GSI Can Affect the Bioavailability of Sediment-Associated Contaminants to Benthic Invertebrates

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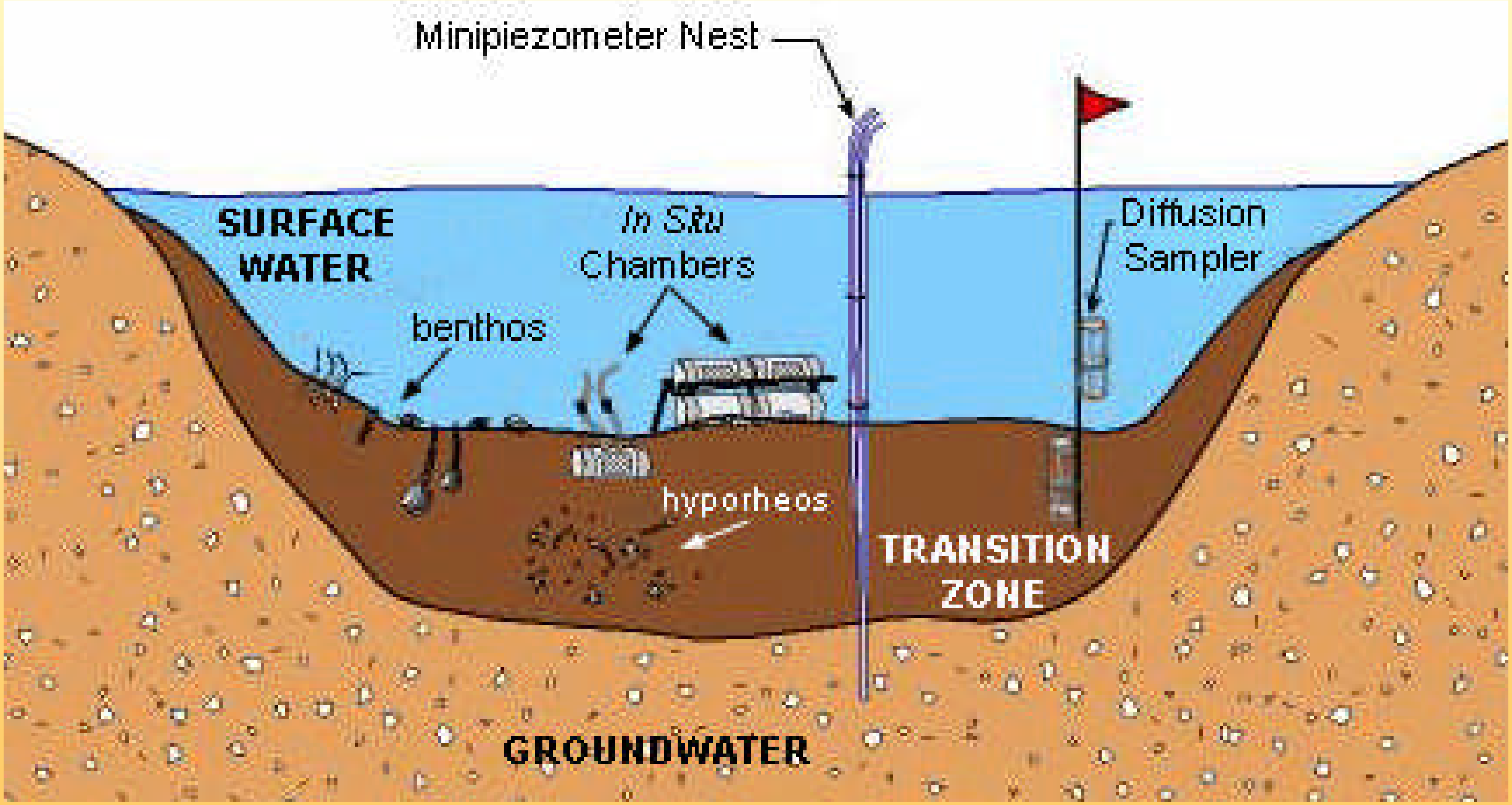
Sediment Toxicity Assessment and GW-SW Interactions

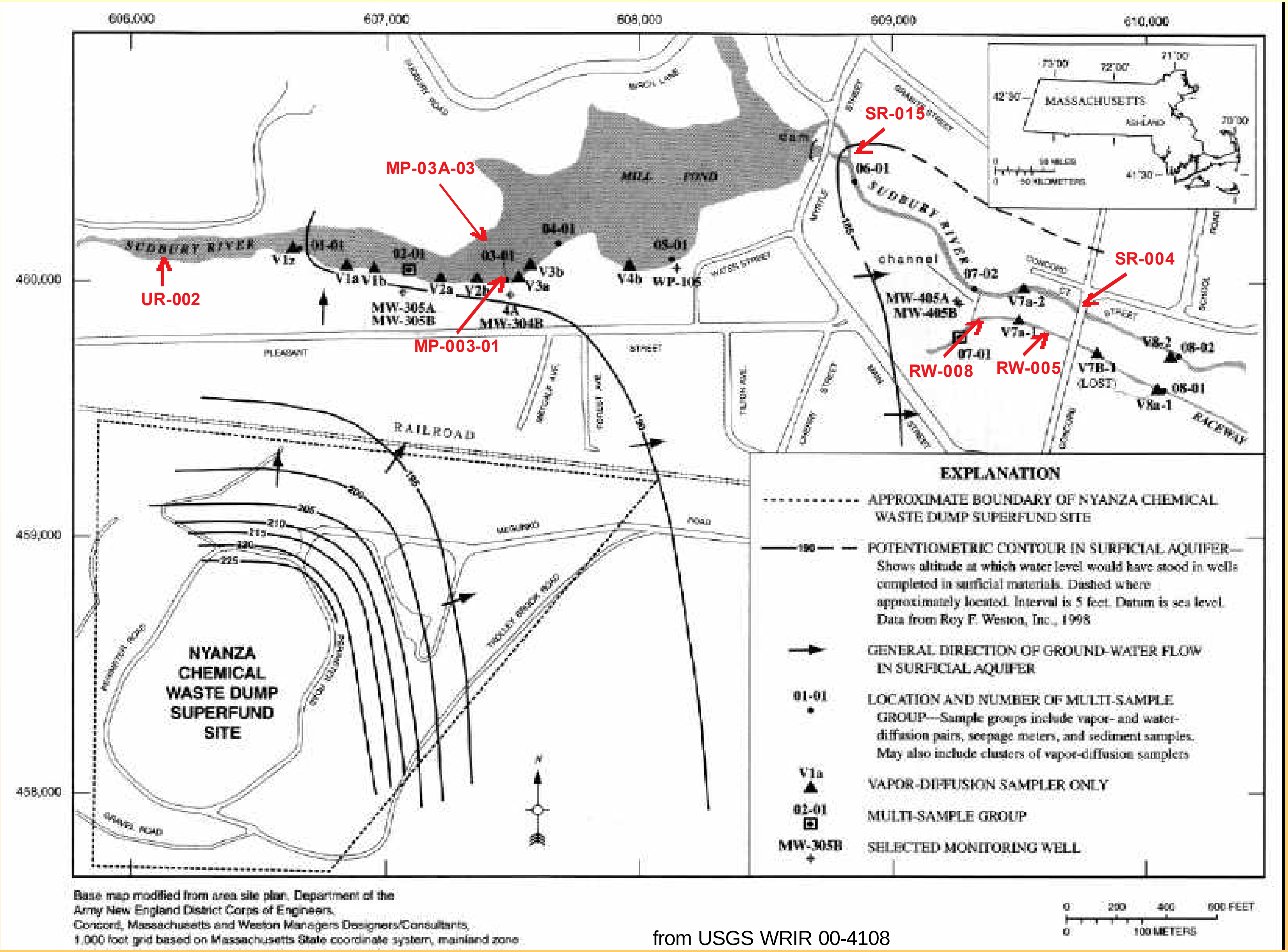
- GW-SW interactions in relation to sediment toxicity important in ecological risk assessment

- GSI issues exist at numerous contaminated sites:
  - 75% all RCRA/Superfund w/in 1/2 mile of surface water
  - 51% NPL sites with surface water contaminated (most via groundwater transport)
  - observed at many sites we have studied

Integrated *In Situ* Assessment Design



Nyanza - Sudbury River System



from USGS WRIR 00-4108

Hydrological Measurements - Sudbury River - Nyanza Study

Site	Hydrological Conditions[a]	Δh (cm) Range	VHG (cm/cm) Range
UR-002	Upwelling	0.2 – 0.9	0.004 – 0.060
MP-03A-03	Upwelling	0.2 – 10.3	0.013 – 0.137
MP-003-01 [b]	Mixed Up/Down	-0.2 – 9.70	-0.006 – 0.129
SR-015	Upwelling	0.3 – 0.7	0.007 – 0.013
SR-004	Upwelling	0.4 – 7.0	0.011 - 0.093
RW-008	Upwelling	0.4 – 3.8	0.011 – 0.051
RW-005	Upwelling	0.5 – 1.7	0.009 – 0.053

