



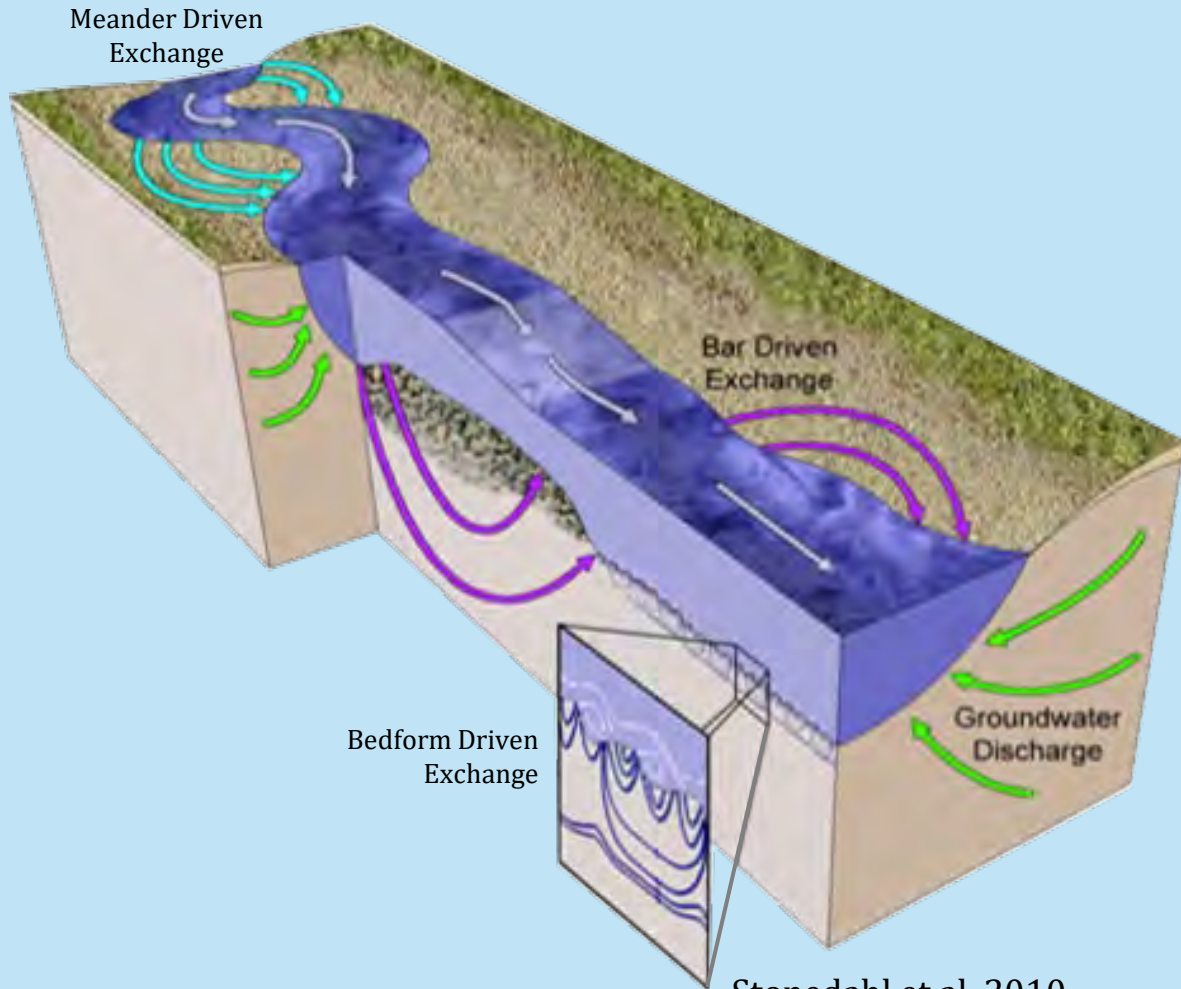
# Implications of function choice in modeling hyporheic exchange

Hayley Oakland

Samuel Fritz, Anna French,  
Lindsey Albertson, Geoffrey Poole



# Hyporheic exchange



Stonedahl et al. 2010

## 1. Why hyporheic exchange?

How it's measured and modeled

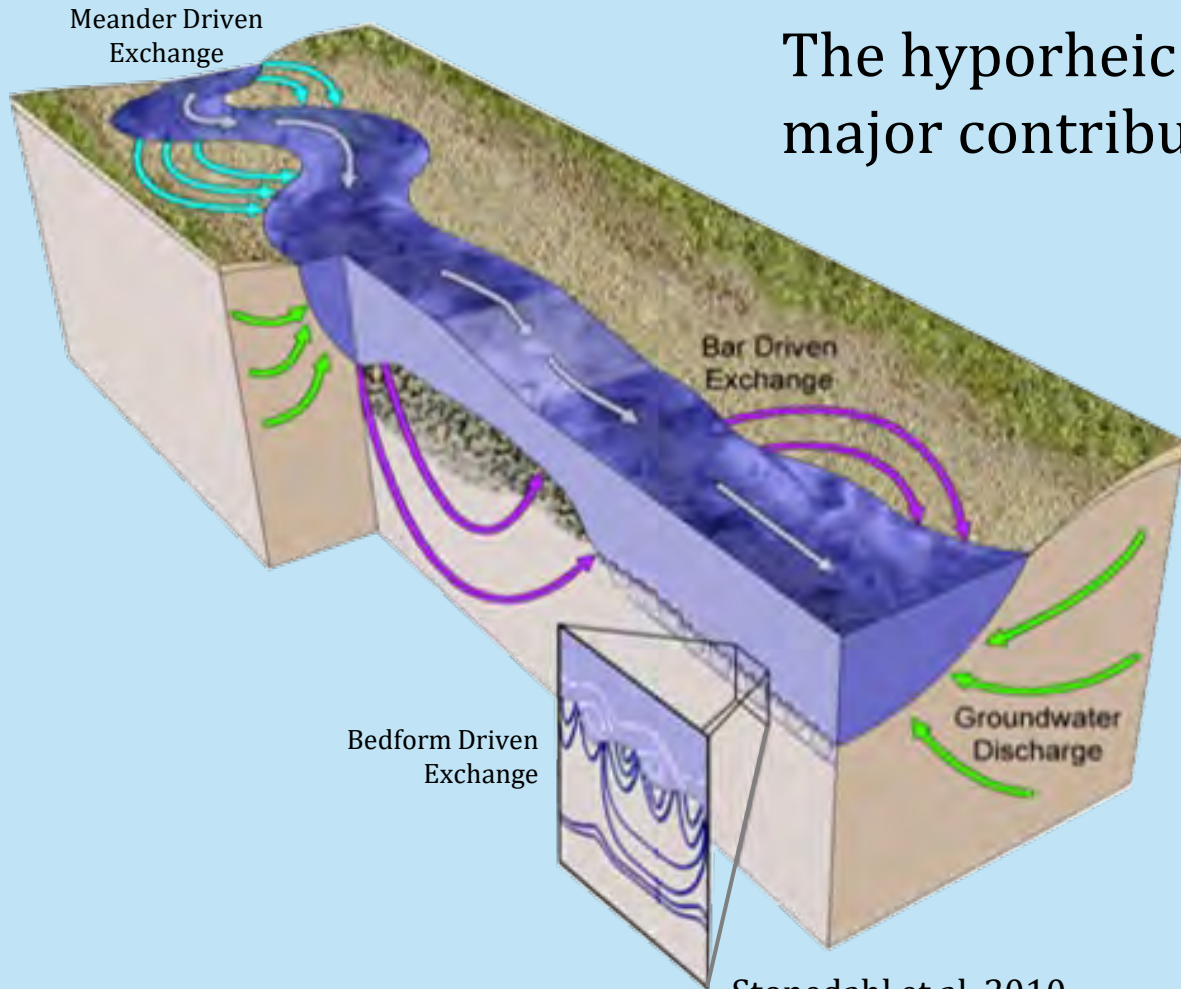
- Model assumptions – well-mixed vs. stratified hyporheic zones
- Fits to real data

