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Priority substances and emerging contaminants in selected Norwegian rivers

The River Monitoring Programme 2018

Photo: NIVA

Norwegian Institute for Water Research

REPORT

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Summary

Riverine inputs and direct discharges to Norwegian coastal waters in 2018 have been estimated in accordance with the OSPAR Commission's principles. This report focuses on EU Water Framework Directive priority substances as well as river basin-specific pollutants (trace metals and organic pollutants) that were monitored with bottle sampling in water and biota sampling (fish). Levels observed were compared with annual average environmental quality standards (AA-EQS) or EQS(biota). A more detailed study of the distribution of emerging contaminants in the river Alna was undertaken.

Elvetilførsler og direkte tilførsler til norske kystområder har blitt estimert for 2018 i henhold til Norges obligasjoner under OSPAR-konvensjonen. Denne rapporten fokuserer på Vannrammedirektivets prioriterte forbindelser i tillegg til nedbørfeltspesifikke stoffer (spormetaller og organiske forbindelser) som ble analysert i vann- og biotaprøver (fisk). Observerte konsentrasjonsnivåer ble sammenlignet med grenseverdier for årlig gjennomsnitt (AA-EQS) og for biota (EQS(biota)). En mer detaljert analyse av nye miljøgifter ble gjennomført i Alna.

Four keywords	Fire emneord
1. Water Framework Directive	1. Vannrammedirektivet
2. Priority substances	2. Prioriterte stoffer
3. Emerging contaminants	3. Nye miljøgifter
4. River monitoring	4. Elveovervåkning

This report is quality assured in accordance with NIVA's quality system and approved by:

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The Norwegian River Monitoring Programme

Priority substances and emerging contaminants in selected Norwegian rivers

Preface

The Norwegian Environment Agency (NEA) commissioned the Norwegian Institute for Water Research (www.niva.no), in collaboration with consortium partners, to carry out the monitoring activities within the Norwegian River Monitoring Programme. Results from the 2018 monitoring activities are presented in four thematic reports, of which this report presents the "contaminants" results, consisting of data on the Water Framework Directive (WFD) priority substances and emerging contaminants from a selection of rivers.

Besides NIVA, the "contaminants" part of the River Monitoring Programme has involved the following collaborating partners: The Norwegian Water Resources and Energy Directorate (NVE), the Norwegian Institute for Air Research (NILU), the Norwegian Institute for Nature Research (NINA), and the Institute for Energy Technology (IFE). Contact persons at NEA has been Gunn Lise Haugestøl and Eivind Farmen.

At NIVA, Hans Fredrik Veiteberg Braaten co-ordinated the river monitoring programme in 2018. Other co-workers at NIVA include Ian Allan (main author of this report, interpretation of data), Marthe Torunn Solhaug Jenssen (coordination and participation to field work, coordination of sample analysis), Kine Bæk (responsible for organic analyses, and main contact with NILU for the analyses undertaken there), and Marit Villø (contact person at NIVA's laboratory for inorganic chemistry analyses).

NVE has been responsible for the hydrological modelling, Eurofins has carried out the mercury analyses, NILU has analysed selected priority substances and emerging contaminants, and IFE has determined stable isotopes in biota. NINA has been responsible for collection of fish, with coordination by Marthe Torunn Solhaug Jenssen. Water samples were collected by NVE's local fieldworkers. NIVA has been responsible for the urban river sampling of fish, sediment and water in Alna and training of NVE's local fieldworkers in water filtration for samples from Bjerkreimselva, Orreelva, Otra, Vegårdselva and Vikeldalselva.

Quality assurance of the report has been carried out by Sondre Meland, NIVA.

Oslo, Nov. 11th 2019

Hans Fredrik Veiteberg Braaten

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Summary

The monitoring of rivers as part of the Norwegian River Monitoring Programme (NRMP) is conducted annually (on a yearly basis) and is partly focused on the estimation of contaminant loads to the sea in response to Norway's obligations in the Oslo-Paris Convention. For the period 2013-2016, the focus was on the measurement of contaminant levels and loads in three rivers, namely the Alna, Drammenselva and Glomma. For 2017 and 18, the programme was modified by increasing the number of monitored rivers from three to ten. In addition, the number of contaminants was increased (increased focus on WFD priority substances) and changes in the matrices selected for analysis were conducted. Hence, the relevance of the programme's results to fulfil monitoring objectives of the EU Water Framework Directive (WFD) was enhanced.

For five rivers, the monitoring of priority substances and river basin specific substances was performed by bottle sampling with a sampling frequency of 4 times per year. One sampling location per river (usually the NRMP sites) was used and results were compared with EU WFD annual average environmental quality standards (AA-EQS). For priority organic substances the water EQS given in EU directives are expressed as total concentrations in the "whole water" sample (i.e. with no separation of liquid and particulate phases). For metals, these refer to filtered concentrations (0.45 µm). A further five rivers were monitored by analysing WFD priority substances and other lipophilic substances in composite fish samples obtained from three sampling locations per river.

A second component of this RMP was a more detailed investigation of the distribution of relatively more emerging substances in the River Alna. This work focused on selected UV filters, organophosphorus compounds (OPs), bisphenols and Perfluoro chemicals (PFAS). Since these compounds vary widely in their physico-chemical properties, a range of sampling methodologies were employed for this task. It included composite water sampling, suspended particulate matter sampling, and biomonitoring of brown trout (*Salmo trutta*). Sampling was undertaken on two occasions, in June and September 2018.

The concentrations of priority substances in water were below EQS for most riverine sampling locations. Bottle sampling resulted in a significant amount of (much) data below limits of quantification (LOQ), i.e. left-censored data. In most cases LOQs fulfilled WFD method performance criteria. Bottle sampling in the rivers Bjerkreimselva, Orreelva, Otra, Vegårdselva and Vikeldalselva showed that concentrations of polycyclic aromatic hydrocarbons (PAHs) were the highest (closest to or above WFD AA-EQS) for the sampling site of the Rivers Orrelva and Vegårdselva. Whole water concentrations of benzo[a]pyrene were close to or above AA-EQS at the selected monitoring locations for these two rivers. The Σ_7PCBs was below LOQ for all rivers, however this sum of LOQs is significantly higher than the proposed AA-EQS of 0.0024 ng L^{-1}. PBDEs were not found above LOQ in any of the samples collected from the five rivers. Similar results were obtained for HBCDD isomers with no HBCDD found above LOQ in any of the samples analysed in 2018. However, the LOQ is close to the EQS. Metal concentrations were well below AA-EQS for all rivers. Mean concentrations of MCCPs were close to or at AA-EQS level or above for all rivers. Data for SCCPs, alkylphenols, chlorfenvenphos, cybutryne and DEHP were mostly below LOQ and below EQS. LOQ values for 4-tert-octylphenol were at or above EQS level for all rivers.

Fish monitoring of Alna, Gaula, Ørsta, Nausta, Ranaelva in 2018 showed that Σ_7PCBs and PBDEs are close to or above EQS_{biota} in all samples. This agrees with the results from the reference river

monitoring programme that showed concentrations of these substances above EQS in fish samples[1] and with results of this monitoring programme obtained in 2017. Concentrations of hexachlorobenzene, pentachlorobenzene, and γ-HCH in fish samples (*S. trutta* and *S. salar*) from the five rivers are well below EQS_{biota} values. Improvements in the sensitivity of the analysis for these compounds could be seen when comparing with 2017 data.

Levels of other priority substances in fish samples from these five rivers were well below respective EQS_{biota}, except for the average of three measurements of MCCPs in fish samples from the Alna that is above the EQS_{biota}. Lipid-based concentrations of hexachlorobenzene and PCBs are highest in fish from the Rivers Alna (*S. trutta*) and Ranaelva (*Salmo salar*). Pentachlorobenzene and *p,p'*-DDE concentrations are highest in fish from the Alna and Ranaelva, respectively.

The programme of monitoring of the distribution of emerging contaminants in the Alna river for 2018 was simplified compared with 2017. Sampling in 2018 focussed essentially on water, suspended particulate matter (SPM) and fish (brown trout). UV filters were consistently found both in suspended particulate matter and water samples. Fish monitoring showed variable results. The most consistently detected UV filters in brown trout were BP3, EHMC and OC. This somewhat differs from 2017 when UV-327 and 328 were more consistently found above LOQ in fish. SPM remained the matrix of choice for the detection and quantification of OPs in 2018. Organophosphorus compounds consistently detected in SPM were TEP (CAS number 78-40-0), TiBP (126-71-6), TnBP (126-73-8), and TBEP (78-51-3), TCEP (115-96-8), TCPP (13674-87-8), sumTCP (1330-78-5), TPP (115-86-6), TnBP (126-73-8), TDCPP (13674-87-8) and EHDP (1241-94-7). TCPP, TPP, TnBP, sumTCP, and EHDP were consistently detected in all fish samples analysed but concentrations did not exceed a few ng g^{-1} w.w. The bisphenols BPA, BPS and BPF were all found in water samples with BPA (4,4'-BPA) present in highest concentrations, approximately an order of magnitude above the concentrations of the other ones. BPA and BPF were the only bisphenols found above LOQ in brown trout samples. Estimated $logK_{oc}$ values for UV filters, bisphenols and OPs tend to show equilibrium distribution between suspended organic carbon and water.

Bioaccumulation factors (BAF) and biota-sediment accumulation factors (BSAF) were calculated for selected emerging contaminants in brown trout. A good agreement of lipid-based logBAFs with $logK_{ow}$ can be seen for certain chemicals. For others such as octocrylene, BAFs are clearly overestimated by K_{ow} indicating that some processes such as metabolism may contribute to lowering biota concentrations. SPM-based BSAF in the range of 0.001-1 also tend to show limited potential for bioaccumulation or biomagnification for these emerging contaminants in fish.

The list of PFAS compounds detected in water samples/SPM is similar to that obtained in 2017. In general, the identity and relative levels of PFAS compounds above LOQ in Alna river water agree with stormwater data from the "Urbanfjord project", indicating stormwater runoff from impervious areas may be a non-negligible source of PFAS chemicals to River Alna. PFDA, PFDoA, PFTrDA, PFTeDA, PFOS, PFDS and PFOSA were measured above LOQ in most fish samples. PFOS showed the highest concentrations of all PFAS compound monitored. Logarithm of brown trout bioconcentration factors (logBCF) could be calculated for selected PFAS compounds.

[1] http://www.miljodirektoratet.no/Documents/publikasjoner/M1002/M1002.pdf

Sammendrag

Tittel: Vannrammedirektivets prioriterte stoffer og nye miljøgifter i et utvalg norske elver
År: 2019
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For et utvalg store elver estimerer *Elveovervåkingsprogrammet* årlige tilførsler av miljøgifter til norske havområder som en del av Norges forpliktelser under Oslo-Paris konvensjonen. Frem til og med 2016 ble konsentrasjoner og tilførsler av miljøgifter målt og beregnet i de tre elvene Alna, Drammenselva og Glomma. Dette som en del av *Elvetilførselsprogrammet*. I 2017 ble programmet utvidet fra tre til ti elver, samt at resultater skal innfri målsetningene for overvåking i EUs Vannrammedirektiv. Dette betyr også at et økt antall miljøgifter bestemmes (økt fokus på Vannrammedirektivets prioriterte stoffer) i flere matrikser (vann, biota og partikulært materiale).

I 2018 ble overvåking av prioriterte stoffer og andre vannregionspesifikke forbindelser gjennomført ved innsamling av vannprøver fra fem utvalgte elver (Bjerkreimselva, Orreelva, Otra, Vegårdselva, Vikeldalselva). Prøvene ble samlet fra en stasjon (stasjonen som benyttet i Elveovervåkingsprogrammets «grunnprogram») fire ganger per år og resultater ble sammenlignet med vannforskriftens grenseverdi for årlig gjennomsnitt (AA-EQS). For prioriterte organiske forbindelser er verdiene for miljøkvalitetsstandarder (EQS) oppgitt som totalkonsentrasjon i ufiltrerte vannprøver, mens verdiene for metaller refererer til filtrerte vannprøver (0,45 μm). Ytterligere fem elver ble overvåket ved å analysere prioriterte stoffer og andre lipofile forbindelser i blandprøver av fisk fra tre ulike stasjoner i hver elv (Alna, Gaula, Ørsta, Nausta, Ranaelva).

I tillegg ble det gjennomført en mer detaljert analyse av utvalgte nye miljøgifter i Alna. Arbeidet i Alna fokuserte på bestemmelse av UV-stoffer, organofosfater, bisfenoler og perfluorerte forbindelser (PFAS). Disse forbindelsene varierer i sine respektive fysisk-kjemiske egenskaper og ulike prøvetakingsmetoder ble benyttet, inkludert innsamling av blandprøver av vann, suspendert partikulært materiale (SPM) og fisk (brunørret, *Salmo trutta*). Prøveinnsamling ble gjennomført ved to anledninger, i juni og september 2018.

For de fleste prøvelokalitetene som ble undersøkt i 2018 var konsentrasjonene av de prioriterte stoffene lavere en vanndirektivets EQS-verdier. Stikkprøver av vann førte til at store deler av datamaterialet hadde konsentrasjoner under gjeldende analytiske kvantifiseringsgrenser (LOQ) selv om LOQ stort sett innfridde vannforskriftens ytelseskriterier. Et unntak er summen av syv polyklorerte bifenyler (Σ_7PCB) i vannprøver der LOQ er signifikant høyere enn den foreslåtte AA-EQS (0.0024 ng L^{-1}). Som en konsekvens ble konsentrasjonene av Σ_7PCB bestemt til under LOQ for alle stasjonene i Bjerkreimselva, Orreelva, Otra, Vegårdselva og Vikeldalselva. I vannprøver ble de høyeste konsentrasjonene av polysykliske aromatiske hydrokarboner (PAH) funnet i Orreelva og Vegårdselva der nivåene var i nærheten av eller over Vannrammedirektivets AA-EQS. Konsentrasjoner av benzo[a]pyren var i nærheten av eller over AA-EQS for utvalgte stasjoner i de samme to elvene. Heller ikke *polybrominerte difenyletere (PBDE) eller summen av isomerer av heksabromocyklododekan (HBCDD) ble detektert i noen av elvene. For HBCDD er* LOQ relativt lik AA-EQS*. Gjennomsnittlig konsentrasjoner av mellomkjedete klorerte parafiner (MCCP) var i nærheten av eller over AA-EQS. For*

kortkjedete klorerte parafiner (SCCP), alkylfenoler, klorfenvinfos, cybutryne og ftalater (DEHP) var de fleste målinger under LOQ og under EQS. Konsentrasjonen av filtrerte metaller var lavere enn AA-EQS for alle de fem elvene.

Overvåking av fiskeprøver (brunørret og laks (*Salmo salar)*) fra Alna, Gaula, Ørsta, Nausta og Ranaelva i 2018 dokumenterte konsentrasjoner av Σ_7PCB og PBDE i nærheten av eller over gjeldende EQS for biota (EQS_{biota}) for alle prøver. Dette samsvarer med resultater fra både overvåkningen av referanseelver og tidligere funn i Elveovervåkingsprogrammet, der konsentrasjoner over EQS_{biota} for disse stoffene ble funnet i fiskeprøver fra andre elver. Konsentrasjoner av heksaklorobenzen, pentaklorobenzen og γ-HCH i fiskeprøvene var godt under gjeldende EQS_{biota}. Analysemetodenes sensitivitet for disse stoffene er tydelig forbedret ved sammenligning med data fra Elveovervåkingsprogrammet i 2017. For andre prioriterte stoffer var alle målinger godt under EQS_{biota}, med unntak av gjennomsnittet av tre målinger av MCCP i fiskeprøver fra Alna. Fettbaserte konsentrasjoner av heksaklorobenzen og PCB var høyest i fisk fra Alna (brunørret) og Ranaelva (laks). Konsentrasjoner av pentaklorobenzen og *p,p'*-DDE var høyest i fisk fra henholdsvis Alna og Ranaelva.

For utvalgte nye miljøgifter i vannprøver fra Alna ble det gjennomført en enkel sammenligning av data mellom overvåkingsårene 2017 og 2018. Innsamlingen av prøver i 2018 fokuserte på vann, suspendert partikulært materiale (SPM) og fisk (brunørret). UV-stoffene ble konsekvent kvantifisert i prøver av SPM og vann, mens overvåking av disse stoffene i biota viste mer varierende resultater. I fisk innsamlet i 2018 ble BP3, EHMC og OC oftest detektert. Dette er ulikt resultatene fra 2017, da UV-327 og UV-328 ble kvantifisert oftest. Som i 2017, var organofosfatene lettere å detektere i prøver av SPM enn i blandprøver av vann fra Alna i 2018. Organofosfater som konsekvent ble kvantifisert i prøver av SPM inkluderer TEP, TiBP, TnBP, TBEP, TCEP, TCPP, ΣTCP, TPP, TDCPP og EHDP. TCPP, TPP, TnBP, ΣTCP og EHDP ble detektert i alle fiskeprøver som ble analysert, men konsentrasjonene var relativt lave (noen få ng g^{-1} våtvekt). Bisfenolene BPA, BPS og BPF ble alle detektert i vannprøver fra Alna, der BPA (4,4'-BPA) ble funnet i konsentrasjoner omtrent 10 ganger høyere enn de andre forbindelsene. BPA og BPF var de eneste bisfenolene som ble funnet i konsentrasjoner høyere enn LOQ i fiskeprøver.

Estimerte fordelingskoeffisienter ($logK_{OC}$) for UV-stoffer, bisfenoler og organofosfater viser at forbindelsene er likevektsfordelt mellom suspendert organisk karbon og vann. Bioakkumuleringsfaktorer (BAF) og biota-til-sediment-akkumuleringsfaktorer (BSAF) ble beregnet for et utvalg nye miljøgifter i fiskeprøver av brunørret. Lipidbaserte logBAF stemmer godt overens med $logK_{ow}$ for enkelte forbindelser. For andre forbindelser, som for eksempel oktocrylene, er BAF tydelig overestimert sammenlignet med $logK_{ow}$, en indikasjon på at prosesser som metabolisme kan bidra til å redusere konsentrasjoner i biota. Beregninger av BSAF (basert på SPM) i intervallet 0.001-1 viser at forbindelsene har et begrenset potensial for bioakkumulering og biomagnifisering i fisk.

PFAS-forbindelser som ble detektert i vannprøver og SPM i Alna i 2018 er omtrent de samme som ble detektert i 2017. Identitet og konsentrasjonsnivåer av PFAS detektert over LOQ i Alna fra Elveovervåkingsprogrammet i 2018 stemmer godt overens med data for overvannsprøver fra prosjektet *Miljøgifter i en urban fjord*, en indikasjon på at overvann er en viktig kilde til PFAS i Alna. PFDA, PFDoA, PFTrDA, PFTeDA, PFOS, PFDS og PFOSA ble målt til konsentrasjoner over LOQ i de fleste fiskeprøver. De høyeste konsentrasjonene av PFAS var av PFOS. Det var mulig å beregne biokonsentrasjonsfaktorer (BCF) for utvalgte PFAS.

1 Introduction

The Norwegian River Monitoring Programme (RMP) monitors the contaminant loads from Norway to the sea as part of Norway's obligations in the Oslo-Paris Commission (OSPAR). OSPAR's main aim is to protect the marine environment of the North East Atlantic[2]. Reporting of the EU Water Framework Directive (WFD) priority substances and emerging contaminants is part of this monitoring.

A total of 20 rivers was monitored in Norway as part of the RMP in 2018 where five of these were prioritised for the determination of WFD priority substances (PS), river basin-specific pollutants and emerging contaminants (Table 1). Additionally, five rivers were sampled for fish, including Alna, Gaula, Ørsta, Nausta and Ranaelva, where emerging contaminants were analysed.

Table 1. Parameters investigated in the Norwegian River Monitoring Programme 2018

A summary table of groups of parameters investigated in the Norwegian River Monitoring Program (RMP). Rivers, Bjerkreimselva, Orrelva, Otra, Vegårdselva, and Vikeldalselva were investigated for EU Water Framework Directive (WFD) priority substances and emerging contaminants in 2018.

