Hinkley Center
for Solid and Hazardous
Waste Management

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FULL PROPOSAL COVER SHEET

1. TITLE OF PROJECT
Landfill Leachate Management with Adsorbent-enhanced Constructed Wetlands

2. IS THIS A RESPONSE TO SPECIFIC RESEARCH AGENDA ITEM? ☐ NO ☒ YES
(If "Yes," state the Category and Idea)
Category: LANDFILL LEACHATE Idea:

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4. DATES OF PROPOSED PERIOD OF SUPPORT *(month, day, year—MM/DD/YY)*		5. COSTS REQUESTED FOR INITIAL BUDGET PERIOD	6. DIRECT COST AT PRE PROPOSAL
From 09/01/21	Through 08/31/22	5a. Direct Costs ($) 56,145	6a. Direct Costs ($) 56,145

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10. APPLICANT ORGANIZATION CERTIFICATION AND ACCEPTANCE: I certify that the statements herein are true, complete and accurate to the best of my knowledge, and accept the obligation to comply with Hinkley Center terms and conditions if a grant is awarded as a result of this application. I am aware that any false, fictitious, or fraudulent statements or claims may subject me to criminal, civil, or administrative penalties.

SIGNATURE OF OFFICIAL NAMED IN 9.
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DATE

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Landfill Leachate Management with Adsorbent-enhanced Constructed Wetlands

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ABSTRACT

The dominant landfill leachate management method in Florida is discharge to publicly owned treatment works (POTWs). However, high concentrations of ammonia, recalcitrant organic compounds, metals and salinity in leachate interfere with POTW treatment processes. Results from our Phase I Hinkley Center funded project show that subsurface-flow constructed wetlands (CWs) enhanced with low-cost adsorbent materials (zeolite and biochar), remove much more ammonia (91%), COD (55%) and UV456 absorbance (67%) than a CW without adsorbent materials (ammonia: 63%; COD: 28%; UV456: 33%). *The overall goal* of this Phase II project is to optimize the design and operation of low-cost, low-complexity adsorbent-enhanced CWs for landfill leachate management. This research will help reducing the volume of leachate needing treatment in POTWs and will allow Florida municipal solid waste managers to reliably meet discharge and/or reuse standards. Specific objectives are to: (1) Investigate treatment of high-strength leachate collected from Florida landfills in bench-scale adsorbent-amended bioreactors; (2) Investigate long-term leachate quality and quantity performance of pilot CWs operated at Hillsborough County's SE landfill under varying conditions; (3) Evaluate the effects of uncertainty on leachate quality/quantity and adsorbent composition on CW performance using process modeling; (4) Use simulation software and economic analysis to evaluate the post-treatment feasibility of CW-treated leachate by ultrafiltration reverse osmosis (UF-RO) to meet reuse or disposal requirements. This project will fund 4 students (1 PhD, 2 MS, and 1 undergraduate) and will engage 13 experts in the Technical Awareness Group.

INTRODUCTION

There are more than 1,900 active landfills in the US, accepting over 250 million tons of municipal solid waste (MSW; USEPA, 2014). Landfills in the US generate a total of 61.1 million m^3 of leachate (Lang et al., 2017), a toxic substance which must be properly collected and treated to prevent ground and surface water pollution (USEPA, 2000). Most leachate in Florida is discharged to publicly owned treatment works (POTWs); however, high concentrations of total ammonia nitrogen (TAN), chemical oxygen demand (COD), recalcitrant organic matter, metals and salinity interfere with physical, chemical and biological processes at POTWs. Prior studies have shown that constructed wetlands (CWs) are a cost-effective method for onsite landfill leachate treatment (Vymazal and Kröpfelová, 2009) and volume reduction (Ogata et al., 2015). While detailed design principles exist for wastewater CWs (Kadlec and Wallace, 2008), documentation of leachate management in CWs has been sporadic, with results from case studies suggesting a wide range of performance dictated by design, operation, and leachate characteristics (Mulamoottil et al., 1999). Thus, enhancing CW performance using low-cost media materials and investigating how CWs could be designed and operated for varying leachate characteristics would greatly alleviate key leachate management issues and improve the potential for its safe discharge and reuse.

The overall goal of this project is to develop low-cost, low-complexity adsorbent-enhanced CWs for landfill leachate management that could reduce leachate volume and allow MSW managers to meet Florida discharge and/or reuse standards. The research is grounded in our Phase I Hinkley

Center funded project of low-cost adsorbents in CWs (http://constructed-wetlands.eng.usf.edu/). This proposal directly addresses the general issue of landfill leachate management, which has been a consistent item in the Hinkley Center research agenda since 2004.

Specific objectives of the proposed project are to:

(1) Investigate treatment of high-strength leachate collected from Florida landfills in bench-scale adsorbent-enhanced bioreactors;

(2) Investigate long-term leachate quality and quantity performance of pilot-scale CWs operated at Hillsborough County's SE landfill under varying conditions;

(3) Evaluate the effects of uncertainty on leachate quality/quantity and adsorbent composition on CW performance using process modeling;

(4) Use simulation software and economic analysis to evaluate the post-treatment feasibility of CW-treated leachate by ultrafiltration reverse osmosis (UF-RO) to meet reuse or disposal requirements.

BACKGROUND

Landfill Leachate: The flow rates and composition of landfill leachate are highly variable due to differences in waste composition, design and operation, moisture content, oxygen availability, climate, and landfill age. Landfill leachate is difficult to treat in conventional POTWs due to high and variable TAN, refractory organic matter, metals and salinity concentrations (Zhao et al. 2012). Impacts of landfill leachate on POTWs include: 1) nitrification inhibition by high free ammonia (FA) concentrations and toxic metals, 2) increased aeration demands (and thus energy requirements), 3) increased organic carbon requirements for denitrification due to low concentrations of readily biodegradable COD (rbCOD), 4) UV-quenching substances interfere with UV disinfection (Bolyard, 2016), and 5) high salinity interferes with oxygen transfer and sludge settling and the ability of POTWs to meet effluent conductivity standards. Onsite leachate treatment systems include landfill recirculation, evaporation, aerated lagoons and sequencing batch reactors. Physical and chemical processes, such as filtration, flocculation, ion exchange (IX), granular activated carbon adsorption and membrane processes (i.e., UF-RO), are also used for leachate treatment (USEPA, 2000). Landfill leachate can be treated to meet industrial and/or agricultural reuse standards. For instance, reclaimed leachate has been previously used for landfill cover irrigation (Justin et al., 2008).

