Miina Härma Gymnasium

Uku Andreas Reigo

Artificial Lakes as Sources of Pollution: the Example of Haage and Ropka Water Reservoirs

GLOBE program student report

Supervisors:
Ronald Laarmaa, MSc
Helgi Muoni, PhD

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Abstract

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Haage and Ropka water reservoirs were created in the 1970s near pre-existing settlements. Both bodies of water are relatively shallow and have had problems with water quality, due to which sediment and vegetation removal procedures have been carried out. Due to the increase of human population in the settlements surrounding the lakes, the ecological status of these lakes changes rapidly, being additionally empowered by the quick flow of water. Therefore, contemporary analyses have to be made to monitor them.

The aim of this paper is to analyse the water quality of Haage reservoir and Ropka reservoir, also to find out whether sediments stuck behind the dam negatively influence the quality of the water in the outflow.

Recording of the characteristics of the sites and collecting of water samples were carried out at five timepoints from September 17 to November 24, 2017. To measure different water quality parameters, the YSI Pro Plus 6600 (YSI Incorporated) and the AQUANAL™-Oekotest Water Laboratory (Sigma-Aldrich) testcase were used. Total phosphorus and total nitrogen concentrations were measured in the laboratories of the Estonian University of Life Sciences' (EULS) Chair of Hydrobiology and Fishery.

Using the aforementioned data, the amount of phosphorus and nitrogen moving through the lake was calculated (the respective increase or decrease reflecting the effect of the body of water and the dam in question).

We found that the amount of nitrogen increased in both lakes, more in Ropka, while the amount of phosphorus rose slightly in Haage, but decreased severely in Ropka.

Uku Andreas Reigo, author

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1. Introduction

A water reservoir is an artificial body of water, created to enhance a landscape, satiate agricultural or other needs for water, serve as a destination for drainage pipes, or prevent flooding downstream. Water reservoirs can also be used to generate energy or serve as a spot for fishing and recreation. Usually, water reservoirs are created by blocking a pre-existing source of flowing water with a dam, forcing the water to rise to a pre-determined level (Veetõkestusobjektide kaardistamine ja …, 2009). Inevitably, reservoirs and other similar artificial bodies of water are ecosystems like any other. The influence of human activities upon the quality of their water is intense, due to them almost always being located next to the agricultural or residential development. Frequent tests on the water quality and composition as basic surveillance methods are increasingly important here to support the sustainability and diversity of these artificial ecosystems.

In Estonia, water reservoirs also serve the purposes stated above. This paper focuses on Haage and Ropka water reservoirs, which are located in close proximity to Tartu, the second largest city in Estonia. To evaluate the influence of human activities upon the water quality, repeated measurements of nitrogen and phosphorus at the inflow and outflow of the two reservoirs were collected and analysed.

As both lakes are impounded, analysing the water at the inflows and outflows may give insight as to whether the dams have any effect on the water quality due to sediments getting stuck behind them.

We suggest that the dams do have a negative effect, but the lakes are still suitable for recreational use, as the residential and agricultural development is not extreme.

1.1. Location and general characteristics of Haage and Ropka water reservoirs

Haage and Ropka reservoirs are located in close proximity to residential areas and are also in a comfortably short driving distance from the city of Tartu. This is the reason why both have been used mainly for recreational purposes, including swimming and fishing. After the creation of the reservoirs, both nearby settlements experienced an increase in the number of family residences and cottages near the lakes, indicating that the existence of the lakes was a factor in the population increase (Laul & Rosin, 2005). Both lakes also have some agricultural development near them, possibly contaminating the water. As both lakes serve as public places for fishing and swimming, their water quality is a matter of continuing importance.

Haage reservoir, also known as Loku reservoir, is located about 8 km from Tartu. The surface area is around 9 ha and the average depth is 1.9 m, while the maximum depth is 3.9 m (Keskkonnaregister, viewed 26.02.2018). It is surrounded by the villages of Haage and Pihva (figure 1).

