Technical solutions for advanced wastewater treatment in Switzerland

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Meeting February 23, 2022, online event

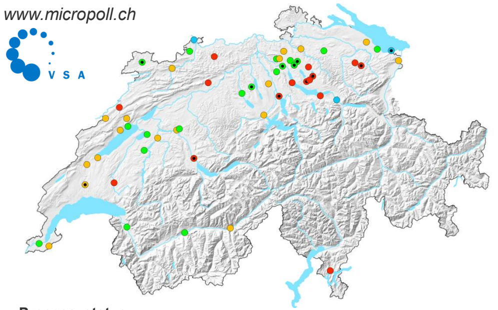
Nature Needs No Pill

Table of content

Eggen et al. ES&T (2014) 48, 7683
dx.doi.org/10.1021/es500907n

Status Quo on upgraded WWTPs (Sept 2021)

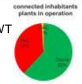
www.micropoll.ch



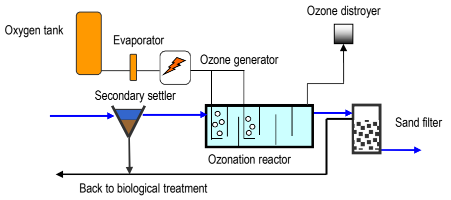
Quelle: Bundesamt für Landestopographie

Selected process (Sept. 2021)	WWTPs oper-ating	WWTPs planned /under constr-uction
Ozonation + sand filtration	6	14
PAC with sedimentation and sand filtration	2	2
PAC dosing onto sand filtration	2	7
PAC dosing into biology	1	2
GAC in moving bed	1	12
GAC filter	1	8
Combination ozonation and AC	1	1
Total	**14**	**46**

Sept. 2021: 11 % of Swiss population connected to AWWT (62% ozonation)



Ozonation



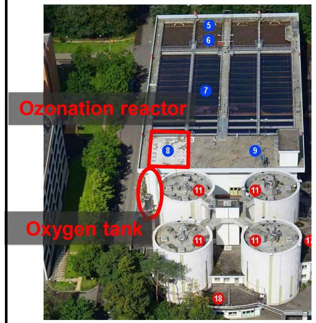
- economic, technically feasible, robust in operation
- 0.4 – 0.6 gO_3/gDOC; Regulation of ozone dose via ΔSAK_{254} (UV absorption in-out)
- biologically active post-treatment (e.g. sand filtration) is needed

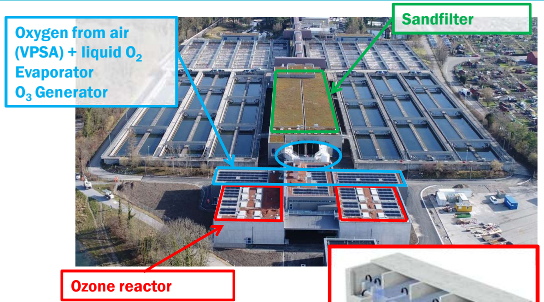
Ozonation reactor
- 6-8 chambers
- Ozone dosage in chambers 1 (or 1+3)
- 6-8 m water depth
- Injectors or diffusors
- HRT minimal 13 min (at Q_{max})

Source: WWTP ARA Neugut

Ozonation + sandfiltration in full scale

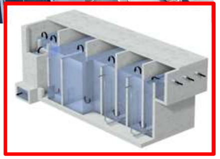
WWTP Neugut, Dübendorf
www.neugut.ch





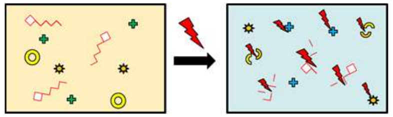
WWTP Werdhölzli, Zürich
Source: ERZ (www.erz.ch)

Find optimized form of reactor with hydraulic simulations



Problematic of ozonation

- Well functioning biological treatment needed (higher ozone consumption with high DOC or nitrite)
- Ozonation is an oxidative process in which micropollutants are NOT mineralized
- Transformation products are formed from micropollutants (mostly unknown)
- By-products can be formed from matrix



- Formation of nitrosamines (e.g. NDMA)
- Formation of bromate out of bromide
- Ecotox tests necessary
- biologically active post-treatment (e.g. sand filtration) is needed to reduce potentially toxic, biologically degradable reaction products

An ozonation is not suitable for every type of wastewater
→ test suitability of ozonation (avoid formation of toxic by-products)

