BATTELLE 2023 SEDIMENTS CONFERENCE

Economical Innovations for Improved Chemical Mass Flux Quantitation in Sediment

Presented by: Michael Gefell, PG, Anchor QEA

Collaborators: Kevin Russell, Anchor QEA
Donald Rosenberry, USGS

USGS science for a changing world

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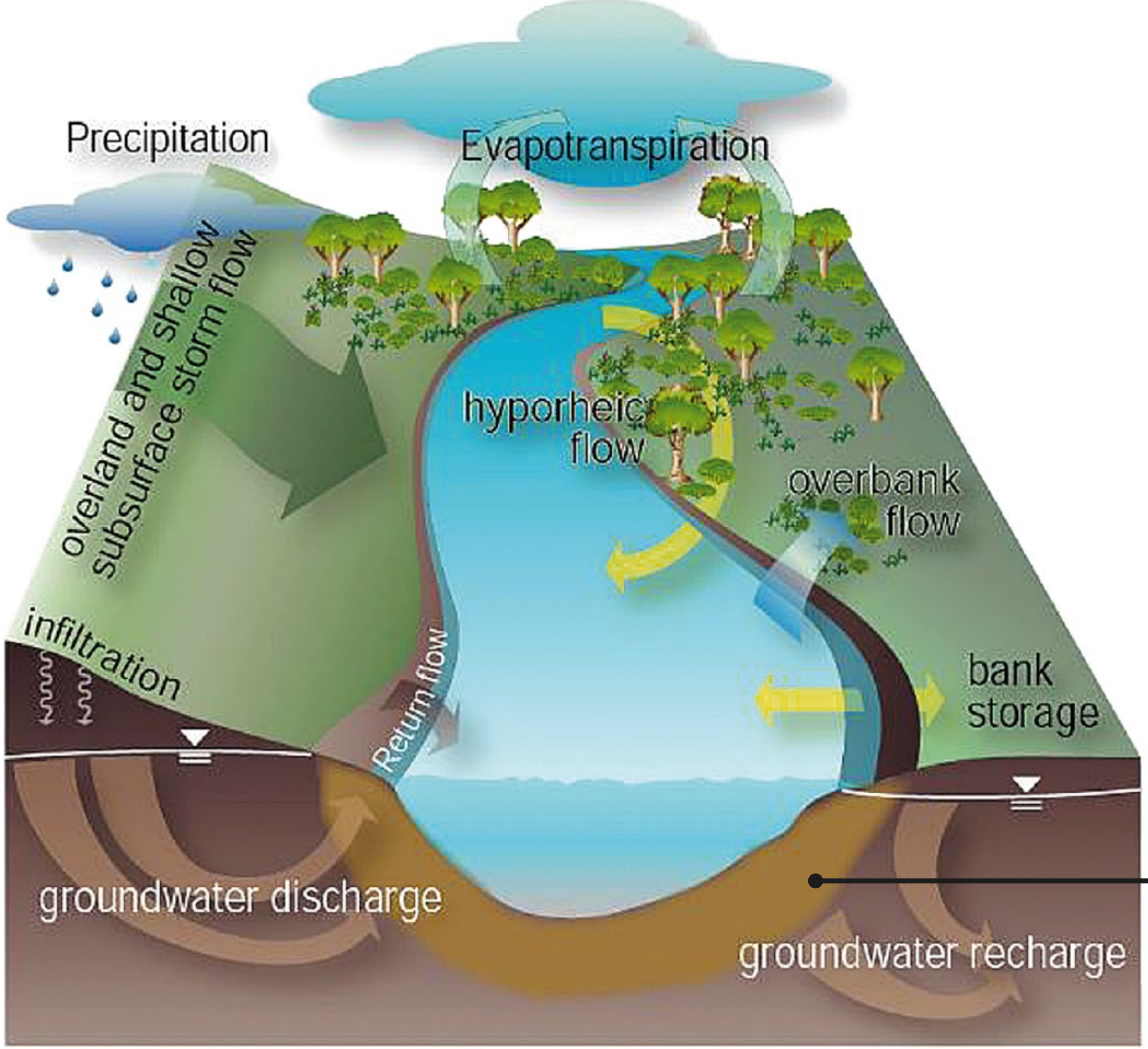


Context for mass flux assessment

Source: Boano et al. (2013)

CHALLENGE

What sorts of economical innovations can improve chemical mass flux measurements in sediment?

