# Healthy Harbor

## *A Human-Powered Bicycle to Filter Urban Water Systems*

## FINAL DESIGN REPORT

**Bass Connections in Energy: Innovation and Design**


Kirsten Lew ’16
Gi Jung Lee ‘16
Cheng Ma ‘16
Megan McGufficke ‘16
Daniela Radvak ‘16
Liam Regan M.E.M.
Molly Rosenstein ‘16

Dr. Josiah Knight | Dr. Emily Klein


1 May 2016

# Table of Contents

# 1 Executive Summary

The Baltimore Inner Harbor is an extremely contaminated urban water source, which inspired our team to design a product that would mitigate the environmental issues plaguing the Harbor. We ~~eventually~~ decided to build a water filter, and Baltimore Harbor provides a perfect setting for this human-powered filtration system. While the system also filters contaminants from the water, its most influential aspect is the heightened awareness and public involvement it brings to water pollution issues. Through a careful decision analysis in the fall in the Bass Connections Innovation and Design Class, the team designed the filtration system. Coupled with strategic planning measures, the Healthy Harbor Group completed an alpha level prototype of a system that uses a human powered bike to pump polluted water through gravity fed sand filters. When the water leaves the filter, it does so in nearly potable conditions. The user receives instant feedback that the water is being cleaned and leaves with a heightened awareness of harbor health moving forward. The following report details the processes that yielded the final prototype and all of the design details. It also considers a full marketing plan that attempts to position the prototype in a manner that allows for market penetration and scalability as a functioning, fledgling limited liability corporation.

# 2 Introduction to the Problem

Water pollution is a problem that plagues many urban environments that are located next to large bodies of water, and Baltimore's Inner Harbor is no exception. The Inner Harbor's water quality has plummeted to a point that makes it unsafe for swimming and fishing due to high levels of contamination. Baltimore's Annual Healthy Harbor Report Card, which monitors changes in water contamination, gave the Inner Harbor's water quality a grade of D-, and the overall Baltimore water system received an F[1]. There are three main sources of pollution that threaten the harbor's health: sewage, storm water runoff, and trash. Due to Baltimore's 100-year-old sewage system, raw sewage intermittently enters local waterways, which ultimately end up in the Harbor. This occurs primarily during rainstorms, when rainwater infiltrates cracks in the sewer system, compromising the system's capacity to hold the sewage. When this untreated sewage overflow ends up in the Harbor, it is contaminates the water with fecal bacteria and other pathogens. Storm water runoff occurs when rainwater runs over impervious surfaces in the urban environment such as streets or rooftops. The rain picks up pollutants from these surfaces and eventually rush down the storm drains where this untreated water is carried into the Baltimore Harbor. Trash, whether accumulated via careless littering or illegal dumping, ends up in the Baltimore waterways and Harbor, threatening the ecosystem's health, human health, and the economy due to the unsightly appearance of trash build-up near the Inner Harbor's main tourist district.

This chronic problem reached a tipping point when the U.S. Justice Department sued the city of Baltimore in 2002 for its leaky sewage system that illegally releases millions of gallons of raw sewage into the Baltimore Harbor annually. While Baltimore agreed to eliminate all sewage

[1] Waterfront Partnership of Baltimore, "Baltimore's Annual Healthy Harbor Report Card 2014", 2014.

overflows and repair the old system by January 1st, 2016, they are currently only about halfway to this goal[2], which explains the low water quality ratings of the Harbor. With an ambitious goal of cleaning up the Harbor by 2020, the Waterfront Partnership of Baltimore's Healthy Harbor Initiative built and launched the "Mr. Trash Wheel", a solar-powered water wheel that collects garbage and debris from the Harbor and deposits it into a dumpster to be properly disposed. While several hundred tons of trash have been removed from the Harbor since the trash wheel's debut in May 2014, the Harbor's water is far from being swimmable and fishable by 2020.

While improvements to Baltimore's sewage system and city infrastructure are beyond the scope of our project, we aim to target the pollution issue directly by developing a system that will filter the polluted water in the Harbor. While several different water quality indicators are utilized by the Healthy Harbor Initiative, including fecal bacteria levels, chlorophyll *a* levels, nitrogen and phosphorous levels, dissolved oxygen levels, and water clarity, we will focus primarily on eliminating fecal bacteria—the main issue plaguing the Harbor. With our proposed human-powered water filter, we will directly remove the fecal bacteria associated with sewage infiltration of the water, meeting EPA guidelines for swimmable and fishable water.

# 3 Technical Design

## 3.1 Bicycle Frame Design

The team adapted the design of a typical bike according to the project's objective. The end product is an assembly that consists of a commercial bike frame, customized front and back ends to support the frame, pump located inside the front stand, and a bottom railing that supports the entire structure. While the pump, chains and gears are standard purchased parts, the system mostly consists of parts machined by the team. The customized parts are: a front rod, front rod-stand connections with a pin, front stand, back stand, gear-hub, and bike-system mount.

[2] The Environmental Integrity Project, "Stopping the Flooding Beneath Baltimore's Streets: The city's failure to comply with a federal sewage consent decree, and how delay harms homeowners and the Inner Harbor", Dec. 15, 2015.


**Figure 1: Picture of Bike-Powered System**

As shown in the Figure 1 above, a box-shaped front stand is made of 1” square steel tubes, a ¼” thick steel plate and .134” thick steel plate on bottom and top respectively welded to the frame built with the steel tubes. A hole is pierced into each plate that sets the front rod at a 70° angle. The front rod sits inside a shorter yet larger-diameter circular steel tube and is welded. The welded piece sits inside another larger-diameter circular steel tube; these pieces are held in place with a pin through the holes. There is also a short collar welded to the top of the rod to prevent the bike frame from sliding through the rod.

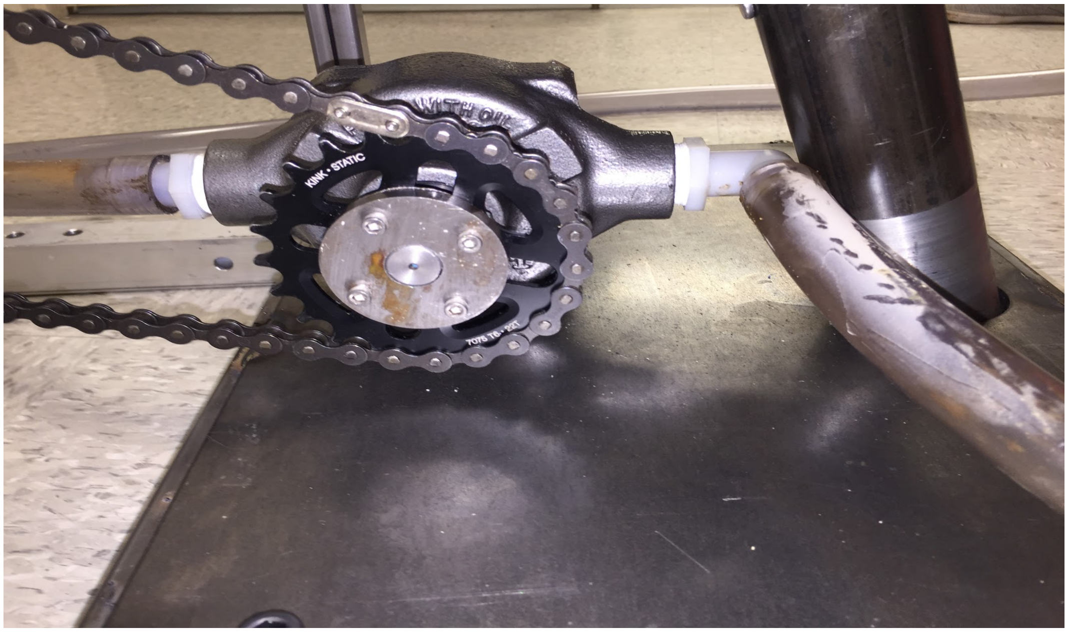

**Figure 2: Picture of Inside of Box-Frame**

Figure 2 shows the pump, which is located inside the front stand. The pump is secured to the plate using two threaded hex screws that go through two vertical ½” slots on the plate. The presence of the slots enables adjustments of the location of the pump according to changes in the chain length. One end of the pump is connected with a tube for water to come in while the other end is connected with a tube for water to flow out. The team had to use an elbow shaped fitting for one tube due to space constraints.

To connect the pump with the chain, a smaller gear is attached onto the shaft of the pump. In order to fix the gear onto the shaft, a ½ ” hub is machined with four vertical and horizontal threaded holes. The four vertical holes connect the hub to the gear with bolts and nuts while the gear-hub is fixed onto the pump shaft through the four horizontal holes. The gear assembly and chain enable a bike-rider to power the system to pump the water by pedaling.

**Figure 3: Picture of Back Stand and Frame Attached**

While the front stand encloses a rather-complex system, the back stand (Figure 3) is a simple upside down T-shaped structure built with 1-½" square steel tube. A hole is drilled towards the top of T-shaped structure for a ½" diameter cylindrical rod to go through. The rod is prepared with its ends lathed down to a smaller diameter so that the bike frame can be supported by the stand. In addition, the position of the cylindrical rod is fixed with standard ½" sleeves and setscrews.

The bottom railing consists of two rectangular aluminum bars of length 4.75 feet and 1-½" square section and thickness of ⅛". The entire structure is mounted onto the railing by four ⅝" screws, two connecting the back stand to the railing and two connecting the front stand to the railing.

