Joint cross border actions towards the cleaner Gulf of Finland

Results from the Finnish-Russian SEVIRA project

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Abstract

Joint cross border actions towards the cleaner Gulf of Finland

The SEVIRA project was part of the Southeast Finland – Russia CBC program 2014–2020. The background to the project was the recommendations produced by the Gulf of Finland Year in 2014, especially the recommendations for improving the condition of the eastern Gulf of Finland. Understanding the changes in the state of the Eastern Gulf of Finland is complex due to the fact that the ecological state of all the rivers flowing into it is not monitored.

The project focused on three rivers in the Finnish-Russian border region (Virojoki, Rakkolanjoki, Sestrajoki). The aim was of the study to improve the condition of the catchment area and that of the Gulf of Finland. To achieve this goal, the state of the water bodies was intensively monitored (mathematical modeling) and an important part was raising of public awareness. Residents were asked for their views on their nearby watersheds and were instructed in civic monitoring of the environment. In addition, school trips were organized for schoolchildren in local flowing waters. The aim was to increase students' environmental awareness and interest in the surrounding environment: when young people have a connection to their environment there is an increasing willingness to protect it.

The project resulted in a Road Map for local decision-makers to improve the status of watersheds. The main recommendations of the Road Map are presented below presented thematically

According to the results of **river monitoring**, the current sampling produces fairly reliable load estimates for the Virojoki and Rakkolanjoki rivers. However, monitoring can be further improved by increasing the sampling frequency and intensifying sampling in wet weather periods. In order to refine the load values in the Gulf of Finland, it makes more sense to invest in the monitoring of uncontrolled rivers than to intensify the monitoring of rivers that are already being monitored. In the future, it would be a good idea to look at river loads by basin instead of by country-specific reduction targets. A pool-specific analysis could be done, for example, in the framework of HELCOM.

Coastal monitoring showed that water quality in Vyborg and Virolahti bays has improved over the last 10 years. Continuous monitoring is needed also in the future in theses bays. In particular, the location of fish farms should be further assessed to minimize their negative effect on water quality. A further challenge is to study the contribution of local load reductions compared with the effects of the open Baltic Sea to changes in the state of the eastern Gulf of Finland.

According to the **modeling results**, changes in land use (agriculture and forestry, construction, etc.) should be considered when assessing the development of nutrient loads. If the worst-case scenarios for climate change do not materialize, the effects of climate change on the state of the environment of the studied area will remain moderate. As an observation at the regional level, it was stated that it is important to develop water treatment in the Lappeenranta area to reduce nutrient loads in the Rakkolanjoki River.

According to **citizen surveys**, there was a lot of dissatisfaction with the state of the waters on both sides of the border. However, citizens are willing to take action to improve the state of the waters. Municipalities should disseminate information about water quality among residents: what I can personally do to improve the condition of local waters. Based on a citizen survey, the establishment of a local water protection and restoration association around all three rivers can be recommended.

It was found according to the surveys, that there is a need to increase people's **environmental awareness** and knowledge of sustainable lifestyle. It is also important to listen more carefully the values and expectations of local people about the development of their area. Public organizations should therefore play a greater role in raising people's environmental awareness and understanding. Effective forms of interaction are needed for co-operation between public authorities and citizens.

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Keywords: Finland-Russia co-operation, river monitoring, coastal monitoring, nutrient models, climate change scenarios, public opinion polls, environmental education

Tiivistelmä

Yhteistyöllä kohti puhtaampaa Suomenlahtea

SEVIRA-hanke oli osa Kaakkois-Suomi–Venäjä CBC-ohjelmaa 2014–2020. Hankkeen taustana olivat Suomenlahti-vuoden 2014 tuottamat suositukset erityisesti itäisen Suomenlahden tilan parantamiseksi. Itäisen Suomenlahden tilan muutosten ymmärtämistä vaikeuttaa erityisesti se, ettei kaikkien siihen laskevien jokien tilaa seurata.

Hanke kohdistui kolmen joen alueelle Suomen ja Venäjän rajaseudulla (Virojoki, Rakkolanjoki, Sestrajoki), ja tavoitteena oli parantaa valuma-alueen vesistöjen ja Suomenlahden tilaa. Tämän tavoitteen saavuttamiseksi vesistöjen tilaa seurattiin intensiivisesti (monitorointi), tehtiin matemaattista mallitusta ja osallistettiin alueen asukkaita. Asukkailta kysyttiin näkemyksiä lähivesistöistään ja heitä opastettiin ympäristön kansalaisseurantaan. Lisäksi koululaisille järjestettiin opintoretkiä alueen virtavesien äärellä. Tavoitteena oli lisätä oppilaiden ympäristötietoutta ja kiinnostusta lähiluontoon: tuttua ympäristöä halutaan suojella.

Hankkeen tuloksena syntyi tiekartta paikallisille päättäjille valuma-alueiden vesien tilan parantamiseksi. Tiekartan pääsuositukset esitetään seuraavassa teemoittain.

Jokimonitoroinnin tulosten mukaan nykyinen näytteenotto tuottaa melko luotettavia kuormitusarvioita Virojoelle ja Rakkolanjoelle. Monitorointia voidaan kuitenkin vielä parantaa lisäämällä näytteenottotiheyttä ja tehostamalla näytteenottoa sateisina aikoina. Suomenlahden kuormitusarvojen tarkentamiseksi on järkevämpää panostaa valvomattomien jokien seurantaan kuin tehostaa jo tällä hetkellä monitoroitavien jokien seurantaa. Jokikuormituksia olisi hyvä tarkastella jatkossa allaskohtaisesti maakohtaisten vähennystavoitteiden sijaan. Allaskohtainen tarkastelu voitaisiin tehdä esimerkiksi HELCOMin puitteissa.

Rannikkomonitorointi osoitti, että Viipurin- ja Virolahden vedenlaatu on parantunut viimeisen 10 vuoden aikana. Monitorointia tarvitaan myös jatkossa. Eritysesti kalankasvattamoiden sijoittaminen pitäisi arvioida tarkemmin, jotta niiden vedenlaadulle aiheuttama haitta voidaan minimoida. Jatkohaasteena on tutkia, mikä osuus paikallisilla toimenpiteillä ja toisaalta avoimella Itämerellä on itäisen Suomenlahden rannikkoalueen tilan muutoksiin.

Mallinnustulosten mukaan maankäytön muutokset (maa- ja metsätalous, rakentaminen jne.) tulee ottaa huomioon arvioitaessa ravinnepäästöjen kehitystä. Jos pahimmat ilmastonmuutosskenaariot eivät toteudu, ilmastonmuutoksen vaikutukset tutkitun maa-alueen ympäristön tilaan pysyvät maltillisina. Aluetason havaintona todettiin, että on tärkeää kehittää Lappeenrannan alueen vedenpuhdistusta Rakkolanjoen ravinnepäästöjen alentamiseksi.

Kansalaiskyselyiden mukaan molemmin puolin rajaa oli paljon tyytymättömyyttä vesien tilaan. Kansalaiset ovat kuitenkin halukkaita ryhtymään toimiin vesien tilan parantamiseksi. Kuntien tulisi levittää tietoa veden laadusta asukkaiden keskuudessa: mitä voin henkilökohtaisesti tehdä paikallisten vesien tilan parantamiseksi. Kansalaistutkimuksen pohjalta voidaan suositella paikallisen vesiensuojelu- ja ennallistamisyhdistyksen perustamista kaikkien kolmen joen alueelle.

Kyselyjen perusteella havaittiin, että ihmisten **ympäristötietoisuutta** ja tietoa kestävästä elämäntavasta on tarvetta lisätä. On tärkeää myös kuunnella nykyistä paremmin paikallisten ihmisten arvoja ja odotuksia alueensa kehittämisestä. Julkisten organisaatioiden tulisikin ottaa entistä suurempi rooli ihmisten ympäristötietoisuuden ja -ymmärryksen kasvattamisessa. Viranomaisten ja kansalaisten väliseen yhteistyöhön tarvitaan toimivia vuorovaikutustapoja.

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Asiasanat: Suomi-Venäjä yhteistyö, jokiseuranta, rannikkoseuranta, ravinnemallit, ilmastonmuutosskenaariot, kansalaiskyselyt, ympäristökasvatus

Sammandrag

Mot en renare Finska viken genom samarbete

SEVIRA-projektet var en del av det gränsöverskridande samarbetsprogrammet Sydöstra Finland–Ryssland CBC 2014–2020. Bakgrunden till projektet var rekommendationerna som utarbetades under samarbetsprojektet Gulf of Finland Year 2014, och särskilt rekommendationerna om att förbättra tillståndet i östra Finska viken. Det är svårt att förstå förändringarna i Finska vikens tillstånd eftersom det ekologiska tillståndet hos alla floder som utmynnar i Finska viken inte övervakas.

Projektet fokuserade på tre floder i området kring den finsk-ryska gränsen (Virojoki, Rakkolanjoki, Sestrajoki). Syftet med studien var att förbättra tillståndet i avrinningsområdet och i Finska viken. För att uppnå den här målsättningen övervakades vattendragen noggrant (med matematiska modeller) och en viktig aspekt var att höja allmänhetens medvetenhet. Invånare ombads ge sina åsikter om avrinningsområdena i deras närhet och fick anvisningar för övervakning av miljön. Dessutom arrangerades skolutflykter för skolbarn till lokala vattendrag. Syftet var att öka elevernas miljömedvetenhet och intresse för närmiljön – en välbekant miljö är värd att skydda.

Projektet resulterade i en vägkarta för lokala beslutsfattare för att förbättra avrinningsområdenas tillstånd. De huvudsakliga rekommendationerna från vägkartan presenteras nedan enligt tema.

Enligt resultaten av **flodövervakningen** ger den aktuella provtagningen rätt pålitliga belastningsuppskattningar för floderna Virojoki och Rakkolanjoki. Övervakningen kunde dock ytterligare förbättras genom att öka provtagningsfrekvensen och intensifiera provtagningen under perioder med mycket nederbörd. För att få mer exakta belastningsvärden i Finska viken lönar det sig att investera i övervakning av okontrollerade floder i stället för att intensifiera övervakningen av floder som redan står under övervakning. I framtiden skulle det vara en bra idé att undersöka floders belastning per område i stället för enligt landspecifika reduceringsmålsättningar. En poolspecifik analys kunde till exempel genomföras inom ramen för HELCOM.

Kustövervakning har visat att vattenkvaliteten i Viborgska viken och Vederlax vik har förbättrats under de senaste 10 åren. Ständig övervakning av dessa vikar krävs också i framtiden. I synnerhet borde placeringen av fiskfarmer undersökas ytterligare för att minska den negativa effekten på vattenkvaliteten. Ytterligare en utmaning är att studera hur lokala belastningsminskningar jämfört med effekterna av den öppna Östersjön påverkar förändringar i den östra Finska vikens tillstånd.

Enligt **modellresultaten** bör förändringar i markanvändning (jord- och skogsbruk, byggande osv.) beaktas vid bedömningen av hur näringsbelastningen utvecklas. Om klimatförändringens värsta scenarier inte blir verklighet, kommer klimatförändringens effekter på miljön i det undersökta området att vara moderata. Som observation på regional nivå konstaterades att det är viktigt att utveckla vattenbehandlingen i Villmanstrandområdet för att minska näringsbelastningen i floden Rakkolanjoki.

Enligt **invånarenkäter** var invånare på båda sidorna om gränsen ytterst missnöjda med vattendragens tillstånd. Invånarna är dock villiga att vidta åtgärder för att förbättra vattendragens tillstånd. Kommuner bör informera sina invånare om vattenkvaliteten: ”vad kan jag själv göra för att förbättra lokala vattendrags tillstånd?” Utifrån en invånarenkät rekommenderas att en lokal organisation för skydd och återställande av vattendrag kring alla tre floder upprättas.

Enkätresultaten visar att det finns ett behov av att öka allmänhetens **miljömedvetenhet** och kunskaper om en hållbar livsstil. Det är också viktigt att lyssna mer ingående på de lokala invånarnas värden och förväntningar på utvecklingen av deras boningsort. Offentliga organisationer borde därför ha en större roll när det gäller att öka allmänhetens miljömedvetenhet och kunskaper. Effektiva interaktionsformer krävs för att offentliga organisationer och invånare ska kunna samarbeta..

Nyckelord: Samarbete Finland-Ryssland, flodövervakning, kustövervakning, näringsmodeller, klimatförändringsscenarier, opinionsundersökningar, miljöutbildning

Резюме

Совместные трансграничные действия ради чистоты Финского залива

Проект «SEVIRA/ СЕВИРА» был реализован в рамках программы приграничного сотрудничества «Юго-Восточная Финляндия – Россия 2014–2020 гг». Рекомендации «Года Финского залива 2014», связанные с мероприятиями по улучшению состояния восточной части Финского залива, определили цели проекта «СЕВИРА». Для понимания изменений, которые происходят в восточной части Финского залива необходимо иметь достоверную информацию о состояние рек, которые в него впадают.

Работы в проекте были связаны с изучением трёх рек пограничной зоны России и Финляндии (река Виройоки, река Селезнёвка (Ракколанйоки) и река Сестра). Основная цель проекта - улучшение состояния Финского залива и водоёмов его бассейна. Для достижения этой цели была выполнены программа интенсивного мониторинга состояния водоёмов и расчёты по математическим моделям. Важную роль во время мероприятий проекта принадлежала местным жителям. Были выполнены опросы населения, изучалось их мнение о состоянии ближайших водоёмов, распространялась информация о деятельности общественных природоохранных организаций. Для учащихся местных школ на прибрежных территориях рек были организованы и проведены экскурсии. Цель этих походов – распространение знаний об экологии, пробуждение интереса к изучению природы и желания сохранить окружающую среду родных мест.

Результат реализации проекта – создание плана действий, «дорожной карты» для местных администраций, для лиц, которые принимают решения, связанные с будущим состоянием водосборных бассейнов. Основные рекомендации «дорожной карты» можно коротко представить по следующим темам:

Современная программа отбора проб и мониторинг состояния рек позволяет получить надёжную информацию о нагрузках на водосборах реки Виройоки и реки Селезнёвки. Тем не менее, результативность мониторинга может быть повышена, если пробы будут отбираться чаще, особенно в дождливые сезоны года. Для уточнения размера нагрузки, которая поступает в Финский залив, необходимо исследовать реки, которые в настоящее время не входят в программу мониторинга и продолжать уделять внимание уже организованному мониторингу на реках. В будущем поступление нагрузок и водоохранные мероприятия необходимо уточнять по каждой реке отдельно, а не суммарно по странам. Проверки по отдельным водоёмам или бассейнам можно выполнять в рамках деятельности «Хелкома».

Мониторинг морских акваторий показал, что состояние Выборгского залива и залива Виролахти в течение последних 10 лет улучшилось. Мониторинг необходимо продолжать и в будущем. Особое внимание необходимо уделять выбору мест расположения садков рыборазводных предприятий, а их вредные воздействия на качество воды следует эффективно минимизировать. Определённый научный интерес представляет изучение влияния локальных водоохранных мероприятий на улучшение состояния всего Балтийского моря и восточной части Финского залива.

Результаты моделирования показали, что изменения в землепользовании (сельское и лесное хозяйство, застройка и т.д) необходимо учитывать при определении и регулировании поступления загрязнений, нагрузки, которая связана с питательными веществами. В том случае, если самые пессимистические сценарии изменений климата не осуществляться, то состояние исследованных земельных угодий сильно не изменится. На региональном уровне результаты проекта подтвердили, что важным мероприятием является повышение эффективности очистки сточных вод города Лаппеенранта. Это приведёт к уменьшению поступления питательных веществ в реку Селезнёвку.

На основе опросов местных жителей по обе стороны границы было установлено, что население недовольно состоянием водоёмов. При этом местные жители сами готовы участвовать в проведении водоохранных мероприятий. Местные администрации могут в больших объёмах распространять информацию о качестве воды и о том, что каждый житель может сделать для улучшения состояния ближайшего водоёма. На основе исследований общественного мнения можно рекомендовать создание общественных организаций по охране водоёмов, групп по проведению водоохранных мероприятий в бассейнах всех трёх рек.

Опросы показали, что у местных жителей существует определённый недостаток в **экологических** знаниях и сведений об устойчивом развитии. Весьма важным является учёт ценностей, которые признаны населением, ожидания обычных людей в сфере регионального развития. Общественные организации должны взять на себя бóльшую роль в распространении экологической информации, повышать уровень в понимании вопросов охраны окружающей среды. Между официальными органами и местным населением должен преобладать дух сотрудничества и результативного взаимодействия.

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Ключевые слова: Сотрудничество между Россией и Финляндией, мониторинг рек, мониторинг морских побережий, модель поступления питательных веществ, сценарии изменений климата, опросы населения, экологическое просвещение.

Contents

Preface

The "Water meets people—learn, act, influence (SEVIRA)" -project is a part of the South-East Finland–Russia cross-border cooperation (CBC) Programme 2014–2020. It is one of the three programmes implemented at the border regions between Finland and Russia under the European Neighbourhood Instrument (ENI). In the period 2014–2020 the Programme offered funding in four thematic objectives, with more specified priorities. The SEVIRA project was under the priority No. 3: "Attractive, clean environment and region", including the topics of environmental protection, climate change mitigation and disasters prevention or management.

The project was implemented in collaboration with five organizations. The leading partner was Finnish Environment Institute (SYKE). The other partners were the Centre for Economic Development, Transport and the Environment for Southeast Finland, the Institute of Limnology, Russian Academy of Sciences, the Federal State Budgetary Institution Northwest Administration for Hydrometeorology and Environmental Monitoring, and the Ecocentrum Ltd.

The SEVIRA project supported the plans of Regional Councils of Kymenlaakso and South Karelia in promoting a clean, high-quality and attractive living environment. Further, the project followed the marine protection objectives set forth in the framework of the EU Marine Strategy and Water Framework Directive, the Maritime Doctrine of the Russian Federation, EU Strategy for the Baltic Sea Region and the North-West Russia Development Strategy.

1 Introduction

1.1 The background of the project

The Gulf of Finland (GOF) is the most eutrophicated sub-basin of the Baltic Sea. While the state of the GOF is linked via water exchange to that of the Baltic Sea main basin, the eutrophication of coastal waters is also aggravated by local nutrient sources. The relative impact of local pollution increases towards the east and is the more decisive the more sheltered the area is we are dealing with. However, local pollution is easier to reduce, and the reductions are realized in a much shorter time frame and cost efficiently.

The lack of knowledge on the land-based nutrient fluxes – transported mainly by rivers to the eastern GOF – hampers mitigating local nutrient discharges. The nutrient inputs from the Russian territory are particularly uncertain due to relatively infrequent and spatially restricted monitoring.

The GOF Year 2014 produced recommendations to improve the state of the GOF environment, approved as a declaration by the Ministries of the Environment of Estonia and Finland and the Ministry of Natural Resources and the Environment of Russia. Among others, it was recommended that more reliable estimates of the nutrient load into the GOF are required. For this to happen, comprehensive monitoring of rivers and point sources should by arranged based on both conventional sampling and novel automatized methods. A growing share of rivers should be permanently monitored, those rivers which contribute substantially to the nutrient load should be monitored most frequently. Anthropogenic climate change poses challenges for water management in future. It is projected to increase precipitation in the future, and hence, land-based nutrient load, thus deteriorating eutrophication.

The structure of the SEVIRA-project is described in Fig1. The background of the project was the need for more reliable estimates of the nutrient load into the GOF, suggested already in the Gulf of Finland Year 2014 declaration and also indicated by joint Finnish-Russian Commission on the utilization of Frontier Waters. To fulfil these aims, extensive monitoring of various variables was carried out in the study are. Also modeling tools were used extensively, especially to study the effects of climate change to the environment. An important prat of the project was to rise environmental awareness among citizens. As final result, a Road Map was developed interactively between scientists, decision-makers and he citizens to give recommendations for local decision-makers how to improve the state of the environment of the study area.

1.2 The objectives, study areas and target groups

The project's objective was to take steps forward to improve the environmental state in a sub-area of the GOF by combining scientific and societal actions in the surrounding catchment area. Management of the environmental state of the GOF, so that it truly takes the variable land-based load characteristics into account, cannot be realized on the entire basin level. Rather, the coastal areas have to be handled as separate cases that are tailored to meet local requirements. The results of this project represent a way to deal with local characteristics and provides steps forward in the environmental management in a realistic scale which can be applied to other coastal areas of the GOF. This way the project shared the targets of the Year of Ecology 2017 in Russia, which highlighted the nutrient load reductions and environmental awareness.

The study area covered the cross-border area between Finland and Russia where co-operation between the countries represented a societal challenge. We focused on three rivers. The Sestra River in Russia is polluted by sparse population and leisure homes, the Virojoki River is an agriculturally impacted river in Finland, and the transboundary Seleznevka (Rakkolanjoki) River forms an example of a river receiving some wastewater load from the Finnish side, transported via lower reaches located in Russia into the GOF. Target group included local citizens and decision-makers. Beneficiaries were the local people, nongovernmental organizations and local environment administration, whose objectives was driven forward. Monitoring data were widely used by scientists and environmental administration who delivered it further in clear form to authorities, rescue departments and public. Finally, improved knowledge on land-based nutrient fluxes served the entire Baltic Sea protection process.

As an improvement in the state of cross-border rivers is vital for the recovery of the project's study area, a cross-border cooperation is crucial. Joint work is needed to improve monitoring programs, to guarantee correct use of shared data and to disseminate widely the findings to the public and decision makers. Sharing information and best practices upgraded data and its use on both sides of border. The aim was to increase communication, share of know-how and good practices among water authorities working at same catchment on different sides of the border and in the transboundary monitoring. The idea was also to encourage local residents and operators to monitor the status of their nearby waters and to hear what they think about the status of their surrounding waters, how they use their waters and whether they would be prepared to take different measures to improve their status.

1.3 Activities for monitoring, modelling and increasing awareness

The project consisted of a number of separate activities, which were ultimately interlinked (Fig. 1). In the monitoring task, workshops and actual monitoring visits were organized to execute frequent hydrological monitoring. A comprehensive monitoring scheme was applied to estimate nutrient fluxes to the GOF and the status of transboundary waters. Monitoring was also carried out by citizens. Regarding the modelling task, a combined approach of measurements and modelling was used to examine impacts of eutrophication at the transboundary coastal region and bays in nearby border. The risk sites for eutrophication and the most effective counter measures to decrease it were determined based on hydrological and nutrient-related processes. Workshops were held to get feedback on modelling results from river basin managers and other stakeholders. In the activity on involving local people, enhanced services and open data usage were demonstrated in schools and on the field with stakeholders. The interest on the nearby waters was raised by student fieldtrips, which helped to become familiar with water status and ecosystems. Furthermore, the citizen surveys and interviews were carried out to raise knowledge level about water quality, and to find out the public's willingness to take part in monitoring actions and in enhancing the water quality. For the dissemination of the project results, several Round Tables were held between the project group, local decision-makers and NGOs and citizens in Finland and in Russia to commit the decision-makers and present and discuss about environmental information and environmentally friendly consumer habits with the public. As the project final outputs, practical guidelines and the Road Map for concrete actions towards the improved state of the Finnish-Russia cross-boundary water-areas were presented.

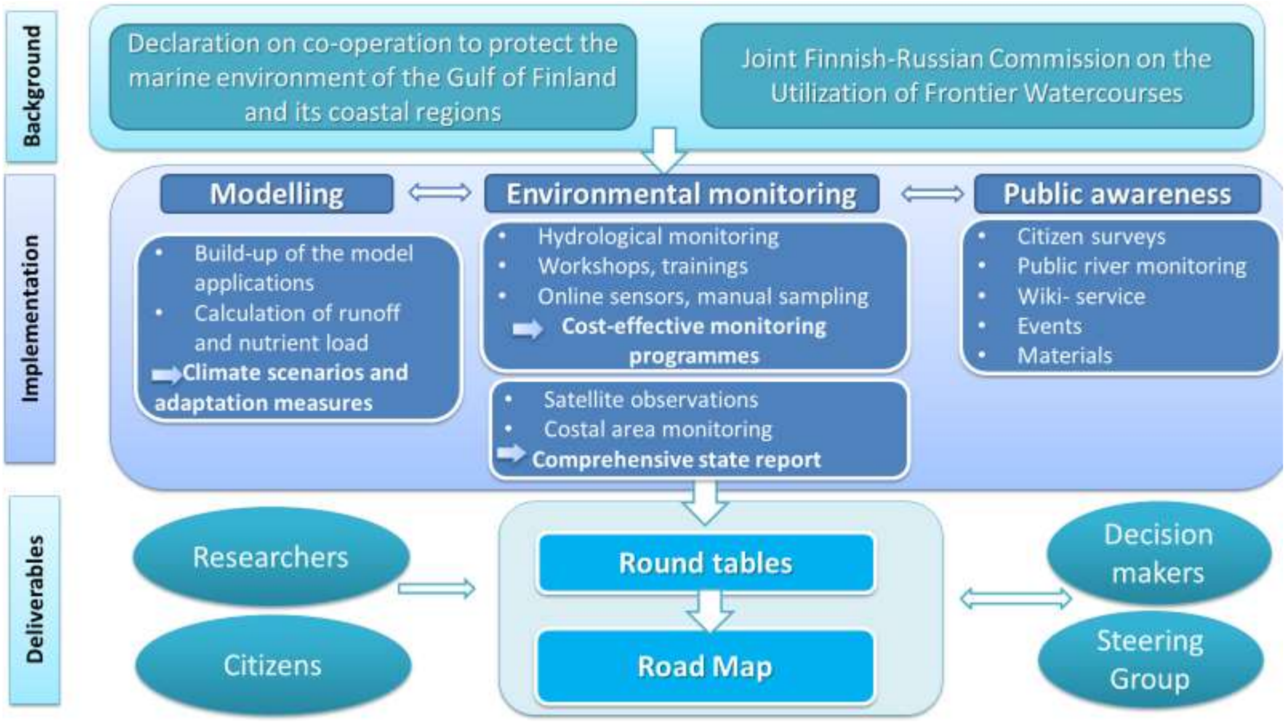


Figure 1. Activities of the SEVIRA project

2 Site descriptions

Our study area includes three catchments draining into the Gulf of Finland (Fig. 2). The catchments are the Virojoki in Finland, the Sestra in the Russia and the transboundary Hounijoki/Buslovka. The Rakkolanjoki/Seleznevka is a sub-catchment of the Hounijoki/Buslovka catchment, according to the hydrological river drainage basin classification (Ekholm 1992). Thus, officially the river draining into the Bay of Vyborg is called the Hounijoki rather than the Rakkolanjoki. However, it has become common to call the river reach between the monitoring sites 4 and 5 in Russia the Seleznevka, i.e. the Rakkolanjoki.

Figure 2. River monitoring sites.

Table 1. River monitoring sites

River	Country	Site number	Site name	Monitoring
Sestra	RUS	1	Gulf of Finland entrance	Water samples
Sestra	RUS	2	AGK Beloostrov	Stage height, water samples, ADCP measurements
Sestra	RUS	3	Viborgskoe shosse	Water samples
Hounijoki	RUS	4	Seleznevo	Water samples
Rakkolanjoki/Seleznevka	RUS	5 a	Luzhayka (upstream of the Hounijoki confluence)	On-line water quality monitoring, water samples, ADCP measurements
Hounijoki	RUS	5 b	Luzhayka (downstream of the Hounijoki confluence)	Stage height, water samples, ADCP measurements
Rakkolanjoki/Seleznevka	RUS	6	Kutuzovo	Water samples
Rakkolanjoki/Seleznevka	FIN	7 a	Rakkolanjoki Vormuinmäki (Gauge number 0601000)	Stage height, ADCP measurements
Rakkolanjoki/Seleznevka	FIN	7 b	Rajav 001	Water samples

River	Country	Site number	Site name	Monitoring
Hounijoki	FIN	8	Myllymäenkoski (Gauge number 0605800) Hounijoki 041 FIN-RUS border	Stage height, water samples, ADCP measurements
Hounijoki	FIN	9	Alajoki Vainikkala	Water samples
Virojoki	FIN	10	Salmen silta (Gauge number 1100500)	Stage height and water samples

2.1 Sestra River

The Sestra catchment (381 km^2) is located in the north-eastern Russia. The Sestra River is 74-km long and drains into the man-made reservoir – Sestroretsky reservoir, which has an outlet to the Gulf of Finland at site 1 (Fig. 2). The average annual precipitation in the area during the last decade was 648 mm. The land elevation ranges between 10 and 170 m above sea level (a.s.l., Fig. 3). Podzols and peat are the dominant soil types. Forests (68%) form the most common land-use class. Marshes (11%) are concentrated in the northern and southern parts (near the Sestroretsky reservoir) of the catchment. The rest of the Sestra catchment area is covered by fields (7%), meadows (5%), urban areas (3%) and water (6%).

At the measuring station near the Sestra outlet (site 2), the average flow was 5.95 m^3/s (2019) and it ranged between 1.59 and 24.5 m^3/s. Below the site, there is a wastewater treatment plant belonging to the Sestroretsk municipality. Within the catchment there is, however, the settlement Beloostrov, with 2 295 people living in houses not connected to the sewer networks and with an onsite wastewater treatment.

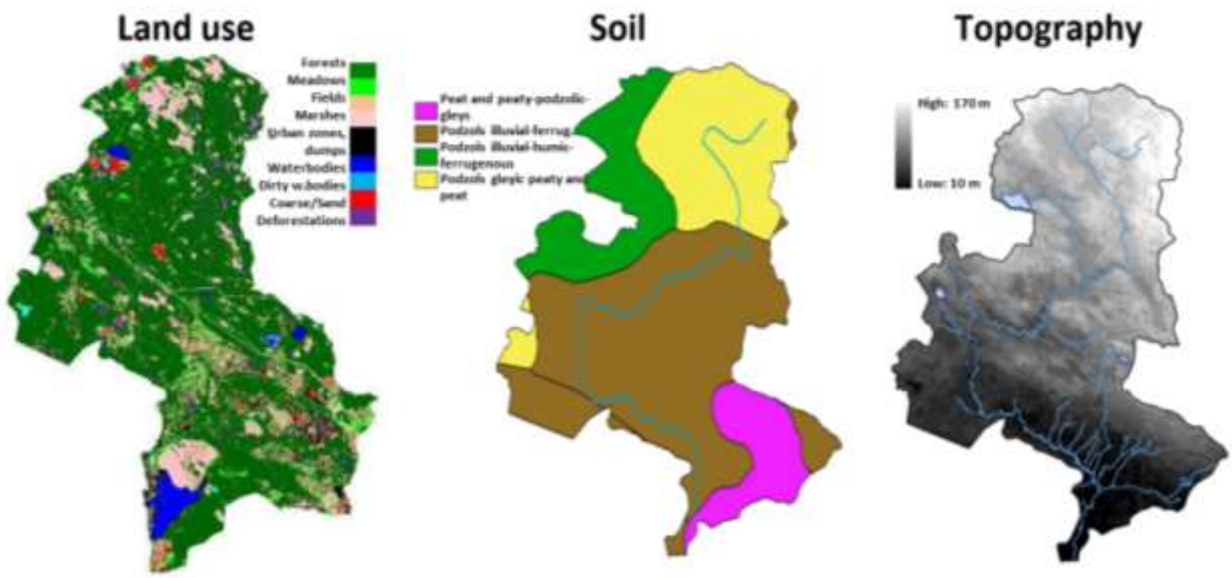


Figure 3. Land use, soil type and topography of the Sestra catchment.

2.2 Virojoki River

The Virojoki catchment (357 km^2) is located in south-eastern Finland. The 43-km long Virojoki River drains into the Virolahti Bay, which is a bordering body of water between Finland and Russia. The average annual precipitation in the area during the last decade was 728 mm. Land elevation ranges between 0 and 122 m a.s.l. Rock (<1m soil layer) is the dominant (42%) soil type, followed by clayey (16%), moraine (15%) and peat (14%) soils. In terms of land use, forest (79%) is by far the dominant class. Agricultural areas (13%) are concentrated in the central and southern parts of the catchment on mostly clayey soils (SYKE 2014). The rest of the Virojoki catchment area is covered by urban areas (3%), water (3%) and wetlands (2%, Fig. 4).

At the Salmen Silta measurement station near the river outlet, the average (2000–2019) flow was 4.0 m^3/s and it ranged between 0.1 and 33 m^3/s. In the upper reaches of the catchment there are two peat mining areas. However, these point sources account for a negligible part of the anthropogenic nutrient loading, the largest shares (87% of total P and 67% of total N loading) originating from agriculture (Vemala-model, Huttunen et al. 2016). Within the catchment there are 1 133 people living in properties not connected to the sewer networks, i.e. with onsite wastewater treatment. On top of this there are 476 summer cottages.

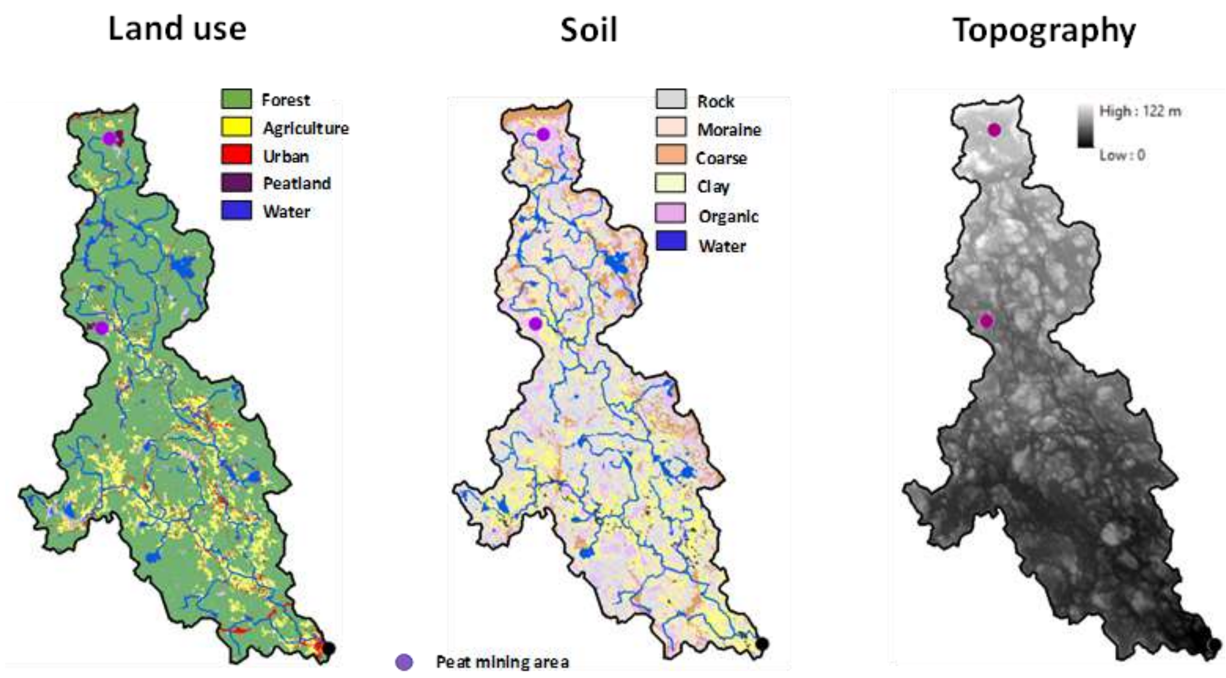


Figure 4. Land use, soil type and topography of the Virojoki catchment.

2.3 Rakkolanjoki/Seleznevka River

The Rakkolanjoki cross-border catchment is located in south-eastern Finland and north-eastern Russia. The definition of catchment size is not straightforward likely due to varying topographic information. The catchment size has been determined to be between 190 and 215 km^2. The 33-km long Rakkolanjoki River is a tributary of the Hounijoki River, which drains into the Bay of Vyborg. The average annual precipitation in the area (Lappeenranta) during the years 1981–2010 was 648 mm. The land elevation ranges between 0 and 115 m a.s.l.. 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 (72%) is the dominant class. Agricultural areas (14%) are concentrated in the northern parts of the catchment in the Finnish side, on mostly clayey soils (Fig. 5). Urban areas – mainly the Finnish city of Lappeenranta – cover 10% of the Rakkolanjoki catchment. Water and wetlands cover ca. 2% of the catchment.

The average modeled flow in 2000–2016 was 2.2 m^3/s and it ranged between 0.3 and 19 m^3/s. In the Rakkolanjoki catchment there is one major source of point pollution, i.e. the wastewater treatment plant of the Lappeenranta town (72 000 inhabitants). This large point source accounts for 48% of total P and 67% of total N loading (Vemala-model, Huttunen et al. 2016) from the Rakkolanjoki catchment into the Russian side. Within the Finnish side of the catchment there are 1 343 people living in houses not connected to the sewer networks, i.e. with onsite wastewater treatment. On top of this there are 72 summer cottages.

