ATTACHED GROWTH BIOLOGICAL TREATMENT OF RESIDENTIAL GRAY WATER WITH ELJEN® GSF MODULES AND #20 FILTER SAND

Philip T. McCreanor[1], Eric Daniels[2], Emilie Vanness[3], Mohini Patel[3], Ta'Keda Eastern[3]

ABSTRACT

A 5,700 L (1,500 gal.) concrete septic tank was used as the vessel for a gray water treatment system serving a 3-bedroom home in Macon, Ga. The tank was separated into two compartments with capacities of 1,900 L (500 gal.) and 3,800 L (1,000 gal.). The first compartment, 1,900 L, received the gray water flows from the house and provided an opportunity for gravity settling. The settled gray water gravity over flowed from this compartment through a bristle-type septic filter and into the 3,800 L compartment which contained an attached growth biological treatment unit (AGBTU) and sump. The AGBTU consisted of a single-layer of three Eljen® GSF modules over 43 cm (17 in.) of #20 filter sand. A sump was created beneath the AGBTU by wrapping Atlantis D-Raintank™ modules with a high-strength, single-strand, woven geotextile. The effluent was discharged from the sump via a ½-HP high-head effluent pump connected to three sub-surface drip emitter tubing fields. Pump operation was managed with an Infiltrator® AquaWorx Intelligent Pump Control Panel. The system has been operated in both recirculating (forward flush discharged to the settling tank) and single-pass (no forward flush) modes.

This paper focuses on single-pass operation of the treatment system from October 2017 through December 2018. The households average potable water consumption during this time period was 964 lpd (254 gpd) of which 63% or 610 lpd (161 gpd) was used for bathing/showering and laundry. Settled gray water had average COD, BOD_5, $CBOD_5$, TS and TSS of 322, 154, 146, 265, and 35 mg/l, respectively, with an average pH of 6.5. Single pass operation of the system from October 2017 through December 2018 resulted in an AGBTU loading rate of approximately 274 lpd/m^2 (6.7 gpd/ft^2) and produced an effluent with average COD, BOD_5, $CBOD_5$, TS, and TSS values of 80, 18, 11, 214 and 3 mg/l, respectively, with an average pH of 6.4.

INTRODUCTION

According to United States Geological Survey Water Science School (2018), the United States is experiencing groundwater depletion. Reusing water as much as possible for various beneficial purposes reduces the amount of withdrawal from groundwater and surface water sources. Siegrist (1977) posited the potential benefits of separating residential black and gray wastewater flows. Gray water reuse reduces potable water demand and subsequent wastewater flows to municipal treatment facilities. Gray water can be re-used indoors for toilet flushing and outdoors for irrigation purposes. The data presented in Figure 1 suggests that on average the gray water produced from shower, bath, and laundry activities exceeds the water demand for toilet flushing and is almost equal to the demand for outdoor water use. The indoor re-use of gray water for toilet flushing requires significant modification of the indoor potable water plumbing, disinfection, provisions for make-up water, and homeowner education. Outdoor re-use via sub-surface irrigation does not involve modifications to the indoor potable water plumbing, disinfection, or provisions for make-

[1] Ph.D, Professor, Mercer University, School of Engineering, Macon, GA, mccreanor_pt@mercer.edu.
[2] Senior Technical Lead, Eljen Corporation, Windsor, CT.
[3] Environmental engineering student, Mercer University, School of Engineering, Macon, GA.

up water and homeowner educational requirements are minimal. Therefore, this project focused on the treatment of residential gray water with discharge of the effluent via sub-surface drip emitters.

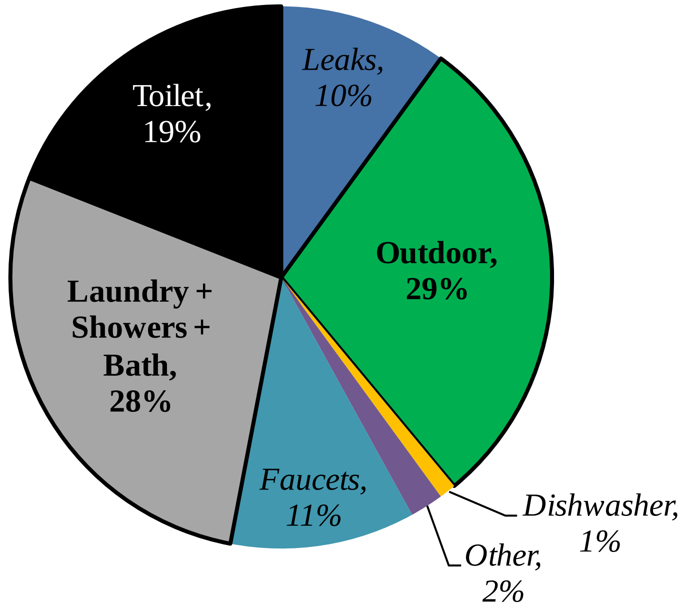

Figure 1. Typical residential water usage, Innskeep and Attari (2014).

EXPERIMENT METHODOLOGY

A gray water treatment system with a three-zone, sub-surface, drip emitter field was installed at a three-bedroom Habitat for Humanity home in Macon, GA. The system receives gray water flows from shower/bath and laundry sources and treats it using settling, coarse filtration, and an AGBTU. The treated water was then discharged through a sub-surface drip emitter system which irrigates portions of the lawn, Figure 2.

