Scenarios for reduction of nutrient load from point sources in Estonia

Karin Pachel, Marija Klõga and Arvo Iital

ABSTRACT

This study aimed to develop scenarios for a further decrease of point source nutrient load in Estonia to achieve the nutrient reduction target levels set up by the HELCOM Baltic Sea Action Plan produced in 2007. A possible reduction in the total phosphorus (TP) and total nitrogen (TN) load has been assessed based on the requirements set up by Estonian and EU legislation as well as the HELCOM recommendations. Scenarios were developed for four urban pollution load classes with different requirements for waste water quality at the outlet of the wastewater treatment plant (WWTP). The results revealed that the load of TP and TN to the sea and to inland surface water bodies can be reduced by 68 and 352 tonnes, respectively, when following the most stringent HELCOM recommendation for the quality of sewerage outlets. These possibly reduced loads form only about 30% of required TP and 40% of TN annual reduction levels in Estonia which are 220 tons of phosphorus and 900 tons of nitrogen. Therefore, further decrease can mostly be made possible by lowering the diffuse load and that can also be problematic.

Key words | Baltic Sea Action Plan, nitrogen, phosphorus, point source pollution, scenario building, waste water treatment

Karin Pachel (corresponding author)
Marija Klõga
Arvo Iital
Department of Environmental Engineering,
Tallinn University of Technology,
Ehitajate tee 5,
19086, Tallinn,
Estonia
E-mail: *karin.pachel@ttu.ee*

INTRODUCTION

Eutrophication of inland waters and the sea enhanced by anthropogenic input of nitrogen and phosphorus is one of the main environmental concerns in the Baltic Sea Region (Ulen & Weyhenmeyer 2007). Although riverine transport is the most important pathway for input of nutrients to the sea (Stålnacke 1996), both diffuse as well as point source loads should be decreased when aiming at considerably lower overall inputs. The decrease will be more pronounced when the efficiency of wastewater treatment is higher by introducing high-grade (tertiary) treatment. This measure together with the increased number of people who are connected to wastewater treatment plants will provide an almost immediate response (Humborg *et al.* 2007; Bryhn 2009).

Recently the ministers of the environment of the member states of HELCOM adopted an action plan to considerably reduce the anthropogenic nutrient load to the Baltic Sea and restore a good ecological status by 2021 (HELCOM 2007a). To achieve this, country-specific annual nutrient input reduction targets were proposed, based on the principle of maximum allowable nutrient inputs to the sea that were set at the level of about 21,000 tons of phosphorus and 600,000 tons of nitrogen. Estonia agreed to annual reduction target levels of 220 tons of phosphorus and 900 tons of nitrogen.

The first municipal biological WWTP with activated sludge tanks and a capacity of 25,000 m^3 sewage water per day was constructed in Estonia in Narva city in late 1960s. In 1965–1967 the first experimental oxidation ponds and small activated sludge plants were constructed. Most of the around 500 small-scale (<2,000 population equivalents, PE) urban wastewater treatment plants operating today were constructed between the 1970s and the 1990s. Approximately one fifth of them are oxidation ponds. Most of the WWTPs are more than 20 years old and some have been in operation even 40 years without any major renovation

doi: 10.2166/nh.2012.136

and are, therefore, depreciated and outdated. Nutrient removal in these WWTPs is a critical issue because they were designed mainly for efficient removal of organic matter and not phosphorus and nitrogen. During the construction period some decades ago eutrophication was not recognised as an important issue.

The Baltic Sea States Ministers of Environment Declaration even in 1988 (HELCOM 1988) called for a 50% reduction in anthropogenic load by nitrogen and phosphorus to the Baltic Sea by the year 1995. Although very few special measures have been implemented in Estonia, the overall target for the 50% reduction in nutrient loads to the sea was achieved (Pachel 2002). Probably, there were many other factors besides of the improved wastewater treatment that led to this decreasing trend, e.g. diminished water consumption by industries and households caused by the economic regression and reduced diffuse load from agriculture. In 2000, Estonia was responsible for about 27,000 tons of nitrogen and nearly 1,000 tons of phosphorus, which formed 3.6 and 2.8%, respectively, of the whole Baltic Sea pollution load. Load entering the sea via rivers formed 25,273 tons of nitrogen and nearly 877 tons of phosphorus (HELCOM 2004). By 2007 the respective levels decreased to about 20,000 and nearly 800 tons, respectively (Loigu & Leisk 2008).

