5 Quantification of the Risk for the Port of Rotterdam

5.1 Introduction to the approach of risk quantification

The risks that are going to be quantified in this report do not primarily concern environmental or human health issues, i.e. regarding the potential for adverse environmental effects to organisms or drinking water quality at the port of Rotterdam, but rather the additional costs caused by the fact, that exceeding the CTT could make it necessary to dispose the sediments in a contained depot rather than relocate them at the North Sea.

The material from historical contaminated sites has to be resuspended and transported, before it will become an issue for the Port of Rotterdam in the above-mentioned respect. This can be a quite complex issue: Less contaminated sediment can cover the deeper deposits, but during stronger currents, deeper layers can be eroded as well. Sediment may be mobilized by erosion in still water zones, river banks and flood plains, and parts of the mobilized sediments can be contaminated with quite a large spectrum of concentrations of various contaminants (Chapter 1.2).

Even surface sediments are sometimes highly contaminated as has been shown in chapter 4:

a) There is still a consisting contaminant source that keeps the immissions at high levels. This can be either a primary source, such as industrial emissions like they have been observed for TBT and only recently stopped in the Lippe area (chapter 4) or it can be a secondary source, called historic contamination such as the HCB contaminated material in the High and Upper Rhine, which is intermittently transported downstream, mixing with and thus contaminating previously clean sediments on its way.

b) Exceptionally high current velocities remove freshly deposited, clean surface material during flood events. Unexpectedly, historic contaminations may suddenly be exposed. This may be the reason, why at the High Rhine barrage "Augst" HCB concentrations of 2500 µg/kg[1] were measured in surface sediment during a survey in July 1999 (Zipperle & Deventer, 2003), while previous sampling surveys had only shown low concentrations (M. Keller, BfG, personal communication). In May 1999 the High Rhine experienced a flood with a return period of about 100 years, which probably caused significant erosion along the Rhine (see below) and may have swept away the uncontaminated material on top of the contaminated material.

Despite the uncertainties with sources and processes, there is clear evidence from sediment profiles in Ketelmeer, that contaminated material is transported from historic sites downstream on a short time scale: After the flood event in May 1999, highest concentrations of HCB were measured in the top sediment layer at a sand pit near the mouth of the river IJssel.

[1] several sediment samples were taken with a van-Veen grab (up to 15 cm depth) and homogenized

Whether historical contaminated sediments can be eroded, and subsequent hazards arising from particle-associated contaminants for the downstream regions must be considered depends on processes such as mechanical consolidation and chemical diagenesis. The latter process generally leads to a reduction of the reactivity of solid matrices and of the bioavailability of contaminants (sections 1.4 and 1.5.1). As yet, however, the data base for calculations on the erodibility of sediments is still limited (although significant advancement has been made by the group of Westrich in this field; see section 1.2) and even less information is available for the estimation of overall "ageing" effects, i.e., the reduction of mobility and toxicity of particle-bound contaminants.

As these data are missing, a reasonable way to come to conclusions on the risk for the port of Rotterdam, is the following:

- Assessment of those areas of concern that would have a sufficiently high contaminant level to presumably raise the concentration in the port above CTT level, despite dilution processes that might occur during transport downstream.
- Gathering evidences for actually or potentially occurring resuspension events. Erosion criteria thresholds will be included in the assessment wherever they can be quantified. Increases in loads and concentration of suspended particulate contaminants is another indication of resuspension events.
- From the relationship between concentration in suspended particulate matter (SPM) and water discharge, information can be drawn on the influence of diffuse sources. If the eroded suspended matter is generally contaminated, the concentration does not change with discharge (Figure 5.2, PCB). This indicates diffuses sources.
- If, however only uncontaminated material (surface run-off and bed erosion) is eroded, the contaminant concentration in suspension decreases, due to mixing with the uncontaminated material (Figure 5.1, HCB).
- In the case of erosion at contaminated sites (point source), the contaminant particle concentration is constant or increases with discharge.

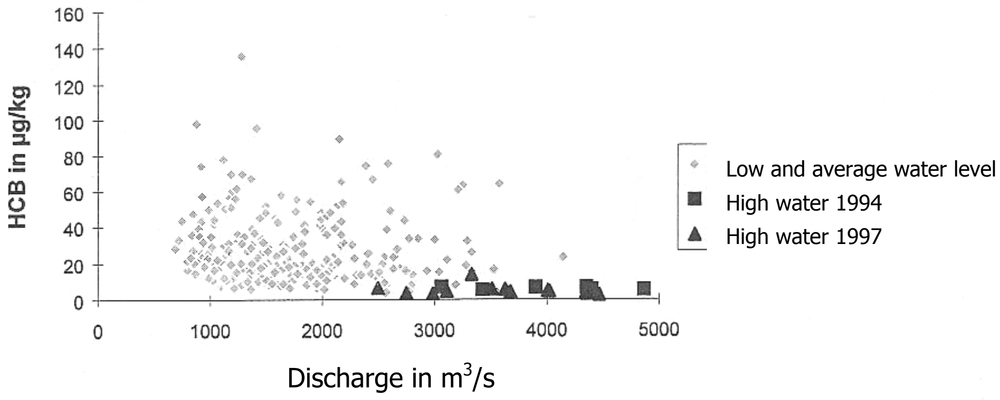


Figure 5.1 HCB concentration of suspended matter at Koblenz / Rhine between 1991 and 1997 (BfG, 1997)

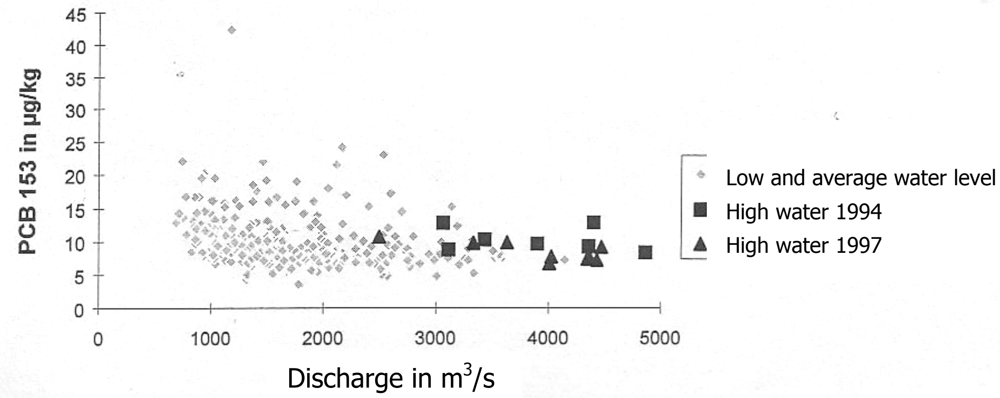


Figure 5.2 PCB concentration of suspended matter at Koblenz / Rhine between 1991 and 1997 (BfG, 1997)

However, the connection between flood events and concentration of contaminants on suspended matter is not simple as the resuspension of large amounts of relatively uncontaminated material obstruct the detection of eroded, heavily contaminated sites. Whether deeper sediments are eroded depends on the shear stresses that are applied by the water current, on the consolidation of the material, but also on the availability of sediment. Under high discharge conditions in winter, erosion of previously (fresh) deposited sediment can occur and the amount of temporarily stored sediment will decrease (Asselman, 1999). In a series of flood events, one following quickly after the other, this can lead first to an exposure of older layers followed by erosion processes. Accordingly, a case by case consultation of flood event data may sometimes be helpful, as is shown in Figure 5.3, where the copper load of suspended matter was increased at the last flood event of a sequence of high waters in 1995. Hence, interpretation of SPM and its contaminant concentration needs consideration of the hydrological regime, flood events and preferably erosion thresholds.

The risk for the Port of Rotterdam is highest, if the concentration in the suspended matter increases due to resuspension of heavily contaminated material, **and** the load of this contaminated SPM is high.

Not only the quality but also the quantity of material is important to assess whether a risk exists: Low amounts of highly contaminated material will be diluted due to mixing processes in the port itself, whereby concentrations from several sites that are below the CTT thresholds may accumulate and add up above the CTT tresholdvalue.

The determination and interpretation of loads transported with suspended matter has to be done carefully as a number of uncertainties in sampling and analytical methods decrease the accuracy.

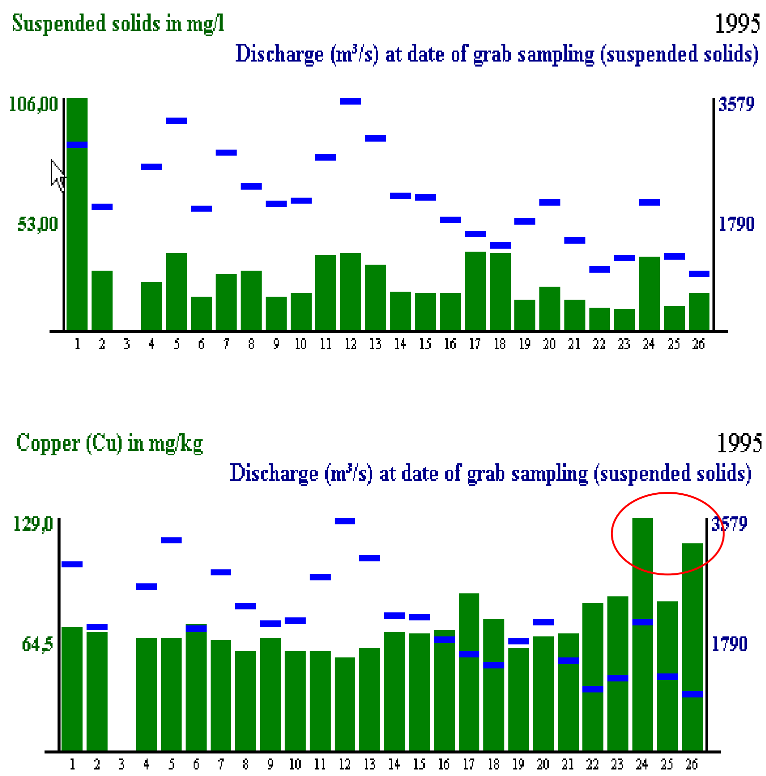


Figure 5.3 Suspended solids and copper concentrations on suspended solids at monitoring station Koblenz/Rhein in 1995, compared to the discharge at the time of sampling. The red circle indicates increased copper concentrations at low SPM at the 3rd high water.

5.2 The hydrological regime, flood events, and sediment dynamics of the Rhine catchment area

5.2.1 The hydrological regime and flood events

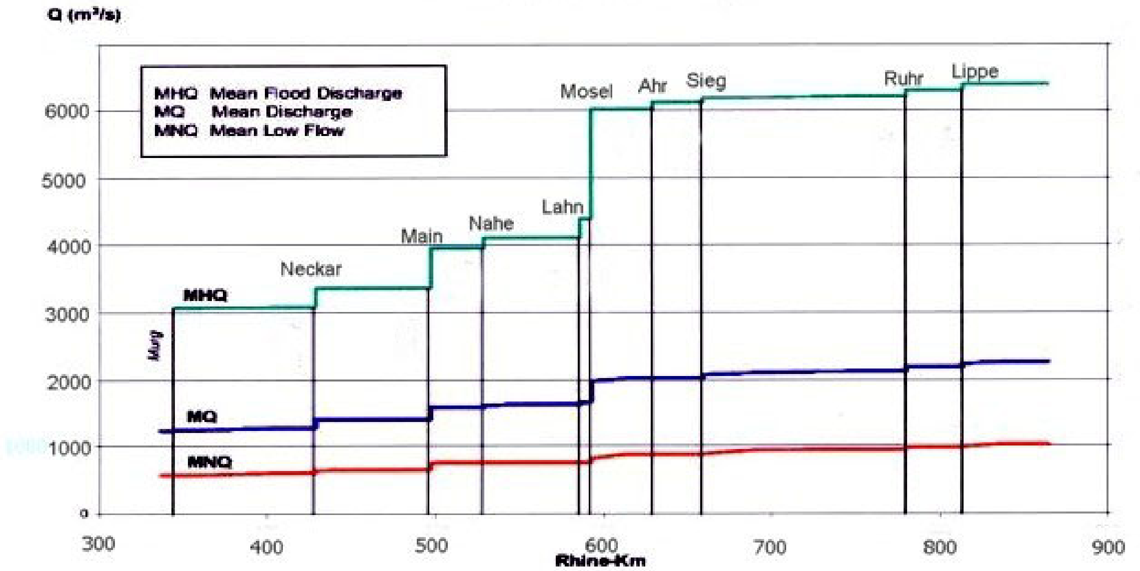


Figure 5. 4 River Rhine discharges

(Deutsches Gewässerkundliches Jahrbuch 1994, time series 31/93)

The Rhine is the largest river in Western Europe. Its drainage basin upstream of Rees is about 165000 km^2. Figure 5.4 shows the mean low flow (MNQ), mean discharge (MQ), and mean flood discharge (MHQ) as averaged values calculated from the time series 1931 up to 1993 (see Box 5.1.). The strong influence that the large tributaries Neckar, Main and Mosel can have on the Rhine water regime during high waters becomes obvious. However, due to the heterogeneity of the catchment area and its meteorological conditions, building up of high waters and their impacts show strong regional differences and no high flood is alike another one (BfG, 1996; Engel, 1999). Therewith the shown figure has to be seen as showing average, hence theoretical values for the flood discharge and not a typical hydrological event.

The discharge of the River Rhine is strongly influenced by the amount and timing of precipitation, snow storage and snowmelt in the Alps, the evapotranspiration during the summer period, and changes in groundwater and soil water storage. Storage of precipitation in the snow cover in winter, and its melting in spring and summer, together with summer rains, lead to pronounced runoff maxima in summer in the High and Southern Upper Rhine. Between Worms and Mainz, along the Northern Upper Rhine, precipitation starts dominating the discharge regime. Accordingly high waters mainly occur during winter in the Lower Rhine area. Usually, the floods in spring and summer in the Southern

Rhine catchment have no influence on the Lower Rhine (LUA, 2002). An exception was the spring flood in January/February of 1999 when high discharges were experienced in the whole Rhine catchment area.

Box 5.1 Abbreviations of water discharge levels

MNQ **mean low discharge**
MQ **mean water discharge**
MHQ **mean flood discharge**
HHQ **highest experienced discharge**

HQ_x **flood return period. X indicates the frequency in years, with which such a high water is expected**

The high water of 1995

The exceptional highwater of 1995 was triggered by strong rainfalls in the montaineous regions of the Alps in January which filled the soil pores and lead to increased water runoff. While at the Upper Rhine, the discharges only increased to a high water situation for one day (4000 m^3/s at Maxau corresponding to an HQ_{15}), the catchment areas of the tributaries Sauer, Saar, Mosel, Nahe, and Main were strongly impacted by the precipitation between January 25th and February 4th. At the confluence of the Main, the extreme water flow in this tributary increased the discharge of the Rhine River up to 6000 m^3/s (Engel, 1999) (Figure 5.5). Regional, extreme rainfalls in the catchment areas of Ruhr and Lippe on January 29th 1995 added to the Rhine discharge and resulted in an HQ_{100}-situation, when the water finally reached the last German water level measuring post in Emmerich.

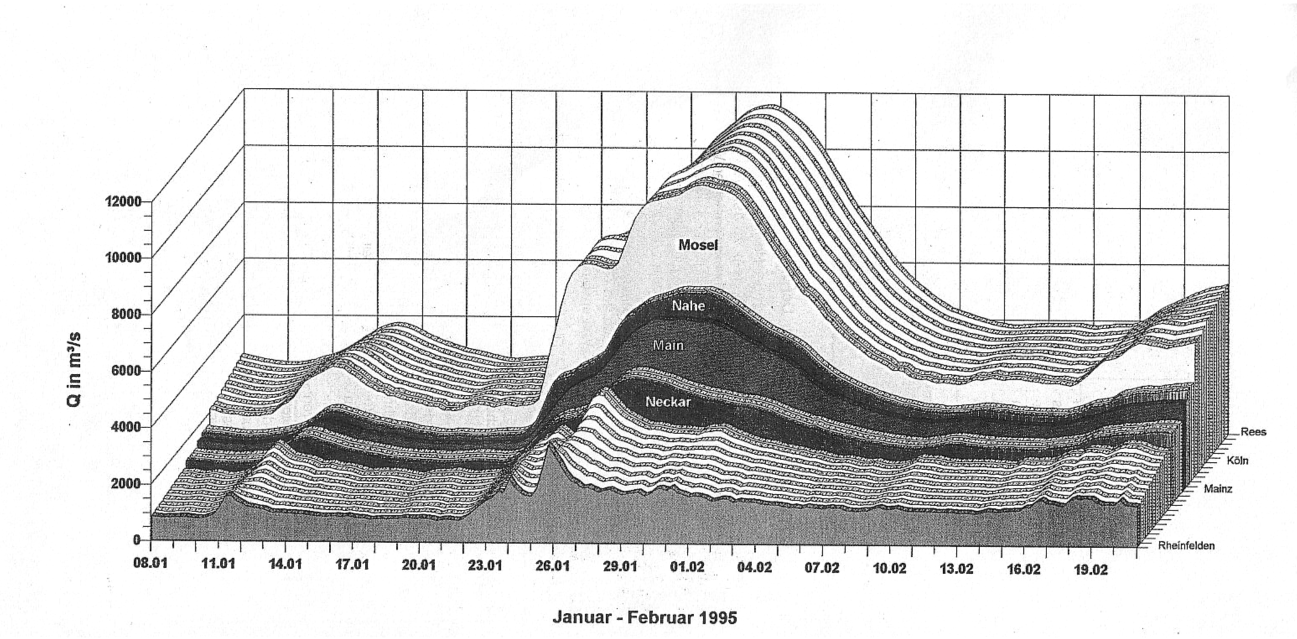


Figure 5.5 Flood wave along the Rhine during the high water event in spring 1995 (BfG, 1996)

The high waters in 1999

Three flooding events are recognizable in 1999: In Feburary, in June and in December (Figure 5.6)

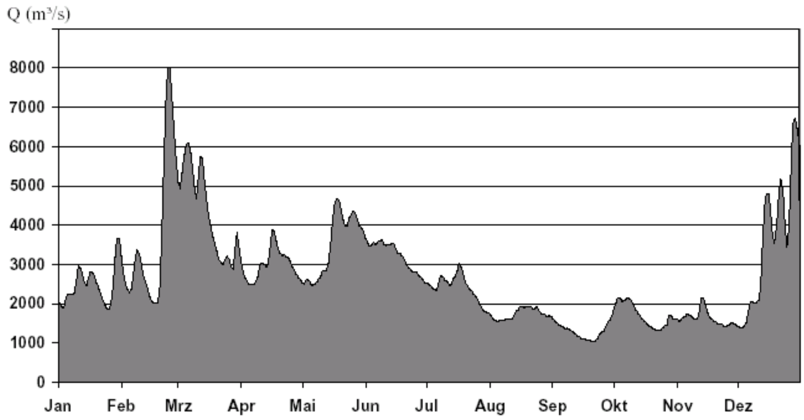


Figure 5.6 Change of discharge with time at the Lower Rhine during 1999 (gauging station Köln/Rhein), based on daily discharge measurements of the BfG.

