QUARTERLY PROGRESS REPORT

March 2022 – May 2022

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

PRINCIPAL INVESTIGATORS:

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

Work accomplished during this period:

During this third quarter progress was made on the following objectives: Continuing pilot-scale constructed wetlands (CW) studies (Task 2) and constructed wetland performance uncertainty modeling (Task 3). Two manuscripts entitled "*Feasibility of Landfill Leachate Reuse through Adsorbent-Enhanced Constructed Wetlands and Ultrafiltration-Reverse Osmosis*" and "*Hybrid Constructed Wetlands Amended with Zeolite/Biochar for Enhanced Landfill Leachate Treatment*" are currently being prepared for publication. Two conference presentations are scheduled for June 2022, at the Association of Environmental Engineering and Science Professors (AEESP) bi-annual meeting in St. Louis MO and the American Ecological Engineering Society (AEES) annual meeting in Baltimore MD.

Task 2 Updates - Pilot-scale Hybrid Constructed Wetlands

During this quarter, two pilot scale hybrid CWs without/with zeolite/biochar addition (Control-CW and Adsorbent-CW) were continuously operated at the Southeast Hillsborough County Landfill. Under conditions of hydraulic retention time (HRT) 7d and feeding frequency of 7 min/h, an additional horizontal flow (HF) CW filled with woodchips and gravel (1:1 by volume) (Woodchip-CW) was constructed after the HF cell in Adsorbent-CW to improve denitrification (Phase 5). The two CWs were operated for ~80 days, then daily leachate inflow was increased from 40 L/d to 60 L/d to achieve a higher hydraulic loading rate (HLR; 4.0 cm/d for Control-CW/Adsorbent-CW and 2.3 cm/d for Adsorbent-CW + Woodchip-CW) and a lower HRT (4.5d for Control-CW/Adsorbent-CW and 7.4d for Adsorbent-CW + Woodchip-CW) (Phase 6). The experimental phases are summarized in Table 1.

Table 1. Experimental phases for CWs.

Phase	Inflow (L/d)	HLR (cm/d)	HRT (d)	Feeding frequency	Electron donor supplement	# days operation
1	NA	NA	NA	Regular recirc.	No	50
2	24	1.6	**11**	15min/2h*	No	250
3	40	2.7	**7**	15min/2h*	No	100
4	40	2.7	7	**7min/h***	No	140
5	40	2.7-1.2 (1.5)	7+4 (11)	7min/h*	**Woodchips**	80
6	60	4.0-1.7 (2.3)	**4.5+2.9** (7.4)	6min/30min*	Woodchips	60

Note: *Feeding frequency of x/y means pump on for time x every time y; Woodchip wetland increased 4d and 2.9d of HRT at Phase 5 and 6, respectively.

(1) Nitrogen Removal

Nitrogen species concentrations in raw leachate and CW effluent are shown in Figures 1. Overall, zeolite addition to Adsorbent-CW effectively reduced free ammonia concentration to below the inhibitory level for nitrifiers and enhanced NH_4^+-N removal. During Phase 5, Control-CW and Adsorbent-CW decreased NH_4^+-N concentration to ~150 mg/L and ~110 mg/L with NH_4^+-N removals of 63% and 72%, respectively. Woodchip-CW further reduced NH_4^+-N concentration to ~60 mg/L with a total NH_4^+-N removal of 84%. During Phase 6, due to the increased HLR and increased NH_4^+-N concentrations in the raw leachate, NH_4^+-N removals of Control-CW, Adsorbent-CW, and Woodchip-CW decreased to 46%, 64%, and 78%, respectively. However, the nitrification rate of the Control-VF increased from 70 mg/L/d (Phase 5) to 76 mg/L/d (Phase 6) and the Adsorbent-VF increased from 78 mg/L/d (Phase 5) to 157 mg/L/d (Phase 6) (data not shown), indicating a good nitrification performance even under high HLR conditions.

NOx (mainly nitrate) accumulation was observed in both HF-CWs. NO_3^--N concentrations of Control-HF were ~81 mg/L (Phase 5) and ~42 mg/L (Phase 6). NO_3^--N concentrations of Adsorbent-HF were ~97 (Phase 5) and ~93 mg/L. The Woodchip-CW significantly reduced NO_3^--N concentrations to ~9 mg/L (Phase 5) and ~44 mg/L (Phase 6), resulting in a total inorganic nitrogen removal of 82% (Phase 5) and 70% (Phase 6). Increasing HLR increased denitrification rate in Woodchip-CW from 37 mg/L/d (Phase 5) to 61 mg/L/d (Phase 6). The improved total nitrogen (TN) removal after adding the Woodchip-CW showed that the system was carbon limited for denitrification.