During the past 15–20 years considerable efforts have been made to raise the performance of WWTPs in Estonia, especially in larger cities. This factor is the major reason for a more than 70% decrease in nitrogen and phosphorus point load to the recipient water bodies in 2007 compared with 1992 (EER 2009). In 2007 most waste water passed through advanced tertiary treatment and only about 1% was released to the environment without any treatment (Figure 1).

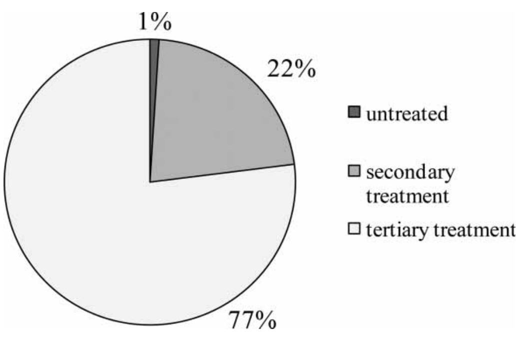

Figure 1 | Efficiency of wastewater treatment in Estonia in 2007.

Although the overall situation is rather good, there is still remarkable temporal and spatial variability in treatment quality depending on, for example, the use of chemicals for phosphorus removal in WWTPs. Especially, in many smaller settlements the treatment is still insufficient (Pachel 2010). In larger municipalities the number of households and industries connected to the sewerage systems has grown, increasing the amount of nutrient-laden wastewater delivered to the treatment plants. This situation is probably the main reason for the increasing trend in phosphorus concentrations in some rivers in Estonia (Iital *et al.* 2010).

This study aimed at:

- Assessment of point source load of nitrogen and phosphorus by four classes of urban pollution load in Estonia in 2007.
- Developing scenarios to decrease point source nutrient load to the Baltic Sea considering major requirements set up by legal documents adopted in Estonia, in EU and by HELCOM for discharging wastewaters into water bodies.
- Assessment of the impact of these measures to decrease the overall load that enables reaching the target levels set up by the HELCOM Baltic Sea Action Plan.

The year 2007 was selected as a base year for scenario building. Point source load of nitrogen decreased in connection to the overall lowered water consumption by 7% in 2008–2009 due to economic depression. Therefore, 2007 represents more realistically recent loading levels needed for the assessment of future developments. In 2007 the total wastewater load to inland surface water bodies and directly to the sea was about 1,400 tons of nitrogen and 130 tons of phosphorus, when not considering cooling waters and ground water pumped out due to mining activities (EER 2009). Direct discharges to the coastal waters formed 55–60% of the total load of nitrogen and phosphorus, while the rest was discharged to inland water bodies.

STUDY AREA, DATABASE AND METHODS

Treatment of waste water monitoring system in Estonia

The total number of WWTPs in Estonia submitting annual water use reports is about 1,200 and include both larger settlements (i.e. Tallinn, Pärnu, Narva and Tartu) exceeding 100,000 PE as well as settlements with a load level below 2,000 PE. In accordance with the Estonian Water Act and Regulation of the Minister of Environment on the procedure for issue and revocation of special water use permits (RT I 2010), a water user should possess a permit for special use of water if the limit values on the water use exceed the established levels. Additionally pollution load by the main pollution parameters is available in the state databank.

The number of settlements discharging their waste waters directly to the sea is limited, but includes the largest city Tallinn (about 430,000 inhabitants) and Pärnu (about 44,000 inhabitants). In addition, four out of 15 settlements with a pollution load of 10,000–100,000 PE (Haapsalu, Kohtla-Järve, Kuressaare and Sillamäe) and five out of 23 sized 2,000–10,000 PE (Loksa, Paldiski, Aseri, Kunda and Kärdla) also let their treated waste water discharge directly to the sea.

Frequency of self-monitoring of waste water effluents is 4–12 times a year and involves all facilities covered by the water use permits. Additional monitoring is carried out by environmental authorities to supervise outlets of the WWTPs. In our scenario building only total TN and TP were considered. The analysis on the waste water samples were carried out in accredited laboratories in Estonia by using standardised method SFS 5505 for TN and EVS-EN ISO 6878 for TP.

Requirements for waste water treatment

The nutrient reduction scenarios considered four major requirements set up by legal documents adopted in Estonia, in EU and by HELCOM for discharging waste waters into water bodies:

- Regulation of the Government of Estonia No. 269 from 31 July 2001 on the procedure for discharging waste water into water bodies or soil (RT I 2001).
- Council Directive of 21 May 1991 concerning urban waste water treatment (EC 1991).
- HELCOM Recommendation 28E/5, adopted on 15 November 2007, having regard to Article 20, Paragraph 1b of the Helsinki Convention Municipal Wastewater Treatment (HELCOM 2007b).
- HELCOM Recommendation 28E/6, adopted on 15 November 2007, having regard to Article 20, Paragraph 1b of the Helsinki Convention (HELCOM 2007c).

