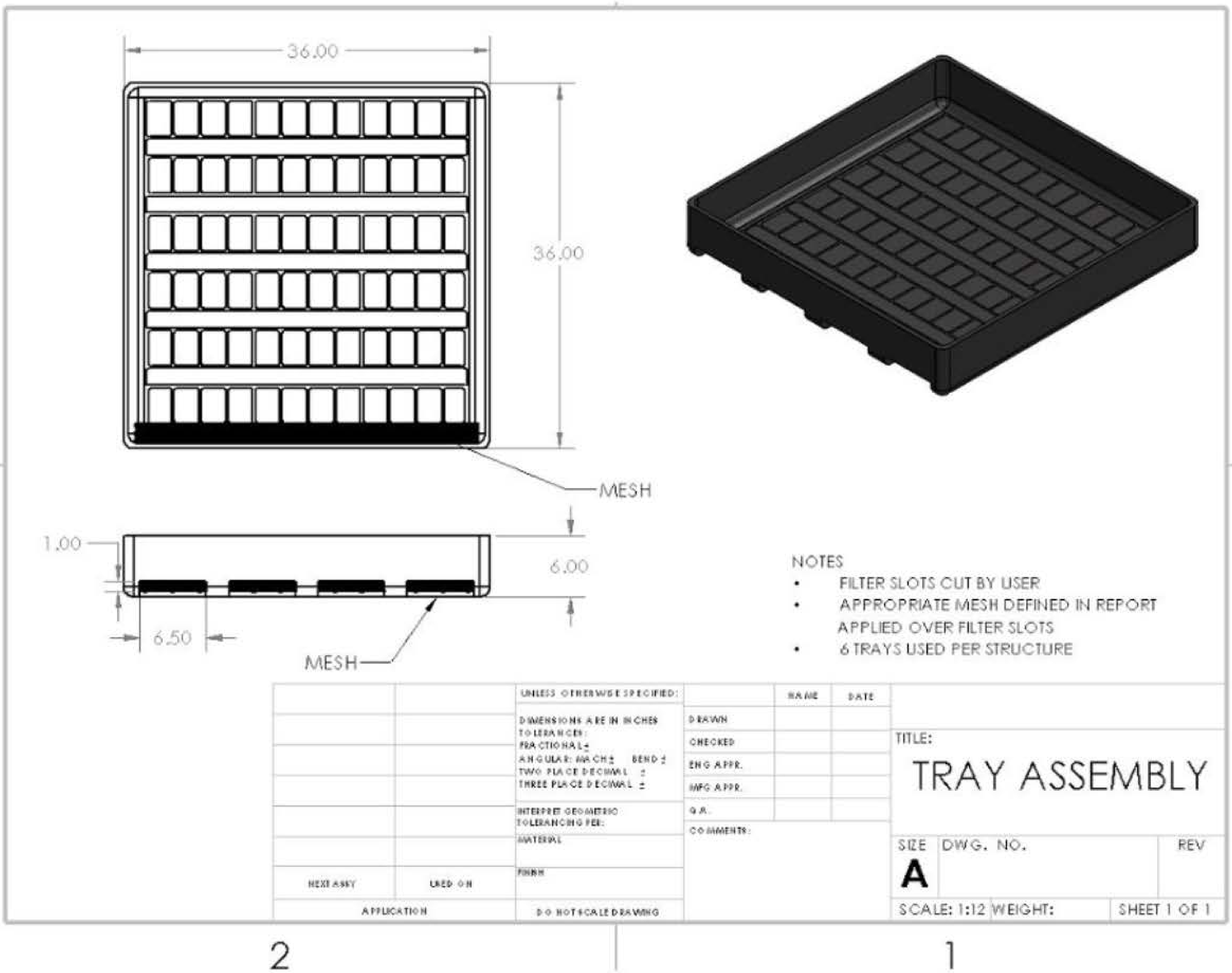
36.00
36.00
MESH
1.00
6.00
6.50
MESH
NOTES
• FILTER SLOTS CUT BY USER
• APPROPRIATE MESH DEFINED IN REPORT APPLIED OVER FILTER SLOTS
• 6 TRAYS USED PER STRUCTURE
B
B
A
A
2
1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
TRAY ASSEMBLY
SIZE
A
DWG. NO.
REV
SCALE: 1:12
WEIGHT:
SHEET 1 OF 1

For all months except April, the DRP portion of the influent concentration was low enough that the switchgrass, alfalfa, and duckweed were able to uptake 100% of DRP present given a retention time of about 57 minutes in each tray. While the species chosen would be efficient at extracting phosphorus, the total contribution of the plant removal is relatively small compared to the total phosphorus removed after the alum filter. The biological component of the system could be made more effective, however, if it were adapted to a scenario where the influent DRP concentration was higher and if the system could run for a longer period of time, such as in warmer climates where plants can be grown year-round. The uptake rate of plants is also known to increase as more phosphorus is present in the nutrient solution (Kovar, 2009).

Chemical Methodology and Design

There are currently 2 main phosphate coagulants being used in wastewater treatment, Aluminium Sulfate (Alum) and Ferric Chloride (FeCl3). Each with its advantages and disadvantages as seen below in Table 2.

Table 2: Comparison of the advantages and disadvantages of Alum and FeCl3

	Alum	FeCl3
Reactions	$Al^{3+} + HnPO_4^{3-n} \leftrightarrow AlPO4 + nH^+$	$Fe^{3+} + H_nPO_4^{3-n} \leftrightarrow FePO_4 + nH^+$
Optimal pH range	5 – 7	6.5 – 7.5
Advantages	- Inexpensive - Tolerant to temperature fluctuation	- no pH requirement - Easy to apply
Disadvantages	- Utilizes hydroxide and alkalinity - Produces a lot of sludge	- Very corrosive for piping - Price fluctuation - High initial [Cl^-] in water - Filter clogs more readily

Even though the pH of the lake is more similar to the optimal pH range of the ferric chloride, the high concentration of chlorine in the lake would require an increased dosage of coagulant to make the reaction thermodynamically favorable. In addition, due to the large flocculation size and the lower porosity of the cake membrane, the filter would clog more easily. Hence, alum was chosen as the phosphate coagulant.

magnified in both Lake Waubesa and Lake Kegonsa, where smaller basin volume results in a higher total phosphorus concentration (Carpenter, 2013). Below are two contrasting graphs that show this difference; there has not been a single year since 1980 where lakes Waubesa and Kegonsa have had concentrations below the mesotrophic boundary. The mesotrophic boundary is defined as the point where microbial activity goes from manageable to excessive (Dane County Regional Planning Commission, 2015). The value shown in the graphs below indicates that 0.024 mg P / L is the mesotrophic boundary for the Yahara lakes.

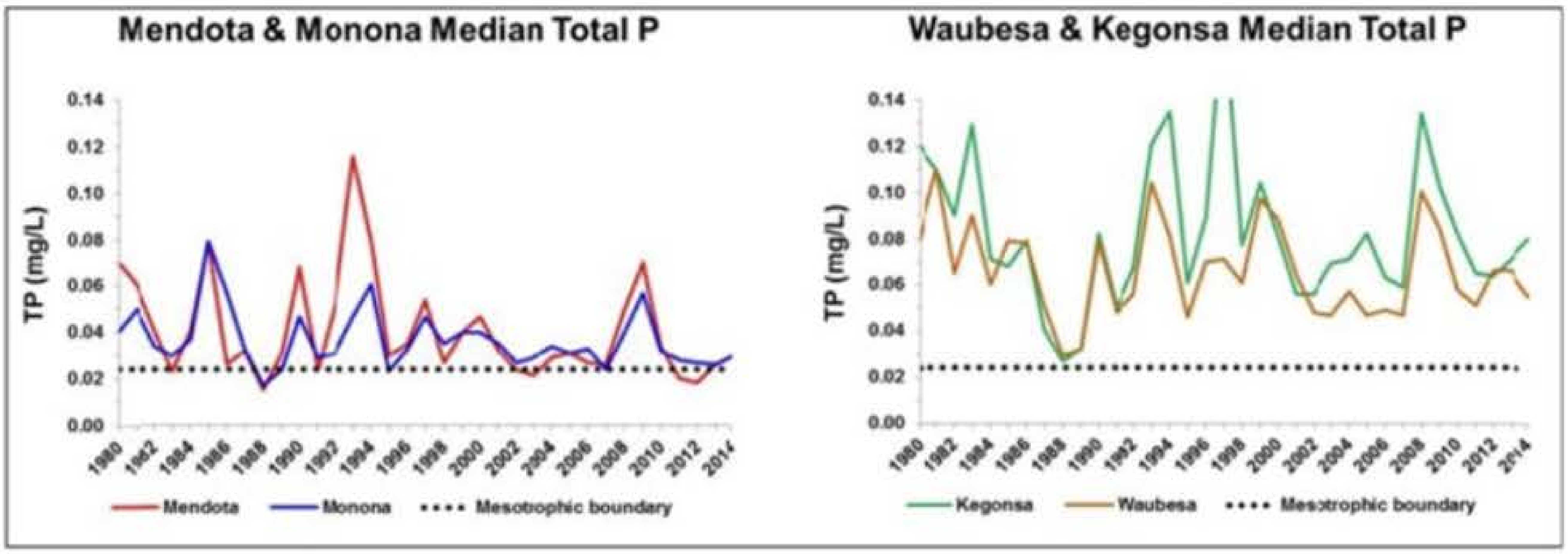

Figure 1: Total P Concentrations in the Surface Waters of Yahara Lakes, 1980-2014
Source: Richard Lathrop – UW Madison Center for Limnology

Throughout the entire Yahara lake chain, additional phosphorus is the culprit of most blue-green algae and cyanobacteria blooms. These blooms not only produce a foul smell and undesirable aesthetic consequences, but they release toxins into the water that affect humans and wildlife. In the past, Dane County has seen several animal deaths and the death of a teenager in 2002 as a result of swimming in affected lakes (Duncan, 2015). More recently, projects have been implemented to better control the amount of phosphorus loading in Lake Mendota, but algal blooms and beach closures continue to occur. The graph below shows the amount of beach closures in the Yahara lake chain from 1996 – 2014. In 2012-2014 alone, there were just under 200 beach closures for the Yahara lake chain (Dane County Regional Planning Commission, 2015). Eutrophic blooms affect more than the recreational culture of Dane County as well. Lake ecosystems and their food webs can change depending on how often eutrophication occurs. It is

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would likely require more harvesting and better maintenance, so the potential for phosphorus uptake in the species should be weighed against the profitability of the crop.

The system would also see a greater effectiveness if it utilized a larger amount of chemical filters with longer residence times. In addition, the biofilter balls could have a mesh embedded into them, so as to increase the nucleation surface area available for aluminium hydroxy phosphate precipitation.

Although the cost of removal is above other treatment options, the perceived value is increased as it is able to remove phosphorus in specific areas of the waterway, while the majority of other treatment systems are stationary and only alter flows of water that are downstream of the facility. The process is mainly limited by the residence time, for both the biological and chemical processes, in order to effectively remove the nutrients as well as the size of the system compared to the amount of water it is able to treat.

Alternative solutions

Floating island wetland with aeration pump

1. This design incorporates 5 transportable pieces that fit together at the site in order to create one larger system.
2. The innermost portion contains an aeration pump that sends water out through stream channels.
3. The stream channels run through the four other sections of the system, which are bioreactors that incorporate microfilm as well as high nutrient absorbing plants.