Figure 1. Location of researched sites – Haage and Ropka reservoirs (from left: in Europe, in the Baltics and map of south-west area of Tartu, including Haage and Ropka water reservoirs marked with red circles). The merging point of the outflowing rivers is indicated with a grey arrow (Republic of Estonia Land Board map application (visited 27.02.2018), with author's additions).

Haage reservoir was created in 1977 with a planned 12.4 ha surface area. In 1994, there were reports of swimmers getting rashes from the water likely due to agricultural poisons (but the reason is still unknown). The reservoir was cleaned after that (Haage küla arengukava …, 2006).

Ropka reservoir is located about 9 km from Tartu. The surface area is also about 9 ha and the average depth is 2.3 m (Keskkonnaregister, visited 26.02.2018). It is located near Külitse village. Lake Ropka was created in 1978 to raise the recreational value of the surrounding area. The lake was emptied in 2010 and a large-scale removal of mud and vegetation was carried out in 2011.

Haage and Ropka reservoirs are not located on the same river, though the river Kikkaoja which is flowing through Haage reservoir merges downstream with the river Ilmatsalu which is flowing through Ropka reservoir.

The amount of residential development surrounding lake Ropka is much greater than that of lake Haage. It is important to notice that residential area reaches immediately the coastline of lake Ropka along about 2/3 of its length, whereas for lake Haage, building line has been planned further away from the coastline.

2. Materials and methods

The anthropogenic external load (diffuse pollution) is a major factor influencing the ecological status of inland water bodies that are located in close proximity of human establishments. This can be evaluated and analysed after measuring several observable characteristics. For this purpose, we chose some hydrophysical and hydrochemical quality indicators, namely the amounts of nitrogen (N) and phosphorus (P) to reflect the pollution state of the two reservoirs.

To investigate whether the reservoirs have been polluted by human activities and/or sediments getting stuck behind the dam, we measured the amount of nitrogen (N) and phosphorus (P) in the in- and outflow. An increased amount of biogenes in the outflow indicates internal or external nutrient enrichment from the catchment area.

For that purpose, water samples were collected from the inflows (IF) and outflows (OF) as shown on the map below (figure 2) and were stored in airtight plastic containers (500 ml).

