Old contaminated sediments in the Rhine basin during extreme situations

Synergy project Water Quality and Calamities

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Abstract

Sediments play an important role in water resources management. In the past, hazardous contaminants from municipal and industrial wastewater effluents and from agriculture were discharged in large quantities into the water bodies and accumulated within the bottom sediments. Today, relatively unpolluted recent sediment surface layers cover older contaminated sediments. Due to increasing water discharges associated with high precipitation and heavy rainfall events (climate change) and land use changes there is an increasing risk of the resuspension of old contaminated sediment layers and the transport of the particle-bound pollutants downstream in river systems over long.

In this study we focus on the potential release of the old contaminated sediments in the Rhine basin during extremely high discharges and low flows. The main aims of this study are to make an overview of the relevant knowledge gaps and to identify advisable research directions on the basis of existing information (data) and models.

The main conclusion of this study is that insight is missing in the expected remobilisation and recontamination levels of contaminated sediments during extreme situations. The focus not only has to go on the historical contamination but also on the present-day contaminations, and on the identification of actual and potential problems.

Better sediment and water quality measurements (e.g. one hour samples during flooding events) and models (source location) will allow us to get a better understanding of the sediment dynamics in the Rhine basin during extreme situations. This will give us a deeper insight in the substance interactions with sediment and in the water column (geometry of the pollutants).

References	

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Appendices

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1   Introduction

1.1   Scope

Sediments play an important role in water resources management. In the past decades, hazardous contaminants (e.g. heavy metals, organic toxicants and agrochemicals) from municipal and industrial wastewater effluents and various diffuse sources from agriculture were discharged in large quantities into the water bodies. Subsequently, the contaminants accumulated within the bottom sediments of these water bodies.

Today, relatively unpolluted recent sediment surface layers cover older contaminated sediments (in German "Altlasten") deposited in slowly flowing water bodies, which are either permanently or temporarily connected to the main river channel such as near bank groyne fields in waterways or harbours, river dead arms, flood plains and flood retention reservoirs (Förstner and Owens, 2007).

Nevertheless, there is an increasing risk of the resuspension of old contaminated sediment layers and the transport of the particle-bound pollutants downstream in river systems over long distances due to the potential for increasing water discharges associated with both:
i) Anthropogenic activities like land use changes and
ii) Climate change i.e. increased precipitation and heavy rainfall events.

In the Water Framework Directive (WFD) the definition of calamities is the following (Delft Cluster project, 2007): "incidents in which water is accidentally polluted", as result of "circumstances of natural cause or force majeure which are exceptional or could not reasonably have been foreseen, in particular extreme floods and prolonged droughts, or the result of circumstances due to accidents which could not reasonably have been foreseen". Although flood events are natural events, they may have an impact on the condition of a river system, i.e. when (historic) polluted deposits are involved in the process. The quality of the transported matter depends on the quality of the flooding water and the quality of the remobilized deposits within the catchment area.

High discharges may cause the contamination of not-yet-polluted surface water bodies and unpolluted soils subject to flooding. The flood event in the River Rhine in 1999 has illustrated the enormous erosion capacity of flowing water associated with the mobilization, transport and partial deposition of contaminated sediments in tidal harbours, estuaries and coastal areas (Förstner and Owens; 2007).

1.2   Problem definition

Although flood and drought events are natural events, they may have an impact on the condition of a river system, especially when polluted deposits are involved in the process. Extreme droughts, associated with climate change, might increase the risk of deposition of contaminated sediments in slowly flowing water bodies. Due to the potential for increasing water discharges, associated also with climate change, there is an increasing risk of the resuspension of contaminated sediment layers and the transport of the particle-bound pollutants downstream in river systems over long distances. Flood events in the River Rhine have shown the enormous erosion capacity of flowing water associated with the mobilization, transport and partial deposition of contaminated sediments in tidal harbours, estuaries and coastal areas.

In the past, the River Rhine was highly polluted. Contaminants from point and diffuse sources were discharged in large quantities into the Rhine water. Subsequently, these contaminants accumulated within the bottom sediments. Nowadays, relatively unpolluted recent sediment surface layers cover older contaminated sediments deposited in slowly flowing water bodies.

The concept of the mechanism remobilization of old buried contamination "Altlasten" during high-discharge-events is shown in the conceptual picture in Figure 1.1 . We realize that extreme discharge conditions (floods as well as droughts) may affect the water quality and sediment quality in other ways than only remobilisation of old deposited contaminants. During exceptional natural causes which, like during extreme floods mobilisation of contaminated soils and stocks of contaminants from present-day industries or polluted sites outside the usual river bed may cause incidents in which water is accidentally polluted or calamities.

Rhine 'normal'

Rhine 'extreme'

Resuspension   **Mixing & dilution**   **Load**
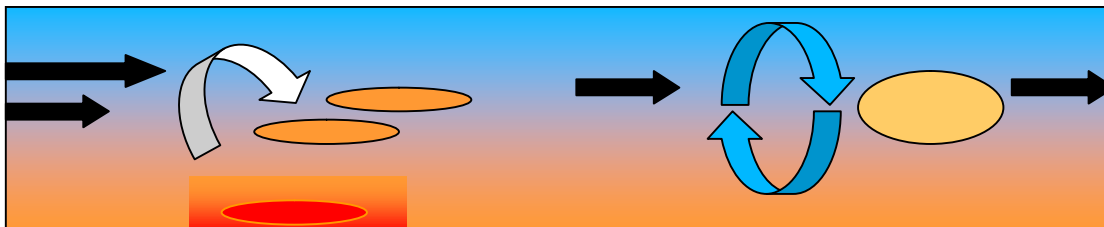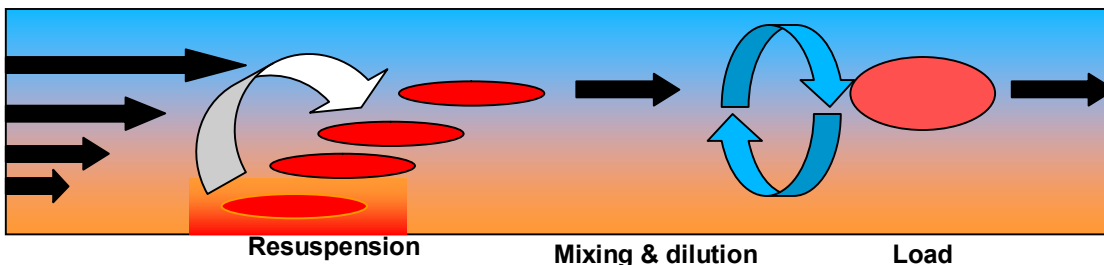
Figure 1.1   Conceptual model of remobilization of buried contamination from the river bed during extremely high discharges

1.3   Research aims

In this study we focus on the problem of the old contaminated sediments (Altlasten) in the Rhine basin during extremely high discharges (floods) and low flows (droughts). The pathway for the transport of historical contamination downstream, to which this study gives attention, is via the sediments from still water zones.

The main aims of this study are to make an overview of the relevant knowledge lagoons and to identify advisable research directions based on the existing information and models. This study should grant the most possible start in the direction of trying to understand better the transport of historical contamination via sediments from still waters and related processes.

In this study we will give special attention to the following main research questions:
- What are the sources of contaminated sediments within the Rhine basin?
- How can the old contaminated sediments help to explain the changes in water quality during extremely high discharges?
- Which data about the (old) contaminated sediments in the Rhine basin are available?
- Which data are necessary to model the release and sedimentation of polluted sediments?

This study has a matching relation with the Delft Cluster project Water Quality and Calamities. In this DC project work Deltares and KIWA together and the focus goes to the autonomic developments of the water and sediments quality under the influence of extreme weather circumstances, climate change and anthropogenic calamities.
Relevant topics of the Delft Cluster project where the results of this study can be an input for are:
- Risks of the distribution of the old contaminated sediments from sediment traps in the Rhine, like dams, on the quality of the Dutch floodplains during extremely high discharges.
- The effects of old contaminated sediments on soil and groundwater quality in floodplains
- Prognoses of the long term development of the recontamination level based on changes in land use and climate.

1.4   The Rhine basin area

1.4.1   Description

The Rhine is the longest and one of the most important rivers in Europe (see Figure 1.2). It has a total length of 1,320 km, which can be divided in six segments: Alps Rhine, High Rhine, Upper Rhine, Middle Rhine, Lower Rhine and Rhine Delta (see table below).

Table 1.1   Division of the Rhine in sections (according to ICPR)

Alps Rhine	From Swiss Alps to Constanz (Boden) lake
High Rhine	From discharge Contanz (Boden) lake to Basel
Upper Rhine	From Basel to Bingen
Middle Rhine	From Bingen to Köln
Lower Rhine	From Köln to Lobith
Rhine delta	From Lobith to the North Sea

The Rhine starts in the Swiss Alps and from there the Alps Rhine flows to the Constanz lake (535 km^2 water surface and 48 billion m^3 volume), which is very important for the catchment of rain and snow water from the Alps, and for an even discharge to the downstream Rhine sections.

Between Schaffhausen and Iffezheim (High Rhine and the German-French Upper Rhine) 21 weirs have been constructed. On the one hand, these weirs are used for generating electricity (about 7000 GWh/year), and on the other hand for navigation, especially in the German-French Upper Rhine.

Until Bonn, the Middle Rhine flows in a typical erosion valley. The Middle Rhine is known because of the stones, rocks river bed. In this section the Rhine has a higher flow velocity and a flooding area with a very small surface due to the erosion trench.

From Bonn the German lower Rhine starts, with the characteristic of flowing through, or close to big cities.

From Bimmen/Lobith the Rhine Delta starts. Until Nijmegen it continues as Upper Rhine and divides in three main reaches: the Waal, the Nederrijn and the IJssel. These main reaches form the Delta area and end in the North Sea. The Rhine reaches are embanked with dikes and there are many dams / weirs.

Important tributaries to the Rhine are the Aare, the Neckar, the Main, and the Mosel.
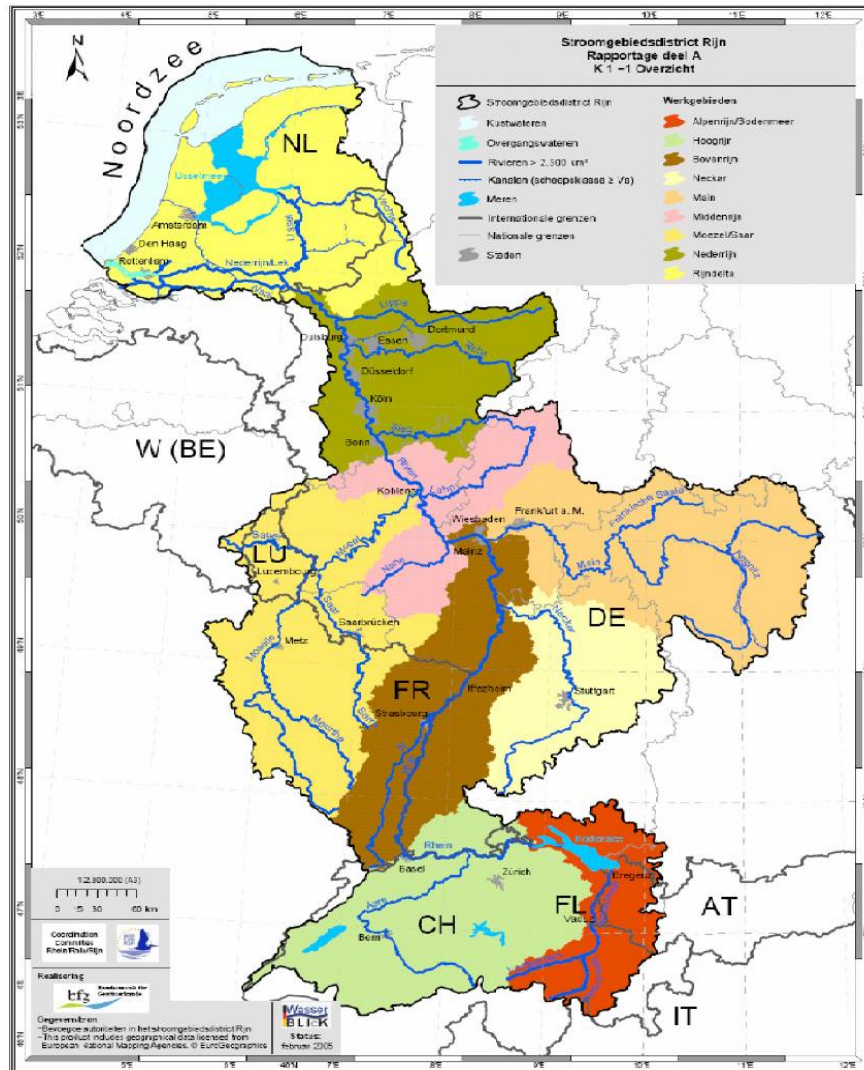
Figure 1.2 Rhine basin

1.4.2 Discharge Regime / Extreme discharges

The Rhine has a mixed discharge regime. The discharged water consists of melt water and rainwater (WL | Delft Hydraulics, 2006). The melt water from the middle age (snow and ice between 700 and 3000 meters high) determines the discharge from Basel downstream, with a discharge peak in the summer months of June, July and August. The discharge downstream of Basel that is generated by precipitation has a discharge peak in the months of January, February and March.

The yearly average flows are 338 m^3 s^{-1} in Constanz, 1,260 m^3 s^{-1} in Karlsruhe-Maxau and 2,270 m^3 s^{-1} in Rees, at the Dutch border.

According to Asselman & Wijngaarden (2002), high discharges of the Rhine in the Netherlands mainly are the result of excessive rainfall during the winter period. These authors give a peak discharge range between 5,000 and 10,000 m^3 s^{-1}.

The figure below shows the discharges at Lobith in the years 1993, 1995 and 1999.
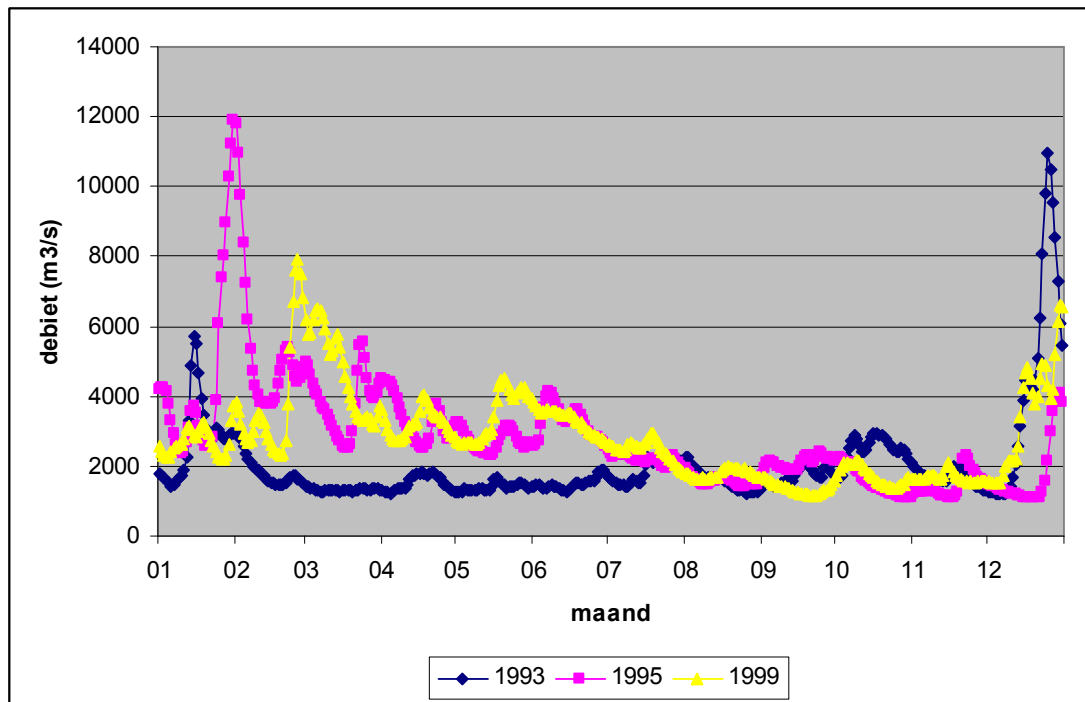
Figure 1.3 Discharges (m³/s) at Lobith in the years 1993, 1995 and 1999. Data from Waterbase

1.4.3 Functions of the river Rhine

According to the International Commission for the Protection of the Rhine (ICPR) The Rhine basin area of about 200,000 km^2 is divided between nine countries (see Table 1.2, Figure 1.2)

Table 1.2 Rhine basin (source ICPR)

Country	Surface (km^2)
Italy	< 100
Switzerland	28,000
Liechtenstein	< 200
Austria	2,400
Germany	106,000
France	24,000
Luxemburg	2,500
Belgium	< 800
the Netherlands	34,000

The Rhine is one the most intensively used rivers on earth. About 58 millions inhabitants live in the Rhine river basin. About 98% of the municipalities in the basin of the Rhine are connected to sewage treatment plants. Most of the big industrial companies have their own waste water treatment plant. Direct discharges have been forced back in the last years. This results in diffuse sources becoming more important, which does not mean that they are the only contribution nowadays. For a further reduction in the emission of harmful substances (including nutrients) also diffuse sources have to be taken into account.

A considerable part of the total chemical production in the world occurs in the Rhine district. Moreover, the mining activities, especially in the Mosel/Saar region and in the Ruhr area and the brown coal winning in the area around the left bank of the German lower Rhine have to be mentioned. The mining activities have decreased strongly, but even today, the effects are still clearly recognized at many places.

Other functional uses of water along the Rhine are the water withdrawals for purposes of cooling, irrigation of agricultural grounds and hydro-electric power.

Furthermore, nowadays the Rhine is the most important navigation way of Europe. The waterways of the Rhine and Mosel have the status of international navigation ways. Via the Rhine and connected water ways, products transferred in the ports of Amsterdam, Rotterdam and Antwerp are transported to Luxemburg, France, Switzerland and the area of the Danube.

The Rhine distributes drinking water to almost 20 million people. Direct withdrawals (Constanz Lake), withdrawals of bank filtrate or withdrawals of water infiltrated through dunes can be found along the Rhine.

Due to the high pressure on the river caused by the human activities mentioned above, the Rhine was strong polluted in the past. In the beginning of the sixties of the last century, Switzerland, France, Germany and the Netherlands have signed an agreement (through the ICPR) with the aim of improving the quality of the Rhine water. As a consequence of this act the chemical, biological and hydromorphological quality of the Rhine has improved strongly, compared to 20 to 30 years ago. Point source pollution has been significantly reduced, so that nowadays the efforts to further improve the water quality are directed more towards reducing diffuse pollution sources. Since 2000, the focus is on protection of the ecology in the Rhine district, protection against high discharges and protection of the shallow groundwater that interacts with the Rhine water.

1.5   Rapport structure

Chapter 2 gives an overview of the different contaminating sources and the contaminants. The development of the sources in space and time is also commented in Chapter 2.

Extreme situations may alter the quality of the sediments, as well as the water quality. The quality of sediments during extreme situation in the River Rhine is addressed in chapter 3. Chapter 4 deals with the water quality in extreme situations. Both chapters cover the relations of the sediment quality in three situations: normal situations, flood, and drought.

Chapter 5 gives an inventory of the available data regarding water and sediment quality information. Chapter 6 gives an overview of the requirements for a contaminated sediment transport model, and the available models for the entire Rhine catchment. The information (data & models) gaps are in both chapters addressed.

Finally, discussion, conclusions and recommendations are handled in Chapter 7.

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2   Sources of contaminated sediments within the Rhine catchment

2.1   Introduction

Surface water and sediments of the Rhine catchment area have been and still are influenced by different contaminating sources. This chapter gives an overview of these different contaminating sources. Generally, the contaminants can be classified into nutrients, heavy metals, and organic micro pollutants. This chapter treats also each group of contaminants separately and will include a survey of more specified sources and source locations. Finally, the development of the sources in space and time is commented at the end of this chapter.

2.2   Description of the sources

The International Commission for the Protection of the Rhine (ICPR) has made a general survey of these sources in order to fulfil the requirements of the Water Framework Directive (see also literature list). The ICPR identified fourteen different emission pathways by which contaminants can enter the Rhine catchment:
- Atmospheric deposition
- Groundwater
- Drift and farmland run-off (in Dutch "erfafvoer")
- Erosion
- Run-off
- Drainage
- Rain water (outlet)
- Communal
- Mixed sewerage; surplus discharge
- Untreated waste water
- Sewerage; not connected to communal
- Industry
- Direct discharge
- Natural background

Communal and industrial sources can be identified by the presence of waste water treatment plants and industrial areas, respectively. Figure 2.1 and Figure 2.2 show the locations of these communal and industrial sources in the Rhine catchment area. Two large clusters of sources can be identified:
- Ruhr area; a high amount of large waste water treatment plants and chemical and mining industry close to the Rhine River. Tributaries, like the Lippe, also contain other industrial activities.
- Rotterdam harbour area; relatively low amount of waste water treatment plants, but a lot of industrial activity, especially chemical industry.

