

RUDINĖ RIVER ENVIRONMENTAL STATE'S ASSESMENT AND IMPROVEMENT

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Abstract. This article analyses the Ignalina city wastewater treatment plant's (WWTP) impact on water quality of the river Rudinė and presents assessment of environmental quality of this surface water body. Assessment is based on data about the quality of wastewater during the 1998-2008, provided by JSC „Ignalina water“. Anthropogenic impact on water quality of the river Rudinė is evaluated taking into account both point and diffuse pollution sources. Concentrations of total nitrogen (N), total phosphorus (P) and biochemical oxygen demand (BOD₇) in three different sections of the river Rudinė are modeled by employing surface water quality mathematical model MIKE BASIN and compared with maximum allowable concentrations (MAC) defined in national legislation.

According to the results of mathematical modeling, Ignalina WWTP significantly affects total P concentration in the river section from WWTP to the tributary Narsupė: estimated increase is up to 0.6 mg/l and MAC is exceeded 6 times. Total N concentration increases only slightly, while BOD₇ even decreases. The largest amount of diffuse pollution comes from inhabitants who generate wastewater not treated in a centralized system (approximately 78% of BOD₇, 65% of total N, 92% of total P). BOD₇ constitutes the largest part among the common pollution indicators of the river Rudinė (78 %). The tributary Narsupė also has a significant impact on water quality in the river: concentrations of BOD₇, total N and total P in this river segment are respectively 6.37 mg/l, 2.51 mg/l and 0.47 mg/l, and exceed respective maximum allowed concentrations of 6 mg/l for BOD₇, 2.5 mg/l for total N and 0.1 mg/l for total P. Analysis of tax for environmental pollution shows that reconstruction of the WWTP in 2003 has resulted in reduction of this tax approximately by 90% and clearly proves the necessity and viability of the reconstruction.

Keywords: mathematical modeling, wastewater treatment plant, point pollution, diffuse pollution, surface water quality, tax for environmental pollution.

1. Introduction

Water quality of surface water bodies is among top priority environmental problems not only in Lithuania but in the whole European Union (EU). Naturally, these problems receive special attention and probably the largest part of environmental investments within the last decade was oriented towards this environmental sector. Efficient management of water quality in surface water bodies becomes more and more relevant with ongoing changes of industrial scopes and branches, variation of water demand and consumption in households and construction of new, modern wastewater treatment plants (Bukantis et al. 2008; Vaitiekūnienė and Vincevičienė 2001).

Ignalina district is among Lithuanian districts having the highest number of lakes and rivers thus issues of surface water quality are especially relevant. As any other major agglomeration in Lithuania, Ignalina town has its wastewater treatment plant, which was constructed as early as 1975. Since treated wastewater from the plant is discharged into a sedimentation field adjacent to the river

Rudinė, this water body was selected for the assessment described below.

Surface water quality is largely determined by the amounts and properties of pollutants, discharged into water bodies. Municipal utilities, industry and agriculture are recognized as major sources of water pollution. According to the character of dispersion, municipal and industrial wastewater discharges are considered as point pollution sources, while pollution from agricultural territories is defined as diffuse pollution. These sources produce the main chemical pollutants of surface waters: organic substances and compounds of nitrogen and phosphorus.

High concentrations of nitrogen and phosphorus in the water of lakes and slow flowing rivers promote the process of eutrophication – intensive growth of algae and associated increased amounts of organic substances during the warm season. Large amounts of these substances negatively affect chemical status of surface water bodies and, respectively, their ecological status (Bukantis et al. 2008; Conley et al. 2009; Correll 1998).

Hence the main and the most effective measure for improving ecological status of surface water bodies is to

reduce pollution with organic substances and nitrogen and phosphorus compounds. Pollution reduction measures are required by a number of legal documents, such as Council Directive 91/271/EEC concerning urban wastewater treatment, Council Directive 96/61/EC concerning integrated pollution prevention and control, Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy, Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources as amended by Regulations 1882/2003/EC and 1137/2008/EC, as well as Lithuanian legislation transposing requirements provided in above mentioned Directives and Regulations. These legal documents also include requirements for efficient water quality management and achieving the main water policy objective of the EU and Lithuania – good surface water status.