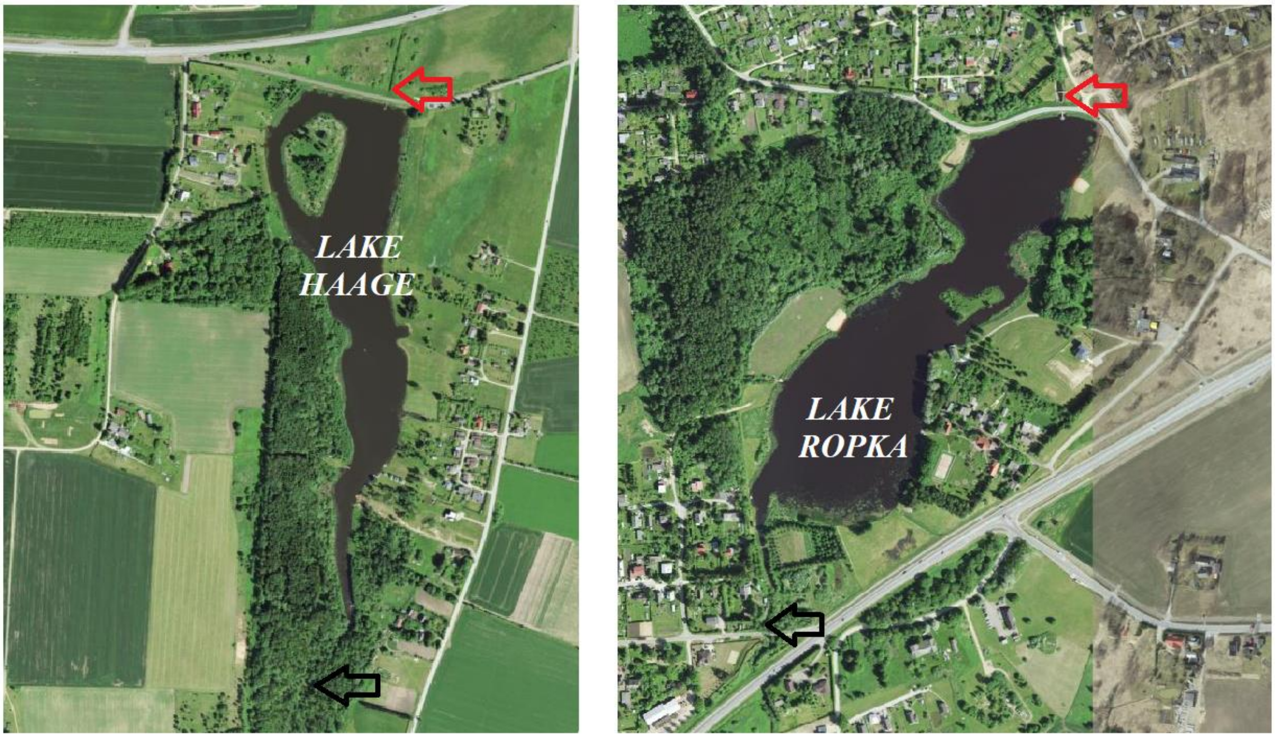

Figure 2. Investigation sites of Haage and Ropka reservoirs. Black arrow indicates location of inflow and red arrow indicates location of outflow (Republic of Estonia Land Board map application (visited 27.02.2018), with author's additions).

Samples were taken at 5 consequent timepoints as follows:

1. September 15, 2017
2. September 17, 2017
3. October 22, 2017
4. October 24, 2017
5. November 24, 2017

Measurements of pH, phosphate (PO_4), nitrate (NO_3), nitrite (NO_2), ammonium (NH_4) and total hardness (Ca/Mg) were carried out using the AQUANAL™-Oekotest Water Laboratory (Sigma-Aldrich) testcase for the water samples collected at the timepoints 1-4.

Measurements of temperature (˚C), oxygen saturation (%), oxygen concentration (mg/L), electrical conductivity (µS/cm^2), total dissolved solids (TDS, mg/l), pH and salinity (PSU) were carried out using the YSI Pro Plus (YSI Incorporated) multisensor probe at all timepoints.

The samples taken at the last timepoint (November 24, 2017) were sent to the laboratories of Estonian University of Life Sciences (EULS) to measure the concentrations of total phosphorus (P) and total nitrogen (N).

Measuring the volumetric flow rate (Q, m^3/s) of the rivers Kikkaoja and Ilmatsalu (in- and outflows of the reservoirs, figure 2) based on the methods described by A. Maastik (2006) using only the float method (or cross-section method). For that, the average depth and average width of flow cross-section were measured with a tapeline or a rope with meter markings. The used river-sections during the measurements were 10 meters long where possible, but at some locations, the sections had to be reduced to accommodate special circumstances. Using a stopwatch we measured the time a matchstick took to flow from one end of the chosen section to the other. This process was repeated 3-4 times at each location.

By multiplying the concentrations of nutrients with the amount of water flowing through the river at our point of measurement, total daily amounts of nitrogen and phosphorus flowing through these spots were calculated. This process is also known as investigation of water-mass balance which could give us answer about the hydrological regime and the chemical flow and quantities.

3. Results and discussion

3.1. Data collected before the restoration works

Research and analysis of these lakes have been conducted twice in the past (according to our knowledge). The first one was carried out in 1994 and only Haage reservoir was examined therein. The paper, “Loku veehoidla seisundist”, was written by Helle-Viivi Tolk and Tanel Punga, students of Hugo Treffner Gymnasium.

The second paper, ”Ropka (Külitse) ja Loku (Haage) veehoidlate seisundist”, was written by Erkki Laul and Riho Rosin, students of Tartu Kivilinna Gymnasium. They researched the same two lakes, Ropka and Haage, in 2005.

3.2. Environmental characteristics of investigated sites

The in- and outflows varied greatly in terms of the surrounding landscape and features (figure 3). In lake Haage, the inflow (figures 2 and 3A) was about 200 meters inside forest with very muddy ground at some places (figure 4). The stream appeared not to be used regularly, as there were no signs of human activity. The outflow of the same reservoir was directly next to a road with moderate amount of traffic and there was a small parking place about 50 meters from the dam (figures 2 and 3B).
The measuring site for the inflow of lake Ropka was directly under the bridge on the outskirts of the settlement (figures 2 and 3C). The outflow was also next to a road, in the middle of the settlement, with residences nearby in all directions (figures 2 and 3D). It also had a bridge for pedestrian use. On the days of probing, a house was under construction about 50 meters from the outflow.

