1,52 | 1,55 | 1,57
0,4 | 2,75 | 2,80 | 2,84
0,5 | 4,38 | 4,43 | 4,47
0,6 | 6,97 | 7,05 | 7,14
0,7 | 14,34 | 14,66 | 14,98
0,8 | 25,53 | 25,89 | 26,25
0,9 | 36,72 | 37,12 | 37,51
Mass (mg/mg)
Vs (m/h)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
10-2
10-1
100
101
102

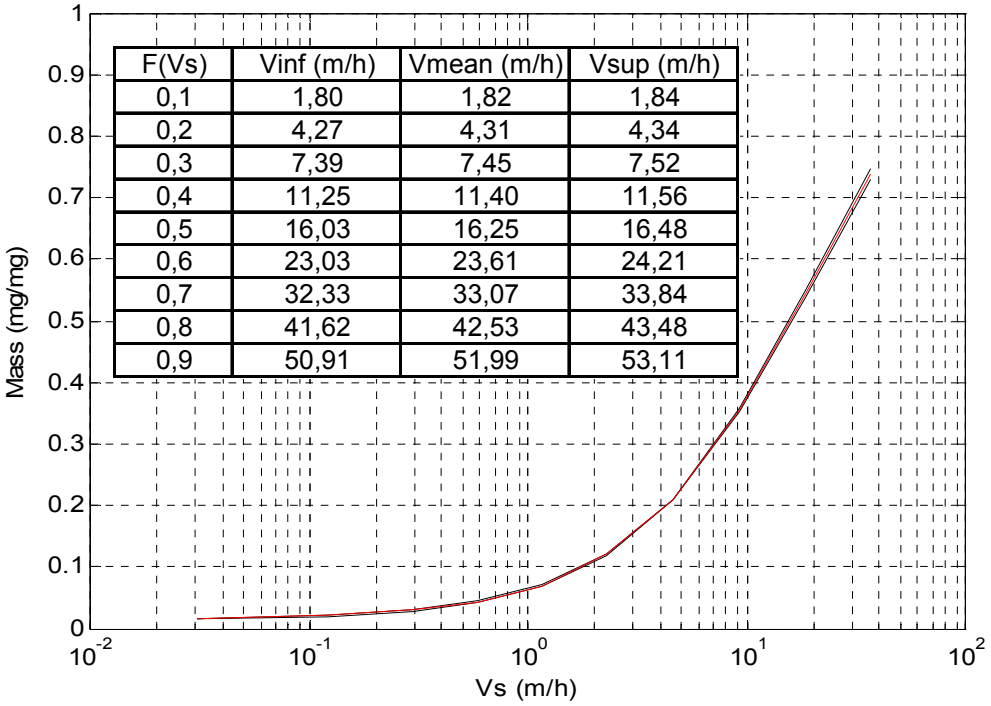
Sample keeping in fridge for different terms of time

One day



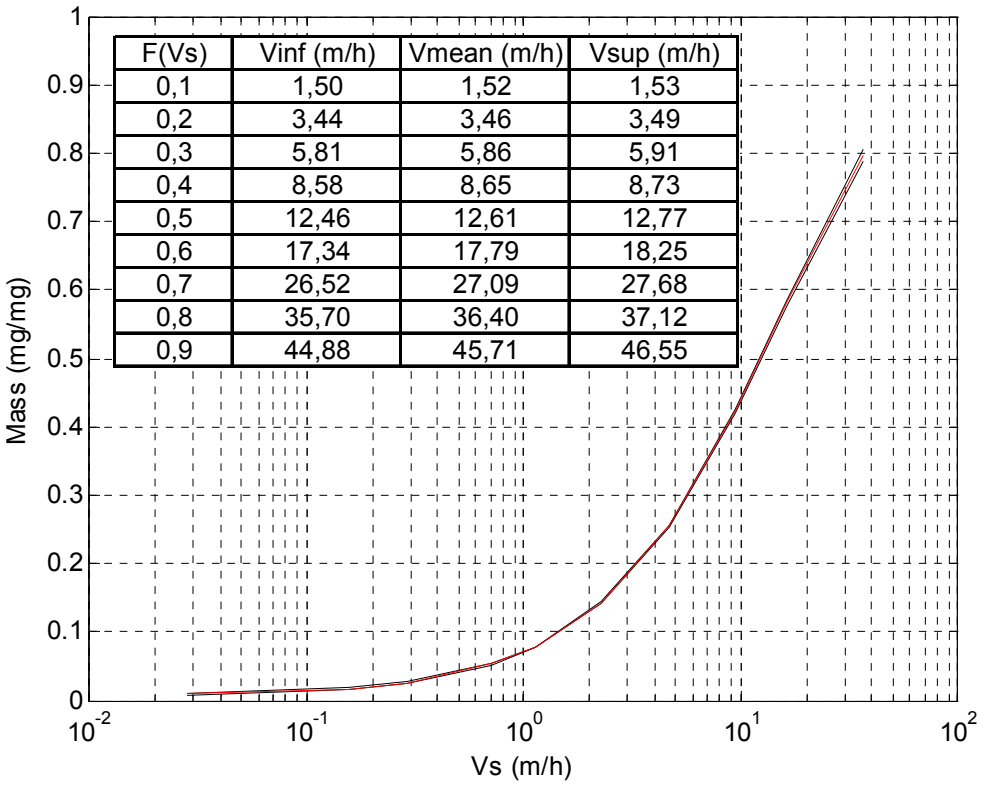
F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	1,53	1,60	1,66
0,2	3,49	3,57	3,64
0,3	5,92	6,03	6,14
0,4	8,63	8,77	8,91
0,5	12,91	13,18	13,47
0,6	17,36	17,69	18,02
0,7	25,90	26,68	27,49
0,8	35,35	36,24	37,13
0,9	44,81	45,79	46,78

Five days



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	1,80	1,82	1,84
0,2	4,27	4,31	4,34
0,3	7,39	7,45	7,52
0,4	11,25	11,40	11,56
0,5	16,03	16,25	16,48
0,6	23,03	23,61	24,21
0,7	32,33	33,07	33,84
0,8	41,62	42,53	43,48
0,9	50,91	51,99	53,11

21 days



F(Vs)	Vinf (m/h)	Vmean (m/h)	Vsup (m/h)
0,1	1,50	1,52	1,53
0,2	3,44	3,46	3,49
0,3	5,81	5,86	5,91
0,4	8,58	8,65	8,73
0,5	12,46	12,61	12,77
0,6	17,34	17,79	18,25
0,7	26,52	27,09	27,68
0,8	35,70	36,40	37,12
0,9	44,88	45,71	46,55

APPENDIX D : GEOSTATISTICAL INTERPOLATION

Determination of the hydrocarbon parameter in two positions of the stormwater storage tank by using the Kriging Interpolation

```
Instruction tables:


library(gstat)
library(lattice)

Coordinates of each trap:

X=read.table("X.txt",h=TRUE)
Y=read.table("Y.txt",h=TRUE)
HT=read.table("HT.txt",h=TRUE)

Table of variables:

Vicas=data.frame(X,Y,HT)
```

Programm operation

1. VARIOGRAMM

The relation between the distance and the variable is described by a variogramme.

```
v.ltpb <- variogram(log(HT)~1, loc=~x+y, Vicas)
plot(v.ltpb, pl=T)
```

2. DEFINITION OF PARAMETERS BY AN ESTIMATED MODEL

To characterise the measured values by a tended curve a function is to estimate.

```
(m.ltpb.f <- fit.variogram(v.ltpb, m.ltpb))
plot(v.ltpb, pl=T, model=m.ltpb.f)
```

3. INTERPOLATION BY ORDINARY KRIGING IN A GRILLE OF PREDICTION BY USING THE CALIBRATED MODELE OF THE PRECEDENT STEP

To predict the settling velocities V50 the model calibrated in the further step will be used.

Define an interpolation grille:

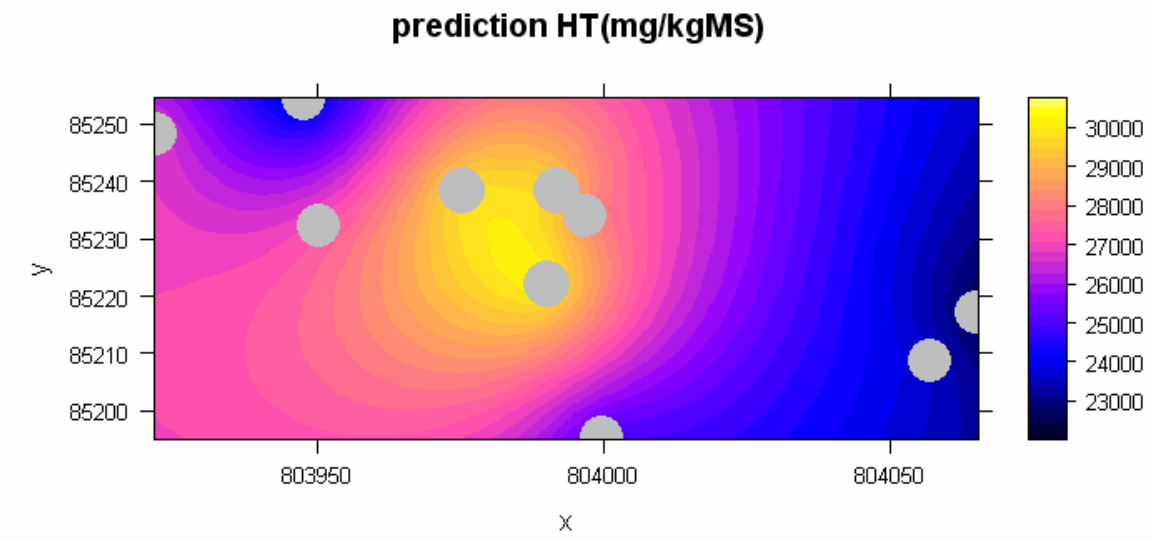
```
grd=makegrid(X,Y,100000,100000)
```

For the ordinary kriging:

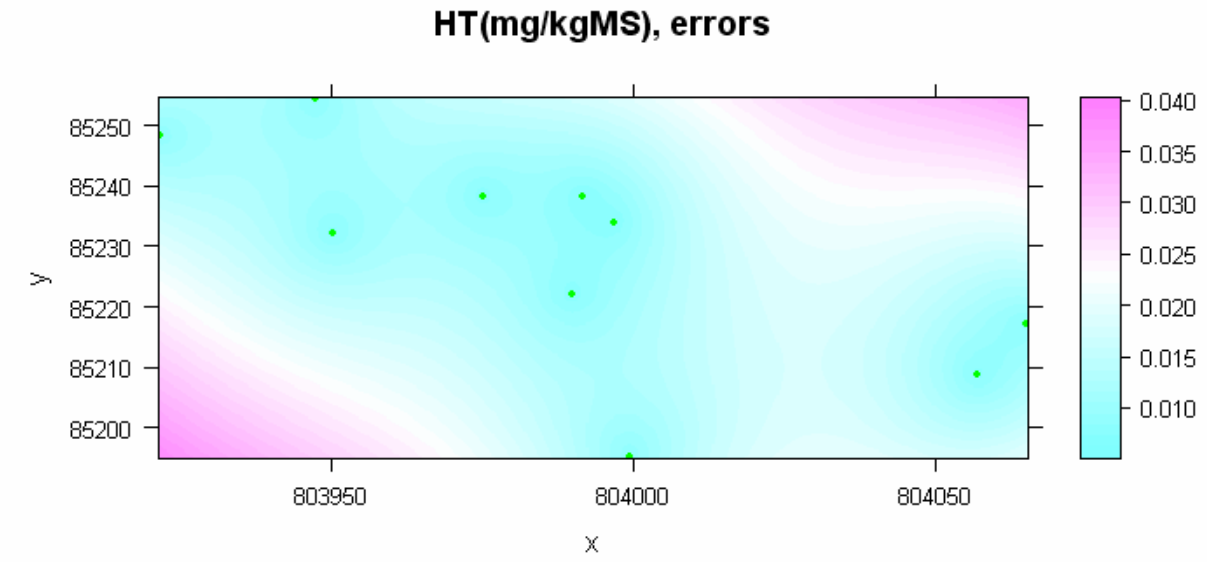
```
k.o <- krige(HT ~1, ~x+y, Vicas, grd, m.ltpb.f)
```

4. MAP OF PREDICTION AND OF ERRORS

```
levelplot(var1.pred ~ x+y, k.o, aspect=mapasp(k.o),
col.regions=bpy.colors(64), cut=32,
main="prediction HT(mg/kgMS)",
panel = function(x, ...) {
panel.levelplot(x, ...)
lpoints(Vicas$x,Vicas$y, col="grey", pch=20,
cex=1.6 * (log10(Vicas$HT) - 1.3)) })
```



```
levelplot(var1.var ~ x+y, k.o, aspect=mapasp(k.o),
col.regions=cm.colors(64), cut=32,
main="HT(mg/kgMS), errors",
panel = function(x, ...) {
panel.levelplot(x, ...);
lpoints(Vicas$x,Vicas$y, col="green", pch=20, cex=.6)
})
```



5. VALIDATION

To confirm the results it is to choose a grille and to leave aside one or more well known point/s of the precedent prediction. A second operation of the programm delivers another map of prediction and the points led beside can be read off the new predicted table and compared with the precedent result.

To chosse a grille it is possible to take, for example:

```
k.o[1:1000,]
```

To evaluate the precision of the model it is also possible to make a **cross validation**. Each point is led aside and the prediction is made out of the remaining points beside the well known trap positions by using the variogramm. So it is possible to determine the errors of each point (which have been zero in the precedent prediction):

```
cv.o <- krige.cv(HT ~ 1, ~x+y, Vicas, model=m.ltpb.f)
str(cv.o)
```

```
`data.frame':   12 obs. of  8 variables:
 $ x         : num  803997 803990 803992 803975 803950 ...
 $ y         : num  85234 85222 85238 85238 85232 ...
 $ var1.pred: num  1.31 1.49 1.50 1.21 1.10 ...
 $ var1.var : num  0.184 0.341 0.182 0.371 0.430 ...
 $ observed : num  1.905 0.902 1.362 0.457 1.604 ...
 $ residual : num   0.596 -0.585 -0.142 -0.748  0.509 ...
 $ zscore   : num   1.391 -1.003 -0.332 -1.228  0.776 ...
 $ fold     : int  1 2 3 4 5 6 7 8 9 10 ...
```

```
1.131983
```

To see the created file:

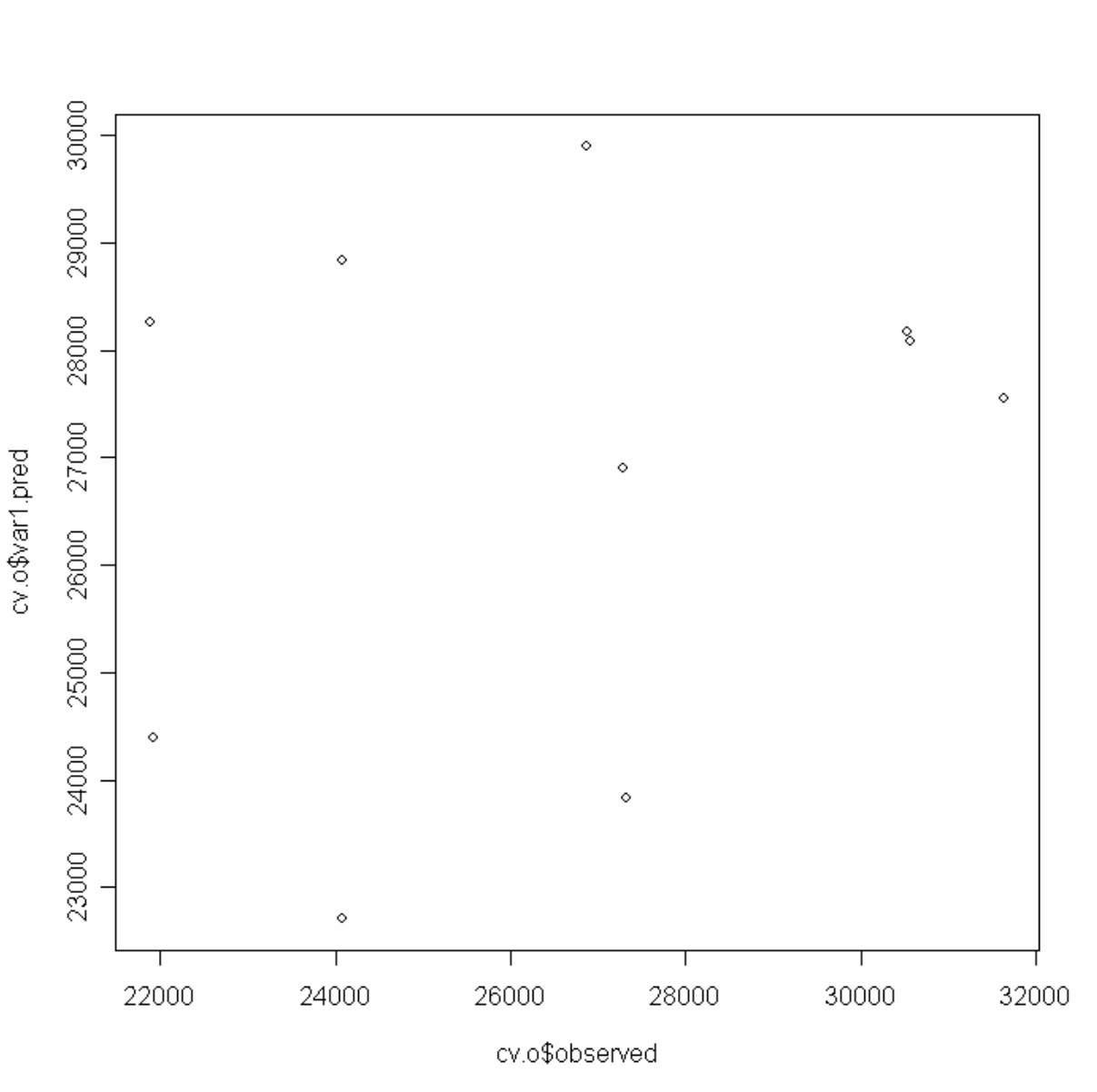
```
cv.o
```

```
          x            y  var1.pred     var1.var  observed     residual
zscore fold
1   803996.8  85234.00   29899.47  0.01101488      26868  -3031.4732 -
28884.430    1
2   803989.9  85222.00    27555.26  0.01320503       31642    4086.7429
35563.749    2
3   803991.8  85238.29    28076.74  0.01084322       30578    2501.2643
24020.413    3
4   803975.2  85238.33    28173.11  0.01382729       30532    2358.8928
20060.404    4
5   803950.3  85232.18    26896.34  0.01720030       27287     390.6569
2978.705    5
6   803947.5  85254.37    28256.60  0.01795024      21885  -6371.5962 -
47556.854    6
```

```
7   803999.5  85195.21   28831.41  0.02602867      24075  -4756.4129 -
29481.771    7
8    803922.0  85248.28    23827.66  0.02703075       27326    3498.3424
21278.120    8
9   804064.9  85217.08   24392.06  0.01820618      21931  -2461.0585 -
18239.483    9
10  804056.9  85208.64    22709.31  0.01618176       24088    1378.6929
10838.138   10
```