February 1999: Strong snow falls in the Alpine area resulted in a flood return period of HQ_5 to HQ_{10} in the High and Upper Rhine. The elevated water levels from upstream were amplified by high discharges in the Middle Rhine tributaries, which were a consequence of sustained strong precipitation in that region of the catchment area due to a very mild winter in 1998/1999. As is shown by Figure 5.7, especially the rivers Neckar, Main (gauging station Mainz) and Mosel (gauging station Bonn) contributed to the high water which still affected the Lower Rhine. For the gauging station Worms (Neckar) and Kaub (Main) the discharges reached the level of flood return periods between HQ_{10} and HQ_{25} (table 5.1). The combination of the high discharges in the Southern Rhine area and in the Middle Rhine in this spring led to an extraordinary flood event because it impacted the whole river Rhine.

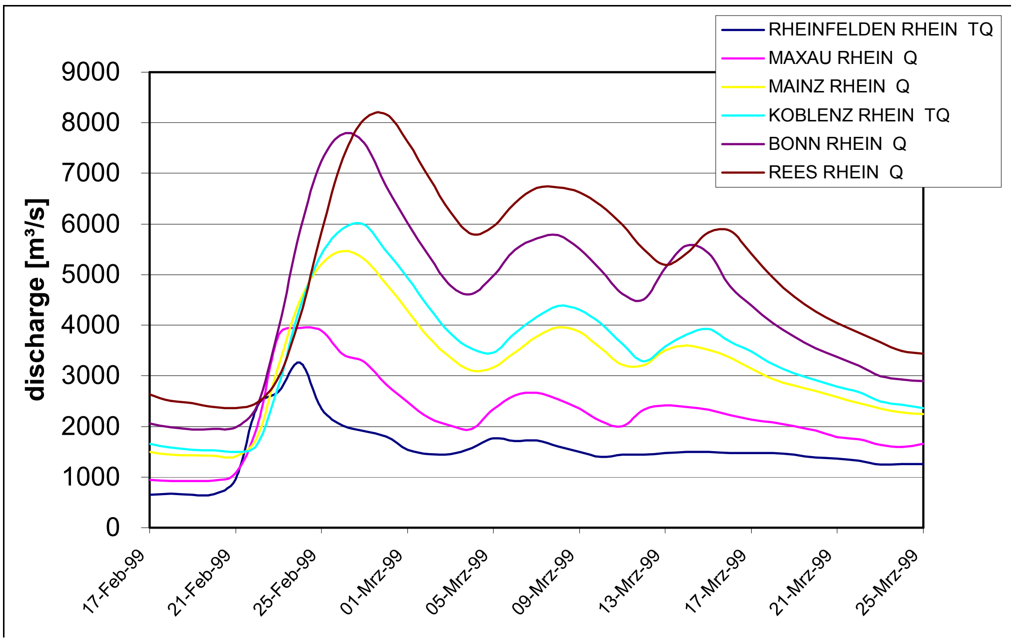


Figure 5.7 Hydrographs from the Rhine monitoring stations during the February flood in 1999

Although the flood ebbed away to a two-years flood downstream, it had a flood return period of more than 5 years in the Upper and Middle Rhine and in the Southern tributaries Neckar and Nahe. Also the flood in the Ruhr was high with an HQ_4 (table 5.1)

Table 5.1 Hydrological data of gauging stations along the Rhine River and selected tributaries.

gauging station	river km	discharge [m^3/s]	date 1999	flood return period
Rheinfelden	148,3	3470	22.2	HQ10
Maxau	362,3	4160	22.2	>HQ5
Speyer	400,6	4160	23.2	>HQ5
mouth Neckar	428,5	1690	21.2	>HQ5<HQ10
Worms	443,4	4770	23.2	>HQ10<HQ25
mouth Main	496,8	934	24.2.	>HQ1
Mainz	498,3	5500	24.2	>HQ5
mouth Nahe		256	21.2	<MHQ
Kaub	546,2	5930	24.2	>HQ10<HQ25
mouth Lahn		216	23.2	<MHQ
mouth Mosel	592,5	2040	23.2	>HQ1<HQ5
Andernach	613,8	7770	24.2	>HQ2<HQ5
mouth Sieg	659,x	391	02.3.	<MHQ
Köln	688,8	8100	24.2	>HQ2<HQ5
mouth Wupper		71,9	02.3.	<MHQ
mouth Erft		25,1	03.3.	<MHQ
Düsseldorf	744,2	8040	25.2	>HQ2<HQ5
mouth Ruhr	780	755	03.3.	HQ4
mouth Lippe	814	256	04.3.	>MHQ
Rees	837,4	8260	26.2	>HQ2<HQ5

May 1999: Extensive thaw in spring and summer amplified by sustained precipitation in the catchment areas of the Alpine Rhine led to an extreme flood event in the Lake of Constance which is considered a centennial flood (HQ_{100}) (Figure 5.8). At the measuring station Cologne ("Köln"), however, this event was only classified by a less than 2-years flood return period (ca. 4600 m^3/s), which was half the discharge of the high water in Cologne in February (table 5.1). This extreme flood in the High Rhine may explain the exceptionally high HCB concentrations that were measured in Augst during a sampling survey of the LFU Baden-Württemberg in Juli 1999: High water currents had probably removed younger and less consolidated material, in which case they may have exposed the deeper layers with higher HCB contamination.

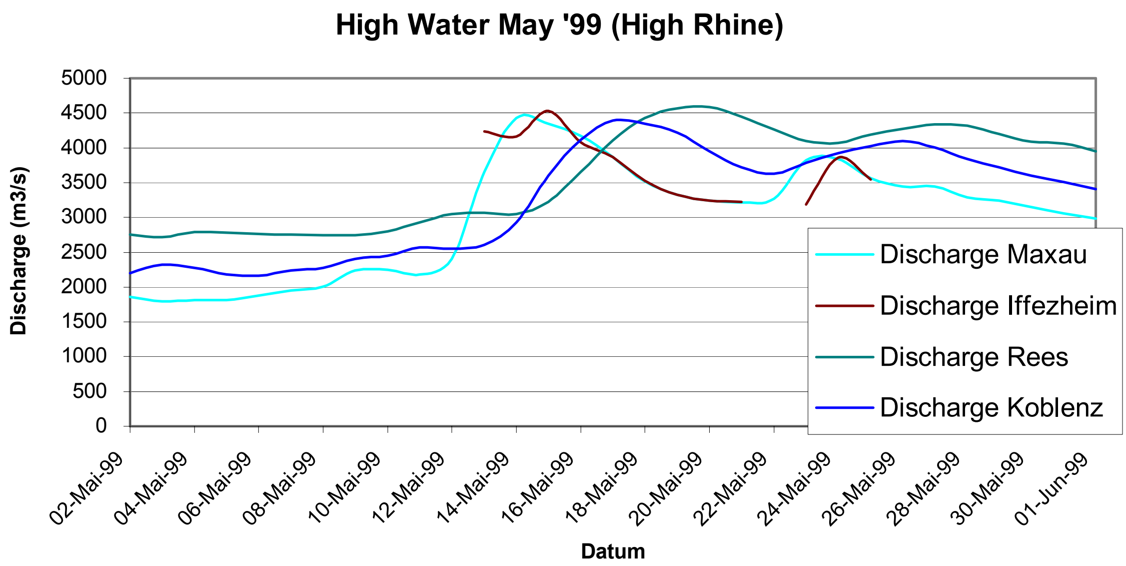


Figure 5.8 Flood event in May 1999: Discharges at different monitoring stations

December 1999: The winter 1999/2000 was again very mild and resulted in high precipitation, leading to elevated water discharges in the Middle Rhine and a high water period in the Lower Rhine at the end of 1999.

5.2.2 Sediment dynamics

Under present climate and land-use conditions, the total annual sediment supply from the hill slopes into the channels in the entire Rhine basin is estimated to be about 3 to 7 million tons (Asselman, 1999; Asselman *et al.*, 2003). From transport measurements that have been carried out by the BfG it was concluded that only about 27% of this amount reaches the German-Dutch border and the remainder is deposited at intermediate locations. In the Alpine rivers, most sediment is deposited in lakes, such as the Lake of Constance ("Bodensee"). In the German tributaries, much sediment is stored in low water zones, e.g. behind weirs. In the Rhine downstream of Andernach, floodplain sedimentation plays an important role in storage of suspended sediment (Asselman *et al.*, 2003). Analyses of suspended sediment concentrations measured in the downstream part of the River Rhine at Andernach and Rees indicate that sediment depletion occurs during a hydrological year and during individual floods. Apparently, sediment is deposited under low flow conditions during summer. During winter floods, part of the temporary stored sediment is eroded and the amount of available sediment decreases (Asselman, 1999).

The suspended matter load in the Rhine and its tributaries has decreased since the 70s mainly due to communal and industrial wastewater treatment plants, but also through accumulation in storage basins. Therewith less material that could be resuspended is available (IKSR, ????). Whether this situation significantly adds to the sediment depletion and increases the erodibility of sediments needs to be investigated.

The suspended matter concentration varies strongly depending on the discharge and flood situation.

Figure 5.9 depicts the average suspended matter concentrations at the monitoring station Koblenz at the Rhine and at the Mosel (source: ICPR). The very high suspended matter concentration in the year of the high flooding events 1999 are clearly indicated.

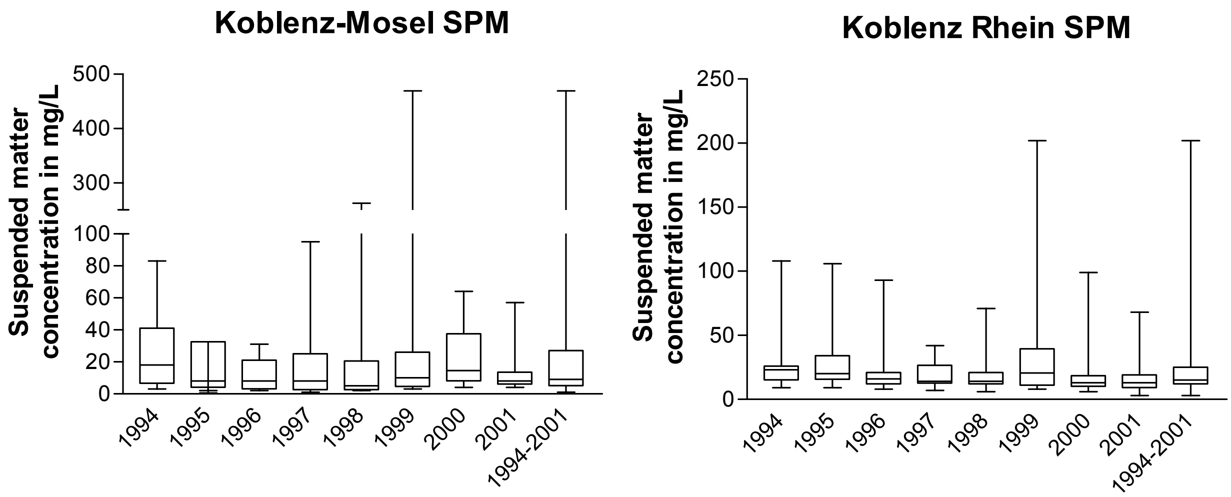


Figure 5.9 Suspended matter concentration from 1994 to 2001 at the monitoring station Koblenz at the Rhine (right) and at the Mosel (left)

Figure 5.10 shows the SPM concentration in the Rhine and its lowland tributaries during normal discharges (Source: LUA) (periods of high water are not considered). The median in all shown tributaries is in the magnitude of 10 to 20 mg/L. The number of data that have been available for this graph are small (5 to 10) for the tributaries and give only an indication, whereby the data basis for the Rhine was large with more than 1000 data points.

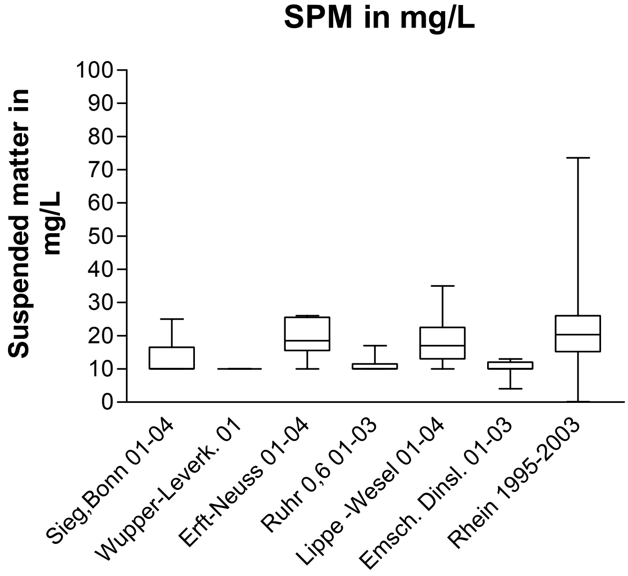


Figure 5.10 Suspended matter concentration in mg/L in the Rhine and its lowland tributaries (source: LUA)

The suspended matter load is difficult to assess, due to a number of reasons: while the data on discharges are relatively accurate due to the continuous data recording at the water-level measurement points, and well known relationships between water levels and discharges, the determination of concentrations and especially where suspended matter is involved, show a high uncertainty because of analytical variations, but more so because of the inhomogeneity in the distribution of suspended matter in the cross-section of a river. The Federal Institute for Hydrology recommends load determination on the basis of composite samples, which are automatically gathered at short time intervals and then mixed at a certain time frame (e.g. every two weeks) to increase the accuracy of yearly load estimations. Conservation of samples for that time period in a way, that allows the differentiation between suspended matter and dissolved fractions, has not been achieved yet. Therefore the current estimations of suspended matter load in the literature as well as in this report have to regarded cautiously and while being aware, that the calculated data can be prone to errors of more than 100% (Hilden, 2003). Nevertheless, figure 5.11 gives an impression on the roughly estimated suspended matter load during the high water event between January 22nd and February 12th 1995 with the extreme contributions of the rivers Main and Mosel.

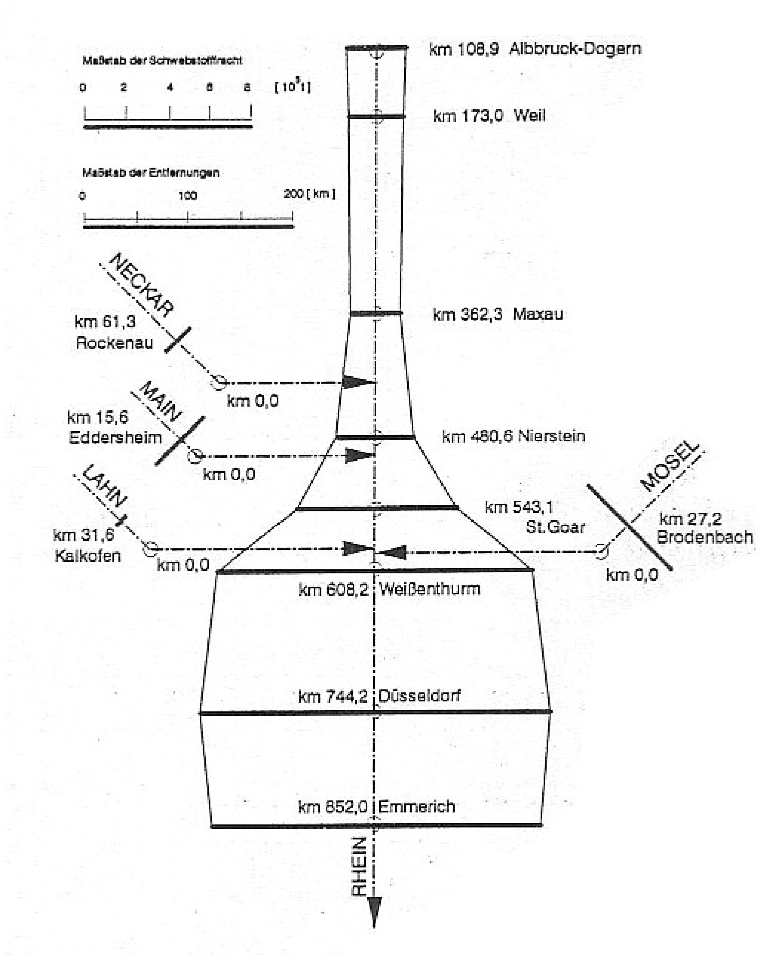


Figure 5.11 Loads of suspended matter in Rhine, Neckar, Main, Lahn and Mosel during high water between January 22nd and February 12th 1995 (from (BfG, 1996))

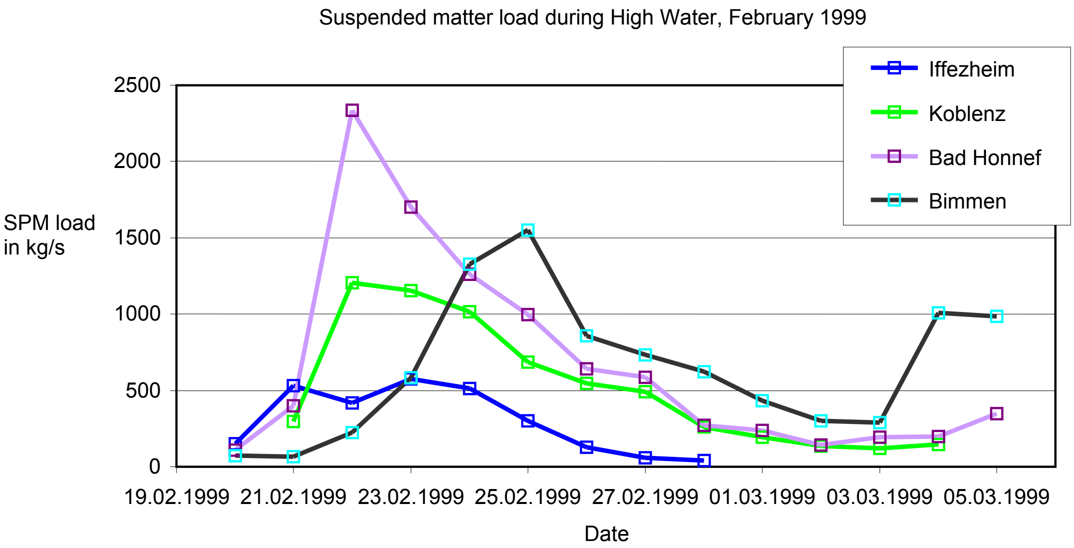


Figure 5.12 Suspended matter load along the Rhine during High Water in February 1999

Figure 5.12 indicates the transport of suspended matter downstream the Rhine during the flood event in 1999. The high increase in load between Koblenz and Bad Honnef could indicate the influence of the Mosel tributary, which - like in 1995 - largely added to the overall SPM load.

