Multiple Objective Treatment Aspects of Bank Filtration

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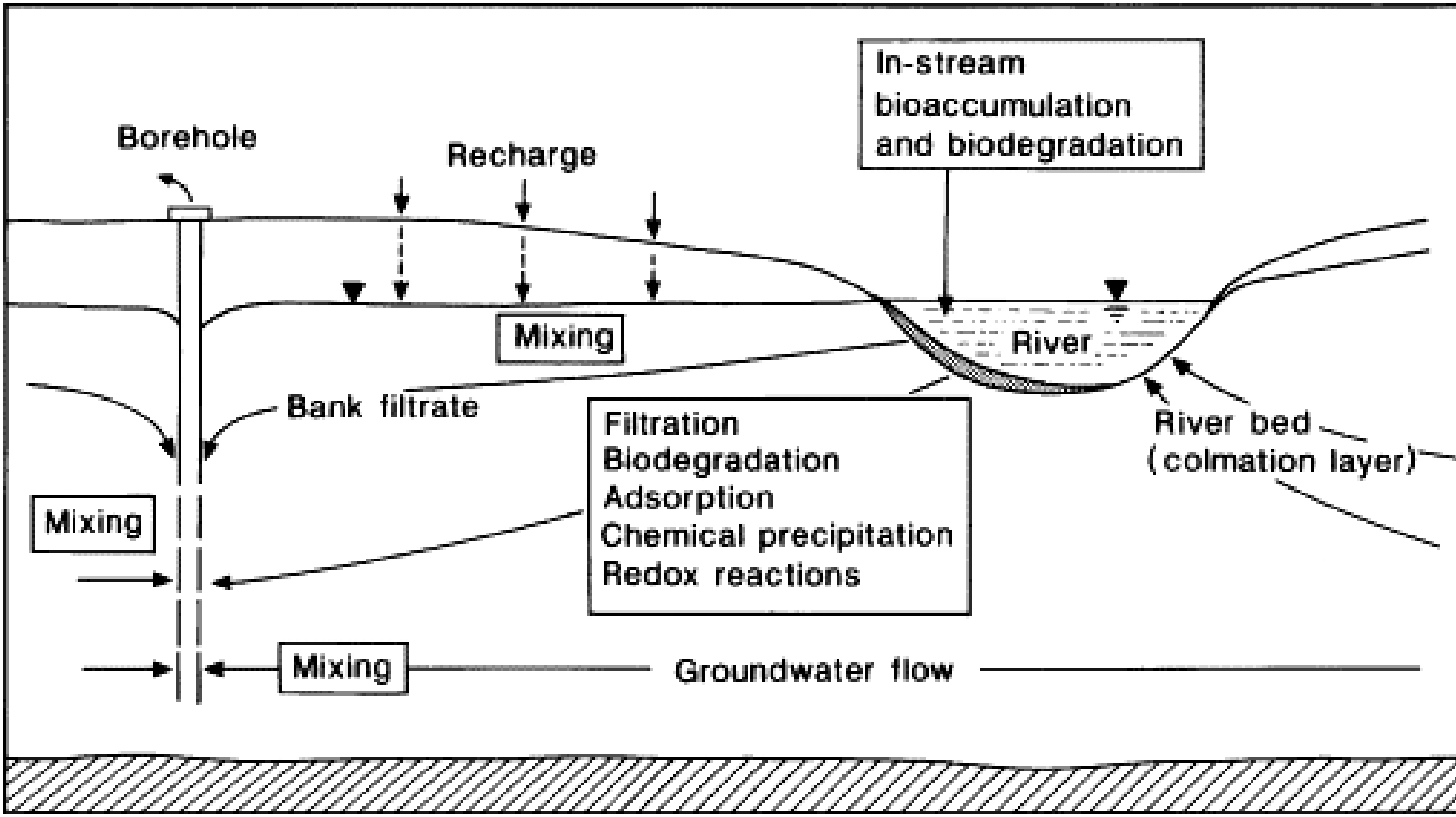
SWITCH
UNESCO-IHE Institute for Water Education

Bank Filtration (Managed Aquifer Recharge)



(Source: Worch, 2004)

Organic Micropollutants (OMPs) in Water

Related terms:

Emerging contaminants, persistent pollutants

and trace organics

- Pharmaceutically Active Compounds (PhACs)
- Personal Care Products (PCPs)
- Endocrine Disrupting Compounds (EDCs)

10 years ago? Development in analytical instruments

PhACs in drinking water ?

<u>March 09, 2008</u>
AP reported that **41 Million Americans** drink water contaminated with antibiotics, anticonvulsants, mood stabilizers and sex hormones

<u>August 08, 2004</u>
UK guardian reported about **Prozac** in the drinking water.

Why OMPs are of concern to water utilities?

- Occurrences of OMPs in water sources are increasing
- Conventional water and wastewater treatment plants are not able to remove them effectively
- Some compounds are suspected to cause serious impacts on aquatic environments
- No guidelines or standards for most of them
- Water recycling and reuse (zero discharge concept) may increase the concentration of OMPs unless remove them during recycling processes
- Effects of many of these contaminants on human health and aquatic environment are not fully understood, but people need to drink (No choice!)

Removal Methods for Organic Micropollutants

- Advanced oxidation processes(e.g., Ozone/UV/H_2O_2)
- Granular activated carbon
- Membrane Filtration (NF/RO)
- **Natural Treatment Systems: Managed Aquifer Recharge**

  - Drinking Water Treatment
    - ♦ **Bank Filtration** (BF) – river or lake
    - ♦ Artificial Recharge (AR)
  - Wastewater Treatment and Reuse
    - ♦ Soil Aquifer Treatment (SAT)

Research objectives

1) To investigate the fate of EDCs (estrogen compounds) and PhACs during BF

2) To analyze removals of selected OMPs with hydrogeochemical conditions and spatial parameters using principal component analysis in order to statistically delineate removal trends at BF and AR sites.

3) To develop a modeling framework for the assessment and prediction of treated water quality from a BF system, especially focusing on OMPs

Methods

I

Laboratory-based soil column and batch studies

- Understand removal mechanisms of OMPs

II

Analysis of field data from BF and AR field sites

- Use PCA to find factors influenced OMP removal
- Develop a screening tool for OMPs for a BF system

III

QSAR (Quantitative Structure Activity Relationship)

•Predict the fate (% removal) of known and unknown compounds based on compound properties

Selected OMPs

Physicochemical properties of selected PhACs and odour compounds

Name	MW (g/mol)	pKa	log Kow	log D (pH=8)	Charge pH=8
Gemfibrozil	250.3	4.7	4.77	2.22	HP-Ionic
Diclofenac	296.2	4.2	4.51	1.59	HL-Ionic
Bezafibrate	361.8	3.6	4.25	0.69	HL-Ionic
Ibuprofen	206.3	4.9	3.97	1.44	HL-Ionic
Fenoprofen	242.3	4.5	3.9	1.11	HL-Ionic
Naproxen	230.3	4.2	3.18	0.05	HL-Ionic
Ketoprofen	254.3	4.5	3.12	0.41	HL-Ionic
Clofibric acid	214.6	3.2	2.88	-1.08	HL-Ionic
Carbamazepine	236.3	n.a.	2.45	2.58	HP-Neutral
Geosmin	182.3	n.a.	3.57	3.27	HP-Neutral
2-MIB	168.3	n.a.	3.31	2.70	HP-Neutral
Phenacetine	179.2	n.a.	1.67	1.68	HL-Neutral
Paracetamol	151.2	n.a.	0.27	0.23	HL-Neutral
Pentoxifylline	278.3	n.a.	0.29	0.48	HL-Neutral
Caffeine	194.2	n.a.	-0.07	-0.45	HL-Neutral

