Quantifying the impact of shallow wastewater injection on groundwater nutrient fluxes to surface waters in the Florida Keys National Marine Sanctuary

November 2023 project update

Project leads: **Miquela Ingalls and Lee Kump**

Students: **Kate Meyers, Megan Martin, Jin Choi, Cameron Brown, Dante Senmartin, and Leo Volchek**

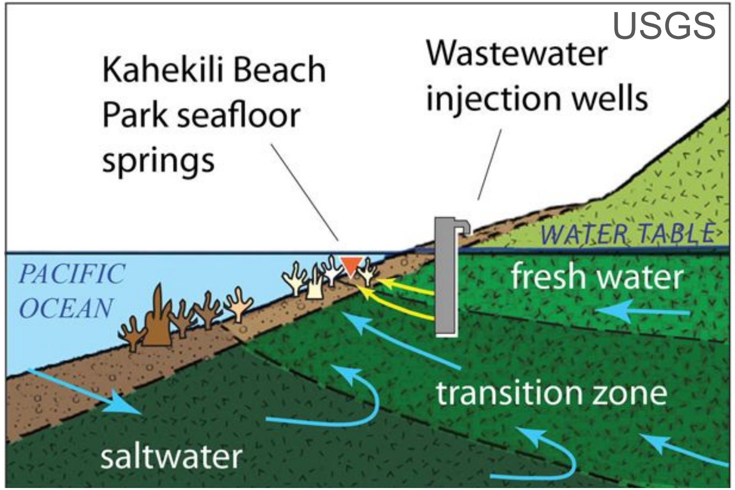
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

PennState College of Earth and Mineral Sciences

Motivation: Maui Decision in Clean Water Act case

"...require a permit when there is a direct discharge from a point source into navigable waters or when there is the *functional equivalent of a direct discharge*."

County of Maui v. Hawaii Wildlife Fund et al., 2020



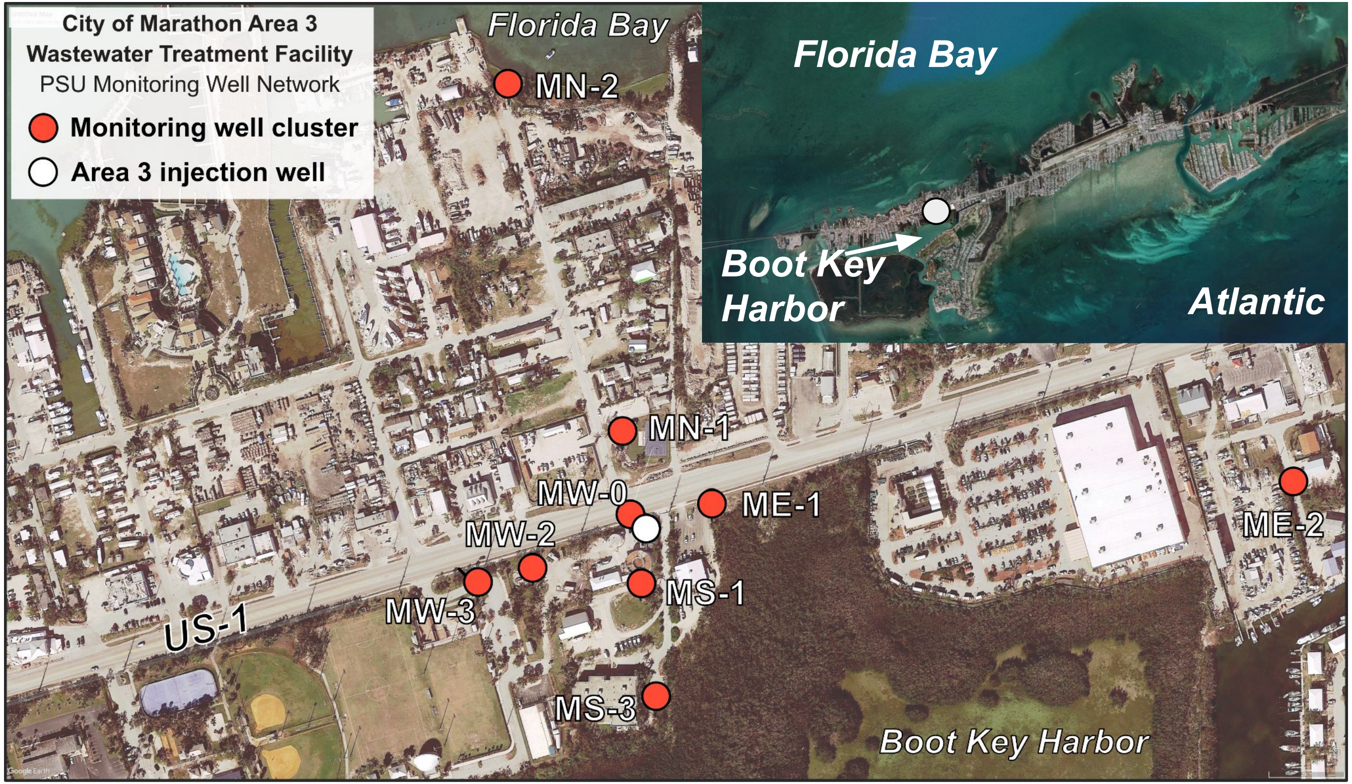
Fackrell, et al. 2016

Critical question: Is shallow injection the functional equivalent of direct discharge into surface waters?

Study site: Marathon Area 3 Wastewater Treatment Facility

Treated effluent injected to 18 - 27 meters depth

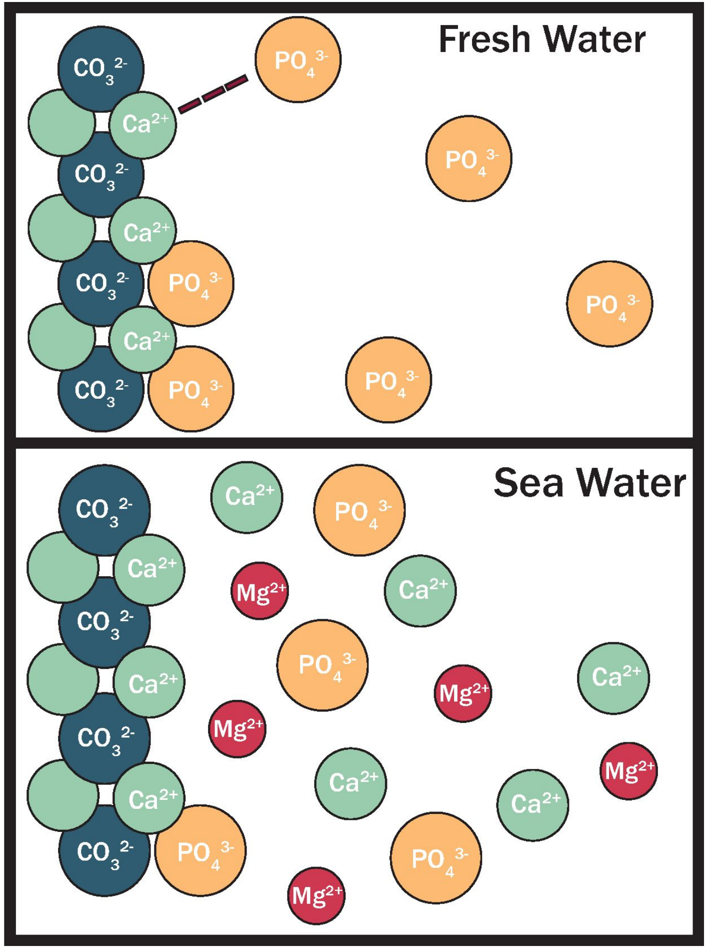
9 sampling well clusters (10’, 20’, 50’, 90’) were installed in spring 2021 and 2022



Motivation

Expectations: Efficient **microbial denitrification** and abiotic **adsorption of phosphate** onto the carbonate bedrock will remove nitrate and phosphate nutrients from the effluent prior to emergence into the nearshore waters of the halo zone.

Critical question: Is shallow injection the functional equivalent of direct discharge to surface waters?



Objectives

(1) to characterize wastewater **plume geometry, composition and migration** at a single disposal facility in the FKNMS,

(2) to quantify the impact of shallow well effluent injections on **nitrogen and phosphorus contents** of groundwater and nearshore water in the halo zone

(3) to evaluate **generalizability** of our findings to sites with different geology, effluent chemistry and volume, and plume migration, with the goal of informing FDEP regulatory decisions.