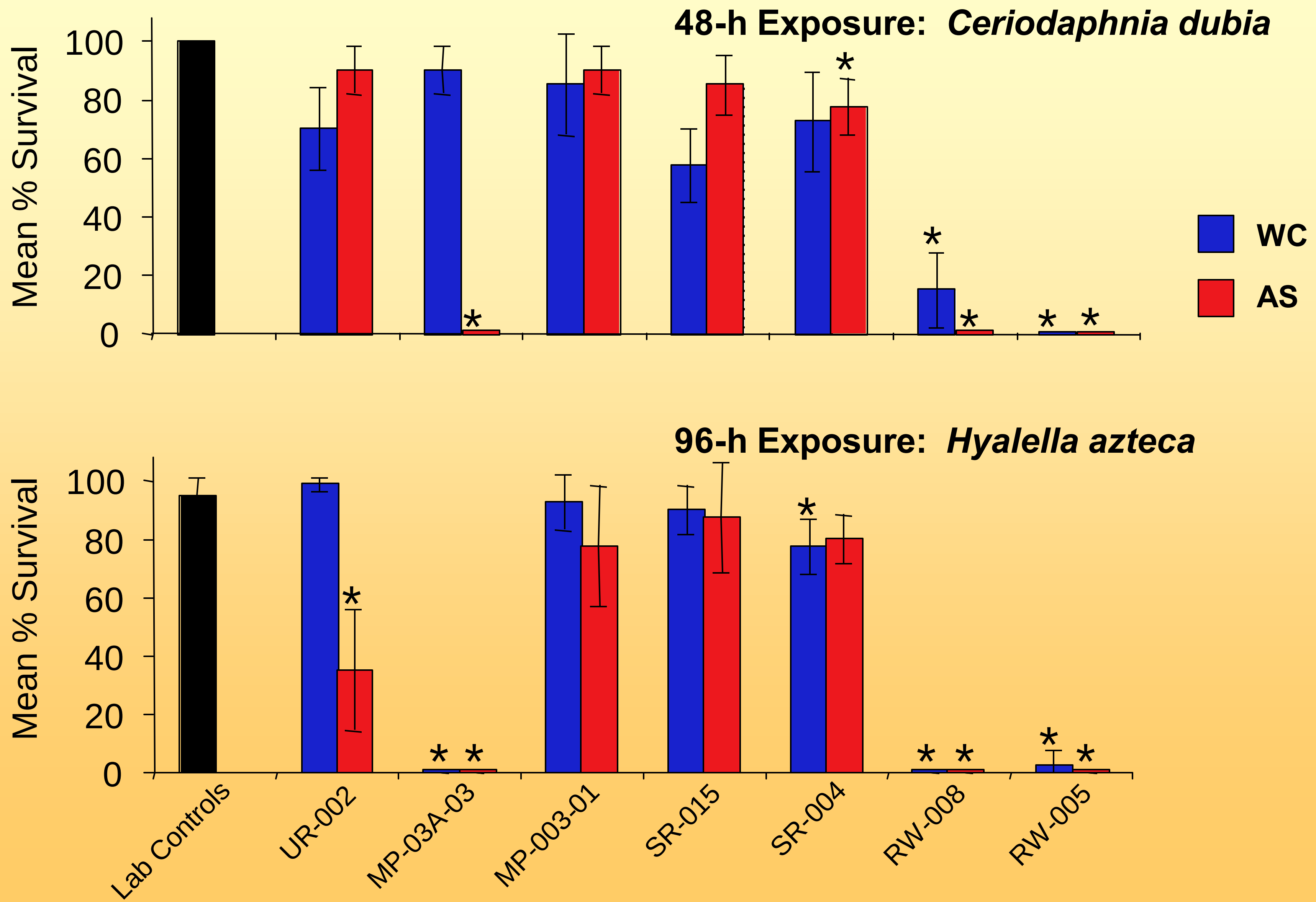
[a] Determined from manometer readings of two nested mini-piezometers (20, 40, 60 and 80 cm depths)

[b] Deep water site

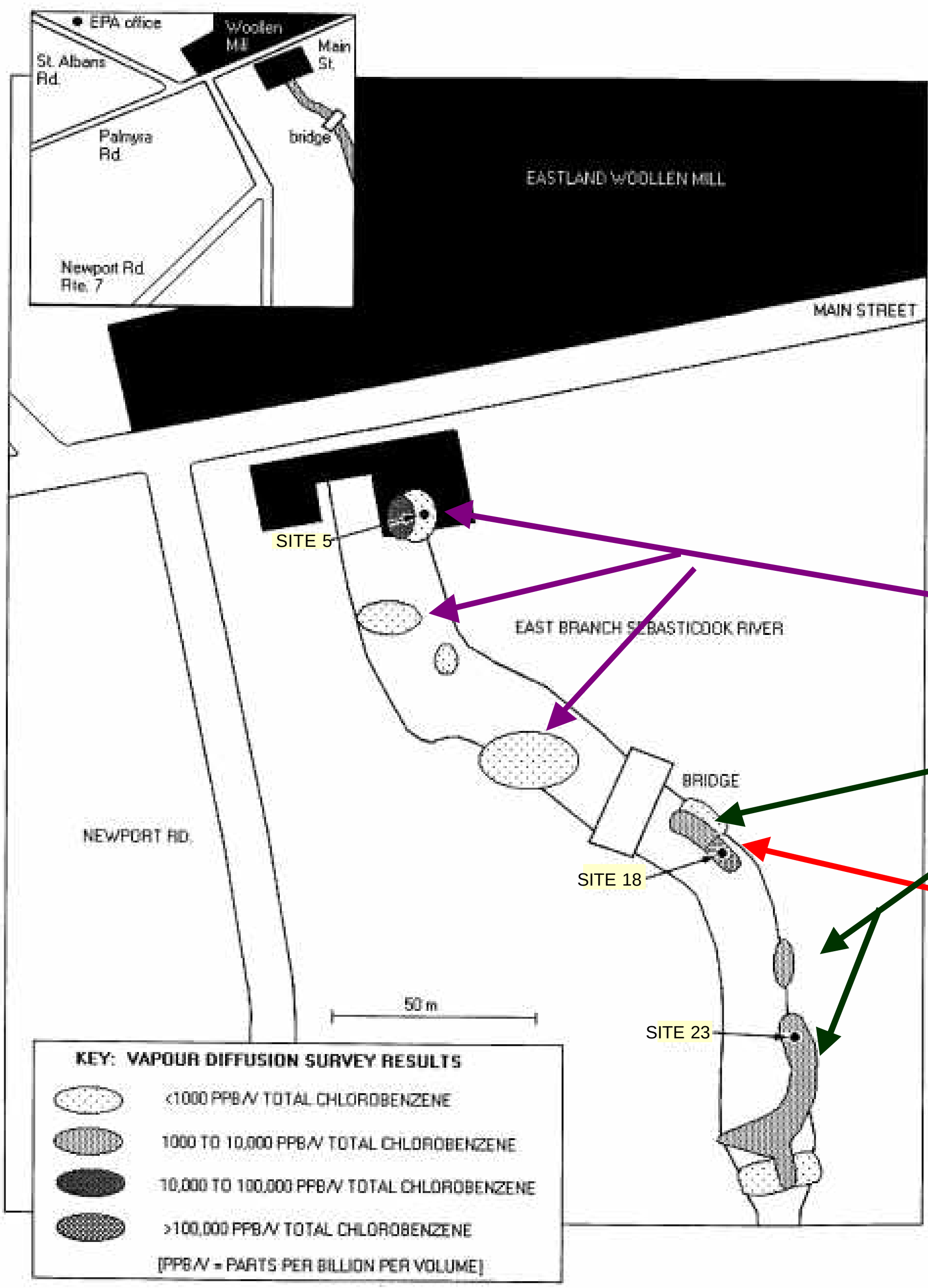
Chemistry - Nyanza Study

- Metals (incl. Ag, As, Cd, Cu, Hg, Ni, Pb, Zn) exceeded WQC in groundwater at all 7 sites and SQGs in sediments at 6 sites
- VOCs exceeded criteria in the groundwater at 3 sites and in the sediments at 4 sites
- Most exceedances in the Mill Pond and Raceway sites
- Contaminants detected in samples from chamber waters reflected groundwater and sediments

In Situ Exposure Nyanza Study



Eastland Woolen Mill Corinna, ME



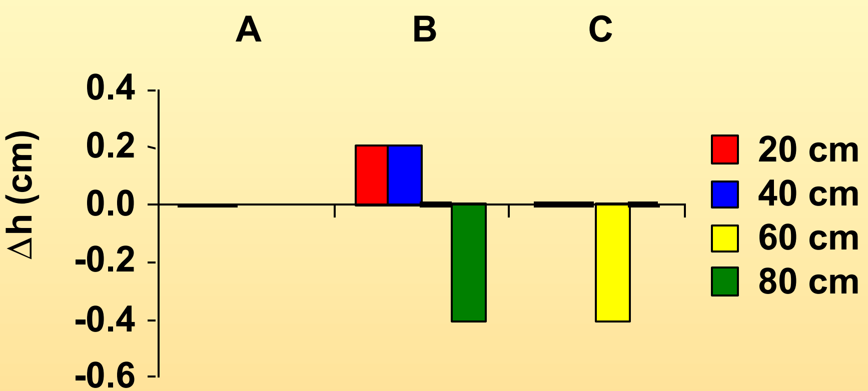
Total chlorobenzene (vapor diffusion)

