Memo

To
Anyone concerned about the subject adressed in this memo

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Subject
Downstream ecological risks in the Meuse from historically contaminated upstream river banks

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Management summary

Floods and storm flows can remobilize historically contaminated sediments from upstream riverbanks. During extreme high water events, the river erodes the riverbanks and transports the contaminated sediment further downstream. Here the contaminants can significantly affect chemical and ecological water quality. Although the scientific evidence base for this is overwhelming, it hardly resulted in policy responses yet.

A possible reason for this policy inertia might be a lack of appealing ‘own backyard’ examples. Therefore, Deltares elaborated a flood event affecting the severely contaminated Flémalle site near Liege (a former coke plant site) as just one typical example for many of such riverbank sites along the Meuse.

Based on a hypothetic but realistic flood event, we estimated the resulting ecological risks in the Meuse surface water downstream of the Flémalle site. For this, we used the state-of-the-art EXPOBASIN model and selected benzene, fluoranthene and cadmium as representative contaminants.

The results clearly demonstrate that especially the concentrations of fluoranthene easily exceed the Water Framework Directive Maximum Allowable Concentration Environmental Quality Standards (MAC-EQS). Sediment dwelling crustaceans are likely to suffer acute toxicity effects at the downstream areas were the remobilized sediments settle again.

1 Introduction

1.1 Problem

Global climate projections currently available anticipate crucial changes regarding extreme weather conditions, oceanographic conditions and the water regime of rivers. These changes will in turn severely modify basic fluvial processes like currents and erosion, thus inducing important physical, geochemical and biological reactions. Several recent research activities, such as undertaken in the European Commission funded integrated projects AquaTerra (www.eu-aquaterra.de) and Modelkey (www.modelkey.org), concluded that floods and storm flows will remobilize historically contaminated soil or sediment from riverbanks and floodplains. Furthermore, they concluded that the remobilized contaminated material is eroded and transported further downstream, where it affects chemical and ecological water quality. Although the underpinning scientific evidence base is overwhelming, it hardly resulted in policy responses yet (Brils, 2010).

1.2 Objective of this memo

There are many possible reasons for this policy inertia. One possible reason for this policy inertia is the lack of appealing examples of quantified 'cause-impact relationships'.[1] _

The objective of this memo is therefore to elaborate an appealing 'own back yard' example, where clearly quantified downstream risks result from remobilized contaminants from upstream riverbanks.

We hope that this memo will help to trigger a more thorough analysis of such risks, e.g. to start with the Meuse basin, which is the case example in this memo. Based on such a thorough risk analysis, contaminated sites on riverbanks could be prioritized for taking measures, including cost-effective measures aimed at reducing the risks of erosion/remobilization.

1.3 Case example: the Flémalle coke plant site

As case example, we selected the Meuse river basin and specifically the historically contaminated Flémalle riverbank site near Liege in Wallonia. This former coke plant site is heavily contaminated with a cocktail of heavy metals, polycyclic aromatic hydrocarbons, aromatic compounds and cyanide. We selected this site because there is enough background information available from the AquaTerra project, where the site was meticulously studied.

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[1] Another possible factor for this policy inertia is the fact that current water quality management focuses more on continuous point sources and diffuse pollution and less on prevention of incidental pollutant release. Also the fact that water management and the WFD focus more on water quality and less on quality of suspended matter, sediments and floodplains, could explain the lack of interest in the remobilization of contaminated sediments.

Although the Flémalle site is currently being remediated[2], we think it is still suitable as real world case example as on the banks of the Meuse, several other historically and severely contaminated industrial sites remain. Contamination at many of these sites is located near, or even at the soil surface, which makes it very susceptible to mobilization and erosion during flooding.

To our knowledge, so far no full river basin scale risk analysis is performed for the remobilization of contaminated sediment and riverbanks of the Meuse. However, SPAQuE (www.spaque.be) has inventoried the contaminated sites in the Walloon part of the Meuse[3].

2 Materials & methods

2.1 General

Briefly, the study approach is as follows:

A hypothetic but realistic flood event is simulated. It is assumed that part of the contaminated riverbank at the Flémalle site is eroded because of this flood event. The resulting transport of dissolved and particle bound concentrations of contaminants is modeled with the state-of-the-art EXPOBASIN model (see appendix A). The resulting downstream concentrations are compared to target values and conclusions are drawn with respect to the ecological risks.

The study approach consists of three different steps:

1. Collection of data for the Flémalle site and for defining of a realistic flooding induced erosion event (see section 'Data collection');
2. Gathering of information regarding the background concentrations and loads of key substances in the Meuse river (see section 'Background concentrations and loads');
3. Set-up of the EXPOBASIN model for the Meuse basin and execution of simulations for a presumed erosion event at the Flémalle site (see section 'Model set-up').

2.2 Data collection

2.2.1 Summary of available information for the Flémalle site

Information in this section has been derived from Batlle Aguilar (2008) and GoogleEarth.

The study site of Flémalle is a former coke plant (1922-1984) site, at the North bank of the Meuse, upstream of the city of Liège (see figure 2.1).
The area of the former coke plant is 11 ha, from the hill slope to the Meuse River. This study focuses on an area of about 8 ha, 400m x 200m, close to the river (figure 2.2). The top layer of the site consists of a backfill layer, composed of material from industrial building dismantlement. The thickness of this layer is variable, estimated between 5 m (depressed area) to 7.5 m (plateau area). This implies that the total volume of the backfill layer in the area along the river is about 5.10^5 m^3.

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[2] See e.g.: http://www.spaque.be/actualites/ActualiteLecture.php?idnews=799

[3] See: http://www.spaque.be/actualites.php?Categorie=Réhabilitation%20de%20sites