The treatments system and sump are contained in a 5,700-L (1,500-gal.), concrete septic tank that has been split into two sections, a 1,900-L (500-gal.) settling tank and a 3,800-L (1,000-gal.) compartment that houses the AGBTU and sump, Figure 3. The gray water from the home enters the settling tank where gravity overflow causes the settled gray water to pass through a bristle-type septic filter and into a loop manifold of perforated, 10.2-cm (4 in.) diameter, SCH40 PVC-DWV pipe located above the AGBTU. The settled and coarse-filtered gray water then trickles through the AGBTU which consists of three Eljen® GSF modules over a 43-cm (17 in.) layer of #20 filter sand, Figure 4. A ~5 cm (~2 in.) thick layer of 6/10 rock was used to transition between the #20 filter sand and the sump which was constructed by wrapping Atlantis D-Raintank™ modules with a high-strength, single-strand, woven geotextile. Figure 5 provides particle size distribution curves for the #20 filter sand and 6/10 rock. Liquid levels in the sump were monitored with a transducer and an Infiltrator® AquaWorx Intelligent Pump Control (IPC) Panel. The AquaWorx IPC Panel was also used to control a ½-HP high-head effluent pump which discharged the effluent through a 150-mesh (100-micron) WYE filter and into a drip-emitter zone. An indexing valve was used to cycle the discharge among the three, equally sized, sub-surface drip zones.

Monitoring of the treatment system's performance involved collecting samples from the settling tank and before and after the 150-mesh WYE filter. These points are referred to as 'Settled', 'Bio-

Treated', and 'WYE-Filtered', respectively, Figure 2. Flow meters were used to quantify potable water consumption and treated gray water production. Hydraulic performance of the system was monitored by measuring flow rates and pressures at various points in the system.

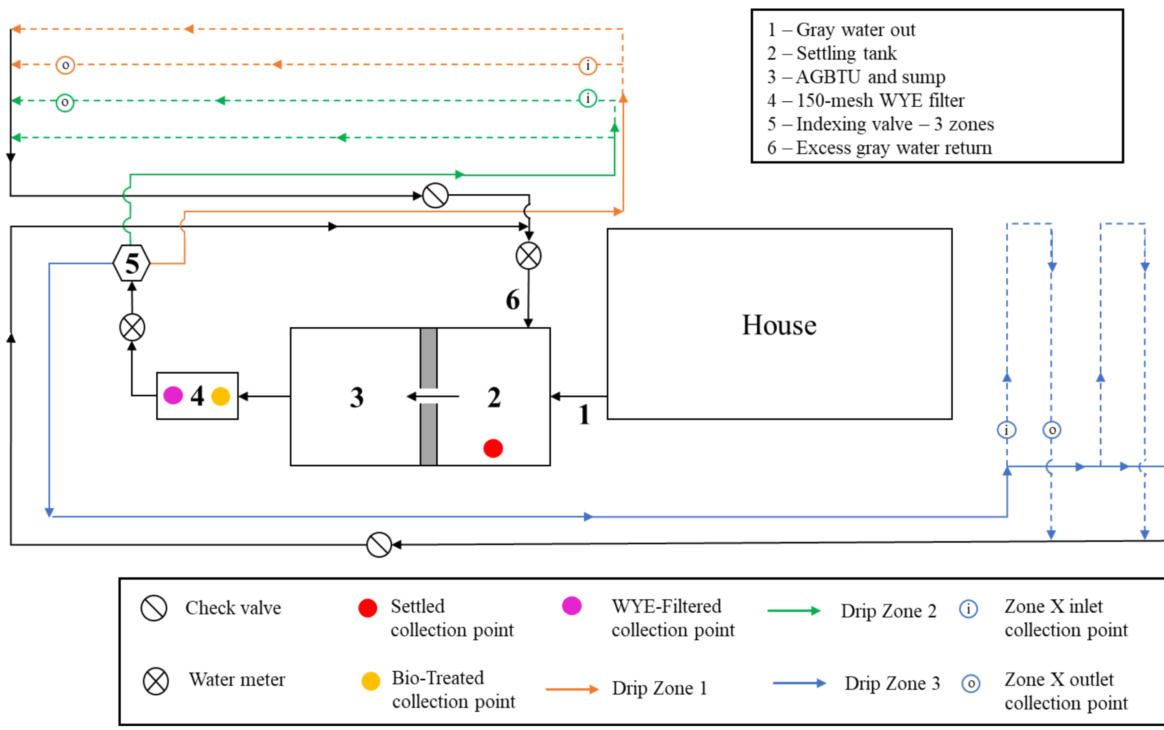

Figure 2. Plan view of the gray water treatment system and sub-surface, drip-emitter zones.