Objectives

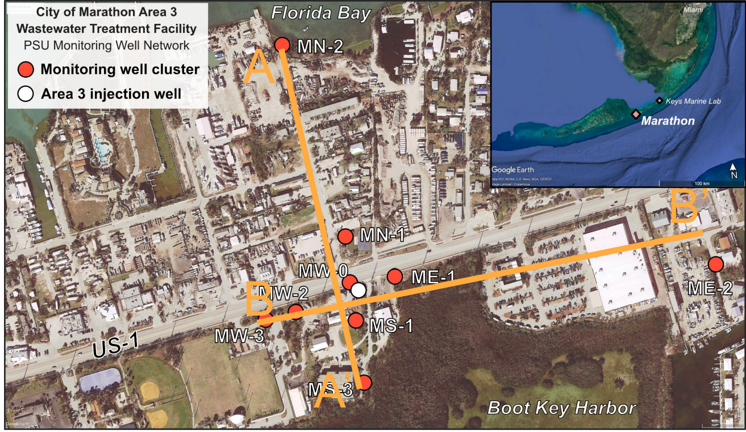
(1) to characterize wastewater **plume geometry, composition and migration** at a single disposal facility in the FKNMS,

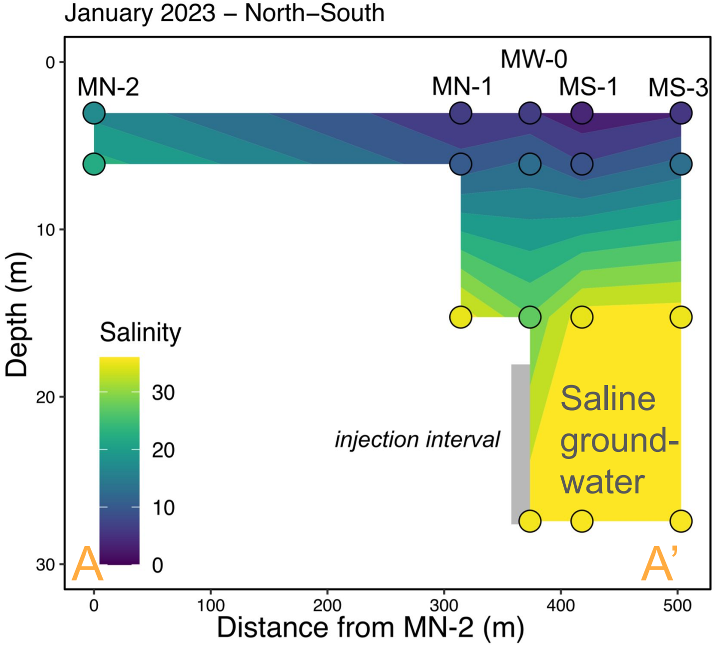
(2) to quantify the impact of shallow well effluent injections on **nitrogen and phosphorus contents** of groundwater and nearshore water in the halo zone

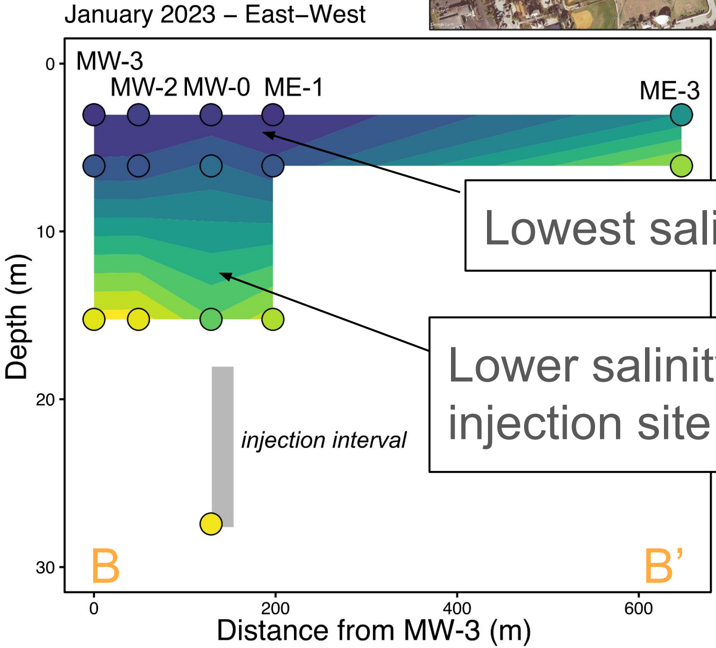
(3) to evaluate **generalizability** of our findings to sites with different geology, effluent chemistry and volume, and plume migration, with the goal of informing FDEP regulatory decisions.

	Objectives 1 + 2	**Objective 3**
COMPOSITION →	Nutrient, dissolved ion, and pharmaceutical analyses	
GEOMETRY →	Salinity, pharmaceuticals Resistivity surveys	→ FEFLOW groundwater transport modeling
MIGRATION →	Dye tracer study Nearshore nutrient analyses	

