Engineering a Plant-Based Device to Filter Pollutants from Urban Runoff Water

Grant Proposal

Lily Pattison

Massachusetts Academy of Math and Science

85 Prescott St, Worcester, MA 01605

Table of Contents

Executive Summary

When it rains, storm runoff in urban areas picks up harmful pollutants that build up on impervious surfaces, like sediment, oils and grease, and heavy metals, and carries them to delicate bodies of water. These pollutants later greatly destroy aquatic ecosystems, contaminate water sources, and disrupt recreation (US EPA, 2021). Impervious, or impermeable, surfaces are surfaces that do not absorb water. Some of these include roofs, roads, or parking lots (Charters et al., 2017). This process, also known as nonpoint source pollution, is reported to be the leading cause of inadequate water quality in the United States (US EPA, 2022). Many existing solutions to filter out pollutants from runoff, like grassy swales along highways, take up large areas of space, and are not applicable in an urban setting where there is little available space. The goal of this project is to engineer an affordable solution to urban runoff that filters out the greatest percent of pollutants and has a small footprint, making it applicable in an urban setting.

Keywords: urban runoff, pollutants, impervious surfaces, nonpoint source pollution, grassy swales

Engineering a Plant-Based Device to Filter Pollutants from Urban Runoff Water

In recent years, a movement toward greener and more sustainable architecture has become increasingly important. Sustainable architecture and design contains five major elements: sustainable site design, energy, indoor environmental quality, conservation of materials, and water conservation and quality (Ragheb, 2016). For my project, I will focus on improving the quality of water that is entering aquatic ecosystems.

Water pollution worldwide is a major problem, as it leads to the destruction of aquatic ecosystems, contamination of drinking sources, and disruption of recreational activities. Nonpoint source pollution, or urban runoff, including sediment, motor oil and grease, and heavy metals like iron and zinc, from impervious surfaces such as roads, parking lots, and sidewalks enters delicate aquatic ecosystems, harming fish and wildlife populations and killing native vegetation (United States Environmental Protection Agency, 2021). Nonpoint source pollution occurs when runoff water from storms picks up pollutants that are present on impervious surfaces. These pollutants build up on impervious surfaces during periods of little or no precipitation. When a storm does occur, large quantities of pollutants accumulate in runoff and are carried to storm drains or gutters, where they later enter larger bodies of water. Nonpoint source pollution is reported to be the leading cause of inadequate water quality in the United States (United States Environmental Protection Agency, 2022).

Grassy swales are long, shallow channels with dense grass or other vegetation, and are one of the most common forms of stormwater control (*Grassed Swales Maintenance*, 2022). Grassy swales and other bioswales use soil, plants, and other materials, like woodchips, to filter runoff and slow the flow of water (WPI, n.d.). During a storm, runoff water flows to the area, where the grass acts as a biofilter by removing pollutants from the water before it reaches larger bodies of water (*Grassed Swales Maintenance*, 2022). One study reports that grassy swales remove about 74% of sediment, 88% of oil and grease, and 35-79% of metals (Barrett et al., 1998). In addition, they reduce the speed of runoff and aid the infiltration of water into the ground.

However, grassy swales often take up large sections of land, which may not always be available in crowded urban settings where buildings and infrastructure have already been developed on land (United States Environmental Protection Agency, 1999). The minimum length for a grassy swale is 20 feet, while the width is 6 feet (*Grassy Swales*, n.d.). Grassy swales tend to have an even greater footprint, as the total surface area of the swale must be at least one percent of the area that drains into it in order to be effective (US Environmental Protection Agency, 1999). This is 500 square feet for every acre. In some dense cities, there is simply not enough undeveloped land to place grassy swales for filtering pollutants. Unfortunately, other solutions, like permeable roads, can be very expensive. For my project, I aim to design a prototype filtration system that is as effective as grassy swales at filtering pollutants but has a small footprint.

Section II: Specific Aims

The aim of this project is to design a solution to filter out pollutants in water from urban runoff before they enter waterways and damage aquatic ecosystems. In addition, the solution must have a small footprint in order to be applicable in an urban setting where there is a small area of available, undeveloped space. Based on research, I expect plants like grass to be effective at filtering out pollutants in urban runoff, and plan to design a solution that is based on plants.

Specific Aim 1: Create a prototype that is effective at filtering out sediment, motor oil, and heavy metals, the main pollutants in urban runoff.

Specific Aim 2: The prototype incorporates a small footprint and is applicable in an urban setting.

