Occurrence of selected pharmaceuticals in wastewater effluents from hospitals (Ullevål and Rikshospitalet) and VEAS wastewater treatment works

Preface

NIVA and NILU were commissioned by The Norwegian Pollution Control Authority (SFT) to establish the occurrence of selected pharmaceutical substances in wastewater from two Oslo hospitals, Ullevål and Rikshospitalet, and VEAS wastewater treatment works (WTW) influent, sludge and effluent during 2006. The results of the study are reported here.

The results show that Oslo hospitals contribute to the pharmaceutical loads entering VEAS WTW. Depending on their physico-chemical properties, some of these pharmaceutical compounds are removed by the WTW, some bind to the sludge particles and some are released into the Oslo fjord environment. Of those substances released from the WTW, gram quantities are released per day into Oslo fjord. A simple environmental risk assessment of the effluent suggests that only the antibiotic ciprofloxacin, and only at certain times, poses an acute risk to the aquatic environment. The results of this simple environmental risk assessment must be viewed with caution due to the absence of measured environmental concentrations in the receiving waters, and without a full understanding of the chronic effects associated with the selected pharmaceuticals.

The VEAS samples were provided by Arne Haarr (VEAS) and the Oslo hospital samples by Anne Siri Haddeland (Oslo kommune). Sample analysis at NIVA was performed by Katherine Langford with support from Lill-Ann Kronvall and Merete Grung. At NILU sample analysis was performed by Christian Dye and Martin Schlabach with support from Arve Bjerke, Christin Bråten, and Iren Sturtzel. The project was lead by Kevin Thomas (NIVA). This report was written by the above individuals from NIVA and NILU.

Oslo, March, 2007

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1. Abstract

The occurrence of thirteen pharmaceutical compounds selected by SFT, and seven similar pharmaceuticals, was quantitatively determined in effluents from two major Oslo hospitals, Rikshospitalet and Ullevål, along with influent, sludge and final effluent from the city's VEAS wastewater treatment works (WTW). The pharmaceutical compounds analysed were:

Pharmaceutical	**Application**
• Cefuroxime	Antibiotic
• Chlortetracycline	Antibiotic
• Ciprofloxacin	Antibiotic
• Cyclophosphamide	Antitumor, antineoplastic agent
• Demeclocycline	Antibiotic
• Diclofenac	Anti-inflamatory and antirheumatic
• Doxycycline	Antibiotic
• 17β-estradiol	Natural steroid hormone
• Estriol	Natural steroid
• Estrone	Natural steroid
• 17α-Ethinylestradiol	Hormonal contraceptive
• Ibuprofen	Analgesic, Antiinflamatory and antirheumatic
• Ifosfamide	Antitumor, antineoplastic agent
• Meclocycline	Antibiotic
• Metoprolol	Betablocker
• Oxytetracycline	Antibiotic
• Paracetamol	Analgesic
• Sulfamethoxazole	Antibiotic
• Tetracycline	Antibiotic
• Trimethoprim	Antibiotic

Composite hospital effluents were collected over a twelve-week period and were showed to contain paracetamol, metoprolol, diclofenac, ibuprofen, 17β-estradiol, estriol, estrone, oxytetracycline, tetracycline, doxycycline, chlorotetracycline, demeclocycline, trimethoprim, ciprofloxacin, sulfamethoxazole, cyclophosphamide and ifosfamide. Three were not detected above the limit of detection; cefuroxime, 17a-etinylestradiol and meclocycline. The pharmaceuticals occurred at variable concentrations, however paracetamol and the antibiotic ciprofloxacin were consistently detected at the highest concentrations in the hospital effluents. Paracetamol, metoprolol, diclofenac and ibuprofen (as well as 17β-estradiol and estriol) were detected in all of the hospital effluents collected, whilst the antibiotic trimethoprim was also detected in all of the samples collected from Ullevål hospital.

Composite influent, sludge and effluent samples were collected from VEAS WTW over a seven week period. The influent into VEAS WTW contained all of the same selected substances detected in the hospital effluents except for oxytetracycline, chlorotetracycline, demeclocycline, cyclophosphamide and ifosfamide. Paracetamol was consistently detected at the highest concentrations with all other detected compounds present at median concentrations of tens/hundreds of ng L^{-1}. Paracetamol, metoprolol, diclofenac, ibuprofen, 17β-estradiol, estriol, estrone, trimethoprim and ciprofloxacin were detected in all of the influent samples collected. VEAS sludge samples contained a different profile of substances reflecting their physico-chemical properties. Hydrophobic antibiotics such as oxytetracycline,

tetracycline and ciprofloxacin were detected in all of the collected sludge samples. Their absence in the influent samples collected suggests that they enter the works bound to effluent particles with the dissolved fraction observed in the hospital effluents partitioning onto particulate matter within the sewerage network. The risk posed to the environment by these particle bound pharmaceuticals will be dependent on how the material is disposed/used. The final effluent from VEAS WTW contained reduced concentrations of many pharmaceuticals, including paracetamol, ibuprofen and sulfamethoxazole. For other compounds, such as metoprolol, diclofenac and trimethoprim the removal efficiencies were not as high with often there being higher concentrations in the effluent than the influent. It is hypothesised that this may be due to the deconjugation of conjugated metabolites during treatment to form parent compounds and has previously been reported for a number of pharmaceutical compounds. These effluent concentrations represent median inputs varying from low g day^{-1} (e.g. paracetamol and ibuprofen) to nearly 200 g day^{-1} (e.g. metoprolol and trimethoprim) into Oslo fjord. However, the effluent concentrations varied significantly and on certain sampling occasions the maximum environmental loading was significantly higher than the median.

Since this study did not include samples from the receiving waters of Oslo fjord it has been necessary to derive quasi-measured environmental concentrations (quasi-MEC) from the effluent concentrations by assuming that the effluent is subject to a minimum of ten-fold dilution once it is discharged into the fjord. These quasi-MEC were then used to derive risk quotients based on comparison with predicted no-effect concentrations (PNEC). No median quasi-MEC/PNEC was greater than 1 suggesting that during most of the study period the quantities released are unlikely to cause acute harm to aquatic organisms. Only for ciprofloxacin was the maximal quasi-MEC/PNEC greater than 1 (15) suggesting that at certain times the quantities of ciprofloxacin being released from VEAS WTW may pose an acute threat to certain aquatic organisms. This simple environmental risk assessment must however be treated with caution since they do not reflect the environmental processes that discharged pharmaceuticals will be subjected to in receiving waters (e.g. persistence is not considered). In addition, the risk is essentially based upon acute effects where it is most likely that pharmaceuticals will have a specific mode of action which may in turn not be detected through the use of existing laboratory tests.

2. Norsk sammendrag

På oppdrag fra SFT ble forekomsten av tretten legemidler, samt sju lignende legemidler, målt i avløpet fra de to største sykehusene i Oslo (Rikshospitalet og Ullevål sykehus). De samme legemidlene ble også målt i vannprøver (innløp og utløp) og slam fra VEAS; renseanlegget som mottar hovedtyngden av avløpet fra Oslo. De analyserte forbindelsene var følgende:

- Cefuroxime
- Chlortetracycline
- Ciprofloxacin
- Cyclophosphamide
- Demeclocycline
- Diclofenac
- Doxycycline
- 17β-estradiol
- Estriol
- Estrone
- 17α-Ethinylestradiol
- Ibuprofen
- Ifosfamide
- Meclocycline
- Metoprolol
- Oxytetracycline
- Paracetamol
- Sulfamethoxazole
- Tetracycline
- Trimethoprim

Døgnblandprøver fra sykehusenes avløp ble samlet en gang i uken over en 12 ukers periode, og inneholdt paracetamol, metoprolol, diclofenac, ibuprofen, 17β-estradiol, estriol, estrone, oxytetracycline, tetracycline, doxycycline, chlorotetracycline, demeclocycline, trimethoprim, ciprofloxacin, sulfamethoxazole, cyclophosphamide og ifosfamide. Tre legemidler ble ikke påvist over deteksjonsgrensen; dette gjaldt cefuroxime, 17a-etinylestradiol og meclocycline. Forekomsten av legemidlene varierte, men paracetamol og ciprofloxacin (antibiotikum) var legemidlene som gjennomgående ble påvist i høyest konsentrasjoner. Alle prøvene fra avløp fra sykehusene inneholdt paracetamol, metoprolol, diclofenac og ibuprofen (samt 17 β-estradiol og estriol), mens trimethoprim (antibiotikum) ble funnet i alle avløpsprøvene fra Ullevål sykehus.

Døgnblandprøver av innløpet til VEAS renseanlegg, utløpsprøver samt slam fra renseanlegget ble samlet en gang i uken over en 7 ukers periode. Innløpsprøvene til renseanlegget inneholdt de samme legemidlene som ble funnet i avløpene fra sykehusene, med unntak av oxytetracycline, chlorotetracycline, demeclocycline, cyclophosphamide og ifosfamide. Også her var paracetamol gjennomgående den forbindelsen som ble påvist i høyest konsentrasjon. De andre forbindelsene ble påvist i mediankonsentrasjoner i området 10-100 ng L^{-1}. Paracetamol, metoprolol, diclofenac, ibuprofen, 17β-estradiol, estriol, estrone, trimethoprim og ciprofloxacin ble påvist i alle prøvene fra innløpet til VEAS. Som forventet ut fra ut fra de ulike kjemisk-fysiske egenskapene til forbindelsene, ble det påvist et annet mønster av forbindelser i slamprøvene enn i vannprøvene. De hydrofobe forbindelsene oxytetracycline, tetracycline og ciprofloxacin ble påvist i alle slamprøvene. Fraværet av disse forbindelsene i

vannprøver fra innløpet til VEAS tyder på den løste fraksjonen av disse forbindelsene binder seg til partikler i avløpsnettet mellom utløpet fra sykehusene og innløpet til VEAS. Risikoen for miljøet for disse forbindelsene er avhengig av hva som skjer videre med slam fra renseanlegget. Vannprøver fra utløpet av VEAS renseanlegg inneholdt lavere konsentrasjoner enn innløpet for mange av legemidlene som ble målt, blant annet paracetamol, ibuprofen og sulfamethoxazole. For andre legemidler som metoprolol, diclofenac og trimethoprim var renseeffektiviteten ikke like høy, og det ble ofte observert høyere konsentrasjoner i vannet fra utløpet enn i innløpet for disse komponentene. En forklaring på dette kan være en dekonjugering av metabolitter (for eksempel sulfonerte eller glukuroniderte omdanningsprodukter) tilbake til mor-substansen som finner sted i løpet av renseprosessen. Dette er tidligere rapportert for en rekke legemidler. Konsentrasjonene av legemidlene representerer en daglig tilførsel til Oslofjorden i størrelsesorden noen gram pr. dag (paracetamol og ibuprofen) til nesten 200 g pr. dag (for eksempel metoprolol og trimethoprim). Konsentrasjonene av legemidler i vannprøvene fra avløpet varierte imidlertid betydelig, og var i noen tilfelle langt høyere enn mediankonsentrasjonen.

I denne studien ble det ikke tatt prøver av resipienten (Oslofjorden). Det var derfor nødvendig å beregne miljøkonsentrasjoner for resipienten basert på de målte konsentrasjonene i utløpet fra VEAS samt en antagelse om en fortynningsgrad på minst 10 når utløpet slippes ut i fjorden. De estimerte miljøkonsentrasjonene ble brukt for å estimere risikokvotienter basert på en sammenligning mot rapporterte PNEC-verdier. Forholdet mellom beregnet median miljøkonsentrasjon og PNEC var < 1 for alle de undersøkte legemidlene, noe som tyder på at mengdene som ble tilført miljøet i det meste av det undersøkte tidsrommet ikke utgjorde noen risiko for vannlevende organismer. Imidlertid ble det for ciprofloxacin observert at den maksimale beregnede miljøkonsentrasjonen ved noen anledninger var større enn PNEC-verdien (maksimal beregnet miljøkonsentrasjon/PNEC=15), noe som tyder på at konsentrasjonen av denne forbindelsen tidvis kan utgjøre en akutt risiko for vannlevende organismer. Dataene fra denne enkle miljøriskovurderingen må tolkes med forsiktighet, siden vi ikke vet hva som skjer med legemidlene i miljøet etter at de er sluppet ut i resipienten (det er ikke tatt hensyn til persistensen til forbindelsene). Risikoen er også hovedsakelig basert på studier av akutt-toksisitet, mens effekten av legemidler, som ofte har en spesifikk biologisk virkningsmekanisme, ikke vil kunne avdekkes i de studiene som benyttes i laboratoriet i dag.

3. Introduction

The release of pharmaceutical compounds and their metabolites into the aquatic environment has become an increasing concern over recent years. Human pharmaceuticals are typically released into the environment following their ingestion and subsequent excretion via the wastewater treatment network. In addition, the inappropriate disposal of unused medicines can also contribute to the overall burden. In Norway as much as 140 tonnes per annum of a drug can be sold with much of this being excreted and released into the sewerage network (e.g. paracetamol; Table 1). Compounds not exclusively used as human medicines can also enter the environment from non-human uses such as livestock treatment, aquaculture and pet care.

To investigate the potential risk posed to the aquatic environment in Norway by pharmaceutical substances, the Norwegian Pollution Control Authority (SFT) has to date commissioned two previous studies;

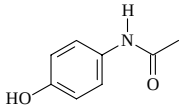
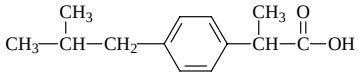
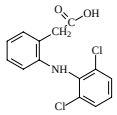
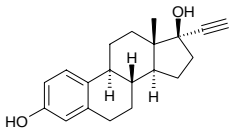
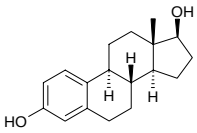
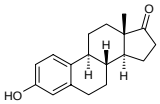
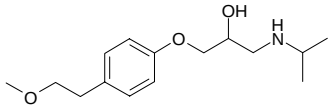
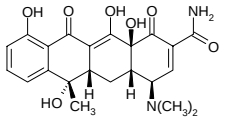
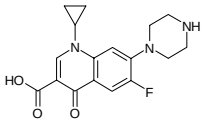
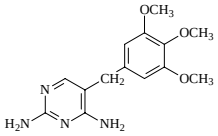
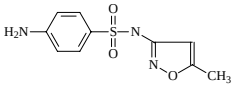
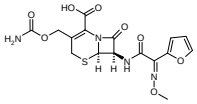
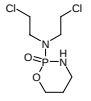
- Screening of selected pharmaceuticals and cosmetics (*In Norwegian*) (2006) [1]
- Initial assessment of eleven pharmaceuticals using the EMEA guideline (2006) [2]

The first was a screening project that demonstrated the occurrence of certain selected pharmaceutical compounds in the Norwegian aquatic environment, whilst the latter provided a simple environmental risk assessment of eleven prioritised pharmaceuticals (Table 1). This was performed using the European Agency for the Evaluation of Medicinal Products (EMEA) guidelines for the risk assessment of human pharmaceuticals, using predicted environmental concentrations (PEC) and predicted no-effect concentrations (PNEC) based upon literature values.

