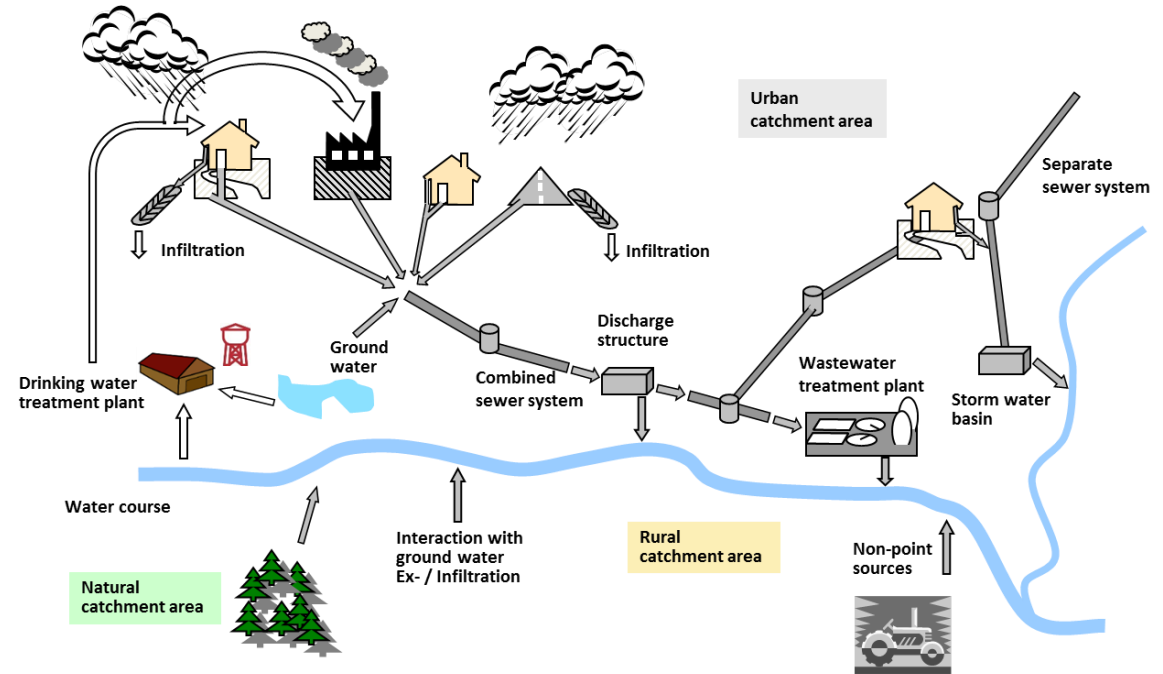
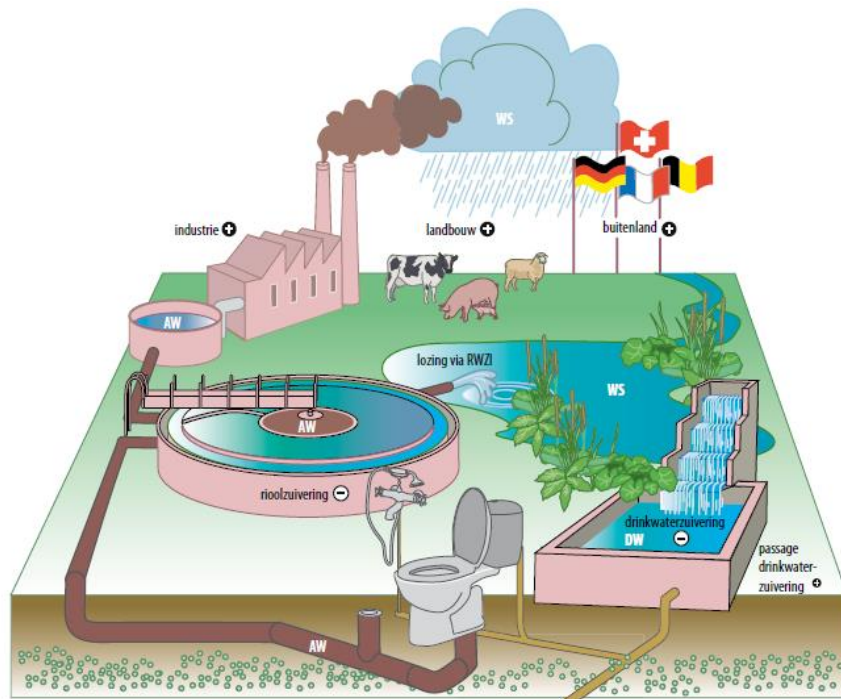