Characterizing plume geometry: salinity





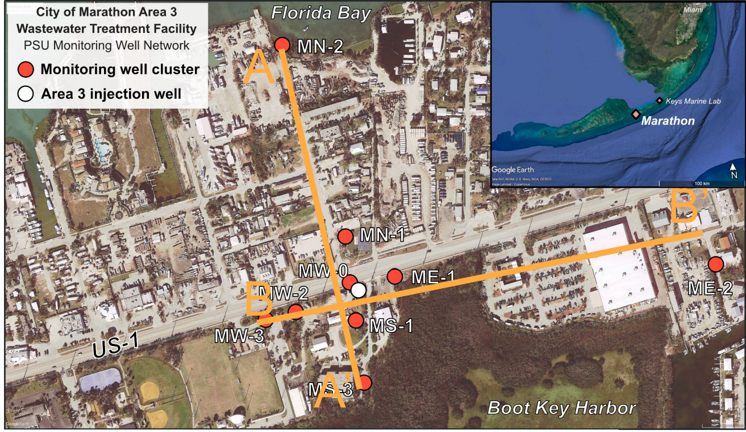


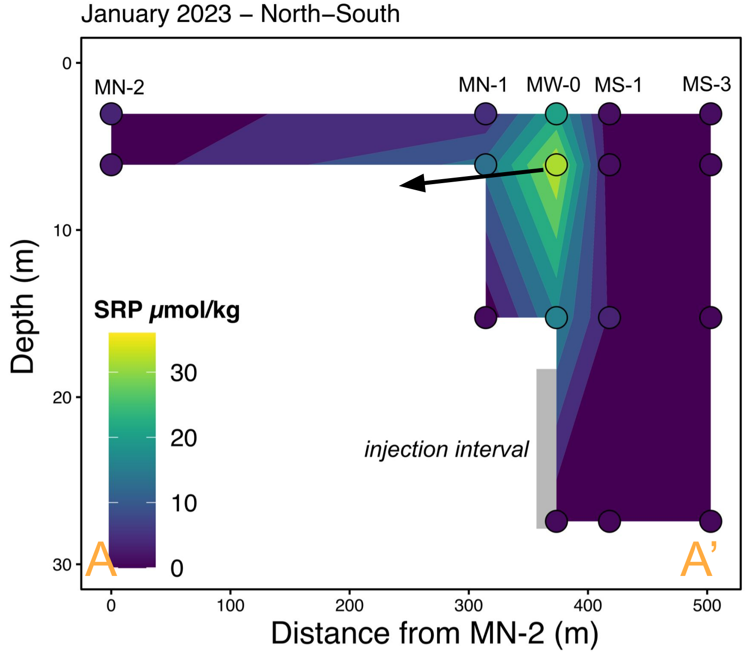
Lowest salinity at the surface

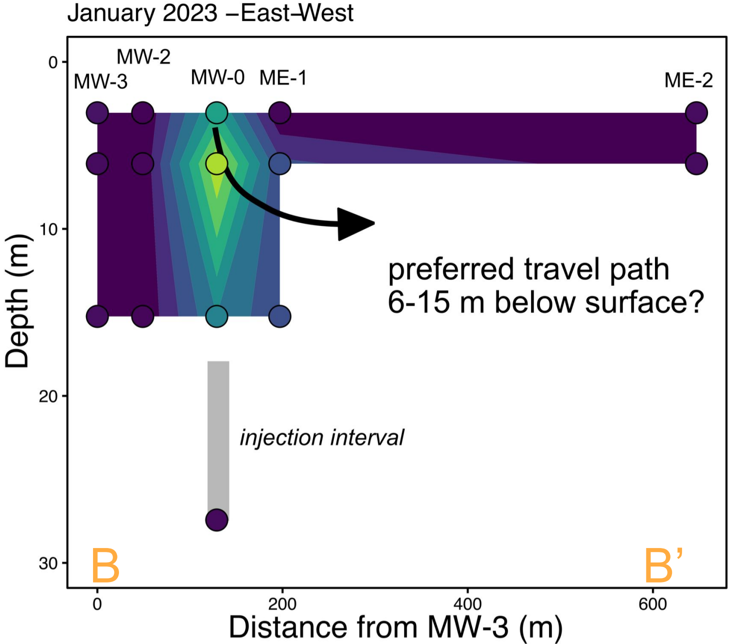
Lower salinity plume at injection site

Characterizing plume geometry: Soluble Reactive Phosphorus

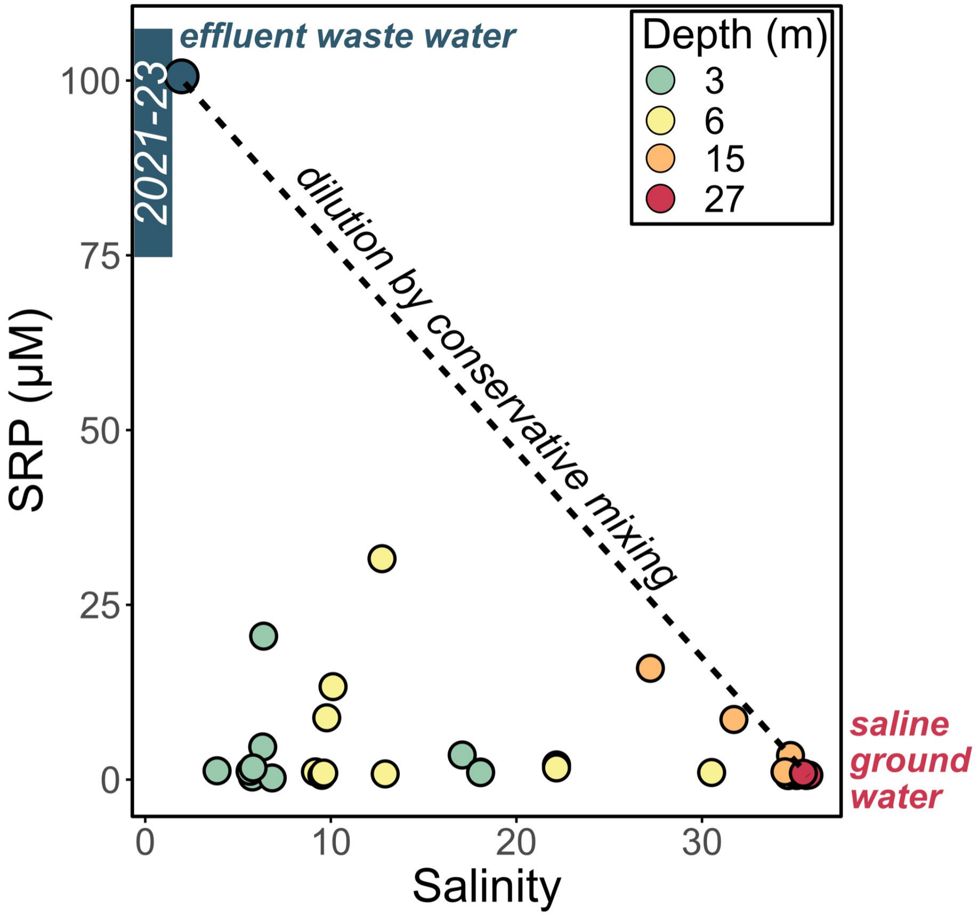
SRP_{EWW} = 75 - 100 μmol/kg





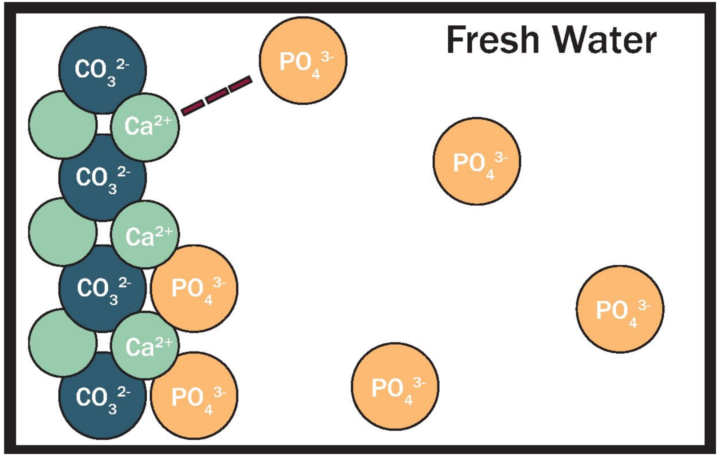


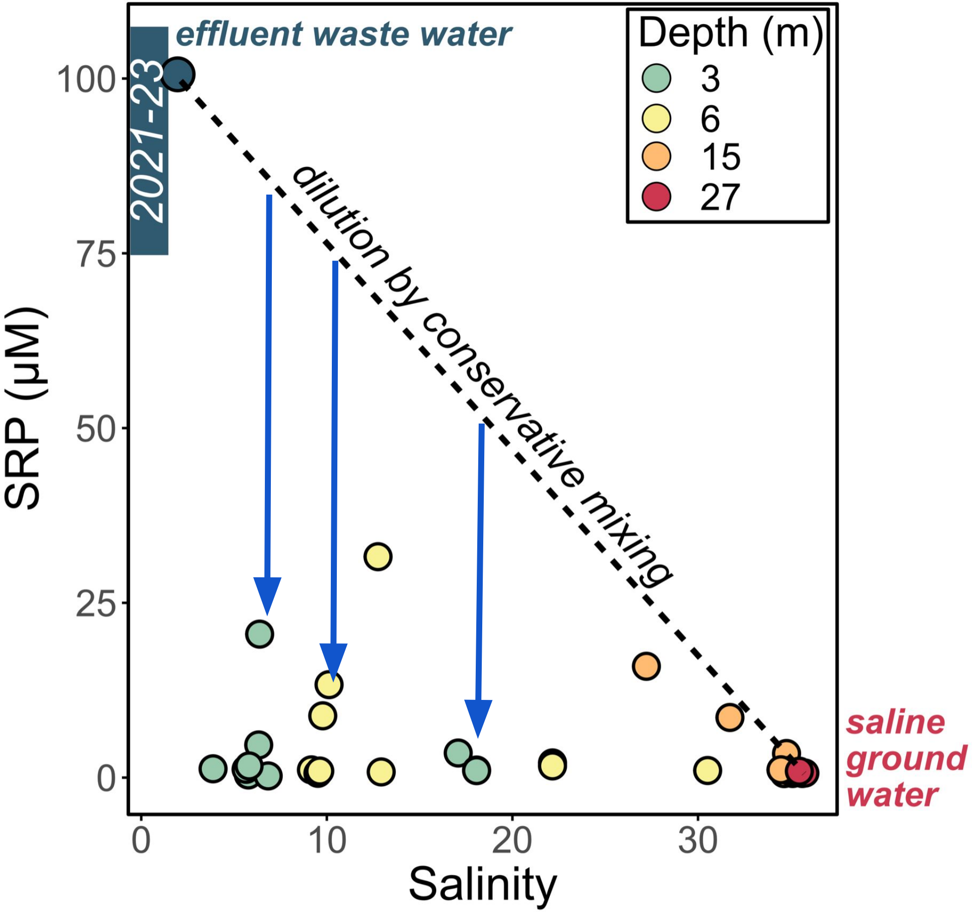
Groundwater phosphate does not follow conservative mixing



Groundwater phosphate does not follow conservative mixing

ADSORPTION?



