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Feasibility Study to Evaluate On-Site Treatment of Wastewater for Non-Potable Reuse

Report submitted to:
Donna Cosper, P.E., Project Manager
Program Support and Texas OSSF Research Grant Program
Texas Commission on Environmental Quality
P.O. Box 13087, MC - 235
Austin, Texas 78711-3087
Donna.Cosper@tceq.texas.gov

Report Submitted by:
Anish Jantrania, Associate Professor & Extension Specialist
Texas A&M AgriLife Research & Extension
720 E Blackland Road
Temple, TX 76502
(254) 774-6014
ajantrania@tamu.edu

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Executive Summary

Reuse of treated wastewater is one of the five strategies identified by the Texas Water Development Board as a solution to bridge the gap between water demand and supply in Texas. To address this gap, large municipalities are making serious investments in evaluating the feasibility of indirect and direct potable reuse (IPR and DPR) technologies. But, what about the homes and businesses owners that rely on onsite sewage facilities (OSSF)? While IPR and DPR concepts/technologies are not expected to be available for OSSF users soon, onsite wastewater treatment technologies tested under NSF/ANSI Standards 350 (onsite reuse water quality standards), may be adequate for indoor non-potable reuse (INPR) of treated wastewater for toilet flushing. This project evaluated field performance of two such technologies operating at the TAMU OSSF Center in Bryan, TX. Both technologies are aerobic treatment units (ATUs) one with a membrane filter and other with a typical inverted cone type settling chamber. Effluent quality was compared against the NSF/ANSI report and TCEQ reuse water quality standards to determine feasibility for onsite blackwater non-potable reuse.

Raw wastewater from the RELLIS campus sewer line was amended to increase BOD and TSS concentrations to a typical residential strength and the amended wastewater was dosed every hour to both the treatment systems. MBR treatment system/train was comprised of trash-tank, aerobic tank with membrane filter, and final effluent tank in which Ozone was added for disinfection. Non-MBR treatment system/train also has a trash-tank, aerobic tank with inverted cone settling chamber, and final effluent tank in which UV light and liquid chlorinator are used for disinfection. Automated samplers were used to collect hourly composite samples from the trash-tank and the final effluent tank. Sampling period started in December 2020 and continued till August 2021, during which eight samples were collected and analyzed every month by a private certified laboratory. System performances were evaluated under normal and abnormal operating conditions. During February an extreme freeze in Texas made sampling only possible for six days instead of eight. Both the systems performed reasonably well during the deep freeze period; however effluent quality deteriorated. Original plan was to analyze samples for only TSS, Turbidity, and *E. coli* BOD analysis was added to the list in February and total nitrogen parameters were added in April.

Total of 1,275 wastewater quality results were obtained during the nine-month sampling period and water meter readings were recorded to determine average daily load for each month. An Excel spreadsheet was used for wastewater quality and quantity data analysis. Average daily flow to MBR system was 13% higher than that to non-MBR system (259 GPD versus 227 GPD). Average influent BOD and TSS in amended wastewater were 294 mg/L and 242 mg/L. BOD and TSS reduction in the trash-tank for MBR system were higher compared to non-MBR system because the MBR system uses an effluent filter. However, both systems achieved >95% reduction of BOD and TSS in the final effluent. Average TSS and Turbidity levels in MBR system effluent (1 mg/L and 1 NTU) were significantly less than in non-MBR system (11 mg/L and 14 NTU), demonstrating effectiveness of both the membrane filtration and ozonation. Average *E. coli* level in MBR system effluent (17 MPN/100 mL) was not significantly different from non-MBR system effluent (28 MPN/100 mL), indicating equivalent effectiveness of ozone and UV + Chlorine for disinfection. Additional field evaluation of a treatment-train with triple disinfection (ozone + UV + Chlorine) following an ATU or other equivalent onsite aerobic treatment system is recommended to genuinely assess the feasibility of blackwater reuse for indoor toilet flushing.

Section 1. Introduction and Background

On February 4, 2019, TOGP issued the first Request for Grant Application (RFGA), in which following four research topics were identified as "Eligible Projects" that must be addressed to make a project eligible for funding (TCEQ RFGA No 582-19-93772, 2019):

1. Adequacy of Current Designs of Aerobic Treatment Unit with Higher Strength Wastewater
2. Dosing vs. Non-Dosing of Aerobic Treatment Unit
3. Implementation of Low-Pressure Dose Systems with Various Configurations
4. **Black Water Non-Potable Reuse**

The RFGA stated following explanation for the 4th research topic:
"As Texas' population grows, water availability continues to be a growing need. The state acknowledges that reuse is part of the solution. Currently, domestic on-site wastewater is rarely reused in Texas, with the exception of graywater systems. Current rules governing wastewater (blackwater) reuse are the same for large wastewater treatment plants as they are for small on-site wastewater facilities. The study should include consideration of "real world" conditions for on-site systems, such as potentially varying facility maintenance requirements, monitoring requirements and frequency, exposure risk to the public, and potentially varying system inputs. Research under this category could take into account systems that meet NSF Standard 40, NSF Standard 350, or NSF Standard 350-1 requirements, and could include research concerning whether modification of standard on-site wastewater "treatment trains" or maintenance requirements could result in higher quality, reliable effluent for reuse purposes."

As indicated in the RFGA, Texas' population has been growing and is expected to grow during this century. While most of the dwellings in Texas are served by centralized water and wastewater (sewer) systems, about 20% are served by On-Site Sewage Facilities (OSSFs). Texas A&M University (TAMU) research and extension team (TAMU OSSF team) is involved in various activities related to OSSF, including maintaining an inventory of the OSSFs. Total number of dwellings using OSSFs in Texas end of year 2020 is estimated to be more than 2.3 million which is expected to grow at a rate of about 30,000 per year based on the historical data. Figure 1 shows increasing use of aerobic treatment unit (ATU) spray type OSSFs (measured as number of permits issued per year) in Texas to meet the demands in areas where soil and site conditions are not suitable for septic tank drain field type OSSFs. An ATU approved by TCEQ that meets NSF/ANSI Standard 40 (NSF, 2018), followed by either a chlorine or a UV (Ultraviolet) disinfection unit is required for ATU spray systems.

Reuse of treated wastewater is one of the five strategies identified by the Texas Water Development Board as a solution to bridge the gap between water demand and supply in Texas. Large municipalities are making serious investments for indirect and direct potable reuse (IPR and DPR) of adequately treated wastewater. But, what about the homes and businesses that are not served by municipal water and wastewater systems, i.e., the OSSF users? While IPR and DPR concepts/technologies are not expected to be available for OSSF users in near future, onsite wastewater treatment technologies evaluated under NSF/ANSI Standards 350 (NSF, 2020), may be adequate for indoor non-potable reuse (INPR) of treated wastewater for toilet flushing. As shown in Figure 2, toilet flushing accounts for about 27% of water demand in a residential home and as high as 51% in hotel industry.

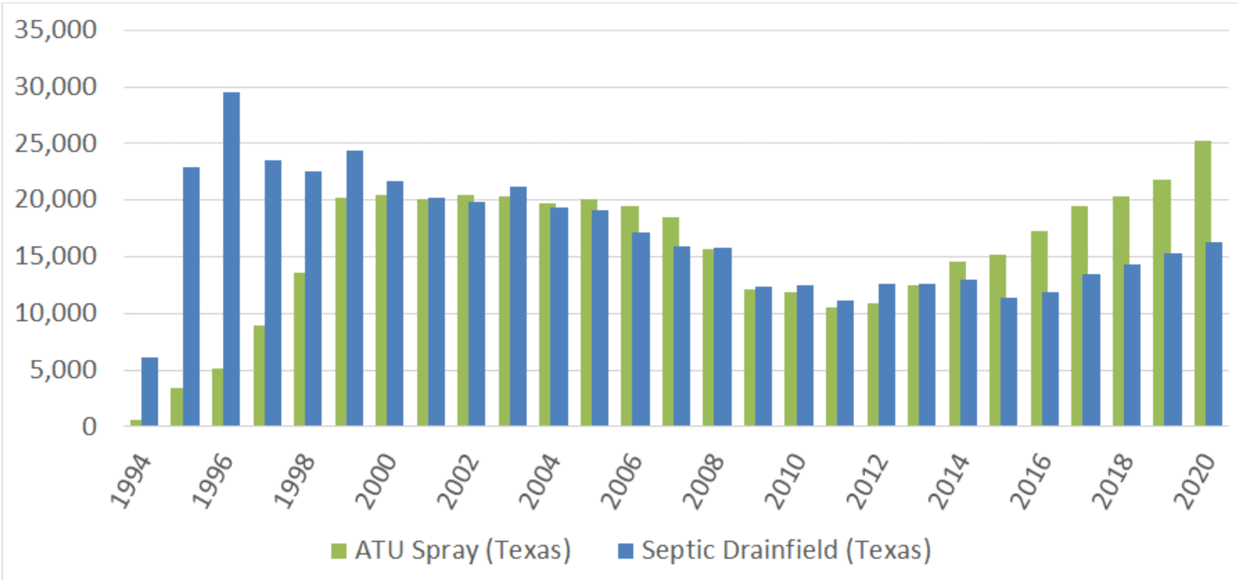


Figure 1: Trend showing increasing use of aerobic treatment unit (ATU) spray in Texas since mid-1990s. Y-axis shows the number of permits issued in Texas and X-axis is the year. Data complied from the TCEQ OARS information received annually since year 2016.

With more than half the new OSSFs permits issued for ATU type systems, there is a potential to reduce the demand on fresh water supply by millions of gallons per year if reuse of treated wastewater for toilet flushing is adequately addressed under the TCEQ Chapter 285 Regulations. As indicated in the RFGA, domestic on-site wastewater is rarely reused in Texas, with the exception of graywater systems, and one of the reasons is lack of regulatory guidance. Commercial buildings where toilet flushing is the main contributor to wastewater stream, reusing treated wastewater is quite beneficial. For example, the Navarro Safety and Rest Area on I-45 operated by Texas Department of Transportation (TxDOT) claims to reuse wastewater for toilet flushing (Photo-1), however due to treatment-train challenges reuse was abandoned a few years ago.

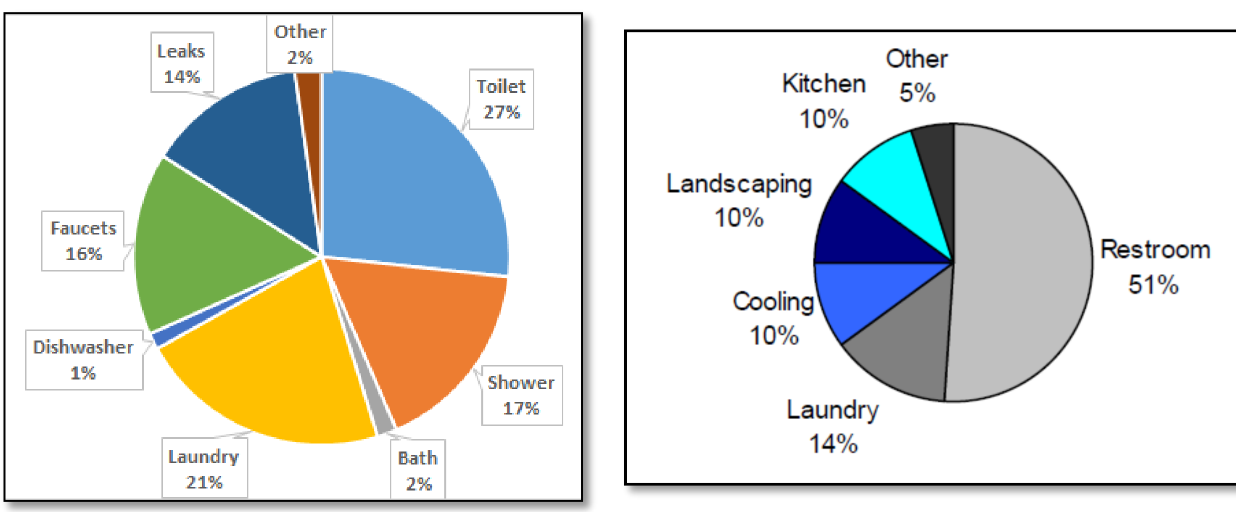


Figure 2: Indoor water use percentage distribution found in a residential home (left) and in the hotel industry (right). (References: US EPA Onsite System Design Manual for residential home, and a report from Pacific Institute Website for hotel industry).

Photo 1: TxDOT operated safety and rest area building with dual plumbing for reusing reclaimed water (treated wastewater) to flush toilets and urinals.

The TxDOT site offered a great opportunity to study the technical problems associated with reusing treated wastewater indoor for toilet flushing at a busy public area. The wastewater treatment at this site is an aerobic treatment with membrane system. Section 3 includes details on the operational problems faced at this site and potential solution considered to address them.

TAMU OSSF team operates a hands-on training, research, and demonstration center on RELLIS Campus (Figure 3) with capacity to conduct a field scale applied research project to address the concerns raised under the fourth research topic related to *Black Water Non-Potable Reuse* as well as other three topics. In the last week of March 2019, TAMU-OSSF team submitted three proposals to TCEQ to address all four questions raised in the RFGA. The proposal specific to the Black Water Non-Potable Reuse was submitted through Texas A&M AgriLife Extension with the goal to find answers for the following three questions:

1. Would the effluent quality from onsite wastewater reuse technologies under variable field conditions be comparable to the test results obtained under controlled NSF/ANSI Standard 350 testing protocol?
2. How would the overall performance of a reuse technology with a membrane filtration unit compared with the one without the membrane filtration unit?
3. Are any modifications to a standard onsite wastewater treatment-train and/or operation and maintenance requirement necessary for ensuring reliable effluent quality for indoor non-potable reuse purpose?

Note that the original proposal to TCEQ was to study only the membrane technology, however the second question was modified based on the input received from the advisory committee meeting held on RELLIS Campus during the first quarter of the project.

In early 2016, a membrane bioreactor (MBR) system donated by Bio-Microbics (BioBarrier® MBR 0.5) was installed and used during a federally funded Research and Extension Experience for Undergraduate (REEU) program. To add a non-membrane system, TAMU-OSSF team reached out to Clearstream to replace an existing Standared-40 ATU with their reuse technology (Model 500 DA) tested under Standard-350. Clearstream agreed and their unit was installed at the Center in March 2020 and started in August 2020 (installation was delayed due to Covid-19). In this report, these two technologies are identified only as **MBR** and **non-MBR** systems. Details on both systems are presented in the following sub-section.

Figure 3: TAMU OSSF Center aerial view showing layout of the treatment tanks used for all three research projects.

Section 1.1 Reuse Systems Studied in this Project

Figure 4 presents cross sections of both the MBR and non-MBR treatment tanks studied in this project. Amended raw wastewater from a common 3,000-gallon Feed Tank (noted as C in Figure 3) was time-dosed (24 equal doses per day) at a pre-determined daily flow rate. (Details on wastewater amendments are included in the ATU project report). The MBR unit shown in Figure 4, shows the trash tank (primary treatment) and aerobic tank (MBR) as one unit. However, the MBR system installed at the Center has two separate tanks, each a 500-gallon capacity Infiltrator Tank (IM-540), one used as a trash tank and the other used for the MBR (see installation photos in Section 2). The non-MBR tank is a one concrete tank with three chambers, first chamber is a trash tank, second chamber is a final effluent pump tank, and the third chamber is aerobic tank unit. Note that the MBR system has an effluent filter in the trash tank, while the non-MBR system does not has an effluent filter. The effluent from the MBR system is dosed into a 500-gallon Infiltrator tank in which Ozone is pumped for disinfection. The effluent from the non-MBR system is disinfected using UV first and then liquid Chlorine, both operating in the final pump tank. Liquid chlorine was added as necessary to maintain at least 0.1 mg/L residual, while the Ozone system operated on a 40-minute ON and 20-off cycle. Table 1 gives summary of the treatment train for MBR and non-MBR system.

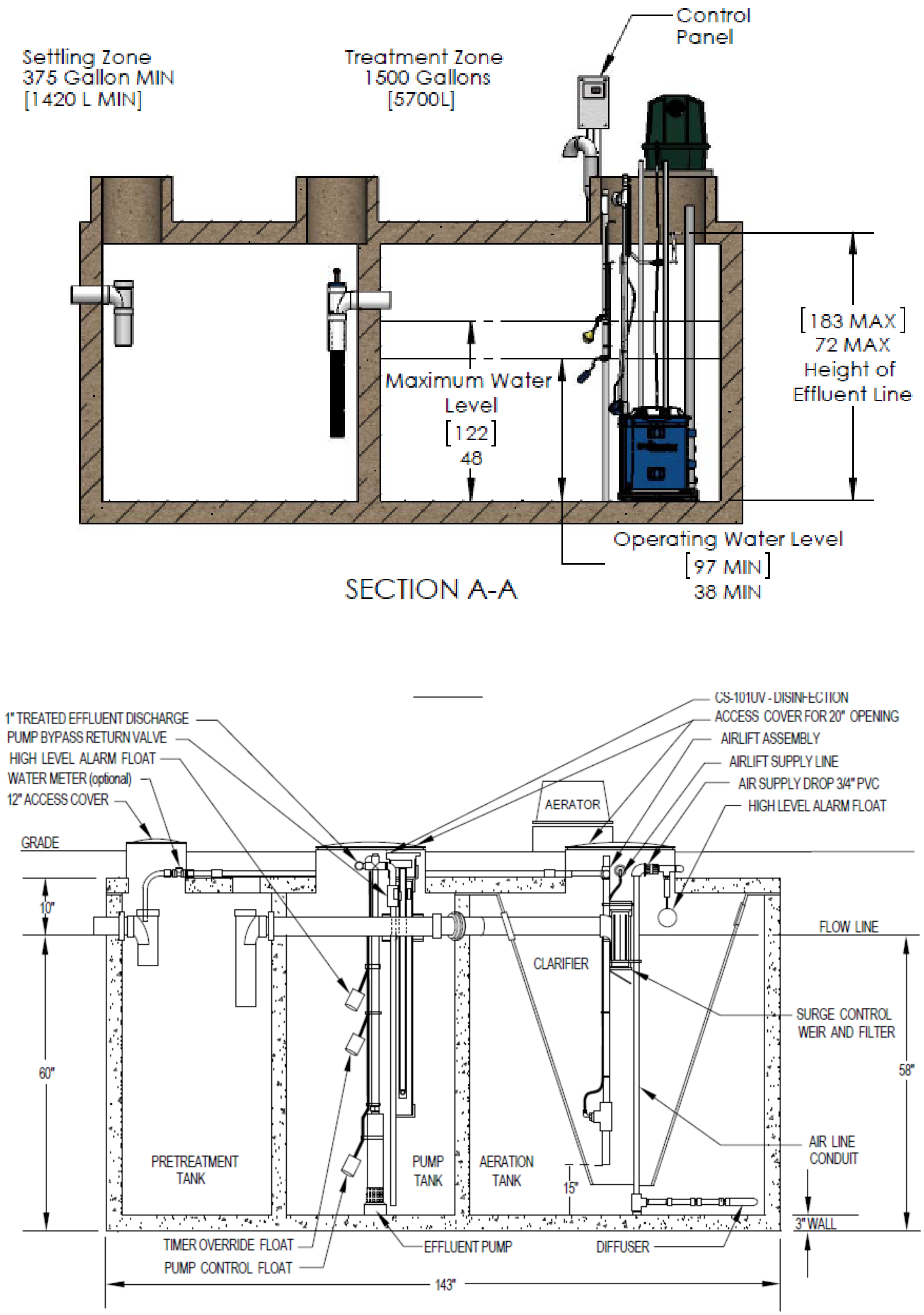


Figure 4: Section views of MBR (top) and non-MBR treatment tanks. (Graphics for this figure were obtained with permission from manufacturers' literature)

Table 1: Treatment Train for MBR and non-MBR Systems Studied in the Project.

Treatment Train Component	MBR System	non-MBR System
Trash tank (primary treatment)	500-gallon Infiltrator Tank IM-540	First compartment of the three-compartment 1,850-gallon concrete tank (500 gal)
Effluent filter	Yes (4” SaniTEE®)	Not used
Aeration tank (secondary treatment)	500-gallon Infiltrator Tank IM-540 with BioBarrier® membrane cartridge and aeration assembly.	Third compartment of the three-compartment 1,850-gallon tank with a conical shaped clarifier and aeration assembly. (850 gal)
Aeration system	Air Blower ½ HP GAST Model R3105-12, operating continuously when during filtration mode and on a 60-min ON 60-min OFF cycle during relaxation mode air diffusion through membrane cartridge	Air Compressor (linear) model #CS103ET6 and air diffusion through one fine bubble diffuser installed near the bottom of aeration tank.
Clarification system	Membrane filter and vacuum pump turn operated based on the liquid level in the aeration tank to separate solids from activated sludge; vacuum pump runs ONLY if the aeration is on, i.e., system will not discharge if aeration is turned off.	Inverted cone shaped clarifier located inside the aeration tank to separate solids from the activated sludge
Sludge return	Not used; however, On and Off aeration feature is used to create anoxic conditions for denitrification.	Air lift pump submerged into clarifier operated by a timer for sludge return at an adjustable rate.
Disinfection and effluent discharge	Ozonation in a 500-gal tank (Aerobic Guard) and an effluent discharge pump for final discharge into RELLIS sewer.	UV light and liquid chlorinator in the 2nd compartment of the tank (500 gal), and an effluent discharge pump to RELLIS sewer.

Section 1.2 NSF/ANSI Standard 350 for Reuse Systems

NSF International developed Standard 350, which is designated as ANSI (American National Standards Institute) Standard, for Onsite Residential and Commercial Water Reuse Treatment Systems. The Standard is revised routinely, and the current version of the Standard is listed as NSF/ANSI 350 – 2020 (https://webstore.ansi.org/Standards/NSF/NSFANSI3502020). Onsite wastewater treatment systems designed to produce reuse quality water are tested against the Standard 350 by several testing facilities operating in the USA. The reuse systems studied in this project have successfully completed the Standard 350 testing. The MBR system (without the Ozone) was tested at the Massachusetts Alternative Septic System Test Center (MASTC) and the final report containing the test results is dated March 2012. The non-MBR (without the liquid chlorinator) was tested at the Gulf Coasat Test (GCT) center and the final report containing test results is dated October 2016.

NSF/ANSI Standard 350 establishes minimum material, design, construction, and performance requirements for onsite residential and commercial water reuse treatment systems. Manufacturers of such a system are required to submit egineering details on their treatment technologies and test centers (e.g., NSF and GCT) evaluate performance of the technologies following the testing protocole outlined in the Standard 350. During the performance evaluation period of SIX months (26 weeks or 182 days), effluent samples are collected and analyzed for several water quality parameters listed and results are evaluated against the effluent quality standards set for reuse wate quality. Table 2 gives summary of effulent quality criteria for residential (R) and commercial (C) classification of reuse systems tested under the Standard 350.

Table 2: Summary of effluent criteria for residential and commercial reuse systems (NSF, 2020)

Parameters	Class R for Residential Systems		Class C for Commercial Systems	
	Average	Single Max	Average	Single Max
$CBOD_5$ (mg/L)	10	25	10	25
TSS (mg/L)	10	30	10	30
Turbidity (NTU)	5	10	2	5
E. coli[1] (MPN/100 mL)	14	240	2.2	200
pH (SU)	6.0 to 9.0	NA[2]	NA	NA
Storage vessel disinfection (mg/L)[3]	0.5 to 2.5	NA	0.5 to 2.5	NA
Color	MR[4]	NA	NA	NA
Odor	Nonoffensive	NA	Nonoffensive	NA
Oily film and foam	Nondetactable	Nondetactable	Nondetactable	Nondetactable
Energy consumption	MR	NA	MR	NA

[1] Calculated as geomean
[2] NA: Not Applicable
[3] If chlorine is used for disinfection, total residual chlorine concentration range
[4] MR: Measured and reported only.

Standard 350 also specifies influent wastewater characteristics requirements during the performance evaluatition period. The requirement for the 30-day average BOD_5 concentration of wastewater is between 100 mg/L and 300 mg/L, and for the 30-day average TSS concentration is between 100 mg/L and 350 mg/L,

Note that the influent requirements specified in the Standared 350 are for BOD5 while those specified for the effluent are for CBOD5, mainly because the aerobically treated effluent should be nitrified and should have significantly less organic carbon compared to the raw untreated influent wastewater. BOD5 measures both carbonaceous biochemical oxygen demand (CBOD) and nitrogenous biochemical oxygen demand (NBOD). For this project, the research team decided to measure only BOD5 in both influent and effluent, and measure all three nitrogen parameters (Ammonia, Total Kjeldahl Nitrogen, and Nitrate/Nitrite) in both influent and effluent to evaluate performances of MBR and non-MBR systems. Details on findings are presented in Section 4, Results and Discussion.

Prior to starting this research project, manufacturers of MBR and non-MBR technologies provided the final reports from the Stanard 350 testing for their respective technologies. Table 3 gives summary of the effluent quality test results for both the technologis. Note that the performance evaluation testing for the MBR and the non-MBR technologies were done at different test centers and different time periods, however the testing was conducted following the Standard 350 procedures. Detailed information on the test and the results are presetented in the reports, copies of which can be obtained from the manufacureres. The summary results for effluent quality for key parameters are presented in Table 3, which indicate both technologies meeting the effluent quality requirements specified in the Standard 350 and shown in Table 2.

Table 3: Effluent quality results from test reports for MBR and non-MBR technologies as reported in their respective test reports.

Parameters	MBR		Non-MBR	
	Average	Single Max	Average	Single Max
$CBOD_5$ (mg/L)	<2	4	4	7
TSS (mg/L)	<2	<2	7	10
Turbidity (NTU)	0.25	0.63	2.5	3.9
E. coli[1] (MPN/100 mL)	1.3	4	2	6
pH (SU)	6.2 to 8.1	8.1	6.81	6.97
[1]Calculated as geomean				

One of the goals of this study was to compare the effluent quality results obtained from the field study conducted at the TAMU-OSSF Center where these two technologies were used as a treatment train component as specified in Table 1 and exposed to variable field operating conditions, normal and abnormal conditions.

Section 1.3 Current TCEQ Regulations for Reuse Systems

As stated in the RFGA, "… domestic on-site wastewater is rarely reused in Texas, with the exception of graywater systems. Current rules governing wastewater (blackwater) reuse are the same for large wastewater treatment plants as they are for small on-site wastewater facilities…" however, use of ATU-spray (surface application) and drip (subsurface application) is steadily increasing especially in areas where soil and site conditions do not meet the state and local codes for use of septic systems. Use of OSSF is regulated under the State Regulations Title 30, TAC Chapter 285 (TCEQ, 2017) while the use of Reclaimed Water (i.e., reuse systems) is regulated under the State Regulations Title 30 Chapter 210 (TCEQ, 1997).

The 285 Regulations were amended in 2016 and Sections 285.81 was added that specified requirements and conditions for potentially reducing the size of an OSSF disposal system with a graywater reuse system or a combined reuse system. In the same year, the 210 Regulations were amended, and Subchapter F was added that specified use of graywater and alternative onsite water in Sections 210.81 – 210.85. The 285 Regulations offer design guidance related to changes in wastewater flow and quality when requesting reduced size disposal system for graywater and combined water reuse facilities. While the 210 Regulations offer water quality requirements for toilet or urinal flushing for water reuse systems. Relationship between the two sets of regulations is confusing and not practical for application in regulating reuse of blackwater or combined water indoors for toilet flushing. Hence there is a need for developing recommendations that could be used to amend the 285 Regulations for addressing reuse of treated wastewater for toilet flushing.

Subchapter C of the 210 Regulations specifies water quality standards for two types of reclaimed (i.e., reuse) water, Type I and Type II. Type I water can be used for a variety of purposes including toilet or urinal flushing, thus of interest to this project. Section 210.33 specifies Type I reclaimed water standards as shown in Table 4.

Table 4: Type I reclaimed water quality standards (from Section 210.33(1))

BOD_5 or $CBOD_5$	5 mg/l
Turbidity	3 NTU
Fecal coliform or *E. coli*	20 CFU/100 ml*
Fecal coliform or *E. coli*	75 CFU/100 ml**
Enterococci	4 CFU/100 ml*
Enterococci	9 CFR/100 ml**

* 30-day geometric mean

** maximum single grab sample

Note that there is a typo in the unit for Enteococci for maximum single grab value, it should be CFU and not CFR as noted in the last requirement.

Section 210.82 is also relevant to this project as it defines several terms and specifies general requirements for alternative water reuse systems. The following excerpt from Section 210.82(8) was used along with information presented in Tables 2, 3, and 4 for the purpose of assessing the performance of MBR and non-MBR systems studied in this project:

> (8) Water from an alternative water reuse system that is used for toilet or urinal flushing must meet the following requirements. Property owners may refer to the regulatory guidance document that is required by the Texas Health and Safety Code, §341.039, for assistance in complying with these requirements.
>
> (A) For residential toilet or urinal flushing, *Escherichia coli (E. coli)* must be less than 14 most probable number (MPN) or colony-forming units (CFU) per 100 milliliters for 30-day geometric mean and less than 240 MPN or CFU per 100 milliliters maximum single grab sample. For industrial, commercial, or agricultural toilet or urinal flushing, *E. coli* must be less than 2.2 MPN or CFU per 100 milliliters for 30-day geometric mean and less than 200 MPN or CFU per 100 milliliters maximum single grab sample.
>
> (B) Total suspended solids must be less than 10.0 milligrams per liter for 30-day geometric mean and less than 30.0 milligrams per liter maximum single grab sample.

It is interesting to note that the reuse water quality standards for *E. coli* and TSS used in the NSF Standard-350 (Table 2) and specified in the TCEQ Regulations 210.82 (shown in the excerpt above) are the same for both 30-day average and single maximum values. However, the reuse water quality standards for BOD_5 or $CBOD_5$ and Turbidity used in the NSF Standard 350 and specified in the TCEQ Regulations 210.33 for Type I water (Table 4) are different.