Schindler Wildhaber (2015) Wat Res. 75, 324
http://dx.doi.org/10.1016/j.watres.2015.02.030

Exotoxicological tests in ozonation

Ecotoxicological tests:
(I) WW effluent, (II) After ozonation, (III) After biodegradation

WWTP	A			B			C			D		
	(I)	(II)	(III)	(I)	(II)	(III)	(I)	(II)	(III)	(I)	(II)	(III)
TA98-S9					↓	↓		↑	↑			
TA98+S9		↓	↓					↑	↑			↓
TA100-S9												
TA100+S9												
YG7108-S9		↑			↑			↑			↑	
YES		↓	↓		↓	↓		↓	↓		↓	↓
YAS												
Algae Phot.		↓	↓		↓	↓		↓	↓		↓	↓
Algae growth			↓		↓	↓		↓	↓		↓	↓
C. dubia			n.a.			n.a.			↓		↑	
Fishegg								↑	↓			

suitable (A, B) — not recommended (C) — unclear (D)

Wunderlin et al. (2015) AQUA & GAS No 7/8, 28-38
https://micropoll.ch/Mediathek/behandelbarkeit-von-abwasser-mit-ozon-testverfahren-zur-beurteilung/

Schindler Wildhaber (2015) Wat Res. 75, 324
http://dx.doi.org/10.1016/j.watres.2015.02.030

Main tests:
- Ames test
- combined algae assay
- *C. dubia* reproduction test
- (fish embryo toxicity test)
- (umuC)
- (Bioluminescence inhib.)

Evaluation of a full-scale wastewater treatment plant with ozonation and different post-treatments using a broad range of *in vitro* and *in vivo* bioassays

Cornelia Kienle[a,*], Inge Werner[a], Stephan Fischer[b], Christina Lüthi[a], Andrea Schifferli[a], Harrie Besselink[c], Miriam Langer[a], Christa S. McArdell[b], Etiënne L.M. Vermeirssen[a]

Kienle (2022) Wat Res. 212, 118084
https://doi.org/10.1016/j.watres.2022.118084
Open access

Formation of ozonation by-products at WWTP Neugut

Occurrence of **NDMA**:

Fig. 5. Concentrations of NDMA in BIO-EFF, OZO-EFF and SF-EFF for various specific ozone doses ranging between 0.54 and 0.97 g O3/g DOC.
From: Bourgin et al. (2018) Wat. Res. 129, 486-498
https://doi.org/10.1016/j.watres.2017.10.036

N-Nitrosodimethylamin (NDMA) :
- *Formation in ozonation: < 30 ng/L, but occurring in WWTP influent*
- *Elimination in sand filter: 65%*
- *Concentration after sand filtration: < 50 ng/L*

Bourgin et al. (2018) Wat. Res. 129, 486-498
doi.org/10.1016/j.watres.2017.10.036

NDMA guideline value for drinking water by World Health Organization (2008): 100 ng/L
NDMA prov. drinking water value Germany: 10 ng/L

Bromate formation

Soltermann et al. (2016) ES&T 50, 9825−9834;
Soltermann et al. (2016) A&G 10, 64-71

Figure 4. Bromate yields from ozonation of bromide-containing (40−700 μg L−1) wastewaters as a function of the specific ozone dose.
From: Soltermann et al. (2016) ES&T 50, 9825−9834;
DOI: 10.1021/acs.est.6b01142

Bromide:
<0.05 mg/L ~75% WWTPs

Bromide source (0.1-100 mg/L):
- Chemical industry
- Landfill leachate
- municipal waste incinerators (KVA)

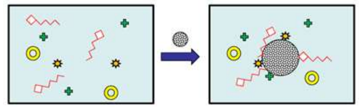
Brominated Flame Retardants (BFR) in incinerators:

Scheme 1. Fate of Brominated Flame Retardants in Municipal Waste Incinerators and the Discharge of Bromide to Surface Waters
From: Soltermann et al. (2016) ES&T 50, 9825−9834;
DOI: 10.1021/acs.est.6b01142

- Formation of bromate increases strongly at > 0.4 $gO_3/gDOC$
- No bromate reduction / retention in sand filter or (aerobic) GAC
- Bromate drinking water standard from EPA (2012) und WHO (2005): 10 µg/L