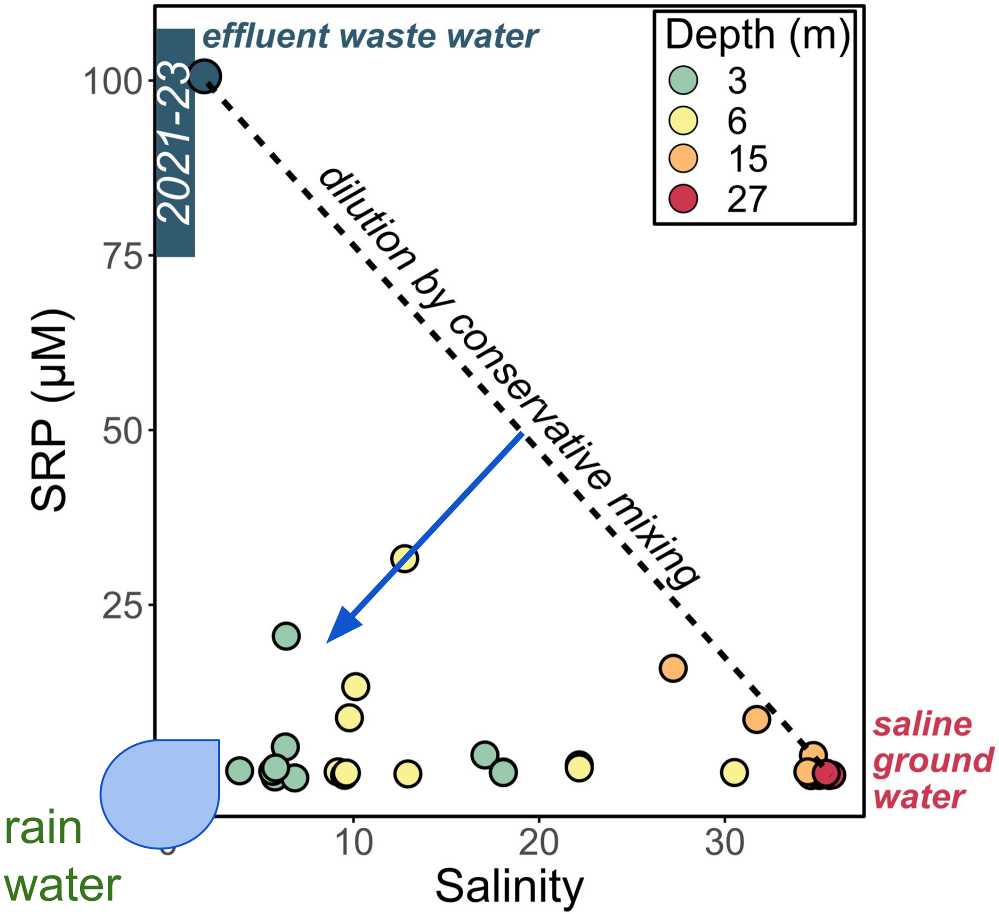


Groundwater phosphate does not follow conservative mixing

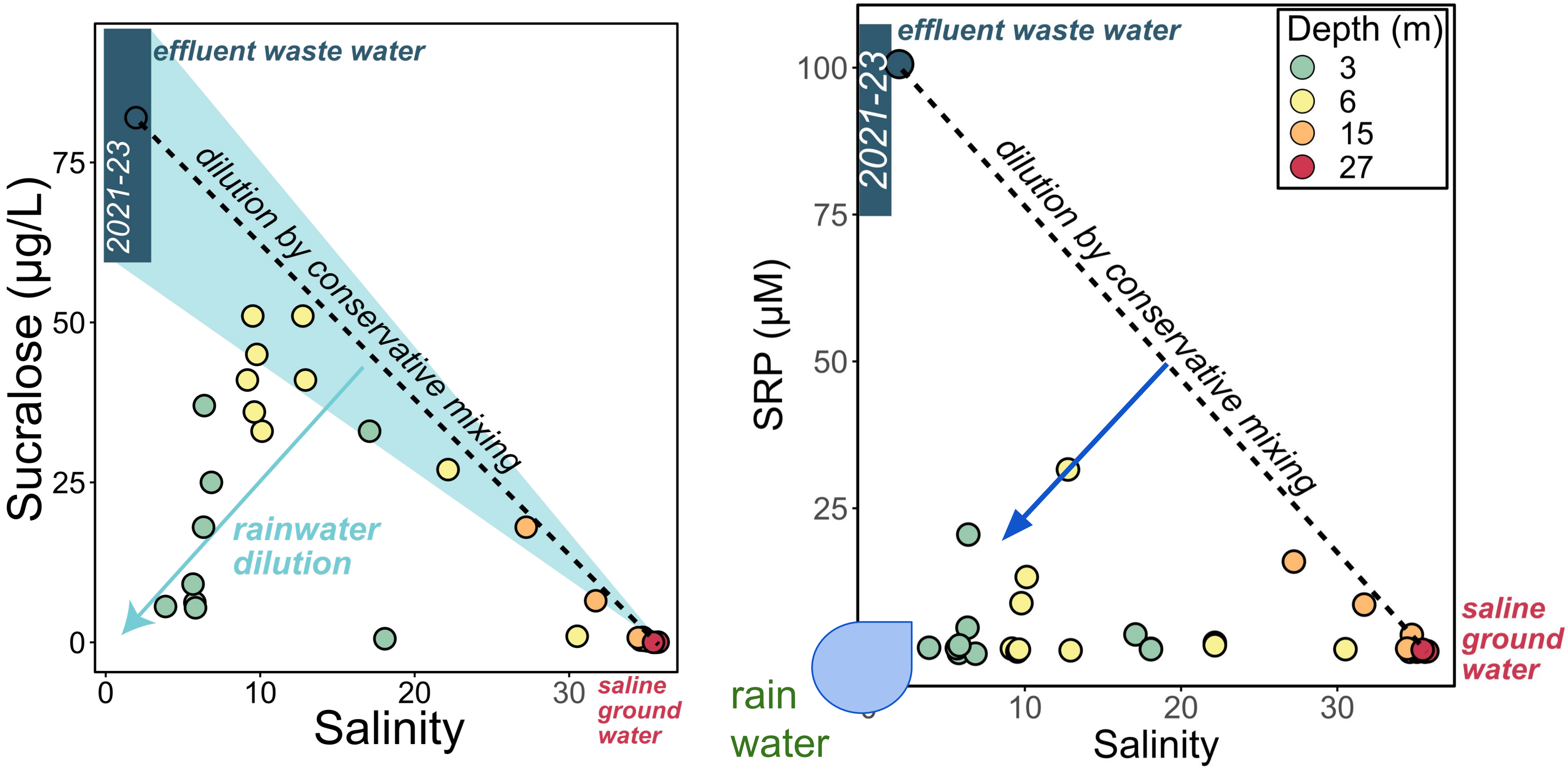
Three end members:

1. Rainwater (low S, low SRP)
2. Saline Groundwater (high S, low SRP)
3. Wastewater (low S, high SRP)

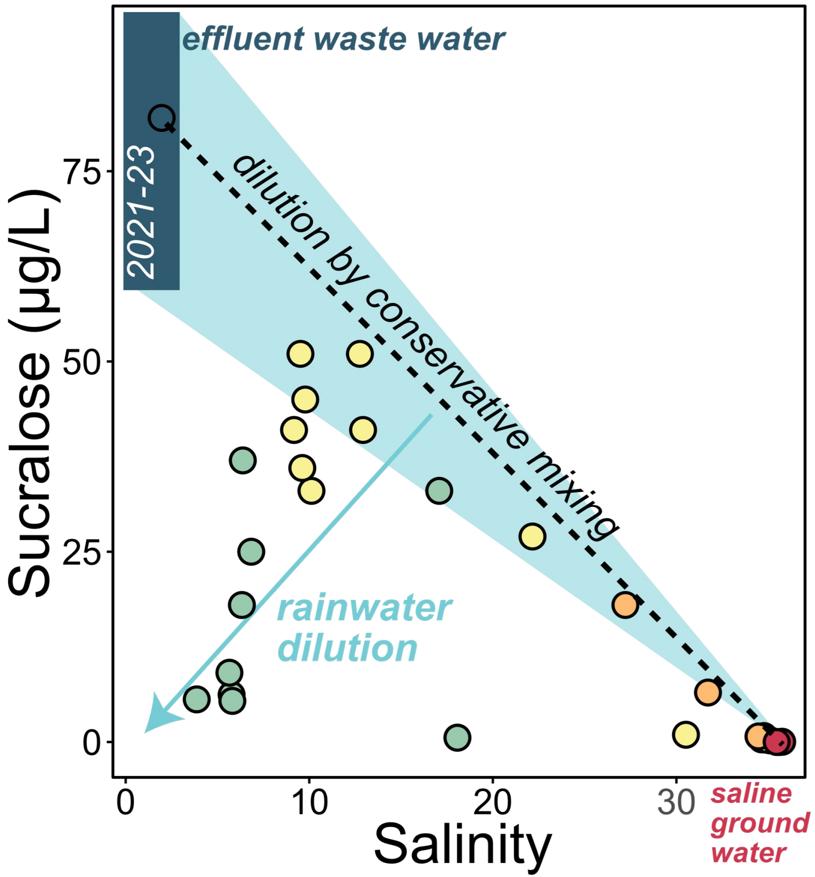
Use S to trace seawater, sucralose to trace wastewater

