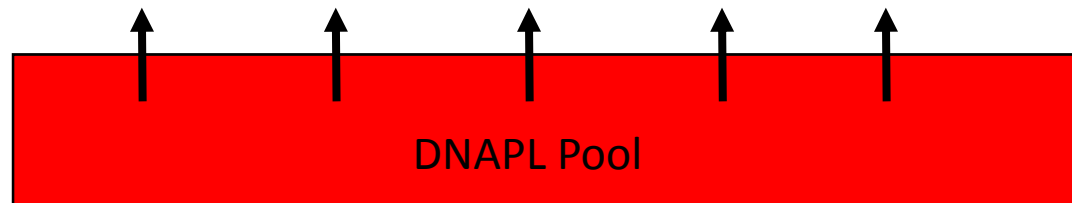


# EISB in DNAPL Source Zones

## Section 4

# EISB Concept – DNAPL Dissolution Enhancement

Rate of dissolution depends on concentration gradient at NAPL-water interface.

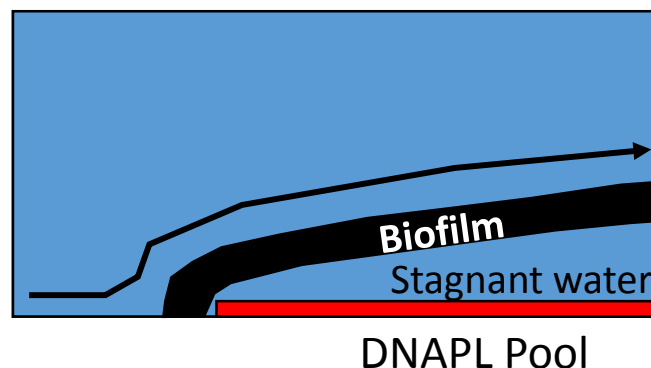


**EISB:** Larger concentration gradient → Faster dissolution

# Chu et al. (2003) Model Results

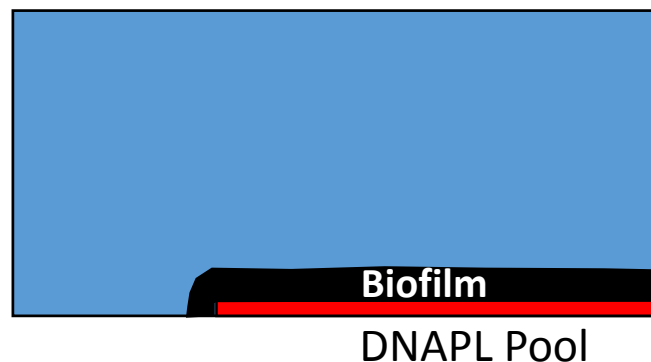
## Case 1:

- Low electron donor concentration
- Biofilm grew away from NAPL-water interface
- Less effective dissolution enhancement
- Created no-flow zone above NAPL



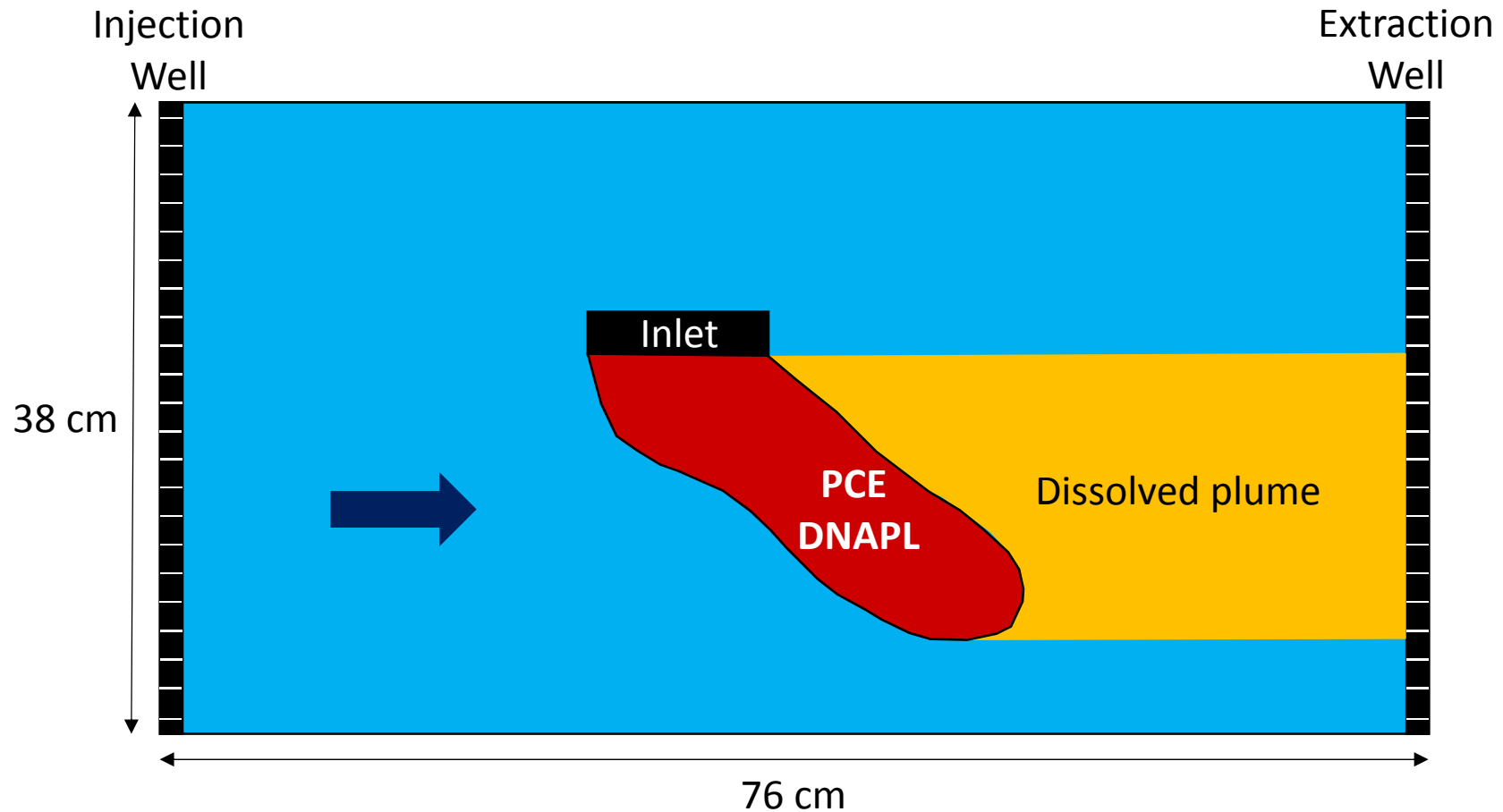
## Case 2:

- Unlimited electron donor
- Biofilm grew adjacent to NAPL-water interface
- Most effective enhancement due to maximum concentration gradient