Specific Aim 3: The prototype is affordable, requires low maintenance, and is able to absorb and filter large amounts of water.

At the conclusion of this project, I expect to have designed, built, and tested a small-scale prototype that is effective at filtering out pollutants from water when compared to the current grassy swale design. In addition, it should incorporate a small footprint, require low maintenance, and be applicable in an urban setting, able to absorb large amounts of water, and affordable.

Section III: Project Goals and Methodology

Relevance/Significance

As previously mentioned, water pollution, specifically from nonpoint sources, leads to the destruction of fragile aquatic ecosystems that bring biodiversity to our planet and control the ecological processes that keep Earth thriving. In addition, it impacts humans as well, leading to contamination in drinking water sources and disruptions in recreational activities, such as swimming or fishing. By learning more about water pollution, including discovering new ways to prevent or decrease it, we are helping to counteract the harm that we have done to our planet.

This project will help create a way for dense urban areas to decrease their water pollution. In addition, it will lead to new observations in this field that could aid future researchers to learn more about and improve upon this field even further. Furthermore, this project will provide educational experiences for not only me as a student, but other members of the community, and raise awareness about this important issue.

Innovation

This project aims to improve upon current water pollution filtration methods. Current methods are not applicable in an urban setting with little available space, so my prototype will fill the need for better urban runoff filtration methods in dense cities.

Methodology

First, I will create various prototype designs and, using a decision matrix, choose the prototype that satisfies the most criteria to build. After building my plant-based prototype, I will begin testing it with my three pollutants: TSS (suspended solids in the form of sediment), motor oil, and heavy metal particles. I will first introduce each pollutant into the water, and use the tests described below to measure the quantity of each pollutant. After running the water through my device, I will test it again for each pollutant.

To test for TSS, I plan to use a turbidity sensor. This is a device that uses light to quantify the cloudiness of a liquid (*Measuring Turbidity, TSS, and Water Clarity*, n.d.). I will use sediment in the form of soil and stir it into the water. After passing through my prototype, there should be less sediment than initial levels.

As motor oil will separate from water, I plan to put the water and motor oil mixture in a thin beaker and let it sit until the two liquids separate. Then, I can measure the volume of oil that is present.

To simulate heavy metals, I will use methylene blue, a dye with similar properties to heavy metal particles. This can also be measured using a turbidity sensor.

With the data collected through multiple tests of levels of each pollutant before and after the runoff goes through my prototype, I will compare the average percentage of pollutant removed with data from previous studies of grassy swales to determine whether or not my prototype is effective.

Specific Aim 1: Create a prototype that is effective at filtering out sediment, motor oil, and heavy metals, the main pollutants in urban runoff.

Justification and Feasibility

The top criterion for this project is that the prototype is as or more effective than the current grassy swale filtration system. This new design should be able to replace grassy swales in urban areas. This means that this design needs to work just as well as grassy swales if it is to replace them.

Summary of Preliminary Data

After thorough research, I plan to compare the efficiency of my prototype at removing these three pollutants to the efficiency of grassy swales collected by two studies. Tables 1 and 2 show a table of the studies' data.

Pollutant	Median % Removal
Total Suspended Solids	81
Oxygen Demanding Substances	67
Nitrate	38
Total Phosphorus	9
Hydrocarbons	62
Cadmium	42
Copper	51
Lead	67
Zinc	71

Table 1: Data from US Environmental Protection Agency, 1999; "Effectiveness of Design Swales"

Parameter	Roadway	Grassy Swale	Removal (%)
Total Coliform (CFU/100mL)	3,678	188,197	-
Fecal Coliform (CFU/100mL)	1,934	101,545	-
Fecal Streptococcus (CFU/100mL)	6,909	89,482	-
TSS (mg/L)	104	27	74
VSS (mg/L)	23	7	72
BOD_5 (mg/L)	7.5	4.1	46
COD (mg/L)	51	33	35
Total Carbon (mg/L)	34	18	48
Dissolved Tot. Carbon (mg/L)	17	15	9
NO_3-N (mg/L)	0.88	0.36	59
Total Phosphorus (mg/L)	0.15	0.10	31
Oil & Grease (mg/L)	3.9	0.5	88
Cu (mg/L)	0.014	0.007	49
Fe (mg/L)	2.066	0.442	79
Pb (mg/L)	0.014	0.009	35
Zn (mg/L)	0.074	0.019	74

Table 2: Data from Barrett et al., 1998; "Removal Efficiency of a Grassy Swale"

Expected Outcomes

I expect the percent of each pollutant removed to resemble that of grassy swales.