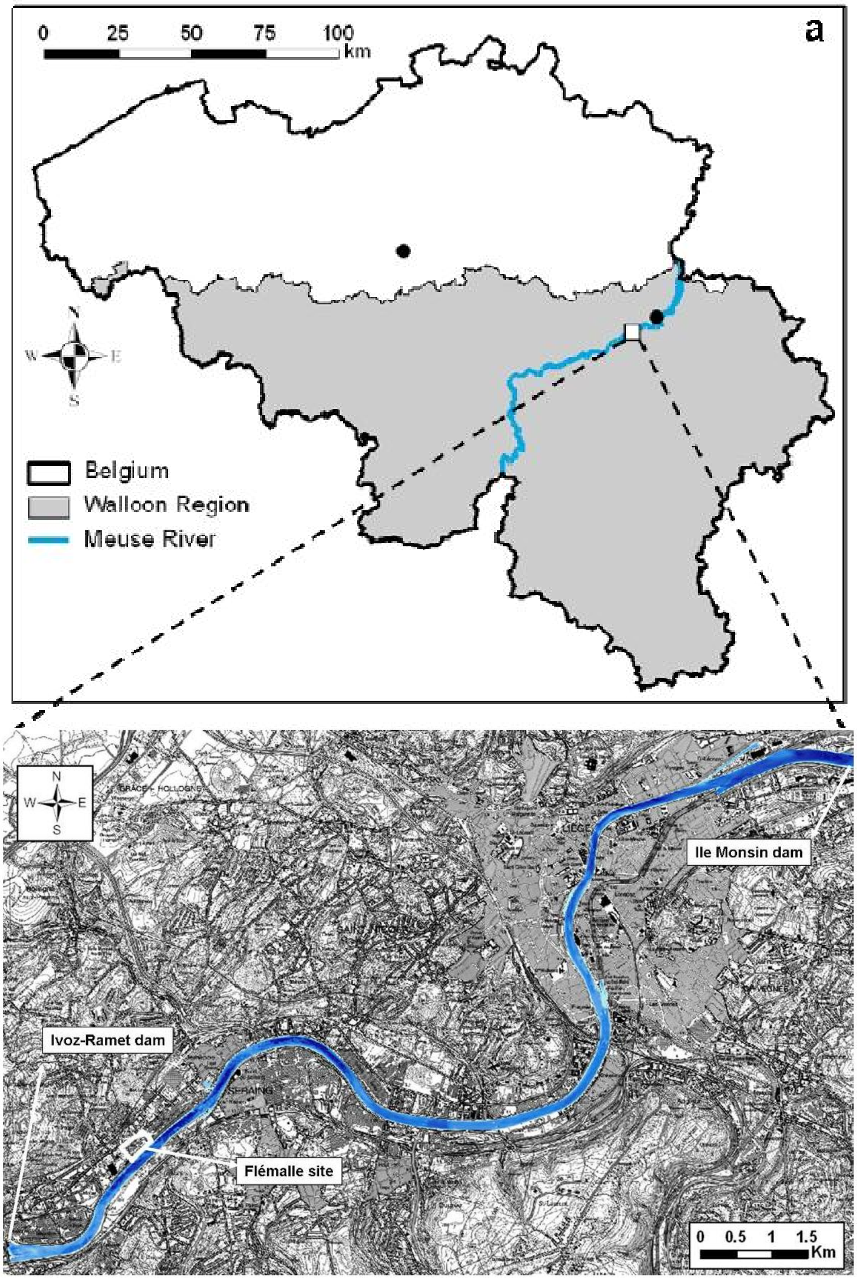

Figure 2.1 Location of the study site.

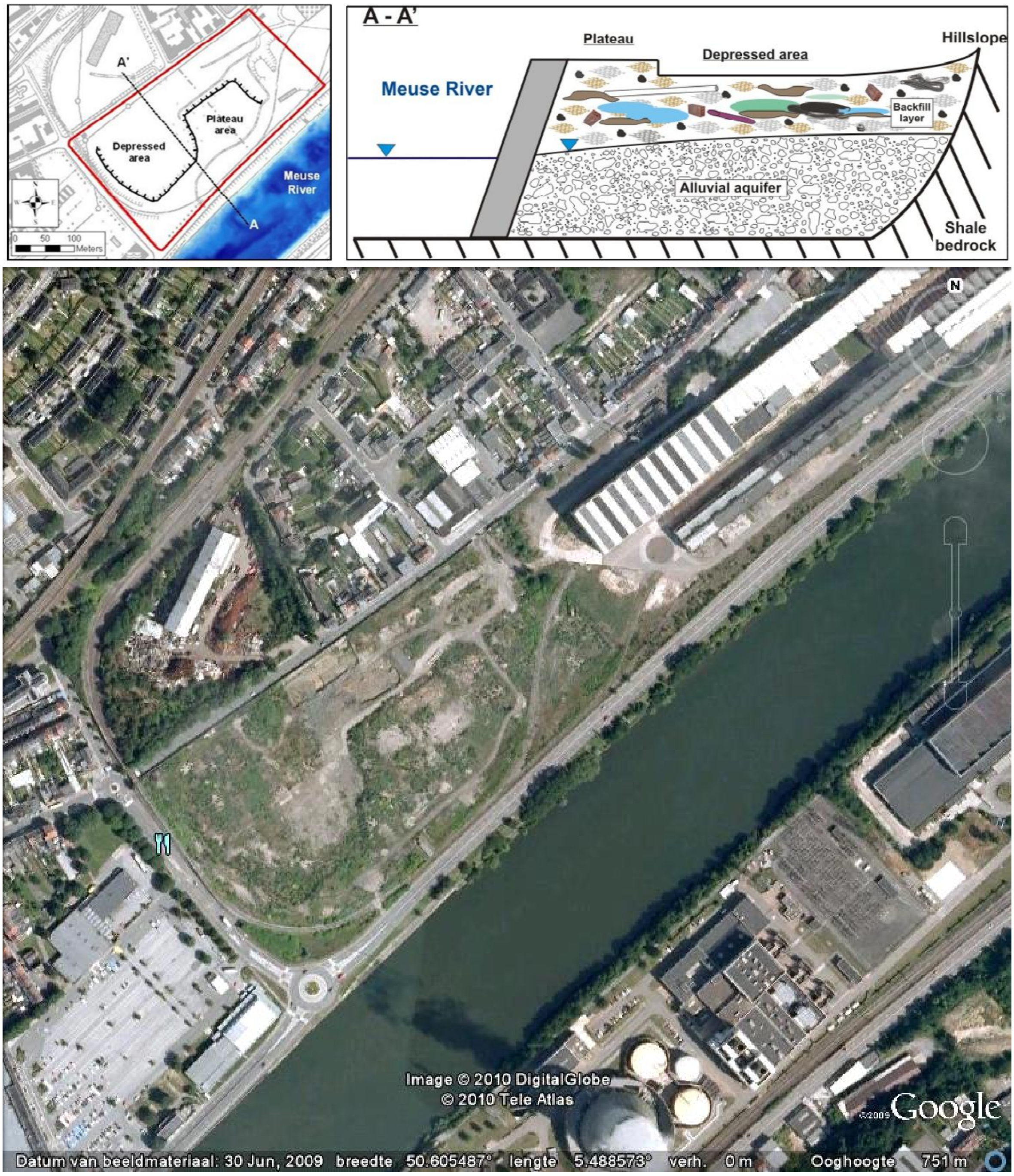

Figure 2.2 Plan view and cross-section of the study site.

Soil quality data from the top layer are presented in table 2.1 (Batlle Aguilar, 2008). We do not distinguish between years or sampling depths, since there is a non-uniform distribution of sampling sites and sampling depths over the years.

Table 2.1 **Summary of soil quality data for the Flémalle site (Batlle Aguilar, 2008)**

Substance	N (of analyses)	P90 value (mg/kg)	Median value (mg/kg)
Benzene	31	4,995	80
Toluene	31	2,235	not calculated
Ethylbenzene	31	140	not calculated
Xylene	31	1,446	not calculated
Naphthalene	31	32,000	not calculated
Fluoranthene	31	8,600	460
Mineral oils	13	100,000	not calculated
As	14	81.6	not calculated
cadmium	14	86	2.67
Zn	14	1,300	not calculated
Pb	14	840	not calculated

Estimates of the quantity of chemicals in the backfill layer can be obtained by multiplying the volume of the layer (5.10^5 m^3) with the dry density (estimated as 1560 $kg.m^{-3}$, at a porosity of 0.4) and the median quality of the layer as listed in table 2.1. In this memo, we focus on benzene, fluoranthene and cadmium, as representative hazardous contaminants for some of the main substance groups measured at the Flémalle site, i.e.: aromatic compounds, polycyclic aromatic hydrocarbons and heavy metals.

