On the Reactive Transport at Catchment Scales with StorAge Selection Functions

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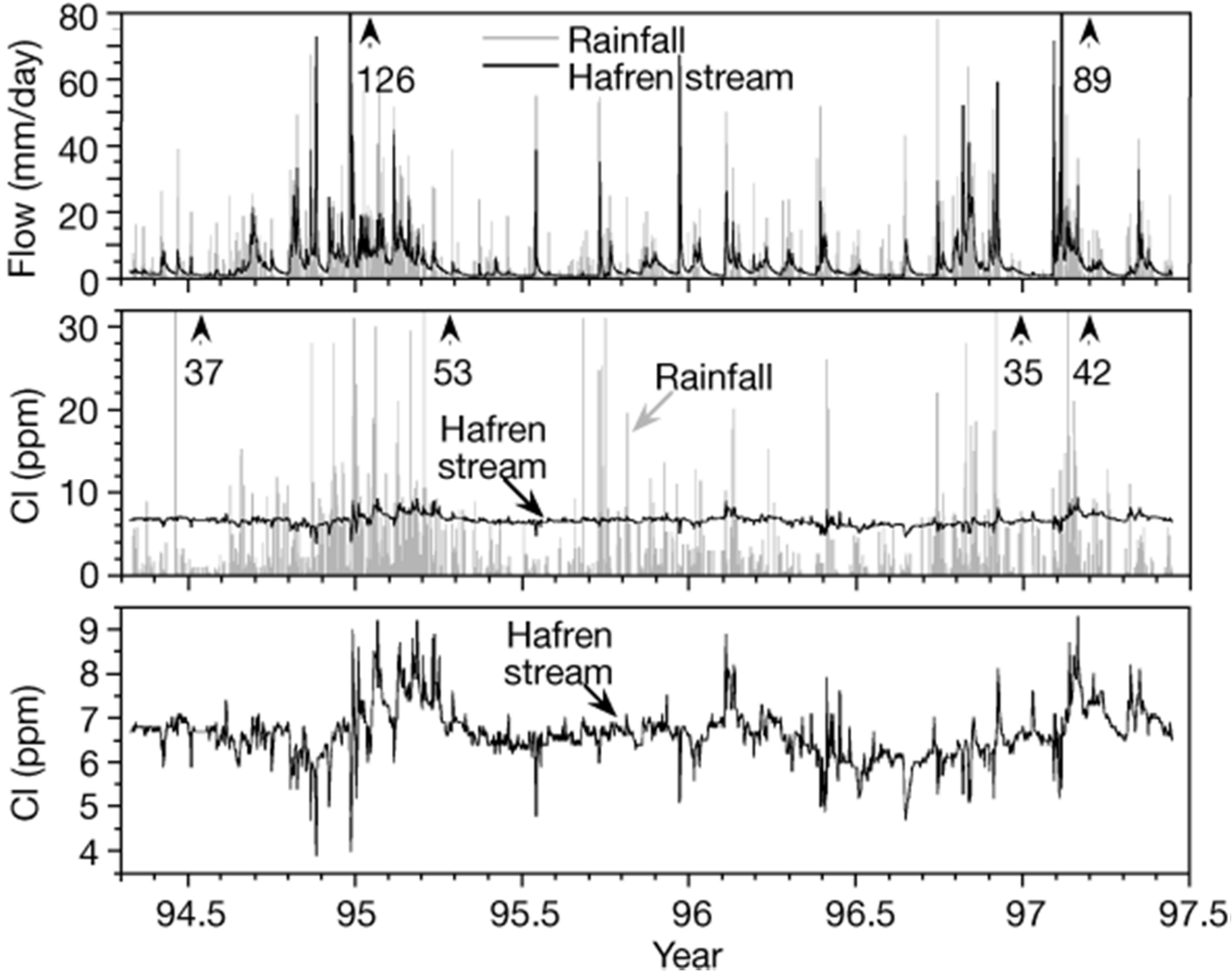
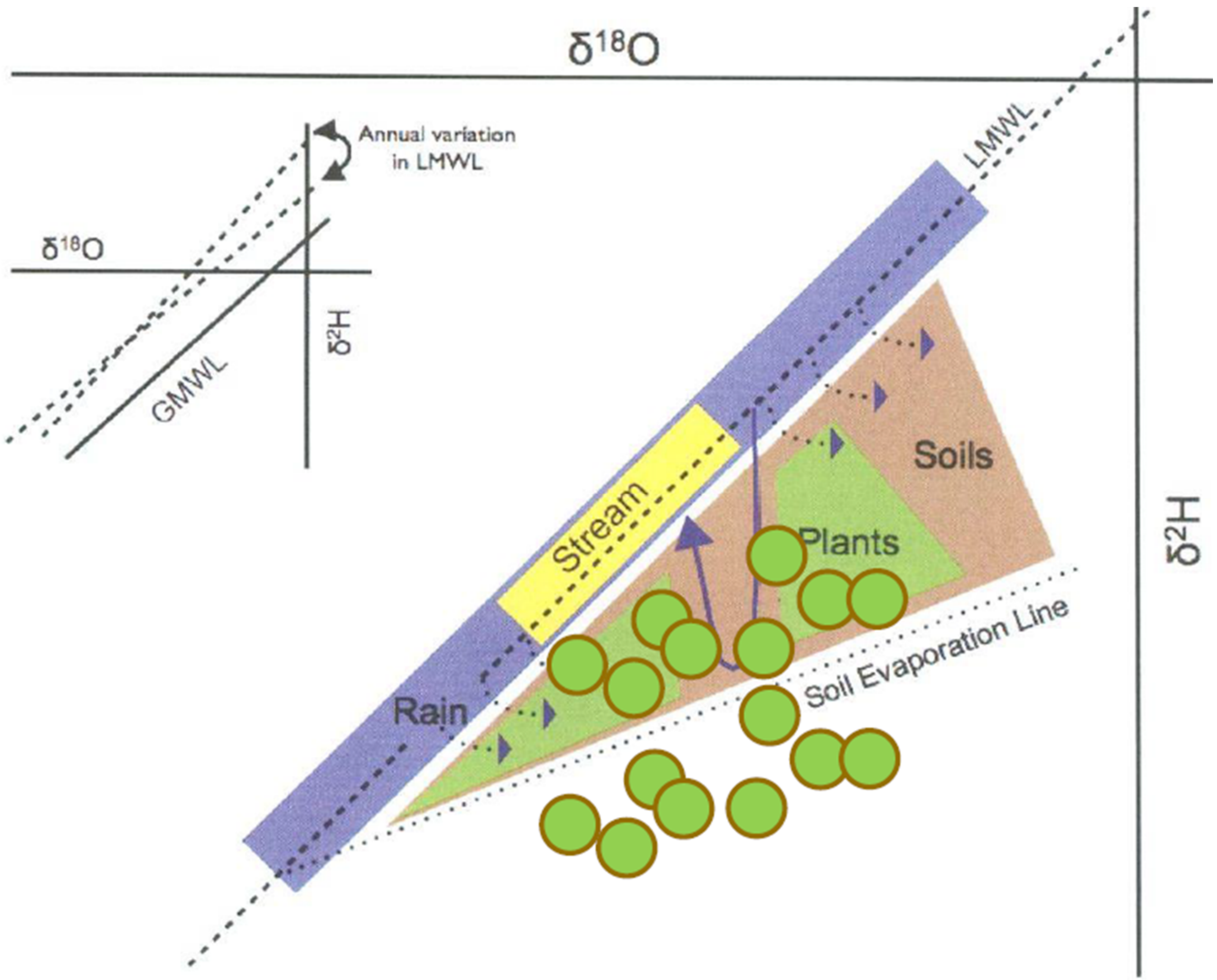
Outline