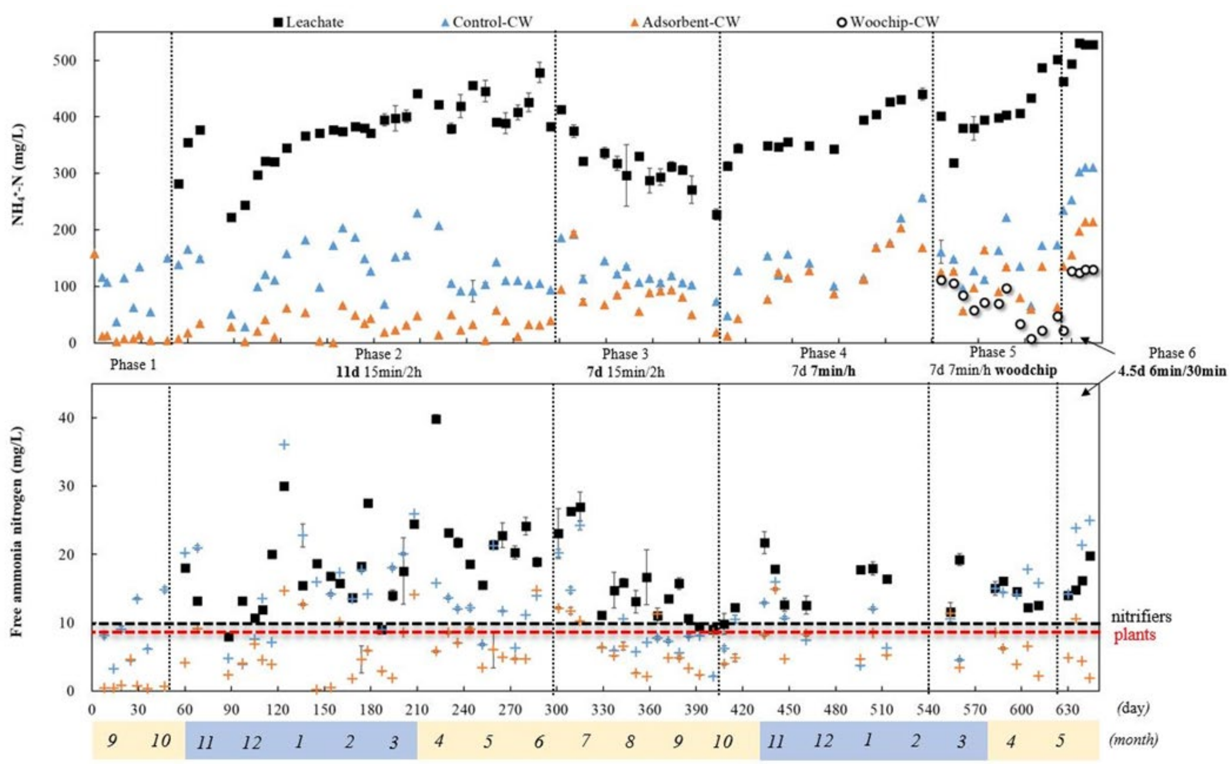

Figure 1. Changes of nitrogen species concentration. Note: months marked in yellow represent warm season, and months marked in blue represent cold seasons.

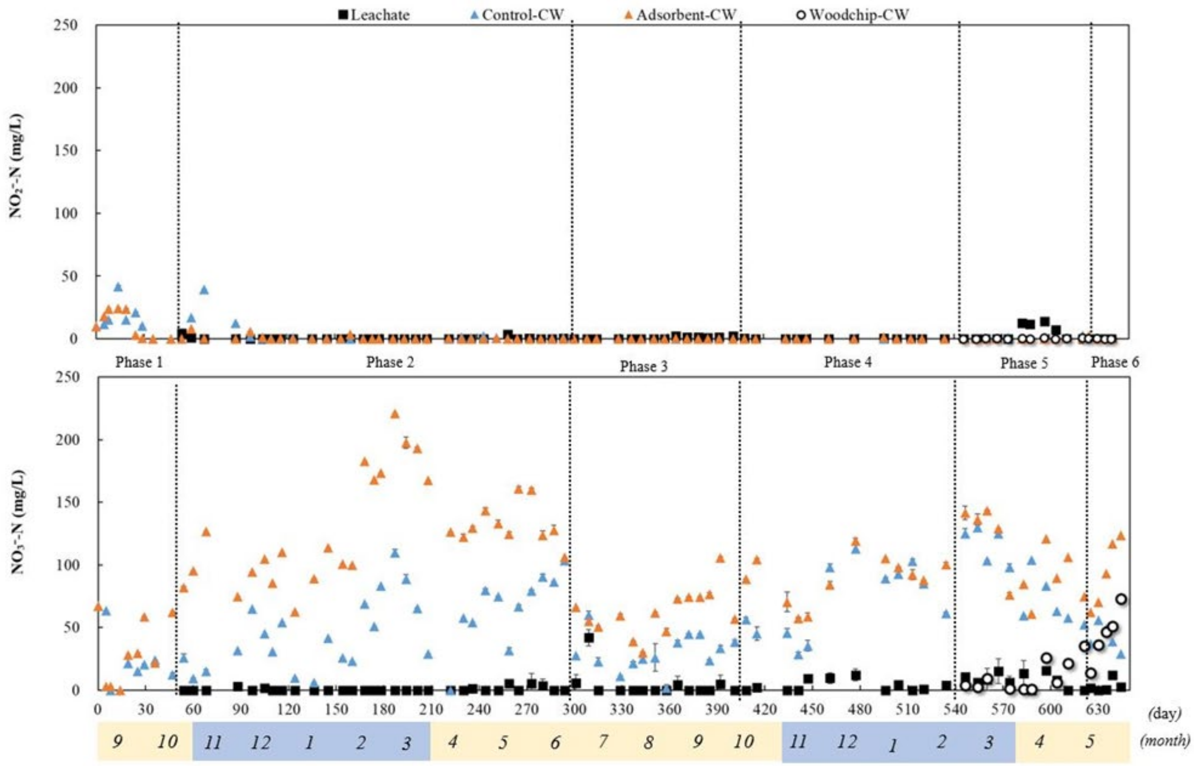

Figure 1 cont. Changes of nitrogen species concentration. Note: months marked in yellow represent warm season, and months marked in blue represent cold seasons.