Wastewater treatment works effluent is widely regarded as the primary pathway for human pharmaceutical compounds to enter the aquatic environment and it is the efficiency of works in removing the pharmaceutical compounds present in effluents that is a key factor when assessing the quantities released into the aquatic environment. Typically wastewater treatment works will receive effluent from industrial and domestic sources. Pharmaceuticals can therefore enter the sewerage system from a multitude of sources, however homes and hospitals are likely to be the main contributors.

The same eleven prioritised pharmaceutical compounds selected for simple risk assessment (Table 1) were also selected for occurrence screening in samples collected from two Oslo hospitals (Ullevål and Rikshospitalet) and the wastewater treatment works (VEAS) which receives effluent from these hospitals and the Oslo area. This report describes the results of targeted screening for the occurrence of the eleven human pharmaceuticals listed in Table 1 in composite effluent samples collected from Ullevål and Rikshospitalet hospitals and composite effluent and sludge samples collected from VEAS wastewater treatment works (WTW). The occurrence data will allow for an improved assessment of the risk these prioritised pharmaceuticals pose to the aquatic environment through the use of measured environmental concentrations (MECs) and not PECs, thus removing an element of uncertainty.

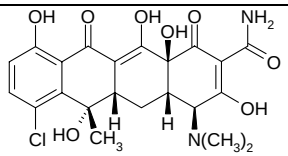
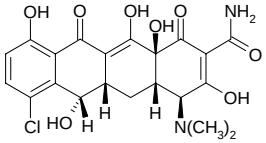
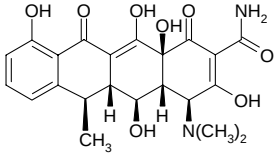
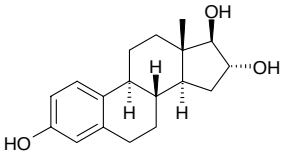
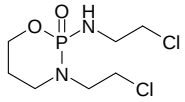
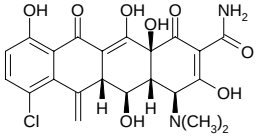
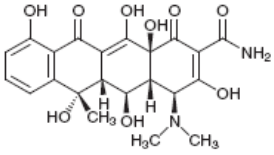
Table 1 Pharmaceuticals selected by SFT for monitoring

Substance	Volume sold† (Kg)	CAS	Structure	Application
Paracetamol	140 464	103-90-2		Analgesic
Ibuprofen	26 954	15687-27-1		Analgesic, anti-inflammatory and antirheumatic product,
Diclofenac	1 588	15307-86-5		Anti-inflammatory and antirheumatic product
17α-Ethinylestradiol	2	57-63-3		Hormonal contraceptive
17β-estradiol	-	50-28-2		Natural hormone and used in hormone replacement therapy
Estrone	-	53-16-7		Natural hormone and metabolite of 17β-estradiol
Metoprolol	5 646	37350-58-6		Beta-blocker
Tetracycline	1 068	60-54-8		Antibiotic
Ciprofloxacin	880	85721-33-1		Antibiotic
Trimethoprim	534	738-70-5		Antibiotic
Sulfamethoxazole	218	723-46-6		Antibiotic
Cefuroxime	110	55268-75-2		Antibiotic
Cyclophosphamide	17	50-18-0		Antitumor, antineoplastic agent

† based upon sales figures for Norway in 2005. (www.legemiddelforbruk.no)

In addition, the following seven substances were also measured in the samples collected (Table 2).

Table 2 *Additional compounds analysed*

Substance	CAS	Structure	Application
Chlortetracycline	57-62-5		Antibiotic
Demeclocycline	127-33-3		Antibiotic
Doxycycline	564-25-0		Antibiotic
Estriol	50-27-1		Natural hormone (pregnancy)
Ifosfamide	3778-73-2		Antitumor, antineoplastic agent
Meclocycline	73816-42-9		Antibiotic
Oxytetracycline	6153-64-6		Antibiotic

4. Methods and materials

4.1 Sampling locations

Wastewater influent, effluent and dewatered sludge samples were collected from VEAS (Vestfjorden Avløpsselskap) [59° 47.588N 10° 30.040E] at Slemmestad in weeks 32 to 38 in 2006. VEAS serves a population of 440 000 in both the Oslo and Akershus county areas with an overall population equivalent of 610 000. The effluent undergoes both chemical and biological treatment before discharge (www.veas.nu).

Hospital effluent samples were collected from Ullevål Hospital [59° 56.147N 10° 44.461E] and Rikshospitalet [59° 56.951N 10° 42.861E] in Oslo in weeks 32 to 43 in 2006 (Figure 1).

Ullevål University Hospital is the largest hospital in Norway and is located in central Oslo. It has more than 8 600 employees with a total of 1 200 beds. Ullevål admits some 45 000 patients per year and its outpatient clinics have about 400 000 consultations per year. 28 000 patients are admitted annually to Rikshospitalet as inpatients. In addition 17 000 patients p.a. are given day-treatment, and there are approximately 130 000 outpatient consultations.

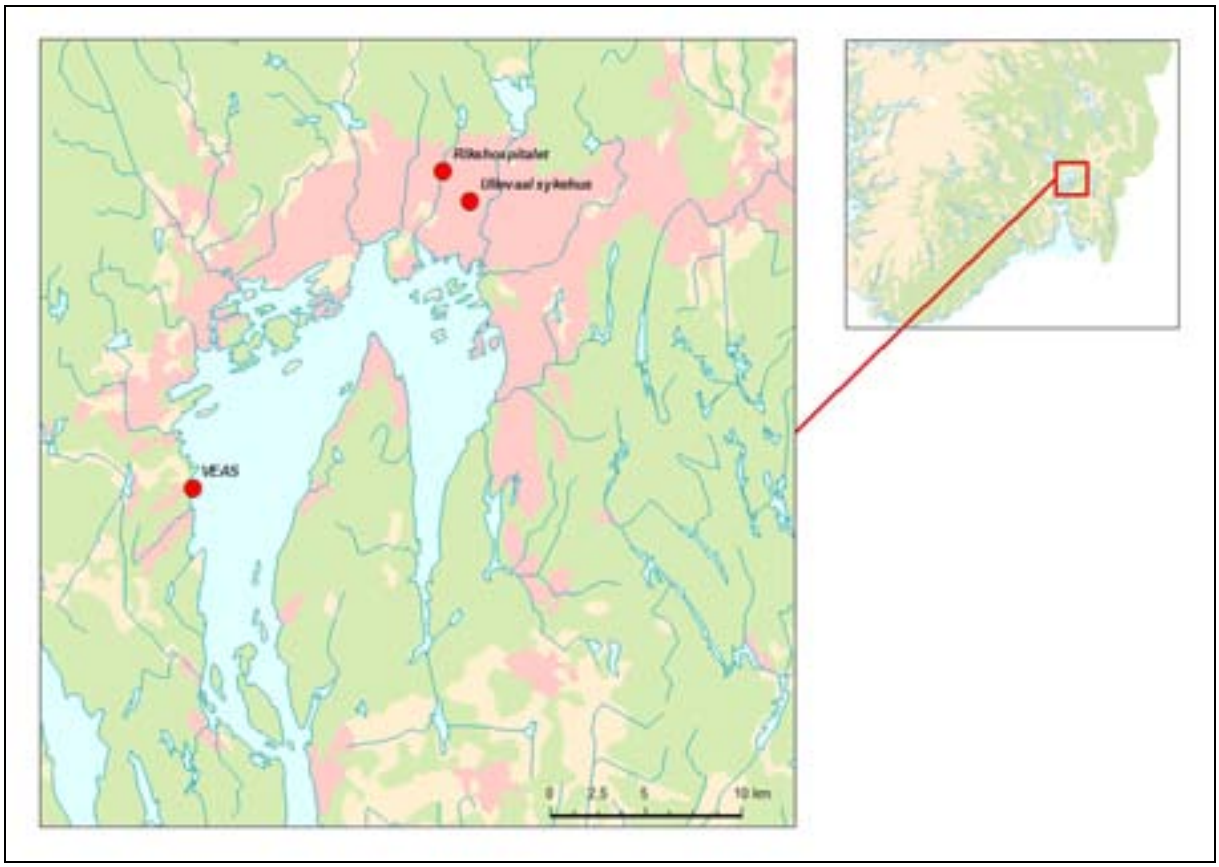


Figure 1 Map showing the locations of Rikshospitalet, Ullevål hospital and VEAS WTW

4.2 Sample collection, receipt and storage

Aqueous phase samples were collected as 2.5 L, 24 hour composite samples, and 500 ml dewatered sludge samples were collect by grab sampler. Glass bottles for collection of aqueous samples were silanised prior to sample collection. After collection all samples were stored in coolboxes and delivered on the sample collection day to the laboratory where aqueous samples were stored at 4 ^{o}C and sludge samples at -20 ^{o}C. Aqueous samples were all extracted within 24 hours and sludge samples within 3 months.

4.3 Analysis of selected pharmaceuticals

4.3.1 Paracetamol, metoprolol, diclofenac and ibuprofen

Aqueous phase sample extraction: Influent and effluent samples (1 L) were filtered (0.45 µm GFC) prior to acidification to pH3 by the addition of hydrochloric acid. 50 ng of internal standard (fluoxetine d_4, caffeine ^{13}C, paracetamol d_4 and tamoxifen ^{13}C) was then added before SPE extraction. StrataX SPE (Phenomenex) columns were conditioned by the addition of 5 ml methanol, 5 ml water and then 5 ml (acidified to pH3 by the addition of hydrochloric acid). After conditioning, the sample was applied to the column under vacuum at a flow rate of approximately 2 ml/min. The column was air dried for approximately 30 minutes before analyte elution. Elution used 4 ml MeOH, 4 ml MeOH (2% acetic acid) and finally 4 ml MeOH (2% ammonium hydroxide). Eluants were then evaporated under nitrogen to approximately 100 µl and reconstituted with methanol:water (10:90) up to 1 ml. A blank and a spiked reference sample were extracted alongside each batch of samples.

Sludge sample extraction: Dewatered sludge samples (5 g) were mixed with hydromatrix and extracted by accelerated solvent extraction (ASE). The ASE method consisted of pre-fill method: acetone/water (3:7); equilibration, 5 min; static time, 5 min; flush volume, 60%; purge time, 60 s; static cycles, 3; and temperature, 80 ^{o}C. Extracts were evaporated under nitrogen to approximately 5 ml and 500 ml water was added in preparation for sample cleanup. The cleanup stage used StrataX columns and followed the same protocol as described for the extraction of aqueous phase samples. A blank and a spiked reference sample were also extracted.

LC/MS analysis: LC/MS analysis used a Waters Alliance HPLC coupled to a Waters Quattro Premier triple quadruple mass spectrometer. Analytes were separated on a Luna 5 µ C18 column (Phenomenex; 250 x 2 mm) with C18 guard column. The mobile phases for positive mode detection were water and modified methanol (20 mM ammonium acetate), and in negative mode were water and methanol. A simple gradient elution from 5% to 95% organic solvent over 20 minutes separated all compounds. The first 4 minutes of the HPLC run were sent to waste to ensure high sensitivity throughout the run. Positive mode separation is demonstrated by the chromatogram in Figure 2. All analytes were detected using Multiple Reaction Monitoring, paracetamol, metoprolol and diclofenac were detected in positive mode and ibuprofen in negative mode. The optimised mass spectrometry parameters showing parent and daughter ions are shown in Table 3. Pharmaceuticals were quantified using fluoxetine-d_4 internal standard.

Table 3 Optimised MS parameters

Pharmaceutical	Cone Voltage (V)	Parent *m/z*	Collision Energy (V)	Daughter *m/z*	Retention time (mins)
Paracetamol	30	151.8	18	109.8	7.55
Metoprolol	30	268	23	115.8	12.86
Diclofenac	20	296	12	250	18.62
Ibuprofen	-15	205.2	-10	161.2	21.74

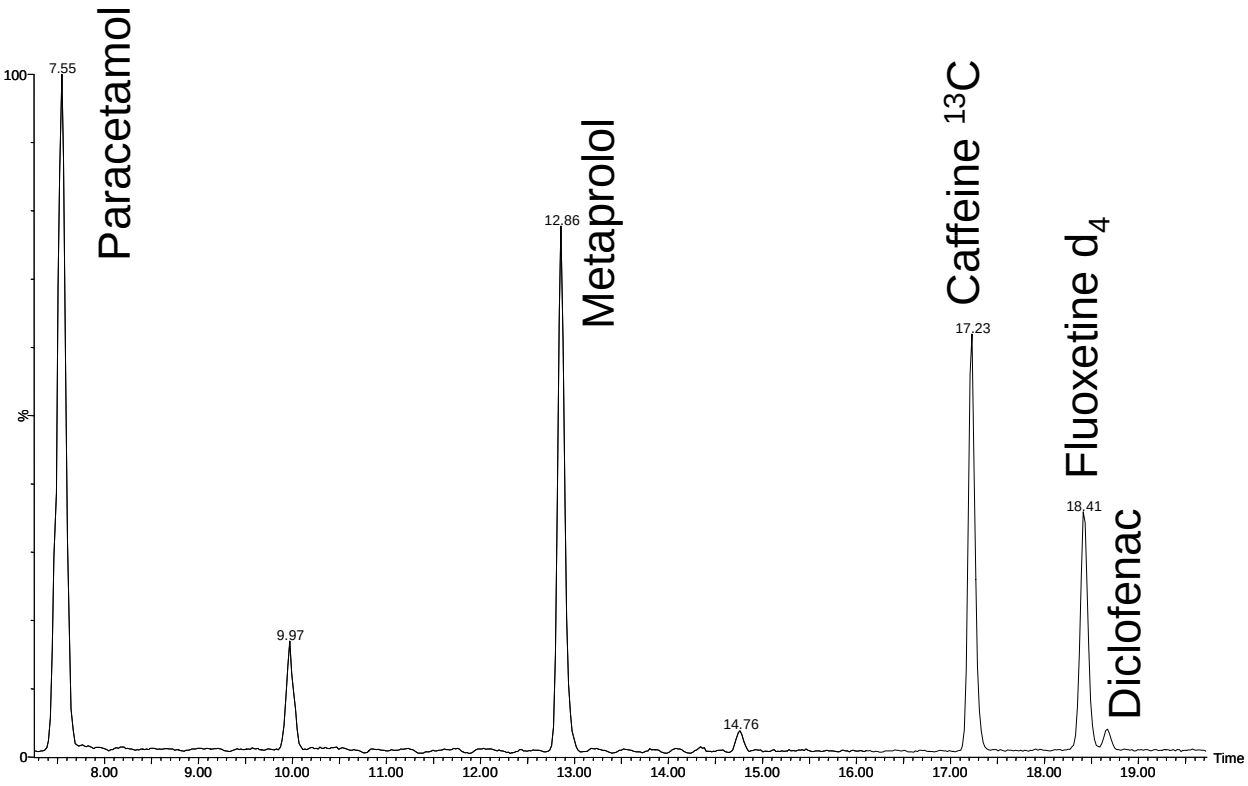


Figure 2 Total mass chromatogram of selected pharmaceuticals

4.3.2 17α-Ethinylestradiol, 17β-estradiol, estrone and estradiol

The water samples were filtered (0.45 µm GFC) and acidified using a small aliquot of sulphuric acid or hydrochloric acid. A complexing agent, Na_2-EDTA, was added and the samples were slowly agitated for an hour. SPE-columns (Oasis HLB column, 200 mg) were cleaned and activated prior use with hexane, ethyl acetate, methanol and water. The filtrates were weighted, spiked with surrogate standards and subsequently concentrated on the SPE-columns. The SPE-columns were rinsed with water, and then eluted using methanol accompanied with ethyl acetate. The eluates were pooled and evaporated to dryness and used for LC-MS analysis.

