ANEXO 6

Influent loads – observed trends at large wastewater treatment plants in Sweden

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Abstract

Data has been collected from five large municipal wastewater treatment plants (WWTPs) in Sweden and one in Finland in order to observe the trend over time of the nitrogen, phosphorus and the organic material load in influent wastewater. The influent load has been related to the number of actual connected physical persons, i.e. not population equivalents. The nitrogen load per connected person has increased at all the WWTPs. Comparative studies of household wastewater have been made over time at Rya WWTP in Gothenburg. These indicate that the increase in nitrogen is caused by the population and not by industries. The increase per capita can be explained by a change in food preferences, i.e. because of an increased meat consumption during the last decades. If the meat consumption will increase further, it will mean increasing costs for the WWTPs and increased greenhouse gas emissions globally. The phosphorous load and the BOD load have decreased.

Keywords

BOD, meat consumption, nitrogen, phosphorus, wastewater

Introduction

The nitrogen load to Rya Wastewater Treatment Plant (WWTP) in Gothenburg has increased more than can be explained by the increased population in its catchment area. At the same time, nitrogen discharge limits will soon become more stringent for Swedish WWTPs (Naturvårdsverket, 2012). A comparison with five large WWTPs in Sweden has been made in order to observe if the trend are similar at other plants.

One important factor that affects the nitrogen load is the connected persons' food preferences, or more precisely the protein consumption. In Sweden, the protein in purchased food has increased from 87 to 110 gram person^{-1} d^{-1} from 1980 to 2011, which is an increase of 27% (Jordbruksverket, 2013a). Proteins contain about 16% nitrogen, thus, during the same period; the nitrogen in the purchased food has increased from about 14 to 18 g person^{-1} d^{-1}.

An increased nitrogen load will have an impact on treatment costs. In this study the trends of nitrogen, phosphorus and BOD loads to five large WWTPs in Sweden (194,000-765,000 population equivalents (pe) (1 pe = 70 g BOD_7 person^{-1} d^{-1})) are compared in order to determine if the trend of increased nitrogen load is a local phenomenon or a general trend. The loads has been related to the unit physical connected persons rather than pe since the amount of BOD per person fluctuates significantly according to the results in this study.

Method

Data from 1992-2012 has been collected from five large WWTPs in Sweden in order to observe the trend over time of the nitrogen, phosphorus and the organic material load in the influent. Comparative studies of household wastewater have been made over time in parts of the catchment area of Rya WWTP. These studies have been used to see if the increase of nitrogen is caused by the population or for example the connected industries. Statistics from Jordbruksverket (the Swedish Board of Agriculture) and Livsmedelsverket (the Swedish National Food Agency) have been used to correlate the nitrogen load to the food preferences in Sweden.

Results and discussion

The nitrogen load to Rya WWTP has gradually increased from 12-13 g N person^{-1} d^{-1} to 14 g N person^{-1} d^{-1} (Figure 1). The studies of household wastewater indicate that the increase in nitrogen is caused by the population and not by industries. In two housing areas in Gothenburg, extensive sampling and analysis of the wastewater has been carried out 1988 and 2006 (DGE Mark & Miljö, 2010). The number of persons living in these two areas has been almost the same during the sampling periods, 3091 persons in 1988 and 3041 persons in 2006. According to these studies, each connected person contributed with 9 g N person^{-1} d^{-1} in 1988, and had increased to 11 g N person^{-1} d^{-1} in 2006. This load is only from households; hence, the persons will also contribute when they are at work, in school etc. A comparison has also been made with the caffeine in the household wastewater. In 2006, 75% of the caffeine came from the households (Paxéus, 2011). If the share of nitrogen which is excreted at home is the same as the share of caffeine, this implies that the total nitrogen contribution from sanitary wastewater to Gryaab has increased from 11 to 14 g N person^{-1} d^{-1} between 1988 and 2006 (Figure 1).

