Landfill Leachate Management with Adsorbent-enhanced Constructed Wetlands

PIs: Mauricio Arias, PhD, PE
Sarina Ergas, PhD, PE

University of South Florida
Department of Civil & Environmental Engineering
Tampa, FL

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Hinkley Center for Solid and Hazardous Waste Management

Outline

1. Introduction to Technical Awareness Group and team members
2. Background on Landfill Leachate and Constructed Wetlands
3. Summary of Phase I Results and Metrics
4. Phase II Research Plan
5. Practical Specific Benefits For End Users
6. Timeline and Milestones
7. Project deliverables, Dissemination Plan

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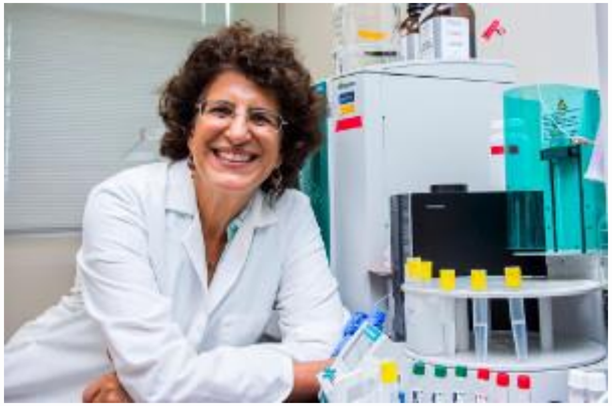
TAG Members

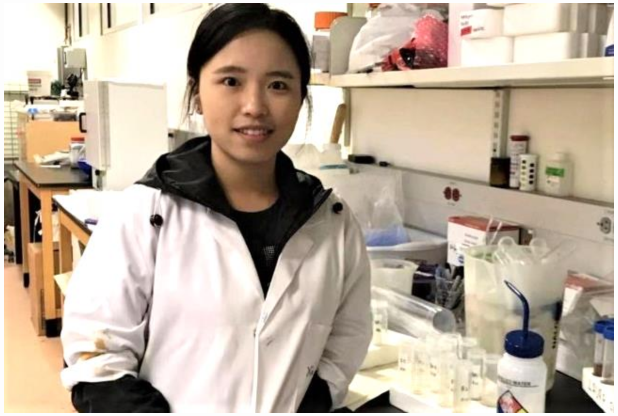
Name	Position/Affiliation
James S. Bays	Technology Fellow, Jacobs Engineering
Kimberly A. Byer	Solid Waste Management Division Director, Hillsborough County
Stephanie Bolyard	Research Engineer, NCDOT Research and Development Office
William J. Cooper	Prof. Emeritus, UC Irvine (Courtesy Prof. Environmental Engineering UF)
Ashley Danely-Thomson	Assistant Professor, Florida Gulf Coast University
Viraj deSilva	Sr. Treatment Process Leader / Freese and Nichols, Inc.
Scott Knight	Wetland Solutions, Inc.
Ashley Evans	Market Area Engineer, Waste Management, Inc., Florida
James Flynt	Chief Engineer, Orange County Utilities Department, Solid Waste Division
Melissa Madden-Mawhir	Senior Program Analyst, FDEP
Marcus Moore	Facilities Manager, Hillsborough County Water Resources Dept.
Luke Mulford	Senior Professional Engineer, Hillsborough County
Larry E. Ruiz	Landfill Operations Manager Hillsborough County

Team members



Sarina Ergas (Co-PI)

Mauricio Arias (Co-PI)



Xia Yang (PhD Student)

Thanh Lam (MS Student)

Nicholas Truong (Undergrad Student)

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BACKGROUND

Problems with Landfill Leachate

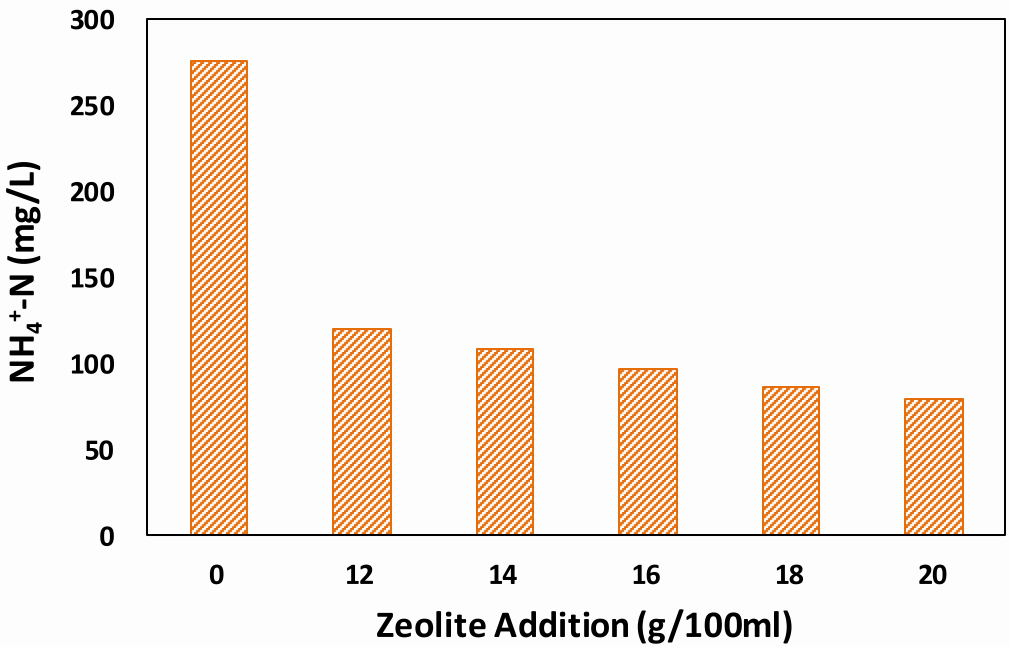
- Discharge to POTWs - common in Florida.
- High ammonia, color, recalcitrant organic matter and metal concentrations disrupt POTW processes.
- Hybrid vertical/horizontal subsurface flow constructed wetlands - cost-effective for onsite leachate treatment.

Douglas Road Landfill Leachate Treatment Wetland IN

(courtesy Jim Bays Jacobs Engineering)

Zeolite Minerals Enhance Ammonia Removal

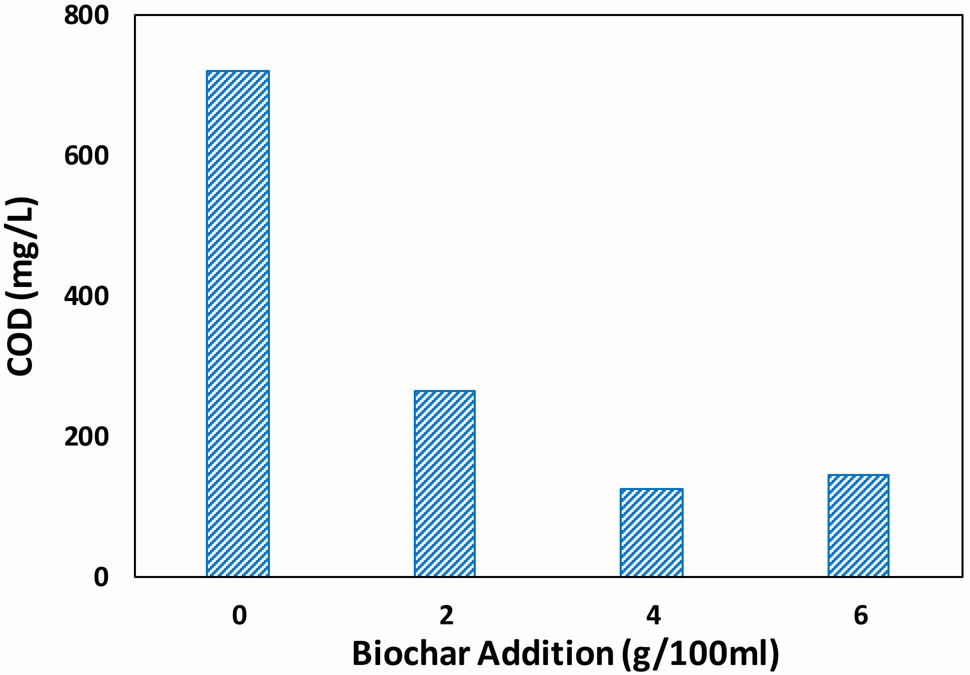
- Porous aluminosilicate minerals.
- High cation exchange capacity and selectivity for NH_4^+.
- Clinoptilolite - most abundant and commonly used zeolite.
- Widely used as chemical sieve, food and feed additive, odor control (cat litter).
- Enhances ammonia retention and nitrification.



Ammonia removal in landfill leachate by clinoptilolite
Source: batch adsorption studies by our group.

Biochar Enhances sCOD and Color Removal

- Produced by pyrolysis of organic feedstock (e.g., wood chips) at high temperature under O_2 limitations.
- High surface area, organic matter adsorption, and moisture holding capacity.
- Improves agricultural productivity.
- Enhances growth of beneficial microorganisms.
- Reduces plant stress due to inhibitors (metals, ammonia).

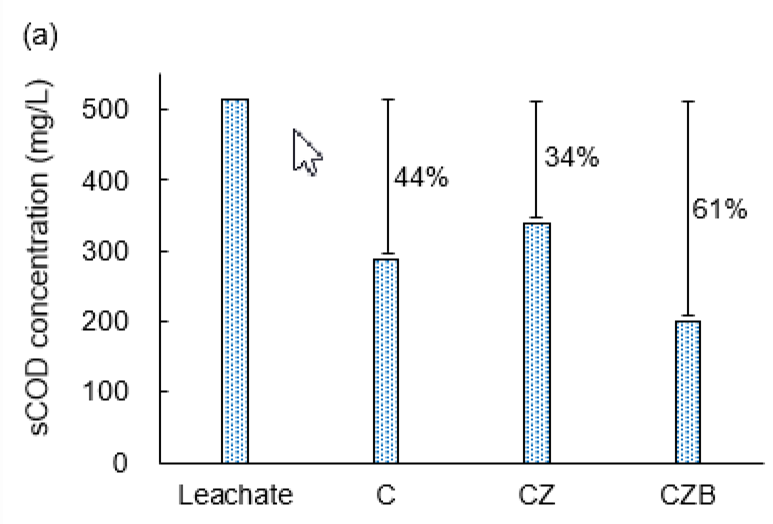


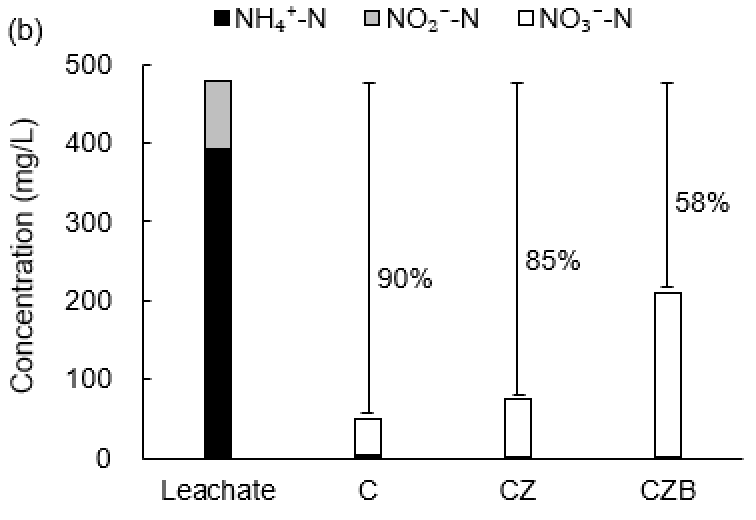
COD removal in landfill leachate by biochar.
Source: batch adsorption studies by our group.

