Case study Switzerland: upgrading of wastewater treatment plants with an advanced treatment step to improve surface water quality

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Eawag: Swiss Federal Institute of Aquatic Science and Technology

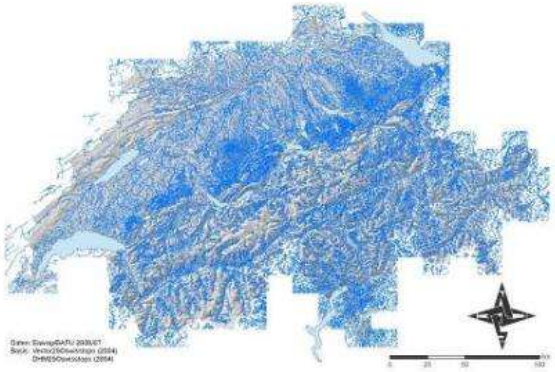
Content

Project «Strategy Micropoll» :

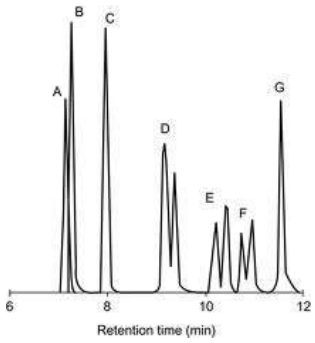
- Financed by the Swiss Federal Office for the Environment, 2006-12
- Micropollutants from treated wastewater

Where? Which substances? Which measures?