<1000 ppb/v
1000 -> 10,000
10,000 -> 100,000
>100,000

Maine 1999: Hydraulic Heads

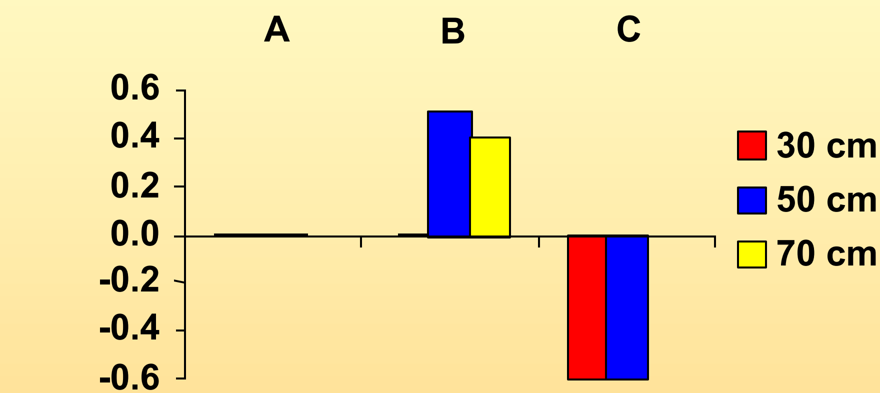
Piezometer Nest

Site 5

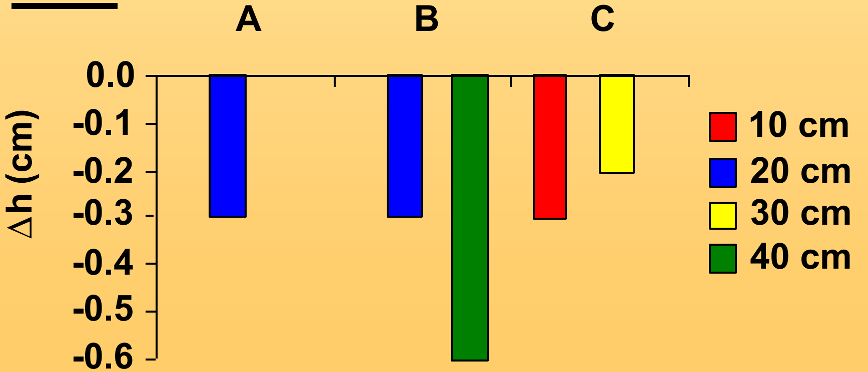


Piezometer Nest

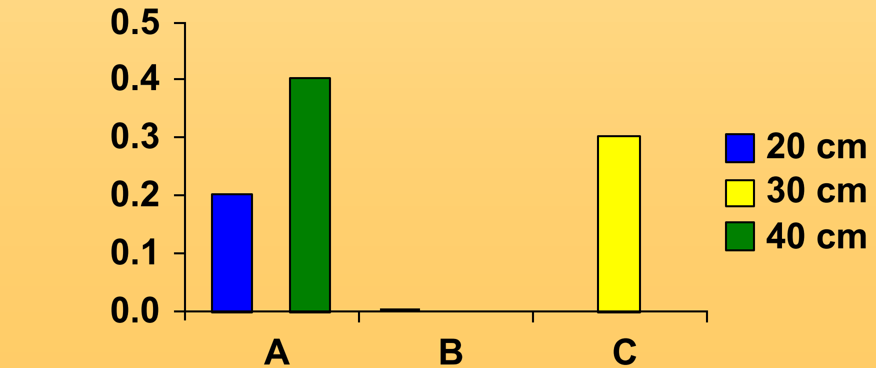
Site 18



Site 23

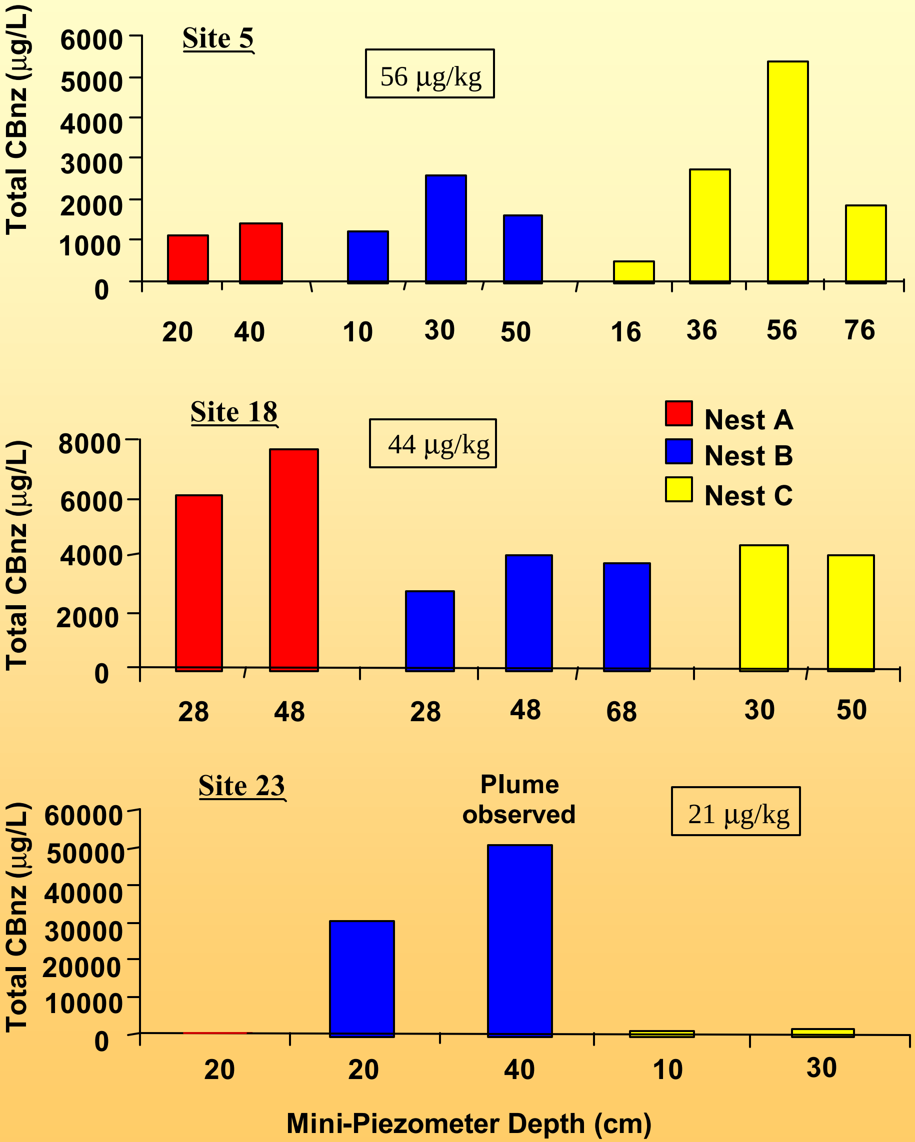


Pristine



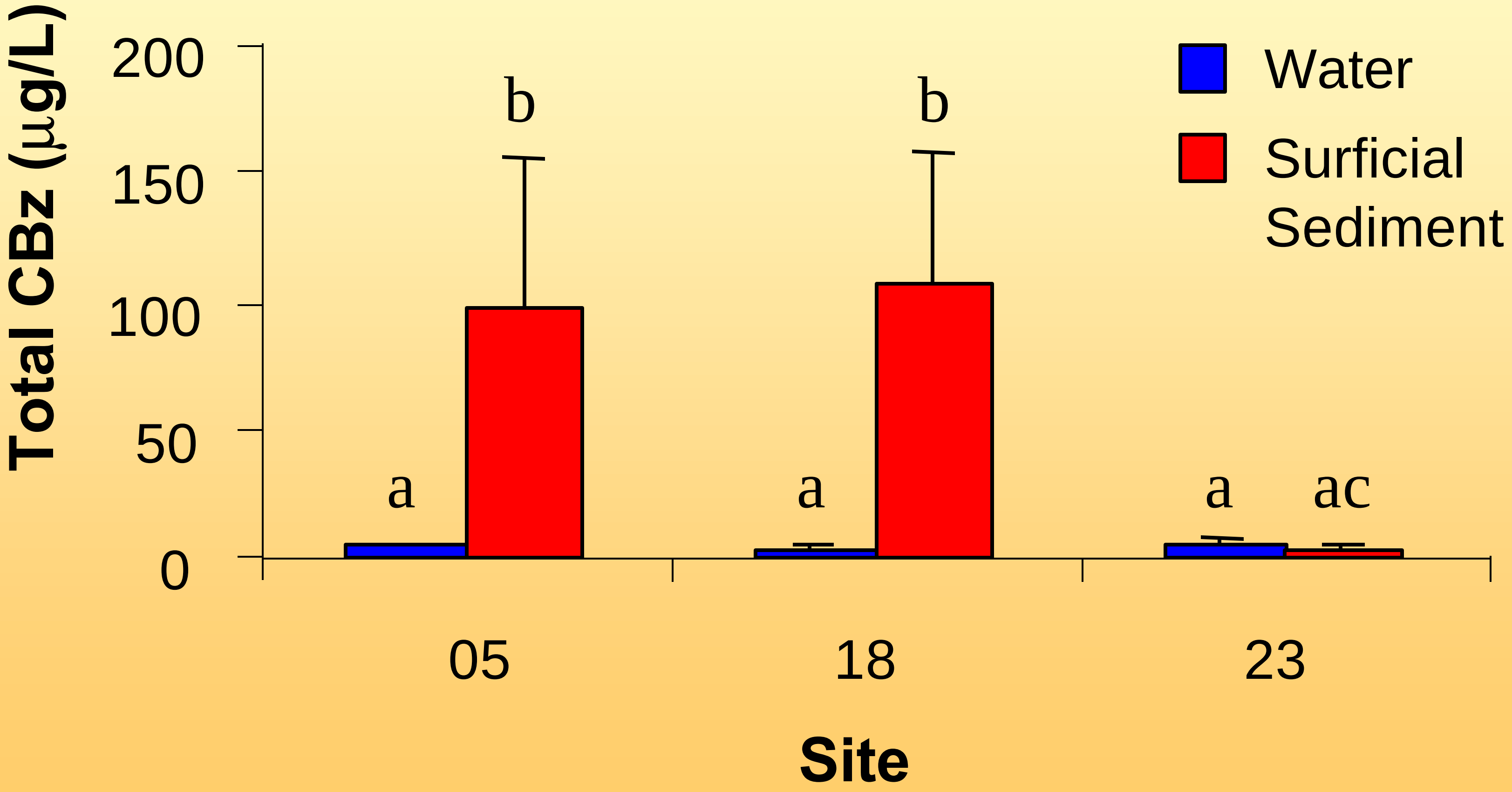
(Greenberg, M.S. et al. *Environ. Toxicol. Chem.* 21(2):289-297, 2002)