# Sleep et al. (2006) DNAPL EISB Study

Source: Modified from Sleep et al. (2006)

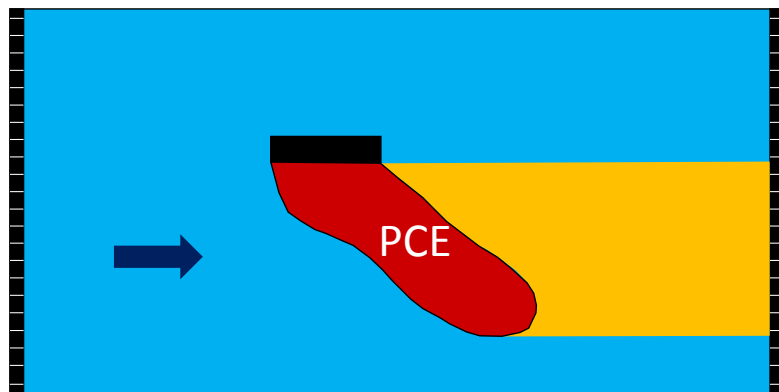


Source zone dimensions: 12 cm x 18 cm x 2.5 xm  
Initial NAPL Saturation ( $S_n$ ): 6.9% (residual DNAPL)

# Sleep et al. (2006) DNAPL EISB Study

- PCE DNAPL introduced at  $t=0$  (10 mL, 16.1 g)
- Soil from Dover AFB

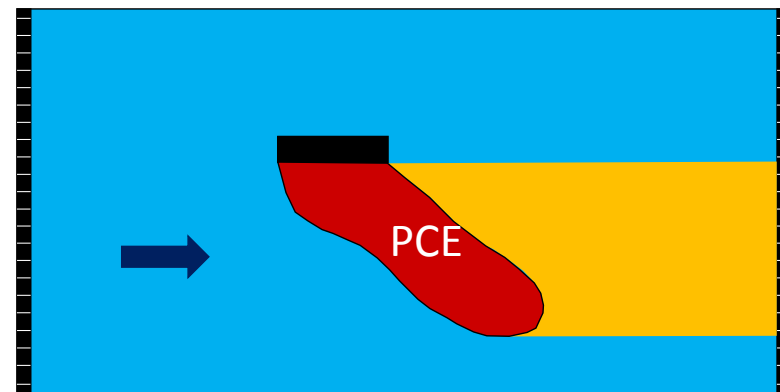
BOX 1



## Biostimulation only

- PCE did not degrade
- Methane build-up

BOX 2



## Biostimulation + Bioaugmentation

- PCE degraded to ethene
- Methane build-up

# EISB Monitoring

- Molarity (M) = # moles per liter of water (mol/L)
- Total molarity of chlorinated ethenes ( $M_{CES}$ )
  - PCE + TCE + cis-1,2-DCE + vinyl chloride + ethenes
- $MW_{PCE}$  = molecular weight of PCE (g/mol)
- Equivalent PCE concentration ( $C_{PCE}$ ) indicates total mass discharge from DNAPL
  - Represents amount of PCE dissolved from the DNAPL, based on measured PCE + daughter species conc.

$$C_{PCE} = 1000 M_{CES} MW_{PCE}$$

Units:

$C_{PCE}$  in mg/L

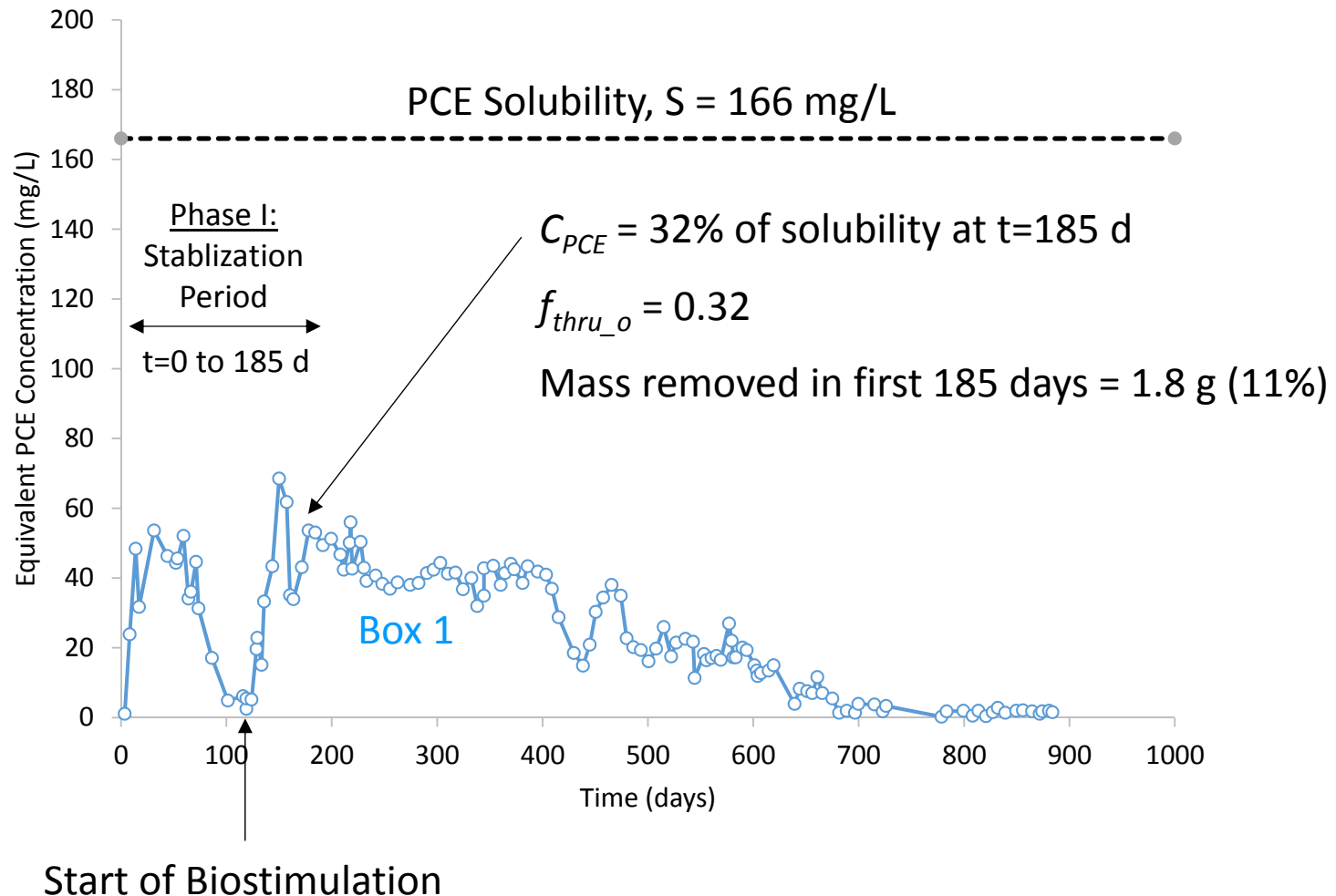
$M_{CES}$  in mol/L

$MW_{PCE}$  in g/mol

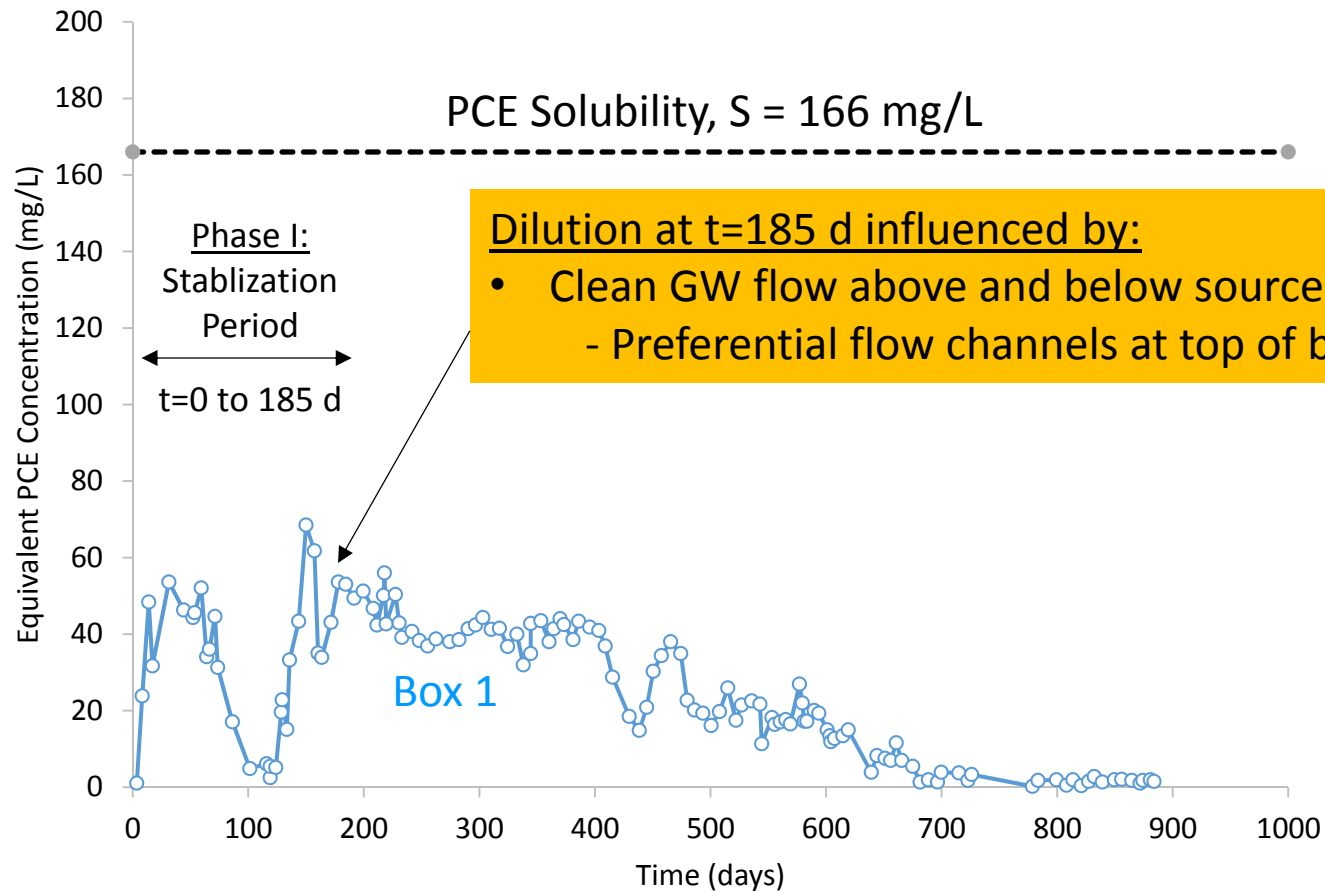


# Effluent PCE Concentrations

Source: Modified from Sleep et al. (2006)