Situation analysis

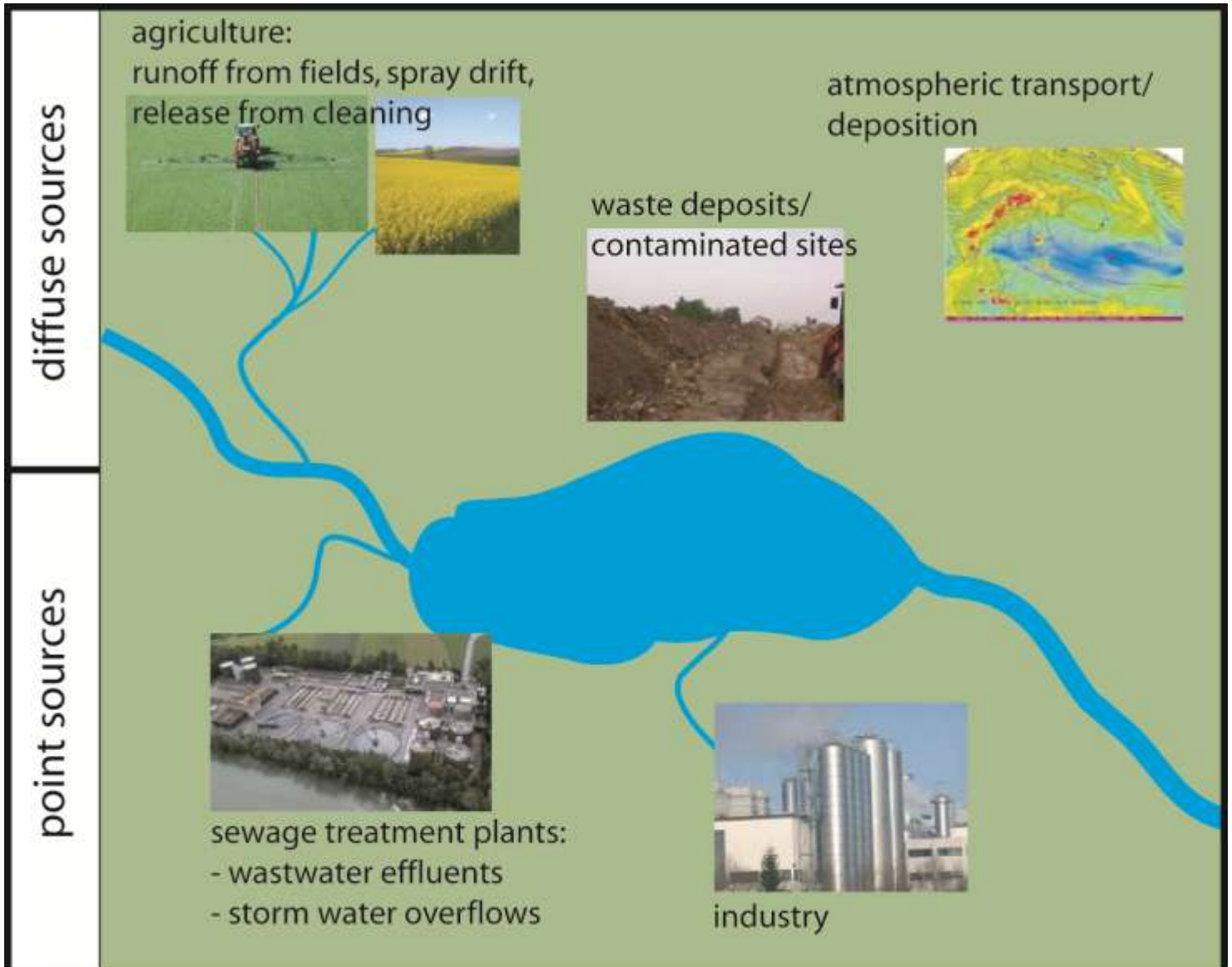


Assessment of substances

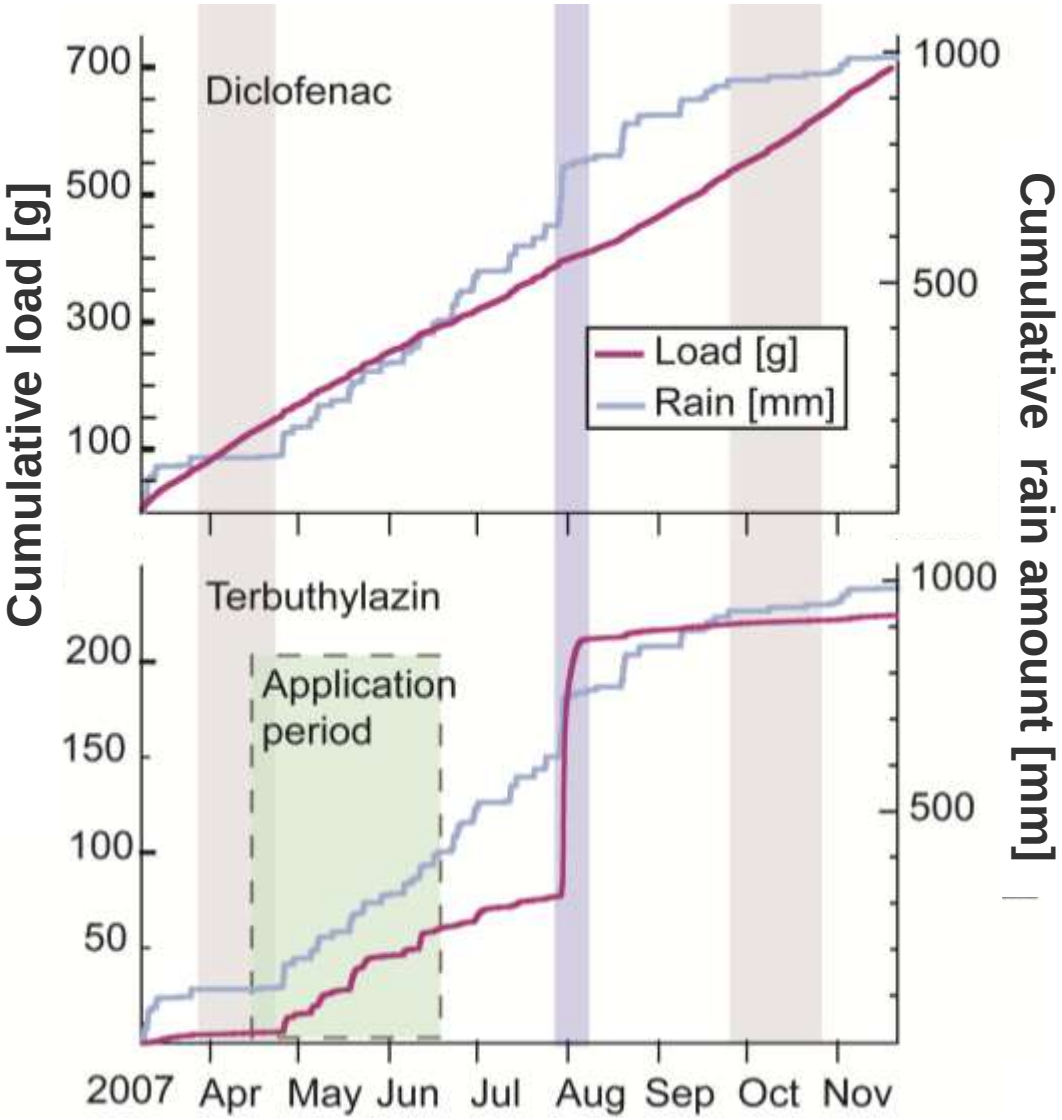


Measures

Input pathways into surface waters



Cumulative loads & rainfall

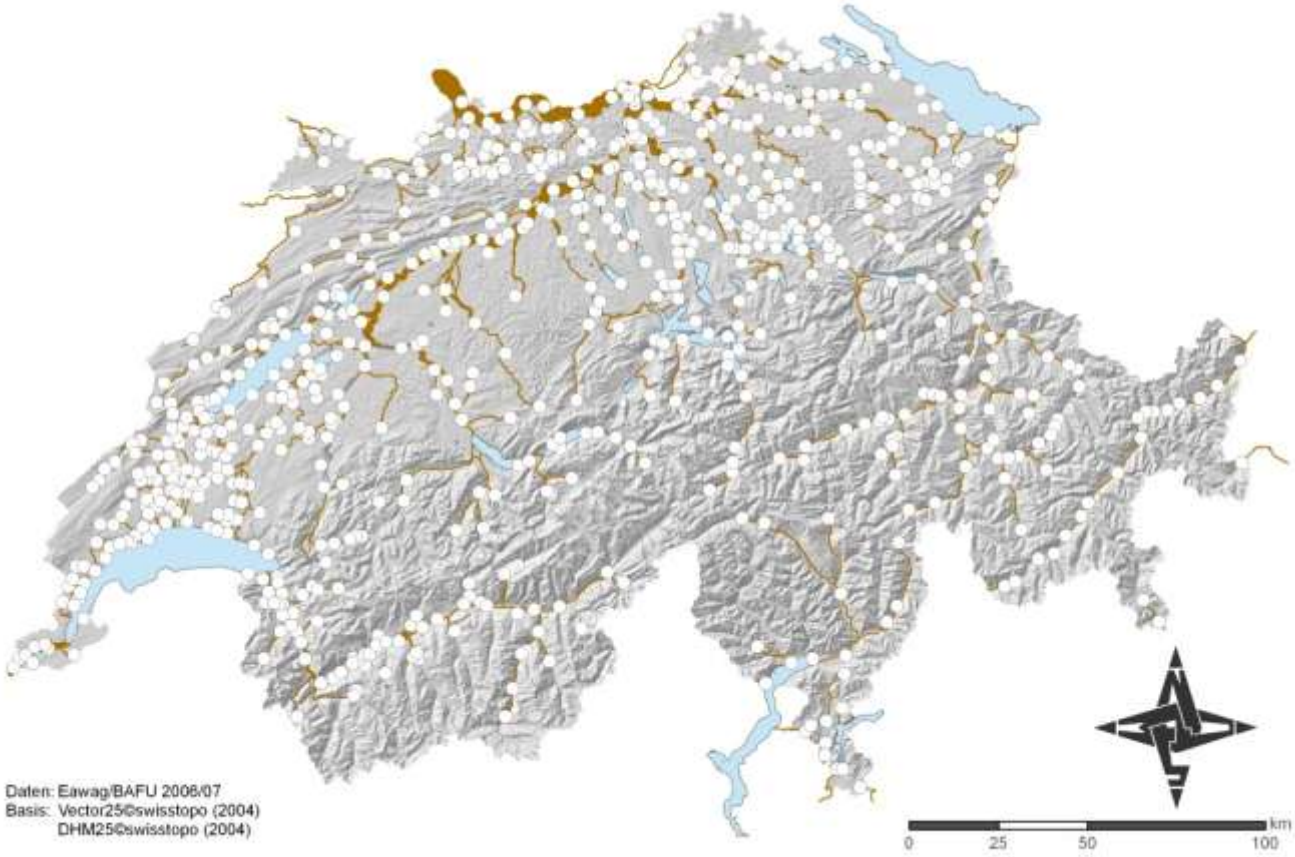


Treated wastewater is the most important continuous point source for micropollutants

Wittmer et al. Wat. Res. 2011

Situation analysis: Mass Flow Model

Switzerland
~6‘000 km river stretches containing treated wastewater,
742 wastewater treatment plants (>500 PE)
>14‘000 digitized stretches

