CBC 2014-2020
SOUTH-EAST FINLAND - RUSSIA

WATER MEETS PEOPLE
LEARN, ACT & INFLUENCE

SEVIRA

Report on continuous water quality measurement in Rakkolanjoki, Russia

Sirkka Tattari & Jari Koskiaho
Finnish Environment Institute
SYKE

Content

Purpose of measurement

Continuous water quality measurements are increasingly being made for a variety of purposes both in Finland and in Russia. In Finland, such type of measurements has been made for more than ten years and they have mainly been project-based. Projects in Finland have led to situation that today a nationwide network of continuous meters is currently being built in Finland (Lepistö ym. 2019). In Russia, less measurements have been made, but in recent years their use has increased in projects (see e.g. ECO-Bridge project https://www.syke.fi/en-US/Research__Development/Research_and_development_projects/Projects/Joint_crossborder_environmental_monitoring_system_Ecobridge)
.
The main objectives of the measurement typically are:

- Testing of a new measurement method
- On-line measuring systems will provide reliable real-time data on the quality of water, if the quality assurance is taken care of
- Measurements give more accurate information on the uncertainty in the nutrient loading estimate
- Measurements can be used in the calibration and testing of models
- Measurements provide information on sudden load emissions that may occur in the catchment area
- Continuous water quality monitoring improves citizens' access to information on the environment

Although the measuring system is so-called automatic on-line monitoring, it needs always well-organized on-site maintenance (e.g. Pellerin et al. 2013). In addition, measurements also require quality control (see Tattari et.al. 2019; Wagner et al. 2006). Quality control is usually made manually, but also automatic methods exist (Kahiluoto et al. 2019).

The aim of the SEVIRA project was primarily to test the operation of a continuous water quality measurements in a transboundary river. Another goal was to make recommendations on how to make the measurements functional and reliable. Continuous water quality data can also be utilized to optimize routine manual water sampling interval and timing.

Rakkolanjoki catchment

The Rakkolanjoki cross-border catchment (215 km^2) is located in south-eastern Finland and north-eastern Russia. The 33-km long Rakkolanjoki river drains the watershed into the Bay of Vyborg in the Gulf of

Finland. The average annual uncorrected precipitation in the area during the last decade was 552 mm. The land elevation ranges between 0 and 115 m above sea level, the highest altitudes being in the northern parts of the catchment (Figure 1).

Rock (<1m soil layer) is the dominant (37%) soil type, followed by coarse (20%), clayey (17%), moraine (11%) and peat (11%) soils. In terms of land use, forest (62%) is the dominant class. Agricultural areas (11%) are concentrated in the northern parts of the catchment in the Finnish side, on mostly clayey soils. Urban areas – mostly by the Finnish city of Lappeenranta – cover 7% of the Rakkolanjoki catchment. Water occupies 6%) and wetlands 2% of the catchment (see Figure 1).

The average (2000–2016) flow (Finnish side) was 2.2 $m^3 s^{-1}$ and it ranges between 0.3 and 19 $m^3 s^{-1}$. In the Rakkolanjoki catchment there is one major source of point pollution, i.e. the wastewater treatment plant of the Lappeenranta city (72 000 inhabitants). Within the Finnish side of the catchment there are 1 343 people living in properties not connected to the sewer networks, i.e. with onsite wastewater treatment. On top of this there are 72 summer cottages.

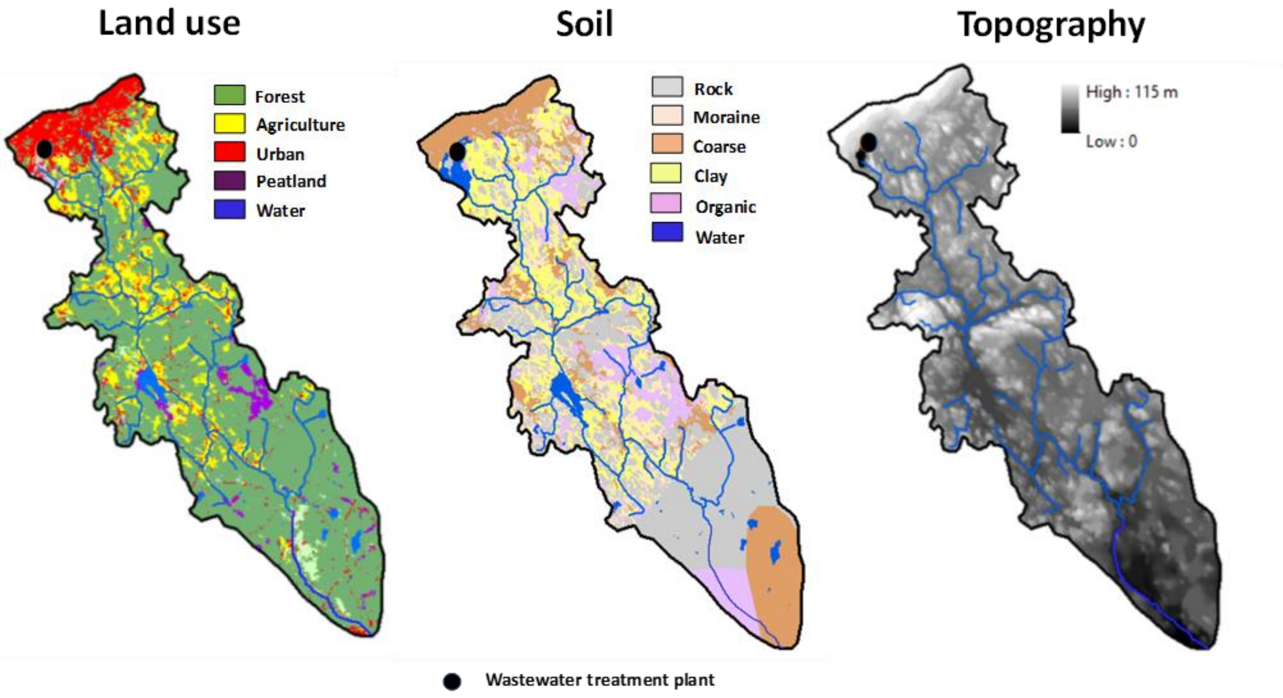

Figure 1. Land use, soil and topography of the Rakkolanjoki watershed. The figures also show the main river and tributaries of the river and the lakes.

Equipment supplier

At the beginning of the project, it was decided that the device is procured from Finland. Two responses were received to the official tender. Of these two, the EHP Environment Oy was chosen as the equipment supplier. Throughout the tender, we assumed that the equipment supplier can visit the site to service the equipment when needed. However, local maintenance of the device was planned to be done by a Russian partner. After all, this plan did not materialize, since the Covid-19 pandemic changed plans. From March 2020, the FIN-RUS border was closed and travelling from Finland was not possible after March 2020. This made maintenance of the measuring device significantly more difficult.

Installation of measuring equipment

As part of the SEVIRA-project, continuous water quality measurements started on the Russian side in late autumn 2019. To accomplish this, a suitable location was searched together with the Russian partner. One of the main selection criteria was a safe measurement site that an occasional passer-by could not reach. Such a place was found in the back yard of a private person whose house was on the bank of the Rakkolanjoki river.

Another challenge arose from how we get all the measuring equipment imported from Finland to Russia. As the customs formalities were quite bureaucratic, we ended up using a private transportation company. This proved to be a good choice and the equipment installation could be started. Official papers for border crossing were made for the transfer of the device. The papers pointed out that the equipment will be transferred back to Finland after the end of the project.

An on-line water quality meter was installed in the Rakkolanjoki river on October 24th, 2019. The observation station measures turbidity, electrical conductivity, organic carbon, and chlorophyll-A over with the frequency of one hour. The nitrate-nitrogen sensor was installed a bit later in November 2019 (see Figures. 2-3).

Figure 2. Sensors used in the Rakkolanjoki.

Figure 3. Equipment installation work in the Rakkolanjoki Nov. 2019.