River	Group of parameters estimated (n=yearly sampling events)			
	General water chemistry*	**Metals****	**WFD priority substances***	**Emerging contaminants**
Bjerkreimselva	n = 12	n = 4	n = 4	n = 4
Orreelva	n = 12	n = 4	n = 4	n = 4
Otra	n = 12	n = 4	n = 4	n = 4
Vegårdselva	n = 12	n = 4	n = 4	n = 4
Vikedalselva	n = 12	n = 4	n = 4	n = 4

*Includes pH, dissolved, total and particulate organic carbon, fractions of nutrients P and N, silicate. ** Includes arsenic (As, total), lead (Pb, dissolved), cadmium (Cd, dissolved), chromium (Cr, total), copper (Cu, total), mercury (Hg, dissolved), nickel (Ni, dissolved) and zinc (Zn, total).

1.1 EU WFD priority substances

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (hereafter the Water Framework Directive, WFD), was adopted in 2000. The Norwegian Environment Agency has since worked on the application of the WFD in Norway through the development of EQS[3,4] at national-level and guidelines for monitoring[5]. The framework aims to protect and restore clean waters across Europe and ensure its

[2] https://www.ospar.org/about

[3] http://www.miljodirektoratet.no/Documents/publikasjoner/M608/M608.pdf

[4] https://www.miljodirektoratet.no/Documents/publikasjoner/M241/M241.pdf

[5] http://www.miljodirektoratet.no/Documents/publikasjoner/M922/M922.pdf

long-term, sustainable use, including river basins[6]. The WFD is an environmental management tool, used to determine the overall quality of a water body depending on ecological and/or chemical status. The WFD includes a list of substances that are considered "problematic" for European waters, the so-called priority substances[7]. Environmental Quality Standards (EQSs) are used to assess the chemical status of water bodies using maximum acceptable concentration (MAC) and/or annual average concentration (AA) for the priority substances. Depending on whether the MAC and/or AA are met or not, the chemical status of the water body is described as "good" or "not good"[8].

Currently, the list of priority substances consists of 33 compounds for which EQSs have been derived[9] (Table 2).

Table 2. List of Water Framework priority substances (including CAS numbers and AA-EQS and MAC-EQS)

Number	**CAS number**	**Name of priority substance**	**MAC (µg L^{-1})**	**AA (µg L^{-1})**
1	15972-60-8	Alachlor	0.7	0.3
2	120-12-7	Anthracene	0.4	0.1
3	1912-24-9	Atrazine	2.0	0.6
4	71-43-2	Benzene	50	10
5	not applicable	Brominated diphenylether		
	32534-81-9	Pentabromodiphenylether (congener numbers 28, 47, 99, 100, 153 and 154)	n.a.	0.0005
6	7440-43-9	Cadmium and its compounds	< 0.45 (class 1) 0.45 (class 2) 0.6 (class 3) 0.9 (class 4) 1.5 (class 5)	< 0.08 (class 1) 0.08 (class 2) 0.09 (class 3) 0.15 (class 4) 0.25 (class 5)
7	85535-84-8	Chloroalkanes, C_{10}-C_{13}	1.4	0.4
8	470-90-6	Chlorfenvinphos	0.3	0.1
9	2921-88-2	Chlorpyrifos	0.1	0.03
10	107-06-2	1,2-Dichloroethane	n.a.	10
11	75-09-2	Dichloromethane	n.a.	20
12	117-81-7	Di(2-ethylhexyl)phthalate (DEHP)	n.a.	1.3
13	330-54-1	Diuron	1.8	0.2
14	115-29-7	Endosulfan	0.01	0.005
15	206-44-0	Fluoranthene	1	0.1
16	118-74-1	Hexachlorobenzene	0.05	0.01
17	87-68-3	Hexachlorobutadiene	0.6	0.1
18	608-73-1	Hexachlorocyclohexane	0.04	0.2
19	34123-59-6	Isoproturon	1.0	0.3
20	7439-92-1	Lead and its compounds	n.a.	7.2
21	7439-97-6	Mercury and its compounds	0.07	0.05
22	91-20-3	Naphthalene	n.a.	2.4
23	7440-02-0	Nickel and its compounds	n.a.	20
24	25154-52-3	Nonylphenols	2.0	0.3
	104-40-5	(4-nonylphenol)	n.a.	0.1
25	1806-26-4	Octylphenols	n.a.	0.007
	140-66-9	(4-(1,1',3,3'-tetramethylbutyl)-phenol)	1	0.4

[6] http://ec.europa.eu/environment/water/participation/pdf/waternotes/water_note1_joining_forces.pdf

[7] http://ec.europa.eu/environment/water/water-dangersub/pri_substances.htm#list

[8] https://circabc.europa.eu/sd/a/0cc3581b-5f65-4b6f-91c6-433a1e947838/TGD-EQS%20CIS-WFD%2027%20EC%202011.pdf

[9] http://ec.europa.eu/environment/water/water-framework/priority_substances.htm

26	608-93-5	Pentachlorobenzene	n.a.	n.a.
27	87-86-5	Pentachlorophenol	0.1	0.05
28	not applicable	Polycyclic aromatic hydrocarbons	n.a.	Σ = 0.03
	50-32-8	(Benzo(a)pyrene)	n.a.	
	205-99-2	(Benzo(b)fluoranthene)	n.a.	Σ = 0.002
	191-24-2	(Benzo(g,h,i)perylene)	n.a.	
	207-08-9	(Benzo(k)fluoranthene)	4	1
	193-39-5	(Indeno(1,2,3-cd)pyrene)	0.0015	0.0002
29	122-34-9	Simazine	n.a.	0.4
30	not applicable	Tributyltin compounds	n.a.	2.5
	36643-28-4	(Tributyltin-cation)	n.a.	0.03
31	12002-48-1	Trichlorobenzenes	1.4	0.4
32	67-66-3	Trichloromethane (chloroform)	0.3	0.1
33	1582-09-8	Trifluralin	0.1	0.03

1.2 Emerging contaminants

Human development and anthropogenic processes result in the emission of a wide range of chemicals to the natural environment. While the European WFD focuses initially on a restricted list of priority (hazardous) substances and river basin-specific substances, emerging contaminants are defined as chemicals that are not currently regulated but can impact on human or ecological health (Richardson, 2009). These substances can be found in aquatic environments all over the world, including freshwaters and the marine environment (Loos et al., 2009; Schwarzenbach et al., 2010; Schwarzenbach et al., 2006). Examples of emerging contaminants include industrial chemicals, plastic additives, disinfection by-products, pharmaceutical and personal care products and their degradation products or persistent organic chemicals. In this report we specifically focus on substances identified in the past in the Norwegian environment through the Screening Programme[10]:

- **Bisphenols:** Bisphenols are commonly used in production of plastics and paint, and in Norway occurring typically in important products of plastic. Data on releases of bisphenols to the Norwegian environment is very limited, only reported for bisphenol A. Estimations suggest that the use of bisphenol A in chemicals are reduced from approximately 60 tons in 2000 to 11 tons in 2015.
- **UV-filters:** UV-filters are typically used to stabilise paint, rubber, and plastics to protect the material against sunlight. The substances are found several places in the Norwegian environment, including water (Atlantic cod liver (*Gadus morhua*)) of the Oslo fjord and sediments in Lake Mjøsa, and are also documented in human breastmilk. The use of UV-filters is declining in Norway, estimated at 1.19 tons in 2009 and 0.39 tons in 2015.
- **Per- and Polyfluoroalkyl Substances (PFAS):** PFAS have been used in industrial processes and consumer products since the 1950s, examples including textile impregnation, food packaging, firefighting foam, kitchen equipment coating, and ski wax. PFAS are shown to accumulate in food chains.
- **Organophosphorus flame retardants (OPFRs):** OPs are commonly used in plastic products as flame retardants and softeners, and in paint products. Releases of organophosphates to the Norwegian environment is difficult to estimate and data is very limited. These substances are

[10] http://www.miljodirektoratet.no/Documents/publikasjoner/M176/M176.pdf

documented at high levels in organisms in the Arctic, including the Arctic fox, birds, seals, and fish and have been found in Arctic river water (Allan et al., 2018).

The abovementioned groups of emerging contaminants have been, and still are, regulated differently. Different PFAS have been regulated in Norway since 2002, and several OPs have been regulated since 2012. UV-filters have been on the Norwegian priority list since 2017, targeted to be phased out by 2020. UV-filters are not regulated in the EU, but are on the candidate list of substances of very high concern[11]. Of the bisphenols, only Bisphenol-A is regulated, and have been on the Norwegian priority list since 2007, targeted to be phased out by 2020.

1.3 Project aims

The main purpose of the Norwegian RMP is to document levels of contaminants and nutrients in Norwegian rivers; document and provide information on effects of climate change; and to classify rivers per the WFD. In this report, contaminant data is presented, focusing on the WFD priority substances and the emerging contaminants. The following three of the RMP's main objectives will be answered in this report:

1. Measure concentrations of contaminants in Norwegian rivers, including the WFD priority substances and selected emerging contaminants;
2. Contribute to a strengthening of the knowledge on emerging contaminants and their fate in the Norwegian natural environment;
3. Estimate loads of selected contaminants to the coastal waters for an estimation of the contribution of pollution from terrestrial to coastal areas.

Objective 1 is answered by investigating concentrations of priority substances and emerging contaminants in water samples from five selected study rivers every third month.
Objective 2 is answered by focusing on Alna as a study case, by sampling fish, water, and particles at two events (spring and summer). Additionally, emerging contaminants were investigated in fish from five additional rivers, Alna, Gaula, Ørsta, Nausta and Ranaelva. Objective 3 is answered by using relevant concentrations obtained to answer aim 1 in combination with hydrology data to calculate loads of selected contaminants to the sea for the five study rivers.

[11] https://echa.europa.eu/web/guest/candidate-list-table

2 Methods

2.1 Sampling methodologies

2.1.1 Sampling for priority substances in five rivers

Water samples were collected four times in 2018 in the five rivers Storelva (Vegårdselva), Otra, Bjerkreimselva, Orreelva and Vikedalselva (Figure 1) for the measurement of "whole water" concentrations of priority substances. The term "whole water" concentration refers to the total concentration of the substance in the whole water sample and is used in the WFD to separate from the dissolved concentration of the metals lead (Pb), nickel (Ni), mercury (Hg) and cadmium (Cd) where the water has undergone 0.45 µm filtration before analysis. In each river and at every sampling event 4 amber glass bottles (2.5 L) were filled with river water sampled approximately 0.5 m below the water surface for organic pollutants. Before sampling the amber glass bottles were cleaned by heating in a muffle furnace at 550 °C before being rinsed with appropriate solvents.

Filtered and unfiltered water for metals and mercury were sampled at the same time. NIVA personnel trained local samplers to perform on site water filtration during the first of the four sampling rounds in February. Sampling of water for filtered metal analysis Pb, Ni, Cd) was undertaken using acid washed 60 mL Nalgene bottles (in a protective ziplock plastic bags to reduce contamination). The bottles were filled with ion-exchanged water containing 1% ultrapure/suprapure HNO_3. At sampling the bottle was emptied of the diluted acid downstream the sampling point and rinsed trice with ion-exchanged water. Disposable 0.45 µm Millipore membrane filters and 20 or 50 mL disposable syringes were used to filter the water. The membrane filter was initially rinsed by passing through 20 mL ion-exchanged water and then with 5-10 mL of the river water prior to sampling.

Water for Hg analysis was sampled in 60 mL amber glass bottles. For the filtered Hg samples, the same procedure for rinsing the bottle and filtration was conducted. Bottles for unfiltered water samples were rinsed trice in river water before the samples were collected.
Only data from the filtered water samples will be presented in this report. The unfiltered metals are sampled more frequently and are presented in the main RMP. Additional information on the sampling stations can be found in the main RMP (M-1508|2019)[12].

Table 3: Location of the 5 rivers and water sampling dates for the EU Water Framework Directive (WFD) priority substances and emerging contaminants in 2018.

River*	River number**	Latitude(N)	Longitude (E)	Sampling date 1	Sampling date 2	Sampling date 3	Sampling date 4
18-Storelva (Vegårdselva)	018-127-R	58.669996	8.980983	07.02.2018	02.05.2018	06.08.2018	01.10.2018
21-Otra	021-28-R	58.184772	7.958148	07.02.2018	07.05.2018	07.08.2018	01.10.2018
27-Bjerkreimselva	027-92-R	58.488772	6.001949	06.02.2018	08.05.2018	06.08.2018	09.10.2018
28-Orreelva	028-16-R	58.732567	5.529958	06.02.2018	07.05.2018	06.08.2018	01.10.2018
38-Vikedalselva	038-11-R	59.499647	5.913991	05.02.2018	07.05.2018	13.08.2018	01.10.2018

* River number in NVE database. **Vann-nett ID

[12] The Norwegian river monitoring programme – water quality status and trends 2018 (M-1508|2019)

Figure 1. Location of the water sampling stations in Storelva (Vegårdselva), Otra, Bjerkreimselva, Orreelva and Vikedalselva and the fish sampling stations in Rana, Gaula, Ørstaelva, Nausta and Alna.

2.1.2 Suspended particulate matter sampling for emerging contaminants

Suspended particulate matter (SPM)-associated contaminants were sampled in the Alna using *continuous flow centrifugation* (CFC) twice a year. Deployment of the CFC at a secure site (with electrical power supply) near the river allowed for the continuous collection of SPM for a period of 5 days (Table 4). The SPM samples collected were stored at -20 °C. More details of sampling with CFC can be found in earlier reports (Allan et al., 2009; Allan et al., 2011). The same sampling site were used for the time-proportional water sampling (Table 4).

Table 4. Deployment periods for the time proportional water sampling and continuous flow centrifuge in river Alna in 2018

Sampling event 1	24-29.5.2018 (5 days)
Sampling event 2	12-17.10.2018 (5 days)

2.1.3 Time-proportional water sampling for emerging contaminants

Representative and time integrated water sampling for emerging contaminants was done using automatic water sampling (Teledyne ISCO Avalanche automatic water sampler (ISCO sampling)) Automatic water sampling made it possible to do replicate sampling collected as mixed samples over a longer time period.

The ISCO sampling was conducted twice in 2018, five days in May and for five days in October at the same time as the CFC was in the river (Table 4).

Eight 950 mL polyethylene bottles for replicate samples for 4 analyses were installed in the ISCO-sampler. Sampling approximately 800 mL water per sample over 5 days, making space for liquid-liquid extraction in the bottle. The ISCO-sampler were programmed to conduct eight sampling events of 20 ml per 24 hours. The bottles were refrigerated (3 °C) in the ISCO sampler during the sampling event. In addition, 4 blank bottles filled with ultrapure water for 2 replicate analyses were included. The distilled water of the blanks was sampled through the ISCO avalanche system and tubing to expose the blanks to the same condition at the samples. All bottles were left open in the ISCO avalanche during the sampling period. After retrieval the samples were kept cold or stored at -20 °C until they were thawed for extraction and analysis for the contaminants of interest.

The system's tubing was rinsed in spring water and ultrapure water before use. In addition, the ISCO-sampling system was rinsed on site in river water with maximum flushing for about 10 minutes before the program was started. The sample bottles and blank bottles were cleaned before sampling.

The bottle cleaning procedure were as follows:
The bottles and lids were washed in warm alkaline soap water (washing machine) then:

- Rinsed in RO-water (washing machine)
- Rinsed in methanol (manually)
- Rinsed twice in distilled water (manually)
- Rinsed twice in distilled water containing 2% acetic acid (manually)
- Rinsed in ultrapure water (manually)

2.1.4 Sampling of fish for priority contaminants in five rivers

Brown trout (*Salmo trutta*) and Atlantic salmon (*Salmo salar*) were sampled by electrofishing in the five rivers Alna, Gaula, Ørstaelva, Nausta and Rana (Figure 1) for the analysis of priority substances. Sampled stations and information are shown in Table 5 and 6. The fish selected for analysis for each station of the same river were as homogenous as possible with respect to size. After capture the fish were wrapped in clean aluminium foil and kept frozen until arrival at the NIVA lab. The electrofishing was done according to the international standard NS-ISO-14011 and Norwegian standard NS-9455. Details on the methodology can be found in the companion biology report (M-1510|2019)[13].

The length and weight of each fish were measured. Species, sex and maturity stage were noted, and shells and otoliths were saved for potential future age determination. The captured fish were generally small. Thus, to get enough material to carry out the analyses whole fish were used in the all the pooled

[13] Classification of ecological and chemical status in Norwegian rivers according to the Water Framework Directive. River Monitoring Programme 2018 (M-1510| 2019)

samples, except for one of the pooled samples in Alna and Nausta where the fish were larger, so muscle tissue and liver samples were taken. For each river, three pooled samples containing two to ten fish were homogenised and sent for analysis. There was enough fish material to make one pooled sample for each station in Ørsta and Gaula. For Alna and Rana, the pooled samples were grouped according to fish length as too few stations were available. The Nausta fish came from 5 different stations and was pooled in order to get enough material. Information on the composition of the pooled samples can be found in Table 5 and 6, and information on individual fish in Attachment 1.

Table 5. Overview of the five rivers that were sampled for fish for priority contaminants in 2018

The coordinates give downstream start point for electrofishing

County	River name	Sampling date	Latitude (N)	Longitude (E)	Station ID
Oslo	Alna	08.08.2018	59.953271	10.881196	EO-Alna-4
	Alna	08.08.2018	59.9045007	10.792346	OSLEALN/EO-Alna-1
Trøndelag	Gaula, Gravråk	17.09.2018	63.245502	10.242445	EO-Gaula-1
	Gaula, Lundamo	06.09.2018	63.146036	10.262219	EO-Gaula-3
	Gaula, Borten Losen	06.09.2018	63.201008	10.289328	EO-Gaula-2
Møre og Romsdal	Ørstaelva	08.08.2018	62.18809	6.1458649	EO-Ørsta-1
	Ørstaelva	08.08.2018	62.18368	6.19565	EO-Ørsta-2
	Ørstaelva	08.08.2018	62.21232	6.24795	EO-Ørsta-3
Sogn og Fjordane	Nausta	01.11.2018	61.51891	5.73000	EO-Nausta-3
	Nausta	01.11.2018	61.53716	5.77649	EO-Nausta-16
	Nausta	01.11.2018	61.53845	5.77975	EO-Nausta-17
	Nausta	01.11.2018	61.54243	5.78655	EO-Nausta-19
	Nausta	01.11.2018	61.57082	5.80921	EO-Nausta-30
Nordland	Rana	07.11.2018	66.334127	14.28241	EO-Rana-1

Table 6: Overview of the five river stations that were sampled for fish for priority contaminants in 2018 and the composition of the pooled fish samples.