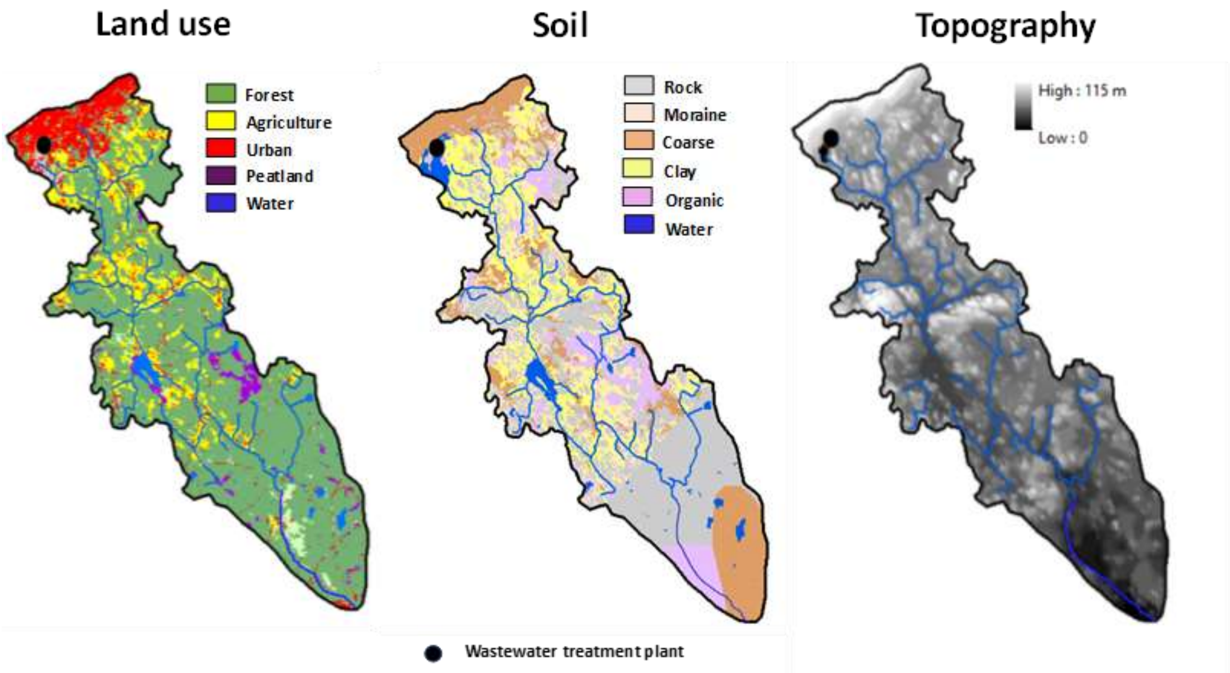


Figure 5. Land use, soil type and topography of the Rakkolanjoki catchment and waste water treatment plant in the city of Lappeenranta.

3 River hydrology and water quality monitoring

3.1. Motivation for the riverine sampling

Human impact on the state of the Baltic Sea is largely realized by the pollutant transport by rivers. In the case of the Gulf of Finland, rivers transport some 90% of the anthropogenic load of phosphorus (P) and 80% of nitrogen (N) (Raateoja and Setälä 2016). To reduce the load in a cost-effective fashion, the amount and origin of riverine loads must be known. However, the reliable estimation of riverine loads is hampered by the rapid changes in their water quality and flow, especially in rivers which cannot temporarily store water in standing water bodies. Thus, the number and timing of samples, i.e., sampling frequency and strategy, together with the load calculation method are of crucial importance. Too infrequent or ill-timed sampling may result in inaccurate load estimates and biased water protection measures, while too frequent sampling increases costs but not necessarily the precision of load estimates.

While flow is usually available on daily basis, water samples are taken less frequently. In the rivers discharging into the north-eastern Gulf of Finland, water samples are typically taken 12 times a year, but there are also some entirely unmonitored rivers. If water samples are taken on 12 days a year (3%), the concentrations for the remaining 353 days (97%) must be estimated, in one way or another.

According to the recommendation by HELCOM (2019), the riverine sampling strategy should cover the whole flow cycle including low, mean and high river flows, with special emphasis on periods of expected high river flow and paying attention to potential hysteresis (the concentrations at a certain flow may differ before and after the flow peak). A minimum of 12 samples should be collected over a year (Ekholm et al. 1995 & Rekolainen et al. 1995). Overall, for substances transported in association with suspended solids (SS), lower bias and better precision is obtained with higher sampling frequency (Kronvang & Bruhn 1996).

3.2. Aims and activities of river monitoring

Our aim was to formulate guidelines for a sound and cost-effective sampling strategy in small- to medium-sized rivers discharging into the Gulf of Finland. To this end, we collected 20–26 annual samples from three rivers and studied how load estimates are changed when the data is thinned. In addition, three different methods were used in the load estimation.

The basis for high quality flood, drought and load estimations for water sustainability and protection is formed by accurate and continuous hydrological measurements. Herby, one of the aims of the river monitoring in the SEVIRA project was to enhance the quality of the surface water level and discharge data for the rivers. Therefore, new monitoring equipment were installed in the Seleznevka, Virojoki and Sestra Rivers. In addition to technical improvements, communication and sharing of know-how and best practices between Finnish and Russian hydrological specialists were also enhanced by several joint seminars and field excursions. Water level stations in the Virojoki, Seleznevka (Rakkolanjoki), Hounijoki and Sestra Rivers were established and renewed. For visual remote monitoring, cameras were installed in the Finnish water level stations. As the amount of water is the key variable in the load estimations, the stage-discharge curves for the SEVIRA rivers were evaluated. Furthermore, new discharge measurements were performed to validate the accuracy of the curves.

3.3 Material and methods in river monitoring

3.3.1. Flow monitoring

Flow data for the Seleznevka and the Virojoki were obtained from an existing gauging station maintained by the Environmental administration in Finland (Table 1). A stage–discharge rating curve had been developed earlier using Acoustic Doppler Current Profiler (ADCP) discharge measures from the field site which was used in conjunction with 15-min resolution stage height data, to calculate discharge. New stage-discharge rating curves were developed for the Sestra and the Seleznevka in Russia. The existing rating curves in the Finnish side were improved with additional ADCP measurements (Fig. 6). The discharge for the Seleznevka at the Luzhayka was determined based on water stage data from the Seleznevka, monitoring site in Finland together with the ADCP measures at the Luzhayka monitoring site locating upstream from the confluence of the Hounijoki and Seleznevka Rivers. A stage–discharge rating curve was also developed for the lower reach of the Sestra (Site 2, Fig. 2), and the stage height was measured with one hour frequency to determine discharge. This discharge was then used, as adjusted by the catchment area, at the Sestra upper reach monitoring site (Site 3, Fig. 2).

Figure 6. Discharge measurements performed by South-Eastern Finland ELY-centre and SYKE in the Rakkolanjoki (FIN) using an Acoustic Doppler Current Profiler (ADCP) and an electromagnetic flow meter. © Pekka Vähänäkki

3.3.2 Water quality analyses and flux determination methods

Water samples were collected from all the three rivers and the samples were analysed in Finnish and Russian laboratories. The monitoring period started in November 2018 and ended in May 2021. Thus, the material fluxes were determined for the years 2019 and 2020, when a full year water quality and flow data was available. The annual number of total P and total N analyses during 2019–2020 varied from 20 to 26 depending on year and monitoring site.

We analysed the effect of sampling frequency as well as the calculation method on annual material export. The annual SS and nutrient losses were determined with (1) the entire amount of data (n = 20–26), (2) using every second sample (n = 10–13) and (3) using every third sample (n = 6–9).

Three methods were used for annual load (kg/y) calculations:

1. Linear interpolation: $Load = \sum_{i=1}^{365} Q_{daily\ mean} \times c_{daily\ mean}$
2. Mean concentrations: $Load = Q_{annual\ mean} \times c_{annual\ mean}$
3. Flow weighted mean: $Load = Q_{annual\ mean} \times c_{annual\ flow-weighted\ mean}$

where Q is flow and c the concentration of the analyte. In the linear interpolation method, the daily mean concentration was determined by linearly interpolating from the previous and the next determined concentrations. The area specific nutrient losses (kg/km^2/y) were determined by dividing the loads with the catchment area.

3.4 River monitoring results

3.4.1 Flow variation

The annual mean flow of 4.4 m^3/s in 2019–2020 in the Virojoki corresponds to the long-term average of 4.0 m^3/s (2000–2020). Similarly, the annual mean flow of 1.9 m^3/s of the Seleznevka in the Finnish monitoring site in 2019–2020 was close to the mean flow of 1.8 m^3/s in 2016–2020 (the flow monitoring was started in the Seleznevka only in 2015). Runoff in all the rivers showed a clear snowmelt peak in the spring of 2019, a long wet period starting from autumn 2019 and lasting to spring 2020 and a moderate peak in autumn 2020 (Fig. 7). In summer, runoff was mostly low. The study period can be seen to represent the current climatic conditions, where winters may be either traditionally cold and snowy (2019) or mild without frost and snow (2020). The mild winter and high precipitation resulted to flooding and high nutrient loads in many Finnish rivers in February 2020. In the Virojoki the mean flow in February 2020 was 13.4 m^3/s, the long-term February mean being 3.1 m^3/s. The February flow was comparable in magnitude with a snow-melt period, which during traditional, cold winters takes place typically in April. The mean runoff was quite similar in all the rivers, the Sestra showing the highest values (Figs. 7 and 8). Despite the seasonal differences, the mean runoff in years 2019 and 2020 were similar (Fig. 8).

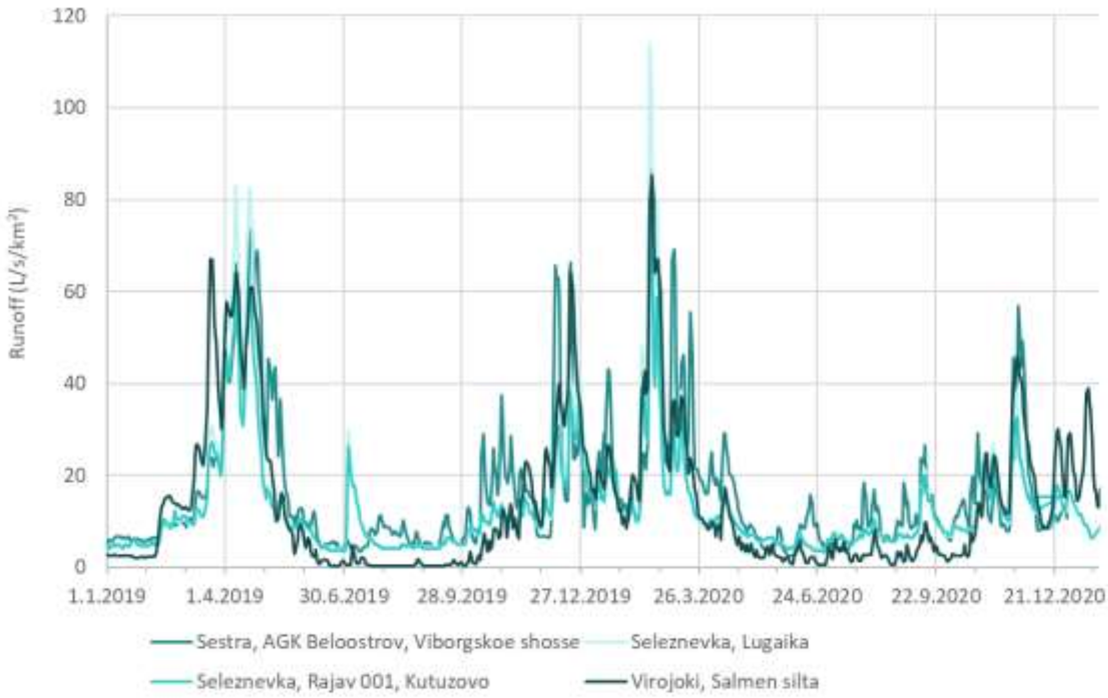


Figure 7. Runoff in the Sestra, Seleznevka and Virojoki Rivers in 2019 and 2020.

There was no continuous stage height measurement in the Seleznevka, at the Luzhayka measuring site where the on-line high-frequency water quality measurement was conducted and water samples collected (Site 5a). However, flow was measured there with an ADCP several times during 2019–2020. The combination of the stage height data from the Seleznevka, Rajav 100 station and the ADCP measurement data from the Luzhayka resulted in a good flow time series for the Luzhayka (Site 5a). The estimated flow time series fits well together with the measurements (Fig. 9).

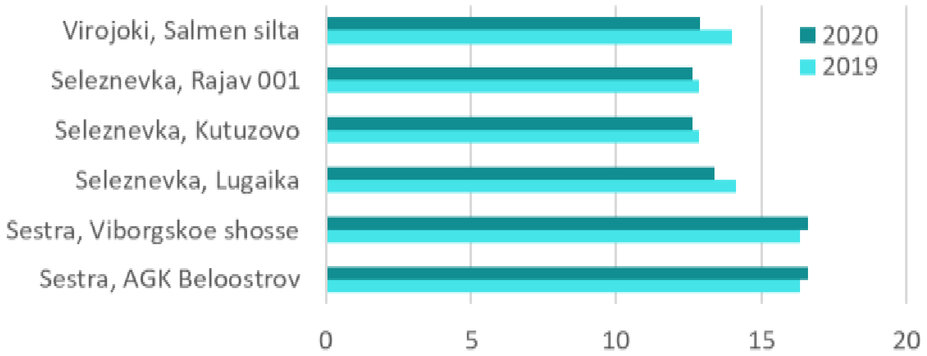


Figure 8. Annual mean runoff (L/s/km²) in 2019 and 2020.

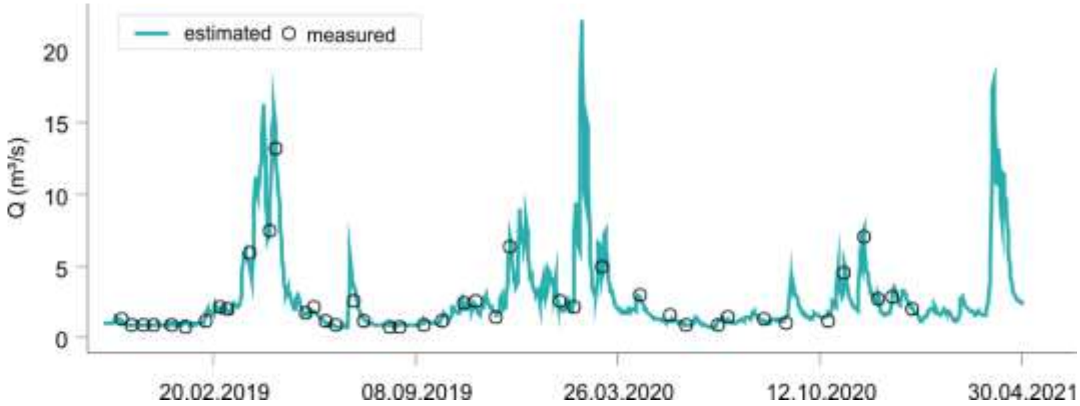


Figure 9. Daily average estimated flow and ADCP measured flow values in the Seleznevka, Luzhayka. The continuous estimated flow timeseries is based on rating curve determined between stage height at the Rajav 100 site in Finland and the ADCP measured flow values at the Luzhayka site upstream of the Hounijoki and Seleznevka confluence.

3.4.2 River water quality

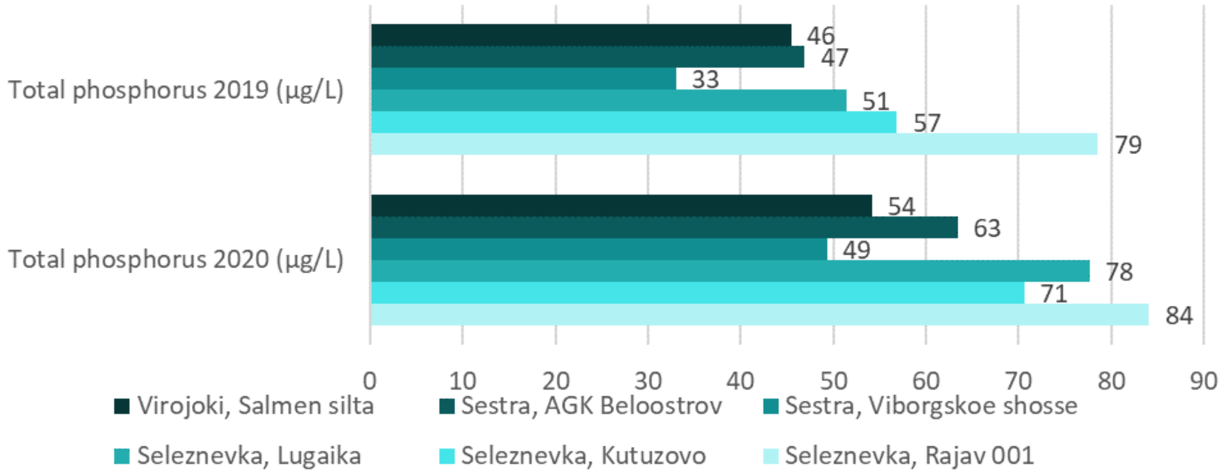
The water quality analyses in 2019 and 2020 indicate that the Sestra and the Virojoki have lower total N and nitrate N concentration than the transboundary Seleznevka. The average total N concentrations during 2019 in the upper and lower monitoring stations of the Sestra were 410 and 850 µg/L (Fig. 10), respectively, showing an increase in the loading towards the sea. The annual average total N concentration in the Virojoki was 950–1000 µg/L (2019–2020). In the Seleznevka, the annual average total N concentration varied between 2000 and 2900 µg/L in different sites. The high N concentration in the Seleznevka is probably not only due to wastewaters from the City of Lappeenranta, Finland, but also to intensive land use in agriculture, urban development and forestry. For instance, only 5–7% of the Sestra catchment is under agricultural use, whereas corresponding share is 19% in the the Finnish part of the Seleznevka catchment .

The annual average total P concentration was in the Virojoki 46 µg/L, in the Sestra 33–63 µg/L and 51–84 µg/L in the Seleznevka (Fig. 10). Although total P concentrations were also lower in the Sestra than in the Seleznevka, the difference was smaller. During winter the P concentrations were sometimes equal in these rivers. In addition, the annual total P levels were at the lower reach of the Sestra higher than in the Virojoki during both monitoring years.

To find out the reasons for increased concentrations of nutrients in the lower reach of the Sestra River, we surveyed the river banks on October 28, 2020 (Fig. 11–12). The water quality of the Sestra is likely impacted by pollution from the scattered settlements, since the total N concentration in the lower reach was most of the time higher than in the upper reach (Fig. 13). The same applied to the total P (Fig. 14), dissolved reactive P (DRP), nitrate N and conductivity. The Sestra field survey revealed that in the surveyed area:

- There were no industrial or municipal enterprises.
- There were mainly modern cottages, but also a few old private houses.
- The modern cottages (villas) had no direct sewage flows into the river. However the requirements for water protection zones were not always followed, since constructions like fences were built too close to the river. In many cases farm buildings were located directly on the shore and there was no water protection zone.
- Old private houses located mainly in the village of Beloostrov possibly had illegal sewage flows on the banks of the river (Fig. 12).
- The ditches draining the surface runoff (stormwaters) were directed right into the river.

According to the Finnish national classification of river waters (Aroviita et al. 2019), the P levels indicate a moderate ecological status for the Seleznevka upper and lower reaches and good ecological status for the Sestra and the Virojoki. Here, the water body type of all rivers was assumed to be affected by clay soils in their catchments. For this type there are no classification based on N concentrations.



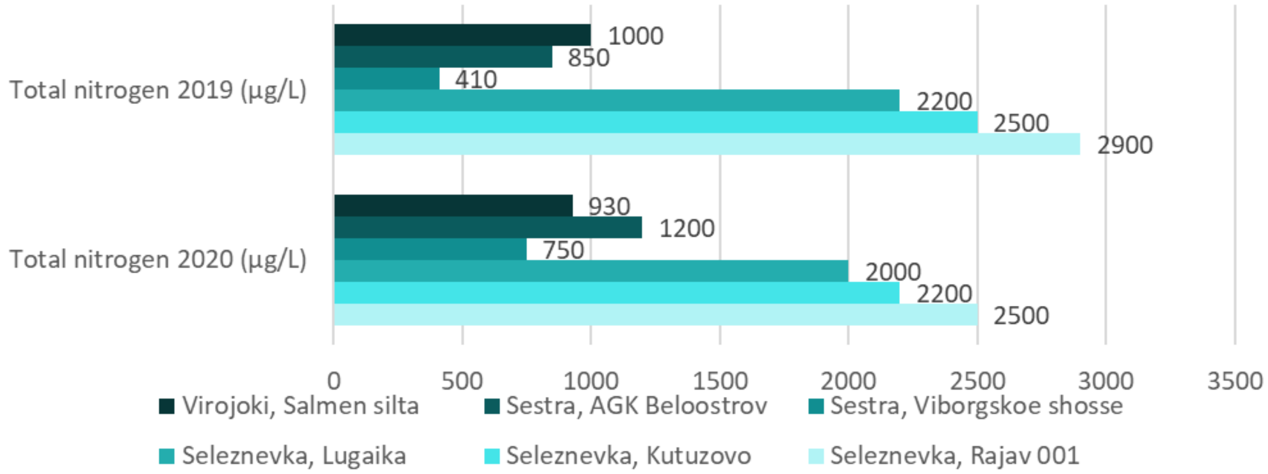


Figure 10. Annual mean total phosphorus and total nitrogen concentrations in 2019 and 2020.

Figure 11. The sampling site in the downstream part of the Sestra at the AGK Beloostrov (photo by IL-RAS).

Figure 12. Places of possible illegal sewage flows on the banks of the Setra River (photos by ILRAS).

3.4.3 Nutrient concentrations in relation to river flow

In general, when nutrient concentrations increase in river water parallel with the flow, it suggests diffuce loading as the major nutrient source. By contrast, point source loading, such as effluents from a wastewater treatment plant, tends to be diluted as the flow increases, forming an inverse relationship between the concentrations and the flow. In addition to human impact and land use, the soil in the catchment impacts water quality variation and concentration-flow relationship.

We analysed the relationship between flow and total SS concentration determined from the Nuclepore filter filtrated water samples. There was a positive relationship between the SS concentration and the flow in the Sestra lower reach (Site 2), the Luzhayka site and in the Finnish station of the Seleznevka (r(df = 23) = 0.61, p = 0.0012; r(21) = 0.67, p = 0.0005; r(24) = 0.61, p = 0.0012, respectively). However, we found no correlation between the flow and SS concentration in the agriculturally loaded Virojoki. It is also notable that the correlation between the flow and SS concentration was not significant in the Sestra, in case the SS concentration was detemined by using the Vladisart filtration.

A positive correlation between flow and total P or particulate P was actually found only in the Sestra lower reach (total P: r(43) = 0.54, p = 0.0001) and the Seleznevka Kutuzovo (particulate P: r(52) = 0.52, $p < 0.0001$). In the Finnish side of the Seleznevka River we found no correlation between the flow and P. The reason behind the differing results between these two nearby stations in the Seleznevka remained unsolved.

There was no clear relationship between N concentration and flow in the Sestra or the Seleznevka, whereas in the Virojoki both total N r(27) = 0.50, p = 0.0053 and nitrate N r(27) = 0.52, p = 0.0036 correlated positively with the flow. This result suggests that rain induced N flushing from scattered sources has relatively low impact on the observed water quality in the Sestra and the Seleznevka. The field percentage in the Sestra catchment area is low, and thus the N input from agriculture is probably small. Compared to the Sestra River, a larger share of the cathment is allocated to agriculture in the Virojoki and the Seleznevka. The agricultural fields accout 13% of the catchment area of the Virojoki and 19% of the Seleznevka catchment area at the country border. In addition to agricultural loading, the Seleznevka River is suffering from the City of Lappeenranta municipal waste waters, thus the possible positive relationship between diffuse agricultural loading and the flow is masked by the point source nutrient input into the river.

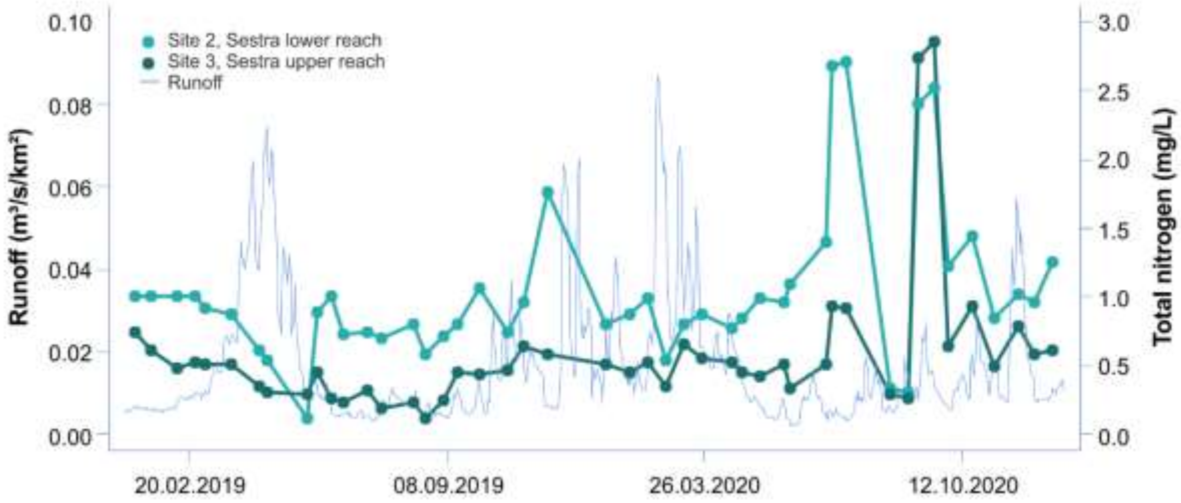


Figure 13. Linearly interpolated total nitrogen concentrations and runoff in the lower reach of Sestra at the AGK Beloostrov (Site 2) and in the upper reach at the Viborgskoe shosse (Site 3).

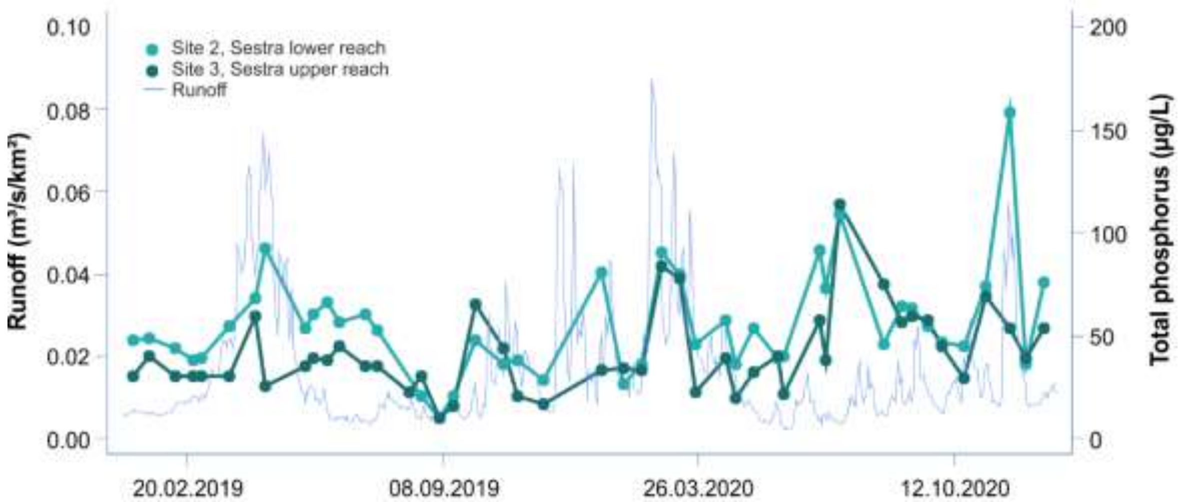


Figure 14. Linearly interpolated total phosphorus concentrations and runoff in the lower reach of Sestra at the AGK Beloostrov (Site 2) and the upper reach at theViborgskoe shosse (Site 3).

3.4.4 Phosphorus export estimates and the impact of sampling frequency

The estimated total P export ranged from 17 to 40 kg/km^2/year among the rivers and years as determined using the entire data (n = 20–26, Table 2). The level is typical of mixed land use catchments or caused by point source loading. From forestry-impacted areas in Finland, the total P export is typically less than 10 kg/km^2/year and from semi-natural sites less than 5 kg/km^2/y, whereas the export from agricultural land is larger than from forested or pristine areas (De Wit et al. 2020).

In the Seleznevka, the total P export decreased downstream from the country border, reflecting the dilution of the municipal wastewater load by the city of Lappeenranta. By contrast, in the Sestra the export increased towards the sea, possibly due to the settlements in the lower reaches (Table 2).

The total P export was higher in 2020 than in 2019 (Table 2) despite the fact that the mean annual runoff was quite similar during these years. In the Sestra, the mean runoff was only 1% higher in 2020 than in 2019, but the total P exports were 28%–65% and total N exports 25%–84% higher in 2020 than in 2019. In the Seleznevka and the Virojoki, the mean runoff was 3% and 8% smaller in 2020 than in 2019, respectively, but the total P exports were yet higher in 2020. Thus, the result indicates that the hydrology variation like seasonal precipitation distribution, rain intensity, soil water storage capacity, soil frost and snow melt had an influence on the elevated total P concentrations during 2020, as well as on the annual flux estimates in all monitoring sites. The linearly interpolated total P concentrations based on water sampling were most of the time during 2020 higher than in 2019 (Figs. 15–17). We assume that the point source loading has been quite similar during the years 2019 and 2020.

We hypothesize that the most accurate annual nutrient export estimates are those obtained by the most intensive water sampling, as shown in the Table 2. We also determined the annual total P export estimates based on a reduced number of samples to evaluate the effect of sampling frequency on the annual estimates. When only a half of the samples were used, the bias of the annual total P export estimates compared with the estimates determined with the entire data ranged from −24% to +28% (Table 3). However, only in the Luzhayka site during year 2020 the difference between the estimates was larger than 20%. The median bias in all the other monitoring sites was less than 15%, which indicates that the annual sampling frequency of 10 to 13 times results in quite accurate total P export estimates. In general, the variation and bias in export estimates increased when the sampling was reduced to one third (n = 6–9).

Table 2: Total phosphorus (P) and total nitrogen (N) export (kg/km^2/year) during 2019 and 2020 determined with entire number of water samples (n = 20–26).

Monitoring site	Method	Total P, 2019	Total P, 2020	Total N, 2019	Total N, 2020
Virojoki	Linear interpolation	20	21	529	392
	Mean concentration	20	22	455	380
	Flow-weighted mean	19	24	559	427
	Mean	**20**	**22**	**514**	**400**
Seleznevka, Rajav 001	Linear interpolation	29	30	1296	1045
	Mean concentration	32	34	1191	995
	Flow-weighted mean	28	32	1280	1025
	Mean	**30**	**32**	**1256**	**1022**
Seleznevka, Kutuzovo	Linear interpolation	24	28	998	861
	Mean concentration	23	28	998	888
	Flow-weighted mean	26	30	1013	853
	Mean	**25**	**29**	**1003**	**867**
Seleznevka, Luzhayka, Site 5a	Linear interpolation	23	36	1020	810
	Mean concentration	23	33	968	831
	Flow-weighted mean	23	38	975	798
	Mean	**23**	**36**	**988**	**867**
Sestra, Viborgskoe shosse	Linear interpolation	17	28	219	350
	Mean concentration	17	26	212	390
	Flow-weighted mean	18	28	212	355
	Mean	**17**	**27**	**214**	**365**

Monitoring site	Method	Total P, 2019	Total P, 2020	Total N, 2019	Total N, 2020
Sestra, AGK Beloostrov	Linear interpolation	29	37	425	533
	Mean concentration	24	33	436	626
	Flow-weighted mean	30	40	396	514
	Mean	**28**	**37**	**419**	**558**

Table 3: Bias (in %) in annual total phosphorus (P) and total nitrogen (N) export estimates due to reduced sampling in 2019 and 2020.

River monitoring site	n	Min bias Total P	Max bias Total P	Median absolute bias Total P	Min bias Total N	Max bias Total N	Median absolute bias Total N
Virojoki	11–13	−12	7	**3**	−8	6	**4**
Seleznevka, Rajav 001	11–13	−3	3	**1**	−3	2	**1**
Seleznevka, Kutuzovo	11–12	−16	18	**13**	−5	9	**3**
Seleznevka, Luzhayka, Site 5a	11–12	−24	28	**16**	−4	7	**3**
Sestra, Viborgskoe shosse	11–12	−14	18	**5**	−3	4	**1**
Sestra, AGK Beloostrov	10–12	−17	12	**10**	−9	7	**3**

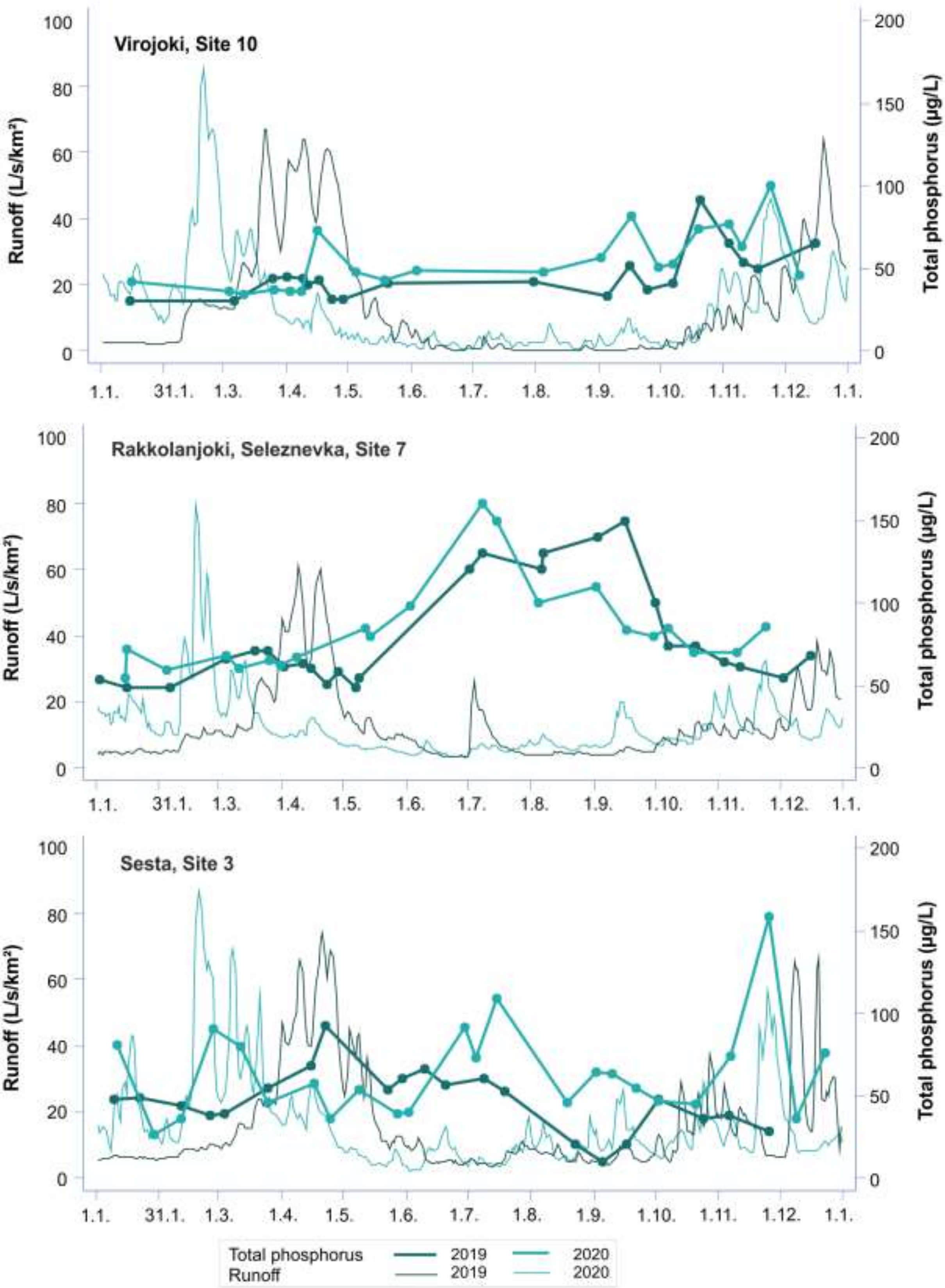


Figure 15. Total phosphorus concentrations (dots=sampling, thick line=interpolated concentration) and runoff (weak line) in the Virojoki (Site 10), the Seleznevka (Site 7) and the Sestra (Site 2).

3.4.5 Nitrogen export estimates and the impact of sampling frequency

The estimated annual total N export ranged from 200 to 1300 kg/km^2/year among the rivers and years as determined using the entire data (Table 2). In the Sestra, the total N export was 25%–84% higher in 2020 than in 2019, whereas in the Seleznevka and the Virojoki the total N export estimates in 2020 were from −12% up to −26% smaller than in 2019. Thus, both the total N and the total P export were higher in 2020 than in 2019 in the Sestra, whereas the behaviour of the total N and total P export was different in the Seleznevka and the Virojoki.

When only half of the samples were used, the bias of the annual total N export estimates compared with the estimates determined with the entire data ranged from −9 to +9% (Table 3). The median bias was in all monitoring sites ≤4%, which indicates that the annual sampling frequency of 10 to 13 times results in accurate total N export estimates. The variation and bias in estimated total N export increased moderately in case the sampling was reduced to one third (n = 6–9). However, it is not recommended to reduce sampling below 10 annual samples, since the total N concentration timeseries e.g. from the Sestra show that irregular N concentration peaks appear in the river. In case of reduced sampling strategy the peak concentrations would likely be missed.

3.4.6 Impact of calculation method on phosphorus and nitrogen export estimates

The median absolute difference in the annual nutrient export estimates between the linear interpolation method and the two other methods was only 6% (total P) or 3% (total N) when all the samples (n = 20–26) were taken into account in the six monitoring stations. Thus, the differences in the export estimates produced with the three different estimation methods were usually minor when all available monitoring data was used in the nutrient export estimates (Table 2). The difference was usually less than 10%. The maximum difference in annual nutrient export estimates due to calculation methods ranged from −16% up to +17% (total P) and from −14% up to +17% (total N) depending on site and year.

The year 2020 sampling in the Sestra lower reach is an example when the use of the mean concentration method results in an overestimation the “true” total N export, since several high total N concentration peaks were analysed during low flows (Fig. 13). The total N export 626 kg/km^2 for 2020 in the Sestra lower reach calculated with the mean concentration method was significantly larger compared with the two other methods (see Table 2). The annual mean total N concentration was 1.2 mg/L, whereas the annual flow-weighted mean concentration was only 1.0 mg/L. Hence, the linear interpolation method and the flow-weighted mean concentration method capture the “true” loading better in this case.

3.4.7 Comparison of FIN/RUS analytical results

Particulate and dissolved matter are operationally separated in water samples using filtration. To test the protocols in Finnish and Russian laboratories, the SEVIRA project organized a test in which the water samples collected from the Russian monitoring sites were pretreated with two different filter types before analyses of DRP and total SS. The filters included the Vladisart cellulose acetate filter ФМАЦ-0.45µm and the Whatman/Nuclepore polycarbonate filter 0.4 µm. The material, pore size and the manufacturing technique of these filters differ. According to the Finnish experience, the Nuclepore filters are the most efficient in retaining particulate matter from river waters. Therefore, we expected that the use of the Vladisart filter produces higher DRP concentrations than those determined with the Nuclepore filter. In other words, the smallest particles are more likely to go through the Vladisart filter, resulting in overestimating the true DRP concentration and underestimation of SS concentration in river water.