The developed scenarios assumed that Estonian population remains on the same level or decreases slightly up to 2050 (Maamägi 2007; Servinski 2010). We also assumed that a possibly expanding industrial sector does not increase the overall waste water pollution load due to the advanced technologies.

In Estonia, waste water from small sources of pollution (less than 2,000 PE) must also be treated before discharging into water bodies and should correspond to the level required in the water permit. The requirements cannot be more stringent than the limit values provided for waste water discharges from sources between 2,000 and 10,000 PE. The EU Urban Wastewater Treatment Directive (EC 1991) requires appropriate treatment of urban waste water entering collecting systems from agglomerations of less than 2,000 PE.

In HELCOM region, alternatively, the concentration of phosphorus in treated wastewater should not exceed 0.5 mg l^{-1} or a 90% reduction should be achieved by 2014 for agglomerations above 10,000 PE. Single family houses, small businesses and settlements up to 300 PE in areas without sewerage systems are not allowed to discharge untreated waste waters directly to natural water bodies.

In general, HELCOM recommendations are more stringent on both phosphorus and nitrogen and Estonian regulation is more stringent on phosphorus compared with the EU Urban Wastewater Treatment Directive (Table 1). According to the Water Act all Estonian surface water bodies are defined as pollution sensitive. Therefore, the limit value for TP for agglomerations below 2,000 PE was lowered to 1.5 mg l^{-1} compared with the 2 mg l^{-1} as proposed by HELCOM. All limit values used for scenario building in our study are presented in Table 1.

Pollution load reduction was calculated by considering the required concentration levels at the outlet of WWTPs assuming that the amount of the waste water will remain at the level of 2007. Retention of nutrients in inland surface waters was not accounted for in our calculations and therefore the real river load of point source phosphorus and nitrogen to the sea is somewhat lower.

Table 1 | Limit values for TP and TN concentrations in wastewater discharges in Estonia, EU and HELCOM area

Parameter	Legislation	<2,000 PE[a] mg l^{-1}	2,000–10,000 PE mg l^{-1}	10,000–100,000 PE mg l^{-1}	>100,000 PE mg l^{-1}
TP	EE	1.5	1.5	1	1
	EU	–	2	2	1
	Helcom	2.0	1.0	0.5	0.5
TN	EE, EU	–	–	15	10
	Helcom	35 (or ≥30% removal)	≥30% removal	15	10

[a]PE (population equivalent) means the organic biodegradable load having a 5-day biochemical oxygen demand (BOD_5) of 60 g of oxygen per day (HELCOM 2007c).

RESULTS AND DISCUSSION

Wastewater treatment efficiency in 2007 – baseline scenario

In 2007 there were 41 settlements in Estonia with the pollution load exceeding 2,000 PE. About 70% of the Estonian population resides in these urban areas and 92% of them use the services of a public sewerage system. At the moment 72% of the population of Estonia is supplied with a public sewerage system. Domestic and industrial wastewaters are usually treated together in urban municipal wastewater treatment plants. The number of industries with separate treatment facilities is limited.

In 2007, the total wastewater load to inland surface water bodies and directly to the sea, when not considering cooling and mine waters, was 1,397 tons of nitrogen and 126 tons of phosphorus. Most of the load originates from the four larger towns: Tallinn, Tartu, Narva and Pärnu (in total 600,000 inhabitants). The share of point load from the settlements between 2,000 and 10,000 PE is the lowest (Figure 2). It can be explained by the relatively low number of inhabitants (all together about 90,000) and limited industrial activity in addition to the rather well functioning WWTPs. Since 1999 seven new WWTPs were constructed and 12 were renovated in settlements of this size (Table 2). HELCOM recommendations in WWTPs from 2,000 to 10,000 PE will be achieved by 2018.

About 230,000 inhabitants lived in agglomerations with pollution load 10,000–100,000 PE in 2007. The share of nitrogen load from these settlements is about 30% and phosphorus load about 20%, which is quite high due to the relatively higher share of people connected to the sewerage systems compared with the Estonian average. Most of the WWTPs of that size were constructed in 1974–1986 (Table 2) and have been renovated recently. Four facilities are less than 10 years old.

