APPENDIX PART B: PRESENT AND FUTURE QUALITY OF SEDIMENTS IN THE RHINE CATCHMENT AREA – HEAVY METALS

Chapter 2: Immission analysis

2.2a Overview of water quality data

River	Station	Pollutants	Year	Reference
Rhein	Reckingen	Cd, Cu, Hg, Pb, Zn	1990-1996	ICPR (Braun, personal communication), BfG (Walther, pers. Communication)
Rhein	Weisweil	Cd, Cu, Hg, Pb, Zn	1983-1996	ICPR (Braun, personal communication), BfG (Walther, pers. communication)
Rhein	Karlsruhe	Cd, Cu, Hg, Pb, Zn	1983-1998	Rheingütestation Worms (Diehl, personal communication)
Rhein	Seltz Lauterbourg	Cd, Cu, Hg, Pb, Zn	1983-1996	ICPR (Braun, personal communication)
Neckar	Mannheim	Cd, Cu, Hg, Pb, Zn	1984-1997	BfG (Walther, pers. communication)
Regnitz	Hausen	Cd, Cu, Hg, Pb, Zn	1982-1998	Bayerisches Landesamt für Wasserwirtschaft (Bach, personal communication)
Main	Viereth	Cd, Cu, Hg, Pb, Zn	1982-1998	Bayerisches Landesamt für Wasserwirtschaft (Bach, personal communication)
Main	Kahl a. Main	Cd, Cu, Hg, Pb, Zn	1982-1998	Bayerisches Landesamt für Wasserwirtschaft (Bach, personal communication)
Main	Bischofsheim	Cd, Cu, Hg, Pb, Zn	1990-1997	BfG (Walther, pers. communication)
Rhein	Mainz	Cd, Cu, Hg, Pb, Zn	1980-1998	Rheingütestation Worms (Diehl, personal communication)
Mosel	Palzem	Cd, Cu, Hg, Pb, Zn	1984-1997	BfG (Walther, pers. communication)
Saar	Kanzem	Cd, Cu, Hg, Pb, Zn	1984-1997	IKSS
Mosel	Koblenz	Cd, Cu, Hg, Pb, Zn	1983-1998	ICPR (Braun, personal communication), BfG (Walther, pers. Communication)

River	Station	Pollutants	Year	Reference
Rhein	Bad Honnef	Cd, Cu, Hg, Pb, Zn	1980-1998	ICPR (Braun, personal communication)
Rhein	Koblenz	Cd, Cu, Hg, Pb, Zn	1983-1998	ICPR (Braun, personal communication)
Sieg	Menden	Cd, Cu, Hg, Pb, Zn	1980-1998	Landesumweltamt Nordrhein West-falen (Ulkan, pers. communication)
Wupper	Obladen	Cd, Cu, Hg, Pb, Zn	1980-1998	Landesumweltamt Nordrhein West-falen (Ulkan, pers. communication)
Rhein	Duesseldorf-Flehe	Cd, Cu, Hg, Pb, Zn	1980-1998	Landesumweltamt Nordrhein West-falen (Ulkan, pers. communication)
Erft	Eppinghoven	Cd, Cu, Hg, Pb, Zn	1985-1998	Landesumweltamt Nordrhein West-falen (Ulkan, pers. communication)
Ruhr	Ruhr-confluence	Cd, Cu, Hg, Pb, Zn	1980-1994, 1997	Landesumweltamt Nordrhein West-falen (Ulkan, pers. communication)
Emscher	Emscher-confluence	Cd, Cu, Hg, Pb, Zn	1980-1998	Landesumweltamt Nordrhein West-falen (Ulkan, pers. communication)
Lippe	Wesel	Cd, Cu, Hg, Pb, Zn	1980-1998	Landesumweltamt Nordrhein West-falen (Ulkan, pers. communication)
Rhein	Lobith Bimmen	Cd, Cu, Hg, Pb, Zn	1983-1998	ICPR (Braun, personal communication)

