2018-2019

FINAL REPORT

UniverCity Year

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Lowering phosphorus levels in Browntown

CIVIL ENGINEERING 421: ENVIRONMENTAL SUSTAINABILITY ENGINEERING

UNIVERCITY YEAR

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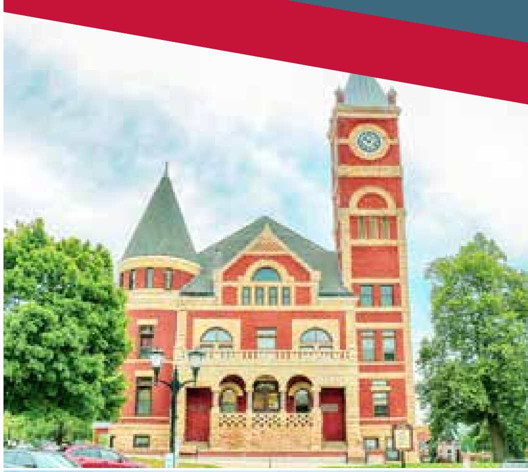

UniverCity Alliance

UNIVERSITY OF WISCONSIN–MADISON

Group Members	Contribution
REDACTED	Chemical Treatment, Professional contact liaison, Final Recommendation, Intro, Images and Tables
REDACTED	Algae Treatment, Final Revisions, Executive Summary, Methods
REDACTED	Variances, Video Editing, Paper Formatting, Executive Summary, Methods Analysis

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LIST OF ACRONYMS

mg/L	–	Milligrams per Liter
pH	–	-log (hydrogen ion concentration)
WPDES	–	Wisconsin Pollutant Discharge Elimination System
BOD	–	Biochemical Oxygen Demand
BOD5	–	The 5-day Biochemical Oxygen Demand, or BOD5, is Water Quality Parameter
mL	–	Milliliter
WDNR	–	Wisconsin Department of Natural Resources
TP	–	Total Phosphorus

1.0 Executive Summary

The WI DNR has changed legislation regarding phosphorus levels in municipal wastewater. The change, lowering standards from 4.8 mg/L to 0.075mg/L, created noncompliance issues for the Browntown, WI municipal wastewater treatment facility. The system operator, Rob, has emphasized that any changes to the system must comply with the city's public budget of $270,000 (for all divisions). Rob made a previous attempt to lower the effluent phosphorus level to 1.0 mg/L, an intermediate level set by the WDNR. 0.75 gallons alum over three days were applied at the start of this trial period and after failure to achieve 1mg/L, dosage was increase to 0.75 gallons each day, which still failed to reach target levels. The goal of this project was to examine the chemical treatment trial for possible errors, investigate alternative methods for lowering effluent phosphorus levels, and review WDNR variances which could provide relief from the economic difficulty of achieving 0.075 mg/L phosphorus in effluent wastewater.

Throughout the analysis of methods, the three paradigms of sustainability – environmental, social and economic - were utilized to assess each method's potential impact. The scope of our project considers phosphorus level in the effluent the most important environmental impact factor. High levels of phosphorous in effluent can cause eutrophication in the receiving waters. The economic impact of each method was considered in the context of potential excess cost that would fall on the public budget and down the line, the citizens of Browntown. A new system may cut into Browntown's already tight public budget, and again could increase tensions in the community. These primary ideals were used to assess and analyze the proposed solutions.

The first possible solution considered for solving Browntown's noncompliance, was applying for a variance which allows Browntown's wastewater effluent phosphorus levels to exceed.075 mg/L indefinitely or for a limited time until a new solution is found. An MDV has the ability to do just this, however, Browntown did not meet the requirements for the application. The job density of Browntown is 26 jobs per square mile but be eligible for an MDV, this number must be greater than 50. The other variance analyzed was an IEV - similar to an MDV, except, instead of requiring multiple discharge point sources, one facility is acceptable. An IEV requires that the annual household sewerage costs are greater than 2% of the median household income. Browntown does meet the criteria for this variance as long as the proposed project causes a household price increase of 2% of the median household income.

Chemical testing was re-evaluated through bench test with alum and ferric chloride. Using samples from the Browntown wastewater treatment plant, specific doses of each coagulant were tested to get a sense of achievable limits with chemical treatments. The lowest level of phosphorus our tests achieved was 1mg/L using 391 mg of alum per liter of water. While this level does not meet the DNR standards, it is lower than the levels Rob previously achieved testing alum. The reason for not reaching the predicted stoichiometric value of .075 mg/L phosphorus in the bench test could be caused by a higher total suspended solids value remaining in the sample fluid or inaccurate Hach TP test kit sampling. The difference in effectiveness between our bench test and Rob's trial could be due to interactions of the coagulant with activated sludge, which is present in the wastewater system but was not present in our jars. The capital cost of chemical treatment is also estimated to be $264,960 and annual cost is estimated to be $26,015, a large portion of Browntown's budget. Social skepticism is expected since the previous trials of alum failed. However, after our lab analysis and discussion with professionals familiar with wastewater facilities, we are confident that alum treatment can work under the right conditions and doses

Algae treatment is an increasingly popular method for removal of excess nutrients in wastewater. Algae can uptake phosphorus and be harvested for useful byproducts. Harvesting the algae removes phosphorus from the system. Introducing algae to the system would require a large amount landscaping and construction resulting in an estimated capital cost of $813,448 – a cost that would likely require outside funding. Harvesting algae does supply some income via the byproducts that can be sold. However, the operations of an algae cultivation facility in conjunction with the wastewater treatment facility would still have a net annual cost of $10,322. Browntown may be able to receive funding to operate this type of facility by applying for government grants or may be required to pay for it out of its public budget. Growing algae in wastewater previously reduced phosphorus levels by as much as 85%, and lab tests have shown that algae can reduce phosphorus levels to as little as $6.8*10^{-8}$ mg/L when grown in the right conditions. This fact has positive implications for Browntown's ability to be compliant with the DNR's new standard. Social issues may be expected if large scale landscaping and construction are necessary to accommodate an algae facility, and if the annual cost is passed on to members of the Browntown community. However, algae byproduct recycling can provide a new source of income and support environmentally and economically sustainable practices, which may be favored by community members.

After carefully analyzing the results of the proposed methods it was decided that algae cultivation for phosphorus uptake doubled with applying for an individual economic variance (IEV) will be the best recommendation to lower the phosphorus level in Browntown's wastewater effluent. Algae cultivation in wastewater for treatment was chosen because it demonstrates the most effective method for removing phosphorus; it can lower phosphorus in wastewater by approximately 85%, however laboratory analysis shows potential to lower phosphorus levels to as little as 6.8 * 10^-8 mg/L. Also, algae produces byproducts that can be repurposed in fertilizers, food additives and biodiesel production creating revenue for the Browntown municipality and offsetting operation and maintenance costs. Socially, algae is favorable over chemical treatment. Community members of Browntown displayed resistance to chemical treatment because of a previously failed chemical treatment using alum attempt guided by Delta 3 Engineering. Additionally, Browntown should apply for an IEV. An IEV will give the municipality of Browntown time to plan and implement an algae treatment system by extending their current phosphorus limit time period within the applied WDPES term rather than immediate adoption of the new 0.075 mg/L. This provides relief for the community of Browntown to reach WDNR phosphorus wastewater effluent concentration levels.

2.0 INTRODUCTION:

Browntown is a small village in Green County, Wisconsin with a population of around 280 people spread across 120 households. The municipal wastewater treatment facility is a two-cell aerated lagoon system. Lagoon systems are especially popular in small rural communities because enough land is available, and they are relatively inexpensive to construct, operate, and maintain (University). An initial site visit to Browntown's lagoon system took place on September 28, 2018. During this visit, Rob Radz, a local farmer and the operator of the treatment facility, explained the specific logistics of Browntown's lagoon, and elaborated on current and future monitoring techniques and effluent parameters rrequired by the Wisconsin DNR. The lagoon system in Browntown is made up of two aerated lagoons that have an

18-inch clay liner to prevent leaching from the ponds into surrounding soil. Both lagoons are also surrounded by tall grasses to prevent erosion and surface runoff from entering, which can be seen in figure 1.