### 3.1.2 Description of Approach (Bike)

First and foremost, the power source had to be selected. The consideration criteria for power source were determined through team discussion. The table below (Chart 1) is a Pugh chart, which was used to select which power source was going to be used for the bike system. The Pugh chart weights every criteria differently and each criteria is graded 1 through 5. The team filled out the Pugh chart for the five options of power source: bike, rowing erg, treadmill, elliptical, hand pump.

| Harbor-to-bulkhead | Weight | Bike | Row | Treadmill | City Workout Elliptical | Hand Pump *like a railroad thing |
|---|---|---|---|---|---|---|
| Durability | 12 | 4 | 2 | 1 | 5 | 5 |
| Light weight | 5 | 5 | 2 | 1 | 2 | 3 |
| aesthetics | 10 | 5 | 1 | 1 | 4 | 2 |
| Comfort* | 8 | 3 | 4 | 1 | 5 | 2 |
| $ | 12 | 4 | 2 | 1 | 5 | 5 |
| Efficiency | 13 | 4 | 3 | 1 | 4 | 2 |
| Safety | 10 | 3 | 3 | 5 | 5 | 5 |
| security | 8 | 2 | 2 | 3 | 5 | 5 |
| audience | 15 | 5 | 4 | 3 | 5 | 1 |
| Maintenance | 7 | 4 | 3 | 3 | 5 | 5 |

**Chart 1: Pugh Chart for Power Source Determination**

As a result of Pugh analysis, an elliptical and bike ranked top 1 and 2 respectively. However, the bike was chosen over the elliptical because of its lightweight and ease of machinability.

There were two options for transferring mechanical energy from pedaling the bike to power the pump: direct drive or converting mechanical energy to electrical energy and using a motor to drive the pump. The team made a list of pros and cons for each option and decided that direct drive was the better option. The advantage of using a motor is that it would be easier to turn the shaft of the pump because torque from the motor could be greater than torque applied from pedaling. However, since there was not much resistance to turning the shaft of the pump, the team decided direct drive was enough to power the pump. Also, using a motor would require purchasing additional parts and there would be loss of energy during the energy conversion process.

The team spent a lot of time on choosing the right pump to use. First, the team researched all the types of pumps available such as a piston pump, diaphragm pump, and flexible vane pump. Then the team narrowed down the possibilities according to the list of criteria the pump had to satisfy:

- Be self-priming
- Able to pump water up to 3 feet
- Able to pump at least 1 gallon/hour
- Clog resistant

Originally, the team had wanted to design for the pump to be suitable for the freezing conditions in Baltimore during the winter. However, the pumps that could be used when the temperature is below freezing were either not self-priming or could not pump water up to 3 feet. Therefore, the team had to abandon the freezing resistant criteria. Ultimately, the team chose the piston pump because it satisfied all the requirements and the team was already familiar with it from disassembling one in lab for ME421.

The team had to design front and back stands to support the bike frame and house the pump. Most of the weight would be in the front of the since the pump would be housed in the front stand, and the back stand had a simple upside down T-shape. Some shapes that were considered for the front stand were a triangular prism (Figure 4) and a rectangular box (Figure 5), as shown below.

**Figure 4: Front stand as triangular prism**

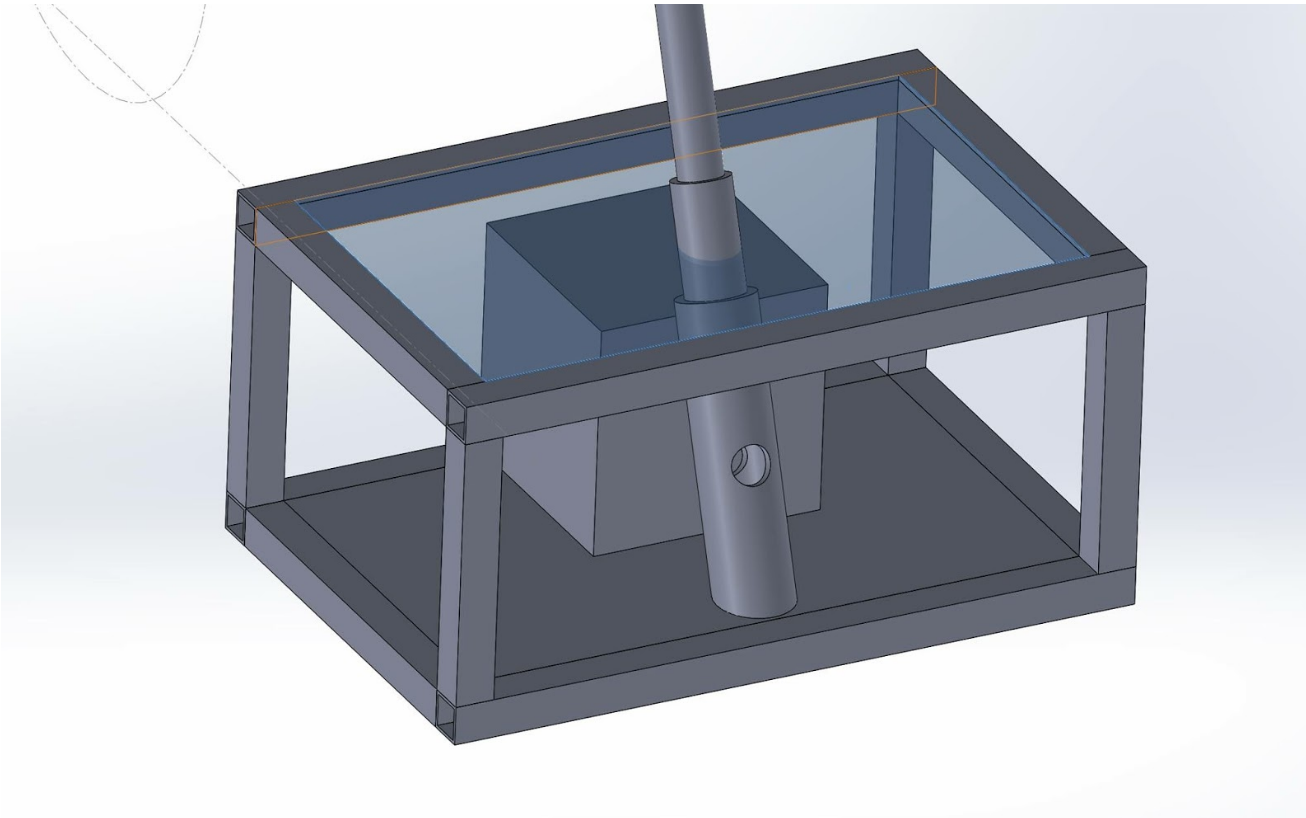

**Figure 5: Front stand as rectangular box**

The team considered the sturdiness, aesthetics, and level of difficulty to machine each shape. Although triangular shapes are typically more sturdy than rectangular ones, the team decided to use the rectangular box design because there was limited time before the deadline and it would be much more difficult to machine metal bars at an angle for the prism. In addition, using steel rather than aluminum as the material for the rectangular box would make it stronger. The stress analysis of the stand can be found in the next section.

From examining a commercial bike and estimating its slant angle, the team decided to tilt the long rod part of the front stand at approximately 70 degrees. A collar was placed on the rod to prevent the bike frame from sliding down the rod. The final position of the collar was determined by manually adjusting its position until the bike seat could tilt at a comfortable angle for the user.

Some of the design decisions came about when the team encountered problems during testing. The chain of the bike has to align with the sprocket on the pump, which means that the position of the pump in the front stand has to be adjustable. Originally, the team had drilled only two holes on the plate to secure the pump. After realizing this problem, the team milled the plate such that the two holes turned into two slots, allowing more room to adjust the position of the pump. Another unforeseen problem was that when the stands were welded, their shapes deformed slightly and caused some misalignment in the entire system. Due to the misalignment, the bike chain would come off after a few rotations. The team's solution to this problem was to manually adjust the alignment of the structure until the chain did not come off and then fix the structure in that position to a pair of railings on the bottom.

## 3.2 Stress Analysis

In order to check that the bike stands would be able to hold up to the weight of a person, a finite element analysis was performed. The average weight of an adult female in the United States is about 140 to 190 pounds, while for adult males it is 170 to 205 pounds[3]. Therefore, taking the upper end of this range, the team proceeded with the assumption that the average person in the United States would weigh 200 pounds. It was also assumed that the weight of the person would be distributed equally between the front and rear stands.

First, finite element analysis was performed on the front stand. As can be seen in Figure 6, the force was applied in the direction of gravity, meaning that the area of highest concern was the rod connecting the front stand to the bike as it has a large force applied to it by the weight of the bike and person. However, the results showed that the maximum stress in the front stand was 14 psi, while the yield strength of the steel used is 32,000 psi. This results in a factor of safety of over 2,000. Based on this, regardless of the possibility of a heavier person using the setup or a larger percentage of the weight being distributed to the front stand, the front stand is under no risk of failing from intended use.

Next, the rear stand was analyzed. The 100 pounds was assumed to be distributed between the two areas of the small rod where the bike rests as shown in Figure 7. This force was also applied in the direction of gravity. This small rod was under the highest consideration for failure because of its relative thinness when compared to the other parts of the rear stand. The highest stress experienced in the front stand, 5,200 psi, was in this rod as expected. The yield strength for the rear stand is the same as for the front stand, so the factor of safety comes out to be a little over 6. While this is far smaller than the factor of safety of the front stand, it is still a significantly large value that the team is not concerned about the rear stand failing at any point under its intended use.

Considering the high factors of safety for this assembly, an option could have been to use less or lighter material in order to construct the stands, especially the front stand. However, this was decided against for several reasons. First of all, aluminum could have been used to produce a lighter assembly, but because of the difficulties involved in welding aluminum, the team decided to use steel instead to make manufacturing easier. Additionally, the team was not concerned about using as little material as possible because having a heavier stand was more advantageous in this situation. The team did not want the plate that had the pump bolted to it to flex while the rider was driving the pump. Therefore, the team wanted a thicker plate that would provide a base for the pump while also insuring that it would stay in line with the bike. The team also wanted the stands to be heavier so that the whole assembly would not be able to move or tip over during normal use.

[3] McDowell et al. "Anthropometric reference data for children and adults: United States, 2003–2006". National health statistics reports; no 10. Hyattsville, MD: National Center for Health Statistics. 2008.