Total Chlorobenzenes in Pore Water



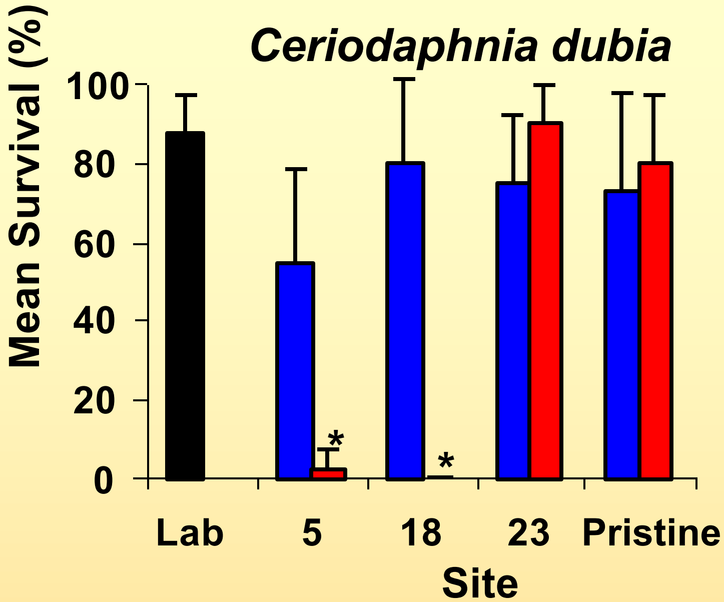
(Greenberg, M.S. et al. *Environ. Toxicol. Chem.* 21(2):289-297, 2002)

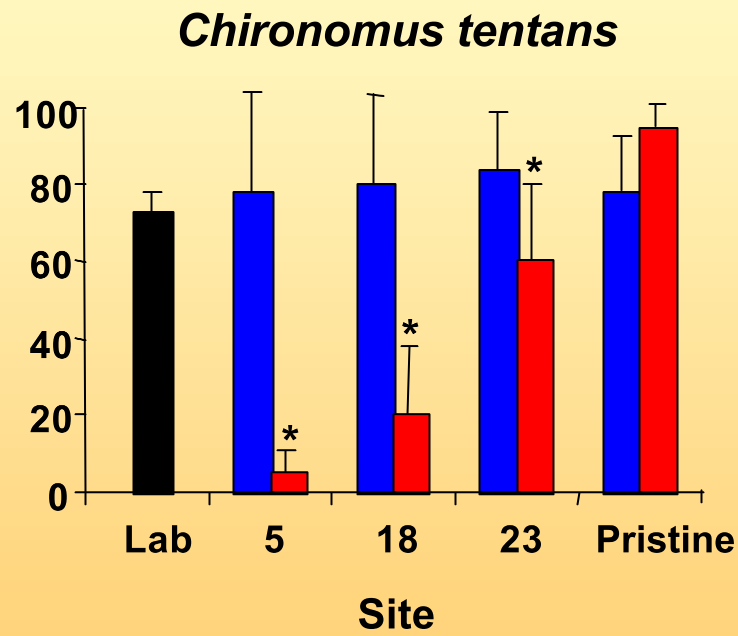
Total Chlorinated Benzene Exposure Levels Within *In Situ* Chambers

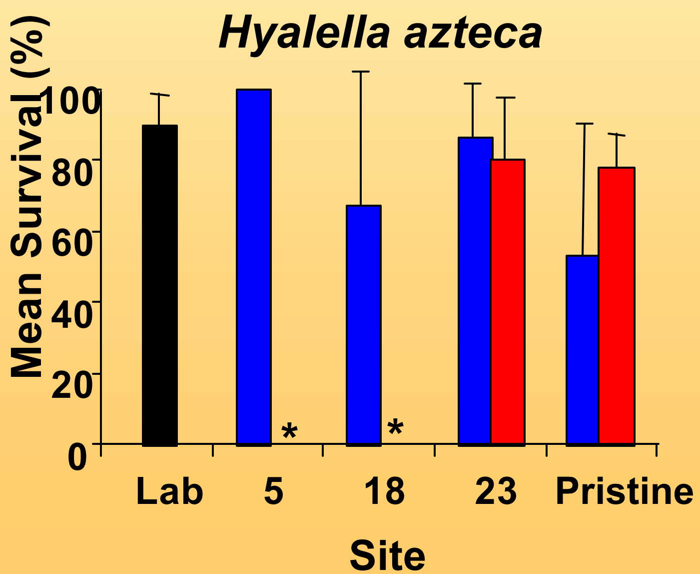


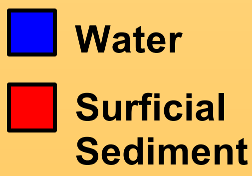
(Greenberg, M.S. et al. *Environ. Toxicol. Chem.* 21(2):289-297, 2002)