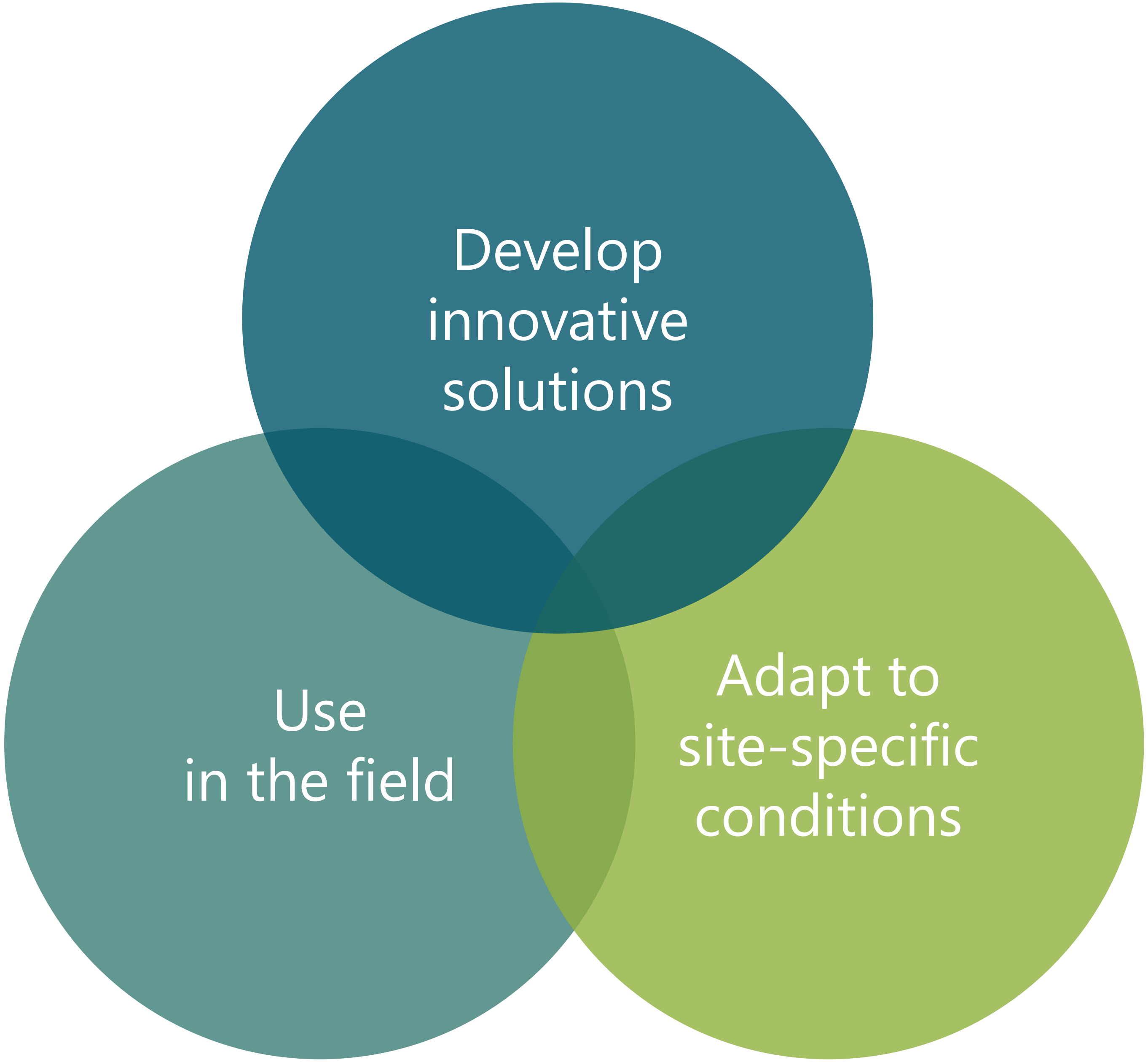
Chemical Mass Flux

- $J = C \times q$
  - where: J = chemical mass flux per unit area per unit time, C = concentration in fluid phase, and q = seepage rate (aka Darcy flux or specific discharge)
    - $q = K \times i$
    - K = hydraulic conductivity
    - i = hydraulic gradient
- Two fluid phases: dissolved phase (porewater) and NAPL

Source: Kueper et al. (2003)

APPROACH + METHODS

Economical Innovations

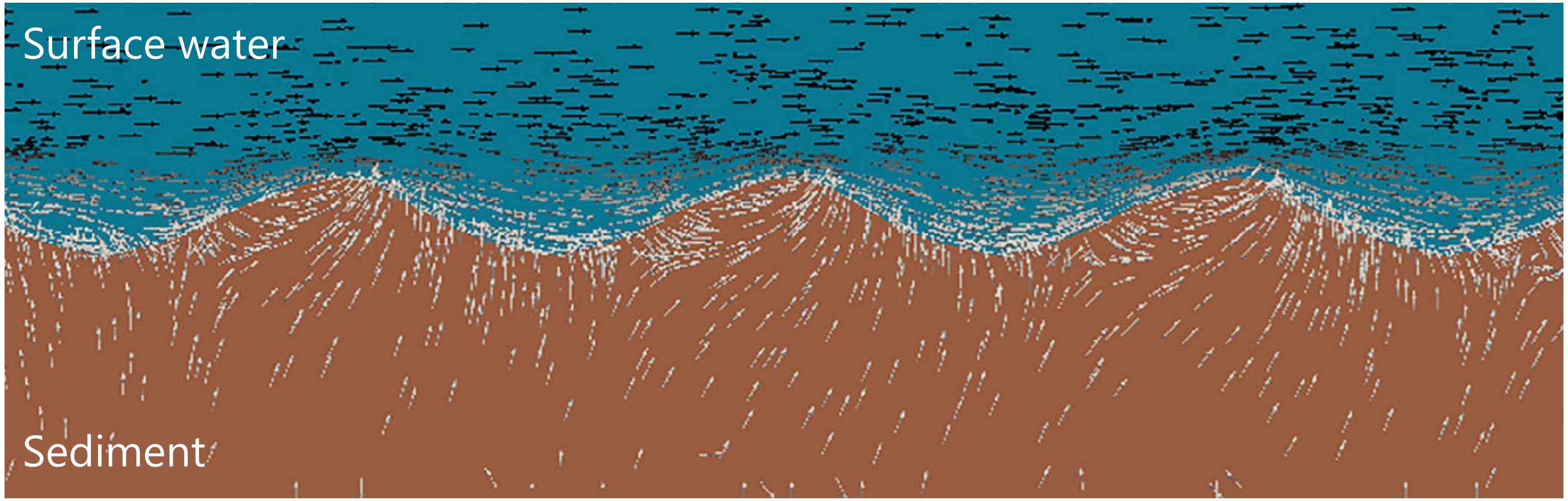


CHALLENGE

Dissolved-Phase Mass Flux—*Porewater Seepage and Concentrations*

Porewater Seepage—Spatial Variability

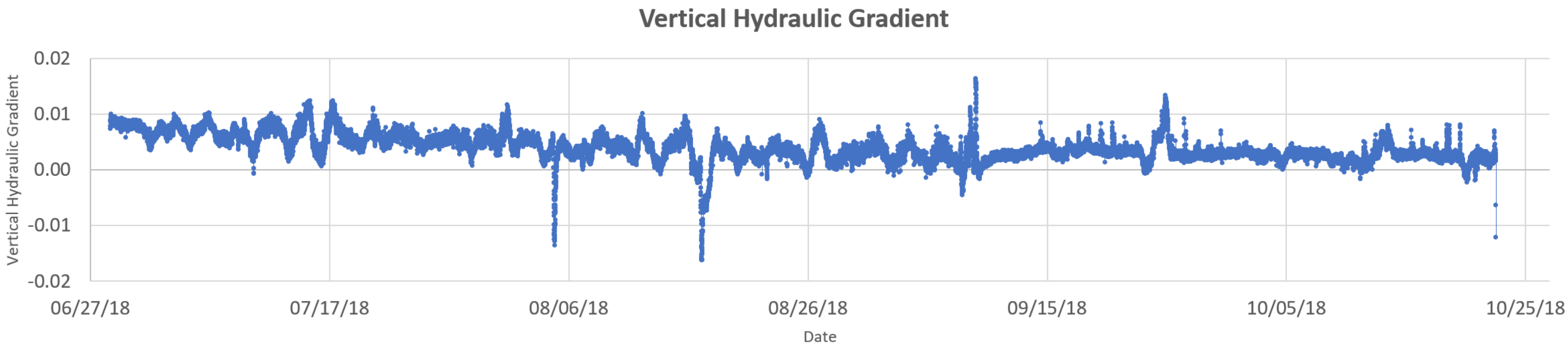
- Hyporheic flow, heterogenous sediment
  - Multiple data collection locations
  - Stratigraphy, geomorphology, and known areas with chemicals of interest