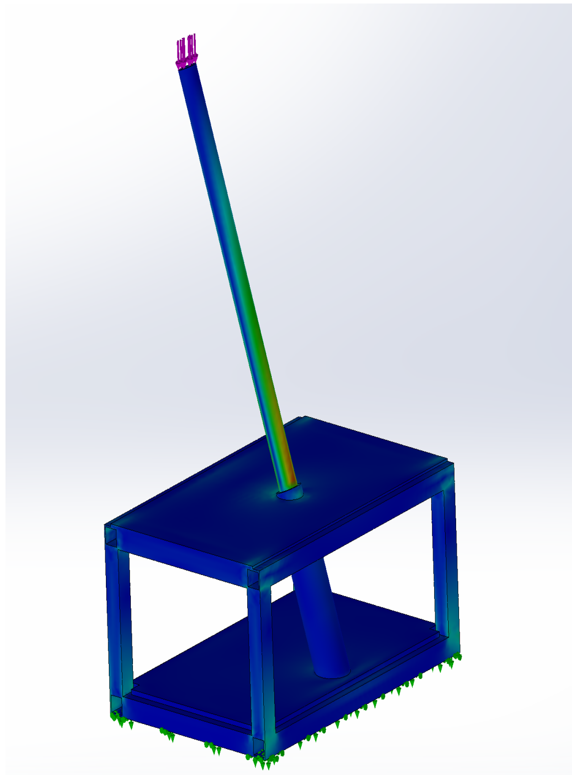

**Figure 6: Stress results from a finite element analysis of front stand for the bike assembly**

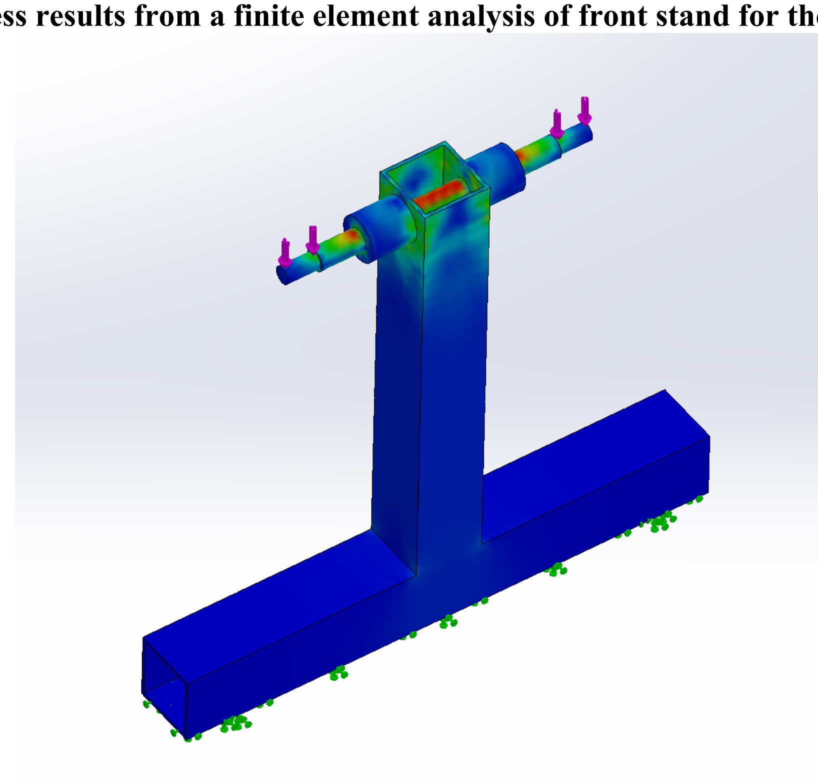

**Figure 7: Stress results from a finite element analysis of rear stand for the bike assembly**

### 3.2.1 Finite Element Analysis Information

Average weight of a person: 185 lbs, so assumed 100 lbs per stand.[4]

**Front stand (Figure 6):**

Force of 100 lbs total
Max stress: 3.598 e 7 N/m^2 * 0.000145038 = 5,200 psi
Yield strength: 2.206 e 8 N/m^2 * 0.000145038 = 32,000 psi
FOS: 6.131

**Rear stand (Figure 7):**

Force of 100 lbs total
Max stress: 9.874 e 4 N/m^2 * 0.000145038 = 14.32 psi
Yield strength: 2.206 e 8 N/m^2 * 0.000145038 = 32,000 psi
FOS: 2000

## 3.3 Testing (Bike & Pump)

**(a) Pump Testing #1 - with old pump**
The team initially ordered a pump from McMaster Carr that had the desired flow rate. To test the pump, the team secured the pump to a table and had one tube connecting the pump to a bucket full of water and another one connecting the outlet of the pump to an empty bucket. The bucket was approximately 3 feet under the pump. The team used a hand crank to rotate the shaft of the pump to simulate direct drive. Upon testing, the team discovered that it was very difficult to raise the water by 3 feet with this pump and had to search for another one with less resistance.

**(b) Pump Testing #2 - with new pump**
When the new pump arrived, the team conducted a similar test as with the old pump. This pump successfully raised water up to 3 feet. Then the team incrementally changed the distance between the bucket of water and the pump until the team determined that at 5 feet, the pump starts experiencing difficulty. The conclusion of the test was that this pump would suffice for the Baltimore Harbor.

**(c) Baltimore Demonstration**
The team traveled to Baltimore to test the bike prototype and a miniature filter at a location where the bike could be installed. The bike drew up a large quantity of water with relative ease. Now that the bike is functional, the team could focus on finishing touches of painting the bike with an anti-corrosive coating.

[4] McDowell et al. "Anthropometric reference data for children and adults: United States, 2003–2006". National health statistics reports; no 10. Hyattsville, MD: National Center for Health Statistics. 2008.

## 3.4 Filtration Barrel Design

In order for the system to actually clean the water in the Harbor, we needed to construct some sort of filtration system that would be fed by the water pumped out by the human-powered bicycle. Our team set out to find the most effective, low-maintenance, and easy-to-construct design, which ended up being a slow-sand filtration system.

We quickly located a resource that outlined the construction processes for several different types of slow sand water filters. We chose a design by David Tarsi, who published a document that summarizes his eight years of designing sand filtration systems. His results from the particular filtration system we chose to assemble met EPA-guidelines for swimmable and fishable water[5]. The results of our personal filtration system have been conducted at Duke's Water Cooling Plant; these results will be discussed in a subsequent section of this report.

## 3.4.1 Assembly of Slow Sand Filter

### i. Preparation of 55 Gallon Drums

Three 55 gallon closed-top polyethylene drums were purchased commercially from ULINE. The barrels obtained were closed-top barrels, so we needed to saw the tops off to construct the piping system on the inside. Drainage holes were drilled into the bottom of each barrel. These holes were then each fitted with a ½ inch male unthreaded pipe adapter purchased from McMaster. This type of adapter is easily attached to a female pipe adapter that can be attached to a hose to carry the clean water out after it has passed through the filter.

### ii. Construction of internal PVC piping

Next we assembled the drainage pipes which collect the water that has been filtered through the system. This pipe arrangement lies at the bottom of the barrel. The drainage pipe system consists of three PVC pipes with holes drilled in the side arranged side-by-side and attached with PVC elbows, cross-fittings, and t-fittings. (See Figure 8). The drain pipes were then placed at the bottom of each barrel and attached to the male adapter using a 5/8 inch diameter hose. (See Figure 9)

[5] Tarsi, David. "Slow Sand Water Filters: How They Work and How To Build Them," 2016.

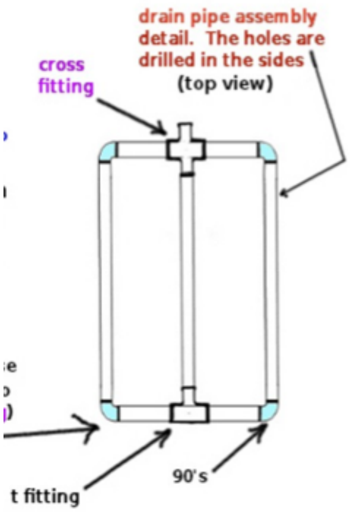


Figure 8: Drain Pipe

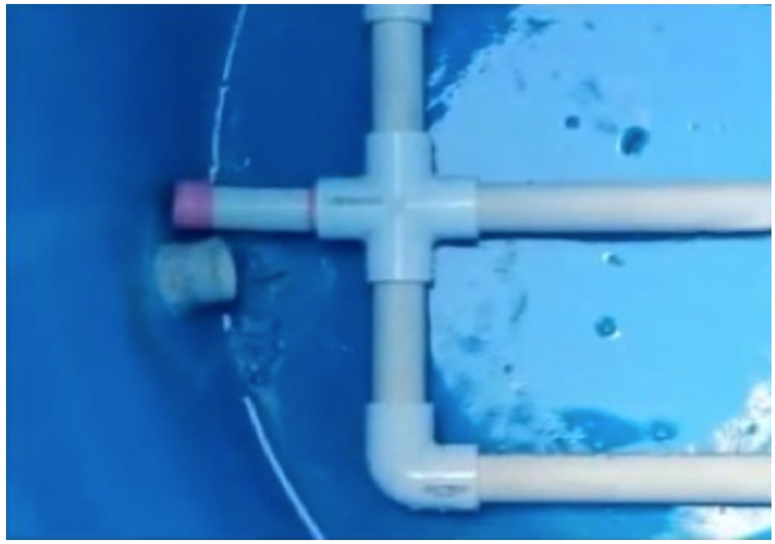

Figure 9: Drain Pipe Attachment in Barrel Bottom

### iii. Construction of sand/gravel column

The PVC pipes at the bottom of the barrel were covered with washed pea-size 3/8 inch diameter gravel purchased from Home Depot. The gravel was checked to make sure it was larger than the holes drilled in the drainage pipe to prevent blockage. The gravel layer is approximately 4 inches deep. The majority of the filtration column is white sand, which has been sifted, washed and baked to ensure a contaminant-free filter. The effective size of the sand was approximately 0.4 mm. The sand layer is approximately 20 inches deep, leaving 12 inches of water at the top, creating substantial pressure for the water to flow through the system. (Figure 10 provides a basic picture, but the measurements we used and size of sand differed from this diagram)