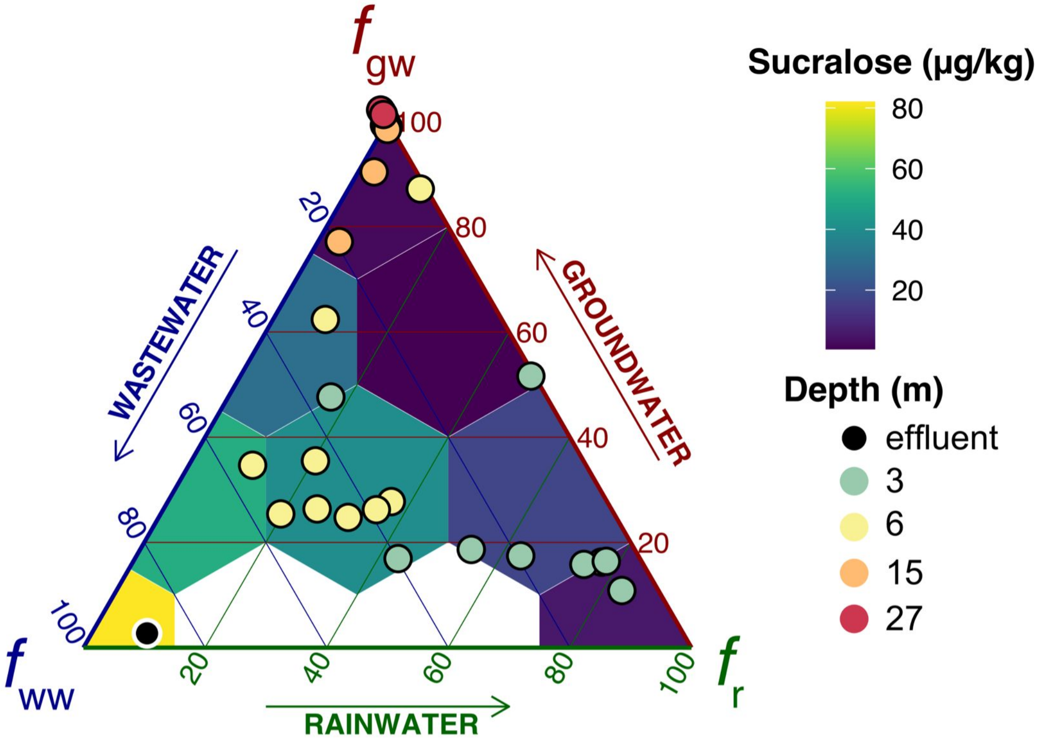


Using sucralose as a conservative tracer of waste water

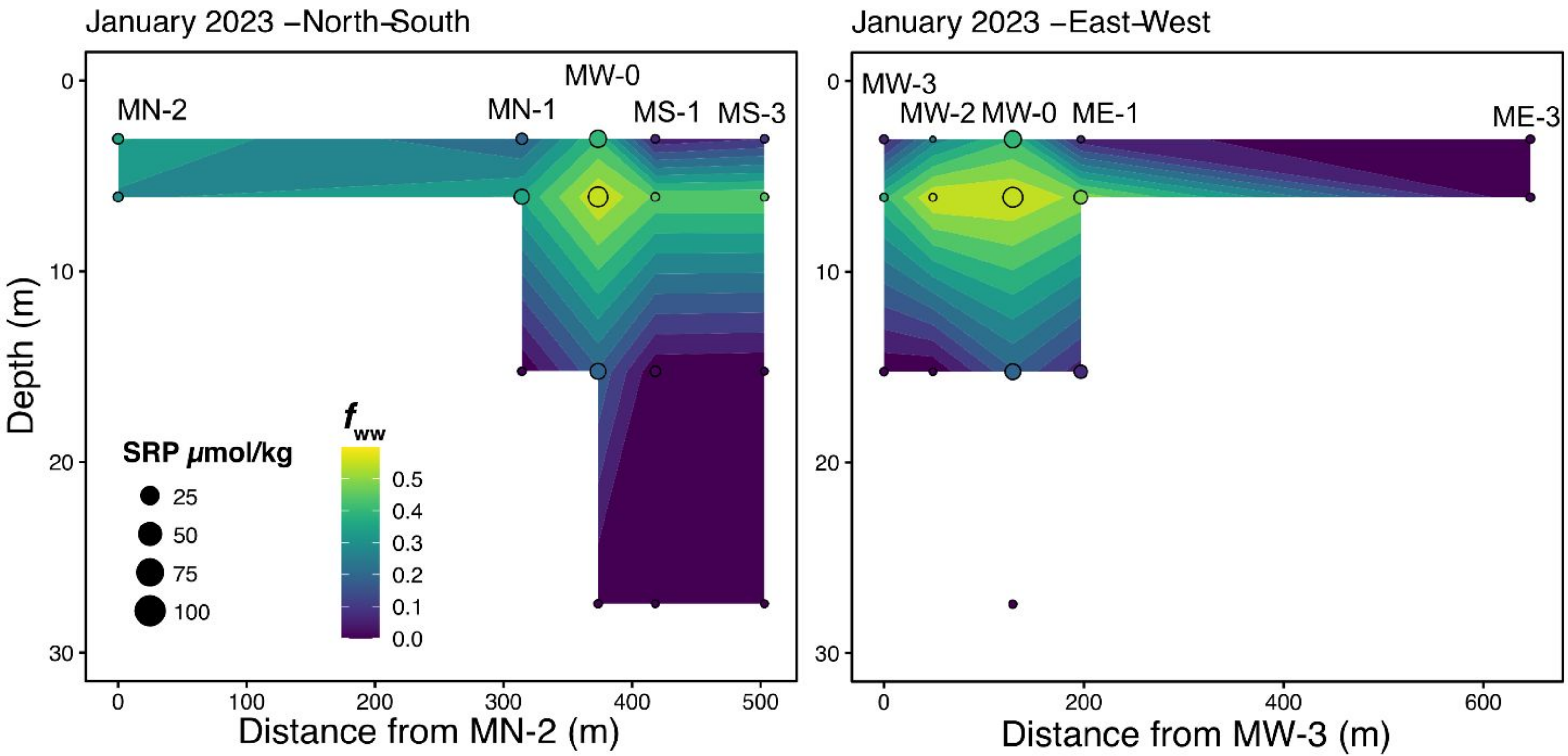


Using sucralose as a conservative tracer of waste water

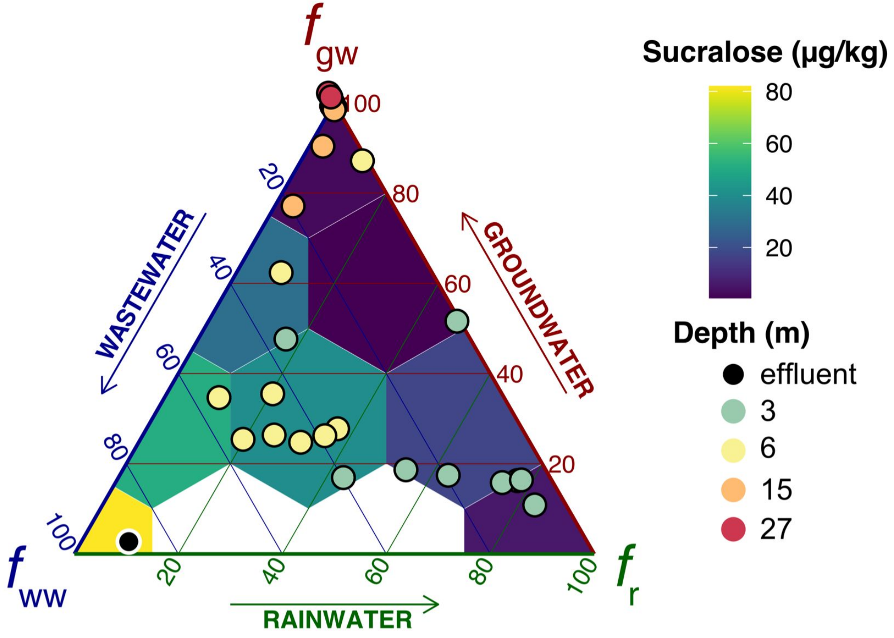


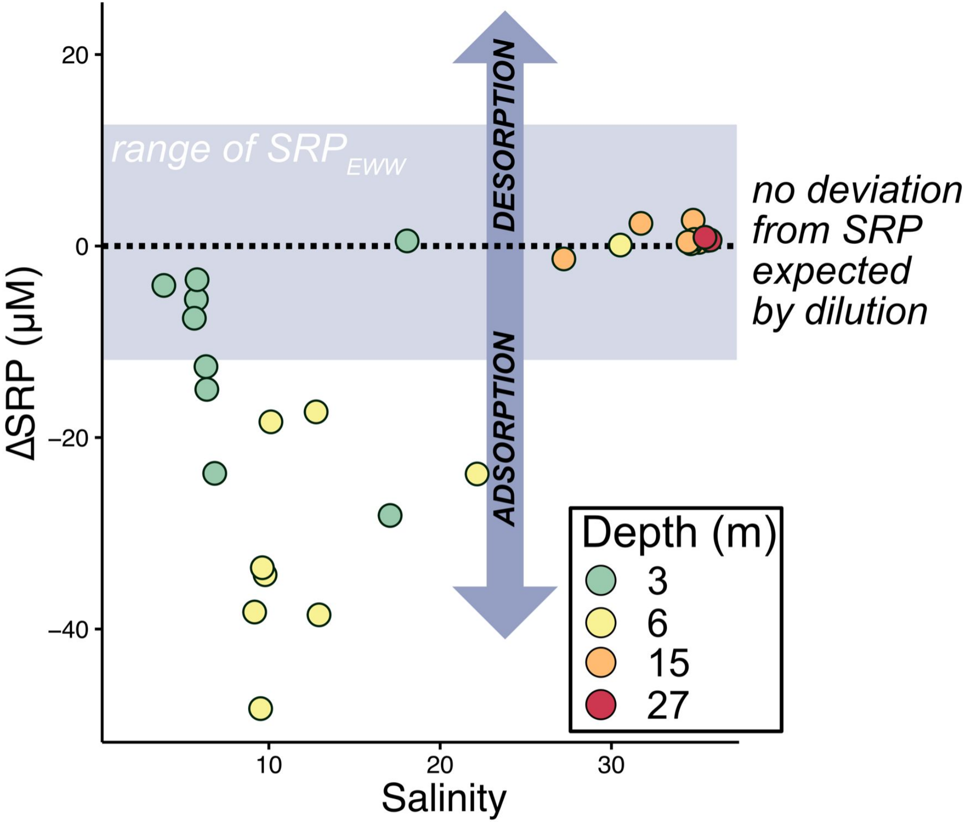


3D distribution of wastewater sets expectation for SRP if functional equivalent of direct discharge



