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Safer Advanced Wastewater Treatment Plants

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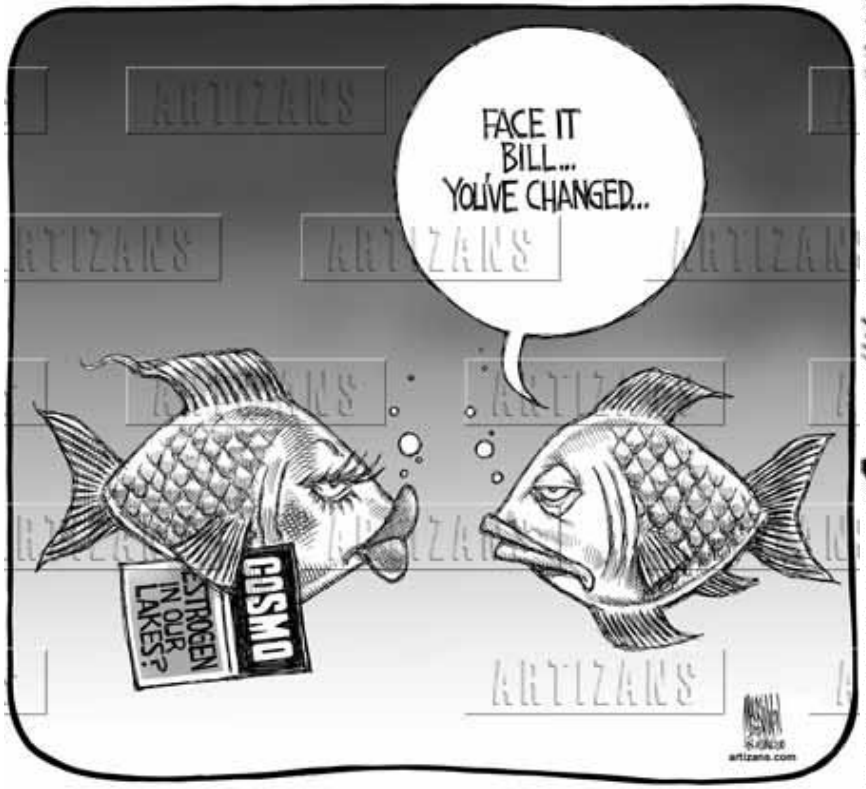
Safer Advanced WWTPs ➲ content

- Introduction
  - What is advanced WWTPs & why do we bother?
- Materials and Methods
  - “Safer advanced” WWTP demonstrator
  - How to assess if advanced WWTPs are “safer”
- Results
- Wrap up & conclusions

Intro ➲ advanced WWTPs & why bother

- Emerging pollutants
  ➲ ubiquitous in water



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Intro ➲ why bother about advanced WWTPs

- WWTPs ➲ major entry pathway for certain EPs
- Impact on human & environmental health?
  - Hot topic for current issue ➲ REUSE
- Two parallel & interconnected approaches
  - High efforts to reduce emissions of emerging pollutants:
    ➲ advanced WWT (discussed & implemented)
  - High efforts to study impact (environment & WWTP):
    ➲ chemical & biological criteria