- Travel Time Distributions and Age
- StorAge Selection Functions
- Reactivity from High-res data
- Potential pitfalls with common assumptions in SAS modelling

Why Age Matters



Two Water-Worlds Hypothesis



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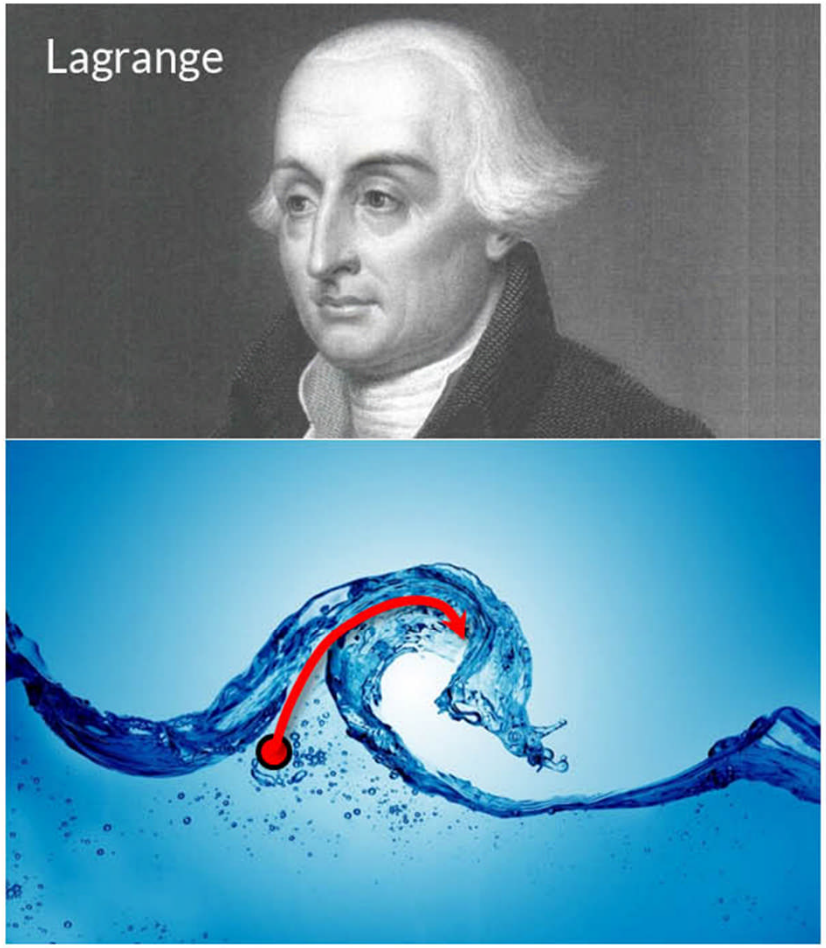
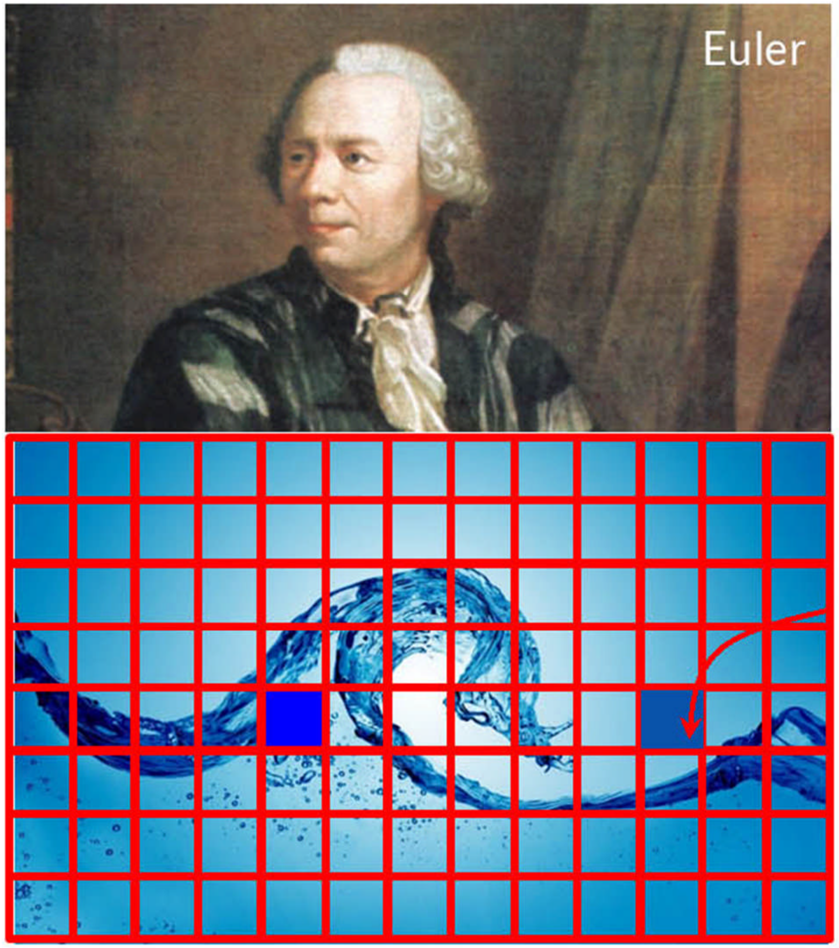
Modelling over the Ages