The predicted observed relation can be plot by:

```
plot(cv.o$observed,cv.o$var1.pred)
```



The coefficient of correlation is calculated by:

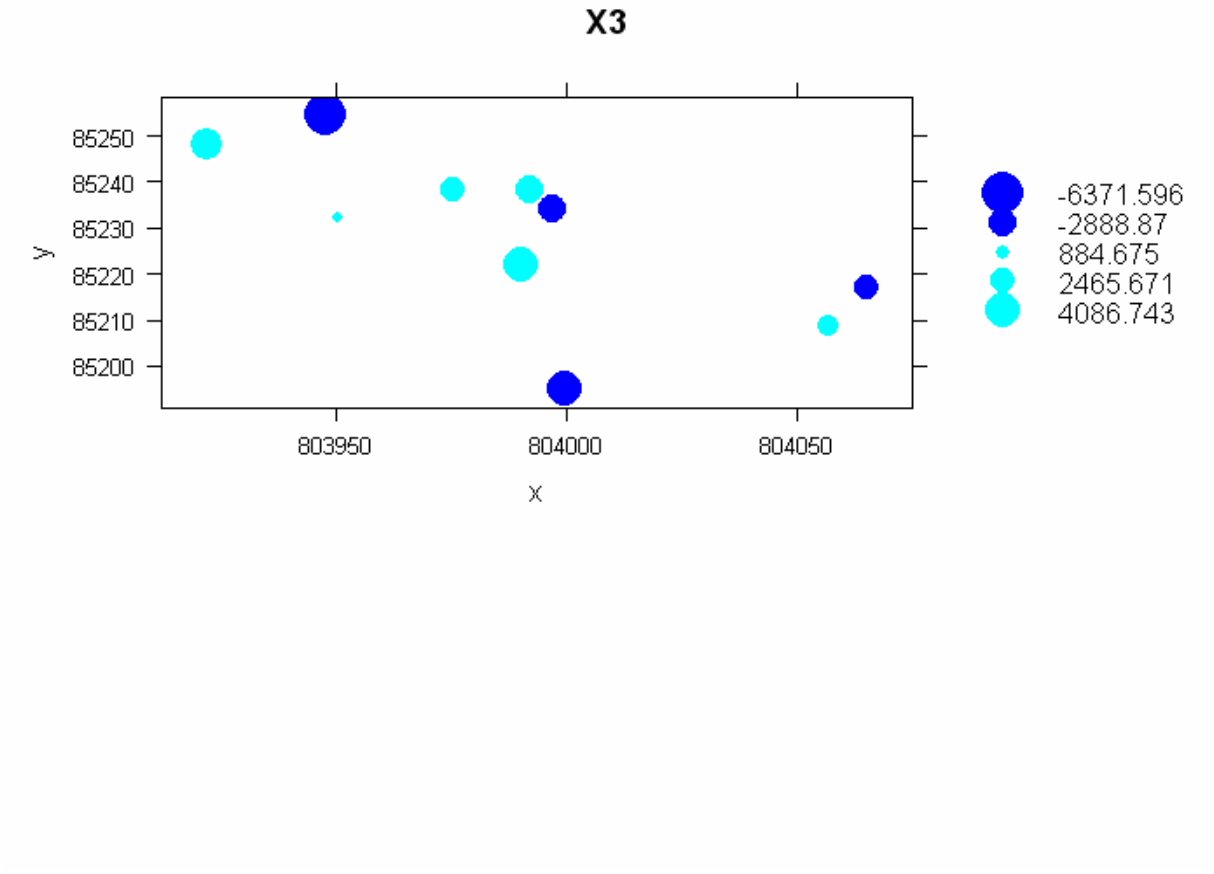
```
library(boot)
forcorr=data.frame(cv.o$observed,cv.o$var1.pred)
```

```
corr(forcorr);corr(forcorr)^2
```

```
[1] 0.2940818
[1] 0.08648409
```

To draw the table of errors:

```
bubble(data.frame(cbind(cv.o$x, cv.o$y, cv.o$residual)), col=c(4,5))
```



6. PREDICTION FOR THE 12 COORDINATES OF THE TRAP POSITIONS

To read the 12 coordinates:

```
X12=read.table ("X12.txt", h=TRUE)
Y12=read.table ("Y12.txt", h=TRUE)
```

Define an interpolation grille of exactly 12 points:

```
grdA=data.frame(X12,Y12)
```

grdA

```
          x        y
1  803996.8 85234.00
2  803989.9 85222.00
3  803991.8 85238.29
4  803975.2 85238.33
5  803950.3 85232.18
6  803947.5 85254.37
7  803999.5 85195.21
8  803922.0 85248.28
9  803902.4 85248.51
10 804064.9 85217.08
11 804056.9 85208.64
12 804033.5 85185.70
```

For the ordinary kriging:

```
k.o <- krige(HT ~1, ~x+y, Vicas, grdA, m.ltpb.f)
k.o
```

```
          x        y var1.pred     var1.var
1  803996.8 85234.00    26868.00   0.000000e+00
2  803989.9 85222.00    31642.00   1.693929e-33
3  803991.8 85238.29    30578.00   2.775558e-17
4  803975.2 85238.33    30532.00   2.775558e-17
5  803950.3 85232.18    27287.00   0.000000e+00
6  803947.5 85254.37    21885.00   0.000000e+00
7  803999.5 85195.21    24075.00   0.000000e+00
8  803922.0 85248.28    27326.00   2.775558e-17
9  803902.4 85248.51    26585.13   2.501070e-02
10 804064.9 85217.08    21931.00   0.000000e+00
11 804056.9 85208.64    24088.00   0.000000e+00
12 804033.5 85185.70    24134.65   2.316479e-02
```

To read the coordinates of the two positions which have been missed before out of the prediction table:

```
Here it is position 9 and position 12 of the precedent table.
(Pos.9: 26585.13 / Pos.12: 24134.65)
```

Then the parameter of HT can be changed into 12 Positions from 10 positions.

Kriging Interpolation by using the Gstat programm for the first measurement serie (Campaign1)

```
Instruction tables:

library(gstat)
library(lattice)

Coordinates of each trap:

X=read.table("X.txt",h=TRUE)
Y=read.table("Y.txt",h=TRUE)
V50=read.table("V50.txt",h=TRUE)

Table of variables:

Vicas=data.frame(X,Y,V50)
```

PROGRAMM OPERATION

1. VARIOGRAMM

The relation between the distance and the variable is described by a variogramme.

```
v.ltpb <- variogram(log(V50)~1, loc=~x+y, Vicas)
plot(v.ltpb, pl=T)
```

2. DEFINITION OF PARAMETERS BY AN ESTIMATED MODEL

To characterise the measured values by a tended curve a function is to estimate.

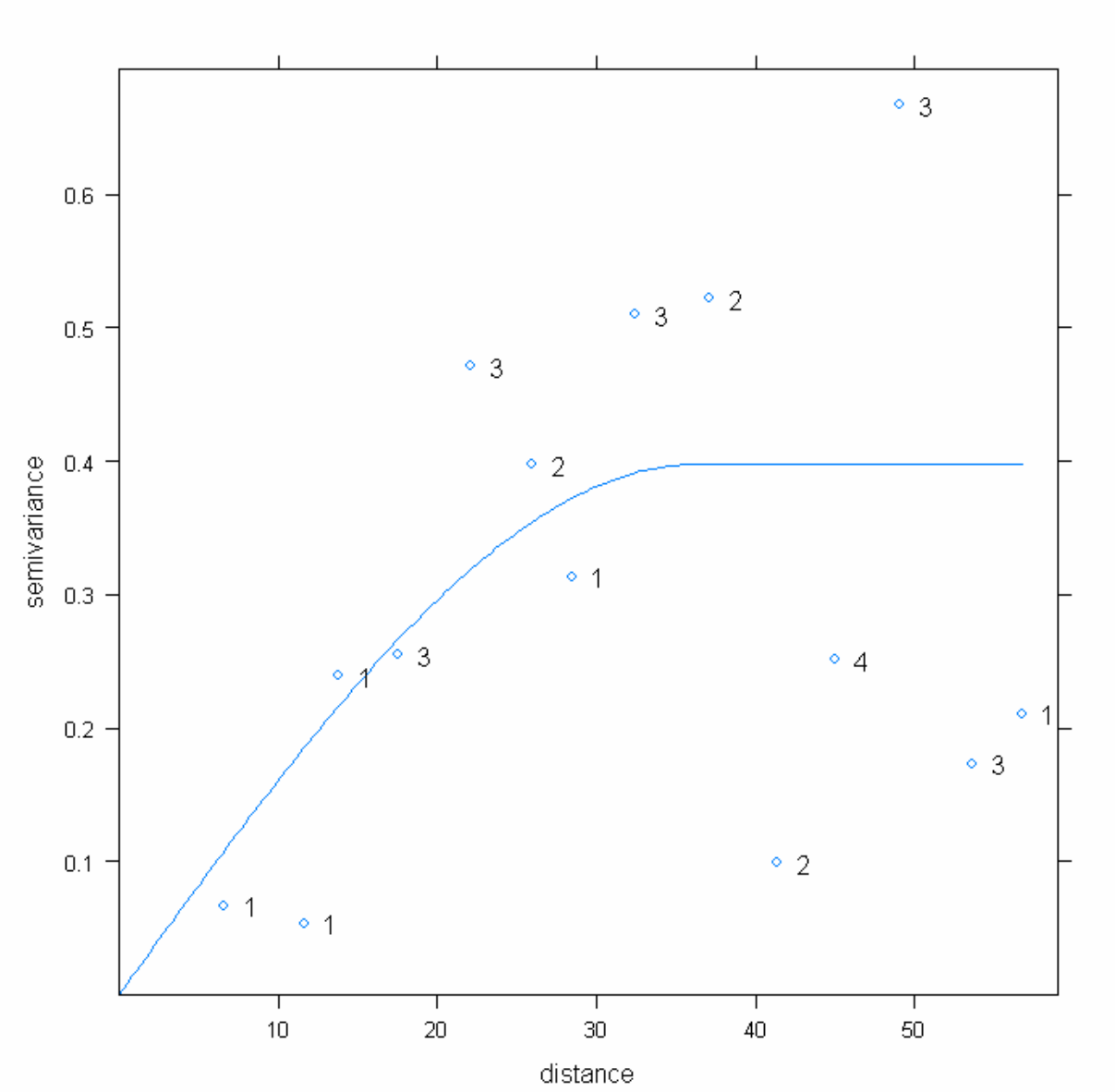
```
m.ltpb <- vgm(0.55,"Sph",37,0.00)
plot(v.ltpb, pl=T, model=m.ltpb)
```

3. MODEL CALIBRATION

The curve will be optimated by looking for the best parameters.

```
(m.ltpb.f <- fit.variogram(v.ltpb, m.ltpb))
plot(v.ltpb, pl=T, model=m.ltpb.f)
```

```
model     psill    range
1   Nug 0.0000000  0.00000
2   Sph 0.3974249 36.18365
```



4. INTERPOLATION BY ORDINARY KRIGING IN A GRILLE OF PREDICTION BY USING THE CALIBRATED MODELE OF THE PRECEDENT STEP

To predict the settling velocities V50 the model calibrated in the further step will be used.

Define an interpolation grille:

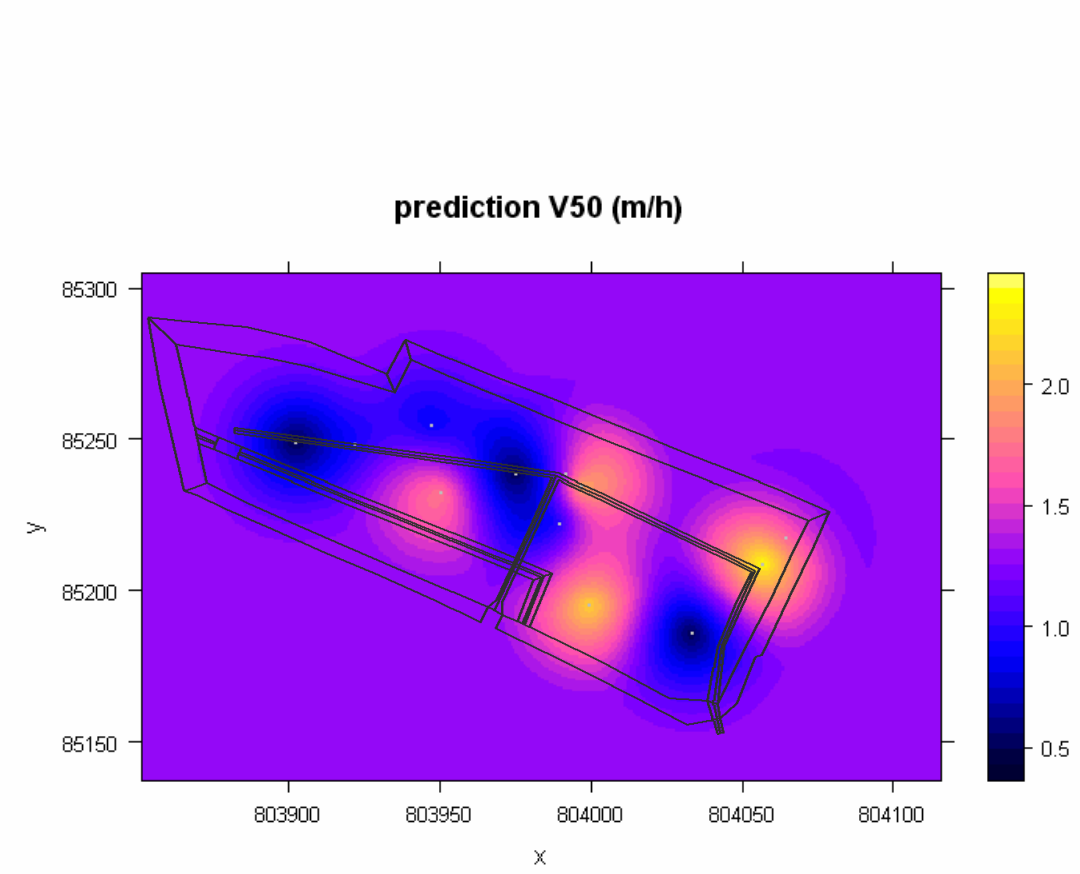
```
grd=makegrid(Xb,Yb,100000,100000)
```

For the ordinary kriging:

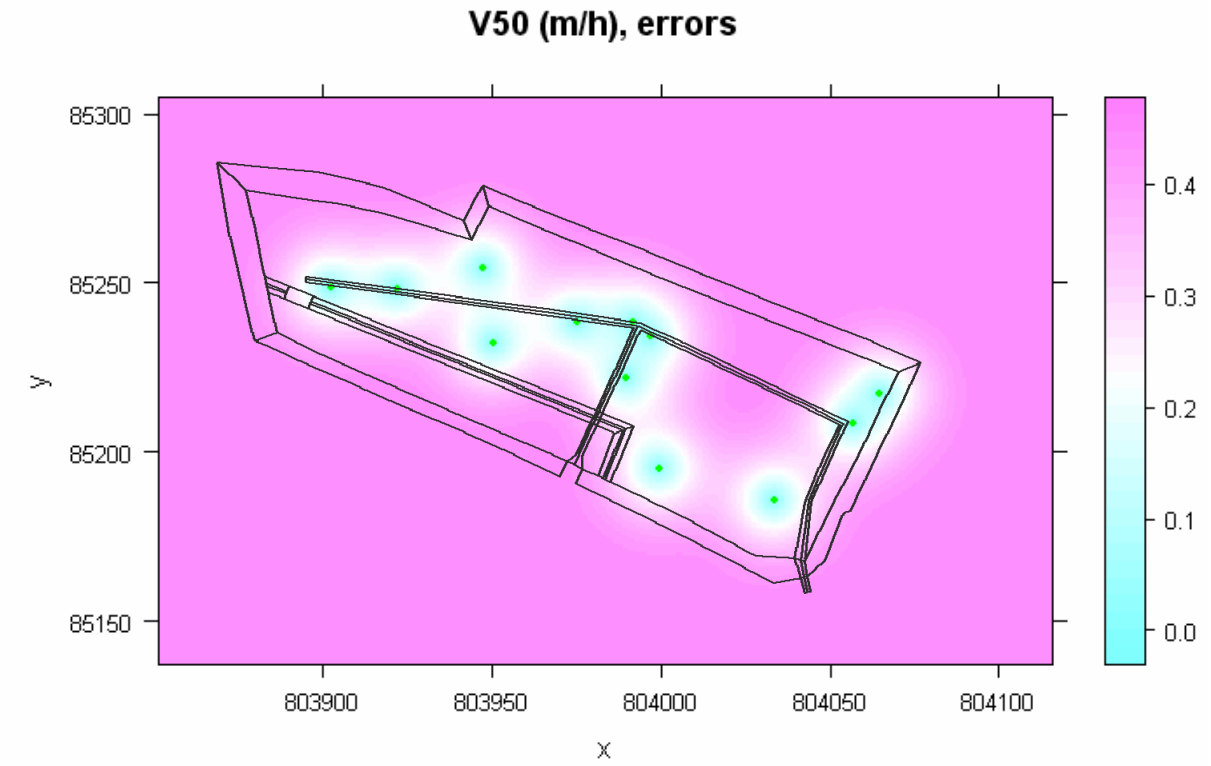
```
k.o <- krige(V50 ~1, ~x+y, Vicas, grd, m.ltpb.f)
```

5. MAP OF PREDICTION AND OF ERRORS

```
levelplot(var1.pred ~ x+y, k.o, aspect=mapasp(k.o),
col.regions=bpy.colors(64), cut=32,
main="prediction V50 (m/h)",
panel = function(x, ...) {
panel.levelplot(x, ...)
lpoints(Vicas$x,Vicas$y, col="grey", pch=20,
cex=1.6 * (log10(Vicas$V50) - 1.3)) })
```



```
levelplot(var1.var ~ x+y, k.o, aspect=mapasp(k.o),
col.regions=cm.colors(64), cut=32,
main="V50 (m/h), errors",
panel = function(x, ...) {
panel.levelplot(x, ...);
lpoints(Vicas$x,Vicas$y, col="green", pch=20, cex=.6)
})
```



6. VALIDATION

To confirm the results it is to choose a grille and to leave aside one or more well known point/s of the precedent prediction. A second operation of the programm delivers another map of prediction and the points led beside can be read off the new predicted table and compared with the precedent result.

To chosse a grille it is possible to take, for example:
k.o[1:1000,] ou k.o.[1:10,]

To evaluate the precision of the model it is also possible to make a **cross validation**. Each point is led aside and the prediction is made out of the remaining points beside the well known trap positions by using the variogramm. So it is possible to determine the errors of each point (which have been zero in the precedent prediction):

```
cv.o <- krige.cv(V50 ~ 1, ~x+y, Vicas, model=m.ltpb.f)
str(cv.o)
```

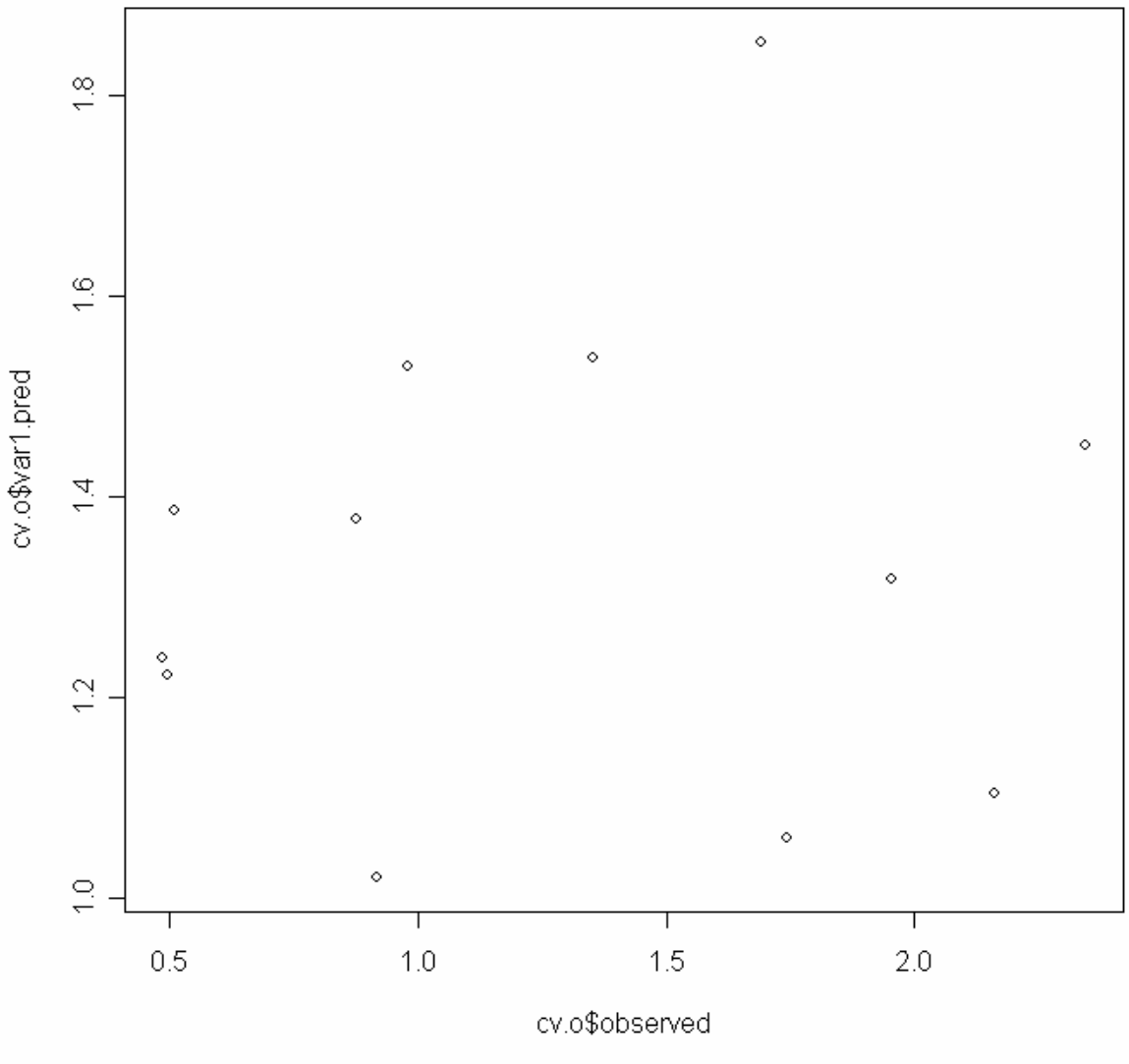
To see the created file:

```
cv.o
```

	x	y	var1.pred	var1.var	observed	residual	zscore	fold
1	803996.8	85234.00	1.318265	0.1693464	1.9526316	0.6343669	1.5415321	1
2	803989.9	85222.00	1.530831	0.3165432	0.9783333	-0.5524981	-0.9820063	2
3	803991.8	85238.29	1.538908	0.1674906	1.3545455	-0.1843624	-0.4504817	3
4	803975.2	85238.33	1.222087	0.3454655	0.4942105	-0.7278769	-1.2383847	4
5	803950.3	85232.18	1.060035	0.4053575	1.7421053	0.6820702	1.0712972	5
6	803947.5	85254.37	1.377220	0.4069352	0.8757895	-0.5014304	-0.7860462	6
7	803999.5	85195.21	1.104369	0.4463235	2.1600000	1.0556312	1.5801099	7
8	803922.0	85248.28	1.020170	0.3857416	0.9178947	-0.1022756	-0.1646735	8
9	803902.4	85248.51	1.239335	0.3988971	0.4847059	-0.7546294	-1.1948221	9
10	804064.9	85217.08	1.853972	0.2951733	1.6900000	-0.1639717	-0.3018077	10
11	804056.9	85208.64	1.450833	0.2941728	2.3454545	0.8946220	1.6494469	11
12	804033.5	85185.70	1.386455	0.4518297	0.5111765	-0.8752782	-1.3021431	12

The predicted observed relation can be plot by:

```
plot(cv.o$observed,cv.o$var1.pred)
```



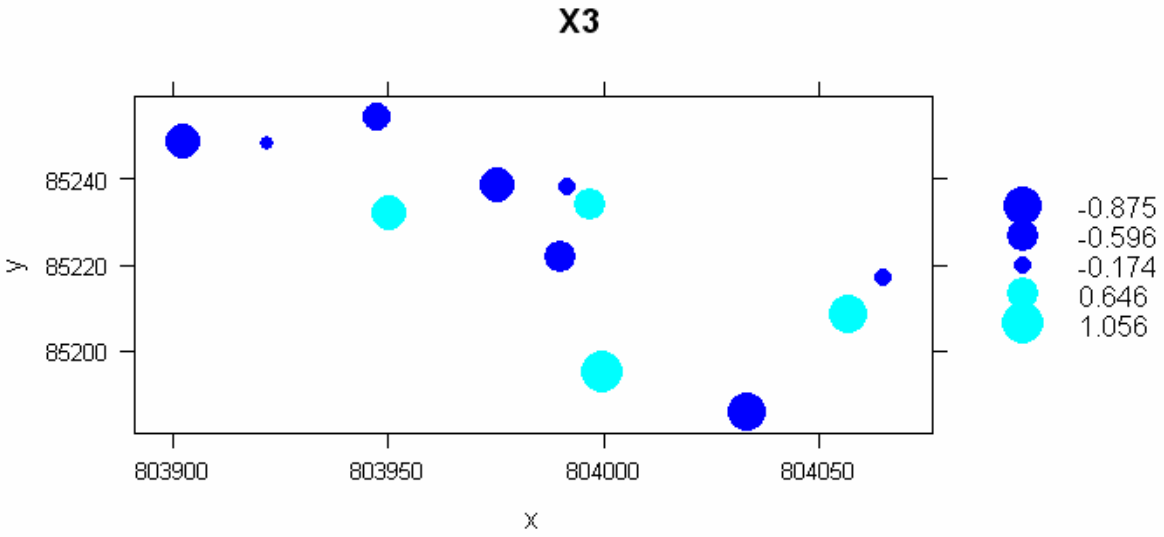
The coefficient of correlation is calculated by:

```
library(boot)
forcorr=data.frame(cv.o$observed,cv.o$var1.pred)
corr(forcorr);corr(forcorr)^2
```

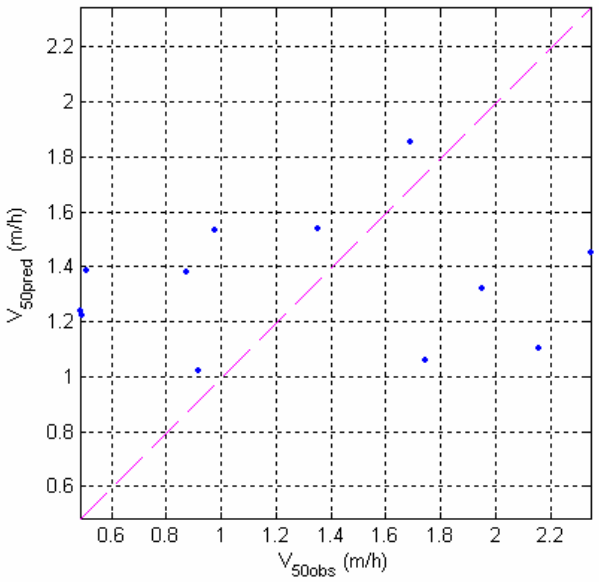
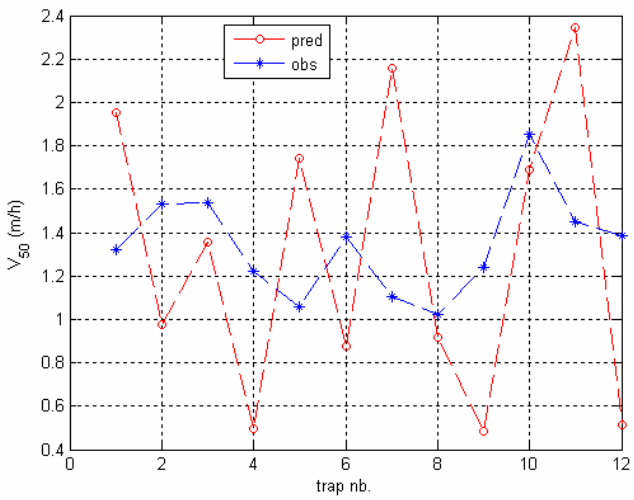
```
[1] 0.09833503
[1] 0.009669778
```

To draw the table of errors:

```
bubble(data.frame(cbind(cv.o$x, cv.o$y, cv.o$residual)), col=c(4,5))
```



The following figures show the relation between the predicted and the observed values of the settling velocity V50. In this case it is apparent that there is no big correlation between these values. The Root Mean Square Error of Prediction (RMSEP) is quite high regarding the predicted values (FIG.1). Figure 2 shows the alternate curves of predicted and observed values.

ORDINARY KRIGING FIG.1	ORDINARY KRIGING FIG.2
	
r=0.098336,r²=0.0096699, RMSEP=0.66306	Predicted and Observed Values

Kriging Interpolation by using the Gstat programm for the second measurement serie (Campaign2)

```
Instruction tables:

library(gstat)
library(lattice)

Coordinates of each trap:

X=read.table("X.txt",h=TRUE)
Y=read.table("Y.txt",h=TRUE)
V50=read.table("V50.txt",h=TRUE)

Table of variables:

Vicas=data.frame(X,Y,V50)
```

PROGRAMM OPERATION

1. VARIOGRAMM

The relation between the distance and the variable is described by a variogramme.

```
v.ltpb <- variogram(log(V50)~1, loc=~x+y, Vicas)
plot(v.ltpb, pl=T)
```

2. DEFINITION OF PARAMETERS BY AN ESTIMATED MODEL

To characterise the measured values by a tended curve a function is to estimate.

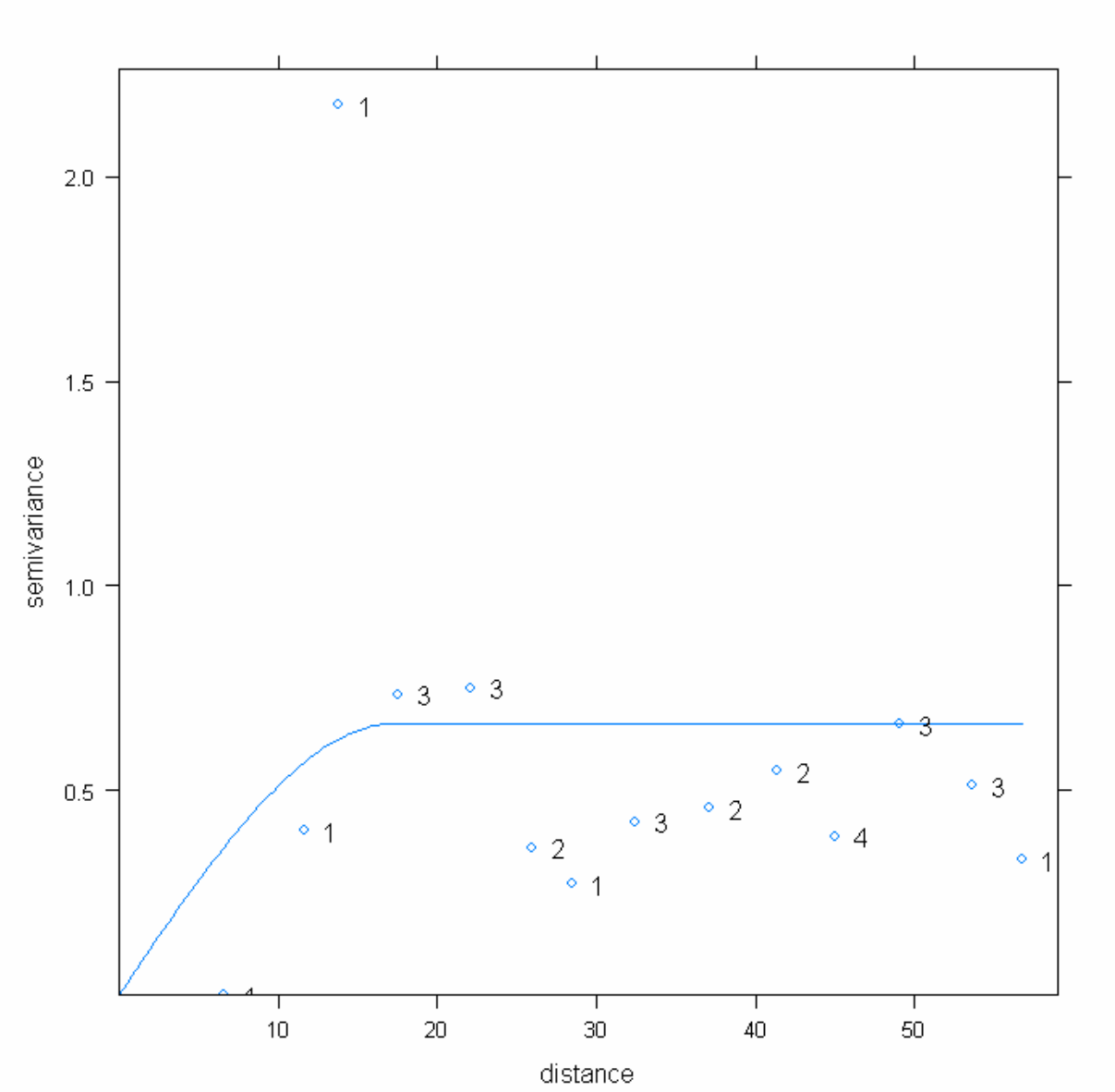
```
m.ltpb <- vgm(0.55,"Sph",37,0.00)
plot(v.ltpb, pl=T, model=m.ltpb)
```

3. MODEL CALIBRATION

The curve will be optimated by looking for the best parameters.

```
 (m.ltpb.f <- fit.variogram(v.ltpb, m.ltpb))
plot(v.ltpb, pl=T, model=m.ltpb.f)
```

```
model    psill    range
1   Nug 0.000000  0.00000
2   Sph 0.663587 17.30921
```



4. INTERPOLATION BY ORDINARY KRIGING IN A GRILLE OF PREDICTION BY USING THE CALIBRATED MODELE OF THE PRECEDENT STEP

To predict the settling velocities V50 the model calibrated in the further step will be used.