In USA, drinking water is typically used for indoor toilet flushing as most of the dwelling are plumbed with a single water line entering the dwelling to bring in drinking water for all fixtures. However, new dwellings both for private and public use are being built with dual plumbing allowing use of different water quality for potable and non-potable (e.g., toilet flushing) purposes. Battery Park City urban water reuse project is one of the oldest examples of onsite wastewater reuse projects where wastewater from each high-rise apartment building is collected and treated onsite (in the basement of the high-rise apartment building) using a membrane bioreactor (MBR) technology and then disinfected using UV, ozone, and Chlorine (triple disinfection) before sending back into each apartment dwelling for toilet flushing. Details of the project can be found at https://nsuwater.com/portfolio-item/battery-park/ and in a case-study released by the Water Environment Research Foundation (WERF). Following were the minimum performance standards for the design of the Battery Park reuse system:

BOD < 10 mg/l
SS < 10 mg/l
Fecal Coliform < 100 per 100 ml
E. Coli < 2.2 per 100 ml
pH = 6.5 to 8.0
Turbidity < 0.5 NTU for 95% of samples; < 5 NTU at all times

Section 2. Material and Methods

As mentioned in the previous section, on February 4, 2019, the first Request for Grant Application (RFGA) was issued for OSSF research, in which following four research topics were identified as "Eligible Projects" that must be addressed to make a project eligible for funding (TCEQ RFGA No 582-19-93772, 2019):

1. Adequacy of Current Designs *of Aerobic Treatment Unit* with Higher Strength Wastewater
2. Dosing vs. Non-Dosing *of Aerobic Treatment Unit*
3. Implementation of Low-Pressure Dose Systems with Various Configurations
4. Black Water Non-Potable Reuse

The RFGA document contained details on each topic, submission process, and selection criteria based on a 100-point scale using nine distinct scoring criteria. A non-mandatory pre-proposal conference was held on February 11, 2019 and the response to the RFGA was due on April 1, 2019. TAMU-OSSF team attended the pre-proposal meeting and clarify several items including an idea that would allow for combining the first and second topics into one project and preparing three responses to be submitted from two different agencies housed within the TAMU System, Texas A&M AgriLife Research and AgriLife Extension. Representatives from TCEQ were receptive to the concept, allowing the TAMU-OSSF team to prepare and submit three proposals to address four topics. Following three project proposals were submitted to TCEQ from TAMU's OSSF team, first from AgriLife Research while second and third from AgriLife Extension:

1. Evaluation of Equalized Dosing and High-Strength Wastewater on the Performance of Aerobic Treatment Units (ATU)
2. Implementation of Low-Pressure Dose Systems with Various Configurations (LPD)
3. **Feasibility Study to Evaluate On-Site Treatment of Wastewater for Non-Potable Reuse (Reuse)**

On May 2, 2019, TAMU-OSSF team received emails from TCEQ indicating that the proposal review committee selected all three proposals for funding and asked the team to follow-up with the detailed instruction related to finalizing the contracts. The TAMU Office of Sponsored Research Services finalized the contract agreements with TCEQ to start the projects on September 1, 2019. The two-year project plan for each of the three projects was divided into eight quarters, four quarters per year starting September 1, 2019. During the two-year project period, eight quarterly reports were submitted to TCEQ, copies of which are included in Appendix-A, A summary of work completed in each quarter for the Reuse project is reported in this section.

TAMU-OSSF team organized a project kick-off meeting on September 12, 2019 and invited TCEQ staff as well as industry representatives (TOWA members) to discuss the overall plans for all three projects. Twenty-four people participated in the meeting and discussed the plans for conducting the TCEQ funded projects under the RFGA Number 582-19-93772. The group was formally recognized as the TOGP advisory committee, and the members agreed to meet once a year with the TAMU-OSSF team to discuss the progress. One of the main recommendations made by committee members on the Reuse project was to add a non-MBR type reuse system and study the performance of both MBR and non-MBR reuse technologies. Note that the original plan proposed in response to RFGA was to study performance of only the MBR system type reuse system which was already in operation at the Center. Thus, Reuse project was modified and TAMU-OSSF team was charged with installing a non-MBR reuse technology, which was tested under the NSF/ANSI Standard 350. Clearstream® Wastewater Systems, Inc. (https://www.clearstreamsystems.com/) agreed to replace their NSF-40 ATU system which has been in operation since the start of the Center in the mid-1990s with their new reuse system at no cost. However, due to COVID-19 Pandemic restricted working conditions, installation of the non-MBR technology was completed in July 2020.

Figure 5 shows the wastewater flow schematics for the Reuse project while the Photo-2 shows the MBR and non-MBR systems as installed at the Center along with the automated effluent sampling stations installed for both the systems. As indicated in Table 1, the treatment train for the MBR system includes primary trash tank, aerobic treatment unit with membrane filtration, and ozone tank for disinfection. The treatment train for the non-MBR system also includes the primary trash tank, aerobic treatment unit with gravity settling chamber (inverted cone type clarifier), and UV + Chorine disinfection system. While the influent and final effluent samples were collected using the automated composite samplers (1-1, 1-2, 1-3, and 1-4 respectively for the MBR and non-MBR systems placed inside the white boxes (a) and (b) shown in Photo-2) programed to collect 24 samples per day, an additional sampling point (1-5, the white short pipe next to MBR) was used to collect grab samples of the effluent from MBR, before the Ozone tank.

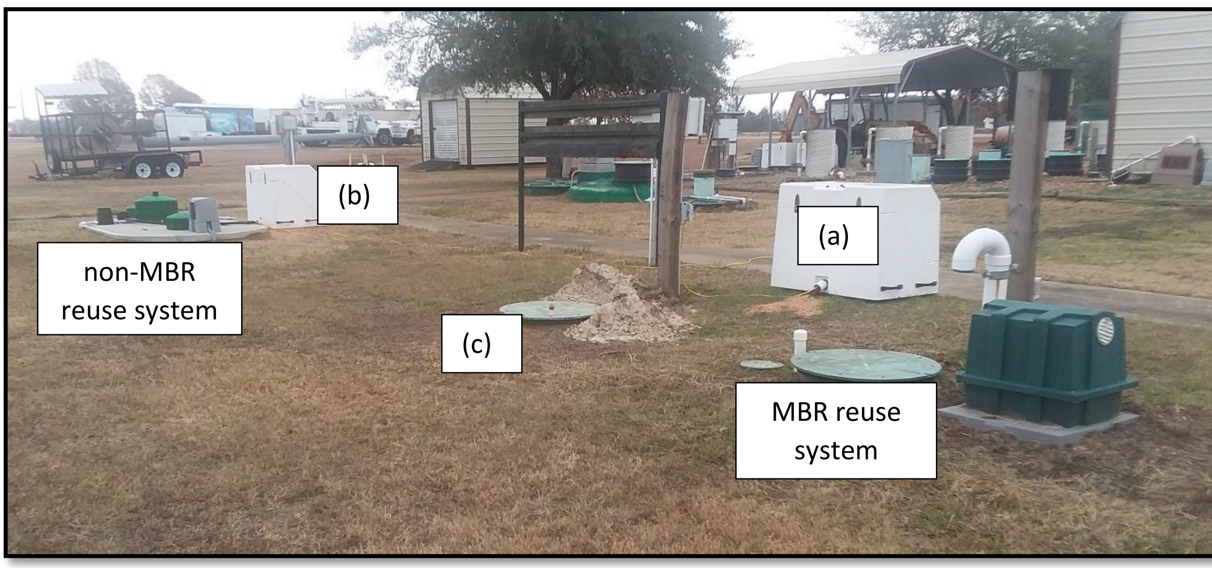


Photo-2: Field layout of the MBR and non-MBR reuse systems. (a) and (b) are the weather-proof boxes each housing two refrigerated composite samplers. (c) is ozone tank for MBR effluent.

Effluent quality monitoring plans were modified from the originally proposed to add two additional monitoring points from the non-MBR reuse technology. The Quality Assurance Project Plan (QAPP) was completed and approved by TCEQ, the private laboratory (Aqua-Tech) and TAMU in September 2020, a few months delay due to COVID-19 restrictions on work conditions. Another major task delayed due to COVID was the reconfiguration of the RELLIS sewer line to collect required raw wastewater flow for all three research projects. TAMU Utility services completed the work in the fifth quarter (September-November 2020).

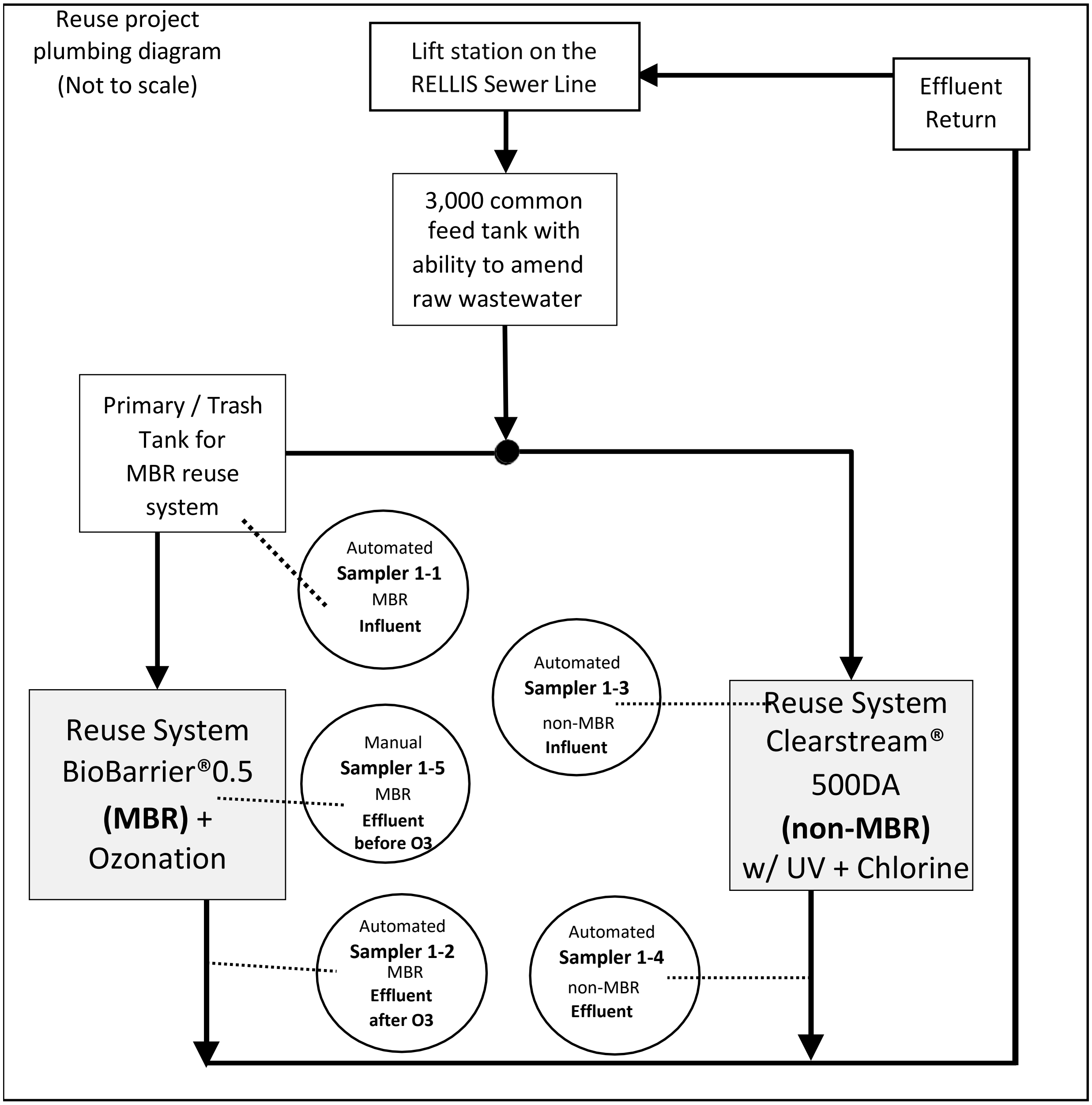


Figure 5: Reuse project plumbing diagram with location of five sampling points. *Note that the influent and final effluent composite sampling was done using automated samplers (1-1, 1-2, 1-3, and 1-4), however the MBR effluent grab sample before Ozonation was collected from a manual sampling port 1-5 for a graduate student research project.*

On August 4, 2020, the primary/trash tank of BioBarrier MBR 0.5 was pumped out and activated sludge from the MBR aeration tank was re-distributed: 1/3 to seed the Clearstream unit, 1/3 wasted, and 1/3 remaining in the MBR aeration tank. Both units were started with 100 gallons per day wastewater feed and 100 gallons of activated sludge from MBR as seed. During the fifth quarter of project, the old membrane was replaced with a new one in the MBR system, and the disinfection units (UV + liquid Chlorinator) were installed in the non-MBR system. Both systems started receiving almost equal flow of the amended wastewater flow from the feed-tank, and all four automated samplers were programmed and made ready to initiate sampling.

Section 2.1 Experimental design proposed versus performed

Following experimental design was originally envisioned and proposed for the reuse project:

Experimental Design:

- Operate reuse system under "normal" conditions
  - Influent flow within ±10% 225 GPD, BOD/TSS 300 mg/L, blower operation according to manufacturer's recommendations, alarm(s) attended within 24 hr.;
  - Effluent sampling and observation for 6 months;
- Operate reuse system under "abnormal" conditions
  - Influent flow variations as shown in the following table, blower operation on/off during a week, alarm(s) ignored for >48 hr. to simulate system abuse;
  - Effluent sampling and observation for 6 months;

Influent flow variation

Test Run	gal/day	BOD_5 mg/L	BOD_5 lb/day
TR1	225.0	300	0.56
TR2	180.0	375	0.56
TR3	157.5	900	1.18
TR4	180.0	1000	1.50

Neglected operation and monitoring conditions simulation during TR2, 3, and 4:

1. Blower turned off and remained off for three days or until odor is noticed;
2. Alarms ignored for more than two days or until effluent surfacing noticed;
3. System operation not monitored for three weeks.

Due to delays in starting the experimental program and challenges experienced for adjusting the BOD loading in ATU project, the experimental design for the Reuse project was modified to focus mainly on the operational negligence. Real world examples of neglect include not adding chlorine, aerator malfunction, or malfunctioning ozone generating unit. The revised experimental design was implemented during seven test runs (T0 – T6) starting December 2020. Example of a sampling schedule and effluent quality parameters to be lab tested are shown in Figure 6. Typically eight samples were collected during each test-run.

- T0: Start-up and trial run of the sampling equipment (December 2020); both MBR and non-MBR units were dosed on hourly basis at about 220 gallons per day flow rate. A digital flow meter was installed on the non-MBR final effluent line in December 2020 and an analog flow meter was installed on the MBR effluent line in February 2021.

- T1: Both units were operated under the "normal" operating conditions (January 2021) dosing amended wastewater from the feed tank with BOD and TSS concentrations between 100 mg/L and 300 mg/L, representing typical residential wastewater quality and quantity.

Sampling Points =>	LIFT STATION	FEED TANK	Sampler 1-1	Sampler 1-2	Sampler 1-3	Sampler 1-4	Sampler 2-1	Sampler 3-1	Sampler 3-2	Sampler 3-3		*Total # of Samples*
Parameters							**Only two times**					
BOD	x	x	x	x	x	x	x	x	x	x		*74*
TSS	x	x	x	x	x	x	x	x	x	x		*74*
Turbidity			x	x	x	x						*32*
E Coli			x	x	x	x						*32*
NH3N			x	x	x	x						*32*
TKN			x	x	x	x						*32*
NO3N NO2N			x	x	x	x						*32*

Figure 6: Example of the sampling schedule and list of water quality parameters prepared for the lab each month during the experiment.

- T2: First round of "abnormal" operating conditions (interruptions in the disinfection systems over the weekend, i.e., four days) was planned during the month of February 2021, however the extreme cold and freezing conditions experienced throughout Texas added second set of abnormal conditions (extreme cold weather operations) during this period. Due to extreme weather conditions, only **six samples** were collected instead of eight and the interruption in disinfection system continued for **eleven days** instead of originally planned four days.

- T3: Turn-off disinfection units one more time from Thursday to Tuesday (3/18-3/23) while BOD load is increased by adding one lb/day amendments (chickenfeed) in trash-tank during the entire month of March. From the ATU project, one pound of amendment addition was approximately 0.4 pound of additional BOD load to the treatment unit which would be equivalent to adding two additional people on the system.

- T4: Turn-off aeration units over the weekend from Friday (4/16) to Monday (4/19) to study effects of no-aeration on effluent quality. Once again, the plan to conduct this test run had to be abandoned within few hours when it was realized that the MBR system was not designed to discharge effluent when the aeration is turned-off. Since the MBR system had to be operated with the aeration on, test-run T4 was discontinued for both systems, however Nitrogen reduction test was started on non-MBR system. The manufacturer of the non-MBR system approached the research team and requested to add Total Nitrogen for monitoring with and without recirculation in the non-MBR system. The private lab was informed to add Ammonia-N, Nitrate/Nitrite-N, and Total Kjeldahl Nitrogen (TKN) for both the reuse systems.

- T5: Original plan was to turn-off both disinfection and aeration systems over the weekend from Friday (5/14) to Monday (5/17) to study effects of worst-case scenario; however, from the experience during T4, it was decided not to start T5 as planned. Instead, the Nitrogen reduction test continued during this period and with 80% recirculation of aerobic effluent to trash-tank in non-MBR system to study effects on reduction of Total Nitrogen (TN = TKN + Nitrate/Nitrite-N). Reuse water quality standards in NSF/ANSI test protocol and in Texas regulations (Table 2 and Table 4) do not address Total Nitrogen, however short discussion is included in Section 4 about effects of recirculating a portion of aerobic effluent into trash-tank on nitrogen reduction.

- T6: Operate both the systems under normal operating conditions from 6/15 to 6/29 to study how both the systems recover from the "abnormal" operating conditions. Normal operation of both the systems continued during July and August, however, sampling frequency was reduced in consideration of the funds remaining for the sample analysis. Original plan was to stop sampling end of T6, but total of eight additional samples were collected (two in July and six in August) to see if the effluent quality recovers back to what was observed during the first two months of experiment (Dec and Jan).

Section 2.2 Conducting the experiments and field observations

Since Reuse was one of the three experiments conducted in this project (ATU and LPD being the other two), the research team worked cooperatively on all three projects. The research team including three Principal Investigators (PIs) and several Co-PIs (support team members). The research team for the Reuse project included the following:

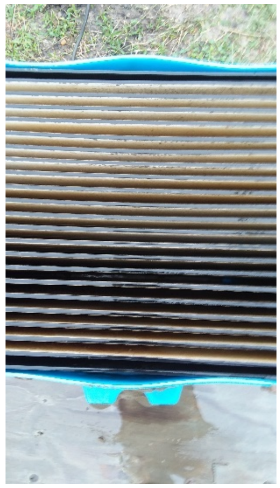
- Anish Jantrania (PI)
- Ryan Gerlich (Co-PI)
- Mesut Ozdemir (primary support team member)
- June Wolfe (Co-PI)
- Gabriele Bonaiti
- Aqua-Tech, the contract laboratory that collected and analyzed water quality samples.

Two major construction projects had to be completed before starting the Reuse project, first was realignment of the RELLIS sewer line to increase the raw wastewater flow to the Center and second was replacement of the old Clearstream ATU with the new Reuse system. Ryan led both projects and got the Center ready for Reuse and the other two projects. Another major challenged faced by the entire research team was to increase the raw wastewater strength. Initial review of the RELLIS raw wastewater data collected from the TAMU Utilities indicated very low BOD and TSS values (typically < 100 mg/L) for the RELLIS Wastewater. June Wolfe led the efforts to determine number of amendments that could be added in the common feed tank that would increase the BOD and TSS values to > 100 mg/L, which is typical for a single family home raw wastewater. Consultation with the plant operator for TAMU, the research team discovered that a local supplier (Producers Cooperative Association) sales FEED material that could increase BOD and TSS. Based on several weeks of field testing, the research team determined that adding 10 lb/day of the FEED material in the feed tank, the BOD and TSS values for the amended wastewater was increased. It was also determined that FEED material needed to be added daily (7 day/week) to maintain the quality of amended wastewater in a reasonable range of BOD and TSS (values between 100 and 300 mg/L). Mesut Ozdemir took responsibility to do this work, for which entire research team is very thankful. Photo 3 shows the wastewater amendment process at the feed tank.

Photo 3: From top left to bottom right – 50 lb bag of FEED material, details on ingredients contained in the FEED material, tank lid modification for allowing easy access to add the FEED material daily, and finally Mesut adding the 10 lb of FEED material daily during the experiment.

Since the non-MBR system was installed just before the start of this experiment, the research team wanted to restart the MBR system to ensure that both the systems were starting in the same new conditions with same seed material quantity and quality. Thus, it was necessary to change the membrane in the MBR system. Ryan took the lead on that project and Photo 4 shows the process for changing membrane in the MBR done in early December 2020.


(a)


(b)


(c)


(d)


(e)


(f)

Photo 4: (a) removal of the old membrane cassette from the MBR-aeration tank; (b) close-up of membrane fouling (about 18 months in use); (c) close-up of the new membrane cassette that will replace the old one; (d) carefully draining wastewater from the old cassette, (e) replacing the old cassette with the new one, and (f) re-assembling the membrane unit for putting it back in the MBR aeration tank; difficult work that must be done by a trained person with at least one helper

The membrane in the MBR system was cleaned in-situ about 18 months prior to the replacement (around June 2019). Since MBR system has been used during the summer research program for undergraduates since 2016, many observations were made for the MBR effluent quality. Photo 5 shows the effects of Ozonation on the effluent quality from MBR system and reasons to continue using Ozone in the MBR system in this project.

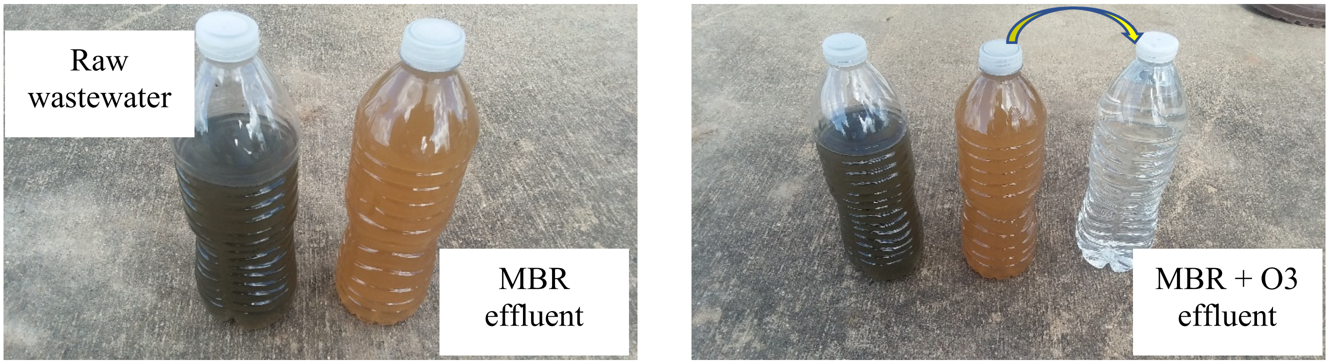


Photo 5: Left MBR effluent without Ozonation versus Right MBR effluent with Ozonation (November 20, 2020–Membrane in use since April 2016, last in-situ cleaning done in May 2019)

During the experimental period (December 2020 to August 2021), three types of field tests were conducted by Ryan to determine sludge accumulation in trash tank using sludge judge, sludge accumulation in aeration tank using settleability test, and chlorine residual test (only for the non-MBR). Photo 5 shows how these field tests were conducted.

Photo 5: Sludge judge test for assessing sludge depth in trash-tank, settleability test for assessing sludge accumulation in aeration tank, and residual chlorine test to determine residual chlorine levels in the non-MBR system effluent. Sludge was not wasted during the experiment.

As shown in Photo 5, Ozone is effective in removing the fine sludge particulates found in MBR effluent. Experiment conducted by the Undergraduate students in previous years showed that a simple charcoal filter (granular activated carbon, GAC) was also equally effective in doing the same. Based on that knowledge, a small field experiment was conducted during the second quarter of this project at the TxDOT safety and rest area where wastewater reuse MBR system had been experiencing effluent color problems for years. In December 2020, the PI visited the TxDOT site and demonstrated effects of charcoal filtration system to decolor MBR effluent. During the second visit to the site in February, Ozone demonstration for decoloring MBR effluent was done. Photo 6 shows both the demonstration.

Photo 6: From top left to bottom right – field demonstration of charcoal filter (contained in the bottom green bucket) and ozonation (tall clear pipe in which ozone was pumped) to improve color of MBR effluent at the TxDOT wastewater reuse treatment plant.

Based on these two field demonstrations, TxDOT has decided to install a full-scale Ozone system at the facility and start reusing treated wastewater for toilet and urinal flushing. However, due to COVID-19 disruption in supply chain for electronic components used in the Ozone system, final installation is delayed until Spring of 2022.

Section 3. Results and Discussion

The entire two-year project period was divided into eight quarters. Quarterly Progress Reports for each project were submitted to TCEQ as required by the contract. The research program officially kicked-off with an in-person meeting on RELLIS Campus on September 12th, 2019 (before COVID). 24 people representing industry (TOWA Board), regulatory agency (TCEQ and DRs), and academia (TAMU) participated in the meeting. An informal advisory group was formed with the intent to offer suggestions to the TAMU OSSF team on all aspects of the three research projects. The group's second meeting was held virtually on November 18th, 2020 (during COVID), and the final meeting is planned for early November 2021.

During the second and third quarters (February to May 2020), the TAMU OSSF team, like the rest of the world, experienced major delays due to the COVID Pandemic shutdown. Field installation of on-site treatment units for ATU and Reuse projects, as well as the construction of LPD field took longer time than originally planned due to campus-wide requirements of social distancing, fear of exposure to the virus, and product shortages. However, all the necessary field work was completed by the end of fifth quarter, about six months later than planned.

Section 3.1 Raw wastewater quantity delivery to the Center

The amount of daily wastewater flow from the RELLIS sewer to the Center was increased from less than 500 gallons per day (GPD) to meet demand from all three projects. This was done by realigning the sewer line connections to the existing lift station. The required maximum flow to run all three projects was about 1,500 GPD. Daily flow to each project was monitored either by meter readings (Reuse project) or by recording pump run time (LPD project) or by a high-tech control panel designed to accurately record daily flow using digital signal received from flow meter (ATU project).

Based on the data shared by the PIs for the LPD and ATU projects records of the daily flow delivered to their research site, the reuse project PI developed Table 5 for the total wastewater flow used during the experiment for all three projects. NOTE that the total wastewater delivered to the Reuse site ("Reuse Total") includes the flow to Hoot aerobic system, which was NOT part of the Reuse project. Table 6 presents average daily flow by month during the experiment to MBR and non-MBR systems.

Table 5: Total daily wastewater flow (GPD) to all three-research areas during the experiment.

Month	ATU	Reuse Total	LPD	TOTAL
December	450	589	0	1,039
January	450	574	0	1,024
February	360	545	204	1,109
March	317	585	154	1,056
April	314	619	220	1,153
May	224	597	210	1,031
June	221	588	190	999
July	228	575	214	1,017
August	226	589	221	1,036

Table 6: Total daily flow (GPD) to non-MBR and MBR reuse systems measured from meter readings. Overall GPD values for non-MBR and MBR systems were 227 and 259, respectively.

Month	non-MBR	MBR
December	219	219
January	275	275
February	223	241
March	242	250
April	227	278
May	218	271
June	217	267
July	207	264
August	211	267

Despite the best efforts of the researchers, equal distribution of daily flow between the non-MBR and MBR systems was not achieved. Overall, MBR system received about 13% more flow compared to the non-MBR system.

The non-MBR system is also monitored by the manufacturer using a proprietary remote monitoring system called RMSYS (Remote Monitoring/Management System), that records daily flow based on the pump run-time and pump discharge rate. Table 7 presents the comparison of the average daily flow data measured by the meter installed on the discharge line of the non-MBR system and from the online monitoring system. NOTE that the manufacturer shared the daily flow data file and the average daily flow by month was calculated by the PI.

Table 7: Comparison of the average daily flow (GPD) calculated from the meter reading and from online monitoring.

Month	non-MBR GPD	
	Meter	Online
December	219	229
January	275	234
February	223	222
March	242	253
April	227	228
May	218	224
June	217	223
July	207	213
August	211	213

Table 7 indicates that the daily flow monitoring by RMSYS was relatively accurate (± 15%) and it can be done much easier compared to meter reading in field.

Section 3.2 Raw wastewater quality adjustment using organic amendment

Field data collections began in December 2020 and concluded in August 2021. A detailed sampling scheduled was established for all three projects and was shared with a local private laboratory whose services were retained to collect samples, perform necessary analysis, and prepare monthly reports. Table 8 presents the total number of samples collected for all three projects, indicating more than two thousand samples analyzed during the experiment. The sample analysis numbers shown in Table 8 do not include the lab work done to calibrate use of amendments for increasing the organic strength of the RELLIS raw wastewater.

Table 8: Number of samples collected for seven parameters from various locations and projects.

	Common for all Projects		Research Project			TOTAL
Parameter\Location	Lift Station	Feed Tank	ATU	LPD	Reuse	
BOD (5 day)	102	118	276	24	231	751
Total Suspended Solids	79	82	237	24	265	687
E. Coli	N/A	N/A	N/A	N/A	252	252
Turbidity					245	245
Ammonia as N					94	94
Nitrate/Nitrite as N					94	94
Total Kjeldahl Nitrogen as N					94	94
	181	*200*	*513*	*48*	*1275*	**2217**

One of the major challenges of conducting onsite wastewater research using real wastewater from a campus sewer is to increase average BOD5 and TSS levels to within a range typically expected from an individual home. To achieve this goal, 10 lb/day of organic amendment was added in the feed tank which helped in both raising the average BOD5 from 185 to 364 mg/L as shown in Table 9. Average value of TSS is mis-leading due to one very high value observed in the month of July for reasons unknown.