Source: Broecker et al. (2021)

Porewater Seepage—Temporal Variability

- Tides, storms, and seasons
  - Multiple measurement “snapshots” or long periods (typically months)



4-month data collection period

Potential Pitfalls

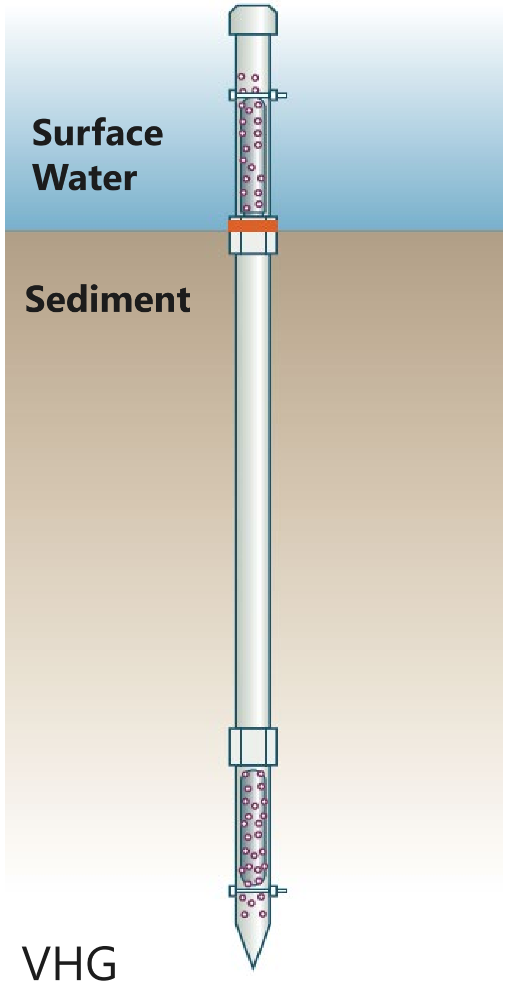
- Seepage meters
  - Fouling by biota or gas
  - Possible instability in soft sediment
  - Difficult to install in hard sediment
  - Hyporheic flow complexities
  - Impractical to deploy for long periods
- Piezometers
  - Destruction by flood, ice, and debris
  - Colocated vertical permeability measurement required—standard methods have significant costs

Source (top photograph): Best et al. (2019)

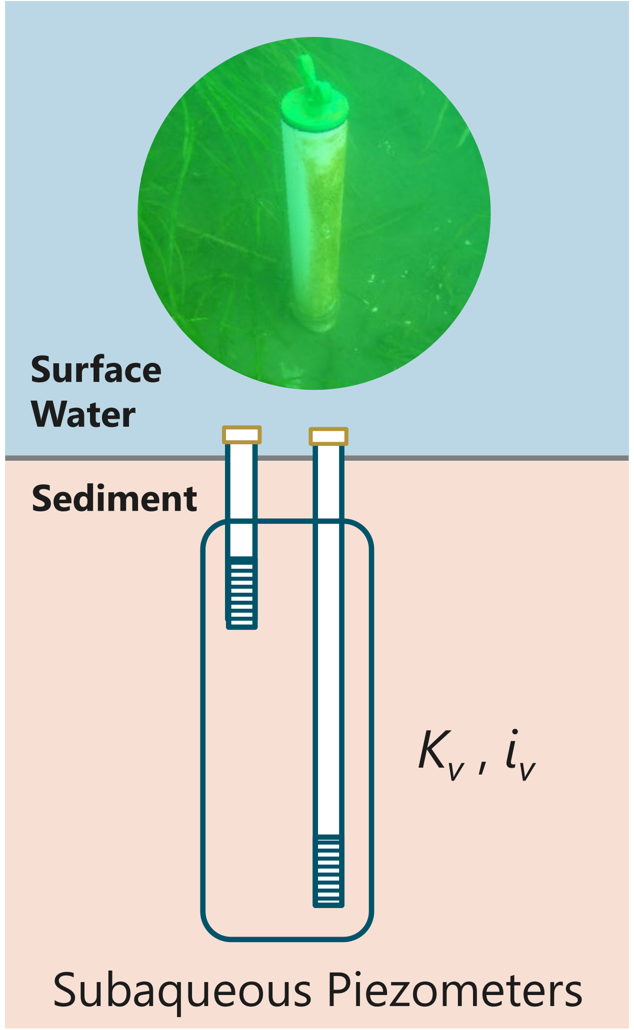
Hydraulic Gradient

ECONOMICAL INNOVATION

- Vertical hydraulic gradient (VHG) device with transducers
  - Dr. Donald Rosenberry, USGS
- Subaqueous piezometers with transducers
- Big picture: avoid hyporheic zone and collect continuous data