Constructed Wetlands: CWs treat leachate through physical, chemical and biological processes (Sun and Austin, 2007; Vymazal and Kröpfelová, 2009). Leachate management with CWs is especially suitable to Florida, where the warm climate is conducive to year-round plant growth, high biological activity, and high rates of evaporation and transpiration (ET). Hybrid subsurface flow CWs that combine vertical flow (VF) and horizontal flow (HF) processes provide both the high oxygen transfer rates needed for nitrification and anoxic conditions needed for denitrification. Prior long-term studies of hybrid VF-HF CW treatment of landfill leachate show that they can provide moderate removal of total suspended solids (TSS), biochemical oxygen demand (BOD), total nitrogen (TN) and metals (Bulc, 2006; Silvestrini et al, 2019; Saeed et al, 2020; Saeed et al, 2021). CW can also reduce the net volume of leachate via ET when compared to evaporation alone (Ogata et al., 2015; Białowiec et al, 2014). Landfill leachate treated by CWs; however, can have high concentrations of dissolved solids and heavy metals, making it unsuitable for irrigation or industrial reuse. CWs are, however, an excellent pretreatment alternative for UF-RO (Huang et al., 2011).

Mathematical Models of Constructed Wetlands for Landfill Leachate: Although there is no comprehensive design manual for leachate treatment CWs, it is known that their design must be site-specific due to highly variable leachate flow rates and composition, as well as local soil and climate conditions (Kadlec and Zmarthie, 2010). Mathematical models are a powerful tool used in design and operations to predict how CW performance would be affected by site-specific conditions. Though CW models are common (e.g., Cancelli et al., 2019; Ophithakorn et al., 2013), the integration of adsorptive media in performance modeling is a novel idea with limited research results up to date. For instance, a recent study simulated the adsorption of biochar in a VF-CW for wastewater reclamation (Nguyen et al., 2021), showing that machine learning algorithms could accurately estimate effluent concentrations. No studies up to date, however, have used process models to predict the effect of adsorption material on CW performance.

Adsorbent Media for Leachate Treatment: A number of studies have shown that adsorbent material addition can enhance microbial degradation in bioreactors (Aponte-Morales et al., 2016; 2018). In these systems, the contaminants are first adsorbed to the adsorbent surface and subsequently degraded by the attached biofilms. Importantly, the adsorbents are *bioregenerated* in-situ; therefore, no fresh adsorbent needs to be added to the bioreactor and no regenerant brines are produced that need further treatment or disposal. Natural zeolite minerals, such as chabazite or clinoptilolite, are low-cost materials with a high IX capacity and selectivity for NH_4^+. Addition of zeolite to CWs has been shown to enhance ammonia removal by both reducing FA toxicity to microorganisms and increasing its residence time in the reactor (Yalcuk and Ugurlu, 2009; Araya et al, 2016; Abedi & Mojiri, 2019). Biochar is a by-product of organic waste pyrolysis with a high specific surface area and adsorption capacity for soluble COD (sCOD) and color. Biochar has been widely used in CW for municipal wastewater treatment. Given its adsorptive capacity for COD and color, biochar has a great potential for leachate treatment. In addition, biochar addition to CWs increases plant growth by reducing the stress of toxic metals and organics on plants (Kasak et al. 2018; Gupta et al, 2016; Zhou et al, 2017). Furthermore, as it contains abundant redox-active functional components (e.g., phenolic moities), biochar has been shown to accelerate denitrification and reduce nitrous oxide emissions (Cayuela et al, 2013; Chen et a, 2018; Sathishkumar et al, 2020). Despite the promising results with zeolite and biochar separately, no prior studies have investigated both of these materials together to address the combined challenges of TAN and recalcitrant organic matter in landfill leachate.

Research Gaps: Giving the current status of the scientific literature on the use of adsorbent-enhanced CW for landfill leachate management, the following are key knowledge gaps that our proposed research will help resolve:

- What are the effects of leachate strength and hydraulic loading on CW performance?
- What is the cumulative effect of zeolite and biochar addition on TAN and recalcitrant organic matter removal in VF-HF CWs?
- What are the effects of uncertainty in leachate quality, loading rates, and adsorbent addition on CW performance?
- Does the addition of biochar promote wetland plant growth and leachate transpiration?
- Can adsorbent-amended VF-HF CWs provide a good pre-treatment method for UF-RO to produce reclaim water?

PHASE I RESULTS

Our recent Hinkley Center project has thus far demonstrated a great improvement in leachate treatment using bioreactors amended with low-cost adsorbents (zeolite and biochar). In our initial studies, three bench-scale Sequencing Batch Biofilm Reactors (SBBRs) were operated with different media materials: 1) light weight expanded clay aggregate (LECA) as a control (C-SBBR), 2) LECA + zeolite (CZ-SBBR), and 3) LECA + zeolite + biochar (CZB-SBBR). The three SBBRs were operated with alternating anoxic and aerobic stages with leachate from Hillsborough County's Southeast Landfill. Excellent TAN removal (> 99%) was achieved in all three SBBRs throughout the study. The combined addition of zeolite and biochar in CZB-SBBR resulted in significantly higher sCOD (61-83%) and color (82-95% as UV456) removal compared with C-SBBR (42-44% and 28-33%) and CZ-SBBR (34-45% and 20-35%). Although high effluent NO_3^- concentrations were initially observed in the biochar amended reactor, after > 1 year of operation NO_3^- accumulation has declined and TN removals are > 70%, most likely due to combined nitrification/denitrification and anammox activity. The CZB-SBBR is still being operated with leachate in our laboratory and is available for additional bench-scale studies with higher strength leachate in Phase II (see Task 1).