In Situ Exposure
Maine Chlorobenzene Study





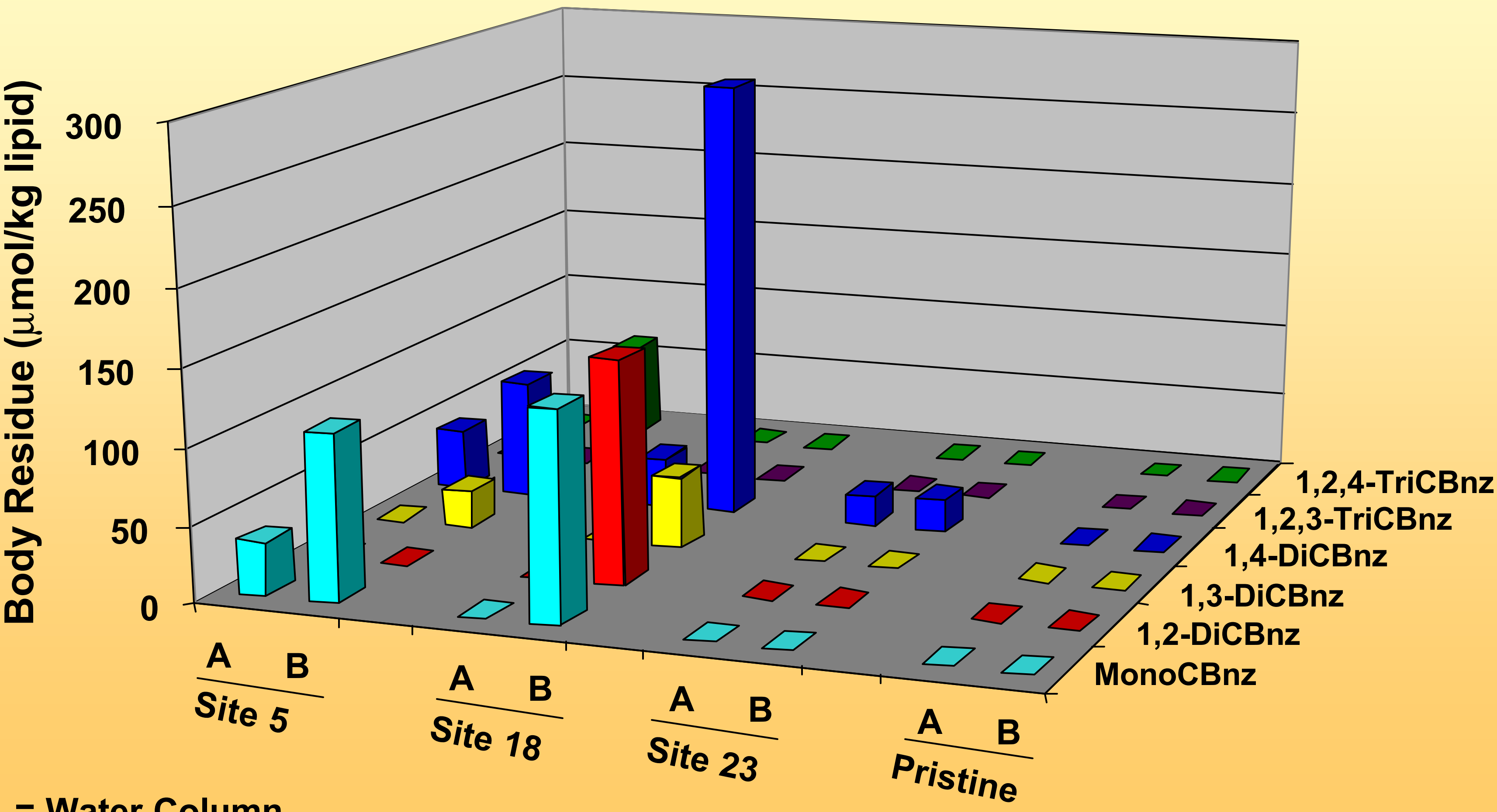




*** Significantly different from field reference site, Pristine ($p < 0.05$)**

(Greenberg, M.S. et al. *Environ. Toxicol. Chem.* 21(2):289-297, 2002)

96-h *In Situ* Bioaccumulation
L. variegatus, Maine Chlorobenzene Study



A = Water Column
B = Surficial Sediments

(Greenberg, M.S. et al. *Environ. Toxicol. Chem.* 21(2):289-297, 2002)

Conclusions: Field Studies

- Mini-piezometer data provide a unique *in situ* characterization approach--must document GW-SW conditions
- Data from mini-piezometers improved interpretation of exposure-effects relationships
- Downwelling was shown to reduce exposure in one system

Conclusions: Field Studies

- Upwelling conditions were shown to increase exposure and effects when sediments and groundwater were contaminated
- Integrated approaches are essential in a holistic assessment of sediment toxicity

Bioaccumulation Model

Objectives

- Develop a bioaccumulation model that accurately predicts tissue concentrations for benthic species exposed to contaminated sediments
- Evaluate model by comparing predictions to *in situ* bioaccumulation at sites containing contaminated sediments

Methods

- Laboratory:
  - Model compounds: FLU and TF
  - Toxicokinetics tests (sediment bioaccumulation; waterborne kinetics)
  - Sediment desorption kinetics (Tenax®-TA beads)

- Model development:
  - Parameterized with laboratory and literature data
  - Used kinetic rate constants for pore water uptake
  - Used desorption data to determine pore water concentrations
  - Upwelling and downwelling included by addition of a pore water flow term

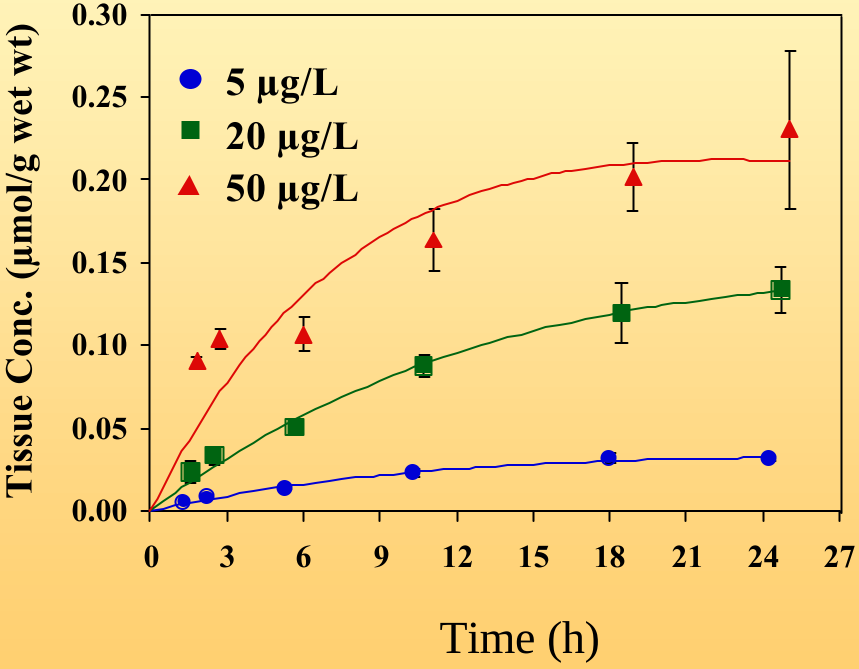
Methods

- Model validation:
  - Bioaccumulation of chlorobenzenes by *in situ* exposed L. variegatus simulated
  - Chlorobenzene parameters obtained from literature
  - Simulated steady state concentrations compared to measured tissue residues

