Attenuation of a discharging chlorinated ethene (CE) plume: use of streambed point velocity probes (SBPVP), streambed passive flux meters (SBPFM) and contaminant mass discharge (CMD)

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Attenuation of a discharging chlorinated ethene (CE) plume: use of streambed point velocity probes (SBPVP), streambed passive flux meters (SBPFM) and contaminant mass discharge (CMD)

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Introduction

Chlorinated ethenes (CE) are common groundwater contaminants and pose risk to groundwater and surface water. To conduct proper risk assessment at stream sites, knowledge on CE attenuation is essential, but these processes are still not fully understood.

An approach to assess CE attenuation of discharging plumes is CMD calculations. These require CE fluxes, which can be obtained by streambed SBPFM data or by combining concentrations and SBPVP data.

OBJECTIVES

1) **Compare bank, streambed and in-stream CMD estimates obtained from:**
   - **CE concentrations and Darcy's law,**
   - **CE concentrations and SBPVP data**
   - **SBPFM data**
2) **Assess the attenuation of a CE plume discharging to a stream by including CMD calculations.**

Preliminary results

Plume core discharge to stream

Spatial pattern of SBPFM-derived concentrations agree with water samples (Fig 4).

Highest CE fluxes occurred at high concentration zones → CE flux is controlled by concentrations (Fig. 4).

Assessment of attenuation through CMD

Plume core and total CMD estimates at the streambed are comparable to corresponding bank CMD estimates (Table 1).

→ no/limited mass loss from bank to streambed.

In-stream CMD is comparable to total bank and streambed CMD estimates (Table 1)

→ no/limited mass loss from bank to fully mixed point.

Similar molar ratios for bank, streambed and in-stream CMD (Fig. 5)

→ no/limited dechlorination, despite favorable redox conditions.

Residence times from bank to streambed

Short residence times from bank to streambed (Table 2)

→ no time for degradation.

Table 2: Average Darcy fluxes (± standard deviation) and residence times from bank to streambed at plume core transect. Assumptions: n=0.37 [1], travel distance=10 m.

Method	Darcy flux (m/d)	residence time (d)
SBPVP	2.2 ± 1.6	1.7
SBPFM	0.14 ± 0.11	27
Darcy	1.0	3.7

In-stream mixing

Stream water concentrations are non-uniformly distributed at plume core transect (Fig. 4).

Transverse in-stream mixing occurs to point of fully mixed conditions 200 m further downstream (Fig 6).

→ Implications for stream water sampling strategy.

Table 1: Preliminary CMD at plume core transect (along 1m stream reach) and total CMD (along entire plume width) for CE at the bank, streambed and in stream.

	Method	CMD plume core (kg/y, PCEeq)	Total CMD (kg/y, PCEeq)
Bank	PVP (mean q)	8.6	204
	PVP (varying q)	7.7	269
	Darcy	13	372
Streambed	SBPVP	63	310
	SBPFM	10	pending
	Darcy	23	pending
In-stream	From GW	-	558

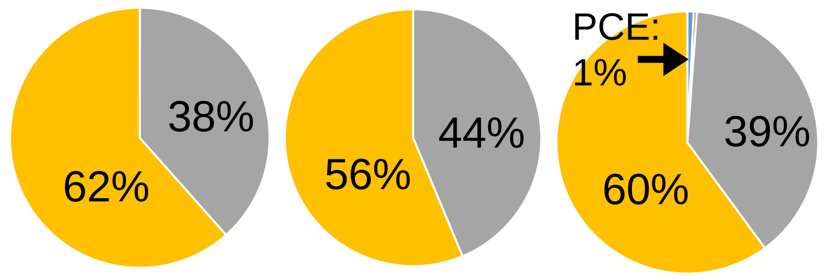


Fig. 5: Molar ratios of CMD (grey: cis-DCE, yellow: VC) at bank, streambed and in-stream. Methods not shown suggest similar trend.