Figure 1. One of the aerated lagoons at Browntown, WI. Picture taken during the initial site visit.

The first lagoon has four aerators and the second lagoon has two aerators, which run 24 hours per day. These aerators are powered by two three horsepower blower motors located in a building off to the side of the lagoons (R. Radz, personal communication, Sept. 28, 2018). The blower's alternate being used one at a time. The settling time (i.e. the time it takes for the wastewater to move through lagoon two) is about 66 days (A. Dutcher, personal communication Nov. 28, 2018). After the water exits lagoon two it enters a small chlorine treatment tank. Chlorine is pumped in from a small, nearby shed where sodium bisulfate is added to remove the chlorine (R. Radz, personal communication, Sept. 28, 2018). The treated effluent is then discharged before entering Skinner Creek

The Browntown lagoon system has a WPDES permit to discharge the treated effluent water to Skinner Creek, which was effective July 1, 2013 through June 30, 2018. This permit requires monitoring of flow, BOD, total suspended solids, nitrogen and ammonia, total residual chlorine, fecal coliform, pH, and phosphorus. The DNR monitoring requirements, effluent limits, and sampling frequency are adapted from the WDPES permit provided to the project by Rob Radz and summarized in Table 1.

Table 1. Current water quality measurements and limits for Browntown, WI before new permit changes enacted

Parameter	Limit Type	Limit	Sample Frequency
Flow	No Limit, flow is built by design	0.015 MGD	Continuous
BOD5	Monthly avg.	30 mg/L	Weekly
BOD5	Weekly avg.	45 mg/L	Weekly
Total Suspended Solids	Monthly avg.	60 mg/L	Weekly
Nitrogen, Ammonia Variable limit	Using daily pH, look up daily max variable ammonia limit from the pH dependent table	mg/L	Weekly
Nitrogen, Ammonia	Report daily max ammonia result and compare to daily max variable limit determined above	mg/L	Weekly
Total Residual Chlorine	Daily Max	38 µg/L	Daily (May 1 through Sep 30)
Fecal Coliform	Daily Max	400 #/100 mL	Weekly (May 1 through Sep 30)
pH	Daily Min - Max	6.0 - 9.0	Daily
Phosphorus	Monthly Avg.	4.8 mg/L	Weekly

According to records, the effluent Phosphorus discharge has always been below the previously required DNR limits of 4.8 mg/L. However, a change to the WPDES permit regarding phosphorus limits has occurred. The new effluent phosphorus limit will be 0.075 mg/L Starting on June 30th, 2022. Documentation must be submitted to the WDNR proving that there are plans in place to meet this change before June 30th, 2022.

Figure 2 depicts average monthly phosphorus levels from 2016 through 2018. This graph shows that Browntown's lagoon system has not achieved results low enough to be in compliance with the new limit. Clearly, a change to the system must be made. With help from the WDNR, Rob attempted to use Aluminum Sulfate (Alum) to decrease phosphorus levels based on a plan developed by Delta 3 Engineering, Inc. out of Platteville, WI. Alum was pumped into a small manhole located between the two lagoons so that it was added to the water moving from lagoon one to lagoon two. According to instructions given by Delta 3 Engineering, Rob was adding 0.75 gallons of alum per day to start and 1.5 gallons per day by the end. Rob says that the addition of alum to the system caused phosphorus levels to increase and is confirmed in a report from Delta 3 Engineering (Engineering, D. 3., 2017). More work will need to be done to understand what caused the alum to fail in this system.

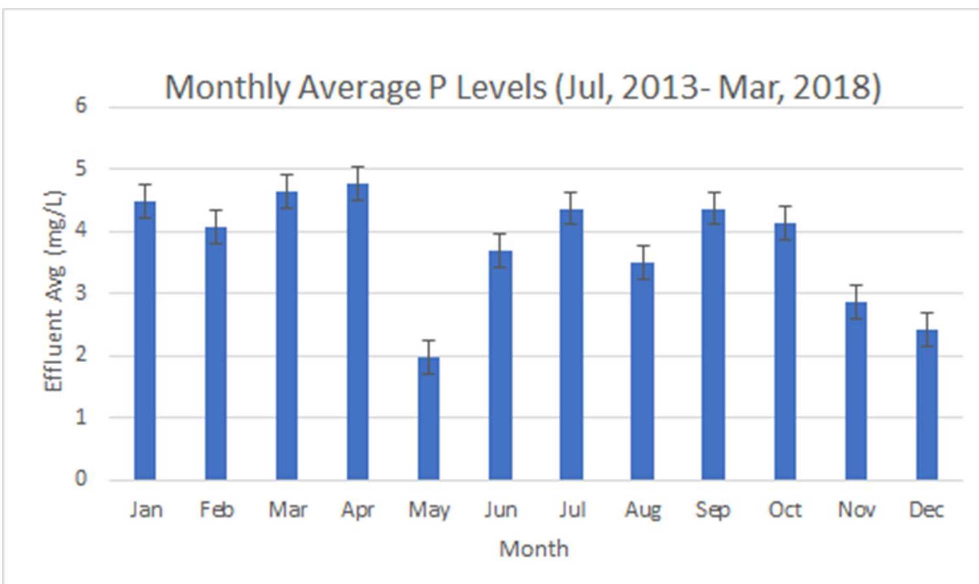


Figure 2. Monthly Average Phosphorus levels of Browntown, WI. Data adapted from Browntown wastewater records provided by WDNR contact Nathan Wells.

3.0 QUESTION:

The main purpose of this project is to find a way to upgrade Browntown's existing lagoon system to be in compliance with the WDNR's new effluent phosphorus limit in the most inexpensive way possible. This project is intended to encompass all three paradigms of sustainability when creating and assessing methods to address the problem. The way this project encompasses all three paradigms are as follows:

3.1 Environmental:

Too much phosphorus from human activity entering waterways leads to unnatural algal blooms and eutrophication in freshwater lakes (Nutrient Pollution: The Problem, 2017). The nature of the Mississippi basin combined with runoff from agricultural and wastewate effluent discharging into it also play a role in increasing the size of the hypoxic zone in the Gulf coast (EPA, 2017). Every community, no matter the size, contributes to the total issue at hand. These environmental impacts need to be considered when analyzing Browntown's discharge of treated wastewater into Skinner Creek.

3.2 Social:

Browntown is a predominantly farming community (R. Radz, personal communication, Sept. 28, 2018). Phosphorus limits are a sensitive topic with farmers because there is an idea that farms are a major contributor to pollution causing eutrophication. Also, it is frustrating for the wastewater treatment plant to have to achieve such low limits when working with a simplistic treatment system and limited budget. Government intervention and regulation affecting the community's everyday lives can be a controversial issue in the States. When government officials enter a community and demand lower contaminant limits, it puts a strain on most residents who do not favor government regulation. It is important that the severity of phosphorus pollution is understood by the community but addressed in a way that will not place undue stress on them.

3.3 Economic:

Many of Browntown's residents are retired and qualify as low-income families (R. Radz, personal communication, Sept. 28, 2018). The town's entire public works budget for the year is roughly \$270,000, with \$75,000 dedicated to wastewater treatment (R. Radz, personal communication, Sept. 28, 2018). An inexpensive alteration or addition to the current system is ideal for the circumstances in Browntown. Understandably, a solution could be met with resistance from community members as well. The lack of expert operators for a complex system is also a factor to be considered because there is no extra money to draw individuals to the town, and certainly not enough to build a complex facility to handle the issue with current large-scale treatment methods.

3.4 Project Scope:

The methods that will be used to address the Phosphorus effluent concentration problem are discussed in the following section. To apply these methods, the Browntown wastewater facility's second aeration basin will be the system boundary. Figure 3 is a simplified aerial view of the aeration basins and delineate, in red, the boundaries used in the analysis.