2.2b Overview of average discharge and heavy metal loads in the period 1983-1987

River	Station	Discharge	Load				
			Cd	Cu	Hg	Pb	Zn
		[m3/s]	[t/a]				
Rhein	Weisweil	1051	0.9	97	1.5	46	947
Rhein	Karlsruhe	1321	6.9	150	3.9	105	1012
Rhein	Seltz Lauterbourg	1295	6.5	477	2.6	150	1667
Neckar	Mannheim	177	1.2	41	0.3	21	182
Regnitz	Hausen	39	0.5	17	0.4	9	55
Main	Viereth	109	1.3	32	1.2	16	132
Main	Kahl a. Main	184	1.4	50	0.9	11	190
Rhein	Mainz	1734	9.4	400	3.4	138	1754
Mosel	Palzem	181	1.6	21	0.4	19	189
Saar	Kanzem	101	2.1	16	0.2	39	214
Mosel	Koblenz	394	2.1	68	1.4	129	901
Rhein	Bad Honnef	2136	11.9	746	7.1	326	3064
Rhein	Koblenz	1860	8.8	387	7.4	218	2710
Sieg	Menden	56	0.6	26	0.3	37	351
Wupper	Obladen	20	0.4	27	0.3	17	84
Rhein	Duesseldorf-Flehe	2449	12.8	905	12.8	508	4177
Erft	Eppinghoven	17	0.2	3		11	41
Ruhr	Ruhr-confluence	86	1.7	56	0.4	34	318
Emscher	Emscher-confluence	17	0.2	11	0.1	5	50
Lippe	Wesel	49	0.7	24	0.2	15	141
Rhein	Lobith Bimmen	2504	22.2	874	7.9	652	4911

2.2c Overview of average discharge and heavy metal loads in the period 1993-1997

River	Station	Discharge	Load				
			Cd	Cu	Hg	Pb	Zn
		[m3/s]	[t/a]				
Rhein	Reckingen	453	0.6	17		14	104
Rhein	Weisweil	1082	0.7	51	0.5	35	275
Rhein	Karlsruhe	1264	4.3	135	1.2	51	474
Rhein	Seltz Lauterbourg	1269	6.2	255	2.8	90	850
Neckar	Mannheim	155	0.6	24	0.1	9	79
Regnitz	Hausen	32	0.1	8.8	0.1	2.2	19
Main	Viereth	97	0.2	13.3	0.3	3.9	36
Main	Kahl a. Main	177	0.5	56	0.3	13	215
Main	Bischofsheim	213	1.0	59	0.6	25	195
Rhein	Mainz	1629	7.6	237	3.1	89	877
Mosel	Palzem	145	0.7	19	0.2	8	103
Saar	Kanzem	76	0.6	11	0.1	7	55
Mosel	Koblenz	328	1.1	54	0.6	50	389
Rhein	Bad Honnef	2109	6.7	465	1.8	194	1696
Rhein	Koblenz	1735	5.2	266	2.5	181	1290
Sieg	Menden	56	0.3	10	0.1	21	181
Wupper	Obladen	16	0.1	6	0.0	8	22
Rhein	Duesseldorf-Flehe	2263	6.2	422	0.8	194	1696
Erft	Eppinghoven	10	0.1	2	0.0	4	21
Ruhr	Ruhr-confluence	79	0.3	20	0.1	7	103
Emscher	Emscher-confluence	19	0.1	6	0.0	2	30
Lippe	Wesel	42	0.2	13	0.1	3	62
Rhein	Lobith Bimmen	2201	6.4	458	2.2	269	2069

2.2d Overview of point source discharges in the Rhine drainage area

River	Station	Qpoint 1983-1987 [$m^3 s^{-1}$]	Qpoint 1993-1997 [$m^3 s^{-1}$]
Rhein	Reckingen	33	33
Rhein	Weisweil	72	72
Rhein	Karlsruhe	88.5	88.5
Rhein	Seltz/Lauterbourg	84	84
Neckar	Mannheim	42	42
Regnitz	Hausen	8.1	8.1
Main	Viereth	13.8	13.8
Main	Kahl a. Main	25.5	25.5
Main	Bischofsheim	40.5	40.5
Rhein	Mainz	187.5	187.5
Mosel	Palzem	8.1	8.1
Mosel	Koblenz	30	30
Rhein	Bad Honnef	241.5	241.5
Rhein	Koblenz	208.5	208.5
Rhein	Duesseldorf-Flehe	270	270
Rhein	Lobith Bimmen	339	339

2.2e Results of the immission analysis for estimating diffuse contributions to the metal loads in the River Rhine over the period 1983-1987

River	Station	Q	Total load	Diffuse sources	Total load	Diffuse sources	Total load	Diffuse sources	Total load	Diffuse sources	Total load	Diffuse sources
1983-1987			Cd		Cu		Hg		Pb		Zn	
		[m3/s]	[t/a]	[%]	[t/a]	[%]	[t/a]	[%]	[t/a]	[%]	[t/a]	[%]
Rhein	Weisweil	1051	0.9	92	97	93	1.5	78	46	87	947	91
Rhein	Karlsruhe	1321	6.9	92	150	92	3.9	72	105	93	1012	91
Rhein	Seltz Lauterbourg	1295	6.5	91	476	89	2.6	91	150	89	1667	76
Neckar	Mannheim	177	1.2	36	41	69	0.2	68	21	68	182	61
Rhein	Mainz	1734	9.3	58	400	71	3.4	87	138	68	1754	49
Mosel	Palzem	181	1.6	32	21	97	0.4	97	19	97	189	97
Mosel	Koblenz	394	2.1	92	68	90	1.4	91	129	88	901	90
Rhein	Bad Honnef	2136	11.9	71	746	86			326	85	3063	86
Rhein	Koblenz	1860	8.8	88	387	84	7.3	83	218	81	2710	87
Rhein	Duesseldorf	2449	12.8		905		12.8		508		4177	
Rhein	Lobith Bimmen	2504	19.8	73	874	82	7.9	86	652	75	4911	80