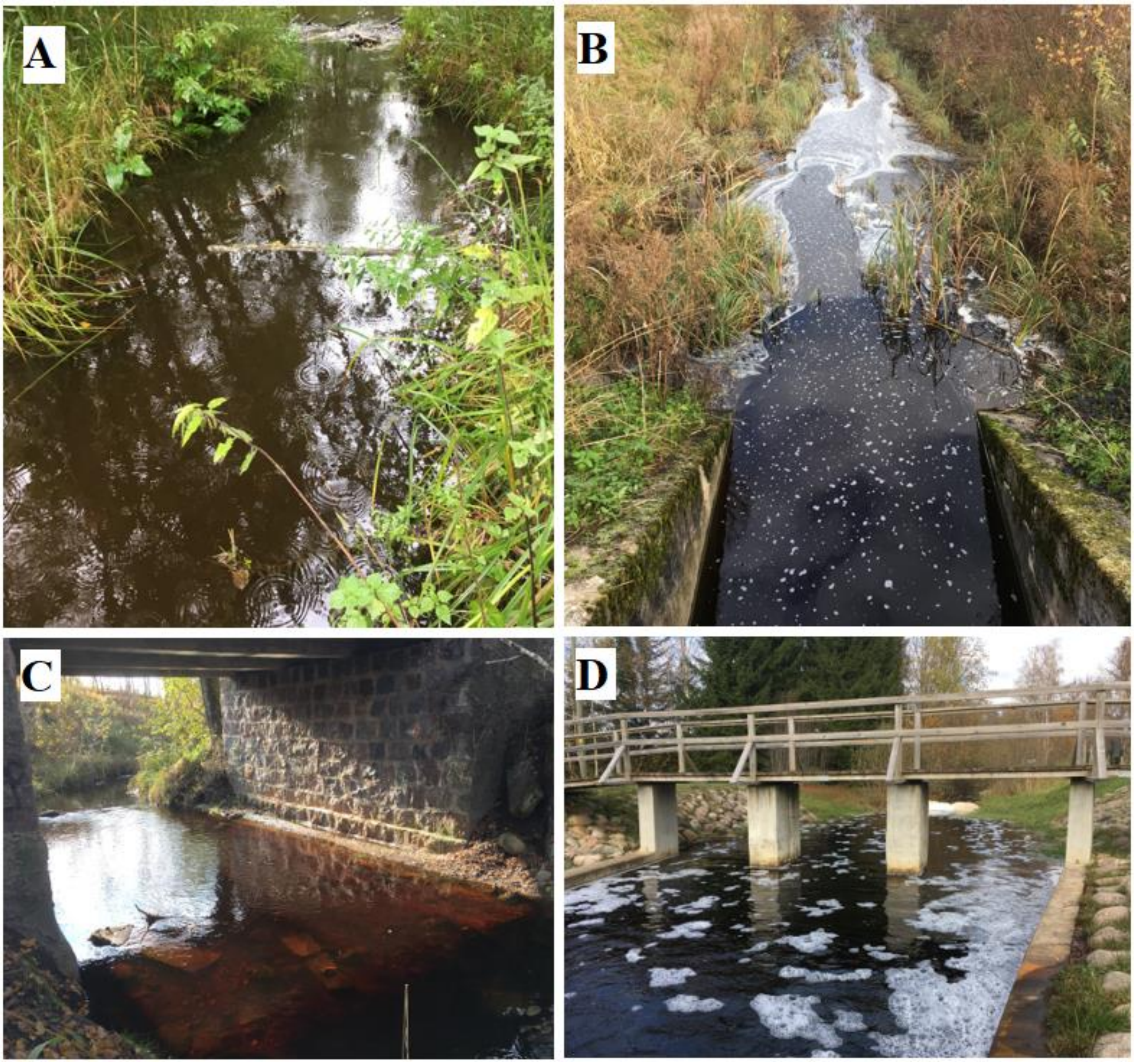

Figure 3. In- and outflows of Haage and Ropka reservoirs. A – inflow of Haage reservoir; **B** – outflow of Haage reservoir; **C** – inflow of Ropka reservoir; **D** – outflow of Ropka reservoir. Photos by R. Laarmaa, taken 15.09.2017 (A) and 22.10.2017 (B, C and D).

