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# Priority substances and emerging contaminants in selected Norwegian rivers – The River Monitoring Programme 2019

Photo: NIVA

Norwegian Institute for Water Research

# REPORT

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Summary

Riverine inputs and direct discharges to Norwegian coastal waters in 2019 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. Levels observed were compared with annual average environmental quality standards (AA-EQS). 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 2019 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. Observerte konsentrasjonsnivåer ble sammenlignet med grenseverdier for årlig gjennomsnitt (AA-EQS). 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 River Monitoring Programme is carried out by the Norwegian Institute for Water Research in collaboration with consortium partners. Results from the 2019 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 under the main programme.

Besides NIVA, involved collaborating partners include the Norwegian Water Resources and Energy Directorate (NVE) and the Norwegian Institute for Air Research (NILU). Contact persons at the Norwegian Environment Agency (NEA) has been Gunn Lise Haugestøl, Preben Danielsen and Eivind Farmen.

Hans Fredrik Veiteberg Braaten and Cathrine Gundersen (both NIVA) co-ordinated the river monitoring programme in 2019. 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, and NILU has analysed selected priority substances and emerging contaminants. 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 Vosso, Nausta, Driva, Orkla and Nidelva.

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

Oslo, Nov. 11th 2020

Hans Fredrik Veiteberg Braaten

# Table of contents

# 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 2017-2019, the programme was modified by increasing the number of monitored rivers from three to fifteen. 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 four 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 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 2019 with multiple samples collected on each occasion.

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 Driva, Nausta, Nidelva, Orkla, and Vosso showed that concentrations of polycyclic aromatic hydrocarbons (PAHs) were slightly higher (and closest to WFD AA-EQS) for the sampling site of the River Vosso. The mean whole water concentration of benzo[a]pyrene was close to or above AA-EQS at the selected monitoring locations for this river. The $\Sigma_7$PCBs 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 mostly well below AA-EQS for all rivers. Elevated concentrations of Cd, Cu and Zn were observed for the river Orkla with Zn concentrations at EQS level.

MCCPs were below LOQ with LOQ at or above AA-EQS. Data for SCCPs, alkylphenols, chlorfenvenphos, cybutryne and DEHP were mostly below LOQ and below EQS. For 2019, LOQ values for 4-tert-octylphenol were well below EQS level and allowed quantification of the compound at concentrations a factor of 4 or more below EQS.

The programme of monitoring of the distribution of emerging contaminants in the Alna river for 2019 was simplified compared with 2017 and slightly modified compared with 2018. Sampling in 2019

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. SPM remained the matrix of choice for the detection and quantification of OPs in 2019. Organophosphorus compounds consistently detected in SPM were 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), TXP (25155-23-1), TEHP (78-42-2) and EHDP (1241-94-7). TCPP, TPP, TnBP, sumTCP, and EHDP were consistently detected in all fish samples analysed but concentrations did not exceed 10 ng $g^{-1}$ w.w. As for data from previous years, 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 log$K_{oc}$ values for UV filters and OPs tend to show equilibrium distribution between suspended organic carbon and water. Log$K_{ow}$ does not appear to be as good a predictor as log$K_{oc}$ for certain OPs (TCEP, TCPP), bisphenols and BP3.

Bioaccumulation factors (BAF) and biota-sediment accumulation factors (BSAF) were calculated for selected emerging contaminants in brown trout. These data are in line with data reported for 2018. A good agreement of lipid-based logBAFs with log$K_{ow}$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 and 2018. 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. A slightly higher number of PFGAS compounds were found above LOQ in fish liver samples compared with previous years. PFOS showed the highest concentrations of all PFAS compound monitored. Logarithm of brown trout bioconcentration factors (logBCF) could be calculated for selected PFAS compounds.

# Sammendrag

Tittel: Vannrammedirektivets prioriterte stoffer og nye miljøgifter i et utvalg norske elver
År: 2020
Forfatter(e): Ian Allan, Marthe Torunn Solhaug Jenssen, Kine Bæk, Hans Fredrik Veiteberg Braaten
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*Elveovervåkingsprogrammet* estimerer årlige tilførsler av miljøgifter til norske havområder for et lite utvalg elver som en del av Norges forpliktelser under Oslo-Paris konvensjonen. I perioden 2013-2016 ble konsentrasjoner og tilførsler av miljøgifter målt og beregnet i Alna, Drammenselva og Glomma, som en del av *Elvetilførselsprogrammet*. I perioden 2017-2019 er programmet utvidet fra tre til 15 elver, samt at resultater skal innfri målsetningene for overvåking i EUs Vannrammedirektiv. Dette betyr at flere miljøgifter bestemmes (økt fokus på Vannrammedirektivets prioriterte stoffer) i flere matrikser (vann, biota og partikulært materiale).

For fem elver, Driva, Nausta, Nidelva, Orkla og Vosso, ble overvåking av prioriterte stoffer og andre vannregionspesifikke forbindelser gjennomført ved innsamling av vannprøver. Prøvene ble i 2019 samlet fra én 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).

Det ble også gjennomført en mer detaljert analyse av utvalgte nye miljøgifter i Alna, inkludert bestemmelse av UV-stoffer, organofosfater, bisfenoler og perfluorerte forbindelser (PFAS). Siden disse forbindelsene varierer i sine respektive fysisk-kjemiske egenskaper ble ulike prøvetakingsmetoder benyttet: innsamling av blandprøver av vann; suspendert partikulært materiale (SPM); og fisk (brunørret, *Salmo trutta*). Feltarbeidet ble gjennomført ved to anledninger, i juni og september 2019.

Konsentrasjonene av prioriterte stoffer var lavere en vanndirektivets EQS-verdier for de fleste prøvelokalitetene som ble undersøkt i 2019. Stikkprøver av vann ga stort sett konsentrasjoner under gjeldende analytiske kvantifiseringsgrenser (LOQ), selv om LOQ stort sett innfridde vannforskriftens ytelseskriterier. Prøvene fra Driva, Nausta, Nidelva, Orkla og Vosso viste høyest konsentrasjoner av polysykliske aromatiske hydrokarboner (PAH), og nivåer nærmest den foreslåtte AA-EQS, i Vosso. Konsentrasjoner av benzo[a]pyren i vann var i nærheten av eller over AA-EQS for utvalgte stasjoner i Vosso. Summen av syv polyklorerte bifenyler ($\Sigma_7$PCB) var under LOQ i alle undersøkte elver, men det er verdt å merke seg at LOQ er signifikant høyere enn den foreslåtte AA-EQS (0.0024 ng $L^{-1}$). Polybrominerte difenyletere (PBDE) og summen av isomerer av heksabromocyklododekan (HBCDD) ble ikke detektert i noen av elvene. Men LOQ er i nærheten av AA-EQS for disse stoffene. Konsentrasjonen av filtrerte metaller var stort sett lavere enn AA-EQS for alle de fem elvene. Forhøyede konsentrasjoner av Cd, Cu og Zn ble funnet i Orkla, der Zn-konsentrasjonene var på nivå med EQS. Nivåer av mellomkjedete klorerte parafiner (MCCP) var under LOQ, med LOQ lik eller høyere enn AA-EQS. Data for kortkjedete klorerte parafiner (SCCP), alkylfenoler, klorfenvinfos, cybutryne og ftalater (DEHP) var stort sett under både LOQ og AA-EQS. I 2019 var LOQ for 4-tert-octylfenol lavere enn EQS og muliggjorde en kvantifisering av forbindelsen 4-ganger lavere enn EQS.

For utvalgte nye miljøgifter i vannprøver fra Alna ble det i 2019 fokusert på prøver av vann, 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. For kvantifisering av organofosfater er SPM å foretrekke slik som tidligere år. Organofosfater som ble detektert i SPM inkluderer 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), TXP (25155-23-1), TEHP (78-42-2) og EHDP (1241-94-7). TCPP, TPP, TnBP, sumTCP, og EHDP ble detektert i alle fiskeprøver, men ingen konsentrasjner var høyere enn 10 ng $g^{-1}$ (våtvekt). Slik som tidligere år ble bisfenolene BPA, BPS og BPF funnet i vannprøver, med høyest nivåer av BPA (4,4'-BPA). BPA og BPF var de eneste bisfenolene som ble funnet i konsentrasjoner høyere enn LOQ i fiskeprøver. Estimerte fordelingskoeffisienter ($logK_{OC}$) for UV-stoffer og organofosfater viser at forbindelsene er likevektsfordelt mellom suspendert organisk karbon og vann. $LogK_{OW}$ virker å være en mindre god prediktor enn $logK_{OC}$ for enkelte organofosfater (TCEP, TCPP, bisfenoler og BP3).

Bioakkumuleringsfaktorer (BAF) og biota-til-sediment-akkumuleringsfaktorer (BSAF) ble beregnet for et utvalg nye miljøgifter i fiskeprøver av brunørret. Resultatene stemmer godt overens med det som ble dokumentert i 2019. Lipidbaserte logBAF stemmer godt overens med $logK_{ow}$ for enkelte forbindelser. For andre forbindelser, som for eksempel oktocrylene, er BAF tydelig overestimert sammenlignet med $logK_{ow}$, noe som kan være en indikasjon på at prosesser som metabolisme reduserer konsentrasjoner i biota. I tillegg viser beregninger av BSAF (basert på SPM) i intervallet 0.001-1 at forbindelsene har et begrenset potensial for bioakkumulering og biomagnifisering i fisk.

Listen over PFAS-forbindelser som ble detektert i vannprøver og SPM i Alna i 2019 er lik det som ble dokumentert i 2017 og 2018. Identifikasjon og konsentrasjonsnivåer av PFAS detektert over LOQ i Alna fra Elveovervåkingsprogrammet i 2019 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. Sammenlignet med tidligere år ble et noe høyere antall PFGAS-forbindelser funnet i konsentrasjoner over LOQ i fiskelever. Av alle PFAS-forbindelser som ble bestemt, var det høyest konsentrasjoner av PFOS. Biokonsentrasjonsfaktorer (som logBCF) var mulig å beregne for utvalgte PFAS-forbindelser.

# 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[1]. 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 2019 where five of these were prioritised for the determination of WFD priority substances (PS), river basin-specific pollutants and emerging contaminants (Table 1).

**Table 1. Parameters investigated in the Norwegian River Monitoring Programme 2019**

**A summary table of groups of parameters investigated in the Norwegian River Monitoring Program (RMP). Rivers Driva, Nausta, Nidelva, Orkla and Vosso were investigated for EU Water Framework Directive (WFD) priority substances and emerging contaminants in 2019.**

| River | Group of parameters estimated (n=yearly sampling events) | | | |
|---|---|---|---|---|
| | **General water chemistry*** | **Metals**** | **WFD priority substances** | **Emerging contaminants** |
| Driva | n = 12 | n = 4 | n = 4 | n = 4 |
| Nausta | n = 12 | n = 4 | n = 4 | n = 4 |
| Nidelva | n = 12 | n = 4 | n = 4 | n = 4 |
| Orkla | n = 12 | n = 4 | n = 4 | n = 4 |
| Vosso | 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[2,3] at national-level and guidelines for monitoring[4]. The framework aims to protect and restore clean waters across Europe and ensure its

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

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

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

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

long-term, sustainable use, including river basins[5]. 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[6]. 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"[7].

