A Portable Stormwater Runoff Collection and Treatment System for Urban Agriculture and Food Security

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Design and Development of a Portable Non-point Stormwater Runoff Collection and Treatment System

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Abstract

With the fast increase of urban population, vast quantities of energy and water are being consumed whilst harmful quantities of wastewater and stormwater runoff are generated through the creation of massive impervious areas. Food security is becoming an increasingly important issue, especially urban residents here in US. There is an urgent need of developing effective and economical feasible solution for the best management practices to minimize storm water runoff, reduce soil erosion, maintain groundwater recharge, and minimize surface water and groundwater contamination from combined sewer overflows. In this study, a novel stormwater collection and treatment system is developed, which can harvest and store stormwater from densely populated urban areas and use it to produce food at relatively low costs. This system consists of an expandable storage tank that has a minimum volume and occupied space of 5 cubic feet and can expand to a theoretical maximum volume of 9 cubic feet almost doubling the size of the tank. The filtration system is a mechanical filtration with a filter size of 250 microns and a chemical filtration system with a mesoporous nanostructured material to filter heavy metals and other pollutants. This proposed system will help reduce food miles (carbon emissions) and virtual water consumption and serves to highlight the need for more sustainable land-use planning.

Key words: Nanotechnology, Stormwater Runoff, Water Treatment, Water Quality
Introduction

Urbanization increases the variety and amount of pollutants carried into our nation's waters. In urban and suburban areas, much of the land surface is covered by buildings, pavement and compacted landscapes with impaired drainage. These surfaces do not allow rain and snow melt to soak into the ground which greatly increases the volume and velocity of stormwater runoff. As the runoff flows over the land or impervious surfaces (paved streets, parking lots, and building rooftops), it accumulates debris, chemicals, sediment or other pollutants that could adversely affect water quality if the runoff is discharged untreated. These pollutants can harm fish and wildlife populations, kill native vegetation, foul drinking water, and make recreational areas unsafe and unpleasant. The porous and varied terrain of natural landscapes like forests, wetlands and grasslands traps rainwater and snowmelt and allows them to filter slowly into the ground. In contrast, impervious (nonporous) surfaces like roads, parking lots and rooftops prevent rain and snowmelt from infiltrating, or soaking, into the ground. Most of the rainfall and snowmelt remains above the surface, where it runs off rapidly in unnaturally large amounts. Storm sewer systems concentrate runoff into smooth, straight conduits. This runoff gathers speed and erosional power as it travels underground. When this runoff leaves the storm drains and empties into a stream, its excessive volume and power blast out streambanks, damaging streamside vegetation and wiping out aquatic habitat. These increased storm flows carry sediment loads from construction sites and other denuded surfaces and eroded streambanks. They often carry higher water temperatures from streets, roof tops and parking lots, which are harmful to the health and reproduction of aquatic life. The loss of infiltration from urbanization may also cause profound groundwater changes.

Although urbanization leads to great increases in flooding during and immediately after wet weather, in many instances it results in lower stream flows during dry weather. Many native fish and other aquatic life cannot survive when these conditions prevail. Urbanization increases the variety and amount of pollutants carried into streams, rivers and lakes. These pollutants can harm fish and wildlife populations, kill native vegetation, foul drinking water supplies, and make recreational areas unsafe and unpleasant. Thus, how to effectively manage the stormwater runoff is a serious problem for urban area, especially the Washington metropolitan area. In District of Columbia (DC), stormwater entering storm sewers does not receive any treatment before it enters the Potomac and Anacostia Rivers and Rock. The cumulative effects of stormwater runoff on water bodies are evident in both the Potomac and Anacostia Rivers, which regularly receive untreated stormwater, now suffer from poor water quality. If not properly managed, the volume of stormwater can flood and damage homes and businesses, flood septic system drainfields, erode stream channels, and damage or destroy fish and wildlife habitat. Because less water soaks into the ground, drinking water supplies are not replenished and streams and wetlands are not recharged. This can lead to clean water shortages and increased food price for more serious food security crisis. All these will require better urban runoff water management solution.

In addition to that, a distributed optimal technology networks (DOT-NET) has been proposed by scientists as an alternative to the ‘huge centralized’ water treatment plant. The DOT-NET concept is predicated upon the ‘distribution and strategic placement of relatively small and highly efficient treatment systems at specific locations’ in existing water supply networks[1]. Such satellite water
treatment systems would process relatively low flow rates and would use ‘off-the-shelf’ treatment technologies of the most advanced nature to meet the water needs of population clusters such as housing subdivisions, apartment complexes and commercial districts. The US Environmental Protection Agency (EPA) is also evaluating the use of a number of decentralized water treatment concepts as ‘small system compliance technology’. These include package treatment plants (i.e., factory assembled compact and ready to use water treatment systems), point-of-entry (POE) and point-of-use (POU) treatment units designed to process small amounts of water entering a given unit (e.g., building, office, household, etc.) or a specific tap/faucet within the unit. The protection of water treatment systems against potential chemical and biological terrorist acts is also becoming a critical issue in water resources planning. Advances in nanoscale science and engineering are providing unprecedented opportunities to develop more cost effective and environmentally acceptable water purification processes.

