QUARTERLY PROGRESS REPORT

September 2021 – December 2021

PROJECT TITLE: Landfill Leachate Management with Adsorbent-Enhanced Constructed Wetlands

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PROJECT WEBSITE: http://constructed-wetlands.eng.usf.edu/

Work accomplished during this period:

During this first quarter progress was made on the following objectives: bench-scale sequencing batch biofilm reactor (SBBR) operation and studies (Task 1), continuing pilot-scale constructed wetlands (CW) studies and bench-scale wood chip studies (Task 2), and reuse feasibility study with ultrafiltration (UF) and reverse osmosis (RO) for water reuse applications (Task 4).

Task 1 - Bench-scale Sequencing Batch Biofilm Reactor

A SBBR was set up as described in the Phase I Final Report. This SBBR contained lightweight expanded clay aggregate (LECA), clinoptilolite, a natural zeolite mineral with a high ion exchange capacity for ammonium, and biochar. The SBBR was operated with high-strength landfill leachate from Orange County's Landfill, specifically Cell 7B/8. The SBBR was operated to achieve total nitrogen (TN) removal without external carbon addition through the following cycle: 1) rapid fill, 2) 3.5-day low aerobic react, and 3) rapid drain. The initial hydraulic retention time (HRT) was set at 18.9 days to match a similar total ammonia nitrogen (TAN) loading rate that the SBBR was known to be able to handle. The HRT was subsequently reduced to 14 days after 12 cycles and further reduced to 10.5 days after 8 cycles.

(1) Nitrogen Removal

Total Inorganic Nitrogen Removal: Zeolite had excellent NH_4^+ adsorption capacity in batch adsorption tests done previously by our group members. Total inorganic nitrogen (TIN) consists of ammonium (NH_4^+-N), nitrate (NO_3^--N), and nitrite (NO_2^--N). As shown in Figure 1 by the low effluent TIN concentrations, especially at an HRT of 18.9 and 14 days, the presence of clinoptilolite assisted in high NH_4^+ removal. High TIN removal rates of 82.9, 109, and 122 mg/L-day were observed at HRTs of 18.9, 14, and 10.5 days, respectively. Due to low influent BOD_5/TN and calculated high free ammonia concentrations, the high TIN removals were most likely due to mechanisms such as shortcut nitrogen removal and partial nitritation/anammox.

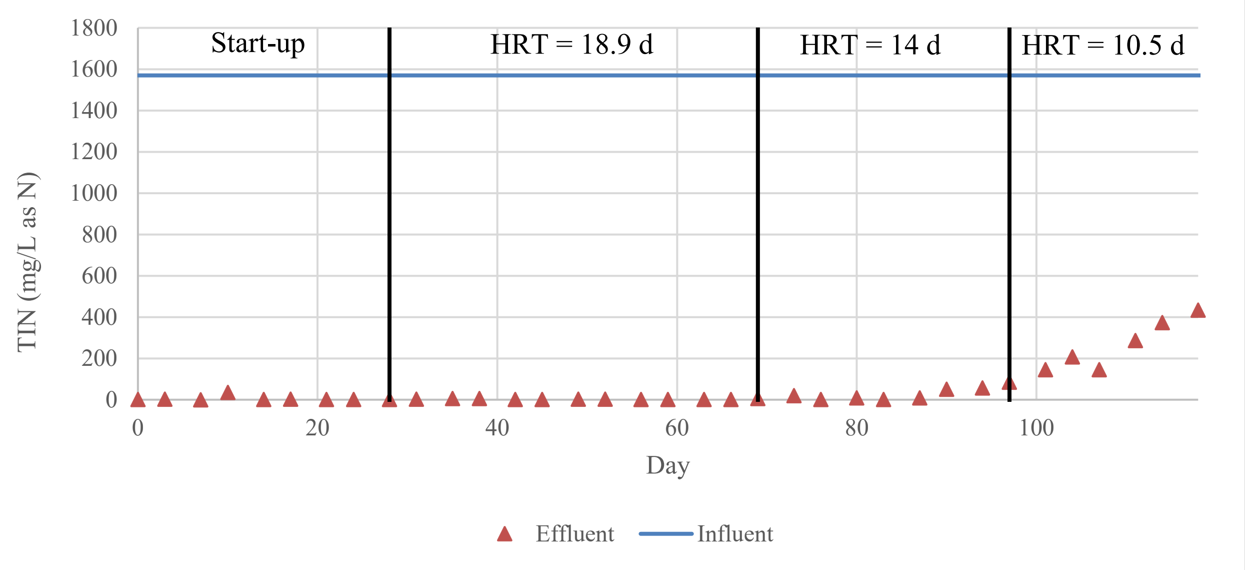

Figure 1. Influent and Effluent Concentrations of TIN for Varying HRTs.

Total Nitrogen Removal: The results of NH_4^+-N, NO_3^--N, NO_2^--N, and Org-N measurements with calculated free ammonia (FA) concentrations are shown in Figure 2. High FA levels can reduce nitrification-denitrification efficiency due to inhibition of ammonia-oxidizing bacteria (AOBs) and nitrite-oxidizing bacteria (NOBs). As the TAN started to increase during the 14-day HRT, it can be assumed that the FA concentrations increased to inhibitory levels to AOB, therefore limiting the growth and sustainability of the microorganism.

