Université de Liège

LHGF
Laboratoire d'Hydrographie et de Géomorphologie fluviatile

Analysis of the temporal dynamics of suspended sediment fluxes using discrete sampling and continuous turbidity measurements in the Meuse and Scheldt watersheds (Wallonia, Belgium)

Jean VAN CAMPENHOUT

PhD student, Assistant professor

In association with Geoffrey HOUBRECHTS, PhD & Prof. François PETIT

18th JGM, Chambéry

2016 JGM JJG AFdP SAVOIE

Laboratory of Hydrography and Fluvial Geomorphology
University of Liège (Belgium)

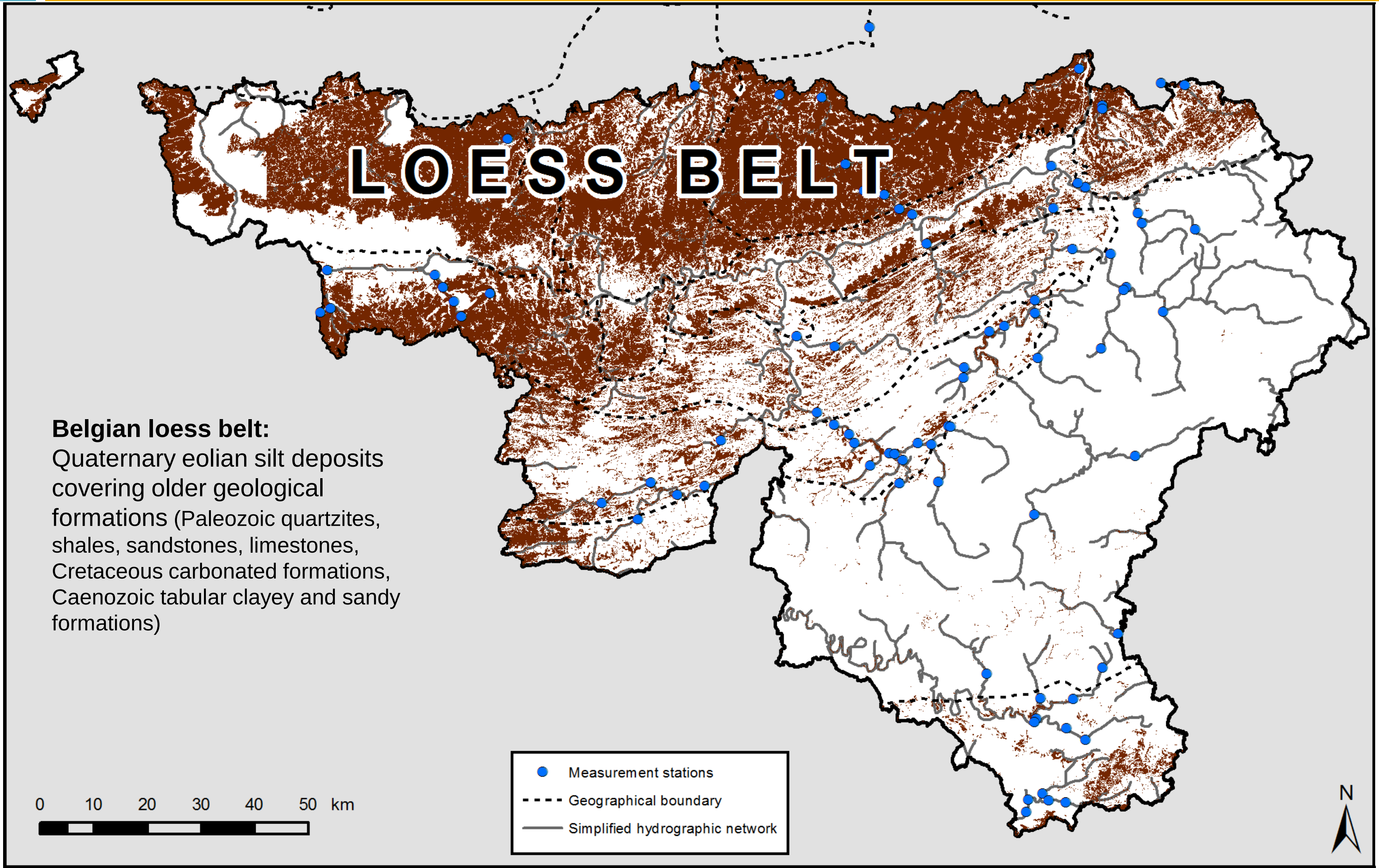
June 27, 2016

Structure of the presentation

- Location of the study area
- Suspended sediment load in rivers – how to measure it?
  - Manual sampling method: application to the **Meuse** watershed
    - Interpolation & extrapolation using flow rate series
    - Regionalization of denudation rates
  - Automatic sampling method: application to the **Scheldt** watershed
    - Turbidity measurements analysis
    - Automatic sampling results
    - Comparison of several methods to estimate sediment transport rates
  - Technical issues encountered due to high sediment load concentrations
  - Effects of the sampling frequency on the sediment yield estimation
  - Hysteresis phenomena in high temporal resolution turbidity data
- Analysis prospects and conclusions

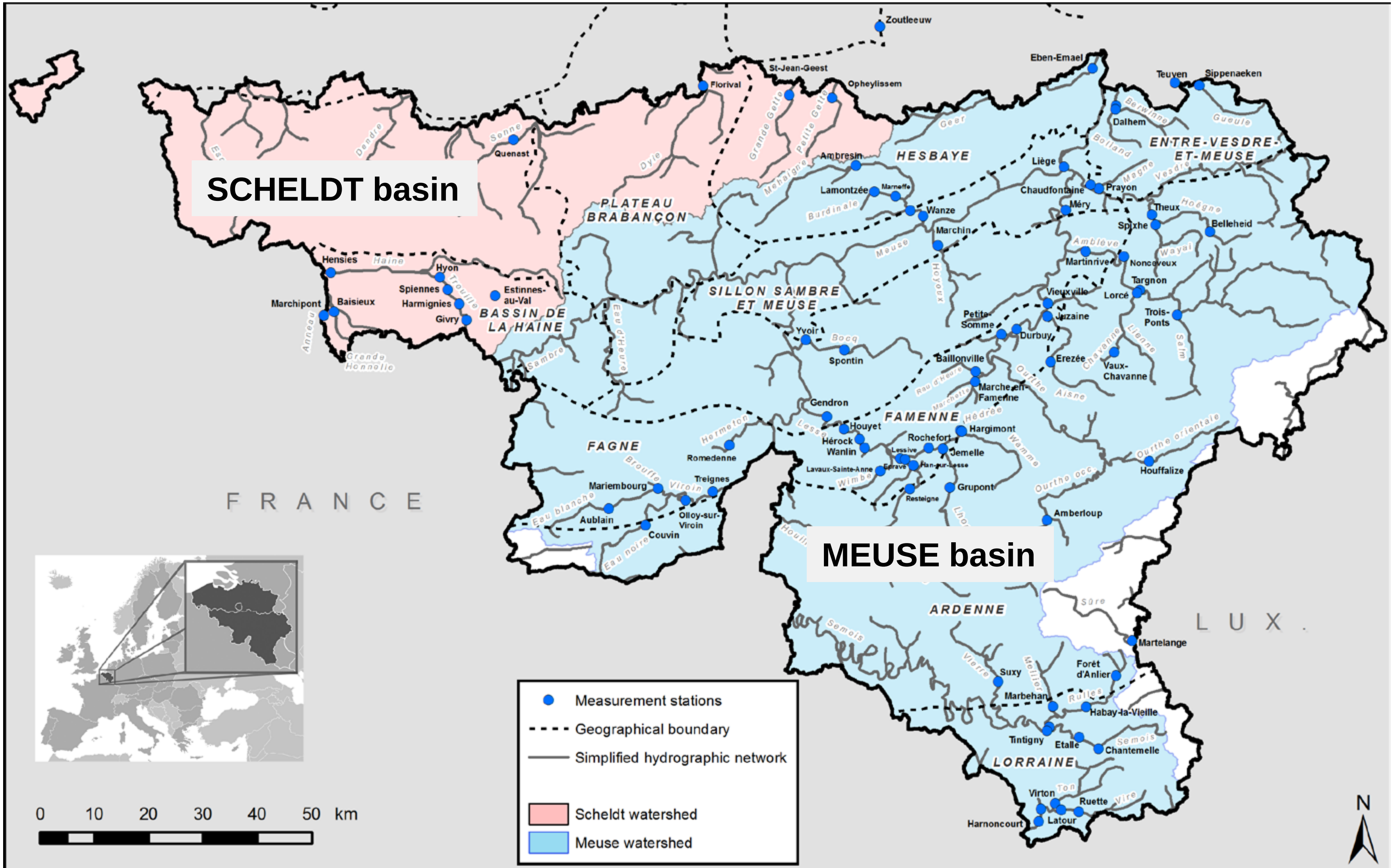
Location of the study area

80 measurement stations in Wallonia



Location of the study area

Scheldt basin & Meuse basin



Suspended sediment load in rivers – how to measure it?

