

C1.4 - Environmental risk

TIERED APPROACH FOR ENVIRONMENTAL RISK ASSESSMENT OF EMERGING POLLUTANTS IN AQUATIC SYSTEMS

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ABSTRACT

During the last three decades the presence of emerging pollutants such as pharmaceuticals, personal care products, disinfection by-products and industrial additives in aquatic systems has been the focus of much public concern and also scientific consideration. The continuously increasing contamination of surface and ground-waters with these pollutants is one of the key environmental problems. To solve the water quality problems caused by these hazardous micropollutants a complex and efficient risk management strategy is required.

Hungarian CDFILTER project aimed to develop new cyclodextrin-based sorbents suitable for monitoring bioactive micropollutants and for removal of these pollutants from drinking water and treated wastewater. The most important decision support tool of the CDFILTER research was the risk-based evaluation and management where the river Danube used both as a source of drinking water resource and as a wastewater receiver has been played central role.

As part of the risk management a tiered strategy for environmental risk characterization of micropollutants in aquatic ecosystems has been developed.

Hereby this paper presents the main results of first tier of the tiered strategy, the prioritization approach with the scoring (ranking) system and the CDFILTER Priority List.

Keywords: *cyclodextrin-based sorbent, emerging pollutant, micropollutant, prioritization, priority list, risk management*

INTRODUCTION

The occurrence of organic micropollutants in ground- and surface waters has become an important concern, mainly because of possible related environmental and health effects (Khetan and Collins 2007, Kümmerer 2009, NTP 2008, Pal *et al* 2010, Yoon *et al* 2010).

Numerous studies have been published on the occurrence, fate and effects of emerging pollutants in different parts of the world, including a wide range of sources and aquatic systems (Bendz *et al* 2005, Khan *et al* 2004, Schäfer *et al* 2002, Sedlak *et al* 2005, Smital *et al* 2004). Although most of these chemicals are present at trace concentrations, there has been emerging concern about many micropollutants because of their biological activities adversely impacting aquatic life and human health (Fent *et al* 2006, Ferrari *et al* 2006). Primary effects of these substances are well known, but their long-term effect on the ecosystem and their secondary effects are largely unknown (Crane *et al* 2006, Ferrari *et al* 2006).

So this worldwide growing pollution of surface and ground-waters with a vast number of synthetic or natural organic compounds has been one of the key environmental problems facing civilization recently (Angelakis and Durham 2008, Boyd *et al* 2003, Daughton 2004). The number and frequency of detections of emerging pollutants are increasing and the detectable levels are reducing due to the improving analytical techniques (Daughton 2004).

Water policy has listed some of these emerging compounds as priority hazardous pollutants, but many of them are not listed in official registries (Directive 2011/0429/EC, ICPDR 2003).

The literature shows, that many of these micropollutants survive biodegradation, and finally being discharged into receiving waters, e.g. surface waters (Carballa *et al* 2004, Dlugolecka *et al* 2006, Gomes *et al* 2003, Kahn *et al* 2004, Miege *et al* 2009, Oulton *et al* 2010, Yu-Chen *et al* 2010).

Therefore the environmental and health risk associated with these previously unknown or unrecognized chemicals in the aquatic systems has been a very important concern recently (Carlsson *et al* 2006, Enick and Moore 2007, Webb 2001).

Prioritization models and schemes for emerging contaminants have been developed in order to support decisions in connection with monitoring and risk reduction (Guillén *et al* 2012, Murray *et al* 2010, Sanderson and Thomsen 2009, Stuart *et al* 2012).

Regarding the water quality problem caused by these hazardous micropollutants a complex and efficient risk management system involving risk assessment and risk reduction is necessary. First of all, tools to assess the long-term impact and risk of these pollutants on aquatic ecosystems and human health must be developed or refined and implemented (Koschorrek *et al* 2002, Schwarzenbach *et al* 2006). Secondly, effective waste water treatment technologies are necessary, because conventional techniques do not provide effective elimination of these organic contaminants (Castiglioni *et al* 2006, Oulton *et al* 2010, Schaar *et al* 2010, Schwarzenbach *et al* 2006, Verlicchi 2010).