The frozen samples of sludge were thawed and spiked with internal standard (D3-8-estradiol in the case of hormones). The samples were extracted in methanol using whirl mixing and sonication. The hormone extracts prepared from the sludge samples were cleaned up by centrifuge steps and solid phase ion exchange in order to reduce the matrix effects. The extracts were further cleaned up by liquid-liquid extraction and solid phase extraction.

Quantification was performed on an Agilent 1100 liquid chromatography system (Agilent Technologies, Waldbronn, Germany), equipped with an auto-sampler, a quaternary pump, an on-line degassing system and a diode array detector (UV). The compound separation was performed using a reversed phase C18 column (Atlantis dC18, 2.1 mm ID x 150 mm length, 3µm, Waters, Milford USA). A stainless steel inlet filter (Supelco, 0.8 µm) was used in front of a pre-column with the same stationary phase as the separation columns. Gradient elution was performed with water as solvent A and acetonitrile as solvent B and addition of ammonium hydroxide post column in order to improve the analytical sensitivity. The binary gradient had a flow rate of 0.25 ml min-1 and started with 80 % A. Solvent B was introduced linear up to 100% at 10 minutes and kept isocratic until 12 minutes. The flow rate was increased to 0.5 ml/min 12.2 min for column flushing and equilibration. The total runtime was 21 mins. The analytical detector was a Micromass LCT orthogonal-acceleration time-of-flight (TOF) mass spectrometer (MS) equipped with a Z-spray electrospray ion source and a 4 GHz time to digital converter (TDC) (Micromass Ltd., Wythenshawe, Manchester, UK). The instrument was operated in negative mode for estrogens. The electrospray source parameters were optimised to the following values: Negative mode: sample cone 38 V, capillary voltage 2.85 kV, extraction cone 3 V, source temperature 125 °C, desolvation temperature 350 °C, cone gas flow 241 h^{-1} and desolvation gas flow 6001 h^{-1}. Positive mode: sample cone 16 V, capillary voltage 3.5 kV, extraction cone 3 V, source temperature 125 °C, desolvation temperature 350 °C, cone gas flow 241 h^{-1} and desolvation gas flow 6001 h^{-1}. The pusher frequency was operated in automatic mode. The data processing and instrument (HPLC/HRMS) control were performed by the MassLynx software, and quantitation was performed with signal extraction of a peak width of 90 amu (typical).

4.3.3 Selected antibiotics and chemotherapeutants

The water samples were filtered (0.45 µm GFC) and acidified using a small aliquot of sulphuric acid or hydrochloric acid. A complexing agent, Na_2-EDTA, was added and the samples were slowly agitated for an hour. SPE-columns (Oasis HLB column 200 mg) were cleaned and activated prior use with hexane, ethyl acetate, methanol and water. The filtrates were weighted, spiked with surrogate standards and subsequently concentrated on the SPE-columns. The SPE-columns were rinsed with water, and then eluted using methanol accompanied with acetone. The eluates were pooled and evaporated to dryness and used for LC-MS analysis.

The frozen samples of sludge were thawed and spiked with internal standard (meclocycline). The sample extractions were performed by means of aqueous ion pair extraction followed by a solid phase extraction dean up step. The further sample treatment was the same as the treatment of the water samples.

The quantification was performed on the same instrument as in section 4.3.2. Gradient elution was performed with 0.075% formic acid in water as solvent A and 0.075% formic acid in acetonitrile as solvent B. The binary gradient had a flow rate of 0.2 ml min-1 and started with 100 % A. Solvent B was introduced linear up to 99% at 22 minutes and kept isocratic until 32 minutes. At 32.5 minutes the setting was 100 A and the column was equilibrated up to a runtime of 40 minutes with increased flow rate (0.5 ml/min). The analytical detector was operated in positive ion mode and the electrospray source parameters were optimised to the following values; sample cone cycling 20/30 V, capillary voltage 2.8 kV, extraction cone 3 V, source temperature 130 °C, desolvation temperature 350 °C, cone gas flow 241 h^{-1} and desolvation gas flow 600 1 h^{-1}.

5. Results

A summary of the occurrence data generated by this study is presented in Tables 1 to 5. A complete set of data are presented in Appendix A.

5.1 VEAS WTW

5.1.1 Paracetamol, metoprolol, diclofenac and ibuprofen (analgesics and beta-blocker)

Paracetamol. metoprolol, diclofenac and ibuprofen were detected in all of the influent samples collected from VEAS WTW (Table 4 ; Figure 3). Paracetamol was detected at the highest maximal concentration (43 223 ng L^{-1}) and a median concentration of 3 469 ng L^{-1}. All four compounds were detected in the effluent samples with metoprolol and diclofenac present in all the samples collected (Figure 4). The post treatment effluent concentrations were lower than the influent samples. For example the median effluent concentration of paracetamol was 31 ng L^{-1}. Paracetamol was not detected in the sludge samples collected, whilst metoprolol, diclofenac and ibuprofen were detected at low frequencies (Table 5, Figure 5).

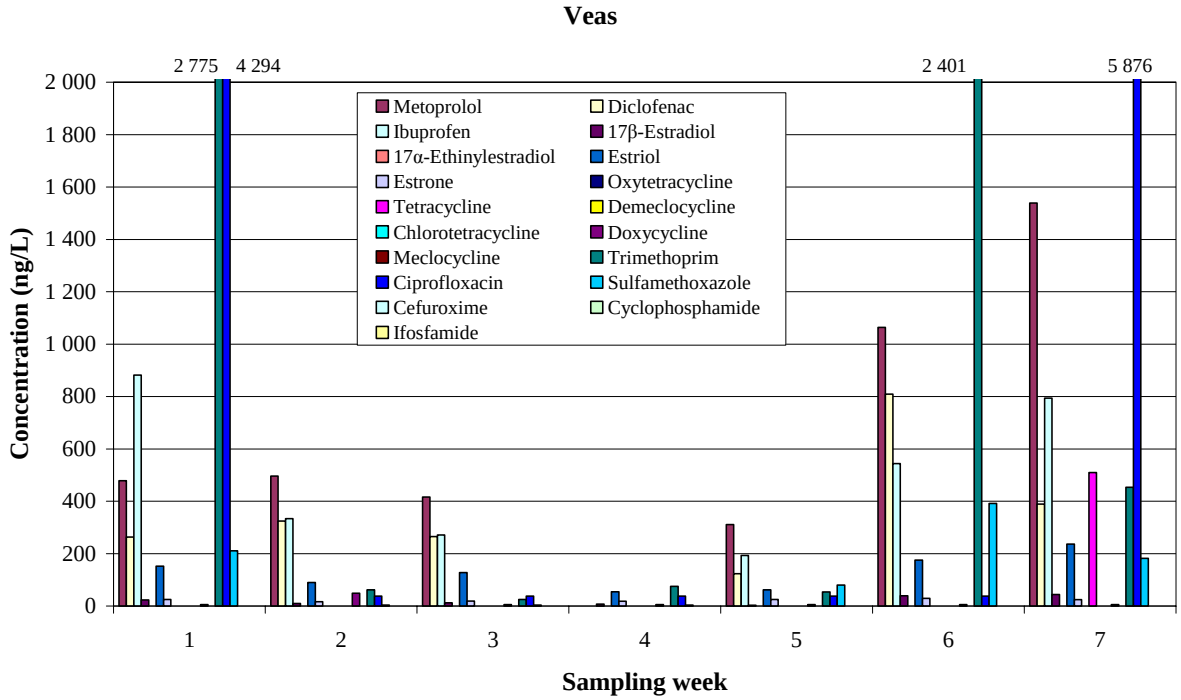


Figure 3 Concentration of selected pharmaceuticals (excluding paracetamol) in VEAS WTW influent samples (Concentrations > 2 000 ng L^{-1} are labelled)

5.1.2 17α-Ethinylestradiol, 17β-estradiol, estrone and estradiol (steroid hormones)

17β-Estradiol, Estriol, and Estrone were detected in all of the influent samples collected from VEAS WTW (Table 4 ; Figure 3). 17β-Estradiol and estrone were also detected in effluent samples, however, with lower concentrations. 17α-Ethinylestradiol could not be detected in any sample. Estrone was detected in all sludge samples.

Table 4 Summary of the targeted pharmaceutical concentrations in VEAS WTW influent and effluent samples

Sample type	Pharmaceutical	Median	Mean	Max.	Min.	Frequency (%)
		(ng L^{-1})				
Influent	Paracetamol	3469	12 424	43 223	1 746	100
	Metoprolol	487	717	1 539	311	100
	Diclofenac	295	362	809	123	100
	Ibuprofen	439	503	882	193	100
	17β-Estradiol	18	23	44	7	100
	17α-Ethinylestradiol	-	-	<0.3	<0.3	0
	Estriol	128	128	237	54	100
	Estrone	25	23	30	17	100
	Oxytetracycline	-	-	<12	<12	0
	Tetracycline	-	-	510	<15	14
	Demeclocycline	-	-	<3	<3	0
	Chlorotetracycline	-	-	<6	<6	0
	Doxycycline	-	-	49	<5	14
	Meclocycline	-	-	<7	<7	0
	Trimethoprim	75	835	2 775	25	100
	Ciprofloxacin	-	-	5 876	<38	29
	Sulfamethoxazole	197	216	391	<4	57
	Cefuroxime	-	-	<125	<125	0
	Cyclophosphamide	-	-	<2	<2	0
	Ifosfamide	-	-	<2	<2	0
Effluent	Paracetamol	31	942	4 319	20	71
	Metoprolol	654	595	772	372	86
	Diclofenac	259	256	368	162	86
	Ibuprofen	40	178	619	13	57
	17β-Estradiol	-	-	5	4	29
	17α-Ethinylestradiol	-	-	<0.3	<0.3	0
	Estriol	-	-	3	<3	14
	Estrone	-	-	8	<3	29
	Oxytetracycline	-	-	1 207	<12	14
	Tetracycline	-	-	<15	<15	0
	Demeclocycline	-	-	<3	<3	0
	Chlorotetracycline	-	-	<6	<6	0
	Doxycycline	-	-	82	<5	14
	Meclocycline	-	-	<7	<7	0
	Trimethoprim	747	726	1 260	<2	86
	Ciprofloxacin	-	-	742	<38	14
	Sulfamethoxazole	-	-	211	<38	29
	Cefuroxime	-	-	<125	<125	0
	Cyclophosphamide	-	-	<2	<2	0
	Ifosfamide	-	-	71	<2	14

-: No mean and median calculated for analytes with a frequency <50%.

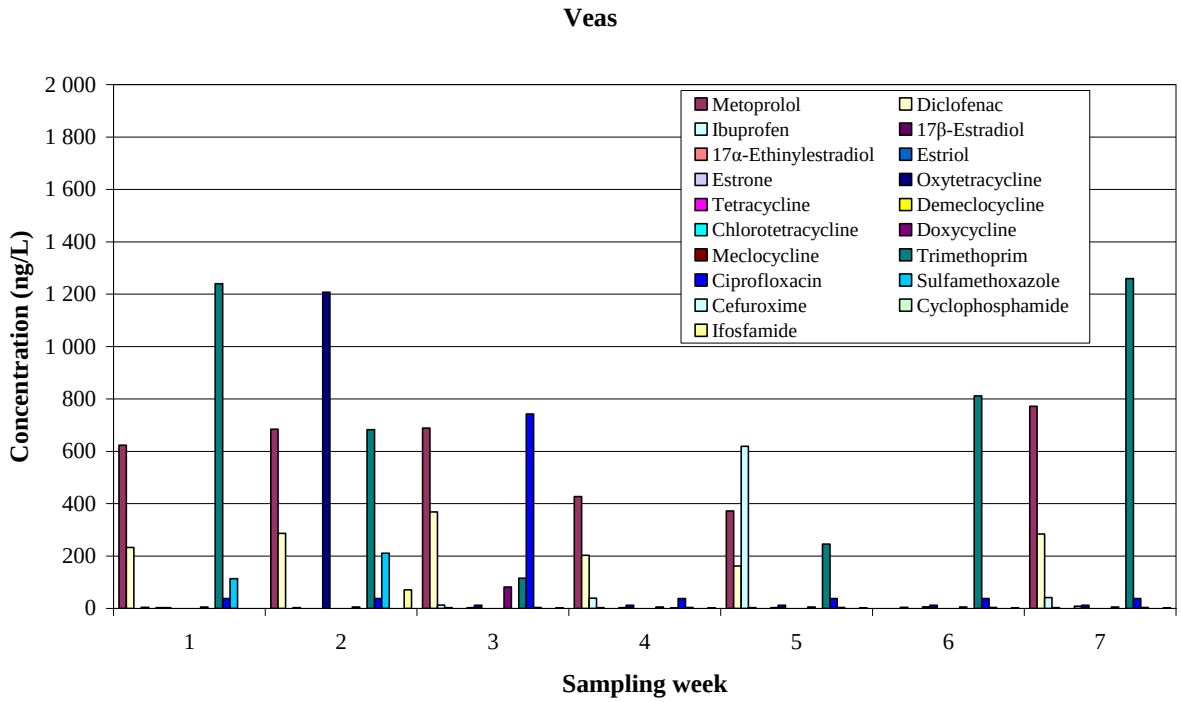


Figure 4 *Concentration of selected pharmaceuticals (excluding paracetamol) in VEAS WTW effluent samples*

Table 5 *Summary of the targeted pharmaceutical concentrations in VEAS WTW sludge samples*

Pharmaceutical	Median	Mean	Max.	Min.	Frequency (%)
	(ng g^{-1} wet weight)				
Paracetamol	-	-	<20	<20	0
Metoprolol	-	-	21	<4	14
Diclofenac	7	10	20	<4	57
Ibuprofen	17	20	33	<4	57
17β-Estradiol	-	-	7	<0.5	43
17α-Ethinylestradiol	-	-	<0.1	<0.1	0
Estriol	-	-	4	<0.5	14
Estrone	4	5	14	2	100
Oxytetracycline	270	542	2 057	<12	100
Tetracycline	422	2 247	6 733	159	100
Demeclocycline	-	-	<3	<3	0
Chlorotetracycline	-	-	<6	<6	0
Doxycycline	89	257	1 293	<10	100
Meclocycline	-	-	<7	<7	0
Trimethoprim	-	-	<4	<4	0
Ciprofloxacin	7 241	26 397	9 7470	4 015	100
Sulfamethoxazole	-	-	171	<4	29
Cefuroxime	-	-	<45	<45	0
Cyclophosphamide	-	-	<4	<3	14
Ifosfamide	-	-	<3	<3	0

-: No mean and median calculated for analytes with a frequency <50%

5.1.3 Selected antibiotics

Trimethoprim and ciprofloxacin were detected in all water samples both influent and effluent in varying but high concentrations. Sulfamethoxazole were detected from time to time, tetracycline and doxycycline sporadically, whereas the other antibiotics could not be detected in influent samples. The hydrophobic antibiotics oxytetracycline, tetracycline and ciprofloxacin were detected in all of the collected sludge samples, with the highest maximal sludge concentration (97 500 ng g^{-1}) for ciprofloxacin.