# Pharmaceuticals in the water cycle

Jan Peter van der Hoek

# The water cycle

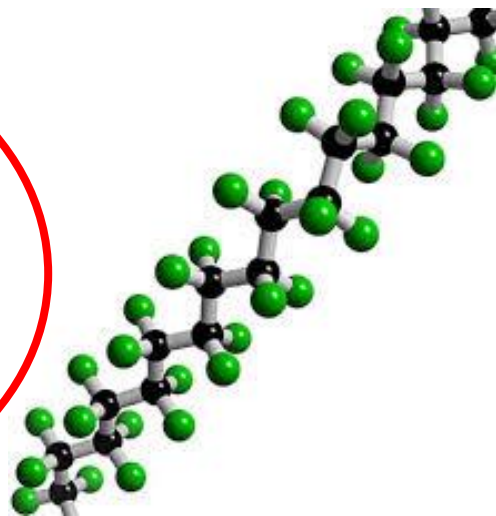


Erft Verband

# The water cycle threatened by pollution with contaminants of emerging concern



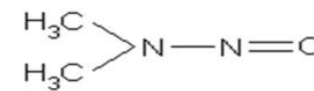
Pharmaceuticals



Perfluor compounds



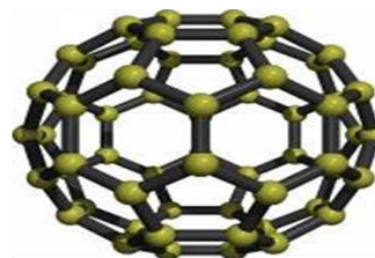
Endocrine disruptors



NDMA



Pesticides



Nanochemicals



Drugs of abuse

# The water cycle threatened by pollution with Pharmaceuticals

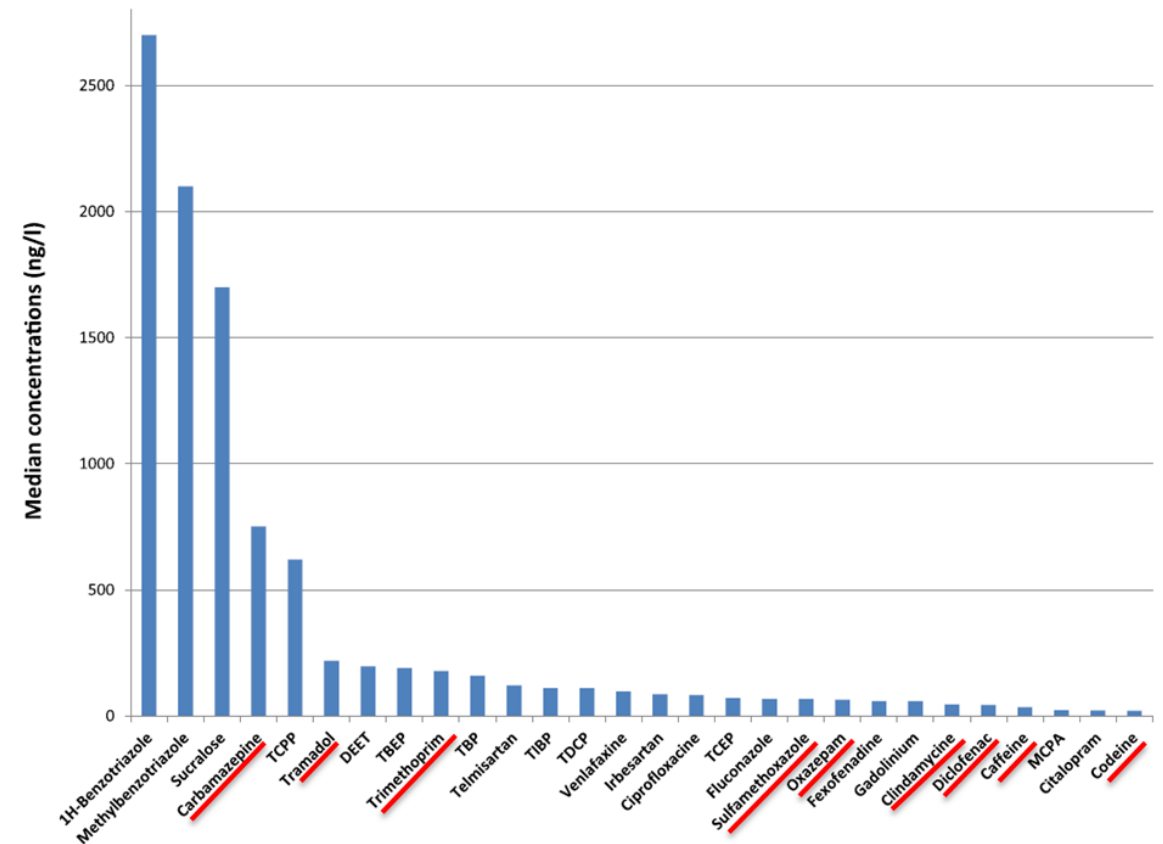
- Wastewater treatment effluents
- Surface waters
- Groundwater
- Drinking water