Uncertainties of Load estimations

Load estimations are prone to a number of potential sampling or measuring errors, which directly affect the total value of SPM and contaminant concentration:

Different sampling techniques: A campaign for comparing the different sediment sampling devices that are used at in the Rhine riparian states was performed by the International Commission for the Hydrology of the Rhine basin (IKHR). The results showed a difference of up to 30 percent depending on the sampling technique.

Inhomogeneous SPM distribution in the water body: Incomplete mixing of tributaries and Rhine at the measuring station like e.g. at the Station Bad Honnef (right Rhine bank located) where Mosel and Rhine are not completely mixed, sampling can result in inadequate calculation of the SPM concentration.

Insufficient sampling frequency: Annual load calculation must rely on regular measurements. When sampling flood events, the sampling frequency must be proportional to the discharge, otherwise the load can not be calculated properly. A sufficient number of samples must be taken at the rising and falling stage.

Analytical Errors: Laboratory analysis of SPM and contaminant concentration usually exhibits an error up to 30 % (Keller, BfG, pers. communication). (See also chapter 2.2: Quality Control of Field and Laboratory Data).

5.3 Erosion thresholds in reservoirs of Rhine, Main and Neckar

The International Commission for the protection of the Rhine (ICPR) recently commissioned an investigation on the resuspension risk of sediments in the upper river Rhine. All together 6 headwaters where investigated in the upper Rhine namely Markolsheim, Gerstheim, Strasbourg, Gambsheim. Furthermore, sediment sampling and field investigations were conducted in the Dutch portion of the river Rhine at Amerongen and Hollandsch Diep. In addition, sediment cores were taken and erosion stability tests were performed with samples from the headwater of Eddersheim in the tributary Main and in the headwater of the weir Ruhrwehr Duisburg in the tributary Ruhr. The ICPR study was performed from the year 2000 to 2003 for all the above mentioned weirs except Rheinau which was investigated in 1999. Unfortunately, the ICPR report is not yet finished. However, the essential results and conclusions are presented below:

Knowing the critical erosion shear stress the remobilization risk for the investigated sites was attributed to a hydrologic scenario (e.g. the flood event in January 1999 ~100 year flood). The sediment stability was investigated by the SETEG-System at the University of Stuttgart to detect the depth dependent critical erosion shear stress. With a 2D hydraulic model the actual bed shear stress was calculated for different hydrological discharge scenarios specified by their statistical return period resulting in Q_{10}, Q_{20} Q_{50}, Q_{100}.

Table 5.2 Sediment stability in the headwaters of the Upper Rhine and major tributaries

Weir / River	River station	Critical shear stress [Pa]	Calculated discharge [m³/s] with associated shear stress [Pa]		
	[km]	min/max	HQ_{10}	HQ_{50}	HQ_{100}
Gerstheim/ Rhine	~268,5	1-5	no numerical calculation		
Strasbourg/ Rhine	~283,9	0,5-6	4500 3,5-4,5	4700 4,5-5	
Marckolsheim/ Rhine	~234	0,5-8	see Point 3.1		
Gambsheim/ Rhine	~309,0	0,5-8	3240 0,4-0,8	4700 0,9-1,8	5100 0,9-1,8
Iffezheim/ Rhine	~333,9	0,5-3	4800 1->3	5200 2,7->3	
Eddersheim/ Main	~15,7	0,5-9	972 (HQ) 7-9	2280 (Q_{50}) 7-10	2580(Q_{100}) 7-11
Ruhrwehr Duisburg/ Ruhr	~4,3	0,5-9			1500 (Q_{100}) 7-9
Amerongen/ Rhine		1,05-7	6570/ 1-5	11765 (Q_{50}) 3-4	12675 (Q_{100}) 3-4
Hollandsch Diep/ Rhine		< 1 (Sand) 2-7 (cohesive material)	no numerical calculation		

Table 5.3 Erosion risk in reservoirs along the Rhine

Reservoir/River	
Gerstheim/ Rhine	No numerical calculation
Strasbourg/ Rhine	Small erosion risk, due to flow direction and higher stability of the upper sediment layer (20 cm)
Gambsheim/ Rhine	At a discharge of 3240 m³/s there is no remarkable erosion. At a discharge of 4700 m³/s and 5100 m³/s the critical shear stress is exceeded and erosion takes place
Iffezheim/ Rhine	Both numerical calculations shows a significant excess critical shear stress -> high erosion risk
Eddersheim/ Main	Small erosion risk, due to the cohesive material. Only the upper sandy sediment layer (10 cm) on the left side are mobil. Due to the higher shear stress no fine material is found on the right bank.
Ruhrwehr Duisburg/ Ruhr	High erosion risk of the upper less stable layers (0-10 cm and 10-40 cm). Stable conditions below 40 cm.
Hollandsch Diep/ Rhine	no numerical calculation

In 14 of all together 27 Neckar reservoirs the major part - 1.3 Million tons - of sediments are accumulated. The sediment contamination is most severe upstream of the weir Lauffen. The investigation shows that the sediment bound Cadmium concentration between 1980 and 1996 is reduced from about 7 mg/kg less than 1 mg/kg. Nevertheless, there is a remobilization risk for discharges beyond 1100 m³/s.

To estimate the risk of contaminated sediment erosion, the University of Stuttgart made an investigation on the sediments with the SETEG-System followed by a pollutant transport modeling for the navigation portion of the river Neckar (160 km) between Plochingen and Mannheim (river mouth) with the COSMOS Model (Haag et. al 1997, 1999 & 2002). On the average the critical shear stress of mass erosion of the fine-grained bed sediment for the reservoir Lauffen is 4.6 N/m^2. The erosion resistance of the sediment in the other reservoirs is likely to be in the same range. The model was calibrated on the cadmium load measured at the point of confluence near the city Mannheim by the LfU Karlsruhe. Thereafter, a numerical simulation was performed to predict the future trend of cadmium input to the river Rhine. The results show a distinct future decrease of annual cadmium load to the river Rhine.

An investigation of the flood in January 1995 showed an increase of particulate heavy metal concentration in the river flow direction with the maximum measured in Lauffen (LfU 1996).

5.4 Estimated risk to the Port of Rotterdam due to substances of concern

5.4.1 Introduction to the approach

In this chapter, those areas will be identified that show a high enough contaminant concentration in sediments that they would theoretically be able to exceed the CTT levels at the Port of Rotterdam, if this material became resuspended and transported downstream under the assumption of worst case conditions.

This can only be a rough assessment due to a number of constraints such as:

- lack of those data that would allow a consistent and reliable simulation of suspended matter within the Rhine under the influence of its tributaries.
- lack of information about erosion/sedimentation patterns in the Rhine.
- the heterogeneity of high water situations: Depending on kind and location of origin, high waters are usually limited to certain river drainage areas, such as the high water from 1995, which was most pronounced in the Mosel area, as opposite to the flood in January/February 1999, which affected the whole Rhine basin.
- The concentration of suspended material does usually not correlate with the peak in high water flow, although this will be assumed under the present scenarios.

In the following scenarios, the existing data on contaminant concentration in surface sediments that were available for this study and which were the basis for the classification of the areas of concern in chapter 4, will be compared with the minimal concentrations that would be necessary to exceed the CTT values in the Port under consideration of dilution effects by non-contaminated suspended material during transport downstream (see figure 5.13) and making a number of assumptions:

In order to take into account situations at normal water flow (MQ), at average high water flow (MHQ), and at exceptionally high water flow (HHQ) the assumptions for the simulation of risk-relevant concentration data were set as follows (see figure 5.13 for illustration):

- It is assumed that the suspended matter concentration in all tributaries and in the Rhine are the same and depend on the water flow situation. In order to get an idea of the transported SPM-load, a calculation was done which is depicted in Table 5.4, using average SPM concentrations deduced from the data depicted in figures 5.9 and 5.10:

  MQ – 20 mg/L; MHQ – 150 mg/L; HHQ – 250 mg/L.

- It is assumed that the whole sediment contamination at a specific site is transferred to the water phase and transported as such. Hence, sediment concentration equals the concentration of contaminants in the suspended material. No immediate dilution with suspended matter from upstream is included in the calculation.

o It is assumed, that the concentration at Kleve-Bimmen will equal the concentration in the Port of Rotterdam. Therewith CTT-values are directly compared with the calculated concentrations.

o For the initial approach, it will be assumed, that a flood event affects the Rhine and its tributaries at the same time, which is usually not the case. An exception here was the high flood in January/February 1999, which impacted the whole river basin. As consecutive flood events in the tributaries increase the probability of risk rather than reduce it with regard to the necessary concentrations to exceed the CTT values, these situations will be discussed exemplarily.

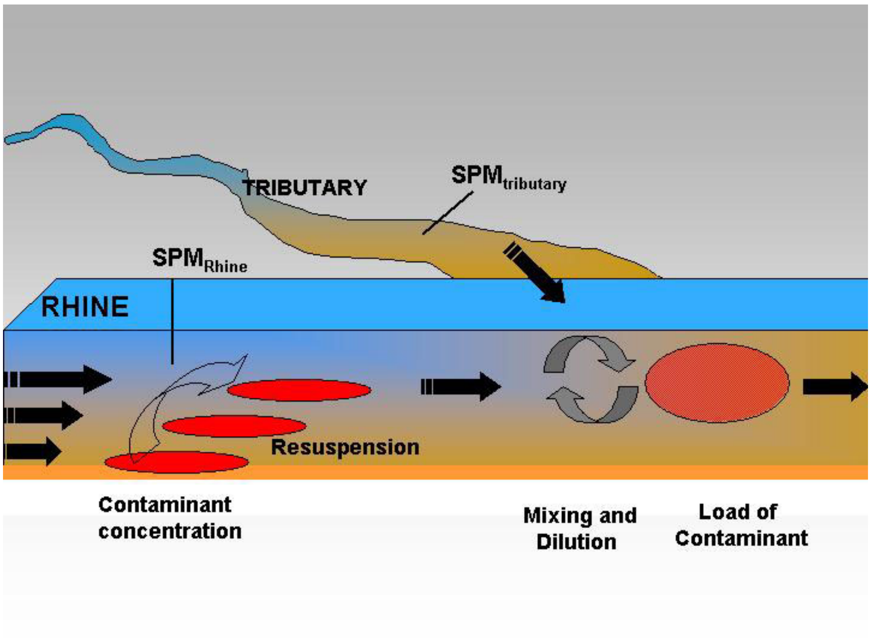


Figure 5.13 Assumptions of the case study to assess the risk for the port that is represented by substances of concern.

For generalisation purposes, mean values for the discharges at the different scenarios MQ, MHQ and HHQ, published at the "Deutsches Gewässerkundliches Jahrbuch", which summarizes the hydrological data per year, and based on data of the time period between 1931 and 1993 were used for the calculations (see fig. 5.1).

The flow budget of the River Rhine was calculated from the data in Table 5.4. A factor, which accounts for the dilution by the Rhine water and its SPM concentration was determined for the different tributaries and areas in the Rhine basin.

In tables 5.4 to 5.7, those sediment or rather SPM-concentrations were calculated which would – given the assumptions that we made – could lead to an increase in contaminant concentration in the port under a given scenario.

Calculation of the minimal concentration at location A, that could lead to an exceedance of the CTT value in the Port of Rotterdam, if it becomes resuspended and transported downstream, being diluted by suspended matter originating mainly from the tributaries.

Formula: $X_A = X * Q_{KB}/Q_A$

X_A : The concentration at location A which would be needed for the respective CTT value at Rotterdam to be exceeded.
X : CTT-value for the respective substance
Q_{KB} : suspended matter load at Kleve-Bimmen
Q_A : suspended matter load at location A

Table 5.4 Flow rates of the Rhine and its tributaries at three different flood scenarios. Assigned are theoretical SPM concentrations in order to calculate the suspended matter load in the Rhine basin.

	Stream-km	MQ m^3/s	SPM µg/kg	Load kg/s	Addition	MHQ m^3/s	SPM µg/kg	Load kg/s	Addition	HHQ m^3/s	SPM Extreme	Load kg/s	Addition
Maxau/Iffezheim	362,3	1260	20	**25,2**	**25,2**	3190	150	**479**	**478,5**	4550	250	**1138**	**1137,5**
Neckar	428,5	135	20	**3,4**	**28,6**	1230	150	**185**	**663,0**	2690	250	**673**	**1810,0**
Main	496,8	192	20	**3,8**	**32,4**	975	150	**146**	**809,3**	2010	250	**503**	**2312,5**
Lahn Leun-Neu	25,1	32,5	20	**0,7**	**33,1**	287	150	**43**	**852,3**	746	250	**187**	**2499,0**
Mdg.Mosel	592,5	313	20	**6,3**	**39,4**	2110	150	**317**	**1168,8**	4179	250	**1045**	**3543,8**
Andernach	613,8	2020	20	**40,4**	**40,4**	6340	150	**951**	**951,0**	10600	250	**2650**	**2650,0**
Mdg. Sieg	659	52,4	20	**1,0**	**41,4**	561	150	**84**	**1035,2**	1053	250	**263**	**2913,3**
Mdg. Wupper		14,5	20	**0,3**	**41,7**	110	150	**17**	**1051,7**	181	250	**45**	**2958,5**
Mdg. Erft		18,2	20	**0,4**	**42,1**	32,4	150	**5**	**1056,5**	47,1	250	**12**	**2970,3**
Düsseldorf	744,2	2140	20	**42,8**	**42,8**	6540	150	**981**	**981,0**	10800	250	**2700**	**2700,0**
Mdg. Ruhr	780	69,9	20	**1,4**	**43,5**	557	150	**84**	**1140,1**	907	250	**227**	**3197,0**
Mdg. Lippe	814	42,6	20	**0,9**	**44,4**	242	150	**36**	**1176,4**	396	250	**99**	**3296,0**
Rees	837,4	2270	20	**45,4**		6770	150	**1016**		11800	250	**2950**	
Kleve Bimmen	865		24	**55,1**		6600	170	**1122**			329	**3882**	

Table 5.5 Target concentrations above which a potential increase in the sediment concentration in the Port of Rotterdam occurs under conditions of MQ

MQ	CTT HCB, DDT (µg/kg)	PCB (µg/kg)	PAH (mg/kg)	Zn (mg/kg)	Ni (mg/kg)	Pb	Hg	Cu	Cr	Cd
CTT-Values	20	100	8	365	45	110	1,2	60	120	4
Maxau/Iffezheim	44	219	17	798	98	241	3	131	262	9
Neckar	324	1621	130	5915	729	1783	19	972	1945	65
Main	287	1435	115	5237	646	1578	17	861	1722	57
Lahn Leun-Neu	1695	8477	678	30941	3815	9325	102	5086	10172	339
Mdg.Mosel	176	880	70	3213	396	968	11	528	1056	35
Andernach	27	136	11	498	61	150	2	82	164	5
Mdg. Sieg	1052	5258	421	19190	2366	5783	63	3155	6309	210
Mdg. Wupper	3800	19000	1520	69350	8550	20900	228	11400	22800	760
Mdg. Erft	3027	15137	1211	55251	6812	16651	182	9082	18165	605
Düsseldorf	26	129	10	470	58	142	2	77	154	5
Mdg. Ruhr	788	3941	315	14386	1774	4335	47	2365	4730	158
Mdg. Lippe	1293	6467	517	23605	2910	7114	78	3880	7761	259
Rees	24	121	10	443	55	134	1	73	146	5
Kleve Bimmen	20	100	8	365	45	110	1	60	120	4

Table 5.6 Target concentrations above which a potential increase in the sediment concentration in Port of Rotterdam occurs under conditions of HMQ

