Cost-Effective Hybrid Constructed Wetlands for Landfill Leachate Reclamation

Sarina Ergas, Mauricio Arias,
Xia Yang, Lillian Mulligan, Thanh Lam, Erica Dasi,
Magdalena Shafee

Department of Civil & Environmental Engineering

10/1/2020

TAG Members

TAG Member	Position/Affiliation
James S. Bays	Technology Fellow, Jacobs Engineering
Kimberly A. Byer	MSW Management Division Director, Hillsborough County
Stephanie Bolyard	Research & Scholarship Prog. Manager, EREF
William J. Cooper	Prof. Emeritus, UC Irvine, Courtesy Prof. Environmental Engineering UF
Ashley Danley-Thomson	Assistant Professor, Florida Gulf Coast University
Ashley Evans	Market Area Engineer, Waste Management, Inc., Florida
Melissa Madden-Mawhir	Senior Program Analyst, FDEP
Larry E. Ruiz	Landfill Operations Manager, Hillsborough County

Outline

- Background, Hypotheses and Objectives
- Research Update
  - Lab-scale Sequencing Batch Biofilm Reactors (SBBRs)
  - Pilot-scale CW at Southeast Landfill
  - CW modeling
  - Enhancing denitrification using iron-sulfur minerals
  - Leachate reuse alternatives
- Practical specific benefits for end users
- Metrics

Problems with Landfill Leachate

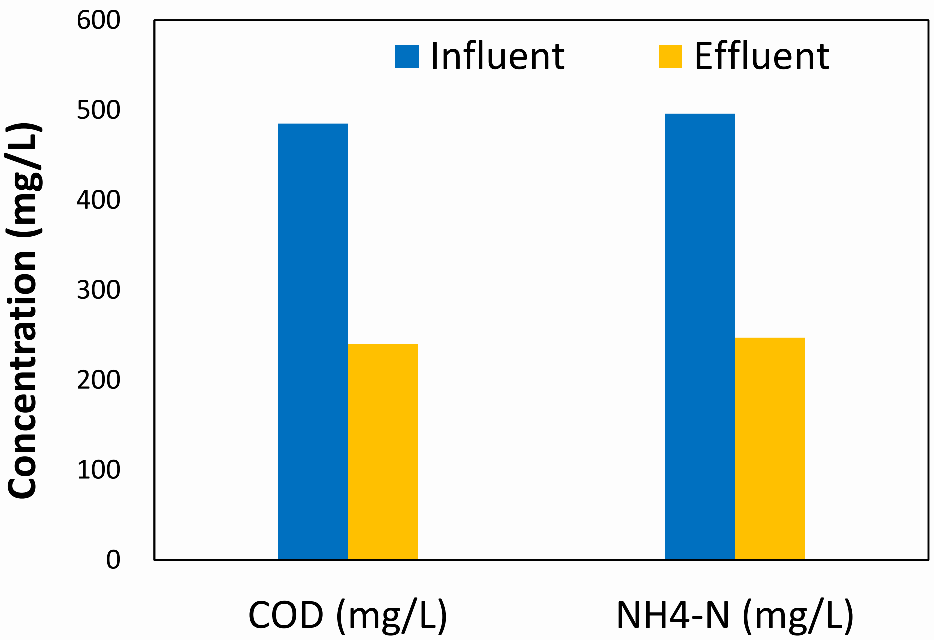
- Discharge to POTWs - common in Florida.
- High ammonia, recalcitrant organic matter and metal concentrations disrupt POTW processes.
- Hybrid vertical/horizontal subsurface flow constructed wetlands - cost-effective for onsite leachate treatment.

Douglas Road Landfill Leachate Treatment Wetland IN

(courtesy Jim Bays Jacobs Engineering)

CWs for Landfill Leachate Treatment

- Well documented for removal of organic compounds, nitrogen and trace metals.
- Reduces leachate volume by evapotranspiration.
- Year-round warm temperatures favor plant growth and biogeochemical processes that promote good performance.
- Hybrid Vertical Flow - Horizontal Flow Subsurface CWs enhance nitrification/denitrification.



Source: case study based on Bulc (2006)

Questions from Hinkley Research Agenda

- What innovative technologies are available to engineer wetlands capable of treating landfill leachate?
- What cost-effective pretreatment processes should the leachate undergo to meet secondary drinking water standards?
- What processes, chemicals, or plants are best suited to mitigate the negative impact of humic acids as a pretreatment process at a landfill?

UNIVERSITY OF SOUTH FLORIDA

Guiding Hypotheses

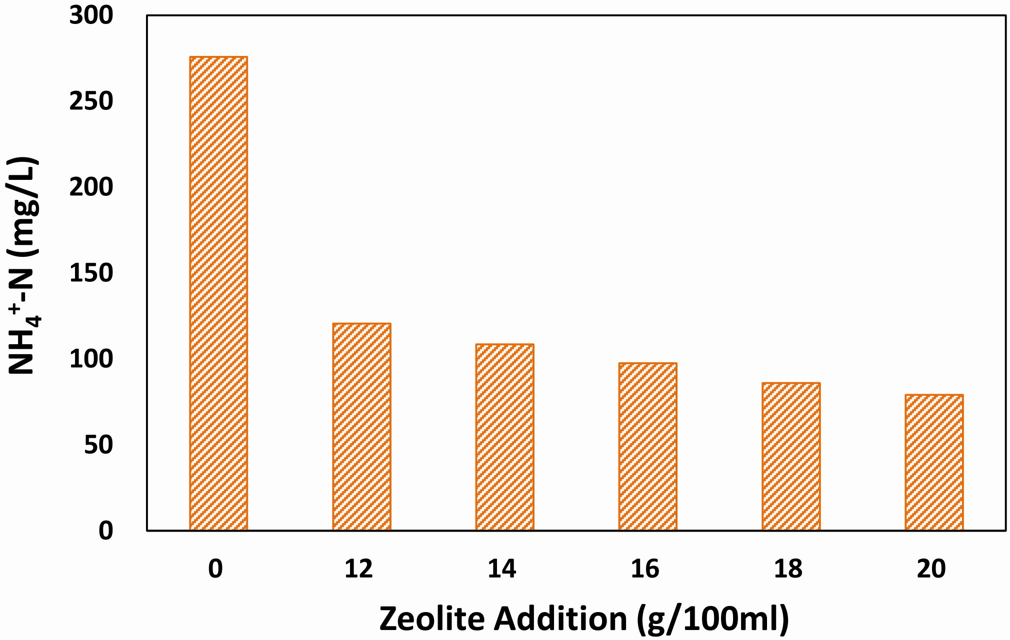
- Addition of zeolite, a natural mineral with a high NH_4^+ affinity, to VF-CW media reduces free ammonia toxicity to microorganisms and enhances biological nitrogen removal.
- Addition of biochar, a low-cost material produced from organic feedstocks such as wood chips, to HF-CW media enhances plant growth and retains recalcitrant organic matter, such as humic acids, to enhance its heterotrophic biodegradation.
- Adsorbent amended hybrid CWs can provide a cost-effective and low complexity landfill leachate treatment method compared with conventional onsite leachate treatment systems.

Research Objectives

1. Treat leachate in bench-scale SBBRs with and without adsorbent to investigate the effects of adsorbent and aid pilot-scale CW design;
2. Compare conventional and adsorbent amended hybrid CW performance for landfill leachate treatment in pilot study;
3. Develop a numerical process model to predict the performance of the of the hybrid CWs under varying operational and leachate characteristics;
4. Enhance leachate denitrification in CWs using iron-sulfur minerals;
5. Carry out a preliminary assessment of post-treatment requirements for reuse applications.

Natural Zeolite Minerals

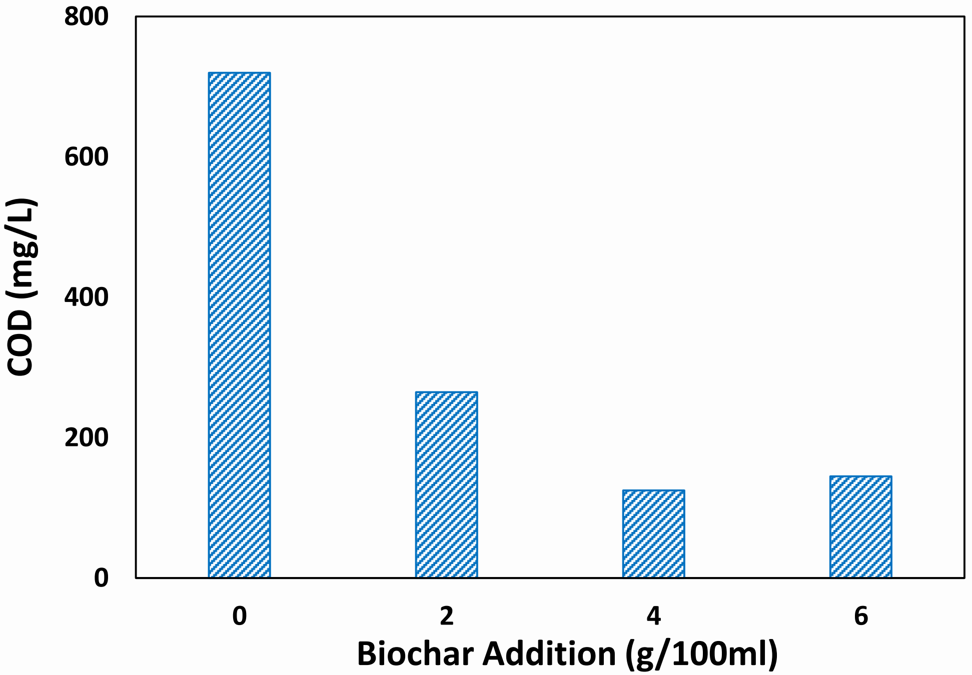
- Porous aluminosilicate minerals.
- High cation exchange capacity and selectivity for NH_4^+ and K^+.
- Clinoptilolite - most abundant and commonly used zeolite.
- Widely used as chemical sieve, food and feed additive, odor control (cat litter).



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

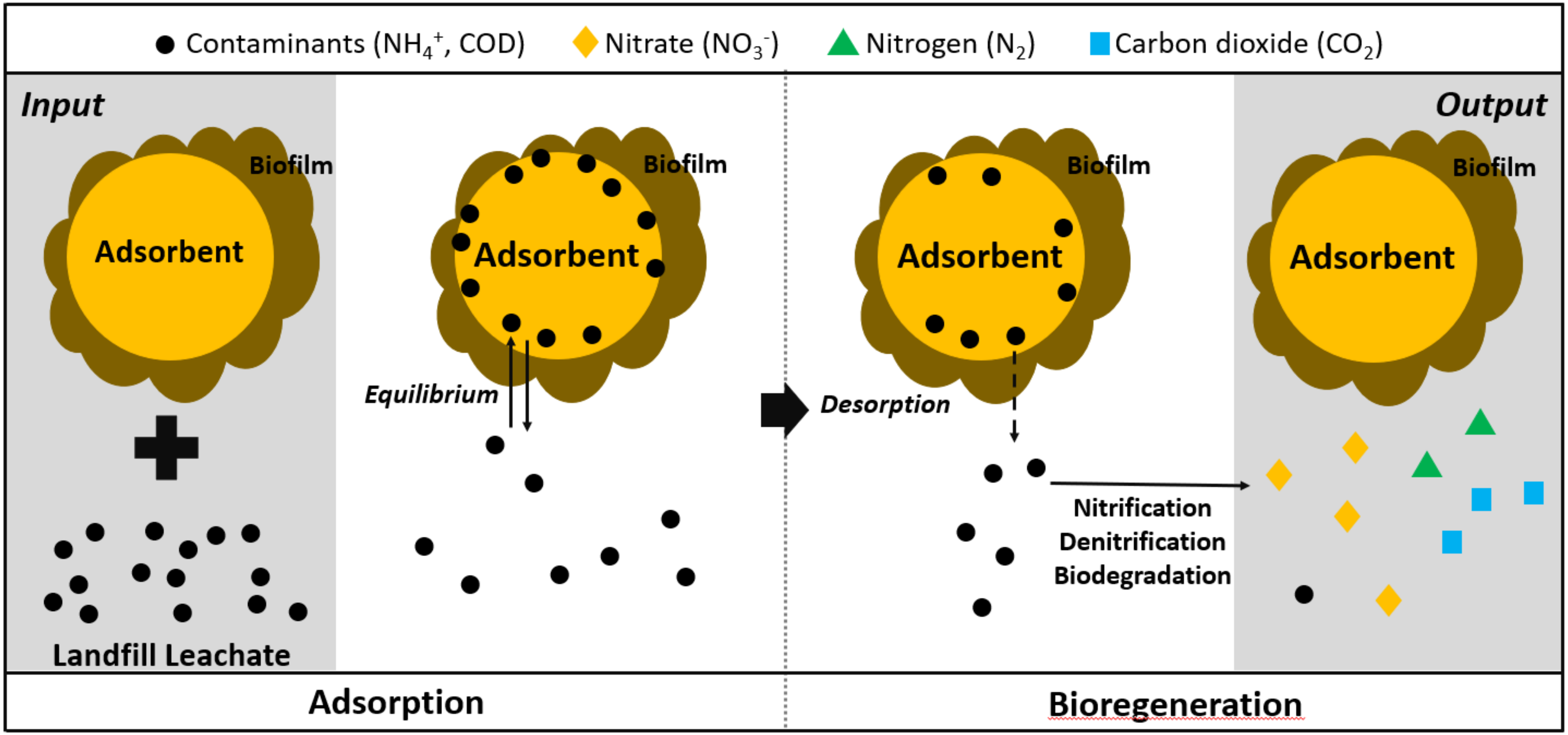
Biochar

- Low-cost material produced by pyrolysis of organic feedstock (e.g., wood chips) at high temperature under O_2 limitations.
- High surface area, cation exchange capacity, moisture holding capacity.
- Improves productivity of agricultural soils.
- Enhances growth of beneficial microorganisms.