Based on the successful bench scale study, two pilot-scale hybrid VF-HF CWs were designed for a side-by-side comparison of leachate treatment performance with and without adsorbent addition (Fig. 1). G-CW contains a conventional gravel medium, while GZB-CW includes zeolite in the VF stage to enhance nitrification and biochar in the HF stage to enhance recalcitrant organic matter removal. The units were set up at Hillsborough County's SE landfill in August 2020. An acclimation phase was applied for 50 days, followed by 20 days of flow-through operation without plants. Cattail (*Typha spp*) and cordgrass (*Spartina*) were planted in early November.

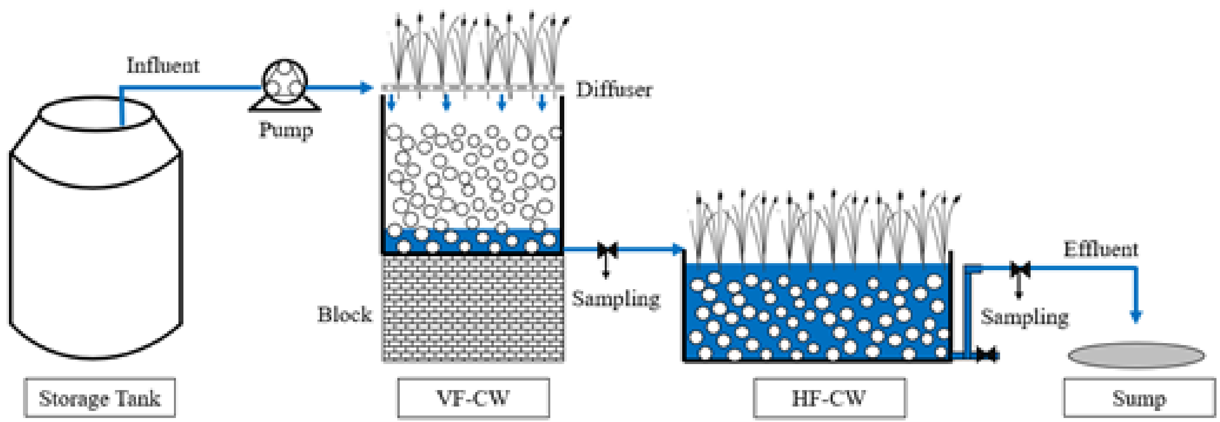

Figure 1. Pilot VF-HW CW schematic.

As shown in Fig. 2 (a), sCOD removal efficiency is significantly higher in the adsorbent-enhanced VF-HF CW (55%) than in the unamended control (28%). Biochar addition also effectively enhanced color removal from 33% to 67% (data not shown). sCOD and color trends were similar to those in the bench-scale study, confirming that adsorption of recalcitrant organic matter enhances biodegradation. Moreover, zeolite addition increased TAN removal from 63% to 91% (Fig. 2(b)). In the intermittently loaded VF-CW, NH_4^+ adsorbs to zeolite during the wetting period and is subsequently nitrified as oxygen fills the media pores during the drainage period. NO_3^- accumulation has been observed in the effluent from both CWs (Fig. 2(b)), most likely due to limited organic carbon availability for denitrification due to the low BOD_5/COD ratio (~ 0.1) of the leachate. A low-cost solid electron donor supplement, such as wood chips, will be used to enhance denitrification in Phase II (see Task 2). As shown in Fig. 3, biochar addition improved the growth of cordgrass and cattails. This is likely due to reduced heavy metal toxicity or enhanced growth of beneficial microorganisms in the rhizosphere, which has been shown in other studies (Rizwan et al, 2016; Elad et al, 2011). Overall, the excellent results documented thus far with the adsorbent-enhanced pilot CW justify long-term performance monitoring under varying conditions.

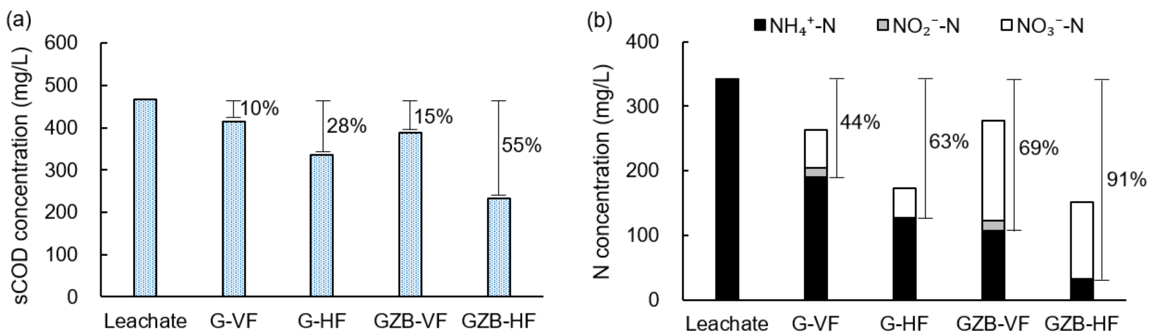

Figure 2. Changes in CWs with/without adsorbents: (a) sCOD; (b) N species. G-VF and G-HF are vertical and horizontal stages of conventional gravel CWs. Percentages represent net removal of (a) sCOD and (b) NH_4^+ from raw leachate at each stage. GZB-VF and GZB-HF are vertical and horizontal stages of adsorbent-enhanced CWs.