Discharges from the small WWTPs with a load below 2,000 PE are relatively high due to pure treatment efficiency and formed 19% of the overall annual nitrogen and 25% of phosphorus load (Figure 2). Information on small WWTPs and annual reports in the national register are incomplete and have many gaps regarding the treatment efficiency. Wastewater volumes and loads entering WWTPs are not measured either. Therefore, wastewater load is often estimated based on the expert judgements and abstracted amount of raw water.

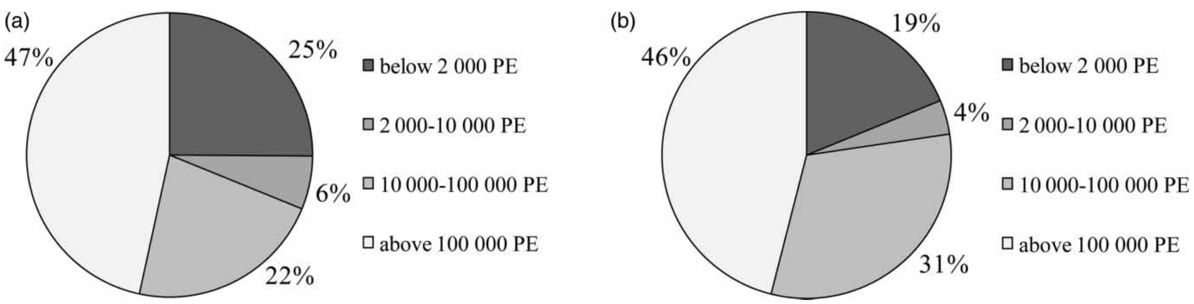

Figure 2 | Division of total phosphorus (a) and nitrogen (b) load from point sources between four urban load classes in Estonia in 2007.

Table 2 | Wastewater treatment efficiency in settlements with pollution load over 2,000 PE in 2007

Settlement	Recipient	Treatment level	TN, %	TP, %	Construction year	Last renovation year
Pollution load over 100,000 PE						
Tallinn	Coast	Tertiary	75	85	1981, 1984, 1993, 1998	2004
Narva	Inland	Tertiary	83	89	1967	2005
Pärnu	Coast	Tertiary	87	94	1980, 1991	1996
Tartu	Inland	Tertiary	74	89	1996	2003
Pollution load between 10,000 and 100,000 PE						
Ahtme	Inland	Secondary	68	83	1974	2008
Kehra	Inland	Secondary			1977	2007
Kohtla-Järve	Coast	Secondary	66	14	1978, 2009	
Kuressaare	Coast	Tertiary	76	96	1991, 2001	
Põltsamaa	Inland	Tertiary	82	90	1982	2003
Põlva	Inland	Tertiary	96	98	1982	1998
Rakvere	Inland	Tertiary	86	97	1990	2004
Sillamäe	Coast	Tertiary	70	86	1981	2000
Viljandi	Inland	Tertiary	85	94	1978, 2005	
Haapsalu	Coast	Tertiary	30	94	1982, 1997	2001
Maardu	Coast	Secondary	90	93	1978	
Paide	Inland	Tertiary	77	76	1978	1996
Rapla	Inland	Tertiary	90	99	1982	1998
Valga	Inland	Tertiary	91	98	1977, 2001	2004
Võru	Inland	Tertiary	37	95	1986	1997
Pollution load between 2,000 and 10,000 PE						
Aseri	Coast	Secondary	55	63	1989	
Elva	Inland	Secondary	33	79	1976	2003
Jõgeva	Inland	Tertiary	90	97	1977, 2001	
Jüri	Inland	Secondary	61	75	1985	2007
Kadrina	Inland	Tertiary	79	95	2000	
Keila	Inland	Tertiary	82	98	1979, 2001	2007
Kilingi-Nõmme	Inland	Tertiary	51	77	1995	2008
Kohila	Inland	Tertiary	69	67	1985, 2007	
Kose	Inland	Tertiary	81	75	1979	1999
Kunda	Coast	Secondary	85	83	1975	2008
Kärdla	Coast	Tertiary	87	94	1996	2009
Loksa	Coast	Tertiary	37	68	1986, 2005	
Märjamaa	Inland	Tertiary	48	70	1976, 1999	2009
Otepää	Inland	Secondary	72	86	1996	
Paldiski	Coast	Tertiary	53	62	1957, 2007	
Räpina	Inland	Secondary	79	59	1985	2009
Tamsalu	Inland	Tertiary	85	95	1973, 1998	
Tapa	Inland	Tertiary	84	78	1997	
Türi	Inland	Secondary	83	93	1996	2008
Väike-Maarja	Inland	Tertiary	94	98	1974	2000
Vändra	Inland	Secondary	94	69	1982	1999

Most of the waste water requiring treatment go through biological and/or biological-chemical treatment. The efficiency of phosphorus removal in most of the bigger WWTPs is between 70 and 98%. For nitrogen, the treatment efficiency is much lower (Table 2).