Currently, the list of priority substances consists of 45 compounds for which EQSs have been derived[8] (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)<br>0.45 (class 2)<br>0.6 (class 3)<br>0.9 (class 4)<br>1.5 (class 5) | < 0.08 (class 1)<br>0.08 (class 2)<br>0.09 (class 3)<br>0.15 (class 4)<br>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 |

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

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

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

[8] 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 |
| 34 | 115-32-2 | Dicofol | - | |
| 35 | 1763-23-1 | Perfluorooctylsulphonate acid (PFOS) | 36 | 0.00065 |
| 36 | 124495-18-7 | Quinoxyfen | 2.7 | 0.15 |
| 37 | See footnote[a] | Dioxin and dioxin-like compounds | - | |
| 38 | 74070-46-5 | Aclonifen | 0.12 | 0.12 |
| 39 | 42576-02-3 | Bifenox | 0.12 | 0.012 |
| 40 | 28159-98-0 | Cybutryne | 0.016 | 0.0025 |
| 41 | 52315-07-8[b] | Cypermethrin | 0.0006 | 0.000008 |
| 42 | 62-73-7 | Dichlorvos | 0.0007 | 0.0006 |
| 43 | See footnote[c] | Hexabromocyclododecane | 0.5 | 0.0016 |
| 44 | 76-44-8/1024-57-3 | Heptachlor and heptachlor epoxide | 0.0003 | 0.0000002 |
| 45 | 886-50-0 | Terbutryne | 0.34 | 0.065 |

[a] This includes: 7 polychlorinated dibenzo-*p*-dioxins: 2,3,7,8-T4CDD (CAS 1746-01-6), 1,2,3,7,8-P5CDD (CAS 40321-76-4), 1,2,3,4,7,8-H6CDD (CAS 39227-28-6), 1,2,3,6,7,8-H6CDD (CAS 57653-85-7), 1,2,3,7,8,9-H6CDD (CAS 19408-74-3), 1,2,3,4,6,7,8-H7CDD (CAS 35822-46-9), 1,2,3,4,6,7,8,9-O8CDD (CAS 3268-87-9) 10 polychlorinated dibenzofuran: 2,3,7,8-T4CDF (CAS 51207-31-9), 1,2,3,7,8-P5CDF (CAS 57117-41-6), 2,3,4,7,8-P5CDF (CAS 57117-31-4), 1,2,3,4,7,8-H6CDF (CAS 70648-26-9), 1,2,3,6,7,8-H6CDF (CAS 57117-44-9), 1,2,3,7,8,9-H6CDF (CAS 72918-21-9), 2,3,4,6,7,8-H6CDF (CAS 60851-34-5), 1,2,3,4,6,7,8-H7CDF (CAS 67562-39-4), 1,2,3,4,7,8,9-H7CDF (CAS 55673-89-7), 1,2,3,4,6,7,8,9-O8CDF (CAS 39001-02-0) 12 dioxin-like polychlorinated biphenyls: 3,3',4,4'-T4CB (PCB 77, CAS 32598-13-3), 3,3',4',5-T4CB (PCB 81, CAS 70362-50-4), 2,3,3',4,4'-P5CB (PCB 105, CAS 32598-14-4), 2,3,4,4',5-P5CB (PCB 114, CAS 74472-37-0), 2,3',4,4',5-P5CB (PCB 118, CAS 31508-00-6), 2,3',4,4',5'-P5CB (PCB 123, CAS 65510-44-3), 3,3',4,4',5-P5CB (PCB 126, CAS 57465-28-8), 2,3,3',4,4',5-H6CB (PCB 156, CAS 38380-08-4), 2,3,3',4,4',5'-H6CB (PCB 157, CAS 69782-90-7), 2,3',4,4',5,5'-H6CB (PCB 167, CAS 52663-72-6), 3,3',4,4',5,5'-H6CB (PCB 169, CAS 32774-16-6), 2,3,3',4,4',5,5'-H7CB (PCB 189, CAS 39635-31-9).[b] CAS 52315-07-8 relates to a mixture of isomers of cypermethrin; alpha-cypermethrin (CAS 67375-30-8), beta-cypermethrin (CAS 65731-84-2), theta-cypermethrin (CAS 71697-59-1) og zeta-cypermethrin (52315-07-8); [c]This includes 1,3,5,7,9,11-hexabromocyclododecane (CAS 25637-99-4), 1,2,5,6,9,10-hexabromocyclododecane (CAS 3194-55-6), α-hexabromocyclododecane (CAS 134237-50-6), β-hexabromocyclododecane (CAS 134237-51-7) and γ- hexabromocyclododecane (CAS 134237-52-8).

## 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[9]:

- **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 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[10]. 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.

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

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

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). 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.

# 2 Methods

## 2.1 Sampling methodologies

### 2.1.1 Sampling for priority substances in five rivers

Water samples were collected four times in 2019 in the five rivers Vosso, Nausta, Driva, Orkla and Nidelva (Figure 1, Table 3) 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 or 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)[11].

**Table 3: Location of the 5 rivers and water sampling dates for the EU Water Framework Directive (WFD) priority substances and emerging contaminants in 2019.**

| River* | River number** | Latitude(N) | Longitude (E) | Sampling date 1 | Sampling date 2 | Sampling date 3 | Sampling date 4 |
|---|---|---|---|---|---|---|---|
| **62-Vosso** | 062-219-R | 60.647738 | 6.001103 | 05.02.2019 | 06.05.2019 | 12.08.2019 | 07.10.2019 |
| **84-Nausta** | 084-218-R | 61.532926 | 5.753347 | 05.02.2019 | 13.05.2019 | 29.08.2019 | 07.10.2019 |
| **109-Driva** | 109-54-R | 62.667641 | 8.558497 | 08.02.2019 | 06.05.2019 | 05.08.2019 | 02.10.2019 |

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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **121-Orkla** | 121-56-R | 63.203108 | 9.770769 | 11.02.2019 | 06.05.2019 | 05.08.2019 | 07.102019 |
| **123-Nidelva** | 123-29-R | 63.393651 | 10.387974 | 06.02.2019 | 13.05.2019 | 05.08.2019 | 02.10.2019 |

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

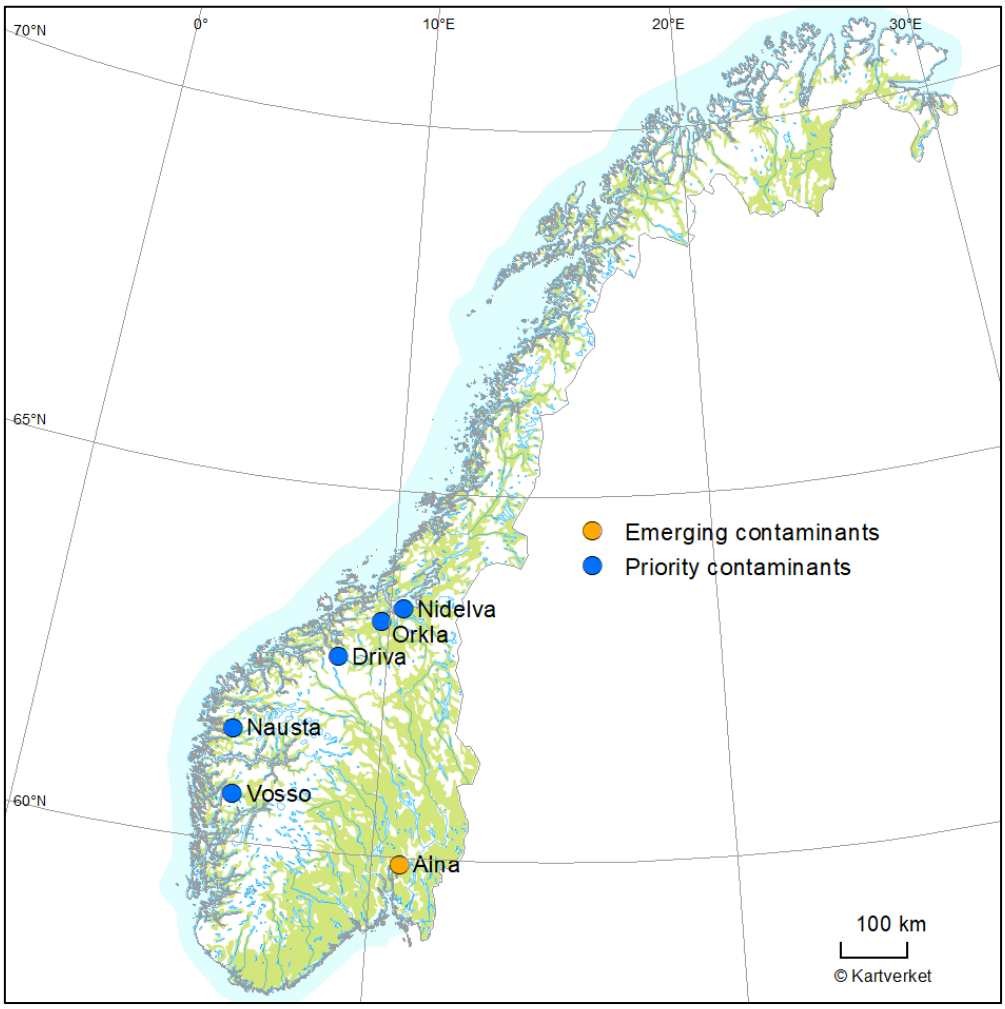


*Figure 1*. Location of the water sampling stations in Vosso, Nausta, Driva, Orkla and Nidelva and the Alna sampling station.

### 2.1.2Suspended particulate matter sampling for emerging contaminants

Suspended particulate matter (SPM)-associated contaminants were sampled in the Alna river (Figure 1, 2) using *continuous flow centrifugation* (CFC) in spring and autumn, with three sampling events each time. 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 between 6-11 days at each sampling event (Table 4). The collected SPM samples 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 water sampling (Table 4).

**Table 4. Deployment periods for the time proportional water sampling and continuous flow centrifuge and water sampling in river Alna in 2019**

| Sampling event | SPM | Water samples |
|---|---|---|
| **Spring – 1** | 14.05-21.05.2019 (8) | 21.05.2019 |
| **Spring – 2** | 21.05-28.05.2019 (8) | 28.05.2019 |
| **Spring – 3** | 28.05-07.06.2019 (11) | 07.06.2019 |
| **Autumn – 4** | 19.09-26.09.2019 (8) | 26.09.2019 |
| **Autumn – 5** | 26.09-01.10.2019 (6) | 01.10.2019 |
| **Autumn – 6** | 01.10-07.10.2019 (7) | 07.10.2019 |

### 2.1.3 Water sampling for emerging contaminants in Alna

Water sampling for emerging contaminants in Alna were conducted at the end of each SPM event. Hence three times in spring and three times in autumn (Table 4)

At each sampling event water was sampled in 2, 2.5 L amber bottles for emerging contaminants, 1 L plastic bottle for PFAS and 0.5L plastic bottle for STS. The Alna river water was sampled approximately 0.5 m below the water surface. One of the amber glass bottles were cleaned by heating in a muffle furnace at 550 °C the other was rinsed with appropriate solvents. The plastic bottles were rinsed trice in the river water before sampling.

### 2.1.4 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, 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[12] . 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 (*Salmo trutta*) from Alna were collected for emerging contaminants by electrofishing in May and October 2019 (Table 5, Figure 2). On both occasions the aim was to collect five fish from three

[12] 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

different size groups, but it was problematic to meet this standard and 11 fish were collected in May and 12 in October. The brown trout were packed in clean aluminum foil and kept cool after sampling until frozen at –20°C.

The 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. Scales, otoliths and bile were removed for potential future age determination and analysis. In total 23 fish were sampled, totalling to 6 samples of which 4 where pooled (Table 6). The brown trout in pooled sample 1 were small, thus whole fish was used instead of muscle. The average length of the fish in the 6 samples ranged from 11.9 – 28.7 cm. An overview of sample composition can be found in Table 6, and details on individual fish in Attachment 1. The samples were kept frozen (-20 °C) until homogenization and analysis.

