A Comprehensive Review, and Cost-Benefit Analysis for Brewery Wastewater Treatment Methods In New York State: A Feasibility Report on the Brewery SPDES Permit

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Prepared by:
Valerie Aubley, Kyra Frederick, Lydia LaGorga, Emily Wood
vg5@cornell.edu | kcf29@cornell.edu | lcl66@cornell.edu | ew465@cornell.edu
B.S. Candidates
Department of Biological and Environmental Engineering
Cornell University

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I. Abstract

In this study, available technologies were evaluated for feasibility of establishing compliance for brewery wastewater treatment with the NY Department of Environmental Conservation proposed SPDES permit. After extensive review of relevant literature and case studies, four secondary treatment solutions were identified as valid treatment solutions, namely, (1) Commercial Bioelectrochemical Enhanced Solution, (2) Submerged Membrane Bioreactor, (3) Upflow Anaerobic Sludge Blanket Reactor (UASB), and (4) Sequential Anaerobic-Aerobic Treatment. These technologies were then reevaluated for applicability within effluent compositions and resource constraints of New York State brewers. A final treatment solution suitable to the interests of both the DEC and New York brewers is proposed as primary treatment through sedimentation, followed by secondary biological treatment by a UASB digester.

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1. Problem Scope

Brewery wastewater management presents economic burdens and environmental hazards on municipal wastewater treatment plants as brewery wastewater is of significantly higher strength than domestic wastewater. Strength is measured in terms of chemical or biochemical oxygen demand (COD or BOD, respectively), a measure of organic content in brewing water. BOD in brewery process water can vary between 6,000-20,000 mg BOD/L [5], [4]. Brewery streams overload municipal wastewater treatment facilities designed for domestic waste strengths of 150-200 mg/L, pushing them to violate National Pollutant Discharge Elimination System (NPDES) permit limits [62].

Risk of contamination, combined with increased water scarcity and aging infrastructure, has motivated the New York Department of Environmental Conservation to set effluent restrictions for breweries. This report was prepared to assist the NY DEC's Bureau of Water Permits in establishing a General Permitting process for SPDES by outlining treatment technologies for NY brewery industries [61]. The SPDES will be the first standardized wastewater management permit for the craft beverage industry within New York State. It is of interest for both NY State and craft breweries to implement onsite wastewater management systems. Fines associated with effluent restrictions depress profitability, preventing breweries from keeping pace with their market demand. To confront these challenges and ensure continued sustainable growth, breweries of all sizes must be proactive and strategic about water and process water management.

The Advanced Notice of Proposed Permit [61] gives a brief overview of the General Permitting process for NY State Breweries. These will consist of determining eligibility, assessment of existing or newly designed treatment facility by a licensed Professional Engineer (PE), submittal of a Notice of Intent, inspection and subsequent continual monitoring, recordkeeping and reporting.

Common methods used to treat brewery waste include physical, physicochemical, and biological treatment [36]. Biological treatment can be characterized as aerobic or anaerobic solutions. Both are effective alternatives to centralized municipal solutions [36]. For a more detailed overview of current treatment methods being utilized by breweries see Appendix A. To select a solution that suits the needs of the brewer, these key considerations should be optimized:

(1) Treatment: address relevant major process water issues (pH, BOD, nutrients and solids)
(2) Economics: evaluate total life cycle cost and overall environmental benefit
(3) Land Area: minimize land space requirements for process design

2. Review of Available Technologies

Methodology:

Process recommendations were made following a comprehensive review of wastewater treatment solutions currently being used by breweries, with special attention to cost, feasibility, long-term adaptability, and compliance potential. The Brewers Association's Wastewater Management Guidance Manual [4], [5] was consulted as a baseline after which various research articles were reviewed in order to make recommendations. All contributors involved in the preparation of this report conducted review separately and final recommendations were made following a group discussion of findings, weighing treatment potential, advantages, and limitations of each individual technology.

2.1. Technology 1 - Commercial Bioelectrochemical Enhanced Solution

How it works: The EcoVolt Reactor is a microbial electrochemical technology (MEC that leverages a process called electromethanogenesis to help breweries cost-effectively and sustainably treat their process water while generating renewable resources such as clean energy and clean water [2]. Electromethanogenesis, a form of electrofuel production, produces methane by biological conversion from electrical current and carbon dioxide carried out by MECs [9]. Biologically coated anodes consume pollutants in the water, converting them into electrons. Simultaneously, biological cathodes convert electrons and carbon dioxide into methane gas. Their reported biogas production has higher percentages of methane (70-80%) [2] than is achieved in traditional anaerobic systems without BES enhanced systems. This produces an advantage for breweries allowing them to offset their energy consumption by producing fuel efficiently and with a low emissions footprint.

Benefits and Limitations: The Ecovolt offers both improved process economics and increased water security, an important strategic benefit in the face of climate change concerns. It eliminates challenges associated with traditional anaerobic treatment by transforming process water into a source of revenue, producing biogas for renewable electricity and heat, and clean recyclable water [33]. It also offers easy and inexpensive data management, complex systems automation and ready-to-install fabrication. Designed for scaling, the EcoVolt allows breweries incremental expansion of treatment capacity to match their growth [20]. Additionally, what makes the EcoVolt particularly attractive is that it is accessible to breweries as a service [22]. Brewers have the option of allowing Cambrian Innovation to own and operate the EcoVolt solutions, allowing brewers to focus on their core competencies-- making beer-- while realizing immediate savings around wastewater and energy. Other forms of BES-enhanced anaerobic treatment solutions exist. However, the commercialized EcoVolt is optimal as it enables quick and reliable solutions for New York breweries to comply with the new SPDES permit. It should be noted, however, that Cambrian Innovation's Ecovolt has primarily been utilized by Brewers in California in which water scarcity and sustainable management is of higher priority than may be for New York brewers [44]. Additionally, due to the high quality nature of BES-enhanced anaerobic wastewater treatment, this solution may be of higher cost than what may be appropriate for small scale brewers. The EcoVolt goes above and beyond compliance. Small brewers may find this solution extraneous and seek out lower cost, lower operation solutions to achieve compliance with the SPDES permit.

Case Studies of Technology:
Several brewing companies which currently utilize the EcoVolt solution provide strong indications of the EcoVolt Reactor's successful performance.

<u>CASE 1: Bear Republic Brewing Company in Cloverdale, CA</u>
Bear Republic Brewing Company in California faced water supply and process water discharge limits and explored the EcoVolt as an onsite process water treatment solution to support their expansion plan and reduce the load on the city of Cloverdal's overworked treatment infrastructure [25]. (See Figure 1 in Appendix E for the layout of the Bear Republics Ecovolt treatment site.) Their system removed 80% of the BOD in Bear Republic's process water and produces an average methane fraction of 70%, reducing the brewery's reliance on natural gas. It supports their current annual production of 82,000 barrels per year and is reported to be easily expandable to support their planned growth in production of 150,000 barrels per year.

<u>CASE 2: Lagunitas Brewing Company in Petaluma, CA</u>

Lagunitas Brewing Company was burdened with steep economic and environmental costs having to truck more than 50,000 gal per day of high strength process water (40% of their total flow) to a municipal treatment plant over 50 miles away [26]. They had three concerns which are applicable to most brewing companies when it came to process water management 1) find a cost-effective, compact process water treatment solution that could be expanded as the brewery expands; 2) eliminate trucking of process water to save money and reduce their overall carbon footprint; and 3) reuse water usage to reduce capacity fees associated with increased water scarcity and assure sustainable growth. After installation of the EcoVolt they reported efficient removal of 99% of contaminants which enabled the reuse/recycling of treated water. The self powered installation treats over 120,000 gal of spent process water per day and produces over 80,000 gal of clean recycled water per day. Overall, the system enabled the Lagunitas Brewing Company to cut their water footprint 40% a day while generating 130kW of electrical power and 40,000 terms of heat per year [26]. As another indicator of the EcoVolt producing satisfying results for brewers, is that Lagunitas selected the EcoVolt for their new brewery in Azusa California after observing the system's success in the Petaluma factory.

Summary: Cambrian Innovation reports a maximum BOD removal efficiency of 80% for flow rates from 474 kg/day to 1,896 kg/day (Appendix E - Table 2). Given this data provided, the EcoVolt can be concluded as an appropriate and effective treatment method of brewery wastewater for a flow rate of 500 kg/day.

2.2. Technology 2- Submerged Membrane Bioreactors

How it works: Membrane bioreactors systems use cross flow filtration and differences in hydrostatic pressures to separate solids from liquids [12]. Of the breweries using MBR systems, most utilize submerged, rather than sidestream, reactors. Submerged MBR filters use micrometer sized pores to separate the influent liquid from its solids [3]. As wastewater enters through the membrane pores, bacteria, viruses and organic material are left behind in the aerated tank. On the bottom and sides of the tank, an aerobic microbial community breaks down the filtered organics, reducing BOD and COD levels. Around the submerged membranes, oxygen streams flow into the tank, supplying present bacteria with oxygen to break down organic material. The stream also provides scouring action to the membrane pores, preventing membrane fouling [3]. As organics are broken down, surplus activated sludge (SAS) settles along the bottom of the tank. Figure 2 in Appendix E. provides a diagram of the process.

Benefits and Limitations: MBRs are effective in removing COD, BOD, nitrogen, phosphorous, bacteria and viruses [24]. It can treat brewery waste with properties exceeding those outlined in Table 1 in Appendix E, while producing effluent properties below that required of the NY DEC [14], [1]. The case studies below display the effectiveness of MBR technology in meeting effluent standards similar to the DEC outlined regulations. Further benefits include the potential for water reuse in agricultural applications or the brewing process itself, since MBRs treat effluent to a potable quality [36]. Low maintenance, labor time, and land usage contribute to the simplicity of the system, since MBRs operate based on concentration gradients and hydrostatic pressure [17], [12]. Additionally, the technology ranges in sizes, making it applicable to the different brewery sizes of NY. Limitations include a required constant supply of oxygen to provide scouring action and allow aerobic digestion of organic matter [4], [5]. These factors increase operation costs and maintenance. MBRs require prior physical treatment to remove solids greater than 3 mm [3]. Cleaning in place (CIP) is required biannually to optimize membrane preformation and enhance life expectancy [12]. CIP does not require the disassemblement of machinery [1] and can be performed by a trainer worker without the supervision of an engineer [32]. However, the required CIP further increases costs, as breweries will have to train workers and obtain cleaning materials on a regular basis. Filters are also prone to fouling, where pores are blocked by particulate matter. Proper maintenance is required to keep fouling at a minimum [1]. Additionally, as surplus activated sludge (SAS) settles in the tank, removal is required. The newer emergence of this technology further increases cost and limits availability to NY breweries.

Case Studies of Technology:

<u>Case 1: Batemans Brewery Memtreat System; Skegness, UK</u>

Batemans Brewery installed ACWA's Memtreat system, a membrane bioreactor (MBR) technology, to ensure regulations were met. The system can process an influent flow of 83 m^3/day, with raw loading at the upper range of the brewery wastewater properties outlined in Table 1 in Appendix E. The system produces effluent with a pH between 6-9, BOD and COD respectively less than 60 mg/L and 120 mg/L and TSS less than 10 mg/L [3]. Supplemental effluent data is provided in Table 3 in Appendix E. The MBR effluent is well within the DEC's effluent requirements, making MBRs a potential candidate for the general permit process for brewery wastewater treatment.

<u>Case II: Stone Brewing Company; Escondido, CA, USA</u>

San Diego introduced a National Pollution Discharge Elimination Permit (NPDES), requiring Stone Brewing Company to meet minimum standards [14]. The company installed HYDRAsub membrane bioreactors from Hydranautics Nitto Group Company [32] .

Stone Brewing Company processes an average of 100,000 gallons of wastewater per day, which is larger than the scale of 500 kg/hr that this report is investigating [15]. However, as shown in the case study of Bateman Brewery, MBRs can be used for smaller waste flows on a scale similar to that of New York breweries. Stone Brewery waste lies in the midrange of the brewery wastewater properties outlined in Table 1 [15] . The treated effluent meets California's wastewater regulations, which are similar to that currently proposed by the NY DEC [14]. The company uses reclaimed water to brew their beer, significantly reducing their external water usage, increasing sustainability and reducing production costs [42].

2.3. Technology 3 - Upflow Anaerobic Sludge Blanket Reactor

How it works: UASB Reactors are watertight tanks that are efficient at treating wastewater. In a typical reactor, there is a "sludge blanket," which is a dense layer created from microbial growth and suspended solids from the influent waste [47]. The wastewater enters the reactor from the bottom, and flows upward through the sludge blanket where the microorganisms break down the organic compounds from the influent. Figure 3 in Appendix E shows a cross section of a typical UASB design. As a consequence of this degradation, bubbles of gas, called biogas, are created. The bubbles, along with the upflow of influent water helps to ensure the blanket is well mixed, without any external mechanism. After flowing through the sludge blanket, the treated water leaves through the top effluent pipe [47].