Point source load scenarios

A higher overall reduction in nutrient point source load is achieved when the HELCOM recommendations with regard to waste water treatment are followed. The load of phosphorus can be reduced by 54% compared with the 2007 level. A decrease of about 25% of TP can be achieved by following all the Estonian regulations in all WWTPs and the load will be about 20% lower when the relevant EU directive is implemented (Figure 3). The reduction levels of total nitrogen are equal when following the Estonian and EU regulations, however somewhat lower compared with the levels that can be achieved by implementing the relevant HELCOM recommendations (Figure 4).

The largest decrease in TP load is possible from agglomerations with more than 100,000 PE (Figure 5), particularly in the Tallinn WWTP which could contribute by about 25 tons reduction. A further decrease in the phosphorus load is also possible if the maximum permissible allowed phosphorus concentration in the outlet of large WWTPs (PE over 10,000) is equal to or below 0.5 $mg\,l^{-1}$ (Figure 5). The foreseen reduction in the WWTPs with load below 2,000 PE is about 18 tons. This decrease will take place on account of discharges to inland surface water bodies. A possible decrease from the settlements with load of 10,000–100,000 PE is about 16 tons. The possibility for a further decrease in P load from settlements with 2,000–10,000 PE is rather limited due to the relatively high phosphorus removal efficiency (Table 2) already achieved in many WWTPs.

The largest reduction of nitrogen can be achieved in settlements with pollution load between 10,000 and 100,000 PE, exceeding twice the amount of the category of more than 100,000 PE (Figure 5). In both categories most of the reduction is possible from direct discharge to the sea. Total nitrogen reduction efficiency of at least 30% could be achieved in all WWTPs with load between 2,000 and 10,000 PE to fulfil the marked requirements. Most of the settlements in the category below 2,000 PE discharge into inland surface water bodies. Nitrogen removal

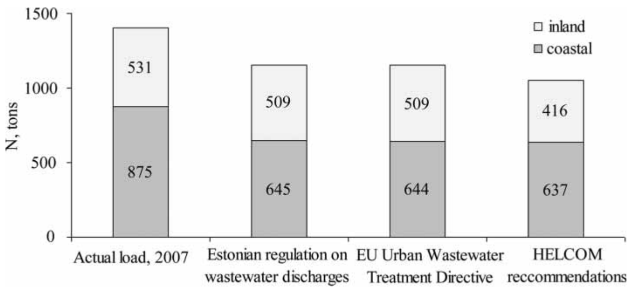

Figure 4 | The load of total nitrogen from WWTPs in 2007 and potential load according to Estonian, EU and HELCOM scenarios.

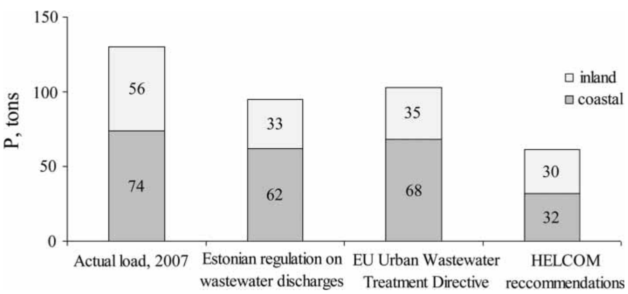

Figure 3 | The load of total phosphorus from WWTPs in 2007 and potential load according to Estonian, EU and HELCOM scenarios.