# Wastewater treatment effluents

90 European wastewater treatment plants



Loos et al., Water Research 47 (2013), 6475-6487

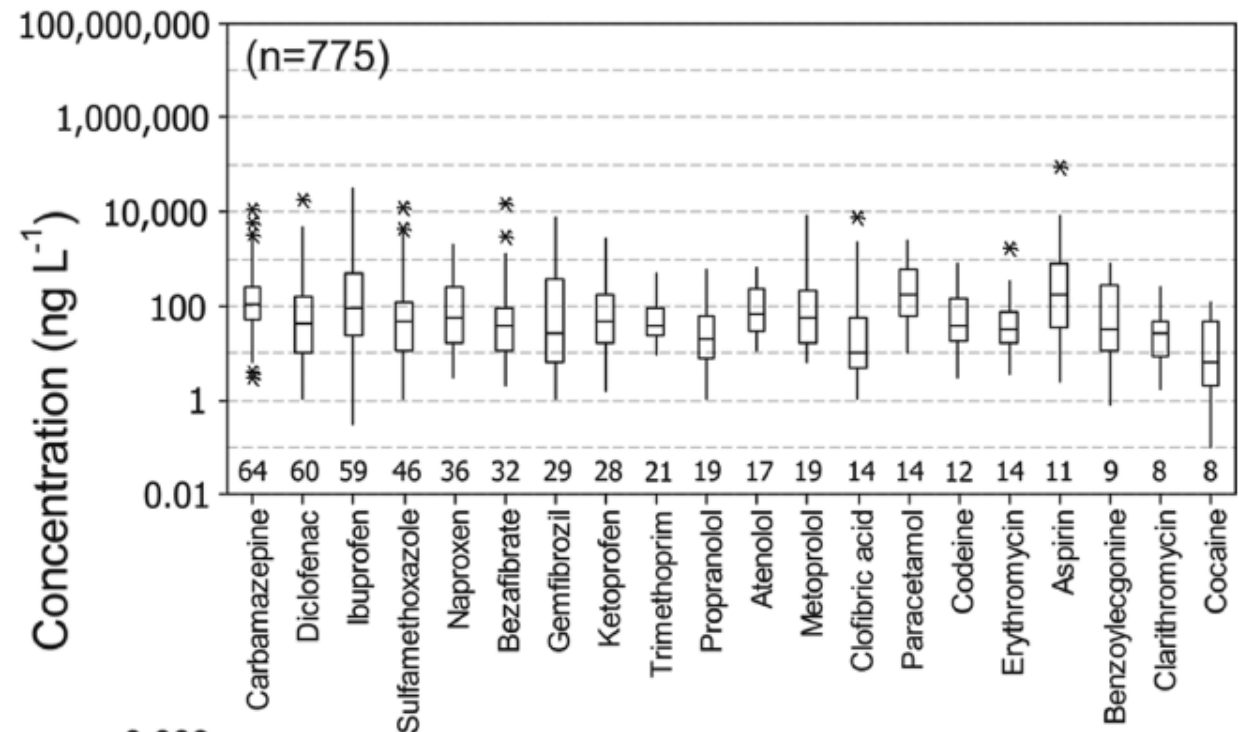


# Surface waters

## European river waters



Hughes et al., *Env. Sci. Technology* 47 (2013), 661-677

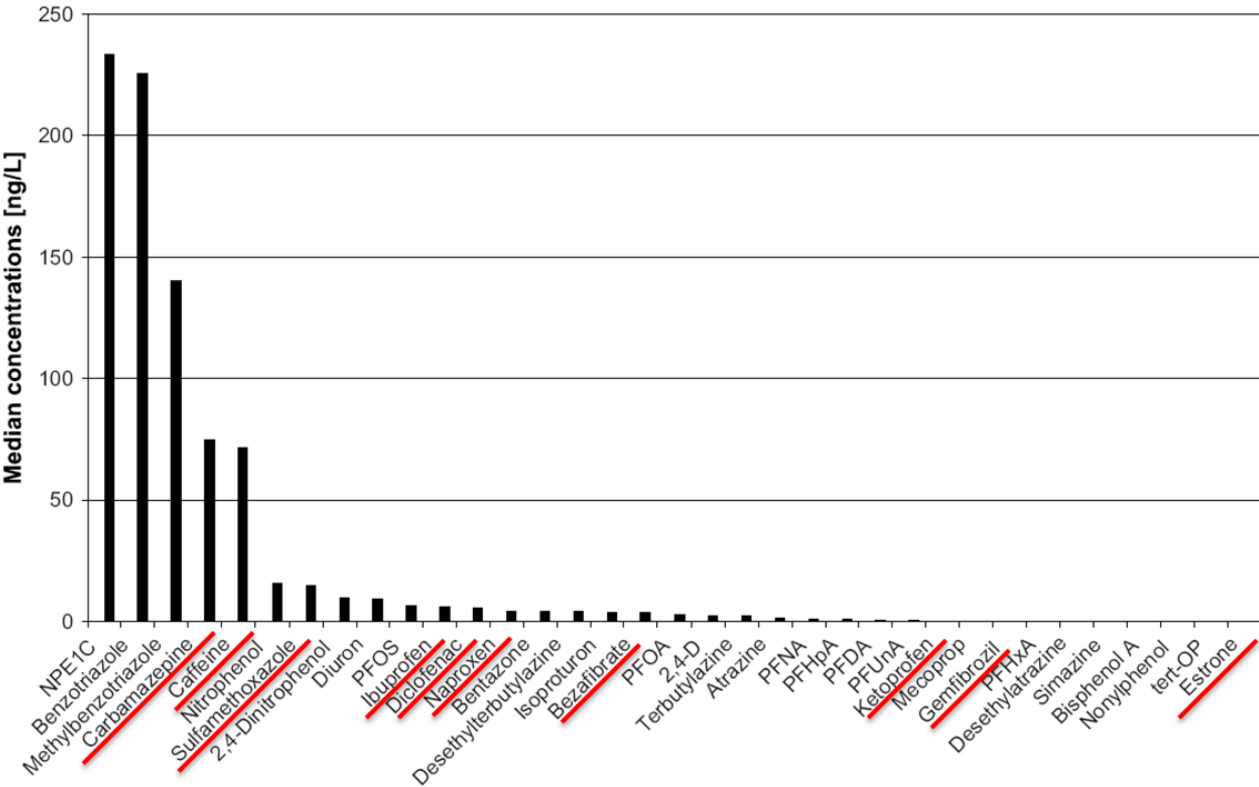


# Surface waters

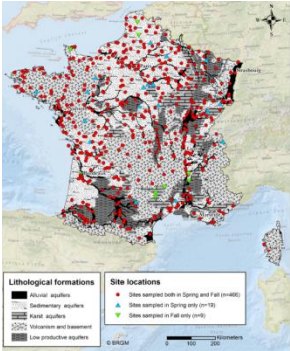
## European river waters



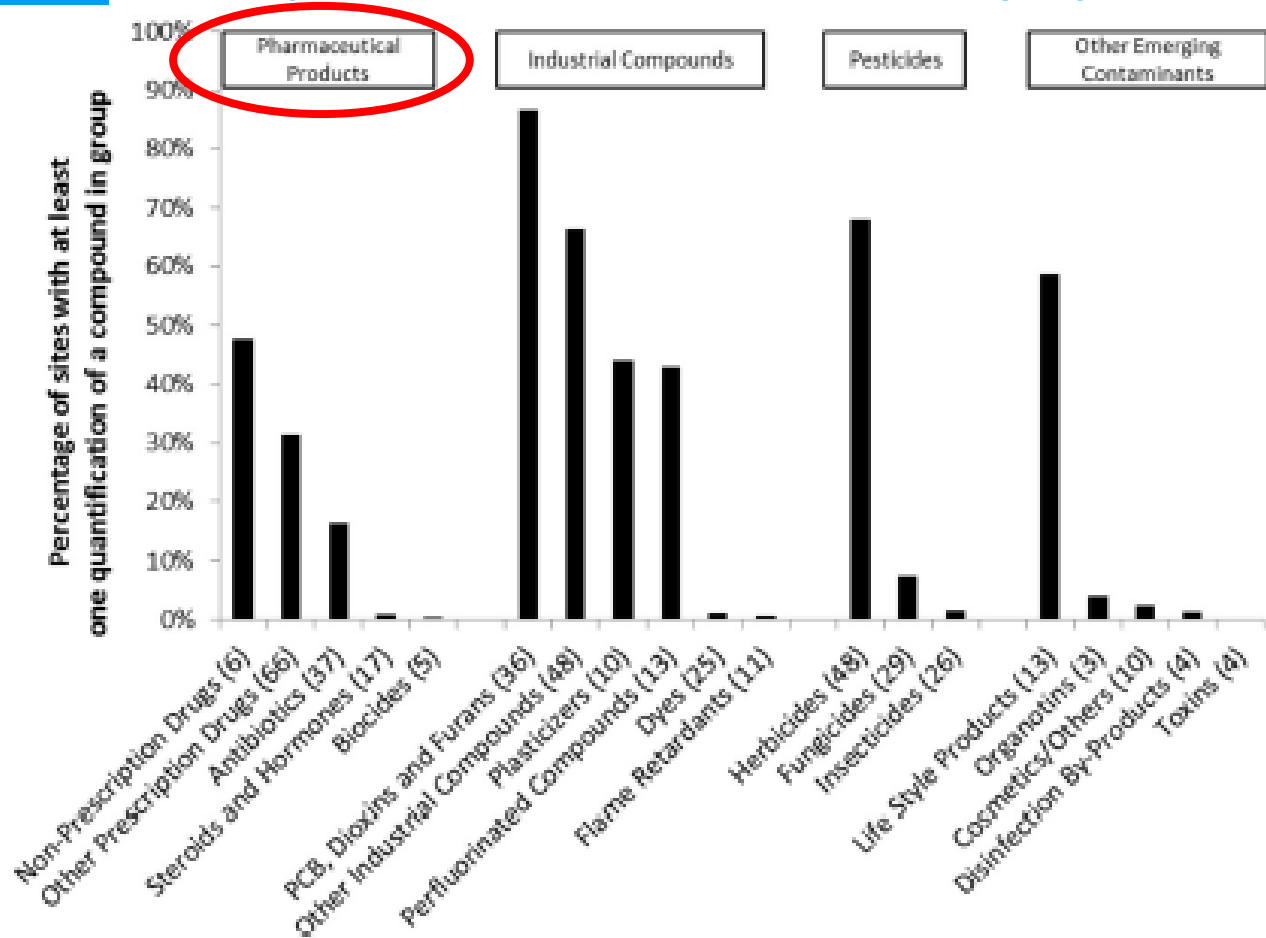
Loos et al., Environmental Pollution 157 (2009), 561-568



# Groundwaters



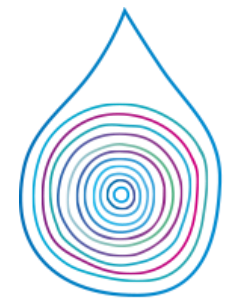
Lopez et al., Science of the Total Environment 518-519 (2015), 562-573