Intro ➲ why SAFER advanced WWTPs

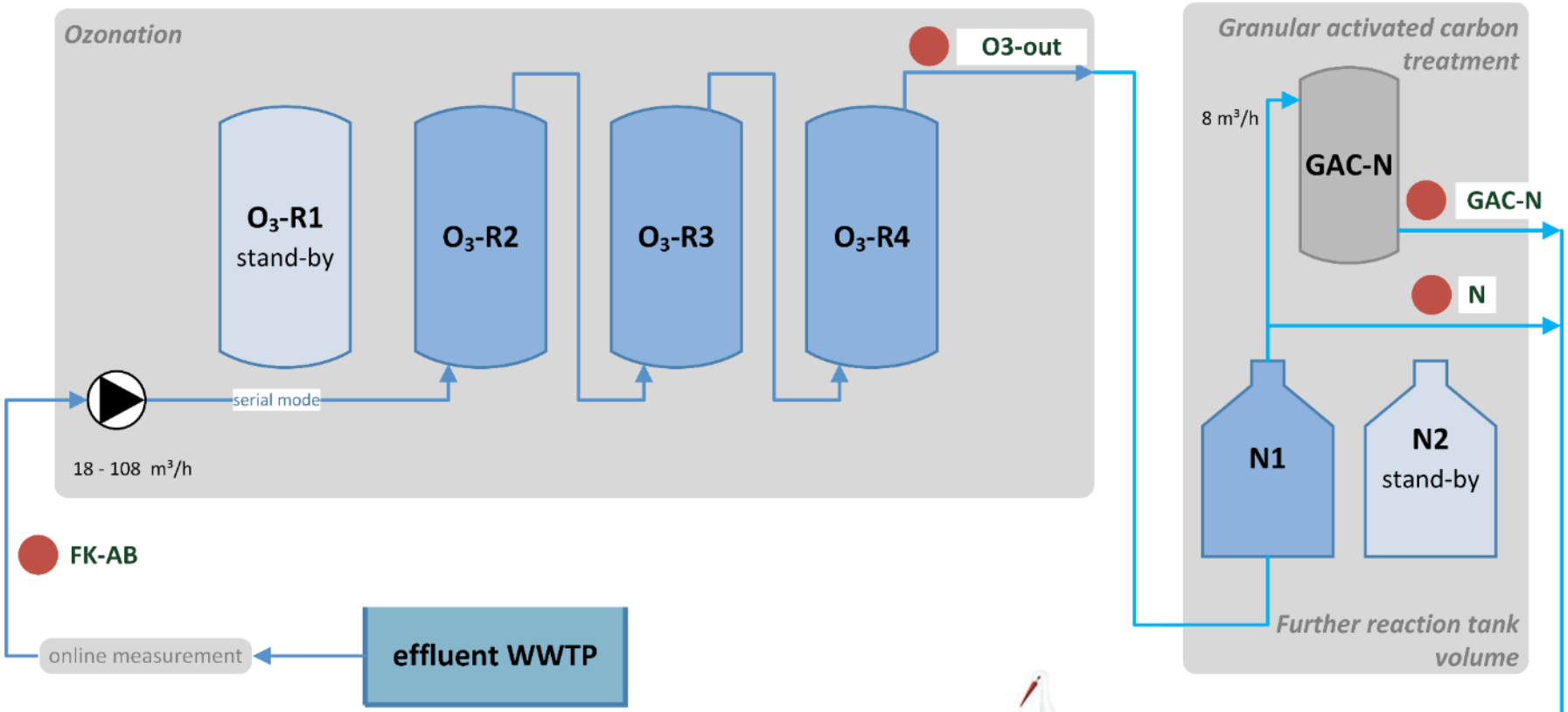
- advanced WWT ➲ ozonation & PAC/GAC treatment
  - Both technologies have their strengths, but also limitations
  - AND neither technology results in a “zero-EP-emission”
- multi-barrier concept for safer advanced WWTPs!!
  - Ozonation as first treatment step
  - Granular activated carbon as second treatment step
  - Bioassays ➲ crucial aspect for evaluation
    ➲ specific endpoints & mixture toxicity

Motivation for ongoing research project

- Currently groundwater as receiving water body for treated WW (low loaded nutrient removing WWTP)
  - ➲ "Aquifer recharge"
  - ➲ Now: UV-disinfection as additional treatment implemented
- Higher capacity for biological treatment needed
- Upgrade WWTP with advanced treatment?

➲ Is the process combination of O_3 & GAC (= assessed in previous project) the right choice for SAFER advanced WWT under the specific local conditions?