Table 9: Average BOD_5 and TSS measured in Lift Station and Feed Tank during the experiment.

	Lift Station			Feed Tank		
Parameter	Min	Max	Avg	Min	Max	Avg
BOD (5 day), mg/L	ND	>2,200	185	125	1,210	364
TSS, mg/L	8	11,000	690	100	1,020	251

The sampling results from the lift station and the feed tank when plotted as shown in Figure 6 indicates that the variability in BOD decreased due to amendment added in the feed tank. The overall standard deviation (StdDev) values for both BOD and TSS were lower for the feed tank compared to the lift station. (StdDev for lift station BOD, TSS ~ 200 and 1,400, while for feed tank they were ~ 150 and 130). Thus, the wastewater quality adjustment by adding organic amendment in the feed tank was successful.

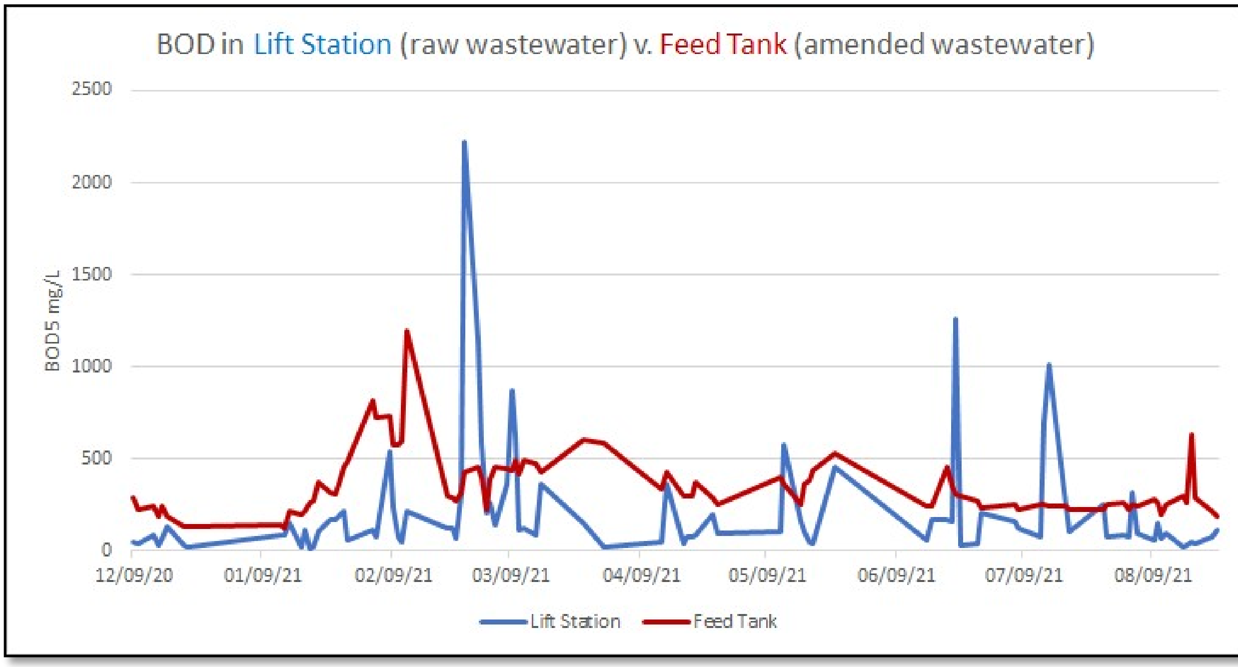


Figure 7: Effects of amending raw wastewater by daily addition of organic amendment in feed tank effluent BOD_5.

Section 3.3 Treatment train and sampling locations and effluent quality observations

For this research project, Feed Tank (FT) is the raw wastewater source (like a home), even though as mentioned in Section 3.2, FT contains amended wastewater derived from mixing of 10 lb/day organic feed material as mentioned in Section 2. Figure 8 shows the wastewater flow path and the sampling locations for the non-MBR and MBR treatment trains.

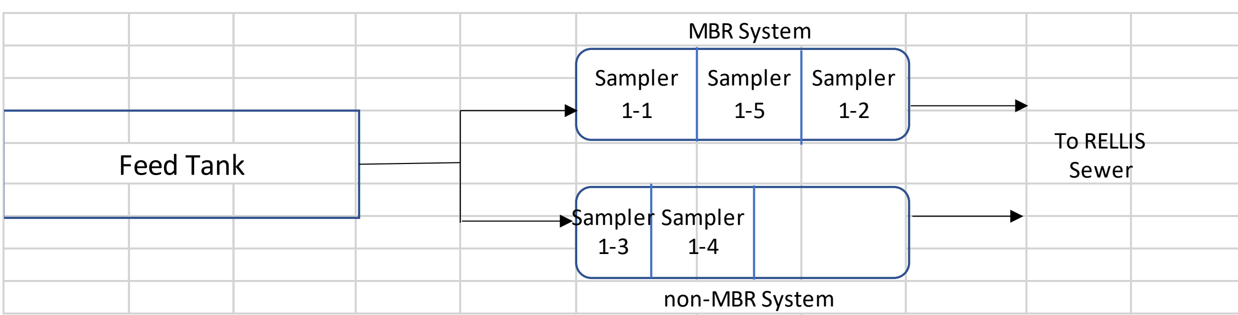


Figure 8: Treatment train for the MBR and non-MBR systems with the location of sampling points. NOTE: Influent wastewater to both the systems was from the Feed Tank. See Table 1 for details on Treatment Train Components for both the systems.

Samplers 1-1, 1-2, 1-3, and 1-4 were the ISCO Refrigerated Composite Samples, while Sampler 1-5 was the sampling port installed on the MBR discharge line (before Ozone tank). The trash-tank configuration for MBR and non-MBR tanks were different, which was reflected in the BOD and TSS sample results averaged for the entire period and during each month as shown in Table 10. NOTE that the trash-tank in MBR system has an effluent filter, while non-MBR system does not have an effluent filter, and the hydraulic retention time (HRT) for both the trash tanks is about the same based on the average daily flow observed during the sampling period.

Table 10: Performance of trash-tank (primary treatment) and overall-system (secondary + disinfection treatments) observed for the reduction of BOD, TSS, Turbidity, and *E. coli* in the MBR and non-MBR systems.

Sampling period	MBR Trash Tank				non-MBR Trash Tank			
	BOD		TSS		BOD		TSS	
	FT	1-1	FT	1-1	FT	1-3	FT	1-3
Dec	205	NA	161	45	205	NA	161	50
Jan	228	NA	137	66	228	NA	137	65
Feb	389	311	248	101	389	361	248	205
Mar	370	268	287	352	370	283	287	370
Apr	320	81	171	140	320	182	171	260
May	381	64	324	108	381	142	324	333
Jun	292	76	262	124	292	199	262	1157
Jul	237	83	334	151	237	235	334	1800
Aug	252	98	216	75	252	183	216	603
AVG.	294	137	242	129	294	221	242	471
Average Reduction	54%		47%		25%		Negative	

NOTE that FT is the influent to both trash tanks, 1-1 is partially treated effluent from trash tank in MBR system and 1-3 is effluent from trash tank in non-MBR system.

Sampling period	MBR System				non-MBR System			
	BOD		TSS		BOD		TSS	
	FT	1-2	FT	1-2	FT	1-4	FT	1-4
Dec	205	NA	161	0	205	NA	161	18
Jan	228	NA	137	0	228	NA	137	12
Feb	389	2	248	1	389	34	248	4
Mar	370	2	287	1	370	19	287	17
Apr	320	2	171	1	320	5	171	10
May	381	2	324	2	381	9	324	10
Jun	292	2	262	0	292	6	262	11
Jul	237	14	334	5	237	6	334	8
Aug	252	4	216	2	252	4	216	6
AVG.	294	3	242	1	294	11	242	11
Average Reduction	99.1%		99.6%		96.2%		95.4%	

NOTE that FT is the influent to both systems, 1-2 is the final effluent from the MBR system and 1-4 is the final effluent from the non-MBR system.

Sampling period	MBR System				non-MBR System			
	Turbidity		*E. coli*		Turbidity		*E. coli*	
	1-1	1-2	1-1	1-2	1-3	1-4	1-3	1-4
Dec	117	1	156,502	45	42	11	58,695	150
Jan	130	1	96,809	31	100	14	110,660	21
Feb	153	2	40,615	93	242	45	60,162	103
Mar	321	1	180,762	25	299	21	276,199	61
Apr	156	1	85,076	5	219	9	96,414	8
May	114	1	61,905	5	182	8	61,350	57
Jun	95	1	175,442	7	235	4	31,406	5
Jul	61	3	375,839	23	484	5	172,850	9
Aug	54	2	173,596	15	200	4	171,410	11
AVG.	142	1	123,545	18	197	14	94,377	25
Average Reduction	99.2%		99.985%		93.1%		99.973%	

NOTE that Turbidity and E. coli were not measured in FT, but measured in 1-1 and 1-3, which are the sampling locations for the trash-tank effluent in MBR and non-MBR systems.

The experimental sampling started on December 9, 2020; however, both the systems start-up date was August 4, 2020, using the same quality and quantity of seed material (activated sludge from MBR with TVSS ~ 2,000 mg/L). On December 2, 2020, the old membrane was replaced with the new membrane in the MBR system, just a few days before the start of sampling period. Both systems were operated in "normal" conditions during the months of December, January, June, July, and August (five out of nine months during the sampling period).

Following "abnormal" conditions experienced or created during the sampling period:

1. Extreme cold and freezing condition during February.
2. Disinfection units' interruption during February and March.
3. Organic matter amendment in trash-tank @ 1 lb/day (~ 0.2 lb/day extra BOD) during the month of March.
4. Aeration units turned off just for about three hours on April 16th that caused MBR system to stop discharging effluent (design feature).
5. 80% recirculation of aerobic effluent to trash-tank during the month of May only in non-MBR system for Nitrogen reduction.

The overall performance of both the MBR and non-MBR systems observed during the sampling period was similar to the information reported in their respective test reports (Table 3). Excel spreadsheet functions were used for analyzing the sample dataset, which was downloaded from the private lab's website. Field measurements, e.g., pH, were not available electronically.

Average and single max values for the selected parameters calculated from all the test results are presented in Table 11. Number of samples (n) and standard deviation (StdDev, spread around mean or average value) parameter are presented in Table 12. *Greater values of StdDev means higher variability in the observations compared to lower values.*

Table 11: Effluent quality results from sample analysis dataset for the MBR and non-MBR technologies as observed during the entire sampling period (Dec-20 – Aug-21).

Parameters	MBR		Non-MBR	
	Average	Single Max	Average	Single Max
BOD_5 (mg/L)	3	22	11	50[2]
TSS (mg/L)	1	5	11	38[3]
Turbidity (NTU)	1	6	14	80[2]
E. coli[1] (MPN/100 mL)	17	980[2]	28	921[2]

[1]Calculated as geomean, excluding 0 reading. [2]Observed in Feb-2021. [3]Observed in Dec-2020.

Table 12: Effluent quality results from sample analysis dataset for the MBR and non-MBR technologies as observed during the entire sampling period (Dec-20 – Aug-21).

Parameters	MBR		Non-MBR	
	n	StdDev	n	StdDev
BOD_5 (mg/L)	50	3	48	11
TSS (mg/L)	66	1	64	7
Turbidity (NTU)	62	1	60	15
E. coli (MPN/100 mL)	62	134	60	170

During the sampling period, every attempt was made to collect samples from all four samplers (1-1, 1-2, 1-3, and 1-4), however due to technical difficulties (sample tube out of the jar, power tripping, extreme weather conditions, etc.) 14 samples (~ 5%) were missed out of 256 total possible samples (4 samplers x 8 sampling events/month x 8 months).

Tables 13-a, -b, -c and 14-a, -b present the descriptive statistics (n, Avg, Min, Max, etc.) for the sample results. Note that the BOD analysis was not done during the first two months of the sampling period. Figures 9 and 10 shows the BOD, TSS, Turbidity, and *E. coli* variabilities in effluent from the MBR and non-MBR systems. Note that for plotting effluent quality data, missing values were replaced by the averages calculated between two values. The raw data set for effluent quality used for statistical analysis and chart plotting is included in Appendix-B. Appendix-D includes raw data set for Nitrogen and wastewater amendment calculations.

Table 13-a: Descriptive statistics for the MBR system

MBR										
Location	Sampler 1-1 Influent									
	n		Average		Min		Max		StdDev	
	BOD	TSS	BOD	TSS	BOD	TSS	BOD	TSS	BOD	TSS
0-Dec	N/A	8	N/A	45	N/A	22	N/A	72	N/A	18
1-Jan	N/A	8	N/A	66	N/A	51	N/A	82	N/A	13
2-Feb	6	6	311	101	203	72	443	120	99	19
3-Mar	8	8	276	352	178	252	420	687	62	143
4-Apr	8	8	81	140	61	93	118	202	18	44
5-May	8	8	64	108	0	77	81	144	27	22
6-Jun	12	12	76	124	62	51	84	220	8	67
7-Jul	2	2	83	151	53	98	113	204	42	75
8-Aug	6	6	98	75	83	40	129	174	18	52
	50	*66*								
Location	Sampler 1-2 Effluent									
	n		Average		Min		Max		StdDev	
	BOD	TSS	BOD	TSS	BOD	TSS	BOD	TSS	BOD	TSS
0-Dec	N/A	8	N/A	0	N/A	0	N/A	1	N/A	0.4
1-Jan	N/A	8	N/A	0	N/A	0	N/A	3	N/A	1.1
2-Feb	6	6	2	1	1	0	5	5	1.5	2.0
3-Mar	8	8	2	1	1	0	3	2	0.8	0.9
4-Apr	8	8	2	1	1	0	5	2	1.5	0.9
5-May	8	8	2	2	0	0	6	3	2.1	1.2
6-Jun	12	12	2	0	0	0	5	1	1.7	0.5
7-Jul	2	2	14	5	5	2	22	8	12.0	4.2
8-Aug	6	6	4	2	1	1	9	5	3.4	1.8
	50	*66*								

Table 13-b: Descriptive statistics for the MBR system

MBR			*Geomean for E.Coli*							
Location	Sampler 1-1 Influent									
	n		Average		Min		Max		StdDev	
	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*
0-Dec	8	8	117	156,502	75	54,800	140	365,000	23	111,374
1-Jan	8	8	130	96,809	86	36,500	160	1,200,000	25	399,326
2-Feb	6	6	153	40,615	130	365	170	308,000	19	111,634
3-Mar	8	8	321	180,762	37	55,000	470	816,000	132	263,640
4-Apr	8	8	156	85,076	130	30,800	180	435,000	18	138,646
5-May	8	8	114	61,905	93	4,870	140	185,000	19	67,906
6-Jun	8	8	95	175,442	70	54,800	120	921,000	17	366,063
7-Jul	2	2	61	375,839	58	365,000	64	387,000	4	15,556
8-Aug	6	6	54	173,596	27	57,500	92	261,000	25	75,957
Location	Sampler 1-2 Effluent									
	n		Average		Min		Max		StdDev	
	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*
0-Dec	8	8	1	45	1	0	1	194	0.2	75
1-Jan	8	8	1	31	1	0	2	365	0.4	124
2-Feb	6	6	2	93	1	11	6	980	2.1	368
3-Mar	8	8	1	25	1	6	2	88	0.6	28
4-Apr	8	8	1	5	1	1	2	49	0.3	16
5-May	8	8	1	5	1	0	2	14	0.5	5
6-Jun	8	8	1	7	1	0	1	44	0.1	17
7-Jul	2	2	3	23	2	20	3	26	0.8	4
8-Aug	6	6	2	15	1	5	3	26	0.8	7

Table 13-c: Descriptive statistics for the MBR system

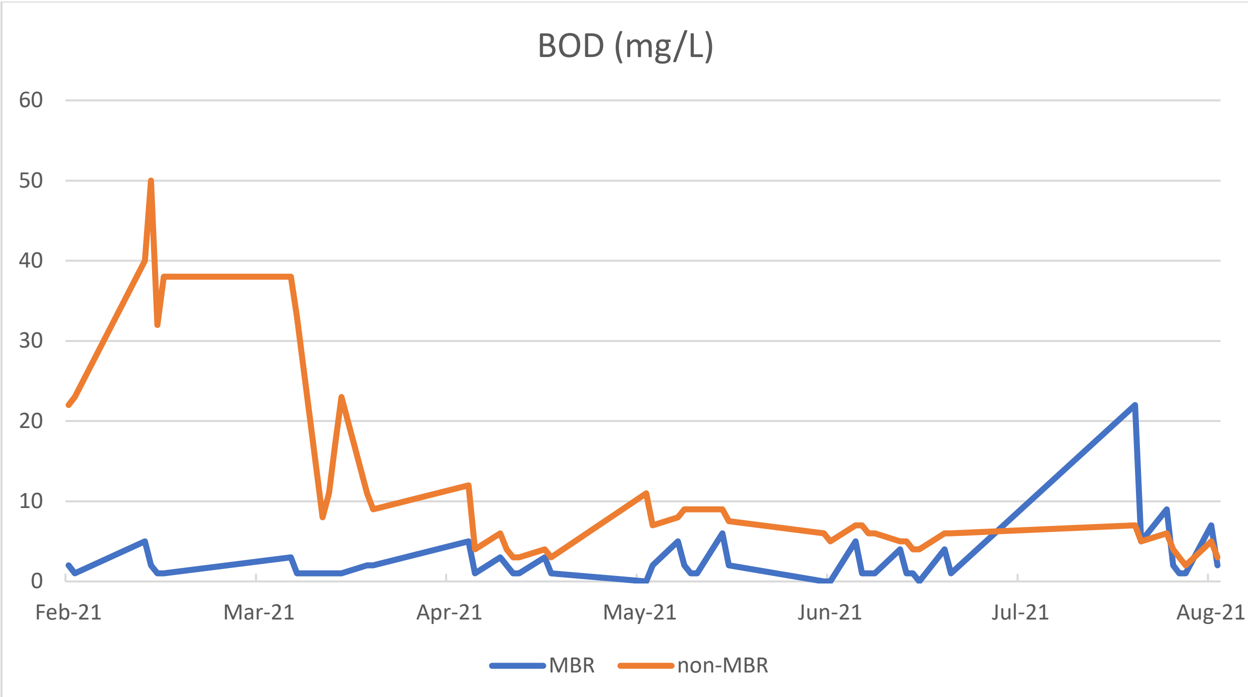
MBR										
Location	Sampler 1-5 Effluent									
	n		Average		Min		Max		StdDev	
	BOD	TSS	BOD	TSS	BOD	TSS	BOD	TSS	BOD	TSS
0-Dec										
1-Jan										
2-Feb										
3-Mar										
4-Apr										
5-May										
6-Jun	4	4	1	2	0	0	1	5	0.5	2.1
7-Jul										
8-Aug										
	4	*4*								
Location	Sampler 1-5 Effluent									
	n		Average		Min		Max		StdDev	
	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*
0-Dec										
1-Jan										
2-Feb		1		0		0		0		0
3-Mar		6		3		0		4		1.6
4-Apr										
5-May										
6-Jun										
7-Jul										
8-Aug										
		7								

Table 14-a: Descriptive statistics for the non-MBR system

non-MBR										
Location	Sampler 1-3 Influent									
	n		Average		Min		Max		StdDev	
	BOD	TSS	BOD	TSS	BOD	TSS	BOD	TSS	BOD	TSS
0-Dec	N/A	8	N/A	50	N/A	24	N/A	87	N/A	22
1-Jan	N/A	8	N/A	65	N/A	53	N/A	80	N/A	10
2-Feb	6	6	361	205	208	122	546	316	130	77
3-Mar	23	8	283	370	213	134	498	827	94	203
4-Apr	8	8	182	260	101	68	245	472	53	149
5-May	7	7	142	333	66	76	293	1040	82	370
6-Jun	12	12	199	1157	54	72	1260	9680	336	2696
7-Jul	2	2	235	1800	211	1520	258	2080	33	396
8-Aug	6	6	183	603	132	142	247	980	39	304
	64	*65*								
Location	Sampler 1-4 Effluent									
	n		Average		Min		Max		StdDev	
	BOD	TSS	BOD	TSS	BOD	TSS	BOD	TSS	BOD	TSS
0-Dec	N/A	8	N/A	18	N/A	8	N/A	38	N/A	10
1-Jan	N/A	8	N/A	12	N/A	8	N/A	18	N/A	4
2-Feb	6	6	34	4	22	2	50	7	11	2
3-Mar	7	7	19	17	8	6	38	35	12	11
4-Apr	8	8	5	10	3	7	12	16	3	3
5-May	7	7	9	10	7	6	11	12	1	3
6-Jun	12	12	6	11	4	5	7	17	1	4
7-Jul	2	2	6	8	5	7	7	8	1	1
8-Aug	6	6	4	6	2	5	6	7	1	1
	48	*64*								

Table 14-b: Descriptive statistics for the non-MBR system

non-MBR			*Geomean for E.Coli*							
	Sampler 1-3 Influent									
	n		Average		Min		Max		StdDev	
	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*
0-Dec	8	8	42	58,695	18	14,400	97	201,000	26	64,865
1-Jan	8	8	100	110,660	59	51,700	120	770,000	25	244,090
2-Feb	6	6	242	60,162	180	548	310	613,000	55	222,467
3-Mar	8	8	299	276,199	31	130,000	590	870,000	167	259,179
4-Apr	8	8	219	96,414	100	27,200	380	461,000	95	149,499
5-May	7	7	182	61,350	56	38,700	510	173,000	171	48,498
6-Jun	8	8	235	31,406	99	2,230	530	242,000	129	88,285
7-Jul	2	2	484	172,850	88	86,600	880	345,000	560	182,716
8-Aug	6	6	200	171,410	78	19,600	380	461,000	101	198,887
	Sampler 1-4 Effluent									
	n		Average		Min		Max		StdDev	
	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*	Turbidity	*E. Coli.*
0-Dec	8	8	11	150	3	0	23	437	7	143
1-Jan	8	8	14	21	9	0	24	172	6	57
2-Feb	6	6	45	103	16	0	80	921	28	375
3-Mar	7	7	21	61	7	12	36	770	11	278
4-Apr	8	8	9	8	6	0	14	190	3	66
5-May	7	7	8	57	6	19	9	162	1	61
6-Jun	8	8	4	5	3	0	6	14	1	5
7-Jul	2	2	5	9	5	4	5	20	0	11
8-Aug	6	6	4	11	4	1	6	71	1	27



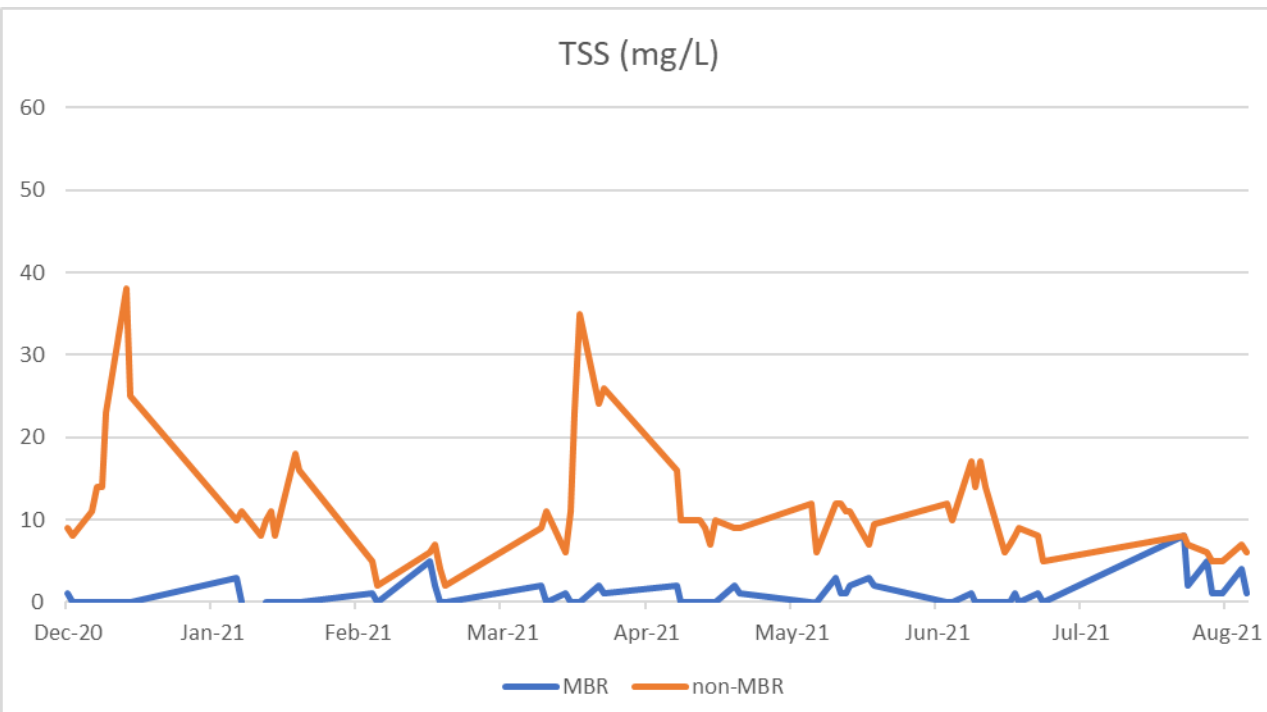
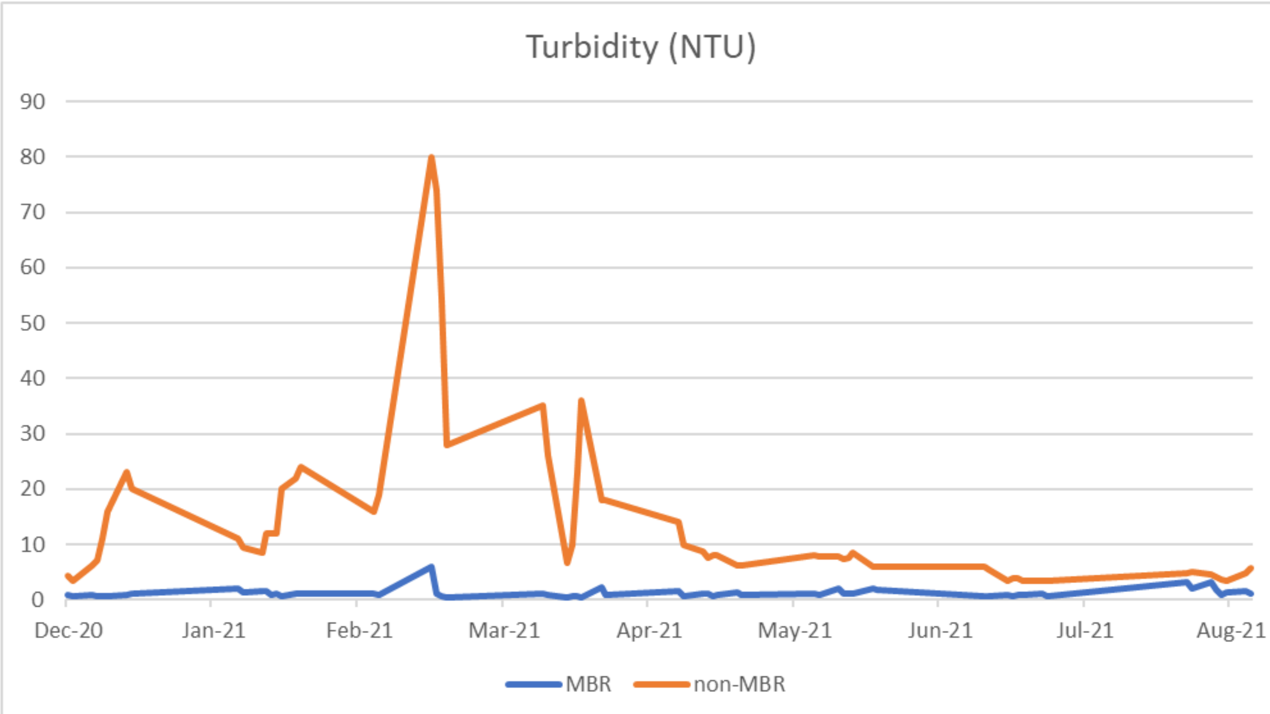


Figure 9: BOD and TSS sample results during the observation period for the effluent (reuse water) from the MBR and non-MBR systems.