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

Adsorption and Bioregeneration

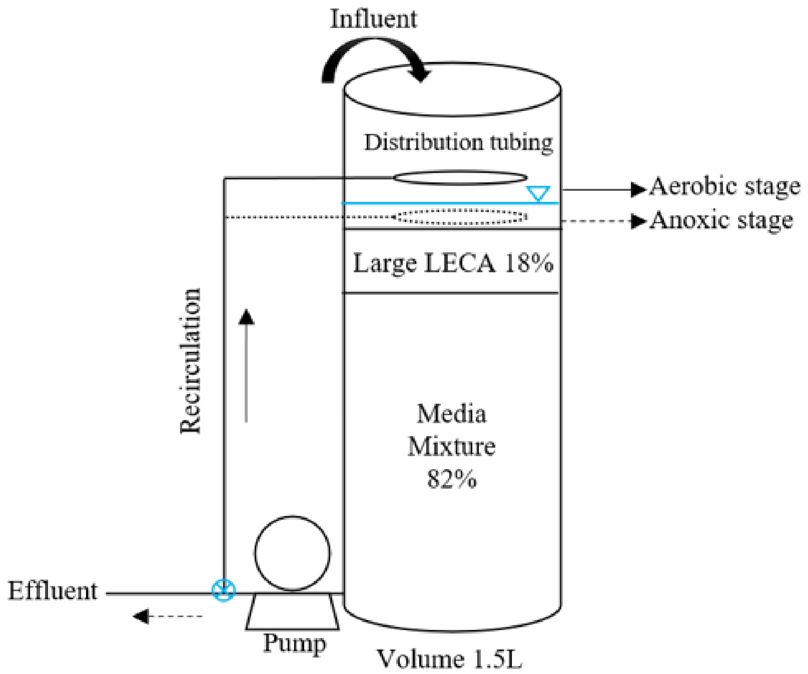


Source: modified from Aponte-Morales et al. (2018) Bioregeneration of chabazite during nitrification of centrate from anaerobically digested livestock waste: Experimental and modeling studies. *Environmental science & technology*, *52*(7), 4090-4098.

Research Objectives

1. Treat leachate in bench-scale SBBRs with and without adsorbent to investigate the effects of adsorbent and aid pilot-scale CW design;
2. Compare conventional and adsorbent amended hybrid CW performance for landfill leachate treatment in pilot study;
3. Develop a numerical process model to predict the performance of the of the hybrid CWs under varying operational and leachate characteristics;
4. Enhance leachate denitrification in CWs using iron-sulfur minerals;
5. Carry out a preliminary assessment of post-treatment requirements for reuse applications.

Bench-scale Sequencing Batch Biofilm Reactors (SBBRs)



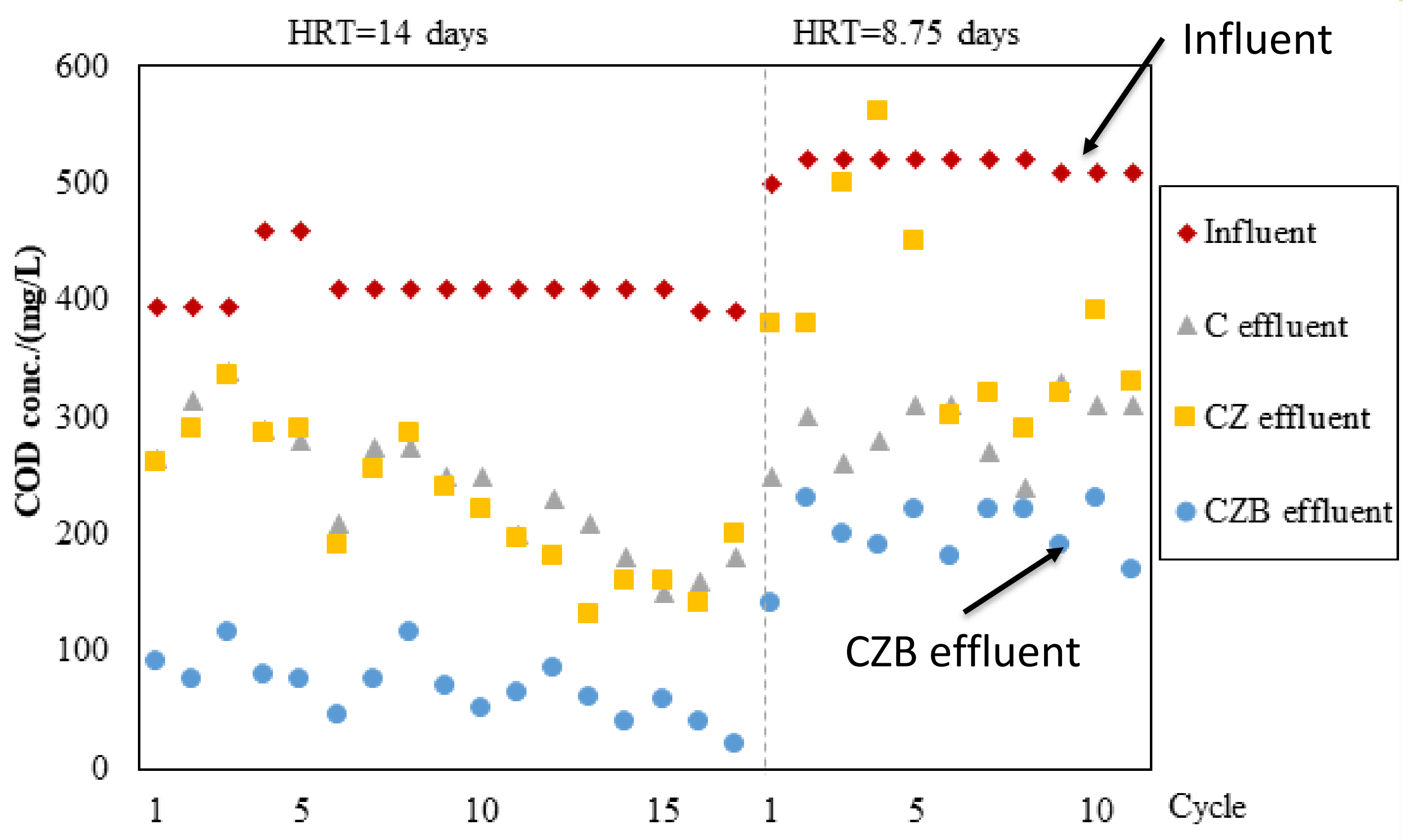
LECA
C

LECA +
Zeolite
CZ

LECA +
Zeolite +
Biochar
CZB

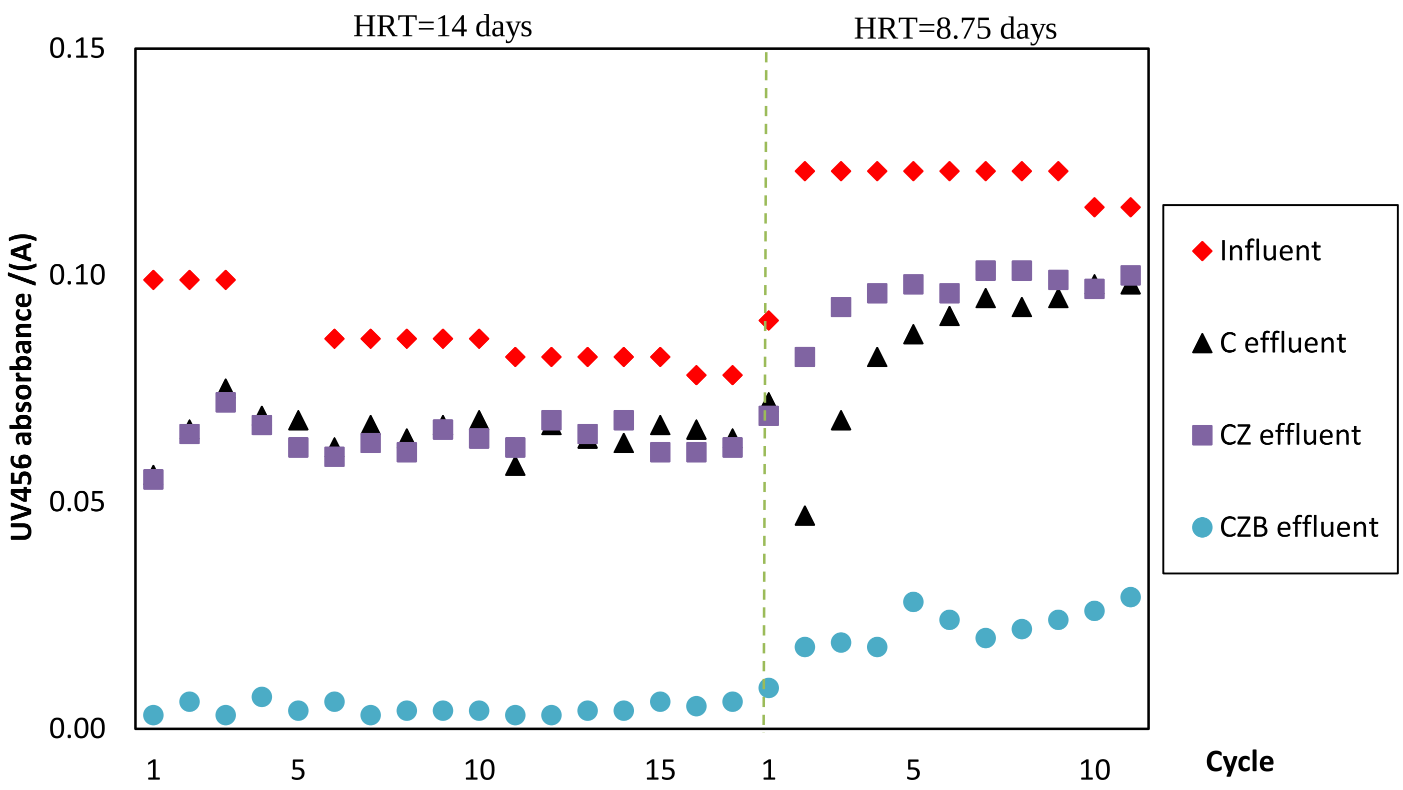
Phase	# days operation	HRT	EBCT
1	6	100% recirc.	NA
2	84	14 days	47 days
3	38	8.75 days	29 days

Bench-Scale SBBR -- sCOD



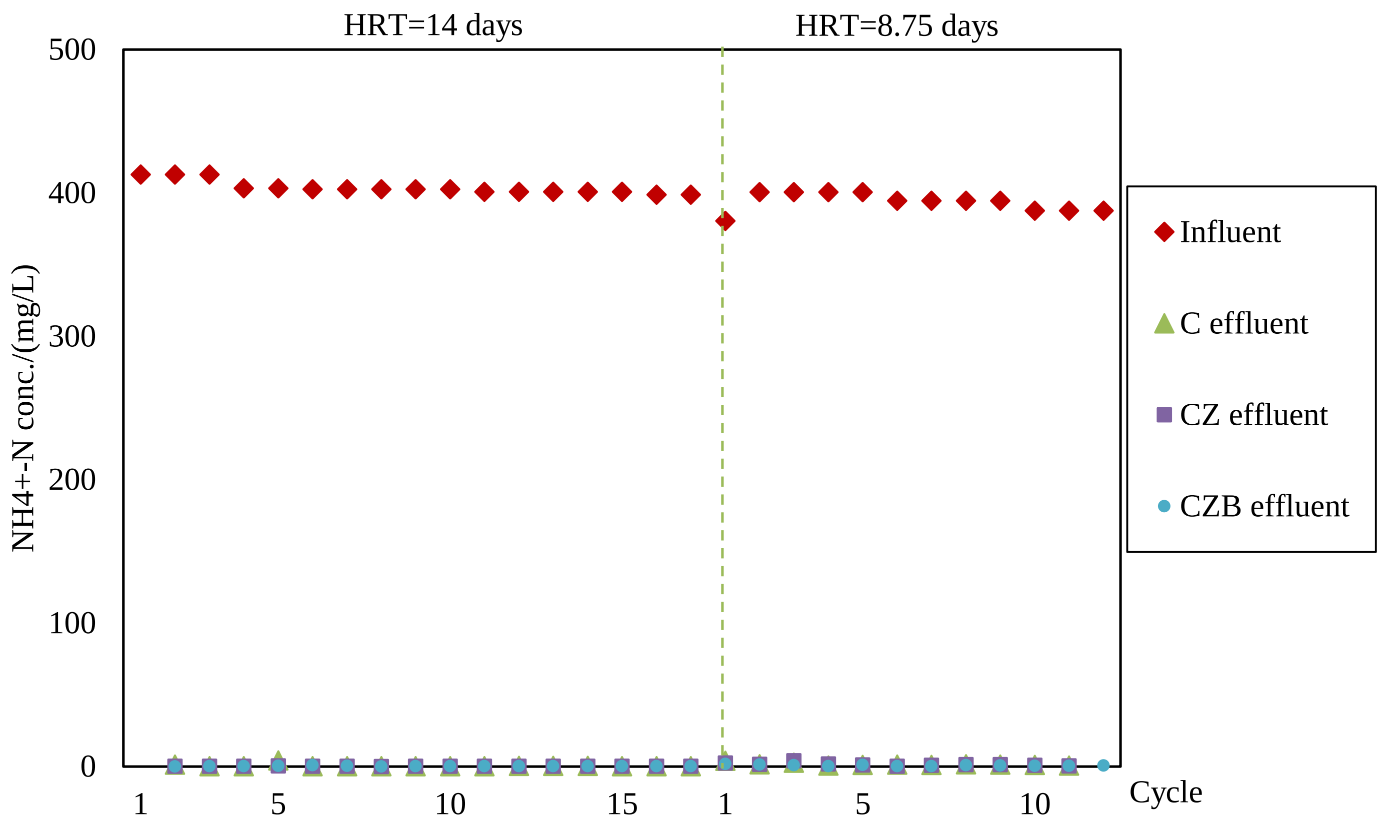
Biochar addition enhances COD removal.