Benefits and Limitations: UASB reactors require a low energy input, and provide potential to be entirely energy self sufficient [60]. The biogas produced from the degradation of organic material can be harvested and used as an energy source in the brewery. The little to no external energy requirement for UASB function means less of an impact from traditional energy sources that harm the environment. The operational costs for this method compares with 10% of the operational costs of a more traditional, aerated system [60]. Its maintenance and operation requirements are low, making this system very similar to a septic tank but with higher quality effluent [47]. In rare cases, the effluent of this treatment system contains more suspended solids than the influent [60]. This is likely due to the main method of filtration being the presence of the sludge blanket. Another downfall to this system is the potential for odor caused by gases produced in the treatment process [60]. If a brewery has a restaurant or often gives tours on location, the smell could be off putting and bad for business. UASB reactors can be scaled to treat varying flow rates [60], though they tend to not be as effective for smaller scale domestic wastewater [47]. The general rule is that higher strength wastewater, like a stream with a large concentration of organics, will be most successfully treated by this method. Brewery wastewater tends to have high BOD concentrations, indicating that a UASB reactor may be suitable for a 500kg/day waste stream. UASB reactors, while useful for BOD removal, are not effective at nutrient removal [60]. If excess phosphorus and nitrogen are existing in a brewery waste stream, the UASB effluent could serve as fertilizer for agricultural use. In most cases, however, it appears necessary for the UASB effluent stream to be treated again in a traditional treatment plant to ensure it is safe to be released back into the environment.

Case study of Technology: UASB Implementation for Rural China Brewery
One UASB pilot plant was run for five months for a brewery located in rural China. The study proved to be successful at treating the brewery waste, as shown by the consistent reduction of COD by 92%, and BOD by over 89%, after the start-up period of about one month [48]. From this study, a few important points emerge for successful treatment using UASB. One is the effect of temperature on reactor performance. This pilot plant operated at 26° C, but this study suggests the sludge activity, and therefore effectiveness of treatment could be increased by 60% if the operational temperature was raised to 37° C [48]. Taking this information into account for application to a New York brewery, temperature in the winters would not be able to reach this optimal temperature, unless significant energy was put into a heating system. However, depending on the brewing schedule of the brewery, winters may not need to have the highest level of organic removal. Retention time is another important factor, which, depending on flow rates, could be a limiting factor of success of this method. Another relevant characteristic is the effect of suspended solids on acidity, BOD, and COD levels. This study suggests an improvement could be made by increasing the area for sludge settling [48]. Again, taking into account the small scale breweries, space is likely a limiting factor for their treatment method.

Summary:
From the literature reviewed, UASB appears to be an efficient, low maintenance, and low cost method for New York brewery waste treatment. However, with variability between breweries, there is no pre-set version that can be purchased, installed as is, and be immediately highly functional. Therefore, the DEC would need to allow for an adjustment period for this method, as it will take time for reactor performance to reach its maximum potential. Aside from the start up time, adjustments will likely need to be made in the way of temperature, and pH, and potentially size.

2.4. Technology 4 - Sequential Anaerobic-Aerobic Treatment

How it Works: Brewery companies have historically used Upflow Anaerobic Sludge Blanket Reactors (UASB) for the anaerobic process, and Activated Sludge (AS) or Membrane Bioreactors (MBR) for the aerobic component. Additionally, the anaerobic and aerobic components may also be combined into a single multilayer reactor [19]. A description of MBR and UASB function can be found above in sections 2.2 and 2.3 respectively. The activated sludge process contains two main steps: first the water flows through a suspension of aerated microorganisms which degrade organic matter in the wastewater. Second, the water flows through a liquid-solid separation process, where excess sludge is removed [27]. Figure 4 in Appendix E shows an example treatment train for a UASB-AS system, where the ‘Reactor’ and ‘Secondary Sedimentation Tank’ refer to the two components of activated sludge treatment. Cell recycle from the secondary sedimentation tank to both the anaerobic and aerobic reactors (indicated by dotted arrows) is crucial for maintaining high microorganism concentrations [27].

Benefits and Limitations: Using a sequence of anaerobic and aerobic treatment exploits the advantages of each process, producing a more efficient and effective treatment process [54]. Research shows the UASB-AS system requires 40% less energy for the aeration process, and produces 60% less sludge than a standard AS system on its own [27]. The reduction of excess sludge is an important factor for breweries considering biological waste treatment, because collecting and disposing of sludge requires maintenance and money. Total operational costs can be lowered further if the biogas produced by the anaerobic portion of the system is harvested and burned for fuel, especially since using concentrated waste has the potential for high energy yields [27]. However, this energy production can be limited when methane dissolves in the effluent stream. The system also provides denitrification services if the activated sludge effluent is recycled back to the anaerobic digester. Finally, [27] suggests that the primary clarifier can be removed from the treatment train when using a UASB reactor for the anaerobic component, since it acts as an equalization tank. This simplifies the overall treatment layout and conserves space. The main limitation of sequential anaerobic-aerobic treatment is that expenses increase as organic matter becomes more concentrated [27]. Additionally, hydrogen sulfide (H_2S) produced in the anaerobic process leads to foul odors. The case studies below demonstrate the success of anaerobic-aerobic sequential systems.

Case Studies of Technology:

Case 1: Grolsch Brewery, Enschede, The Netherlands

The Grolsch brewery company was facing rising sewer surcharges and decided to start treating wastewater on site [19] . Even a UASB reactor was too large to fit in its Enschede location, so the brewery decided to install a single combined anaerobic-aerobic reactor. Strict design limitations were set for the reactor, requiring minimal odor production, visibility of the reactor, and sludge production. The plant opened in May of 1994, with a 10.5 kg/day design loading rate and operating 5-6 days per week. Data for the first 2.5 years of operation showed success of the reactor with a total COD removal efficiency of 80% and a soluble COD removal efficiency of 94% [19] . Additionally, biogas and sludge production rates can be found in Table 4 of Appendix E.

Case 2: Research for Treatment of Brewery Waste, Tiajin, China

Researchers in Tianjin, China tested the efficacy of a UASB-MBR treatment process based on a local brewery [17]. For scaling reference, the outflow rate was 4,992 m^3/day. The UASB reactor had a COD removal efficiency between 50 and 75%, and the overall COD removal efficiency after MBR treatment was approximately 95% [17]. Additionally the UASB-MBR effluent satisfied The Reuse of Urban Recycling Water Standards (GB/T18921-2002) in China, which can be found in Figure 9 of Appendix E.

Summary: Sequential anaerobic-aerobic treatment shows promise for small breweries looking to treat waste on site. These designs are compact, low cost, and energy efficient. The specific combination of anaerobic and aerobic processes chosen can be tailored to a brewery's individual design constraints and budget. Additionally, case studies demonstrate that real-world organic, nitrogen, and phosphorous removal efficiencies easily satisfy the design requirements set by the DEC. Breweries choosing this treatment design should remember that foul odors may be produced and that appropriate measures should be taken to handle hydrogen sulfide production.

3. Design Requirements and Constraints

The recommendation of this study focuses on NY breweries with effluent streams of 500 kg/hr, under the assumption the brewing process operates eight hours a day for 260 days of the year. The majority of beer production occurs in the summer, fall and spring due to market demand [6], so we assume 30% of production occurs during each of these seasons, and 10% occurs in the winter. Brewery wastewater is comprised of rinse water from mash and lauter tuns, storage tanks, kegs, fermenters and whirlpool processes, as well as spent grains, cellulose, sugars, amino acids, proteins and yeast residue [4], [5]. These materials contribute to the high levels of BOD, COD, nitrogen and dissolved solids that characterize brewery waste. However, depending on the type of brew and additives, exact amounts of the above pollutants vary [5].

Of New York's four hundred breweries, 386 are categorized as craft breweries, independently owned and making less than six million barrels per year [31], [5]. To meet DEC requirements, treatment must modify total suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD), total phosphorus (TP,) and acidity (pH) of their brewery's wastewater. The DEC proposes total nitrogen (TN) levels; however, even the highest ranges of TN in brewery waste are below DEC standards, so it will not be taken into consideration while evaluating treatment options. Table 1 in Appendix E outlines average brewery wastewater composition and the required effluent levels recommended by the DEC. This status poses user constraints in terms of costs, maintenance, and supervision, thus limiting the applicability of treatment technology.

The upfront cost and lifetime operation cost of treatment should balance the state and municipal surcharges that a brewery would otherwise face for not treating their waste [5]. Since most breweries do not retain a licensed engineer, treatment systems must be easily operated, cleaned, and maintained. For this reason, automated sampling and notification systems, called pulse output mechanical meters, for each DEC specified parameter is recommended [5], [4]. This ensures brewery waste treatment is tailored to the given composition of waste, and will alert brewers if effluent is not meeting standards. It also eliminates manual reading errors. This technology is readily available from several different suppliers, including Brewery Wastewater Design [65] and Alfa Laval [64], making it accessible to NY brewers. In addition, increasing the level of automation during treatment and its accompanying cleaning process is recommended to facilitate user friendly operation.

4. Proposed Process

4.1. Rationale for Recommendation

To determine if brewers in New York State have an interest in the sustainable options of wastewater management, twenty breweries from the list of 91 New York State breweries were randomly sampled [28] and analyzed to determine whether the company engaged in sustainable branding. Of the twenty breweries sampled, 85% did not engage in sustainable branding, indicating that sustainability should not be a leading factor in the recommendation process. These findings align with recommendations from [4], [5], whose sustainability benchmarking report only emphasizes sustainability within the context of meeting effluent compliance and with respect to economic feasibility [5]. This suggests sustainable wastewater management recommendations should be made with more emphasis on immediate financial implications rather than long term environmental stewardship.
Given the design constraints of NY breweries presented in Section 3 and findings about the percentage of NY brewers engaging in sustainable branding, our recommendation for treatment solutions prioritizes cost and

simplicity. The proposed processes (1), (2) and (4) outlined in Section 2, while more sustainable technologies due to their potential of wastestream reuse as potable water, are more costly and operator intensive, and far exceed the DEC pollutant guidelines. Therefore, we recommend process (3), the UASB digester, for secondary treatment as the optimal solution when considering cost, simplicity and maintenance. Primary treatment through sedimentation, and secondary treatment by upflow anaerobic sludge blanket (UASB) digestion is recommended.

4.2. Overview of Main Unit Operations

Brewery waste will exit the brewery using a centralized drain system already commonly present in breweries [4] and enter a holding tank called an equalization basin. Presumably, the tank and treatment system will be outside of the brewery. Waste will be held here until the assumed eight hours of operation are finished, allowing for equal mixing of the organics to ensure a constant loading during waste treatment operations and continuous flow. From there, waste will be drained into the sedimentation tank at a rate of 500 kilograms per hour, where passive removal of solids will occur, effectively lowering BOD, COD and TP levels. From here, the waste will flow into the anaerobic UASB, filling the tank from bottom up. At the bottom of the UASB is a bed of sludge, containing microbes that break down organics and effectively lower BOD, COD and TP levels. Microbes will create sludge and methane gas, the latter of which will be collected at the top of the UASB for potential use as energy. If breweries opt out of using the resulting methane, the UASB tank will still operate as outlined and the gaseous byproducts will passively be released or burned. Treated water will float to the top of the UASB, naturally seperating from the untreated waste and flowing out of the UASB into a final collection tank to be brought to the municipal treatment plant. A schematic of this process is provided in Appendix E - Figure 4. Throughout this process, pulse output mechanical meters will be placed at the outlet of the holding tank, the outlet of the sedimentation tank and the final holding tank for the treated waste. The meters will automatically check the effluent levels and will alert the brewery if certain parameters are not being met.

4.3. Mass Balances and Costs

Holding Tank Calculations

The size of the holding tank needed to be large enough to accomodate the largely varying flow rate throughout the day. It was assumed that brewery waste would only be produced during an 8 hour workday from 9 AM - 6 PM. The time varying volume of water in the equalization tank was calculated by subtracting the continuous flow of water out of the tank from the intermittent flow into the tank, and multiplying by the hour of the day. This 'hour of the day' was offset by a value of 9 to account for the 9 AM start of the workday. An additional safety factor of $500\ L$ was added to the reactor volume, to ensure continuous flow to the UASB reactor. The result was a piecewise function for volume in the holding tank as a function of time of day. The maximum value of this equation, $3.2\ m^3$, was taken to be the volume of the equalization tank.