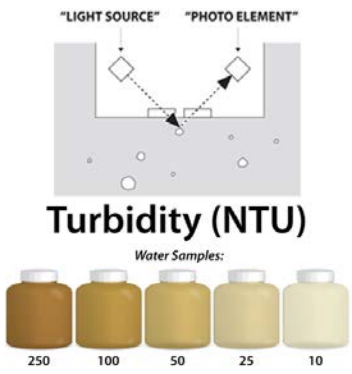
- **Direct measurements:**
  - Subsurface or deep manual water sampling (bucket, watertrap, isokinetic sampler, …)
  - Automatic sampling through hose (ISCO samplers)
  - → Laboratory analysis: vacuum filtration of samples with 1.2-µm glass fiber filters → Direct estimation of the sediment concentration

- **Indirect measurements:**
  - Turbidity measurement (backscattered infrared beam) and relationship between the suspended load concentration and the turbidity value (in NTU)

Manual subsurface sampling during flood event

Watertrap sampling

Automatically triggered sampler



Turbidity measurement principle

Turbidity probe and cleaning device

Manual sampling method: application to the Meuse watershed

- Manual sampling at 80 stations ~ 2,000 samples
- Uniformity tests in the water column and section
- Defining relationship

  $SSC = a\,Q^{b}$

  SSC: susp. sed. concentration ($mg.l^{-1}$)

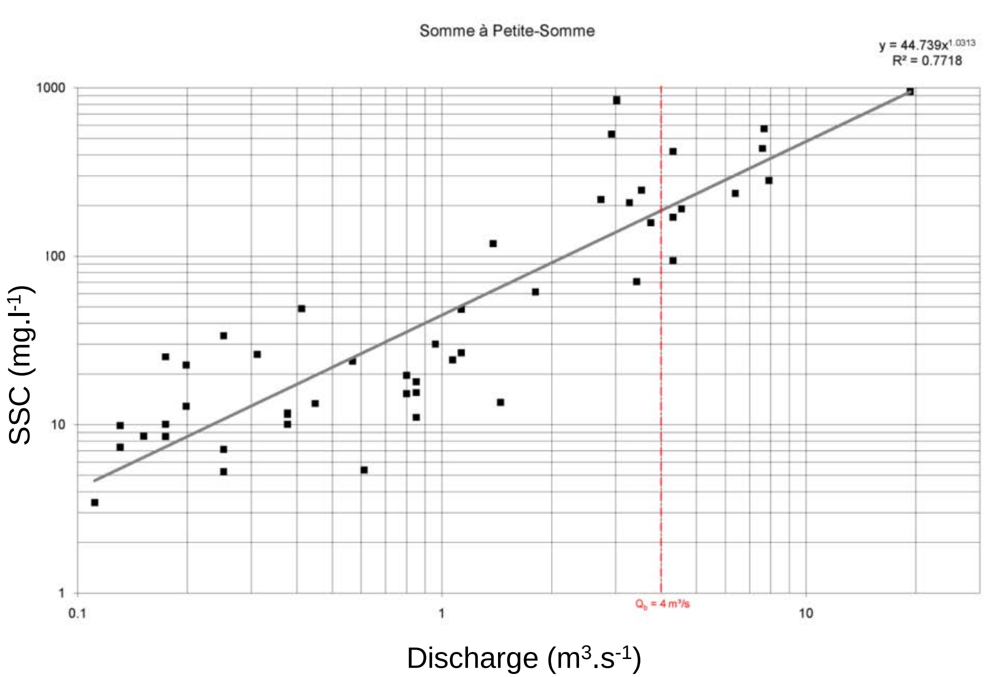
  Q: discharge ($m^3.s^{-1}$)

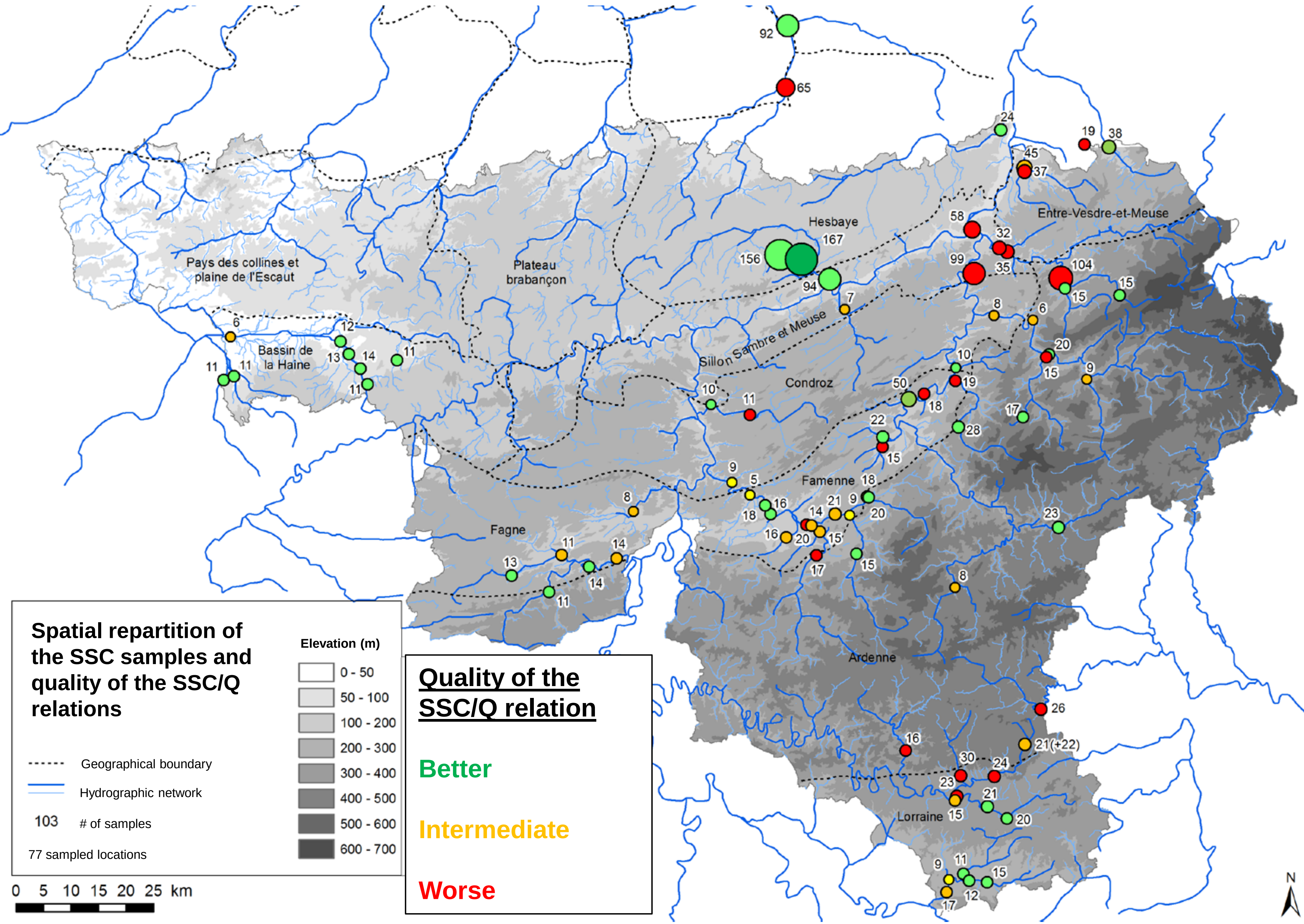
  a, b: parameters
- Evaluation of the quality of each relation (R^2)

SOMME à PETITE-SOMME

Bassin versant : 37,0 km²
Coordonnées Lambert : x = 224.515 m ; y = 115.322 m

Cs maximale : 952 mg/l (25/08/2006) Q = 19,311 m³/s $Cs = 44{,}739\ Q^{1{,}0313}$	Année(s) hydrologique(s) : 2004-2009 Nombre d'observations : 50 $R^2 = 0{,}77$