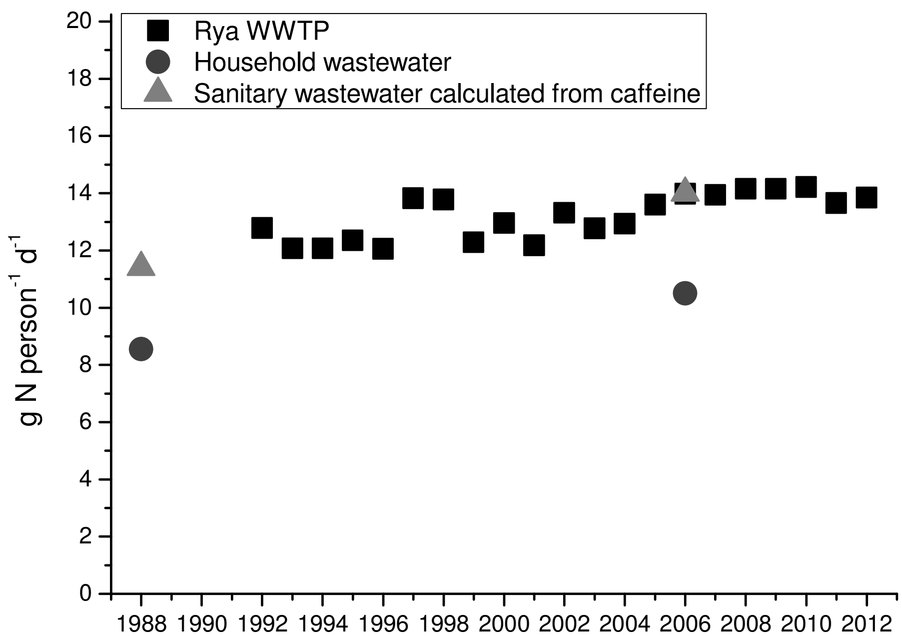

Figure 1. Nitrogen in the influent wastewater at Rya WWTP compared to nitrogen from households and the total load of sanitary wastewater.

Nitrogen

In Figure 2, a diagram shows an increasing trend of the median of the influent nitrogen load to the five WWTPs, from 1992 to 2012, see also Appendix I. The load has on average increased from 12-13 g N person^{-1} d^{-1} in the beginning of the period to 14 g N person^{-1} d^{-1} in the later years. Despite large variations between the WWTPs each year, the trend is increasing nitrogen loads. A similar trend can be seen at Viikinmäki WWTP in Finland (data not shown). Short term variations such as wet-weather conditions in combined sewer systems could affect the load. Increased nitrogen load per connected person will mean increased energy demand for wastewater treatment and hence increasing operational costs. If the capacities of the WWTPs are exceeded it will also mean larger discharge of nitrogen to the receiving waters.