For anionic PhACs, HP: Hydrophobic = log D > 2, HL: Hydrophilic = log D < 1

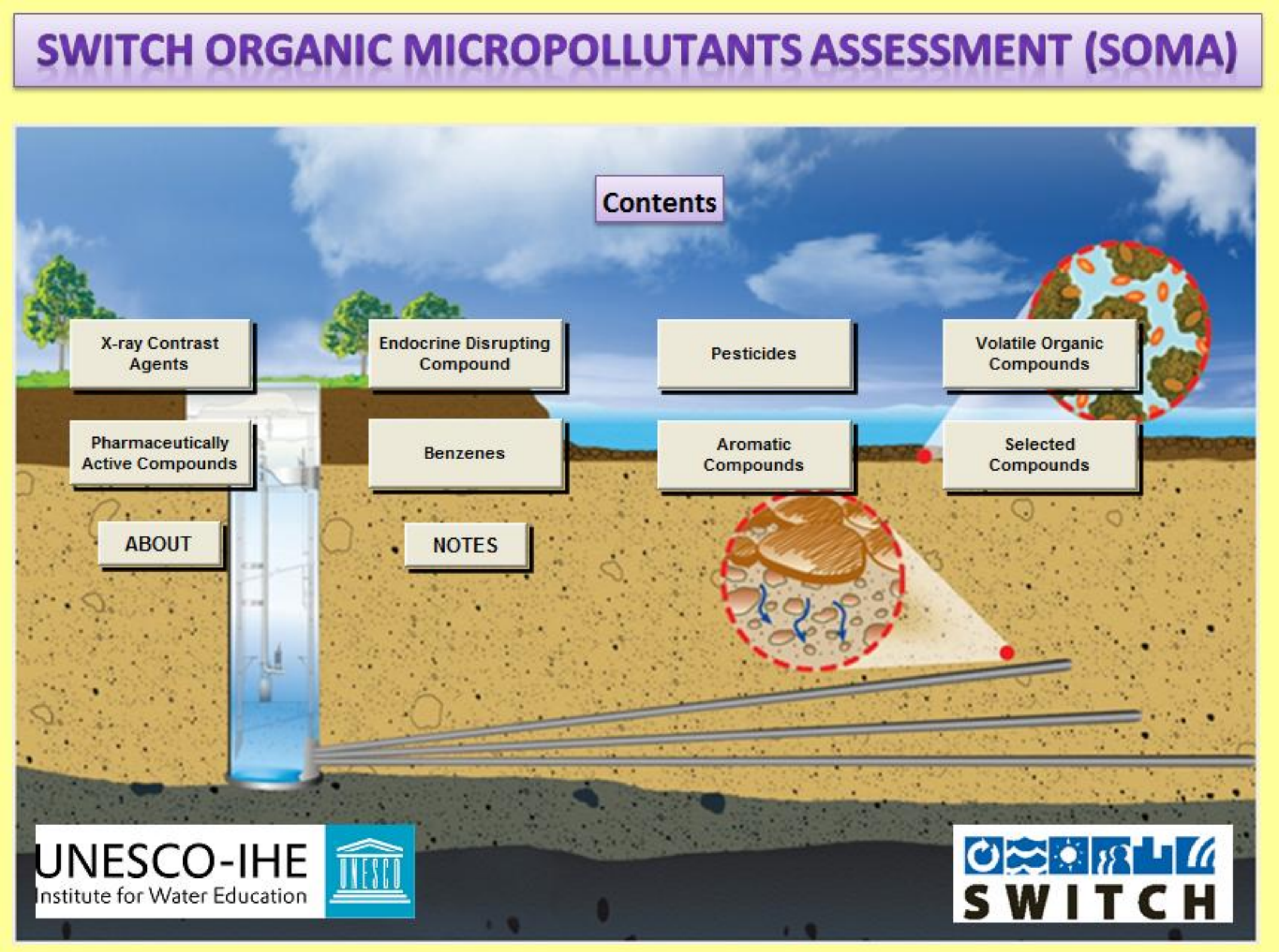
Conclusions - I

- Most of the selected hydrophilic-neutral PhACs and some anionic PhACs exhibited removal efficiencies greater than 90% using different water types (batch study, contact time: 60 days).
- Biodegradation was found to be the important mechanism for anionic PhACs which has high mobility during infiltration.
- Carbamazepine showed a persistent behavior in all water types.
- Removal efficiencies of paracetamol, pentoxifylline, phenacetine and caffeine (hydrophilic-neutral) were significantly reduced under abiotic conditions.
- The removal of carbamazepine, clofibric acid, diclofenac, and gemfibrozil was not influenced by microbial activity (ATP)

Conclusions - II

- PCA analysis is a useful tool to investigate intercorrelations among many variables observed at BF and AR sites and illustrated the dependence between OMP removal and hydrogeochemical conditions
- Due to complexity of hydrogeochemical conditions, SWITCH organic micropollutant assessment (SOMA) based on residence time and travel distance can be used as a screening tool to assess the behavior of OMPs

SWITCH OUTPUTS from Natural Systems for Treatment



SOMA

HOME

Endocrine Disrupting Compounds

Initial Concentration: 3 µg/l

Please enter the Residence time and Distance of well from surface water in cells below

Residence Time: 30 Days

Distance of Well from Surface Water: 30 Metres

See below

Residence Time Output - Removal Efficiency Range: >91 %

Distance Output - Removal Efficiency Range: >91 %

Instructions

Input Required	?
Output/Result	
Instruction	

Input either distance of well from surface water or residence time but **NOT BOTH.**

Limits of Application

These guidelines also apply to complexing agents.
The limits of application of the guidelines proposed are:-

Influent range: 0.0009 - 1000 (µg/l)
Effluent range: 0.0001 - 22.4 (µg/l)
Residence Time: 0 - 32 Days
Distance : 0 - 35 m

To view full guidelines developed click link: Guidelines

SOMA

Proposed Guidelines for the Removal of Pesticides

Influent Range (µg/l)	Effluent Range (µg/l)	Distance (Metres)	Removal Eff. (%)	Residence Time (days)	Removal Eff. (%)
0 - 29,350	0 - 22,860	0-20	20 - 38	0 -10	23 - 67
		20-40	38 - 58	10 - 40	67 - 86
		40-110	58 - 70	40 - 60	>86
		110 - 190	70 - 82		
		190 - 230	82 - 99		

Sources used for Guideline development:
Sites: Sites: Platte River, Illinois River, River Lek, Mohawk River, column experiments, Cedar River, River Elbe, Lake Tegel, Lake Wannsee, River Glatt,