PHASE I RESULTS AND METRICS

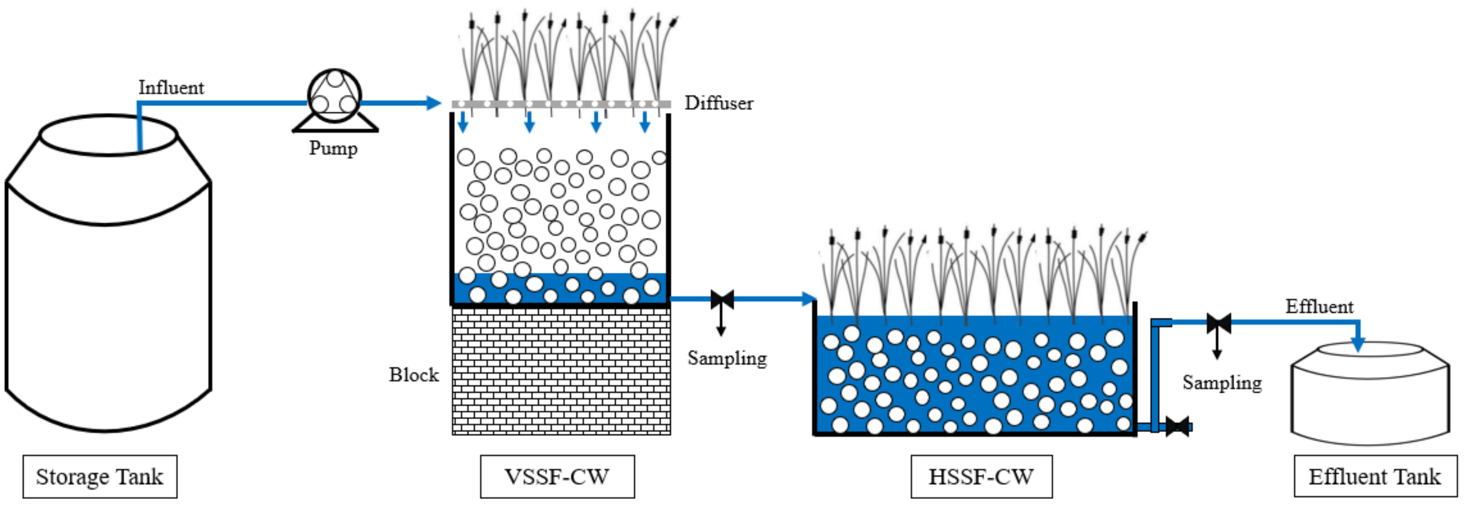
Phase I Results: Bench-scale sequencing batch biofilm reactor (SBBR)

- 3 Bench-scale SBBRs operated with leachate for > 1 yr
  - Expanded clay (C)
  - Expanded clay + zeolite (CZ)
  - Expanded clay + zeolite + biochar (CZB)
- Excellent ammonia removal in all systems.
- High sCOD and color removal with biochar.
- Data for scale up for pilot systems.

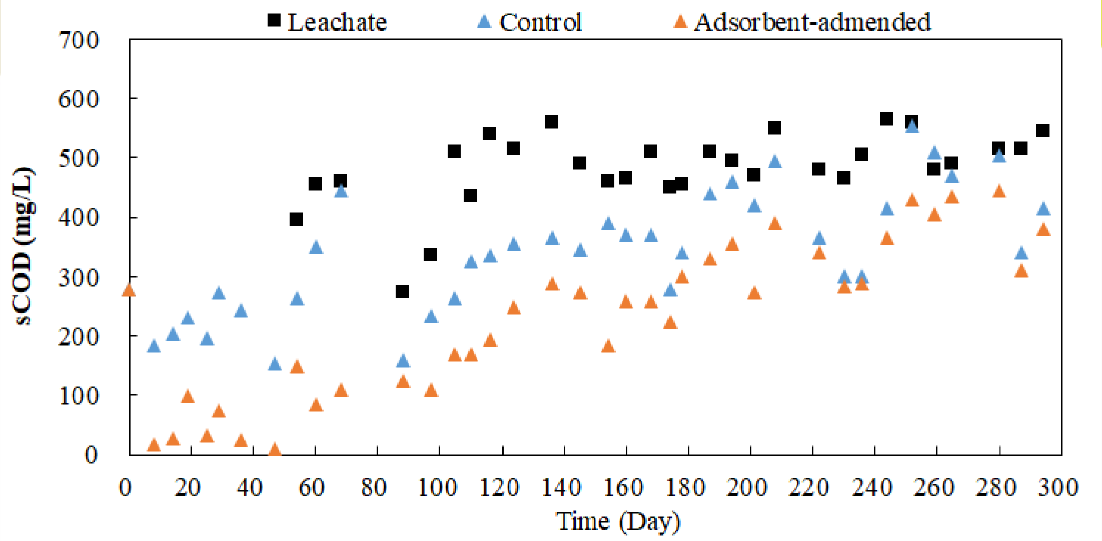




Phase I Results: Pilot-scale CW Design and Construction



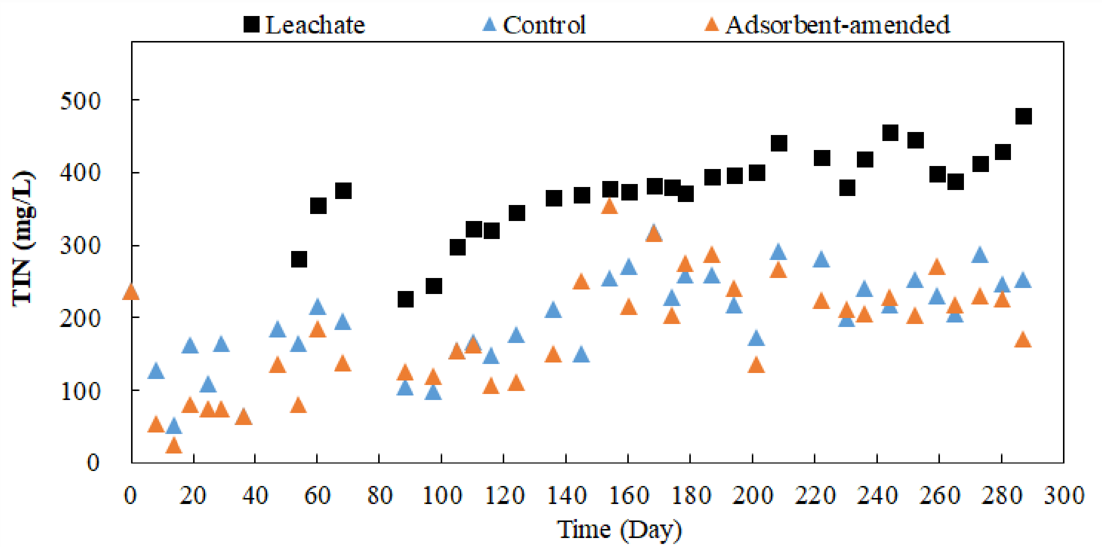
Phase I Results: COD and Nitrogen Removal



Removal :

Control : 23%

Adsorbent-amended: 43%



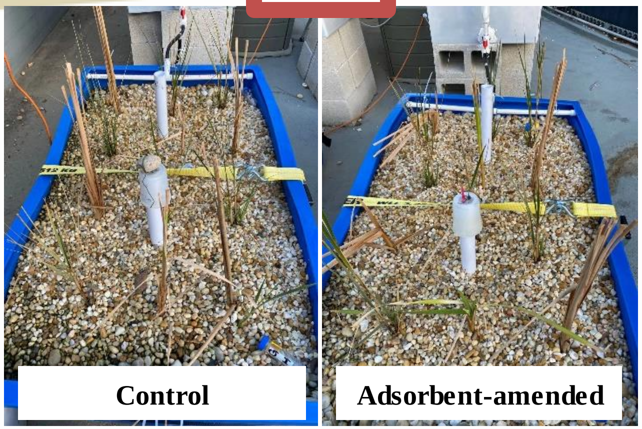
Removal :