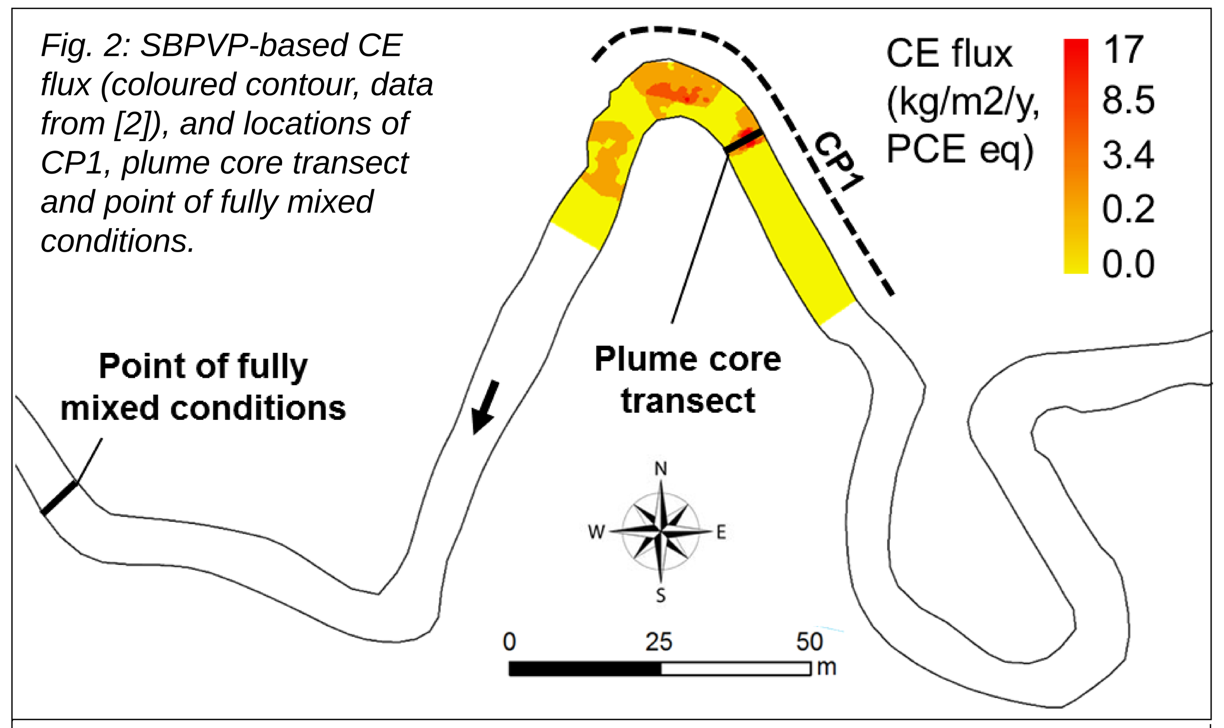


Fig. 2: SBPVP-based CE flux (coloured contour, data from [2]), and locations of CP1, plume core transect and point of fully mixed conditions.