Potential Pitfalls and Alternative Strategies

In the event that the percent removed is too low and the design is not effective, I will redesign for greater effectiveness and test again.

Specific Aim 2: The prototype incorporates a small footprint and is applicable in an urban setting.

Justification and Feasibility

In addition to the design being as or more effective than grassy swales, it must also be unique in that it can be applied in an urban setting where there is very little available space. Many current solutions to filter pollutants from runoff water take up too much space, and can not be applied where they are needed most: in dense cities with greater levels of motor vehicles and other sources of water pollutants. Creating a design with a small footprint is vital to its application in urban areas.

Expected Outcomes

I expect my design's footprint to be smaller than that of grassy swales and able to be integrated into an urban environment.

Potential Pitfalls and Alternative Strategies

In order to achieve this, the surface area of layers filtering the water must be greater, but in a smaller footprint. If my design does not prove to be able to maintain its effectiveness in a smaller footprint, I may need to redesign and modify the materials I plan to use.

Specific Aim 3: The prototype is affordable, requires low maintenance, and is able to absorb and filter large amounts of water.

Justification and Feasibility

If this design is to be used in real life urban areas, it must able to handle the amount of water that will flow into it during a large storm event and remain effective if no one is able to do regular maintenance on it. In addition, the materials used should be simple and affordable to provide an easier way for cities to implement this design.

Expected Outcomes

The final cost of the device should not be overly expensive. In addition, the device should be able to handle large quantities of water. It should not need maintenance more than one time each year.

Potential Pitfalls and Alternative Strategies

Currently, the device should meet the cost expectations. In the event that I need to change the materials I use, the overall cost of the design may increase. The lowest cost possible should always be maintained without sacrificing effectiveness or footprint. In addition, the ability to handle large quantities of water and require little to no maintenance may not be possible while maintaining aims 1 and 2. In this event, the device may need to include an overflow for cases where it may not be able to handle all the runoff at a particular time, for example, a large storm.

Section III: Resources/Equipment

Materials for Prototype

My current prototype design, shown in Figure 3, consists of a frame made from four PVC pipes for legs. Each of the three layers will be made of a plastic container with holes drilled in the bottom for water to get through. The bottom clear container will collect the water after it has completely passed through. Inside the top container is four layers of varying materials: large gravel, small gravel, sand, and wood mulch. These materials are already available to me, so I will not need to purchase them. The bottom two layers contain grass,

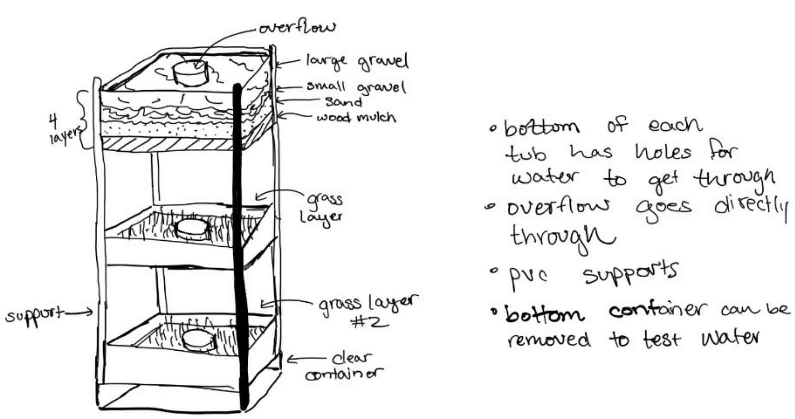


Figure 1: Initial prototype sketch

which is also available to me. Overall, the cost of the prototype itself should be minimal.