The results corroborated our expectations: the Nuclepore filters did capture more efficiently particulate matter from the river water samples. On average, the use of the Vladisart filter gave higher

DRP concentrations than the use of the Nuclepore filter (Fig. 16). The mean DRP concentration (2019–2021) in the Seleznevka stations Luzhayka and Kutuzovo were 15 µg/L (n = 40) and 13 µg/L (n = 38), respectively, when the Nuclepore filter was used. Accordingly, the DRP concentration in the Sestra upper and lower reach stations were 8 µg/L (n = 23) and 11 µg/L (n = 24), respectively. In the Seleznevka, the Vladisart filter gave 13–31% higher mean DRP concentrations and in the Sestra 34–75% higher than the Nuclepore filter. Moreover, the Vladisart filtration gave 19–28% (Sestra) or 15–16% (Seleznevka) lower mean SS concentration than the Nuclepore filtration in 2020.

The SS exports were determined for the year 2020, when 12 to 16 water samples were analysed using both filtration methods as shown in Fig. 17. A large difference in the export estimates was brought about by the filter type, the Vladisart filter giving generally the lowest SS export estimates. The Vladisart filtration -based SS flux estimates were in the Sestra upper reach monitoring (Site 3) 20% lower than the estimates with the Nuclerpore filtration. The difference in the SS export estimates due to filtration method was even larger i.e. 28% in the Sestra lower reach. In the Seleznevka the Vladisart filtration resulted in an average of 11% (Kutuzovo) and 16% (Luzhayka) lower SS flux estimates than the Nuclepore filtration. It seems that the SS particle size distribution varies between these two rivers, the Sestra having a higher portion of fine particles that pass through the Vladisart filter but are trapped by the Nuclepore filter.

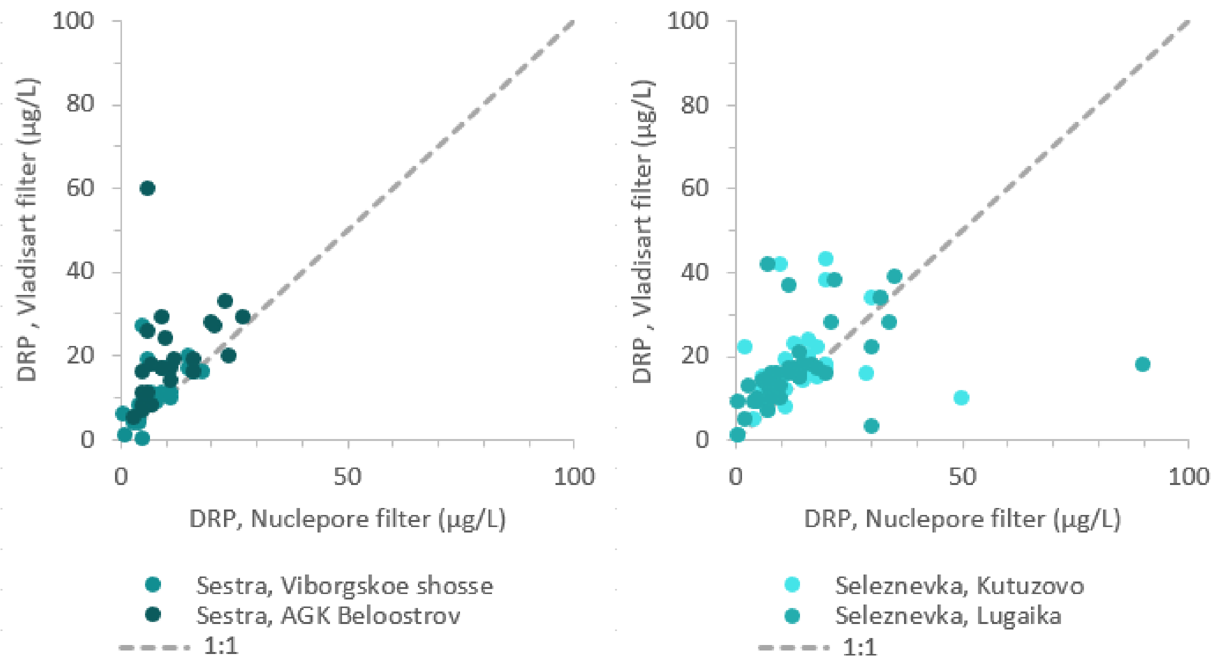


Figure 16. Dissolved reactive phosphorus (DRP) concentrations in 2019–2021.

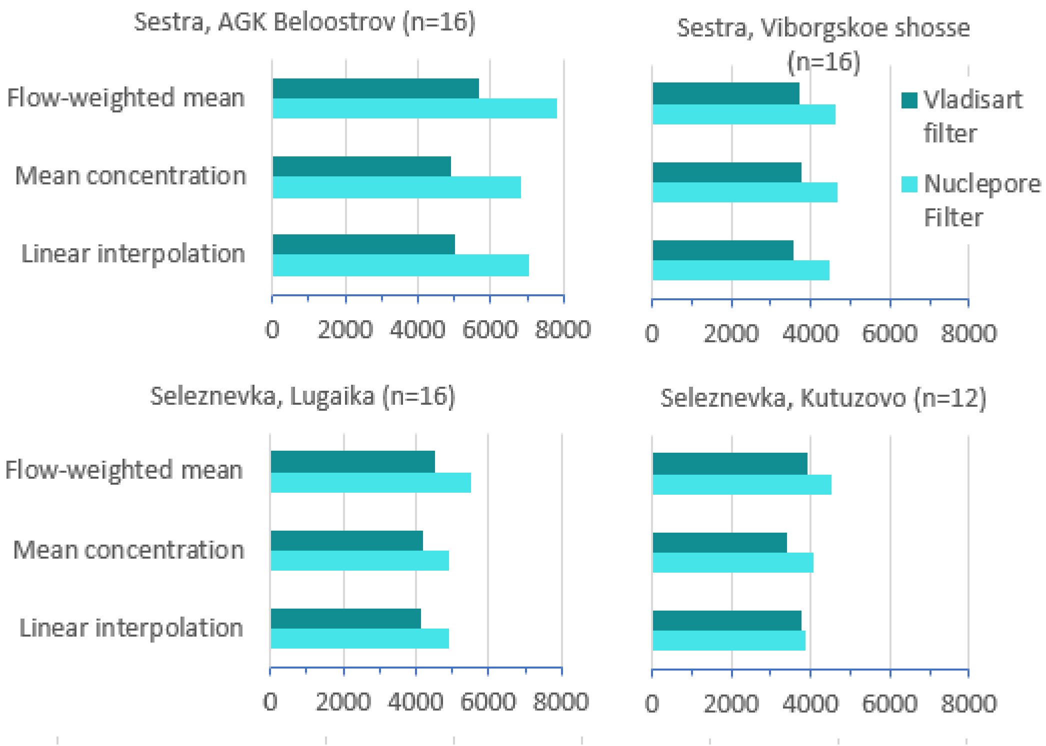


Figure 17. Annual suspended solids flux estimates (kg/km²/year) in 2020 with three methods using the Vladisart and the Nuclepore filter filtration.

3.5 Recommendations

Our analysis on the three, relatively small rivers discharging into the eastern Gulf of Finland show that the calculation method and sampling frequency did affect the riverine load estimates for nutrients and other variables, but the effect was yet quite modest. The relatively low effect was partly due to the low correlation between the concentrations and flow, and to the lack of clear seasonality. In addition, occasional concentration peaks appeared to be rare, although a few times tracked by the on-line sensors. The nutrient losses in the river catchments were quite typical for such rivers, indicating both diffuse and point-source loading. However, no major unknown pollution sources (“surprises”) were found.

We conclude that 12 samples produce tolerable total N and P export estimates for these rivers. The result is in line with the HELCOM monitoring recommendation that a minimum of 12 samples should be collected over a year (HELCOM 2019). Although sampling about 12 times a year is realized in many rivers, there are also others that have remained entirely unmonitored. According to HELCOM, 11% of the catchment of the Gulf of Finland is unmonitored based on data in 2019 (HELCOM 2022). This area included the Sestra River, which was not monitored before the SEVIRA project. We recommend all the rivers discharging into the Gulf of Finland be sampled at least 12 times a year. If resources allow, sampling frequency should preferably be increased to 24 times a year. Focusing sampling to flood periods is also recommended, because such periods are responsible for most of the material flux into the Gulf of Finland. Unfortunately, climate change hampers the pre-set estimation of wet seasons as the potential winter floods may occur any time between October and April during mild winters. We also recommend taking a few samples during dry periods, since low runoff causes only little dilution for potential point sources and so-called incidental losses may be revealed. If identifying incidental losses is the main goal of monitoring, online sensors are the obvious additional technique of choice.

Regarding the estimating the nutrient load to the sea, the riverine sampling sites should be as close to the river outlet as possible. However, as shown by our results, the concentrations in a river may either decrease or increase from the upper to the lower reaches. Thus, sampling in several sites along the river stretch may give additional information on the sources of pollutants.

In addition to sampling, the analysis protocol affects the reliability of load estimates. Our analysis showed that the filters used in Russia allow particles to enter the “solution” phase, thereby giving too low results for SS and too high results for dissolved nutrient fractions.

The surface water level and discharge stations in Finland are classified according to a three-stage monitoring class. Nowadays the transboundary rivers in the Finnish side are rated as second stage regional stations, but we recommend that their status should be upgraded to first national scale stations. This would allow more frequent data quality control and more frequent checks of the stage-discharge curves with measurements. It is needed for the sustainable development of cross-boundary water resources. Co-operation in specialist level is also important in developing the monitoring methods and enhancing the exchange of data. We encourage both Finnish and Russian hydrologists to develop methods and ways for co-operation as well as to continue the measurements.

4 Coastal monitoring and assessment

Main purpose of the coastal monitoring work in the SEVIRA project was to create up to date information on the quality and ecological status of coastal waters within the study area, i.e. the North-Eastern parts of the Gulf of Finland (GOF). One of the key themes was to increase co-operation and exchange knowledge between Finland and Russia, and the monitoring and assessment part followed this line. In particular, the partners planned and arranged jointly specific field campaigns in the Bay of Vyborg during the project lifetime. In addition, the project made use of Finnish national monitoring in the Bay of Virolahti. During the project lifetime, from 2019 to 2021, the project carried out sampling campaigns in the coastal sea areas on the Finnish and Russian sides. The monitoring material from the field campaigns, arranged both in the Bay of Vyborg and in the Virojoki Bay, was used to assess the current state of these coastal water areas, which was the main aspect of the assessment work. Another aspect of the assessment was to analyse long-term monitoring results in the coastal waters of the Eastern GOF. For this, the project took advantage of measurements made on both sides of the border since 1996. In addition to station sampling, the project utilised also satellite observations and an archive of automated online measurements collected by a ferrybox-system, Alg@line. Satellite observations were used to generate annual maps of chl-a level for the state assessment of these coastal waters. In addition, the project set up a chain of virtual monitoring station sites that will continue to provide satellite observations within the study area after the SEVIRA project. The long-term status assessment shows that water quality and condition in the coastal area of the eastern GOF have improved over the last decade. There is a long-term positive trend in the quality of the coastal water areas of Bay of Vyborg and Virolahti bay. The same applies to the adjacent inner and outer archipelago regions. These positive trends show in all analysed water quality parameters, each of which act as an indicator of eutrophication.

4.1 Joint monitoring in Russian and Finnish coastal waters

During the project lifetime, the partners carried out sampling and measurement campaigns in the sea areas on the Finnish and Russian sides. The monitoring material from the field campaigns, arranged both in the Bay of Vyborg and in the easternmost parts of the coastal waters of Finland (focus in the Virojoki Bay), were used to assess the current state of these areas. For the Bay of Vyborg, the planning of the monitoring was a joint effort and co-operation between the partners. On the Russian side, the key partner in organizing the water quality monitoring was the Northwest Administration for Hydrometeorology and Environmental Monitoring (North-West AHEM) and on the Finnish side, the ELY Center for South-East Finland. SYKE was responsible for the production and analysis of the satellite observations of water quality. The sampling cruises were carried out and organized by the Russian partner. Water quality data on the Finnish side was obtained through a monitoring program commissioned by the ELY Centre (Monitoring Program for National Water Management Planning). Minor additions to this were made based on the requirements by the SEVIRA project.

4.1.1. Coastal station sampling

The purpose of the monitoring actions was to draw a coherent overview of the water quality in the coastal area under study. For this purpose, the sampling periods for the specific field campaigns arranged were agreed for the same weeks both in the Bay of Vyborg and in the easternmost parts in Finland. The station sampling was complemented with satellite observations from the same area and concurrent periods.

The coastal study area covered the easternmost GOF. Special attention was put on these areas (Fig. 18):

- The Vyborg Bay (the inner bay area in front of the city of Vyborg over to the mouth of the bay) in the Russian side.
- The coastal waters of the municipality of Virolahti and nearby the city of Hamina (including an inner archipelago area Tammio, which is isolated due to islands and bottom thresholds).
- The eutrophicated Virolahti Bay on the Finnish side close to the border.
- The easternmost outer archipelago area in Finland (areas from the Huovari region at the border zone to the "offshore" Haapasaari islands in the city of Kotka).

In the Bay of Vyborg, specific attention was put on the river Rakkolanjoki estuary and on the river water route towards the open sea areas in the eastern GOF. The stations (Fig. 18) were mostly chosen based on earlier sampling sites (see chapter 4.1.1.1) and thus enable the analysis of the changes in eutrophication within the bay starting as early as 1996.

On the Finnish side of the coastal study area, the project utilized altogether seven monitoring stations out of a larger set of stations belonging to the national water quality monitoring programme. These stations belong to the ELY Centre's monitoring program and partly to the environmental permit monitoring program for the fish farms at the Virolahti bay (Fig. 18). Like the stations in the Bay of Vyborg, the selected ones provide long-term information on the water quality and can thus be used to analyze the changes in the eutrophication.

During the SEVIRA project, three annual joint sampling periods were arranged during mid-August. During these periods, a sampling cruise was arranged both in the Bay of Vyborg and at the sampling stations in the Finnish coastal region (19. −23.8.2019, 10.−14.8.2020 and 9.−13.8.2021). The water quality sampling focused on surface water and near-bottom water samples. Same water quality parameters and sampling depths were applied in both countries (Table 4). Samples taken from the Bay of Vyborg were analyzed at North-West AHEM's laboratory in St. Petersburg and Finnish coastal samples according to the national monitoring program (at Eurofins Environment Testing Finland Oy's laboratory). The monitoring efforts focused on determining the changes in eutrophication; therefore, the most relevant parameters were nutrients (e.g. total phosphorus and nitrogen, full list in Table 4) and chlorophyll-a (chl-a). Chl-a is a green pigment used by phytoplankton and algae in photosynthesis. Its concentration reflects the abundance of phytoplankton present in the water. In Finnish monitoring programs, the total amount of phytoplankton in water is measured by analyzing the chl-a content of a water sample. Chl-a is used widely as a water quality classification parameter, like in the EU's Water Framework Directive (Ferreira et al., 2007) and in the surface water trophic state determination in Russia (Vincent, 1960). Where possible, measurable parameters were supplemented with analyzes for satellite data interpretation, such as Secchi depth and the absorption of Colored dissolved organic matter (CDOM, laboratory analyzes on the Finnish side, Table 4).

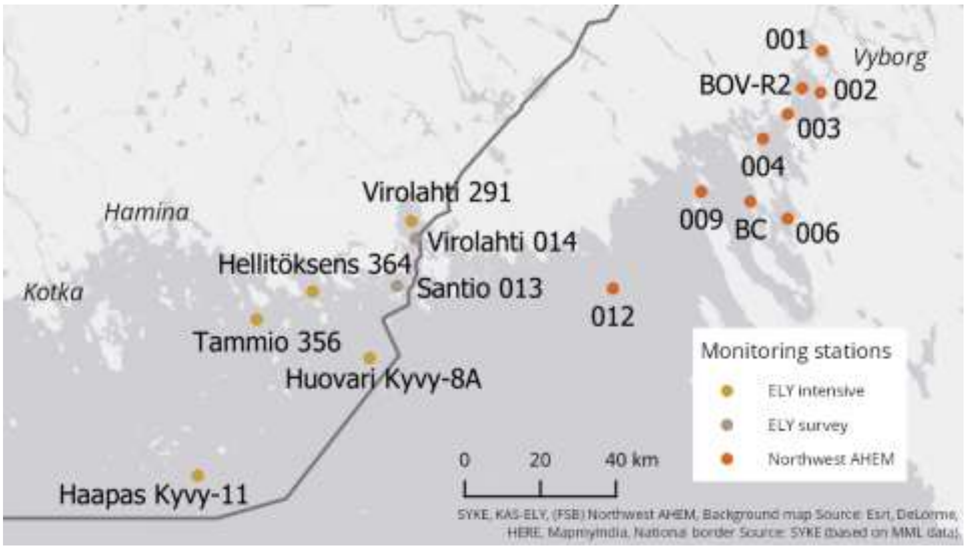


Figure 18. SEVIRA-monitoring stations in near-border coastal region conducted in the framework of ELY's monitoring program and in the Vyborg Bay (orange dots) sampled by North-West AHEM during 2019-2021. Annual water sampling intensity in Finnish monitoring stations: survey stations (grey dots) and intensively measured stations (5 - 18 samples/year, yellow dots).

Table 4. Sampling depths and analysed water quality parameters from SEVIRA sampling stations in the Bay of Vyborg (by North-West AHEM) and in the coast of Finland (by ELY) in 2019–2021. Sampling: surface (1 m) and near bottom (b-1m). a_{CDOM} = Absorption coefficient of CDOM.

Bay of Vyborg and Coast of Finland	For combined EO/satellite monitoring purposes
total phosphorus (µg/l) *	Secchi depth (m)
phosphates (on phosphorus) (µg/l)	turbidity (FNU)
total nitrogen (µg/l) *	total organic carbon (mg/l)
nitrite + nitrate nitrogen (µg/l)	a_{CDOM} at 400 nm (1/m)
ammonium nitrogen (µg/l)	a_{CDOM} at 750 nm (1/m)
chl-a (µg/l) **	Surface temperature
water temperature (°C)	
pH	
conductivity (mS/m)	
salinity (‰)	

* both filtered and non-filtered in the Bay of Vyborg
** 0−2 m in both, and Secchi depth dependent in coast of Finland

4.1.1.1. Available historical datasets for the analysis of long-term changes

As a background material, SEVIRA partners took advantage of the monitoring results collected during the Vyborg Bay Joint Monitoring project (1996–2006) with complementing results from North-West AHEMs monitoring (1996–2014). The Vyborg Bay Joint Monitoring was a historical co-operation project between the Russian and Finnish organisations, that regularly sampled 2–4 times a year covering winter, early summer, late summer and autumn periods in the Vyborg Bay area. For all abovementioned years, the monitoring results were available for the period of late summer, the most relevant period to the status assessment of eutrophication. In the Vyborg Bay Joint Monitoring project, water quality samples were transported to Finland for analysis and archived in water quality register maintained by SYKE (VESLA database, available in open data OIVA portal).

Alg@line is a monitoring network that collects information on the state of the Baltic Sea using continuous measuring devices on passenger and merchant ships. The network is coordinated by SYKE. In the period 2004–2012, the City of Helsinki Environment Center and the Southeast Finland ELY-Center) participated in the implementation of Alg@line project's coastal route section in the Eastern GOF. The ship routed between cities of Helsinki and Kotka and Hamina and at times all the way to Lappeenranta-Savonlinna through Saimaa channel. The Alg@line sampling system includes a flow-through chl-a fluorometer installed in the passenger ship. The system onboard contains an automated bottle sampler. These water samples, later analyzed in a laboratory, were utilized for the quality assurance and transformation of the fluorometer values to chl-a concentrations (e.g., Rantajärvi et al., 1998). Within the SEVIRA project, the Alg@line data was used as additional water quality data for the sampling stations that coincided with the ship route. On the Vyborg Bay, the observations were available for the stations describing the main part of the river influence towards the outer parts of the coastal waters (stations 004, 009 and 012, Fig. 18). On the Finnish side, the Alg@line data was available for two of the stations (Santio 013 and Tammio 356). Annual mean concentrations of chl-a summer period (July−August) were calculated from the Alg@line data and used in conjunction with station sampling results. Although there are some differences in the Alg@line flow-through observations in contrast to station sampling (e.g. obtained while the ship is on move in cruise speed), the data complements well the status assessment over the years without station sampling results available.

4.1.2. Satellite observations i.e. Earth Observations (EO)

In addition to the coastal station sampling, the SEVIRA project utilized satellites providing observations from the Eastern GOF. The great benefit of satellite observations is that during cloudless periods, the observations are available on both sides of the country border at the same time. The frequency of satellite overpass was several times per week. Satellite observations can be utilized for the days and areas that have been cloudless during the satellite overflight. We utilized mainly satellite observations provided by the European Union's flagship satellite series, the Copernicus program. This space program produces a wide range of observations suitable for environmental monitoring in various aspects. Along with Copernicus program satellites, also NASA Landsat-series satellite instrument observations were utilized in the project.

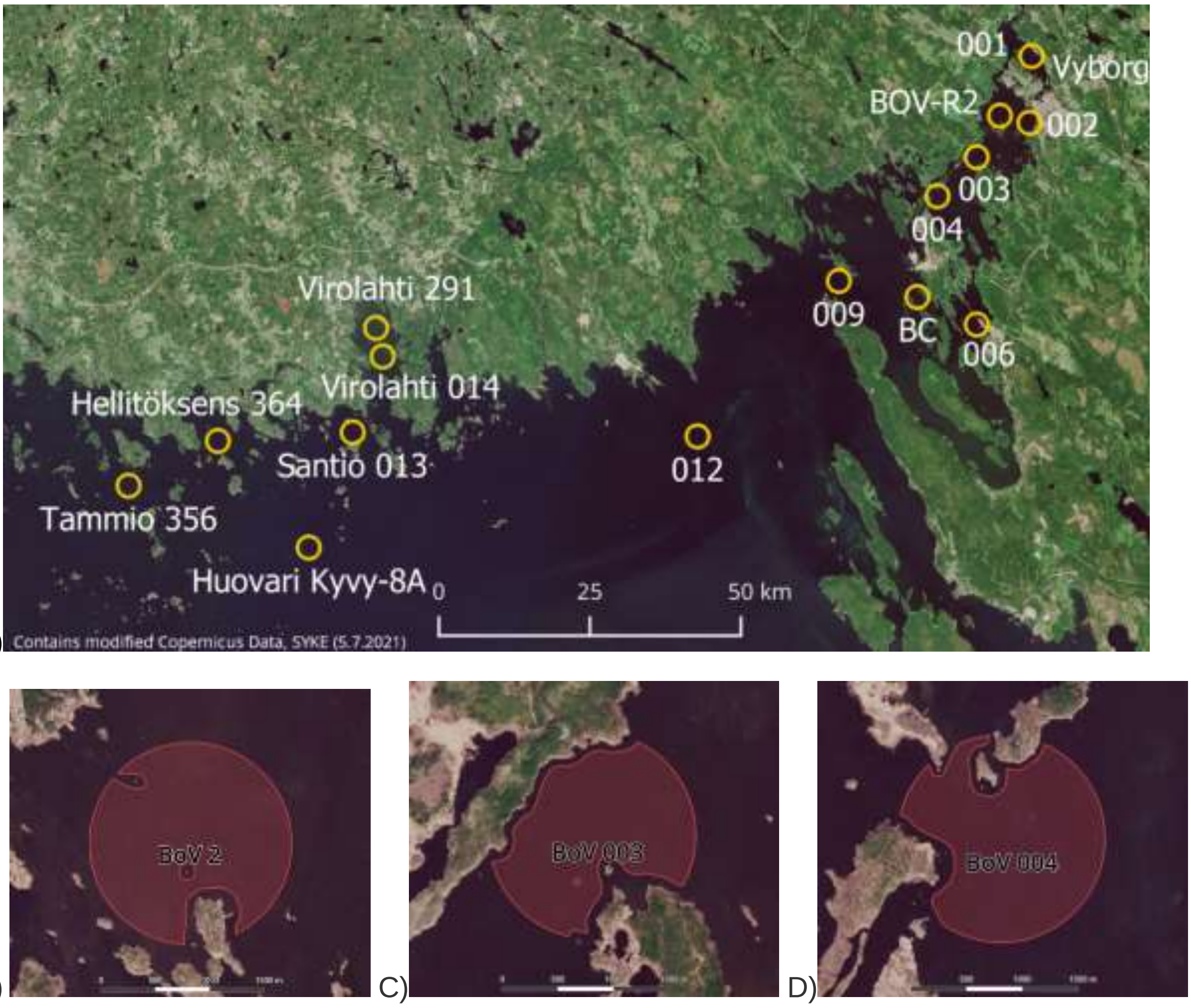
The use of satellite observations focused on determining chl-a that describes the algal abundance. The other water quality parameters that have been analyzed from satellite observations, or EO datasets, are turbidity, absorption of colored dissolved organic matter (a_{CDOM}) and temperature.

Satellite observations can be utilised to follow and identify interesting phenomenas on daily basis. For example, if there is an evident cyanobacteria bloom occurring in the Eastern GOF or turbidity incoming via rivers to the coastal estuary, a daily chl-a or turbidity map reveals the areal extent of the phenomenon. On the other hand, a summary, or aggregation, of the observations accounting all noncloudy satellite observations during summerly period can be calculated. These combinations of summerly observations can be used to assess the state of coastal waters and to compare with e.g., previous years or other types of monitoring methods.

Sentinel satellite series provide two types of optical instruments that are practical for monitoring water quality. Currently, OLCI (Ocean and Land Colour Instrument) instruments onboard the first two of Sentinel-3 satellites observe daily with a 300m ground observational resolution. Likewise, Sentinel-2 satellite series MSI (Multispectral Instrument) instruments are installed onboard two consecutive satellites. Their overpasses are synchronized so that typically one to three weekly observations are received from a certain area, like eastern GOF. Among the NASAs Landsat series, the project made use of both instruments OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor).

The processing of satellite observations at SYKE is highly automated. The satellite observation data handling is a stepwise process, where image pixels at various wavelengths are analyzed mainly by models. Valid observations (non-cloudy water areas) are analyzed with a bio-optical model that estimate e.g. the concentration of chl-a or the value of turbidity for each image pixel (Attila et al. 2013, Attila et al. 2018). Also, areas covered by land, islands or shallow water are excluded. The final phase of the processing, quality assurance done by an expert, ensures that uncertainty caused by coarse errors passing the automated processing chain are excluded. The uncertainty in the observations is caused mainly by occasional overestimations due to partial clouds or ice cover in coastal waters during the wintertime and spring. Other sources of uncertainty in the observations are due to occasional underestimations by cloud shadows of nearby clouds.

Main part of satellite observations was shared through SYKEs open TARKKA-service (syke.fi/TARKKA/en). During the SEVIRA project, a total of nine new ‘virtual’ satellite monitoring stations were implemented in TARKKA service to represent relevant sites in the Bay of Vyborg (Fig. 19A). The satellite observations are collected from the areas surrounding monitoring station sites. Islands and shallow areas are excluded from these station areas in the Bay of Vyborg (Fig. 19B−E) and at the Virolahti Bay (Fig. 19F−I).



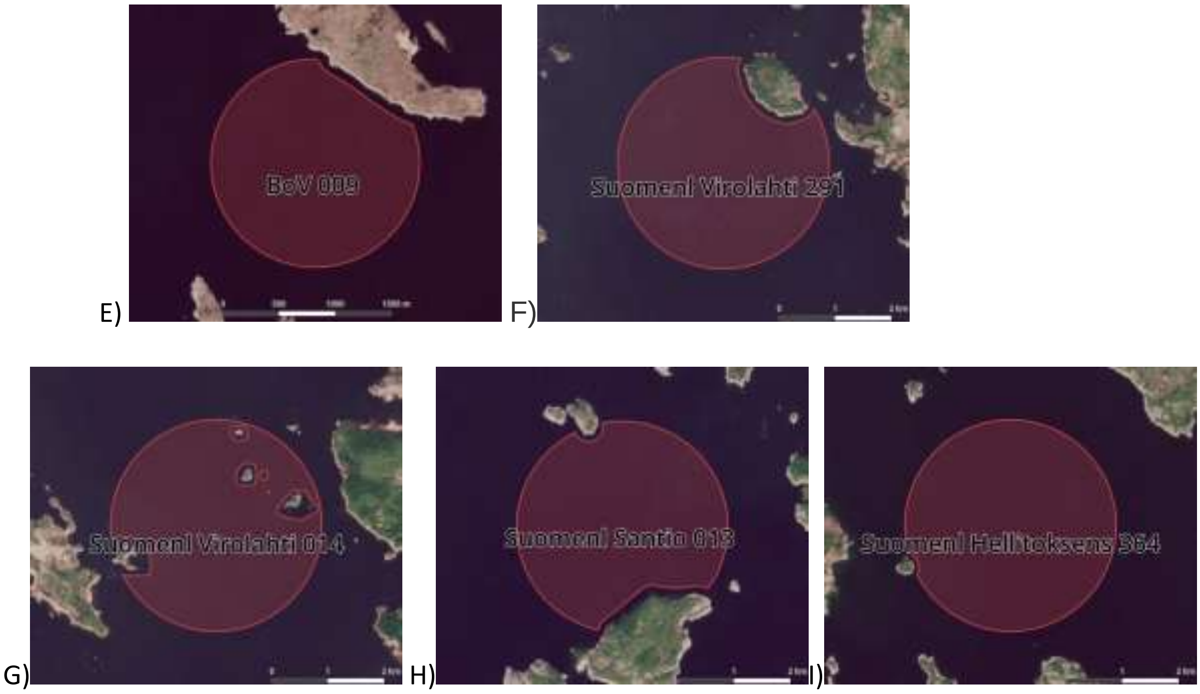


Figure 19. A) Satellite monitoring stations were added/updated to the TARKKA (syke.fi/TARKKA/en) interface in 2021. Observations of these virtual station sites (yellow circles in the map) continue to be used to monitor fluctuations in surface water temperature, algae, and turbidity also in the future. B−E) examples of extraction areas around station sites in the Bay of Vyborg. F−I) examples of extraction areas around station sites at the Virolahti Bay. Shallow areas and areas nearby land and islands are excluded. For each virtual station, the radius around the station site central coordinate is 930m.

4.2. Coastal monitoring results

4.2.1 Chl-a content of surface water in water quality samples

The chl-a concentration in the surface water layer varied considerably both between the stations and the years. In the innermost parts of Vyborg Bay, the chl-a concentration was typically the highest, reflecting the high eutrophic state of the area (Fig. 20). Chl-a concentration was gradually lowered towards the mouth of the Bay from ~ 30 to ~ 10 µg/l. During the sampling in 2019, the concentrations in the Vyborg Bay were unusually low compared to the previous years, or other sampling periods, or the EO-based assessment, which raised suspicion about their representativeness.

Virolahti Bay is a shallow inland bay with a high inflow via river Virojoki. In the bay, the chl-a concentrations were notably higher (~ 15 µg/l) than in the inner archipelago (~ 5 µg/l) indicating eutrophic conditions. This was expected as the bay has a limited water exchange with the offshore regions. At the station locating off the bay area (Santio 013) and in the inner archipelago stations further west (Hellitöksens 364 and Tammio 365) the chl-a concentration indicated moderate trophic state. At the outer archipelago monitoring stations (Huovari Kyvy-8a and Haapas Kyvy-11) as well as at the outermost station (012) on the Russian side, the chl-a concentrations were moderate being in accordance with the previous monitoring results. The differences in the chl-a concentrations between the analyzed outermost monitoring stations were small.

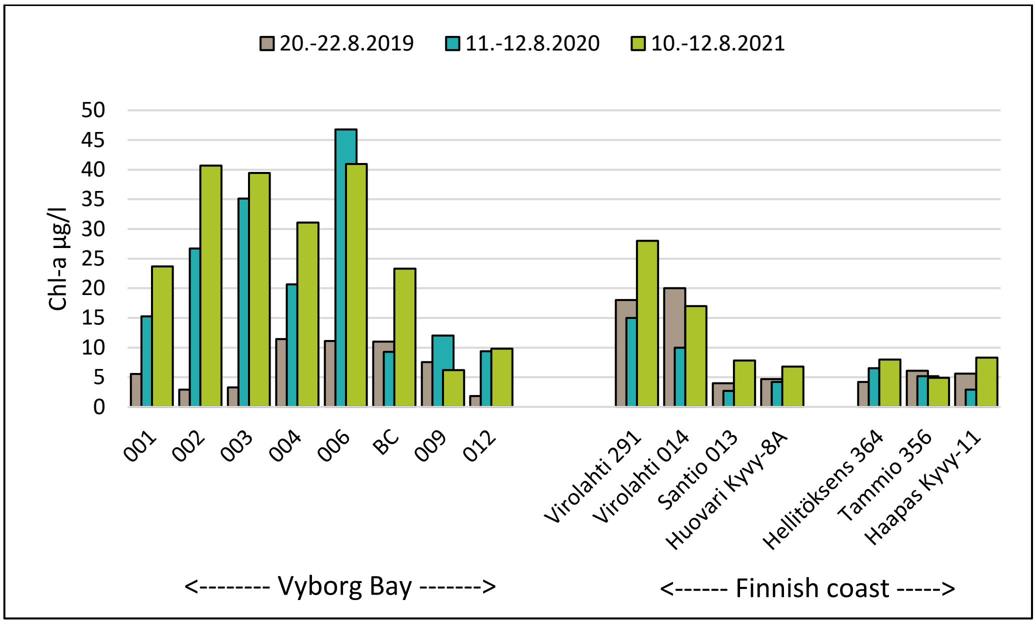


Figure 20. Chl-a content in surface water samples (0–2 m) in Vyborg Bay and Finnish coastal stations on mid-August sampling occasions in 2019 (grey bars), 2020(cyan bars) and 2021(green bars).

4.2.2. Nutrient concentrations in surface water and near-bottom layer

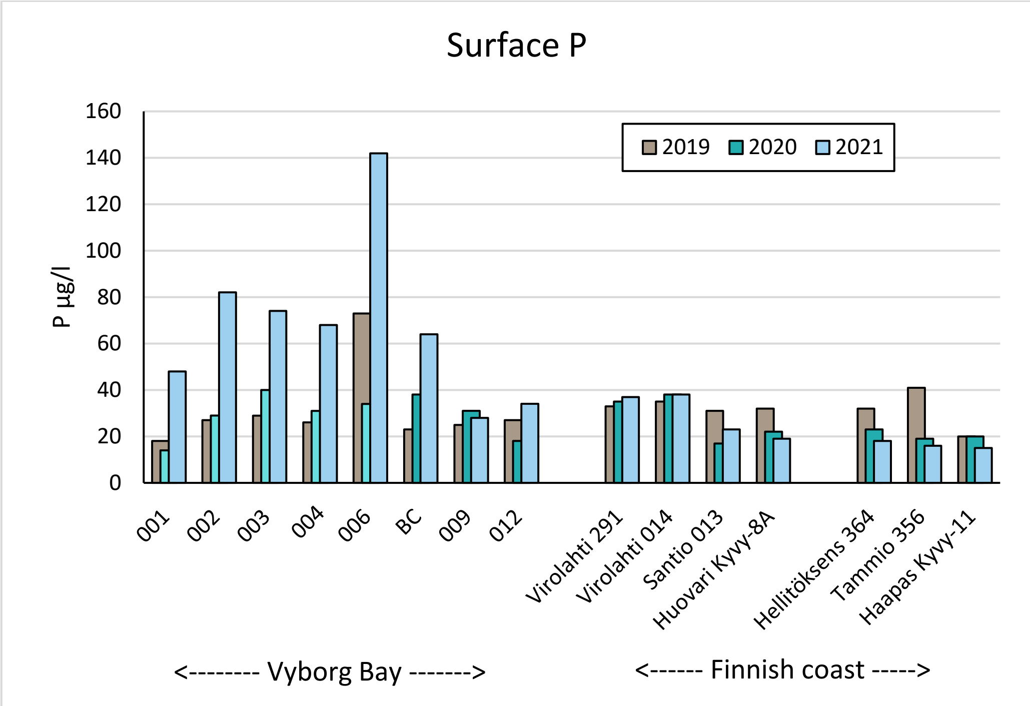
The availability of phosphorus and nitrogen ultimately regulates the algal growth. Concentrations of late summer total phosphorus (P) and total nitrogen (N) in the surface waters have been used along with the chl-a concentration as indicators of the trophic state of the water. Both P and N concentrations are commonly higher in the coastal area than in the open sea area in the GOF. Especially in estuaries, the N concentration is markedly higher than in the open sea.

Considering the pronounced coast-offshore continuation in the study area the surface P concentration showed only a moderate variation during the studied years (Figure 21). Having said this, the year 2021 in the inner Vyborg Bay was distinct, having twice the concentration level observed in the other years (~ 60 vs 30 µg/l). Whether this was a manifestation of the abnormally high internal or external loading cannot be ascertained. The fact that the high P concentration levels were found near to the bottom, too, suggests for the former option.