2.2f Results of the immission analysis for estimating diffuse contributions to the metal loads in the River Rhine over the period 1993-1997

River	Station	Q	Total load	Diffuse sources	Total load	Diffuse sources	Total load	Diffuse sources	Total load	Diffuse sources	Total load	Diffuse sources
1993-1997			Cd		Cu		Hg		Pb		Zn	
		[m3/s]	[t/a]	[%]	[t/a]	[%]	[t/a]	[%]	[t/a]	[%]	[t/a]	[%]
Rhein	Reckingen	453	0.6	88	17	89			14	86	104	89
Rhein	Weisweil	1082	0.7	91	51	91	0.5	90	35	89	275	91
Rhein	Karlsruhe	1264	4.3	86	135	92	1.1	92	51	90	474	92
Rhein	Seltz Lauterbourg	1269	6.2	78	254	89	2.8	89	90	90	850	92
Neckar	Mannheim	155	0.5	68	24	68	0.1	71	9	61	79	66
Main	Bischofsheim	213	1.0	80	59	79	0.6	76	25	79	195	75
Rhein	Mainz	1629	7.6	88	237	86	3.1	84	89	85	877	82
Mosel	Palzem	145	0.7	95	19	96	0.2	97	8	97	103	92
Mosel	Koblenz	328	1.1	90	54	90	0.6	92	50	90	389	92
Rhein	Bad Honnef	2109	6.7	88	465	89	1.7	88	194	87	1696	88
Rhein	Koblenz	1735	5.2	82	266	86	2.5	78	181	82	1290	86
Rhein	Duesseldorf	2263	6.2	86	422	85	0.8	85	194	85	1696	85
Rhein	Lobith Bimmen	2201	6.4	83	458	74	2.2	61	269	77	2069	79

2.3 Comparison with other studies

Behrendt (1993) analysed the point and diffuse contributions of cadmium, lead and zinc in the River Rhine for the period 1973-1987. The comparison of results from Behrendt to our estimates over the period 1983-1987 is shown in the table below. The greatest difference in total measured load and contribution of diffuse sources is observed for Lobith. The difference in the volume of point discharge causes this discrepancy for this period. In his former study Behrendt (1993) used a point discharge of 900 $m^3 s^{-1}$, whereas to current knowledge, in this study the point discharge was changed to 340 $m^3 s^{-1}$. Besides this difference in point discharge, the method for estimating point and diffuse contributions to the total measured load has also been elaborated by correcting for the amount of baseflow within a catchment. For the other stations Behrendt also used higher point discharge volumes which explains the other discrepancies as well.

Comparison of results from Behrendt (1993) to our results over the period 1983-1987

River	Station	Substance	Total load [t/a]	Diffuse load [%]	Total load [t/a]	Diffuse load [%]
			Behrendt	Behrendt	Our estimates	Our estimates
Rhine	Seltz	Cadmium	7.5	79	6.5	91
Rhine	Lobith	Cadmium	25.9	59	19.8	73
Mosel	Koblenz	Cadmium	4.7	83	2.1	92
Rhine	Seltz	Lead	161	83	150	89
Rhine	Koblenz	Lead	329	76	218	81
Rhine	Lobith	Lead	704	66	652	75
Mosel	Koblenz	Lead	169	82	129	88
Rhine	Seltz	Zinc	1218	84	1667	76
Rhine	Koblenz	Zinc	2709	78	2710	87
Rhine	Lobith	Zinc	4946	57	4911	80
Neckar	Mannheim	Zinc	254	34	182	61
Mosel	Koblenz	Zinc	1096	85	901	90

Chapter 3: Modelling of point and diffuse sources in the Rhine catchment area

3.1.2 Mean yearly emission of heavy metals from wastewater treatment plants

Specific emission of heavy metals per inhabitant [M_{POP}, g inhabitant^{-1}a^{-1}]	Cd	Cu	Hg	Pb	Zn
Used emission factor 1983-1987	0.06	5	0.06	4.5	30
Used emission factor 1993-1997	0.06	5	0.06	4.5	30
Zessner-1999	0.06	5	0.03	1.8	33
Koppe and Stozek - 1993	0.22	7.2	0.073	7.1	25
De Waal and Maalefijt -1982	0.05	7.2	-	1.2	8.9
ATV -1984		8.2	0.055	5.5	27.3
STORA-1985	0.05	6.5	-	0.9	8.1
CUWVO-1986	0.035	4.7	0.014	0.63	5.82
RIZA-1999	0.057	13	0.03	3.7	28