The materials cost for the equalization tank was calculated by assuming a cylindrical geometry. Basic calculus was used to determine the minimum surface area of the tank ($12.1\ m^2$) required to hold $3.2\ m^3$ of water, with the assumption that minimizing materials cost was more important than minimizing land area. The total cost for this holding tank was estimated to be \$645, based on the price of plastic water tanks.

Sedimentation Calculations

It was assumed that the majority of TSS removal would occur in the sedimentation basin. Therefore, the sedimentation basin would be required to treat anywhere between 2,000 and 500 mg/L TSS, corresponding to removal efficiencies of 95% and 20%. This wide range has important implications for brewery wastes with low TSS content, since they could use much smaller sedimentation tanks or rely solely on biological processes for TSS removal. However, the 'worst case scenario' TSS concentration was chosen for calculations.

A formula for the minimum plan-view area needed to meet DEC standards for TSS removal was constructed by combining Stokes' Law with the equations for critical settling velocity, and particle removal efficiency. To simplify calculations, it was assumed that all particles had the same density and were roughly the same size. This assumption was made so that the TSS removal efficiency required by the DEC could be approximated as the particle removal efficiency, which was needed in calculations. Note that this assumption is slightly unrealistic for a highly variable wastestream, and a more in depth analysis should be done at a higher level in the design process. Zdanowska measured the distribution of particle sizes for brewery wastewater in Table 5 of Appendix E [46]. A particle diameter that was one standard deviation below the median value in this table was chosen for calculations. The density of particles was assumed to be the density of spent grain (432 kg/m^3), however it was quickly realized that this density was much less than that of water [55]. A solution to this problem could be adding a more dense material to the waste stream, such as kaolinite clay, and a flocculation process. For calculation purposes, the density of particles was therefore chosen to be the density of kaolinite clay. Using these numbers, the area needed for the sedimentation tank was 1.8 m^2. The height of the sedimentation tank was not considered to be a critical design component, but could be pinpointed at higher levels of the design process by considering hydraulic residence time. An arbitrary height of 2 m was chosen for the sake of cost analysis because it was on the same order of magnitude as the sedimentation tank area. Since sedimentation is a passive process, the only cost requirements were materials costs, scaling to the surface area of the tank. To calculate the surface area, a rectangular prism geometry with a 4:1 side ratio and an open top was assumed. The total sedimentation cost was estimated to be about $380.

The amount of phosphorus removed in the sedimentation process was calculated by multiplying the percentage of phosphorus in spent grain (0.46% wt), by the TSS removed in sedimentation. The amount of phosphorus continuing to the UASB reactor was equal to the initial phosphorus concentration minus the concentration removed. This calculation was based on a 30% TSS removal rate in the sedimentation tank, which is on the low side of TSS removal as calculated above. These calculations resulted in a 6.9% removal of phosphorus.

The sedimentation tank was also assumed to remove BOD as a large component of brewery waste includes organic particles. Mihelcic and Zimmerman claim that a primary grit or sedimentation chamber can remove approximately 30% of influent BOD [56]. Assuming an initial BOD concentration between 500 and 1,500 mg/L, conservation of mass was used to determine the effluent BOD proceeding to the UASB reactor. If 30% of BOD is removed, then the effluent concentration would be 70% of the influent concentration. This number was found to be between 350 and 1,050 mg/L.

UASB Calculations

The volume required to meet DEC regulations on organics was calculated following the assumption that the process can be modeled as a steady state plug flow reactor with first order decay [40]. Additionally, it was assumed that brewery waste was only produced 8 hours out of the whole day. The k-value used for calculations was 0.954 day^{-1} at a temperature of 37 ℃. However, this k-value was specifically in reference to the removal of COD. A BOD:COD ratio of 6:7 was used to infer a 35% removal rate of COD from the sedimentation tank. This removal rate was applied to determine the initial concentration of COD flowing into the UASB reactor (3900 mg/L), in the same way that the BOD mass balance was performed. Once the influent COD concentration was determined, the flow rate, k-value, and desired ratio of initial and final COD were plugged into the 1st order decay expression. Rearranging this expression produced a UASB volume of 10.69 m^3 needed to achieve DEC standards for organics. The cost required to build a cylindrical tank of this size was calculated in the same way as the cost for the holding tank, and came to $1,395. This price does not include the staff needed to operate the machinery year round, the price of installation itself, nor the maintenance costs that may arise.

Phosphorus is removed in the UASB reactor through Phosphorus accumulating organisms (PAOs) which consume organic material. This removal requires a sufficient organic to phosphorus ratio in the initial wastewater stream, which would be satisfied if the treated wastewater contained DEC levels of BOD [59]. The effluent phosphorus concentration for the UASB was calculated by multiplying the effluent BOD concentration by a conversion ratio, which was 30 parts BOD to 1 part Total Phosphorus. This produced an effluent phosphorus concentration of 5 mg/L, corresponding to a removal efficiency of 86.6%.

4.4. Energy Balance and Costs

To determine the energy intensiveness of our proposed treatment, an energy balance was carried out. The electricity cost to fuel the removal processes would cost an annual $6,208.47. This cost was found under the assumption that sedimentation is a passive process requiring no additional fluid or shaft work, nor heat flow. The UASB operates at 37 degrees celsius in order to reach the optimal first order decay rate of 0.954 day^{-1} for COD removal [40]. Since we assume the treatment occurs outside and with the seasonal operation periods outlined in Section 3 and by [6], we calculated the average temperature for each season using monthly data provided by US Climate Data website [66] , which is recorded in Appendix B. We then assumed that the UASB is an open system with no acceleration, significant height change, shaft nor flow work, allowing us to equate rate of enthalpy change to rate of heat change. We then used the latent heat of water and its specific heat capacity at constant pressure [23] to bring the waste water from the average seasonal outside temperature to 37 degrees celsius. We then assumed that the UASB would have to be heated for eight hours a day for 260 days per year [49], [4], creating a mass of about 27,762 kilograms per hour. By multiplying this mass rate by each of the specific enthalpies for each season we find the rate of enthalpy change, which by assumption of the open system, is the rate of heat required for the UASB operation. To find operation costs, units of rate of heat were converted into kilowatt hours, and then multiplied by the seasonal averages of electricity prices [13]. To find annual costs, the electrical costs for each season were summed, resulting in an annual cost of $6,208.47 required to operate the UASB at ideal conditions. Appendix B contains the table for each of the transitional values, as well as an example calculation for the winter season.

Additionally, the money saved each year by using biogas as fuel was calculated as function of COD removal. Table 4 of Appendix E [19] provides a biogas production rate of 0.47 m^3 of biogas per kg of COD removed. Multiplying this rate with the 14.4 kg of COD removed per day (calculated previously) leads to a biogas production rate of $2,470.32\ m^3/yr$. According to AQPER [67], each cubic meter of biogas contains the equivalent of 6kWH of heat energy and according to BLS [68] the average price per kWh in New York is $0.21/kWh. This means that the total cost saved by biogas production is approximately $3,112

5. Regulatory Implications

Using mass and energy balances, our report demonstrates that our proposed process is able to meet COD and BOD guidelines set by the DEC. For TSS, our processes would require additional flocculation as a downstream solution following sedimentation. For total nitrogen, raw brewery waste effluent, even in its highest ranges, already meet DEC guidelines. Total phosphorus (TP) varies greatly depending on the type of beer being brewed [4], and so ensuring phosphorus accumulating organisms (PAOs) are present in the UASB would address the required dephosphorization.

5.1. Meeting BOD and COD Standards

The success of BOD and COD removal can be determined by dividing the amount removed over the initial amount present. These numbers are high which indicate a reliable treatment system. Using mass balances, a sedimentation tank of 1.8 m^2 and a UASB reactor of size 10.93 m^3, removal successes of 86% and 92% for BOD and COD, respectively. Under these conditions, they were determined to exactly meet DEC regulations of 150 mg/L and 300 mg/L with regards to the upper levels of BOD and COD. Ensuring proper removal of these organics is a crucial step in brewery wastewater management, as they tend to affect the municipal treatment plants' operation the most.

5.2. Meeting TSS Standards

The plan-view area needed for a sedimentation tank that meets DEC standards for TSS removal was calculated to be 1.8 m^2. The critical caveat to this recommendation is that a flocculation process must be implemented beforehand with the addition of a dense particulate matter such as kaolinite clay. This is because the density of spent grain (432 kg/m^3) is much less than the density of water (998 kg/m^3) and it is unlikely that many solids suspended in brewery waste would settle out on their own [55]. The additional flocculation requirement was not anticipated in the original recommendation, and raises questions about the utility of a sedimentation tank in the treatment train. Choosing the coagulant dose for flocculation is an extremely imprecise process, which would require frequent monitoring and a highly trained eye to adjust on the spot. Even so, brewers should consider the implementation of a grit chamber for removal of extra large particles, and may rely on the anaerobic and aerobic processes for more suspended solids removal. Due to the high organic composition of brewery wastewater, it is likely that many suspended particles are also organic and can therefore be broken down in the UASB reactor.

5.3. Meeting Phosphorus Standards

Depending on the type of brew, total phosphorus (TP) level treatment ranges from no modification to a required 37.5% reduction. Based upon the percentage of TP present in the brewers spent grain produced from malt and barley, a portion of TP will be removed through the sedimentation process. We assume that the upper level of TP is present in TSS, where we assume the upper level of TSS is present, and that the average rate of solid removal (30%) occurs. We calculated the product of weight composition of phosphorus in spent grains by the upper TSS levels and the average solids removal rate, and subtracted it from the upper range of TP, finding that only 6.9% of TP is removed during sedimentation, thus sedimentation would only meet effluent standards if the phosphorus range was between 5 and 16.035 mg/L. This requires either an additional downstream process, such as chemical flocculation using alum or another metal salt [59] to precipitate phosphorus, or the integration of PAOs into the UASB system. To keep material costs low and operation simple, we further investigated the removal rates and maintenance of a PAO community in the UASB. Common PAOs include acinetobacter and rhodocyclus microbacteria, which can be cultivated in anaerobic sludge and effectively break down organics and phosphorous, thus lowering TP levels and preventing additional energy costs since it will be integrated into the UASB process [59]. Using the effluent ratio of 30:1 for treated BOD to treated TP, we calculated the final TP level as 5 mg/L by multiplying the final BOD concentration by the ratio provided by [59]. While this final concentration is within regulations, it relies heavily on the treated concentration of BOD and the ability of our UASB to process to DEC standards.

5.4. Meeting pH Standards

Levels of acidity in the brewing process can range from a pH of 3 to a pH of 12 [5] , this range indicates the need for neutralization. Acidity and alkalinity both affect the success of the treatment process, and the environment. The presence of yeast, in large quantities, contributes to the formation of organic acids [5] . These acids, when left alone, could harm the infrastructure of municipal treatment systems, as well as the brewers' own machinery. Adjusting pH with chemicals, and flocculation is the most common pretreatment method [5] . Because this specific recommendation relies on sedimentation already, the brewer would need to simply choose the most feasible chemical pretreatment system for their waste before letting it run through the grit chamber and UASB. Many pH monitoring systems are available for purchase, and automated systems for neutralization could be installed if the brewery has the financial resources [5].

5.5. Summary of Design Confidence

Our proposed processes meet DEC guidelines assuming the maximum levels of BOD and COD strength. After applying standard sedimentation removal rates and using literature on decay rates of UASBs to specify the needed volume, our group feels confident that the process will meet BOD and COD requirements as long as the max effluent of a 500 kg/hr stream is equal to or less than a COD level of 6,000 mg/L.

The ability of a brewery to meet TSS standards relies on its ability to insert a flocculation process before the sedimentation step. This may not be possible due to space requirements and the need for a well-trained eye to monitor coagulant dosage. However, it is possible that organic degradation in the UASB reactor could contribute significantly to TSS removal and further calculations should be conducted to confirm the extent to which this is true.

For meeting TP regulations, we do not have full confidence in the proposed process of introducing a PAO community to lower upper ranges of phosphorous levels. PAO communities depend heavily on influential ratios of phosphorus to BOD, so the fluxuations would pose an issue to microbes [59]. Additional phosphorus could be added to the process to ensure the health of PAOs, but this would be operator intensive. However, introducing an entire coagulation process as a downstream solution to ensure TP regulations are met is a costly solution for a variable pollutant.

6. Recommendations and Conclusions

Our recommendation is made with consideration of the solutions ability to address relevant major process water issues (pH, BOD, nutrients and solids), reduce cost, increase overall environmental benefit and minimize land area. Taking this into account, a proposed system utilizing a particle sedimentation chamber, followed by biological treatment with UASB is best fitting for the needs of brewers and the limits of the DEC. The limitations section includes a description of constraints of our process design.

