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Science for the Environment – Environment for Society: bridging the gap between scientists and practitioners in environmental science

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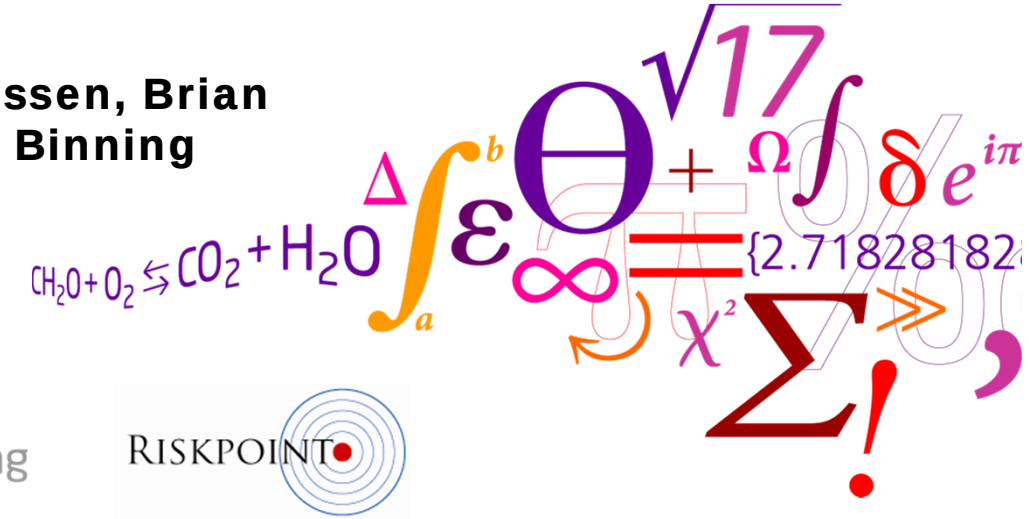
Integrated assessment of the impact of aqueous contaminant stressors on surface water ecosystems

Ursula S. McKnight, Jes J. Rasmussen, Brian Kronvang, Poul L. Bjerg, Philip J. Binning



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RISKPOINT

Impacts of chemical stressors

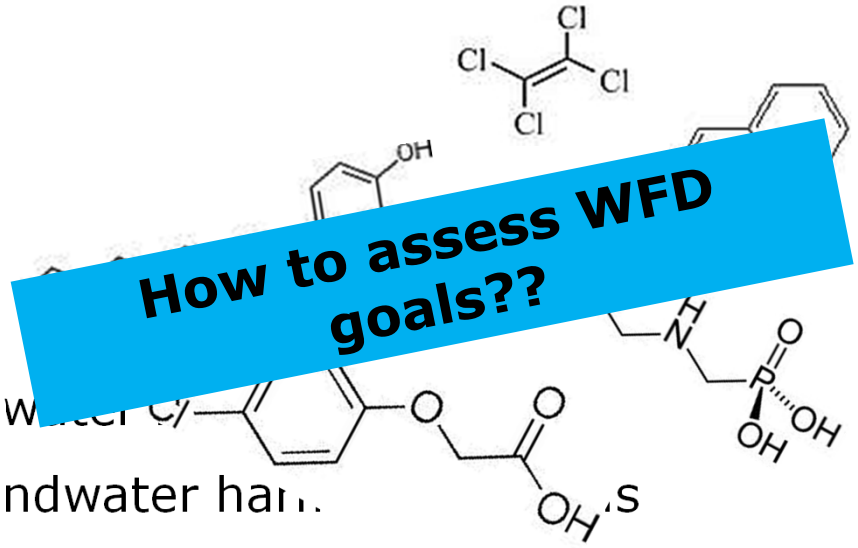
- **Part I: Which contaminated sites are problematic?**
  - How can we prioritize these sites?
  - Which management strategy makes sense?

- **Part II: Which chemical stressors are problematic?**
  - Do groundwater pollutants impact surface water?
    - Chlorinated solvents
    - Pesticides
  - Are ecosystems at risk (how do we determine "good" ecological status)?

Outline

EU Water Framework Directive

Member states must guarantee "good" ecological status of their waters



How to assess WFD goals??