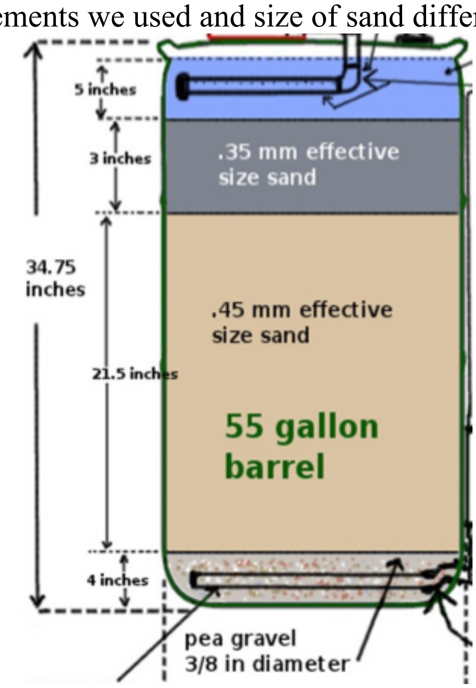


Figure 10: Sand/Gravel Filtration Column

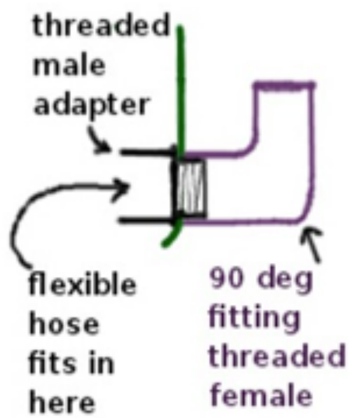


**Figure 11: Output Hole PVC Attachment**

### iv. Construction of PVC Output Pipe

At the bottom of the barrel near the output hole, the output pipe was attached to the male adapter already put in place during the drainage pipe assembly. (See Figure 11) A 90 degree threaded female PVC pipe fitting was used to connect the output hole to the output pipe. The output pipe is a ½ inch PVC pipe that attaches to the end of this elbow connection and runs vertical along the side of the barrel. Our original output pipe was almost as tall as the barrel itself, but it had to be shortened in order to increase the flow rate of the filter. The output pipe is tied to the barrel with a rope, which prevents it from falling to the side. We also installed a ¼ inch overflow pipe near the top of the barrel. The overflow leads directly back to the input source, so that water does not leak from the filter when the input flow rate is higher than the output flow rate.

### v. Construction of Input Pipes

A hole was drilled in the top of the barrel to insert the input pipes. The input pipes consist of two PVC pipes connected with two elbow pipes and a T-connector that attaches the pipes to the drilled hole in the top of the barrel. (See Figure 12) The input pipes have small holes drilled in them and the holes are facing upwards. This allows the water to drip down onto the sand rather than being forced upon it. This creates a more even distribution of water across the filtration system, being careful not to disturb the fragile top layer of sand where the bacterial layer forms.

**Figure 12: Input Pipes**

## 3.4.2 Description of Approach (Filter)

Our main goal was to design a filtration system that will effectively remove the harmful organic and inorganic compounds present in the Baltimore Harbor. To work in conjunction with the human-powered bicycle portion of the system, we needed a filter that would be able to handle varying levels of water flow rates and the harsh winters in Baltimore. We also wanted a filtration system that would be relatively low-maintenance, cost-effective, and easy to construct. Initially, we considered two different designs for our filtration system: an organic filter and a slow sand filter.

a. **Organic (Living Plants) Filter**

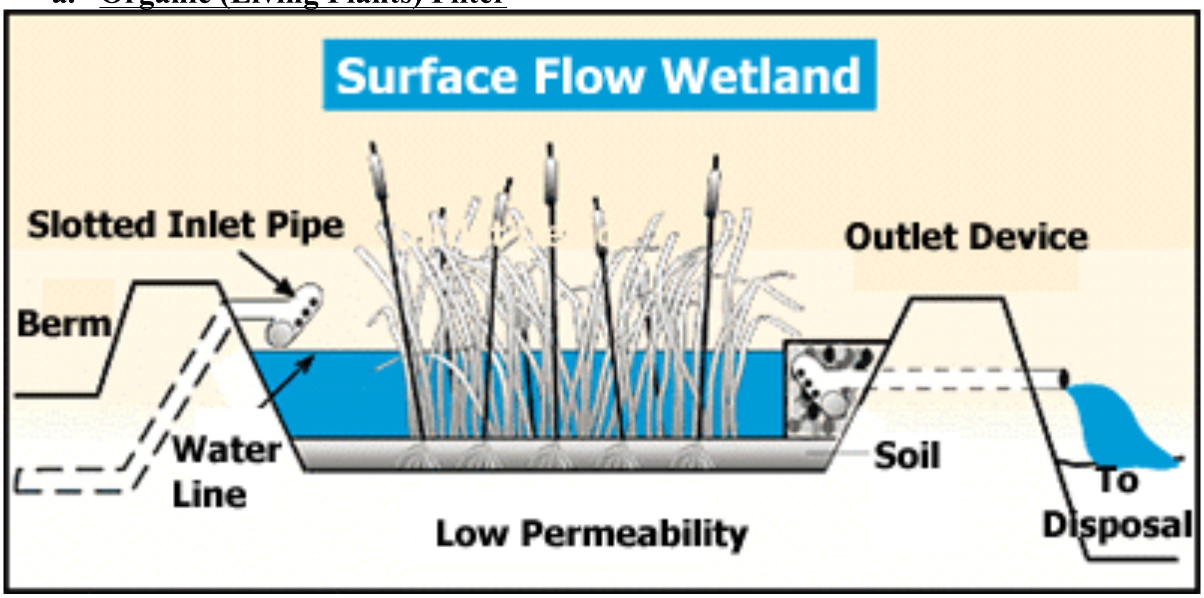


**Figure 13: Basic Set-Up of Wetlands Filtration System**

Using an organic filter would require constructing a small wetlands system over which the harbor water would be distributed. Many plants naturally remove heavy metals and fecal bacteria when the water passes through their root systems. An organic filter would be appealing to passersby and beautify the landscape by introducing plants to the edge of the harbor. The filter would not require daily maintenance, but the plants and system would need to be monitored to ensure proper growth and prevent clogging of the system. The plants also require trimming and harvesting maintenance seasonally. The construction of an organic filter would require the researching and purchasing of plants native to Baltimore that are capable of natural filtration. As we began to research the costs of such plants, we realized that this type of filter would be difficult to carry out within our budget. A basic set-up of this type of filter is shown in Figure 13 above.

**b. Slow Sand Filter**

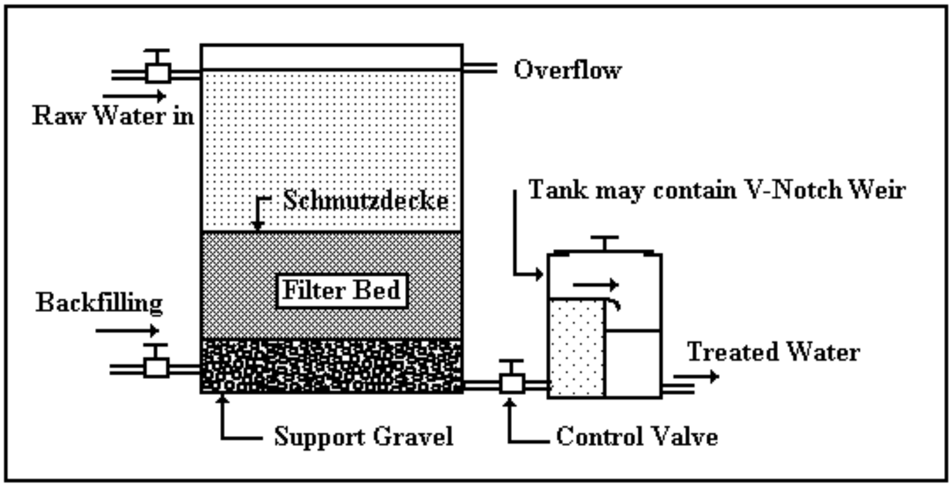


**Figure 14: Basic Set-Up of Slow Sand Filter**

Using a slow sand filter would require constructing a cylindrical container and placing various layers of gravel and sand inside through which the harbor water would circulate. As water runs through the system, bacteria naturally form within the sand that are extremely effective in filtering out pollutants and organic compounds. As water flows slowly through a container filled with sand; a layer of living organisms forms on (and in) the top few inches of sand. In this layer of organisms, disease-causing microbes are destroyed and consumed by predatory microbes. The toxins are digested and secreted as harmless minerals. A slow sand filter would also produce potable water, exceeding our initial goal of swimmable and fishable water. The sand filter would require very little maintenance, as the sand never needs to be replaced, though some maintenance could be required to prevent clogging. One drawback is that the system will not work during freezing temperatures, as the bacteria perish and only naturally re-form when the temperatures rise above freezing again in the spring. This system would be very inexpensive due to the low cost of sand and gravel. It is also relatively simple to construct. A basic set-up of this type of filter is shown in Figure 14 above.

**c. Final Decision**

Based on the high level of effectiveness, low maintenance levels, and budget constraints, we decided to choose the slow sand filter for this project.

# 3.5 Testing (Filter)

After just two weeks, the filtration system started to show positive results indicating that the microbial layer had begun to form. Water samples from the Duke Stormwater Reclamation Pond were analyzed for E. coli and total coliform before and after filtration. The preliminary tests did not detect any E. coli, but 518.6 MPN/100 mL of total coliforms were detected with a 95% Confidence Interval of 166 - 871.2 MPN/100 mL. An electric pump was set up to constantly cycle water through the filter for two weeks in order to grow the biolayer that would consume and break down harmful bacteria. The filtered water samples had a massive reduction in total coliforms with only 3.1 MPN/100 mL and a 95% Confidence Interval of 0.7-8.9 MPN/100 mL.