Spatial repartition of the SSC samples and quality of the SSC/Q relations
Geographical boundary
Hydrographic network
103 # of samples
77 sampled locations
Elevation (m)
0 - 50
50 - 100
100 - 200
200 - 300
300 - 400
400 - 500
500 - 600
600 - 700
0 5 10 15 20 25 km
Quality of the SSC/Q relation
Better
Intermediate
Worse
Pays des collines et plaine de l'Escaut
Plateau brabançon
Hesbaye
Entre-Vesdre-et-Meuse
Bassin de la Haine
Sillon Sambre et Meuse
Condroz
Famenne
Fagne
Ardenne
Lorraine
N

Interpolation & extrapolation using discharge series

- Extrapolation to the whole discharge series to estimate medium-term evolution of the watershed erosion variability
- Comparison of multiple interpolation and extrapolation techniques taking into account the sampling chronology
- Estimation of the yearly denudation rate, expressed in t.km^{-2}.yr^{-1}.

$$\mathrm{TL1} = \frac{\sum_{i=1}^{n} A_i C_i}{\sum_{i=1}^{n} A_i} \frac{\sum_{i=1}^{n} A_i Q_i}{\sum_{i=1}^{n} A_i} n$$

$$\mathrm{TL2} = \frac{\sum_{i=1}^{n} A_i C_i}{\sum_{i=1}^{n} A_i} \frac{\sum_{i=1}^{n} Q_i}{n} n = \overline{C} \cdot \mu \cdot n$$

$$\mathrm{TL3} = \frac{\sum_{i=1}^{n} A_i C_i Q_i}{\sum_{i=1}^{n} A_i} = \overline{CQ} \cdot n$$

$$\mathrm{TL4} = \frac{\dfrac{\sum_{i=1}^{n} A_i C_i Q_i}{\sum_{i=1}^{n} A_i}}{\dfrac{\sum_{i=1}^{n} A_i Q_i}{\sum_{i=1}^{n} A_i}} \frac{\sum_{i=1}^{n} Q_i}{n} n = \overline{CQ} \frac{\mu}{\overline{Q}} \cdot n$$

$$\mathrm{TL5} = \overline{CQ} \frac{\mu}{\overline{Q}} . n \left(\frac{1 + \frac{1}{n_d} \frac{S_{CQ}}{\overline{CQ}} \frac{1}{\overline{Q}}}{1 + \frac{1}{n_d} \frac{S_{Q^2}}{\overline{Q}^2}} \right)$$

with

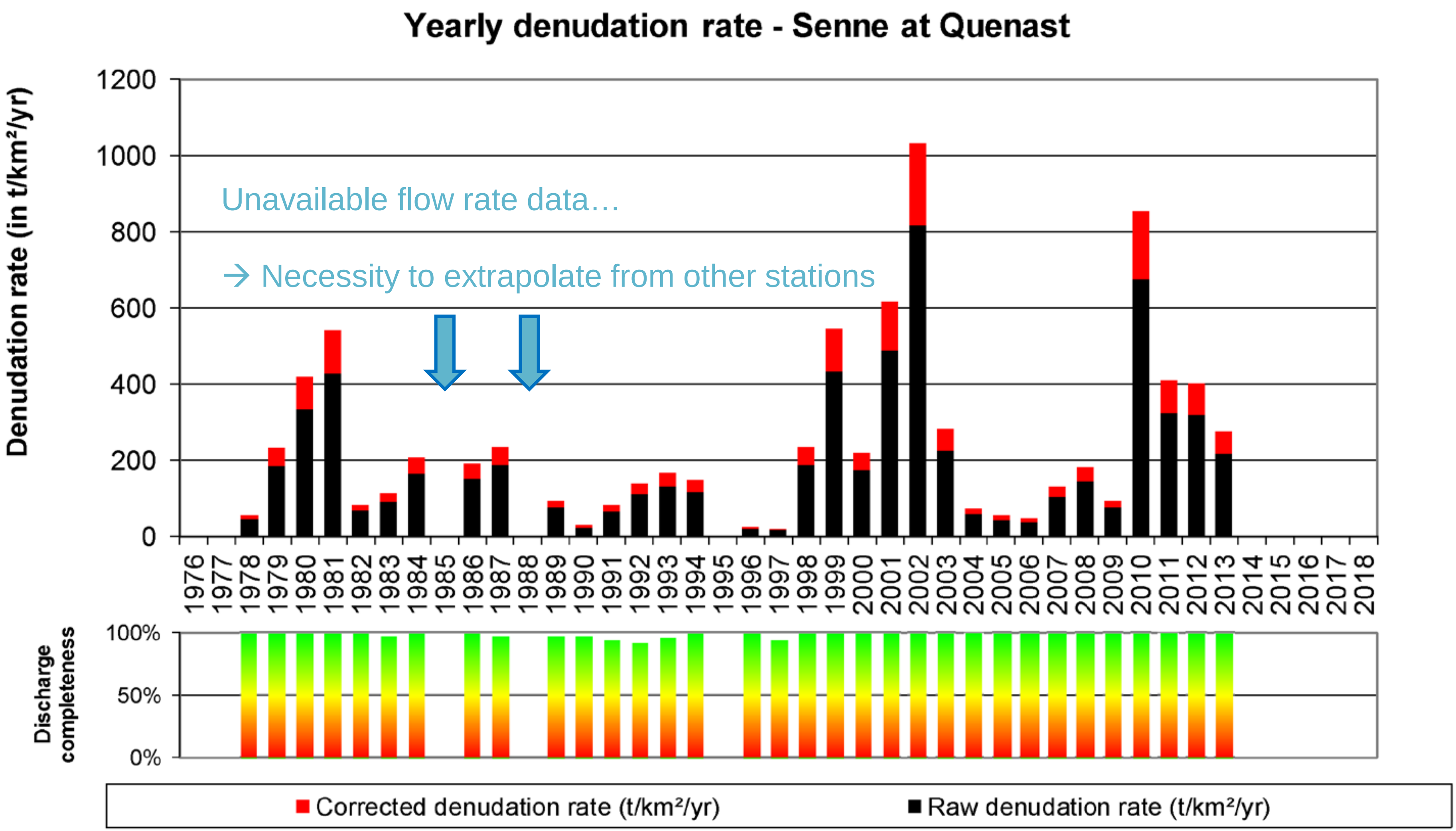
$$S_{CQ} = \frac{1}{n_d - 1} \left(\sum_{i=1}^{n} A_i C_i Q_i - n_d \overline{Q} \overline{CQ} \right)$$

$$S_{Q^2} = \frac{1}{n_d - 1} \left(\sum_{i=1}^{n} A_i Q_i - n_d \overline{Q}^2 \right)$$

