QUARTERLY PROGRESS REPORT

December 2021 – February 2022

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

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Work accomplished during this period:

During this second quarter progress was made on the following objectives: Continuing pilot-scale constructed wetlands (CW) studies and bench-scale wood chip studies (Task 2), and constructed wetland performance uncertainty modeling (Task 3). Task 1 (bench-scale sequencing batch biofilm reactor (SBBR) operation and studies) and Task 4 (feasibility study with ultrafiltration (UF) and reverse osmosis [RO] for water reuse applications) were completed during the first quarter and two manuscripts are currently being prepared for publication.

Task 1 - Bench-scale Sequencing Batch Biofilm Reactor

A SBBR filled with lightweight expanded clay aggregate, clinoptilolite, and zeolite treating high-strength landfill leachate from Orange County's Landfill was comprehensively operated and evaluated. Detailed results and discussion are shown in the First Quarterly Report for Phase II. The graduate student working on this, Thanh Lam, graduated with a Master's degree. Therefore, Task 1 is finished.

Task 2 Updates - Pilot-scale Hybrid Constructed Wetlands

As discussed in the First Quarterly Report for Phase II, leachate feeding frequency was increased from 15 min/2h to 7 min/h to improve oxygen transfer for nitrification. Two pilot scale hybrid CWs without/with zeolite/biochar addition (G-CW and GZB-CW) were continuously operated at the Southeast Hillsborough County Landfill for ~140 days after changing the feeding frequency.

Due to carbon source limitation for denitrification, nitrate accumulation was observed for both CWs, especially in GZB-CW (See First Quarterly Report). During this quarter (Phase II), wood chips were introduced as a carbon source to enhance denitrification. Based on the results of batch-scale wood chip reactors (First Quarterly Report), a 2nd HF CW with woodchips and gravel at 1:1 (by volume) (GW-HF) was constructed as shown in Figure 1. The GW-HF has the same working volume as the existing HF cells (Table 1), thus GW-HF has the same HRT and HLR conditions as existing HF cells. Cordgrass (*spartina alterniflora*) and cattails will be planted in the new cell during the third quarter.

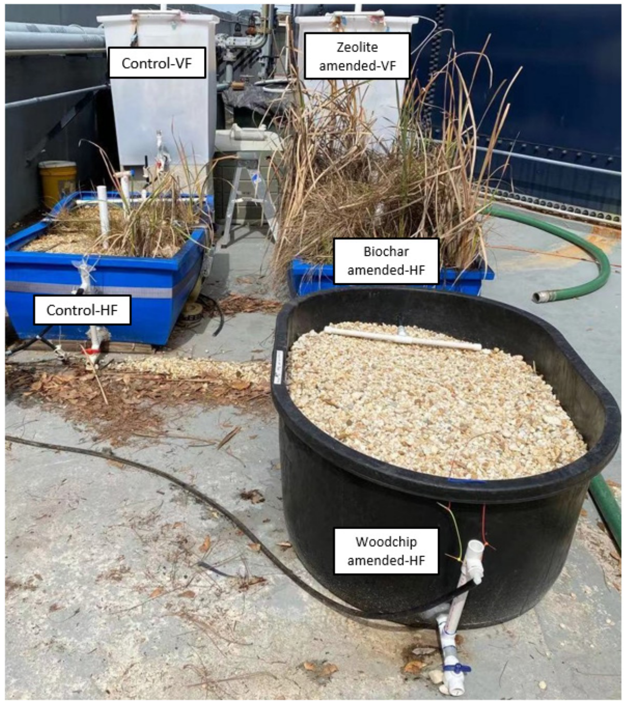

Figure 1. A 2nd HF wetland (GW-HF) was constructed after GZB-HF.

Table 1. Characteristics of CW cells.

	Current VF-CW	Current HF-CW	Wood chips HF-CW
V (L)	250	430	430
Aspect ratio (L:W, m)	1.0 (0.6 : 0.6)	1.8 (1.4 : 0.8)	1.4 (1.4 : 1.0)
Area (m^2)	0.4	1.1	1.4
Water depth (D, m)	0.6	0.36	0.31

(1) Nitrogen Removal

Nitrogen species concentrations in raw leachate and CW effluent are shown in Figures 2 and 3. NH_4^+-N concentrations decreased to 12 mg/L for GZB-HF and 48 mg/L for G-HF during the first week after changing the feeding frequency (Figure 2). However, NH_4^+-N concentration increased to 87-204 mg/L for GZB-HF and 100-258 mg/L for G-HF. This was most likely due to the lower temperature during winter season, which inhibited nitrification (Hwang and Oleszkiewicz, 2007). Hence, the two CWs will be continuously operated through spring season without changing the operating conditions to investigate the effects of temperature on CW performance.