Control : 52%

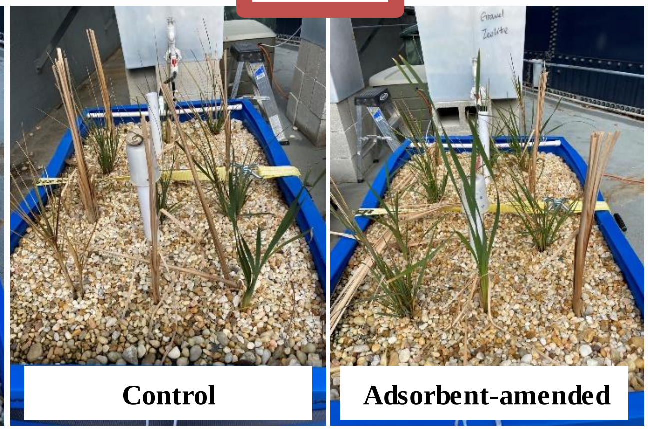
Adsorbent-amended: 57%

Phase I Results: Vegetation Performance

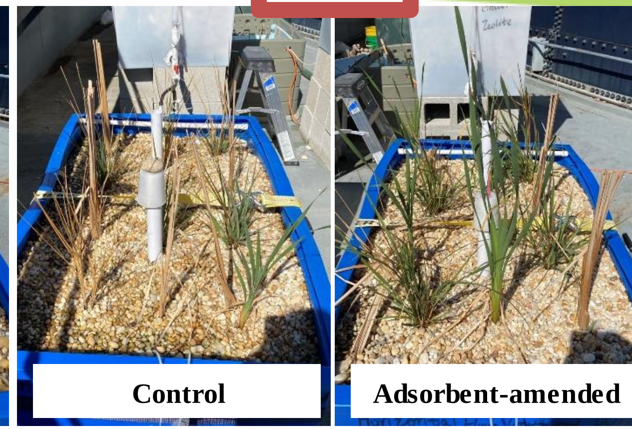
Day 97



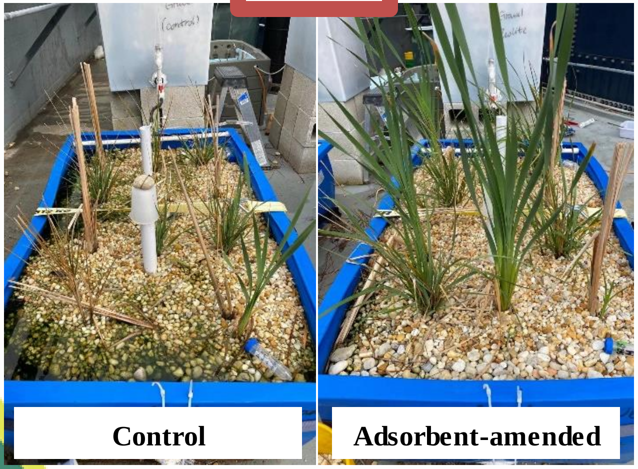
Day 132



Day 154



Day 174



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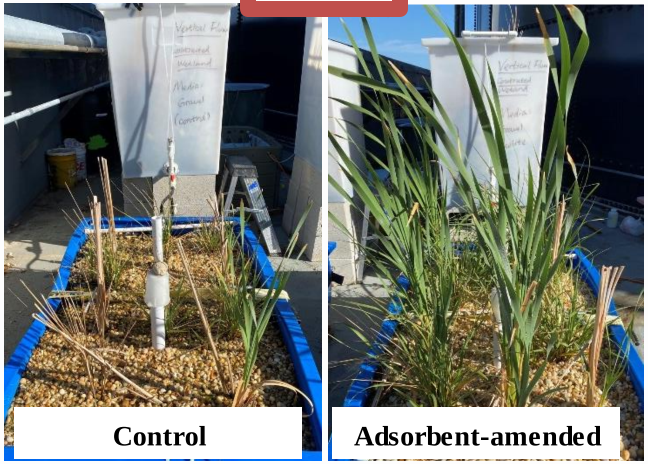
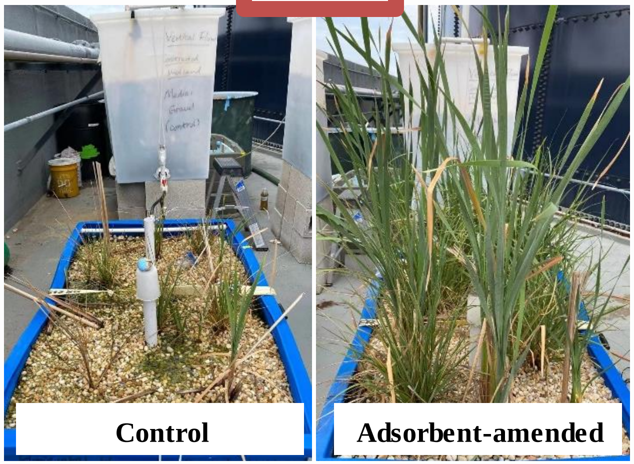
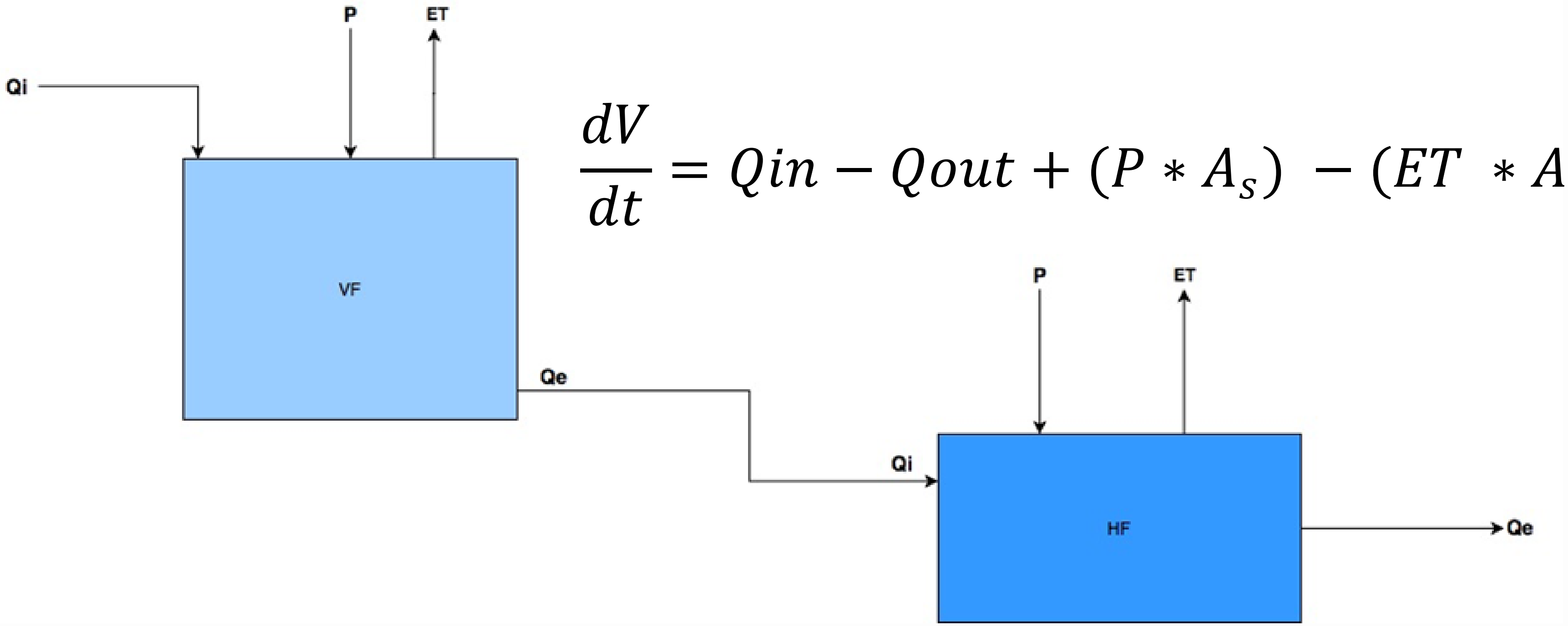


Day 230



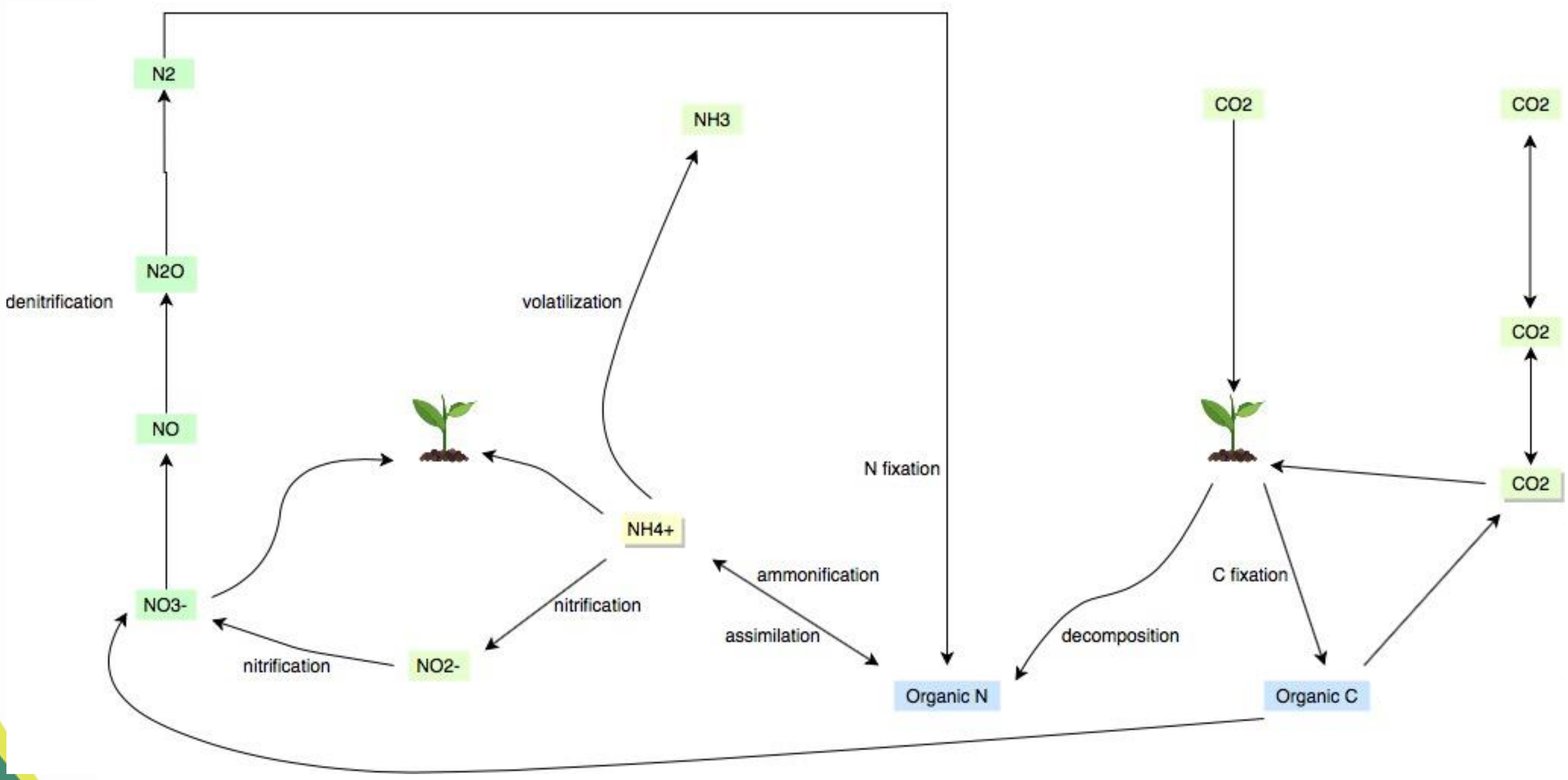
Phase I Results: CW Model

- Numerical process model
  - Water budget and nutrient balance
- Python 3.7 – coding language
- Anaconda – platform software



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

Phase I Results: Model Ammonia Removal



Phase I Metrics

Three 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.
- Mulligan, L. (2021) Development of a Numerical Process Model for Adsorbent Amended Hybrid Constructed Wetlands, MS Thesis, Department of Civil & Environmental Engineering, University of South Florida.
- Gao, B. Yang, X., Dasi, E.A., Lam, T., Arias, M.E., and Ergas, S.J. (2021) Enhanced Landfill Leachate Treatment in Sequencing Batch Biofilm Reactors (SBBRs) Amended with Zeolite and Biochar, *J. Chemical Technology and Biotechnology.*

Presenter(s)	Venue	Date
B. Gao	**Thesis Defense**	3/11/2020
All team members	**TAG Meetings**	11/21/2019 10/01/2020
S. Ergas, M. Arias	**SWANA Hinkley Center Symposium**	10/14/2020
T. Lam	**Class Presentation**	11/17/2020
T. Lam, L. Mulligan	**S-STEM Scholars Roundtable**	11/20/2020
X. Yang	**American Ecological Engineering Society meeting**	05/26/2021
L. Mulligan	**Thesis Defense**	6/11/2021

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Phase I Metrics: Past Student Researchers

Erica Dasi (PhD student)

Xufeng Wei (MS)

Bisheng Gao (MS)

Lillian Mulligan (MS)

Magdalena Shafee (Undergrad)

Irene Castillo (Community College)

PHASE II RESEARCH PLAN

Research Questions

1. What are the effects of leachate strength and hydraulic loading on adsorbent enhanced bioreactor performance?

2. What is the cumulative effect of zeolite and biochar addition on TAN and recalcitrant organic matter removal in VF-HF CWs?

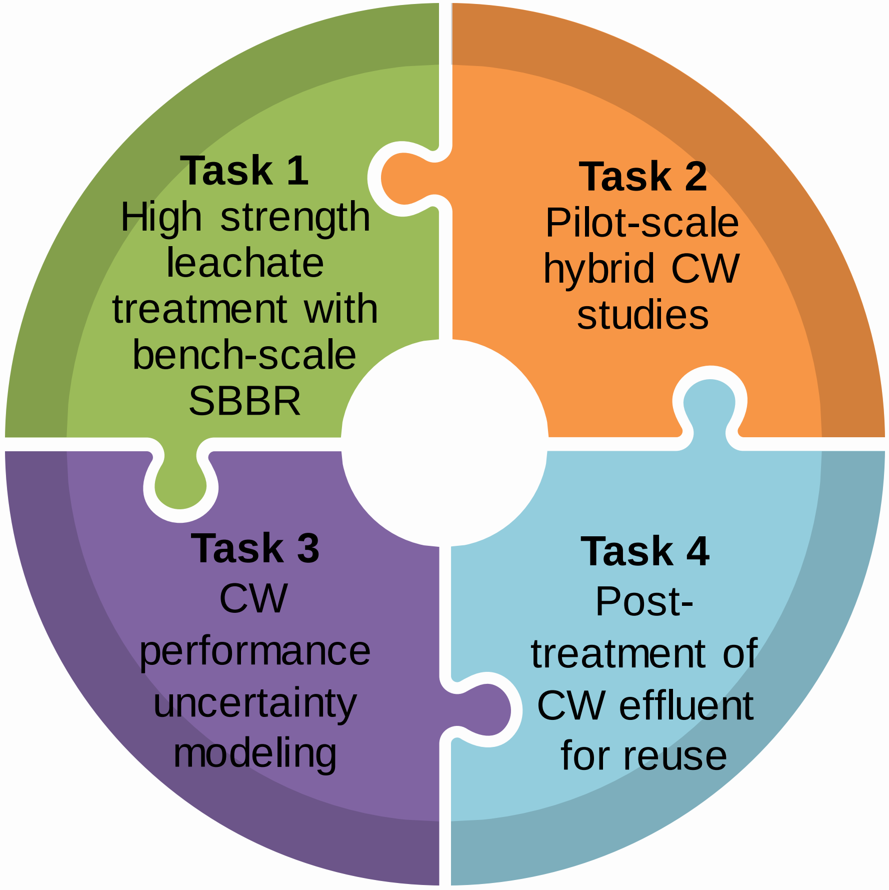
3. What are the effects of uncertainty in leachate quality, loading rates, and adsorbent addition on CW performance?