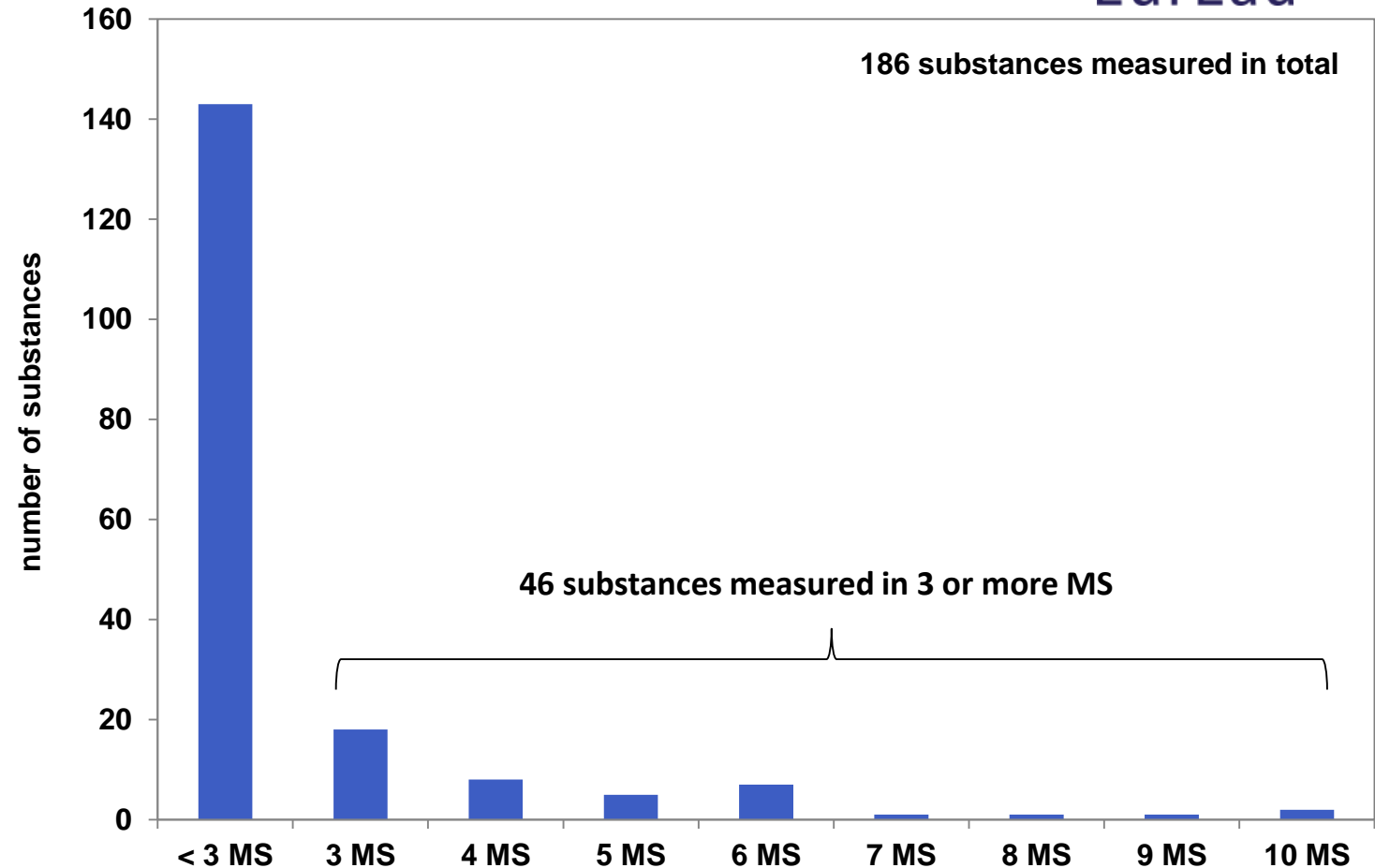


# Surface waters

## Drinking water resources



EurEau

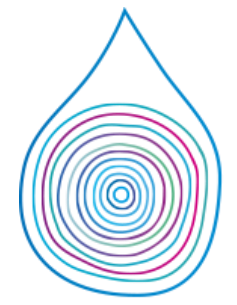


# Surface waters

## Drinking water resources

Diclofenac	Analgesic
Ibuprofen	Analgesic
Carbamazepine	Antiepileptic drug
Naproxen	Analgesic
Atenolol	Beta blocker
Erythromycine	Antihypertensive drug
Bezafibrate	Lipid-lowering drug
Ethinyl estradiol	Estrogen
Ketoprofene	Antibiotic
Metoprolol	Beta blocker
Sulfamethoxazole	Antibiotic
Trimethoprim	Antibiotic

Amidotrizoic acid	X-Ray contrast medium
Caffeine	Alkaloid
Clarithromycine	Antibiotic
Clindamycine	Antibiotic
Iohexol	X-ray contrast medium
Iomeprol	X-ray contrast medium
Iopamidol	X-ray contrast medium
Iopromid	X-ray contrast medium
Metformin	Antidiabetic drug
Paracetamol	Analgesic
Primidon	Anticonvulsant
Sotalol	Beta blocker



EurEau

# Drinking water resources - NL



BTO 2013.049| November 2013

## BTO rapport

Vóórkomen en  
voorkómen van  
geneesmiddelen in  
bronnen van drinkwater



- 99 pharmaceuticals analysed
- All more than once
- In total 728 “hits”
- 98 analyses > 100 ng/l

Stof	functie	Stof	functie
Sulfachloropyridazine	Antibioticum	Ifosamide	Antikanker
Sulfadiazine	Antibioticum	Oxazepam	Sedativum, antiepilepsie
Sulfadimethoxine	Antibioticum	<i>Guanylurea</i>	TP metformine
Sulfamerazine	Antibioticum	Metformine	Anti zuikerziekte
Sulfapyridine	Antibioticum	Amidotrizoic acid	Röntgencontrast-middel
Sulfaquinoxaline	Antibioticum	Diatrizoic acid	Röntgencontrast-middel
sulfamethoxazole	Antibioticum	Iohexol	Röntgencontrast-middel
Tiamuline	Antibioticum	Iomeprol	Röntgencontrast-middel
Trimethoprim	antibioticum	Iopamidol	Röntgencontrast-middel
<i>4-acetaminophen sulfate</i>	TP paracetamol	Iopromide A	Röntgencontrast-middel
4-formylaminoantipyrine	Afbraakproduct phenazone-type geneesmiddelen	Ioxaglic acid	Röntgencontrast-middel
AAA	Afbraakproduct phenazone-type geneesmiddelen	Ioxitalaminic acid	Röntgencontrast-middel
AMPH	Pijnstillers, ontstekingsremmers	Enalapril	ACE remmer
Acetyl salicylic acid	Pijnstillers, ontstekingsremmers	Furosemide	Vochtafdrijvend
Diclofenac	Pijnstillers, ontstekingsremmers	Hydrochlorotriazide	Vochtafdrijvend
Dimethylamino-phenazone	Pijnstillers, ontstekingsremmers	Atorvastatine	cholesterolverlagers
4-formylaminoantipyrine	TP phenazon groep	Bezafibrate	Cholesterolverlagers
Hydroxy ibuprofen	TP ibuprofen	Clofibric acid	Cholesterolverlagers
Ibuprofen	Pijnstillers, ontstekingsremmers	Phenofibric acid	Cholesterolverlagers
Ketoprofen	Pijnstillers, ontstekingsremmers	Gemfibrozil	Cholesterolverlagers
Lidocaine	Pijnstillers, ontstekingsremmers	Pentoxifylline	Onstekingsremmers,
Mesalazine	Pijnstillers, ontstekingsremmers		
Naproxen	Pijnstillers, ontstekingsremmers		
<i>o-desmethyl naproxen</i>	Pijnstillers, ontstekingsremmers		
<i>o-desmethyl tramadol</i>	Pijnstillers, ontstekingsremmers		
Paracetamol	Pijnstillers, ontstekingsremmers		

Stof	functie	Stof	functie
10,11-trans-diol-carbamazepine	TP carbamazepine	Theofylline	antibenaauwdheid
2-hydroxy carbamazepine	TP carbamazepine	Diazepam	Sedativum, antiepilepsie
Fluoxetine	Antidepressivum	Temazepam	Sedativum, antiepilepsie
<i>Norfluoxetine</i>	TP fluoxetine	<i>alfa-hydroxy metoprolol</i>	Betablokker
<i>O-Desmethyl venlafaxine</i>	TP venlafaxine	Atenolol	Betablokker
Paroxetine	Antidepressivum	Bisoprolol	Betablokker
Venlafaxine	Antidepressivum	Metoprolol	Betablokker
Losartan	Bloedrukverlager	<i>o-desmethyl metoprolol</i>	Betablokker
Valsartan	Bloedrukverlager	Pindolol	Betablokker
Acetyl sulfadiazine	TP sulfadiazine	Propranolol	Betablokker
Anhydro erythromycine A	TP erythromycine	Sotalol	Betablokker
Ciprofloxacin	Antibioticum	Clenbuterol	Hormoon
Claritromycine	Antibioticum	Cortisol	Hormoon
Clindamycine	Antibioticum	Cortisone	Hormoon
Doxycycline	Antibioticum	Phenoterol	Hormoon
Erythromycin A	Antibioticum	Prednisolone	Hormoon
Erythromycin-H2O	Antibioticum	Salbutamol	Hormoon
Lincomycin	Antibioticum	<i>3-hydroxy carbamazepine</i>	TP carbamazepine
Metronidazole	Antibioticum	<i>Carbamazepine-10,11-epoxide</i>	TP carbamazepine
<i>N-4-acetyl sulfamethoxazole</i>	TP sulfametoxazole	Carbamazepine	Antiepilepsie
Oxytetracycline	Antibioticum	Oxycarbamazepine	Antiepilepsie
Penicillin V	Antibioticum	Primidone	Antiepilepsie
Roxythromycine	Antibioticum	Cyclophosphamid	antikanker