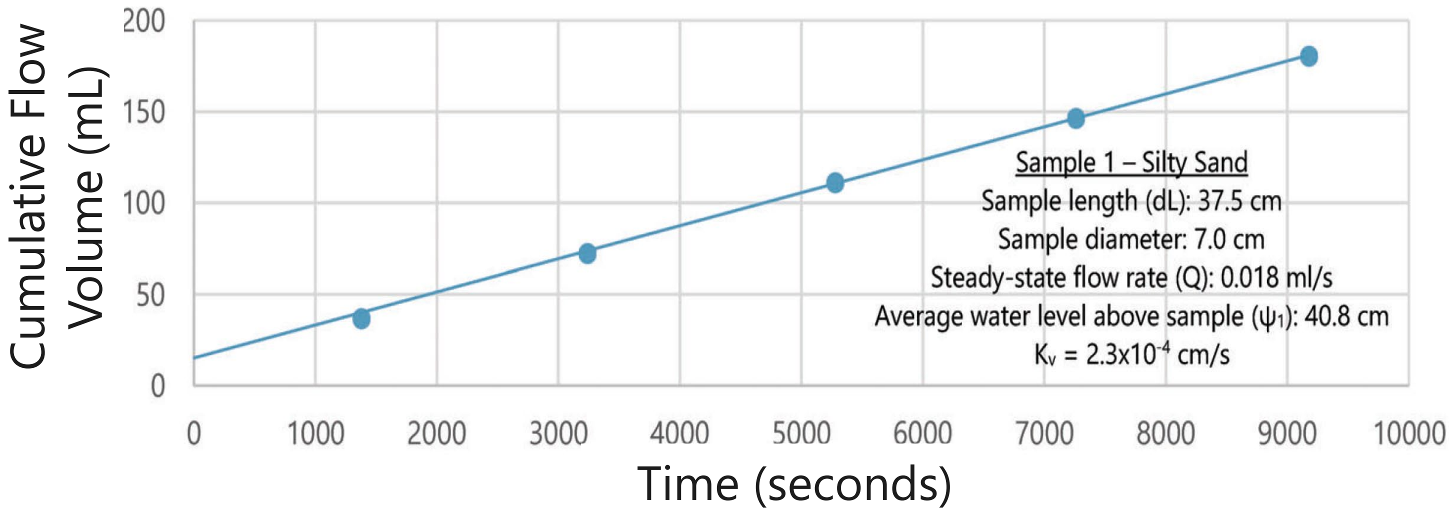
VHG



Source (VHG graphic): Best et al. (2019)

Hydraulic Conductivity

- Measure vertical hydraulic conductivity (K_v) of whole sediment core by gravity drainage
- Avoid: sample cutting, packing, shipping to lab, transferring to lab test cell, over-consolidation, and use of multiple small samples



$$K_v = \frac{Q}{\left[\frac{A\,dh}{dL}\right]}$$

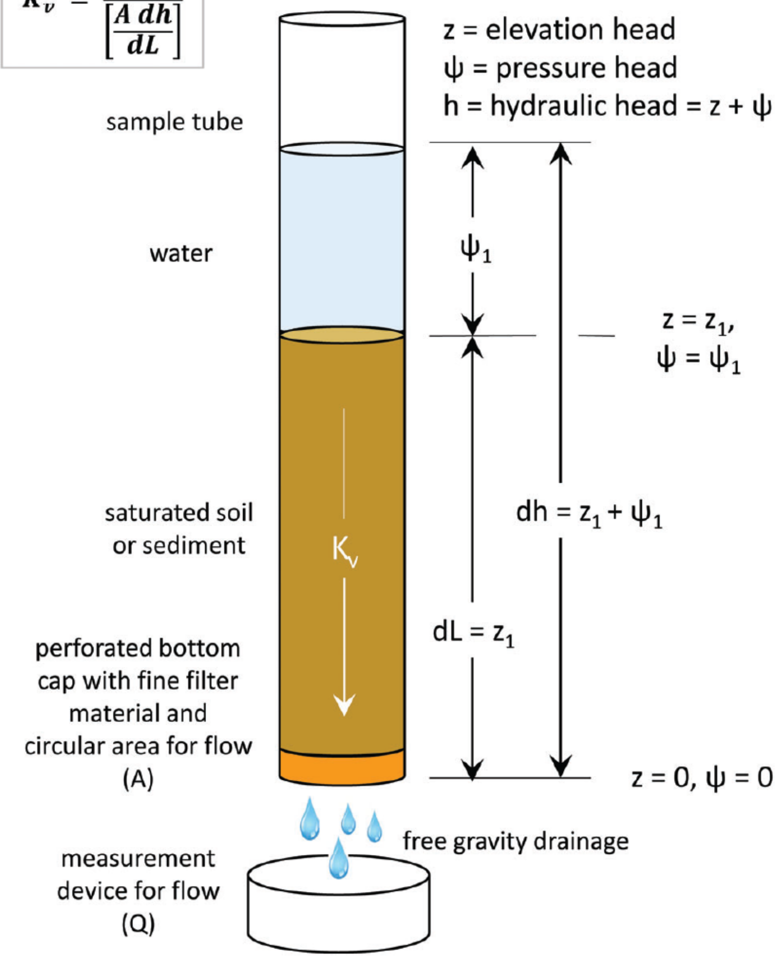
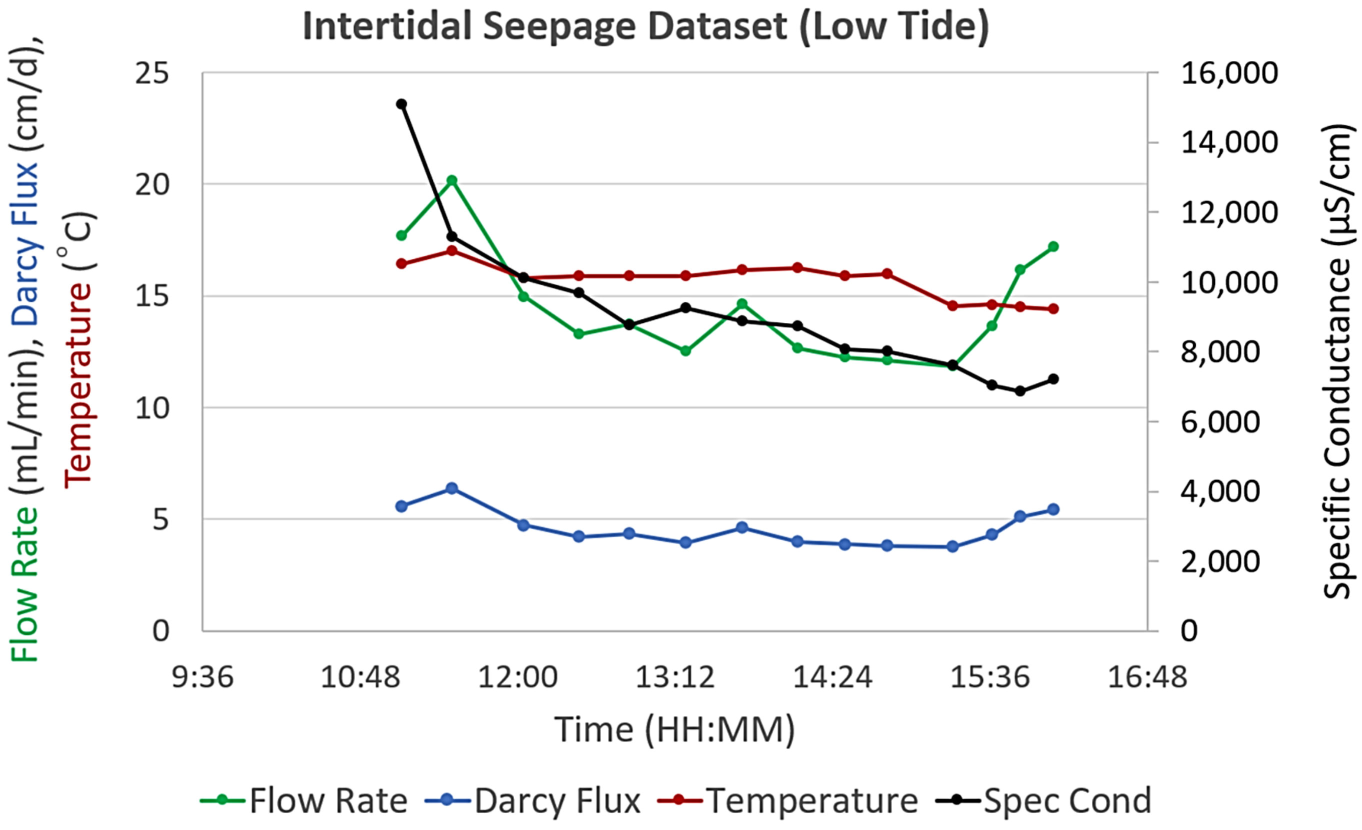