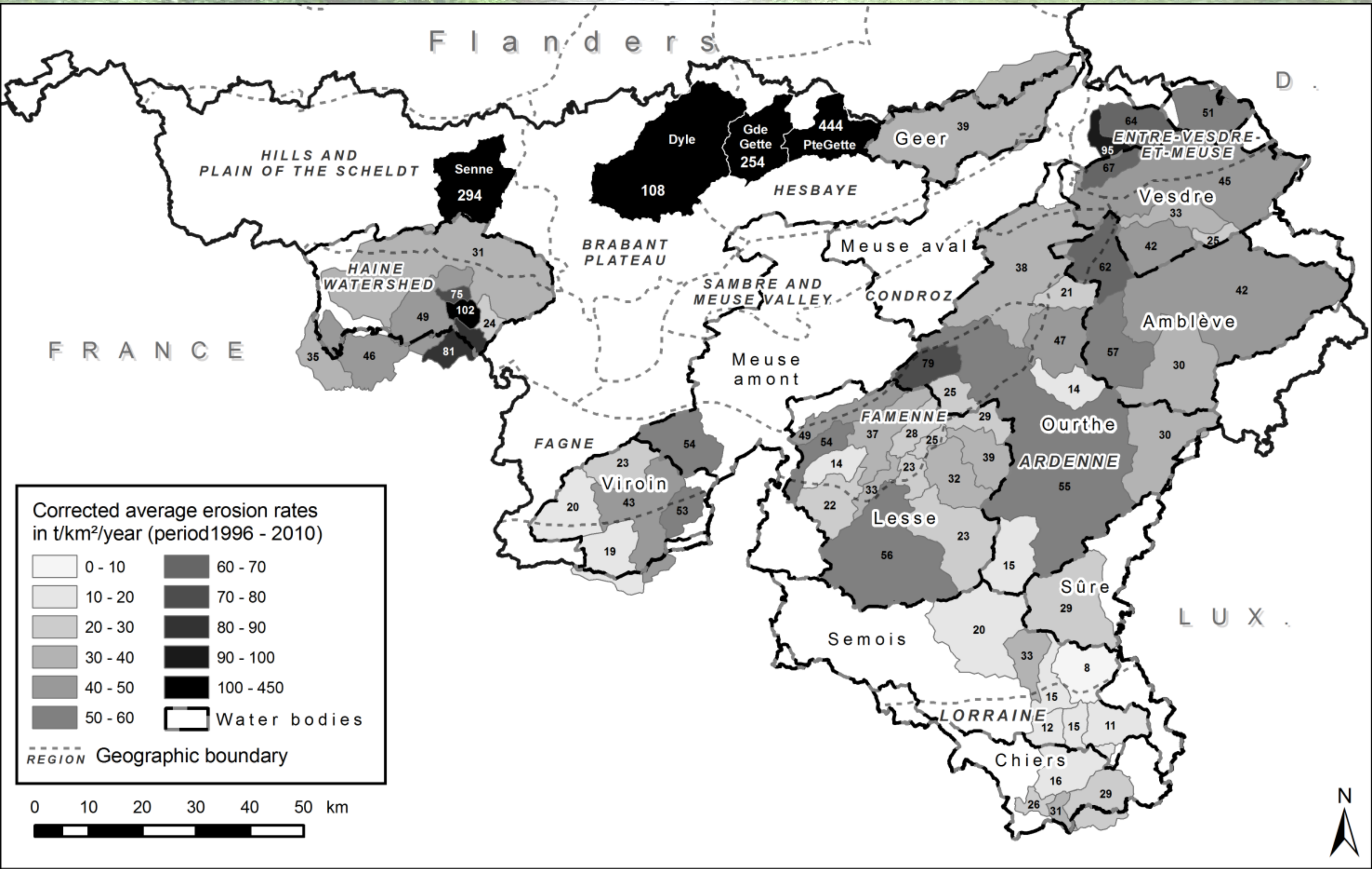
$$\mathrm{TL6} = \sum_{m=1}^{M} \frac{C_m^{\mathrm{int}} Q_m}{M}$$

Source : Delmas et al., 2011:
River basin sediment flux assessments

Example of yearly denudation rate in the Senne River at Quenast (Scheldt basin) taking into account the Ferguson (1986, 1987) correction ratio.



Regionalization of denudation rates



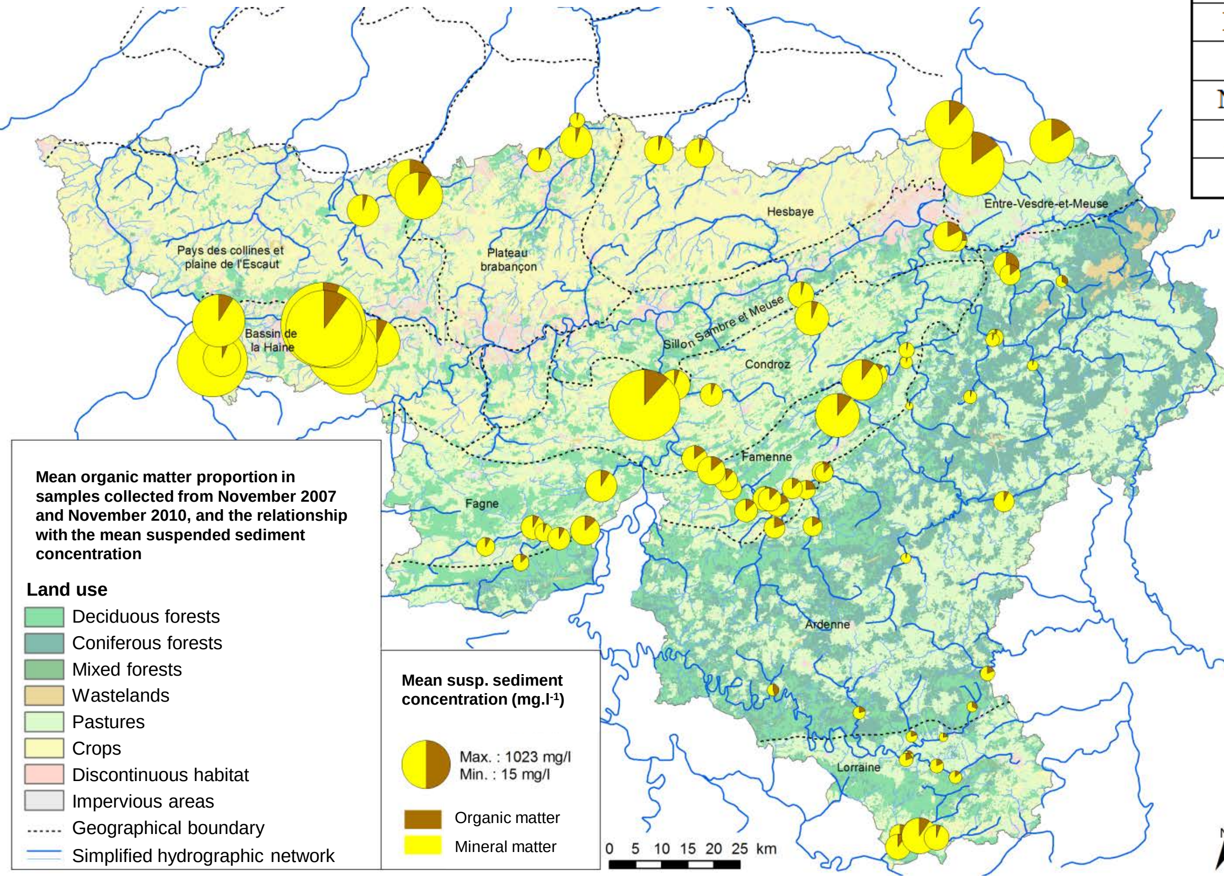
Regionalization of denudation rates

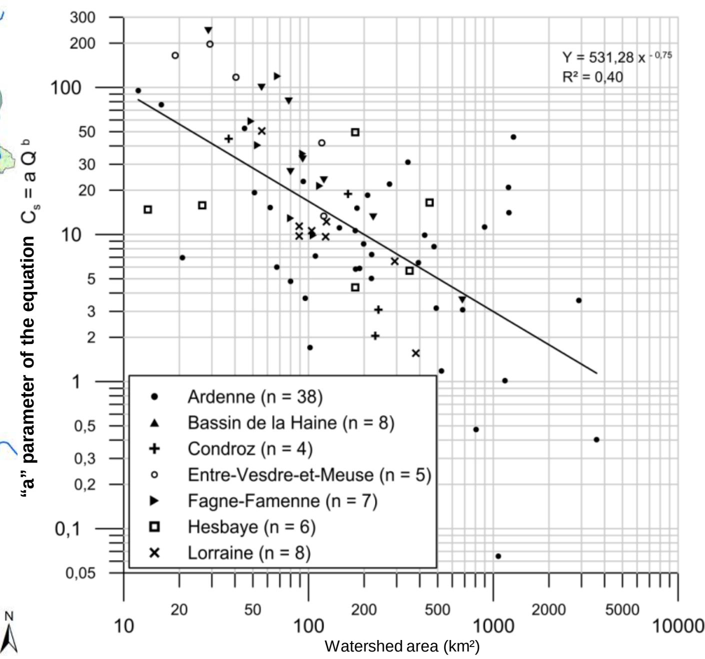
- Denudation rates estimated for the period 1996-2010 in watersheds ranging from 16 to 2,900 km^2
- Different geographical areas with soil and geology specificities
- Effect of these environmental settings on the denudation rate:
  - Several hundreds of tons per km^2 and per year in the loess belt (Senne, Dyle and Gette watersheds) with a huge sensibility to extreme hydrological events
  - Only about 20 $t.km^{-2}.yr^{-1}$ in Lorraine (no loess, no steep slopes)
  - About 34 $t.km^{-2}.yr^{-1}$ in Ardenne (shallow soil development, low availability of loamy sediment)
  - Around 69 $t.km^{-2}.yr^{-1}$ in Entre-Vesdre-et-Meuse, transitional area between the Ardenne and the loess belt.
- Attempts to correlate the denudation rate with the physical characteristics (soil depth, rainfall intensity, land use, …) but many intricate parameters are involved