Define an interpolation grille:

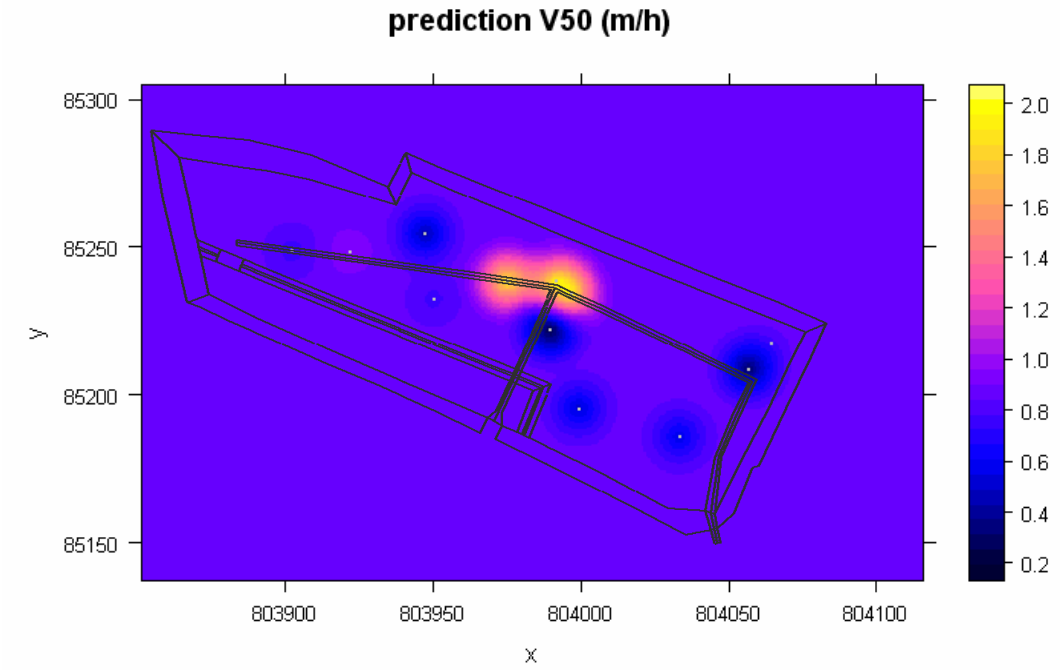
```
grd=makegrid(Xb,Yb,100000,100000)
```

For the ordinary kriging:

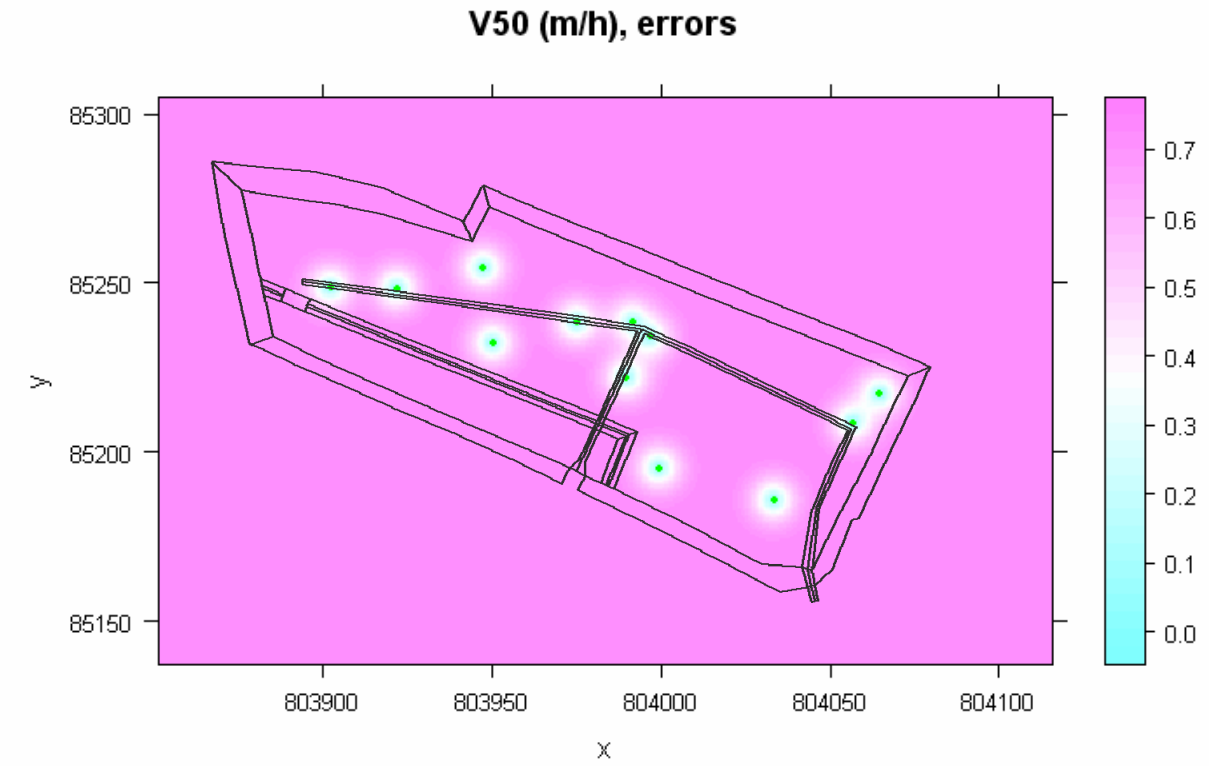
```
k.o <- krige(V50 ~1, ~x+y, Vicas, grd, m.ltpb.f)
```

5. MAP OF PREDICTION AND OF ERRORS

```
levelplot(var1.pred ~ x+y, k.o, aspect=mapasp(k.o),
col.regions=bpy.colors(64), cut=32,
main="prediction V50 (m/h)",
panel = function(x, ...) {
panel.levelplot(x, ...)
lpoints(Vicas$x,Vicas$y, col="grey", pch=20,
cex=1.6 * (log10(Vicas$V50) - 1.3)) })
```



```
levelplot(var1.var ~ x+y, k.o, aspect=mapasp(k.o),
col.regions=cm.colors(64), cut=32,
main="V50 (m/h), errors",
panel = function(x, ...) {
panel.levelplot(x, ...);
lpoints(Vicas$x,Vicas$y, col="green", pch=20, cex=.6)
})
```



6. VALIDATION

To confirm the results it is to choose a grille and to leave aside one or more well known point/s of the precedent prediction. A second operation of the programm delivers another map of prediction and the points led beside can be read off the new predicted table and compared with the precedent result.

To chosse a grille it is possible to take, for example:
k.o[1:1000,] ou k.o.[1:10,]

To evaluate the precision of the model it is also possible to make a **cross validation**. Each point is led aside and the prediction is made out of the remaining points beside the well known trap positions by using the variogramm. So it is possible to determine the errors of each point (which have been zero in the precedent prediction):

```
cv.o <- krige.cv(V50 ~ 1, ~x+y, Vicas, model=m.ltpb.f)
str(cv.o)
```

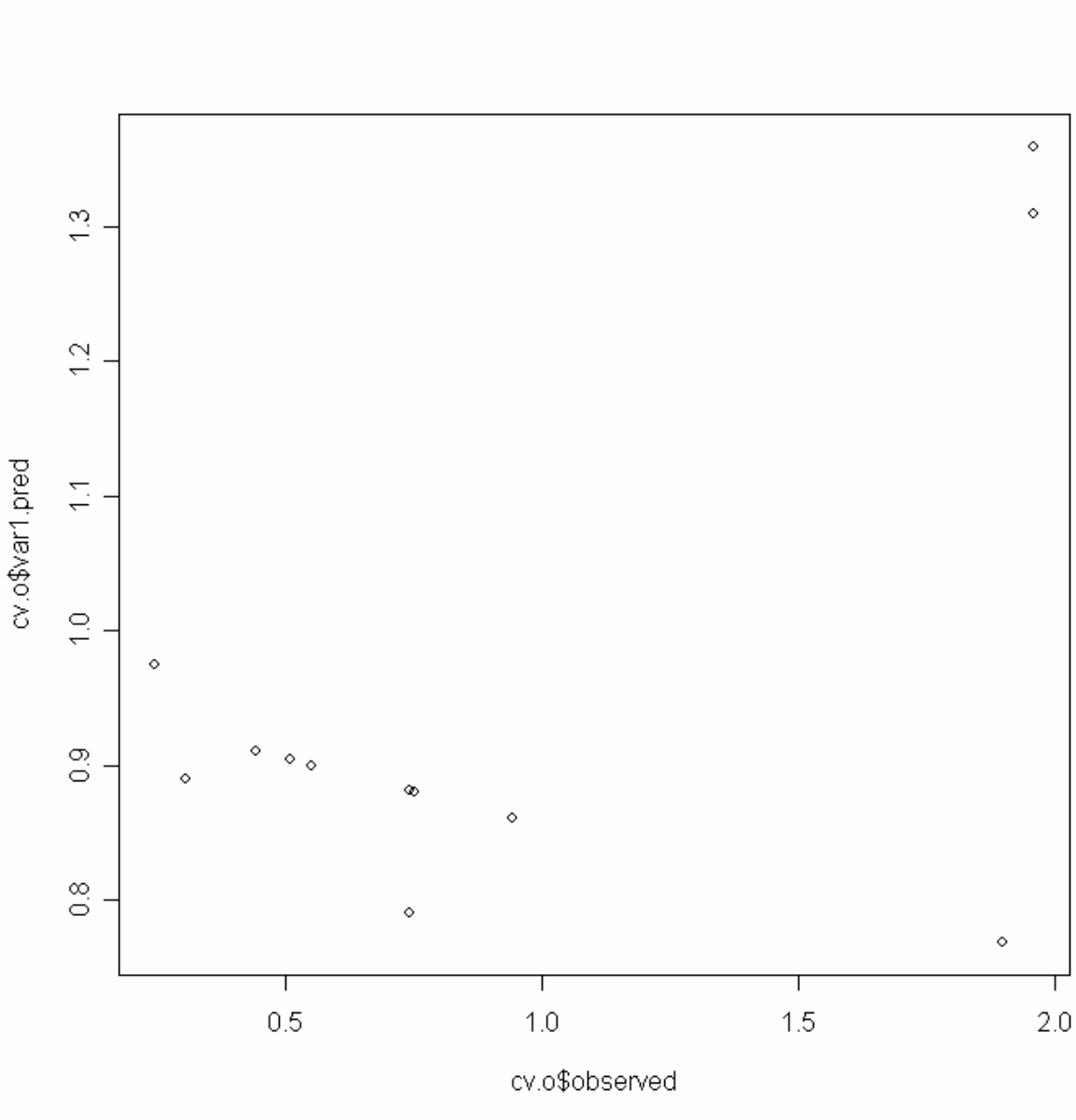
To see the created file:

```
cv.o
```

	x	y	var1.pred	var1.var	observed	residual	zscore	fold
1	803996.8	85234.00	1.3101778	0.5399824	1.9600000	0.64982223	0.88431048	1
2	803989.9	85222.00	0.9750234	0.7213229	0.2433333	-0.73169009	-0.86151397	2
3	803991.8	85238.29	1.3597399	0.5464190	1.9600000	0.60026011	0.81203842	3
4	803975.2	85238.33	0.7684739	0.7293726	1.9000000	1.13152606	1.32492054	4
5	803950.3	85232.18	0.8803088	0.7296666	0.7500000	-0.13030884	-0.15254980	5
6	803947.5	85254.37	0.9111260	0.7296666	0.4405263	-0.47059970	-0.55092111	6
7	803999.5	85195.21	0.9043836	0.7296666	0.5082353	-0.39614831	-0.46376244	7
8	803922.0	85248.28	0.8611675	0.7296666	0.9422222	0.08105473	0.09488906	8
9	803902.4	85248.51	0.8810950	0.7296666	0.7421053	-0.13898973	-0.16271234	9
10	804064.9	85217.08	0.7904043	0.6970968	0.7421053	-0.04829909	-0.05784854	10
11	804056.9	85208.64	0.8901182	0.6970968	0.3029412	-0.58717707	-0.70327074	11
12	804033.5	85185.70	0.9003243	0.7296666	0.5490000	-0.35132428	-0.41128790	12

The predicted observed relation can be plot by:

```
plot(cv.o$observed,cv.o$var1.pred)
```



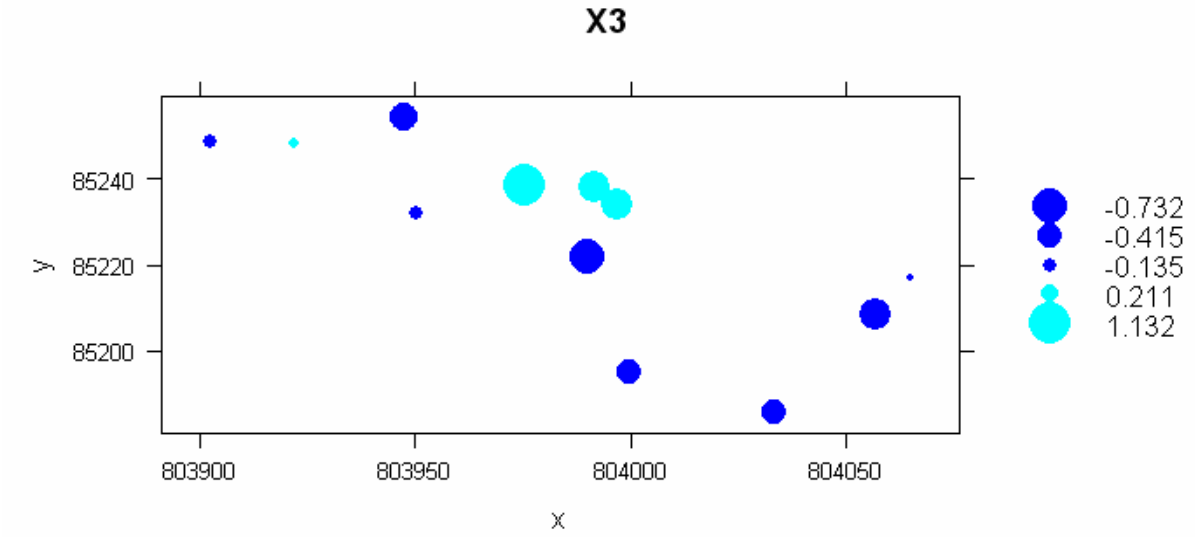
The coefficient of correlation is calculated by:

```
library(boot)
forcorr=data.frame(cv.o$observed,cv.o$var1.pred)
corr(forcorr);corr(forcorr)^2
```

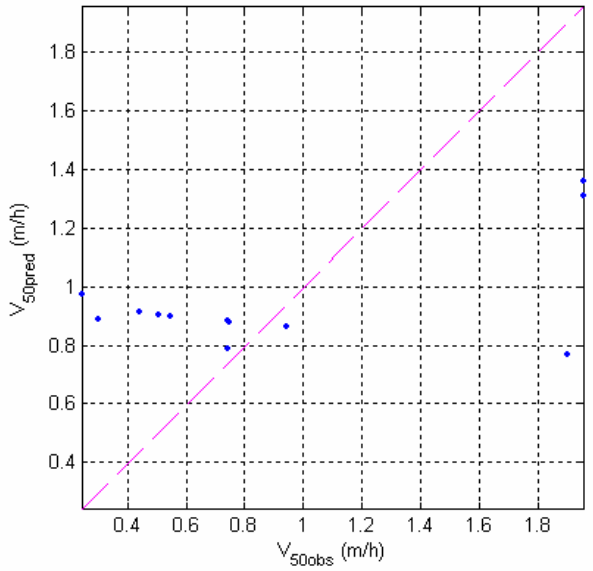
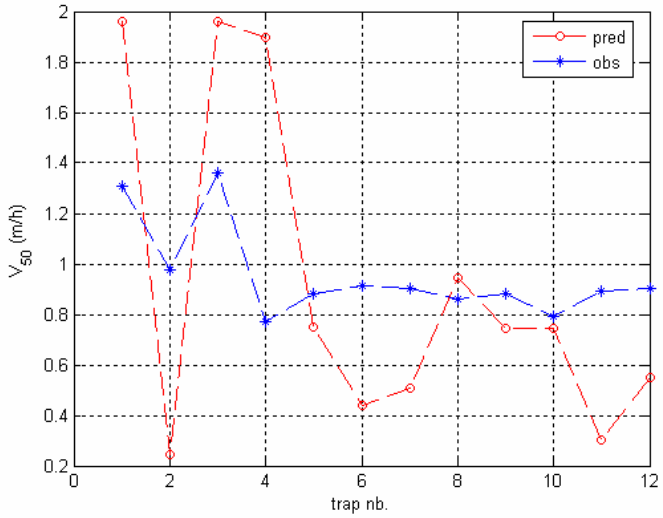
```
[1] 0.5644118
[1] 0.3185607
```

To draw the table of errors:

```
bubble(data.frame(cbind(cv.o$x, cv.o$y, cv.o$residual)), col=c(4,5))
```



Like it was shown in the anterior table, the relation between the predicted and the observed values of the settling velocity V50 is shown in the following figures. Even here it is obvious that there is no big correlation between these values. The Root Mean Square Error of Prediction (RMSEP) is a little lower but still quite high regarding the predicted values (FIG.1). Figure 2 shows that the curves of predicted and observed values vary also strong.