Stof	functie	Stof	functie
Phenazon	Pijnstillers, ontstekingsremmers		
Propyphenazone	Pijnstillers, ontstekingsremmers		
<i>Salicylic acid</i>	TP acetyl salicylic acid		
Tramadol	Pijnstillers, ontstekingsremmers		
Terbutaline	antibenaauwdheid		

# Top 20 most present pharmaceuticals in river Rhine and river Meuse

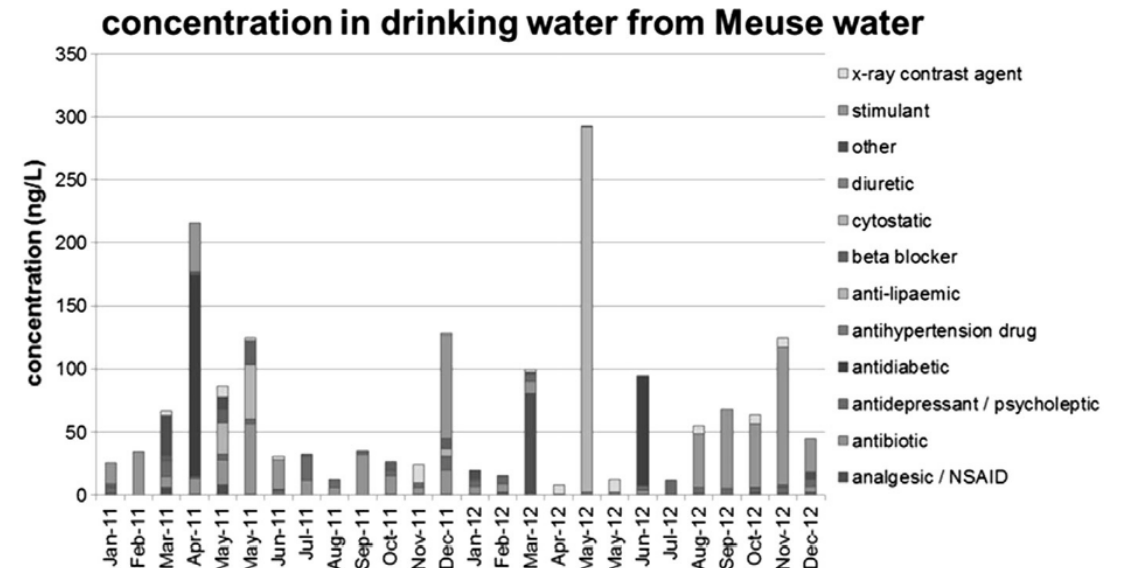
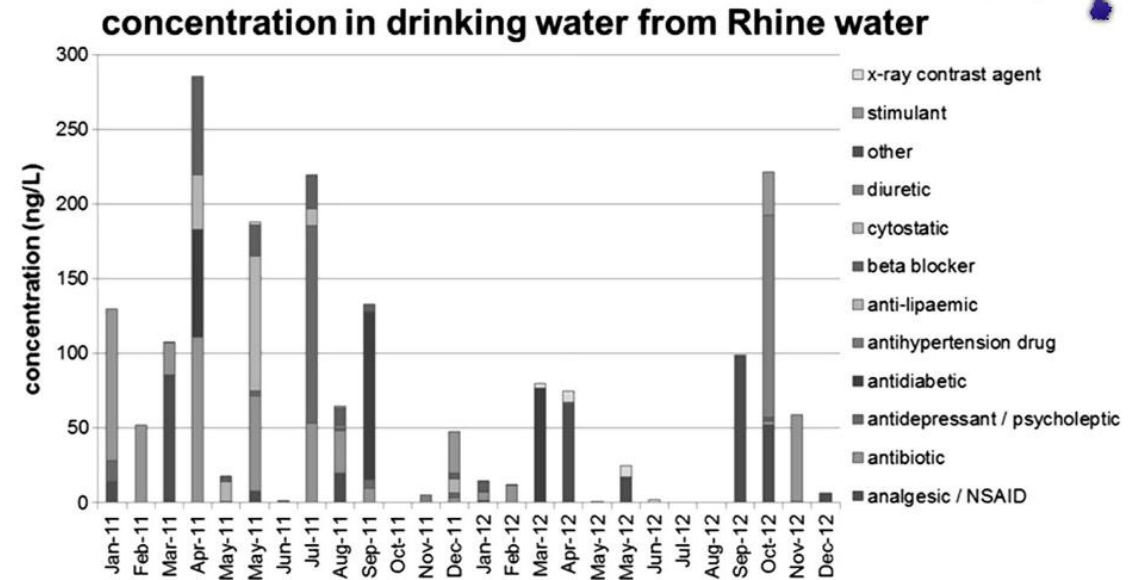


	Rijn (gem.)	Rijn (max.)		Maas (gem.)	Maas (max.)
Metformin	456.6	955.5	Guanylurea	3425.0	4400.0
Iomeprol	315.4	631.5	Metformin	1265.0	2200.0
Amidotrizoic acid	183.5	315.5	10,11-trans-diol-carbamazepine	215.0	260.0
Iopromide	163.2	343.5	Hydroxy ibuprofen	147.0	219.0
Iopamidol	150.5	234.5	Salicylic acid	130.0	130.0
Salicylic acid	130.0	130.0	Amidotrizoic acid	125.16	290.0
Metoprolol	96.9	483.4	Iomeprol	116.9	208.0
Lidocaine	88.9	465.9	Iopromide	108.2	209.4
Metronidazole	70.5	102.0	o-desmethyl tramadol	85.0	90.0
Iohexol	69.7	102.9	Iopamidol	69.5	115.0
Ioxitalaminic acid	55.5	93.0	Sotalol	66.9	180.0
Carbamazepine	49.3	85.0	Iohexol	65.4	78.4
Paracetamol	47.5	149.2	Lidocaine	64.4	220.6
Clindamycine	42.3	111.3	Metronidazole	64.0	73.1
Valsartan	42.2	67.1	Metoprolol	63.6	245.8
Hydrochlorotriazide	35.9	62.0	Tramadol	61.4	140.0
AAA	32.4	43.0	Clindamycine	61.1	74.0
Primidone	30.9	80.0	Valsartan	60.6	75.1
Tiamuline	29.9	120.0	Ioxitalaminic acid	52.0	83.3
Tramadol	29.3	62.0	Naproxen	44.6	187.73