4. Does the addition of biochar promote wetland plant growth and leachate transpiration?

5. Can adsorbent-amended VF-HF CWs provide a good pre-treatment method for UF-RO to produce reclaim water?

Tasks Overview

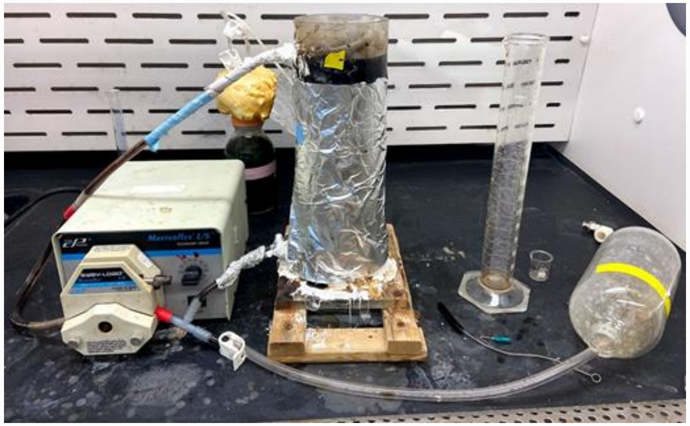
Project Goal: To optimize the design and operation of low-cost, low-complexity adsorbent-enhanced CWs for landfill leachate management.



Task 1: High Strength Leachate Treatment with Bench-scale SBBR

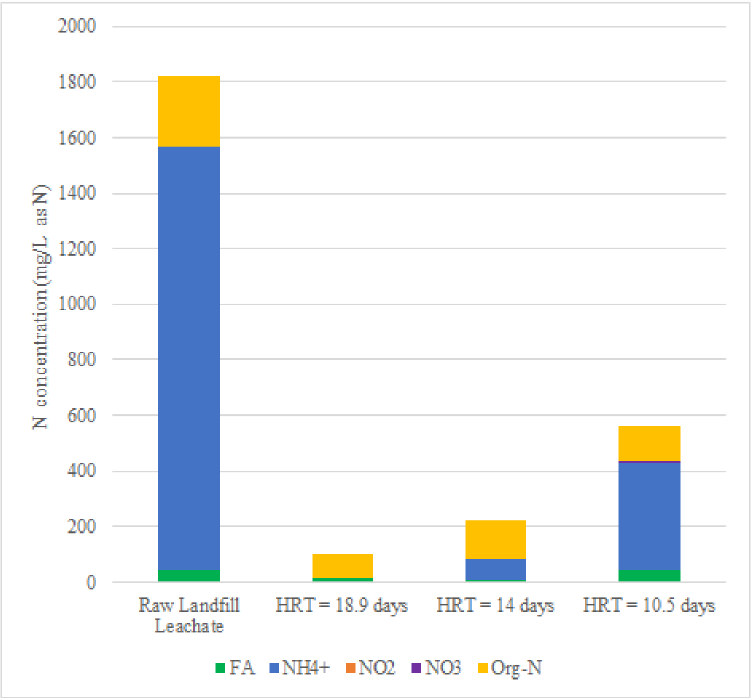
Objective: Investigate treatment of high-strength leachate collected from Florida landfills in bench-scale adsorbent amended SBBR.

Parameter	Hillsborough County SE	Orange County Cell 7B/8
NOx (mg/L)	80	BDL
TAN (mg/L)	375	1,550
sCOD (mg/L)	460	6,200
Elec. Cond. (mS/cm)	13.7	19.7
UV254 (A)	3.51	92.8
UV456 (A)	0.242	5.69

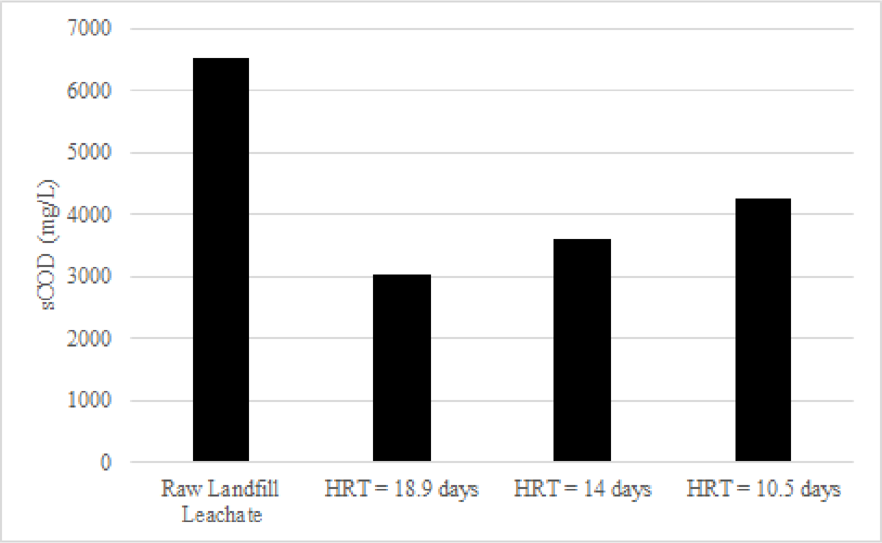


Task 1 Results: Nitrogen and sCOD

Nitrogen



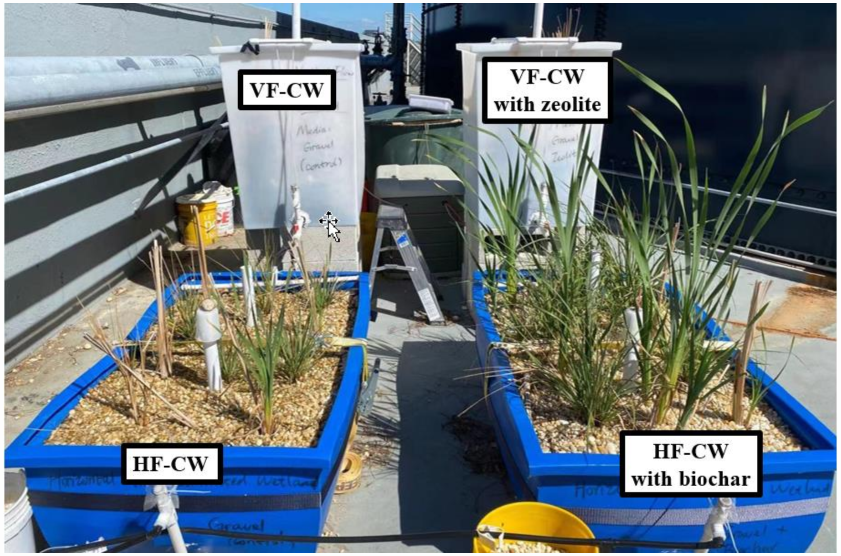
sCOD



- Ammonia ion exchange and bio-regeneration is steady throughout the study – no adsorbent addition needed
- sCOD and color adsorption declines overtime – adsorbent addition needed

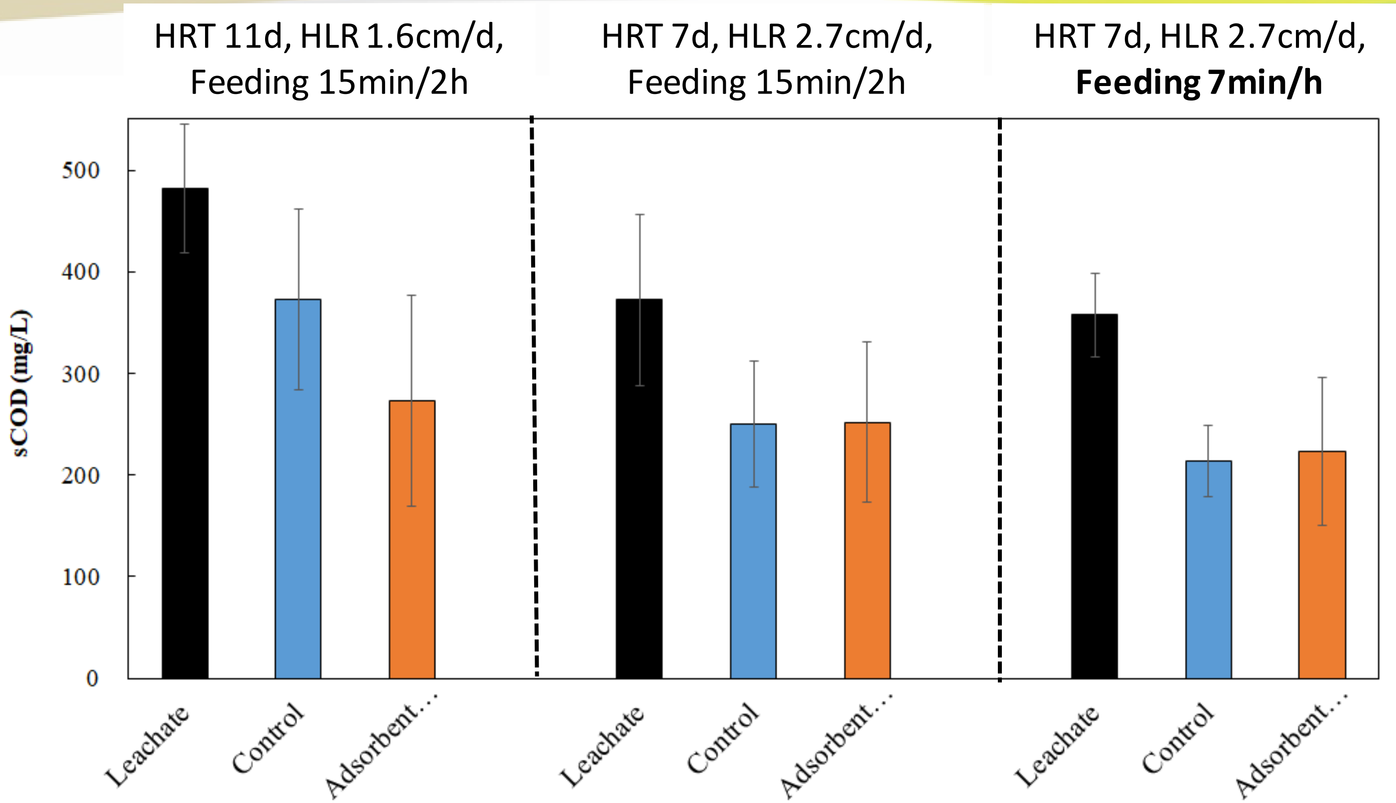
Task 2: Pilot-scale Hybrid CW Studies

Objective: Investigate long-term leachate quality and quantity performance of pilot-scale CWs operated at Hillsborough County's SE landfill under varying conditions.