Figure 1. Schematic equipment setup and parameters used to calculate K_v from gravity drainage tests.

Source (figures): Gefell et al. (2019)

ECONOMICAL INNOVATION

Intertidal Zone Seepage

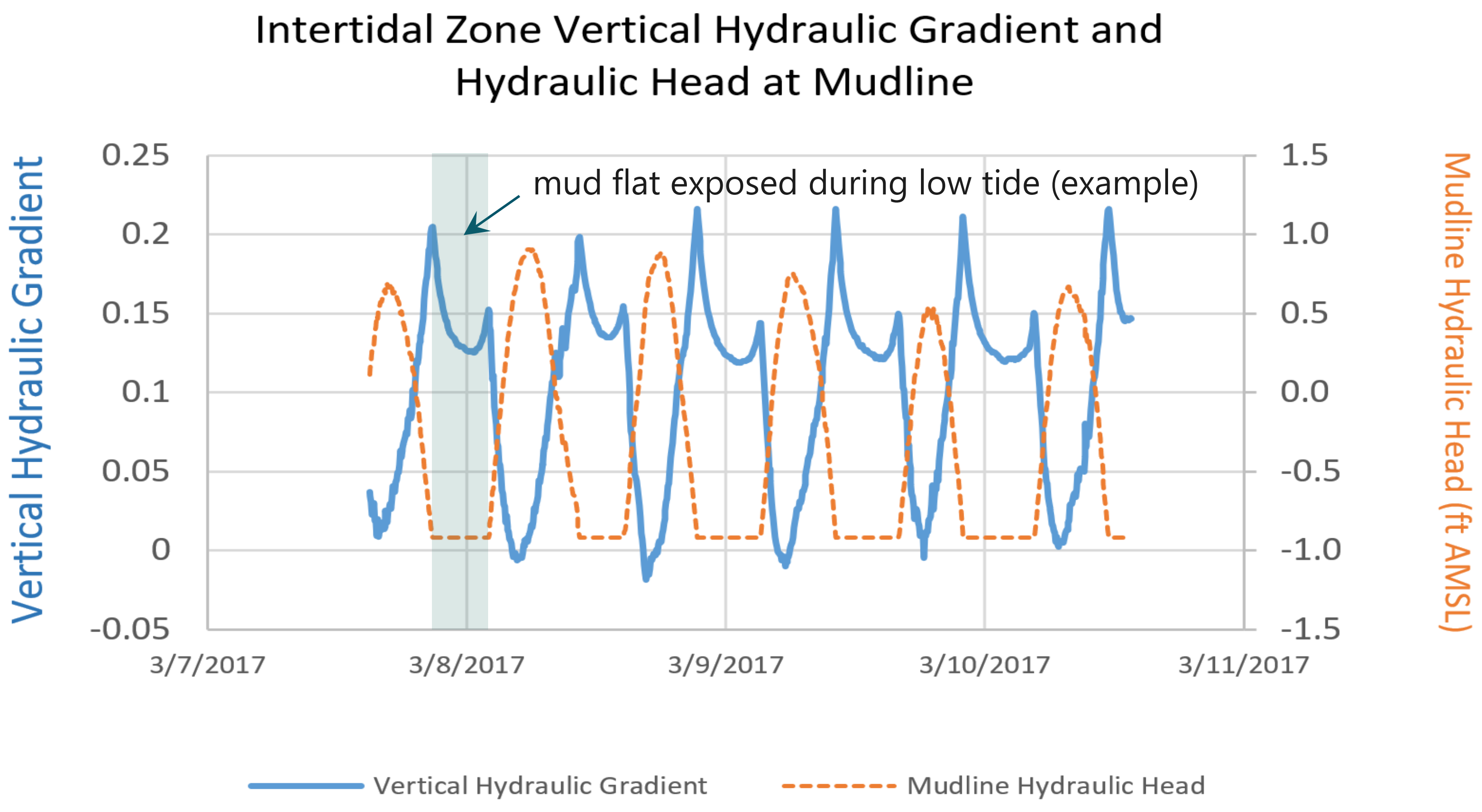


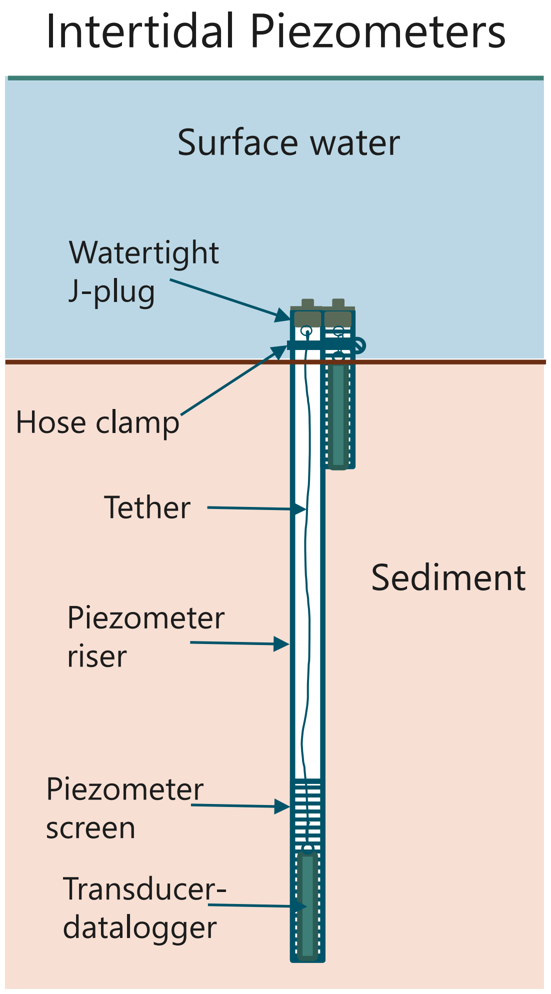
Calculate K_v and combine with full gradient dataset for comprehensive seepage evaluation

Intertidal Zone Gradient

ECONOMICAL INNOVATION

- Vertical gradient from piezometer pair or VHG rod

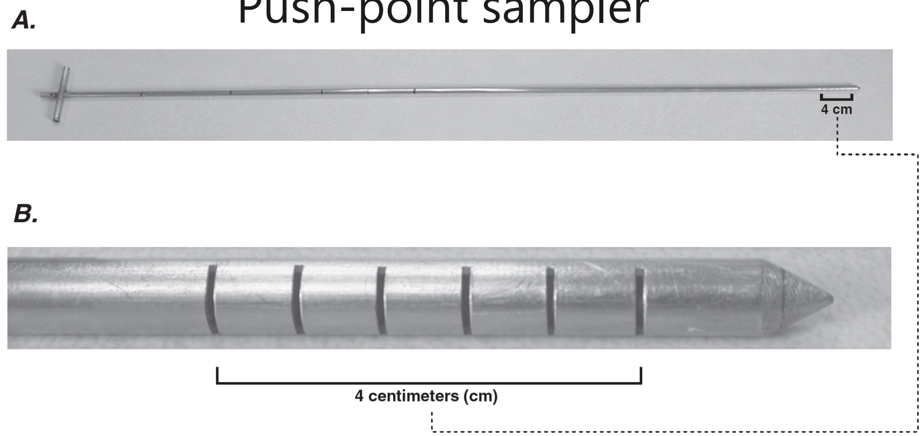