HMQ	HCB, DDT (µg/kg)	PCB (µg/kg)	PAH (mg/kg)	Zn (mg/kg)	Ni (mg/kg)	Pb	Hg	Cu	Cr	Cd
CTT-Values	20	100	8	365	45	110	1,2	60	120	4
Maxau/Iffezheim	47	234	19	856	106	258	3	141	281	9
Neckar	122	608	49	2220	274	669	7	365	730	24
Main	153	767	61	2800	345	844	9	460	921	31
Lahn Leun-Neu	521	2606	209	9513	1173	2867	31	1564	3128	104
Mdg.Mosel	71	355	28	1294	160	390	4	213	425	14
Andernach	24	118	9	431	53	130	1	71	142	5
Mdg. Sieg	267	1333	107	4867	600	1467	16	800	1600	53
Mdg. Wupper	1360	6800	544	24820	3060	7480	82	4080	8160	272
Mdg. Erft	4617	23086	1847	84265	10389	25395	277	13852	27704	923
Düsseldorf	23	114	9	417	51	126	1	69	137	5
Mdg. Ruhr	269	1343	107	4902	604	1477	16	806	1611	54
Mdg. Lippe	618	3091	247	11282	1391	3400	37	1855	3709	124
Rees	22	110	9	403	50	122	1	66	133	4
Kleve Bimmen	20	100	8	365	45	110	1	60	120	4

Table 5.7 Target concentrations above which a potential increase in the sediment concentration in PoR occurs under conditions of HHQ

HHQ	CTT HCB, DDT (µg/kg)	PCB (µg/kg)	PAH (mg/kg)	Zn (mg/kg)	Ni (mg/kg)	Pb	Hg	Cu	Cr	Cd
CTT-Values	20	100	8	365	45	110	1,2	60	120	4
Maxau/Iffezheim	68	341	27	1246	154	375	4	205	410	14
Neckar	115	577	46	2107	260	635	7	346	693	23
Main	155	773	62	2820	348	850	9	464	927	31
Lahn Leun-Neu	416	2082	167	7598	937	2290	25	1249	2498	83
Mdg.Mosel	74	372	30	1356	167	409	4	223	446	15
Andernach	29	146	12	535	66	161	2	88	176	6
Mdg. Sieg	295	1475	118	5383	664	1622	18	885	1770	59
Mdg. Wupper	1716	8579	686	31315	3861	9437	103	5148	10295	343
Mdg. Erft	6594	32970	2638	120340	14836	36267	396	19782	39564	1319
Düsseldorf	29	144	12	525	65	158	2	86	173	6
Mdg. Ruhr	342	1712	137	6249	770	1883	21	1027	2055	68
Mdg. Lippe	784	3921	314	14313	1765	4314	47	2353	4706	157
Rees	26	132	11	480	59	145	2	79	158	5
Kleve Bimmen	20	100	8	365	45	110	1	60	120	4

5.4.2 Indication of risk by simulation of sediment transport from contaminated sites

In this chapter, the following different situations are assessed:

1) "business as usual", meaning normal discharge (MQ) and no management measures like dredging activities are carried out. As we assume, that the whole sediment is transferred to the water column and former sediment concentrations are not the concentrations in the suspended matter, this scenario is a worst case scenario, because it neglects dilution with suspended matter from upstream.

2) HQ – average high water discharges and HHQ – exceptionally high water charges. The latter addresses a flood with a return period of 50 to 100 years.

   Calculations for these scenarios are not done on worst case assumptions, as it is assumed that all rivers experience flood events at the same time, and, hence, the dilution in this simulation is higher, than if the crest of a flood wave in a tributary arrives at its mouth before the high water of the Rhine. The different influence of this timing will be addressed exemplarily at the end of this paragraph for the Lippe River.

Hexachlorobenzene: In our worst case scenario under "business as usual" conditions (BAU), and under the assumption, that remobilized sediment does not settle along the Rhine, a concentration above 44 µg/kg of HCB in the sediment of the barrage Iffezheim is sufficient to exceed the CTT-value when transported to the Port of Rotterdam (table 5.5). Measured HCB concentration in Iffezheim-sediments exceed the concentration of either of the flood scenarios (44 to 68 µg/kg) by far with an average HCB concentration of 140 µg/kg and elevated concentrations of 400 to 600 µg/kg in the upper sediment layers (Witt *et al.*, 2003). Concentrations of more than 2000 µg/kg were found in 20 to 30 cm depth in 1994 (Keller, 1994). In opposite to the sediment in Marckolsheim, the next barrage upstream of Iffezheim, where up to 4000 µg/kg HCB was found in consolidated layers in 40 and 100 cm depth (Witt *et al.*, 2003), the upper layer in Iffezheim is likely to be resuspended at water flow rates of more than 3000 m^3/s (Witt *et al.*, 2003). This corresponds to our 2^{nd} scenario ("MHQ"). The concentrations, needed under the first two scenarios conditions to surpass CTT-levels are not very different for the Upper Rhine (44 and 47 µg/kg) (table 5.5 and 5.6). The elevated levels of 68 µg/kg that are necessary under HHQ conditions are due to the higher dilution in this situation and are equally easy exceeded.

It can therewith be stated, that on the basis of our worst case scenario: a concentration at Iffezheim of more than 44 µg/kg poses a risk for the Port of Rotterdam in terms of CTT-exceedance.

Downstream of the barrages, mainly in small harbour basins, high HCB concentration are found up to 96 µg/kg in the Baggerloch Müllerhof in the Lower Rhine, Loreley (106 µg/kg) and Speyer Floßhafen (109 µg/kg) in the Middle Rhine. These small Rhine harbours and basins with elevated HCB-concentrations could theoretically add a significant amount to the HCB load if their sediment of an approximate area of 20000 m^2 were remobilized, following our worst case assumptions.

High HCB concentrations that have been measured at the mouth of the Lippe (436 µg/kg) will according to our calculation not present a risk for the Port of Rotterdamunder MQ conditions (calculated minimal value: >1200 µg/kg) due to the high dilution effect with downflowing suspended material. This, however, presumes, that mixing is total (which it isn't between Lippe and Bimmen, according to Dr. Vogt, LUA, personal communication), and that no additional HCB-contaminated suspended matter comes from upstream.

Under HQ and HHQ conditions, the minimally necessary concentration level decreases and approaches the range of actually measured HCB levels. If a more realistic view were adapted and assumed that the Lippe wave crest enters the Rhine while the main river does not show an increased water discharge yet, the risk would increase considerably, as will be shown below.

Polychlorinated Biphenyls: According to the results shown in tables 5.5. till 5.7, no elevated PCB concentrations from tributary sediments can increase the concentrations in the Port of Rotterdam above CTT level, not even the high PCB concentrations in the River Ruhr (up to 462 µg/kg). The highest risk with regard to PCB that can be deduced from the present sediment data is located again at small Rhine harbours (e.g. Loreley with 211 µg/kg) and at the flooded quarry Müllerhof at river km 848 with PCB-concentrations of 332 µg/kg near the Dutch-German border.

Polycyclic Aromated Hydrocarbons: Areas of concern with regard to PAHs are the small harbor Wanheimer Süd with concentrations of more 69 mg/kg and 107 µg/kg (compared to a calculated minimal concentration of 10 to 11 mg/kg) and the other small harbor basins in Duisburg, which could increase the CTT concentrations. The Ruhr showed PAH concentrations in the upper sediment layer of more than 2500 µg/kg in 1994 10 km from the mouth of the tributary, but much lower values 3 years later (18 µg/kg). If the older material were resuspended, the Ruhr could significantly contribute to the PAH risk because its concentration would clearly exceed the minimal concentrations of 315 mg/kg (MQ), 107 mg/kg (MHQ) and 137 (HHQ). As our calculations indicate that the dilution effect is highest for the Ruhr-material at normal flow conditions, this risk is present at all times and increased during "business as usual conditions".

DDT: In some sediment samples from the Upper Rhine (Kehl, Bellenkrappen) and in the harbor "Loreley" elevated DDT levels up to 113 µg/kg were found which are above the calculated level for exceeding the CTT level under any flow condition.

Zinc, **copper, chromium**: Only the Rhine harbor basins would have a high enough concentration to increase the CTT at Rotterdam.

Nickel: No concentrations that would be high enough to cause an increase at the Port of Rotterdam were recorded

Lead: No concentrations that would be high enough to cause an increase at the Port of Rotterdam were recorded

Mercury: areas where the threshold value can be exceeded, are small harbors upstream like Loreley and harbors in the Duisburg area (Aussenhafen, Diergardt harbor) with more than 2 mg/kg.

Cadmium: On the basis of the available data, the only concentrations which could lead to an increase above CTT-level would be the extremely high concentrations in the Neckar (Gundelsheim: 36 µg/kg) under conditions of high water flow (MHQ: 24 µg Cd/kg; HHQ: 23 µg/kg).

On the basis of the very rough model that we used, and the sediment data, that were available, we can conclude on the following "areas of risk":

With regard to HCB, the upper Rhine barrages and sediments, small Rhine harbors and basins downstream can lead to an exceedance of CTT levels in the Port of Rotterdam – according to our worst-case assumption for BAU conditions. PCB concentrations at the Loreley harbor and the basin "Müllerhof" may present a risk. The Ruhr with regard to PAH, the Duisburg area and here the harbour Wanheimerort Süd with respect to PAH and copper and Duisburg-Diergaardt with respect to Dioxins show values above our calculated safe levels. Also the Aussenhafen Duisburg with regard to mercury can - according to our worst-case assumption - become a risk for the Port of Rotterdam.

Although this is a very simple approach and the assumptions are coarse, there are some statements that are illustrated by it: Comparing the outcomes of the HMQ and the HHQ scenario, the higher suspended matter load is partially compensated by the higher discharges. Concentrations in tributaries, calculated for the MQ scenario differ from the HMQ by a factor of about 2 to 4 – according to the increase in discharges. Mostly the sediment concentrations in the tributaries differ by a number of magnitudes from the data that were calculated here as being necessary to exceed CTT levels.

Restrictions with regard to the used approach

It has to be emphasized, however, that the flood waves from the tributaries often reach the Rhine and travel down the river before the high water discharge from the main river itself reaches their mouth. A confluence of flood waves from main river and tributaries that would amplify the whole flood situation, as it is simulated here, occurs rather seldom, for the Wupper e.g. with a less than 100 yrs probability (LUA, 2002). The influence high water discharge in tributaries have for the risk situation, if they do not merge with the flood wave of the Rhine, are more pronounced the lower the water level in the Rhine (and hence the dilution) and the shorter the distance to the Port of Rotterdam. Exemplarily, two situations are compared: (A) the situation when a flood wave of the Lippe representing a medium high water (MHQ) of the Lippe enters the Rhine which also carries high water (MHQ), and (B) the situation when the main river still shows normal flow conditions (MQ) at the mouth of the tributary, while this is transporting elevated loads towards the river (B). Situation (A) equals the case that has been shown in table 5.6. Table 5.8 depicts the concentration thresholds of the substances of concern under the different situations, taking into account the different dilution factors. (A) repeats the concentrations that were calculated in table 5.6 as those at the Lippe that could lead to exceedance of the CTT levels in Rotterdam under MHQ conditions. Under (B) those concentration values are given that account for the lower dilution of the Lippe suspended sediment if the Rhine discharges are still normal. Comparing those concentrations that were measured along the Lippe – the highest value measured in Lippe sediments and those at the mouth – a conclusion can be drawn, whether these sediments could lead to an exceedance at the Port of Rotterdam, given the conditions described here.

Table 5.8 Comparison of calculated concentration thresholds for exceedance of the CTT at the Port of Rotterdam at two high water scenarios A and B with the sediment surface concentrations that were measured at the Lippe tributary.

	Threshold concentrations at the Lippe above which a risk for the port could exist		Real concentations in Lippe sediments	
S.o.C	scenario A	scenario B	Lippe, mouth	Lippe (max)
HCB (µg/kg)	618	34	42	140
PCB (µg/kg)	3091	170	81	222
TBT (µg/kg)	3091	170	20 (2003) 278 (1994)	112 (2003)
PAH (mg/kg)	247	14		15
Zn (mg/kg)	11282	620	468	603
Ni (mg/kg)	1391	76		
Pb (mg/kg)	3400	187	67	96
Hg (mg/kg)	37	2	1,3	1,8
Cu (mg/kg)	1855	102	70	137
Cr (mg/kg)	3709	204		
Cd (mg/kg)	124	7		

Under these conditions, the Lippe may be able to substantially transport contaminants towards the Port of Rotterdam at concentrations that may exceed the CTT level. Due to the high HCB concentrations in the Lippe at its mouth, these will probably represent the highest risk, whereby along the river also other substances exceed the critical thresholds (HCB, PCBs, PAHs, mercury, copper and possible TBT if old sediments become resuspended).

The risk that is represented by the tributaries has therewith be regarded with great care, as – depending on the water discharge of the Rhine at the time of flood event in the tributary – it can be much higher than has been shown by the calculations above.

5.5 Indications for resuspension and transport of contaminants in suspended matter – exemplarily described for Cadmium and HCB

5.5.1 Introduction

In this chapter, indications are discussed that point to potential resuspension processes and transport of contaminants downstream. Comparisons of concentrations in suspended matter at different locations and in dependence of the discharges are carried out, and loads are calculated for different monitoring stations in order to identify where and under what circumstances re-introduction of contaminated material into the sediment cycle occurs. Although load estimations have a high uncertainty, they are used here as one line of evidence in the chain of argumentation and as an indication of the quantity of material that might impact the port's sediment.

To estimate concentration and load at the monitoring stations along the river Rhine and the tributaries (Neckar, Main Mosel, Ruhr) for normal discharge and flood returning periods, an evaluation of data from routine measuring programs (performed by the BfG, LfU, LUA, Ruhrverband, HLUG) and, if available, additionally data from flood events, gained at the selected monitoring stations, where used.

Data sheets and databases usually contain the concentration of contaminants in mg/kg or µg/kg so the load [mass/s] was calculated using the following formula:

Load [mass/s] = Concentration contaminant [mass/kg_{SPM}]* SPM concentration [mg/l]* Discharge [m^3/s]* correction factor for units

The monitoring stations do not record discharge values, so the discharge data had to be taken from the closest gauging station. In the annex "recording data" the recording data from the different monitoring and gauging stations, the time measuring period for the routine measuring program and the available flood event data are listed.

All parts of information are used as lines of evidence in the final analyses of potential areas of risk for the Port of Rotterdam.

The substances of concern **cadmium** and **hexachlorobenzene** are chosen as examples because

- they are routinely measured in monitoring programmes
- they are known to have different distribution patterns: cadmium has been emitted mainly in the Upper Rhine, North of Karlsruhe, comprising Neckar, Main and the industrial area of Ludwigshafen, and in the Ruhr area, while HCB has been introduced into the environment essentially at two sites: At Rheinfelden in the Higher Rhine and in the Lippe catchment area of the Lower Rhine (Chapter 4).
- In the Rhine they are mostly (Cd) or almost exclusively (HCB) adsorbed to suspended matter.

5.5.2 Evidence for cadmium-resuspension

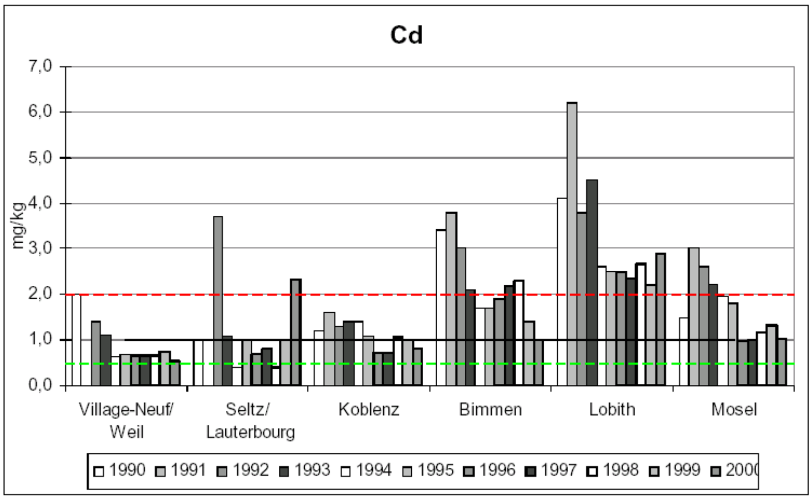


Figure 5.14 Average annual concentration in mg/kg suspended matter at different monitoring stations and ICPR target value (1 mg/kg).

Figure 5.14 depicts the average annual cadmium concentration in SPM, measured at the different ICPR monitoring stations from 1990 to 2000. According to these average data, no annual $cadmium_{SPM}$-concentration has been measured that exceeded the CTT-level of 4 mg/kg since 1993. The comparatively higher values at Lobith are assumed to derive from the Ruhr-Area (IKSR, 2002).

Single peak-concentrations exceeded the CTT value in 1998 at Bimmen/Lobith (12 mg/kg) and 2000 in Lauterbourg (7,3 mg/kg) (ICPR-monitoring data). The increased values at Bimmen/Lobith in 1998 were measured at the end of the year after a high flood in Nordrhein-Westfalen. This points to an input from the tributaries Erft and Ruhr where high concentrations of cadmium have been measured.