2.2.2 Defining a realistic flooding induced erosion event

Our assessment starts with the assumption that a flood event may occur, which causes flooding and thus induces soil erosion at the Flémalle site. We did however not address the question which precise river discharge is required to cause such an event and how frequently such an event could occur, now or in the future under the influence of climate change. Our purpose is to present an example of the possible risks that an erosion event poses on local and downstream ecology.

Our next step was to estimate a realistic eroded mass resulting from the assumed flood event. First, we investigate the shear stresses, which can be anticipated at the site during a flood event. A basic gravity-bed friction equilibrium approach (Manning formula, Jansen *et al*., 1979) allows us to estimate typical (average) values for the local shear stress. The shear stress τ ($N.m^{-2}$) can be estimated as $\tau = H \cdot I \cdot \rho \cdot g$, where H is the local water depth (m), I the longitudinal bed slope ($m.m^{-1}$), ρ the density of water ($kg.m^{-3}$) and g the acceleration of gravity ($m.s^{-2}$) (Van Gils *et al*., 2009a). Although dams regulate the Meuse in Belgium, we assume that this approach is a useful approximation at extreme water levels outside the main river bed. Looking at the river profile, a representative longitudinal slope of the Belgian part of the Meuse is about 0.4 mm/m (data obtained from CCM2.1 database, Vogt *et al*., 2007, 2008). Thus, the shear stress can be approximated by $3.9 \cdot H$, which means that a value of about 2 $N.m^{-2}$ is obtained at 0.5 m water depth, about 4 $N.m^{-2}$ is obtained at 1.0 m water depth, etc. We note that these are estimated spatial averages, and we expect a significant spatial heterogeneity, due to local topography details and due to differences in hydraulic roughness.

Next, we investigate the critical shear stress for erosion of the Flémalle site (the shear stress required to start erosion). Within the MODELKEY project, a research team lead by Dr. Westrich, found critical shear stresses for erosion in the range of 0.3-7 $N.m^{-2}$ for aquatic sediments in groyne fields along the middle Elbe River (Brack and Hein, 2010). Heise *et al*.

(2004) report on sediment stability in the river Rhine and report values ranging from 0.5 - 9 $N.m^{-2}$. The research team led by Dr. Westrich in MODELKEY also concluded that sediment stability is typically highly heterogeneous, so that erosion already starts at relatively low shear stresses.

Based on the considerations above, we assume that as soon as there will be substantial inundation of the site, there will be patches that start eroding. Since the site is characterized by elevation gradients (figure 2.2), we expect that the onset of erosion in certain spots will start a process of eroding gullies with steep local sides, which will become unstable, and thus accelerate the overall erosion process.

The research team led by Dr. Westrich in MODELKEY also investigated typical rates of erosion, and found values in the range of 1-20 $g.m^{-2}.s^{-1}$ (Brack and Hein, 2010). Thus, we arrive at a rough estimate of a realistic mass of eroded material from the Flémalle site. Assuming a typical flooding event of 24 hours duration, erosion over 20% of the total surface of 8 ha and an erosion rate of 8 $g.m^{-2}.s^{-1}$, the total eroded mass is about $1.1 \cdot 10^7$ kg (which represents roughly 1.4% of the total fill volume).

2.3 Background concentrations and loads

Since our objective is to address possible impacts in the surface water just across the Walloon-Dutch border, we use the observed concentrations and loads of chemicals at the border station of Eijsden in the Netherlands as a reference. This station is located about 30 km downstream of Liège. We retrieved data from 'Waterbase' (www.waterbase.nl).

The literature provides different ways to carry out river load calculations. The resulting loads may depend strongly on the selected method (Klavers and De Vries, 1993). In this memo, we used the method recommended by OSPAR. This method is equivalent to the "weighed concentrations method" as reported by Klavers and De Vries (1993). If the availability of data does not support the use of the weighed concentrations method, the direct method is applied. Based on data obtained from Waterbase, we calculated annual mean concentrations and annual loads.

2.4 Model set-up

We used the EXPOBASIN model (see appendix A) to estimate the downstream impacts of the assumed eroded quantity of contaminated mass from the Flémalle site. The Meuse river network has been set up as shown in figure 2.3.

The model was forced with a hydrological period of one year encompassing the highest flood recorded in the last decades (see figure 2.4), being the 1993 flood which reached a peak discharge peak at Eijsden of 3050 m^3/s on 22 December 1993 (see figure 2.5). We introduced it in the model as a river discharge time-series at that location. The model creates a realistic distribution (in space and time) of the transporting fluxes of water and fine particles. This allows an estimate of the fate of the released chemicals (decay, volatilisation, settling of fraction sorbed to particles in flood plains), and provides estimates of the "excess" concentrations (relative to background levels), in water, suspended particulate matter (SPM), sediment and biota. For details, we refer to Van Gils *et al*. (2009a).