All wastewater treatment plants shall conform provisions of Lithuanian Wastewater Management Regulation (Lietuvos 2006) hence it is important that the assessment of water quality is performed by taking into the account maximum allowable concentrations (MAC) defined in the mentioned legal document.

Although point pollution sources cause major impacts on water environment, large portion of total pollution to rivers and streams also comes from diffuse pollution sources (especially nitrogen compounds).

The main sources of diffuse pollution are fertilizers (both mineral and organic) and erosion products, leached from soil as well as untreated wastewater, discharged into the environment from households not connected to proper wastewater treatment systems. Assessment and control of diffuse pollution is much more complicated since diffused sources are not easily pinpointed and the scope of such pollution is difficult to measure (Aplinkos 2007).

Outdated and worn equipment of Ignalina wastewater treatment plant was not able to meet the new strict environmental requirements and increased quantities of wastewater produced in the town thus reconstruction and rehabilitation of the plant was carried out during 2000-2002. Environmental effects and economical viability of this reconstruction is also taken into account in the assessment provided in this article.

2. Methodology

The Rudinè (Rūdinè, Rūdynè) river (id. 12110038) basin covers an area of 38.5 km², total length of the river is estimated at 14.2 km (Gailiušis et al. 2001, Valstybinè 2009). The basin belongs to Žeimena river basin (2813 km²) and constitutes 0.14 % of its total area. The river Rudinè basin contains two main sub-basins - Narsupè (6.4 km²) and R-1 (2.1 km²). Surface water bodies occupy 1.94 km² (5.0 % of total basin area), while forests cover 1585 ha or 41.18 % of the basin. Total agricultural area within the Rudinè river basin is 1973 ha, and the area of urban agglomerations amounts to mere 0.97 km² and constitutes 2.530% of total basin area.

This article analyses diffuse pollution from three main sources within the river Rudinè basin: pollution from households not connected to central wastewater treatment system, background pollution (leachate from forests) and pollution from agricultural areas. The scope of pollution is based on data of the year 2008 and assessed by the amounts of biochemical oxygen demand (BOD₇), total nitrogen and total phosphorus (kg/year). Pollution loads are calculated by using coefficients provided below.

According to Lithuanian Wastewater Management Regulation, pollution loads of a single inhabitant living in a household without proper wastewater treatment system are as follows (Lietuvos 2006):

$$\text{BOD}_7 \text{ 70 g/day} = 25.5 \text{ kg/year};$$

$$\text{N} - 12 \text{ g/day} = 4.38 \text{ kg/year};$$

$$\text{P} - 2.7 \text{ g/day} = 0.98 \text{ kg/year}.$$

Background pollution loads are estimated by the area of forests in the river basin (data from Aukštaitija integrated monitoring station):

$$\text{BOD}_7 - 2.4 \text{ kg/ha per year};$$

$$\text{N} - 0.8 \text{ kg/ha per year};$$

$$\text{P} - 0.04 \text{ kg/ha per year}.$$

Pollution loads from agricultural areas: (based on data from Graisupis monitoring station, Environmental Protection Agency, Lithuania):

$$\text{BOD}_7 - 4.8 \text{ kg/ha per year};$$

$$\text{N} - 1.6 \text{ kg/ha per year};$$

$$\text{P} - 0.04 \text{ kg/ha per year}.$$

Minor agglomerations within the river Rudinè basin and about 20% of inhabitants of Ignalina town are not connected to centralized wastewater treatment system (managed by JTC "Ignalina water" 1998 - 2008). In 2009, total number of inhabitants living in households not connected to centralized wastewater treatment system amounted to 1859.

Based on data provided above, it is possible to estimate total pollution load (TPL), which is calculated by the following formula:

$$TPL = PP + BP + AP + HP \quad (1)$$

where: *PP* – point pollution; *BP* – background pollution; *AP* – pollution from agricultural areas; *HP* – pollution from households not connected to centralized wastewater treatment system.