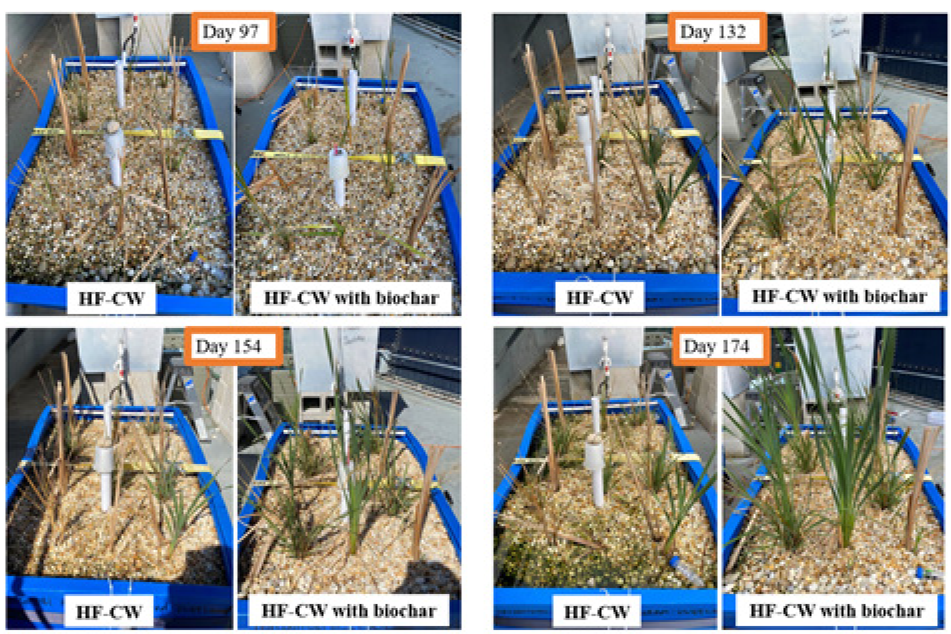

Figure 3. Pilot scale CWs in the SE Hillsborough County landfill.

Phase I Metrics: In addition to the research findings described above, and despite restrictions the COVID-19 pandemic brought to our ability to perform experimental and field research, our Phase I Hinkley Center funded project accomplished the following performance metrics:

1. Six graduate students worked on this project: Bisheng Gao (MS), Xufeng Wei (MS), Xia Yang (PhD), Lillian Mulligan (MS), Thanh Lam (MS), Erica Dasi (PhD). Gao and Yang were directly funded on this project, while other funds were leveraged to support Mulligan, Lam and Dasi. Wei worked on an independent study as a self-funded.
2. One undergraduate research assistant (Magdalena Shafee) worked in this project.
3. Two scientific publications:
    - Gao, B. (2020) Enhanced Nitrogen, Organic Matter and Color Removal from Landfill Leachate by Biological Treatment Processes with Biochar and Zeolite, MS Thesis, Department of Civil & Environmental Engineering, University of South Florida.
    - Gao, B. Yang, X., Arias, M. Ergas, S.J. Enhanced nitrogen, organic matter and color removal from landfill leachate in a sequencing batch biofilm reactor (SBBR) with biochar and zeolite addition, *J. Chemical Technology & Biotechnology* (To be submitted in April 2021).
4. Four presentations (See Table 1).
5. Additional funding leverage from results of this project:
    - NSF S-STEM scholarship for MS students Lillian Mulligan and Thanh Lam.
    - Teaching Assistantship for MS student Thanh Lam.
    - McKnight Doctoral Fellowship for PhD student Erica Dasi.
    - USF Strategic Investment Pool grant to acquire equipment to produce biochar.

Table 1. Summary of presentations during the Phase I project.

Title	Presenter(s)	Venue	Date
Enhanced Nitrogen, Organic Matter and Color Removal from Landfill Leachate by Biological Treatment Processes with Biochar and Zeolite	B. Gao	Thesis Defense	3/11/2020
Cost-Effective Hybrid Constructed Wetlands for Landfill Leachate Reclamation	All team members	TAG Meeting	10/1/2020
Cost-Effective Hybrid Constructed Wetlands for Landfill Leachate Reclamation	S. Ergas, M. Arias	SWANA Hinkley Center Symposium	10/14/2020
Constructed Wetlands	T. Lam	Class Presentation	11/17/2020
Cost-Effective Hybrid Constructed Wetlands for Landfill Leachate Reclamation	T. Lam & L. Mulligan	S-STEM Scholars Roundtable Meeting	11/20/2020

PHASE II RESEARCH APPROACH

The proposed project will build on our excellent Phase I results. As suggested by our TAG, we will test higher strength landfill leachate in our bench-scale CZB-SBBR. We will study the long-term performance of pilot-CWs, with and without adsorbent addition, under varying loading rates and during different seasons. We will also investigate the use of wood chips as a low-cost electron donor to enhance denitrification. With the use of a mathematical model, we will evaluate the effect of influent composition and removal uncertainty on CW performance and post-treatment requirements for discharge or reuse.

Task 1: High strength leachate treatment with bench-scale SBBR: The objective of this task is to investigate treatment of high-strength leachate collected from Florida landfills in bench-scale adsorbent amended SBBRs. Our bench-scale adsorbent amended SBBR has been operated for > 1 year in our laboratory with leachate from Hillsborough County's SE Landfill. Although we have achieved excellent results, the SE landfill leachate has a moderate strength compared with other Florida landfills (Table 2). In Phase II, the SBBR will be challenged with higher-strength leachate from Orange County (Cell 7B/8) under varying hydraulic loading rates (HLRs). Influent and effluent water quality will be monitored as described below.

Table 2. Characteristics of landfill leachates.

Parameter	Hillsborough County SE	Volusia County (2017)*	Orange County Cell 7B/8	Orange County Cells 9-12	Orange County Pump Station
NOx (mg/L)	80	37.98	BDL	BDL	BDL
TAN (mg/L)	375	137.73	1,549	2,015	1,826
sCOD (mg/L)	460	2,710	6,198	6,458	8,570
Cond. (mS/cm)	13.74	8.13	19.7	21.7	18.7
UV254 (A)	3.514	N/A	92.8	79.7	143.5
UV456 (A)	0.242	N/A	5.69	4.86	5.5

*Data from Volusia County, BDL = Below Detection Limit; N/A = Not Available.