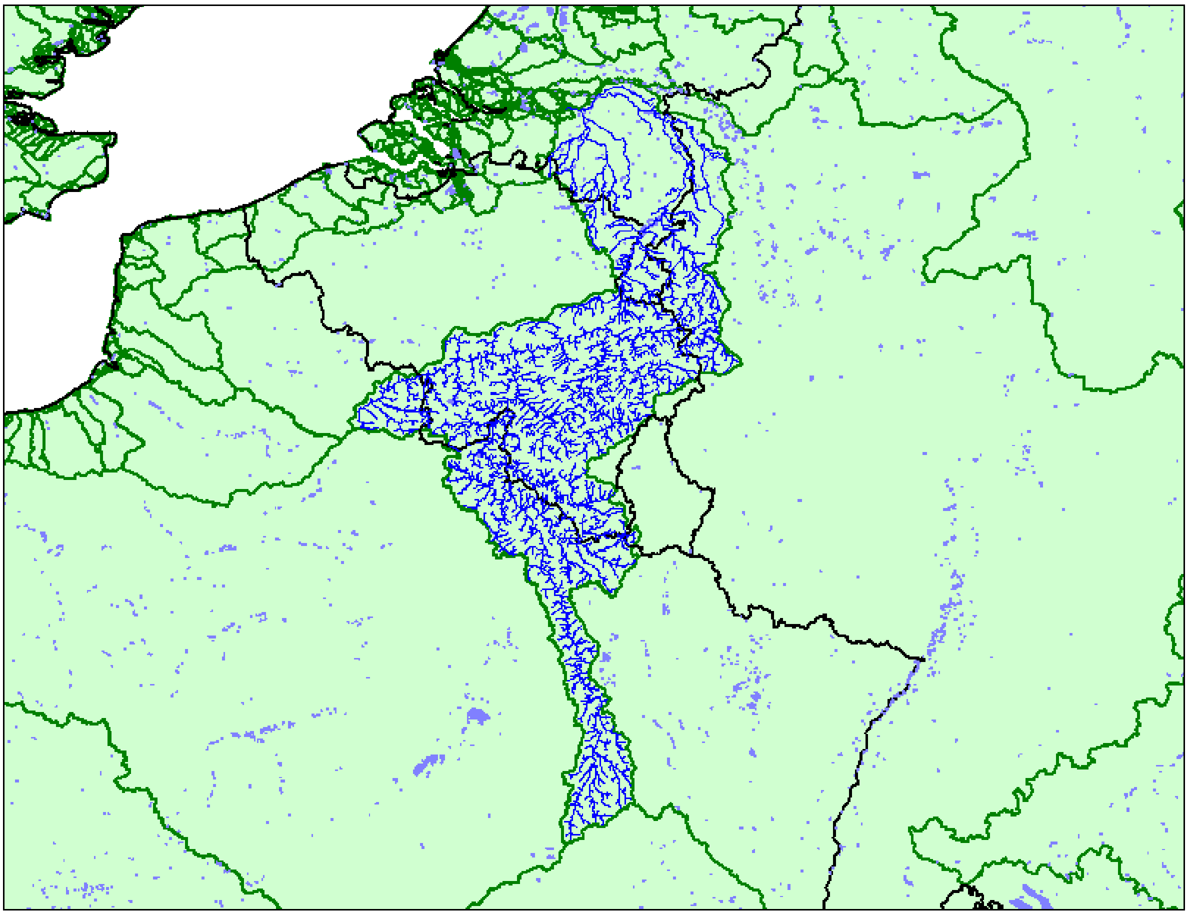

Figure 2.3 River network in the EXPOBASIN application to the Meuse river.

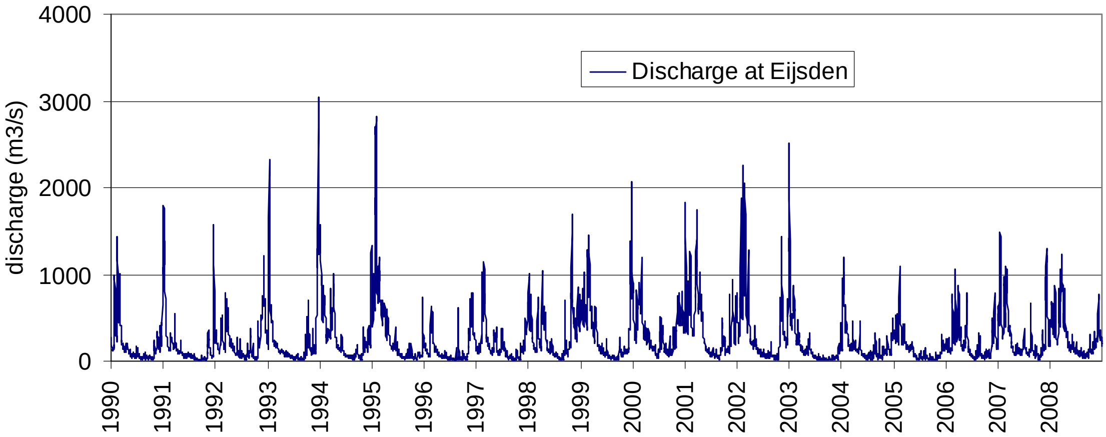

Figure 2.4 Meuse discharge at Eijsden for 1990-2008 (www.waterbase.nl).

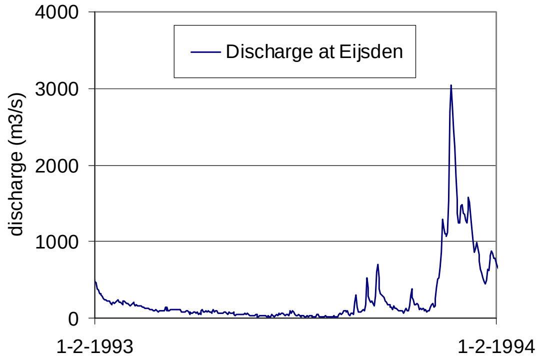

Figure 2.5 **Meuse discharge at Eijsden from 1 February 1993 to 1 February 1994.**

Again it is stressed that we do not pretend that this 1993 flood would be enough to cause the Flémalle site to erode (probably not, because otherwise it would already have taken place in 1993). We just have used the 1993 discharge values in order to present a realistic flood event.

In this case, we try to arrive at absolute exposure estimates not only for dissolved concentrations but also for compounds sorbed to fine particles, which is strictly speaking out of the validated range of applications of EXPOBASIN (see appendix A). Therefore, we verified the simulated time series of SPM (see Appendix B).

The model was further forced with an erosion event on 22 December 1993, as discussed in section 2.2.2. The estimated eroded masses of benzene, fluoranthene and cadmium are presented in table 2.2. The behaviour of the modelled contaminants was characterized by the parameters presented in table 2.3.

Table 2.2 **Eroded mass of contaminants.**

Parameter	**Unit**	**Benzene**	**Fluoranthene**	**Cadmium**
Eroded mass of soil	kton	10.92	10.92	10.92
Contaminant content of soil	mg/kg	80	460	2.67
Eroded mass of contaminants	kg	874	5023	29.2

Table 2.3 **Contaminant properties.**

Parameter	**Unit**	**Benzene**	**Fluoranthene$^{(2)}$**	**Cadmium**
Partition coefficient metals, $K_{solid\text{-}water}$	m^3/kg	n.a.	n.a.	130 (1)
Partition coefficient organics, log K_{oc}	log(l/kgOC)	2.93 (2)	6.28 (2)	n.a.
Henry's constant	$Pa.m^3/mol$	0.00539 (3)	$8.3\ 10^{-6}$ (3)	n.a.
Decay rate	1/d	$1.13\ 10^{-6}$ (3)	$1.13\ 10^{-7}$ (3)	n.a.

(1) Van der Kooij *et al.*, 1991.

(2) Estimated field K_{OC}, based on MODELKEY research (Brack and Hein, 2010).

(3) MODELKEY, KEYTOX database.

EXPOBASIN does not provide an estimate of the background levels of contaminants. The results need to be superimposed on observed background levels. These were already discussed in section 2.3.

3 Results and discussion

3.1 Background concentrations and loads

Table 3.1 provides a summary of the background concentrations and loads and compares them to the available data on the Flémalle fill soil quality and to the assumed erosion scenario (1.4% of the fill volume, see section 2.4). We note that the ratio between the eroded mass and the annual load is highly variable between the different substances. For cadmium, the eroded mass is only 1.5 % of the annual load at Eijsden. For benzene the eroded mass is about equal to the annual river load, and for fluoranthene, the eroded mass is almost 9 times higher than the annual load. Graphs of the annual discharge, SPM load, cadmium load and fluoranthene load are provided in Appendix C.

Note that the total eroded amount of soil equals 11 kt (dry weight). This amounts to 3.6% of the average annual load of SPM at Eijsden (300 kt/y, 1999-2008) or 0.8% of the SPM load in 1993 (1400 kt/y).