Water in the plume migration pathway show net adsorption



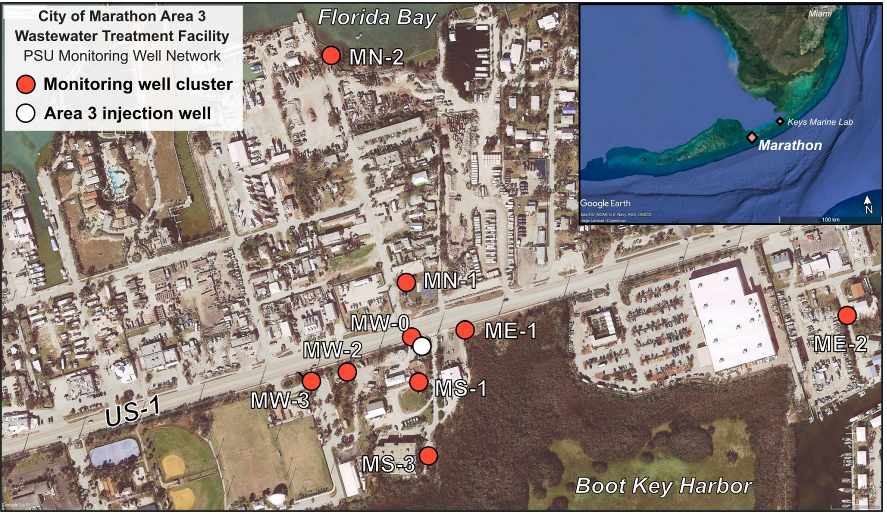


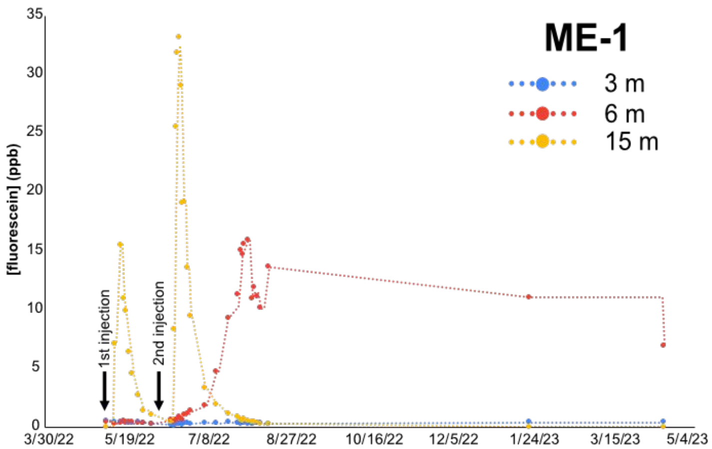
$$SRP_{EWW} \times f_{ww} = SRP_{expected}$$

