TEXTE 23/00

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Nutrient Emissions into River Basins of Germany

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Summary

The model **MONERIS** (**MO**delling **N**utrient **E**missions in **RI**ver **S**ystems) was developed and applied to estimate the nutrient inputs into river basins of Germany by point sources and various diffuse pathways. The model is based on data of river flow and water quality as well as a geographical information system (GIS), which includes digital maps and extensive statistical information.

Whereas point emissions from waste water treatment plants and industrial sources are directly discharged into the rivers, diffuse emissions into surface waters are caused by the sum of different pathways, which are realised by separate flow components (see Figure 1). This separation of the components of diffuse sources is necessary, because nutrient concentrations and relevant processes for the pathways are mostly very different.

Consequently seven pathways are considered:

- point sources
- atmospheric deposition
- erosion
- surface runoff
- groundwater
- tile drainage
- paved urban areas

Along the pathway from the source of the emission into the river substances are governed by manifold processes of trans-formation, retention and loss. Knowledge of these processes of transformation and retention is necessary to quantify and to predict nutrient emissions into the rivers in relation to their sources.

Since current knowledge of the processes and the up to now limited database especially for river basins of medium and large size, the description of the processes can not be done by detailed dynamic models.

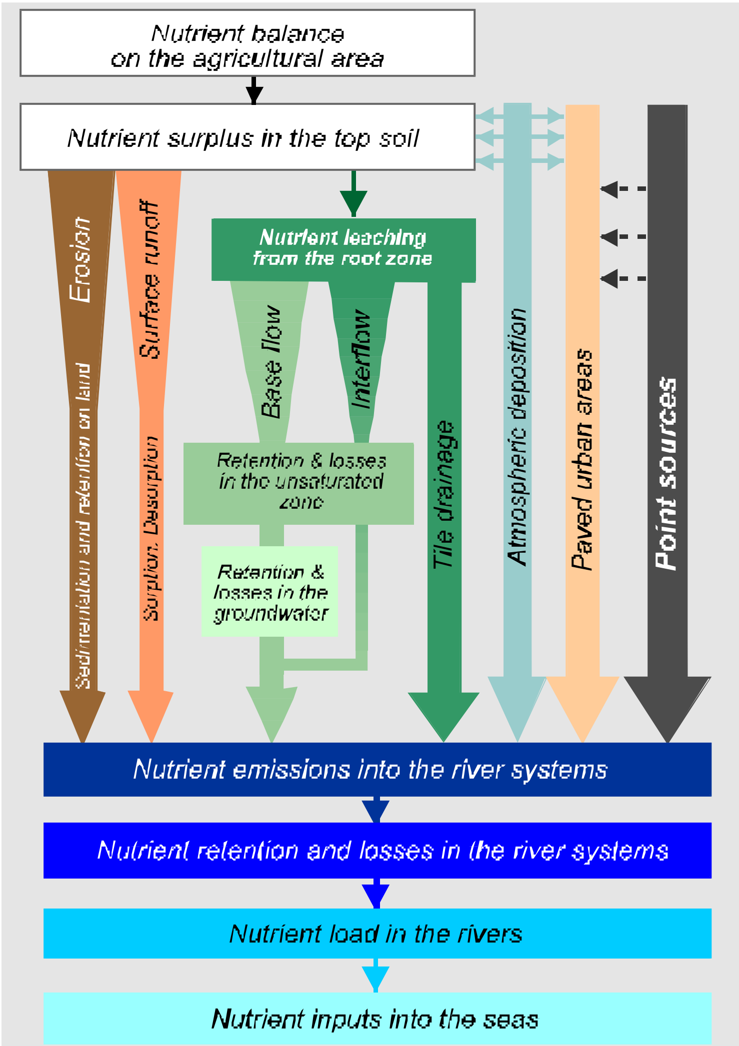

Figure 1: Pathways and processes within MONERIS.

Therefore, MONERIS estimates the different pathways with already existing and new conceptual approaches, which are developed especially for the modelling in the medium and large spatial scale. Topics of the model development were:

- to develop a GIS-supported method for regional differentiated estimation of diffuse and point emissions for river basins of a size of more than 500 km²,
- to establish a submodel for regionally differentiated estimation of nutrient discharges from waste water treatment plants by a countrywide detailed inventory of these waste water treatment plants,
- to establish a submodel for inputs of nutrients and suspended solids caused by erosion, which can be applied to all investigated river basins. This model is based on the modified uniform soil loss equation but considers only those areas, which are relevant for a input into the river system. The submodel was validated with observed loads of suspended solids and particulate phosphorus for river basins,
- to develop a submodel which allows the estimation of groundwater concentrations of nitrogen from the nitrogen surplus in agricultural areas by means of a retention function. This retention function is dependent on the hydrogeological conditions, the rate of groundwater recharge and the nitrogen surplus itself. The retention model includes first raw estimates of the residence time of water within the unsaturated zone and aquifer of the river basins,
- to develop a GIS-supported submodel for regionally differentiated estimation of the agricultural areas modified by tile drainage. The submodel is based on soil types and a classification of soil water conditions and is validated by overlaying digitised maps of tile drained areas with a soil map,
- to establish a submodel for different pathways of nutrient emissions within urban areas considering the regional differences in the sewer systems and the development of storage volume especially for combined sewer systems and
- to establish a submodel for nutrient retention and losses in surface waters, which can be applied for all river basins. This model is based on the dependency of the nutrient retention on the hydraulic load or the specific runoff in the river system. The model allows the estimation of the nutrient loads from the nutrient inputs in a river basins. Therefore, a direct comparison of calculated and observed nutrient loads is possible for river basins upstream of a monitoring station.