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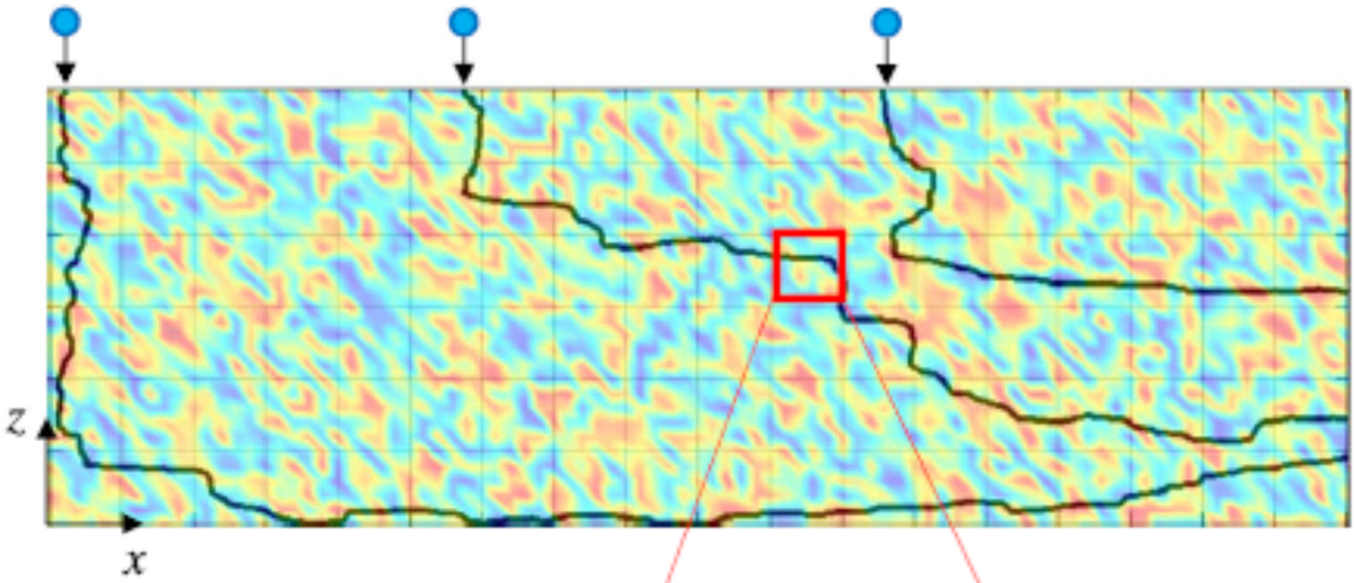
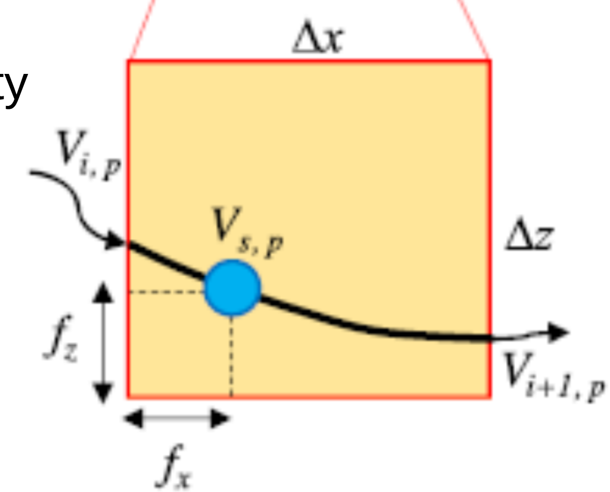
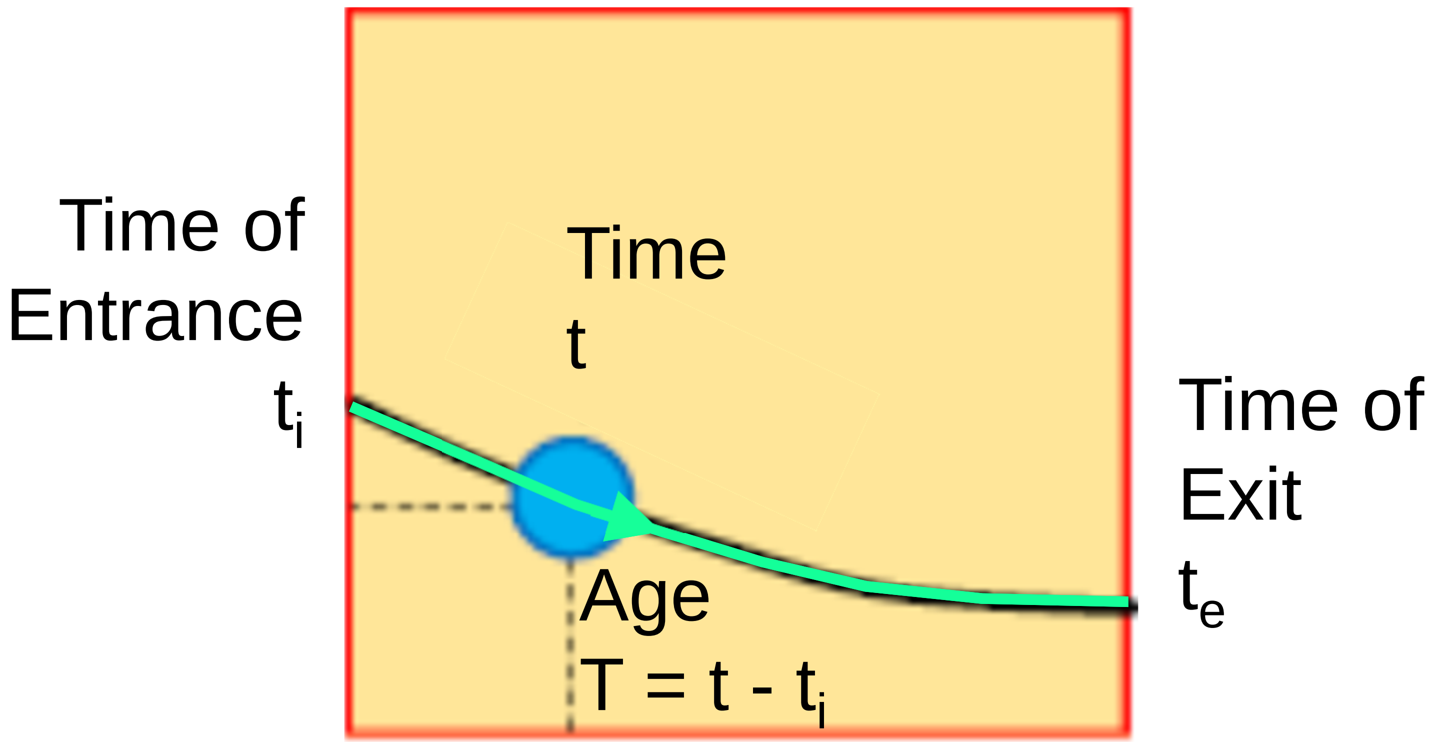
A Eulerian Catchment



- Explicitly define the heterogeneity
- Parameterize the physics
- Recover the travel-times from particle tracking