# Drinking waters

Houtman et al., *Science of the Total Environment* 496 (2014), 54-62



# Future perspective

## Demographic projections of future pharmaceutical consumption in the Netherlands

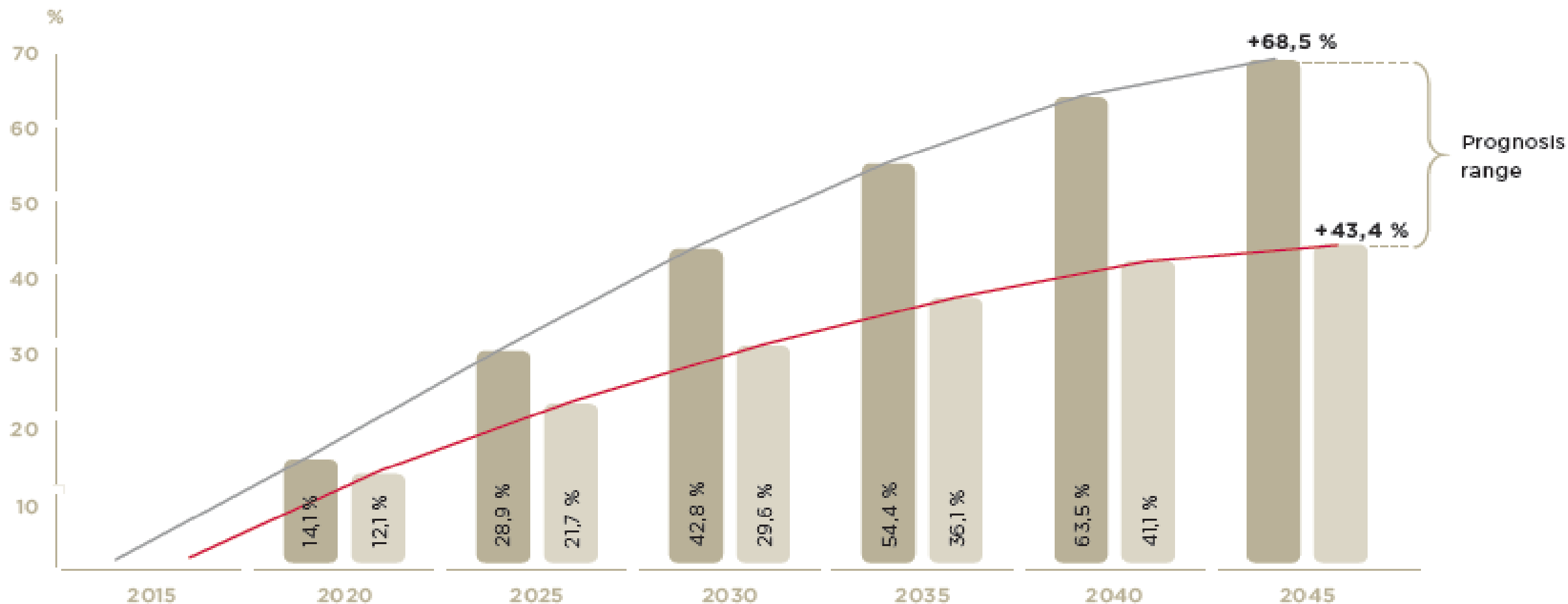
N. G. F. M. van der Aa, G. J. Kommer, J. E. van Montfoort and  
J. F. M. Versteegh

**Table 1** | Forecast of consumption of 33 selected pharmaceuticals, based on projections of demographic changes in the Dutch population between 2007 and 2050. Results are given per pharmaceutical group

Pharmaceutical group	Consumption 2007 (kg)	Consumption 2020 (kg)	Consumption 2050 (kg)	Total growth % 2007–2020	Total growth % 2007–2050
Antidiabetics <sup>1</sup>	230.211	284.559	296.737	24	29
Analgesics <sup>2</sup>	133.976	163.489	224.916	22	68
Heart and cardiovascular <sup>3</sup> (antihypertensives/ lipid modifying agents)	70.613	87.418	96.245	24	36
Antirheumatics <sup>4</sup>	51.758	55.387	55.963	7	8
Antiinfectives/antibiotics <sup>5</sup>	33.754	36.719	40.201	9	19
Antiepileptics <sup>6</sup>	21.675	23.891	24.557	10	13
Gastrointestinal drugs <sup>7</sup>	7.827	9.239	10.094	18	29
Antigout preparations <sup>8</sup>	4.430	5.544	6.096	25	38
Antidepressants/tranquiliser <sup>9</sup>	665	747	1.071	12	61
Anticancer drugs <sup>10</sup>	19	23	23	19	18
Sex hormones/estrogens <sup>11</sup>	16	16	15	–3	–6
<b>Total</b>	<b>554.945</b>	<b>667.032</b>	<b>755.917</b>	<b>20</b>	<b>36</b>



# GROWTH PROGNOSIS FOR THE CONSUMPTION OF PRESCRIPTION DRUGS FOR HUMAN USE



Upper-end scenario  
Lower-end scenario

Source: civity analysis 2017

# The challenge of pharmaceuticals

- Safe drinking water is a human right
- Access to appropriate medication is a human right
- Pharmaceutical residues in surface water and ground water



# Abatement options

- Source protection
- Removal at wastewater treatment plants
- Removal at drinking water treatment plants
- Decentralized treatment
- ....and many more....

# Source protection

22.12.2000

EN

Official Journal of the European Communities

L 327/1

I

(Acts whose publication is obligatory)

**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**

L 330/32

EN

Official Journal of the European Communities

5.12.98

**COUNCIL DIRECTIVE 98/83/EC**

**of 3 November 1998**

**on the quality of water intended for human consumption**

- Water Framework Directive
  - “[..] avoiding deterioration in their quality to reduce the level of purification treatment [..]” Art. 7 (3)
- Drinking Water Directive
  - *Emphasizing precautionary principle in water policies*