One special topic of the model development was that the different submodels were be validated by using independent data sets, for example the groundwater model was developed with the observed nitrogen concentrations in the groundwater and not on the base of the observed nutrient loads in the rivers.

The use of a GIS allows a regional differentiated quantification of nutrient emissions into river systems. Therefore, estimates were not only carried out for large river basins. Altogether the MONERIS model was applied to 300 different river basins for the two time periods 1983-1987 and 1993-1997. The temporal changes of nutrient emissions were calculated for the different hydrological conditions in both periods as well as under the assumption of identical hydrological conditions in order to estimate the changes caused by human factors.

The results of the calculations of the nutrient emissions into the German parts of the largest river basins Danube, Elbe, Rhine and Weser as well as for the German parts of the catchments of North Sea, Baltic Sea and Black Sea and all of Germany are presented in Tables 1 to 4 and Figures 2 to 5.

Nitrogen emissions into the river basins of Germany were about 819 kt N/a in the period 1993-1997 and thus 266 kt N/a, or 25% lower than in the period 1983-1987. This means that the target of the 50% reduction of nitrogen loads from Germany into the North Sea and the Baltic Sea could not be achieved. The main cause for the decrease of the nitrogen emissions into the river systems was the large reduction of nitrogen discharges from point sources by 46%. On the other hand the estimated decrease of diffuse emissions was only about 10%. The input via groundwater is with 48% the dominant pathway in the period 1993-1997. The share of point sources in nitrogen emissions amounts to about 28%. The contributions of erosion, surface runoff and atmospheric deposition to the total nitrogen input are low and amount to about 2% only for each of these pathways.

The total phosphorus emissions into the German river basins were about 37 kt P/a in the period 1993-1997. Compared with the period 1983-1987, the phosphorus emissions were reduced by about 57 kt P/a or 60%. The target of a 50% reduction of the phosphorus loads into the seas was reached. Again the decrease of phosphorus emissions is mainly caused by a 80% reduction of point sources. The decrease of diffuse phosphorus emissions was larger than for nitrogen, which is caused by a 56% reduction of the emissions from urban areas. In spite of the enormous reduction of phosphorus discharges from point sources these sources remain the dominant pathway of phosphorus emissions with 34% in the period 1993-1997. Among the diffuse pathways, emissions by erosion dominate and represent 22% of the total input.

Amongst the individual river catchments and also the basins of North Sea, Baltic Sea and Black Sea the nutrient inputs as well as the shares in the various nutrient input pathways vary to a relatively large extent as shown in Tables 1 to 4 and Figures 2 to 5.

In spite of the substantial decrease of the nitrogen surplus in agricultural areas a slight reduction of the nitrogen emissions to the groundwater based upon identical hydrological conditions can only be estimated for the Rhine basin. For the other river basins, one has to assume that nitrogen inputs via this pathway will still increase during the nineties due to the long residence times of water in the unsaturated zone and in the aquifer. Only after the year 2000 the reduced nitrogen surplus will be followed by a slow reduction of the nitrogen concentrations in the groundwater and thus of total nitrogen inputs via this pathway.

Inputs to those parts of the Danube, Elbe and Rhine basins outside of Germany amounted to a total of 231 kt N/a and 16 kt P/a in the period 1993-1997. This corresponds to shares of 15% (nitrogen) and 29% (phosphorus) for the Danube basin upstream of Jochenstein. For the Elbe basin upstream Zollenspieker the shares in nutrient emissions originating outside of Germany were 37% for nitrogen and 43% for phosphorus. In the Rhine basin upstream of Lobith 30% of the nitrogen emissions and 41% of the phosphorus emissions originated from those parts of the basin that are outside of Germany.

The nutrient loads, which were calculated from the measured flow and nutrient concentrations, show similar changes as the nutrient emissions for the periods 1983-1987 and 1993-1997 for the investigated river basins.

The nutrient inputs estimated with MONERIS compare well with the results of other authors as well as with the results of other methods of source apportionment. The deviation between the estimated diffuse nutrient emissions are in a range of 30%.

The nutrient loads of the individual river catchments were calculated from the nutrient emissions accounting the retention and loss processes within the river systems of the catchments for the two periods. These calculated loads were compared with the load estimates based on the measured flow and nutrient concentrations in both time periods. The comparison shows that for nitrogen the deviation between the calculated and observed loads is for 148 of 168 river basins lower than 30%. Only for 13 basins, usually smaller basins with low loads of dissolved inorganic nitrogen, the deviation is larger than 40%.

For phosphorus, in general, the deviation between the calculated and observed load is slightly larger than for nitrogen. But the tendency is the same that the deviation is increasing with the decrease of the size of the basins and the phosphorus load. This phenomenon can be caused by larger errors in the estimates of nutrient emissions and in the “measured” loads for smaller basins.