Mathematical models allow analyzing the effects of point pollution sources (in our case – Ignalina wastewater treatment plant), identifying, managing and controlling their pollution, predicting impacts on surface water quality (Sakalauskienè et al. 2002). Water quality modeling (by employing water balance and quality model MIKE BASIN) is based on three main parameters: BOD₇, total nitrogen and total phosphorus (Aplinkos 2004, DHI Water & Environment 2003, MIKE by DHI 2011). The results of modeling are expressed as pollution concentrations in any taken point of the river water, taking into

account both point and diffuse pollution amounts and pollution loads.

In order to increase accuracy of the modeling results, the river was divided into three sections: from the river source to the wastewater treatment plant of Ignalina town (4.6 km from the river mouth); from the wastewater treatment plant to the tributary Narsupė (0.65 km from the river mouth) and from this tributary to the river mouth.

Water quality modeling assumes that water is fully mixed at the point of discharge:

$$C = \frac{C_1 Q_1 + C_2 Q_2}{Q_1 + Q_2}; \quad (2)$$

where: C – concentration at the point of discharge (mg/l); C_1 – concentration before the point source (mg/l); Q_1 – water flow before the point source (m³/s); C_2 – concentration of discharge from the point source (mg/l); Q_2 – flow of the discharge from the point source (m³/s).

Because of lacking data from hydrological observations, water flows of the three river sections were calculated using the following formula:

$$Q_f = (A_s \cdot R) / 1000 \quad (3)$$

where: Q_f – water flow of the river (it's section), m³/s; A_s – area of the river basin, km²; R – run-off, l/s/km².

Concentrations, modeled by employing MIKE BASIN were used to calculate water quality in respective river sections using the following formula:

$$C_{riv} = C_b + C_{hp} + C_{ag} \quad (4)$$

where: C_{riv} – concentration of a pollutant in the river water, mg/l; C_b – concentration of a pollutant in discharges from background pollution, mg/l; C_{hp} – concentration of a pollutant in discharges from households not connected to centralized wastewater treatment system, mg/l; C_{ag} – concentration of a pollutant in discharges from agricultural areas, mg/l.

Additionally, it was taken into account that discharges from households not connected to centralized wastewater treatment system within Narsupė basin fall into the lakes Gavys and Gavaitis, where retention of biogenic substances takes place. Retention of these substances in lakes (RET indicator) is expressed by the amount of pollutant / lake area / time unit (g/m²/yr). For the purpose of this article, RET indicator was estimated by employing the method of mass balance, i.e. by estimating the difference between the inflow and outflow of biogenic substances. The following retention values of pollutants from households not connected to centralized wastewater treatment system were calculated for the lakes Gavys and Gavaitis: 28770 kg/yr of BOD₇, 2630 kg/yr of total nitrogen and 1315 kg/yr of total phosphorus.

Economical appraisal of reconstruction of the wastewater treatment plant is based on legally established

order of calculation for environmental pollution taxes (Lietuvos 1999, 2000, 2003, 2009) and estimated for the time period between 1998 and 2008. Tax for actual discharged pollution per time unit (in our case – per year) is calculated by the following formula:

$$T_n = A_n \cdot T \cdot I_n \cdot [c] \quad (5)$$

where: A_n – amount of actually discharged pollutant per time unit (in our case – per year), t; T – tariff (tax rate) for respective pollutant, Lt/t; I_n – indexation coefficient of the taxation period; $[c]$ – coefficient (equals 1.2); n – accounting period (in our case – year).

During the time period between 1998 and 2008, wastewater discharges from the treatment plant operated by JTC „Ignalina water“ did not exceed amounts defined in their permit for integrated pollution prevention and control (IPPC permit) hence pollution tax is calculated for the amounts of actually discharged pollutants.