6.1. General Permit for Brewery and Winery Industry

Due to the complex and variable nature of operations [38], flow composition [11], and waste handling methods [11] in each respective industry, establishing a general permit for both the brewery and winery industries would be misguided. Existing permits were reviewed in order to find a basis for a recommendation regarding the applicability of a general discharge permit.

Most states do not have existing winery or brewery discharge permits, but rather the industries are regulated through nationwide discharge permits applicable to all industries within state lines. In some cases, such as in Oregon, wineries are exempt from the state water pollution control permits for food processors [30]. In states with existing and separate winery and brewery discharge permits, discussion regarding the introduction of a general permit for both industries is minimal.

Washington State houses a Winery General Permit, and is pending establishment of a permit specific to Brewery, Distillery and Cidery industries [43]. After a review of available data and speaking with industry experts, the Ecology department of Washington explained that "the production process, annual schedule, and wastewater characteristics from meaderies, cideries, distilleries, and breweries is different enough from wineries, that this first permit cycle should focus on wineries only" [43]. Although a permit applicable to both industries would streamline the SPDES permitting process, as well as reduce costs and administrative burdens, it can be concluded a general permit may not be appropriate for both brewery and winery industries in New York State as well.

Should it be determined that a more technical review be required for the NY State DEC, Cornell Agritech's Craft Beverage Institute is equipped with appropriate resources for research [16]. However, it should be noted that this review should only be conducted if absolutely necessary. If every state were to conduct their own review regarding the applicability of a joint Winery and Brewery wastewater discharge permit, it would significantly impede the United States progress toward sustainable development. If possible, with sufficient and reliable data provided by the Washington state review, New York state should move forward with the establishment of a separate permit.

6.2. Process Limitations

Based on calculations made for our process (see Appendix B) we estimate a yearly operating cost of approximately \$6,200/year, and an upfront cost of construction and permit acquisition of approximately \$4,100. Additionally our system will require available land space of 7.5 m^2. Although these costs appear high, we estimate that they are low in comparison to other available technologies. Further consultation needs to be made with NY State Brewers about whether this high cost is manageable for brewers eligible under this SPDES permit. As seen within the calculations, we have assumed that brewers would not need to hire a year round wastewater operator for maintenance of our proposed process. Sampling, recordkeeping, reporting, and other maintenance tasks will be time consuming but doable by existing brewery staff. The land area usage of 7.5 m^2 is also low in comparison to other technologies and we find it reasonable for the DEC to expect this land area availability of brewers.

Our process, as described within the rationale for decision making, is not the most sustainable option available for wastewater management. It is advised that given the high threat of climate change and water scarcity, that solutions mentioned within the Review of Available Technologies section which offer water recycling, be utilized by sustainability conscious brewers. It should be noted that the NPR conducted a survey [63] which found that consumers are willing to pay more for beer which is produced sustainably and therefore it can be concluded that sustainable wastewater management may be in the interest of a economically focused brewer. Nevertheless, our systems capture of biogas allows for renewable energy production to the degree of allowing the offset of $3,100/year. This component incorporates sustainability metrics by allowing the offset of CO_2 emissions by avoiding the purchase of energy produced by fossil fuels and other non-renewable energy sources.

Limitations of our process are particularly relevant to brewers which use hops in the brewing process. Breweries which utilize high volumes of hops in their brewing process may experience issues with traditional anaerobic treatment technologies due to the bacteriostatic behavior of hops. Aerobic solutions may be more relevant in this case. Additionally odor problems may occur due to reduce gases that are dissolved in the effluent and may escape. High influent $SO4^{2-}$ concentrations may limit the applicability of anaerobic sewage treatment as it results in the conversion of organic BOD/COD to inorganic BOD/COD [7].

Should brewers choose not to install the holding tank included in our design, an increase in process water composition and loading fluctuations may occur and can cause washout of granular biomass [7]. For brewers that do include a holding tank in the treatment process design, they may still be at risk of inconsistencies in treatment functionality if they do not operate on weekends, face a facility shutdown, or change brewing processes throughout the year. A consistent daily flow is required for the operation of our proposed design. Keg cleaning may also result in high process water compositions which can put a brewer at risk of violating SPDES permit requirements. We estimate that given the high rate of pollutant removal of our design that it is possible keg cleaning may not affect breweries ability to maintain compliance with the SPDES permit's 30-day average composition requirements.

6.3. Summary

Although limitations associated with our recommendation are lengthy, calculations and case studies [48] confirm our process would be able to help brewers achieve a compliant wastewater management program. Our design minimizes cost, simplifies operation, minimizes land area requirements, is sustainable through renewable energy generation by biogas production, and aids in the preservation of New York waterways by pollutant reduction.

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9. Appendix

- Appendix A: Overview of current available technologies for brewery wastewater treatment
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Appendix A - Overview of current available technologies for brewery wastewater treatment

Physical Pretreatment

Physical treatment removes coarse solids rather than dissolved materials. Most breweries use drain screens to remove larger materials, such as bottle caps or pallet chunks. Drain screens are easily cleaned, maintained, and installed, and eliminate the need for a bar rack or screen chamber later in the treatment process [4]. Some breweries utilize side streaming, which uses a separate drain system to collect high concentration organics [5]. However, side streaming is utilized only if the wastewater after treatment regularly fails to meet BOD or COD regulations, since installing an entirely separate drain system is expensive [4]. Sedimentation or coagulation-flocculation are used to treat smaller solids, such as TSS [36]. Sedimentation is passive, allowing solids to settle out for removal, while coagulation-flocculation uses chemicals to destabilize solids and encourage physical separation [36]. Most breweries choose sedimentation tanks over coagulation-flocculation because sedimentation does not require chemical additives, making it lower cost and maintenance [4]. Physical treatment is commonly used by NY and is recommended by New York State Brewers Association, highlighting the prevalence of this treatment method in NY [52].

Aerobic Solutions

Aerobic treatment adds oxygen to process water to facilitate the biological degradation of organic matter, which is then converted to biomass, carbon dioxide and water. Aerobic treatment solutions that may be selected by breweries include constructed wetlands, membrane bioreactors (MBRs) and activated sludge processes [36]. Constructed wetlands [41] have a low upfront capital investment, low effluent levels, easy operation and low maintenance costs. However, disadvantages include requiring a large land area, high energy costs and odorous byproducts, while failing to capture any value trapped in brewery process water. Due to these factors, constructed wetlands are not commonly used in NY breweries. MBRs [35] and other advanced activated sludge processes require less physical space, treat process water efficiently and reliably, and do not require odor control measures. The NY DEC already approved the use of excess sludge for land application, encouraging an increase in usage of aerobic sludge processes [53]. However, these solutions require more maintenance than their anaerobic counterparts, and due to the newer, pricer nature of MBRs, these processes are not as widely used in the NY brewing industry.

Anaerobic Solutions

Anaerobic treatment requires higher upfront investment than its aerobic counterpart, but offers lower operating costs, produces renewable energy and generates around 80% less biosolids [29], [18]. Anaerobic solutions use anoxic conditions and methanogenic bacteria to break down waste, producing less sludge than aerobic processes. However, they are sensitive to pH, temperature, volatile fatty acids and ammonium [29]. Anaerobic digesters, such as upflow anaerobic sludge blanket reactors, are commonly used by NY breweries who have treatment processes, such as Utica's Matt Brewing Company. Like aerobically created sludge, the DEC has already approved the land usage of anaerobically produced sludge [53]. Anaerobic solutions can be complemented by bioelectrochemical systems (BES), which use fuel cells to generate electricity [33]. BES and other complementary systems are not commonly used in NY due to their limited availability, but their stabilization of treatment, reduction in operating costs, and potential to create renewable energy make the emergence of these processes a potential candidate in aiding brewery wastewater treatment [34].

Appendix B: Calculations

FLOW RATE CALCULATION

Assumptions:

1. The mass of the total suspended (TSS) and dissolved (TDS) particles is negligible and therefore we can assume a brewery wastewater density equal to the density of water, 1000kg/m^3.
2. We assume brewery production occurs at a regular 9:00 am - 5:00 pm schedule and therefore the flowrate provided as 500kg/hr occurs only for 8 hours a day.

Given: Q = 500 kg/hr

Definition of Variables

$Q_{AVG} = \text{ average flow rate over a time span of } 24 \text{ hours } (\frac{L}{day})$

$Q_{AVG} = \frac{500\ kg}{hr} \times \frac{m^3}{1000\ kg} \times \frac{8hr}{day} \times \frac{1000\ L}{1\ m^3} = 4000\ \frac{L}{day}$

HOLDING TANK CALCULATION

Tank Volume

Assumptions:

1. The given flow rate only runs for a period of 8 hours per day.

Definition of Variables:

$V_T = $ *volume of wastewater inside the holding tank*

$V_{IN} = $ *volume of wastewater flowing into the tank from the brewery*

$V_{OUT} = $ *volume of wastewater flowing out of the tank from the brewery*

$T = $ *time of day* $(at\ 9\ am\ T = 9,\ at\ 3\ pm\ T = 15)$

Calculations:

$V_T = flow\ rate \times\ time$

$V_{IN} = Q_{AVG} \times \frac{1\ day}{8\ hr} \times T$ (Here, the flow rate is readjusted with a 8hr time frame because we assumed the production cycle only runs for 8 hours)

$V_{OUT} = Q_{AVG} \times \frac{1\ day}{24\ hr} \times T$ (Here the flow rate is readjusted to 24 hours to assure there is a continuous flow through the treatment system for 24 hours. UASBs are sensitive to variable flow rates and severe threat can occur to the functionality of the bacteria should there be no continuous flow through the system outside of operating hours)

$V_T = V_{IN} - V_{OUT}$

$V_T(T) = (Q_{IN} \times T) - (Q_{OUT} \times T)$

The volume inside the holding tank can be modeled as such: The volume inside the holding tank is a function of the time of day given that the volume inside the holding tank will not be the same at any time of day assuming an 8 hour production span per day. Note the (T-9) in the formula. This is caused by the assumption that the operation cycle begins at 9am. T in this equation reflects the time of day, not time elapsed. Also note the 500 . This was incorporated into the model as a safety measure to assure that there is always a consistent flow to the UASB digester within the treatment process.. Similarly, because an 8hr operation time was assumed, this equation is a piecewise function dependent on the time of day

$V_T(T) = (Q_{AVG}(\frac{L}{day}) \times \frac{1\ day}{8\ hr} \times (T-9)) - (Q_{AVG}(\frac{L}{day}) \times \frac{1\ day}{24\ hr} \times (T-9)) + 500\ L \quad 9 \leq T \leq 17$

The highest volume of wastewater in the reactor will occur at the end of the production day at T=17 or at 5:00pm. The highest volume required should also be the size of the holding tank.

$V_T(17) = (4000\frac{L}{day} \times \frac{1\ day}{8\ hr} \times (17-9)) - (4000\frac{L}{day} \times \frac{1\ day}{24\ hr} \times (17-9)) + 500 = 3166.67\text{ L} \approx 3.2m^3$

Material Use

The material requirements for the holding tank can be calculated assuming the holding tank is cylindrical using the formula for the volume of a cylinder. To determine the dimensions of the holding tank, we assumed that using less materials is of higher importance than using less landscape. The minimum surface area required to hold $3.2\ m^3$ of wastewater is calculated as follows

$SA_T = surface\ area\ of\ cylindrical\ holding\ tank$

$SA_T' = derivative\ of\ surface\ area\ of\ cylindrical\ holding\ tank$

$h = height\ of\ the\ holding\ tank$

$r = radius\ of\ holding\ tank$

$V_T = h\pi r^2$

$h = \frac{V_T}{\pi r^2}$

$SA_T = 2\pi r^2 + 2\pi rh = 2\pi r^2 + 2\pi r\frac{V_T}{\pi r^2}$

If we set the SA_T'=0 and solve we get the optimal value for the radius and height to give the minimum surface area required to hold $3.2\ m^3$ of wastewater.

$SA_T' = 4\pi r - 2\frac{3.2}{r^2} = 0 \qquad \Rightarrow r \approx 0.8\ m$

$h = \frac{V_T}{\pi r^2} = \frac{3.2}{\pi\times 0.8^2} \qquad \Rightarrow h \approx 1.6\ m$

$\Rightarrow SA_T \approx 12.1\ m^2$

Land Area

Using the value for radius calculated in the above section and assuming the holding tank is cylindrical, we can calculate the land space requirement for use of a holding tank.

$LA_T = Land\ area$

$LA_T = \pi r^2 \approx 2\ m^2$

SEDIMENTATION TANK CALCULATIONS

Land Area

The plan-view area needed for the sedimentation basin can be calculated by combining the equations for Stokes' settling velocity, critical settling velocity, and particle removal efficiency, which are shown in order below.

