Natural Treatment of Stormwater Runoff

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Abstract

In the Northeastern region of the United States, there is a growing problem in the collection and treatment of stormwater runoff. In recent years the region has experienced record amounts of rainfall with the projections pointing to this trend continuing. The Sanitation Department in most of these areas is responsible for the collection of this stormwater, meaning that the runoff is combined with, and treated as wastewater. Most of the current water treatment systems cannot handle these increased demands during large storms and as result hundreds of thousands of gallons of waste are dumped into the surrounding rivers and streams during and shortly after these large storms.

The US Environmental Protection Agency (EPA) is levying fines and promulgating additional regulations for these violations, so a long term solution is necessary. The proposed method of addressing these needs involves mimicking the natural water cycle which would naturally allow the water to be absorbed into the ground and then evaporated as opposed to flowing directly into the sanitation system. This study looked at a local urbanized region, Pittsburgh Pennsylvania, as a case study considering the locale and its urbanization, the current infra-structure, and the current and future requirements for storm water runoff mitigation.

The study defined the problem, considered the current legal implications, and then looked at the types of technologies that could be implemented to address this problem. The technology ultimately recommended would be a roof spray technology that is capable of collecting the excess stormwater runoff, storing it, and then spraying it onto a roof where it would be evaporated. This system would reduce the excess water runoff created during storms that the sanitation systems cannot adequately handle. The concept for this runoff solution is provided with an analysis of the actual issues underlying these runoff problems.

Keywords: stormwater; runoff; roof spray technology, wastewater, natural water cycle, evaporation

1. Introduction

The collection and treatment of stormwater runoff has become a growing problem in many parts of the globe and particularly in the Northeastern portion of the United States. In many of these regions stormwater and raw sewage use the same above and below ground channels. This paper focuses on the region centered around Pittsburgh in the Allegheny County of Pennsylvania. With record amounts of rainfall from numerous storms over the past few years, the Allegheny County Sanitation Department has often been unable to meet the runoff demands it has been tasked to handle. The result of this has been hundreds of thousands of gallons of waste being dumped directly into the rivers and streams of the area, during and shortly after these heavy storms. Some of this is due to the rate and volume of the rain fall but most is due to the urbanization of the land, which covers the natural landscape with buildings and pavement. Thus, the precipitation from these storms can no longer be handled due to the lack of undeveloped land which historically provided water retention and evaporation to take place in a natural setting.

With the city currently facing fines from the Environmental Protection Agency for overflow dumping in the natural waterways, proposed solutions are being sought to provide an inexpensive solution to these runoff problems, and one that can grow as the region develops. Many potential solutions have been proposed and discussed but most will have enormous upfront costs while others could become obsolete before they are even finished. Local ordinances continue to be passed sacrificing money and property to install catch basins and other water retention solutions, which are often inadequate to the need. These retention solutions are expensive to construct and maintain and they reduce the available land for other developmental activities. With time, these local requirements plus additional laws and regulations will continue to grow placing even larger burdens on businesses and property owners while often producing limited or sometimes zero long-term benefits.

2. The Environmental Situation

When land is altered from its original, natural state it upsets the way nature originally managed local and downwind atmospheric conditions including storms and rainfall occurrences. Parking lots, buildings, roads, cities, and other infrastructure are vastly inferior in their capability to deal with excess rainwater runoff than the ground is. This inability to absorb rainfall in developed regions results in massive amounts of runoff entering the local waterways including in some cases the primary sewage collection system. This runoff, in addition to contributing heavily to flooding, erosion, and the destruction of the ecosystems they support, can easily overload the wastewater treatment facility.

For Allegheny County, Pennsylvania a rainfall episode as small as one tenth of an inch can be too much to treat - resulting in the dumping of whatever water cannot be processed (which includes wastewater and sewage as well as storm runoff) into the river or body of water nearby. This pollution of water sources is damaging to the aquatic environment and can be harmful to downstream communities. This series of problems is currently being addressed by the policies of the Environmental Protection Agency in the U.S. through fines imposed on the polluting facility- a cost that is normally passed along to the consumer and taxpayer.

The EPA is also continuing to promulgate new regulations about on-site water retention for land owners. Increasing the requirements and providing increased fines and penalties for failure to enact and uphold the requirements has caused many regions to rethink the problems and to seek more proactive and less expensive solutions. Their effort and those of other environment groups, however, are more directed to treatments for the symptoms, rather than proposing a solution to the problem. Our society's social and economic developments have detracted from the earth's natural ability to collect and recycle precipitation back into the atmosphere, which needs to be taken into consideration if a solution is to have a long-term and responsive outcome.