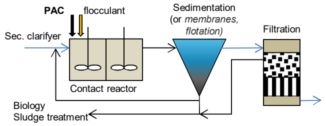
Activated carbon – adsorptive process

- Micropollutants get attached (adsorbed) to the activated carbon

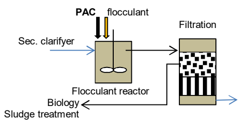


- Several raw materials: stone- and brown coal, wood, turf, several pericarps (e.g. coconut)
- Several grain sizes
  - Granular activated carbon (GAC): 0.3-2.4 mm
  - Powdered activated carbon (PAC): 20-50 µm
  - («Super»-fine activated carbon: < 1 µm)

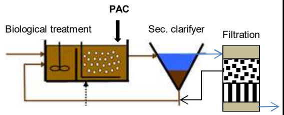
PAC – different possibilities



separate contact reactor
«Ulmer-technology»



Dosing onto filter



Directly into biological treatment

PAC dosage about 1.5 gPAC/gDOC

Higher PAC dosage expected (about 2-3 gPAC/gDOC)

- Robust and efficient technology to remove MPs
- Generally higher DOC removal compared to ozonation
- ΔSAK_{254} (UV absorption in-out) for monitoring
- addition of a flocculant (4–15 mg $FeCl_3$/L or 0.1–0.4 gFe/gPAC)
- Filter is needed to retain PAC (<5%)
- PAC regeneration is not possible and needs to be incinerated
- PAC is recirculated into the biological treatment

Siegrist et al. (2018) IWA book

PAC in full scale

separate contact reactor
«Ulmer-technology»

WWTP Bachwis, Herisau
www.herisau.ch

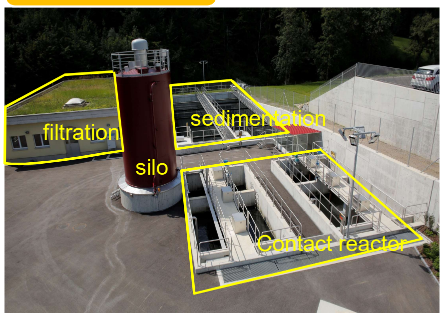
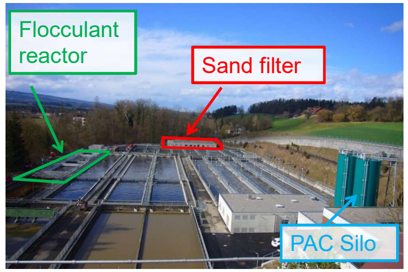


Photo: A. Joss / H. Messmer, August 2015

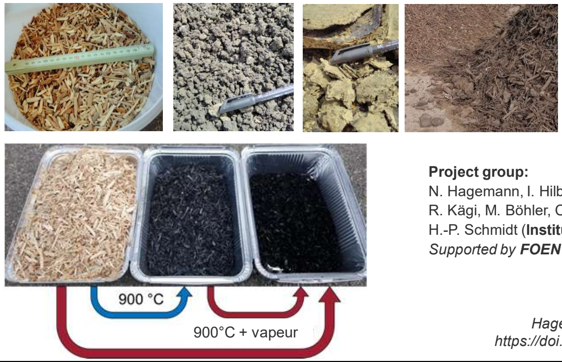
Dosing onto filter



WWTP Schönau, Cham
www.zg.ch/behoerden/weitere-organisationen/gvrz/klaeranlage-schoenau

PAC application: innovation to lower footprint

Project Empyrion: produce AC out of Swiss wood, biogenic waste and sewage sludge

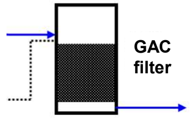


Project group:
N. Hagemann, I. Hilber, T. Bucheli (**Agroscope**),
R. Kägi, M. Böhler, C. McArdell, A. Maccagnan (**Eawag**),
H.-P. Schmidt (**Institut Ithaka**)
*Supported by **FOEN***

Hagemann (2020) STOTEN 730, 138417
https://doi.org/10.1016/j.scitotenv.2020.138417

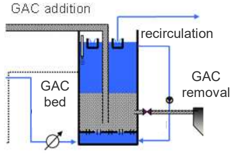
GAC treatment

- no additives necessary
- simple in operation and maintenance
- existing sand filters could be converted to GAC filters
- GAC can be regenerated and reused (lower CO_2 footprint)
- Retention of suspended solids (GAC filters)