Figure 4. Collecting water samples near the inflow of Haage reservoir, where the ground is not stable. Author after arrival to the measuring site on September 15th, 2017 (photo: R. Laarmaa).

Dynamics of some environmental parameters measured by multimeter probe YSI Pro Plus 6600, such as conductivity (E, $\mu S/cm^2$), pH and oxygen concentration (O_2, mg/L), are shown in figure 5.

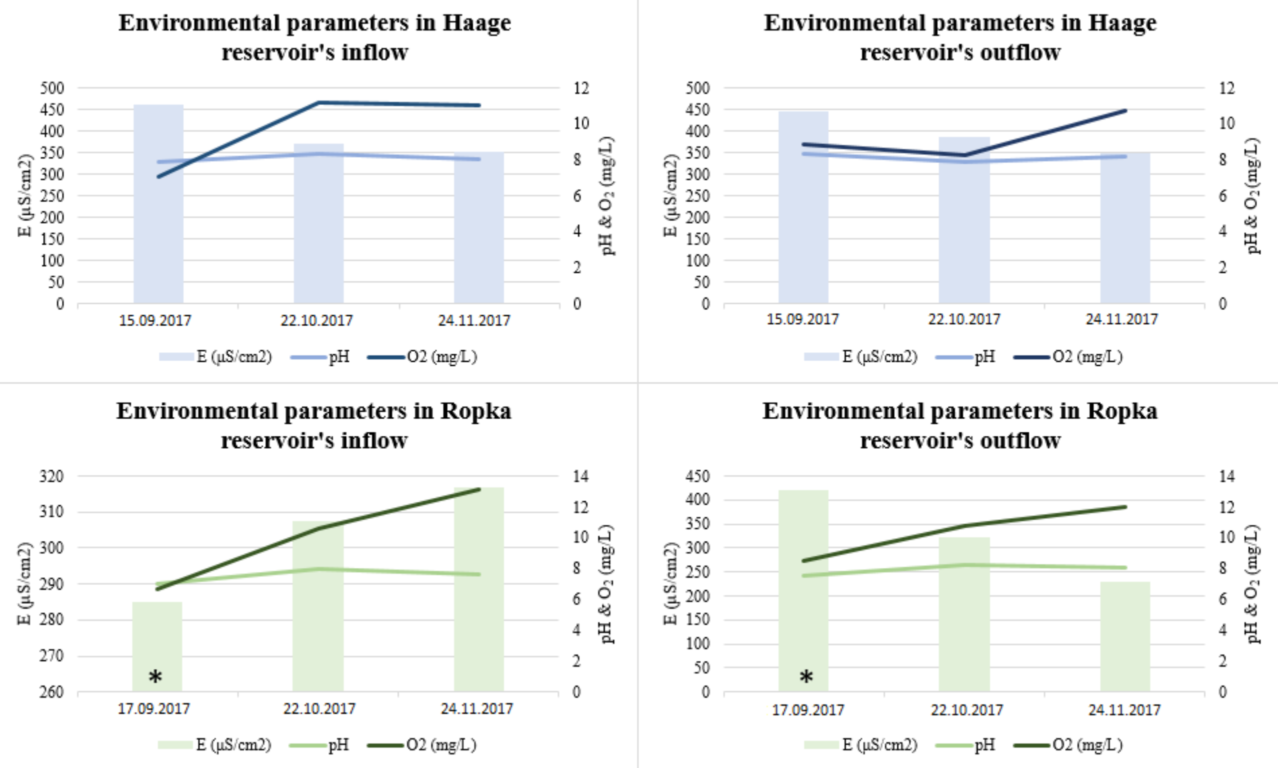

Figure 5. Some environmental parameters in Haage (blue) and Ropka (green) reservoirs 15.09.2017 – 24.11.2017. * *There were technical problems with the multisensor, therefore pH values that are reported in 17.09.2017 are measured with the AQUANAL™-Oekotest Water Laboratory.*

These results (conductivity and pH) indicate that the water in the reservoirs can be described as quite hard and therefore the reservoirs are quite tolerant ecosystems. Oxygen conditions indicate the good quality of the water ecosystem.