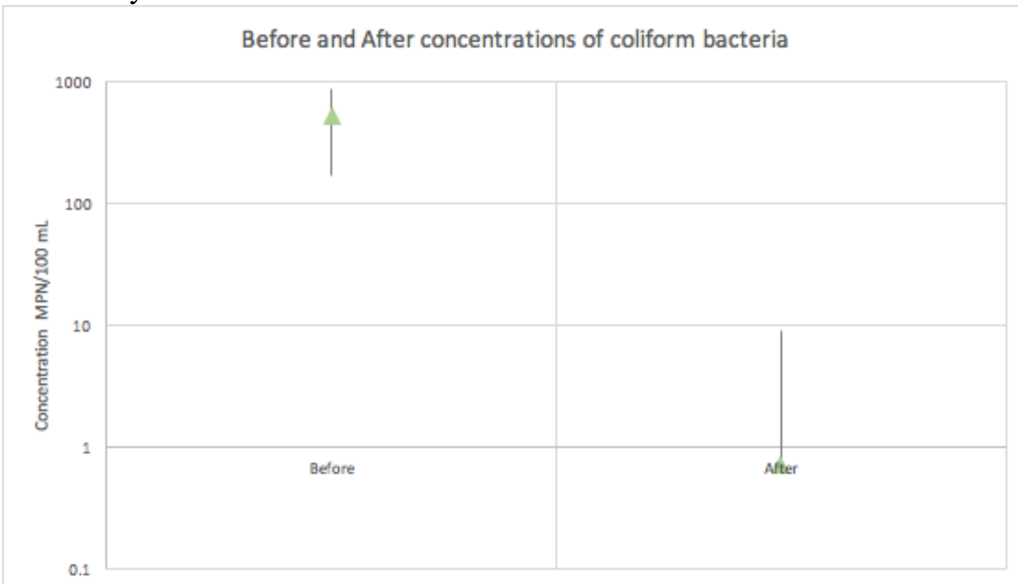


**Chart 2: Chart showing reduction in coliform bacteria**

It can take 2-3 weeks for the biolayer to develop enough to cover 90% of the surface area of the sand, but reductions in bacterial contaminants in filtered water continue to incrementally improve even beyond 6 weeks. Total coliforms are generally measured for the purpose of predicting the presence of fecal bacteria and EPA Drinking Water Standards require that no more than 5% of samples test positive for total coliform in a month. We can therefore assume that after additional time is given to allow the biolayer to fully develop, water exiting our slow sand filtration system would meet EPA standards for total coliform in drinking water. Unfortunately we did not have access to water contaminated with E. coli to run through the filter and analyze to confirm that the system would remove E. coli and meet the relevant EPA standard. However, we saw a significant improvement in the clarity of the water before and after filtration (Figure 15).

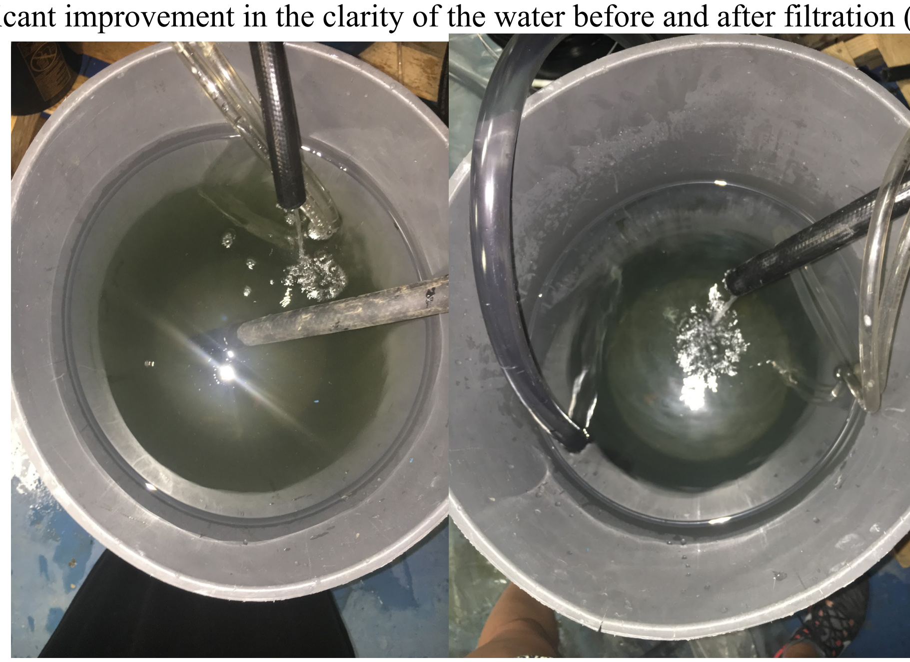

**Figure 15: Before (Left) and After (Right) Filtration**

## 3.6 Overall System Function

While our design has two separate components, the human-powered bicycle pump and the filtration barrels, the two components must work in harmony for the system to function successfully. Below is a picture of the full system installed in the Duke Chilled Water Plant on Lasalle with labeling and a description of how the system works.

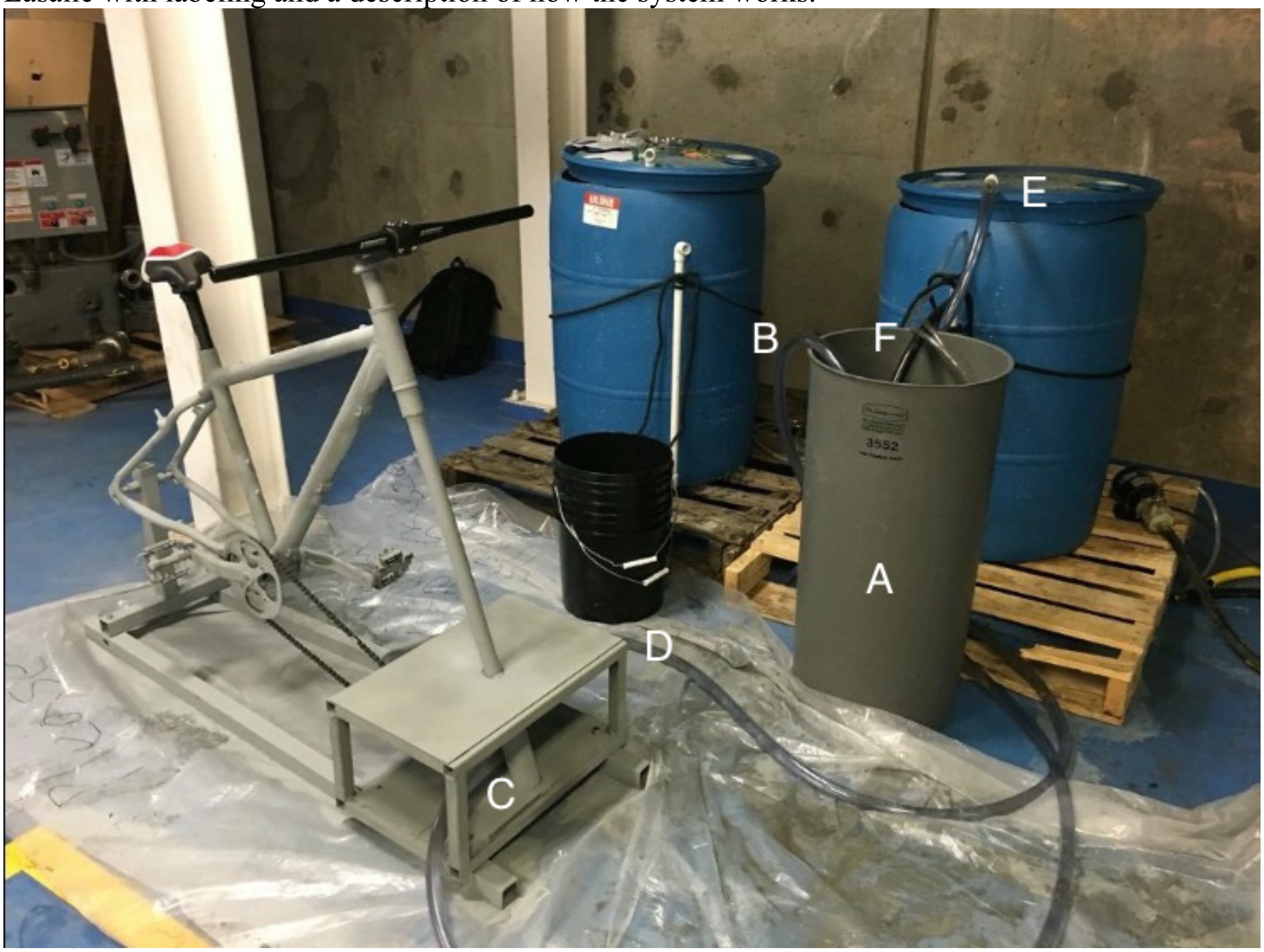


**Figure 16: Fully Functioning System**

Part A on the diagram represents the water that will be in the Harbor or any other urban water system where the device is used. When a person is pedaling on the bike, the water is withdrawn from the water source via the clear tubing (Part B). The water travels down this tubing and circulates through the pump, located at Part C on the diagram. The water exits the pump via the other side and enters the clear tubing labeled Part D on the diagram. Next, the water is pumped up into the input pipe on the filtration barrel (Part E). The sand then slowly filters through to the bottom of the barrel, being purified it trickles down. Once it reach the bottom, the pressure pushes the clean water out through a PVC pipe that is hidden behind the grey trash can. The clean water then exits the filtration barrel through the black hose labeled F.

# 4 Environmental Analysis

In the broader context of Baltimore Harbor, this system would make a negligible dent in the overall harbor water quality. It would take 64 years for one bike with one filter to clean an Olympic size swimming pool (assuming it would have activity 4 hours every day). However, if a fleet of 25 bikes each with 3 filters were used, over the same time frame, it could filter an Olympic size pool in under one year (314 days).