Other emission pathways, like groundwater and drainage water, do not contribute to one specific location in the Rhine River and are therefore called diffuse. Agriculture and urban activity largely influence the contaminant content of these diffuse sources. An indication of the contribution of each source (communal, industry and diffuse) to the total discharge of different contaminants in the Rhine river is given in Table 2.1.
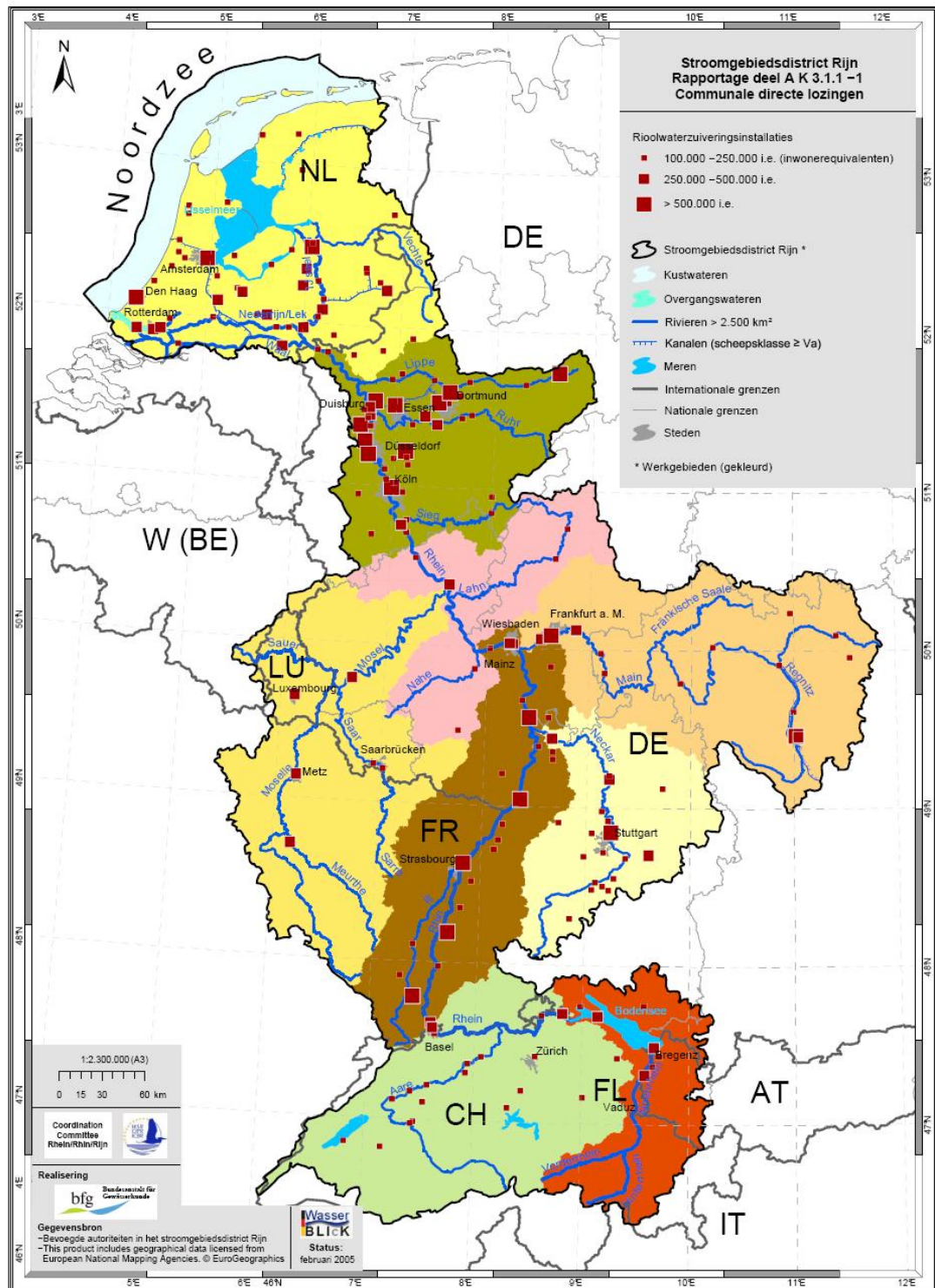
*Figure 2.1   Locations of waste water treatment plants of the Rhine catchment area. The size of the block
symbol indicates the size of inhabitant equivalents (amount of inhabitants which are
connected to the waste water treatment plant) (ICBR, 2005b)*
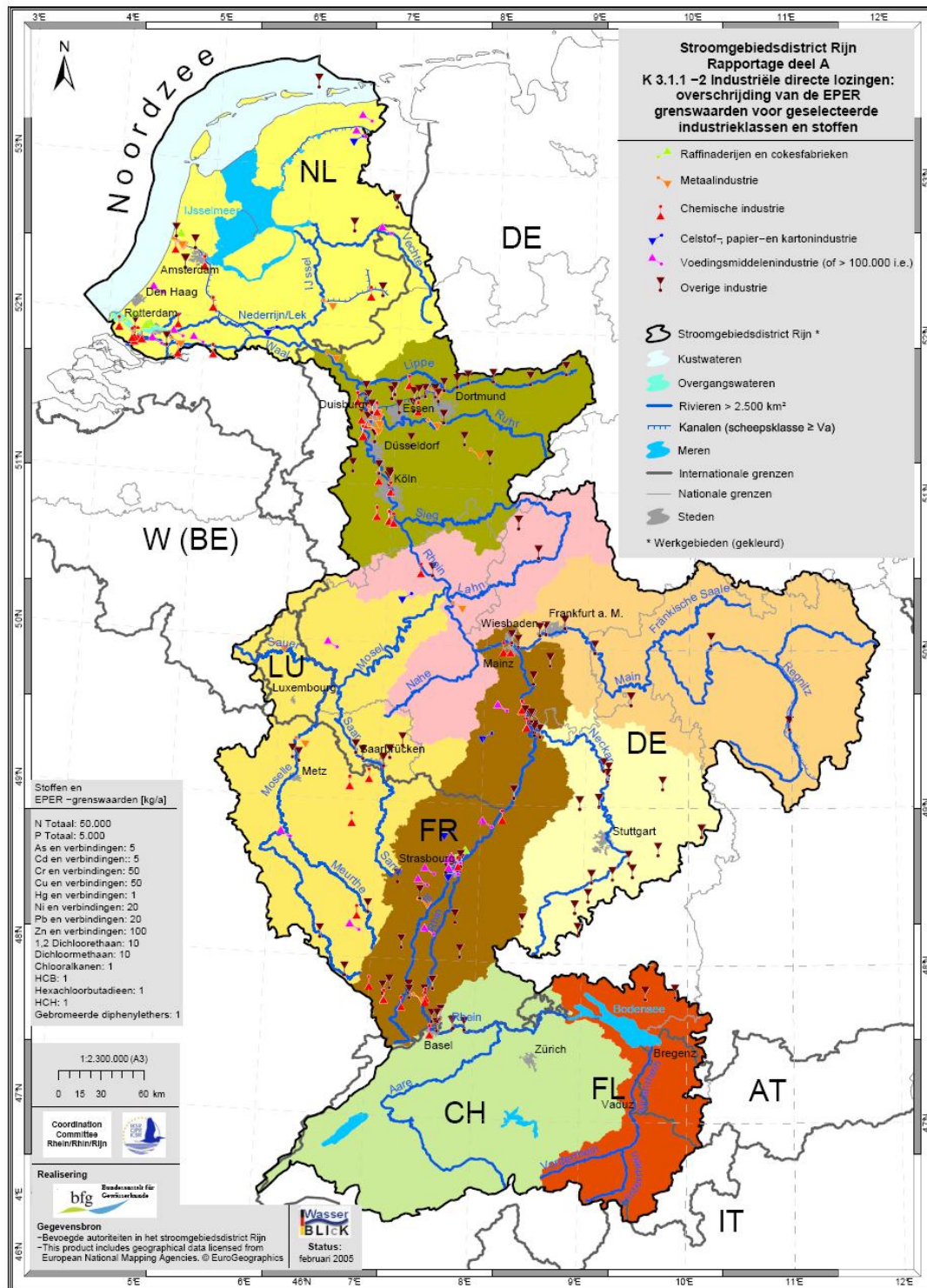
Figure 2.2 Locations of industrial active areas of the Rhine catchment area. The colour of the symbol indicates the kind of industry: green = refinery and coking plants; orange = metal industry; red = chemical industry; blue = cellulose, paper and cardboard industry; pink = food industry; brown = others (ICBR, 2005b)

Contaminant	Communal (kg)	Industry (kg)	Diffuse (kg)	Total (kg)
Total-N	107.120.000	22.853.000	289.881.000	419.854.000
Total-P	9.719.000	2.424.000	14.032.000	26.175.000
Cr	11.467	34.791	88.205	134.643
Cu	56.820	48.139	213.627	318.586
Zn	357.689	107.071	1.223.103	1.687.863
Cd	863	809	6.350	8.022
Hg	353	306	1.222	1.881
Ni	31.979	30.993	105.036	168.008
Pb	23.827	19.265	148.882	191.974
Lindane	0	1	219	220

Generally, the contaminants can be classified into three groups;

1. Nutrients

2. Heavy metals

3. Organic micro pollutants

In the following sections each group will be treated separately and will include a survey of more specified sources and source locations.

2.2.1   Nutrients

Contamination of nutrients in the Rhine catchment area is a problem that started in the 20th century. Nutrients are mostly indicated as total-N (nitrate, nitrite and ammonium) and total-P (phosphate, ortho-phosphate) concentration or discharge. Nutrients are a threat to surface water quality posing problems to the ecological functioning of a river system as a consequence of eutrophication. The main contribution of nutrients to the river catchment originates from agriculture. Figure 2.3 and Figure 2.4 specify the contribution of the emission pathways mentioned before to the emission of total-N and total-P in the Rhine catchment.

Almost half of the emission of total-N originates from drainage and groundwater (diffuse sources), which are directly related to agriculture. About 30% of the total-N emission originates from point sources (mainly waste water treatment plants), but also a substantial contribution comes from natural background. Total-P emission mainly originates from point sources with almost 40% of the total emission originating from waste water treatment plants. Erosion, run-off and drainage and groundwater are also important contributors to the total-P emission.
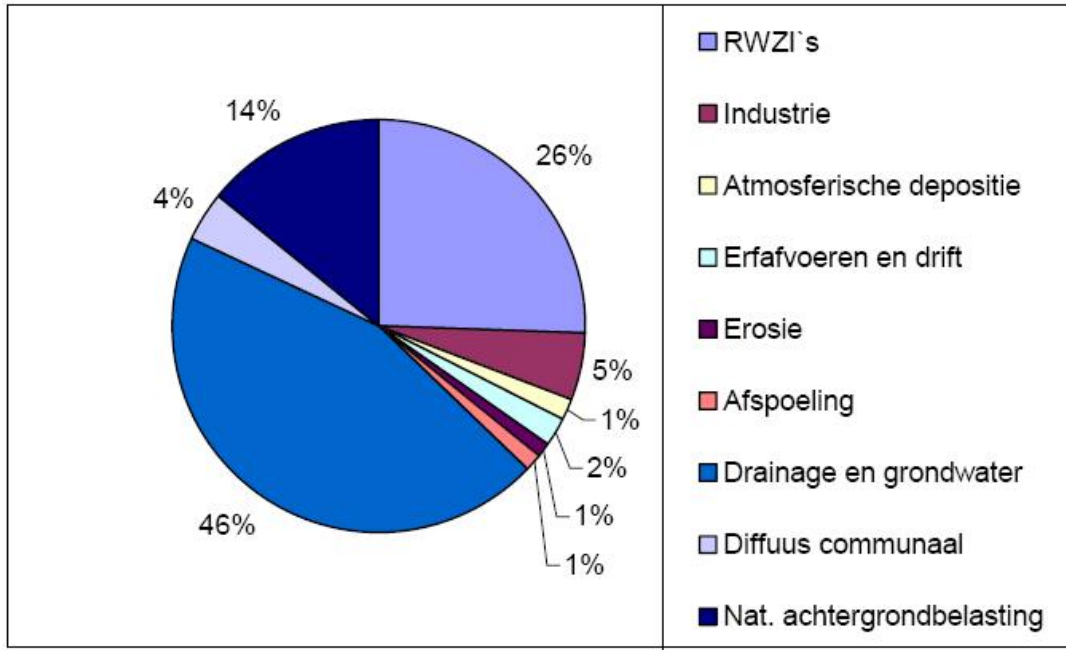
Figure 2.3   Contribution of communal, industrial and diffuse emission pathways to the total emission of total-N in 2000 (total emission = 420 kT) (ICBR, 2003). RWZI = Wastewater treatment plant, Industrie = Industry, Atmosferische depositie = atmospheric deposition, Erfavoeren en drift = Farmland and drift, Erosie = erosion, Afspoeling = run-off, Drainage en grondwater = drainage and groundwater, Diffuus communaal = diffuse communal, Nat. achtergrondbelasting = Natural background
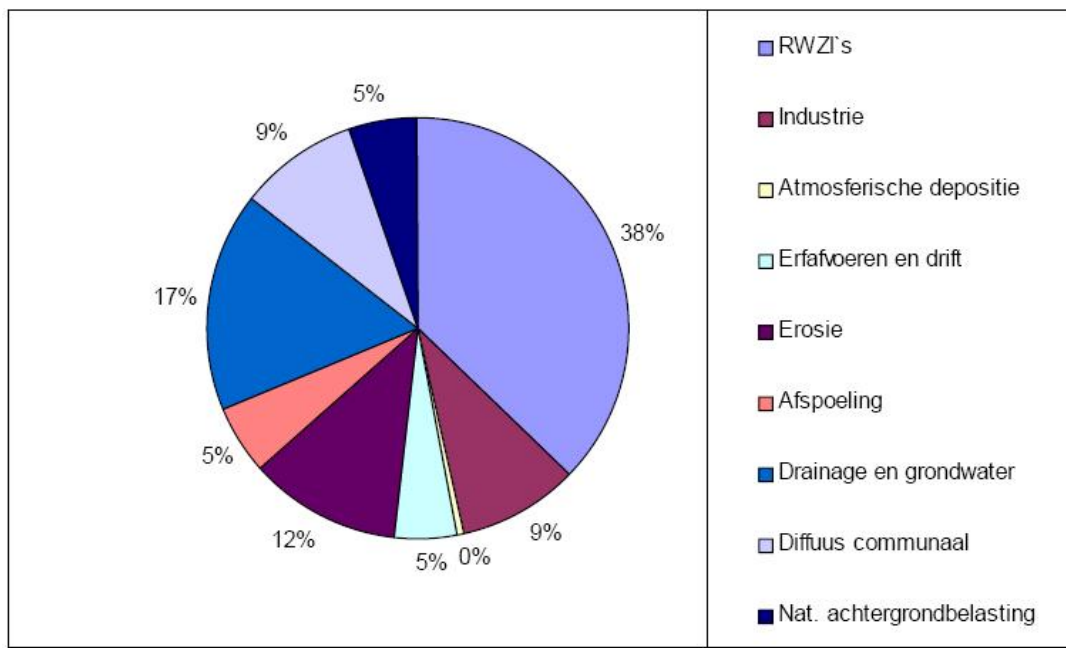
Figure 2.4   Contribution of communal, industrial and diffuse emission pathways to the total emission of total-P in 2000 (total emission = 26 kT) (ICBR, 2003). RWZI = Wastewater treatment plant, Industrie = Industry, Atmosferische depositie = atmospheric deposition, Erfavoeren en drift = Farmland and drift, Erosie = erosion, Afspoeling = run-off, Drainage en grondwater = drainage and groundwater, Diffuus communaal = diffuse communal, Nat. achtergrondbelasting = Natural background

2.2.2   Metals

Metal contamination in the environment has been a problem for more than 150 years. Since the beginning of the Industrial Revolution (around 1850) metal concentrations started to increase in the environment by input of mining and industries. In the last decades also agriculture contributes to metal contamination by use of metals in fertilizers.

Metals have a high affinity for the particulate phase and are mostly adsorbed to the clay fraction, depending on the input source (metals originating from mining waste can also be adsorbed to the silt or sand fraction). Metals adsorbed to the particulate phase can be transported with the suspended matter flow or stored in river bed or floodplain sediment. Table 2.2 indicates the specified (industrial) sources and locations of production for heavy metals of concern in the Rhine catchment area with the main focus on the German part of the Rhine.

Table 2.2   Potential industrial sources of heavy metals of concern in the Rhine catchment from 1985 to 1996 (Heise & Förstner, 2004)

|	**Zn**	**Cu**	**Hg**	**Cd**	**Ni**	**Cr**	**Pb**
Source / industry	Pigment production, Zinc plate production, petrochemical plants, Chloro-alkali-production, Fertilizer production, Steel industry	Galvanic processes, Paper industry, Fertilizer production, Steel industry	Chloro-alkali production, Pesticide production, Paper industry, Fertilizer production, Steel industry	Pigment production, Zn-production, Petrochemical plants, Chloro-alkali-production, Fertilizer production, Steel industry	Paper industry, Fertilizer production, Steel industry	Paper industry, Petrochemical plants, Chloro-alkali-production, Fertilizer production, Steel industry, Leather producing industry	Chloro-alkali-production, Pesticide production, Paper industry, Fertilizer production, Steel industry
Diffuse source	Surface run-off	Antifouling paint, Surface run-off	Surface run-off	Agriculture Battery			
Location of production	Krefeld Duisburg Kaysersberg (Elsass) Düsseldorf		Rheinberg Uerdingen Dormagen Leverkusen Hürth, Weseling Ludwigshafen Frankfurt Marl (Lippe)	Ludwigshafen Leverkusen Krefeld Duisburg Düsseldorf			

Table 2.2 lists all (industrial) sources which still can contribute to the contamination of the Rhine. As metals are mostly adsorbed to the particulate phase, also historical sources are important to locate and identify. These historical sources ("Altlasten") are specified for the German part of the Rhine by verifying the composition of (old) bed sediment. Table 2.3 lists the areas of concern for each specified metal. A special attention requires the Lippe. For none of the metals is this tributary an 'area of concern', not even, for instance, due to the mercury production at Marl.

Table 2.3   Areas of concern (clarified in text) in the Rhine catchment area and their main contaminating compounds (heavy metals) in sediments, notified by the colour <mark>yellow</mark> (Heise & Förstner, 2004)

	High and Upper Rhine	Upper and Middle Rhine	Lower Rhine		Tributaries							
			Harbour Duisburg Ruhr area	Harbour	Neckar	Main	Mosel	Emscher	Wupper	Ruhr	Erft	Lippe
Cd			■	■	■	■		■		■	■	
Cr			■	■					■			
Cu				■	■		■	■	■	■		
Hg	■	■				■		■	■			
Ni				■			■	■			■	
Pb			■	■			■	■	■	■	■	
Zn			■	■			■	■	■	■	■	

2.2.3   Organic micro pollutants

Organic micro pollutants include a wide variety of substances with different sources and pathways to be introduced into the catchment area. In the river system most organic pollutants are adsorbed to the particulate bulk organic phase and transport and storage is therefore comparable with heavy metals. Table 2.4 lists the potential sources of the most important organic micro pollutants in the Rhine catchment area. Production of some organic pollutants is restricted nowadays.

Table 2.4   *Potential industrial sources of organic substances of concern in the Rhine catchment (Heise &*
Förstner, 2004)

	PAH	**PCB**	**HCB**	**TBT**	**DDT + DDD + DDE**	**Dioxins**	**Chloro-organics, esp. γ-HCH**
Source/ industry	Coking plant, Aluminium-industry	PCB production, Use in transformers, use in capacitors, as hydraulic oil in plastics	Production of: Tetrachloroethene, Trichloroethene, PCNB Electrode, PVC production	Antifouling Fungicides	Industrial emissions, Insecticides	Production of chlorophenol Steel, iron and metal working industries	Pesticide, PVC production, paper industry
Diffuse source	Incineration	Building-material, Wood protection, Disposal sites	Tyres, Seed protection, Agriculture, Wood protection			Incineration, Combustion	Disposal sites
Location of production	Duisburg-Hochfeld Linz	Leverkusen Ludwigshafen	Leverkusen Rheinfelden Arnhem Uerdingen Dormagen Frankfurt Mannheim	Seseke (Lippe)			Köln, Mohnheim, Mannheim
Production restricted?		Selling and use prohibited since 1989 (Germany)		Application of TBT containing antifouling paints for ships < 25 m 10.12.89	In most countries application is forbidden.	No intentional production	Marketing and use prohibited

The composition of bed sediment was also used for organic micro pollutants to identify the hotspots of the "Altlasten". Table 2.5 gives a survey for the most important organic pollutants.

Table 2.5   Areas of concern in the Rhine catchment area and their main contaminating compounds (organic micro pollutants) in sediments, notified by the colour yellow *(grey = no measurements or only single data on organic substances) (Heise & Förstner, 2004)*

	High and Upper Rhine	Upper and Middle Rhine	Lower Rhine		Tributaries							
		Harbour	Duisburg Ruhr area	Harbour	Neckar	Main	Mosel	Emscher	Wupper	Ruhr	Erft	Lippe
Aldrin						grey	grey				grey	
DDT + DDD + DDE	yellow	yellow				grey	grey				grey	
Dioxins + furans			yellow			grey	grey				grey	
HCB	yellow	yellow		yellow		grey	grey				grey	yellow
PAH						grey	grey	yellow		yellow	grey	
PCB	yellow			yellow		grey	yellow			yellow	grey	
TBT						grey	grey				grey	yellow

Results of heavy metals and organic micro pollutants are used to identify the areas which are at risk. A location or area is classified "at risk" when one or more substances exceed the "Chemistry Toxicity Test" (CTT)-value. The CTT-value gives the chemical concentration thresholds in sediments, above which relocation of dredged material is forbidden. Figure 2.5 illustrates the locations which are at risk in the German part of the Rhine River. A short survey of the substances of concern for each area is given (also implemented in Table 2.2 to Table 2.5):

1. High and Upper Rhine (down- and upstream of Iffezheim weir):
   - Class 3 (clarification below figure 2.5) classification due to exceptionally high HCB (up to 2,500-3,000 µg/kg) and some elevated PCB, lead and DDT.
   - HCB in these sediments is a consequence of emissions from a former chlorosilane production site in Rheinfelden.
2. Worms-Bauhafen harbour (rkm 443):
   - Class 3 classification due to high HCB concentrations (up to 460 µg/kg) and slightly elevated levels of Cu and Hg.
3. Tributary, Main:
   - Class 3 classification due to high Hg and Cd (up to 60 mg/kg) and high PAHs.
4. Loreley harbour (rkm 555):
   - Class 3 classification due to high amounts of Zn, Cd, Cu, Hg, Pb, PCB, PAH, sum DDT + DDD + DDE and HCB (up to 106 µg/kg).
5. Tributary; Mosel:
   - Class 3 classification due to high amounts of heavy metals.
6. Tributary; Wupper:
   - Class 3 classification due to high amounts of heavy metals except Cd. Also increased values of PAHs (up to 36.2 mg/kg).
7. Tributary; Erft:

- Class 3 classification due to high amounts of Zn (up to 5200 mg/kg), Cu (98 mg/kg), Pb (641 mg/kg) and Ni (1678 mg/kg), but low concentrations at the confluence with the Rhine.

8. Duisburg/Ruhr area:
    - Class 3 classification due to high amounts of heavy metals (Zn, Pb, Cu and Cr), PCBs and PAHs, also high dioxins. At some locations high HCB concentrations.

9. Tributary; Ruhr:
    - Class 3 classification due to high amounts of Zn, Cd, Cu, Cr, Pb and Ni. After river km 136 also PCBs (up to 462 µg/kg) and PAHs (up to 1277 mg/kg!)