## 2. What does stratification mean?

- Distribution of water age, exchange rate

## 3. Implications for understanding biogeochemistry

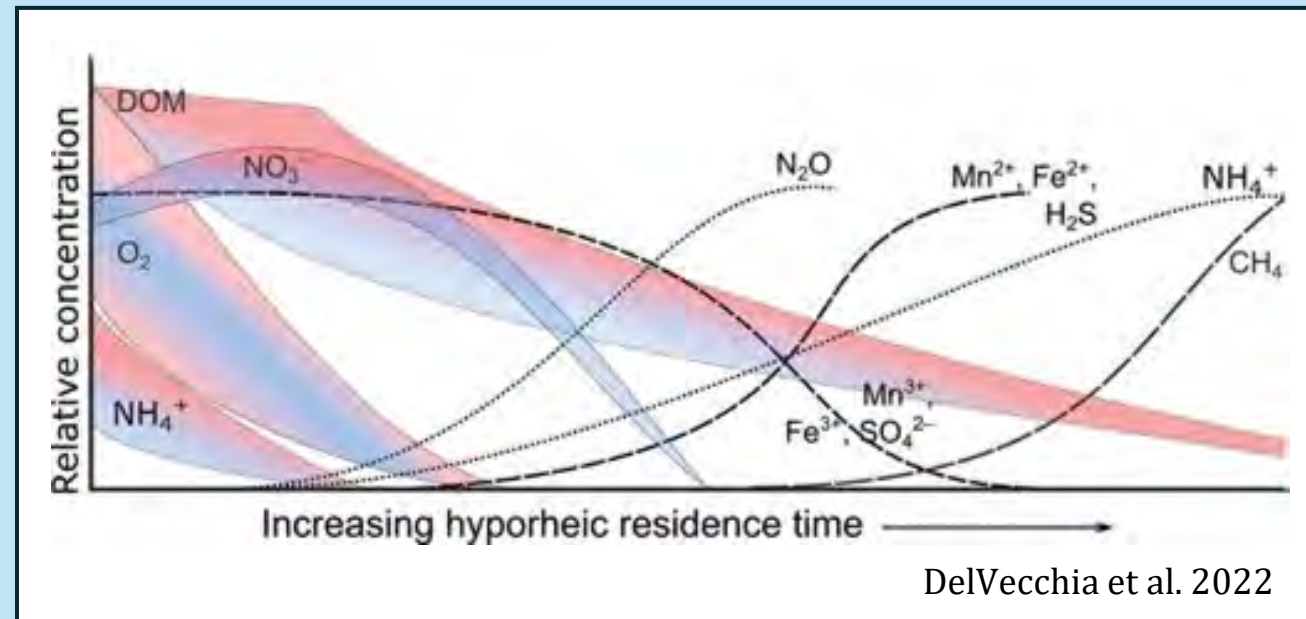
# Hyporheic exchange



Stonedahl et al. 2010

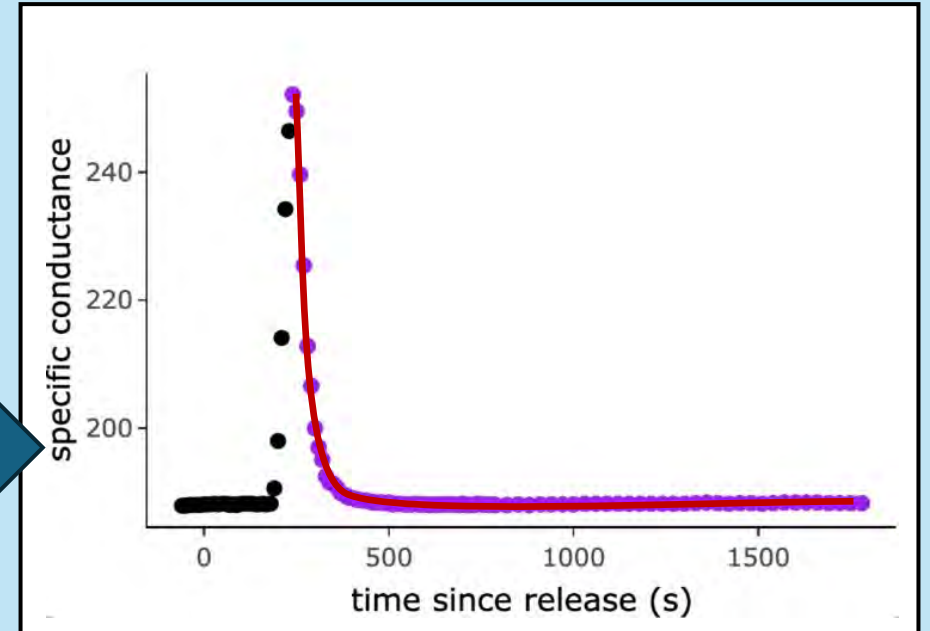
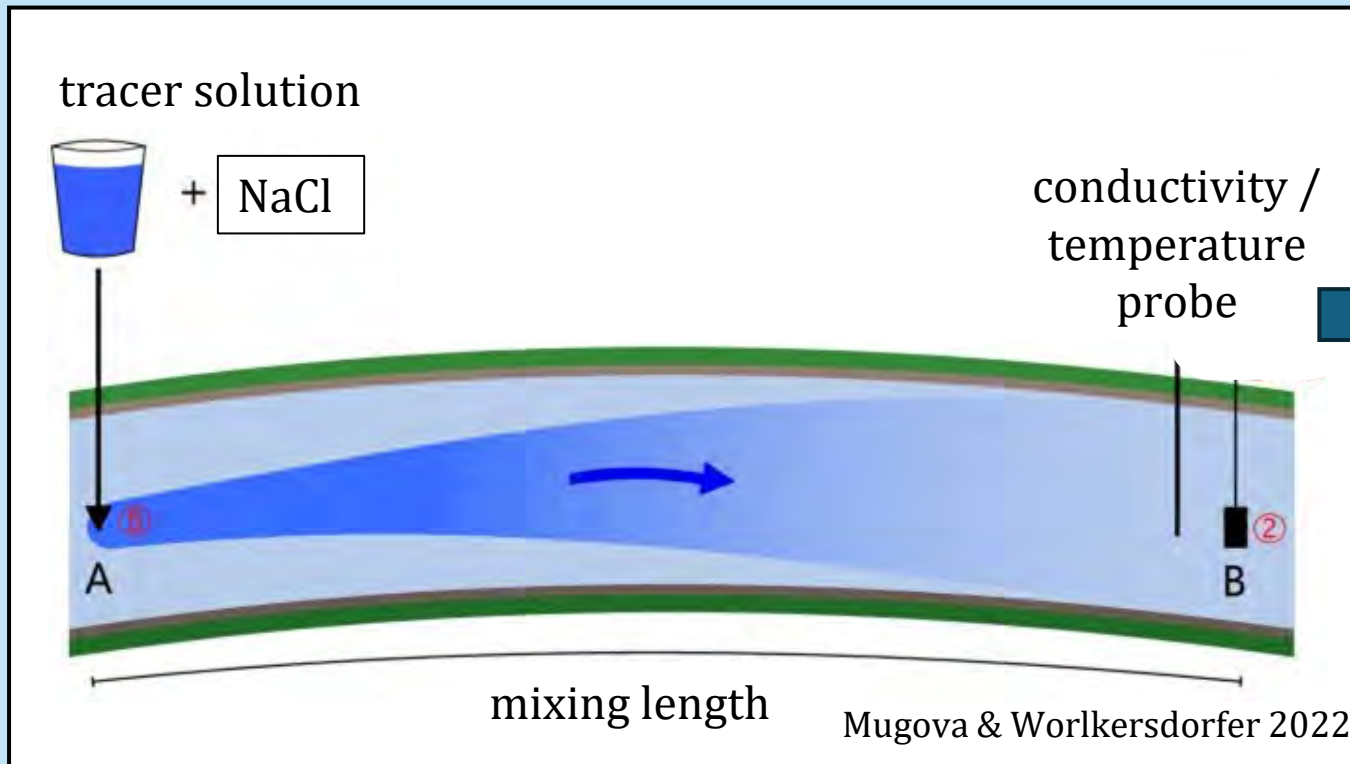
The hyporheic zone and its exchange with surface water is a major contributor to dynamics of whole stream ecosystem...

- Temperature
- Nutrient spiraling
- Ecosystem energetics and metabolism



DeVecchia et al. 2022

# Measuring hyporheic exchange



— hyporheic exchange model

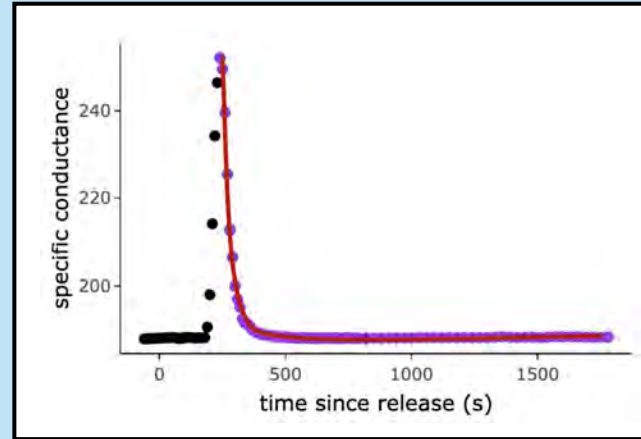
Rate of tracer dilution ::  
rate of hyporheic exchange

Time to equilibrium ::  
maximum hyporheic residence time

# Hyporheic exchange models

## Well-mixed assumption

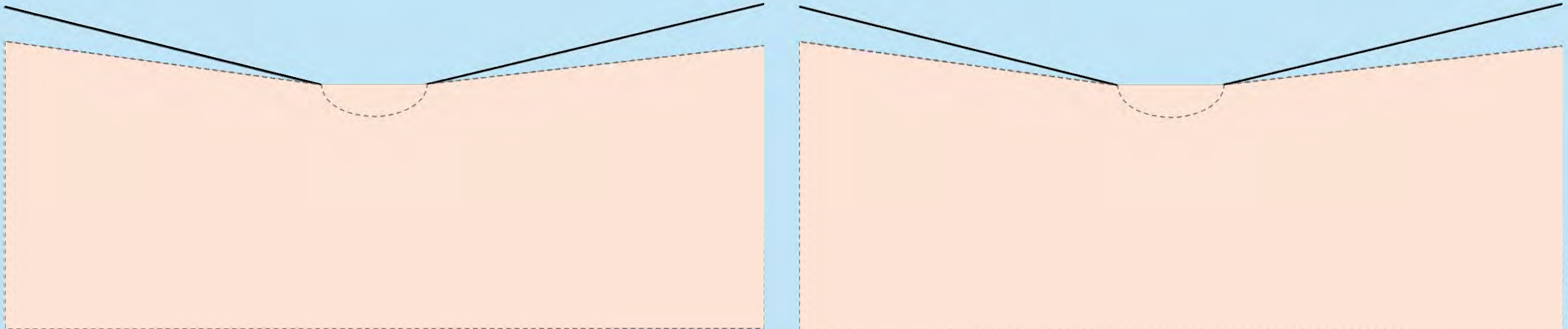
- Exponential hyporheic transit time distribution



## Stratified assumption

- Power law hyporheic transit time distribution

$$\frac{dC_c}{dt} = \frac{q_{\downarrow}}{D} (\bar{C}_{\uparrow} - C_c)$$



# Hyporheic exchange models

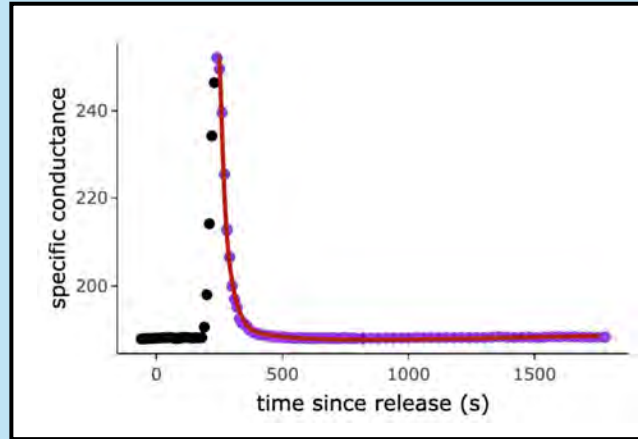
## Well-mixed assumption

- Exponential hyporheic transit time distribution

$$\bar{C}_\uparrow = \bar{C}_h$$

$$\bar{C}_\uparrow = \frac{C_{h_0} V_h + (C_{c_0} - C_{c_t}) V_c}{V_h}$$

Change in channel concentration per mass / hyporheic water change in time volume



## Stratified assumption

- Power law hyporheic transit time distribution

$$\bar{C}_\uparrow \neq \bar{C}_h$$

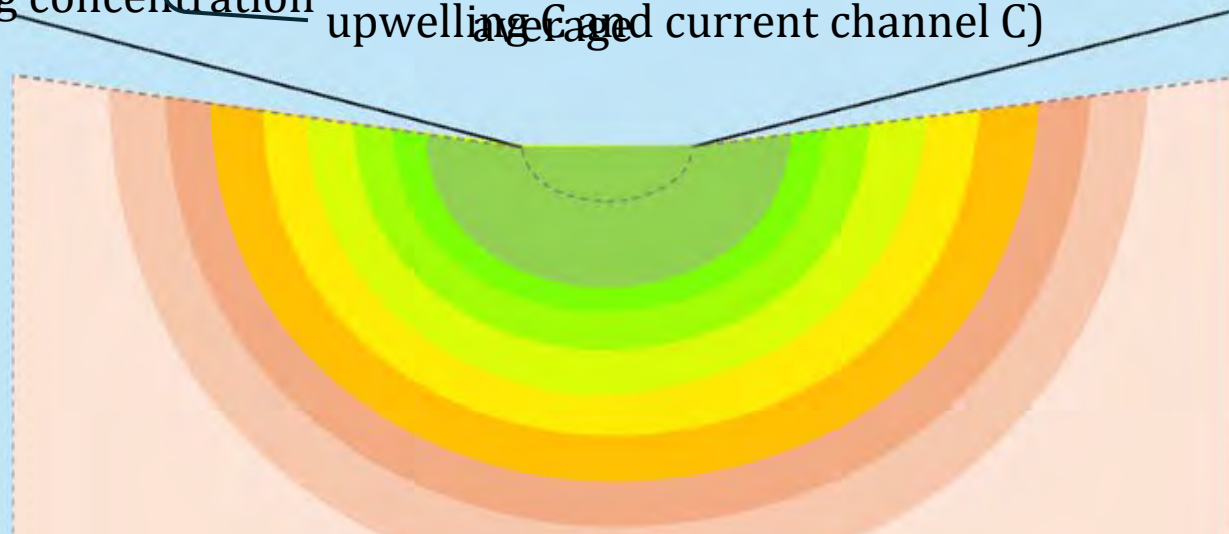
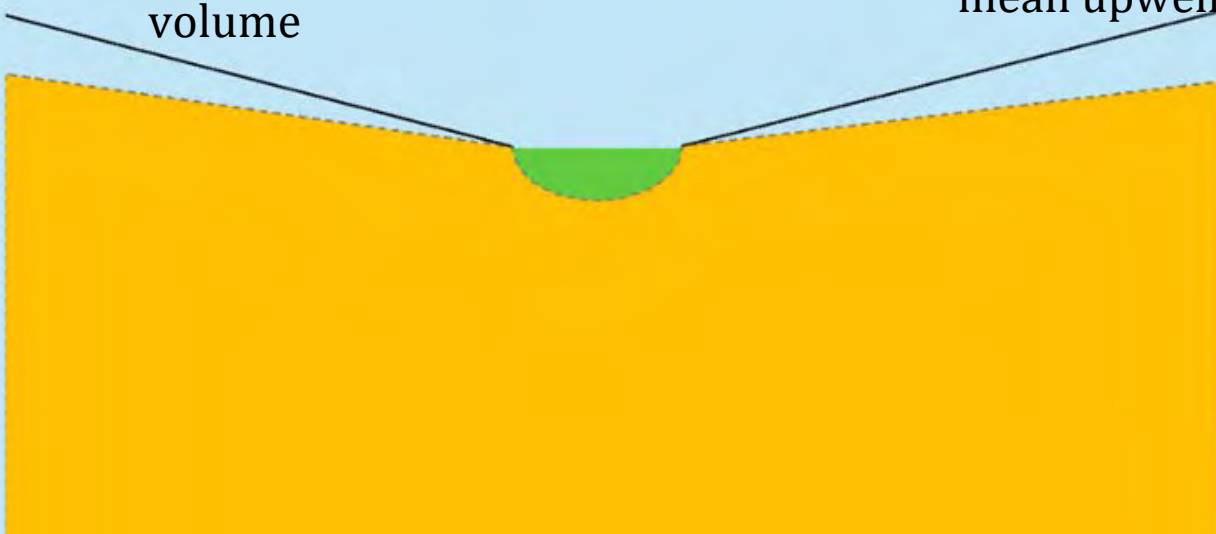
$$\bar{C}_\uparrow = \int_0^{\tau_n} E(t, \alpha) C_{c_{t-\tau}} d\tau$$

How much that fraction of depth is changing (weighted average of different upwelling age and current channel C)