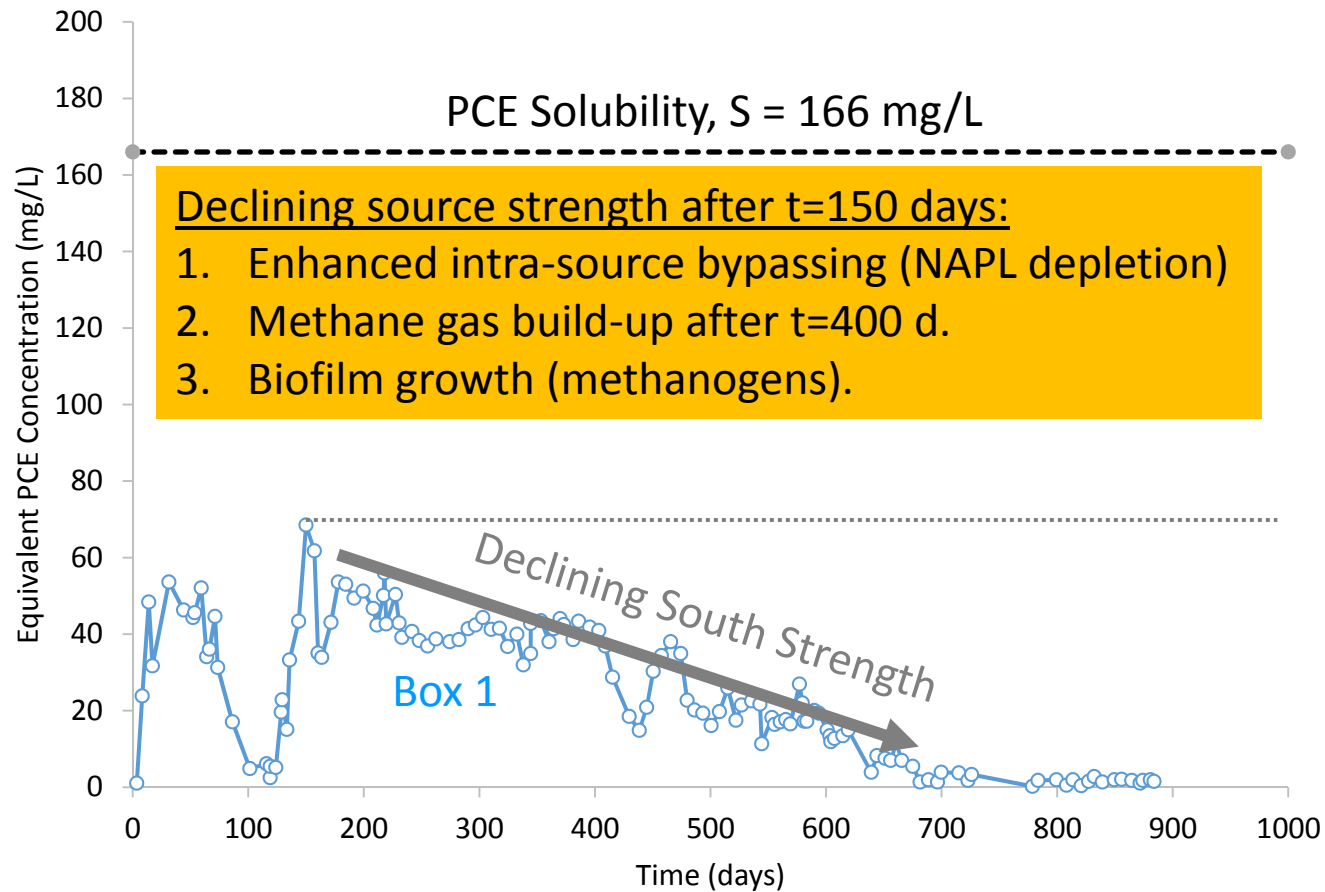


# Effluent PCE Concentrations

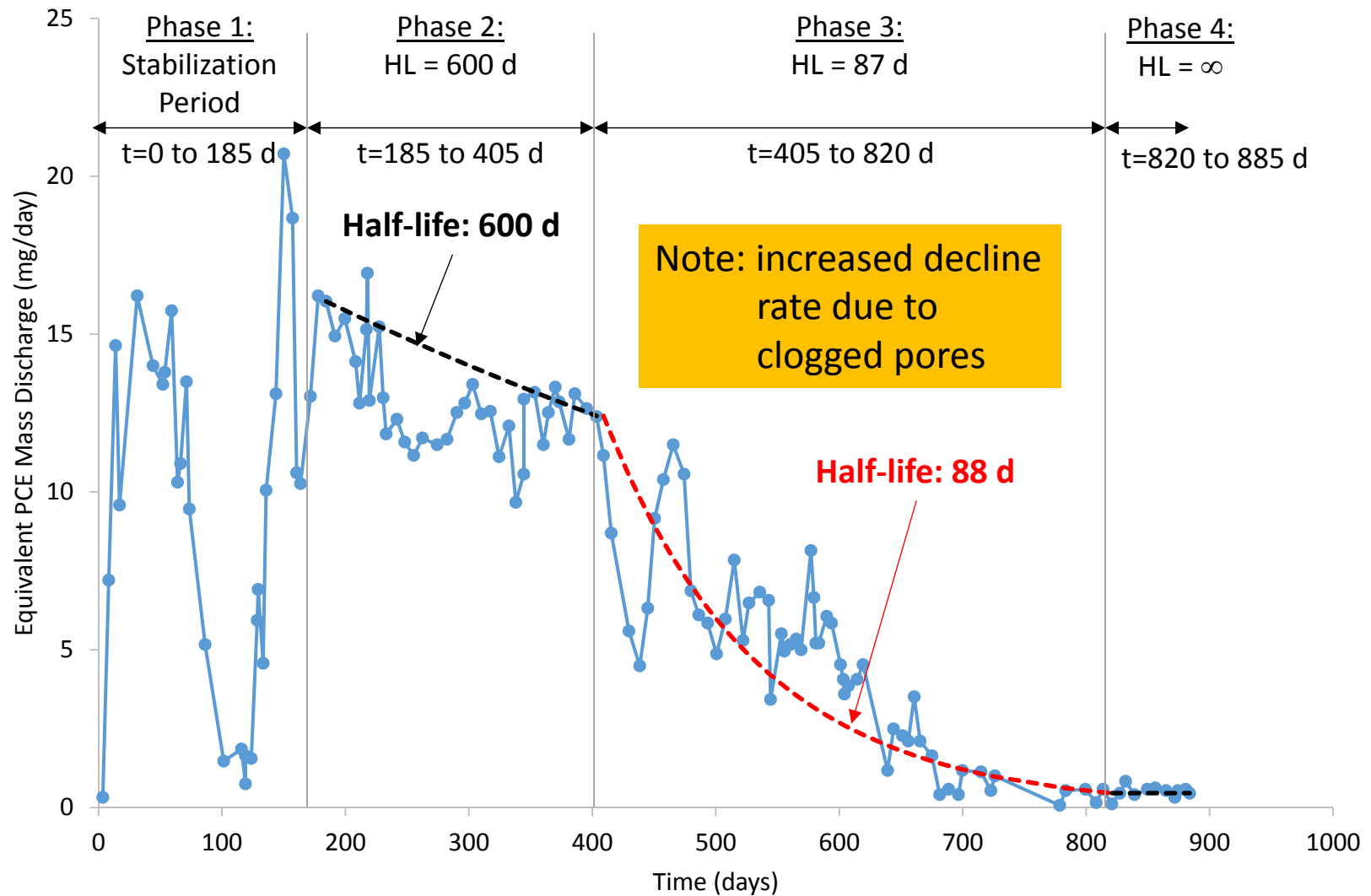




# Effluent PCE Concentrations

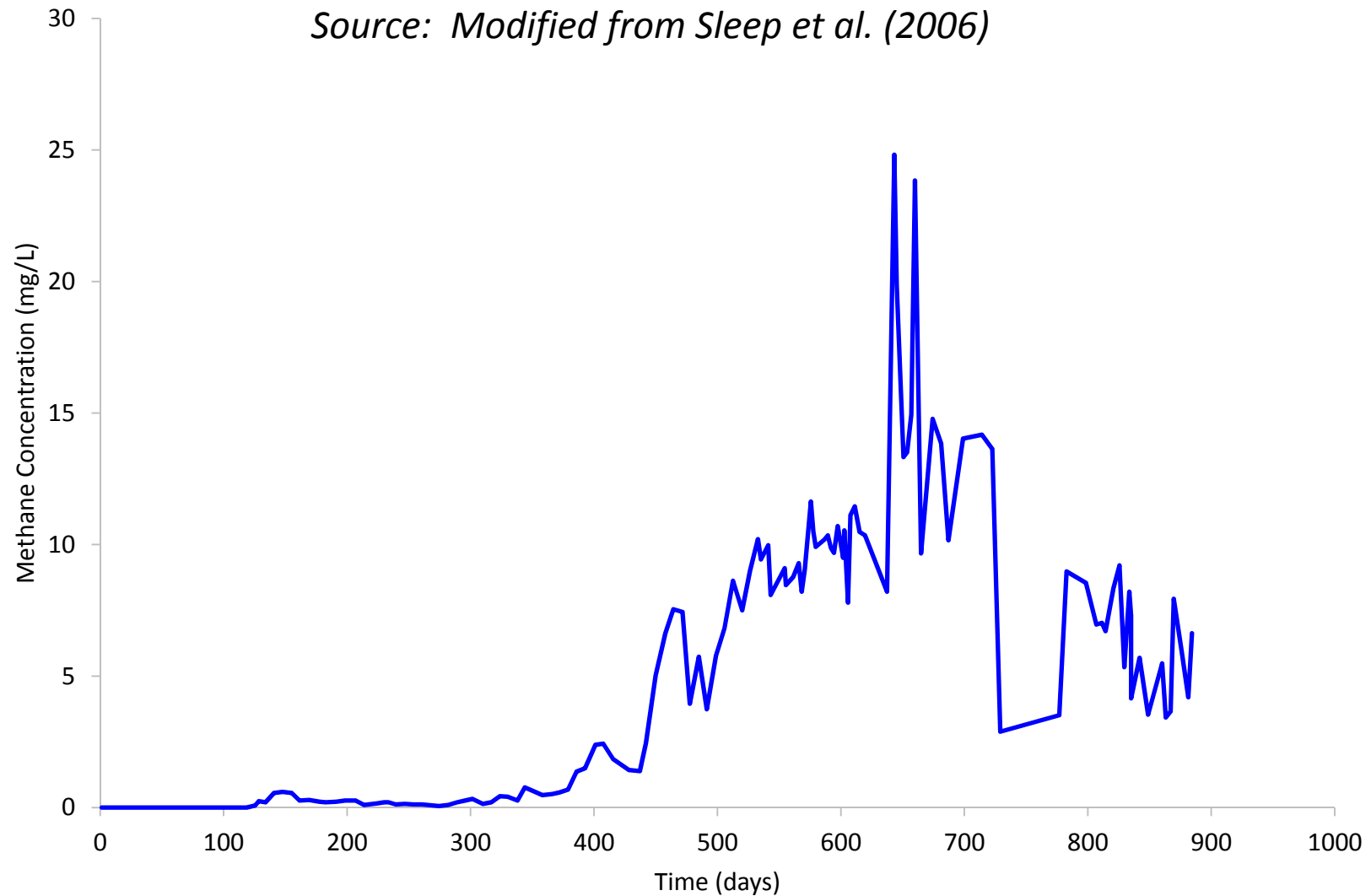