3. Results and analysis

Comparative analysis of data on the quality of wastewater during the 1998-2008 period, provided by JTC „Ignalina water“ and calculation of point source pollution load and diffuse pollution load allowed to estimate total pollution load (TPL) within the river basin (Figure 1). The results of calculations show that diffused pollution is largely determined by households not connected to centralized wastewater treatment system, while background pollution generates the smallest fraction of all three pollutants (BOD₇, N and P). Comparison of these pollutants (parameters) shows that BOD₇ constitutes the largest part of total pollution load, while total phosphorus – the smallest.

Concentrations of each pollutant in the three above mentioned river sections are further assessed by employing mathematical modeling of water pollution dispersion and using data on point and diffuse pollution sources as well as total pollution load.

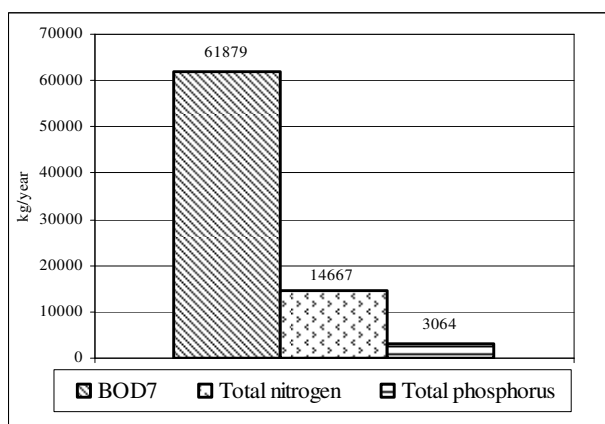


Fig 1. Total pollution load of BOD₇, total nitrogen and total phosphorus in the river Rudinė basin in 2008, kg/year

The results of modeling allow evaluating water quality of the river Rudinė and the effects of major point pollution sources and tributaries.

Results of the assessment indicate that water quality according to BOD₇ is 4.57 mg/l, i.e. does not exceed maximum allowed concentration (MAC) after consider-

ing the river basin area of the section from the river source to the wastewater treatment plant of Ignalina town (4.6 km from the river mouth), and taking into account diffuse pollution load from this area.