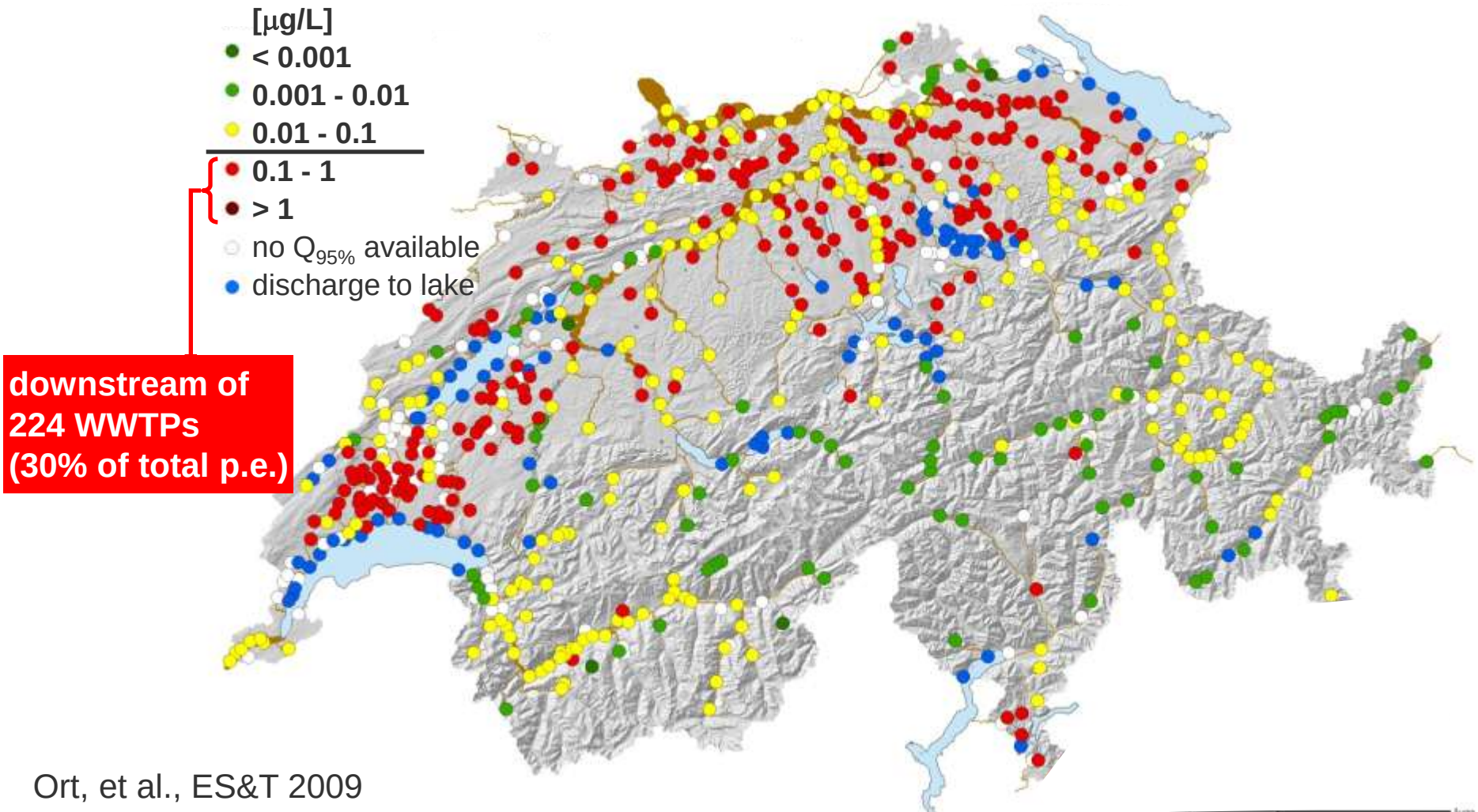


Ort, et al., ES&T 2009

Diclofenac in Rivers including metabolites, modeled at base flow $Q_{95\%}$

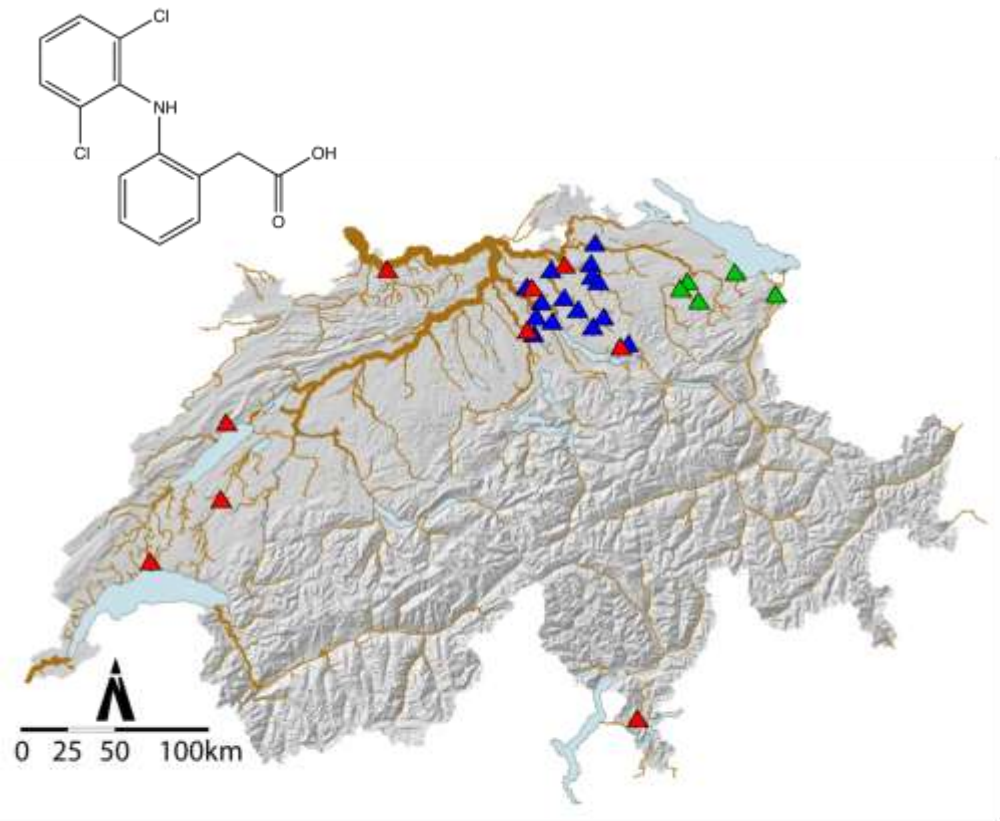
Assumptions

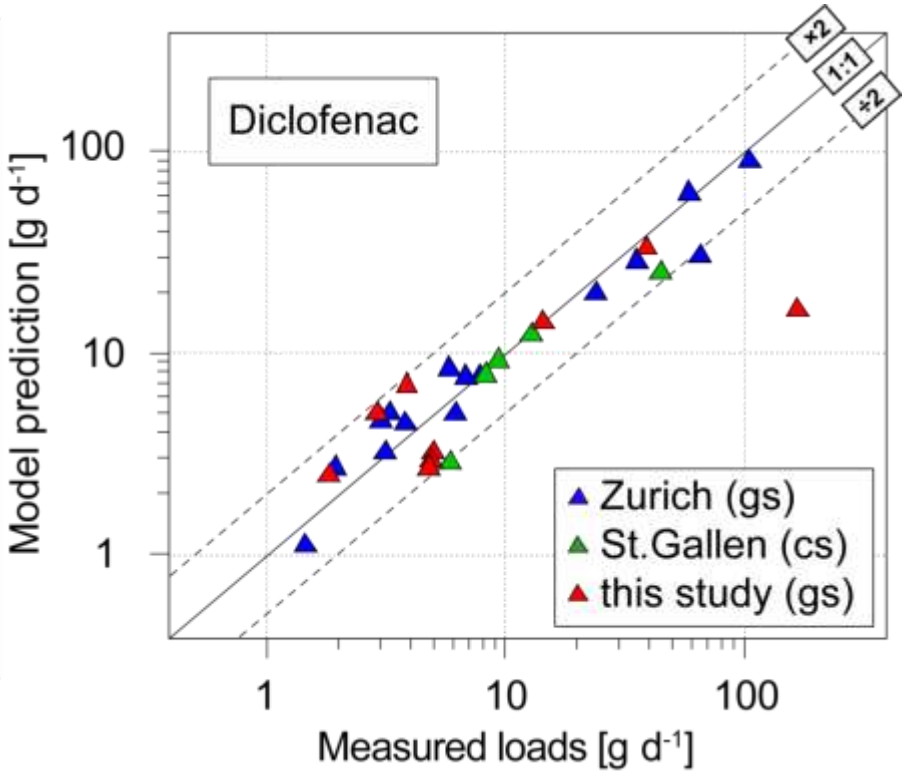
- Consumption 4 t/y,
- 15% unchanged to sewer
- Elimination in WWTP ∅ 25%
- No degradation in receiving waters



