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

Project Plan

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College of Earth and Mineral Sciences
Meet our chief analytical chemists

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Incoming PSU MS student

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BS, Franklin & Marshall, ‘19  
Incoming PSU PhD student
What do we know about the problem?

Despite stricter regulations on wastewater management in FL, the surface waters in the FKNMS still bear elevated nutrient loads (FDEP RAD, 2018; Briceño & Boyer, 2020).

23 WBIDs are impaired for nutrients within the halo zone (<500 m from shore)

Table 1. WBIDs with impairments in the Florida Keys

<table>
<thead>
<tr>
<th>WBID</th>
<th>Waterbody Name</th>
<th>Location</th>
<th>Stakeholders in WBID</th>
</tr>
</thead>
<tbody>
<tr>
<td>6006A</td>
<td>South Key Largo</td>
<td>Northern Keys</td>
<td>Key Largo Wastewater Treatment, FDOT, Monroe County FDOT</td>
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<tr>
<td>6006B</td>
<td>Middle Key Largo</td>
<td>Northern Keys</td>
<td>Key Largo Wastewater Treatment, Monroe County FDOT</td>
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<tr>
<td>6006C</td>
<td>Upper Key Largo</td>
<td>Northern Keys</td>
<td>Monroe County FDOT</td>
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<tr>
<td>6009</td>
<td>Plantation Keys</td>
<td>Northern Keys</td>
<td>Village of Islamorada FDOT</td>
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<td>6010</td>
<td>Long Key</td>
<td>Central Keys</td>
<td>City of Layton, Monroe County FDOT</td>
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<td>6011A</td>
<td>Vaca Key</td>
<td>Central Keys</td>
<td>City of Marathon, FDOT</td>
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<td>6011B</td>
<td>Key Colony</td>
<td>Central Keys</td>
<td>City of Key Colony Beach, FDOT</td>
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<tr>
<td>6011C</td>
<td>Grassy Key</td>
<td>Central Keys</td>
<td>City of Marathon, FDOT</td>
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</table>

Note: Gray shading denotes WBIDs impaired for DO, in addition to nutrient impairment.
What do we know about the problem?

Effluent plumes are **buoyant**, and rapidly return to the surface after injection.

Griggs et al., 2003

Key Largo Limestone

No Holocene mud cap at Marathon + ~45% porosity, high permeability = **rapid groundwater migration**

Images: http://www.uwosh.edu/faculty_staff/hiatt/Teaching/360_Florida/2005_Ancient.html
What do we know about the problem?

Nitrate and phosphate were effectively removed from the slower velocity flow path margins by microbial N cycling and phosphate adsorption onto karst at Key Colony Beach, but nitrogen loads remained high in the central, faster flow paths.

EPA wastewater effluent standards @ Marathon Area 3 WWTF: 3 ppm N03-N; 1 ppm PO4-P

Griggs et al., 2003
Uptake and adsorption effectively remove N + P in slow flow margins

Non-conservative behavior = effective uptake; not just mixing with saline groundwater

Griggs et al., 2003

Expected: $^{15}$N enrichment during denitrification
Observed: $N_2-NO_3$ fractionation associated with denitrification

Phosphate adsorbs onto carbonate in flow through experiments
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 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.
Broad overview of work plan

(1) Characterize the geometry, travel time, and surface emergence of wastewater plume nutrient loads

(2) Report the N and P nutrient content of groundwater and nearshore surface waters

(3) Calculate the stability of dissolved phases within the wastewater effluent and groundwaters as an assessment of water quality, mineral reactivity and nutrient removal efficiency

(4) Assimilate geochemical data with SEAWAT reactive transport model to evaluate the transferability of knowledge to wastewater management in FKNMS and other carbonate aquifers

(5) Assess the causative relationship between shallow injection well effluent and high nutrient loads and other anthropogenic contaminants to nearshore surface waters
Study site: Marathon Area 3 Wastewater Treatment Facility

5 sampling wells will be drilled in early summer by J & C Drilling.

An additional 5 wells will be drilled early 2022; locations selected based on preliminary characterization of plume geometry.
Well design

piezometer cap
1" PVC piezometer
20/40 mesh sand
10 ft.
Portland cement

0.01" slotted screen well point
50 ft.

fine sand or bentonite

60 ft.

Well diagram with layers: piezometer cap, 1" PVC piezometer, 20/40 mesh sand, Portland cement, 0.01" slotted screen well point, fine sand or bentonite, and the well cap.
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 $N_2$ gas concentrations** to quantify magnitude of denitrification along flow path

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

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

**Dissolved ion concentrations**: calculate N and P speciation from dissolved ions, temperature, and salinity to evaluate chemical reactivity and sequestration potential
Ex.: buoyant wastewater injection plume at Maui


Maliva et al., 2007, Hydrogeology (wastewater injection in SE FL, 10 year effluent migration)
Hypothesis testing

**Hypothesis:** Short residence times of shallow wastewater effluent injections in the aquifer reduces the efficiency and permanence of nutrient removal.

**Experiment:** Inject mixed seawater + effluent to reduce density contrast between the plume and surrounding saline groundwater

**Predicted outcome:** Increased residence time in subsurface karst will increase denitrification efficiency and phosphate adsorption onto KLL
## Current work schedule

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<th>Major Tasks</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
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<td><strong>Fieldwork</strong></td>
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<td>Well installation</td>
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<td>Tracer Testing (Field Fluorescence)</td>
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<td>Blending Experiment</td>
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<td><strong>Analyses + Modeling</strong></td>
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<td>Plume modeling (FEFLOW)</td>
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<tr>
<td>Nutrient concentrations (N, P, C)</td>
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<tr>
<td>Dissolved gases (N₂, Ar)</td>
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<tr>
<td>Nitrogen isotopes (N₂, NO₃⁻)</td>
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<tr>
<td>Dissolved ions, total ALK</td>
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<td>Pharmaceutical concentrations (tracing)</td>
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<td><strong>Synthesis</strong></td>
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<td>Data reduction</td>
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<td>PHREEQC modeling/phase ID</td>
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<td>Report and manuscript writing</td>
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<tr>
<td>Conferences</td>
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+ Participation from FOLKs citizen scientists

**Location**
- Penn State
- Marathon, FL
- FDEP Central Lab
- USGS Reston, VA
- FIU DEP-certified lab
- Elsewhere