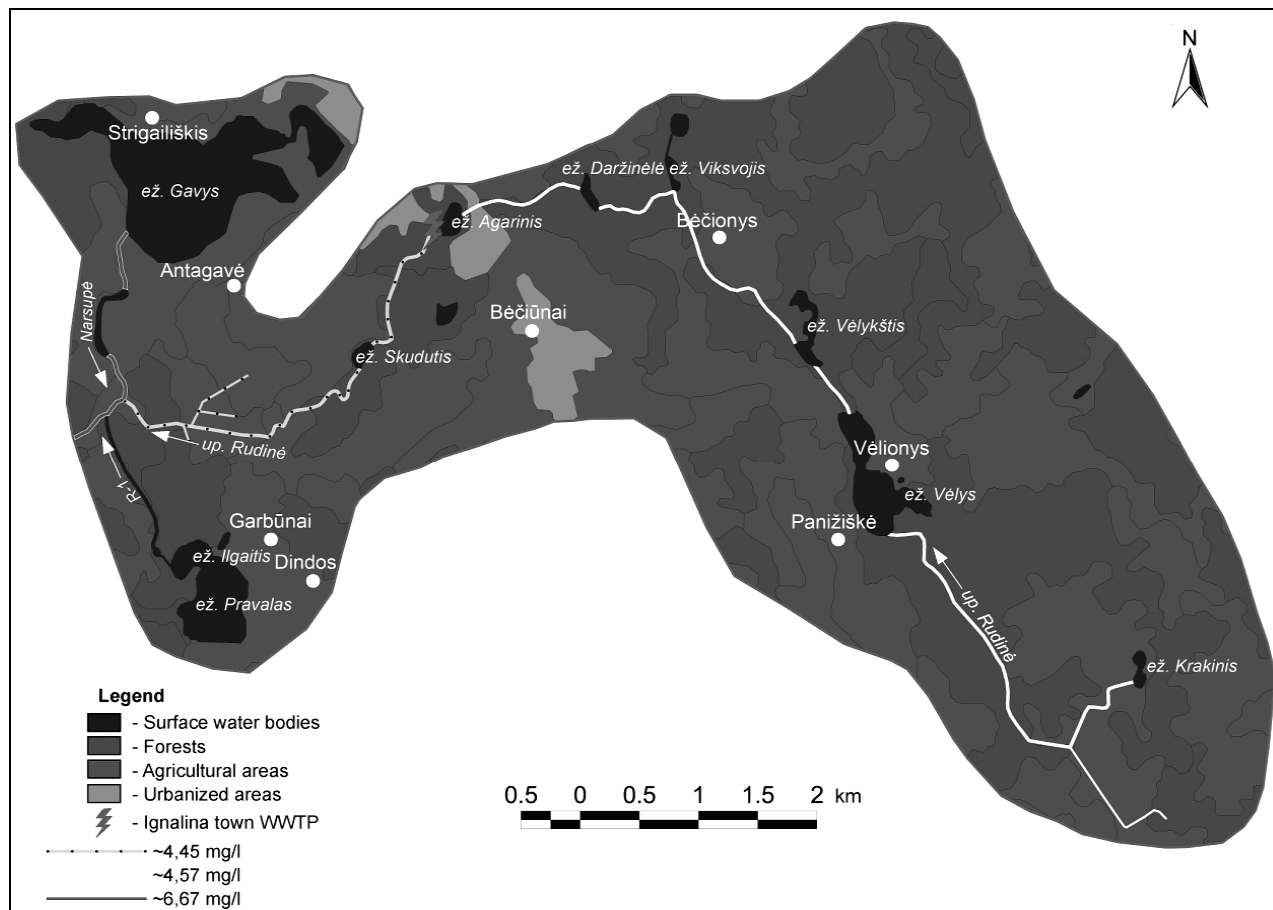


Fig 2. Concentrations of BOD₇ in the river Rudinė, mg/l

However, the tributary Narsupė has a significant negative impact and water quality decreases to 6.37 mg/l BOD₇ (Figure 2).

It is assumed that this significant increase is caused by wastewater discharges from households in this part of the river basin which are not connected to centralized wastewater treatment system: there are totally 1614 inhabitants living in these households and it constitutes to 87% of total number of inhabitants living within the river Rudinė basin who generate wastewater not treated in a centralized system.

The above methodology was also used to estimate concentrations of total nitrogen and phosphorus and to assess their dynamics in the river Rudinė.

Contrary to the estimations of BOD₇, concentrations of total nitrogen are different in respective sections of the river Rudinė (see Figure 3). In the section from the river

source to the wastewater treatment plant of Ignalina town, concentration of total nitrogen (taking into account diffuse pollution) amounts only to 1.23 mg/l, while maximum allowed concentration is 2.5 mg/l. However, at the wastewater discharge point concentration of total nitrogen increases to 1.95 mg/l thus it is assumed that wastewater treatment plant may have an effect on concentration of total nitrogen in the river Rudinė. In the river section from the tributary Narsupė to the river mouth, concentration of total nitrogen is significantly higher and reaches 2.51 mg/l, exceeding maximum allowed concentration of 2.5 mg/l. Once again, it is very likely that higher amounts of nitrogen are related to wastewater discharges from households in this part of the river basin which are not connected to centralized wastewater treatment system.

