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Development of Estonian nutrient discharge standards for wastewater treatment plants

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Abstract. In order to comply with the Urban Wastewater Treatment Directive's, Water Framework Directive's, Helsinki Commission and Estonian National Wastewater Treatment requirements to reveal the wastewater pressures and impacts on the receiving water, the aim of this work was to develop optimal Estonian Nutrient Discharge Standards for wastewater treatment plants. Wastewater treatment plants treatment efficiency, total pollution load coming from different size of treatment plants and feasibility for stricter treatment requirements and accompanying socio-economic impacts are evaluated with consideration of environmental benefits, brought by the investment. Limit values for small-scale (below 2000 population equivalent) treatment plants were proposed.

Key words: wastewater treatment, pollution load, water quality, effluent, receiving water body, water service.

1. INTRODUCTION

The nature of water problems requires the integration of technical, economic, environmental, social and legal aspects into a coherent framework [1]. As noted in [2], operations (control) in the life cycle of a project must logically follow from planning, design and construction. It is important to keep in mind the well-known fact that the watershed, the receiving water body, urban wastewater treatment and sewer network should be considered as parts of an integrated whole. It is important to create balance between social, economic, technical and environmental aspects [3] and to take into account different alternatives, which help to find an optimal solution and to answer the key question how to identify the best technical solution among several feasible alternatives (different ecological criteria and correlation between ecology and costs must be estimated to meet the Water Framework Directive) [4–6]. Estonian regulations impose stricter wastewater treatment requirements than those set by the European Council 21 May 1991 directive 91/271/EEC for urban wastewater treatment (UWWTD). The UWWTD is based on the European Union integrated water policy main document, Water Framework Directive 2000/60/EC (WFD), which establishes a framework for Community action in water policy to protect inland surface waters, transitional waters, coastal waters and groundwater and to achieve good status of these waters. It also promotes sustainable water use [7]. The UWWTD's main goal is to protect the environment from the adverse effects of urban wastewater discharges and discharges from certain industrial sectors [8]. If the UWWTD requirements are not enough to achieve good status of water bodies and discharge is one of the important point-pollution source for water body, additional wastewater treatment will be required [9,10]. Therefore, wastewater treatment plants (WWTPs) treatment efficiency, total pollution load, coming from treatment plants of different size, and feasibility for stricter treatment requirements and accompanying socio-economic impacts are evaluated with consideration of environmental benefits, brought by the investment. In this study, all the WWTPs in the nitrate vulnerable zone are assessed in terms of biochemical oxygen demand (BOD_7), chemical oxygen demand (COD), suspended solids (SS), total phosphorus (TP) and total nitrogen (TN) discharge requirements. Estonian water bodies are very vulnerable to eutrophication due to small catchments area's and low flow rate. The stream system is relatively dense; the network of rivers longer than 10 km is 0.23 km/km^2. Most rivers are short and there are only 10 rivers longer than 100 km and only 13 rivers have their mean annual average flow over 10 m^3. The total runoff of Estonian rivers in an average year is 11.7 km^3, being only 5.5 km^3 in very dry (95% probability) years. Upper parts of Estonian rivers are particularly poor in water and in low water periods the flow can be almost zero [11,12]. This situation causes problems in using rivers as recipients for wastewater discharge because flow of dry periods does not dilute wastewater sufficiently, thus highly efficient wastewater treatment is required [1].

Eutrophication is caused by excessive nutrients such as phosphorus and nitrogen in water body from either natural or anthropogenic sources. Agricultural chemicals, industrial, and municipal wastewater consists of organic components, phosphorus and nitrogen, contribute to eutrophication process. The other Baltic countries are also considering the problem of phosphorus and nitrogen removal and, therefore, several studies have investigated different methods of removing nutrients from wastewater [13–16]. To limit eutrophication, the HELCOM Baltic Sea Action Plan set stricter urban wastewater treatment requirements [17–19]. However, socio-economic impacts due to more stringent requirements must be examined to achieve satisfactory water quality. In addition, the Estonian regulation requires that all investments must ensure full cost recovery and must be recovered through water tariffs. The optimal wastewater treatment requirement must be determined to achieve good status of the water body with wastewater treatment cost in conformity with environmental benefits. The treatment efficiency of different WWTPs will be determined so that the required investments will result in the maximum efficiency in the reduction of the effluent pollution load. Optimal limit values for small-scale (below 2000 p.e.[1]) [20] WWTPs are also discussed during this study by using common treatment technologies.

2. ASSESSMENT OF THE POLLUTION LOAD OF WWTPs

In Estonia, WWTPs' effluent quality requirements are regulated in the Regulation of the Government No. 269, 31 July 2001 under "Requirements for discharge of wastewater into surface water and soil". Effluent requirements established in the regulation referred to above are much more stringent than those set in the UWWTD [21]. Although the fundamental principles of the directive have been adopted into the Estonian regulation, additional requirements are implemented due to the vulnerability of Estonian water bodies. Estonian rivers have commonly a low flow rate and, due to human activity, a high eutrophication potential. Breaking the eutrophication, one of the most important tasks of water authorities [22] is still the major environmental problem [23–29]. UWWTD of the EU merely sets the minimum requirements for wastewater discharge; wastewater limit values are developed based upon specific country's situation. If stricter requirements are necessary to achieve the objective of other directives, member states have to implement more stringent requirements according to economic reality and socio-economic impact. In addition, financial costs to upgrade WWTPs shall be proportionate to the environmental benefits. To ensure sustainable infrastructure, the necessary expenses incurred in the operation of the system have to be covered with the water tariffs according to Estonian legislation. To make water service accessible to the general public, the public sewage system areas (agglomerations) are determined so that public water service price shall not apply more than 4% of the annual average net income of households in that area in Estonia. This threshold is often quoted in the range of 3%–5% of household income in OECD countries [30]. Estonian, European Union and Helsinki Commission regulations of effluent limit values are shown in Table 1.