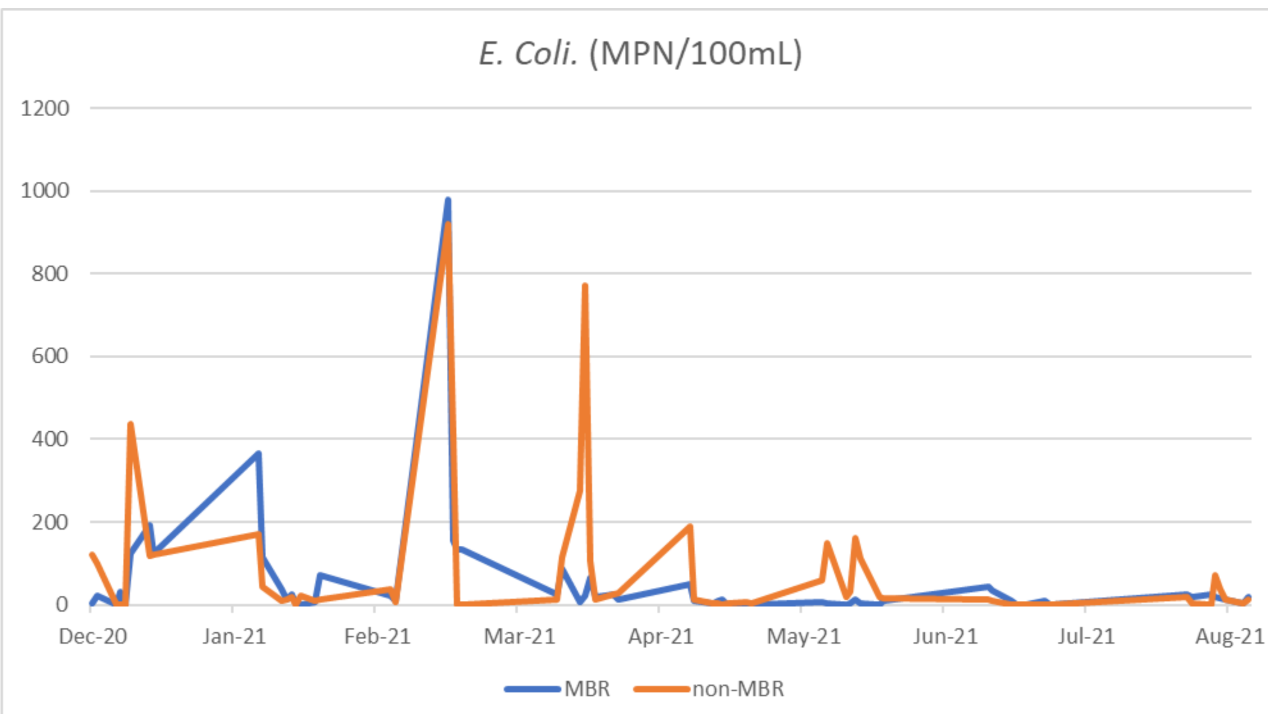


Figure 10: Turbidity and *E. coli* sample results during the observation period for the effluent (reuse water) from the MBR and non-MBR systems.

Section 3.4 Effluent quality during normal and abnormal operating conditions

As indicated earlier, the sampling period from December 2020 to August 2021 (9 months) can be divided in two categories – normal and abnormal conditions (NC and AC, respectively). Both systems were operated in normal conditions (NC) during five months: December, January, June, July, and August; and during the rest of the four months abnormal conditions (AC) were either created or occurred due to extreme weather conditions (e.g., extreme freeze during February).

One of the objectives of this project was to observe and compare performance of MBR and non-MBR systems during normal and abnormal conditions. Many photos of effluent quality were taken during the project, however the two taken in February before and after the extreme freeze are worth including in this report (Photo-7). NOTE that the cloudiness observed in 1-4 sample was mainly due to extreme cold weather, typically due to air bubbles found in cold samples. However, samples from 1-2 sampler were always clearer than those from 1-4, which is reflected by higher average turbidity value for 1-4 compared to 1-2 as shown in Table 11.

Photo-7: Left - Effluent before winter storm shut-down (Feb. 11); Right - Effluent after winter storm shut-down Feb. 22)

While Tables 11 and 12 presents effluent quality results from the entire nine-month sample period, Tables 15 and 16 presents the averages and single max values for the effluent quality parameters observed during the normal and abnormal conditions (NC and AC).

Table 15: Effluent quality observed during normal conditions (NC)

	MBR		non-MBR	
	Average	Single Max	Average	Single Max
BOD	7	22	5	7
TSS	1	8	11	38
Turbidity	2	3	8	24
E. Coli	20	365	17	437

Table 16: Effluent quality observed during abnormal conditions (AC)

	MBR		non-MBR	
	Average	Single Max	Average	Single Max
BOD	2	6	16	50
TSS	1	5	10	35
Turbidity	1	6	21	80
E. Coli	16	980	41	921

Information presented in Tables 13-a, 13-b, 14-a and 14-b indicates that both MBR and non-MBR systems' performance during normal and abnormal operating conditions varied. However, additional statistical analysis was performed to determine (a) if the difference in performance was significant, and if so (b) which system performed better during abnormal conditions. Section 3.6 presents details on the statistical analysis performed on both data sets.

Section 3.5 Effluent quality observed versus TCEQ Chapter 210 reclaimed water quality standards

Section 1.3 discusses the current TCEQ regulations for reuse systems, effluent quality standards specified for the Type I reclaimed water (Table 4), and standards for alternative water reuse systems, specifically for toilet or urinal flushing. Table 17 provides a summary of the current TCEQ regulatory reuse water standards and compares them against the effluent quality observed during the entire sampling period.

Table 17: The MBR and non-MBR effluent quality observed during the sampling period versus the current TCEQ reuse water quality standards.

Parameters	Type-I (TCEQ Section 210.33)	Alternative water reuse (TCEQ 210.82)	MBR System	Non-MBR System
BOD_5 (mg/L)	5	NA	3	11
TSS (mg/L)	NA	Avg. 10 Max 30	Avg. 1 Max 5	Avg. 11 Max 38
Turbidity (NTU)	3	NA	1	14
E. coli[1] (CFU or MPN/100 mL)	Avg. 20 CFU Max 75 CFU	Avg. 14 MPN Max 100 MPN	Avg. 17 MPN Max 980 MPN	Avg. 28 MPN Max 921 MPN

[1]*E. coli* test if done by counting the number colonies grown on agar plates then the results are expressed as CFU (Colony Forming Units); however, if done by comparing positive and negative patterns on the tubes and calculated using statistical tables then the results are expressed as MPN (Most Probable Number). See the following website for a relatively easy to understand discussion on the difference between CFU and MPN: https://www.differencebetween.com/difference-between-cfu-and-vs-mpn/

Effluent quality observed during the study period indicates that neither MBR nor non-MBR system met all the requirements of the reuse water quality standards specified in the current TCEQ regulations. However, MBR system met the standards for BOD5, TSS, and Turbidity and non-MBR system almost met the TSS standards. Use of Ozone in the MBR system appears to be the main reason for meeting the TSS and Turbidity standards. Both the MBR and non-MBR technologies, when tested under the NSF/ANSI Reuse Standard 350, met the effluent quality requirements specified in the standards (Table 3) for residential reuse. Note that Ozone and Chlorine were not used for the MBR and the non-MBR technologies, respectively, at the NSF/ANSI Standard 350 test sites.

Section 3.6 Is the difference between MBR and non-MBR systems statistically significant?

Table 11 shows the average (mean) values for BOD, TSS, Turbidity, and *E. coli* observed during the entire sampling period, from December 2020 to August 2021. To determine if the difference in the means is statistically significant or not, the dataset was analyzed using the paired-sample hypothesis test available in Excel. Since the paired-sample test in Excel requires equal number of data pairs for each parameter, the dataset was slightly adjusted by removing the missing data lines, e.g., if BOD value is not available for non-MBR but available for MBR for a date then the value for MBR was removed. Thus, the values for "n" shown in Table 11 do not match with the values shown below in the Excel result tables, Tables 18, 19, 20, and 21.

The t-test results indicate that the difference in the average effluent quality for BOD, TSS, and Turbidity were statistically significant at 95% confidence interval, but the difference in the average effluent quality for *E. coli* was not statistically different. Ozone disinfection was used for the MBR effluent, while UV and liquid Chlorine were used for the non-MBR effluent.

Null hypothesis Ho: The difference between MBR system and non-MBR system is statistically not significant, i.e., *mean values are statistically same.*

Alternate hypothesis Ha: The difference between MBR system and non-MBR system is statistically significant, i.e., *mean values are statistically different.*

Table 18: t-Test results for BOD mean values.

t-Test: Paired Two Sample for Means	**for BOD**	
	MBR	*non-MBR*
Mean	2.604166667	11.27083333
Variance	12.03147163	134.116578
Observations	48	48
Pearson Correlation	-0.046533305	
Hypothesized Mean Difference	0	
df	47	
t Stat	-4.904462483	
P(T<=t) one-tail	5.80558E-06	
t Critical one-tail	1.677926722	
P(T<=t) two-tail	1.16112E-05	
t Critical two-tail	2.011740514	
Since t-Stat (-4.90) is < t-Critical (-2.01); reject Ho		
That means the MBR and non-MBR Means are Significantly Different		
Also,		
Since P value is very small (<0.05); reject Ho		
That means the MBR and non-MBR Means are Significantly Different		

Table 19: t-Test results for TSS mean values.

t-Test: Paired Two Sample for Means	**for TSS**	
	MBR	*non-MBR*
Mean	0.936507937	11.12698413
Variance	2.318484383	47.7578085
Observations	63	63
Pearson Correlation	-0.183156818	
Hypothesized Mean Difference	0	
df	62	
t Stat	-11.01402398	
P(T<=t) one-tail	1.56556E-16	
t Critical one-tail	1.669804163	
P(T<=t) two-tail	3.13112E-16	
t Critical two-tail	1.998971517	

Since t-Stat (-11.01) is < t-Critical (-1.99); reject Ho
That means the MBR and non-MBR Means are Significantly Different
Also,
Since P value is very small (<0.05); reject Ho
That means the MBR and non-MBR Means are Significantly Different

Table 20: t-Test results for Turbidity mean values.

t-Test: Paired Two Sample for Means	**for Turbidity**	
	MBR	*non-MBR*
Mean	1.184745763	13.63728814
Variance	0.744418469	235.9651373
Observations	59	59
Pearson Correlation	0.34460955	
Hypothesized Mean Difference	0	
df	58	
t Stat	-6.340475164	
P(T<=t) one-tail	1.85924E-08	
t Critical one-tail	1.671552762	
P(T<=t) two-tail	3.71847E-08	
t Critical two-tail	2.001717484	

Since t-Stat (-6.34) is < t-Critical (-2.00); reject Ho
That means the MBR and non-MBR Means are Significantly Different
Also,
Since P value is very small (<0.05); reject Ho
That means the MBR and non-MBR Means are Significantly Different

Table 21: t-Test results for *E. coli* mean values (note that Excel does not allow Geomean function for the t-Test, thus the mean values are higher compared to Table 11).

t-Test: Paired Two Sample for Means	**for *E. Coli***	
	MBR	*non-MBR*
Mean	52.57627119	80.43389831
Variance	18947.42632	29443.46952
Observations	59	59
Pearson Correlation	0.678204477	
Hypothesized Mean Difference	0	
df	58	
t Stat	-1.673276661	
P(T<=t) one-tail	0.049829329	
t Critical one-tail	1.671552762	
P(T<=t) two-tail	0.099658659	
t Critical two-tail	2.001717484	
Since t-Stat (-1.67) is > t-Critical -2.00; do not reject Ho		
That means the MBR and non-MBR Means are NOT significantly different		
Also,		
Since P value is very large (>0.05); cannot reject Ho		
That means the MBR and non-MBR Means are NOT significantly different		

Tables 15 and 16 present effluent quality observed during normal conditions (NC) and abnormal conditions (AC). Statistical analysis was also done to determine if the differences in mean (average) values for BOD, TSS, Turbidity, and *E. coli* were significant or not. Table 22 presents the summary of t-test results where Y means the differences were statistically significant and N means the differences were not statistically significant.

Table 22: Summary of the t-test results for the effluent quality data observed during "normal" and "abnormal" operating conditions.

Effluent Quality	Is the Difference in Mean Values Significant During NC?	Is the Difference in Mean Values Significant During AC?
BOD	N	Y
TSS	Y	Y
Turbidity	Y	Y
E. coli	N	N

Both the MBR system and non-MBR system performance was relatively similar during the "normal" and "abnormal" operating conditions with one exception, the difference in the mean value for BOD during "normal" conditions was not significant. Appendix-C contains detailed t-test tables for the "normal" and "abnormal" conditions.

Section 3.7 Nitrogen reductions in MBR and non-MBR systems with and without recirculation.

Neither the TCEQ 210 reuse water quality standards nor the NSF/ANSI-350 test protocol for reuse systems specify effluent quality requirements for nitrogen reduction. However, the non-MBR system studied in this project is designed for enhanced reduction in total nitrogen by recirculating the aerobic effluent from the aeration tank to the trash tank at a variable rate. The MBR system uses alternating aeration cycle (60-min ON and 60-min OFF during relaxation period, i.e., no discharge period) to achieve denitrification (reduction of nitrates to nitrogen gas), reducing total nitrogen in final effluent. The effects of both the recirculation feature and alternating aeration cycles on total nitrogen reduction were studied during the months of April, May, July and August-2021 during which nitrogen sampling was conducted for 24 times. Aqua-Tech lab was instructed to add Ammonia-N, Nitrate/Nitrite-N, and Total Kjeldahl Nitrogen (TKN) in the effluent quality parameter list for testing for all four samplers (1-1, 1-2, 1-3, and 1-4). Total Nitrogen (T-N) was calculated using the following formula:

$$\text{Total Nitrogen (TN)} = \text{TKN} + \text{Nitrate/Nitrite-N}$$

Nitrogen data analysis results for both the systems are presented in Figures 11 and 12. The MBR system was operated in its normal operating conditions while the non-MBR system was operated without recirculation in April and with 80% recirculation in May, June, and July.

TN-In	TN-Out	% TN Reduction	*% BOD Reduction*
48	32	34%	96%
45	31	30%	99%
45	27	40%	96%
45	28	38%	97%
40	31	21%	99%
45	33	27%	99%
44	35	21%	95%
40	44	-8%	98%
48	33	31%	N/A
49	35	30%	97%
44	35	20%	93%
43	36	16%	97%
44	36	17%	99%
48	36	24%	99%
46	35	24%	93%
44	37	17%	97%
61	40	35%	100%
48	38	22%	100%
36	31	14%	98%
33	29	13%	98%
34	27	21%	94%
39	26	32%	99%
49	29	40%	95%
46	30	35%	99%

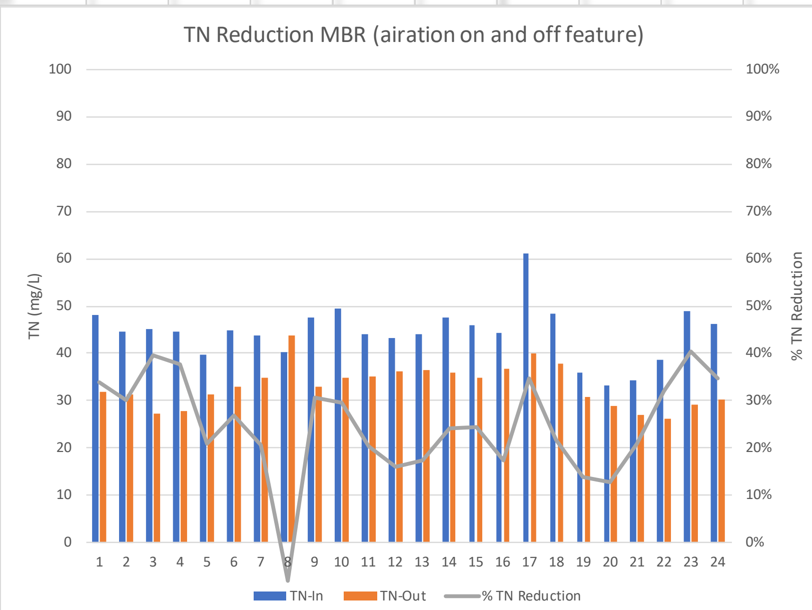


Figure 11: Total nitrogen and the BOD reductions in the MBR system during the nitrogen study period. Note that average reduction observed was 25% and the range was 0 to 40% reduction.

TN-In	TN-Out	% TN Reduction	*% BOD Reduction*
49	44	10%	89%
52	44	16%	98%
53	37	29%	97%
67	38	43%	98%
65	37	43%	99%
49	39	20%	97%
73	39	46%	98%
86	45	47%	99%
14	10	27%	87%
17	9	45%	93%
31	8	74%	93%
13	9	32%	86%
67	9	86%	97%
14	9	34%	92%
39	8	80%	96%
88	12	87%	97%
70	11	84%	98%
48	12	75%	97%
33	11	67%	97%
46	12	74%	98%
62	13	79%	99%
46	24	48%	97%
61	26	57%	99%

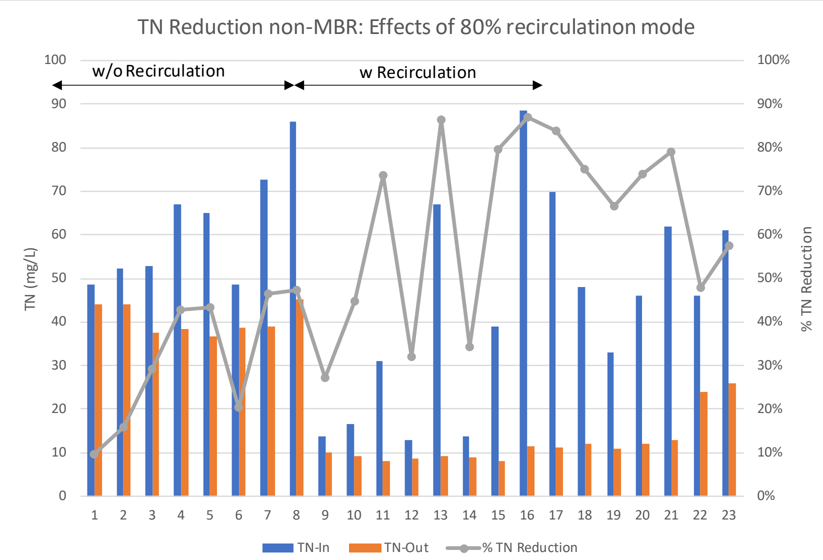


Figure 12: Total nitrogen and BOD reductions in the non-MBR system during the nitrogen study period. Note that the 80% recirculation of the aerobic effluent into the trash tank increased the reduction significantly without causing any negative effects on the BOD reduction.

For the non-MBR system, average total nitrogen reduction rate increased from 30% in April to 60% in May when the recirculation of aerobic effluent to trash tank started. Nitrogen reduction rate of > 80% were observed four times during the months of May and July when recirculation was on, the highest rate observed was 87% and lowest total nitrogen in effluent recorded was 8 mg/L on May 17 and May 24, 2021. Nitrogen reduction rate started decreasing in July and August once the recirculation was stopped indicating that recirculation of aerobic effluent to the trash tank has potential to increase reduction of total nitrogen. Raw data tables for the influent and effluent nitrogen content for both the systems are included in the Appendix-D.

Section 3.8 Examples of facilities where reclaimed blackwater is used for toilet flushing

At the start of this project, PI was familiar with three facilities, two in Texas and one in Virginia, where onsite treatment systems are used for treating blackwater to produce reuse quality water for flushing toilets and urinals. However, during the project period it was found that one of the two facilities in Texas (Carter Park in Harris County) does not have blackwater reuse system, instead has rainwater reuse system. At the second facility in Texas (TxDOT Safety Rest Area on I-45 in Navarro County, see Photo 8), a MBR system for reclaimed Type I water was permitted by TCEQ in April 2009 (TCEQ Authorization No. R14854001). As shown in Photo 1, inside the bathrooms a prominently displayed notice informs the public that "To conserve water this building uses reclaimed water to flush toilets and urinals." However, in late 2019 (during the first quarter of this project), PI was approached by TxDOT requesting technical assistance with the MBR treatment system, because the system was not producing reclaimed water suitable for toilet flushing mainly due to yellowish color present in the final effluent as shown in Photo 9. PI visited the site twice, first in December 2020 and then in February 2021, to demonstrate possible solutions for removing the color using either a charcoal filter (activated carbon) or ozonation. Due to Covid-19 Pandemic, system modifications have been delayed this site, however PI has learned that in December 2020, the hollow-fiber membrane were replaced and work to include ozonation in the final effluent tank is underway at this facility. Work is expected to be completed in Spring 2022 which will allow the reuse of water for toilet and urinal flushing in Summer 2022.

Photo 8: Navarro County Safety Rest area on I-45. The building on the left houses the onsite wastewater treatment plant designed to produce reuse water for flushing toilets and urinals in public restrooms located on North and South bound I-45.

Photo 9: Left: The yellow color present in the MBR effluent was not adequate for reuse (Photo provided by TxDOT employee in November 2019). Middle: After of Ozone, and Right: After GAC filter (Middle and Right pictures taken in January 2022 by the PI during site visit; Ozone system has been installed, and TxDOT is in the process of installing GAC filter and chlorination systems)

Reuse of treated wastewater onsite for toilet flushing has been successfully demonstrated by a project done in late 1990s (circa 1997) in Fauquier County, Virginia. When a community center, Midland Lodge #238, was being remodeled it ran into a permitting problem with the local health department. The site was not approved for replacing the old septic system with a new one, which triggered the need for an alternative on-site wastewater treatment system. A greenhouse wetland system was installed to treat wastewater and the facility was refitted with dual plumbing. Treated wastewater was then reused for toilet flushing.

Photo 10 shows the greenhouse wastewater treatment system and the condition of the toilet bowl after more than 15 years of use. The community center maintains the system and performance has been excellent. The center has a well for drinking water source and dual plumbing (two water lines entering and one sewer line existing the building) for reusing treated wastewater.

Photo 10: Wetland in a climate-controlled greenhouse on-site wastewater treatment system for a community center in Virginia. Treated wastewater is disinfected using UV and polished using an inline charcoal filter just before reusing it for toilet flushing.

The natural wetland system operated in a climate control greenhouse produces excellent quality effluent as shown in the photo taken in September 2021 when the PI visited the facility. The system was originally built to reduce the effluent discharge in liquid form from the dwelling because the site was not permittable for a disposal system due to soil type. ET (evapotranspiration) losses from the greenhouse along with the reuse of treated water for toilet flushing significantly reduced the amount of liquid discharge at this location. However, flow meter readings are not available to accurately measure the reduction. During the second round of TOGP funding, a facility like this will be carefully studied at the TAMU-OSSF Center starting in December 2022.

Section 4. Conclusions and Recommendations

In response to TCEQ RFGA No 582-19-93772 issued on February 4, 2019, the TAMU-OSSF research team proposed three projects (ATU, LPD, and Reuse) to address four research topics presented in the RFGA. All three proposals were accepted for funding and the start date for the two-year projects were September 1, 2019. This report focuses on the Reuse project which was conducted in conjunction with the ATU and LPD projects at the TAMU OSSF Research and Extension Center located on RELLIS Campus in Bryan, TX.

Two major construction projects had to be completed before starting the Reuse project. The first was realignment of the RELLIS sewer line to increase the raw wastewater flow to the Center and second was replacement of the old Clearstream® ATU with the new Reuse system. Raw wastewater flow to the Center was successfully increased from less than 500 GPD to more than 1,500 GPD by reconnecting the existing lift station with the main sewer line to meet the anticipated influent demand from all three research projects. The lift station pumps are controlled by the water level in the 3,000-gallon feed tank to ensure adequate supply of raw wastewater and to return excess flow back to the main sewer line. Locally available organic material (FEED) was used to amended raw wastewater for increasing BOD and TSS levels from less than 100 mg/L to more than 250 mg/L by adding 10 lb./day in the 3,000-gallon feed tank. The second project as explained in the Section 2 was undertaken to accommodate the recommendations made by the advisory group during the project kick-off meeting held on September 12, 2019, to compare MBR with a non-MBR reuse system. Clearstream company donated their reuse technology tank for this project.

The reuse research project was designed to find answers to the three research questions identified in Section 1 of this report. Those three questions were developed based on the text contained in the RFGA Number 582-19-93772 also shown in the Section 1. While the effluent quality data collected during the nine-month of data collection period of this project are used to answer the three research questions, information from the existing TxDOT and Virginia reuse sites helps to answer the three questions raised in the RFGA.

Performance of two types of reuse treatment trains, MBR system and non-MBR system, were studied during the nine-month sampling period. Both systems were exposed to "normal" and "abnormal" operating conditions during the study period. Amended wastewater from the feed tank was time-dosed on an hourly basis into the trash-tank of each system. Average daily flow to the MBR system during the study period was 259 GPD (ranged from 219 to 278 GPD) and to the non-MBR system was 227 GPD (ranged from 219 to 275 GPD). Average BOD and TSS concentrations were 294 mg/L and 242 mg/L, respectively. Composite samples from the trash-tank (samplers 1-1 and 1-3) and final effluent tank (samplers 1-2 and 1-4) for both the systems were collected and analyzed by a private certified laboratory. Limited number of grab samples were collected from the sampling point 1-5 during the months of February, March, and June mainly to support other ongoing research projects, mainly a graduate research project related to effects of reuse water on plant growth (Ozdemir, 2021) and a summer program for undergraduate research and extension experience (REEU, 2021).

The overall performance of both the MBR and non-MBR systems observed during the sampling period was similar to the information reported in their respective NSF/ANSI Standard 350 test reports as shown in the Table 3 of Section 1. However, it is important to note two differences, first that the treatment train studied in this project was different from the one studied at the NSF/ANSI Standard 350 test centers and second that a composite sampler was used for *E. coli* samples in this study as opposed to grab samples collected at the NSF/ANSI Standard 350 test centers.

Main differences in the treatment trains include use of ozonation in the MBR system and use of liquid chlorine in the non-MBR system. BOD from MBR system was consistently less than 10 mg/L, however BOD the non-MBR system was greater than 10 mg/L during the first three months and then stayed below 10 mg/L for the remaining six months, even though both the systems were started at the same time. Average and single max BOD values for MBR system as shown in Table 11 were 3 and 22 mg/L and for non-MBR were 11 and 50 mg/L, indicating MBR system performing slightly better than non-MBR system. The NSF/ANSI Standard 350 test results shown in Table 3 also indicates similar performance for BOD reduction. Note that an activated sludge system with a membrane (known as MBR) are designed to operate at much higher mixed liquor suspended solids (MLSS) concentration compared to a standard activated sludge system without a membrane, thus MBR outperforms non-MBR for BOD reductions.

TSS and Turbidity from the non-MBR system were consistently higher compared to the MBR system and the difference in average values were significant at 95% confidence interval. This is due to two main reasons, first the membrane in MBR system consistently allows higher removal of TSS compared to non-MBR and second the use of ozonation in this project for MBR effluent that allowed consistently almost complete reduction of TSS. Similar observations were made during the NSF/ANSI Standard 350 test results shown in Table 3, where average and single max values for TSS for MBR (without ozone) were less than those for non-MBR system. Visual observations made at the research site for the MBR effluent before and after ozonation (Photo 5) and at the TxDOT site (Photos 6 and 9) supports the effects of Ozonation for reducing the turbidity.

Overall, both systems achieved >95% reduction in BOD and TSS loading, with effluent BOD and TSS <10 mg/L from the MBR system and <11 mg/L for the non-MBR system. Average TSS and Turbidity levels in MBR system effluent (1 mg/L and 1 NTU) were significantly less than in non-MBR system (11 mg/L and 14 NTU), demonstrating effectiveness of both the membrane filtration and ozonation used in the MBR treatment-train.

Average and single max values for *E. coli* for MBR system effluent (17 and 980 MPN/100 mL) were not significantly different than those for non-MBR system effluent (28 and 921 MPN/100 mL) as shown in Tables 11 and 21, indicating equivalent effectiveness of ozone and UV + Chlorine for disinfection of aerobic effluent. Note that these values are higher than what reported during the NSF/ANSI Standard 350 testing (see Table 3) and the main reason is the difference in sample collection methods. In this project 24-hour refrigerated composite samplers were used while in the NSF/ANSI Standard 350 testing grab samples were used for *E. coli* analysis.

At the end of this research project in August, the sampling tube observations indicated slimy layer grown in the sampling tube indicating a strong potential for bacterial regrowth that could result in higher values of *E. coli* in sample results. Furthermore, six grab samples collected in March from sampling port 1-5 (MBR effluent before ozonation) had average *E. coli* concentration of 3 MPN/100ml with a range from 0 to 4 MPN/100ml, while for the same month eight samples collected from 1-2 (MBR effluent after ozonation) had average *E. coli* concentration of 25 MPN/100ml with a range from 6 to 88 MPN/100ml (Tables 13-b and 13-c). These observations clearly indicate the regrowth problems happening with composite sampling technique.

Reduction in total nitrogen was significantly increased when the non-MBR system was operated in 80% recirculation mode (i.e., 80% of aerobic effluent was returned to trash-tank daily). Total nitrogen reduction observed in MBR system ranged from 0 to 40%, while that in the non-MBR system ranged from 10% to 86%. While there are no standards for total nitrogen in reuse water, it is important to note that nutrient build-up overtime in reuse water has potential to adversely affect the toilet and other plumbing fixtures. More studies and field observations are needed to assess the impact of total nitrogen and total phosphorus concentrations in reuse water on plumbing fixtures.

From the observations made in this study, the three research questions specifically developed for this project by the research team are answered as following:

1. Would the effluent quality from onsite wastewater reuse technologies under variable field conditions be comparable to the test results obtained under controlled NSF/ANSI Standard 350 testing protocol? YES. It is important to note that a 24-hour refrigerated composite sampler was used for collecting *E. coli* samples for MBR and non-MBR reuse systems as opposed to use of grab sample at the NSF/ANSI Standard 350 test sites. Analysis of the sampling tubes used in the composite samplers at the end of the sampling period indicated strong potential for regrowth of *E. coli* during the composite sample collection, resulting in consistently higher count of *E. coli* in final effluent from both the reuse systems used in this project. Three grab samples collected from the ozone tank during the month of November were analyzed in on-campus laboratory for *E. coli*, and all three samples had values less than 14 MPN/100 ml. Based on the availability of funding in future, research team plans to collect grab samples from both the reuse systems for *E. coli* testing.

2. How would the overall performance of a reuse technology with a membrane filtration unit compared with the one without the membrane filtration unit? Overall performance was comparable. Addition of Ozone and/or a granular activated carbon (GAC) has potential to improve the overall performance of both MBR and non-MBR units. Further studies are needed.