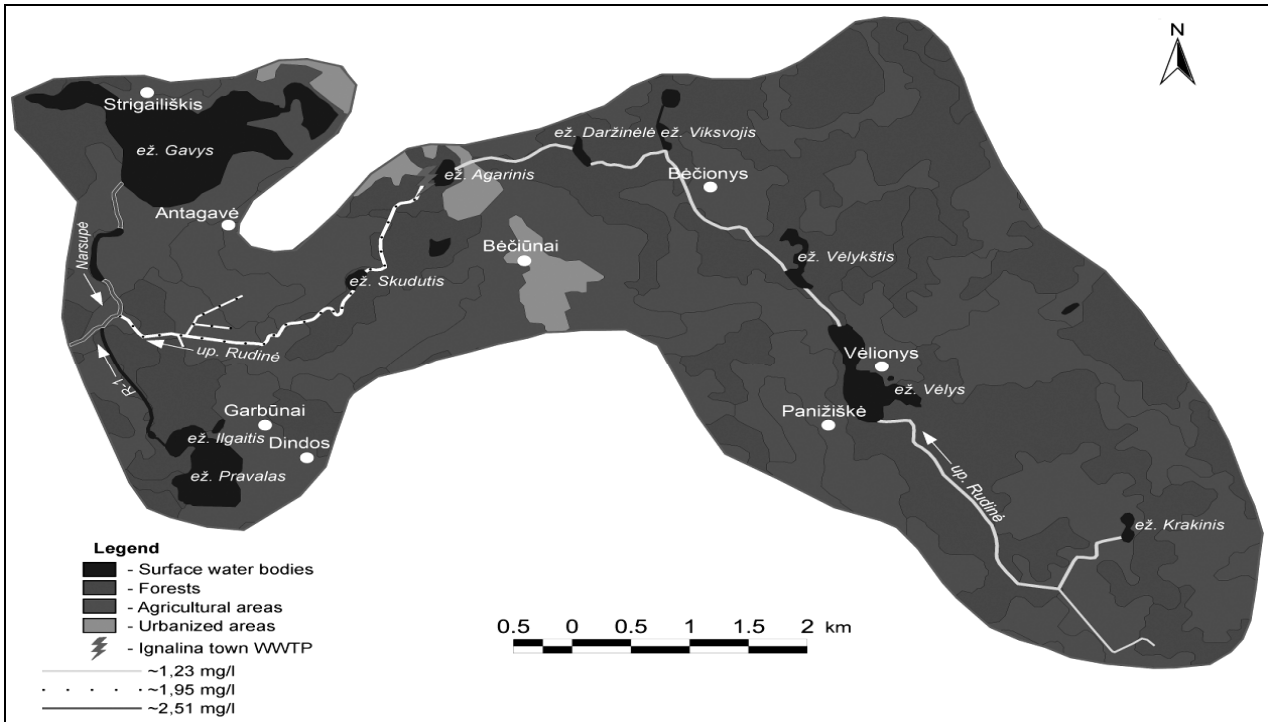


Fig 3. Concentrations of total nitrogen in the river Rudinė, mg/l

Results of mathematical modeling show quite different tendencies in case of total phosphorus (see Figure 4). Concentration of total P is only 0.1 mg/l in the section from the river source to the wastewater treatment plant of Ignalina town, however it increases up to 0.6 mg/l (MAC – 0.1 mg/l, hence it is 6 times exceeded) in the section from the wastewater treatment plant to the tributary Narsupė and slightly decreases down to 0.47 mg/l (i.e. still exceeds MAC by 4.7 times) in the section from this tributary to the river mouth.

In general, the results of mathematical modeling allow assuming that both Ignalina WWTP and the tributary Narsupė affect the amounts of total phosphorus and nitrogen in the river Rudinė, however discharges from the WWTP have no negative impact in terms of biochemical oxygen demand (BOD). On the contrary, concentration of BOD₇ decreases after the WWTP discharge point.