(2) sCOD and Color Removal

The sCOD concentrations and color in the raw leachate and CW effluent is shown in Figure 2. At Phase 5, sCOD removals were 24% for Control-CW and 29% for Adsorbent-CW at Phase 5. Woodchip-CW increased sCOD concentration due to the release of organic carbon with sCOD removal of 9%. At Phase 6, the increased HLR and sCOD concentration in raw leachate decreased sCOD removal to 20% (Control-CW) and 22% (Adsorbent-CW). While sCOD removal in Woodchip-CW increased to 21%, which indicates an enhanced denitrification occurred with higher organic matter consumption.

Color removals were 4% for Control-CW, 7% for Adsorbent-CW, and -59% for Woodchip-CW at Phase 5. Increasing HLR at Phase 6 decreased color removals to -13%, -7%, and -15% for Control-CW, Adsorbent-CW, and Woodchip-CW, respectively.

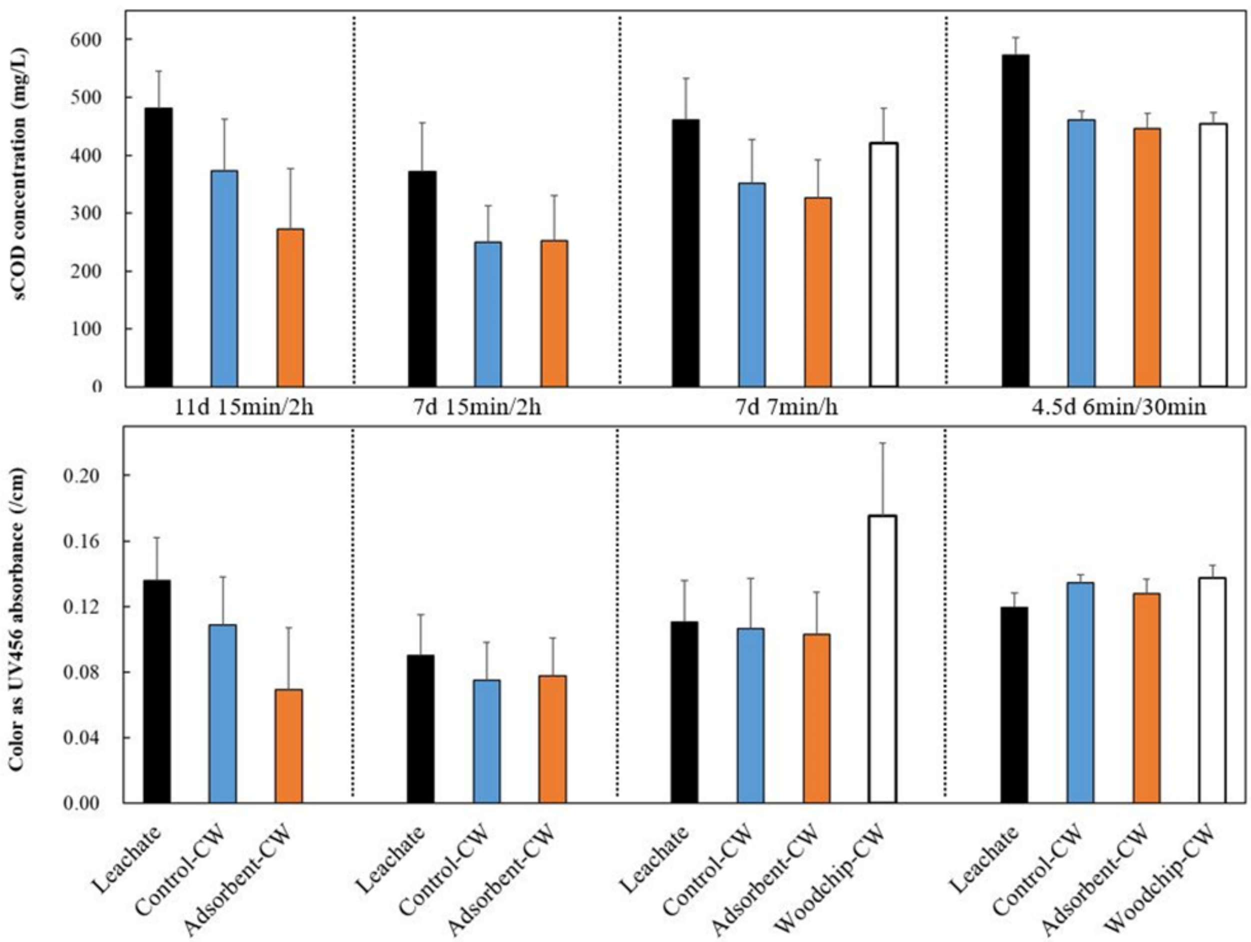

Figure 2. sCOD concentration and color in CWs.

Task 3 - CW Performance Uncertainty Model

During this quarter, a computer model has been set up using the HYDRUS software to simulate the control vertical subsurface flow using van Genuchten-Mualem module. The model set-up has been briefly discussed below.

Model Set-up

Wetland Geometry: The geometry implemented in the model consisted of a media tank of 0.4 m^2 area with 3 layers of main gravel and fine gravel and a drainage layer of coarse gravel. The geometry of the wetland is presented in Figure 3.