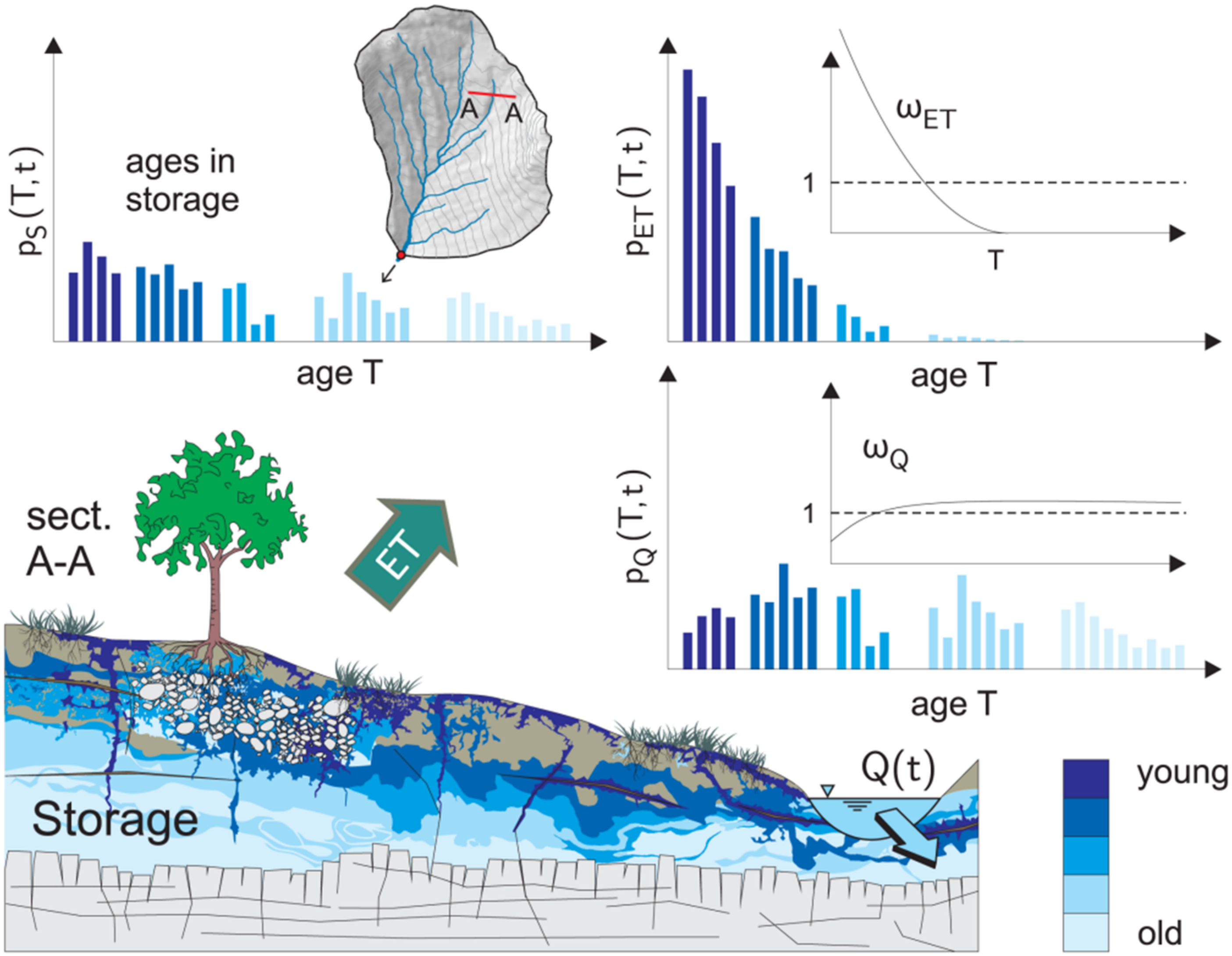


Time, Residence Time (Age), and Travel Time



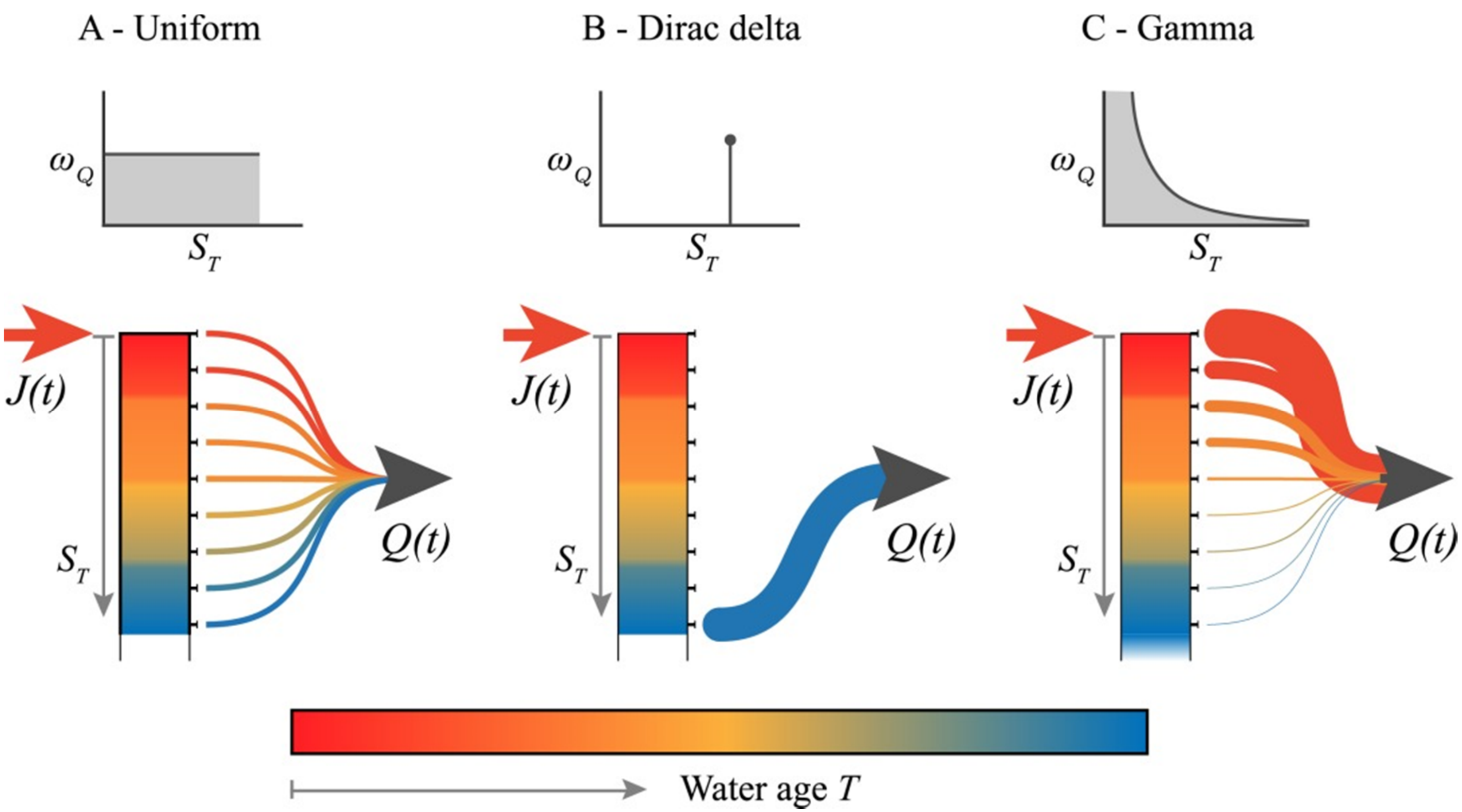
Travel Time
$T_r = t_i - t_e$

A Lagrangian Catchment



Rinaldo et al., (2015) WRR

Contribution of Stored Water of Various Ages to Stream Flow

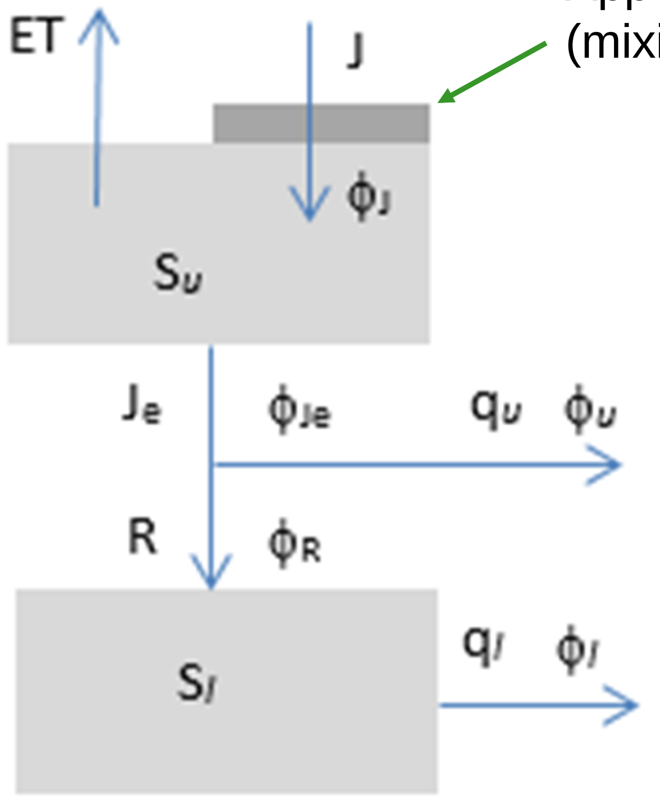


Harman (2014) WRR 51(1) https://doi.org/10.1002/2014WR015707

A Simple Pesticide Transport Model

Applied pesticide
(mixing layer)