Kinetics of waterborne FLU in *L. variegatus*

$$\frac{\mathrm{d}C_a}{\mathrm{d}t} = k_u C_w^0 e^{-\lambda t} - k_e C_a$$

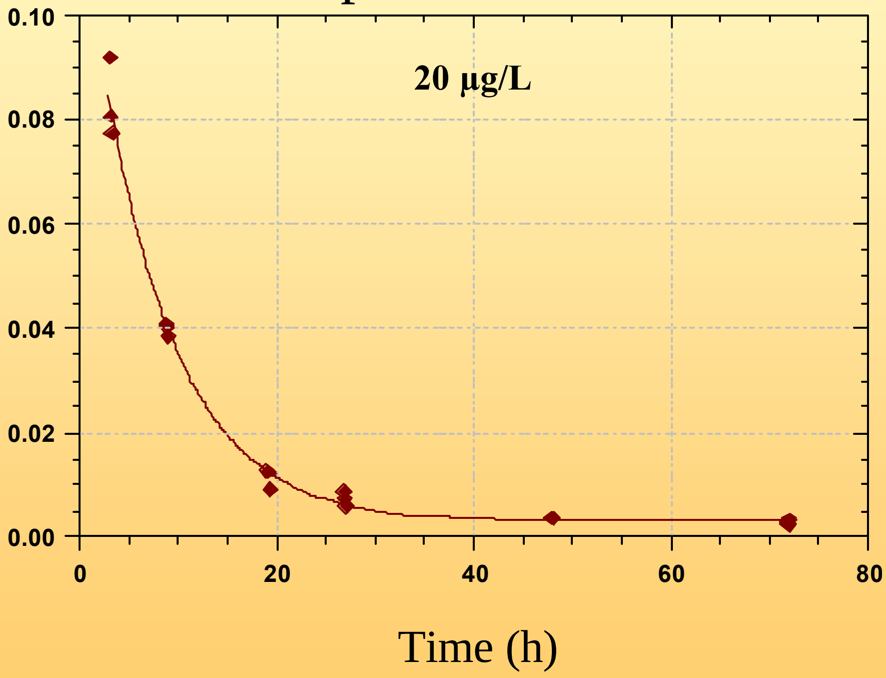
Bioconcentration



k_u = 150 (±14) mL•g^{-1}•h^{-1}

k_e = 0.076 (±0.035) h^{-1}

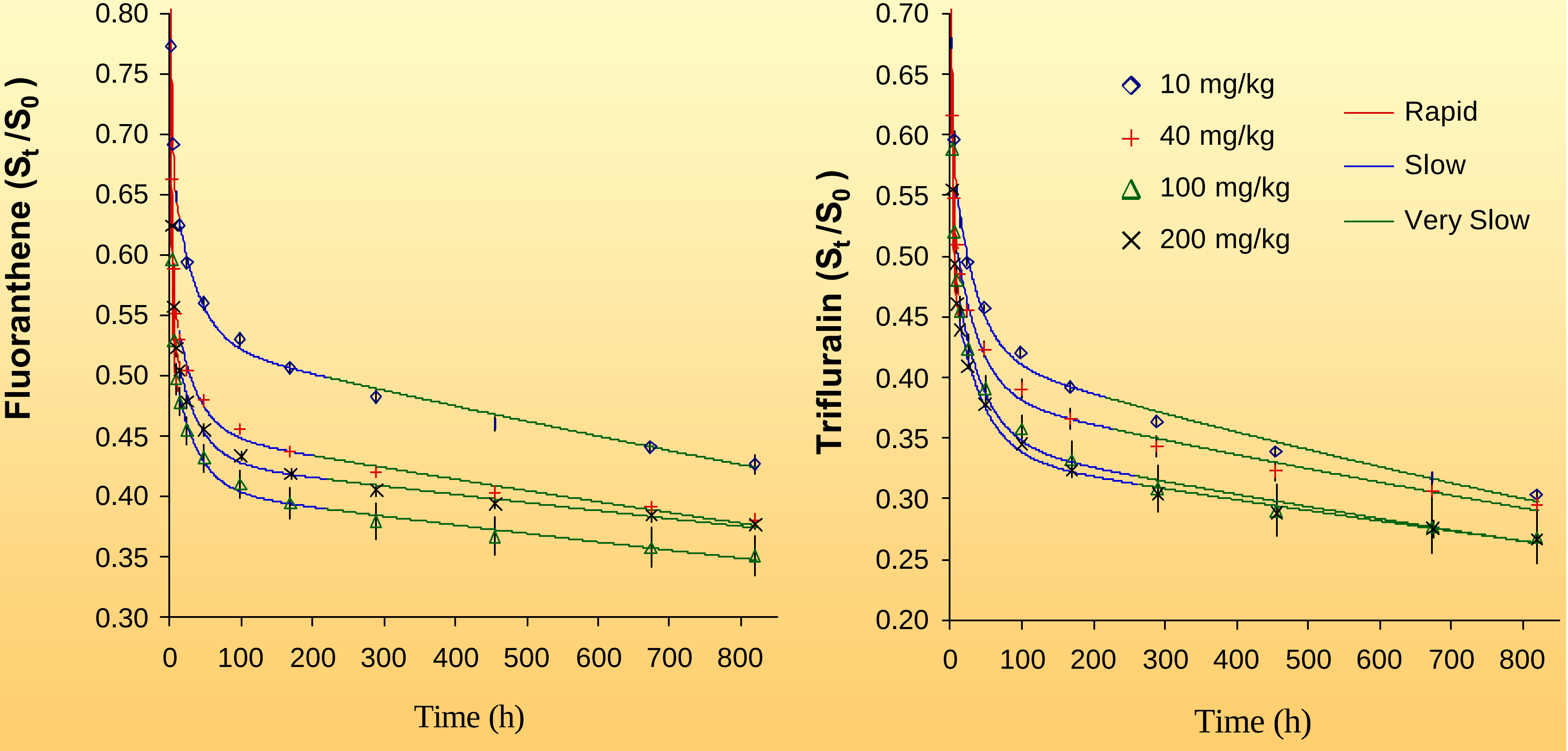
Post-exposure elimination



$k_{e(m)}$ = 0.13 (±0.0035) h^{-1}

Desorption: Lake Huron Sediments

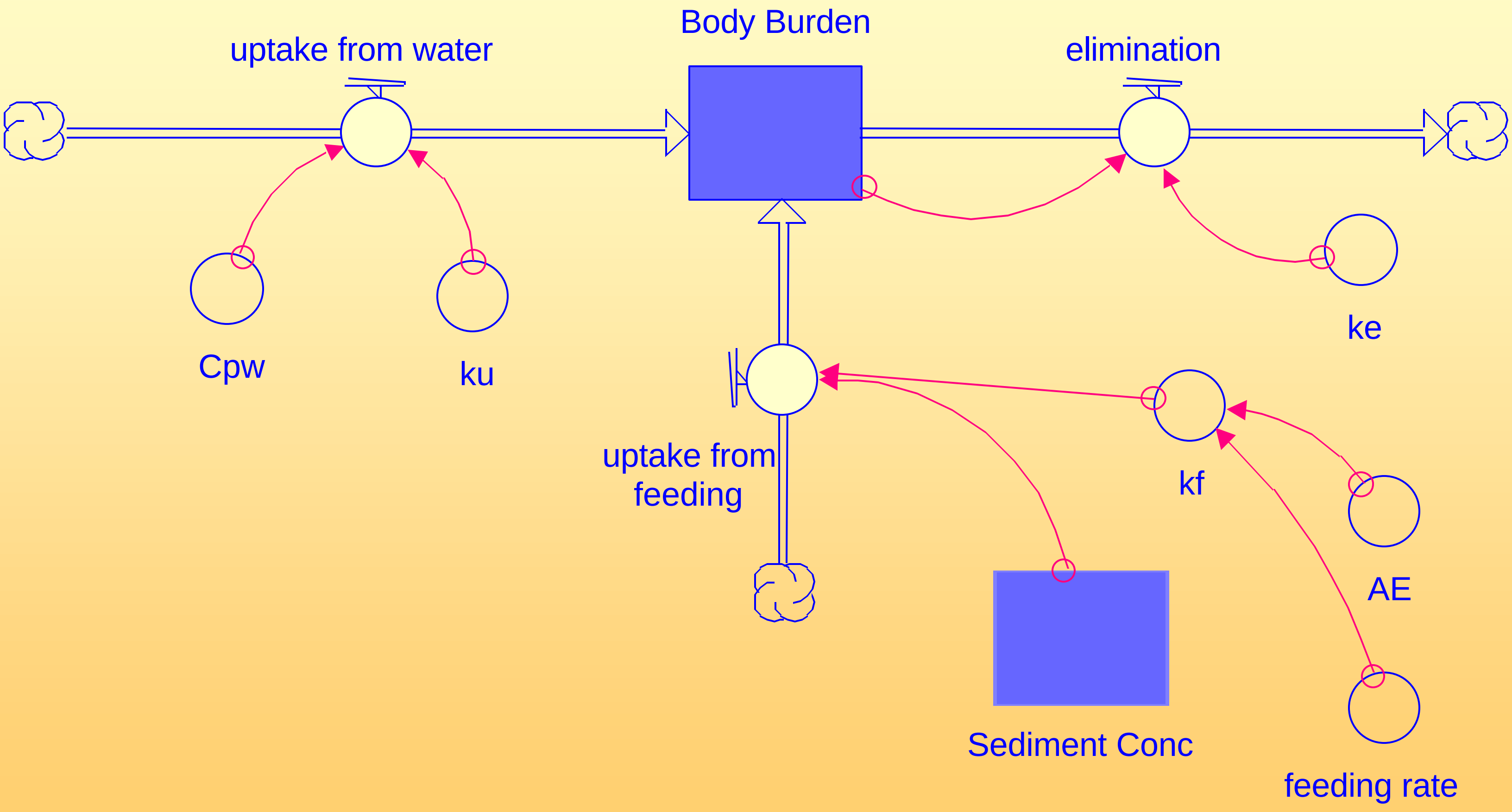
$$S_t / S_0 = F_{rapid}(e^{-k_{rapid} * t}) + F_{slow}(e^{-k_{slow} * t}) + F_{veryslow}(e^{-k_{veryslow} * t})$$



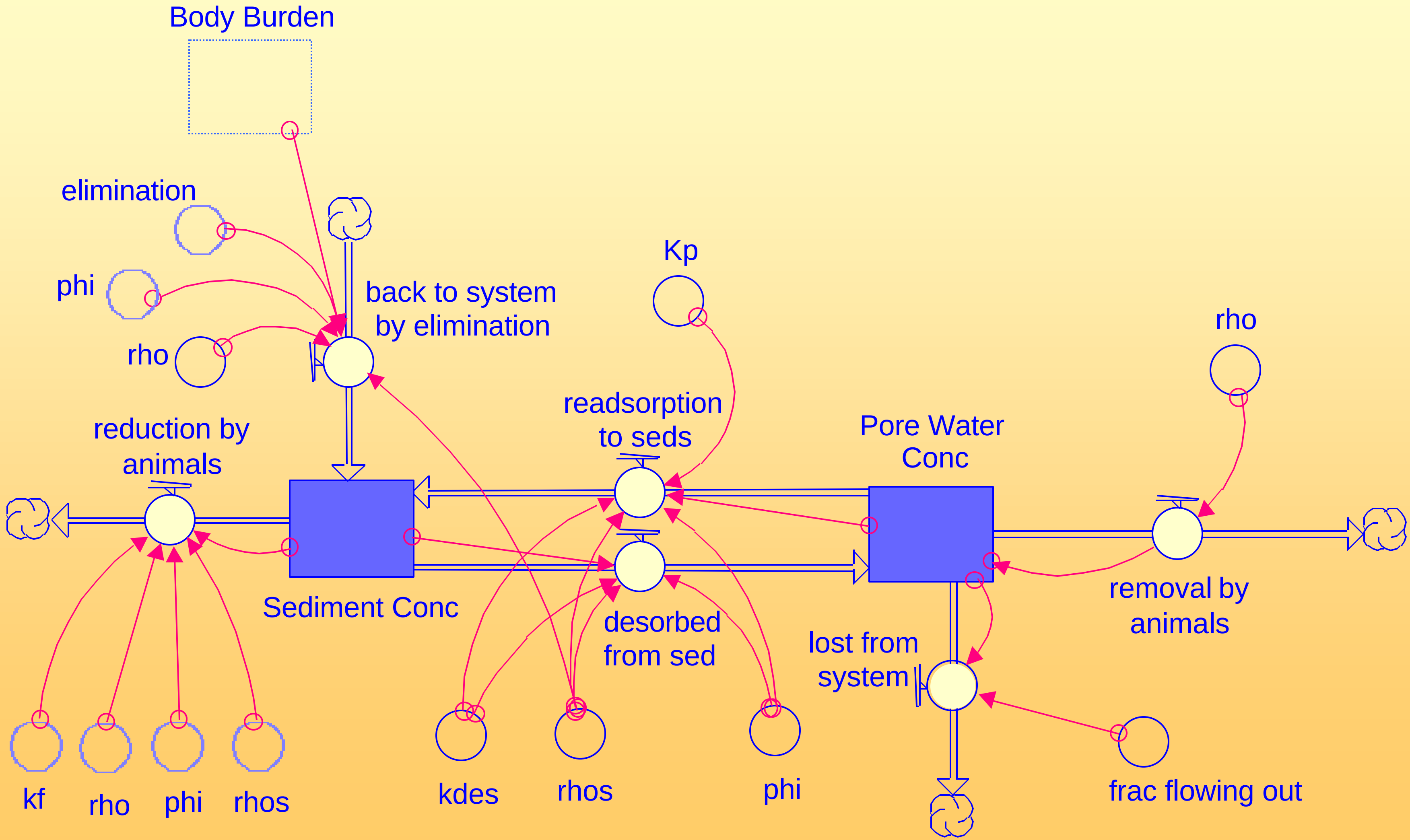
<u>Desorption Rates:</u>
10^{-2} - 10^{-4} h^{-1}