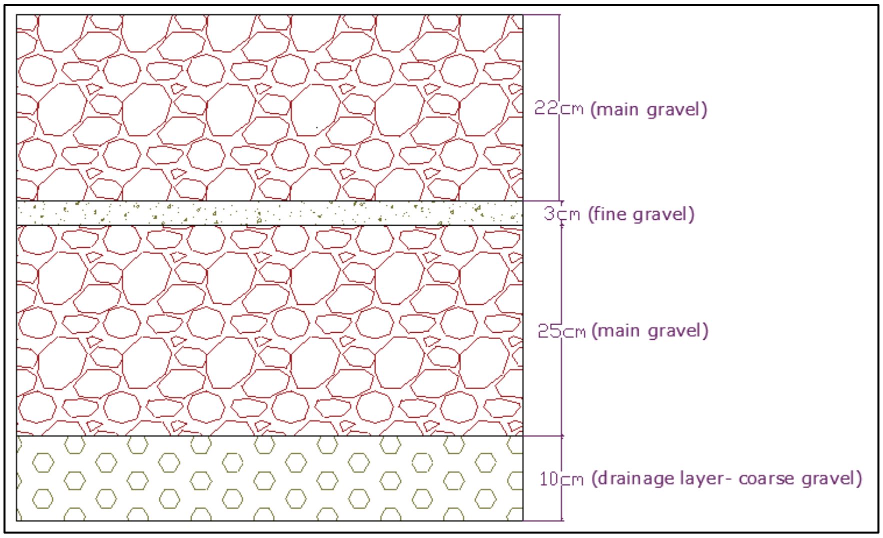

Figure 3: Geometry of VSSF Constructed Wetland

Time Variable Boundary Conditions: The flow has been simulated for 3 days (From April 19, 2021 to April 21, 2021), with an initial time step of 1 hour. The maximum iteration criteria have been set to 100 for precision. The precipitation data for these days have been collected from Weather Underground (Lithia, FL Weather History, wunderground.com) to use for time-variable boundary conditions. During this 3-days period, 24 L of landfill leachate was pumped into the CW tanks intermittently (15min/2hour) controlled by a timer each day. The same amount of effluent was discharged to maintain HRT of 11 days. Thus, the hydraulic loading rate (HLR) has been calculated using following equation, assuming that free drainage occurs at the bottom of the wetland:

HLR= Inflow Rate/Area = 0.033cm/min

Soil Hydraulic Properties: In order to use the Van Genuchten model, a series of soil hydraulic parameters need to be defined. These parameters include the residual water content θr, saturated water content θs, parameter a and n in the soil water retention function, saturated hydraulic conductivity Ks and tortuosity parameter in the conductivity function I. The values for these parameters (Genuchten, 1982; Mallant et al., 2003) are tabulated in Table 2.

Table 2: Van Genuchten Parameters for Soil Layers

Soil Layer	θr	θs	a (1/cm)	n	Ks (cm/min)	I
Main /Coarse Gravel	0.005	0.42	0.493	2.19	40	0.5
Fine Gravel	0.03	0.33	0.007	2.96	19	0.5

Model Data Analysis and Results

For the VSSF system described above, the Hydrus model was set up for 8 different hydraulic loading rates (HLR) to establish a relation between the inflow rate and outflow rate measured per hour. Outputs for different loading rates can be found in the Appendix A. The summary of these output data is presented in Table 3 and graphed in Figure 4. The polynomial relationship between HLR and Bottom Flux will be now used to solve the water mass balance of our control vertical and horizontal tanks.

Table 3: Summary of Model Outputs

HLR (cm/min)	Bottom Flux (cm/min)
0.02	0.0045
0.025	0.0046
***0.033**	**0.0048**
0.04	0.005
0.045	0.0055
0.05	0.006
0.06	0.007
0.07	0.008

*marked value is the HLR of the control system.

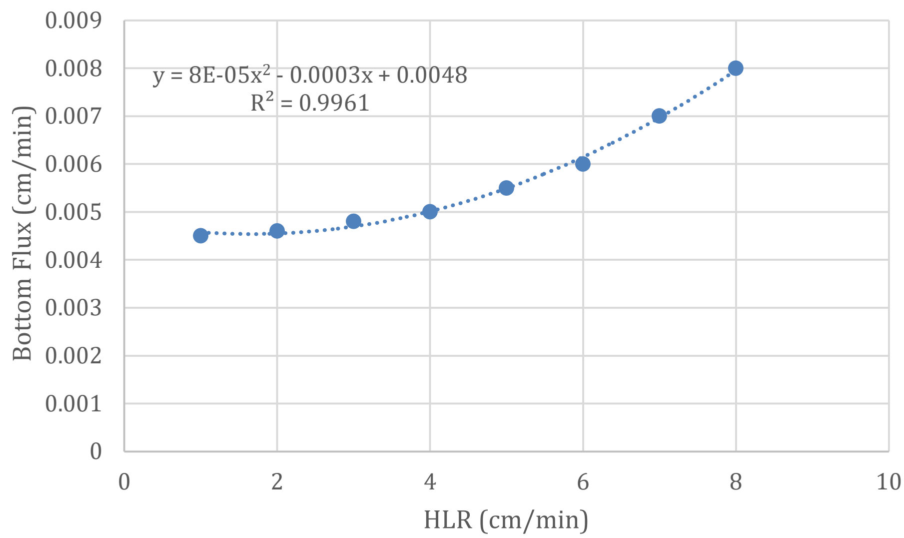

Figure 4: Bottom Flux vs HLR Curve

Project Metrics

1. List of 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, graduated and secured full time employment with the Southwest Florida Water Management District.
- A poster entitled "*Adsorbent enhanced constructed wetlands for landfill leachate treatment*" will be exhibited by Dr. Sarina Ergas at the Association of Environmental Engineering & Science Professor bi-annual meeting on June 28-30, 2022, in St. Louis, MO.
- An oral presentation entitled "*Hybrid Constructed Wetlands Amended with Zeolite/Biochar for Enhanced Landfill Leachate Treatment*" will be given by Xia Yang at the American Ecological Engineering Society annual meeting on May 21, 2022, in Baltimore, MD.