3. Are any modifications to a standard onsite wastewater treatment-train and/or operation and maintenance requirement necessary for ensuring reliable effluent quality for indoor non-potable reuse purpose? YES, a treatment-train with triple disinfection (ozone + UV + chlorine) following a Standard 350 ATU or equivalent onsite aerobic treatment system is recommended for ensuring reliable effluent quality necessary for indoor non-potable reuse purpose. Final filtration using granular activated carbon filter may be necessary to treat for any residual color.

From the observations made in this study, the four research questions *paraphrased from the RFGA* are answered as following:

1. *How would the varying facility maintenance and monitoring frequency/requirements affect the use of onsite reuse systems in Texas?* YES, varying requirements would adversely affect the use of onsite reuse systems in Texas because reusing effluent indoor for toilet flushing is more

serious than reusing effluent for outdoor spray irrigation from public health standpoint. However, with the uniform application of the requirements for routine monitoring and reporting of the onsite reuse system by either a licensed service provider or by an educated and responsible homeowner in all jurisdictions, it is possible to allow safe implementation of the onsite reuse systems in Texas.

2. *Is there a potential risk to public health from onsite reuse systems, and if so, how best to minimize the risk?* YES, onsite reuse systems just like any other wastewater treatment systems has potential to malfunction and discharge poor quality effluent with high levels of pathogens and/or effluent with odor (from ammonia or other offensive gases) or color (yellow tint). However, an on-site reuse treatment-train that is designed with adequate safeguards, such as triple disinfection (Ozone, UV, and Chlorine) and/or with a GAC filter and is operated by a licensed operator or by an educated and responsible end-user, overall risks to public health can be minimized. Observations from the TXDOT reuse facility clearly indicate needs for adequate post-treatment such as ozone and GAC filters to remove yellow color found routinely and high levels of ammonia found occasionally. The TXDOT facility is operated by a licensed wastewater operator who had to discontinue use of reuse water due to color problems. At this site, ozone, GAC filter, and liquid chlorination systems are planned to be added during 2022 and reuse of treated wastewater is expected to start before the end of the year. 20+ years of observations from a greenhouse reuse project in Virginia indicate that a natural system when operated in conjunction with a UV light and a GAC filter is adequate for reusing treated wastewater to flush toilet in a public place!

3. *Are there any exposure risk to public health from onsite reuse systems?* NO more than what is acceptable from the use of ATU-spray system. Indoor reuse for toilet flushing brings reuse water closer to the homeowner for a single-family home system or to the public for a business or public place like the TXDOT rest area, but at the same time effluent is contained in a plumbing fixture like a toile bowl or a urinal, and not sprayed in open air.

4. *Would modification of standard on-site wastewater "treatment trains" or maintenance requirements could result in higher quality, reliable effluent for reuse purposes?* YES and NO, to obtain highest possible quality effluent reliably for reuse purposes, modifications of conventional onsite systems that uses aerobic treatment unit and single disinfection system (chlorination or UV light) will be necessary, but not for maintenance requirements. This research indicates that use of Ozone and/or a granular activated carbon (GAC) filter are two effective means for disinfection and for removing small particulates responsible for yellowish color in reuse water. To ensure adequate disinfection, this research suggests use of triple-disinfection process first to reduce the *E. coli* concentration using Ozone and UV, and then use liquid chlorine to prevent regrowth within the reuse piping network. To ensure color of reuse water is esthetically acceptable, this research suggests use of GAC filter before chlorination. An ideal treatment-train for a reuse system should have four components: (1) NSF/ANSI Standard 350 approved aerobic treatment unit, (2) Ozone + UV disinfection system, (3) GAC Filter, and (4) Liquid Chlorination. Maintenance requirements specified in Chapter 285 for Secondary Treatment and Surface & Surface Application (§285.91, Table XII) should be adequate for reuse systems if the service provider or the end-user is properly trained to operate, maintain, and inspect the reuse system routinely.

The research team makes the following six recommendations for future consideration:

1. Continue operating both the reuse systems (MBR and non-MBR), secure funding for *E. coli* analysis for at least 15 samples for each system (representing about 20% of the samples collected during the sampling period of the research project), collect grab samples for *E. coli* analysis, and compare the results with the results reported Tables 13-b and 14-b of this report.

2. Secure fundings to make changes in the existing reuse treatment trains at the TAMU-OSSF Center such that the final effluent from the MBR and non-MBR ATU is sent to a triple disinfection tank comprised of ozone, UV, and liquid chlorine units followed by a GAC filter to determine if the effluent quality would consistently meet the TCEQ 210 reuse standards for *E. coli* and Turbidity.

3. Add a new aerobic treatment process comprised of a wetland operated in a climate control greenhouse for processing effluent from both primary (septic tank) and secondary (ATU) treatment units and compare the pre- and post-triple disinfection effluent quality with the observations made in this project and from the modified treatment-train as mentioned above.

4. Conduct a survey among the homebuilders in Texas to determine level of interests and need for indoor reuse of reclaimed water to flush toilets and urinals in public and private dwellings. Note that this type of reuse will require building the dwellings with dual plumbing, which may be cost prohibitive. Also include questions related to interests in integrated DPR and rainwater harvesting systems to meet the future water demands.

5. Conduct a survey of Authorized Agents (AAs) and Designated Representatives (DRs) to assess effectiveness of the current regulatory requirements (285 Rules) related to treatment train and operation and maintenance of ATU-Spray systems. Analyze the responses to determine strength and weaknesses in the current requirements and work with an Onsite Water Reuse (OWR) advisory group to develop recommendations for rule change.

6. Form the OWR advisory group of 15 people (representatives from TAMU, TOWA, and TCEQ) and develop recommendations for changes in regulatory requirements for treatment-train and operation of Onsite Water Reuse systems in Texas.

References

TCEQ, 2017, On-Site Sewage Facility (OSSF) Rules 285 Compilation, RG-472. (https://www.tceq.texas.gov/rules/indxpdf.html#285)

TCEQ, 2016, Use of Graywater and Alternative Onsite Water, Rules 210, Subchapter F. (https://www.tceq.texas.gov/assistance/water/reclaimed_water.html)

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Pacific Institute, Retrieved from https://pacinst.org/wp-ontent/uploads/2013/02/appendix_e3.pdf September 2019.

US EPA, 2002, Onsite Wastewater Treatment System Manual. Washington, DC.

Water Environment Research Foundation (WERF), Case Study: Battery Park City Urban Water Reuse *(PDF document available on request from the PI)*

Ozdemir, M., 2021, The Effects of Irrigation with Wastewater On Soil Properties, Plant Response, And Accumulation Of Heavy Metals, A Thesis Submitted to the Graduate and Professional School of Texas A&M University in partial fulfillment of the requirements for the degree of Master of Science.

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Appendix-A Quarterly Reports

Quarterly Progress Report #1
Work Period: September 1, 2019 – November 30, 2019

For Texas On-Site Sewage Facility (OSSF) Research Contract #582-19-96829

Feasibility Study to Evaluate On-Site Treatment of Wastewater for Non-Potable Reuse

Report submitted to:

Kelly Wilson, Technical Specialist
Office of Compliance and Enforcement
Texas Commission on Environmental Quality
P.O. Box 13087, MC - 235
Austin, Texas 78711-3087
Kelly.Wilson@tceq.texas.gov

Report Submitted by:

Anish Jantrania, Associate Professor & Extension Specialist
Texas A&M AgriLife Research & Extension
720 E Blackland Road
Temple, TX 76502
(254) 774-6014
ajantrania@tamu.edu

December 13, 2019

Following tasks were completed during the first quarter of this project:

1. Project contract signed and funding account established by the Texas A&M Extension Services. Appendix A contains the 1st page of the signed contract document.

2. Texas OSSF Grant Program (TOGP) Committee Meeting #1 was organized and held on the Texas A&M RELLIS Campus on September 12, 2019 from 10AM to 3PM. 24 people representing academic institution, onsite wastewater industry, and regulatory agency participated in this first meeting to discuss this and two other projects funded by TCEQ under the RFGA Number 582-19-93772. Appendix B contains the agenda for the meeting, list of participants (project advisory group), and handout distributed for this project in the meeting. The list of participants agreed to serve as the committee member for this project. Based on the discussion and input from the participants, **one major change was made in the experimental design** for this project that is to add an NSF Standard 40 Clearstream unit in the research project and compare its performance with the NSF Standard 350 Bio-Microbics unit in a real-world operating condition against the effluent quality requirements specified in Chapter 210.82(8). The PI, Dr. Jantrania, expressed concerns about the cost associated with the additional effluent monitoring from Clearstream and indicated that he will report back to the committee if there is any problem absorbing the additional cost within the current budget.

3. Revised 2-page description of this project including the final experimental design was finalized along with the plumbing diagram for the project. Appendix C contains this information.

4. The PI, Dr. Jantrania, made a presentation about this project to the Capstone Design Class (BAEN-479) students on September 25 to see if any of the students would agree to participate in the project and work with the PI and Co-PI on various tasks related to conducting the experiment. On October 7th we received a confirmation that three students (Jordan Taylor, Tatiana Baig, and Paige Fergeson) are interested in working with us on the OSSF project. Ryan Gerlich met with the students at the research site On October 18th our research team met with the Capstone students to discuss details and to visit the research site to get the students familiar with the OSSF projects. Students agreed to work with Ryan Gerlich to go through the required safety training during the next few weeks and to get approved for conducting field and laboratory work for this project. On December 5th, Dr. Jantrania received an email from the Texas A&M Office of Biosafety indicating that all three students have successfully completed their training and are approved to work on this project.

5. Finally, Dr. Jantrania worked with the other PIs and Co-PIs on finalizing the QAPP document which will be submitted to TCEQ for their review and approval this month.

In the second quarter, we will focus on getting both the reuse technology units ready for the experiment and install the composite samplers to collect influent and effluent samples.

Appendix – A

TCEQ Contract No.: 582-19-96829

Texas Commission on Environmental Quality

CONTRACT SIGNATURE PAGE

Contract Name: Feasibility Study to Evaluate On-Site Treatment of Wastewater for Non-Potable Reuse

Contract Number: 582-19-96829

Performing Party: Texas A&M AgriLife Extension Service

Performing Party Identification Number: 35555555552

Maximum Authorized Reimbursement: $105,681.00

Effective Date: ☒ Date of last signature

Expiration Date: ☒ 8/31/2021

☐ If checked, this Contract requires matching funds. Match Requirement:

☐ If checked, this Contract is funded with federal funds.

CFDA Number:
Federal Grant Number:

This Contract is entered under: ☐ Gov't Code ch. 771 (Interagency) ☐ Gov't Code ch. 791(Interlocal) ☐ Water Code § 5.229 (Intergovernmental) ☒ Water Code § 5.124 (Grant)

The Texas Commission on Environmental Quality (TCEQ), an agency of the State of Texas, and the named Performing Party, a state agency or local government of the State of Texas, enter this agreement (Contract) to cooperatively conduct authorized governmental functions and activities under the laws of the State of Texas.

The Parties agree as follows: (a) to be effective, the Contract must be signed by an authorized official of the TCEQ and the Performing Party; (b) this Contract consists of all documents specified in the list of Contract Documents following this page; and (c) as authorized by TCEQ, Performing Party will conduct Contract Activities as part of its own authorized governmental functions and TCEQ will reimburse Allowable Costs subject to the Texas Uniform Grant Management Standards (UGMS) and this Contract.

Texas Commission on Environmental Quality (TCEQ)

[signature]
Authorized Signature

Ramiro Garcia, Jr.
Printed Name

Deputy Director
Title

8/5/2019
Date

[signature]
Procurements & Contracts Representative

AUNDRE PETTY, CTPM, CTCM
Printed Name

7/29/19
Date

Texas A&M AgriLife Extension Service (Performing Party)

[signature]
Authorized Signature

Julie Bishop JK
Printed Name

Associate Executive Director, Texas A&M University, Sponsored Research Services
Title

7.26.19
Date

Appendix – B

1. Meeting Agenda
2. List of participants
3. Handout for the reuse project

AGENDA

TOGP discussion meeting #1

Thursday September 12, 2019
10:00 AM – 3:00 PM
CIR Building Room 1107, Texas A&M RELLIS Campus

10:00 – 11:00	**Welcome, Project Background, and Individual Introduction of all participants** Anish Jantrania and all participants
11:00 – Noon	**Project #1 (RT 2.3.1 and RT 2.3.2 – ATU), and Group Discussion** June Wolfe
Noon – 1:00	**LUNCH and Discussion**
1:00 – 1:45	**Project #2 (RT 2.3.3 – LPD), and Group Discussion** Gabriele Bonaiti
1:45 – 2:15	**Project #3 (RT 2.3.4 – Reuse), and Group Discussion** Anish Jantrania
2:15 – 3:00	**Visit the Research Site (OSSF Center)**
Around ~ 3:00	**Adjourn (From the OSSF Center)**

Additional Instruction:

Please sign-in and make sure that the parking is taken care of.

Bathroom location…

Lunch will be served in the Lobby and bring your plates back in the room.

List of participants / Project Advisory Group:

First and Last Name	Representing	Email
Alisa S. Max	TCEQ	Alisa.Max@hcpid.org
Andrew Isbell	TCEQ	aisbell@co.walker.tx.us
Anish Jantrania	TAMU	ajantrania@tamu.edu
Bob Lamkin	TCEQ	rlamkin@brazoscountytx.gov
Gabriele Bonaiti	TAMU	g.bonaiti@tamu.edu
Homero Castaneda	TAMU	hcastaneda@tamu.edu
Jessica Paul	TCEQ	jpaul@brazoscountytx.gov
Jim Dyer	TOWA	aadvanced@comcast.net
Jim Prochaska	TOWA	Jim@JNMTechnologies.com
Jonathan Haynes	TCEQ	Jonathan.Haynes@tceq.texas.gov
June Wolfe	TAMU	jwolfe@brc.tamus.edu
Kelly Wilson	TCEQ	Kelly.Wilson@Tceq.Texas.Gov
Kristi Mills-Jurach	TCEQ	Kristi.Mills-Jurach@tceq.texas.gov
Patrick Kern	TOWA	patrick@paramountwastewater.com
Randi Weber	TOWA	rpwcon18@gmail.com
Randy Chelette	TOWA	randy@txowa.org
Ron Moomaw	TOWA	ronaldmoomaw@gmail.com
Ronald Hebert	TCEQ	Ronald.Hebert@tceq.texas.gov
Ryan Gerlich	TAMU	rgerlich@tamu.edu
Tanya Mitchell	TCEQ	Tanya.Mitchell@tceq.texas.gov
Tom Heitman	TCEQ	tom.heitman@tceq.texas.gov
Velumani Subramaniam	TAMU	velu@cinvestav.mx
Vonda "Sissy" Bob	TOWA	Sta1stp1@gmail.com
Wiley Cloud	TOWA	wiley@blockcreek.com

Two-page handout for the reuse project distributed during the meeting:

Feasibility Study to Evaluate On-Site Treatment of Wastewater for Non-Potable Reuse (Reuse)

Jantrania, Gerlich, Bonaiti, and Wolfe

Summary:
This research effort addresses one of the four eligible projects listed in TCEQ Solicitation 582-19-9377, **RT-2.3.4**, questioning the need for modification of standard on-site wastewater treatment-train or maintenance requirements to improve quality and reliability of effluent for non-potable reuse purposes. The National Sanitation Foundation (NSF) Standard 350 are used for performance evaluation of on-site residential and commercial water reuse treatment technologies. NSF Standard 350 effluent quality requirements are similar to those for toilet flushing reuse effluent quality specified in the TCEQ Chapter 210.82(8). BioBarrier® MBR on-site wastewater treatment technology will be used under "normal" and "abnormal" operating conditions in this research project. Performance will be assessed by measuring *E. coli* and TSS concentrations in effluent to determine if the reuse water quality standards are met under various operating conditions. Information on non-residential reuse facility operating in Harris County and at TXDOT rest area will be gathered, analyzed, and used along with the results from our experiment to determine the need for modification in technical or regulatory requirements.

Goals:

1. To compare performance of an NSF Standard 350 approved reuse technology in a real-world operating condition against the effluent quality requirements specified in Chapter 210.82(8);
2. To collect performance information on commercial reuse systems operating in Harris County and at TXDOT facilities;
3. To prepare a concise report specifying the need for modifications of standard on-site wastewater treatment-train or maintenance requirements to improve quality and reliability of effluent for non-potable reuse purposes.

Objectives:

1. Perform necessary changes to the BioBarrier® system to get ready for this experiment;
2. Finalize "normal" and "abnormal" operating conditions and operate the unit to collect data;
3. Conduct phone interview and site visits with Harris County and TXDOT to gather design and operational information on their non-potable reuse facilities;
4. Prepare data sets on effluent quality observed at the center and at other reuse facilities for analysis to determine answers to the research questions;
5. Prepare detailed and summary reports along with PowerPoint presentation for submittal.

Research Questions

Q1: Does an NSF Standard 350 approved reuse technology operating in a real-world condition meet the effluent quality requirements specified in Chapter 210.82(8)?
Q2: Is the experience with existing on-site reuse facilities operating in Harris County and at TXDOT rest-facilities satisfactory?
Q3: Are modifications needed to a standard on-site wastewater treatment train or maintenance requirements to improve quality and reliability of effluent for non-potable reuse?

Deliverables:

1. Experimental design specifying real world operating conditions for performance evaluation of the BioBarrier® MBR unit operating at the research center;
2. Justification for the experimental design conditions to simulate real-world operation;
3. Effluent quality data collected during the experimental evaluation of the BioBarrier® MBR;
4. Data and information gathered from Harris County and TXDOT facilities operating effluent reuse system for toilet flushing;
5. Quarterly progress and budgetary reports;
6. Final report describing all results and findings.

Tentative Experimental Design:

- Operate reuse system under "normal" conditions
  - Influent flow within ±10% 225 GPD, BOD/TSS 300 mg/L, blower operation according to manufacturer's recommendations, alarm(s) attended within 24 hr.;
  - Effluent sampling and observation for 3 to 6 months;
- Operate reuse system under "abnormal" conditions
  - Influent flow variations as per Project 1, blower operation on/off during a week, alarm(s) ignored for >48 hr. to simulate system abuse;
  - Effluent sampling and observation for 3 to 6 months;

Influent flow variation from Project 1 (tentative)

Test Run	[gal/day]	[mg/L]	[lb/day]
TR1	225.0	300	0.56
TR2	180.0	375	0.56
TR6	157.5	900	1.18
TR7	180.0	1000	**1.50**

Neglected operation and monitoring conditions simulation during TR2, 6, and 7 (tentative):

1. Blower turn off and remained off for three days or till odor is noticed;
2. Alarms ignored for more than two days or till effluent surfacing noticed;
3. System operation not monitored for three weeks.

Appendix – C

Revised two-page handout for the reuse project and Plumbing Diagram

Feasibility Study to Evaluate On-Site Treatment of Wastewater for Non-Potable Reuse (Reuse)

Jantrania, Gerlich, Bonaiti, and Wolfe

Summary:
This research effort addresses one of the four eligible projects listed in TCEQ Solicitation 582-19-9377, **RT-2.3.4**, questioning the need for modification of standard on-site wastewater treatment-train or maintenance requirements to improve quality and reliability of effluent for non-potable reuse purposes. The National Sanitation Foundation (NSF) Standard 350 are used for performance evaluation of on-site residential and commercial water reuse treatment technologies. However, most commonly used aerobic treatment unit (ATU) in Texas is the NSF Standard 40 unit. NSF Standard 350 effluent quality requirements are similar to those for toilet flushing reuse effluent quality specified in the TCEQ Chapter 210.82(8), but NSF Standard 40 effluent quality requirements are not. BioBarrier® MBR (NSF-350) and Clearstream® (NSF-40) on-site wastewater treatment technologies will be used under "normal" and "abnormal" operating conditions in this project. Performance will be assessed by measuring *E. coli* and TSS concentrations in effluent to determine if the reuse water quality standards are met under various operating conditions. Information on non-residential reuse facility operating in Harris County and at TXDOT rest area will be gathered, analyzed, and used along with the results from our experiment to determine the need for modification in technical or regulatory requirements.

Goals:

1. To compare performance of an NSF-350 and NSF-40 approved technologies in a real-world operating condition against the effluent quality requirements specified in Chapter 210.82(8);
2. To collect performance information on commercial reuse systems operating in Harris County and at TXDOT facilities;
3. To prepare a concise report specifying the need for modifications of standard on-site wastewater treatment-train or maintenance requirements to improve quality and reliability of effluent for non-potable reuse purposes.

Objectives:

1. Perform necessary changes to the BioBarrier® and Clearstream® on-site wastewater treatment technologies and get them ready for this experiment;
2. Finalize "normal" and "abnormal" operating conditions and operate the unit to collect data;
3. Conduct phone interview and site visits with Harris County and TXDOT to gather design and operational information on their non-potable reuse facilities;
4. Prepare data sets on effluent quality observed at the center and at other reuse facilities for analysis to determine answers to the research questions;
5. Prepare detailed and summary reports along with PowerPoint presentation for submittal.

Research Questions

Q1: Do NSF-350 and NSF-40 approved technologies operating in a real-world condition meet the effluent quality requirements specified in Chapter 210.82(8)?

Q2: Is the experience with existing on-site reuse facilities operating in Harris County and at TXDOT rest-facilities satisfactory?

Q3: Are modifications needed to a standard on-site wastewater treatment train or maintenance requirements to improve quality and reliability of effluent for non-potable reuse?

Deliverables:

1. Experimental design specifying real world operating conditions for performance evaluation of the BioBarrier® MBR and Clearstream® units operating at the research center;
2. Justification for the experimental design conditions to simulate real-world operation;
3. Effluent quality data collected during the experimental evaluation of both the technologies;
4. Data and information gathered from Harris County and TXDOT facilities operating effluent reuse system for toilet flushing;
5. Quarterly progress and budgetary reports;
6. Final report describing all results and findings.

Final Experimental Design:

- Operate reuse system under "normal" conditions
    - Influent flow within ±10% 225 GPD, BOD/TSS 300 mg/L, blower operation according to manufacturer's recommendations, alarm(s) attended within 24 hr.;
    - Effluent sampling and observation for 3 to 6 months;
- Operate reuse system under "abnormal" conditions
    - Influent flow variations as per Project 1, blower operation on/off during a week, alarm(s) ignored for >48 hr. to simulate system abuse;
    - Effluent sampling and observation for 3 to 6 months;

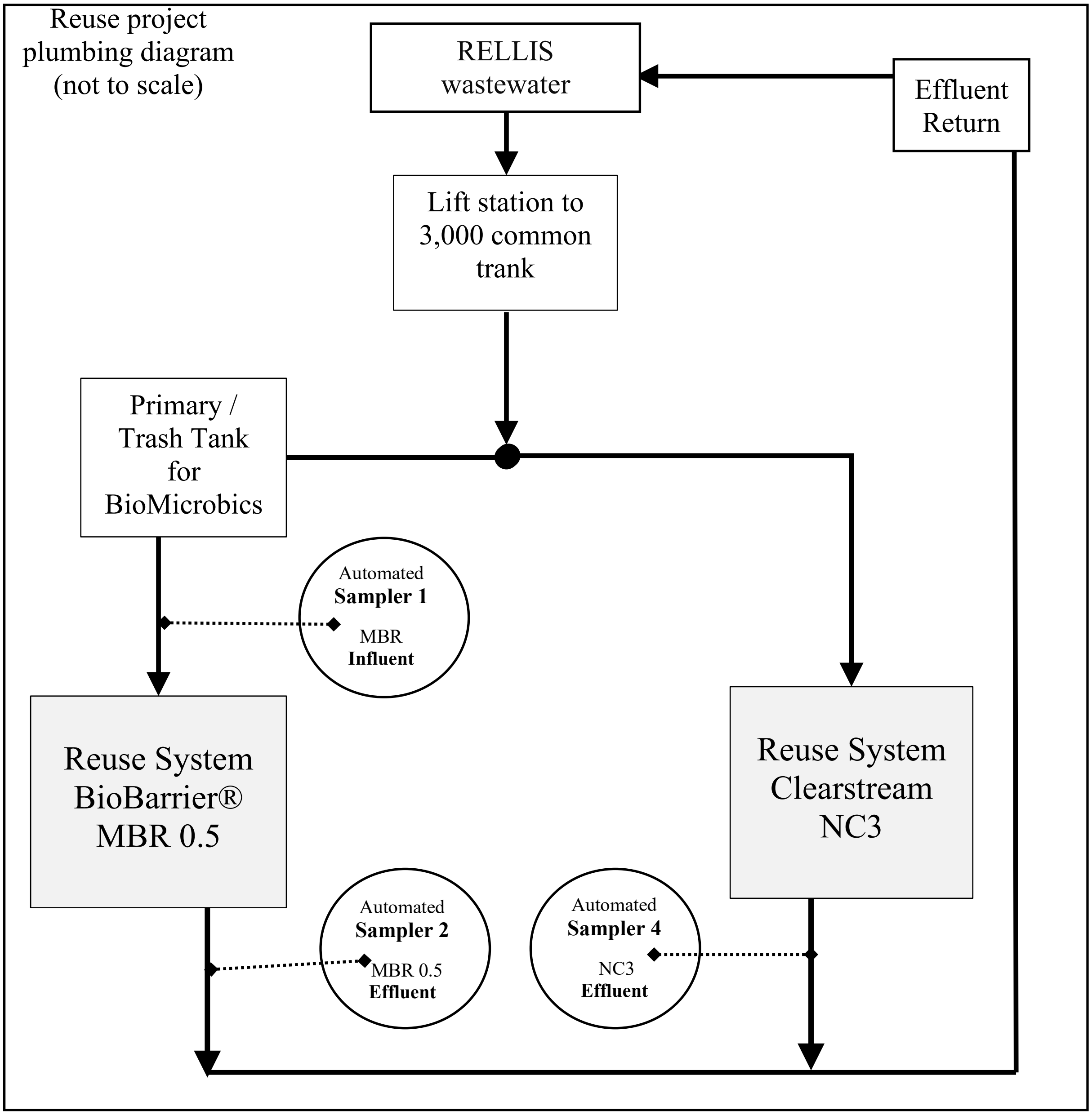
Influent flow variation from Project 1 (tentative)

Test Run	[gal/day]	[mg/L]	[lb/day]
TR1	225.0	300	0.56
TR2	180.0	375	0.56
TR6	157.5	900	1.18
TR7	180.0	1000	**1.50**

Neglected operation and monitoring conditions simulation during TR2, 6, and 7 (tentative):

1. Blower turn off and remained off for three days or till odor is noticed;
2. Alarms ignored for more than two days or till effluent surfacing noticed;
3. System operation not monitored for three weeks.

Plumbing diagram for Reuse Project:



Quarterly Progress Report #2
Work Period: December 1, 2019 – February 29, 2020

For Texas On-Site Sewage Facility (OSSF) Research Contract #582-19-96829

Feasibility Study to Evaluate On-Site Treatment of Wastewater for Non-Potable Reuse

Report submitted to:

Kelly Wilson, Technical Specialist
Office of Compliance and Enforcement
Texas Commission on Environmental Quality
P.O. Box 13087, MC - 235
Austin, Texas 78711-3087
Kelly.Wilson@tceq.texas.gov

Report Submitted by:

Anish Jantrania, Associate Professor & Extension Specialist
Texas A&M AgriLife Research & Extension
720 E Blackland Road
Temple, TX 76502
(254) 774-6014
ajantrania@tamu.edu

March 15, 2020

Following tasks were completed during the second quarter of this project:

1. Representatives from Clearstream wastewater treatment company visited the research center site mid-January and met with our research team to discuss and finalize delivery of their reuse technology. During this meeting we learned that we will be getting Clearstream **Model 500DA** performance of which was evaluated in year 2016 by the Gulf Coast Testing LLC under the ANSI 350 Reuse Technology Standards, like the standards used for BioMicrobics BioBarrier evaluation at NSF. Thus, in our reuse project we will be comparing two technologies both which are evaluated under the ANSI/NSF 350 standards at two different testing facilities (NSF and Gulf Coast Testing), one with a membrane filter (BioBarrier) and one without (500DA). We will revise our research plan to reflect this change and submit the revised plan to TCEQ during the next quarter. In late January we received the test report on 500DA unit from Clearstream which will be used to determine average, minimum, and maximum influent BOD levels during the testing at the Gulf Coast test center.

2. During the last week of February, the one-piece concrete tank Clearstream 500DA unit was delivered to our test site. Before the delivery date, Ryan Gerlich dug out the old Clearstream Standard 40 unit, which was in operation at the Center since the beginning of the Center in early 1990 (about 30 years ago). Activated sludge from operating Cleastream unit was carefully transferred to the Hoot unit so that it can be used to "seed" both the reuse technologies next month. See pictures in Appendix A showing the sludge transfer and installation of the new Clearstream unit.

3. Dr. Jantrania met with the representatives from TxDOT at the Navarro safety (rest) area off I-45 North, where a wastewater reuse technology is in operation. TxDOT informed us that the effluent from the reuse technology is not meeting the effluent standards for reusing water, thus the effluent is not reused for toilet flushing as planned and it discharged in a creek instead. During the first site visit in December, Dr. Jantrania met with the plant operator, observed the operation of the MBR system, and noticed that the effluent has a yellow tint which was similar to what we have from the MBR unit operating at our research center. During our 2019 REEU summer program, we were able to remove the yellow tint using two technologies, activated carbon filter and ozone. Dr. Jantrania had taken with him a simple activated carbon filtration system with him to the TxDOT site. The operator filled about five gallons of the MBR effluent in the filter and we found that the yellow color was successfully removed by filtration (see pictures in Appendix B). TxDOT and Dr. Jantrania scheduled another meeting at the site in February to test the Ozone treatment for color removal.