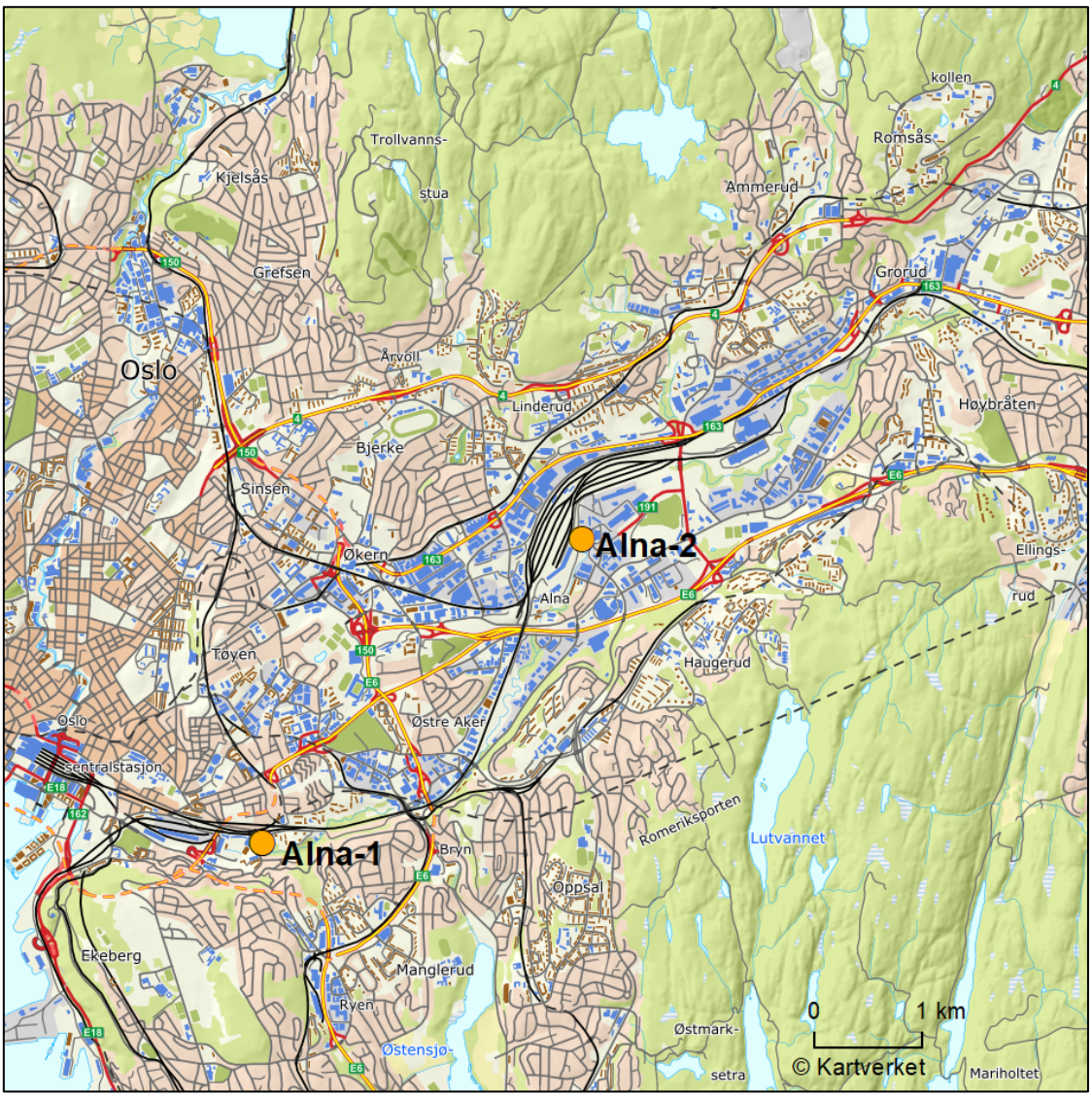


*Figure 2.* Location of the sampling stations in river Alna. The brown trout (*Salmo trutta*) for emerging contmainants were sampled at Alna- 1 and Alna-2. The SPM and water were collected at Alna-1.

## Table 5. Location of the Alna sampling stations in 2019

| Station ID | Area | Latitude (North) | Longitude (East) |
|---|---|---|---|
| **Alna-1, SPM** | Svartdalsparken | 59.9045007 | 10.7923461 |
| **Alna-2** | Alfaset | 59.93159274 | 10.84242296 |

**Table 6. Overview of the Alna pooled fish samples in 2019**

| Station ID | Sample no | Sampling date | Species | Tissue* | Fish IDs* | Mean length (cm)* | Mean weight (g)* |
|---|---|---|---|---|---|---|---|
| Alna - 1 | 1 | 21.05.2019 | *Salmo trutta* | WO, LI | 1-9 | 11.9 (1.2) | 21.1(5.7) |
| Alna - 1 | 2 | 21.05.2019 | *Salmo trutta* | MU, LI | 10 | 19.7 | 103.5 |
| Alna - 1 | 3 | 21.05.2019 | *Salmo trutta* | MU, LI | 11 | 28.7 | 317.3 |
| Alna - 2 | 4 | 03.10.2019 | *Salmo trutta* | MU, LI | 16-20 | 16.1 (0.6) | 54.3 (5.9) |
| Alna - 2 | 5 | 03.10.2019 | *Salmo trutta* | MU, LI | 21-25 | 19.2 (1.6) | 90.3 (26.6) |
| Alna - 2 | 6 | 03.10.2019 | *Salmo trutta* | MU, LI | 27,28 | 23.1 (1.2) | 167.7 (27.4) |

***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**

## 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 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 no loss of analytes. 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)*". After extractions the water 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 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

Alkylphenols (octylphenol, nonylphenol) were analysed at NILU. 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).

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

Filtered water samples were preserved in supra-pure 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. 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). 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 (Bispenols AF, AB, B, E, FL, M and Z), the results are likely less accurate than those for which these labelled standards are used.

### 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 in fish liver, SPM and water. 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.

## 2.3 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[13].

### 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 7. PAHs are above LOQ most frequently in water samples from river Vosso. Between 2 and 4 PAHs were found above LOQ in two of 4 samples from the other rivers. "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 over 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 monitored in 2017 and 2018. For benzo[a]pyrene, the average concentration in River Vosso is close to WFD AA-EQS. The average concentration of benzo[a]pyrene calculated from the four sampling events at the Vosso river sampling site was 0.16 ng $L^{-1}$ (SD= 0.1) is close to the EQS value of 0.17 ng $L^{-1}$. Data from the three remaining rivers are below LOQ, however these LOQs are at EQS level, rendering the comparison with EQS difficult.

**Table 7. "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 | Driva | Nausta | Nidelva | Orkla | Vosso | AA-EQS |
|---|---|---|---|---|---|---|
| Naphthalene | <2 | <2 | <2 | <2 | <2 | **2000** |
| Acenaphthylene | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | 1280 |
| Acenaphthene | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | 3800 |
| Fluorene | 0.35 (0.25) | 0.17 (0.07) | 0.28 (0.18) | 0.25 (0.15) | 0.26 (0.15) | 1500 |
| Phenanthrene | 0.73 (0.41) | 0.29 (0.12) | 0.48 (0.27) | 0.43 (0.25) | 0.60 (0.4) | 500 |
| Anthracene | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | **100** |
| Fluoranthene | 0.19 (0.1) | 0.16 (0.11) | 0.25 (0.19) | 0.18 (0.1) | 0.38 (0.29) | **6.3** |
| Pyrene | 0.13 (0.07) | 0.14 (0.07) | <0.2 | <0.2 | 0.17 (0.13) | 23 |
| Benz[a]anthracene | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | 18 |

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

| | | | | | | |
|---|---|---|---|---|---|---|
| Chrysene | <0.2 | <0.2 | <0.2 | <0.2 | 0.18 (0.16) | 70 |
| Benzo[b,j]fluoranthene | <0.2 | <0.2 | 0.13 (0.07) | 0.14 (0.08) | 0.17 (0.09) | |
| Benzo[k]fluoranthene | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | |
| Benzo[a]pyrene | <0.2 | <0.2 | <0.2 | <0.2 | 0.16 (0.1) | **0.17** |
| Indeno[1,2,3-cd]pyrene | <0.2 | <0.2 | <0.2 | <0.2 | 0.15 (0.08) | |
| Dibenzo[ac/ah]anthracene | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | 14 |
| Benzo[ghi]perylene | <0.2 | <0.2 | <0.2 | <0.2 | 0.22 (0.22) | |
| ***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 2019 (Table 8). 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 and 2017 indicate that while *p,p'*-DDT and $\Sigma_3$DDTs remain under LOQ, these are now approximately an order of magnitude below EQS. As for data from 2017/2018, 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 8. "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 | **Driva** | **Nausta** | **Nidelva** | **Orkla** | **Vosso** | **WFD AA-EQS** |
|---|---|---|---|---|---|---|
| Pentachlorobenzene | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | **7** |
| Hexachlorobenzene | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | |
| γ-HCH | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | **20** |
| PCB28/31 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | |
| PCB52 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | |
| PCB101 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | |
| PCB118 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | |
| PCB153 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | |
| PCB138 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | |
| PCB180 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | |
| $\Sigma_7$PCBs | <0.9 | <0.9 | <0.9 | <0.9 | <0.9 | 0.0024 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *p,p'*-DDE | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | |
| *p,p'*-DDD | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | |
| *p,p'*-DDT | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | **10** |
| $\Sigma_3$DDTs | <0.7 | <0.7 | <0.7 | <0.7 | <0.7 | **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 9). PBDEs were not found above limits of quantification in "whole water" samples collected from any of the five rivers sampled in 2019. This is in line with data from rivers sampled in 2018. Limits of quantification for 2019 are in line with those obtained in 2018 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 9. "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 | **Driva** | **Nausta** | **Nidelva** | **Orkla** | **Vosso** | **WFD AA-EQS** |
|---|---|---|---|---|---|---|
| PBDE28 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | |
| PBDE47 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | |
| PBDE100 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | |
| PBDE99 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | |
| PBDE154 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | |
| PBDE153 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | |
| $\Sigma_5$PBDEs | <0.13 | <0.13 | <0.13 | <0.13 | <0.13 | **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 10). However, limits of quantifications for the sum of HBCDD isomers of 3 ng $L^{-1}$ is above the WFD AA-EQS value of 1.6 ng $L^{-1}$.

**Table 10. "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 | Driva | Nausta | Nidelva | Orkla | Vosso | WFD AA-EQS |
|---|---|---|---|---|---|---|
| α-HBCDD | <1 | <1 | <1 | <1 | <1 | |
| β-HBCDD | <1 | <1 | <1 | <1 | <1 | |
| γ-HBCDD | <1 | <1 | <1 | <1 | <1 | |
| $\Sigma_3$HBCDD | <3 | <3 | <3 | <3 | <3 | **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 11, the concentrations of SCCPs and MCCPs in all five rivers sampled in 2019 are below 500 and 150 ng $L^{-1}$, respectively. These LOQ are high and slightly above WFD AA-EQS.

**Table 11. "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 | Driva | Nausta | Nidelva | Orkla | Vosso | AA-EQS |
|---|---|---|---|---|---|---|
| SCCP | < 500 | < 500 | < 500 | < 500 | < 500 | **400** |
| MCCP | < 150 | < 150 | < 150 | < 150 | < 150 | 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 2019 as was undertaken in 2017. Data are shown in Table 12. As for 2018, 4-n-Octylphenol, 4-n-nonylphenol were not found above limits of quantification in any of the samples from the five rivers under study in 2019. For nonylphenol, LOQs are approximately a factor of ten below 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 12. "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 | **Driva** | **Nausta** | **Nidelva** | **Orkla** | **Vosso** | **AA-EQS** |
| Nonylphenol | <46 | <56 | <52 | <41 | <44 | **300** |
| Octylphenol | <34 | <39 | <36 | <30 | <28 | |
| 4-tert-octylphenol | 19 (10) | 25 (17) | 15 (12) | 19 (19) | 12 (7) | **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 2019 (Table 13). This mimicks data from 2017 and 2018. For chlorfenvinphos, these limits of quantification were a factor of 1000 below the WFD AA-EQS, while they were over a factor of ten below the WFD AA-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, all but one measurements were below LOQ at a level of 20 ng $L^{-1}$. These values are well below the WFD AA-EQS of 1300 ng $L^{-1}$. One sample from River Vosso had a concentration of DEHP of 630 ng $L^{-1}$.