The calculation of different scenarios shows that the target of a 50% reduction of the nitrogen load into the seas can not be reached by measures focused on the decrease of the nitrogen emissions from point and diffuse sources alone. Additional measures aimed at an increased retention and losses of nitrogen near by or within the surface waters of a river system (e. g. buffer strips, establishing renaturalization of wetlands, small reservoirs) are necessary.

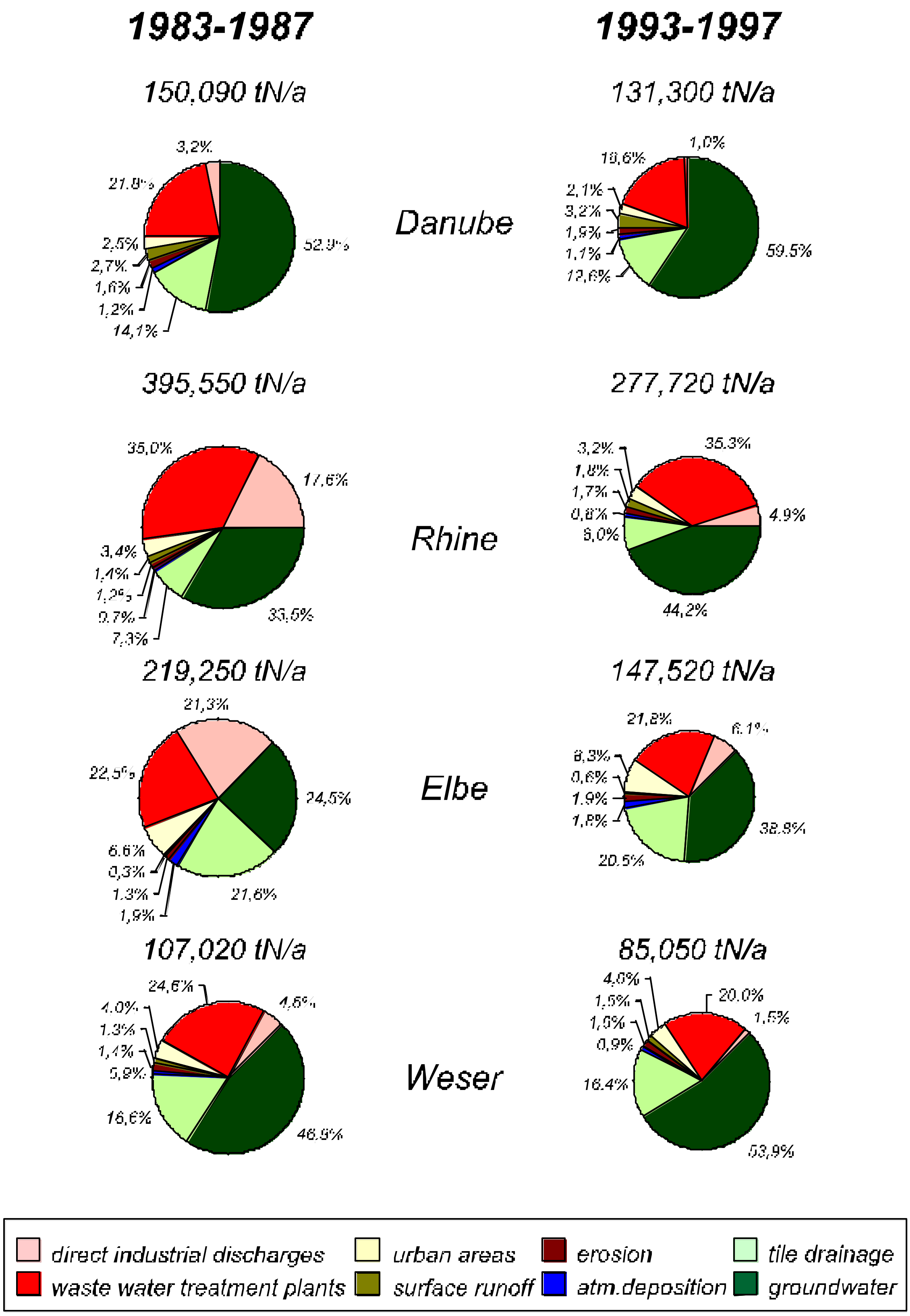

Figure 2: Nitrogen inputs via the various pathways into German river basins in the time periods 1983-1987 and 1993-1997.