Task 2: Pilot-scale hybrid CW studies: The objective of Task 2 is to investigate long-term leachate quality and quantity performance of pilot-scale CWs operated at Hillsborough County's SE landfill under varying conditions. As described previously, control and adsorbent-enhanced pilot-scale hybrid VF-HF CWs have been operated at the SE Hillsborough County landfill for ~ 8 months (Fig. 1). In Phase II, we will continue pilot operation to collect data with more mature plant growth and in different seasons. As the current HLR (1.6 cm/d) is relatively low (typical HLR 2-20 cm/d), a large CW surface area (2.4 - 4.7 hectares) would be needed to treat the daily leachate volume produced by the SE landfill (100,000-200,000 gallons/day). Therefore, the HLR will be increased every two months to collect data under a range of loading conditions (Table 3). In addition, we will investigate the potential to decrease effluent NO_3^- concentrations by adding wood chips to the HF-CW media. In our prior research (He et al., 2018), wood chips were shown to be a low-cost, slow-release organic substrate to enhance denitrification. The use of wood chips in the HF-CW avoids the use of complex chemical feed systems (e.g., for methanol addition). Initial batch microcosm studies with different types of wood chips (softwoods and hardwoods) will be conducted with nitrified CW effluent to verify that wood chip addition can improve denitrification kinetics. If this is shown to be successful, the amount of wood chips needed will be calculated based on effluent NO_3^- concentration, flow rate and denitrification stoichiometry. The current HF-CW tanks will either be amended with the wood chips or a post-denitrification stage will be added depending on the amount of wood chips needed.

Table 3. Experimental phases for CWs.

Phase	Flow Rate (L/d)	HLR (cm/d)	HRT (d)	EBCT (d)	Electron donor supplement	# days operation
I	24	1.6	11	29	/	250
II	24	1.6	11	29	Wood chips	60
	40	2.7	7	17		60
	60	4.0	4.5	11		60
	80	5.3	3	9		60

HLR = hydraulic loading rate, HRT = hydraulic residence time, EBCT = empty bed contact time.

High-resolution sensors will continue to be used to record leachate depth, temperature, and electrical conductivity within the CWs at 15-min intervals during the entire length of the study. These sensors are used to monitor changes in influent leachate quality, to accurately estimate the performance of the CWs and hydraulic conditions (loading, retention time, and head), and to detect clogging in the event this becomes an issue in the cells. Moreover, temperature and conductivity data are used in conjunction with leachate characterization data to understand biological activity and fate of minerals through the CWs. Each cell is instrumented with one multiparameter logger. Instruments will be serviced and data downloaded monthly.

Task 3: CW performance uncertainty modeling: The objective of Task 3 is to evaluate the effects of uncertainty on leachate quality/quantity and adsorbent composition on the performance of a pilot-scale CW system. Under Phase I, we developed a process model that tracks the mass balance of water, oxygen, and nitrogen species through the CWs. The overall water balance equation is as follows (Chapra, 1997):

$$\frac{dV}{dt} = Qin - Qout + (P * A_s) - (ET * A_s)$$

Where dV is the change in volume, dt is the change in time (days), Qin is the inflow rate (m^3/day), $Qout$ is the outflow rate, P is rainfall precipitation (m), A_s is the wetland surface area (m^2), and ET is evapotranspiration (m). Separate water balance equations are used for the VF and HF tanks, since the size and flow rates of the tanks vary. The outflow rate of the VF tank is assumed to be equal to the inflow rate of the HF tank. Evapotranspiration is calculated using Thornthwaite's Method (Thornthwaite, 1948). The general mass balance equation for dissolved oxygen is as follows (Jorgensen and Bendoricchio, 2001):

$$\frac{d(DO)}{dt} = Reaeration - Consumption + Production$$

Where $d(DO)$ is the change in dissolved oxygen concentration (mg/L). Reaeration is accounted for with the following model:

$$\frac{d(DO)}{dt} = k_R * (DO_s - DO)$$

Where k_R is the transfer coefficient and DO_s is the saturation dissolved oxygen concentration (mg/L), and DO is the initial dissolved oxygen concentration (mg/L). The effects of wind are ignored since both wetlands are subsurface flow. The Benson and Krause (1984) model can be used to estimate DO_s.

Consumption of oxygen is due to aerobic biodegradation of Chemical Oxygen Demand (COD) and Nitrogenous Oxygen Demand (NOD). COD can be modeled using first-order kinetics:

$$\frac{d(COD)}{dt} = -k_d * COD$$

Where COD is the concentration of organic matter measured as COD (O_2 mg/L) and k_d is the rate coefficient (day^{-1}).

NOD is calculated with the first order kinetic equation for the oxidation of nitrogen:

$$\frac{d(NOD)}{dt} = \delta * k_N * NH_4^+$$

Where δ is the stoichiometric coefficient for the process (g O_2/g NH_4^+), k_N is the rate coefficient (day^{-1}), and NH_4^+ is the concentration of ammonia (mg/L).

Mass balances for organic nitrogen, nitrate, and ammonia are used to keep track of nitrogen in the system. Mass and volume are calculated simultaneously at each time step. Concentration is then simply calculated as $C = {}^{M}/_{V}$. The mass balances for Organic Nitrogen, Nitrate, and Ammonium are estimated as follows:

$$\frac{d(Org_N)}{dt} = Qin * (Org_N)_i - Qout * (Org_N) * -(r_m * V) - (r_s * V)$$

$$\frac{d(NO_3)}{dt} = Qin * (NO_3)_i - Qout * (NO_3) + (r_n * V) - (r_{dn} * V)$$

$$\frac{d(NH_4)}{dt} = Qin * (NH_4)_i - Qout * (NH_4) - (r_n * V) + (r_m * V) + (r_{dn} * V)$$

Where $(Org_N)_i$ is the influent concentration of organic nitrogen (mg/L), r_m is the rate of mineralization ($mg \cdot L^{-1} \cdot day^{-1}$) and r_s is the rate of settling ($mg \cdot L^{-1} \cdot day^{-1}$). $(NO_3)_i$ is the influent concentration of nitrate (mg/L), r_n is the rate of nitrification ($mg \cdot L^{-1} \cdot day^{-1}$) , $(NH_4)_i$ is the influent concentration of ammonia (mg/L), and r_{dn} is the rate of denitrification ($mg \cdot L^{-1} \cdot day^{-1}$). V is the storage on a given day that is solved based on the water balance (L). Preliminary results of the water balance were estimated with data collected at the Lithia weather station, showing ET estimates of typical magnitude and seasonality as expected for CWs in Florida (Fig 4). For most of the year (with the exception of large storms during a selected number of days), ET exceeds rainfall, suggesting that CWs are capable of reducing the net volume of leachate needing treatment offsite.