**Table 13. "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 | **Driva** | **Nausta** | **Nidelva** | **Orkla** | **Vosso** | **AA-EQS** |
| Chlorfenvinfos | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | **100** |
| Cybutryne | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | **2.5** |
| DEHP | <20 | <20 | <20 | <20 | <20** | **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.
**One value at 630 ng $L^{-1}$

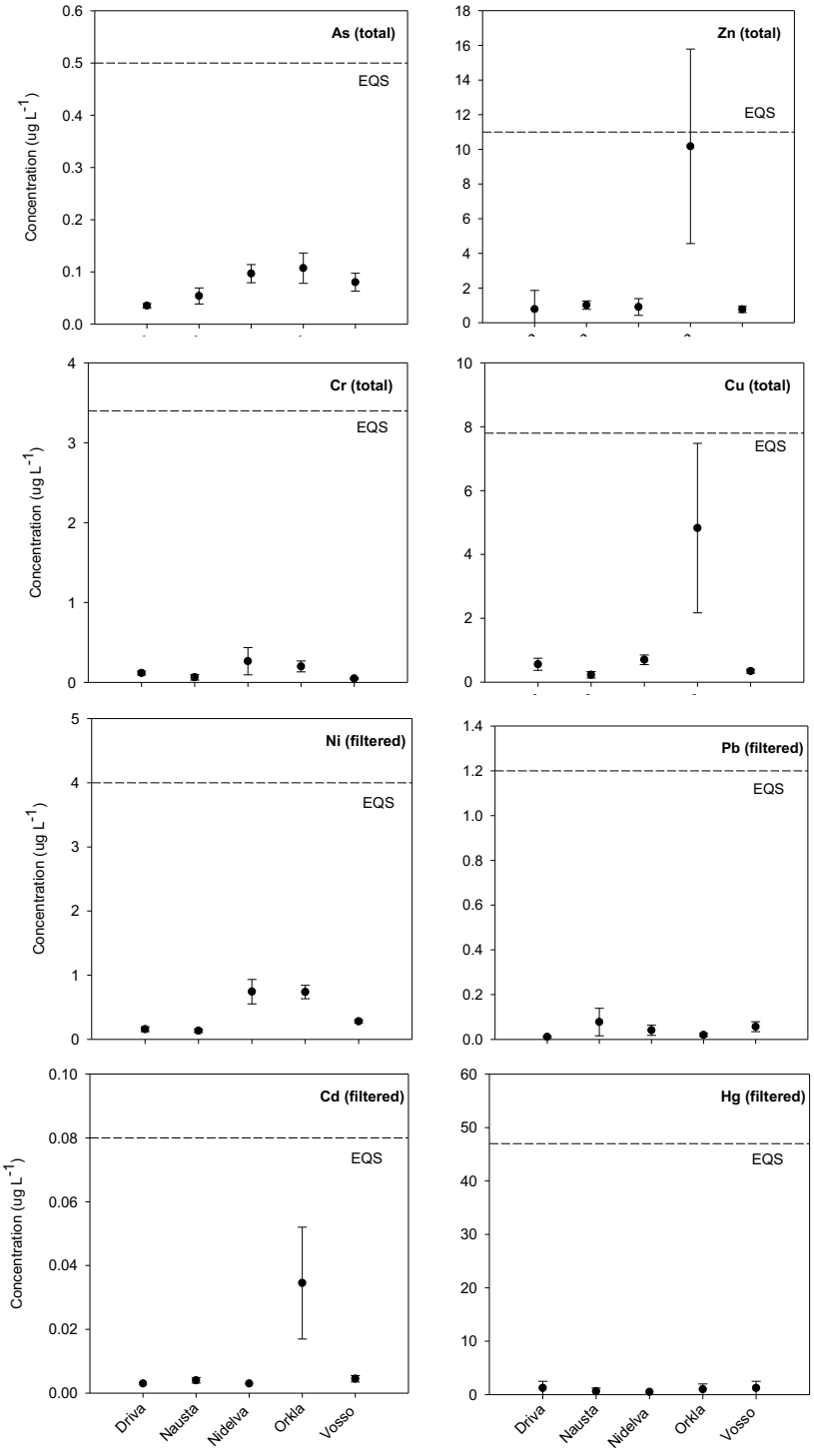


*Figure 3.* Annual average filtered metal concentrations (and standard deviation, n=4) in five rivers. The dotted reference line represents the AA-EQS for specific elements. For Hg, note that the unit is ng $L^{-1}$ and datapoints for the last three rivers represent the LOQ at 1 ng $L^{-1}$.

### 3.1.8Metals

Trace metals (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn) were sampled four times a year in the Rivers Driva, Nausta, Nidelva, Orkla and Vosso in 2019. 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, Cr, Cu, Hg, Ni and Pb in all five rivers are below proposed AA-EQS values. The river Orkla shows elevated levels of Cd, Cu and Zn. The average concentration for Zn of 10 μg $L^{-1}$ is very close to the AA-EQS. Average values for Cd and Cu are only a factor of two below EQS level. For As Cr and Ni, highest average concentrations are found for Rivers Nidelva and Orkla. 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 Driva, Nausta, Nidelva, Orkla and Vosso for 2019

Yearly fluxes or discharges were estimated for these five rivers based on bottle sampling conducted four times in 2019 and data for selected chemicals or classes of chemicals are shown in Table 14.

The highest flux of PAHs was found for the rivers Driva and Vosso and yearly discharge estimate of 24.5 kg $y^{-1}$ is closest to the data from the Numedaslågen sampled in 2017 or the Otra in 2018. 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 or 2018, yearly discharges of 7 indicator PCB congeners could not be estimated for 2019. Fluxes are likely to be under 0.6 kg g $y^{-1}$ for the river Nausta to under 2.5 kg $y^{-1}$ for the river Driva. Detailed fluxes are given in Tables A1 to A7 in Appendix 2.

**Table 14. Estimates of yearly discharge (kg/year) of selected chemicals or sets of chemicals in five rivers for 2018**

| Chemical | **Driva** | **Nausta** | **Nidelva** | **Orkla** | **Vosso** |
|---|---|---|---|---|---|
| $\Sigma_{16}$PAHs | 14 | 3 | 13 | 7 | 14 |
| Pentachlorobenzene | <0.27 | <0.07 | <0.27 | <0.15 | <0.25 |
| Hexachlorobenzene | <0.27 | <0.07 | <0.27 | <0.15 | <0.25 |
| γ-HCH | <0.27 | <0.07 | <0.27 | <0.15 | <0.25 |
| *p,p'*-DDE | <0.27 | <0.07 | <0.27 | <0.15 | <0.25 |
| *p,p'*-DDT | <0.27 | <0.07 | <0.27 | <0.15 | <0.25 |
| $\Sigma_7$PCBs | <2.5 | <0.6 | <2.4 | <1.4 | <2.3 |

## 3.2 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. For each sampling period of 2019, three consecutive samples were collected both for bottle samples as well as for continuous flow centrifugation. Data for each sampling period are reported as a mean of triplicate measurements.

### 3.2.1 UV filters in River Alna

All substances, except for UV-329 were found well above LOQs in the 6 SPM samples. As for SPM samples from 2017 and 2018, OC was found in highest concentrations in 2019. 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). OC, UV-327 and UV-328 were found above LOQ in all water samplesUV-329 was detected in one water sample while BP3 was found in four out of the six water samples. Results from water and SPM sampling are provided in Table 15. There are no major differences in the average SPM concentrations of UV filters between June and October. Standard deviations range from 10 % to under 50 %. Whole water concentrations of UV filters are highest for OC with concentrations of 7.7 and 16.3 ng $L^{-1}$. The slightly higher concentration for the autumn sampling period is in line with the SPM concentrations showing slightly higher concentrations in October. Higher concentrations in water are also found for BP3 for the October sampling. EHMC was consistently below LOQ in water samples while it could be observed in all SPM samples. Relative levels of the different UV filters found in 2019 are in line with data from 2018.

**Table 15. 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) | |
|---|---|---|---|---|---|
| | | June | October | June | October |
| Benzophenone (BP3) | 119-61-9 | 0.15 (0.09) | 1.1 (0.4) | 36 (9) | 26 (7) |
| 2-ethyl-hexyl-4-trimethoxycinnamate (EHMC-Z) | 5666-77-3 | <0.2 | <0.04 | 4.6 (0.7) | 5.2 (0.9) |
| EHMC-E | 5466-77-3 | <1.5 | <0.2 | 17 (3) | 24 (6) |
| Octocrylene (OC) | 6197-30-4 | 7.7 (2.2) | 16.3 (2.5) | 733 (76) | 1097 (464) |
| 2-(2'-Hydroxy-3',5'-di-tert-butylphenyl)-5-chlorobenzotriazole (UV-327) | 3864-99-1 | 0.13 (0.05) | 0.05 (0.03) | 0.95 (0.2) | 0.61 (0.07) |
| 2-(2H-Benzotriazol-2-yl)-4,6- ditert pentylphenol (UV-328) | 25973-55-1 | 0.62 (0.3) | 0.33 (0.3) | 2.5 (0.6) | 2.3 (0.5) |

| | | | | | |
|---|---|---|---|---|---|
| 2-(2'-hydroxy-5'-tert-octyllphenyl)benzotriazole (UV-329) | 3147-75-9 | <0.5 | 0.4 (0.7) | <1.0 | <1 |
| Mean of triplicate measurements (standard deviation in brackets) | | | | | |

As shown in Table 16, BP3 was only found above LOQ in the whole fish sample from the sampling event in the spring. In 2019, EHMC, OC, UV-327 and UV-329 were not found above LOQ in any of the fish samples. a (LOQ = 0.03-1.9 ng $g^{-1}$). These compounds with logP values above 3 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 favored bioaccumulation. The UV filter UV-328 was found in muscle samples from spring and autumn sampling. SPM and water sampling were conducted at the last site it is possible to access the river at before it joins the fjord. Fish samples were from further upstream and differences in levels of the chemicals measured in water and those the fish were exposed to are possible. It is also possible that the home range of these fish extends further upstream in the river where contaminant concentrations are lower.

**Table 16. UV filter concentrations in brown trout (muscle/liver and whole fish) sampled in River Alna in May and October 2019**

| Chemical | CAS number | May 2019 (21.05.2019) | | October 2019 (03.10.2019) | |
|---|---|---|---|---|---|
| | | 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)[c] |
| Benzophenone (BP3) | 119-61-9 | 0.13 | <0.08 | | <0.08 |
| 2-ethyl-hexyl-4-trimethoxycinnamate (EHMC-Z) | 5666-77-3 | <0.03 | <0.03 | | <0.03 |
| EHMC-E | 5466-77-3 | <0.12 | <0.12 | | <0.12 |
| Octocrylene (OC) | 6197-30-4 | <1.9 | <1.9 | | <1.9 |
| 2-(2'-Hydroxy-3',5'-di-tert-butylphenyl)-5-chlorobenzotriazole (UV-327) | 3864-99-1 | <0.04 | <0.04 | | <0.04 |
| 2-(2H-Benzotriazol-2-yl)-4,6- ditert pentylphenol (UV-328) | 25973-55-1 | <0.08 | 0.13 (0.07) | | 0.06 |
| 2-(2'-hydroxy-5'-tert-octyllphenyl)benzotriazole (UV-329) | 3147-75-9 | <0.3 | <0.3 | | <0.3 |
| [a]Data from one sample; [b]Mean of two samples; [c]Mean of three samples | | | | | |

### 3.2.2 Organophosphorus compounds in the River Alna

Table 17 shows, as in 2018, that a slightly higher number of OPs could be seen in SPM samples than in water samples.