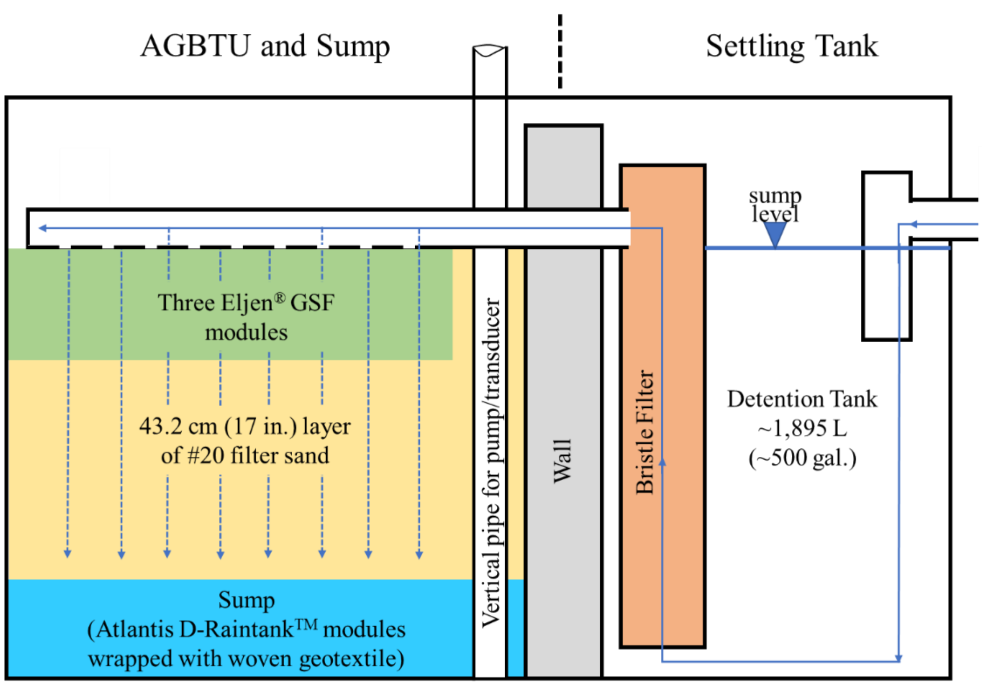

Figure 3. Cross-sectional view of the 5,700-L concrete septic tank containing the settling tank, bristle filter, AGBTU, and sump.

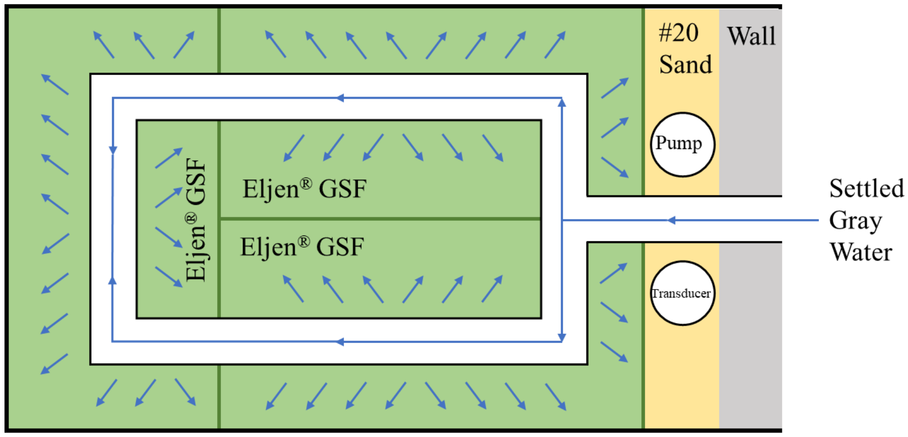

Figure 4: Plan view of the AGBTU compartment in the 5,700-L concrete septic tank.

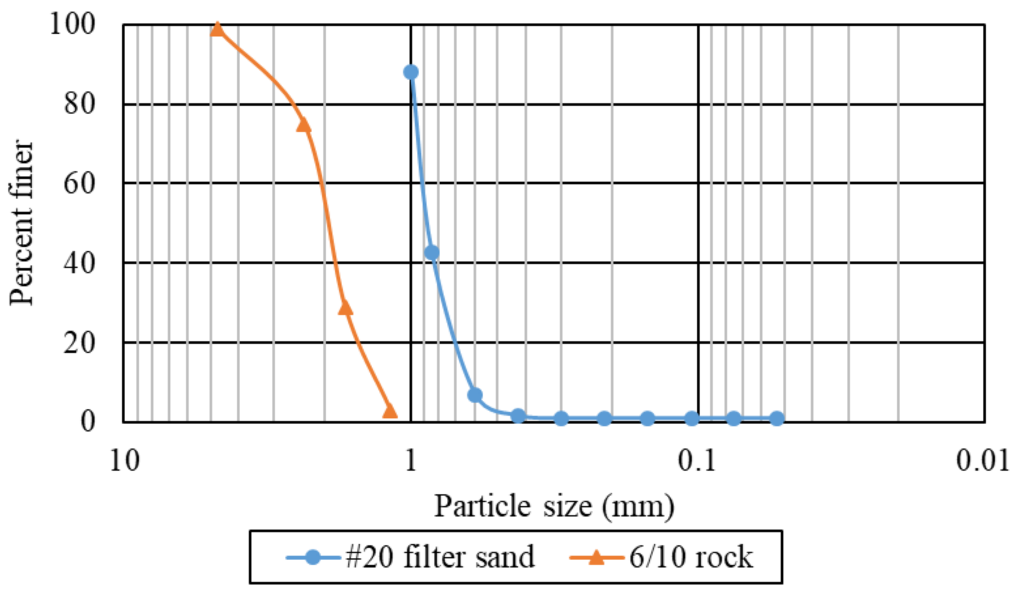

Figure 5: Particle size distribution curves for the #20 filter sand and 6/10 rock.

The Settled sample was retrieved from the settling tank with a vertical sampler while the Bio-Treated and Wye-Filtered samples were collected via valves installed before and after the 150-mesh filter, respectively.