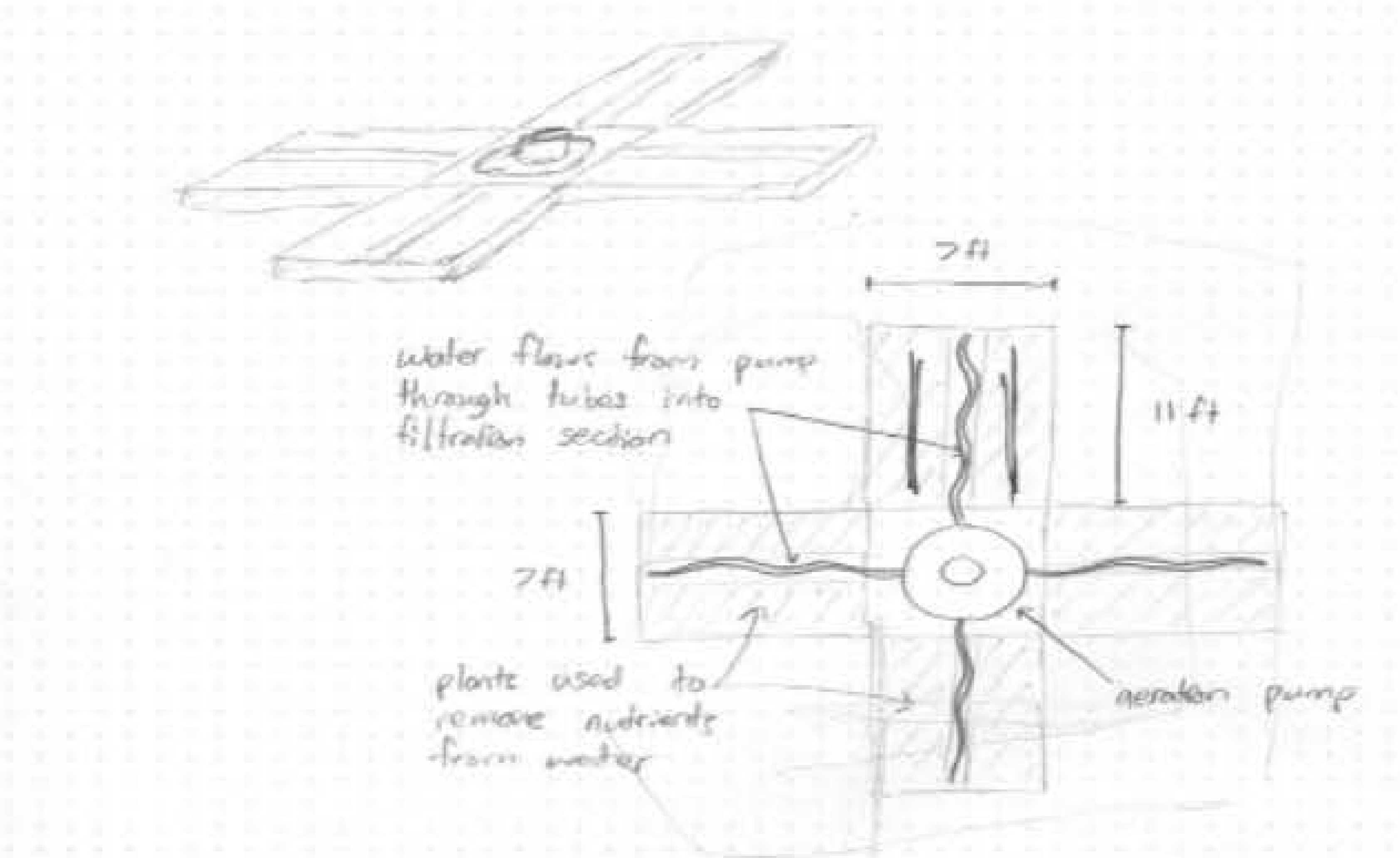


Figure 7. Floating island wetland concept sketch

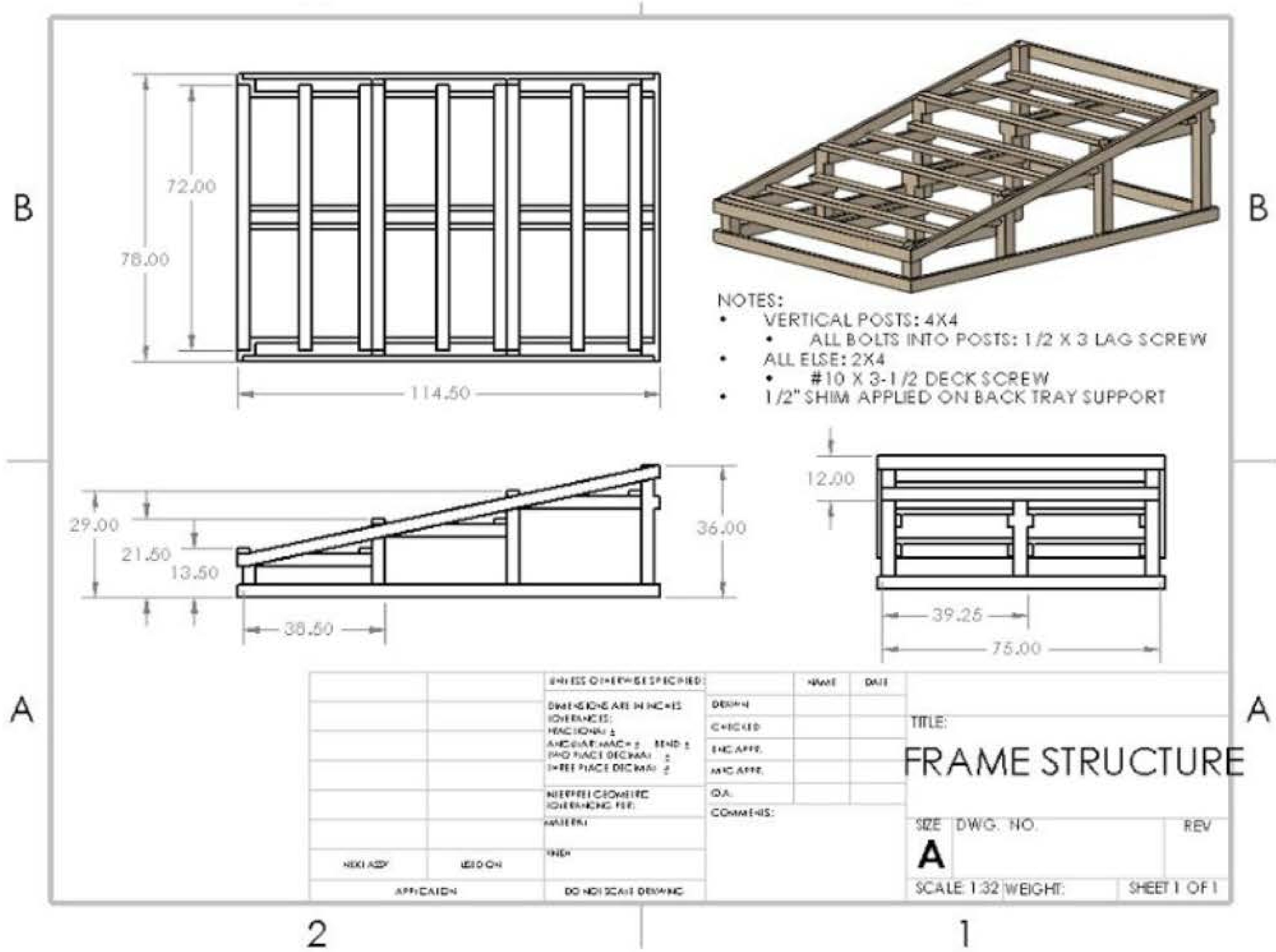
Membrane filter with pump

1. This will be a physical method of filtering through membranes.

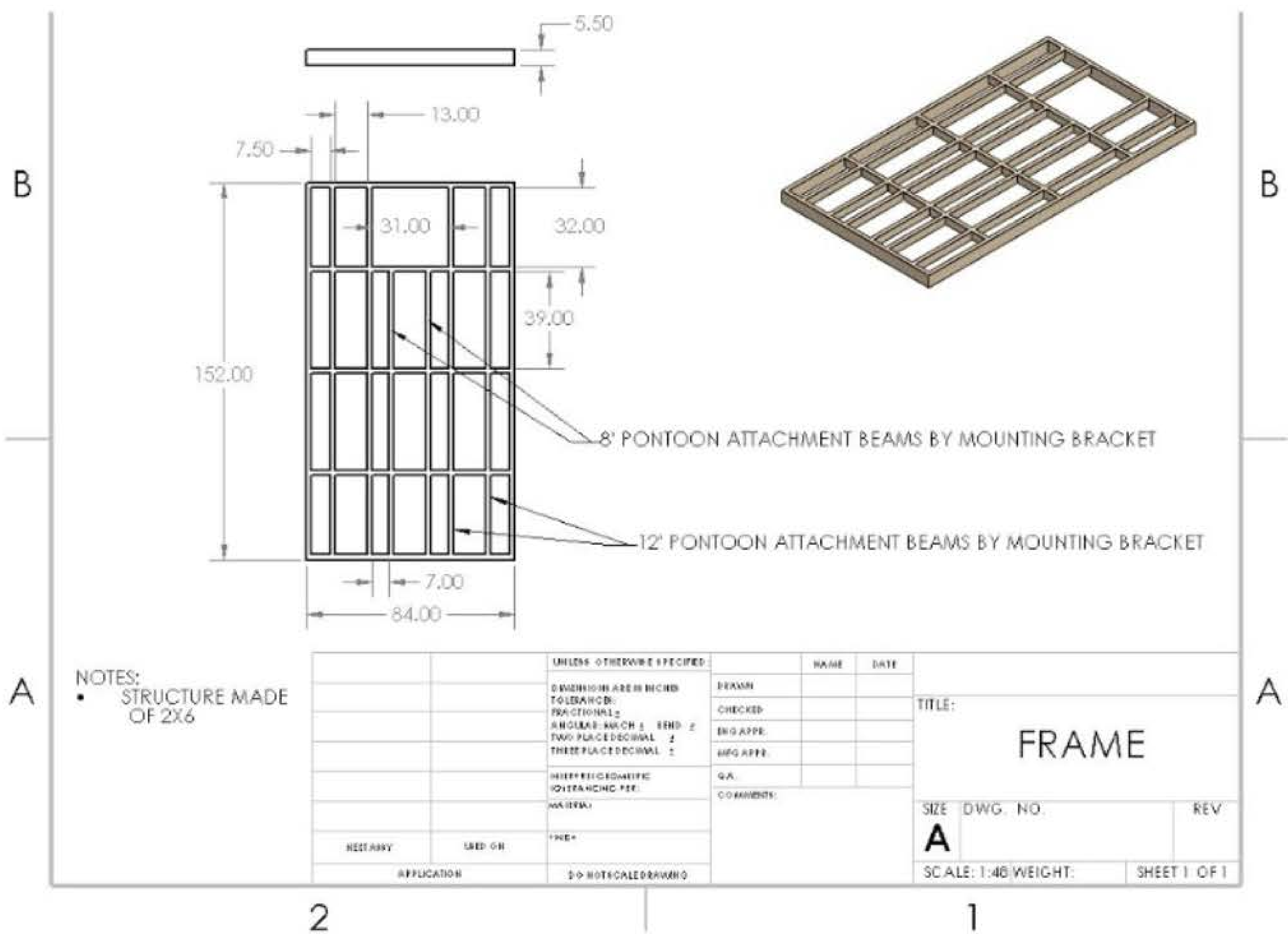
Original design specs

Safety

- Our design needs to be structurally safe in the case of external forces such as swimmers/animals climbing on it, capsizing, strong wind and wave conditions, and heavy storms whilst floating in the lake.
- Our design must remain buoyant if one of the floats is compromised.
        - (Plastic Pontoon, 2018)
- It must be appropriately anchored in relation to the weight of the structure, surface material of the lake bed, and depth of water.
    - Anchor depth has to reach 25ft
        - Bathymetric map of mendota (WI DNR, 2018)
    - Anchor must hold for an average wind speed of 6 mph (~5 knots)
        - (Benedetti, 1996)
        - (Mantus Marine, 2018)
    - Anchor type must effectively embed in the bottom conditions found in the Yahara River Valley
        - (West Marine, 2018)
        - (WI DNR, 2018)
- The tethering system must be able to withstand an average wave height of 12 inches (Clifford, 2018).
- Our design needs to be easily recognizable to other recreational lake users in order to avoid collisions, and contain signage or fences in order to prevent interaction.
- The color scheme of the barge must be and highly visible for patrons of the lake for easy avoidance.
    - The design should incorporate an element of orange which designates danger and physical hazards, without the design being too jarring and intimidating.
        - (SafetySign, 2018)
        - The American National Standards Institute (ANSI) Z535.2 Standard for Environmental and Facility Safety
- Flashing white light to provide warning lake users at night.
        - (WI DNR, 2018)
- Our system will display reflective tape to improve visibility with "controlled area symbol" and Universal symbols for No entry
        - (Rolyan Buoys & Floats, 2010).

