Evaluating Trace Metal Mobilization During Managed Aquifer Recharge

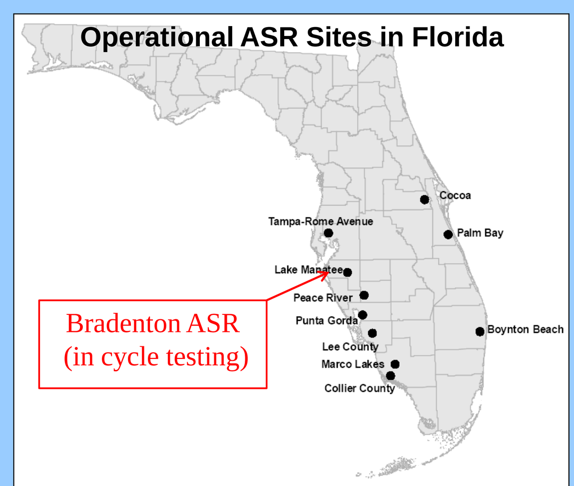
Stuart B. Norton and Mike D. Annable, University of Florida, Department of Environmental Engineering Sciences
(contact: stuartnorton@me.com; annable@ufl.edu)

• Background •

Research Focus :

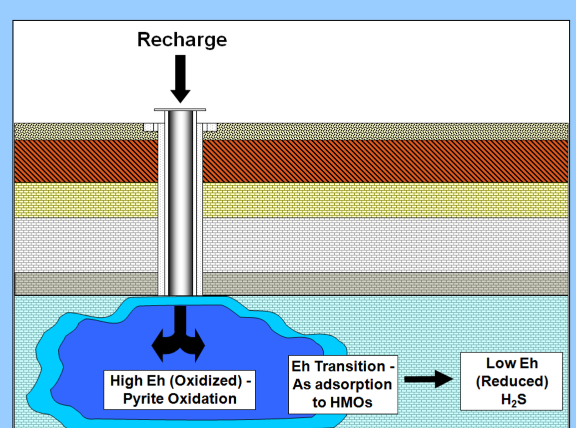
Trace metal (e.g., arsenic, iron, molybdenum) mobilization during recharge has affected the long-term viability of Managed Aquifer Recharge (MAR) techniques, including Aquifer Storage and Recovery (ASR) and Artificial Recharge (AR).

Since new Arsenic MCL (10 µg/L), Arsenic has become primary constraint for MAR

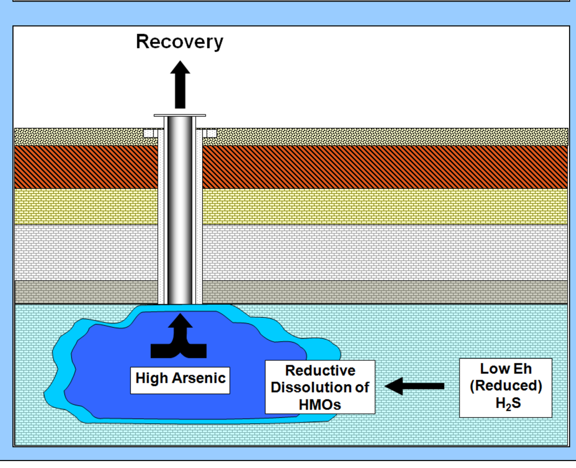


Objective: Construct a 3-D reactive transport model of an ASR site to simulate arsenic mobilization and transport processes; use the calibrated model to simulate long-term AR operations

Test Hypothesis:



During recharge:
- arsenic rich pyrite is oxidized, primarily by DO, releasing metals
- metals sorb to newly precipitated HMOs near borehole
- native (H_2S rich) water is displaced



During recovery:
- native (H_2S rich) water returns near borehole
- reductive dissolution of HMOs releases metals back into solution
- > 100 µg/L As detected in ASR wells in Florida

Project Roadmap:

Task 1
Site Selection
Historical Data Review
Model Review

Task 2
Core Collection
Batch-scale Experiments
Model Batch Experiments

Task 3
Design Column Experiments
Preliminary Column Tests
Model Column Experiments