Laboratory analysis results presented in this paper include chemical oxygen demand (COD) five-day biochemical oxygen demand (BOD_5), five-day carbonaceous biochemical oxygen demand ($CBOD_5$), total solids (TS), suspended solids (TSS), and pH.

LABORATORY ANALYSIS PROCEDURES

COD Analysis

The COD analyses were conducted in duplicate for the Settled, Bio-Treated, and WYE-Filtered samples using Hach® Method 8000 and High-Range, Mercury free, COD2 digestion vials. These vials were digested with a Hach® COD Reactor and read with a Hach® DR2800 spectrophotometer.

BOD$_5$ and CBOD$_5$ Analyses

The BOD$_5$ analysis was conducted in triplicate for the Settled, Bio-Treated, and WYE-Filtered samples while the CBOD$_5$ analysis was conducted in triplicate for the Settled and Bio-Treated samples. Both the BOD$_5$ and CBOD$_5$ analyses involve filling a 300 mL bottle with sample and aerated deionized water that has been treated with a Hach® Nutrient Buffer Pillow. Successful BOD$_5$ and CBOD$_5$ experiments require that the dissolved oxygen level drops by at least 2 mg/L but does not go below 1 mg/L. The sample is the source of dissolved oxygen demand while the aerated nutrient water supplies dissolved oxygen. The COD analysis results were used to guide selection of the volume of sample used in these experiments. Hach® Formula 2533™ Nitrification Inhibitor was added to the CBOD$_5$ bottles prior to addition of the sample and aerated nutrient water. Initial and day five dissolved oxygen values were measured using a Hach® HQ440D meter with a LDO probe. BOD$_5$ and CBOD$_5$ were calculated using Equation 1.

$$BOD_5 \text{ or } CBOD_5 \text{ (mg/L)} = \frac{(D_0 - D_5)}{P} \quad (1)$$

where

D_0 = Initial dissolved oxygen measurement (mg/L)
D_5 = Day 5 dissolved oxygen measurement(mg/L)
P = Dilution factor (volume of sample used (mL)/300mL)

Total and Suspended Solids Analysis

The total and suspended solids analyses were conducted in at least duplicate and triplicate where possible according to HACH® Methods 8271 and 8158, respectively. The TS analysis involved adding measured volumes of sample to 70-mm diameter aluminum pans of known weight. The pan and sample were then dried at 105°C and reweighed. The TS concentration was calculated using Equation 2. The TSS analysis involved preparing a Hach® 47-mm 934AH filter and placing it in 50-mm aluminum pan. The pan and filter were dried at 105°C and then weighed. A known volume of sample was then vacuum filtered through the filter paper. The pan, filter, and retained solids were then dried at 105°C. The TSS concentration was calculated using Equation 3.

$$\text{TS (mg/L)} = \frac{W_{TS+pan} - W_{pan}}{V_s} \quad (2)$$

where

W_{TS+pan} = Weight of the pan after the sample has dried at 105°C (g)
W_{pan} = Initial weight of the pan (g)
V_s = Volume of sample used (mL)

$$\text{TSS (mg/L)} = \frac{W_{SS+pan+filter} - W_{pan+filter}}{V_s} \quad (3)$$

where:

$W_{TS+pan+filter}$ = Weight of the pan, filter, and solids after dried at 105°C (g)
$W_{pan+filter}$ = Initial weight of the pan and filter (g)
V_S = Volume of sample used (mL)

mesh filtration) reduced BOD_5 by 89%. This indicates that coarse filtration and the AGBTU are the most important processes for reducing BOD_5 and that supplemental fine filtration will have little additional impact on BOD_5.

In some situations, $CBOD_5$ is the regulatory parameter of interest and the stipulation is often that it not exceed 25 mg/L. The $CBOD_5$ monitoring results presented in Figure 8 indicate that the effluent $CBOD_5$ exceeded 25 mg/L in two of the eleven monitoring events. The average $CBOD_5$s of the Settled, and Bio-Treated samples were 146, and 11 mg/L, respectively. On average, there was a 92% reduction in $CBOD_5$ due to coarse filtration and the AGBTU.

Total solids, Figure 9, for the Settled, Bio-Treated, and WYE-Filtered samples averaged 265, 214, and 219 mg/L, respectively. Results presented in Figure 9 suggest that coarse filtration, AGBTU, and 150-mesh filtration will typically decrease TS levels. In a few instances, the TS levels measured in the Bio-Treated and Wye-Filtered samples were greater than the TS level in the Settled sample. This counter-intuitive result highlights the fact that these sampling results capture unique points in time for each sampling position and that there is a lag time between the gravity overflow from the settling tank and the arrival of effluent in the sump. The elevated TS levels in the Bio-Treated and WYE-Filtered samples were likely related to a similar elevation in TS levels that occurred in the settling tank several days earlier.