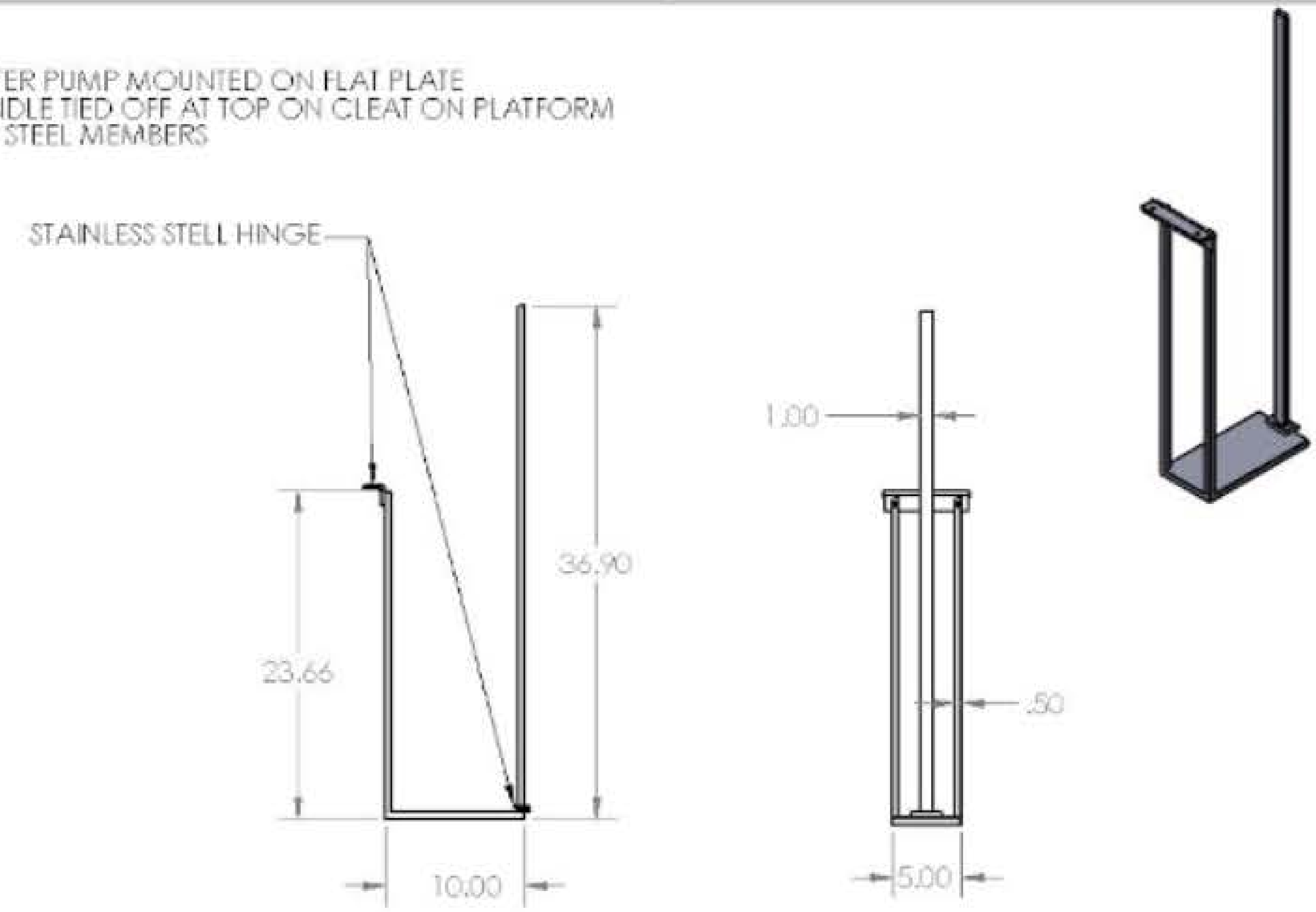


72.00
78.00
114.50
NOTES:
• VERTICAL POSTS: 4X4
• ALL BOLTS INTO POSTS: 1/2 X 3 LAG SCREW
• ALL ELSE: 2X4
• #10 X 3-1/2 DECK SCREW
• 1/2" SHIM APPLIED ON BACK TRAY SUPPORT
29.00
21.50
13.50
38.50
36.00
12.00
39.25
75.00
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
FRAME STRUCTURE
SIZE
DWG. NO.
REV
A
SCALE: 1:32
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING



5.50
13.00
7.50
31.00
32.00
39.00
152.00
8' PONTOON ATTACHMENT BEAMS BY MOUNTING BRACKET
12' PONTOON ATTACHMENT BEAMS BY MOUNTING BRACKET
7.00
84.00
NOTES:
• STRUCTURE MADE OF 2X6
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
FRAME
SIZE
DWG. NO.
REV
A
SCALE: 1:48
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

NOTES:
- WATER PUMP MOUNTED ON FLAT PLATE
- HANDLE TIED OFF AT TOP ON CLEAT ON PLATFORM
- 1/2" STEEL MEMBERS



TITLE: WATER PUMP SHELF

SIZE A DWG. NO. REV

SCALE: 1:12 WEIGHT: SHEET 1 OF 1

NOTES:
- 4" PIPE DIAMTER
- HOLES CUT BY USER
- ONE END CUT AT 2 DEGREE ANGLE
- PIPE FITTING SIZE PER INSTRUCTION

NOTES:
- ALL PONTOONS 24" DIAMETER
- MOUNTED WITH BRACKET
- 2 - 12' PONTOONS
- 1 - 8' PONTOONS

TITLE: PONTOON, FLOW DIVIDER, CLEAT

SIZE A DWG. NO. REV

SCALE: 1:32 WEIGHT: SHEET 1 OF 1

Abstract

The Yahara Watershed, located in central Dane County, Wisconsin, is a 170,000 acre natural drainage basin which has seen an increase in excess nutrients funneling into its waterways from agricultural runoff over the last few decades, causing eutrophication and large algal blooms (UW-Madison Luminology, 2014). In order to combat the influx of nutrients, a phosphorus bioreactor system was designed and evaluated for effectiveness of phosphorus removal on the northern side of the watershed, where the concentration in the river is measured at 0.12 mg of P/L (Cite). Constructed on a small floating barge, the bioreactor system pumps a stream of water through both biological and chemical removal trays targeting the dissolved reactive phosphorus, which is the limiting nutrient in the water. The biological system, which is comprised of a combination of duckweed, switchgrass, and alfalfa, uptakes the nutrients through the plant root system as a 1.5 L/min water stream flows through it, and has a 0.008 lb of P/year expected removal rate. The chemical system utilizes alum ($Al_2(SO_4)_3$) to react with the phosphorus from the water stream after it leaves the biological system, and is expected to remove 0.068 lb of P/year. The expected lifetime of the structure itself is 10 years, in which it would theoretically remove a total of 0.754 lbs of phosphorus over the entirety of its use. The calculated total cost of the system is $5650, which induces a cost of $7500/lb of phosphorus removed over the 10 year period.

Keywords

- Yahara Lake Chain
- Phosphorus concentration
- Phosphorus Loading
- Eutrophication
- Algae Blooms
- Cyanobacteria
- Lake Mendota, Monona, Waubesa, Kegonsa
- Madison, Dane County, Wisconsin

- 30.12(3m)(c)2. **2.** The structure or deposit will not be detrimental to the public interest.
- 30.12(3m)(c)3. **3.** The structure or deposit will not materially reduce the flood flow capacity of a stream.

Economic analysis

The project does not have a specific budget constraint. Instead, the economic analysis will be done by comparing the cost of our design solution to the cost of known phosphorus remediation techniques. The most reliable measurement of the cost of phosphorus removal would be the average cost of removal in a wastewater treatment plant. These values are the best measure we have as of now, because wastewater treatment plants are able to monitor the change in phosphorus concentration in accordance with the cost of the input materials. The average cost of phosphorus removal in a wastewater treatment plant is $51 - $130 per pound of removed phosphorus. This value was calculated by using the average cost per pound of Phosphorus removed from these peer reviewed journals: (Bashar, 2017) (Keplinger, Houser, Tanter, Hauck, Beran, 2004) (Jiang, Beck, Cummings, Rowles, Russell, 2005). The cost increases as the desired output concentration decreases. The cost effectiveness of these phosphorus removal systems will be very different from our system because wastewater treatment plants work with high influent concentrations. Still, this number provides us with a good standard cost to work with, especially since data on the costliness of intralake phosphorus removal systems is sparse.

Even with a standard value for comparison, this project cannot be bound within the parameters of a set of numbers. It may turn out that the end product will have a higher cost than traditional wastewater treatment methods, but if the bioreactor design is successful there will be net benefits that could justify a higher cost. This includes improvements in ecosystem health, less days lost to beach closings, and less unwanted smells and sights that often accompany eutrophication. Once the design is finalized and the materials and maintenance costs are available to us, we will be able to determine the cost per each reactor and the annual maintenance and storage expenses. The net benefits of our system will be evaluated, and a monetary

Biological Component Results

The amount of phosphorus taken up by the biological component of the system is inherently dependent on the concentration of plant-available DRP present in the incoming water. On average, only about 7.5% of the total phosphorus concentration at the Yahara inlet is plant-available.

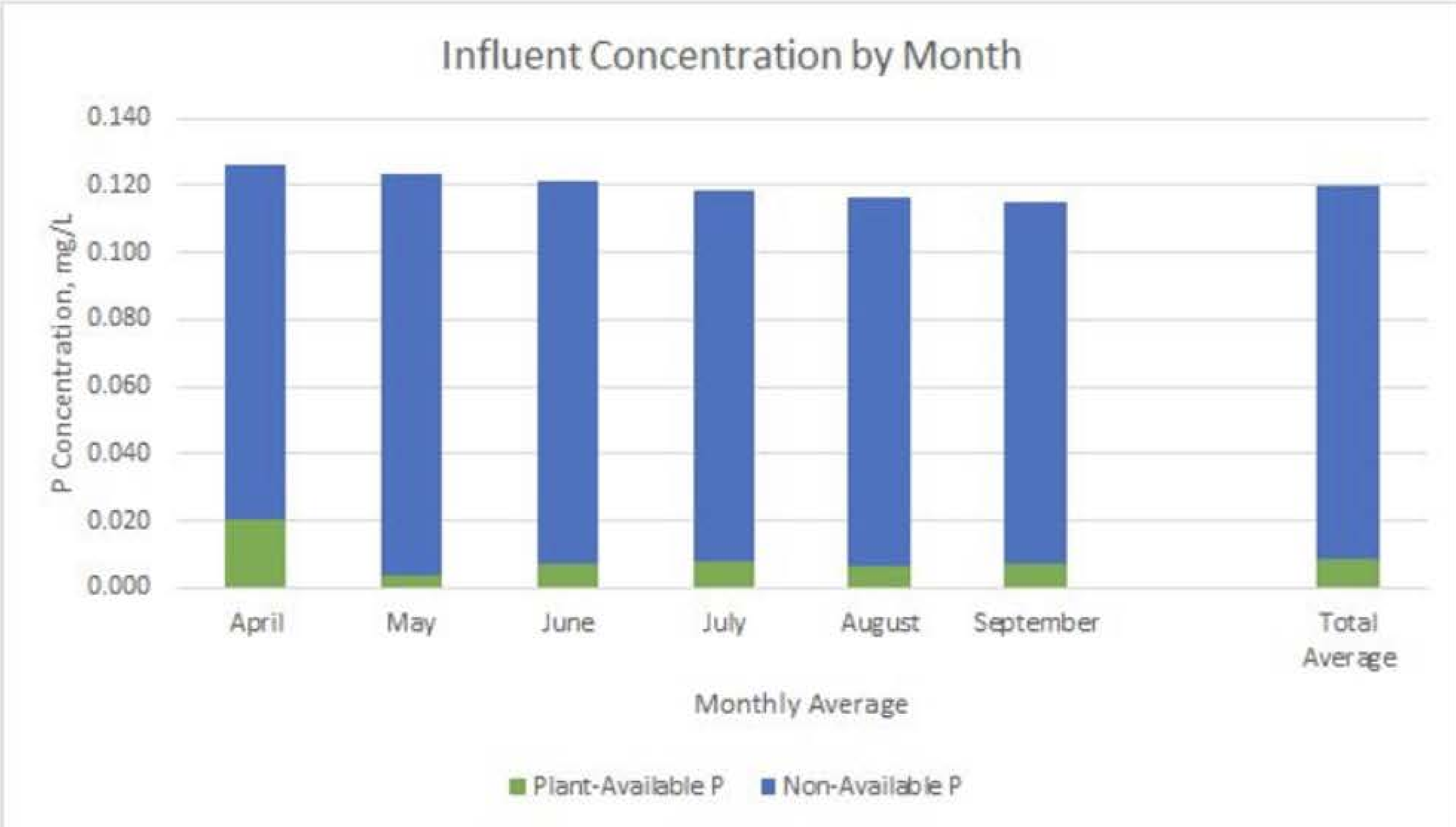


Figure 3: Total P concentration coming into the system, shown as both plant-available and non-available P

Table 1: Total P removal in lbs by the system's biological component

Removal Month	Operation Time, Days	Total Water Treated, L	Total Influent DRP, lb	DRP Removed by Plants, lb	Plant Removal Efficiency of DRP, %
April	30	64800	0.0030	0.0024	83.0
May	31	66960	0.0006	0.0006	100
June	30	64800	0.0011	0.0011	100
July	31	66960	0.0011	0.0011	100
August	31	66960	0.0010	0.0010	100
September	30	64800	0.0010	0.0010	100
Yearly Average	183	395280	0.0078	0.0078	100
10 Year Average	1830	3952800	0.0779	0.0779	97.6

representation of the net benefits seen as "revenue". Then, a return on investment could be calculated using these values.