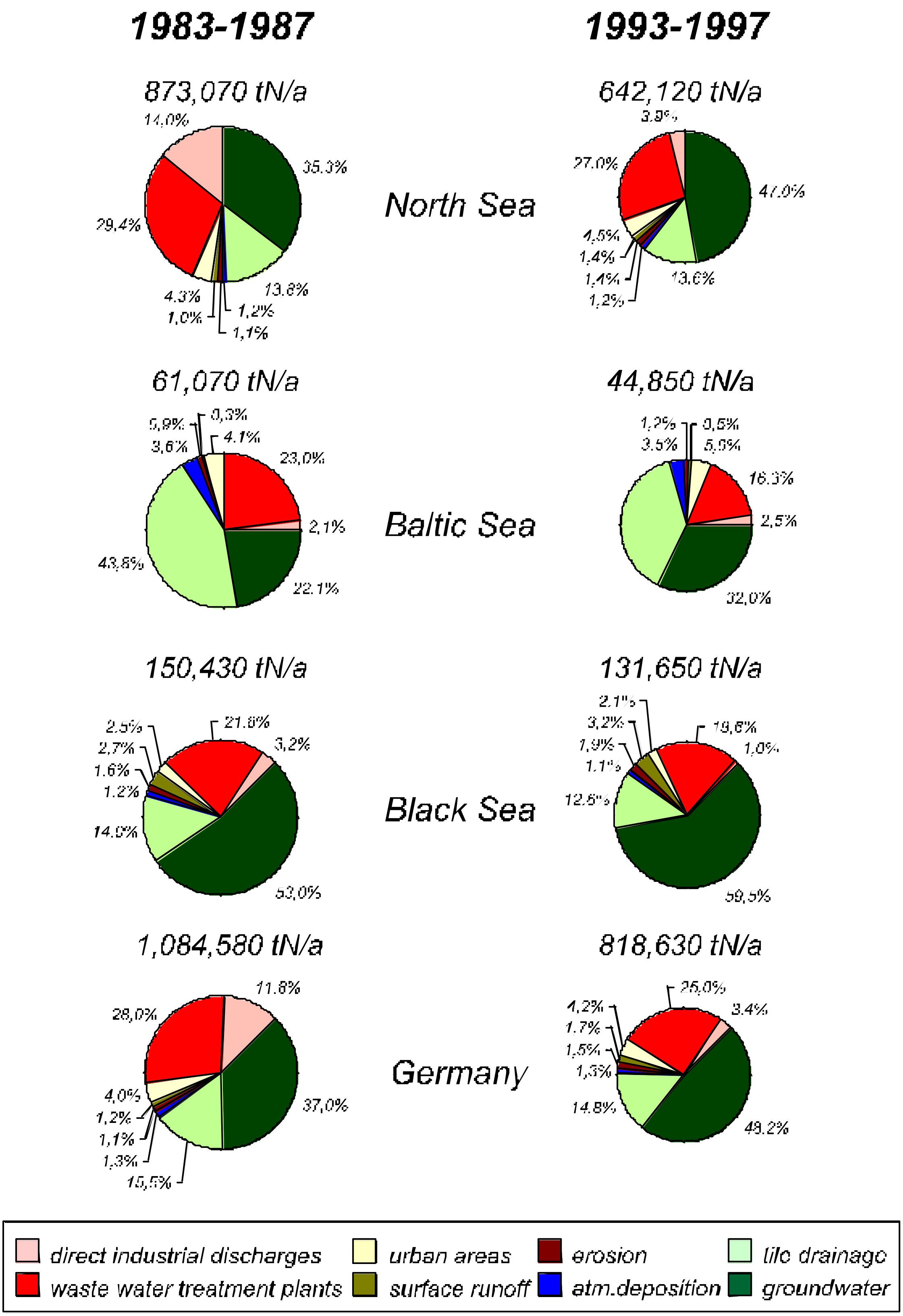

Figure 3: Nitrogen inputs via the various pathways into German catchments of North Sea, Baltic Sea, Black Sea and for all of Germany in the time periods 1983-1987 and 1993-1997.