Full names, abbreviations and CAS numbers of the OPFRs are given in Tables 17 and 18. TEHP showed the highest level in SPM with concentration in the µg $g^{-1}$ g range which is substantially higher than in previous years. TCPP and TBEP were also in some of the highest amounts in SPM (145-183 ng $g^{-1}$ dw) with concentrations in a similar range as those measured the previous year (2017/2018). They also exhibit the highest concentrations in whole water samples with concentrations in the range 48 to 390 ng $L^{-1}$. Compounds detected in SPM samples and to a lesser extent in water samples included TCEP, TiBP, TPP, TDCPP, TnBP, and TBEP. TCEP, TCPP, sum TCP and EHDP and TXP were consistently detected in sediment and to a lesser extent in water sample. Other compounds such as TPrP, BdPhP, IPPP and TTBPP were not detected in any of the composite water or SPM samples. This result is the same as in 2018.

**Table 17. 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) | |
|---|---|---|---|---|---|
| | | June | October | June | October |
| Tri ethylphosphate (TEP) | 78-40-0 | 39 (21) | 16 (4) | N/A | N/A |
| Tri(2-chloroethyl)phosphate (TCEP) | 115-96-8 | 11 (2) | 5.5 (1.2) | 1.6 (0.9) | 4.6 (1.1) |
| Tripropylphosphate (TPrP) | 513-08-6 | <0.2 | <0.2 | <0.01 | <0.01 |
| tri(1-chloro-2-propyl)phosphate (TCPP) | 13674-87-8 | 74 (10) | 48 (4) | 183 (90) | 195 (22) |
| Tri-iso-butylphosphate (TiBP) | 126-71-6 | 14 (7) | 5.8 (2) | 0.84 (0.25) | 0.31 (0.4) |
| Butyl diphenylphosphate (BdPhP) | 2752-95-6 | <0.1 | <0.1 | <0.01 | <0.01 |
| Triphenylphosphate (TPP) | 115-86-6 | 14 (10) | 5.1 (3) | 47 (13) | 33 (28) |
| Dibutyl phenyl phosphate (DBPhP) | 2528-36-1 | <0.1 | <0.1 | <0.02 | <0.02 |
| Tri-n-butyphosphate (TnBP) | 126-73-8 | 8.5 (2.2) | 11 (3.3) | 0.95 (0.5) | 1.7 (1.6) |

| | | | | | |
|---|---|---|---|---|---|
| tri(1,3-dichloro-2-propyl)phosphate (TDCPP) | 13674-87-8 | 11 (7) | <8 | 4.0 (1.7) | 5.7 (2.7) |
| tri(2-butoxyethyl)phosphate (TBEP) | 78-51-3 | 355 (215) | 390 (448) | 160 (61) | 145 (59) |
| Tricresylphosphate (sumTCP) | 1330-78-5 | <0.3 | <0.3 | 33 (11) | 28 (3) |
| 2-ethylhexyl-diphenyl phosphate (EHDP) | 1241-94-7 | 2.2 (2.2) | <1.9 | 72 (31) | 43 (10) |
| Trixilylphosphate (TXP) | 25155-23-1 | <0.4 | <0.4 | 4.1 (0.9) | 6.4 (2.3) |
| 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 | 0.36 (0.3) | 0.57 (0.6) | 1386 (193) | 1179 (176) |

N/A: Not analysed; mean of triplicate measurements, standard deviation in brackets

The concentrations of OPs in whole fish and muscle samples of brown trout from River Alna are shown in Table 18. Data are in line with results reported for 2018. TCPP, TPP, and sumTCP were consistently detected in all fish samples analysed. TBEP, TnBP, TiBP were found above LOQ in some but not all of the composite fish samples and levels are close to LOQ. None of the concentrations exceeded 5 ng $g^{-1}$ ww fish. In general, the pattern of chemicals found above LOQ in fish samples in 2019 is similar to that from 2018. OP compounds found in the highest amounts in fish were EHDP and TPP at concentrations of 1.1-3.6 and 7-10.2 ng $g^{-1}$ ww, respectively. These are in line with results reported for 2018.

**Table 18. Organophosphorus flame retardant concentrations in brown trout (muscle and whole fish) sampled in River Alna in May and October 2019**

| Chemical (abbreviation) | CAS number | May 2019 | | October 2019 | |
|---|---|---|---|---|---|
| | | 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)[c] |
| Tri ethylphosphate (TEP) | 78-40-0 | - | - | - | - |
| Tri(2-chloroethyl)phosphate (TCEP) | 115-96-8 | <0.4 | <0.4 | | <0.4 |
| Tripropylphosphate (TPrP) | 513-08-6 | <0.05 | <0.05 | | <0.05 |

| | | | | | |
|---|---|---|---|---|---|
| tri(1-chloro-2-propyl)phosphate (TCPP) | 13674-87-8 | 0.35 | 0.18 (0.01) | | 0.13 (0.1) |
| Tri-iso-butylphosphate (TiBP) | 126-71-6 | 0.34 | 0.18 (0.15) | | <0.15 |
| Butyl diphenylphosphate (BdPhP) | 2752-95-6 | <0.05 | <0.05 | | <0.05 |
| Triphenylphosphate (TPP) | 115-86-6 | 9.6 | 10.2 (1.7) | | 7.0 (2.1) |
| Dibutyl phenyl phosphate (DBPhP) | 2528-36-1 | <0.05 | <0.05 | | <0.05 |
| Tri-n-butylphosphate (TnBP) | 126-73-8 | 0.31 | 0.1 (0.07) | | <0.1 |
| tri(1,3-dichloro-2-propyl)phosphate (TDCPP) | 13674-87-8 | <0.2 | <0.2 | | <0.2 |
| tri(2-butoxyethyl)phosphate (TBEP) | 78-51-3 | 0.23 | 0.20 (0.02) | | <0.1 |
| Tricresylphosphate (sumTCP) | 1330-78-5 | 0.81 | 0.48 (0.04) | | 0.26 (0.09) |
| 2-ethylhexyl-diphenyl phosphate (EHDP) | 1241-94-7 | 3.6 | 2.5 (0.33) | | 1.1 (0.2) |
| Trixilylphosphate (TXP) | 25155-23-1 | <0.1 | <0.1 | | <0.1 |
| tris(isopropylphenyl) phosphate isomers (IPPP) | 26967-76-0 | - | - | | - |
| tris(p-tert-butylphenyl) phosphate (TTBPP) | 78-33-1 | - | - | | - |
| tris(2-ethylhexyl) phosphate (TEHP) | 78-42-2 | <0.2 | <0.2 | | <0.2 |
| [a]Data from one sample; [b]Mean of two samples; [c]Mean of three samples | | | | | |

### 3.2.3 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 19. 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. This is very consistent with data reported for 2018. Two other bisphenols, 4,4'-BPS and 4,4'-BPF were found in water samples at concentration of 8.3-15 ng $L^{-1}$ in line with data from 2018 (17-26 ng $L^{-1}$). As result of lower limits of quantification for

2019, it is also possible to measure 2,4'-BPS, 2,2 and 2,2'-BPF in water samples. 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. Relative standard deviations of the triplicate measurements between 10 and 25 % are relatively low and consistent with OP and UV filter data.

**Table 19. Bisphenol concentrations in water and suspended particulate matter of the River Alna**

| Chemical | Water concentration (ng/L) | | SPM concentration (ng/g dry weight) | |
|---|---|---|---|---|
| | June | October | June | October |
| 2,4'-BPA (837-08-1) | <5 | <2 | <0.9 | <0.9 |
| 4,4'-BPA (80-05-7) | 159 (119) | 46 (10) | 149 (18) | 92 (7) |
| 2,4'-BPS (5397-34-2) | 0.99 (0.6) | 0.41 (0.2) | <0.2 | <0.2 |
| 4,4'-BPS (80-09-1) | 8.3 (2) | 14 (7) | 1.2 (0.2) | 1.0 (0.1) |
| 2,2'-BPF (2467-02-9) | 0.95 (0.6) | 0.66 (0.12) | 2.8 (0.4) | 1.7 (0.2) |
| 2,4'-BPF (2467-03-0) | 18 (3) | 9.3 (0.8) | 15 (3) | 8.5 (0.7) |
| 4,4'-BPF (620-92-8) | 15 (0.4) | 8.6 (0.5) | 9.9 (1.5) | 6.6 (0.6) |
| BP-AF (1478-61-19) | <1.5 | <0.8 | <0.5 | <0.3 |
| BP-AP (1571-75-1) | <6 | <4 | <1.1 | <1.2 |
| BPB (77-40-7) | <8 | <4 | <1.3 | <1.0 |
| BPE (2081-08-5) | <5 | <3 | <1.0 | 0.96 (0.5) |
| BP-FL (3236-71-3) | <10 | <6 | <2.0 | <1.7 |
| BPM (3236-71-3) | <2 | <1.5 | <0.5 | <0.5 |
| BPZ (843-55-0) | <9 | <9 | <1.8 | <1.8 |
| Mean of triplicate measurements; standard deviations in brackets | | | | |

The table below (Table 20) shows the bisphenol concentrations in whole fish and muscle samples of brown trout from the river Alna. Compounds such as 4,4'-BPA, 4,4'-BPS, 2,2'-BPF, 2,4'-BPF and 4,4'-BPF consistently found in water and SPM samples were also present in whole fish and fish muscle samples from 2019. The fish data is also in agreement with relative levels of bisphenols observed in water and SPM. Highest concentrations were for 4,4'-BPA (9.3-18 ng $g^{-1}$ ww), followed by 2,4'-BPF and 4,4'-BPF with concentrations close to 4 ng $g^{-1}$ ww. The concentration of remaining bisphenols found above LOQ are an order of magnitude below this. No major differences can be seen between composite samples of whole fish and muscles from May and October.

**Table 20. Bisphenol concentrations in brown trout (muscle and whole fish) sampled in River Alna in May and October 2019**

| Chemical | May 2019 | | October 2019 | |
|---|---|---|---|---|
| | 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)[c] |
| 2,4'-BPA (837-08-1) | < 0.3 | <0.3 | | <0.3 |
| 4,4'-BPA (80-05-7) | 13.7 | 9.3 (1.4) | | 18 (13) |

| | | | | |
|---|---|---|---|---|
| 2,4'-BPS (5397-34-2) | <0.07 | <0.07 | | <0.07 |
| 4,4'-BPS (80-09-1) | 0.37 | 0.39 (0.02) | | 0.37 (0.07) |
| 2,2'-BPF (2467-02-9) | 0.44 | 0.47 (0.04) | | 0.44 (0.3) |
| 2,4'-BPF (2467-03-0) | 4.2 | 4.4 (0.5) | | 4.5 (2.3) |
| 4,4'-BPF (620-92-8) | 4.2 | 4.2 (0.7) | | 4.2 (1.9) |
| BP-AF (1478-61-19) | 0.16 | 0.12 (0.02) | | 0.10 (0.04) |
| BP-AP (1571-75-1) | <0.4 | <0.4 | | <0.4 |
| BPB (77-40-7) | <0.4 | <0.4 | | <0.4 |
| BPE (2081-08-5) | <0.3 | <0.3 | | 0.2 (0.1) |
| BP-FL (3236-71-3) | <0.7 | <0.5 | | <0.6 |
| BPM (3236-71-3) | <0.11 | <0.5 | | <0.5 |
| BPZ (843-55-0) | <0.5 | <0.5 | | <0.5 |
| [a]Data from one sample; [b]Mean of two samples; [c]Mean of three samples | | | | |

### 3.2.4 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 calculated from data obtained in 2019 for organophosphorus flame retardants, bisphenols and UV filters are plotted on Figure 4 against the octanol-water partition coefficients ($logK_{ow}$) for these chemicals. This figure also shows data obtained in 2018 for comparison. BAFs for PCBs were calculated from fish concentrations reported in the 2018 report and freely dissolved concentrations estimated by passive sampling in 2016. The 1:1 relationship is also shown on the graph. The data obtained in 2019 tend to support the 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). For other bisphenols, (BPF and BPS), logBAFs are above the 1:1 line. 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. This is also the case for UV-328 that we can add for the first time to this figure.