Bench-Scale SBBR -- UV456



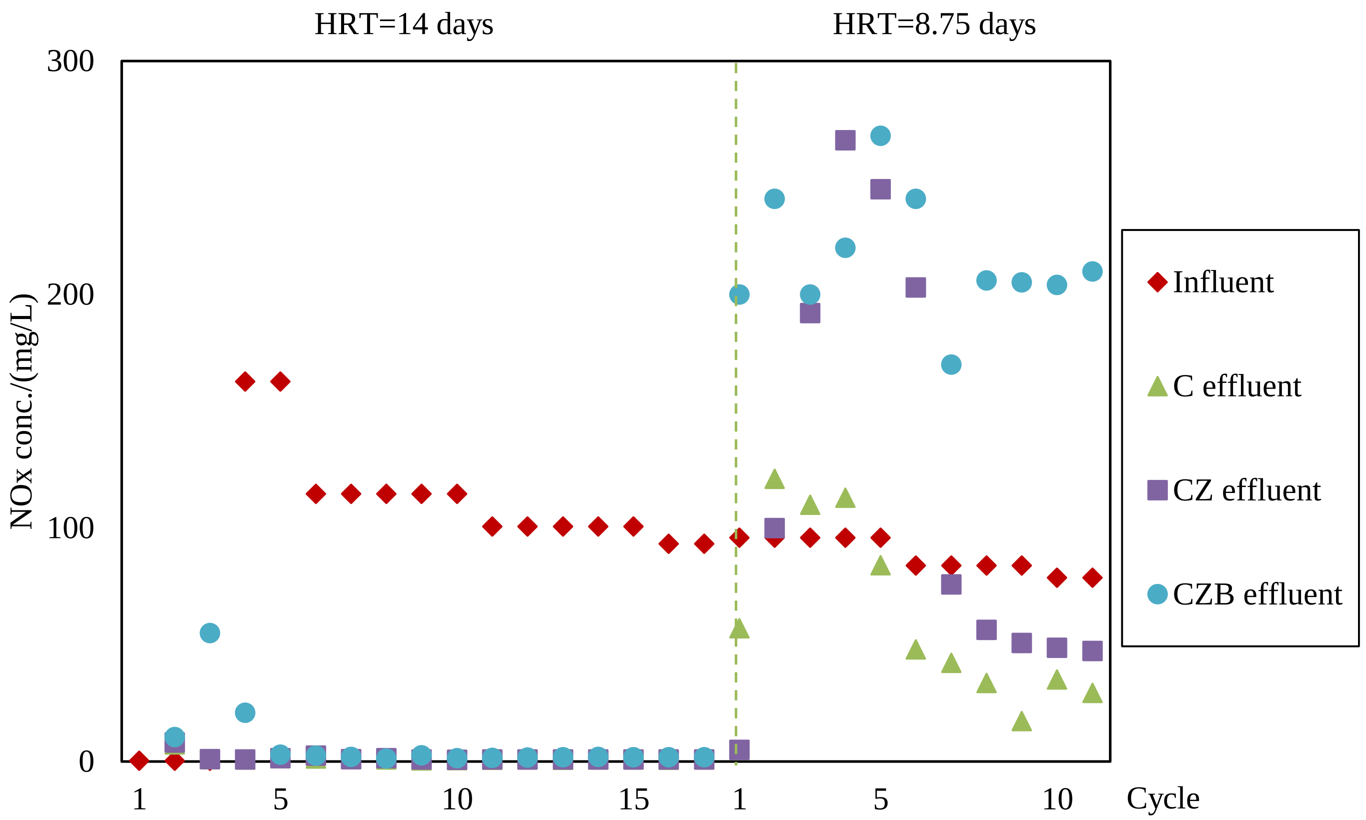
Biochar addition enhances color removal.

Bench-Scale SBBR -- NH_4^+-N



All three SBBRs achieved excellent ammonia removal.

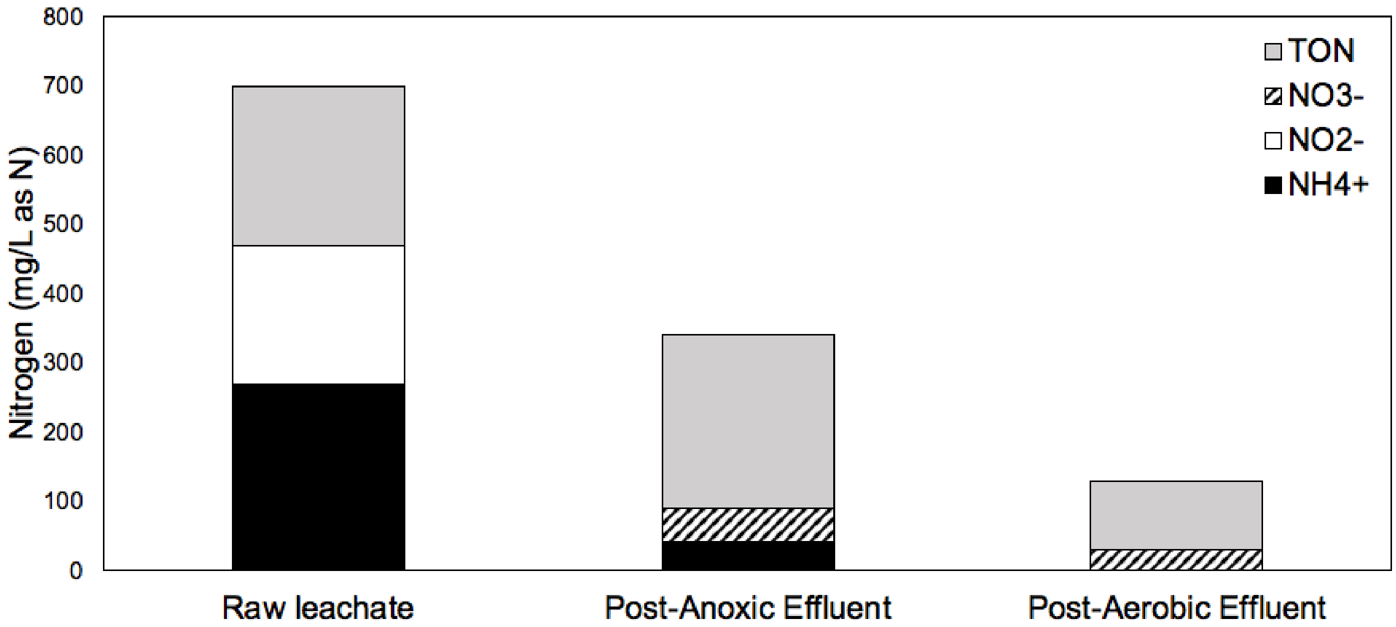
Bench-Scale SBBR -- NO_X-N



CZB had low TN removal possibly due to organic carbon limitations

"Snapshot" of N species after long-term operation of CZB SBBR

TON = Total organic nitrogen



High TN removal observed with long-term operation of reactor (~ 1 year) possibly due to anammox activity.

LECA
Zeolite
Biochar
CZB

Research Objectives

1. Treat leachate in bench-scale SBBRs with and without adsorbent to investigate the effects of adsorbent and aid pilot-scale CW design;
2. Compare conventional and adsorbent amended hybrid CW performance for landfill leachate treatment in pilot study;
3. Develop a numerical process model to predict the performance of the of the hybrid CWs under varying operational and leachate characteristics;
4. Enhance leachate denitrification in CWs using iron-sulfur minerals;
5. Carry out a preliminary assessment of post-treatment requirements for reuse applications.

Hillsborough County's Southeast Landfill

- Class 1 landfill, waste tire processing, & composting operations.
- Partial onsite leachate treatment by activated sludge BNR with glycerol addition.
- Leachate hauled to county POTW.
- County interested in the potential implementation at adjacent wetlands.
- Operations staff enthusiastic about project.

Southeast Hillsborough County Landfill in Lithia, FL

Pilot-Scale CW Design

- 2 pilot-scale hybrid VF-HF CWs.

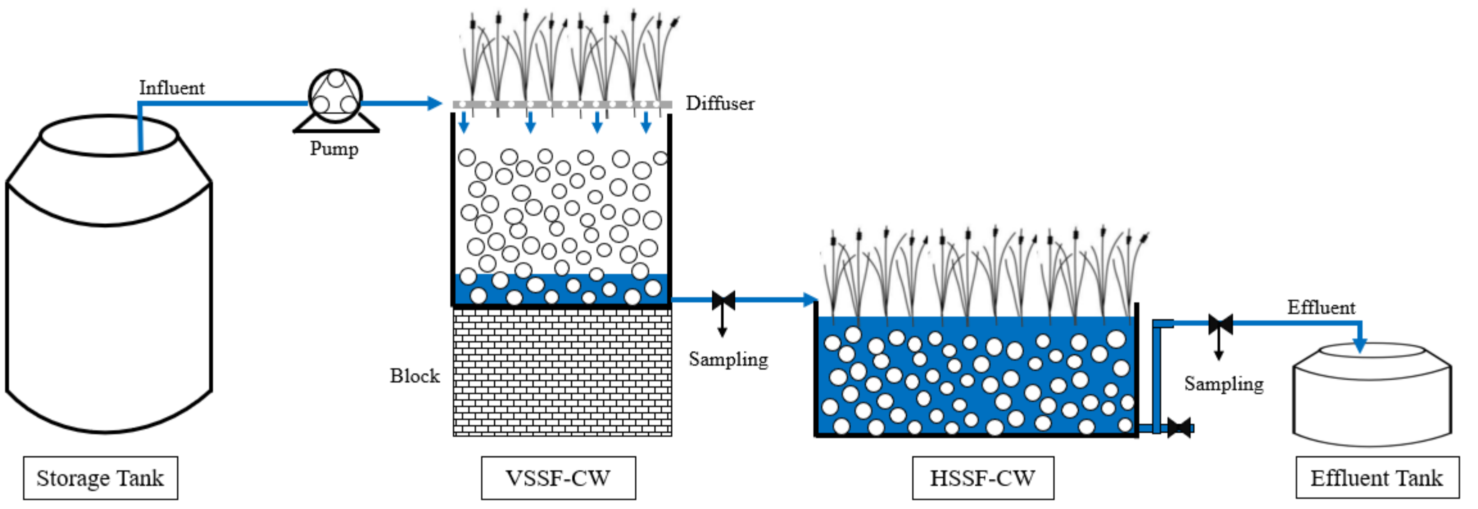
CW	V-CW medium	HF-CW medium	Feed
CW#1	gravel	gravel	raw leachate
CW#2	gravel + zeolite	gravel + biochar	

- Will be planted with low cost, low maintenance, leachate tolerant plants (cattail and cordgrass)

Cattail

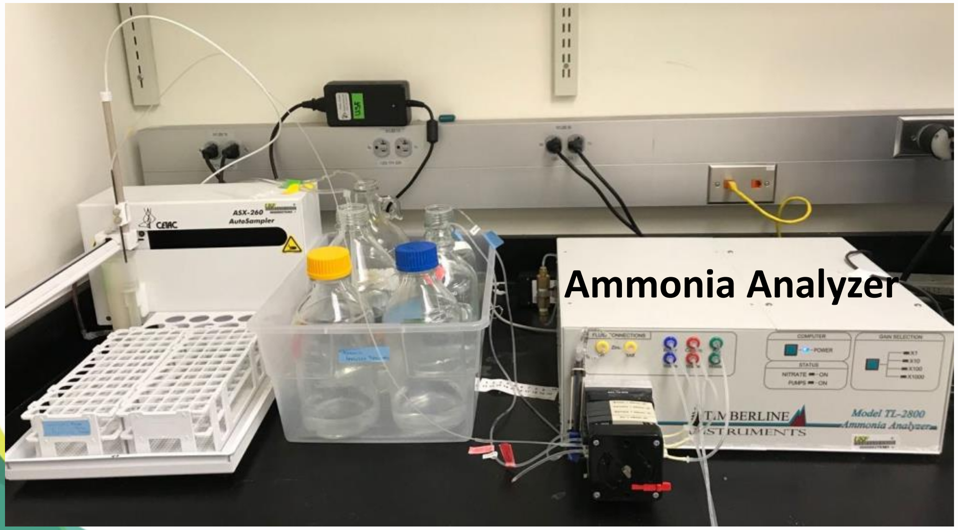
Cordgrass

Pilot-Scale CW Design



Pilot CW Startup & Monitoring

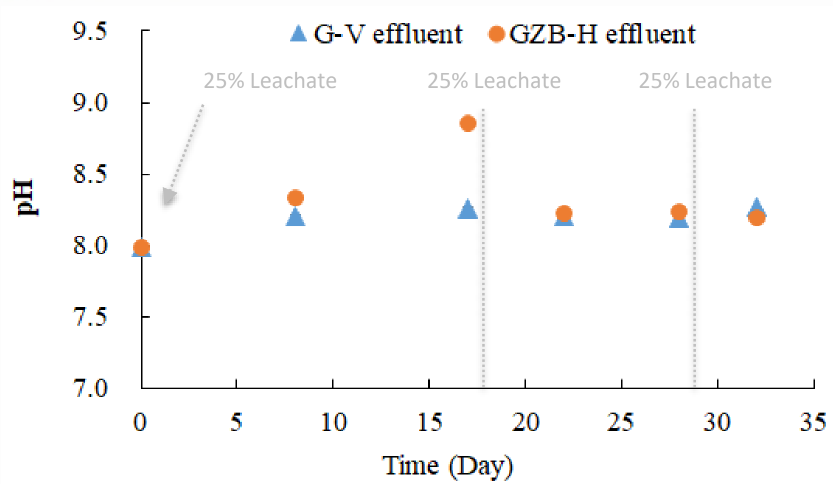
- Seed wetlands with sludge from onsite leachate treatment reactors.
- Gradually increase % leachate in influent: 25%, 50%, 75%, 100%.
- Plant systems with cattail and cordgrass – coming soon!
- Monitoring: pH, alkalinity, TSS/VSS, N species, sCOD, BOD5, UV254, UV456.
- Levelogger sensors for water level, temperature & conductivity every 10 mins.