ORDINARY KRIGING FIG.1	ORDINARY KRIGING FIG.2
	
R=0.56441, r²=0.31856, RMSEP=0.5393	Predicted and Observed Values

Kriging Interpolation and CO-Kriging by using the Gstat programm for the third measurement campaign

```
Instruction tables:


library(gstat)
library(lattice)

Coordinates of each trap:

V50=read.table("V50.txt",h=TRUE)

Xb
Yb

Table of variables:

Vicas=data.frame(X,Y,V50)
```

PROGRAMM OPERATION

1. VARIOGRAMM

The relation between the distance and the variable is described by a variogramme.

```
v.ltpb <- variogram(log(V50)~1, loc=~x+y, Vicas)
plot(v.ltpb, pl=T)
```

2. DEFINITION OF PARAMETERS BY AN ESTIMATED MODEL

To characterise the measured values by a tended curve a function is to estimate.

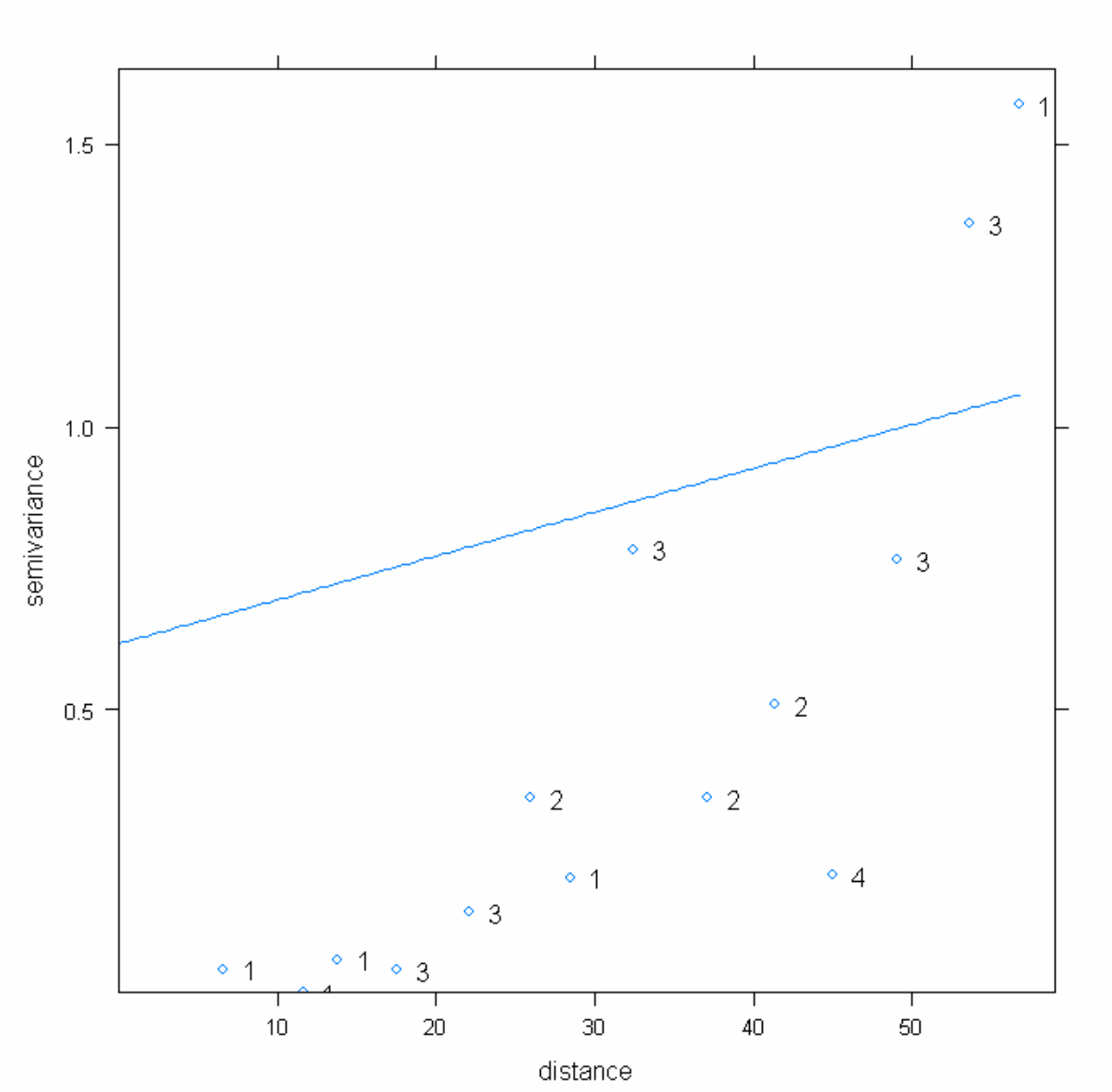
```
m.ltpb <- vgm(0.20,"Sph",20,0.00)
plot(v.ltpb, pl=T, model=m.ltpb)
```

3. MODEL CALIBRATION

The curve will be optimated by looking for the best parameters.

```
(m.ltpb.f <- fit.variogram(v.ltpb, m.ltpb))
plot(v.ltpb, pl=T, model=m.ltpb.f)
```

```
model         psill    range
1   Nug   0.03037529   0.0000
2   Gau 104.37880360 512.4192
```



4. INTERPOLATION BY ORDINARY KRIGING IN A GRILLE OF PREDICTION BY USING THE CALIBRATED MODELE OF THE PRECEDENT STEP

To predict the settling velocities V50 the model calibrated in the further step will be used.

Define an interpolation grille:

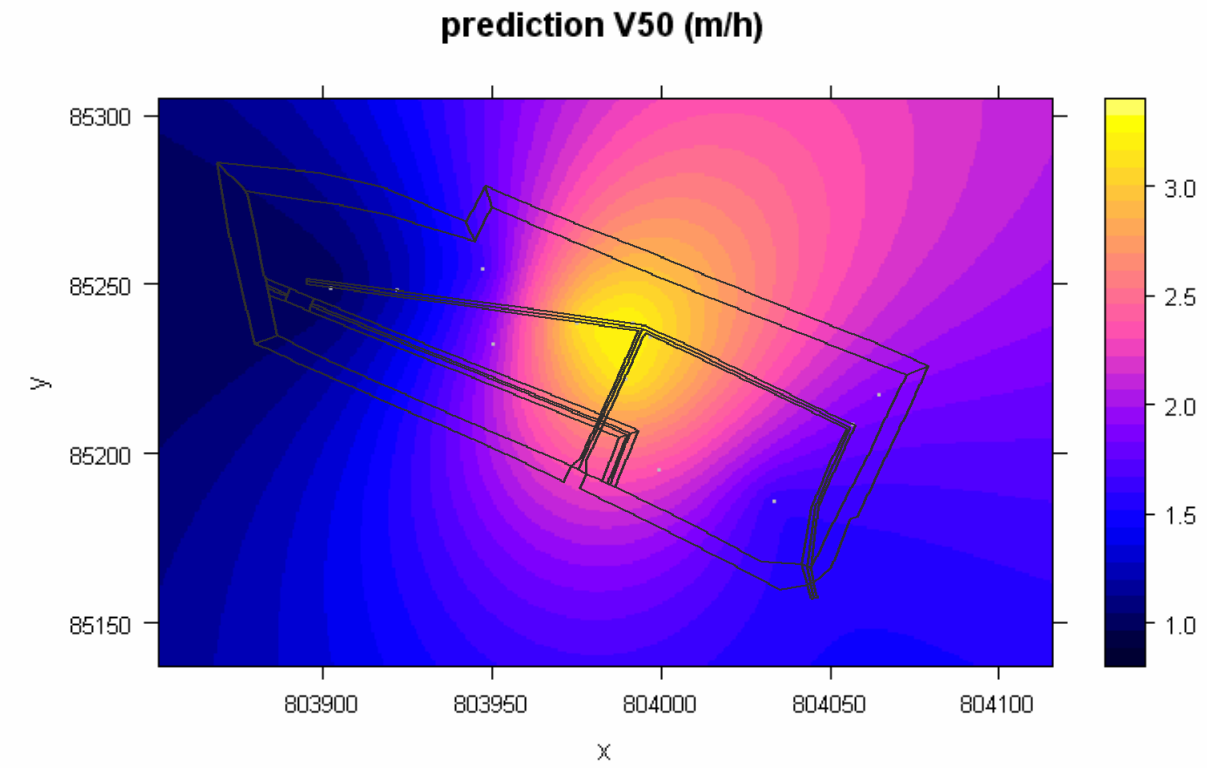
```
grd=makegrid(Xb,Yb,100000,100000)
```

For the ordinary kriging:

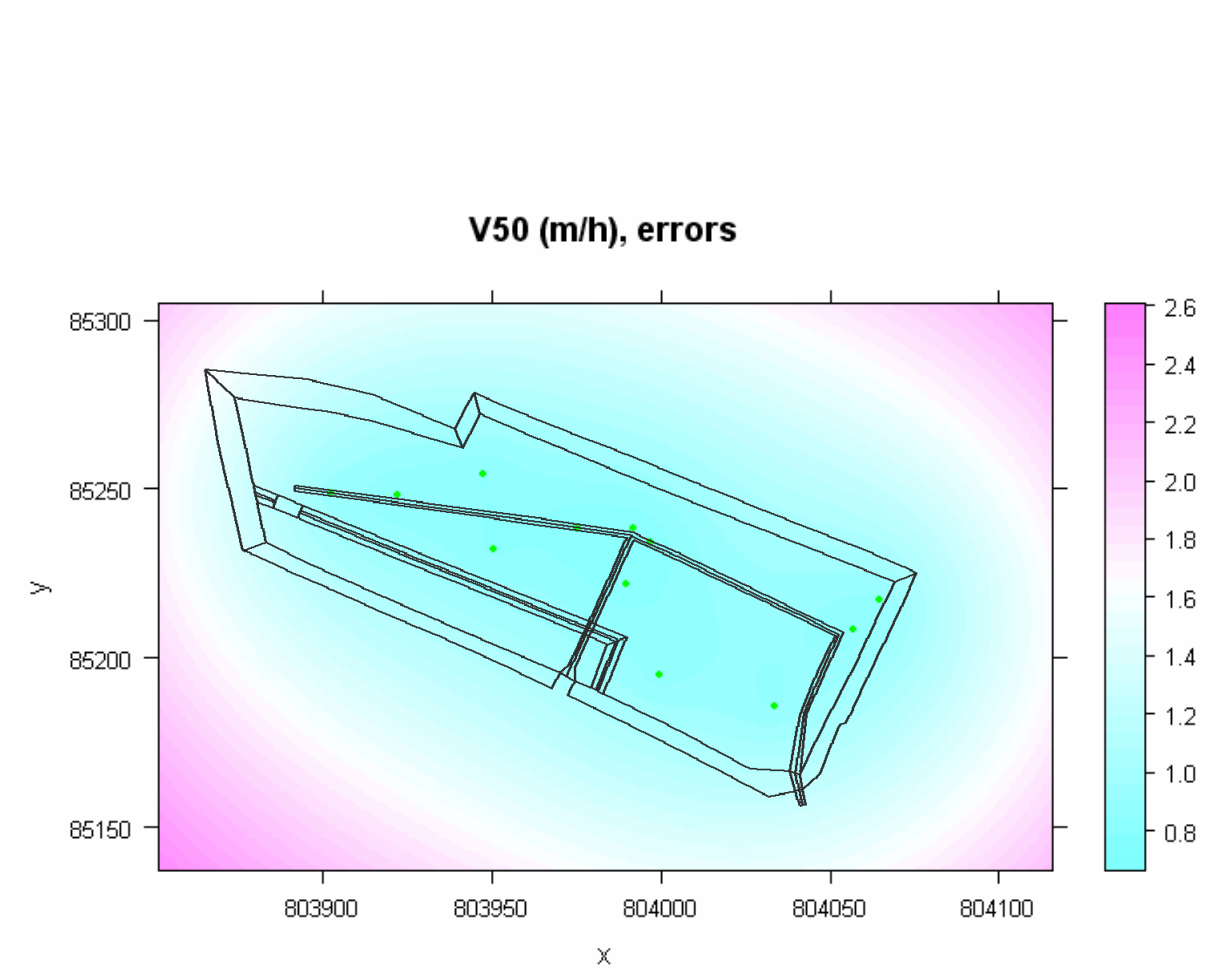
```
k.o <- krige(V50 ~1, ~x+y, Vicas, grd, m.ltpb.f)
```

5. MAP OF PREDICTION AND OF ERRORS

```
levelplot(var1.pred ~ x+y, k.o, aspect=mapasp(k.o),
col.regions=bpy.colors(64), cut=32,
main="prediction V50 (m/h)",
panel = function(x, ...) {
panel.levelplot(x, ...)
lpoints(Vicas$x,Vicas$y, col="grey", pch=20,
cex=1.6 * (log10(Vicas$V50) - 1.3)) })
```




```
levelplot(var1.var ~ x+y, k.o, aspect=mapasp(k.o),
col.regions=cm.colors(64), cut=32,
main="V50 (m/h), errors",
panel = function(x, ...) {
panel.levelplot(x, ...);
lpoints(Vicas$x,Vicas$y, col="green", pch=20, cex=.6)
})
```



6. VALIDATION

To confirm the results it is to choose a grille and to leave aside one or more well known point/s of the precedent prediction. A second operation of the programm delivers another map of prediction and the points led beside can be read off the new predicted table and compared with the precedent result.