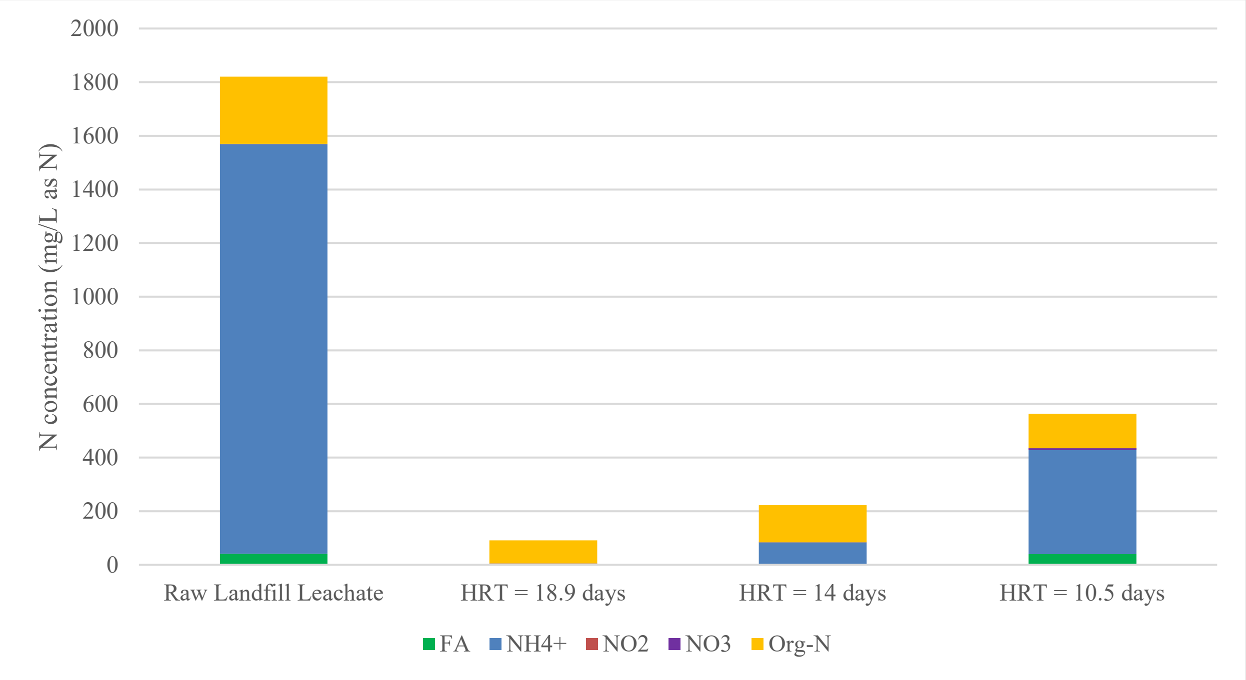

Figure 2. Changes in Nitrogen Species to date in our study.

(2) sCOD Removal

In previous batch adsorption tests done by our group (see Phase I Quarterly Report 1), biochar was found to have a high chemical oxygen demand (COD) removal efficiency. The results of soluble COD (sCOD) concentrations are shown in Figure 3. High sCOD removal rates of 168, 217, and 223 mg/L-day were observed at HRTs of 18.9, 14, and 10.5 days. The minimal difference between the 14-day and 10.5-day HRT conditions indicates that biochar was reaching its maximum adsorptive capacity.

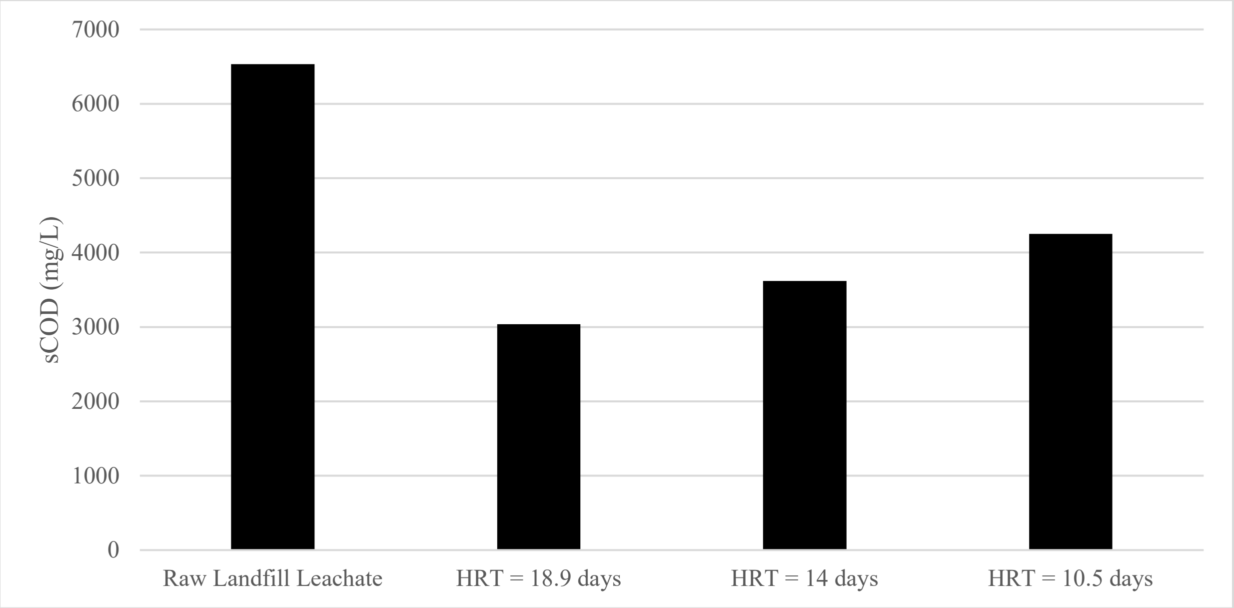

Figure 3. Changes in sCOD concentrations to date in our study.

(3) Color Removal

Landfill leachate has a deep color that is problematic in WWTP where it quenches UV disinfection and can create toxic chlorinated disinfection by-products. Color removal was achieved through biochar adsorption and biodegradation. In the SBBR study, it was measured at two wavelengths: 254 nm to characterize common natural organic compounds that have a maximum absorbance at that specified wavelength and 456 nm to measure color in wastewater. Decreasing color removal was observed throughout the study, as shown in Figure 4. Desorption in the 456 nm was observed in the 10.5-day HRT. The results indicate that biochar had met its maximum adsorptive capacity for organic matter, especially for those reflective at the 456 nm wavelength.

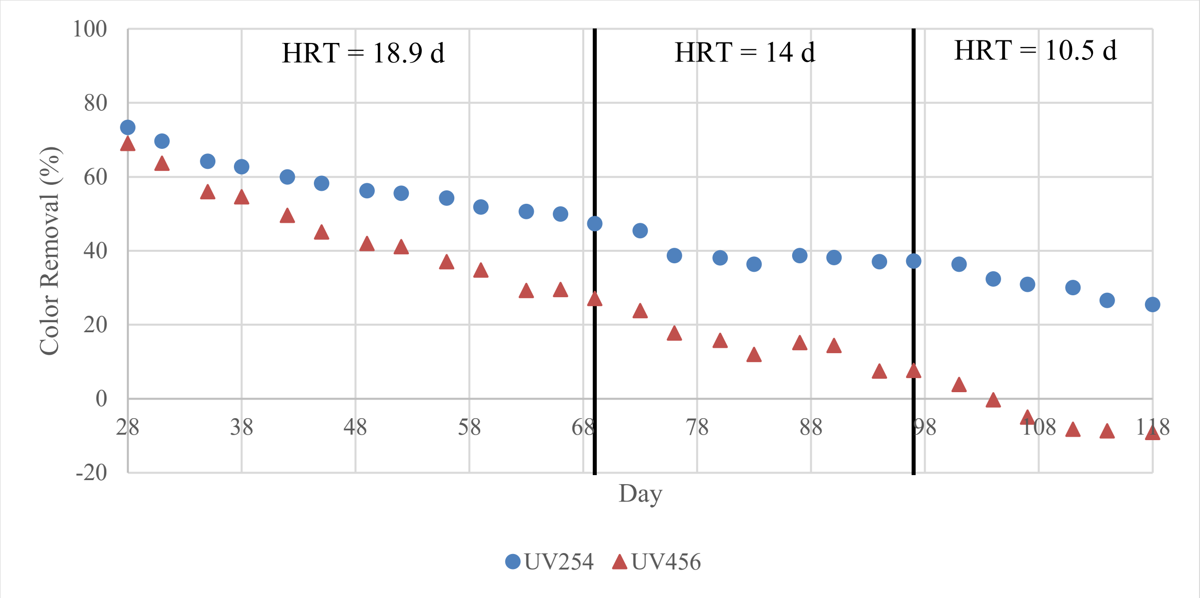

Figure 4. UV254 and UV456 Color Removal Efficiencies for Varying HRTs.