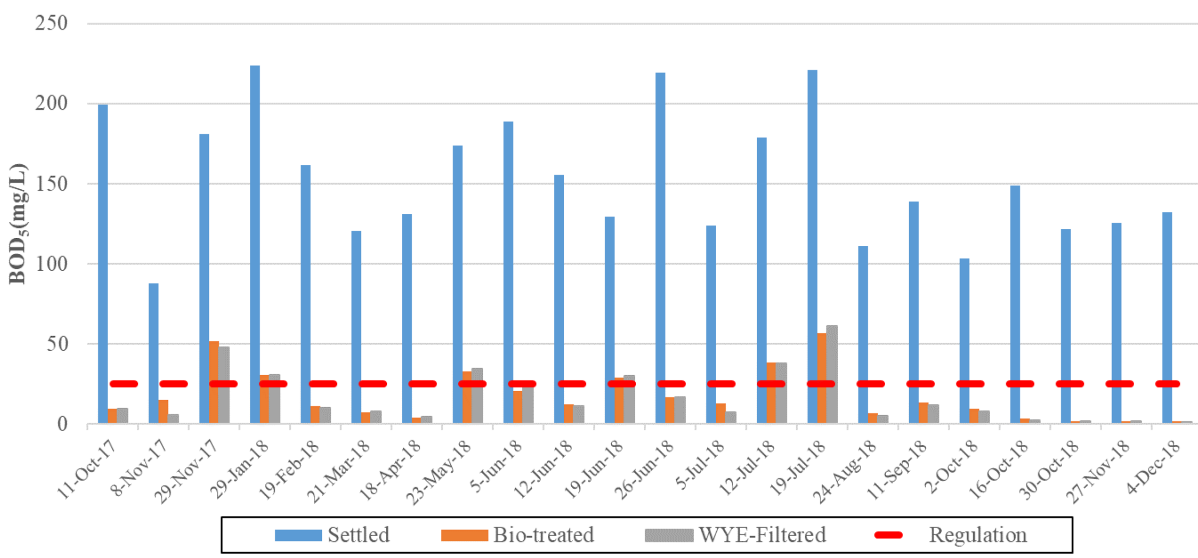

Figure 7. BOD_5 levels in the Settled, Bio-Treated, and WYE-Filtered samples, the Georgia BOD_5 regulatory limit for sub-surface discharge via drip emitters is 25 mg/l.

Georgia regulations, GaDPH (2016), specify that an effluent discharged via sub-surface drip emitters should have a TSS no greater than 30 mg/l. The TSS monitoring results presented in Figure 10 indicate that the effluent complied with this regulation on all twenty-three monitoring events. The average TSSs of the Settled, Bio-Treated, and WYE-Filtered samples were 35, 3, and 3 mg/L, respectively. On average, there was a 92% reduction in TSS due to coarse filtration and the AGBTU and that 150-mesh filtration had no additional impact on TSS reduction. This indicates that coarse filtration and the AGBTU are the most important processes for reducing TSS and that supplemental fine filtration will have little additional impact on TSS.

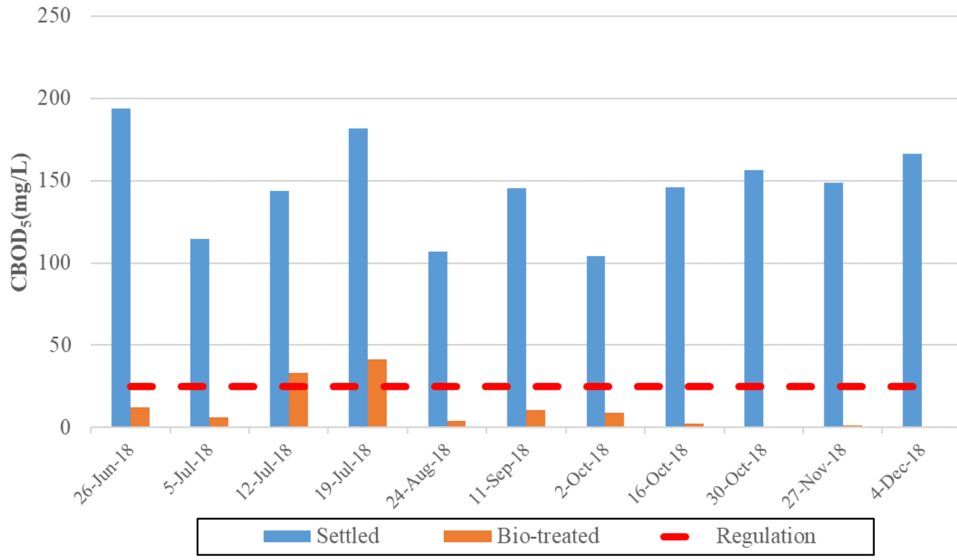

Figure 8. $CBOD_5$ levels in the Settled, Bio-Treated, and WYE-Filtered samples, 25 mg/l $CBOD_5$ is used in some situations as the regulatory limit for effluents.