4. The second site visit to the TxDOT reuse facility happened in mid-February during with representatives from Aerobic Guard Company came to demonstrate use of their Ozone treatment technology to remove the yellow color from the effluent. The same Ozone technology is being used at the research site to polish the MBR effluent. During this site visit we noticed the effluent quality was better than what was observed during the previous visit in December and had less yellow tint. However, ozone treatment did make the effluent better by removing the yellow tint. TxDOT has requested Aerobic Guard to

submit a proposal to conduct a bench-scale six month long study to further evaluate application of their Ozone treatment at the site to see if that will "fix" the problem and allow TxDOT to reuse wastewater for toile flushing.

5. Working with TxDOT is allowing us to better understand challenges associated with applications of reuse technologies in real-world. We plan to continue working with the TxDOT during next quarters and learn how Ozone technology performs at this site. We also plan to get in touch with the Harris County to schedule our first site visit to the reuse site operating in Harris County.

6. We wish to note that our reuse project is running behind by about two months based on the timeline outlined in our proposal. However, we should be able to catch-up during the next two quarters.

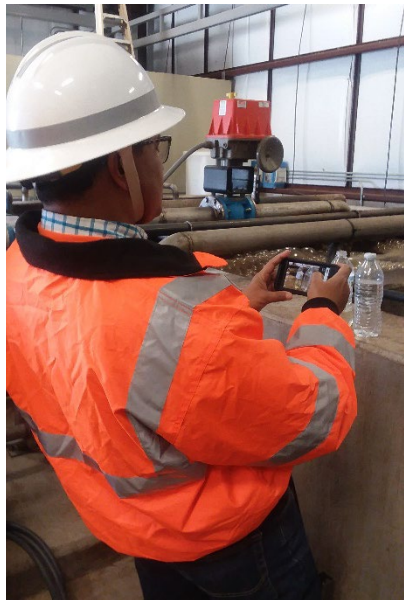
In the third quarter, we will focus on getting both the reuse technology units started treating wastewater, schedule first round of influent and effluent sampling using composite samplers and finalize the recipe for influent amendments for increasing BOD concentrations. In the next quarter, we will also continue to learn from the reuse technologies operating at the TxDOT safety area and in Harris County.

Appendix – A

Installation of the Clearstream Reuse Technology at our Research Center:

Transferring activated sludge from old Clearstream unit to Hoot unit for future use:

Appendix B TxDOT Safety Area Reuse System Site Visits (December and February)



Quarterly Progress Report #3
Work Period: March 1, 2020 – May 31, 2020

For Texas On-Site Sewage Facility (OSSF) Research Contract #582-19-96829

Feasibility Study to Evaluate On-Site Treatment of Wastewater for Non-Potable Reuse

Report submitted to:
Kelly Wilson, Technical Specialist
Office of Compliance and Enforcement
Texas Commission on Environmental Quality
P.O. Box 13087, MC - 235
Austin, Texas 78711-3087
Kelly.Wilson@tceq.texas.gov

Report Submitted by:
Anish Jantrania, Associate Professor & Extension Specialist
Texas A&M AgriLife Research & Extension
720 E Blackland Road
Temple, TX 76502
(254) 774-6014
ajantrania@tamu.edu

June 15, 2020

According to our proposed work plan, we were planning to do the following tasks during the 3rd and 4th Quarters of the Year 1:

1. Start the six 30-day period experiment and collect first 30-day field- and lab-data while operating the reuse technology under "ideal-normal" operating conditions.

2. Follow the experimental design and implement changes in operating conditions of the reuse technologies including flow variability and neglected maintenance/monitoring scenarios during the next four 30-day periods.

3. Operate the reuse technology under "ideal-normal" operating conditions during the last 30-day period.

4. Collect sample results from the field and laboratory reports and start developing the dataset that will be used for statistical analysis later.

5. Discuss progress report with the TOGP Committee members in the fourth quarter and arrange a field visit to the research facility for the members if there is an interest to do so.

This quarter suffered operational complexity and delays due to the Corona-19 virus outbreak. Beginning 16 March 2020.

Texas A&M AgriLife Research suspended all field and laboratory activities, including those related to this project. On 20 March, this suspension was extended until 1 May; only critical activities and services were permitted which caused project delays. Beginning 15 May, AgriLife approved limited field and laboratory research activity under special Covid-19 operational procedures. These limitations remained in effect through this reporting quarter (Q3).

Covid-19 situation did not allow us to start any of the above mentioned five tasks.

However, we did conduct the following tasks that were not specified in our workplan:

1. Prepared and delivered a short presentation on all three research projects at the Texas Onsite Wastewater Association's Annual Conference in Waco in second week of March, just before the start of Covid-19 shut-down.

2. Worked with the PIs of the other two projects and Mr. Gerlich on developing the recipe for the Manufactured High Strength Wastewater (MHSW) and discussed various strategies to get finalize the recipe during the next quarter once the Covid-19 restrictions are relaxed for our work-study students to get back to laboratory work.

3. Re-started discussion with the Texas A&M University Utility staff and leaders to get the pressure sewer and lift-station installed at the RELLIS Campus WWTP to increased raw wastewater flow at our research site. In the last week of May, we were told that we need to work on purchasing and installing all the electrical component for this task and the Utility will do only the pressure line installation. We have started contacting local pump

suppliers to get specifications and quotes for installation of a pump-control package that will allow us complete the electrical component of the pressure sewer installation task and then we expect the Utility to complete the installation of the pressure sewer line so that we can have the raw wastewater amount necessary for all three research projects.

4. We have recognized a need for having our own laboratory building at the research center to be able to perform a large number of COD and BOD tests for fine-tuning MHSW recipe and having a capacity to conduct other field measurements of wastewater quality such as pH, DO, EC, etc. Our team met with the leadership of TEEX, RELLIS, and AgriLife twice during this quarter to start discussion for acquiring and installing a portable building that would serve as our field-laboratory at our research site. The capital cost of this facility will be absorbed from operation budget of our current OSSF program. We expect to have our field-laboratory in operation in the next few months.

5. Our team worked on preparing text for a technical paper describing all three research projects for presentation at the Annual International Meeting (AIM) of American Society of Agricultural and Biological Engineering (ASABE) in July.

During the 4th quarter, we expect to complete the installation of the pressure sewer line and be able to test the MHSW recipe to make the raw wastewater suitable for conducting both the Reuse and ATU projects. We plan to address all the comments we received on the QAPP during the month of June and get the final version approved before the end of next quarter. All our work plan now depends on Covid-19 situation and our ability to get work done at our research center.

Quarterly Progress Report #4
Work Period: June 1, 2020 – August 31, 2020

For Texas On-Site Sewage Facility (OSSF) Research Contract #582-19-96829

Feasibility Study to Evaluate On-Site Treatment of Wastewater for Non-Potable Reuse

Report submitted to:

Donna Cosper, P.E., Project Manager
Program Support and Texas OSSF Research Grant Program
Texas Commission on Environmental Quality
P.O. Box 13087, MC - 235
Austin, Texas 78711-3087
Donna.Cosper@tceq.texas.gov

Report Submitted by:

Anish Jantrania, Associate Professor & Extension Specialist
Texas A&M AgriLife Research & Extension
720 E Blackland Road
Temple, TX 76502
(254) 774-6014
ajantrania@tamu.edu

September 15, 2020

TEXAS A&M AGRILIFE RESEARCH | EXTENSION

During the 4th Quarter of the Year 1, the following tasks were completed:

1. Installation of one new and restart of one existing reuse technology:

    a. Installation of Clearstream 500-DA tank and restart of existing BioBarrier MBR 5.0

    Cleastream 500-DA reuse treatment tank and BioBarrier MBR 0.5 tank

    b. Finally, on August 4th primary/trash tank of BioBarrier MBR 0.5 was pumped out and activated sludge from the 300 gallon MBR aeration tank was re-distributed: 1/3 to seed the Clearstream unit, 1/3 wasted, and 1/3 remaining in the MBR aeration tank. **Both units were started with 100 gallons per day wastewater feed and 100 gallons of activated sludge from MBR as seed.**

    c. Following pictures show the activated sludge from MBR unit observed during a 30-minute settleability test:

    Activated Sludge T=0-minute

    50% Settling at T=30-minutes.

    This material was used to seed the new Clearstream unit as well as to restart the existing BioBarrier MBR unit; thus, both units are started with the same material.

2. Met with pump and control supplier to develop specifications for the pressure sewer line (~600 ft) needed to transfer raw wastewater from the RELLIS Campus wastewater treatment plant to the OSSF Research Center. The following Google Map shows the proposed pressure sewer line:

3. The proposed scope of work (including details on pump and control) has been submitted to the TAMU Utility department responsible for assisting with the installation of the pressure sewer line. The plan will be discussed next month (September) to estimate to time and tasks necessary to obtain additional flow of raw wastewater from RELLIS Campus Sewer system to the OSSF Research Center Lift Station.

4. The OSSF team continued to work on developing the recipe for the Manufactured High Strength Wastewater (MHSW) using Dextrose and Milk Powder. The goal of finalizing the recipe during this quarter was not achieved, however it is expected to be finalized early next quarter.

5. QAPP revisions were prepared and submitted to TCEQ on August 21st. The final document is expected to be signed early part of the next quarter.

6. The OSSF team worked under the leadership of Dr. June Wolfe to develop a Microsoft Access database that will be used for recording and management of water quality sample analysis results from all three projects (details presented in the ATU report).

7. The OSSF team presented two papers during the Virtual Annual International Meeting (AIM) of American Society of Agricultural and Biological Engineering (ASABE) in mid-July, both related to this research program (*ASABE Paper Numbers – 2000034 and 2000715*).

Note on special Covid-19 conditions occurring during Quarter 4:

AgriLife anticipated reaching 100% resumption of normal research activity by 1 July 2020. Given continued Covid-19 activity statistics and agency requirements, as of 26 August 2020 AgriLife has been able to increase office and laboratory activities/occupancy to only 75% of normal. However, project activities progressed under Covid-19 safety guidance requirements.

Overall status of the reuse project at the end of first year and plans for the next year:

- Installation and starting of Clearstream (non-MBR) reuse system and restart of BioBarrier MBR reuse system using the same seed material – **Completed**, both units are operational and receiving 100 gallons per day raw wastewater, **starting August 4, 2020**.

- Increasing wastewater flow to the research center by installing a pressure sewer line from the RELLIS Treatment Plant (or from some other point within the Campus sewer system) to the lift station currently feeding the research center – **Not Completed, work in progress**; expected to be completed in next quarter (**Y2-Q1**).

- Start operation of both reuse technologies under "normal" operating conditions (TR1) at the design flow rate 225 GPD – **Not completed, waiting for increased flow rate, expected to be completed in the next quarter (Y2-Q1 or Q2)**.

- Start operation of both reuse technologies under "abnormal" operating conditions (TR2 and TR3) – **Expected to start in Y2-Q2 or Q3.**

- Finalize recipe for MHSW and finalize QAPP document - **Not Completed, work in progress**; **expected to be completed in the next quarter** (**Y2-Q1**).

- Discuss progress report with the TOGP Committee Members in the fourth quarter and arrange a field visit to the research facility for the members (if there is an interest). **Not Completed, work in progress**; **expected to be completed in the next quarter** (**Y2-Q1**).

- Set-up field laboratory at RELLIS Campus OSSF Research Center – **Not Completed**, work in progress; Detailed specification and drawings have been prepared. Supplier proposals are under review and the building is expected to be installed at the OSSF Research Center before the end of the year (**Y2-Q2**).

Quarterly Progress Report #5
Work Period: September 1, 2020 – November 30, 2020

For Texas On-Site Sewage Facility (OSSF) Research Contract #582-19-96829

Feasibility Study to Evaluate On-Site Treatment of Wastewater for Non-Potable Reuse

Report submitted to:
Donna Cosper, P.E., Project Manager
Program Support and Texas OSSF Research Grant Program
Texas Commission on Environmental Quality
P.O. Box 13087, MC - 235
Austin, Texas 78711-3087
Donna.Cosper@tceq.texas.gov

Report Submitted by:
Anish Jantrania, Associate Professor & Extension Specialist
Texas A&M AgriLife Research & Extension
720 E Blackland Road
Temple, TX 76502
(254) 774-6014
ajantrania@tamu.edu

December 15, 2020

During the 1st Quarter of the Year 2 (i.e., Quarter 5), the following tasks were completed:

1. Task to increase the flow of raw wastewater to the research center was finally completed during this quarter after a long wait. Instead of installing a pressure line from the inlet end of RELLIS wastewater treatment facility, a simpler solution was developed. RELLIS main sewer line present close to the existing lift-station was tapped and a 4-inch gravity line was connected to the lift-station (See Photos in Appendix A). The flow of raw wastewater was partially blocked in the manhole that allowed additional raw wastewater to flow into the lift-station, increasing availability of raw wastewater in the lift-station. Note that the lift-station has ability to return the unused wastewater into the RELLIS sewer line on the other side of the manhole, thus giving the necessary amount (about 2,000 GPD) of raw wastewater be pumped from the lift-station to the feed tank.

2. Sampling pumps were installed to collect grab-sample from the lift-station and the feed-tank on a routine basis for sample collection to study the effects of adding chickenfeed in the feed-tank. During this quarter chickenfeed was added to increase strength of raw wastewater. Work-study student is conducting COD analysis inhouse and a limited number of samples are sent to the contract lab (Aqua-Tech) for BOD and COD analysis. Overall goal of this exercise is to determine frequency and amount of chickenfeed needed to get the raw wastewater BOD values in the range of 250 to 350 mg/l. Appendix-B contains information on chickenfeed used and a chart showing COD values of raw wastewater from lift-station and amended wastewater from feed-tank. Note that the amended wastewater from the feed-tank will be used to dose all three research projects (ATU, LPD, and Reuse).

3. Automatic samplers were installed at both the Reuse treatment sites to collect influent and effluent composite samples from the Clearstream 500-DA and the BioMicrobics MBR-0.5 reuse systems. A trial run of the sampling activities is planned for the early part of the next quarter and research trails are scheduled to start by mid-January.

4. Team presentations made during the Mega-Conference organized by the National Onsite Wastewater Recycling Association (NOWRA) related to all three research projects and the Texas funding model to support onsite wastewater research activities. There is a lot of interests at the national level in this project and we will have another opportunity to present this and future work next year during the 2021-Mega-Conference scheduled to take place in Texas.

5. TOGP Advisory Group meeting was held virtually on November 18th during which all three PIs presented the progress report and one of the Co-PIs (Ryan Gerlich) gave a virtual tour of the research center showing the work completed as of November 18th for all three projects.

Note on special Covid-19 conditions occurring during Quarter 5:

Given continued Covid-19 activity statistics and agency requirements, as of 26 August 2020 AgriLife has maintained office and laboratory activities/occupancy at 75% of normal. Project activities continue to progress under university Covid-19 safety guidance requirements.

The following tasks will be addressed during Quarter 6 (2^{nd} Quarter of Year 2):

1. Change the membrane in the BioMicrobics Reuse system, install the disinfection (UV and Cl) in the Clearstream Reuse system, and get both the units ready to start the "baseline" trial run to practice staff coordination and verify automatic samplers' operation.

2. Finalize the amount and frequencies for adding chickenfeed in the feed tank to maintain desired BOD values (250 to 350 mg/l) of raw wastewater and determine the amount needed for developing conditions such as homeowner abuse by excess waste loading due to temporary increase in number of residents in both Reuse systems.

3. Finalize the operation plans for both Reuse systems under other "abnormal" conditions such as aeration and/or disinfection system not working for part of the week during the 3^{rd} and 4^{th} quarters of this year (i.e., during the 7^{th} and 8^{th} quarters). NOTE that four research trials are proposed for this project and details on those trials will be finalized in the next quarter.

4. Reconnect with TxDOT and Harris County contacts to obtain current information on the Reuse systems operating at their facilities and schedule site visits during the 7^{th} and/or 8^{th} quarters.

5. Set-up field laboratory at RELLIS Campus OSSF Research Center during the next quarter.

Appendix A:

Construction photos showing the work done to increase the raw wastewater flow to the lift-station:

Top Left: Excavation work to expose underground pipe network; Top Right: Underground pipe network, clay pipe is the main sewer line and other PVC pipes are connections between the lift-station and the feed tank. Bottom large picture shows above ground conditions, concrete manhole (on left) and the fiberglass lift-station (on right).

Close-up of the clay sewer line in the area where it will be tapped in for connection to the lift station.

Creating the connection between the clay sewer line and the manhole using a 4-inch gravity sewer line (green color pipe).

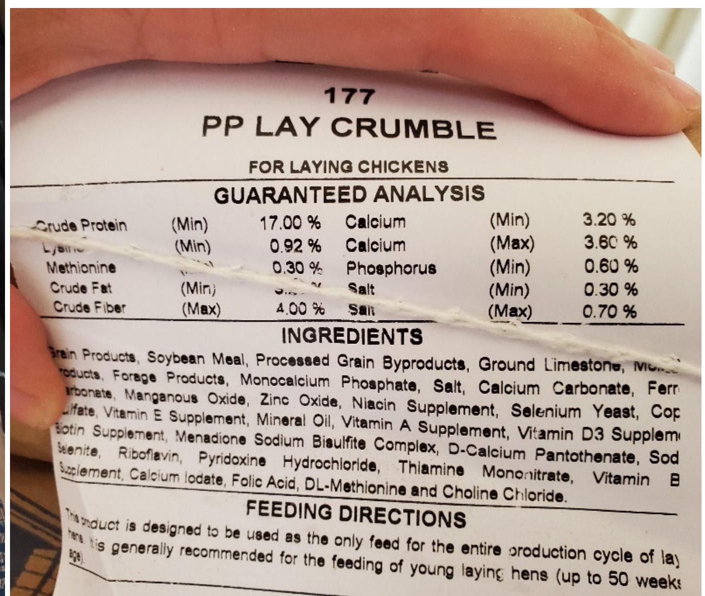
Sewer line connected to the lift-station using a 4-inch gravity sewer pipe (green color pipe).

A small concrete dam constructed to create backflow in the main sewer line to increase flow to the lift station.

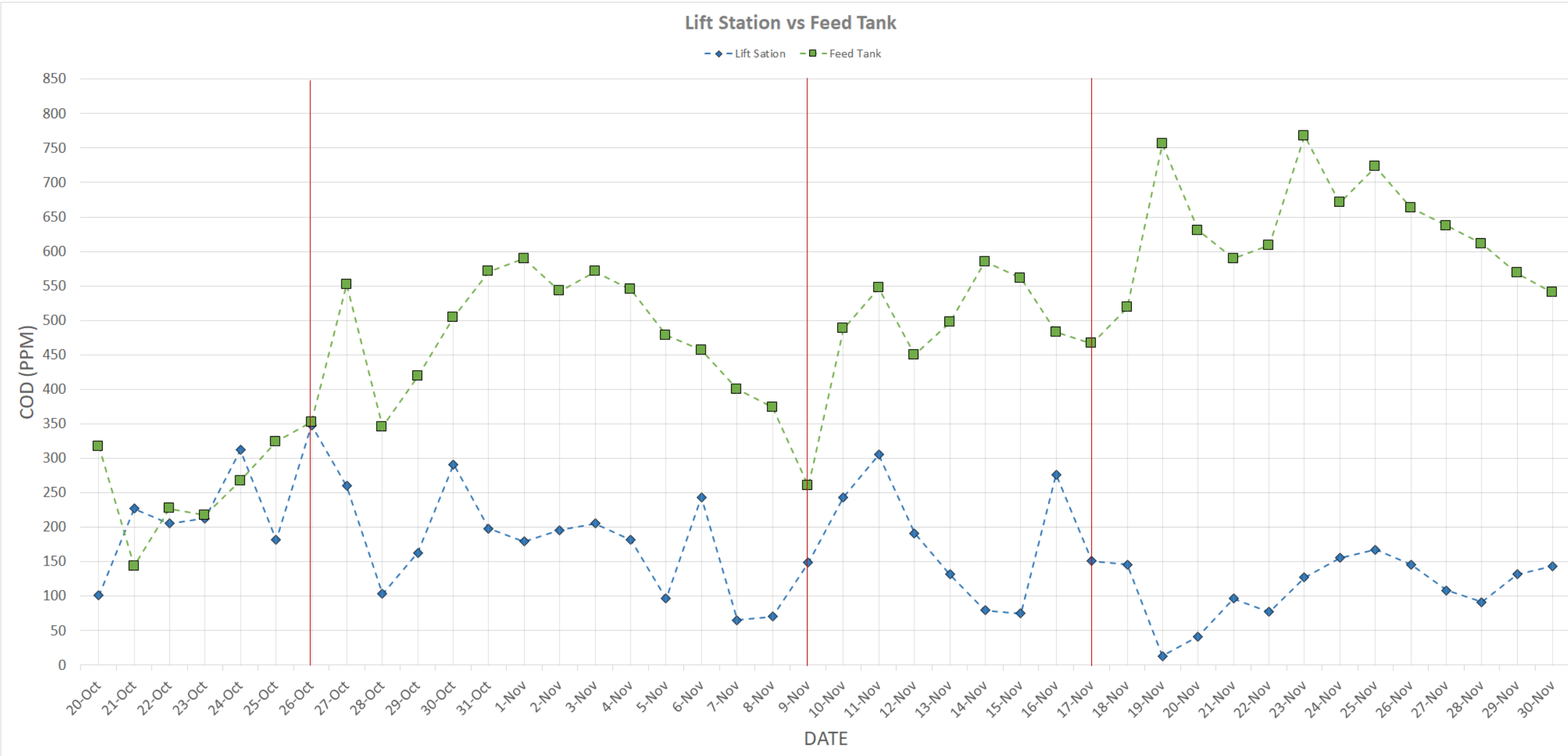

Work completed and site back to normal conditions.

Appendix B:

Use of chickenfeed material to increase raw wastewater strength.



Effects of adding 50 lb of chickenfeed material to increase COD in raw wastewater (material added on 20-Oct, 9-Nov, and 17-Nov)



Also note that the Appendix A of the ATU report presents the relationship between the chickenfeed and BOD in raw wastewater. Our goal is finetune this chart during the next quarter by adding small portion every other day and observe the changes in BOD values. *NOTE that Appendix-A of the ATU quarterly report shows the relationship between chickenfeed concentration and expected BOD in the feed-tank.*

Quarterly Progress Report #6
Work Period: December 1, 2020 – February 28, 2021

For Texas On-Site Sewage Facility (OSSF) Research Contract #582-19-96829

Feasibility Study to Evaluate On-Site Treatment of Wastewater for Non-Potable Reuse

Report submitted to:

Donna Cosper, P.E., Project Manager
Program Support and Texas OSSF Research Grant Program
Texas Commission on Environmental Quality
P.O. Box 13087, MC - 235
Austin, Texas 78711-3087
Donna.Cosper@tceq.texas.gov

Report Submitted by:

Anish Jantrania, Associate Professor & Extension Specialist
Texas A&M AgriLife Research & Extension
720 E Blackland Road
Temple, TX 76502
(254) 774-6014
ajantrania@tamu.edu

March 15, 2021

During the 2nd Quarter of the Year 2 (i.e., Quarter 6), the following tasks were completed:

1. Both reuse systems were checked for normal operating conditions; the membrane in the BioMicrobics (MBR-Reuse) system was replaced (see pictures in Appendix A) and the disinfection systems (UV and Cl) in the Clearstream (non-MBR Reuse) system were brought online by the company during the month of December. NOTE that membrane replacement was done on December 2nd before the start of the test run (TR0), but the disinfection system in Clearstream was brought on-line on December 10th, while the TR0 started on December 8th.

2. Conducted TR0 for sample collection, analysis, and getting reports from the private laboratory (Aqua-Tech) during December. Analyzed the BOD results from Lift Station and Feed Tank to adjust the amount and frequency for adding chickenfeed in the feed tank, as well as modified the process to add the chickenfeed easily in the feed tank. See Appendix B for details chickenfeed addition to increase BOD in the feed tank.

3. Confirmed that both the reuse technologies were operating in "normal" conditions during the TR0, and continuous sampling equipment installed to collect composite samples of influent to and effluent from both the reuse technologies performed as expected. Effluent quality data from TR0 are presented in Appendix D.

4. Experiments 1 and 2 (TR1 and TR2) were completed in January and February. Both the systems were operated under "normal" operating conditions during TR1 (January), while "abnormal" operating conditions (disinfection systems stopped working) were planned for TR2 (February). While all eight samples were collected in TR1, only six samples were collected TR2 due to a weeklong severe freezing condition in Texas. Appendix C contains screenshots from media showing the cold conditions and photos of the research site covered in ice/snow. TR2 was halted during the week of February 15th due to poor road conditions that prevented the private lab from collecting samples. Both the reuse systems continued receiving wastewater, however the disinfection systems malfunction simulation continued for 11 days (from 2/11 to 2/22) instead of just 4 days (from 2/11 to 2/15 as originally planned. General observations of both the reuse systems conducted on Monday 2/22 showed no adverse effects of "abnormal" operating conditions due to cold weather or due to in operating disinfection systems.

5. Finalized the details on operating conditions that will be used to study performance of both the reuse systems during the remaining experiments (TR3 – TR5). Following is the summary of those conditions:
   a. TR-3: Turn-off disinfection units from Thursday to Tuesday (3/18-3/23) while BOD load is increased by adding 1 lb./day chickenfeed in trash-tank.
   b. TR-4: Turn-off aeration units over the weekend from Friday (4/16) to Monday (4/19) to study effects of no-aeration on effluent quality.
   c. TR-5: Turn-off both disinfection and aeration systems over the weekend from Friday (5/14) to Monday (5/17) to study effects of worst-case scenario.
   d. TR-6: Operate both the systems under normal operating conditions from 6/15 to 6/29 to study how both the systems recover from the "abnormal" operating conditions.

6. Launched a webpage dedicated to the TOGP research program on the TAMU's OSSF website and requested TCEQ project manager to make the page accessible from their website. The link for the page is https://ossf.tamu.edu/togp-research/ and in next quarter we plan to develop a dashboard for presenting effluent quality results from each test run.

Note on special Covid-19 conditions occurring during Quarter 6:

AgriLife continues to follow TAMU COVID-19 safety guidance including the wearing facemasks, maintaining social distance, and traveling with only 1 person per vehicle. Details on the guidance https://www.tamu.edu/coronavirus/index.html. Due to delays caused by the ongoing COVID restriction and short delay due to February winter storm, we request a 3-month (September, October November) no-cost extension to complete the data analysis and final reporting tasks. We expect to spend all funds allocated for this project by the end of August and continue working on data analysis, reporting, and final presentation task without charging for any time or material to this grant project.

The following tasks will be addressed during Quarter 7 (3rd Quarter of Year 2):

6. Complete the three experiments (TR3, TR4, and TR5) of "abnormal" operating conditions for both reuse systems without causing drastic failure to any of the systems and bring both the systems to normal operating conditions (TR6) in June.

7. Continue observations related to effects of chickenfeed addition on BOD increase and determine if a predictive model is possible for future studies.

8. Conduct sludge tests and settleability tests on both the reuse technologies to determine the sludge accumulations in both trash tank and in aeration tank. If removal of sludge from any of the four tanks is necessary than appropriate amount sludge will be removed and recorded. Note that the sludge removed will be discharged into RELLIS sewer.

9. Reconnect with TxDOT and Harris County contacts to obtain current information on the Reuse systems operating at their facilities and schedule site visits during the 7th and/or 8th quarters. (This task was not completed during the last quarter)

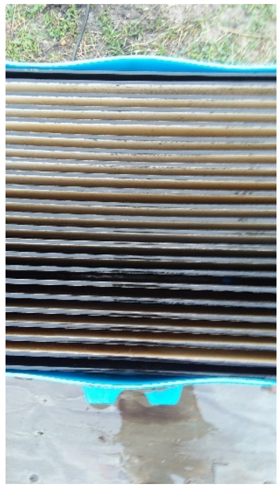
10. Set-up field laboratory at RELLIS Campus OSSF Research Center during the next quarter. (This task was not completed during the last quarter)

11. Continue modifications of the TOGP webpage to add a dashboard showing the effluent quality results for all three projects for each of the six test runs.

Appendix A:

Replacement of the membrane filter in the MBR-Reuse System December 2:

(b)



(b)

(c)

Three pictures showing (a) first removal of the old membrane cassette from the MBR-Reuse system tank; (b) close-up of membrane fouling (about 18 months in use); and (c) close-up view of the new membrane cassette that will replace the old one.

(d)

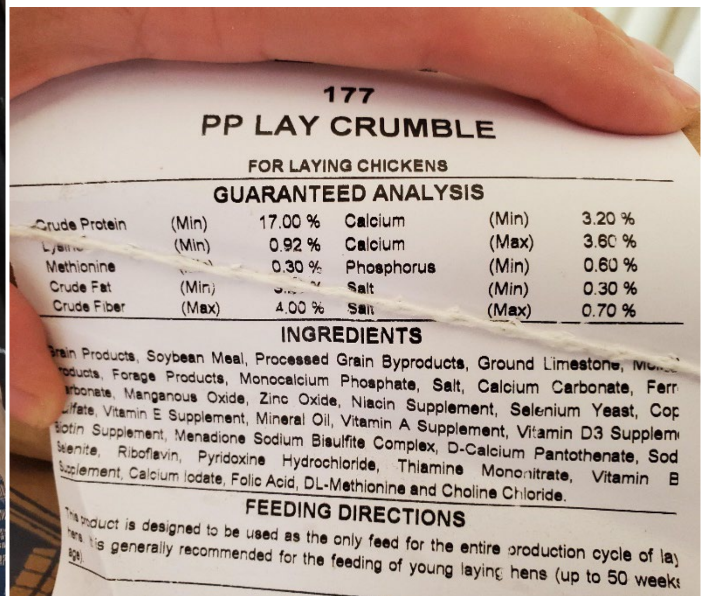
(e)

(f)

Two pictures showing (d) carefully draining wastewater from the old cassette, (e) replacing the old cassette with the new one, and finally (f) re-assembling the membrane unit for putting it back in the MBR-Reuse system tank; difficult work that must be done by a trained person with at least one helper.