Equipment for Testing

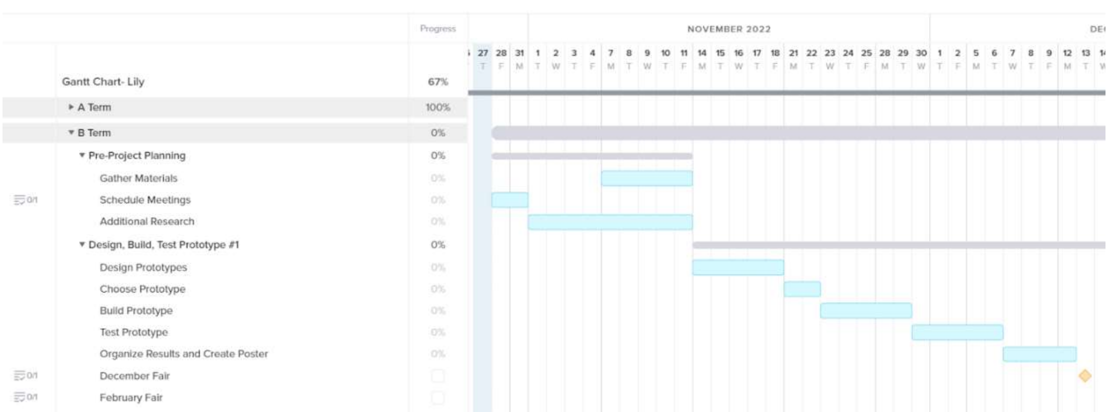
To test my prototype, I will need sediment and motor oil to be introduced to water. To simulate heavy metals, I will use methylene blue, a dye with similar properties to heavy metal particles. I will need a turbidity sensor and beakers. All these materials are readily available to me with no cost. In addition, I will need protective eyewear and a lab coat, which will also not need to be purchased.

Section V: Ethical Considerations

Importance

By reducing water pollution from Nonpoint Sources, this project is helping to protect our waterways from destruction to aquatic ecosystems, drinking water contamination, and disruptions to recreation. Keeping aquatic ecosystems healthy contributes to the overall health of the environment, working to keep our planet well. In addition, this project will bring awareness to water pollution and may even inspire people to work in their own lives to reduce water pollution.

Section VI: Timeline



Section VIII: References

Barrett, M. E., Irish, L. B., Malina, J. F., & Charbeneau, R. J. (1998). Characterization of Highway Runoff in Austin, Texas, Area. Journal of Environmental Engineering, 124(2). https://doi.org/10.1061/(asce)0733-9372(1998)124:2(131)

Charters, F. J., Cochrane, T. A., & O'Sullivan, A. D. (2017). Characterising urban zinc generation to identify surface pollutant hotspots in a low intensity rainfall climate. Water Science and Technology, 76(6), 1370–1377. https://doi.org/10.2166/wst.2017.306

Environmental Protection Agency. (1999, September). Storm Water Technology Fact Sheet Vegetated Swales. EPA. Retrieved December 10, 2022, from https://nepis.epa.gov/Exe/ZyNET.exe/200044A8.txt?ZyActionD=ZyDocument&Client=EPA&Index=1995+Thru+1999&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&UseQField=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5CZYFILES%5CINDEX+DATA%5C95THRU99%5CTXT%5C00000015%5C200044A8.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-
&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8%2Fr75g8%2Fx150y150g16%2Fi425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results+page&MaximumPages=1&ZyEntry=3 US

US EPA, O. (2021, December 6). Nonpoint Source: Urban Areas. Www.epa.gov.https://www.epa.gov/nps/nonpoint-source-urbanareas#:~:text=In%20addition%20to%20these%20habitatdestroying%20impacts%2C%20pollutants%20from

Grassed Swales Maintenance. (2022). Aqualis. https://www.aqualisco.com/service/stormwater-management/grassed-swales/?adlt=strict&toWww=1&redig=E01C87DFDE62433D81169757998656D1

Grassy Swales. (n.d.). City of Sandy, OR. Retrieved November 28, 2022, from https://www.ci.sandy.or.us/publicworks/page/grassy-swales?adlt=strict&toWww=1&redig=486FFAE06F8245FAAB3E787CE8715D91

Measuring Turbidity, TSS, and Water Clarity. (n.d.). Environmental Measurement Systems. Retrieved November 29, 2022, from https://www.fondriest.com/environmental-measurements/measurements/measuring-water-quality/turbidity-sensors-meters-and-methods/?adlt=strict&toWww=1&redig=AA1D5E452CCB462D894063C35F07B2EB

Ragheb, A., El-Shimy, H., & Ragheb, G. (2016). Green Architecture: A Concept of Sustainability. Procedia - Social and Behavioral Sciences, 216, 778–787. https://doi.org/10.1016/j.sbspro.2015.12.075

WPI. (n.d.). *Sustainable WPI*. WPI. Retrieved December 10, 2022, from https://www.wpi.edu/offices/sustainability/sustainable-wpi?adlt=strict&toWww=1&redig=48CB8B4293C048B18A060DF52F0D5BB0

US EPA. (2022, July 7). Basic Information about Nonpoint Source (NPS) Pollution | US EPA. US EPA. https://www.epa.gov/nps/basic-information-about-nonpoint-source-nps-pollution