Batch Adsorption Tests: In a previous adsorption study done by our group, there are no obvious synergistic or antagonistic effects of TAN and sCOD removal efficiencies between zeolite and biochar (see Gao et al., 2021). An adsorption study for NH_4^+ removal by clinoptilolite and sCOD and removal by biochar was carried out comparing fresh media mixtures with media recovered from the SBBR that has been in use for 2 years. Figure 5 shows the removal of TAN by clinoptilolite and the removal of sCOD by biochar. The study confirmed that zeolite's bioregenerative capability for TAN did not decrease with the SBBR media after two years of usage compared to the fresh media. However, biochar had reached its maximum adsorptive capacity for sCOD.

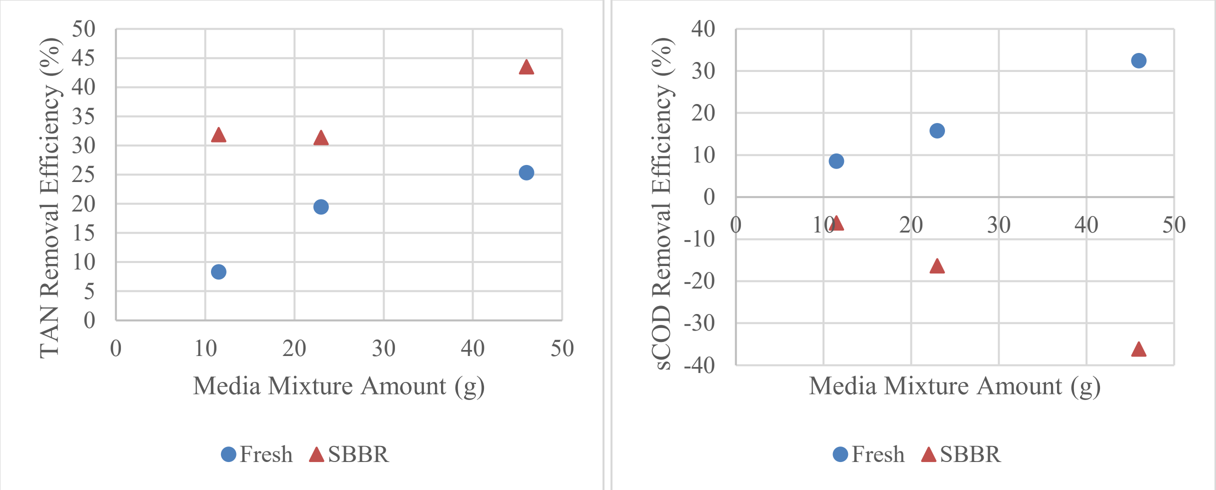

Figure 5. Removal of TAN (Left) and sCOD (Right) by Fresh and SBBR Media Mixtures.

Task 2 - Pilot-scale Hybrid Constructed Wetlands

Two pilot scale hybrid CWs (G-CW and GZB-CW) were continuously operated at the Southeast Hillsborough County Landfill since Phase I. G-CW (control) was filled with gravel media in both VF and HF cells. In GZB-CW, Vertical Flow (VF) cell was amended with 10% (by volume) of zeolite for nitrification enhancement, and Horizontal Flow (HF) cell was amended with 13% (by volume) of biochar for organic matter and color removal enhancement. Detailed CW system design/setup information and Phase I results are shown in Phase I Final Report. During this quarter (Phase II), as shown in Table 1, firstly, the Hydraulic Loading Rate (HLR) for both CWs was increased from 1.6 cm/d to 2.7 cm/d to investigate the effects of HLR on contaminant removal. Secondly, the feeding frequency was increased from 15 min/2h to 7 min/h, which aims to improve oxygen transfer for better ammonia removal.

Table 1. Operating conditions for pilot scale CWs.

Phase	Flow Rate (L/d)	HLR (cm/d)	HRT (d)	Feeding frequency
I	24	1.6	11	15 min/2h
II	40	2.7	7	15 min/2h
	40	2.7	7	7 min/h

(1) Nitrogen Removal

Nitrogen species concentrations in raw leachate and CW effluent are shown in Figure 6. The ammonia (NH_4^+-N) concentration in GZB-VF (117-142 mg/L) was lower than G-VF (152-193 mg/L) at all conditions, indicating that zeolite addition enhanced ammonia removal by the combined effects of adsorption and nitrification. However, increasing HLR resulted in an increased NH_4^+-N concentration in GZB-HF (Figure 6a and 6b), which is likely due to the limited dissolved oxygen in HF cell. Hence, feeding frequency was increased to enhance oxygen transfer. As shown in Figure 6c, NH_4^+-N concentration in GZB-HF decreased from 75 mg/L (Figure 6b) to 45 mg/L (Figure 6c). In addition, nitrate (NO_3^-) accumulation was observed in both CWs, especially in GZB-CW, which is due to the increased rate of nitrification combined with readily biodegradable carbon source limitation. A second HF cell filled with wood chips serving as a carbon source will be constructed in quarter 2 to enhance denitrification.