$v_s = \frac{g(\rho_p - \rho_f)d_p^2}{18\mu}$ *(Stokes' settling velocity)*

g = *acceleration due to gravity*

ρ_p = *particle density*

ρ_f = *wastewater density*

d_p^2 = *particle diameter*

μ = *dynamic viscosity of water (assumed at 25 °C)*

$v_c = \frac{Q}{A}$ *(critical settling velocity)*

Q = *volumetric flow rate*

A = *plan-view area of the sedimentation tank*

$f_{particle} = \frac{v_s}{v_c}$ *(particle removal efficiency)*

Putting these equations together with some algebraic rearrangement produces a formula for the minimum plan-view area needed by the sedimentation tank to achieve DEC standards:

$$A = \frac{18\mu f Q}{g(\rho_p - \rho_f) d_p^2}$$

Assumptions:

1. The majority of TSS removal occurs in the sedimentation process. Therefore this process is responsible for removing at least 400 mg/L TSS and up to 1900 mg/L TSS per DEC standards. The 'worst case scenario' value was used for calculations.

$$f_{TSS} = \frac{2000\ mg/L\ -100\ mg/L}{2000\ mg/L} = 95\%$$

$$f_{TSS} = \frac{500\ mg/L\ -100\ mg/L}{500\ mg/L} = 80\%$$

2. All particles were assumed to have the same density as spent grain (432 kg/m^3) [55]. However, this is a problem, because the density of spent grain is less than water. Brewers could work around this by adding a more dense material to their waste stream, such as kaolinite clay, and a flocculation process to increase the overall density of particles. Essentially, brewers would need to make their waste dirtier in order to make it cleaner. The density of particles used in calculations was therefore chosen to be that of kaolinite clay, which is 2650 kg/m^3 [57].

3. Additionally, all particles were assumed to have a diameter of 0.192 mm, which was one standard deviation below the median particle size in brewery wastewater (see Table 5 in Appendix E for the distribution of particle sizes). With the assumption of uniform size and density, the TSS removal efficiency can be approximated as the particle removal efficiency. Note that this assumption is slightly unrealistic for a highly variable wastestream, and a more in depth analysis should be done at a higher level in the design process.

$$f_{TSS} \approx f_{particle}$$

$$A = \frac{18\mu f Q}{g(\rho_p - \rho_f) d_p^2} = \frac{(18)(0.0008891\ Pa\cdot s)\ (0.95)(4000\ \frac{L}{day})(\frac{1\ day}{86400\ s})}{(9.81\ m/s^2)(2650\ \frac{kg}{m^3} - 1000\ \frac{kg}{m^3})(0.000192\ m)^2} = 1.18\ m^2$$

Material Use:

The materials requirement for the sedimentation tank can be calculated assuming a rectangular prism geometry with an open top. The plan view area needed for the sedimentation basin was calculated in the *Land Area* section above. Assume a 4:1 side ratio for simplicity. The height of the sedimentation basin can be calculated from the hydraulic residence time and plan-view area as follows:

Θ = *hydraulic residence time*

V = *volume of the sedimentation tank*

Q = *volumetric flow rate of brewery wastewater*

$= \frac{V}{Q}$
$h = \frac{V}{A}$
$\Rightarrow\ h\ =\ \frac{Q}{A}$
Therefore the residence time should be minimized to reduce the height and keep construction costs as low as possible.The corresponding surface area of the sedimentation tank can be calculated as follows:

$SA = A + 2h\sqrt{\frac{A}{4}} + 2h\sqrt{4A}$

TSS Removal

The TSS removal efficiency required to meet DEC standards depends largely on the influent TSS concentration. This efficiency can be calculated by dividing the TSS removed by the TSS originally present.

High Influent TSS: $\frac{2000\ mg/L - 100\ mg/L}{2000\ mg/L} = 95\%$

Low Influent TSS: $\frac{500\ mg/L - 100\ mg/L}{2000\ mg/L} = 20\%$

The required removal efficiencies range from 20% to 95%. This large range means that low TSS breweries can get away with much smaller sedimentation tanks, whereas large breweries might need to add an additional settling basin, or add a flocculation step to the process.

Phosphorus Removal

Assuming an upper range of total phosphorus (TP) and TSS levels, and the spent grain to phosphorus composition provided by [58], a portion of TP will be removed during sedimentation. This is found by multiplying the percentage of phosphorus in spent grain by the TSS upper range removed by sedimentation, then subtracting the removed amount from the upper range of TP.

Upper range of TP: 40 mg/L
P% in brewers spent grain: 0.46% wt
TSS upper level: 2,000 mg/L
Removal Rate of TSS: 30%

Remaining P: $(40) - (.0046 \cdot 2,000 \cdot 0.3) = 37.24$ mg/L
P% Removed: $\frac{(40 - 37.24)}{40} = 6.9\%$
Range of Applicability: $15 + (15 \cdot 0.069) = 16.035$ mg/L

The UASB must aid in phosphorus removal, or an additional chemical process to coagulate phosphorous must be implemented, if the effluent level is above 16.035 mg/L of phosphorus; otherwise, DEC guidelines will not be met.

BOD Removal

According to Mihelcic and Zimmerman, a primary grit or sedimentation chamber removes approximately 30% of influent BOD [56]. Assuming an initial concentration of 1500 mg/L, the BOD proceeding to the UASB reactor can be calculated with a mass balance.

Upper Range: $BOD_{effluent} = 0.70 \cdot BOD_{influent} = 0.70 \cdot 1500\ mg/L = 1050\ mg/L$
Lower Range: $BOD_{effluent} = 0.70 \cdot BOD_{influent} = 0.70 \cdot 500\ mg/L = 350\ mg/L$

Since the DEC requires the BOD in brewery effluent to be 150 mg/L or below, a UASB process must follow the sedimentation tank to meet regulations.

UASB CALCULATIONS

Reactor Volume

Operating at C=37º and a reaction rate of k= 0.954day^{-1}

*Assume Plug Flow Reactor

*Assume steady state

H_20 density = 1 kg/L

Organic waste density = .00569811 kg/L

Wastewater Density = 1.00569811 kg/L

Initial COD concentration= 6,000 mg/L

BOD:COD = 6:7 (Inyang et al.)

%BOD removed by grit chamber = 30%

%COD removed by grit chamber= $\frac{7*30\%}{6} = 35\%$

Influent Concentration (C_1) = $6,000\ mg/L \bullet 35\% = 3,900\ mg/L$

DEC required Effluent Concentration (C_2) = 300 mg/L

$$\frac{500\ kg/hr}{1.00569811\ kg/L} = 497\ L/hr$$

$$(497\ L/hr) \bullet (8\ hr\ brewing/day) = 3976\ L/day\ Wastewater$$

$$V = \frac{-Q}{k} ln(\frac{C_2}{C_1})$$

$$V = \frac{-(3976\ L/day)}{(0.954/day)} ln(\frac{300\ mg/L}{3,900\ mg/L})$$

V= 10,690 L

V = 10.69 m^3 Required UASB Volume under given conditions to meet DEC standards.

The proposed UASB will run at 37º Celsius and have a *k* value under a conventional monod temperature based standard of 0.954 day^{-1} [40] for calculations involving COD removal. The upper extreme of COD concentration was used to best model the largest necessary reactor required under these conditions. The ratio of BOD:COD was used to determine the approximate COD removed via the sedimentation tank, and therefore how much COD is left to be removed by UASB. Assuming the reactor can be modeled as a plug flow reactor, due to its continuous flowing system and COD concentration gradient, the largest necessary volume to meet proposed DEC standards was determined to be 10.69 m^3 using the formula above.

Material Use

The materials requirements for the UASB digester can be calculated assuming the UASB digester is cylindrical using the formula for the volume of a cylinder. To determine the dimensions of the UASB digester such as inner radius, we assumed that using less materials is of higher importance than using less landscape. The minimum surface area required to hold $8.397\ m^3 \approx 8.4\ m^3$ of wastewater is calculated as follows

$SA_R = surface\ area\ of\ cylindrical\ UASB$ reactor

$SA_R' = derivative\ of\ surface\ area\ of\ cylindrical\ UASB\ reactor$

$h = height\ of\ the\ UASB\ reactor$

$r = radius\ of\ UASB\ reactor$

$V_R = h\pi r^2$ (calculated above as approximately $8.4\ m^3$)

$h = \frac{V_R}{\pi r^2}$

$SA_R = 2\pi r^2 + 2\pi rh \;=\; 2\pi r^2 + 2\pi r\frac{V_R}{\pi r^2}$

If we set the $SA_R{}'$=0 and solve we get the optimal value for the radius and height to give the minimum surface area required to hold 8.4 m^3 of wastewater.

$SA_R{}' = 4\pi r \;- 2\frac{8.4}{r^2} = 0 \qquad\qquad \Rightarrow\; r \;\approx 1.1\; m$

$h = \frac{V_R}{\pi r^2} \;=\; \frac{8.4}{\pi\times0.8^2} \qquad\qquad \Rightarrow\; h \;\approx 2.2\;\; m$

$\Rightarrow\; SA_R \;\approx 22.8\; m^2$

Land Area

Using the value for radius calculated in the above section and assuming the UASB digester tank is cylindrical, we can calculate the land space requirement for use of a UASB digester.

$LA_R \;= Land\ area\ occupied\ by\ the\ UASB\ digester$

$LA_R \;= \pi r^2 \;\approx 3.8\; m^2$

COD and BOD Removal

The success of BOD and COD removal can be determined by dividing the amount removed over the initial amount present. These numbers are high which indicate a reliable treatment system.

BOD: $\frac{1050\ mg/L\ -\ 150\ mg/L}{1050\ mg/L} = 86\%$

COD: $\frac{3900\ mg/L\ -\ 300\ mg/L}{3900\ mg/L} = 92\%$

Phosphorus Removal

If raw wastestream levels of TP exceed 16.035 mg/L of phosphorus, the UASB must be equipped to lower these levels. Phosphorus accumulating organisms (PAOs) remove phosphorus by consuming organic materials. Assuming that there is a sufficient organic to phosphorus ratio in the initial wastewater stream and assuming that the treated wastewater contains DEC levels of BOD, PAOs can reduce TP to DEC regulations [59].

Treated BOD to TP Ratio: 30:1 Remaining TP: 150 mg/L BOD $\cdot\,(\frac{1\ part\ TP}{30\ parts\ BOD})$ = 5 mg/L TP

Exiting Upper level of BOD: 150 mg/L

Upper level of TP: 37.24 mg/L Final TP Percent removed: $\frac{37.24\ -\ 5}{37.24} = 86.6\%$

This final concentration of TP is well within DEC standards, although it relies very heavily on the treatment and availability of BOD.

Biogas Production:

Biogas production rates can be seen in Table 4 in Appendix B [19] as 0.47 m^3/kg COD removed. Earlier we estimated a COD removal rate of:

$\frac{3900\ mg/L\ -\ 300\ mg/L}{3900\ mg/L} = 92\%$

The mass of COD removed is 3900mg/L-300mg/L=3600mg/Lx4000L/day=14.4kg/day

Biogas production: $\frac{0.47\ m^3\ biogas}{kg\ COD\ removed} \times \frac{14.4\ kg\ COD\ removed}{day} \times \frac{365\ days}{year} = 2470.32\ m^3/yr$

According to AQPER [67], each cubic meter of biogas contains the equivalent of 6kWH of heat energy. According to BLS [68] the average price per kWh in New York is \$0.21/kWh

Price saved by biogas production per year= 2470.32 m^3/yr $\frac{2470\ m^3}{year} \times \frac{6kWh}{m^3\ biogas} \times \frac{\$0.21}{kWh} = approx.$ \$3112

Energy Calculations for Heating

Assumptions:

1. Sedimentation is a passive in this process, requiring no work or heat inputs
2. The UASB operates at an optimal temperature of 37 degrees celsius, aligning with our first order decay coefficient [40]
3. The rate of kinetic energy, potential energy and work are negligible because there is no acceleration, significant height change nor shaft or flow work in the system.
4. Assume 260 work days per year, with eight hours of operation per day [49], [4], [5].