Measurement differences between Finland and Russia

The traditional water quality data of the river Rakkolanjoki measured at both sides of the border during 2018–2021 were first looked over. The Finnish monitoring site was titled “Rakkolanjoki rajav 001” and the Russian one closest to the border “Seleznevka–Kutuzovo” and the one with automatic monitoring devices “Seleznevka–Lugaika” (Figure 4). From Table 1 we can see that the nutrient concentrations were higher in the Finnish than in the Russian side. The difference was bigger for dissolved nutrient fractions (PO_4-P and NO_3-N) than for total P and N. For example, while the average Ptot in the Russian side was ca. 80% of that in the Finnish side, PO_4-P was, respectively, only 30–40%. The difference may be, on the one hand, due to the differences in the laboratory analysis methods and to the numbers of the analyzed samples. On the other hand, dilution may have occurred in Russian side between the Finnish Rakkolanjoki and the Russian Lugaika monitoring sites.

Generally, the dissolved fractions constituted higher share of Ptot and Ntot in the Finnish than in the Russian stations. At the Rakkolanjoki site PO_4-P concentration was on average 53% of Ptot concentration, while it was only 18% at Kutuzovo site and 25% at Lugaika, respectively. In terms of NO_3-N of Ntot, the Rakkolanjoki site showed, again, the highest share (74%). Meanwhile in Kutuzovo and Lugaika NO3-N concentrations were, on average, 40% and 47% of those of Ntot, respectively. The share of NH4-N was rather low (ca. 4% of Ntot) in both Finnish and and Russian sites. This indicates low importance of animal husbandry in the Rakkolanjoki area.

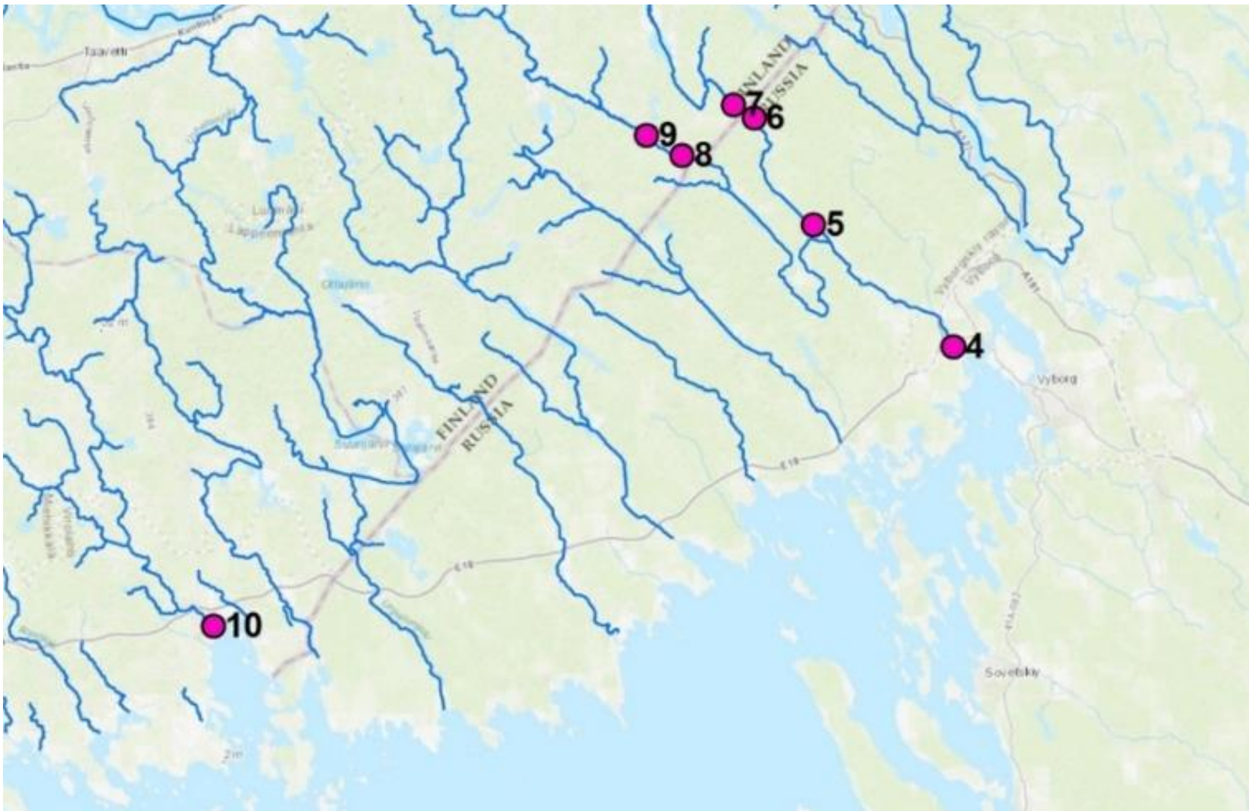

Figure 4. Map of the monitoring sites dealt with in the SEVIRA project. The Finnish site is “Rakkolanjoki rajav 001” = 7. The Russian sites are “Seleznevka–Kutuzovo” = 6 and “Seleznevka–Lugaika” = 5. Figure was made by Maria Kämäri, SYKE.

Table 1. Average and maximum nutrient concentrations measured at the Finnish monitoring site “Rakkolanjoki rajav 001” (FIN7) and the Russian sites “Seleznevka–Kutuzovo” (RUS6) and “Seleznevka–Lugaika” (RUS5). The number of water samples varies depending on the analysis, in Finland n = 19-78, in Russia N = 29-52, ie in that period of about 3 years 2018-2021

	Ptot (µg/l)			PO_4-P (µg/l)			Ntot (µg/l)			NO_3-N (µg/l)			NH4 (µg/l)		
	FIN7	RUS6	RUS5	FIN7	RUS6	RUS5	FIN7	RUS6	RUS5	FIN7	RUS6	RUS5	FIN7	RUS6	RUS5
MEAN	77	62	64	41	11	16	3116	2455	2179	2299	987	1019	138	108	88
MAX	190	119	239	110	34	90	6800	6150	5380	5600	3270	3700	640	690	600

We examined the correlations between turbidity against total suspended solids (TSS) and Ptot concentrations and thus checked how well turbidity could be used as a surrogate for TSS and Ptot. The results of the Finnish monitoring site (Figure 5) showed that while turbidity correlated reasonably well with TSS (R^2 = 0.79, Fig. 4a), the correlation was non-existent with Ptot (R^2=0.09, Fig. 4b). This is an obvious consequence of the high share of dissolved PO_4-P of Ptot. As for the Russian sites, turbidity was not included in the laboratory analyses. However, the absent correlations between TSS and Ptot (see Figure 6) indicate that turbidity would not be very good surrogate of Ptot here, either. Turbidity is typically a very good surrogate of Ptot in clay soils. The coefficients of determination (R^2) were only 0.02 and 0.06 in the Kutuzovo and Lugaika monitoring sites, respectively.

The examinations of correlations between combined nitrite-nitrate nitrogen (NO23-N) and Ntot (Figure 6) showed higher dependencies than those with turbidity-TSS-Ptot. In the Finnish Rakkolanjoki monitoring site the R2 value was even 0.94. In the Russian Kutuzovo and Lugaika sites the R2 values were passable; 0.42 and 0.34, respectively.