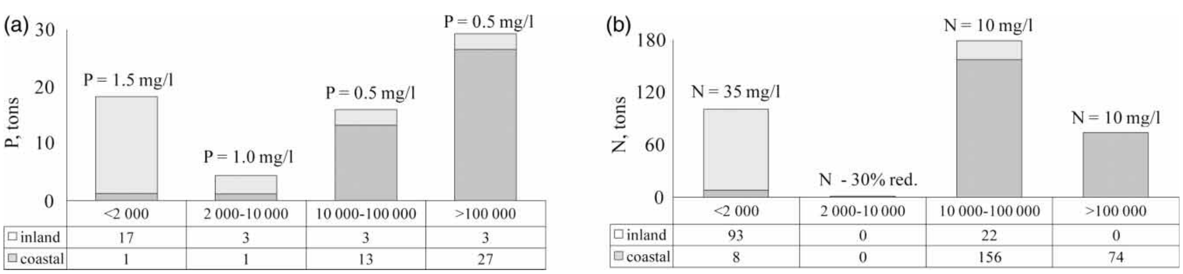

Figure 5 | Potential for total phosphorus (a) and nitrogen (b) reduction in WWTPs in Estonia by PE classes by following HELCOM and Estonian (<2,000 PE for phosphorus) targets.

efficiency for these small settlements is not yet regulated in Estonia.

Comparison of the two major catchments: the Gulf of Finland (GoF), including the Lake Peipsi basin and the Gulf of Riga (GoR), including Väinameri area, revealed that approximately 90% of phosphorus and nitrogen load originate from the GoF catchment area (Figures 6 and 7). Most of the load is discharged directly to the sea. Contrary to this, most of the nutrients in the GoR basin are discharged into inland water bodies.

The proportion of the Lake Peipsi basin in the GoF catchment is about 180 tons (15%) of nitrogen and nearly 20 tons (18%) of phosphorus load. Most of the load enters into Lake Peipsi via rivers. The possible reduction for nitrogen and phosphorus into Lake Peipsi is about 16 and 8 tons, respectively, when following the most stringent scenario.

The potential for reduction of phosphorus in the GoF catchment area is highest in the category of load above 100,000 PE (Figure 8), including the direct discharge from Tallinn (25 tons) and discharge to the Narva River from the town Narva (3 tons). A decrease from the settlements between 10,000 and 100,000 PE (Kohtla-Järve, Sillamäe, Maardu, and Ahtme) could contribute the most with regard to nitrogen load. The regional WWTP in Kohtla-Järve (deep outlet into the sea) contributes the most in the category of 10,000–100,000 PE.

A possible decrease in nitrogen load from Tallinn accounts for 73 tons. A further reduction of nitrogen

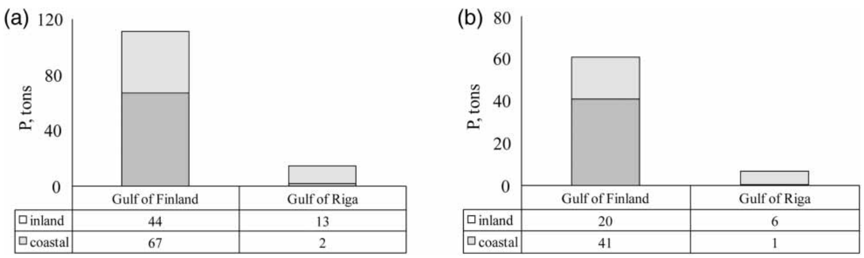

Figure 6 | Total phosphorus point load (a) and potential reduction (b) in the Gulf of Finland and Gulf of Riga catchments.

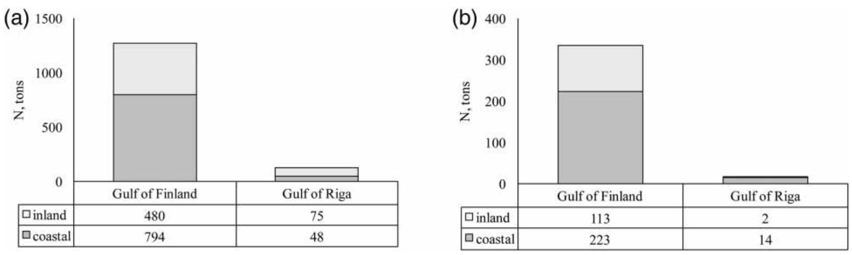

Figure 7 | Total nitrogen point load (a) and potential reduction (b) in tons in the Gulf of Finland and Gulf of Riga catchments.

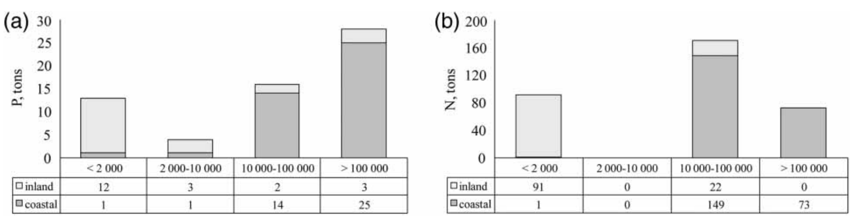

Figure 8 | Potential for reduction of total phosphorus (a) and total nitrogen (b) load in the Gulf of Finland catchment area aggregated by the size of agglomerations.