Nitrate accumulation occurred within both CWs with the NO_3^--N concentration of 28-75 mg/L for G-HF and 59-133 mg/L for GZB-HF. After addition of the wood chip CW (GW-HF) NO_3^--N concentration decreased to ~4 mg/L, resulting in an overall total inorganic nitrogen removal of 70% (Figure 3). More samples will be collected to evaluate the long-term treatment performance.

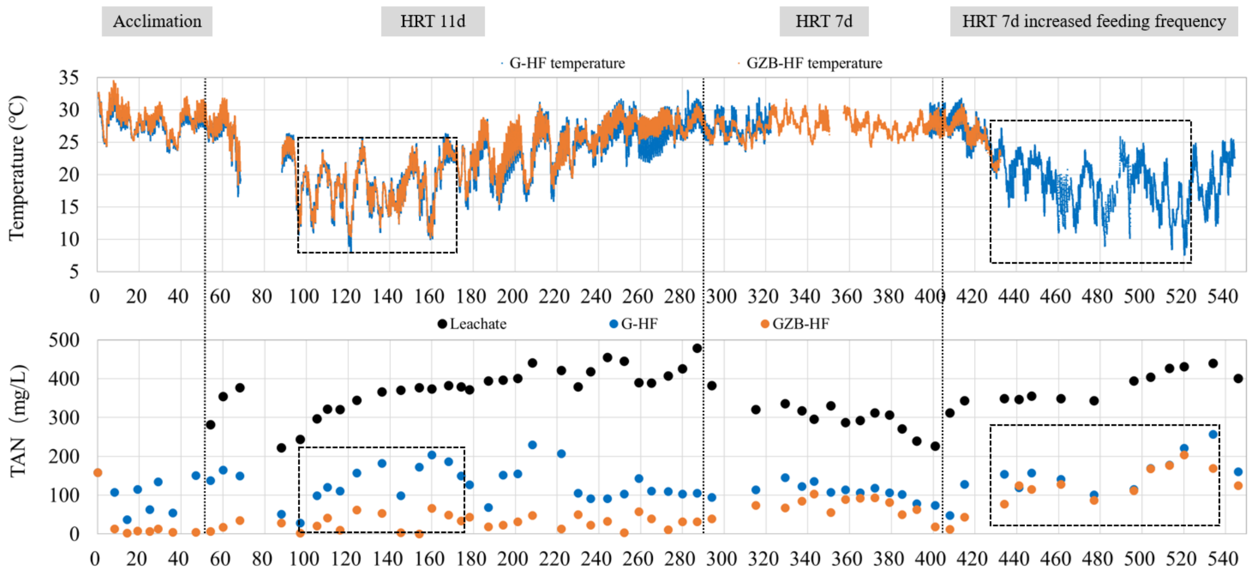

Figure 2. Changes of temperature and ammonia concentration.