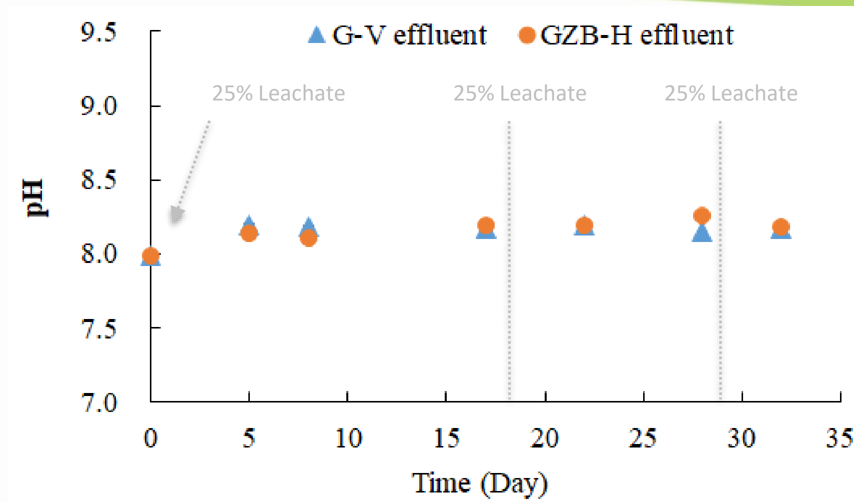


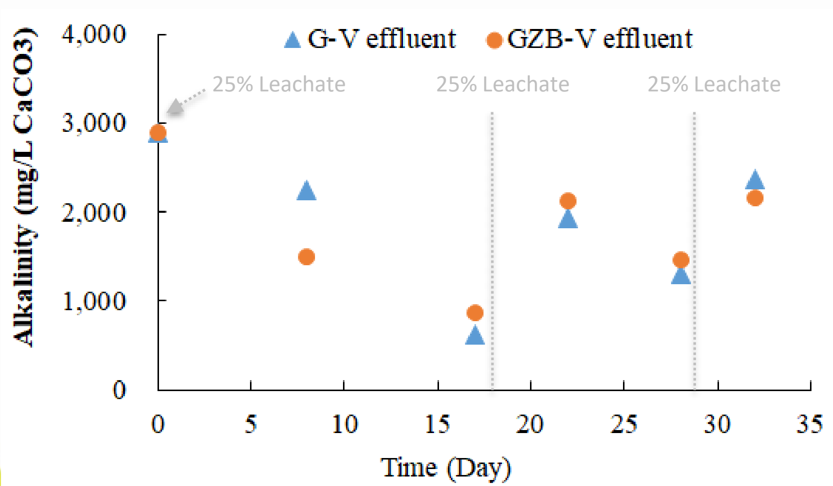
CW Monitoring -- pH & Alkalinity

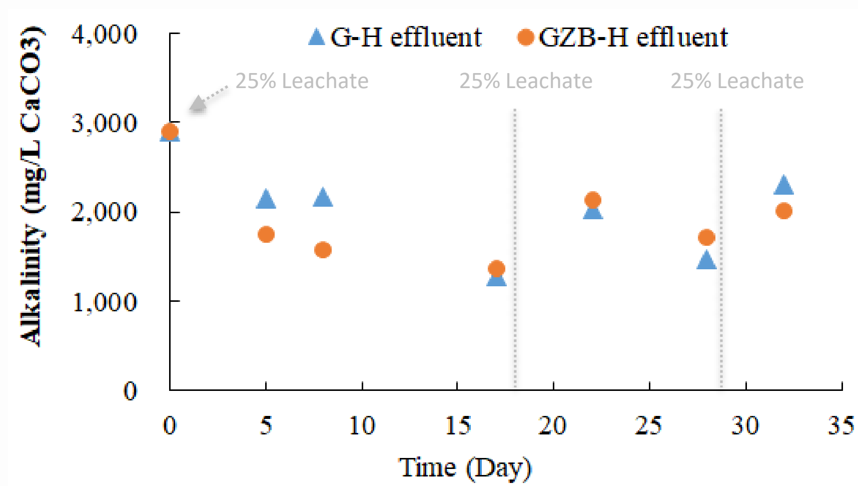
Vertical Flow CW

Horizontal Flow CW

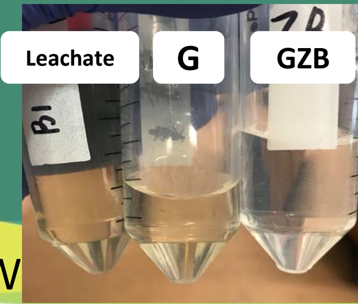




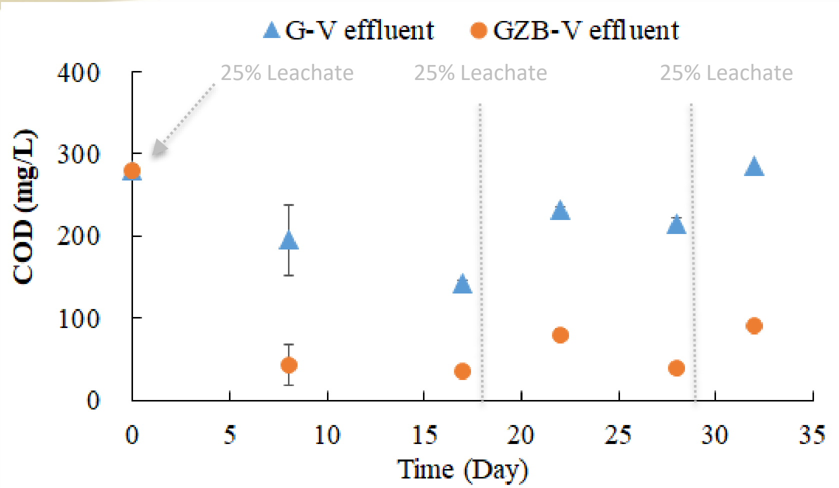




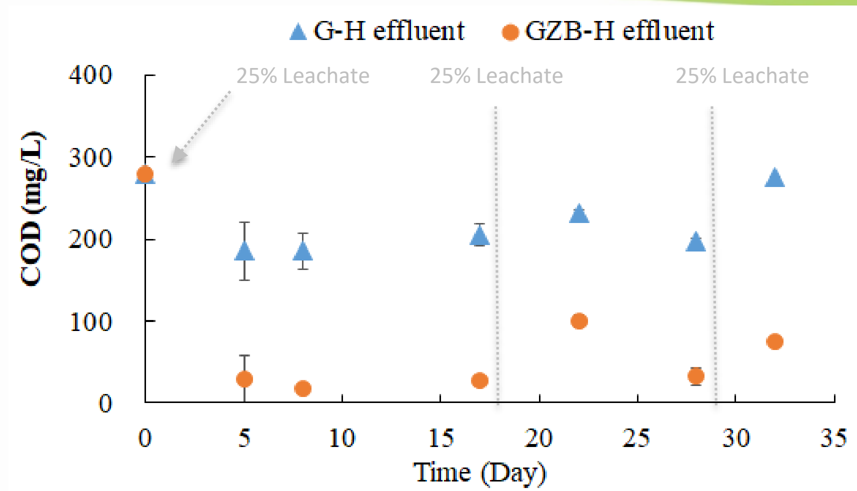
CW Monitoring – sCOD & Color

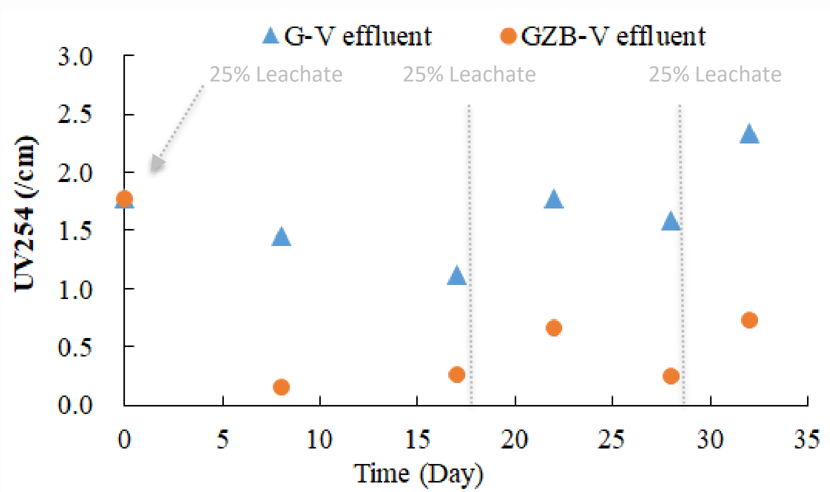


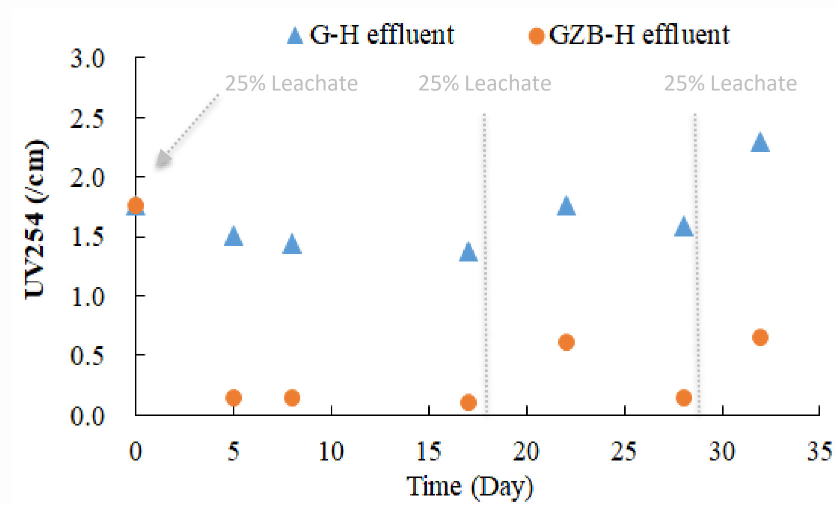
Vertical Flow CW



Horizontal Flow CW

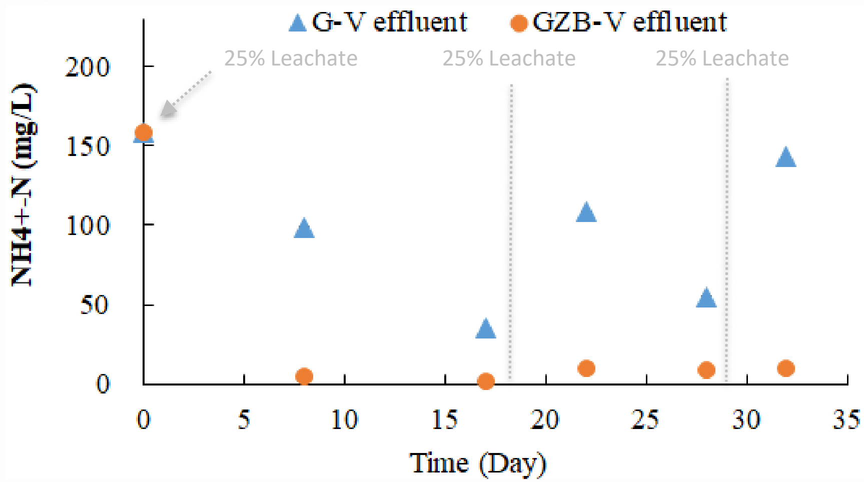




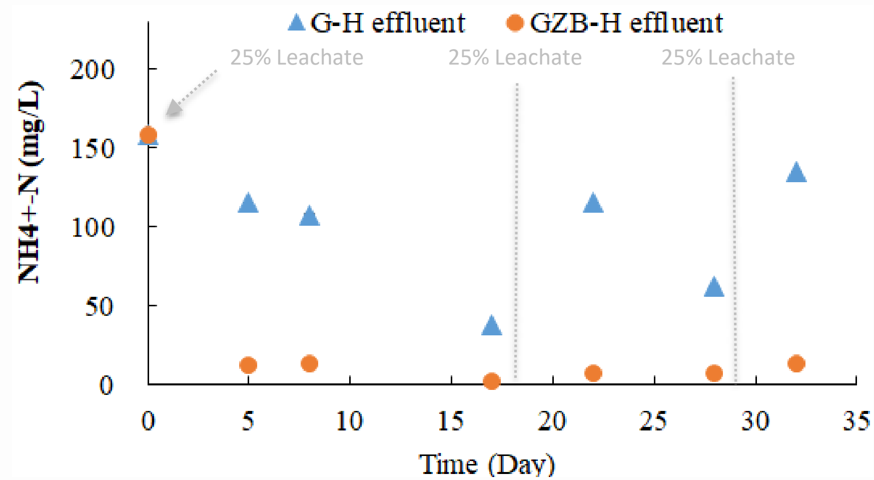