3.1.3 Atmospheric deposition of heavy metals

Atmospheric deposition rate [g/(ha/a)]	Reference	Cd	Cu	Hg	Pb	Zn
1983-1987	Used emission factor	3.5	44	0.4	120	400
1993-1997	Used emission factor	2	30	0.2	40	250
1985	Wet deposition-West Germany (Nguyen et al., 1990)	1-3	12.8		29-125	75-620
1985	Wet deposition-West Germany (Brechtel, 1989) Mean	2-33 6			50-640 190	90-4900 540
1985	Wet deposition-Holland (Feenstra et al., 1986) Dry deposition Total deposition	2.75 0.4 3.15	55 7 62		100 43 143	400 32 432
1985	Wet deposition-Holland (DHV-RIZA, 1985) Dry deposition Total deposition	1.6 1 2.6	12 10 22	1	122 42	236 36
	Total deposition (Wilcke and Doehler, 1995)	2.5	52.6		57.2	540
1985	Total deposition- Rhine area (Baart	1.3	9.6	1.4	160	84

Atmospheric deposition rate [g/(ha/a)]	Reference	Cd	Cu	Hg	Pb	Zn
	& Diederen, 1991)					
1978-1982	Total deposition-RIVM			0.54-1.35		
1985	Wet deposition-Holland (RIVM, 1984/1985)	1.4	5.9	0.3		91.5
	Dry deposition	1	23.6	0.16		26.2
	Total deposition	2.4	29.5	0.46		117.7
1989	Wet deposition-Holland (Copoolse et al., 1993)	1	15		44	144
	Dry deposition	0.48	10		29	51
	Total deposition	1.48	25	0.66	73	195
1991	Total deposition – Bayern (Müller et al., 1991)	1.0	25		63	1130
1991	Wet deposition-Holland (Raad et al., 1993)	1	19		36	65
	Dry deposition	0.5	1.5		43	30
	Total deposition	1.5	20.5		87	97.5
1980	Total deposition (Rautengarten, 1993)	3.8			330	257
1985	Total deposition (Rautengarten, 1993)	2.3			233	131
1988	Total deposition (Rautengarten, 1993)	2.0			195	115
1995-1996	Wet deposition (EMEP,1996)			0.13		
1996	Total deposition-Rhine (ICPR, 1999)	2	30	0.2	40	250

3.1.4 Heavy metal concentrations in surface runoff

Concentration in surface runoff [µg/l]	Reference	Cd	Cu	Hg	Pb	Zn
1983-1987	Used emission factor	0.14	10	0.05	2	30
1993-1997	Used emission factor	0.1	7.8	0.05	1.5	26
1997	Beudert (1997)	0.25	7.8		5.6	26
1997	Umweltbundesamt (1997)	0.14	2		1.5	11.8
1996	ICPR (1999)	2	15	0.05	15	200

3.1.5 Heavy metal contents of agricultural topsoil in the Rhine catchment area

Concentration of top-soil [mg/kg]	Cd	Cu	Hg	Pb	Zn
Baden-Württemberg	0.2	19	0.1	27	60
Bayern	0.23	17.3	0.08	31.3	68.3
Hessen	0.24	15.2	0.07	25.2	62.3
Nordrhein-Westfalen	0.4	12	0.06	30	67
Rheinland-Pfalz	0.27	16.5	0.13	24	62.5
Saarland	0.32	13.7	0.06	28.8	76.6
ICPR	0.3	20	0.1	27	60

3.1.6 Heavy metal concentrations in drainage water

Concentration in drainage water [µg/l]	Reference	Cd	Cu	Hg	Pb	Zn
1983-1987	Used emission factor	0.2	7.1	0.05	1.97	26
1993-1997	Used emission factor	0.2	7.1	0.05	1.97	26
1992	Hahn et al. (1992)	< 0.02	< 3		< 1.9	
1995	Wilcke and Doehler (1995)	0.4	7.1		1.97	80
1993	Fiedler and Rossler (1993)	2-6	2-30		1-<40	<5-550
1996	ICPR (1999)	2	15	0.05	15	200

3.1.7 Heavy metal concentrations in groundwater

Concentration in groundwater [µg/l]	Reference	Cd	Cu	Hg	Pb	Zn
1983-1987	Used emission factor	0.025	1.3	0.01	0.5	9
1993-1997	Used emission factor	0.025	1.3	0.01	0.5	9
Saarland	1988-1999	0.05-4	0.5-82	0.02-0.16	0.25-6600	2-945
Nordrhein – Westfalen		< 0.50	< 10	< 0.5	< 0.5	< 10
Baden Wuertemberg		0.025		0.025	0.25	5
Bayern	1986-1999	0.05-3.2	0.2-140	0.05-5	0.05-16	0.5-3900
Saarland	1985-1999	0.05	5	0.03	0.75	11
Fauth et al. (1985)	1977-1983	0.3	1.3		1	9
ICPR	1996	0.02	1	0.01	0.83	3.5