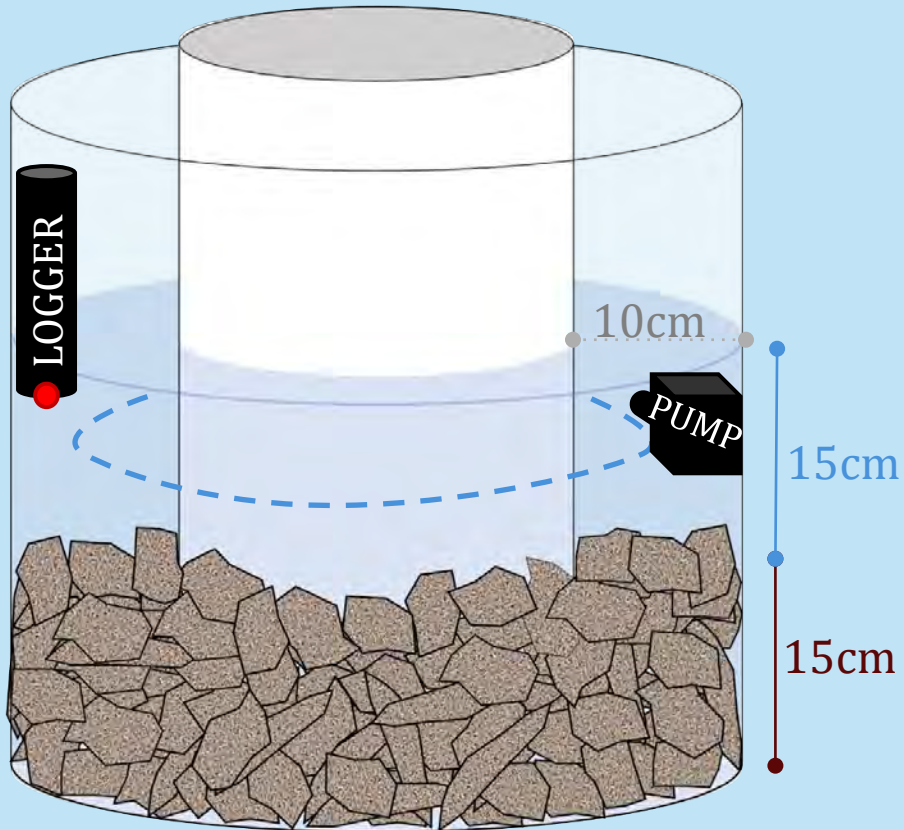
$$\frac{dC_c}{dt} = \frac{q_\downarrow}{D} (\bar{C}_\uparrow - C_c)$$

fraction of depth changing per time

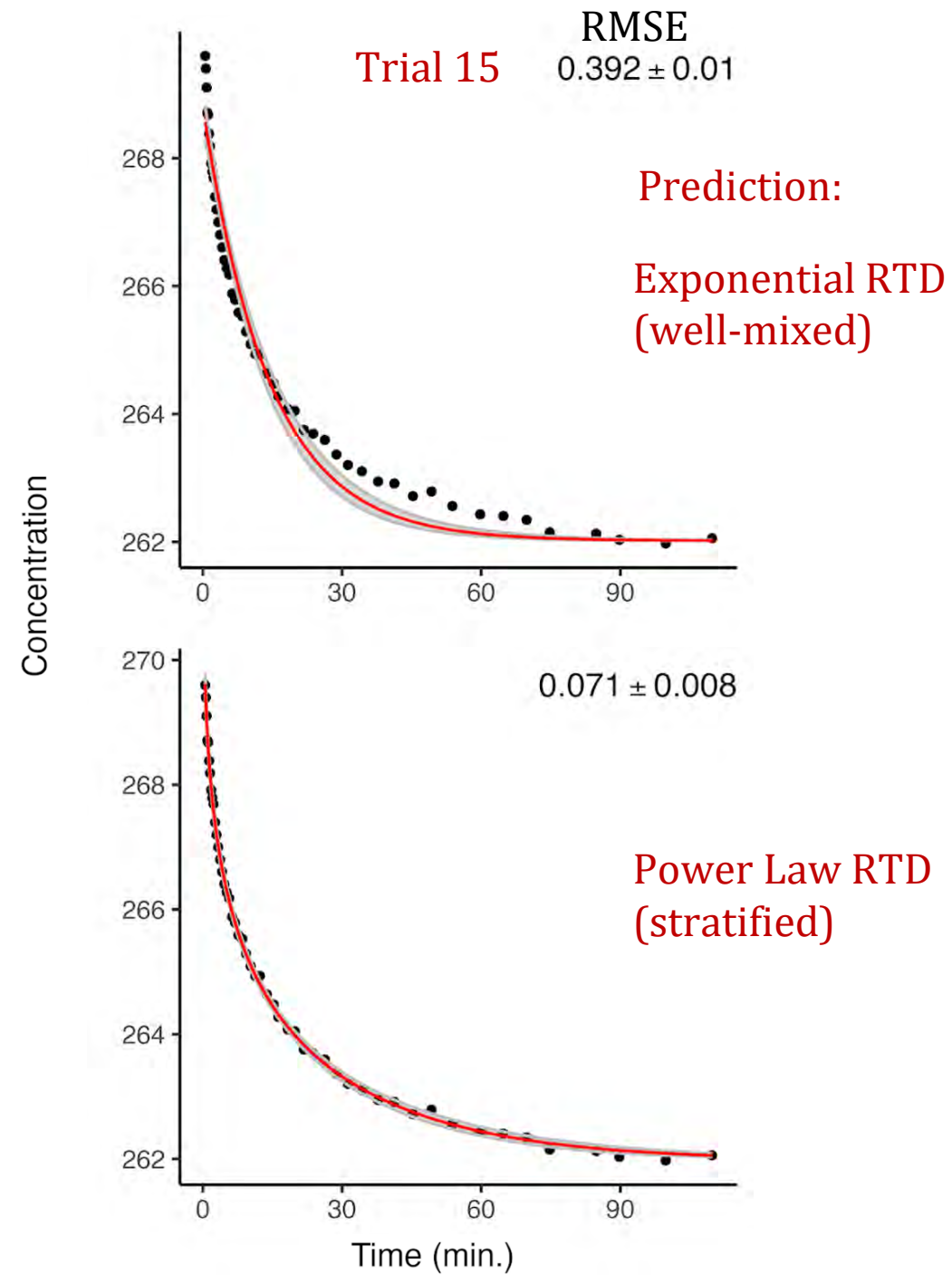
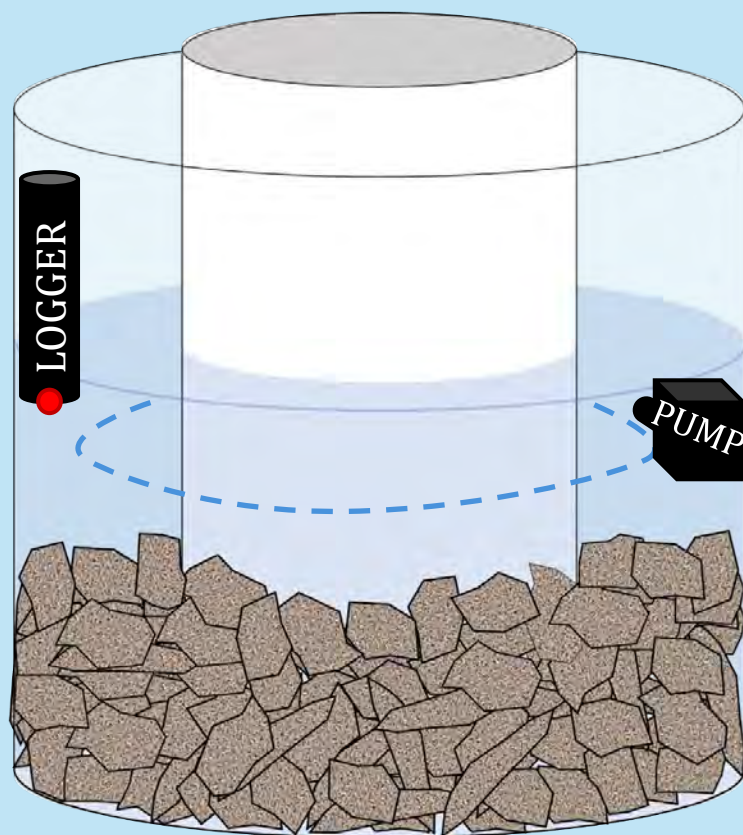
mean upwelling concentration