Ort, et al., ES&T 2009

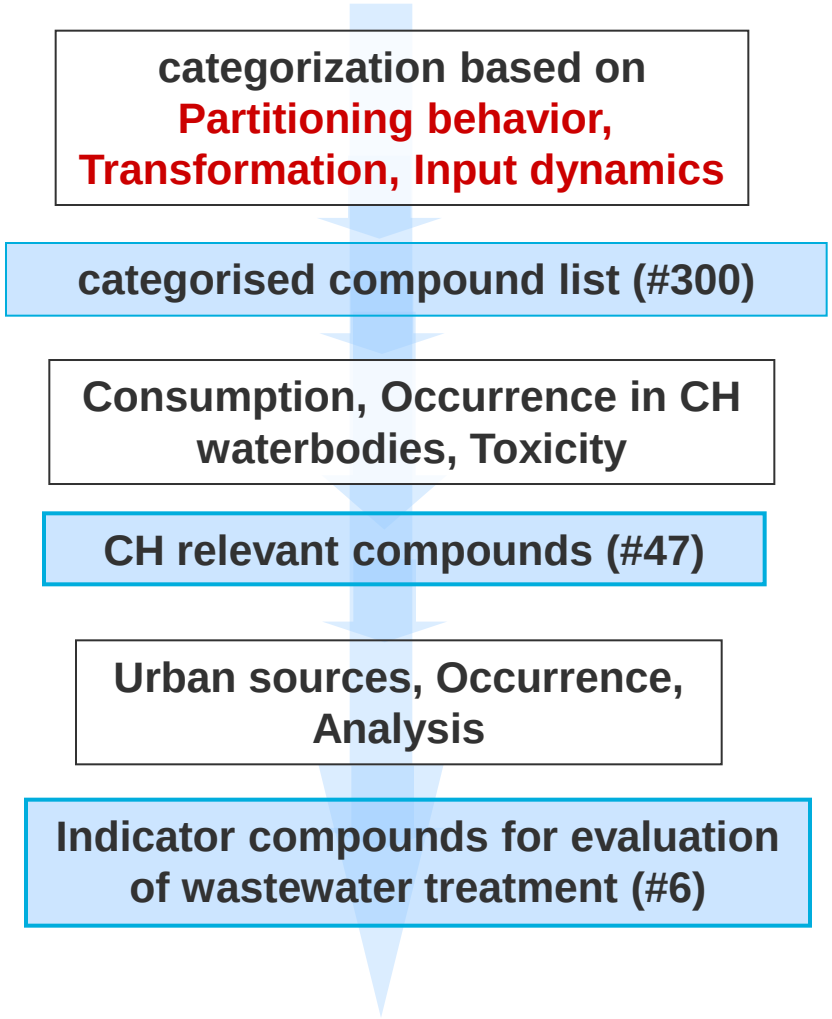
Diclofenac: Prediction vs. Measurements





Ort, et al., ES&T 2009

Assessment of urban substances

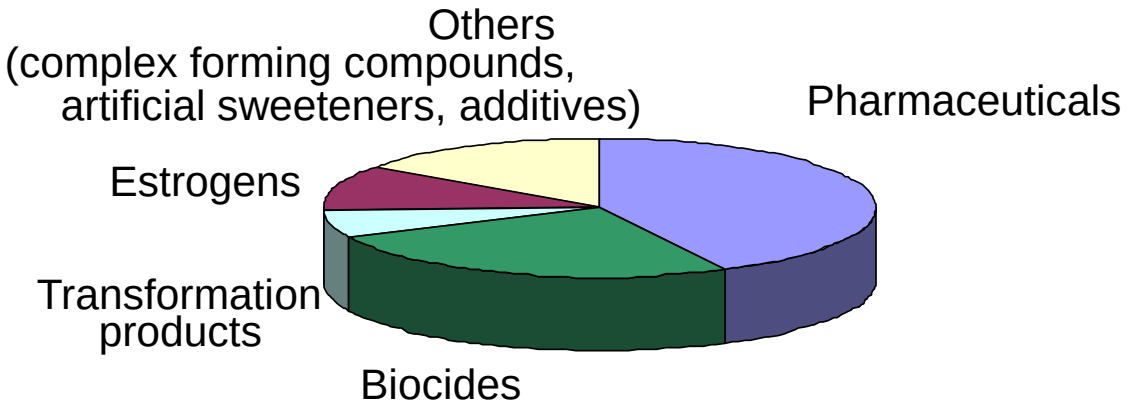


- **Usage is permitted in CH**
- **Continuous input:**
  pharmaceuticals, biocides
- **Persistence:**
  not-readily biodegradable, $t_{1/2} > 60$ d
  no hydrolysis $t_{1/2} \geq 1$ d
- **Distribution:**
  into aqueous phase ≥ 10 %
- **Widespread occurrence**
  > 20 %
- **High specific toxicity**
  e.g. estrogens

Götz et al., Environ Sci Pollut Res 2009

Relevant substances & Environmental Quality Standards

I. List of 47 substances



II. Proposals for EQS

by Ecotox center according to Technical Guidance EU

oekotoxzentrum
centre ecotox

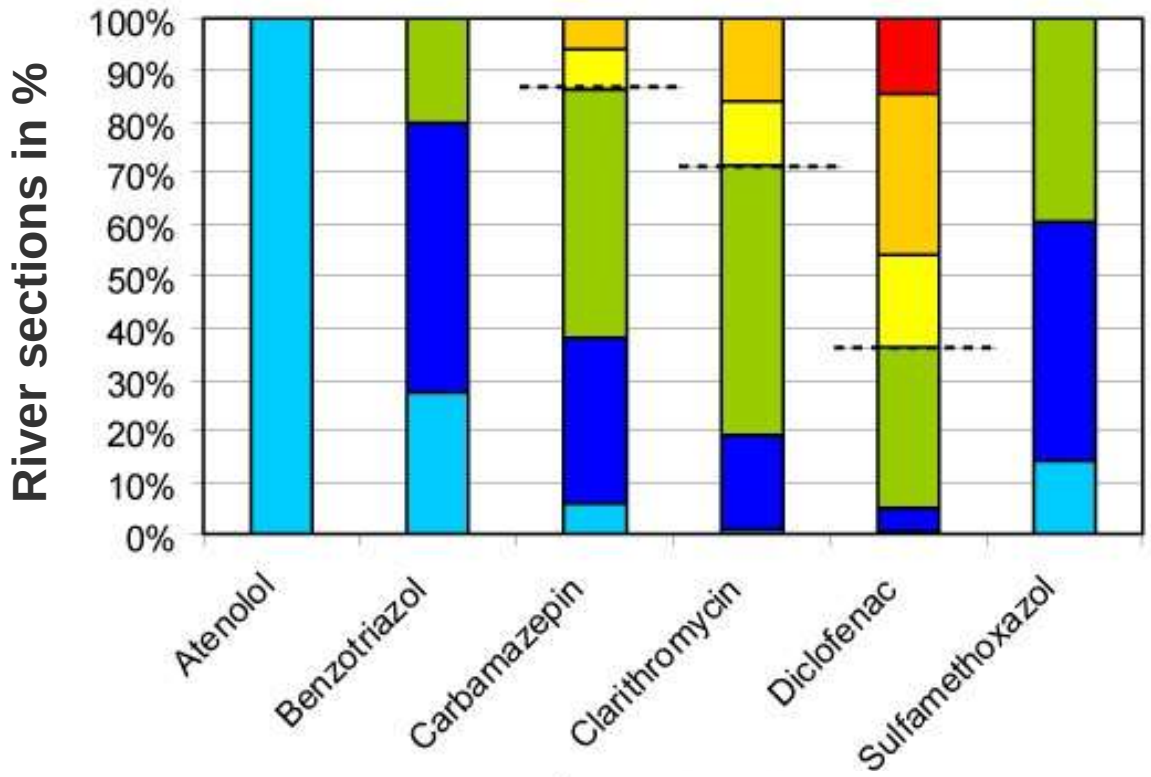
Schweizerisches Zentrum für angewandte Oekotoxikologie | Eawag-EPFL

III. Monitoring concept

Götz et al., ESPR 2010; GWA 2010, assessment report 2011

Assessment of freshwater quality

Modeling of concentration at $Q_{95\%}$ of 543 river sections and comparison with anual average EQS



Substance	AA-EQS (µg/L)
Atenolol	150
Benzotriazole	30
Carbamazepine	0.5
Clarithromycin	0.06
Diclofenac	0.05
Sulfamethoxazole	0.12

Options for action

- **Regulatory measures & information**
  e.g. restriction of substances
- **Central measures at WWTPs**
  optimization, additional treatment steps
- **Decentral measures**
  measures at main emitters,
  decentralized treatment

Umwelt-Wissen 17/09, BAFU

Selection of Treatment processes

Requirements

- Elimination of a broad range of compounds
- No formation of problematic products
- Cost efficiency
- Good technical implementation