Table 3.1 **Background concentrations and loads compared to Flémalle data.**

	Benzene	**Fluoranthene**	**Cadmium**
Average concentration (1999-2008) SPM (mg/kg), Eijsden	n.a.	1.74	24.0
Median concentration observed in Flemalle fill (mg/kg)	80	460	2.67
Average river load (1999-2008) total (kg/y), Eijsden	*815*(1)	*577*(2)	4600
Average river load (1999-2008) in SPM (kg/y), Eijsden	n.a.	577	1922
Eroded mass (1.4% of fill), Flémalle site (kg)	874	5023	29.2
Ratio eroded mass / annual load	1.07	8.71	0.015

Note 1: Many samples are below the detection limit of 0.1 µg/L. The load has been roughly estimated by multiplying the annual water discharge and the detection limit.
Note 2: Load calculation for total water concentrations is not reliable, due to many missing values. Load in SPM has been assumed representative for the total load.

3.2 Simulation results

3.2.1 Fate of eroded chemicals

The fate of the chemicals released during the erosion event is summarised in table 3.2.
The model results indicate that up to Eijsden at the Dutch border there is hardly any retention of the eroded mass under the assumed high flow conditions. This is due to the short travel time and to the fact that the river valley is narrow on this stretch. Towards Keizersveer however, the river valley widens, particles settle in the flood plains and riparian zones and the sorbed fluoranthene and cadmium stay behind in the flood plains.

Table 3.2 **Fate of eroded chemicals.**

	Eroded mass (kg)	Mass passing Eijsden (kg)	Mass passing Keizersveer (kg)	Retention up to Eijsden	Retention up to Keizersveer
Benzene	874	873	856	0.1%	2%
Fluoranthene	5023	4915	1714	2%	66%
Cadmium	29.2	29	10	2%	67%

3.2.2 Exposure of the aquatic environment

The concentrations of benzene, fluoranthene and cadmium following the erosion event are calculated along the path of the river. The maximum concentrations at Eijsden are presented in table 3.3. This table shows that the total concentrations more or less reflect the eroded mass. The dissolved fraction is high for benzene and low for cadmium and fluoranthene. The latter two substances show a much stronger sorption to particles. Consequently, the total concentration of fluoranthene is higher than that of benzene, but the dissolved concentration is higher for benzene.

Table 3.3 **Maximum simulated concentrations at Eijsden.**

	C-total (µg/l)	C-dissolved (µg/l)
Benzene	3.32	3.29
Fluoranthene	18.67	1.1
Cadmium	0.108	0.004

As discussed above, particles settle in the floodplains and riparian zones along the river. The quality of the deposits is shown in figure 3.1, in this case for the substance fluoranthene, in µg/kg of dry weight.

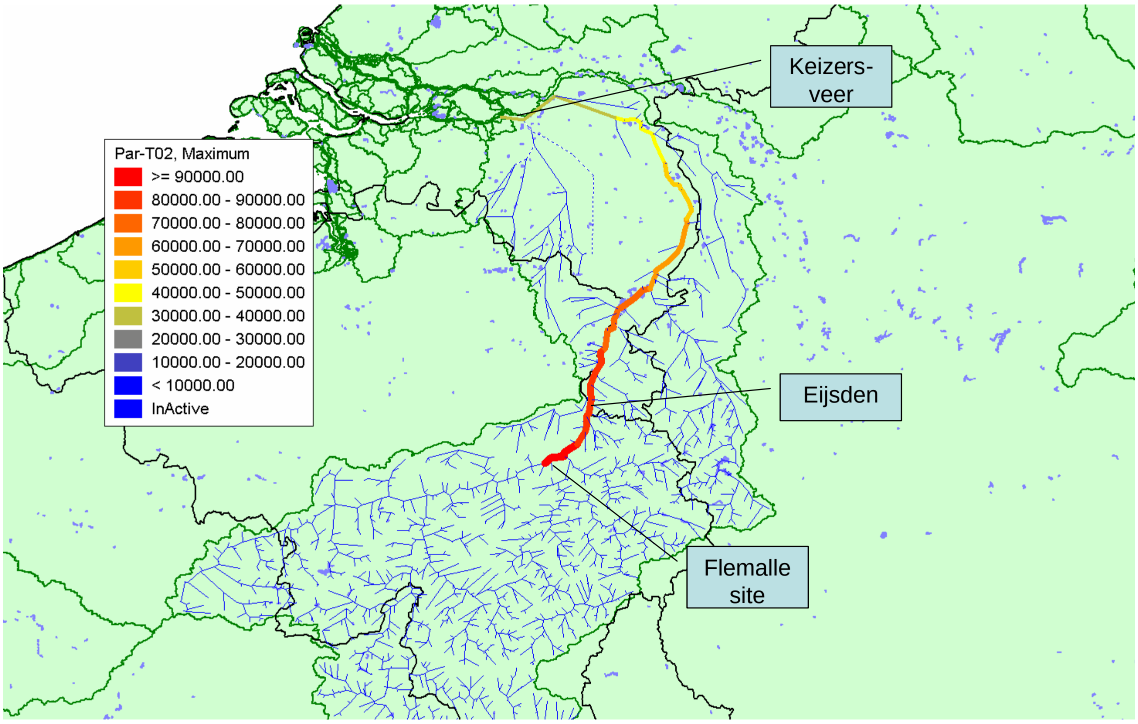

Figure 3.1 **Quality of deposited sediments (µg/kg of fluoranthene).**

3.2.3 Tentative assessment of effects

In order to value these concentrations, we first compare them to Maximum Allowable Concentration Environmental Quality Standards (MAC-EQS) defined under the Water Framework Directive (EC, 2008). The relevant MAC-EQS values and the maximum concentrations simulated at Eijsden are are presented in table 3.4 These results demonstrate that the fluoranthene concentrations are well above the MAC-EQS.

Table 3.4 Evaluation of MAC-EQS at Eijsden.

	MAC-EQS (µg/L)	Maximum concentration at Eijsden (µg/L)	Maximum ratio (-)
Benzene	50	3.32	0.07
Fluoranthene	1	18.67	18.67
Cadmium (dissolved)	0.45-1.5 (dependent of hardness)	0.004	<<1

When the calculated fluoranthene concentrations in the freshly deposited sediment (figure 3.1) are compared to the Environmental Quality Standard (EQS) for sediment / suspended particulate matter (CIS-WFD, 2005), it becomes very clear that the EQS values of 1.1 mg/kg dw is exceeded by a factor 30 (Keizersveer) to 80 (Eijsden).

When the calculated fluoranthene concentrations in sediment are used as input for a so called PAF-calculation (Potentially Affected Fraction) (De Zwart, 2005), it appears that 90 mg/kg dw fluoranthene (Eijsden) in sediment leads to a 48% PAF for macro fauna. A fluoranthene content of 30 mg/kg dw (Keizersveer) still leads to a 33% PAF for macro fauna. These PAF values are calculated with a species sensitivity distribution (SSD) based on chronic EC50 values for macro fauna.
LC50 values for sediment dwelling crustaceans presented in CIS-WFD (2005) vary from 3.4 to 5.1 mg/kg dw and are also by far exceeded.