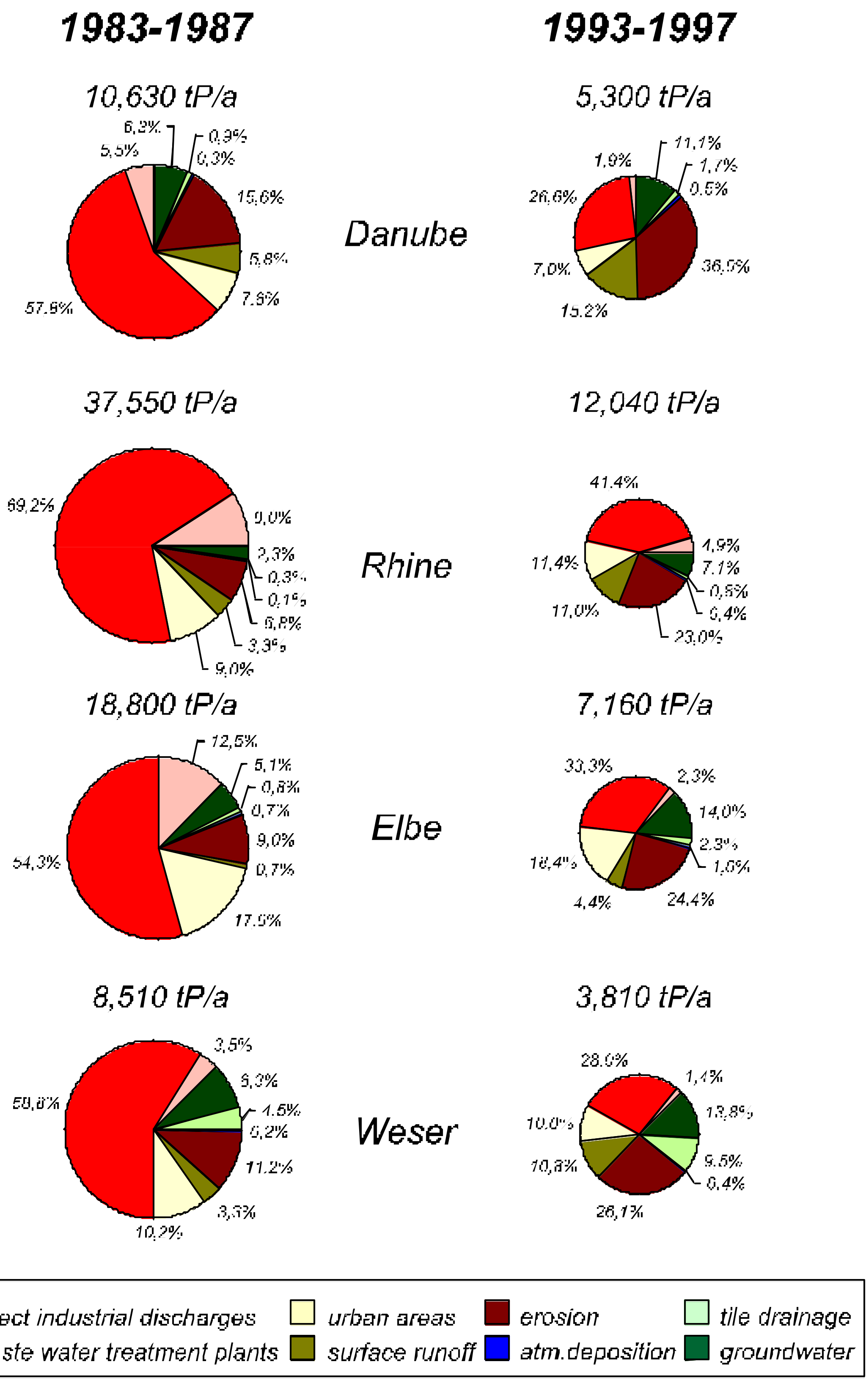

Figure 4: Phosphorus inputs via the various pathways into German river basins in the time periods 1983-1987 and 1993-1997.