Based on the above assumptions, the energy balance and its economic stipulations are calculated only for the UASB. In calculating the cost of operation, we model the UASB as an open system, where the rate of enthalpy is equal to the rate of heat flow, which is shown in Appendix E Table 6. Waste will be stored in an outdoor tank prior to treatment to ensure continuous flow during operation, and so the mass will be the same temperature as the outside air. Average seasonal temperature for upstate NY are provided in Appendix E Table 6, along with electricity costs [13]. To find the heat required to raise the wastewater to 37 degrees celsius, latent heat for the specific heat capacity of liquid water at constant pressure was used [23], then multiplied by the wastewater flow rate to obtain the rate of enthalpy, and therefore the rate of heat needed. Cost was found by multiplying the seasonal rate of heat values by their electricity costs and the hours of operation. The majority of operations occurring in the summer, fall and spring, creating an annual production cost of \$6,208.47.

$$\Delta\dot{H} + \Delta\dot{E}_k + \Delta\dot{E}_P = \dot{Q} - \dot{W}_S$$
$$\Delta\dot{H} = \dot{Q}$$
$$\Delta\dot{H} = \dot{m}\int_T^{37} c_p\, dT \text{ ; T = seasonal average temp, } \dot{m} = 500 \text{ kg/hr wastewater, } c_p = 75.4 \times 10^{-3} \frac{kJ}{mol\,{\circ}C}$$

Example Calculation: Winter

$$\Delta\dot{H} = \dot{m}\int_T^{37} c_p\, dT$$
$$= \left(\frac{500\ kg}{hr} \cdot \frac{1000g}{1\ kg} \cdot \frac{1\ mol}{18.01\ g\ H_2O}\right)\int_{-3.5}^{37} .0754\, dT$$
$$= 84{,}778\ \frac{kJ}{hr} = 23.6 \text{ kWh / hr}$$

$$\text{Seasonal Cost} = (\text{Utility cost}) \cdot \Delta\dot{H} \cdot (\text{Hours of Operation})$$
$$= (\$0.197/\text{kWh}) \cdot (23.6 \text{ kWh/hr}) \cdot (208 \text{ hr})$$
$$= \$967.03$$

The total annual cost of heating the system to the chosen operating temperature of 37 degrees celsius is \$6,208.47/year.

Average Seasonal Temperature and Electricity Cost for NY

Season	Average Temperature	$\Delta\dot{H}$	Utility Cost	Seasonal Hours	Seasonal Cost

Winter	-3.5 C°	23.6 kWh / hr	\$0.197 / kWh	208 hr	\$967.03
Spring	8.35 C°	16.67 kWh / hr	\$0.197/ kWh	624 hr	\$2,049.20
Summer	20.95 C°	9.34 kWh / hr	\$0.207/ kWh	624 hr	\$1,206.43
Fall	10.2 C°	15.6 kWh / hr	\$0.204 / kWh	624 hr	\$1,985.81

LAND AREA

The calculation for total land area is the rough estimate of how much land the brewery must have available in order to install our recommended wastewater treatment solution. Calculations for land area for each system were calculated in above sections. This calculation can only be seen as an approximation.

Assumptions:

1. Area required for piping installation is negligible and therefore can be left unaccounted for.
2. Each component within the system can be placed directly alongside one another
3. Material Volume and associated costs take precedent over land area requirement

Definition of variables

LA_S = *land area occupied by entire system*

LA_T = *land area occupied by holding tank* ≈ 2 m^2

LA_D = *land area occupied by sedimentation tank* ≈ 1.8 m^2

LA_R = *land area occupied by UASB digester* ≈ 3.8 m^2

$LA_S = LA_T + LA_D + LA_R = 2\ m^2 + 3.8\ m^2 + 1.8 m^2 = 7.4\ m^2$

COST ESTIMATE:

System Cost

The calculation of system cost is a rough estimate using approximate estimates given by the DEC's Advanced Notice of Proposed Permit [61], system calculations made above and commercially available tanks of similar size to volume calculated for each component in the system.

Yearly operating cost:

*We assumed brewers would not have to hire a wastewater operator given the simplicity of our design and experience with BOD and COD testing. It is not easy but can be done by untrained brewery staff members.

According to the Advanced Notice of Proposed permit [61] these costs can be expected for operation each year:

Costs associated with contemplated sampling – \$50-60 per week* 52 weeks/year ~ \$3,100/year

Energy usage cost calculated above: approximately \$6,200/yr

Cost saved from biogas production: \$3, 100/*yr*

<u>Total Operating cost per year:</u> Totals measured above - cost saved from biogas production:

\$3,100+\$6,200-\$3,100= approximately \$6,200/year

Upfront construction and permitting cost:

According to the Advanced Notice of Proposed Permit [61] these costs can be expected for operation each year:

Costs associated with certified inspector septic tank inspections – ~\$200

Cost of general permit fee- \$110 per year (this fee is set in statute)

Cost associated with PE evaluation of existing system – expected between \$500-1,500

Cost of holding tank - \$645 for a volume tank of ≈ 3.2 m^3 [69]

Cost of Insulation materials: Fiberglass insulation materials to be fasted on outside of reactor is roughly \$0.64-1.19 per square foot [70]. We chose \$1/ft^2 as a reference $= \frac{\$1}{ft^2} \times \frac{10.76\, ft^2}{m^2} \times 22.8\ m^3$ \$ = approximately \$250

Cost of UASB digester: \$1,550 for a volume of $\approx 8.4\ m^3$ [70]

Cost of Sedimentation Tank: in order to find a cost, a rough estimate was made of a tank volume of 1.7m^3 given an assumed height of 2m: \$380 [71].

Total upfront cost of wastewater treatment and permit acquisition=sum of bills listed above: \$200+\$110+\$1000+\$645+\$250+\$1550+\$380=approximately \$4100

Appendix C: Annotated Bibliography

1. Enitan, A.M., Adeyemo, J. "Estimation of Bio-Kinetic Coefficients of Brewery Wastewater." *International Journal of Environmental and Ecological Engineering* **8** (2014). https://publications.waset.org/9998485/pdf

This article investigates the efficiencies of BOD and COD removal from brewery waste using a UASB process and determines the reaction rate coefficients of the anaerobic bacteria. The authors found that removal efficiencies were very high for BOD and COD levels, but additional nitrogen was needed to ensure that COD:N:P ratios were sufficient for the bacteria to break down organics. The article also provided rate constants, which were vital to this report's calculations on UASB size and feasibility of application to NY breweries. The article also found that the rate constant is very dependent on the type of loading that the UASB receives, especially the ratio of COD:N:P. However, the design and methodology modeling of a full scale UASB was entirely reliant on a publication by Enitan et al, which required that our report investigate the additional article to corroborate the applicability of the rate constant to our brewery wastewater.

2. Cronin, C., Lo, K.V. "Anaerobic Treatment of Brewery Wastewater Using UASB Reactors Seeded with Activated Sludge." *Biosource Technology* **64** (1998). 33-38. https://reader.elsevier.com/reader/sd/pii/S0960852497001545?token=9E682DF1D0E6C062B1C276FC703A497B2A2A8B70FF2C39C866C0E32A13F9A0831D5386573A70A0A8E9A1CF28CD8DD8F7

This article reviewed the effluent from a brewery wastestream after it was treated with sedimentation and a minimized UASB. The sedimentation lowered locally obtained brewery waste to a constant COD level, so that efficiencies of COD removal due to UASB could be solely attributed to the UASB. The information regarding the sedimentation tank to remove suspended solids enabled our report to see the effectiveness of the physical treatment process on lowering levels of organics. Additionally, the report found that high levels of TSS can inhibit the efficiency of UASB, which encourages the use of sedimentation, or some other physical process, in order to optimize removal rates from brewery waste. The report also found that significant startup time was needed to the activated sludge in the UASB to become normalized and thus produce constant rates of nutrient concentrations in the effluent. The only information lacking in this report was the scale of the process. The article reviewed sedimentation followed by UASB on very small sized reactors of a height 168 cm and a diameter of 11.5 cm. The waste that our report focuses on would require UASB treatment on a greater scale.

3. Enitan, A.M., Kumari, S., Swalaja, F.M., Adeuemo J., Ramdhani N., Bux, F. "Kinetic modelling and characterization of microbial community present in a full scale UASB reactor treating brewery effluent." *Microbial Ecology* **67**, no. 2 (2014). 358-368. https://link.springer.com/article/10.1007%2Fs00248-013-0333-x

This publication analyzes the microbial community present in a UASB and the reaction rates of the bacteria to predict the removal efficiencies of nutrients present in brewery wastewater streams. The article finds that methanogenic bacteria are highly important in both the removal of organics and the production of biogas in the UASB, making the community an important predictor of whether UASB can treat certain influent loadings. This article was very useful in

providing information on the mechanisms of a full scale UASB and how the system can be used for brewery wastewater treatment. It also corroborated the effectiveness of UASBs in removing brewery contaminants. However, the article does not mention physical pretreatment, nor elaborate on TSS removal. Since these two components are very important to the DEC's permitting specifications, more literature review was required.

4. Fang, H.H.P,, Guohua, L. Jinfu, Z., Bute, C., Guowei, G. "Treatment of Brewery Effluent by UASB Process." *Journal of Environmental Engineering* **116**, no. 3 (1990). 454-460. https://ascelibrary.org/doi/pdf/10.1061/%28ASCE%290733-9372%281990%29116%3A3%28454%29

    This study analyzes the implementation of a UASB process on brewery waste. The findings include the efficiency of UASB in removing BOD, COD and TSS levels, while analyzing the mechanisms and operator responsibilities of keeping the UASB process reliable. Due to its specificity to our recommended treatment process, this article was very helpful in providing specific BOD, COD and TSS removal rates, which displayed that UASB are able to treat waste streams to effluent levels that would meet the DEC specified levels. It also provided vital schematics that furthered our understanding of how a UASB operates and treats waste, and highlighted the technology's applicability to upstate NY breweries. This article lacks information on how the sizing and loading may change the removal rates. The experiment also focuses on a brewery that produces 1,200 m^3 of waste per day, which is significantly larger than our waste water stream of 500 kg operating eight hours a day.

5. Mahmoud, N., Zeeman, G., Gijzen, H., Lettinga, G. "Solids removal in upflow anaerobic reactors, a review." *Bioresource Technology* **90** (2003). 1-9. https://core.ac.uk/download/pdf/86432378.pdf

    This article analyzes the mechanisms of UASBs and physical parameters that impact its effectiveness, including organic loading and temperature. As temperature increases, it optimizes the UASB performance due to the decreasing viscosity of waste influent. As organic loading increases, there is only a slight variation in the effluent levels, indicating that higher organic loading rates correlate with higher removal rates. This information provided was very useful for our report as it provided insight into how municipal verses brewery loading may change the efficiency rates of UASBs. This disadvantage to this article was lack of specifics in the range of loading: it provided a broad overview of scientific literature but did not provide any specific data to highlight its findings.

6. von Sperling, M., Freire, V.H., de Lemos Chernicharo, C.A. "Performance evaluation of a UASB - activated sludge system treating municipal wastewater." *Water Science and Technology* **43**, no. 11 (2001). 323- 328. https://pdfs.semanticscholar.org/f5fe/992f482ed7d503351a003c6f7449ce495103.pdf

    This article investigates the resulting effluent levels after applying a sequential anaerobic-aerobic treatment process for treating municipal solid waste. Waste undergoes physical treatment before entering the UASB, which is very similar to the process that this report proposes. The waste then undergoes activated sludge treatment, which is not applicable to the final recommendation of this report. The outcome of the treatment process was a reliable, lower maintenance waste treatment process, which met the standards of Belo Horizonte, Brazil effluent regulations. Additionally, though this article investigates municipal rather than brewery waste and uses a dual system rather than solely UASB, it still includes important details on the individual efficiency of UASB reactors. This was useful in determining whether UASB reactors can be applied to the wastewater streams of New York breweries based upon COD, BOD and TSS removal efficiencies. It also revealed the inner workings of UASB systems, as well as potential limitations suchs as failing to meet discharge levels. This article was missing brewery waste specific outcomes, and the specific causes of UASB effluent failures.

7. Sousa, V.P., Chernicharo, C.A.L.. "Innovative conception and performance evaluation of a compact on site treatment system." *Water Sci. Technol.*, **54**, no 2 (2006). 87-94. https://iwaponline.com/wst/article/54/2/87/12794/Innovative-conception-and-performance-evaluation

This article reviews the effectiveness of a compact, on-site treatment process for municipal solid waste. While the waste stream is not identical to that of a brewery waste stream, the high organic loading and scale of operations suggests that similar methods may be as effective in treating brewery waste. Additionally, the article provides important information regarding sedimentation tanks and their importance in reducing TSS and BOD before waste undergoes anaerobic treatment in a UASB. The mechanisms of this article's treatment process is very similar to that outlined in our report, making this article useful in learning more about sedimentation tanks. However, sedimentation tanks are not the main focus of the literature, requiring further literature investigation for their application in brewery waste treatment.