Additional parameters
(particle size distribution, organic matter content)

- Regionalization of suspended particle size indexes
- Negative correlation between the "a" parameter of the SSC equation and the watershed area

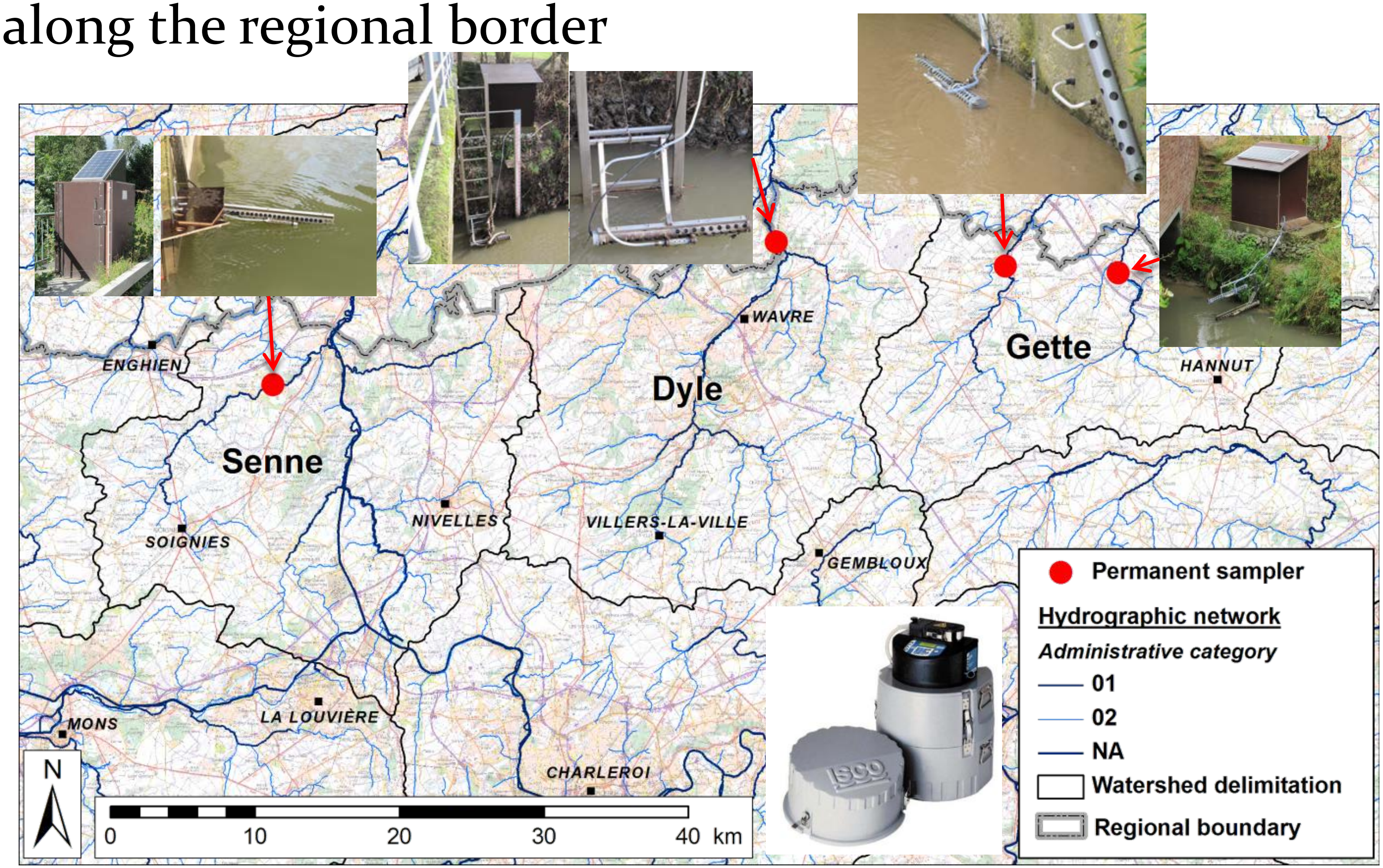
Geographical area	D_{50} (µm)	D_{90} (µm)	D_{99} (µm)	#of samples
Ardenne	11.1	58.0	266.2	54
Entre-Vesdre-et-Meuse	11.8	52.5	188.7	25
Fagne-Famenne	7.3	35.6	141.4	17
Hainaut	14.2	51.1	134.7	22
Héritage ardennais	10.6	60.2	236.8	18
Hesbaye	17.9	59.0	220.5	6
Nord de la Lorraine	6.0	42.1	132.5	5
Plateau brabançon	16.6	101.2	277.0	16
Sud de la Lorraine	13.6	105.4	286.5	14





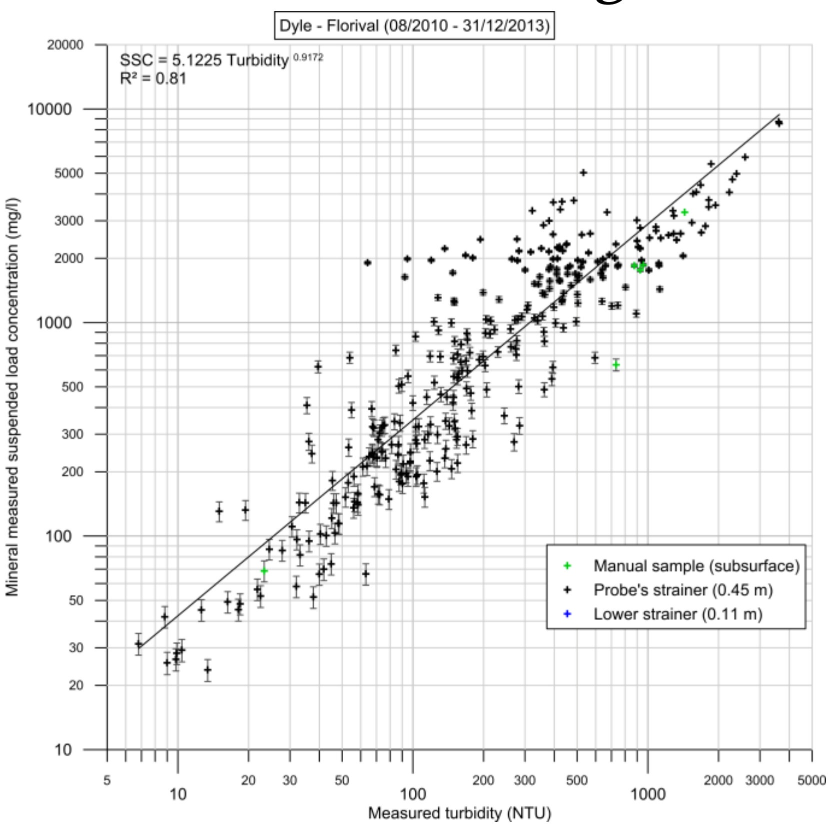
Automatic sampling method: application to the Scheldt watershed

- 6 turbidity probes, 4 automatic samplers at 4 locations along the regional border

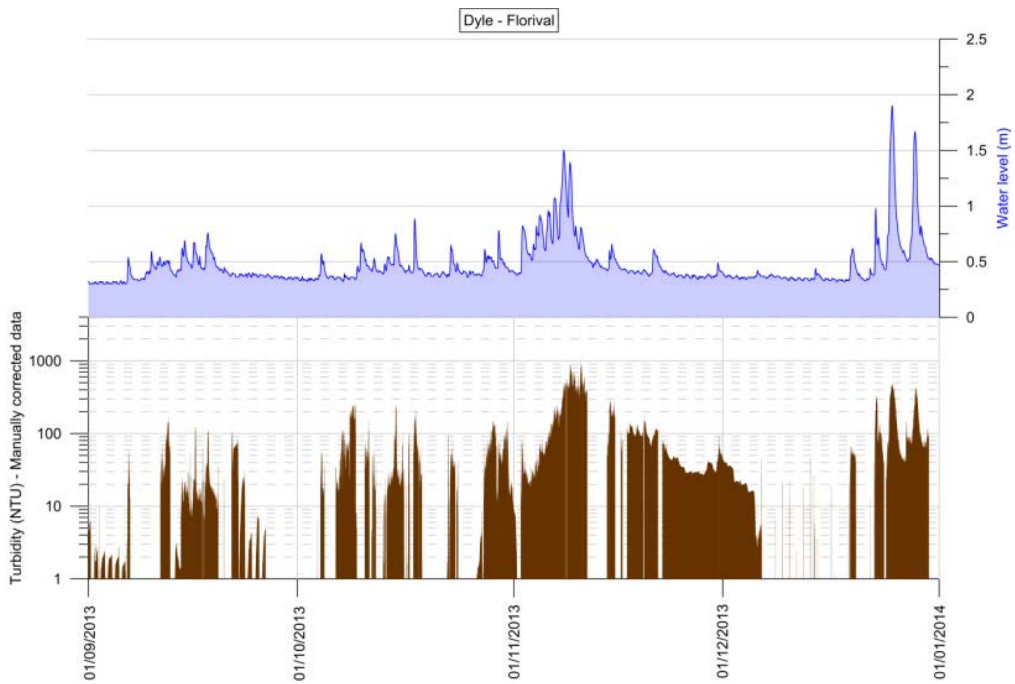


Turbidity measurements analysis

- 5-min interval turbidity measurements on 4 stations
- Manual cleaning of outliers or invalid data