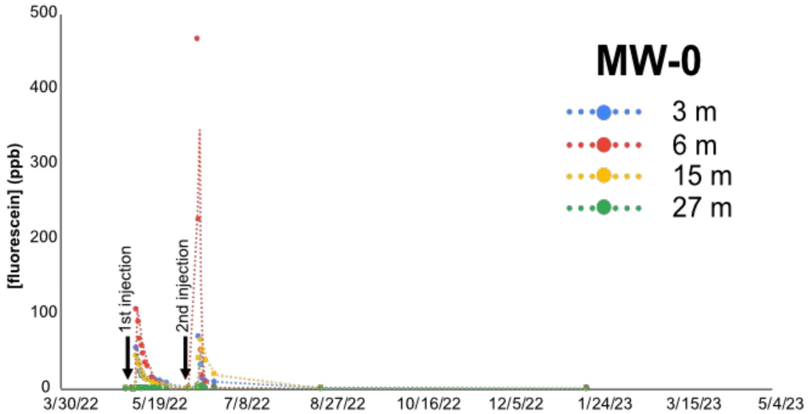
$$(SRP_{EWW} = 75 - 100\ \mu mol/kg)$$

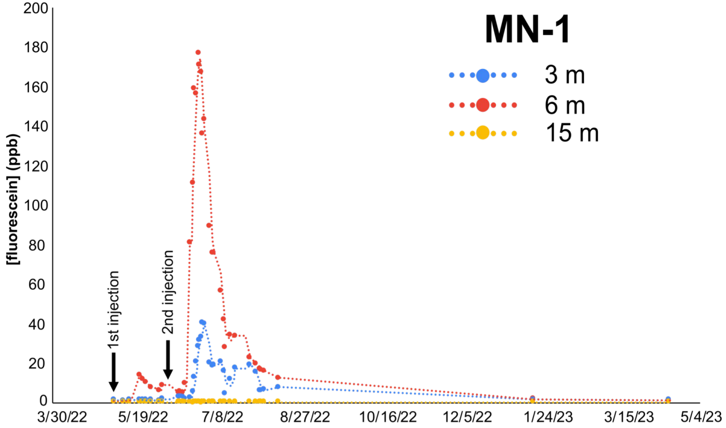
Dye tracer study

Dye introduced to Area 3 injection well May and June 2022



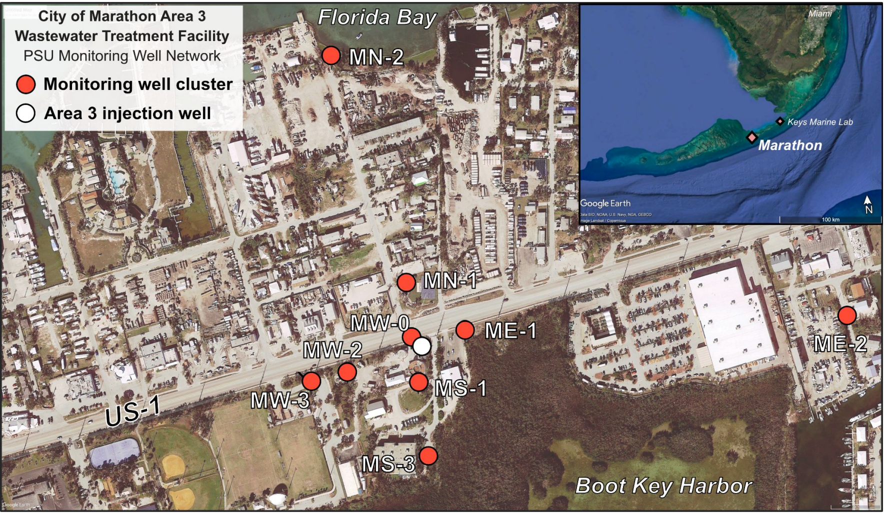


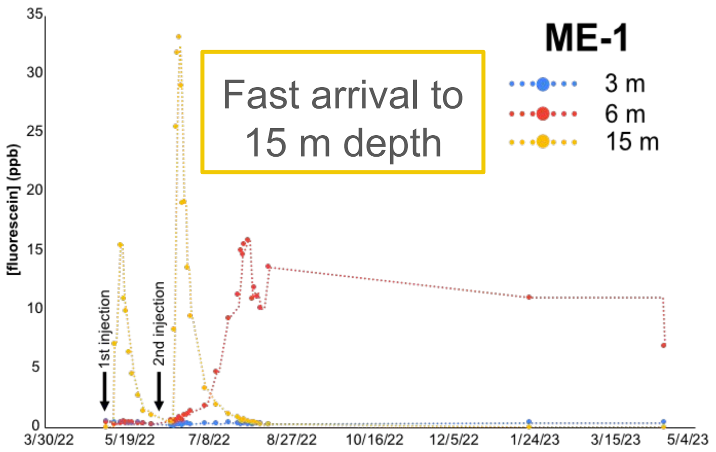


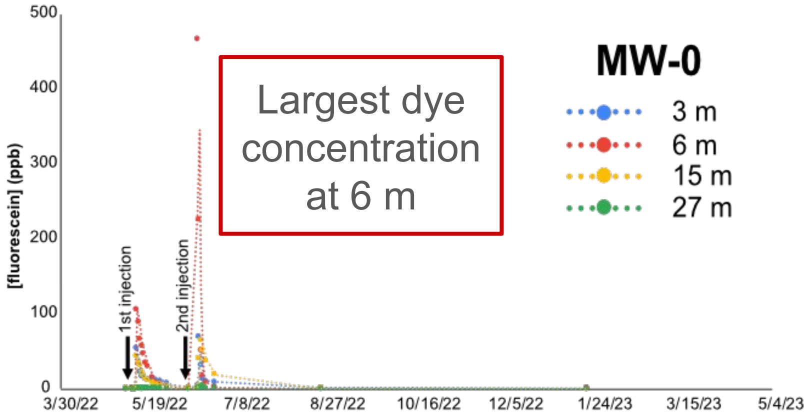


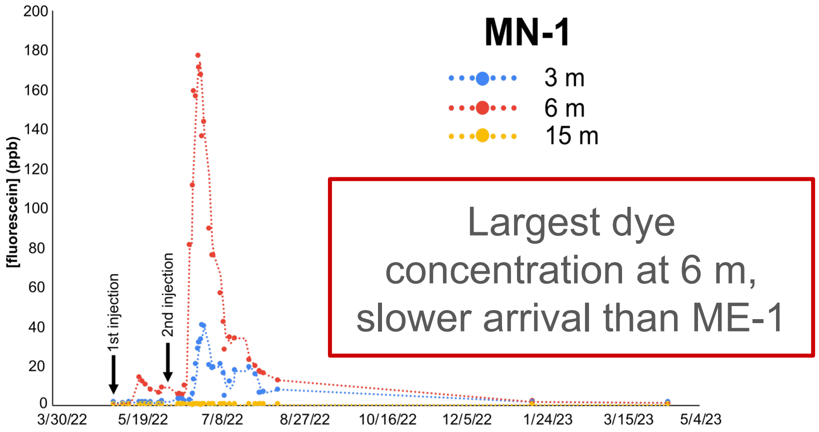
Dye tracer study

Dye introduced to Area 3 injection well May and June 2022

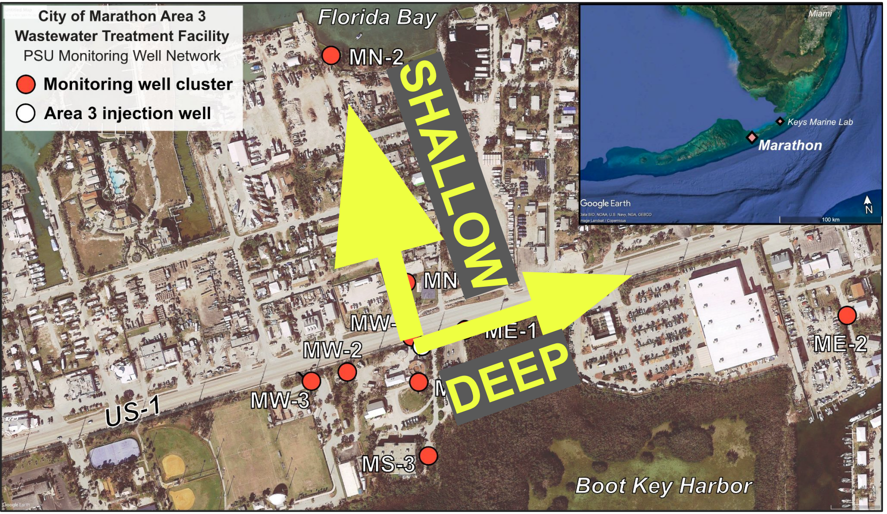


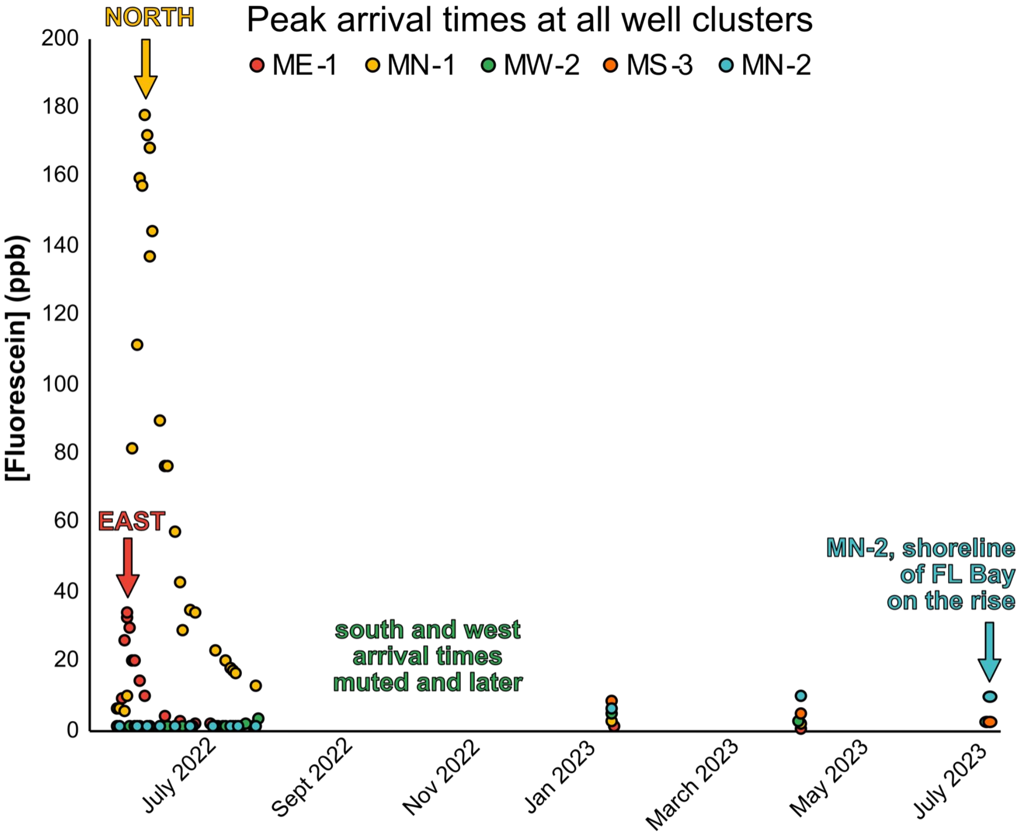






Dye tracer study confirms dominant flow paths to the north and east





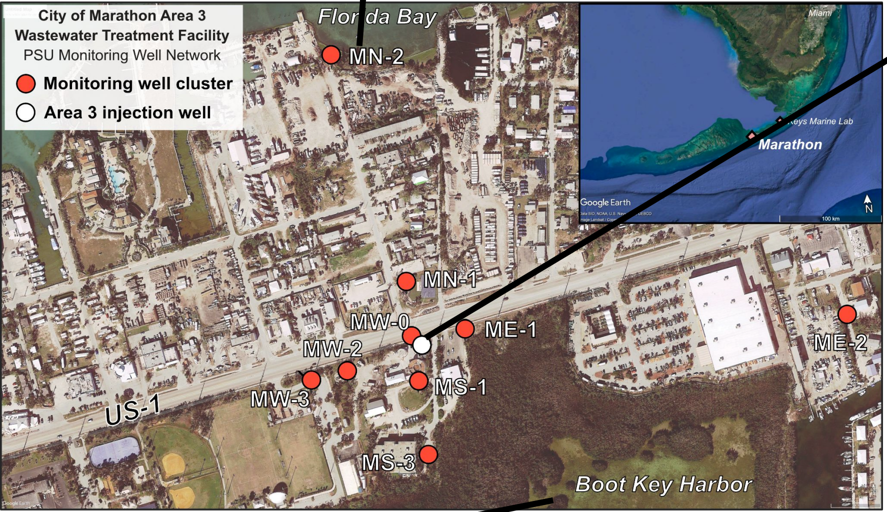
Anthropogenic sucralose (phosphate?) detected in FL Bay and Boot Key Harbor