Aerobic
$t_{1/2}$ = 20 days

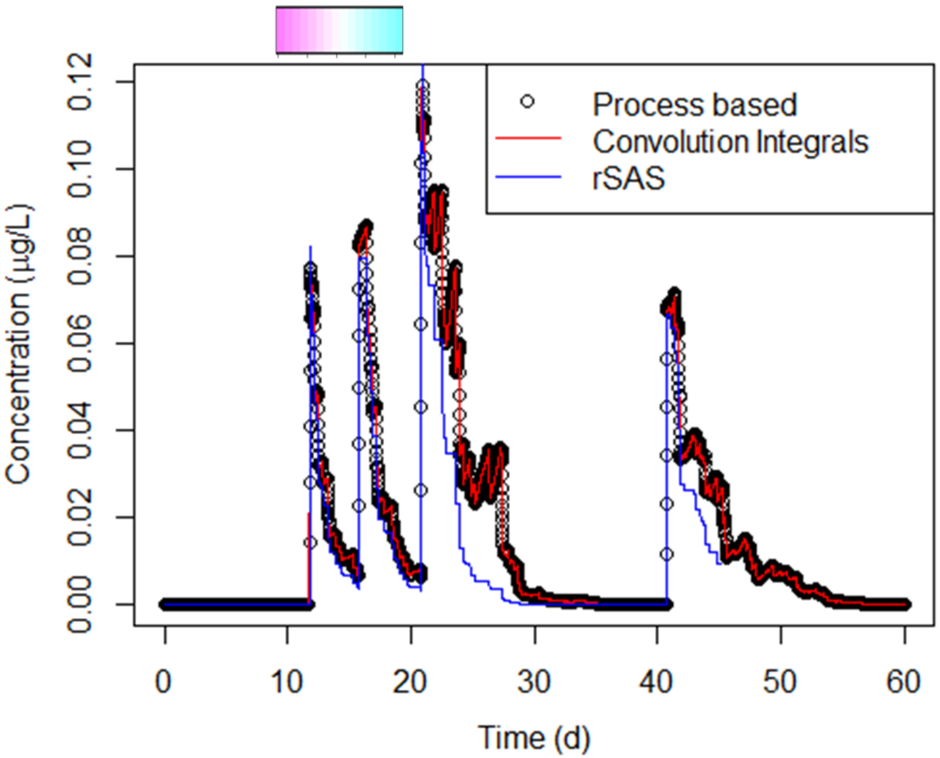


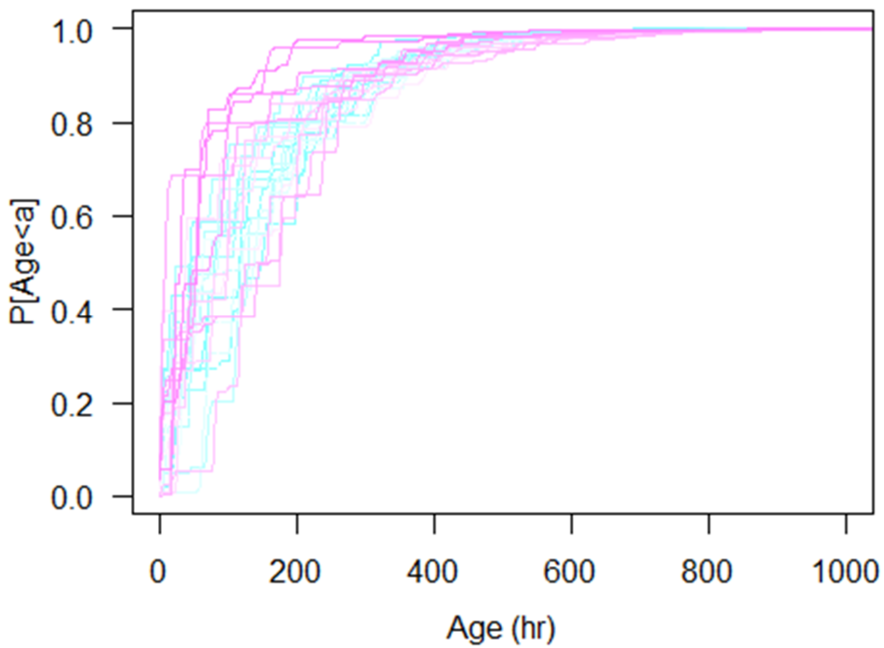
Anaerobic
$t_{1/2}$ = 200 days

Uniform ω_Q
+
Uniform ω_Q
+
Uniform ω_Q
↓
Non-uniform ω_Q

Modified from Bertuzzo et al., 2013, WRR

Variability of Residence Times





Basic Equations and Common Assumptions

Tracers

Stream concentration = sum over all input times of input concentration (C_{in}) at time t_i and the distribution of stream water ages (p_Q) at time t

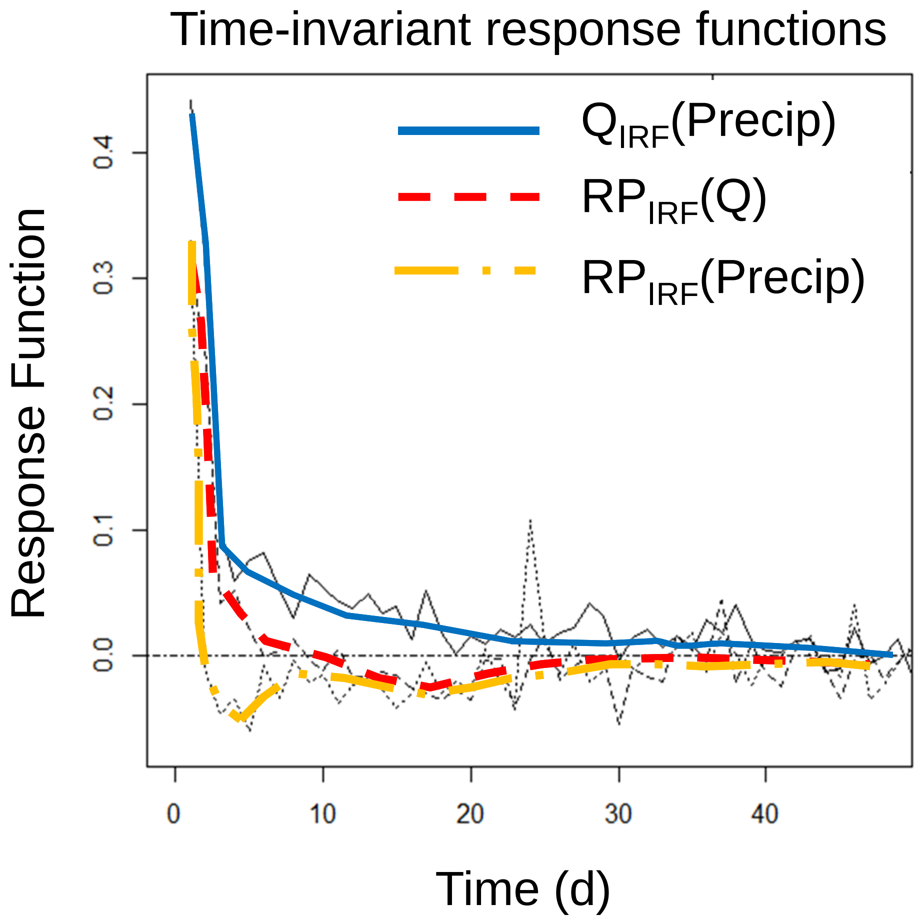
$$C_Q(t) = \int_{-\infty}^{t} C_{in}(t_i) p_Q(t - t_i, t) dt_i$$