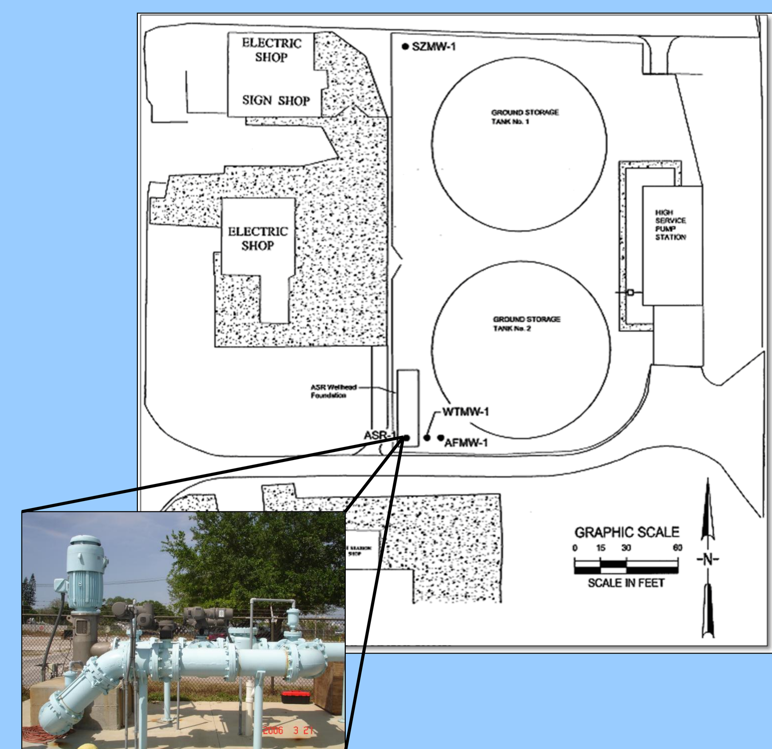
Task 4
Reactive Transport Model

Task 5
Formal Report - Propose future phases

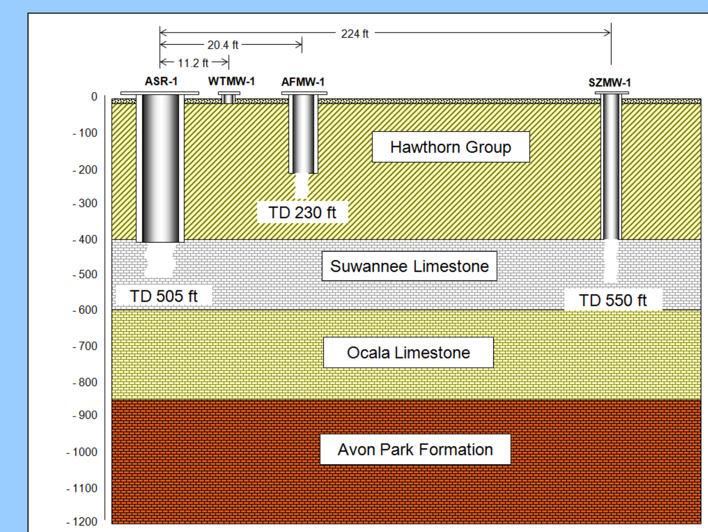
• Iterative Approach •

Field Studies:

Bradenton ASR Site Layout



Hydrogeology and Well Details



Bradenton ASR Cycle Tests (standard potable water (high DO) ASR):
- 4 small volume (10 MG) tests – Cycles 1-4
- 1 large (160 MG) test – Cycles 5-6a
- 1 (40MG) pre-Degas test – Cycle 7

Currently in full-volume (160 MG) Degas (low DO) test cycle – Cycle 8

Core Collection

Methods:
- Wireline core of entire Suwannee Limestone (290-470 ft bls)
- Preserved 135 ft of cores in PVC vessels
- 10 ft unpreserved (stored in core boxes)
- PVC vessels evacuated to -28.5 inch Hg and applied 12-15 psi N_2 head

Sample Preservation

Data

Data

Lab Experiments:

Batch Experiments

Photo courtesy FGS

Batch-scale studies being conducted at FGS will investigate:
- metal release from core materials
- core preservation techniques
- effects of DOC and NOM on metal mobilization

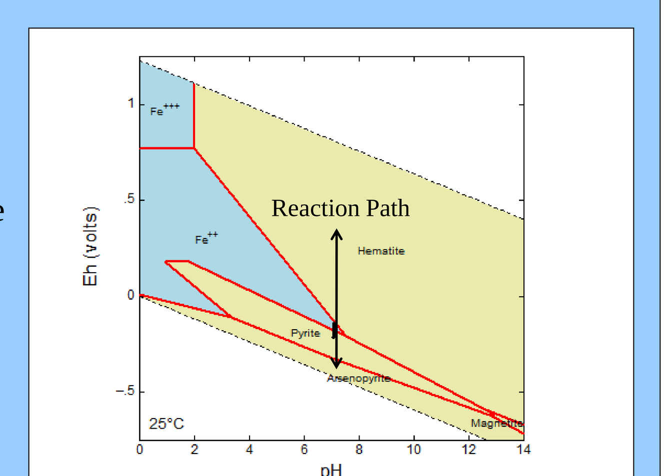
Falling Head Permeameters

Falling head permeameters are being used to:
- aid design of core-column experiments (e.g., flow rates, sample volumes, core sleeve/seal)
- determine vertical conductance (Kv) values for use in numerical modeling

Computer Models

Modeling batch and column experiments with PHREEQC can:
- help constrain input parameters and datasets for reactive transport models
- test reaction rates, including surface complexation under expected column pore-water velocities
- confirm appropriateness of thermodynamic database

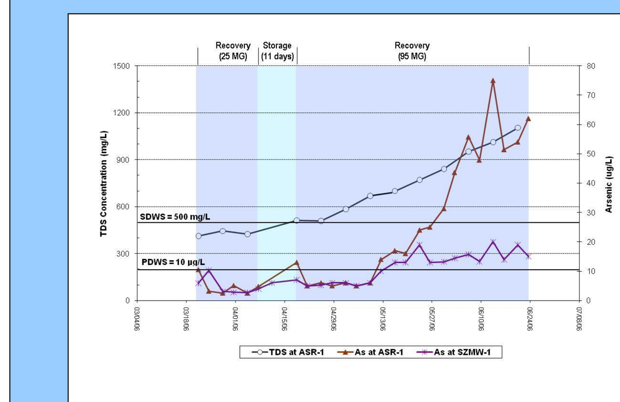
Example: reaction path models can be useful for illustrating geochemical processes and batch results

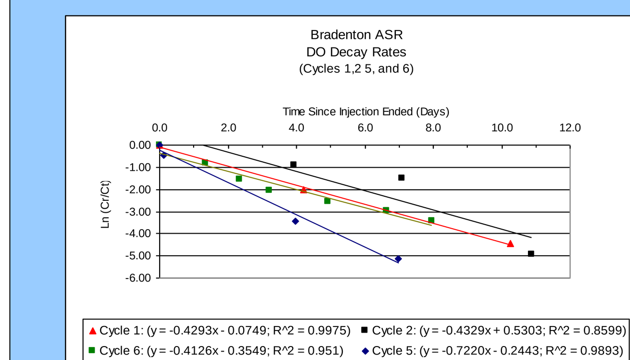


Reactive Transport Modeling using PHT3D:
- links transport code MT3DMS with geochemical code PHREEQ-C
- flow simulated using MODFLOW-2000
- more information at www.pht3d.org

• Preliminary Results •

Field Studies:





Results from cycle testing at Bradenton indicate:
- relatively low concentration of arsenic at SZMW-1 vs ASR-1 suggest arsenic transport is retarded in matrix
- peak arsenic of 75 µg/L at ASR-1 indicated most arsenic remains near the injection borehole
- TDS indicates recovery to near background (TDS = 1200 mg/L) levels

Further analysis of ASR field results can be beneficial. Example:
- Push-Pull analytical techniques can be applied to determine reaction rates.
- DO consumption at Bradenton = 0.49/day at 25ºC