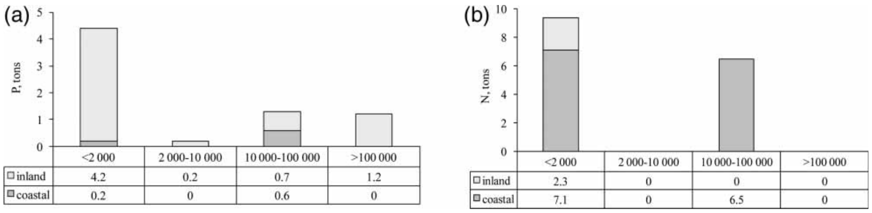

Figure 9 | Potential for reduction of total phosphorus (a) and total nitrogen (b) load in the Gulf of Riga catchment area aggregated by the size of agglomerations.

load from WWTPs with load between 2,000 and 10,000 PE is not foreseen, as the required nitrogen removal efficiency of 30% has been already achieved in all WWTPs. Most of the phosphorus (12 tons) and nitrogen (91 tons) reduction should be achieved by reducing their load into inland water bodies in the category below 2,000 PE (Figure 8).

Most of the potential reduction of phosphorus in the GoR catchment area can be achieved from inland sources in all PE classes. Contrary to this, nitrogen load can be decreased from direct sources to the sea (Figure 9). The largest decrease in both phosphorus and nitrogen is possible in the category of settlements with pollution load below 2,000 PE. A possible reduction of nitrogen load in Haapsalu, representing a settlement with load between 10,000 and 100,000 PE, is the most remarkable. No decrease is foreseen in the category with pollution load between 2,000 and 10,000 PE.

The study results show that about 20% of phosphorus and 25% of nitrogen could be eliminated from the total load discharged from Estonia directly to the Baltic Sea, assuming that effluent values of wastewater are in agreement with the most stringent requirements (Table 3). Actual load can even be lower because concentrations in many outlets are already below the limit values. Not all loads from WWTPs to inland water bodies reach the sea due to retention of nutrients in river systems. This aspect should be taken into account when assessing the total river load to the Baltic Sea. A more precise assessment of the retention capacity of Estonian rivers requires further investigations.

Table 3 | Comparison of potential for reduction of wastewater load in Estonia with reduction target values of the Baltic Sea Action Plan (HELCOM 2007a)

	Reduction	TP, tons	TN, tons
Baltic Sea Action Plan	Total	220	900
Potential for reduction	Coastal	42	238
	Inland	26	114
	Total	68	352

Study results confirm that the focus for reduction, at least in the Baltic Sea, should be on phosphorus, as has been proved by Boesch et al. (2006) and Ulen & Weyhenmeyer (2007). Despite of the fact that a further reduction of phosphorus point source load is possible to some extent, most of the nutrients load should be diminished from diffuse sources, e.g. agriculture. Cost–efficiency for further upgrading WWTPs in the countries that have the highest overall connection rates to public sewerage in Europe and have a proportion of tertiary treatment over 80%, i.e. in Germany, Denmark, Switzerland, Austria, Finland, Norway and the Netherlands, can be questionable and marginal costs for each abated kilogram or ton might be high (Bryhn 2009; Elofsson 2010). Diffuse load of nitrogen and phosphorus including losses from manure storages formed 59 and 30%, respectively, of total diffuse load to the inland surface water bodies in 2009 (Iital et al. 2010).

CONCLUSIONS

It has been shown that the point source load of phosphorus can be reduced by more than 50% and nitrogen by about 25% compared with the 2007 level when the most stringent regulations in all WWTPs are followed.

In addition, actions focused particularly on the larger agglomerations exceeding 10,000 PE will have a direct impact on the load to the sea. Further decreases of both the nitrogen and phosphorus loads from very small settlements below 2,000 PE will have a direct effect on the recipient inland surface water bodies.

The decrease is more pronounced in WWTPs of the Gulf of Finland catchment area for both nitrogen and phosphorus.

The potential for further reduction of wastewater load to the Baltic Sea after reaching the target levels for wastewater treatment set up by HELCOM is probably limited, and requires further cost efficiency analysis of more enhanced treatment. Therefore, further decrease can mostly be possible by lowering diffuse load, mainly from agriculture, but that can also be problematic.