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

Chero-Osorio, Sheyla. Carbon Diversion, Partial Nitritation/Anammox Enrichment, and Ammonium Capture as Initial Stages for Mainstream Ion Exchange-Deammonification Process. Diss. University of South Florida, 2022.

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:
    - The TAG members were invited to visit our pilot system at the SE Hillsborough County Landfill. TAG member visited the site on November 22, 2021, providing direct feedback to the Co-PI and one of the grad students.
    - Members of the project team participated in 2022 Science and STEM Leadership Academy Session, in which we demonstrated principles of waste diversion from landfill and bioenergy production to 16 teachers to let them encourage middle and high school students participating in authentic research activities.

Appendix A

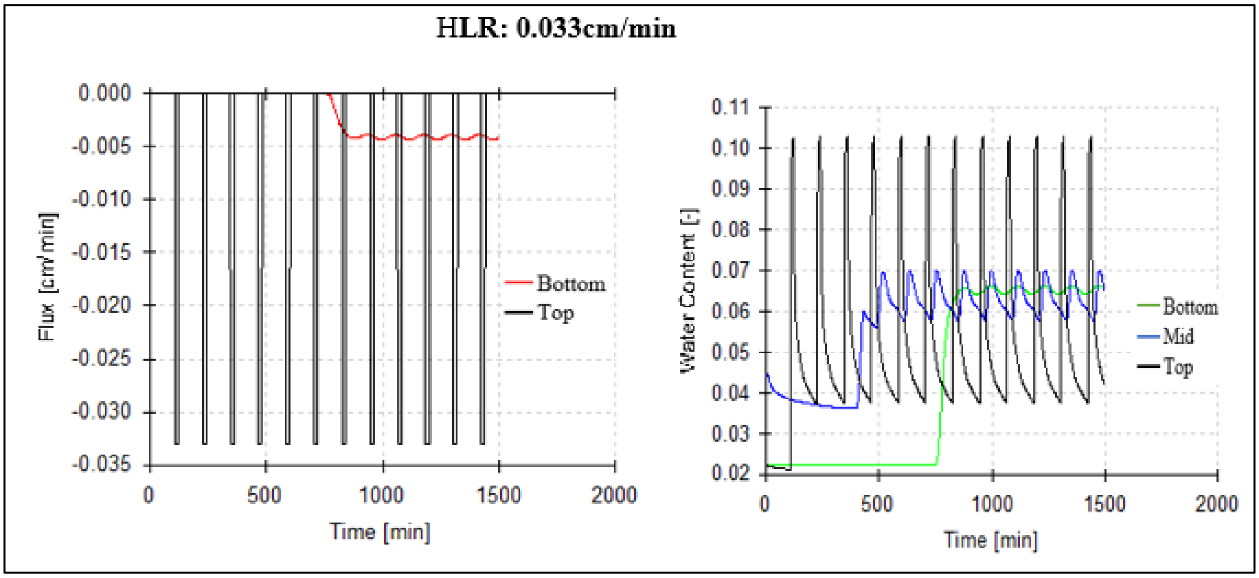

Figure 1: Hydrus Model Outputs for HLR 0.033cm/min

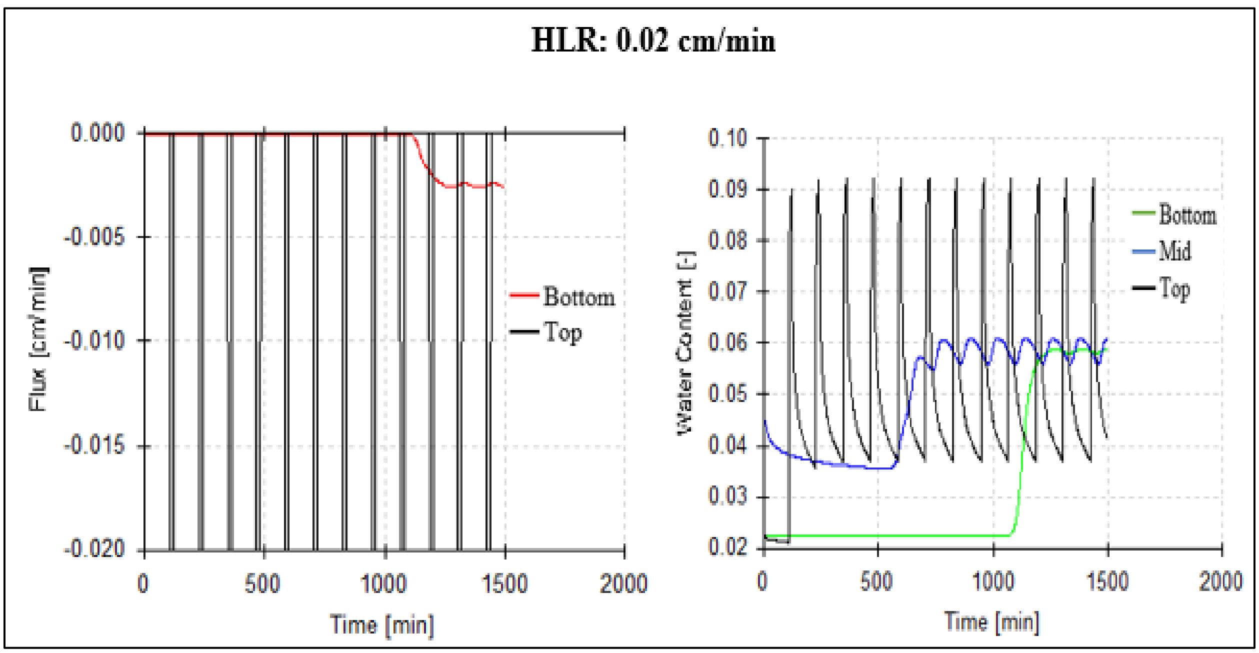

Figure 2: Hydrus Model Outputs for HLR 0.02cm/min

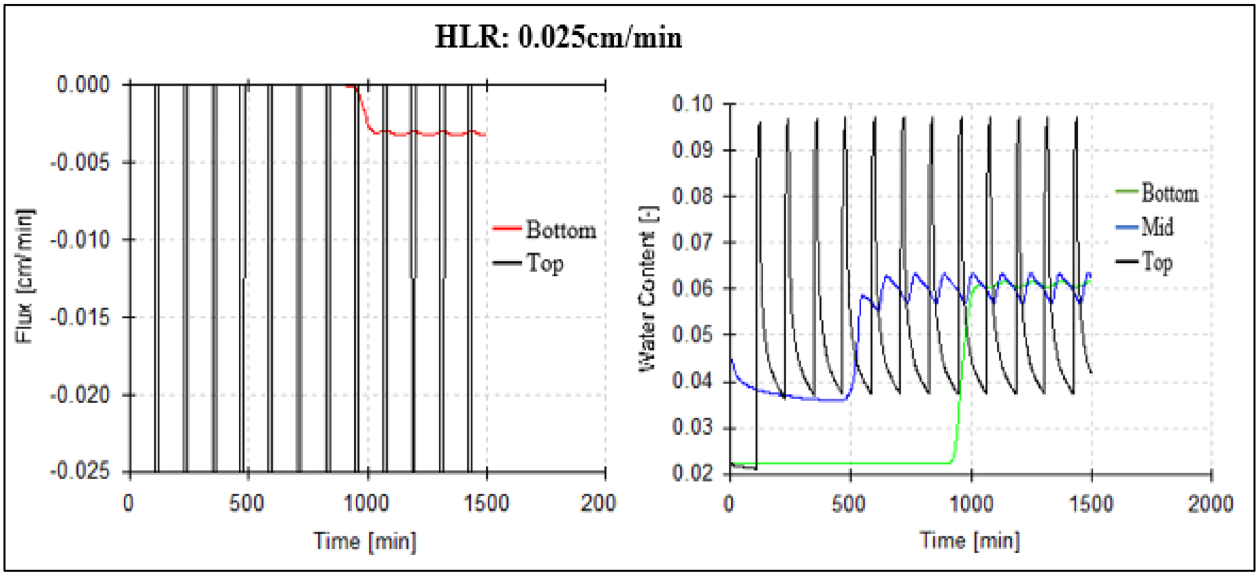

Figure 3: Model Outputs for HLR 0.025cm/min

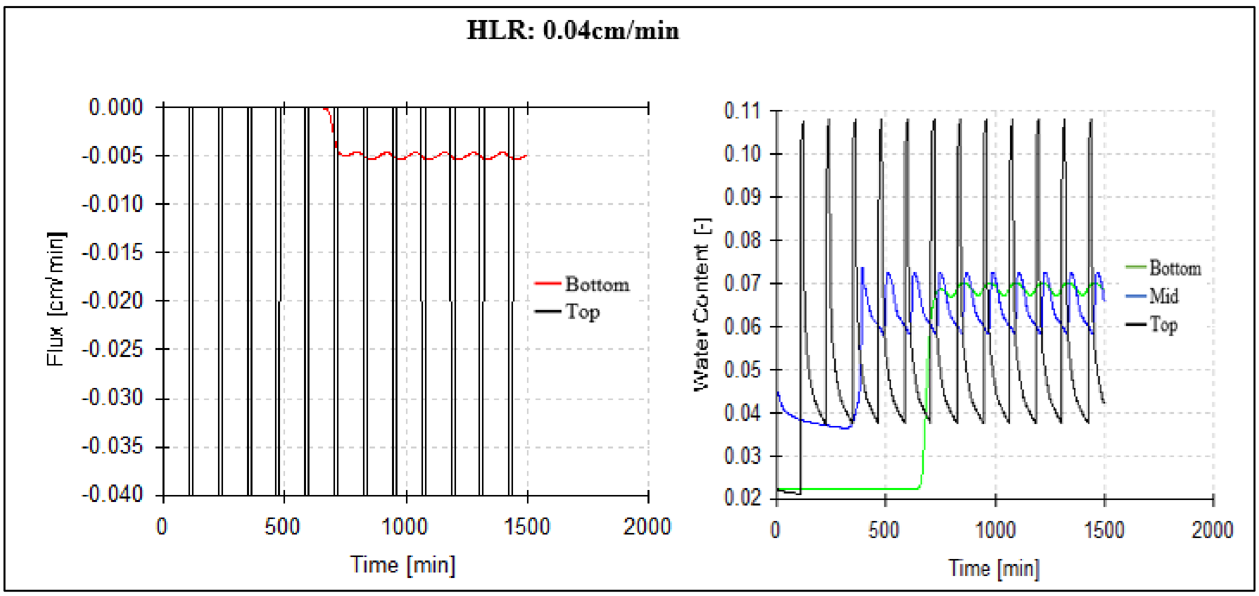