Florida Bay

0.075 µg/kg 0.68 µmol/kg

Effluent wastewater

82 µg/kg 116 µmol/kg



Canals

0.37 µg/kg 0.70 µmol/kg

TP target for nearshore waters

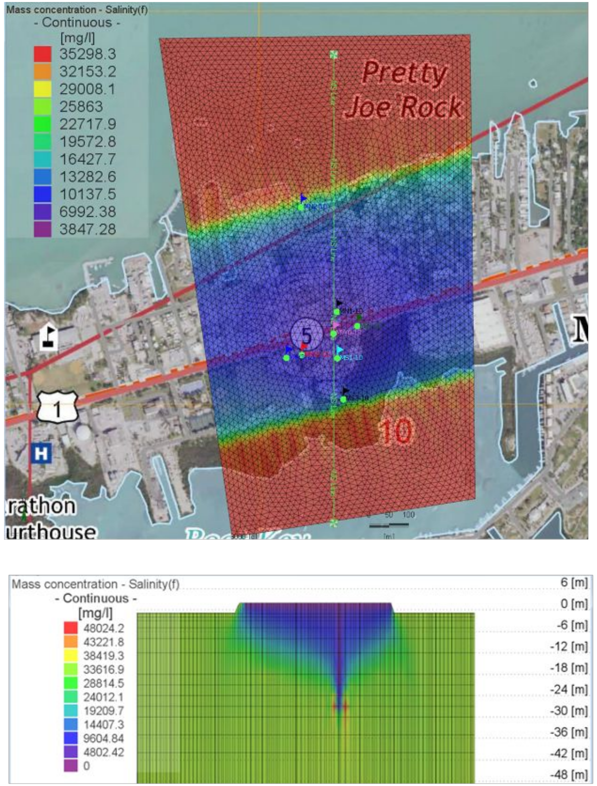
0.42 µmol/kg

0.29 µg/kg 0.62 µmol/kg

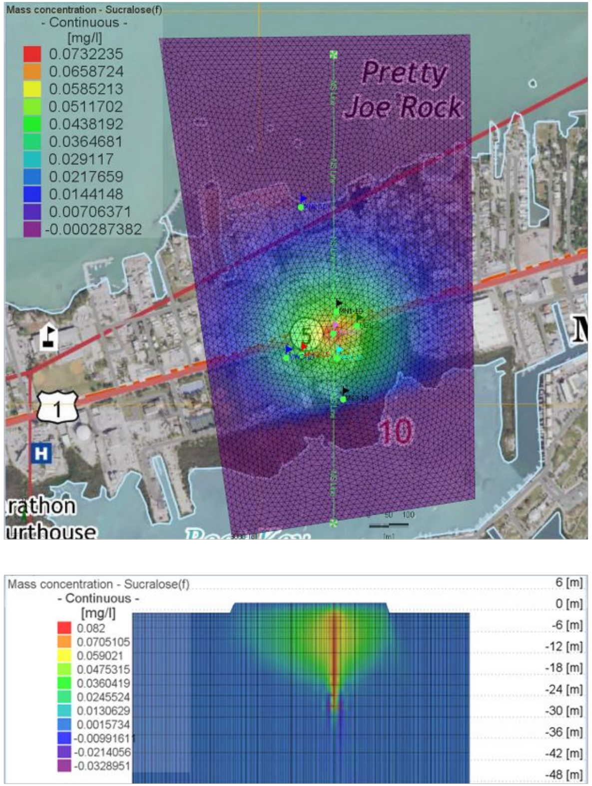
Boot Key Harbor

FL Keys Reasonable Assurance Document (FDEP, 2018)

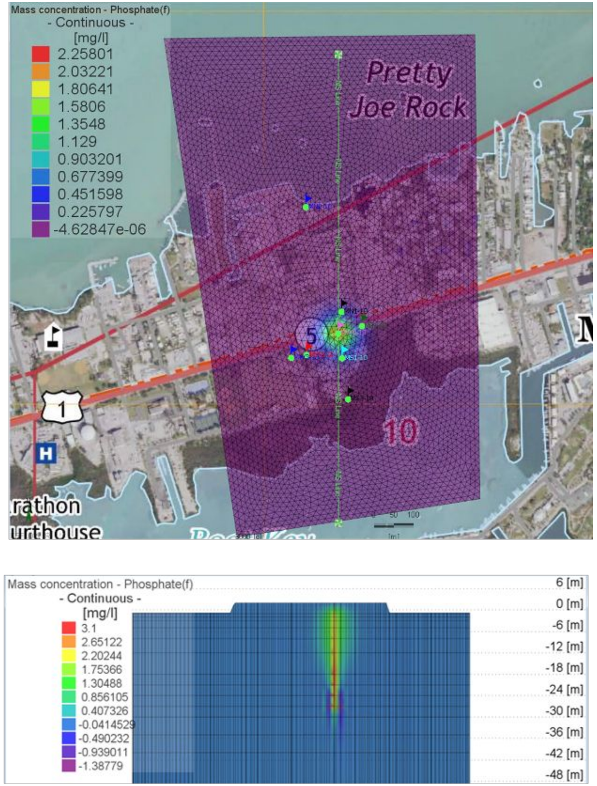
Preliminary Model Results (at 3m depth and NS xsection)



Salinity



Sucralose



Phosphate

Conclusions

- Wastewater injection at Area 3 in Marathon, Florida creates **a wastewater plume that rises to the surface and spreads laterally**, mixing with a small, natural freshwater lens.
- **Phosphate is diluted through mixing** with the freshwater lens and the saline groundwater, and partially removed from the wastewater plume through **interaction with the limestone substrate**.
- Sucralose appearing at terminus of subsurface wastewater flowpaths in Florida Bay, Boot Key Harbor, and adjacent canals likely of wastewater origin: **wastewater is impacting surface waters**.

SUMMARY: Although not the functional equivalent of direct discharge, shallow wastewater injection at Area 3 is releasing nutrients and other contaminants to surface waters of the halo zone of the Florida Keys.

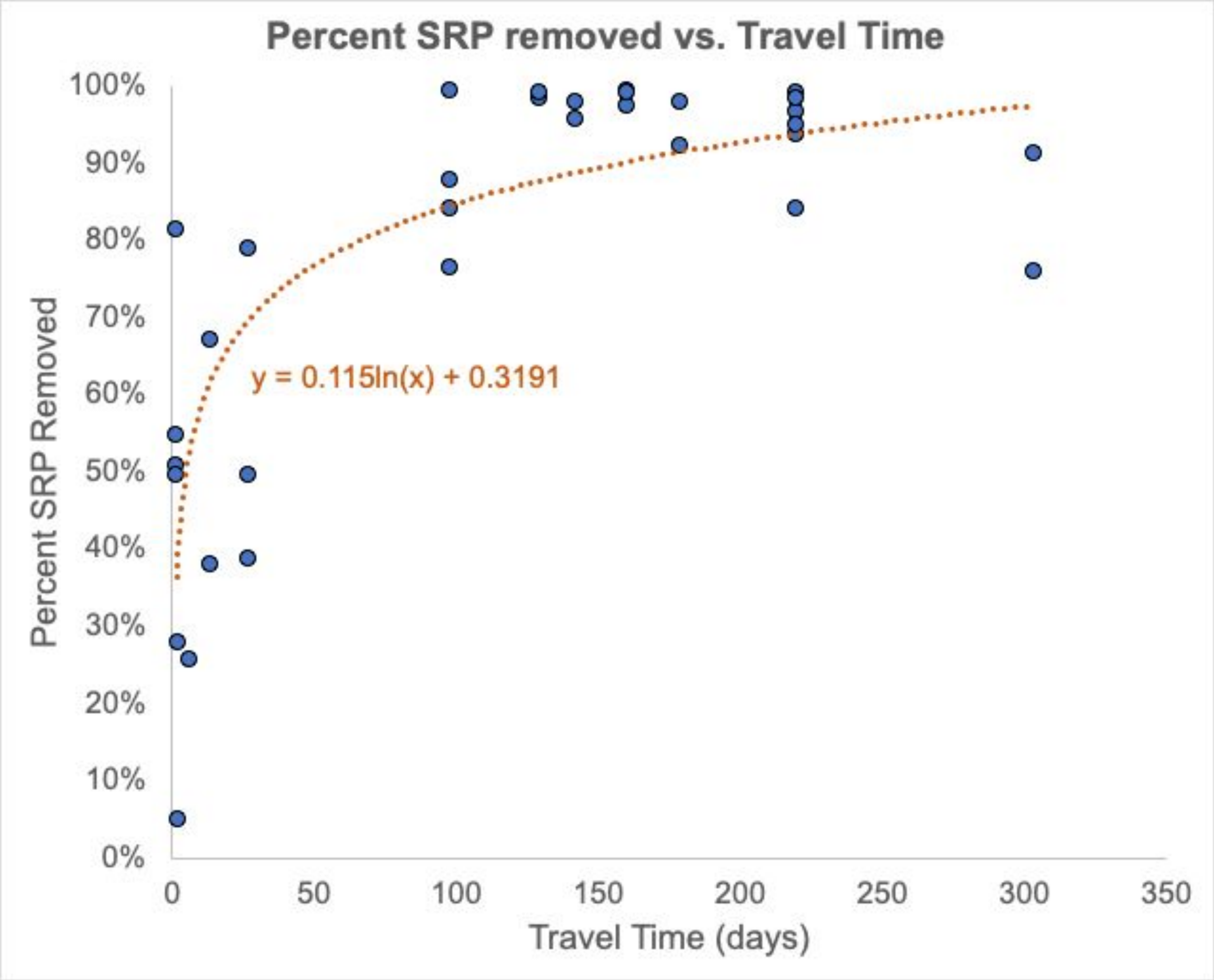
Questions?

United States Environmental Protection Agency

PennState
College of Earth
and Mineral Sciences

Left to right:
Cameron Brown
Kate Meyers
Megan Martin
Lee Kump
Miquela Ingalls

Extra slides


Percent SRP removed vs. Travel Time
y = 0.115ln(x) + 0.3191
Percent SRP Removed
Travel Time (days)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
50
100
150
200
250
300
350

Analytical overview - all in NELAC-certified labs

Nutrient concentrations (Total Nitrogen, Phosphate, Ammonium) within the main flow path and slower velocity margins of plume

Dissolved ion concentrations: calculate N and P speciation from dissolved ions, temperature, and salinity to evaluate chemical reactivity and sequestration potential

Dissolved N_2 gas concentrations to quantify magnitude of denitrification along flow path

$\delta^{15}N$ of dissolved N_2, NH_4^+, NO_3^- and **NO_2^-** to quantify the contribution of denitrification versus other nitrate reduction processes

Tracer studies: pharmaceuticals + fluorescence (rhodamine and fluorescein dye injections)