10. Tributary; Lippe:
    - Class 3 classification at some locations due to high amounts of Zn, Cu, PCBs, PAHs and high levels of HCB (up to 436 µg/kg) close to the mouth.
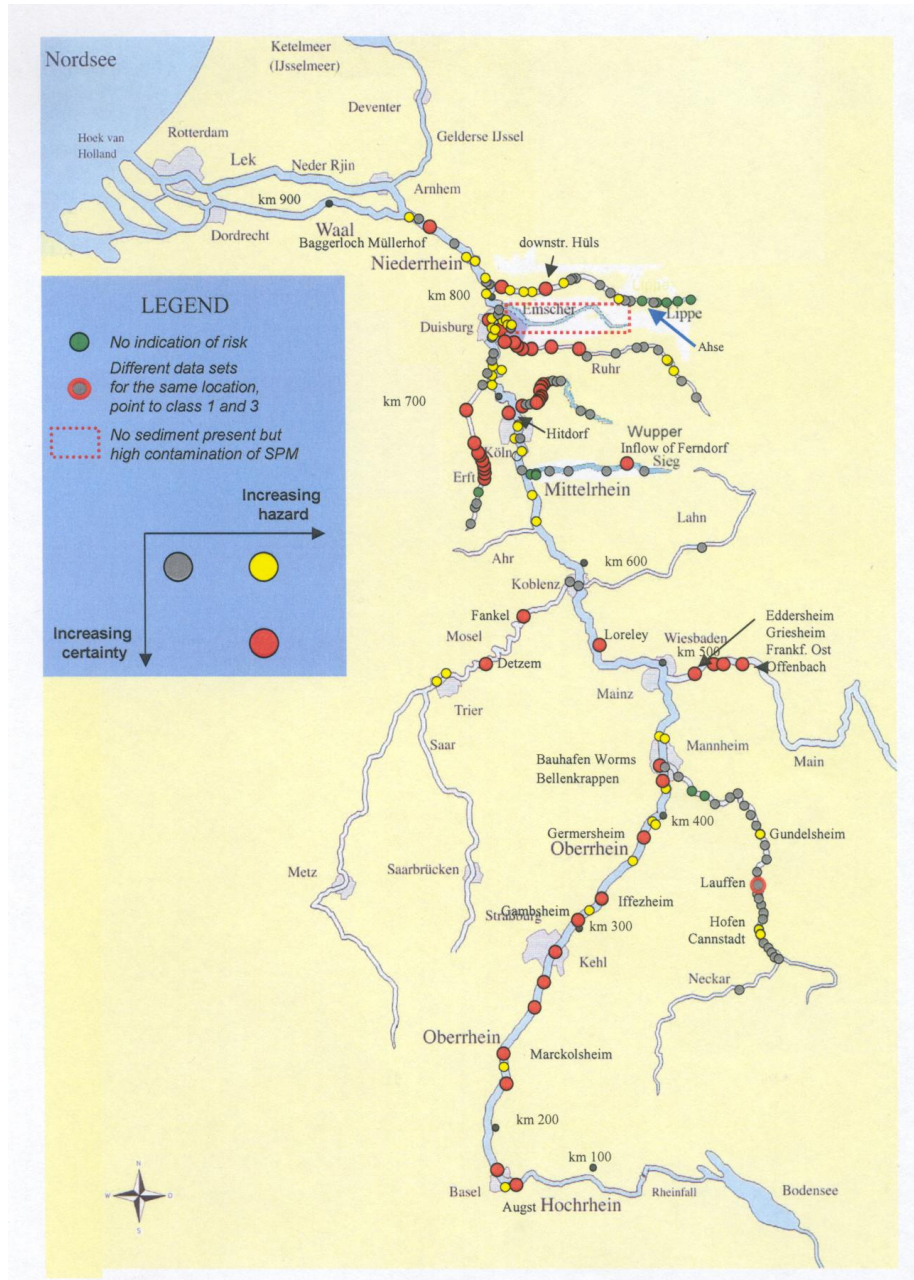
*Figure 2.5   Locations which are at risk in the German part of the Rhine River deduced from the heavy
metal and organic micro pollutant concentrations in sediments exceeding the Chemistry
Toxicity Test-value. Grey dots (class 1): Potential hazard area with some concentrations
exceeding the CTT thresholds with a factor 1-2. Yellow dots (class 2): Potentially high hazard
with concentrations higher than class 1 but also some uncertainty involved. Red dots (class
3): High hazard with high certainty, concentrations levels comparable with class 2 but where
the amount of available data and/or the number of compounds exceeding the CTT threshold
make a hazard highly probable (Heise & Förstner, 2004)*

2.3   Development of the sources in space and time

A large contribution of contaminants to the Rhine catchment originates from industrial areas and other point sources (compare Figure 2.2 with Figure 2.5). Most industries are still active, but direct discharge of wastes to the river system is restricted since the 1970's. Also the production of some organic micro pollutants for industrial and agricultural use is restricted nowadays. Therefore, the contribution of point sources decreases in the last few decades, while diffuse sources become more important. Especially the memory effect of old contaminated sediment ("Altlasten") inside the river catchment plays a vital role for the distribution of contaminants and is a known problem for the Rhine catchment area, also because the location of old contaminated sediment and resuspension risk is not known (Heise & Förstner, 2004).

"Altlasten" can be defined as the stock of old contaminated sediment which is present in river bed and floodplain sediments of a river catchment. A few aspects are important for the release of the "Altlasten" and the total load of a contaminant in the river flow, which is illustrated in Figure 2.6.
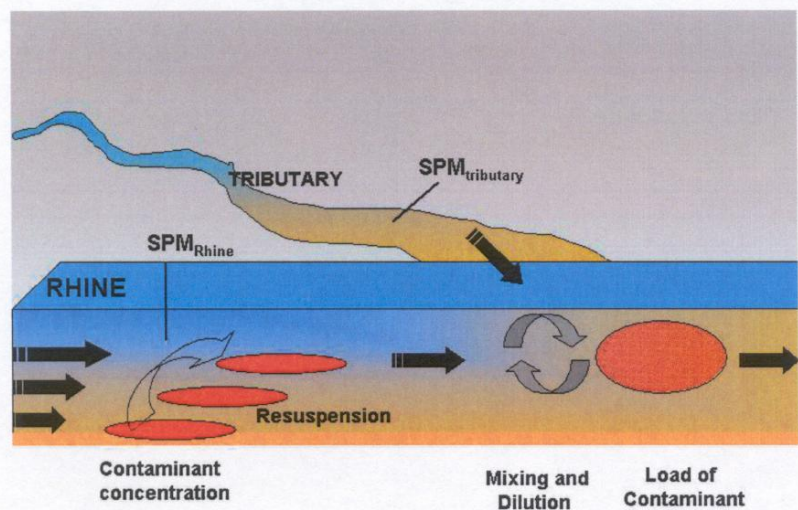
Figure 2.6   Different aspects which determine the release of "Altlasten" and the total load of a contaminant in the river catchment (Heise & Förstner, 2004)

The most important aspect which determines the contribution of "Altlasten" to the dynamic suspended matter flow is the discharge and flow velocity. Higher discharge and flow velocity leads to more resuspension of river bed sediment and possibly floodplain sediment during extreme flow conditions. The amount of resuspension depends on the sediment distribution and physical characteristics of the sediments. For example, smaller grains can be resuspended more easily than larger grains because of the difference in weight. Contributions of tributaries are important during both low and high flow conditions and can dilute or enrich the contribution of "Altlasten" in the main stream (Rhine river) when sources of "Altlasten" are, respectively, absent or present, in the tributary itself. After a long period of low flow conditions a layer of fresh sediment can cover the "Altlasten" sediments. The contribution of "Altlasten" is therefore also related to the thickness of the fresh sediment layer, which is relatively large after the summer period (if low flow conditions occurred) and can be quickly reduced when periods of high discharge occur often.

The contribution of the old contaminated sediments is already largely diluted, mixed and dispersed along the Rhine catchment area. The exact stock of contaminated sediments is not known, but high contaminant concentrations in suspended matter and sediments of locations in the upstream sections of the Rhine River indicate a still continuing distribution of recent and historical contaminants (Table 2.5). Natural decomposition of the stored organic micro pollutants might occur in the river catchment and decreases the contribution of the toxic substance. Some part of the "Altlasten" sediments will never be released under normal conditions as they are buried deep under younger sediment layers. Dredging of the sediment top layers in the Rhine catchment area will risk the exposure of the older "Altlasten" sediments to the current suspended matter flow and distribution to areas downstream.

2.4   Missing data/information

Although a lot of information can be extracted from the reports of ICPR and Heise & Förstner (2004) about the subject of contaminant sources in the river Rhine, still a large deal of information and data are missing. Especially in the Dutch part of the Rhine the transport and distribution of "Altlasten" and the areas which are at risk are not known, as sampling is mainly focused on suspended sediments and not on sediments in the river bed. For a good interpretation of the risk of resuspended old sediments (Altlasten) also information is needed about the variation of the contaminant concentration with depth. From this information the stock of contaminated sediments in the Rhine catchment area can be deduced. Data for this kind of interpretation is still missing.

3 Quality of the sediments in extreme situations in the Rhine basin

3.1 Introduction

Due to the potential for increasing water discharges, there is an increasing risk of the resuspension of old contaminated sediment layers and the transport of the particle-bound pollutants downstream in river systems over long distances. Flood events in the River Rhine have shown the enormous erosion capacity of flowing water associated with the mobilization, transport and partial downstream deposition of contaminated sediments. Not only high discharges, but also low discharges may alter the quality of the sediments, as well as the water quality. The quality of sediments during extreme situation in the River Rhine is addressed in this chapter. Chapter 4 deals with the water quality in extreme situations. Both chapters cover the relations of the sediment quality in three situations: normal situations, flood, and drought.

3.2 Relation between sediment quality and discharge in normal situations

The concentration of contaminants in the suspended particulate matter (SPM) of a river depends on the load of the SPM, the amount of contaminants that adsorb to the sediment particles, and the amount of contaminants that are present as carbon, mineral and/or tar particles in the SPM. The SPM quality is therefore first and foremost dependent on the (relative) contribution of the different sources of SPM and contaminants.

Sediment in a river system originates from soil erosion in the basin area, bank erosion and erosion of sediment deposited in the river bed during periods of low flow. Only part of the eroded sediment reaches the mouth of a river, much is (temporarily) deposited in small headwaters, reservoirs and lakes. In the river Rhine, Asselman et al (2003) estimated that only about 27% of the sediment that has reached the river channel in the German part will also reach the German-Dutch border.

When the discharge of a river increases, so will the capacity for sediment transport. However, the relation between discharge and SPM concentration in the river Rhine is reported by many authors to be supply-limited (e.g. Middelkoop, 1997; Asselman, 1997; etc). When the discharge increases, SPM concentrations will increase initially due to the increased transport capacity of the flow. After a while, easily available sediment supplies have run out, causing a drop in SPM concentrations. SPM will usually reach peak concentrations before the actual discharge peak (see Figure 3.1). This phenomenon is called 'clockwise hysteresis'; a different SPM concentration - discharge relation during the rising limb of the flood wave compared to the falling limb.
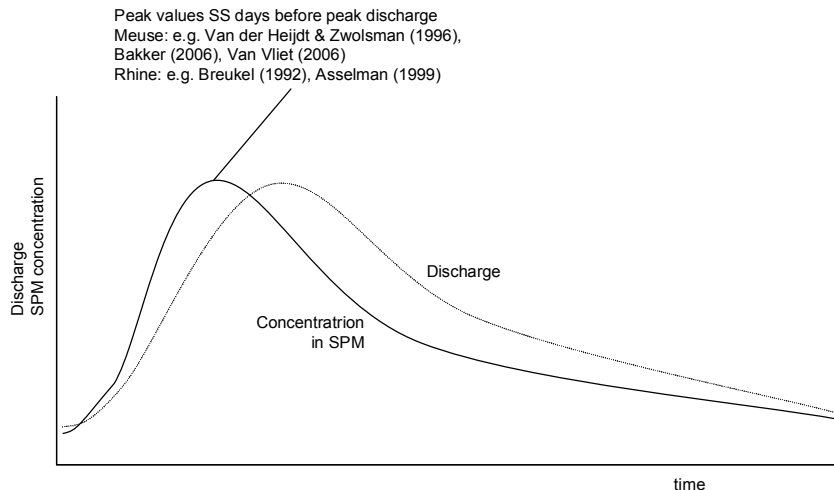
Peak values SS days before peak discharge
Meuse: e.g. Van der Heijdt & Zwolsman (1996),
Bakker (2006), Van Vliet (2006)
Rhine: e.g. Breukel (1992), Asselman (1999)

Discharge

Concentratrion
in SPM

Discharge
SPM concentration

time

Figure 3.1   Schematic representation of the peak values of the concentration of suspended particulate matter before peak discharge

Contaminant sources have been discussed in chapter 2. Contaminants are introduced in the river system by a multitude of sources, both dissolved in the water phase and adsorbed to SPM. Contaminants previously deposited ('Altlasten') fall in the latter group. The dissolved contaminants will partly adsorb to the SPM in the river, depending on the adsorption properties of the contaminant. The relative contribution of relatively clean 'fresh' sediment, dissolved contaminants introduced in the river system and the redistribution of previously deposited sediment-bound contaminants is a controlling factor for the SPM quality in the river Rhine. During periods of low flow, SPM concentrations are low, but a lot of sources still introduce contaminants in the river system. Therefore, SPM quality can be poor. During periods of high river flow, SPM concentrations increase. SPM quality can improve due to dilution of the SPM with clean sediment material from the surrounding area (Asselman, 2003; Van der Heijdt & Zwolsman, 1997).

Grain size distribution is also a key factor in contaminant concentrations of the SPM, as contaminants predominantly adsorb to the clay and organic matter fraction. Van der Heijdt & Zwolsman (1997) attributed a decline in contaminant concentration of SPM in the river Meuse during the 1993 flood to the dilution of the sediment with relatively clean terrestrial silt. Bakker (2006) re-interpreted an expanded dataset of this flood and studied the relation between grain size distribution and contaminant concentration at different locations. The relation between discharge and grain size distribution in the SPM appeared to be a location- and event-specific one, as the dilution effect, caused by input of coarse sand (150-250 µm), differed substantially between locations (Bakker, 2006). Asselman (2003) observed a decreasing median grain size with increasing discharge in the river Rhine (see Figure 3.2). There was no data available for extreme discharges.
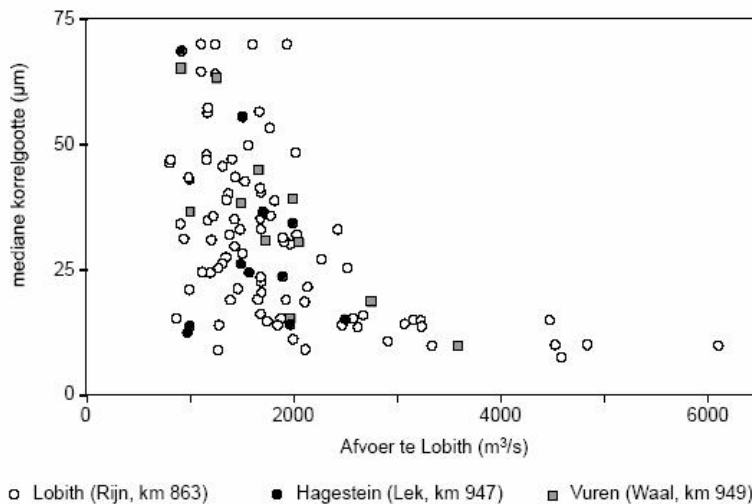
Figure 3.2   Median grain size ('mediane korrelgrootte') of the SPM at different locations along the river Rhine, as a function of discharge at Lobith ('afvoer te Lobith') (Asselman, 2003)

Data of sediment-associated heavy metal concentrations obtained at Lobith shows an improvement in the SPM quality with increasing discharge (Figures 3.3 and 3.4, Asselman, 2003). A similar relation is shown by Heise and Förstner (2004) for HCB (Figure 3.5). PCB concentrations, however, do not exhibit this decline with increasing discharge (Figure 3.6). Heise and Förstner (2004) attributed this to a difference in the pollution degree of the eroded material: the dilution effect only occurs if the eroded material is relatively clean.

A number of conclusions can be drawn on the present relationship between SPM quality and discharge. During low-flow conditions, the river water can only transport a limited amount of SPM. Combined with the ongoing pollution, contaminant concentrations can be relatively high. When the discharge increases, more sediment is eroded and transported in the river flow. If the sediment is relatively clean, the SPM is diluted and the contaminant concentration decreases. However, as the exact relationships are event- and location-specific, contaminant concentrations in the SPM are difficult to predict accurately.

Figure 3.3   SPM-associated heavy metal concentrations ('concentratie') versus Rhine discharge ('afvoer') at Lobith (Asselman, 2003)

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$$y = 3756.5x^{-0.4792}$$
$$R^2 = 0.4191$$

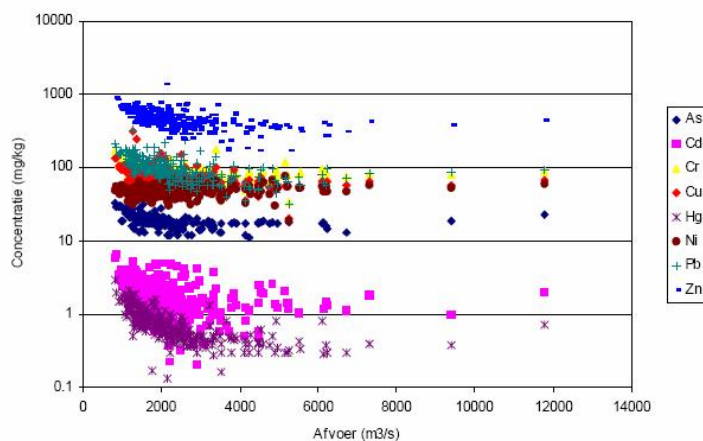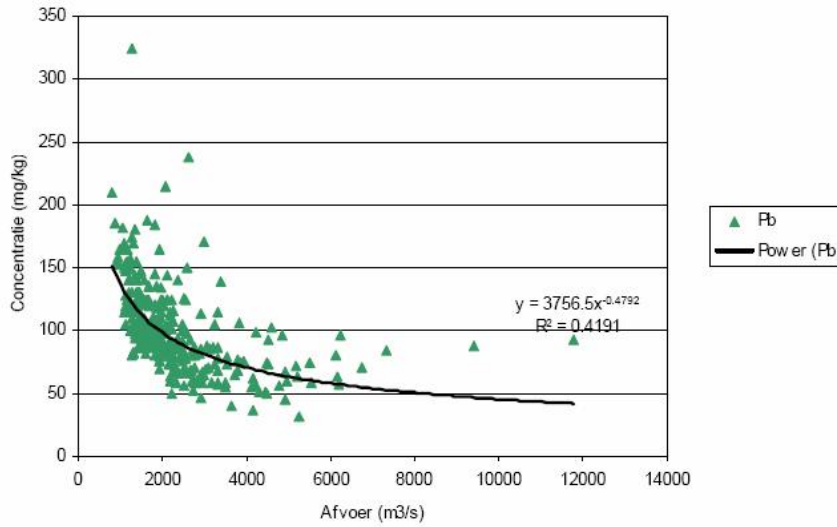*Figure 3.4*   *SPM-associated lead concentrations ('concentratie') versus Rhine discharge ('afvoer') at Lobith (Asselman, 2003)*
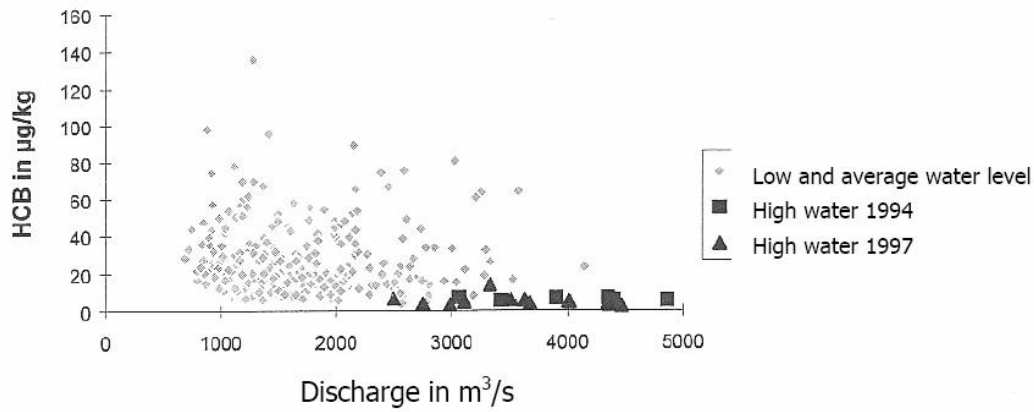

Figure 3.5   *SPM-associated HCB concentrations versus Rhine discharge (Heise & Förstner, 2004)*
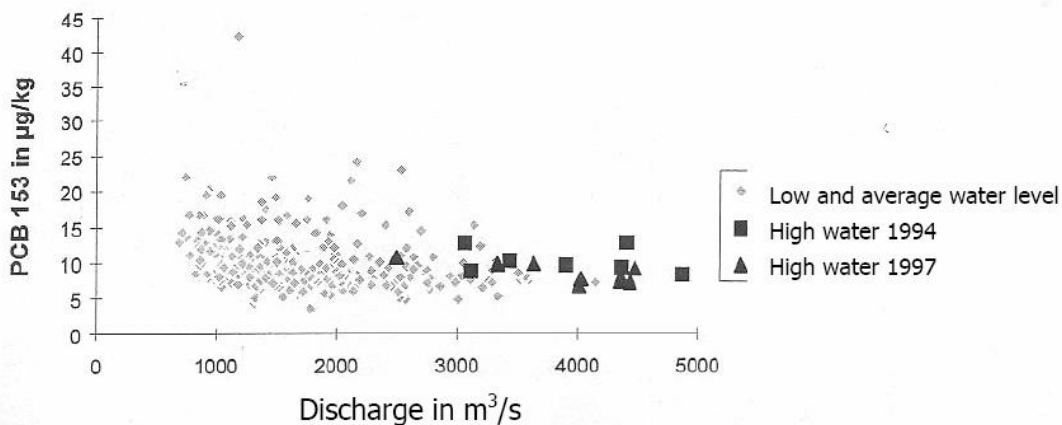

Figure 3.6   *SPM-associated PCB-153 concentrations versus Rhine discharge (Heise & Förstner, 2004)*

3.3   Sediment quality during floods

3.3.1   Problems in the Rhine basin

As mentioned in section 3.1, the SPM quality in the river Rhine depends on different processes and aspects. Variable input of contaminant sources in space and time makes it hard to predict the sediment quality in the Rhine catchment area. From the report of Heise & Förstner (2004) it is known that high concentrations of contaminants are stored in the upstream part of the Rhine catchment. These old contaminated sources ("Altlasten") can be resuspended and distributed to downstream areas. In chapter 2 it was already indicated that the concentrations of the "Altlasten" are sometimes very high, showing high risks for ecology in river bed and floodplain sediments.