3.1.8a Heavy metal concentrations in indirect industrial discharges (based on Rautengarten, 1993, Schäfer,1999)

	Cd [µg/l]	Cu [µg/l]	Hg [µg/l]	Pb [µg/l]	Zn [µg/l]
1983-1987	25	1000	30	230	2000
1993-1997	4.6	150	1.5	150	500

3.1.8b Overview of traffic related emission factors in the Rhine basin

Traffic related emissions [TE_i –g/cap/a]	Reference	Cd	Cu	Pb	Zn
1983-1987	Used emission factor	0.08	5.2	11	19.3
1993-1997	Used emission factor	0.068	3.2	2.6	16.3
1983-1987	Behrendt (1993)	0.15		34.9	22.5
1983-1987	Rautengarten (1993)	0.053		11.1	19.3
1988	Rautengarten (1993)	0.047		8.6	16.8
1975	Shaheen (1975)			118	14.7
1979	Christensen and Guinn (1979)			36.8	22.5
1985	Hoffman et al. (1985)	0.15		33	16.5

3.1.8c Corrosion [E_D] in urban areas

Corrosion in urban areas [g/(ha/a)]	Reference	Cd	Cu	Hg	Pb	Zn
1983-1987	Used emission factor	5.9	-	-	-	1963
1993-1997	Used emission factor	3.1	-	-	-	1030
1983-1987	Corrosion -West Germany (Behrendt, 1993)	2.6				1300
1985	Corrosion-Rhine basin (Rautengarten, 1993)	5.5				1697

3.1.8d Atmospheric deposition [E_A] in urban areas

Atmospheric deposition in urban areas [g/(ha/a)]	Reference	Cd	Cu	Hg	Pb	Zn
1983-1987	Used emission factor	7	90	1	240	780
1993-1997	Used emission factor	4	60	0.4	80	500

3.1.8e Specific heavy metal loads in urban areas

Substance	Reference	Year	Total	Atmosphere	Traffic	Corrosion
Cd [g/(ha/a)]	This study	1983-1987	23	7	10.1	5.9
Cd [g/(ha/a)]	This study	1993-1997	11.2	4	4.1	3.1
Cu [g/(ha/a)]	This study	1983-1987	545	90	455	-
Cu [g/(ha/a)]	This study	1993-1997	340	60	280	-
Hg [g/(ha/a)]	This study	1983-1987	11	-	-	-
Hg [g/(ha/a)]	This study	1993-1997	4.5	-	-	-
Pb [g/(ha/a)]	This study	1983-1987	625	240	385	-
Pb [g/(ha/a)]	This study	1993-1997	171	80	91	-
Zn [g/(ha/a)]	This study	1983-1987	3419	780	676	1963
Zn [g/(ha/a)]	This study	1993-1997	2101	500	571	1030
Cd [g/(ha/a)]	Behrendt (1993)	1983-1987	17.2	8.4	5.3	3.5
Pb [g/(ha/a)]	Behrendt (1993)	1983-1987	850	450	530	-
Zn [g/(ha/a)]	Behrendt (1993)	1983-1987	3320	780	790	1750
Cd [g/(ha/a)]	Luettel (1997)	1993	12.5	6	5.4	0.95
Pb [g/(ha/a)]	Luettel (1997)	1993	713	204	509	-
Zn [g/(ha/a)]	Luettel (1997)	1993	1728	453	805	470
Cd [g/(ha/a)]	Fuchs et al. (1999)	1995	18			
Cu [g/(ha/a)]	Fuchs et al. (1999)	1995	312			
Hg [g/(ha/a)]	Fuchs et al. (1999)	1995	1.55			
Pb [g/(ha/a)]	Fuchs et al. (1999)	1995	154			
Zn [g/(ha/a)]	Fuchs et al. (1999)	1995	1748			

3.2.9a Results of the emission analysis for estimating diffuse contributions to the heavy metal emissions in the River Rhine over the period 1983-1987