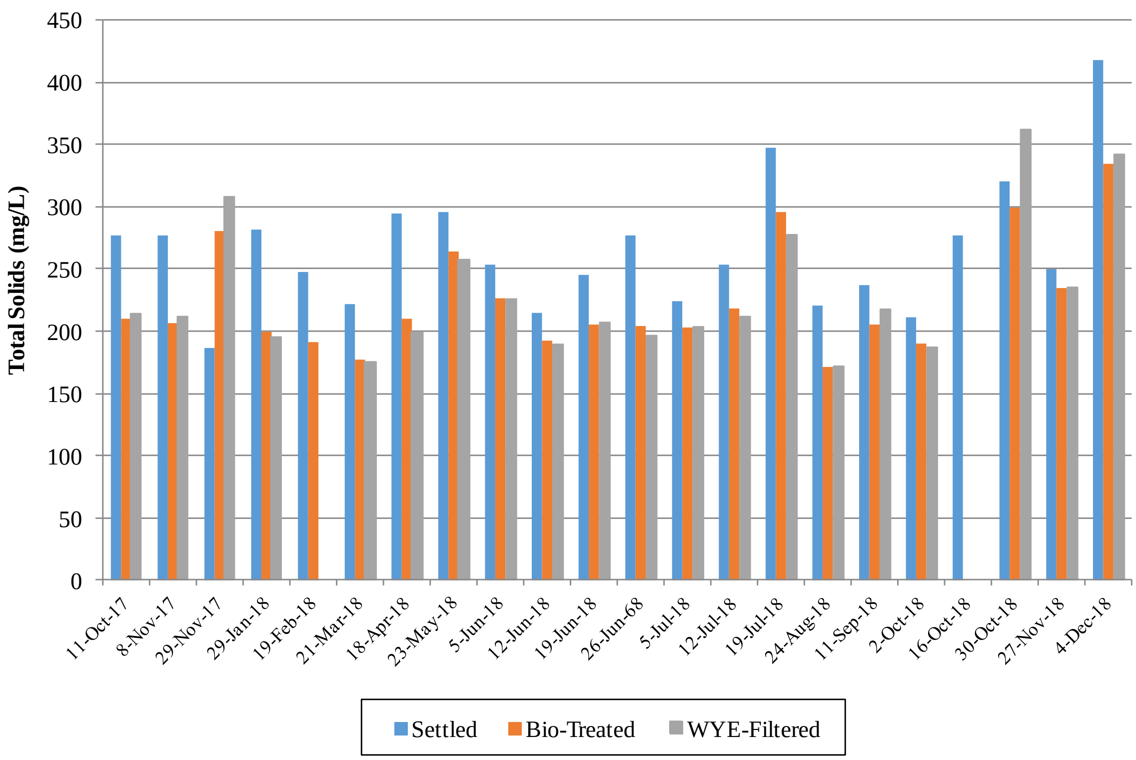

Figure 9. Total solids levels in the Settled, Bio-Treated, and WYE-Filtered samples.

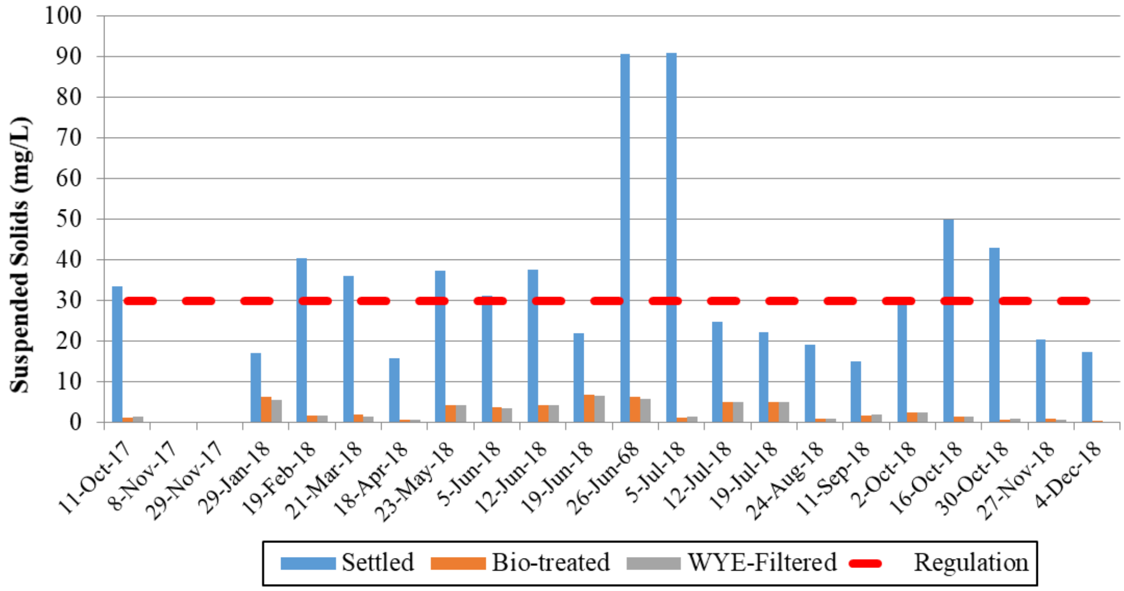

Figure 10. Suspended solids levels in the Settled, Bio-Treated, and WYE-Filtered samples, the Georgia TSS regulatory limit for sub-surface discharge via drip emitters is 25 mg/l.

Gray water is often thought to have an elevated pH due to the presence of soaps and detergents. Monitoring results from this project, Figure 11, suggest that the pH of gray water is neutral to slightly acidic. The average pHs of the Settled, Bio-Treated, and WYE-Filtered samples were 6.5, 6.4, and 6.3, respectively.