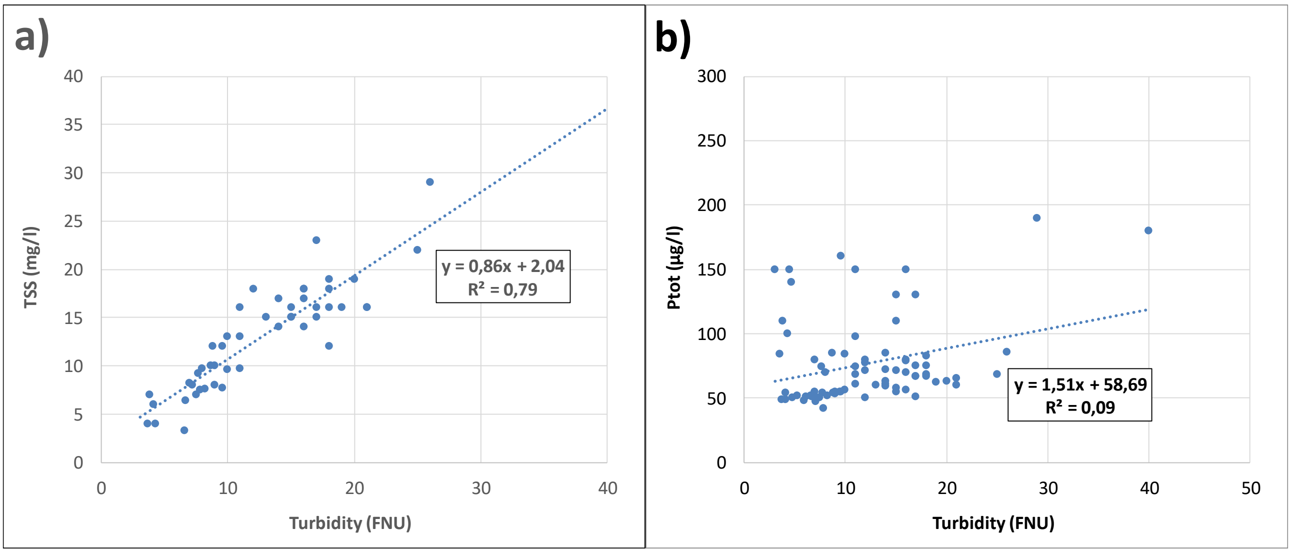

Figure 5. Linear regressions between turbidity and total suspended solids (TSS, a) and turbidity and total P (Ptot, b) as determined from the data collected at the Finnish Rakkolanjoki monitoring site.

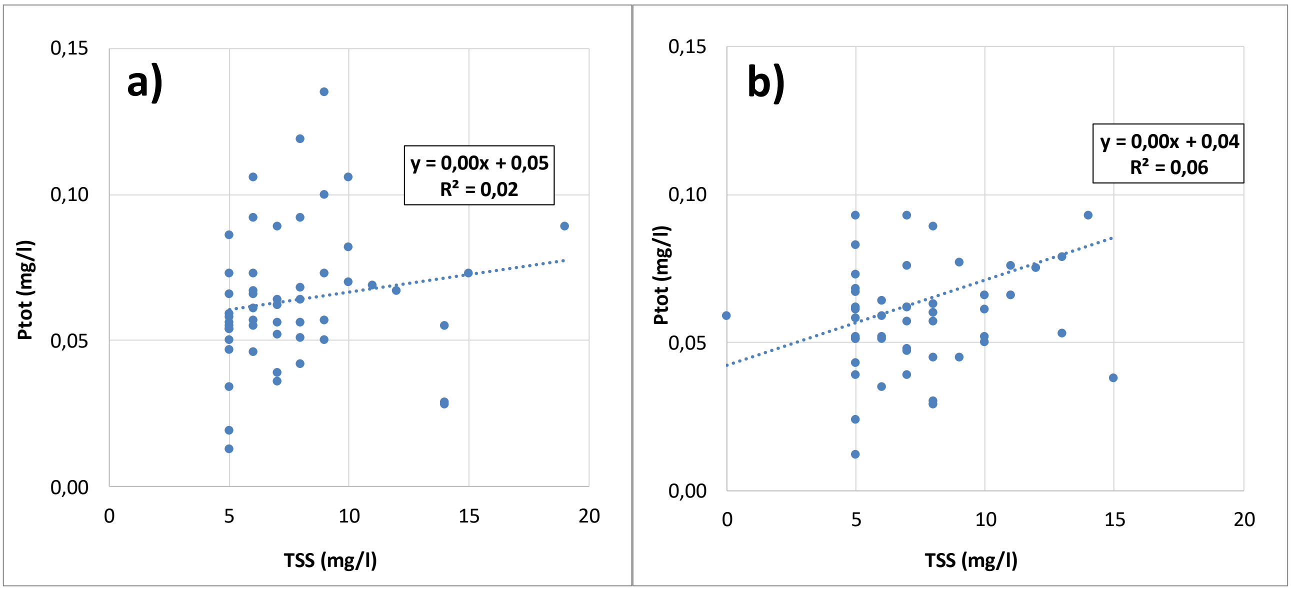

Figure 6. Linear regressions between total suspended solids (TSS) and total P (Ptot) in the Russian Kutuzovo (a) and Lugaika (b) monitoring sites.

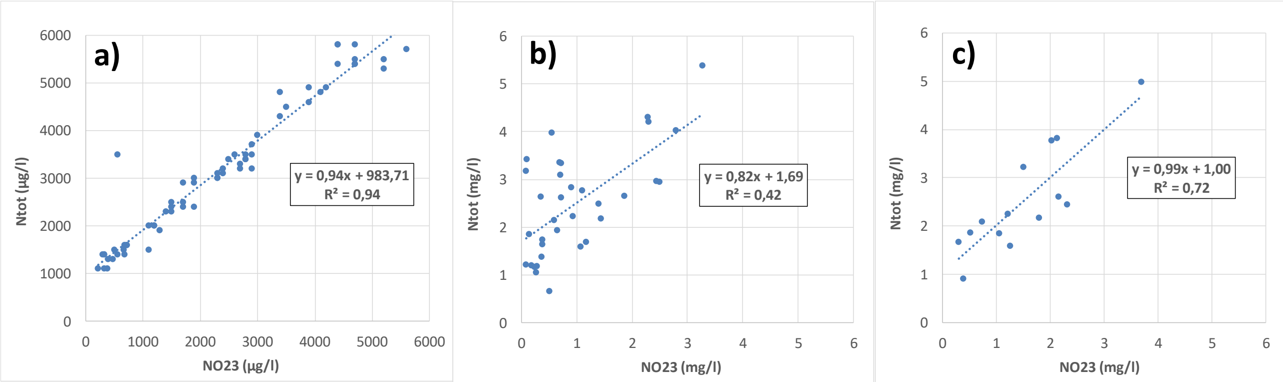

Figure 7. Linear regressions between combined nitrite-nitrate nitrogen (NO23-N) and total N (Ntot) in the Finnish Rakkolanjoki (a) and in the Russian Kutuzovo (b) and Lugaika (c) monitoring sites.

Measurement results

Water temperature measurement

The temperature measurements were successful and corresponded well to the measurements made at RUS5 station (Figure 8). The water temperature was at its highest at about 23 degrees and at its lowest around zero. In general, the water temperature measurements were successful, and there were no interruptions in the time series.

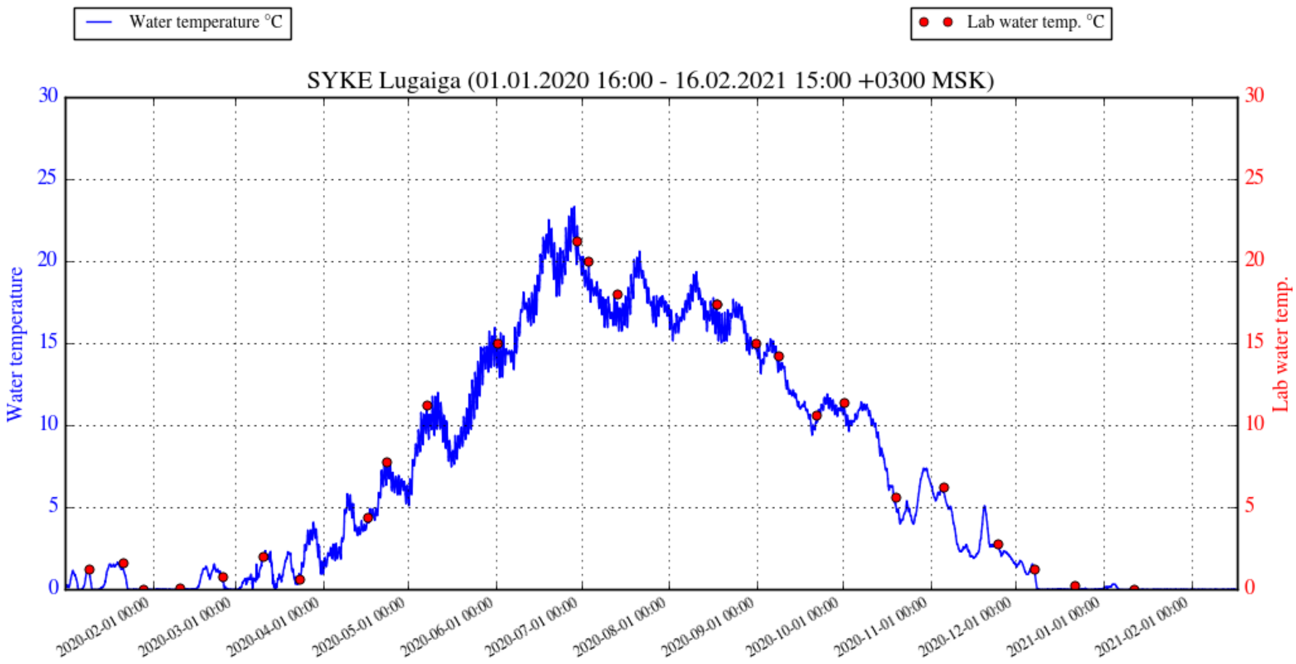

Figure 8. River water temperature measured at the automatic station (blue line, unit °C) and observation station RUS5 (red circles, unit °C).