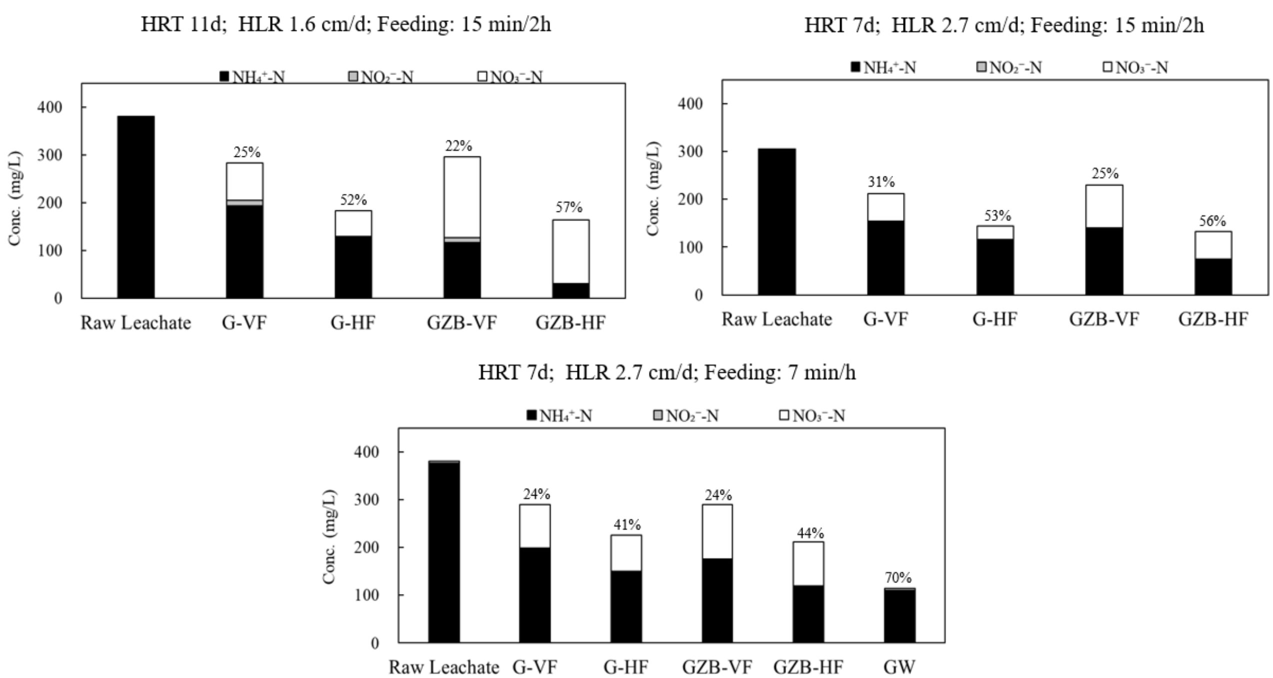

Figure 3. N species concentration in CWs under varying conditions.

(2) sCOD and Color Removal

The sCOD concentration in the raw leachate and CW effluent is shown in Figure 4. sCOD removals were 23-32% for G-CW and 31-43% for GZB-CW. However, the release of organic matter from wood chips in GW-HF increased effluent sCOD concentration to ~575 mg/L with the sCOD removal of -32%. Similar pattern was observed for color (Figure 5). Color removals were 10-17% for G-CW, 8-49% for GZB-CW, and -188% for GW-HF. With the consumption of organic matter in GW-HF for denitrification, lower sCOD concentration and lighter color in GW-HF effluent is expected over time.

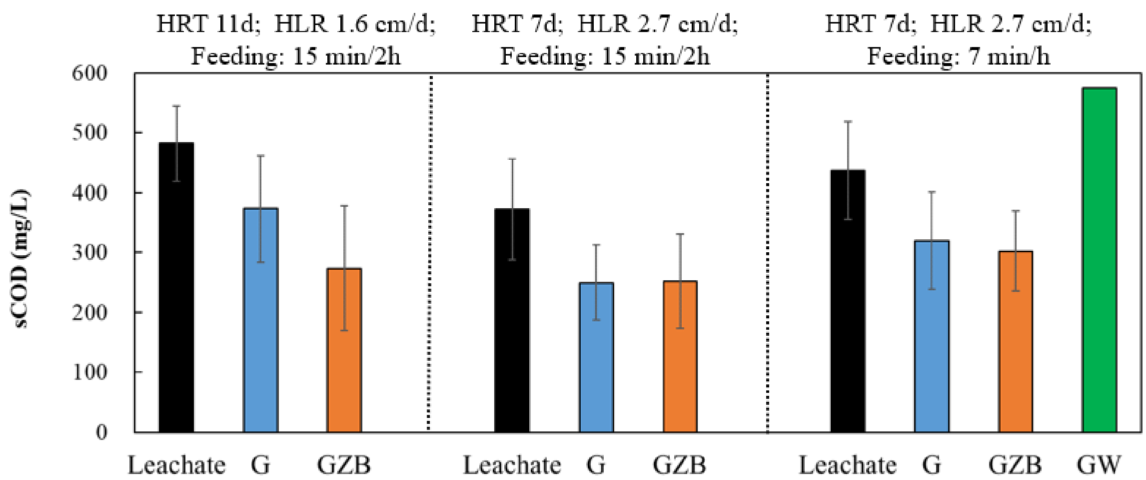

Figure 4. sCOD concentration in CWs under varying conditions.