Addressing these issues the Hungarian CDFILTER project aimed to develop new cyclodextrin-containing sorbents suitable for monitoring bioactive micropollutants and for removal of these pollutants from drinking water and treated wastewater (Gruiz *et al* 2011). The most important decision support tool of the CDFILTER research was the risk-based evaluation and management (Figure 1).

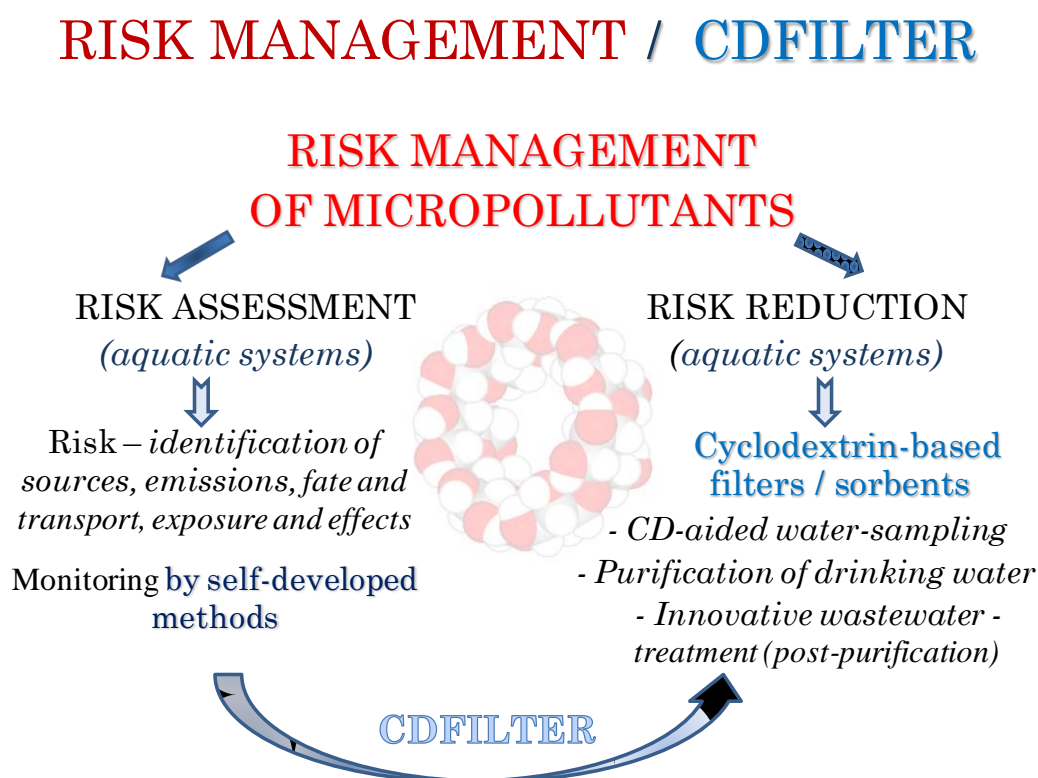


Figure 1. Risk management concept of CDFILTER project for micropollutants in water systems

To focus our research on the large and complex topic as risk assessment and risk reduction of organic micropollutants inventory of chemicals had to be drawn up.

To cope with the vast amount of organic micropollutants occurring in the environment, a priority list of organic micropollutants was worked out and the assessment of removal possibilities with cyclodextrin-based filters have been focused on the high priority chemicals of the list.

The river Danube used both as a source of drinking water resource and as a wastewater receiver has been played central role in the project.