The table shows species, sampled tissues (muscle (MU), liver (LI) and whole organism (WO)), subsamples (Fish ID) and mean lengths (cm) and weights(g) with standard deviation (SD) for each pooled sample

River name	St.ID	Sample nr	Species*	Tissue	Fish Ids	Mean length (SD)	Mean weight (SD)
Alna	EO-Alna-4	7	*Salmo trutta*	WO	35,38,39,40,44	14.1(1.3)	31.6(8.4)
Alna	EO-Alna-4, EO-Alna-1	8	*Salmo trutta*	WO	45,48,50,52,53,41,42,36,37,43	9.8(2.6)	13.3(8.7)

Alna	EO-Alna-4	9	*Salmo trutta*	MU	46,47,49,51	19.1(5.2)	122.0(113.5)
Gaula	EO-Gaula-1	1	*Salmo salar*	WO	1,2,3,4,5	12.5(0.4)	18.5(3.0)
Gaula	EO-Gaula-3	2	*Salmo salar*	WO	6,7,8,9,10	11.9(0.5)	14.2(2.4)
Gaula	EO-Gaula-2	3	*Salmo salar*	WO	11,12,13,14,15	13.0(0.5)	20.8(1.6)
Ørstaelva	EO-Ørsta-1	1	*Salmo salar*	WO	1,2,3,4,8	13.3(1.8)	27.8(13.0)
Ørstaelva	EO-Ørsta-2	2	*Salmo salar*	WO	6,7,8,9,10	11.3(0.6)	15.2(2.4)
Ørstaelva	EO-Ørsta-3	3	*Salmo salar*	WO	11,12,13,14	9.6(1.0)	9.1(3.0)
Nausta	EO-Nausta-16, EO-Nausta-17	1	*Salmo trutta*	WO	1,2,3,4,5	11.9(0.7)	18.1(3.4)
Nausta	EO-Nausta-17, EO-Nausta-19	2	*Salmo trutta*	WO	6,7,8	13.4(0.9)	26.5(4.0)
Nausta	EO-Nausta-3, EO-Nausta-30	3	*Salmo trutta*	MU, LI	9,10	18.3(2.6)	72.2(34.6)
Rana	EO-Rana-1	1	*Salmo salar*	WO	1,2,3,4,5,6	11.7(0.5)	16.7(1.4)
Rana	EO-Rana-1	2	*Salmo salar*	WO	7,8,9,10,11,12	11.3(0.3)	13.8(0.7)
Rana	EO-Rana-1	3	*Salmo salar*	WO	13,14,15,16,17,18	10.9(0.2)	10.3(4.5)

*Brown trout (*Salmo trutta*); Atlantic salmon (*Salmo salar*)

2.1.5 Fish sampling for emerging contaminants in River Alna

The Alna river, situated in Oslo was chosen as the urban river site. The river is highly affected by human activity, e.g. the catchment is affected by for example industrial emissions, stormwater from various impervious areas (e.g. roads, streets and roofs), sewage water, pollution from old industrial sites and leakage from discarded landfills. The presence of emerging contaminants such as OPs, fragrances or UV filters has been previously documented in Alna river (Allan et al., 2013; Pintado-Herrera et al., 2016).

Collection and sampling of biological material followed the guidelines of the Norwegian environmental specimen bank[14] . This implies stricter demands regarding use of personal care products and other potential contaminant sources during capture and later handling of the samples.

Sampling of brown trout

Brown trout from Alna were collected for emerging contaminants by electrofishing in June and September 2018 (Table 7, Figure 2). On both occasions the aim was to collect five fish from three different size groups. The fish were packed in clean aluminum foil after capturing and kept cool until frozen at –20°C.

Fish were thawed and dissected on clean aluminum foil. Nitrile gloves were used during handling. Glass containers was sealed with aluminum foil and burnt at 550 °C before use. The length, weight, sex and maturity stage were recorded if possible. Shells and otoliths were removed for potential future age determination). In total 30 fish were sampled, totalling to 6 pooled samples. Each of the six pooled

[14] Miljøprøvebanken, 2015. Procedure 001: Collection and sampling of freshwater fish, ver.1.1. Can be downloaded from: https://mpbank.files.wordpress.com/2018/04/mpb-eng-procedure-1-freshwater-fish.pdf

samples were composed of five fish of as equal size as possible. The brown trout in pooled sample 1 and 6 were small, thus all the analytes were done in whole fish. For the rest of the fish, muscle and liver were dissected out. The average length of the fish in the pooled samples ranged from 11.1 – 29.1 cm. An overview of sample composition can be found in Table 8, and details on individual fish in Attachment 1. The samples were kept frozen (-20 °C) until homogenization and analysis.

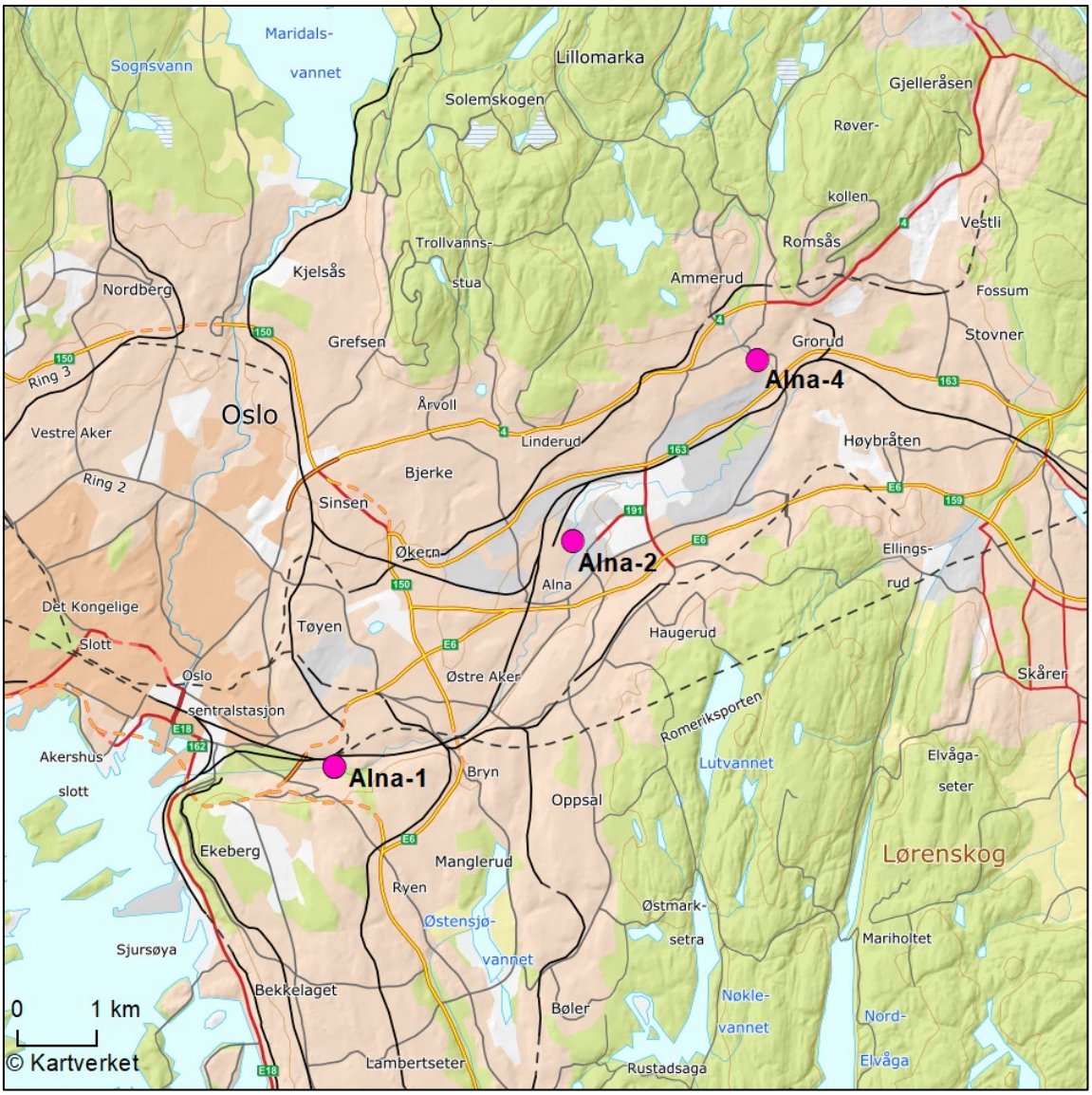

Figure 2. Location of the sampling stations in river Alna. The brown trout (*Salmo trutta*) for emerging contmainants were sampled at Alna-2, while brown trout for priority substances were sampled at Alna 1 and 4. The SPM and water were sampled at Alna-1.

Table 7. Location of the Alna sampling stations

Station ID	Area	Latitude (North)	Longitude (East)
EO-Alna-1	Svartdalsparken	59.9045007	10.7923461
EO-Alna-2	Alfaset	59.93159274	10.84242296
EO-Alna-4	Grorud	59.9532713	10.881196

Table 8. Overview of the Alna pooled fish samples

The table shows species, sampled tissues (muscle (MU), liver (LI) and whole organism (WO)), subsamples (Fish ID) and mean lengths (cm) and weights(g) with standard deviation (SD) for each pooled sample

Station ID	Sample nr	Sampling date	Species	Tissue	Fish Ids	Mean (SD) length (cm)	Mean (SD) weight (g)
EO-Alna - 2	1	06.06.2018	*Salmo trutta*	WO	1,2,3,4,5	11.1(0.4)	18.6(3.0)
EO-Alna - 2	2	06.06.2018	*Salmo trutta*	MU, LI	10,11,12,13,14	15.8(1.1)	55.6(12.6)
EO-Alna - 2	3	06.06.2018	*Salmo trutta*	MU, LI	15,16,17,18,19	19.0(1.0)	100.2(9.7)
EO-Alna - 2	4	19.09.2018	*Salmo trutta*	MU, LI	20,21,22,23,34	29.1(3.4)	275.2(102.5)
EO-Alna - 2	5	19.09.2018	*Salmo trutta*	MU, LI	24,25,26,27,28	21.7(1.2)	127.4(21.3)
EO-Alna - 2	6	19.09.2018	*Salmo trutta*	WO	29,30,31,32,33	15.3(0.6)	43.3(7.4)

2.2 Chemical analysis and quality assurance

2.2.1 Priority substances in water and fish samples

Polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCDD) chlorfenvinphos, cybutryne, DEHP, PAHs and organochlorinated compounds

The priority organic substances PBDEs, hexachlorobenzene (HCB), HBCDD, pentachlorobenzene (PeCB), lindane/hexachlorocyclohexane (γ-HCH), PAHs, chlorfenvinphos, cybutryne, DEHP, polychlorinated biphenyls (PCBs) and DDTs were analysed at NIVA. These substances were analysed in fish and water samples.

For the determination of concentrations of the priority substances in water, a mixture of recovery standards was added directly in the bottles used for sampling before the liquid-liquid extraction began. The internal standards consist mainly of isotope labelled standards that follows both extraction and pre-concentration of the samples and are used to quantify the analytes. The water samples were then extracted using an organic solvent to ensure good yields of the analytes. The extraction was done directly in the water bottles to reduce possible contamination of the samples and to ensure as little loss of analytes as possible. The method did to a large degree follow the guidelines given in ISO 28581 "*Water quality - Determination of selected non-polar substances –Method using gas chromatography with mass spectrometric detection (GC-MS)*".

Before extraction, the fish samples were homogenized. A mixture of recovery standards, consisting primarily of isotopically-labelled standards were then added to the samples. These follows both extraction and pre-concentration and were used to quantify the analytes. Biota samples were extracted twice with an organic solvent to ensure good yields. After extractions both water and biota samples where cleaned up using gel permeation chromatography (GPC), concentrated sulphuric acid and/or primary-secondary amine (**PSA**) sorbent.

HBCDD was analysed on a LC-qToF, this is a full-scan instrument enabling identification of more substances. The remaining analytes were quantified on a GS-MS (GC-EI-MS and GC-NCI-MS) or GC-MS/MS.

For all the NIVA analyses in this report, the limits of detection (LOD) and quantification (LOQ) were calculated for each sample, using the accepted standard method; three times the signal/noise ratio (z/n) and nine times the z/n ratio, respectively.

NIVA's laboratory is accredited by Norwegian Accreditation for ISO/IEC 17025. NIVA is not accredited for any of the organic compounds in this report, but to the extent possible, documentation, preparation, analysis and calculations are performed in accordance with accredited methods. NIVA participates in intercalibrations where possible. Samples were analysed in groups with at least one additive standard sample and a blank control.

Short- and medium chained chlorinated paraffins (S/MCCP)

The short- and medium chained chlorinated paraffins (S/MCCP) were determined at the Norwegian Institute for Air Research (NILU). Prior to extraction, a mixture of isotope labelled standards was added to the samples for quantification purposes. The water-, sediment- and fish samples were extracted with organic solvents and concentrated under nitrogen flow, followed by a clean-up procedure with concentrated sulfuric acid on a SPE column to remove lipids and other interferences prior to analysis. The samples were analysed on a GC-HRMS (Waters Autospec or Agilent GC-qTof 7200) in ECNI mode.

For all the NILU analyses in this report the limits of detection (LOD) and quantification (LOQ) were calculated for each sample, using the accepted standard method, i.e. the average of blanks plus 3 and 10 times the standard deviation for blanks, for LOD and LOQ, respectively.

NILU's laboratories are accredited by Norwegian Accreditation for ISO/IEC 17025. NILU is not accredited for the analysis for of the organic compounds in this report, but as far as possible, the documentation, sample preparation, analysis and calculation procedures were conducted according to the accredited methods.

Alkylphenols and bisphenols

Alkylphenols and bisphenols (octylphenol, nonylphenol, bisphenols A, S, F and bisphenols-AF, AB, B, E, FL, M and Z) were analysed at NILU. Bisphenols are described here as a part of the analysis for alkylphenols, though the compounds belong under the emerging contaminant section (2.2.2)
Prior to extraction, the fish and SPM samples were added a mixture of isotope labelled bisphenols and alkylphenols for quantification purposes. The SPM and fish-samples were extracted with organic solvents and concentrated under nitrogen flow, followed by a cleaning procedure on a SPE column to remove lipids and other interferences prior to analysis. Water samples were concentrated and purified on a SPE column. After elution from the SPE column, the water sample extracts were further concentrated under nitrogen and subjected to instrumental analysis.

The samples were analysed by LC-QToF (Agilent 65/50) or LC-ToF (Waters Premier). For the emerging bisphenols the analysis was performed in full scan mode. This was done to be able to use the raw data in future retrospective non-target screening.

Due to the lack of specific isotopically-labelled standards, relevant to additional bisphenols (Bisphenols AF, AB, B, E, FL, M and Z), the results are likely less accurate than those for which these labelled standards are used.

Lead (Pb), Nickel (Ni), Cadmium (Cd) and mercury (Hg) in filtrated water samples

Filtered water samples were preserved in nitric acid (HNO_3) before analyses. Cd, Ni and Pb were determined at NIVA according to analytical method NS-EN ISO 17294-1 and NS EN ISO 17294-2 modified. The level of detection and level of quantification (LOD/LOQ) were 0.0010/0.0030, 0.013/0.040 and 0.017/0.005 µg/L for Cd, Ni and Pb respectively. NIVA is accredited for the analytical method (NS-EN ISO/IEC 17025, Test 009). Mercury was analysed at Eurofins according to method NS-EN ISO 12846 modified. The level of detection was 0.0003 µg Hg/L and level of quantification was 0.001 µg Hg/L. Eurofins is accredited for the analytical method (NS-EN ISO/IEC 17025, Test 003).

Lipid content in biological samples was determined gravimetrically after extraction, before clean up together with the determination of PBDEs at NIVA.

2.2.2 Emerging contaminants in water, Suspended Particulate Matter (SPM) and brown trout from Alna

Bisphenols

Bisphenol A, S, F and the extra compounds bisphenol-AF, -AB, -B, -E, -FL, -M and -Z were analysed in SPM, water and fish by NILU. The analysis of Bisphenols is described as part of the analysis for alkylphenols in the section above.

UV filters

UV chemicals (octocrylene, benzophenone and ethylhexylmethoxycinnamate, UV-327, UV-328 and UV-329) were determined by NIVA. A mixture of isotope labelled internal standards were added to the samples, following both the extraction and pre-concentration steps. Before extraction SPM were freeze-dried and fish samples were homogenized. The extraction of the UV-chemicals from water samples, suspended material and homogenized fish samples were similar to that described for PBDEs, HCB, HBCDD, QCB, HCH, HBCDD, PAHs, chlorfenvinphos, cybutryne, DEHP, PCBs and DDT above. All samples were cleaned up using GPC, before analysis. Some of the samples were also purified using PSA.

UV chemicals were analysed using GC-MS/MS (Agilent).

Per and polyfluorinated substances (PFAS)

PFAS were determined by NIVA. Prior to extraction, a mixture of isotope labelled PFAS were added to the samples following the sequence of both extraction and pre-concentration with organic solvents and used in the quantification of the analytes. Samples of suspended particulate material (SPM) and biota were extracted using acetonitrile and buffers for pH-control. The water samples were pre-concentrated and cleaned on a SPE column. All extracts were pre-concentrated under nitrogen before analysis. PFAS were determined using a LC-qToF-MS. As it is a full-scan instrument, it gives the possibility to identify more compounds later.

Chlorinated and non-chlorinated organophosphorus compounds

Chlorinated and non-chlorinated OPs were determined by NILU. Prior to extraction, a mixture of isotope labelled OP-standards were added to the sample for quantification. All samples, including fish, water, and sediment, were extracted using organic solvents. The extracts were reduced under a stream of nitrogen followed by a clean-up using silica column to ensure good recovery and removal of fat and other interferences. The OPs were quantified using GC-MS (Waters Quattro micro GC/MSMS) and LC-MS/MS (Thermo Vantage).

Lipid content in biological samples was determined gravimetrically after extraction with organic solvent at NILU.

2.2.3 Stable Isotopes

The ratio between the stable nitrogen isotopes ^{14}N and ^{15}N ($\delta^{15}N$), the carbon isotopes ^{12}C and ^{13}C ($\delta^{13}C$), and the sulfur isotopes ^{32}S and ^{34}S were determined by IFE (Institute for Energy Technology), based on Vander Zanden and Rasmussen (2001). Analyses were performed according to standard protocols without removing lipids nor carbonates prior to analysis. Important steps of the method include combustion in an element analyzer, reduction of NO_x in a Cu-oven, separation of N_2 and CO_2 on a GC-column followed by determination of ^{15}N, ^{13}C, and ^{34}S on an Isotope Ratio Mass Spectrometer (IRMS).

LOD and LOQ was calculated from analysis of international reference materials distributed by the IAEA (International atomic energy agency), USGS (U.S. Geological Survey) and NIST (National Institute of Standards and Technology) as well as in house laboratory standards. This was done for each sequence and can vary somewhat. Typically, IFE need 5 mg sample to achieve the accuracy and precision needed.

Standards with known values were analyzed in all sequences as unknown samples. The results of these analyses were followed closely and was used as parameters to determine if the sequences were approved or not. They were also used to track if the results were stable over time. IFEs internal trout standard was used for $\delta^{13}C$ and $\delta^{15}N$, and NBS 127 (BaSO4) reference material from IAEA for $\delta^{34}S$.

IFE is certified after the demands in ISO9001:2008 and ISO14001:2004.

2.3 Calculation procedures

Since in many cases, datasets included censored data (i.e. data below limits of quantification), a common procedure was used for dealing with these data. Hence, the following procedure was used to calculate means and standard deviations for priority substances concentrations in water samples from 5 rivers:

- When all 4 data points from one river were above LOQ, the mean and standard deviation (SD, n = 4) were estimated.
- When some of the data were below LOQ, these were given a value of half the LOQ, before the mean and SD were calculated.
- When all data were below LOQ, data was reported as below mean LOQ.
- When the data from the blanks were above LOQ, data from samples that were below 3x the blank value were given the value <3xblank.

This procedure was employed for all types of samples where multiple replicates data were available. For the calculation of fluxes or discharges to sea, considering the low number of samples or litres of water sampled, no attempts were done to calculate discharge-weighed concentrations or fluxes.

3 Results

3.1 EU WFD Priority substances and other relevant chemicals in water of five rivers

In this section, we report estimates of annual average concentrations calculated from four "whole water" samples collected at one sampling site per river per year. We compare these estimates with annual average EQS published by the Norwegian Environment Agency in 2016[15].

3.1.1 Polycyclic Aromatic Hydrocarbons (PAHs)

Annual average concentrations of individual PAHs based on four water samples collected in 2018 are given in Table 11. PAHs are above LOQ most frequently in water samples from rivers Orrelva, Otra and Vegårdselva. Concentrations were generally highest for the Orrelva, followed by those from Otra and Vegårdselva and lowest for river Bjerkreimselva and Vikedalselva. "Whole water" concentrations of naphthalene and anthracene were well below WFD AA-EQS for all rivers. For fluoranthene, the estimated annual average concentration in all five rivers are approximately an order of magnitude below the AA-EQS of 6.3 ng L^{-1}. These values are in line with concentrations measured in the rivers Drammenselva, Glomma and Numedalslågen in 2017. For benzo[a]pyrene, the WFD AA-EQS is exceeded for the river Orrelva. The average concentration of benzo[a]pyrene calculated from the four sampling events at the Orrelva sampling site was 0.22 ng L^{-1} (SD= 0.17) is above the EQS value of 0.17 ng L^{-1}. The concentration of benzo[a]pyrene is also close to EQS for the river Vegårdselva. Data from the three remaining rivers are below LOQ, however these LOQs are at EQS level, rendering the comparison with EQS difficult.