5.1.4 Cyclophosphamide and ifosfamide

Cyclophosphamide could not be detected in any sample while ifosfamide was detected in one effluent sample.

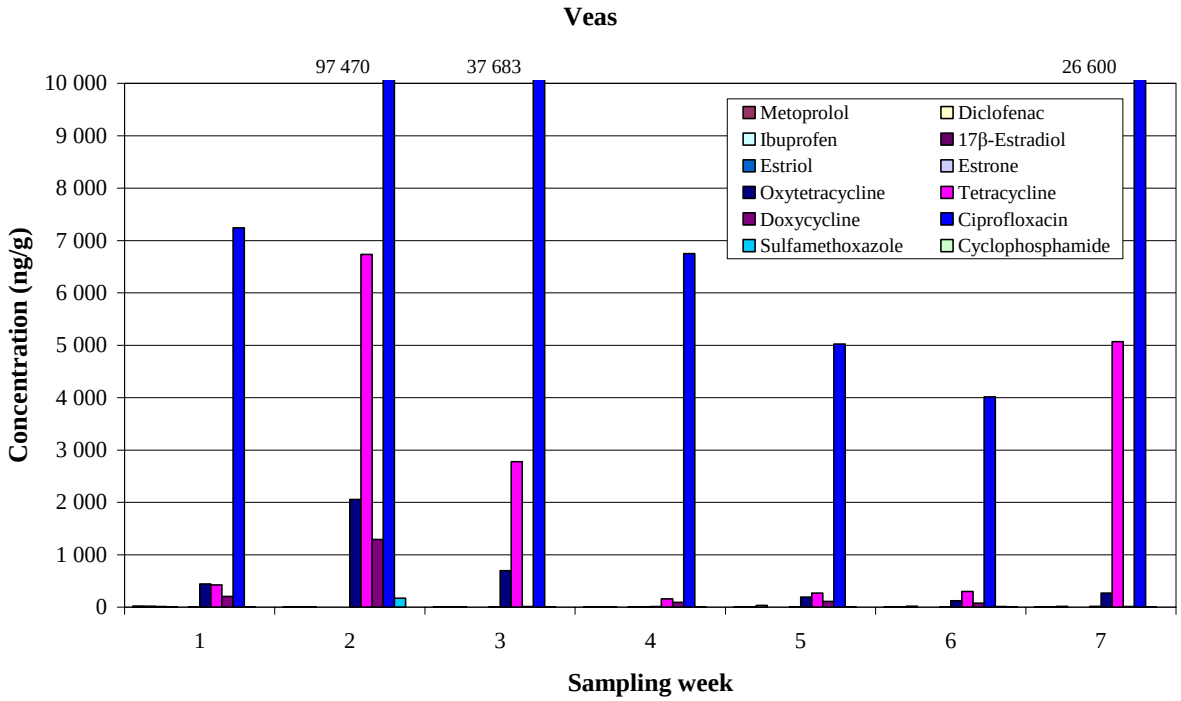


Figure 5 *Concentration of selected pharmaceuticals (excluding paracetamol) with concentrations > LOD in VEAS WTW sludge samples. Concentrations > 10 000 ng g^{-1} are labelled.*

5.2 Ullevål

5.2.1 Paracetamol, metoprolol, diclofenac and ibuprofen

Paracetamol, metoprolol, diclofenac and ibuprofen were detected in all of the effluent samples collected from Ullevål hospital (Table 6, Figures 6 and 7). Paracetamol was detected at the highest maximal concentration of all the selected pharmaceuticals (177 674 ng L^{-1}) with a median concentration of 46 928 ng L^{-1}. Metoprolol, diclofenac and ibuprofen were detected at lower median concentrations of between 417 and 951 ng L^{-1}.

Table 6 Summary of the targeted pharmaceutical concentrations in Ullevål effluent samples

Pharmaceutical	Median	Mean	Max.	Min.	Frequency (%)
			(ng L^{-1})		
Paracetamol	46 928	58 372	177 674	13 874	100
Metoprolol	951	1 072	2 232	419	100
Diclofenac	784	819	1 629	238	100
Ibuprofen	417	499	987	69	100
17β-Estradiol	28	28	42	<3	100
17α-Ethinylestradiol	-	-	<0,3	<0.3	0
Estriol	319	353	784	180	100
Estrone	35	34	47	19	100
Oxytetracycline	-	-	3 743	<12	25
Tetracycline	-	-	1 537	<15	50
Demeclocycline	-	-	<3	<3	0
Chlorotetracycline	-	-	<6	<6	0
Doxycycline	-	-	403	<5	42
Meclocycline	-	-	<7	<7	0
Trimethoprim	1 813	4 302	14 993	50	100
Ciprofloxacin	35 787	31 102	54 049	<38	75
Sulfamethoxazole	326	484	1 375	<4	83
Cefuroxime	-	-	<125	<125	0
Cyclophosphamide	-	-	21	<2	8
Ifosfamide	12	56	338	<2	100

-: No mean and median calculated for analytes with a frequency <50%

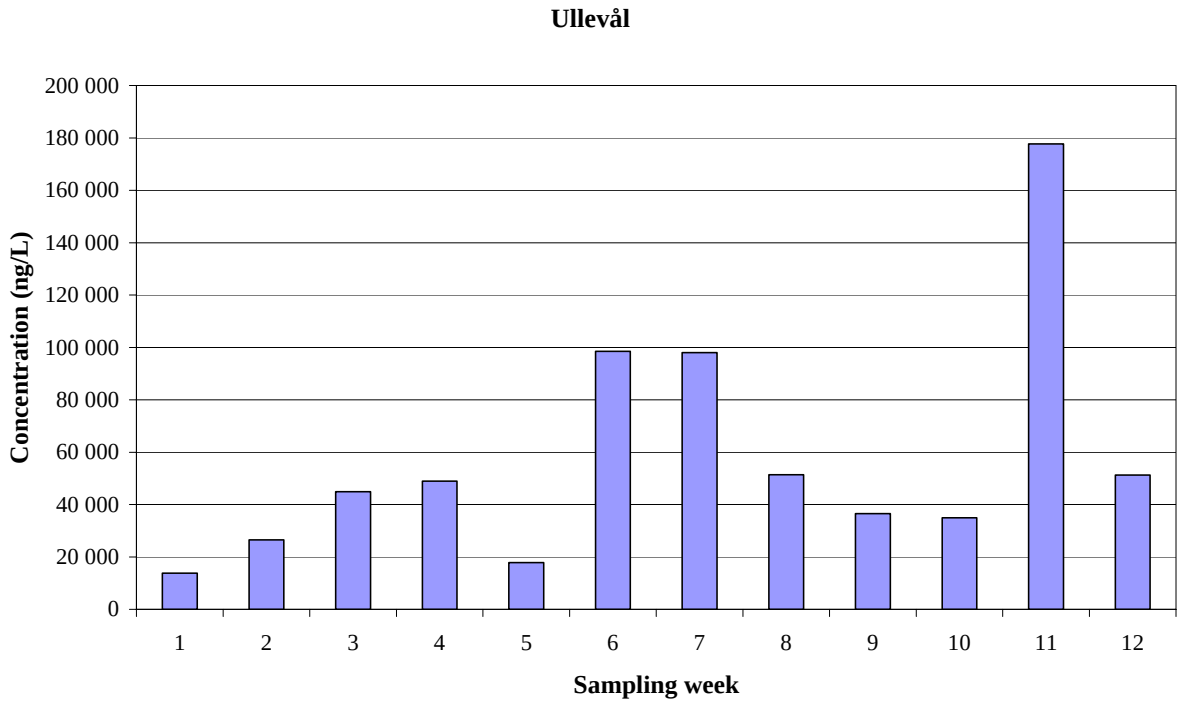


Figure 6 Concentration of paracetamol in Ullevål hospital effluent samples

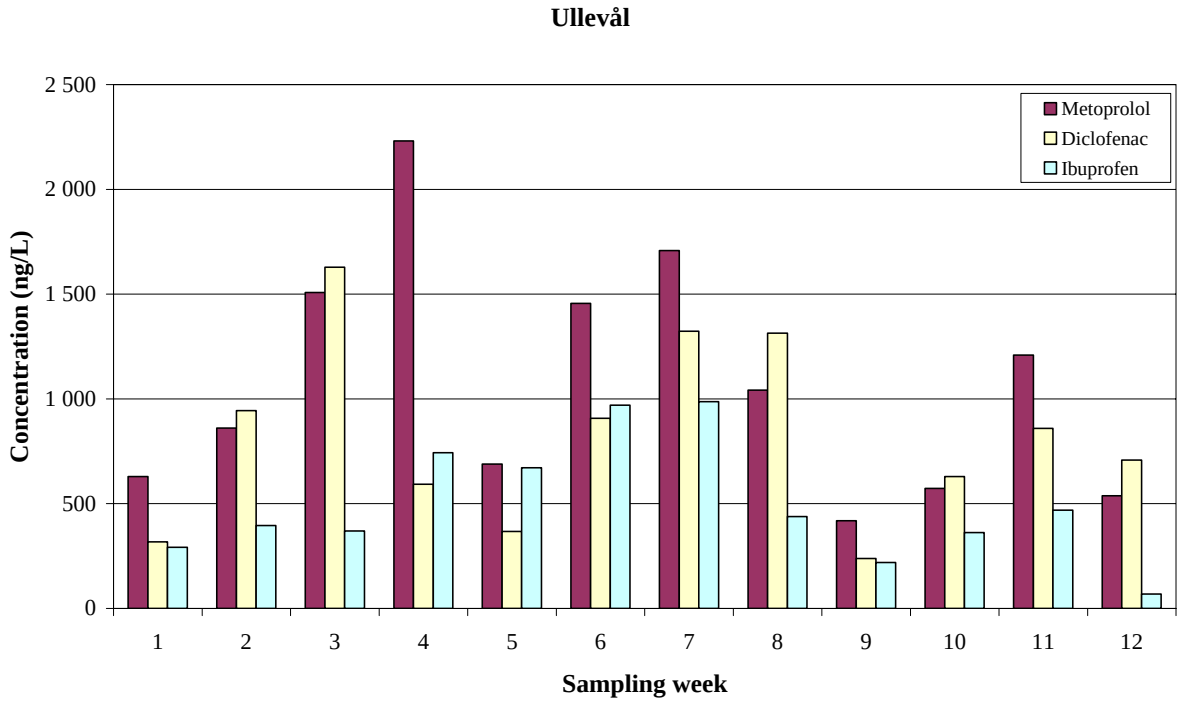


Figure 7 *Concentration of metoprolol, diclofenac and ibuprofen in Ullevål hospital effluent samples*

5.2.2 17α-Ethinylestradiol, 17β-estradiol, estrone and estradiol

17β-Estradiol, Estriol, and Estrone were detected in nearly all of the effluent samples collected from Ullevål hospital (Table 6; Figure 8). 17α-Ethinylestradiol could not be detected in any sample.