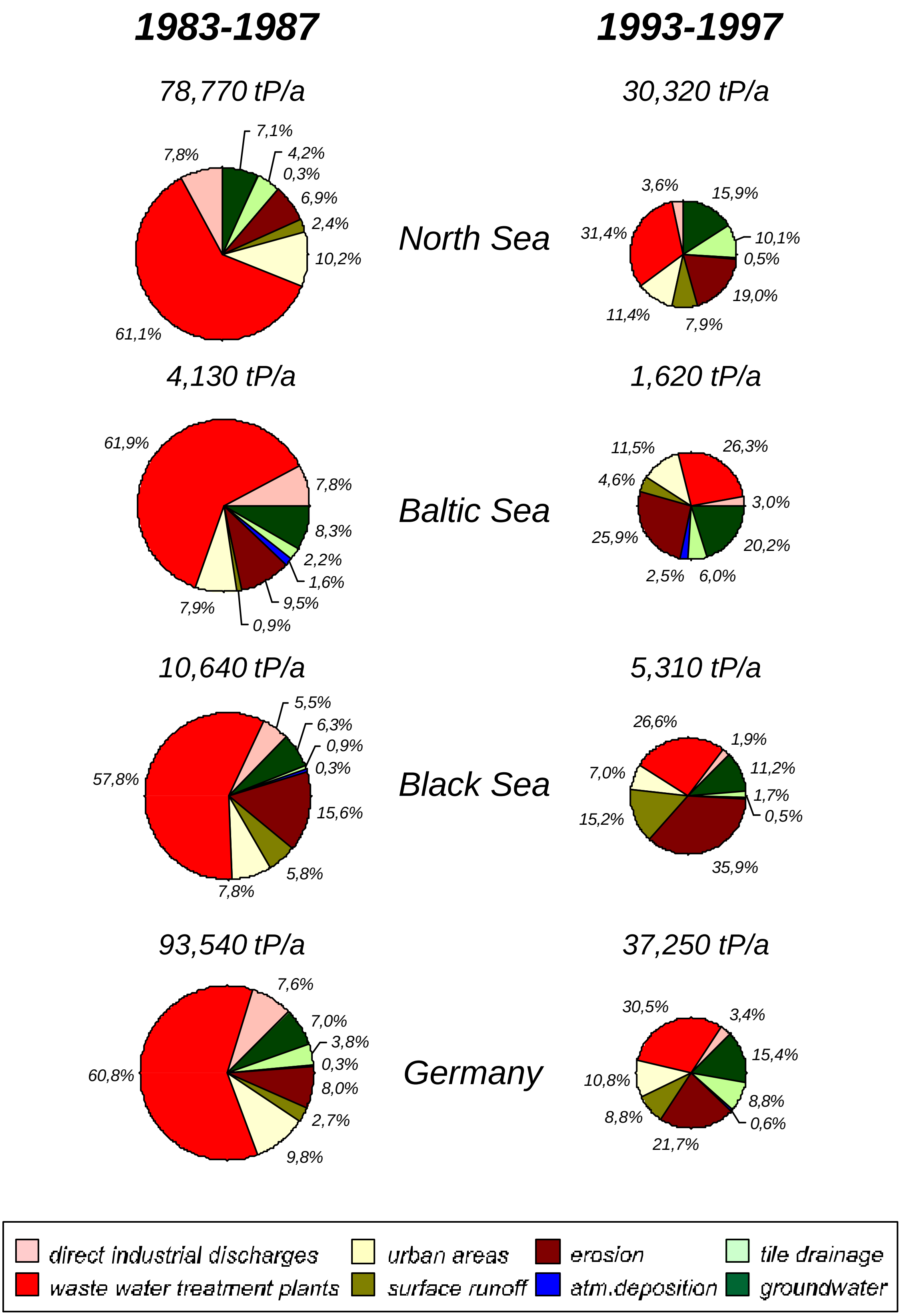

Figure 5: Phosphorus inputs via the various pathways into German catchments of North Sea, Baltic Sea, Black Sea and for all of Germany in the time periods 1983-1987 and 1993-1997.

Table 1: Nitrogen inputs via various pathways, their contributions to the total input and their changes for the German parts of the Elbe, Rhine and Danube basins and the Weser for the periods 1983-1987 and 1993-1997.

Pathway		Elbe			Weser			Rhine			Danube		
		1983-87	1993-97	Change	1983-87	1993-97	Change	1983-87	1993-97	Change	1983-87	1993-97	Change
Groundwater	[t N/a]	53,760	57,270	*+6.5%*	50,060	45,820	*-8.5%*	132,580	122,750	*-7.4%*	79,400	78,090	*-1.6%*
	[%]	24.5	38.8		46.8	53.9		33.5	44.2		52.9	59.5	
Tile drainage	[t N/a]	47,460	30,340	*-36.1%*	17,740	13,910	*-21.6%*	28,690	22,340	*-22.1%*	21,110	16,600	*-21.4%*
	[%]	21.6	20.6		16.6	16.4		7.3	8.0		14.1	12.6	
Erosion	[t N/a]	2,880	2,830	*-1.6%*	1,460	1,400	*-4.3%*	4,570	4,610	*+1.0%*	2,340	2,490	*+6.2%*
	[%]	1.3	1.9		1.4	1.6		1.2	1.7		1.6	1.9	
Surface runoff	[t N/a]	570	890	*+56.9%*	1,340	1,380	*+3.1%*	5,660	5,110	*-9.7%*	4,090	4,190	*+2.3%*
	[%]	0.3	0.6		1.3	1.6		1.4	1.8		2.7	3.2	
Atmospheric deposition	[t N/a]	4,060	2,700	*-33.3%*	960	740	*-22.5%*	2,760	2,300	*-16.8%*	1,790	1,440	*-19.8%*
	[%]	1.9	1.8		0.9	0.9		0.7	0.8		1.2	1.1	
Urban areas	[t N/a]	14,430	12,250	*-15.1%*	4,270	3,440	*-19.4%*	13,580	8,850	*-34.8%*	3,830	2,800	*-26.7%*
	[%]	6.6	8.3		4.0	4.0		3.4	3.2		2.5	2.1	
Sum diffuse sources	**[t N/a]**	**123,160**	**106,290**	***-13.7%***	**75,820**	**66,690**	***-12.0%***	**187,840**	**165,970**	***-11.6%***	**112,560**	**105,610**	***-6.2%***
	[%]	**56.2**	**72.0**		**70.8**	**78.4**		**47.5**	**59.8**		**75.0**	**80.4**	
Municipal WWTP`s	[t N/a]	49,330	32,230	*-34.7%*	26,310	17,050	*-35.2%*	138,250	98,010	*-29.1%*	32,750	24,420	*-25.4%*
	[%]	22.5	21.8		24.6	20.0		35.0	35.3		21.8	18.6	
Direct industrial discharges	[t N/a]	46,760	9,000	*-80.7%*	4,890	1,320	*-73.1%*	69,450	13,740	*-80.2%*	4,780	1,270	*-73.4%*
	[%]	21.3	6.1		4.6	1.5		17.6	4.9		3.2	1.0	
Sum point sources	**[t N/a]**	**96,090**	**41,230**	***-57.1%***	**31,200**	**18,360**	***-41.1%***	**207,700**	**111,750**	***-46.2%***	**37,530**	**25,690**	***-31.5%***
	[%]	**43.8**	**28.0**		**29.2**	**21.6**		**52.5**	**40.2**		**25.0**	**19.6**	
Sum all sources	**[t N/a]**	**219,250**	**147,520**	***-32.7%***	**107,020**	**85,050**	***-20.5%***	**395,550**	**277,720**	***-29.8%***	**150,090**	**131,300**	***-12.5%***
	[%]	**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**	

Table 2: Nitrogen inputs via various pathways, their contributions to the total input and their changes for the German parts of the North Sea, Baltic Sea and Black Sea basins and all of Germany for the periods 1983-1987 and 1993-1997.