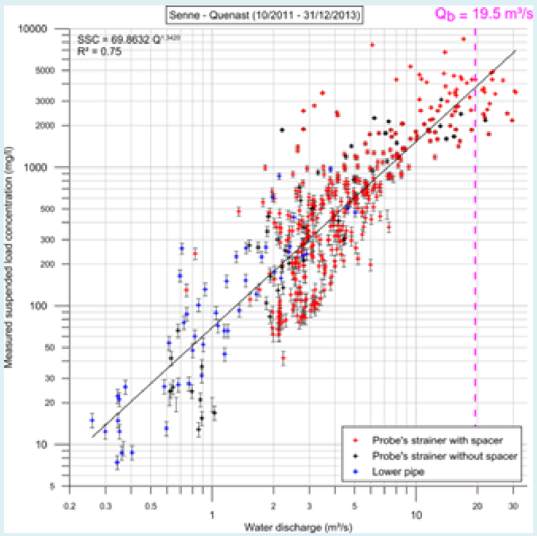


Relationship between the inorganic suspended load and the turbidity (Dyle)



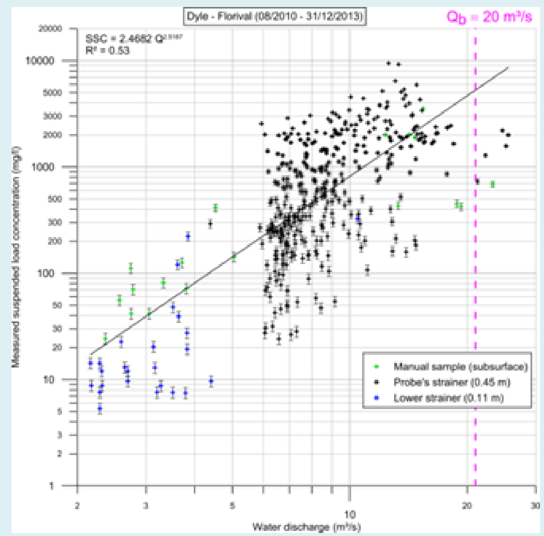
Example of corrected turbidity data and water level (3rd quarter 2013)

Automatic sampling results



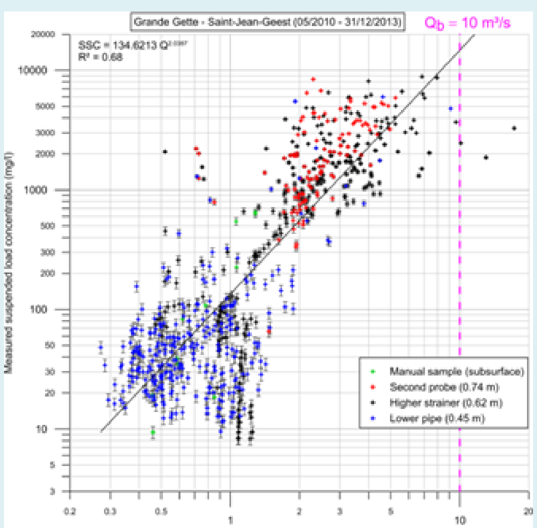
Senne:

471 suspended load samples
+
55 particle size analysis



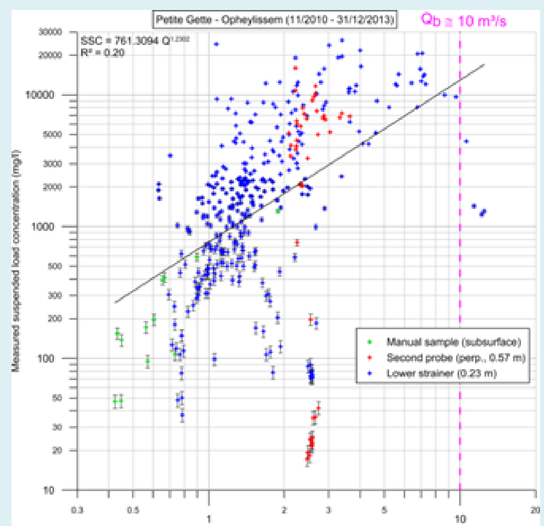
Dyle:

395 suspended load samples
+
112 particle size analysis



G^{de} Gette:

656 suspended load samples
+
121 particle size analysis



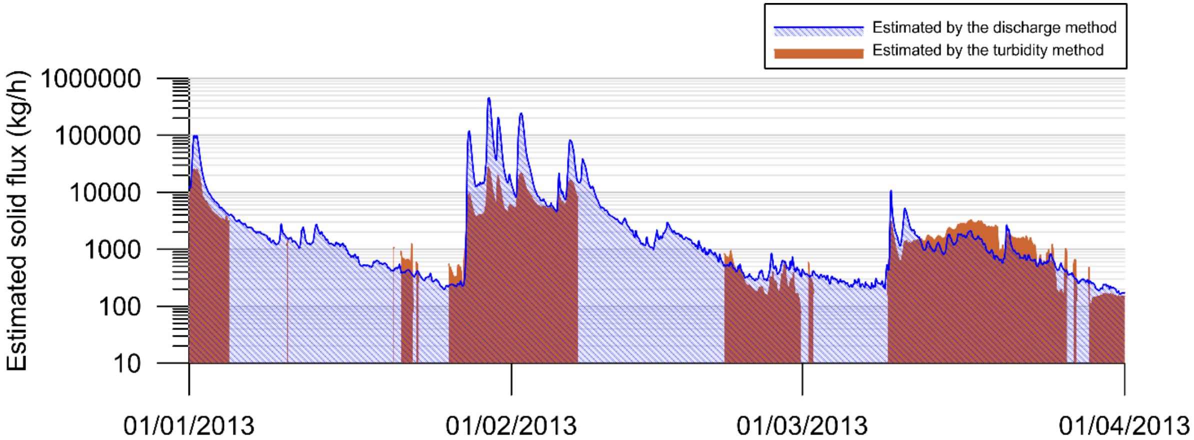
P^{te} Gette:

376 suspended load samples
+
97 particle size analysis

Comparison of several methods to estimate sediment transport

- Computation of the sediment budget using the discharge method (link between the SSC and the flow rate) or the turbidity method when data is available (immersed probe, without clogging)