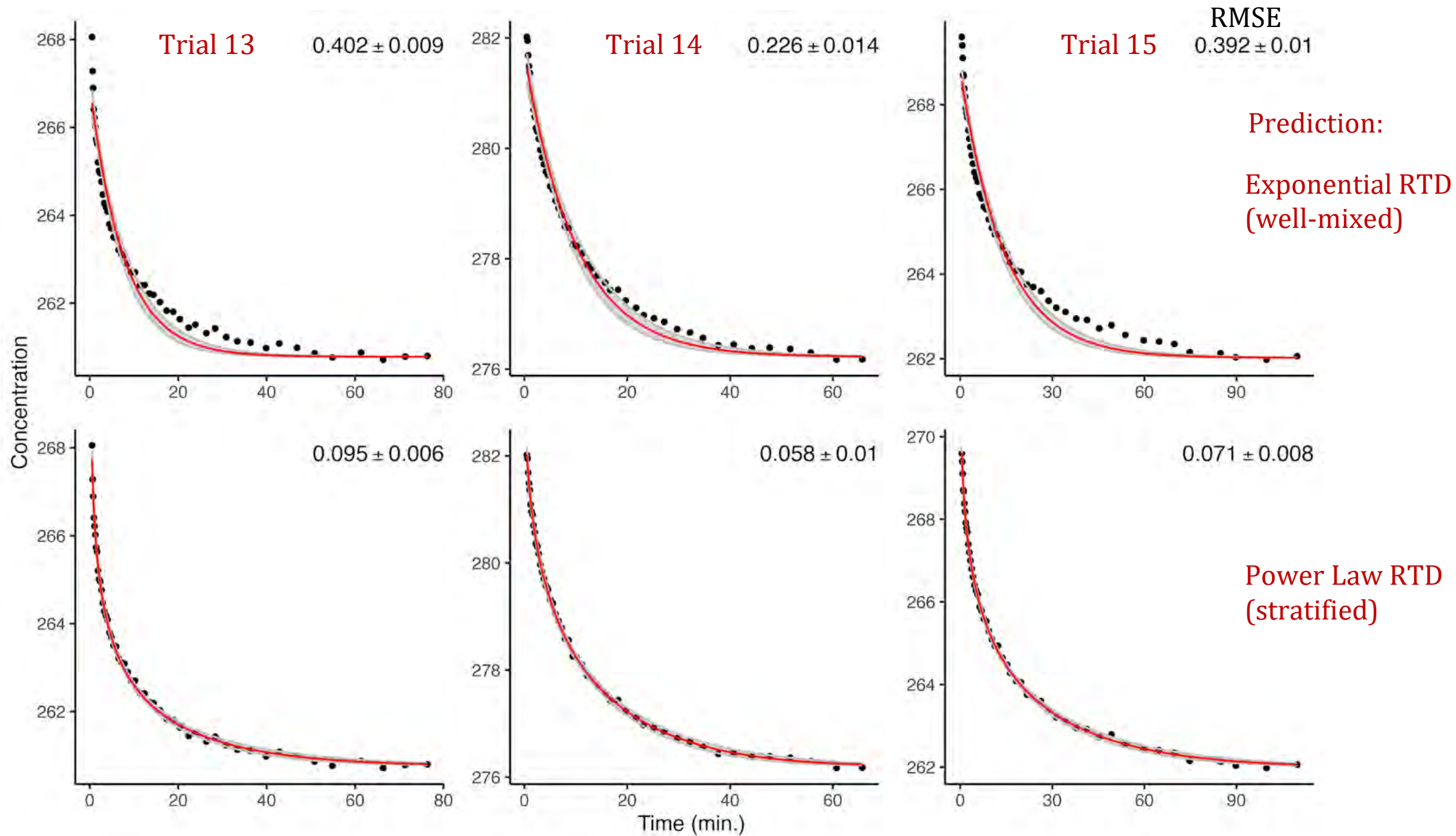


# Hyporheic exchange in experimental flumes

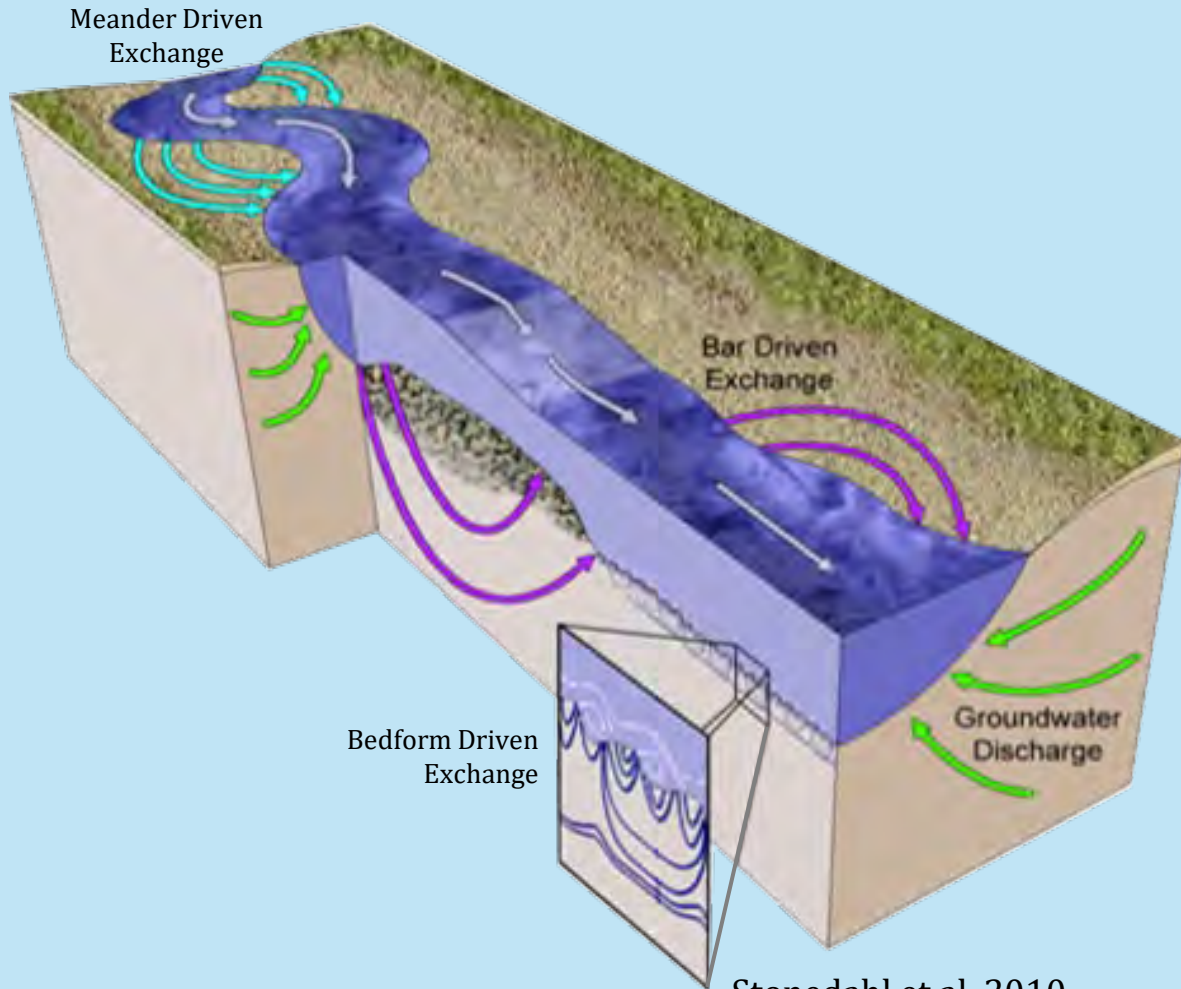


- Raceway (~10cm wide x 15cm deep channel, 15cm sediment)
- Aquarium pump to spin water
- Conductivity/temperature logger
- 15 flumes, salt tracer release in each
- Fit 2 models (well-mixed vs. stratified assumption) with Bayesian algorithm





# Hyporheic exchange



Stonedahl et al. 2010

1. Why hyporheic exchange?

1. How it's measured and modeled

- Model assumptions – well-mixed vs. **stratified hyporheic zones**
- Fits to real data

2. What does stratification mean?

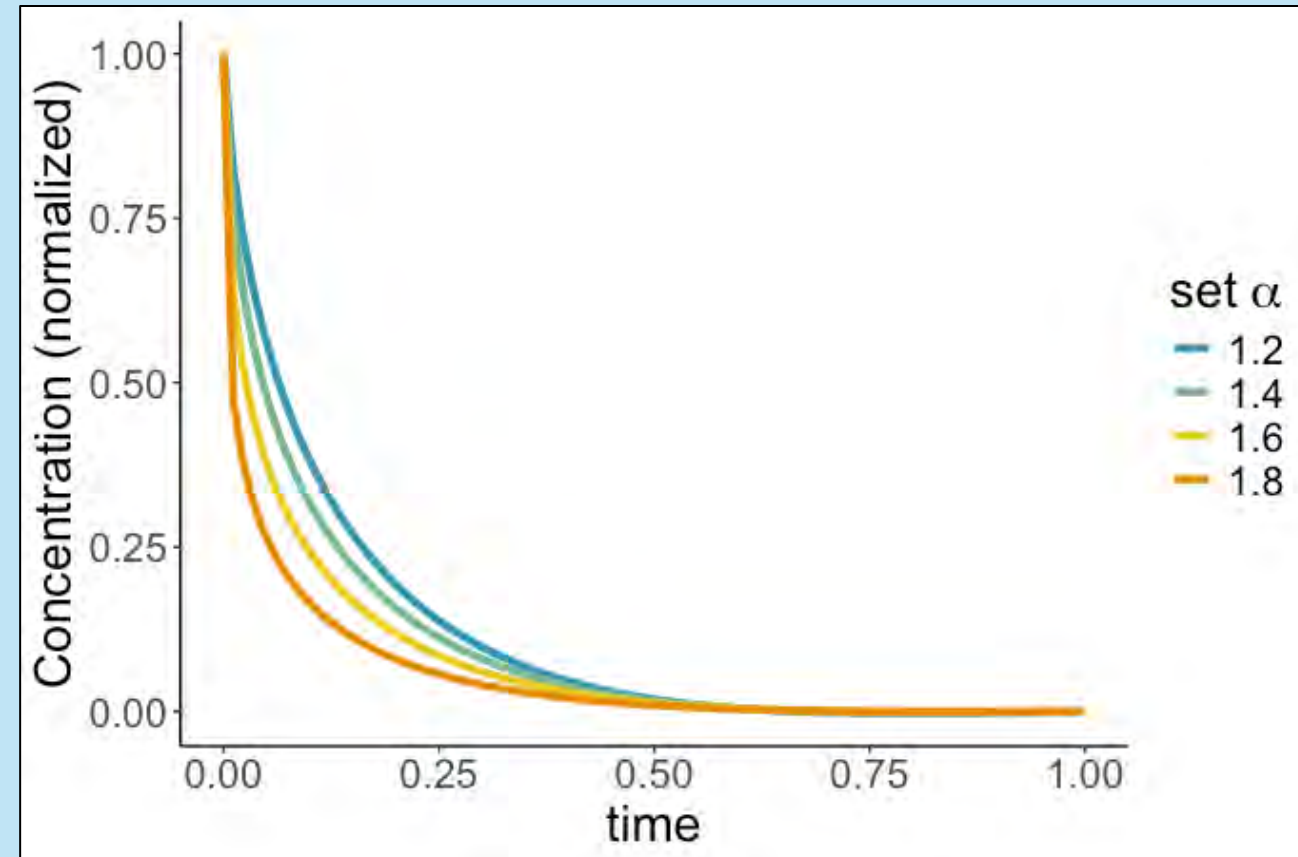
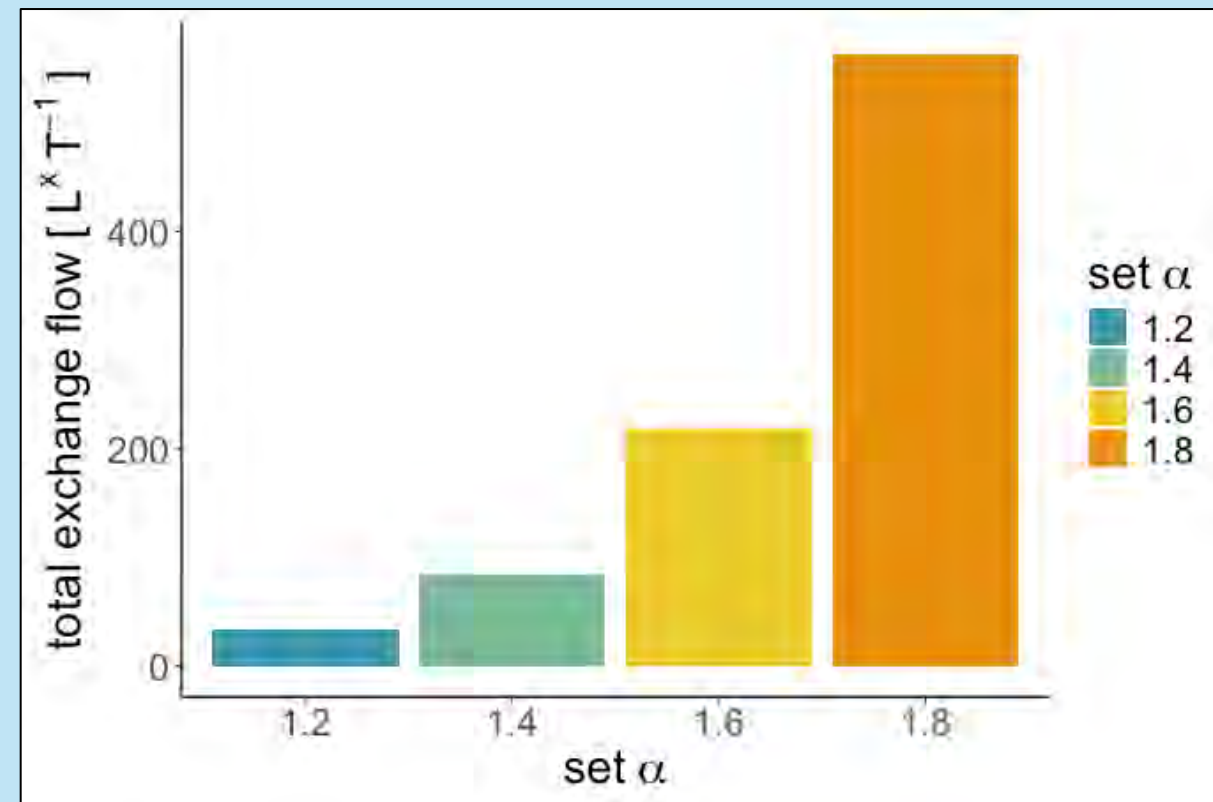
- Distribution of water age, exchange rate

3. Implications for understanding biogeochemistry

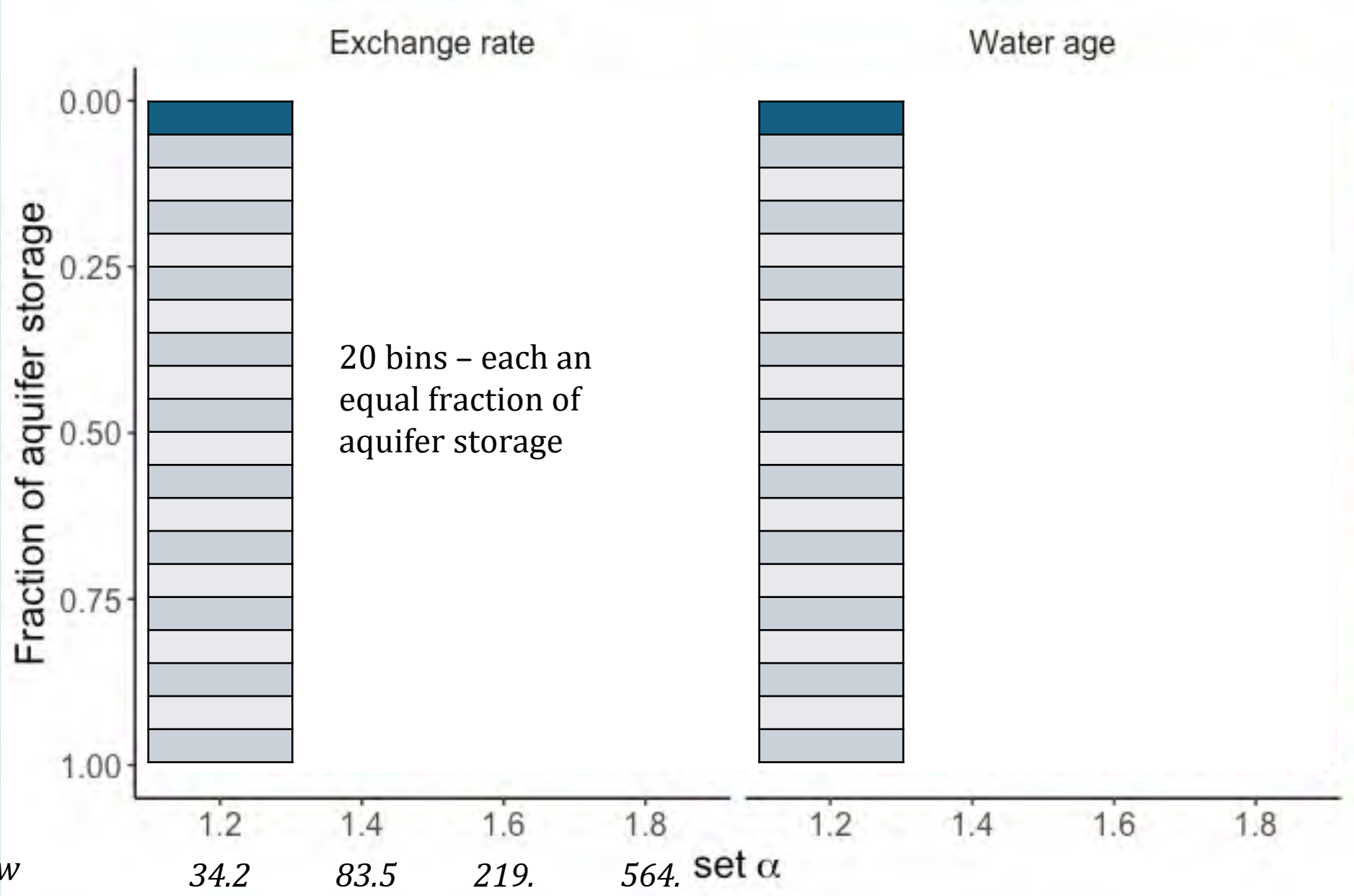
# What does stratification mean?