Electrical conductivity measurement

At the beginning of 2020, laboratory measurements of electrical conductivity were clearly higher than readings from a continuous sensor (see Fig. 9). In May and summer, the readings matched quite well. In September, October and November, sensor readings were higher than laboratory results. In December and early 2021, the results were again very comparable.

The experience of the summer 2020 showed that the cleaning interval of optical lenses was too long, or the air pressure bottle leaked and thus the optical lens cleaning did not work properly. Figure 10 shows a few events in which the electrical conductivity decreases significantly during cleaning. However, it can be seen that sudden drop in data does not happen with all cleanings. Data creeping/crawling caused by too long cleaning interval is difficult to fix because there is no information at what point it started and when it ends.

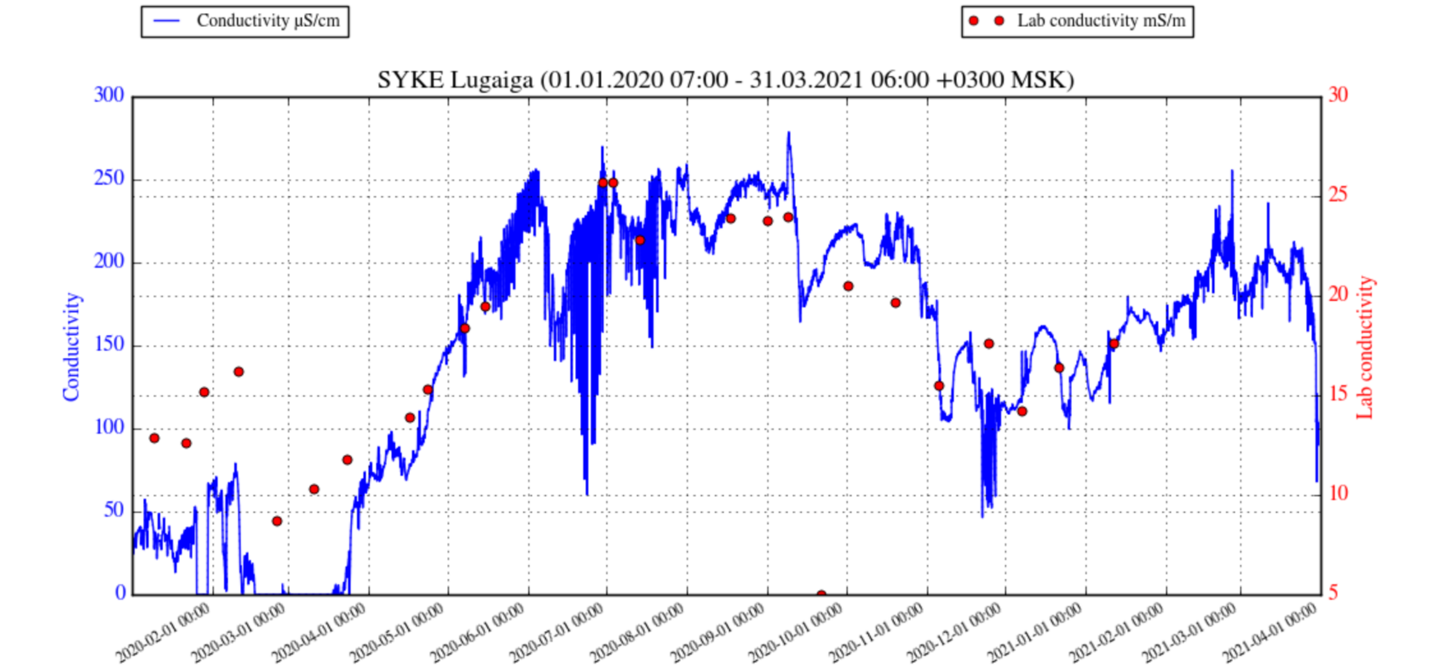

Figure 9. Continuous (1-hour frequency) electrical conductivity measured at theLugaika station (blue line, unit mS/m) and manual observations made at Nurmi Lugaika (red circles, unit, 10^{-4} S/cm).

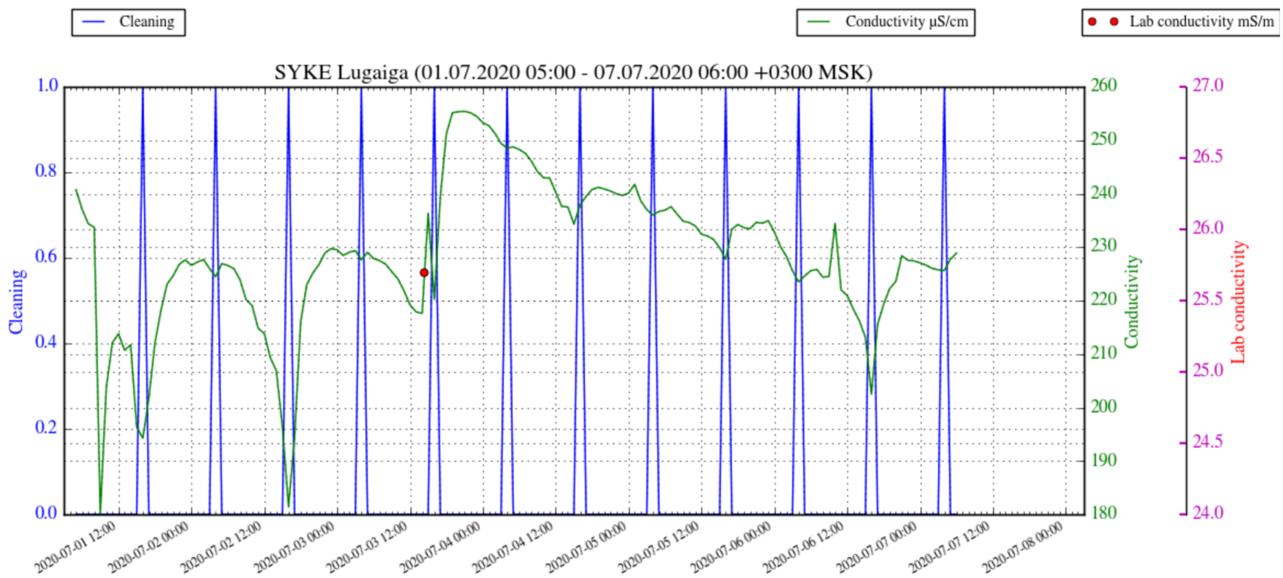

Figure 10. Electrical conductivity measured at the Lugaika station (green line, unit 10-4 S/cm) and manual grab sample observation at RUS5 (red circles, unit, mS / m) during one week in summer 2020. Blue vertical lines indicate the time when the automatic cleaning of optical lens is done.

Finnish inland lakes are typically low in salinity because the hard bedrock is poorly weathered. Therefore, the electrical conductivity of water varies in a narrow range of 5–10 mS / m. Finnish river waters conduct electricity at 10–20 mS / m, but if rivers flow through cultivated areas, the electrical conductivity rises to 15–20 mS / m. In the Rakkolanjoki, the concentrations are higher than 20 mS / m, but still below 30 mS / m. The Lappeenranta wastewater treatment plant may be the reason for slightly higher than typical readings.