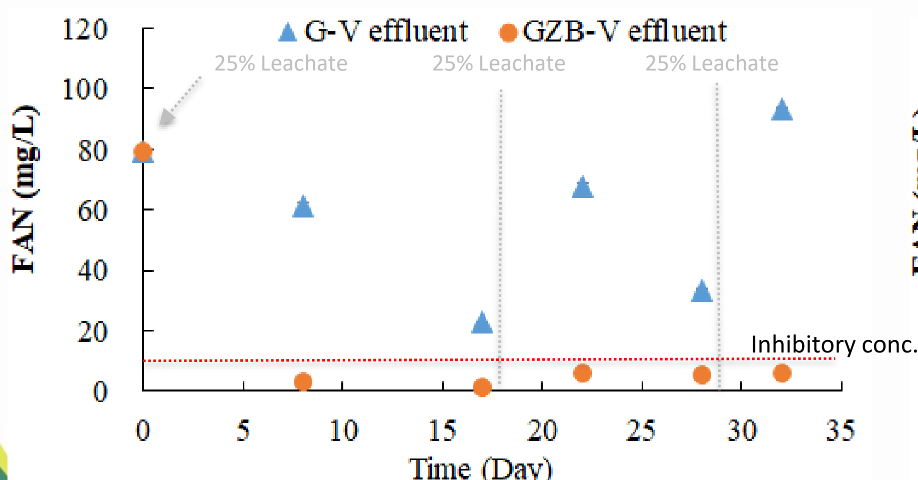
CW Monitoring -- TAN & FAN

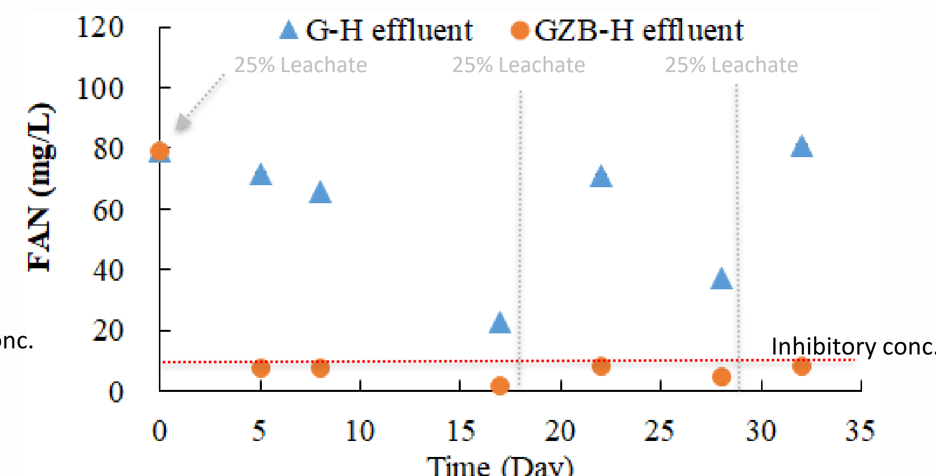
Vertical Flow CW



Horizontal Flow CW

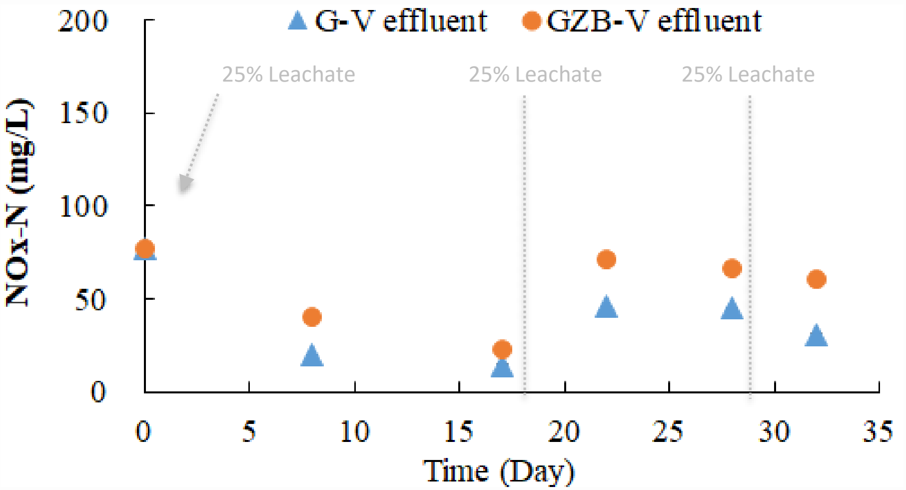




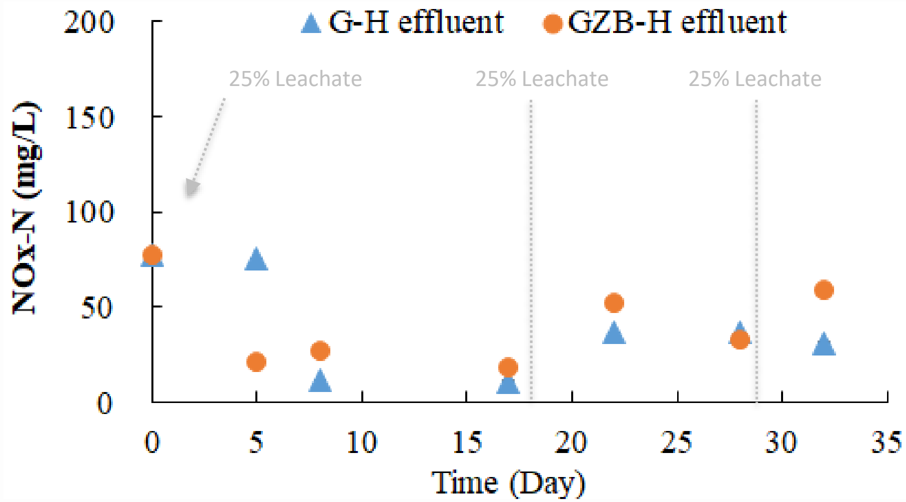


CW Monitoring – Nox (NO_2^--N + NO_3^--N)

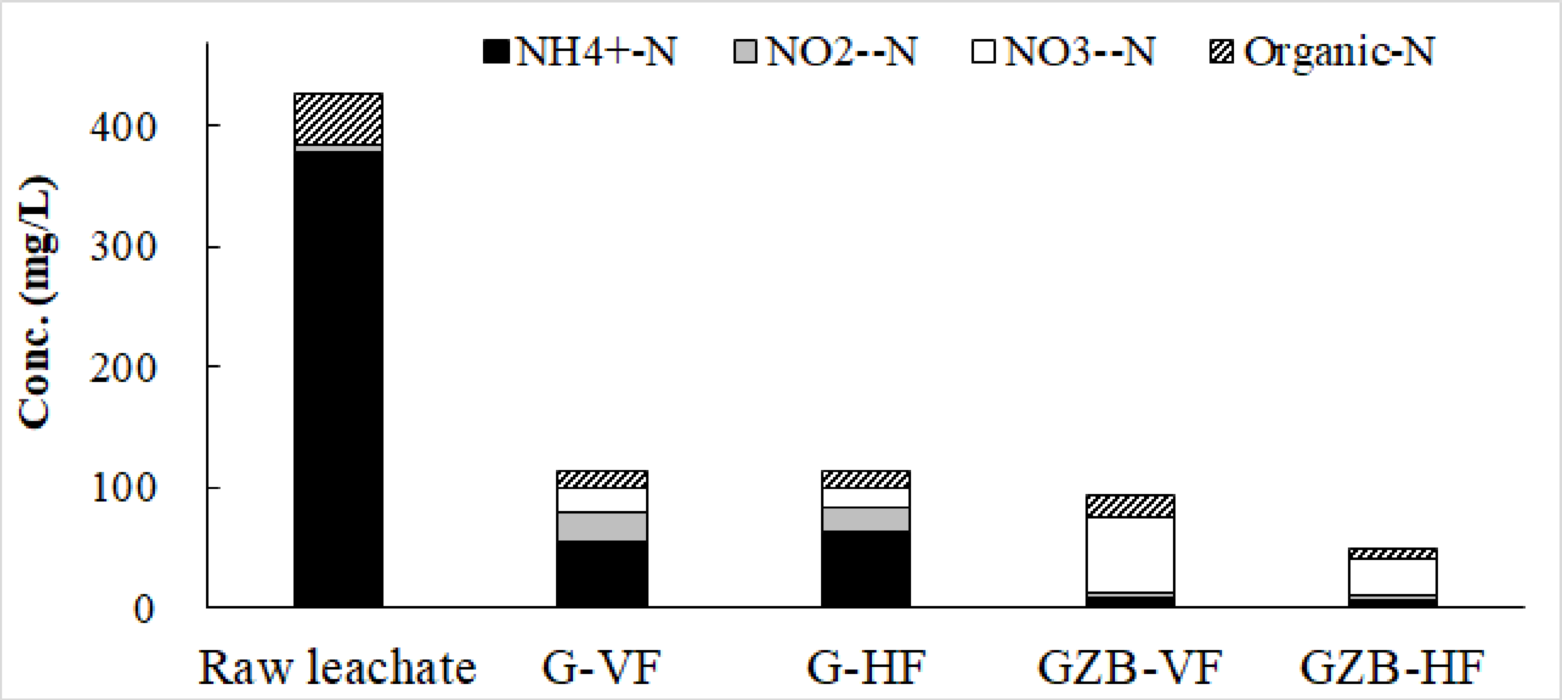
Vertical Flow CW



Horizontal Flow CW



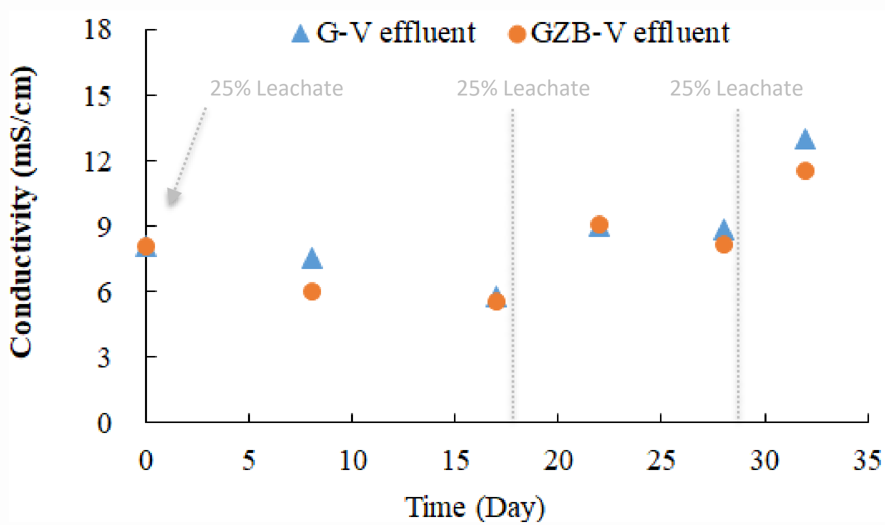
“Snapshot” of Preliminary Monitoring N Results



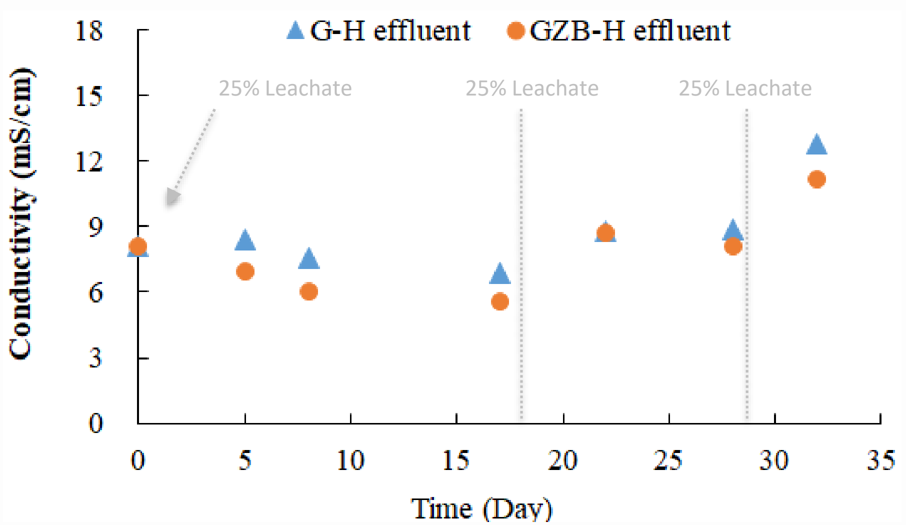
GZB had better nitrification but had nitrate accumulation.