To chosse a grille it is possible to take, for example:

```
k.o[1:1000,]    ou    k.o.[1:10,]
```

To evaluate the precision of the model it is also possible to make a **cross validation**. Each point is led aside and the prediction is made out of the remaining points beside the well known trap positions by using the variogramm. So it is possible to determine the errors of each point (which have been zero in the precedent prediction):

```
cv.o <- krige.cv(V50 ~ 1, ~x+y, Vicas, model=m.ltpb.f)
str(cv.o)
```

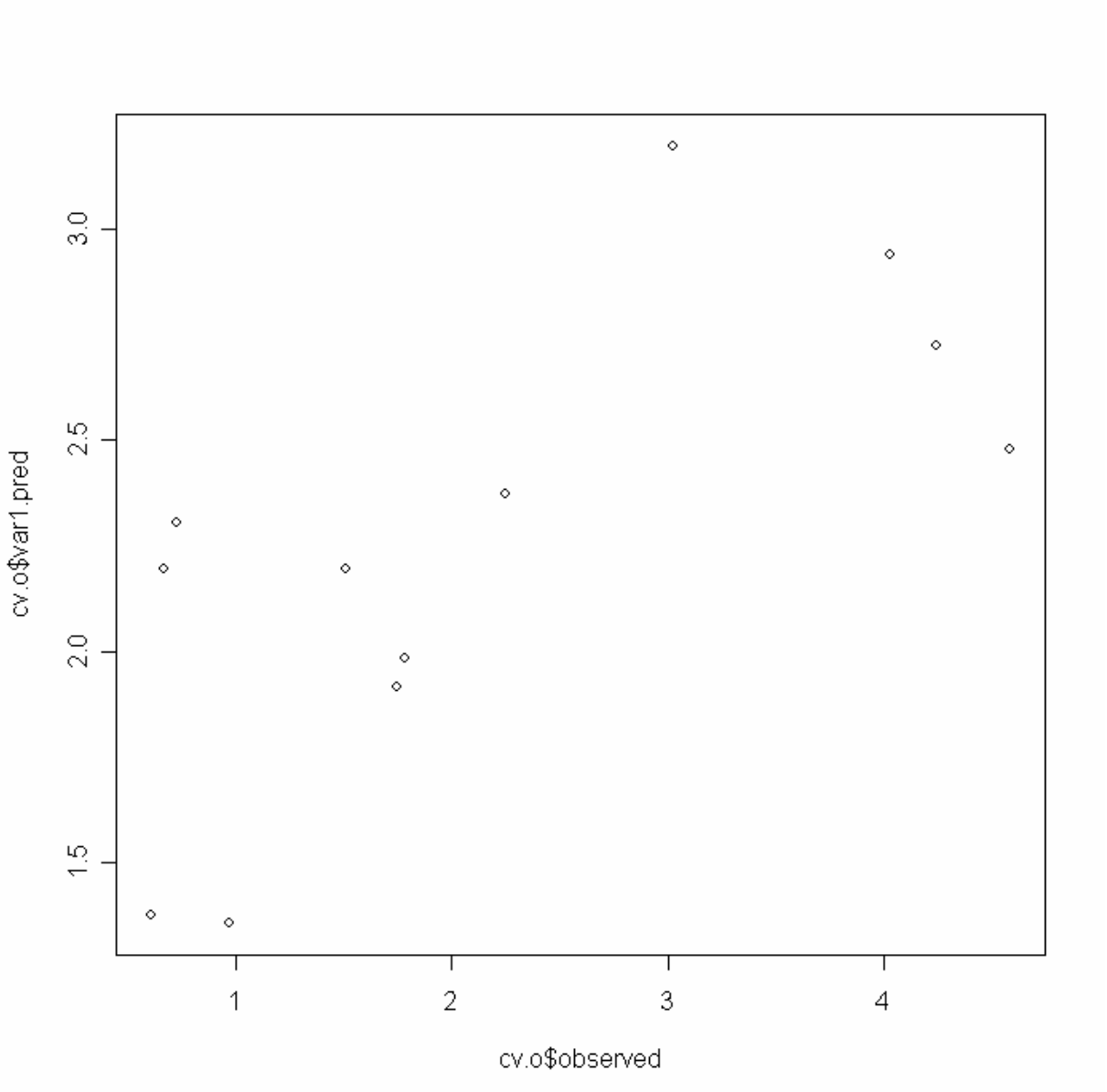
To see the created file:

```
cv.o
```

	x	y	var1.pred	var1.var	observed	residual	zscore	fold
1	803996.8	85234.00	3.196318	0.8531323	3.0263158	-0.1700023	-0.1840545	1
2	803989.9	85222.00	2.724033	0.8630811	4.2500000	1.5259670	1.6425528	2
3	803991.8	85238.29	2.937301	0.8519174	4.0294118	1.0921109	1.1832268	3
4	803975.2	85238.33	2.479327	0.8730067	4.5894737	2.1101468	2.2584157	4
5	803950.3	85232.18	2.195330	0.9344453	1.5095238	-0.6858065	-0.7094547	5
6	803947.5	85254.37	2.195170	0.9650989	0.6661905	-1.5289793	-1.5563802	6
7	803999.5	85195.21	2.372313	1.0280879	2.2473684	-0.1249447	-0.1232261	7
8	803922.0	85248.28	1.356550	0.9844243	0.9650000	-0.3915497	-0.3946351	8
9	803902.4	85248.51	1.377261	1.2182413	0.6031579	-0.7741028	-0.7013454	9
10	804064.9	85217.08	1.984816	1.1039378	1.7850000	-0.1998158	-0.1901768	10
11	804056.9	85208.64	1.915056	1.0007677	1.7421053	-0.1729508	-0.1728844	11
12	804033.5	85185.70	2.304354	1.0978117	0.7222857	-1.5820685	-1.5099458	12

The predicted observed relation can be plot by:

```
plot(cv.o$observed,cv.o$var1.pred)
```



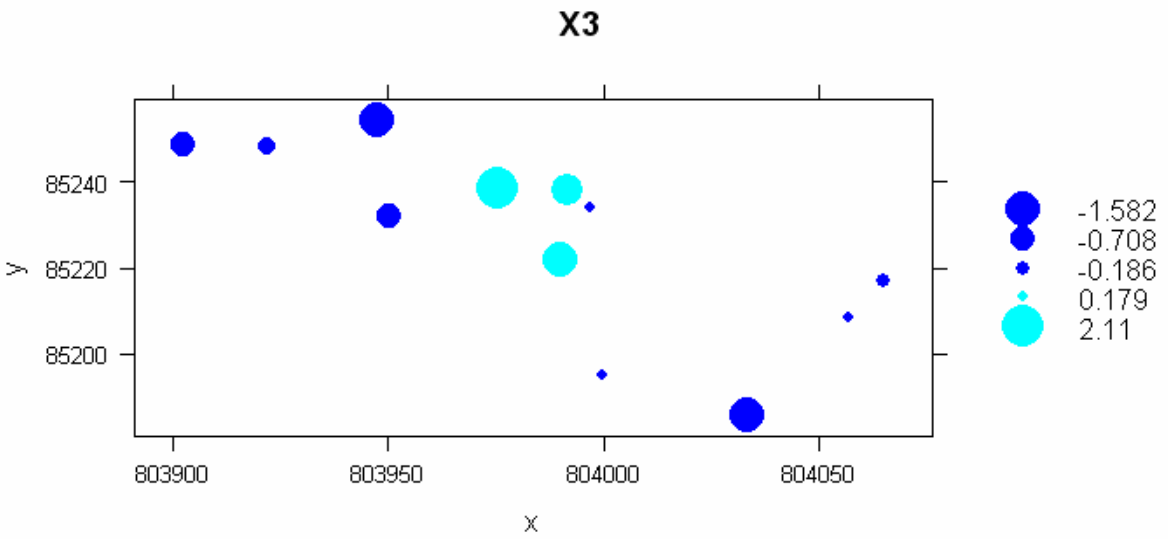
The coefficient of correlation is calculated by:

```
library(boot)
forcorr=data.frame(cv.o$observed,cv.o$var1.pred)
corr(forcorr);corr(forcorr)^2
```

```
[1] 0.7125733
[1] 0.5077607
```

To draw the table of errors:

```
bubble(data.frame(cbind(cv.o$x, cv.o$y, cv.o$residual)), col=c(4,5))
```



7. CO – KRIGING

Table of covariables:

Positions	HT (mg/kgMS)	Cd (mg/kgMS)	Cu (mg/kgMS)	Pb (mg/kgMS)	Zn (mg/kgMS)
Trap1	26 868	14,1	260,4	371,0	1 160,8
Trap2	31 642	11,1	290,8	381,0	1 202,8
Trap3	30 578	10,6	277,2	363,0	1 165,7
Trap4	30 532	10,5	278,3	345,0	1 192,0
Trap5	27 287	7,6	234,1	270,0	1 014,0
Trap6	21 885	6,4	218,5	239,0	881,9
Trap7	24 075	10,1	221,3	369,0	990,1
Trap8	27 326	6,9	239,3	247,0	1 056,2
Trap9	26 585	6,7	240,1	246,0	983,2
Trap10	21 931	5,1	170,1	208,0	743,8
Trap11	24 088	6,8	194,5	235,0	836,4
Trap12	24 135	4,0	123,5	173,0	537,7

To choose the most correlated co-variable the following aspects must be taken into account:

- it must be correlated with the variable objective
- it should appear stronger in the sample than other available co-variables
- it must have a space structure
- it must have a space covariance with the variable objective

To create the matrix of covariables:

```
covars=as.matrix(read.table("covars.txt",h=T))
covars
```

```
     Cd    Cu  Pb      Zn    HT
1  14.1 260.4 371 1160.8 26868
2  11.1 290.8 381 1202.8 31642
3  10.6 277.2 363 1165.7 30578
4  10.5 278.3 345 1192.0 30532
5   7.6 234.1 270 1014.0 27287
6   6.4 218.5 239  881.9 21885
7  10.1 221.3 369  990.1 24075
8   6.9 239.3 247 1056.2 27326
9   6.7 240.1 246  983.2 26585
10  5.1 170.1 208  743.8 21931
11  6.8 194.5 235  836.4 24088
12  4.0 123.5 173  537.7 24135
```

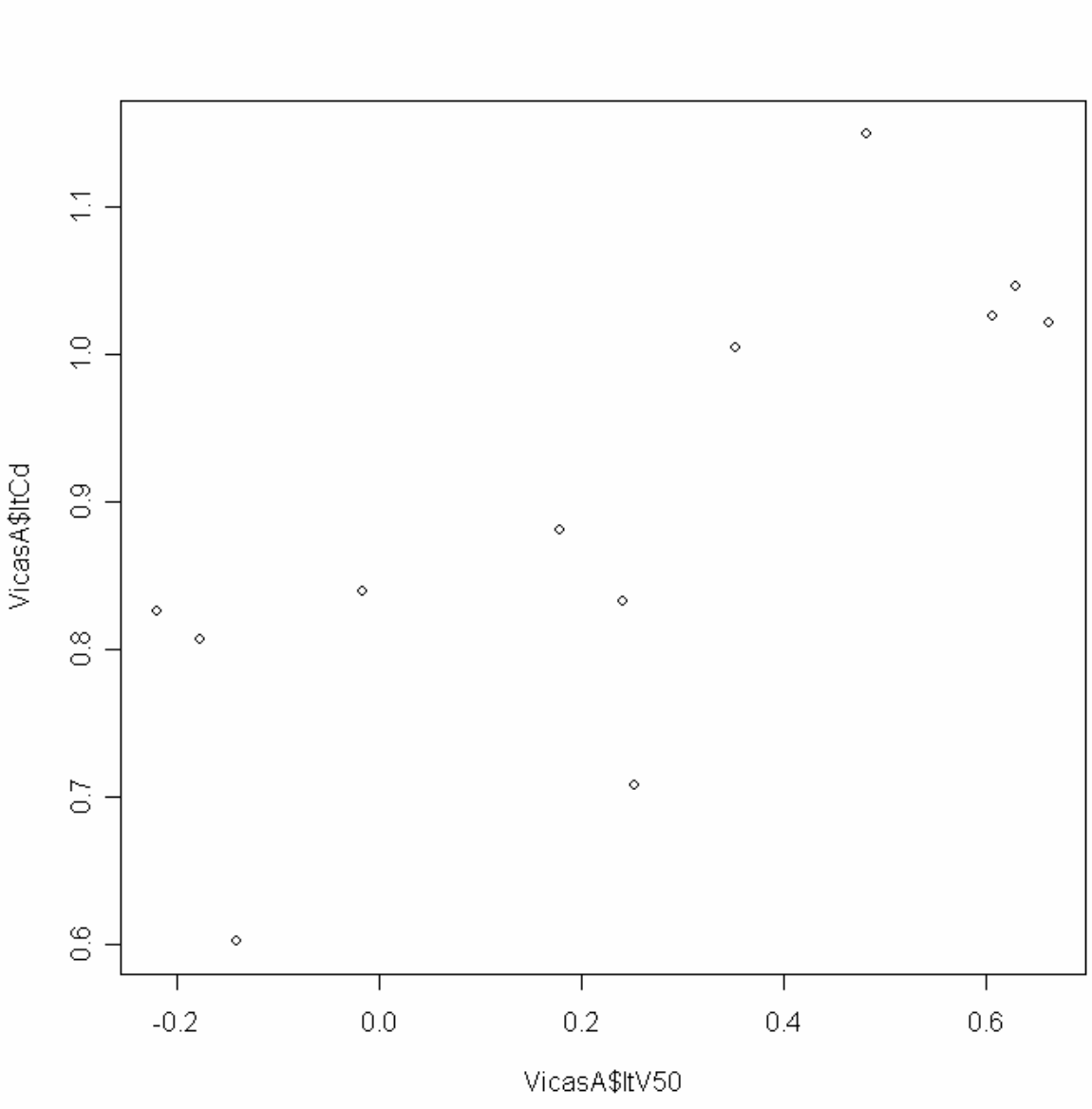
```
VicasA=data.frame(Vicas,covars)
VicasA=cbind(VicasA,ltV50=log10(VicasA$V50),ltCd=log10(VicasA$Cd),lt
Cu=log10(VicasA$Cu),ltPb=log10(VicasA$Pb),ltZn=log10(VicasA$Zn),ltHT
=log10(VicasA$HT))
str(VicasA)
```

```
`data.frame':   12 obs. of  14 variables:
 $ x    : num  803997 803990 803992 803975 803950 ...
 $ y    : num  85234 85222 85238 85238 85232 ...
```

```
 $ V50  : num  3.03 4.25 4.03 4.59 1.51 ...
 $ Cd   : num  14.1 11.1 10.6 10.5 7.6 6.4 10.1 6.9 6.7 5.1
 $ Cu   : num  260 291 277 278 234 ...
 $ Pb   : num  371 381 363 345 270 239 369 247 246 208 ...
 $ Zn   : num  1161 1203 1166 1192 1014 ...
 $ HT   : num  26868 31642 30578 30532 27287 ...
 $ ltV50: num  0.481 0.628 0.605 0.662 0.179 ...
 $ ltCd : num  1.15 1.05 1.03 1.02 0.88 ...
 $ ltCu : num  2.42 2.46 2.44 2.44 2.37 ...
 $ ltPb : num  2.57 2.58 2.56 2.54 2.43 ...
 $ ltZn : num  3.06 3.08 3.07 3.08 3.01 ...
 $ ltHT : num  4.43 4.50 4.49 4.48 4.44 ...
```

To examines the correlation between V50 and the other variables:

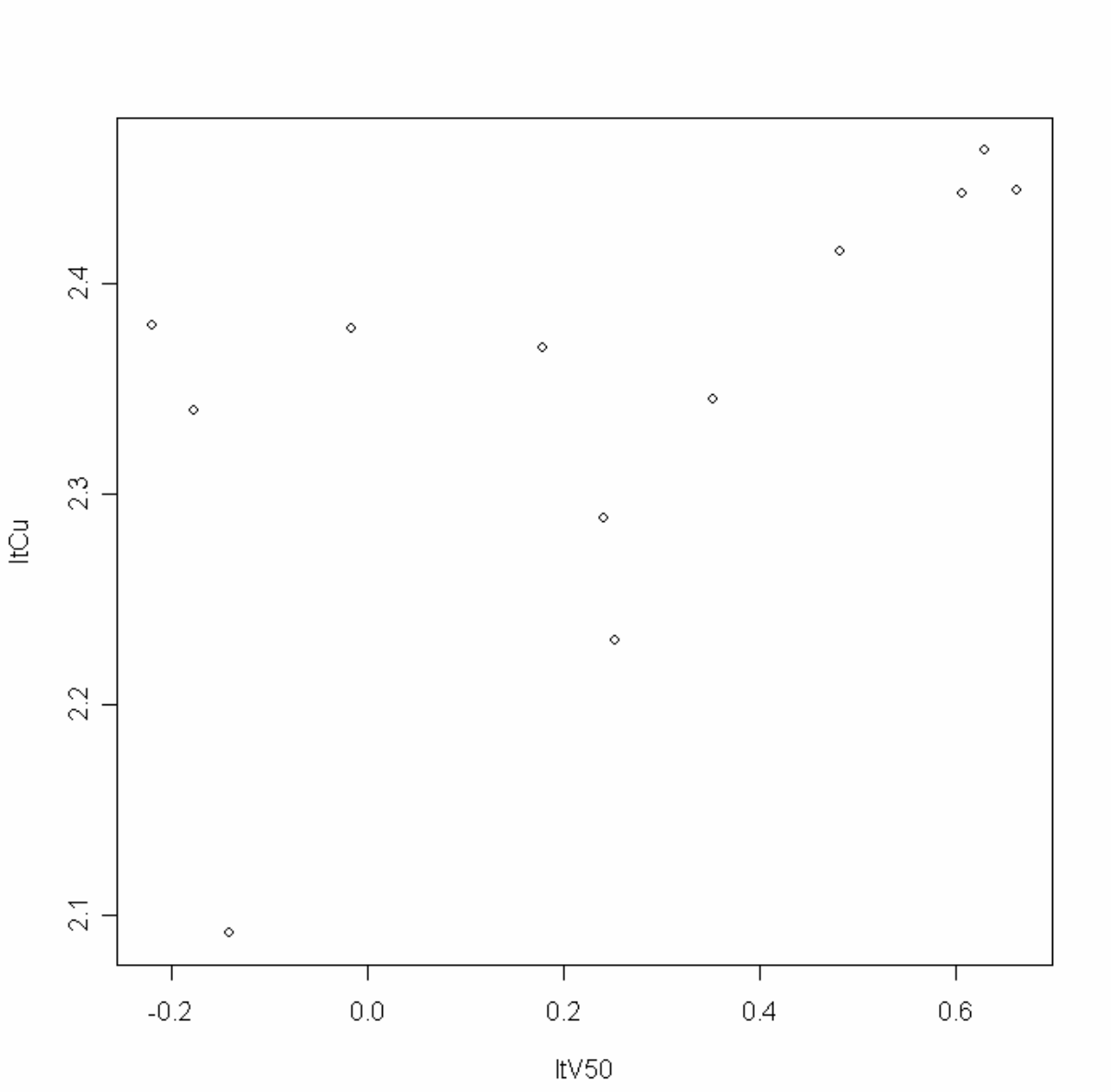
```
plot(VicasA$ltV50,VicasA$ltCd)
```




```
attach(VicasA)
cor(ltV50,ltCd)
```

```
[1] 0.7664802
```