Results of Asselman (2003), however, showed a decrease of contaminant concentration with increase of discharge. This dilution effect shows that input of eroded, relatively clean material dominates the SPM quality and input of "Altlasten" is less pronounced. It should be mentioned, however, that the relations derived by Asselman (2003) (figure 3.3 and 3.4) do not include a lot of data with discharges of more than 6,000 m^3/s. For a better understanding of variation in contaminant concentration in SPM during a flood more information is needed.

3.3.2   Processes involved with sediment quality during floods

Input of sediments during a flood depends on the discharge and the eroding force of the water flow (bottom shear stress τ_b) for erosion of sediment inside and outside the river channel. Erosion of previously deposited sediment takes place when the bottom shear stress exceeds the forces that keep the sediment at the bottom. The bottom shear stress is dependent on the velocity of the flow, as is apparent from equation 3-1. The forces that withstand erosion can be represented as a 'threshold shear stress for erosion', denoted as τ_e. This simple concept is used in the well-known Krone-Partheniades formula (equation 3-2). The 'threshold shear stress for erosion' is a function of a.o. grain size and the sorting of the sediment and is difficult to determine.

$$\tau_b = \rho g \frac{u^2}{C^2}$$
3-1

$$E = M \frac{\tau_b - \tau_e}{\tau_e}$$
3-2

τ_b bottom shear stress
ρ fluid density
g   gravitation acceleration
u   flow velocity
C   Chézy roughness parameter
E   erosion rate
M   erosion parameter
τ_e threshold shear stress for erosion

The grain size distribution is an important parameter for the distribution and composition of contaminants inside the river channel as most contaminants are adsorbed to the clay and organic matter fraction. At low flow velocities, only a low amount of mainly fine material will be transported in the river, while at higher flow velocities also coarser material can be distributed. The effects of the grain size distribution can also be found back with the deposition of contaminants on the floodplain section. The contribution of

fine material (clay fraction) increases with increasing distance to the river channel. Coarse material will settle down close to the river channel when the water flow velocity is not high enough for transport. Middelkoop (2000) determined this effect in the Rhine-Meuse delta. Figure 3.7 represents an example for the floodplain section of the Meuse, where a clear increase in metal concentration was observed with increasing distance to the river channel, together with an increase of the clay and organic matter fraction.

The quality of the SPM and floodplain sediment has significantly improved over the years. This is shown in Figure 3.8 where zinc concentrations in suspended matter at Lobith for the period of 1988-2004 are presented (Thonon, 2006). The ongoing deposition of sediments will therefore have buried heavily polluted older sediments. The topmost, clean, layer of sediment will be eroded before the older polluted layer becomes prone to erosion. An initial flood may erode the upper layer, leaving the polluted layer exposed. If a second flood erodes this polluted layer, the SPM quality will be worse than that of the first flood.
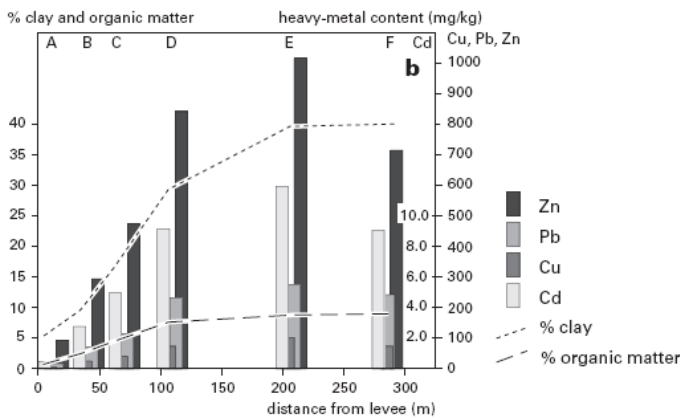
Figure 3.7   Spatial distribution of clay, organic matter and heavy metal content with increasing distance to the river channel, during the December 1993 flood of the river Meuse near Bern (Middelkoop, 2000)
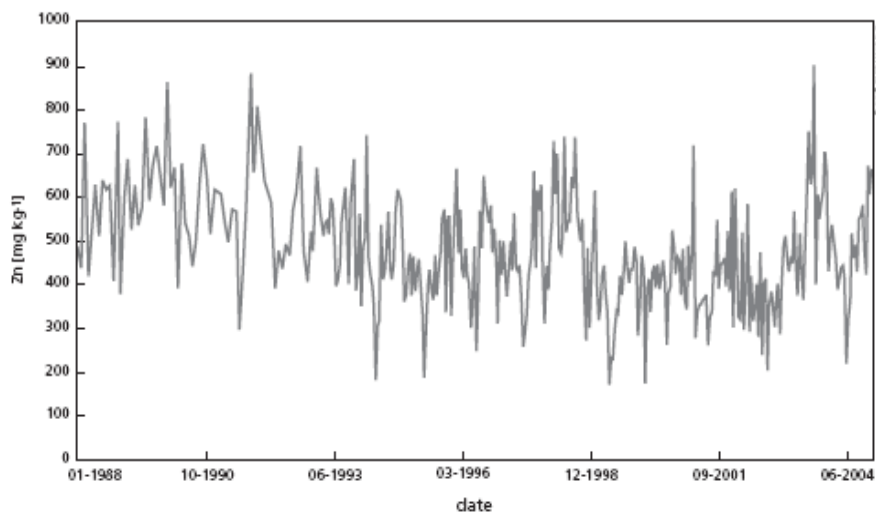
Figure 3.8   Zinc concentration in SPM at Lobith for period of 1988−2004 (Thonon, 2006), based on data of Waterbase)

3.4   Sediment quality during droughts

During periods of low flow, the input of SPM is also low, as mentioned in section 3.1. It becomes clear from figures 3.3 to 3.6 that the contaminant concentrations in SPM increase at low discharges in the river Rhine. Increase of contaminant concentrations is mainly subscribed to restricted dilution of water or clean (coarse) sediment material. The variable input of different sources along the river channel becomes relatively more important. A general investigation of SPM quality during droughts has not been performed yet. Still, it can be expected that also high contaminant concentrations in SPM will be present as the dilution effect is also much lower.

4   Quality of the water in extreme situations in the Rhine basin

4.1   Introduction

As already mention in Chapter 3, extreme situations may alter not only the quality of the sediments, but also the water quality. Chapter 4 deals with the water quality in extreme situations in the River Rhine. This chapter covers the relations of the water quality in three situations: normal situations, flood situations, and drought situations.

4.2   Relation between water quality and discharge in normal situations

The concentration of contaminants in surface water depends on various factors and differs between various groups of substances (e.g. conservative substances, nutrients, heavy metals, organic micro pollutants). Apart from the emission of contaminants, the concentration of substances in surface water is also strongly affected by flow conditions and water temperature. Studies of Van Bokhoven (2006) and Van Vliet (2006) for the Rhine and Meuse river indicate significant changes in water quality under varying discharges and (for some substances) also under varying water temperatures. Concentration-discharge relations established for various substances indicate different responses between different groups of substances. However, relations between discharge and concentration were quite consistent for substances within the same group. As conservative substances (e.g. Cl, Br, F, SO_4, etc.) are non-reactive in surface water, the concentration is strongly affected by discharge changes. The relation between discharge and concentration of these substances can be described according to the equation of Van der Weijden & Middelburg (1989):

$$C = a\,/\,Q + b$$

Where:

   C = concentration of substance in river water (mg/l)

   Q = discharge (m^3/s)

   a = chemical load (g/s)

   b = background concentration (mg/l)

As an example, the concentration-discharge relation is presented for chloride and sulphate at Lobith for the period of 2000-2005 in Figure 4.1a and b. Both figures show distinct increases in concentration under low flow conditions, due to a reduced dilution effect of point source effluents. In unfiltered samples, low flows may have two opposite effects: 1) high total concentrations as result of the less dilution effect; and 2) low total concentrations as result of the low amount of SPM. The first effect under lower

discharge can be seen in the total concentrations of phosphate (Figure 4.1c). However, peaks in total concentrations occur under high flow conditions, which can be explained by the increased amount of SPM under higher discharges and the high adsorption capacity of SPM for phosphate. Increased total concentrations under higher discharges are also observed for heavy metals (e.g. lead; Figure 4.1d) and PAHs, which have also a high adsorption affinity to SPM. Distinct linear increases in concentrations of heavy metals and PAHs are observed under higher SPM concentrations. This is presented for lead in Figure 4.2.

a)

Lobith 2000 - 2005

$y = 91687/Q + 44.9$
$R2 = 0.85$

b)

Lobith 2000 - 2005

$y = 45304/Q + 36.6$
$R2 = 0.85$

c)

Lobith 2000 - 2005

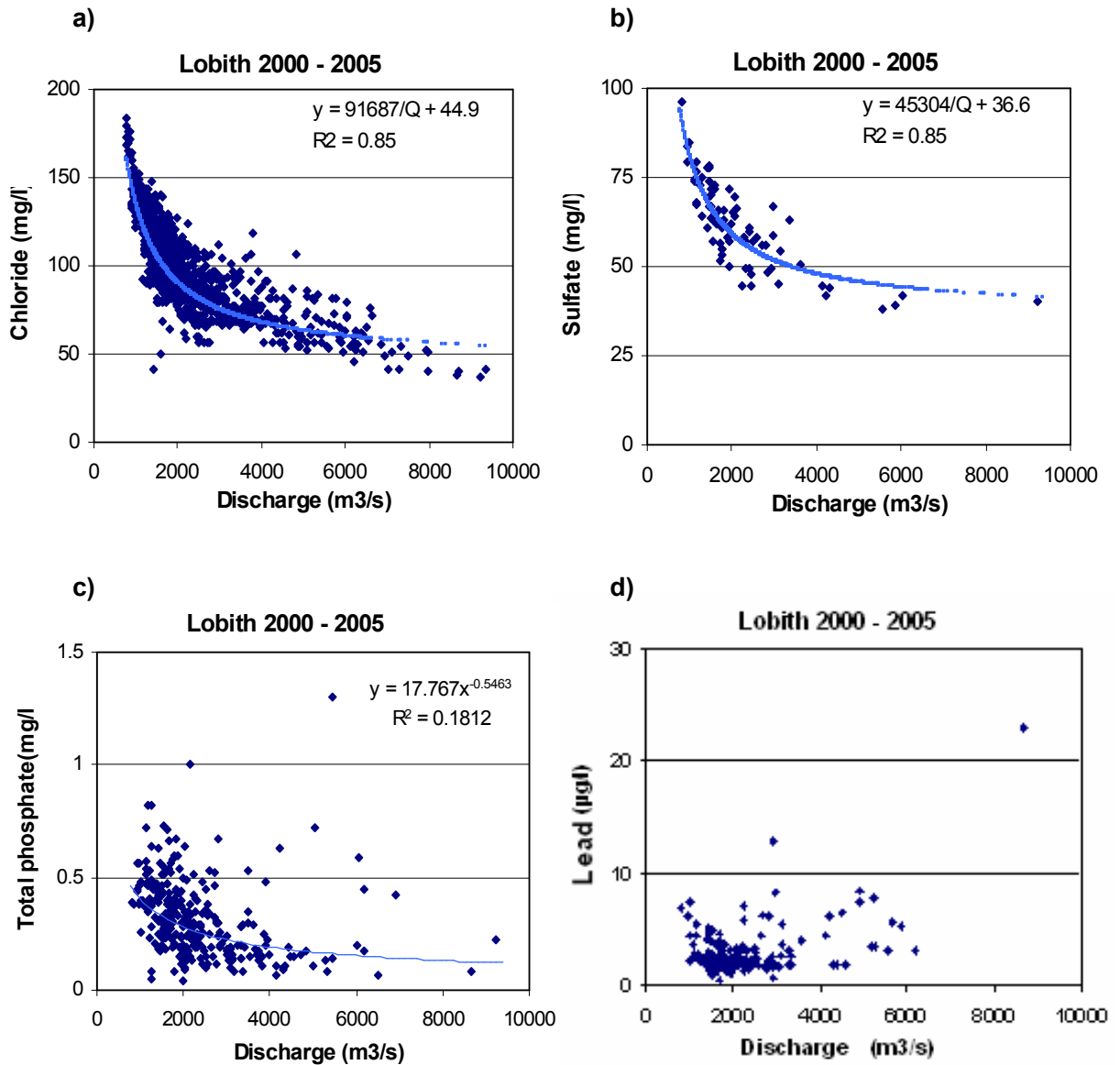$y = 17.767x^{-0.5463}$
$R^2 = 0.1812$

d)

Lobith 2000 - 2005

Figure 4.1   *Concentration - discharge relation for chloride (a), sulphate (b), total phosphate (c), total
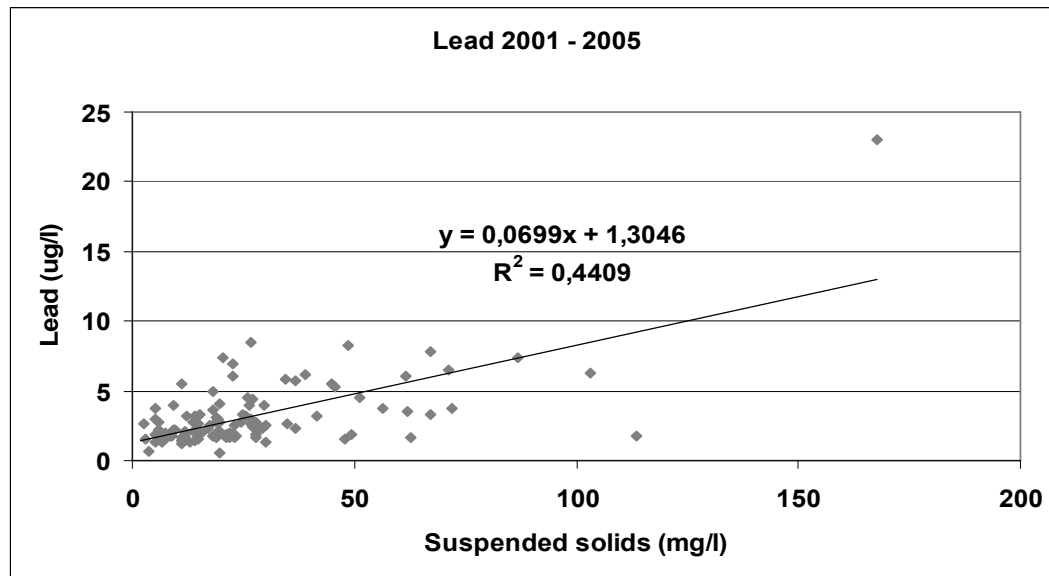lead (d) at Lobith for the period 2000-2005*

*Figure 4.2   Relation between total lead and SPM concentration at Lobith for the period 2001-2005 –
                   unfiltered samples (Van Bokhoven, 2006)*

4.3   Water quality during floods

4.3.1   Problems in the Rhine basin

As mentioned in section 4.1, the water quality in the river Rhine depends on different processes and aspects. Variable input of contaminant sources in space and time makes it hard to predict the water quality in the Rhine catchment area.

The water quality of the Rhine River was investigated at the Lobith location during the floods of 1988, 1992, 1995, 1998 and 2003 by Van Bokhoven (2006). Although the amount of measurements was quite small, distinct increases in the total concentrations (in unfiltered samples) of heavy metals, PAHs and phosphate were observed in the Rhine River during the flood events. These increases are mainly due to higher concentrations of SPM, originating from resuspended bed sediments and increasing supplies of soil leaching and overland flow.

4.3.2   Processes involved with water quality during floods

As above mentioned, increased total concentrations have been observed for heavy metals, PAHs and total phosphate, due to increased concentrations of SPM under high flow conditions for the river Rhine. For the Meuse River, a larger amount of measurements was available for the investigated floods compared to the Rhine. Results also indicate distinct increases in concentrations of substances adsorbed to SPM during floods (Van Vliet & Zwolsman, 2007). As an example, concentrations of SPM and total lead are presented for the Meuse at Eijsden during the 1995 flood (Figure 4.3 a and b). The distinct increase in the total lead concentration under higher SPM concentrations resulted in exceeding of the BKMO standard (In Dutch "Besluit Kwaliteitsdoelstellingen Metingen Oppervlaktewater", in English "Resolution Quality objectives Measurements Surface water) for several heavy metals and PAHs during the investigated floods of 1993, 1995 and 2003. In contrast to substances adsorbed to SPM, distinct decreases were observed in concentrations of dissolved compounds, like chloride (Figure 4.4a), nitrite and ammonium, due to increased dilution under higher flow conditions. Although

the nitrate concentration is also affected by increased dilution, relatively constant concentration responses were observed during the three investigated floods of 1993, 1995 and 2003 (Figure 4.4b). This can be explained by increased nitrate supply by soil leaching and overland flow during high flow conditions, which counterbalances the effect of the increased dilution (Van Vliet, 2006)
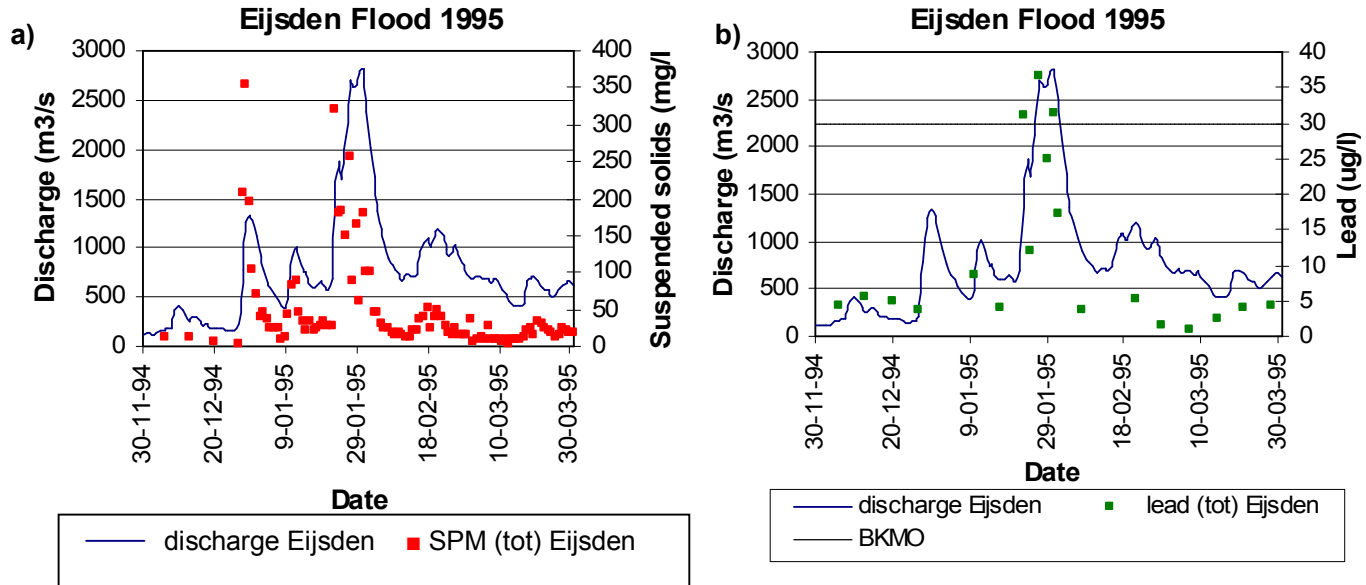

Figure 4.3   Concentration of suspended solids (a) and total lead (b) of Meuse at Eijsden during the 1995-flood (Van Vliet, 2006)
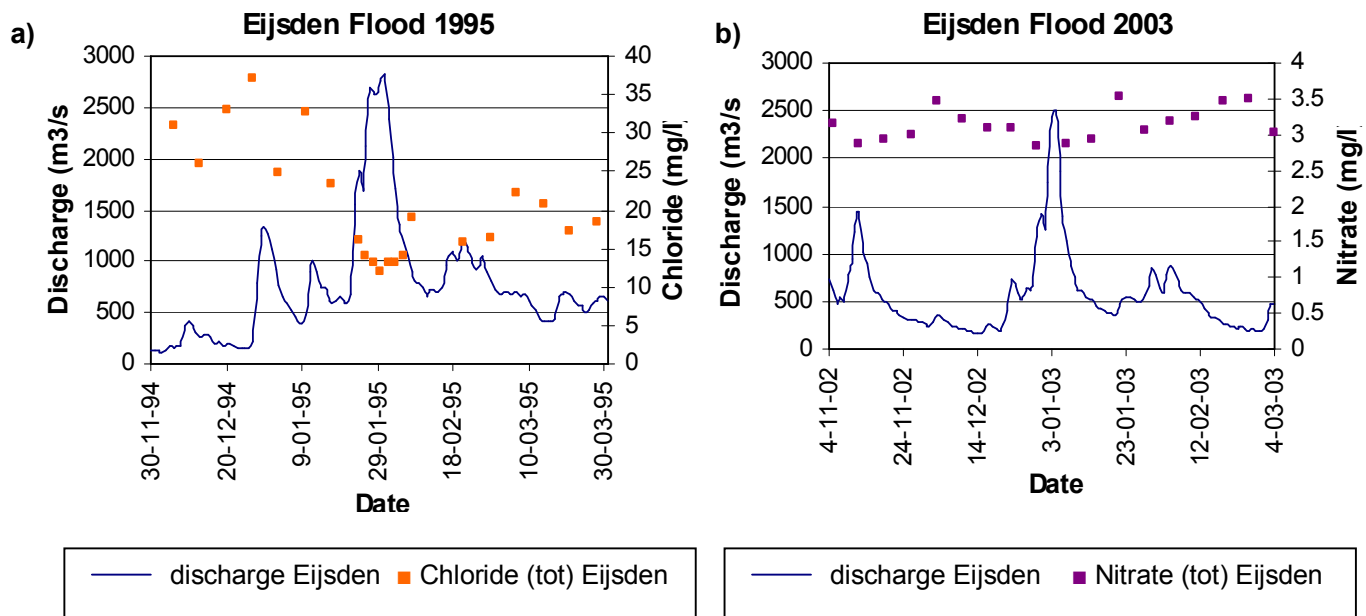

Figure 4.4   Concentration of chloride (a) and nitrate (b) of Meuse at Eijsden during the 1995- and 2003-flood (Van Vliet, 2006)

4.4   Water quality during droughts

4.4.1   Problems in the Rhine basin

The contaminant concentration in water increases at low discharges in the river Rhine (see figures 4.1 and 4.2). This situation is mainly subscribed to restricted dilution of water. The variable input of different sources along the river channel becomes relatively more important. Van Bokhoven & Zwolsman (2007) established high concentrations of different contaminants during the droughts of 1976, 1991 and 2003, where threshold values for the ecological status and drinking water function were exceeded for several contaminants. A general investigation of suspended matter quality during droughts has not been performed yet. Still, it can be expected that also high contaminant concentrations in SPM will be present, as the dilution effect is also much lower.