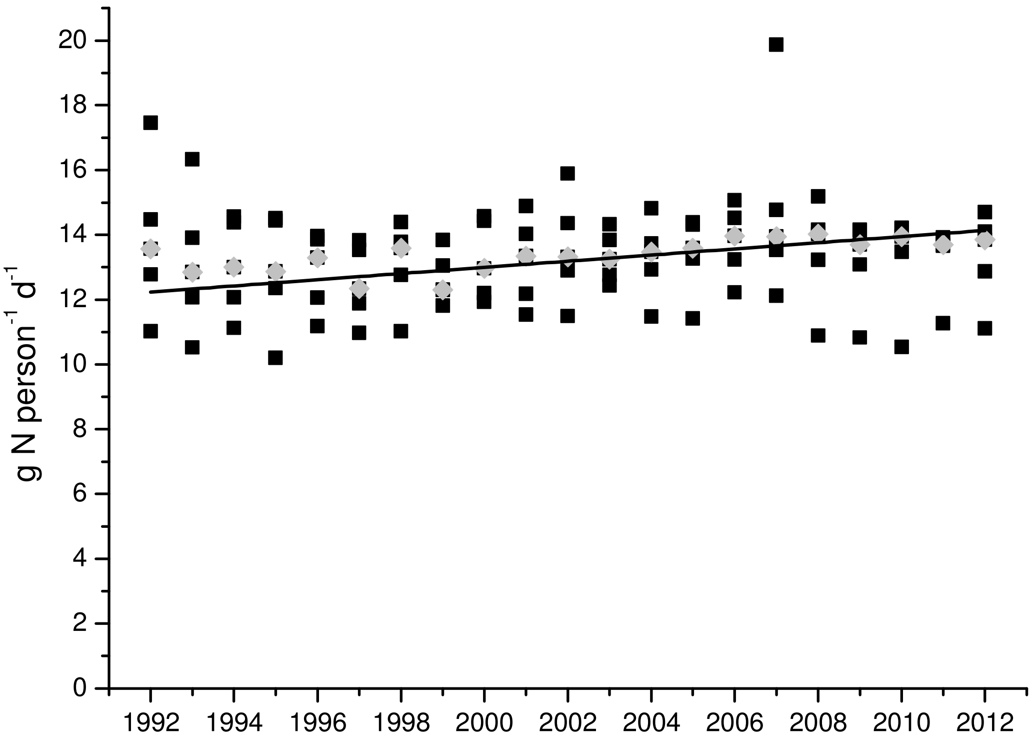

Figure 2. Influent nitrogen load to the five WWTPs. The black squares indicate the values each year for the five WWTPs, the grey diamonds indicate the median value for the five plants. The black line shows the linear fit to the median values.

The protein in purchased food has increased a lot during the last decades in Sweden (Table 1).Unfortunately not all purchased food is consumed, and not all of the nitrogen from food will end up in the sewage. There have been a number of dietary surveys in Sweden where the participants keep diaries of their actual food intake each day. These investigations have been conducted by Livsmedelsverket in 1989, 1997-98 and 2010-11 and show increased protein consumption similar to the statistics of purchased food (Livsmedelsverket 1990, 1999 & 2012). The protein intake in the most recent study was 72 g d^{-1} for women and 92 g d^{-1} for men. This is lower than in the statistics from Jordbruksverket, which is a result of the two different methods, the former is based on purchased food and the latter is based on actually consumed food (Table 1). The gap can probably be explained by the waste of eatable food in the households.

Table 1. Differences between the surveys at Jordbruksverket and Livsmedelsverket

	Jordbruksverket – *purchased* food		Livsmedelsverket- *consumed* food	
	Protein, g person^{-1} d^{-1}	Nitrogen, g person^{-1} d^{-1}	Protein, g person^{-1} d^{-1}	Nitrogen, g person^{-1} d^{-1}
1980	87	13.9		
1989	-	-	74.5	11.9
1990	89			
1995	89	14.2		
1998	-	-	81.2	13.0
2000	97	15.5		
2005	102	16.3		
2009	110	17.6		
2010	112	17.9		
2011	110	17.6	80.6	12.9

Of the total energy intake, the proportion of protein has increased during 1989-2011 from 14.6 to 17.0% of the energy (E%) for men and from 14.7 to 16.8 E% for women (Livsmedelsverket, 2012). The share of protein has increased at the expense of the share of fat, while the share of carbohydrates has remained stable (Livsmedelsverket, 2012).

The increasing nitrogen load at the five WWTPs together with the statistics from Jordbruksverket and Livsmedelsverket is shown in Figure 3.