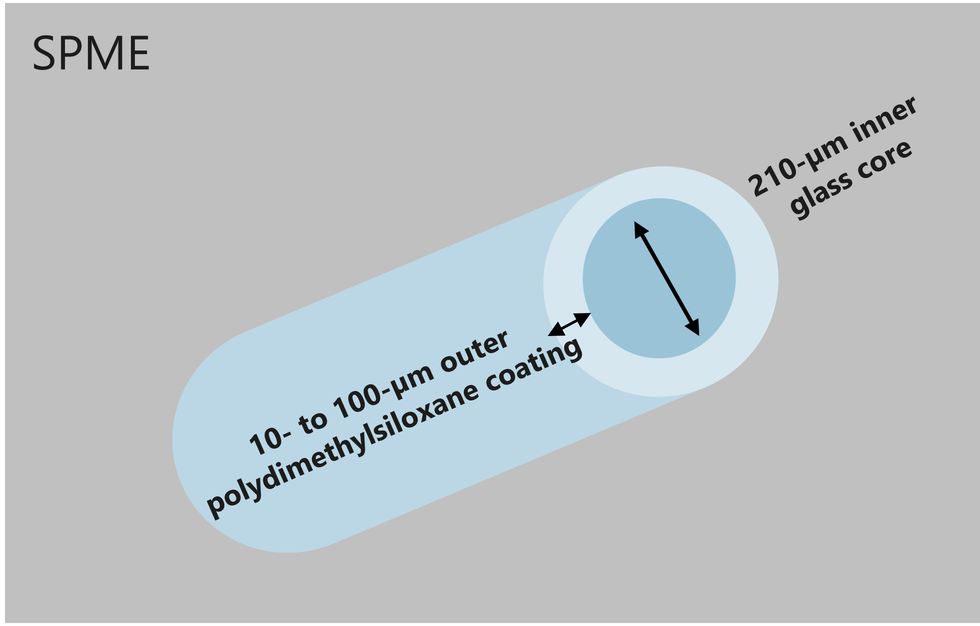


Porewater Concentrations

- Spatially variable (3D)
  - Multiple sampling locations
  - Target anticipated future dredge depth (if known)
- Common data collection methods
  - Calculation: sediment–porewater partitioning
  - Pumped sampling: push point, drill casing
  - Passive sampling: solid-phase microextraction (SPME), polyethylene samplers

Push-point sampler

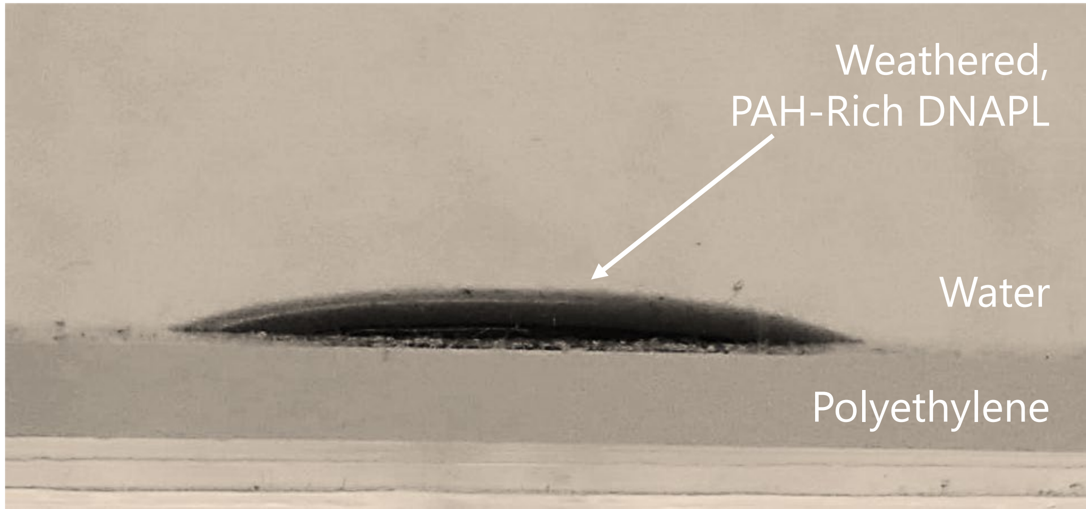




Sources: Zimmerman et al. (2013) and Burgess (2013)