4.4.2   Description of the processes involved

Effects of droughts on the water quality of the Rhine River at Lobith are investigated by Van Bokhoven & Zwolsman (2007). Concentration responses of 41 water quality parameters, relevant for the ecological status and drinking water function of the Meuse, were investigated during the droughts of 1976, 1991 and 2003, and compared with the water quality during reference periods. The results indicate a general deterioration of the water quality of the Rhine during droughts, with respect to water temperature, eutrophication and conservative substances. Surface water standards for drinking water production and ecological status were mainly exceeded for temperature and chlorophyll-a. Table 4.1 and Table 4.2 list the minimum, maximum and average values for temperature and chlorophyll-a during the investigated droughts and reference periods, which were defined as the (part of the periods of the) years previous to and after the drought.

The decline in water quality is primarily caused by favourable conditions for the development of algae blooms (high water temperatures, long residence times, high nutrient concentrations) and a reduction of the dilution of point source effluents.

Table 4.1   Water temperature at Lobith during the summer droughts of 1976 and 2003 and during the reference periods (Van Bokhoven & Zwolsman, 2007)

Summer June-August	Total nr . of measurements	min (ºC)	max (ºC)	average (ºC)	N > 25ºC
1975	92	14.9	23.8	20.1	0
1976	92	16.3	25.2	21.5	4
1977	92	16.4	22.8	19.7	0
2002	92	18.7	24.3	21.7	0
2003	92	18.9	27.5	23.1	18
2004	91	18.3	25.9	21.5	1

Table 4.2   *Chlorophyll-a concentration at Lobith during the summer droughts of 1976 and 2003 and
during the reference periods (Van Bokhoven & Zwolsman, 2007)*

Summer June-August	Total nr.of measure-ments	chl.a – min (µg/l)	chl.a – max (µg/l)	average chl.a (µg/l)
1975	9	13	54	31
1976	13	26	151	88
1977	12	18	98	54
2002	6	2	30	15
2003	6	3	40	26
2004	6	5	18	11

Table 4.3   *Mean concentration of chloride, fluoride, sulphate and sodium during the drought periods of
1976, 1991, and 2003 compared to the reference periods (Van Bokhoven, 2006)*

Dry summer Mean (mg/l)	n	Cl	n	F	n	SO$_4$	n	Na
1975	17	168	11	0.5	15	74	2	95
1976	**18**	**315**	**17**	**0.6**	**18**	**108**	**1**	**108**
1977	18	222	16	0.4	18	80	18	88
1990	122	329	4	0.21	4	91	12	141
1991	**106**	**320**	**3**	**0.22**	**3**	**97**	**11**	**153**
1992	122	271	4	0.16	4	78	13	122
2002	119	123	2	0.19	8	65.7	8	56.5
2003	**122**	**179**	**2**	**0.19**	**8**	**84.8**	**8**	**80.6**
2004	121	117	2	0.10	9	74.0	9	58.2

5   Available data

5.1   Introduction

Based on the existing information (data) and models, this study wants to make an overview of the relevant knowledge lagoons and to identify advisable research directions. On of the main research questions was: *which data about the (old) contaminated sediments in the Rhine basin are available?* This chapter gives a first inventory of the available data regarding water and sediment quality information. The information (data) gaps are in this chapter also addressed.

5.2   Databases containing water and sediment quality information

In this paragraph two databases containing measurement series of sediment and water quality are described: Waterbase; and the database of the ICPR. Section 5.3 summaries other available data.

5.2.1   Waterbase

Waterbase (http://www.waterbase.nl) is the routine water and sediment quality programme performed by RIZA (Institute for Inland Water Management and Waste Water Treatment of the Netherlands), now succeeded by the 'Waterdienst' (Centre for Water Management). Waterbase contains data series of surface water and suspended sediment quality at certain monitoring locations in the Dutch part of the Rhine catchment area. Sampling and measurements of nutrients, heavy metals, PAHs and PCBs are executed on a 2-weekly or 4-weekly basis and are available for (parts of) the period 1988-2006. Analyses of suspended sediment quality can be used for assessing the possible contribution of "Altlasten" in the Dutch part of the Rhine. As an example, Figure 5.1 presents a screen dump with the locations of monitoring stations where lead concentrations in suspended sediment are measured.
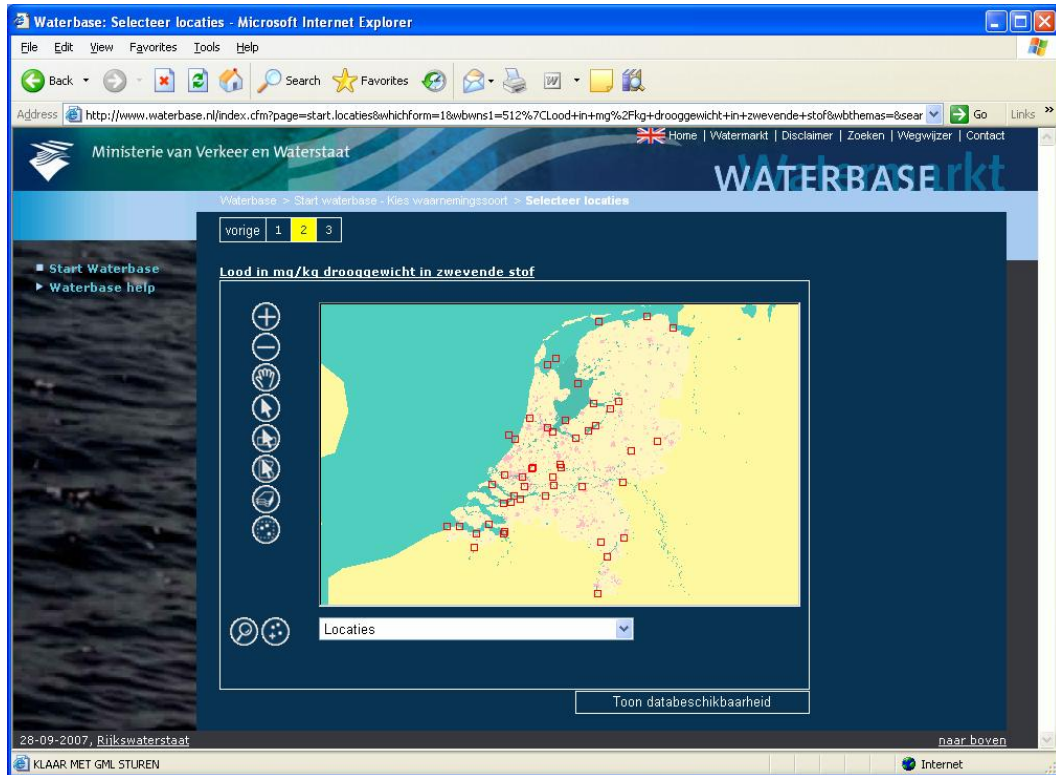
Figure 5.1   Screen dump with the locations of monitoring stations in the Netherlands where concentrations of lead in suspended sediment are measured (http://www.waterbase.nl)

Table 5.1 lists the sampling frequency and period for surface water and suspended sediments. Locations Hagestein and Vuren are still sampled and measured nowadays, but the chemical analyses of these locations cannot be found on the Waterbase website. The data of these locations are maintained by the "Regionaledienst Oost-Nederland". These results can be obtained from Marleen Kalsbeek (marleen.kalsbeek@rws.nl) or Frank Oosterbroek (frank.oosterbroek@rws.nl) of the "Regionaledienst Oost-Nederland".

Table 5.1   *Survey of monitoring locations in the Dutch part of the Rhine. Locations are in downstream order with location Lobith at the Dutch-German border and location Maassluis at the mouth. Sampling frequencies and sampling periods are only given for metal analysis. Sampling frequency and period is separated into surface water sampling (SW) and suspended matter sampling (SPM)*

Location	Part of the Rhine	SW frequency	SW period	SPM frequency	SPM period
Lobith	Bovenrijn	2-weekly	1968-now	2 or 4-weekly	1988-now
Driel boven	Nederrijn	8-weekly	1988-1992	--	--
Kampen	IJssel	4 or 8-weekly	1968-now	8-weekly	1990-now
Hagestein	Lek	4-weekly	1969-1992	8-weekly	1990-1992
Nieuwegein	Lekkanaal	2 or 4-weekly	1986-now	8-weeky	1993-now
Vuren	Waal	4 or 8-weekly	1968-1992	4 of 8-weekly	1990-1992
Hardinxveld	Merwede	8-weekly	1989-1992	--	--
Papendrecht	Beneden Merwede	8-weekly	1986-1988	--	--
Kinderdijk (rkm 984)	Noord/Lek	One time	1974	--	--
Kinderdijk aan de Lek (rkm 988)	Lek	4-weekly	1982-1992	--	--
Gouderak	Hollandse IJssel	4 or 8-weekly	1982-1992	8-weekly	1992
Gouda voorhaven	Hollandse IJssel	4-weekly	1997-now	4-weekly	1992-now
Brienenoord	Nieuwe Maas	4-weekly	1982-now	4-weekly	1992-now
Puttershoek	Oude Maas	4-weekly	1974-now	4-weekly	1992-now
Oud-Beijerland	Oude Maas	8-weekly	1986-1992	--	--
Maassluis	Nieuwe Waterweg	2 or 4-weekly	1972-now	2 of 4-weekly	1988-now

5.2.2   Database of the International Commission for Protection of the Rhine

The database of the ICPR (International Commission for Protection of the Rhine) (http://had.bafg.de:8080/iksr%2Dzt/) contains data of water and sediment quality at the main monitoring stations in Germany and the Netherlands. Measurements of nutrients, heavy metals, PAHs and PCBs are available at two-weeks of two-month basis. The data series comprises (parts of) the period 1978-2004. The locations of the monitoring stations in the Rhine basin are shown in Figure 5.2. Screen dumps of the web-based monitoring programme are presented in figure Figure 5.3.
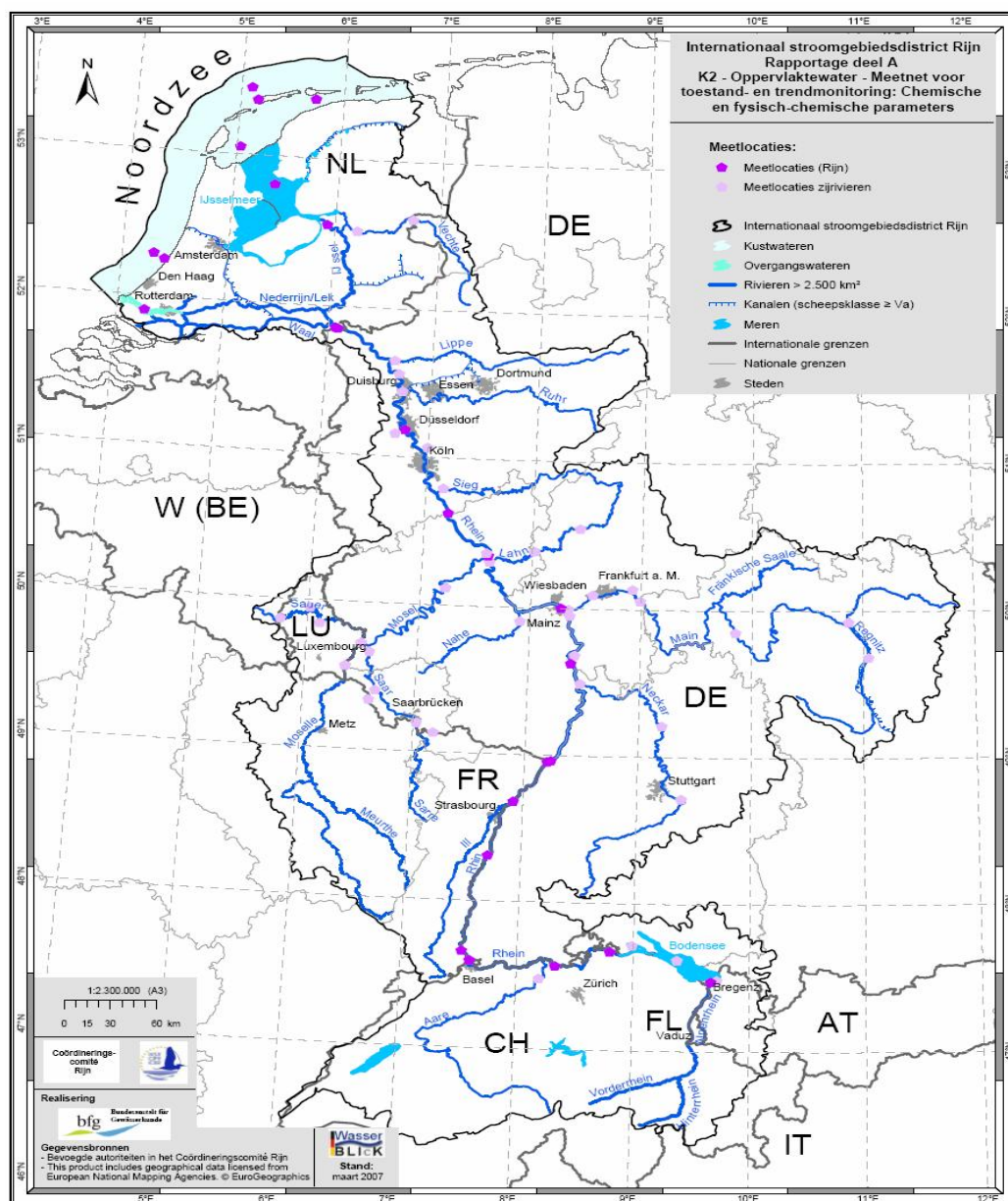
Figure 5.2   Locations of monitoring stations in the Rhine basin (ICPR, 2005b)

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Figure 5.3   *Screen dumps of sediment and water quality database of ICPR*
(http://had.bafg.de:8080/iksr%2Dzt/)

5.3   Other data

- A special "high water" measurement program is realized by RIZA, where suspended matter is sampled more frequently at location Lobith. Samples are taken every day instead of every two weeks. PAHs, PCBs and heavy metals are analyzed in these samples. Further information can be obtained from **Marcel van der Weijden** (marcel.vander.weijden@rws.nl) or **Marga Holierhoek** (marga.holierhoek@rws.nl) from RIZA/Waterdienst.
- The "Regionaledienst Oost-Nederland" also organises special sampling programs during high discharge of the river Rhine in the Netherlands. Further information can be obtained from **Marleen Kalsbeek** (marleen.kalsbeek@rws.nl).
- Dataset of chrome, copper, mercury, nickel, lead, zinc and arsenic in sediment at Lobith measured on 3-hour basis during flood 1990 (Table 5.2).

Table 5.2   Data set of concentration chrome, copper, mercury, nickel, lead, zinc and arsenic in sediment at Lobith measured by RIZA on 3-hour basis during flood 1990 (source: RIZA,1992b)

Overzicht draaiperioden centrifuge.

mon. nr.	data	tijd	debiet	uren
2	16/2	13.45-16.45	2945	15.17
4	16/2	20.45-23.45	3283	22.33
6	17/2	03.15-06.15	3631	28.83
8	17/2	10.30-13.30	4092	36.00
10	17/2	17.30-20.30	4587	43.00
11	17/2	21.00-24.00	4844	46.50
12	18/2	00.30-03.30	5069	50.50
13	18/2	04.00-07.00	5282	53.50
14	18/2	07.30-10.30	5502	57.00
15	18/2	11.00-14.00	5729	60.50
16	18/2	14.30-17.30	5944	64.00
17	18/2	18.00-21.00	6145	67.50
18	18/2	21.30-23.30	6301	70.50
19	19/2	00.00-03.00	6446	73.50
20	19/2	03.30-06.30	6610	77.00
21	19/2	07.00-09.45	6725	80.17
22	19/2	10.00-13.00	6802	83.50
23	19/2	14.00-17.00	6879	87.50
24	19/2	17.30-20.00	6936	90.83
25	19/2	20.30-23.00	6994	94.00
26	19/20	23.30-02.00	7074	96.67
27	20/2	02.30-05.00	7114	99.83
28	20/2	05.30-08.00	7114	102.83
29	20/2	08.30-11.30	7094	106.00
30	20/2	12.30-15.30	7054	110.00
31	21/2	08.00-11.00	6355	129.50
32	21/2	11.30-14.30	6196	133.00
33	22/2	08.00-11.00	5395	153.50
34	22/2	11.30-14.30	5270	157.00
35	23/2	08.30-11.30	4608	178.00
36	24/2	08.30-11.30	3943	202.00

Metalen ongecorrigeerd + correctiefactoren

nr.	Cr	Cu	Hg	Ni	Pb	Zn	As	caco3	o.s.	2um	16um	2cor	16co
2	75.0	72.0	0.7	56.0	140.0	590.0	16.0	7.1	10.7	nb	nb	24.5	45.9
4	78.0	70.0	0.5	54.0	120.0	520.0	16.0	6.8	9.8	36.1	58.6	36.1	58.6
6	78.0	68.0	0.5	55.0	110.0	495.0	17.0	6.9	9.5	36.7	61.5	36.7	61.5
8	64.0	55.0	0.5	44.0	85.0	435.0	15.0	6.5	8.6	31.8	54.7	31.8	54.7
10	61.0	50.0	0.6	44.0	75.0	395.0	14.0	6.1	7.3	nb	nb	34.2	57.7
11	57.0	52.0	0.6	43.0	80.0	435.0	19.0	6.2	8.4	nb	nb	35.5	59.1
12	72.0	64.0	0.5	42.0	95.0	465.0	15.0	7.2	7.3	nb	nb	36.9	60.8
13	71.0	60.0	0.6	47.0	90.0	435.0	14.0	8.8	6.8	37.9	62.1	37.9	62.1
14	76.0	66.0	0.6	50.0	90.0	455.0	15.0	9.9	7.9	36.2	61.5	36.2	61.5
15	74.0	69.0	0.5	46.0	95.0	430.0	21.0	11.9	10.1	nb	nb	37.1	61.8
16	78.0	72.0	0.5	46.0	95.0	440.0	23.0	12.2	9.2	nb	nb	38.0	62.0
17	75.0	67.0	0.5	50.0	80.0	515.0	22.0	13.1	7.3	nb	nb	38.8	62.3
18	74.0	68.0	0.5	50.0	70.0	355.0	20.0	13.4	6.5	nb	nb	39.6	62.5
19	86.0	82.0	0.6	51.0	85.0	400.0	21.0	13.1	7.6	nb	nb	40.3	62.7
20	95.0	76.0	0.6	50.0	85.0	415.0	36.0	12.0	6.7	nb	nb	41.2	63.0
21	105.0	82.0	0.5	51.0	90.0	415.0	25.0	11.9	6.0	42.0	63.2	42.0	63.2
22	110.0	83.0	0.5	55.0	85.0	425.0	21.0	9.8	6.5	55.6	70.4	55.6	70.4
23	77.0	58.0	0.5	40.0	40.0	310.0	18.0	11.9	5.0	51.6	71.7	51.6	71.7
24	96.0	68.0	0.5	51.0	50.0	360.0	12.0	14.5	6.3	38.0	64.0	38.0	64.0
25	73.0	54.0	0.7	39.0	50.0	300.0	18.0	10.5	4.9	48.1	70.3	48.1	70.3
26	115.0	63.0	0.5	68.0	75.0	325.0	20.0	13.4	5.2	40.1	64.2	40.1	64.2
27	110.0	70.0	0.6	64.0	65.0	370.0	20.0	12.4	5.5	35.9	62.8	35.9	62.8
28	84.0	65.0	0.5	49.0	60.0	345.0	20.0	11.9	5.7	45.7	65.6	45.7	65.6
29	89.0	62.0	0.6	54.0	55.0	340.0	26.0	13.3	5.0	46.6	67.9	46.6	67.9
30	70.0	67.8	0.4	44.0	85.0	295.0	20.0	12.5	4.6	46.1	65.5	46.1	65.5
31	64.0	96.0	0.4	43.0	55.0	260.0	20.0	14.8	4.4	48.6	68.0	48.6	68.0
32	80.0	66.0	0.5	56.0	50.0	290.0	22.0	16.3	5.7	44.5	68.0	44.5	68.0
33	72.0	48.0	0.4	49.0	60.0	255.0	22.0	18.9	4.8	40.0	60.5	40.0	60.5
34	64.0	47.0	0.3	48.0	50.0	250.0	20.0	19.1	4.7	42.5	63.5	42.5	63.5
35	69.0	61.0	0.4	47.0	55.0	305.0	20.0	19.2	5.4	40.1	61.6	40.1	61.6
36	78.0	70.0	0.4	50.0	55.0	340.0	22.0	17.4	6.2	40.8	61.3	40.8	61.3

5.4   Missing data/information

Although a high amount of monitoring data of sediment and water quality on two- or four-weekly basis is available (websites of Waterbase and the database of ICPR), the accessibility of detailed and recent datasets on daily (or higher temporal resolution) basis is very low. One or two measurements during a flood event are insufficient to investigate possible changes in sediment and water quality during extremely high flow conditions. Detailed monitoring campaigns during flood events are thus recommended.

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In addition, more information of the exchange of contaminants between bottom sediment and surface water, and of the relation between sediment quality and water quality during flood events is needed to assess the impacts of 'Altlasten' (or contaminated sediment in general) on the water function of the Rhine river.

6 Conceptual models for the redistribution of sediments and pollution during extreme events

6.1 Introduction

As already mentioned, based on the existing information (data) and models, this study wants to make an overview of the relevant knowledge lagoons and to identify advisable research directions. On of the main research questions was: w*hich data are necessary to model the release and sedimentation of polluted sediments?* This chapter gives first an overview of the requirements for a contaminated sediment transport model. Further, the available models for the entire Rhine catchment are discussed in this chapter. Finally, the information (models) gaps are in this chapter also addressed.

6.2 Requirements for a contaminated sediment transport model

The development of a contaminated sediment transport model requires a comprehensive data base including hydrological, morphological and sedimentological data, as well as chemical and biological data to cover sorption, transformation and biodegradation processes.