River	Station	Total emission	Diffuse sources	Total emission	Diffuse sources	Total emission	Diffuse sources	Total emission	Diffuse sources	Total emission	Diffuse sources
1983-1987		Cd [t/a]	[%]	Cu [t/a]	[%]	Hg [t/a]	[%]	Pb [t/a]	[%]	Zn [t/a]	[%]
Rhein	Reckingen	1.4	82	59.3	74	0.7	70	50	76	372	71
Rhein	Weisweil	4.0	78	177.5	68	2.0	66	142	71	1094	66
Rhein	Karlsruhe	6.6	71	305.4	58	2.8	65	213	65	1815	57
Rhein	Seltz Lauterbourg	1.3	62	265.9	63	2.2	64	199	65	1585	61
Neckar	Mannheim	1.1	77	58.0	68	0.7	70	45	61	409	60
Regnitz	Hausen	0.4	78	15.7	67	0.2	72	14	63	119	61
Main	Viereth	0.8	81	34.0	74	0.4	75	29	71	239	67
Main	Kahl a. Main	1.4	83	65.3	77	0.8	77	58	75	447	70
Main	Bischofsheim	2.0	81	87.4	74	1.2	72	78	71	618	67
Rhein	Mainz	10.0	74	466.6	62	5.1	68	350	66	2969	59
Mosel	Palzem	1.3	62	63.7	48	0.6	60	38	50	343	49
Saar	Kanzem	0.9	71	37.7	56	0.4	69	27	58	239	57
Mosel	Koblenz	2.7	66	133.0	52	1.3	64	85	53	762	53
Rhein	Bad Honnef	13.8	73	712.8	55	7.0	68	478	62	4025	59
Rhein	Koblenz	10.9	75	501.1	63	5.6	68	378	66	3209	60
Sieg	Menden	0.3	81	13.3	73	0.2	74	9	62	90	64
Wupper	Obladen	0.3	79	8.9	63	0.1	72	8	59	68	57
Rhein	Duesseldorf	15.4	70	713.1	58	7.8	66	502	63	4484	57
Erft	Eppinghoven	0.1	78	6.7	65	0.1	68	6	62	51	59
Ruhr	Ruhr-Mouth	0.6	80	25.1	70	0.3	74	19	62	180	63
Emscher	Emscher Mouth	0.4	72	15.8	53	0.3	67	15	51	135	51
Lippe	Wesel	0.5	82	19.1	69	0.4	50	16	66	141	63
Rhein	Lobith Bimmen	17.6	71	803.8	59	9.2	66	622	58	5161	57

3.2.9b Results of the emission analysis for estimating diffuse contributions to the heavy metal emissions in the River Rhine over the period 1993-1997

River	Station	Total emission	Diffuse sources	Total emission	Diffuse sources	Total emission	Diffuse sources	Total emission	Diffuse sources	Total emission	Diffuse sources
1993-1997		Cd [t/a]	[%]	Cu [t/a]	[%]	Hg [t/a]	[%]	Pb [t/a]	[%]	Zn [t/a]	[%]
Rhein	Reckingen	0.9	84	45	81	0.4	80	26.9	83	239	83
Rhein	Weisweil	2.4	80	126	77	1.0	75	74.2	79	658	79
Rhein	Karlsruhe	3.5	76	199	70	1.6	71	106.3	76	979	73
Rhein	Seltz Lauterbourg	3.3	77	182	72	1.5	70	101.1	76	897	75
Neckar	Mannheim	0.6	83	36	81	0.3	80	20.8	76	184	76
Regnitz	Hausen	0.2	84	9	82	0.1	81	6.1	80	55	73
Main	Viereth	0.4	88	24	87	0.2	85	16.7	86	133	81
Main	Kahl a. Main	0.7	88	46	87	0.3	85	34.9	87	253	81
Main	Bischofsheim	0.9	87	57	85	0.4	83	41.4	84	315	79
Rhein	Mainz	5.2	79	298	74	2.4	75	173.0	78	1520	74
Mosel	Palzem	0.6	55	40	51	0.3	46	16.8	54	161	56
Saar	Kanzem	0.4	57	24	57	0.2	57	11.4	58	116	61
Mosel	Koblenz	1.4	57	87	55	0.7	52	37.6	57	377	60
Rhein	Bad Honnef	7.1	75	410	71	3.3	70	224.9	74	2038	72
Rhein	Koblenz	5.6	79	319	75	2.5	75	184.9	77	1635	74
Sieg	Menden	0.1	83	8	80	0.1	78	3.3	63	41	72
Wupper	Obladen	0.1	79	5	73	0.0	74	2.5	58	28	68
Rhein	Duesseldorf	7.5	75	438	70	3.5	69	235.7	73	2159	71
Erft	Eppinghoven	0.1	87	3	82	0.0	82	2.1	83	36	37
Ruhr	Ruhr-Mouth	0.3	83	15	80	0.1	79	6.9	66	81	73
Emscher	Emscher Mouth	0.1	76	5	67	0.1	73	3.2	58	37	57
Lippe	Wesel	0.3	89	12	84	0.1	73	7.1	79	71	74
Rhein	Lobith Bimmen	8.4	76	483	70	3.9	70	269.2	71	2361	73

3.4a Comparison of results (emission analysis) with Behrendt (1993)

For the period 1983-1987 we compared the emission estimates for Cd, Pb and Zn to the estimated emissions of Behrendt (1993) as shown in the table below. Behrendt used emissions from point sources as estimated by ICPR (1989). The comparison shows that the diffuse pathway of surface runoff is over-estimated according to the method of Behrendt (1993). The pathways of erosion and groundwater show relatively similar results. Our emissions from urban areas are lower for lead but higher for zinc, which caused by the differences in urban deposition rates. The highest deviation can be observed for cadmium for some of the diffuse pathways (surface runoff and groundwater).