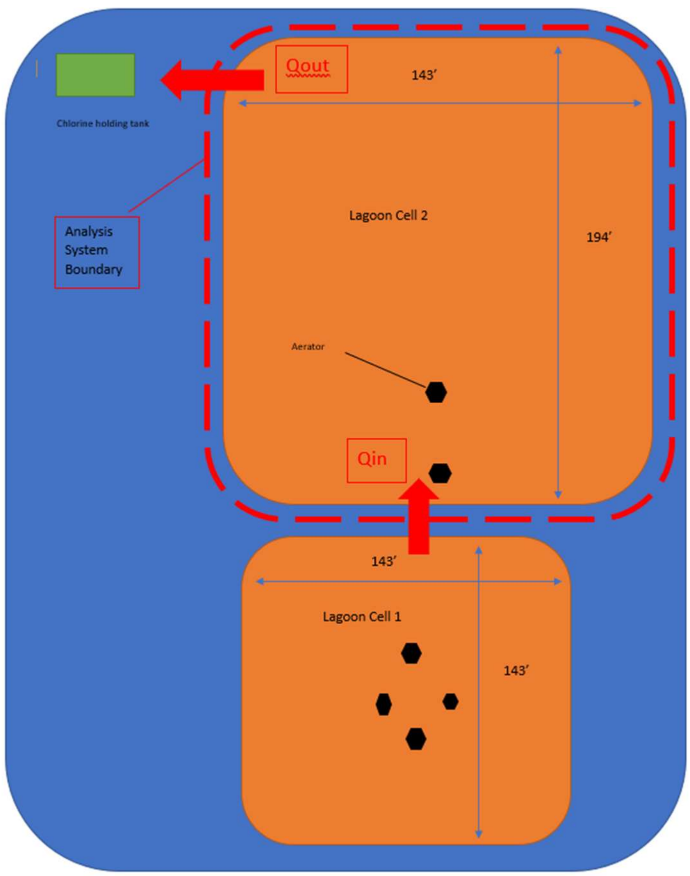


Figure 3. Browntown's two cell lagoon system

Some general assumptions made for this project are as follows:

1. Only Total Phosphorus (TP) levels is an environmental concern.
2. Aeration basin two will be modeled as a completely mixed flow reactor
    a. This implies that the concentration of Phosphorus in the system is uniform, and any added chemicals will be uniformly distributed in the system.
3. Flow in the system is 0.015 MGD
4. For economic analysis, a 20-year loan payment plan with a discount rate of 3% will be used. This is based of Delta 3 Engineering, Inc., analysis of the Browntown compliance plans done in 2017 (Delta 3 Engineering, Inc., 2017).

Other assumptions made for specific sections will be noted at the beginning of them.

4.0 METHODS:

The issue of reducing Browntown effluent wastewater phosphorus levels to 0.075 mg/L or less requires innovative solutions to meet the three factors of the sustainability paradigm. The following methods are in consideration for fixing the issue: compliance variance options, chemical treatment, and algae cultivation for nutrient uptake.

4.1 Compliance Variance:

Chapter NR 217.19 - Variances for stabilization ponds and lagoon systems - in the Wisconsin DNR's policy on wastewater phosphorus levels from lagoon systems could alleviate pressure on the community. There are two variances directly applicable to phosphorus levels in wastewater effluent. Individual Economic Variance (IEV) states that if there is a social or economic burden on a community in pursuit of reducing effluent phosphorus levels, this variance can be applied for. Again, the municipality budget for all of Browntown is $270,000 and this would indeed create an economic hardship, and thus an IEV will be assessed.

The other possible variance is the Multi-Discharger Variance (MDV), it states, "An owner or operator of a permitted wastewater treatment system that consists primarily of a stabilization pond system or a lagoon system may apply for a variance to the phosphorus water quality based effluent limitations pursuant to s. 283.15 (4) (a) 1. f., Stats., using the procedures in this section." The rest of the section then details how a community can receive permission for variance in effluent concentration limits because of the difficulty to reach below 1 mg/L in lagoon systems. The specific legal implications of this section may provide a solution to the compliance issue. If variance is permitted, exploring alternatives to lower effluent phosphorus levels may be desired in anticipation of legislation changes in the future, and to lessen environmental impacts.

3.2 Chemical Treatment:

The limited public works budget for Browntown means that focus will be directed on determining effective and cheap treatments. Therefore, different methods of chemical treatment with Alum or other metal salt coagulants like Ferric Chloride are under consideration. Chemical treatment is the cheapest and least intrusive alternative. It is a widely used treatment plan across wastewater systems of varying size and location around the world for lowering phosphorus and removing particulates (US EPA, 2011). The operator, Rob, is skeptical of chemical treatment because his previous Alum treatment attempt proved unsuccessful. Analysis of chemical treatment with Alum or Ferric Chloride will involve verifying its effectiveness and proposing reconsideration from Rob through possible jar test experiments (Reynolds & Richards, 1996). Samples from the second aeration basin will be taken to conduct the chemical precipitation experiment. The Total Phosphorus (TP) concentration in mg/L and pH of the wastewater are the parameters of interest for the experiment. If economically feasible, a basin where wastewater can be treated before chlorination will be proposed for enhanced mixing and removal of sludge and solids. An economic analysis and required chemical dosing will be created for both Alum and Ferric Chloride options. Costs for the chemical coagulants will be taken from the Hydrite Chemical Company in Cottage Grove, WI. This is where the University of Wisconsin water lab orders their chemicals from, however the distribution for Southern Wisconsin was contacted to acquire pricing to ensure chemicals costs would be accurate. To adequately ensure that technical expertise is included in the decision-making process, industry engineers, University professors, and DNR representatives will be contacted to review the problem.

4.3 Algae Cultivation for Nutrient Uptake:

Algae use in wastewater treatment has been under investigation and in some areas used effectively over approximately the last 75 years (Pittman et al., 2010). Recent innovations in the context of commercial algae production shed a promising light on cultivating algae for wastewater treatment (Abdel-Raouf et al., 2012). Algae is a desirable co-product because it can offer useful byproducts such as lipids for biodiesel production, nutrients for fertilizer creation and derivatives for food products (Goswami et al., 2015) Thus, harvesting algae can provide a profit source to offset the capital and manufacturing costs of the treatment system that houses the algae. In order to analyze the sustainability of algae as a treatment method, the economic, environmental and social aspects must be analyzed. In relation to the system, these will be analyzed with a central focus around phosphorus removal from the lagoon system. To analyze these specifically, factors that will be considered are capital cost, operations cost, algae product benefits, equipment space requirements and finally, effectiveness of phosphorus removal.

5.0 METHOD ANALYSIS:

The criteria that will be used to assess each proposed solution based on economic, social, and environmental considerations are discussed below:

Economic – The cost of each system will be assessed by a cash flow analysis. The cash flow analysis will include the capital cost for each system, as well as the expected yearly Operation and Maintenance (O&M) costs. The timescale for the economic impact will be based off of a 20-year project financing scheme and use a 3% interest, which is based on the valuation done by Delta 3 for previous alum treatment.

Social - After initial site visits and discussion with the operator, it is apparent that there are possible social opinions that may affect the viability of methods that have been proposed. Since, Rob Radz is the main point of contact and the representative of the wastewater treatment facility, his opinion will serve as basis for social considerations. The exact opinions of the operator will be discussed in the results of analysis sections. This report can serve as a basis for further discussion of options available for the town to reduce the effluent Phosphorus concentration.

Environmental - The environmental impact of each solution will be considered by determining the amount of Total Phosphorus (TP) each system can remove. This will allow a comparison of the final level of TP to the effluent limit of 0.075 mg/L. Any amount of Phosphorus over this limit will be considered a negative environmental impact and solutions that achieve the greater removal will be considered optimal in terms of environmental consideration.