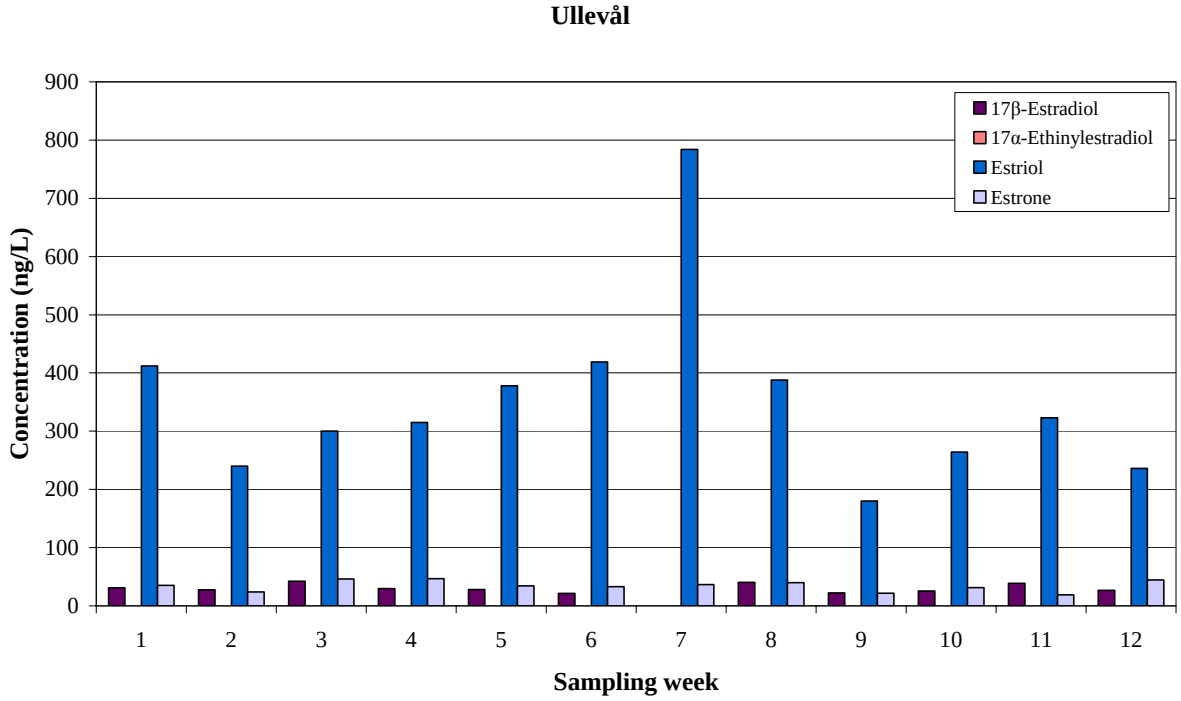


Figure 8 *Concentration of 17α-ethinylestradiol (and other steroid estrogens) in Ullevål hospital effluent samples*

5.2.3 Selected antibiotics

Trimethoprim were detected in all samples from Ullevål hospital (Table 6, Figure 9). Ciprofloxacin, sulfamethoxazole and tetracycline were detected in more than 50 % of all samples. Demeclocycline, chlortetracycline, meclocycline, and cefuroxime could not be detected in any sample. Ciprofloxaxin was detected at the next highest maximal concentration of all the selected pharmaceuticals (54 000 ng L^{-1}) with a median concentration of 24 000 ng L^{-1}.

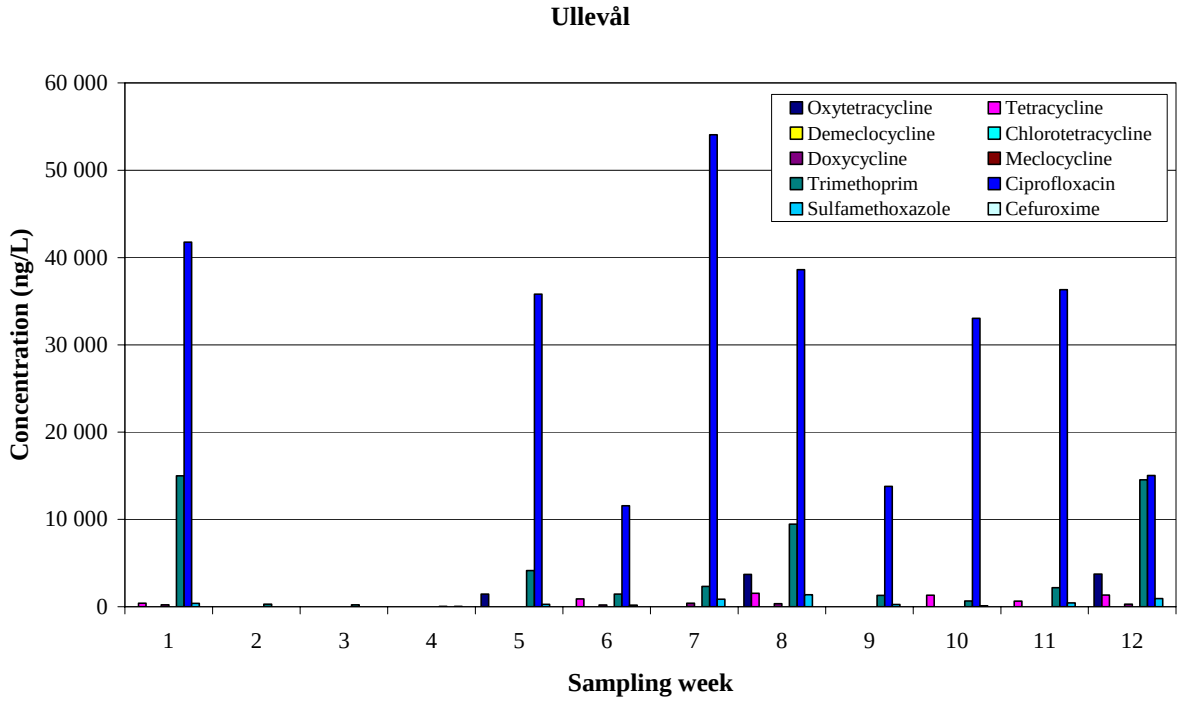


Figure 9 Concentration of selected antibiotics in Ullevål hospital effluent samples

5.2.4 Cyclophosphamide and ifosfamide

Cyclophosphamide was detected in one effluent sample from Ullevål hospital, while ifosfamide was detected in 6 of totally 12 samples with a maximum concentration of 340 ng L^{-1} (Table 6, Figure 10).

5.3 Rikshospitalet

5.3.1 Paracetamol, metoprolol, diclofenac and ibuprofen

As with the effluent from Ullevål hospital, paracetamol, metoprolol, diclofenac and ibuprofen were detected in all of the effluent samples collected from Rikshospitalet (Table 7, Figures 11 and 12). Paracetamol was again detected at the highest maximal concentration of all the selected pharmaceuticals (1.3 x10^6 ng L^{-1}) at a median concentration of 197 258 ng L^{-1}. Metoprolol, diclofenac and ibuprofen were detected at lower median concentrations of between 1 220 and 3 408 ng L^{-1}.

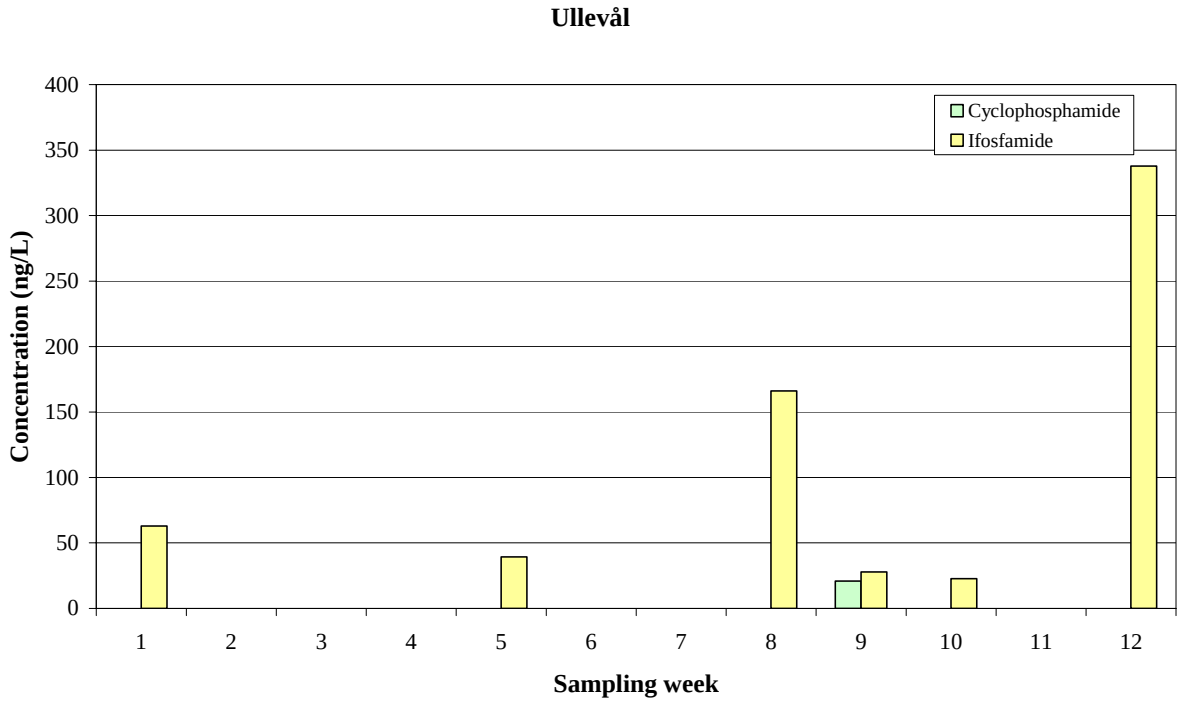


Figure 10 *Concentration of cyclophosphamide and ifosfamide in Ullevål hospital effluent samples*

Table 7 *Summary of the targeted pharmaceutical concentrations in Rikshospitalet effluent samples*

Pharmaceutical	Median	Mean	Max. (ng L^{-1})	Min.	Frequency (%)
Paracetamol	197 258	329 852	1 368 474	5 421	100
Metoprolol	3 408	5 811	25 097	455	100
Diclofenac	1 550	2 737	14 934	365	100
Ibuprofen	1 220	2 440	8 957	392	100
17β-Estradiol	41	43	72	21	100
17α-Ethinylestradiol	-	-	<0,3	<0,3	0
Estriol	452	502	785	320	100
Estrone	14	17	29	7	92
Oxytetracycline	-	-	2 294	<12	33
Tetracycline	1 252	1 385	4 178	<15	83
Demeclocycline	-	-	52	<3	8
Chlorotetracycline	-	-	69	<6	8
Doxycycline	-	-	336	<5	25
Meclocycline	-	-	<7	<7	0
Trimethoprim	3 074	4 249	11 899	<2	92
Ciprofloxacin	16 753	18 630	39 843	<38	83
Sulfamethoxazole	1 325	1 515	4 107	<4	92
Cefuroxime	-	-	<125	<125	0
Cyclophosphamide	-	-	<2	<2	0
Ifosfamide	-	-	291	<2	50

-: No mean and median calculated for analytes with a frequency <50%

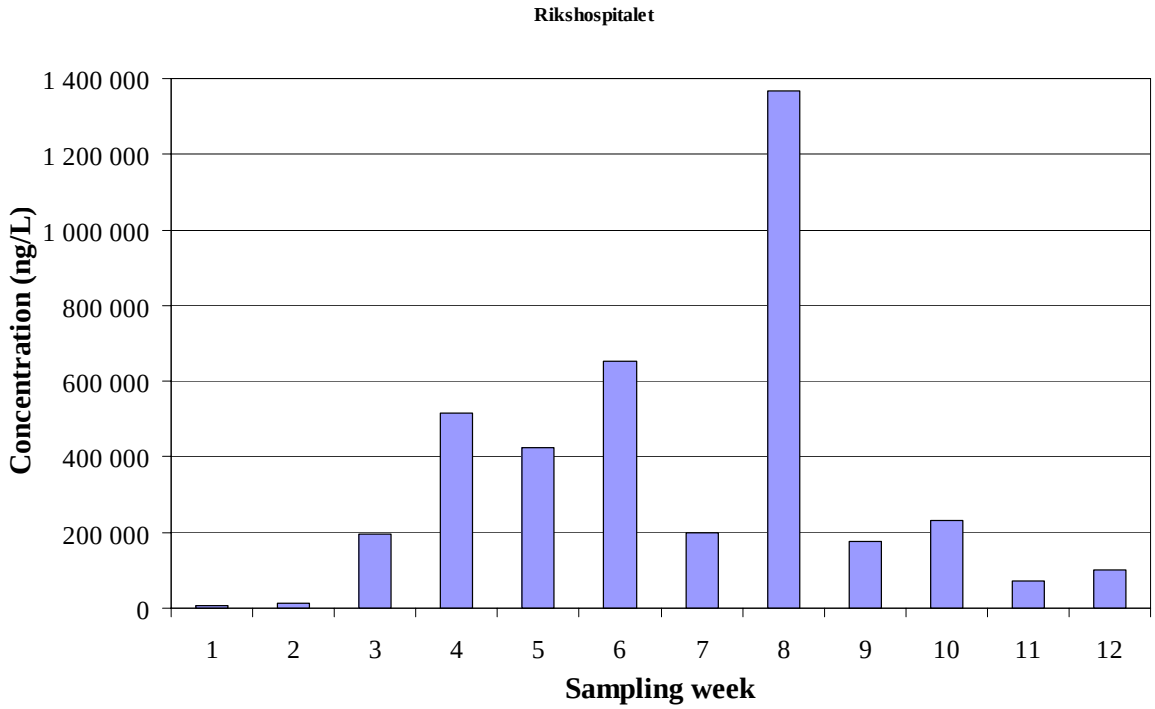


Figure 11 Concentration of paracetamol in Rikshospitalet effluent samples

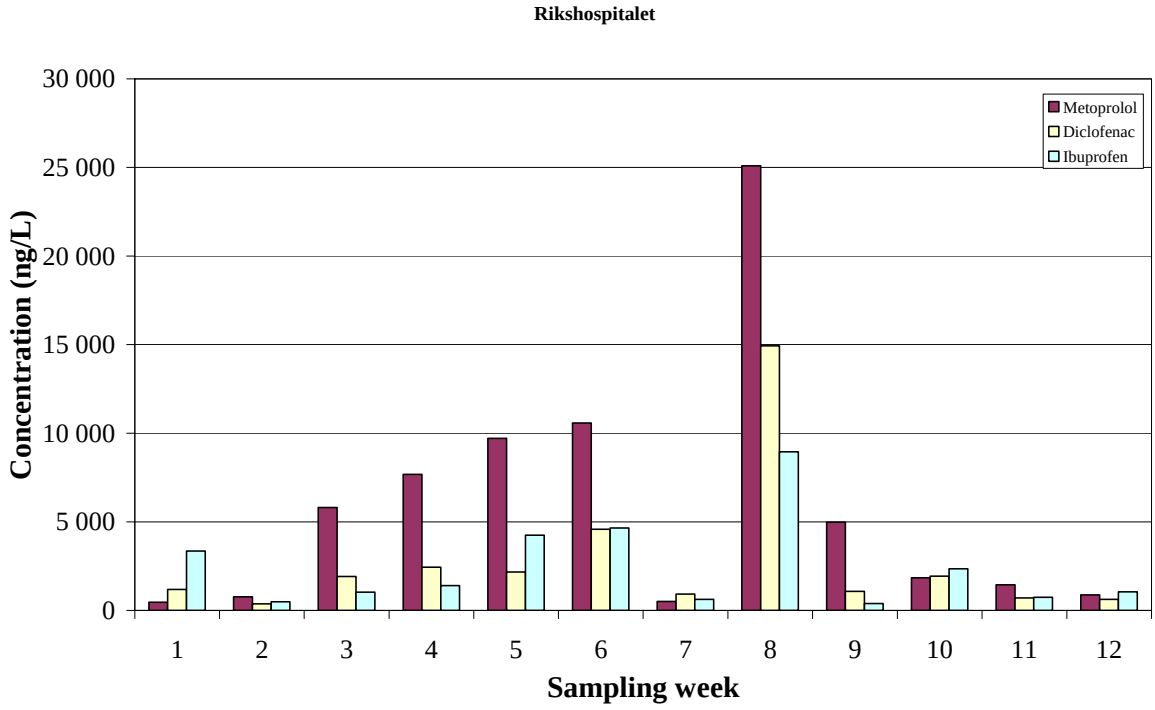


Figure 12 Concentration of metoprolol, diclofenac and ibuprofen in Rikshospitalet effluent samples

5.3.2 17α-Ethinylestradiol, 17β-estradiol, estrone and estradiol

17β-Estradiol, estriol, and estrone were detected in nearly all of the effluent samples collected from Rikshospitalet (Table 7; Figure 13). 17α-Ethinylestradiol could not be detected in any sample.