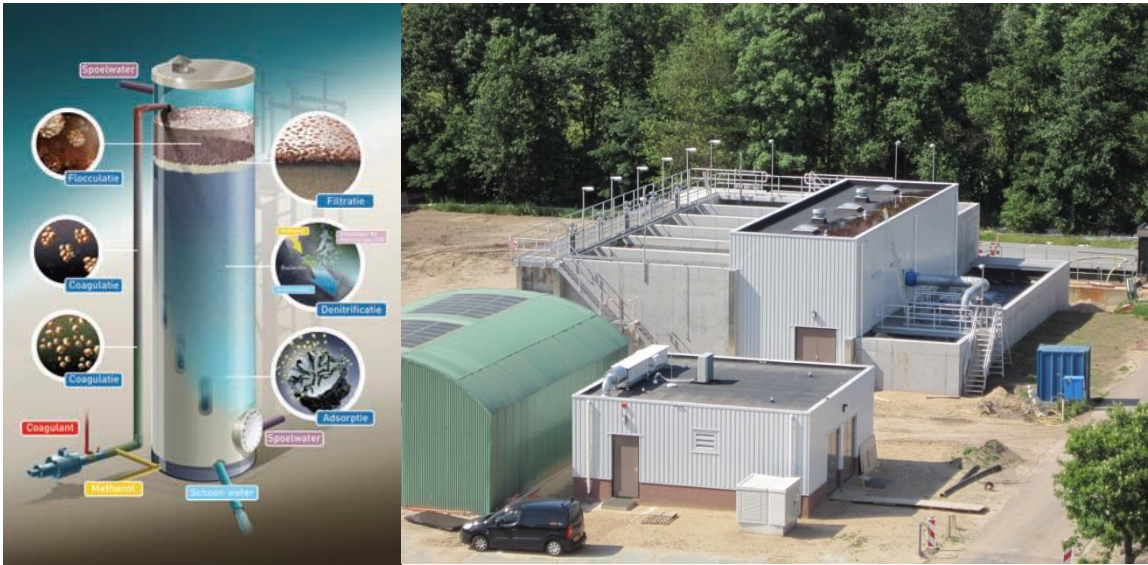
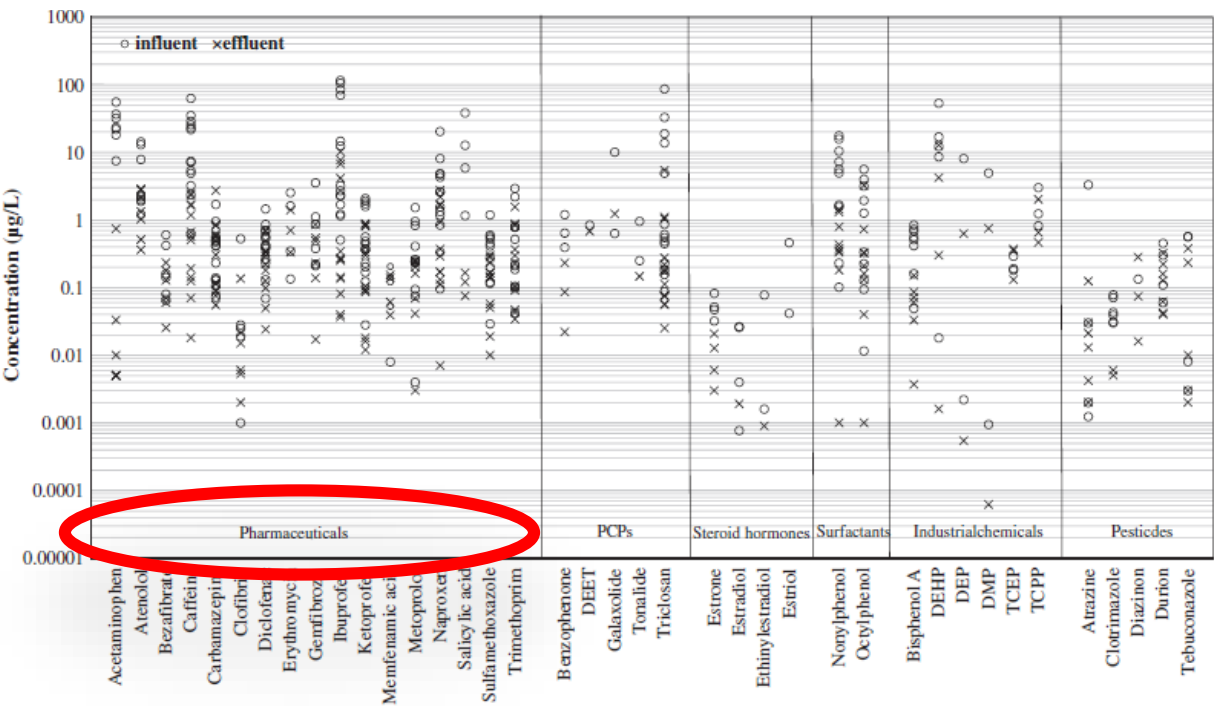
# Wastewater treatment

Requires additional steps

	Amsterdam-West	Westpoort
Capacity		
• p.e.	814,800	402,000
• m³/day	168,000	53,000
Treatment efficiency (%)		
• COD	93	94
• N	85	92
• P	91	93



Luo et al, Science of the Total Environment 473-474 (2014), 619-614

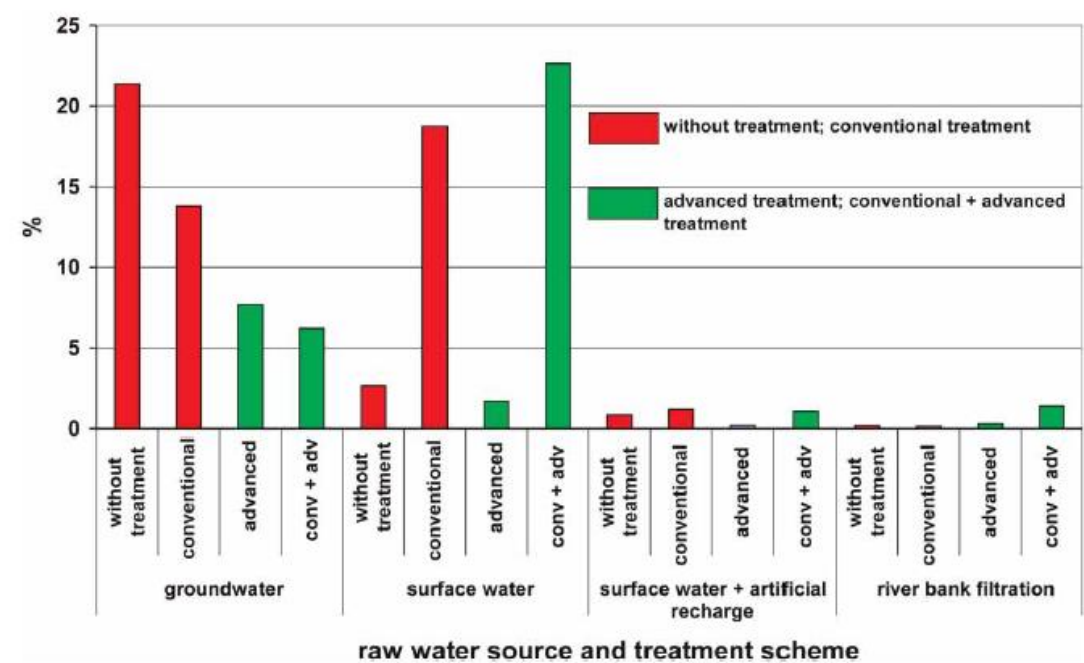




# Drinking water treatment

Requires advanced treatment

Van der Hoek et al., Journal of Water Supply: Research and Technology-AQUA 63.2 (2014), 124-130



Process	Emerging contaminant												
	1,4-dioxaan	amidotrizohezuur	atrazine	benzeen	bisphenol-A	carbamazepine	diethylftalaat	diglyme	lopamidol	MTBE	NDMA	PFOA	PFOS
RO													
O <sub>3</sub> + BACF													
UV + H <sub>2</sub> O <sub>2</sub> + BACF													

Removal/conversion:

■ = poor (0-40%) ■ = moderate (40-60%) ■ = good (60-80%) ■ = very good (80-100%)