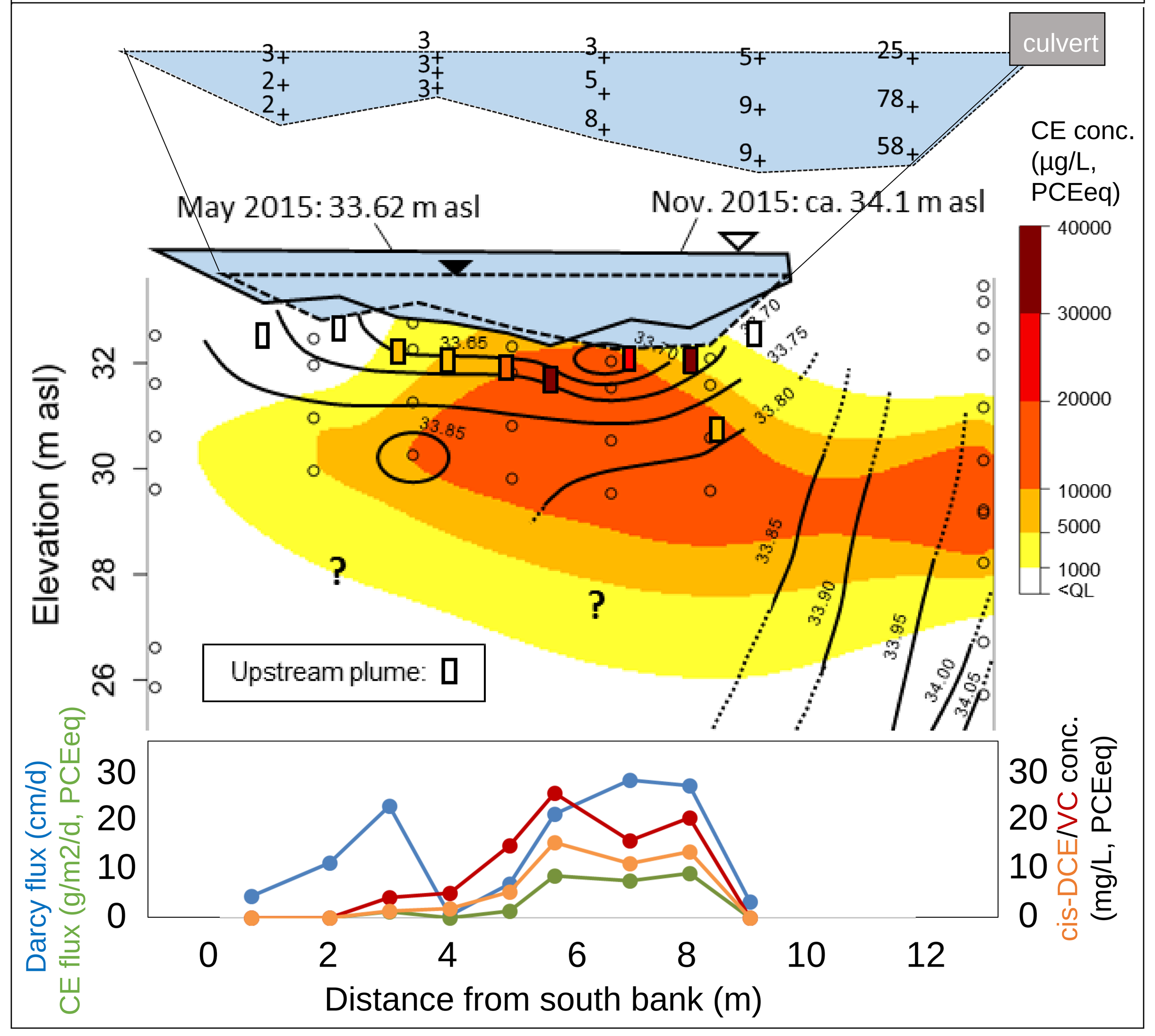
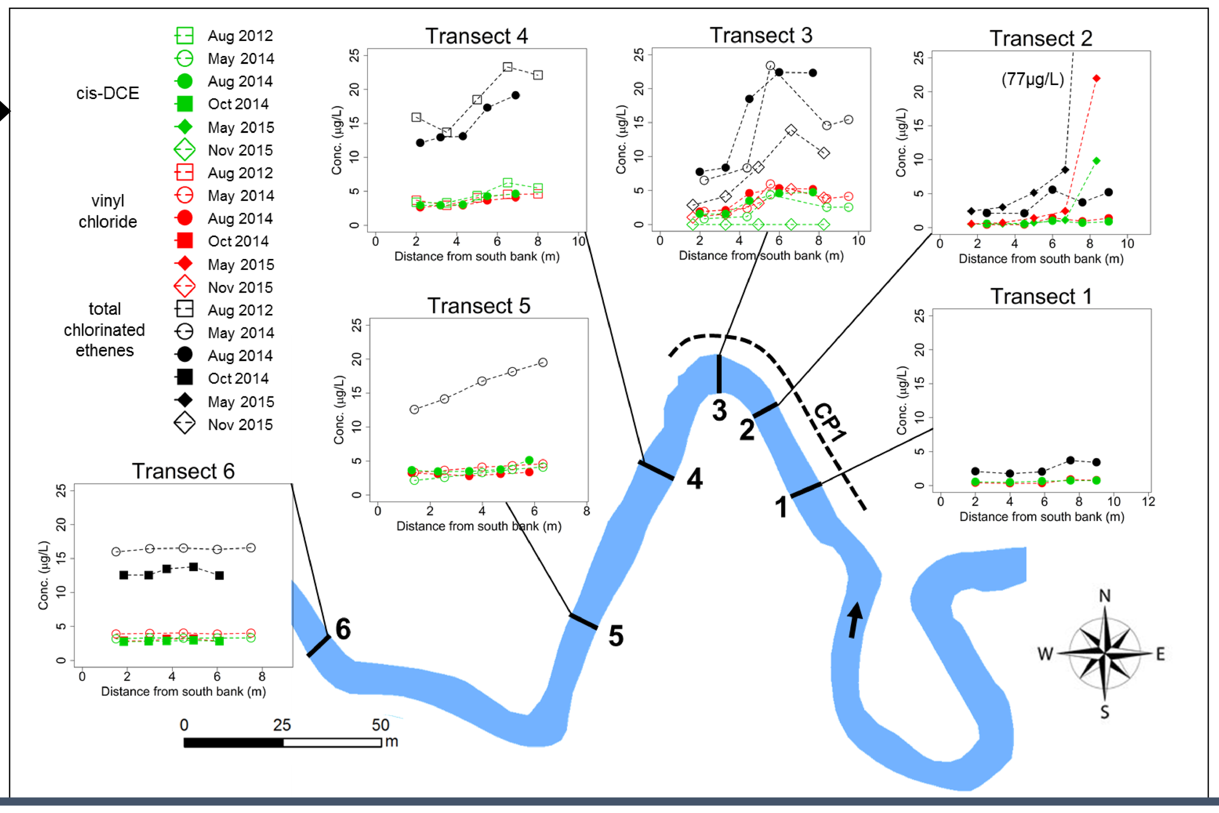