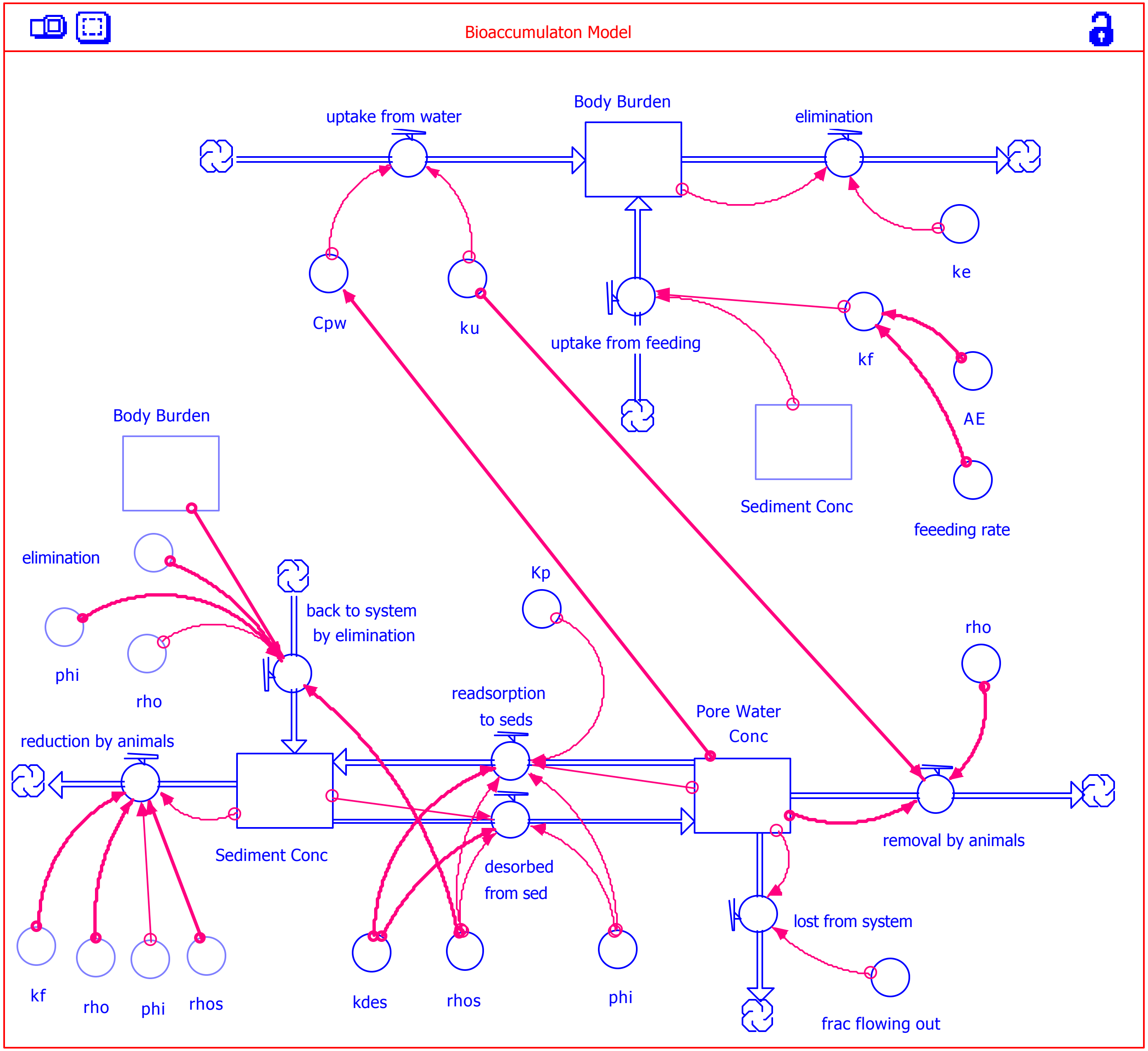
Rapid $t_{99.9}$ 0.5 d
Slow $t_{99.9}$ 12 d
Very Slow $t_{99.9}$ 3 y

Organism Sector



Sediments & Pore Water Sector

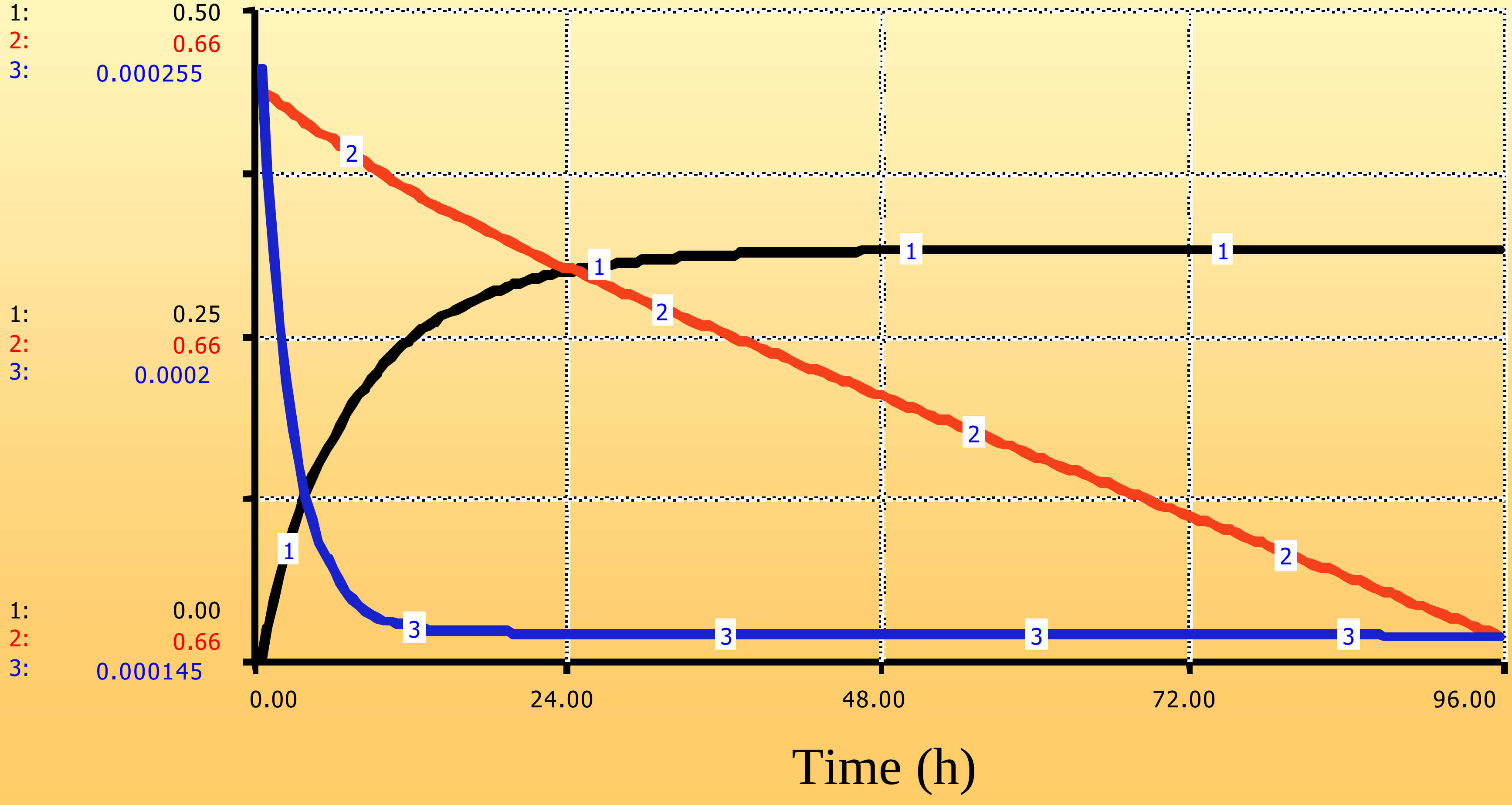




Bioaccumulaton Model
Body Burden
uptake from water
elimination
Cpw
ku
ke
uptake from feeding
kf
AE
Sediment Conc
feeeding rate
Body Burden
elimination
phi
rho
back to system
by elimination
Kp
rho
readsorption
to seds
Pore Water
Conc
reduction by animals
Sediment Conc
desorbed
from sed
removal by animals
lost from system
frac flowing out
kf
rho
phi
rhos
kdes
rhos
phi