Once calibrated and validated, the model will be used to evaluate optimal conditions for leachate treatment and volume reduction (via ET). The model will also be used to assess the effect of uncertainty in leachate quality, loading rates, and adsorbent addition on CW performance. This will be done using the Sobol sensitivity method recently evaluated in Arias' lab (Benjamin et al., 2020; Kaura et al., 2019). This evaluation will be carried out using primary data from the pilot CWs, but calculations will also be scaled up for a system capable of treating the average leachate discharge from the Hillsborough County's SE landfill (100,000-200,000 gal/day).

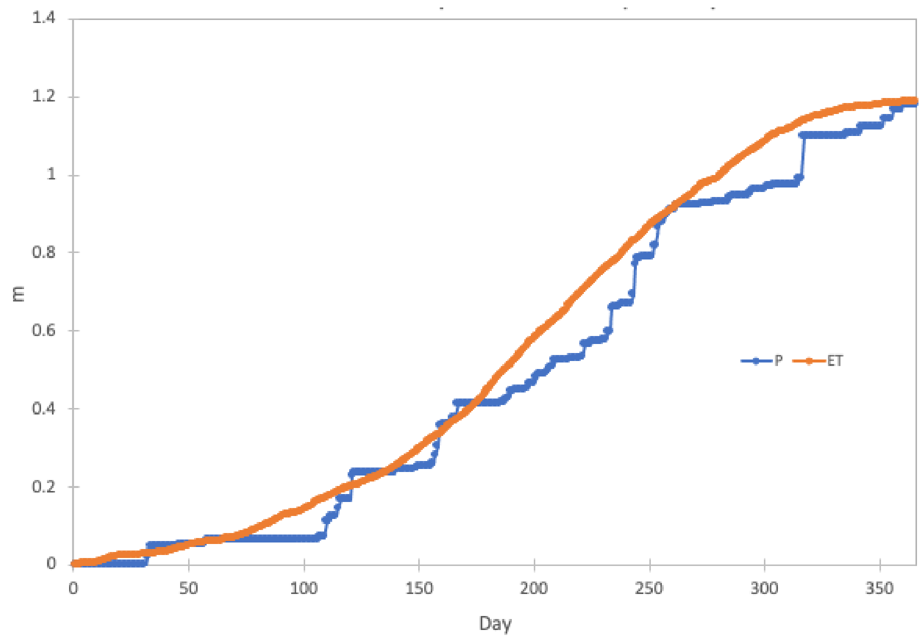

Figure 4. Cumulative precipitation and simulated evapotranspiration for 2020.

Task 4: Post-treatment of CW effluent for reuse: Under Phase I, a preliminary evaluation of reuse potential of treated leachate determined that industrial reuse and non-food crop irrigation would be the most feasible reuse alternative after post-treatment (e.g., UF-RO) to reduce the high effluent high conductivity (>6,000 µS/cm). In Task 4, we will evaluate the most technically and economically viable landfill leachate treatment and reuse strategy using Hillsborough County as a case study.

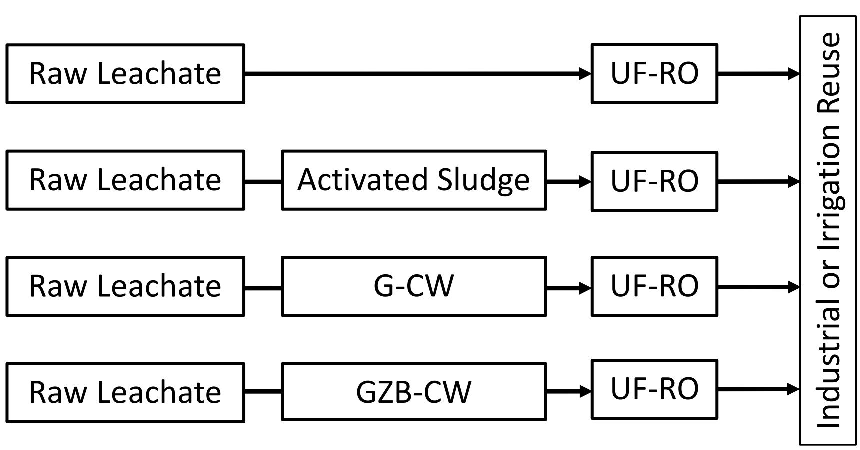

Figure 5. Potential strategies for landfill leachate reuse to be evaluated in Task 4 of Phase II.

Four different UF-RO feeds will be considered (Fig. 5): 1) Raw leachate, 2) leachate treated at Hillsborough County's onsite activated sludge process, 3) effluent from the control pilot CW (G-CW), and 4) effluent from the adsorbent amended CW (GZB-CW). UF-RO simulations will be carried out using DuPont's WAVE Software (Dupont, 2021). Flow rates will be adjusted to account for water gains/losses in the CWs based on our water balance (Task 3). In addition to the parameters currently being monitored, the software requires characterization of a suite of anions, cations and metals, turbidity, and silt density index (SDI). A preliminary analysis of selected parameters needed for the WAVE software is shown in Table 4. The SDI values indicate that a membrane filtration, such as UF, would be needed prior to RO for both treated and untreated leachate to reduce membrane fouling. Pretreatment using cloth media filtration may also provide an acceptable level of treatment. Effluent quality data from the simulations will be compared with Florida regulatory standards for irrigation, industrial reuse (e.g., cooling water), and spray application on the landfill. An economic assessment of the process will include capital and O&M costs (including RO concentrate disposal) and benefits (e.g., avoided costs of other disposal alternatives). The acceptability of the process to end users will be considered in the assessment through discussions with TAG members.