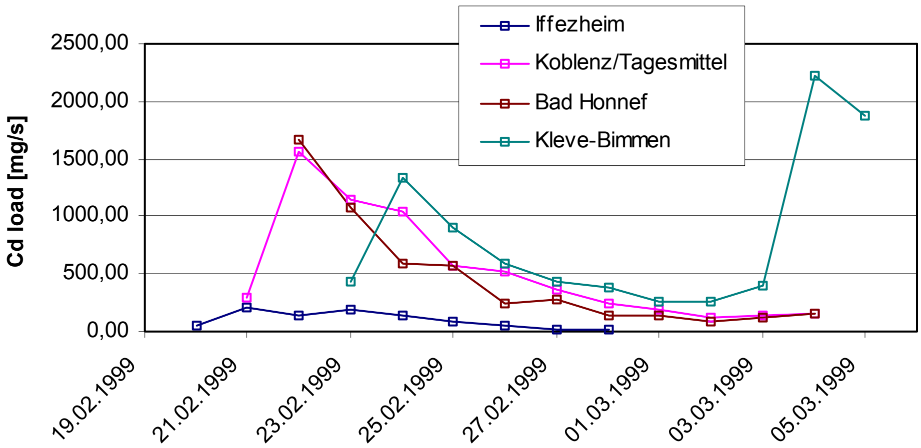


Figure 5.15 Cd load at monitoring stations along the river the Rhine

This observation, that some cadmium input may derive from the Ruhr Area tributaries during floods, is supported by data from a measuring campaign that was executed by the State Institute for Environmental Protection Baden-Württemberg [LfU] (station Iffezheim), The Federal Institute of Hydrology [BfG] (station Koblenz) and North Rhine-Westphalia State Environment Agency [LUA] during the flood event in February/March 1999 (Figure 5.15): A strong increase of the cadmium-load was calculated for March at the Station Kleve–Bimmen. With an estimated transport time of suspended matter between Bad Honnef and Kleve-Bimmen of roughly 1 or 2 days, there should have been some indication of increased levels, if the material came downstream with the Rhine. As no corresponding peak was reported, the second cadmium-load peak in March 1999 was likely to derive from the Ruhr Area.

Figure 5.16, depicting the discharge and the cadmium concentration of the River Ruhr, shows the corresponding peaks of the discharge at Hattingen and the total Cadmium concentration in the water. This increase can be due to erosion of groynefields and other still water zones (Nusch, Ruhrverband). The critical discharge for sediment erosion in the River Ruhr is about 200 m^3/s, which – together with the high erosion risk of the upper 40 cm at the Ruhr weir ("Ruhrwerk") in Duisburg at the confluence of the rivers (Table 5.3) may lead to increased discharge of cadmium-loaded suspended matter into the Rhine. According to Klopp and Kornatzki (1981) an increase of cadmium concentrations through surface runoff can be excluded.

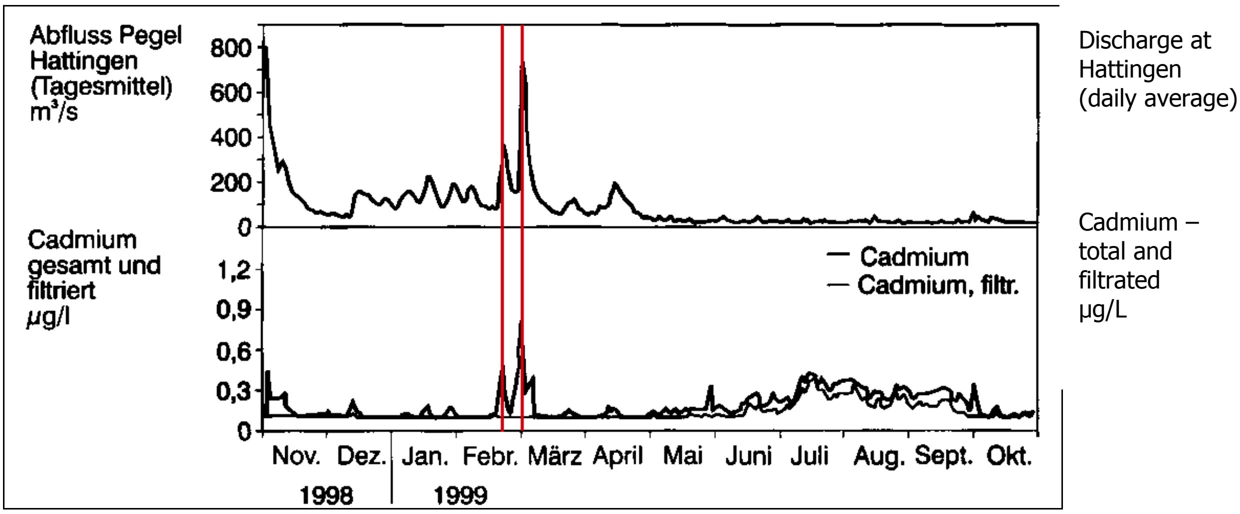
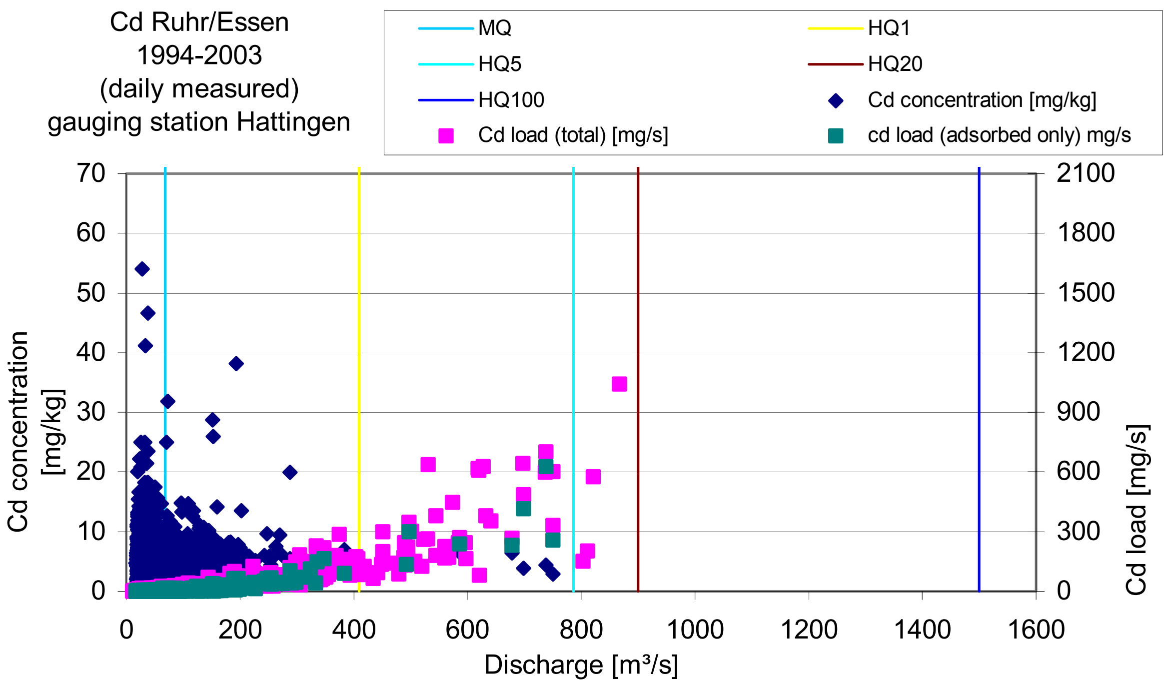


Figure 5.16 Discharge and cadmium concentration for the hydrological year 1999 (from Ruhrverband 2000).

Figure 5.17 shows cadmium concentrations and cadmium loads with discharges, measured between 1994 and 2003 at the Ruhr (top graph) and at Kleve-Bimmen (bottom graph). The peak concentration of 55 mg/kg in the Ruhr is exceptionally high when compared with monitoring stations at Iffezheim (<1mg/kg), Koblenz (2 mg/kg), and Bad-Honnef (<3 mg/kg). The decrease with increasing water flow indicates, that point sources are responsible for the initial high concentrations (see chapter 5.1). Concentrations at Kleve-Bimmen (<7 mg/kg) (Fig. 5.17) are much lower than in the Ruhr due to dilution (and/or deposition). However, it still frequently shows concentrations > 2 mg/kg that are higher than those of most other stations and tributaries, and this may be considered as a strong indication of the influence of the Ruhr.



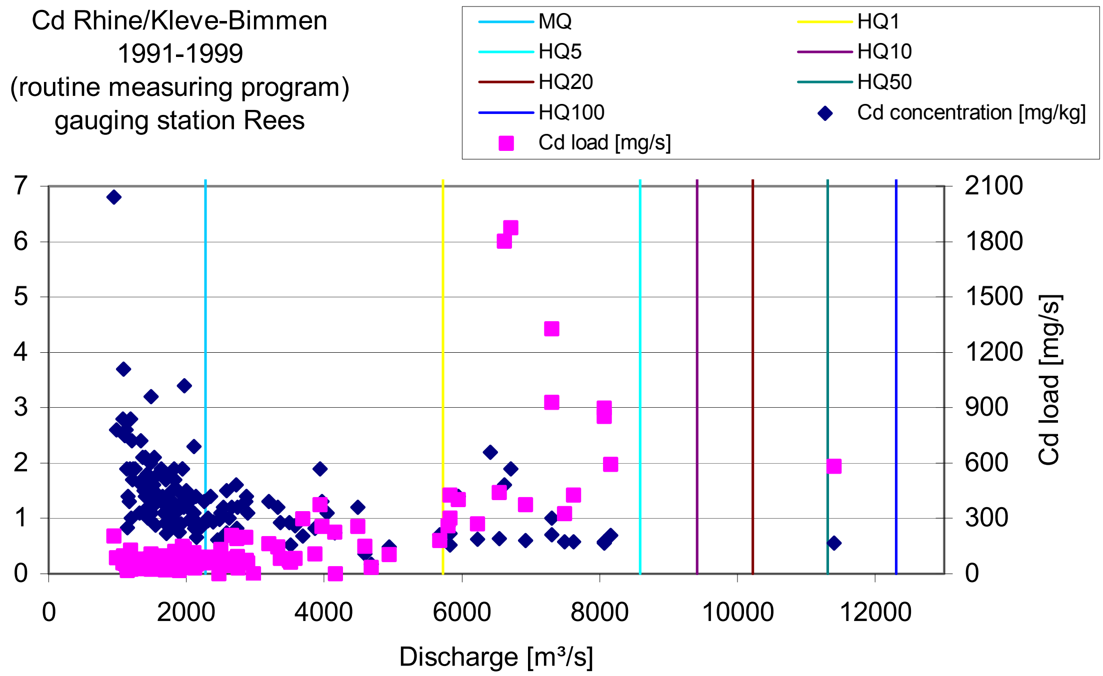


Figure 5.17 cadmium concentrations and loads at the routine measuring stations Hattingen and Rees, depicted depending on the discharge. Vertically, the different flood return periods are indicated.

Apart from strong evidence, that some Cadmium resuspension and transport takes place from the Ruhr towards the Rhine, the cadmium-load peaks that are shown in Fig. 5.15 for Koblenz and Bad Honnef at the end of February must have originated from the area North of the Upper Rhine barrages, as the load at Iffezheim is comparatively small.

Areas of concern with regard to cadmium in the Upper and Middle Rhine between Iffezheim and Koblenz are the Main and Neckar. Although a company at Ludwigshafen near Mannheim has been known to emit Cadmium to the Rhine, no data were available that point to any still persisting historic contaminated site with regard to cadmium in this area.

The increase in load could be attributed to the River Neckar, unfortunately during this flood event no measurements in the Neckar were executed (Storck, LfU). Investigation by Haag et. al showed, that the critical discharge for erosion of highly contaminated sediments in the head water at the power station Lauffen amounts to about 1100 m^3/s. In February 1999 the discharge in Lauffen reached 1100 m^3/s, so it can be assumed, that erosion of cadmium-contaminated sediment really happened. The contribution of the river Main to the total cadmium load in Koblenz cannot be specified, because no measuring campaign was performed during flood events (Seel, HLUG). However, it has been shown, that the accumulated material at the barrage of Eddersheim near the mouth of the Main only has a small erosion risk (table 5.3). Hence, input from the Main may be limited.

5.5.3 Evidence for HCB-resuspension

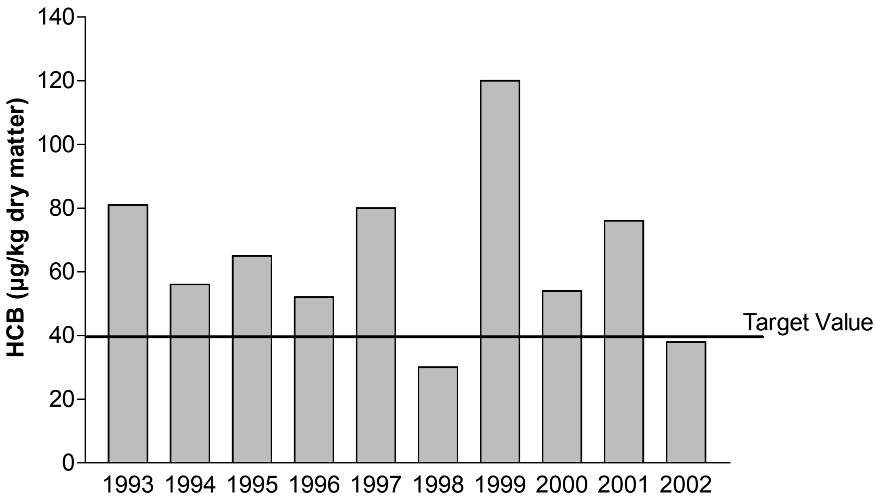


Figure 5.18 HCB-concentrations in suspended matter of the Rhine near Iffezheim (90% percentile) between 1993 and 2002 (Source: LfU 2003)

As depicted in figure 5.18, the suspended matter in Iffezheim in 1999 showed concentrations of up to 120 µg/kg pointing to a strong resuspension of contaminated material at this barrage during that year's flood event. Figure 5.19 shows the time dependency of the HCB transport rate during the flood. For Iffezheim with increasing discharge (20.2. – 2500 m^3/s; 21.2. – 4100 m^3/s) an increase of the HCB load up to 3000 µg/s could be observed. This is primarily due to the erosion of HCB contaminated sediments in the five lower barrages in the Upper Rhine and is in good agreement with investigations of Witt et. al. (2003) who found that release of HCB occurs at flow rates more than 3000 m^3/s.

Between Iffezheim and Koblenz almost no change of HCB load can be detected (Figure 5.19).

At Bad Honnef an increase to 70000 µg/s was measured. Between Koblenz and Bad Honnef only the river Mosel (no HCB contamination known; Breitung, BfG 2003) discharges into the Rhine. This increase could point to a resuspension of HCB contaminated sediments from still water zones (groyne fields) and possibly from small harbours along the Rhine that effect the HCB load. As there was an almost full bank flow with relatively high flow velocities, contaminated sediments in the groynefields are likely to be resuspended, resulting in an increase of the contaminant load as indicated in the diagram. However, due to the previously described uncertainties and high variances of suspended matter load estimations (chapter 5.2.2), no sound evidence can be assigned to these relatively small and on few data points relying differences in load transport. The same is true for the increase in load between Bad Honnef und Kleve-Bimmen from ca. 70000 µg/s to ca. 90000 µg/s. It could be explained by HCB input from the Lippe, but, again, these differences are too small and too little reliable to be seen as evidence.

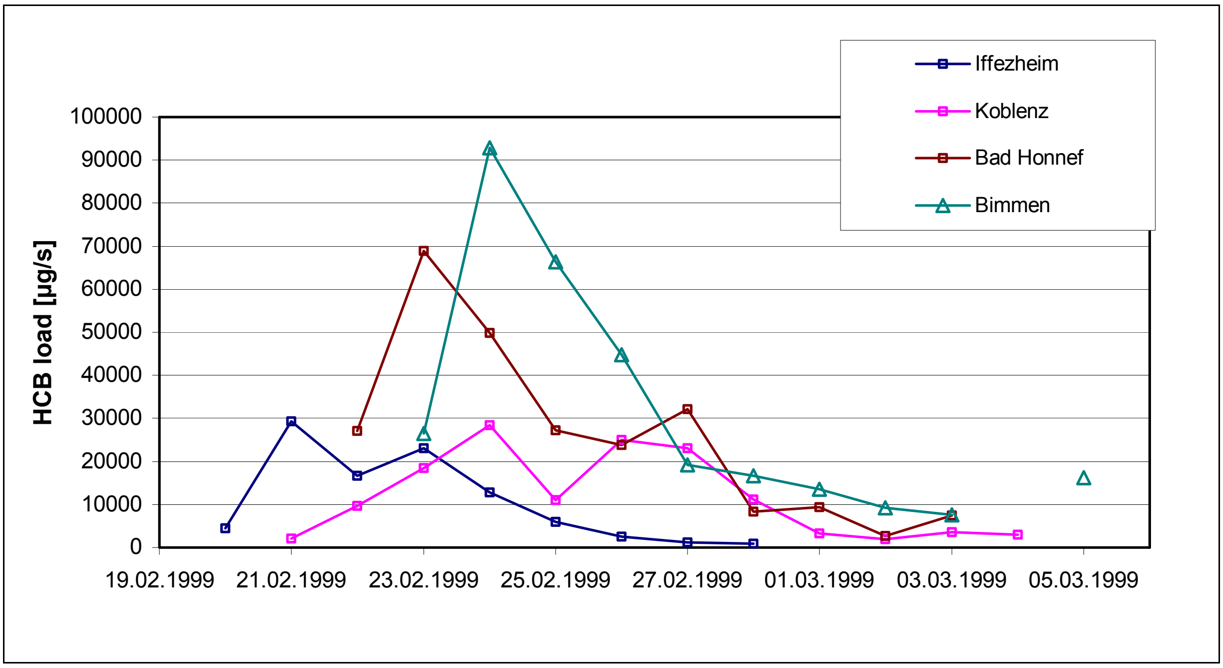


Figure 5.19 HCB load at monitoring stations along the river the Rhine during the flood event in 1999

Figure 5.20 shows HCB concentrations and loads in Iffezheim in relation to water discharges at the gauging station Maxau, downstream of Iffezheim. First resuspension occurs already at an HQ_1, which leads to HCB concentrations up to 270 µg/kg. These increase even further (~340 µg/kg), when an HQ_{10} is surpassed.