# Through-Discharge Decline Half-Life

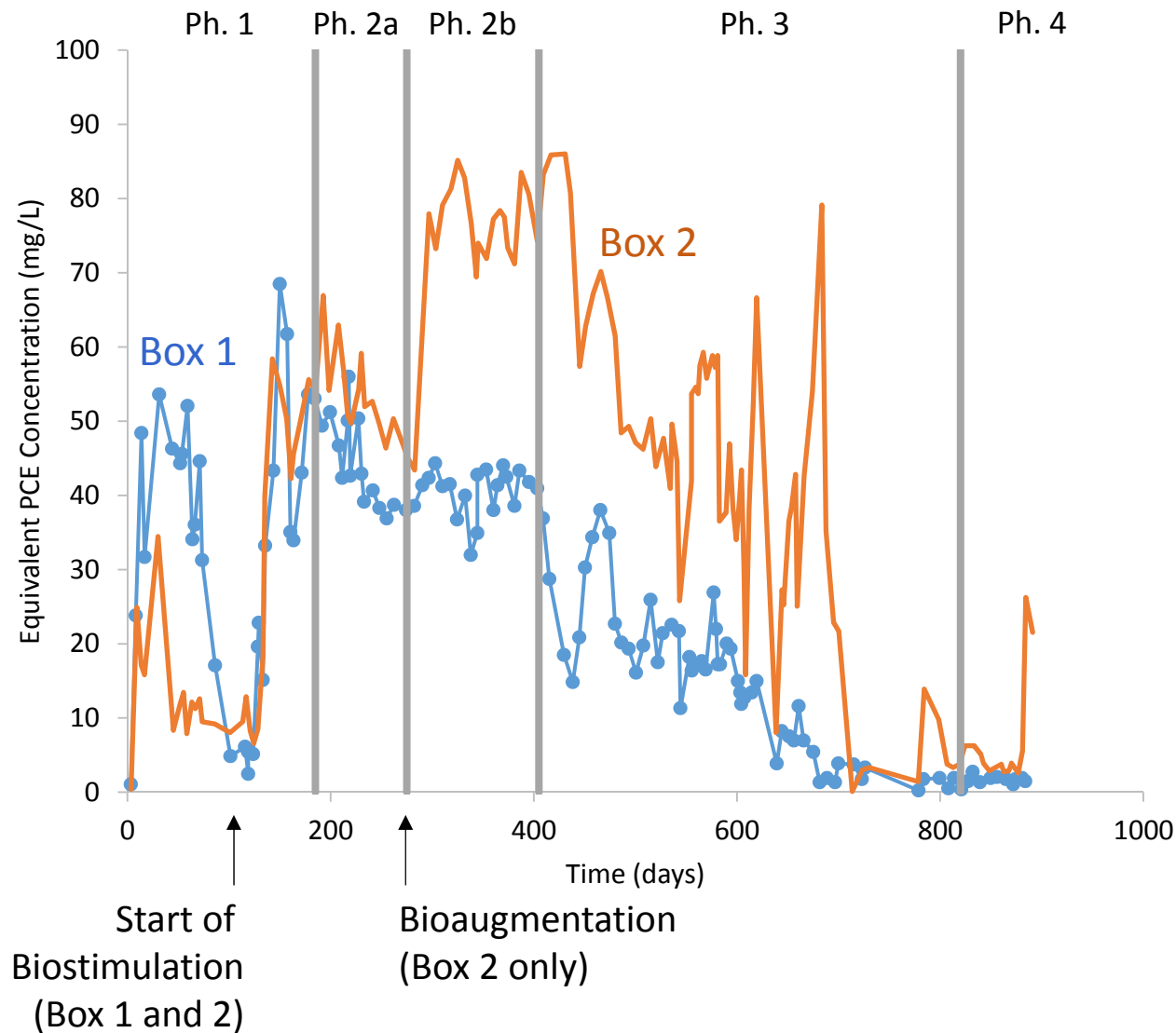


# Effluent Methane Trends

Source: Modified from Sleep et al. (2006)