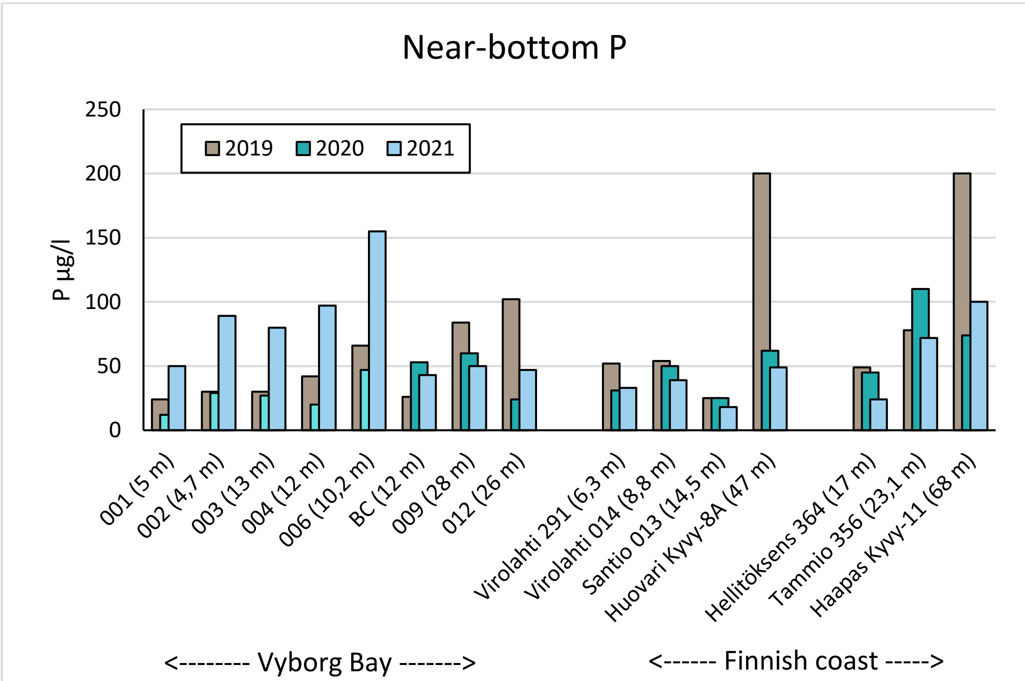
The deep P concentrations were expectedly higher than met in the surface. The abnormally high deep P concentrations at the stations Huovari Kyvy-8A and Haapasaari Kyvy-11 in 2019 (~ 200 µg/l) were associated with high near-bottom salinities, thus providing evidence for the advection of deep-water masses high in P and salinity and poor in oxygen to these sites. It is not uncommon to see this kind of fluctuation in the GOF.

A striking feature of the phosphate-phosphorus (PO_4-P) field during the study was the extremely high concentration level occurring in the Finnish surface waters in 2019 (Figure 10). This level (~ 20 µg/l) is almost comparable to the wintertime PO_4-P levels when the annual course of the PO_4-P is at its maximum. This deviation from the typical summertime nutrient setup can be explained only by upwelling event taken place in the area prior to the sampling. Upwelling - according to its name - causes deep-water masses to incline to the surface layer due to wind forcing. The deep phosphorus levels were already high due to deep-water advection (see above). On top of that the PO_4-P concentration exhibited a clear coast-offshore continuation especially in the Vyborg Bay from ~ 15 to ~ 5 µg/l. Further, the year

2021 set apart from the other years by its higher PO_4-P levels in the Vyborg Bay, as already observed with P.



A)



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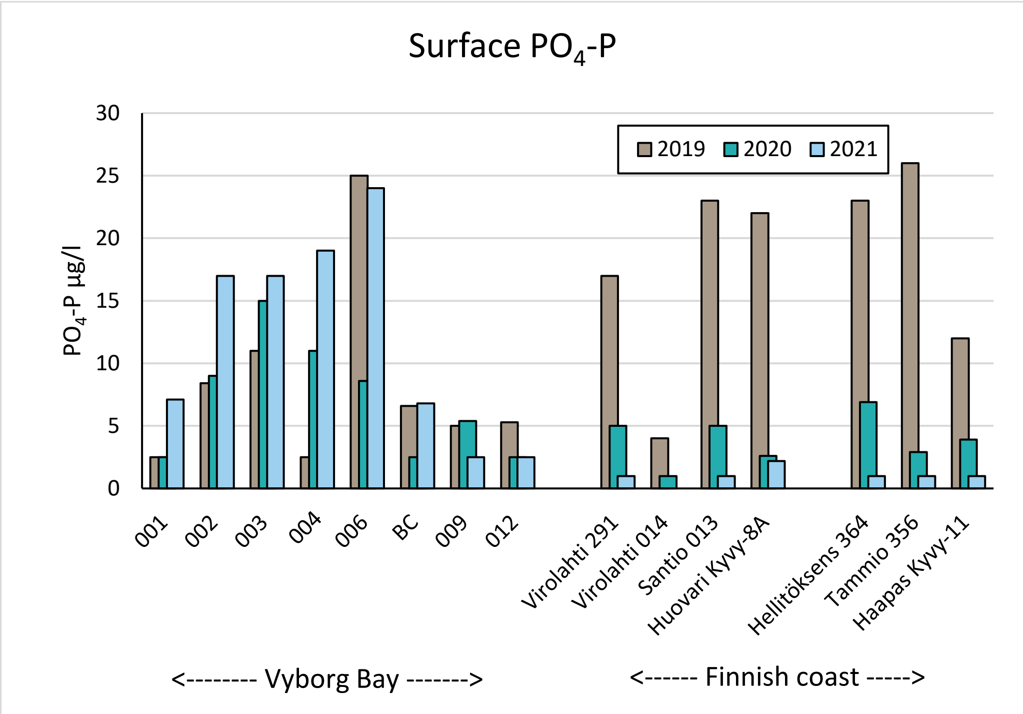

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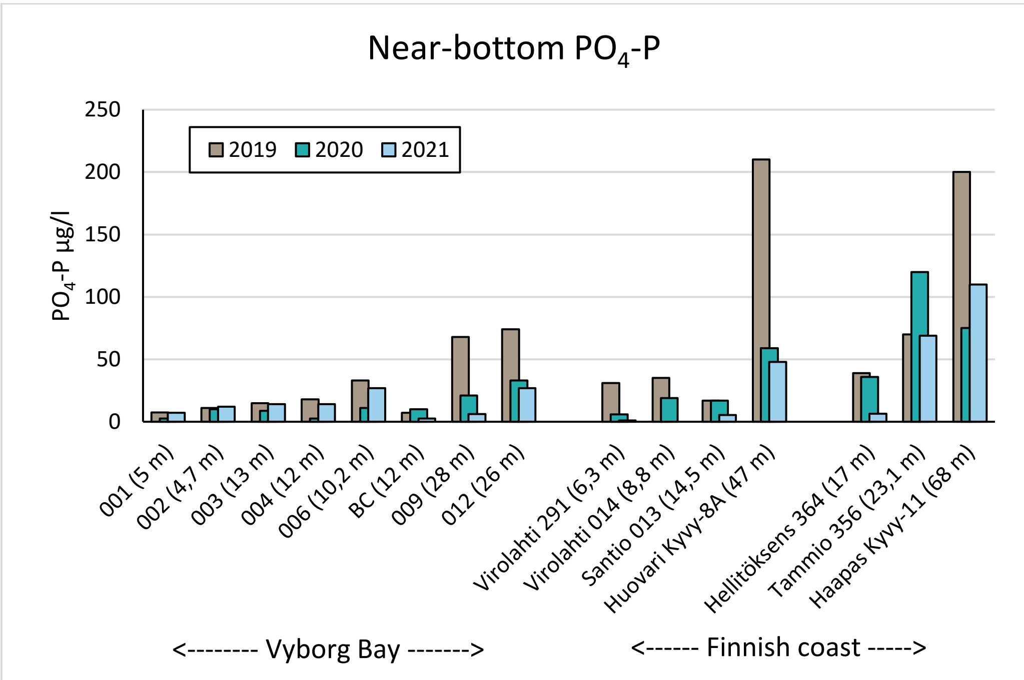
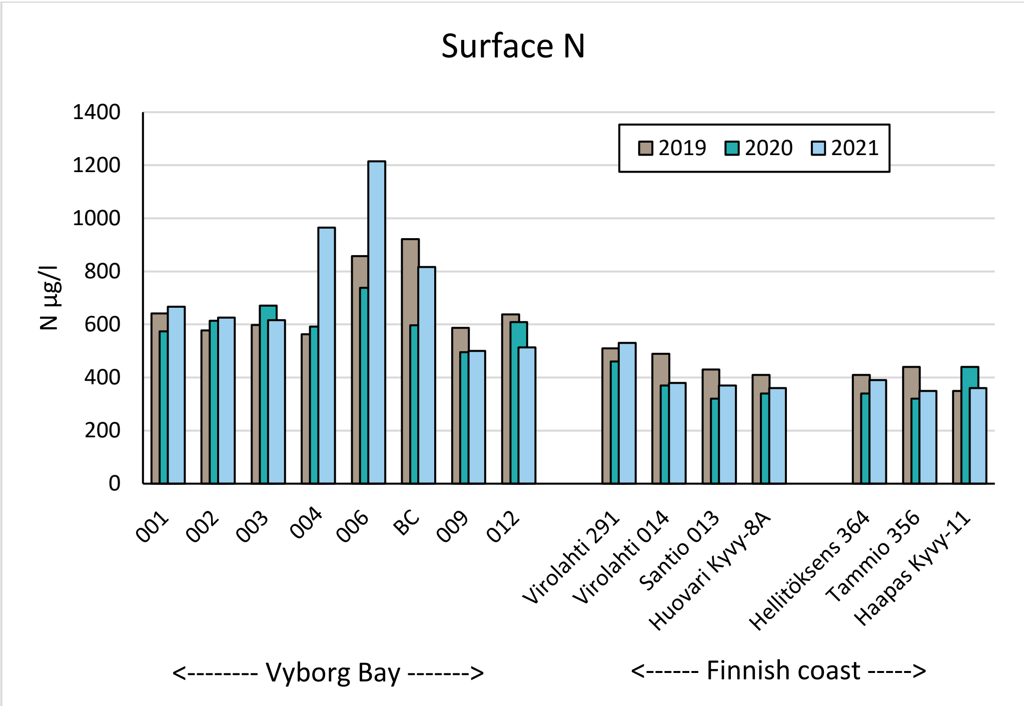


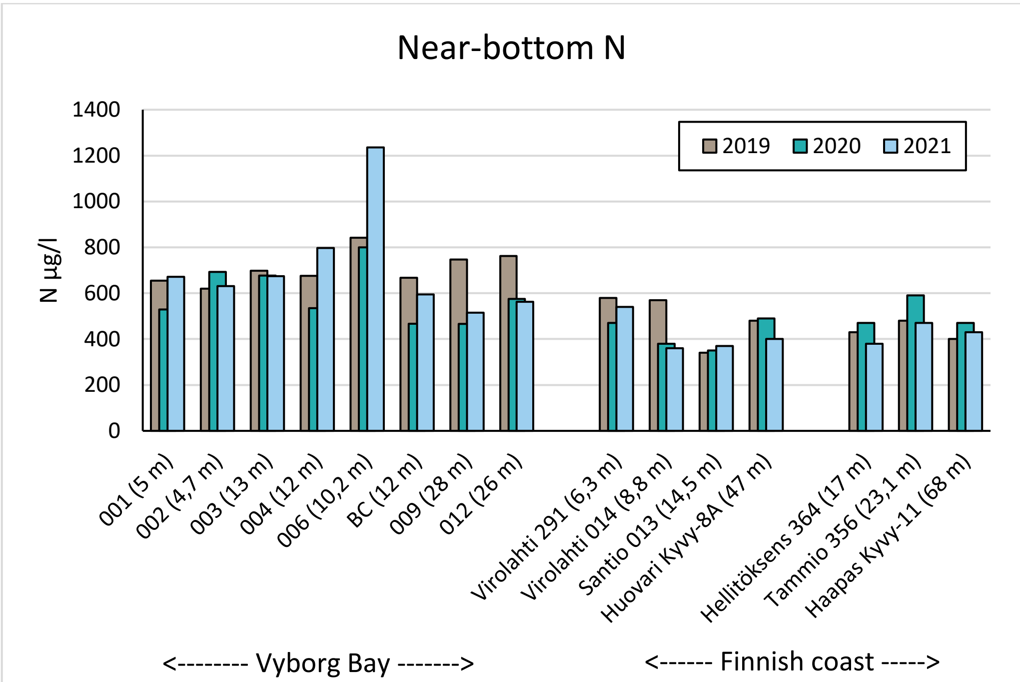
D)

Figure 21. A) Surface and B) near bottom total phosphorous (P, not filtered, µg/l) and C) surface and D) near bottom phosphate phosphorus (PO_4-P, µg/l) concentrations in water column at Vyborg Bay and Finnish coastal stations on mid-August sampling occasions in 2019 (grey bars, sampling during week 34), 2020 (green bars, week 33) and 2021 (blue bars, week 32). In 2020, P concentration was analyzed only from filtered samples at stations 001−006 (light green bars).

Generally, N is more inert in its occurrence in the water than P. That could be observed here, too. The N concentration varied only moderately between the studied years, the studied areas and vertically (Figure 22). The stations in the Vyborg Bay area had a higher N level (~ 600 µg/l) than was found in the Finnish side (~ 400 µg/l). Apart from that feature there occurred no distinct patterns.


Surface N
N µg/l
1400
1200
1000
800
600
400
200
0
2019 2020 2021
001
002
003
004
006
BC
009
012
Virolahti 291
Virolahti 014
Santio 013
Huovari Kyvy-8A
Hellitöksens 364
Tammio 356
Haapas Kyvy-11
<-------- Vyborg Bay ------->
<------ Finnish coast ----->

A)

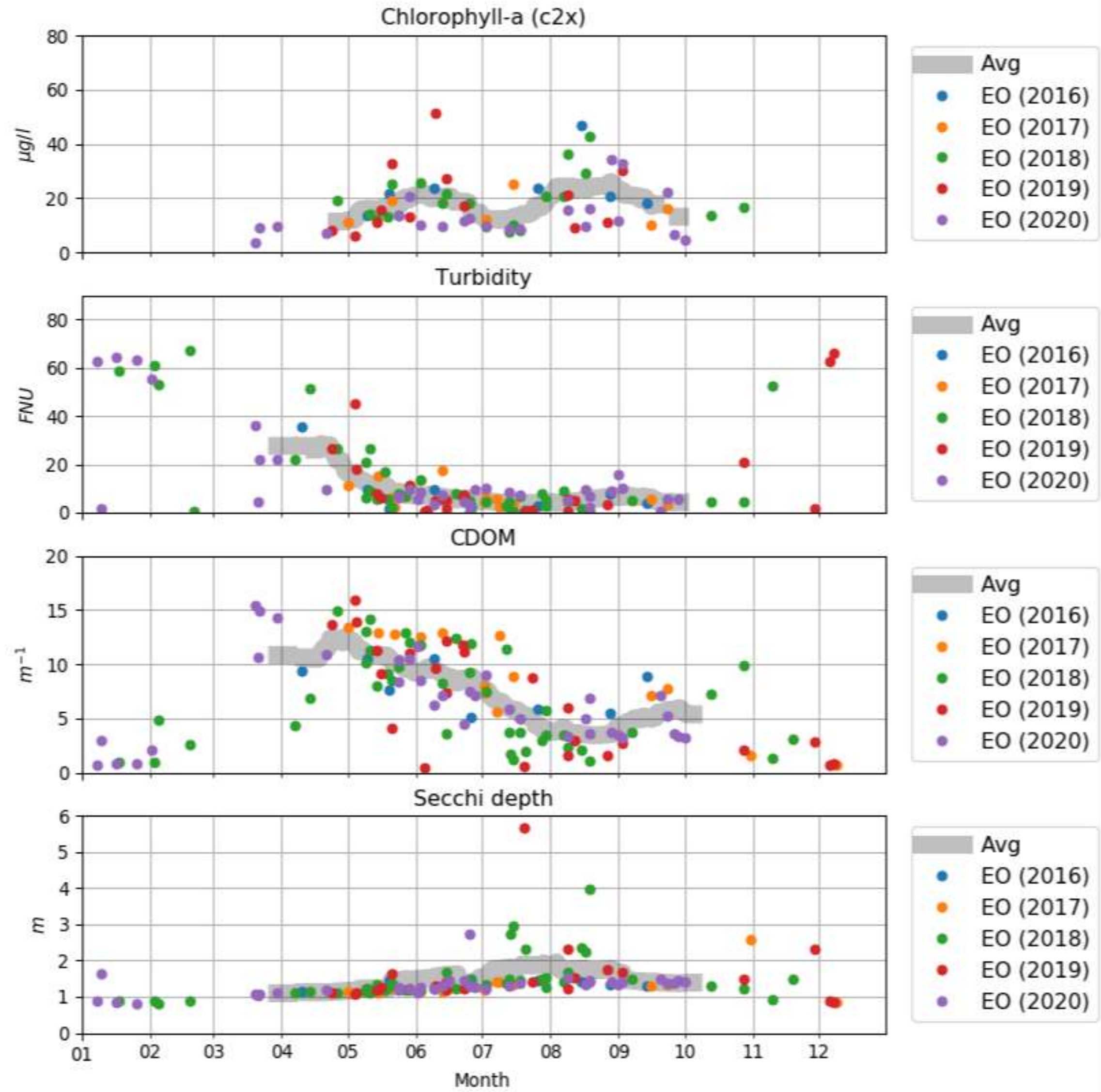

Near-bottom N
N µg/l
1400
1200
1000
800
600
400
200
0
2019 2020 2021
001 (5 m)
002 (4,7 m)
003 (13 m)
004 (12 m)
006 (10,2 m)
BC (12 m)
009 (28 m)
012 (26 m)
Virolahti 291 (6,3 m)
Virolahti 014 (8,8 m)
Santio 013 (14,5 m)
Huovari Kyvy-8A (47 m)
Hellitöksens 364 (17 m)
Tammio 356 (23,1 m)
Haapas Kyvy-11 (68 m)
<-------- Vyborg Bay ------->
<------ Finnish coast ----->

B)

Figure 22. Total nitrogen (N, not filtered, µg/l), concentrations in water column in A) surface and B) near bottom layer at Vyborg Bay and Finnish coastal stations on mid-August sampling occasions in 2019 (grey bars, sampling during week 34), 2020 (green bars, week 33) and 2021 (blue bars, week 32).

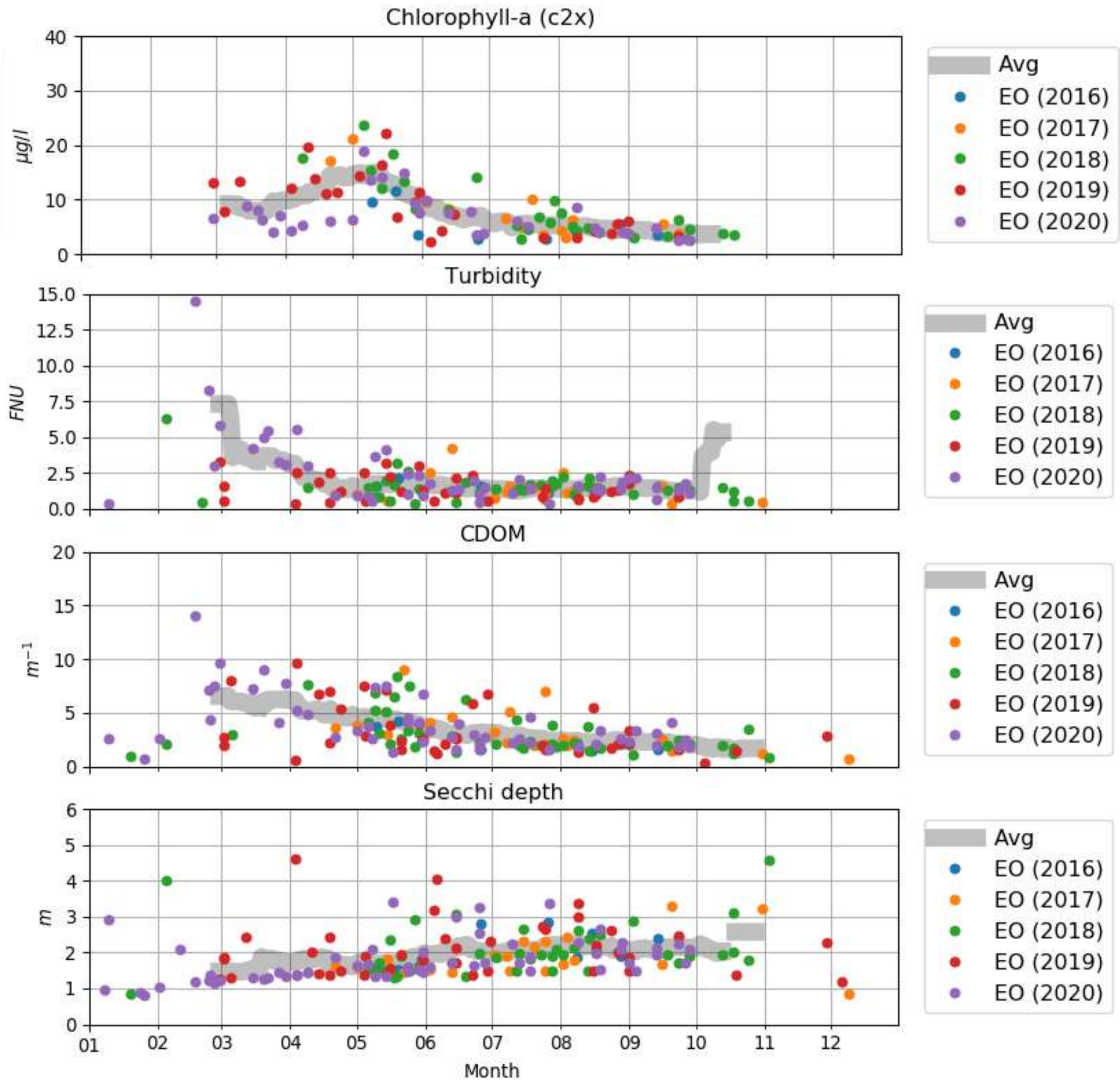
4.2.3. Satellite observations results

Satellite observations (abbreviation EO in tables and figure legends hereinafter) from the station sites (Chapter 4.1.2.) were analyzed using time series from the coastal stations and years 2016−2020. The time series exemplify typical seasonality and range of the analyzed water quality parameters at the stations in the inner parts of the River Rakkolanjoki estuary and in the outer part of the Vyborg Bay (Fig. 23). The seasonal variation in chl-a time series reflects springtime and summerly phytoplankton bloom periods and phytoplankton bloom minimum (in June). Likewise, turbidity is high during the spring, with concurrent melting of snow, frost and ice and increased runoff from drainage basin. Mostly, when the turbidity is high in coastal waters, it originates from the drainage basin and enter to the coastal waters via rivers. During the summer, turbidity is relatively low in the most parts of the coastal waters. In estuaries, especially in enclosed bays, the turbidity can at times be high in the summertime. Mostly this due to heavy rains increased by the river runoff. Occasionally, in shallow areas, also resuspension caused by strong winds can increase the turbidity. Absorption of CDOM was high in the Bay of Vyborg, as presumed based e.g. land cover information in the drainage basin. Ice-cover season observations were excluded from the analysis.



Chlorophyll-a (c2x)
μg/l
Turbidity
FNU
CDOM
m^{-1}
Secchi depth
m
Month
01
02
03
04
05
06
07
08
09
10
11
12
Avg
EO (2016)
EO (2017)
EO (2018)
EO (2019)
EO (2020)

A)



B)

Figure 23. Time series of satellite observations (EO in legend) at A) the innermost station site at the proximity of river Rakkolanjoki estuary (BoV-R2) and B) the outermost station at the Vyborg Bay (BoV-012) for water quality parameters (from top to bottom) chl-a, turbidity, CDOM and Secchi depth, for the years 2016−2020.

During the project, a total of nine virtual satellite observation sites were implemented in the Bay of Vyborg (Fig. 19). Likewise, six stations for the sea areas on the Finnish side were established to complement the existing ones. As a result, there are now altogether 15 sites providing satellite observations in the Eastern GOF (Fig. 24). Until the end of the project, the number of days, when satellite observations were obtained is large, but varies slightly per station and water quality parameter (Table 5). For chl-a, the observations start in 2015. Surface temperature observations are available as early as from 2004 onwards.

Comparisons between satellite observations and water sampling have been made at the sites where observations of the satellite observations and corresponding water quality sample data are available. The water samples at station and satellite observations were not observed during the same day, which hampers the possibility to make extensive statistical analysis between the two observational methods. Therefore, the good mutual correspondence between the field campaign measurements and satellite observations can be best visualized using time series (examples in Fig. 25 A and B).

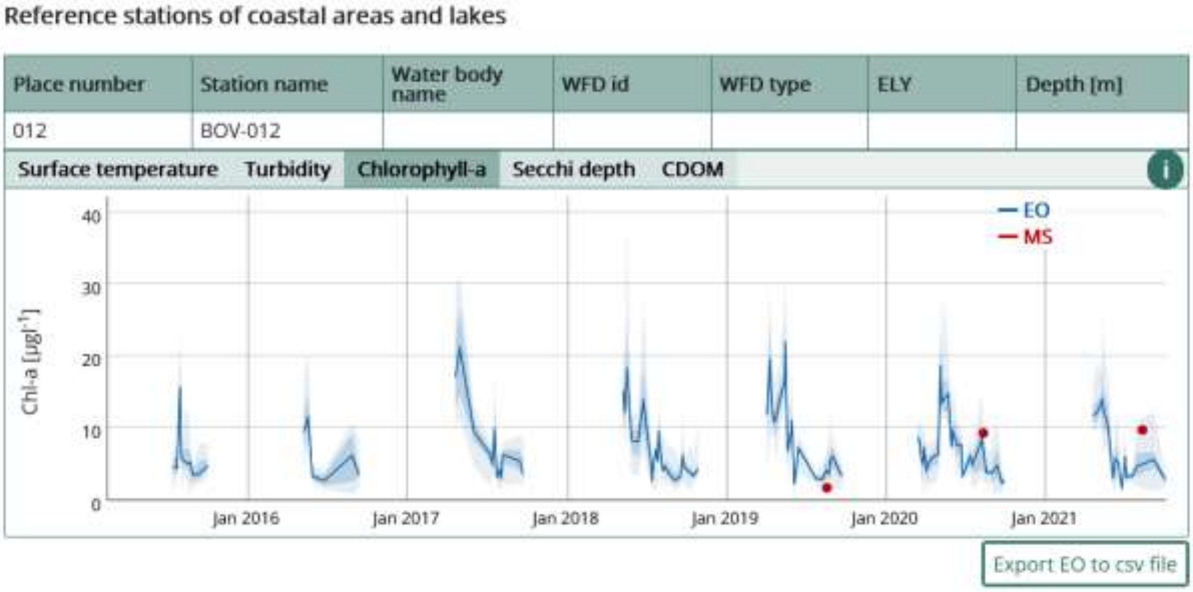
Table 5. The number of EO observation days at station sites from the river Rakkolanjoki estuary towards the open sea station (BoV−012). The number of observations is lower at stations that locate in narrow parts of the bay, like BoV−003 (map in Fig. 19). The table gives representative examples out of the 13 stations in total.

Station	N of EO Chl-a observation days per station (2016−2021)	N of EO Turbidity observation days per station (2015−2021)	N of EO Temperature observation days per station (2004−2021)
BoV R2	87	99	659
BoV-003	88	93	458
BoV-004	102	105	576
BoV-009	116	128	687
BoV-012	127	138	793

As a result of the comparisons of stations sampling monitoring and EO, new reference stations have been added to SYKE's TARKKA-web map service (syke.fi/TARKKA/en, Fig. 24). New observations are updated to the service whenever cloudless observations are available between April and October (Fig. 25). This period is typically ice-free in the area. The observations are available in TARKKA reference station time series couple of days after the satellite overpass, i.e. after the satellite observations have passed the automated processing and quality assurance phase (Chapter 4.1.2).

Figure 24. A) Map showing the permanent stations in TARKKA-interface. Station-wise satellite observations and station sampling during SEVIRA field campaigns can be accessed through TARKKA-service (syke.fi/TARKKA/en, panel on the left and icon 'Reference data'-> 'Coastal and lake reference stations'). The areas covered by the satellite observation time series can be accessed from the left panel, icon 'Additional spatial data' and activating the 'Reference station regions' material. In this example figure, the areas are shown with blue circles. The observations for each station can be reached by clicking the station site symbol.

A)



B)

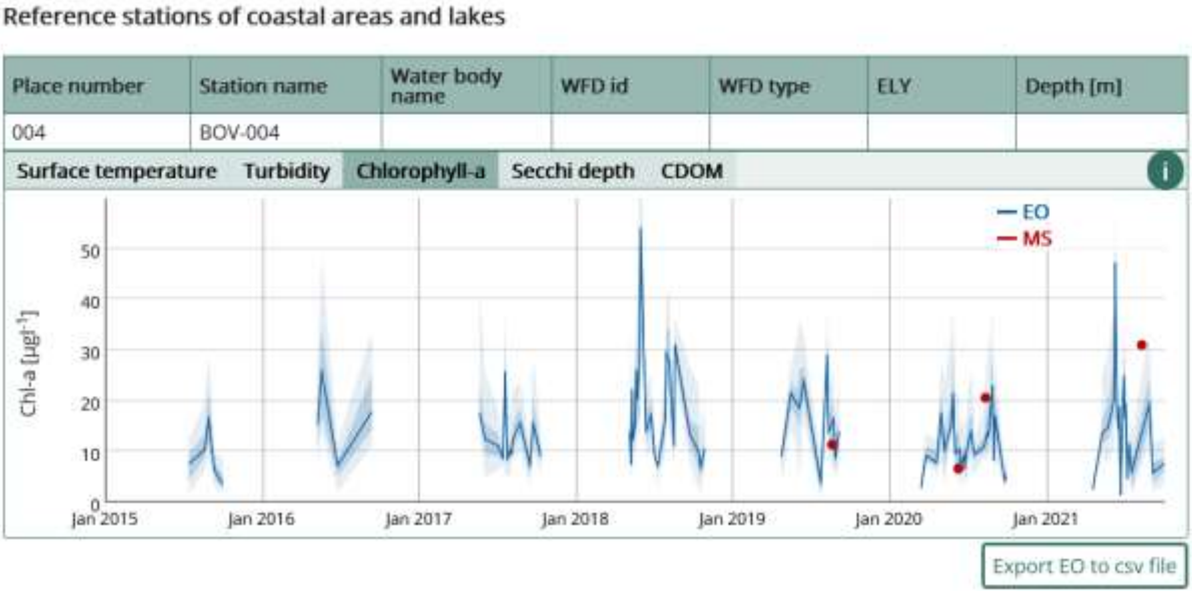
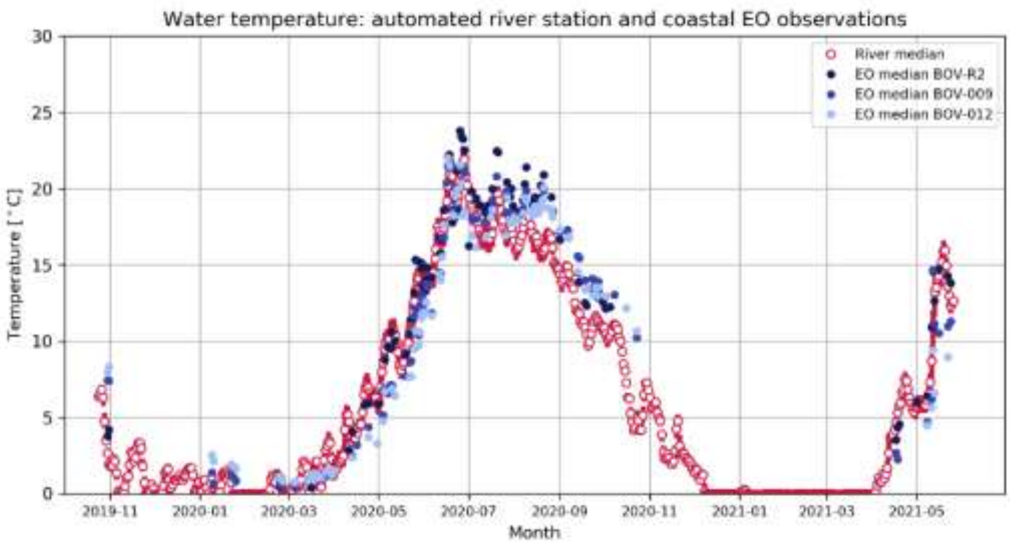


Figure 25. Examples of satellite observations and the SEVIRA project station sampling at reference station time series in the Bay of Vyborg. Chl-a observations at stations B) BoV−012 and C) BoV−004. Numerical statistics can be exported in csv-files from the lower right corner of the time series window for surface temperature and each of the water quality parameter (chl-a, turbidity, CDOM and Secchi depth).

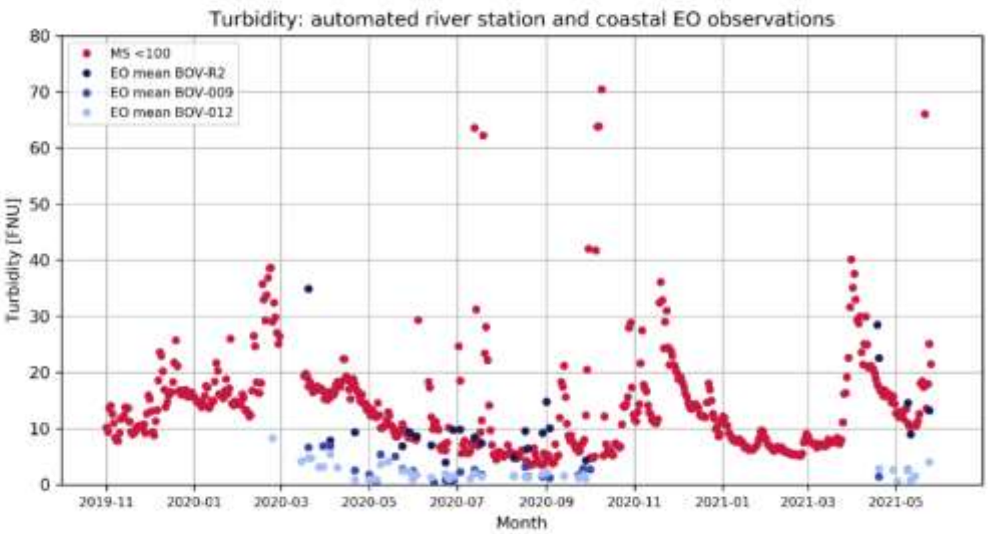
Comparison of coastal satellite observations and river station measurements

In situ high-frequency river water quality data from the Seleznevka (Chapter 3.3) and satellite observations at the coastal waters show good mutual correspondence (Fig. 26). The satellite observations form a continuous transect from the river outlet to the open sea (stations BOV-R2, BoV-009 and BOV-

012, map of station sites in Fig. 19). Satellites provide temperature observations practically daily, therefore the temporal frequency of both sea and riverine data is high (Fig. 26A). The two types of temperature observations and their mutual correspondence is an illustrative case for demonstrating the benefits of joint monitoring by modern monitoring methods, like in this case in situ river water quality sensor and satellite observations at the coastal areas of interest. Turbidity values are higher in the river and decrease towards the open sea station (BOV-012 in Fig. 26B) as the influence of river water mixes with less turbid coastal water. Combination of these two observations from two different data sources demonstrate well the spreading of the turbid riverine water to the coastal waters.



A)



B)

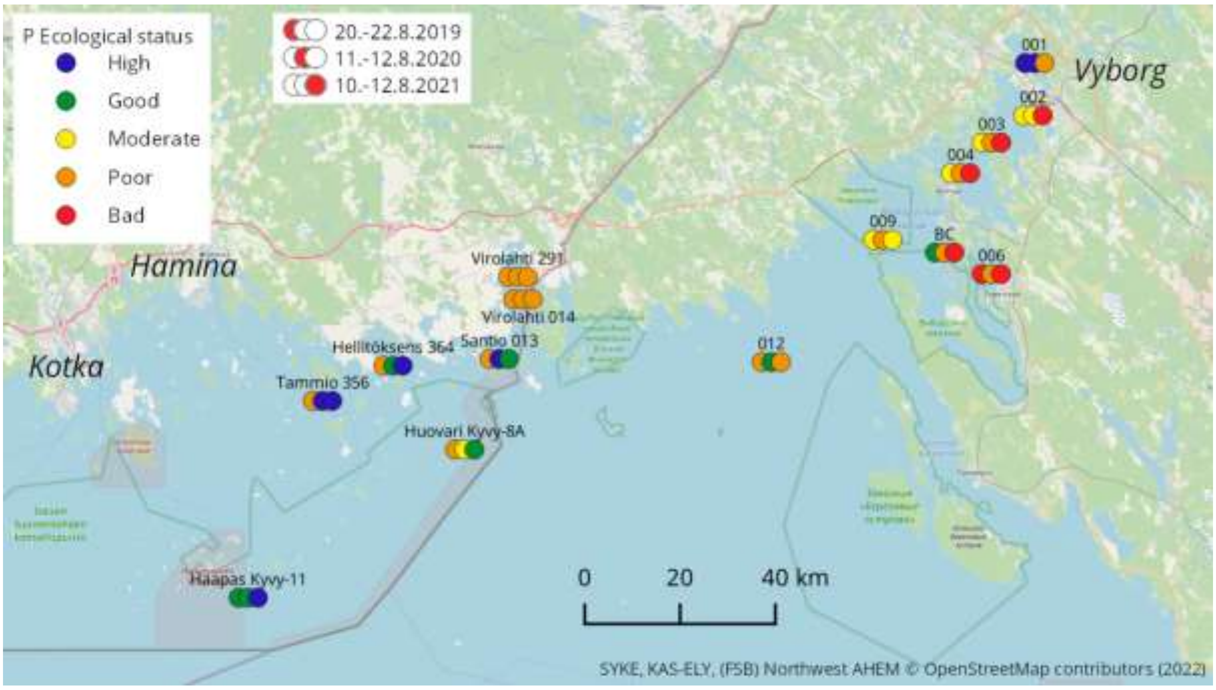
Figure 26. Time series of A) temperature and B) turbidity measurements of the in situ high-frequency sensor in the Seleznevka river site Luzhayka (red dots) and satellite observations (EO in legend) at three coastal stations (BOV-R2, BOV-009 and BOV-012) that form a continuous transect from the river outlet to the open sea (map of the coastal station sites in Fig. 19).