Plant scheme ➲ demonstrator plant

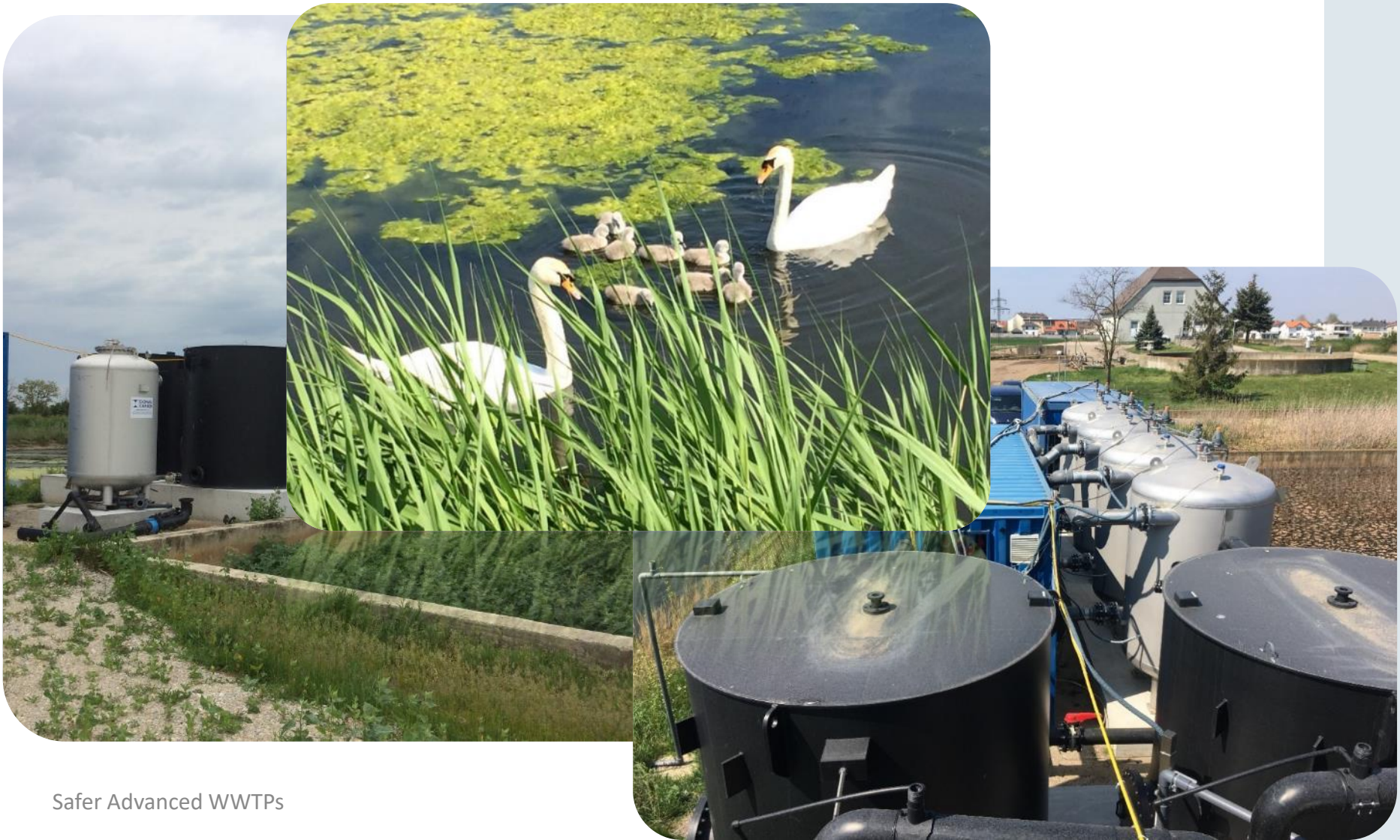


DOC mg/L	NH_4-N mg/L	NO_3-N mg/L	NO_2-N mg/L
4.1 ± 0.7	0.1 ± 0.1	0.75 ± 0.52	0.05 ± 0.04

SAFER advanced WWTP demonstrator

- Ozonation
  - designed for dry weather flow
  - 18-108 m^3/h ➲ HRT: 7-40 min
  - Applied specific O_3 dose: 0.4-0.7 g O_3/g DOC
  - O_3-transfer ➲ injectors
- GAC
  - 1 filter unit (pressure vessel)
  - 8 m^3/h ➲ HRT: 15 min

Safer advanced WWTP demonstrator



Sampling program

- Chemical analyses
  - Conventional WW parameters
  - 10 indicator substances (CBZ, DCF, SMX, BT, Ace etc.)
- Microbiological analyses
  - bacterial parameters and protozoa
  - antibiotic resistance
- Toxicological assessment ➲ in vitro bioassays
  - test battery of **Calux®** assays (SPE-extracts)
  - REACH test battery (COMET, Ames)

Interpretation of CALUX-results

➲ Two approaches

- Comparison of results before and after advanced wastewater treatment process steps
  ("net reduction or increase of effects")

- Comparison of results with effect-based trigger values (EBTs)

Selection of CALUX tests

- Assessment of 12 WWTPs by CALUX in the frame of the Joint Danube Survey
- Qualitative CALUX-results