Comparison of the total emissions in the Rhine basin for the period 1983-1987

Source	Moneris	Behrendt	Moneris	Behrendt	Moneris	Behrendt
	Cd [t/a]	Cd [t/a]	Pb [t/a]	Pb [t/a]	Zn [t/a]	Zn [t/a]
Industry	2.7	6.0	96	240	766	2010
Wastewater treatment plant	2.4		165		1469	
Atmospheric deposition	1	-	30	-	149	-
Surface Runoff	0.9	3.7	12	140	149	370
Erosion	1.3	2.3	103	90	482	420
Drainage	0.3	-	3	-	45	-
Groundwater	1.3	3.2	29	60	496	530
Urban areas	7.7	7.7	183	285	1606	1395
Total emissions (excl. Netherlands)	17.6	22.9	622	815	5161	4725

3.4b Comparison of results (emission analysis) with ICPR (1999)

The results from MONERIS for the period 1993-1997 were compared to the emissions estimates of the year 1996 reported by International Rhine Commission (1999). First, a remark should be made on the emission estimates of the ICPR, since the total emissions for the heavy metals are generally lower than the observed loads measured at Lobith (see appendices 2.2b-c). This already indicates that the emissions estimated by the ICPR are under-estimated.

In the table below the total emissions per sector upstream of Lobith are shown. The emissions from wastewater treatment plants according to MONERIS are for all heavy metals higher than the estimates from the ICPR (about 200%). For emissions from surface runoff MONERIS also gives higher estimates. Emissions from drainage are lower than the estimates from the ICPR, which is caused by the fact that the ICPR used very high heavy metal concentrations for the drained water. The emissions from urban areas from MONERIS are relatively comparable to those given by the ICPR. The emissions from erosion are also higher compared to the estimates from the ICPR. This is mainly caused by the fact that the estimates of the ICPR do not contain an enrichment of heavy metals in the finer sediments. Another distinction is the fact that the ICPR does not estimate emissions from groundwater. The total emissons of MONERIS are therefore higher than the total emissions of the ICPR (127% for cadmium to 279 % for mercury).

Comparison of the total emissions in the Rhine basin for the period 1993-1997

Source	Mon.	ICPR	Mon.	ICPR	Mon.	ICPR	Mon.	ICPR	Mon.	ICPR
	Cd [t/a]	Cd [t/a]	Cu [t/a]	Cu [t/a]	Hg [t/a]	Hg t/a]	Pb [t/a]	Pb [t/a]	Zn [t/a]	Zn [t/a]
Industry	<0.7	<0.54	38.7	38.7	0.2	<0.3	19	<19.1	127	127
Wastewater treatment plant	1.4	<0.78	105.4	<56.5	0.9	<0.31	59	<31.4	515	445
Atmospheric deposition	0.6	0.34	9.0	5.4	0.1	0.04	12	6.9	75	43
Surface Runoff	0.7	0.05	53.9	3	0.3	0.01	10	0.5	151	10
Erosion	1.3	0.31	76.7	20.68	0.7	0.1	93	27.9	462	62
Drainage	0.3	1.4	11.8	10.5	0.1	0.04	3	10.5	45	140
Groundwater	1.2	-	102.0	-	0.5	-	25	-	463	-
Urban areas	2.2	2.99	85.4	92.9	1.1	0.64	47	86.4	522	412
Total emissions (excl. Netherlands)	8.2	<6.44	482.9	<232	3.9	<1.4	269	<184	2361	1256

3.4c Comparison of results (emission analysis) with Fuchs & Scherer (1999)

The results from MONERIS for the period 1993-1997 can also be compared to the emissions estimates reported by Fuchs and Scherer (preliminary results, 1999). Fuchs and Scherer also used MONERIS to estimate heavy metal emissons in the German Rhine basin. The emissions from wastewater treatment plants were calculated with heavy metal concentrations in effluents. In the table below the total German emissions per sector upstream of Lobith are shown. The emissions from wastewater treatment plants differ for MONERIS and the emissions as estimated by Fuchs. This caused by the different methods both studies used in estimating the emissions from wastewater treatment plants. The variation in between the emissions from surface runoff, drainage water, and groundwater is caused by the differences in the concentrations used for drainage water, groundwater and surface runoff. The total emissions in Germany estimated with MONERIS are higher for copper, mercury, lead and zinc, but lower for cadmium. assuming the same industrial emissions, the differences in total heavy metal emissions are within 25%, which is reasonable. Only for cadmium is the difference between both studies higher.