4.3. Ecological status assessment of the studied coastal waters

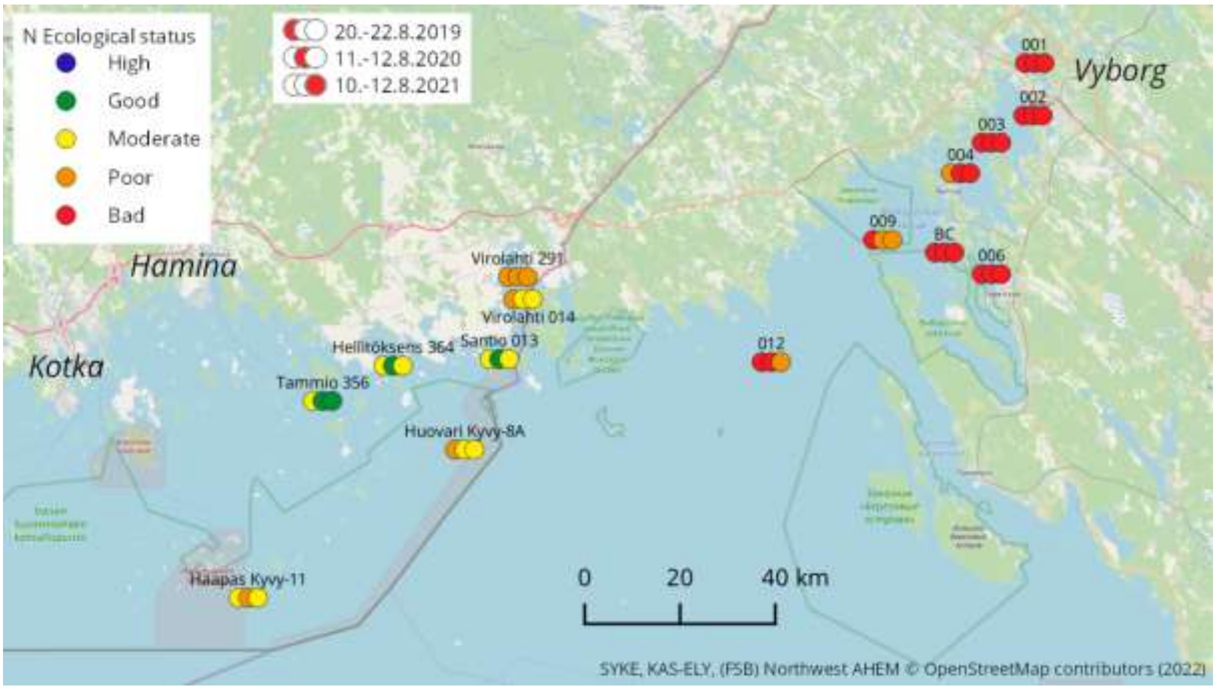
4.3.1 Annual ecological status during project years 2019–2021

Ecological status assessment and water quality classification is defined either by national or international regulations, like the directives in EU. Although the regulations may differ in detail between the water areas they apply, like lakes, coastal and open sea ares, there are similar elements in them. As for example, most regulations are based on water quality classes and boundaries between the classes that define the ecological status. Status assessment regulations typically use nutrients and chl-a as one of the classification indices. In the EU countries, these requirements are defined for the coastal water areas by the Water Framework Directive (WFD, Ferreira et al., 2007), in which the ecological classification consists of five classes (high, good, moderate, poor, and bad). In the SEVIRA project, annual classification of the coastal study areas was made based on the measured nutrients and satellite observations of chl-a concentrations in 2019–2021 (Fig.27).

A)



B)



C)

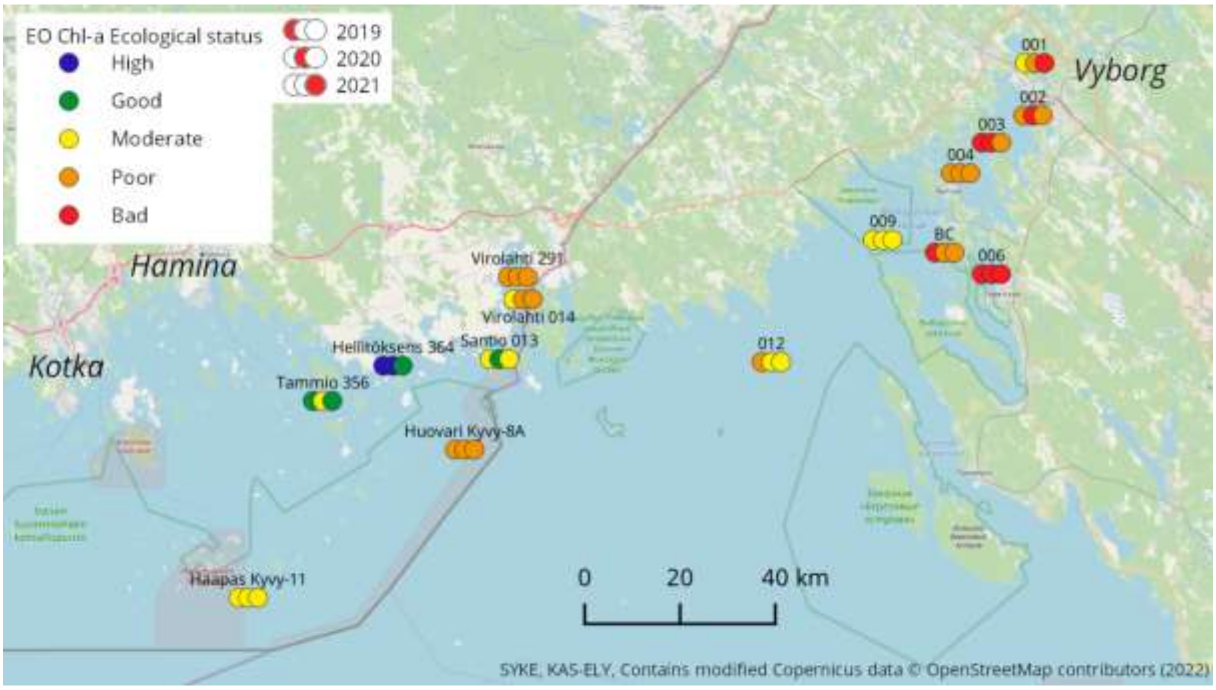


Figure 27. Ecological status defined based on the a) P, B) N measured during the field sampling and C) aggregate of July-August satellite observations of chl-a concentrations measured during SEVIRA project years.

In Russia, the surface water assessment is based on threshold values of the trophic state classification. The North-West AHEM has used classification according to Vinberg (1960) theory with the following criteria's for chl-a concentrations:

1. oligotrophic - less than 1 µg/l
2. mesotrophic- 1−10 µg/l

3. eutrophic- 10−100 µg/l
4. hypereutrophic - more than 100 µg/l

According to this trophic state classification, the average surface water (0−2 m) chl-a concentrations during late-summer sampling occasions suggests an eutrophic state with relatively high chl-a concentration levels. This applies to all examined years (2019−2021) and the inner parts of the Bays of Vyborg and Virolahti. Correspondingly, the outer parts of the Vyborg Bay (stations 009 and 012) and the associated areas of the inner and outer archipelago off the coast of Finland are classified as being in a mesotrophic state according to the trophic classification limits (Table 6).

Table 6. Trophic state classification for the coastal sampling according to the trophic classification method (Vinberg, 1960) for late summer chl-a concentrations in 2019–2021.

	Chl-a, August 2019–2021	
Station №	Average concentration chl-a (0−2 m), µg/l	Trophic status
001	14,8	Eutrophic
002	23,4	Eutrophic
003	26,0	Eutrophic
004	21,1	Eutrophic
006	33,0	Eutrophic
BC	14,5	Eutrophic
009	8,6	Mesotrophic
012	7,0	Mesotrophic
Virolahti 291	20,3	Eutrophic
Virolahti 014	15,7	Eutrophic
Santio 013	4,8	Mesotrophic
Hellitöksens 364	6,2	Mesotrophic
Tammio 356	5,4	Mesotrophic
Huovari Kyvy-8A	5,2	Mesotrophic
Haapas Kyvy-11	5,6	Mesotrophic

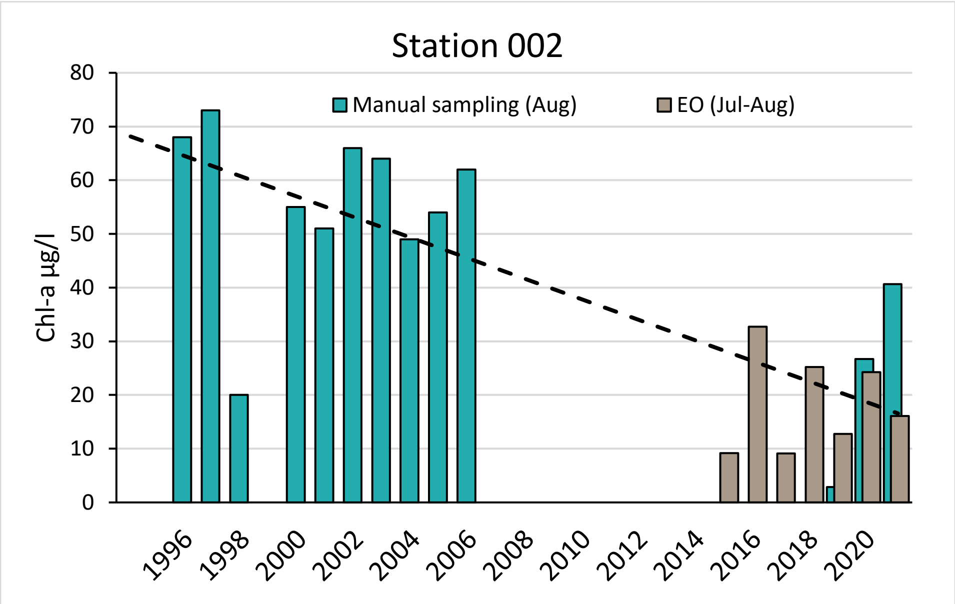
4.3.2. Long-term changes in water quality and level of eutrophication based on chl-a time series

The SEVIRA project put effort in analyzing monitoring observations from multiple data sources. Data was gathered during designated field campaigns (Chapter 4.1), Alg@line ferrybox observations, as well as long term monitoring station data sets by Russian and Finnish authorities (from 1996 on). Also, satellite observations of chl-a were used. The datasets, their coverage within the timeframe and their source databases are listed here:

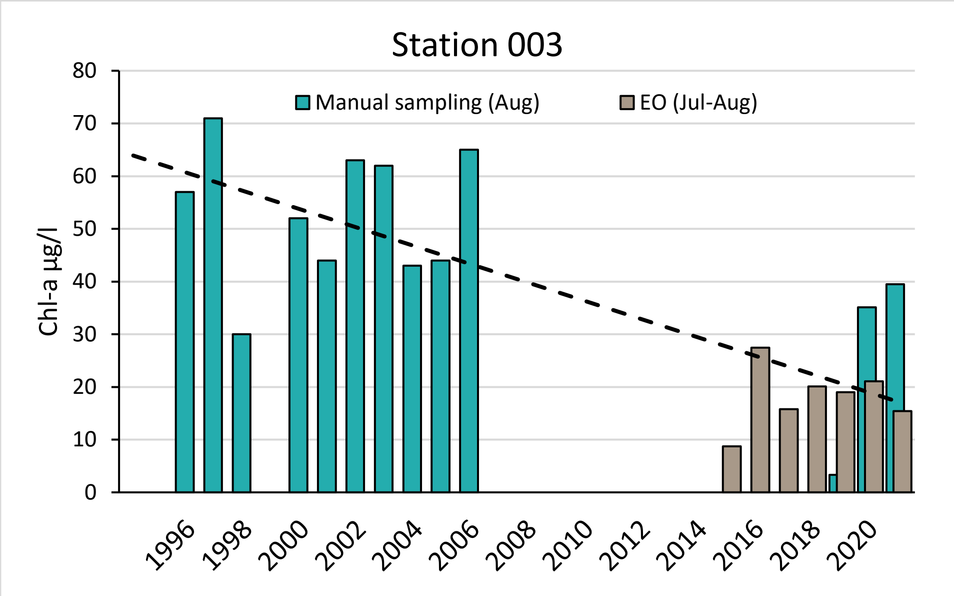
- Results of late summer chl-a in the Vyborg Bay Joint Monitoring project (during 1996−2006, VESLA database by SYKE).
- Finnish national monitoring program for water management planning: The water quality results of the monitoring program carried out by the ELY Center in 1996−2021 and the results obtained in the obligatory monitoring of Virolahti (averages of July−August observations VESLA database, by SYKE).

- Late summer chl-a results obtained in connection with the Alg@line project for the period 2004−2012 (average results for July−August where available; three stations in the Vyborg Bay and two in the inner archipelago stations in Finland).
- Late summer chl-a results calculated from EO satellite data for 2016−2021 (mean level of aggregated results from the period of July−August (SYKE's Status database, dataset downloadable in TARKKA service, see chapter 4.2.3).
- Results obtained during the Vyborg Bay sampling cruises carried out in August 2019−2021 during the SEVIRA project.

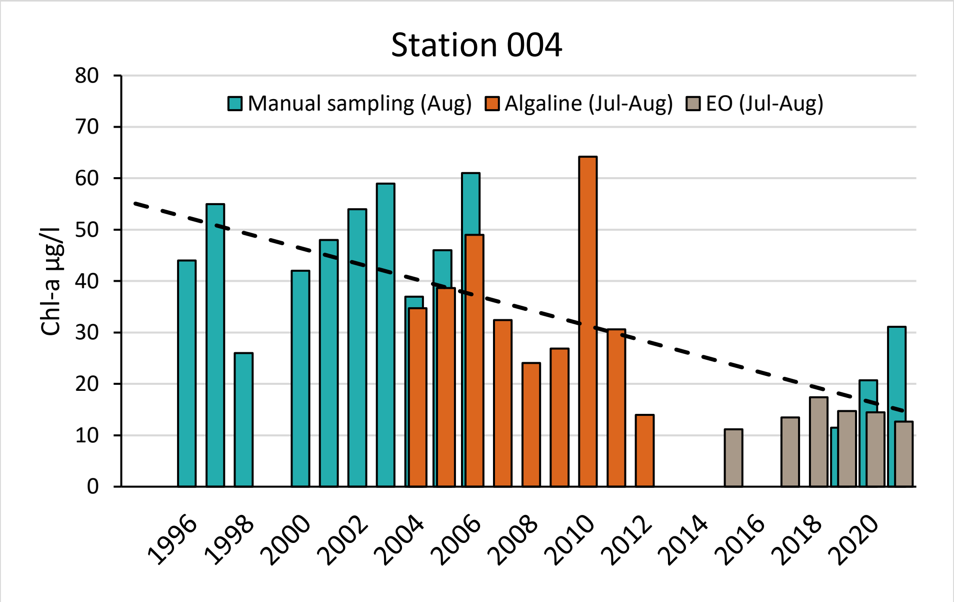
With respect to chl-a, these various data sources were combined, and a joint analysis of the state of easternmost coastal areas of the GOF was made. Based on the results of chl-a in the surface water, clear improvement in water quality and a decrease in eutrophication can be observed in the Vyborg Bay area during the first decades of the 21st century (Fig. 28). Based on the observations collected during the annual late summer periods, the chl-a concentration has decreased considerably in the inner part of the bay. Likewise, similar trend tendency can be seen in the mouth of the bay, although there/in that area the chl-a concentration was not high to start with. Similar development has also been observed in Finnish coastal waters (Fig. 29). The chl-a concentration in the surface water has decreased both in the outer archipelago and in the inner archipelago. In Virolahti Bay, the concentrations are still high and indicate prevalent eutrophic conditions.



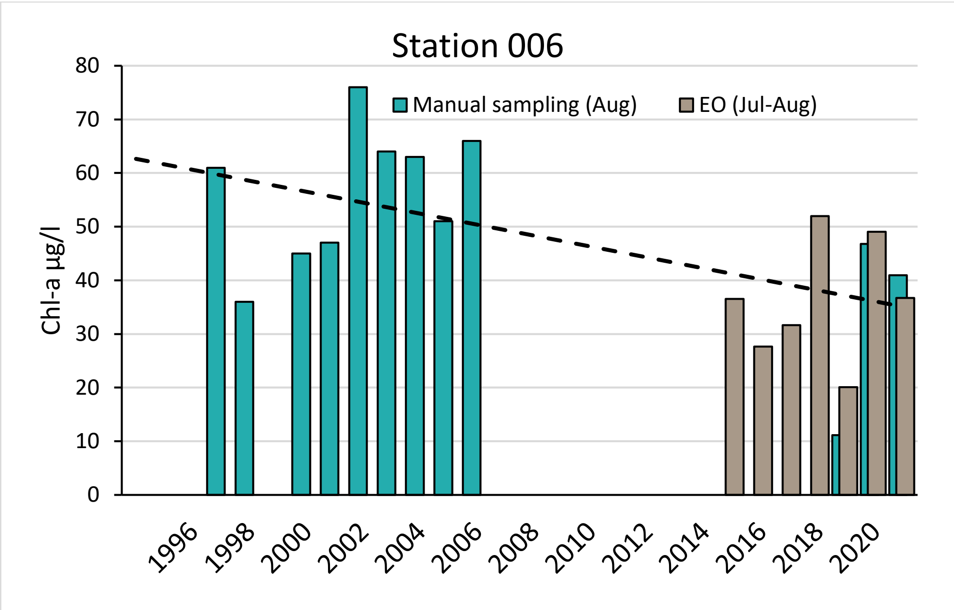
A)


Station 003
Manual sampling (Aug)
EO (Jul-Aug)
Chl-a µg/l
80
70
60
50
40
30
20
10
0
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020

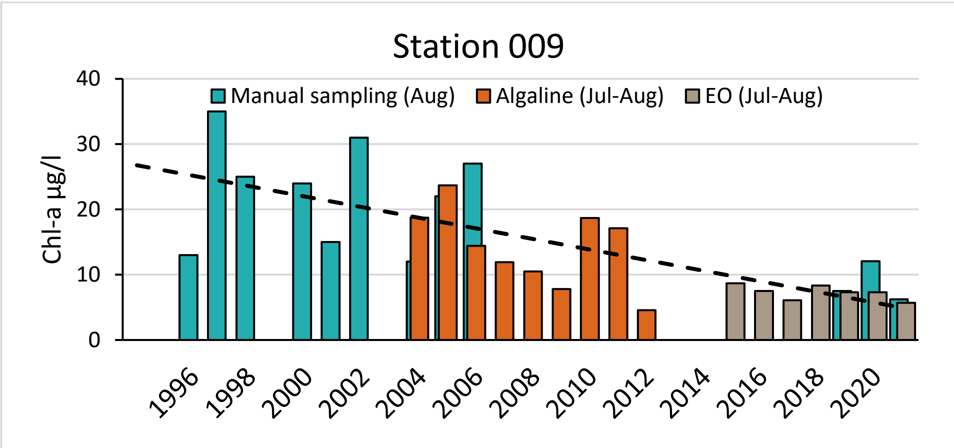
B)


Station 004
Manual sampling (Aug)
Algaline (Jul-Aug)
EO (Jul-Aug)
Chl-a µg/l
80
70
60
50
40
30
20
10
0
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020

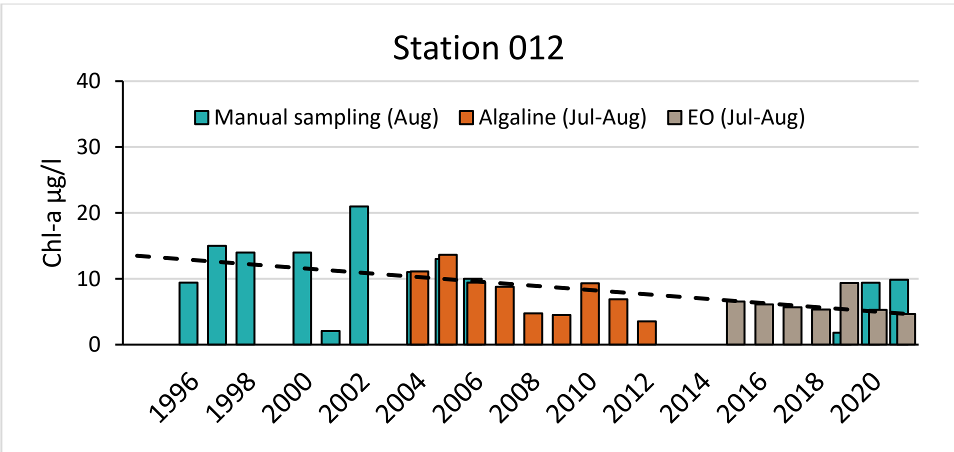
C)



D)

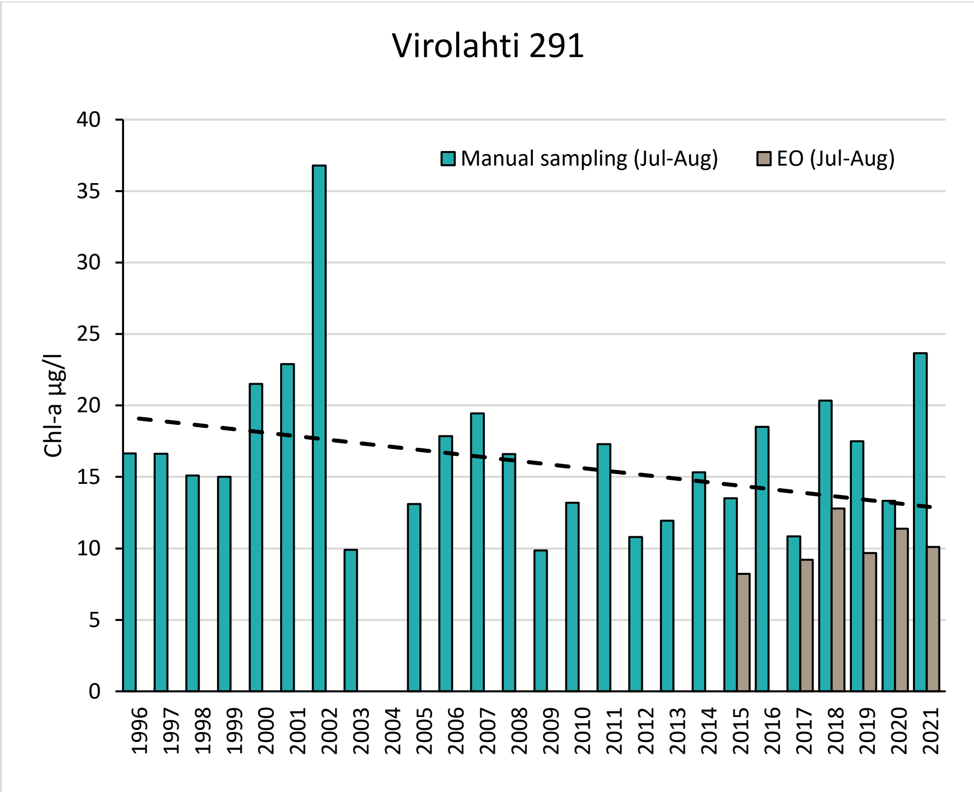


E)

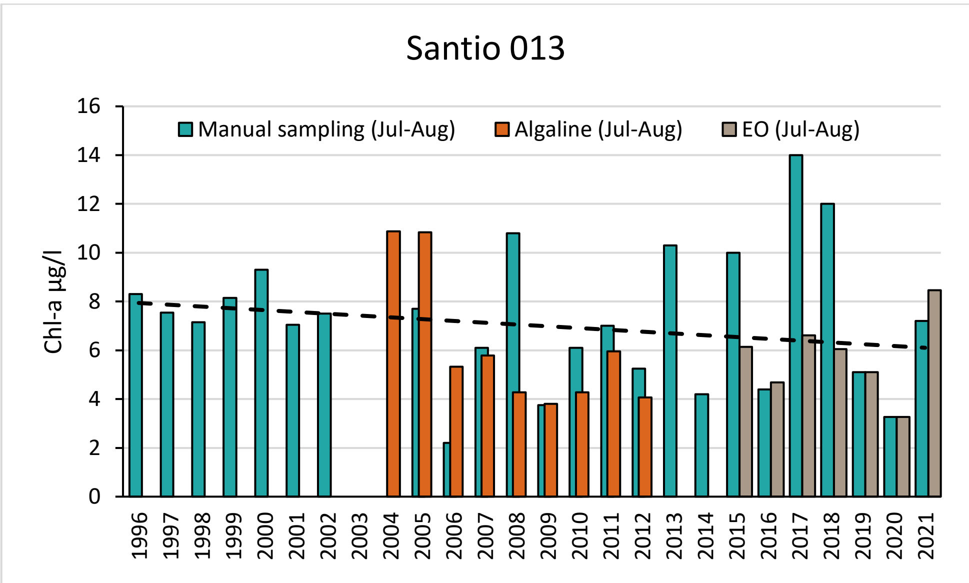


F)

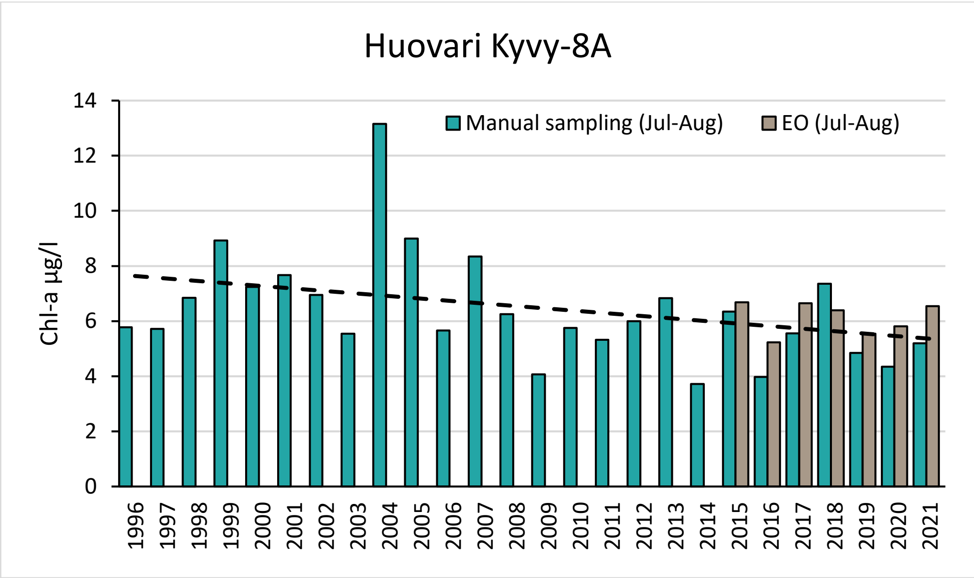
Figure 28. Average late summer chl-a concentrations in surface water in the Vyborg Bay sampling stations starting from the year 1996. Station sites from A) to F) to represent the transect from the Rakkolanjoki estuary (A) towards the outer parts of the Vyborg Bay (F) (map of station sites in Fig. 18). Data from Vyborg Bay Joint Monitoring Program (cyan bars, 1996−2006), from Alg@line-data reconstruction (orange bars, 2004−2012) and 2015−2021, from satellite observations results (EO, 2015-2021, grey bars).


Virolahti 291
Manual sampling (Jul-Aug)
EO (Jul-Aug)
Chl-a µg/l
40
35
30
25
20
15
10
5
0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021

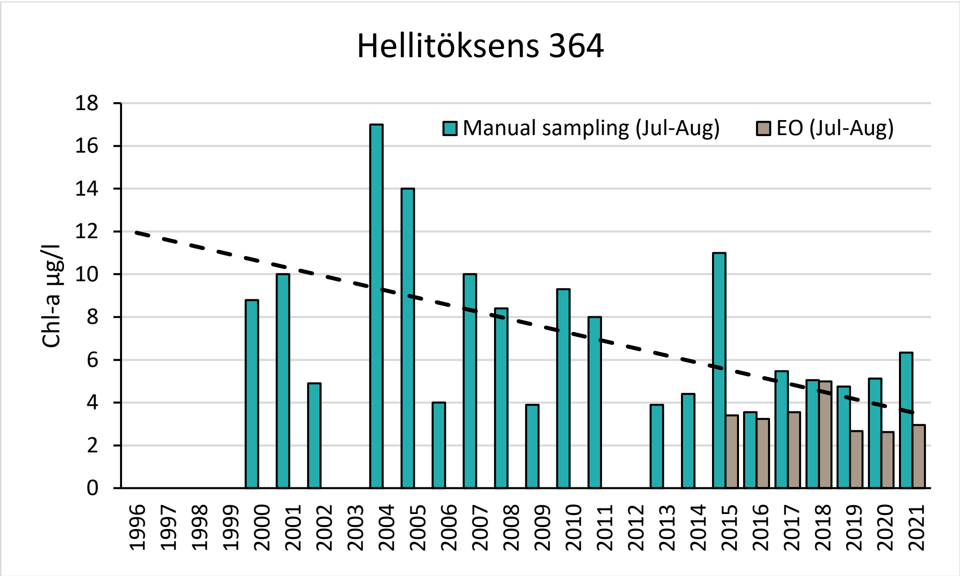
A)


Santio 013
Manual sampling (Jul-Aug)
Algaline (Jul-Aug)
EO (Jul-Aug)
Chl-a µg/l
16
14
12
10
8
6
4
2
0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021

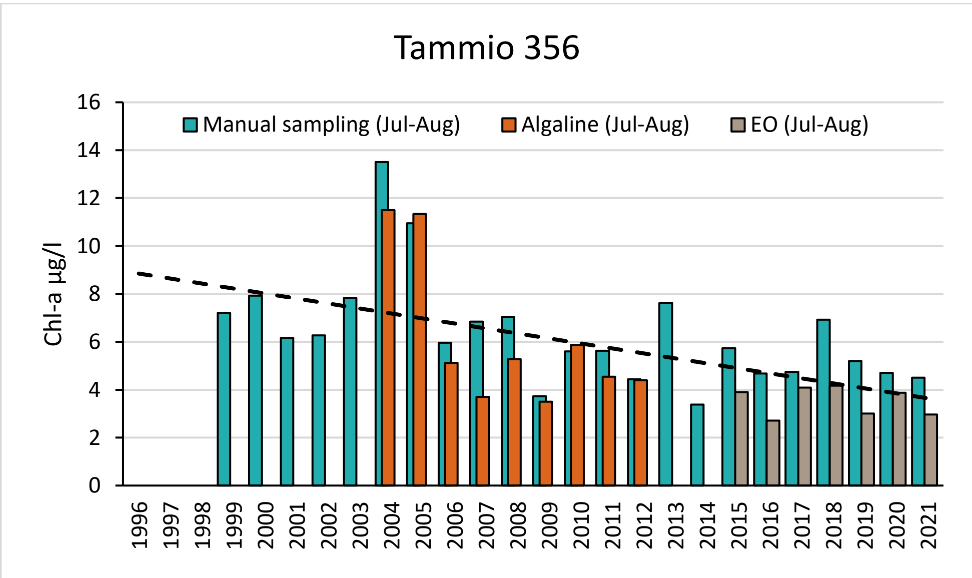
B)


Huovari Kyvy-8A
Manual sampling (Jul-Aug)
EO (Jul-Aug)
Chl-a µg/l
0
2
4
6
8
10
12
14
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021

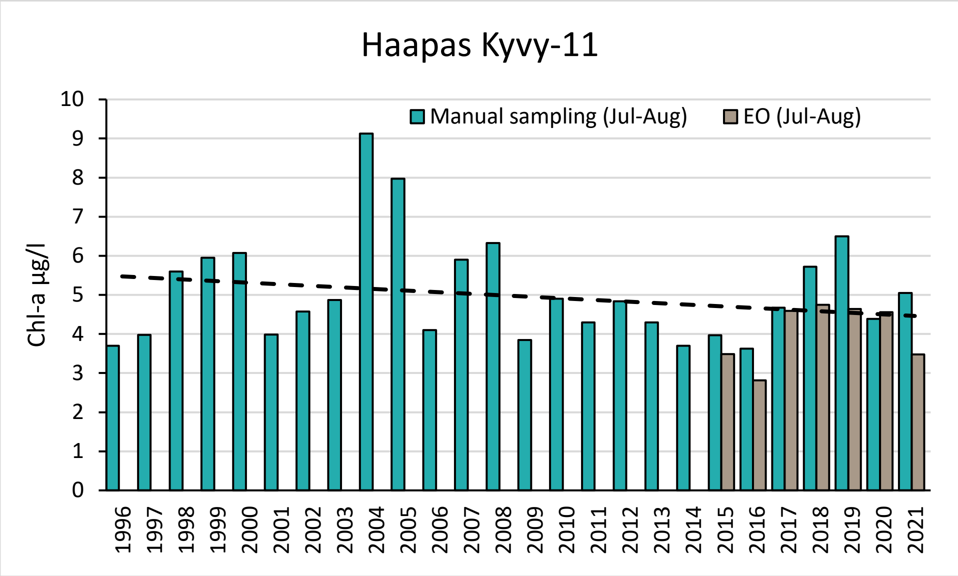
C)


Hellitöksens 364
Manual sampling (Jul-Aug)
EO (Jul-Aug)
Chl-a µg/l
0
2
4
6
8
10
12
14
16
18
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021

D)


Tammio 356
Manual sampling (Jul-Aug)
Algaline (Jul-Aug)
EO (Jul-Aug)
Chl-a µg/l
0
2
4
6
8
10
12
14
16
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021

E)

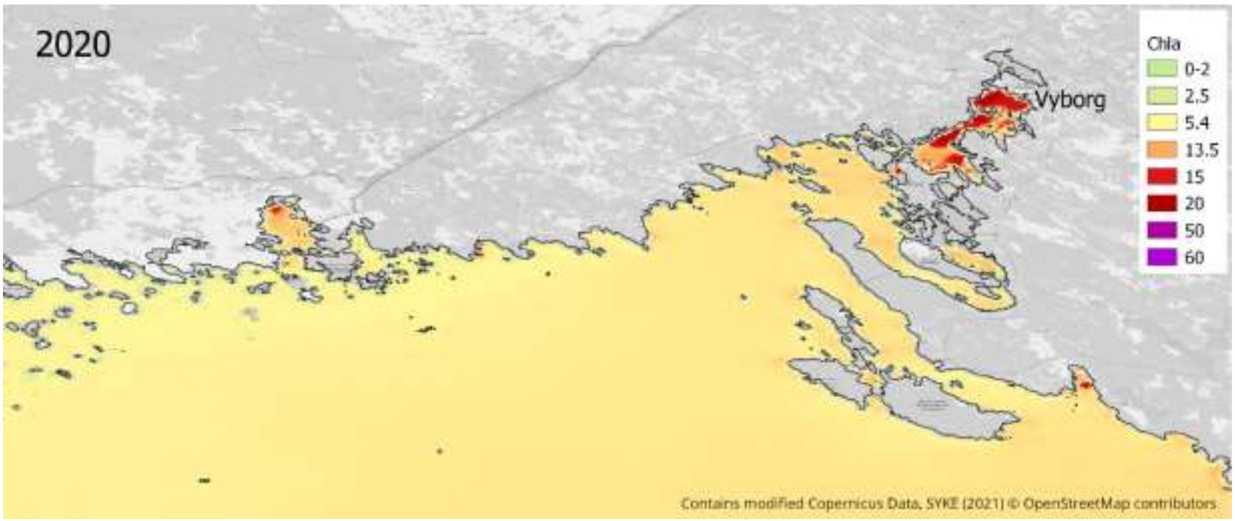


F)

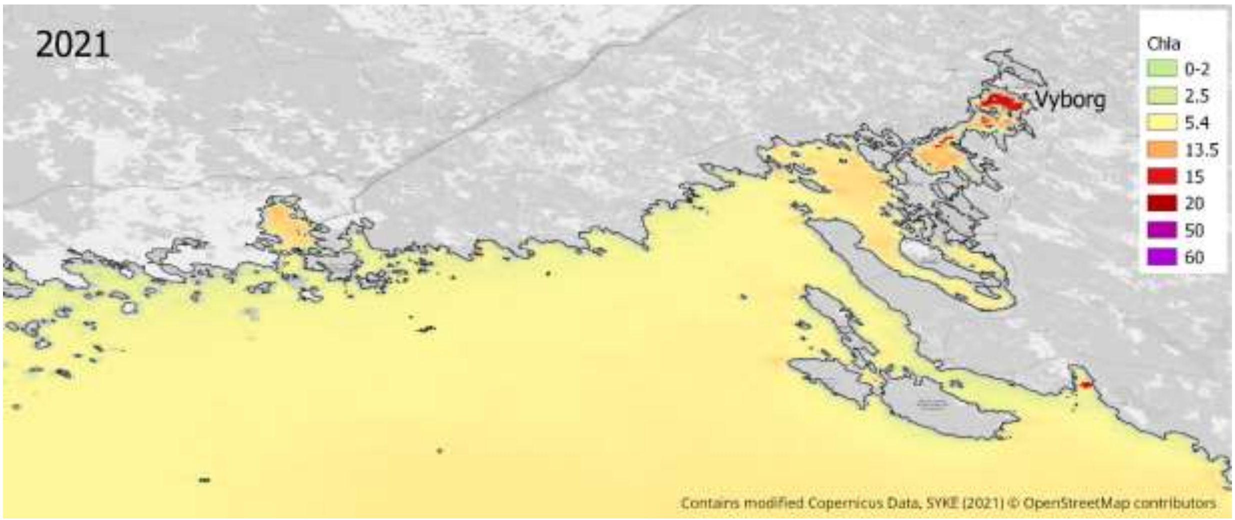
Figure 29. Average late summer chl-a concentrations in the surface water in the Finnish coastal monitoring stations during 1996-2021 (cyan bars), from Alg@line-data reconstruction (orange bars in B and E, 2004-2012) and from satellite observations results (EO, 2015-2021, grey bars).

Water quality maps based on satellite observations of chl-a (2003–2011 and 2016–2021) can provide a wholistic view of the study area in spatial and temporal means (Fig. 30 and 31). The use of satellite observations along with other monitoring data typically increases the reliability of the status assessment, as the number of annual observations increases from two to three station sampling cruises to statistics based on hundreds of thousands of individual measurements. Also, the spatial coverage extends from pointwise station locations and covers the coastal waters and bays, which gives more credibility to the status assessment. Annually produced maps cover the period from the beginning of July to the first week of September, which is the period applied in WFD (for the coastal waters in Finland, Fig. 30 and 31).