Fig. 4: CE conc. based on water samples (coloured contour), SBPFMs (coloured rectangles) and hydraulic head (m asl) (line contours). Lower graph: SBPFM Darcy fluxes (blue curve), CE fluxes (green), conc. of cis-DCE (orange) and VC (red).

Fig. 6: In-stream concentrations in transects across the stream [1].



Methods

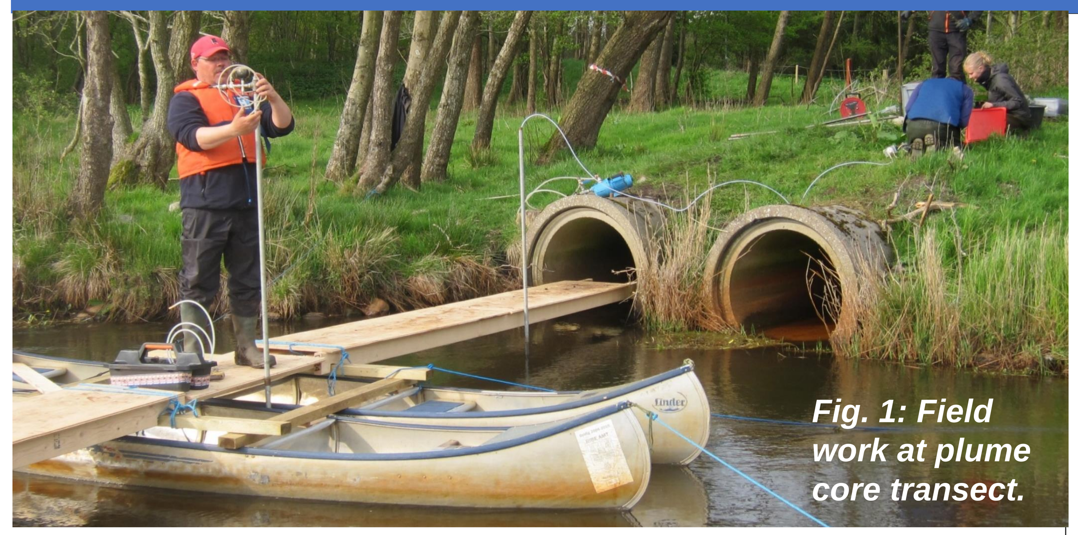


Fig. 1: Field work at plume core transect.

Study site: Grindsted stream, DK (Fig. 1)

- Geology: sandy
- Average annual discharge: 2000 L/s.
- Impacted by contaminated site 1.5 km north of stream

Stream bank flux

Combining concentrations and water fluxes from Darcy's law and PVPs along CP1 (Fig. 2), using Eq.1 [1]:

$$J = cq = cvn \quad (1)$$

Streambed flux

SBPVP (Fig 3A): Combining concentrations and SBPVP seepage velocities in coloured area in Fig 2, using Eq.1 [2].