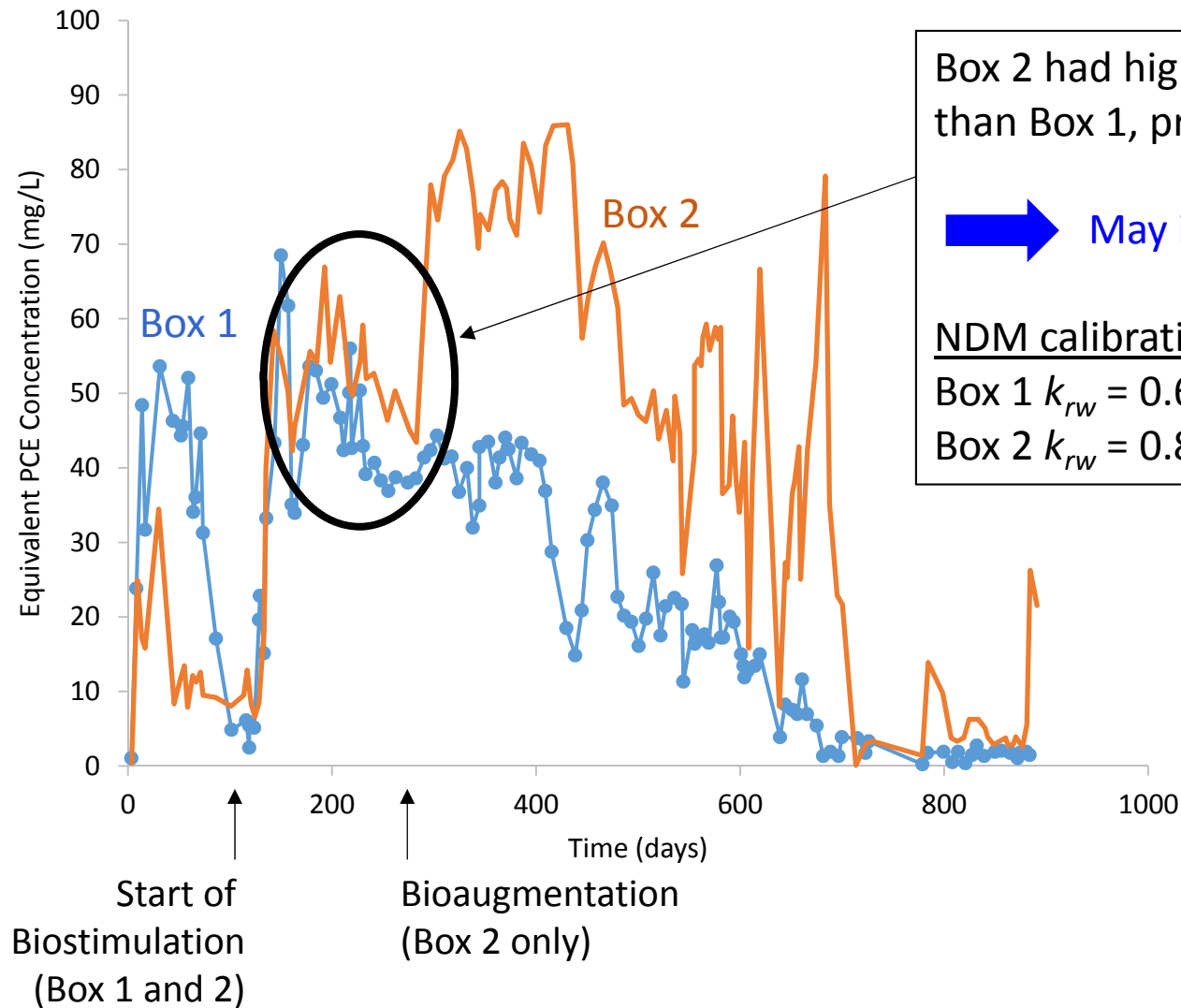


# Box 2 with Bioaugmentation



<u>Phase</u>	<u>Time (d)</u>
1	0 to 185
2a	185 to 275
2b	275 to 405
3	405 to 820
4	820 to 885

# Box 2 with Bioaugmentation



Box 2 had higher source strength than Box 1, prior to bioaugmentation.

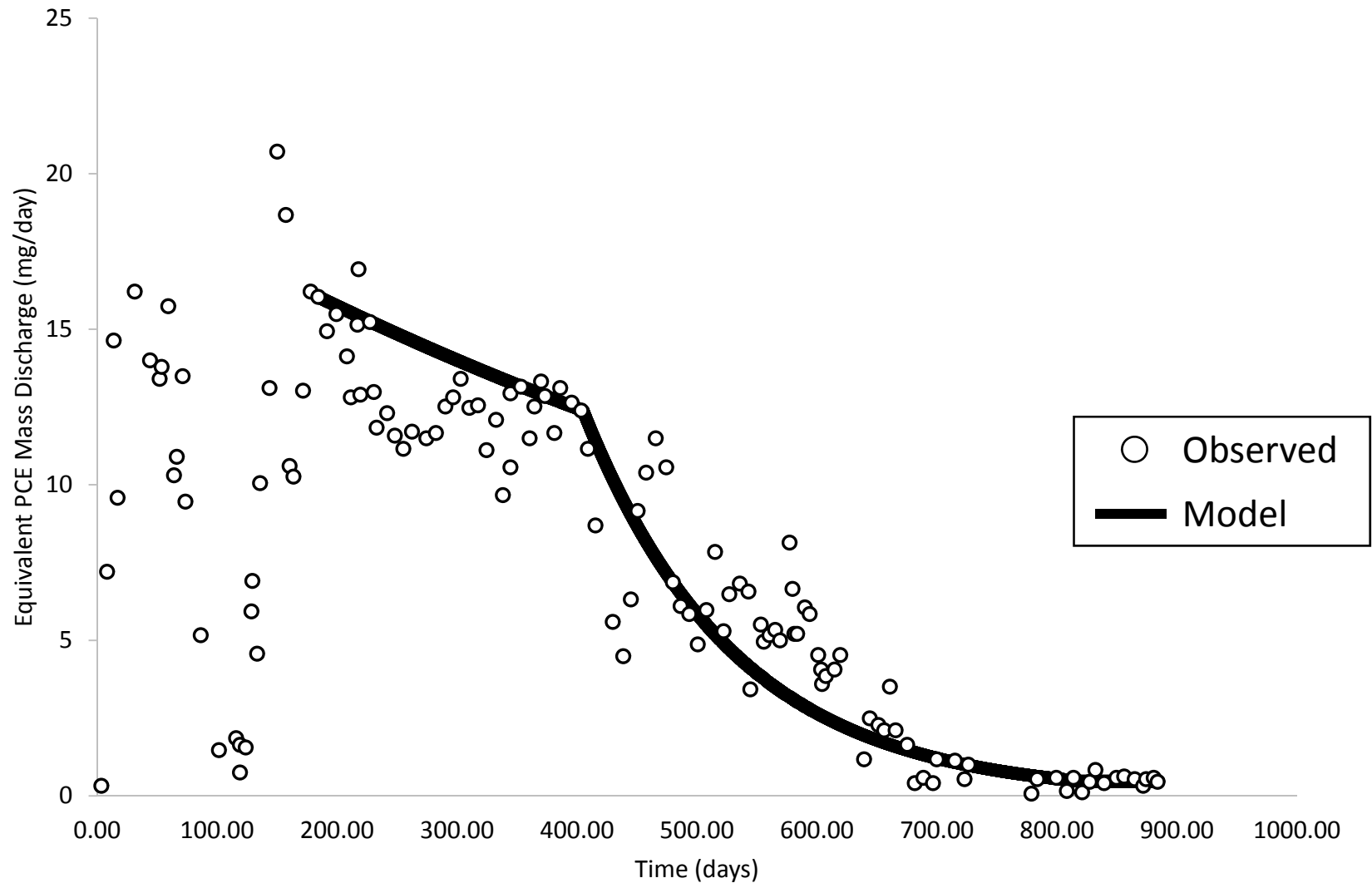
➔ May indicate higher  $k_{rw}$  for box 2.