If the contaminated suspended matter settles in floodplains, the contamination not only affects the ecosystem but could also lead to economical damage due to reduced possibilities for cattle grazing and recreation and higher costs for dredging and soil excavation.

4 Epilogue

4.1 Concluding remarks

In this memo, we have tentatively investigated the potential downstream effects of a hypothetic but realistic erosion event at the Flémalle former industrial site. The assumed erosion event comprises the erosion of a small share (1.4%) of the volume of the fill material at this site (being 7,000 m^3) over a period of 24 hours. Based on soil quality data obtained at the Flémalle former industrial site, this hypothetic erosion event causes the release of 29.2 kg cadmium, 874 kg of benzene and 5023 kg of fluoranthene. Other substances have not yet been analysed in this memo. The eroded mass of benzene is about equal to the annually averaged river load of this substance at the Walloon-Dutch border (1999-2008); the eroded mass of fluoranthene is 9 times higher than the annual river load.

The fate of the eroded amounts of cadmium, benzene and fluoranthene has been simulated with the EXPOBASIN model, using data from the December 1993 flood event in the Meuse to generate time and space dependent fluxes of water and SPM, which carry the substances downstream and determine their fate. The results show that the eroded substances are carried downstream. Cadmium and fluoranthene show significant sorption to particles, and therefore these substances are partly deposited in floodplains and riparian zones on their way towards the Rhine-Meuse-estuary. The simulated concentrations of fluoranthene downstream of the Flémalle site significantly exceed the Water Framework Directive Maximum Allowable Concentration Environmental Quality Standard (MAC-EQS). At Eijsden, the ratio of the maximum concentration and the MAC-EQS amounts to 18.7. Similarly, the concentrations in suspended matter and in deposited sediment layers are expected to exceed relevant Environmental Quality Standards. In freshly deposited sediment, LC50 values for sediment dwelling crustaceans are exceeded and the predicted toxicity by the PAF method is significant.

The simulated erosion event is considered realistic, if the study area will undergo significant flooding for a period in the order of 24 hours. The probability that such a flooding event will actually take place (now or in the future influenced by climate change) has not been investigated.

The analysis presented here focuses on three substances only. Quality data for the Flémalle fill exist for 11 substances. A similar assessment can be made for the remaining substances, but this was not possible given the limited budget we had available for the work done to write this memo.

The present risk assessment successfully relied on two elements (a) a data analysis based on long-term monitoring data, and (b) the use of the EXPOBASIN model, which consistently combines information about the eroded mass, the river hydrology and SPM dynamics and substance properties to provide estimated downstream loads and concentrations.
It is noted that EXPOBASIN calculations actually consist of two steps: (1) the calculation of a realistic distribution (in space and time) of the transporting fluxes of water and fine particles in the river network, and (2) the actual water quality / exposure simulation. The intermediate results from step (1), together with the estimated emission can be considered a complete set of input data for any water quality model capable of simulating the transport and fate of chemicals. Within EXPOBASIN, we use a dedicated version of DELWAQ for this purpose

(DELWAQ is the water quality simulation programme embedded in Sobek, Delft3D, but it has also been coupled to SIMONA, RCA, Telemac, etc.).

4.2 Recommendations

We obtained the present results for one site and for a limited set of substances only. In view of these results, we recommend to take a closer look at the issue of downstream risks resulting from mobilized contaminants from upstream Meuse riverbanks. We particularly recommend the next approach, focused on the entire Meuse river basin:

1. Gather all available information on contaminated sites and the concentrations of hazardous substances at these sites;
2. Screen and prioritise these sites and substances, e.g. in the way as done in this memo;
3. Then at the identified ‘hot-spot’ sites, asses in more detail the actual risk of remobilisation of the “hot-spot” sites and its resulting impacts to downstream ecology.

This environmental risk analysis could eventually be extended with the economical impacts on downstream areas. With the results of this analysis the stakeholders can be identified and the economical aspects of possible solutions can be explored. Comparison of the impacts of remobilized contaminated sediment with the impacts of other sources, should also be addressed in further studies.

With the above identified steps 1 to 3, the contaminated Meuse riverbank sites that pose an actual risk to downstream ecology could be prioritized for further analysis of for taking measures, including measures aimed at reducing the risks of erosion/mobilization.

4.3 Acknowledgements

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APPENDIX A: The EXPOBASIN model

The EU Water Framework Directive (WFD) requires the achievement of good ecological and chemical status in European river basins. MODELKEY (511237 GOCE, FP6) provides strong evidence that toxic chemicals affect the ecological status of European rivers. This was demonstrated on different scales in the case study rivers Elbe, Scheldt and Llobregat. The last MODELKEY newsletter (see www.modelkey.org) provides a summary of these results.

Within MODELKEY, Deltares developed an exposure model aiming at supporting a basin-scale risk assessment for hydrophilic and hydrophobic chemicals[4] (Van Gils *et al.*, 2009). The model, called EXPOBASIN, establishes spatial relations between causes (sources of contamination) and downstream impacts (ecological risk). The model takes into account geometry, hydrology and fine sediment dynamics of European river basins, and the assessment of bio-availability and bio-accumulation is included as well. As a result, the exposure is quantified not only in terms of water concentrations, but also in terms of sediment concentrations and concentrations in biota. By using existing pan-European databases, applications to all European river basins can easily be set up (see figure below).