Annual state assessment maps of chl-a with EO observations have been calculated for years 2020 and 2021 (Fig. 30). As background information, analogous maps for the years 2003–2011 were generated (Fig. 31). The maps confirm the findings shown in station site time series (Fig. 28 and 29): the ecological condition of coastal waters has improved from what it was at the start of 21st century.



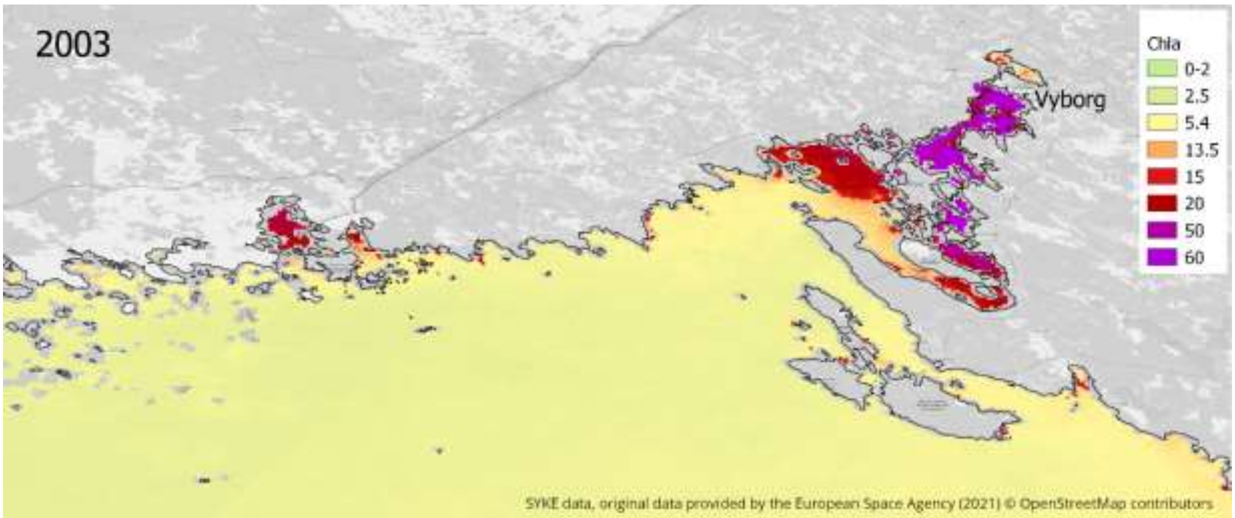
A)



B)

Figure 30. Water quality maps for status assessment purposes are based on summerly aggregate of chl-a observations of OLCI instrument onboard Sentinel-3 satellites A) in 2020 and B) in 2021.

A)



B)

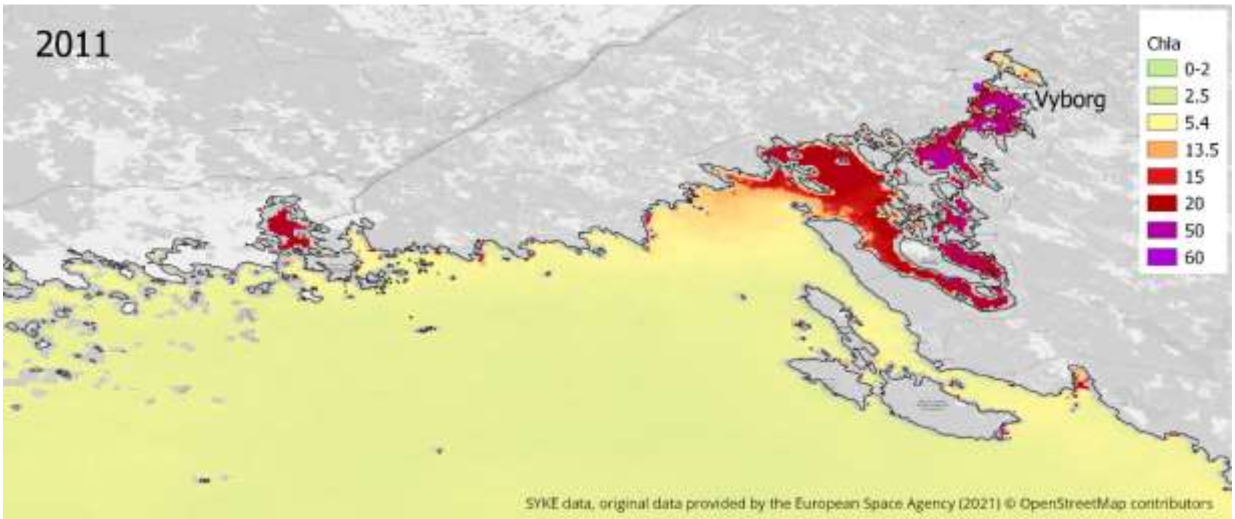


Figure 31. Water quality maps for status assessment purposes are based on summerly aggregate of chl-a observations A) at the beginning of 2000's in 2003 and halfway of the 25-year period B) in 2011. Years 2003 and 2011 represent typical average of the period within the timeframe 2003–2011. For these years, the chl-a maps are based on ENVISAT MERIS satellite instrument observations and methods described in Attila et al. (2018).

4.4 Conclusions based on long term analysis of water quality observations

The water quality data collected in SEVIRA cover the last 25 years and indicate the changes taken place in water quality and the level of eutrophication. We can conclude that there is a long-term positive trend in the status of coastal water areas of the Bays of Vyborg and Virolahti (as well as adjacent inner and outer archipelago region). Water quality and environmental condition in these coastal areas have improved over the last decade. An environmentally positive trend can be retrieved from all analyzed water quality parameters, each of which act as an indicator of eutrophication. The trend is clear both in terms of the reduction of nutrients and a decreasing chl-a concentration (as a proxy for the abundance of phytoplankton). Furthermore, in the coastal waters of the eastern GOF, both the cyanobacteria prevalence and the extent of verified cyanobacterial blooms have decreased, and the water has got clearer.

Despite of these positive changes in water quality, eutrophication is still a prevailing problem in large parts of the study area. This applies to the coastal estuaries and bays where the influence from the drainage basin is the most relevant through river inflow. At Virolahti Bay, another source of nutrients is aquaculture, i.e., local fish farms at the mouth of the bay. Furthermore, the magnitude of the internal load as a source of phosphorus and this load’s effect on the eutrophication of the coastal and bay areas are largely unknown.

The occurred reduction in the land-based nutrient load is reflected in the quality of the coastal waters only after a long delay. Still, the changes can be observed when the cut in the load is sufficient. The improved and currently efficient wastewater treatment of St. Petersburg have had a marked effect on the water quality in the eastern GOF. A change for the better was first observed in the outer archipelago in the easternmost part of the Finnish coast but in recent years also in the inner archipelago due to local mitigation measures of eutrophication.

Monitoring of the coastal waters are needed so that the changes in water quality can be verified in the forthcoming years. This applies both to the Bay of Vyborg and the easternmost coastal waters of Finland. In the coastal area of south-eastern Finland, monitoring under the EU water management is a regular feature and implemented comprehensively. However, there is variation in the spatiotemporal coverage of water quality parameter observations bringing uncertainty to the analysis of long-term changes. The use of satellite observations has brought new opportunities for utilizing spatially and temporally comprehensive water quality observations. This is important for the areas and periods that are not currently covered well or at all by the national monitoring programs in station sampling. Within this project, new autonomous stations providing satellite observations were added to SYKEs TARKKA-service. These will continue providing observations of water quality and temperature after the project.

To gain a better status of water quality in the inland bays (e.g., Virolahti) the nutrient loads from the drainage basin should be reduced. Furthermore, an effective water management requires addressing the role of the internal loading of nutrients. In the Vyborg Bay, a further study identifying the relative amounts of varying sources of pollution is still needed. This is important for establishing effective water protection measures and continued mitigating of the effects of eutrophication in the bay. A further challenge is to estimate the influence of the main basin of the Baltic Sea, which at times extends as far as to the eastern part of the GOF. It is not just the local nutrient loads we must look at when assessing the state of the open sea and the outer archipelago region. On top of these, the climate change will shape the future of the eastern GOF.

5 Modeling

5.1 Modeling made by ILRAS

5.1.1 Land use changes in Vironjoki and Rakkolanjoki catchments during 2000–2018

Changes in the land use in both the Virojoki and Rakkolanjoki catchments have been small over the last 20 years (Table 7). Agriculture area has decreased in the Virojoki area by 163 ha (=3.0%), while there has been a slight increase (11 ha, 0.3%) in the Rakkolanjoki River basin. The built area in both catchments has increased, in the Virojoki by 133 ha (=10%) and in the Rakkolanjoki by 109 ha (=5.5%). Based on these results, it is impossible to predict the direction or magnitude of the changes in the future. However, it is assumed that the changes will be small, some percents per two decades.

Table 7. Changes (ha) in agricultural and built areas during 2000–2006, 2006–2012 and 2012–2018 in the Virojoki and Rakkolanjoki catchments in Finland.

Period	Virojoki		Rakkolanjoki		Virojoki		Rakkolanjoki	
	increase in agri area (ha)	decrease in agri area (ha)	increase in agri area (ha)	decrease in agri area (ha)	increase in built area (ha)	decrease in built area (ha)	increase in built area (ha)	decrease in built area (ha)
2000–2006	+12	−75	+64	−17	+24	-	+63	−1
2006–2012	+4	−92	+6	−62	+16	-	+50	−25
2012–2018	+9	−21	+26	−6	+93	-	+22	-
Σ	**+25 (0.5%)**	**−188 (3.5%)**	**+96 (2.6%)**	**−85 (−2.3%)**	**+133 (10%)**	**-**	**+135 (6.8%)**	**−26 (−1.3%)**

5.1.2 Calculation of runoff and nutrient load under present conditions

5.1.2.1 Description of the used models

The runoff model ILHM (Institute of Limnology Hydrological Model) was developed at the Institute of Limnology at Russian Academy of Sciences (ILRAS) (Kondratyev & Shmakova 2005, 2019; Kondratyev 2007) for calculations of snowmelt and precipitation induced runoff from the catchment areas, as well as those of water levels in waterbodies. The model has a conceptual framework, and it describes the processes of snow accumulation and snowmelt, evaporation and soil moisture in the uppermost, aerated soil layer, runoff formation, as well as runoff within a homogeneous catchment, the characteristics of which are assumed to be constant for the entire modeled area.

The model functions with monthly and annual time steps. During the simulation, the catchment is represented as a homogeneous storage that accumulates incoming water and then gradually allows it to flow away. The values of the basic parameters of the hydrological model, determining the shape of the runoff hydrograph, are determined to be depending on the ratio of the water area to the overall area of the catchment.

The model also takes into account the depth of the water body receiving runoff from the catchment, evaporation from water surface and water outflow (Fig. 32). The model results have been compared with data in several sites located in 12 north-western regions of Russia and two in Finland.

The nutrient loading model ILLM (Institute of Limnology Load Model) was developed based on existing modeling of runoff and removal of nutrients from the catchment areas and nutrient inputs into the water bodies (Kondratyev 2007; Kondratyev et al. 2011, 2021; Kondratyev & Shmakova 2019). The recommendations of HELCOM for assessing the load on water bodies of the Baltic Sea were also implemented into the model (HELCOM 2005). The model was designed to solve processes associated with the quantification of nutrient load formed by point and nonpoint sources of pollution, and to forecast of its changes under the influence of possible anthropogenic and climatic changes. The model incorporates the existing capabilities of data input from the Russian state monitoring system of water bodies, as well as of materials of state statistical reporting on wastewater discharges and agricultural activities in catchment areas.

The model also allows the calculation of the removal of nutrients from the catchment with the influence of hydrological factors and retention by the catchment. The output of the model is an evaluation of the nutrient load and its components on the water body from the catchment (Fig. 32).

The ILRAS nutrient loading model has been verified at a number of sites located in the Northwest region of Russia in the catchment areas of five rivers (Kondratyev et al. 2011). According to the Balthazar II project's (see https://helcom.fi/helcom-at-work/projects/balthazar) results, "the ILLM model can be used to calculate the nutrient load on Baltic Sea from non-monitored and partly-monitored areas in Russian part of catchment area". In conclusions on the project RusNIP II Implementation of the Baltic Sea Action Plan (BSAP) in Russian Federation (RusNIP II 2015) is said that "The ILLM model is most suitable for use in relatively large catchments".

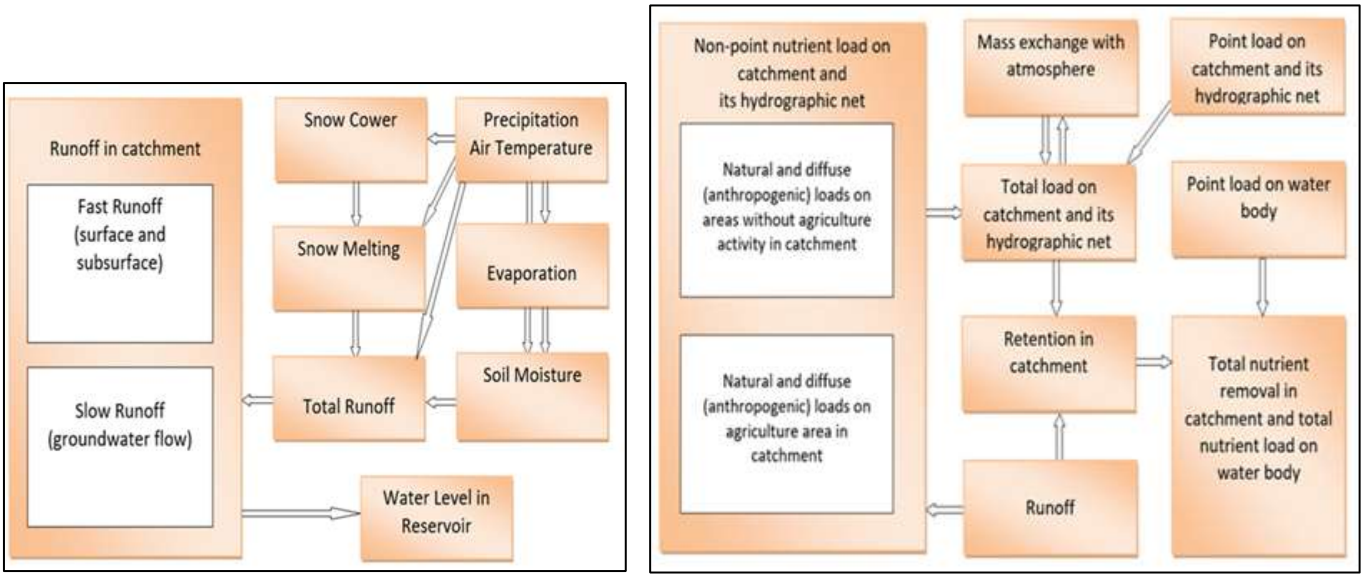


Figure 32. Schematic pictures/flow charts of the hydrological model ILHM (left) and the load model ILLM (right).

As a reference, or benchmark, for ILHM and ILLM models, the VEMALA model was used. VEMALA is an operational, national scale nutrient loading model for Finnish watersheds (Huttunen et al. 2016). It simulates nutrient processes, leaching and transport on land and in rivers and lakes. The model simulates nutrient gross load, retention and net load from Finnish watersheds to the Baltic Sea. It includes two main sub-models, the Watershed Simulation and Forecasting System (WSFS) hydrological model (Vehviläinen 1994) and the VEMALA water quality model (Huttunen et al. 2016). The model has been developed over the years and successive versions have been developed leading to a more process-based nutrient loading model. The model has been used to assess the climate change effects on flooding and adaptation of agriculture to climate change (Huttunen et al. 2015).

5.1.3 Model calibration and testing made by ILRAS

The model calibration and testing were carried out using data on discharges and concentrations of total nitrogen and total phosphorus. For the River Virojoki and the River Sestra the calculations were carried out for the river outlets. For the River Rakkolanjoki outlet there was not enough data for calibration and thus the available long term data series from the sampling point Luzhayka was used.We used not only the data obtained in the SEVIRA project, but also based on previous monitoring. The setting of meteorological variables (average monthly values of precipitation and air temperature) was carried out based on the data from the Vyborg meteorological station.

The runoff model was calibrated based on 2013–2016 data for the River Rakkolanjoki (Luzhayka) and 2008–2014 for the River Virojoki and the River Sestra. The model testing (validation) was carried out for the periods 2017–2020 for the River Rakkolanjoki (Luzhayka) and 2015–2019 for the River Virojoki and the River Sestra. The measured and calculated monthly runoff coincided rather well, as suggested by rather high Nash-Sutcliffe (NS, Nash & Sutcliffe, 1970) model efficiency coefficients; NS = 0.56, 0.79 and 0.61 for the rivers Sestra, Vironjoki and Rakkolanjoki, respectively.

As for the nutrient loads, the ILLM model was calibrated against the average values based on observational data for the period 2019–2020 (Table 8).

Table 8. Average total phosphorus (P) and total nitrogen (N) loads from the catchments. Runoff was estimated to be 375 mm/year for all catchments.

Catchment / Period	Total P load t/year	kgP/ha	Total N load t/year	kgN/ha
Sestra / 2008–2014	6.0	0.16	200	5.2
Virojoki / 2008–2014	6.9	0.19	150	4.2
Rakkolanjoki (Luzhayka) / 2013–2016	8.0	0.37	170	7.9

The largest point source of nutrients in the catchments is the wastewater treatment plant of City of Lappeenranta located in the upper part of the catchment of the Rakkolanjoki River (total P: 3.3 t/year, total N: 201 t/year). A significant contribution to the nutrient load in the rivers is due to the scattered settlements that have no access to a centralized wastewater treatment plant. In these settlements, there live about 2 295 inhabitants in the Sestra catchment, 3 227 inhabitants in lower part of the Rakkolanjoki catchment and 1 133 inhabitants in the Virojoki catchment.

Nutrient load calculation for scattered settlements was made based on HELCOM recommendations (0.9 kg P and 4.4 kg N per person per year). The contribution to the load by Russian agricultural enterprises was 0.91 t/year P and 14.0 t/year N for the Sestra catchment, and 1.93 t/year P and 29.4 t/year N for the lower part the Rakkolanjoki catchment area. Atmospheric deposition was assumed to be 5 kg/km^2/year P and 770 kg/km^2/year N.

The values of parameters characterizing losses of nitrogen and phosphorus from the different types of land uses were taken from the results of previous studies carried out on small tributaries of the Gulf of Finland (Kondratyev et al., 2019).

5.1.4 Building up the scenarios and estimation of future nutrient loads

5.1.4.1 Climate scenarios

The climate scenarios for the area including the three studied catchments were calculated using the last version of the climate model of the Institute Pierre-Simon Laplace (IPSL-CM5A). It is based on a physical atmosphere-land-ocean-sea-ice model, and it also includes a representation of the carbon cycle, the stratospheric chemistry and the tropospheric chemistry with aerosols. The IPSL-CM5A model participates in the World Climate Research Program Coupled Model Intercomparison Project Phase 5 (WCRP CMIP5).

The IPSL model provides meteorological input data for both ILLM and SWAT (see chapter 5.2) models. In total, four different scenarios of human socio-economic activity were recommended, expressed as a Representative Concentration Pathways (RCPs), namely RCP2.6, RCP4.5, RCP6.0, and

RCP8.5. The numbers here indicate the additional amount of radiation energy (W/m^2/s) that will be accumulated by the atmosphere as a result of greenhouse gas emissions. In our study, we chose only two scenarios - the best (favorable) and the worst (unfavorable) in terms of environmental impacts, specified as RCP2.6 and RCP8.5, respectively.

Data on the selected scenarios are available in the Archives of the European Center for Medium-Range Weather Forecasts [https://cds.climate.copernicus.eu/cdsapp#!/search?type=dataset&keywords=((%20%22Temporal%20coverage:%20Future%22%20))].

Meteorological outputs of ILHM model with a time step of 1 year are presented in Figure 5.2. The linear trends illustrate probable changes in the Vyborg Bay area until the year 2100 under the RCP 2.6 and RCP 8.5 scenarios. Using the unfavorable scenario RCP 8.5, the model predicts significant increases of precipitation, air temperature and evaporation for the study region. Runoff is also predicted to increase (Fig. 33 low right) but, due to the counteracting effect of increasing evaporation, not as strongly as precipitation. Meanwhile, the RCP 2.6 scenario, which assumes a significant reduction in greenhouse gas emissions into the atmosphere, leads even to a small (3–6% compared to the period 2006–2015) decrease in runoff at the end of the 21st century.

Since the physico-geographical conditions of the Sestra, the Virojoki and the Rakkolanjoki catchments are similar and the same climatic scenarios were used in all calculations, there were no major differences between the forecast estimations among the three catchments.

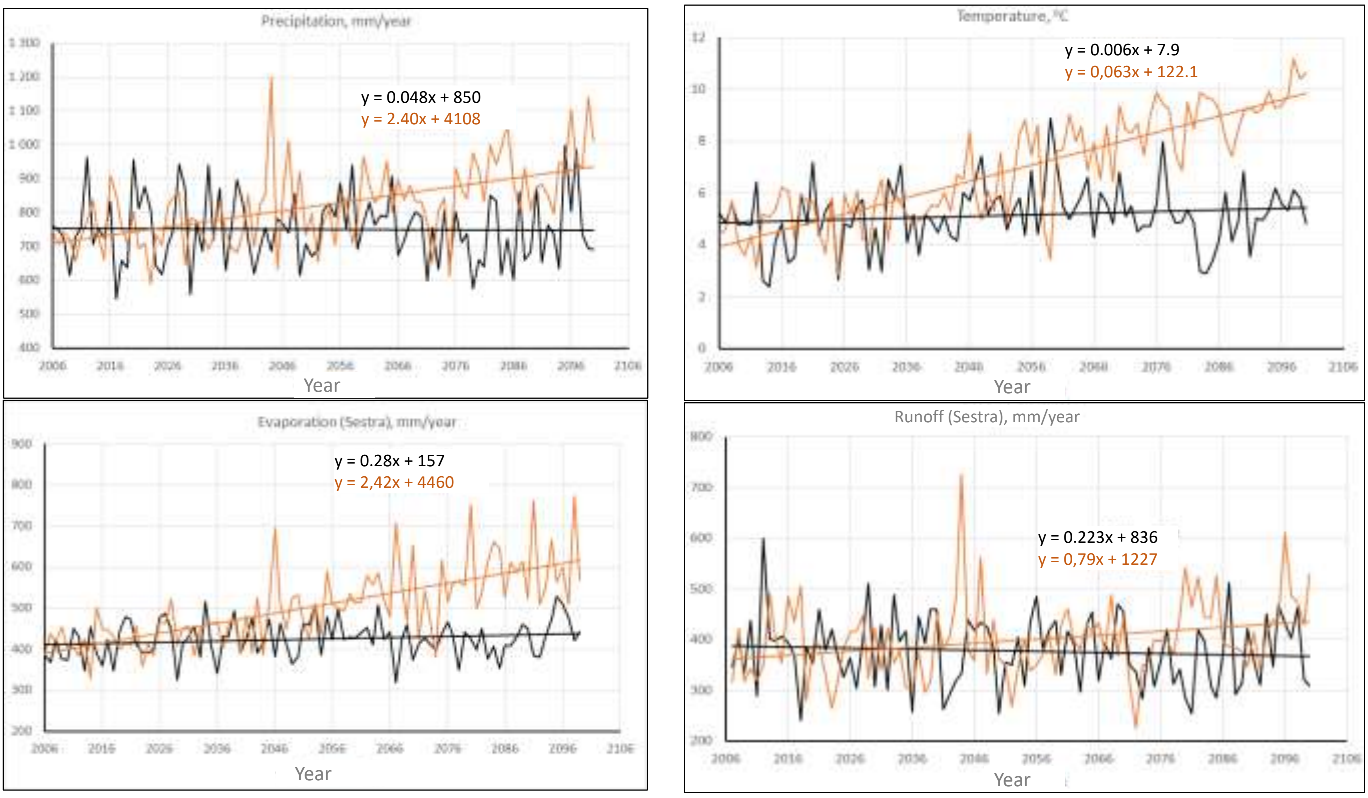


Figure 33. Possible changes of annual precipitation, temperature and evaporation in the Vyborg Bay region and the runoff of the Sestra river for the perspective to year 2100 according to the scenarios RCP 2.6 (1=black lines) and RCP 8.5 (2=orange lines).

Of the studied catchments, the highest values of nutrient loads during the period 2006–2015 were found in the Rakkolanjoki (Luzhayka site) catchment (see Table 9). This can be explained by the discharge from the relatively large sewage treatment plant in the City of Lappeenranta. The lower nutrient load from the Virojoki catchment area is probably due to high forest coverage and the insignificance of point source loads in the area. The calculated changes in nutrient loads as predicted for the period 2091–

2100 (Table 9) depend both on climate change (through runoff) and on the characteristics of nutrient load on the catchment. It should be noted that all the input variables of the model (except for the runoff) used during calculations, remained comparable to the present conditions.

The favorable RCP 2.6 scenario may lead to a decrease in nitrogen and phosphorus leaching by 7 and 5%, respectively by the end of the 21st century in relation to the period 2006–2015. Implementation of the unfavorable scenario RCP 8.5 will cause an increase in load up to 46% for phosphorus and 48% for nitrogen in comparison with the reference period.

The used RCP 8.5 climatic scenario is extreme, and therefore it may not be realized. Most likely the real changes of greenhouse gas emissions are smaller than according to RCP 8.5 forecasts. Therefore, by the end of the 21st century, we hardly expect such significant changes in the hydrological regime and nutrient load in the studied rivers.

Table 9. Total nitrogen (N) and total phosphorus (P) specific load assessment for 2006–2015 and 2091–2100 using RCP 2.6 and RCP 8.5 scenarios.

	RCP 2.6		RCP 8.5	
	2006–2015	2091–2100	2006–2015	2091–2100
Sestra				
Runoff (mm/year)	402	386	368	458
Total P specific load (kg/ha year)	0.21	0.20	0.18	0.26
Total N specific load (kg/ha year)	4.65	4.32	3.92	5.77
Virojoki				
Runoff (mm/year)	403	379	375	458
Total P specific load (kg/ha year)	0.24	0.23	0.22	0.27
Total N specific load (kg/ha year)	5.06	4.83	4.78	5.61
Rakkolanjoki (Luzhayka)				
Runoff (mm/year)	400	387	362	455
Total P specific load (kg/ha year)	0.33	0.32	0.29	0.38
Total N specific load (kg/ha year)	10.94	10.58	9.81	12.43
Rakkolanjoki (outlet)				
Runoff (mm/year)	403	385	369	458
Total P specific load (kg/ha year)	0.29	0.28	0.26	0.34
Total N specific load (kg/ha year)	7.63	7.24	6.91	8.71

The future nutrient loads were also calculated with the VEMALA model (Huttunen et al. 2016) using the same climate scenarios as the ILLM model and assuming that no new water protection measures were done. The VEMALA calculations were made for the larger Hounijoki river basin, whose tributary the Rakkolanjoki river is. During the reference period (2006–2015) the average specific total N load was 7.0 kg/ha/year. Using the RCP 2.6 meteorological input for the period 2010–2100 the average total N load was clearly lower (6.0 kg/ha/year) than during the reference period. During the last decade of the century (2091–2100) the average total N load was predicted to be 5.6 kg/ha/year. With RCP 8.5 data, the predicted total N load increased (6.4 kg/ha/year 2010–2100, 6.7 kg/ha/year 2091–2100) as compared to RCP 2.6, but unlike the ILLM scenario result it was still lower than the average load during the reference period (Fig. 34).

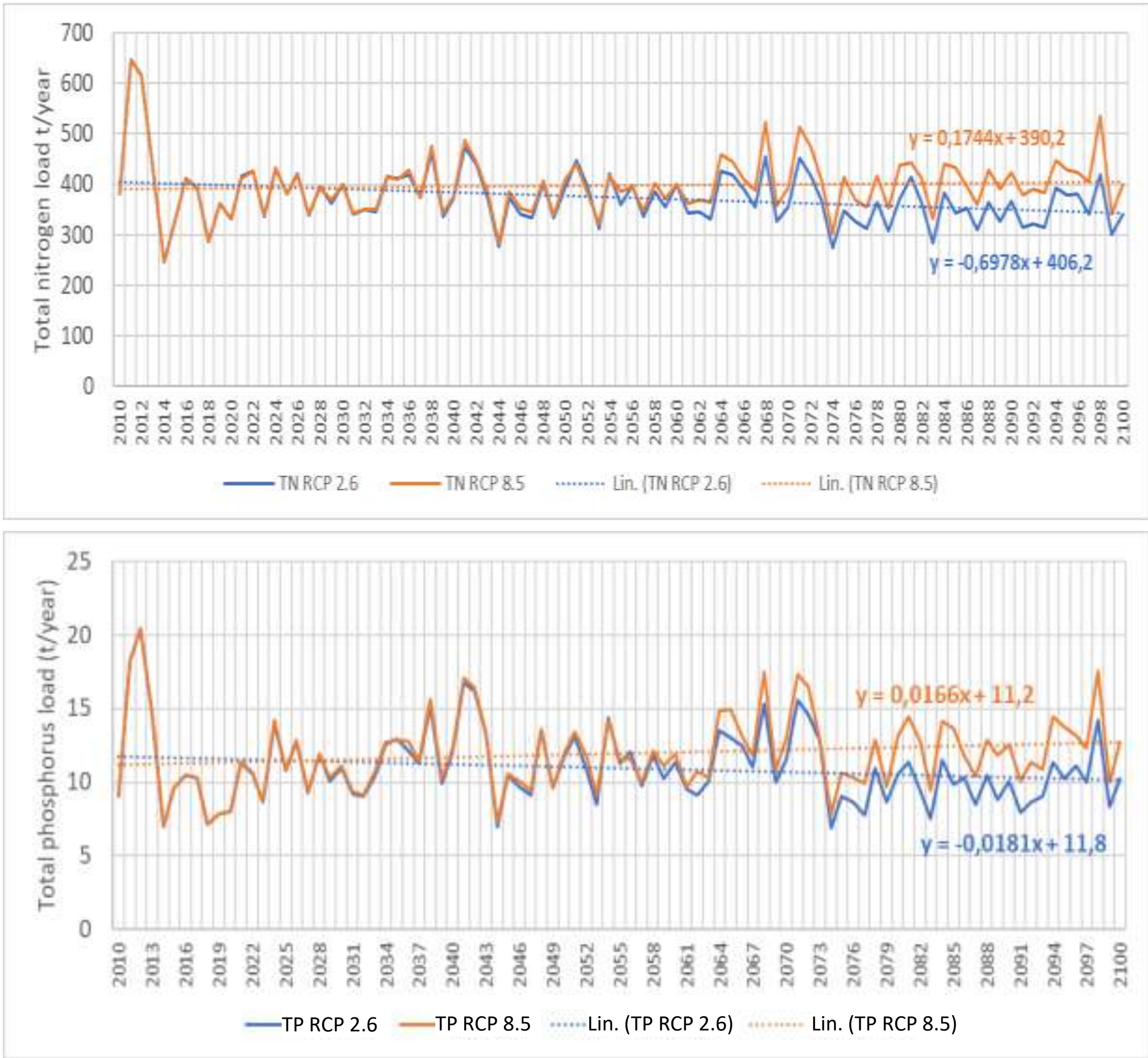


Figure 34. The future total nitrogen (TN, upper graph) and total phosphorus (TP, lower graph) load as calculated using RCP 2.6 and RCP 8.5 meteorological data with the VEMALA model for the Hounijoki River basin.

During the reference period (2006–2015) the average total P load, as calculated with VEMALA, was 0.19 kg/ha/year. The average total P load was slightly lower (0.18 kg/ha/year) using the RCP 2.6 meteorological data as input for the period 2010–2100 (0.16 kg/ha/year for 2091–2100). With RCP 8.5 data the total P load increased (0.19 kg/ha/year for 2010–2100, 0.20 kg/ha/year for 2091–2100) slightly compared to RCP 2.6, especially during the last decade 2091–2100 (Fig. 34).

The two models gave a different view of the future. Both the models predict a reduction in nutrient load by 2091–2100 with RPC 2.6 data. The load reduction calculated with the VEMALA model was 20% for total N and 15% for total P, while the load reduction for both nutrients was only 5% with ILLM. The ILLM model predicted quite large increase in nutrient loading (26–28%) while VEMALA model gave 6% increase for total P load, and −5% decrease for total N load (see Table 10).

Table 10. Comparison of changes in total nitrogen (N) and total phosphorus (P) loading by two different models using RCP 2.6 and RCP 8.5 climate scenarios.

	ILLM Rakkolanjoki	VEMALA Hounijoki	ILLM Rakkolanjoki	VEMALA Hounijoki
		Change ref → RCP 2.6		Change ref → RCP 8.5
Total N load change	−5.1%	−19.9%	+26.1%	−5.3%
Total P load change	−5.2%	−15.1%	+28.1%	+5.9%

5.1.4.2 Land use changes

Besides climate changes and their effect on runoff, it is possible that nutrient removal from the catchments will be affected by anthropogenic changes in land use, as well as the modernization / closing of point sources of wastewater discharge (e.g., industrial, agricultural, municipal). Possible scenarios of the point source loading are nowadays based on Russian state plans for the development of the territory. At this moment, there are no plans to organize any large enterprises in the studied catchments (at the Russian side). Therefore, in this project we do not make scenarios for changes in point loading, except in the Rakkolanjoki, where SWAT model was used to estimate the effects of improving the efficiency of the wastewater treatment plant in the City of Lappeenranta.

Typically, the gradual changes in land use indicate increases of urbanized and agricultural areas. Here, we studied how much the nutrient load increases when new arable land is cleared or the area is built. Figure 34 summarizes the land use change scenarios.

In Table 11, the increase in nutrient load is shown if the share of agricultural or built area increases by 1 km^2. Building a square kilometer increases the total P load by about 5–6 times more than placing the same size area into agricultural use. In terms of total N, taking the same area as agricultural land results in a slightly higher load than building the area.

Table 11. Increase in total nitrogen (N) and total phosphorus (P) loads (kg/year) if the share of agricultural or built area increases by 1 km^2.

	Sestra	Virojoki	Rakkolanjoki (Luzhayka)	Rakkolanjoki (outlet)
Total P agri (kg/year)	6	8	6	8
Total P urban (kg/year)	29	38	38	38
Total N agri (kg/year)	800	700	600	400
Total N urban (kg/year)	600	500	300	300

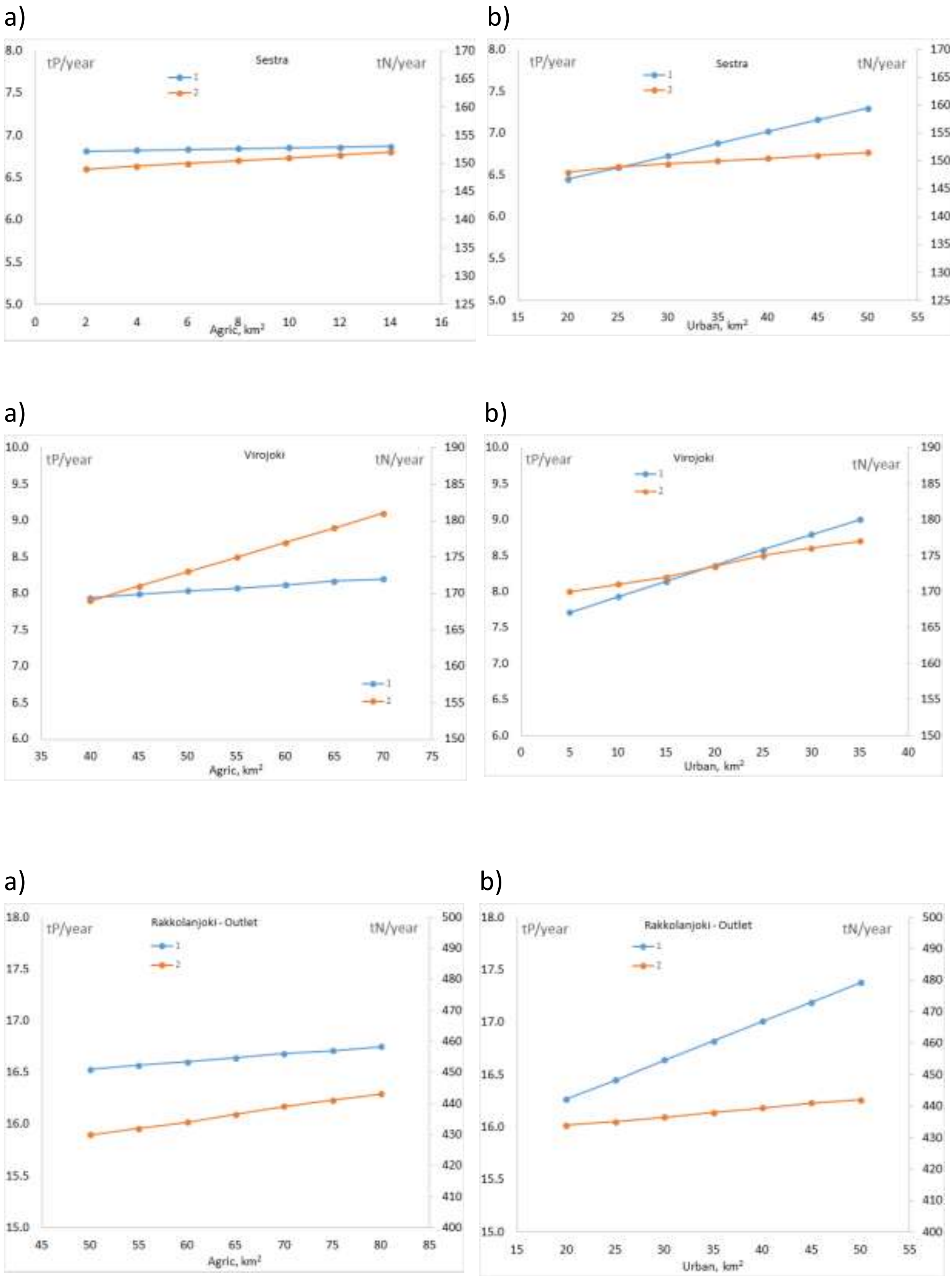


Figure 35. Increase in total phosphorus (1 = blue lines) and total nitrogen (2 = orange lines) loads (t/year) with increasing agricultural (a) or built-up (b) area in the Sestra (up), the Virojoki (middle) and the Rakkolanjoki (low) catchments.