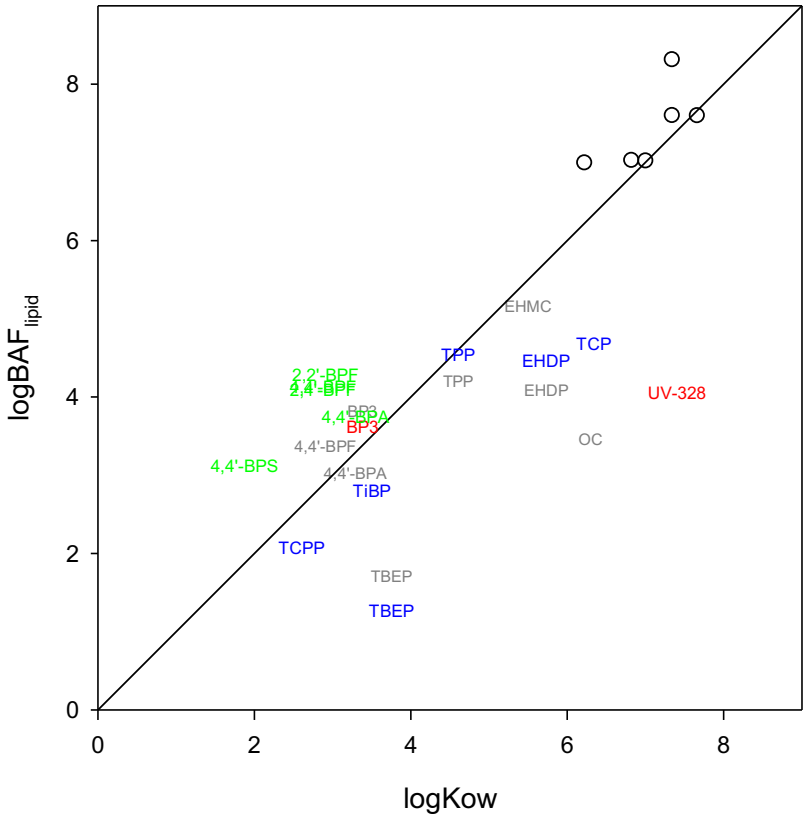


*Figure 4.* Lipid-normalised bioaccumulation factors for emerging contaminants in brown trout (*Salmo trutta*) in River Alna. Abbreviations given in grey are for data reported in 2018. Red, blue and green color-coded abbreviations are for 2019 data. Empty circles represent BAFs for PCBs and are given 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 5, 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. $LogK_{oc}$ values obtained in 2019 are generally in line with those reported in 2018. A wider discrepancy between $logK_{oc}$ and $logK_{ow}$ can be seen for bisphenols, TCPP, TCEP and BP3. Values of logKoc for some UV filters tend to be under the 1:1 line. LogKow values were obtained from the Pubchem database and since many these values are calculated values, some uncertainty can be expected with these. For comparison, $logK_{oc}$ for PCBs from 2016 are also plotted on Figure 5. $LogK_{oc}$ for OPFRs are generally in agreement with literature values (e.g. Zhang et al. 2018).

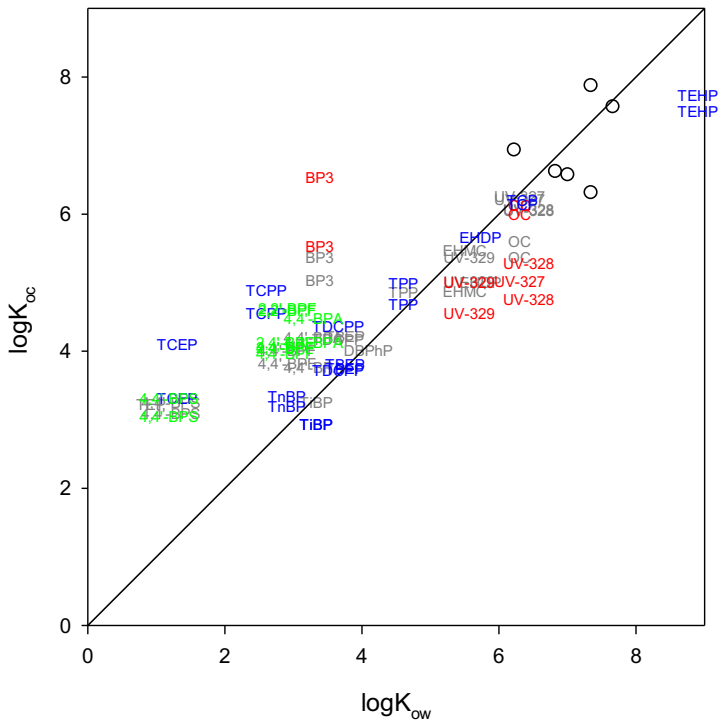


*Figure 5.* Field-based organic carbon-normalised SPM-water distribution coefficients ($K_{oc}$) for emerging contaminants in River Alna in 2019. Abbreviations in grey represent data obtained in 2018 while color-coded data is for 2019. Empty circles represent $K_{oc}$ for PCBs.

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 for 2019 are plotted on Figure 6 together with BSAF for PCBs and data from 2018. 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 based on observed field concentrations. BSAF for BPA for 2018 in the range of 0.1 to 1 were in agreement with data reported in Lee et al. (2015). Data for 2019 tend to be closer to the threshold of 1. As for data from 2018, BSAF for OPFRs for 2019 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).

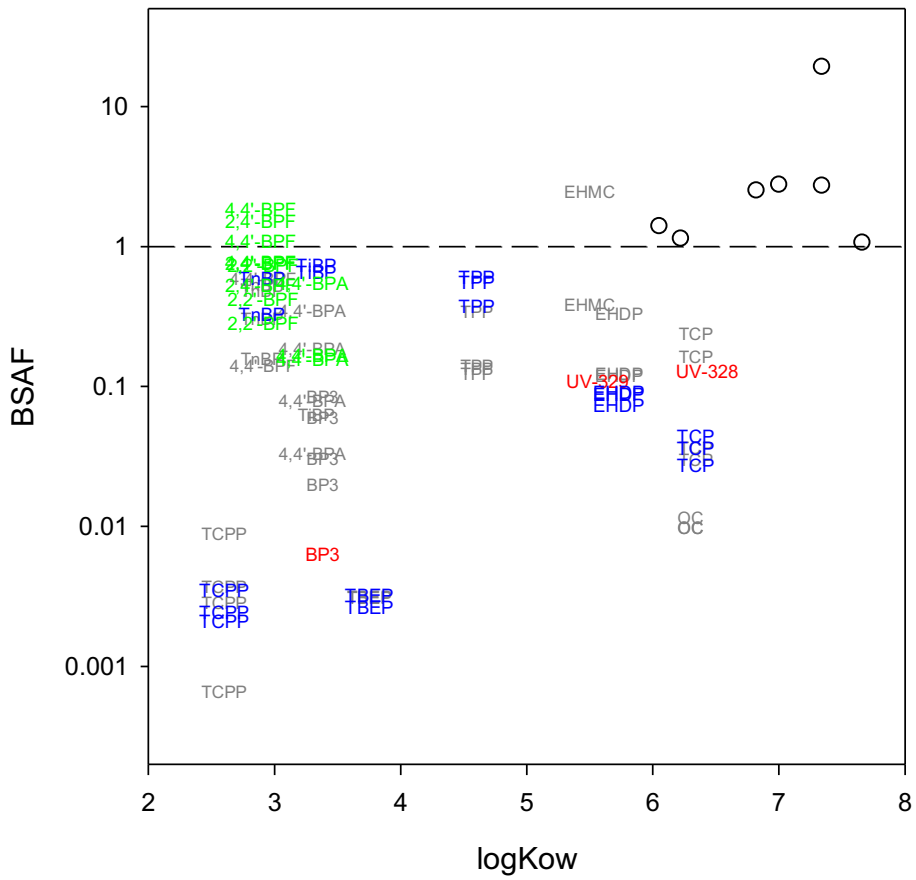


*Figure 6.* BSAF for emerging contaminants in brown trout (*Salmo trutta*) in River Alna in 2019. Abbreviations in grey represent data reported in 2018 and color-coded abbreviations are for data obtained in 2019Empty circles represent BSAF for PCBs.

### 3.2.5PFAS in River Alna

The list of PFAS chemicals being investigated was similar to that reported in 2017. Mean concentrations of PFAS compounds in triplicate water and SPM samples collected in June and October 2019 are reported in Table 21. The concentrations of PFAS compounds found above LOQ were in the range 0.67-3.3 ng $L^{-1}$. As in 2018, PFOS, PFOA, PFBS, PFHxS, PFPA, PFHxA, PFHpA, PFNA and 6:2 FTS were found above LOQ in composite water samples from the Alna. In addition to PFOS, PFDS, 6:2 FTS and 8:2 FTS was measured above limits of quantification in (some) SPM samples. The list of PFAS compounds detected in River Alna in 2018 and 2019 are very similar and similar to that for PFAS chemicals found in stormwaters during Urbanfjord project sampling[14]. 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 7.

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

**Table 21. PFAS concentration 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 |
| Perfluoropentanoate (PFPA) | 356-42-3 | 3.2 (0.2) | 3.3 (0.3) | <0.5 | <0.5 |
| Perfluorohexanoate (PFHxA) | 307-24-4 | 2.9 (0.2) | 2.9 (0.4) | <0.5 | <0.5 |
| Perfluoroheptanoate (PFHpA) | 375-85-9 | 1.1 (0.4) | 1.1 (0.3) | <0.5 | <0.5 |
| Perfluorooctanoate (PFOA) | 335-67-1 | 3.0 (0.4) | 3.2 (0.8) | <0.5 | <0.5 |
| Perfluorononanoate (PFNA) | 375-95-1 | <0.5 | <0.5 | <0.5 | <0.5 |
| Perfluorodecanoate (PFDA) | 335-76-2 | <0.4 | <0.4 | <0.4 | <0.4 |
| Perfluoroundecanoate (PFUdA) | 2058-94-8 | <0.4 | <0.4 | <0.4 | <0.4 |
| Perfluorododecanoate (PFDoA) | 307-55-1 | <0.4 | <0.4 | <0.4 | <0.4 |
| Perfluorotridecanoate (PFTrDA) | 72629-94-8 | <0.4 | <0.4 | <0.4 | <0.4 |
| Perfluorotetradecanoate (PFTeDA) | 376-06-7 | <0.4 | <0.4 | <0.4 | <0.4 |
| Perfluoropentadecanoate (PFPeDA) | 1214264-29-5 | <0.4 | <0.4 | <0.4 | <0.4 |
| Perfluorohexadecanoate (PFHxDA) | 67905-19-5 | <0.4 | <0.4 | <0.4 | <0.4 |
| Perfluorobutane sulfonate (PFBS) | 375-73-5 | 1.1 (0.1) | 1.3 (0.1) | <0.2 | <0.2 |
| Perfluoropentane sulfonate (PFPS) | 2706-91-4 | N/A | N/A | <0.2 | <0.2 |
| Perfluorohexane sulfonate (PFHxS) | 355-46-4 | 2.4 (3.0) | 0.73 (0.06) | <0.2 | <0.2 |
| Perfluoroheptane sulfonate (PFHpS) | 21934-50-9 | <0.2 | <0.2 | <0.2 | <0.2 |
| Perfluorooctane sulfonate (PFOS) | 1763-23-1 | 0.67 (0.06) | 0.73 (0.06) | 0.56 (0.15) | 0.85 (0.17) |

| | | | | | |
|---|---|---|---|---|---|
| 8Cl-perfluorooctane sulfonate (8Cl- PFOS) | N/A | N/A | N/A | N/A | N/A |
| Perfluorononane sulfonate (PFNS) | 17202-41-4 | <0.2 | <0.2 | <0.2 | <0.2 |
| Perfluorodecane sulfonate (PFDS) | 67906-42-7 | <0.2 | <0.2 | <0.2 | 0.14 (0.07) |
| 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 | <2 | <2 |
| N-Ethyl fluorooctane sulfoamidoethanol (etFOSE) | 1691-99-2 | <5 | <5 | <5 | <5 |
| Perfluorooctane Sulfonamidoacetic acid (FOSAA) | 2806-24-8 | N/A | N/A | <0.3 | <0.3 |
| 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 | 1.0 (0.1) | 0.8 (0.1) | 0.42 (0.1) | 0.31 (0.16) |
| 8:2 Fluorotelomer sulfonate (8:2 FTS) | 481071-78-7 | <0.3 | <0.3 | 0.41 (0.1) | |
| 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 |