Table 11. "Whole water" concentrations of PAHs

"Whole water" concentrations* of polycyclic aromatic hydrocarbons in five rivers (ng L^{-1}) and comparison with WFD AA-EQS. Values above the AA-EQS are presented in red-coloured cells.

Chemical	**Bjerkreimselva**	**Orreelva**	**Otra**	**Vegårdselva**	**Vikedalselva**	**AA-EQS**
Naphthalene	<2	<2	<2	<2	<2	**2000**
Acenaphthylene	<1	<1	<1	<1	<1	1280
Acenaphthene	0.72 (0.4)	1.2 (0.9)	0.53 (0.33)	0.55 (0.4)	0.36 (0.2)	3800
Fluorene	0.19 (0.17)	0.46 (0.44)	0.22 (0.14)	0.18 (0.15)	0.15 (0.1)	1500
Phenanthrene	0.53 (0.34)	1.2 (1.2)	0.72 (0.54)	0.72 (0.6)	0.48 (0.34)	500
Anthracene	<0.2	<0.2	<0.2	<0.2	<0.2	**100**
Fluoranthene	0.31 (0.12)	0.85 (0.6)	0.54 (0.3)	0.78 (0.5)	0.24 (0.17)	**6.3**

[15] http://www.miljodirektoratet.no/Documents/publikasjoner/M608/M608.pdf

Pyrene	0.14 (0.08)	0.53 (0.4)	0.24 (0.2)	0.39 (0.34)	0.14 (0.07)	23
Benz[a]anthracene	<0.2	0.14 (0.08)	<0.2	0.14 (0.08)	<0.2	18
Chrysene	<0.2	0.27 (0.22)	0.18 (0.16)	0.33 (0.3)	<0.2	70
Benzo[b,j]fluoranthene	0.18 (0.1)	0.70 (0.6)	0.3 (0.26)	0.61 (0.6)	0.18 (0.03)	
Benzo[k]fluoranthene	<0.2	<0.2	<0.2	0.22 (0.14)	<0.2	
Benzo[a]pyrene	<0.2	0.22 (0.14)	<0.2	0.14 (0.09)	<0.2	**0.17**
Indeno[1,2,3-cd]pyrene	<0.2	0.6 (0.64)	<0.17 (0.08)	0.32 (0.26)	<0.2	
Dibenzo[ac/ah]anthracene	<0.2	0.35 (0.5)	<0.2	<0.2	<0.2	14
Benzo[ghi]perylene	0.17 (0.13)	0.73 (0.82)	0.18 (0.09)	0.35 (0.3)	<0.2	

***Yearly average (with standard deviation in brackets; n = 4 bottle samples); in ng L^{-1}; Note that original WFD AA-EQS are given in bold.**

3.1.2 Organochlorinated compounds (PCBs and pesticides)

In all cases, no organochlorinated compounds were found above LOQ in water samples collected from any of the five rivers sampled in 2018 (Table 12). Based on these measurements, levels measured at thee sampling sites are well below WFD AA-EQS for pentachlorobenzene, lindane (γ-HCH). Slightly improved LOQ for data for 2018 indicate that while *p,p'*-DDT and Σ_3DDTs remain under LOQ, these are now approximately an order of magnitude below EQS. As for data from 2017, the limit of quantification for the sum of concentrations of seven indicator PCBs is significantly higher than the annual proposed average threshold of 2.4 pg L^{-1}.

Table 12. "Whole water" concentrations of organochlorinated compounds

"Whole water" concentrations* of polychlorinated biphenyls and other chlorinated organic compounds in five rivers (ng L^{-1}) and comparison with WFD AA-EQS.

Chemical	**Bjerkreimselva**	**Orreelva**	**Otra**	**Vegårdselva**	**Vikedalselva**	**WFD AA-EQS**
Pentachlorobenzene	<0.15	<0.15	<0.15	<0.15	<0.15	**7**
Hexachlorobenzene	<0.15	<0.15	<0.15	<0.15	<0.15	
γ-HCH	<3	<3	<3	<3	<3	**20**
PCB28/31	<0.6	<0.6	<0.6	<0.6	<0.6	
PCB52	<0.6	<0.6	<0.6	<0.6	<0.6	
PCB101	<0.8	<0.8	<0.8	<0.8	<0.8	
PCB118	<0.6	<0.6	<0.6	<0.6	<0.6	

PCB153	<0.6	<0.6	<0.6	<0.6	<0.6	
PCB138	<0.6	<0.6	<0.6	<0.6	<0.6	
PCB180	<0.6	<0.6	<0.6	<0.6	<0.6	
Σ_7PCBs	<0.5	<0.5	<0.5	<0.5	<0.5	0.0024
p,p'-DDE	<0.6	<0.6	<0.6	<0.6	<0.6	
p,p'-DDD	0.8	0.8	0.8	0.8	0.8	
p,p'-DDT	<1.1	<1.1	<1.1	<1.1	<1.1	**10**
Σ_3DDTs	<2.5	<2.5	<2.5	<2.5	<2.5	**25**
***Yearly average (n = 2 bottle samples); in ng L^{-1}; Note that original WFD AA-EQS are given in bold.**						

3.1.3 Polybrominated diphenyl ethers (PBDEs)

Estimated annual average concentrations of PBDEs in water of the five selected rivers are reported in the table below (Table 13). PBDEs were not found above limits of quantification in "whole water" samples collected from any of the five rivers sampled in 2018. This is in line with data from rivers Drammenselva, Glomma, Numedalslågen and Skien sampled in 2017. Limits of quantification for 2018 were slightly better than those obtained in 2017 and this means that LOQ for the sum of PBDEs for comparison with WFD AA-EQS is approximately one order of magnitude below EQS. Considering the hydrophobicity of PBDEs and their very low solubility in water, concentrations in the hundreds of ng per litre would be expected to be encountered only in contaminated effluents rather in natural river water. While PBDE concentrations are well below the EQS in water samples in the present study, the sum of PBDEs is consistently found above the EQS_{biota} in freshwater fish in European surface waters. This may mean that the EQS_{biota} is more protective than the EQS for water and that EQS values for different matrices are not internally consistent. The EQS_{biota} may also be relevant from a secondary poisoning perspective. However, PBDE metabolism in fish can affect whether PBDE level in fish can be used to estimate the environmental quality of a water body.

Table 13. "Whole water" concentrations of PBDEs

"Whole water" concentrations* of polybrominated diphenyl ethers in five rivers (ng L^{-1}) and comparison with WFD AA-EQS

Chemical	**Bjerkreimselva**	**Orreelva**	**Otra**	**Vegårdselva**	**Vikedalselva**	**WFD AA-EQS**
PBDE28	<0.02	<0.02	<0.02	<0.02	<0.02	
PBDE47	<0.03	<0.03	<0.03	<0.03	<0.03	
PBDE100	<0.02	<0.02	<0.02	<0.02	<0.02	
PBDE99	<0.03	<0.03	<0.03	<0.03	<0.03	
PBDE154	<0.03	<0.03	<0.03	<0.03	<0.03	
PBDE153	<0.04	<0.04	<0.04	<0.04	<0.04	

Σ_5PBDEs	<0.2	<0.2	<0.2	<0.2	<0.2	**1.6**

*Yearly average (standard deviation in brackets; n = 4 bottle samples); in ng L^{-1}; Note that original WFD AA-EQS are given in bold.

3.1.4 Hexabromocyclododecane (HBCDD)

As for PBDEs, hexabromocyclododecane isomers were not found above LOQ in any of the water samples from the five rivers sampled in 2018 (Table 14). However, limits of quantifications for the sum of HBCDD isomers of 1.5 ng L^{-1} is close to the WFD AA-EQS value of 1.6 ng L^{-1}.

Table 14. "Whole water" concentrations of HBCDD

"Whole water" concentrations* of hexabromocyclododecane in five rivers (ng L^{-1}) and comparison with WFD AA-EQS. Values above the AA-EQS are presented with red colour.

Chemical	Bjerkreimselva	Orreelva	Otra	Vegårdselva	Vikedalselva	WFD AA-EQS
α-HBCDD	<0.5	<0.5	<0.5	<0.5	<0.5	
β-HBCDD	<0.5	<0.5	<0.5	<0.5	<0.5	
γ-HBCDD	<0.5	<0.5	<0.5	<0.5	<0.5	
Σ_3HBCDD	<1.5	<1.5	<1.5	<1.5	<1.5	**1.6**

*Yearly average (n = 4 bottle samples); in ng L^{-1}

3.1.5 Short and medium chain chlorinated paraffins (S/MCCPs)

As shown in Table 15, the concentrations of SCCPs are similar for all five rivers and in the range 20-30 ng L^{-1}. This range is approximately at the level of LOQ for the data obtained in 2017. These concentrations are a factor of 15-20 below WFD AA-EQS. For MCCPs, average concentrations are slightly higher and exhibit higher standard deviations. Average concentrations are close to or above the EQS of 50 ng L^{-1}.

Table 15. "Whole water" concentrations of S/MCCPs

"Whole water" concentrations* of short and medium chain chlorinated paraffins in five rivers (ng L^{-1}) and comparison with WFD AA-EQS. Values above the AA-EQS are presented with red colour.

Chemical	Bjerkreimselva	Orreelva	Otra	Vegårdselva	Vikedalselva	AA-EQS
SCCP	29 (7)	24 (8)	27 (5)	21 (13)	21 (5)	**400**
MCCP	100 (80)	48 (24)	49 (27)	92 (82)	33 (24)	50

*Yearly average (n = 4 bottle samples); in ng L^{-1}; Note that original WFD AA-EQS are given in bold. Standard deviations in brackets ().

3.1.6 Alkylphenols

Three alkyphenolic compounds were analysed for in the four water samples collected in 2018 as was undertaken in 2017. Data are shown in Table 16. 4-n-Octylphenol, 4-n-nonylphenol and 4-tert-octylphenol were not found above limits of quantification in any of the samples from the five rivers under study in 2018. Limits of quantification for octyl and nonylphenol were worse than for data from 2017. For nonylphenol, LOQs are approximately a third of the AA-EQS. The LOQs for 4-tert-octylphenol are approximately a factor of two above the WFD AA-EQS value of 100 ng L^{-1}.

Table 16. "Whole water" concentrations of alkylphenols

"Whole water" concentrations* of nonylphenol, octylphenol and 4-tert-octylphenol in five rivers (ng L^{-1}) and comparison with WFD AA-EQS

Chemical	**Bjerkreimselva**	**Orreelva**	**Otra**	**Vegårdselva**	**Vikedalselva**	**AA-EQS**
Nonylphenol	<120	<90	<90	<70	<95	**300**
Octylphenol	<60	<60	<45	<40	<50	
4-tert-octylphenol	<150	<220	<210	<200	<210	**100**

*Yearly average (standard deviation in brackets; n = 4 bottle samples); in ng L^{-1}; Note that original WFD AA-EQS are given in bold.

3.1.7 Others

The pesticide chlorfenvinphos and the biocide cybutryne were not found above limits of quantification in any of the water samples collected from the fiver rivers of interest in 2018 (Table 17). This mimicks data from 2017. For chlorfenvinphos, these limits of quantification were a factor of 100 below the WFD AA-EQS, while they ranged from a third of the WFD AA-EQS to EQS level for cybutryne. We previously were able to detect irgarol/cybutryne in River Alna at a freely dissolved concentration of about 1.4 ng L^{-1} with silicone rubber based passive sampling (Pintado-Herrera et al., 2016). For DEHP, average concentrations estimated for the rivers Bjerkreimselva, Orrelva, Otra and Vegårdselva were between 30 and 60 ng L^{-1} and below LOQ for the Vikedalselva. These values are well below the WFD AA-EQS of 1300 ng L^{-1}.

Table 17. "Whole water" concentrations of other selected PS

"Whole water" concentrations* of chlorfenvinfos, cybutryne and DEHP in five rivers (ng L^{-1}) and comparison with WFD AA-EQS

Chemical	**Bjerkreimselva**	**Orreelva**	**Otra**	**Vegårdselva**	**Vikedalselva**	**AA-EQS**
Chlorfenvinfos	<0.75	<1	<0.75	<0.75	<0.75	**100**
Cybutryne	<0.9	<2.5	<0.5	<0.6	<0.6	**2.5**
DEHP	52 (26)	40 (17)	33 (20)	38 (14)	<55	**1300**

*Yearly average (standard deviation in brackets; n = 4 bottle samples); in ng L^{-1}; Note that original WFD AA-EQS are given in bold.

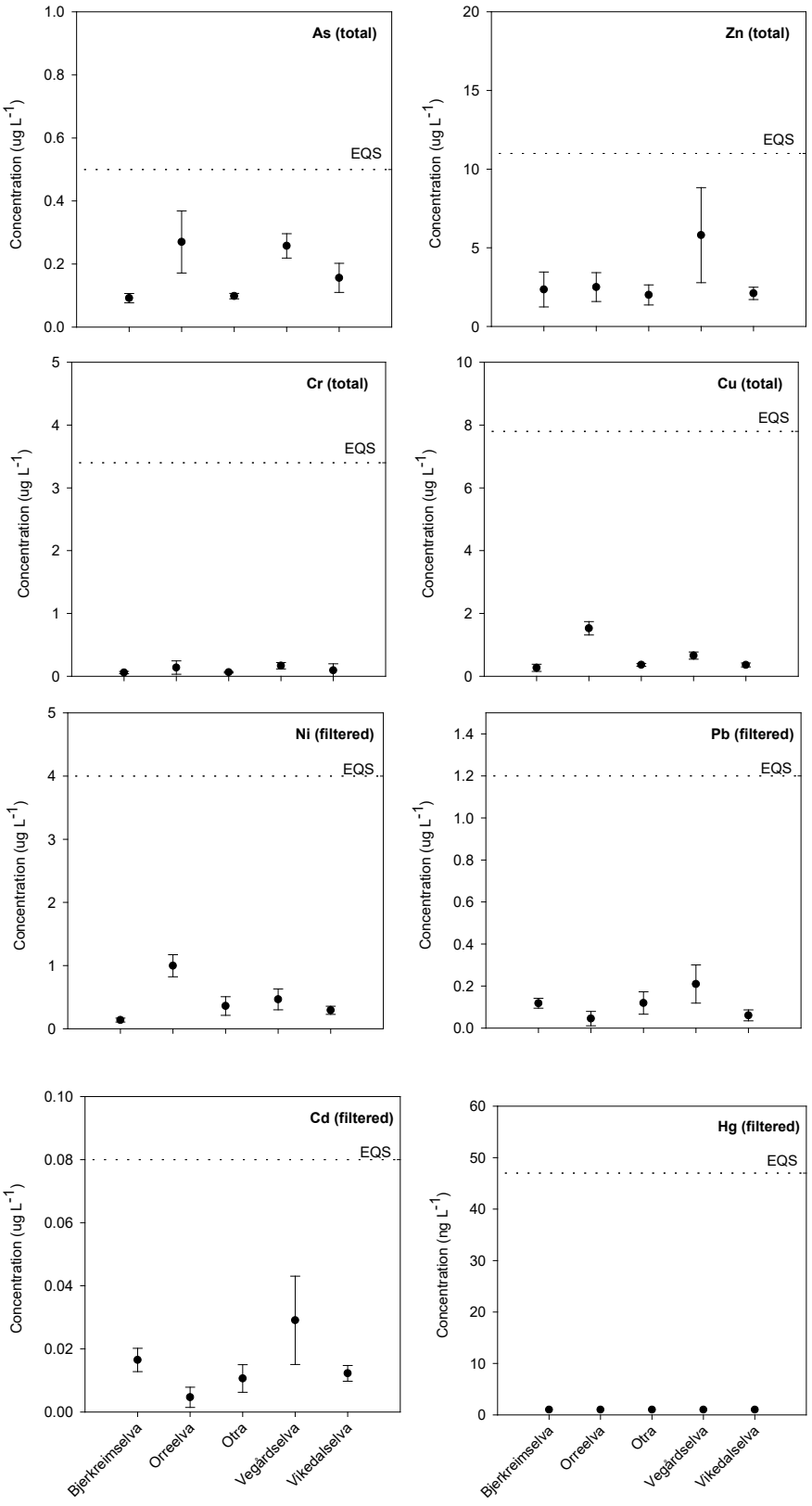

Figure 3. Annual average filtered (Ni, Pb, Cd, Hg) and total (As, Zn, Cr, Cu) metal concentrations (and standard deviation, n=4) in five rivers. The dotted reference line represents the AA-EQS for specific elements. For Hg, note that the unit is ng L^{-1} and datapoints for the last three rivers represent the LOQ at 1 ng L^{-1}.

3.1.8 Metals

Trace metals (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn) were sampled four times a year in the Rivers Bjerkreimselva, Orrelva, Otra, Vegårdselva and Vikedalselva in 2018. For the purpose of comparison with WFD AA-EQS, filtered concentrations (0.45 μm) were measured for Cd, Hg, Ni, and Pb. Estimates of annual average concentrations were calculated from these four datapoints and are compared with WFD AA-EQS values in Figure 3. Estimates of annual average concentrations of As, Cd, Cr, Cu, Ni, Pb and Zn in all five rivers are below proposed AA-EQS values. For elements such as As and Zn, whole water concentrations are slightly closer to EQS than for the other elements. Differences in concentrations of the various metals in waters samples from the five rivers are not major. Concentration of Zn (total), Cd (filtered), or Pb (filtered) tend to be slightly higher for the Vegårdselva than for the other rivers. Estimates of annual average filtered concentrations of Hg were well below the EQS of 47 ng L^{-1}. Most data were below the LOQ of 1 ng L^{-1}.

3.1.9 Yearly discharge of selected chemicals for the Bjerkreimselva, Orreelva, Otra, Vegårdselva and Vikedalselva for 2017

Yearly fluxes or discharges were estimated for these five rivers based on bottle sampling conducted four times in 2018 and data for selected chemicals or classes of chemicals are shown in Table 18. The highest flux of PAHs was found for the river Otra and yearly discharge estimate of 24.5 kg y^{-1} is closest to the data from the Numedaslågen sampled in 2017. For the other rivers, PAH discharges are in the range of that found for the Alna in previous years (Skarbovik et al., 2016). Differences in PAH fluxes to the sea between the rivers are mostly the result of differences in water discharge. As for 2017, yearly discharges of 7 indicator PCB congeners could not be estimated for 2018. Fluxes are likely to be lower than values ranging from 550 g y^{-1} for the Orrelva to under 20 kg y^{-1} for the river Otra. Detailed fluxes are given in Tables A1 to A7 in Appendix 2.

Table 18. Estimates of yearly discharge (kg/year) of selected chemicals or sets of chemicals in five rivers for 2018

Chemical	Bjerkreimselva	Orreelva	Otra	Vegårdselva	Vikedalselva
Σ_{16}PAHs	5.9	1.2	24.5	2.2	1.2
Pentachlorobenzene	<0.2	<0.020	<0.7	<0.05	<0.05
Hexachlorobenzene	<0.2	<0.02	<0.7	<0.05	<0.05
γ-HCH	<3.8	<0.31	<11	<0.7	<0.6
p,p'-DDE	<0.8	<0.08	<2.7	<0.2	<0.2
p,p'-DDT	<1.1	<0.10	<3.6	<0.26	<0.24
Σ_7PCBs	<5.5	<0.55	<20	<1.4	<1.3

3.2 EU WFD Priority substances and other relevant chemicals in fish from 5 rivers

Brown trout and Atlantic salmon (*Salmo trutta* or *Salmo salar*) were sampled from each of the five rivers. The data reported below are for triplicate whole fish composite samples (except for the River Alna for which one sample was for fish muscle and the River Nausta for which one sample was composed of fish liver and muscle). The average lipid content (% of wet weight) of the samples analysed were 3.71 (sd= 0.25), 4.13 (0.4), 2.96 (1.3), 1.93 (0.69) and 1.81 (0.31) for samples from the Alna, Gaula, Ørsta, Nausta and Ranaelva, respectively.