Granular activated carbon filters (0.6-2.4 mm):
tested in different projects, no full scale application yet in Switzerland
- implication of lower elimination at rain events
- Dimensioning unclear (EBCT > 20 min. recommended)
- economic efficiency unclear (AC dose can be similar as PAC)

GAC in moving bed:



Granular activated carbon in a moving bed:
- Smaller particle size compared to GAC (0.2-0.9 mm, µ-GAC)
- batch dosing (~2 gGAC/gDOC) every day

Combined treatment

ozonation + GAC:
in operation in WWTP Altenrhein (since Sept. 2019):
- Pre-ozonation with 0.15-0.3 gO_3/gDOC
- 8 parallel GAC filters
- GAC Filter height 1.8 m
- Average EBCT GAC 20 min

Results pilot scale studies:
A low specific ozone dose (0.2 gO_3/gDOC) as pre-treatment resulted in lifetime of GAC more than 2x longer than pure GAC filter

ozonation + PAC:
tested in WWTP Pro Rheno

WWTP Altenrhein
www.ava-altenrhein.ch

Publications on GAC pilot scale studies

GAK-FILTER FÜR DIE SPURENSTOFFENTFERNUNG
ERFAHRUNGEN UND BETRIEBSERGEBNISSE DER PILOTSTUDIEN ARA FURT/BÜLACH UND GLARNERLAND

AQUA & GAS 48/ No. 1 (2022)

In German only!

Plattform „Verfahrenstechnik Mikroverunreinigungen"
Eawag: Das Wasserforschungsinstitut des ETH-Bereichs

Konsenspapier
zum Ergebnis des Workshops vom 9.12.2019 an der Eawag

Hinweise zur Planung und Auslegung
von diskontinuierlich gespülten GAK-Filtern zur Elimination organischer Spurenstoffe aus kommunalem Abwasser

Dieses Dokument fasst den aktuellen Wissensstand basierend auf den Ergebnissen des Workshops zur granulierten Aktivkohlefiltration vom 9.12.19 zusammen. Es kann bei Bedarf mit neuen Erkenntnissen ergänzt werden. Die Autoren erheben keinen Anspruch auf Vollständigkeit.

Schlussbericht

Elimination von Spurenstoffen durch granulierte Aktivkohle-Filtration (GAK)
Grosstechnische Untersuchungen auf der ARA Furt, Bülach

SCHLUSSBERICHT

Pilotversuche zur erweiterten Abwasserbehandlung mit granulierter Aktivkohle (GAK) und kombiniert mit Teilozonung (O_3/GAK) auf der ARA Glarnerland (AVG)

Ergänzende Untersuchungen zur PAK-Dosierung in die biologische Stufe mit S::Select®-Verfahren in Kombination mit nachfolgender GAK

www.eawag.ch>Bibliothek and www.micropoll.ch

CO_2 footprint

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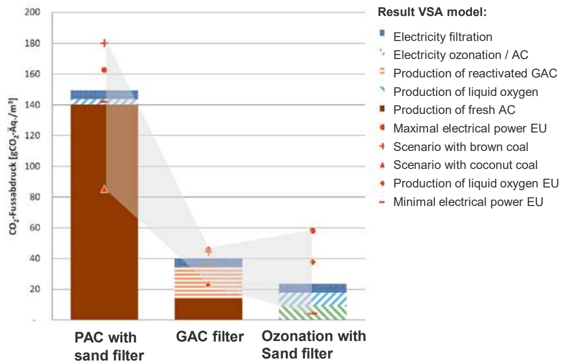
Study of CO_2 footprint of **operating resources** (account for 80% of greenhouse gas emissions (Jekel et al. 2015)



- Large variations depending on the type of activated carbon and electricity mix
- GAC 3x lower than PAC due to regeneration of AC
- Ozonation 2x lower than GAC
- Sustainable AC reduces CO_2 footprint by 40%

➢ CO_2 footprint can be included as a criterion in the choice of technology

Meier and Remy (2020) A&G 2, 26-35
https://micropoll.ch/publikationen

Technologies in comparison

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Technology	Advantages	dissadvantages	Optimal proconditions
Ozonation	High experience, low costs, low space, low CO_2 footprint	Reaction products	Low industry
PAC: Ulmer technology	Low PAC consumption, high experience, Co-occurring DOC removal	High space, higher CO_2 footprint than O_3	Space available
PAC onto sand filter	Low space	PAC consumption little higher than in Ulmer technology, low experience	Little space available
PAC directly into biology	Low space	PAC consumption higher than in Ulmer technology, low experience	Little space available, high reserve in biology
GAC	May be filled into existing filters, can be regenerated (lower CO_2 footprint than PAC)	Low experience, dimensioning questions	Pre-existing sand filters