ACKNOWLEDGEMENTS

We thank the Estonian Environment Information Centre for providing the required data. The study was supported by EU funded project SCENES (Contract no. 036822, http://www.environment.fi/syke/scenes).

REFERENCES

Boesch, D., Hecky, R., O'Melia, C., Schindler, D. & Seitzinger, S. 2006 *Expert Evaluation of the Eutrophication of the Seas Surrounding Sweden*. Swedish Environmental Protection Agency, Stockholm. 54 pp.

Bryhn, A. C. 2009 Sustainable phosphorus loadings from effective and cost-effective phosphorus management around the Baltic Sea. *PLoS ONE* **4** (5), e5417.

EC 1991 *Council Directive Concerning Urban Waste Water Treatment (91/271/EEC)*. European Economic Community, Strasbourg.

EER 2009 *Estonian Environmental Review 2009*. Estonian Environment Information Centre, Tallinn, pp. 86–104.

Elofsson, K. 2010 Cost-effectiveness of the Baltic Sea Action Plan. *Marine Policy* **34**, 1043–1050.

HELCOM 1988 Convention on the protection of the Marine Environment of the Baltic Sea area. Baltic Marine Environment protection Commission – Helsinki Commission. 15–19 February, Ninth Meeting, Helsinki.

HELCOM 2004 The Fourth Baltic Sea Pollution Load Compilation (PLC-4). Baltic Sea Environment Proceedings 93, 188 pp.

HELCOM 2007a HELCOM Baltic Sea Action Plan. HELCOM Ministerial Meeting Krakow, 15 November 2007, Poland, 101 pp.

HELCOM 2007b HELCOM recommendation 28E/5. Municipal wastewater treatment.

HELCOM 2007c HELCOM recommendation 28E/6. On-site wastewater treatment of single family homes, small businesses and settlements up to 300 Person Equivalents (PE).

Humborg, C., Mörth, C.-M., Sundbom, M. & Wulf, F. 2007 Riverine transport of biogenic elements to the Baltic Sea – past and possible future perspectives. *Hydrology and Earth System Sciences Discussions* **4**, 1095–1131.

Iital, A., Pachel, K., Loigu, E., Pihlak, M. & Leisk, Ü. 2010 Recent trends in nutrient concentrations in Estonian rivers as a response to large-scale changes in land-use intensity and life-styles. *Journal of Environmental Monitoring* **12**, 178–188.

Loigu, E. & Leisk, Ü. 2008 Läänemere merekeskkonna kaitse konventsioonist tuleneva Läänemere reostuskoormuste arvutamise projekti (PLC-5) jaoks 2007. aasta reostuskoormuste andmete kogumine, töötlemine ja edastamine. Pollution load 2007 data handling and reporting according to PLC-5 arising from the Convention on the Protection of the Marine Environment of the Baltic Sea. Report, Tallinn University of Technology, Tallinn (in Estonian).

Maamägi, A. 2007 Eesti võimalik rahvaarv ja vanuskoosseis aastani 2050. Population prognosis and age distribution in Estonia up to the year 2050. Eesti statistika. Rahvastik. 2005–2006. *Population* 68–96.

Pachel, K. 2002 Estonian national report on nutrient loads. In: Evaluation of the implementation of the 1988 Ministerial Declaration regarding nutrient load reductions in the Baltic Sea catchment area. Finnish Environment 524, International cooperation, Finnish Environment Institute, Helsinki, pp. 90–102.

Pachel, K. 2010 Water Resources, Sustainable Use and Integrated Management in Estonia. PhD Thesis, TUT Press, Tallinn. 171 pp.

RT I 2001 69, 424, Heitvee veekogusse või pinnasesse juhtimise kord (in Estonian).

RT I 2010 8, 37, *Veeseadus* (in Estonian).

Servinski, M. 2010 Euroopa Liidu rahvastik aastal 2061. The population of the European Union in 2061. *Quarterly Bulletin of Statistics Estonia* **2/10**, 59–87.

Stålnacke, P. 1996 Nutrient loads to the Baltic Sea. Linköping Studies. In: Arts and Science, No. 146. PhD Thesis. Linköping University, Linköping, 188 pp.

Ulen, B. M. & Weyhenmeyer, G. F. 2007 Adapting regional eutrophication targets for surface waters – influence of the EU Water Framework Directive, national policy and climate. *Environmental Science and Policy* **10**, 734–742.

First received 16 December 2010; accepted in revised form 11 April 2011. Available online 16 February 2012