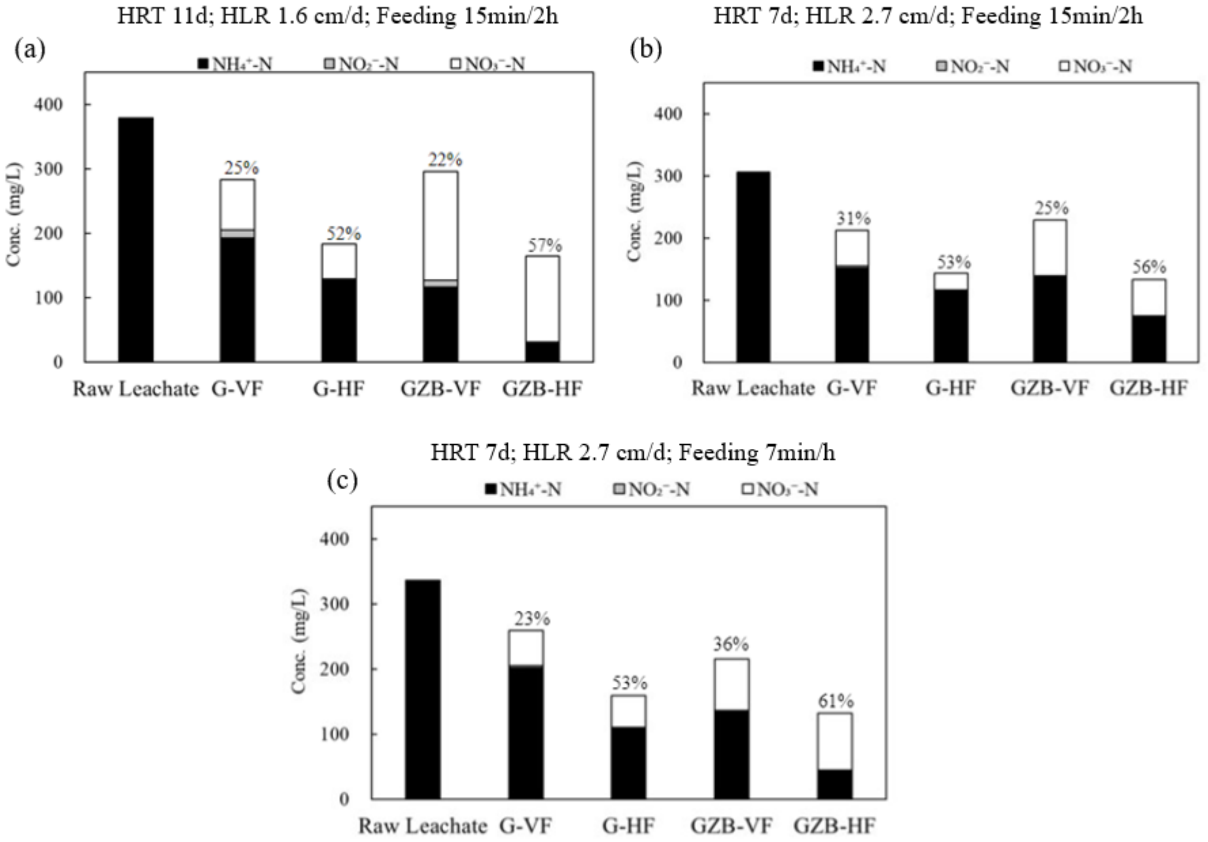

Figure 6. N species concentration in CWs under varying conditions.

(2) sCOD and Color Removal

The sCOD concentration in the raw leachate and CW effluent is shown in Figure 7. For G-CW (control), the effluent sCOD concentration decreased from ~373 mg/L (Phase I) to ~250 mg/L (Phase II) with HLR increase, which is likely due to the decreased sCOD concentration in raw leachate. The sCOD removal in G-CW increased from 23% (Phase I) to 33% (Phase II). For GZB-CW, biochar addition enhanced sCOD removal to 43% compared with G-CW (23%) in Phase I. However, sCOD removal decreased to 32% with HLR increased in Phase II, indicating that biochar was gradually losing the adsorption capacity. Simar pattern was observed for color change as shown in Figure 8. Color removal decreased from 20% (Phase I) to 14% (Phase II) for G-CW and 49% (Phase I) to 10% (Phase II) for GZB-CW. Hence, fresh biochar replenishment is recommended for steady sCOD and color removal from leachate.

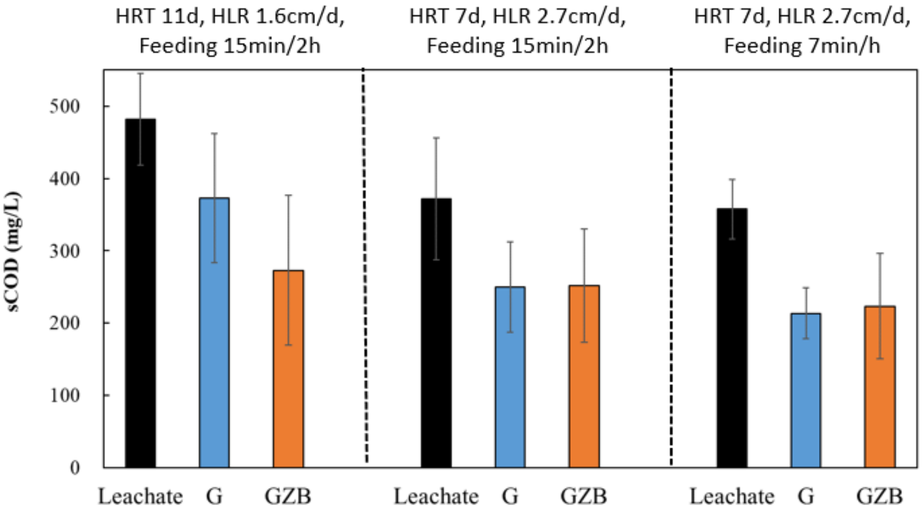

Figure 7. sCOD concentration in CWs under varying conditions.

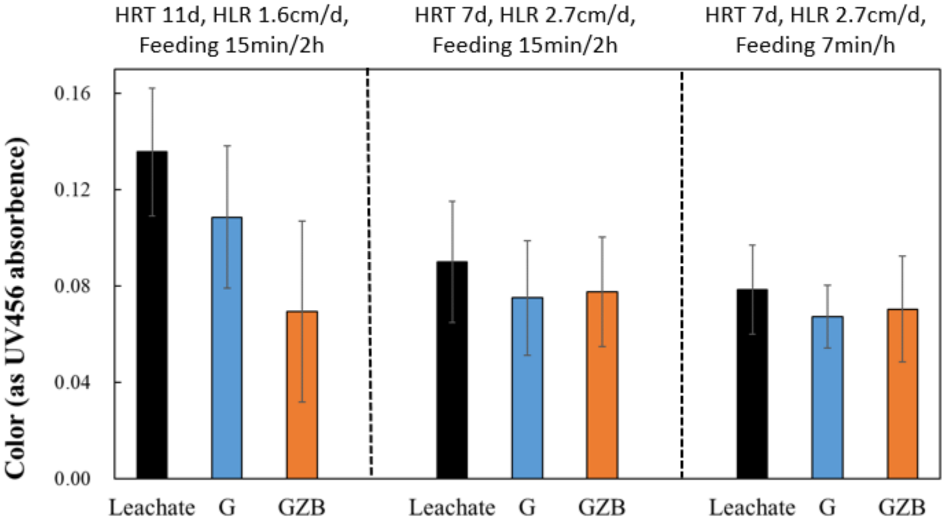

Figure 8. Color changes in CWs under varying conditions.