Table 1 shows that only for a WWTP with pollution load greater than 2000 p.e. [31], a common standard to assess the compliance of WWTPs with requirements is established. National compliance of WWTPs were assessed by the monitoring results of Järvamaa WWTPs during 2008; 83 wastewater samples were taken from 47 different WWTPs; 23 WWTPs or 49% were in compliance with the treatment requirements.

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[1] Population equivalent (p.e.) is a conventional unit of mean daily water pollution, caused by one person. The value of one population equivalent expressed by biochemical oxygen demand (BOD_7) is 60 g of oxygen per day.

Table 1. Estonian National (EE), European Union (EU) and Helsinki Commission (HE) wastewater discharge criteria

Legislation	BOD_7, mgO_2/l	COD, mgO_2/l	SS, mg/l	TP, mgP/l	TN, mgN/l
≥100 000 p.e.					
EE	15	125	15	1	10
EU	25	125	35	1	10
HE	15	–	–	0.5	10
10 000–99 999 p.e.					
EE	15	125	15	1	15
EU	25	125	35	2	15
HE	15	–	–	0.5	15
2 000–9 999 p.e.					
EE	15	125	25	1.5	–
EU	25	125	35	–	–
HE	15	–	–	1	30%
500–1 999 p.e.[2]					
EE	25	125	25	2	–
EU	25	125	35	–	–
HE*	25	–	–	2	35
<500 p.e.[2]					
EE	25	125	25	–	–
EU	25	125	35	–	–
HE**	*Alternative 1*: the requirements based on emissions per capita need not apply where it can be shown that an on-site WWTP results in at most a concentration of BOD_5 of 20 mg/l, P_{tot} 5 mg/l and TN_t 25 mg/l in the effluent of the WWTP. *Alternative 2*: the requirements based on emissions per capita need not apply where it can be shown that an on-site WWTP using the Best Available Technology (BAT) is installed and operated so that the treatment results in a concentration of BOD_5 of at most 40 mg/l and 150 mg/l COD in the effluent of the WWTP.				

* 300–2000 p.e.
** Less than 300 p.e.

To set the realistic standards, the loads from WWTP effluents to receiving water bodies, was estimated. WWTPs effluents' samples results were analysed in different water bodies. The most agricultural intensive area such as Järva county is used. The Nitrates Directive [32] also specified this county as a nitrate vulnerable zone. All water bodies in Järva county have the highest eutrophication potential in Estonia due to intensive agricultural activities. The impact of the

[2] EE and EU do not establish common standards. These standards are developed taking into account the aim of directives and requirements given in the permits of water special use.

pollution load, coming from point source pollution of Järva county on water bodies, is analysed.

The actual pollution loads were calculated in 2008 on the basis of the real flow rate of wastewater and monitoring results of wastewater influent and effluent. Permissible pollution loads have been calculated in 2008 on the basis of real flow rate of wastewater and established Estonian national limit values for pollution indicators (Table 1) [21,33]. The flow rates of wastewater used were obtained from the national database kept by the Estonian Environment Information Centre. WWTPs with the pollution load of 2000 to 10 000 p.e., the average influent concentration for TN was approximately 60 mgN/l. For WWTPs of 150 to 2 000 p.e., the influent concentration was 86 mgN/l and for WWTPs less than 150 p.e. approximately 106 mgN/l [34]. For WWTPs less than 10 000 p.e., the national threshold of TN have not been set (Table 1). Since 30% of the TN removal is achievable if the biological treatment process functions normally and operates properly without enhanced nitrogen removal (such as nitrification-denitrification process) [35] and considering HELCOM recommendation (Table 1), the effluent concentrations for TN are calculated as 30% reduction of concentration of WWTPs' inflow (Table 2).

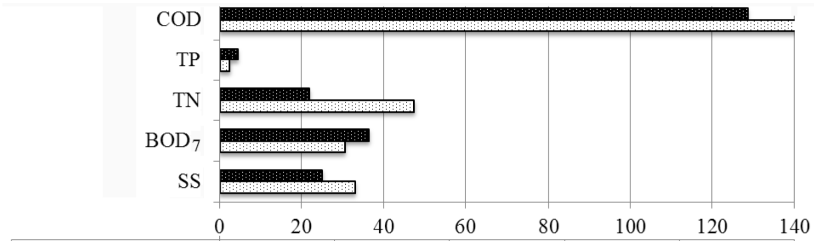
The effluent TP limit value for WWTPs with the pollution load 500–2000 p.e. set in special water permits of 2 mgP/l (Table 1), was also decided to use for WWTPs with load between 300 and 500 p.e. for calculation of permissible pollution load. For WWTPs of smaller load, less than 300 p.e., weaker socio-economical situation was considered in our study, thus lower limit value of 3 mgP/l was the basis for the TP permissible load calculations.

Compared to the UWWTD requirements, the levels would be even higher than the permissible pollution load illustrated in Fig. 1, because the directive requirements are less rigorous than the Estonian national requirements.

Permissible pollution loads have been calculated in 2008 on the basis of the real flow rate of wastewater and established Estonian national limit values for pollution indicators (Tables 1 and 2) [21,33]. The actual pollution loads were calculated on the basis of the real flow rate of wastewater and the monitoring results of the effluent. The difference between the actual and permissible pollution load shows how much it is possible to reduce the total pollution load in conditions where all WWTPs are in compliance with the established requirements.