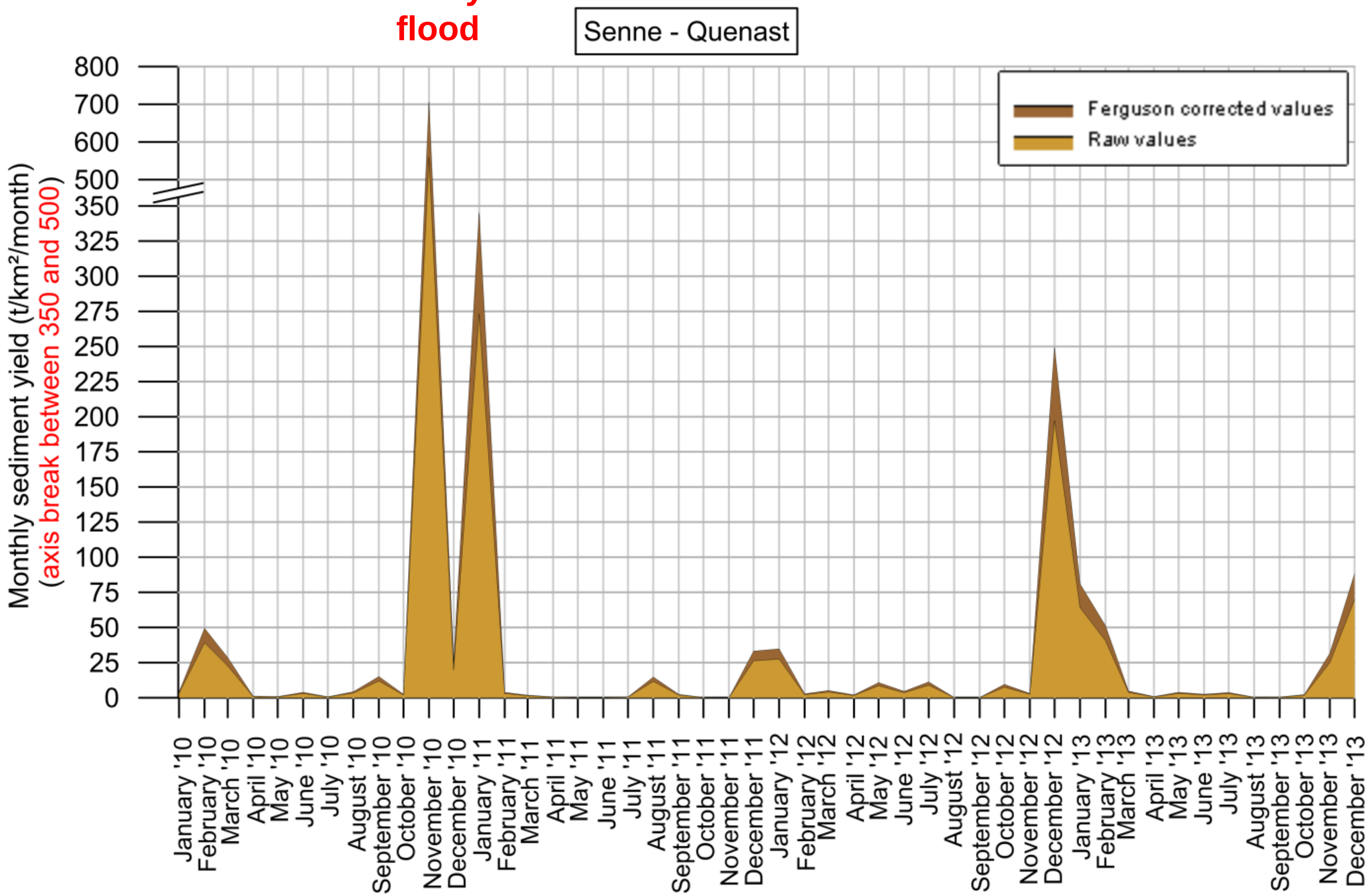
	Corrected data, in t.km^{-2}.year^{-1} (including Ferguson correction)			
	PETITE GETTE	GRANDE GETTE	DYLE	SENNE
2010	326.5	477.1	240.4	841.9
2011	695.6	310.0	223.0	403.1
2012	127.2	77.7	72.1	333.5
2013	357.5	76.4	253.2	270.7



Estimated solid flux on the Senne ; year 2013) comparing discharge and turbidity methods

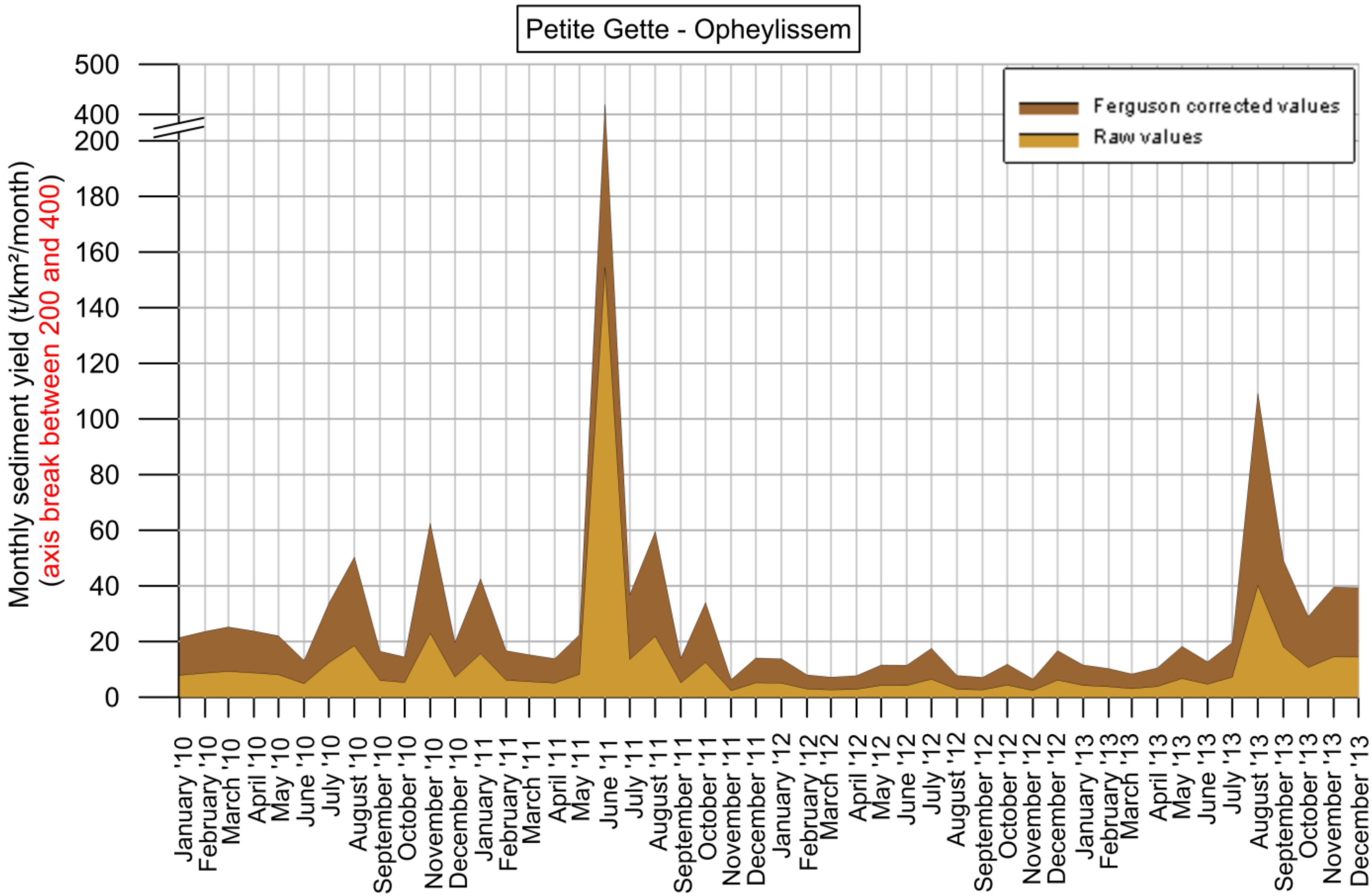
Raw and corrected monthly sediment yield (using the water discharge method)

➢ **100-yr flood**



Raw and corrected monthly sediment yield (using the water discharge method)