(3) Bench-Scale Woodchip Bioreactor Study: A bench-scale woodchip bioreactor study was conducted to see the effectiveness of wood chips to aid the denitrification of NO_3^- -N. Three bioreactors were constructed to compare the ratios of woodchips to gravel by volume. The control reactor was100% gravel, a second reactor had a woodchip to gravel ratio of 1:1 by volume, and the last reactor was 100% woodchips. Each had a gravel layer on top to avoid any woodchips from being buoyant. For the first stage, the hydraulic residence time was 4 days, with a fill and discharge volume of 160 millimeters. In the second stage a lower hydraulic residence time of 3 days was applied, with a higher fill and discharge volume of 230 millimeters.

The results show that wood chips from the Southeast Landfill are suitable substrates to enhance denitrification (Figures 9 and 10). For a 4-day hydraulic residence time, the reactors that had woodchips incorporated performed very well in the denitrification. The control (gravel) reactor performed as expected since it does not have a carbon source that would help promote denitrification. With these results, plans to construct a 2nd horizontal flow constructed-wetland with woodchips and gravel at a 1:1 volumetric ratio will help promote denitrification and ensure good hydraulic conductivity and plant growth. This addition along with the rest of the system will be running at different influent flow rates, hydraulic loading rates and residence times and differing empty bed contact times, each with 60 days of operation per set of parameters.

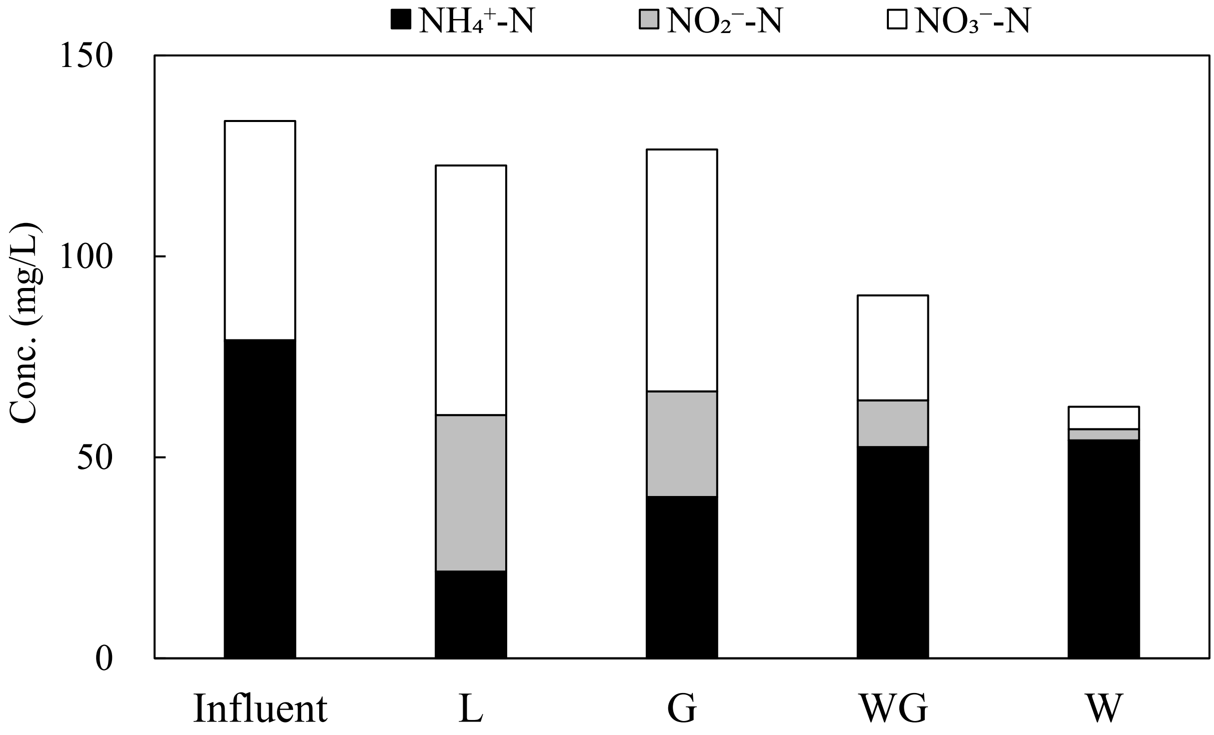

Figure 9. Nitrogen species results from wood reactors from stage 1 (HRT = 4 days). L-Influent, G-Gravel, WG-Woodchips and Gravel (1:1), W- Woodchips.

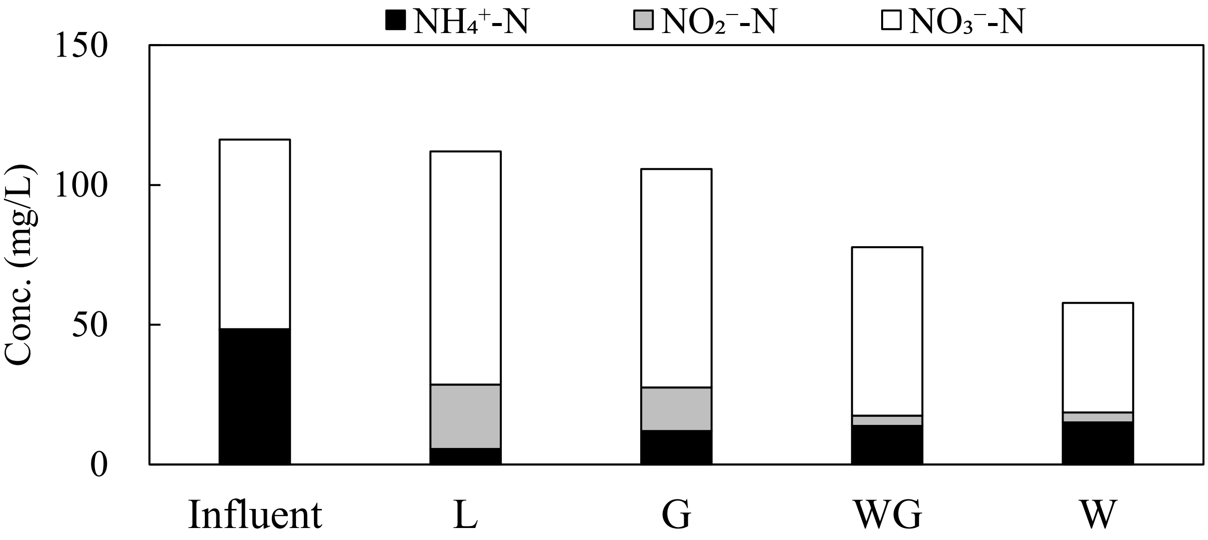

Figure 10. Nitrogen species results from wood reactors from stage 2 (HRT = 3 days). L-Influent, G-Gravel, WG-Woodchips and Gravel (1:1), W- Woodchips.