Safety section

There are many aspects of this project that require intense safety review, since the reactor will be floating in open water. The system will be facing cross traffic with boats, swimmers, and wildlife, so it must be outfitted with appropriate equipment, such as lighting and reflective tape, so it will be highly visible during both day and night. The structure and frame of the system must also be properly reinforced and buoyant enough in the event of extreme circumstances so there is a minimized chance of injuring someone or an accident. This includes anything from intense weather to someone climbing aboard to use as a fishing platform.

calculations assume two independent streams that flow through three separate trays; the first tray being switchgrass, the second tray being alfalfa, and the third tray being duckweed.

Switchgrass (Panicum vergatum)

Switchgrass is a common grass used in riparian buffer zones to treat infiltrating runoff. It is known for its durability in low nutrient conditions. In order to implement switchgrass into the bioreactor, the phosphorus uptake rate must be known. Research based on switchgrass P uptake in soil was able to provide a starting point for the P uptake of switchgrass, but having grown in soil, the P uptake rate was too high. The P uptake rate was based off an experiment conducted in southeastern United States where the soils were fertilized with poultry litter, high in phosphorus. With high phosphorus soils, switchgrass was shown to have a P uptake rate of 300-500 mg/plant over the three month harvest. Manipulating that uptake based on the lake water concentrations provides a phosphorus uptake rate of .58 mg/m^2-day (Missaoui, 2004).

Alfalfa (Medicago sativa)

Although alfalfa does not have common applications for water quality treatment similar to duckweed and switchgrass, alfalfa has the ability to grow hydroponically, and it has the highest P uptake rate amongst similar hays. To determine the phosphorus uptake rate for alfalfa, an experiment was conducted using both young and old shoots of alfalfa where they were grown in various soil conditions ([0 and 70 kg N/ha], [0, 17, 34 kg P/ha]). The data used by this research was that of the young alfalfa shoots along with the lowest nutrient concentrations because the alfalfa will have to be grown from seedlings, and the lowest nutrient conditions best simulate the lake water conditions. Based on those conditions, the alfalfa had a P uptake rate was found to be 1.56 mg/m^2-day (Fan, 2016).

Duckweed (Lemna obscura)

Duckweed was chosen as the last plant in the series and is also the plant with the highest uptake rate. Duckweed is known as a floating aquatic macrophyte and has been studied previously in phosphorus uptake applications, often in wastewater treatment. Data for the amount of phosphorus taken up by duckweed was adapted from a study using different macrophytes for treatment of dairy farm wastewaters. A maximum phosphorus removal rate from duckweed was reported as 109 mg/m^2-day, but it is important to note that not only is this the maximum value, but that the influent concentration of phosphorus in these dairy wastewaters was much higher than our influent phosphorus concentration in the Yahara River. An uptake rate of 20 mg P/m^2-day was used in calculations instead, as this was the average reported uptake during a study period taking place in both winter and summer (DeBusk, 1995).

Appendix

The software VisualMinteq was used to model the chemical reactions within the lake system. https://vminteq.lwr.kth.se/

Dr. Micheal Doran, Adjunct Professor of Civil and environmental Engineering UW-Madison, provided the concentrations of the chemical species found in Lake Mendota, which can be found in the table below.

Table 5. Concentration of Chemical Species found in lake Mendota

Species	mg/L
H+	3.528
Ca2+	60
Mg2+	45
K+	14
Na+	23
SO42-	274
Cl-	328
PO43-	0.001 – 0.2
CO32-	162
NO3-	25
Al3+	0

on voluntary best management practices and, in some cases, legislation being put into place. For the Yahara lakes, which have been subject to nutrient overload for almost a century, it is important that a system is put in place to remediate phosphorus that has already entered the lake system.

This project aims to create a system that Dane County can use outside of the winter months to continuously filter phosphorus out of water, with the ultimate goal being a reduction in eutrophication occurrences that lead to beach closings and health hazards. Because this system would be implemented and maintained by the local county government, it must be a feasible option that provides significant benefit to the lake ecosystem while still being cost effective, low maintenance, and desirable to the local community. While there are no bounds on the mechanism by which our system will remove the phosphorus, our team has decided to go with a bioreactor system in order to design a solution that is free of chemical and advanced physical processes, which would likely be costly and require more maintenance. A bioreactor would also be able to better integrate with the lake ecosystem, as no chemical additives would be used and there is less potential for foreign byproducts.

We plan to begin the project of by designing a stationary, anchored bioreactor that would contain a floating matrix of soil and phosphorus-removing plant species. The biomass growing on the reactor would take up excess phosphorus from the highly concentrated lake water. Depending on the cost and complexity of a stationary reactor, it may be possible to expand the design to allow for movement of the reactor in the lake system. This would likely increase the cost of the project by a large margin, however, especially if a GPS system is used to pilot the reactor.

Project Goal

The project goal is to develop a biological and chemical hybrid system that is able to efficiently remediate the high concentrations of phosphorus in the Yahara lakes while being both cost effective and low maintenance.

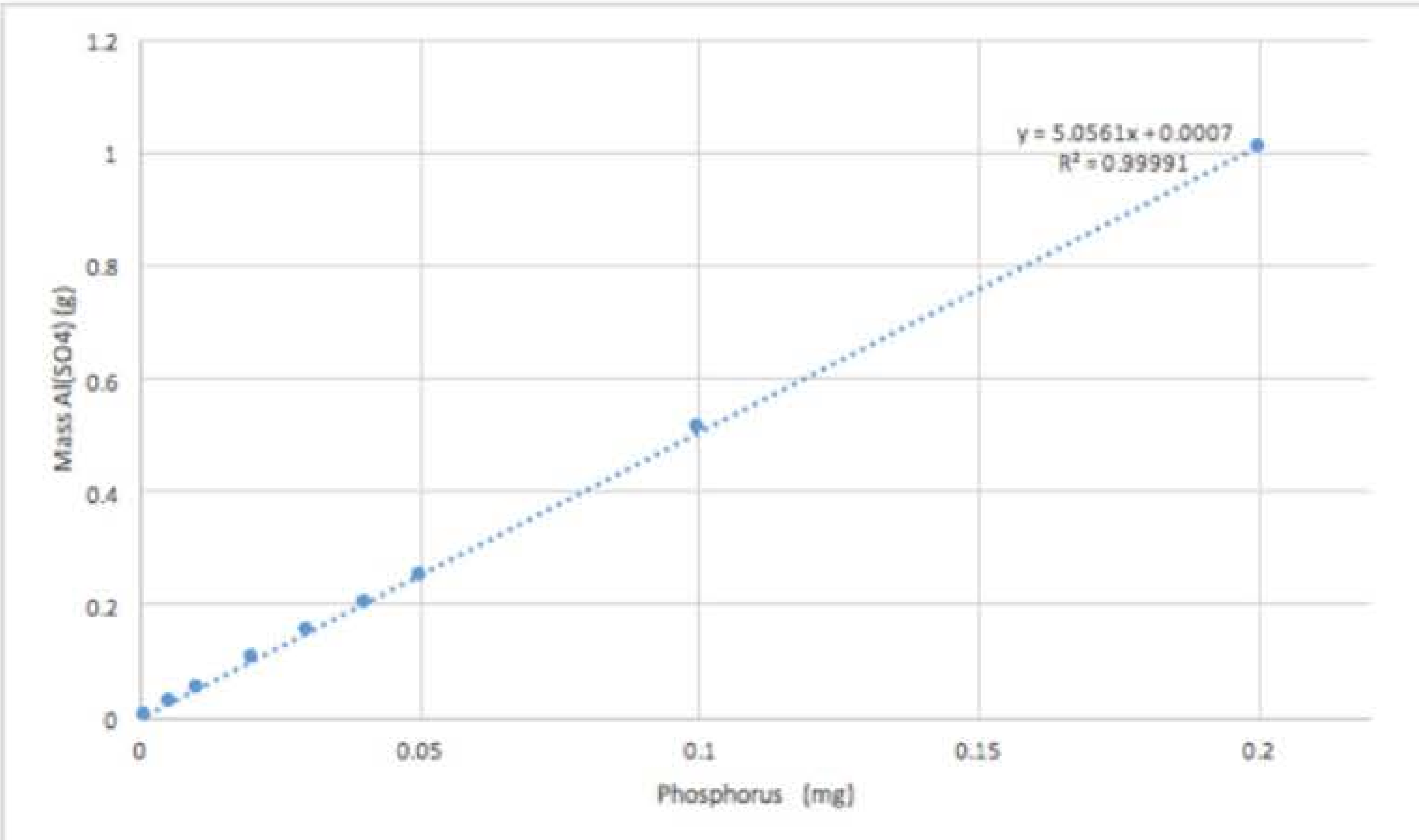


Figure 5: Mass of Alum (g) needed for different Phosphorus concentrations removed (mg)

Limitations:

The chemical modeling using Visualminteq is rather limited as it only accounts for the known chemical species, and is unable to factor in the aluminium reactions with other heavy metals and organic compounds (Awab, Paramalinggam, & Yusoff, 2012). Therefore, experimental dosing would be required to obtain the most optimal mass required for phosphate removal.

In addition, if phosphates are lacking in the water supplied to the chemical filter, alum would instead react with hydroxide. This not only results in a redundant utilization of alum which decreases the amount of alum that could be used to remove phosphates, but forms aluminium hydroxide and other species which could be toxic to fish and some aquatic invertebrates (Gensemer & Playle, 1999).

The aluminium complexation reaction though thermodynamically favourable, would require time for the alum and the phosphates to react. Due to the low concentrations of phosphate within our system, a longer residence time would be required than a typical rapid mixing contact time of 30 to 60s retention time (Coagulation and Flocculation in Water and Wastewater Treatment). Hence, our system may not be as effective in enabling the coagulation reactions to occur.

This aluminium hydroxide precipitate would utilize hydroxides in the water, making the effluent discharge more acidic. If the pH drops to below 6, there would be a higher likelihood that Al3+ ions would be released into the water. Therefore, a pH drop to that extent has to be prevented as it would be toxic to aquatic species (Kennedy & Cook, 1982). However, due to the low retention times, this should not be an issue as the alum would not have consumed enough hydroxides to significantly alter the pH levels.

Chemical Component Results

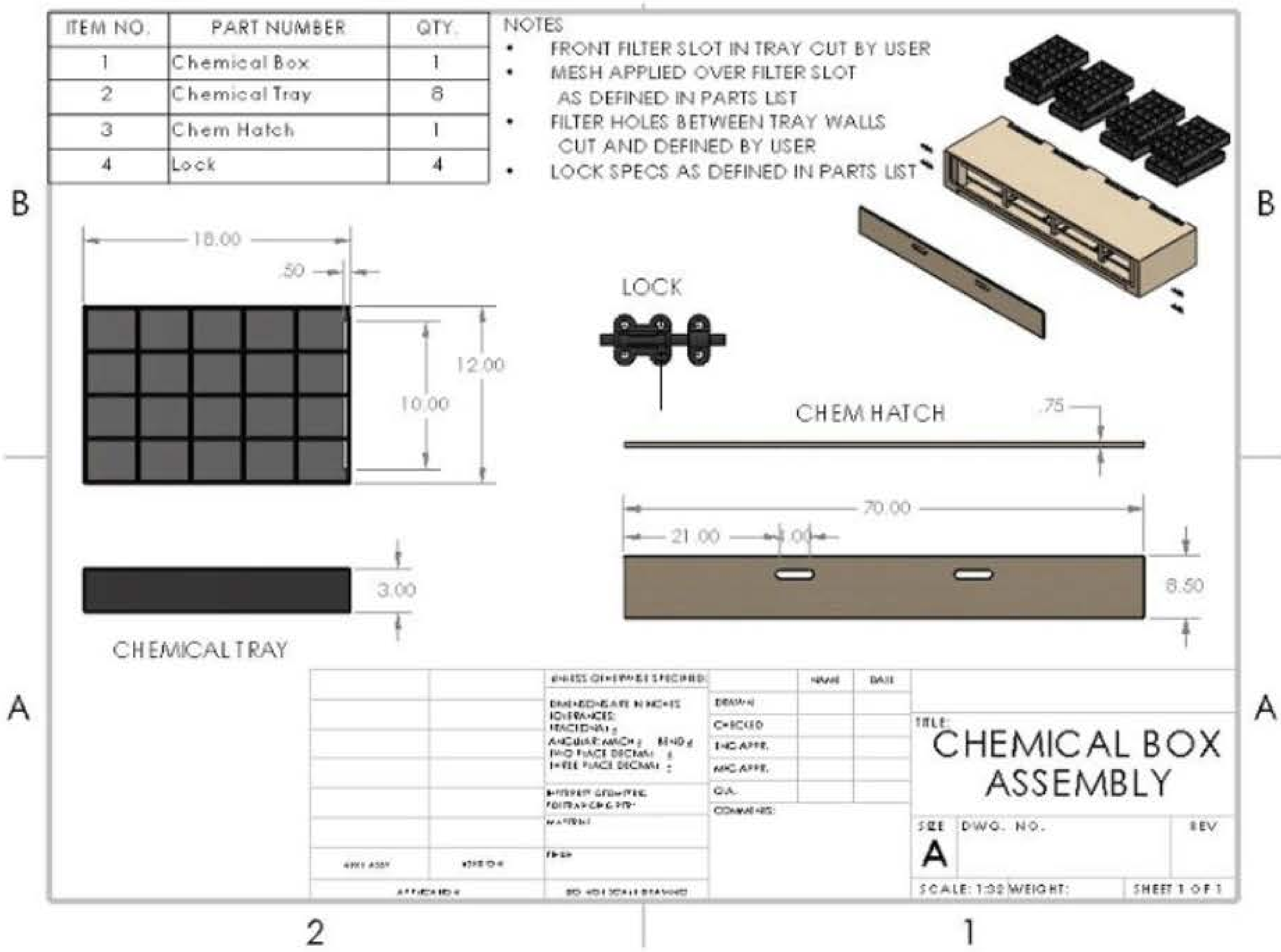
The efficiency of the system was estimated to be 70% as phosphorus removal at higher concentrations of phosphorus (1mg and above) has efficiency values of 80-90% (Wisconsin Wastewater Operator's Association).