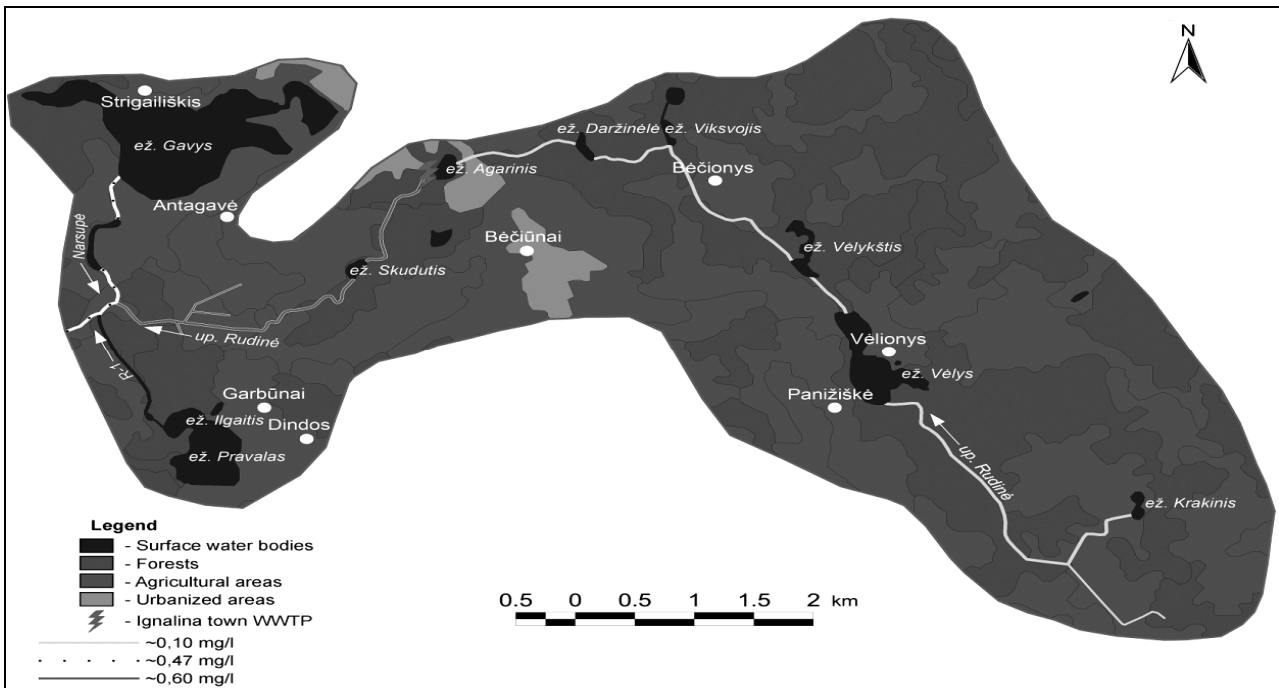


Fig 4. Concentrations of total phosphorus in the river Rudinė, mg/l

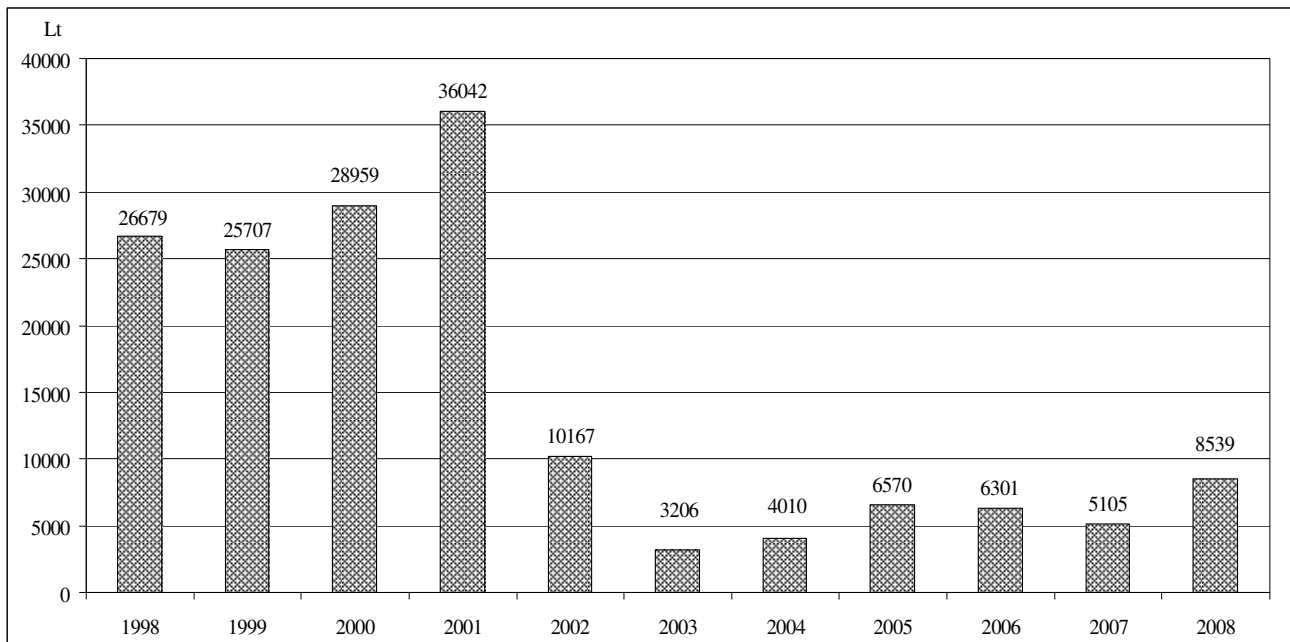


Fig 5. Pollution tax for actually discharged quantities of BOD₇, total nitrogen and total phosphorus (1998 – 2008)

Figures 2 and 4 clearly indicate significant effect of the inflowing river Narsupė on water quality of the river Rudinė. This phenomenon is observed in case of every modeled parameter and can be explained by large number of inhabitants living in households which are not connected to centralized wastewater treatment system within this part of the river Rudinė basin.

Calculations reveal that reconstruction of Ignalina wastewater treatment plant (2002-2003) resulted in significant decrease of environmental pollution taxes paid for actual discharge of BOD₇, total nitrogen and total phosphorus during the investigated time period from 1998 to 2008 (see Figure 5). Compared to the year 2001 the pollution tax decreased by 91% and a further decrease can be seen until the end of 2003. The pollution tax slightly increased during 2004-2006, however remained significantly lower compared to the reporting period of 1998 – 2002 (by 74-82 %). It can be concluded that the tax remained relatively stable during the 2003-2008, except significant decrease in 2003 and a slight increase in 2008. Analysis shows that pollution by total phosphorus has constituted the largest part (up to 60%) of the pollution tax since 2003 and the fee is significantly affected by total yield of treated wastewater which is respectively influenced by different meteorological and other environmental factors.

The above mentioned decrease in pollution tax and estimation of potential costs for river remediation (up to 6.13 million Lt) which might have been needed if the wastewater treatment plant was not reconstructed, clearly prove the necessity and viability of the WWTP reconstruction.

4. Conclusions