Table 4. Preliminary analysis of input water quality parameters for DuPont's WAVE software.

Parameter	Raw Leachate	Activated Sludge Treated Leachate	G-VF-HF CW Effluent	GZB-VF-HF CW Effluent
Turbidity (NTU)	86.3	42.3	2.87	1.58
TSS (mg/L)	118	94.5	30.3	24.2
SDI_{15}	> 6.67	> 6.67	6.44	6.26
pH at 25 C	7.61	6.95	7.83	7.30
NH_4^+-N (mg/L)	366	4.55	144	46.5
NO_3^--N (mg/L)	0	250	79.5	176
NO_2^--N (mg/L)	1.9	0	0.40	0.28

Analytical methods: Influent, mid-process, and effluent samples will be collected from the bench- and pilot-scale reactors weekly. Additional samples will be collected as needed for UF-RO simulations (e.g., from activated sludge effluent). *Standard Methods* (APHA et al., 2018) will be used to measure total and volatile suspended solids (TSS/VSS), turbidity, pH, alkalinity, conductivity, and N and P species concentrations. Organic matter characterization will include measurements of BOD5, COD, UV254 and UV456. Anion and cation analysis will be carried out using a Metrohm Peak 850 Professional An/Cat-ion chromatography (IC) system. Concentrations of metals will be measured at USF's core geochemistry facility. SDI measurements will be performed using ASTM method D19.08.

PRACTICAL SPECIFIC BENEFITS FOR END USERS

As stated in the 2021 Hinkley Center research agenda, "*Leachate management can be a significant component of the Long-Term care estimates based on the current models for leachate generation.*" The use of CWs for onsite landfill leachate management will benefit Florida MSW managers because of their low complexity, low capital and O&M costs, leachate volume reduction potential, and proven long-term performance for removal of organic matter, nitrogen, color, and suspended solids. Operation of CWs with adsorbent enhanced media could reduce the net volume of leachate discharged to POTWs, while improving effluent quality to a level that is much more acceptable. The evaluation of post-treatment by UF-RO will allow us to evaluate the economic feasibility of upgrading CW effluent for discharge or reuse.

PROJECT TIMELINE AND MILESTONES

This project will have four milestones (one associated with each Task) as well as deliverables associated with outreach, TAG meetings, and reports to the Hinkley Center. The timeline for the project by quarter and deliverables are shown in Table 5. Dr. Ergas will lead the bench-scale laboratory studies and analytical chemistry. Dr. Arias will lead pilot scale CW pilot-scale studies and modeling tasks, and will act as the overall project manager. Both faculty members will work together on reuse assessment and research dissemination.

Table 5. Timeline for Project Completion**.**

Task		Q1	Q2	Q3	Q4	Deliverable
1)	Bench-scale studies					Data for uncertainty analysis
2)	Pilot-scale studies					Long term performance data, publication
3)	Uncertainty modeling					Uncertainty analysis, publication
4)	Post-treatment for reuse					Scale-up, economic & acceptability
	Education & outreach					Students, professionals, community
	TAG meetings	■			■	Slides, videos and photos in website
	Quarterly & final reports	■	■	■	■	Reports for Hinkley and USF websites

BUDGET AND JUSTIFICATION

A detailed budget is shown in Table 6. One PhD student, two MS students, and one undergraduate will carry out day-to-day work on the project. Benefits include fringe benefits, health insurance, and tuition. Research supplies are requested for bench and pilot studies, including supplies for chemical and microbiological analysis, sample analysis at USF's geochemistry core facility and maintenance of reactors and instrumentation. Travel funds are requested to visit field sites and dissemination of results at a relevant conference. USF matching (30%) includes faculty salary and benefits for the PIs. It is anticipated that students working on the project will also be eligible to apply for travel funds to present their research (e.g., from USF's office of graduate studies).

Table 6. Proposed budget.

Budget Item	Hinkley Center	USF Cost Share	Total Project
Principle Investigators Salary	-	13,135	13,135
PhD Student	$16,224	-	$13,520
MS Students	$17,337	-	$17,337
Undergraduate Student	$4,680	-	$4,680
Benefits	$2,832	4,158	$6,990
Domestic Travel	$2,314	-	$2,314
Materials & Supplies	5,000	-	$5,000
Tuition	$7,758	-	$7,758
Total	**$56,145**	**$17,319**	**$78,583**

TECHNICAL AWARENESS GROUP

A technical awareness group (TAG) composed of 13 experts in the field of landfill leachate management, CW systems, and other related issues has been formed (Table 7). All TAG members listed have confirmed they are willing to serve as advisors and peer reviewers to ensure project success. The PIs and students associated with this project will hold at least two TAG meetings over the course of the project. TAG meeting remote participation will be made available via

Microsoft Teams. Video recordings, notes and slides from the TAG meetings will be posted on the project website.

Table 7. TAG members**.**

Name	Position/Affiliation	Email
James S. Bays	Technology Fellow, Jacobs Engineering	Jim.Bays@jacobs.com
Kimberly A. Byer	Solid Waste Management Division Director, Hillsborough County	ByerK@hillsboroughcounty.org
Stephanie Bolyard	Research and Scholarship Program Manager, EREF	sbolyard@erefdn.org
William J. Cooper	Prof. Emeritus, UC Irvine (Courtesy Prof. Environmental Engineering UF)	wcooper@uci.edu
Ashley Danely-Thomson	Assistant Professor, Florida Gulf Coast University	athomson@fgcu.edu
Viraj deSilva	Program Manager, ATI Inc.	Viraj.desilva@atiinc.com
Scott Knight	Wetland Solutions, Inc.	sknight@wetlandsolutionsinc.com
Ashley Evans	Market Area Engineer, Waste Management, Inc., Florida	aevans19@wm.com
James Flynt	Chief Engineer, Orange County Utilities Department, Solid Waste Division	James.Flynt@ocfl.net
Melissa Madden-Mawhir	Senior Program Analyst, FDEP	Melissa.Madden@FloridaDEP.gov
Marcus Moore	Facilities Manager, Hillsborough County Water Resources Department	moorem@hillsboroughcounty.org
Luke Mulford	Senior Professional Engineer, Hillsborough County	mulfordL@hillsboroughcounty.org
Larry E. Ruiz	Landfill Operations Manager Hillsborough County	RuizLE@hillsboroughcounty.org

PROJECT DELIVERABLES

Project deliverables include: 1) Quarterly reports, 2) a draft and a final technical report, 3) a project website, 4) TAG meeting overview information (slides, videos and photos), and 5) tracking metrics for faculty, staff and students working on the project. The project website will include the project abstract, full proposal, TAG members and meeting information, photos of investigators and students associated with the project, and acknowledgment of sponsorship and funding from the Hinkley Center (see Phase I deliverables here: http://constructed-wetlands.eng.usf.edu). The website will continue to be updated regularly and will remain active at least 18 months after the project completion.