6.0 RESULTS:

6.1 **Variance Analysis Results**:

The WDNR outlines an economic criterion for communities applying for a variance in based upon their ability to fund a project for reducing phosphorus effluent in wastewater. If the total household annual cost for sewerage pollution control is more than 2% of the median household income (MHI), then Browntown is permitted a variance (Wisconsin Department of Natural Resources, 2018). An analysis done by Delta 3 Engineering shows the MHI is $52,143; 2% of this would be $1042.86 (Delta 3 Engineering, Inc., 2017). The annual cost for each household was calculated to be $1056.6 for the previous chemical addition project, which is 2.03% of the HMI (Delta 3 Engineering, Inc., 2017). The project consisted of adding the chemical SorbeX RE-300 with a polymer to the second cell in the lagoon system (Delta 3 Engineering, 2017). Moreover, Browntown should pursue an IEV as a solution to not having sufficient funds to reach the WDNR's effluent phosphorus level.

Not having to pay noncompliance fines is a social benefit for the Browntown, as community members would not be disgruntled over increased sewerage bills. The residents may be alleviated of any ill will towards government regulations and interference in their everyday lives. Environmental benefits that would result via this route are none. The phosphorus effluent levels would remain the same and continue to contribute to water pollution, therefore this option has negative consequences for the environment.

An MDV is another option for Wisconsin counties if they do not have a feasible means of reaching an effluent level detailed by the WDNR. Browntown would not be able to apply for an MDV to curtail the funding for a project that would reduce the phosphorus levels. Delta 3 Engineering assessed this option and summarized it as such, "...the Village of Browntown is located in Green County which has a secondary score of '1'.... Municipal WWTF's Secondary Indicators from MDV Implementation Guidance.... Since the secondary indicator score is less than '2,' the Village not eligible for the MDV" (Delta 3 Engineering, 2017). The criteria that Browntown failed to meet making them ineligible for MDV is the "jobs per square mile less than 50" category (Delta 3 Engineering, 2017). Browntown fails to exceed 50 jobs per square mile (they have only 26). Further assessment of the paradigms of sustainability is not necessary for this option because it is not applicable to Browntown.

6.2 Chemical Treatment Results:

As stated previously, to prove the effectiveness of chemical addition for removing Phosphorus from the Browntown wastewater, a series of jar tests was performed. The assumptions made during the experiment and the procedure used are outlined below.

Assumptions –

1. pH changes were not considered during the testing because after discussion with Andrew Dutcher, the WDNR plan reviewer, it was determined that significant pH drop using chemical treatment has not been noted as a problem in Wisconsin systems. However, this should be assessed in more detailed future analyses.
2. Only Total Suspended Solids (TSS) and soluble P are considered because these are the major factors of concern in wastewater Phosphorus concentration (D. Noguera, personal communication, Nov. 13, 2018).
    a. TSS values in the wastewater are based off of WDNR records for Browntown and not gathered during the experiment because no turbidimeter to test the samples was available.
3. Assume costs are based on bulk chemicals purchased from Hydrite Chemical Company from Cottage Grove, WI.
4. Water for testing was withdrawn from the pipe leading to the chlorination tank. Assumed it is identical to water in aeration basin two.
5. The hydraulic retention time for the second aeration basin is 66 days. This information was provided by Andrew Dutcher, a DNR plan reviewer familiar with the Browntown facility.
6. A ratio of 4.5 and 9 mols of Ferric Chloride to mols of Phosphorus was used to determine initial dosing (Neethling, 2013), (Rehr, 2005).
7. A ratio of 4 and 8 mols of Alum to mols of Phosphorus was used to determine initial dosing (Neethling, 2013), (Rehr, 2005).
8. Sludge production and subsequent removal was not considered in this analysis.

Jar Test and Total Phosphorus Procedure – Experiment done on 11/19/2018

The TP levels of the samples were determined using the *Total Phosphorus Analysis* procedure provided by UW-Madison laboratory manager Jackie Bastyr Cooper. The testing makes use of the Hach Total Phosphorus Low Range Testing kit. The kit uses a photometric analysis. Chemical reagents are added to the wastewater samples, then mixed and heated, which prompts a color change associated with the level of TP in the sample. A Spec20 spectrophotometer calibrated to 890nm wavelength was used. This wavelength corresponds with the color change induced in the sample by the testing kit. Essentially, the greater the TP level in the sample, the darker the color, which will be output by the Spec20 as an absorbance value. This is directly related to concentration of TP, shown in the calibration curve in figure 3.

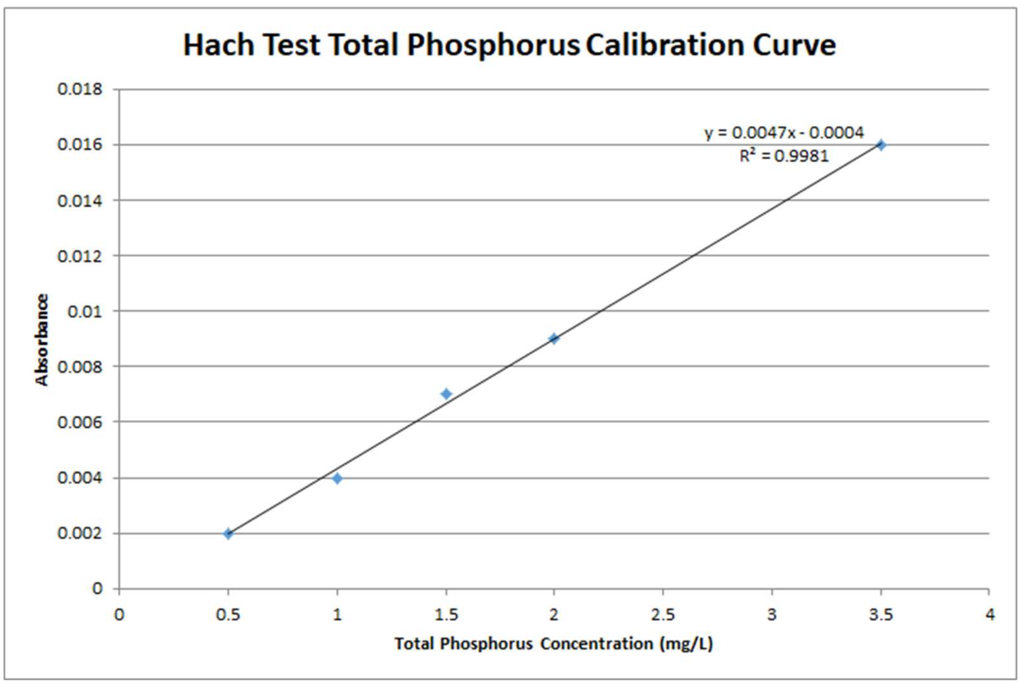


Figure 4. Calibration curve for total Phosphorus levels produced during the jar test experiment.

The average value of TP was determined using Phosphorus effluent data acquired from the DNR for the dates July 2013-September 2018 (N. Wells, personal communication, Nov. 13, 2018). The average value was found to be ~4.42 mg/L of TP. One-liter jar tests were used in this experiment, which places the experimental mass of P in the system at 4.42 mg. Using the molar ratios taken from literature, doses used were 174mg and 348 mg for Ferric Chloride and 196mg and 391mg for Alum.

It is common practice in both drinking water and wastewater treatment systems to perform mini-scale reactor experiments - jar tests - when adding new chemicals or substances to the system (Reynolds & Richards, 1996). This allows for observations to be done on similar water, but at smaller scales (Reynolds & Richards, 1996). Specifically, for chemical treatment, the molar ratios stated above are rules of thumb for precipitation of Phosphorus when using chemicals like Alum or Ferric Chloride, but optimal doses must be experimentally determined for each specific reactor system (Neethling, 2013) (Rehr, 2005). Therefore, to understand the performance of chemical precipitation in the Browntown wastewater system, two jar tests for Alum and Ferric Chloride were performed following an adapted procedure based on the University of Wisconsin-Madison Environmental Engineering Processes (CEE 322) course packet, Lab 2 on coagulation and flocculation.

Initially, one sample of wastewater was tested for initial TP and pH before setting up six individual 1 L jars for testing. The experimental setup included two control jars, two Ferric Chloride jars and two Alum jars. The jars are setup such that 1 and 2 were control jars, 3 and 4 were Ferric Chloride jars, and 5 and 6 were Alum jars. A render of the jar test setup is provided below in figure 5.