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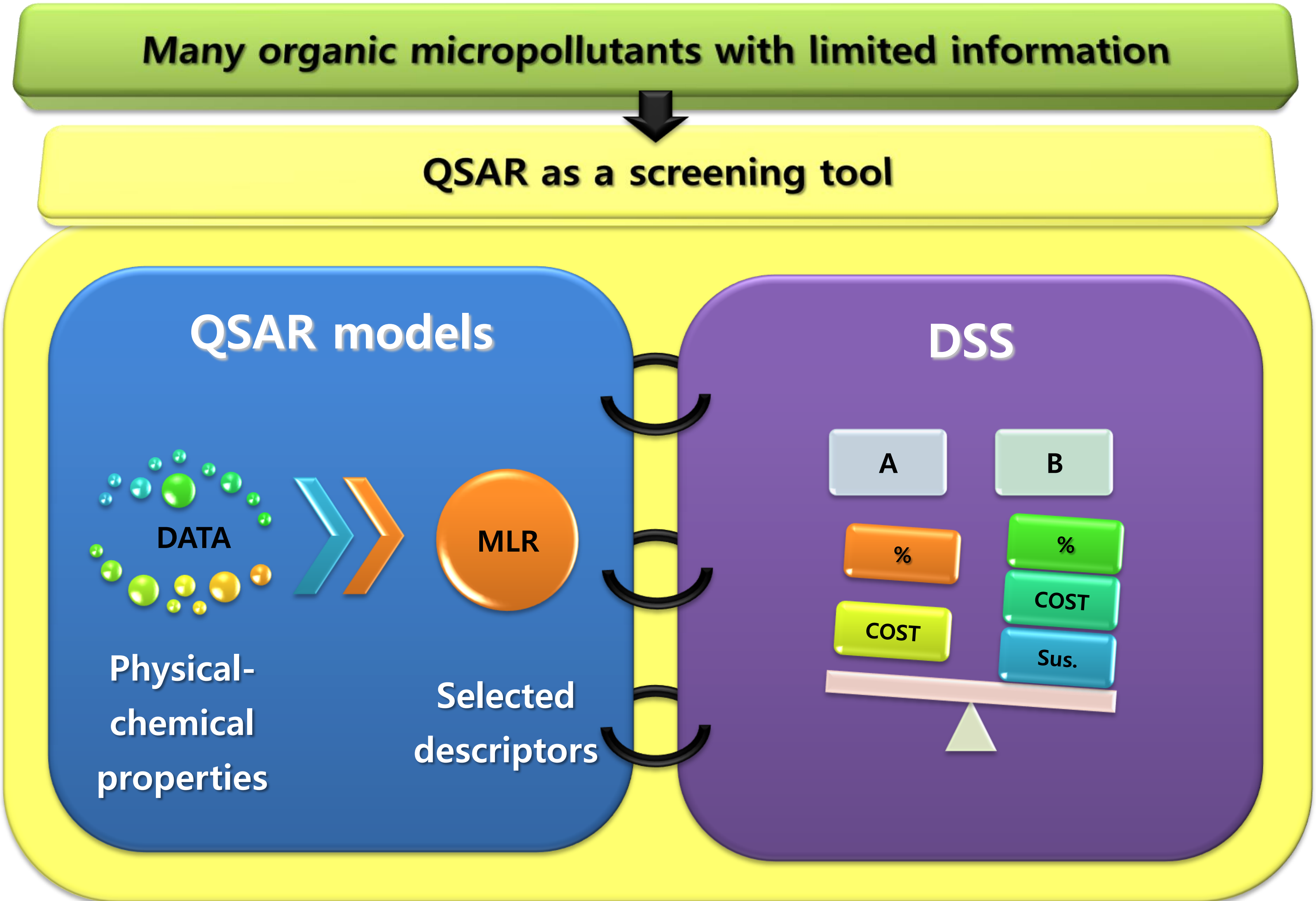
Removal efficiencies of PhACs during BF and ARR

		LOW < 25%	Moderately low 26 - 50%	Relatively high 51-79%	High > 80%	
Antibiotics	Sulfamethoxazole	Rhine A (0-25), Rhine B (0-25)		LaKe Tegel-ARR[1] (53), Elbe (>70)	Lake Wannsee[3] (98), Lake Tegel-LBF[1] (75), Ruhr (>80)	Grünheid et al. (2005) Schmidt et al. (2007) Heberer et al. (2008)
	Acetyl-sulfamethoxazole				Lake Wannsee[3] (>90)	Heberer et al. (2008)
	Clarithromycin			Rhine A (>70), Elbe (>70), Ruhr (>70)	Lake Wannsee[3] (>90)	Schmidt et al. (2007) Heberer et al. (2008)
	Roxithromycin			Ruhr (>70)	Lake Wannsee[3] (>90)	Heberer et al. (2008)
	Trimethoprim				Lake Wannsee[3] (>90), Rhine A (>80), Elbe (>80), Ruhr (>80)	Schmidt et al. (2007) Heberer et al. (2008)
	Clindamycin			Rhine B (>70), Elbe (>70), Ruhr (>70)	Lake Wannsee[3] (>90), Rhine A (>80)	Heberer et al. (2008) Schmidt et al. (2007)
Non-steroidal anti-inflammatory drug (NSAID) and analgesic	Diclofenac			Column 1 (67), Lake Wannsee-well[4] (60),	Rhine A (>80), Rhine B (>80), Elbe (>80), Ruhr (>80), LaKe Tegel-ARR[3] (93), Column 2(>99), Column 3 (>99), Lake Wannsee-well[5] (>80), Lake Wannsee-well[6] (80),	Heberer and Adam (2004) Snyder et al. (2007) Schmidt et al. (2007) Heberer et al. (2004)
	Ibuprofen				Rhine A (>80), Elbe (>80), Ruhr (>80), Column 1 (>99), Column 2(>99), Column 3 (>99)	Schmidt et al. (2007) Snyder et al. (2007)
	Indomethacin			Rhine A (>70), Elbe (>70),	LaKe Tegel-ARR[3] (>95%), Lake Wannsee-well[4] (>99), Lake Wannsee-well[5] (>99), Lake Wannsee-well[6] (>99),	Schmidt et al. (2007) Heberer and Adam (2004) Heberer et al. (2004)
	Naproxen			Elbe (>70), Ruhr (>70)	Rhine A (>80), Column 1 (>98), Column 2 (>98), Column 3 (>98)	Schmidt et al. (2007) Snyder et al. (2007)
	Phenazone	Lake Wannsee[2] (10)		Lake Wannsee[1] (66)	LaKe Tegel-ARR[4] (90)	Massmann et al. (2006) Massmann et al. (2008)
	FAA		Lake Wannsee[2] (36)	Lake Wannsee[1] (72)	Lake Tegel-ARR[4] (89)	Massmann et al. (2006) Massmann et al. (2008)
	AAA		Lake Wannsee[2] (45)		Lake Wannsee[1] (90), LaKe Tegel-ARR[4] (96)	Massmann et al. (2006) Massmann et al. (2008)
	AMDOPH	Lake Wannsee[1] (0), Lake Wannsee[2] (0), LaKe Tegel-ARR[4] (0)				Massmann et al. (2006) Massmann et al. (2008)
	Propyphenazone			LaKe Tegel-ARR[3] (67%), Lake Wannsee-well[5] (79)	LaKe Tegel-ARR[4] (100)	Heberer and Adam (2004) Massmann et al. (2006) (Heberer et al. (2004))
Anti convulsant	Carbamazepine	Rhine A (0-25), Rhine B (0-25), LaKe Tegel-ARR[4] (0), Column 1 (-3), Column 2 (22), Column 3 (13), Lake Tegel-LBF[9] (15), Lake Wannsee[7](10)		Elbe (51-70)	Ruhr (>80)	Massmann et al. (2006) Schmidt et al. (2007) Snyder et al. (2007) Mechlinski and Heberer (2005)
	Dilantin	Column 1 (-11), Column 3 (22)	Column 2 (28)			Snyder et al. (2007)
	Primidone	Tucson (0)	Lake Wannsee-well[4] (33), Lake Wannsee-well[5] (42), LaKe Tegel-ARR[3] (26)		Lake Wannsee-well[5] (83)	Heberer and Adam (2004) Heberer et al. (2004) Drewes et al. (2002)