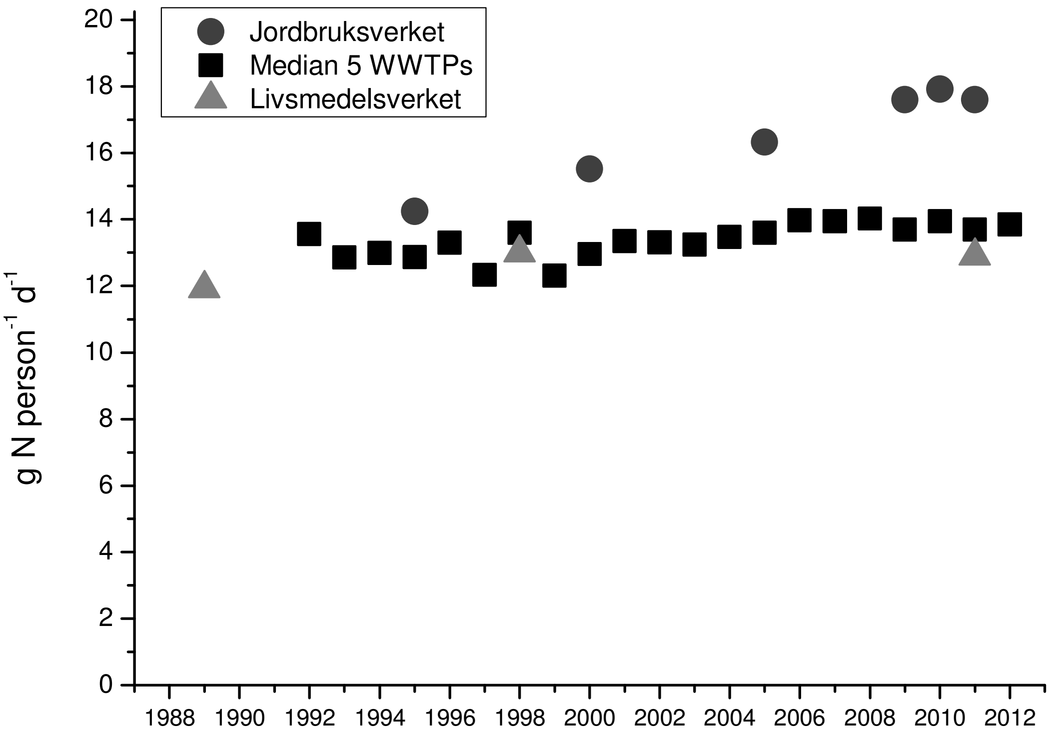

Figure 3. Both the investigation from Livsmedelsverket (triangles) and the one from Jordbruksverket (circles) show an increasing trend of the nitrogen in purchased and consumed food.

The largest source of protein is meat and the total meat consumption in Sweden has increased with 36% during 1980-2011 to 87 kg person^{-1} year^{-1} (Jordbruksverket, 2013a). The supply of protein which originates from meat has increased from 23 to 35 g person^{-1} day^{-1} during 1980-2011, an increase of 52%.

One explanation to the increased meat consumption might be the low price. During 1990-2006 the prices on meat decreased by 12% while the prices for other food increased by 5% (Jordbruksverket, 2013b). Internationally, Swedish people eat a lot of meat but only half as much as in USA and New Zeeland (FAO, 2013) (Figure 4).

Another, presumably worse aspect of the increased meat consumption is the increase of global warming, since meat production accounts for 18-25% of the world's greenhouse gas emissions, which is more than global transports (UNEP 2009; Fiala 2008; Steinfeld *et al*. 2006). According to Steinfeld *et al*. 2006 the livestock production in the world accounts for over 8% of global freshwater use and is among the largest sources of water pollution leading to eutrophication, coral reef degradation, human health issues, antibiotic resistance and disruption of nutrient cycling. What a person chooses to eat makes a difference; reducing meat consumption could bring a range of environmental benefits (Marlow *et al.* 2009).

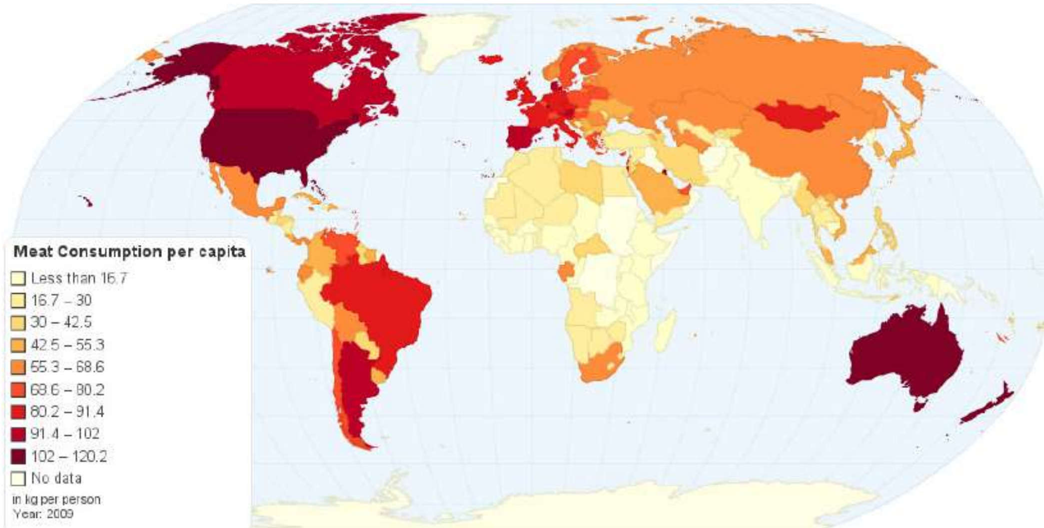

Figure 4. Current worldwide annual meat consumption per capita, based on data from 2009 (ChartsBin, 2013).

Phosphorous and BOD

The phosphorous load to the WWTPs has decreased (Figure 5). This was expected since the use of phosphates in household products has been regulated in Sweden. In March 2008 the use of phosphates in detergents for clothes was forbidden and in July 2011 the use of phosphates in detergents for dishwashers was prohibited (Regeringskansliet, 2013). The BOD load to the WWTPs is also decreasing (Figure 6).