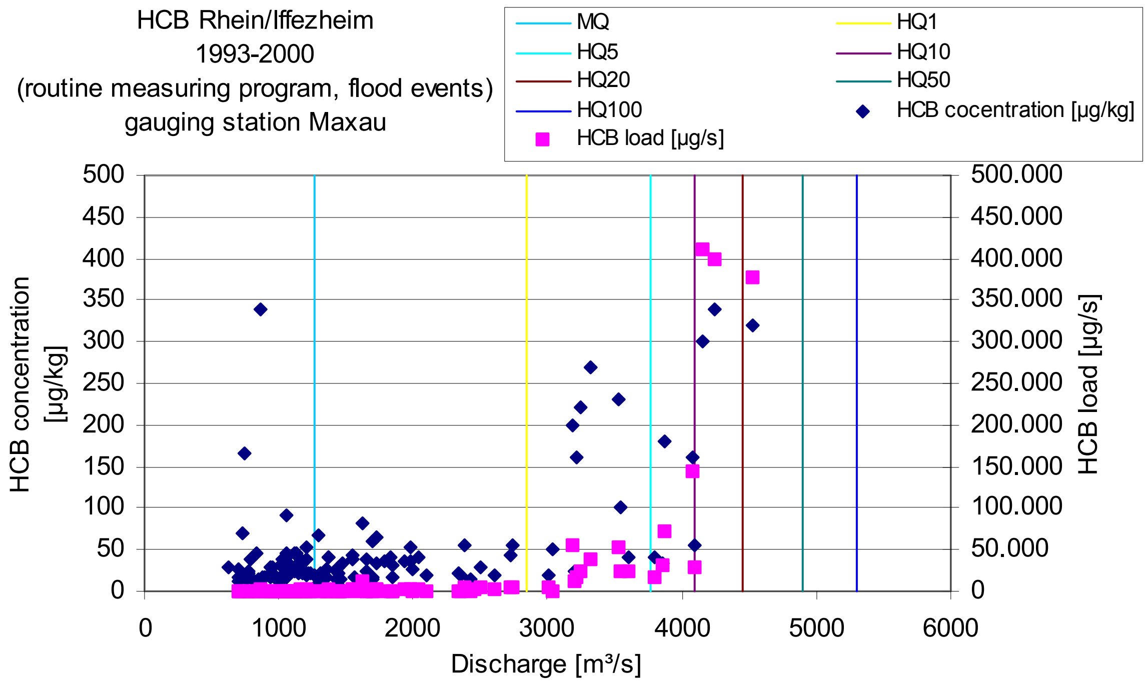
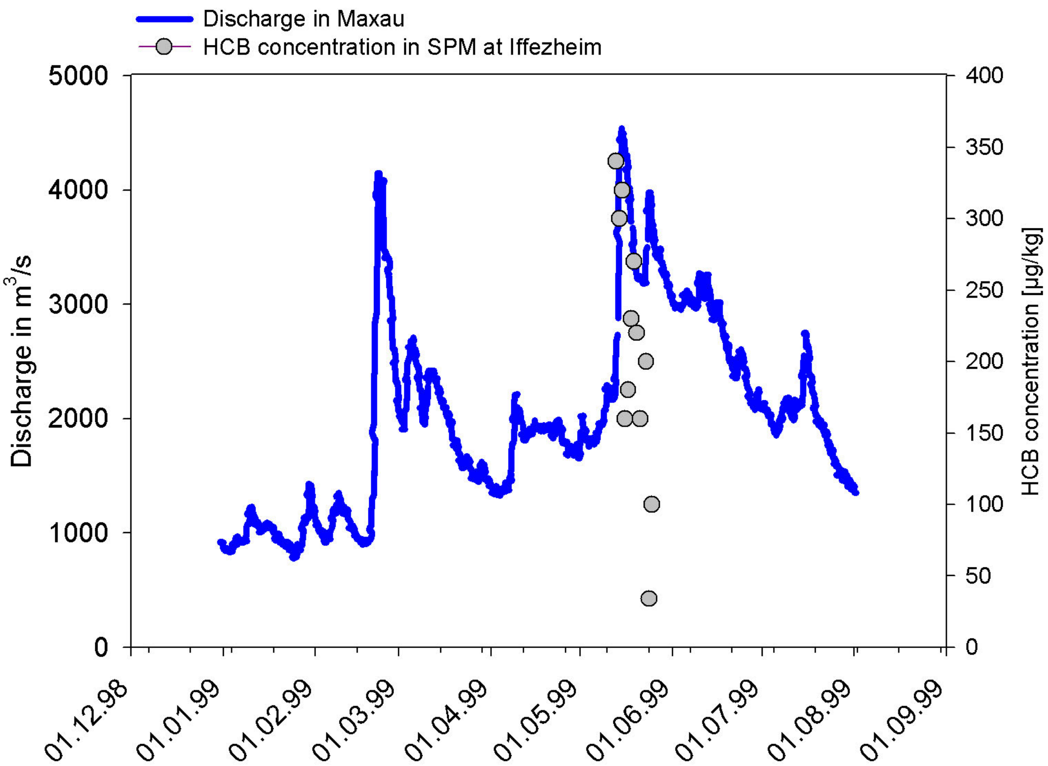


Figure 5.20 HCB concentrations in suspended matter and loads at the routine measuring station Maxau depicted depending on the discharge. Vertically, the different flood return periods are indicated.

Figure 5.21 shows the HCB concentrations in SPM during the May flood in 1999 in Iffezheim and between January and August 1999 in Lobith, compared with the discharges. During the May flood, which was considered a 100 years flood in the High Rhine, HCB concentration in suspended matter increased to almost 350 µg/kg at Iffezheim. And 5 days later, HCB concentrations increased at Lobith at the Dutch-German border: Here the concentrations of 68 µg/kg still exceed the CTT value three times (Data were made available by Doreen ten Hulscher, RIZA).

Either the HCB became resuspended in Iffezheim and transported down the river, or another HCB source is responsible for the increased values at Lobith. There are indications, that the HCB contaminated sediment in the Lippe can be resuspended (see below). However, the flood in May 1999 mainly affected the High and Upper Rhine and had little impact on discharges of the Lower Rhine tributaries. In addition, the variation of the HCB concentration in Lobith corresponds very well with the discharges at Maxau.

Therewith, these data support stongly the assumption, that HCB contaminated material that becomes resuspended in Iffezheim can be transported within a few days to Lobith and is diluted only by a factor 5 during this process.



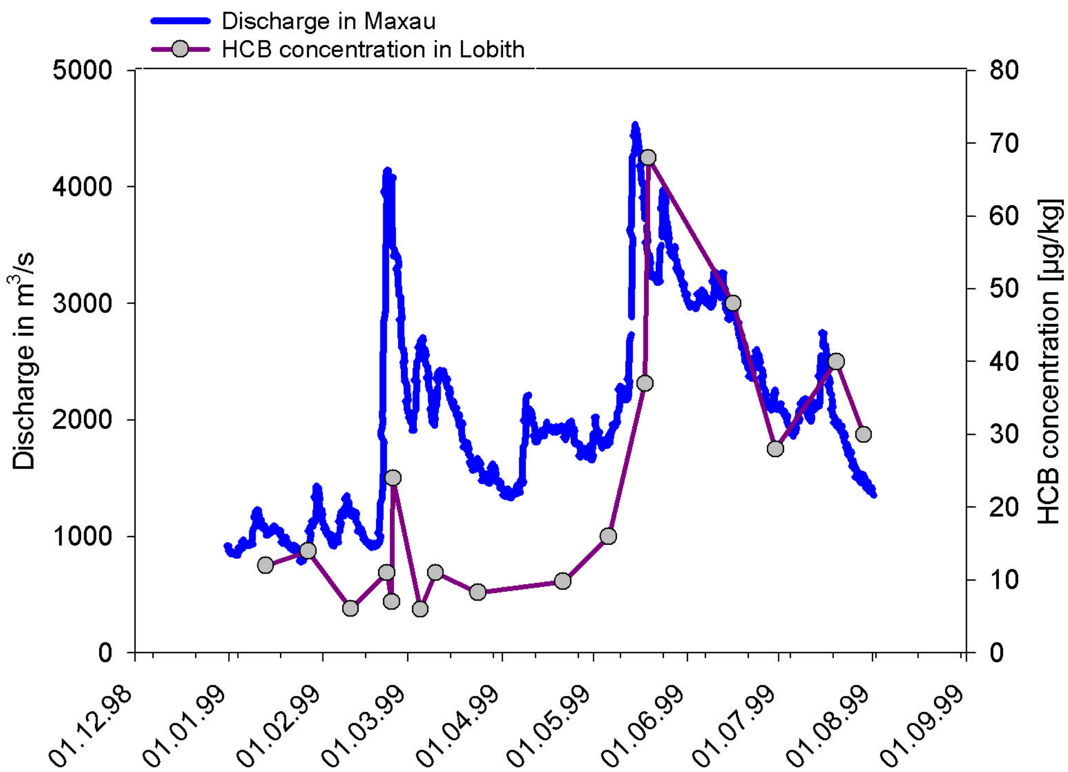
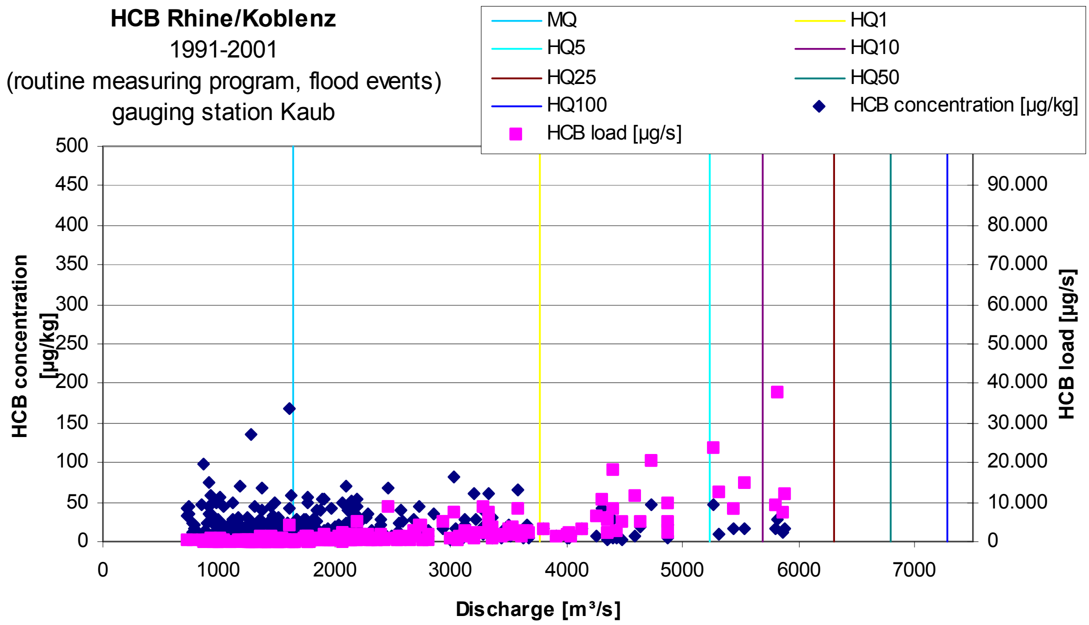


Figure 5.21 HCB concentrations in suspended matter at monitoring stations Lobith and Iffezheim and discharge during the flood event in May 99.



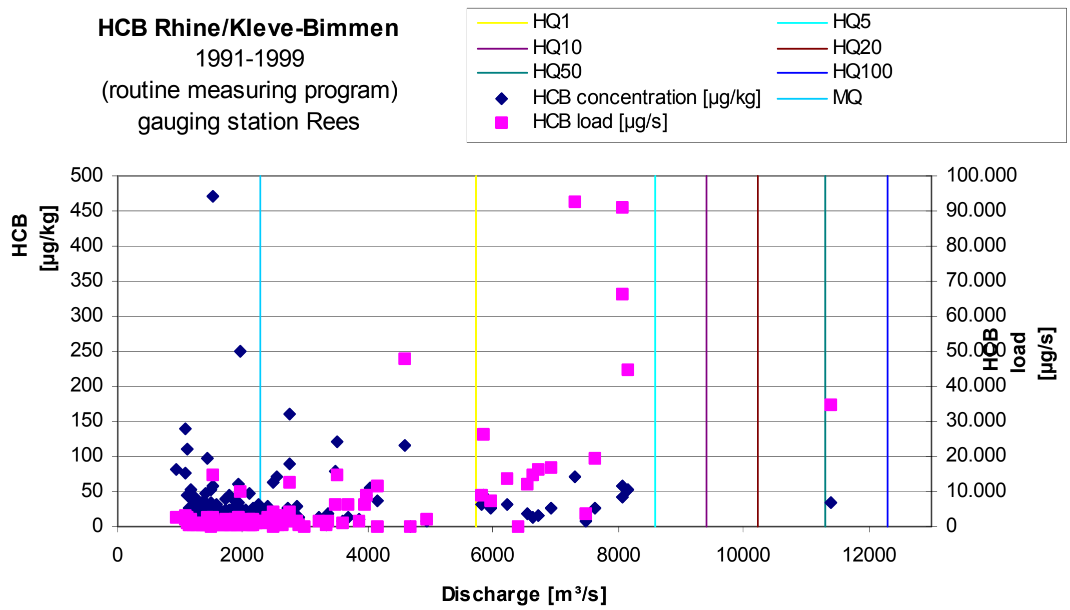


Figure 5.22 HCB concentrations in suspended matter and loads in Koblenz (upper graph, 1990 – 2001) and Kleve Bimmen (lower graph, 1990 – 1999) in relation to discharges measured at the nearest gauging stations

A comparison of load and concentration at the Rhine station in Koblenz and at Kleve-Bimmen is carried out to look for evidences that the tributary Lippe contributes to the HCB load at all (Fig. 5.22). Concentrations at Koblenz rise up to 170 µg/kg, but are usually found to stay below 100 µg/kg. At Kleve-Bimmen, however, concentrations of more than 100 µg/kg with a peak of more than 460 µg/kg have been frequently measured. Two explanations are possible for these high levels, which are not reflected by correspondingly high values in Koblenz: Either no measurements were carried out at Koblenz during high flood events, or the Lippe area, which is the only other substantial HCB source between Koblenz and Kleve-Bimmen, apart from smaller harbors in that region, contributes to the HCB load.

Table 5.9 Estimations of concentration and load for Cadmium and HCB for the different flood return periods at the monitoring stations of the river Rhine and its tributaries

River	Station		MQ (min/max)	HQ1 (min/max)	HQ5 (min/max)	HQ10 (min/max)	HQ20 (min/max)	HQ 50 (min/max)	HQ100 (min/max)
Rhine	Iffezheim	Cd[mg/kg]	0,25 - 0,9	0,25 - 0,9	0,25 - 0,9	0,25 - 0,9	*1)	*1)	*1)
		Cd [mg/s]	1,2 - 35	4,0 - 170	10 - *1)	20 - *1)	*1)	*1)	*1)
		HCB [µg/kg]	5,4 - 120 *2)	10 - 230	30 - 300	55 - 330	70 -370	*1)	*1)
		HCB [µg/s]	130 - 5000	400 - 48000	1600 - 75000	28000 - 420000	40000 - *1)	*1)	*1)
Neckar	Mannheim/	Cd[mg/kg]	0,43 - 2,6	0,43 - *1)	*1)	*1)	*1)	*1)	*1)
	Feudenheim	Cd [mg/s]	1,3 - 35	80 - 450	150 - *1)	*1)	*1)	*1)	*1)
		HCB [µg/kg]	*3) -30	*1)	*1)	*1)	*1)	*1)	*1)
		HCB [µg/s]	*3) - 500	*1)	*1)	*1)	*1)	*1)	*1)
Main	Bischofsheim	Cd[mg/kg]	0,6 - 1,4	0,5 – 1,1	*1)	*1)	*1)	*1)	*1)
		Cd [mg/s]	2,0 - 20	15 - 80	*1)	*1)	*1)	*1)	*1)
Mosel	Koblenz	Cd[mg/kg]	0,3 - 2,4	0,3 - 1,5	0,3 - *1)	*1)	*1)	*1)	*1)
		Cd [mg/s]	0,1 - 20	60 - 200 *2)	180 - *1)	*1)	*1)	*1)	*1)
		HCB [µg/kg]	*3) - 8	*3) - 8	*1)	*1)	*1)	*1)	*1)
		HCB [µg/s]	*3) - 50	*3) - 400	*1)	*1)	*1)	*1)	*1)
Rhine	Koblenz	Cd[mg/kg]	0,18 - 1,9	0,35 - 1,6	0,5 - 1,3	0,6 - 1,2	*1)	*1)	*1)
		Cd [mg/s]	2,4 - 150	100 - 600	300 - *1)	400 - *1)	*1)	*1)	*1)
		HCB [µg/kg]	2,5 - 170	3 - 70	8 - 50	10 - 45	10 - 45	*1)	*1)
		HCB [µg/s]	100 - 4500	1000 - 15000	4000 - 28000	6000 - 36000	8000 - 50000	*1)	*1)
Rhine	Bad Honnef	Cd[mg/kg]	0,18 - 2,3	0,25 - 1,7	0,35 - 1,2	*1)	*1)	*1)	*1)
		Cd [mg/s]	3 - 350	100 - 1450	300 -*1)	*1)	*1)	*1)	*1)
		HCB [µg/kg]	1 - 20	1,2 - 50	1,2 - *1)	1,2 - *1)	1,2 - *1)	*1)	*1)
		HCB [µg/s]	*3) - 1000	400 - 22000	1400 - *1)	17000 - *1)	1900 - *1)	*1)	*1)
Ruhr	Essen	Cd[mg/kg]	0,44 - 54	2 - 15	2,8 - 8	*1)	*1)	*1)	*1)
		Cd [mg/s] (total load)	1,3 - 30	50 - 320	130 - 950	200 - 1100	*1)	*1)	*1)
		AOX [mg/kg]	250 - 11000	70 - 750	30 - 200	30 - 120	*1)	*1)	*1)
		AOX [mg/s]	250 - 2400	1700 - 12500	5000 - *1)	*1)	*1)	*1)	*1)
Rhine	Kleve-Bimmen	Cd[mg/kg]	0,5 - 4	0,17 - 2,3	0,3 - *1)	*1)	*1)	*1)	*1)
		Cd [mg/s]	30 - 210	35 - 1500	350 - *1)	*1)	*1)	*1)	*1)
		HCB [µg/kg]	1 - 250	3 - 100	10 - 60	*1)	*1)	*1)	*1)
		HCB [µg/s]	200 - 15000	200 - 75000	5000 - *1)	*1)	*1)	*1)	*1)

*1) estimation not possible; *2) neglect of outliers; *3) below detection limit; *4) no flood return period data available

Table 5.9 gives an overview over the ranges of concentrations and loads of HCB and cadmium in relation to the different discharge levels. In some cases it has been difficult or not possible to give exact range values for the corresponding flood return period, due to the low number of flood event measuring campaigns, the complex catchment area of the river Rhine with many tributaries as well as the variability of the flood measurements. Additional uncertainties arise as available flood event data were not measured at all monitoring station.