NDM calibration (Carey):

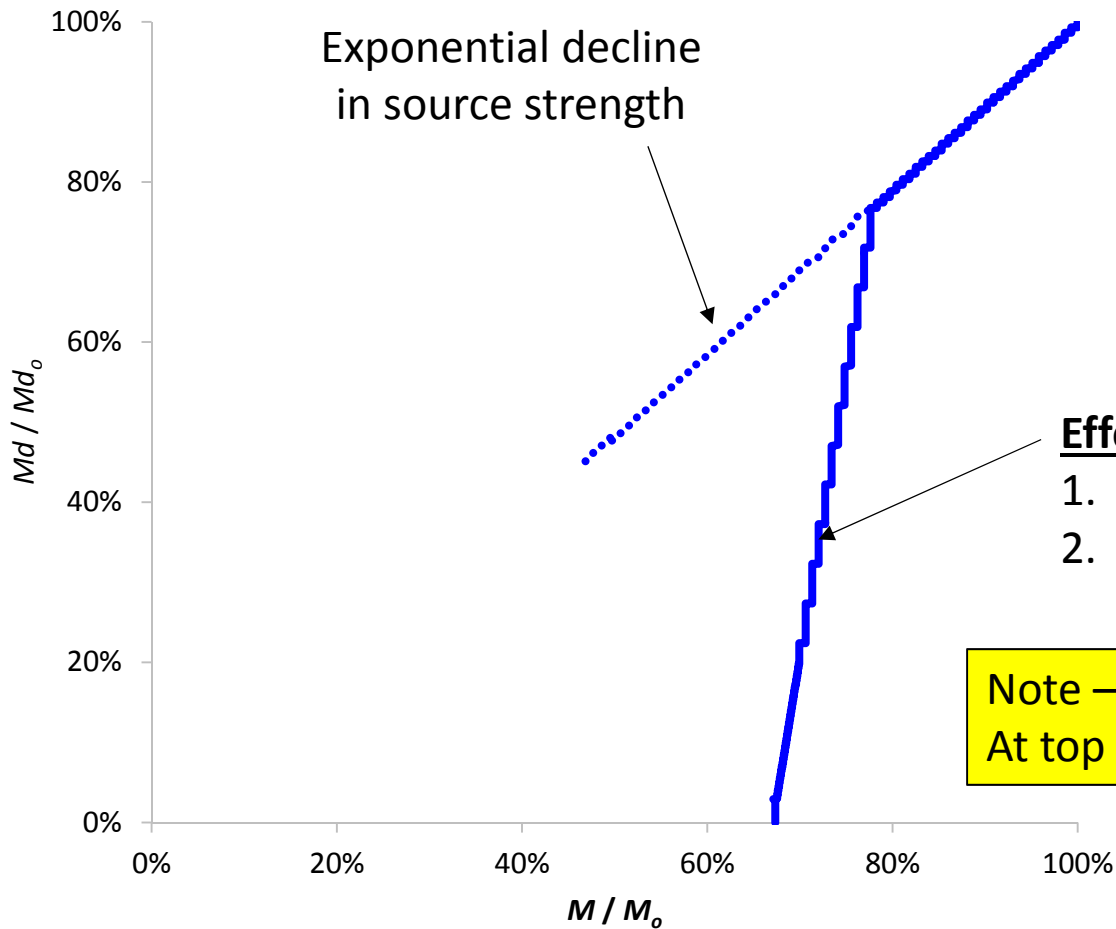
Box 1  $k_{rw} = 0.68$

Box 2  $k_{rw} = 0.85$

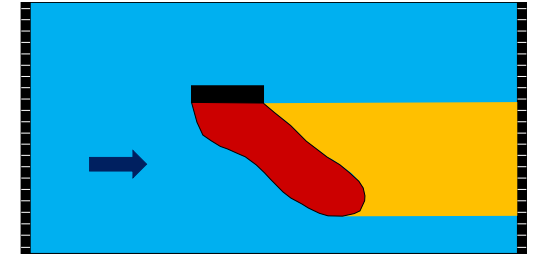
# Box 1 – NDM Model vs. Observed



# Box 1 Model Sensitivity Analysis



Box 1: Biostimulation only  
(no PCE degradation)