There is an urgent need of developing effective and economical feasible solution for the best management practices to minimize storm water runoff, reduce soil erosion, maintain groundwater recharge, and minimize surface water and groundwater contamination from combined sewer overflows[2]. In the last decade, researchers from universities and nongovernment organizations, as well as industry consultants, have proposed new techniques and methodologies to remedy wastewater which include using micro/nanostructured membrane/filtration, nanoparticle catalytic, and chemical reaction etc[1-12]. However, these methods often times are inapplicable for urban agriculture farm or household, because the cost of the system and requirement of post processing are usually time-consuming and expensive [1, 5, 6]. To address the above issues, an innovative approach to design and develop a novel stormwater collection and treatment system which can harvest and store stormwater from densely populated urban areas and use it to produce food at relatively low costs is urgently needed. This will reduces food miles (carbon emissions) and virtual water consumption and serves to highlight the need for more sustainable land-use planning. It not only provides an efficient alternative approach to removing pollutants at a low cost, but also eliminates the risk of nanoparticles contamination and the hassle of post processing. Furthermore, the processed stormwater runoff can be reused to irrigate the plants in backyard and home gardens to save on precious water resources and help protect the environment.

**Engineering Approaches:**

Residential housing uses standard gutter and down spout system to control roof rainwater runoff. The current design features a plug and play system that required little alteration to the standing runoff system. In addition, a “snap on” fitting for the gutter down spout that functions as a leaf and small debris filter was incorporated into the design. Deionization Resin is a common medium used to filter water systems of all kinds. Most importantly, a new type mesoporous material (MCM-48) based hybrid material with embedded metallic oxide nanoparticles was synthesized and used as the filter media between the down spout filter and the storage unit[13-18].

These DC rain water statistics was used to construct our use models. DC receives about 39.5 inches avg per yr. DC receives on average 2.54 inches avg PR moth. An estimate of the average roof size
for a DC home is about 1000 sq ft. From this information we calculated that DC residents can tap into around 986 gallons per month and 24466 gallons per year. (Rainwater capture potential per month ((1000 sq ft * 2.54 inches)/12)*7.48 = 986.6 gallons - Rainwater capture potential per yr–

((1000 sq ft * 39.25 inches) / 12) * 7.48 = 24466 gallons.

Using data from the Water Conservation website, average the amount of water a typical household would use was calculated and tabulated in Table 1. These calculation help in determining what the unit storage capacity should be.

Table 1. Typical water usage at home in DC

<table>
<thead>
<tr>
<th>Typical water usage at home</th>
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<tbody>
<tr>
<td>Bath</td>
<td>A full tub is about 36 gallons.</td>
</tr>
<tr>
<td>Shower</td>
<td>2-2.5 gallons per minute. Old shower heads use as much as 4 gallons per minute.</td>
</tr>
<tr>
<td>Teeth brushing</td>
<td>&lt;1 gallon, especially if water is turned off while brushing. Newer bath faucets use about 1 gallon per minute, whereas older models use over 2 gallons.</td>
</tr>
<tr>
<td>Hands/face washing</td>
<td>1 gallon</td>
</tr>
<tr>
<td>Face/leg shaving</td>
<td>1 gallon</td>
</tr>
<tr>
<td>Dishwasher</td>
<td>20 gallons/load, depending of efficiency of dishwasher</td>
</tr>
<tr>
<td>Dishwashing by hand:</td>
<td>4 gallons/minute for old faucets. Newer kitchen faucets use about 1-2 gallons per minutes.</td>
</tr>
<tr>
<td>Clothes washer</td>
<td>25 gallons/load for newer washers. Older models use about 40 gallons per load.</td>
</tr>
<tr>
<td>Toilet flush</td>
<td>3 gallons for older models. Most all new toilets use 1.2-1.6 gallons per flush.</td>
</tr>
<tr>
<td>Glasses of water drunk</td>
<td>8 oz. per glass</td>
</tr>
<tr>
<td>Outdoor watering</td>
<td>2 gallons per minute</td>
</tr>
</tbody>
</table>

A sample of houses from a surrounding neighborhood to determine best configuration of down spout filter as the selected samples are listed below in Figure 1. We focused on finding pre constructed parts that could be easily assembled and deployed to different down spout configurations.
Figure 1. Sample downspout configurations used in DC

It can be seen from the Figure 1 above that the downspout location varies from location. Either it is at grade, or is raised with an extension attachment. The user may need to alter their downspout in order to attach any device. One goal of this device aims to create a solution that does not require alteration for downspouts at grade. Another observation is the location of downspouts. The tight placement of housing in DC means not everyone will have adequate space to place a fix volume of storage unit. In total our system is composed of three main parts, The Downspout prefilter, the DS filter, and the Storage Unit. Below is a breakdown and explanation of each part.