5.3.3 Selected antibiotics

Trimethoprim, ciprofloxacin, sulfamethoxazole and tetracycline were detected in more than 50 % of all samples from Rikshospitalet (Table 7, Figure 14). Meclocycline was the only antibiotic compound which could not be detected in any sample from Rikshospitalet. Ciprofloxaxin was detected at the next highest maximal concentration of all the selected pharmaceuticals (14 000 ng L^{-1}) with a median concentration of 40 000 ng L^{-1}.

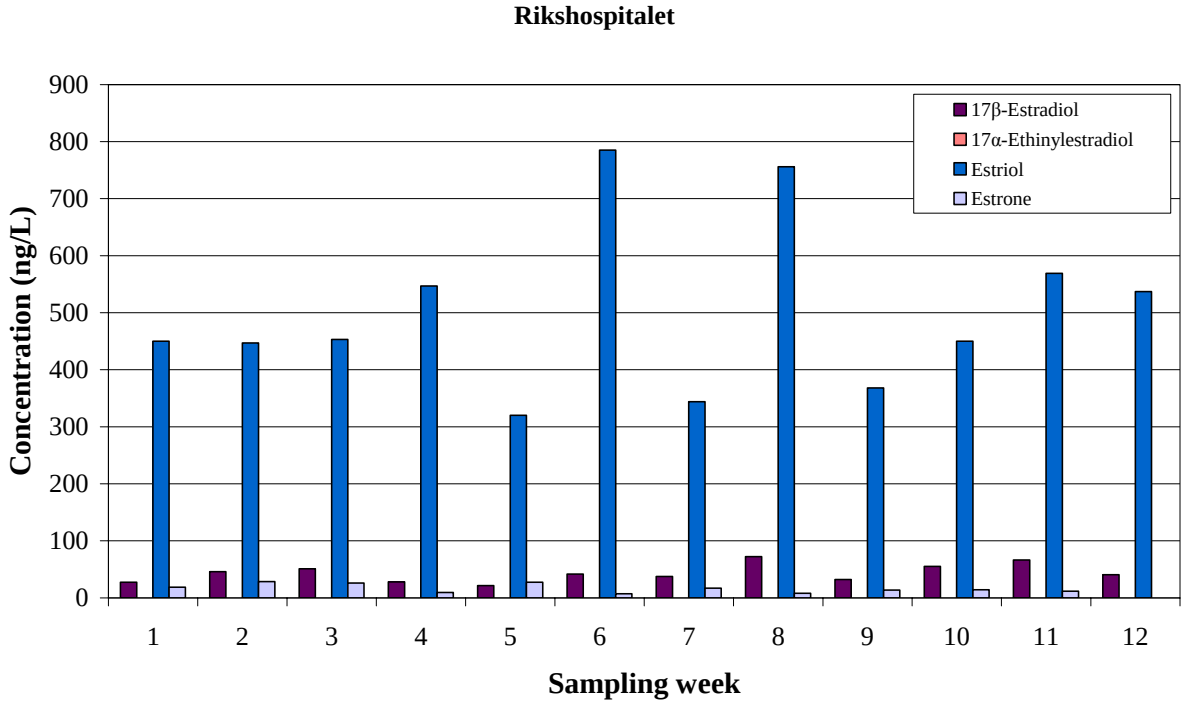


Figure 13 *Concentration of 17α-ethinylestradiol (and other steroid estrogens) in Rikshospitalet effluent samples*

5.3.4 Cyclophosphamide and ifosfamide

Cyclophosphamide could not be detected in effluent samples from Rikshospitalet, while ifosfamide was detected in 6 of totally 12 samples with a maximum concentration of 290 ng L^{-1} (Table 7, Figure15).

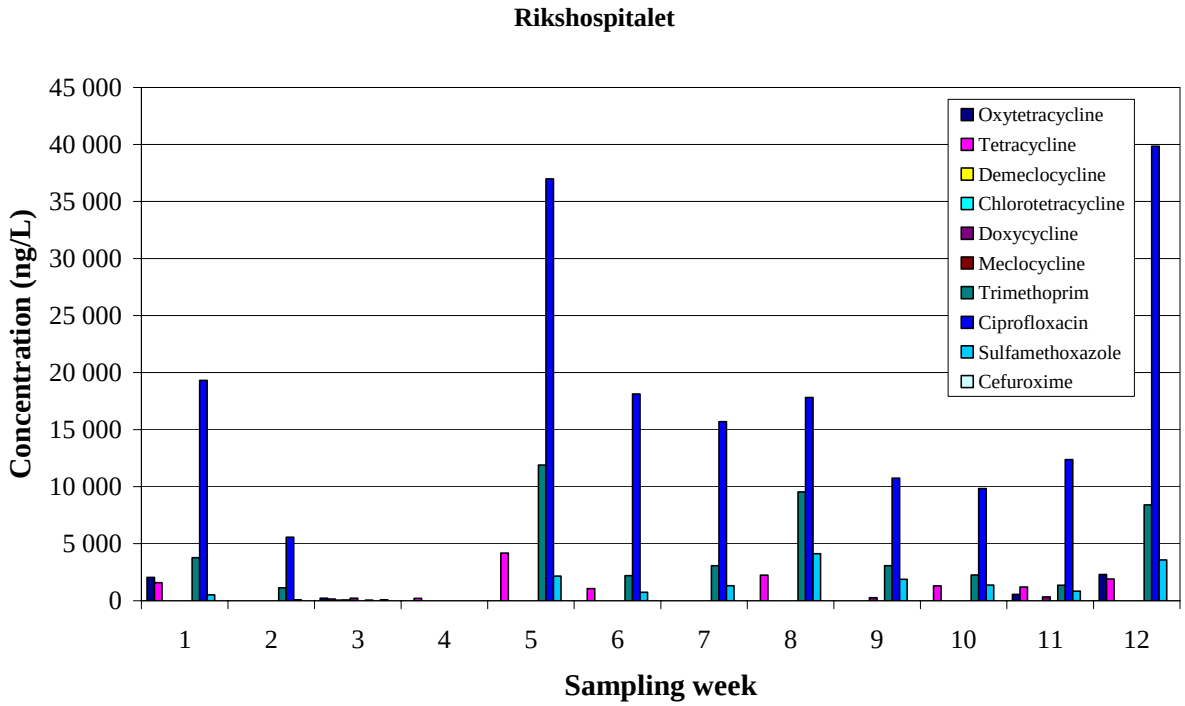


Figure 14 Concentration of selected antibiotics in Rikshospitalet effluent samples

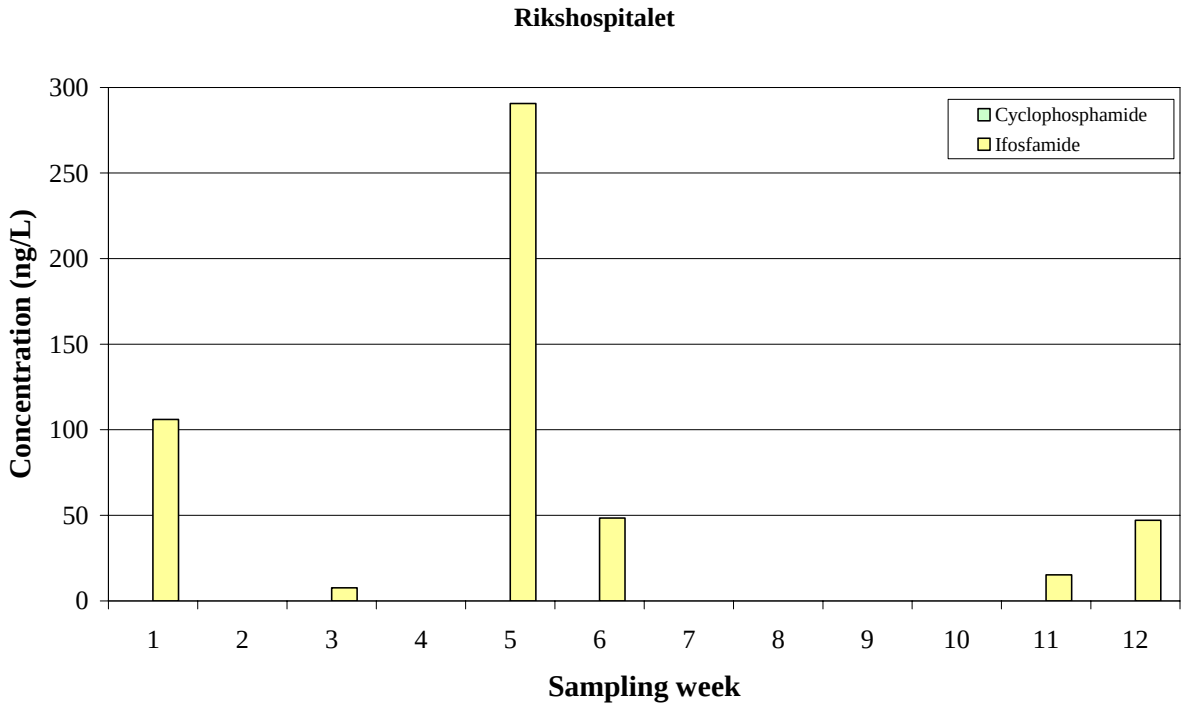


Figure 15 Concentration of ifosfamide in Rikshospitalet effluent samples

5.4 Environmental input

The environmental input of each targeted pharmaceutical was calculated for VEAS WTW using the mean effluent flow rates for the sampling period supplied by VEAS WTW (Table 8). The data are expressed as gram of pharmaceutical compound per day.

Table 8 Load of selected pharmaceuticals entering the aquatic environment from VEAS WTW

Pharmaceutical	Loading (g day^{-1})		
	Median	Maximum	Minimum
Paracetamol	7	1196	7
Metoprolol	181	214	165
Diclofenac	72	102	71
Ibuprofen	11	171	11
17β-Estradiol	0.8	1.,2	0.8
Oxytetracycline	3	334	3
Trimethoprim	189	349	172
Ciprofloxacin	11	206	11
Sulfamethoxazole	45	58	45

Median flow of 3 205 l s^{-1} used.

6. Discussion

6.1 Occurrence and comparison with published data

The occurrence of pharmaceutical compounds in influents and effluents is highly variable and is dependent on the volume of a pharmaceutical being administered at any one time. Since use patterns vary between times and locations then the amount of a pharmaceutical present in wastewater effluents can vary significantly. In this study composite samples were collected in an attempt to obtain information on the release of pharmaceuticals from two major Oslo hospitals and the WTW that treats the region of the city in which they are located. The data are compared with those available in the published literature and the previous study funded by SFT [2](Table 9).

Table 9 Reported WTW effluent occurrence data for the SFT selected pharmaceuticals

Substance	Concentration ($\mu g\ L^{-1}$)	Median ($\mu g\ L^{-1}$)	Location	Reference
Paracetamol	nd		6 WTW, UK	[3, 4]
Diclofenac	0.038-0.489		Selected WTW, Germany	[5]
	0,1-0,7	0,23	Selected WTW, Sweden	[20]
	nd-5.45	0.47	Selected WTW, Europe	[6,7]
		0.81	Selected WTW, Germany	[8]
	0.261-0.598		1 WTW, UK	[4]
	nd-2.34	0.424	Selected WTW, UK	[3]
	0.012-0.56		Selected Greek WTW	[9]
		nd	Selected Canadian WTW	[10]
Ibuprofen	0.017-0.139		Selected WTW, Germany	[5]
	0,008-7,5	1,3	Selected WTW, Sweden	[20]
	0.05-7.11		Selected WTW, Europe	[6]
	nd		1 WTW, USA	[11]
	0.002-0.081		3 WTW, Switzerland	[12]
		0.37	Selected Germany	[8]
	1.9-4.2	2.972	1 WTW, UK	[4]
	0.91-2.1		1 WTW Spain	[13]
	0.99-3.3		Selected WTW, Switzerland	[12]
	<0.02-27.25	3.08	Selected WTW, UK	[3]
		4.0	Selected Canadian WTW	[14]
	<LOD		Bekkelaget WTW, Oslo, Norway	[1]
	0.18/0.24		VEAS WTW, Oslo, Norway	[1]
Sulfamethoxazole	0.3-1.5		Selected WTW, Germany	[15]
	nd-0.09	0.05	Selected WTW, Europe	[6]
	<0.05-0.132	<0.05	Selected WTW, UK	[3]
	nd-0.871	0.243	Selected WTW, Canada	[16]
	0.073/0.13		Bekkelaget WTW, Oslo, Norway	[1]
	0.092-0.16		VEAS WTW, Oslo, Norway	[1]
Trimethoprim	218-322		1 WTW, UK	[4]
	nd-1.288	0.07	1 WTW, UK	[3]
	0.16/0.34		Bekkelaget WTW, Oslo, Norway	[1]
	0.26/0.43		VEAS WTW, Oslo, Norway	[1]
Ciprofloxacin	<LOD		Bekkelaget WTW, Oslo, Norway	[1]
	<LOD		VEAS WTW, Oslo, Norway	[1]
		0,31	Selected WTW, Wisconsin USA	[22]
Cyclophosphamide	0,002-0,01		Selected WTW, Switzerland	[21]

< LOD= less than limit of detection

6.1.1 Rikshospitalet and Ullevål hospitals

Hospitals are by their general nature a point source of pharmaceutical substances into the sewage network [17]. It therefore no surprise that where high volumes of pharmaceutical substances are in use, high concentrations of pharmaceuticals are present in the hospitals wastewater effluent. In general the pharmaceutical content of the hospital effluent will reflect the substances and volume of the particular drug being administered there [17].