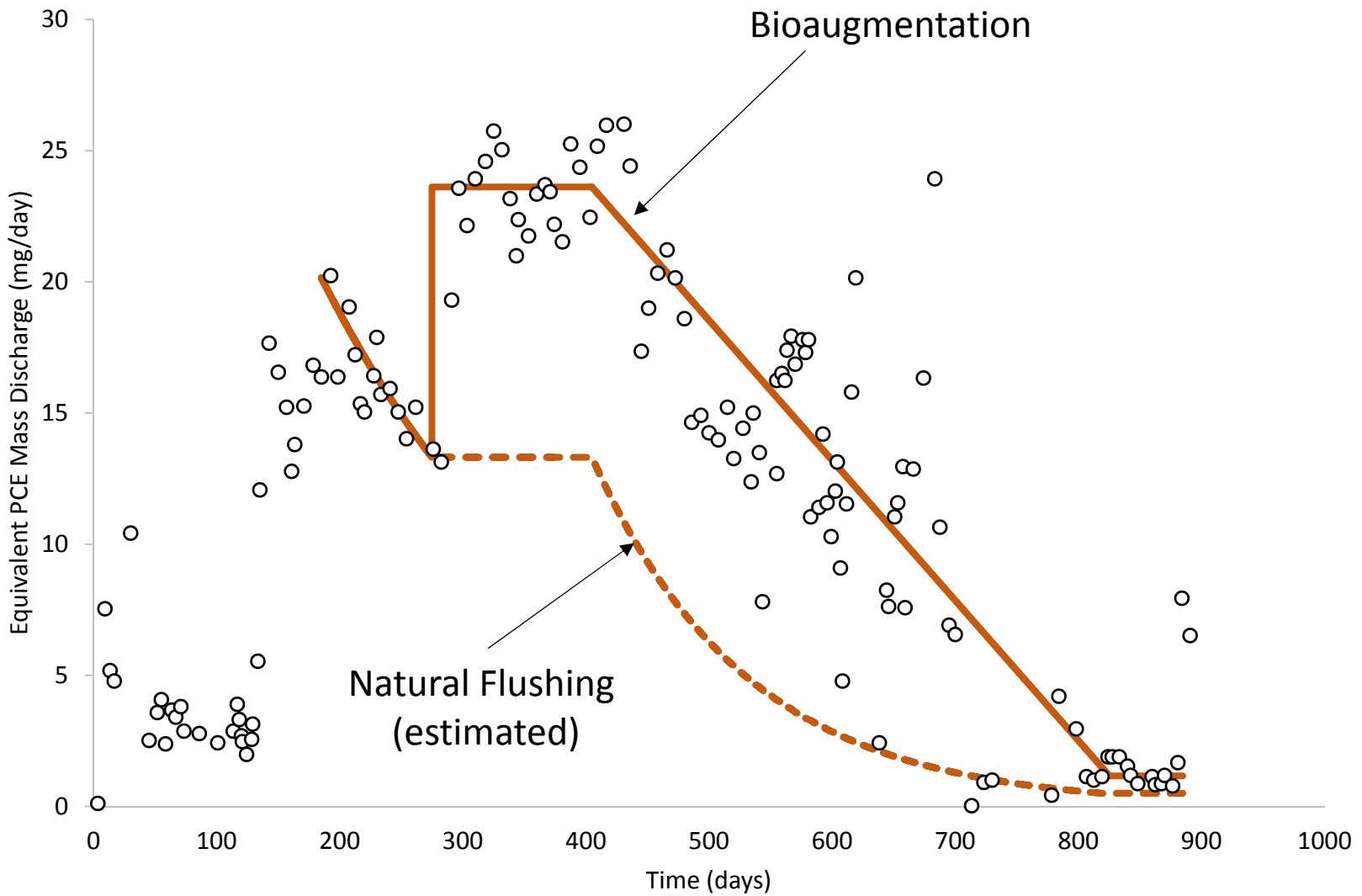


## Effects of clogging from gas bubbles:

1. Poor mass removal efficiency
2. Increased risk reduction

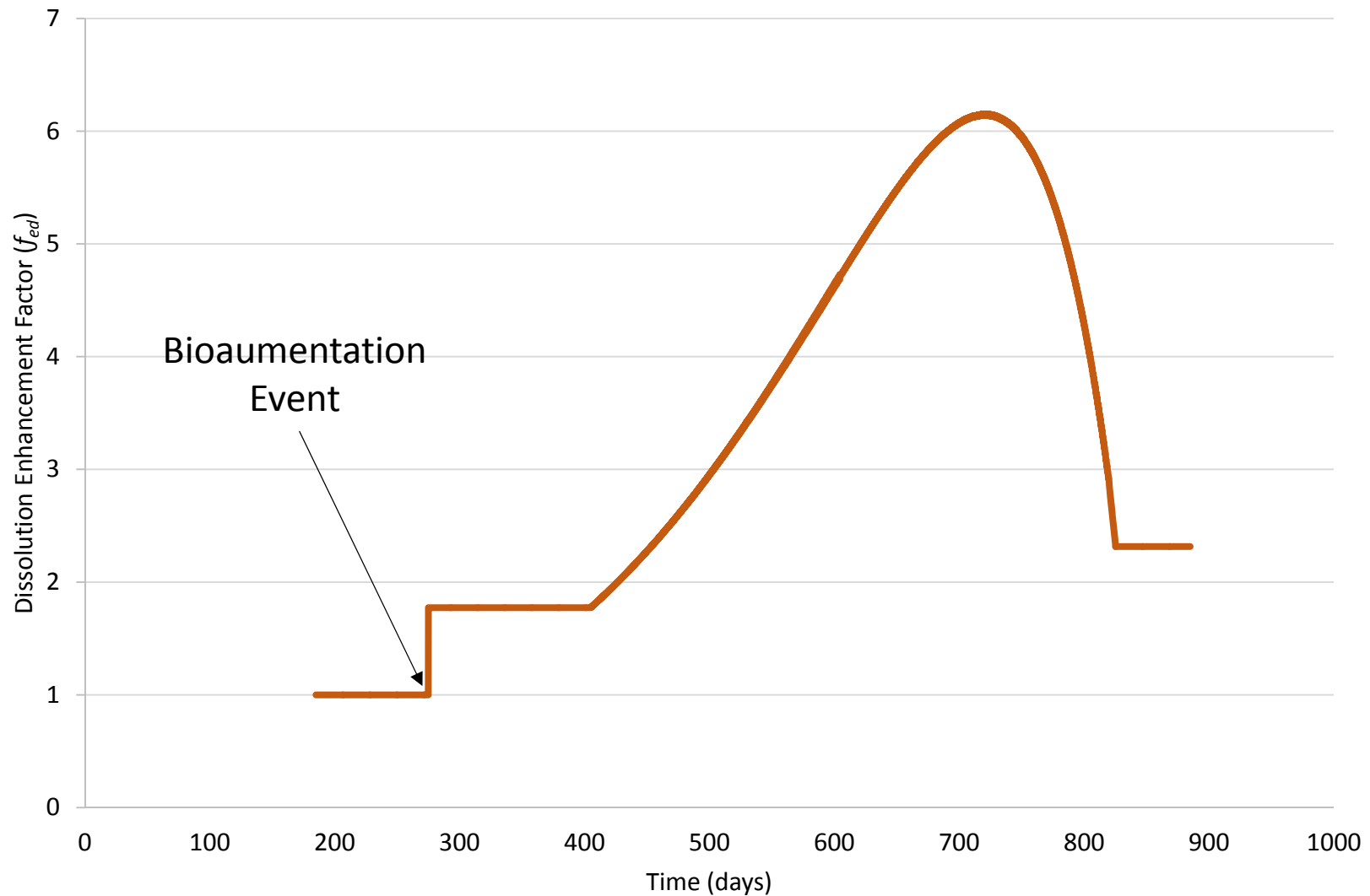
Note – preferential channels observed  
At top of tank (above NAPL source zone)

# Box 2 – Natural and Enhanced Dissolution





# Box 2 – Enhanced Dissolution Factor ( $f_{ed}$ )



# Competition for Electron Donor

- Sleep et al. (2006) estimated % of electron donor utilized for PCE degradation and other processes
- After bioaugmentation, dechlorination accounted for 1% to 7% of electron donor transformation
- Up to t=320 d: Fe-reduction 60% to 100
- After t=320 d: Methanogenesis 49% to 66% (when iron depleted)
- Competition for electron donors will reduce DNAPL dissolution enhancement



# Summary

- EISB may enhance DNAPL dissolution
- Mass removal effectiveness limited by:
  - Pore clogging by biofilm and/or gas bubbles
    - May still result in significant source strength and risk reduction
  - Competition for electron donor
  - Inadequate supply of electron donor at DNAPL-water interface (e.g. pool)
    - Causes bioclogging above interface which inhibits water flow adjacent to DNAPL surface and limits DNAPL dissolution.



# Questions?



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