5.2 Soil and Water Assessment Tool, SWAT

Soil and Water Assessment Tool (SWAT, Arnold et al. 1998) is a river basin scale model developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watershed with varying soils, land use and management conditions over long periods of time (Gassman et al., 2007).

SWAT is a soil-hydrological simulation scalable river basin model. It was developed to determine and assess the impact of human economic activity on large and complex basin structures, on the state of water resources. Input variables of SWAT characterize different impacts on the soil-hydrological system within the model basins or sub-basins. The model time-step is one day and it can be used to solve many problems, e.g., forecasting the consequences of the anthropogenic impact of agricultural production on the hydrological and soil components of the landscape, on bottom sediments, on the migration of pesticides and their decay products, and on the yield of agricultural crops.

5.2.1 Building up the SWAT application

SWAT model was applied by the Russian State Hydrometeorological University (RSHU) using the platform of QGIS geographic information system to assess the removal of nutrients from the catchment of the river Rakkolanjoki.

The following source data were used:

- Digital elevation map (DEM) (source: National Land Survey of Finland)
- Stream reaches file to be integrated into the DEM (source: SYKE open data)
- Land-use (CORINE land cover 2018, source: SYKE open data) and soil maps (source: Geological Survey of Finland GTK) Daily meteorological measurements: temperature, solar radiation, wind speed, rainfall, relative humidity for the study period 2011–2018 (source: Finnish Meteorological Institute)
- Observational data file for model verification: concentrations of simulated nutrients in the Rakkolanjoki, water flow (daily) (source: SYKE open data)

The SWAT-project (or -application) for the Rakkolanjoki catchment was automatically set at the European global coordinate reference system ETRS89/TM35FIN (N, E).

Our SWAT-project proceeded by the following steps:

- In the first step of model construction, the DEM and the stream reaches files were added. As a result, the model divided the Rakkolanjoki river catchment into 11 subbasins (Fig. 36). Also the locations of the river outlet, the monitoring station and the source of point loading were placed in this step.
- In the second step landuse and soil maps were added. Land use in the catchment area was divided as follows: forest (61%), agricultural (15%), wetlands (13%), urban (8%), hay (2%), water (1%). As for the soil types, the catchment is dominated by rocks, followed by moraines, coarse-grained soils, fine-grained soils (clay) and peat soils. A threshold of 4% was set for landuse, soil and slope classes to be included in Hydrological Response Units (HRUs), which are the unique combinations of those three characteristics in a subbasin. For example, "forest – peat soil – <1% slope – in subbasin #1" is a unique HRU and (with 4% threshold) forest, peat soils and <1% slope all have to represent more than 4% of land use, soil type and slope, respectively, in subbasin #1. As a result in our case, the subbasins were divided into 278 Hydrological Response Units (HRUs). A report describing each HRU was automatically created by the model.

- In the third step the weather database was prepared with the WGEN program. After the weather data was added, the SWAT model was activated. At this stage, the modeling period was set from 1.1.2009 to 31.12.2018 with first two years skipped (i.e., the actual modeling period started from 1.1.2011 and the two first years were for model initialization ("warm-up").
- In the fourth step first model run producing several output files for the visualization of the results was executed.
- In the final step model calibration was performed. The calibration was first done manually, and then with the help of the special built-in program SWAT-CUP (Calibration Uncertainty Program).

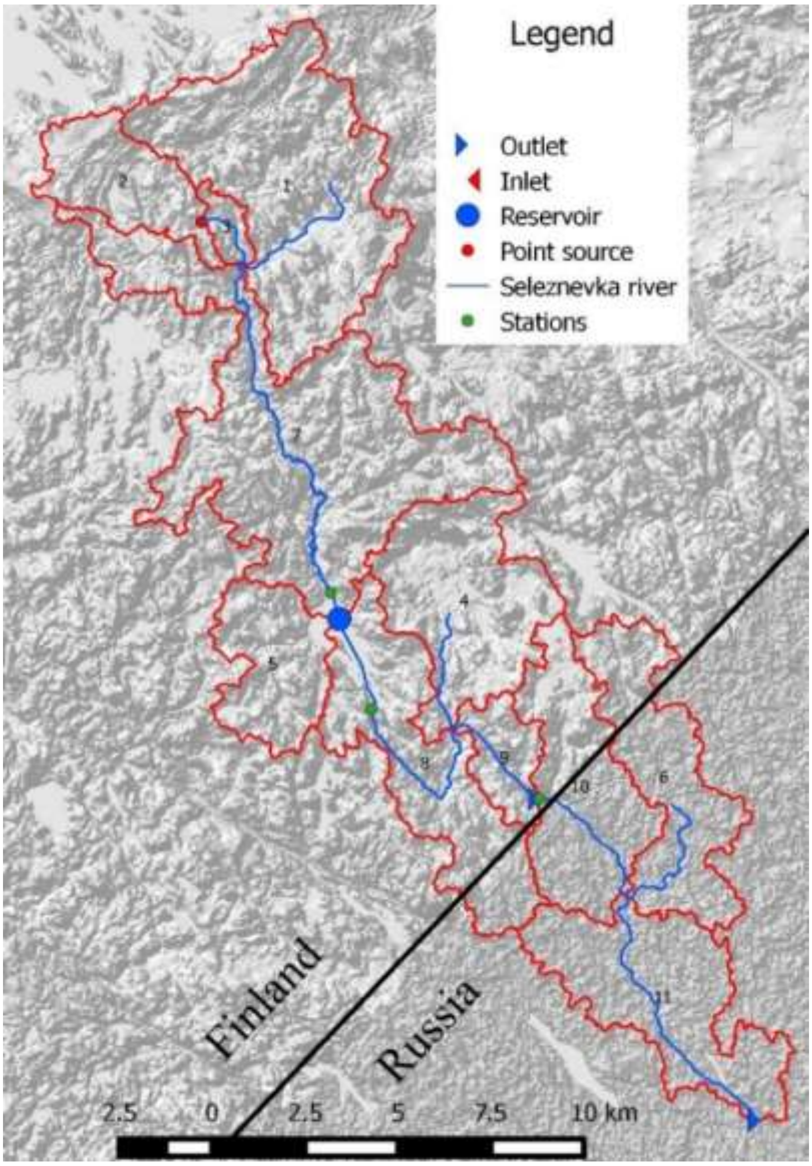


Figure 36. The catchment and the sub-catchments of the River Rakkolanjoki as delineated by SWAT.

5.2.2 Model calibration

The main attention was given here to three variables: river flow, total nitrogen load and total phosphorus load. So, we investigated the changes in the parameters which influence those variables the most:

Hydrological parameters

- Available water capacity of the soil layer
- Soil evaporation compensation factor
- Threshold depth of water in the shallow aquifer required for return flow to occur
- Groundwater "revap" coefficient controlling water movements in shallow aquifer
- Threshold depth of water in the shallow aquifer for "revap" to occur
- Saturated hydraulic conductivity
- Average slope length
- Manning's 'n' value for overland flow
- Deep aquifer percolation fraction

Total N load parameters

- Denitrification threshold water content
- N percolation coefficient
- Initial nitrate-N concentration in the soil layer
- Residue decomposition coefficient
- Fraction of algal biomass that is N
- N uptake distribution parameter
- Rate factor for humus mineralization of active organic nutrients (N and P)
- Denitrification exponential rate coefficient
- Initial organic N concentration in the soil layer

Total P load parameters

- P percolation coefficient
- P soil partitioning coefficient
- P sorption coefficient
- P uptake distribution parameter
- Initial organic P concentration in surface soil layer
- Fraction of algal biomass that is P
- Initial labile (soluble) P concentration in surface soil layer
- Rate factor for humus mineralization of active organic nutrients (N and P)

The SWAT model was calibrated by stepwise changes of its parameters to bring the output values of flow, total N load and total P load to as close as possible to those calculated by the VEMALA model (Huttunen et al. 2015). VEMALA model is at operational use in Finland and thus more reliable "benchmark" for calibration than sparsely taken water samples. As can be seen from Table 5.5, the flow and nutrient loads calculated by SWAT satisfactorily correspond to those calculated by the VEMALA model.

Figure 5.6 shows an example of calibration of the flow with the SWAT-CUP tool. As shown by the red and blue curves in Fig. 5.6, most of the measured flow peaks coincided with the simulated values.

Table 12. Average values of flow and total nitrogen (N) and total phosphorus (P) loads of the River Rakkolanjoki as calculated by the VEMALA and SWAT models.

	Flow (m^3/s)	Total N (kg/ha/year)	Total P (kg/ha/year)
Vemala	1.4	12.6	0.3
SWAT	1.6	14.2	0.5

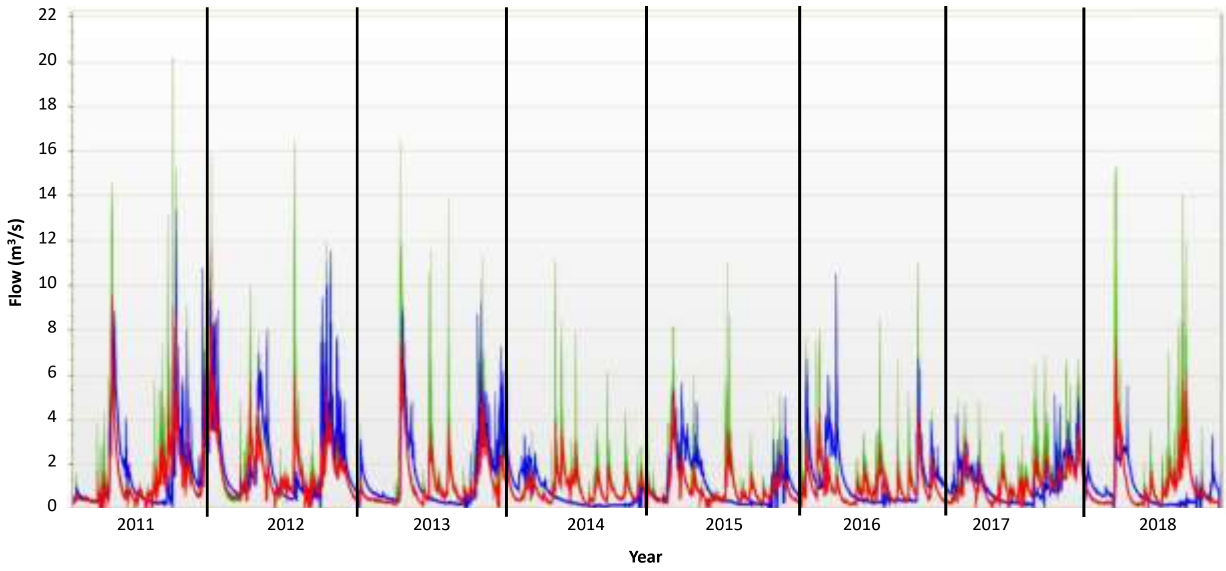


Figure 37. Example of flow calibration with SWAT-CUP tool. The blue curve describes the flow (m³/s) measured at the transboundary station of the river Rakkolanjoki. The red curve describes the flow of the best estimation obtained with SWAT-CUP. The green curve denotes 95% prediction uncertainty limits.

5.2.3 Scenario calculations

Three scenarios (Table 13) were formed and their effects on loading estimated:

- Wastewater treatment plant of the City of Lappeenranta, reduction of load by 50% and 100%
- Best management practices (BMPs) in agriculture (buffer zones and constructed wetlands)
- Climate scenarios

Table 13. Scenario runs for total nitrogen (N) and total phosphorus (P) loads using the SWAT model.

		Flow (m³/s)	Total N (kg/ha)	Total P (kg/ha)
Baseline values		**1.57**	**14.19**	**0.45**
Scenario 1: change of point loading	Decrease 50%	1.43	9.58	0.39
	Decrease 100%	1.29	5.14	0.33
Scenario 2: BMPs in agriculture	Buffer zones	1.57	13.85	0.39
	Constructed wetlands	1.57	14.14	0.46
	Buffer zones and con-structed wetlands	1.57	13.81	0.40
Scenario 3: climate change	RCP 2.6	1.61	13.38	0.52
	RCP 8.5	1.68	13.27	0.42

Scenario 1: Reduced point source loading

Lappeenranta wastewater treatment plant is located in the 2nd sub-basin at northwesternmost part of the catchment (Fig. 36). So, the parameters were changed only for this sub-basin. The results presented in Table 13 are calculated for the 9th sub-basin at the national border (see Fig. 36). Table 13 shows that when the nutrient loads from the point source decrease, this is seen at outlet at the border, as well. The largest change is observed in total N load with absence of point source load (100% decrease); the load at the border decreases by almost to a third of the original value.

Scenario 2: Best management practices in agriculture

The changes presented in Table 13 were applied to each sub-basin. It can be seen that the changes did not affect the runoff values. By creating the buffer zones (15 m along the main ditches in arable areas), the loads of total N and total P slightly decreased. When wetlands (in every sub-basin one wetland with an area of 0.5% of the above catchment) were added, there was negligible reduction in N load and the P load even increased slightly. If both buffer zones and wetlands are added to each sub-basin, then the nutrient loads decreased.

Scenarios 3: Climate change scenarios

The modeling period for climate change scenarios was from 01.01.2006 to 31.12.2100 (2-year initialization period was skipped and the actual starting date of the modeling period was thus 01.01.2008). Here, we used the daily CMIP5 data from IPSL-CM5A-LR (Institute Pierre Simon Laplace-The fifth phase of the Coupled Model Intercomparison, France, see chapter 5.1.4.1).

The Representative Concentration Pathways (RCPs, see chapter 5.1.4.1) were used in our SWAT modeling. We applied also here the favorable (RCP 2.6) and the unfavorable (RCP 8.5) scenarios in terms of environmental impacts. The used time step was 1 day.

Figure 38 shows that the RCP 2.6 scenario, assuming a significant reduction in greenhouse gas emissions into the atmosphere by 2100, leads to a small (3–6% compared to the period 2006–2060) increase in runoff at the end of the 21st century. The implementation of the unfavorable RCP8.5 scenario will lead to an increase in precipitation and surface temperature in the region and will cause an increase in runoff up to 17% relative to the reference period.

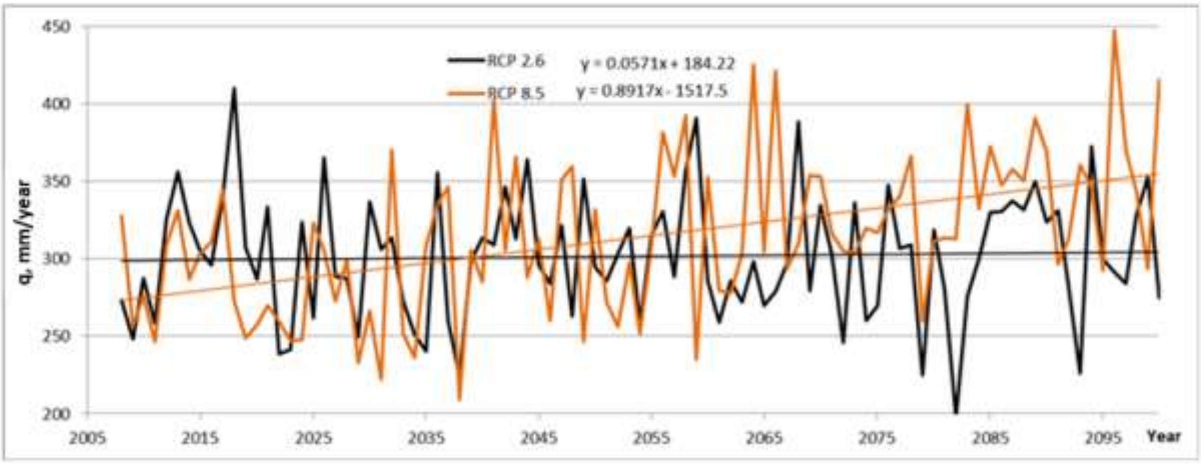


Figure 38. Modelled annual runoff and its predicted changes in the River Rakkolanjoki (mm/year) by 2100 according to the scenarios RCP 2.6 (black curve) and RCP 8.5 (orange curve).

5.3 Concluding remarks

Changes in land use in the Virojoki and the Rakkolanjoki catchments have been small over the last 20 years. Agricultural land has decreased in the Virojoki catchment by 3% and in the Rakkolanjoki catchment by 0.3%. The built-up area in both catchments has increased, in the Virojoki catchment by 10% and in the Rakkolanjoki catchment by 5.5%. The future development is unclear, but even small changes in land use have a potential to mask the positive effects of nutrient load reductions obtained by water protection measures (e.g., agricultural best management practices).

The RCP 2.6 and RCP 8.5 climate scenarios were used as meteorological inputs for all the models. The linear trends modelled by the ILHM illustrate, according to the RCP 2.6 secenario, a possible decrease in the Vyborg Bay area until year 2100 in precipitation and a negligible increase in air temperature. The RCP 8.5 scenario assumes a significant increase in precipitation and air temperature in the region. The RCP 8.5 climatic scenario is extreme, and may not be realized. Most likely the real changes of greenhouse gas emissions are smaller than the RCP 8.5 forecasts. Therefore, by the end of the 21st century not very significant climate induced changes can be expected in the hydrological regimes of the studied rivers.

The ILLM model predicts that increases in both agricultural and urbanized areas lead to gradual increase in nutrient loading. The catchment area of the River Rakkolanjoki (Luzhayka site) has the maximum agricultural area (13% of the total catchment area). The maximum share of urbanized areas (9% of the total catchment area) is in the Sestra catchment. According to the ILLM model, building a square kilometer increases the P load by about 5–6 times more than clearing the same area into agricultural use. This conclusion, however, holds true most likely in the Sestra river basin, where agriculture is less intensive than in (the Finnish side of) Rakkolanjoki and Vironjoki catchments. In terms of N load, similar difference between agricultural and urban land uses was not found.

The scenarios simulated by SWAT suggest that most effective way to reduce nutrient loading of the River Rakkolanjoki is to make improvements in the Lappeenranta wastewater treatment plant. The simulated applications and their extents of agricultural water-protection measures (BMPs) were obviously too modest for substantial reductions in nutrient loading. On the other hand, agriculture is in the first place responsible for just 7% of the total N load and 27% of the total P load carried by the River Rakkolanjoki, the major part originating from point sources.

6 Public awareness

The SEVIRA project aimed at increasing public environmental awareness to promote sustainability in people's daily life, and to boost their interest to take care of the environment. Awareness raising was supported by several tasks, as follows:

- Promoting schoolteachers to carry out outdoor studies with new material for education and offering citizens a wider knowledge-base for sustainable living and decreasing negative impacts on natural waters.
- Providing new and enhanced public river monitoring and restoration services and demonstrating them during the field trips.
- Organizing transboundary discussions between local decision-makers, citizens, and researchers.
- Increasing public knowledge about nearby surface waters and gain information about their preferences and willingness to volunteer for improved water status.

These aims were applied in co-operation 1) *with the local schools* by organizing student field courses on surface water issues, surveying the need for information and materials for teachers, and providing educational materials, and 2) *with other local stakeholders* via Round Table discussion, questionnaires and interviews.

6.1 Field trips and educational materials

Several field trips for local middle school students on both sides of the Finnish-Russian border were organized during the project. Also, multiple educational materials were produced for volunteer river monitoring. This material was introduced in several webinars to teachers providing them with wider knowledge of the subject. Field trips in Finland took place in the municipalities of Virojoki and Joutseno to study several local rivers (Fig. 39). During these field trips middle school students and their teachers were guided to river monitoring and were taught to measure basic water quality parameters (pH, Secchi depth, turbidity, oxygen), river flow, and to study river ecosystems by identifying species. At the Russian side several school field trips took place on the Sestra River, where in addition the concentration of nitrate-N was measured.

Figure 39. School students were studying the river ecosystem at the Jussilankoski in May 2019.

In the connection to the field trips for experts to study water quality of the Russian part of the Seleznevka/Rakkolanjoki and Sestra river, Russian teachers and school students did volunteer investigatory field trips to these rivers. Collected monitoring data was saved to the Google Map, providing a better understanding of the state of the environment, thus creating value for all (Waylen et. al. 2019).

Video training course on River Watch methods was produced and published by Ecocentrum and "Friends of the Baltic" on YouTube (in Russian, with English subtitles). With the help of these video methods, anyone can quickly learn how to use the tools and water quality reagents available from the "Friends of the Baltic" team. The publication *"River Watch. Manual for public environmental monitoring"* , available in the https://ecocentrum.ru/, was published by Ecocentrum and Friends of the Baltic in both Russian and in English. It describes the main methods on how to study river ecosystems. The River Watch data exchange service is presented in the following Chapter 6.2.

Two educational learning packages for middle and secondary schoolteachers, in Finnish, were compiled. "Get to know your near-by waters" (Lähivedet tutuksi 2022) is a comprehensive teacher's manual, which contains instructions on how to organize a field trip to near-by aquatic habitats. It contains two instructional video sets entitled: 1) "Water monitoring kit backpack and water quality measurements", and 2) "The importance of water quality to the ecosystem and their connections to human activity in drainage basin". The package includes multiple student exercises and information for teachers planning a field trip. Several information cards, "Manual cards", on water quality measurements, bottom fauna identification, river flow measurements and safety instructions are also included (Fig. 40). The videos and manual cards are available both in Finnish and in Russian.

Figure 40. The species identification cards can be used to identify bottom species. Cards are available both in Finnish and in Russian (left). A mobile game can be use in a field trip to answer questions (right).

In addition, the package supports teachers to organize a longer activity: a "Get to know your near-by waters" – week (Fig. 41). The extended programme links multiple school subjects around the field course and can thus serve as a starting point for the understanding of more complicated environmental issues, such as the climate change. Relevant open data services are also introduced.

Figure 41. Developed education package,"Get to know your near-by waters", supports and gives teacher ideas how to apply multiple school subjects around the field course.

The other educational learning package "Research the waters using satellite data" (Tutkitaan Vesiä Satelliiteilla 2021) is a compact teacher's manual in Finnish on how to use SYKE's web map TARKKA service (www.syke.fi/TARKKA) in education for visualizing openly available satellite imagery. The TARKKA service can be used to study several subjects, such as ice conditions, water temperature and the blue green algae situation of the Baltic Sea and lakes. The manual provides information on satellite instruments that have an open-data policy, and various exercises on how the TARKKA can be used for environmental monitoring. It also shows how to use satellite images to complement the information retrieved from station sampling.

Also, *the booklet "Clean waters – healthy people"*, targeted to the general public is available. It describes sources of eutrophication, simple ways for public monitoring and measures on "how to help our rivers", including personal actions.

The outcomes of the annually (2019–2021) organized youth conferences on "Eco-monitoring of the rivers and environment" were published on the project website. These publications compiled the reports by young enthusiasts and were describing their river watch results and other environmental investigations (Fig. 42).

Figure 42. Figure shows collections of annual conference reports in Russian on the "Eco-monitoring of the rivers and environment". The documents support the development of the school river conservation and youth environmental awareness raising programmes.

6.2 River Watch – transboundary data exchange service

Currently there exists in Russia a Google Map -based service to monitor surface waters, mainly in St. Petersburg and Leningrad oblast (Russian part of the Gulf of Finland basin), but only to some extent in transboundary waters. Clearly, more open data are needed from the Russia to enhance monitoring in transboundary waters and to improve the policy for Russian open data in future.

To collect and provide open data of transboundary waters, both Finnish and Russian, a pilot version of wiki-based transboundary data exchange service, called River Watch, was developed in the SEVIRA project. The pilot version was demonstrated and tested during the field trips for the public and the data collected from transboundary waters were saved at the River Watch. During the project, the Finnish-Russian River Watch was linked to the SYKE's open data service that includes information on Finnish water resources and surface waters. Currently, only satellite data are available from both sides of the border. While most of the Finnish open data services are designed for expert users, one exception is the Lake-SeaWiki (jarviwiki.fi).

The manual for public river watch (Friends of the Baltic 2022) was published to show the benefits of public monitoring as a part of finding practical environmental solutions. It describes how to investigate hydrological parameters of rivers, organoleptic methods (such as color and transparency), bioindication (with water plants and invertebrate organisms), physical and chemical measurements, nutrients, pH, oxygen, mineralization, hardness, etc. The manual also includes step by step advice on how public can promote solutions for improving water quality. However, further work is needed for maintenance and marketing until the River Watch monitoring system can be used operationally.

6.3 Stakeholder discussions

During the SEVIRA project several public awareness activities took place. Transboundary Round Table discussions between the project group, local decision-makers and citizens were carried out. The discussion themes were: "Climate, water, energy, resources, microplastics and marine waste -

cooperation for the protection of nature on the shores of the Baltic Sea". In Russia, in 2019 and 2020, two multistakeholder Round Tables were held in City of Vyborg located in the Leningrad Oblast. The themes were: "Ecological condition of water bodies of the Leningrad region: solutions for the Vyborg district". In May 2021, the interregional environmental action "Sestra River Festival" was held in Saint-Petersburg. The event brought together 74 participants from St. Petersburg and the Leningrad Oblast as part of teams of school children, teachers, and public organizations. In 2019, 2020 and 2021 the annual youth conferences "Eco-monitoring of the rivers and environment" were held in Saint-Petersburg. Several trainings were held by Friends of the Baltic for school children, teachers, and active locals on the methods of rapid testing of water quality in rivers. Expeditions for experts to learn more about water quality of the Russian part of the Seleznevka/Rakkolanjoki and Sestra river were organized by Ecocentrum and Friends of the Baltic.

6.4 Giving and gaining information via questionnaires and interviews

Several surveys were designed and completed for locals to better understand their attitudes and needs for nearby surface waters, and to identify challenges, knowledge gaps, and opportunities for transboundary river cooperation. The survey results are presented in Chapter 7 in more detail and in Väisänen et al. (2021a, 2021b) and in Ecocentrum, Friends of the Baltic (2019, 2021). These surveys revealed that residents do not always have accurate information of the ecological state of the nearby waters. The residents are interested to follow the condition of rivers if they are provided with appropriate information and monitoring knowledge. Willingness to participate in voluntary river monitoring was lower in Finland. However, both countries share interest to monitor litter, ice cover, algae, and water depth. Previous surveys have also confirmed that it is important to provide background information about rivers, such as water quality, ice conditions and changes in water level, to enhance public monitoring. Almost all the residents, 85 % in Russia, are concerned about water quality and are ready to take personal actions to reduce water pollution.

In addition, a short survey was implemented on which eight Finnish teachers responded. They highlighted several factors to enhance current materials to improve teaching about water status and monitoring. The services and materials should be easily accessible, contain relevant educational materials for teachers and students, include expert education for teachers, and contain more usable open data.

6.5 Conclusions about enhancement of volunteering

Nature conservation is intrinsically linked with understanding the values and expectations of local people and how they wish to address their natural resources. Key elements for positive outcomes are generating experiences that increase co-operation and an exchange of knowledge between stakeholders.

Involving residents in river quality monitoring increases their environmental awareness and supports involvement in local development. The Finnish-Russian River Watch system responds to this challenge. It contributed to deeper understanding of water quality changes and environmental sensitivity needed for the community to take environmental actions. Currently, the River Watch wiki is limited to Finnish-Russian transboundary waters, and the maintenance of the bilingual system needs a qualified coordinator. At this point it still needs to be determined if it is a sustainable and cost-effective information exchange system.

Increasing awareness for young people through school-based environmental education was one important approach of the Project. Environmental school education is a crucial element for building positive attitudes and encouraging environmental protection actions. Through the educational materials and actions, both in Russian and Finnish schools, the Project was motivating youth towards a lifelong interest in environment protection. Teachers were highly motivated and participating in the training webinars. Based on their positive feedback, the Project educational material produced will not only be used in the schools to increase environmental consciousness, but also in local communities.

Through Project actions public organizations have an opportunity to take advantage of the number of additional tools for increasing public environmental awareness and in addressing school environmental education. It is also a promising component for transboundary cooperation, essential for the shared water environment.

7 Citizens' views and preferences on the surface waters

In this chapter, we describe and compare the results of the surveys and interviews carried out in the SEVIRA project in 2019–21. The material to be analysed contains a total of 543 responses to the Finnish questionnaires and 600 responses to the Russian interviews. In particular, we look at the significance given to water bodies, their use, and perceived status. In addition, the aim was to examine the willingness of residents to participate in various activities for improving the state of their local water bodies. The importance of the local waters for the respondents was evident e.g., in how important they consider the potential improvement of the status of waters in their area in general and how they have used the surface waters in their area recently e.g. for recreational purposes. The two Finnish questionnaires applied were nearly identical in the Virojoki and the Rakkolanjoki river basins as were the interview questions included in the Russian surveys for the Sestra and the Seleznevka study areas. Although the Russian and Finnish studies were different in implementation and scope, some of the questions were similar to allow comparison. The Finnish survey applied a stated preference method, e.g., the contingent valuation method to estimate non-use values of improved surface water quality.

7.1. Aim of the resident surveys

The aim of surveys was to study how people experience and value local river, lake or coastal waters and if they would be willing to do voluntary actions to improve their status in the future. In Finland the goal was also to consult the permanent residents of the area and non-resident holiday homeowners about the status of the water bodies in their area, the factors that have affected them, their improvement, and their willingness to participate in monitoring and improving the condition of the waters in their area. The aim was also to provide up-to-date information to residents on the status of local freshwaters and plans to improve their status.

In Russia, the aim of the studies in the River Seleznevka and the River Sestra basins were to analyze residents' attitudes to water resources in how they perceive the state of waters and use these resources and whether they would be interested in participating in citizen monitoring of these waters. The results of the study were told to be used to prepare practical recommendations for local authorities to improve the condition of the water bodies (Ecocentrum, Friends of the Baltic, 2019, 2021).

7.2. Survey data

The data of the Russian surveys consisted of two interviews at the place of residence of respondents, combined with street interviews carried out in the city of Sestroretsk for the River Sestra (here on Sestra) during July–August 2021 and Seleznevskoe rural settlement of Vyborg municipal district for the

Seleznevka River basin (here on Seleznevka) in June 2019 (n=300 in both areas, Ecocentrum, Friends of the Baltic, 2019, 2021).

The Finnish data consisted of a mail and internet survey conducted in the River Virojoki basin (here on Virojoki) during December 2020 and January 2021 and the River Rakkolanjoki basin (here on Rakkolanjoki) during January and February 2021. The target groups were the Finnish-speaking persons aged 18–79 who live in the river basin or live elsewhere but own a free time cottage in the area (here on cottage owners). The questionnaires were prepared in collaboration with SEVIRA project experts and commented by the project steering group. The questionnaires were sent as a random sample to 734 persons in total in Virojoki and to 1,009 persons in Rakkolanjoki (one adult per household). In Virojoki the recipients were contacted four times and in Rakkolanjoki three times. The final data consisted 329 responses from Virojoki and 242 responses from Rakkolanjoki. (Väisänen et al. 2021a, Väisänen et al. 2021b, Lehtoranta et al. 2021.).

7.3. Perceived surface water status

The residents were asked if they had noticed any changes in the state of the waters in the river basin during last decade and if so, what kind of changes. On the Russian side interviews people were asked if they had noticed changes in the state of the water during last five years. The most common answer in all areas, except in Rakkolanjoki, was that the state of the waters had deteriorated in recent years, and this was most often the case in Seleznevka and Virojoki (44% and 39% of respondents, respectively). On the contrary, only about a tenth of the respondents felt that the situation had improved in recent years. Most residents in Rakkolanjoki (53%), a third in the Virojoki area (31%) and only just over a tenth of the respondents on the Russian side could not assess the change (Fig. 43). Interestingly, the cottage owners in Virojoki had noticed deterioration of the state of the waters more often and improvement more seldom than the permanent residents.

Hence, changes in water bodies were reported to varying degrees in the study areas. In Virojoki the changes were, for example, eutrophication and overgrowth: “Onkamaajärvi has continued to eutrophicate and overgrow.”, “The Lake Lapjärvi is eutrophic, water lilies are growing year by year. The clarity of water is constantly decreasing.” In Rakkolanjoki, changes for the worse had been noticed by 19% of respondents, but in the Seleznevka region they had been noticed by the majority (59%) of the respondents. According to the respondents, the waters are generally “contaminated”, the quality of drinking water has deteriorated, and drought and fish deaths have been observed. Only a few respondents on the Russian side were satisfied with the state of the River Seleznevka or the Vyborg Bay: only 15% were very or fairly satisfied with the state of the River Seleznevka and the corresponding figure was 9% in the Vyborg Bay. During the last five years, about half of the respondents had noticed abnormalities in the status of the River Seleznevka in the form of algal blooms, turbidity, or odor. A larger share of respondents in Virojoki (39%) than in Rakkolanjoki (19%) felt that the waters had changed for the worse over the last ten years. (Lehtoranta et al. 2021).

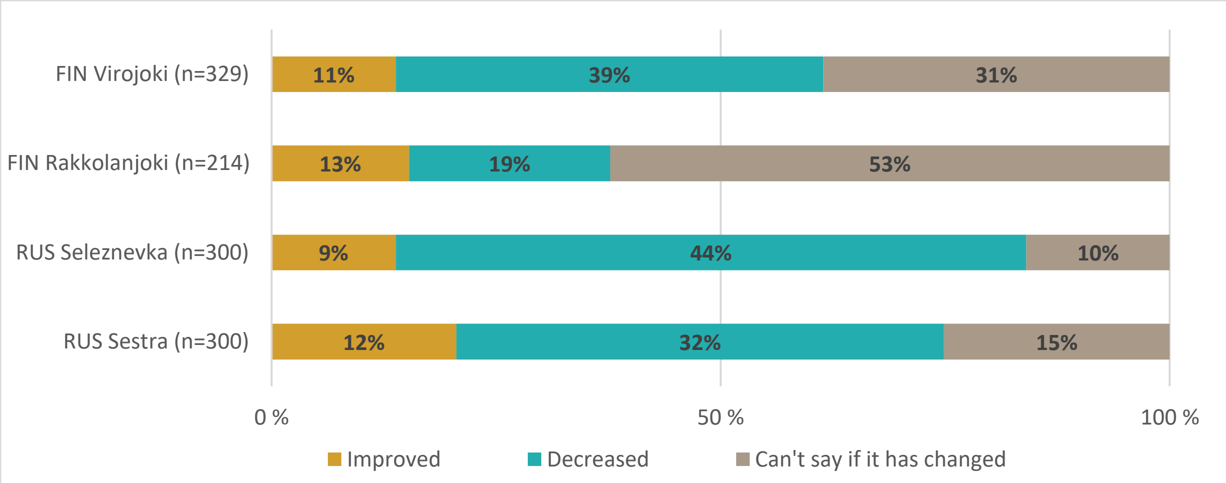


Figure 43. What changes people have noticed in each area.

Most of the respondents in Russia were dissatisfied with the ecological status of the river and the bay (62% in Sestra and 58% Seleznevka). The causes of dissatisfaction were analyzed using a binary logistic regression model. Four factors significantly increased the probability of experiencing dissatisfaction with the status, and these were as follows:

- the interviewee's observations on the deteriorating ecological status of the rivers,
- the interviewee's observations of changes in the state of the Vyborg Bay or Lake Sestroretsky Razliv, over the past five years,
- if the interviewee was from the River Seleznevka basin and
- if he/she expressed interest in water quality research.

The causes of experienced worsening in status were analyzed using a logistic regression model. In Finland several factors statistically significantly increased the likelihood of experiencing deterioration in the state of the local waters, and these factors were:

- if the respondent lived or spent time in the River Virojoki basin,
- if the respondent was interested in water monitoring,
- if the respondent was a user of local waters,
- if the most familiar water body was a lake,
- if the respondent did not much learn about the state of the waters from the questionnaire,
- if the respondent was concerned about the state of the waters after answering the questionnaire.

The respondents of the Finnish questionnaires were shown a map of the ecological status of the waters according to Water Framework Directive river basin classification and asked whether it matched the impression they had about the state of the local waters (Fig. 44). In Virojoki 38% and in Rakkolanjoki 27% of the respondents wasn't surprised by the classified ecological status. Very few respondents (4%) in Virojoki said the ecological status of the waters in the map looked much better than they had assumed. In Virojoki 13% and in Rakkolanjoki 4% said it looked a bit better than they had assumed. In both areas, 23% of the respondents thought the map showed a bit worse state of the waters than they had assumed, and 5% in Virojoki but 18% in Rakkolanjoki thought the classification status was much worse than they had assumed. Fifteen percent in Virojoki and 26% in Rakkolanjoki could not say (Fig. 45).