Comparison of the total emissions in the German Rhine basin for the period 1993-1997

Source	Moneris	Fuchs	Moneris	Fuchs	Moneris	Fuchs	Moneris	Fuchs	Moneris	Fuchs
	Cd [t/a]	Cd [t/a]	Cu [t/a]	Cu [t/a]	Hg [t/a]	Hg [t/a]	Pb [t/a]	Pb [t/a]	Zn [t/a]	Zn [t/a]
Industry	0.3		26.7		0.2		15.6		47.2	
Wastewater treatment plant	1.0	1.6	75.8	67.4	0.7	1.4	36.2	18.7	314.2	338.4
Atmospheric deposition	0.2	0.2	3.7	3.7	0.0	0.0	4.9	4.9	30.9	30.9
Surface Runoff	0.3	0.4	23.9	6.6	0.2	0.0	4.6	8.3	75.0	64.1
Erosion	0.7	0.5	45.7	73.7	0.4	0.2	53.6	33.1	242.1	172.2
Drainage	0.2	0.4	7.6	7.6	0.1	0.1	2.1	2.1	27.9	86.1
Groundwater	0.8	0.3	63.1	15.4	0.3	0.3	15.4	6.1	286.4	30.7
Urban areas	1.7	3.3	66.2	64.8	0.8	0.4	37.3	39.8	402.8	328.9
Total emissions in Germany	5.4	7.1	312.8	239.1	2.7	2.5	169.7	113.1	1426.6	1051.2

Chapter 4: Trends in the quality of suspended particulate matter in the Rhine and link to the quality of dredged material in Rotterdam

4.4.2a Comparison of results from diffuse contributions to the heavy metal load for several stations of the River Rhine over the period 1983-1987

River	Station	Cd		Cu		Hg		Pb		Zn	
		Diffuse % MON*	Diffuse % IM*	Diffuse % MON*	Diffuse % IM*	Diffuse % MON*	Diffuse % IM*	Diffuse % MON*	Diffuse % IM*	Diffuse % MON*	Diffuse % IM*
Rhein	Weisweil	78	92	68	93	66	78	71	87	66	91
Rhein	Karlsruhe	71	92	58	92	65	72	65	93	57	91
Rhein	Lauter-bourg	62	91	63	89	64	91	65	89	61	76
Neckar	Mannheim	77	36	68	69	70	68	61	68	60	61
Rhein	Mainz	74	58	62	71	68	87	66	68	59	49
Mosel	Palzem	62	32	48	97	60	97	50	97	49	97
Mosel	Koblenz	66	92	52	90	64	91	53	88	53	90
Rhein	Bad Honnef	73	71	55	86	68		62	85	59	86
Rhein	Koblenz	75	88	63	84	68	83	66	81	60	87
Rhein	Lobith-Bimmen	71	73	59	82	66	86	58	75	57	80

4.4.2b Comparison of results from diffuse contributions to the heavy metal load for several stations of the River Rhine over the period 1993-1997

River	Station	Cd		Cu		Hg		Pb		Zn	
		Diffuse % MON*	Diffuse % IM*	Diffuse % MON*	Diffuse % IM*	Diffuse % MON*	Diffuse % IM*	Diffuse % MON*	Diffuse % IM*	Diffuse % MON*	Diffuse % IM*
Rhein	Reckingen	84	88	81	89	80		83	86	83	89
Rhein	Weisweil	80	91	77	91	75	90	79	89	79	91
Rhein	Karlsruhe	76	86	70	92	71	92	76	90	73	92
Rhein	Lauterbourg	77	78	72	89	70	89	76	90	75	92
Neckar	Mann-heim	83	68	81	68	80	71	76	61	76	66
Main	Bischofsheim	87	80	85	79	83	76	84	79	79	75
Rhein	Mainz	79	88	74	86	75	84	78	85	74	82
Mosel	Palzem	55	95	51	96	46	97	54	97	56	92
Mosel	Koblenz	57	90	55	90	52	92	57	90	60	92
Rhein	Bad Honnef	75	88	71	89	70	88	74	87	72	88
Rhein	Koblenz	79	82	75	86	75	78	77	82	74	86
Rhein	Duesseldorf	75	86	70	85	69	85	73	85	71	85
Rhein	Lobith-Bimmen	76	83	70	74	70	61	71	77	73	79

MON* means results from MONERIS
IM* means results from immission method

Appendices 4.4.2a-b show that for most stations along the Rhine the differences in both methods is less than 20% which is acceptable considering the uncertainties in both methods.