TIERED STRATEGY FOR ENVIRONMENTAL RISK ASSESSMENT OF EMERGING POLLUTANTS

As part of the CDFILTER risk management a three-step tiered strategy for environmental risk characterization of micropollutants in aquatic systems has been developed. This tiered approach provided a systematic way of determining what level of investigation is appropriate for the site of concern, minimising unnecessary investigations, and allowing more efficient risk management tasks.

As the first tier of the tiered strategy, a qualitative risk assessment system was developed and applied. Hereby we present the main results of first tier: the prioritization approach with the scoring (ranking) system and the CDFILTER Priority List.

Emerging pollutants in aquatic systems

The Danube River is one of the most important natural axes in South-East-Europe. From source to mouth, the Danube passes 10 countries, 4 capitals and draws water from 19 nation states. This makes the Danube River Basin the most international one in the World (ICPDR).

The river absorbs raw sewage from cities, pesticides from agriculture as well as chemicals and waste from factories and oil from transport by ships. Numerous industrial factories and plants in oil refining, chemicals, pulp, metallurgy and refining often release pollutants into the many small rivers and tributaries that feed into the Danube River. Inadequately treated waste water often still ends up in the Danube so hazardous and toxic compounds are also a major hazard. Therefore anthropogenic activity has severely affected the Danube ecosystems leading to serious problems with water quality and quantity, and significant reductions in biodiversity (ICPDR).

The river Danube has been played central role in CDFILTER risk management tasks where the river used both as a source of drinking water resource and as a wastewater receiver.

CDFILTER Inventory of micropollutants

Prioritizing of micropollutants in aquatic systems can be carried out in different ways, depending on the selection criteria used. The selection method proposed in our research was developed from the perspective of the surface waters and drinking water quality, related to environmental and human health. Potentially hazardous, risky micropollutants were selected for screening exercise taking into account their occurrence in surface waters, in the river Danube and treated waste waters in Hungary, moreover their production / use volumes. Low removal efficiency in the wastewater treatment was also taken into considerations in set up of micropollutants inventory.

This preliminary list is comprised of about 58 emerging contaminants including pharmaceuticals, industrial compounds, pesticides, nanomaterials, flame retardants and surfactants, personal care products, as well as caffeine and nicotine.

Substance data sheet of emerging pollutants

Detailed substance data sheets were worked out for each chemical, including information about the volume of production, its use, and the physical, chemical, biological properties of the substance. Details of their occurrence and fate in the aquatic ecosystems moreover environmental and human toxicity data were also provided. Data and characteristics of the substances were collected from data bases with environmental aspects and from own measurements. Data sheets of chemicals have been prepared by scientific experts and peer reviewed.

Prioritization approach

The *Tier 1* was intended to be a qualitative screening process.

A comprehensive protocol was developed and set up to determine the rank of substances in the Priority List. Amount of production and consumption, physicochemical data, biodegradability as well as environmental and human health effects were taken into account aiming prioritization.

Prioritization system (Table 1) was developed to serve as a risk management tool in scoring and ranking of chemicals of CDFILTER inventory.