CW Monitoring -- Conductivity

Vertical Flow CW



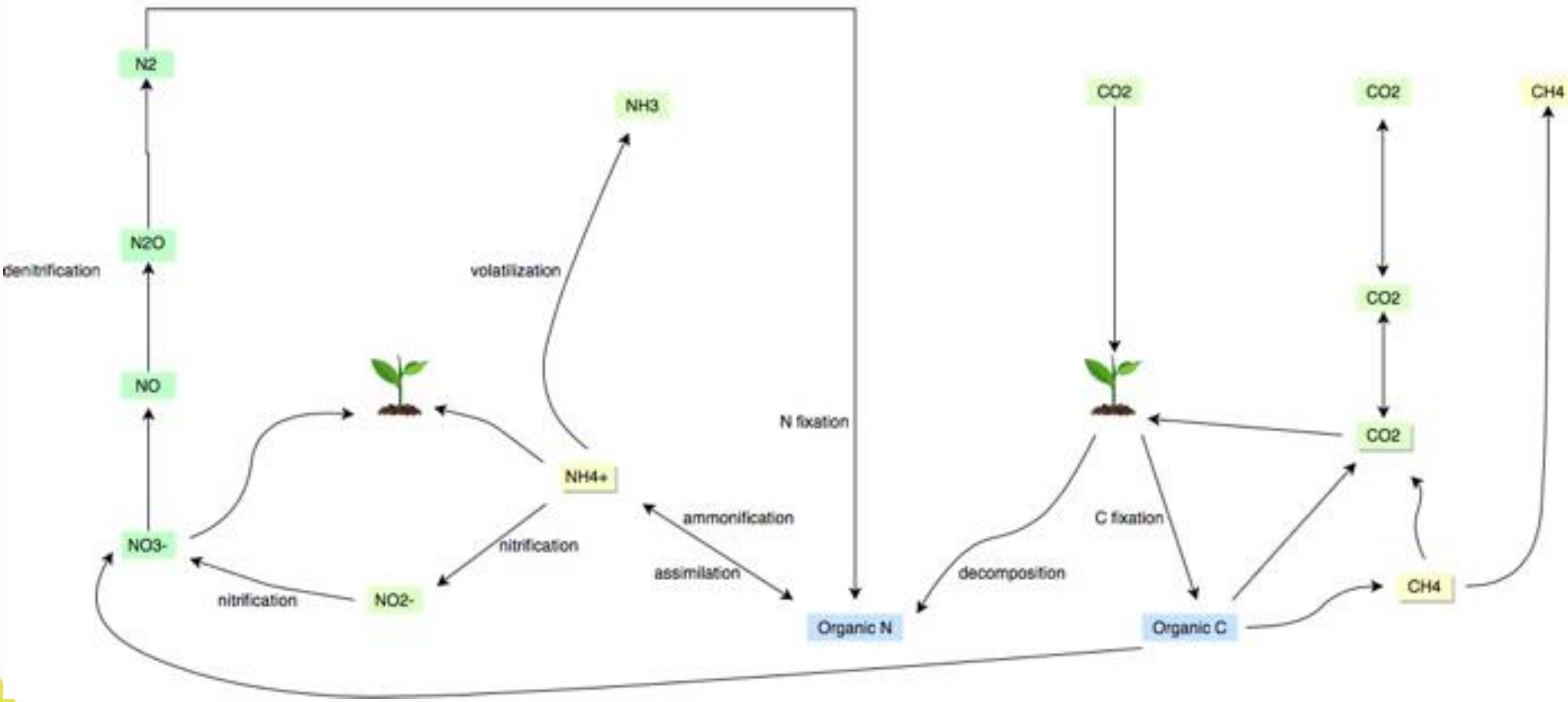
Horizontal Flow CW



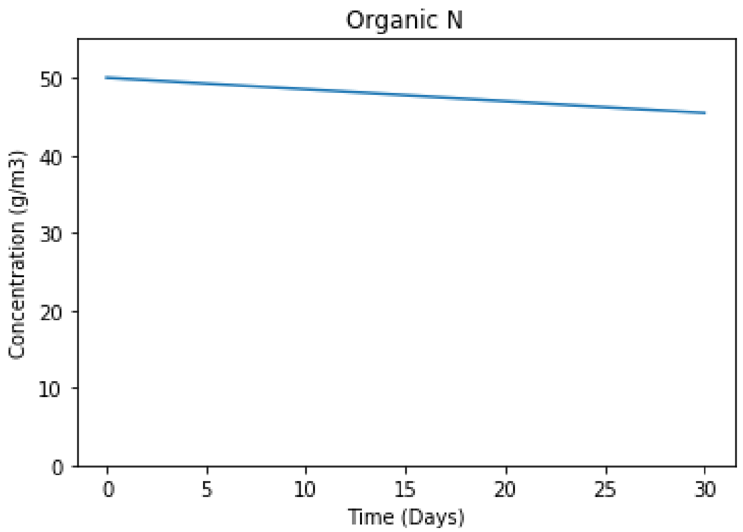
Research Objectives

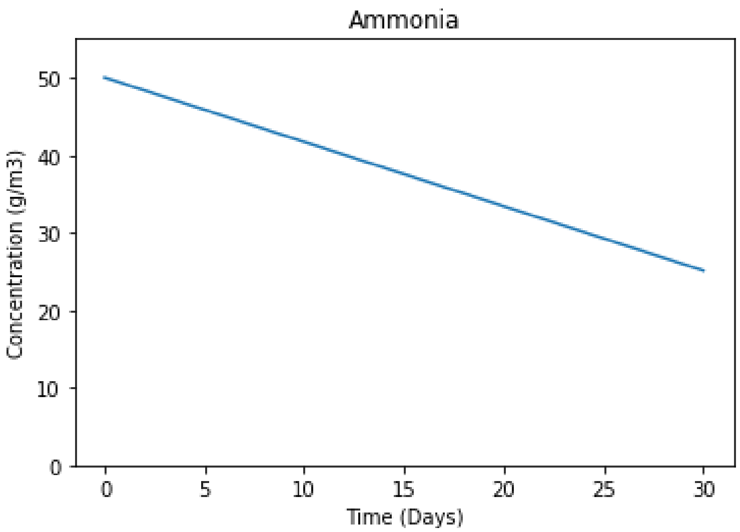
1. Treat leachate in bench-scale SBBRs with and without adsorbent to investigate the effects of adsorbent and aid pilot-scale CW design;
2. Compare conventional and adsorbent amended hybrid CW performance for landfill leachate treatment in pilot study;
3. Develop a numerical process model to predict the performance of the of the hybrid CWs under varying operational and leachate characteristics;
4. Enhance leachate denitrification in CWs using iron-sulfur minerals;
5. Carry out a preliminary assessment of post-treatment requirements for reuse applications.

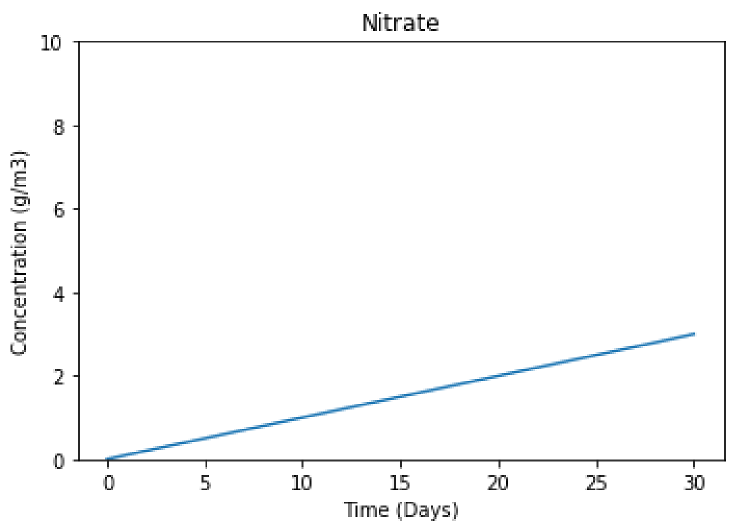
Conceptual Model



Preliminary Modeling Results







- CMFR, one tank
- Control reactor (no zeolite/biochar)
- Assumes steady flow rate
- Nitrate accumulation observed

Research Objectives

1. Treat leachate in bench-scale SBBRs with and without adsorbent to investigate the effects of adsorbent and aid pilot-scale CW design;
2. Compare conventional and adsorbent amended hybrid CW performance for landfill leachate treatment in pilot study;
3. Develop a numerical process model to predict the performance of the of the hybrid CWs under varying operational and leachate characteristics;
4. Enhance leachate denitrification in CWs using iron-sulfur minerals;
5. Carry out a preliminary assessment of post-treatment requirements for reuse applications.

Microcosm Study

- Examining feasibility of iron-sulfur minerals to support denitrification of nitrified leachate
  - Currently testing sphalerite + **oyster shells (OS)***
- Include appropriate controls;
  - S^0 + OS (+); uninoculated (-) controls

Microcosms

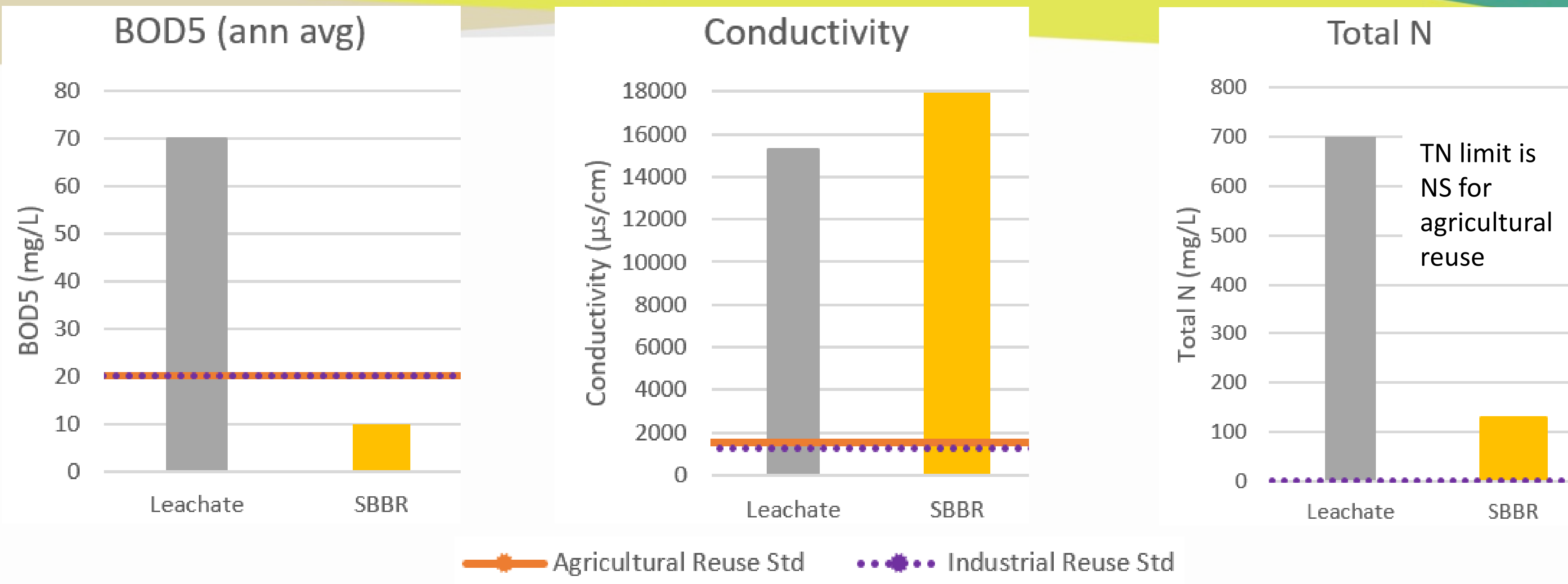
Nitrified effluent from CZB SBBR

Results will be featured in next quarterly report & TAG meeting

Research Objectives

1. Treat leachate in bench-scale SBBRs with and without adsorbent to investigate the effects of adsorbent and aid pilot-scale CW design;
2. Compare conventional and adsorbent amended hybrid CW performance for landfill leachate treatment in pilot study;
3. Develop a numerical process model to predict the performance of the of the hybrid CWs under varying operational and leachate characteristics;
4. Enhance leachate denitrification in CWs using iron-sulfur minerals;
5. Carry out a preliminary assessment of post-treatment requirements for reuse applications.

Water Reuse Potential



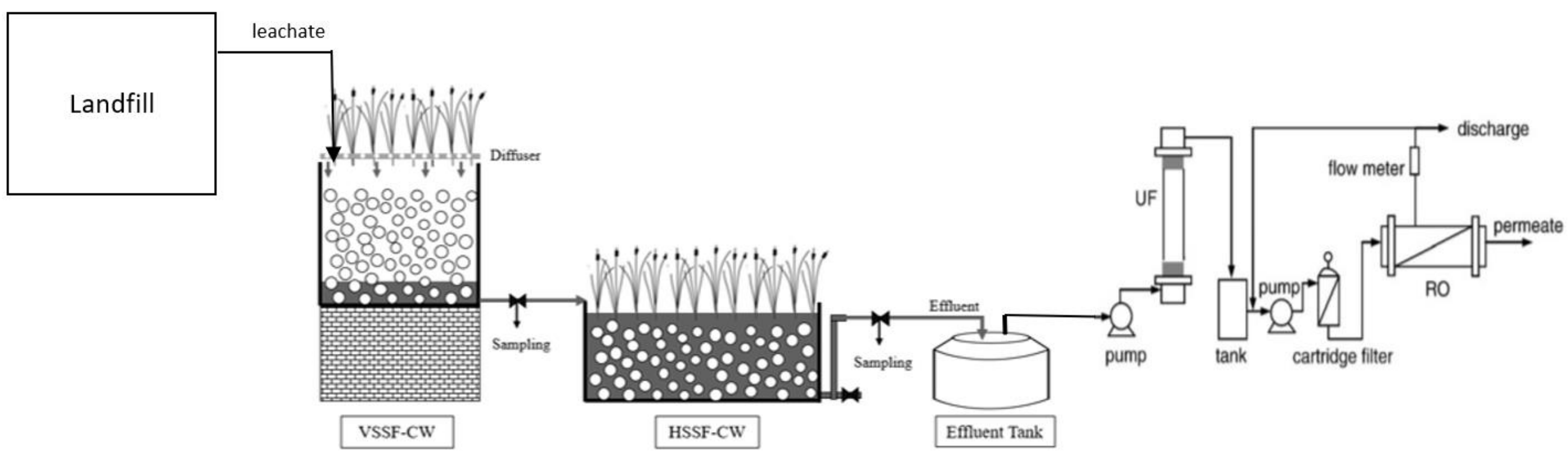
Heavy Metals	Leachate	SBBR	Agricultural reuse std	Industrial reuse std
As (mg/L)	0.009	0.014	NS	< 0.006
Cu (mg/L)	0.106	0.084	< 0.003	< 0.003
Zn (mg/L)	0.049	0.052	NS	< 0.021

Hybrid CWs reuse standards for conductivity & heavy metals cannot be met based on SBBR data.