The samples collected from Rikshospitalet and Ullevål showed high variability from week to week (Figures 6 to 15). Such variation has been reported previously and is most likely to be due to variations in the consumption of pharmaceuticals. Over the twelve week period, paracetamol was present in the collected effluents from both hospitals at the highest concentrations. Metoprolol, diclofenac, ibuprofen, tetracycline, trimethoprim, ciprofloxacin and sulfamethoxazole were detected at the highest concentrations in the hospital effluents. The concentrations of most of these substances were greatest in the effluents collected from Rikshospitalet, however the median concentration of ciprofloxacin was highest in Ullevål hospital effluents. The frequency at which the selected pharmaceuticals were detected was similar at both hospitals, however cyclophosphamide was only detected at Ullevål on a single occasion. What the data do show is that the two hospitals contribute to the general pharmaceutical load from domestic effluent that is entering VEAS WTW. Also the pharmaceuticals prioritised by SFT are the most frequent to occur and at measurable concentrations. Sampling over 12 weeks has also provided a good basis for understanding the variance in pharmaceutical concentrations in effluents discharged from Oslo hospitals. What the data do not allow is the calculation of load data in order to establish the overall contribution to VEAS influent from the city's two largest hospitals. No flow data was collected at the time of sampling (Oslo kommune, Personal Communication).

6.1.2 VEAS WTW

Of the thirteen SFT prioritised pharmaceuticals only 17α-ethinylestradiol, cefuroxime and cyclophosphamide were present in the influent at concentrations below the limits of detection of the methods used. Cyclophosphamide is a very low volume pharmaceutical in Norway (17 kg $year^{-1}$) and was detected on only two occasions at low ng g^{-1} concentrations in sludge samples which suggests that it is relatively hydrophobic and may partition quickly on to particles, although no adsorption data are available. The influent and effluent concentrations reflect dissolved quantities of these substances with the influent concentrations generally reflecting the sales volume of a drug and the effluent reflecting the affect of the WTW process. For example, paracetamol has a low log K_{OW} of 0.46 and therefore would be expected to predominantly exist in the dissolved phase. Of the selected pharmaceuticals paracetamol is sold in the greatest quantities in Norway (1.4×10^5 Kg $year^{-1}$) and a recent SFT report predicted influent concentrations of 15 µg L^{-1} based on the European Agency for the Evaluation of Medicinal Products (EMEA) guidelines which is similar to the maximal concentration of 12 µg L^{-1} [2]. Previous studies have shown high rates of paracetamol during WTW treatment with low discharge concentrations (Table 9). Very few data are available for metoprolol, however it is the third most sold pharmaceutical selected for this study and with a low log K_{OW} of 1.88 it occurs mainly in the dissolved phase. Diclofenac has been investigated in a number of studies and the median effluent concentration (259 ng L^{-1}) is in the same range as those reported for other European countries (12-5 000 ng L^{-1}, Table 9). Of the antibiotics studied, tetracycline and ciprofloxacin are the most sold, however their general hydrophobicity suggests that they rapidly bind to particles (see next section) which is

reflected in low influent and effluent concentrations. Sulfamethoxazole and trimethoprim, although used at considerably lower volumes, are much less likely to adsorb to particulates and therefore influent and effluent concentrations. A previous study of ciprofloxacin reported <LOD concentrations in VEAS WTW, which is surprising given the volumes sold and the high concentrations measured in the hospital effluents. The concentrations of sulfamethoxazole and trimethoprim measured in VEAS WTW are again similar to those reported for other European WTW and in a previous SFT funded study that included VEAS and another Oslo WTW, Bekkelaget (Table 9). The previous study also reported ibuprofen concentrations of 0.18 and 0.24 ng L^{-1} in VEAS effluent which is within the range of concentrations reported in this study (40-610 ng L^{-1}).

6.2 Removal efficiency of VEAS WTW and sludge concentrations

During the seven weeks of sampling at VEAS, the concentrations of selected pharmaceuticals entering the works varied considerably. The efficiency of the works in removing the selected pharmaceuticals from the influent before discharge was, however much more stable (Figure 16). For example, the influent concentration of paracetamol and ibuprofen was typically reduced by 99-100% before discharge. Although these data are specific in time and to the works, they compare favourably with other studies [3,4,8]. However, on occasions there are higher concentrations of the ibuprofen and paracetamol in the effluent than influent (e.g. week 5). It may be that this is due to the design of the sampling programme where composite samples were used and where the effluent samples may not necessarily be representative of the influent. For other compounds such as metoprolol, diclofenac and trimethoprim the removal efficiencies were not as high with often there being greater concentrations present in the effluent than the influent. This is a common phenomenon and has been seen before when studying the flux of pharmaceuticals through WTWs [4]. This has been previous reported for trimethoprim and propranolol (an analogue of metoprolol), and there are two possible causes [4]. Pharmaceuticals are often excreted as polar conjugates (sulphates or glucuronides) which can become deconjugated back to the parent pharmaceutical during the treatment process [8,18,19,20]. It may also be due to a process which causes the suppression of the signal from the MS which can occur when high levels of organic matter from the raw influent extracts enter the MS detector. All efforts are made to avoid the suppression of the detector signal during the analysis but it cannot be ruled out totally as a cause of variation in the data.

A major factor influencing the removal of pharmaceuticals during WTW processes is their ability to interact with solid particles, because this facilitates their removal by physical–chemical (settling, flotation) or biological processes (biodegradation). However, compounds with low adsorption coefficients tend to remain in the aqueous phase, which favours their mobility through the WTW and into the receiving waters. The elimination of pharmaceuticals is an extremely complex process with many possible removal mechanisms in operation. In this study, the sorption behaviour of the selected pharmaceuticals was investigated through the analysis of sludge samples from the works (Table 5). Although high concentrations of paracetamol were recorded as entering the works, none was detected in the sludge samples analysed. This is understandable considering paracetamol's low sludge-specific equilibrium sorption constant (K_d) of ~40 kg L^{-1} and low persistence. Ibuprofen, diclofenac and metoprolol were present in 14 to 50% of the sludge samples analysed at low ng g^{-1} concentrations which is a function of their influent concentrations and respective K_d of ~450, 164 and 37 kg L^{-1}. Tetracycline, doxycycline and oxytetracycline were detected in all or nearly all of the sludge samples analysed although the effluent concentrations were below the

method used's limits of detection. Tetracycline has a reported K_d of 8 400 kg L^{-1} suggesting that it will strongly partition onto particulate matter and will therefore be primarily found bound to particles. The influent samples in this study were analysed for dissolved concentrations of tetracycline and it is likely that any tetracycline in the influent was bound to particulates that were removed by filtration prior to analysis. It is therefore apparent that the tetracycline that is present in the hospital effluents in dissolved form adsorbs to particles whilst travelling through the sewerage network and is bound to particulates when it enters the works at VEAS. Tetracycline is not readily biodegradable and therefore accumulates on particulates present in the sludge. Ciprofloxacin was present at higher concentrations in the sludge (Median = 7 µg g^{-1}) than any other analyte and has previously been reported at concentrations of between 2 and 3 µg g^{-1} in Oslo city WTWs [1]. Again low concentrations were measured in the influent with high concentrations being determined in the hospital effluents. Ciprofloxacin has a reported organic carbon-specific equilibrium sorption constant (K_{OC}) of 61 000 suggesting that again the high quantities of ciprofloxacin measured in the hospital effluent samples are adsorbing to particles in the sewerage network and then subsequently being detected in sludge. In addition, 30% of administered ciprofloxacin is excreted as the glucuronide metabolite which will deconjugate in the WTW to form ciprofloxacin, which in turn will adsorb to particules. Therefore although the dissolved concentrations of ciprofloxacin entering the works are low, the total quantities of ciprofloxacin appear to be high. It is recommended that in future studies the suspended solid content of effluents and influents are also analysed for hydrophobic pharmaceuticals in order to better calculate the mass balance of pharmaceutical substances through the WTW.

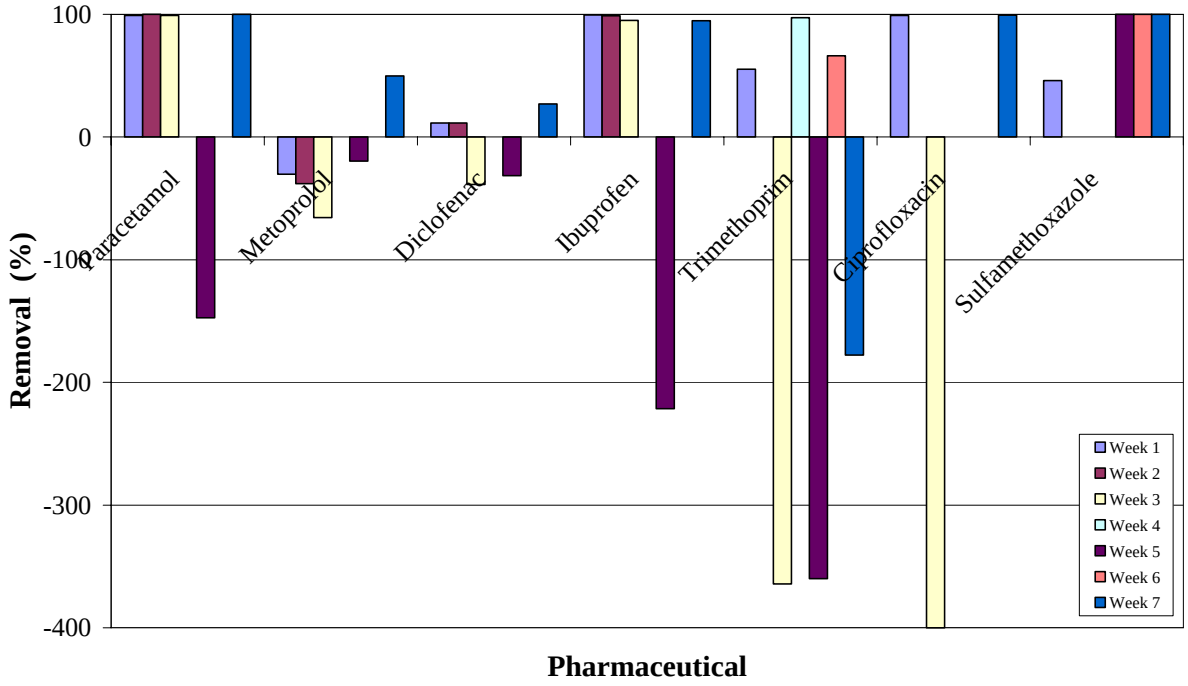


Figure 16 *Comparison of VEAS WTW influent and effluent concentrations of selected pharmaceuticals over 7 weeks. Positive values represent removal of the selected pharmaceuticals by the WTW, whilst negative values represent higher concentrations in the effluent than influent.*

6.3 Environmental input

The load data calculated within this report are dependent on the effluent flow rate and concentration of targeted pharmaceutical during the sampling period. The patters of input follow the concentrations of selected pharmaceutical in the final effluent. The median loads are commonly in the low g day^{-1} range, while regularly reaching the order of tens or hundreds of g day^{-1}. Within the context of this targeted study, metoprolol, diclofenac, trimethoprim and to a lesser extent sulfamethoxazole are all regularly providing a significant environmental input. However, the maximal loads are significantly higher and the variability in the effluent concentration suggests that at times much higher quantitative of pharmaceuticals are being released.

The concentration of the target compound within the Oslo fjord, and therefore any associated biological effect, is very much dependant on the volume of the receiving waters and the degree of dilution that occurs. This study did not assess the occurrence of these selected pharmaceutical substances in receiving water. Therefore in the next section quasi-measured environmental concentrations (quasi-MECs) are used.

6.4 Simple risk assessment

A comparison of the predicted no-effect concentrations (PNEC) with quasi-measured environmental concentrations (MECs) of pharmaceutical compounds is shown in Table 6. Only for ciprofloxacin is the quasi-MEC/PNEC ratio >1. This indicates that the remaining pharmaceutical compounds targeted are not being discharged from VEAS at levels likely to cause acute toxicity for the range of organisms tested. However, limited ecotoxicological data are available on which to base these conclusions and it may be that the use of chronic bioassays conducted over the life-cycle of various organisms from different trophic levels may be more appropriate for the risk assessment of pharmaceuticals. In addition, these quasi-MECs are based solely on dilution of the effluent and do not take into account any other environmental processes. Caution should also be taken when interpreting the quasi-MEC/PNEC data for 17α-ethinylestradiol since the PNEC (0.1 ng L^{-1}), is below the limit of detection of 0.3 ng L^{-1}. In order to improve the environmental risk assessment of the compounds present in VEAS effluent it is recommended that the occurrence of these compounds are determined in receiving waters.

Table 10 Comparison of mean and maximal quasi-measured environmental concentrations (Quasi-MEC) with predicted no-effect concentrations (PNEC)

	Quasi-MEC[1] (ng L^{-1})		PNEC[2] (ng L^{-1})	Quasi-MEC/PNEC	
Pharmaceutical	Median	Maximal		Median	Maximal
Paracetamol	3	432	9 200	3.2×10^{-4}	0.05
Metoprolol	65	77	31 000	2×10^{-3}	2.5×10^{-3}
Diclofenac	26	37	115	0.23	0.32
Ibuprofen	4	62	20 000	2×10^{-4}	3.1×10^{-3}
17α-Ethinylestradiol	nd	nd	0.1	-	-
Tetracycline	nd	nd	90	-	-
Trimethoprim	68	126	16 000	4.3×10^{-4}	7.9×10^{-4}
Ciprofloxacin	4	74	5	0.8	**15**
Sulfamethoxazole	16	21	118	0.14	0.18
Cefuroxime	nd	nd	91 000	-	-
Cyclophosphamide	nd	nd	1 120 000	-	-

[1] Effluent concentration divided by a dilution factor of 10. [2] PNEC obtained from SFT Report TA 2216/2006 [2]. nd: compound not detected in any final effluent sample collected. – No risk quotient calculated due to insufficient data.