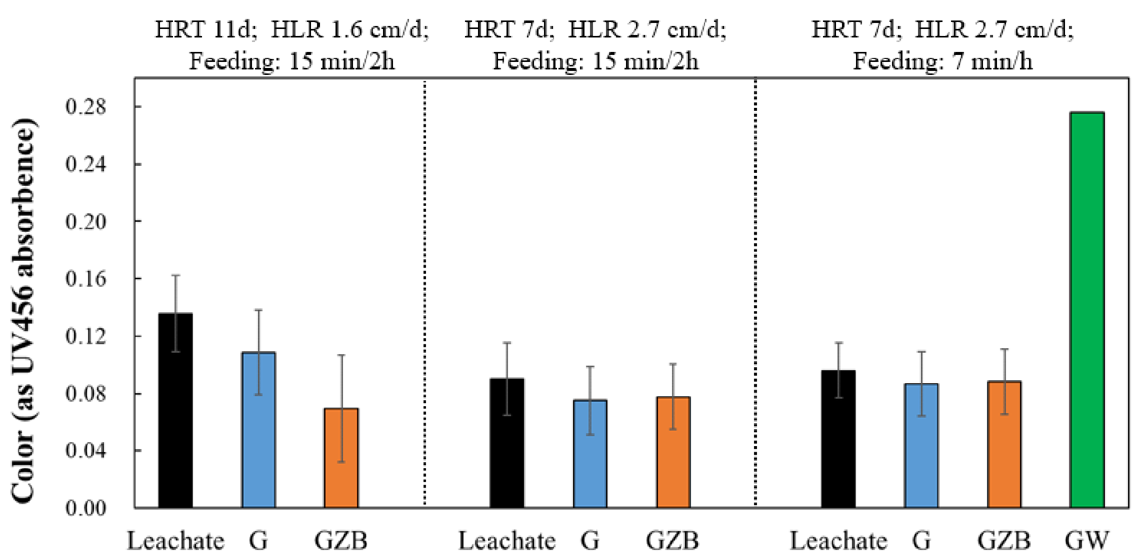

Figure 5. Color changes in CWs under varying conditions.

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 of this project. A new graduate student, Nisa Ishfaqun, was recruited to work on this aspect of the project. After a semester delay on her arrival, she joined the project in January of 2022. Currently we are working on improving the hydraulics representation of the model to more accurately estimate the actual retention time and flow of leachate out of the vertical and horizontal wetland cells.

The simulation of Constructed Wetlands can be challenging due to a large number of physical, chemical and biological processes going on simultaneously. Although there have been numerous empirical models in practice for a while now for water flow processes in constructed wetlands, mechanistic modeling approaches are the preferred option. While the horizontal flow processes are comparatively easier to simulate, the simulation of processes that govern the vertical flow system are more complex.

For modeling the vertical subsurface flow, we assume that the flux of leachate runs through the system from the top to bottom of the bed and neglect the horizontal flow (Giraldi et al., 2010). A qualitative diagram for the system can be found in Figure 6.