Task 3 - CW Performance Uncertainty Model

A baseline computer model representing nitrogen, oxygen and carbon in the treatment wetland – and the effects of soil amendments- was developed during Phase 1. The graduate student working on this, Lillian Mulligan, graduated with a Master's degree and moved on from the university to seek employment in the private sector. Since then, we have recruited another masters student to work on the project, Nisa Ishfaqun. She was supposed to start working in the project during the Fall semester, but delays in processing her student visa due to COVID forced her to postpone her enrollment until January of 2022. Because of this unforeseeable situation, no major achievements have been made yet for Task 3 during this phase.

Task 4 - Post-treatment of Constructed Wetland Effluent for Reuse

Due to high salinity and metal concentrations present in landfill leachate even after being treated in CWs, post-treatment by UF and RO is recommended prior to reuse applications. Hillsborough County Southeast Landfill was used as a case study. The Hillsborough County Southeast Landfill is estimated to generate 100,000 to 200,000 gallons of leachate per day. All alternatives were scaled up to the maximum flowrate of 200,000 gallons per day (gpd). For a comparative assessment, four different feed streams were evaluated (Figure 11): Raw landfill leachate, landfill leachate treated through the onsite conventional activated sludge (AS) system, G-CW effluent, and GZB-CW effluent. Experimental simulation was done through the DuPont's Water Application Value Engine (WAVE) software.

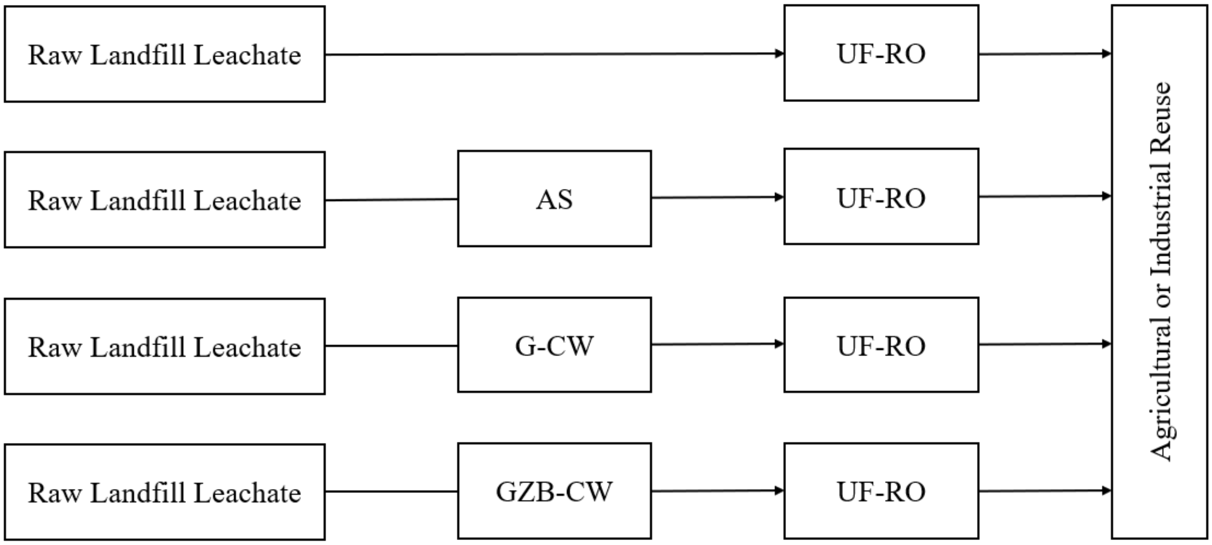

Figure 11. Potential Reuse Strategies for Landfill Leachate.

(1) Reuse Standards

Water reuse entails treating wastewater with a high degree of treatment, primarily with advanced treatment methods such as UF and RO. Reclaimed landfill leachate may not be suitable for public access reuse or potable water reuse, therefore agricultural reuse for non-food crops and industrial reuse is recommended. Table 2 summarizes the water quality guidelines for the two water reuse standards based on USEPA water reuse guidelines, FDEP reuse water quality standards, and recommendations from case studies.

Table 2. Summary of Water Quality Guidelines for Non-food Agricultural and Industrial Reuse.

Water Quality Parameter	Agricultural Reuse (Non-food crops)	Industrial Reuse
$CBOD_5$ (mg/L)	≤ 20	≤ 20
BOD_5 (mg/L)	≤ 30	≤ 30
TSS (mg/L)	≤ 20	≤ 20
Turbidity (NTU)	NS	NS
pH	7.0 – 8.0	7.9 – 8.7
Fecal Coliform (#/100 mL)	≤ 200	≤ 200
TOC (mg/L)	NS	NS
Electrical Conductivity (µS/cm)	< 1,360	< 1,120
Hardness (mg/L as $CaCO_3$)	NS	< 270
Total Alkalinity (mg/L as $CaCO_3$)	< 337	< 160
TP (mg/L)	< 0.05	< 4.1
TN (mg/L)	NS	< 2.3
NO_3^--N (mg/L)	< 9.34	< 0.1
NH_3-N (mg/L)	< 0.02	< 0.25
Barium (mg/L)	NS	< 0.022
Copper (mg/L)	< 0.003	< 0.003
Lead (mg/L)	NS	< 0.003

Note: NS = Not specified by the author(s) or organization

(2) Ultrafiltration and Reverse Osmosis Design

The DuPont WAVE software was used for experimental simulation due to its integration of UF and RO into a single software. UF module chosen was the Ultrafiltration SFP-2880, where it is compatible with industrial wastewater, has a higher effective membrane area, and a high permeability; therefore, fewer modules are required for the high inflow rate. A common UF design configuration was designed for the four feed streams comprised of 3 online trains and 1 offline train with 6 modules each. The RO element chosen was the Fortilife™ XC80, where it is compatible with industrial wastewaters, has a high active area, has high rejection rates, and can handle high flowrates and salt concentrations. A common RO design configuration was designed for the four feed streams, consisting of a first stage with 2 pressure vessels with 6 elements each and a second stage with 2 pressure vessels with 3 elements each. Figure 12 showcases the common UF-RO design configuration for the four feed streams.