According to Westrich (2007), in order to calculate the immission data at a specific site, the following factors are relevant to be considered:
- spatial and temporal resolution
- water and sediment quality processes implemented
- number of hazardous sites involved
- quality of data about in-situ contaminants
- pathway and tributaries, between emission and immission site
- physical and biochemical processes involved
- database for model calibration and validation

Although a certain area may contain a large amount of polluted sediment, this does not automatically imply that this site poses a risk for the river eco-system. Sites with high pollution levels only form a (potential) risk for downstream locations when the sediments or the pollutants are mobilized again. Heise et al. (2004) provide an overview of processes that may lead to the mobilisation of sediment associated contaminants. The factors and processes that affect the solubility and mobility of sediment-bound metals comprise:
- decreased pH from mining effluents or from acid precipitation,
- increased salt concentrations;
- increased occurrence of complexing agents (DTPA, EDTA, NTA);
- changing redox conditions, for instance after floodplain deposition of contaminated anoxic dredged materials.

Although these processes may pose a risk for organisms at the polluted sites and the ecological potential for the river system, flood events characterised by high flow velocities that may result in erosion and events that may result in the delivery of polluted sediment into the river system are the most important processes in the context of this study. Transport and fate of contaminants in the water body are significantly influenced by the ratio of the concentration in the dissolved and the particulate phase.

The following sections give a brief overview of the main processes for the modelling of the sediment transport and the distribution of heavy metals.

6.2.1　Sediment transport

A contaminated sediment transport model may consider different fractions of sediment like sand, silt and clay. Each fraction has its own sedimentation characteristics. Moreover, the sediment can be divided in different layers with a given thickness.

The sediment transport is modelled with a resuspension - sedimentation approach. The bed shear stress is the determining parameter for resuspension and sedimentation. The bed shear stress is a function of the flow velocity, the roughness of the river bed and the water depth. At low bed shear stresses, sedimentation of suspended particles prevails. At intermediate bed shear stresses, sedimentation and resuspension are in a state of equilibrium. When the flow velocity and bed shear stress exceed a certain threshold level, resuspension will occur, see also Figure 6.1

The sedimentation velocity and the critical shear stress for sedimentation are different for each suspended solids fraction. On the other hand, the resuspension velocity and the critical shear stress for resuspension apply to all three sediment fractions. These three sediment fractions are assumed to be mixed within the sediment layer. The resuspension flux of each sediment fraction depends on the relative amount of the particular fraction in the sediment layer.

The resuspension of the sediments is controlled by the tangential tension at the bottom caused by the flow and by the waves created by the wind.
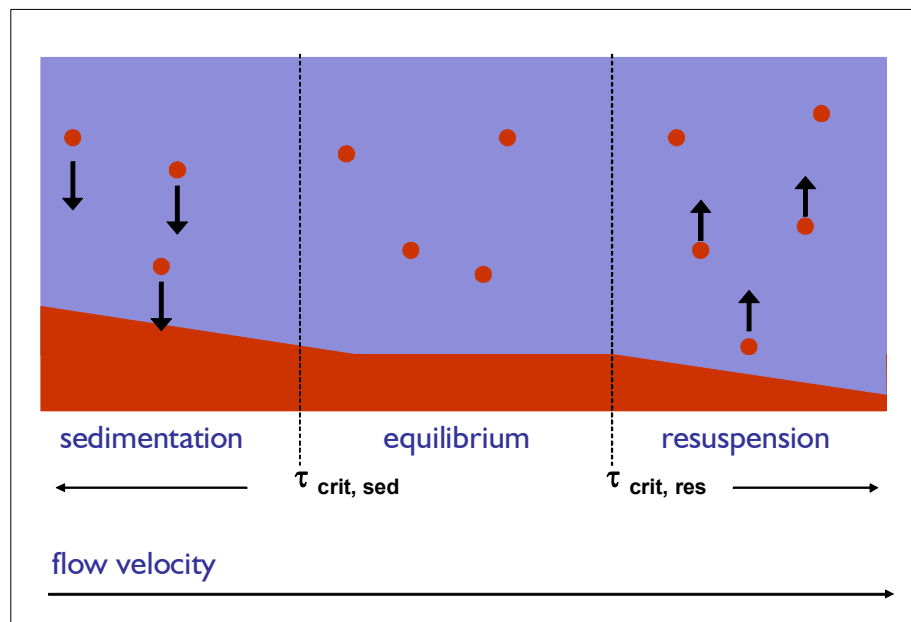

Figure 6.1 Resuspension –sedimentation in the sediment model

6.2.2　Pollutants: case of heavy metals

The level of detail and the number of substances added in the model depend on the water quality problem to be investigated and of course on the behaviour of the water

system. In the case of modelling heavy metals, they are mainly adsorbed to the suspended solids and to the bed sediment particles. The affinity of heavy metals for a sediment fraction in particular can be different and each affinity can be specified in the water quality model. Moreover, it is possible to adjust the adsorption coefficient for each metal in the water and in the sediments. Figure 6.2 shows some processes in a model for copper. The same processes are similar for other metals. The pink box on the left side represents the dissolved copper. Suspended solid, yellow box on the left side can also be understood as SPM (including particulate organic matter). The pink/yellow box on the right side gives the particulate phase of copper. An important process that is missing is the complexation of the copper with dissolved organic carbon.
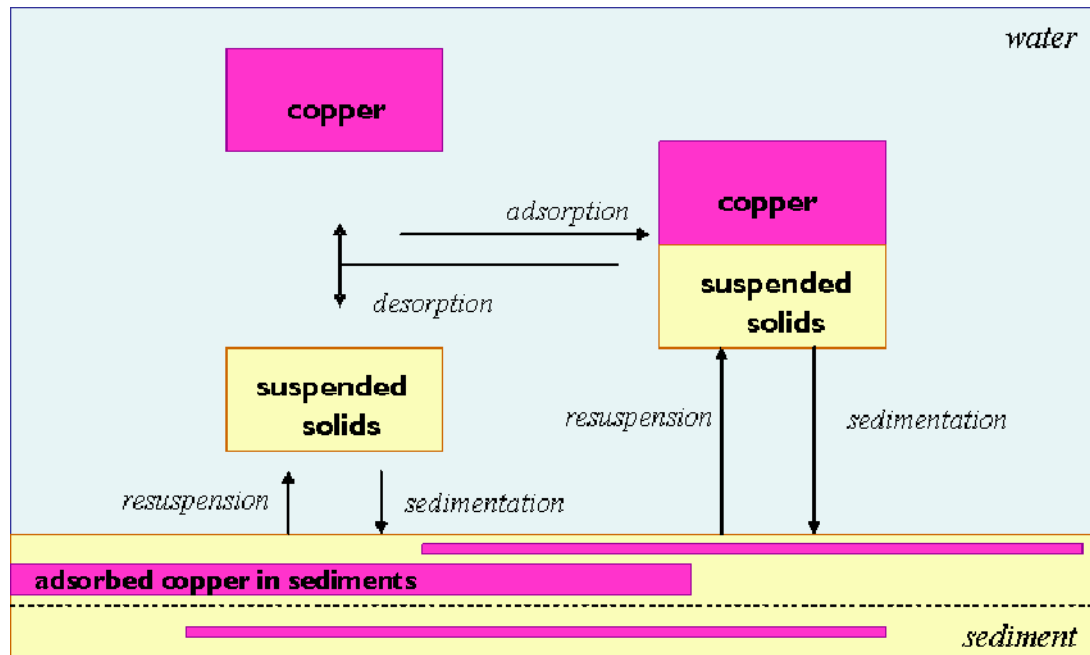

Figure 6.2 Model for copper in the water and in the sediment in Delwaq

6.3   Available models for the Rhine basin

This section gives a brief overview of the available models for the entire Rhine basin.
The models described are:
- The Rhine Alarm Model (RAM)
- The FEWS DE
- SOBEK models
- WAQUA models Rhine branches
- Suspended particulate matter model Rhine – Meuse mouth

6.3.1   The Rhine Alarm Model (RAM) (WL | Delft Hydraulics, 2006a)

The RAM has been developed especially for the simulation of the distribution and transport (including decay) of contaminant discharges during a calamity. The RAM works properly and includes only the main tributaries of the Rhine River. However, with the RAM, only stationary discharges can be calculated, based on the measured water levels and/or flows in monitoring stations in the Rhine River. The RAM has the option of including decay in the simulation, but it does not include other processes, such as sorption to suspended matter. Furthermore, it is not possible to model sediment transport with the RAM.

The RAM is used to calculate an approximation of the travel time and the concentration of a given pollutant. The travel time is estimated through the flow velocities which are coupled to the mass balance. The following parameters influence the travel time (see Figure 6.3):
1) a longitudinal dispersion coefficient (α);
2) the presence of dead zones (β); and
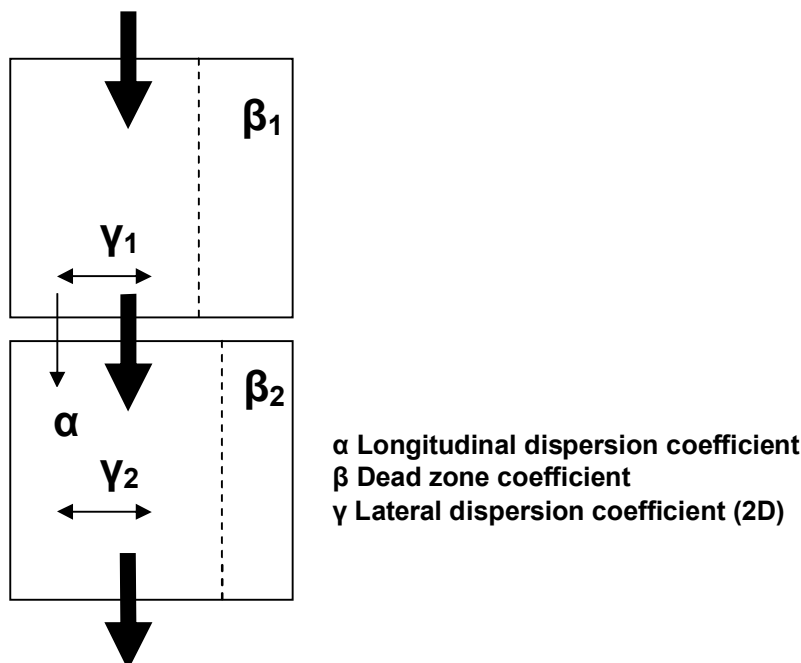3) a lateral dispersion coefficient (γ).

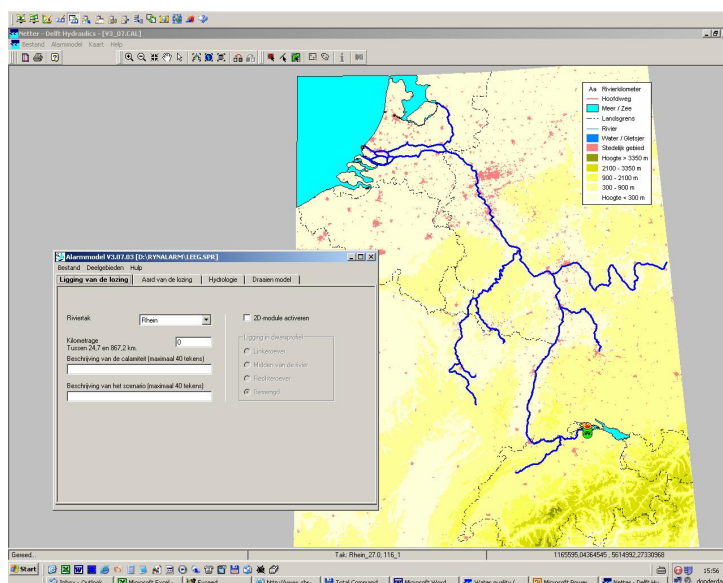*Figure 6.3 Parameters influencing the travel time in the RAM*

Figure 6.4 User interface of the Rhine Alarm Model

6.3.2   Flood Early Warning System – Germany (FEWS-DE)

Forecasts are made on the basis of observed hydrological and meteorological observations, as well as meteorological forecasts. The models that work under FEWS-DE are the HBV model (HBV stands for *Hydrologiska Byrans Vattenbalansavdelning*) and SOBEK River Enginering (RE).

In the Rhine catchment the hydrological and meteorological observations and the meteorological forecasts are used to provide boundary conditions for a calibrated HBV rainfall-runoff. For the calculation of runoff from the Rhine sub-catchments, the HBV hydrological model is used. This is a conceptual hydrological model, which requires observed/forecast precipitation and temperature as boundary inflow at each sub catchment centre-point and then calculates the outflow for that sub-catchment.

The HBV schematisation divides the total catchment area of the Rhine in 134 sub-catchments. This model has a time step of 1 hour, and has been derived from a day time step model of the Rhine basin, with small amendments to the parameters made for the switch to the hourly time step calculation.

The HBV model calculates runoff flowing into the Rhine and its tributaries. Subsequently, these inflows are used as inputs for two hydraulic models of the Rhine (SOBEK RE, see next paragraph). The first model covers the reach between Maxau and Lobith, and the second one the reach from Andernach to Lobith.
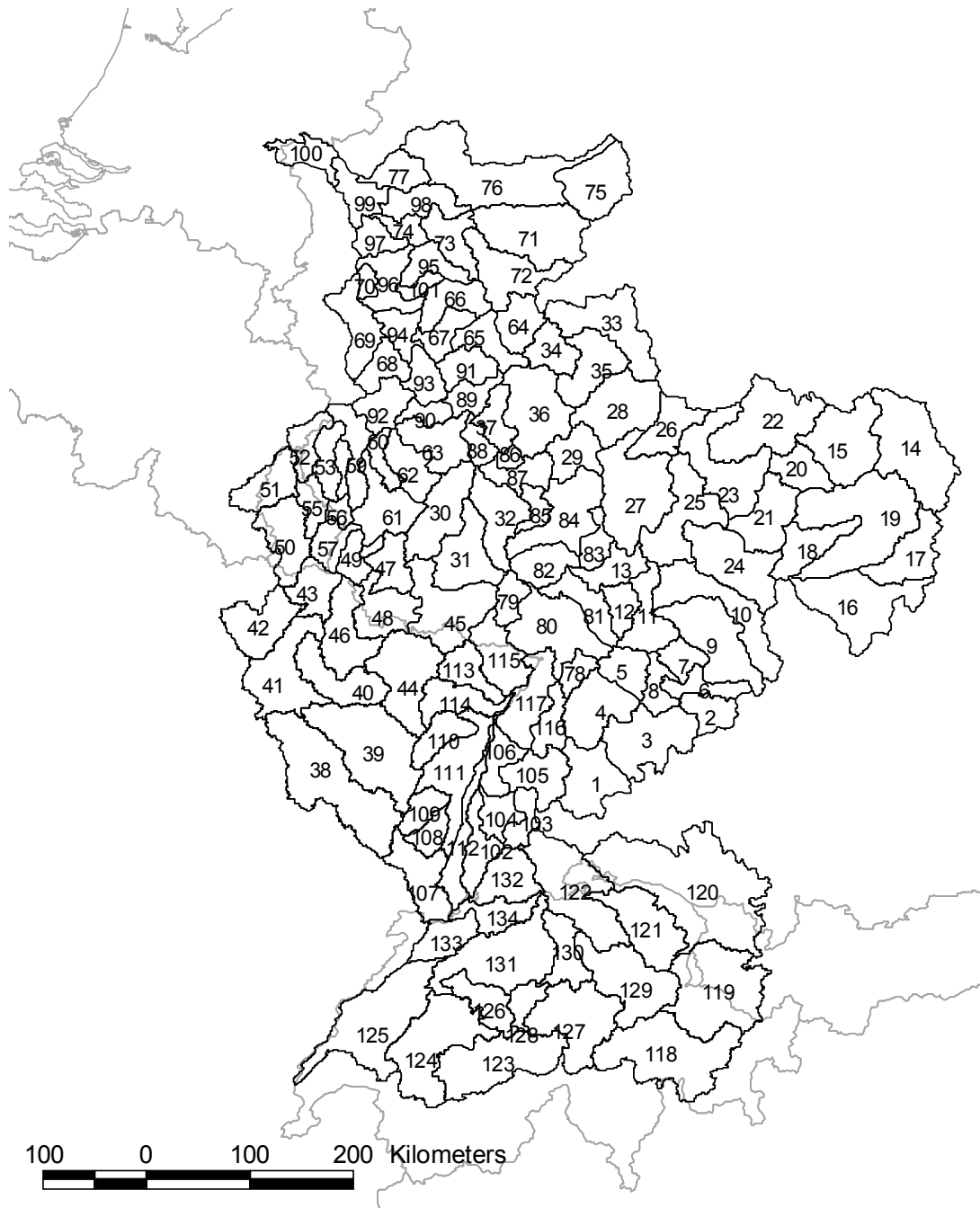
Figure 6.5   Overview of HBV sub-catchments; the numbers are the same as those used in the FEWS-ID for the sub-catchments (e.g. I-RN-0118)

6.3.3   Sobek models for the Rhine basin

Two SOBEK River Engineering (RE) models are used in FEWS-DE for hydrodynamic modelling of the Rhine:

- Andernach-Lobith model. This model has Andernach as the upstream boundary where (error corrected) HBV flows from the entire Rhine basin upstream of Andernach are input. In the forecast phase, an external forecast for Andernach may be available from the *Wasser und Schifffahrtsdirektion* (WSD) Mainz. If so, this will be used in preference to the HBV forecast values.
- Maxau-Lobith Model. This model has Maxau as the upstream boundary where (error corrected) HBV flows from the entire Rhine basin upstream of Maxau (including Switzerland). This is also the case for the other large tributaries (Rhine to Maxau, Rockenau on the Neckar, Raunheim on the Main, Kalkofen on the Lahn and Cochem on the Mosel). Again, an external forecast for Maxau may be available from the WSD Mainz. If so, this will be used in preference to the HBV forecast values.

Inputs in SOBEK are the error corrected HBV values where available and the simulated values where no error correction is applied. At sites where the gauge at which the HBV outflow is available coincides with the boundary of the SOBEK model, then these corrected flows are used directly in SOBEK as boundary condition. Where this is not the case (for smaller tributaries) the gauge may not coincide with a SOBEK boundary. In these cases the HBV calculated flows are first scaled and possibly delayed to account for the travel time to the main Rhine River, as well as for the increase in catchment area.

The SOBEK model schematisations include a large number of offline storage reservoirs. At 68 locations between Maxau and Lobith these lateral outflows are included in the model.

6.3.4   WAQUA models Rhine branches

WAQUA is the water movement model in 2 dimensions of the Dutch Ministry of Transport, Public Work and Water Managenment (Rijkswaterstaat) to calculate the water levels and current velocities in the Rhine branches. This model is used to evaluate the effects on the water levels within the framework of permit request for the Norm Management (in Dutch *Wet beheer rijkswaterstaatwerken, WBR*). No water quality processes (e.g. SPM or mud or heavy metals processes) are included in the WAQUA models Rhine branches. These models consider the main Rhine River branches and the division points downstream of Lobith (Rhine Delta). The WAQUA models were based on a 70 -100 meter rooster or on a 40 meter roosters. In order to be able to evaluate the *WBR* permit requests in sufficient detail, the department ANSR of the Regional service *Oost-Nederland* asked in 2007 WL | Delft Hydraulics to calibrate 4 WAQUA models on the basis of a 20 meter rooster (WL | Delft Hydraulics, 2007). These models are (see Figure 6.6):

- The "*Boven-Rijn*" (from Lobith until Tolkamer) plus the Waal (from Emmerich until Hardinxveld);
- The "*Boven-Rijn*" plus the Pannerdensch canal plus Neder-Rijn plus Lek (from Emmerich until Krimpen a/d Lek);
- The "*Boven-Rijn* plus the Pannerdensch canal plus IJssel plus Ketelmeer (van Emmerich until Ketelbrug);

- The division point area, "*Boven-Rijn"* plus the Pannerdensch canal plus the upstream parts of the Waal, Neder-Rijn and IJssel.

The models were calibrated for the low discharges in 1995 and the high discharges in 1995, and validated for the high discharges 1993. The results showed that the average water level differences were 0.5 cm, -1.4 cm and -5.5 cm during the low discharges in 1995, high discharges in 1995 and high discharges in 1993, respectively.
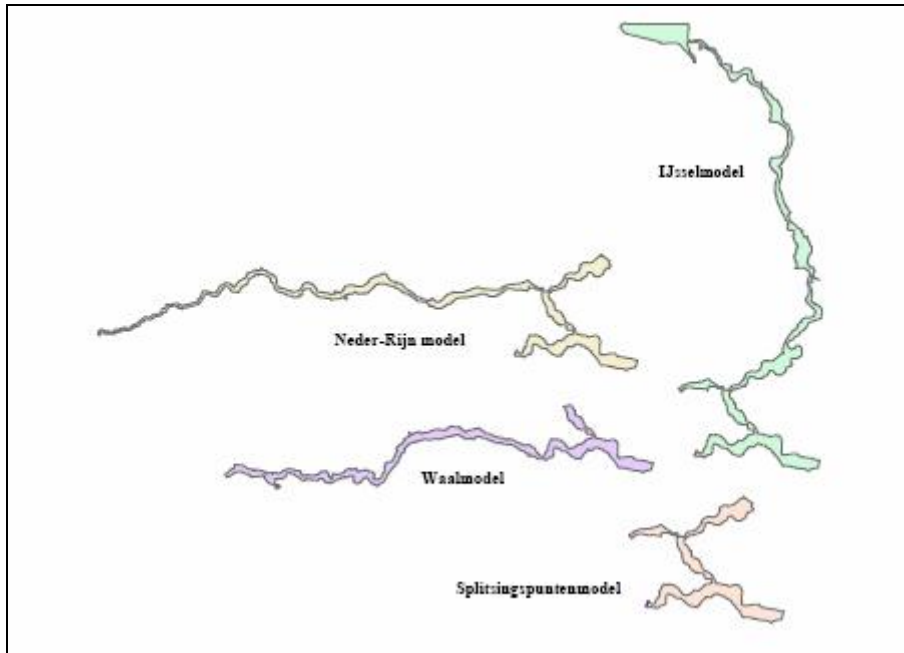
Figure 6.6   Contours calibration models

6.3.5   Suspended Particulate Matter (SPM) Rhine – Meuse mouth (WL | Delft Hydraulics, 2006b)

In 2005 Rijkswaterstaat asked WL | Delft Hydraulics to model the suspended particulate matter (SPM) for 2 areas: The nine ditches of the Waal at Gameren and the Rhine – Meuse mouth. These models were aimed to get a better insight in the patrons of erosion and sedimentation, to make a sediment balance for the study areas and to simulate the dispersion and distribution of different mud fractions. The case study for the nine ditches of the Waal was finished in 2006 successfully. For the Rhine – Meuse mouth study another research was carried out in 2006 to calibrate the model for three discharges on the basis of new measurements of the composition and properties of the SPM.