Table 19 shows the whole fish concentrations measured for organochlorinated compounds. More sensitive analysis with GC/MSMS at NIVA allowed the quantification of organchlorinated compounds below LOQ in samples from 2017. Pentachlorobenzene was at concentrations ranging from 0.01 ng g^{-1} ww for the samples from Ranaelva to 0.13 ng g^{-1} ww for the Alna. These values are well below the EQS_{biota} of 50 ng g^{-1} for pentachlorobenzene. Hexachlorobenzene was also consistently found in fish samples at concentrations ranging from 0.18 to 1.2 ng g^{-1} ww in whole fish, an order of magnitude or more below EQS_{biota}. The sum of concentrations for the seven indicator PCBs were in the range 0.74-18 ng g^{-1} ww. These values are above the proposed EQS_{biota} of 0.6 ng g^{-1} ww for Σ_7PCBs for all river sampled in 2018, consistent with data obtained for the five rivers sampled in 2017. Lindane (γ-HCH) was found above LOQ for fish samples from the River Alna with values barely above LOQ. These LOQs are close to three order of magnitude below the EQS_{biota} for lindane.

Table 19. Concentrations of polychlorinated biphenyls and other chlorinated organic compounds in fish from five rivers

Chemical	**Alna**	**Gaula**	**Ørsta**	**Nausta**	**Ranaelva**	**EQS_{biota}**
Pentachlorobenzene	0.13 (0.05)	0.03 (0.01)	0.01 (0.01)	0.02 (0.02)	0.01 (0.003)	50
Hexachlorobenzene	1.2 (0.08)	0.43 (0.05)	0.22 (0.7)	0.18 (0.07)	0.42 (0.16)	10
γ-HCH	0.02 (0.01)	<0.01	<0.01	<0.01	<0.01	61
PCB28/31	1.3 (0.3)	0.13 (0.09)	0.05 (0.02)	0.03 (0.001)	0.13 (0.05)	
PCB52	1.7 (1.0)	0.08 (0.04)	0.03 (0.02)	<0.03	0.32 (0.2)	
PCB101	2.8 (1.6)	0.23 (0.1)	0.10 (0.02)	0.06 (0.05)	1.0 (0.2)	
PCB118	2.2 (1.2)	0.25 (0.1)	0.12 (0.01)	0.09 (0.02)	0.89 (0.1)	
PCB153	4.2 (1.4)	0.67 (0.2)	0.40 (0.01)	0.24 (0.06)	3.2 (0.09)	
PCB138	4.3 (1.8)	0.51 (0.12)	0.30 (0.02)	0.20 (0.05)	2.4 (0.1)	
PCB180	1.3 (0.4)	0.25 (0.06)	0.13 (0.01)	0.09 (0.03)	1.1 (0.1)	
Σ_7PCBs	18 (8)	2.1 (0.6)	1.1 (0.1)	0.74 (0.21)	9.1 (0.7)	0.6

p,p'-DDE	1.9 (0.13)	0.87 (0.2)	1.1 (0.9)	1.0 (0.9)	3.5 (0.3)	
p,p'-DDD	1.0 (0.5)	<0.3	<0.3	<0.3	0.6 (0.3)	
p,p'-DDT	0.42 (0.17)	0.11 (0.02)	0.2 (0.2)	0.3 (0.3)	0.19 (0.1)	
Σ_3DDTs	3.3 (0.7)	1.1 (0.2)	1.4 (1.1)	1.5 (1.2)	4.2 (0.7)	

***Data shown as the average (and standard deviation in brackets, n = 3) of contaminant measurements in triplicate composite fish samples expressed in ng g^{-1} wet weight.**

The results of the monitoring of brominated flame retardants in fish from the five selected rivers is presented in Table 20. A comparison with EQS_{biota} is shown for the sums of PBDE congeners and HBCDD isomers. The Σ_6PBDEs ranging from 0.13 ng g^{-1} ww for fish from Nausta to 2.1 ng g^{-1} ww for Alna is above the EQS_{biota} of 0.0085 ng g^{-1} ww for all rivers. The sum of concentrations of HBCDD isomers is over two orders of magnitude below EQS_{biota}. These results are similar to those found in other countries. PBDE concentrations in fish from the German specimen bank (1995-2014) were all above EQS_{biota} while those for HBCDD were mostly below EQS_{biota} (Fliedner et al., 2016). In the data reviewed by Eljarrat and Barcelo (2018), most PBDE concentrations in European and North American fish exceeded the WFD EQS. Comparatively, a much lower number of exceedances were found for HBCDD.

Table 20. Concentrations of brominated flame retardants compounds in fish from five rivers

Chemical	**Alna**	**Gaula**	**Ørsta**	**Nausta**	**Ranaelva**	**EQS_{biota}**
PBDE28	0.01 (0.001)	0.01 (0.003)	<0.01	<0.01	0.01 (0.006)	
PBDE47	0.77 (0.3)	0.64 (0.8)	0.62 (0.13)	0.04 (0.02)	0.34 (0.07)	
PBDE100	0.18 (0.01)	0.14 (0.13)	0.25 (0.04)	0.02 (0.01)	0.11 (0.01)	
PBDE99	1.0 (0.34)	0.8 (0.8)	1.4 (0.22)	0.05 (0.04)	0.08 (0.02)	
PBDE126	-	-	-	-	-	
PBDE154	0.03 (0.01)	0.03 (0.02)	0.04 (0.01)	<0.01	0.04 (0.01)	
PBDE153	0.06 (0.001)	0.04 (0.03)	0.06 (0.02)	<0.01	0.01 (0.002)	
PBDE183	<0.02	<0.02	<0.02	<0.02	<0.02	
Σ_6PBDEs	2.1 (0.7)	1.7 (1.7)	2.3 (0.2)	0.13 (0.06)	0.59 (0.1)	0.0085
α-HBCDD	1.6 (0.5)	<0.5	<0.5	<0.5	<0.5	
β-HBCDD	<0.5	<0.5	<0.5	<0.5	<0.5	
γ-HBCDD	<0.5	<0.5	<0.5	<0.5	<0.5	
Σ_3HBCDD	2.1 (0.5)	<1.5	<1.5	<1.5	<1.5	167

*Data shown as the average (and standard deviation given in brackets; n = 3) of contaminant measurements in triplicate composite whole fish samples expressed in ng g^{-1} wet weight.

As shown in Table 21, the concentrations of short and medium chain chlorinated paraffins in brown trout and Atlantic salmon from the five selected rivers are mostly below EQS_{biota}. The average concentration of MCCPs in brown trout from the River Alna is well above the EQS_{biota} value of 170 ng g^{-1} ww. However, a high variability between the three samples can be seen. The average concentration of MCCPs in Ranaelva is within a factor of two below EQS level.

Table 21. Concentrations of short and medium chain chlorinated paraffins in fish from five rivers

Chemical	**Alna**	**Gaula**	**Ørsta**	**Nausta**	**Ranaelva**	**EQS_{biota}**
SCCP	17 (13)	8.0 (1.4)	7.9 (2.4)	3.5 (1.6)	11 (6.5)	6000
MCCP	701 (1120)	39 (37)	24 (21)	3.2 (1.8)	100 (165)	170

*Data shown as the average (and standard deviation given in brackets, n = 3) of contaminant measurements in triplicate composite whole fish samples expressed in ng g^{-1} wet weight.

Concentrations of selected alkylphenols and DEHP are reported in the table below (Table 22).
As for data from the 2017 campaign, no 4-n-octylphenol or 4-n-nonylphenol could be found above LOQ in any of the fish samples from the five selected rivers. For 4-n-nonylphenol, LOQs are at least two orders of magnitude below EQS_{biota} of 3000 ng g^{-1} ww. The limit of quantification for 4-tert-octylphenol is set relatively high (350 ng g^{-1} ww), most likely as a result of blank and contamination problems during sample preparation. LOQs are therefore very high particularly considering the proposed EQS_{biota} of 0.004 ng g^{-1} ww. Only the data for fish from Snarumselva are above LOQ and five orders of magnitude above EQS_{biota}.

Table 22. Concentrations of alkylphenols and DEHP in fish from five rivers

Chemical	**Alna**	**Gaula**	**Ørsta**	**Nausta**	**Ranaelva**	**EQS_{biota}**
4-n-octylphenol	<100	<280	<200	<120	<100	
4-n-nonylphenol	<50	<72	<100	<70	<80	3000
4-tert-octylphenol	<51	<65	<100	<70	<75	0.004
DEHP	<250	<250	<250	<250	<250	2900

*Data shown as the average (and standard deviation in brackets, n = 3) of contaminant measurements in triplicate composite whole fish samples expressed in ng g^{-1} wet weight.

In order to compare levels of chlorinated benzenes, PCBs, DDTs, and PBDEs, fish concentrations on a wet weight basis were corrected for the lipid content of the samples since, it is acknowledged that the main component for the sorption and accumulation of these persistent, hydrophobic and non-ionised chemicals in fish is the lipids. Lipid-normalised concentrations are presented in Figure 4.

Hexachlorobenzene concentrations are higher in brown trout from the Alna and Atlantic salmon from Ranaelva than in fish from the other rivers. This pattern I the same for the sum of seven indicator PCB congeners. Concentrations of pentachlorobenzene are higher for the fish from the Alna than for fish from the other rivers. A different pattern emerges for p,p'-DDE where levels appear similar for the Rivers Alna, Gaula, Ørsta and Nausta and significantly lower than those observed in salmon from the Ranaelva (t-test, P< 0.05). For PBDEs, data are quite variable and more variable than for the other chemicals. Concentrations are lowest for River Nausta (brown trout) and highest in salmon samples from the Ørsta.

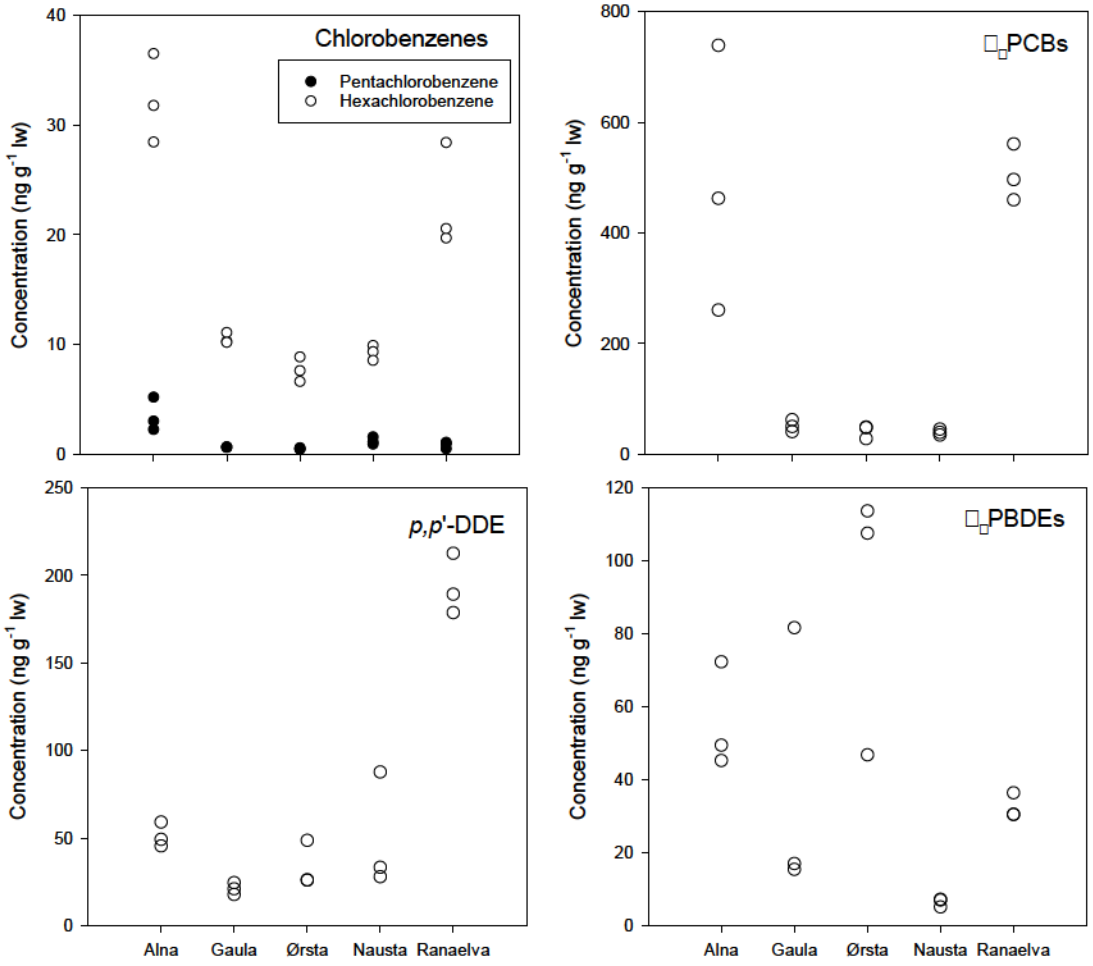

Figure 4. Lipid-normalised concentrations of selected contaminants or sums of contaminants in composite fish samples (n=3) from five rivers sampled in 2018.

3.3 Emerging contaminants in River Alna

Emerging contaminants including a series of UV filters, organophosphorus flame retardants, bisphenols and perfluoro chemicals were quantified in a range of matrices from river Alna. These included composite water samples, suspended particulate matter samples (SPM) and brown trout.

3.3.1 UV filters in River Alna

All substances were found well above LOQs in the two SPM samples. As for SPM samples from 2017, OC was found in highest concentrations in 2018. Most of these substances are relatively hydrophobic and distribute favorably to particulate organic carbon. In past studies, substances such as BP3 and OC were also quantified at concentrations of hundreds of ng per litre in River Alna (Pintado-Herrera et al., 2016).

Results from automated composite water sampling (with ISCO autonomous sampling unit) and SPM sampling are provided in Table 23. Composite water sampling is not necessarily ideal for sampling of certain UV filters. Because of the sampling process with the automated sampler, there is generally more manipulation of the water samples that with one grab sample, and hence more possibilities of contact of the water being sampled with plastic tubing and other parts of the automated sampling unit resulting in contamination. The UV filters were found above LOQ at concentrations in the range 0.5-53 ng L^{-1}. Whole water concentrations were also highest for OC while the lowest were for UV-327.

Table 23. UV filter concentrations in water and suspended particulate matter of the River Alna

Chemical	CAS number	Water concentration (ng/L)		SPM concentration (ng/g dry weight)	
		Sample 1	Sample 2	Sample 1	Sample 2
Benzophenone (BP3)	119-61-9	6.5	4.4	55	80
2-ethyl-hexyl-4-trimethoxycinnamate (EHMC)	5466-77-3	2.0	1.8	12	41
Octocrylene (OC)	6197-30-4	39	53	1240	970
2-(2'-Hydroxy-3',5'-di-tert-butylphenyl)-5-chlorobenzotriazole (UV-327)	3864-99-1	0.16	0.23	23	31
2-(2H-Benzotriazol-2-yl)-4,6- ditert pentylphenol (UV-328)	25973-55-1	0.57	0.83	53	75
2-(2'-hydroxy-5'-tert-octyllphenyl)benzotriazole (UV-329)	3147-75-9	1.0	0.53	8.4	9.8

As shown in Table 24, BP3 was consistently found above LOQ in whole fish or fillet/muscle samples from the two sampling events. EHMC and OC were also detected in some but not all muscle or whole fish samples. While in 2017, UV-327, UV-328 and UV-329 were found at sub ng g^{-1} wet weight in whole fish and muscle samples, none of these chemicals were above LOQ in 2018 samples (LOQ = 0.1-0.6 ng g^{-1}). These compounds have logP values above 3 and have been shown to accumulate in fish (Gago-Ferrero et al., 2015). The authors concluded from biota-sediment accumulation factors, that levels of excretion were low and favoured bioaccumulation.

Table 24. UV filter concentrations in brown trout (muscle/liver and whole fish) sampled in River Alna in June and September 2018

Chemical	CAS number	June 2018		September 2018	
		Whole fish conc. (ng g^{-1} ww)[a]	Muscle conc. (ng g^{-1} ww)[b]	Whole fish conc. (ng g^{-1} ww)[a]	Muscle conc. (ng g^{-1} ww)[b]
Benzophenone (BP3)	119-61-9	3.37	0.77	0.96	0.67
2-ethyl-hexyl-4-trimethoxycinnamate (EHMC)	5466-77-3	<2.5	6.8	<2.5	4.4
Octocrylene (OC)	6197-30-4	8.9	<3.5	6.7	2.6
2-(2'-Hydroxy-3',5'-di-tert-butylphenyl)-5-chlorobenzotriazole (UV-327)	3864-99-1	<0,1	<0,1	<0.1	<0.1
2-(2H-Benzotriazol-2-yl)-4,6- ditert pentylphenol (UV-328)	25973-55-1	<0,3	<0,3	<0.3	<0.3
2-(2'-hydroxy-5'-tert-octyllphenyl)benzotriazole (UV-329)	3147-75-9	<0,6	<0,6	<0.6	<0.6

[a]Data from one sample; [b]Mean of two samples

3.3.2 Organophosphorus compounds in the River Alna

Table 26 shows that a slightly higher number of OPs could be seen in SPM samples than in composite water samples. One issue with composite water sampling with the ISCO sampler was the level of contamination in the blanks. This resulted in relatively high LOQs for the following chemicals, TCPP (LOQ of 948 ng L^{-1}), TEP (LOQ of 364 ng L^{-1}), TCEP (LOQ of 154 ng L^{-1}), DBPhP (5.5 and 6.7 ng L^{-1}), TBEP (LOQ of 51 ng L^{-1}) and TnBP (LOQ of 21 ng L^{-1}). Full names and CAS numbers of the OPFRs are given in Tables 25 and 26.

No OPFRs were found above LOQ in the sample from May 2018. As for the 2017 data, TCPP was in highest amounts in SPM (220 and 825 ng g^{-1} dw) with concentrations in a similar range as those measured the previous year. Compounds detected in SPM samples and to a lesser extent in water samples included TEP, TCEP, TiBP, TPP, TDCPP, TnBP, and TBEP. TCEP, TCPP, sum TCP and TEHP were consistently detected in sediment and to a lesser extent in water sample. Other compounds such as TPrP, BdPhP, and TXP were not detected in any of the composite water or SPM samples.