Stratified assumption – power law hyporheic transit time distribution

- Simulate data across reasonable  $\alpha$  values, unit maximum residence time ( $\tau_n = 1$ ) (all else, such as volumes, held constant)

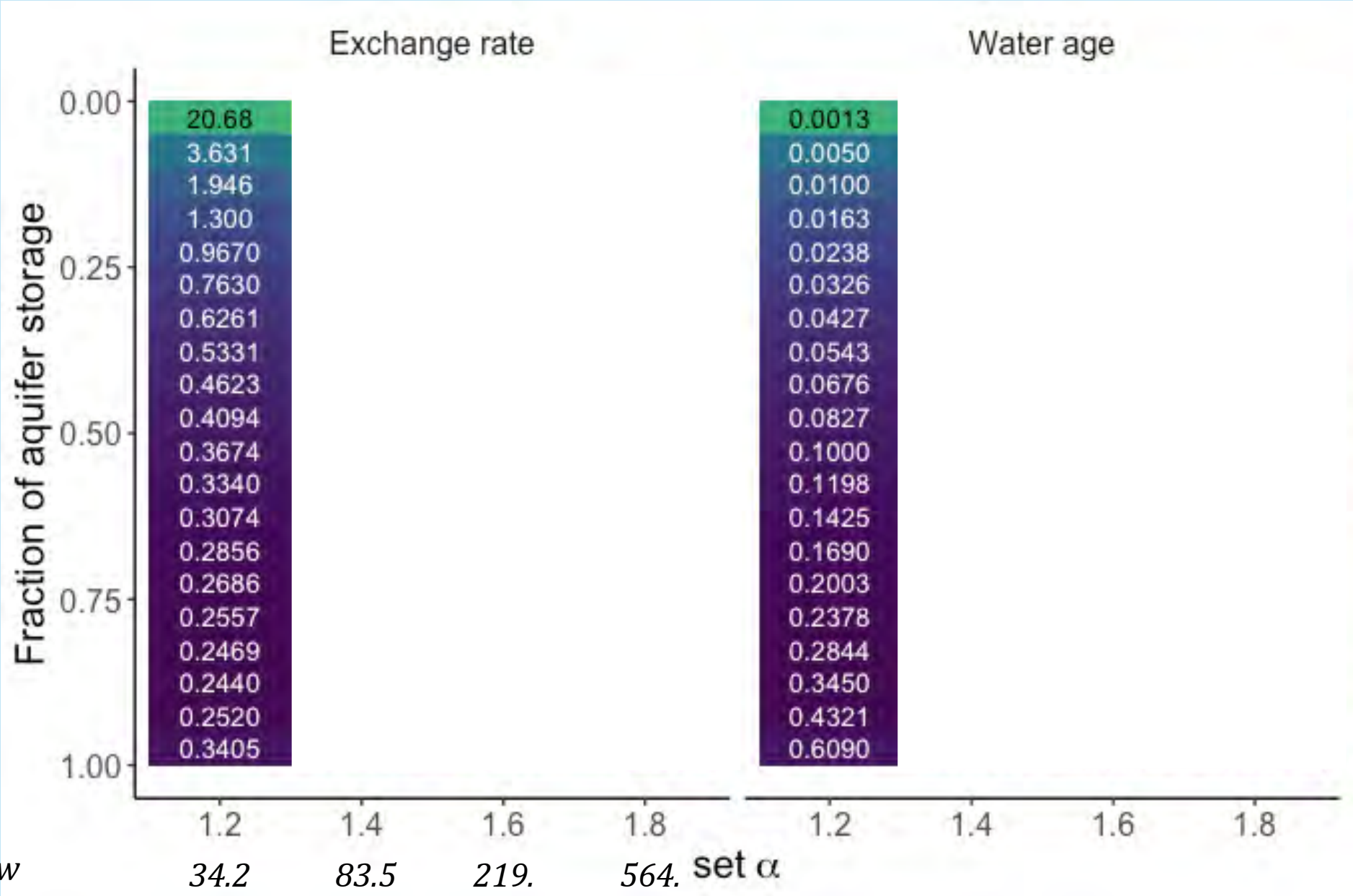


# What does stratification mean?



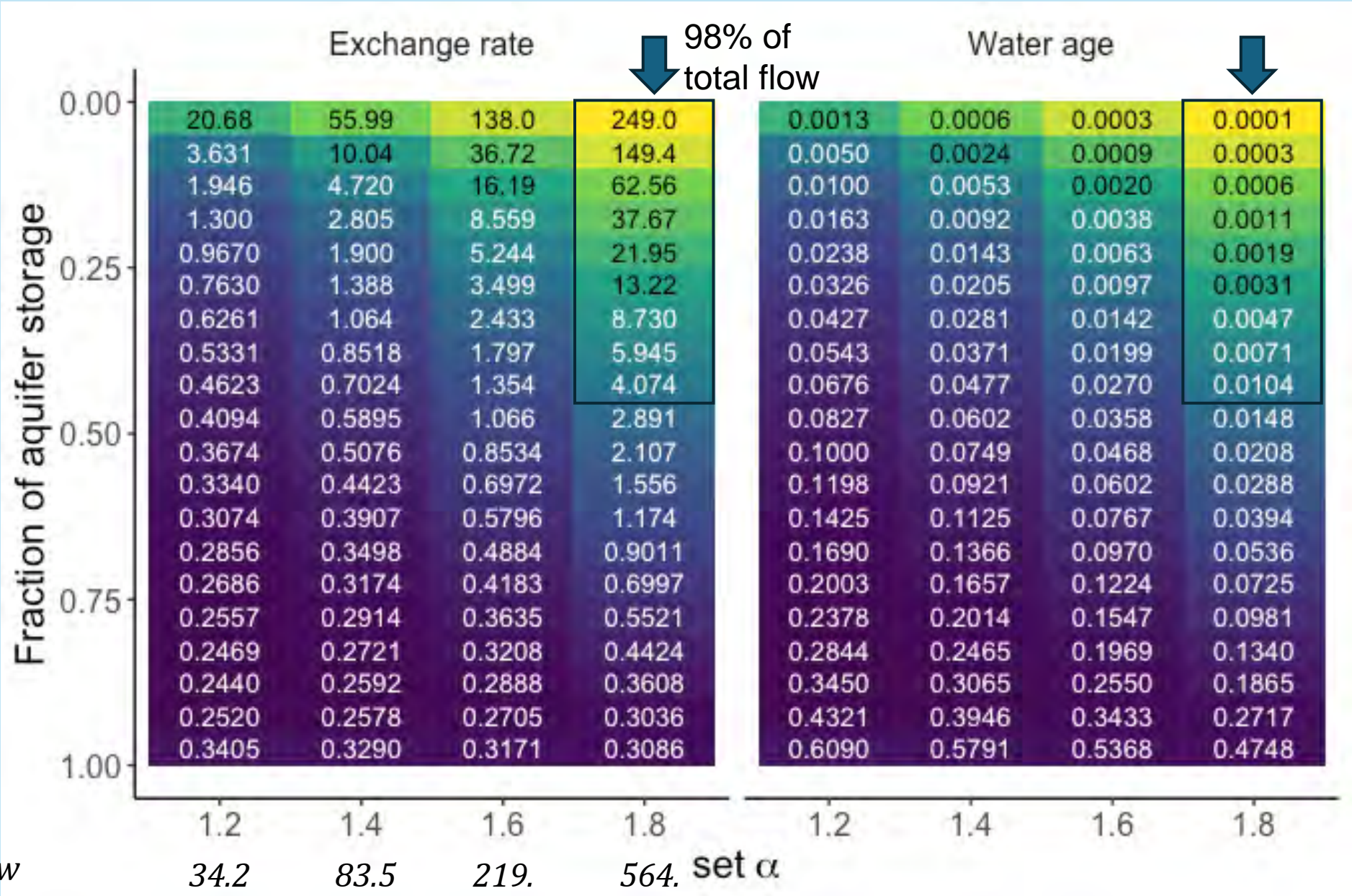
Total exchange flow  
Eq. 7.17

# What does stratification mean?

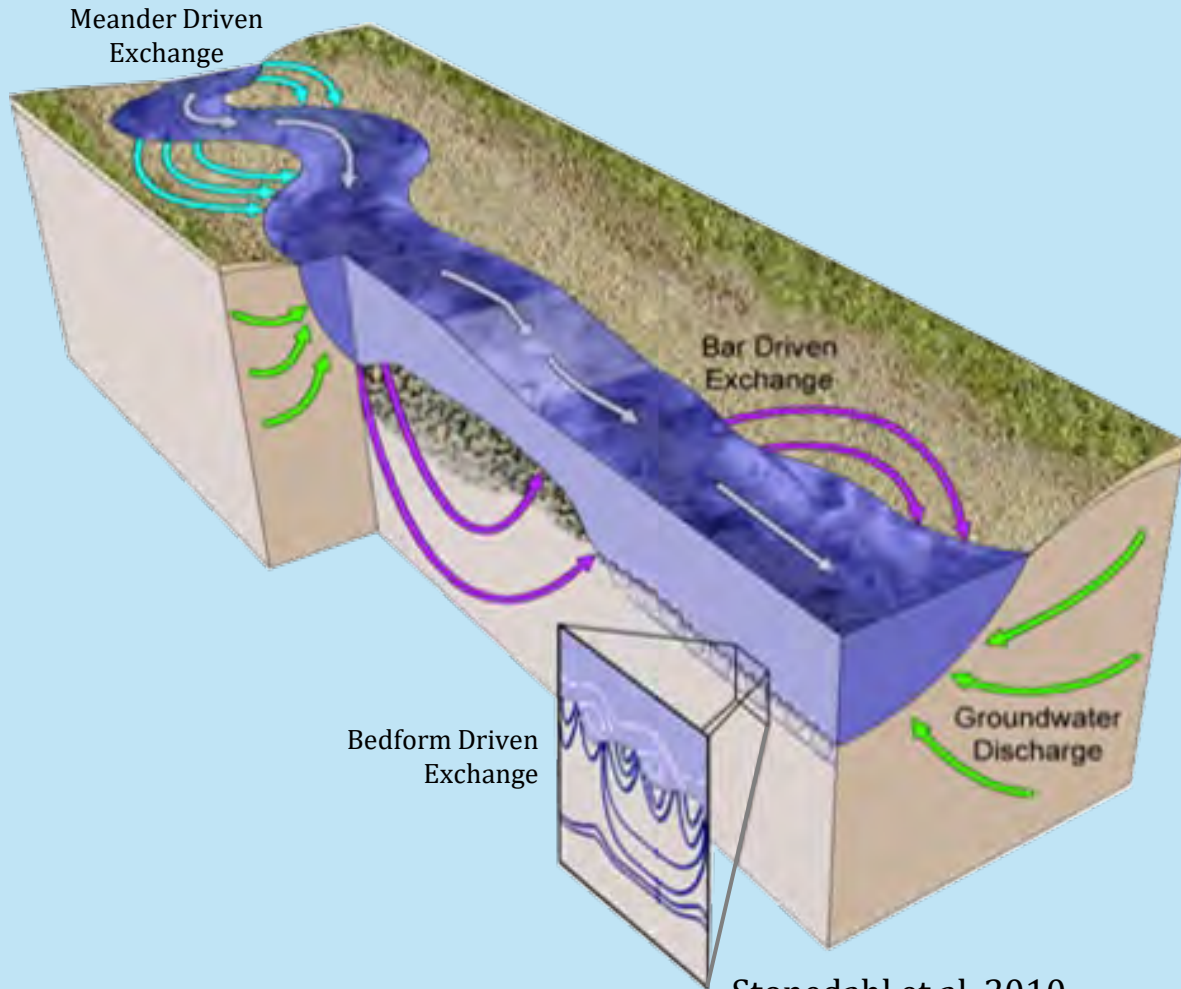


Total exchange flow  
Eq. 7.17

# What does stratification mean?



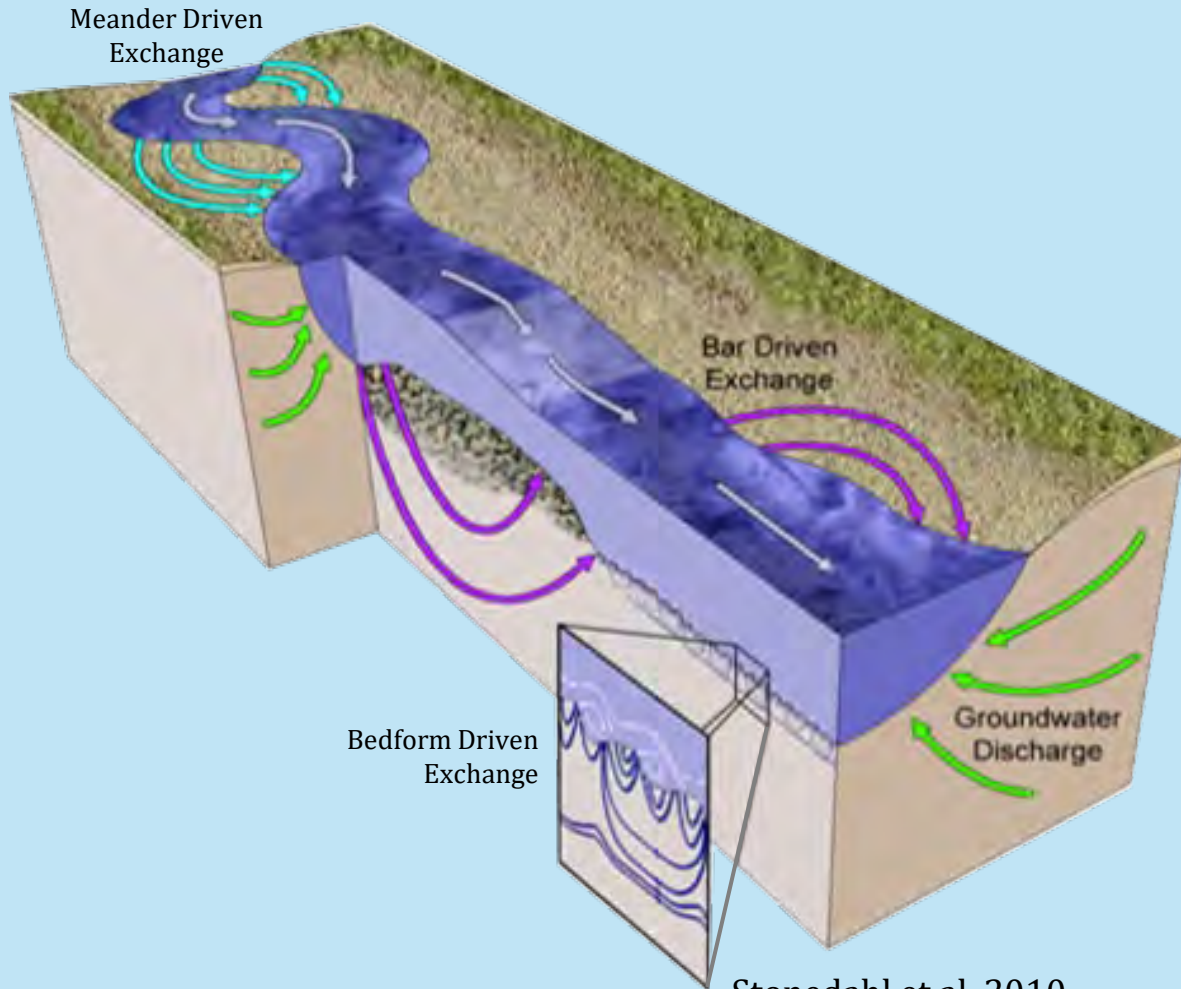
# Hyporheic exchange



Stonedahl et al. 2010