This past March, a storm released 12.6 million gallons of sewage (coliform bacteria) into the harbor. If no additional contaminants were added, it would take 6.8 years to clean the sewage with 25 bikes, each with three filters, being pedaled 24 hours a day.

# 5 Social Benefits

Three main benefits of our human-powered filtration system are raising awareness of environmental problems, encouraging community engagement, and promoting exercise as a healthy lifestyle choice. First, many ecologically engineered products and systems go over the head of the people they are meant to serve. They can be too scientific, too technical or too foreign as people are not aware of them and their benefits. This system aims to bridge the gap between ecological engineering and community awareness. While environmental problems can become commonplace and easily ignored, the physical existence of the filtration system sitting at the water's edge will refocus passersby attention on the poor water quality in Baltimore Harbor. When more people are aware of environmental problems, environmental activism is much more valued and effective. Thus, the bike and barrels serve as a physical reminder of the importance of water quality, which constantly raises environmental awareness of those who pass by the system.

Additionally, the bicycle is an interactive system that encourages community engagement. The filter requires human participation in order to work, so it will need community engagement in order to work. As an installation in the Baltimore Harbor, the initial installation will include informative signage that catches the attention of passersby. Our goal is for the sign to be eye-catching and aesthetically appealing so as to engage as many community members as possible. Our hope is that riding the bicycle and physically seeing the clean water leaving the filtration system will excite the community members who utilize the system and encourage them to become involved in other environmental initiatives involving the Harbor. Our signage combined with the aesthetic appeal of the bicycle will bring about this community involvement.

Thirdly, another social benefit of our filtration system is the fact that it incorporates exercise into environmental sustainability. Exercise is an activity that has been increasing in popularity over the past few years, and riding the bike is like riding any other stationary bicycle. Tapping into the exercise trend is a great way to get people involved in enhancing water quality while also encouraging a healthy lifestyle. Future applications of the bicycle filtration system would be setting up an entire group of bicycles next to the water in order to run an exercise spinning class, further incorporating exercise. Thus, our system helps to keep the people who use the bike healthy, and it also furthers the ultimate goal of making the harbor as healthy as possible.

# 6 Business Plan

## 6.1 Healthy Harbor LLC Overview

Assuming the prototype developed through the Bass Connections program at Duke University is a commercially viable product, the group will file as an LLC and start the company "Healthy Harbor." Healthy Harbor is a subscription-based gym-grocery store located in the vicinity of large public water sources that utilize the water as the resistance for a large portion of its workout stations. The water that is pumped out of the harbors will be fed to slow sand filters in an effort to cleanse the water source of the location and provide fresh, safe produce in the grocery element of the store. Each member will be given an access card that can be swiped at each of the workout machines and will be awarded credit towards consumables produced by the gym for generating locally-used electric power or pumping water into the watering tank for the plants. Healthy Harbor enhances the community exercise and grocery store experience as well as encourages the discovery of the community's aquatic ecosystem because it allows every member to contribute to the betterment of its local environment.

Healthy Harbor is being developed during a time when a majority of Baltimore's population needs healthy food alternatives and more accessible exercise facilities. The primary target market is the African-American population in Baltimore, which garners about two thirds of the population. The first market to be targeted however will be those that maintain environmentally friendly habits and lifestyles to quickly penetrate the market, grab a significant market share, and let the network effects grow organically from there. Healthy Harbor's value increases dramatically as more community members and leaders subscribe to the gym service. It is in our customer base's best interest to spread the word about Healthy Harbor, support us and help us grow. We are attempting to create a more communicative community and stimulate neighborliness through exercise and healthy dieting choices. Word of mouth advertising will be essential in attracting new consumers, especially since there will be trial membership element that will allow potential members to test Healthy Harbor.

Healthy Harbor will double down on frontloading our marketing efforts at launch through traditional and new media to help start this community chain reaction. We plan to utilize our connections and create new ones within the environmental, African-American, and gym enthusiast communities as well as within our local networks to help spread the Healthy Harbor name and drive users to subscribe to the service. Maintaining a social media presence is an easy way to get in touch with consumer markets in the hopes of gaining feedback and improving our product.

Healthy Harbor offers an experience that no other competitors currently offer, though there are many substitutes and combinations available. We know that our pricing structure and unique value proposition will draw customers though, especially since this space is very new and becoming rapidly popular. As long as we can launch successfully and gain momentum early on, we know that the network effects, partnering with activist groups in the community, and word of mouth advertising will help us become the market leader and sustain profitability into the future.

The primary revenue source for Healthy Harbor is customer subscription and grocery retail, which we will be able to grow in-house and create a positive feedback loop of commercially viable products for our customers. Being able purchase groceries and earn credit towards them while exercising should become extremely valuable to our customers, and we plan to expand our product selection as we partner with local businesses and produce suppliers in Baltimore.
Initially our primary objectives will be a successful launch and widespread customer satisfaction, so that the network effect chain reaction may begin as early as possible. After that we will focus on increasing our conversion rate of normal gym members to Healthy Harbor and maintaining high customer loyalty. As Healthy Harbor innately gives back to its community, this should not be a problem. It is important that we first focus on the functionality and features of the product, as well as other factors from the end-user's point of view, before we begin to focus on higher monetization. We don't want to risk having an inferior product on the market and lose out on potential market share in exchange for generating revenue earlier than expected.

## 6.2 Market Analysis

The environmental product and service market is one of high growth and diversity. The subscription-based gym service and sustainable co-op/grocery store model have never been combined to the point where there is an outright market leader; so Healthy Harbor will be a market prospector in a general sense of the combination. There is a market for both separately, however, and there are industry leaders in each of the markets. Healthy Harbor is to be "the first with innovative new product offerings" in blending the grocery store and gym business models to form a new kind of gym experience that gives the consumer much more than a healthier body[6]. It gives them a sense of community and a way to reinvigorate their city's natural ecosystems.

In order for Healthy Harbor to be successful, the customer decision-making process will have to be applied its marketing mix. A potential customer will realize that there is convenience in being able to shop for one's groceries before or after exercising and in being able to apply the work out credit the customer generates during their time in the facility towards their overall grocer cost. Depending on the customer's level of interest, they will do some form of information search, typically just a quick Google search. They will proceed to search for and evaluate alternatives to Healthy Harbor, eventually resulting in a purchase decision. Because gyms in this space tend to be more expensive, customers may be more inclined to choose Healthy Harbor with its added grocery store value. Success in this early use stage is essential in maintaining customer relationships.

[6] Mohr J, Slater S, Sengupta S. (December, 2013) *Marketing of High-Technology Products and Innovations.*

There are two primary customer segments within our market. First, there is the customer base that will primarily use the function of the gym rather than the grocery store. The biggest potential for the growth of Healthy Harbor is to obtain as many consumers of this particular type as possible. Hopefully over time, and with the incentive of more products in the grocery store, a number of users will convert from their traditional gyms to Healthy Harbor. The more casual work out consumers composes the other customer segment. They will be drawn to the convenience of being able to casually exercise and then get their healthy and sustainable groceries. They are a secondary priority segment, as they are not innovators in in terms of rate of adoption.

Baltimore city has over 600,000 citizens, which is an appropriate population to engage this service with. Currently, there are health needs that the city is trying to meet under the Today Show's program "Shine a Light." There are rapid trends towards obesity with over a third of the population of Baltimore being considered obese and 40% of the city is located in areas with poor access to food – so called "food deserts." Having a company that can provide for both of these needs at the same time as opposed to splitting them up is advantageous for Healthy Harbor. In the immediate Inner Harbor area, there are 4 gyms. While these gyms cannot provide all that Healthy Harbor can, they are located in a city that means there is convenient access to small grocery stores like the one Healthy Harbor plans to provide. There are substitutes, which can be combined to emulate Healthy Harbor's basic functions. The gyms are The Maryland Athletic Club, CrossFit Harbor East, Merritt, and the Harborview Health Club.

The Harborview Health Club is a competitor for the target audience that live in the Harborview neighborhood as only they can join. It also costs $50 a year in addition to the Harborview rent costs. The facility lacks detail and only supplies the basics and a two-lane lap pool.

The Maryland Athletic Club, commonly referred to as the MAC, boasts itself as Baltimore's best athletic club. The first two months cost $60 total, and then the following months are up to the member's discretion for the parts of the facility they would like to use. The most basic cost is $75 dollars after the first two months.

CrossFit Harbor East's facilities lack most of the basic workout equipment, only a studio for classes to take place. It costs $40 a month and has very poor ratings in terms of customer service. There is no place to exercise independently there; customers must sign up with coaches for exercise classes.

Merritt is the most established in terms of locations in Baltimore. There are three locations and it costs $60 a month to become a member there. As a member, you may use any of the three locations and there is a full facility. They have classes and an Olympic sized pool. They are the largest of the gyms in Baltimore. There are spas and resident dieticians, but those features cost more to use. Though providing the same services, Healthy Harbor is much more inexpensive to use than the other four gyms in the immediate Inner Harbor area. It also offers more with the grocery store and the community involvement than do its competitors. While the 4 competitor gyms aim for exclusivity, Healthy Harbor attempts to nurture community – resonating with the target audience.

Because the grocery store's primary focus is not to generate revenue, but add value to the overall product, the competing grocery stores in the area are not being considered. Each, the farmers' market and Healthy Harbor, would cross-promote each other at events that each stages. The produce in the grocery component of the Healthy Harbor site will have their supplies which adds value to their end-to-end solution and Healthy Harbor will have a stand each day of the market to add value and market presence to the brand. It is also a competitive partnership because Healthy Harbor will be selling its own produce in the store and at the market. The incorporation of the farmers' market into Healthy Harbor is to help hedge the amount of competition that Healthy Harbor will have with it - creating a dynamic and complex partnership that is mutually understood between the two parties. The farmers' market is much more of a specialty market, which is why the collaboration can exist. It does not provide a gym service to its customers, but rather the specialty and high-quality food products that Healthy Harbor would also like to be associated with.