The results showed that the simulated SPM followed the measurements well. In particular, the results at the *Boven Merwede* and at the *Nieuwe Merwede* were comparable with the measurements (boundary dominance).

The Rhine – Meuse mouth has a clear system working (see Figure 6.7). The driving force behind the SPM behavior is the bottom shear stress. This happens at high discharges at the Waal and the Meuse. Due to this, at the *Boven Merwede* and the *Nieuwe Merwede* the SPM does not get the chance to settle down. Besides this, when some bottom material is present, resuspension plays also a role in these areas.

In the Hollandsch Diep and in the Biesbosch the bottom shear stress is lower and the SPM settles down. Besides this, the fine sand fractions and possible the mud come slowly down. The fine mud does, however, not sink in the Hollandsch Diep.

The shear stress is clearly under the influence of the tide. At high discharges the current will stagnate and will result in a low shear stress. At that moment the SPM in the Hollandsch Diep and in the Biesbosch will get the chance to settling down.
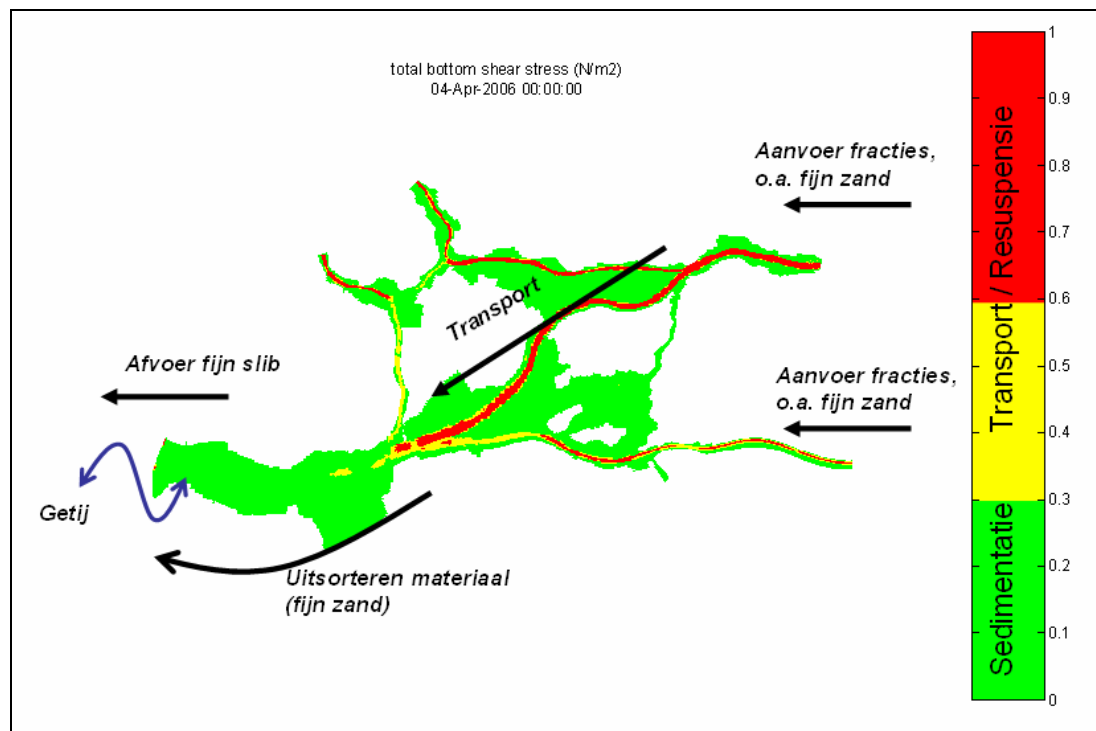
Figure 6.7   System working Rhine – Meuse mouth. As boundary for the sedimentation the threshold for the coarse SPM is chosen.

6.4   Discussion

The RAM simulates the distribution and transport (including decay) of discharges during a calamity, but it does not include processes such as sorption of pollutants to suspended matter. It does not allow the modelling of sediments, either. Some recommendations of the RAM have been recommended. One of them is to include the interaction with suspended matter. In order to do that a numeric model of the RAM has to be built. In this case special attention has to be given to the dead zones included in the RAM.

SOBEK RE is an old version of SOBEK Rural. The user-interface and the possibilities for changing the schematisation are improved in SOBEK Rural. Furthermore, in SOBEK Rural more attention is given to the coupling between the hydrodynamic/hydrology and the water quality and ecology, and to the coupling to the rainfall-runoff model. In SOBEK RE more attention is paid to the morphologic aspects, salt intrusion and other hydrodynamic aspects.

WL | Delft Hydraulics aims at the migration of all functionalities in SOBEK-RE to SOBEK Rural. We expect this to be accomplished in the near future. However, we cannot give a clear date when this will happen. This also means a migration of the Rhine model in SOBEK-RE to SOBEK Rural. This aspect is very important for modelling the water and sediment quality. Normally (in standard situations) SOBEK is used in projects where the coupling with water quality is important. Once a hydrodynamic model for the Rhine is available in SOBEK, this model has to be calibrated. In particular the SOBEK-RE model for the Rhine is calibrated for high discharge situations and not for low flow situations. For the water quality, low flow situations are very important.

In 2006 WL | Delft Hydraulics carried out a study into the influence of heat discharges on the water quality of the Rhine (WL | Delft Hydraulics, 2006c). In this study, a DELWAQ temperature model for the Rhine was built in SOBEK. In this model the hydrology and hydrodynamics of the Rhine was strongly simplified stemming from a lack of proper cross sections and non-closed water balances. One important conclusion of this study was that using too simple hydrodynamics means a limitation for the calibration of the water quality model (e.g. a temperature model or a model for the transport and fate of the contaminated sediments). At the present the SOBEK-RE model for the Rhine corresponds to the best available hydrodynamic model for the entire river catchment. However, the compatibility of this model with the water quality model is not yet ufficient.

Another point of attention regarding the modelling of the sediments in the Rhine basin is the dimension of the model required. The RAM and SOBEK-RE model of the Rhine are 1D applications. For the modelling of SPM sedimentation in the river bed but also in the floodplains, and to study the erosion patrons a 2D application is needed. Considering the detailed level of information required of the area of study (e.g. 20 x 20 m grids with the topography), as well as the detailed data (spatially as well as temporally) regarding the SPM and substances concentrations, a 2D model for entire Rhine basin is quite ambitious and according to the available information such a model does not exist. Moreover, the calibration of a 2D model is very complex and time consuming.

The WAQUA models Rhine branches and the SPM model Rhine – Meuse mouth are models that can be used as starting point for studying the old contaminated sediment during extreme situations. The first one is more a hydrodynamic 2D model of the main branches of the Rhine downstream Lobith. This model does not includes SPM, sediments or heavy metals modelling, but this model can be extended to the relevant water quality processes and substances. The second model is a 2D SPM model (where the sediments are included to a certain extend) that can be used to study the effects of extreme situations on the water and SPM quality.

7   Discussion and conclusions

7.1   Introduction

The discussion, conclusions and recommendations presented in this chapter are based on the literature research, the workshop of November 2 2007 (see appendix A) and the discussion session of December 17 2007 (see appendix B).

7.2   Discussion

7.2.1   Definition of calamities

From the WFD questions arise that may include problems related to contaminated sediments. An important remark is the definition of the release of the old sediment during extreme situations: Is it considered as calamity or "after care" situation? However, looking at the contaminated sediments and including them in the WFD studies will not only help to succeed the reporting phase but it will also give an extra value for water managers. In this context the following question require attention: When defining the norms, have the average or the peak values been taken as the starting-point, and what should be done in order to protect ecology and other functions?

The answers to these questions are important for the implementation of the WFD. According to Zwolsman & van Vliet (2007), article 4.6 of the WFD says that a temporal degradation of the state of water bodies is not in conflict with the directive when the degradation is the result of exceptional natural circumstances or natural circumstances that were impossible to anticipate. These authors state that this definition means extreme floods or droughts with a long duration. In this context the following question arises: Are the effects of high discharges on the water and sediment quality sufficiently well known?

With regard to water quality of the Rhine during flood events, Van Bokhoven (2006) mentions an increased (total) concentration for heavy metals, PAHs and total phosphate, due to increased concentrations of suspended sediment under high flow conditions for the river Rhine.

Results of Asselman (2003), showed a decrease of contaminant concentration in sediments with increase of discharge as a result of the input of eroded, relatively clean material which dominates the suspended sediment quality. This author, however, did not include a lot of data with discharges of more than 6,000 m^3/s. Peak discharges of the Rhine range between 5,000 and 12,000 $m^3 s^{-1}$. Higher discharge and flow velocities lead to more resuspension of river bed sediment during extreme flow conditions. Some part of the "Altlasten" sediments will never be released under normal conditions, as they are buried deep under younger, less polluted sediment layers. Dredging of the sediment top layers in the Rhine catchment area will risk the exposure of the older contaminated sediments to the water flow, leading to possible erosion and distribution to areas downstream. However, this can be defined as a site specific problem and therefore it is important to start at the areas of concern into account (see Chapter 2).

The Waterdienst does not confirm that release of Altlasten can be considered as calamity, because there are uncertainties about whether re-suspension of Altlasten will lead to critical situations affecting functions of the Rhine River. Re-suspension of contaminated sediment under high flow conditions is expected to increase the total load. However, uncertainties exist about whether re-suspension of Altlasten will result in deterioration of sediment and water quality, as re-suspended contaminated sediment will mix and will be diluted by fresh less polluted sediment. In addition, the impact of increased concentrations in suspended matter on water quality and ecological and human risks are uncertain.

In the context of calamities, the definition of the actual and potential problems during extreme situations and the effects on the functions in the Rhine basin (such as agriculture, ecology, recreation) require special attention. Examples of stakeholders that can be seen as problem owners in the Dutch part of the Rhine are:
- Drinking water: Kiwa, Waterworks companies
- Waterdienst (Centre for Water Management)
- Managers of nature reserve areas
- Forest managers
- Port of Rotterdam
- Municipalities along the Rhine, like the Municipality of Rotterdam

Besides the actual and potential problems during extreme situations, the focus also has to go to the areas where problems are expected. In order to define areas where old contaminated sediments (Altlasten) can be released, the following information is needed:
- Locations and volume of contaminated sediment, and contamination level of sediment in the river bed.
- Locations of areas where contaminated sediment are covered by thin layers of fresh (less polluted) sediment.
- Sediment deposition areas where re-suspension can take place. Areas behind weirs and groyne fields are important to focus on, as these sites are both sinks and sources.

7.2.2   Pathways for the transport of historical contamination

In our study the focus is laid upon the problem of the old contaminated sediments in the Rhine basin during extremely high discharges. However, when looking at calamities other pathways have to be taken into account as well.

The acute problem with the substance hexachlorobezene (HCB) during the incident in Iffezheim at the beginning of 2005 can be mentioned as an example of emissions from historical contamination during management decisions. In front of a dam in the Rhine at south German Iffezheim about 350.000 m^3 contaminated sludge was accumulated (Kempen, 2007). The sludge was also responsible of water quality problems. Due to the accumulated sediments, the water could not flow downstream by the opening of the dam causing a big pressure on the dikes. The German regional water direction decided to pump the sludge to the other side of the dam and relocate it into the Rhine. The accumulated sludge consisted of fresh and old sediment ("Altlasten"). The old sediment layer was contaminated with 40 to 50 kg HCB (Kempen, 2007).

Studies in the Elbe and New Orleans indicated that inundation of areas behind the dikes can have a large impact on the quality of sediment and water (more important than Altlasten).

Figure 7.1 shows the different pathways and processes for the transport of historical contamination. It is important to take them into account as well. For example:
- Emissions from mining waters (oxidation effects)
- Flooding of installations and distribution of chemicals
- Flooding of contaminated floodplains
- Emissions due to management decisions (e.g. dredging of river bed sediments)
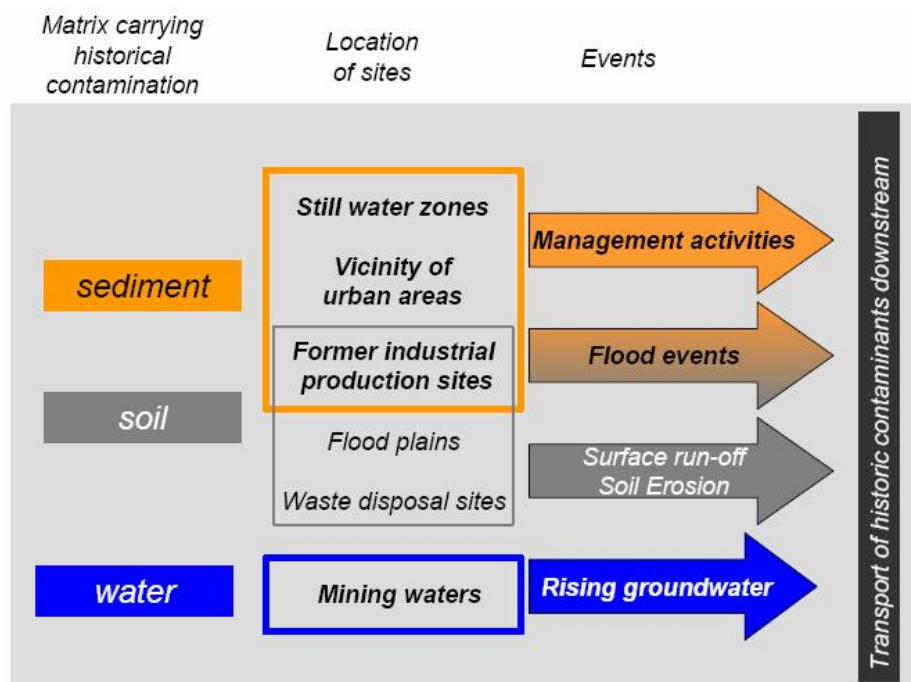
Figure 7.1   Pathways and processes for the transport of historical contamination downstream (Heise et al., 2004)

7.2.3   Data availability

Based on the data inventory, we concluded that datasets of sediment and water quality in the Rhine are available for the main German and Dutch monitoring stations. However, the amount and temporal resolution of measurements are insufficient for establishing relations between sediment quality and discharge under extreme high flow conditions (high frequent measurements on at least one basis are necessary). Detailed datasets of sediment quality, which have been used in the study of Heise and Förstner (2004), are existing, but not freely available.

Sediment and water quality measurements at intervals less than one hour during flooding events are missing. At the moment, only Lobith and Kampen present the highest monitoring frequency (see table below). However, when studying the sediment

dynamics during extreme high discharges, this frequency is not high enough because the peaks in the sediment and water quality may not be measured.

Table 7.1 Monitoring frequency at Lobith and Kampen

Location	SW	SPM
Lobith	2-weekly	2 to 4 weekly
Kampen	4-8 weekly	8 weekly

According to the Waterdienst, other sources of data regarding the water and sediment quality of the Rhine can be found in the following studies and/or projects:

- Extra monitoring programmes of contaminated sediment are available for Koblenz and Lauterbourg. In the downstream parts of the Rhine, sediment quality was measured at different depths in cores (e.g. in Hollands Diep).
- University of Stuttgart (group of professor Westrich) did experiments to quantify the critical shear stress for erosion and re-suspension. The International Commission for Protection of the Rhine (ICPR) was stakeholder in this study. In general, results indicated that sediment is re-suspended at higher critical shear stress than previously expected. The depth and geometry of contaminated sediments in the river bed were also investigated in this study. Sediment quality at different depths were analysed in cores taken in upstream parts of the Rhine.
- In scope of the Rhine Treaty, a Sediment Management Plan is being created (will be finished in February 2008). This plan focuses on contamination level, volume of contaminated sediment and ranks 'areas of concern'. A list of problems in the different countries of the Rhine basin are summarized in fact sheets.
- Information is also available of the release of Altlasten at Iffezheim and effects detected at Lobith in 1998 and 1999.

It is recommended to prepare monitoring programmes of sediment and water quality for future floods events. A plan needs to be made with locations where measurements will be taken, and the equipment that will be used.

7.2.4   Modelling

The technical knowledge and experience is available to model re-suspension and deposition of (contaminated) sediment. However, uncertainties associated with parameter definition make it difficult to simulate the responses in sediment quantity and quality realistically. Extensive analysis of data is needed to get more insights into the dominating processes and model parameters. Series of high frequent measurements are needed to validate the simulated sediment quality by the model.

Making a 2D model for the entire Rhine basin can be very complex. First of all, the cells have to be fine enough, which means a very detailed infromation. Furthermore, the calibration of a 2D model is always difficult.

A model that has not been mentioned is the particle tracking model of Thonon (2006) for floodplain sedimentation in the lower Rhine floodplains in the Netherlands. The aim of this model was to predict changes in patterns and quantities of overbank deposition when environmental variables such as climate, upstream land use and floodplain topography change.

From the process point of view, it is important to understand when the sediments run out. In this context the term "sediment hysteresis" requires attention, in relation to peak discharge, peak sediment quantity and sediment quality.

7.3   Concluding remarks and recommendations

The following are the concluding remarks of this study.
- The "Synergy project" is just a start to build up cooperation.
- The contamination pathways taken into account for the study of calamities should be more complete than only the remobilization of old contaminated sediments in the river.
- Assess whether re-suspension of Altlasten will result in significant deterioration of sediment quality, because this is still unknown. In addition, the impact on water quality (dissolved concentrations) needs to be investigated, as well as the potential ecological and human risks.
- There is a missing insight in the expected remobilisation and recontamination levels of contaminated sediments during extreme situations. Therefore, the topic of contaminated sediments during extreme situations requires to be studied in a broader context. This means not only extremely high discharges (flood), but also extremely low discharges (droughts); not just the historical contamination but also the present contamination.
- Besides this, a better insight is needed in:
  - the interactions of substances with sediment and water
  - the geometry of the polluted sediments inside the riverbed and floodplains
  - processes of sediment dynamics,
- Stakeholders have to be included in the definition of actual and potential problems.
- Focus on the areas at risk and areas of concern in the lower part of the Rhine, in particular deposition areas (Hollandsch Diep, Haringvliet, Noordzee, IJsselmeer, Waddenzee). These areas can be interesting for case studies.
- Sediment and water quality measurements at intervals less than one hour during flooding events are missing.
- Regarding the modelling, a strong recommendation is to focus first on the source locations and later extend, when possible, the study to the entire basin of the Rhine River. This will help to better understand the dynamics of the system.
- Furthermore, we have to give attention to the development, extension and/or improvement of 2D water quality models that include SPM, sediments and substances like heavy metals and organic micro pollutants for local/regional areas within the Rhine catchment. Starting points can be the WAQUA models Rhine branches and/or the SPM model Rhine – Meuse mouth.
- Different levels of ambition can be defined:
  - Forecasting the (local)water quality of the Rhine based on relations between discharge / sediment quality / water quality
  - Long term sustainable planning and prediction
  - Short term calamities

8 Literature

8.1 Literature of contaminated sediment sources

Heise and Förstner (2004) *Inventory of historical contaminated sediment in Rhine Basin and its tributaries*. Final report. Technical University Hamburg, Germany

Heise and Förstner (2006) *Risks from historical contaminated sediments in the Rhine basin*. Water, Air and Soil Pollution 6, 625-636
http://bis.tutech.de/B/?page=downloads

Gebersdorf, S.U., T. Jancke & B. Westrich (2007). *A comprehensive approach to evaluate sediment properties and their covariance patterns over depth in relation to erosion resisitance – First investigations in natural sediments at three contaminated reservoirs.* J. Soils Sediments 7 (1), 25-35.

ICBR (2001) *Rhein 2020 Programm zur nachhaltigen Entwicklung des Rheins* Rhein-Ministerkonferenz 2001
http://www.iksr.org/index.php?id=79

ICBR (2003) *Bestandsaufnahme der Emissionen prioritärer Stoffe 2000.* Bericht Nr. 134.

ICBR (2005a) *Rijn zonder grenzen - Inventarisatie 2004 in het stroomgebiedsdistrict Rijn.* Coördineringscomité Rijn
http://www.iksr.org/index.php?id=239

ICBR (2005b) *Internationaal stroomgebiedsdistrict Rijn - Kenmerken, beoordeling van de milieueffecten van menselijke activiteiten en economische analyse van het watergebruik.* Rapportage aan de Europese Commissie inzake de resultaten van de inventarisatie conform de Richtlijn 2000/60/EG van het Europees Parlement en de Raad van 23 oktober 2000 tot vaststelling van een kader voor communautaire maatregelen betreffende het waterbeleid. (Artikel 15 (2), 1 e gedachtestreepje) (Deel A = overkoepelend deel)
http://www.iksr.org/index.php?id=241

ICBR (2007) *Rapportage inzake de coördinatie van de toestand- en trendmonitoringsprogramma´s conform artikel 8 en artikel 15, lid 2 KRW in het internationale stroomgebiedsdistrict Rijn (Rijndistrict) (deel A – rapportage)* Coördineringscomité Rijn
http://www.iksr.org/index.php?id=238

8.2 Literature of water and sediments quality in normal situations

ICBR (2001) *Rhein 2020 Programm zur nachhaltigen Entwicklung des Rheins* Rhein-Ministerkonferenz 2001
http://www.iksr.org/index.php?id=79

ICBR (2002) *Vergleich des Iszustandes des Rheins 1990 bis 2000 mit den Zielvorgaben –* 70 Plenarsitzung – 2/3 juli 2002 – Bern

ICBR (2004a) *Stroomopwaarts balans Rijnactieprogramma*
Internationale Kommission zum Schutz des Rheins/ Commission Internationale pour la Protection du Rhin/ InternationaleCommissie ter Bescherming van de Rijn

ICBR (2004b) *Vergleich des Iszustandes des Rheins 1990 bis 2001 mit den Zielvorgaben –* 70 Plenarsitzung – 8/9 juli 2004 – Bern

ICBR (2005a) *Rijn zonder grenzen - Inventarisatie 2004 in het stroomgebiedsdistrict Rijn.* Coördineringscomité Rijn
http://www.iksr.org/index.php?id=239

ICBR (2005b) *Internationaal stroomgebiedsdistrict Rijn - Kenmerken, beoordeling van de milieueffecten van menselijke activiteiten en economische analyse van het watergebruik.* Rapportage aan de Europese Commissie inzake de resultaten van de inventarisatie conform de Richtlijn 2000/60/EG van het Europees Parlement en de Raad van 23 oktober 2000 tot vaststelling van een kader voor communautaire maatregelen betreffende het waterbeleid. (Artikel 15 (2), 1 e gedachtestreepje) (Deel A = overkoepelend deel)
http://www.iksr.org/index.php?id=241

ICBR (2007) *Rapportage inzake de coördinatie van de toestand- en trendmonitoringsprogramma´s conform artikel 8 en artikel 15, lid 2 KRW in het internationale stroomgebiedsdistrict Rijn (Rijndistrict) (deel A – rapportage)* Coördineringscomité Rijn
http://www.iksr.org/index.php?id=238

8.3   Available data and reports of water and sediment quality during floods

Japenga, J., K.H. Zschuppe, A.J. de Groot, & W. Solomons (1990) *Heavy metals and organic micropollutants in floodplains of the River Waal, a distributary of the River Rhine, 1958-1981.* Netherlands Journal of Agricultural Science 38, 381-397.