Table 2. Average TN concentrations of WWTPs influent and TN limit values for WWTPs effluent using 30% reduction

Pollution load of the WWTP, p.e.	Average C of TN in influent of the WWTP, mg/l	Removal proportion, %	TN limit values in effluent of the WWTP, mg/l
2000–9999	60	30	42
150–1999	86	30	60
<150	106	30	74



	SS	BOD_7	TN	TP	COD
■ Actual pollution load	24.98	36.38	21.79	4.27	128.64
□ Permissible pollution load	32.92	30.42	47.38	2.36	231.17

Fig. 1. Point source pollution load in Järva county in 2008, t/y.

As Fig. 1 shows, the actual pollution load discharged to the receiving water bodies is smaller than the load which is in accordance with the national requirements of COD, TN and SS. Figure 1 also suggests that WWTP should be upgraded to remove TP. TP pollution load discharged to the receiving water bodies is higher than what is allowed according to the permissible point source pollution load. Among the non-compliant plants, most of them have the problems in removing phosphorus and organic matter. Compared to the pattern in Fig. 1 with the average concentrations of pollutants, many non-compliant plants have problems with phosphorus removal but just some of plants have problems with removal of organic matter. High concentration or high flow rate (e.g. Roosna-Alliku, Järva-Jaani) has a major impact on total pollutant loads.

The HELCOM Baltic Sea Action Plan enables for removal of TN to use either 30% of reduction or limit values in concentrations, which is for less than 10 000 p.e. WWTPs 35 mg/l, respective total permissible load of TN is 38 t/y. Figure 1 shows that using reduction percentage, the quantity of TN is 47 t/y, which is 24% more pollution than using the concentration 35 mg/l for all WWTP less than 10 000 p.e.

3. SOCIO-ECONOMIC IMPACT OF NITROGEN DISCHARGE STANDARDS

To achieve goals set by the HELCOM recommendations [18], treatment requirements for less than 10 000 p.e. WWTPs by selecting either 30% of reduction of the TN or limit concentration of effluent to 35 mgN/l. Costs for nitrogen removal to achieve 35 mgN/l were estimated and are summarized in Table 3. In Tables 3 and 6, for investment calculations results of the project report [34] are used.

Table 3. The additional expenditure for implementing TN concentration of 35 mg/l bargain for existent technologies

Size of WWTP, p.e.	Exploitation cost for TN removal, EUR/y	Investment cost for TN removal, EUR	Total additional cost for nitrogen removal, EUR/y
≥100 000	0	0	0
10 000–99 999	0	0	0
2 000–9 999	3 800–12 800	128 000	2000–8600
500–1 999	960–3 800	43 500	2000–7000
300–499	700–960	222 000	4500–7000
150–299	320–700	146 000	2300–4500
50–149	130–320	74 800	1100–2300
10–49	30–130	34 500	260–1100
<10	30	8 700	260

Table 2 shows that to achieve TN concentration of 35 mg/l, 42% of total nitrogen reduction rate for WWTP with the pollution load of 2000 to 10 000 p.e., 59% for 150 to 2000 p.e. and 67% for less than 150 p.e. WWTPs is needed. However, such treatment efficiency can only be achieved by using tertiary treatment such as nitrification and denitrification processes. To ensure the functioning of nitrification-denitrification processes for 2000 to 9999 p.e. WWTPs, further investments in technological devices and pipes, 36 500 EUR is required; 91 500 EUR is required for tank expansion. Therefore the total capital is 128 000 EUR per WWTP.

According to EU rules, the amount of investments should result in proportional environmental benefits. Therefore, total investment and environmental benefits in terms of pollution load reduction for different sizes of WWTPs are plotted in Fig. 2.

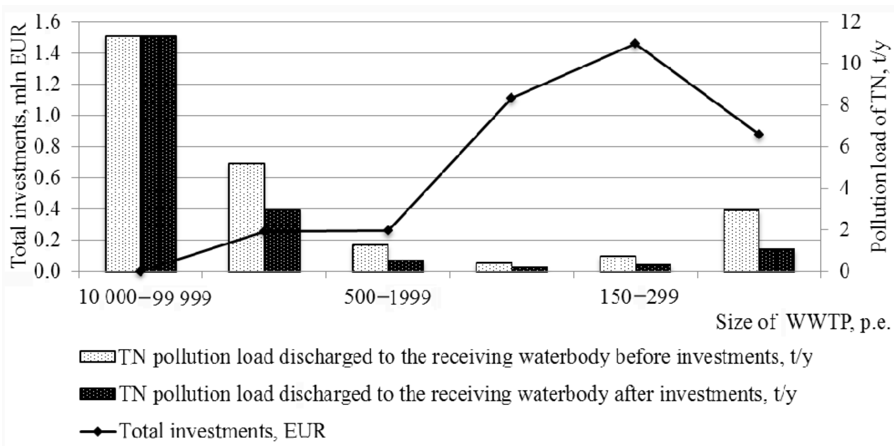


Fig. 2. Pollution load of TN before and after introducing stricter limit values and additional investments.