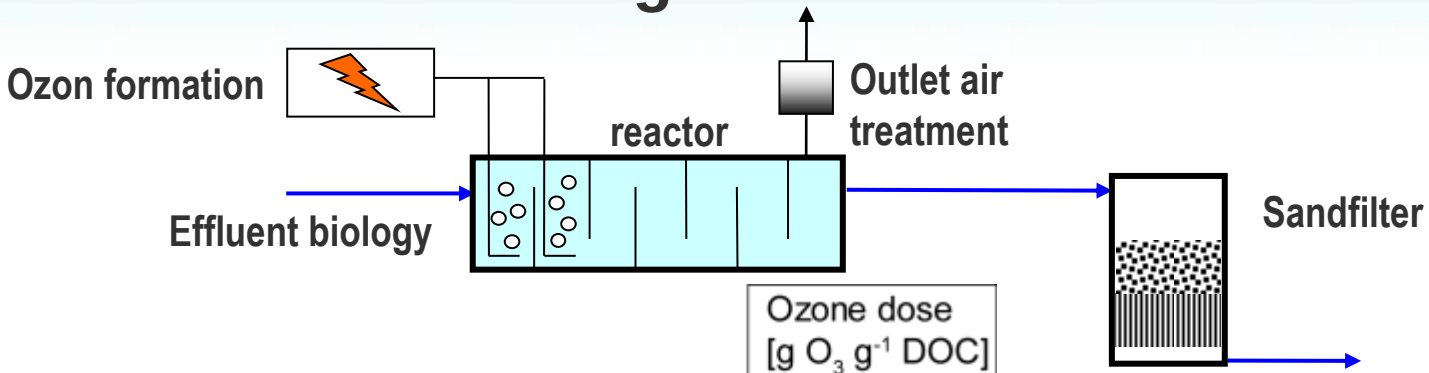
Ozonation
pilot plant at Regensdorf

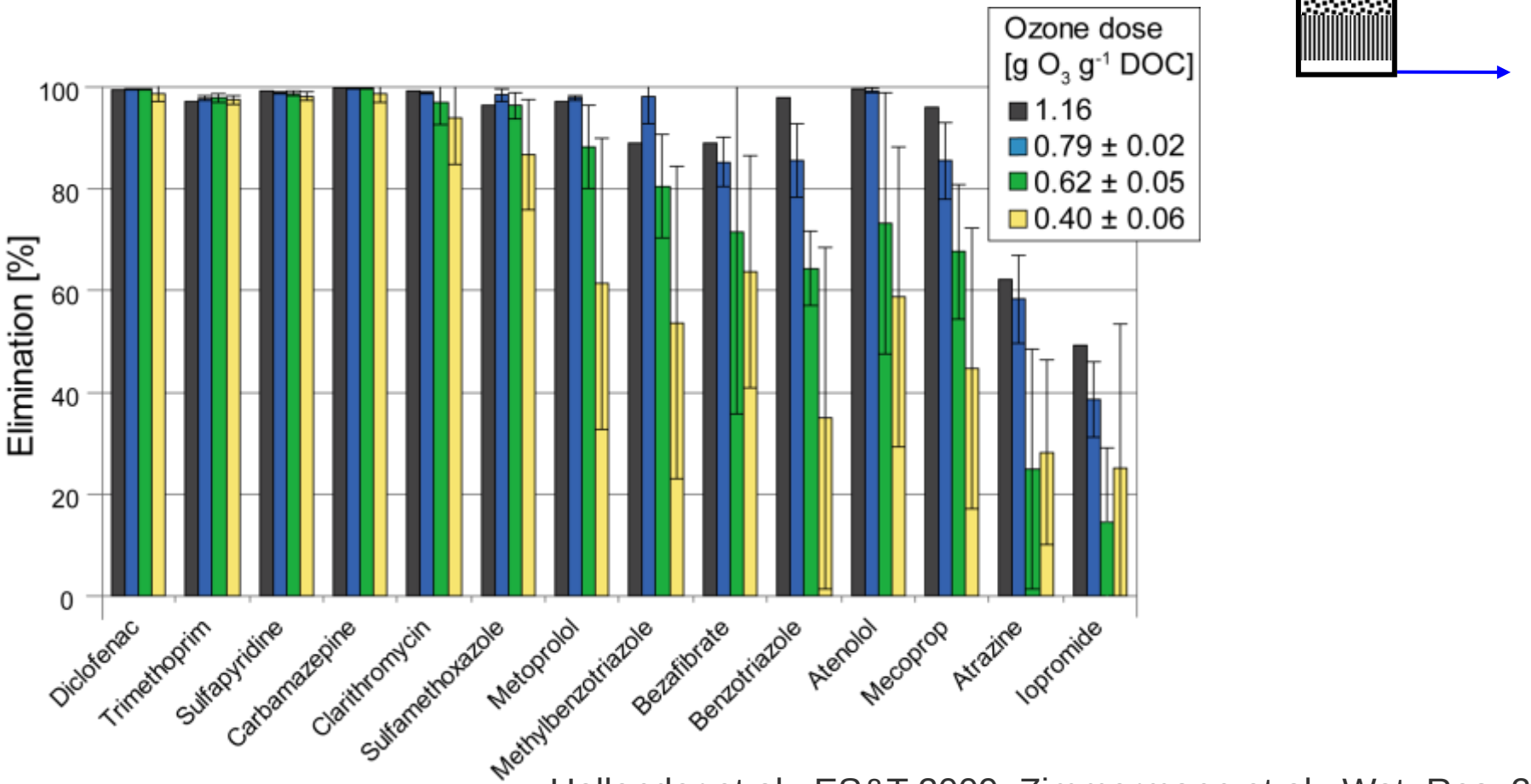
Foto Christian Abegglen

Activated carbon adsorption
pilot plant at Lausanne

Foto Christian Abegglen

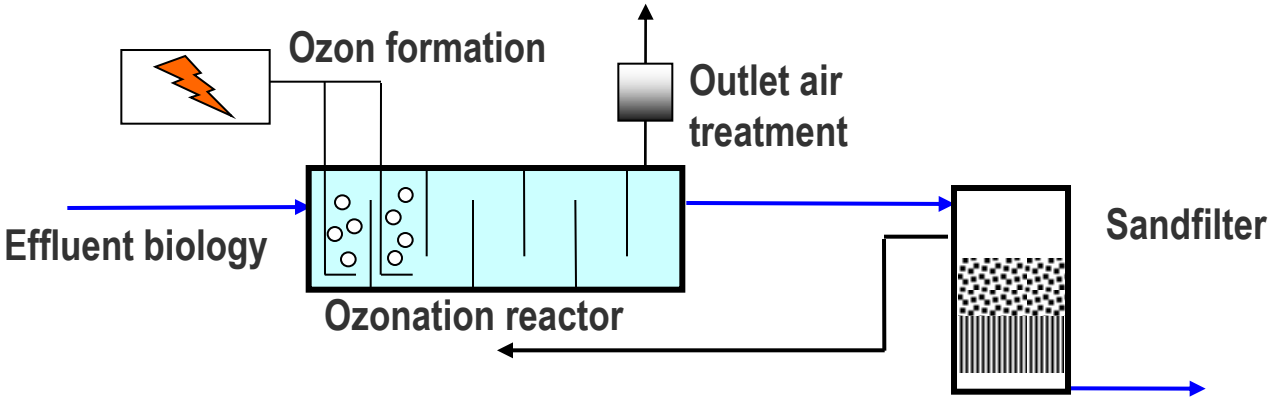
Evaluation of treatment technologies: ozonation