Figure 4: Model Outputs for HLR 0.04cm/min

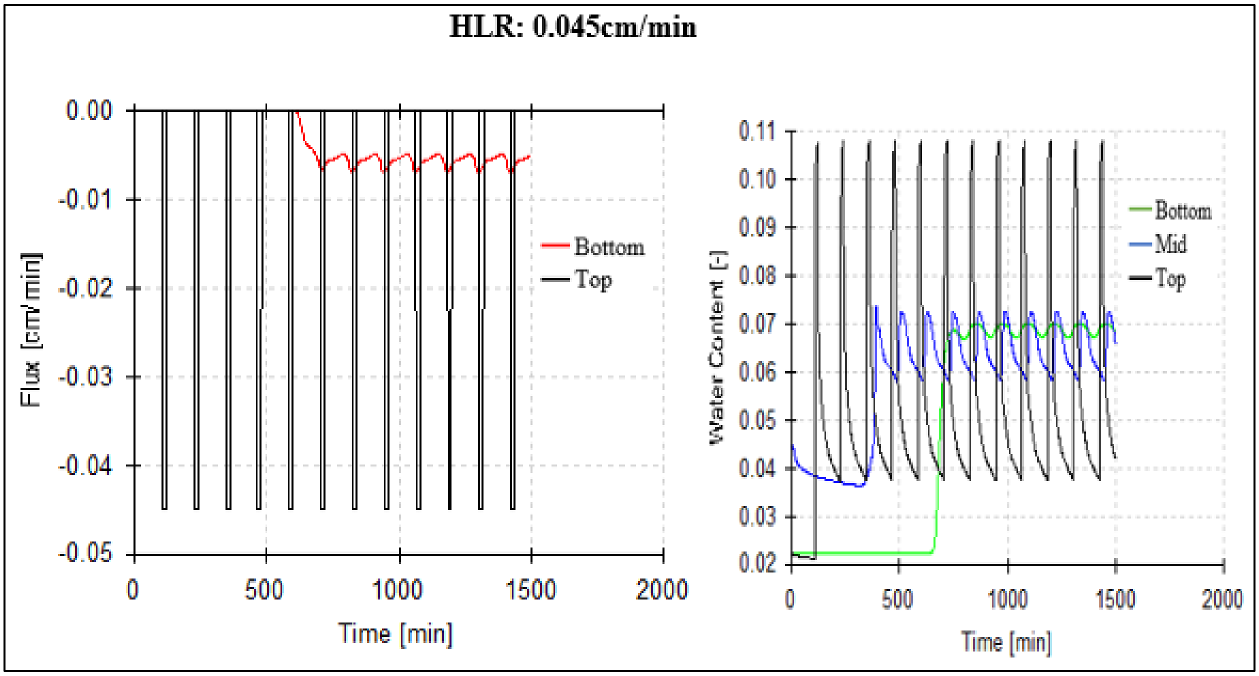

Figure 5: Model Outputs for HLR 0.045cm/min

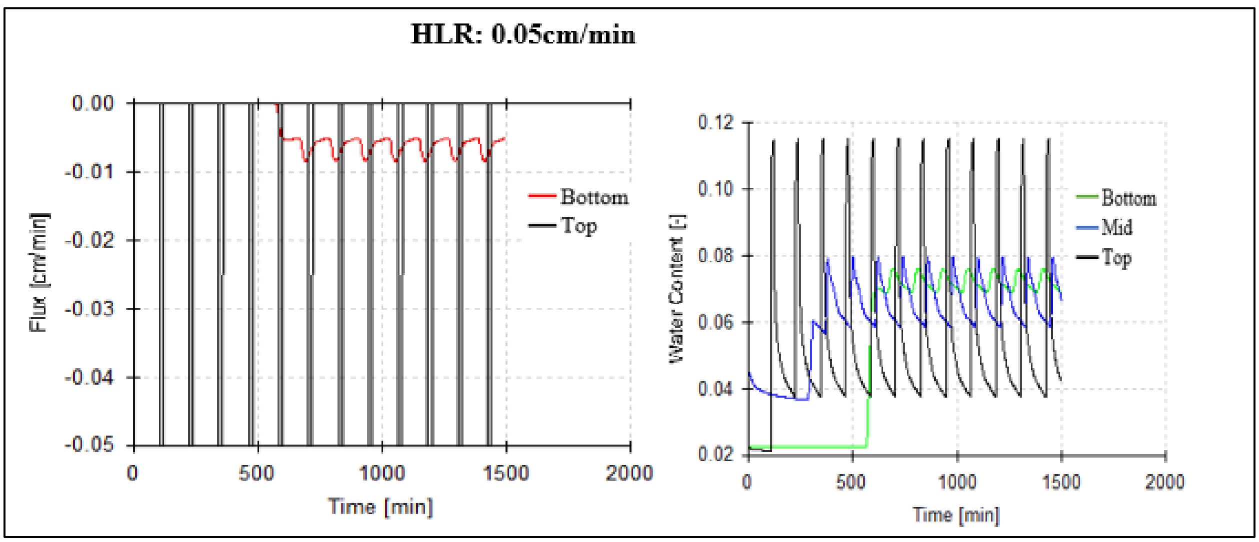

Figure 6: Model Outputs for HLR 0.05cm/min

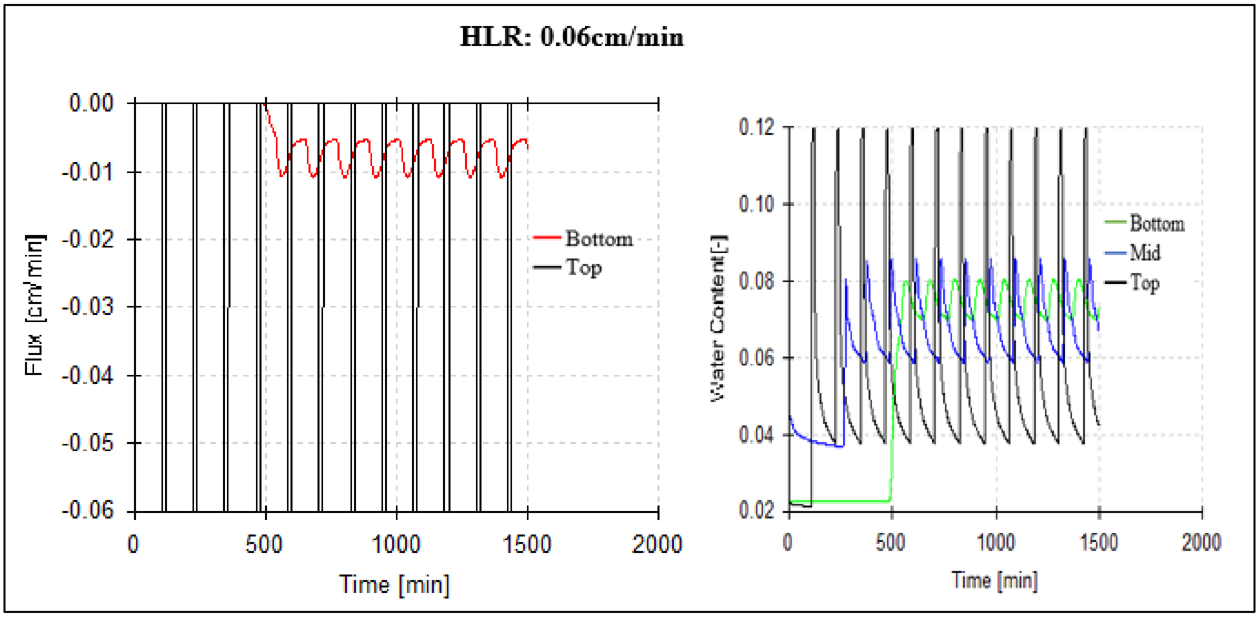

Figure 7: Model Outputs for HLR 0.06cm/min

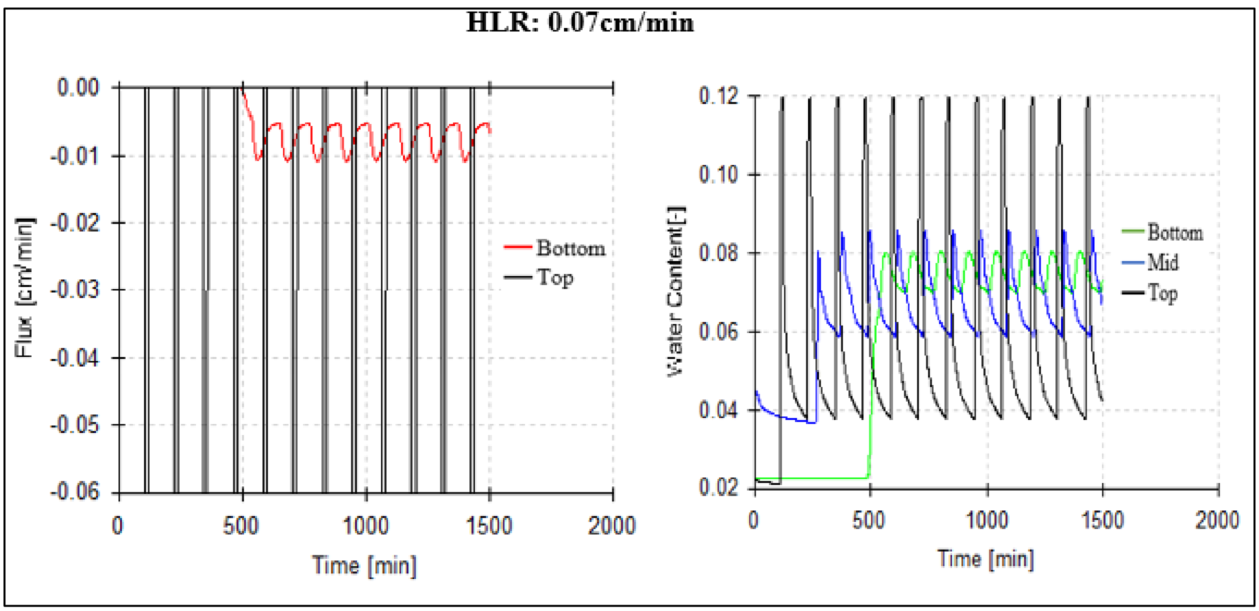

Figure 8: Model Outputs for HLR 0.07cm/min