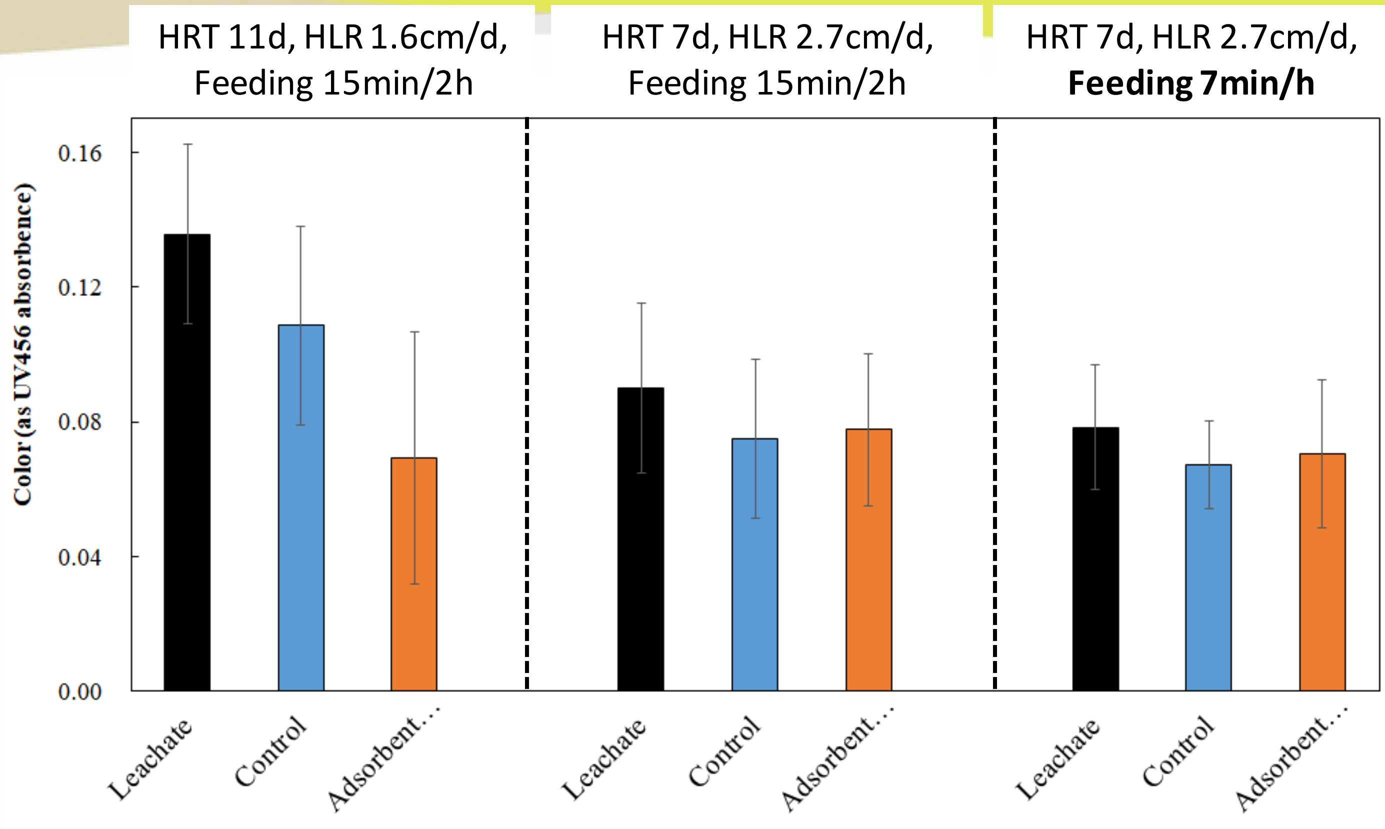
Phase	Flow Rate (L/d)	HLR (cm/d)	HRT (d)	Feeding frequency
I	24	1.6	11	15 min/2h
II	40	2.7	7	15min/2h
	40	2.7	7	7min/h

Task 2 Results: sCOD removal



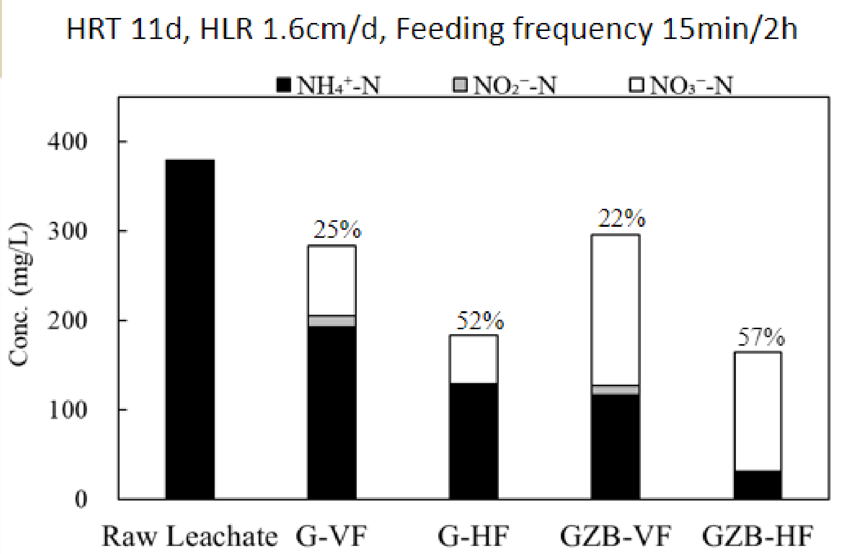
	HRT 11d, Feeding frequency 15min/2h	HRT 7d, Feeding frequency 7min/h	HRT 7d, Feeding frequency 7min/h
Control	23%	33%	40%
Adsorbent-amended	43%	32%	37%

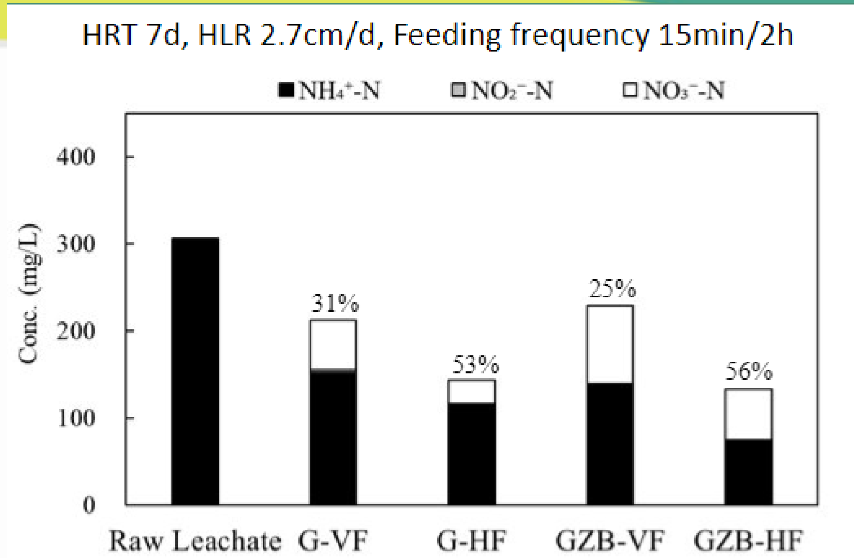
Task 2 Results: Color removal

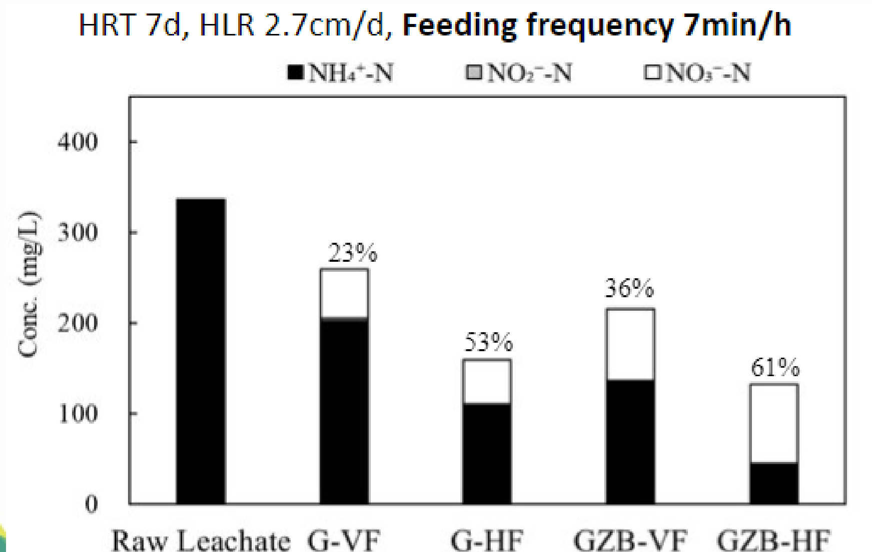


	HRT 11d, Feeding frequency 15min/2h	HRT 7d, Feeding frequency 7min/h	HRT 7d, Feeding frequency 7min/h
Control	20%	17%	14%
Adsorbent-amended	49%	14%	10%

Task 2 Results: N species







G: control system; GZB: adsorbent-amended system; VF: vertical flow; HF: horizontal flow

- Zeolite enhanced ammonia removal.
- Nitrate accumulation was observed.

Task 2: Pilot-scale Hybrid CW Studies

Objective: Investigate the possibility of using woodchips for denitrification enhancement.

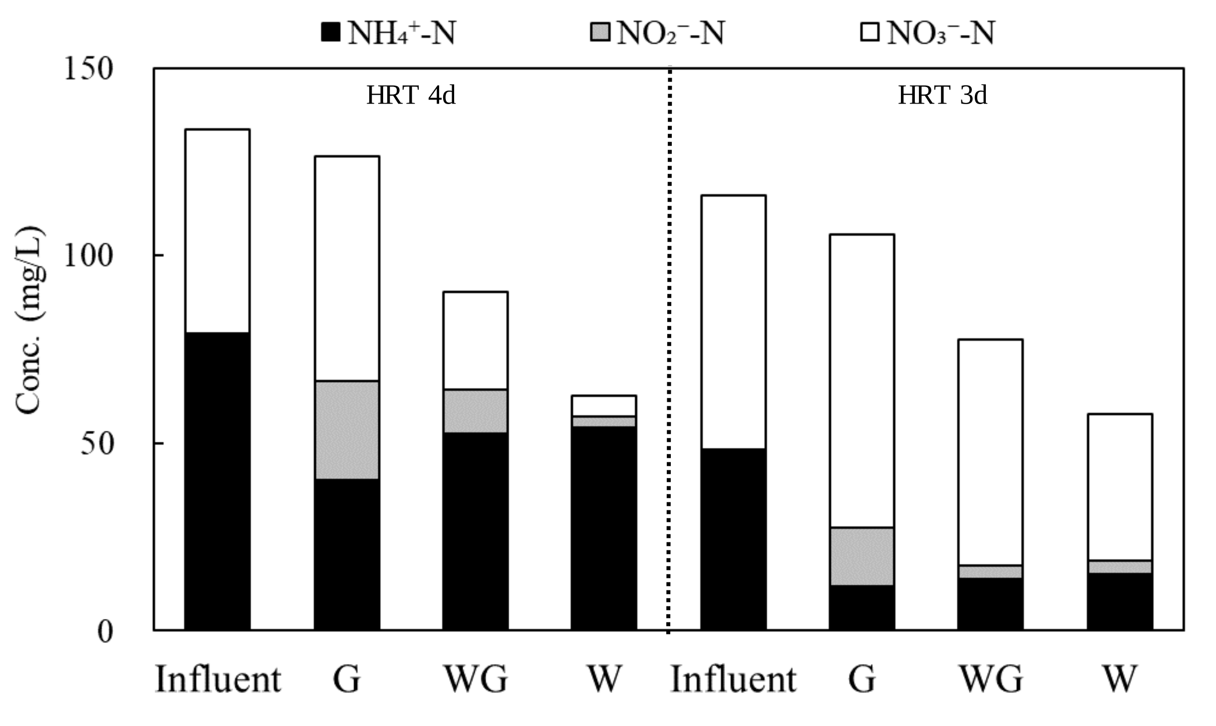
G
Gravel (100%)

WG
Woodchips : gravel =1:1

W
Woodchips (100%)

Stage	Liquid vol. (mL)	HRT (d)	Fill/Discharge vol. (mL)
I	700	4	160
II	700	3	230

Task 2 Results: N species



Batch studies show that wood chips from landfill promote denitrification.