Removal efficiencies of PhACs during BF and ARR

		LOW < 25%	Moderately low 26 - 50%	Relatively high 51-79%	High > 80%	
Antidepressants	Meprobamate			Column 1 (53), Column 2 (71), Column 3 (74)		Snyder et al. (2007)
	Fluoxetine				Column 1 (>99), Column 2 (>99), Column 3 (>99)	Snyder et al. (2007)
	Diazepam	Column 1 (-8),	Column 2 (42),	Column 2 (65),		Snyder et al. (2007)
Beta blocker	Atenolol				Rhine A (>80), Elbe (>80), Ruhr (>80)	Schmidt et al. (2007)
	Metoprolol,				Rhine A (>80), Rhine B (>80), Elbe (>80), Ruhr (>80)	Schmidt et al. (2007)
	Bisoprolol			Rhine A (>70), Ruhr (>70)		Schmidt et al. (2007)
	Sotalol				Rhine A (>80), Rhine B (>80), Elbe (>80), Ruhr (>80)	Schmidt et al. (2007)
Lipid regulators	Bezafibrate				Rhine A (>80), Rhine B (>80), Elbe (>80), Ruhr (>80), LaKe Tegel-ARR[3] (>97%)	Heberer and Adam (2004) Schmidt et al. (2007)
	Fenofibric acid			Rhine A (>70)		Schmidt et al. (2007)
	Clofibric acid	Lake Tegel-LBF[3](-20), Lake Wannsee-well[4] (-52), Lake Wannsee-well[5] (-48), Lake Wannsee-well[6] (-37)		Rhine B (>70) LaKe Tegel-ARR[3] (75), Lake Tegel-LBF[4](64), Lake Tegel-LBF[5](75), Lake Tegel-LBF[6](71)	Ruhr (>80)	Heberer and Adam (2004) Heberer et al. (2004) Schmidt et al. (2007) Scheytt et al. (2004)
	Gemfibrozil	Column 1 (-3),			Column 1 (>99), Column 2 (>99), Column 3 (>99)	Snyder et al. (2007)
X-ray contrast media	AOI		Lake Tegel-ARR[1] (30)	Lake Tegel-LBF[1] (60), Lake Tegel-LBF[7] (63)		Grünheid et al. (2005) Schittko et al. (2004)
	Iopromide			Column 1 (64), Lake Tegel-LBF[8] (75)	Lake Tegel-LBF[1] (82), Lake Tegel-ARR[1] (89), Rhine A (>80), Rhine B (>80), Elbe (>80), Ruhr (>80), Column 2(93), Column 3 (95), Lake Tegel-LBF[7] (95)	Grünheid et al. (2005) Schmidt et al. (2007) Snyder et al. (2007) Schittko et al. (2004)
	Iopamidol	Rhine A (0-25)	Rhine B (26-50)	Elbe (>70)	Ruhr (>80)	Schmidt et al. (2007)
	Iomeprol				Rhine A (>80), Rhine B (>80), Elbe (>80), Ruhr (>80)	Schmidt et al. (2007)
	Ioxhexol				Rhine A (>80), Rhine B (>80), Elbe (>80), Ruhr (>80)	Schmidt et al. (2007)
Psycho-stimulant	Caffeine				Column 1 (95), Column 2(97), Column 3 (98)	Snyder et al. (2007)
Steroid hormone	Estradiol (E2)				Column 1 (>99), Column 2 (>99), Column 3 (>99), NW2 (>99), NW4(>99), 2U(>99%), 6U(>99%)	Mansell and Drewes (2004) Snyder et al. (2007)
	Estriol (E3)				Column 1 (>99), Column 2 (>99), Column 3 (>99), NW2 (>99), NW4(>99), 2U(>99%), 6U(>99%)	Mansell and Drewes (2004) Snyder et al. (2007)
	Estrone (E1)				Lake Tegel-LBF[2] (>99), Lake Tegel-ARR[2] (>99), Column 1 (>99), Column 2 (>99), Column 3 (>99),	Zuehlke et al. (2004) Snyder et al. (2007)
	Progesterone,				Column 1 (>99), Column 2 (>99), Column 3 (>99)	Snyder et al. (2007)
	Testosterone				Column 1 (>99), Column 2 (>99), Column 3 (>99), NW2 (>99), NW4(>99), 2U(>99%), 6U(>99%)	Mansell and Drewes (2004) Snyder et al. (2007)

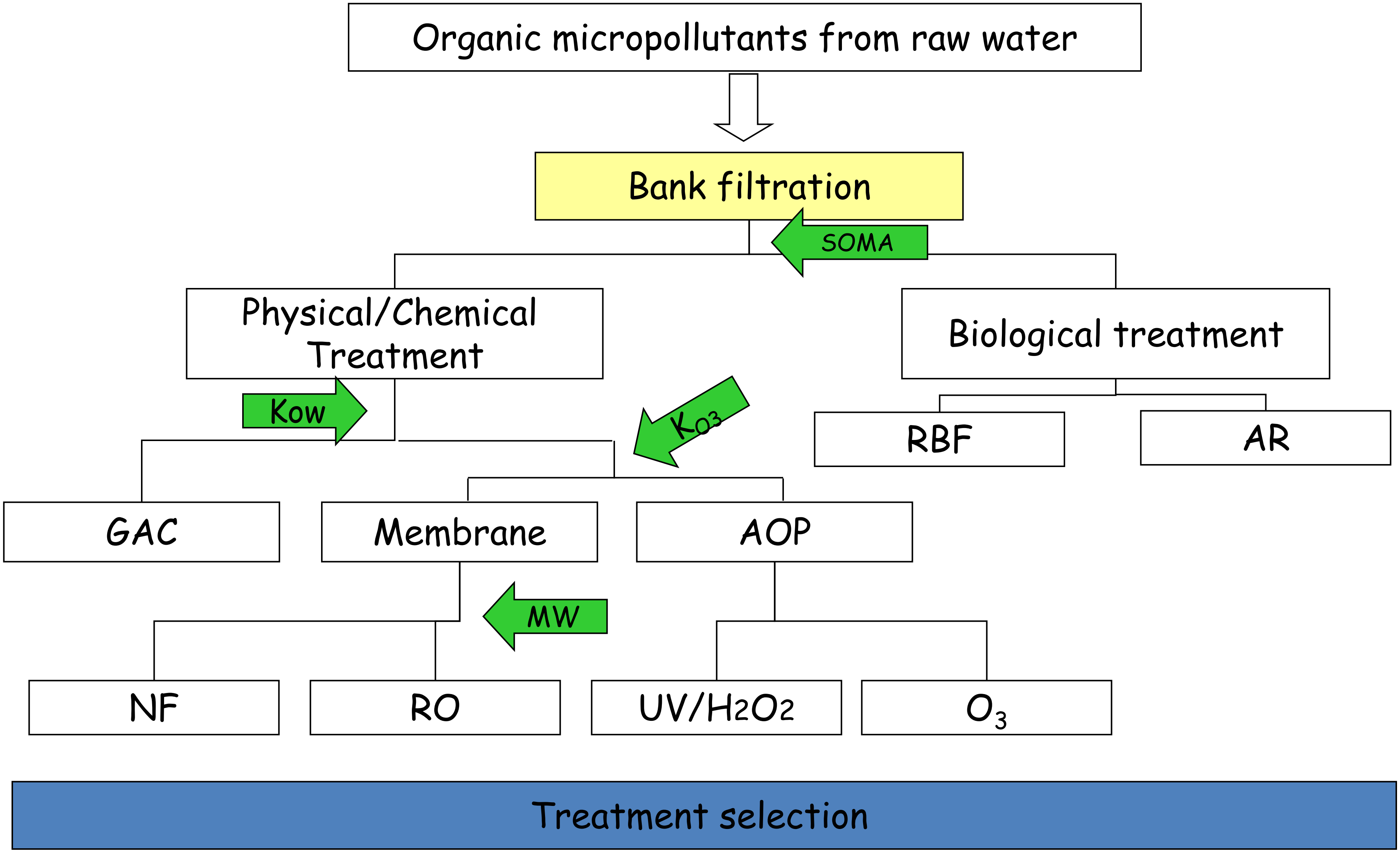
QSAR and Decision support system



Conclusions - III

- The proper selection of the molecular descriptors that define or correlate with different mechanisms taking place during BF is very important to get a representative QSAR model.
- The developed QSAR model can link important physicochemical properties to the removal of OMPs, and the models could be useful to predict the fate of a new compound with limited information during BF.