Table 25. Organophosphorus flame retardant concentrations in water and suspended particulate matter of the River Alna

Chemical	CAS number	Water concentration (ng/L)		SPM concentration (ng/g dry weight)	
		Sample 1	Sample 2	Sample 1	Sample 2
Tri ethylphosphate (TEP)	78-40-0	< 364	516	26	68
Tri(2-chloroethyl)phosphate (TCEP)	115-96-8	< 154	< 154	3.2	4.3
Tripropylphosphate (TPrP)	513-08-6	< 0,3	< 0.3	< 0.01	< 0.01
tri(1-chloro-2-propyl)phosphate (TCPP)	13674-87-8	< 948	< 948	220	825
Tri-iso-butylphosphate (TiBP)	126-71-6	< 7.0	36	2.5	5.1
Butyl diphenylphosphate (BdPhP)	2752-95-6	< 0.1	< 0.1	< 0.05	< 0.05
Triphenylphosphate (TPP)	115-86-6	< 2.8	16	16	92
Dibutyl phenyl phosphate (DBPhP)	2528-36-1	< 0.1	0.46	< 0.05	0.37
Tri-n-butyphosphate (TnBP)	126-73-8	< 21	< 21	0.83	2.1
tri(1,3-dichloro-2-propyl)phosphate (TDCPP)	13674-87-8	< 2.7	10.7	3.3	12.4
tri(2-butoxyethyl)phosphate (TBEP)	78-51-3	< 51	135	137	179
Tricresylphosphate (sumTCP)	1330-78-5	< 1.5	< 1.5	18	41
2-ethylhexyl-diphenyl phosphate (EHDP)	1241-94-7	< 2.6	8.5	12	68
Trixilylphosphate (TXP)	25155-23-1	< 0.3	< 0.3	< 0.1	< 0.1
tris(isopropylphenyl) phosphate isomers (IPPP)	26967-76-0	N/A	N/A	N/A	N/A
tris(p-tert-butylphenyl) phosphate (TTBPP)	78-33-1	N/A	N/A	N/A	N/A

tris(2-ethylhexyl) phosphate (TEHP)	78-42-2	< 0.3	1.05	< 0.06	< 0.06

N/A: Not analysed

The concentrations of OPs in whole fish and muscle samples of brown trout from River Alna are shown in Table 26. TCPP, TPP, TnBP, and sumTCP were consistently detected in all fish samples analysed. TBEP, EHDP and TXP were found above LOQ in three of the four composite fish samples. None of the concentrations exceeded 5 ng g^{-1} ww fish. In general, the pattern of chemicals found above LOQ in fish samples in 2018 is similar to that from 2017.

Table 26. Organophosphorus flame retardant concentrations in brown trout (muscle and whole fish) sampled in River Alna in June and September 2018

Chemical (abbreviation)	CAS number	June 2018		September 2018	
		Whole fish conc. (ng g^{-1} ww)	Muscle conc. (ng g^{-1} ww)[a]	Whole fish conc. (ng g^{-1} ww)	Muscle conc. (ng g^{-1} ww)[b]
Tri ethylphosphate (TEP)	78-40-0	< 1.0	< 1.0	< 1.0	< 1.0
Tri(2-chloroethyl)phosphate (TCEP)	115-96-8	< 0.05	< 0.05	< 0.05	< 0.05
Tripropylphosphate (TPrP)	513-08-6	< 0.01	< 0.01	< 0.01	< 0.01
tri(1-chloro-2-propyl)phosphate (TCPP)	13674-87-8	0.59	0.45	0.33	0.64
Tri-iso-butylphosphate (TiBP)	126-71-6	0.11	< 0.15	< 0.15	< 0.15
Butyl diphenylphosphate (BdPhP)	2752-95-6	< 0.02	< 0,02	< 0.02	< 0.02
Triphenylphosphate (TPP)	115-86-6	1.5	0.51	7.8	8.6
Dibutyl phenyl phosphate (DBPhP)	2528-36-1	< 0.02	< 0.02	< 0.02	< 0.02
Tri-n-butyphosphate (TnBP)	126-73-8	0.19	0.10	0.20	0.28
tri(1,3-dichloro-2-propyl)phosphate (TDCPP)	13674-87-8	< 0.10	< 0.10	< 0.10	< 0.10

tri(2-butoxyethyl)phosphate (TBEP)	78-51-3	0.31	< 0.20	0.330	< 0.20
Tricresylphosphate (sumTCP)	1330-78-5	3.1	0.67	0.73	0.41
2-ethylhexyl-diphenyl phosphate (EHDP)	1241-94-7	2.8	< 1.0	5.0	2.2
Trixilylphosphate (TXP)	25155-23-1	< 0.04	0.086	0.12	0.053
tris(isopropylphenyl) phosphate isomers (IPPP)	26967-76-0	N/A	N/A	N/A	NA
tris(p-tert-butylphenyl) phosphate (TTBPP)	78-33-1	N/A	N/A	N/A	NA
tris(2-ethylhexyl) phosphate (TEHP)	78-42-2	< 0.22	< 0.22	< 0.01	< 0.22
[a]Data from one sample; [b]Mean of two samples					

3.3.3 Bisphenols in River Alna

The concentrations of a wide range of bisphenols in composite water samples and SPM from the River Alna are given in Table 27. BPA was found above LOQ both in water samples and SPM samples at concentration levels of hundreds of ng L^{-1} or ng g^{-1} dw. Two other bisphenols, 4,4'-BPS and 4,4'-BPF were found in water samples at concentration of 17-26 ng L^{-1}. These were also measured above LOQ in SPM samples. A few other bisphenols were also detected in SPM (4,4'-BPS, 2,2'-BPF, 2,4'-BPF, and 4,4'-BPF). BPA was in concentrations approximately an order of magnitude higher than the other bisphenols in both water and SPM samples.

Table 27. Bisphenol concentrations in water and suspended particulate matter of the River Alna

Chemical (CAS number)	Water concentration (ng/L)		SPM concentration (ng/g dry weight)	
	Sample 1	Sample 2	Sample 1	Sample 2
2,4'-BPA (837-08-1)	<21	<28	<9	<4.5
4,4'-BPA (80-05-7)	109	385	135	177
2,4'-BPS (5397-34-2)	<4.9	<4.5	<1.4	<0,83
4,4'-BPS (80-09-1)	17	18	1.7	2.6
2,2'-BPF (2467-02-9)	<3,44	< 4,49	< 13	3.7
2,4'-BPF (2467-03-0)	<32,2	< 36,4	< 16	15.2
4,4'-BPF (620-92-8)	26	19	14	15.4
BP-AF (1478-61-19)	<5,7	<7,8	<1.0	<0,83
BP-AP (1571-75-1)	<27	<24	<6,2	<4.0
BPB (77-40-7)	<27	<30	<12	< 6,2
BPE (2081-08-5)	<26	<24	<9,5	< 4,7
BP-FL (3236-71-3)	<38	<31	<17	< 8,5
BPM (3236-71-3)	<8.3	<13	<5,1	< 2,6
BPZ (843-55-0)	<28	<34	<21	< 9,4

The table below (Table 28) shows the bisphenol concentrations in whole fish and muscle samples of brown trout from the river Alna. Bisphenols were very sparsely found in muscle or whole fish samples from the two sampling events in 2018. The only compound consistently detected in fish samples was 4,4'-BPA in concentrations ranging from 3.5 to 11 ng g^{-1} ww. Concentrations on wet weight basis were slightly higher in muscle samples than in whole fish samples. Bisphenol F (4,4'-BPF) was found at levels close to LOQ in the composite muscle sample from June 2018 and in the whole fish sample from September 2018.

Table 28. Bisphenol concentrations in brown trout (muscle and whole fish) sampled in River Alna in June and September 2018

Chemical (CAS number)	June 2018		September 2018	
	Whole fish concentration (ng g^{-1} ww)[a]	Muscle concentration (ng g^{-1} ww)[b]	Whole fish concentration (ng g^{-1} ww)	Muscle concentration (ng g^{-1} ww)[b]
2,4'-BPA (837-08-1)	< 5.3	<4.9	<1.4	<4.3
4,4'-BPA (80-05-7)	7.7	11	3.5	9.1
2,4'-BPS (5397-34-2)	<0.82	<0.72	<0.32	<0.72
4,4'-BPS (80-09-1)	<1.2	<1.1	<0.33	<0.98
2,2'-BPF (2467-02-9)	<0.78	<0.77	<0.23	<0.67
2,4'-BPF (2467-03-0)	<6.8	<6.2	<1.8	<5.5
4,4'-BPF (620-92-8)	<3.4	1.8	1.3	<2.7
BP-AF (1478-61-19)	<1.3	<1.2	<0.34	<1.1
BP-AP (1571-75-1)	<4.2	<3.8	<1.1	<3.4
BPB (77-40-7)	<5.4	<5.0	<1.4	<4.4
BPE (2081-08-5)	<4.2	<4.0	<1.1	<3.3
BP-FL (3236-71-3)	<6.3	<5.8	<1.7	<5.2
BPM (3236-71-3)	<2.2	<1.8	<0.60	<1.7
BPZ (843-55-0)	<6.0	<6.0	<1.7	<5.2

[a]Data from one sample; [b]Mean of two samples

3.3.4 Emergent contaminant distribution in River Alna

For compounds whose concentrations were above LOQ both in fish and in water or SPM, it was possible to calculate bioaccumulation factors (BAF in L kg^{-1}):

$$BAF = \frac{C_{Fish}}{C_w}$$

With C_{Fish} and C_w, contaminant concentrations in fish (ng g^{-1}) on a wet weight or lipid basis and in water (ng L^{-1}). logBAFs for organophosphorus flame retardants, bisphenols and UV filters are plotted on Figure 5 against the octanol-water partition coefficients ($logK_{ow}$) for these chemicals. BAFs for PCBs were calculated from fish concentrations reported earlier in this report and freely dissolved concentrations estimated by passive sampling in 2016. The 1:1 relationship is also shown on the graph. For PCBs, logBAFs are mostly close to or above the 1:1 relationship. BAFs for the bisphenols and the UV filters BP3 and EHMC or the OPFR TPP tend to be close to the 1:1 relationship. BAFs for BPA are also in agreement with BCFs reported in Lee et al. (2015). BAFs for the UV filter OC and the flame retardants EHDP and TBEP tend to be under the 1:1 relationship. This means that observed

bioaccumulation is lower than what can be predicted from their hydrophobicity. It is likely that metabolism leads to these lower than expected BAFs.

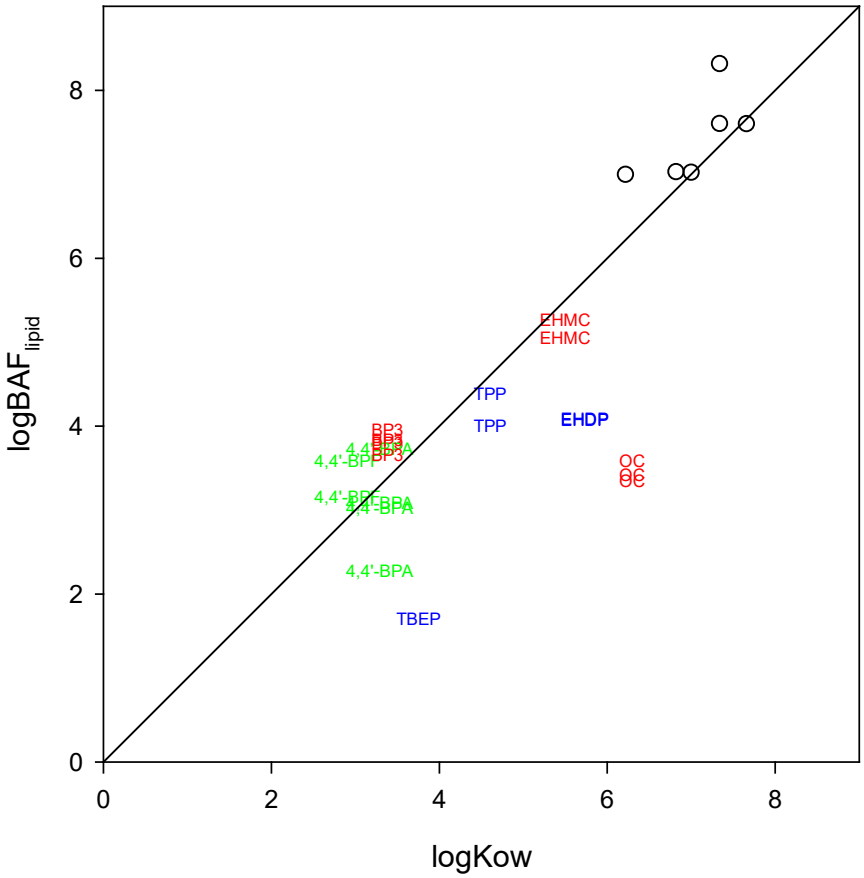

Figure 5. Lipid-normalised bioaccumulation factors for emerging contaminants in brown trout (*Salmo trutta*) in River Alna. Empty circles represent BAFs for PCBs and are given for comparison.

The quantification of emerging contaminants both in water and in SPM means field-based organic carbon-normalised suspended particulate matter-water distribution coefficients (K_{oc}) can be estimated:

$$K_{oc} = \frac{C_{SPM,OC}}{C_w}$$

With $C_{SPM,OC}$ the OC-normalised SPM concentration and C_w the concentration in water. As shown on Figure 6, most $logK_{oc}$ values for emerging contaminants of interest are close to the 1:1 relationship with logKow and demonstrate agreement between water and SPM concentrations measured for these compounds. A wider discrepancy between $logK_{oc}$ and $logK_{ow}$ can be seen for bisphenol S, TEP and BP3. For comparison, $logK_{oc}$ for PCBs from 2016 are also plotted on Figure 6. These $logK_{oc}$ values do not show a very high sorptive capacity of the SPM. LogKoc for OPFRs are generally in agreement with literature values (e.g. Zhang et al. 2018).

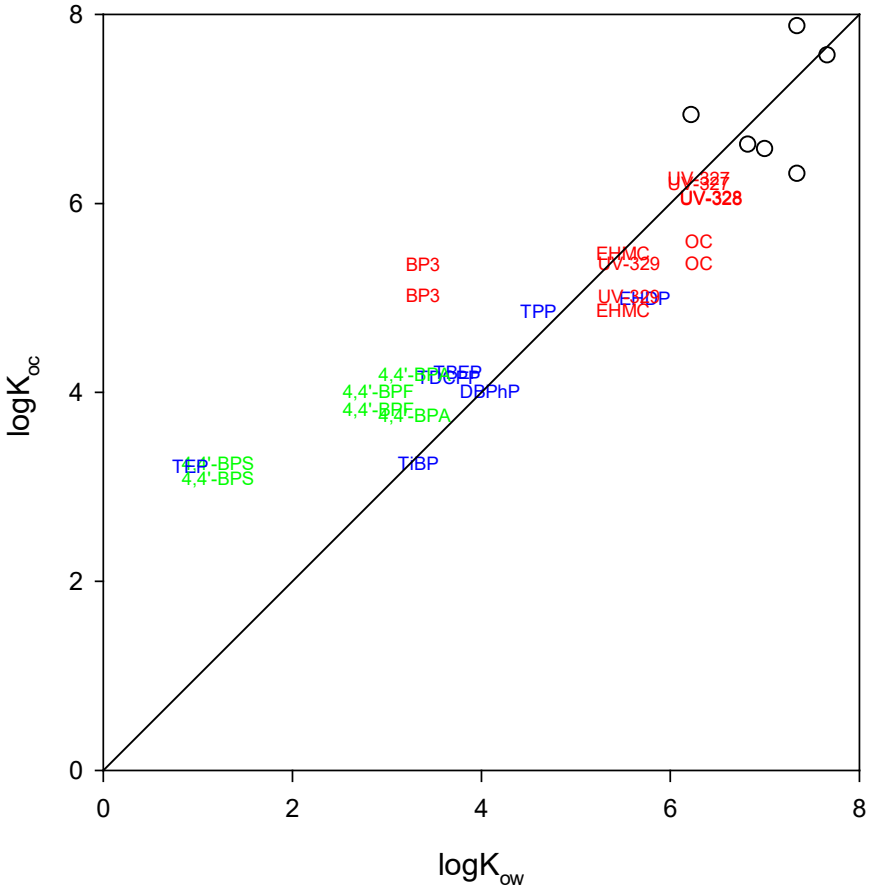

Figure 6. Field-based organic carbon-normalised SPM-water distribution coefficients (K_{oc}) for emerging contaminants in River Alna in 2018. Empty circles represent K_{oc} for PCBs.

Finally, fish concentrations can also be compared with SPM concentrations through the calculation of biota-sediment accumulation factors (BSAF) (Burkhard, 2003):

$$BSAF = \frac{C_{Fish,lip}}{C_{SPM,OC}}$$

BSAF for emerging contaminants are plotted on Figure 7 together with BSAF for PCBs. BSAF for PCBs in the range of 1-10 are in agreement with BSAF estimated for lake trout by Burkhard et al (2004). BSAF for emerging contaminants are generally below 1 indicating low potential for bioaccumulation or bioamplification based on observed field concentrations. BSAF for BPA in the range of 0.1 to 1 are in agreement with data reported in Lee et al. (2015). BSAF for OPFRs span two orders of magnitude and are in the range 0.01 to 1. Fish BSAF < 1 were also reported by Giulivo et al. (2017).

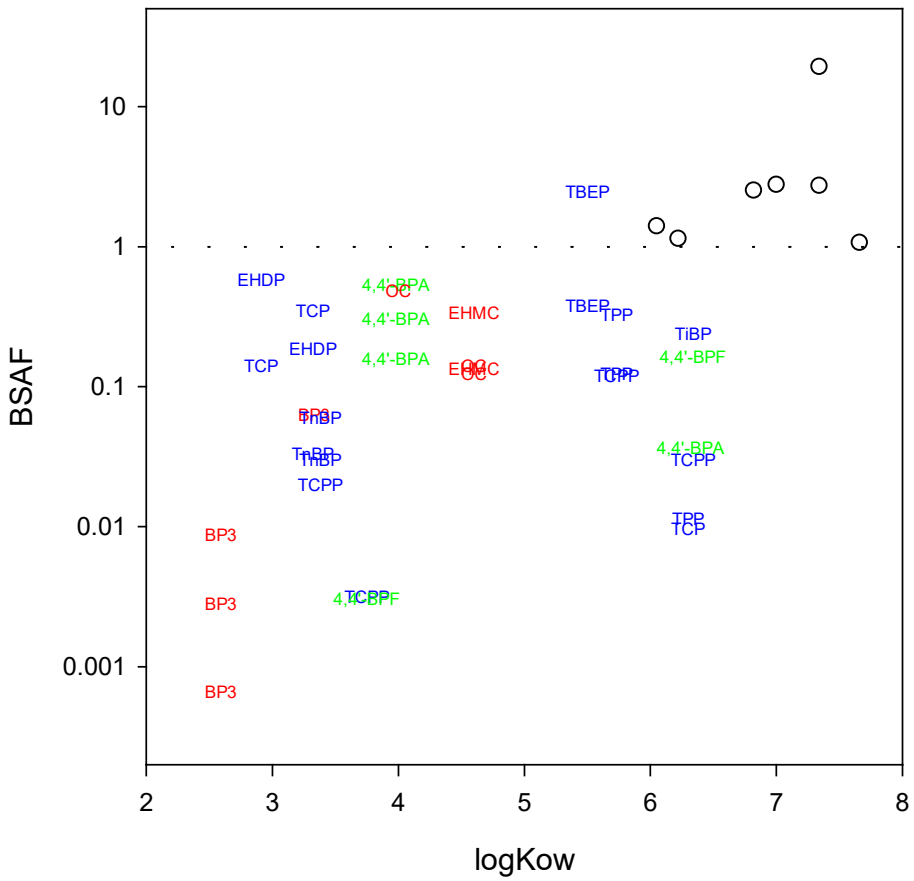

Figure 7. BSAF for emerging contaminants in brown trout (*Salmo trutta*) in River Alna in 2018. Empty circles represent BSAF for PCBs.

3.3.5 PFAS in River Alna

The list of PFAS chemicals being investigated was extended slightly compared with that reported in 2017 Concentrations of PFAS compounds in composite water and SPM samples are reported in Table 29. Data from the two composite water samples are very consistent and there were no issues of blanks/contamination for PFAS compounds. The concentrations of PFAS compounds found above LOQ were in the range 0.6-14 ng L^{-1}. PFOS, PFOA, PFBS, PFHxS, PFPA, PFHxA, PFHpA, PFNA and 6:2 FTS were found above LOQ in composite water samples from the Alna. Only PFOS was measured above limits of quantification in SPM samples. The list of PFAS compounds detected in River Alna is very similar to that for PFAS chemicals found in stormwaters during Urbanfjord project sampling[16]. In addition, a relatively good agreement between the distribution of PFAS compounds in Alna river water and in Oslo stormwaters can be seen in Figure 8.