< EBT | 1-3 x EBT | 3-10 x EBT | >10 x EBT

WWTP	ERα	anti-AR	GR	PPARγ	PAH	Nrf2	PXR
1	>10 x EBT	1-3 x EBT	< EBT	1-3 x EBT	>10 x EBT	1-3 x EBT	1-3 x EBT
2	3-10 x EBT	3-10 x EBT	< EBT	< EBT	>10 x EBT	1-3 x EBT	3-10 x EBT
3	< EBT	3-10 x EBT	1-3 x EBT	< EBT	3-10 x EBT	< EBT	1-3 x EBT
4	3-10 x EBT	3-10 x EBT	1-3 x EBT	< EBT	>10 x EBT	1-3 x EBT	3-10 x EBT
5	1-3 x EBT	3-10 x EBT	< EBT	< EBT	>10 x EBT	3-10 x EBT	>10 x EBT
6	1-3 x EBT	3-10 x EBT	< EBT	< EBT	>10 x EBT	1-3 x EBT	3-10 x EBT
7	>10 x EBT	1-3 x EBT	1-3 x EBT	< EBT	>10 x EBT	1-3 x EBT	1-3 x EBT
8	>10 x EBT	1-3 x EBT	1-3 x EBT	< EBT	>10 x EBT	3-10 x EBT	3-10 x EBT
9	3-10 x EBT	1-3 x EBT	1-3 x EBT	< EBT	>10 x EBT	1-3 x EBT	1-3 x EBT
10	3-10 x EBT	3-10 x EBT	< EBT	< EBT	>10 x EBT	1-3 x EBT	1-3 x EBT
11	1-3 x EBT	3-10 x EBT	1-3 x EBT	< EBT	>10 x EBT	3-10 x EBT	3-10 x EBT
12	1-3 x EBT	1-3 x EBT	< EBT	< EBT	3-10 x EBT	1-3 x EBT	3-10 x EBT

Applied Calux bioassay battery

Bioassay	Parameter	Measured endpoint or molecular target
anti-AR	Anti-androgens	Anti-androgenic activity
cytotox	Cell death	Cytotoxic activity
ERa	Estrogens	Activation of estrogen receptor
Nrf2	Nrf2	Induction of oxidative stress response
p53 +/-S9	p53 transcriptional activators	Genotoxic activity +/- metabolic activation
PAH	Polycyclic aromatic hydrocarbons	Activation of aryl hydrocarbon receptor
PXR	Xenobiotic sensing	Activation of pregnane x receptor

Preliminary EBTs (acc. to Escher et al., 2018)*

Calux assays	Reference material	Environmental EBT
anti-AR	Flutamide	14.4 µg BEQ/L
ERa	17β-Estradiol	0.3 ng BEQ/L
Nrf2	Dichlorvos	26 ng BEQ/L
	Curcumin	21 µg BEQ/L
PAH	Benzo[a]pyrene	6.2 ng BEQ/L
PXR	Di(2-ethylhexyl)-phthalate	272 ng BEQ/L
	Nicardipine	54 µg BEQ/L

* EBT for estrogenicity considered mature;