Combined Biological and Chemical Results

It is assumed that the bioreactor will be in use from April through September and will work 24 hours a day, 7 days a week. Table 3 below shows the total amount of water treated as well as the total phosphorus removed by each mechanism. Figure e displays the amount of phosphorus removed by both plants (green) and alum (blue) from the total phosphorus present in the influent.

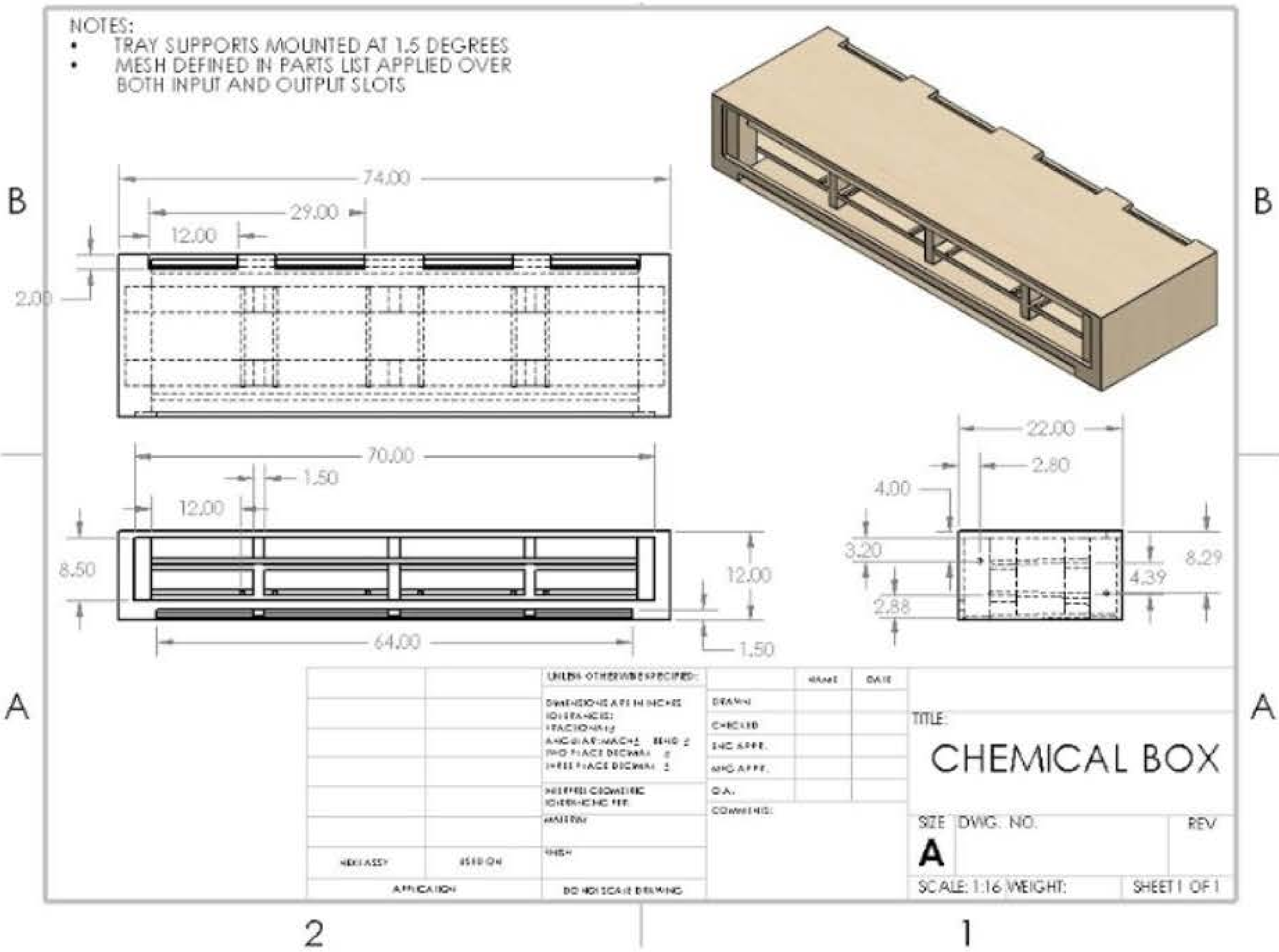
Table 3: Amount of water treated by the system and the corresponding phosphorus removed

Removal	Operation Time, Days	Total Water Treated, L	P Input, lb	P Removed by Plants, lb	P Removed by Chemical, lb	P Output, lb	Efficiency, %
April	30	64800	0.018	0.002	0.011	0.005	74.1
May	31	66960	0.018	0.001	0.012	0.005	71.0
June	30	64800	0.017	0.001	0.011	0.005	71.9
July	31	66960	0.018	0.001	0.011	0.005	72.0
August	31	66960	0.017	0.001	0.011	0.005	71.7
September	30	64800	0.016	0.001	0.011	0.005	71.8
Yearly Average	183	395280	0.105	0.008	0.068	0.029	72.2
10 Year Average	1830	3952800	1.046	0.078	0.678	0.290	72.2



ITEM NO.	PART NUMBER	QTY.
1	Chemical Box	1
2	Chemical Tray	8
3	Chem Hatch	1
4	Lock	4

NOTES
• FRONT FILTER SLOT IN TRAY CUT BY USER
• MESH APPLIED OVER FILTER SLOT AS DEFINED IN PARTS LIST
• FILTER HOLES BETWEEN TRAY WALLS CUT AND DEFINED BY USER
• LOCK SPECS AS DEFINED IN PARTS LIST
18.00
.50
12.00
10.00
3.00
CHEMICAL TRAY
LOCK
CHEM HATCH
.75
70.00
21.00
1.00
8.50
TITLE:
CHEMICAL BOX ASSEMBLY
SIZE DWG. NO. REV
A
SCALE: 1:32 WEIGHT: SHEET 1 OF 1
B
A
2
1



NOTES:
• TRAY SUPPORTS MOUNTED AT 1.5 DEGREES
• MESH DEFINED IN PARTS LIST APPLIED OVER BOTH INPUT AND OUTPUT SLOTS
74.00
29.00
12.00
2.00
70.00
1.50
12.00
8.50
12.00
64.00
1.50
22.00
2.80
4.00
3.20
2.88
8.29
4.39
TITLE:
CHEMICAL BOX
SIZE DWG. NO. REV
A
SCALE: 1:16 WEIGHT: SHEET 1 OF 1
B
A
2
1

Phosphorus Bioreactor

Rachel Hollingworth, Jacob Olson, Xavier Santana,
Derek Ho, Andrew Meng

Biological Systems Engineering

12/17/18

The effluent of the plant systems leads directly to the chemical system and is split into 4 separate flows through 2 trays of chemicals per flow. Each tray (1'x1.5'x ¼') due to structural limitations can only contain 40lbs (18.15kg). Hence, each tray would be filled with 17.8 kg of Aluminum sulfate and 0.35kg of bio-filter balls. The biofilter balls would facilitate water flow through the compacted chemical trays and increase the nucleation surfaces areas to improve precipitation rates. The trays as depicted in the figure below would be modified to allow water to flow through. These trays would be arranged at an angle, with the shorter edge raised to facilitate a meandering cascading water flow.

To increase residence time of the water flowing through our system, small holes would be drilled in the inner compartment walls to create a controlled flow path. Holes would be drilled along the path in figure y below to create meandering flow channels.The final compartment would have multiple holes drilled on its base to allow water to escape the tray. This water would be fed to a subsequent tray with a similar pattern before being released back into the lake. Each hole would be covered with a wire mesh to capture the aluminium hydroxyl phosphate precipitate. Further experimentation would be required to obtain the optimal mesh size that would allow a high flow rate yet not be clogged by the precipitate.

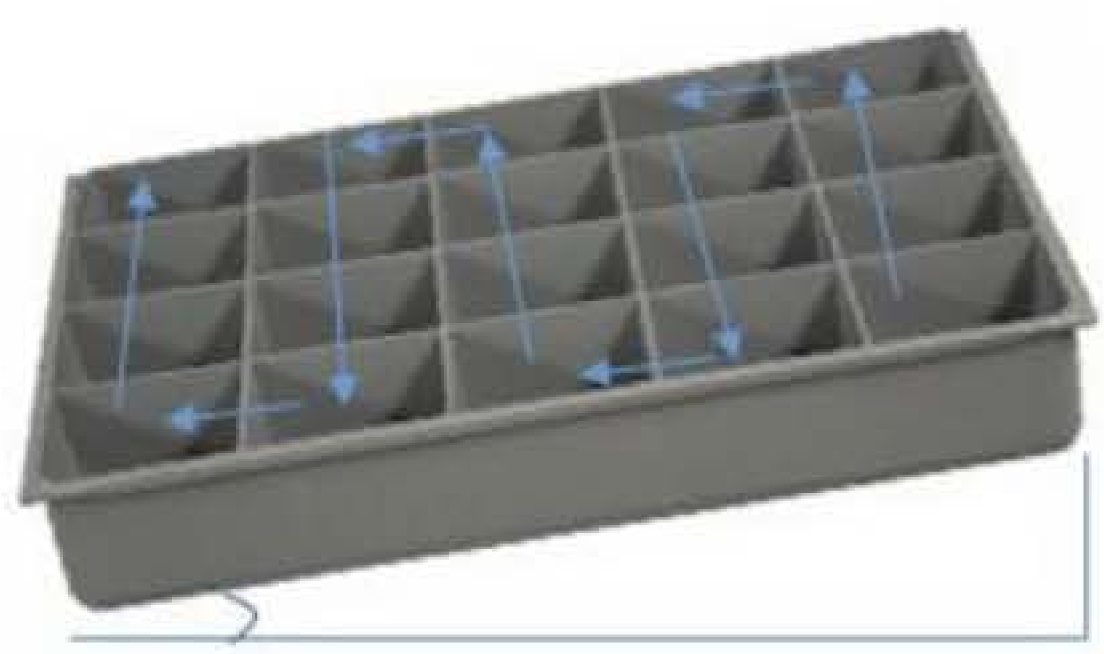


Figure 4: Retrofitted chemical compartment tray

With the 17.8kg of Alum packed into each tray, the mass of phosphorus removed can be calculated using the graph below in figure d, where (g Alum) = 5.0561*(mg Phosphorus) + 0.0007. Using this equation,each tray would theoretically be able to precipitate out 3520.5mg of Phosphorus. Therefore, the total filtering capacity of 8 trays should be able to remove 28,164mg of Phosphorus. With an influent rate of 0.025L/s with an average concentration of 0.11mg P/L from the plant effluent, an average of 7,905mg of phosphorus would be entering the chemical fitration system. At this rate, the trays would be fully saturated after 3 months and would need to be refilled with new alum. In addition, the alum would lose up to 75% of its ability to adsorb phosphates after 90 days (de Vincente et al, 2008).