Assessing process selection using QSAR models



Benefits from DSS based on QSAR models

Emerging contaminants with very limited information

Quick measures from water contaimation

Design a multi-barrier system

Protect drinking water resources

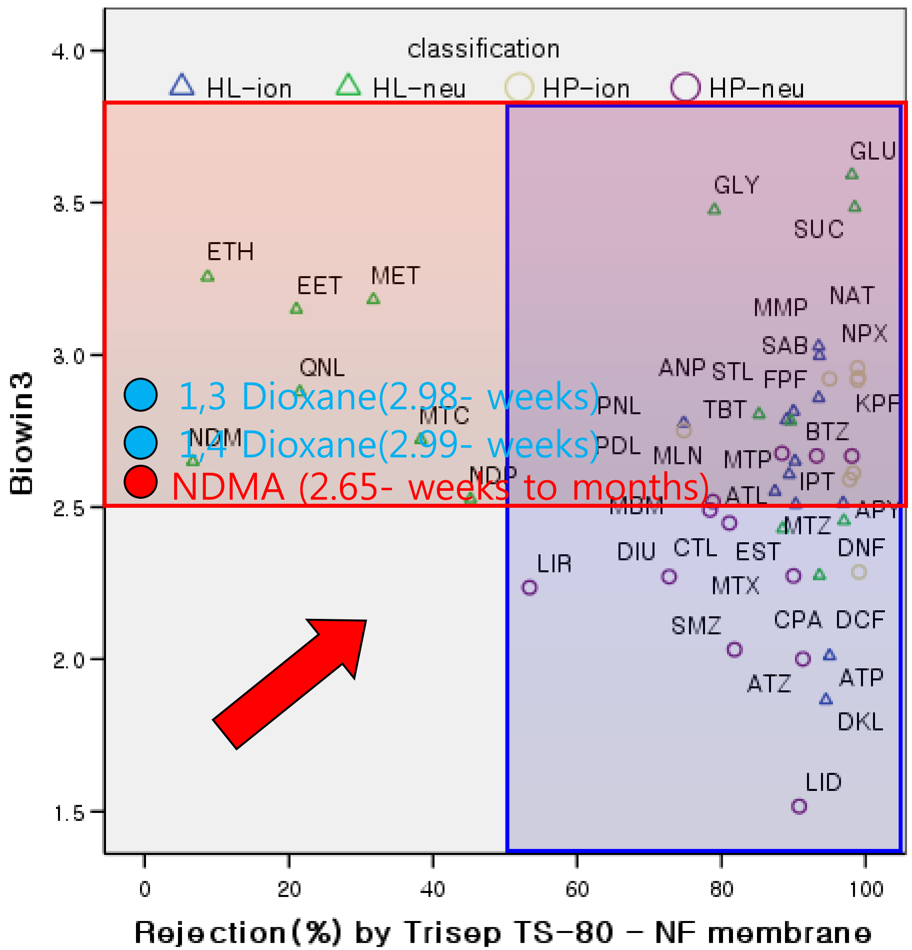
Public confidence

Practical implications of the finding and further research

- BF is an effective barrier in the multi-barrier approach for removing OMPs for safe drinking water supply.
- Most OMPs can be removed during bank filtration, although to varying extents.
- The developed QSAR model can link important physicochemical properties to the removal of OMPs, and the models could be useful to predict the fate of a new compound with limited information during MAR.
- Further research is necessary to investigate the fate of OMPs during soil passage using different types of soil.
- More research should be carried out on the combination of managed aquifer recharge with other advanced water treatment processes (e.g., NF/RO, AOPs and ion exchange systems).

Hybrid System for Removal of OMPS using BF and NF Membrane

BF



Membrane

BIOWIN 3

5.0	hours
4.5	hours - days
4.0	days
3.5	days - weeks
3.0	weeks
2.5	weeks - months
2.0	months
1.0	longer

Publications (2006-2010) supported by SWITCH

Book Chapters: 3

International journals: 5 (published) + 2 (submitted)

International conferences (Full paper): 8

1 Ph.D thesis

5 MSc theses

International referred journals

Maeng, S.K., Sharma, S.K., Amy, G.L., Magic-Knezev, A., 2008. Fate of effluent organic matter (EfOM) and natural organic matter (NOM) through riverbank filtration. Water Science & Technology, 57(12), 1999–2007.

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Sharma S.K., Baghoth, S.A., Maeng, S.K., Salinas Rodríguez, S.G., ... Chapter 3. Natural Organic Matter: Characterization Profiling as ... Process Selection and Performance Monitoring. In "Handbook on ... Processes", A. van Nieuwenhuijzen and J. van der Graaf (eds.), IWA...

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Amy, G.L., Maeng, S.K., Jekel, M., Ernst, M., Villacorte, L.O., Yangali Quintanilla, V., Kim, T.U., Reemtsma, T., 2008. Advanced water/wastewater treatment process selection for organic micropollutant removal: a quantitative structure-activity relationship (QSAR) approach. In: Singapore International Water Week, 23-27, June, 2008, Singapore.