# End of pipe solutions are not sustainable

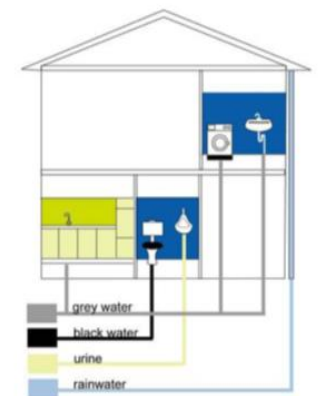
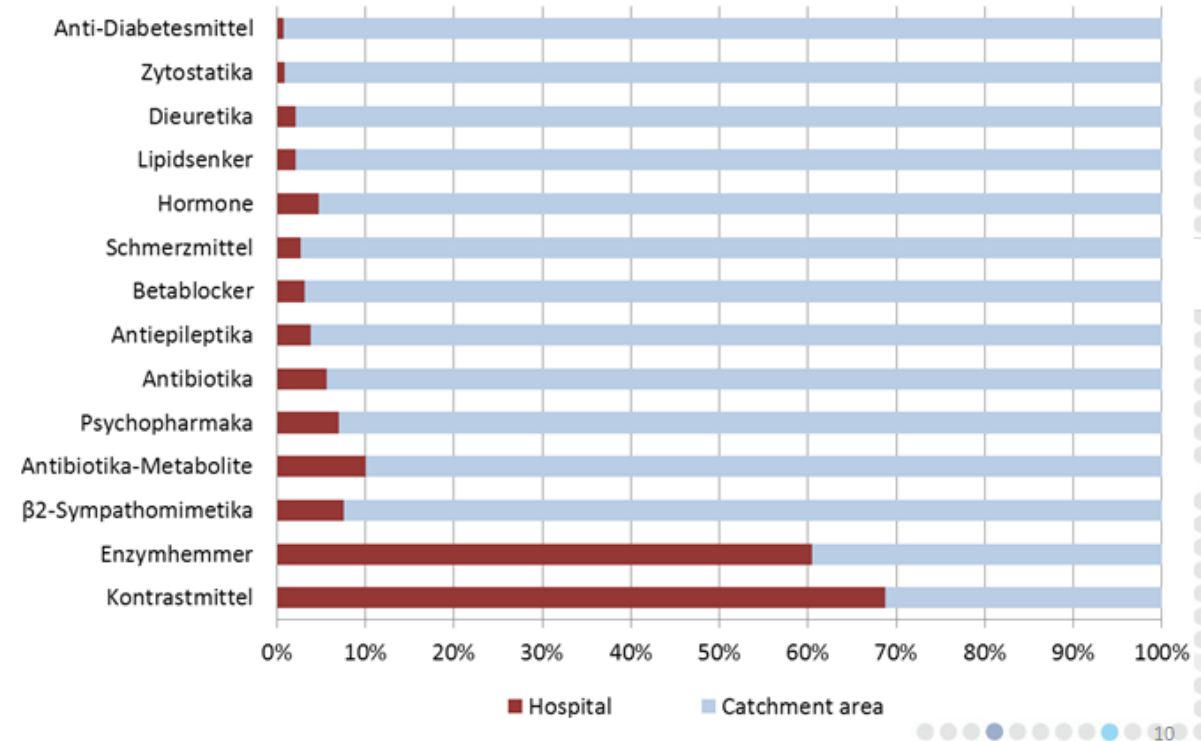
- Economically unsustainable: water bills might increase €10-20/person/year
- Environmentally unsustainable: increase in energy, chemicals consumption and chemical-by-products
- 100% removal hardly achievable
- Against circular economy approach

# Decentralized treatment

e.g. hospital wastewater, separate urine collection



## Compound-specific consideration is needed





# ...and many more...

- Green pharmacy

PUBLIC RELEASE: 9-SEP-2015

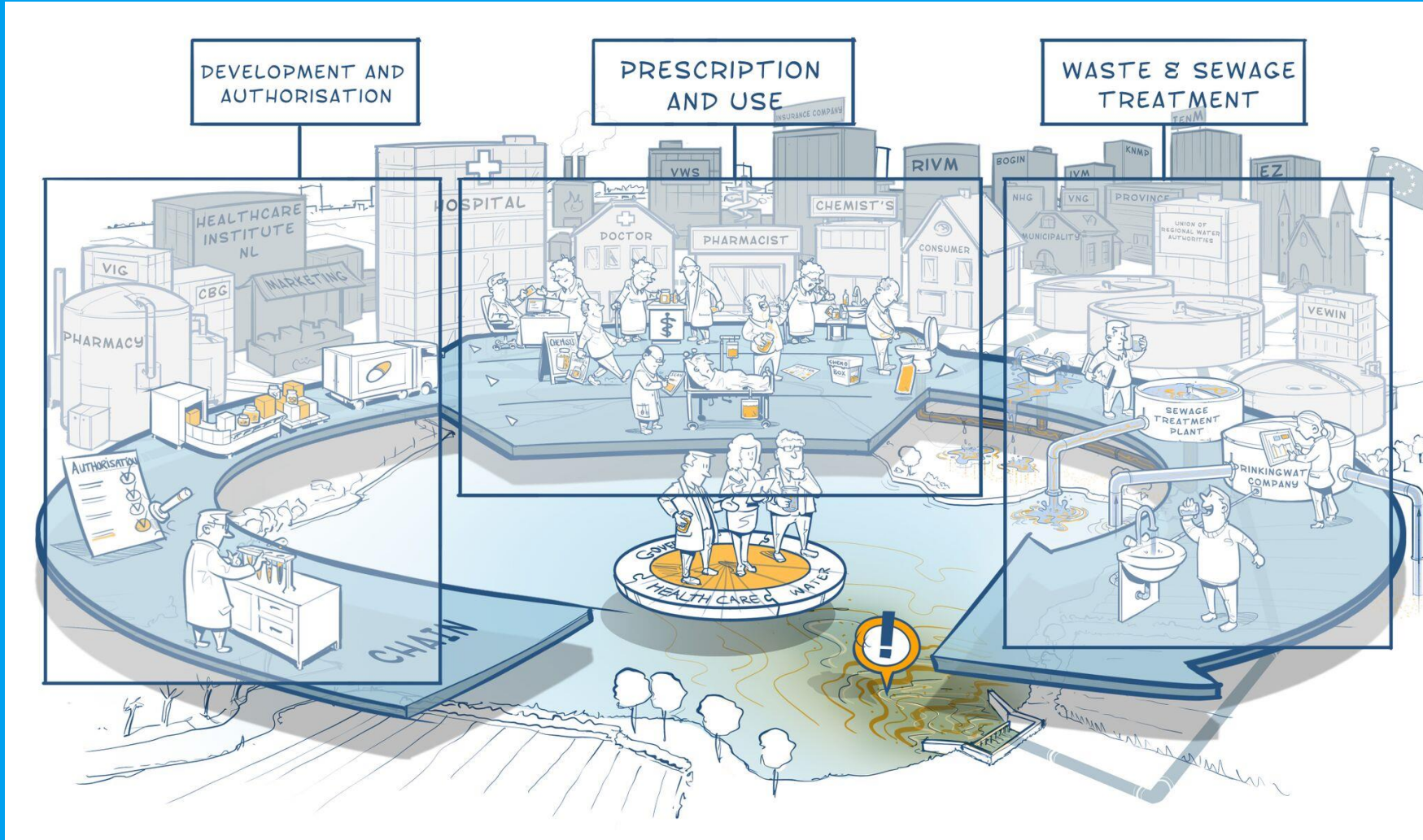
Making pharmaceuticals that degrade before they can contaminate drinking water

AMERICAN CHEMICAL SOCIETY

In recent years, researchers have realized that many products, including pharmaceuticals, have ended up where they're not supposed to be -- in our drinking water. But now scientists have developed a way to make drugs that break down into harmless compounds before they contaminate our taps. Their report appears in ACS' journal *Environmental Science & Technology*.

- Eco-label on packaging
- Compulsory prescriptions for medications with high environmental impact
- Raise awareness and promote healthier lifestyles
- Bring back programs
- Etc....

# The way forward: active cooperation and committed exchange with all involved actors at different levels



# To conclude

- Pharmaceuticals in the water cycle is a problem
- End-of-pipe solutions are not the preferred solutions
- The way forward: active cooperation of all stakeholders