Figure 2 suggests that WWTPs, discharging less pollution load to the receiving water bodies, need higher investments to achieve TN limit concentration of 35 mg/l. WWTPs with the pollution load less than 10 000 p.e. have significantly higher TN load of the influent than WWTPs with pollution load more than 10 000 p.e. Therefore, at least 40% of reduction of TN is required for WWTPs with the pollution load of 2000 to 10 000 p.e., and for 300 to 2000 p.e., about 60% of reduction of TN and less than 300 p.e. up to 67% of reduction. However, for WWTPs with the pollution load less than 500 p.e., TN reduction, and the amount of investments are not comparable. The WWTPs less than 500 p.e. discharge to the receiving water body about 4 t TN per year, of which 1.6 t come from Väätsa landfill. At the same time, 3.3 millions of EUR investment will reduce the discharge only 2.5 t per year, which is half of the nitrogen removal for 7000 p.e. WWTP discharge quantity of TN per year, if there is no existent nitrogen removal process. It should be noted that the reduction is calculated as maximum reduction, on condition that there is no existent nitrogen removal process today at all. The actual reduction of the TN pollution load may be up to 30% less than is indicated in Fig. 2, because the existing biological treatment processes can remove up to 30% of TN. In Fig. 2, two bigger than 10 000 p.e. plants (Järva-Jaani and Paide) discharge to the receiving water body 11.3 t TN/y, and smaller than 10 000 p. e. plants (a total of 45 plants) form all together 10.5 t/y. Implementation of the C_{TN} of 35 mg/l means higher water service price for population. Table 4 gives an overview of the necessary additional expenses by implementing TN limit value of 35 mg/l and its impact on the price of water service to the population.

Table 4 describes the exploitation costs entailed implementation of TN concentration of 35 mg/l. Based on Fig. 2 and Table 4, implementation of C_{TN} of 35 mg/l for WWTPs with the pollution load less than 500 p.e. would be

Table 4. The socio-economic impact of implementing TN limit concentration of 35 mg/l

Pollution load of WWTP, p.e.	No. of WWTP	Actual TN pollution load of effluent, t/y	C_{TN} in influent, mg/l	C_{TN} in effluent, mg/l	Reduction rate of TN, %	Additional exploitation cost per WWTP for TN removal, EUR/y	Additional cost in water price, EUR/m^3	TN pollution load of effluent after investments, t/y
≥100 000	0	0	61	10	84	0	0	0
10 000–99 999	2	11.30	61	15	75	0	0	11.30
2 000–9 999	2	5.18	61	35	43	5300	0.021	2.95
500–1 999	6	1.25	86	35	59	4500	0.025	0.51
300–499	5	0.42	86	35	59	5800	0.35	0.17
150–299	10	0.72	86	35	59	3500	0.38	0.29
<150	22	2.92*	106	35	67	1300	0.54	1.05

* Pollution load contains also the load of Väätsa landfill, which is 1.6 t of TN per year.

infeasible from the economical and environmental aspects. Implementation of C_{TN} of 35 mg/l for WWTPs with the pollution load less than 500 p.e., the water service price will rise from 0.35 to 0.54 EUR/m^3. At the same time, a smaller quantity of TN reaching the water body has a marginal importance comparing it to the TN total pollution load reaching the water body. Great investment difference for plants of different size is due to the fact that in WWTPs with the pollution load more than 500 p.e., the TN removal will be achievable improving the existing technologies, but for WWTPs less than 500 p.e. the TN level 35 mg/l will be possible to achieve only by constructing a new WWTP.

In summary, the authors have an opinion that the implementation of C_{TN} 35 mg/l for WWTPs with the pollution load less than 10 000 p.e. is justified only if the concentration 35 mg/l is used for WWTPs with the pollution load between 500 and 9999 p.e., and WWTPs between 300 and 499 p.e. are used either with the reduction rate of 30% or C_{TN} of 60 mg/l, which can be achieved as a result of properly operated biological treatment processes without enhanced nitrogen removal.

4. SOCIO-ECONOMIC IMPACT OF PHOSPHORUS DISCHARGE STANDARDS

The HELCOM Baltic Sea Action Plan pays special attention to nutrient removal and the recommendations set the limit values for both, TN and TP concentration, to restrict the eutrophication of the Baltic Sea [17–19]. The socio-economic impact for using stricter requirements of TP is discussed below. The impact assessment is based on limit values of TP, proposed by the HELCOM as listed in Table 5.

Table 6 gives an overview of the expenditures to achieve the TP requirements for different sizes of WWTPs.

All the additional expenditures are calculated as maximum expenditures, which means that the cost for implementing stricter TP requirements are calculated by assuming that all WWTPs with pollution load less than 2000 p.e. do not have phosphorus removal. For WWTPs with the pollution load less than 2000 p.e., where the phosphorus requirement is applied already today, additional expenditures given in Table 6 with the stricter phosphorus requirements do not

Table 5. Phosphorus discharge standards according to HELCOM recommendations

Pollution load of WWTP, p.e.	TP, mgP/l
≥100 000	0.5
10 000–99 999	0.5
2 000–9 999	1
300–1 999	2
<300	2

Table 6. The additional expenditure for implementing stricter requirements for TP for existent technologies

Size of WWTP, p.e.	Exploitation cost for TP removal, EUR/y	Investment cost for TP removal, EUR	Total additional cost for TP removal, EUR/y
≥100 000	1500–6800	9000	5800–9600
10 000–99 999	150–1 500	6100	1900–5800
2 000–9 999	50–150	450	1900–2500
500–1 999	960–4000	3200	1300–2500
150–499	260–960	2400	1100–1300
<150	20–260	450	160–1100

apply. Additionally, WWTPs with the pollution load more than 2000 p.e., the calculation is based on the simplification that today these plants use only chemical phosphorus removal. In case a WWTP has both chemical and biological phosphorus removal today, the considerable additional expenditures are not necessary with new stricter phosphorus requirements and water service price will increase only from 0.03 to 0.04 EUR/m^3.