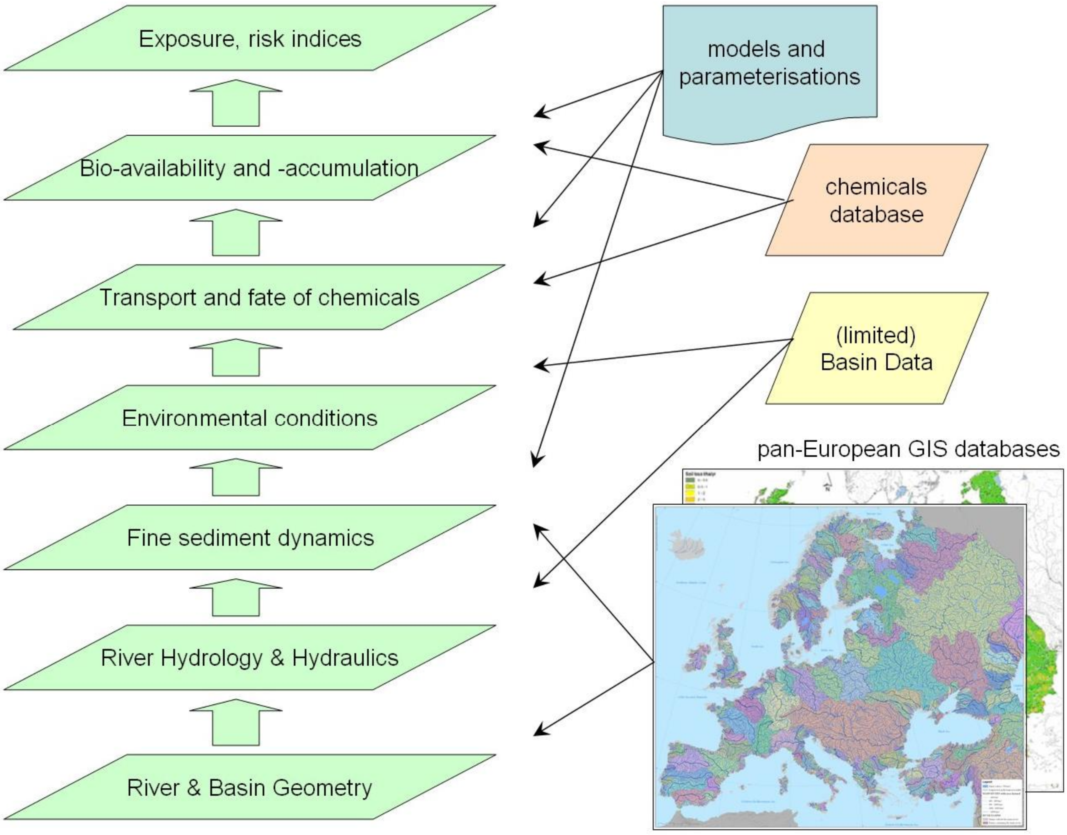

Figure Set-up of the EXPOBASIN model.

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[4] In this context, “exposure” is equivalent to the concentrations of hazardous chemicals in the aquatic environment.

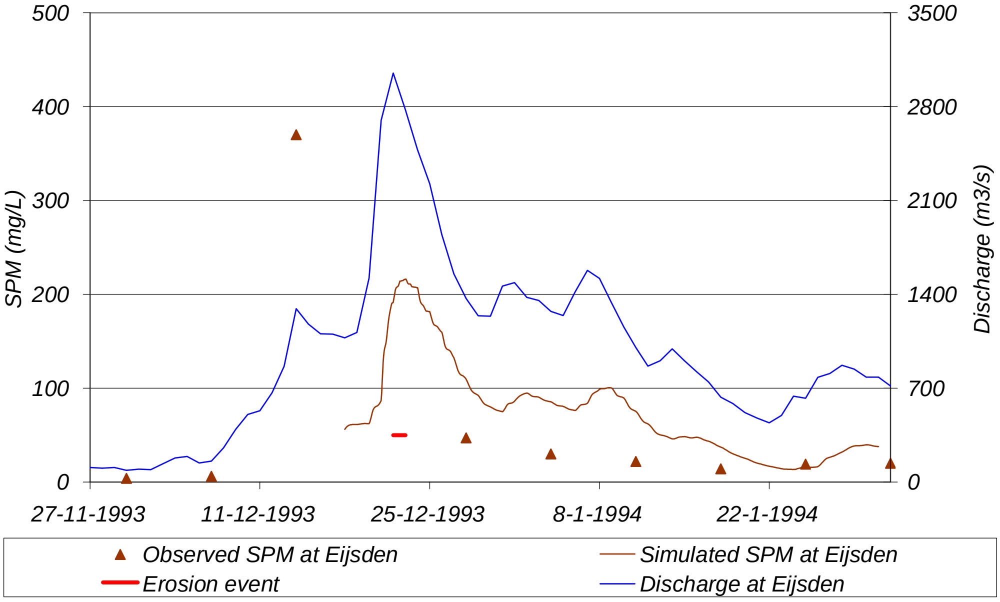
EXPOBASIN provides primarily a quantitative and objective ranking of chemicals and/or sources of contamination, with respect to their estimated downstream impact on the ecology. It can for example be used to support the risk assessment for the potential release of contaminants from historically contaminated sediments as a result of extreme floods, which is a major concern in many European river basins.

The EXPOBASIN model is set up on the basis of pan-European databases providing information on the river basin geometry (CCM2.1), on the input of fine particles due to erosion (PESERA) and on land use (CORINE). Furthermore, the model needs limited input data from the user regarding the river basin hydrology and the environmental conditions. The river hydraulics are parameterised and form the basis for the calculation of the fate of fine particles. The fate and transport of chemicals are modelled based on the previous steps, and on a database of chemical properties. This leads to calculated concentrations in water, suspended particulate matter and sediment. A bio-availability and –accumulation module provides estimates of the concentrations in the aquatic food chain (phytoplankton, invertebrates, fish, and top predators). As a final step, relevant indicators are calculated, expressing the relative environmental risk of the pollution source(s) under investigation.

The calibration/validation of EXPOBASIN, by means of successful applications and assessments for five European river basins, revealed very good results for dissolved compounds. For compounds sorbed to fine particles, the validation of absolute exposure was only partly successful, because the simulated time series of SPM did not always match the available observations. However, it was demonstrated that the model can be applied for prioritizing chemicals or sources of contamination. It was therefore concluded that EXPOBASIN is “fit-for-purpose”, i.e. for use for the work done for this memo.

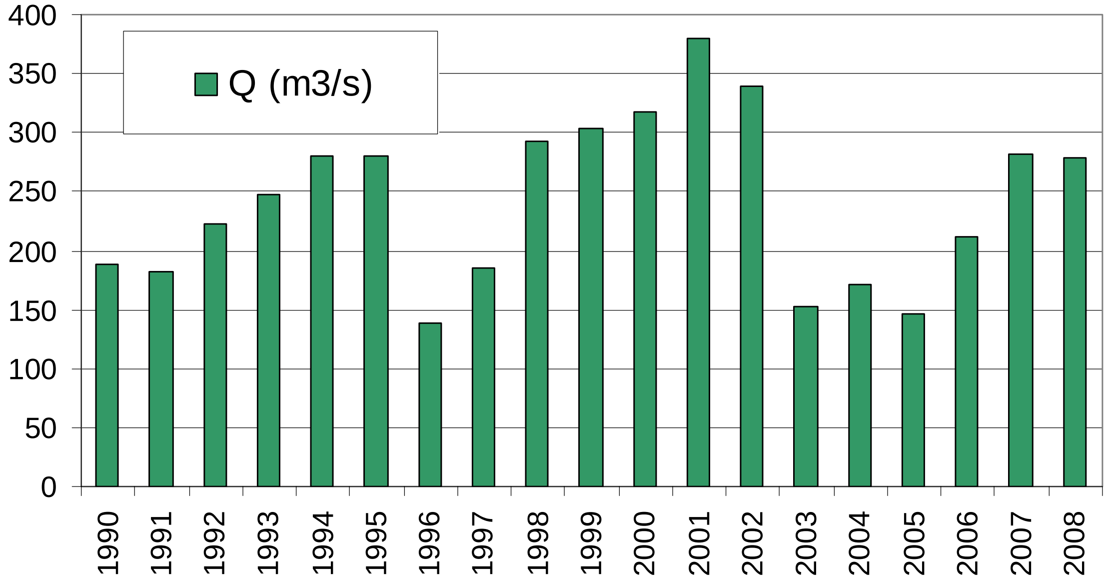
APPENDIX B: Verification of modelled concentrations of SPM