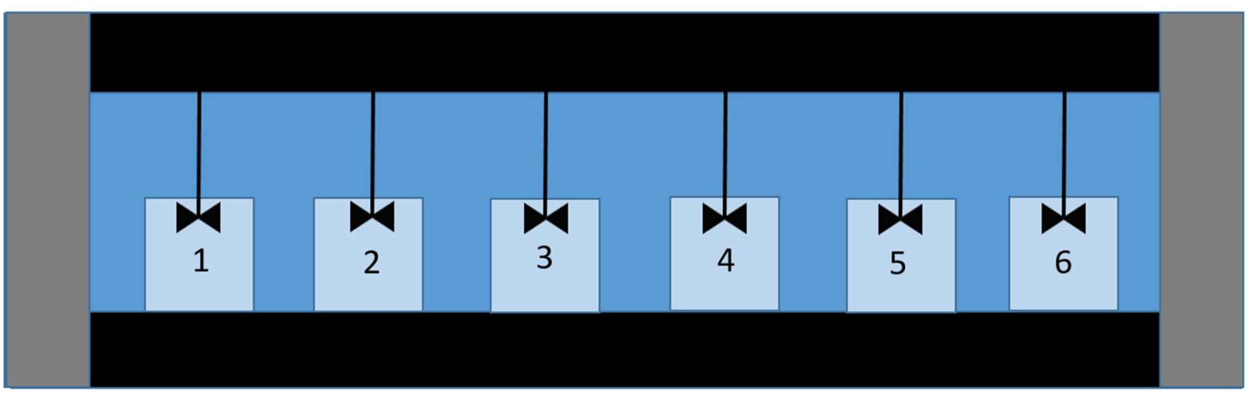


Figure 5. Schematic of the jar tests setup used to test the performance of the chemical treatment options.

As stated in the lab procedure, the jar tests were run for 1 minute with the mixers at 150 rpm. This ensured that the chemicals were distributed rapidly throughout the sample. Then, for 10 minutes, the mixers were set to 30 rpm to promote floc formation as the chemicals bound to phosphorus and formed metal complexes which precipitated out of the water. After the 10-minute period, samples were drawn from each jar and the Hach TP tests were done for each sample. Analysis using the Spec20 provided absorbance numbers for each sample, which were used to find the TP concentration after chemical treatment was performed. A summary of the results and the chemical dosing is found below in table 2.

Table 2. Results of the Hach test kit Total Phosphorus concentration after jar tests performed for varying Ferric Chloride and Alum doses.

Sample	Absorbance	Total P Concentration (mg/L)
Control 1	0.013	2.77
Control 2	0.017	3.62
174mg $FeCl_3$	0.007	1.49
348mg $FeCl_3$	0.006	1.28
196mg Alum	0.006	1.28
391mg Alum	0.005	1.06
Original Waste	0.013	2.77

Neither the Ferric Chloride nor the Alum jars with the determined dosing were able to achieve a TP concentration below the 0.075 mg/L mark set by the Wisconsin DNR. Considering the assumed molar ratios provided earlier, the theoretical minimum doses of Ferric Chloride and Alum to achieve 0.075 mg/L of TP in 1 liter of Browntown municipal wastewater are 117mg of $FeCl_3$ or 131mg of Alum. Based on this, the doses tested should have brought the TP levels to the 0.075 mg/L limit, but this was not achieved with neither the stoichiometric values, nor double the stoichiometric values. This could be attributed to a higher total suspended solids value remaining in the sample fluid or inaccurate Hach TP test kit sampling. The total suspended solids value could not be verified due to a lack of the turbidimeter. However, the main purpose of the jar test was to prove the performance of Ferric Chloride and Alum at removing TP in the Browntown wastewater. TP levels were brought to almost 1 mg/L using 391mg of alum– double the stoichiometric estimated dose. This is a step closer towards the effluent limit, and if economically feasible, may be worth pursuing.

Economic -

In the economic breakdown for a chemical treatment method, most of the capital and operational costs associated with developing a fully operational chemical treatment system will be referencing the *Final Compliance Alternatives Reports* created by Delta 3 Engineering, Inc. The costs associated with purchasing chemicals will be reevaluated using values based on the performance of the jar testing and literature suggestions on Ferric Chloride and Alum ratios and the costs provided by Hydrite Chemical Company. This is in part driven by concerns voiced by specific DNR representatives familiar with the previous treatment plan stating they believed that not enough Alum was used initially. The economic cost of the treatment systems proposed are important both socially and economically for the community.

Based on the hydraulic residence time of 66 days for aeration basin two, which is defined as:

$$\theta = \frac{Q}{V} \quad \textbf{Eq. 1}$$

Where:
V = volume of the system (gallons)
Q = volumetric flowrate (gallon/day)

The total volume of aeration basin two is approximately 3,747,556 L after conversion from gallons. Given the average concentration of TP in the effluent from historical data, the total mass of Phosphorus in the basin is 16,564 g of P. Using the molar ratios referenced previously, the total mass of Ferric Chloride needed to achieve the limit would be 640 – 1280 kg, and for Alum it would be 720 – 1440 kg.

Based on a quote from Hydrite Chemicals Company (Cottage Grove, WI), the cost of Ferric Chloride and Alum are $0.38/lb and $.46/lb, respectively. The percent Ferric Chloride of the liquid solution provided by Hydrite Chemicals is 37-42% and for Alum it is 48-49%. Since, the jar tests indicated it would be possible to reach near a 1.0 mg/L of TP, the amount of chemicals required will be based off of the 1.0 mg/L mark. This has been referenced by Delta 3 Engineering in other reports as the interim level needed for Browntown to be eligible to apply for the MDV mentioned in the variance analysis section (Delta 3 Engineering, Inc., 2017).

A dose of 400 mg/L for both $FeCl_3$ and Alum will be used to reach approximately 1.0 mg/L. Using a flowrate of 0.015 MGD (15,000 gallons/day), and the doses of400 mg/L, a pounds of chemical per day calculation was performed and verified using an online calculator developed by the State of Pennsylvania. The results indicated 50 lbs/day of dry Ferric Chloride or Alum are needed. Since, the chemicals provided would be in liquid form, a conversion from lbs/day of dry chemical to liquid chemical was performed based on the average concentration of the supplies from Hydrite Chemicals.

An average of 39.5% $FeCl_3$ solution was used. This placed the total pounds of solution at ~127 lbs/day of 39.5% $FeCl_3$. At a price of $0.38/lb, the annual cost of $FeCl_3$ is $17,614.9, or $48.26/day and corresponds to 11.6 gallons/day of solution.

An average of 48.5% Alum solution was used. This placed the total pounds of solution at ~105 lbs/day of 48.5% Alum. At a price of $0.46/lb, the annual cost of Alum is $17,629.5, or $48.3/day corresponding to a volume of solution of ~9.6 gallons/day. A table summarizing the chemical costs is provided below.

Table 3. Costs for alum and ferric chloride treatments based on data for products from Hydrite Chemical Company.

Chemical	**Daily Volume Added (gal/day)**	**Daily Cost**	**Annual Cost**
Ferric Chloride (39.5%)	11.6	$48.26	$17,614.9
Alum (48.5%)	9.6	$48.3	$17,629.5

It was determined by Delta 3 Engineering that the capital costs for creating the infrastructure necessary for chemical treatment would include a dedicated building, Ortho-Phosphate analyzer, control panel and programming, plumbing, HVAC, electrical, and chemical feed pumps (Delta 3 Engineering, Inc., 2017). The grand total estimate included a contingency of 20% and engineering fees was $264,960. A table of the cost breakdown from Delta 3 engineering is provided below.

Table 4. Capital costs for chemical treatment implementation determined by Delta 3 Engineering.