Task 2: Pilot-scale Hybrid CW Studies

- A 2nd HF CW with gravel & woodchips (1:1, by vol.) will be constructed to promote denitrification.
- Operation at varying hydraulic loading rates.

Flow Rate (L/d)	HLR (cm/d)	HRT (d)	EBCT (d)	Electron donor supplement	# days operation
40	2.7	7	17		60
60	4.0	4.5	11	**Wood chips**	60
80	5.3	3	9		60

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

Task 3: CW Performance Uncertainty Modeling

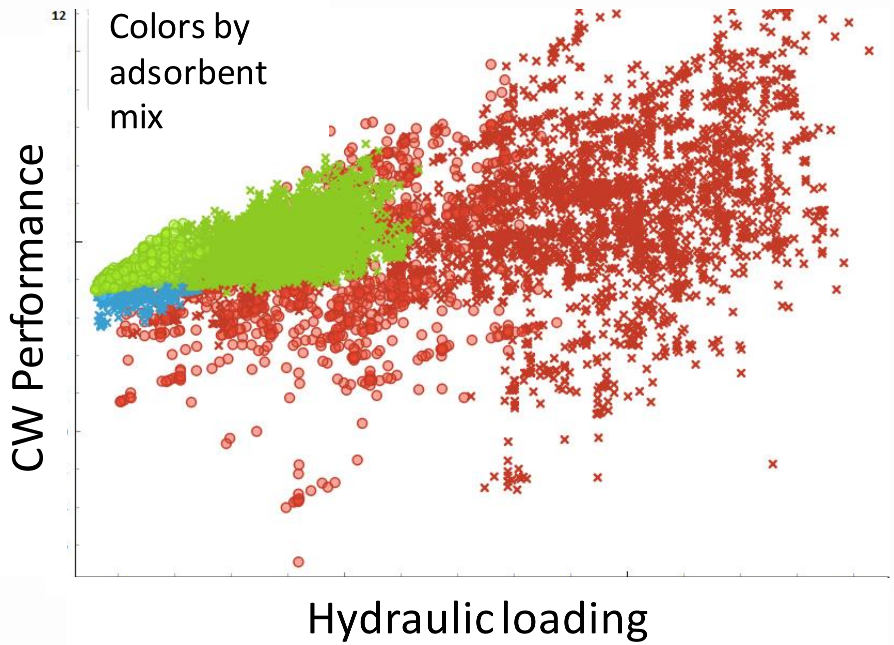
Objective: To evaluate the effects of uncertainty on leachate quality/quantity and adsorbent composition on the performance of a pilot-scale CW system.

- Assess the effect of uncertainty in leachate quality, loading rates, and adsorbent addition on CW performance.

- Scaling up for a system capable of treating the average leachate discharge from the Hillsborough County's SE landfill (60,000-130,000 gal/day).

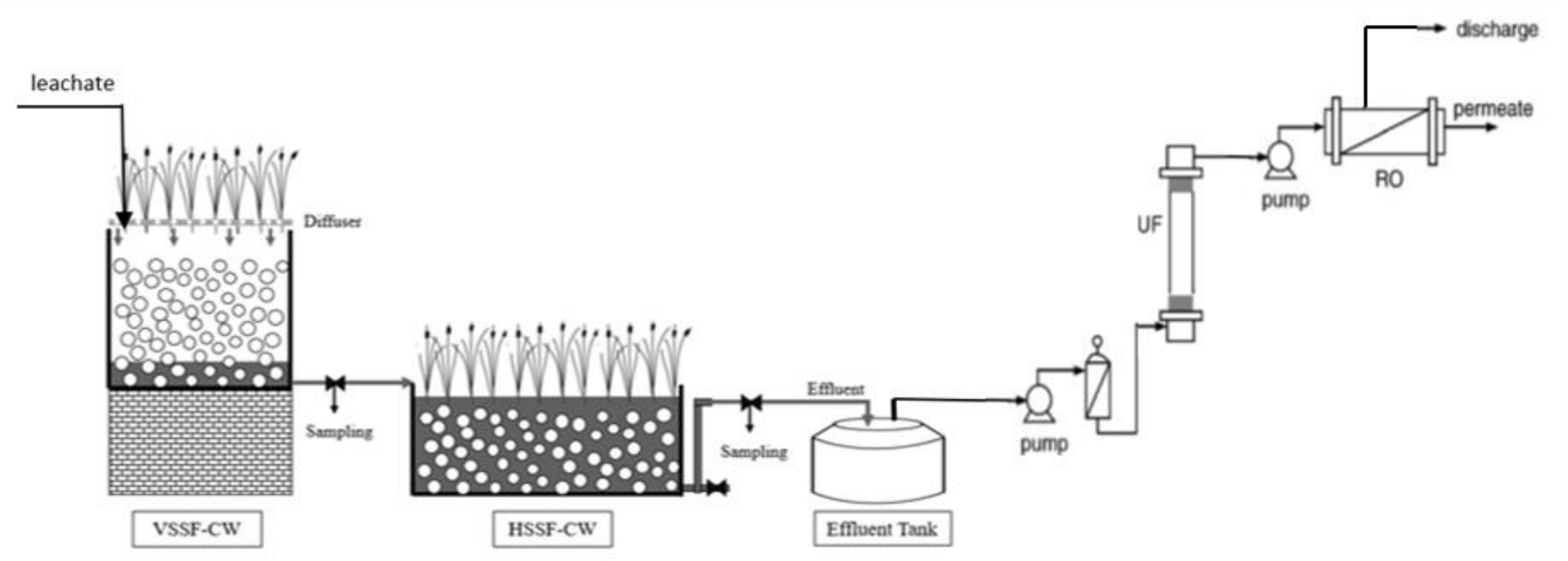
Uncertainty analysis example

(from Benjamin, Zhang, and Arias (2020)



Task 4: Post-treatment of CW Effluent for Reuse

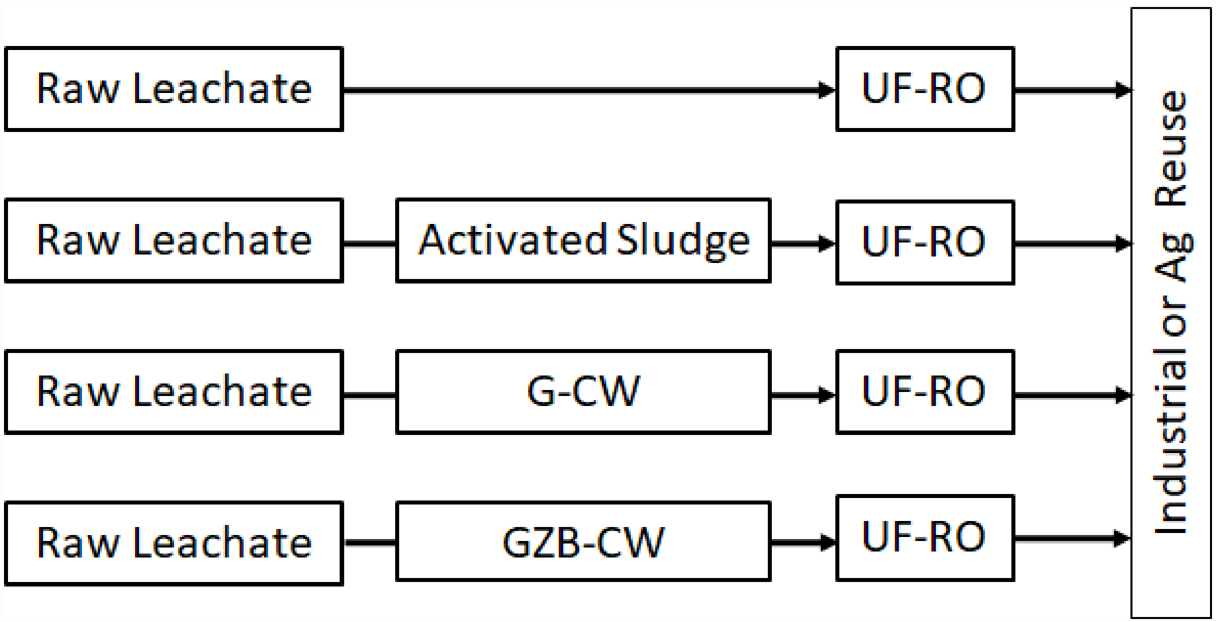
Objective: Evaluate the most technically and economically viable landfill leachate treatment and reuse strategy using Hillsborough County as a case study.



Proposed treatment train for reclaim water production from leachate.

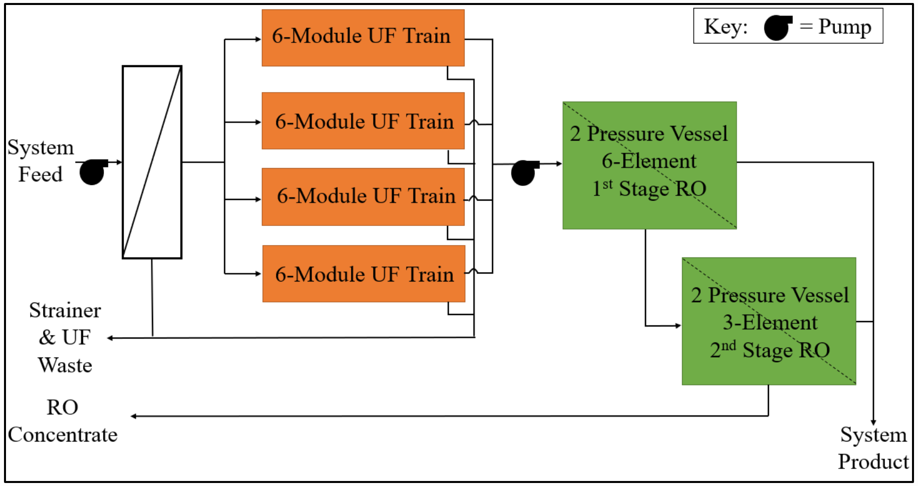
Task 4: Post-treatment of CW Effluent for Reuse

- Effluent from CWs meets agricultural and industrial reuse standards, except for electrical conductivity.
- Design and simulate UF-RO system using WAVE Software