[16] Environmental Contaminants in an Urban Fjord, 2017
https://www.miljodirektoratet.no/globalassets/publikasjoner/m1131/m1131.pdf

Table 29. PFAS concentration in water and suspended particulate matter of the River Alna

Chemical (Abbreviation)	CAS number	Water concentration (ng/L)		SPM concentration (ng/g dry weight)	
		Sample 1	Sample 2	Sample 1	Sample 2
Perfluoropentanoate (PFPA)	356-42-3	4.1	14.1	<1.0	<1.0
Perfluorohexanoate (PFHxA)	307-24-4	4.1	3.9	<0.5	<0.5
Perfluoroheptanoate (PFHpA)	375-85-9	2.5	2.3	<0.5	<0.5
Perfluorooctanoate (PFOA)	335-67-1	7.5	5.9	<0.5	<0.5
Perfluorononanoate (PFNA)	375-95-1	0.9	1.1	<0.5	<0.5
Perfluorodecanoate (PFDA)	335-76-2	<0.5	<0.5	<0.5	<0.5
Perfluoroundecanoate (PFUdA)	2058-94-8	<0.5	<0.5	<0.5	<0.5
Perfluorododecanoate (PFDoA)	307-55-1	<0.5	<0.5	<0.5	<0.5
Perfluorotridecanoate (PFTrDA)	72629-94-8	<0.5	<0.5	<0.5	<0.5
Perfluorotetradecanoate (PFTeDA)	376-06-7	<0.5	<0.5	<0.5	<0.5
Perfluoropentadecanoate (PFPeDA)	1214264-29-5	N/A	N/A	N/A	N/A
Perfluorohexadecanoate (PFHxDA)	67905-19-5	N/A	N/A	N/A	N/A
Perfluorobutane sulfonate (PFBS)	375-73-5	1.1	1.2	<0.1	<0.1
Perfluoropentane sulfonate (PFPS)	2706-91-4	N/A	N/A	N/A	N/A
Perfluorohexane sulfonate (PFHxS)	355-46-4	0.9	0.8	<0.1	<0.1
Perfluoroheptane sulfonate (PFHpS)	21934-50-9	N/A	N/A	N/A	N/A
Perfluorooctane sulfonate (PFOS)	1763-23-1	1.0	0.4	0.6	0.4
8Cl-perfluorooctane sulfonate (8Cl-PFOS)	N/A	N/A	N/A	N/A	N/A
Perfluorononane sulfonate (PFNS)	17202-41-4	N/A	N/A	N/A	N/A
Perfluorodecane sulfonate (PFDS)	67906-42-7	<0.2	<0.2	<0.2	<0.2
Perfluorododecane sulfonate (PFDoS)	85187-17-3	<0.2	<0.2	<0.2	<0.2
Perfluorooctane sulphonamide (PFOSA)	754-91-6	<0.1	<0.1	<0.1	<0.1
N-Methyl fluorooctane sulfonate (meFOSA)	250-665-8	<0.3	<0.3	<0.3	<0.3

N-Ethyl fluorooctane sulfonate (etFOSA)	4151-50-2	<0.3	<0.3	<0.3	<0.3
N-Methyl fluorooctane sulfonamidoethanol (meFOSE)	24448-09-7	<5	<5	<5	<5
N-Ethyl fluorooctane sulfoamidoethanol (etFOSE)	1691-99-2	<5	<5	<5	<5
Perfluorooctane Sulfonamidoacetic acid (FOSAA)	2806-24-8	N/A	N/A	N/A	N/A
N-methylperfluoro-1-octanesulfonamidoacetic acid (me-FOSAA)	2355-31-9	<0.3	<0.3	<0.3	<0.3
N- ethylperfluoro-1-octanesulfonamidoacetic acid (et-FOSAA)	2991-50-6	<0.3	<0.3	<0.3	<0.3
4:2 Fluorotelomer sulfonate (4:2 FTS)	414911-30-1	<0.3	<0.3	<0.3	<0.3
6:2 Fluorotelomer sulfonate (6:2 FTS)	27619-97-2	0.9	0.6	1.05	<0.3
8:2 Fluorotelomer sulfonate (8:2 FTS)	481071-78-7	<0.3	<0.3	<0.3	<0.3
10:2 Fluorotelomer sulfonate (10:2 FTS)	N/A	<0.3	<0.3	<0.3	<0.3
12:2 Fluorotelomer sulfonate (12:2 FTS)	N/A	<0.3	<0.3	<0.3	<0.3

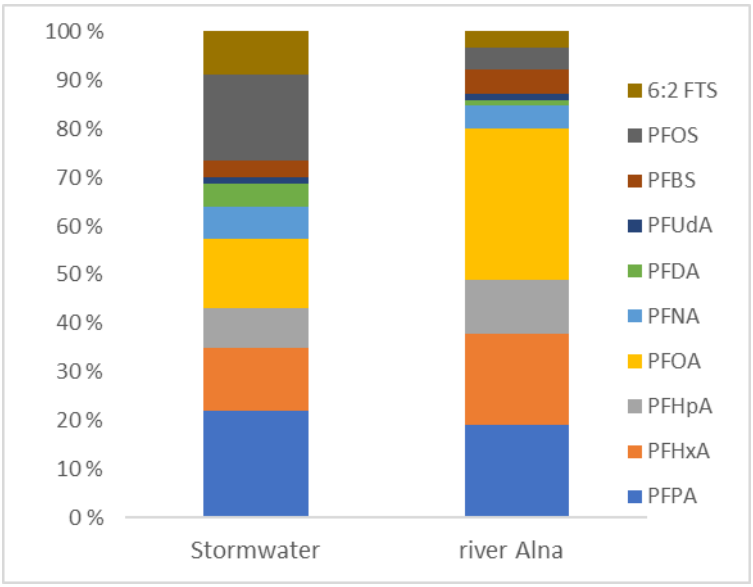

Figure 8. Comparison of the relative distribution of detected PFAS compounds in water of River Alna and in Stormwater samples collected from drains in Oslo for the Urbanfjord project.

PFAS concentrations in brown trout sampled in June and September 2018 are given in Table 30. For each sampling period, "whole fish" and liver concentrations were obtained. Only PFOS and PFOSA were consistently detected in all samples. Concentrations were in the range 1.6-12.2 ng g^{-1} ww for PFOS and 0.35-1.1 ng g^{-1} ww for PFOSA, respectively. In 2017, PFOS concentrations were much higher with concentrations of 14.2 and 13.1 ng g^{-1} ww in whole fish samples and 39 and 144 ng g^{-1} ww for liver samples. PFDA, PFUdA, PFDoA, PFTeDAand PFDS were measured above LOQ in at least half of the fish samples. PFOA, PFNA and PFTrDA were detected in one sample only. In disagreement with the 2017 data, more PFAS chemicals were found above LOQ in whole fish samples than in liver analyses. On a wet weight basis, concentrations are consistently higher in whole fish samples.

TABLE 30. PFAS concentration in brown trout (liver) sampled in River Alna in June and September 2018

Chemical	**Abbr.**	**June 2018**		**September 2018**	
		Whole fish concentration (ng g^{-1} ww)	**Liver concentration (ng g^{-1} ww)[a]**	**Whole fish concentration (ng g^{-1} ww)**	**Liver concentration (ng g^{-1} ww)[b]**
Perfluoropentanoate	PFPA	<0.5	<0.5	<0.5	<0.5
Perfluorohexanoate	PFHxA	<0.5	<0.5	<0.5	<0.5
Perfluoroheptanoate	PFHpA	<0.5	<0.5	<0.5	<0.5
Perfluorooctanoate	PFOA	4.8	<0.5	<0.5	<0.5
Perfluorononanoate	PFNA	0.9	<0.4	<0.4	<0.4
Perfluorodecanoate	PFDA	1	0.35	0.9	<0.4
Perfluoroundecanoate	PFUdA	0.5	<0.4	0.7	<0.4
Perfluorododecanoate	PFDoA	0.9	0.55	1.9	<0.4
Perfluorotridecanoate	PFTrDA	<0.4	<0.4	0.7	<0.4
Perfluorotetradecanoate	PFTeDA	0.4	<0.4	0.8	<0.4
	PFPeDA	<0.4	<0.4	<0.4	<0.4
	PFHxDA	<0.4	<0.4	<0.4	<0.4
Perfluorobutane sulfonate	PFBS	<0.1	<0.1	<0.1	<0.1
Perfluoropentane sulfonate	PFPS	<0.1	<0.1	<0.1	<0.1
Perfluorohexane sulfonate	PFHxS	<0.1	<0.1	<0.1	<0.1

Perfluoroheptane sulfonate	PFHpS	<0.1	<0.1	<0.1	<0.1
Perfluorooctane sulfonate	PFOS	12.2	5.3	9.7	1.6
8Cl-perfluorooctane sulfonate	8Cl-PFOS	N/A	NA	N/A	NA
Perfluorononane sulfonate	PFNS	<0.1	<0.1	<0.1	<0.1
Perfluorodecane sulfonate	PFDS	0.5	<0.1	0.3	<0.1
Perfluorododecane sulfonate	PFDoS	<0.2	<0.2	<0.2	<0.2
Perfluorooctane sulphonamide	PFOSA	1.1	0.35	1.9	0.55
N-Methyl fluorooctane sulfonate	meFOSA	<0.3	<0.3	<0.3	<0.3
N-Ethyl fluorooctane sulfonate	etFOSA	<0.3	<0.3	<0.3	<0.3
N-Methyl fluorooctane sulfonamidoethanol	meFOSE	<2	<2	<2	<2
N-Ethyl fluorooctane sulfoamidoethanol	etFOSE	<2	<2	<2	<2
4:2 fluorotelomer sulfonate	4:2 FTS	<0.3	<0.3	<0.3	<0.3
6:2 fluorotelomer sulfonate	6:2 FTS	<0.3	<0.3	<0.3	<0.3
8:2 fluorotelomer sulfonate	8:2 FTS	<0.3	<0.3	<0.3	<0.3
10:2 fluorotelomer sulfonate	10:2 FTS	<0.3	<0.3	<0.3	<0.3
10:2 fluorotelomer sulfonate	12:2 FTS	<0.3	<0.3	<0.3	<0.3
[a]Data from one sample; [b]Mean of two samples					

Since it was possible to measure concentrations both in fish and in water for selected PFAS compounds, bioconcentration factors (BCF) could be estimated for brown trout. logBCF values for PFNA, PFOA and PFOS, calculated as the logarithm of the concentration in the organism (wet weight basis) divided by that in water, are presented in Table 35. LogBCF estimated for PFOS in 2018 are in the range observed for samples from 2017. For PFOS, the log of SPM-water distribution coefficient of 2.85 on average estimate for River Alna is in excellent agreement with literature values (e.g. Labadie and Chevreuil, 2011).

Table 35. Bioconcentration factors for selected PFAS compounds in the River Alna

Chemical	Bioconcentration factor (logBCF; L kg^{-1})*			
	May 2018		September 2018	
	Whole fish	Liver	Whole fish	Liver
PFOA	2.81	-	-	-
PFNA	3.00	-	-	-
PFOS	4.11	3.75	4.35	3.56

*On a wet weight basis

4 Conclusions

Monitoring based on water samples in the rivers Bjerkreimselva, Orreelva, Otra, Vegårdselva, Vikedalselva in 2018:

- Polycyclic aromatic hydrocarbon (PAH) concentrations were the highest and closest to WFD AA-EQS for the sampling location on Rivers Orrelva and Vegårdselva (annual average concentration of benzo[a]pyrene for the Orrelva is above WFD AA-EQS). Annual average estimates of concentrations for the selected monitoring sites on the other rivers were low or below LOQ but remained close to the AA-EQS for benzo[a]pyrene.
- Most organochlorinated priority substances were below LOQ in most water samples and below AA-EQS for pentachlorobenzene and γ-HCH. The Σ_7PCBs is below LOQ but the sum of LOQs is significantly higher than the proposed AA-EQS of 0.0024 ng L^{-1}.
- PBDEs were not found above LOQ in any of the samples collected from the five rivers. Similar results were obtained for HBCDD isomers with no HBCDD found above LOQ in any of the samples analysed in 2018. However, the LOQ is close to the EQS.

- Metal (filtered and/or total) concentrations were well below AA-EQS for all rivers. The annual average concentrations of As in Orreelva and Vegårdselva, and Cd and Zn in Vegårsdelva tend to be higher than in the other rivers. They remain however a factor of two below EQS.
- Mean concentrations of MCCPs were close to or at AA-EQS level or above for all rivers. Data for SCCPs, alkylphenols, chlorfenvenphos, cybutryne and DEHP were mostly below LOQ and below EQS. LOQ values for 4-tert-octylphenol were at or above EQS level.
- The monitoring of priority substances with bottle sampling results in much data below limits of quantifications. While in many cases limits of quantification are sufficiently low (with respect to WFD analytical performance criteria), the data do not inform us on actual levels or on trends in concentrations. One of the next steps in WFD monitoring programme is to establish robust methodologies to measure trends in concentrations with time. Options for this task for hydrophobic substances include the measurement of SPM-associated concentrations, the use of passive sampling devices and perhaps biota.

Biota monitoring of Alna, Gaula, Ørsta, Nausta and Ranaelva in 2018:

- Concentrations of hexachlorobenzene, pentachlorobenzene, and γ-HCH in fish samples (*brown trout and Atlantic salmon*) from the five rivers are well below EQS_{biota} values. Improvements in the sensitivity of the analysis for these compounds could be seen when comparing with 2017 data.
- The sums of seven indicator PCBs are above the EQS_{biota} value of 0.6 ng g^{-1} wet weight for all rivers.
- On a wet weight basis, the concentration of DDTs in fish from Ranaelva appear higher than for fish from other rivers but remain below the proposed human health based EQS_{biota} of 610 ng/g fish.
- The concentration of PBDEs in whole fish samples from the five selected rivers are well above EQS_{biota}. These exceedances are in line with European and more generally worldwide data. These results are in line with data from rivers sampled within this programme in 2017.
- Concentrations of the three HBCDD isomers are below LOQ and well below EQS_{biota} for fish samples from most rivers. Alpha-HBCDD was above LOQ in fish samples from the Alna.
- Fish concentrations of SCCPs, 4-n-octylphenol, 4-n-nonyphenols and DEHP were well below EQS_{biota} for all five rivers. LOQs for 4-tert-octylphenol were significantly higher than the EQS_{biota} rendering the assessment difficult. The average of three measurements of MCCPs in fish samples from the Alna is above the EQS_{biota}.
- When expressed on a lipid basis, concentrations of hexachlorobenzene and PCBs are highest in fish from the Rivers Alna (*Salmo trutta*) and Ranaelva (*Salmo salar*). Pentachlorobenzene and *p,p'*-DDE concentrations are highest in fish from the Alna and Ranaelva, respectively.
- Biomonitoring provides relatively useful information regarding the relative levels of organochlorine compounds in fish from different rivers. However, these measurements alone do not help us understand the reasons for these differences (e.g. fish different trophic levels or intrinsically different levels of contaminants in the rivers). Measurements above limits of quantification of OCPs in rivers without significant human impact can provide information on baseline or background levels of these compounds in unmpacted Norwegian freshwaters.

Emerging contaminants in the River Alna in 2018:

- UV filters were consistently found both in suspended particulate matter and water samples. Fish monitoring showed variable results. The most consistently detected UV filters in brown trout were BP3, EHMC and OC. This somewhat differs from 2017 when UV-327 and 328 were more consistently found above LOQ in fish.

- As for the data from 2017, SPM sampled in 2018 appeared generally more promising for sampling of organophosphorus compounds in the River Alna than composite water sampling. Organophosphorus compounds consistently detected in SPM were TEP, TiBP, TnBP, and TBEP, TCEP, TCPP, sum TCP, TPP, TnBP, TDCPP and EHDP. Concentrations ranged from 0.83 ng g^{-1} dw for TnBP up to 825 ng g^{-1} dw for TCPP. TCPP, TPP, TnBP, sumTCP, and EHDP were consistently detected in all fish samples analysed but concentrations did not exceed a few ng g^{-1} ww.
- As for 2017, a few bisphenols were detected in the first SPM sample (4,4'-BPA, 4,4'-BPS, 2,2'-BPF, 2,4'-BPF, and 4,4'-BPF). BPA, BPS and BPF were all found in water samples as well. BPA (4,4'-BPA) is present in highest concentrations, at the hundreds of ng L^{-1} or ng g^{-1} dw levels in water and SPM respectively. BPA and BPF were the only bisphenols in found above LOQ in brown trout samples.
- For most substances found both in SPM and water samples, estimated logKoc tend to show equilibrium distribution between organic carbon and water.
- Bioaccumulation factors (BAF) and biota-sediment accumulation factors (BSAF) were calculated for selected emerging contaminants in brown trout. A good agreement of lipid-based logBAFs can be seen for certain chemicals with $logK_{ow}$. For others such as OC, BAFs are clearly lower overestimated by $logK_{ow}$ indicating that some processes such as metabolism may contribute to lowering biota concentrations. SPM-based BSAF in the range of 0.001-1 tend to show limited potential for bioaccumulation or biomagnification for these emerging contaminants. All in all, BAFs and BSAFs tend to show a low potential for these compounds for fish bioaccumulation/magnification.
- PFOS, PFOA, 6:2 FTS, PFBS, PFPS, PFHxS, PFPA, PFHxA, PFHpA, PFNA and PFDA were found at concentrations of 0.4-8 ng L^{-1} in composite water samples from the Alna while only PFOS and 6:2 FTS were measured above LOQ in SPM. This list of PFAS compounds detected in water samples is similar to the 2017 data. In general, the identity and relative levels of PFAS compounds above LOQ in Alna river water is in agreement with stormwater data from the urbanfjord project, indicating storm waters and surface runoff is a non-negligeable source of PFAS chemicals to River Alna.
- PFDA, PFDoA, PFTrDA, PFTeDA, PFOS, PFDS and PFOSA were measured above LOQ in most fish samples. PFOS showed the highest concentrations of all PFAS compound monitored. Logarithm of brown trout bioconcentration factors (logBCF) could be calculated for selected PFAS compounds.

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Appendix A.

Details of the fish samples collected from the Rivers Alna, Gaula, Ørsta, Nausta and Ranaelva in 2018.