8. Amenorfenyo, D.K, Huang, X., Zhang, Y., Zeng, Q., Zhang, N. Ren, J., Huang, Q. "Microalgae Brewery Wastewater Treatment: Potentials, Benefits and the Challenge." *International Journal of Environmental Research and Public Health*, **16**, no. 11 (2010). **https://doi.org/10.3390/ijerph16111910**

This article discusses the potential of using algae in treating brewery waste, but also includes extensive literature review on the current, conventional brewery waste treatment industry. The authors found that brewery waste normally undergoes physical pretreatment if the brewery plans on discharging the waste to a municipal treatment center as to avoid fines and unnecessary transportation fees. This information was useful to our report as similar motivations surround NY breweries as they face impending DEC and municipal waste surcharges. Additionally, the study finds that sedimentation is a cheaper, commonly used physical pretreatment process for breweries, helping inform this report's recommended use of the technology. It also provides information on the benefits of equalized flow and constant loading by using an equalization tank, which is another portion of this report's recommended process. The disadvantage of this article is that its main focus is on how algae can be used as a biological treatment process, so the biological treatment process is different than the one this report recommends. Information still desired is finding the required treatment needed from a UASB following sedimentation.

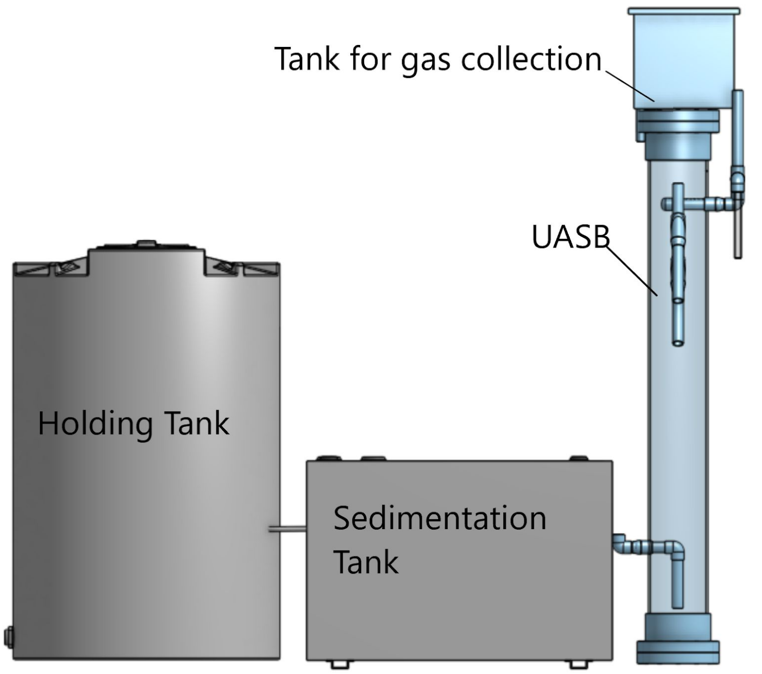
9. Jayanti, S., Narayanan, S. "Computational Study of Particle-Eddy Interaction in Sedimentation Tanks." *Journal of Environmental Engineering* **130**, no. 1 (2004). 37-49. https://ascelibrary.org/doi/pdf/10.1061/%28ASCE%290733-9372%282004%29130%3A1%2837%29

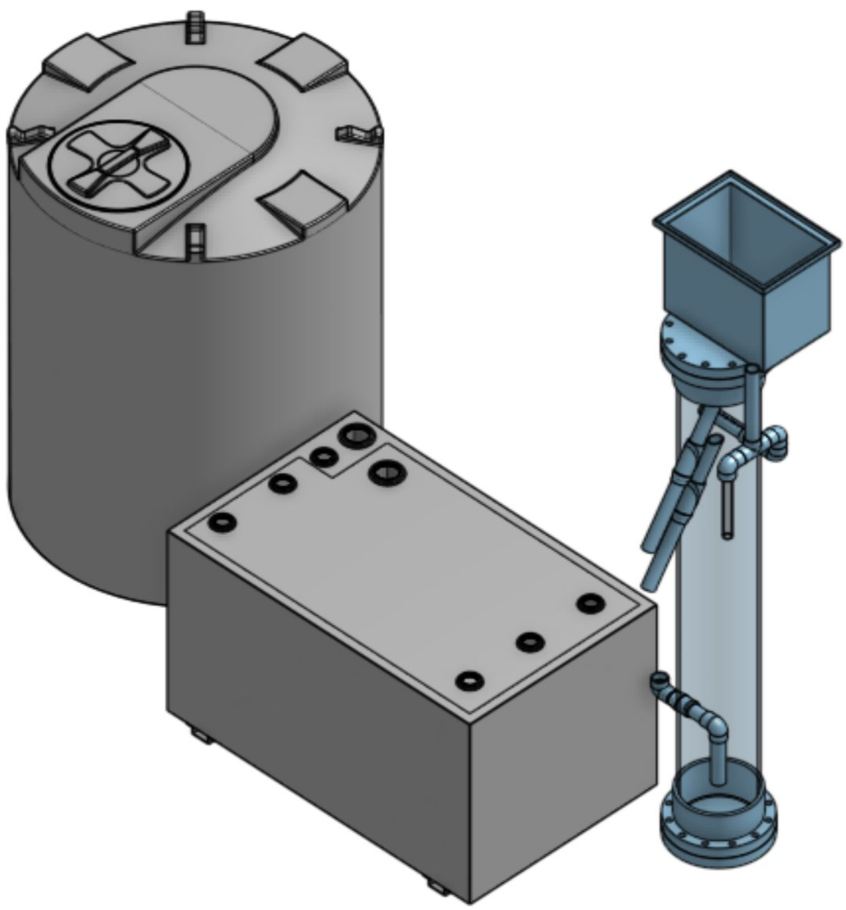
This report details when sedimentation tanks will be most effective in removing suspended particles. It focuses on Type I settling, which does not use chemicals to induce discrete settling. This is applicable to our proposed sedimentation processes because, due to the higher level of maintenance needed for chemical induced physical treatment, this report does not recommend chemically induced coagulation-flocculation. This article provides equations that predict at what flows particle settling will become optimized, which is useful in predicting the TSS removal of waste streams. Although this article focuses on sedimentation tanks to treat municipal waste, it includes a section detailing how hydraulic loading will affect how much and which particles will settle out. More information is needed on brewery specific sedimentation rates.

10. Olajire, A.A. "The brewing industry and environmental challenges." *Journal of Cleaner Production* (2012). 1-21. https://reader.elsevier.com/reader/sd/pii/S0959652612001369?token=2DB9584DD7C4FC7CFC07DE50F80DCD7D03627C1CE956AA8D8C3B93322E72B4698EBDB4BD7CFA83212A3F3C09DFF94732

This article provides an overview of common brewery wastewater treatment practices, including their benefits and limitations, as well as the availability of the technology. Included is a comprehensive review and comparison of physical pretreatments. It finds that spent yeast and the wort boiling process is one of the largest contributors to TSS levels in brewery waste, and that sedimentation and other physical treatments pose the most effective solutions in removing it. The article also highlights the importance of including an equalization tank to ensure consistent flow during the treatment process, as well as stabilizing the loading of the process. It also includes the benefits of UASB reactors, such as including the production of biogas and its potential as an energy source. However, this article lacks in depth information on the scale of current implementation of these processes, and how and when the limitations of these processes arise.

Appendix D: CAD System Design





Created in OnShape computer-aided design (CAD) software system

Appendix E: Tables and Figures

Table 1: Characteristics of Average Brewery Waste and DEC Desired Effluent [61]

Table I. Characteristics of Average Brewery Waste and DEC Desired Effluent

Waste Property	Average Brewery Wastewater Composition	Desired Wastewater Effluent
Total Soluble Solids (mg/L) (TSS)	500 - 2,000	100
Chemical Oxygen Demand (mg/L) (COD)	2,000 - 6,000	300
Biological Oxygen Demand (mg/L) (BOD)	500 - 1,500	150
Total Nitrogen (mg/L) (TN)	17 - 50	50
Total Phosphorus (mg/L) (TP)	5 - 40	15
Wastewater pH	4 - 6	6 - 9

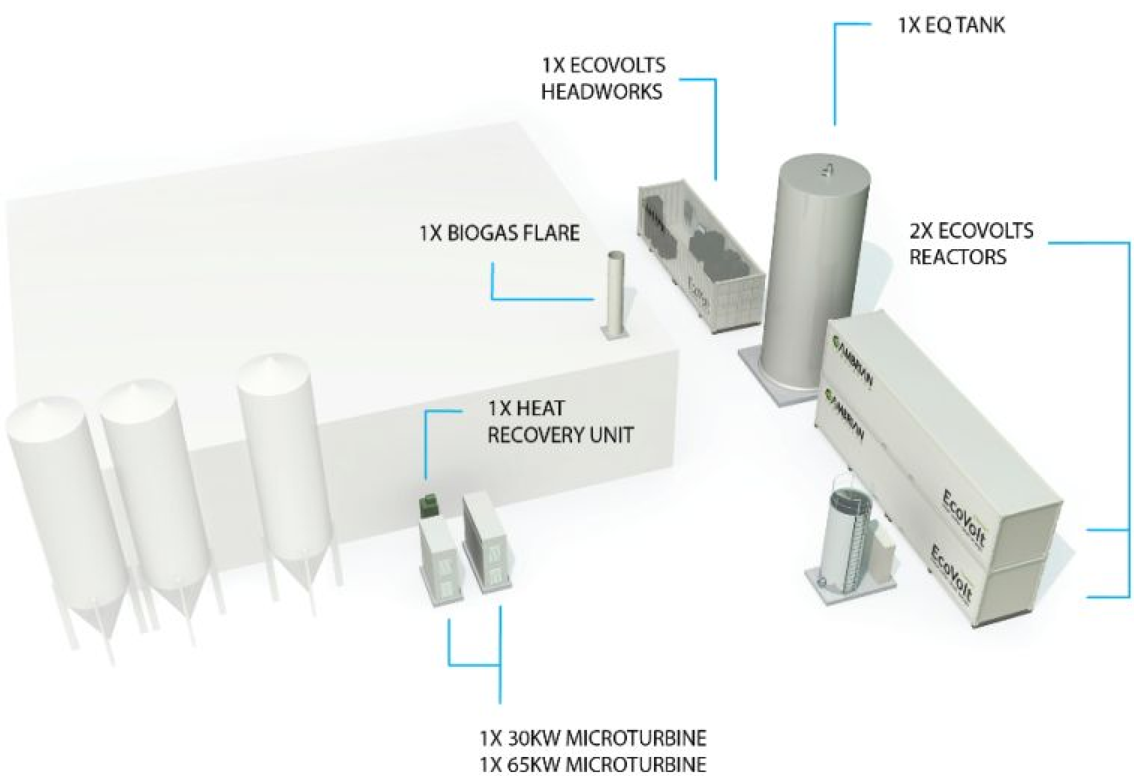


Figure 1: EcoVolt Reactor performance layout at Bear Republic Brewing Company [2].

Table 2: EcoVolt Reactor performance [20]

	EVR1	EVR2	EVR3
EcoVolt Reactor Process Volume (gal)	25,000	50,000	100,000
Average Flow (gal/day)	25,000	50,000	100,000
Maximum Daily Flow (gal/day)	50,000	100,000	200,000
Average BOD Treament (lb/day)	1,045	2,090	4,180
Maximum BOD Removal Efficiency	80%		
Dimensions, ø (ft) x H (ft)	15.4 x 20.95	21.5 x 20.95	41.6 x 20.95
Potential Biogas Generation (scfm)	11.5	23.0	46.0
Potential Biogas Energy Content (MMBTU/hr)	0.5	1.0	2.0

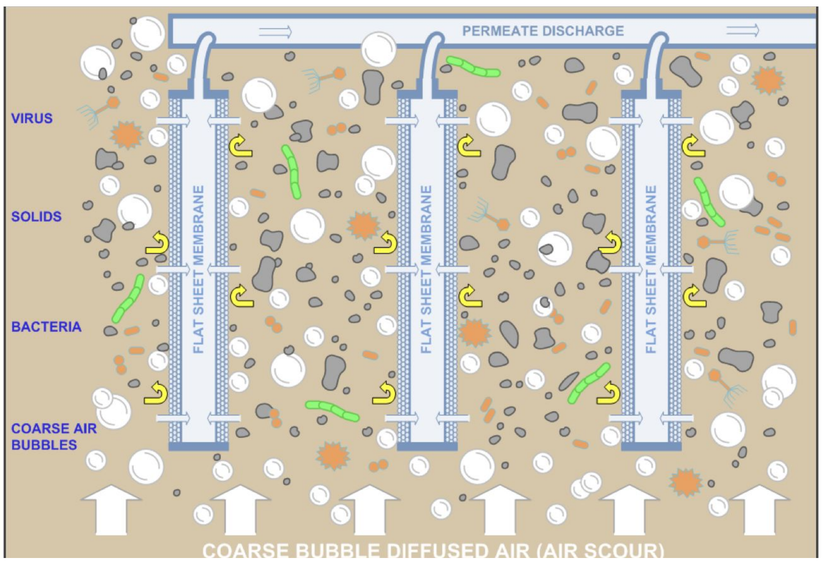


Figure 2. Outline of the ACWA Submerged MBR Process [3]

Table 3. ACWA Memtreat System Design Basis and Effluent Properties **[3]**.