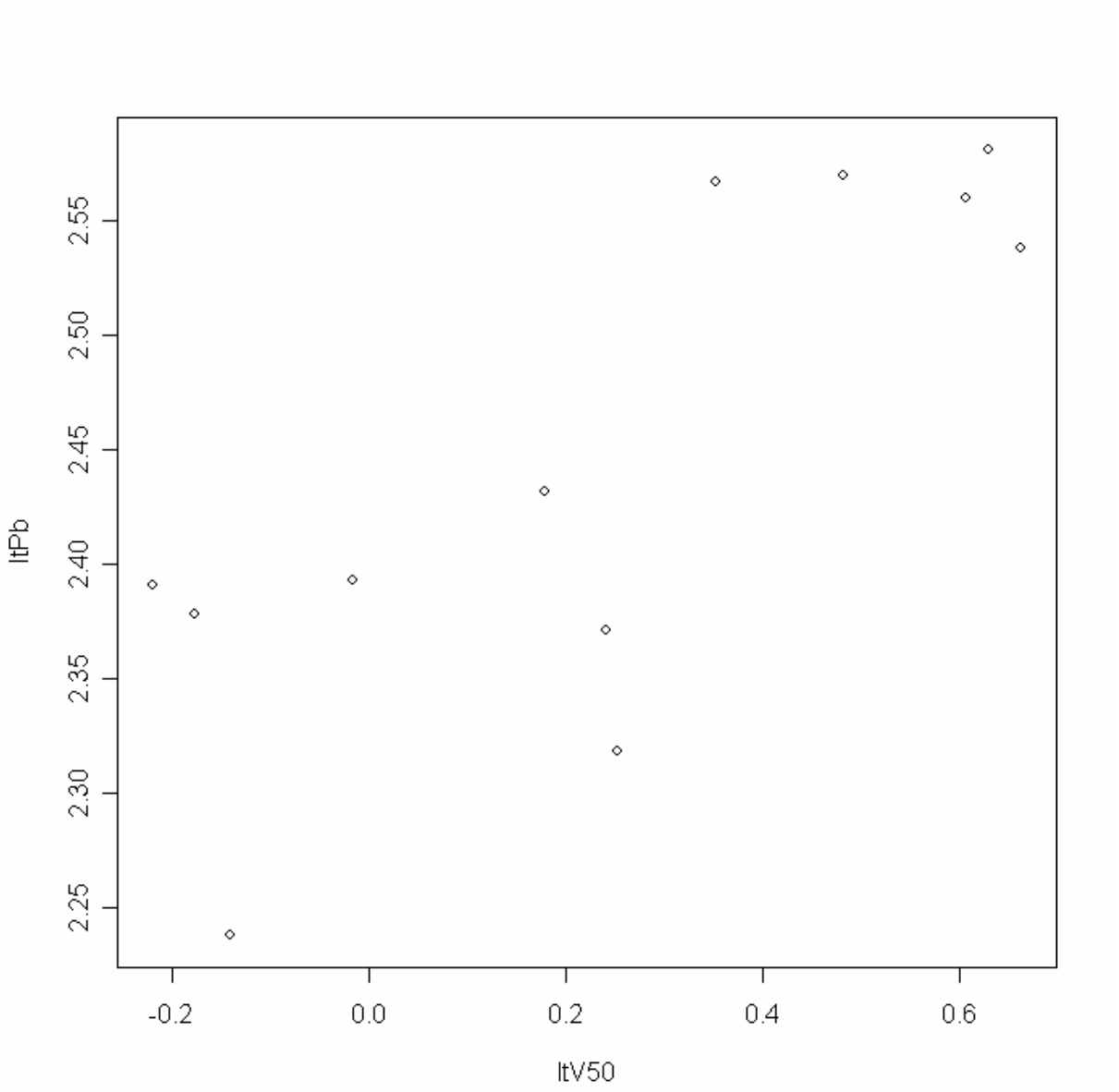
```
plot(ltV50,ltCu)
```




```
cor(ltV50,ltCu)
```

```
[1] 0.5711836
```

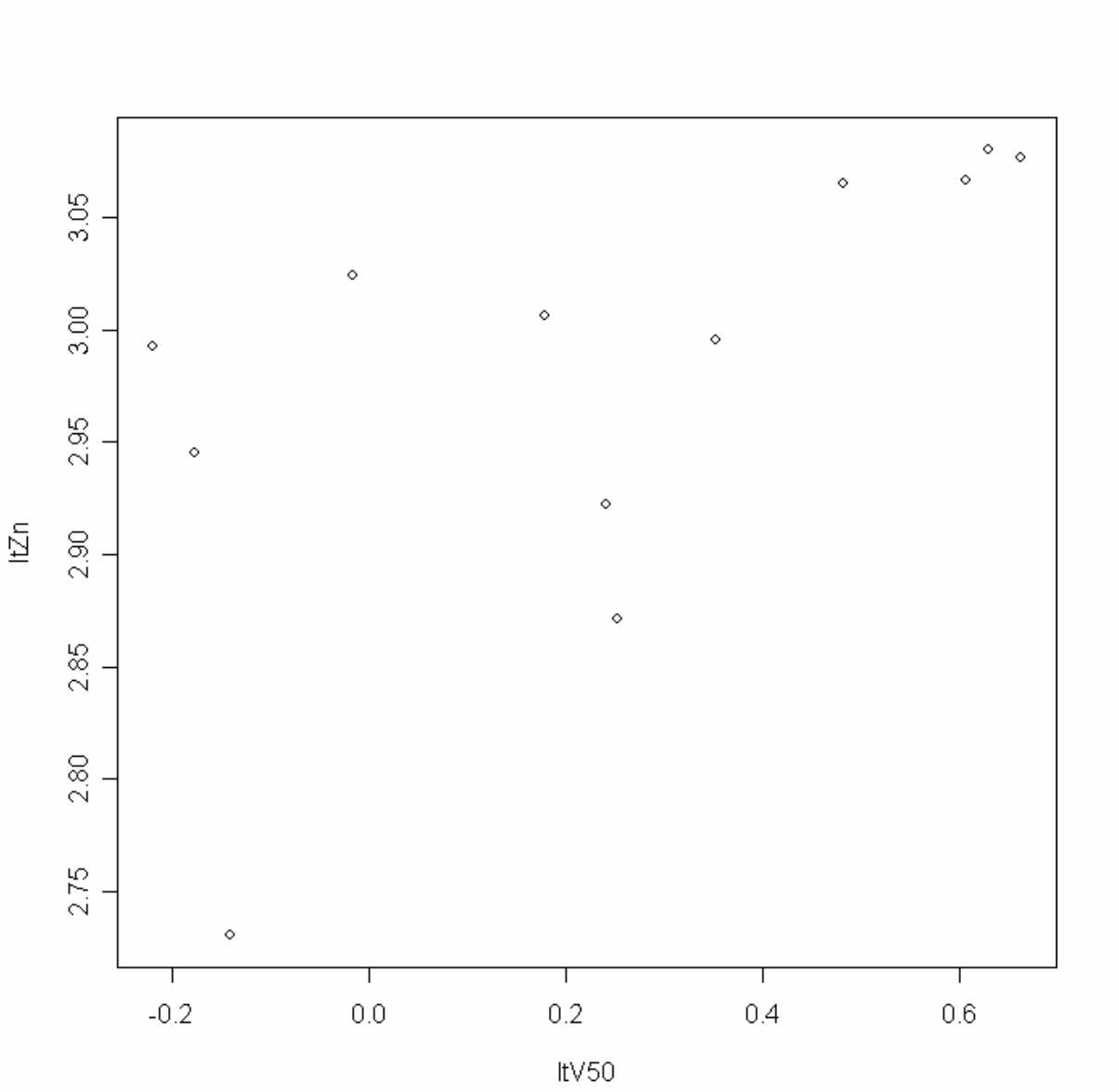
```
plot(ltV50,ltPb)
```




```
cor(ltV50,ltPb)
```

```
[1] 0.793016
```

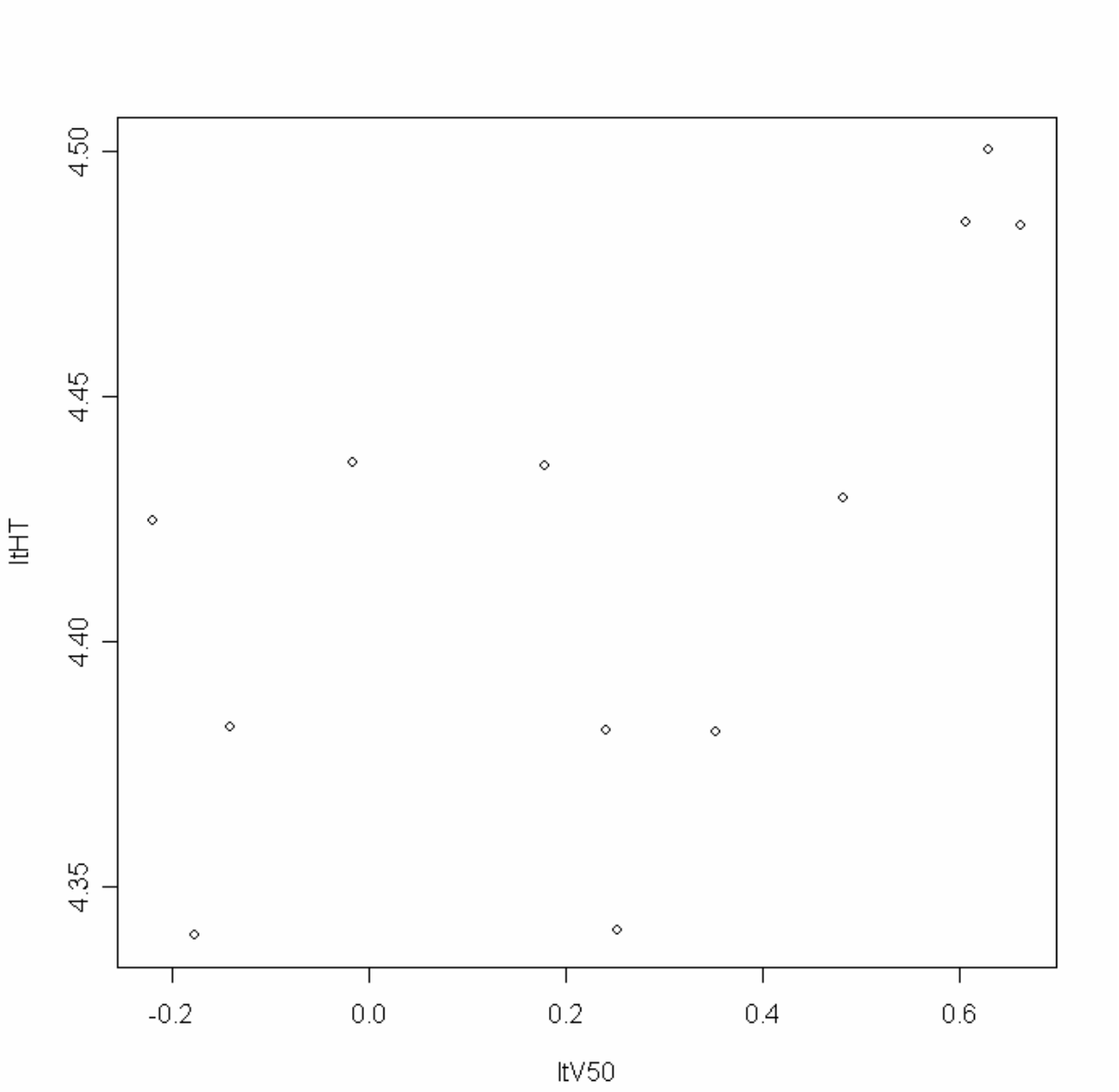
```
plot(ltV50,ltZn)
```




```
cor(ltV50,ltZn)
```

```
[1] 0.6167626
```

```
plot(ltV50,ltHT)
```




```
cor(ltV50,ltHT)
[1] 0.6231823
```

The most related variable is lead (Pb).

It is necessary to define a variogramm for the chosen variable:

To print the variogramm :

```
v.ltPb <- variogram(ltPb ~ 1, ~x+y, VicasA)
plot(v.ltPb, pl=T)
```

Estimation of an model:

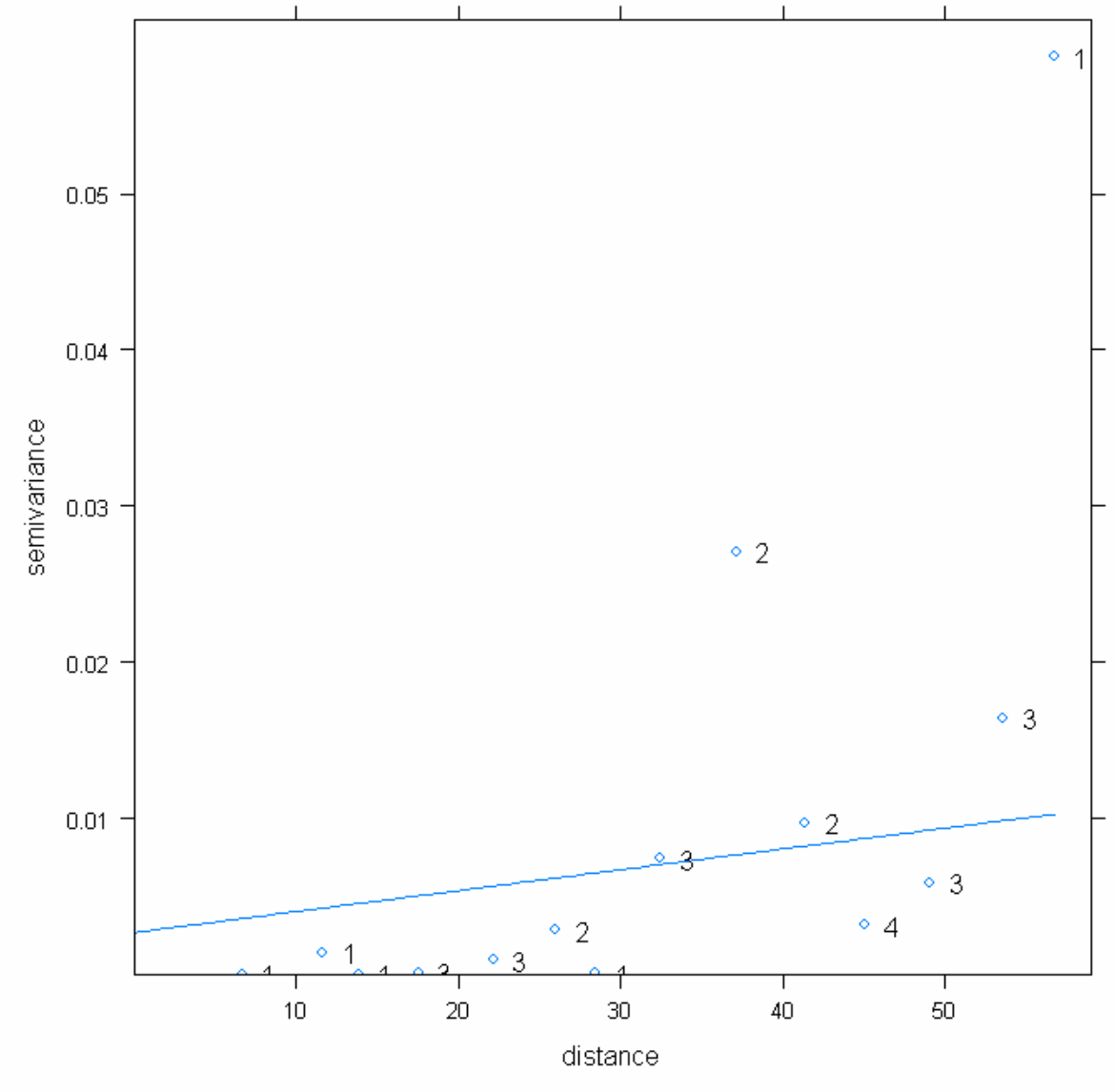
```
m.ltPb <- vgm(.1, "Sph", 20, .000)
plot(v.ltPb, pl=T, model=m.ltPb)
```

Calibration of the model:

```
(m.ltPb.f <- fit.variogram(v.ltPb, m.ltPb))
```

```
  model       psill    range
1   Nug 0.002718175   0.0000
2   Sph 0.044861441 502.2196
```

```
plot(v.ltPb, pl=T, model=m.ltPb.f)
```