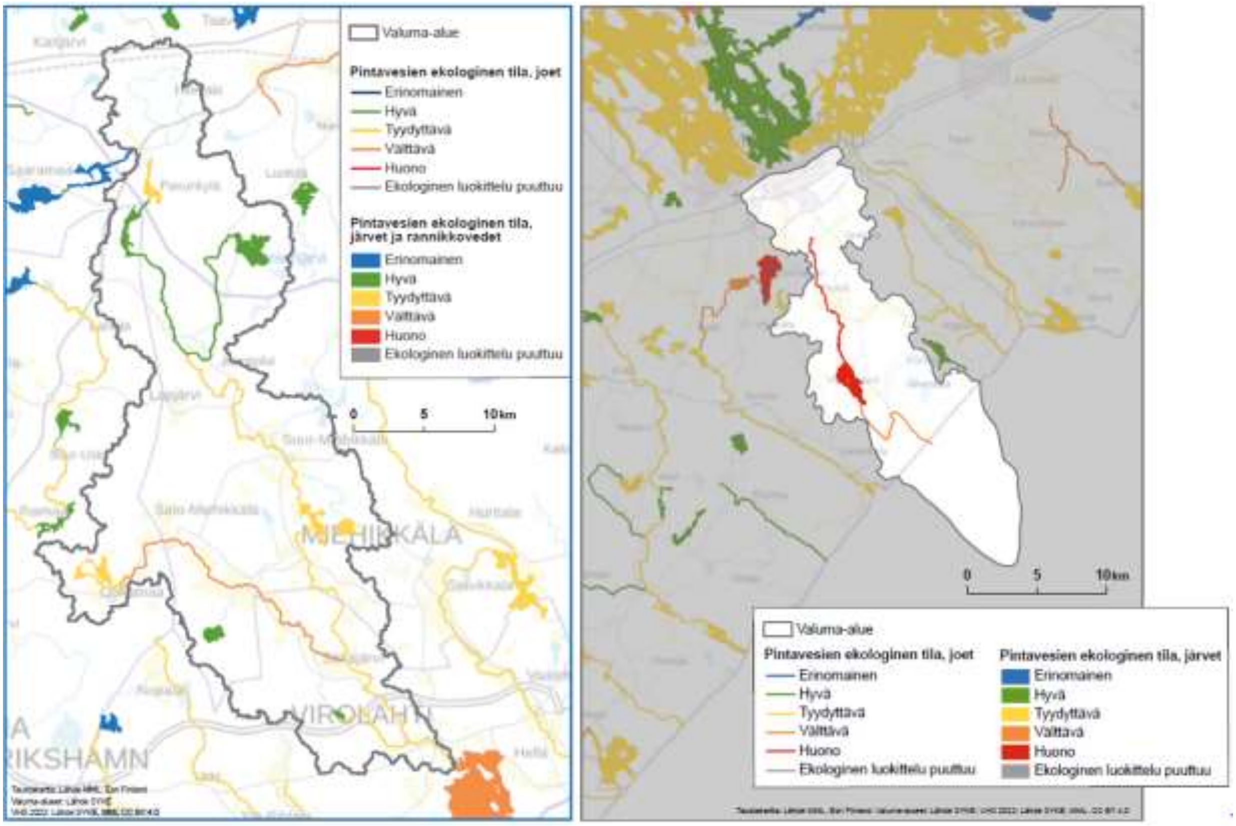


Figure 44. Map of the ecological status of waters in Virojoki (left) and Rakkolanjoki (right)

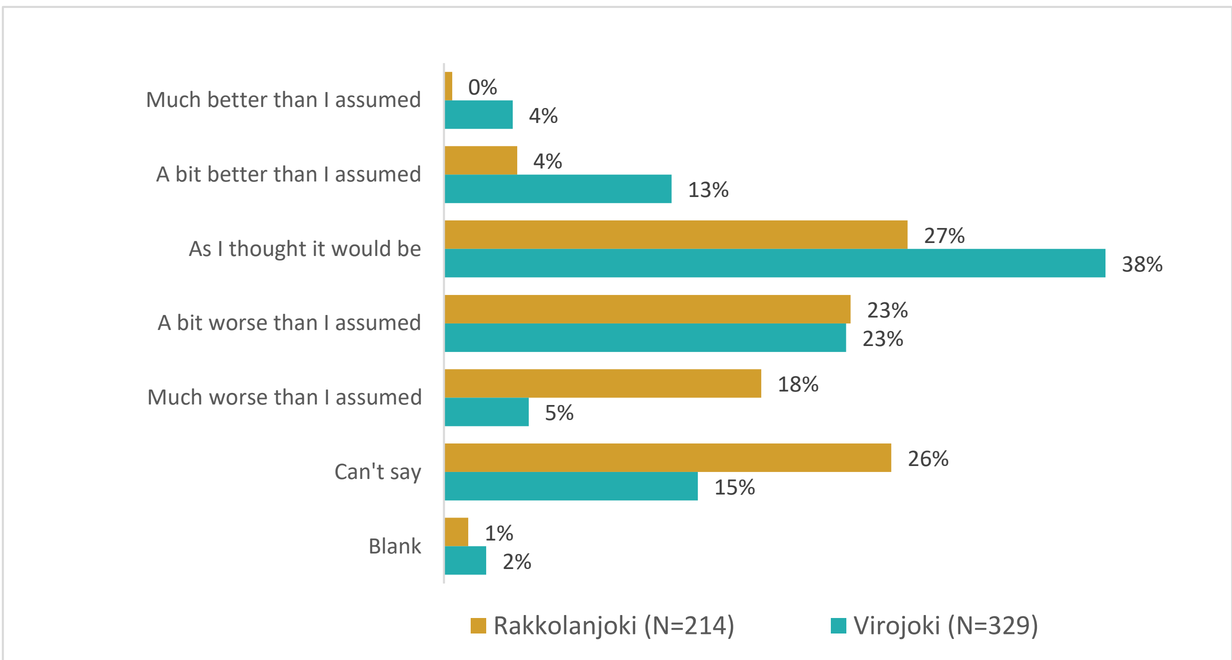


Figure 45. Respondents' reactions to the ecological status of their local waters in Rakkolanjoki and Virojoki.

7.4. Use and importance of waters to locals

In the River Sestra basin the Lake Sestroretsky Razliv was more used for recreational purposes than the river whereas this was the other way around in the River Seleznevka basin where the river was more popular for recreation (Fig. 46). This result is understandable as the River Sestra flows into the artificial reservoir Lake Sestroretsky Razliv on the territory of the city of Sestroretsk, merging with the River Chyornaya. The city of Sestroretsk has 42,189 inhabitants and is the largest settlement in the Kurortny district of St. Petersburg. (Ecocentrum, Friends of the Baltic, 2021) The main uses of freshwater and coastal water bodies in the River Seleznevka basin were recreation and fishing. One fifth (22%) of the interviewed had taken water from the River Seleznevka e.g., for gardening purposes.

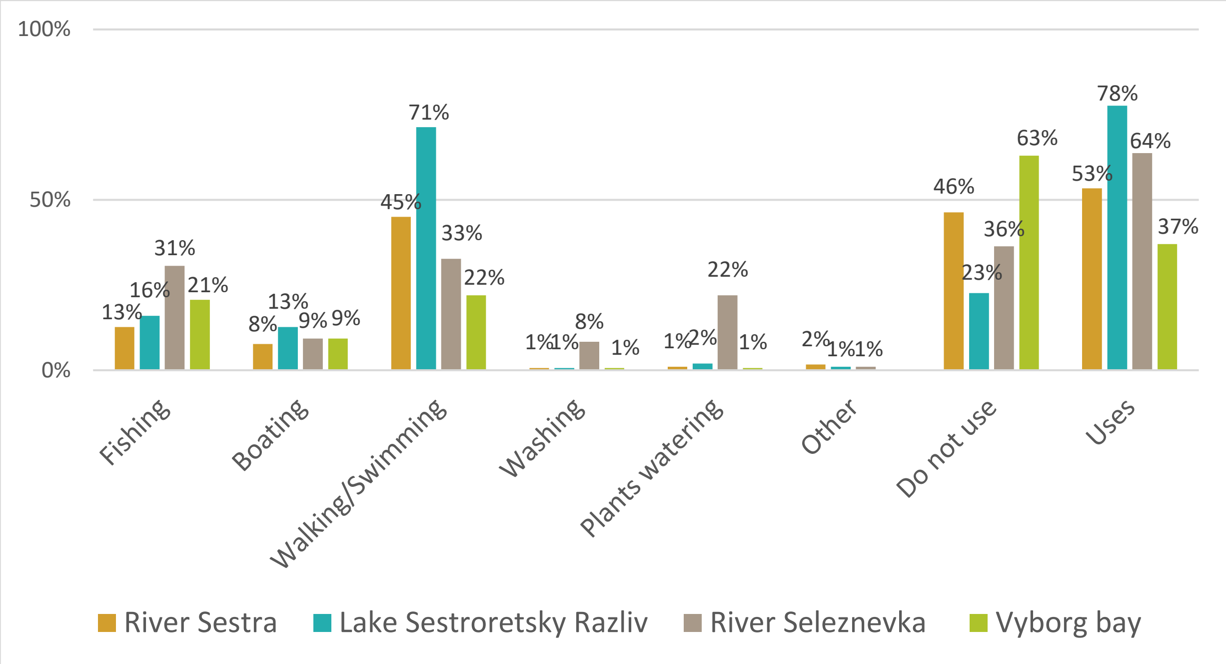


Figure 46. Responses on question about the ways of using waters in the River Sestra and Seleznevka basins (together with 600 responses)

Most (68%) of the respondents in Virojoki either lived or owned a cottage near or by the water. Nearly half of the respondents (45%) owned or had access to a cottage in the river basin and three out of four of these cottages were located near the water. On the contrary, only 16% either lived or had a cottage near or by the Rakkolanjoki. This might explain why the importance given to water bodies differs quite a lot between these two river basins (Fig. 4). Most of the respondents in Virojoki (69%) and 37% in Rakkolanjoki used the waters and shores to explore the nature, admire the scenery or hang out on the shore. Half of the respondents in Virojoki and only 12% in Rakkolanjoki had been fishing during the last three years (or caught crabs or ice fished). Fishing was more common activity in this river on the Russian side as 31% of the interviewed had been fishing in the River Seleznevka basin (13% of the interviewed in the River Sestra basin). Application of water for irrigation was the most popular in Virojoki (33%, in the River Seleznevka 22%). Also boating and water usage for washing and sauna was most popular in Virojoki (31% and 29%). In Virojoki 9% and in Rakkolanjoki 4% hunted waterfowl, and 5% and 2% used freshwaters as part of their livelihood. (Fig. 47)

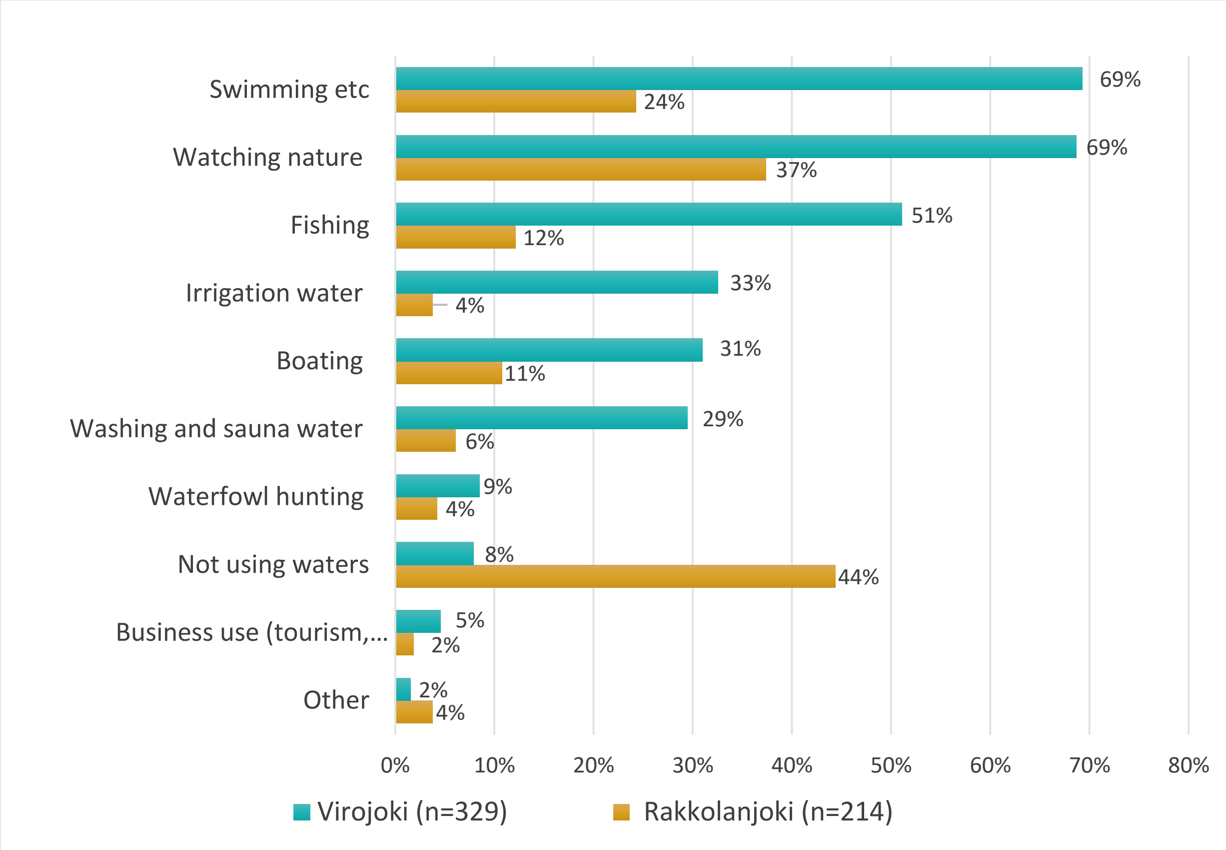


Figure 47. Responses on question about the ways respondents have used freshwaters in the Virojoki and River Rakkolanjoki basin.

Respondents in Finland were also asked if the (perceived) changes in the water status had affected their use of the waters. In Virojoki 38% of the respondents said that it hadn't affected their use of the waters, 19% had decreased their use and only 1% had increased their use of the waters. Three percent had moved to use another waterbody and 8% could not say. Respectively, in Rakkolanjoki 36% of the respondents stated that changes in status hadn't affected their use of the waters, 7% had decreased and 2% increased their use, 4% had moved to use another water bodies and total of 51% couldn't say or didn't answer. Furthermore, the respondents in Finland were asked which of the given water management objectives they thought the most important. They were given six specific targets and asked to rank top three out of them. The objective "Water quality must be improved" was ranked as the most important one. Then came the objective "The sufficient amount of water in rivers and lakes must be ensured" (see Figure 48).

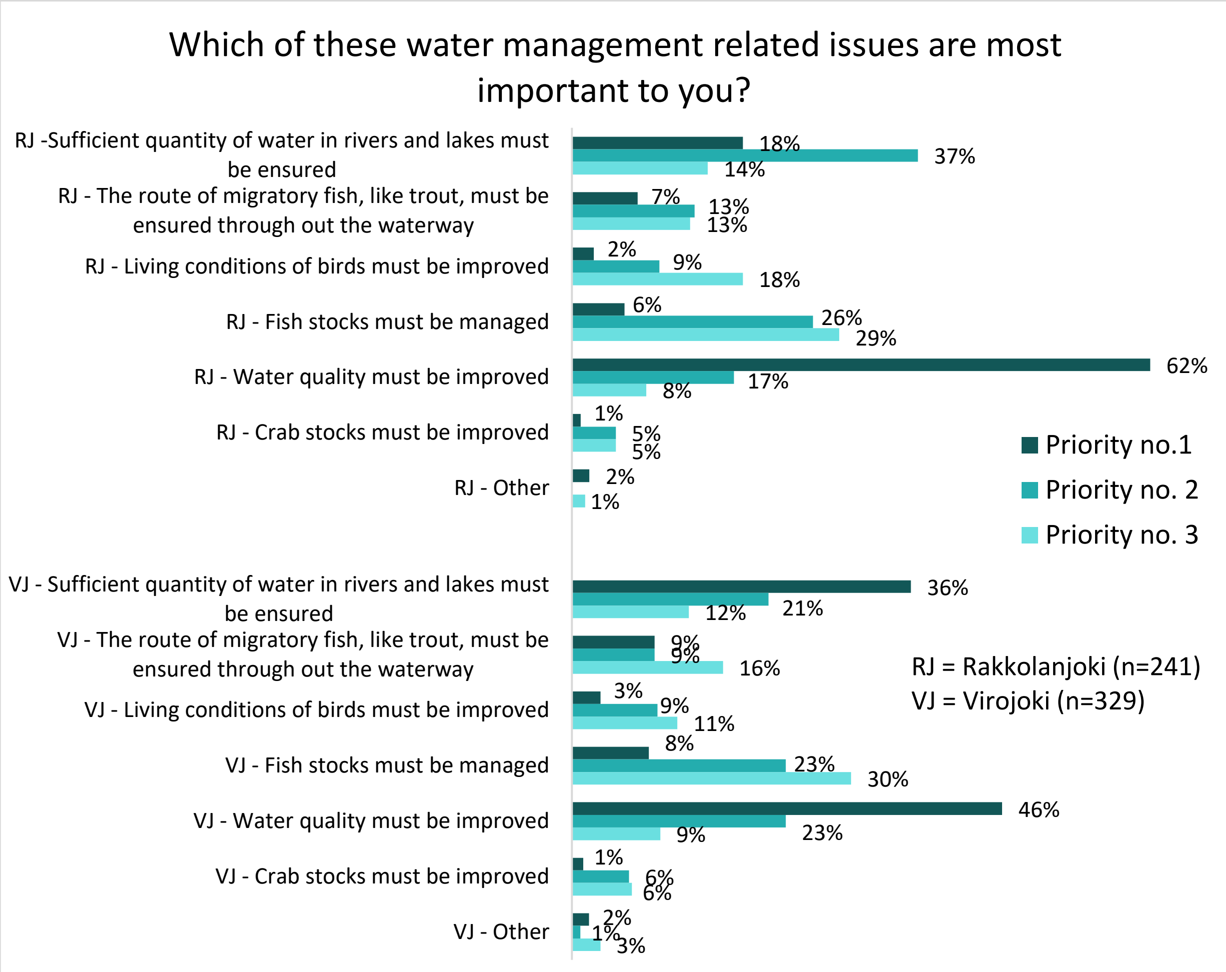


Figure 48. Different water management targets prioritized by the respondents in Finland.

7.5. Willingness to participate water monitoring

The respondents in Russia and Finland were asked about their willingness to participate in monitoring the condition of their local waters over the next three years. Most of the Russian people interviewed were at least willing to consider participating in the monitoring of the nearby freshwaters (Fig. 49): almost one third of interviewees (31%) could participate in monitoring, and 26% of the respondents could consider participating. A total of 37% of the respondents were not interested in it and 6% could not assess their willingness to participate. Three factors increased the willingness to participate:

- interested in water quality research,
- previous knowledge of monitoring on the river and
- whether the respondent had noticed changes for the worse in the state of the Vyborg Bay or Lake Sestroretsky Razliv, over the past five years.

This was analyzed with the binary logistic regression model (1: willingness to participate, else 0).

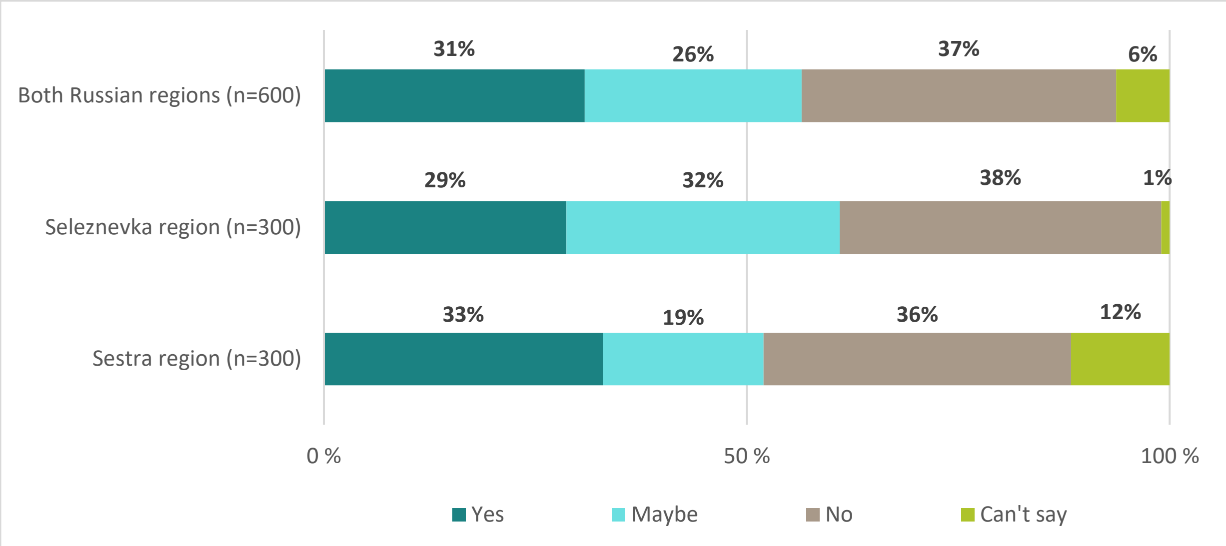


Figure 49. Willingness to participate in the monitoring of the status of nearby water bodies in the River Seleznevka and River Sestra basin in Russia.

The Lake- and Seawiki service (www.jarviwiki.fi) was introduced in the Finnish questionnaires and respondents were asked if they were familiar with it. Only 7% of the respondents had heard about it before. Then respondents were asked if they would be willing to do some voluntary nature observations e.g., with the Lake- and Seawiki service. A total of 7–11% of the respondents in Rakkolanjoki and 13–20% in Virojoki responded that they could at least consider of submitting voluntary nature observations through a citizen-based monitoring service during the next three years. A total of 19% of the respondents in Virojoki and 16% in Rakkolanjoki had kept record of some nature observations and 13% and 9% said they could save their records to a citizen monitoring service.

The willingness to participate voluntary monitoring was lower among the respondents in the Finnish river basins than among Russian respondents. In Finland the respondent was more likely to participate in the monitoring if:

- the respondent already kept records, for example, on ice-melting dates or other nature observations,
- used the area's freshwater or coastal waterbodies,
- had a holiday cottage in the area,
- was young,
- had a college degree and
- had heard of the Lake- and Seawiki service before the survey.

This was analyzed with a binary logistic regression model.

7.6. Willingness to pay for improved water status

Respondents in the Finnish surveys were asked to imagine, that a local water management and restoration association would be established in the river basin, and anyone could join by paying an annual membership fee. The aim of the association would be to secure the achievement of better water status by 2027 and to maintain the status thereafter. The respondents were asked if they would be willing to pay a yearly fee to such association to achieve a better status of the local waters if such association would exist. Respondents in Virojoki were willing to pay on average € 23.40 to € 30.50 per year for a local "water management and restoration association" to achieve a good ecological water status. In Rakkolanjoki, residents were prepared to pay an average of € 13.80 to € 18.40 per year for achieving a moderate ecological status. The likelihood of willingness to pay was higher if:

- the respondents had a higher monthly income,
- their home or cottage was on or near the waterfront,
- the respondent was younger at age,
- the respondent got new information from the survey about the state of the area's waters and
- a lake was the most familiar water body in the area.

Interviewees in Russia were asked about their willingness to pay a small monthly fee to improve the condition of the waters in the Seleznevka or Sestra area. The potential payment was said to take place as part of a monthly water supply charge and would be directed to improving the status of nearby water bodies. About 4% of respondents in the Seleznevka basin and 20% of respondents in the Sestra river basin chose this option as their participation mechanism. Thus, the likelihood of willingness to pay increased if the interviewee:

- was from the River Sestra basin,
- wanted more information about volunteer monitoring,
- had noticed river-related anomalies in the past five years, and
- had used the Gulf of Finland for recreation or otherwise.

Unlike the Finnish studies, the Russian study was not a stated preference survey.

7.7. Conclusions about the surveys

A large majority of the respondents in Finland felt that the survey provided them new information about the state of the waters in the river basin and how residents could be involved in citizen monitoring. The perceptions and attitudes of residents in the two study areas however varied partly due to given relevance of the freshwaters in the river basin.

The results show how the freshwaters of the two close river basins receive different appreciation from the residents within and neighboring countries. In the Virojoki basin the river and the bay play a central role in many residents' everyday life. Beside water status, residents were also worried about the water quantity. Climate change is likely to increase this worry since it can e.g., increase drought and the need for irrigation. Irrigation was already practiced in some extent by third of the respondents in the Virojoki river basin.

In Rakkolanjoki most of the respondents live near the City of Lappeenranta, located on the shore of Lake Pien-Saimaa, which is a very dominant feature of the city but actually not situated in the study basin. On the other hand, especially the upper parts of the River Rakkolanjoki are quite hidden and therefore people are not that aware of them. Typically, the more familiar the local waters are, the more aware and interested people are about them. The River Rakkolanjoki is the discharge point for municipal wastewaters. Although cleaned, over time the wastewaters have deteriorated the state of the River Rakkolanjoki and Lake Haapajärvi. This might also have an impact on peoples' notions about these waters.

Almost half of the residents interviewed in Russia said they will pay more attention to state of the surface waters in the future. Through the survey they also got new information how they could act to improve the state of the surface waters. The survey indicated that residents of the Sestra and Seleznevka basins would like to take part in decisions that affect the status of the local surface waters. The results and the discussions thereafter with stakeholders give encouragement to initiate the creation of public river councils for the Rivers Seleznevka and Sestra. In these river councils discussion and joint decision making would enhance the sustainable use of river ecosystems in cooperation with residents, neighbors, municipal authorities, government, business, public and environmental organizations. Considering the respondents' clear concern about the state of river basins, information should be shared with the public about ways to reduce nutrient and other anthropogenic pressure on natural waters. Furthermore, public organizations, in cooperation with local self-government bodies, should use their potential to inform the population about the value of surface water bodies.

A dissatisfaction about the state of the surface waters existed on both sides of the country border and only 10% of the respondents had noticed improvement in local waters. However, there was also willingness to act on behalf of surface waters. Especially in Russia there was a lot of interest towards citizen monitoring, but also in Finland. Most of the Finnish respondents found local water protection and restoration association as plausible. Still, there is a lot to be done to harness this enthusiasm to support also official monitoring in official contexts. There is a need for more studies how the state of the waters can affect the meaning these waters can have for people. Also, peoples' perceptions about the changes in the state of the waters is an interesting additional indicator and it might be useful to do follow-up more frequently.

8 Recommendations and Conclusions

8.1 River monitoring

The resources of river water sampling in the area of South-East ELY Centre (Finland) allow the collection and analysis of 13 annual water samples yearly. Presently, the sampling is contracted to be performed by a consultant. The sampling schedule is planned at the end of a year for the coming year. The schedule is fixed on a weekly basis and up to 3 samples are allocated to each month. Thus, most often only one sample is collected per month. The present sampling cannot react to the actual weather variation or hydrological situation. As an example, the sampling scheme in the Virojoki River is as follows. No samples are taken in February and June due to mid-winter ice-season and mid-summer low flows, respectively. In April–May, 2–3 monthly samples are collected during this typically wet spring melt season. However, due to climate change, wet seasons may also occur in mid-winter and a wet snow melt season may be lacking. Thus, sampling schedule is recommended to allow more flexible reactions towards actual hydrological conditions.

As a development proposal, operational hydrological forecasts could be utilized to hit the flow peaks. For example, the VEMALA model is run in operational mode and the hydrological forecasts are updated on daily basis. An app suggesting a sampling date based on the hydrological forecast e.g., for the coming week could be useful and increase the reliability of river flux estimates. In practice, a more flexible timing of the water sample collection would require renewal of the water sampling and analysis contracts between the environmental administration and consultants. Alternatively, a programmable sampler could aid in taking samples at critical flow events. Although capturing the flow peaks is crucial, it is recommended to take some samples during the dry periods to reveal potential wastewater load. In terms of load estimation, sampling during dry periods in summer is of secondary importance.

- ⇨ To increase the accuracy of the riverine load estimations of the Gulf of Finland, investing in the monitoring of entirely unmonitored rivers is recommended rather than intensifying sampling in the currently monitored rivers.
- ⇨ The monitoring status of the hydrological stations in the transboundary rivers in Finland should be changed to the national scale status with more frequent data quality control and discharge control measurements.
- ⇨ Monitoring downstream locations, e.g, in the River Sestra and the River Rakkolanjoki is needed to estimate the actual load entering the sea. Sampling in upper reaches may help in identifying the source of the pollutant load.
- ⇨ Collaboration, knowledge sharing and ring tests between Finnish and Russian field and laboratory persons would reveal potential differences between analysis protocols, and benchmarking could improve the analysis performance in both sides of the border.
- ⇨ Currently the HELCOM's Baltic Sea load reduction targets are based on a country level. HELCOM and the Ministry of Natural Resources and Environmental Protection of Russia should consider the possibility of reducing the nutrient load for all major rivers not only at the country level, but also at the sea basin level.
- ⇨ In the future, with the participation of the regional governments of St. Petersburg and the Leningrad region, new voluntary goals to reduce the load for certain categories of water users (municipalities, industrial enterprises, farms) should be determined.

8.2 Coastal monitoring

There has been a long-term positive trend in water quality the Bays of Vyborg and Vironlahti during the last 10 years. The positive trend is clear both in the reduction of nutrients and as a decreasing trend in chl-*a* concentrations. In the coastal waters of the eastern Gulf of Finland, the effects of cyanobacteria blooms have decreased significantly, and the water has clarified. For the future improvements on coastal water quality, reducing the impact of riverine loads on the sea is important (diffuse pollution from agriculture and forestry). The use of satellite observations has brought new opportunities for spatially and temporally comprehensive collection of water quality observations. Within this project, new autonomous stations providing daily statistics on EO observations were added to the TARKKA-service. These automated stations will continue providing observations after the SEVIRA project on both countries.

- ⇨ As a relevant nutrient point source in the area is aquaculture, the location of the farms should be planned accurately.
- ⇨ It is important follow the changes in the quality of coastal waters in the future. In particular, actions should be taken to continue monitoring the water quality in the Vyborg Bay that currently does not have regular monitoring programme.
- ⇨ An additional challenge is to quantify the effects from the main basin of the Baltic Sea, which at times extend as far as to the eastern part of Gulf of Finland. Therefore, it is not just the local pressures to be considered when looking at the open sea and the outer archipelago region. Furthermore, for the future of eastern Gulf of Finland, also the effects of climate change will have to be paid attention.

8.3 Modelling

The results of load estimations and modeling revealed that the share of agricultural land has decreased, and the share of built-up area has been increasing in the study areas. The impact of climate change on hydrology may be small if warming remains moderate. However, along the “RCP 8.5” scenario, the impact will be significant. Hence, local conditions should guide the selection of water protection measures. It is important to understand that the joint impact of various processes – such as nutrient load, eutrophication, biodiversity, carbon sequestration, productivity – is complicated.

- ⇨ Targeting agricultural water protection measures to the most water-sensitive plots of land (phosphorus concentration, slope, fertilization) should be enhanced.
- ⇨ The scenarios simulated with the “SWAT” model suggest that the most effective way to reduce nutrient loading to the River Rakkolanjoki is to make improvements in the Lappeenranta wastewater treatment plant. The simulated extents of agricultural measures set in a management plan were obviously too modest for substantial reductions in nutrient loading.

8.4 Public awareness

Involving residents and students in river monitoring proved to be a practical and effective strategy to generate positive nature conservation outcomes. The surveys helped to better understand people’s values, environmental knowledge, and expectations, as well as how they wish to address natural resource use. By involving people in activities, such as river monitoring, and by better understanding people’s needs, we were able to develop services and educational materials that are useful in boosting local environmental awareness and activity. Environmental education in schools proved to be an important component in advancing environmental awareness both for youth and community.

- ⇨ Based on positive feedback, during the project, use of the developed educational materials are expected to be used by local schoolteachers in the study area and by other stakeholders.
- ⇨ Although, the Finnish-Russian River Watch system seem to be a promising tool leading to environmental awareness and transboundary environmental actions, only 7% of locals had heard about it. In addition, the system development needs further resources for example via the engagement of a bilingual coordinator.

A lot of dissatisfaction about the state of the waters existed on both sides of the border. However, citizens are willing to take action to improve the state of the waters. Received new information about the state of the waters and own initial interest in citizen monitoring, increased willingness of the local people to act or pay for improved surface waters. In future, there might be a call for a new local actor in the area e.g., water protection and restoration association, to expand and increase opportunities also for locals to volunteer and/or pay for improved surface waters. For example, in the Virojoki basin, where there is quite a lot of cottages, the cottage owners were even more willing to pay or act on behalf of their local waters than permanent residents' were. The nearby surface waters can often be an essential part of the overall cottaging experience. There is a need for more studies on how the state of the waters affects the significance of nearby surface waters for the local people.

- ⇨ It would be recommendable for the local authorities to spread information about water quality among residents and holiday cottage owners.
- ⇨ It would be important to also include the owners of a holiday cottage in information campaigns concerning restoration events and other water state related issues in the area instead of focusing only on permanent residents.
- ⇨ Especially on the Russian side many respondents were interested in citizen monitoring, so it would be good to provide more opportunities for such actions.
- ⇨ Peoples' perceptions about the changes in the state of the waters is an interesting indicator, and it might be useful to do follow-ups more frequently.

9 Steps taken towards the cleaner Gulf of Finland

The SEVIRA project strengthed important transboundary environmental activites. It served both the overall conservation and scientific project goals and raised public awareness and consciousness. Public awareness is a key ingredient for positive environmental outcomes that also impact sustainable socio-economic objectives. Clarifying cross boarder similarities and differences provided insights on how to best practically address and strengthen joint Finnish and Russian efforts on these important issues.

Project added value included the following:

An improved transboundary river monitoring system.

Increased spatial extent and observation frequency utilizing quality assurance methods and procedures in hydrological and water quality monitoring improved the robustness of the overall system. Novel monitoring techniques and modelling also enabled the ability to propose a more cost-effective monitoring program. Finland's expertise in designing cost-effective monitoring networks, including the use of automatized sensors and satellite observations, and in analytical protocols, was shared with Russia.

The exchange of Finnish and Russian environmental information and methods increased.

Sharing of data through the River Watch Programme, enhanced by the above-mentioned monitoring of the area, enabled a better understanding of the current situation and served as a basis for more informed decision-making. This will impact future restoration or management measures needed to improve the state of river conservation. For example, the data collected from joint cross-boundary river monitoring increased the common awareness of environmental problems with experts producing new scenarios, based on the enhanced data flow, for future climate change mitigation efforts.

The exchange of accurate data increased environmental information for environmental administrations and citizen involvement.

Increasing data exchange is now providing more accurate environmental information for the environmental administrations and citizen involvement. Through the surveys the project obtained new knowledge of the public's attitudes and perceptions in dealing with ongoing water quality challenges. Still needed is more reliable and frequent water quantity and quality data to serve as the basis of all public discussions.

Experts are joining more in the public dialogue, providing new facts on the study area state of conservation.

Experts and environmental organizations are increasing public awareness. In both countries, the environmental organizations were actively co-operating with citizens solving environmental problems. The project's scientific results were written for laymen so that the broader public might follow them in their everyday activities.

The increased environmental awareness of the locals enhanced willingness to participate in environmental decision-making. Particularly the idea was to motivate and increase people's willingness to influence common environmental matters. Environmentally conscious citizens tend to make decisions beneficial for the environment in their every-day life and are more willing to deliver their concerns and messages to decision-makers within the industry and environmental administration.

Live dialogue between citizens helped to indentify shared recommendations for a series of Project Round Tables. Based on the scenarios, experts advised citizens on practical local measures, such as changing consumer habits, to adapt and minimize the effects of climate change. Guidance to local decision-makers and e.g., landowners on how to take the expected climate change into consideration in the environmental management has also advanced.

Cross-border school cooperation raised awareness and aided the development of environmental monitoring programs in Russia and Finland.

Schools in Finland and Russia were engaged in practical field monitoring and water management exercises. Manuals were developed for teachers and students. Project environmental information was designed so that the public could play an active role in producing information.

Lexicon

ADCP Acoustic Doppler Current Profiler

Alg@line a ferrybox system for automated measurements, operates on merchant ships

BMP Best Management Practice

BSAP Baltic Sea Action Plan

CDOM Coloured Dissolved Organic Matter

CORINE Coordination of Information on the Environment

CUP Calibration Uncertainty Program

Chlorophyll-a (Chl-a) Determines the algae abundance in the water. Monitoring of Chl-a provides information on the effects and state of eutrophication in the water.

DEM Digital elevation map

ELY Centre The Centre for Economic Development, Transport and the Environment

EU European Union

EO Earth Observations, satellite observations

ESA European Space Agency

GOF Gulf of Finland

HELCOM Baltic Marine Environment Protection Commission

HRU Hydrological Response Unit

ILHM Institute of Limnology Hydrological Model

ILLM Institute of Limnology Load Model

ILRAS Institute of Limnology at Russian Academy of Sciences

IPSL Institute Pierre-Simon Laplace

MSI Multi-Spectral Instrument onboard Sentinel-2 satellite series

NASA National Aeronautics and Space Administration (US)

Nitrogen (N) Nitrogen in waters originates from point and diffuse sources from catchment areas. Nitrogen deposition from air is an additional source of nitrogen in surface waters. Nitrogen is typically a limiting nutrient of algae growth during the summer period in the Baltic Sea. Spring bloom may consume algae-available nitrogen from the sea surface waters. This makes conditions favourable for nitrogen-fixing cyanobacterial blooms in case phosphorus is still available.

North-West AHEM North-Westt Administration for Hydrometeorology and Environmental Monitoring

NS Nash-Sutcliffe model efficiency coefficient

OIVA Open data portal by SYKE

OLCI Ocean and Land Colour Instrument onboard Sentinel-3 satellite series

OLI Operational Land Imager

Phosphorus (P) Phosphorus concentration in the Earth's crust is about one gram per kilogram. Weathering of phosphorus naturally from primary minerals is slow and of importance compared to phosphorus mobilisation and leaching to water bodies due to human activites. Phosphorus is an essential plant nutrient. Excess phosphorus in surface water originates typically from municipal waste water treatments plants and from diffuse sources, particularly from agriculture.

QGIS A Free and Open Source Geographic Information System

RCP Representative Concentration Pathways

RSHU Russian State Hydrometeorological University

Sentinel-2 Satellite series by European Space Agency

Sentinel-3 Satellite series by European Space Agency

Suspended solids (SS) Solid materials, including organic and inorganic materials, that are suspended in the water. Determination of suspended solids concentration requires filtration of water samples.

SYKE Finnish Environment Institute

SWAT Soil & Water Assessment Tool

TARKKA Web map service for satellite observations by SYKE (syke.fi/TARKKA/en).

TIRS Thermal Infrared Sensor

Turbidity Turbidity is measured optically. It can measured directly in a stream, lake or sea water with an in situ turbidity sensors or from water samples with laboratory devices. The scattering of light from material in water by clay, silt, inorganic and organic matter, algae, soluble coloured organic compounds, plankton and other microscopic organisms causes water to be turbid. Turbidity is commonly used as a proxy for estimating suspended solids content of water.

WFD Water Framework Directive by the EU

WCRP CMIP5 World Climate Research Program Coupled Model Intercomparison Project Phase 5

WGEN Weather generator of SWAT model

VEMALA A national-scale nutrient loading model for Finnish watersheds

VESLA A database for surface water monitoring station observation in Finland

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