Results

*Stormwater Collection and Treatment System Diagram:*
Figure 2. Stormwater Collection and Treatment System Diagram

Each part is explained as following:

1. Drainage area – Avg DC home rooftop
2. Collection and conveyance system (i.e. gutter and downspouts) – DC home gutter system with front and back spouts ending with an angled end piece at ground level.
3. Pre-screening and first flush diverters – fitted prescreen to spout end piece at inlet and outlet to storage.
4. Storage tank (foil inlay bag with woven Polypropylene outside) – expandable liquid barrier lined material laying at undetermined elevation with fittings for liquid transfer, dark coating to decrease light infiltration discouraging microbe growth and sealed discouraging insect and rodent frequency. Main feature is collapsible for fitting into small spaces, and fitting onto at grade spouts.
5. Water quality treatment (as required by TRAM) – undetermined.
7. The storage bag was equipped with a zipper for easy access. Leak proof rubber striping was added to the front opening of the Mylar bag to prevent small leaks. Sealing the Mylar bag with a outside clamp that screws down onto the Mylar but does not penetrate the bag. This keeps the system intact with and easy to maintain.

**Design conditions**

The capture system above is compiled from parts that can be purchased from the hardware store. The storage system is compiled from parts that are premade as well.

1. Start with a downspout filter for the large particulate funneling the water to a second filter screen for small particulate.
2. The filter screen also acts as a mosquito barrier to the inside of the tank. A reducer coupling housing the filter screen and reduces from the 4 “ down spout filter opening to a 2 “opening.
3. A 2 “inch hose connects to the reducer and out to the tank.
4. The storage unit is a 50 gallon Mylar lined woven polyethylene bag. The Mylar bag is used as a moisture barrier, and the woven ploy is used to house the Mylar bag and support the pressure and weight of the water. The Mylar bag will be heat sealed and then place inside the woven poly bag.
   a. Design the poly bag smaller than the Mylar bag in order to decrease the possibility of over expansion of the inner Mylar bag which has a lower strength then the poly bag. This will remove the need to glue the Mylar bag to the poly bag.
   b. Heat seal the Mylar bag while also folding the opening 5 times to create a tighter seal. The folding pushes the Mylar material together and creates a seal that can be mechanically closed for future reopening.
5. Attach the 2” inlet, outgas/over fill, and garden hose attachment to a pvc plates that will be glued to the inside of the bag and put through holes that exposes it to the outside. The plate will cover a larger glued surface area reducing the possibility of a leak.

**System Test:**

The complete system was attached to the down spout of a typical DC house. The installation took 20 minutes and did not include difficult alteration. The hardest portion of installation involved removing the bottom section of the downspout in order to slide the pre filter fitting into place.
The system fit into the confined space, and did not collect unwanted bugs or rodents. About 4 gallons of water was collected during a rain fall and filter almost 90% of all large and small particles with pre filtration. The dissolved solids filter is still in test phase. The images below show the large and small particulate filters capacity to keep out material that could potential make the water unusable. Lastly the system can be rolled up for easy transport and packing.

![Figure 3. Stormwater Collection and Treatment System Attached to a Downspout](image)

**Characterization for heavy metals removal:**

Contaminated water collected from the stormwater system was used for heat metals removal test. For each synthesized material, 90 mL of the solution was filtered slowly through 6 g of the material and collected in six 15 mL tubes. The collected filtrates were then analyzed for trace metals with ICP-MS.

The results were shown in Figure 4 that the filtration system with the integrated MCM hybrid media can adsorb heavy metals. It gives the best adsorption for Cu, As, Pb, and Cd, but not the best for Cr. Overall, the materials are good adsorbents for Pb, Cd, As, and Cu.
The maximum adsorption of the material for certain metal can be determined based on the negative values in Table 2.

Table 2. Total adsorption of the filtration system with MCM Hybrid Material

<table>
<thead>
<tr>
<th>Material</th>
<th>Total absorption (ppb)</th>
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<tbody>
<tr>
<td></td>
<td>Cr</td>
</tr>
<tr>
<td>MCM Hybrid Material</td>
<td>32.05</td>
</tr>
</tbody>
</table>

**Conclusion:**

Through this research, it has been found that cost of storage, installation onto downspouts, and size of storage are three main barriers to the adoption of rainwater capture systems in urban environments. The design components were addressed by design for ease of installation, low cost, low maintenance, space maximization, safely, and easy transport. This solution is expandable system that has flexible slip fittings that lock onto down spout. This design makes transportation of entire system cheaper, storage in small spaces easier, installation on down spouts simpler, and affordable for a wide spectrum of socio economic groups. Only 5 custom processes are needed in this process that is not labor intensive. In addition, a novel mesoporous MCM hybrid material with embedded nanoparticles has been incorporated to treat the collected stormwater and the results have shown that this material can removal heavy metal contaminants and provide purified water. This would provide an effective way to removal toxic pollutants such as heavy metals while maintain versatile and compact. Overall, this portable stormwater collection and treatment system provides an effective and economical affordable solution to process non-point pollutions, especially the stormwater runoff for urban residents.
Bibliography

[2] 2013, "Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management ", EPA.