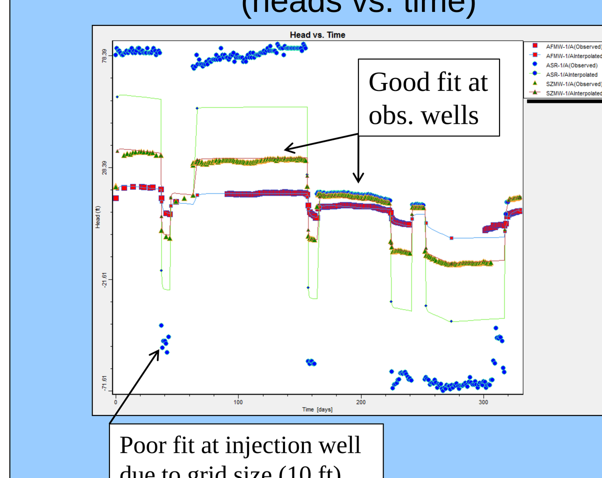
Lab Experiments:

Falling Head Permeameters results:
- Kv range: 6E-2 ft/day to 2E-5 ft/day
- given Kh = 25.6 ft/day; Kv/Kh = 2E-3 to 8E-7 (very low)
- results significantly altered arrival time of the advective front during transport modeling (discussed below)

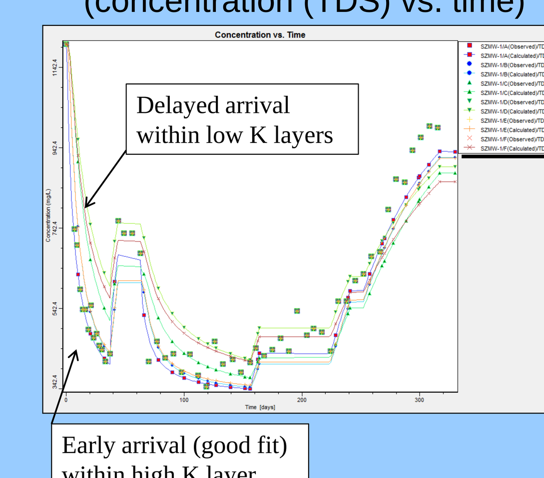
Batch studies (in process):
- samples prepared to test preservation techniques and effects of DOC and NOM addition
- sample was split into preserved (for storage in vacuum desiccators) and unpreserved sample (for storage in FGS core warehouse)

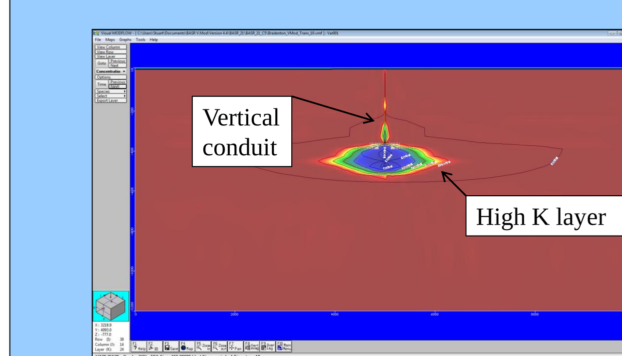
Computer Models:

Flow model calibration
(heads vs. time)

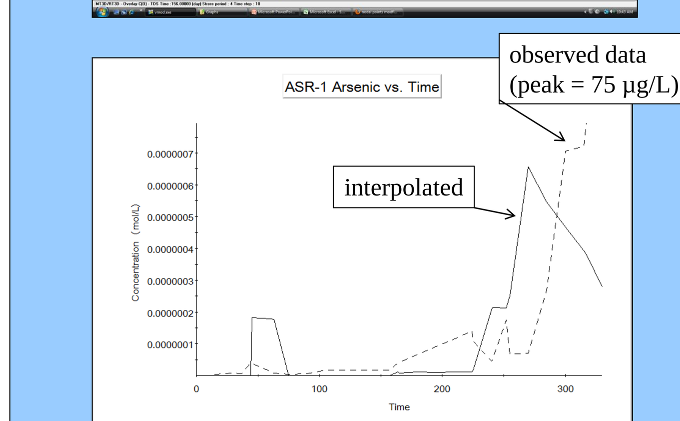


Transport model calibration
(concentration (TDS) vs. time)