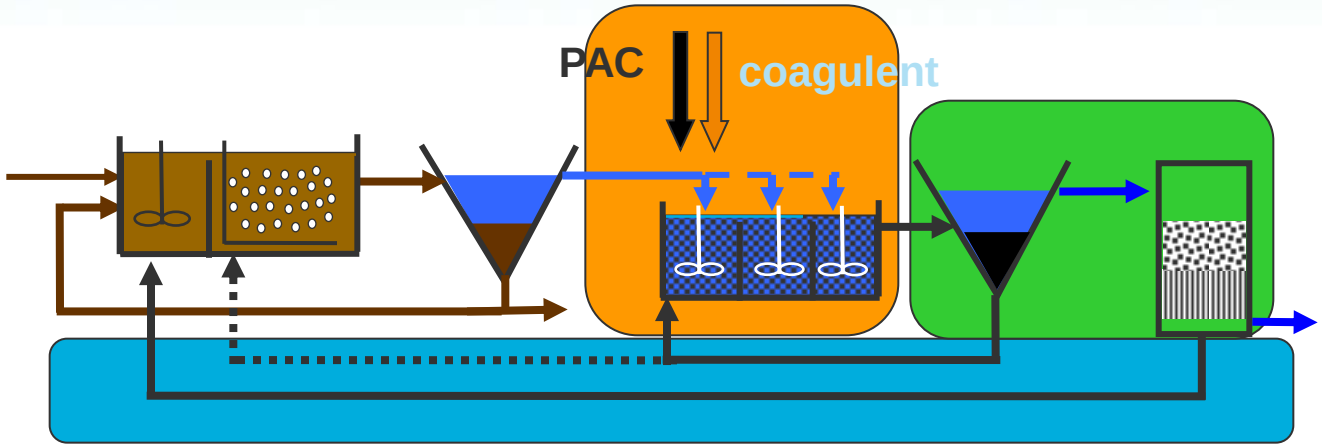
Hollender et al., ES&T 2009, Zimmermann et al., Wat. Res. 2011

Conclusions - ozonation



- **Required Ozone dose (**0.6 – 0.9 g_{O3}/g_{DOC}) **depends on Q, DOC**
- **Regulation of ozone dosage important**
- **Minimal retention time: 5 - 10 min, several compartments necessary**
- **Safety measures: destroying of ozone leaving the plant, ozone sensors**
- **Post-treatment step for biological degradation of formed transformation products**
- **Additonal benefit: reduction of pathogens (**2-3 log units)

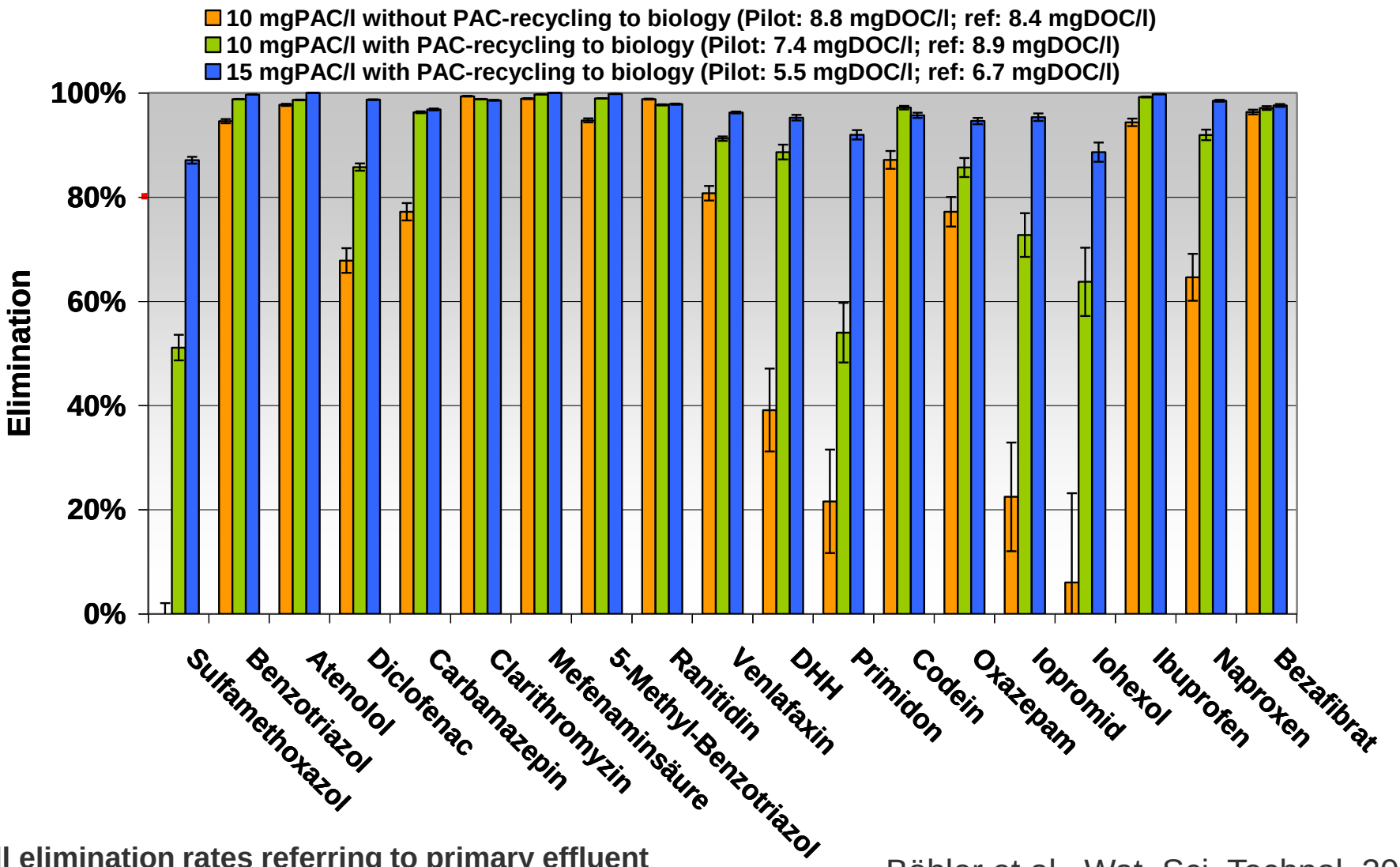
Powdered activated carbon (PAC)



recirculation contact separation

PAC addition to secondary effluent (with sedimentation)

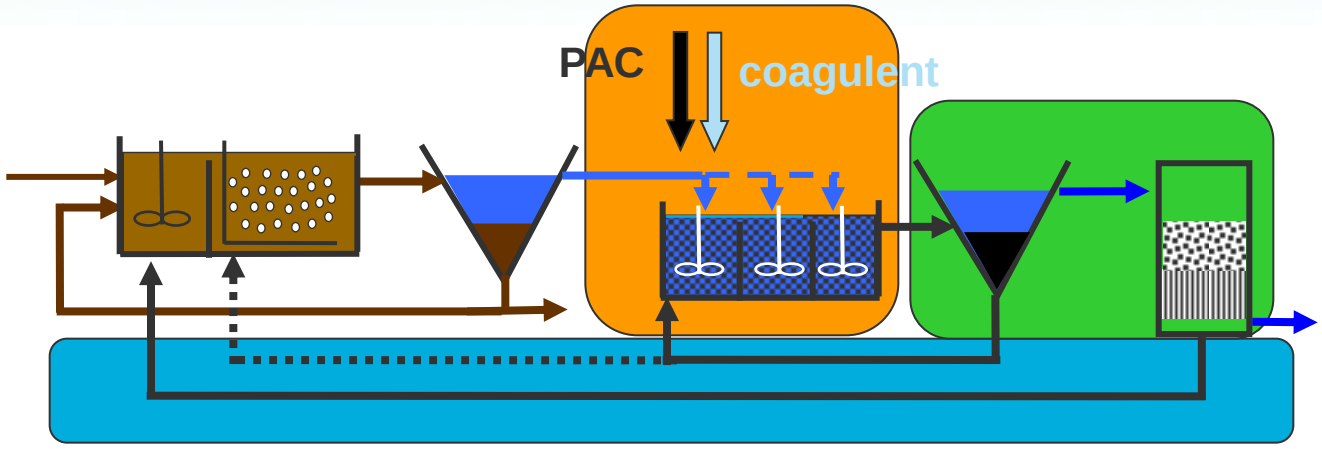
pilot plant Eawag



All elimination rates referring to primary effluent

Böhler et al., Wat. Sci. Technol. 2012

Conclusions - powdered activated carbon (PAC)