A case study

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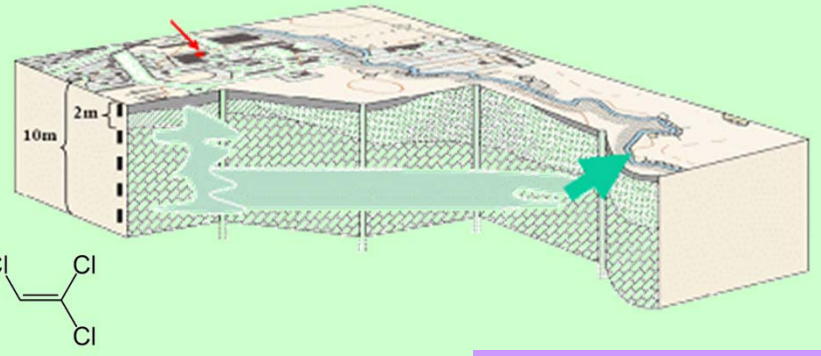
- undwater har
- fu
- va

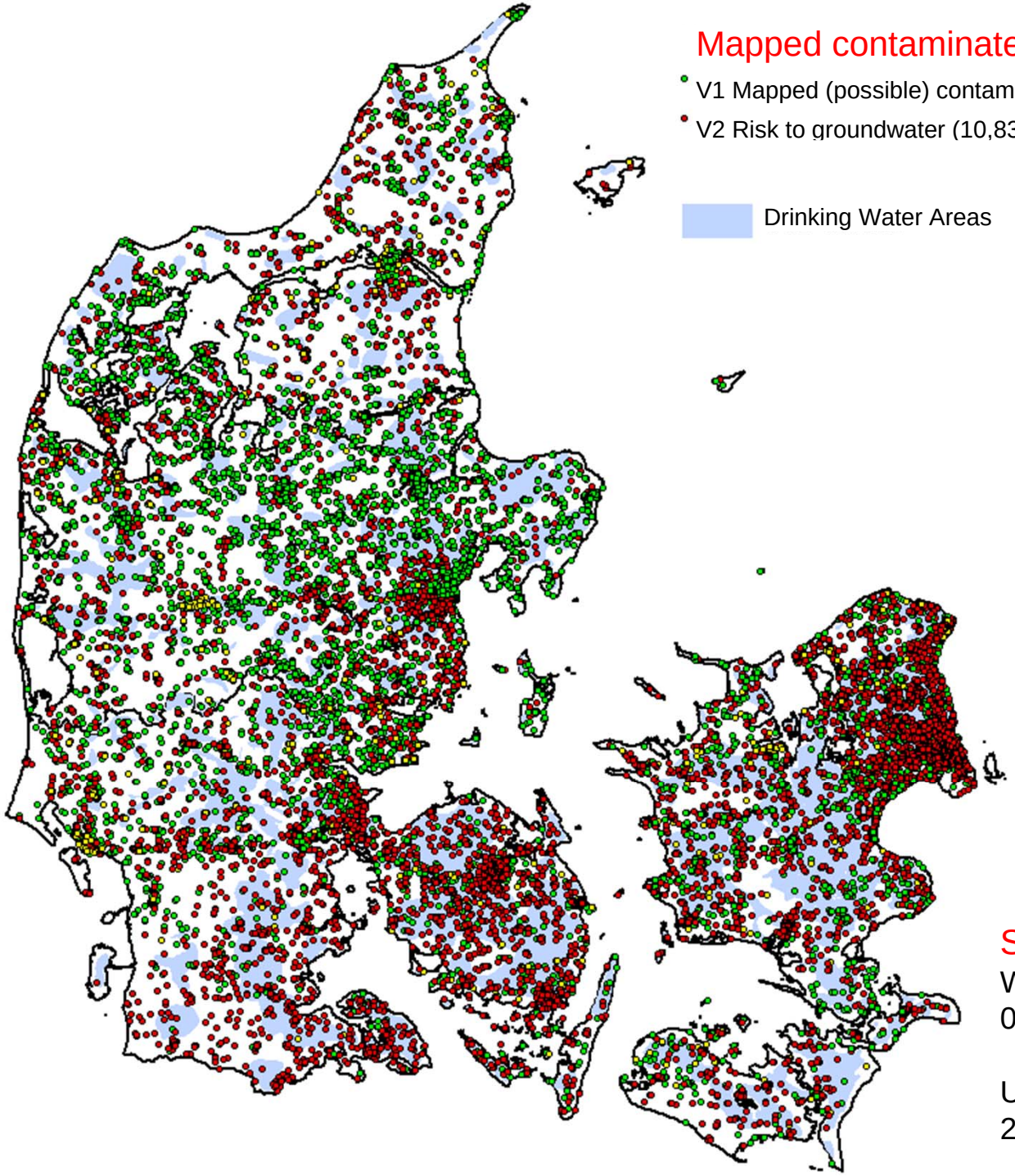


Other contaminants / stressors?