- Why hyporheic exchange?
- How it's measured and modeled
  - Model assumptions – well-mixed vs. **stratified hyporheic zones**
  - Fits to real data
- What does stratification mean?
  - Distribution of water age, exchange rate
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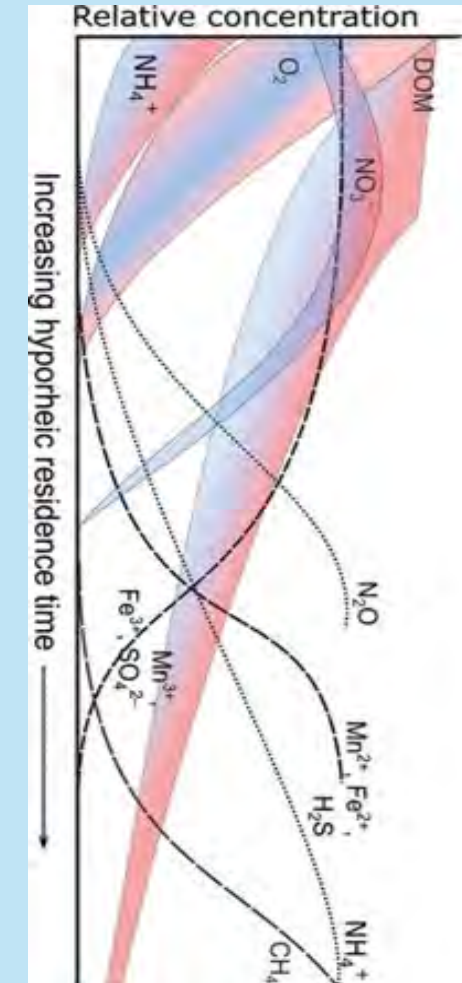
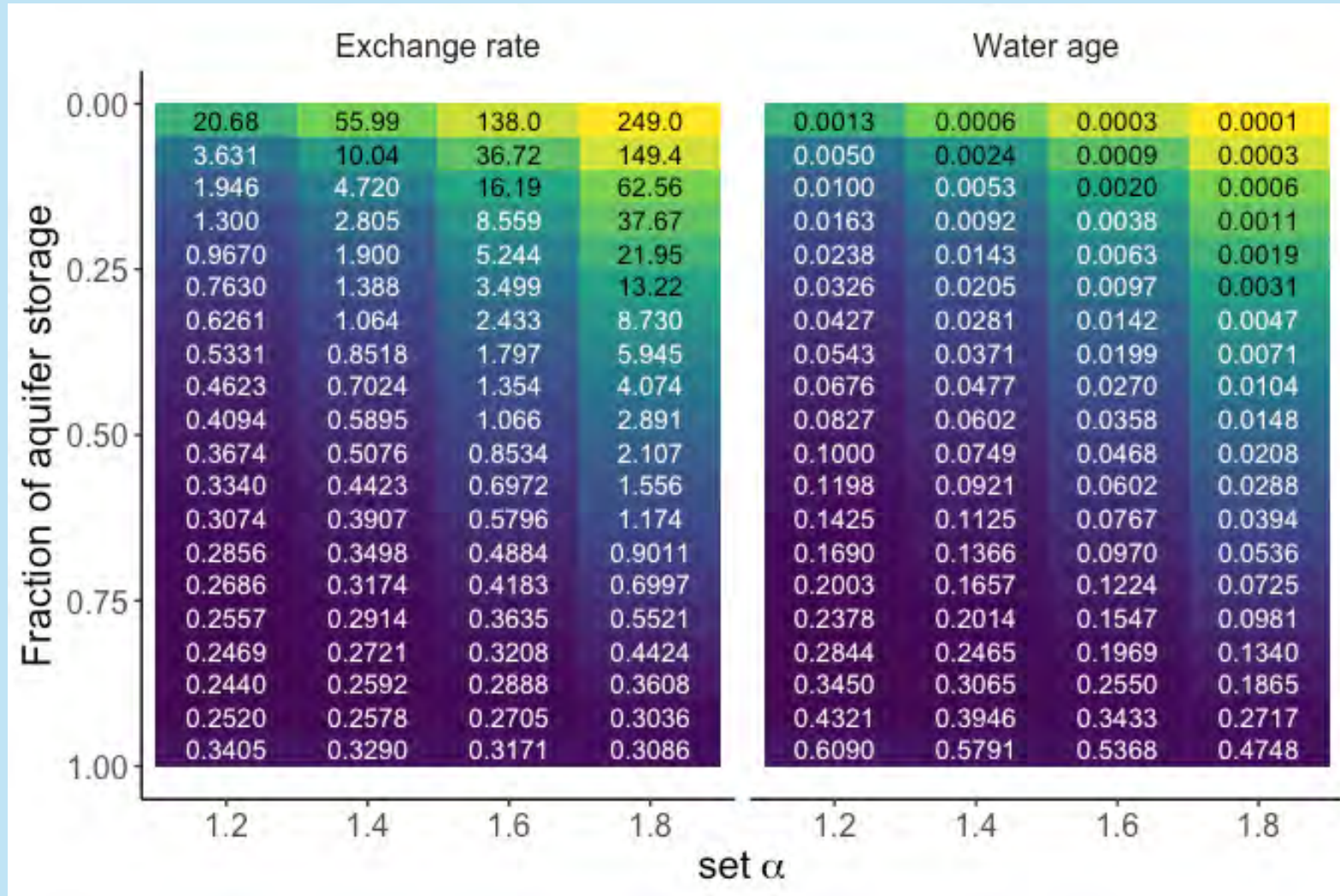
# Hyporheic exchange



Stonedahl et al. 2010

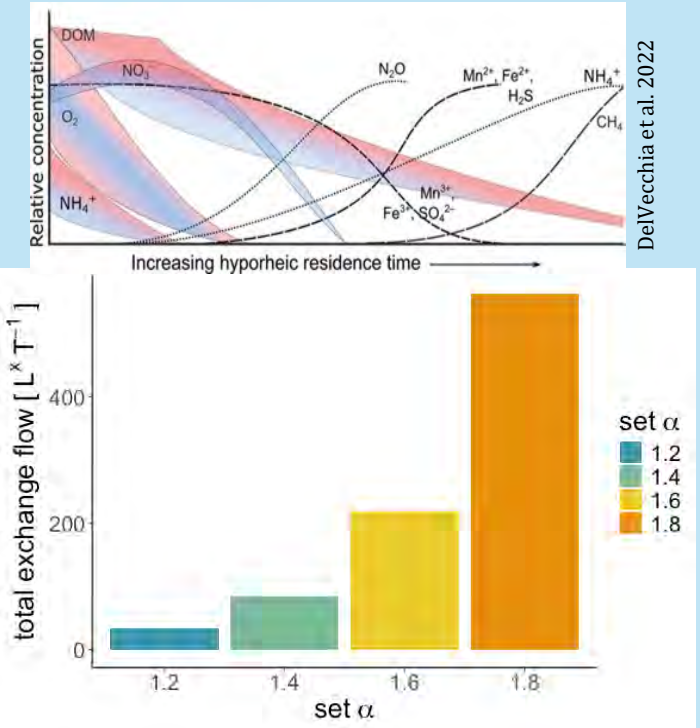
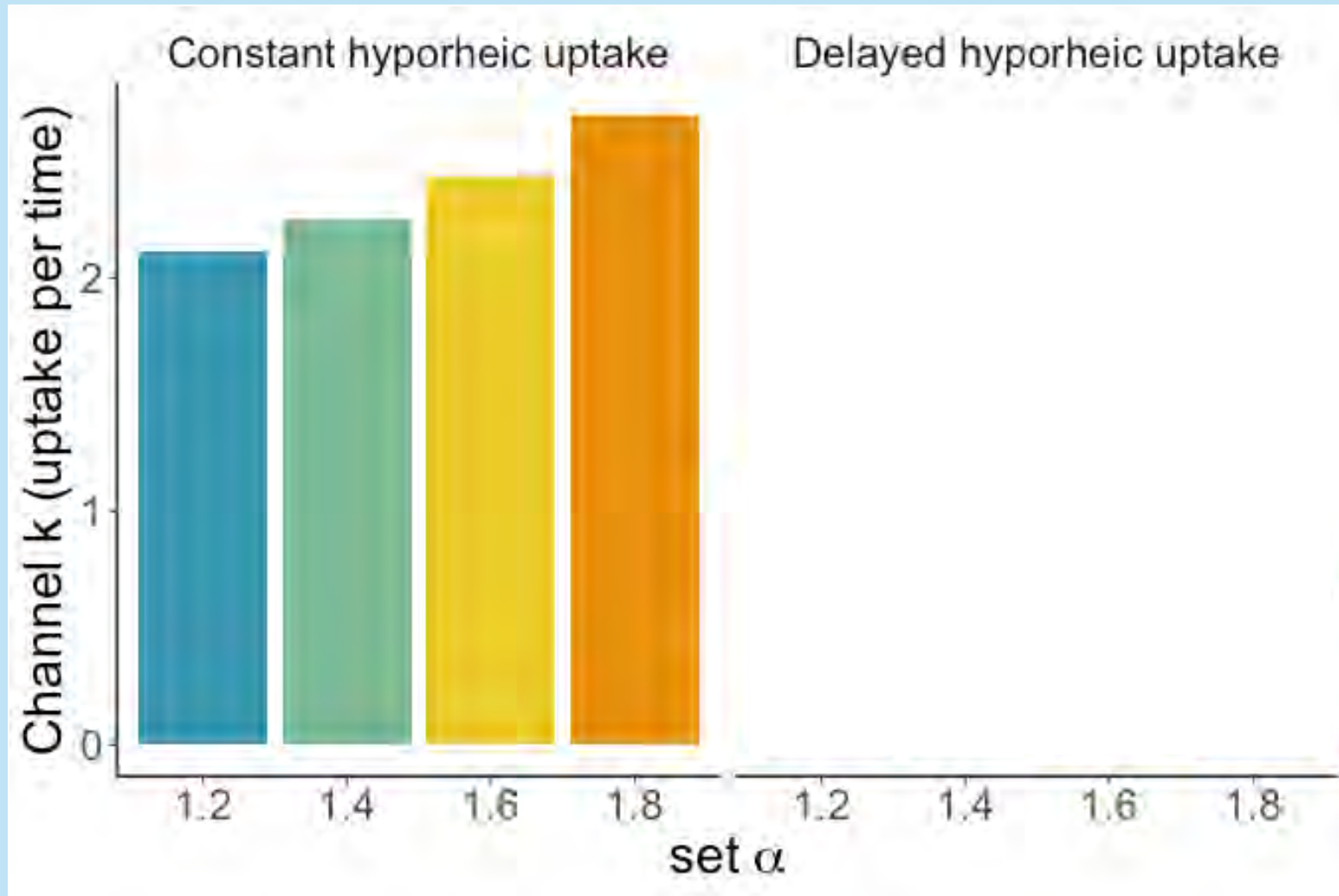
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# Implications of stratification for biogeochemical uptake