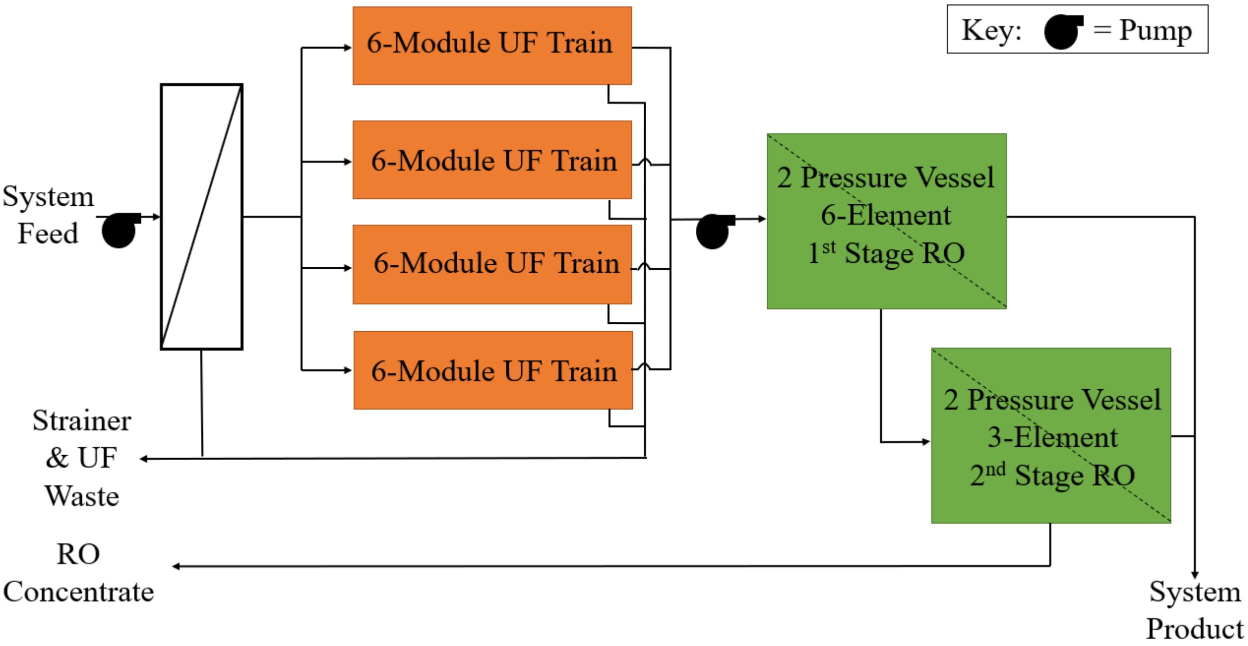

Figure 12. Common UF-RO Design Configuration for the Four Feed Streams.

(3) Optimized GZB-CW Effluent Alternative

An optimized GZB-CW UF design configuration was also designed, consisting of 4 online trains and 1 offline train with 4 modules each. The optimized design reduced the total number of UF modules due to the lower solids content of the GZB-CW effluent compared to raw landfill leachate and AS treated landfill leachate. The optimized GZB-CW RO design configuration was comprised of 2 pressure vessels, with 8 elements each for both stages, to maximize permeate water recovery. Figure 13 showcases the optimized UF-RO design configuration for the GZB-CW effluent. The optimization overall generated an 18.4% enhancement in system product for the GZB-CW system as it increased from 87,700 gpd to 104,000 gpd.

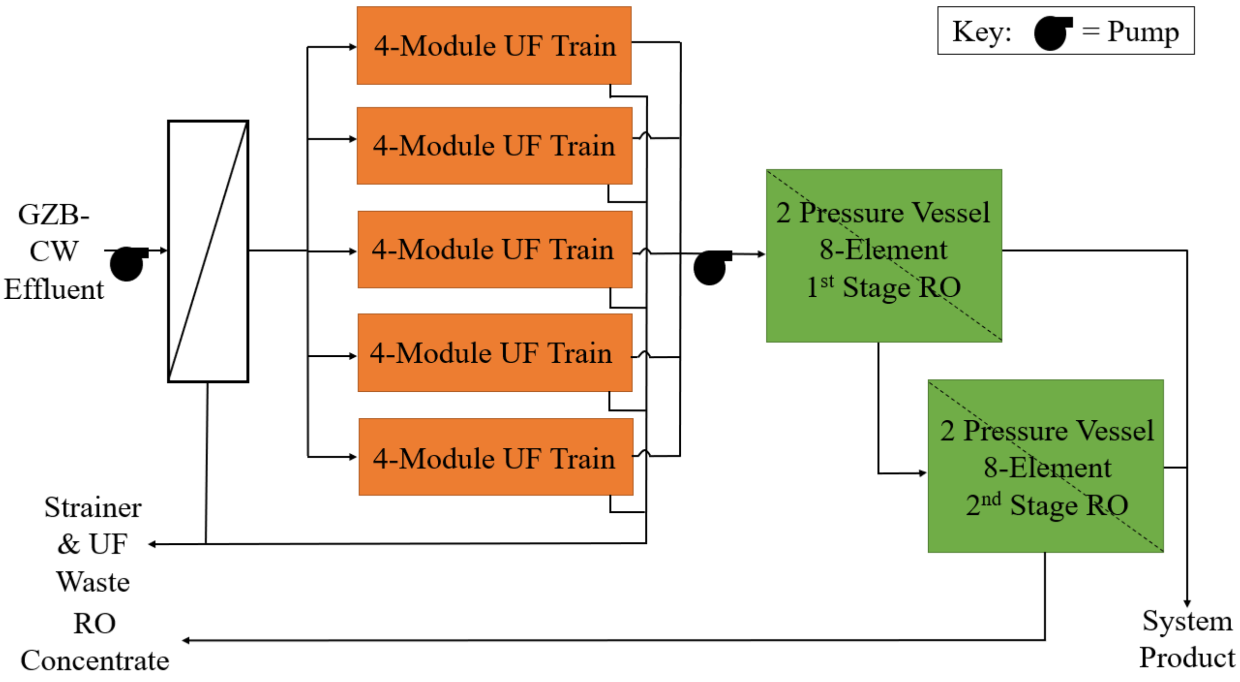

Figure 13. Optimized UF-RO Design Configuration for GZB-CW.

(4) Life Cycle Cost Analysis

An equivalent annual worth analysis was developed on a 20-year design life at an assumed interest rate of 5% for seven different alternatives, including the four feed streams to UF-RO, optimized GZB-CW to UF-RO, raw landfill leachate to direct disposal and GZB-CW effluent to direct disposal. This economic analysis is not reflective of the current Hillsborough County Southeast Landfill state, therefore does not include AS operation and maintenance (O&M) costs, CW capital and O&M costs, and the onsite evaporator O&M costs. Figure 14 shows the summary of equivalent annual costs for all seven different alternatives. The optimized GZB-CW to UF-RO alternative was found to be 63% less costly than the raw landfill leachate to direct disposal alternative.