Other collaborations that will benefit Healthy Harbor are with African-American activists groups: NAACP, National Urban League and Rainbow Push Coalition. These organizations have influence over a target demographic that would provide a long-term revenue stream for Healthy Harbor. Aligning the business model with these groups is essential in capturing a large portion of the competition's market. Healthy Harbor would be able to provide healthier lifestyle choices for this demographic which would lower the high crime rates that are associated with it. Lowering crime rates and increasing the livelihood of this key demographic are objectives of all three organizations.

The macroeconomic forces that Healthy Harbor must heed are the general economics of the city of Baltimore and renting and leasing prices of space. The prices for enrollment in Healthy Harbor's services are low which corresponds with the socioeconomics of the target market. Healthy Harbor will also have to pay attention to prices in commodities as it prices the produce it creates in-house.

## 6.3 Company Analysis

Because of the scale and initial investment the facility will require, Healthy Harbor will require a staging process to lead to the end product, the retail and facility location. Healthy Harbor will have to acquire substantial tangible assets and protect its intellectual property before it can begin installing the facility. This will be carried out in a three-tiered process: alpha prototype testing, beta service testing, and the installation of the facility. The feasibility prototype has already been proved by our working prototype. Currently, we have assembled a human-powered, water pumping system in the form of a bike. This is the alpha prototyping stage. If, during the installation of the bikes along the Baltimore concrete bulkheads, Healthy Harbor can stimulate an audience that will self-organize and autonomously run the project, then the alpha stage will be proven viable.

After the alpha prototype is proven, Healthy Harbor will seek private investment for a small location near the harbor or attempt to buy the location where the bikes were installed for the alpha testing. Either this or partnering with organizations in the area such as Living Classrooms

Foundation or the Museum of Industry to test it beyond an alpha stage. There, Healthy Harbor will run a beta service program that pilots a subscription-based class that people can sign up for and take over a scheduled amount of time. This is an excellent opportunity to capture part of the target audience for the full installation of Healthy Harbor by offering a small portion of what the overall facility will offer. It will also self-generate marketability by being openly public. The Baltimore Inner Harbor is a prime tourist destination and local commuting transit for many Baltimoreans. Being able to watch a class take place during peak operational hours will draw bigger audiences and interest from the target market. If the classes are profitable and create enough of a following, then it will be time to seek further investment for the full facility.

Because the final stage may take about two years to get to, further beta testing will have to go on after its construction. The construction will require purchasing a tangible space of operations that will either have to be leased or rented. There are many elements of the business model that will have to be tested in smaller, regimented populations of the target audience. It is apparent that the key factor of Healthy Harbor's success is creating a strong network effect as quickly as possible. For the concept to be successful, it needs a substantial consumer base that is drawn over a longer time than its competitors not only so it is a useful service to its consumers, but so that it can provide substantial change enough in the community to convert regulars of other gyms. Because there is a longer time frame for the concept to reach the market and there are many tangible assets that will have to be developed and produced, it will require significant investment from an outside source.

There are potential weaknesses and risks associated with the planned business model. The slow-to-market and product development that Healthy Harbor will require is a weakness but as long as the intellectual property is protected under a patent that Healthy Harbor can file, then it can redefine the traditional gym with the sustainable grocery store component and become an industry leader in the immediate area. As the concept is more of a radical innovation, it will require investment capital from an external source that will allow for business autonomy. Without business autonomy, the public image will be distorted as Healthy Harbor relies on being perceived as a company for the community, not the individual. Of course Healthy Harbor will require a substantial amount of investment capital to begin production, but that is the case with most innovative retail and service combination enterprises.

## 6.4 Company Objectives

Healthy Harbor's mission statement is to better their communities by providing a high-tech facility for exercise and hydroponic produce production with an environmentally focused grocery mart helping local food artesian sell their products. Within the venture, a non-financial goal of Healthy Harbor is to create an environment where it is safe to workout without feeling self-conscious and a place to generate savings in the consumer's grocery budget. As Healthy Harbor will cater to a diverse set of communities, there are many different key elements that will have to be performed outside the venture. Building consumer loyalty is an essential non-financial goal of Healthy Harbor. The private gym membership market is highly competitive and there are many direct competitors in Baltimore that will try to emulate the grocery store concept after we bring it to market. We hope to stimulate the community in a way that our typical customer understands the value Healthy Harbor is adding to their community. This is what will set us apart from our competitors and increase our perceived quality.

In terms of the operating profit margin for the gym-half of Healthy Harbor, we would like to our monthly break-even costs to be about $71,000 with an average percent variable cost of 15%. Understanding that the alpha and beta testing will have had long term cost, we would like to be a profit after the first quarter - as Mountain Brook projects theirs to be after 1 month. Our first year financial goals are to profit $50,000 and revenues of $150,000 growing by 50% for the following 3 years after the first. For the grocery store half of Healthy Harbor, we would like to wait to grow that till the second year – using the maximum amount what is grown in-house and buying only a small selection of goods and produce from the partnership with Baltimore's farmers markets. Seeing as the typical profit margin for a grocery store is only about 1.3 percent, Healthy Harbor plans to have the grocery store element be an expense for the first three years of business. It will add value for the consumer as a convenience and innovation on the traditional private gym.

## 6.5 Target Market Analysis

Baltimore has an approximate population of 620 thousand people with a gender ratio of 52:47 percent, women to men, and a median age of 34.4 years old[7]. The target customers are going to be the overlap of those who eat healthy and workout at least 30 minutes for 5 or more days a week. This will insure that the gymnasium element of Healthy Harbor is the primary focus with the water lifting machines and that there will be a secondary focus on sustainable and healthy eating habits. The gym will also be aimed primarily at the African-American community which is a majority 62.5% of Baltimore's population, situated in the more northwestern part of the Inner Harbor. Of the overall population 25 years and over, only 80.5% have a high school diploma or GED equivalent and 50.3% over 15 years of age have never married. The main marketing focus will be to educate these populations: African-American, single, male, and high school educated to target the largest amount of the overall population[8]. Generally, on the East coast, about a quarter of the male African-American workout 30 minutes 5 days a week. In Maryland this same demographic has a "health club participation rate of [about] 17.1 percent," which is about 16,000 people[9]. This demographic is generally less affluent in Baltimore however, so the gym business model will have to follow and innovate on the Planet Fitness model which charges 10 dollars a month for a "judgment free" gymnasium[10]. This is a strategy in line with the sustainable design elements of Healthy Harbor, offering a community center that is unique, offers a variety of services and is ecologically efficient.
Generally, the African-American population is more focused on consistent physical fitness practices than any other race in America and is more willing to pay a nominal fee for a quality gym[11]. The difficult element of the business model and marketing plan will be convincing the

---

[7] *Baltimore, Maryland*. (2012) City-Data. www.city-data.com.
[8] Mendes, E. (June, 2010). *U.S. Exercise Levels Up, but Demographic Differences Remain.* Gallup. Gallup.com
[9] Gaynes, S. (September, 2011). *Health Club Membership By State: How Does Yours Stack Up?* Huffington Post. Huffingtonpost.com
[10] *Planet Fitness*. (2014) "Join Now." Retrieved from https://www.planetfitness.com/
[11] Mendes, E (June, 2010). *U.S. Exercise Levels Up, but Demographic Differences Remain.* Gallup. Gallup.com

community that the co-op component of Healthy Harbor is a viable and safe option for groceries. One way to do this is through trial subscription terms to Healthy Harbor and info sessions at city chapter meetings of the aforementioned African-American activist organizations. Healthy Harbor will attempt to not alienate this large target audience and ruin the possibility of making a positive impact on Baltimore's crime rates and African-American communities.

The value of the service will be based relatively to competitors. As Planet Fitness has one of the highest quality services nationwide and lowest costs for their consumers, the price for the most basic gym services will be 10 dollars a month. To access the grocery store and the crediting system, it will cost consumers 15 dollars a month. This is based on the cost of the agricultural equipment needed to do the hydroponic growing of the produce and the IT system requirements for the crediting system.

## 6.6 Marketing Strategy

In order to aptly create Healthy Harbor's marketing strategy, the target market segment and positioning of the service must be planned as succinctly as possible. Because the majority of Healthy Harbor's user base is going to be in the lower socioeconomic strata, Healthy Harbor needs to be portrayed as a company that is trying to better the community at large – even if the entire community is not directly supporting Healthy Harbor. Through the partnerships with the African-American activist groups and media blasts as the company continues to develop the product line, Healthy Harbor can create a branding image for itself that the community can invest in financially and emotionally. Even in the feasibility prototype stage of the bicycle, incorporating media and contacting local news affiliates to get more exposure for the company will be valuable. It is important to try to ingrain the company into the culture from the bottom up. In terms of Healthy Harbor's competitors, we will be known as a lower-cost, community minded company. This is to juxtapose their exclusive, profit-focused mentality. Healthy Harbor would rather be known for community first, profits later.

The release of new components of Healthy Harbor is closely related to the entire alpha, beta development process. There are checkpoints at each stage and the growth of the company is hinged to them. At first, there will be classes on the bikes installed in the Inner Harbor. Then, if that is successful, there will be in construction of the full facility. As more members sign up for membership, more products will be sourced from local businesses for the grocery store/co-op. The point of the concept is to create a positive feedback loop that allows customers to make suggestions to improve the space so Healthy Harbor can really reflect the image of the community. As more personal investment comes from the community, Healthy Harbor can give more back. It allows the consumer to have more control over the product that turns it into a more profitable venture. Community outreach using social media will also be essential in the communication element that Healthy Harbor tries to stimulate. Mailing lists, email list-serves, a Facebook page, a Twitter account, and a blog are all components of the Healthy Harbor marketing mix that will contribute to its success in bringing in more community members as customers. It also stimulates feedback and criticism that are important for fine-tuning the service.