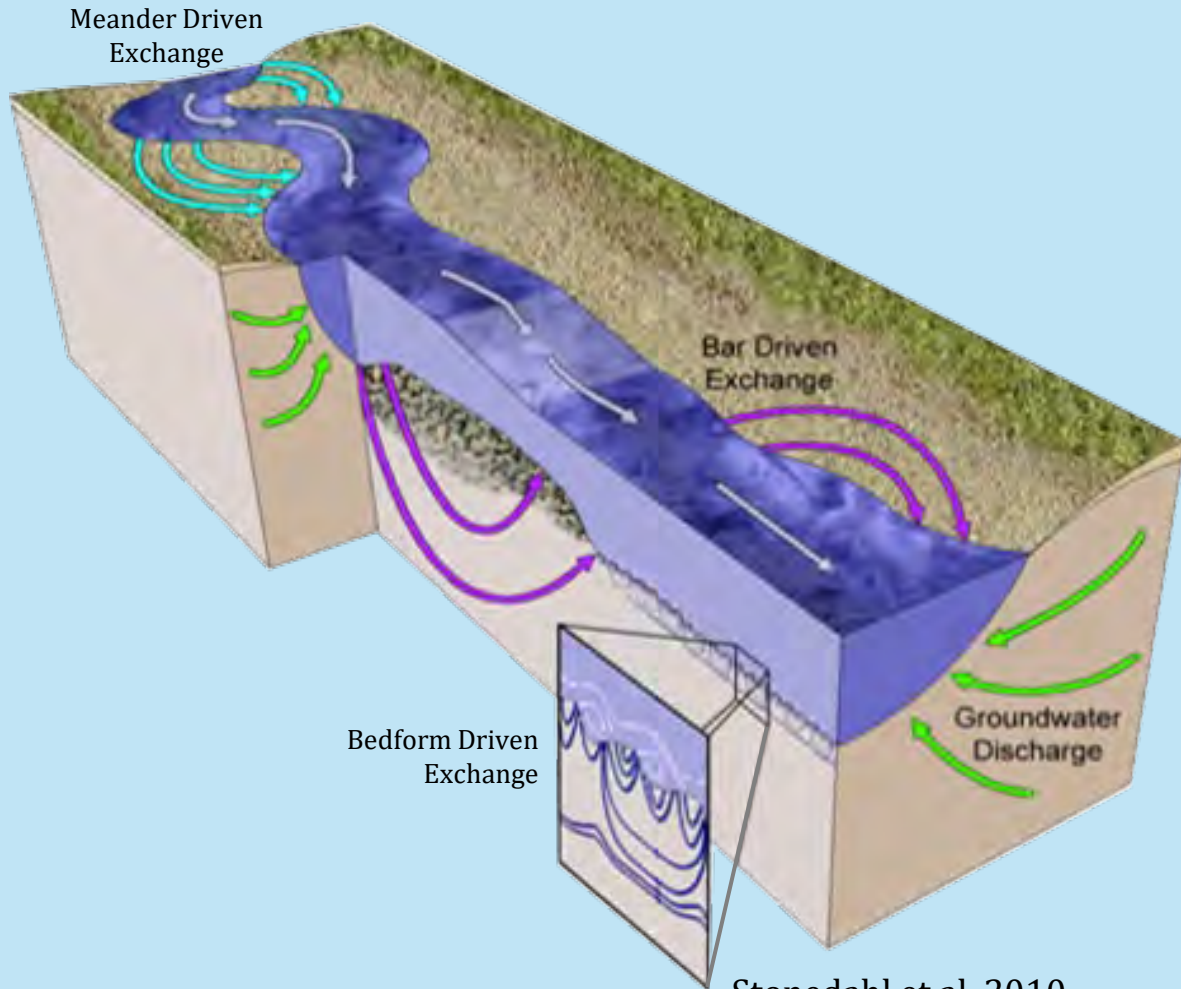
DelVecchia et al. 2022

# Implications of stratification for biogeochemical uptake



More flow  $\neq$   
more uptake!  
(Not all flow  
created equal...)

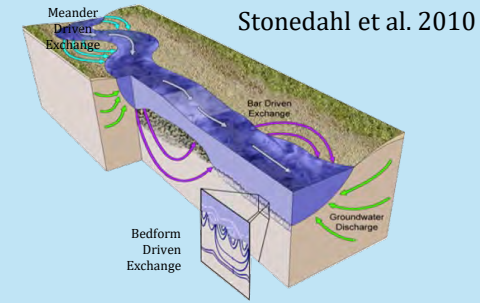
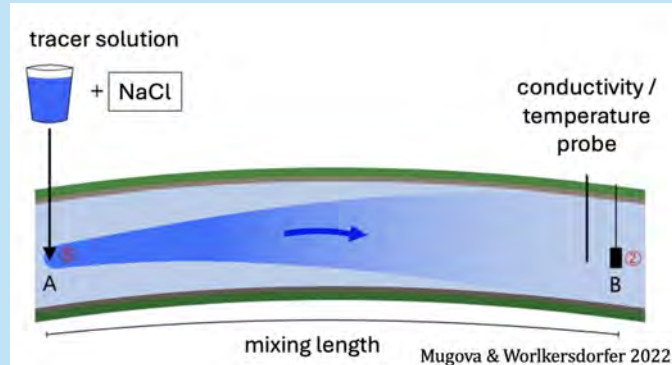
# Hyporheic exchange



Stonedahl et al. 2010

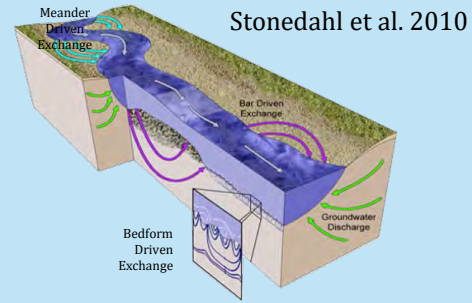
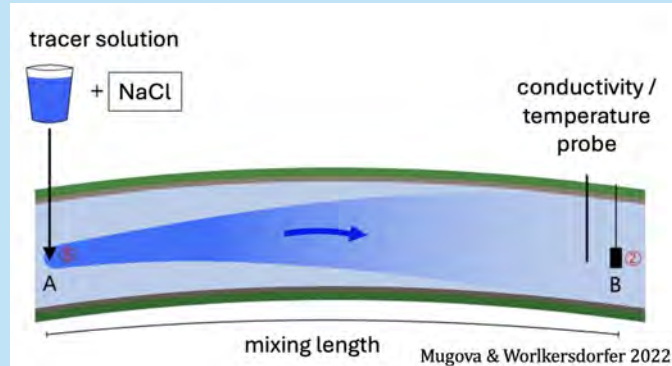
- **Why hyporheic exchange?**
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# Hyporheic exchange

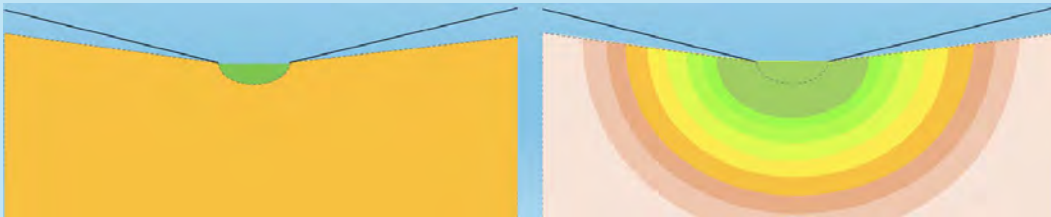


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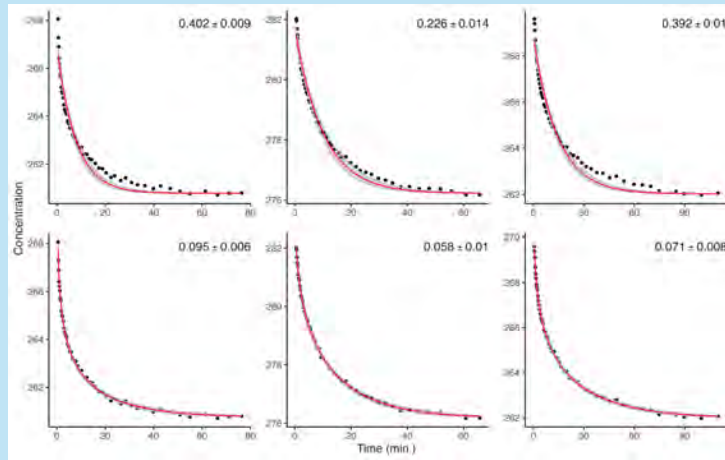
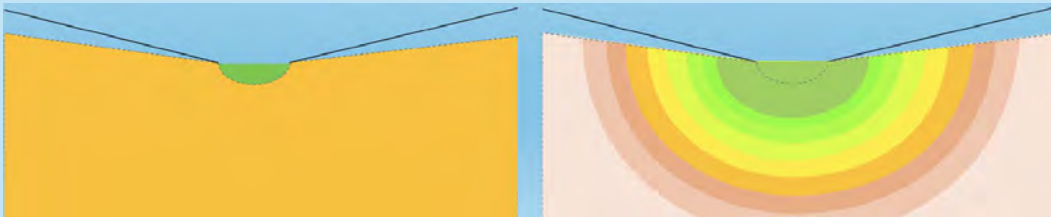
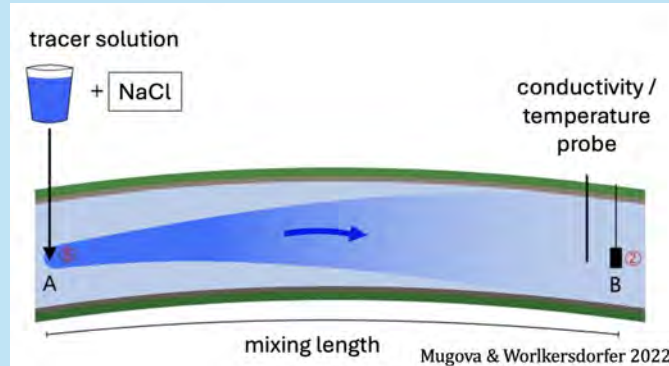
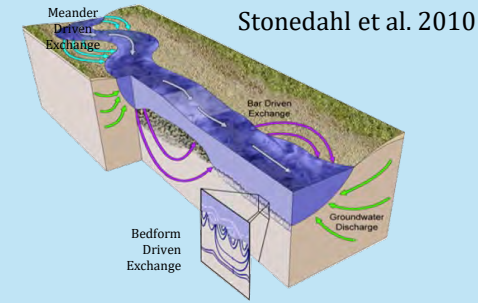
# Hyporheic exchange