Other measurements, which were made with AQUANAL™-Oekotest Water Laboratory testcase were not sensitive enough (measured results were below measurement tolerance). A possible explanation for this may be the inaccuracy of the water laboratory's color scale, as while the scale is accurate enough to show whether there is something seriously wrong with the lake, the difference in color between two adjacent readings is too subtle and the difference in value too big to get any meaningful results.

The readings of phosphate, nitrate, nitrite, and ammonium were either the lowest or second-lowest reading, suggesting that the lake is in good condition. pH readings were within the normal limits for freshwater lakes and total hardness also suggested that the lake is in good condition.

3.3. Water-mass balance investigations

Samples collected at the last timepoint, November 24, 2017, were sent to the Estonian University of Life Sciences laboratories. There, the concentrations of nitrogen and phosphorus were measured. For analysing total nitrogen in the water samples the samples were first mineralized with potassium persulfate ($K_2S_2O_8$) and were measured with UV-spectroscopy. The accuracy of the method is 0.03 mg N per liter. Total phosphorus was analysed colorimetrically with ascorbic acid and ammonium molybdate reactive. The method is based on Hansen & Koroleff (1999).

To find out the amount of phosphorus and nitrogen flowing through the in- and outflows, the total flow of water is required. By multiplying the flow of water during a 24-hour period with the concentration of N or P, the amount of N or P moving through a point during 24 hours can be found. A big increase in N or P when comparing the inflow and outflow reflects to pollution occurring within the reservoir. The results of water flow measurements and the daily amounts of nitrogen and phosphorus passing through the in- and outflows are shown in figure 6.