Turbidity measurement

The average turbidity over the entire measurement period was 23 NTU, with a relative high range of 3-1109 NTU (Figure 11). The baseline turbidity was generally quite low, around 10 NTU. Turbidity peaks typically reflect the flow peaks (see Figure 12). The maximum for the spring seasons was over 60 NTU (see Figures 11-12).

During the ice breaking time 2020, two of the sensors (turbidity, electrical conductivity) loosened from the mounting stands. Therefore, we got both gaps (March 1-16th, 2020) in the measurement series and a need to fix the installation. This was not an easy job to do since due to the Covid-19 pandemic EHP Environment Oy could not travel from Finland to maintain the equipment. Instead the maintenance was done by the Russian partner and the measurements continued despite a small setback. As the Finnish equipment supplier was unable to attend, we cannot be sure that all the equipment was after the break fully operational.

In the summer of 2020, the river water was occasionally full of brown mush mixed with water (see Figures 12-13). The mush was not just floating on the river water surface but throughout the whole water profile. This apparently caused the turbidity values to increase by more than 1000 NTU. Although the turbidity sensor was equipped with mechanical brush for cleaning it obviously was not sufficient to keep the optical lens clean enough (see Figure 12). In such a situation, it is difficult to say whether these high turbidity values really represent the water quality or not.

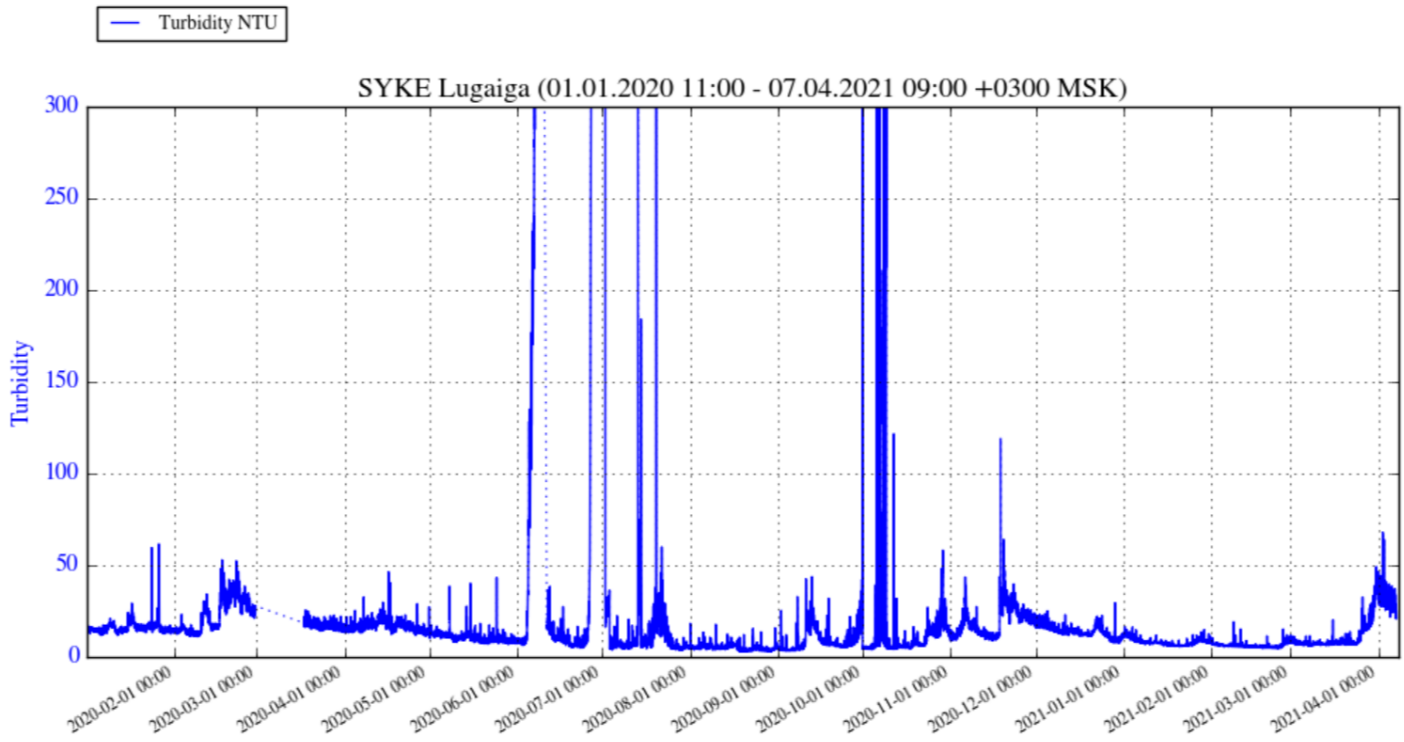

Figure 11. Continuous (1-hour frequency) turbidity measured at the Lugaika station. The dashed blue line represents the missing observations caused by ice breakup in early March.

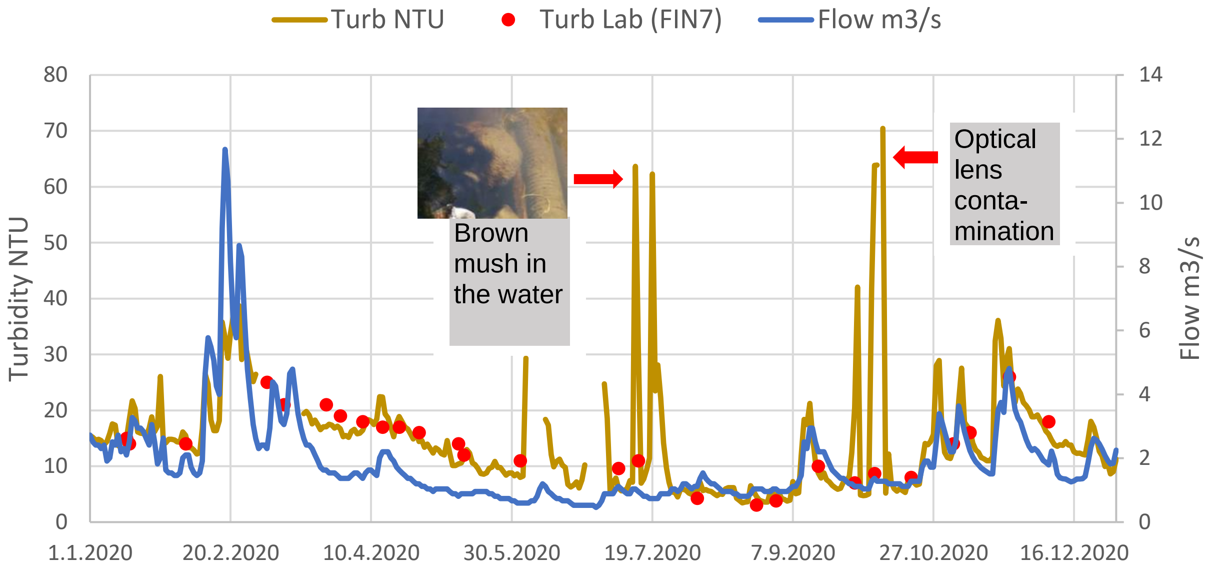

Figure 12. Calculated daily flow and turbidity based on continuous data at the Lukaiga station and laboratory turbidity data at FIN7 station in 2020.

Figure 13. In the summer of 2020, the water level dropped and a lot of light, brown particles were observed in water. The sensor became dirty and the measurements may therefore be incorrect. In such a situation, frequent cleaning of the sensor is necessary.

The monthly averages of turbidity are shown in Figure 14. The highest turbidity concentrations were observed in summer (e.g. June and July 2020) and late autumn. As mentioned above, the high turbidity concentrations in summer are due to brown particles in the water. In April 2021 turbidity was also quite high which is likely due to the melting of spring snow.