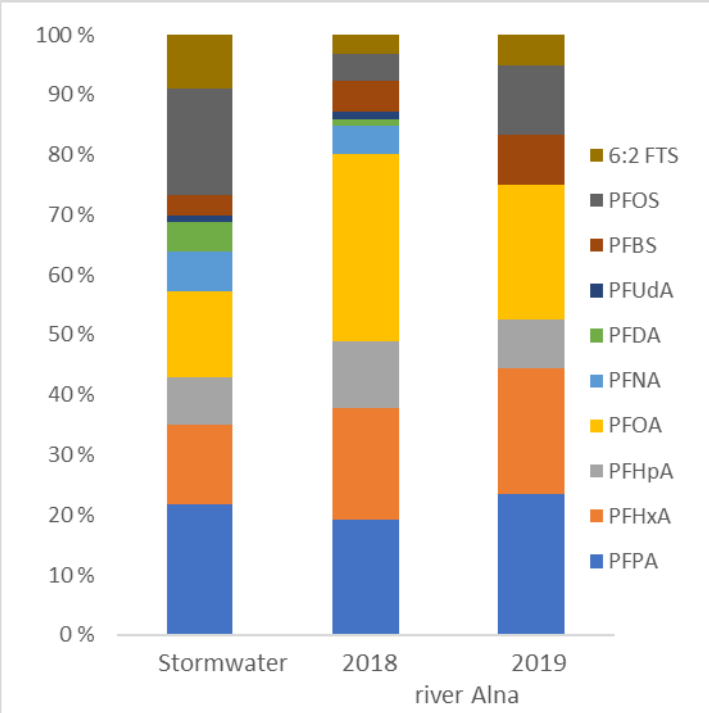


*Figure 7.* Comparison of the relative distribution of detected PFAS compounds in water of River Alna (2018 and 2019) and in Stormwater samples collected from drains in Oslo for the Urbanfjord project.

PFAS concentrations in brown trout sampled in May and October 2019 are given in Table 22. A higher number of PFAS compounds were measured inliver samples in 2019 compared with 2018. Highest PFAS concentrations in fish liver were found for PFOS. PFOS concentrations in fish liver from 2019 were 53 and 35 ng $g^{-1}$ ww and were higher than those measured in 2018 (5.3 and 1.6 ng $g^{-1}$ ww). PFOSA, PFDA, PFDoA, PFTrDA, PFTeDA, PFDS were found on average at concentrations in liver between 2 and 5 ng $g^{-1}$ ww. Concentrations of other compounds that were detected in fish liver samples were below 2 ng $g^{-1}$ ww.

**TABLE 22. PFAS concentration in brown trout (liver) sampled in River Alna in May and October 2019**

| Chemical | CAS number | May 2019 | October 2018 |
|---|---|---|---|
| | | Liver concentration (ng $g^{-1}$ ww)[a] | Liver concentration (ng $g^{-1}$ ww)[b] |
| Perfluoropentanoate (PFPA) | 356-42-3 | <0.5 | <0.5 |
| Perfluorohexanoate (PFHxA) | 307-24-4 | <0.5 | <0.5 |
| Perfluoroheptanoate (PFHpA) | 375-85-9 | <0.5 | <0.5 |
| Perfluorooctanoate (PFOA) | 335-67-1 | 0.5 (0.5) | <0.5 |
| Perfluorononanoate (PFNA) | 375-95-1 | 1.2 (0.5) | 0.8 (0.4) |
| Perfluorodecanoate (PFDA) | 335-76-2 | 2.9 (0.9) | 1.9 (0.9) |

| | | | |
|---|---|---|---|
| Perfluoroundecanoate (PFUdA) | 2058-94-8 | 1.9 (0.5) | 1.3 (0.6) |
| Perfluorododecanoate (PFDoA) | 307-55-1 | 4.4 (1.5) | 2.6 (1.2) |
| Perfluorotridecanoate (PFTrDA) | 72629-94-8 | 2.8 (0.8) | 2.2 (1.2) |
| Perfluorotetradecanoate (PFTeDA) | 376-06-7 | 3.2 (1.3) | 2.0 (0.9) |
| Perfluoropentadecanoate (PFPeDA) | 1214264-29-5 | <0.4 | <0.4 |
| Perfluorohexadecanoate (PFHxDA) | 67905-19-5 | <0.4 | <0.4 |
| Perfluorobutane sulfonate (PFBS) | 375-73-5 | 0.15 (0.04) | <0.2 |
| Perfluoropentane sulfonate (PFPS) | 2706-91-4 | 0.14 (0.08) | <0.2 |
| Perfluorohexane sulfonate (PFHxS) | 355-46-4 | 1.2 (0.9) | 0.8 (0.4) |
| Perfluoroheptane sulfonate (PFHpS) | 21934-50-9 | 0.4 (0.16) | 0.21 (0.11) |
| Perfluorooctane sulfonate (PFOS) | 1763-23-1 | 53 (14) | 35 (20) |
| 8Cl-perfluorooctane sulfonate (8Cl-PFOS) | N/A | NA | NA |
| Perfluorononane sulfonate (PFNS) | 17202-41-4 | <0.2 | <0.2 |
| Perfluorodecane sulfonate (PFDS) | 67906-42-7 | 3.0 (0.2) | 2.3 (2.0) |
| Perfluorododecane sulfonate (PFDoS) | 85187-17-3 | <0.2 | <0.2 |
| Perfluorooctane sulphonamide (PFOSA) | 754-91-6 | 4.1 | 4.4 (1.2) |
| N-Methyl fluorooctane sulfonate (meFOSA) | 250-665-8 | <0.3 | <0.3 |
| N-Ethyl fluorooctane sulfonate (etFOSA) | 4151-50-2 | <0.3 | <0.3 |
| N-Methyl fluorooctane sulfonamidoethanol (meFOSE) | 24448-09-7 | <2 | <2 |
| N-Ethyl fluorooctane sulfoamidoethanol (etFOSE) | 1691-99-2 | <2 | <2 |
| Perfluorooctane Sulfonamidoacetic acid (FOSAA) | 2806-24-8 | <0.3 | <0.3 |
| N-methylperfluoro-1-octanesulfonamidoacetic acid (me-FOSAA) | 2355-31-9 | <0.3 | <0.3 |
| N- ethylperfluoro-1-octanesulfonamidoacetic acid (et-FOSAA) | 2991-50-6 | 0.91 (0.53) | <0.3 |

| | | | |
|---|---|---|---|
| 4:2 Fluorotelomer sulfonate (4:2 FTS) | 414911-30-1 | 0.63 (0.14) | <0.3 |
| 6:2 Fluorotelomer sulfonate (6:2 FTS) | 27619-97-2 | <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 23. 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 3.00 in 2019 is slightly higher than the 2018 value of 2.85 for river Alna and is in excellent agreement with literature values (e.g. Labadie and Chevreuil, 2011).

**Table 23. Bioconcentration factors for selected PFAS compounds in the River Alna**

| Chemical | Bioconcentration factor (logBCF; L $kg^{-1}$)* | | | |
|---|---|---|---|---|
| | May 2019 | | October 2019 | |
| | Whole fish | Liver | Whole fish | Liver |
| PFOA | | 2.24 | | - |
| PFBS | | 2.14 | | - |
| PFHxS | | 2.67 | | 3.04 |
| PFOS | | 4.90 | | 4.68 |

*On a wet weight basis; these logBCFs are for compounds detected both in brown trout and in the water phase.

# 4 Conclusions

**Monitoring based on water samples in the rivers Driva, Nausta, Nidelva, Orkla and Vosso in 2019:**

- Polycyclic aromatic hydrocarbon (PAH) concentrations were the highest and closest to WFD AA-EQS for the sampling location on the River Vosso (annual average concentration of benzo[a]pyrene for the close to 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.
- All organochlorinated priority substances were below LOQ in most water samples and below AA-EQS for pentachlorobenzene and $\gamma$-HCH. The $\Sigma_7$PCBs 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 2019. However, the LOQ is close to the EQS.
- Metal (filtered and/or total) concentrations were mostly well below AA-EQS for all rivers. The annual average concentrations of Cd and Cu in the river Orkla were close to EQS while that for Zn was at EQS level.
- Poor limits of quantification for MCCPs prevented any meaningful comparisons with AA-EQS. Data for SCCPs, alkylphenols, chlorfenvenphos, cybutryne and DEHP were mostly below LOQ and below EQS. LOQ values for 4-tert-octylphenol improved and concentrations in all river were below EQS.
- 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.

**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 only two UV filters detected in brown trout were BP3 and UV-328.
- As for the data from 2017/2018, SPM sampled in 2019 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, TXP, TEHP and EHDP. Concentrations ranged from 0.31 ng $g^{-1}$ dw for TiBP up to over 1000 ng $g^{-1}$ dw for TEHP. TCPP, TPP, sumTCP, and EHDP were consistently detected in all fish samples analysed with concentrations not exceeding a few ng $g^{-1}$ ww except for TPP with concentrations between 7 and 10 ng $g^{-1}$ ww.
- As for 2017 and 2018, a few bisphenols were detected in the SPM samples (4,4'-BPA, 4,4'-BPS, 2,2'-BPF, 2,4'-BPF, and 4,4'-BPF). All these compounds were also found in water samples. BPA (4,4'-BPA) is present in highest concentrations, at the ten to hundreds of ng $L^{-1}$ or ng $g^{-1}$ dw levels in water and SPM respectively. BPA was also found in highest concentrations in brown

trout. In addition to 4,4'-BPS, 2,2'-BPF, 2,4'-BPF, and 4,4'-BPF, BP-AF was also found consistently above LOQ in brown trout samples.

- For most substances found both in SPM and water samples, estimated $\log K_{oc}$ tend to show equilibrium distribution between organic carbon and water. A few compounds deviate from the 1:1 relationship with $\log K_{ow}$ (TCEP, TCPP, and bisphenols).
- 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 $\log K_{ow}$. For others such as OC, TBEP, or UV-328, BAFs are clearly lower overestimated by $\log K_{ow}$ indicating that some processes such as metabolism may contribute to lowering biota concentrations. SPM-based BSAF in the range of 0.001-1 tend to show limited potential for bioaccumulation for these emerging contaminants. All in all, BAFs and BSAFs tend to show a low potential for these compounds for fish bioaccumulation.
- PFOS, PFOA, 6:2 FTS, PFBS, PFPS, PFHxS, PFPA, PFHxA, PFHpA, PFNA and PFDA were found at concentrations of 0.31-3.3 ng $L^{-1}$ in water samples from the Alna while only PFOS and 6:2 FTS were consistently measured above LOQ in SPM. This list of PFAS compounds detected in water samples is similar to the 2017 and 2018 data. In general, the identity and relative levels of PFAS compounds above LOQ in Alna river water are in agreement with stormwater data from the urbanfjord project, indicating storm waters and surface runoff is a non-negligible source of PFAS chemicals to River Alna.
- A higher number of PFAS compounds were found in fish sample in 2019 compared with 2018. Out of 31 PFAS chemicals analysed for, 11 were measured above LOQ in most fish liver samples from the two sampling periods. 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 1