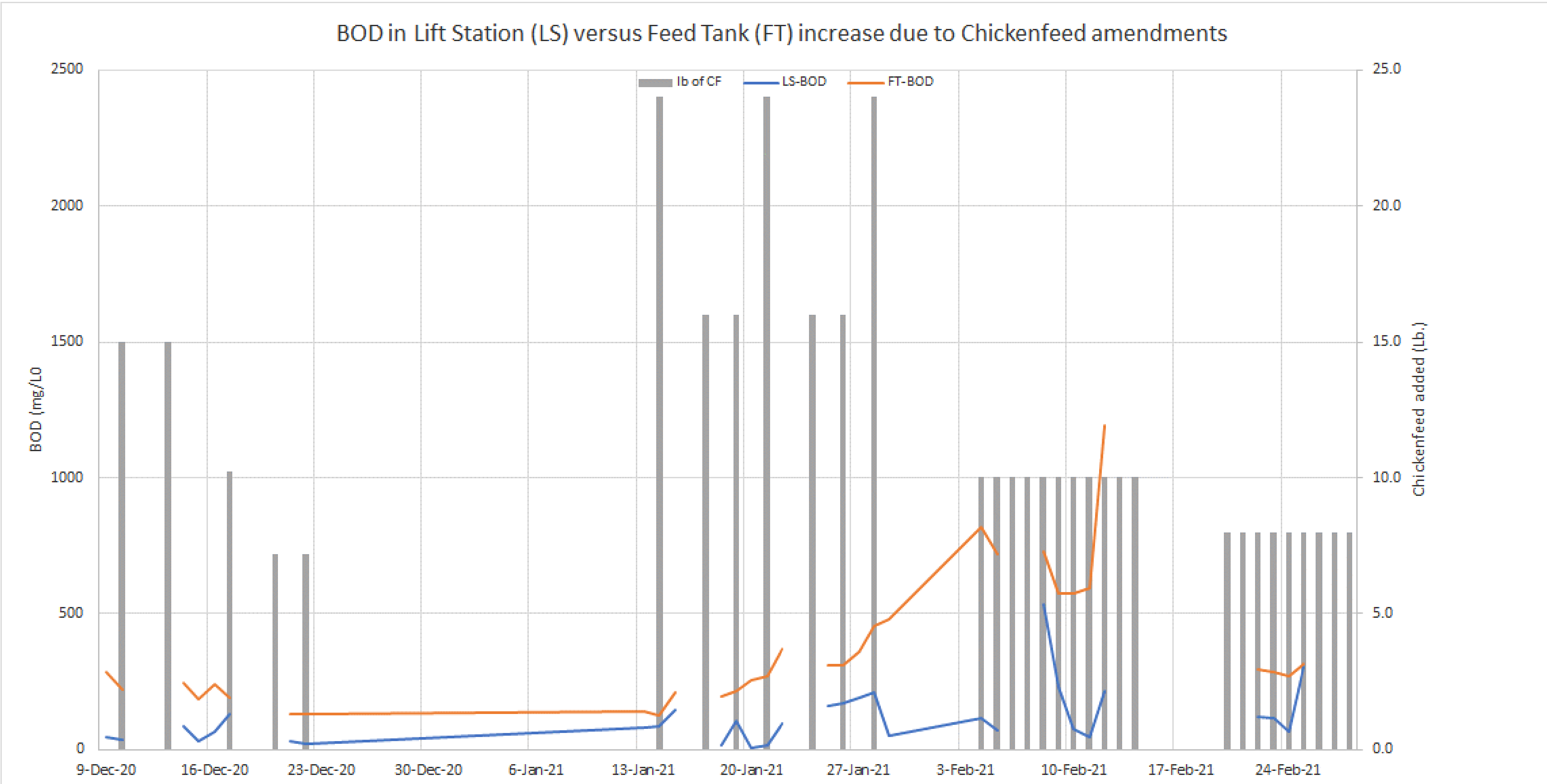
Appendix B:

Use of chickenfeed material to increase raw wastewater strength.



Improved method for adding chickenfeed to increase BOD in raw wastewater in the feed tank.

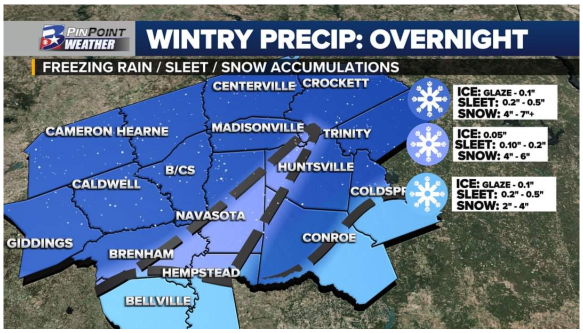
Effects of adding chickenfeed material in Feed Tank to increase BOD in raw wastewater from Life Station



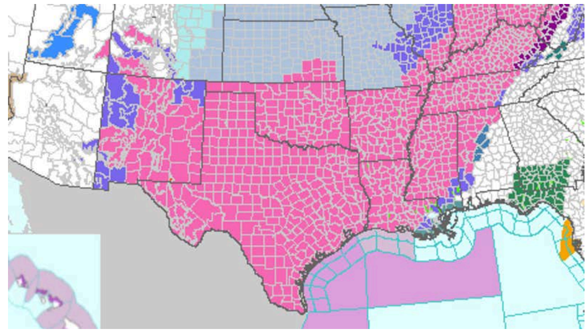
NOTE: TR0 started on December 8th and ended on December 22nd; TR1 started on January 12th and ended on January 26th; and TR2 started on February 9th, paused on February 15th, restarted on February 22nd, and ended on February 25th. See the effects of changing Chickenfeed amount on BOD increase in Feed Tank. Daily wastewater flow ranged from about 900 GPD to 1125 GPD during this observation period.

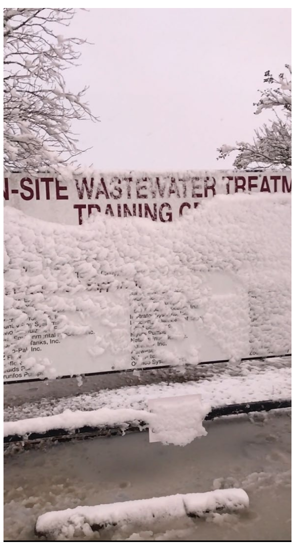
Appendix C:

Extreme cold weather in in Texas and B/CS area mid-February, photos showing the conditions at the Center and effluent quality from the Reuse Systems Before and After the cold week in mid-February. Sampling events were cancelled in the week of February 15th but resumed in the following week. Only six samples collected instead of scheduled eight samples in February.



Weather forecast screen shots from local TV


Weather forecast for the state, bitter cold.


Entrance to the Center


Reuse project area


Snow covered Center.

Effluent before winter storm shut-down (2/11)

Effluent after winter storm shut-down (2/22)

Quarterly Progress Report #7
Work Period: March 1, 2021 – May 31, 2021

For Texas On-Site Sewage Facility (OSSF) Research Contract #582-19-96829

Feasibility Study to Evaluate On-Site Treatment of Wastewater for Non-Potable Reuse

Report submitted to:

Donna Cosper, P.E., Project Manager
Program Support and Texas OSSF Research Grant Program
Texas Commission on Environmental Quality
P.O. Box 13087, MC - 235
Austin, Texas 78711-3087
Donna.Cosper@tceq.texas.gov

Report Submitted by:

Anish Jantrania, Associate Professor & Extension Specialist
Texas A&M AgriLife Research & Extension
720 E Blackland Road
Temple, TX 76502
(254) 774-6014
ajantrania@tamu.edu

June 15, 2021

Texas A&M AgriLife Research | Extension

During the 3rd Quarter of the Year 2 (i.e., Quarter 7), the following tasks were completed:

7. Conducted two experiments TR-3 and TR-4 simulating abnormal operating conditions:
   a. TR-3: Turn-off disinfection units from Thursday to Tuesday (3/18-3/23) while increasing BOD load by adding 1 lb./day chickenfeed in trash-tank.
   b. TR-4: Turn-off aeration units over the weekend from Friday (4/16) to Monday (4/19).

8. Aborted abnormal operating condition experiment in TR-4 due to complications associated with Membrane Bioreactor (MBR) system operation. See pictures and observation notes in Appendix-A for details.

9. Revised experimental plans during the month of May and included tests on the non-MBR unit operations and effluent quality with 80% recirculation of aerobic effluent to compare reduction in total nitrogen between the two reuse technologies, (MBR and non-MBR). See Appendix-B for preliminary data analysis.

10. Incorporated elements of the three current TCEQ-TGOP research projects (i.e., ATU, DPR, REUSE) into the TAMU REEU summer research program curriculum for the undergraduate students. See Appendix-C for details about this program and associated additional data collection planned for the month of June.

Note on special Covid-19 conditions occurring during Quarter 7:

During Quarter 7 AgriLife continued to follow TAMU COVID-19 safety guidance including the wearing facemasks, maintaining social distance, and traveling with only 1 person per vehicle. As of June 1, 2021, AgriLife will resume a 100% occupancy and ease meeting and travel restrictions. Employees who have been vaccinated may work in closer proximity and travel together. The use of masks, social distancing, and hand washing will continue to be encouraged. Guidance details may be found at https://www.tamu.edu/coronavirus/index.html. Due to delays caused by COVID restrictions and February's winter storm, AgriLife Extension requests a 3-month (September, October November of this year) no-cost extension to complete the data analysis and final reporting tasks. All funds allocated for this project will be expended by the end of August-2021.

The following tasks will be addressed during Quarter 8 (4th Quarter of Year 2):

12. REEU (Research and Extension Experience for Undergraduate) program students will include evaluation of the reuse technologies in their study plan during the month of June

13. Chicken feed amendments will be stopped to determine the effects on BOD decrease and determine if a predictive model related to the use of chicken feed to change BOD is possible for future studies.

14. Conduct the final sludge tests and settleability tests on both the reuse technologies to determine the sludge accumulations in both trash tank and in aeration tank. If removal of

sludge from any of the four tanks is necessary than appropriate amount sludge will be removed and recorded. Any sludge removed will be discharged into RELLIS sewer.

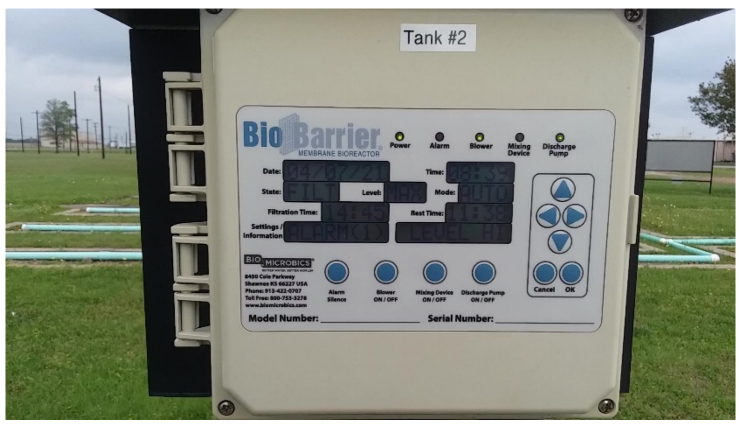
15. Reconnect with TxDOT and Harris County contacts to obtain current information on the Reuse systems operating at their facilities and schedule site visits before the end of August. (This task was not completed during the last quarter, but a visit to the TxDOT site has already been confirmed for Wednesday June 30^{th} as a part of REEU program)

16. Begin formal analysis of effluent quality results, preparation of the final report, and work with the SRS support team on the Project Closeout process related to budget.

Appendix A:

Effects of turning off the aeration on MBR:

(c) (b) (c)



(d)

Photos showing the effects of turning off aeration in the MBR tank (a) within an hour the membrane stopped filtering effluent and tank filled up giving a high-level alarm conditions; (b) the tank was pumped out using a temporary hose connection; and (c) water level dropped to normal operating conditions; (d) alarm conditions eased, and system resumed normal operating conditions, indicated by green lights on the control panel.

The manufacturer of the MBR system (i.e., Bio-Microbics) was contacted about this situation and explained that the current version of the system operating program will NOT allow the membrane filter pump to operate when the blower is turned off. This feature was added to prevent membrane fouling that can occur if the aeration is stopped.

The Non-MBR system was unaffected by turning the blower off. In order to maintain similar experimental conditions in both reuse systems, the decision was made to abort TR-4 original experimental conditions (i.e., operation without aeration) and start a new experiment comparing nitrogen reduction potentials for both the reuse systems under their normal operating conditions.

Appendix B.

Preliminary data analysis tables showing reduction in Total Nitrogen (T-N) measured during the month of April and May. Note that T-N values were calculated using the following formula:

Total Nitrogen (T-N) = Total Kjeldahl Nitrogen (TKN) + Nitrate/Nitrite (NO_3/NO_2)

Sampler 1-1	04/14/21	48	mg/L		Sampler 1-2	04/14/21	32	mg/L		
Sampler 1-1	04/15/21	45	mg/L		Sampler 1-2	04/15/21	31	mg/L		
Sampler 1-1	04/19/21	45	mg/L		Sampler 1-2	04/19/21	27	mg/L		
Sampler 1-1	04/20/21	45	mg/L	44	Sampler 1-2	04/20/21	28	mg/L	33	26%
Sampler 1-1	04/21/21	40	mg/L		Sampler 1-2	04/21/21	31	mg/L		
Sampler 1-1	04/22/21	45	mg/L		Sampler 1-2	04/22/21	33	mg/L		
Sampler 1-1	04/26/21	44	mg/L		Sampler 1-2	04/26/21	35	mg/L		
Sampler 1-1	04/27/21	40	mg/L		Sampler 1-2	04/27/21	44	mg/L		
Sampler 1-1	05/12/21	48	mg/L		Sampler 1-2	05/12/21	33	mg/L		
Sampler 1-1	05/13/21	49	mg/L		Sampler 1-2	05/13/21	35	mg/L		
Sampler 1-1	05/17/21	44	mg/L		Sampler 1-2	05/17/21	35	mg/L		
Sampler 1-1	05/18/21	43	mg/L	46	Sampler 1-2	05/18/21	36	mg/L	35	23%
Sampler 1-1	05/19/21	44	mg/L		Sampler 1-2	05/19/21	36	mg/L		
Sampler 1-1	05/20/21	48	mg/L		Sampler 1-2	05/20/21	36	mg/L		
Sampler 1-1	05/24/21	46	mg/L		Sampler 1-2	05/24/21	35	mg/L		
Sampler 1-1	05/25/21	44	mg/L		Sampler 1-2	05/25/21	37	mg/L		
Sampler 1-3	04/14/21	49	mg/L		Sampler 1-4	04/14/21	44	mg/L		
Sampler 1-3	04/15/21	52	mg/L		Sampler 1-4	04/15/21	44	mg/L		
Sampler 1-3	04/19/21	53	mg/L		Sampler 1-4	04/19/21	37	mg/L		
Sampler 1-3	04/20/21	67	mg/L	62	Sampler 1-4	04/20/21	38	mg/L	40	34%
Sampler 1-3	04/21/21	65	mg/L		Sampler 1-4	04/21/21	37	mg/L		
Sampler 1-3	04/22/21	49	mg/L		Sampler 1-4	04/22/21	39	mg/L		
Sampler 1-3	04/26/21	73	mg/L		Sampler 1-4	04/26/21	39	mg/L		
Sampler 1-3	04/27/21	86	mg/L		Sampler 1-4	04/27/21	45	mg/L		
Sampler 1-3	05/12/21	14	mg/L		Sampler 1-4	05/12/21	10	mg/L		
Sampler 1-3	05/13/21	17	mg/L		Sampler 1-4	05/13/21	9	mg/L		
Sampler 1-3	05/17/21	31	mg/L		Sampler 1-4	05/17/21	8	mg/L		
Sampler 1-3	05/18/21	13	mg/L	28	Sampler 1-4	05/18/21	9	mg/L	9	**68%**
Sampler 1-3	05/19/21	67	mg/L		Sampler 1-4	05/19/21	9	mg/L		
Sampler 1-3	05/20/21	14	mg/L		Sampler 1-4	05/20/21	9	mg/L		
Sampler 1-3	05/25/21	39	mg/L		Sampler 1-4	05/24/21	8	mg/L		

Notice the increase in T-N reduction from 34% to 68% due to recirculation of activated sludge in the non-MBR reuse system. Further statistical analysis will be conducted during next quarter to determine if the changes in T-N reduction were significant for both the reuse systems.

Quarterly Progress Report #8
Work Period: June 1, 2021 – August 31, 2021

For Texas On-Site Sewage Facility (OSSF) Research Contract #582-19-96829

Feasibility Study to Evaluate On-Site Treatment of Wastewater for Non-Potable Reuse

Report submitted to:
Donna Cosper, P.E., Project Manager
Program Support and Texas OSSF Research Grant Program
Texas Commission on Environmental Quality
P.O. Box 13087, MC - 235
Austin, Texas 78711-3087
Donna.Cosper@tceq.texas.gov

Report Submitted by:
Anish Jantrania, Associate Professor & Extension Specialist
Texas A&M AgriLife Research & Extension
720 E Blackland Road
Temple, TX 76502
(254) 774-6014
ajantrania@tamu.edu

September 15, 2021

TEXAS A&M AGRILIFE RESEARCH | EXTENSION

During the 4th Quarter of the Year 2 (i.e., Quarter 8), the following tasks were completed:

1. During the month of June, nine students representing four universities were selected to participate in a five-week Reuse/Water Quality research program, Research and Extension Experience for Undergraduates (REEU). All three OSSF research projects were included in the REEU program. Both reuse technologies were included in the evaluation process and four additional water treatment technologies were studied to determine overall treatment efficiencies of onsite water reuse systems.

2. REEU students were trained on sample collection, field analysis of water quality, and data analysis of laboratory results during the five-week program. Results were presented during the last week as poster and PowerPoint presentations. Two students from the program will present their results at a national conference in October 2021. See Appendix-A for REEU activities and effluent quality lab-reports. The REEU sampling was conducted in addition to the normal sampling activities completed during June.

3. Sample collections for the Reuse Project was paused during the planned eight-day sampling event from July 7 through July 20, to simulate no monitoring conditions while allowing the reuse systems to operate under normal conditions. Last round of sampling for both the reuse technologies started on July 27 and ended on August 10.

4. Sludge depths in trash-tanks and aerobic tanks of both the reuse systems were measured and were found to be within the normal operating limits, thus sludge removal was not done. Both reuse systems operation continued in normal operating conditions during the month of August and visual observations for the effluent quality and odor indicated both units performing in ideal conditions requiring no maintenance.

5. Flow meter readings were recorded for both the units by taking pictures of the flow meters and recording data into a spreadsheet to determine monthly average actual daily flow dosed to both the systems. The final report will include details on flow data as well as water quality data analysis.

6. Abstract submitted for National Onsite Wastewater and Reuse Association conference.

Note on special Covid-19 conditions occurring during Quarter 7:

During Quarter 7 AgriLife continued to follow TAMU COVID-19 safety guidance including the wearing facemasks, maintaining social distance, and traveling with only 1 person per vehicle. As of June 1, 2021, AgriLife resumed 100% occupancy and ease meeting and travel restrictions. Employees who have been vaccinated may work in closer proximity and travel together. The use of masks, social distancing, and hand washing will continue to be encouraged. Current guidance details may be found at https://www.tamu.edu/coronavirus/index.html. Due to delays caused by COVID restrictions and February's winter storm, AgriLife Extension requested and received a 3-month (September, October November of this year) no-cost extension to complete the data analysis and final reporting tasks.

The following tasks will be addressed during the no-cost extension period (Sep-Nov):

1. Preliminary results presentation and discussion on Texas OSSF Research program at the National On-site Wastewater and Reuse Association's (NOWRA) annual meeting in San Marcos, October 18-20.

2. Set-up final spreadsheet with effluent quality results from December 2020 to August 2021 and conduct statistical data analysis and develop monthly summary of effluent quality to determine how reuse systems performed during normal and abnormal operating conditions.

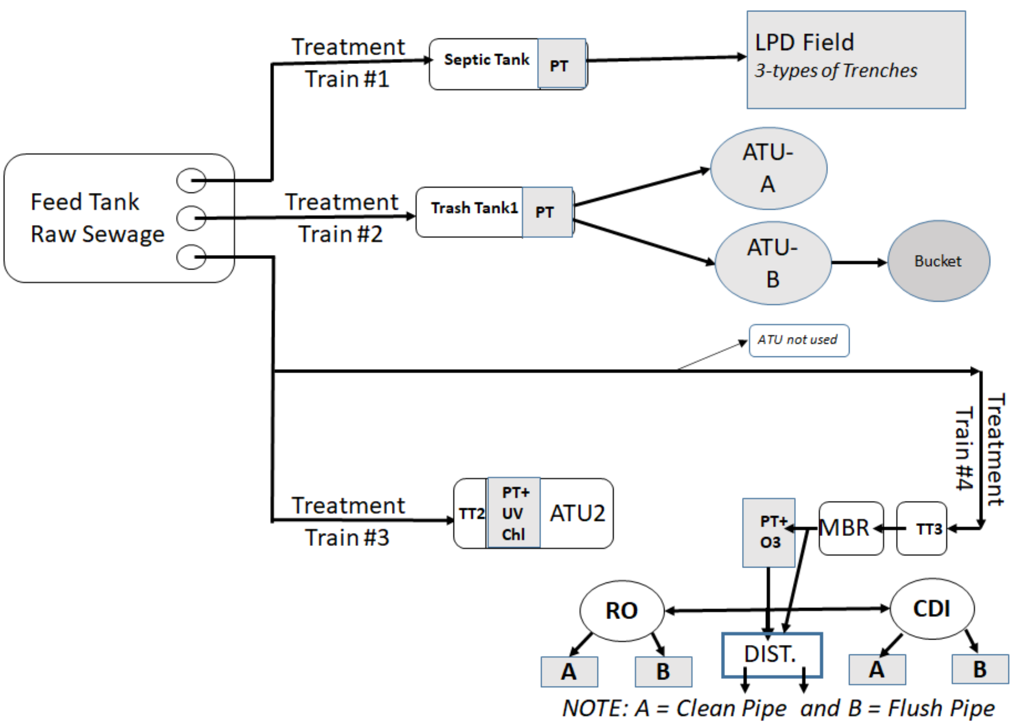
3. Organize the TOGP Advisory Committee meeting in early November and discuss the results and draft reports with the committee members to get their feed-back.

4. Finalize the research report for submission by November 29th and close the research account.

Appendix A:

REEU students collecting effluent sample from MBR and measuring field parameters (DO, pH, Conductivity, etc.) at the research site.

REEU students conducting lab-analysis for nitrogen and coliform on campus and visiting the private lab to learn details water quality analysis process.



General lay out of the onsite wastewater treatment trains studied by REEU Students; note that both the reuse systems (Treatment Train #3 and #4) were included in the study.

Appendix-B Effluent Quality Raw Dataset for Effluent BOD, TSS, Turbidity and *E. coli*

NOTE: Date and values noted in red indicates the day when one of the two samplers did not yield a sample, thus the observation was removed from the paired-sample t-test analysis. Values in *purple* is average value calculated just for plotting Figures 9 and 10.

BOD				TSS			
Date	MBR	Date	non-MBR	Date	MBR	Date	non-MBR
02/10/21	2	02/10/21	22	12/09/20	1	12/09/20	9
02/11/21	1	02/11/21	23	12/10/20	0	12/10/20	8
02/22/21	5	02/22/21	40	12/14/20	0	12/14/20	11
02/23/21	2	02/23/21	50	12/15/20	0	12/15/20	14
02/24/21	1	02/24/21	32	12/16/20	0	12/16/20	14
02/25/21	1	02/25/21	38	12/17/20	0	12/17/20	23
03/17/21	3	03/17/21	38	12/21/20	0	12/21/20	38
03/18/21	1	03/18/21	33	12/22/20	0	12/22/20	25
03/22/21	1	03/22/21	8	01/13/21	3	01/13/21	10
03/23/21	1	03/23/21	11	01/14/21	0	01/14/21	11
03/24/21	1	03/24/21	*17*	01/18/21	*0*	01/18/21	8
03/25/21	1	03/25/21	23	01/19/21	0	01/19/21	10
03/29/21	2	03/29/21	11	01/20/21	0	01/20/21	11
03/30/21	2	03/30/21	9	01/21/21	0	01/21/21	8
04/14/21	5	04/14/21	12	01/25/21	0	01/25/21	18
04/15/21	1	04/15/21	4	01/26/21	0	01/26/21	16
04/19/21	3	04/19/21	6	01/22/21	0	01/22/21	*10.5*
04/20/21	2	04/20/21	4	02/10/21	1	02/10/21	5
04/21/21	1	04/21/21	3	02/11/21	0	02/11/21	2
04/22/21	1	04/22/21	3	02/22/21	5	02/22/21	6
04/26/21	3	04/26/21	4	02/23/21	2	02/23/21	7
04/27/21	1	04/27/21	3	02/24/21	0	02/24/21	4
05/12/21	0	05/12/21	11	02/25/21	0	02/25/21	2
05/13/21	2	05/13/21	7	03/17/21	2	03/17/21	9
05/17/21	5	05/17/21	8	03/18/21	0	03/18/21	11
05/18/21	2	05/18/21	9	03/22/21	1	03/22/21	6
05/19/21	1	05/19/21	9	03/23/21	0	03/23/21	11
05/20/21	1	05/20/21	9	03/24/21	0	03/24/21	*23*
05/24/21	6	05/24/21	9	03/25/21	0	03/25/21	35
05/25/21	2	05/25/21	*7.5*	03/29/21	2	03/29/21	24
06/09/21	0	06/09/21	6	03/30/21	1	03/30/21	26
06/10/21	0	06/10/21	5	04/14/21	2	04/14/21	16
06/16/21	1	06/16/21	6	04/15/21	0	04/15/21	10
06/17/21	1	06/17/21	6	04/19/21	0	04/19/21	10
06/14/21	5	06/14/21	7	04/20/21	0	04/20/21	9

06/15/21	1	06/15/21	7
06/21/21	4	06/21/21	5
06/22/21	1	06/22/21	5
06/23/21	1	06/23/21	4
06/24/21	0	06/24/21	4
06/28/21	4	06/28/21	6
06/29/21	1	06/29/21	6
07/28/21	22	07/28/21	7
07/29/21	5	07/29/21	5
08/02/21	9	08/02/21	6
08/03/21	2	08/03/21	4
08/04/21	1	08/04/21	3
08/05/21	1	08/05/21	2
08/09/21	7	08/09/21	5
08/10/21	2	08/10/21	3

04/21/21	0	04/21/21	7
04/22/21	0	04/22/21	10
04/26/21	2	04/26/21	9
04/27/21	1	04/27/21	9
05/12/21	0	05/12/21	12
05/13/21	0	05/13/21	6
05/17/21	3	05/17/21	12
05/18/21	1	05/18/21	12
05/19/21	1	05/19/21	11
05/20/21	2	05/20/21	11
05/24/21	3	05/24/21	7
05/25/21	2	05/25/21	*9.5*
06/09/21	0	06/09/21	12
06/10/21	0	06/10/21	10
06/16/21	0	06/16/21	17
06/17/21	0	06/17/21	14
06/14/21	1	06/14/21	17
06/15/21	0	06/15/21	14
06/21/21	0	06/21/21	6
06/22/21	0	06/22/21	7
06/23/21	1	06/23/21	8
06/24/21	0	06/24/21	9
06/28/21	1	06/28/21	8
06/29/21	0	06/29/21	5
07/28/21	8	07/28/21	8
07/29/21	2	07/29/21	7
08/02/21	5	08/02/21	6
08/03/21	1	08/03/21	5
08/04/21	1	08/04/21	5
08/05/21	1	08/05/21	5
08/09/21	4	08/09/21	7
08/10/21	1	08/10/21	6

Turbidity					E. coli			
Date	MBR	Date	non-MBR		Date	MBR	Date	non-MBR
12/09/20	0.9	12/09/20	4.4		12/09/20	4.1	12/09/20	122
12/10/20	0.7	12/10/20	3.4		12/10/20	20.9	12/10/20	100
12/14/20	0.8	12/14/20	6.1		12/14/20	0	12/14/20	0
12/15/20	0.6	12/15/20	7		12/15/20	30.9	12/15/20	0
12/16/20	0.6	12/16/20	11		12/16/20	0	12/16/20	0
12/17/20	0.6	12/17/20	16		12/17/20	124	12/17/20	437
12/21/20	0.9	12/21/20	23		12/21/20	194	12/21/20	117
12/22/20	1	12/22/20	20		12/22/20	125	12/22/20	120
01/13/21	2	01/13/21	11		01/13/21	365	01/13/21	172
01/14/21	1.4	01/14/21	9.5		01/14/21	115	01/14/21	42.6
01/18/21	*1.45*	01/18/21	8.6		01/18/21	*38.4*	01/18/21	10
01/19/21	1.5	01/19/21	12		01/19/21	12.8	01/19/21	12.2
01/20/21	0.9	01/20/21	12		01/20/21	24.6	01/20/21	19.9
01/21/21	1	01/21/21	12		01/21/21	5.2	01/21/21	0
01/25/21	1	01/25/21	22		01/25/21	6.3	01/25/21	8.4
01/26/21	1	01/26/21	24		01/26/21	70.3	01/26/21	12.1
01/22/21	0.7	01/22/21	*20*		01/22/21	0	01/22/21	*21.7*
02/10/21	1.2	02/10/21	16		02/10/21	21.3	02/10/21	38.9
02/11/21	0.8	02/11/21	19		02/11/21	11	02/11/21	7.5
02/22/21	6	02/22/21	80		02/22/21	980	02/22/21	921
02/23/21	1.1	02/23/21	74		02/23/21	155	02/23/21	411
02/24/21	0.7	02/24/21	54		02/24/21	133	02/24/21	0
02/25/21	0.5	02/25/21	28		02/25/21	133	02/25/21	0
03/17/21	1.2	03/17/21	35		03/17/21	24.6	03/17/21	12
03/18/21	0.8	03/18/21	26		03/18/21	88	03/18/21	116
03/22/21	0.5	03/22/21	6.6		03/22/21	6.3	03/22/21	276
03/23/21	0.6	03/23/21	10		03/23/21	21.8	03/23/21	770
03/24/21	0.6	03/24/21	*23*		03/24/21	65	03/24/21	*105.7*
03/25/21	0.5	03/25/21	36		03/25/21	19.9	03/25/21	14.5
03/29/21	2.3	03/29/21	18		03/29/21	25.9	03/29/21	24.6
03/30/21	0.8	03/30/21	18		03/30/21	13.4	03/30/21	28.2
04/14/21	1.5	04/14/21	14		04/14/21	48.7	04/14/21	190
04/15/21	0.7	04/15/21	10		04/15/21	9.8	04/15/21	12.1
04/19/21	1.2	04/19/21	8.8		04/19/21	3.1	04/19/21	3
04/20/21	1	04/20/21	7.6		04/20/21	8.6	04/20/21	4.1
04/21/21	0.7	04/21/21	8.1		04/21/21	11.9	04/21/21	0
04/22/21	0.8	04/22/21	8.1		04/22/21	2	04/22/21	3.1
04/26/21	1.3	04/26/21	6.1		04/26/21	2	04/26/21	6.3
04/27/21	0.9	04/27/21	6.3		04/27/21	1	04/27/21	4.1
05/12/21	1	05/12/21	8.1		05/12/21	7.5	05/12/21	60.5

05/13/21	0.9	05/13/21	7.8
05/17/21	2	05/17/21	7.7
05/18/21	1	05/18/21	7.3
05/19/21	1	05/19/21	7.6
05/20/21	1.1	05/20/21	8.5
05/24/21	2	05/24/21	5.9
05/25/21	1.7	05/25/21	*6.0*
06/16/21	0.6	06/16/21	6
06/17/21	0.6	06/17/21	5.5
06/21/21	0.8	06/21/21	3.3
06/22/21	0.6	06/22/21	3.8
06/23/21	0.8	06/23/21	3.8
06/24/21	0.8	06/24/21	3.4
06/28/21	1	06/28/21	3.4
06/29/21	0.6	06/29/21	3.4
07/28/21	3.2	07/28/21	4.8
07/29/21	2	07/29/21	5
08/02/21	3.2	08/02/21	4.5
08/03/21	1.8	08/03/21	4
08/04/21	0.9	08/04/21	3.7
08/05/21	1.4	08/05/21	3.5
08/09/21	1.6	08/09/21	4.9
08/10/21	1	08/10/21	5.7

05/13/21	4.1	05/13/21	150
05/17/21	0	05/17/21	18.5
05/18/21	5.2	05/18/21	32.7
05/19/21	13.5	05/19/21	162
05/20/21	5.2	05/20/21	111
05/24/21	1	05/24/21	19.7
05/25/21	11	05/25/21	*16.3*
06/16/21	43.5	06/16/21	13.5
06/17/21	35.5	06/17/21	8.6
06/21/21	10.8	06/21/21	0
06/22/21	2	06/22/21	0
06/23/21	2	06/23/21	0
06/24/21	0	06/24/21	1
06/28/21	8.4	06/28/21	0
06/29/21	1	06/29/21	0
07/28/21	25.9	07/28/21	19.9
07/29/21	20.1	07/29/21	4.1
08/02/21	25.9	08/02/21	1
08/03/21	18.7	08/03/21	70.6
08/04/21	17.5	08/04/21	38.4
08/05/21	11.9	08/05/21	12.2
08/09/21	5.2	08/09/21	4.1
08/10/21	18.7	08/10/21	12.2

Appendix-C Detailed statistical analysis tables for the effluent quality observed during "normal" and "abnormal" conditions.