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SWITCH

United Nations Educational, Scientific and Cultural Organization

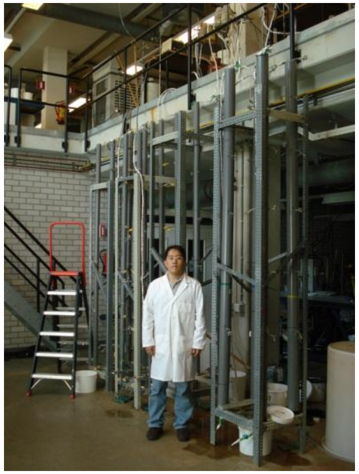
K water 한국수자원공사

HET WATERLABORATORIUM

Thank you

I. **Laboratory-based batch and soil column studies**

- Removal of EDCs
- Removal of PhACs



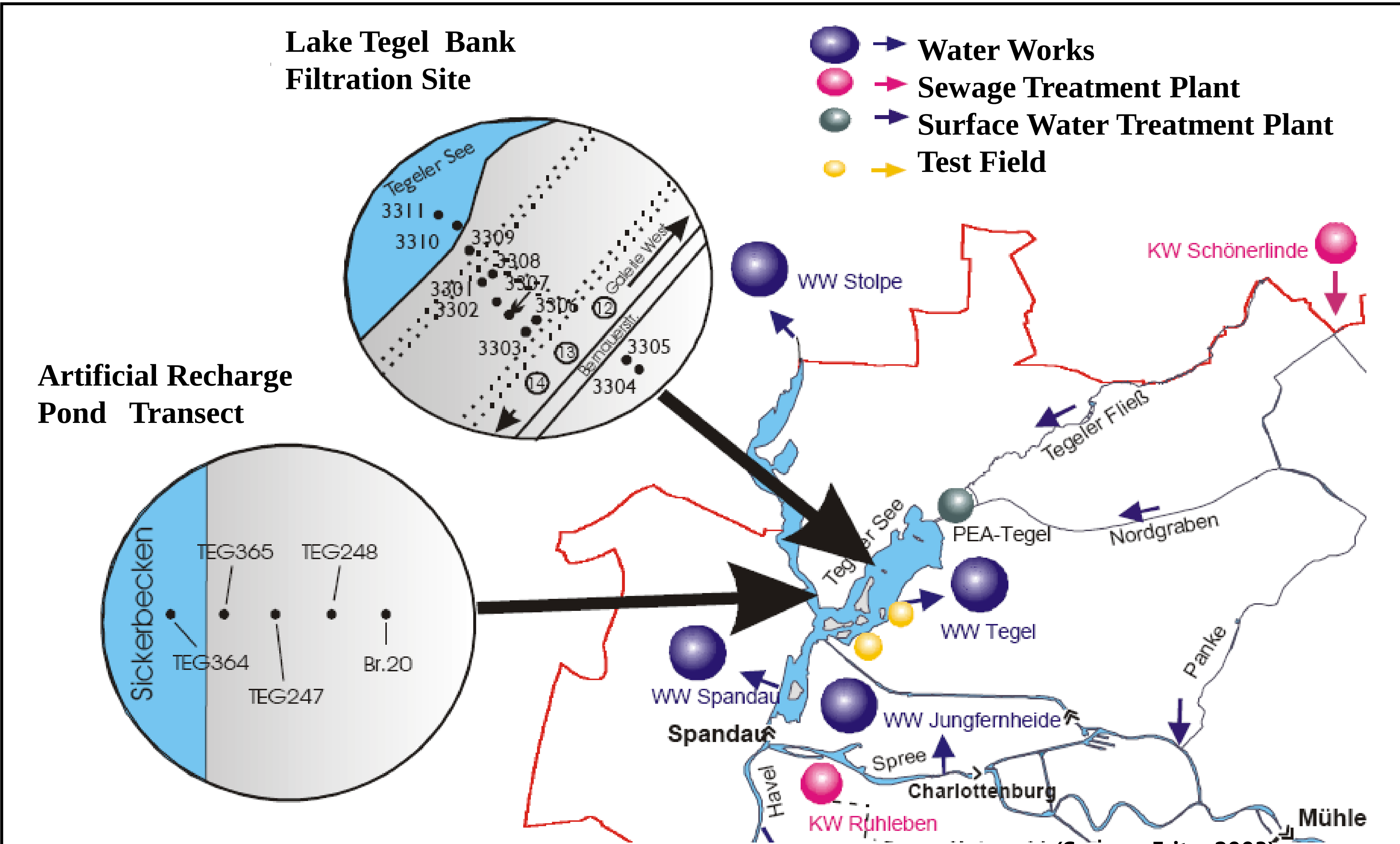
* **Analytical methods**

- ELISA kit and F-EEM for EDCs measurement
- ATP measurement for microbial activity
- PhACs measurement by LC-MS; GC-MS

II. Analysis of field data from BF and SAT field sites

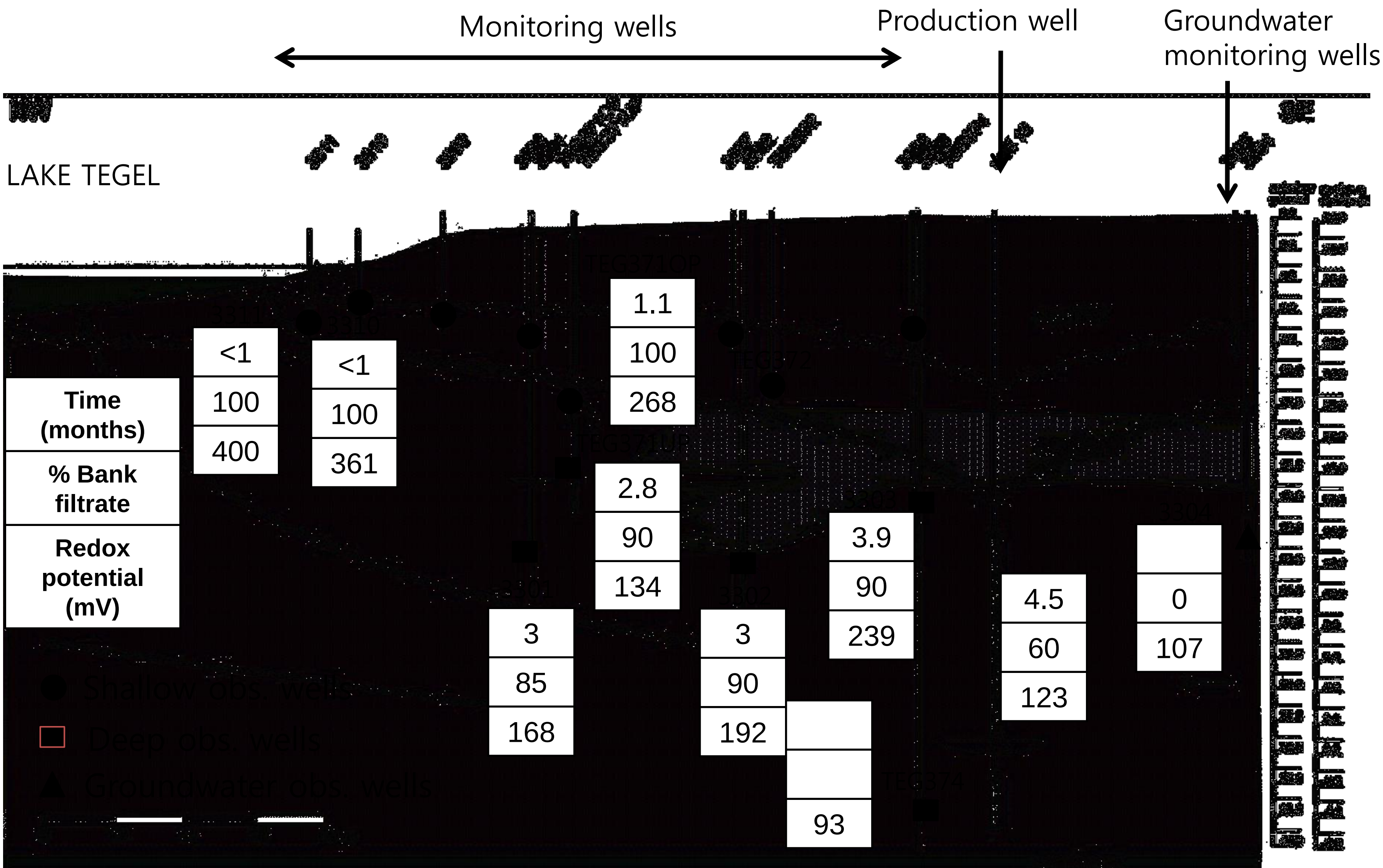
- Investigation of intercorrelations among many variables observed at BF and AR field sites with OMPs using PCA
- Develop a prediction tool for managed aquifer recharge systems to estimate the fate of OMPs with travel distances and residence times

Field sites located in Berlin, Germany (KWB)