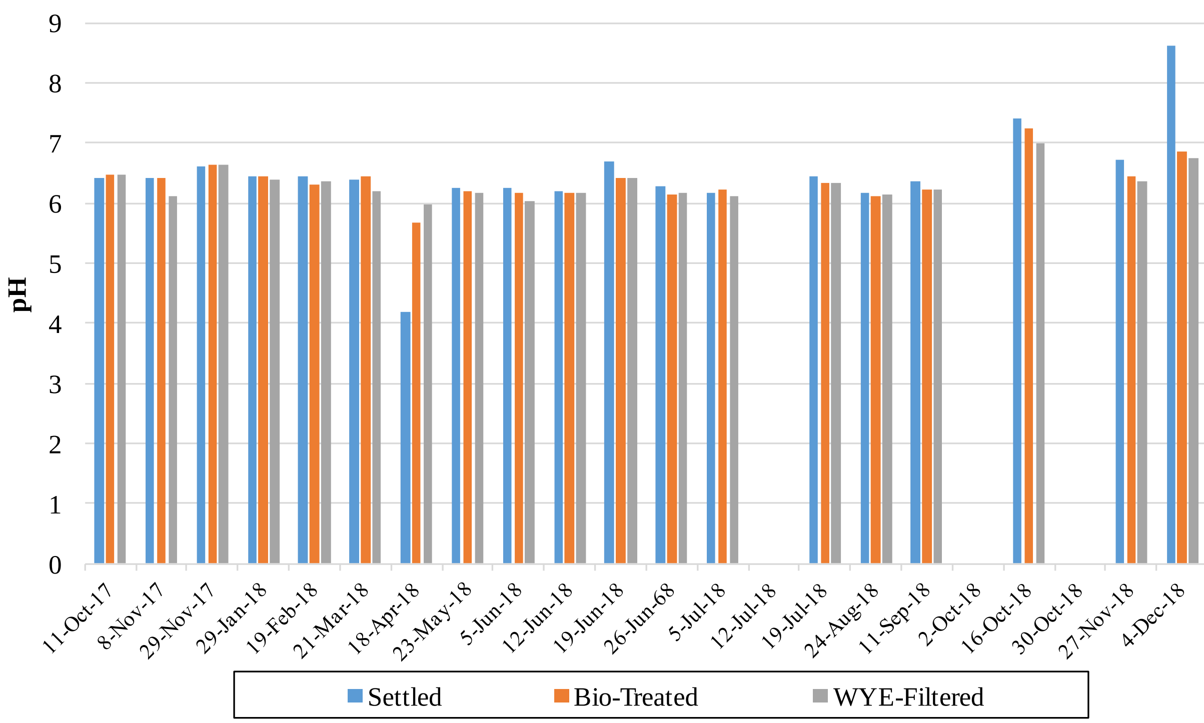

Figure 11. pH levels in the Settled, Bio-Treated, and WYE-Filtered samples.

COD, BOD_5, AND $CBOD_5$ CORRELATIONS

COD values are always expected to be higher than BOD_5 and $CBOD_5$ values because the COD analysis process uses powerful chemicals and high temperatures to chemically oxidize compounds in a sample, while BOD_5 and $CBOD_5$ only measures the compounds that can be broken down by microbes (i.e., biochemically). Similarly, BOD_5 will typically be higher than $CBOD_5$ because BOD_5 includes oxygen consumption associated with nitrification.

A common assumption for domestic wastewater is that the BOD_5 is approximately 2/3 of the COD value. Results from this project, Figure 12, suggest that for gray water BOD_5 is approximately 45% of the COD result while $CBOD_5$ is approximately 47% of the COD value, Figure 13.

The trendline for the relationship between $CBOD_5$ and BOD_5 (Figure 14) suggests that approximately 96% of the BOD5 measurement is associated with oxidation of carbonaceous compounds while 4% of the BOD5 measurement is associated with nitrification.

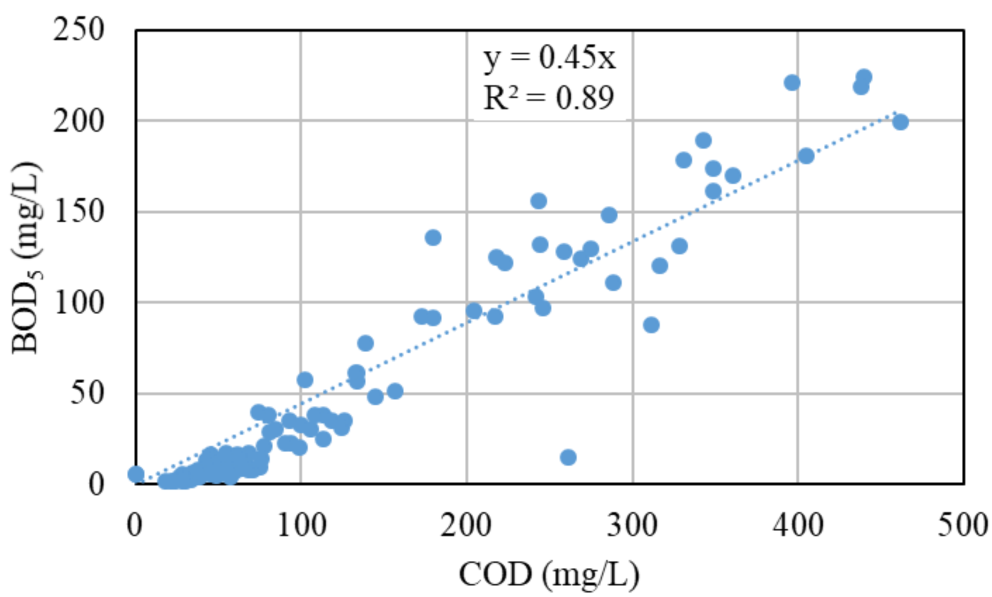

Figure 12. Relationship between BOD_5 and COD.