For WWTPs with pollution load more than 2000 p.e., the impact is calculated so that the TP limit concentration will decrease by 0.5 mgP/l. Table 7 and Fig. 3 show that the C_{TP} is justified if pollution load of WWTP is higher than 300 p.e. For smaller plants, the additional costs for stricter phosphorus removal forms in water service price from 0.27 to 0.43 EUR/m^3, while reduction of TP discharged to the receiving water body has no considerable influence. For WWTP with less than 300 p.e., no dramatic reduction of phosphorus pollution load will result. For the WWTPs with the pollution load between 300 and 10 000 p.e., the price of water service will increase from 0.04 to 0.11 EUR/m^3. The additional investments need implementing stricter TP requirements and the resulting environmental benefits are presented in Fig. 3.

Table 7. Socio-economic impact of implementing stricter phosphorus discharge standards

Pollution load of WWTP, p.e.	No. of WWTP	Actual TP load of effluent, t/y	Influent C_{TP}, mgP/l	Effluent C_{TP}, mgP/l	Additional cost per WWTP for TP removal, EUR/y	Additional cost in water price, EUR/m^3	TP load of effluent after investments, t/y
≥100 000	0	0	13.8	0.5	7 700	0.0	0.00
10 000–99 999	2	2.76	13.8	0.5	3 900	0.006	1.38
2 000–9 999	2	0.48	13.8	1	2 200	0.04	0.32
500–1 999	6	0.38	19.6	2	1 900	0.10	0.25
300–499	5	0.15	19.6	2	770	0.11	0.07
150–299	10	0.18	19.6	2	450	0.27	0.09
<150	22	0.31	22.5	2	130	0.43	0.16

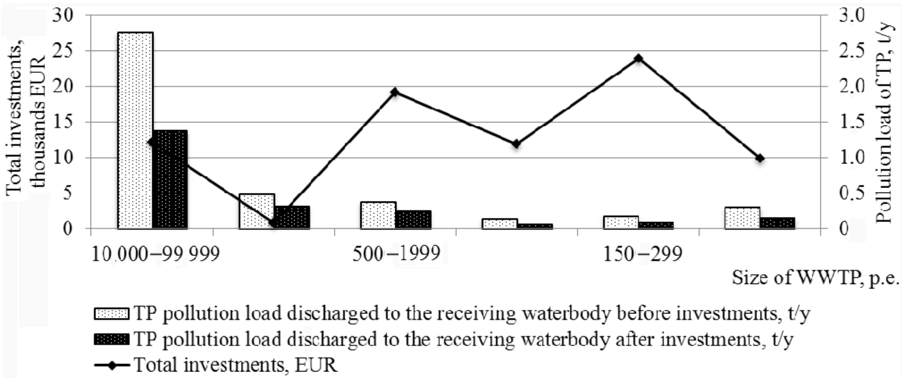


Fig. 3. Pollution load of TP before and after introducing stricter limit values and additional investments.

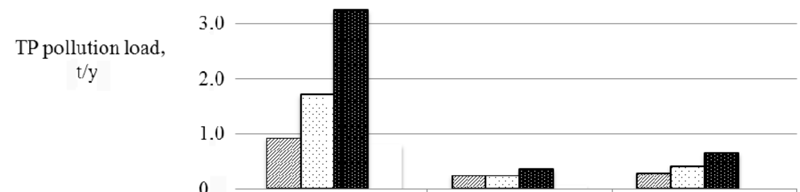
Figure 3 shows that the stricter phosphorus requirements do not lead to the very high investment needs. Investment need is estimated by assuming that WWTPs with pollution load less than 2000 p.e. have no chemical and biological phosphorus removal. When WWTP has chemical phosphorus removal today then the additional investments may not be necessary. Several studies show that phosphorus reduction is achievable even without any specific phosphorus removal strategy if the optimum dose of chemicals is used [36,37]. WWTPs with the pollution load 2000 p.e. or more must apply phosphorus removal according to the existing treatment requirements. Therefore, assessment of investments takes into account that these plants apply the chemical treatment of phosphorus. If these plants apply both chemical and biological phosphorus removal today, the investment needs will be up to 90% less.

5. RECOMMENDATION FOR EFFLUENT STANDARDS OF WWTPs IN ESTONIA

Actual pollution load of WWTP effluent discharged to the recipient and the existing treatment requirements according to the EU requirements are analysed to set the TN and TP standards. Different sizes of WWTP pollution load, discharged to the recipient, were evaluated and additional investments need and environmental benefit were analysed to achieve the EU TN and TP requirements. Different sizes of WWTPs effluent pollution loads, discharged to the recipient, were assessed to determine the cumulative impact on the environment. Figures 4–6 present discharged TP, TN and BOD_7 pollution loads to the receiving water bodies.

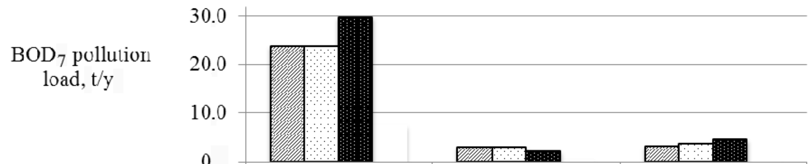
Figure 4 shows the indicative TP limit concentrations, which are the basis for calculating total pollution load of phosphorus. The actual pollution load is found from the monitoring results and real wastewater flow rates in 2008. Permissible pollution load is calculated on the basis of real flow rate of wastewater and established Estonian national limit values for pollution indicators (Tables 1 and 2). WWTP over 2000 p.e. in Fig. 4 is the permissible limit of C_{TP} 1 to 1.5 mgP/l. For WWTP more than 10 000 p.e., the permissible limit concentration is 1 mgP/l and for WWTP between 2000 to 10 000 p.e. the limit concentrations is 1.5 mgP/l (Table 1, EE wastewater discharge criteria). Greater than 10 000 p.e WWTPs are Paide (35 010 p.e.) and Järva-Jaani (12 000 p.e.). WWTPs between 2000–10 000 p.e. are Türi (7632 p.e.) and Koeru (2035 p.e.). Similarly is calculated pollution load using the HE requirement (Table 1, HE wastewater discharge criteria) and on the basis of real flow rate of wastewater.