DISSEMINATION PLAN

Our past performance attests to our commitment to supporting students and disseminating the results of our Hinkley Center funded research. Our 2019 Hinkley project has engaged 2 PhD and 4 MS students and one undergraduate. Prior Hinkley funds to the PIs also engaged two postdocs, 2 PhD students, 6 master's students, and 6 undergraduates. Research was disseminated through 8 reports, 3 MS theses (Hinds, 2015; Dixon, 2018; Gao, 2020), 3 newsletter articles, 10 poster presentations, 4 conference presentations, 4 peer reviewed journal articles and 1 book chapter.

Results from the proposed research will be disseminated to a variety of stakeholders including FDEP and county regulators, MSW directors and staff, private waste management companies and other associated industries, university and K-12 students, engineers, operators, scientists and community members. For instance, the research will be showcased at the USF Engineering Expo, which brings over 10,000 K-12 students, teachers and families to USF each spring. Also, the research will be integrated into 2 graduate courses taught by the PIs (Biological Principles and Ecological Engineering). The research will also be presented to the solid waste professional community at the Florida SWANA meeting, in which we already presented in October of 2020. Results of the research will also be communicated to the scientific community via publication in scientific journals such as *Journal of Ecological Engineering and Design* and *Journal of Chemical Technology and Biotechnology*.

PLAN FOR SEEKING FUNDING FROM OTHER SOURCES

Future research directions include: 1) Investigation of nitrogen and organic matter removal mechanisms by zeolite and biochar in CWs, 2) microbial community and functional genes responsible for the degradation of organic N and UV-quenching substances, 3) full-scale studies of onsite landfill leachate treatment, 4) development of life cycle, optimization, and economic assessment tools for landfill leachate management decision-making. Funding sources include EREF, DoE, USEPA, and NSF.

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Professional Preparation

University of Florida, Gainesville, FL	Environmental Engineering	B.S., 2006
University of Florida, Gainesville, FL	Environmental/Ecological Engineering	M.E., 2007
Univ. of Canterbury, New Zealand	Civil and Natural Resources Engineering	Ph.D., 2014
Harvard University, Cambridge, MA	Sustainability Science	Postdoc, 2014-2016

Research Interests: Ecological Engineering, Environmental Sustainability, Water-Energy-Food Nexus.

Appointments

Assistant Professor, Dept. of Civil and Environmental Engineering, Univ. of South Florida, 2016-Present

Current USF Student Mentoring (7 students have already graduated)**:**

1. Charlotte Haberstroh, PhD Candidate, Civil Engineering-Water Resources (graduating Spring 2021);
2. Joshua Benjamin, PhD Candidate, Environmental Engineering (graduation expected 2021).
3. Michelle Platz, PhD Candidate, Environmental Engineering (graduation expected 2021).
4. Osama Tarabih, PhD Civil Engineering-Water Resources (graduation expected 2021).
5. Cody Stewart, PhD Environmental Engineering (graduation expected 2022).
6. Megan Kramer, PhD Environmental Engineering (graduation expected 2024)
7. Lillian Mulligan, MS Environmental Engineering (graduation expected 2021).
8. Samar Al Mashrafi (graduation expected 2021).
9. Jenna Brooks, BS Civil Engineering

Selected Publications

(Full list here: https://scholar.google.com/citations?user=N808xGgAAAAJ. *Student mentee.)

Haberstroh, C.J.,*, M.E. Arias, Yin, Z., Wang, M. C. Effects of hydrodynamics on the cross-sectional distribution and transport of plastic in an urban coastal river *Water Environment Research* 93 (2) 186-200. 10.1002/wer.1386.

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Education

Humboldt State Univ., Arcata, CA	Environmental Engineering	B.S.	1988
University of California, Davis, CA	Civil Engineering,	M.S.	1990
University of California, Davis, CA	Civil & Environmental Engineering	Ph.D.	1993

Academic Appointments

2011-present	Professor	Civil & Environ. Engineering, Univ. South Florida
2015-2016	Visiting Professor	UNESCO-IHE, Water Education Inst., Delft the Netherlands
2015-2016	Visiting Professor	Technion Israel Inst. Technol., Haifa Israel
2009-2011	Assoc. Professor	Civil & Environ. Engineering, Univ. South Florida
2009-2010	Professor	Civil & Environ. Engineering, Univ. Massachusetts, Amherst
2000-2009	Assoc. Professor	Civil & Environ. Engineering, Univ. Massachusetts, Amherst
1994-2000	Asst. Professor	Civil & Environ. Engineering, Univ. Massachusetts, Amherst
2007-2008	Fulbright Fellow	Civil, Environ. & Ag. Engr., Technion Israel Inst. Technol.

Professional Registration

Professional Engineer, Commonwealth of Massachusetts, Civil Engineering, 1995-present
Board Certified Environ. Engineer, Specialization: Water Supply/Wastewater Engineering, 2012-present

Publications from Prior Hinkley Center Funded Research

Hinds, G.R., Lens, P., Zhang, Q., Erga1s, S.J. (2017) Microbial biomethane production from municipal solid waste using high-solids anaerobic digestion, In *Microbial Fuels: Technologies and Applications*, Serge Hiligsmann (Ed), Taylor & Francis, Oxford, UK.

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