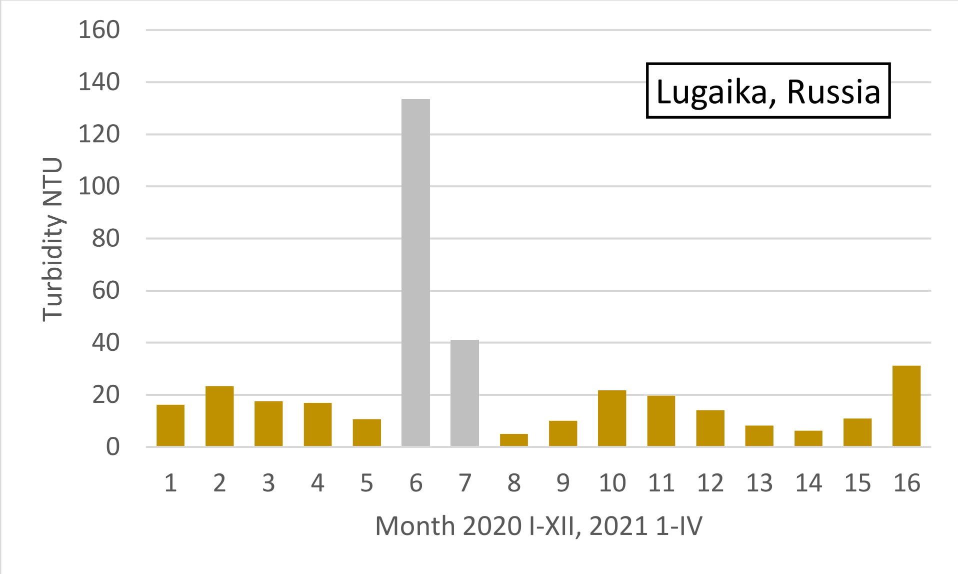

Figure 14. Monthly averages of turbidity over the measurement period January 2020 to April 2021. June-July 2020 values may partly be incorrect due to brown mash in the water and optical lens contamination.

Nitrate-nitrogen measurement

The measurement time series of nitrate-nitrogen is more problematic. There is a lot of daily variation in the measurements and it is uncertain whether they are real or not. Figure 15 shows that the reference measurements (laboratory data) mainly correspond to continuous on-line measurements, except at the turn of 2020/2021 up to the end of year, when continuous measurements give higher values than reference measurements. This period could be due to the gradual fouling of the sensors, although fouling is not usually the cause during the winter when the river has ice cover. The turbidity data for the same period appear to be error-free (see Figure 11). The turbidity sensor is cleaned with a mechanical brush, while the nitrate-nitrogen sensor is cleaned with compressed air. It is likely that the compressed air has run out and therefore the lens is dirty. In the beginning of June, an abnormal laboratory finding is observed. It is likely that in this case the laboratory analysis might be incorrect.

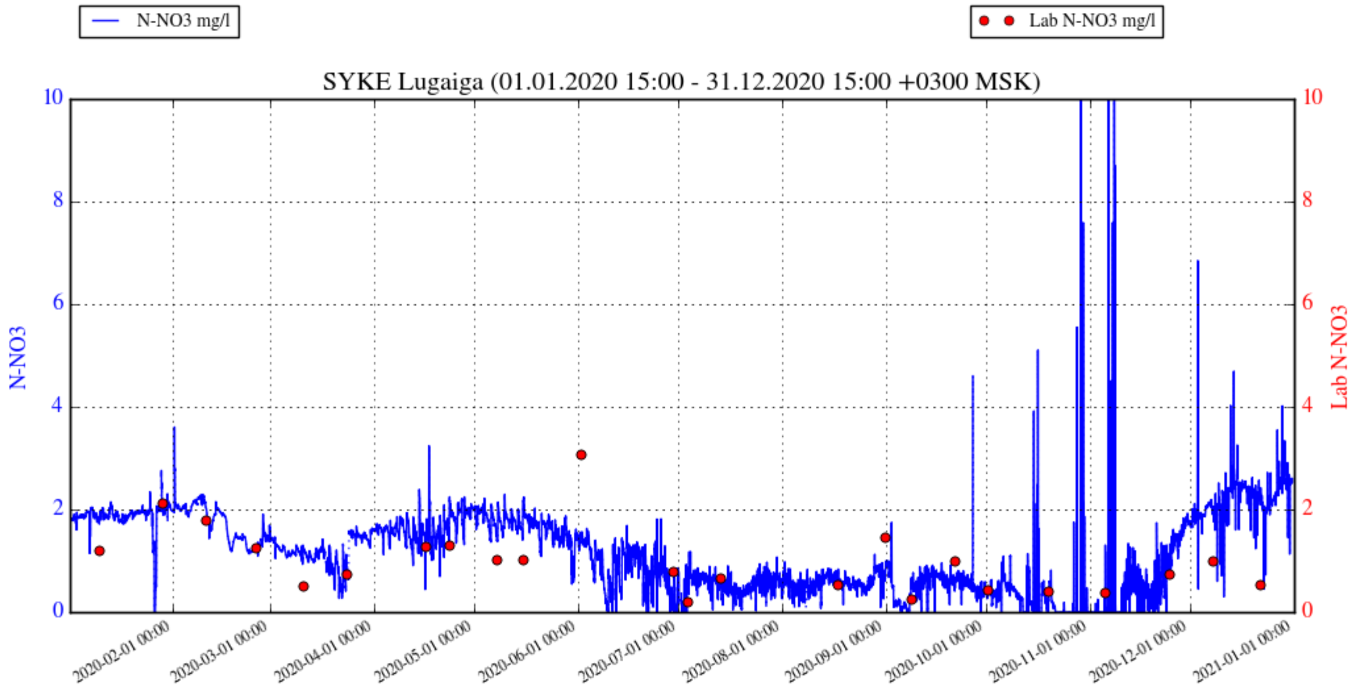

Figure 15. Continuous (1-hour frequency) nitrate-nitrogen measurements at the Lugaika station in 2020 (blue line, unit mg/l) and at station RUS5 (red circles, unit, mg/l).

Chlorophyll-a measurements

Chlorophyll content (chlorophyll-a) measures the abundance of leafy green planktonic algae in water. The result is directly proportional to the algae amount and thus to the eutrophication level of the lake or river. Chlorophyll-a measurements are rarely made in the river environment and therefore we have little information on how chlorophyll-a concentrations vary during the summer.

Figure 16 shows that the first peak (May- mid June 2020) looks typical and error-free. In the case of the three following peaks, the chlorophyll-a data drops suddenly down whenever the optical lens is cleaned. It is obvious that chlorophyll-a is on the rise, but it is uncertain when the rise will end.

The baseline level of chlorophyll-a in late autumn and winter is below 5 µg/l. The maximum of the June 2020 peak is about 50 µg/l. Chlorophyll concentration does not appear to correlate with flow. Chlorophyll is not determined from water samples, so a reference value is not available.

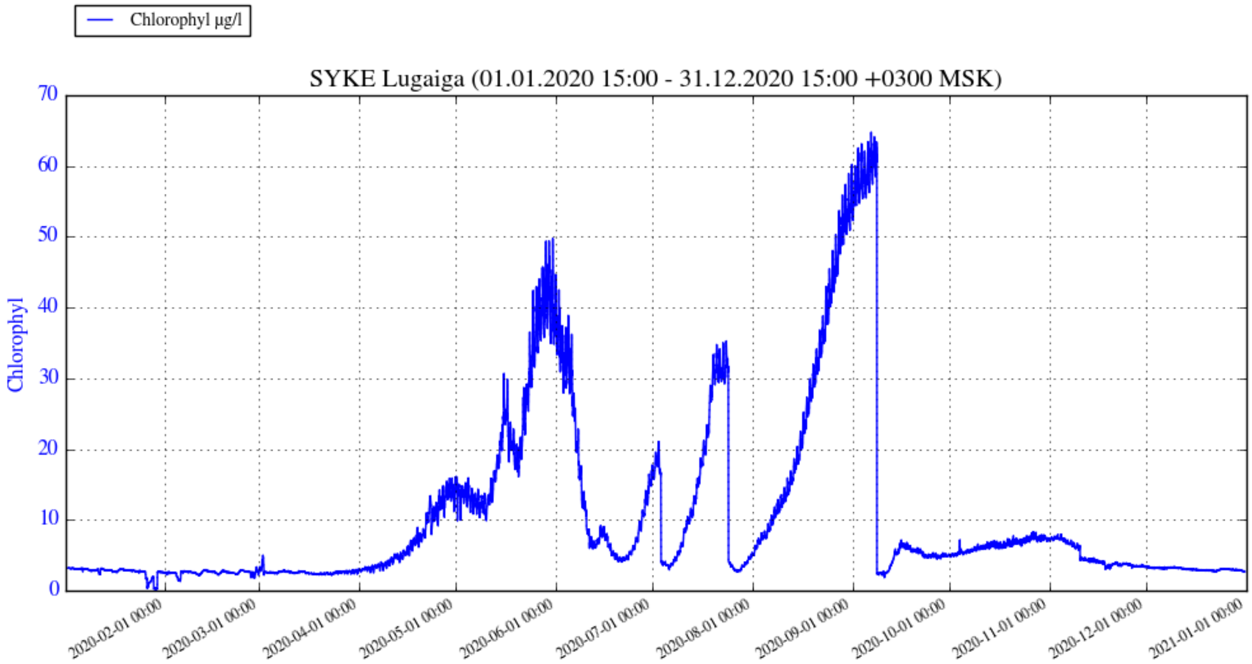

Figure 16. Continuous (1-hour frequency) chlorophyll-a measurements at the Lugaika station in 2020.