Figure 6 shows that actual TN loads, discharged to the receiving water bodies, are considerably smaller than it is permitted by the existing requirements.



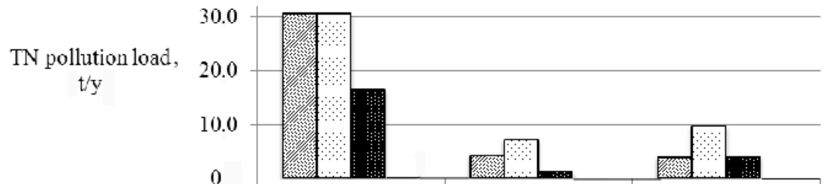
	≥2000 p.e.	500–1999 p.e.	<500 p.e.
▨ Pollution load using HE requirement, t/y	0.92	0.24	0.29
□ Permissible pollution load, t/y	1.71	0.24	0.41
■ Actual pollution load, t/y	3.24	0.36	0.65
Average pollution load per WWTP, t/y	0.81	0.06	0.01

Fig. 4. Actual and permissible TP pollution loads, and effluent TP load using HE requirements for different size WWTPs in Järva county in 2008.



	≥2000 p.e.	500–1999 p.e.	<500 p.e.
▨ Pollution load using HE requirement, t/y	23.80	3.00	3.04
□ Permissible pollution load, t/y	23.80	3.00	3.62
■ Actual pollution load, t/y	29.77	2.13	4.47
Average pollution load per WWTP, t/y	7.44	0.36	0.12

Fig. 5. Actual and permissible BOD_7 pollution load and effluent BOD_7 load using HE requirements for different size WWTP's in Järva county in 2008.



	>2000 p.e.	500–1999 p.e.	<500 p.e.
Pollution load using HE requirement, t/y	30.55	4.19	3.91
Permissible pollution load, t/y	30.55	7.19	9.64
Actual pollution load, t/y	16.48	1.25	4.06
Average pollution load per WWTP, t/y	4.12	0.21	0.11

Fig. 6. Actual and permissible TN pollution load and effluent TN load using HE requirements for different size WWTP's in Järva county in 2008.
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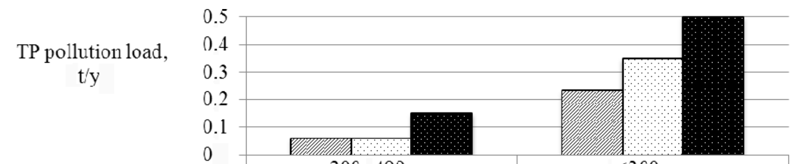
Comparing Fig. 6 to Figs 4 and 5, the balance of nutrients in sewage is not optimal, because the TP and organic matter is partially not removed due to the deficiency of nitrogen in sewage. Therefore, sewage treatment processes need to be improved to ensure the optimal nutrients and organic matter ratio for bacteria. Figs 4–6 imply that the largest pollution load is caused by WWTPs with the pollution load more than 2000 p.e. (in Järva county, 4 WWTPs). There are six WWTPs with the pollution load between 500 and 2000 p.e. and in the group less than 500 p.e. there are 37 WWTPs. Figures 4–6 suggest that to limit the amount of pollution load, all WWTPs with the pollution load more than 2000 p.e. must be reduced. For over 2000 p.e. plants, one WWTP causes about 0.81 t TP pollution load per year. Nationally water permit limits the concentration of TP generally for WWTPs more than 500 p.e. [33,38]. The phosphorus removal will also be required in the future for WWTPs between 300 and 500 p.e. [18]. For WWTPs below 500 p.e., TP load distribution is presented in Fig. 7.

For WWTPs less than 500 p.e., effluent pollution load is comparable with the WWTPs of the size between 500 and 2000 p.e. The TP actual pollution load per



	300–499 p.e.	<300 p.e.
Pollution load using HE requirement, t/y	0.06	0.23
Permissible pollution load, t/y	0.06	0.35
Actual pollution load, t/y	0.15	0.50

Fig. 7. TP load distribution between different size of WWTPs below 500 p.e.

Table 8. New wastewater discharge standards; limit concentration, mg/l

Pollution indicator	WWTP size, p.e.					
	<300	300–499	500–1999	2 000–9 999	10 000–99 000	≥100 000
BOD_7	25	25	25	15	15	15
COD	125	125	125	125	125	125
SS	25	25	25	25	15	15
TP	N/A	2	2	1	0.5	0.5
TN	N/A	60	35	35	15	10

one WWTP for WWTPs less than 500 p.e. is 0.01 t/y, considering the number of these plants, the total pollution load is 0.65 t/y. To compare the effluent pollutant load of WWTPs less than 2000 p.e. with those of more than 2000 p.e., the load from smaller than 2000 p.e. plants is very small. However, taking into account the amount of TP, given in Figs 4 and 7, and socioeconomic impact by implementing stricter requirements for phosphorus removal and also recipients sensitivity of phosphorus, it is expedient to impose the TP limit concentration of 2 mg/l for WWTPs between 300 and 2000 p.e. Also the distribution of the TP load between different sizes of WWTPs is taken into account, according to which more than 2000 p.e. WWTPs effluent load is 80% of TP load and less than 2000 p.e. effluent form only 20% of the total pollution load. Accordingly, the TP reduction requirement is reasonable for WWTPs with the pollution load more than 300 p.e., but by assessing the amount of phosphorus pollution load the limit concentration for TP should not be stricter than 2 mg/l for WWTPs between 300 and 2000 p.e. Based upon the above analysis, new wastewater discharge standards, developed during this study, are given in Table 8.