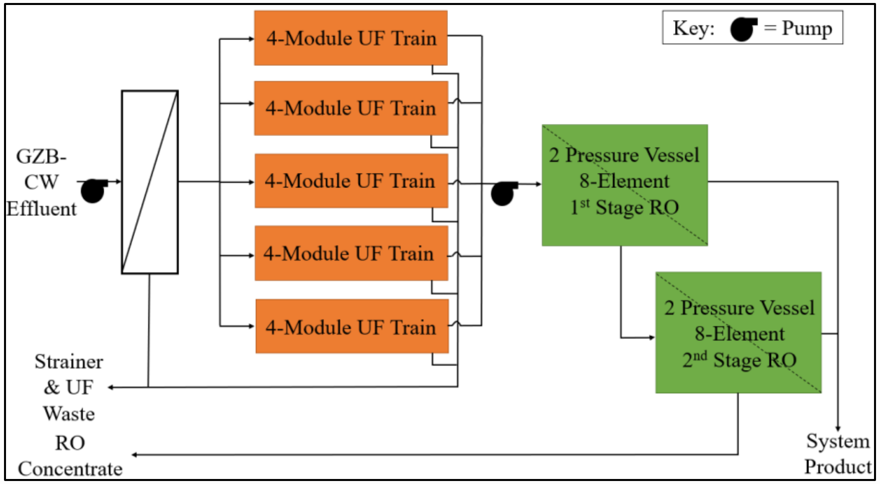


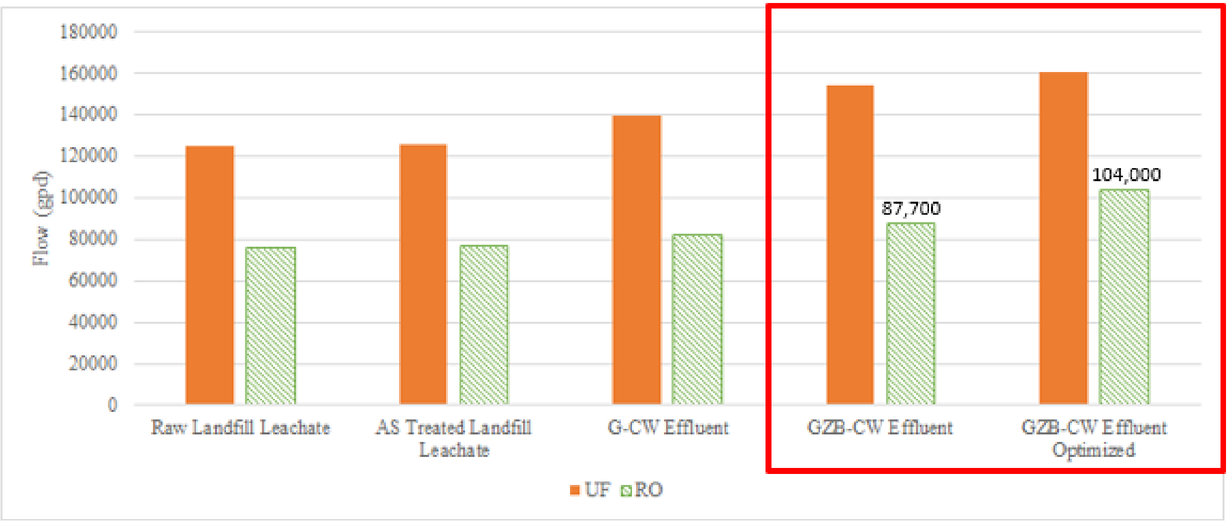
Task 4 Results: Model Configuration and Product Flow Quantities

Common Design Configuration



GZB-CW Optimized Configuration





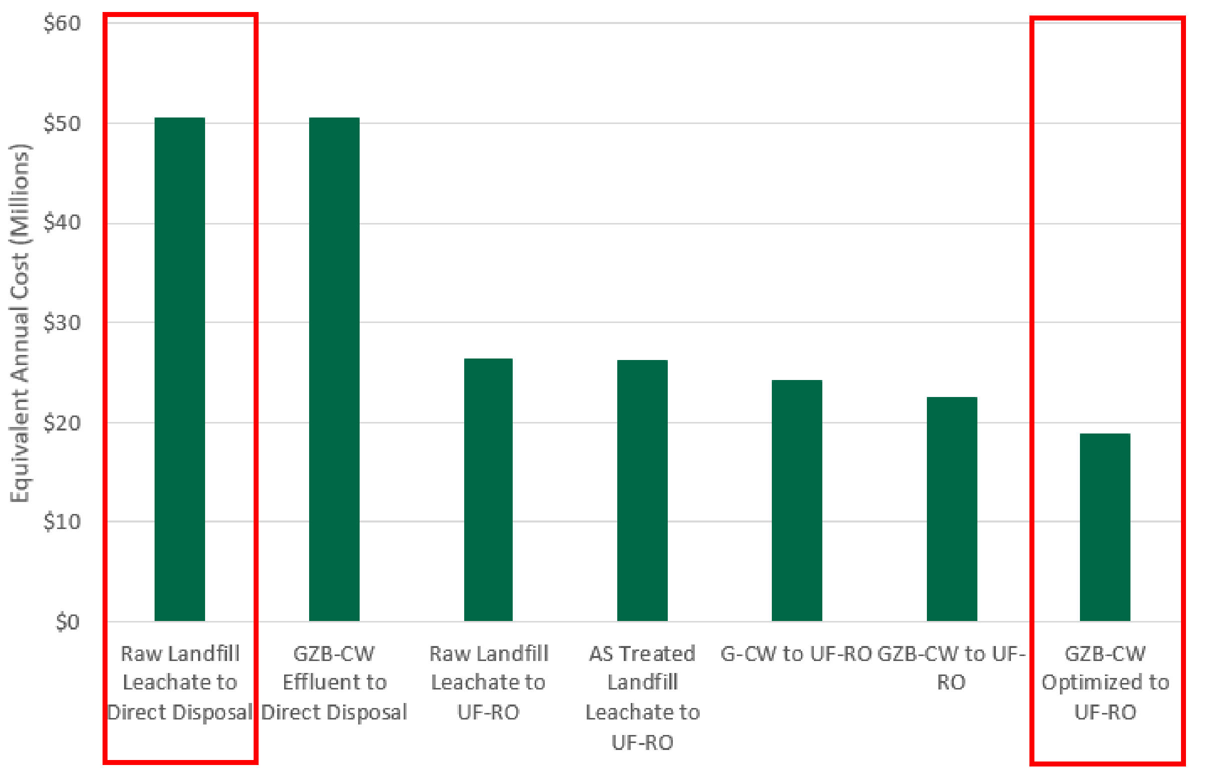
Task 4 Results: Equivalent Annual Cost Analysis

Design life = 20 years

Interest Rate = 5%

Economic analysis does not include:

- Activated sludge O&M costs
- CW capital and O&M costs
- On-site evaporator



Practical Specific Benefits For End Users

"Leachate management can be a significant component of the Long-Term care estimates based on the current models for leachate generation."

- CWs onsite landfill leachate management benefits:
  - Low complexity, low capital and O&M costs.
  - Proven performance for TN, COD, TSS, Color removal.
  - Leachate volume reduction potential.

- Adsorbent enhanced media improves water quality of leachate discharged to POTWs.

- The evaluation of post-treatment by UF-RO has shown the economic feasibility of upgrading CW effluent for irrigation reuse.

Timeline and Milestones

	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

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Project deliverables

1) Quarterly reports.

2) Draft and a final technical report.

3) Updated project website: http://constructed-wetlands.eng.usf.edu).

4) TAG meeting overview information (slides, videos and photos).

5) Tracking metrics for faculty, staff and students working on the project.

Dissemination Plan

Results from the proposed research will be disseminated to a variety of stakeholders:

- ✓ FDEP.
- ✓ County regulators.
- ✓ MSW directors and staff.
- ✓ Private waste management companies and associated industries.
- ✓ University and K-12 students (Graduate courses and Eng Expo).
- ✓ Solid waste engineers and operators (e.g., SWANA).
- ✓ Scientists and community members (conferences, professional meetings and journal publications).

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Thank You!

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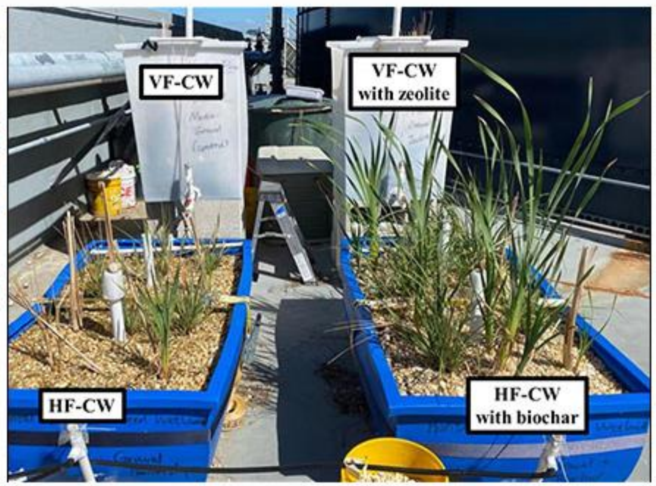
Project Title: Cost-Effective Hybrid Constructed Wetlands for Landfill Leachate Reclamation



PIs: Sarina J. Ergas (sergas@usf.edu), and Mauricio Arias (mearias@usf.edu)

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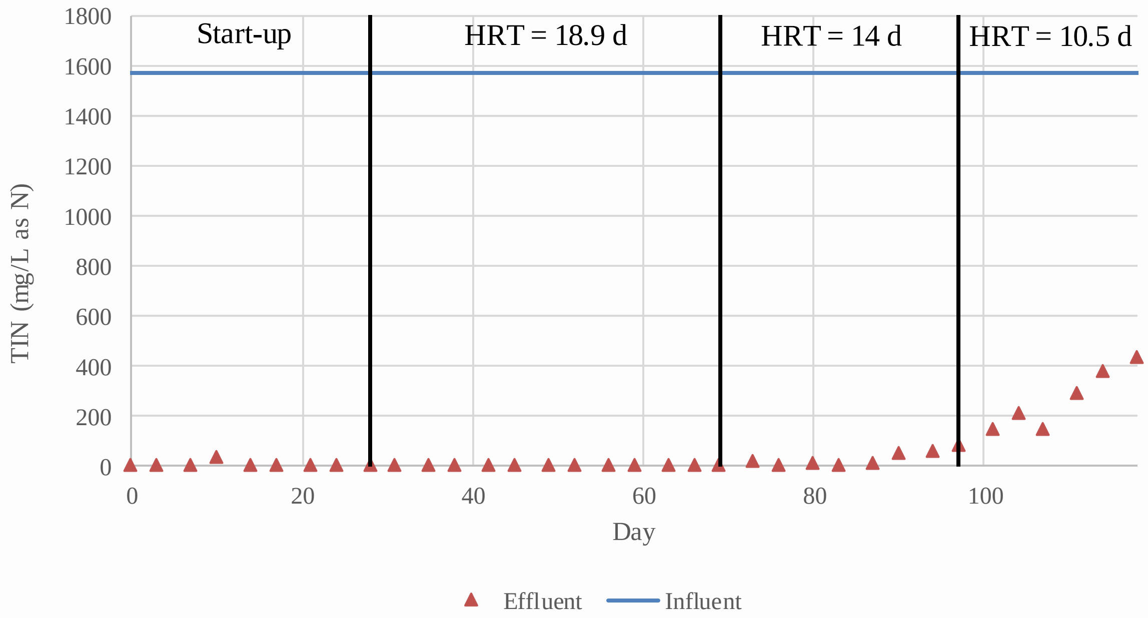
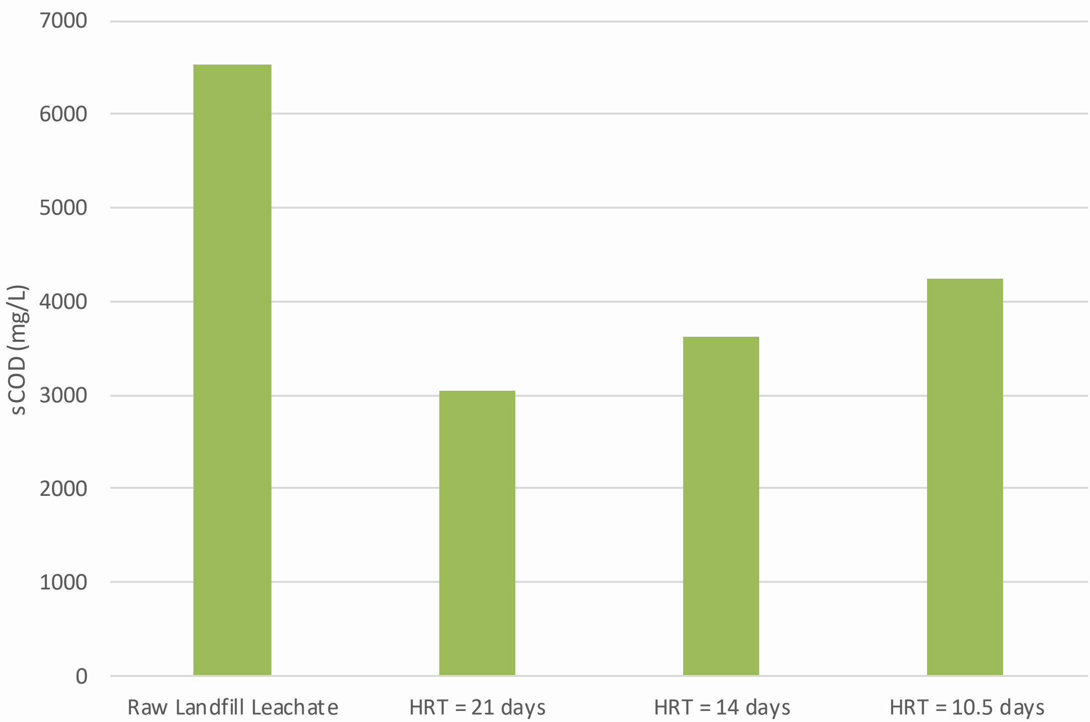
Task 1 Results: Nitrogen Removal