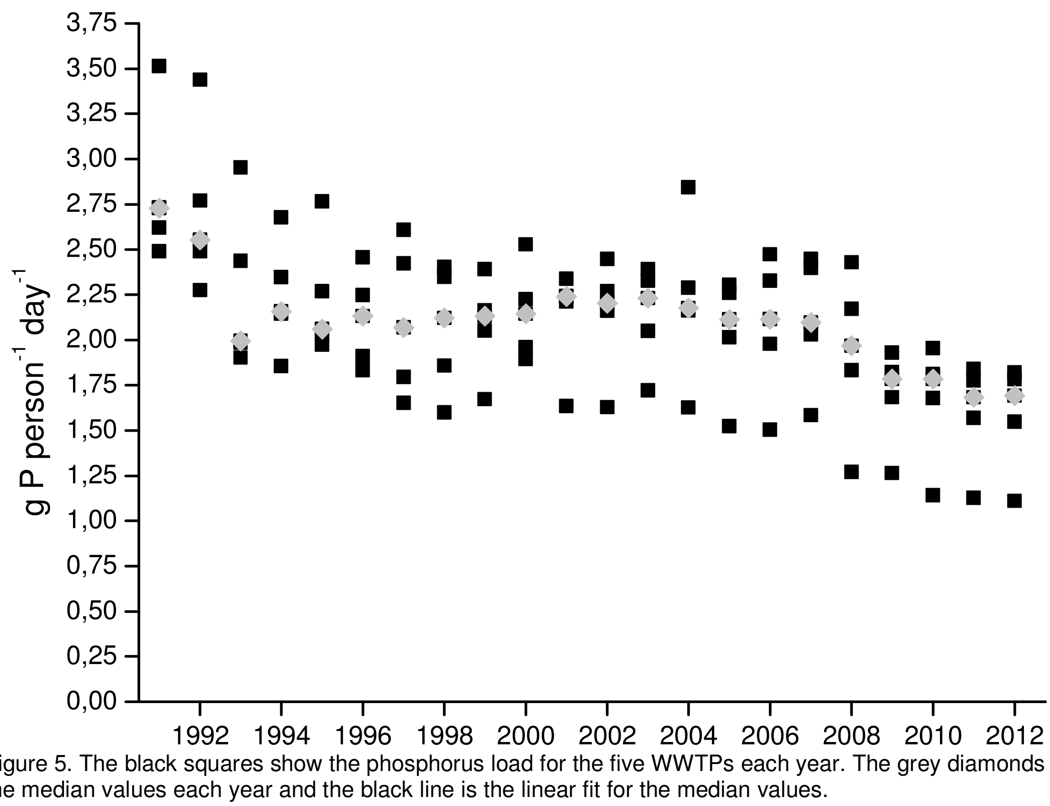

Figure 5. The black squares show the phosphorus load for the five WWTPs each year. The grey diamonds show the median values each year and the black line is the linear fit for the median values.