6. CONCLUSIONS

In Estonia, no national limit values for the effluent of WWTPs with pollution load less than 2000 p.e. are fixed. In this study, pollution load reduction is assessed according to its capital requirements and socio-economic impacts. The main conclusions of this study are the following.

1. Wastewater criteria of nutrients, found during this study, are needed. The national standards for WWTPs with the pollution load less than 2000 p.e. have to be established.
2. Given the origin of pollution and the level of investment required, WWTPs bigger than 2000 p.e. have to be improved to achieve existing standards. The pollution load bigger than 2000 p.e. WWTPs discharge to the receiving water bodies about 80% of the total pollution load.
3. The WWTPs effluent TN requirement of 35 mgN/l is not appropriate for WWTPs below 500 p.e., taking into account the amount of investments and TN pollution load reduction after investments. For WWTPs with the pollution

load less than 500 p.e., the TN reduction and the amount of investments are not comparable. The WWTPs less than 500 p.e. discharge to the receiving water body about 4 t TN per year, of which 1.6 t come from Väätsa landfill; 3.5 millions of EUR investment will reduce it to only 2.5 t TN per year. Therefore we found that this requirement would be infeasible considering economical and environmental aspects. Implementation of C_{TN} of 35 mg/l for WWTPs with the pollution load less than 500 p.e., the water service cost will rise between 0.35 and 0.54 EUR/m^3 while, at the same time, a smaller quantity of TN reaching the water body has a marginal importance comparing it to the TN total pollution load reaching the water body.

4. Taking into account the socioeconomic analysis results, the stricter phosphorus requirements do not lead to very high investment needs. Total investments need is approximately 78 000 EUR in Järva county and after these investments the TP pollution load discharged to the environment will reduce about 2 t/y. Investment need was estimated during this study by assuming that WWTPs with pollution load less than 2000 p.e. have no chemical and biological phosphorus removal. If WWTP has chemical phosphorus removal already today, the additional investments may not be necessary.
5. Implementing stricter wastewater treatment requirements means higher water service cost for population. At the same time, the study shows that to limit eutrophication, the reduction of nitrogen and phosphorus content in effluent discharged into a recipient must attain. Nutrient effluent standards for WWTPs with the pollution load more than 300 p.e. are needed for environmentally and economically reasons. More stringent requirements than is reflected in this study would not be proportionate to the environment effect and does not guarantee comparable pollution load reduction to the investments for WWTPs with less than 300 p.e. Also stricter wastewater treatment requirements than is given in this study may cause the problems of accessibility of water service due to high water price.

REFERENCES

1. Pachel, K. *Water Resources, Sustainable Use and Integrated Management in Estonia*. PhD Thesis, TUT Press, Tallinn, 2010.
2. Beck, M. B. Vulnerability of water quality in intensively developing urban watersheds. *Environ. Model. Softw.*, 2005, **20**, 381–400.
3. Péter, J. Law and sustainability: The impact of the Hungarian legal structure on the sustainability of the water services. *Util. Policy*, 2007, **15**, 121–133.
4. Starkl, M., Brunner, N., Flögl, W. and Wimmer, J. Design of an institutional decision-making process: The case of urban water management. *J. Environ. Manage.*, 2009, **90**, 1030–1042.
5. Xenarios, S. and Bithas, K. Extrapolating the benefits arising from the compliance of urban wastewater systems with the Water Framework Directive. *Desalination*, 2007, **211**, 200–211.
6. Zabel, T., Milne, I. and Mckay, G. Approaches adopted by the European Union and selected member states for the control of urban pollution. *Urban Water*, 2001, **3**, 25–32.