Results ➲ 3 sampling campaigns

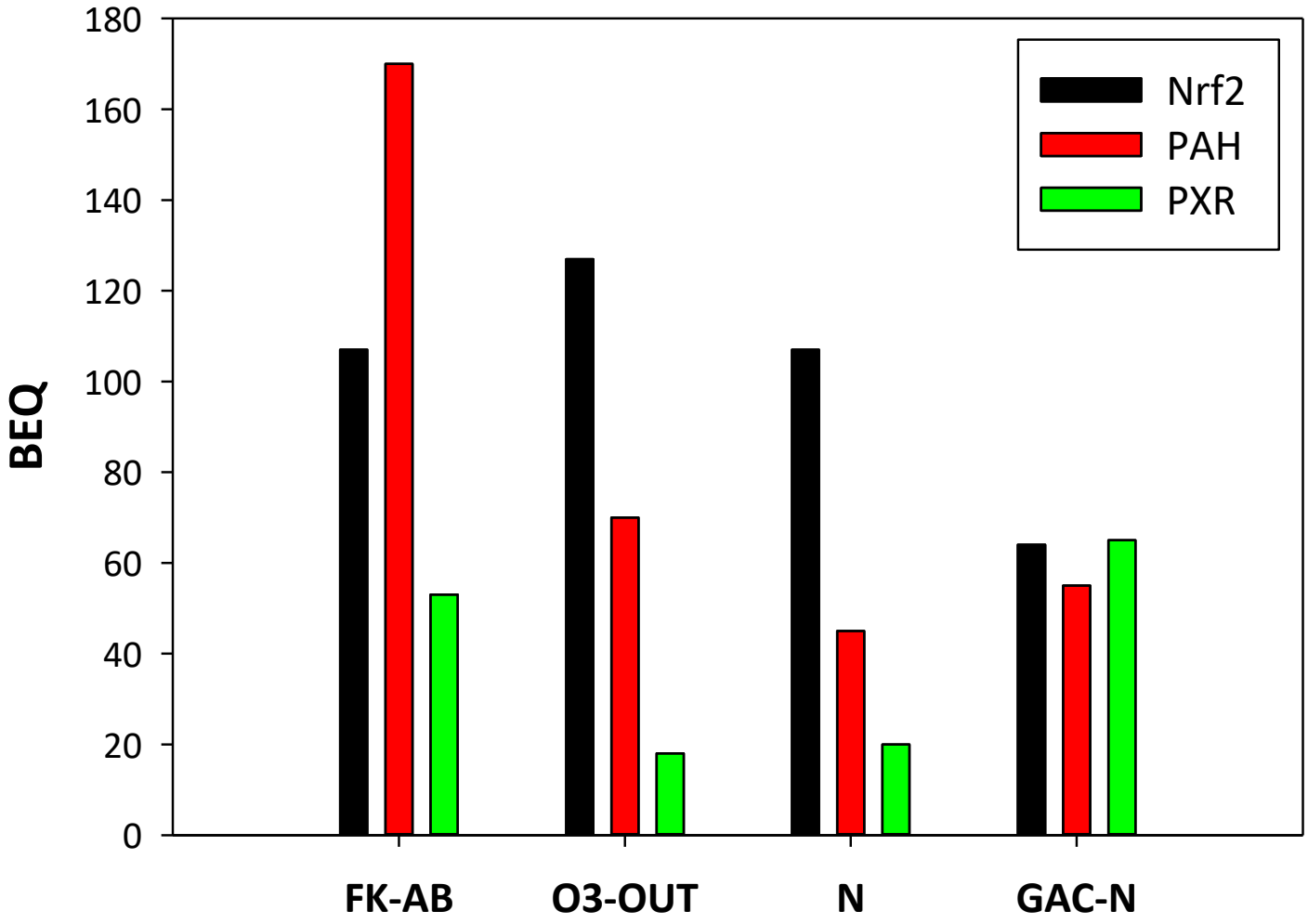
CALUX-Assays	EBT	BEQ				LOQ **			
		FK-AB	O_3-OUT*	N	GAC-N	FK-AB	O_3-OUT	N	GAC-N
Cytotox	n.a.	0.51	0.54	0.64	0.53	0.51	0.54	0.64	0.53
ERa	0.3	0.49	0.07	0.05	0.08	0.04	0.06	0.05	0.05
anti-AR	14.4	6.0	5.3	7.2	5.5	5.3	5.3	7.2	5.5
Nrf2	21	107	127	107	64	*27*	*27*	*27*	*27*
p53	n.a.	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
p53 +S9	n.a.	220	243	300	240	220	243	300	240
PAH	6.2	170	70	45	55	1.0	1.2	1.0	1.0
PXR	54	53	18	20	65	10.2	6.0	6.2	5.9

If BEQ < LOQ → LOQ assumed as result

* ± 0.7 g O_3/g DOC

** average LOQ of single measurements

Results of bioassays > LOQ



Wrap up ➲ before/after WWT steps

- Cytotoxic, anti-androgenic & genotoxic activity < LOQ
- ERa ➲ significant decrease by ozonation (< LOQ)
- Nrf2 ➲ slight increase after ozonation (~20%), but ~40% overall reduction after GAC-filter
- PAH > LOQ➲ significant decrease by advanced WWT
- PXR > LOQ ➲ significant decrease by O_3, GAC ➲ increase for PXR

Wrap up ➲ BEQ vs EBT

- ERa
  - in low loaded WWTP effluent > EBT
  - significant decrease by O_3 < EBT
- anti-AR, PXR < EBT throughout advanced WWT (exception GAC-N vs. PXR)
- Nrf2, PAH >> EBT, even after advanced WWT

Conclusion

- Low loaded WWTPs
  - ➲ an indispensable first step towards safe WWT
- In vitro bioassays
  - ➲ an indispensable tool for toxicity evaluation
  - ➲ added value of whole effluent assessment & considering mixture toxicity
  - ➲ complementary to chemical analysis

Conclusion

- Effect-based trigger values (EBTs)
  ➲ helpful criteria to interpret results
- Low loaded WWTPs
  ➲ some BEQ already low, even < EBTs
- Advanced WWT
  ➲ decrease of BEQ, but not always < EBTs

- **SAFER** advanced WWT ➲ which EBTs to take!?
  ➲ final EBTs needed to give an answer

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