Potential Pitfalls

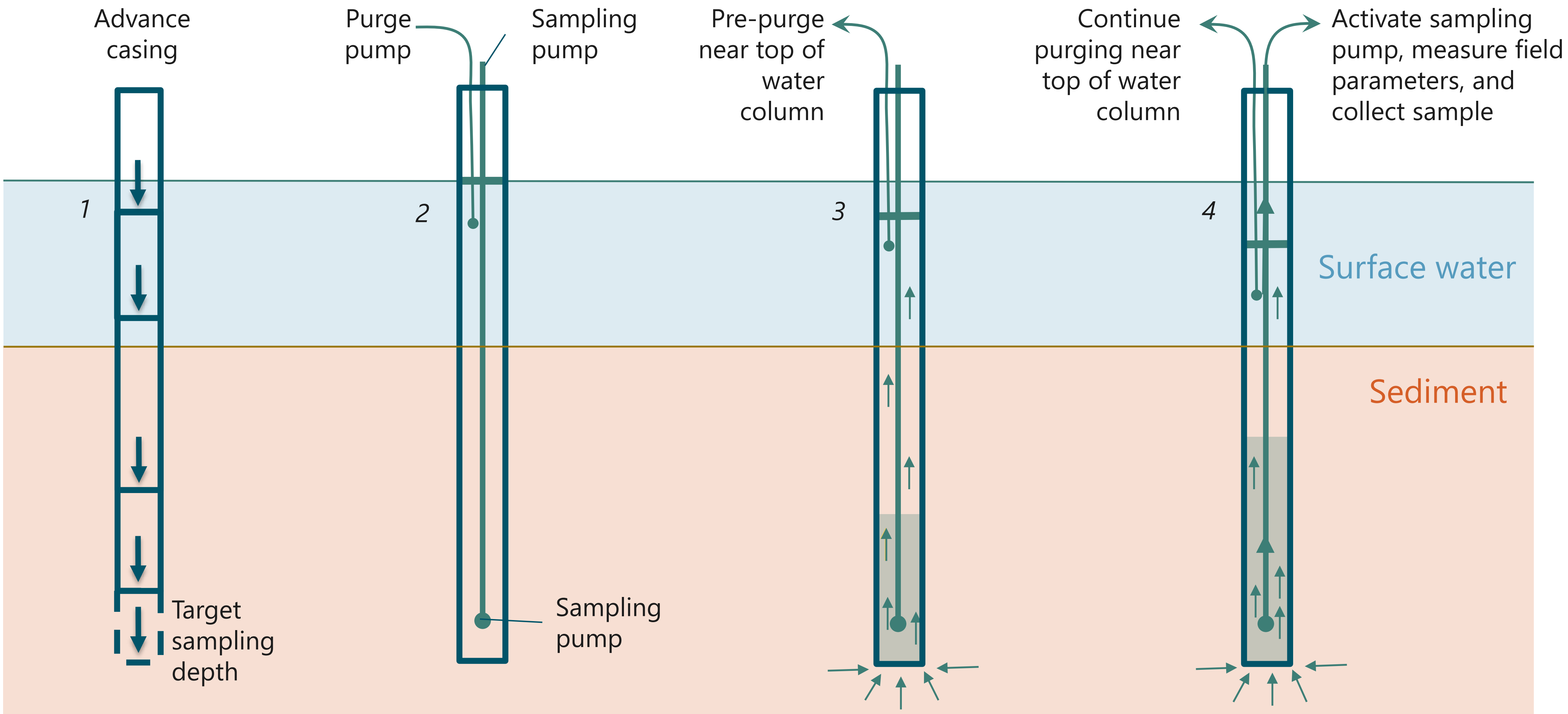
- Hard, gravelly, cobbly sediment—difficult to deploy porewater samplers at depth
- NAPL in sediment complicates partitioning calculations
- Big risk: NAPL inclusion in porewater samples (pumped or passive)—unrealistically high concentrations



Source (bottom photograph): Gefell et al. (2018b)

Porewater Sampling at Depth in Dense, Coarse-Grained Sediment

ECONOMICAL INNOVATION



Exclude NAPL from Porewater Samples

- Porous ceramics
- Water goes through; NAPL doesn't
- Economical, versatile, and effective
  - Diffusion-based equilibration
  - By direct porewater pumping or after sediment centrifuging or gravity drainage

Source: Gefell et al. (2018b)

Learning Lab

Quantifying Aqueous Concentrations in Direct Contact with NAPL-Containing Sediment Using Porous Ceramic Samplers

Tuesday and Wednesday, 2:40 p.m.

CHALLENGE

NAPL Mass Flux—*Quantifying Potential Advection Rate*

NAPL Advection (Flow Through Pores)

- $J_N = \rho_N$ x q_N (NAPL mass flux per unit area per unit time)
  - where: ρ_N = NAPL density and q_N = NAPL seepage rate
- $q_N = K_N \times i_n$
  - where: K_N = NAPL effective hydraulic conductivity and i_n = net gradient
  - only applies if NAPL is capable of moving

K_N Estimation Methods

- Common methods
  - Calculate from NAPL accumulation in wells (via NAPL transmissivity)
  - Calculate based on: $K_N = k_{r,n} K \nu_w / \nu_n$
- Potential pitfalls
  - NAPL rarely seen in wells/piezometers in sediment
  - Accumulation rates unknown
  - Calculation requires several assumptions