Organic carbon measurements

For organic carbon we measured a variable called SAC254. SAC254 is a surrogate parameter which is correlated to various carbon-based parameters such as DOC and TOC at a wavelength of 254 nm. There are points in the measured time series where the contamination of the optical lens is clearly visible (see Figure 17). We didn’t have enough reference measurements (only one DOC observation in January 2020), so we can’t say if the concentration level is correct or not. If the contamination of lenses is due to the air pressure bottle being emptied, then the measurements are incorrect.

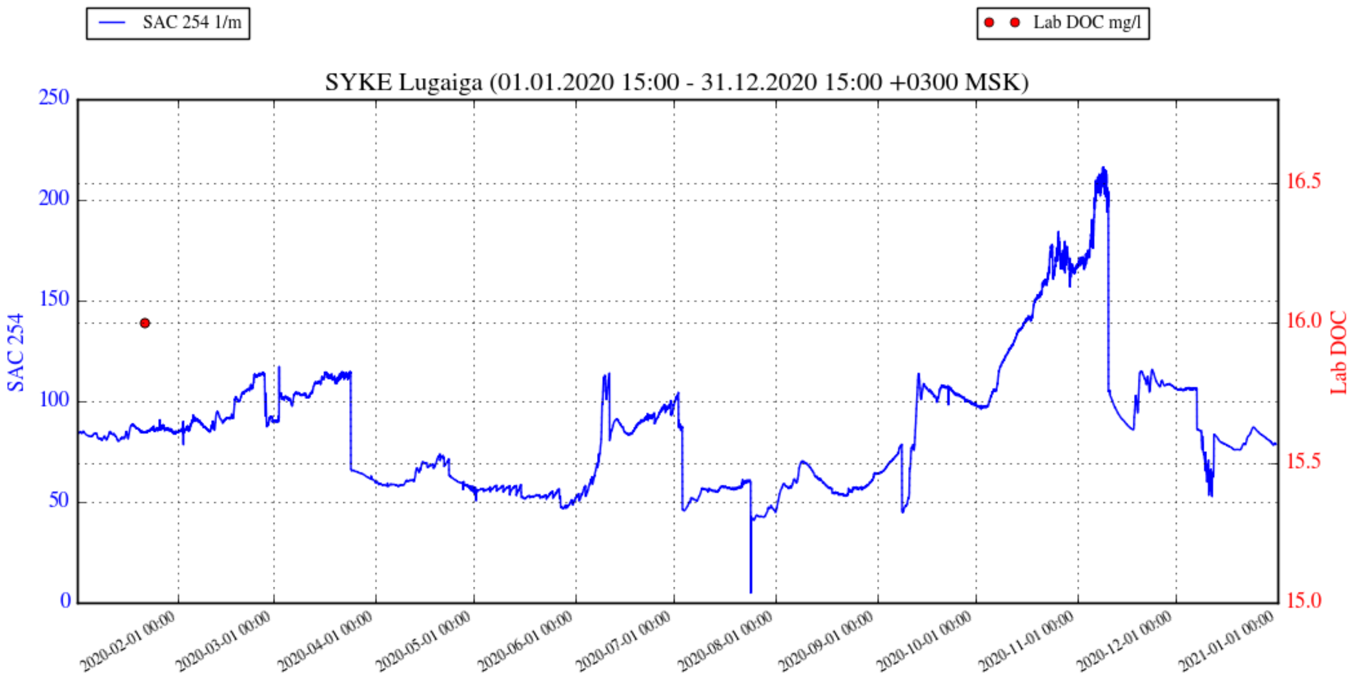

Figure 16. Continuous (1-hour frequency) SAC 254 measurements at the Lugaika station in 2020.

Nutrient load calculation

Loads of Ptot and Ntot for the years were calculated on daily basis from the concentrations analyzed from the water samples taken in the Finnish Rakkolanjoki measurement site (FIN7) and in the Russian Kutuzovo (RUS6) and Lugaika (RUS5) sites. The missing concentrations between the observation days were determined by linear interpolation.

As for the flow, we used the daily dataset simulated by the operative WSFS model of SYKE, as calibrated against the flow measured at the Kutuzovo (see Figure 17).

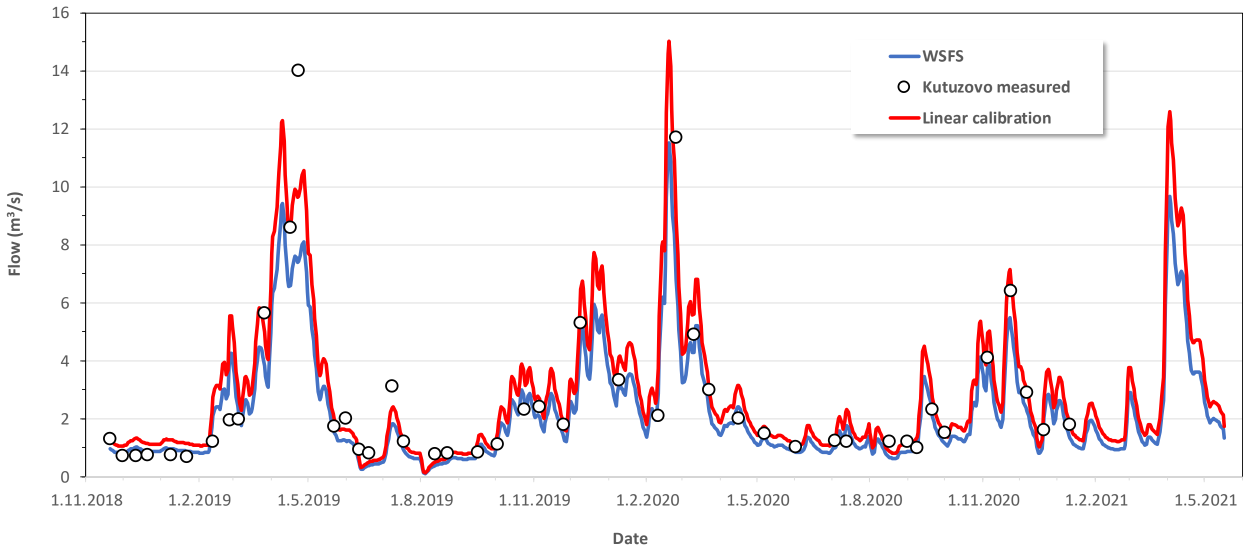

Figure 17. Flow (m^3/s) as simulated by the WSFS model of SYKE (blue curve), as measured at the Kutuzovo measurement site (circles) and as calibrated according to the linear regression equation (y = 1,3037*x, R^2 = 0.84) between the simulated and measured values (red curve).

Daily TSS, Ptot and Ntot loads were calculated as: $L_d = C_d * Q_d * 60 * 60 * 24 * 10^{-3}$ (1)

where L_d = Daily laoding (kg)
C_d = Observed or interpolated concentration of TSS, Ptot or Ntot (mg/l)
Q_d = Daily mean flow (m^3/s)

On annual basis, TSS and Ptot loads were higher at the Finnish than in the Russian measurement sites (Figure 18). Only in 2020 the Ptot load was at highest in the Russian Lugaika site (RUS5). In terms of Ntot, the order of the measurement sites was clear: The highest loads occurred in the Finnish site and the lowest in the Russian Lugaika site in both years.