Profile View:
- shape of fresh-water "bubble" is elongated by flow in high conductivity layer
- vertical conduit allows minor flux across confining layer
- red indicates native groundwater (TDS = 1,200 mg/L)
- blue indicates recharge water (TDS ≈ 320 mg/L)



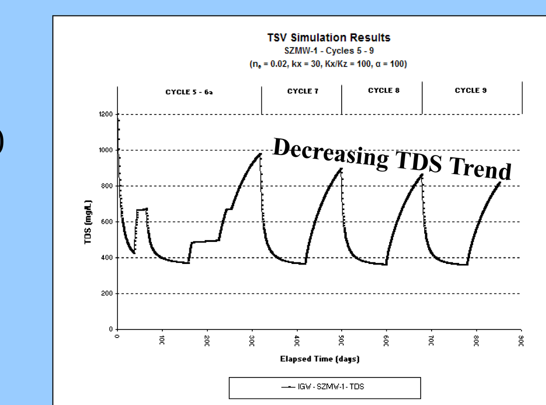
PHT3D - Reactive Transport:
- initial model runs underway
- expect improvement with fit by modifying reactive parameters
- need to verify thermodynamic data, kinetic rates, and metal-complexation processes via batch/column studies and related models

• Future Studies •

Modeling:

Future modeling plans include:
- modeling operational approaches (e.g., Target Storage Volume) for managing arsenic mobilization during ASR and increasing recovery efficiency

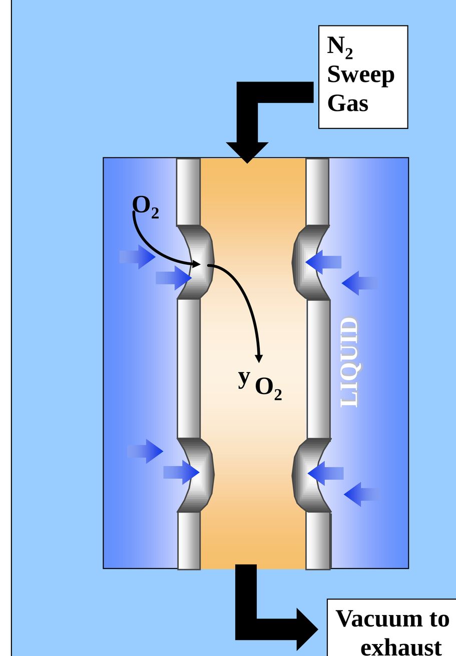
Example: model of multiple (4) cycles at Bradenton indicates improved recovery efficiency



- modeling Artificial Recharge processes including long-term, large-scale recharge events
- modeling pretreatment techniques such as the Bradenton ASR Degas Pilot project

Bradenton ASR Degas Pilot Project

System Specs:
- 1-MGD capacity
- DO removal to 0.02 ppb by membrane
- chloramine removal to 0.5 mg/L by sodium bisulfite



Membrane Degassification:
- uses hydrophobic membranes for gas transfer
- operates with vacuum and N2 sweep gas to liberate DO and sweep condensate
- 16 contactors total (4 x 4 configuration)

Column Studies:

- preliminary column tests are underway to finalize column design
- intact core-column experiments are planned using preserved core materials collected at SWFWMD test well site
- column test will be designed to characterize transport and geochemical processes to support reactive transport modeling

Thanks to our Project Team:

Technical Partners:
UF – EES: J-C Bonzongo, M.D. Annable, S.B. Norton
UF – Civil: M.A. Newman, K.H. Hatfield
UF – Geology: A.R. Zimmerman
UF – S&WS: W.G. Harris
Florida Geological Survey: Jon Arthur, Cindy Fischler
City of Bradenton: Seth Kohn and Claude Tankersley

Funding Partners:
Southwest Florida Water Management District
UF – Water Resources Research Center