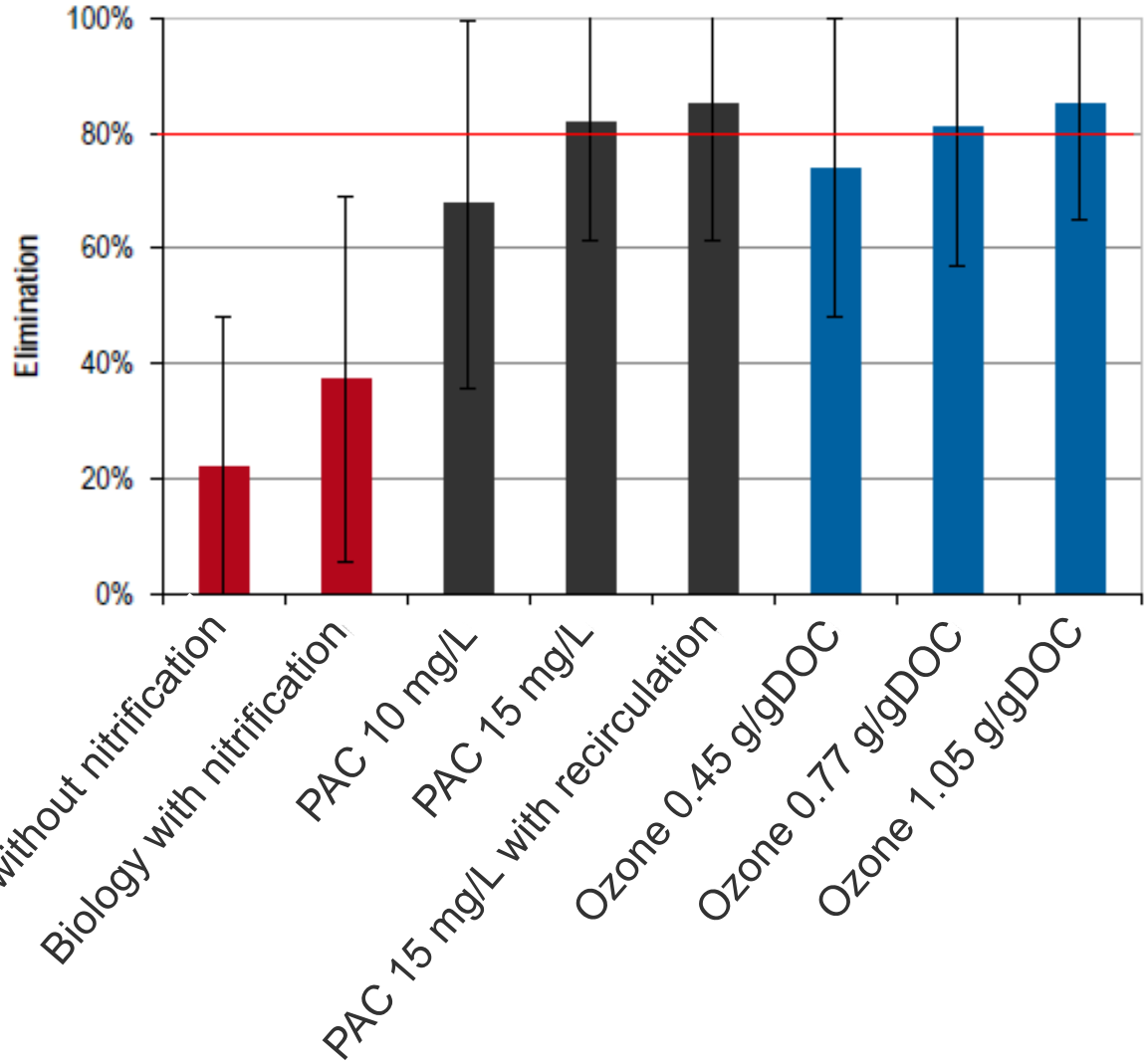


recirculation contact separation

- Required PAC depends on DOC (10-20 mg/L for 5-10 mg DOC/L)
- Minimal retention time: 20 - 30 min
- Recirculation into biology increases elimination by 10 - 50 %
- Sludge production increases by 5-10%
- Separation step necessary
- Safety measures: respiratory protection during work with PAC
- Additional benefit: significant reduction of DOC (ca. 40 %)

Comparison of ozonation vs. powdered activated carbon

Elimination of 40 - 60 substances



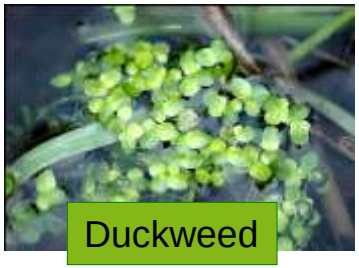
Data from Hollender et al., ES&T 2009; Margot et al., report 2010; Böhler et al., WST 2012

Bioassays

Different trophical levels and modes of action

Primary producers

Algae



Duckweed

Primary consumers

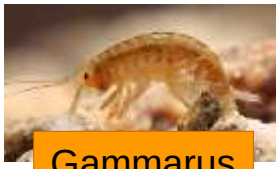
Water flea

Detritus feeders

Lumbriculus

Snail

Shredders



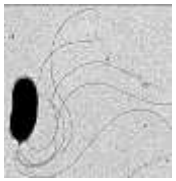
Gammarus

Secondary consumers

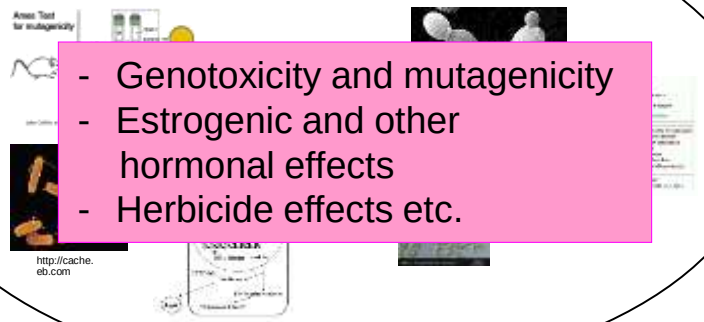
Rainbow trout

Ecosystem effects

Destruents



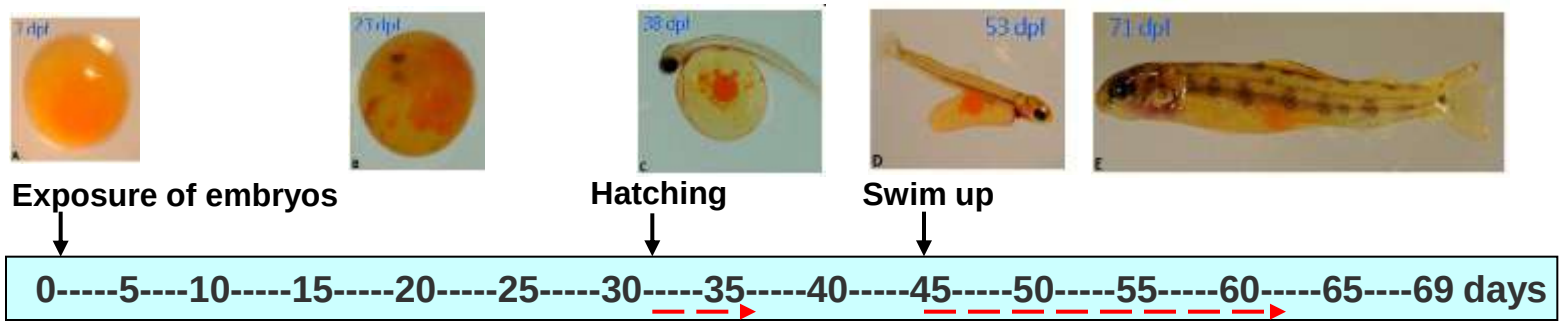
Specific modes of action



- Genotoxicity and mutagenicity
- Estrogenic and other hormonal effects
- Herbicide effects etc.