There will be permitting that will have to go through the city of Baltimore to gain access to the spot and to be able to use the Inner Harbor water for an irrigation system. The permitting process can take a long time, but gaining support from the Mayor of Baltimore who is already backing the Healthy Bay Initiative in Baltimore and the Shine the Light program with the Today Show can help it. Gaining her approval will expedite the permitting process and give positive exposure to Healthy Harbor. To gain access to the bulkheads for the beta prototype classes, we will have to go through the Museum of Industry who has already shown interest in the water quality-altering project.

Creating a website for Healthy Harbor will be crucial in getting any kind of meeting or generating any kind of interest in the project. It will display screenshots of the sites and on-going projects as well as links and sub-pages for partners and affiliates associated with Healthy Harbor. When the final site is created, it will serve as a place to sign up for membership and give suggestions for improvement. Of course, as with any gym membership, potential members will be able to get a trial period that will allow them to explore and use the facilities while they decide whether or not they are going to sign a contract. Contracts will be dictated by time: 1, 3, 6, 12, and 24 membership periods. Benefits, such as food credits or credit multipliers when working out, will be given to those who sign up for longer contract periods. Generally, the price will be 10 dollars a month for up to 6 months, and then it will drop to 9 dollars a month for 12 months and 8 for two-year periods. For the shorter month periods, credit multipliers will increase from 1, to 1.04, to 1.1. This will increase the amount of credit they can generate on the machines to put towards groceries in the grocery store. This benefits locals who are going to be using the facilities over a longer period of time more frequently than others. There will also be a referral program, which also exist at other gyms. For every person that a customer gets to sign a contract with Healthy Harbor for 3 months or longer, they get a 1 dollar reduction to their monthly Healthy Harbor bill. This allows Healthy Harbor to reduce its payroll costs for marketing specialists and collateral. There will of course be at least one marketer on payroll to ensure that Healthy Harbor is being well represented in the media and doing an ample job marketing itself, but this will not happen until there is a full facility. Until then, the core executive board will do the work required for marketing to reduce costs.

Healthy Harbor will run promotional events leading up to the construction of the facility on the bulkheads of the Inner Harbor. First, even as an alpha stage prototype, the bikes will be fixated in the most visited and frequented part of the city – a constant reminder of the company to everyone that passes. Healthy Harbor will hold informal events there frequently, handing out marketing collateral and holding events for free memberships to bolster support for the product. We plan to generate press by contacting the NBC affiliate and partnering with the Shine the Light program that will gain traction over the next two years. Also contacting the Baltimore Sun and having stories run on the various aspects of the product development, i.e. as it is installed in the harbor and when construction begins, to increase exposure of Healthy Harbor.

As for public relations, part of the success of the business plan is dependent on Healthy Harbor's social cause. Positive public relations should be created organically as it continues to penetrate the target market and partner with the African-American activist groups and Farmers' market. It is a pro-environmental business, which is what Baltimore wants to increase its image as a green city.

## 6.7 Budgeting and Control

There are many costs that will happen at all stages of the business model progression and product development progression. There is a lot of physical overhead and development costs. In addition to the bike, other kinds of water pumping exercise machines will have to be created. The design of the bike's pump can be applied across all types of exercise machines, but they will all need some kind of adaption. In the beta stage of development, the agricultural system and the supplies needed to maintain it will need to be purchased. Also, someone will have to maintain the integrity of the system over time, which will have a cost. The machines, once designed will all have to be purchased and the space to put them, purchased, leased, or rented. If Healthy Harbor partners with the Museum of Industry, it may be able to use the space for the beta stage at a discount. The construction of the final product will require significant capital for permitting, space, and design. There will also be licensing costs to run a hydroponic agriculture system for human consumption associated with the building. The final product will require a full staff of employees: dieticians, lifeguards, trainers, administrators, etc. There are no distribution costs associated with our marketing strategy, other than marketing collateral distribution which is a dwarfed costs compared to the others.

As a company that is centered on the community, the system for comparing results to objectives is what the stakeholders, the customers, add to system as feedback. The more the community gives feed back to the company, the more Healthy Harbor can adjust to meet the customer. By closely listening to what the community tells Healthy Harbor, the better Healthy Harbor can reflect the constantly changing needs. The crediting system will also help identify what exercise machines in the gym are being utilized more or less. This will allow Healthy Harbor to order more of one type of machine and remove the ones that are not being as utilized. It creates a dynamic and more customer receptive gym and grocery/co-op environment.

When Healthy Harbor identifies a problem with a customer or a part of the business model, there will have to be a multitude options presented on how to get an appropriate solution. If Healthy Harbor misses an opportunity in marketing or does not reach a stage in the development process that was supposed to be met by a particular date, it will require an investigation on what halted the process and whether or not it is in the company's best interest to continue. Because of the nature of the business plan and marketing plan, the beta stage may be final product. Holding the business plan and ourselves to a higher standard is the only way Healthy Harbor stands a chance at succeeding in the long term and producing the product that each stage requires.

# 7 Regulatory Issues

## 7.1 Water Quality Standards

The Environmental Protection Agency (EPA) issues recommendations for safe recreational water standards under the authority of the Clean Water Act. The CWA section 303(c)(2)(A) dictates that water quality standards must protect, "public health or welfare, enhance the quality of the water and serve the purposes of [the Act]". The latest recreational water quality standards were set in 2012, and while that was the first time they had changed since 1986, there is a possibility that these standards could change. The 2012 standards offer two sets of recommendations, both of which would protect members of the public engaging in recreational water activities in the Harbor. The recommendations include levels for two types of fecal bacteria, Enterococci and E. coli. Our filter output must meet these standards in order to reach our goal of producing swimmable water at the tail end of our filtration system. The recommendations are listed in the table below:

| CRITERIA ELEMENTS | Recommendation 1 Estimated Illness Rate 36/1,000 | | Recommendation 2 Estimated Illness Rate 32/1,000 | |
|---|---|---|---|---|
| **Indicator** | GM (cfu/100 mL) | STV (cfu/100 mL) | GM (cfu/100 mL) | STV (cfu/100 mL) |
| Enterococci (marine & fresh) | 35 | 130 | 30 | 110 |
| *E. coli* (fresh) | 126 | 410 | 100 | 320 |

**Figure 17: EPA Criteria Recommendations for Swimmable and Fishable Water**[12]

## 7.2 Acquiring Permits from City of Baltimore

The City of Baltimore has fairly stringent city ordinances regarding structures that encroach upon public space, so our installation will need to be approved to meet local city ordinances. Our initial goal is to install the system along the bulkhead of the Baltimore Harbor, which as a publically owned space must comply with city regulations. Most likely, our system will need to be approved for a "Minor Privilege" permit, which, "lets business owners, homeowners, and others place private items in the public right-of-way."[13] As both the bicycle and the filtration barrel will sit on the edge of the harbor, they both constitute an encroachment into public space. There is also an annual fee associated with different types of minor privilege permits in Baltimore, which will increase the cost of upkeep for our device. Additionally, applying and securing a permit for the project could take between two and six weeks, which must be taken into consideration if we plan to move forward with installation in the city of Baltimore. While local regulations vary from city to city, if our filtration system is to be adopted around other urban water systems, understanding local city ordinances is key to determining the feasibility of the project in different locations.

[12] United States Environmental Protection Agency, "2012 Recreational Water Quality Criteria," December 2012, https://www.epa.gov/sites/production/files/2015-10/documents/rec-factsheet-2012.pdf.
[13] City of Baltimore, "Licenses and Permits, " permits.baltimorecity.gov.

# 8 Conclusion

Over the course of the past year the Duke Bass Connection Design and Innovation in energy team has successfully developed a proof of concept human-powered water filtration system that has garnered commercial interest from legitimate organizations in Baltimore city. Typically, systems like this can have trouble penetrating any kind of broad, environmentally friendly market. They can be very technical and unable to inform the audience they intend to reach of their benefits. Our system aims to reach a wider audience due to its ability to bridge the gap between engineering, environmental activism, and community engagement. Because of the added exercise component that the bike adds to the experience, it is much more palatable to a wider range of demographics. In addition to that, people living in and around the Baltimore Inner Harbor love keeping their community clean and inviting. The human-powered water filtration system utilizes all of these qualities. The bike powered pump encourages anyone who can ride a bike to hop on and pedal for a few minutes to polluted water back into the bay, increasing dissolved oxygen and reducing coliform bacteria. This is a new and innovative concept in the field of environmental science and is a goal of the Healthy Harbor Initiative to incorporate fun and exciting ways to clean our environment. In looking forward, a beta-prototype should be considered for development so that the interested stakeholders and organizations in Baltimore can tap a new kind of technology to engage the public in the Baltimore Inner Harbor clean up.

# 9 References

*Baltimore, Maryland*. (2012) City-Data. www.city-data.com/city/Baltimore-Maryland.

City of Baltimore. "Licenses and Permits." permits.baltimorecity.gov.

Gaynes, S. "*Health Club Membership By State: How Does Yours Stack Up?" Huffington Post*. September 2011. huffingtonpost.com.

McDowell et al. "Anthropometric reference data for children and adults: United States, 2003–2006." *National Health Statistics Reports*; no 10. Hyattsville, MD: 2008.

Mendes, E. *"U.S. Exercise Levels Up, but Demographic Differences Remain".* Gallup. June 2010. www.gallup.com.

Mohr J, Slater S, Sengupta S. *Marketing of High-Technology Products and Innovations.* December 2013.

*Planet Fitness*. "Join Now." 2014. https://www.planetfitness.com/

Tarsi, David. "Slow Sand Water Filters: How They Work and How To Build Them." 2016.

The Environmental Integrity Project. "Stopping the Flooding Beneath Baltimore's Streets: The city's failure to comply with a federal sewage consent decree, and how delay harms homeowners and the Inner Harbor." Dec. 15, 2015.

United States Environmental Protection Agency. "2012 Recreational Water Quality Criteria." December 2012. epa.gov.

Waterfront Partnership of Baltimore. "Baltimore's Annual Healthy Harbor Report Card 2014." 2014.