Table 1. Scoring and ranking system for micropollutants in surface waters

PARAMETERS	Ranking classification	SCORE
Production (use)	< 1 kg/year	0
	1–100 kg/year	1
	100–1 000 kg/year	3
	1 t–10 t/year	5
	more than 10 t	10
K_{ow} - Octanol-water partition coefficient	100 000–1 000 000	0
	10 000–100 000	1
	1 000–10 000	2
	100–1 000	3
	10–100	5
	<10	10
Abiotic degradability	readily: t _{1/2} = 0–2 days	0
	moderately: t _{1/2} = 2 days–1 week	1
	t _{1/2} = 1 week–1 month	2
	t _{1/2} = 1 month–1 year	3
	persistent: t _{1/2} = more than 1 year	5
Biodegradability	readily: t _{1/2} = 0–2 days	0
	moderately: t _{1/2} = 2 days–1 week	1
	t _{1/2} = 1 week–1 month	2
	t _{1/2} = 1 month–1 year	3
	persistent: t _{1/2} = more than 1 year	5
Endocrine disrupting effects	no	0
	possibly	3
	yes	5
Immune system disrupting effects	no	0
	possibly	3
	yes	5
Tissue (dermal) lesion	no	0
	possibly	3
	yes	5
Mutagen	no	0
	possibly	3
	yes	5
Carcinogen	no	0
	possibly	3
	yes	5
Reproduction / development effects	no	0
	possibly	3
	yes	5
Lowest acute toxicity data (LC₅₀, EC₅₀)	>100 mg/L	0
	100–10 mg/L	2
	1–10 mg/L	3
	>1 mg/L	5
Lowest chronic toxicity data (ecotoxicological) NOEC/LOEC	>100 mg/L	0
	100–10 mg/L	2
	1–10 mg/L	3
	<1 mg/L	5

Key to the table above:

t_{1/2} Half-life : the time taken for the concentration of the compound in a defined compartment (e.g. soil, water) to decline by 50%

LC₅₀ the concentration of the compound that is lethal to 50% of the test organisms

EC₅₀ the effective concentration of the compound that produces a specific measurable effect in 50% of the test organism

NOEC the no observed effect concentration

LOEC the lowest observed effect concentration

Priority List

Following the first scoring step chemicals were ranked on the base of the calculated risk scores (*Ranking 1*). In the next step the interaction between the selected chemicals and cyclodextrins was also considered in order to obtain efficient risk reduction (*Ranking 2*).

In the *Ranking 2* phase following criteria (CDFILTER score) were taken into account to determine the final composite score of micropollutants in the list:

- complexation with cyclodextrin - the interaction between the selected chemicals and cyclodextrins
- availability of analytical methods for measuring trace concentration of micropollutants in aquatic systems,
- availability of ecotoxicity methods to determine the long term effect of micropollutants for aquatic systems and
- availability of own measured values.

The CDFILTER Priority List with risk score and composite score of chemicals is shown in *Table 2*.

Table 2. CDFILTER Priority List

Ranking 1.	Chemicals	CAS number	Risk score	Composite score*	Ranking 2.
1	nicotine	54-11-5	57	87	1
2	bisphenol A	80-05-7	57	86	2
25	oestradiol	50-28-2	44	75	3
8	carbamazepine	298-46-4	51	73.5	4
30	di(2-ethylhexyl)-phthalate (DEHP)	117-81-7	42	73	5
31	dibutyl-phthalate (DBP)	84-74-2	42	73	6
18	gemfibrozil	25812-30-0	46	71	7
21	cotinine	486-56-6	45	70	8
33	2,6-Di-tert-butylphenol	128-39-2	41	70	9
28	diclofenac	15307-86-5	43	69	10
38	progesterone	57-83-0	40	68	11
43	naproxen	22204-53-1	38	68	12
40	ketoprofen	22071-15-4	39	67	13
53	ibuprofen	15687-27-1	35	67	14
9	doxorubicin	23214-92-8	50	66.5	15
3	sulfamethoxazole	723-46-6	55	66	16
20	simazine	122-34-9	45	65.5	17
5	diuron	330-54-1	52	65	18
11	paracetamol	103-90-2	50	65	19
26	atrazine	1912-24-9	43	65	20
39	fenofibrate	49562-28-9	40	65	21
37	norethisterone/ norethindrone	68-22-4	40	64	22
44	metoprolol	37350-58-6	38	64	23
14	carboplatin	41575-94-4	46	62.5	24
16	pentachlorophenol (PCP)	87-86-5	46	62	25
46	triclosan	3380-34-5	37	62	26
47	2,4-dichlorobenzoic acid	50-84-0	37	62	27
24	ethinyloestradiol	57-63-6	44	61	28
34	trifluralin	1582-09-8	41	61	29
45	caffeine	58-08-2	38	60	30