The main point pollution source within the river Rudinė basin is wastewater treatment plant of Ignalina

town, which discharges treated wastewater into a sedimentation field adjacent to the river Rudinė.

The results of mathematical modeling revealed significant impact of discharges from wastewater treatment plant of Ignalina town on the water quality in terms of total phosphorus in the river section from the wastewater treatment plant to the tributary Narsupė (concentration of total P reaches 0.6 mg/l and 6 times exceeds MAC). However, amounts of total N are not significantly affected, and concentration of BOD₇ actually decreases.

The results of mathematical modeling show that the largest amount of diffuse pollution is discharged from households not connected to central wastewater treatment system: approximately 78% of BDS₇, 65% of total N and 92% of total P.

Comparative analysis of the three water pollutants (parameters) shows that BOD₇ constitutes the largest part (up to 78%), while total phosphorus – the smallest (only 4%). Total nitrogen reaches 18% of total pollution load.

Water quality is heavily affected by the tributary Narsupė, which falls into the river Rudinė at a distance of 0.65 km from the river mouth: concentration of BOD₇ reaches 6.37 mg/l, total N – 2.51 mg/l, total P – 0.47 mg/l, i.e. maximum allowed concentrations for all three pollutants are exceeded in the river section from the tributary Narsupė to the river mouth.

Economical appraisal of environmental pollution taxes, calculated according to Lithuanian legislation indicates a significant decrease of the taxes (approximately by 90%) related to reconstruction of Ignalina wastewater treatment plant in 2003. This decrease as well as estimation of potential costs for river remediation which might have been needed if the wastewater treatment plant was not reconstructed proves that the

WWTP reconstruction was timely, necessary from the environmental point of view and economically viable.

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