Pathway		North Sea			Baltic Sea			Black Sea			Germany		
		1983-87	1993-97	Change	1983-87	1993-97	Change	1983-87	1993-97	Change	1983-87	1993-97	Change
Groundwater	[t N/a]	308,240	301,690	*-2.1%*	13,510	14,340	*+6.1%*	79,680	78,390	*-1.6%*	401,430	394,430	*-1.7%*
	[%]	35.3	47.0		22.1	32.0		53.0	59.5		37.0	48.2	
Tile drainage	[t N/a]	120,400	87,280	*-27.5%*	26,780	17,510	*-34.6%*	21,110	16,600	*-21.4%*	168,290	121,390	*-27.9%*
	[%]	13.8	13.6		43.8	39.0		14.0	12.6		15.5	14.8	
Erosion	[t N/a]	9,330	9,270	*-0.6%*	530	530	*+0.5%*	2,340	2,490	*+6.4%*	12,200	12,290	*+0.8%*
	[%]	1.1	1.4		0.9	1.2		1.6	1.9		1.1	1.5	
Surface runoff	[t N/a]	9,080	9,140	*+0.6%*	160	220	*+43.0%*	4,110	4,200	*+2.2%*	13,350	13,560	*+1.6%*
	[%]	1.0	1.4		0.3	0.5		2.7	3.2		1.2	1.7	
Atmospheric deposition	[t N/a]	10,040	7,510	*-25.2%*	2,210	1,560	*-29.4%*	1,790	1,440	*-19.9%*	14,050	10,510	*-25.2%*
	[%]	1.2	1.2		3.6	3.5		1.2	1.1		1.3	1.3	
Urban areas	[t N/a]	37,290	29,060	*-22.1%*	2,520	2,230	*-11.6%*	3,830	2,810	*-26.6%*	43,650	34,100	*-21.9%*
	[%]	4.3	4.5		4.1	5.0		2.5	2.1		4.0	4.2	
Sum diffuse sources	**[t N/a]**	**494,380**	**443,940**	***-10.2%***	**45,700**	**36,390**	***-20.4%***	**112,880**	**105,940**	***-6.1%***	**652,970**	**586,280**	***-10.2%***
	[%]	**56.6**	**69.1**		**74.8**	**81.1**		**75.0**	**80.5**		**60.2**	**71.6**	
Municipal WWTP`s	[t N/a]	256,460	173,110	*-32.5%*	14,070	7,320	*-48.0%*	32,770	24,440	*-25.4%*	303,300	204,860	*-32.5%*
	[%]	29.4	27.0		23.0	16.3		21.8	18.6		28.0	25.0	
Direct industrial discharges	[t N/a]	122,230	25,080	*-79.5%*	1,300	1,140	*-12.4%*	4,780	1,270	*-73.4%*	128,310	27,490	*-78.6%*
	[%]	14.0	3.9		2.1	2.5		3.2	1.0		11.8	3.4	
Sum point sources	**[t N/a]**	**378,690**	**198,180**	*-47.7%*	**15,370**	**8,460**	*-45.0%*	**37,550**	**25,710**	*-31.5%*	**431,610**	**232,350**	*-46.2%*
	[%]	**43.4**	**30.9**		**25.2**	**18.9**		**25.0**	**19.5**		**39.8**	**28.4**	
Sum all sources	**[t N/a]**	**873,070**	**642,120**	*-26.5%*	**61,070**	**44,850**	*-26.6%*	**150,430**	**131,650**	*-12.5%*	**1,084,580**	**818,630**	*-24.5%*
	[%]	**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**	

Table 3: Phosphorus inputs via various pathways, their contributions to the total input and their changes for the German parts of the Elbe, Rhine and Danube basins and the Weser for the periods 1983-1987 and 1993-1997.

Pathway		Elbe			Weser			Rhine			Danube		
		1983-87	1993-97	Change	1983-87	1993-97	Change	1983-87	1993-97	Change	1983-87	1993-97	Change
Groundwater	[t P/a]	950	1,000	*+5.3%*	710	530	*-25.6%*	880	850	*-2.7%*	670	590	*-12.1%*
	[%]	5.1	14.0		8.3	13.8		2.3	7.1		6.3	11.1	
Tile drainage	[t P/a]	140	160	*+13.3%*	380	360	*-4.9%*	100	100	*+0.9%*	100	90	*-9.2%*
	[%]	0.8	2.3		4.5	9.5		0.3	0.8		0.9	1.7	
Erosion	[t P/a]	1,680	1,740	*+3.6%*	960	1,000	*+4.0%*	2,560	2,770	*+7.8%*	1,660	1,910	*+14.8%*
	[%]	9.0	24.4		11.2	26.1		6.8	23.0		15.6	36.0	
Surface runoff	[t P/a]	120	320	*+159.5%*	280	410	*+46.5%*	1,230	1,320	*+6.9%*	620	810	*+30.8%*
	[%]	0.7	4.4		3.3	10.8		3.3	11.0		5.8	15.2	
Atmospheric deposition	[t P/a]	130	70	*-45.9%*	16	14	*-9.7%*	48	46	*-5.4%*	30	29	*-5.7%*
	[%]	0.7	1.0		0.2	0.4		0.1	0.4		0.3	0.5	
Urban areas	[t P/a]	3,200	1,320	*-58.8%*	860	380	*-55.9%*	3,390	1,380	*-59.4%*	820	370	*-55.0%*
	[%]	17.0	18.4		10.2	10.0		9.0	11.4		7.8	7.0	
Sum diffuse sources	**[t P/a]**	**6,230**	**4,620**	*-25.9%*	**3,210**	**2,690**	*-16.1%*	**8,210**	**6,460**	*-21.3%*	**3,900**	**3,790**	*-2.8%*
	[%]	**33.2**	**64.5**		**37.7**	**70.6**		**21.9**	**53.7**		**36.7**	**71.5**	
Municipal WWTP`s	[t P/a]	10,210	2,380	*-76.7%*	5,010	1,070	*-78.7%*	25,970	4,990	*-80.8%*	6,140	1,410	*-77.1%*
	[%]	54.3	33.3		58.8	28.0		69.2	41.4		57.8	26.6	
Direct industrial discharges	[t P/a]	2,350	160	*-93.1%*	300	50	*-81.6%*	3,370	590	*-82.4%*	580	100	*-82.7%*
	[%]	12.5	2.3		3.5	1.4		9.0	4.9		5.5	1.9	
Sum point sources	**[t P/a]**	**12,560**	**2,540**	*-79.7%*	**5,300**	**1,120**	*-78.9%*	**29,340**	**5,580**	*-81.0%*	**6,720**	**1,510**	*-77.5%*
	[%]	**66.8**	**35.5**		**62.3**	**29.4**		**78.1**	**46.3**		**63.3**	**28.5**	
Sum all sources	**[t P/a]**	**18,800**	**7,160**	*-61.9%*	**8,510**	**3,810**	*-55.2%*	**37,550**	**12,040**	*-67.9%*	**10,630**	**5,300**	*-50.1%*
	[%]	**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**	