Integrated Field & Modelling Studies

Ecological impacts

Contaminated sites in Denmark



Mapped contaminated sites

- V1 Mapped (possible) contaminated site (11,309)
- V2 Risk to groundwater (10,839)

Drinking Water Areas

Site density

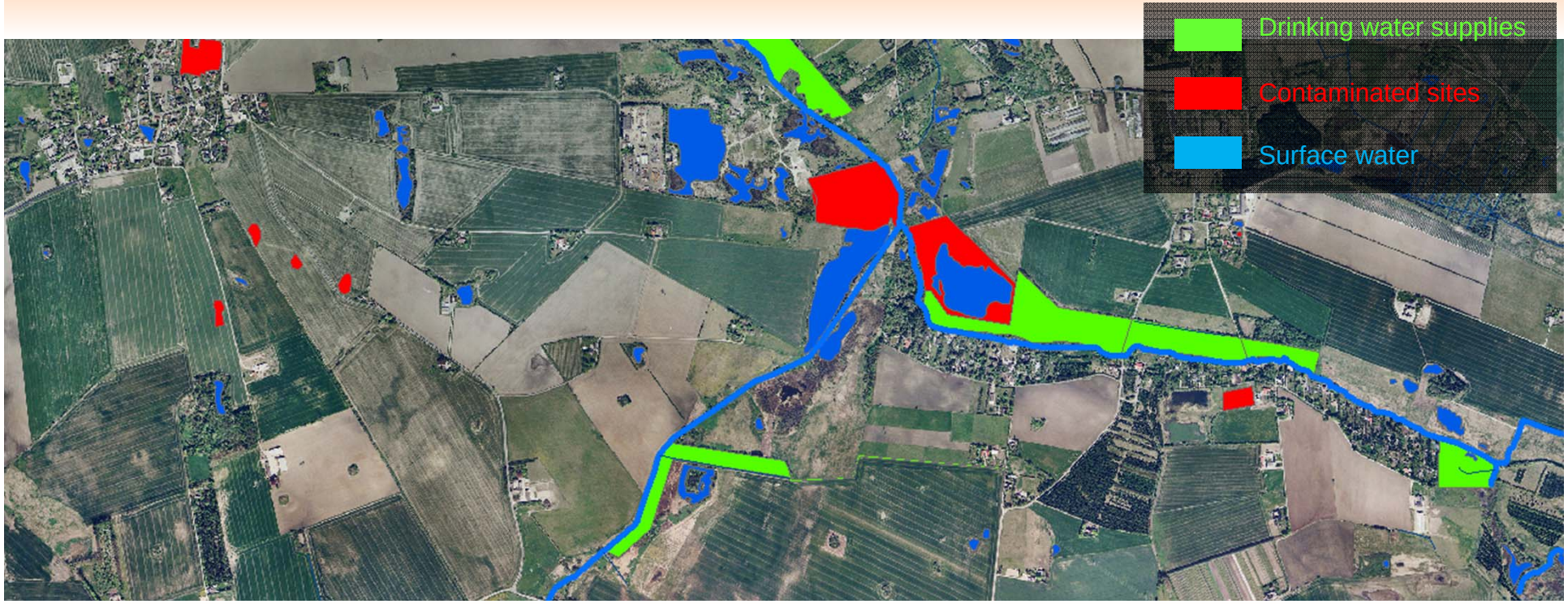
Whole country:
0.5 contaminated sites / km^2

Urban areas:
2 contaminated sites / km^2

EU Water Framework Directive

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000

The Directive establishes a framework for the protection of surface waters and groundwater, and obliges Member States to achieve the objective of good status for all waters by 2015.



Contaminated sites are often < 25 m from surface water

There are 1,326 such contaminated sites in Region Hovedstad alone. **(Jensen og Svensson, 2008)**

Denmark – planning phase 2010-2015

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Foreløbig version 9. september 2010