- **200-yr flood**

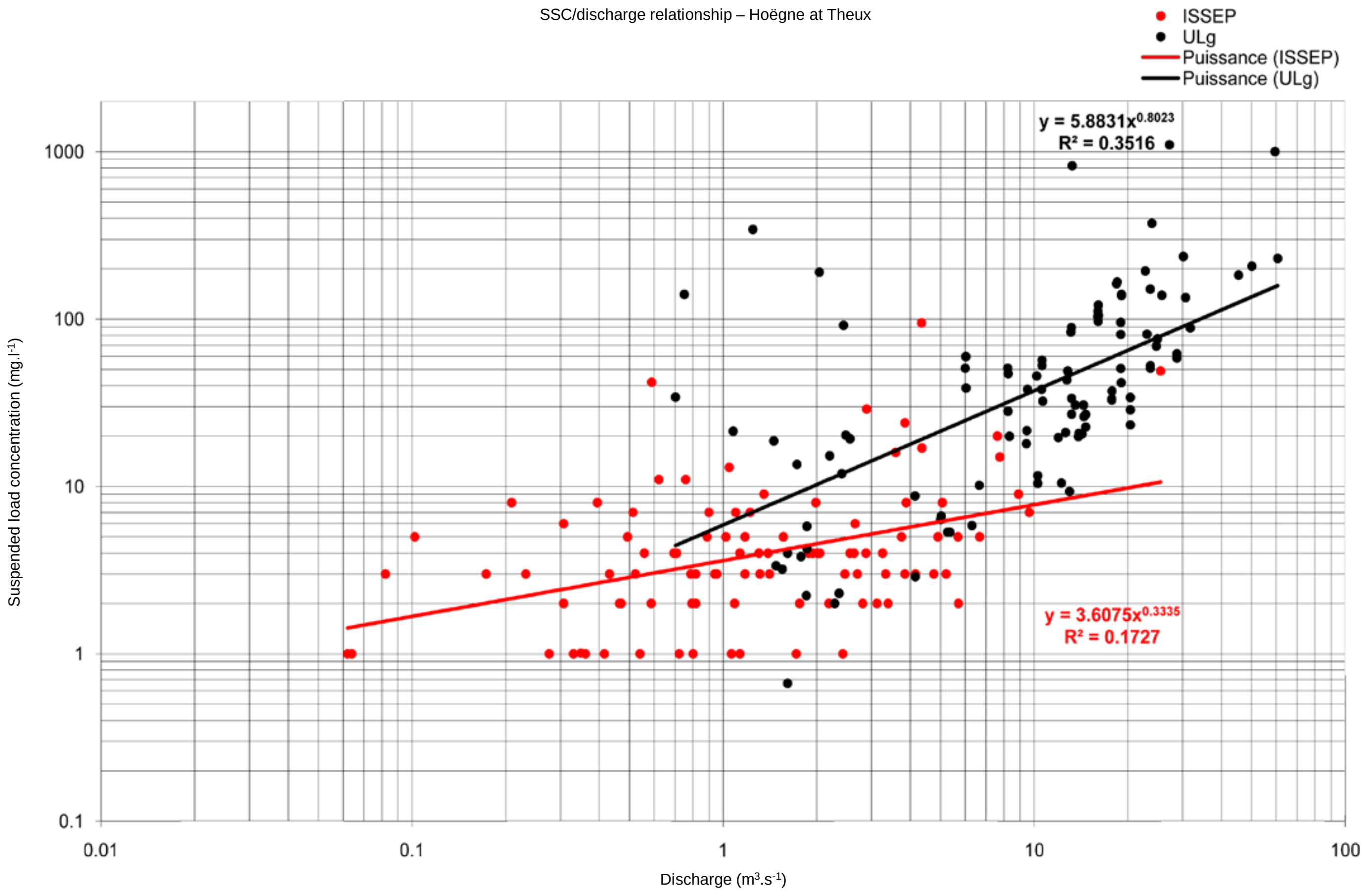


Technical issues encountered due to high sediment load concentrations

- Technical issues due to the clogging of the probes in high sediment concentration environments
- Impossibility to remove automatically the outliers

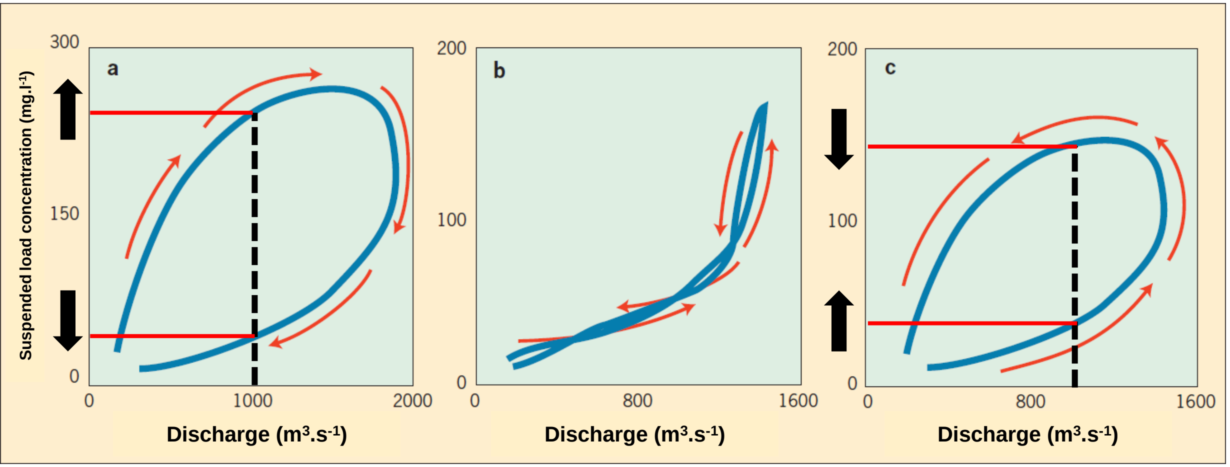
Effects of the sampling frequency on the sediment yield estimation

- Comparison of ULg flood-triggered samples and ISSeP monthly samples made at fixed dates (Scientific Institute of Public Service)



Hysteresis phenomena in high temporal resolution turbidity data

- Sedimentary behaviour of the watersheds: highlighting hysteresis effects → location of the sediment sources and chronology of floods



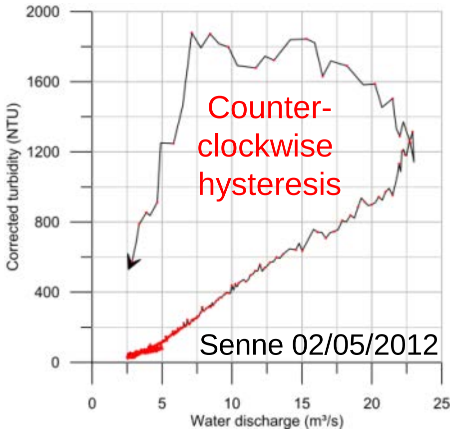
Different types of hysteresis observed in the relation between the concentration of suspended sediment and the discharge during a flood event:

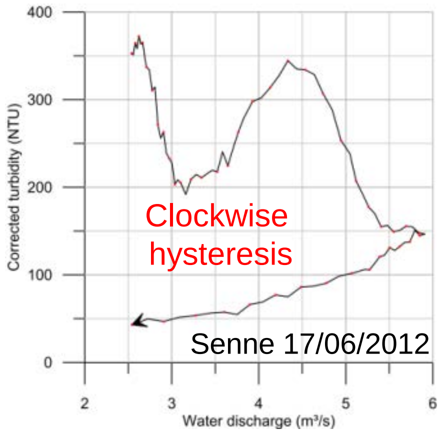
- a- **Clockwise hysteresis** → local sediment sources
- b- Absence of hysteresis;
- c- **Counter-clockwise hysteresis** → distant sediment sources.

(according to Dupont *et al.*, 2001)

Seasonal distribution of each type of hysteresis observed

River and type of flood event	*Spring*	*Summer*	*Fall*	*Winter*
PETITE GETTE				
Clockwise hysteresis	5	6	1	7
Counter-clockwise hysteresis	4	6	5	1
GRANDE GETTE				
Clockwise hysteresis	0	1	4	0
Counter-clockwise hysteresis	1	0	1	0
DYLE				
Clockwise hysteresis	4	3	2	4
Counter-clockwise hysteresis	0	0	1	0
SENNE				
Clockwise hysteresis	3	0	0	0
Counter-clockwise hysteresis	1	0	2	0





Analysis prospects

- PhD researches are focused on these topics:
  - Long-term flow rate series reconstruction in order to compare denudation rates over the longest time series for about 80 watersheds
  - Comparison of the denudation rates comparison obtained through water sampling with literature data estimated from other techniques (C14, cosmogenic radionuclide dating, dam filling) in the same environmental conditions
  - Estimation of the effects of the sampling frequency on the estimation errors and underestimations
  - Determination of the most appropriate technical solutions to measure the concentration of suspended solids in rivers with high silt/loam load

Conclusions

- Comparison of methods for the estimation of the long-term high resolution denudation rate in 80 watersheds from 16 to 2,900 km^2
- Demonstration of a regional differentiation in the erosion rates, particle size and proportion of organic matter due to soil and land cover differences
- Evaluation of field issues in turbidity measurement experiments (clogging of the sensors, ...)
- Characterization of flood chronology, sediment sources temporal and spatial relationships through hysteresis analysis
- Effects of the sampling frequency on the SSC/Q relationships

Dyle, Leuven