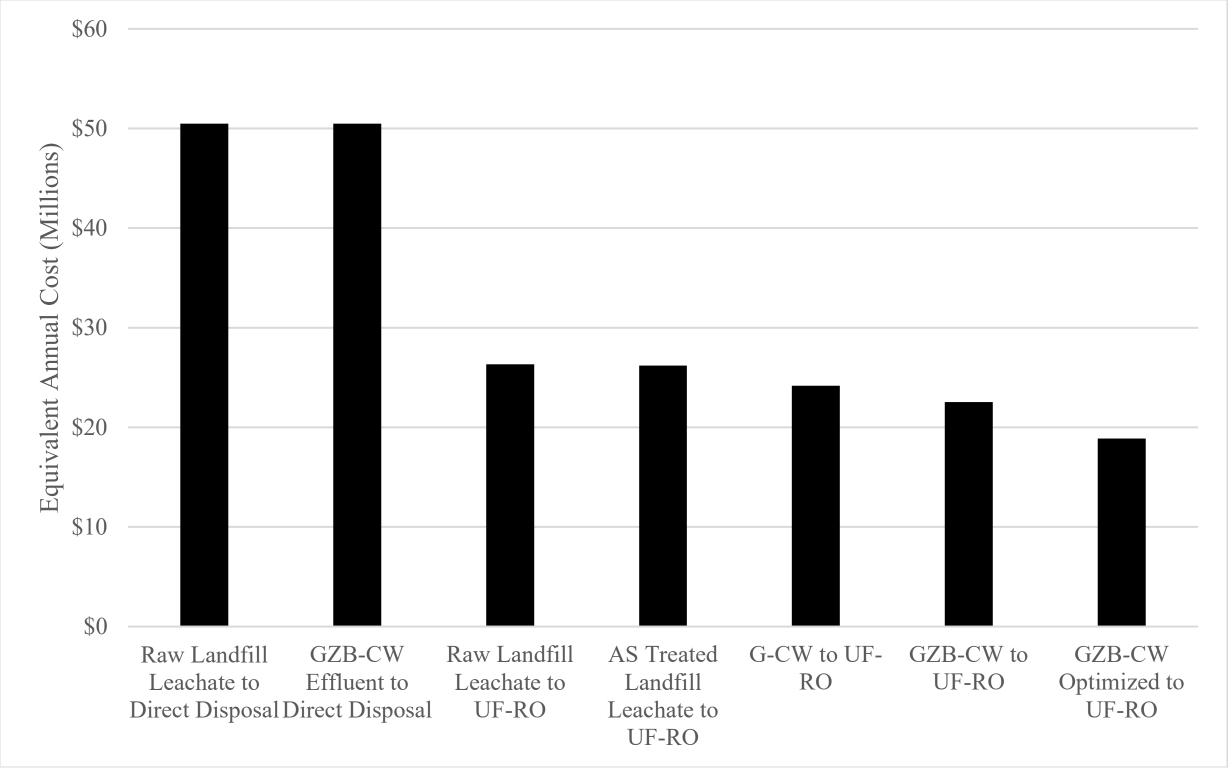

Figure 14. Summary of Equivalent Annual Costs for Various Treatment Alternatives.

TAG Meeting: The first TAG meeting was held on November 17, 2021. Participants included the PIs, graduate students, and TAG members.

Graduate and undergraduate students:

Name	Rank	Department	Institution	Email
Xia Yang	PhD	Civil & Environmental Engineering	USF	xiayang@usf.edu
Thanh Lam	MS	Civil & Environmental Engineering	USF	ttlam@usf.edu
Nicholas Truong	BS	Chemical, Materials, and Biological Engineering	USF	ntruong2@usf.edu

TAG member attendees:

Name	Position/Affiliation	Email
James S. Bays	Technology Fellow, Jacobs Engineering	Jim.Bays@jacobs.com
Stephanie Bolyard	Research Engineer, NCDOT Research and Development Office	scbolyard@ncdot.gov
William J. Cooper	Prof. Emeritus, UC Irvine (Courtesy Prof. Environmental Engineering UF)	wcooper@uci.edu

James Flynt	Chief Engineer, Orange County Utilities Department, Solid Waste Division	James.Flynt@ocfl.net
Marcus Moore	Facilities Manager, Hillsborough County Water Resources Department	moorem@hillsboroughcounty.org
Luke Mulford	Senior Professional Engineer, Hillsborough County	mulfordL@hillsboroughcounty.org

TAG members unable to attend:

Name	**Position/Affiliation**	**Email**
Kimberly A. Byer	Solid Waste Management Division Director, Hillsborough County	ByerK@hillsboroughcounty.org
Ashley Danely-Thomson	Assistant Professor, Florida Gulf Coast University	athomson@fgcu.edu
Viraj deSilva	Sr. Treatment Process Leader / Freese and Nichols, Inc.	Viraj.deSilva@freese.com
Scott Knight	Wetland Solutions, Inc.	sknight@wetlandsolutionsinc.com
Ashley Evans	Market Area Engineer, Waste Management, Inc., Florida	aevans19@wm.com
Melissa Madden-Mawhir	Senior Program Analyst, FDEP	Melissa.Madden@FloridaDEP.gov
Larry E. Ruiz	Landfill Operations Manager Hillsborough County	RuizLE@hillsboroughcounty.org

Link to TAG presentation: TAG presentation slides and recorded narration are posted at http://constructed-wetlands.eng.usf.edu/.

TAG Site Visit: A site visit to the Hillsborough County Southeast Landfill was held on November 22nd, 2021. Participants include the following:

Name	**Position/Affiliation**
Sarina Ergas	PI, Professor, Dept. Civil & Environmental Engineering, University of South Florida
Xia Yang	PhD Student, Dept. Civil & Environmental Engineering, University of South Florida
Thanh Lam	MS Student, Dept. Civil & Environmental Engineering, University of South Florida
James S. Bays	Technology Fellow, Jacobs Engineering

Metrics:

1. List research presentations resulting from (or about) this Hinkley Center Project.
    - Ergas, S.J. (2021) Management of Nutrients and Pathogens Using Hybrid Adsorption Biological Treatment Systems (HABiTS), A*merican Chemical Society Fall Meeting*, Atlanta GA, August 23, 2021.
    - Thanh (Misty) Lam defended her MS thesis this past October 19th . Her thesis was entitled "Use of Biochar and Zeolite for Landfill Leachate Treatment: Experimental Studies and Reuse Potential Assessment".
    - An abstract will be submitted to the American Ecological Engineering Society annual meeting in the next couple of days.

2. List who has referenced or cited your publications from this project.

    Nothing to report on this yet.

3. How have the research results from this Hinkley Center project been leveraged to secure additional research funding? What additional sources of funding are you seeking or have you sought?

    Nothing to report on this yet.

4. What new collaborations were initiated based on this Hinkley Center project?

Leachate from the Orange County landfill has also been used during this second phase of the project. As such, we have been collaborating with Orange County Utilities, and their Solid Waste Division Chief Engineer, James Flynt, has joined our TAG.

5. How have the results from this Hinkley Center funded project been used (not will be used) by the FDEP or other stakeholder?

    Nothing to report on this yet.