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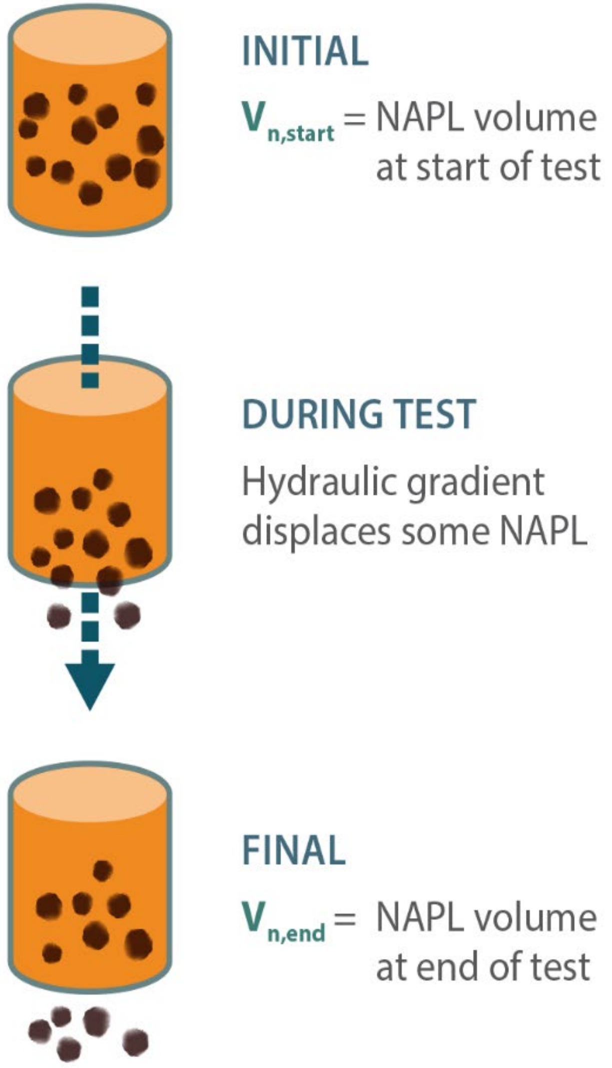
ECONOMICAL INNOVATION

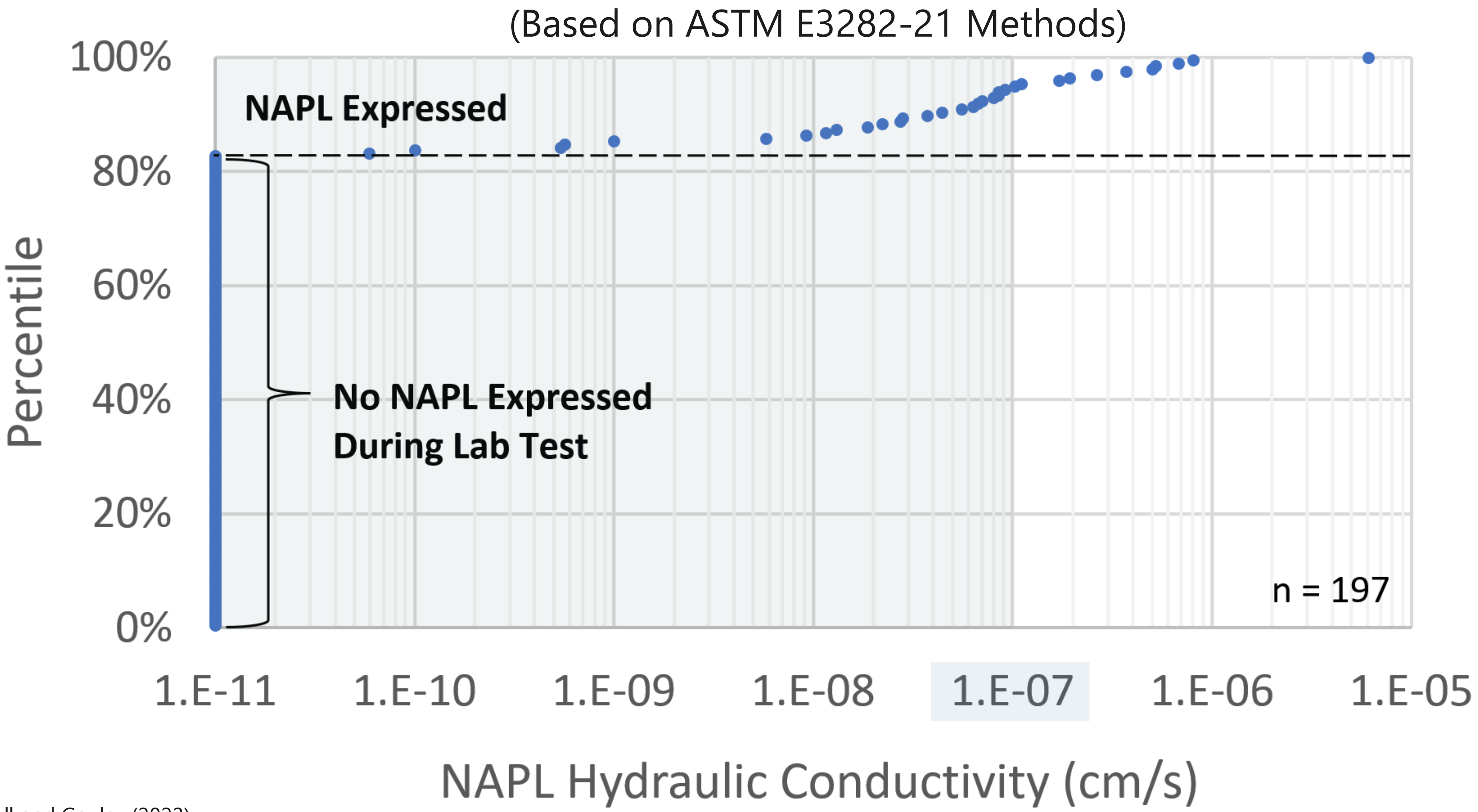
K_N from Laboratory Tests

- Get the full value from NAPL mobility laboratory tests
  - Use ASTM E3282-21 weight-of-evidence methods
  - K_N in sediments often extremely low
- In most cases, NAPL has little or no potential to migrate via advection in sediments



Source: Gefell et al. (2018a)

NAPL Hydraulic Conductivity in Sediment at 10 Sites



Source: Gefell and Gauley (2022)

SOLUTION / LESSONS

- Chemical mass flux is crucial for successful sediment remediation
- Beware of pitfalls in data collection
- Economical innovations can improve versatility in the field, data quality, mass flux quantification, and remedial outcomes

THANK YOU

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