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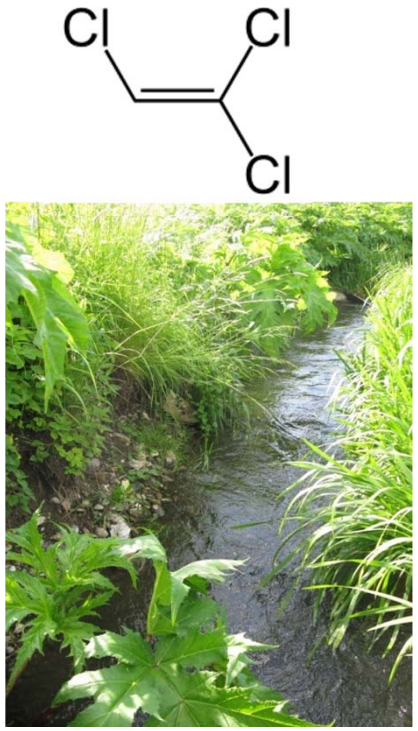
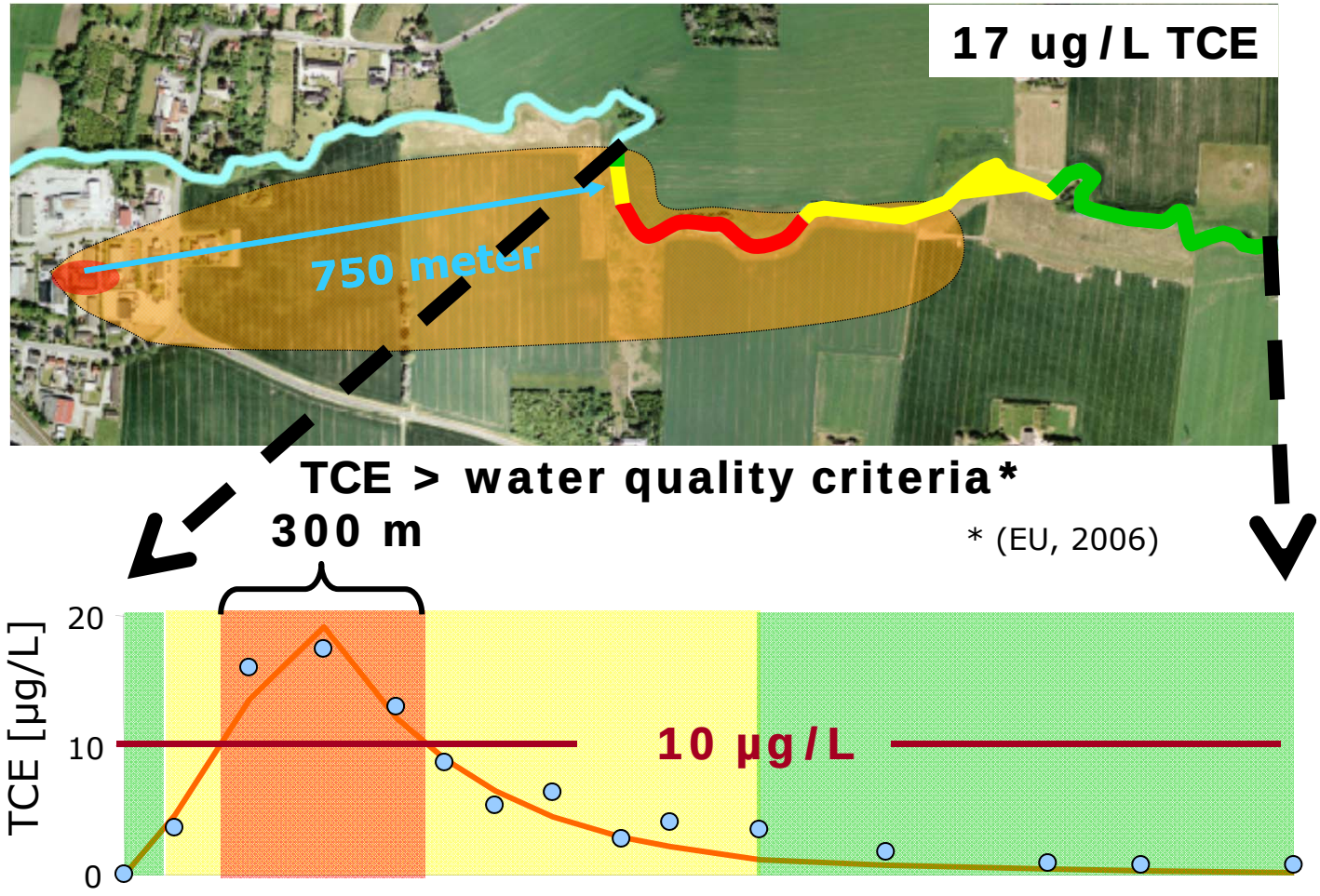
No initiatives will be taken in the planning period with regard to groundwater chemical impact on streams, lakes, coastal waters.

There is insufficient knowledge to adequately describe the contact between surface and groundwater and insufficient methods to model that impact

Case study – Skensved stream

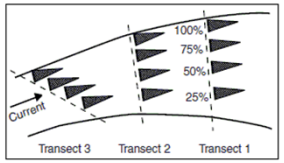




(Christensen & Raun, 2005)

Methods to evaluate ecological risk

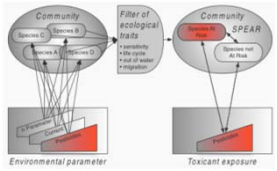
DSFI



Skriver, Friberg & Carl (1999): NERI Technical Report, Vol. 266.

Skriver, Friberg & Kirkegaard (2000): *Verh. Internat. Verein. Limnol.* 27, 1822–1830.

SPEAR



von der Ohe et al. (2007): *J. Environ. Monitor.* 9, 970-978.

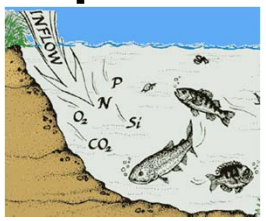
Beketov & Liess (2008): *Environ. Pollut.* 156, 980-987.