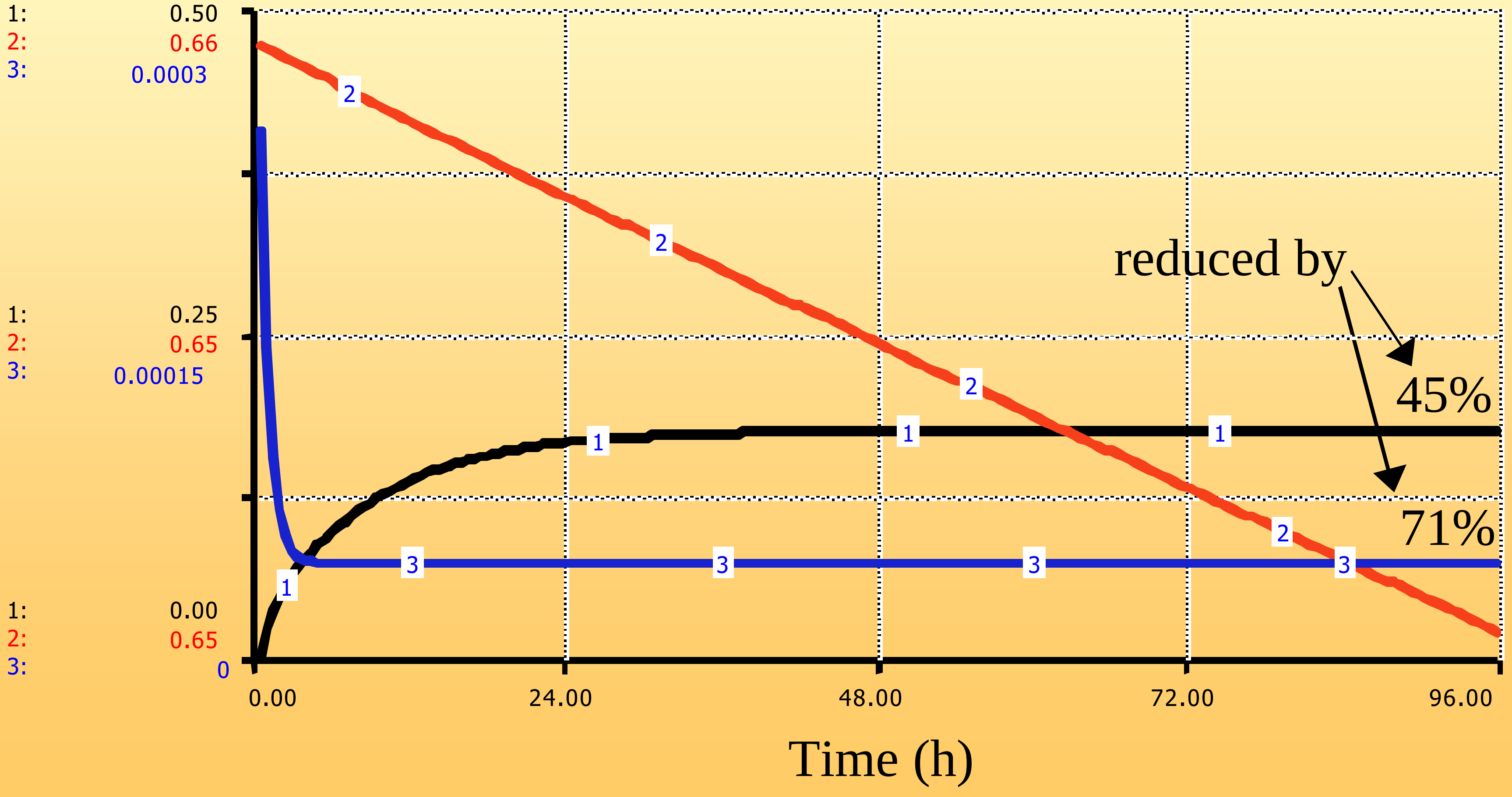
Model output: No pore flow

1. Body Burden (µmol/g wet wt)
2. Sediment Conc. (µmol/g dry wt)
3. Pore Water Conc. (µmol/mL)



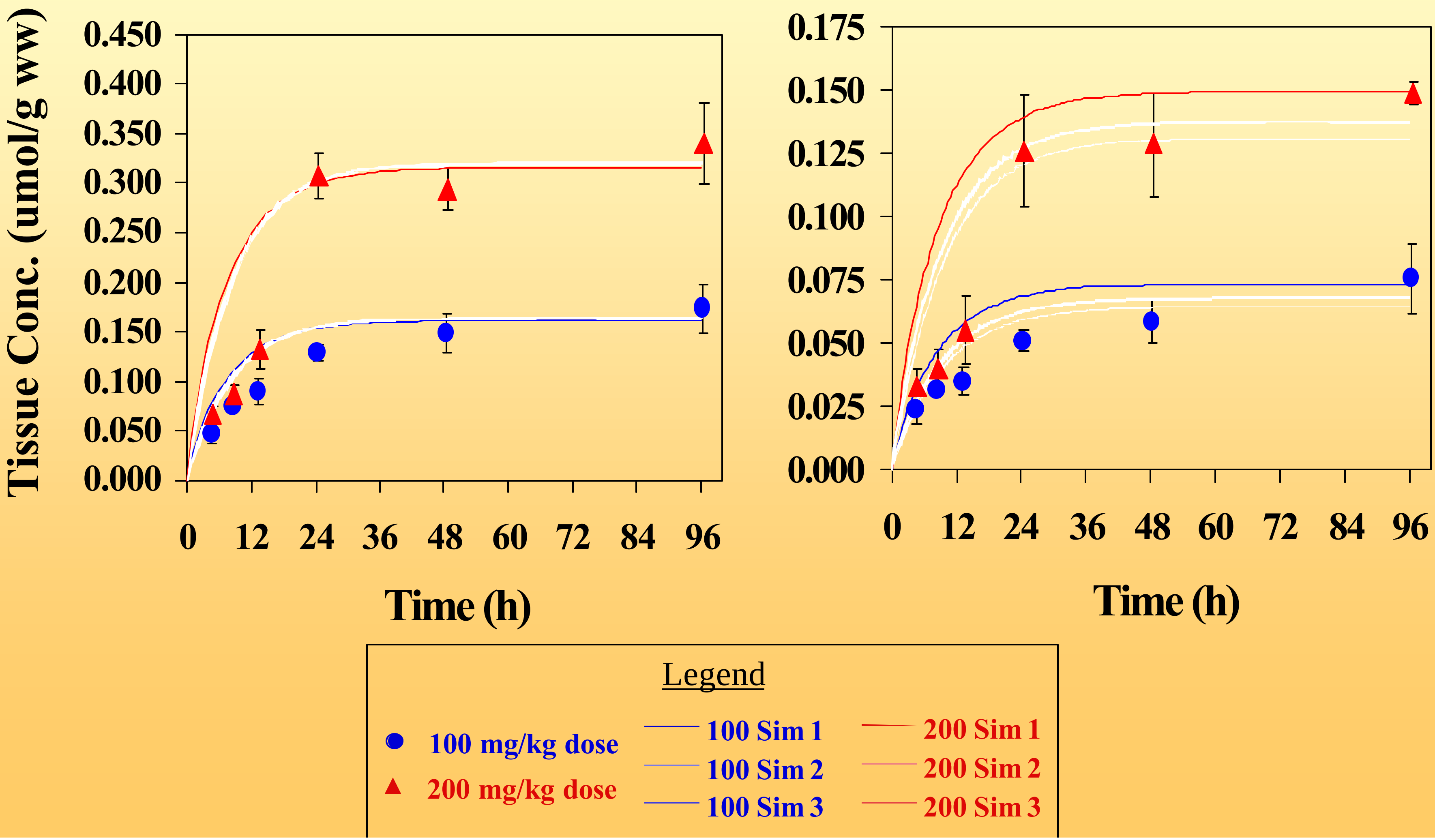
Model output: Full pore flow

1. Body Burden (µmol/g wet wt)
2. Sediment Conc. (µmol/g dry wt)
3. Pore Water Conc. (µmol/mL)



Model predictions and experimental tissue concentrations: Lake Erie, *L. variegatus*

A) Fluoranthene **B) Trifluralin**



Field validation for 1,4-dichlorobenzene

Compound	Site	Measured body burden (µmol/g wet wt)	Predicted body burden (µmol/g wet wt)	Factor	Parameter and value
1,4-DiCB	5	1.02e-03	1.12e-03	1.09	k_u = 0.070 k_e = 0.257 FR = 0.01 q = 0.10
	18	3.74e-03	5.64e-03	1.51	k_u = 0.070 k_e = 0.257 FR = 0.01 q = 0.10
	23	2.31e-04	1.49e-03	6.43	k_u = 0.070 k_e = 0.257 FR = 0.01 q = 1.00
			2.35e-04	1.02	k_u = 0.070 k_e = 0.257 FR = 0.00 q = 0.25

Conclusions

- The model adequately reproduced the C_{ss} observed in laboratory sediment exposures
- Predictions of field bioaccumulation data that were 4 provided a degree of validation of the model
- Qualitative description of upwelling and downwelling in the model indicated that this term is an important determining factor in bioavailability
- The model simulations suggested that *in situ* rates of feeding should be measured, as FR is a sensitive parameter.

The Future…

- Future research will be designed to improve characterization of GSI to improve the modeling of the impact of upwelling and downwelling on exposure, effects and bioaccumulation.