SBPFM (Fig 3B): SBPFM contaminant fluxes along plume core transect (Fig. 1 & 2), using Eq.2 [4]:

$$J = \frac{m}{\alpha \pi r^2 t} \quad (2)$$

Based on tracer removal, Darcy fluxes were obtained from an analogue to Eq.2.

From contaminant flux to CMD

$$CMD = AJ \quad (3)$$

In-stream CMD

Obtained from stream concentrations and corresponding stream discharge at fully mixed conditions (Fig 2) [1].

$$CMD = cQ \quad (4)$$

Contaminant input from culverts (Fig 1) and upstream of plume discharge zone were subtracted.

α = convergence coefficient
A = area of control plane
c = concentration
J = contaminant flux
m = sorbed mass
n = porosity
r = radius of sorbent column
t = test time
v = seepage velocity
q = Darcy flux
Q = stream discharge

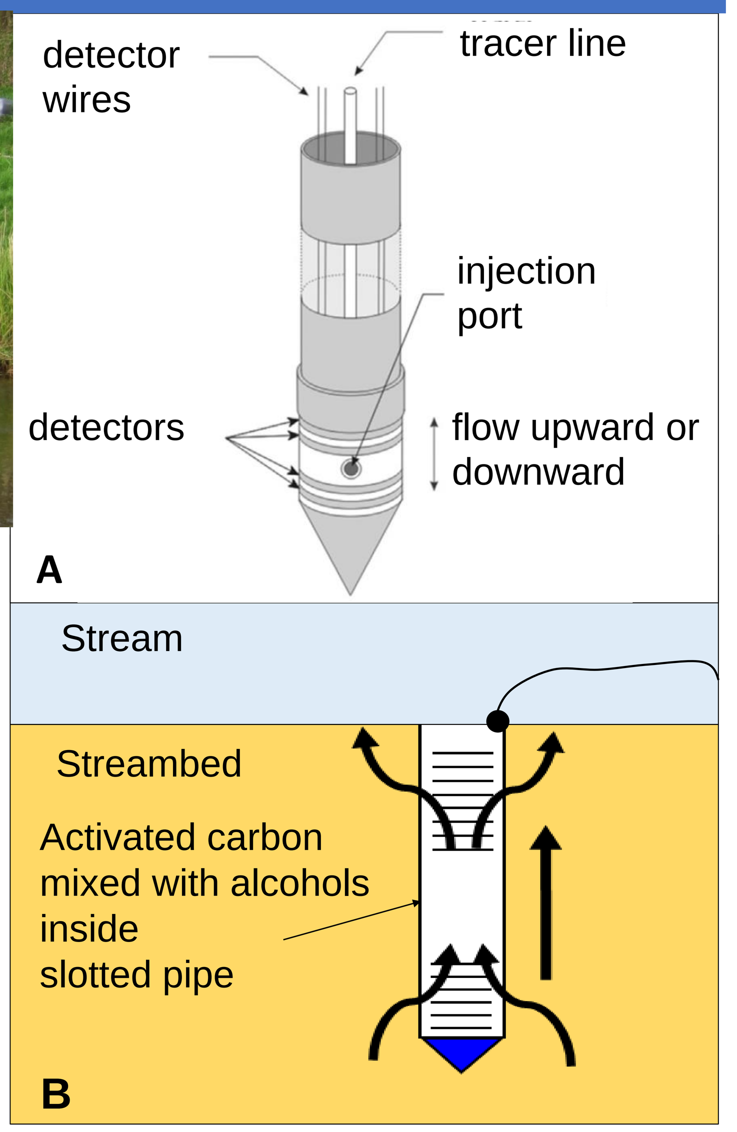


Fig. 3: Principles of the SBPVP (A), modified from [3], and SBPFM (B).

Conclusions

- Total SBPVP-based CMD is comparable to bank estimates.
- Plume core SBPFM-based CMD is comparable to bank estimates.

→ SBPVP and SBPFM are promising tools for estimation of streambed CMD

- Total CMD at bank, streambed and in stream are comparable.
  → No/limited mass loss
- No/limited shift in molar ratios of specific CE → No/limited degradation
- Short streambed residence time is thought to cause the lack/limited degradation despite favorable redox condition.
- In-stream mixing is the dominant attenuation process.

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