Question: Is the difference in means statistically significant during normal operating conditions (December, January, June, July, and August)?

t-Test: Paired Two Sample for Means	**for BOD**	
	MBR	*non-MBR*
Mean	3.4	5.1
Variance	25.30526316	1.989473684
Observations	20	20
Pearson Correlation	0.394624008	
Hypothesized Mean Difference	0	
df	19	
t Stat	-1.632250183	
P(T<=t) one-tail	0.059545089	
t Critical one-tail	1.729132812	
P(T<=t) two-tail	0.119090178	
t Critical two-tail	2.093024054	

Since t-Stat (-1.63) is > t-Critical -2.09; do not reject Ho
That means the MBR and non-MBR Means are NOT significantly different
Also,
Since P value is very large (>0.05); cannot reject Ho
That means the MBR and non-MBR Means are NOT significantly different

t-Test: Paired Two Sample for Means	**for TSS**	
	MBR	*non-MBR*
Mean	0.857142857	11.48571429
Variance	2.949579832	46.08067227
Observations	35	35
Pearson Correlation	-0.291562781	
Hypothesized Mean Difference	0	
df	34	
t Stat	-8.415514259	
P(T<=t) one-tail	3.97218E-10	
t Critical one-tail	1.690924255	
P(T<=t) two-tail	7.94437E-10	
t Critical two-tail	2.032244509	

Since t-Stat (-8.41) is < t-Critical (-2.03); reject Ho
That means the MBR and non-MBR Means are Significantly Different
Also,
Since P value is very small (<0.05); reject Ho
That means the MBR and non-MBR Means are Significantly Different

t-Test: Paired Two Sample for Means	**for Turbidity**	
	MBR	*non-MBR*
Mean	1.15483871	8.45483871
Variance	0.463892473	40.59322581
Observations	31	31
Pearson Correlation	-0.126845545	
Hypothesized Mean Difference	0	
df	30	
t Stat	-6.259846838	
P(T<=t) one-tail	3.37976E-07	
t Critical one-tail	1.697260887	
P(T<=t) two-tail	6.75951E-07	
t Critical two-tail	2.042272456	

Since t-Stat (-6.25) is < t-Critical (-2.04); reject Ho
That means the MBR and non-MBR Means are Significantly Different
Also,
Since P value is very small (<0.05); reject Ho
That means the MBR and non-MBR Means are Significantly Different

t-Test: Paired Two Sample for Means	for ***E. Coli.***	
	MBR	*non-MBR*
Mean	43.39354839	43.50967742
Variance	5672.29529	7495.372237
Observations	31	31
Pearson Correlation	0.557623842	
Hypothesized Mean Difference	0	
df	30	
t Stat	-0.008420757	
P(T<=t) one-tail	0.496668518	
t Critical one-tail	1.697260887	
P(T<=t) two-tail	0.993337036	
t Critical two-tail	2.042272456	

Since t-Stat (-0.008) is > t-Critical -2.042; do not reject Ho

That means the MBR and non-MBR Means are NOT significantly different

Also,

Since P value is very large (>0.05); cannot reject Ho

That means the MBR and non-MBR Means are NOT significantly different

Question: Is the difference in means statistically significant during abnormal operating conditions (February, March, April, and May)

t-Test: Paired Two Sample for Means	**for BOD**	
	MBR	*non-MBR*
Mean	2.035714286	15.67857143
Variance	2.332010582	183.707672
Observations	28	28
Pearson Correlation	0.048888953	
Hypothesized Mean Difference	0	
df	27	
t Stat	-5.32177739	
P(T<=t) one-tail	6.42151E-06	
t Critical one-tail	1.703288446	
P(T<=t) two-tail	1.2843E-05	
t Critical two-tail	2.051830516	

Since t-Stat (-5.32) is < t-Critical (-2.05); reject Ho
That means the MBR and non-MBR Means are Significantly Different
Also,
Since P value is very small (<0.05); reject Ho
That means the MBR and non-MBR Means are Significantly Different

t-Test: Paired Two Sample for Means	**for TSS**	
	MBR	*non-MBR*
Mean	1.035714286	10.67857143
Variance	1.591269841	51.26322751
Observations	28	28
Pearson Correlation	-0.006883371	
Hypothesized Mean Difference	0	
df	27	
t Stat	-7.010250588	
P(T<=t) one-tail	7.7581E-08	
t Critical one-tail	1.703288446	
P(T<=t) two-tail	1.55162E-07	
t Critical two-tail	2.051830516	

Since t-Stat (-7.01) is < t-Critical (-2.05); reject Ho
That means the MBR and non-MBR Means are Significantly Different
Also,
Since P value is very small (<0.05); reject Ho
That means the MBR and non-MBR Means are Significantly Different

t-Test: Paired Two Sample for Means	**for Turbidity**	
	MBR	*non-MBR*
Mean	1.217857143	19.375
Variance	1.081521164	396.8071296
Observations	28	28
Pearson Correlation	0.485027965	
Hypothesized Mean Difference	0	
df	27	
t Stat	-4.943102596	
P(T<=t) one-tail	1.77438E-05	
t Critical one-tail	1.703288446	
P(T<=t) two-tail	3.54877E-05	
t Critical two-tail	2.051830516	

Since t-Stat (-4.94) is < t-Critical (-2.05); reject Ho
That means the MBR and non-MBR Means are Significantly Different
Also,
Since P value is very small (<0.05); reject Ho
That means the MBR and non-MBR Means are Significantly Different

t-Test: Paired Two Sample for Means		
	MBR	*non-MBR*
Mean	62.74285714	121.3142857
Variance	34195.32624	51622.25757
Observations	28	28
Pearson Correlation	0.703337007	
Hypothesized Mean Difference	0	
df	27	
t Stat	-1.896159785	
P(T<=t) one-tail	0.034344001	
t Critical one-tail	1.703288446	
P(T<=t) two-tail	0.068688003	
t Critical two-tail	2.051830516	

Since t-Stat (-1.89) is > t-Critical -2.05; do not reject Ho
That means the MBR and non-MBR Means are NOT significantly different
Also,
Since P value is very large (>0.05); cannot reject Ho
That means the MBR and non-MBR Means are NOT significantly different

Appendix D Nitrogen study dataset and organic amendment calculations spreadsheet

MBR with aeration On and Off daily				TN-In					TN-Out	% TN Reduction
Sampler 1-1	04/14/21	Nitrate/Nitrite as N	0.31		Sampler 1-2	04/14/21	Nitrate/Nitrite as N	31.8		
Sampler 1-1	04/14/21	TKN	47.8	48	Sampler 1-2	04/14/21	TKN	0	32	34%
Sampler 1-1	04/15/21	Nitrate/Nitrite as N	0.47		Sampler 1-2	04/15/21	Nitrate/Nitrite as N	31.2		
Sampler 1-1	04/15/21	TKN	44.1	45	Sampler 1-2	04/15/21	TKN	0	31	30%
Sampler 1-1	04/19/21	Nitrate/Nitrite as N	0.61		Sampler 1-2	04/19/21	Nitrate/Nitrite as N	27.3		
Sampler 1-1	04/19/21	TKN	44.6	45	Sampler 1-2	04/19/21	TKN	0	27	40%
Sampler 1-1	04/20/21	Nitrate/Nitrite as N	0.7		Sampler 1-2	04/20/21	Nitrate/Nitrite as N	27.8		
Sampler 1-1	04/20/21	TKN	43.9	45	Sampler 1-2	04/20/21	TKN	0	28	38%
Sampler 1-1	04/21/21	Nitrate/Nitrite as N	0.85		Sampler 1-2	04/21/21	Nitrate/Nitrite as N	31.4		
Sampler 1-1	04/21/21	TKN	38.9	40	Sampler 1-2	04/21/21	TKN	0	31	21%
Sampler 1-1	04/22/21	Nitrate/Nitrite as N	0.8		Sampler 1-2	04/22/21	Nitrate/Nitrite as N	32.8		
Sampler 1-1	04/22/21	TKN	44	45	Sampler 1-2	04/22/21	TKN	0	33	27%
Sampler 1-1	04/26/21	Nitrate/Nitrite as N	0.69		Sampler 1-2	04/26/21	Nitrate/Nitrite as N	34.8		
Sampler 1-1	04/26/21	TKN	43.1	44	Sampler 1-2	04/26/21	TKN	0	35	21%
Sampler 1-1	04/27/21	Nitrate/Nitrite as N	0.78		Sampler 1-2	04/27/21	Nitrate/Nitrite as N	43.7		
Sampler 1-1	04/27/21	TKN	39.6	40	Sampler 1-2	04/27/21	TKN	0	44	-8%
Sampler 1-1	05/12/21	Nitrate/Nitrite as N	0.88		Sampler 1-2	05/12/21	Nitrate/Nitrite as N	33		
Sampler 1-1	05/12/21	TKN	46.7	48	Sampler 1-2	05/12/21	TKN	0	33	31%
Sampler 1-1	05/13/21	Nitrate/Nitrite as N	1.09		Sampler 1-2	05/13/21	Nitrate/Nitrite as N	34.8		
Sampler 1-1	05/13/21	TKN	48.4	49	Sampler 1-2	05/13/21	TKN	0	35	30%
Sampler 1-1	05/17/21	Nitrate/Nitrite as N	0.85		Sampler 1-2	05/17/21	Nitrate/Nitrite as N	35		
Sampler 1-1	05/17/21	TKN	43.1	44	Sampler 1-2	05/17/21	TKN	0	35	20%
Sampler 1-1	05/18/21	Nitrate/Nitrite as N	0.95		Sampler 1-2	05/18/21	Nitrate/Nitrite as N	36.2		
Sampler 1-1	05/18/21	TKN	42.2	43	Sampler 1-2	05/18/21	TKN	0	36	16%
Sampler 1-1	05/19/21	Nitrate/Nitrite as N	1		Sampler 1-2	05/19/21	Nitrate/Nitrite as N	36.4		
Sampler 1-1	05/19/21	TKN	43	44	Sampler 1-2	05/19/21	TKN	0	36	17%
Sampler 1-1	05/20/21	Nitrate/Nitrite as N	1.1		Sampler 1-2	05/20/21	Nitrate/Nitrite as N	36		
Sampler 1-1	05/20/21	TKN	46.4	48	Sampler 1-2	05/20/21	TKN	0	36	24%
Sampler 1-1	05/24/21	Nitrate/Nitrite as N	0.76		Sampler 1-2	05/24/21	Nitrate/Nitrite as N	34.7		
Sampler 1-1	05/24/21	TKN	45.2	46	Sampler 1-2	05/24/21	TKN	0	35	24%
Sampler 1-1	05/25/21	Nitrate/Nitrite as N	0.94		Sampler 1-2	05/25/21	Nitrate/Nitrite as N	36.7		
Sampler 1-1	05/25/21	TKN	43.5	44	Sampler 1-2	05/25/21	TKN	0	37	17%
Sampler 1-1	07/28/21	Nitrate/Nitrite as N	0.33		Sampler 1-2	07/28/21	Nitrate/Nitrite as N	40		
Sampler 1-1	07/28/21	TKN	60.8	61	Sampler 1-2	07/28/21	TKN	0	40	35%
Sampler 1-1	07/29/21	Nitrate/Nitrite as N	0.45		Sampler 1-2	07/29/21	Nitrate/Nitrite as N	37.8		
Sampler 1-1	07/29/21	TKN	47.9	48	Sampler 1-2	07/29/21	TKN	0	38	22%
Sampler 1-1	08/02/21	Nitrate/Nitrite as N	0.28		Sampler 1-2	08/02/21	Nitrate/Nitrite as N	30.9		
Sampler 1-1	08/02/21	TKN	35.6	36	Sampler 1-2	08/02/21	TKN	0	31	14%
Sampler 1-1	08/03/21	Nitrate/Nitrite as N	0.28		Sampler 1-2	08/03/21	Nitrate/Nitrite as N	29		
Sampler 1-1	08/03/21	TKN	33	33	Sampler 1-2	08/03/21	TKN	0	29	13%
Sampler 1-1	08/04/21	Nitrate/Nitrite as N	0.27		Sampler 1-2	08/04/21	Nitrate/Nitrite as N	27.1		
Sampler 1-1	08/04/21	TKN	34	34	Sampler 1-2	08/04/21	TKN	0	27	21%
Sampler 1-1	08/05/21	Nitrate/Nitrite as N	0.37		Sampler 1-2	08/05/21	Nitrate/Nitrite as N	26.2		
Sampler 1-1	08/05/21	TKN	38.2	39	Sampler 1-2	08/05/21	TKN	0	26	32%
Sampler 1-1	08/09/21	Nitrate/Nitrite as N	0.32		Sampler 1-2	08/09/21	Nitrate/Nitrite as N	29.2		
Sampler 1-1	08/09/21	TKN	48.6	49	Sampler 1-2	08/09/21	TKN	0	29	40%
Sampler 1-1	08/10/21	Nitrate/Nitrite as N	0.45		Sampler 1-2	08/10/21	Nitrate/Nitrite as N	30.1		
Sampler 1-1	08/10/21	TKN	45.7	46	Sampler 1-2	08/10/21	TKN	0	30	35%
		Average =		44			Average =		33	25%
									Max =	40%

non-MBR without and with Recirculation				TN-In					TN-Out	% TN Reduction	
Sampler 1-3	04/14/21	Nitrate/Nitrite as N	0.39		Sampler 1-4	04/14/21	Total Kjeldahl Nitrogen as N	0			
Sampler 1-3	04/14/21	Total Kjeldahl Nitrogen as N	48.3	49	Sampler 1-4	04/14/21	Nitrate/Nitrite as N	44	44	10%	
Sampler 1-3	04/15/21	Nitrate/Nitrite as N	0.47		Sampler 1-4	04/15/21	Nitrate/Nitrite as N	44			
Sampler 1-3	04/15/21	Total Kjeldahl Nitrogen as N	51.8	52	Sampler 1-4	04/15/21	Total Kjeldahl Nitrogen as N	0	44	16%	
Sampler 1-3	04/19/21	Nitrate/Nitrite as N	0.65		Sampler 1-4	04/19/21	Nitrate/Nitrite as N	36.2			
Sampler 1-3	04/19/21	Total Kjeldahl Nitrogen as N	52.3	53	Sampler 1-4	04/19/21	Total Kjeldahl Nitrogen as N	1.29	37	29%	
Sampler 1-3	04/20/21	Nitrate/Nitrite as N	0.58		Sampler 1-4	04/20/21	Nitrate/Nitrite as N	37.6			
Sampler 1-3	04/20/21	Total Kjeldahl Nitrogen as N	66.4	67	Sampler 1-4	04/20/21	Total Kjeldahl Nitrogen as N	0.72	38	43%	
Sampler 1-3	04/21/21	Nitrate/Nitrite as N	0.54		Sampler 1-4	04/21/21	Nitrate/Nitrite as N	36.3			30%
Sampler 1-3	04/21/21	Total Kjeldahl Nitrogen as N	64.4	65	Sampler 1-4	04/21/21	Total Kjeldahl Nitrogen as N	0.51	37	43%	
Sampler 1-3	04/22/21	Nitrate/Nitrite as N	0.62		Sampler 1-4	04/22/21	Nitrate/Nitrite as N	37.6			
Sampler 1-3	04/22/21	Total Kjeldahl Nitrogen as N	47.9	49	Sampler 1-4	04/22/21	Total Kjeldahl Nitrogen as N	1.02	39	20%	
Sampler 1-3	04/26/21	Nitrate/Nitrite as N	0.78		Sampler 1-4	04/26/21	Nitrate/Nitrite as N	37.9			
Sampler 1-3	04/26/21	Total Kjeldahl Nitrogen as N	71.8	73	Sampler 1-4	04/26/21	Total Kjeldahl Nitrogen as N	0.99	39	46%	
Sampler 1-3	04/27/21	Nitrate/Nitrite as N	0.45		Sampler 1-4	04/27/21	Nitrate/Nitrite as N	45			
Sampler 1-3	04/27/21	Total Kjeldahl Nitrogen as N	85.4	86	Sampler 1-4	04/27/21	Total Kjeldahl Nitrogen as N	0.24	45	47%	
Sampler 1-3	05/12/21	Nitrate/Nitrite as N	1.25		Sampler 1-4	05/12/21	Nitrate/Nitrite as N	5.87			
Sampler 1-3	05/12/21	Total Kjeldahl Nitrogen as N	12.5	14	Sampler 1-4	05/12/21	Total Kjeldahl Nitrogen as N	4.12	10	27%	
Sampler 1-3	05/13/21	Nitrate/Nitrite as N	0.78		Sampler 1-4	05/13/21	Nitrate/Nitrite as N	5.23			
Sampler 1-3	05/13/21	Total Kjeldahl Nitrogen as N	15.8	17	Sampler 1-4	05/13/21	Total Kjeldahl Nitrogen as N	3.94	9	45%	
Sampler 1-3	05/17/21	Nitrate/Nitrite as N	2.04		Sampler 1-4	05/17/21	Nitrate/Nitrite as N	4.63			
Sampler 1-3	05/17/21	Total Kjeldahl Nitrogen as N	29.1	31	Sampler 1-4	05/17/21	Total Kjeldahl Nitrogen as N	3.55	8	74%	
Sampler 1-3	05/18/21	Nitrate/Nitrite as N	2.31		Sampler 1-4	05/18/21	Nitrate/Nitrite as N	5.4			
Sampler 1-3	05/18/21	Total Kjeldahl Nitrogen as N	10.6	13	Sampler 1-4	05/18/21	Total Kjeldahl Nitrogen as N	3.36	9	32%	
Sampler 1-3	05/19/21	Nitrate/Nitrite as N	0.61		Sampler 1-4	05/19/21	Nitrate/Nitrite as N	5.4			
Sampler 1-3	05/19/21	Total Kjeldahl Nitrogen as N	66.5	67	Sampler 1-4	05/19/21	Total Kjeldahl Nitrogen as N	3.7	9	86%	61%
Sampler 1-3	05/20/21	Nitrate/Nitrite as N	0.6		Sampler 1-4	05/20/21	Nitrate/Nitrite as N	5.3			
Sampler 1-3	05/20/21	Total Kjeldahl Nitrogen as N	13.2	14	Sampler 1-4	05/20/21	Total Kjeldahl Nitrogen as N	3.78	9	34%	
Sampler 1-3	05/25/21	Nitrate/Nitrite as N	0.59		Sampler 1-4	05/24/21	Nitrate/Nitrite as N	4.35			
Sampler 1-3	05/25/21	Total Kjeldahl Nitrogen as N	38.5	39	Sampler 1-4	05/24/21	Total Kjeldahl Nitrogen as N	3.61	8	80%	
Sampler 1-3	07/28/21	Nitrate/Nitrite as N	2.96		Sampler 1-4	07/28/21	Nitrate/Nitrite as N	8.67			
Sampler 1-3	07/28/21	Total Kjeldahl Nitrogen as N	85.5	88	Sampler 1-4	07/28/21	Total Kjeldahl Nitrogen as N	2.85	12	87%	
Sampler 1-3	07/29/21	Nitrate/Nitrite as N	3.11		Sampler 1-4	07/29/21	Nitrate/Nitrite as N	8.68			
Sampler 1-3	07/29/21	Total Kjeldahl Nitrogen as N	66.7	70	Sampler 1-4	07/29/21	Total Kjeldahl Nitrogen as N	2.6	11	84%	
Sampler 1-3	08/02/21	Nitrate/Nitrite as N	3.77		Sampler 1-4	08/02/21	Nitrate/Nitrite as N	9.27			
Sampler 1-3	08/02/21	Total Kjeldahl Nitrogen as N	44.6	48	Sampler 1-4	08/02/21	Total Kjeldahl Nitrogen as N	2.57	12	76%	
Sampler 1-3	08/03/21	Nitrate/Nitrite as N	0.99		Sampler 1-4	08/03/21	Nitrate/Nitrite as N	9.04			
Sampler 1-3	08/03/21	Total Kjeldahl Nitrogen as N	32.4	33	Sampler 1-4	08/03/21	Total Kjeldahl Nitrogen as N	2.31	11	66%	
Sampler 1-3	08/04/21	Nitrate/Nitrite as N	0.15		Sampler 1-4	08/04/21	Nitrate/Nitrite as N	9.42			
Sampler 1-3	08/04/21	Total Kjeldahl Nitrogen as N	46.1	46	Sampler 1-4	08/04/21	Total Kjeldahl Nitrogen as N	2.42	12	74%	
Sampler 1-3	08/05/21	Nitrate/Nitrite as N	0.3		Sampler 1-4	08/05/21	Nitrate/Nitrite as N	10.9			
Sampler 1-3	08/05/21	Total Kjeldahl Nitrogen as N	62.1	62	Sampler 1-4	08/05/21	Total Kjeldahl Nitrogen as N	2.36	13	79%	
Sampler 1-3	08/09/21	Nitrate/Nitrite as N	0.29		Sampler 1-4	08/09/21	Nitrate/Nitrite as N	23.1			
Sampler 1-3	08/09/21	Total Kjeldahl Nitrogen as N	45.8	46	Sampler 1-4	08/09/21	Total Kjeldahl Nitrogen as N	1.13	24	47%	
Sampler 1-3	08/10/21	Nitrate/Nitrite as N	0.33		Sampler 1-4	08/10/21	Nitrate/Nitrite as N	25.9			
Sampler 1-3	08/10/21	Total Kjeldahl Nitrogen as N	60.6	61	Sampler 1-4	08/10/21	Total Kjeldahl Nitrogen as N	0.28	26	57%	

Lift Station	BOD		Feed Tank	BOD		BOD mg/L	Increased	Avg mg/L	GPD	BOD lb/da
12/09/20	46		12/09/20	287		241		148	1039	1.28
12/10/20	35		12/10/20	221		186				
12/14/20	86		12/14/20	244		158				
12/15/20	33		12/15/20	188		155				
12/16/20	65		12/16/20	243		178				
12/17/20	131		12/17/20	190		59				
12/21/20	32		12/21/20	133		101				
12/22/20	23		12/22/20	130		107				
01/13/21	82		01/13/21	140		58		181	1024	1.54
01/14/21	86		01/14/21	125		39				
01/18/21	19		01/18/21	194		175				
01/19/21	108		01/19/21	215		107				
01/20/21	9		01/20/21	256		247				
01/21/21	16		01/21/21	272		256				
01/25/21	163		01/25/21	311		148				
01/26/21	171		01/26/21	310		139				
01/15/21	146		01/15/21	210		64				
01/22/21	98		01/22/21	368		270				
01/27/21	190		01/27/21	362		172				
01/28/21	213		01/28/21	457		244				
01/29/21	53		01/29/21	482		429				
02/04/21	114		02/04/21	818		704		407	1109	3.77
02/05/21	71		02/05/21	718		647				
02/08/21	535		02/08/21	728		193				
02/09/21	229		02/09/21	575		346				
02/12/21	216		02/12/21	1190		974				
02/26/21			02/26/21	426		426				
02/10/21	78		02/10/21	574		496				
02/11/21	47		02/11/21	592		545				
02/22/21	123		02/22/21	297		174				
02/23/21	117		02/23/21	285		168				
02/24/21	68		02/24/21	269		201				
02/25/21	304		02/25/21	316		12				
03/03/21	207		03/03/21	223		16		203	1056	1.79
03/04/21	259		03/04/21	393		134				
03/05/21	141		03/05/21	451		310				
03/08/21	357		03/08/21	446		89				
03/09/21	869		03/09/21	439		-430				
03/10/21	622		03/10/21	488		-134				
03/11/21	112		03/11/21	418		306				
03/12/21	122		03/12/21	494		372				
03/15/21	83		03/15/21	474		391				
03/16/21	357		03/16/21	427		70				
03/26/21	145		03/26/21	603		458				
03/31/21	21		03/31/21	581		560				
03/19/21	81		03/19/21	306		225				
03/22/21	80		03/22/21	326		246				
03/23/21	261		03/23/21	310		49				
03/24/21	40		03/24/21	344		304				
03/25/21	115		03/25/21	375		260				
03/29/21	152		03/29/21	402		250				
03/30/21	74		03/30/21	461		387				

04/14/21	45		04/14/21	331		286		198	1153	1.90
04/15/21	365		04/15/21	431		66				
04/19/21	40		04/19/21	300		260				
04/20/21	78		04/20/21	296		218				
04/21/21	75		04/21/21	296		221				
04/22/21	80		04/22/21	367		287				
04/26/21	198		04/26/21	286		88				
04/27/21	96		04/27/21	253		157				
05/12/21	101		05/12/21	394		293		401	1031	3.45
05/17/21	158		05/10/21	1210		1052				
05/18/21	100		05/18/21	361		261				
05/19/21	50		05/19/21	376		326				
05/20/21	42		05/20/21	435		393				
05/25/21	450		05/25/21	529		79				
06/16/21	56		06/16/21	239		183		180	999	1.50
06/17/21	163		06/17/21	240		77				
06/21/21	169		06/21/21	456		287				
06/22/21	162		06/22/21	352		190				
06/24/21	30		06/24/21	297		267				
06/28/21	41		06/28/21	271		230				
06/29/21	204		06/29/21	228		24				
07/07/21	159		07/07/21	249		90		130	1017	1.10
07/08/21	125		07/08/21	223		98				
07/13/21	78		07/13/21	246		168				
07/20/21	101		07/20/21	224		123				
07/29/21	78		07/29/21	247		169				
08/02/21	82		08/02/21	257		175		204	1036	1.76
08/03/21	71		08/03/21	222		151				
08/05/21	89		08/05/21	244		155				
08/09/21	60		08/09/21	277		217				
08/10/21	146		08/10/21	259		113				
08/11/21	65		08/11/21	197		132				
08/12/21	96		08/12/21	252		156				
08/16/21	20		08/16/21	297		277				
08/17/21	29		08/17/21	257		228				
08/18/21	46		08/18/21	633		587				
08/19/21	39		08/19/21	289		250				
08/23/21	76		08/23/21	212		136				
08/24/21	112		08/24/21	187		75				