Monthly inspection revealed that the highest loads occurred typically in April (Figure 19). Also the high winter flood of February 2020 can be seen in high loads.

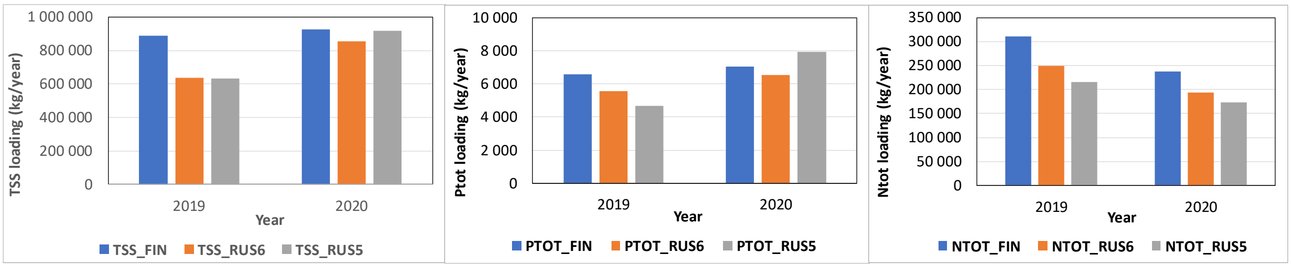

Figure 18. Annual total suspended solids (TSS), total phosphorus (Ptot), and total nitrogen (Ntot) loadings (kg) in 2019 and 2020 in the Finnish Rakkolanjoki measurement site (FIN) and Russian Kutuzovo (RUS6) and Lugaika (RUS5) measurement sites.

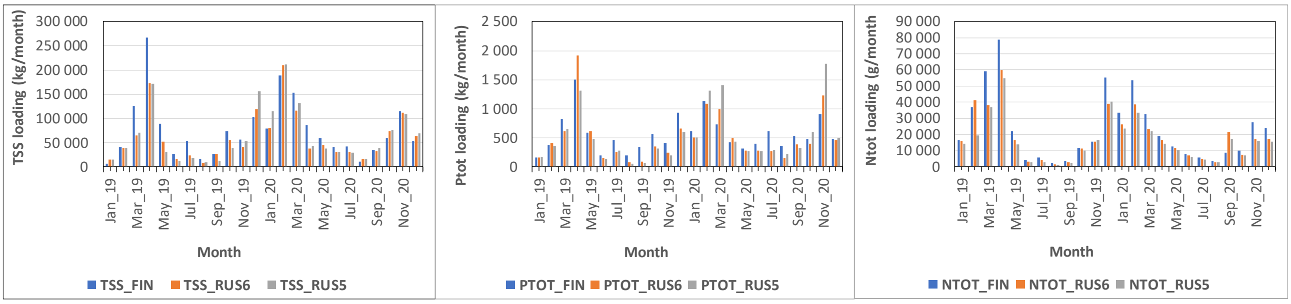

Figure 19. Monthly total suspended solids (TSS), total phosphorus (Ptot), and total nitrogen (Ntot) loadings (kg) in 2019 and 2020 in the Finnish Rakkolanjoki measurement site (FIN) and Russian Kutuzovo (RUS6) and Lugaika (RUS5) measurement sites.

Conclusions

One of the goals of the project was to test the use of a continuous water quality device in Russia. Unfortunately, there were gaps in the measurements due to both the breaking up of ice and too few lens maintenance intervals, especially in summer. Sometimes the compressed air bottle emptied, apparently due to leaks and therefore the automatic compressed air cleaning did not work in an optimal way. The Covid-19 pandemic caused a partial failure of the measurement. If the equipment supplier had originally been selected from Russia, this problem would probably have been, at least partly avoided.

The following recommendations can be drawn based on measurement experience:

- Select the equipment supplier as close as possible to the measuring station (at least from the same country). This is the easiest way to service and maintain the device
- The device is best maintained if a person living near the measurement site is selected to maintain the meter
- Water samples should be taken as close to the sensor as possible
- Water samples should be analyzed for the same variables as those measured continuously on-line
- Measurements should include flow / water level measurements
- If you plan to estimate the total nutrients from the measured variables, it should be determined in advance whether, for example, total nitrogen can be calculated using nitrate nitrogen.
- The catchment area above the measuring point must be delimited

- Land use and point loads in the catchment area should be mapped
- Efforts should be made to monitor the quality of continuous water quality data

Knowing the uncertainty of continuous measurements is key to the usefulness of the results. The use of conversion equations always involves uncertainty, which should be taken into account when using the results. Attention should be paid to the degree of determination (R^2) of the regression equation. During the low flow period, calibration samples are easily obtained, but it is often difficult to obtain water samples at peak flow.

An anomalous data is not automatically an erroneous data, so anomalous results may sometimes require clarification of backgrounds and causes, as well as study other variables collected from the site. It is difficult to give a general guidence for identifying an erroneous data, but they are typically individual, clearly different from other data, the so-called spikes.

It is always recommended that a quality check is performed as soon as possible after the measurement, as this will facilitate the assessment of the quality of the data. Later, it may be difficult to determine the cause of the incorrect measurement result. Reasons must be given for deleting the results.

Another, pre-set goal was to find out what benefits continuous measurements bring compared to traditional water sampling measurements. Can continuous water quality measurement be used to develop a plan for optimal manual water sampling? Continuous measurements provide information on all peaks in the observation series, but peaks cannot be predicted in advance. During the SEVIRA -project, manual water sampling took place frequently, e.g. during 2020, 24 water samples were taken. This amount ensures that e.g. nutrient load estimates are sufficiently accurate. If the number of water samples needs to be reduced for economic reasons, it would be advisable to measure the flow / water level continuously and use this data for water sampling planning.

References

Kahiluoto, J., Hirvonen, J. & Näykki, T. 2019. Automatic real-time uncertainty estimation for online measurements: a case study on water turbidity. Environ Monit Assess 191, 259. https://doi.org/10.1007/s10661-019-7374-7.

Ahti Lepistö, Kari Kallio, Heikki Pitkänen, Mika Raateoja, Elina Röman, Jukka Seppälä, Janne Suomela, Marjo Tarvainen, Sirkka Tattari. 2018. Jatkuvatoimisten vedenlaatuasemien valtakunnallinen verkosto – toteuttamissuunnitelma (Network for continuous water quality measurement stations in Finland – implementation plan). SUOMEN YMPÄRISTÖKESKUKSEN RAPORTTEJA 32 | 2018 Suomen ympäristökeskus SYKE, Helsinki. 49 p. (In Finnish with English abstract). Online: http://hdl.handle.net/10138/288724

Pellerin, B.A., Bergamaschi, B.A., Downing, B.D., Saraceno, J.F., Garrett, J.A., Olsen, L.D. 2013. Optical techniques for the determination of nitrate in environmental waters: Guidelines for instrument selection, operation, deployment, maintenance, quality assurance, and data reporting. U.S. Geological Survey Techniques and Methods 1–D5, 37 p. https://pubs.usgs.gov/tm/01/d5/pdf/tm1d5.pdf

Sirkka Tattari, Marjo Tarvainen, Kari Kallio, Ahti Lepistö, Teemu Näykki, Mika Raateoja, Jukka Seppälä. 2019. Laatukäsikirja jatkuvatoimisille vedenlaadun mittauksille – Opas hyviksi käytännöiksi (Guidelines for Continuous Water Quality Measurements – Guide for good practices). SUOMEN YMPÄRISTÖKESKUKSEN RAPORTTEJA 4 | 2019 Suomen ympäristökeskus SYKE, Helsinki. 42 p. (In Finnish with English abstract). Online: http://hdl.handle.net/10138/299105

Wagner, R.J., Boulger, R.W., Jr., Oblinger, C.J., Smith, B.A. 2006. Guidelines and standard procedures for continuous water-quality monitors. Station operation, record computation, and data reporting. U.S. Geological Survey Techniques and Methods 1–D3, 51 p. + 8 attachments. http://pubs.water.usgs.gov/tm1d3