Item	**Unit Cost ($)**
Building	120,000
Ortho Phosphate Analyzer	30,000
Control Panel and Programming	10,000
Plumbing	10,000
HVAC	10,000
Electrical	7,000

Chemical Feed Pumps	5,000
Contingency (20%)	38,400
Engineering (15%)	34,560
Total Capital Costs	264,960

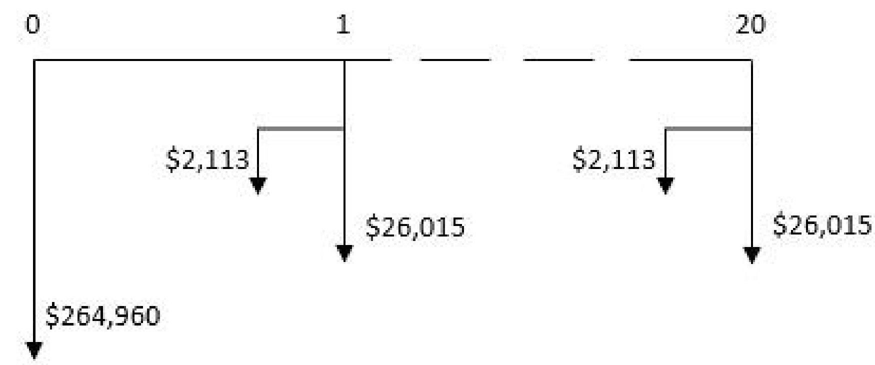
The operation and maintenance costs on an annual basis included electricity, chemical dosing amount, labor, and sludge handling. The annual costs determined by Delta 3 Engineering was placed at $20,400. This cost is contingent on the use of the chemical SorbX RE-300, which runs at $10.00/gallon according to their report. With a total estimated need of 1,200 gallons, the bulk of the annual cost was from the $12,000 associated with the chemical. Based on the chemicals chosen for review in this report, the annual cost of chemicals would be ~$17,700. The increased chemical costs in this analysis may further represent how the system will be too expensive. It is important to note that WDNR representatives were concerned that the amount of Alum added was too low. This was supported by our jar test results and is shown further in the report by the difference between the gallons per day of chemicals suggested by this report versus that suggested by Delta 3 Engineering.

The breakdown of the annual costs is summarized in the table below, which was adapted from the Delta 3 engineering report, but done using the cost of Ferric Chloride determined for this analysis.

Table 5. Annual costs for chemical treatment implementation adapted from Delta 3 Engineering to use this works chemical quantity amount.

Item	Annual Quantity	Annual Cost ($)
Electricity	1 unit	1,400
$FeCl_3$ (39.5%)	4234 gallons	17,614.9 ($4.16/gallon)
Labor	100 hours	4,000 ($40/hr)
Sludge Handling	1 unit	3,000
Total Annual Cost	1 unit	26,015

A cash flow diagram is provided below illustrates how a net present value of chemical treatment was achieved. Since the overall capital costs and operation and management costs are almost equal for the two chemical types, only one was assessed in this portion of the analysis. The extra cost of $1,940 per year is associated with roughly $50/lb of P discharged over the 0.075 mg/L limit if the system can only reach an average of 1.0 mg/L. The $50/lb of P cost was a rough estimate provided by the Wisconsin DNR representative Nathan Wells. Nathan Wells was the point of contact for the Browntown project when the village initially began seeking options to meet the new Phosphorus limits.



NPV = 264960+26015(P/A, 3%, 20yrs)+2113(P/A, 3%, 20yrs)

Figure 6. Cash flow visual for chemical treatment over a 20-year period using a discount rate of 3%. The P/A value was taken from interest tables from the Fundamentals of Engineering exam.

The net present value for the chemical treatment option given a 20-year loan at a 3% discount rate is $683,420. The equivalent annual cost (EAC) of the entire project was determined using the following equation - where n is equal to the number of periods - and is divided amongst all 120 households in Browntown (Investopedia Staff, 2018).

$$EAC = \frac{Asset\ Price\ \times Discount\ Rate}{1-(1+Discount\ Rate)^{-n}}$$ **Eq. 2**

The results of this economic analysis show that a Browntown ratepayer would be responsible for an extra $382.8 per year, which when added to the current rate of $453.36 per year determined by Delta 3 engineering, places the total cost of pollution control per household at $839.16 (Delta 3 Engineering, Inc., 2017). Compared to the median household income (MHI) of $52,143, the total cost of pollution control will rise to roughly 1.6% of the MHI. With this system in place, an interim 1.0 mg/L of Phosphorus could be achieved for a cost below the 2% MHI limit required for IEV (Wisconsin Department of Natural Resources, 2018).

Social -

Readdressing the use of chemical treatment to reduce Total Phosphorus levels in the Browntown wastewater will be met with some resistance by the community. There is skepticism among members voiced during the site visit about whether chemical treatment would work in the Browntown system. However, after conversations with both University of Wisconsin-Madison professors Daniel Noguera and Steve Reusser, as well as with the Wisconsin DNR plan reviewer Andrew Dutcher, there appears to be possible issues with previous treatment procedures (D. Noguera, personal communication, Nov. 13, 2018; S. Reusser, personal communication, Nov. 19, 2018; A. Dutcher, personal communication, Nov. 28. 2018).

Firstly, the hydraulic residence time of the second aeration basin is 66 days, but the pilot test designed by Delta 3 Engineering and performed by Rob Radz had Alum added only from 6/5/18 - 7/5/18 - a time of 31 days. Andrew Dutcher suggested that this may not be an adequately long pilot test to see significant results from the Alum treatment (A. Dutcher, personal communication, Nov. 28. 2018). It would be necessary to extend the pilot to run for at least as long as it takes the second basin to completely cycle its water, which is 66 days (A. Dutcher, personal communication, Nov. 28. 2018). It is one goal of this analysis on chemical treatment and the jar tests performed to prove the ability of chemical addition into Browntown's wastewater as method of reducing TP levels.

Another issue voiced by both Andrew Dutcher and the aforementioned professors is that regarding total suspended solids (TSS) present in the effluent. Phosphorus readily binds to solids in solution, so the Total Phosphorus value includes both solids bound Phosphorus and dissolved Phosphorus (D. Noguera, personal communication, Nov. 13, 2018). Chemical treatment can remove solid-bound Phosphorus by trapping the solids within the precipitated metal complexes formed. However, the TSS removal in the lagoon system could be enhanced with a slight modification suggested by Andrew Dutcher. A simplified schematic of this is shown in the figure 7.

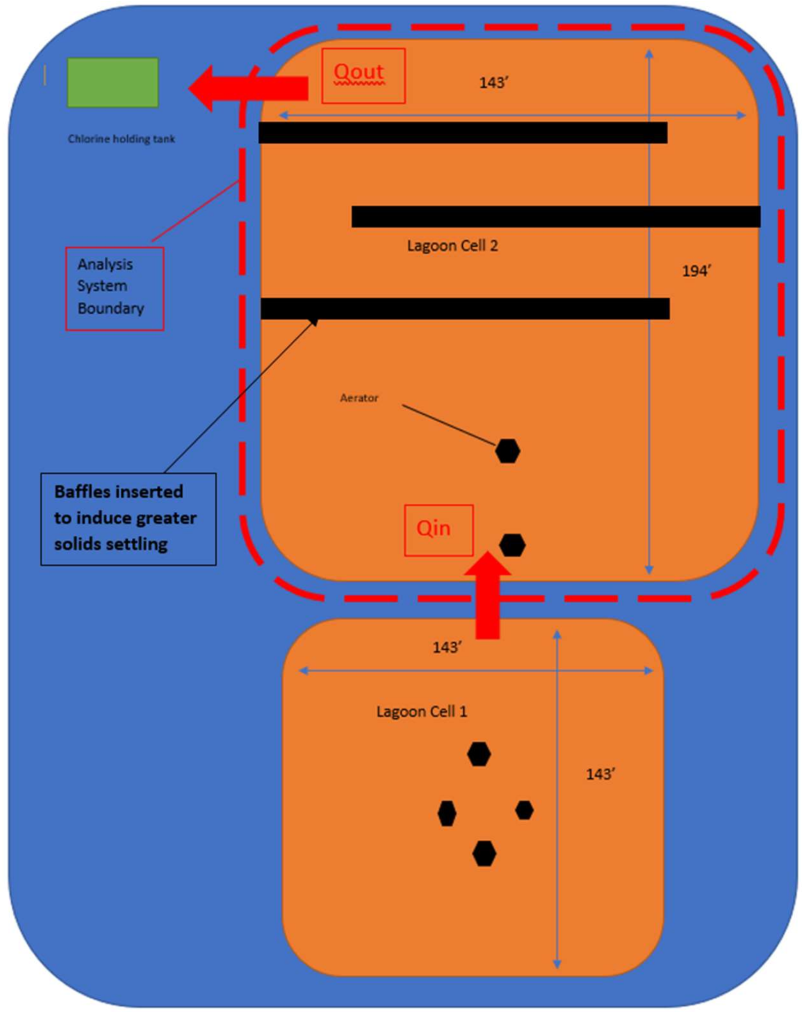


Figure 7. A simplified schematic of where concrete baffles could be placed in aeration basin two to increase settling of solids.