Elimination of MPs in WWTP Neugut

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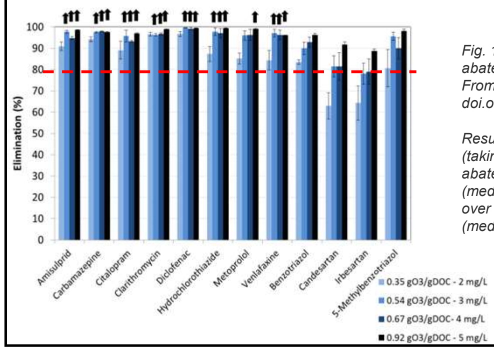
80% elimination of indicator substances:
Ozone dose 2.0-3.3 mg/L (0.55 gO_3/gDOC)



Eawag LC/MS/MS screening:
n=550, including metabolites
(0.55 gO_3/gDOC, two 48h-samples)

Fig. 1. Box-whisker plot depicting the distribution of calculated abatements for all substances during all treatment steps. From: Bourgin et al. (2018) Wat. Res. 129, 486-498 doi.org/10.1016/j.watres.2017.10.036

Result: the average abatement of all substances (taking a zero abatement for all substances with negative abatement into account) over the biological treatment is 34% (median 22%), during ozonation >67% (median >74%), and over the whole WWTP, with and without sand filter, >79% (median >89%).

Bourgin et al. (2018)
Wat. Res. 129, 486-498

Effluent concentrations at WWTP Neugut

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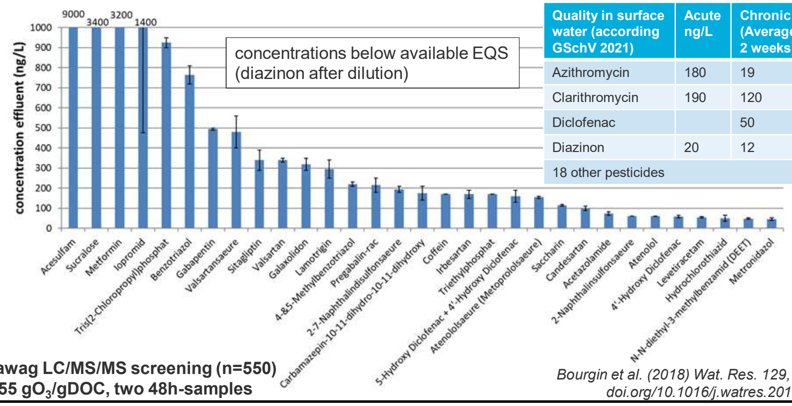

Quality in surface water (according GSchV 2021)	Acute ng/L	Chronic (ng/L) (Average over 2 weeks)
Azithromycin	180	19
Clarithromycin	190	120
Diclofenac		50
Diazinon	20	12
18 other pesticides		

Eawag LC/MS/MS screening (n=550)
0.55 gO_3/gDOC, two 48h-samples

Bourgin et al. (2018) Wat. Res. 129, 486-498
doi.org/10.1016/j.watres.2017.10.036

Clarithromycin: before/after upgrade

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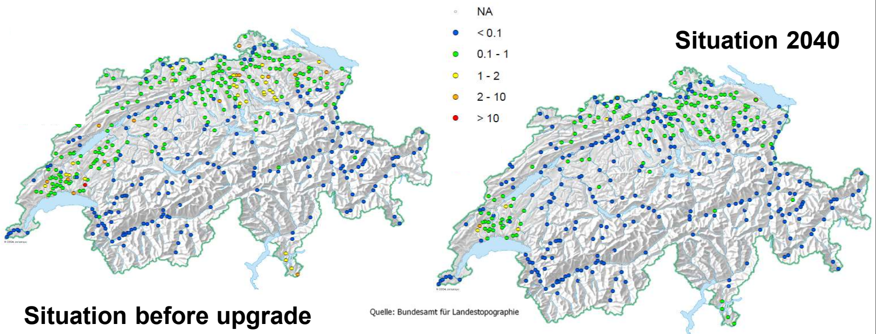
Modeling by Envilab/BAFU (Worst case Q347):
Concentration in rivers relative to environmental quality criteria: 120 ng/L