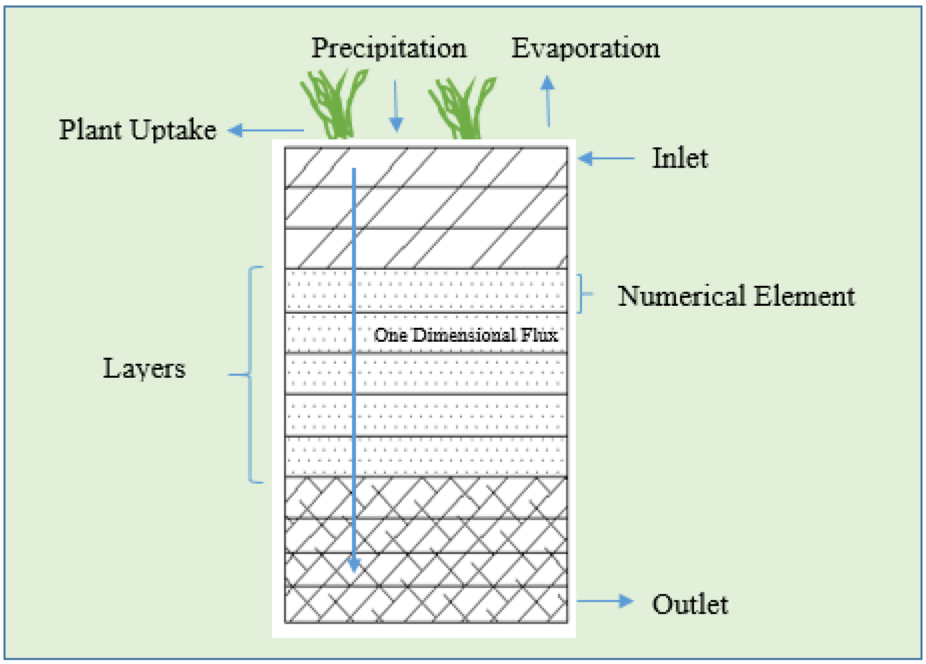

Figure 6. Qualitative Diagram of VF CW System

We will implementing a numerical solution for one dimensional flow systems in our model. The basis for the hydrodynamic analysis of both the vertical and horizontal flow model will be developed based on Richard's equation. This equation is developed for one-dimensional water flow through porous media in saturated-unsaturated condition (Raats, 2001).

$$\frac{d\theta}{dt} = \frac{d}{dz}\left[\kappa\left(\frac{dh}{dz} - 1\right)\right]$$

Where,

θ = Volumetric Water Content [L^3/L^3]

t = Time, [T]

z = Spatial coordinate (positive downwards), [L]

K = Unsaturated hydraulic conductivity, [L/T]

h= Matrix potential, [L]

The numerical solution of Richard's equation is mathematically challenging and thus makes it computationally expensive. In 1997, Schwager and Boller first created the Hydrus model based on Richard's equation to simulate tracer experiments and oxygen transports in intermittent sand filters (Schwager et. al, 1997). Hydrus 1D is the updated version of older Hydrus model that offers a modeling environment for simulation of hydraulic module and solute transport in variably saturated porous media. We will use the latest version of Hydrus 1D (version 4.17) for the VSSF and HSSF water flow systems for our project. Hydrus 1D is a public domain Microsoft Windows-based modeling environment that simulates water flow, solute and heat transport of variably saturated porous media in one dimension. It offers an interactive graphic-based interface for data analysis, discretization of the control volume and graphical presentation of results. It has been popularly applied for many years for efficiently simulating the movement of water and solute transport. The Hydrus model applies numerical solution to Richard's equation described above and incorporates advection dispersion for heat and solute transport. The solution is approached using Galerkin type linear finite element schemes and backward or implicit Euler's method is applied for the integration of time. This model also offers automatic time step adjustment and incorporates plant uptake by introducing a sink term. This model can be applied for non-uniform soil composition. After successfully simulating the hydraulic modules of both the HSSF and VSSF systems, we will be focusing on the simulation of adsorption processes of Biochar and Zeoolite for pollutant removal in the landfill leachate.

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

A model and a cost analysis of different configurations of ultrafiltration and reverse osmosis for constructed wetland posttreatment of landfill leachate was completed. Detailed results and discussion are shown in the First Quarterly Report for Phase II. The graduate student working on this, Thanh Lam, graduated with a Master's degree. A publication manuscript is in preparation.

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". Misty has secured full-time employment as an engineer with Jacobs.
    - Nicholas Troung, who was an undergraduate research assistant in the project, secured an internship with the Southwest Florida Water Management District.
    - An abstract was submitted to the Association of Environmental Engineering & Science Professor conference on February 10, 2022.

- An abstract was submitted to the American Ecological Engineering Society annual meeting on March 4, 2022.

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?

Hillsborough County is looking further into this alternative for landfill leachate treatment.

6. Outreach: Members of the project team participated in USF's Engineering Expo, event in which we demonstrated principles of environmental engineering to middle school students from across the Tampa Bay region.

References:

D. Giraldi, M. de Michieli Vitturi, R. Iannelli,, 2010. FITOVERT: A dynamic numerical model of subsurface vertical flow constructed wetlands, Environmental Modelling & Software, Volume 25

Hwang, J. H., & Oleszkiewicz, J. A. (2007). Effect of cold-temperature shock on nitrification. Water Environment Research, 79(9), 964-968.

Raats, P.A.C., 2001. Developments in soil–water physics since the mid 1960s. Geoderma 100 (3–4), 355–387

Schwager, Andreas & Boller, Markus. (1997). Transport phenomena in intermittent filters. Water Science and Technology. 35. 13-20. 10.1016/S0273-1223(97)00090-5.