The modification presents a series of concrete baffles added to the system, which when placed after the two aeration points, could allow for increased settling of suspended solids out of the wastewater. The effects of this addition were not studied in this paper, and it is only mentioned as another suggestion for Browntown to investigate.

Environmental -

The environmental benefit of achieving even a 1.0 mg/L TP effluent concentration would put Browntown on the path of reaching the WDNR effluent limit. This in turn, would push the community towards being a part of the larger nationwide solution to nutrient loading causing eutrophication of surface water in and around the U.S. The 1.0 mg/L value appears reachable based on the results from the jar tests performed. More studies will have to be done with a greater spread of doses to determine the most optimal and economic one.

It is the hope of this report and experiment on chemical treatment and the alternative testing and design solutions presented to convince the community that if chemical treatment appears to be the best solution, that it warrants further analysis before being ruled out due to previous studies.

6.3 Algae Cultivation for Nutrient Uptake Results:

Assumptions made for this section are as follows:

1. Only effects on P level is considered
2. The cost of algae cultivation equipment can be scaled in relation to the facility size.
3. The hydraulic retention time for the second aeration basin is 66 days. This information was provided by Andrew Dutcher, a DNR plan reviewer familiar with the Browntown facility.

Algae as a means of phosphorous uptake is an innovative way to remove nutrient pollutants from wastewater. Algae cultivation will be analyzed using the parameters discussed under section 3.3 with certain assumptions made in order to align with the focus of this project. To analyze the social, economic and environmental impacts that algae may have, literary analysis will be used. Additional consulting with Rob will be done to get a better idea of the social impact algae cultivation might have.

Economic -

An effort to derive equations for analysis of energy inputs was made. These equations encompassed the main power consumption areas that are essential for healthy algae cultivation: artificial lighting, greenhouse heating, water heating and water mixing. Equations were pulled from previous analysis done by Baligna and Powers (2010) and applied using the specifics of Browntown wastewater treatment system and south-central Wisconsin climate. Unfortunately, values obtained from these equations were not probable (watt values were unrealistically low) and following the derivations of the equations to find potential error proved fruitless. Thus, we decided a new route should be taken for this preliminary analysis.

After consideration, we deemed the best method of estimating cost to be through investigation of previous literature and adjustment of the data to Browntown's operations and size specifications. A 2018 report prepared by Roth Professional Solutions, INC. for the village of Cambria - a town in central WI - includes cost analysis of an algae treatment system. The current Cambria facility includes additional features beyond the Browntown treatment facility. We are, however, only concerned with the secondary settlement tank at the Browntown facility, which closely resembles the Cambria clarifier, and thus a comparison is possible for the parameters of this project. The Cambria facility is designed for up to 125,000 gpd and typical flow is around 80,000 gpd, whereas the Browntown facility is designed for 40,500 gpd and typical flow is about 15,000 gpd. An algae treatment system must be designed to match the rest of the system capacity (40,500 gpd). It will be assumed then, that a rough cost estimate for implementing algae cultivation at Browntown can be achieved by applying the size ratio between the two plants at hand (40,500 gpd/125,000 gpd = .324) to capital costs, operations cost and operations revenue. This is a reasonable assumption since although the report for Cambria does not specify which equipment they used, the space requirements, equipment size, power for operations and harvesting yields will be proportional to the amount of water flowing through the facility. Table 6 provides a breakdown of costs for Browntown scaled from the previous cost analysis done for Cambria by Roth.

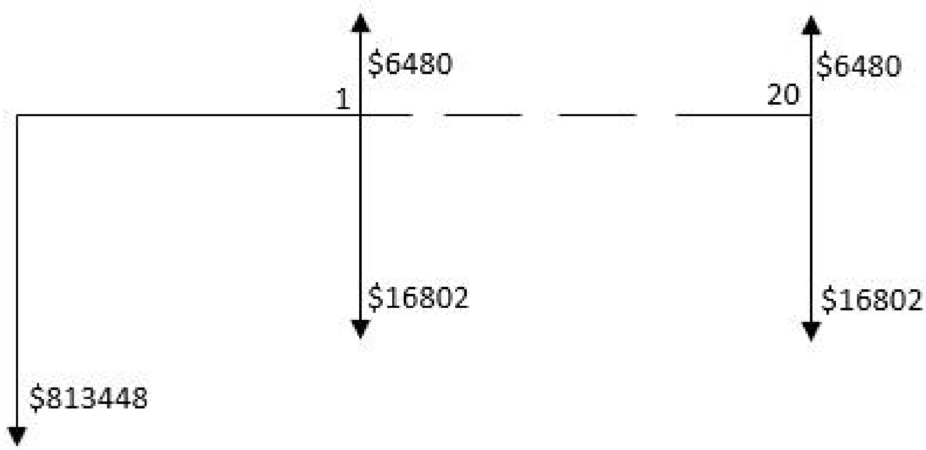
Table 6: Capital and operational costs for algae cultivation for phosphorus uptake.

Addition	Capital Costs	Operation Costs	Operations Revenue
Pumps, conveyance and tankage infrastructure	$136,080	$1,620	$0
ABNR photobioreactor equipment (controls, monitoring electrical, separation, harvesting)	$476,280	$5,832	$6,480
Electrical service, gas service, CO2 supplements, generator fuel	$24,300	$6,480	$0
Site costs	$24,300	$0	$0
Storage building	$48,600	$0	$0
Facilitative Equipment for site	$3,888	$1,620	$0
Legal, consulting, other*	$100,000	$1,250	$0
Total	**$813,448**	**$16,802**	**$6,480**

*Cost is not considered to be scale dependent and thus is not transformed between Cambria and Browntown

Another capital cost estimation method provided by SCHOTT, a company specializing in manufacturing of photobioreactors proves to be within reasonable range of the estimate above. The SCHOTT cost calculator for photobioreactors provided an estimated capital cost of $940,000. This supports our assumption that the scaling ratio between Cambria and Browntown is sufficient for our purposes, and thus the values in table 6 will be used for final analysis.

A cash flow analysis represented by figure 6 (below) reveals a net present cost of $1.01 million over a twenty-year period after considering the capital and operational costs and harvesting revenue discussed above.



$$NPV = 813448+16802(P/A, 3\%, 20yrs)-6480(P/A, 3\%, 20yrs)$$

Figure 8: Cash flow visual for algae over a 20-year period using a 3% discount rate.

The equivalent annual cost (EAC) of the entire project was determined using the equation listed in section 5.2 and divided amongst all 120 households in Browntown. The results of this economic analysis show that the Browntown ratepayer would be responsible for an extra $565.70 per year, which when added to the current rate of $453.36 per year determined by Delta 3 Engineering, places the total cost of pollution control per household at $1019.1. Compared to the median household income (MHI) of $52,143, the total cost of pollution control will rise roughly 2% of the MHI. This puts their excess cost above the value required for an individual economic variance as cited in section 5.1 if the levels are not reduced to .075 mg/L.