Beketov et al. (2009): *Environ. Pollut.* 157, 1841-1848.

$$HQ = \frac{Dose}{Benchmark}$$

Sprenger & Charters (1997): US EPA Guidance document, EPA 540-R-97-006.

Aquatox



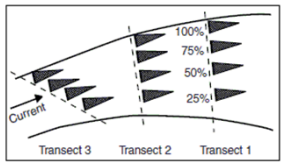
Park & Clough (2004): US EPA Technical Documentation, EPA 823-R-04-002

Park et al. (2008): *Ecol. Model.* 213, 1-15

Field-based methods

- **Danish Stream Fauna Index (DSFI)**
  - ***Official method*** *for biological assessment of running waters*
  - Primarily developed to detect impact of nutrients: taxa analyzed represent gradient in tolerance to low O2 levels

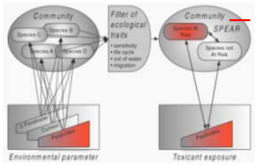
DSFI



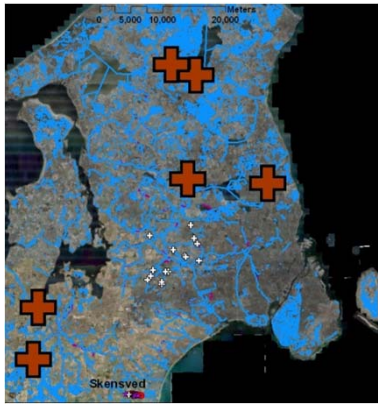
- **Kick-samples + hand-picked samples used to determine index value on basis of indicator taxa and number of diversity groups in sample**

- **SPEcies At Risk Index (SPEAR)**
  - Bio-indicator system based on biological traits; focused on various types of contaminants in fresh waters
  - Spear organics: for **chronic** exposures to xenobiotics
    - Indicative of degree of sensitivity of ecosystem community (sensitive towards community shifts)
    - Not currently linked to WFD classes
  - Spear pesticides: for **pulse** exposures to pesticides
    - Linked to WFD water quality classes (>33 = good ecological status)