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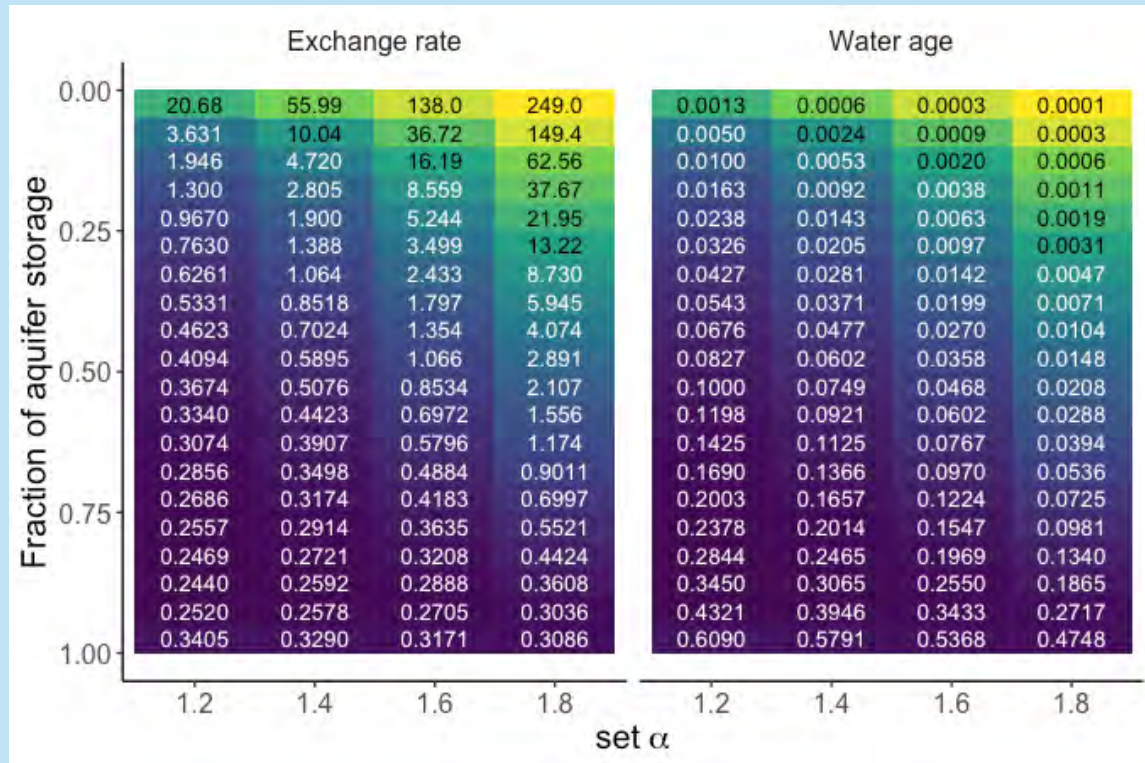
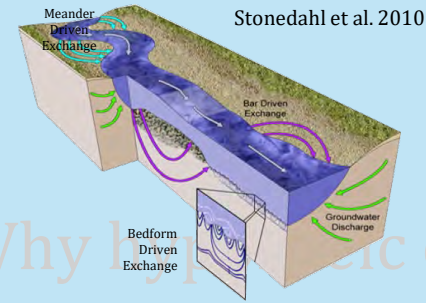


# Hyporheic exchange

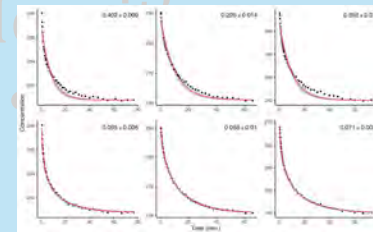
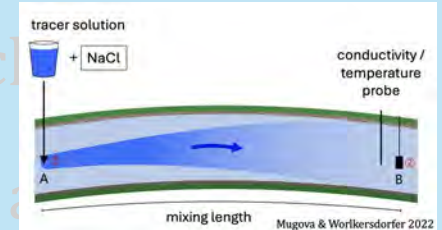


- Why hyporheic exchange?
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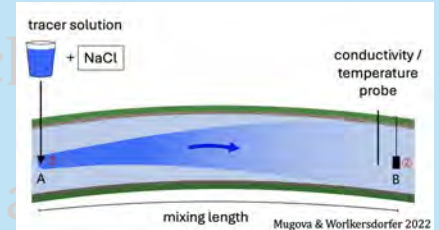
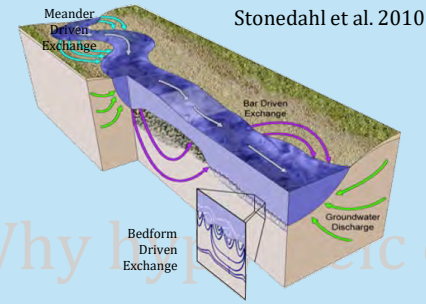
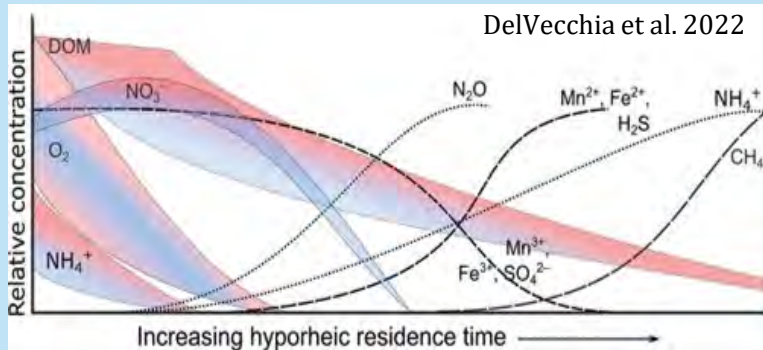


- Why hyporheic exchange?
- Hyporheic exchange mechanisms – well-mixed vs. stratified
- Fits to real data

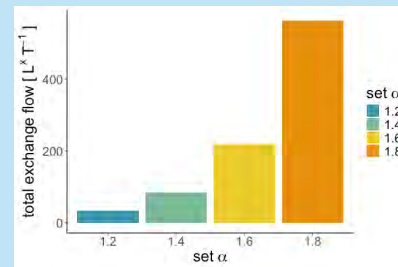
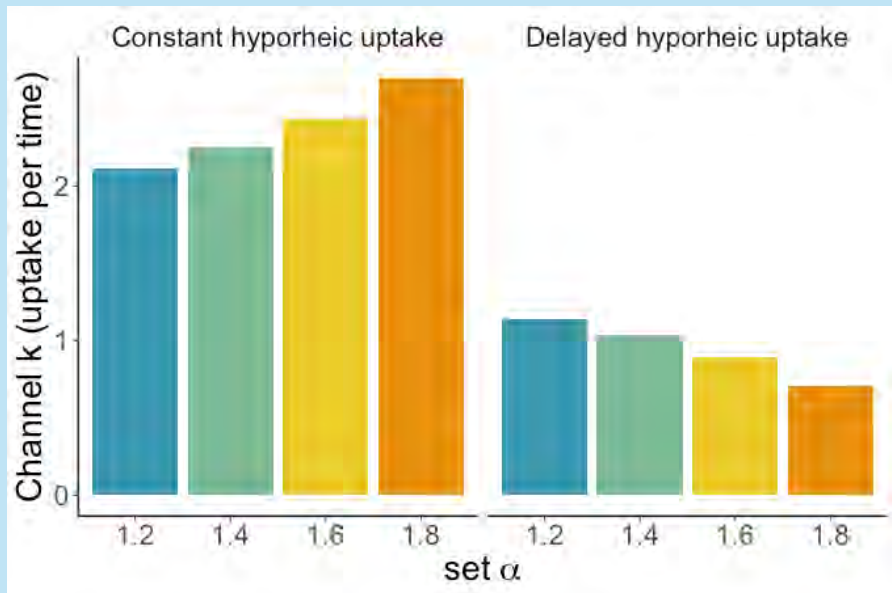
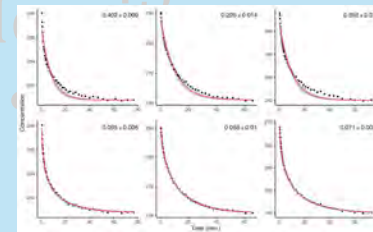


- **What does stratification mean?**
  - Distribution of water age, exchange rate
- Implications for understanding biogeochemistry

# Hyporheic exchange



- Why hyporheic exchange?
- How is it measured?
- Options – well-mixed vs. ...
- fits to real data

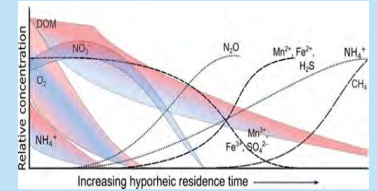
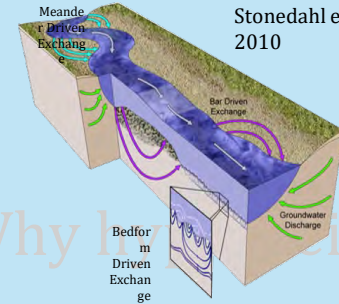


Fraction of aquifer storage	Exchange rate				Water age			
	1.2	1.4	1.6	1.8	1.2	1.4	1.6	1.8
0.00	23.85	55.99	138.0	249.0	0.0113	0.0006	0.0003	0.0001
0.05	3.531	19.04	38.32	149.4	0.0050	0.0004	0.0003	0.0003
0.10	1.948	4.720	16.19	62.58	0.0100	0.0053	0.0020	0.0006
0.15	1.300	2.805	8.569	27.67	0.0163	0.0092	0.0038	0.0011
0.20	0.9870	1.900	5.244	21.98	0.0238	0.0143	0.0053	0.0019
0.25	0.7630	1.388	3.499	13.22	0.0326	0.0205	0.0097	0.0031
0.30	0.6261	1.094	2.433	8.750	0.0427	0.0281	0.0142	0.0047
0.35	0.5331	0.8519	1.707	5.945	0.0543	0.0371	0.0199	0.0073
0.40	0.4623	0.7024	1.154	4.074	0.0676	0.0477	0.0270	0.0104
0.45	0.4098	0.5895	0.806	2.891	0.0827	0.0602	0.0359	0.0148
0.50	0.3674	0.5076	0.6534	2.107	0.1000	0.0749	0.0468	0.0208
0.55	0.3340	0.4423	0.6972	1.556	0.1188	0.0921	0.0602	0.0288
0.60	0.3074	0.3907	0.5796	1.174	0.1405	0.1185	0.0787	0.0394
0.65	0.2858	0.3488	0.4884	0.9011	0.1690	0.1366	0.0970	0.0536
0.70	0.2685	0.3174	0.4183	0.6997	0.2003	0.1657	0.1224	0.0725
0.75	0.2537	0.2914	0.3635	0.5521	0.2378	0.2014	0.1547	0.0981
0.80	0.2469	0.2721	0.3208	0.4424	0.2844	0.2465	0.1969	0.1340
0.85	0.2440	0.2592	0.2898	0.3608	0.3400	0.3065	0.2500	0.1965
0.90	0.2500	0.2576	0.2705	0.3036	0.4131	0.3946	0.3433	0.2717
0.95	0.3405	0.3290	0.3171	0.3080	0.6090	0.5791	0.5368	0.4748

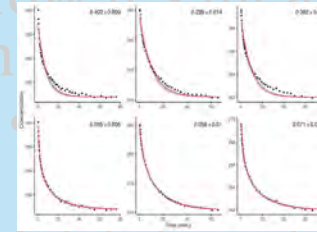
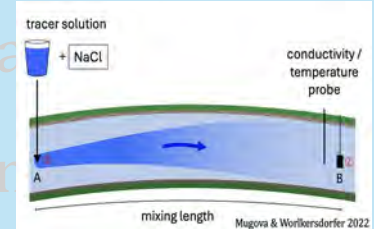
- Implications for understanding biogeochemistry

# Hyporheic exchange

Representing hyporheic stratification likely very important in adequately representing biogeochemical processes!

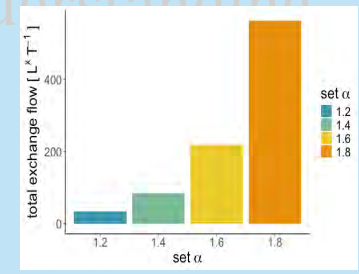
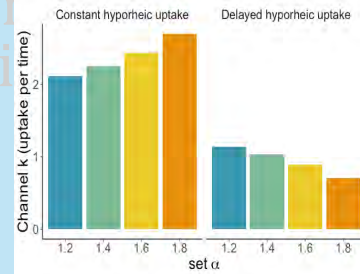


- Why hyporheic exchange is important
- How it's measured and modeled



- What does hyporheic exchange mean?
- Distribution of exchange rates
- Implications for understanding biogeochemistry

Fraction of aquifer storage	Exchange rate				Water age			
	0.00	0.25	0.50	0.75	1.2	1.4	1.6	1.8
0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.05	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
0.10	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
0.15	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
0.20	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
0.25	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
0.30	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
0.35	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
0.40	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
0.45	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
0.50	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
0.55	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
0.60	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
0.65	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
0.70	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
0.75	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
0.80	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
0.85	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
0.90	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018
0.95	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
1.00	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020





# Thank you!

Hayley Oakland  
([hayleyoakland@montana.edu](mailto:hayleyoakland@montana.edu))

Samuel Fritz, Anna French,  
Lindsey Albertson, Geoffrey Poole



*Montana State University*