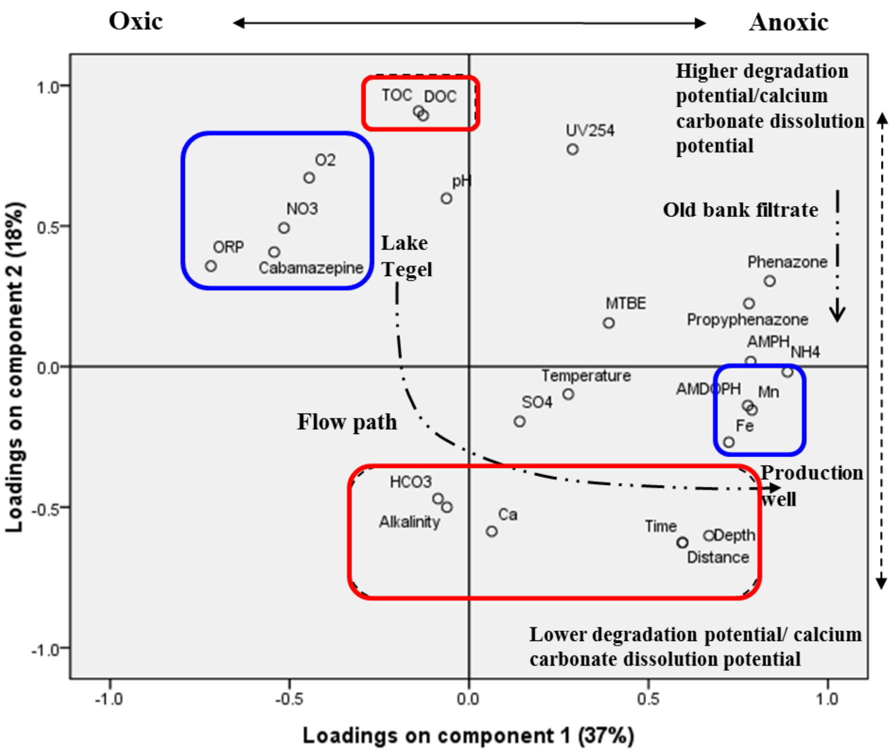
(Source: Fritz, 2003)

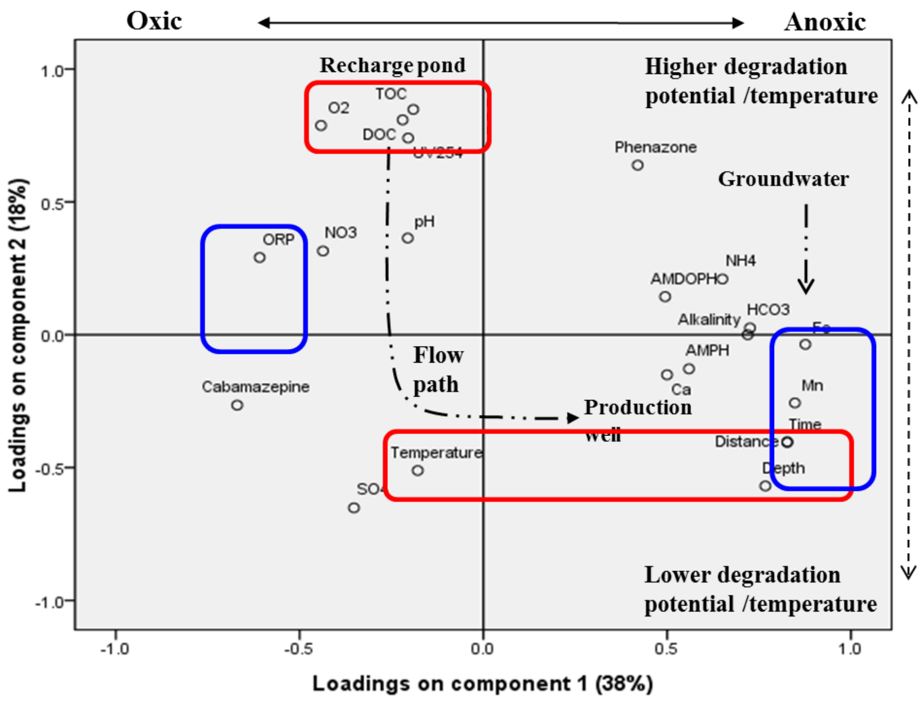
Lake Tegel, KWB, Berlin, Germany



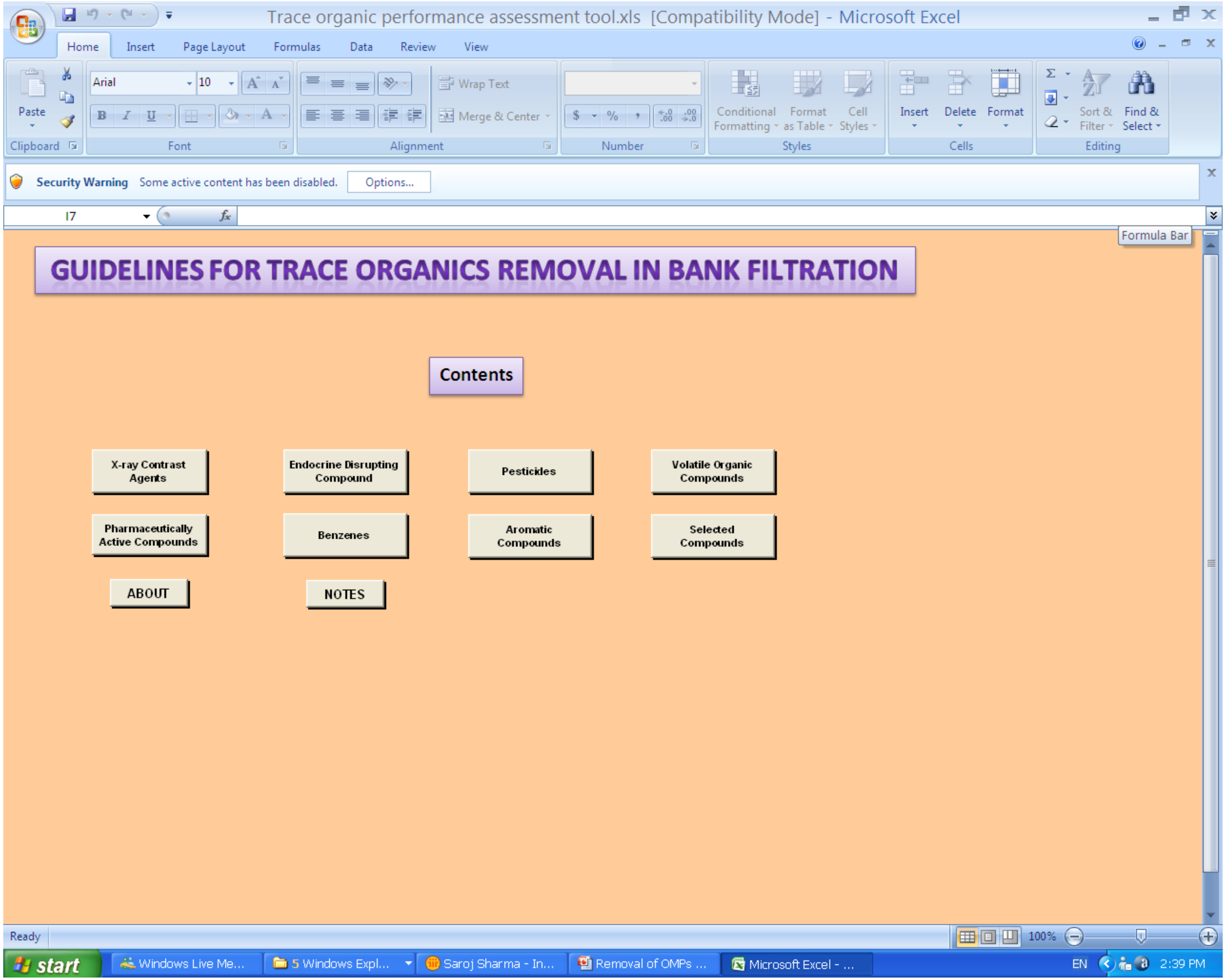
(Modified and adopted from Pekdeger, 2006)