The available data show, however, that already relatively high concentrations of HCB occur at MQ and increase from 120 µg/kg maximum value to 370 µg/kg at HQ_{20}.

Also the load increases, meaning that the source of the material has to be at Iffezheim, because there is only little dilution and no decrease of concentration with discharge. This results in a situation where a **high quantity** of suspended matter with at the same time **increased HCB concentration** is transported downstream with rising discharge levels.

In Koblenz, the concentration decreases with discharge due to dilution with SPM that has no HCB contamination (see chapter 5.2.2). This again points to the upper barrages as the main source of HCB.

At MQ, the magnitude of load between Iffezheim and Koblenz is the same, and also the concentrations are in the same range, which could mean that there is little dilution effect under normal discharge. At the same time, it means with regard to HCB that the situation may be severe for the Port of Rotterdam under MQ conditions as only little decrease in contaminant concentration occurs along the Upper Rhine at normal, average discharge conditions.

cadmium, as compared to HCB, shows a decrease in concentration with discharge. However, as has been stated before, no measurements were recorded during flood events at Neckar and at the Main and, hence, there are not enough data available to verify the sources of this heavy metal.

Summary: on the basis of HCB and cadmium data, there is a strong indication, that sediment from the barrage Iffezheim, from the River Ruhr and possibly from the River Lippe can be resuspended, partly already at very low discharges (MQ with Iffezheim).

5.5.4 Other evidence for resuspension events

Harbors and Groynes in the Upper Rhine like Loreley, Bauhafen Worms

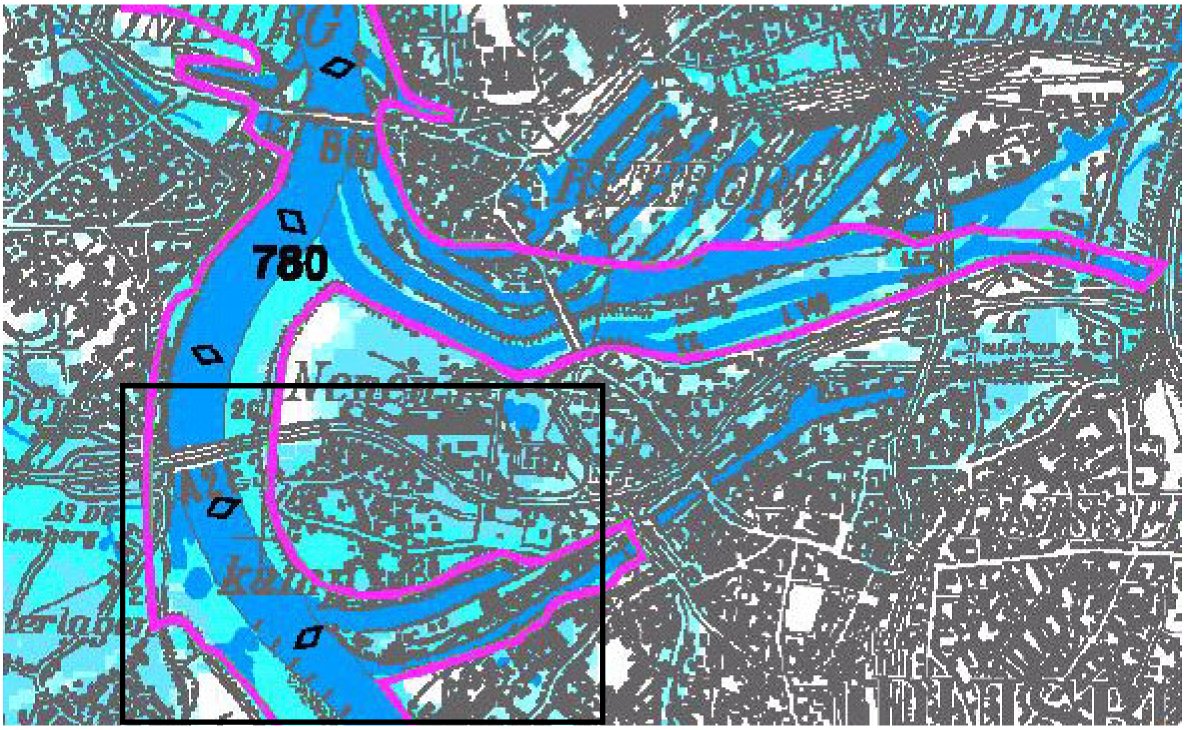
No data on critical erosion thresholds from the harbors or groynes in the Upper Rhine are available. However, groynes are frequently exposed to higher water currents and pobably contribute material towards the suspended matter concentration. As no sediment data from groyes were available, no conclusions can be drawn, whether the exchange of sediment is so frequent, that no historic contamination accumulated or whether these can be regarded as a secondary source of contamination.

Harbours like the Bauhafen Worms and the Loreley habour from where sediment data were made available by the Federal Institute of Hydrology (BfG), serve as shelters for yachts in case of storms and high waters. Accordingly, they will only be exposed to extreme currents to a limited extent and no contribution of locations to the contaminant load of the SPM in the Rhine can be expected (Keller, BfG, pers. Comm.).

<u>Lower Rhine – Duisburg and Ruhr Area</u>

Also in this area, data on erosion thresholds for the Rhine in the Ruhr Area are lacking. A good indicator for resuspension from Duisburg harbors would be dioxin measurements. These, however, have not been carried out so far.

Figure 5.23 gives an overview over the Duisburg harbour area with the highly contaminated basins "Diergardt" and "Aussenhafen".



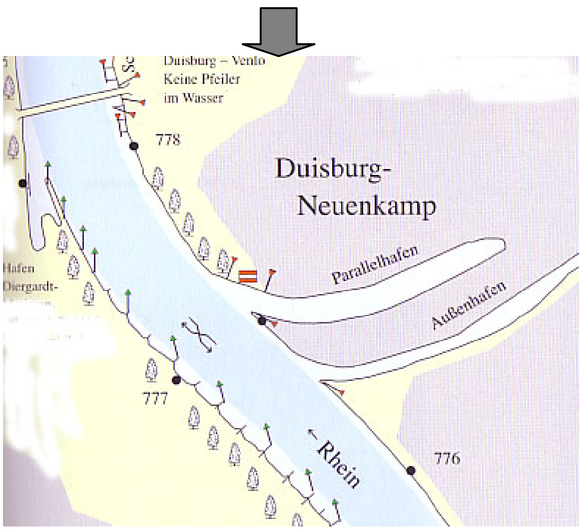


Figure 5.23 Map of Duisburg area with "Hafen Diergardt", "Parallelhafen" and "Außenhafen" (bottom figure, (Fenzl, 2003)) and the borders of the flooded area during an HQ_{100}, purple lines, and an HQ_{10}, green lines (ICPR, 2001)

Under high water conditions, all harbours are flooded. Whether these areas then serve exclusively as sinks of material or also as sourses of SPM cannot be assessed on the available data base.

Lower Rhine – harbors, flooded quarries

To these belong e.g. Hitdorf harbour (Figure 5.24) at the confluence of the Wupper, the harbor basin Neuss, the quarry "Baggerloch Müllerhof" and others. They show high concentrations of heavy metals, HCB and PCB. Sediment samples that were taken at the Hitdorf station in 1985 during a high water showed extremely high contamination with chromium (855 mg/kg), copper (580 mg/kg), zinc (1610 mg/kg), and lead (525 mg/kg). These concentrations were exceptional, even though Hitdorf is known to be contaminated, and they were explained by the environment agency of Nordrhein-Westfalen to belong to old contaminated sediment which had been exposed through removal of newly deposited material by the high water before the sampling. (LUA, 1997). As is shown in Figure 5.24, Hitdorf Harbor is exposed to high waters and according to this experience in 1985, sediment can be resuspended.

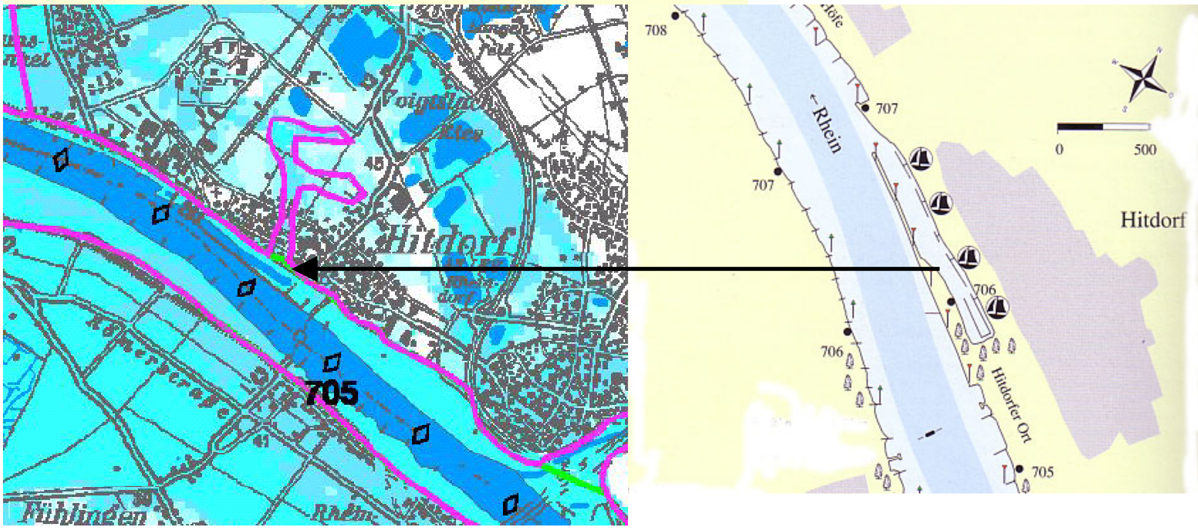


Figure 5.24 Map of Hitdorf harbour (right figure, (Fenzl, 2003)) and the borders of the flooded area during an HQ_{100}, purple lines, and an HQ_{10}, green lines. (ICPR, 2001).
(reproduction of the maps with kind permission of the ICPR and of the Edition Maritim GmbH)

Although the contaminated basins may contribute towards the total load of contaminants, the volume of material that they could contribute is relatively small, so the risk for the Port will be limited.

Mosel

The Mosel has been shown in this study to be of concern with regard to copper, nickel, lead, zinc and PCB.

Analyzing the average annual concentrations in mg heavy metal/kg suspended matter at different monitoring stations, the high contribution by the Mosel becomes obvious. Although mainly limited to the years before 1994, average annual concentrations of all heavy metals still reached the level of the CTT in 1999 (Pb, Zn) or even exceeded it considerably (Cu and Ni). Due to the importance of diffuse sources for copper and here especially precipitation dependent processes like run-off of houses and vineyards, where copper-based compounds are applied as anti-foulings or pesticides, it is difficult to differentiate between resuspension of historic contaminated sites and increased emission of diffuse sources.

Emscher

The Emscher waters, which are highly contaminated are treated in total. The river water treatment plant has been designed to withstand an HQ_{100}, therefore it should be expected that no contaminants on suspended matter are emitted into the Rhine waters to a large extent.

Wupper

A comparison of the contamination pattern of the Wupper with that of the downstream areas of concern like the harbours in the lower Rhine, especially Hitdorf, show that the patterns of heavy metal loads are identical with the exception of cadmium (Table 4.8) which is not considered a substance of concern in the Wupper, but shows elevated concentrations downstream. This can indicate a transport from the Wupper towards the Rhine and its contribution of heavy metal loaded SPM.

Erft

Only few data are available for suspended matter concentration and there is little indication, that the Erft substantially contributes to the Rhine. The relatively high concentration of Cadmium in the Neuss harbour (5.8 mg/kg, total sediment) downstream of the Erft confluence could be an indication of transport of contaminated material along the Erft.

5.2 Summary – areas of risk for Rotterdam

The risk assessment for port sediments due to substances of concern (chapter 4.2) and the areas of concern (chapter 4.3) was done on the basis of information on the quantity of contamination and its resuspension and transport towards Rotterdam. Due to the lack of critical erosion data and information on sediment resuspension, indications were looked for that could hint towards resuspension processes with specific consideration of flooding events. The assessment was done with regard to "business as usual conditions" (BAU) and to different flood scenarios. As floods frequently occur in the Rhine basin and influence resuspension and transport processes, these were of special importance for the conclusions. "BAU" describe situations of average water discharges and without anthropogenic activities that could lead to resuspension of sediment.

Table 5.10 Areas of Risk in the Rhine basin and its tributaries, concluded from evidence of hazard classes of areas of concern, theoretical possibility to exceed the CTT level and indication of resuspension

(+/- no obvious effect; + small effect, ++ significant effect, +++ large effect)

no evidence of risk	risk can not be	evidence for risk	evidence for high risk

Areas of concern	**dominating hazard class**	**theoretical exceedance of CTT upon resuspension**		**indication of resuspension**			**Areas of risk**
				hydrological situation	erosion potential	Increase in SPM load Quantity issue	
chapter 4	***chapter 4.3.2***	***chapter 5.3***		***chapter 5.2***	***chapter 5.4***	***chapter 5.4***	***chapter 5.5.***
Higher and Upper Rhine/ barrages	3	HCB Hg	**MQ** MQ	**BAU**	+ / -	+	
				$>HQ_1$ **$>HQ_{10}$** $>HQ_{50}$	+ ++ +++	+++	
Upper and Middle Rhine / harbours e.g. Loreley	1 - 3	HCB PCB DDT Hg	**MQ** MQ MQ MQ	**BAU**	+ / -	+ / -	
				HQ_{50}	+ / - pers. Comm	+ / - (pers. comm.	
				HQ_{100}	?	?	
Lower Rhine / Duisburg and Ruhr area	1 - 3	PAH Zn Cu Cr Hg Dioxin	**MQ** MQ MQ MQ MQ MQ[1]	**BAU**	+ / -	?	
				$HQ_?$	?	?	
				HQ_{100}			

[1] Dioxins haven't been considered in table 5.10 because no CTT is assigned to them. Concentrations in the Duisburg area however are high enough to present a risk for the Port of Rotterdam when resuspended.

Lower Rhine / Harbours and Flooded quarries	3	HCB PCB PAH Zn Cu Cr Hg	**MQ** MQ MQ MQ MQ MQ MQ	**BAU**	+ / -	?	
				$HQ_?$	?	?	
				HQ_{100}			
Neckar	1	Cd	**MHQ, HHQ**	**BAU**	+ / -	+ ?	
				MHQ	+	+ (HQ 1)	
				HQ_{100}	++		
Main	3 (limited data base)			**BAU**	+ / -	+/-	
				HQ_{50}	+	+	
				HQ_{100}	++		
Mosel	2 – 3 (limited data base)			**BAU**			
				HQ_{10}		+ (HQ1)	
				HQ_{100}			
Emscher	3 (only suspended matter)			**BAU**	+ / -	River water treatment plant	
				HQ_{10}			
				HQ_{100}			
Wupper	3			**BAU**			
				HQ_{10}		+	
				HQ_{100}		+	
Ruhr	3	PAH	**MQ, MHQ, HHQ**	**BAU**	+		
				HQ_{10}		+ (HQ1)	
				HQ_{100}	+++		
Erft	3			**BAU**			
				HQ_{10}			
				HQ_{100}			
Lippe	2			**BAU**			
				HQ_{10}		+	
				HQ_{100}		+	

A certain risk was assigned only to 5 areas along the Rhine river basin of which two were assigned to the high risk class (evidence of high risk) under specific discharge conditions: the Upper Rhine area and here specifically to the sediment that has been accumulated in the barrages and the Ruhr river. For Neckar, Wupper and Lippe here was evidence for risk with higher water discharges.

The **barrages in the Upper Rhine** are the only ones, that may already present a risk during business as usual conditions: Already at normal discharges, increased concentrations of HCB have been measured in suspended matter at Iffezheim. With increasing discharges HCB (and possible mercury) becomes resuspended and transported downstream. With the continuous inflow of contaminated sediments from the barrages further South, the existing sediment disposal sites reaching their upper limits, combined with still high HCB concentrations in the sediment and significant gaps in the understanding of its transport processes, this area becomes an important challenge for future sediment management.

The **Neckar** may also represent a risk to the Port of Rotterdam: A resuspension of cadmium in the barrage Lauffen has been predicted due to its low sediment stability, and increases in cadmium concentration in suspended sediments at this site have been measured. However, whether this load arrives at the Rhine after passing 13 more barrages, is uncertain. Data from the measuring station Feudenheim and Mannheim, the last barrage before the Neckar reaches the Rhine, cannot give any indication as no measurements were done during flood events. There is, however, no cadmium source identified in this report other than the Neckar that could be responsible for cadmium loads of more than 1000 mg/s at stations Koblenz (Rhine) and Bad Honnef, as the concentration and load data from the Main at the confluence with the Rhine are even lower than those of the Neckar.

The **Ruhr** represents a certain risk for the Port of Rotterdam at increased water discharges. High concentrations of PAHs but also of the other substances that are of concern in that river, especially cadmium, are likely to be resuspended and transported downstream. There are a number of management projects that aim at the restoration of the River, which may become of specific importance for the sediment stability and the concentration of suspended matter that is transported along the Ruhr at increased water discharge levels.