Define a Gstat object with the objective variable and the co-variable:

```
(g <- gstat(id = "ltV50", form = ltV50 ~ 1, loc = ~ x+y, data =
VicasA))
```

```
data:
ltV50 : formula = ltV50`~`1 ; locations = ~x + y ; data dim = 12 x
14
```

```
(g <- gstat(g, id = "ltPb", form = ltPb ~ 1, loc = ~ x+y, data =
VicasA))
```

```
ata:
ltV50 : formula = ltV50`~`1 ; locations = ~x + y ; data dim = 12 x
14
ltPb : formula = ltPb`~`1 ; locations = ~x + y ; data dim = 12 x 14
```

Calculation and drawing of the variogramme and the cross variogramme:

```
v.cross <- variogram(g)
str(v.cross)
```

```
Classes gstatVariogram   and `data.frame':          42 obs. of   6
variables:
 $ np     : num  2 2 2 6 6 4 2 6 4 4 ...
 $ dist   : num   6.63 11.63 13.84 17.51 22.12 ...
 $ gamma  : num   -0.000589 -0.000280  0.000852 -0.000067  0.001945
...
 $ dir.hor: num  0 0 0 0 0 0 0 0 0 0 ...
 $ dir.ver: num  0 0 0 0 0 0 0 0 0 0 ...
 $ id     : Factor w/ 3 levels "ltV50.ltPb","ltPb",..: 1 1 1 1 1 1 1
1 1 1 ...
 - attr(*, "direct")=`data.frame':      3 obs. of  2 variables:
  ..$ id       : Factor w/ 3 levels "ltPb","ltV50",..: 3 1 2
  ..$ is.direct: logi  FALSE  TRUE  TRUE
```

```
plot(v.cross, pl=T)
```

Add the models to the gstat object:

```
(g <- gstat(g, id = "ltV50", model = m.ltpb.f, fill.all=T))
```

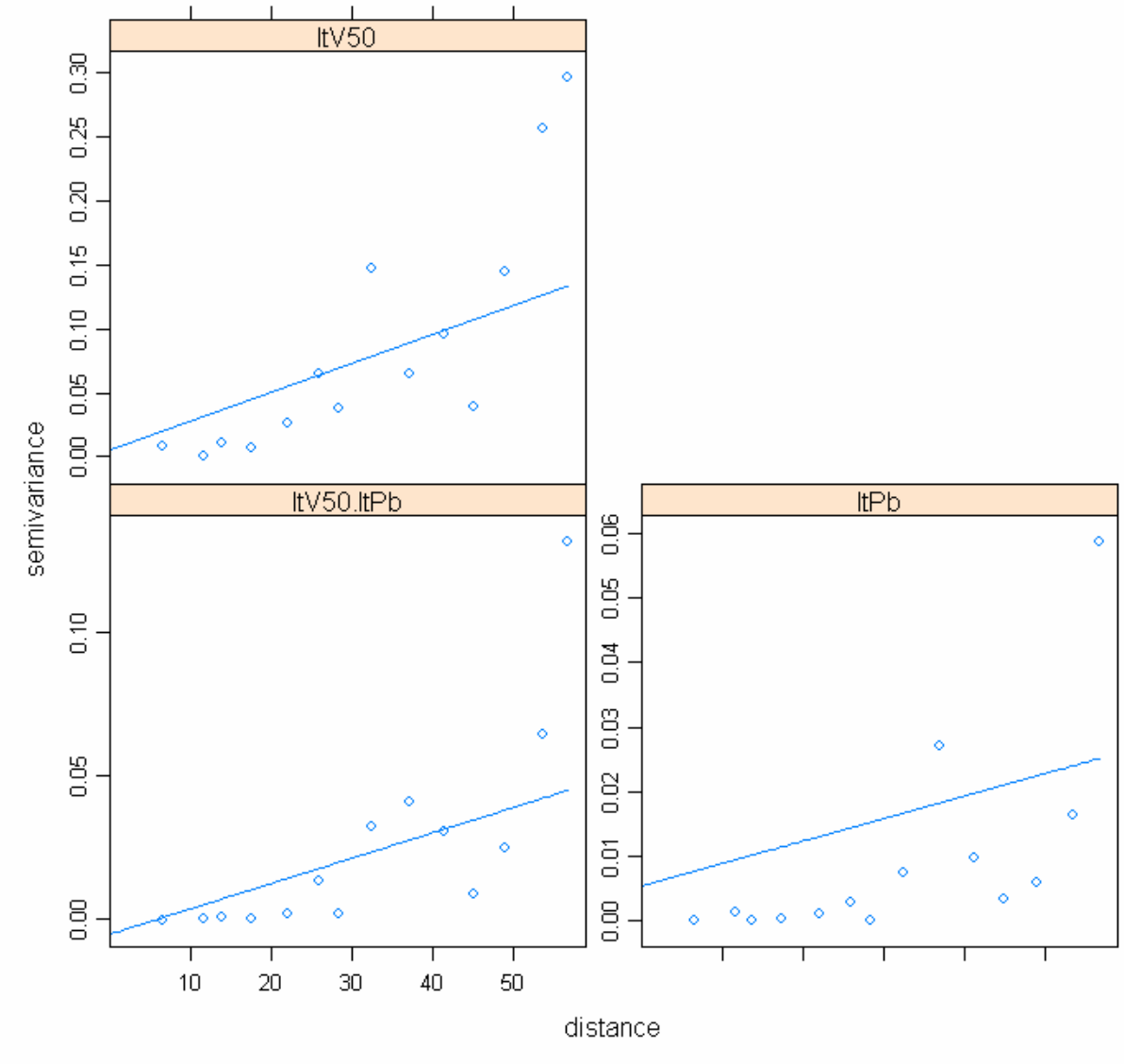
```
data:
ltV50 : formula = ltV50`~`1 ; locations = ~x + y ; data dim = 12 x
14
ltPb : formula = ltPb`~`1 ; locations = ~x + y ; data dim = 12 x 14
variograms:
              model     psill    range
ltV50[1]        Nug 0.6168515    0.000
ltV50[2]        Sph 9.8672215 1909.076
ltPb[1]         Nug 0.6168515    0.000
ltPb[2]         Sph 9.8672215 1909.076
ltV50.ltPb[1]   Nug 0.6168515    0.000
ltV50.ltPb[2]   Sph 9.8672215 1909.076
```

Calibration of the three variogramms of Pb, V50 and the two parameters in correlation:

```
(g <- fit.lmc(v.cross, g))
```

```
data:
ltV50 : formula = ltV50`~`1 ; locations = ~x + y ; data dim = 12 x
14
ltPb : formula = ltPb`~`1 ; locations = ~x + y ; data dim = 12 x 14
variograms:
                model         psill    range
ltV50[1]          Nug  0.005353414    0.000
ltV50[2]          Sph  2.867271767 1909.076
ltPb[1]           Nug  0.005353414    0.000
ltPb[2]           Sph  0.443484125 1909.076
ltV50.ltPb[1]     Nug -0.005353414    0.000
ltV50.ltPb[2]     Sph  1.127647778 1909.076
```

```
plot(variogram(g), model=g$model)
```

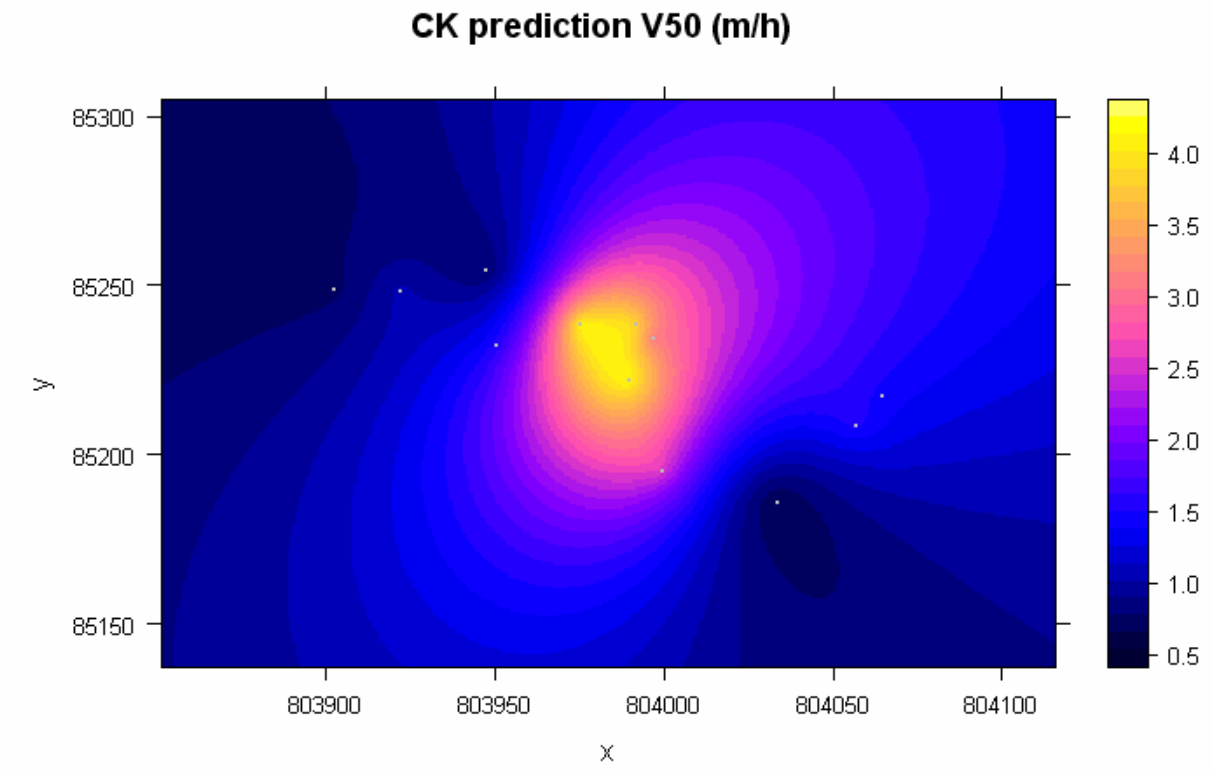


Prediction of V50 by using the co-regionalisation:

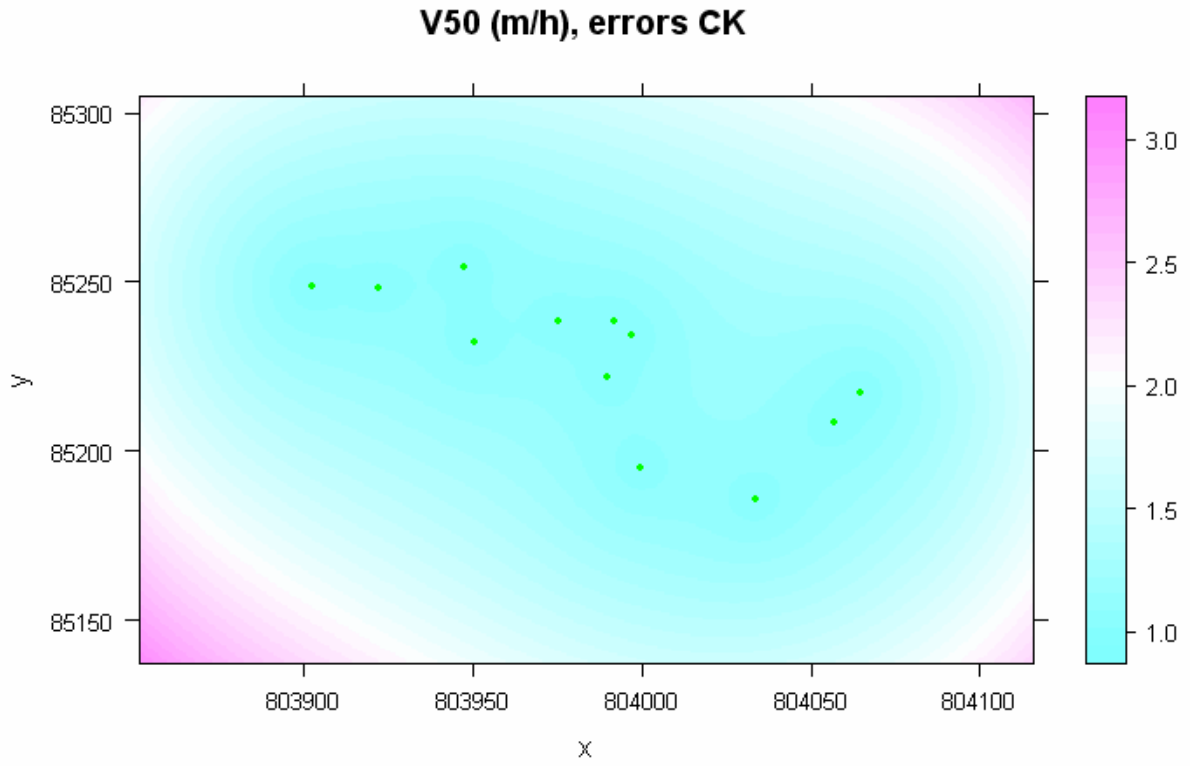
```
k.c <- predict.gstat(g, grd)
str(k.c)
summary(k.c$ltV50.pred); summary(k.c$ltV50.var)
```

```
    Min.  1st Qu.   Median     Mean  3rd Qu.     Max.
-0.33890  0.03292  0.04751  0.06101  0.11660  0.41520
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
0.02930 0.09892 0.13060 0.12260 0.15290 0.15460
```

```
levelplot(10^(ltV50.pred) ~ x+y, k.c, aspect=mapasp(k.c),
col.regions=bpy.colors(64), cut=32,
main="CK prediction V50 (m/h) ",
panel = function(x, ...) {
panel.levelplot(x, ...)
lpoints(Vicas$x,Vicas$y, col="grey", pch=20,
cex=1.6 * (log10(Vicas$V50) - 1.3)) })
```



```
levelplot(10^(ltV50.var) ~ x+y, k.c, aspect=mapasp(k.c),
col.regions=cm.colors(64), cut=32,
main="V50 (m/h), errors CK",
panel = function(x, ...) {
panel.levelplot(x, ...);
lpoints(Vicas$x,Vicas$y, col="green", pch=20, cex=.6)
})
```



Cross validation for the CO – Kriging:

```
cv.c <- gstat.cv(g)
str(cv.c)
summary(cv.c$residual)
sqrt(mean(cv.c$residual^2))
mean(cv.c$residual)
mean(cv.c$residual^2/cv.c$ltV50.var)
```

```
`data.frame':   12 obs. of  8 variables:
data.frame':   12 obs. of  8 variables:
 $ x         : num  803997 803990 803992 803975 803950 ...
 $ y         : num  85234 85222 85238 85238 85232 ...
 $ ltV50.pred: num  0.573 0.535 0.525 0.424 0.219 ...
 $ ltV50.var : num  0.0276 0.0372 0.0271 0.0385 0.0447 ...
 $ observed  : num  0.481 0.628 0.605 0.662 0.179 ...
 $ residual  : num  -0.0918  0.0934  0.0798  0.2373 -0.0405 ...
 $ zscore    : num  -0.553  0.484  0.485  1.210 -0.191 ...
 $ fold      : int  1 2 3 4 5 6 7 8 9 10 ...

   Min.  1st Qu.   Median     Mean  3rd Qu.     Max.
-0.34460 -0.08984 -0.02092 -0.01337  0.11380  0.23730

[1] 0.1752178

[1] -0.01337174

[1] 0.7121698
```

To see the file:

```
cv.c
```

```
          x        y  ltV50.pred  ltV50.var    observed     residual
1  803996.8 85234.00  0.57267416 0.02758093  0.48091424 -0.091759916
2  803989.9 85222.00  0.53497753 0.03719199  0.62838893  0.093411400
3  803991.8 85238.29  0.52548979 0.02707083  0.60524165  0.079751861
4  803975.2 85238.33  0.42448000 0.03848038  0.66176288  0.237282888
5  803950.3 85232.18  0.21931845 0.04470773  0.17883997 -0.040478480
6  803947.5 85254.37  0.16819437 0.04546424 -0.17640158 -0.344595948
7  803999.5 85195.21  0.41274304 0.04902611  0.35167427 -0.061068765
8  803922.0 85248.28 -0.01411962 0.04125263 -0.01547269 -0.001353064
9  803902.4 85248.51  0.08309879 0.05127648 -0.21956898 -0.302667769
10 804064.9 85217.08  0.06657923 0.04218487  0.25163822  0.185058995
11 804056.9 85208.64  0.06591949 0.03701175  0.24107439  0.175154905
12 804033.5 85185.70 -0.05209395 0.05096045 -0.14129097 -0.089197030
         zscore fold
1  -0.552520724    1
2   0.484367695    2
3   0.484718958    3
4   1.209613765    4
5  -0.191440091    5
6  -1.616125874    6
7  -0.275807095    7
8  -0.006661814    8
9  -1.336617325    9
10  0.901014654   10
11  0.910442493   11
12 -0.395124326   12
```

To represent the residue:

```
bubble(data.frame(cbind(cv.c$x, cv.c$y, cv.c$residual)), col=c(4,5))
```