Results of bioassays

- **Specific modes of action:**
  Significant reduction of effects by O_3 and PAC (> 70 %)
  (estrogens > 75 %, glucocorticoids > 60%, progesterones >70%, photosynthesis inhibition > 80 %)
  no mutagenic or genotoxic effects detected
- **No effects in standardized in-vivo tests**, but tests mostly not sensitive enough
- **Leaf-shredding invertebrate** (Gammarus fossarum): higher feeding rate after O_3
- **Worm test** (Lumbriculus variegatus): lower biomass production after O_3 and PAC (perhaps less nutrients)
- **Fish early life stage test**: in Regensdorf (not Lausanne) after ozonation slower development and smaller fish weight, but elimination after sandfiltration

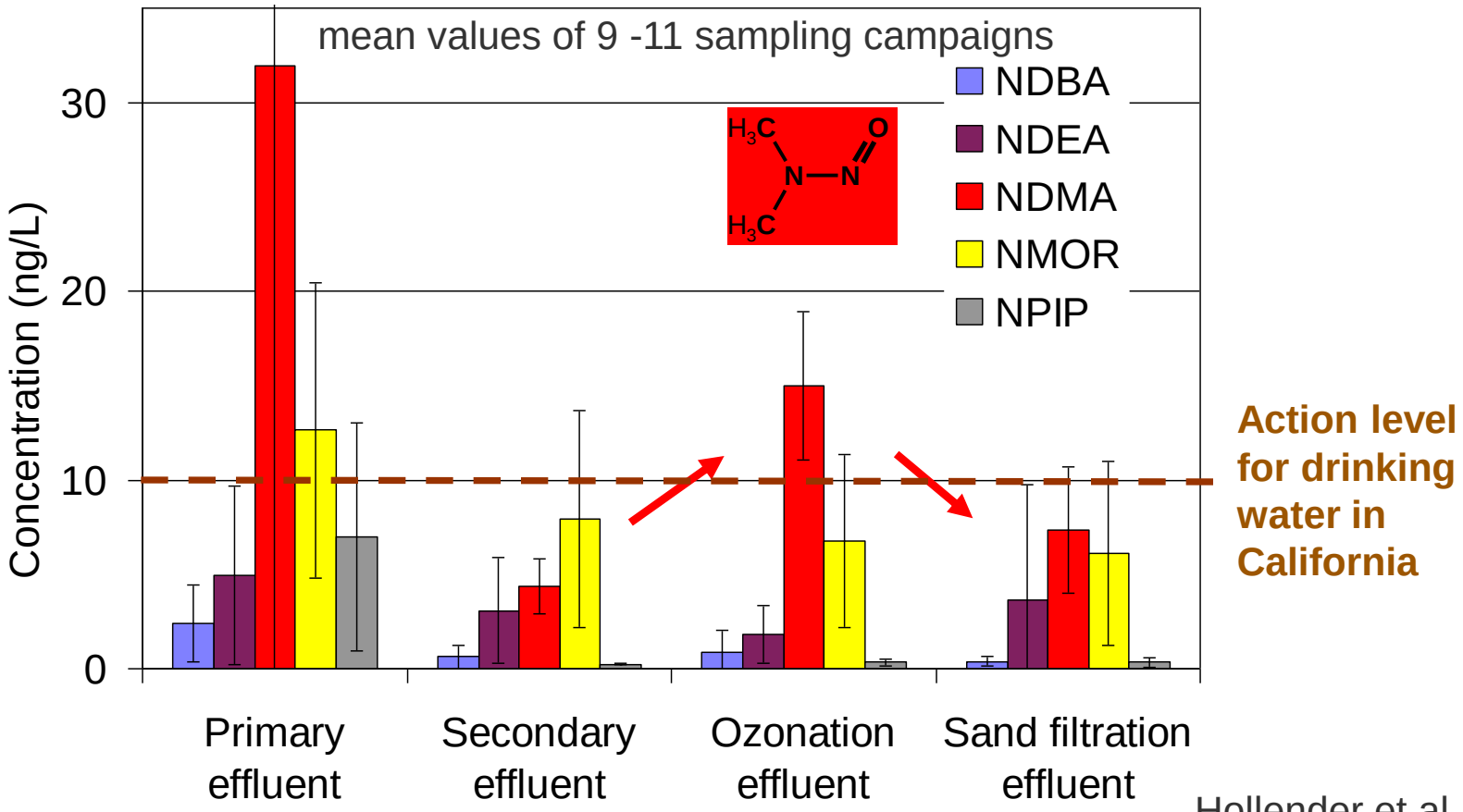


Stalter et al., Wat. Res. 2010, Bundschuh, Wat. Res. 2011; ECT 2011; Kienle et al. Ecotoxcenter 2011

Toxic transformation products or by-products of the ozonation?

- **Bromate:** depends on bromide concentrations, in CH concentrations < PNEC
- **Nitrosamines**: depends on precursors, no values above 10 ng/L

➡ post-treatment like sandfiltration recommended



Hollender et al., ES&T 2009

Energy consumption & costs: Ozonation versus activated carbon

Average values for a WWTP in CH with 50.000 inhabitants

	Energy WWTP kWh/m³	Primary energy kWh/m³	Costs €/m³
Ozonation (3-5 g/m³)	0.05 – 0.10	0.30	0.08
PAC (12-15 g/m³)	0.01 – 0.04	0.37	0.12
WWTP	0.36		0.67

Filtration not included

No robust data for PAC production

Environmental burden of PAC production unknown

Transport (PAC, O_3) not included,

PAC in sludge treatment not included

Abegglen et al., final report 2012

Conclusions «Strategy Micropoll»

- Swiss relevant urban micropollutants have been selected and EQS proposed
- Concentrations of various substances are in the range of expected effects
- Water quality of surface waters can be improved by measures at WWTP (ozonation, activated carbon)
- Technologies are basically ready
- Post-treatment like sandfiltration is recommended
- Upgrade of WWTP increases energy demand and costs
  → careful selection of WWTP

Open research questions

Technology

- Post-treatment: design, necessity
- Production of activated carbon and ozone (energy balance, LCA)
- Other technologies (granulated activated carbon, ferrate)
- Efficient control of technologies

Micropollutants

- Variety of micropollutants (Suspect and Non-target screening)
- Transformation products
- Micropollutants from diffuse sources – importance, mitigation measures

Effects

- Improvement of biotests (suitability, reproduction, cause-effect)
- Effect monitoring in surface waters
- EQS – more substances

Swiss action plan – current status

Modification of Swiss law on water protection proposed by FOEN; motion was approved by government, now financing in consultation

Elimination of micropollutants by 80% in wastewater treatment

Technical measures should be taken at:

- Large WWTPs to reduce high loads (>80.000 inhabitants)
- WWTPs at surface waters with a high wastewater load (> 10%) to improve the ecological status (> 8.000 inhabitants, > 24.000 at lakes)
- WWTPs at surface water that are used for drinking water abstraction (precautionary principle)

- **Ca. 100 WWTPs affected**
- **Investment: ca. 1 billion Euro within 20 years**
- **Subsidy: 75% investment from wastewater fee per inhabitant (max. 7.5 €/p/a)**

Acknowledgements

- Michael Schärer, Ueli Sieber, Stefan Müller (FOEN)
- Hansruedi Siegrist, Marc Böhler, Ben Zwickenpflug, Christoph Ort, Saskia Zimmermann, Urs von Gunten, Christian Götz, Falk Dorusch, Martin Krauss, Heinz Singer, Christa McArdell (Eawag)
- Robert Kase & Cornelia Kienle (Ecotox center)
- Markus Koch (VSA) & Daniel Rensch (AWEL)
- People involved in pilot projects (Regensdorf, Kloten/Opfikon, Lausanne)