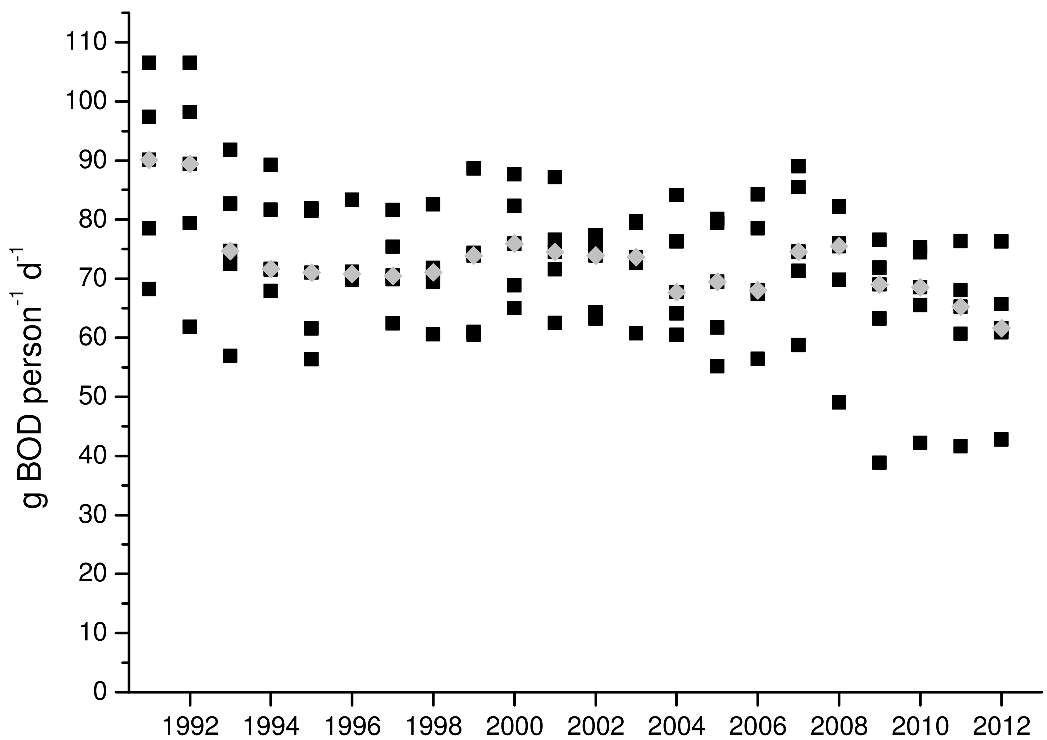

Figure 6. The black squares show the BOD load for the five WWTPs each year. The grey diamonds show the median values each year and the black line is the linear fit for the median values.

Conclusions

The nitrogen load per connected person to WWTPs has increased. The increase can be explained by the changed food preferences in the Swedish society during the last decades, mainly because of an increased consumption of meat. If meat (protein) consumption will stay on today's level, or even increase further, together with stricter discharge limits for nitrogen, it will lead to increasing costs for the WWTPs.
Phosphorus load per capita has decreased in Sweden in connection with the phosphate regulation regarding detergents.

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Appendix 1

Table 1. Actual persons connected to the Swedish WWTPs

Year	Gryaab, Gothenburg	Käppala, Lidingö	Sjölunda, Malmö	Henriksdal, Stockholm	Bromma, Stockholm
1991	551349	320000	245000	571600	258800
1992	551006	325000	245000	578150	257340
1993	553918	331000	247000	579990	258736
1994	565025	335000	251700	589000	261000
1995	572235	336000	254900	594000	264400
1996	572769	338000	257900	606500	269500
1997	577966	342000	261000	607491	272187
1998	584451	376000	264000	620676	275881
1999	588639	390000	267400	630100	278400
2000	592479	386000	270400	639485	282015
2001	605526	390000	272000	644400	284900
2002	607439	393000	276800	649000	286000
2003	612376	393000	279300	653300	286500
2004	620683	395000	282000	683900	286300
2005	621307	400000	286500	689400	287900
2006	628373	400000	290800	698000	291500
2007	633659	400000	295500	705000	294000
2008	640303	410000	300000	721700	301900
2009	649352	440000	300000	736597	303446
2010	658114	440000	300000	752700	311900
2011	666441	450000	291200	767650	316200
2012	693309	455000	303240	782600	320500

Table 2. Nitrogen load person^{-1} d^{-1}

Year	Gryaab	Käppala	Sjölunda	Henriksdal	Bromma	Mean	Median
1991	13.4		11.0	15.0	16.8	14.05	14.21
1992	12.8	14.5	11.0	13.6	17.5	13.86	13.56
1993	12.1	13.9	10.5	12.9	16.3	13.14	12.85
1994	12.1	13.0	11.1	14.6	14.4	13.03	13.00
1995	12.4	12.9	10.2	14.4	14.5	12.87	12.87
1996	12.1	13.3	14.0	13.9	11.2	12.87	13.29
1997	13.8	12.3	11.9	13.5	11.0	12.51	12.34
1998	13.8	12.8	14.4	13.6	11.0	13.11	13.60
1999	12.3	12.3	13.8	13.0	11.8	12.66	12.31
2000	13.0	11.9	14.4	14.6	12.2	13.22	12.96
2001	12.2	13.3	14.9	14.0	11.5	13.20	13.35
2002	13.3	12.9	15.9	14.4	11.5	13.59	13.31
2003	12.8	13.2	14.3	13.8	12.4	13.32	13.25
2004	12.9	13.7	13.5	14.8	11.5	13.29	13.48
2005	13.6	14.4	13.3	14.3	11.4	13.39	13.59
2006	14.0	15.1	13.2	14.5	12.2	13.80	13.97
2007	13.9	19.9	13.5	14.8	12.1	14.85	13.95
2008	14.2	14.0	13.2	15.2	10.9	13.50	14.03
2009	14.2	13.7	13.1	14.1	10.8	13.18	13.70
2010	14.2	13.9	13.5	14.2	10.5	13.28	13.95
2011	13.7	13.7	13.9	13.9	11.3	13.28	13.70
2012	13.9	14.1	12.9	14.7	11.1	13.33	13.85