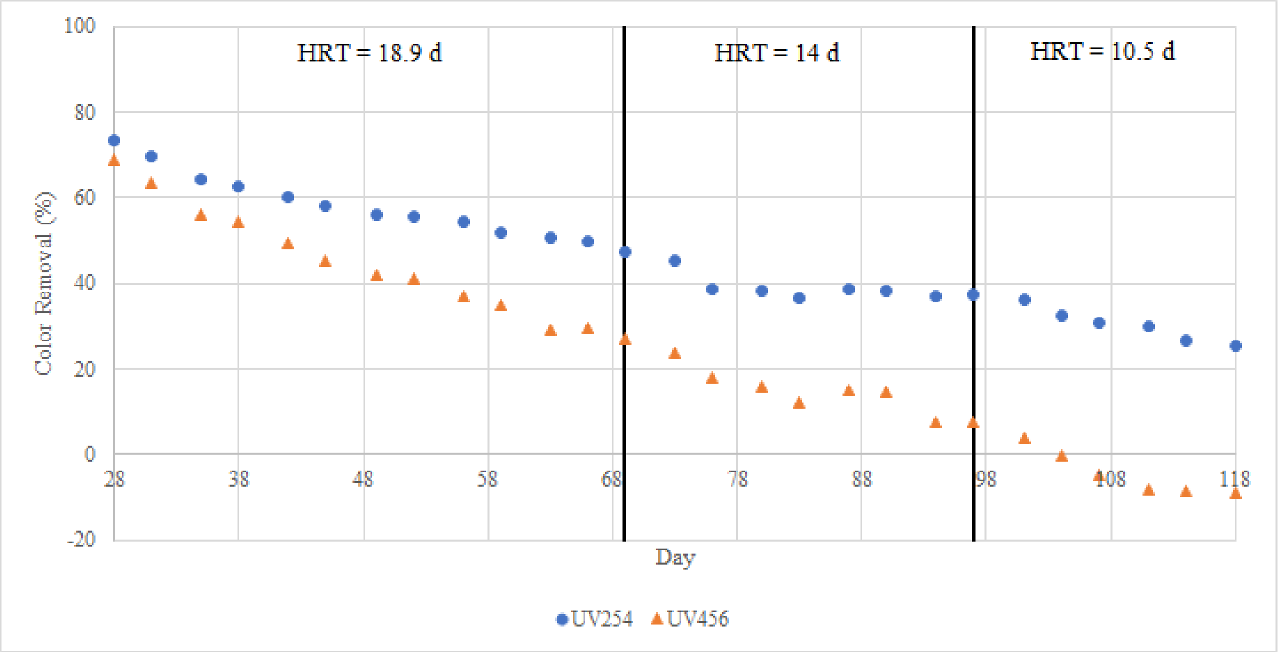
HRT (days)	Average TIN Removal Efficiency (%)	Average TN Removal Efficiency (%)
18.9	99.8	95.5
14	97.3	91.2
10.5	81.6	75.5

Task 1 Results: sCOD Removal



HRT (days)	Average sCOD Removal Efficiency (%)
18.9	48.7
14	46.4
10.5	35.8

Task 1 Results: Color Removal



HRT (days)	Average UV254 Color Removal Efficiency (%)	Average UV456 Color Removal Efficiency (%)
18.9	51.8	34.5
14	36.8	9.81
10.5	28.2	-7.02

Disposal Quantities

Alternative	Raw Landfill Leachate to Direct Disposal	GZB-CW to Direct Disposal	Raw-UF-RO	AS-UF-RO	G-CW-UF-RO	GZB-CW-UF-RO	GZB-CW (Opt.) -UF-RO
Industrial Reuse Quality			78,378	78,722	85,260	90,531	105,537
Concentrate Disposal – Solidification			49,442	49,104	57,233	66,778	56,407
Spray Application[1]	22,262	22,262	22,262	22,262	22,262	22,262	22,262
Hauling to WWTPs[2]	20,000	20,000	20,000	20,000	20,000	20,000	15,794
Solidification	157,738	157,738	29,918	29,912	15,244	428	0

Notes:

[1]: Spray application quantity was determined through review of 2020 Leachate Generation Report (Hillsborough County Solid Waste Management Division, 2021)

[2]: Hauling quantity to WWTPs were capped at 20,000 gpd according to a budgetary quote given by Aqua Clean.

Price Index

UF-RO Capital Costs*

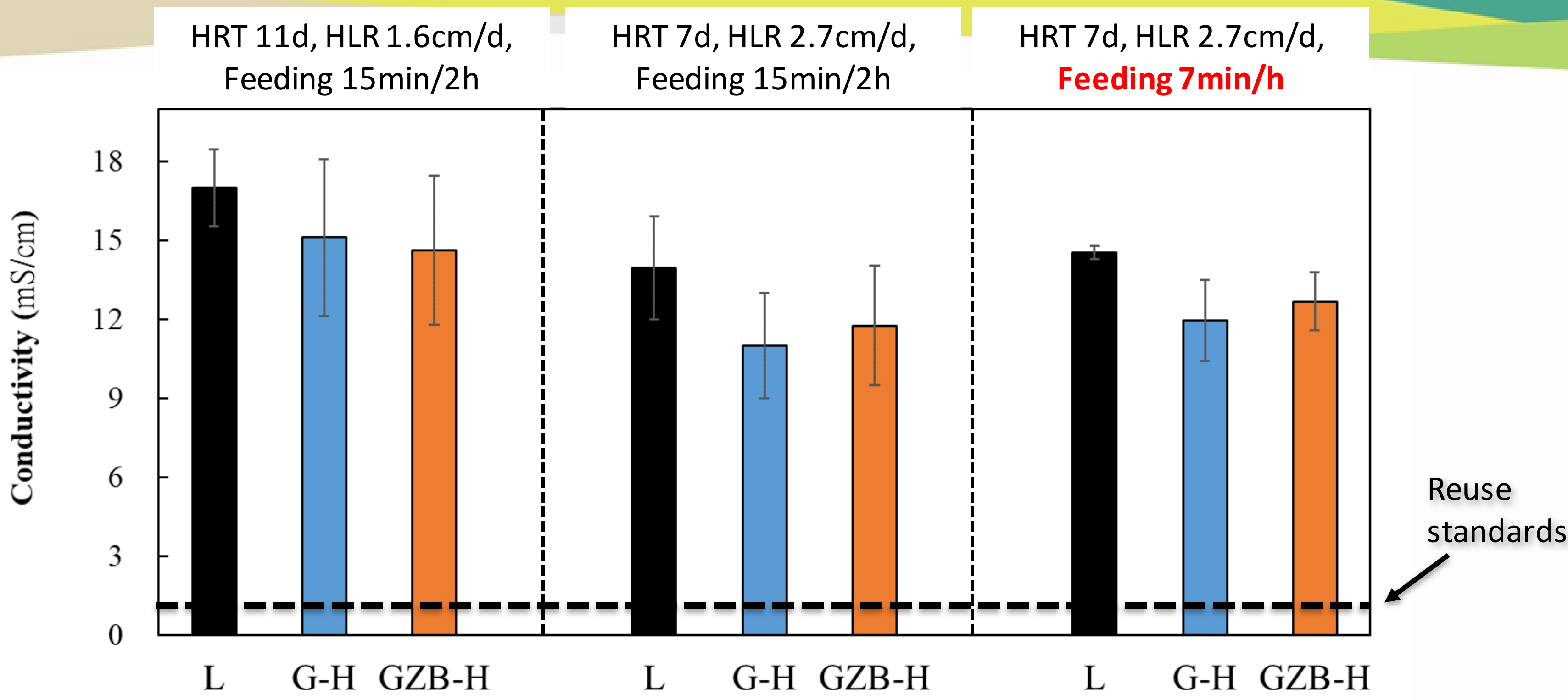
Cost Item	Price	Unit	Price Reference
UF-201K-20 with UF SFP-2860 Module	$275,000	EA	M. Higazy, Pure Aqua, Inc., personal communication, September 17, 2021
UF-262K-26 with UF SFP-2860 Module	$350,000	EA	
SW-48K-2680 with SWC5-LD Element	$250,000	EA	
SW-24K-2380 with SWC5-LD Element	$150,000	EA	
SW-64K-4480 with SWC5-LD Element	$300,000	EA	
UF SFP-2880 Module	$2,200	EA	
UF SFP-2860 Module	$2,000	EA	
RO - SWC5-LD Element	$540	EA	
RO - Fortilife XC80 Element	$945	EA	DWS Advantage
UF System with 20 UF SFP-2880 Module	$279,000	EA	Replacement and Interpolation Calculations with references to Pure Aqua inquiries
UF System with 26 UF SFP-2880 Module	$355,200	EA	
UF System with 24 UF SFP-2880 Module	$329,800	EA	
1-stage RO System with 6 Fortilife XC80 Element	$152,430	EA	
1-stage RO System with 12 Fortilife XC80 Element	$254,860	EA	
1-stage RO System with 16 Fortilife XC80 Element	$306,480	EA	

* = Capital costs were marked up with a 30% contingency due to being budgetary cost estimates

O&M Costs

Cost Item	Price	Unit	Price Reference
UF Chemical – Citric Acid (100%)	$1.52	kg	Default values in WAVE Software
UF Chemical – Hydrochloric Acid (32%)	$0.10	kg	
UF Chemical – NaOCl (12%)	$0.33	kg	
UF Chemical – NaOH (50%)	$0.258	kg	
RO Antiscalant – Hypersperse	$6.77	lb	R. Barbour, SUEZ, personal communication, September 10, 2021
RO Cleaning Chemical – Kleen MCT405	$6.13	lb	
Industrial Energy Costs	$0.0884	kWh	Electricity Local (2021)
Concentrate Waste Disposal – Solidification	$0.85	gal	R. Graziano, AquaClean, personal communication, September 23, 2021
Wastewater Disposal – Hauling to WWTPs	$0.21	gal	R. Shuler, AquaClean, personal communication, October 5, 2021
Industrial Reuse Resale	$0.38	1,000 gal	G. Blair, Orlando Utilities Commission, personal communication, October 6, 2021

Task 2 Results: Conductivity removal



	HRT 11d, Feeding frequency 15min/2h	HRT 7d, Feeding frequency 7min/h	HRT 7d, Feeding frequency 7min/h
G	11%	21%	18%
GZB	14%	16%	13%

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Task 2 Results: sCOD and color