Table 4: Phosphorus inputs via various pathways, their contributions to the total input and their changes for the German parts of the North Sea, Baltic Sea and Black Sea basins and all of Germany for the periods 1983-1987 and 1993-1997.

Pathway		North Sea			Baltic Sea			Black Sea			Germany		
		1983-87	1993-97	Change	1983-87	1993-97	Change	1983-87	1993-97	Change	1983-87	1993-97	Change
Groundwater	[t P/a]	5,560	4,820	*-13.3%*	340	330	*-4.0%*	680	590	*-12.1%*	6,580	5,740	*-12.7%*
	[%]	7.1	15.9		8.3	20.2		6.3	11.2		7.0	15.4	
Tile drainage	[t P/a]	3,320	3,070	*-7.4%*	90	100	*+5.7%*	100	90	*-9.2%*	3,510	3,260	*-7.1%*
	[%]	4.2	10.1		2.2	6.0		0.9	1.7		3.8	8.8	
Erosion	[t P/a]	5,440	5,770	*+6.1%*	390	420	*+7.5%*	1,660	1,910	*+14.9%*	7,490	8,100	*+8.1%*
	[%]	6.9	19.0		9.5	25.9		15.6	35.9		8.0	21.7	
Surface runoff	[t P/a]	1,870	2,400	*+28.8%*	35	70	*+111.0%*	620	810	*+30.8%*	2,520	3,290	*+30.4%*
	[%]	2.4	7.9		0.9	4.6		5.8	15.2		2.7	8.8	
Atmospheric deposition	[t P/a]	230	160	*-29.4%*	70	41	*-39.3%*	30	29	*-5.7%*	330	230	*-29.2%*
	[%]	0.3	0.5		1.6	2.5		0.3	0.5		0.3	0.6	
Urban areas	[t P/a]	8,040	3,460	*-56.9%*	330	190	*-42.9%*	830	370	*-55.0%*	9,190	4,020	*-56.3%*
	[%]	10.2	11.4		7.9	11.5		7.8	7.0		9.8	10.8	
Sum diffuse sources	**[t P/a]**	**24,450**	**19,700**	***-19.5%***	**1,250**	**1,150**	***-8.5%***	**3,910**	**3,800**	***-2.8%***	**29,620**	**24,640**	***-16.8%***
	[%]	**31.0**	**65.0**		**30.4**	**70.7**		**36.7**	**71.5**		**31.7**	**66.2**	
Municipal WWTP`s	[t P/a]	48,150	9,520	*-80.2%*	2,550	430	*-83.3%*	6,150	1,410	*-77.0%*	56,850	11,350	*-80.0%*
	[%]	61.1	31.4		61.9	26.3		57.8	26.6		60.8	30.5	
Direct industrial discharges	[t P/a]	6,160	1,100	*-82.1%*	320	48	*-85.0%*	580	100	*-82.7%*	7,070	1,250	*-82.3%*
	[%]	7.8	3.6		7.8	3.0		5.5	1.9		7.6	3.4	
Sum point sources	**[t P/a]**	**54,310**	**10,620**	***-80.4%***	**2,880**	**470**	***-83.5%***	**6,730**	**1,510**	***-77.5%***	**63,920**	**12,610**	***-80.3%***
	[%]	**69.0**	**35.0**		**69.6**	**29.3**		**63.3**	**28.5**		**68.3**	**33.8**	
Sum all sources	**[t P/a]**	**78,770**	**30,320**	***-61.5%***	**4,130**	**1,620**	***-60.7%***	**10,640**	**5,310**	***-50.1%***	**93,540**	**37,250**	***-60.2%***
	[%]	**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**	