7. European Community. Directive of the European Parliament and of the Council 2000/60/EC establishing a framework for community action in the field of water policy. *Official J. Europ. Commun.*, L327, 2000, 1–73.
8. European Community. Directive of the European Council 91/271/EEC concerning urban wastewater treatment. *Official J. Europ. Commun.*, L135, 1991, 40–52.
9. UWWTD-REP working group. *Terms and Definitions of the Urban Waste Water Treatment Directive (91/271/EEC)*. Brussels, 2007.
10. *Guidance for the Analysis of Pressures and Impacts in Accordance with the Water Framework Directive*. Common Implementation Strategy Working Group 2.1, Office for Official Publications of the European Communities, 2002.
11. Eipre, T. Eesti pinnaveed, nende ratsionaalne kasutamine ja kaitse. In *Eesti NSV Pinnavee kasutamine ja kaitse*. Valgus, Tallinn, 1980, 9–32.
12. *Eesti jõgede ja järvede seisund. Water Pollution and Quality in Estonia*. Environment Data Centre (EDC), National Board of Waters and Environment, Environmental Report 7. Finland, Helsinki, 1993, 5–10.
13. Dauknys, R., Vaboliené, G., Valentukevičiené, M. and Rimeika, M. Influence of substrate on biological removal of phosphorus. *Ekologija*, 2009, **55**, 220–225.
14. Vaboliené, G., Matuzevičius, A. and Valentukevičiené, M. Effect of nitrogen on phosphate reduction in biological phosphorus removal from wastewater. *Ekologija*, 2007, **53**, 80–88.
15. Mažeikiené, A., Valentukevičiené, M., and Rimeika, M. The use of a zeolite filter media for the removal of ammonium ions from wastewater by filtration. In *Proc. 7th International Conference "Environmental Engineering"*. Vilnius, Lithuania, 2008, vol. 2, 619–624.
16. Kirjanova, A. and Dauknys, R. Low-cost wastewater treatment system with nutrient removal for decentralized wastewater treatment. In *Proc. 14th International Conference of Postgraduate Students Juniorstav 2012*. Brno, Czech Republic, Brno University of Technology, 2012.
17. HELCOM. *Helcom Baltic Sea Action Plan*. HELCOM Ministerial Meeting Krakow, Poland, 2007.
18. HELCOM. *HELCOM Recommendation 28E/5. Municipal Wastewater Treatment*. 2007.
19. HELCOM. *HELCOM Recommendation 28E/6. On-site Wastewater Treatment of Single Family Homes, Small Businesses and Settlements up to 300 p.e.* 2007.
20. Ministry of the Environment, Estonia. *The Directive No 1080, 02/07/2009*, 2009.
21. Government of Estonia. Regulation No. 269, 31 July 2001 "Requirements for discharge of waste water into surface water and soil", *Riigi Teataja I*, 2001, **69**, 424.
22. Järvekülg, A. Trophy of the water of Estonian rivers and nutrients limiting the primary production. In *Eesti jõgede ja järvede seisund. Water Pollution and Quality in Estonia*. Environment Data Centre (EDC), National Board of Waters and Environment, Environmental Report 7, Finland, Helsinki, 1993, 29–34.
23. Humborg, C., Mörth, C.-M.¸ Sundbom, M. and Wulf, F. Riverine transport of biogenic elements to the Baltic sea – past and possible future perspectives. *Hydrol. Earth Syst. Sci. Discuss.*, 2007, **4**, 1095–1131.
24. Smayda, T. J. Complexity in the eutrophication–harmful algal bloom relationship, with comment on the importance of grazing. *Harmful Algae*, 2008, **8**, 140–151.
25. Kotta, J., Kotta, I., Simm, M. and Põllupüü, M. Separate and interactive effects of eutrophication and climate variables on the ecosystem elements of the Gulf of Riga. *Estuar. Coast. Shelf Sci.*, 2009, **84**, 509–518.
26. Bryhn, A. C. Sustainable phosphorus loadings from effective and cost-effective phosphorus management around the Baltic Sea. *PLOS ONE*, 2009, **4**; doi:10.1371/journal.pone.0005417.
27. Iital, A., Pachel, K., Loigu, E., Pihlak, M. and Leisk, Ü. Recent trends in nutrient concentrations in Estonian rivers as a response to large-scale changes in land-use intensity and life-styles. *J. Environ. Monit.*, 2010, **12**, 178–188.
28. Elofsson, K. Cost-effectiveness of the Baltic Sea Action Plan. *Marine Policy*, 2010, **34**, 1043–1050.

29. Lenhart, H. J., Mills, D. K, Baretta-Bekker, H., van Leeuwen, S. M., van der Molen, J., Baretta, J. W., Blaas, M., Desmit, X., Kühn, W., Lacroix, G. et al. Predicting the consequences of nutrient reduction on the eutrophication status of the North Sea. *J. Marine Syst.*, 2010, **81**, 148–170.
30. OECD. *Managing Water for All: An OECD Perspective on Pricing and Financing*. Paris, 2009.
31. Ministry of the Environment, Estonia. *The Directive No 1079, 02/07/2009*, 2009.
32. European Community. Directive of the European Council 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources. *Official J. Europ. Commun.*, L375, 1991, 1–8.
33. Ministry of the Environment, Estonia. *Environmental Information Database EELIS*, 2009 (visited 05.01.2009).
34. Alkranel, L. L. C. The impact of stricter wastewater treatment requirements for water companies and other water users. Project Report, Tartu, 2009.
35. Mölder, H. *Reovete puhastusseadmed III*. Tallinna Tehnikaülikool, Tallinn, 1978.
36. Wang, X. J., Xia, S. Q., Chen, L., Zhao, J. F., Renault, N. J. and Chovelon, J. M. Nutrients removal from municipal wastewater by chemical precipitation in a moving bed biofilm reactor. *Process Biochemistry*, 2006, **41**, 824–828.
37. Dueňas, J. F., Alonso, J. R., Rey, Á. F. and Ferrer, A. S. Characterisation of phosphorous forms in wastewater treatment plants. *J. Hazard. Mater.*, 2003, **B97**, 193–205.
38. Ministry of the Environment, Estonia. *Environmental permits information system*; http://klis.envir.ee/klis/ (visited 05.06.2009).

Ühtsete reovee puhastusnormide väljatöötamine Eesti reoveepuhastitele

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On vaadeldud Eesti reoveepuhastite heitvee mõju ulatust suublale ja hinnatud reovee puhastamisele esitatud nõuete asjakohasust. On analüüsitud 83 proovi tulemusi, mis on võetud 47 erinevast Järvamaa reoveepuhasti heitveest. Analüüs on tehtud Järvamaa reoveepuhastite näitel, sest Järvamaa suublad on reostusainete suhtes eriti tundlikud, kuna tegemist on kõrge intensiivsusega põllumajanduspiirkonnaga. Eestis puuduvad ühtsed reovee puhastusnormid reoveepuhastitele, mille reostuskoormus on alla 2000 i.e. On välja töötatud reoveepuhastite reostuskoormuse piirnormid kõikidele reoveepuhastitele, arvestades puhastitest suublasse juhitava reostuskoormuse suurust, piirnormide rakendamisega kaasnevat sotsiaalmajanduslikku mõju ja keskkonnakaitselist aspekti. Suurimat negatiivset mõju keskkonnale avaldavad puhastid, mille reostuskoormus on suurem kui 2000 i.e., kuid reostuskoormuse vähendamine on oluline ka väiksemate kui 2000 i.e. reoveepuhastite renoveerimisel ja ühtsete reoveepuhastusnormide rakendamisel.