Principal Component Analysis

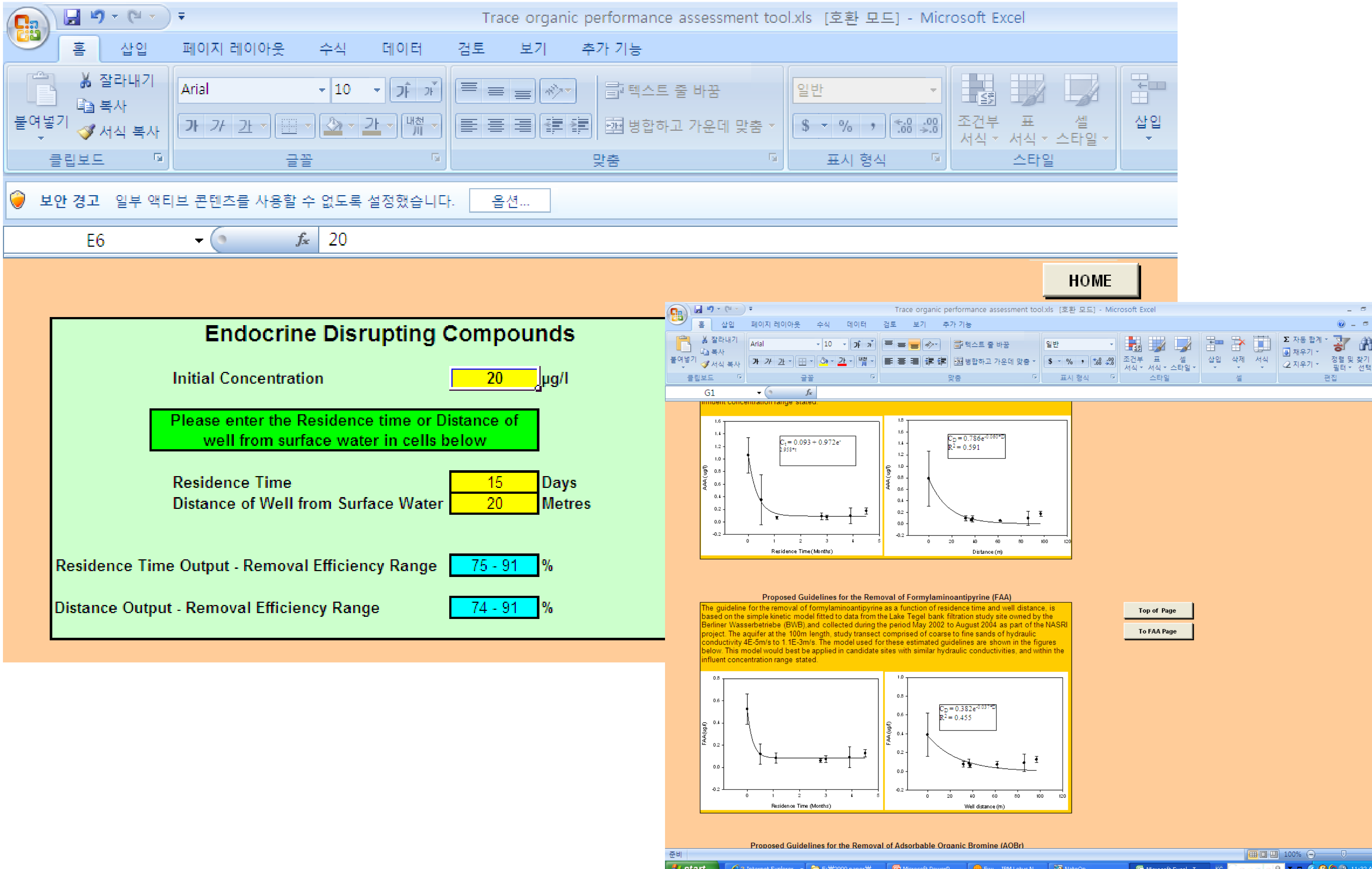




A Prediction Tool for Bank Filtration



A Prediction Tool for Riverbank Filtration

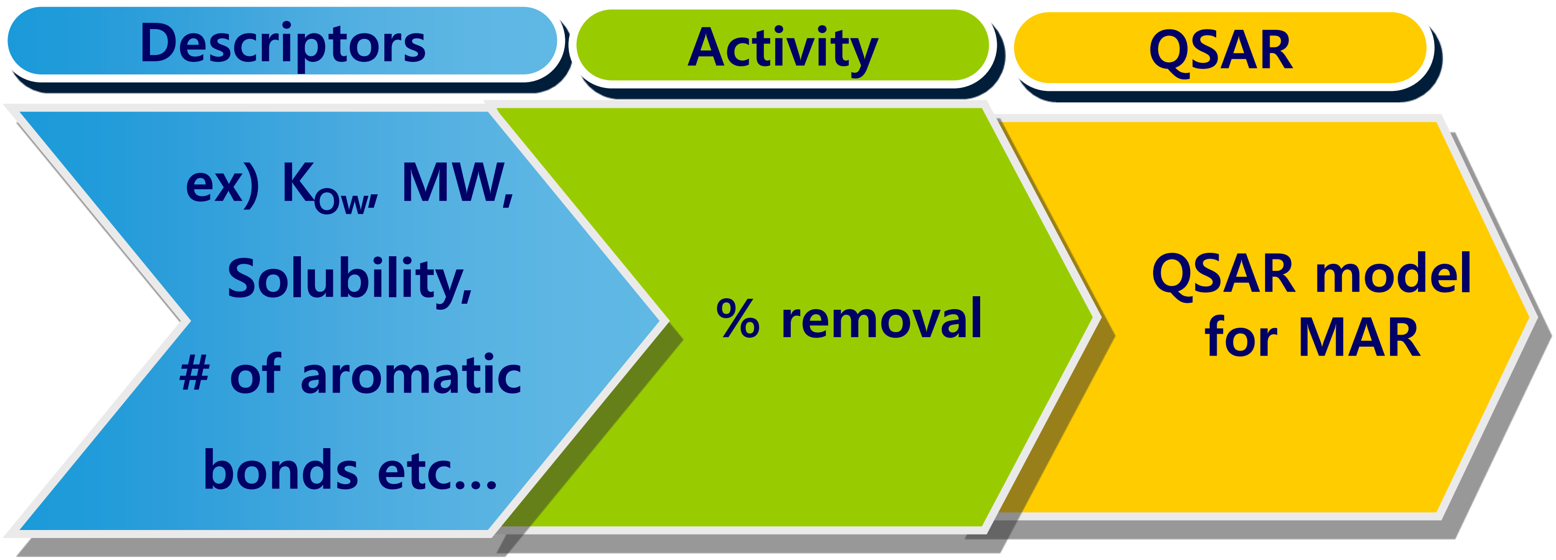


III. QSAR Modeling

- Prediction of the fate of known and unknown compounds based on compound properties and field conditions

QSAR (Quantitative structure-activity relationship)

Removal % = f (Chemical structure, physico-chemical properties)



* Descriptors could be related to size, structure, and functionality of MPs

Limitations of Present QSAR Model: Extending Approach

- Effects of redox (oxic vs. anoxic)
- Effects of travel (residence) time
- Effects of temperature

Assessing process selection using QSAR models