Alna - Emerging contaminants sampling

Alna															
Aquamonitor station	Station ID	Fish ID	Date captured	Species	Length (cm)	Weight (g)	Otholiths	Scales	Sex	Stage	Muscle (g)/Whole organism	Liver (g)	Sample	Mean (SD) length	Mean (SD) weight
EO-Alna - 2		1	06.06.2018	*Salmo trutt*	11	18.37	2	ok			15.4		1		
EO-Alna - 2		2	06.06.2018	*Salmo trutt*	11.6	20.23	2	ok			17.3		1		
EO-Alna - 2		3	06.06.2018	*Salmo trutt*	11.5	22.5	2	ok	M	2	19.8		1		
EO-Alna - 2		4	06.06.2018	*Salmo trutt*	10.6	14.49	2	ok			11.8		1		
EO-Alna - 2		5	06.06.2018	*Salmo trutt*	10.9	17.6	2	ok	F	2	14.8		1	11.1(0.4)	18.6(3.0)
EO-Alna - 2		10	06.06.2018	*Salmo trutt*	16.7	64.27	2	ok	F	2	13.9	1.06	2		
EO-Alna - 2		11	06.06.2018	*Salmo trutt*	15.9	55.68	2	ok	M	2	8.08	0.73	2		
EO-Alna - 2		12	06.06.2018	*Salmo trutt*	17	71.25	2	ok	F	2	13.13	0.88	2		
EO-Alna - 2		13	06.06.2018	*Salmo trutt*	14.8	46.35	2	ok	F	1	7.48	0.64	2		
EO-Alna - 2		14	06.06.2018	*Salmo trutt*	14.4	40.31	2	ok	F	2	6.2	0.53	2	15.8(1.1)	55.6(12.6)
EO-Alna - 2		15	06.06.2018	*Salmo trutt*	19.4	100.87	2	ok			17.2	1.6	3		
EO-Alna - 2		16	06.06.2018	*Salmo trutt*	19.2	100.55	2	ok	F	2/7	16.35	1.7	3		
EO-Alna - 2		17	06.06.2018	*Salmo trutt*	18.9	100.99	2	ok	M	2/7	21.4	1.25	3		
EO-Alna - 2		18	06.06.2018	*Salmo trutt*	17.5	85.68	2	ok	M	2/7	12.12	1.35	3		
EO-Alna - 2		19	06.06.2018	*Salmo trutt*	20.1	112.94	2	ok	F	2/7	15.46	1.87	3	19.0(1.0)	100.2(9.7)
EO-Alna - 2		34	19.09.2018	*Salmo trutt*	32	303.6	2	ok	F	5	29.8	11.28	4		
EO-Alna - 2		20	19.09.2018	*Salmo trutt*	25.5	203.2	2	ok	F	6	29.7	5.3	4		
EO-Alna - 2		21	19.09.2018	*Salmo trutt*	28.5	239	2	ok	F	5	31.9	4.75	4		
EO-Alna - 2		22	19.09.2018	*Salmo trutt*	26.3	189.5	2	ok	F	6	30.7	3.63	4		
EO-Alna - 2		23	19.09.2018	*Salmo trutt*	33.2	440.7	2	ok	F	6	33.4	10.74	4	29.1(3.4)	275.2(102.5)
EO-Alna - 2		24	19.09.2018	*Salmo trutt*	23.4	155.9	2	ok	M	5	37.2	1.6	5		
EO-Alna - 2		25	19.09.2018	*Salmo trutt*	20.6	105.7	2	ok	M	5	23.9	1.28	5		
EO-Alna - 2		26	19.09.2018	*Salmo trutt*	20.8	116.3	2	ok	M	6	29.3	1.63	5		
EO-Alna - 2		27	19.09.2018	*Salmo trutt*	21.5	115.6	2	ok	M	2	32.6	1.6	5		
EO-Alna - 2		28	19.09.2018	*Salmo trutt*	22.4	143.6	2	ok	F	5	30.4	3.7	5	21.7(1.2)	127.4(21.3)
EO-Alna - 2		29	19.09.2018	*Salmo trutt*	15.1	36	1	ok	M	2	33.2		6		
EO-Alna - 2		30	19.09.2018	*Salmo trutt*	15.6	46.5	2	ok	M	5	45		6		
EO-Alna - 2		31	19.09.2018	*Salmo trutt*	14.9	37.4	1	ok	F	2	35.7		6		
EO-Alna - 2		32	19.09.2018	*Salmo trutt*	14.6	42.4	2	ok	M	5	39.8		6		
EO-Alna - 2		33	19.09.2018	*Salmo trutt*	16.2	54.3	2	ok	M	5	52		6	15.3(0.6)	43.3(7.4)

Sampling of five rivers

Alna

Alna															
Aquamonitor station	Station ID	Fish ID	Date captured	Species	Length (cm)	Weight (g)	Otholiths	Scales	Sex	Stage	Muscle (g)/Whole organism	Liver (g)	Sample	Mean (SD) length	Mean (SD) weight
EO-Alna-4		35	08.08.2018	*Salmo trutt*	14.7	38	2	ok	M	4	36.1		7		
EO-Alna-4		38	08.08.2018	*Salmo trutt*	14.5	30.3	2	ok	F	3	27.9		7		
EO-Alna-4		39	08.08.2018	*Salmo trutt*	12.9	22.4	1	ok	Unkn.	2	20.7		7		
EO-Alna-4		40	08.08.2018	*Salmo trutt*	15.8	42.3	2	ok	F	2	39.3		7		
EO-Alna-4		44	08.08.2018	*Salmo trutt*	12.8	25.2	2	ok	Unkn.	2	23.9		7	14.1(1.3)	31.6(8.4)
OSLEALN		45	08.08.2018	*Salmo trutt*	6.9	4.1	2	ok	Unkn.	1	4		8		
OSLEALN		48	08.08.2018	*Salmo trutt*	12.6	27.7	2	ok	F	2	26.5		8		
OSLEALN		50	08.08.2018	*Salmo trutt*	6.9	3.4	2	ok	Unkn.		3		8		
OSLEALN		52	08.08.2018	*Salmo trutt*	6.8	3.8	2	ok	Unkn.		3.4		8		
OSLEALN		53	08.08.2018	*Salmo trutt*	6.5	3.8	2	ok	Unkn.		3.6		8		
EO-Alna-4		41	08.08.2018	*Salmo trutt*	11.1	16.5	2	ok	M	2	15.5		8		
EO-Alna-4		42	08.08.2018	*Salmo trutt*	11.7	18.2	2	ok	M	2	17		8		
EO-Alna-4		36	08.08.2018	*Salmo trutt*	11.6	18	2	ok	Unkn.	2	16.8		8		
EO-Alna-4		37	08.08.2018	*Salmo trutt*	11.7	18.3	2	ok	Unkn.	2	17.3		8		
EO-Alna-4		43	08.08.2018	*Salmo trutt*	11.7	19.4	2	ok	Unkn.	2	18		8	9.8(2.6)	13.3(8.7)
OSLEALN		46	08.08.2018	*Salmo trutt*	20.4	111.1	2	ok	M	5	32.9	1.2	9		
OSLEALN		47	08.08.2018	*Salmo trutt*	25.8	285.7	2	ok	F	5	79.2	6.1	9		
OSLEALN		49	08.08.2018	*Salmo trutt*	14.8	41.8	2	ok	F	2	13.7	0.6	9		
OSLEALN		51	08.08.2018	*Salmo trutt*	15.2	49.2	2	ok	Unkn.		15.2	0.7	9	19.1(5.2)	122.0(113.5)

Gaula

Gaula															
Aquamonitor station	Station ID	Fish ID	Date captured	Species	Length (cm)	Weight (g)	Otholiths	Scales	Sex	Stage	Muscle (g)/Whole organism	Liver (g)	Sample	Mean (SD) length	Mean (SD) weight
EO-Gaula-1	Gravråk	1		*Salmo trutt*	13	21.62	2	ok	F	2	20.3		1		
EO-Gaula-1	Gravråk	2		*Salmo trutt*	12	14	2	ok	F	2	12.9		1		
EO-Gaula-1	Gravråk	3		*Salmo trutt*	12.2	19.2	2	ok	F	2	17.8		1		
EO-Gaula-1	Gravråk	4		*Salmo trutt*	12.6	17.26	2	ok	F	2	16.0		1		
EO-Gaula-1	Gravråk	5		*Salmo trutt*	12.5	20.4	2	ok	F	2	19.4		1	12.5(0.4)	18.5(3.0)
EO-Gaula-3	Lundamo	6		*Salmo trutt*	11.8	12.99	2	ok	M	1	11.9		2		
EO-Gaula-3	Lundamo	7		*Salmo trutt*	12.5	17.83	2	ok	M	1	16.6		2		
EO-Gaula-3	Lundamo	8		*Salmo trutt*	12	15.1	2	ok	F	2	14.0		2		
EO-Gaula-3	Lundamo	9		*Salmo trutt*	11.2	11.65	2	ok	F	2	10.6		2		
EO-Gaula-3	Lundamo	10		*Salmo trutt*	11.8	13.5	2	ok	M	1	12.6		2	11.9(0.5)	14.2(2.4)
EO-Gaula-2	Borten Lose	11		*Salmo trutt*	13	21.04	2	ok	F	2	19.4		3		
EO-Gaula-2	Borten Lose	12		*Salmo trutt*	13.6	23.19	2	ok	F	2	21.3		3		
EO-Gaula-2	Borten Lose	13		*Salmo trutt*	13.2	20.36	1	ok	F	2	18.9		3		
EO-Gaula-2	Borten Lose	14		*Salmo trutt*	12.8	20.58	2	ok	M	1	19.1		3		
EO-Gaula-2	Borten Lose	15		*Salmo trutt*	12.3	18.68	2	ok	F	2	17.3		3	13.0(0.5)	20.8(1.6)

Ørsta

Ørstaelva

Aquamonitor station	Station ID	Fish ID	Date captured	Species	Length (cm)	Weight (g)	Otholiths	Scales	Sex	Stage	Muscle (g)/Whole organism	Liver (g)	Sample	Mean (SD) length	Mean (SD) weight
EO-Ørsta-1	Ørstaelva	1	08.08.2018	*Salmo salar*	12	21.7	2	ok	unkn.		20.5		1		
EO-Ørsta-1	Ørstaelva	2	08.08.2018	*Salmo salar*	16	48.8	2	ok	F	3	46.0		1		
EO-Ørsta-1	Ørstaelva	3	08.08.2018	*Salmo salar*	13	25	2	ok	M	5	23.2		1		
EO-Ørsta-1	Ørstaelva	4	08.08.2018	*Salmo salar*	14	29.5	2	ok	F	2	27.3		1		
EO-Ørsta-1	Ørstaelva	5	08.08.2018	*Salmo salar*	11.5	14.1	2	ok	F	2	13.0		1	13.3(1.8)	27.8(13.0)
EO-Ørsta-2	Ørstaelva	6	08.08.2018	*Salmo salar*	11.5	15.5	2	ok	F	2	14.5		2		
EO-Ørsta-2	Ørstaelva	7	08.08.2018	*Salmo salar*	11	15.2	2	ok	F	2	13.9		2		
EO-Ørsta-2	Ørstaelva	8	08.08.2018	*Salmo salar*	12	17	2	ok	F	2	15.7		2		
EO-Ørsta-2	Ørstaelva	9	08.08.2018	*Salmo salar*	10.5	11.2	1	ok	F	2	10.1		2		
EO-Ørsta-2	Ørstaelva	10	08.08.2018	*Salmo salar*	11.5	17.1	2	ok	F	2	15.9		2	11.3(0.6)	15.2(2.4)
EO-Ørsta-3	Ørstaelva	11	08.08.2018	*Salmo salar*	9.5	8.3	2	ok	F	2	7.4		3		
EO-Ørsta-3	Ørstaelva	12	08.08.2018	*Salmo salar*	9.5	9.1	2	ok	F	2	8.2		3		
EO-Ørsta-3	Ørstaelva	13	08.08.2018	*Salmo salar*	11	13.2	2	ok	M	5	12.1		3		
EO-Ørsta-3	Ørstaelva	14	08.08.2018	*Salmo salar*	8.5	5.9	2	ok	unkn.		5.0		3	9.6(1.0)	9.1(3.0)

Nausta

Nausta

Aquamonitor station	Station ID	Fish ID	Date captured	Species	Length (cm)	Weight (g)	Otholiths	Scales	Sex	Stage	Muscle (g)/Whole organism	Liver (g)	Sample	Mean (SD) length	Mean (SD) weight
EO-Nausta-1	17	1	01.11.2018	*Salmo trutt*	11.2	13.4	2	ok	M?	1	12.8		1		
EO-Nausta-1	16	2	01.11.2018	*Salmo trutt*	11.2	15.9	2	ok	M?	1	15.3		1		
EO-Nausta-1	17	3	01.11.2018	*Salmo trutt*	12.3	20.1	2	ok	M?	1	18.7		1		
EO-Nausta-1	17	4	01.11.2018	*Salmo trutt*	12	19.3	2	ok	M?	1	17.8		1		
EO-Nausta-1	17	5	01.11.2018	*Salmo trutt*	12.7	21.7	2	ok	M?	1	20.2		1	11.9(0.7)	18.1(3.4)
EO-Nausta-1	19	6	01.11.2018	*Salmo trutt*	12.7	23.7	2	ok	M?	1	22.0		2		
EO-Nausta-1	17	7	01.11.2018	*Salmo trutt*	13	24.7	2	ok	M	1	22.8		2		
EO-Nausta-1	17	8	01.11.2018	*Salmo trutt*	14.4	31	2	ok	M	1	28.9		2	13.4(0.9)	26.5(4.0)
EO-Nausta-3	30	9	01.11.2018	*Salmo trutt*	16.4	47.7	2	ok	M	1	17.8	0.4	3		
EO-Nausta-3	3	10	01.11.2018	*Salmo trutt*	20.1	96.6	2	ok	M	4	32.8	1.3	3	18.3(2.6)	72.2(34.6)

Rana

Rana															
Aquamonitor station	Station ID	Fish ID	Date captured	Species	Length (cm)	Weight (g)	Otholiths	Scales	Sex	Stage	Muscle (g)/Whole organism	Liver (g)	Sample	Mean (SD) length	Mean (SD) weight
EO-Rana-1		1	07.11.2018	*Salmo salar*	12.2	18.9	2	ok	M	3-4	17.9		1		
EO-Rana-1		2	07.11.2018	*Salmo salar*	12.2	16.2	2	ok	F	1-2	15.3		1		
EO-Rana-1		3	07.11.2018	*Salmo salar*	11.5	15.9	2	ok	M	3-4	14.9		1		
EO-Rana-1		4	07.11.2018	*Salmo salar*	11.5	17.9	2	ok	F	1-2	16.6		1		
EO-Rana-1		5	07.11.2018	*Salmo salar*	11.9	15.6	2	ok	M	1	14.4		1		
EO-Rana-1		6	07.11.2018	*Salmo salar*	11	15.4	2	ok	M	3-4	14.3		1	11.7(0.5)	16.7(1.4)
EO-Rana-1		7	07.11.2018	*Salmo salar*	11.6	14.4	2	ok	Unkn.	1	13.3		2		
EO-Rana-1		8	07.11.2018	*Salmo salar*	11	14.6	2	ok	F	1-2	13.5		2		
EO-Rana-1		9	07.11.2018	*Salmo salar*	11	14.3	2	ok	F	1-2	13.2		2		
EO-Rana-1		10	07.11.2018	*Salmo salar*	11.3	13.5	2	ok	M	3-4	12.5		2		
EO-Rana-1		11	07.11.2018	*Salmo salar*	11.6	13.2	2	ok	F	1-2	12.4		2		
EO-Rana-1		12	07.11.2018	*Salmo salar*	11	12.9	2	ok	F	1-2	12.2		2	11.3(0.3)	13.8(0.7)
EO-Rana-1		13	07.11.2018	*Salmo salar*	10.6	9.3	2	ok	Unkn.	1	8.6		3		
EO-Rana-1		14	07.11.2018	*Salmo salar*	10.9	13.5	2	ok	M	3-4	12.4		3		
EO-Rana-1		15	07.11.2018	*Salmo salar*	11	11.4	2	ok	F	1-2	10.3		3		
EO-Rana-1		16	07.11.2018	*Salmo salar*	11	13.1	2	ok	M	1	11.6		3		
EO-Rana-1		17	07.11.2018	*Salmo salar*	11	12.7	2	ok	Unkn.	1	11		3		
EO-Rana-1		18	07.11.2018	*Salmo salar*	10.9	1.6	2	ok	F	1	9.8		3	10.9(0.2)	10.3(4.5)

Appendix 2.

Yearly discharges of chemicals from the Rivers Bjerkreimselva, Orrelva, Otra, Vegårdselva and Vikeldalselva for 2018

TABLE A1
Yearly discharge of polycyclic aromatic hydrocarbons in five rivers

	Bjerkreimselva	Orrelva	Otra	Vegårdselva	Vikedalselva
Naphthalene	N/A	N/A	N/A	N/A	N/A
Acenaphthylene	<1.3	<0.13	<4.85	<0.34	<0.31
Acenaphthene	1.0	0.15	2.6	0.2	0.11
Fluorene	0.25	0.06	1.0	0.06	0.05
Phenanthrene	0.71	0.17	3.5	0.25	0.15
Anthracene	<0.3	<0.03	<1	<0.07	<0.06
Fluoranthene	0.42	0.11	2.6	0.27	0.07
Pyrene	0.19	0.07	1.1	0.13	0.04
Benz[a]anthracene	<0.3	0.02	<1.0	0.05	0.06
Chrysene	<0.3	0.04	0.9	0.11	<0.06
Benzo[b,j]fluoranthene	0.24	0.09	1.4	0.21	0.06
Benzo[k]fluoranthene	<0.3	0.03	<1.0	0.07	0.06
Benzo[a]pyrene	<0.3	0.03	<1.0	0.05	0.06
Indeno[1,2,3-cd]pyrene	<0.3	0.08	0.8	0.11	0.06
Dibenzo[ac/ah]anthracene	<0.3	0.05	<1.0	<0.07	0.06
Benzo[ghi]perylene	0.22	0.10	0.9	0.12	0.06
Σ_{16}PAHs	5.9	1.2	24.5	2.2	1.2
*Data in kg/year					

TABLE A2

Yearly discharge of polychlorinated biphenyls and other chlorinated organic compounds in five rivers

	Bjerkreimselva	Orrelva	Otra	Vegårdselva	Vikedalselva
Pentachlorobenzene	<0.2	<0.02	<0.73	<0.05	<0.05
Hexachlorobenzene	<0.2	<0.02	<0.73	<0.05	<0.05
γ-HCH	<4	<0.3	<12	<0.7	<0.6
PCB28/31	<0.8	<0.08	<2.9	<0.2	<0.2
PCB52	<0.8	<0.07	<2.7	<0.2	<0.2
PCB101	<1	<0.10	<3.7	<0.25	<0.3
PCB118	<0.8	<0.07	<2.7	<0.2	<0.2
PCB153	<0.8	<0.07	<2.7	<0.2	<0.2
PCB138	<0.8	<0.07	<2.7	<0.2	<0.2
PCB180	<0.8	<0.07	<2.7	<0.2	<0.2
p,p'-DDE	<0.8	<0.07	<2.7	<0.2	<0.2
p,p'-DDD	<1	<0.10	<3.7	<0.25	<0.3
p,p'-DDT	<1.4	<0.14	<5.1	<0.36	<0.4
Σ_7PCBs	<5.5	<0.55	<20	<1.4	<1.3

*Data kg/year

TABLE A3

Yearly discharge of polybrominated diphenyl ethers in five rivers

	Bjerkreimselva	Orrelva	Otra	Vegårdselva	Vikedalselva
PBDE28	<0.03	<0.003	<0.10	<0.007	<0.006
PBDE47	<0.04	<0.004	<0.15	<0.01	<0.01
PBDE100	<0.03	<0.003	<0.10	<0.007	<0.006
PBDE99	<0.04	<0.004	<0.15	<0.01	<0.01
PBDE154	<0.04	<0.004	<0.15	<0.01	<0.01
PBDE153	<0.05	<0.005	<0.19	<0.014	0.013
Σ_5PBDEs	<0.23	<0.02	<0.82	<0.06	<0.05

*Data in g/year for River Alna and in kg/year for the other rivers

TABLE A4

Yearly discharge of hexabromocyclododecane in five rivers

	Bjerkreimselva	Orrelva	Otra	Vegårdselva	Vikedalselva
α-HBCDD	<0.7	<0.07	<2.4	<0.2	<0.2
β-HBCDD	<0.7	<0.07	<2.4	<0.2	<0.2
γ-HBCDD	<0.7	<0.07	<2.4	<0.2	<0.2
Σ_3HBCDD	<2.0	<0.2	<7.3	<0.5	<0.5

*Data in g/year for River Alna and in kg/year for the other rivers

TABLE A5

Yearly discharge of short and medium chain chlorinated paraffins in five rivers

Chemical	Bjerkreimselva	Orrelva	Otra	Vegårdselva	Vikedalselva
SCCP	39	3	131	7	7
MCCP	135	7	237	31	10

*Data in kg/year for all rivers

TABLE A6

Yearly discharge of nonylphenol, octylphenol and 4-tert-octylphenol in five rivers

Chemical	Bjerkreimselva	Orrelva	Otra	Vegårdselva	Vikedalselva
Nonylphenol	<152	<12	<420	<23	<29
Octylphenol	<81	<7	<207	<14	<15
4-tert-octylphenol	<198	<28	<976	<67	<65

*Data in kg/year for all rivers

TABLE A7

Yearly discharge of chlorfenvinfos, cybutryne and DEHP in five rivers

Chemical	Bjerkreimselva	Orrelva	Otra	Vegårdselva	Vikedalselva
Chlorfenvinfos	<1.0	<0.13	<3.6	<0.25	<0.23
Cybutryne	<1.2	<0.30	<2.3	<0.19	<0.18
DEHP	<70	<5	<161	<13	<17

*Data in kg/year for all rivers

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