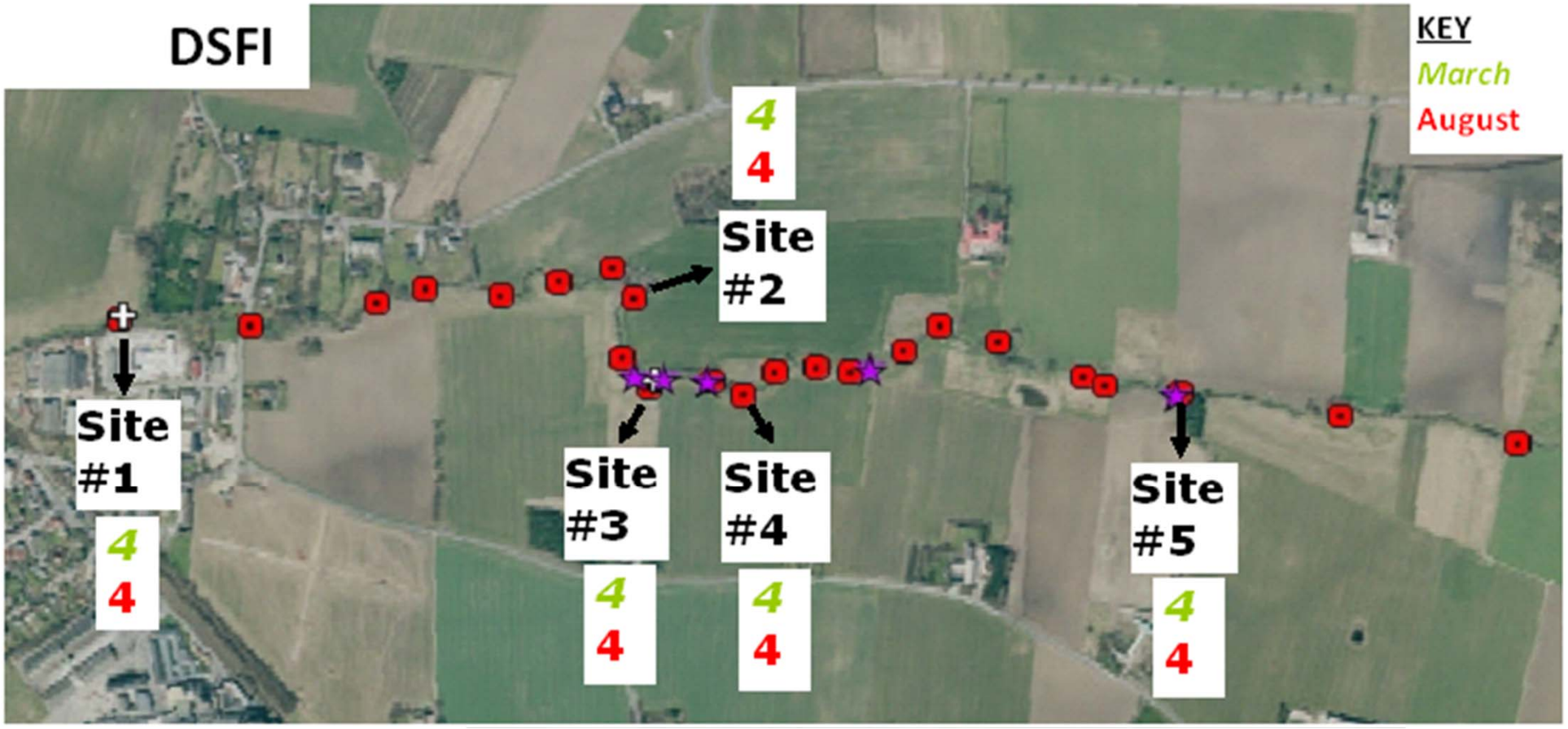
SPEAR



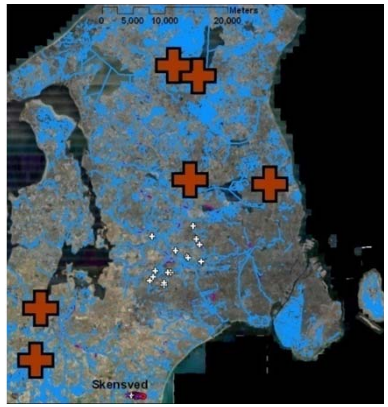
Field-based methods (1)



- **DSFI:** **Moderate** status
- **Reference site values:** 5-7



Field-based methods (2)

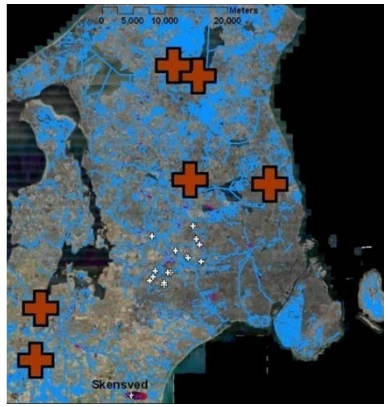


- **Spear organics:** Not yet linked to WFD classes

- **Overview: more negative values → ecosystem less sensitive to xenobiotics**
  - Indication for xenobiotic pollution → ecosystem has adapted to "pressure"

- **Reference site values:** Si = -0.30; -0.18; -0.36; -0.46; -0.14; -0.24

Field-based methods (3)



- **Spear pesticides:**
  - **March data: "poor" status**
  - August data: "bad" to "poor" status, upstream "moderate"
  - Un-impacted streams should NOT show seasonal differences
- **Reference site values:** SPEAR pest. = 46.5; 43.6; 34.7; 32.2; 49.7; 38.4
  - ≥33: "**good**" ecological status

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Integrated modelling approach

Modelling Steps	Approach	Dominant processes
Mass release & GW transport	System Dynamics – CARO-plus	Dispersion Advection Sorption Biodegradation
Coupling of groundwater – surface water systems	Analytical volatilization model 15 g/d TCE	Volatilization Physical (stream) characteristics Partition coefficients (e.g. detritus, organisms) Transformations Nonequilibrium kinetics Ecotoxicology
Ecosystem Dynamics	Indices + modeling	

McKnight et al. (2010): *Ecological Engineering 36, 1126-1137*

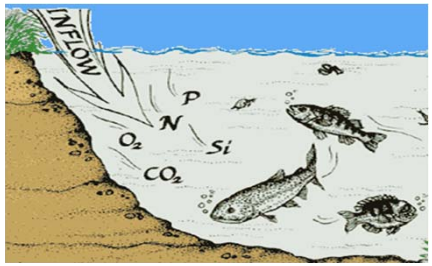
Predictive modeling methods: ecosystem health

- **Hazard Quotient (HQ) index**
  - Screening-level risk calculation to compare levels of chemical contamination (at sites) to levels known to cause harm

$$HQi = \frac{EECi}{LC50i}$$

- HQ_i = Hazard Quotient for compound *i*
- EEC_i = Environmental concentration
- $LC50_i$ = Conc. where 50% species dies

- **AQUATOX**
  - ***Process-based model***, explicitly simulates biological and ecological processes in an ecosystem
  - Predicts the environmental fate and ecological effects of various environmental stressors (nutrients + toxicants)
    - Lots of unknown parameters (used literature values)



Modelling for decision support (DSS)