Table 3. Phosphorus load $person^{-1}$ d^{-1}

Year	Gryaab	Käppala	Sjölunda	Henriksdal	Bromma	Mean	Median
1991	2.73	2.62	2.49	2.73	3.51	2.82	2.73
1992	2.77	2.55	2.49	2.27	3.44	2.71	2.55
1993	2.44	1.99	1.90	1.98	2.95	2.25	1.99
1994	2.35	1.86	2.15	2.16	2.68	2.24	2.16
1995	2.03	1.97	2.06	2.27	2.77	2.22	2.06
1996	2.25	1.83	2.13	2.46	1.91	2.12	2.13
1997	2.61	1.79	2.07	2.42	1.65	2.11	2.07
1998	2.40	1.86	2.12	2.35	1.60	2.07	2.12
1999	2.16	2.05	2.13	2.39	1.67	2.08	2.13
2000	2.22	1.96	2.14	2.53	1.89	2.15	2.14
2001	2.24	2.21	2.24	2.34	1.63	2.13	2.24
2002	2.27	2.16	2.20	2.45	1.63	2.14	2.20
2003	2.05	2.23	2.33	2.39	1.72	2.14	2.23
2004	2.18	2.29	2.16	2.84	1.63	2.22	2.18
2005	2.11	2.26	2.01	2.30	1.52	2.04	2.11
2006	2.11	2.33	1.98	2.47	1.50	2.08	2.11
2007	2.10	2.40	2.03	2.45	1.58	2.11	2.10
2008	1.97	2.17	1.83	2.43	1.27	1.93	1.97
2009	1.82	1.93	1.68	1.79	1.26	1.70	1.79
2010	1.81	1.96	1.68	1.78	1.14	1.67	1.78
2011	1.78	1.84	1.68	1.57	1.13	1.60	1.68
2012	1.78	1.69	1.55	1.82	1.11	1.59	1.69

Table 4. BOD_7 load $person^{-1}$ d^{-1}

Year	Gryaab	Käppala	Sjölunda	Henriksdal	Bromma	Mean	Median
1991	78.5	90.2	106.5	68.2	97.4	88.2	90.2
1992	79.4	89.4	106.5	61.8	98.2	87.1	89.4
1993	74.7	82.7	72.5	56.9	91.8	75.7	74.7
1994	67.9	81.7	71.5	71.6	89.2	76.4	71.6
1995	56.4	81.5	61.6	71.0	81.9	70.5	71.0
1996	70.8	69.8	83.4	70.5	71.2	73.1	70.8
1997	75.4	70.5	81.6	69.9	62.4	72.0	70.5
1998	69.4	71.8	82.6	71.1	60.6	71.1	71.1
1999	60.5	74.4	88.6	73.9	61.0	71.7	73.9
2000	65.0	75.9	87.6	82.3	68.9	75.9	75.9
2001	71.6	74.5	87.1	76.5	62.5	74.4	74.5
2002	64.3	73.9	77.3	76.0	63.2	71.0	73.9
2003	60.8	79.5	72.7	79.7	73.6	73.2	73.6
2004	60.5	76.3	67.7	84.1	64.1	70.5	67.7
2005	61.7	80.1	69.5	79.5	55.2	69.2	69.5
2006	67.4	84.2	68.1	78.5	56.4	70.9	68.1
2007	71.3	89.0	74.6	85.5	58.7	75.8	74.6
2008	69.8	82.2	75.5	75.9	49.0	70.5	75.5
2009	69.0	76.6	71.9	63.2	38.8	63.9	69.0
2010	74.4	75.3	68.5	65.5	42.2	65.2	68.5
2011	76.4	68.0	65.3	60.7	41.6	62.4	65.3
2012	76.3	65.7	60.9	61.6	42.7	61.5	61.6