Parts & components lists

Table 4. Parts list with quantity, cost, and weight

Name	Quantity	Total Cost ($)	Weight (lb)
Components/Extras???			
12 ft Pontoons	2	1900	
8 ft Pontoon	1	750	
Anchor 18 lbs	1	35	
80 ft Rope	1	8.99	
3'x3'x6" Plant Trays	6	234	36
Solar Panel	1	94.99	18.1
Battery	1	172.99	2.74
Battery Casing (platics tool box)	1	8	3
Water pump	1	23.99	1.3
Water pump cover	1	9.29	Negligible
Screen Mesh 48" x 25'	1	25	8
Wood water Sealant 5 gallon	1	49.98	9
KILZ Adhesion	1	17.11	2
Flexible Translucent PE Plastic Sheet 48x24x1/30	7	139.65	1
4" Base Cleat	1	17.55	Negligible
Reflective Tape	1	50	Negligible
Building Materials			
Wedge Frame			164.3
4x4x8	3	23.64	
2x4x8	28	133.56	
Platform Frame			310
2x6x16	6	100.74	

pickerelweed - 5 rhizomes	5 rhizomes		Negligible
alfalfa innoculant - 1 lb	10	69.5	Negligible
Hydroton	2	469	720
Chemical			
Materials			
Aluminum Sulfate (per ton)	1.43	214.5	320
Chemical Tray	8	123.68	32
Biofilter balls	5	194.5	Negligible
Box			66
4x4x8	1	7.88	
3/4x4x8 Plywood	2	67.96	
6" barrel bolt, padlockable	4	19.96	
1x4x8	4	17.48	
2x4x8	1	4.77	
3/4 in. x 72 in. Hardwood Round Dowel	2	12.52	
Total		**5650**	**1750**

Actual design specifications

- Water pump must provide 1.5 L/min of water to the system and the plant trays need to be mounted at ~1.5 degree angle in order to operate at desired residence time
- Solar panel battery and wires correctly insulated/encapsulated in order to ensure they are water-tight
- PVC pipe need KILZ Adhesion coating to ensure UV protection
- All wood incorporated in structure needs waterproof coating
- Caulk applied over screws that mount the plant trays
- Apply for a waterway protection "Miscellaneous Structures" permit
    - A permit would be issued for the structure if the review process finds that all of the following requirements are met:
    - 30.12(3m)(c)1. **1.** The structure or deposit will not materially obstruct navigation.

2. There are several phosphorus-filtering membranes on the market currently, though most are intended for wastewater purposes.
3. There are also phosphorus-removing membrane bioreactors, which combine a filtration process with a bioreactor

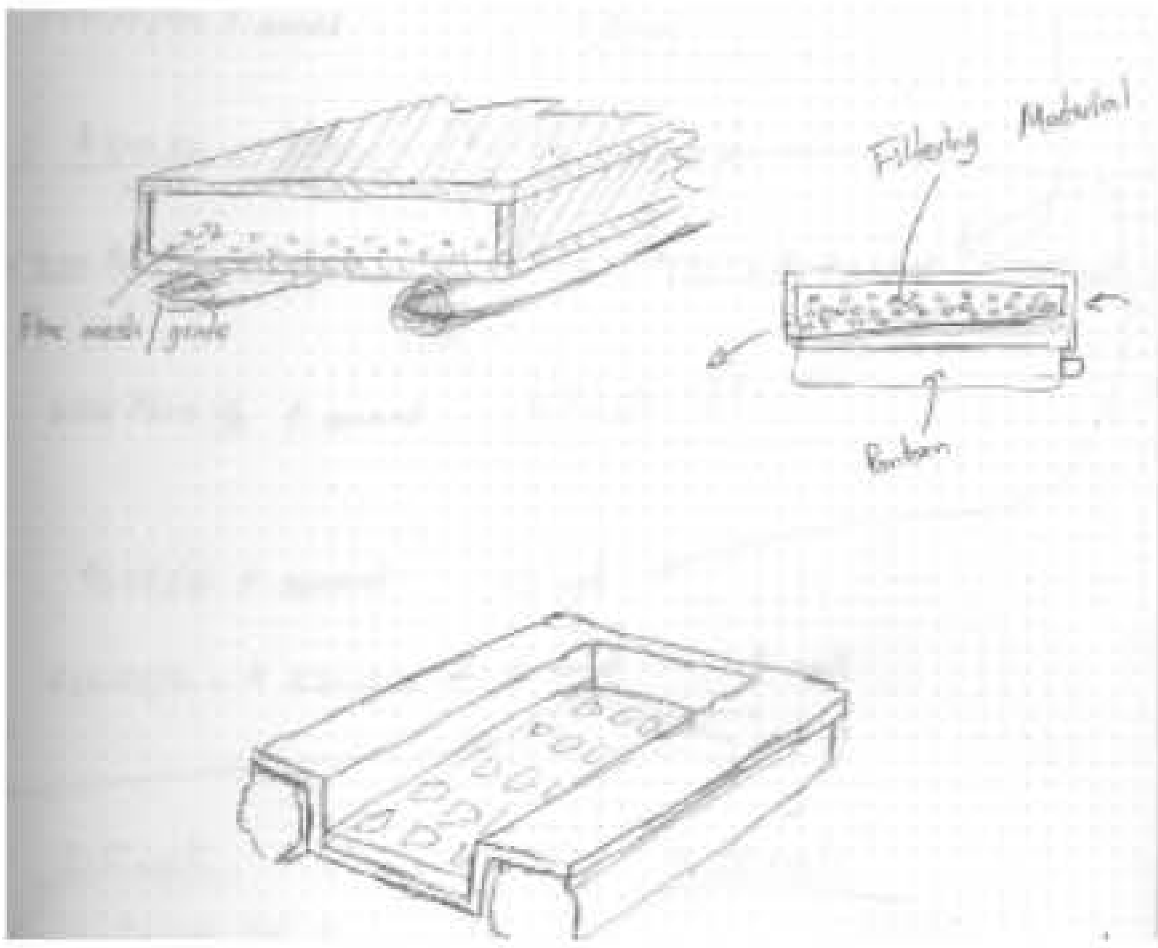


Figure 8. Membrane filter design concept sketch

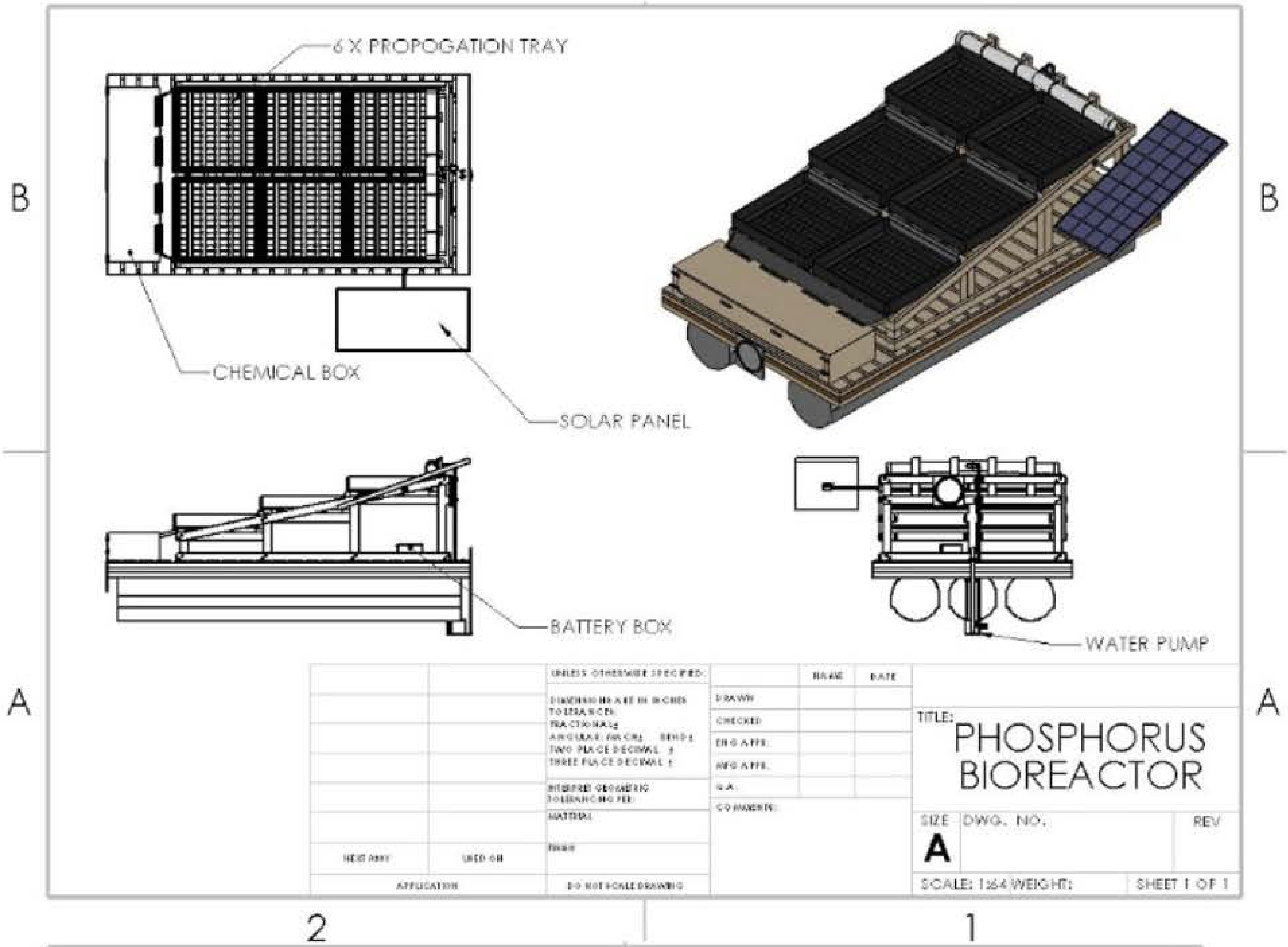
Floating raft with Zebra Mussels

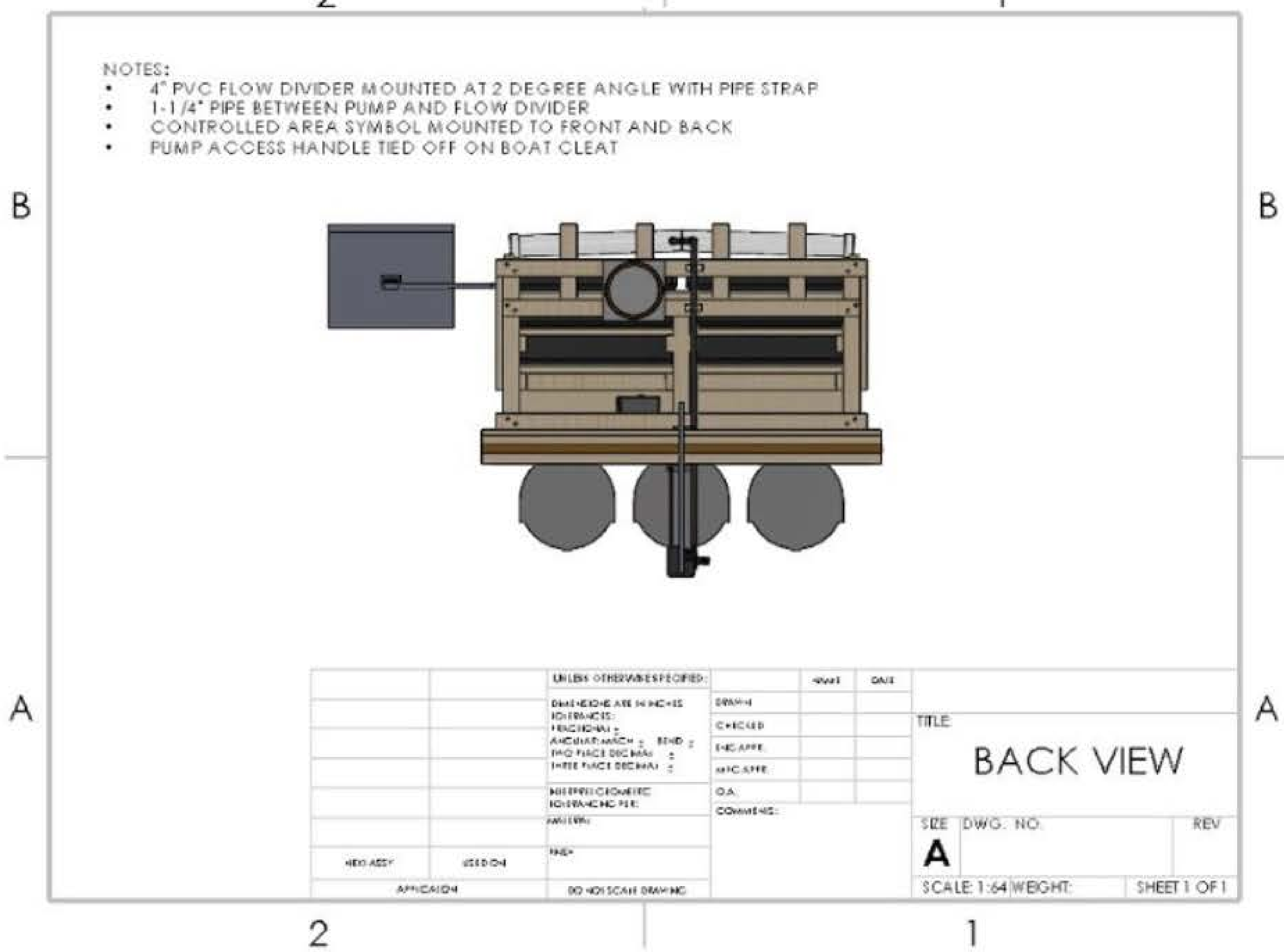
1. This design incorporates a large floating raft with a housing that would contain zebra mussels on the inside.
2. Water would be pumped through the housing to constantly have Phosphorus available to the zebra mussels.
3. As lake water flows through housing chamber the zebra mussels uptake the Phosphorus and the lake water eventually flows out the other end.