Alna - Emerging contaminants sampling in fish

| Alna - Brown trout 2019 | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station ID | Fish ID | Sample ID | Lims-code | Date captured | Date dissected | Species | Length (cm) | Weight (g) | Otholiths | Scales | Sex | Stage | Fleshcolour | Muscle (g)/Whole organism | MU/WO | Liver (g) | Bile | Mean (SD) length | Mean (SD) weight |
| Alna-1 | 1 | 1 | NR-2019-0715 | 21.05.2019 | 15.10.2019 | *Salmo trutta* | 11,2 | 16,8 | 2 | OK | F | 2 | H | 15,44 | WO | 0,23 | OK | | |
| Alna-1 | 2 | 1 | NR-2019-0715 | 21.05.2019 | 15.10.2019 | *Salmo trutta* | 11,1 | 17,1 | 2 | OK | M | 1 | H | 15,75 | WO | 0,25 | OK | | |
| Alna-1 | 3 | 1 | NR-2019-0715 | 21.05.2019 | 15.10.2019 | *Salmo trutta* | 10,2 | 13,7 | 2 | OK | M | 1 | H | 12,57 | WO | 0,15 | OK | | |
| Alna-1 | 4 | 1 | NR-2019-0715 | 21.05.2019 | 15.10.2019 | *Salmo trutta* | 10,5 | 14,5 | 2 | OK | F | 1 | H | 13,31 | WO | 0,26 | OK | | |
| Alna-1 | 5 | 1 | NR-2019-0715 | 21.05.2019 | 15.10.2019 | *Salmo trutta* | 12,3 | 22,8 | 2 | OK | F | 1 | H | 20,96 | WO | 0,38 | OK | | |
| Alna-1 | 6 | 1 | NR-2019-0715 | 21.05.2019 | 15.10.2019 | *Salmo trutta* | 13,7 | 28,6 | 2 | OK | F | 1 | H | 26,4 | WO | 0,57 | OK | | |
| Alna-1 | 7 | 1 | NR-2019-0715 | 21.05.2019 | 15.10.2019 | *Salmo trutta* | 12,6 | 24,5 | 2 | OK | M | 1 | H | 22,76 | WO | 0,36 | OK | | |
| Alna-1 | 8 | 1 | NR-2019-0715 | 21.05.2019 | 15.10.2019 | *Salmo trutta* | 13 | 27,7 | 2 | OK | M | 1-2 | H | 25,73 | WO | 0,46 | OK | | |
| Alna-1 | 9 | 1 | NR-2019-0715 | 21.05.2019 | 15.10.2019 | *Salmo trutta* | 12,6 | 24,3 | 2 | OK | F | 1 | H | 22,51 | WO | 0,37 | OK | 11,9 (1,2) | 21,1(5,7) |
| Alna-1 | 10 | 2 | NR-2019-0716 | 21.05.2019 | 15.10.2019 | *Salmo trutta* | 19,7 | 103,5 | 2 | OK | M | 2 | H | 50,4 | MU | 1,8 | OK | 19,7 | 103,5 |
| Alna-1 | 11 | 3 | NR-2019-0716 | 21.05.2019 | 15.10.2019 | *Salmo trutta* | 28,7 | 317,3 | 2 | OK | F | 2 | H | 132,4 | MU | 8 | OK | 28,7 | 317,3 |
| Alna-2 | 16 | 4 | NR-2019-0716 | 03.10.2019 | 11.10.2019 | *Salmo trutta* | 16,3 | 56 | 2 | OK | F | 1-2 | HLR | 21,55 | MU | 0,77 | OK | | |
| Alna-2 | 17 | 4 | NR-2019-0716 | 03.10.2019 | 11.10.2019 | *Salmo trutta* | 15 | 47,9 | 2 | OK+ | M | 4-5 | HLR | 17,74 | MU | 0,76 | OK | | |
| Alna-2 | 18 | 4 | NR-2019-0716 | 03.10.2019 | 11.10.2019 | *Salmo trutta* | 16,5 | 57,4 | 2 | OK++ | M | 1-2 | HLR | 24,27 | MU | 0,89 | OK | | |
| Alna-2 | 19 | 4 | NR-2019-0716 | 03.10.2019 | 11.10.2019 | *Salmo trutta* | 16 | 48,5 | 2 | OK | M | 1-2 | HLR | 20,31 | MU | 0,63 | OK | | |
| Alna-2 | 20 | 4 | NR-2019-0716 | 03.10.2019 | 11.10.2019 | *Salmo trutta* | 16,5 | 61,5 | 2 | OK | F | 1 | HLR | 26,81 | MU | 1,03 | OK | 16.1 (0.6) | 54.3 (5.9) |
| Alna-2 | 21 | 5 | NR-2019-0716 | 03.10.2019 | 15.10.2019 | *Salmo trutta* | 20 | 106,1 | 2 | OK | F | 5 | HLR | 32,54 | MU | 2,71 | OK | | |
| Alna-2 | 22 | 5 | NR-2019-0716 | 03.10.2019 | 15.10.2019 | *Salmo trutta* | 20,5 | 101,4 | 2 | OK | M | 2 | HLR | 37,48 | MU | 1,5 | OK | | |
| Alna-2 | 23 | 5 | NR-2019-0716 | 03.10.2019 | 15.10.2019 | *Salmo trutta* | 17,8 | 62,5 | 2 | OK | F | 1 | HLR | 21,95 | MU | 0,96 | OK | | |
| Alna-2 | 24 | 5 | NR-2019-0716 | 03.10.2019 | 15.10.2019 | *Salmo trutta* | 17,2 | 61,9 | 2 | OK | M | 1 | HLR | 22,19 | MU | 0,74 | OK | | |
| Alna-2 | 25 | 5 | NR-2019-0716 | 03.10.2019 | 15.10.2019 | *Salmo trutta* | 20,4 | 119,8 | 2 | OK+ | F | 6 | HLR | 29,52 | MU | 3,38 | OK | 19.2 (1.6) | 90.3 (26.6) |
| Alna-2 | 27 | 6 | NR-2019-0716 | 03.10.2019 | 11.10.2019 | *Salmo trutta* | 22,2 | 148,3 | 2 | OK | F | 1-2 | HLR | 61,42 | MU | 3,09 | OK | | |
| Alna-2 | 28 | 6 | NR-2019-0716 | 03.10.2019 | 11.10.2019 | *Salmo trutta* | 23,9 | 187,1 | 2 | OK++ | F | 5-6 | HLR | 63,58 | MU | 6,45 | OK | 23.1 (1.2) | 167.7 (27.4) |

# Appendix 2.

Yearly discharges of chemicals from the Rivers Driva, Nausta, Nidelva, Orkla and Vosso for 2019

**TABLE A1**

**Yearly discharge of polycyclic aromatic hydrocarbons in five rivers**

| | Driva | Nausta | Nidelva | Orkla | Vosso |
|---|---|---|---|---|---|
| Naphthalene | <14 | <4 | <13 | <8 | <13 |
| Acenaphthylene | <0.8 | <0.2 | <0.8 | <0.5 | <0.8 |
| Acenaphthene | <0.8 | <0.2 | <0.8 | <0.5 | <0.8 |
| Fluorene | 1.0 | 0.1 | 0.7 | 0.4 | 0.7 |
| Phenanthrene | 2.0 | 0.2 | 1.3 | 0.7 | 1.5 |
| Anthracene | <0.5 | <0.1 | <0.5 | <0.3 | <0.5 |
| Fluoranthene | 0.5 | 0.1 | 0.7 | 0.3 | 1.0 |
| Pyrene | 0.4 | 0.1 | <0.5 | <0.3 | 0.4 |
| Benz[a]anthracene | <0.5 | <0.1 | <0.5 | <0.3 | <0.5 |
| Chrysene | <0.5 | <0.1 | <0.5 | <0.3 | 0.5 |
| Benzo[b,j]fluoranthene | <0.5 | <0.1 | 0.4 | 0.2 | 0.4 |
| Benzo[k]fluoranthene | <0.5 | <0.1 | <0.5 | <0.3 | <0.5 |
| Benzo[a]pyrene | <0.5 | <0.1 | <0.5 | <0.3 | 0.4 |
| Indeno[1,2,3-cd]pyrene | <0.5 | <0.1 | <0.5 | <0.3 | 0.4 |
| Dibenzo[ac/ah]anthracene | <0.5 | <0.1 | <0.5 | <0.3 | <0.5 |
| Benzo[ghi]perylene | <0.5 | <0.1 | <0.5 | <0.3 | 0.5 |
| *Data in kg/year | | | | | |

**TABLE A2**

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

| | Driva | Nausta | Nidelva | Orkla | Vosso |
|---|---|---|---|---|---|
| Pentachlorobenzene | <0.3 | <0.07 | <0.3 | <0.2 | <0.3 |
| Hexachlorobenzene | <0.3 | <0.07 | <0.3 | <0.2 | <0.3 |
| γ-HCH | <0.3 | <0.07 | <0.3 | <0.2 | <0.3 |
| PCB28/31 | <0.5 | <0.1 | <0.5 | <0.3 | <0.5 |
| PCB52 | <0.5 | <0.1 | <0.5 | <0.3 | <0.5 |
| PCB101 | <0.3 | <0.1 | <0.3 | <0.2 | <0.3 |
| PCB118 | <0.3 | <0.1 | <0.3 | <0.2 | <0.3 |
| PCB153 | <0.3 | <0.1 | <0.3 | <0.2 | <0.3 |
| PCB138 | <0.3 | <0.1 | <0.3 | <0.2 | <0.3 |
| PCB180 | <0.3 | <0.1 | <0.3 | <0.2 | <0.3 |
| *p,p'*-DDE | <0.3 | <0.1 | <0.3 | <0.2 | <0.3 |
| *p,p'*-DDD | <1.4 | <0.3 | <1.3 | <0.8 | <1.3 |
| *p,p'*-DDT | <0.3 | <0.1 | <0.3 | <0.2 | <0.3 |

*Data kg/year

**TABLE A3**

**Yearly discharge of polybrominated diphenyl ethers in five rivers**

| | Driva | Nausta | Nidelva | Orkla | Vosso |
|---|---|---|---|---|---|
| PBDE28 | <0.05 | <0.01 | <0.05 | <0.03 | <0.05 |
| PBDE47 | <0.05 | <0.01 | <0.05 | <0.03 | <0.05 |
| PBDE100 | <0.05 | <0.01 | <0.05 | <0.03 | <0.05 |
| PBDE99 | <0.08 | <0.02 | <0.08 | <0.05 | <0.08 |
| PBDE154 | <0.05 | <0.01 | <0.05 | <0.03 | <0.05 |
| PBDE153 | <0.05 | <0.01 | <0.05 | <0.03 | <0.05 |

*Data in kg/year

**TABLE A4**

**Yearly discharge of hexabromocyclododecane in five rivers**

| | Driva | Nausta | Nidelva | Orkla | Vosso |
|---|---|---|---|---|---|
| α-HBCDD | <3 | <1 | <3 | <2 | <3 |
| β-HBCDD | <3 | <1 | <3 | <2 | <3 |
| γ-HBCDD | <3 | <1 | <3 | <2 | <3 |

*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** | Driva | Nausta | Nidelva | Orkla | Vosso |
|---|---|---|---|---|---|
| SCCP | <1400 | <400 | <1400 | <800 | <1300 |
| MCCP | <500 | <100 | <400 | <300 | <400 |

*Data in kg/year for all rivers

**TABLE A6**

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

| **Chemical** | Driva | Nausta | Nidelva | Orkla | Vosso |
|---|---|---|---|---|---|
| Nonylphenol | <130 | <40 | <140 | <70 | <120 |
| Octylphenol | <100 | <30 | <100 | <50 | <80 |
| 4-tert-octylphenol | 51 | 17 | 41 | 29 | 30 |

*Data in kg/year for all rivers

**TABLE A7**

**Yearly discharge of chlorfenvinfos, cybutryne and DEHP in five rivers**

| **Chemical** | Driva | Nausta | Nidelva | Orkla | Vosso |
|---|---|---|---|---|---|
| Chlorfenvinfos | <0.3 | <0.1 | <0.3 | <0.2 | <0.3 |
| Cybutryne | <0.3 | <0.1 | <0.3 | <0.2 | <0.3 |
| DEHP | <60 | <15 | <54 | <31 | <51 |

*Data in kg/year for all rivers

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