Estimated Raw Waste Water Flows and loads			
Description	**Units**	**Average Value**	**Maximum Value**
Flow	m³/day	83	100
COD	mg/l	5,141	6,520
COD	kg/day	426	652
BOD	mg/l	2,368	3,400
BOD	kg/day	196	340
Suspended Solids	mg/l	1,017	3,220
pH (Typical)	-	4.0 – 6.0	7.0

Expected Grey Water Quality					
Description	**Units**	**Average Value**		**Maximum Value**	
		Required	**Actual**	Required	**Actual**
Flow	m³/day	83	**83**	100	**100**
COD	mg/l	1500	**<120**	2000	**<120**
BOD	mg/l	-	**<60**	-	**<60**
Suspended Solids	mg/l	-	**<10**	-	**<10**
pH (Typical)	-	6-10	**6-9**	6-10	**6-9**

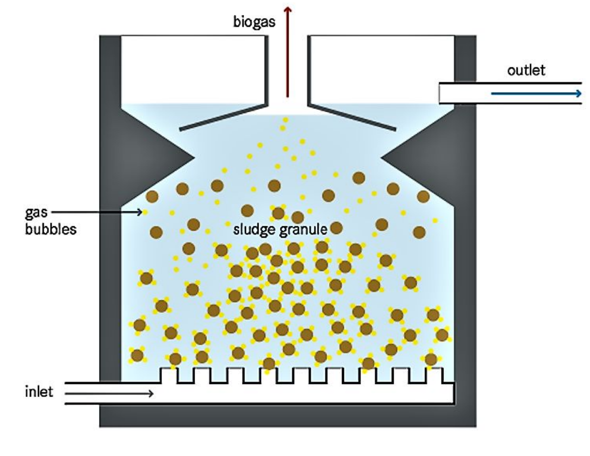


Figure 3: Example of UASB structure [47]

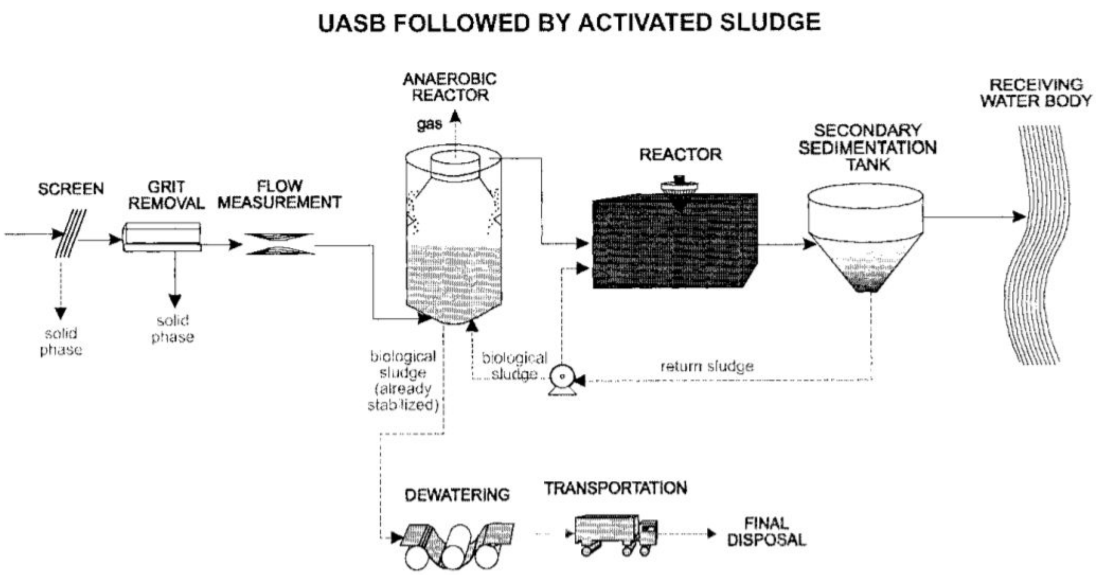


Figure 4: This diagram outlines a possible layout for a sequential anaerobic-aerobic treatment train (UASB-AS), where the solid arrows show the direction of water flow, and the dotted arrows show movement of sludge [54].

Table 4. Biogas and Sludge Production Rates for Grolsch Brewery [19]

Material	Production Rate per COD removed
Biogas (m^3/kg)	0.47
Excess Sludge (kg TS/kg)	<0.01

Table 5: Average Particle Size for Brewery Waste [46]

Particle Size, mm	Average Particle Content of Brewery Waste, %	Average Particle Content of Rapeseed Cake, %
4.75	0.05 [a]	0.39 [a]
3.35	0.08 [a]	1.84 [a]
2.36	0.58 [a]	6.08 [a,b,c]
1.6	3.87 [a,b]	11.69 [c,d]
1.18	14.51 [d,e]	12.66 [c,d]
0.85	28.52 [g]	13.92 [d,e]
0.6	22.21 [f,g]	15.2 [d,e]
0.425	11.49 [c,d]	19.56 [e,f]
0.3	9.11 [b,c,d]	14.12 [d,e]
0.212	4.69 [a,b]	3.73 [a,b]
0.15	3.05 [a,b]	0.54 [a]
0.1	1.75 [a]	0.29 [a]

[a,b,c,d,e,f,g] Mean values with identical letters do not differ statistically significantly at $p < 0.05$.

Table 6: Average Seasonal Temperature and Electricity Cost for NY (ref: Calculations Appendix)

Average Seasonal Temperature and Electricity Cost for NY

Season	Average Temperature	$\Delta\dot{H}$	Utility Cost	Seasonal Hours	Seasonal Cost
Winter	-3.5 C°	23.6 kWh / hr	\$0.197 / kWh	208 hr	\$967.03
Spring	8.35 C°	16.67 kWh / hr	\$0.197/ kWh	624 hr	\$2,049.20
Summer	20.95 C°	9.34 kWh / hr	\$0.207/ kWh	624 hr	\$1,206.43
Fall	10.2 C°	15.6 kWh / hr	\$0.204 / kWh	624 hr	\$1,985.81

Appendix F: Time Management

F.1: Expenditures and Justification

Expert Consulted	Date of Consultation	Time of Meeting	Cost of Meeting	Reason for Meeting
Professor Jillian Goldfarb	12/5/2019	30 min	Assumed no cost	Gain insight on the scope of the project and clarify considerations for the winery comparisons
Alex Roger Maag	12/12/2019	30 min	$150.00	Receive guidance on calculation procedures
Alex Roger Maag	12/16/2019	20 min	$100.00	Discuss assumptions for TSS calculations

Total Cost: $250.00
Total Budget: $500.00

BEE2510 Course Project

All consultations with 2510 staff were recorded and tracked to assure we did not exceed our project budget

Group 6-
Project Lead

This color reflects the days in which Task was completed.
This color reflects the days in which Task was aimed to be completed

Project Start: 11/18/2019
Display Week: 1

SIMPLE GANTT CHART by Vertex42.com
https://www.vertex42.com/ExcelTemplates/simple-gantt-chart.html

Nov 18, 2019 | Nov 25, 2019 | Dec 2, 2019 | Dec 9, 2019 | Dec 16, 2019

TASK	Justification for failure to meet predicted deadlines; Other relevant notes regarding N/A designation etc.	ASSIGNED TO	PROGRESS	START	END
Survey of Best Available Tech.			Emily Kyra Lydia Val		
Locate Technology, compile summary	---	Name		11/18/19	11/20/19
Meet as a group to discuss Methods/Tech	---	All Members		11/20/19	11/20/19
How does Technology work - engineering principles, theory, any particular	---	Task completed by each member for each technology		11/20/19	11/22/19
Advantages of the technology (economic, technical, environmental)	---	Task completed by each member for each technology		11/22/19	11/24/19
Limitations of the technology (economic, technical, environmental)	---	Task completed by each member for each technology		11/24/19	11/26/19
Current implementations of the technology (where/how is it used - at what scale?)	---	Task completed by each member for each technology		11/26/19	11/28/19
Summary of applicability to your waste stream	---	Task completed by each member for each technology		11/28/19	11/29/19
Meet to discuss Final recommendation	---	Task completed by each member for each technology		11/30/19	11/30/19
Comparison to Winery WWTP:			Emily Kyra Lydia Val		
Background research	it was determined after extensive reading that the simpler, more reliable method would be to reference Washingtons description of why they chose to create separate winery and brewery wastewater permits instead of comparing the two processes. This would reduce Report Size and uncertainty in comparing two similar yet asimilar processes. Therefore some of these sectins are described as N/A	Kyra		11/20/19	11/24/19
Analyze winery waste and process to treat it		Kyra		11/30/19	12/5/19
Compare to chosen brewery process		Kyra		12/5/19	12/8/19
Construct a visual for comparison		N/A		12/5/19	12/7/19
Double check that analysis is sensical		Lydia		12/5/19	12/8/19
Mass and Energy Balances			Emily Kyra Lydia Val		
Determine calculation plan	NOTE we were late on developing our final calculations plan as numerous consultations were required prior to start that had not been anticipated when designing Gantt Chart. This issue also lead to a delay in subsequent tasks. These delays are acceptible as potential conflicts could not be predicted before beginning work. In the future we will consider overestimating action item due dates in order to better meet requirements	Emily		11/26/19	11/26/19
Conduct calculations and create summary charts and tables		All (individually)		12/4/19	12/6/19
Analyze data and generate conclusions:		All (as a group)		12/7/19	12/8/19
Research regulatory standards		All (see effleunt and reg section)		11/25/19	11/30/19
Compare to standards and fact check calculations:		Emily		12/7/19	12/9/19
Effluent and Regulations: Cost, Land Area, Volumes and other metrics were added to calcualtions			Emily Kyra Lydia Val		

Note

BEE2510 Course Project

All consultations with 2510 staff were recorded and tracked to assure we did not exceed our project budget

Group 6-
Project Lead

SIMPLE GANTT CHART by Vertex42.com
https://www.vertex42.com/ExcelTemplates/simple-gantt-chart.html

Project Start: 11/18/2019
Display Week: 1

This color reflects the days in which Task was completed.
This color reflects the days in which Task was aimed to be completed

Nov 18, 2019 | Nov 25, 2019 | Dec 2, 2019 | Dec 9, 2019 | Dec 16, 2019

18 19 20 21 22 23 24 25 26 27 28 29 30 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

M T W T F S S M T W T F S S M T W T F S S M T W T F S S M T

TASK	Justification for failure to meet predicted deadlines; Other relevant notes regarding N/A designation etc.	ASSIGNED TO	PROGRESS	START	END
BOD, COD		Lydia		11/25/19	11/30/19
TSS, TDS (N/A)	TDS was determined to be N/A after conversation with Alex. Issues around TSS designation in project assigment were adressed with alex and he clarified mistake regarding Total Soluble Solids description as opposed to Total Suspended Solids. Aforementined issues encountered with calcualtions resulted in subsequent stalling fo these tasks	Kyra		11/25/19	11/30/19
Total Phosphorous: NOTE: The aforementioned issue with calcualtions stalled subsequent		Emily		11/25/19	11/30/19
Total Nitrogen		Emily		11/25/19	11/30/19
pH.		Val		11/25/19	11/30/19
Report Writing			Emily Kyra Lydia Val		
Rough Draft 1		All		12/10/19	12/13/19
Abstract		Lydia		11/30/19	12/9/19
Problem Scope		Kyra		11/30/19	12/9/19
Design Requirements	NOTE: references fail to be in alphabetical order. This was caused by time constraints associated with finals and the time required of renubering all 65 references within the text body inorder to attain alphabetical citation. In the futrue we will refrain from numbering until just before submittal	Val		11/30/19	12/9/19
Proposed Process (11/30)		All		11/30/19	11/30/19
Regulatory Implications		Emily		12/10/19	12/13/19
References		All		12/13/19	12/13/19
Title		All		12/10/19	12/13/19
Peer Review		All		12/13/19	12/13/19
Revise and Edit Report		All		12/14/19	12/15/19
Proofread Report		All		12/16/19	12/16/19
Submit Report		Lydia		12/16/19	12/16/19
Professional Development Lectures	---		Emily Kyra Lydia Val		
Project and Task Management	---	Kyra, Emily		11/19/19	RRB B15
Crash Course on Tech Report Writing	---	Lydia		11/20/19	RRB B15
Communicating Data and Calculations	---	Val		11/21/19	RRB B15