Situation 2040

Situation before upgrade

OTP formation and their fate in post-treatment

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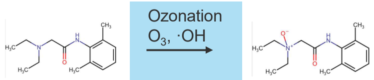
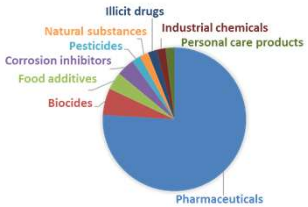
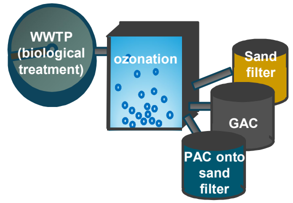


87 abundant micropollutants

Ozonation transformation product (OTP)





WWTP Neugut

WWTP Glarnerland & Altenrhein (GAC with different bed volumes)

WWTP ProRheno (13 mg/L PAC)

Gulde (2021) Wat. Res. 200, 117200
https://doi.org/10.1016/j.watres.2021.117200

Fate of OTPs during post-treatment

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85 OTPs of 40 different parents found

Fig. 4. Relative fate of OTPs in different post-treatment processes, assigned according to their relative signal reduction to three categories: abatement (> 50%), stable (between 50% and -50%), and formation (< -50%).
From: Gulde (2021) Wat. Res. 200, 117200
https://doi.org/10.1016/j.watres.2021.117200
Open access

- Poor abatement in biological post-treatment
- GAC: elimination of OTPs decreases with increasing BV, but still relatively high at 48'000 BV (20 month run time)
- PAC: best abatement of OTPs

Gulde (2021) Wat. Res. 200, 117200
https://doi.org/10.1016/j.watres.2021.117200

Ecological effect: EcoImpact project

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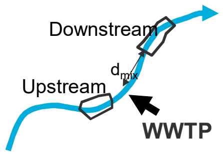
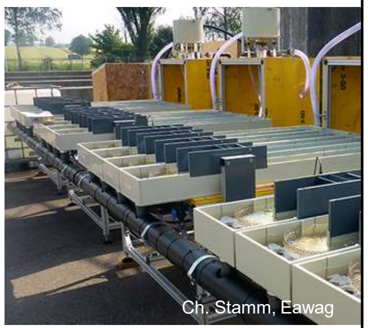
- Project of Eawag and Ecotox-Centre, started in 2013
- Aim: unraveling the ecological impact of micropollutants in streams

Flumes (Maiandros)



https://www.eawag.ch/en/research/water-for-ecosystem/pollutants/ecoimpact



Field surveys

Impact on Ecosystem

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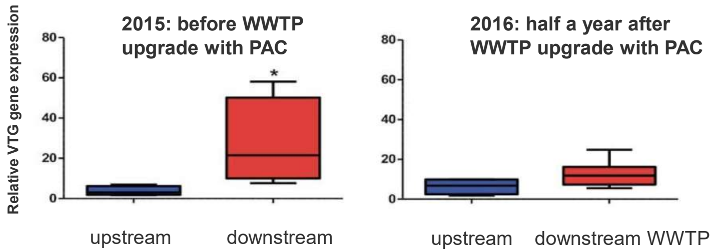
- Vitellogenin gene expression in male fish cells as indicator for estrogenic activity



Zöllig et al. (2017) A&G Nr. 1, 14-23
https://micropoll.ch/Mediathek/pak-stufe-ara-herisau

- Strong relationship between contamination levels and microbial-induced tolerance to pollutants (PICT)

Tlili et al. (2017) Wat. Res. 111, 185-194
Tlili et al. (2020) ES&T 54, 17

Conclusions

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- An efficient and cost- effective elimination of micropollutants can be achieved with ozonation or sorption to activated carbon (PAC addition or GAC-filter)
- The combination O_3/GAC and O_3/PAC are interesting alternatives
- Cost increase for wastewater treatment is only about 10-15%
- A biological post-treatment after ozonation and PAC treatment is needed
- feasibility of ozonation needs to be tested (30’000 - 40’000 CHF):
  - Problematic by-products (NDMA, bromate)
  - Toxicity evaluation of by-products with bioassays
- Elucidation of ozonation transformation products is time intensive and known OTPs are often non biodegradable (OTPs need further attention)
- Ecological impact in streams after WWTP upgrade was observed in the EcoImpact project