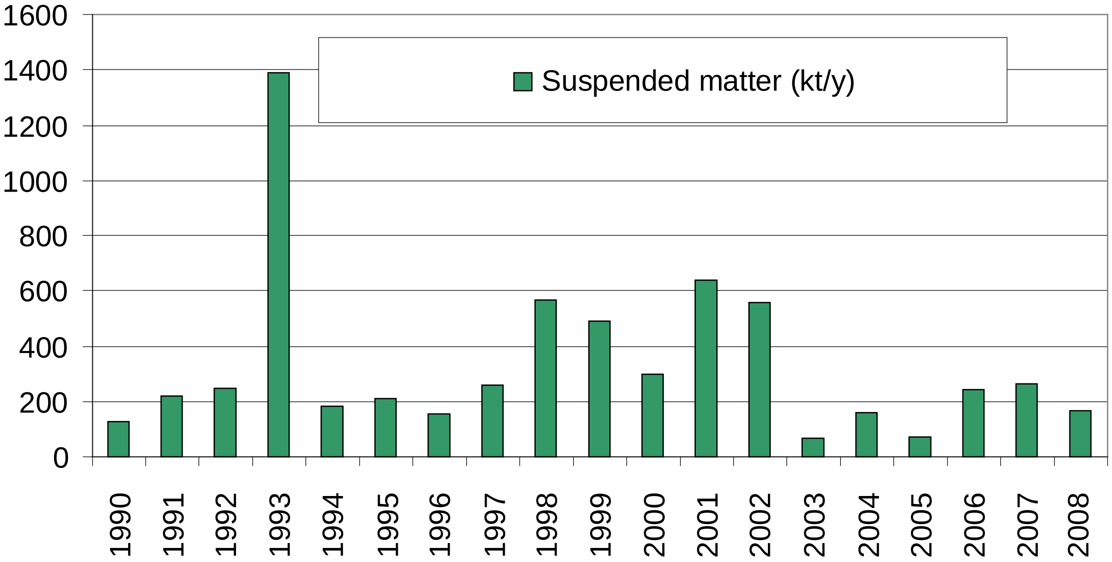
The graph below shows the simulated concentration of SPM at Eijsden, compared to field data. We observe that the sampling frequency is too low to really validate the modelled concentration of SPM. In particular, there is no information to verify that the simulated peak concentration of SPM (>200 mg/L) is right. About 2 weeks before the erosion event, a very high concentration of SPM has been observed at Eijsden (> 350 mg/L). If we look at the discharge as a function of time, we see that this observation coincides with an earlier discharge peak of around 1300 m^3/s. It is known, that after a longer period of low flows, as in the Meuse all through 1993 up to December (see figure 2.5), the first peak flow mobilises a large amount of recent deposits and results in relatively high SPM concentrations. In this case, a second peak flow follows after two weeks. It has a much higher discharge, and thus has a higher eroding capacity, but the pool of erodible material has already been emptied by the first peak flow, and therefore the concentration of SPM is not necessarily as high as during the first peak flow.

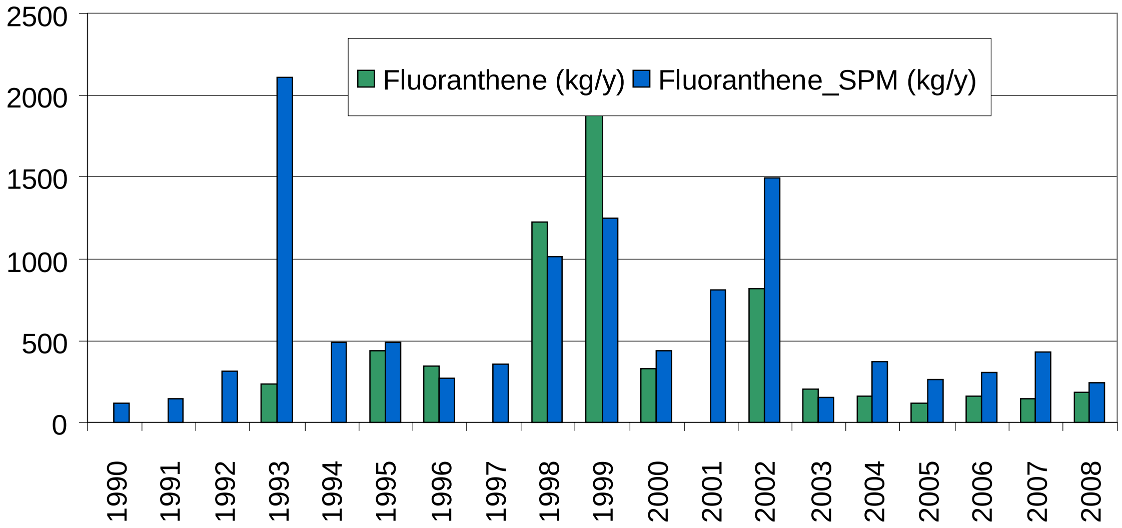


From the results presented here we conclude that the simulated peak concentration of SPM can not be validated, but that the model shows a realistic behaviour, and that the simulated peak concentration probably deviates from the field by less than a factor of 2.

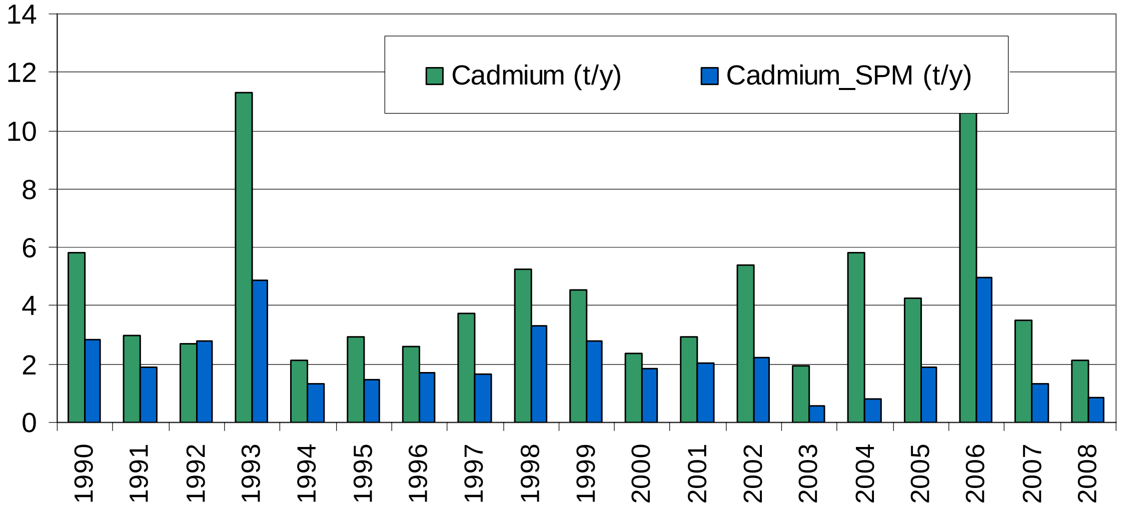
APPENDIX C: Discharge Q, suspended matter fluxes and substance fluxes at Eijsden







2500
2000
1500
1000
500
0
🟩 Fluoranthene (kg/y)
🟦 Fluoranthene_SPM (kg/y)
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008



14
12
10
8
6
4
2
0
🟩 Cadmium (t/y)
🟦 Cadmium_SPM (t/y)
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008