- **Compare modeling approaches with different levels of ecosystem complexity**
  - Evaluate necessity of using complex, "fully-functional" models

- **Determine threshold values for ecological impact**
  - Compare to (contaminated site) source mass flux ranges

- **Generalize findings**
  - Extend model for additional compounds

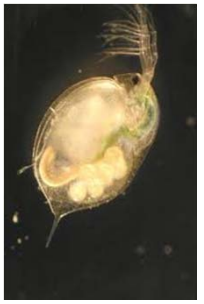
Hazard Quotient Index

- HQ_i (LC_{50i}) mortality* [mg/L]

Measured TCE conc.: 0.017 [mg/L] in 2008

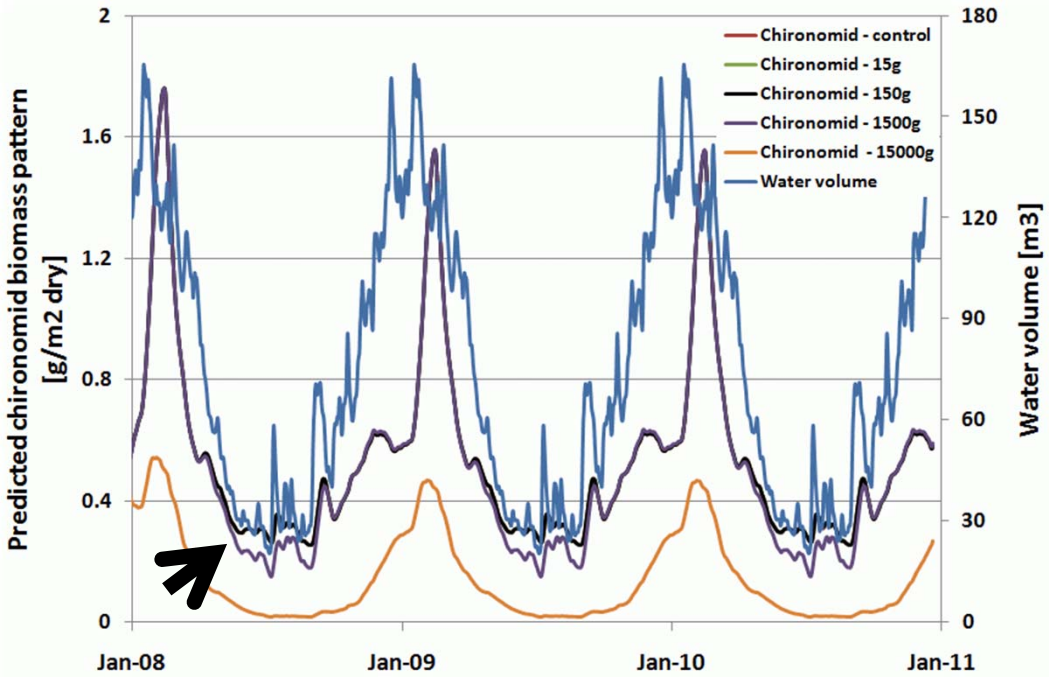
Compound	Chironomid	D. Magna	Stonefly
Benzene	34.0	59.6	130.0
TCE	42.0	18.0	70.0
PCE	1.3*	9.1	3.6
Naphthalene	2.8	2.2	**0.011***
MCPA	55.0	3.0	6.2*
Metamitron	40.2*	101.7	1.1*
Glyphosate	0.353*	11.0	**0.023***
4-nonylphenol	**0.013***	0.104	**0.004***

*regression necessary to produce ecotoxicity data (Web-ICE, US EPA 2010)