Justification

We chose our current design because it fit within our determined design specs and is a relatively basic solution with minimal moving parts, making it more cost effective, easier to manufacture, and having less of a chance of failure. Utilizing both a biological and chemical process, the system is diverse which allows it to have a higher success rate in the case of something not performing as expected. Some of the advantages to the design include it only needs a minimal amount of servicing each season and it incorporates plants that are multifunctional, not only making the bioreactor look more appealing to the public but also can be harvested for use as animal feed. There are also no negative environmental impacts caused by the chemicals being used at our usage rate and no invasive species being introduced into the environment that would need constant controlling. Finally, the design is dimensioned so that it can be transported on the road, which allows for greater effectiveness as it can be placed in many different desired areas. Overall, it was the best design and process for our given parameters.

Engineering Drawings





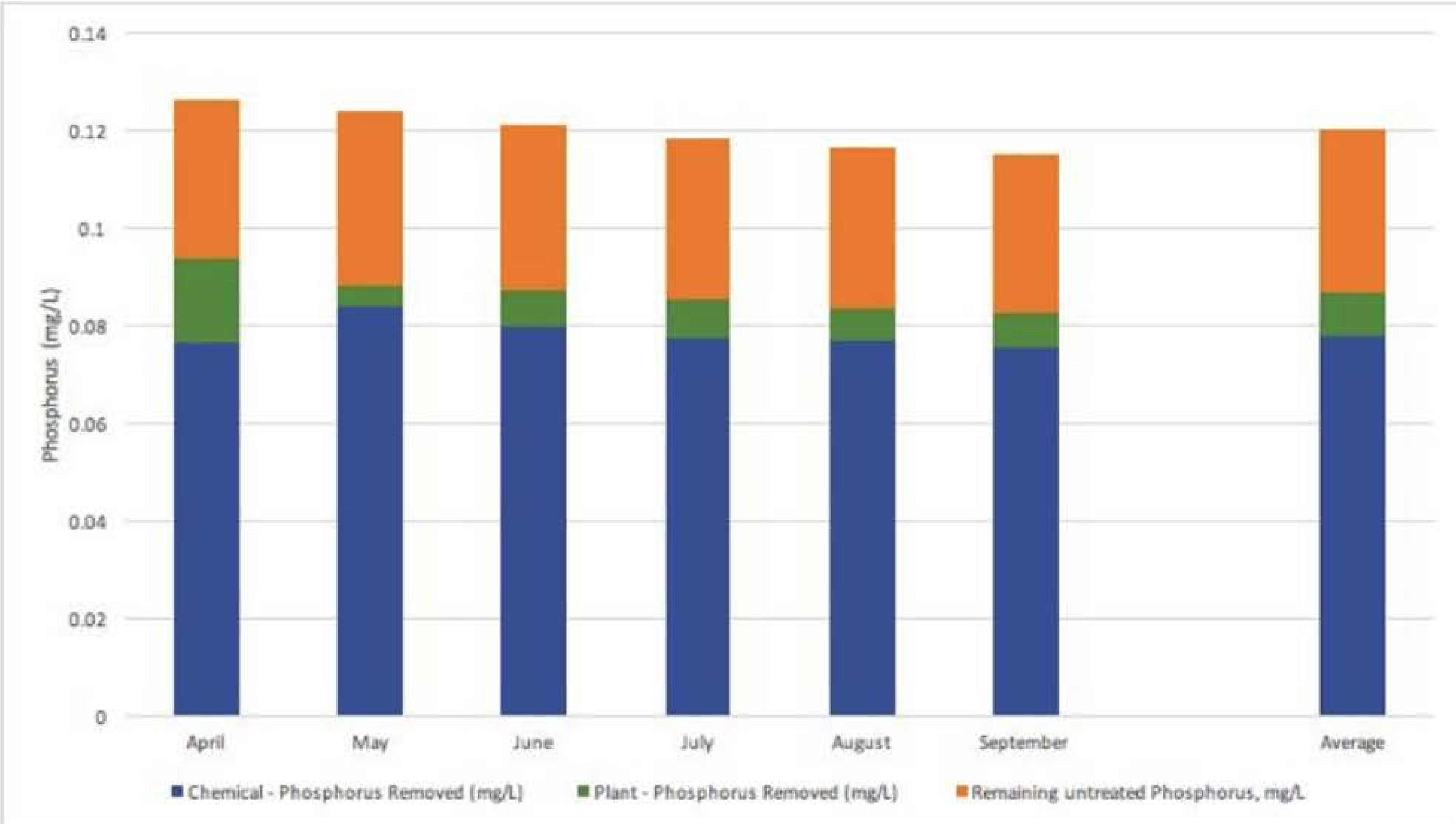


Figure 6: Phosphorus removed by Plants (Green) and Chemicals (Blue) with the remaining untreated Phosphorus (Orange)

The average combined efficiency of the system is 72.2% total phosphorus removal. Through experimentation, however, there is expected to be significant room for increased efficiency.

Several modifications could be tested with the biological component. As described above, the phosphorus removal by plants stands to increase with an increase in DRP concentration. This device is expected to perform much better in a smaller waterbody that has a more concentrated DRP, or alternatively there could be a mechanism added to the bioreactor that would further concentrate the influent stream before sending it to the plant trays. It is also possible that the hydroponic system could be altered to allow for higher flow rates and thus more DRP moving through the system. This would likely have positive results during the months where 100% of the DRP was used by the plants, but in other months where less than 100% of the DRP was removed it may negatively affect uptake by shortening the residence time of each tray. Additionally, the ability of the plant species to be grown in moving water should be considered, as many plants cannot tolerate flow rates greater than 1.5 L/min.

The plant species chosen for this bioreactor were determined based on previous usage in a water treatment setting and each species was implemented equally in the case that one of them did not survive. Ideally the most experimentally effective plants would be used over lower-performing species in coordination with the device's intended location and climate. In some areas it may also be possible to grow a desirable crop using the hydroponic system. This

- The cost effectiveness should be more cost effective than average wastewater remediation methods, which range from \$14 - \$52 per pound of phosphorus removed for effluent concentrations of 1 mg/l to \$51 - \$130 per lb of phosphorus removed for effluent concentrations of 0.05 mg/l.
    - (Bashar, 2017)
    - (Keplinger, Houser, Tanter, Hauck, Beran, 2004)
    - (Jiang, Beck, Cummings, Rowles, Russell, 2005)
- The fabrication of the product should be simple and replicable to maximize the number of reactors that could be made in total. The more reactors that could be launched will greatly increase the area benefitted by the system.
- It must be designed for use during the Spring to Fall season when the lake is open and when there is no ice.
- The construction material used must be buoyant and not leach any unwanted pollutants into the lake.

Data

Plant Methodology and Design

For determining the efficiency of the biological component of the remediation system, a series of calculations was used to model the uptake of dissolved reactive phosphorus (DRP) by the plants. Data for the influent concentrations of phosphorus in milligrams/liter were taken from a daily reporting gauge maintained by the USGS at the Yahara River inlet to Lake Mendota (USGS, 2007-2017). This data, which includes daily readings from 2007-2017, gives the concentrations for both DRP and total phosphorus content of the water. Assuming that the device would be operational for twenty-four hours a day each day in the months April through September, the average concentrations for DRP, plant unavailable phosphorus, and total phosphorus were calculated for each month. These averages were also combined into a total average concentration of the operational months.

The calculations follow the water through the system in batches. The water pump provides 1.5 L/min of flow and is split into two streams for each series of three plant trays. Thus, about 0.75 L/min is flowing through the trays at once. With each tray having a bottom area of 9ft^2 and an assumed water height of 4 inches, the volume in each batch is about 85 L. The concentration of this 85 L is evaluated as it moves from tray 1 to tray 2 to tray 3. The residence time of a batch in each tray at this flow rate and volume is about 57 minutes.

The series of plants was set up in order of phosphorus uptake rates from lowest to highest. This was to ensure all plants would get an adequate amount of plant-available DRP. The

Introduction

The city of Madison, Wisconsin finds itself surrounded by lakes that have shaped the life of its citizens and fostered a strong culture of outdoor recreation throughout the area. Rarely does a resident forget to mention them when boasting of their hometown, and in the summertime the sheer amount of people swimming, fishing, boating, and enjoying local beaches is a testament to the importance of these precious water bodies. But while population and agricultural demands have grown, so too have issues regarding Dane County's water quality. As we look towards the future of life in the State of Wisconsin, it is crucial that we strive to keep our resources not merely in abundance but in a state that allows a healthy ecosystem to flourish.

The biggest issue concerning Dane County's water quality is the annual amount of phosphorus that makes its way into the Yahara lake chain, which includes lakes Mendota, Monona, Waubesa, and Kegonsa. The Yahara watershed that feeds these four lakes is 1,026 sq km of agricultural and urban lands with 553 sq km of that area draining directly into the largest lake of the watershed, Lake Mendota. With a residence time of 4.4 years, water moves into Lake Mendota from the Yahara River and continues downstream to the lower Yahara lakes (Carpenter, 2013). Issues with excess nutrients causing poor water quality have been recorded in Dane County since the 1800s, but became a contentious issue in the 1940s as industrialization, urbanization, and agriculture booms over the past century drastically increased nutrient concentration and subsequent eutrophication in the lakes (Lathrop, 2007). Today, wastewater treatment and better agricultural practices have drastically reduced the amount of nutrients that accumulate in lake waters, and the average amount of phosphorus loading in Lake Mendota to 33,400 kg P / yr, with most of it coming from nonpoint agricultural sources (Lathrop, 2014). This amount is significantly better than that of the past, but water quality issues in all Yahara lakes persist.

While both nitrogen and phosphorus contribute to eutrophication in lakes, nitrogen was found to be the limiting reactant for algal blooms consistently in the Yahara lakes (Lathrop, 2007). After initial phosphorus loading into Lake Mendota, the phosphorus flows downstream into the lower lakes. Thus, each lake in the chain receives phosphorus inputs from the outflow of the upstream lake as well as from the drainage of its own subwatershed. This phosphorus flow is

Kennedy, R. H., & Cook, G. D. (1982). CONTROL OF LAKE PHOSPHORUS WITH ALUMINUM SULFATE: DOSE DETERMINATION AND APPLICATION TECHNIQUES 1. *JAWRA Journal of the American Water Resources Association*, *18*(3), 389-395.

Keplinger, K. O., Houser, J. B., Tanter, A. M., Hauck, L. M., & Beran, L. (2004). *Cost and Affordability of Phosphorus Removal at Small Wastewater Treatment Plants*(Small Flows Quarterly Juried Article). https://dnr.mo.gov/env/wpp/rules/rir/docs/keplinger-etal-2004.pdf

Kovar, J. L., & Claassen, N. (2009). Growth and phosphorus uptake of three riparian grass species. *Agronomy Journal*, *101*(5), 1060-1067.

Lathrop, R. C. (2017). Linking Science and Management for Reducing Blue-green Algal Blooms in the Yahara Lakes [PowerPoint slides].

Lathrop, R.C. (2009). Controlling Eutrophication in the Yahara Lakes: Challenges and Opportunities [PowerPoint slides]. Retrieved from https://nelson.wisc.edu/events/community-environmental-forum/docs/lathrop_012709.pdf.

Mantus Marine. (2018) *Anchor Sizing.* www.mantusmarine.com/mantus-anchor-knowledgebase/anchor-sizing/.

Missaoui, A. M. (2004). Genetic Variation and Heretability of phosphorus uptake in Alamo Switchgrass. *ElSEVIER, Volume 93.* 186-198.

Plastic Pontoon. (2018). Our Products. Retrieved September 19, 2018, from http://www.plasticpontoon.com/products.html

Robertson, D. M., Saad, D. A., Christiansen, D. E., & Lorenz, D. J. (2016). Simulated impacts of climate change on phosphorus loading to Lake Michigan. Journal of Great Lakes Research, 42(3), 536-548.

Rolyan Buoys & Floats. (2010). *Accessories for Water Safety* [PDF file]. Retrieved from https://www.rolyanbuoys.com/static/version1535415005/frontend/RolyanBuoys/default/en_US/pdfs/BuoyCatalog.pdf

SafetySign. (2018). *What Are ANSI Color Codes?* www.safetysign.com/help/h58/what-are-ansi-color-codes.