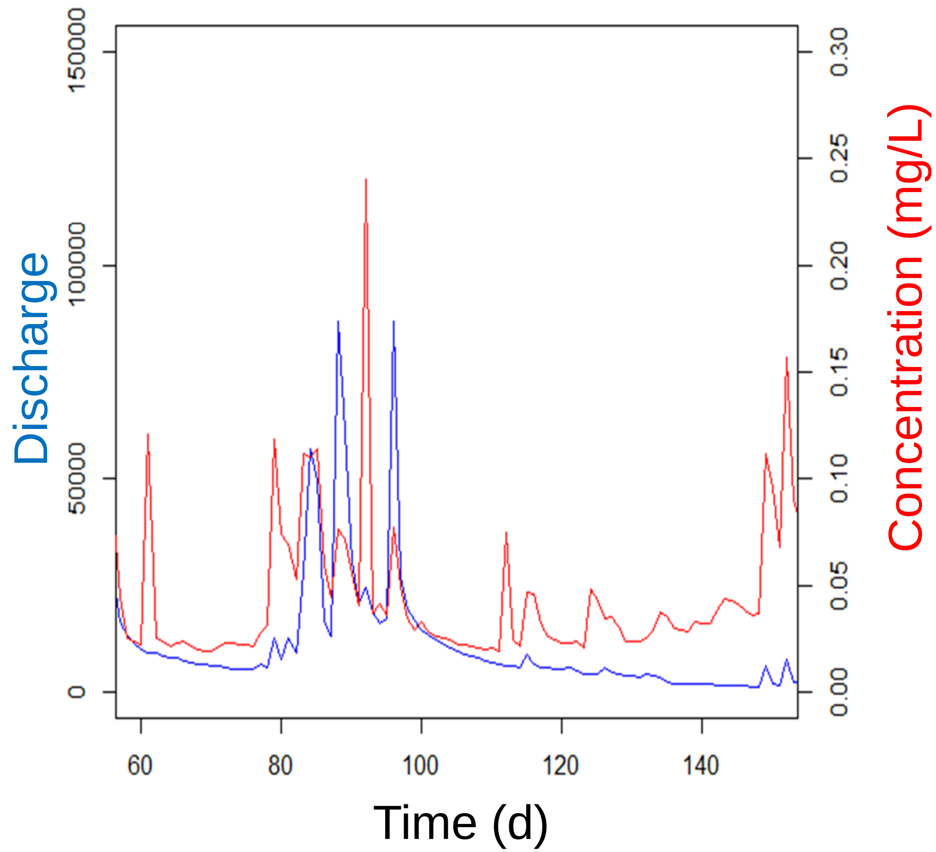
Reactive Solutes

Stream concentration = sum over all input times of resident concentration (C_S) at time t_i and the distribution of solute flux ages (p_F) at time t

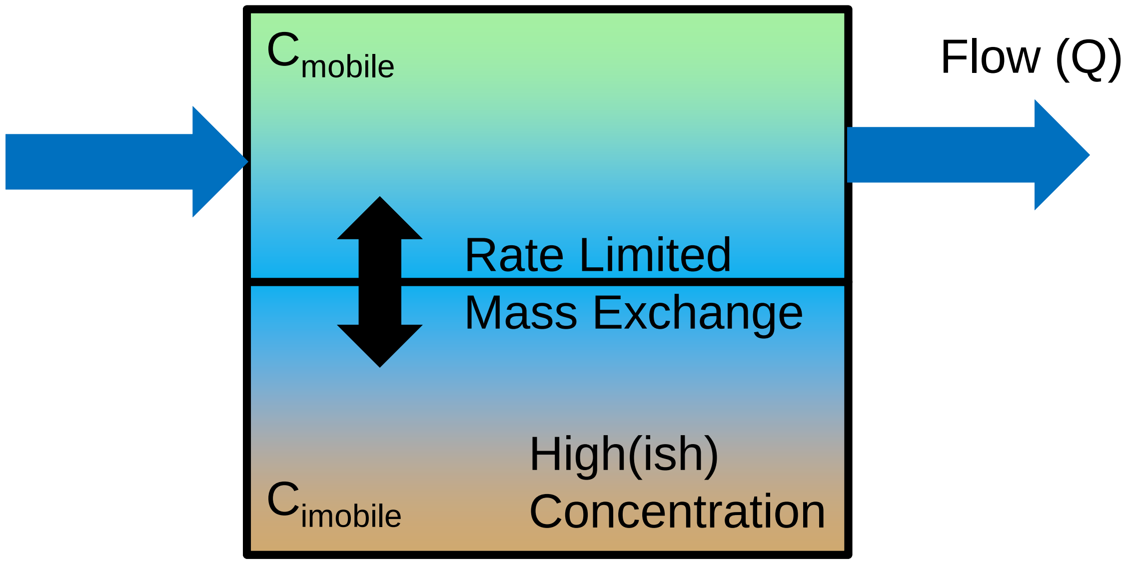
$$C_Q(t) = \int_{-\infty}^{t} C_S(t - t_i, t) p_F(t - t_i, t) dt_i$$