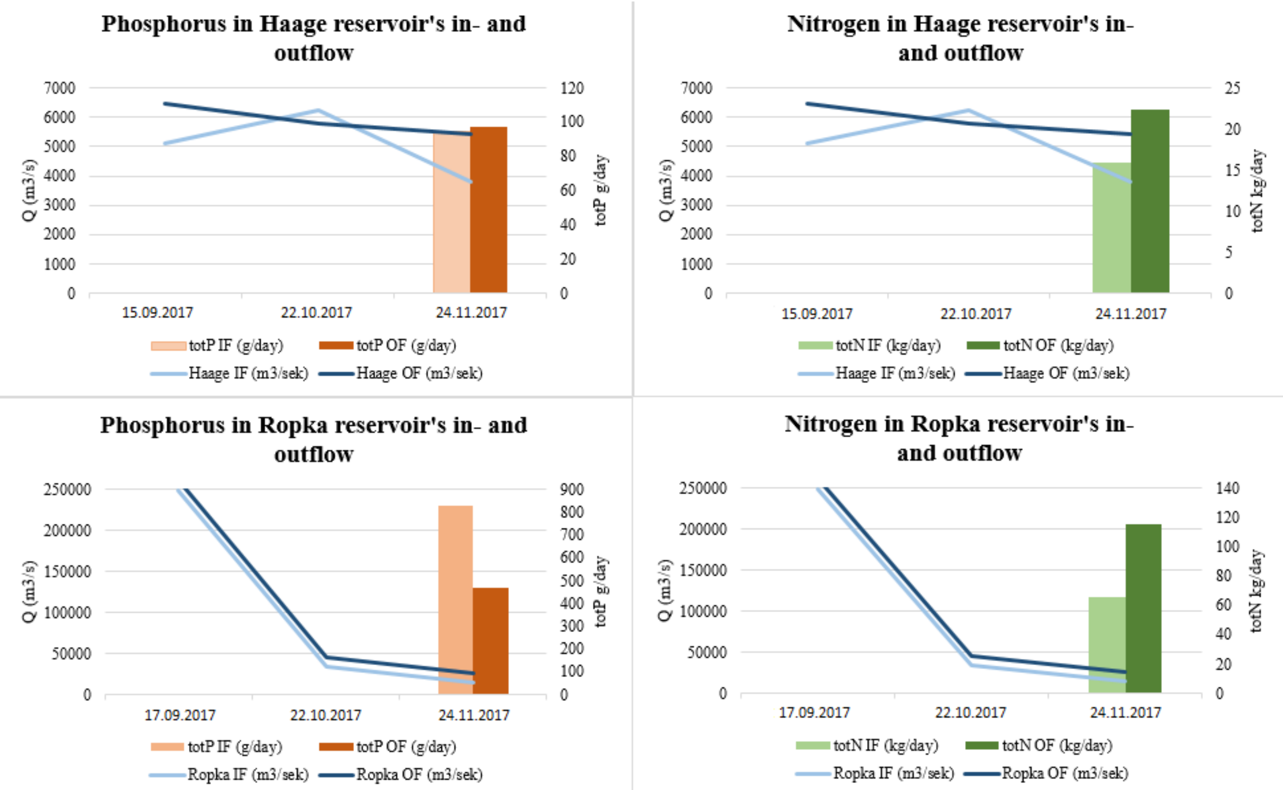

Figure 6. Results of water-mass balance investigations of Haage and Ropka reservoirs.

Q – volumetric flow rate, totN – total nitrogen, totP – total phosphorus, IF – inflow, OF – outflow.

Differences between in- and outflow nutrient amounts indicate instability of ecosystem chemical status and the possibility of anthropogenic external load.

As the amounts of phosphorus and nitrogen rose only slightly in Haage, we can state that the reservoir is in a stable condition. In Ropka reservoir, however, the difference between N and P amounts in the in- and outflow was more remarkable and also contradirectional. Due to this, we can say that Ropka reservoir is in a less stable condition than Haage, but considering the absolute values of the measurements, both lakes are still in a good condition, with no severe problems.

As mentioned above, while in Haage reservoir, both P and N amounts rose slightly, in Ropka the amount of N rose severely while the amount of P decreased. The greater increase in N also correlates with the fact that there is much more residential development around lake Ropka than around lake Haage (figure 2).

Another possible explanation for the severe increase in nitrogen amounts may be the nitrogen cycle. The concentrations of phosphorus and more severely nitrogen are likely influenced by the seasonal dynamics of nitrogen. Nitrogen compounds are much more mobile during autumn period as part of the natural nitrogen cycle. This is due to plant and animal matter dying as the summer ends and is then being broken down in the lakebed. As our sample collection period was late autumn, this may explain a substantial part of the nitrogen rise in both lakes.

Furthermore, the rise in nitrogen amounts may be enforced by the sediments getting stuck behind the dam as the water is slowed down. These sediments are a vault of nutrients for any plants in the lake and can serve as an engine of eutrophication. To evaluate the input from this, a thorough investigation of sediment thickness, compound and distribution would be appropriate.

Conclusions

While the increase in nitrogen in both reservoirs was severe, more measurements and at different times of the year must be carried out to state for certain whether the dams are sources of pollution - the collection and analysing of samples must be carried out at least 4 times a year, at least once in each quarter (Juhend paisjärvede tõttu…, KIK). Another reference (Cooke et al, 2005) even suggests that the investigations should be carried out throughout a year (at least 12 times per year).

Also, we were lacking accurate measurements of organic matter (BHT_5) and ammonium (NH_4), which would have provided more insight into the lakes' condition. However, the measurements so far indicate that the beneficial influence from previous restorations and renovations of the lakes is still effective.

There is no result that indicates a decrease in the usability of lakes Haage and Ropka for recreational purposes, on the contrary, the swimming places are renewed (along with the accessibility to the lakes) and the dams are still in very good condition. While our research suggests the latter do indeed have some negative effect on the water, for the time being this does not exceed the self-balancing capacity of these lakes as ecosystems and does not require intervention.

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