There is some indication that the **Lippe** may contribute to the HCB load in the Rhine (chapter 5.4.2) under high water situations. If the crest of the flood wave reaches the Rhine before the flood of the main river arrives, dilution of suspended matter from the Lippe may even be that low, that its contaminated suspended material could lead to an increase in the HCB concentration in the Port of Rotterdam.

The Lippe case clarifies one of the uncertainties that are immanent to this kind of studies: The heterogeneity of the flood regimes along the Rhine basin complicate general statements about risk, as it influences any dilution effects of contaminated and "clean" suspended matter to a large degree. Working with "average data" may simplify the situation to an extent where uncertainties become very high.

The evidence for a risk that originates in the **Wupper** is very indirect and derives mainly from measurements from the Hitdorf-harbour. This small harbour is influenced by Wupper effluents. It is still contaminated (area of concern class 3) and it shows all the substances that are also of concern for the Wupper area. Therefore the Wupper is assigned as an evidence of risk, although this has to be regarded with great caution.

Therefore it cannot be excluded that risks are present in the area the **Erft**, especially so, as the delayed mixing (and therewith retarded dilution) of the suspended matter of tributary and Rhine becomes more effective for the risk to Rotterdam, the nearer the tributaries are to the port.

Additional uncertainties arise from missing information on sediment stabilities e.g. from **the harbor sediments in the Lower Rhine**, and from the lack of analytical data on contaminants in sediments.

Rather than stating that there will be **areas with no risk** for the Port of Rotterdam, the conclusion can be drawn from the present report, that there are two areas, which present a high risk with high certainty: **The sediment in the barrages of the Upper Rhine and the Ruhr.**

5.7 Sediment management at the areas of concern

5.7.1 Institutional framework in water and sediment management

Due to the federal character of Germany, legal as well as administrative powers are clearly divided between the government of the Federal Republic ("Bund") and the Federal States, the "Länder". In the area of water management, the federal government can only enact framework laws, while the *Länder* are free to determine the actual structure and substance of water management within the limits set out in federal legislation (Kampa *et al.*, 2003). Water policy therefore is an area, where the authority of the *Länder* is most ponounced and this is of consequence for the institutional mechanisms for water and sediment management. The main governmental actors in the area of water management in all *Länder* at the state level are the State Ministries of the environment (*Umweltministerien*) and the State Environment Agencies (*Landesumweltämter*). For the Federal waterways, the Federal Ministry of Transport and its subordinated authorities are responsible. Maintenance and development work on Federal waterways are planned and carried out by the Federal Waterways and Shipping Administration (*Wasser-und Schiffahrtsverwaltung des Bundes WSV*). The responsibilities for the Federal Waterways are split up between the subordinate structures of the Administrations: the Waterways and Shipping Direction (*Wasser- und Schiffahrtsdirektion - WSD*) (figure 5.25).

Environmental aspects that concern the Federal Waterways are covered by the Federal Institute of Hydrology (*Bundesanstalt für Gewässerkunde – BfG*) which provides conceptual guidance and project monitoring (Köthe *et al.*, 1998). All other inland waterways are under the responsibility of the *Länder.* The State Environment Agencies carry out monitoring projects, gather data, analyse data with regard to the state of the environment but they seldom initiate sediment management projects (Figure 5.26). For example dredging projects are managed at the municipal or regional level by the competent local or regional authority (Peters & Hagner, 2001) and are not based on a common, coherent German policy, as has been elaborated in chapter 3.2.2.

Contaminated sites are dealt with on the basis of the German Soil Protection Act, which does not expressively address historical contaminated sediments. However, an indication of the efforts undertaken in this field can be seen from the investment in contaminated sites remediation, which as less than 0.03 ‰ of the gross domestic product (GDP) in Germany, whereas the respective Dutch expenditure is 1.5‰ of the GDP (Source: pilot EIONET data flow, January 2002). Handling of dredged material exhibits characteristic differences, in that the German Federal Waterways and Shipping Administration gives preference to sediment relocation (section 3.1.5), while in The Netherlands the actual focus of sediment policy and management is on subaquatic disposal (sections 3.1.6. and 3.2.1).

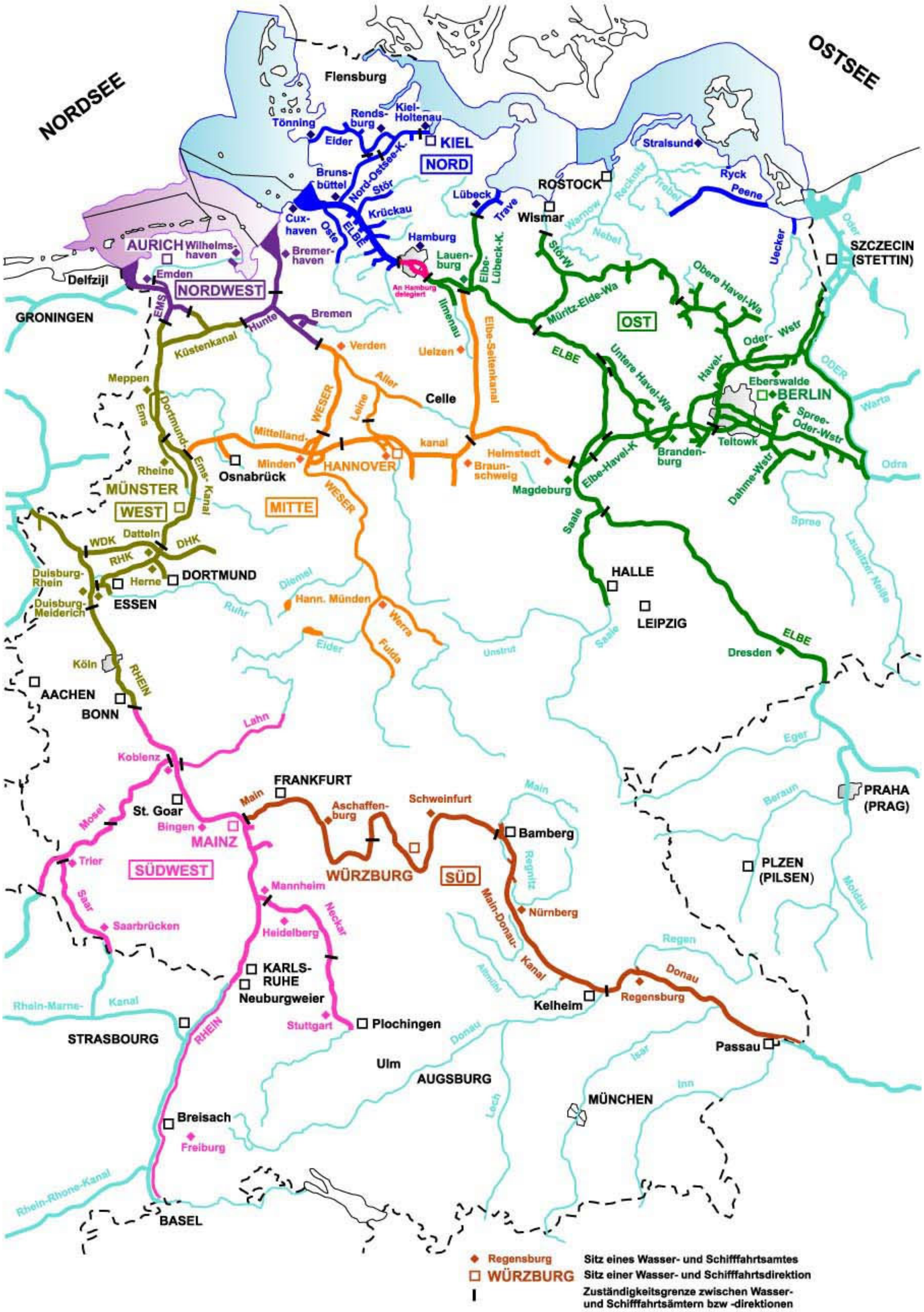


Figure 5.25 "Waterways and Shipping Directions" (WSD☐) and "Waterways and Shipping offices" (WSA ◆) along the Federal Waterways in Germany

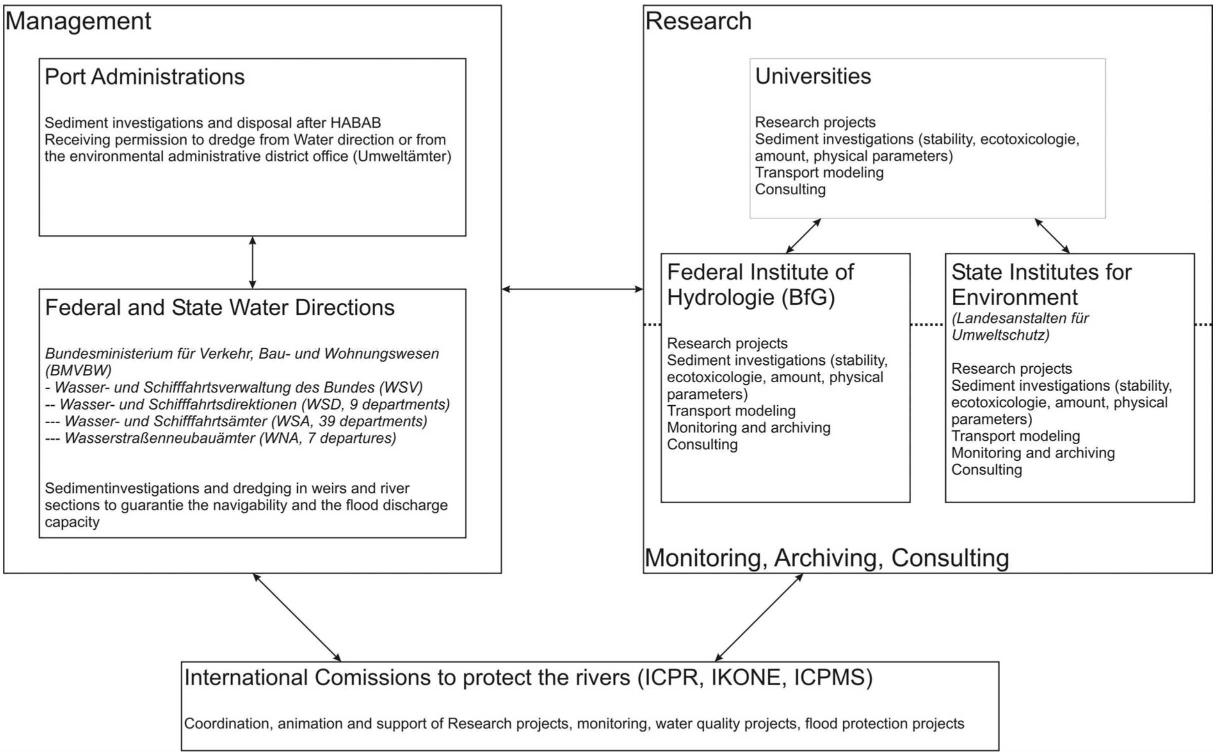


Figure 5.26 Functions and distribution of responsibilities between institutions involved in sediment management issues

5.7.2 Planned and implemented measures for areas of concern

Potential measures to reduce the risk of contaminated sediments fall into the following categories (see also (ATV-DVWK, 2003))):

- **a) reduction of emissions into the aquatic environment**
- **b) removal of contaminated material out of the hydrological cycle.**
- **c) reduction of sediment resuspension and transport of contaminated suspended matter**
- **d) reduction of *in situ* contaminant concentration**

The following will give an overview of what is being done in different areas of concern. Details on measures planned or implemented at the different areas of concern are given in Annex "measures".

a) reductions of emissions into the aquatic environment

Most activities are done on the basis of further reduction of point sources in order to improve water quality and environmental conditions. Examples are the **Lippe** area and the **Emscher** catchment.

High TBT concentrations, that were introduced into the **Lippe** River via the Seseke as a result of an organotin –production plant with an inappropriate treatment system for its wastewater has improved significantly due to a newly developed effluent-processing system. In the Summer of 2004, the renaturation of the small river Seseke is planned. Then the treated effluents of the plant will be guided directly into the **Lippe**.

The **Emscher** is still considered a sewer of industrial effluents. However, when the subsidence stopped, that had been induced by coal-mining, it became possible to restore the **Emscher** waters by technical means. In addition to 3 large wastewater treatment plants in Dortmund, Bottrop and Dinslaken, another, smaller one was built in 2000, which clears the direct industrial effluents from a company at the Landwehrbach. Up to a discharge of 30 m^3/s the whole river water is cleaned at the river water treatment plant in Dinslaken, before being introduced into the River Rhine. The sludge is incinerated totally (Dr. Piegsa, StUA Herten, personal communication). This way, an ecological improvement in the **Emscher** already started, and a long term plan has been set up to support the ecological restoration of the **Emscher** within the next 25 to 30 years (Busch *et al.*, 2001) by decreasing the volume of mine waters (Busch & Büther, 2000) and introducing pre-treatment processes of industrial effluents.

b) removal of contaminated material out of the hydrological cycle

This is the most frequently applied measure to limit the exposure of contaminated sites. Removal of sediment can be initiated by environmental concerns (remediation dredging) or by economical pressures, e.g. if the navigational depth has to be secured or the water discharge of a hydropower plant has to be guaranteed. Several projects have been realized in the Rhine catchment area, that aim at separating dredged contaminated material from the river regime. The different options that have been applied in sediment management in the River basin are:

<u>Disposal of dredged material in gravel pits:</u>

Knöpp suggested the disposal of sand and silt with consolidating properties in subaqueous gravel pits that have a connection with the river (Knöpp, 1989). Under the premises that after a fast consolidation all water flow within the material stops, anaerobic conditions are facilitated and leaching processes reduced. The subaqueous disposal has the advantage that the material is not exposed to quickly changing environmental conditions like temperature, humidity, acid rain. The measure is comparatively cost-efficient, no land is used and it bears the potential to create wetlands.

<u>Disposal in separated river zones:</u>

At the Hengsteysee at the Ruhr, an area of the impounded lake was blocked off the river by a dam from coarse material. Accumulated fine sediment from the lake was flushed into this area and clogged the pores of the dam within 1 to 2 days. No leaching of heavy metals could be detected. However, no future agricultural usage was recommended (ATV-DVWK, 2003).

<u>Subaquatic disposal in a confined site:</u>

Examples are the IJsseloogproject in the Ketelmeer and the "Slufter" in Rotterdam (chapter 3.5.2). In the aqueous surrounding, in case of the IJsseloog project directly inside the Ketelmeer, a ring-shaped dam is constructed from uncontaminated material and filled with dredged material. The water surface inside the pit is kept at a level that is lower than outside in order to prevent efflux of contaminants into the surface or groundwater.

<u>Disposal on terrestrial flushing fields:</u>

Heavy metal and PAH-contaminated sediments from the Hartkortsee in the Ruhr were removed and flushed on two 11 hectares large flushing fields outside of the high water retention areas (Knotte & Brinkmann, 2002).

c) reduction of sediment resuspension and transport of contaminated suspended matter.

The probability of sediment resuspension and its exposure to the environment can be reduced by providing a protective layer on top of the sediment (capping). No evidence of measures that primarily focus on the reduction of sediment resuspension has been gained.

However, measures like restoration of rivers that comprise reduction of flow velocity, realignment of dikes combined with the formation of new retention fields, remediation of flood plains and protective measures against the formation of high flood events, like the "Ruhrauenprogramm", the "Lippeauenprogramm", and the "integrated Rhine programme" of the LfU will all add to reduction of sediment resuspension.

Transport of contaminated suspended matter can be reduced by providing settling basins, in which sediment is trapped and contaminants are kept out of the hydrodynamic cycle, or by storing sediment away from the main current if it has to be removed. Examples for these are the River **Ruhr** with a number of settling basins (chapter 4.5), which were built with the purpose of self-purification, but which now serve as recreational sites for the Ruhr area. It is planned to classify the Ruhr River as "heavily modified water body" according to the WFD, and to change the hydromorphological regime to achieve a good ecological status. This will comprise reducing the effects of the impounding lakes, increasing the current velocity and during that process to dredge the heavy metal contaminated material from the bottom of the lakes.

Another example is the **barrage Iffezheim**. Fine-grained materials, contaminated predominantly with HCB, accumulate at the barrage. Hydraulic structures (moles) were built that serve as confined aquatic disposal sites and also reduce the aggradation. In near future, however, a problem will arise, because there will be a need for new dredging, but the containment at Iffezheim is almost filled. In parallel to plans for building a new disposal site within the river downstream, *in situ* research activities have been started to study the sediment transport and the behaviour of HCB in sediments and suspended matter (Köthe, 2000).

d) reduction of *in situ* contaminant concentration

In situ remediation is usually restricted to those sediments, that contain a limited number of contaminants which can be specifically targeted by organisms. Hence, only one example for *in situ* contaminant reduction was found: A BMBF funded project dealt with biological and chemical stabilisation of contaminated sediment at the Oberhafen in Frankfurt (Main). The aim was to apply a combination of aeration (venting) using the potential of aerobic degradation of the autochthonous microbes and to introduce an oxidising agent (H_2O_2) for the chemical elimination of more persistent organic substances. All organic parameters showed reduction in the sediment after a remediation period of 12 months. PAHs were reduced by stimulating biological degradation in the sediment (Thomas, C.A.U. GmbH, pers. communication).

Challenges in the remediation of historical contamination:

For example the Wupper: The Wupper still has a high contaminant load, which derives mainly from the urban area of Wuppertal, but also partly from upstream where historic contaminated sediments but probably also new emissions increase the contaminant load. The complex situation of having a variety of small and smaller industrial plants, about 17000 sites which are suspected of being contaminated, and an old canalization system in the city, renders any measures fruitless. Sediments of the 2 impounding reservoirs upstream of Wuppertal are potentially flushed out during high water. The small backwater reservoirs certainly will (Lacombe StUA Düsseldorf, pers. communication). Still no realistic possibility to reduce the immissions in the Rhine by the Wupper is envisaged.

5.8 References Chapter 5

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