Learning From High-res Reactive P Response Functions



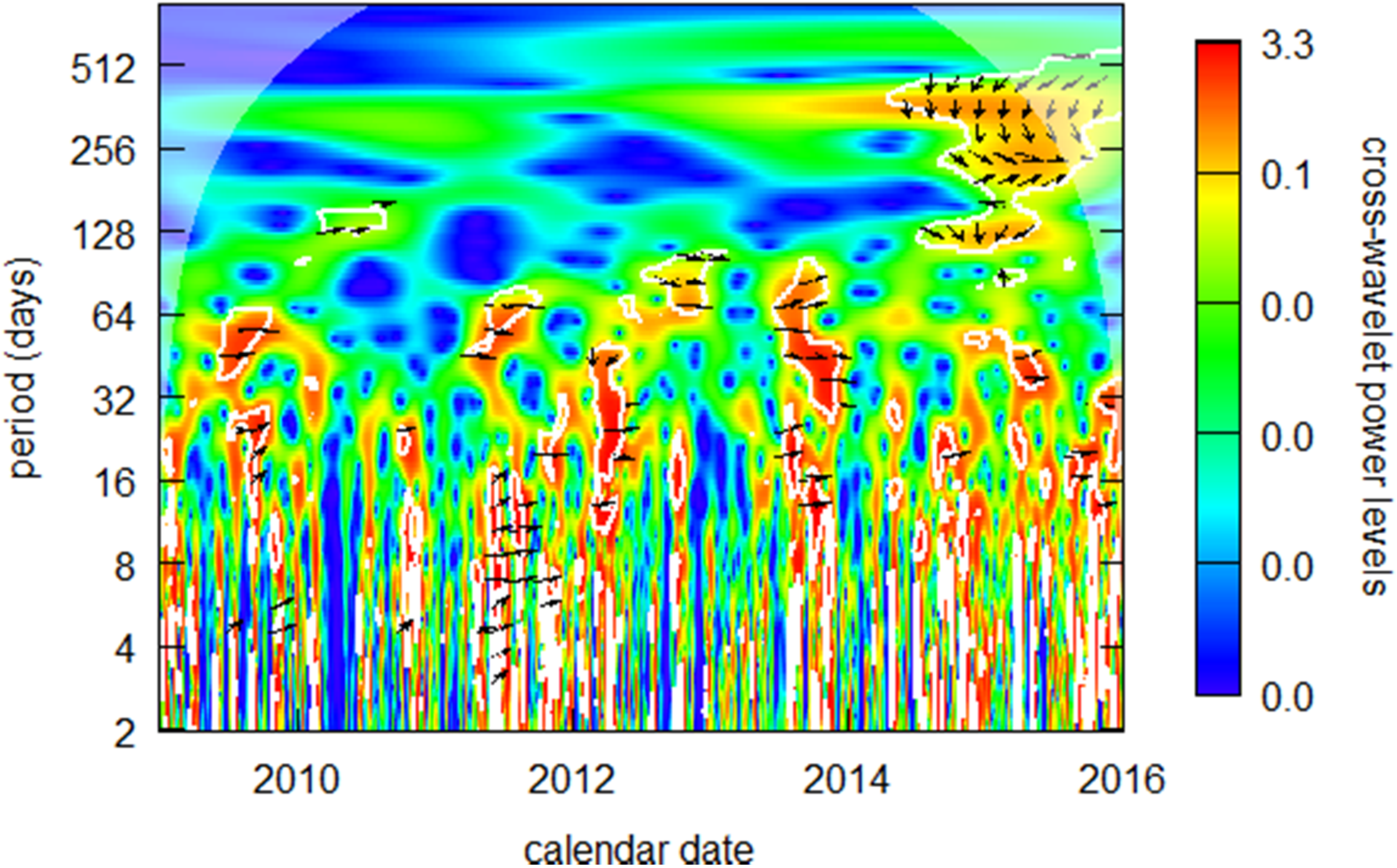


Reactive P Conceptual Model



Gradual build up in concentration in mobile zone (C_{mobile}) when Q is low
Rapid flush of C_{mobile} when Q increases
Rapid dilution of C_{mobile} during high flows to rate limited mass exchange

Cross Wavelet Spectra RP and Precipitation



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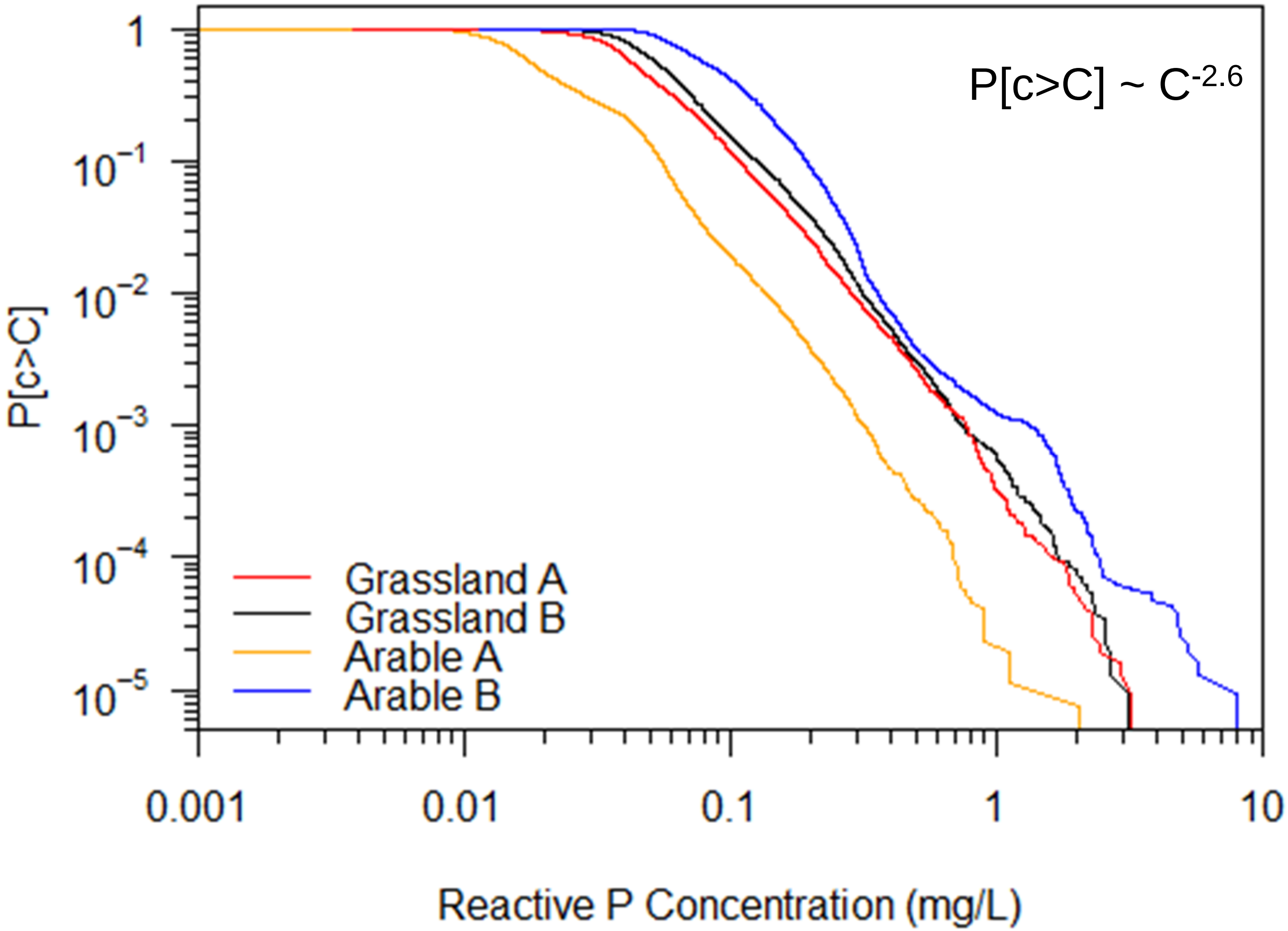
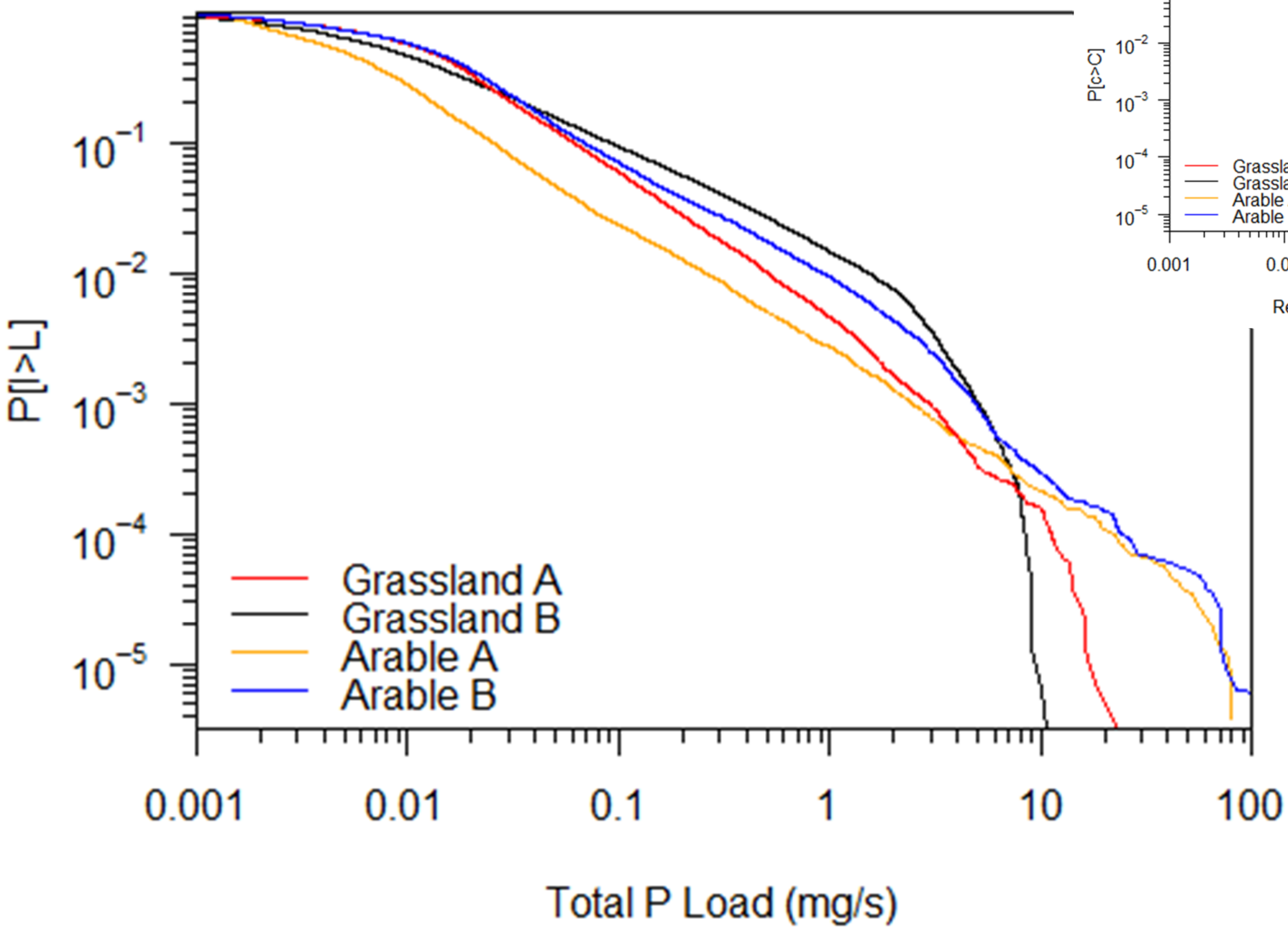
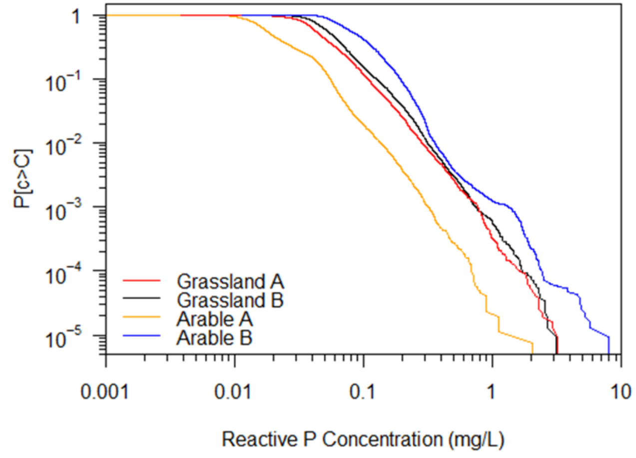
Q: Are these catchments really all that different?