Middelkoop, H. & M. van der Perk (1998) *Modelling Spatial Patterns of Overbank Sedimentation on Embanked Floodplains,* Geografiska Annaler, Physical Geography, Vol 80, No 2, 95-109.

Middelkoop, H. (2000) *Heavy-metal pollution of the river Rhine and Meuse floodplains in the Netherlands*, Netherlands journal of geosciences, vol 79, No 2, 411-428.

Thonon, I. (2006) *Deposition of sediment and associated heavy metals on Floodplains*, proefschrift Faculteit Ruimtelijke Wetenschappen, Universiteit Utrecht, Netherlands Geographical Studies 337

Wolterbeek, H. Th., T.G. verburg, Th,G. van Meerten (1996) *On the 1995 flooding of the rivers Meuse, Rhine and Waal in the Netherlands: metal concentrations in deposited River sediments.* Geoderma 71, 143-156.

Zwolsman, J.J.G., R.M. Kouer en A.J. Hendriks (2000) *Environmental impacts of river floods in the Netherlands,* BMBF Symposium Elbeforschung (Wasser Berlin, 2000), ATV-DVWK-Schriftenreihe, Vol. 21, pp. 33-61.

Asselman, N. (2003) *Slibsedimentatie in noodoverloop- en retentiegebieden*, report WL Delft Hydraulics Q3249. In opdracht van DG Rijkswaterstaat - RIZA

Bakker, I.J.I. (2006) The *composition of suspended particulate matter during floodings of the river Meuse*, MSc report TNO, Utrecht, The Netherlands

CIPR (1998) *Aktionsplan Hochwasser* Internationale Kommission zum Schutz des Rheins/ Commission Internationale pour la Protection du Rhin/ InternationaleCommissie ter Bescherming van de Rijn
http://www.iksr.org/index.php?id=81

Delsman, J. (2002) *Reconstruction floodplain sedimentation rates from heavy metal and caesium-137 profiles: an inverse modeling approach*, MSc-thesis, Department of physical geography, Utrecht University, The Netherlands

ICBR (2001) *Umsetzung des Aktionsplans Hochwasser bis 2000*
Internationale Kommission zum Schutz des Rheins/ Commission Internationale pour la Protection du Rhin/ InternationaleCommissie ter Bescherming van de Rijn.
http://www.iksr.org/index.php?id=80

Middelkoop, H. en M. van der Perk (2003) *Herverontreiniging met zware metalen van slib op uiterwaarden langs de Rijntakken*. Departement Fysische Geografie, Faculteit Ruimtelijke Wetenschappen, Universiteit Utrecht. In opdracht van RIZA.

RIZA (1991) *Waterkwaliteitsmetingen in de Maas tijdens een periode van hoogwater december 1990/januari 1991*, RIZA report nr. 91.045x.

RIZA (1992a) *Waterkwaliteitsmetingen in de Maas tijdens een periode van hoogwater december 1990*, RIZA report nr. 92.042x.

RIZA (1992b) *Hoogwater in de Rijn; veranderingen in het zwevend stof*, RIZA reportnr 92.061x.

RIZA (1994) *Meetverslag zwevende stof metingen in de Maas tijdens hoogwater december 1993*, RIZA reportnr. 94.160x.

Van Bruggen, M., P.B.M Stortelder, C. van de Guchte, W.F. van Hooft (1995) *Hoogwater januari en februari 1995: Kwlaiteit en risico's van het door Rijn en Maas aangevoerde rivierslib.* RIZA en RIVM, report nr 609021006.

Van Bokhoven, A.J. (2006) *The impact of climate change on the water quality of the Rhine River, KIWA Water Research report 2006.056 (s)* (internship), Nieuwegein, The Netherlands.

Van Vliet, M.T.H. (2006) *Effects of droughts and floods on the water quality and drinking water function of the river Meuse* – a preview of climate change? KIWA Water Research (internship)report 2006.073 (s), Nieuwegein, The Netherlands.

8.4   Available data and reports of water and sediment quality during droughts

Van Bokhoven, A.J. (2006) *The impact of climate change on the water quality of the Rhine River, KIWA Water Research report 2006.056 (s)* (internship), Nieuwegein, The Netherlands

Van Bokhoven, A.J. & J.J.G. Zwolsman (2007) *Klimaatverandering en de waterkwaliteit van de Rijn,* H2O 9, p. 34-37

Van der Weijden, C.H., J.J. Middelburg (1989) *Hydrogeochemistry of the river Rhine –
long-term and seasonal variability, elemental budgets, base levels and pollution*. In: Water
Research 23, pp. 1247-1266

Van Vliet, M.T.H. (2006) *Effects of droughts and floods on the water quality and drinking
water function of the river Meuse* – a preview of climate change? KIWA Water Research
report 2006.073 (s) (internship), Nieuwegein, The Netherlands

Van Vliet, M.T.H.. & J.J.G. Zwolsman (2007) *Klimaatverandering en de waterkwaliteit van
de Maas,* H2O 9, p. 29-33.

Other literature cited in this rapport

Asselman, N.E.M., 1997. *Suspended Sediment in the River Rhine – the Impact of Climate
Change on Erosion, Transport and Deposition*. Proefschrift, Departement Fysische
Geografie, Universiteit Utrecht.

Asselman, N.E.M.; Wijngaarden, M. van (2002). *Development and application of aa 1D
floodplain sedimentation model for the River Rhine in the Netherlands.* Journal of Hydrology
268: 127 – 142.

Asselman, N.E.M.; Middelkoop, H. van Dijk, P.M. (2003). *The impact of changes in climate
and land use on soil erosion, transport and deposition of suspended sediment in the River
Rhine*. Hydrol Processes 17:3225-3244

Delft Cluster project (2007). *Inceptierapport Waterkwaliteit en calamiteiten.* Delft Cluster-
publication: 7514-228-17

Förstner U. and Owens, P.N. (2007). *Sediment dynamics and pollutant mobility in rivers:
An interdisciplinary approach*. Chapter 1. Westrich, B. en Förstner U. (eds). Springer

Kempen, J. van (2207). *Interstatelijke civiele sancties wegens grensoverschrijdende
milieuvervuiling. Universiteit Utrecht*. ISBN: 978-90-5213-143-6.

Thonon, I (2006). *Deposition of sediment and associated heavy metals on floodplains*.
Thesis report. Univerity Utrecht

Van der Heijdt, L.M. & J.J.G. Zwolsman, 1997. *Influence of flooding events on suspended
matter quality of the Meuse River (The Netherlands)*. In: G.H. Leavesly, H.F. Lins, F. Nobilis,
R.S. Parker, V.R. Schneider & F.H.M. van de Ven (eds), Destructive water: water-caused
natural disasters, their abatement and control (proceedings of the international conference
on …, held at Anaheim, California, USA). IAHS publication 239, pp 285-294

Westrich B. (2007). *Sediment dynamics and pollutant mobility in rivers: An interdisciplinary
approach*. Chapter 2. Westrich, B. en Förstner U. (eds). Springer

WL | Delft Hydraulics (2007). *Kalinbratie 20 m WAQUA model Rijntakken.* Rapport
Q4276.00

WL | Delft Hydraulics (2006a). *Delft 3D – WAQ. Detailed description of processes.
Technical Reference Manual.*

WL | Delft Hydraulics (2006b). *Zwevende stof Rijn-Maasmonding*. Rapport Q4201.00

December 2007   *Q4453.00*   *Title*
Synergy project Water Quality and
Calamities

WL | Delft Hydraulics (2006c). *De invloed van warmtelozingen op de watertemperatuur van de Rijn*. Rapport Q4214.00

WL | Delft Hydraulics (?). *Rhine Alarm Model. Technical Reference Manual.*

Zwolsman, G and Van Vliet, M (2007). Effect van een hittegolf op de waterkwaliteit van de Rijn en de Maas. H20, nummer 22, jaar 2007.

A   Report workshop

Report Workshop "Old contaminated sediments in the Rhine basin during extreme situations"

Date	Friday November 2 2007
Location	Room 2.025, TNO, Utrecht
Presence	Ingrid Bakker (TNO), Jacco Booster (GeoDelft), Joost Delsman (WL), Joost Icke (WL), Jan Joziasse (TNO), Hilde Passier (TNO), John Hin (Waterdienst/RIZA), Jaap Olie (GeoDelft), Reinaldo Peñailillo (WL), Gerard van Meurs (GeoDelft), Marcel van der Perk (UU), Hans van Duijne (TNO), Michelle van Vliet (TNO), GertJan Zwolsman (KIWA)
Absence	Hannie Maas (Waterdienst/RIZA), Jannie Pijnenburg (Waterdienst / RIKZ), David Burger (WL), Gerard Klaver (TNO)

Program (in Dutch)

Tijd	Activiteit
09.00 – 09.15	Aankomst
09.15 – 09.30	Welkomwoord **Gerard van Meurs**
09.30 – 09.45	Voorstelronde
09.45 – 10.15	Presentatie: "Synergieproject werkzaamheden: Concept verontreinigde sedimenten in de Rijn tijdens extreme situaties" **Hilde Passier** (Deltares)
10.15 – 10.35	Presentatie "Slibgolven in de Rijn en de Maas - relevantie voor de drinkwater sector" **GertJan Zwolsman** (KIWA)
10.35 – 10.50	Koffiepauze
10.50 – 11.10	Presentatie "Transport en retentie van sediment en verontreinigingen in de Rijn en Maas delta" **Marcel van der Perk** (UU)
11.10 – 12.00	Discussie • Is de probleemdefinitie goed om de beleidsvragen te formuleren? • Inventariseren kennisleemtes • Inventariseren onderzoeksvragen en samenwerking
12.00 – 12.15	Samenvatting resultaten / Afsluiting

DISCUSSION

Older data
Salomons and Japinga may have old databases with useful data of quality during floods

Risk areas the Netherlands
There is no map of risk areas for remobilization of contaminated sediments in floodplains in the Netherlands, however a lot of information is available from recent projects (Ruimte voor de Rivier; saneringsprogramma) so that a map could be constructed after all.

Calamities

In this study we focus on the problem of the old contaminated sediments in the Rhine basin during extremely high discharges. However, when looking at calamities other pathways has to be taken into account (Gertjan Zwolsman, Jaap Olie, John Hin) as well. For example:

- Emissions from mining waters (oxidation effects)
- Flooding of installations and distribution of chemicals
- Flooding of contaminated floodplains

As an example the problem with the substance HCB during the incident in Iffezheim is mentioned (2005?).

The figure below shows the different pathways and processes for the transport of historical contamination. It may be important to taken them also into account.
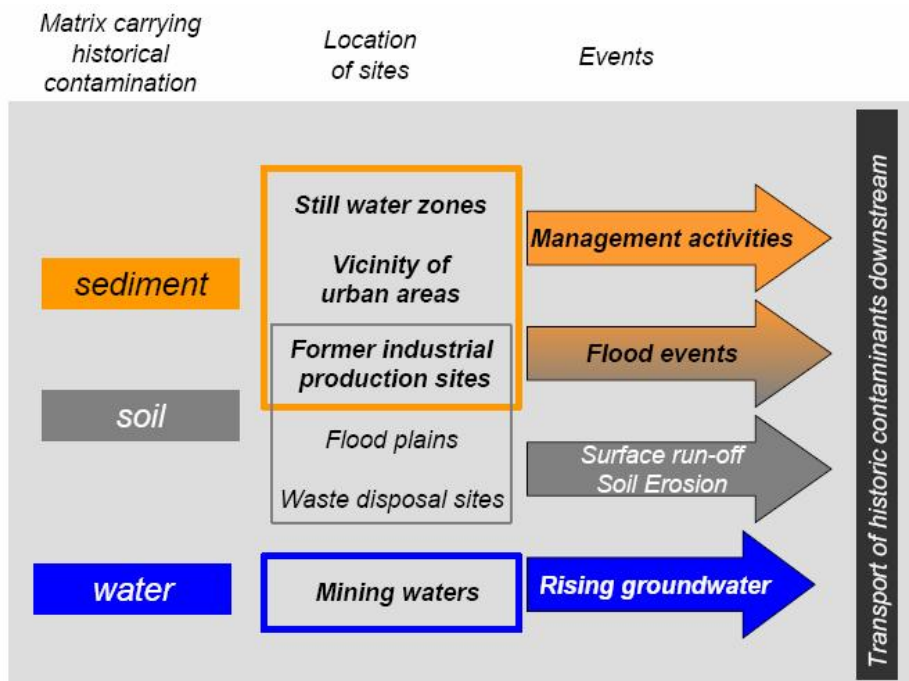
Figure 8.1 Pathways and processes for the transport of historical contamination downstream (Heise et al., 2004)

From the process point of view, it is important to understand when the sediments run out. In this context the term "sediment hysteresis" requires attention in relation to peak discharge, peak sediment quantity, and sediment quality (Gertjan Zwolsman)

Problem owners

Following the context of calamities it is important to define the problems during extremely high discharges and the effects on the functions of the Rhine (agriculture, ecology, recreation). Regarding this, it may be interesting to look also at the biotic part of the system.

For the identification of the problem owners and actual and potential problems, this study has to invite, besides Kiwa (drinking water functions) and the Waterdienst (Centre for Water Management), other stakeholder to participate, e.g.:

- Managers nature areas
- Forest managers
- Port of Rotterdam
- Municipality Rotterdam
- ICPR: International commission for the protection of the Rhine (contact via Waterdienst)

Water Framework Directive

From the WFD questions arise that may include problems with contaminated sediments (John Hin). Looking at the contaminated sediments and including them in the WFD studies will not only help to succeed the reporting phase but it will also give an added value for water managers.

In this context two main questions require attention:

- When defining the norms, are the average or the peak values taken into account; and what should be done in order to protect ecology and other functions?

- What does the WFD say regarding the concentrations and fulfilling the norm? and what should be done in order to protect ecology and other functions?

An important remark is the definition of the release of the old sediment during extreme situations: Is it considered as calamity or "after care" situation. according to the Waterdienst this issue is seeing as an "after care" situation (Reinaldo Peñailillo)

Modelling the Rhine basin
Making a 2D model for the entire Rhine basin can be very complex (Joost Icke). First of all, the cells have to be fine enough. Furthermore, the calibration of a 2D model is always difficult.

Thonon (thesis report "Deposition of sediment and associated heavy metals on floodplains", 2006) modelled floodplain sedimentation in the lower Rhine floodplains in the Netherlands using particle tracking. The aim of his research was to predict changes in patterns and quantities of overbank deposition when environmental variables such as climate, upstream land use and floodplain topography change.

A strong recommendation for our study regarding the modellering is to focus first on the source locations and later extend the study to the entire basin of the Rhine river (Joost Icke). This will help to better understand the dynamics of the system.

Monitoring of locations at risk
According to Gertjan Zwolsman, the locations at risk in the Netherlands have been identified (mainly sedimentation areas).

At the moment, only at Lobith and Kampen a frequent monitoring can be found (Ingrid Bakker, Michelle van de Vliet, Gerjan Zwolsman).

Location	SW	SPM
Lobith	2-weekly	2 to 4 weekly
Kampen	4-8 weekly	8 weekly

Special attention has to be given to the fact that not all information can be found on the database Waterbase on the Internet. Extra data can be delivered by Regional Directions (DONAR database)

In Germany, the locations that are monitored are mainly the WFD-locations (John Hin)

Conclusions and concluding remarks
- The "Synergy project" is just a start to build up cooperation. To write a complete project plan, the contaminations pathways taken into account should be more complete than only the remobilization old contaminated sediments in the river.
- Measurements: sediment and water quality measurements at intervals less than one hour during flooding events are missing
- Modeling: give attention to the source locations, development of new models
- Definition of problems and problem owners. Include other stakeholders to identify actual and potential problems. In order to do this, an idea is to formulate an interview plan. This plan can be tested with the Waterdienst during the discussion day

B   Report discussion session

Report discussion session "Historic contaminated sediments in the Rhine basin during extreme situations"

Date	Monday December 17 2007
Location	Vergadercentrum Vredenburg, Utrecht
Presence	Ingrid Bakker (Deltares/TNO), John Hin (Waterdienst), Dorien te Hulscher (Waterdienst), Erwin Meijers (Deltares/WL), Jaap Olie (Deltares/Geodelft), Leonard Oste (Waterdienst/Deltares), Hilde Passier (Deltares/TNO), Reinaldo Peñailillo (Deltares/WL), Almer de Swaaf (Waterdienst), Michelle van Vliet (Deltares/TNO).
Absence	none

Program (in Dutch)

Tijd	Activiteit
13.15-13.30	Aankomst
13.30 – 13.45	Welkom: Doel discussiemiddag, voorstelronde **Reinaldo Peñailillo**
09.45 – 10.15	Presentatie: "Verontreinigde sedimenten in de Rijn tijdens extreme situaties" **Hilde Passier**
14.15-14.30	Koffiepauze
14.15-14.30	Interview/Discussie
14.30-15.30	**Conclusies**

DISCUSSION

Focus of Waterdienst

The Waterdienst recommends to focus on the problem and on the areas where problems are expected.

In order to define areas where old contaminated sediments (Altlasten) can be released, the following information is needed:
- Locations and volume of contaminated sediment, and contamination level of sediment in the river bed.
- Locations of areas where contaminated sediment are covered by thin layers of fresh (less polluted) sediment.

Special attention needs to be paid on sediment deposition areas where re-suspension can take place. Areas behind weirs and 'kribvakken' are important to focus on, as these sites are both sinks and sources.

In addition to erosion under high flow conditions, release of Altlasten can also take place as a result of human influences (dredging of river bed sediments).

During the workshop of November, it was mentioned that - apart from historical contaminants in bed sediments (Altlasten) - other pathways has to be taken into account as well (e.g. flooding of installations and distribution of chemicals, emission from mining waters). Studies in the Elbe and New Orleans indicated that inundation of

areas behind the dikes can have a large impact on the quality of sediment and water (more important than Altlasten). However, the Waterdienst recommends to still focus on Altlasten-subject, as it will be very complex to take all pathways into consideration (John Hin). Information of water quality effects due to inundation of industrial zones can be provided by the calamity group of the Waterdienst.

The Waterdienst does not confirm that release of Altlasten can be considered as calamity, because there are uncertainties about whether re-suspension of Altlasten will lead to critical situations affecting functions of the Rhine river. Re-suspension of contaminated sediment under high flow conditions is expected to increase the total load. However, uncertainties exist about whether re-suspension of Altlasten will result in deterioration of sediment and water quality, as re-suspended contaminated sediment will mix and will be diluted by fresh less polluted sediment. In addition, the impact of increased concentrations in suspended matter on water quality and ecological and human risks are uncertain.

Data availability and monitoring programs

Based on the data inventory, we concluded that datasets of sediment and water quality in the Rhine are available for the main German and Dutch monitoring stations. However, the amount and temporal resolution of measurements are insufficient for establishing relations between sediment quality and discharge under extreme high flow conditions (high frequent measurements on at least one basis are necessary). Detailed datasets of sediment quality, which have been used in the study of Heise and Förstner (2004) are existing, but not freely available.

The Waterdienst mentioned that extra monitoring programmes of contaminated sediment are available for Koblenz and Lauterbourg (Dorien te Hulscher). In the downstream parts of the Rhine, sediment quality was measured at different depths in cores (e.g. in Hollands Diep).
Information is also available of the release of Altlasten at Iffezheim and effects detected at Lobith in 1998 and 1999.

It is recommended to prepare monitoring programmes of sediment and water quality for future floods events. A plan needs to be made with locations where measurements will be taken, and the equipment that will be used.

Models

The technical knowledge and experience is available to model re-suspension and deposition of (contaminated) sediment. However, uncertainties associated with parameter definition make it difficult to simulated the responses in sediment quantity and quality realistically. Extensive analysis of data is needed to get more insights into the dominating processes and model parameters. Series of high frequent measurements are needed to validate the simulated sediment quality by the model.

Related projects/studies

Studies and projects related to the synergy project "Historic contaminated sediments in the Rhine basin during extreme situations" are listed below:

- University of Stuttgart (group of professor Westrich) did experiments to quantify the critical shear stress for erosion and re-suspension. The International Commission for Protection of the Rhine (ICPR) was stakeholder in this study. In general, results indicated that sediment is re-suspended at higher critical shear stress than previously expected.
  > The depth and geometry of contaminated sediments in the river bed were also investigated in this study. Sediment quality at different depths were analysed in cores taken in upstream parts of the Rhine (Dorien te Hulscher can send more information about this study).
- After the flood of 1995, the problem of Altlasten were studied by RWS and results are summarized in Note Jan Uil. (Almer de Swaaf will try to find the memo)
- In scope of the Rhine Treaty, a Sediment Management Plan is being created (will be finished in February 2008). This plan focuses on contamination level, volume of contaminated sediment and ranks 'areas of concern'. A list of problems in the different countries of the Rhine basin are summarized in fact sheets (contact Dorien te Hulscher)
- Noordwaard project (Waterdienst/Royal Haskoning/WL) focuses on sources and pathways of transport of Altlasten in the Biesbosch. Models are used to quantify the amount of re-suspension under high flow conditions and deposition. This project can be interesting as a case study (contact Almer de Swaaf, Erwin Meijers)
- Ketelmeer west. Sediment traps will be use to measure sediment transport during winter for a period of 5 years. Data will become available. (contact Dorien te Hulscher?)
- Project 'Nalevering' can provide data and information of desorption of organic micro pollutants and heavy metals.

Conclusions, recommendations and continuation of project

- Focus on the areas at risk and areas of concern in the lower part of the Rhine, in particular deposition areas (Hollands Diep, Haringvliet, Noordzee, IJsselmeer, Waddenzee). These areas can be interesting for case studies.

- Assess whether re-suspension of Altlasten will result in significant deterioration of sediment quality, because this is still unknown. In addition, the impact on water quality (dissolved concentrations) need to be investigated, as well as the potential ecological and human risks.

The outcomes of this inventory study will be used in the Delft Cluster Project "Water Quality and Calamities". The Deltares institutes (WL, TNO and Geodelft) and KIWA Water Research are participating in this project. The general focus is on water and sediment quality during extreme events.