United States Geological Survey (USGS). (2007-2017). *USGS Current Conditions for USGS 05427850 Yahara River at State Highway 113 at Madison, WI.* Retrieved from https://waterdata.usgs.gov/nwis/dv/?site_no=05427850&agency_cd=USGS&referred_module=qw

West Marine. (2018). *Selecting the Right Anchor.* www.westmarine.com/WestAdvisor/Selecting-The-Right-Anchor.

WI DNR. (2018). *Controlling Invasive Species.* dnr.wi.gov/lakes/lakepages/LakeDetail.aspx?wbic=805400&page=facts.

WI DNR. (1981). *Lake Survey Map* [PDF File]. https://dnr.wi.gov/lakes/maps/DNR/0805400a.pdf

WI DNR. (2018). *Lake Water Quality 2018 Report*. Retrieved September 20, 2018, from https://dnr.wi.gov/lakes/waterquality/Station.aspx?id=133318

WI DNR. (2018). *Swim Raft Permit Requirements.* [PDF File]. https://dnr.wi.gov/topic/waterways/factsheets/SwimRaftFactsheet.pdf

Wisconsin Wastewater Operator's Association (n.d) Retrieved from https://www.wwoa.org/files/News/134.pdf

Yonge, D. (2012). A Comparison Of Aluminum And Iron-based Coagulants For Treatment Of Surface Water In Sarasota County, Florida. University of Central Florida. http://stars.library.ucf.edu/cgi/viewcontent.cgi?article=3434&context=etd

UW-Madison Luminology. (2014). https://wsc.limnology.wisc.edu/about/watershed

de Vicente, I., Huang, P., Anderson, F.O., & Jensen, H. S. (2008). Phosphate adsorption by fresh and aged aluminum hydroxide. Consequences for the lake restoration. *Environmental science & technology*, 42(17), 6650-6655

Figure 4. Compartment Box, 20 Compartments, 40 lb. (n.d.). Retrieved from https://www.zoro.com/durham-drawer-insert-20-compartments-gray-124-95-20-ind/i/G6211287/

Table 2.Data adapted from USGS Water Quality Daily Data at the Yahara River at State Highway 113 station in Madison, WI.

Table 4. https://www.homedepot.com/, http://www.plasticpontoon.com/24inch.html, amazon.com

Figure 10. Data adapted from USGS Water Quality Daily Data at the Yahara River at State Highway 113 station in Madison, WI.

Operational

- The design will include a bioreactor component as well as a chemical filter part of the remediation system
- The biological treatment method would utilize plants that are accustomed to taking up phosphorus in an aquatic setting
- The chemical treatment method would utilize either one of these reagents: aluminum based coagulant, ferric based coagulant or calcium carbonate, or a combination of the listed reagents. The selection of the most effective method would depend on its potential side effects like toxicity and pH change as well as reagent cost/ lb phosphorus removed.
    - (Yonge, 2012)
- The bioreactor should filter out 40% (+/- 20%) of total phosphorus from influent water taken into the system. The varying percent can be justified from the fluctuation in phosphorus levels in lake throughout the usable months.
    - (Brown, M. T., 2018)
    - (WI DNR., 2018)
- The bioreactor should have a significantly long lifespan with yearly maintenance. A life expectancy of 10 years is desirable.
- The design needs to be placed within 200 feet of the shoreline (WI DNR, 2018).
- It must be able to be hitched up on a trailer for easy transport and would have a maximum width of 8.2 ft (boat trailer dimension in most states). It should also be less than 14.1 ft tall to allow vertical clearance under bridges. It must also be able to utilize a boat ramp to launch the boat.

Environmental

- Our design should utilize vegetation that is able to seamlessly integrate into the Dane County lake ecosystem and can efficiently remediate phosphorus through biological pathways.
- The design must be safe for the surrounding ecosystem. It must not contain materials or chemicals that pose risk to the lake, and the location of our device should be chosen with the physical interactions of our system and the wildlife surrounding it in mind.
- It should also not introduce or allow further population of invasive species to flourish.

Cost & Manufacturing

- Overall, the cost of this project must be feasible for Dane County. Recurring costs are to be avoided, yearly maintenance costs should be minimized, and the implementation and storage of the device should not be labor intensive or excessive.

References

Awab, H., Paramalinggam, P. T., & Yusoff, A. R. M. (2012). Characterization of alum sludge for reuse and disposal. *Malaysian Journal of Fundamental and Applied Sciences*, *8*(4).

Bashar, R., Gungor, K., Karthikeyan, K. G., & Barak, P. (2018). Cost effectiveness of phosphorus removal processes in municipal wastewater treatment. Chemosphere.

Benedetti, Michael. (1996). *Ocean Topic in Greater Depth* www.aos.wisc.edu/~sco/clim-history/stations/msn/madwind.html.

Brown, M. T. (2018). *A Floating Island Treatment System for the Removal of Phosphorus from Surface Waters.* [PDF File]. Retrieved from (https://ac.els-cdn.com/S2095809918301875/1-s2.0-S2095809918301875-main.pdf?_tid=72d424e6-efc6-407c-8d7f-0cfe70737af4&acdnat=1537451751_fa231a43435be689fe84ce8d0f3a0f84

Clifford, H. (2018). *Lake Mendota Wave Height and Period Calculator*. Retrieved September 20, 2018, from http://homepages.cae.wisc.edu/~chinwu/CEE514_Coastal_Engineering/2007_Students_web/Heather_Brady/MendotaWaves.html#Results

Coagulation and Flocculation in Water and Wastewater Treatment. (n.d.). Retrieved from https://www.iwapublishing.com/news/coagulation-and-flocculation-water-and-wastewater-treatment

Dane County Regional Planning Commission, Dane County (Wis.). Department of Planning, Development. Community Analysis, Planning Division, & Capital Area Regional Planning Commission (Wis.). (2015). Regional Trends, Dane County, Wisconsin. The Commission.

DeBusk, T. A., Peterson, J. E., & Reddy, K. R. (1995). Use of aquatic and terrestrial plants for removing phosphorus from dairy wastewaters. *Ecological Engineering*, *5*(2-3), 371-390.

Fan, J. W. & Du, Y.L. (2016). Forage yield, Soil water depletion, shoot nitrogen and phosphorus uptake and concentration of young and old stand of Alfalfa. *ELSEVIER*

Gensemer, R. W., & Playle, R. C. (1999). The bioavailability and toxicity of aluminum in aquatic environments. *Critical reviews in environmental science and technology*, *29*(4), 315-450.

Jiang, F., Beck, M., Cummings, R., Rowles, K., & Russell, D. (2005). *ESTIMATION OF COSTS OF PHOSPHORUS REMOVAL IN WASTEWATER TREATMENT FACILITIES: ADAPTATION OF EXISTING FACILITIES*(Water Policy Working Paper #2005-011). https://pdfs.semanticscholar.org/91d8/73a8ab8f12a7faffacf7f05f308a500169e0.pdf

well known that eutrophication can cause the mass dying of fish as lake oxygen levels reach dangerously low levels. Historically, the Yahara lakes have experienced this as well as other ecosystem phenomena connected to eutrophication including increased carp populations and changes in aquatic plant densities. Today, there is concern that new invasive species may find similar advantages in the Yahara's eutrophic conditions, such as the zebra mussel, a crustacean that has already infested several Wisconsin lakes (Lathrop, 2007).

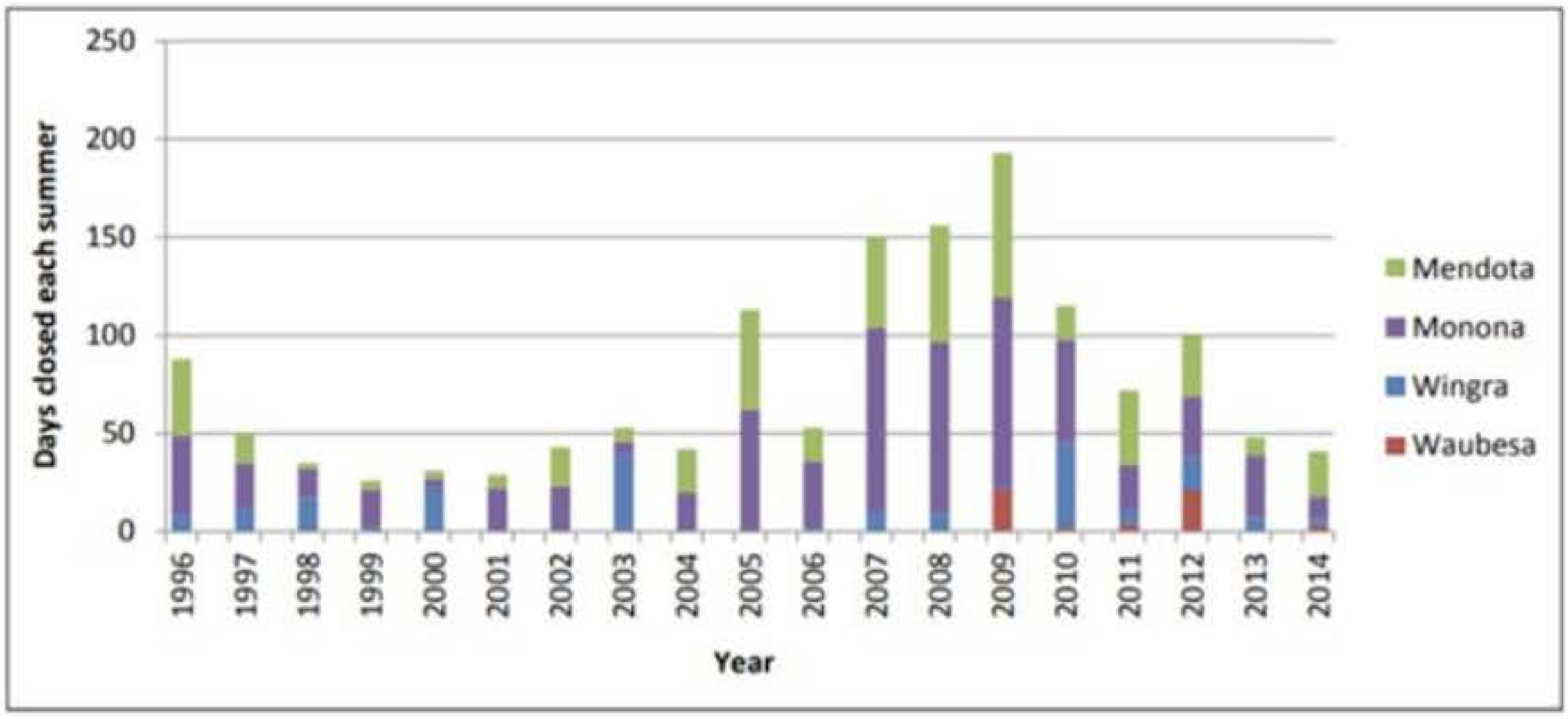


Figure 2: Madison Area Beach Closures by Year
Source: Madison and Dane County Public Health data

It is apparent that even with better controls, the phosphorus load in the Yahara lake chain is not being altered enough to prevent future issues. Additionally, there is reason to believe that phosphorus loading will worsen as time goes on, as global warming patterns are expected to increase rainfall runoff which transports phosphorus to water bodies (Robertson, 2016). Phosphorus data from recent years where Wisconsin has experienced flooding also show that these unexpected influxes of water contribute to an increase in summer phosphorus concentrations (Dane County Regional Planning Commission, 2015). The need to curb phosphorus loading into the Yahara lakes is time sensitive and directly impacts the future health of the Yahara lake ecosystem and the urban populace that surrounds it. Currently, most efforts to reduce the amount of phosphorus in the lake chain revolve around preventative measures to keep excess phosphorus from reaching lake waters. But many preventative efforts are also dependent

2x6x8	5	48.95	
1-5/32x6x12	11	75.68	
Water Pump Shelf & Solar Panel Mount			
2 Stainless Steel Hinges 3" x 1"	2	24.5	0.4
Galvanized Steel Sheet 12g 1'x1'	1	20	4.53
20' Galvanized Steel Flat Bar 1/4" x 1"	1	30	18.18
3' Galvanized pipe 1"	1	12	5
1" Galvanized Pipe Floor Flange	1	4	1
1" Galvanized Steel Tube Strap - 4 Pack	1	2	1
PVC and Piping			
4"x10'	1	18.34	20
4" Cap	2	4.42	Negligible
4" PVC 2-Hole Pipe Strap	4	6.36	Negligible
1-1/4" PVC 2-Hole Pipe Strap	2	1.1	Negligible
10' Black Vinyl Tubing	1	12	2
Poly Pipe Barbed Insert Tee	1	1	Negligible
Poly Pipe Barbed Insert Female Adapter	2	3	Negligible
Plants			
Duckweed - 100 live duckweed plants	10	72.3	Negligible
Switchgrass	10	299.4	Negligible