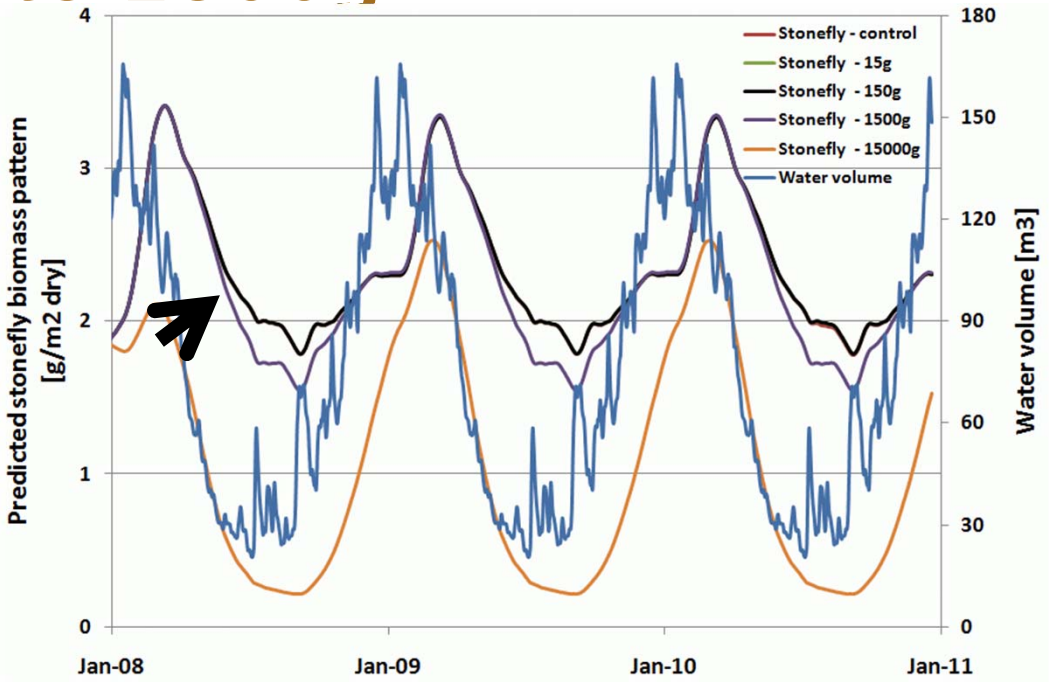
AQUATOX prediction of ecosystem impacts

TCE



Threshold: 150g to 1500g

TCE



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Aquatox – threshold values – mass discharge [kg/yr]

Source mass flux ranges: 0.0003 to 58,400 kg/yr (ITRC, 2010)

	Chironomid	Stonefly	Brown trout
Benzene	55-550	55-550	55-550*
TCE	55-550	55-550	55-550*
PCE	**5.5-55***	55-550	55-550*
Naphthalene	55-550	**0.5-5.5**	**5.5-55***
MCPA	>55000*	55-550*	>55000
Metamitron	550-5500*	55-550*	550-5500*
Glyphosate	550-5500	55-550*	**0.5-5.5**
4-nonylphenol	**0.2-0.5***	**0.02-0.2***	**0.5-5.5***

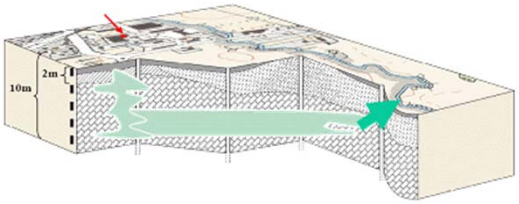
*regression necessary to produce ecotoxicity data (Web-ICE, US EPA, 2010)

Aquatox – biomass [g/m2 dry] perturbation concentration [ug/L]

Compound	Chironomid	Stonefly	Brown trout	Concentration in surface water (Location) [ug/L]
Benzene	350	375	500*	11 (Japan)
TCE	400	550	35*	17 (Denmark)
PCE	**7***	30	50*	23 (Canada)
Naphthalene	550	**1.5**	**20**	**1 (Spain)**
MCPA	>120,000*	600*	>120,000	3 (Denmark)
Metamitron	6000*	180*	4000*	1 (Denmark)
Glyphosate	4350	160*	**5**	**300** (Denmark)**
4-nonylphenol	**0.08***	**0.14***	**1.5***	**0.6 (China)**

*regression necessary to produce ecotoxicity data (Web-ICE, US EPA, 2010)
**Glyphosate: max. conc. value extracted from NOVANA database

Conclusions



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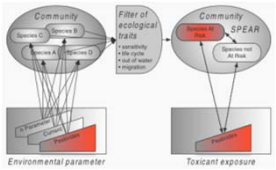

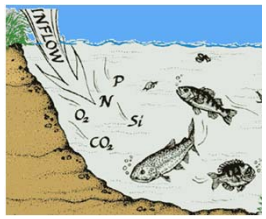

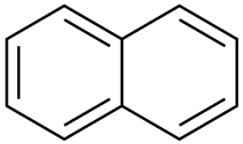

- **Ecological impact of TCE (contaminated site):** seems to be minimal at Skensved. Caution: Spear organics result!

- **Need suitable field methods to appropriately characterize ALL stressors acting on an ecosystem:** need to distinguish stressor effects and capture seasonal trends. **Typically have multiple stressor environments!**

- **Modelling to predict ecological risk: sufficient methods available!** Ongoing research: finalization of DSS (point sources in gw → gw-sw interactions → ecological impacts)

- **Which sites/chemical stressors are problematic?**
  - 4-nonylphenol & naphthalene: potentially risky to ecosystems
  - Glyphosate, metamitron & PCE: depends on which organisms/method utilized

Acknowledgments

- **Danish Research Council (RiskPoint Project, grant no. 2104-07-0035)**

- **Jonathan Clough, Dr. Richard Park & Marjorie C. Wellman (AQUATOX support)**

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  - Assoc. Prof. Anders Baun
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