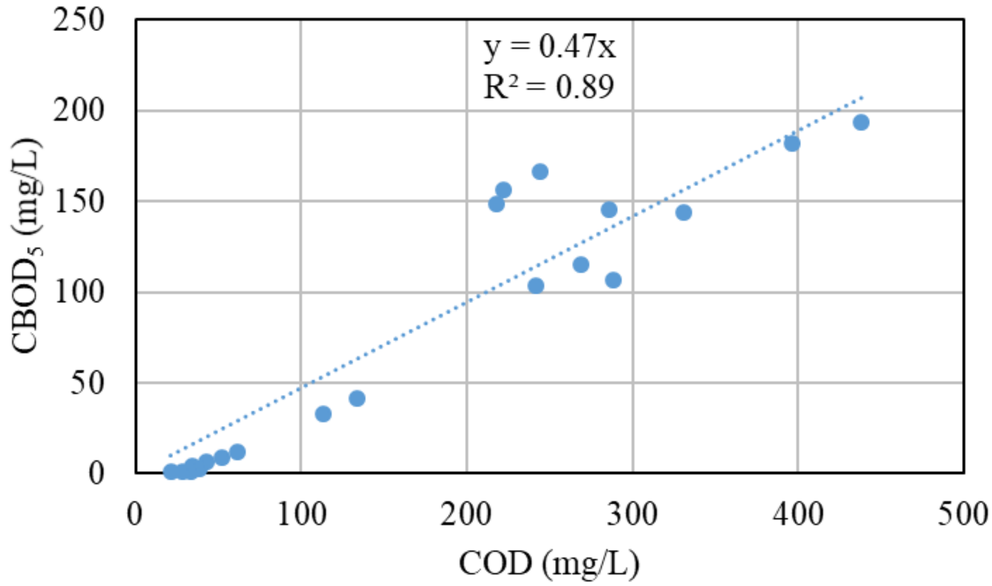

Figure 13. Relationship between $CBOD_5$ and COD.

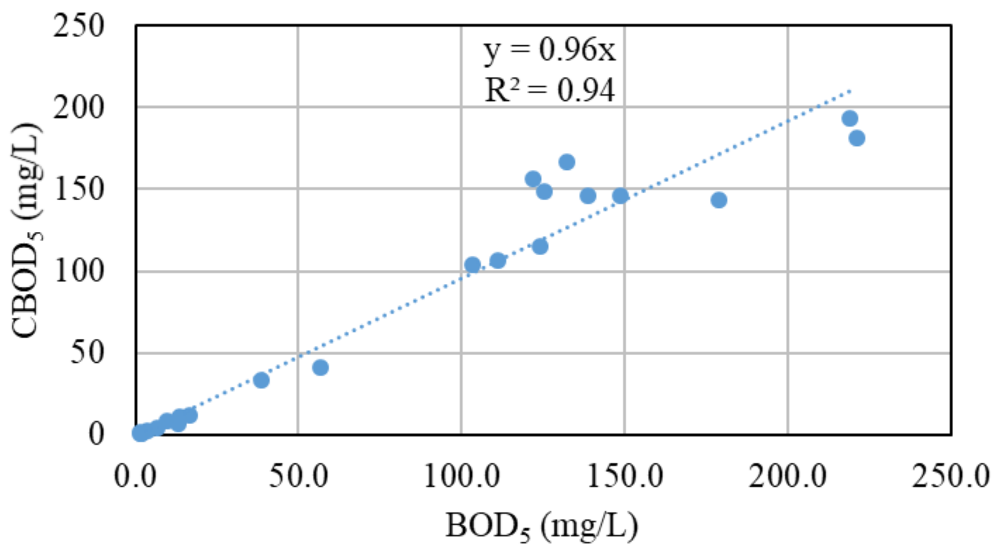

Figure 14. Relationship between $CBOD_5$ and BOD_5.

CONCLUSION

This research project demonstrates that a residential gray water treatment system that utilizes settling, coarse filtration, and an AGBTU consisting of Eljen® GSF modules over 43-cm of #20 filter sand can produce an effluent that meets the common regulatory limit of 25 mg/L BOD5 and 30 mg/L TSS when loaded at 274 lpd/m^2.

ACKNOWLEDGEMENTS

This research project has received financial support from a Mercer University Seed and Service Learning Grant, a State Farm Service Learning Grant, Mercer University Office of the QEP - Research That Reaches Out funding initiatives, the Brazil Science Mobility Program, and a Phase I US EPA People, Prosperity, and the Planet grant. Materials to support laboratory and field projects have been donated by Eljen®, Atlanta Sand, and Infiltrator®. Officials and inspectors with Georgia's Department of Public Health, Environmental Health Program have been generous with their time and expertise. Macon Area Habitat for Humanity has been a critical community partner to this effort. HOW Contracting Service installed the concrete tank system while Taylor Septic Services aided in the design of and installed the plastic tank and liner system. Finally, the data associated with this research project has been generated by the efforts of dozens of Mercer University School of Engineering students and would not have been possible without their diligent and conscientious work.

REFERENCES

Georgia Department of Public Health (GaDPH), Environmental Health Section. (2016). Manual for On-site Sewage Management Systems.

Inskeep, Benjamin D. and Attari, Shahzeen Z. 2014. The Water Short List: The Most Effective Actions U.S. Households Can Take to Curb Water Use. Environment: Science and Policy for Sustainable Development, 56:4, 4-15.

Siegrist, Robert. 1977. Waste Segregation As a Means of Enhancing Onsite Wastewater Management. Journal of Environmental Health, 40:1, 5-9.

USGS. 2016. Groundwater depletion. The USGS Water Science School. water.usgs.gov/edu/gwdepletion.html. Accessed 5 Nov. 2018.