7. Conclusions

- Occurrence data have been obtained for twenty pharmaceutical compounds in wastewater effluent samples collected from Rikshopitalet and Ullevål hospitals as well as influent, sludge and effluent from VEAS WTW.
- Eleven pharmaceutical compounds selected by SFT (17β-estradiol, estrone paracetamol, metoprolol, diclofenac, ibuprofen, tetracycline, trimethoprim, ciprofloxacin, sulfamethoxazole and cyclophosphamide) and six other compounds (estriol, chlorotetracycline, demeclocycline, oxytetracycline, doxycycline and ifosfamide) were detected in wastewater effluents from hospitals and the influent at VEAS WTW.
- Nine SFT selected pharmaceutical compounds (paracetamol, metoprolol, diclofenac, ibuprofen, trimethoprim, ciprofloxacin, 17β-estradiol, estrone, and sulfamethoxazole) and three other compounds (oxytetracycline, doxycycline and ifosfamide) were detected in the final effluents collected at VEAS WTW.
- 17α-Ethinylestradiol, meclocycline and cefuroxime were not detected in any of the effluent samples collected.
- Eight SFT selected pharmaceuticals (diclofenac, ibuprofen, tetracycline, ciprofloxacin, 17β-estradiol, estrone, sulfamethoxazole and cyclophosphamide) and three other compounds (estriol, oxytetracycline and doxycycline) were detected in the dewatered sludge from VEAS WTW.
- VEAS WTW effluent concentrations represent median quantities of up to 190 g day^{-1} (for trimethoprim) entering Oslo fjord showing that significant amounts are entering Norwegian surface waters from WTW effluent discharges.
- Risk quotients calculated from quasi-MEC, derived from VEAS WTW effluent concentrations, showed that for most of the target compounds there is little acute risk to the aquatic environment. The maximal quasi-MEC for ciprofloxacin at times exceded the PNEC and therefore may pose a risk to certain aquatic organisms.

8. References

1. Møskeland, T., *Screening of selected pharmaceuticals and cosmetics*. 2006, Statens forurensningstilsyn (SFT). Norwegian Pollution Control Authority Report No. 2156/2006.
2. Grung, M., T. Källqvist, and K.V. Thomas, *Initial assessment of eleven pharmaceuticals using the EMEA guideline in Norway*. 2006, Statens forurensningstilsyn (SFT). Norwegian Pollution Control Authority Report No. TA 2216/2006.
3. Ashton, D., M. Hilton, and K.V. Thomas, *Investigating the environmental transport of human pharmaceuticals to streams in the United Kingdom.* Science of the Total Environment, 2004. **333**: p. 167-184.
4. Roberts, P.H. and K.V. Thomas, *The occurrence of selected pharmaceuticals in wastewater effluent and surface waters by the lower Tyne catchment.* Science of the Total Environment, 2006. **356**: p. 143-153.
5. Stumpf, M., et al., *Determination of pharmaceuticals in sewage plants and river water.* Vom Wasser, 1996. **86**: p. 291-303.
6. Andreozzi, R., M. Raffaele, and P. Nicklas, *Pharmaceuticals in STP effluents and their solar photodegrataion in the aquatic environment.* Chemosphere, 2003. **50**: p. 1319-1330.
7. Ferrari, B., et al., *Ecotoxicological impact of pharmaceuticals found in treated wastewaters: study of carbamazepine, clofibric acid, and diclofenac.* Ecotoxicology and Environmental Safety, 2003. **55**: p. 359-370.
8. Ternes, T.A., *Occurrence of drugs in German sewage treatment plants and rivers.* Water Research, 1998. **32**: p. 3245-3260.
9. Koutsouba, V., et al., *Determination of polar pharmaceuticals in sewage water of Greece by gas chromatography-mass spectrometry.* Chemosphere, 2003. **51**: p. 69-75.
10. Metcalfe, C.D., et al., *Occurrence of neutral and acidic drugs in the effluents of Canadian sewage treatment plants.* Environmental Toxicology and Chemistry, 2003. **22**: p. 2872-2880.
11. Boyd, G.R., et al., *Pharmaceuticals and personal care products (PPCPs) in surface and treated waters of Louisiana, USA and Ontario, Canada.* Science of the Total Environment, 2003. **311**: p. 135-149.
12. Buser, H.-R., T. Poiger, and M.D. Muller, *Occurrence and environmental behaviour of the chiral pharmaceutical drug ibuprofen in surface waters and in wastewater.* Environmental Science and technology, 1999. **33**: p. 2529-2535.
13. Carballa, M., et al., *Behaviour of pharmaceuticals, cosmetics and hormones in a sewage treatment plant.* Water Research, 2004. **38**: p. 2918-2926.
14. Metcalfe, C.D., et al., *Distribution of acidic and neutral drugs in surface waters near sewage treatment plants in the Lower Great Lakes, Canada.* Environmental Toxicology and Chemistry, 2003. **22**: p. 2881-2889.
15. Hartig, C., T. Storm, and M. Jekel, *Detection and identification of sulphonamide drugs in municipal wastewater by liquid chromatography coupled with electrospray ionisation mass spectrometry.* Journal of Chromatography A, 1999. **854**: p. 163-173.
16. Miao, X.-S., et al., *Occurrence of antimicrobials in the final effluents of wastewater treatment plants in Canada.* Environmental Science and Technology, 2004. **38**: p. 3533-3541.
17. Heberer, T. and D. Feldmann, *Contribution of effluents from hospitals and private households to the total loads of diclofenac and carbamazepine in municipal sewage*

effluents - modelling versus measurements. Journal of Hazardous Materials, 2005. **122**: p. 211-218.

18. Miao, X.-S., B. Koenig, and C.D. Metcalfe, *Analysis of acidic drugs in the effluents of sewage treatment plants using liquid chromatography-electrospray ionisation tandem mass spectrometry.* Journal of Chromatography A, 2002. **952**: p. 139-147.
19. Heberer, T., *Tracking persistent pharmaceutical residues from municipal sewage to drinking water.* Journal of Hydrology, 2002. **266**: p. 175-189.
20. Andersson, J, Woldegiorgis, A., Remberger, M., Kaj, L., Ekheden, Y., Dusan, B., Svenson, A., Broström-Lundén, E., Dye, C., Schlabach, M., *Results from the Swedish National Screening Programme 2005; Sub report 1: Antibiotics, Anti-inflammatory substances, and Hormones.* 2006, B1689, IVL Swedish Environmental Research Institute.
21. Buerge, I.J., Buser, H.-R., Poiger, T., and Müller, M. D., *Occurrence and Fate of the Cytostatic Drugs Cyclophosphamide and Ifosfamide in Wastewater and Surface Water.* Environmental Science and Technology, 2006, **40**: p. 7242-7250.
22. Karthikeyan, K.G., Meyer, M.T., *Occurrence of antibiotics in wastewater treatment facilities in Wisconsin, USA.* Science of the Total Environment **361**: p.196-207.

Appendix A: Raw data

Aq = ng L Solid = ng g	Paracetamol	Metoprolol	Diclofenac	Ibuprofen	estradiol	etinylestradiol	estriol	estrone	oxytetracycline	tetracycline	demeclocycline	chlorotetracycline	doxycycline	meclocycline	trimethoprim	ciprofloxacin	sulfamethoxazole	cefuroxime	cyclophosphamide	ifosfamide
09.08.2006																				
VEAS sludge	<20	21	20	13	7	<0,1	<1	9	444	422	<3	<6	206	<7	<4	7241	<4	<45	<4	<3
VEAS influent	2439	478	263	882	24	<0,3	152	25	<12	<15	<3	<6	<5	<7	2775	4294	211	<125	<2	<2
VEAS effluent	<20	623	233	<4	5	<0,3	3	<3	<12	<15	<3	<6	<5	<7	1240	<38	114	<125	<2	<2
Riks	5421	455	1185	3353	27	<0,3	450	19	2053	1582	<3	<6	<5	<7	3767	19325	522	<125	<2	106
Ullevål	13874	629	317	292	31	<0,3	412	35	<12	406	<3	<6	227	<7	14993	41752	391	<125	<2	63
16.08.2006																				
VEAS sludge	<20	<4	8	<4	<0,5	<0,1	<0,5	2	2057	6733	<3	<6	1293	<7	<4	97470	171	<45	<3	<3
VEAS influent	3142	496	324	334	10	<0,3	90	17	<12	<15	<3	<6	49	<7	62	<38	<4	<125	<2	<2
VEAS effluent	0	684	287	<4	<3	<0,3	<3	<3	1207	<15	<3	<6	<5	<7	683	<38	211	<125	<2	71
Riks	12697	769	365	492	46	<0,3	447	29	<12	<15	<3	<6	<5	<7	1123	5567	90	<125	<2	<2
Ullevål	26546	861	944	396	28	<0,3	240	24	<12	<15	<3	<6	<5	<7	299	<38	<4	<125	<2	<2
23.08.2006																				
VEAS sludge	<20	<4	5	<4	<0,5	<0,1	<0,5	4	695	2779	<3	<6	<10	<7	<4	37683	<4	<45	<3	<2
VEAS influent	3796	416	266	271	12	<0,3	128	19	<12	<15	<3	<6	<5	<7	25	<38	<4	<125	<2	<2
VEAS effluent	31	689	368	13	<3	<0,3	<3	11	<12	<15	<3	<6	82	<7	116	742	<4	<125	<2	<2
Riks	196937	5817	1915	1033	51	<0,3	453	26	224	151	52	69	217	<7	50	<38	93	<125	<2	8
Ullevål	44916	1507	1629	370	42	<0,3	300	46	<12	<15	<3	<6	<5	<7	224	<38	<4	<125	<2	<2
30.08.2006																				
VEAS sludge	<20	<4	6	<4	1	<0,1	4	2	<12	159	<3	<6	89	<7	<4	6749	<4	<45	<3	<3
VEAS influent	No data	No data	No data	No data	7	<0,3	54	19	<12	<15	<3	<6	<5	<7	75	<38	<4	<125	<2	<2
VEAS effluent	318	427	203	40	<3	<0,3	<3	<3	<12	<15	<3	<6	<5	<7	<2	<38	<4	<125	<2	<2
Riks	514168	7679	2440	1392	28	<0,3	547	10	<12	203	<3	<6	<5	<7	<2	<38	<4	<125	<2	<2
Ullevål	48940	2232	593	743	30	<0,3	315	47	<12	<15	<3	<6	<5	<7	50	<38	48	<125	<2	<2
06.09.2006																				
VEAS sludge	<20	<4	<4	33	<0,5	<0,1	<0,5	4	193	268	<3	<6	111	<7	<4	5024	<4	<45	<3	<3
VEAS influent	1746	311	123	193	<3	<0,3	62	25	<12	<15	<3	<6	<5	<7	53	<38	80	<125	<2	<2
VEAS effluent	4319	372	162	619	<3	<0,3	<3	<3	<12	<15	<3	<6	<5	<7	245	<38	<4	<125	<2	<2
Riks	425073	9712	2167	4250	21	<0,3	320	28	<12	4178	<3	<6	<5	<7	11899	36980	2147	<125	<2	291
Ullevål	17826	689	368	671	28	<0,3	378	34	1449	<15	<3	<6	<5	<7	4151	35787	261	<125	<2	39
13.09.2006																				
VEAS sludge	<20	<4	<4	17	<0,5	<0,1	<0,5	2	120	299	<3	<6	77	<7	<4	4015	10	<45	4	<3
VEAS influent	20197	1064	809	544	39	<0,3	176	30	<12	<15	<3	<6	<5	<7	2401	<38	391	<125	<2	<2
VEAS effluent					4	<0,3	<3	6	<12	<15	<3	<6	<5	<7	811	<38	<4	<125	<2	<2
Riks	653357	10570	4579	4654	42	<0,3	785	7	<12	1065	<3	<6	<5	<7	2198	18122	745	<125	<2	48
Ullevål	98546	1455	908	970	21	<0,3	419	33	<12	904	<3	<6	197	<7	1447	11567	179	<125	<2	<2
20.09.2006																				
VEAS sludge	<20	<4	<4	17	2	<0,1	<0,5	14	270	5069	<3	<6	<10	<7	<4	26600	<4	<45	<3	<2
VEAS influent	43223	1539	390	794	44	<0,3	237	25	<12	510	<3	<6	<5	<7	454	5876	182	<125	<2	<2
VEAS effluent	<20	772	285	41	<3	<0,3	<3	8	<12	<15	<3	<6	<5	<7	1260	<38	<4	<125	<2	<2
Riks	197579	503	919	625	38	<0,3	344	17	<12	<15	<3	<6	<5	<7	3080	15686	1325	<125	<2	<2
Ullevål	98024	1707	1323	987	<3	<0,3	784	36	<12	<15	<3	<6	403	<7	2335	54049	873	<125	<2	<2
27.09.2006																				
Riks	1368474	25097	14934	8957	72	<0,3	756	8	<12	2242	<3	<6	<5	<7	9532	17819	4107	<125	<2	<2
Ullevål	51451	1042	1314	439	41	<0,3	388	40	3695	1537	<3	<6	331	<7	9456	38598	1375	<125	<2	166
04.10.2006																				
Riks	177700	4975	1073	392	32	<0,3	368	14	<12	<15	<3	<6	262	<7	3074	10750	1869	<125	<2	<2
Ullevål	36493	419	238	220	22	<0,3	180	22	<12	<15	<3	<6	<5	<7	1297	13793	258	<125	21	28
11.10.2006																				
Riks	231210	1840	1937	2353	55	<0,3	450	14	<12	1298	<3	<6	<5	<7	2262	9835	1370	<125	<2	<2
Ullevål	34945	573	629	362	26	<0,3	264	31	<12	1321	<3	<6	<5	<7	658	33030	107	<125	<2	23
18.10.2006																				
Riks	73096	1437	706	734	66	<0,3	569	12	548	1205	<3	<6	336	<7	1351	12371	826	<125	<2	15
Ullevål	177674	1209	859	468	39	<0,3	323	19	<12	626	<3	<6	<5	<7	2178	36308	420	<125	<2	<2
25.10.2006																				
Riks	102506	875	622	1048	41	<0,3	537	<3	2294	1907	<3	<6	<5	<7	8409	39843	3572	<125	<2	47
Ullevål	51234	538	708	69	26	<0,3	236	45	3743	1339	<3	<6	292	<7	14534	15031	923	<125	<2	338

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Kevin V. Thomas (NIVA)	2007	37	

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Tittel - norsk og engelsk
Occurrence of selected pharmaceuticals in wastewater effluents from hospitals (Ullevål and Rikshospitalet) and VEAS wastewater treatment works

Miljøovervåking av utvalgte legemidler- 2006

Sammendrag – summary
Forekomsten av 19 lignende legemidler målt i avløpsvann fra Rikshospitalet og Ullevål sykehus. De samme legemidlene ble målt i vannprøver (innløp og utløp) og slam fra VEAS renseanlegg. Seksten av legemidlene ble påvist avløpsprøver og innløpet til VEAS, mens tolv ble påvist i utløp fra VEAS. Utløpskonsentrasjoner fra VEAS viser at opptil 190 g legemiddel daglig slippes ut i Oslofjorden. Det ble utført en enkel risikovurdering basert på de målte verdiene.

4 emneord	4 subject words
Legemidler	Pharmaceutical compounds
Overvåking	Monitoring
Avløpsvann	Wastewater
Riskikovurdering	Risk assessment