A: Differently organized sources and flux distributions





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Damköhler Number Da = $k_r T_r$

- $k_r \sim 0.1\ T_r^{-0.76}$ Da $\sim 0.1\ T_r^{0.24}$

Residence Time Distribution

Dynamic Damköhler

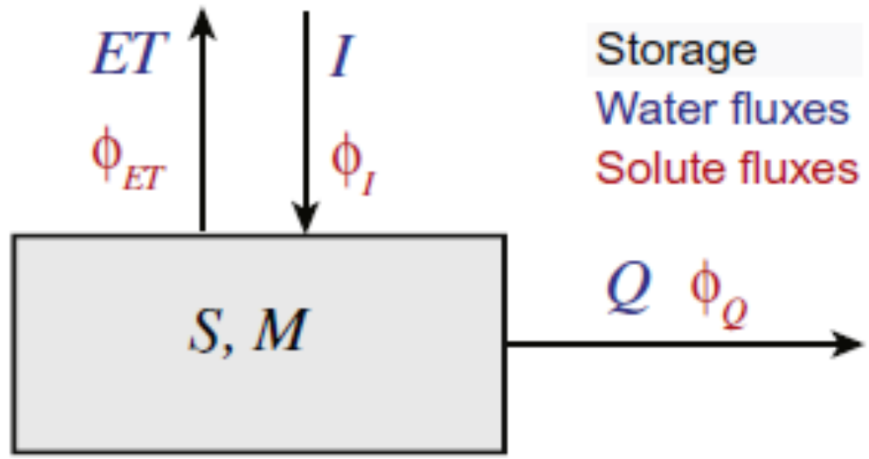
$$\phi_Q(t) = \int_{-\infty}^{t} \phi_{In}(t_i)\,\overbrace{\frac{Q(t)}{S(t)}\, e^{-\int_{t_i}^{t}\frac{Q(x)}{S(x)}dx - \int_{t_i}^{t}\frac{\alpha\, ET(x)}{S(x)}dx - k(t-t_i)}}^{\text{Residence Time Distribution}}\, dt_i$$

Mixing

Steady Conditions

$$\frac{\phi_Q}{\phi_{in}} = e^{-Da}$$

$$T_r = \frac{S}{Q}$$



A Possible Resolution

Use Tracers to Establish the rSAS function and p_Q then weigh p_F by p_Q

Tracers

Stream concentration = sum over all input times of input concentration (C_{in}) at time t_i and the distribution of stream water ages (p_Q) at time t

$$C_Q(t) = \int_{-\infty}^{t} C_{in}(t_i) p_Q(t - t_i, t) dt_i$$

Reactive Solutes

Stream concentration = sum over all input times of resident concentration (C_S) at time t_i and the distribution of solute flux ages (p_F) at time t

$$C_Q(t) = \int_{-\infty}^{t} C_S(t - t_i, t) p_F\left(t - t_i, t | p_Q(t - t_i, t)\right) dt_i$$

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Summary

- The SAS approach
  - current flavour-of-the-month for catchment-scale solute transport modelling
  - intuitive interpretation of hydrological processes contributing to solute export
- Reactive solutes remain a challenge
- Combining multiple highres solutes can possibly help untangle
  - Sources
  - Pathways; and
  - Mitigation timescales
- Need good input data!