Environmental -

Algae cultivation in wastewater has positive implications for environmental quality, especially in relation to effluent phosphorous levels, as it can recycle nutrients such as phosphorus (Dalrymple et al., 2013; Patel et al., 2012; Kuenzler and Ketchum, 1962.) Cultivation of algae in wastewater has previously reduced phosphorus levels by as much as 85% (Dalrymple et al., 2013) Lab analysis of *Phaeodactylum tricornutum* revealed that original solutions with phosphate ranging from 3.3 mg/L to 7.6 mg/L were diminished to as little as $6.8*10^{-8}$ mg/L by the algae strain studied (Kuenzler and Ketchum, 1962). While this is a bench test and many differences exist between an operational wastewater system (flow, sludge, other nutrients), the range of concentrations of phosphorus present at the beginning of the test encompass Browntown's current effluent level and the final levels are well below the DNR's new limit of 0.075 mg/L.

In addition to lower phosphorus levels, algae provide byproducts after harvesting that are not only valuable, but can take the place of certain fossil fuels, providing a renewable fuel source. Lipids from biofuels can be extracted and transformed into biofuels via transesterification (Dalyrimple, et al., 2013). The overall process of biofuel production of biofuels from wastewater grown algae is shown to have a positive net energy yield, supporting the environmental sustainability of an algae treated wastewater system (Lardon et al., 2009; Clarens et al., 2010). In addition, products such as food additives, nutrient supplements, fertilizers and cosmetics can also be made using algae products or product derivatives (Goswami et al., 2015).

Algae cultivation may have some negative environmental impacts in conjunction with the benefits. The area surrounding Browntown's wastewater facility is classified as wetland by the WI DNR. Wetlands are important for water quality, flood control, storage of carbon dioxide and their ecological importance (Mitch and Gosselink, 1993; Mitch et al., 2013). The Browntown wastewater lagoons are positioned atop a knoll with little room to construct more buildings. A cultivation facility would need to be built within reasonable distance from this knoll and thus landscaping may need to take place to accommodate a facility. Largescale landscaping in an area classified as wetlands could have negative environmental impacts on natural systems normally kept in balance by the surrounding wetland.

Social -

The social aspects of building an algae cultivation facility in conjunction with the Browntown wastewater treatment plant is subjective and hard to predict. Rob indicated that the citizen of Browntown are strongly opposed to adaptive management, a solution the WI DNR suggested. With this in mind, it is thought that the citizens of Browntown will at least consider implementation of an algae treatment before resorting to adaptive management. Implementing a cultivation faculty would, however, require a bit of construction and land use. In any project, land use and building are often contested to some degree as it may be thought of as an 'eye sore'. The area around the wastewater treatment plant is also considered wetland by the WDNR. If construction of an algae cultivation facility requires alterations of these wetlands, backlash from environmental conservationists may arise.

7.0 Final Recommendation:

It was determined after consideration of the three routes available for Browntown treach compliance with the WDNR Phosphorus effluent limit of 0.075 mg/L that algae cultivation for nutrient uptake system would best reach the water quality standards required by the WDNR and work within the social and economic constraints of the Browntown community.

As deduced through conversations with the facility operator and referenced in the report compiled by the engineering consulting firm Delta 3 Engineering Inc., the community is resistant to employing adaptive management measures suggested by the WDNR for nonpoint source control of Phosphorus in the watershed. Therefore, point source control options in regard to the wastewater treatment facility were pursued as viable options to account for the social desires of the community. Furthermore, a roughly 30-day pilot test for chemical treatment of the second aeration basin was performed by the village using liquid Alum to reduce phosphorus levels to reach compliance. However, the treatment proved to be unsuccessful and for an interim period seemed to increase phosphorus levels in the effluent. The failure and subsequent increase in phosphorus levels damaged the confidence the facility operator had in the ability of chemical treatment to achieve the effluent limits. It is these social factors at play in the attempt to reach compliance that made the algae system seem most desirable. Apart from the already understood social factors at play, the added economic benefit of harvesting the algae grown for fertilizer in the community may be received well by the residents as the village and surrounding areas consists of retired and active farmers.

The economic analysis of the chemical and algae treatment options proved the chemical treatment system to be the most cost-effective at reaching an interim limit of 1.0 mg/L. The added cost to each ratepayer's yearly bill for chemical treatment would be $382.8 per household, versus the added cost of $565.7 per household for the algae treatment over the 20-year period for a loan used. This report recognizes the fact that with the rate increase from algae, the total bill for pollution control per household would increase to roughly $1,019.1, which is about 2% of the median household income for Browntown. This makes Browntown eligible for an individual economic variance (IEV), which would give Browntown more time to implement an effective treatment system and not receive fines. In an effort to reach full compliance without needing to alter the facility Phosphorus effluent limit, the algae system should be pursued in tandem with the community seeking grants from both federal and state sources. The algae system represents an innovative biological solution for addressing point source Phosphorus effluents. It is recommended in the spirit of community projects and collaboration per the Wisconsin Idea that the Village of Browntown seek to implement the algae system in partnership with the University of Wisconsin-Madison. One example of a grant potentially pursuable by the collaborative effort would be the Freshwater Harmful Algal Blooms water research grant provided by the U.S. EPA (US EPA, 2016). The algae system would reduce nutrient loading in surface water systems, which prevents eutrophication of the water system; limiting the nutrient loading from point sources could fall under this grant (Nutrient Pollution: The Problem, 2017). If proven to work for small facilities and developed enough to reduce capital costs, algae systems could be used to reduce point source nutrient loading in larger basins like the Mississippi River Basin (EPA, 2017). It would take nationwide measures to effectively address massive eutrophication problems like the development of the Anoxic Zone in the Gulf of Mexico (EPA, 2017). The algae system proposed in this report can accomplish extremely efficient Phosphorus reductions in wastewater effluents.

Specifically, this report focused on reducing the Phosphorus effluent concentrations for Browntown's wastewater treatment facility to 0.075 mg/L. The algae cultivation for nutrient uptake system has been proven in lab systems to achieve Phosphorus concentrations of $6.8\text{x}10^{-8}$ mg/L. The chemical treatment proposed in this report was determined to be able to reach an effluent concentration of 1.0 mg/L. The potential of the algae system to reach extremely high removal efficiencies places it at the top of the methods for reaching compliance. Every mass of

Phosphorus over the 0.075 mg/L limit was considered as a negative environmental impact. The variance solution would possibly result in no change to the current effluent standards and the chemical treatment reaching 1.0 mg/L would still allow for 3.47 kg of Phosphorus to remain in the second aeration basin at steady state concentration. Since neither of the other two options bring Browntown within compliance without variations to the effluent limit, the algae system should be pursued.

The algae cultivation for nutrient uptake system proposed in this report addresses all three paradigms of sustainability for bringing Browntown into Phosphorus effluent concentration compliance. The needs and concerns of the community are considered in regard to skepticism of previous treatments and an added bonus of community produced fertilizer. Economics and cost of the system pose the greatest challenge; however, the cost of the system is not too great to be insurmountable. The increase in the cost is just at the 2% of the MHI mark, and grants or partnerships could be pursued by the community with research and government institutions. The premise of this project serves as a basis for educational institutions to invest in community development. Lastly, the environmental impact of the Browntown facility in terms of Phosphorus discharge would be almost completely eliminated and well below the WDNR limit. It is the hope of this paper that the algae system is investigated further by the community and institutions seek to partner with the wastewater facility to realize the potential of algae to no longer be the foe in the battle against eutrophication, but an invaluable ally.

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About UniverCity Year

UniverCity Year is a three-phase partnership between UW-Madison and one community in Wisconsin. The concept is simple. The community partner identifies projects that would benefit from UW-Madison expertise. Faculty from across the university incorporate these projects into their courses, and UniverCity Year staff provide administrative support to ensure the collaboration's success. The results are powerful. Partners receive big ideas and feasible recommendations that spark momentum towards a more sustainable, livable, and resilient future. Join us as we create better places together.

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UniverCity Alliance
UNIVERSITY OF WISCONSIN–MADISON

univercityalliance@wisc.edu
608-890-0330
univercity.wisc.edu