Ranking 1.	Chemicals	CAS number	Risk score	Composite score*	Ranking 2.
13	verapamil	52-53-9, hydrochloride: 152-11-4	46	59	31
6	nonylphenol	25154-52-3	51	58	32
17	benzothiazole	95-16-9	46	58	33
19	epoxiconazole	135319-73-2	45	58	34
23	bezafibrate	41859-67-0	44	58	35
4	metamizole (sodium salt)	68-89-3	52.5	57.5	36
10	bis(tributyltin) oxide	56-35-9	50	57	37
15	cyproterone	2098-66-0, acetate: 427-51-0	46	57	38
36	daunorubicin	20830-81-3, hydrochloride: 023541-50-6	40	56.5	39
7	urethane/ethyl carbamate	51-79-6	51	56	40
27	isoproturon	34123-59-6	43	56	41
29	simvastatin	79902-63-9	43	56	42
32	chlorpyrifos	2921-88-2	41	56	43
48	medroxyprogesteron	520-85-4, acetate: 71-58-9	37	55	44
12	aminophenazone	58-15-1	48.5	53.5	45
22	2,4-dichlorophenoxyacetic acid (2,4-D)	94-75-7	44	53	46
42	benzotriazole	95-14-7	38	49	47
49	metolachlor	51218-45-2	36	49	48
50	S-metolachlor	87392-12-9	36	49	49
35	phenylbutazone	50-33-9	41	47	50
55	penicillins	penicillin G: 61-33-6, penicillin: 1406-05-9	34	47	51
41	sodium glutamate, glutamic acid	sodium glutamate: 142-47-2, glutamic acid: 56-86-0	39	46	52
54	benfluralin	1861-40-1	34	46	53
56	diflubenzuron	35367-38-5	33	45	54
51	nanoTiO ₂	13463-67-7	36	44	55
57	tris(nonylphenyl) phosphite (TNPP)	26523-78-4	31	43	56
52	taurine	107-35-7	35	40	57
58	propofol	2078-54-8	27.5	32.5	58

*Composite score – The composite score is the sum of the risk score completed with the CDFILTER score

The highest priority pollutants for further risk management task included industrials (BPA, DEHP, DPA), pesticides (diuron) and PPCPs (carbamazepine) because they occur frequently in the freshwater environment and pose environmental and human health risk. Overall, the qualitative predictions are roughly in agreement with literature values.

Further risk management task and results

The prioritized chemicals were assessed in the second tier by a generic quantitative risk assessment methodology. The generic risk quotient (RQ_{generic}) was calculated for selected micropollutants based on generic exposure assessment and effect assessment. The *Predicted Environmental Concentration* (PEC) was determined using European default parameters where the produced/used volume of chemicals was taken into account. The *Predicted No Effect Concentration* (PNEC) was also calculated, that is the concentration of chemicals that causes no adverse effect to the environment. The PEC/PNEC ratio was calculated used as an indicator of risk ($RQ = \text{PEC}/\text{PNEC}$).

The last tier was the site specific risk assessment which gave a more detailed picture on the local risks. In the case of *Site specific Risk Assessment* the PEC/PNEC approach was also applied too, but instead of default values the site specific measured concentrations and site specific environmental parameters were used. Local risk quotient was calculated for the river Danube and treated wastewater discharging surface water bodies in the case of selected micropollutants (Figure 2).



Figure 2. CDFILTER - tiered risk assessment methodology for micropollutants in water

The application of the developed risk assessment methodology during the research resulted in more accurate risk characterisation of the selected micropollutants both in qualitative and quantitative terms. On the basis of the comprehensive risk assessment results and the performed establishing experiments the technology for risk reduction using cyclodextrin sorbents was developed.

In the case of higher priority pollutants such as bisphenol-A and β -estradiol the outstanding risk reduction capability of cyclodextrin filters has been demonstrated.

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