Notes: NS= not specified by the Florida state’s reuse regulation; avg = average; ann = annual; std = standard

Water Reuse Potential

In prior studies*, CWs provided excellent pretreatment for UF & RO.
Combined CW, UF and RO, resulted in a conductivity removal efficiency of 98.3%.



*Source: Huang, X. F., Ling, J., Xu, J. C., Feng, Y., & Li, G. M. (2011). Advanced treatment of wastewater from an iron and steel enterprise by a constructed wetland/ultrafiltration/reverse osmosis process. *Desalination*, *269*(1-3), 41-49.

Next Steps

- Bench and Pilot-Scale Experiments
  - Continue operations and monitoring
  - Increase leachate loading rates to pilot
  - Add macrophytes (cattails and cordgrass to pilot)

- Enhancing denitrification with iron-sulfur minerals
  - Microcosm study
  - Add downstream reactors to pilot CW

- RO Analysis
  - Design and simulate RO system
    - WAVE Design Software by DuPont Water Solutions
  - Estimations of capital and O&M costs

Hinkley Center Metrics -- Practical Specific Benefits for End Users

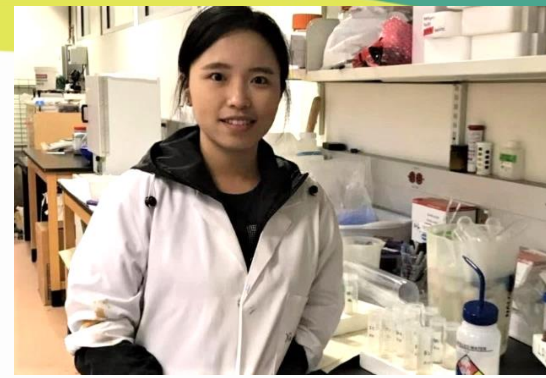
"The treatment of landfill leachate is a big issue both economically and environmentally for most landfills and wastewater treatment plants."

- Hinkley Center Research Agenda

- Hybrid CWs for onsite treatment have low complexity, low capital and O&M costs and proven long-term performance for removal of organic matter, nutrients and metals from landfill leachate.
- Addition of low-cost adsorbent materials, clinoptilolite and biochar, can reduce system land requirements and improve effluent quality.
- Effluents from the proposed CWs can be safely discharged to POTWs or treated further to meet reclaim water standards.

Hinkley Center Metrics -- Students

Name	Degree	Status
Xia Yang	PhD	Ongoing (expected in 2021)
Bisheng Gao	MS	Graduated
Lillian Mulligan	MS	Ongoing (expected in 2021)
Xufeng Wei	MS	Graduated
Thanh Lam	MS	Ongoing (expected in 2022)
Erica Dasi	PhD	Ongoing (expected in 2021)
Magdalena Shafee	BS	Ongoing (expected in 2021)



Hinkley Center Metrics -- 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.
- Abstract was submitted to the American Ecological Engineering Society Annual Meeting in Quarter 2; however, the conference was cancelled due to the COVID-19 pandemic. We plan to submit an abstract for the 2021 conference.
- Manuscript in preparation: Gao, B. Yang, X., Arias, M. Ergas, S.J. (in preparation) 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*.

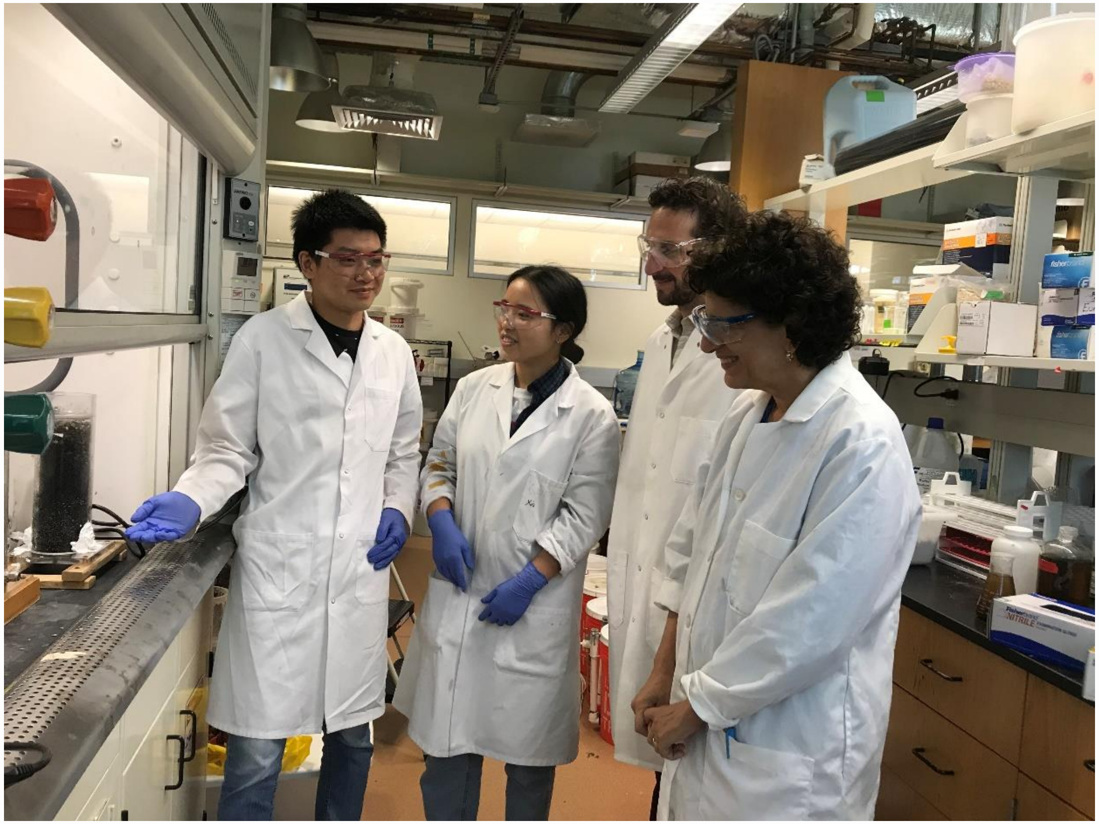
Hinkley Center Metrics -- Leveraging Other Funding

- Erica Dasi - Sloan University Center of Exemplary Mentoring (UCEM) at USF, Florida Educational Fund McKnight Doctoral Fellowship program
- Magdalena Shafee – College of Engineering Research Experience for Undergraduates (REU) program.
- Lillian Mulligan and Thanh Lam – National Science Foundation funded S-STEM Scholarship Program: Graduate Student Scholarships to Advance Community Engaged Solutions to the Grand Challenge of Managing Nitrogen

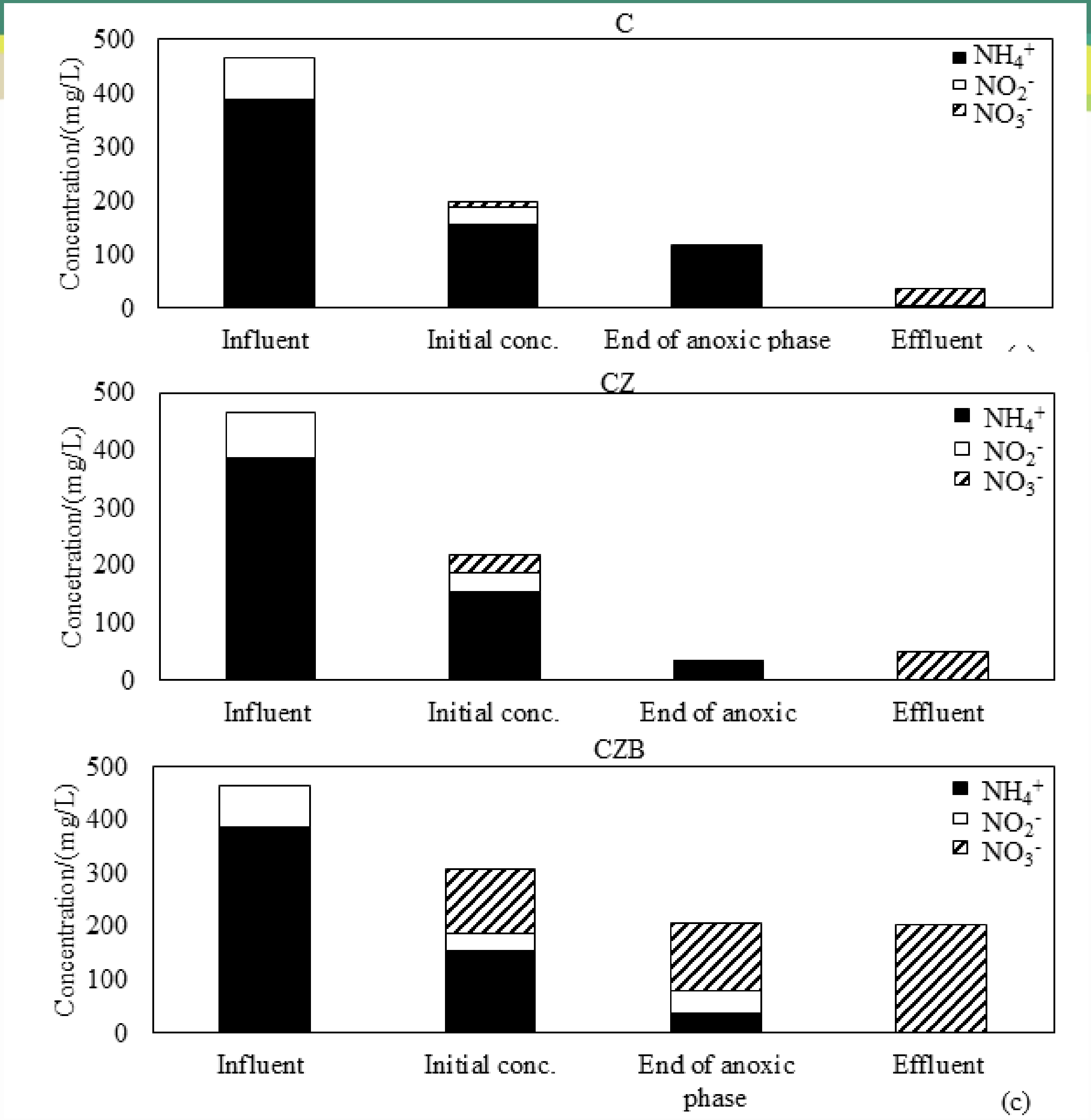
Questions?

reclaim
water • nutrients • energy

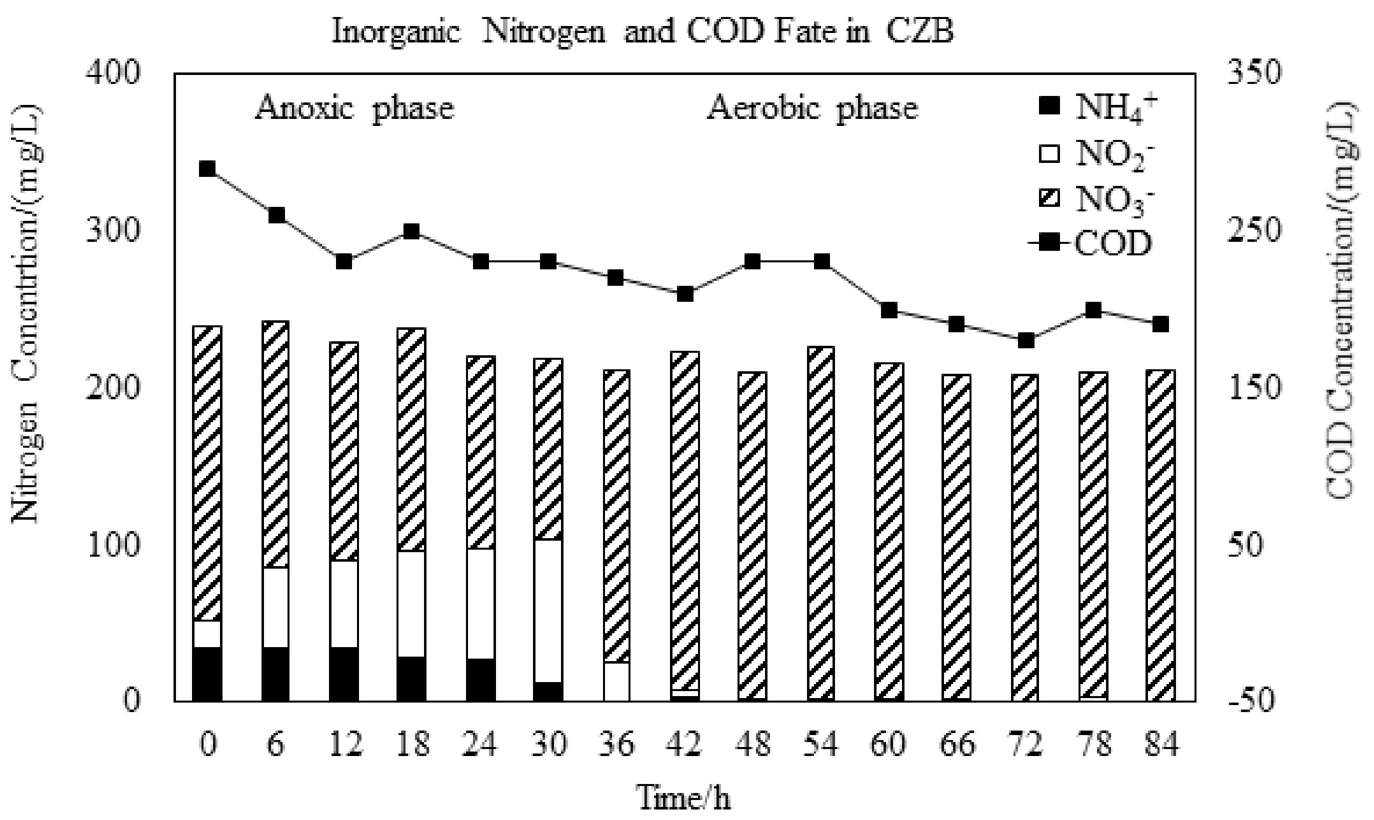
usf-reclaim.org



Lab-scale experimental results --- Inorganic N species



Lab-scale experimental results --- Inorganic N and sCOD Fate in CZB



SBBR results – summary

- All three SBBRs achieved high NH_4^+ removals (over 90%) at both HRTs.
- Biochar enhanced COD removal significantly with removal of 83% and 61% at HRTs of 14 and 8.75 days, respectively.
- Biochar amended SBBR had higher color removal of 95% and 82% at HRTs of 14 and 8.75 days, respectively.
- Biochar addition caused effluent NO_3^- accumulation at shorter HRT due to adsorption.

Preliminary Monitoring Results

Leachate characteristics

	Day 0 (25%)	Day 17th (25%)	Day 28th (25%)
pH	7.77	7.81	7.89
Conductivity (mS/cm)	16.26	17.48	18.38
Alkalinity (mg/L)	6825	5625	5375
COD (mg/L)	570	480	445
UV254 (/cm)	4.005	3.460	3.344
TN (mg/L)	404	426	386
NH4+-N (mg/L)	445	378	378
NO2--N (mg/L)	0	0	0
NO3--N (mg/L)	21	6	0

Preliminary Monitoring Results

System acclimation:

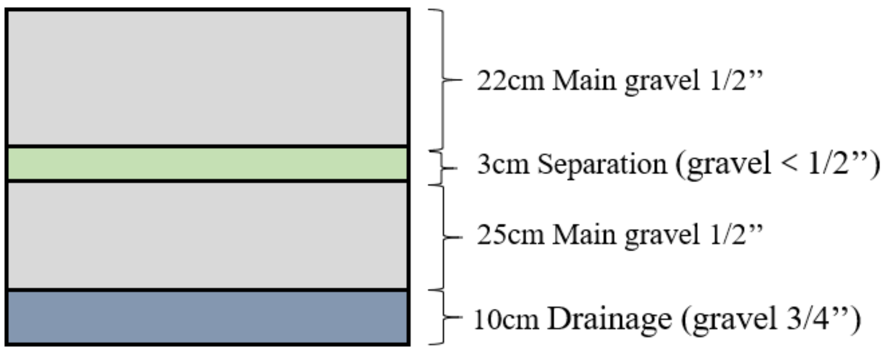
- Operate CWs with ground water to check for leaks, and hydraulic function.
- Inoculate with sludge from the activated sludge treatment system:

  sludge+25% leachate+75% ground water to make TS 1000 mg/L.

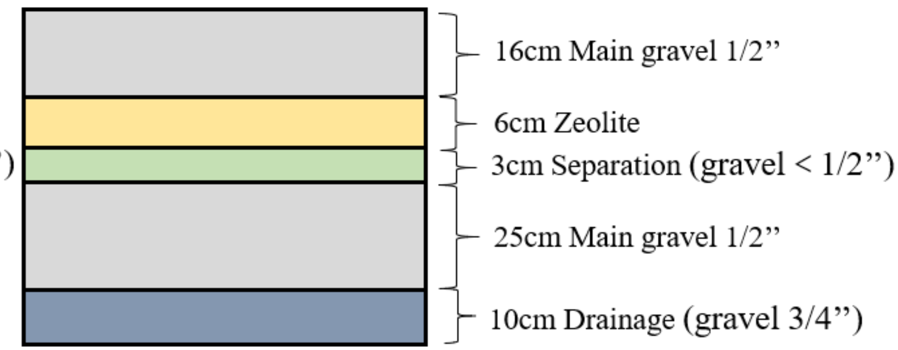
- Increase to 50% leachate.
- Increase to 75% leachate.
- Increase to 100% leachate.
- Plant the CWs with cattail and cordgrass and continue operation.

Pilot-scale CW design

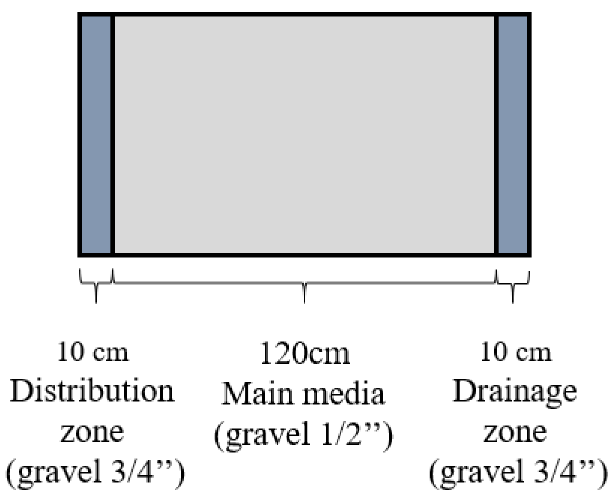
VF: gravel (as control)



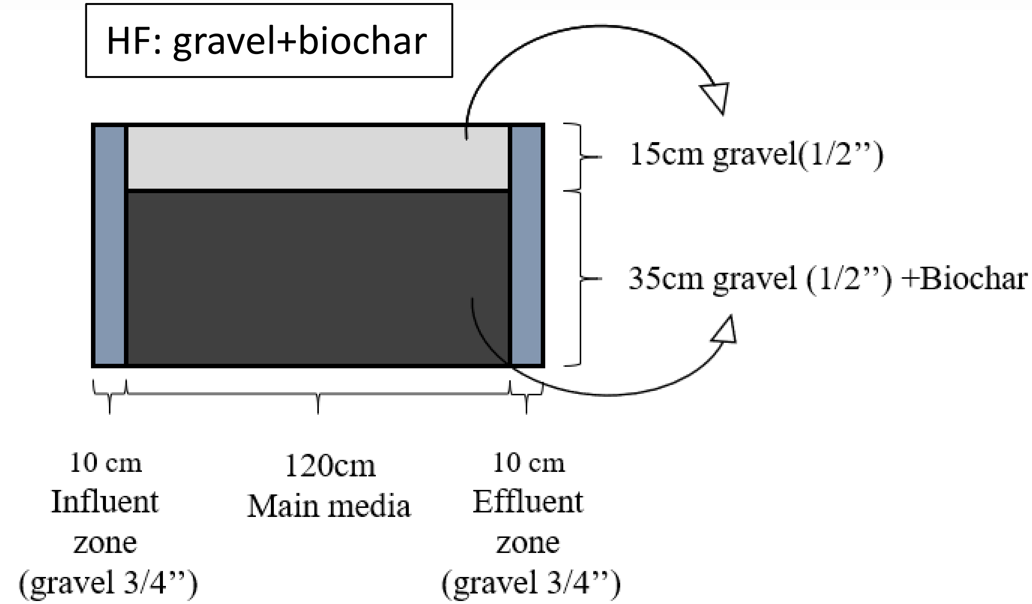
VF: gravel+zeolite



HF: gravel (as control)



HF: gravel+biochar



Water Reuse Potential

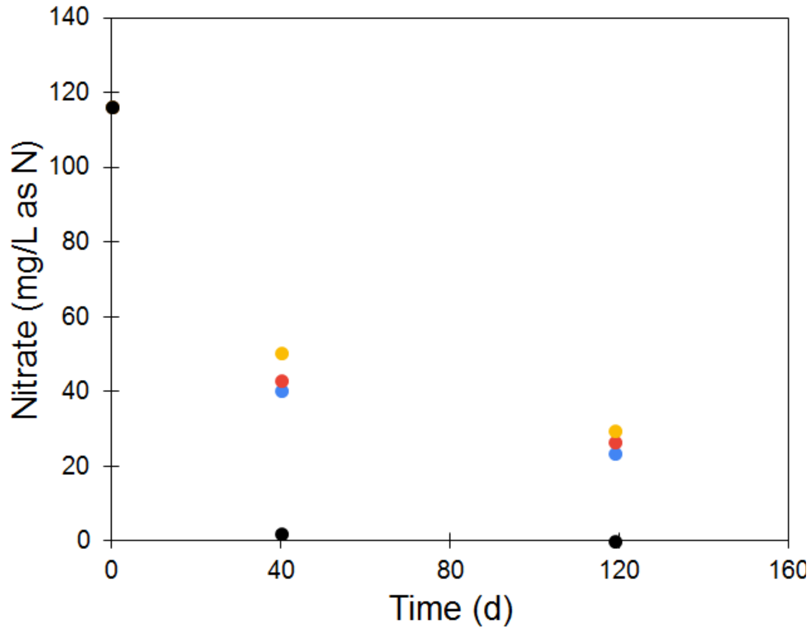
Water Quality Parameter		Leachate	SBBR	Agricultural reuse	Industrial reuse
BOD_5 (mg/L ann avg)		50 - 70	< 10	< 20	< 20
pH		7.6 - 7.9	7.50 - 8.24	7 - 8	7.9 - 8.7
Conductivity (μs/cm)		12,700 – 15,300	15,740	< 1,360	< 1,120
Total N (mg/L)		700	130	NS	< 2.3
NO_3 – N (mg/L)		21	210	< 9.34	< 0.1
NH_4 – N (mg/L)		300 - 450	0.01 - 1.64	< 0.02	< 0.25
Metals	As (mg/L)	0.009	0.014	NS	< 0.006
	Cu (mg/L)	0.106	0.084	< 0.003	< 0.003
	Pb (mg/L)	-0.006	-0.006	NS	< 0.003
	Zn (mg/L)	0.049	0.052	NS	< 0.021

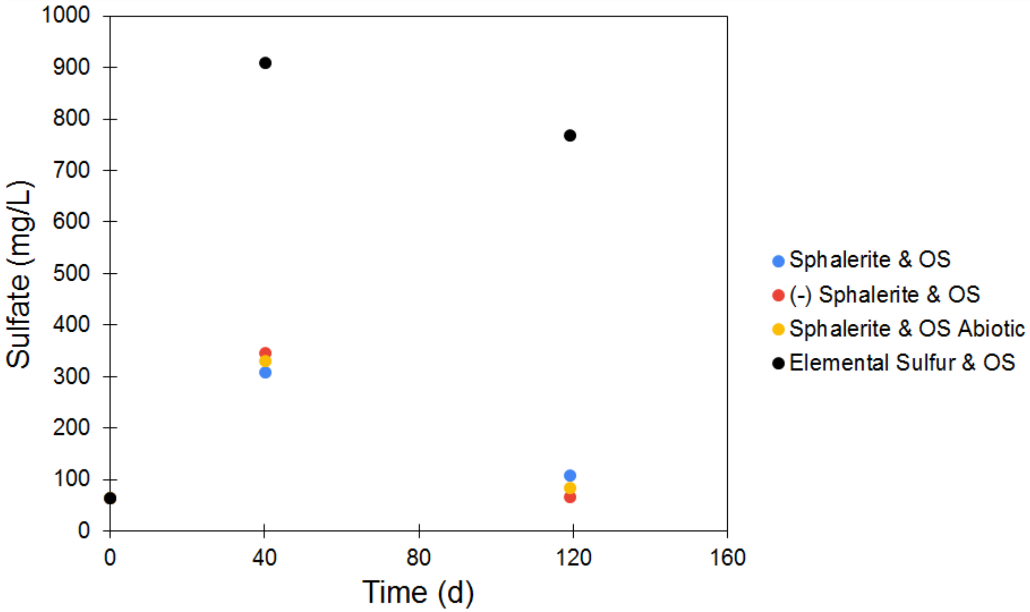
Notes: NS= not specified by the Florida state's reuse regulation; avg = average; ann = annual.

Microcosm study preliminary results

$$0.556FeS + NO_3^- + 0.889H_2O \rightarrow 0.5N_2 + 0.556SO_4^{2-} + 0.556Fe(OH)_3 + 0.111H^+$$

(Iron-sulfur based denitrification)





Nitrate production & sulfate production observed between days 0-40, indicating sulfur-based denitrification occurred