Another aspect of this problem is that there is a lack of incentive for investment in technologies that might mitigate these problems. Clearly, urbanization will continue thus increasing land development and the resulting increase in impermeable, non-natural surface area. Property owners have little motivation to install technology that would reduce the rain water runoff because they are not aware of, or have seen demonstrated, a potential financial benefit to offset their cost, plus environmental benefits usually do not have enough influence on most people’s concerns or actions.

2.1 Current Solution Methods

According to the EPA, people impact the natural flow of water through the construction of buildings and homes, land irrigation, and other infrastructures that prevent water from returning to the earth and evaporating naturally. The response to this issue has resulted in the development of urban and rural implementations of environmentally conscious infrastructures to aid in the offsetting of the excess runoff. Unfortunately, current methods neglect to consider the economic impact and the feasibility which could result if the current systems factored in more of a lifecycle approach to the problems, which in several cases could include a financial incentive that could not be ignored.

In general, methods to decrease water runoff are categorized by retention and detention. Retention describes the function of containing water and naturally filtering out contaminants. Examples of retention technologies include retention ponds, rainwater harvesters, rain barrels, and cisterns. Detention defines the collecting of water temporarily then allowing it to return to the surrounding ground at a reduced rate or as the ground is able to absorb it. These structures include rain gardens, planter boxes, and soakage trenches [1]. While many methods address the issue of stormwater runoff, no single strategy can solve the runoff problem completely. Only a combination of current technologies, with many that will be developed in the future, can lead to an acceptable long-term solution.

2.3 Project Objective

The subject of this program was to investigate and proposed at least one way to mitigate the negative effects of storm water runoff. The result of this study was the proposal to address excessive rain water runoff by focusing on simulating the natural water cycle of precipitation, absorption into the ground and filtration, and evaporation of the collected rainwater back into the atmosphere, in contrast to simply channeling the water into the sewage system. The impetus behind the study was that precipitation that falls onto a roof or parking lot should be returned back to “Mother Nature" in a similar fashion to how it would if the building or developed area was not there in the first place.

The primary objective of this study was to consider a system or combination of systems that could reduce the amount of excess stormwater runoff that is either returned to the watershed or sent to a wastewater treatment plant. The proposition was that any reduction will help to decrease or stop the overflow from wastewater treatment plants, help to reduce localized water damage and reduce the danger caused by high and fast moving water. Such a system should also provide a financial benefit to the land owner, incentivizing its implementation. In the final analysis it was determined that a roof-based evaporative system could be implemented to meet the rain water runoff needs and if developed properly it could be cost neutral or, even better, profitable.

To date few evaporative technologies have been considered or provided as a potential long-term solution for this problem. Most of these system, in the past, were used as a form of air conditioning where most were abandoned because of the increasing popularity and cost effectiveness of central air conditioning. This also resulted since previous evaporative roof-spray technologies were not cost effective. One of the primary reasons for their failure was the need to use treated water from the city's fresh water system. However, combining a modified roof-spraying technology with the collection of stormwater runoff creates a potential solution to this ever-growing rainwater runoff issue while also producing potential environmental and financial benefits.

With proper harvesting, storage, filtration, and setup techniques, roof spraying technology has the ability to compete with current methods of rainwater retention and treatment, while providing competitive prices, minimal space requirements, savings on structural cooling costs, and increased workplace efficiency. This technology has the ability to reduce the sewage overflow problems caused by storm water runoff in most regions and will be a large next step in restoring the ecosystem to its natural condition.

2.4 Stormwater Collection Technology

Rainwater not absorbed by the ground is primarily affected by "i) clearing or altering vegetation cover, ii) increasing the land slope with artificial ground cover, and iii) reducing soil permeability by the soil compaction and application of chemicals [2]." Clearing the vegetation from the ground increases the surface runoff, which can also cause an increase in soil erosion adding additional clean-up burden downstream. Increasing the slope of the land also causes the water increased erosion and it decreases the soils permeability by reducing the contact time between the water and the soil. Bench terraces can be added perpendicularly to slow runoff to assist in capturing excess flow, and thus helping to allow for contact time with the soil [2]. In all of these scenarios a major factor is in the cost of providing solutions to these intermittent and damaging events. Note also that several of these solutions are only applicable to new construction where older structures may not be economically altered.

Even for some of these older structures there are a variety of techniques that can be implemented to help alleviate these problems. For example, most buildings have gutter systems already in place to control the flow of building runoff and ultimately to stop erosion around the base of the structure. The basic concept of a gutter system is that rain falls on the roof, or catchment area, of the structure. The rain then flows down the designed slope of the roof into the gutters which collect the water. The gutters then direct the course of the rain towards an outflow pipe that is vertical thus taking the water down in elevation, reducing the erosion potential. From this point multiple things can happen including releasing the water away from the building using more piping, connecting to a sewer system pipe, or flowing the water into a collection basin, or a cistern for future use like shown in Figure 1.

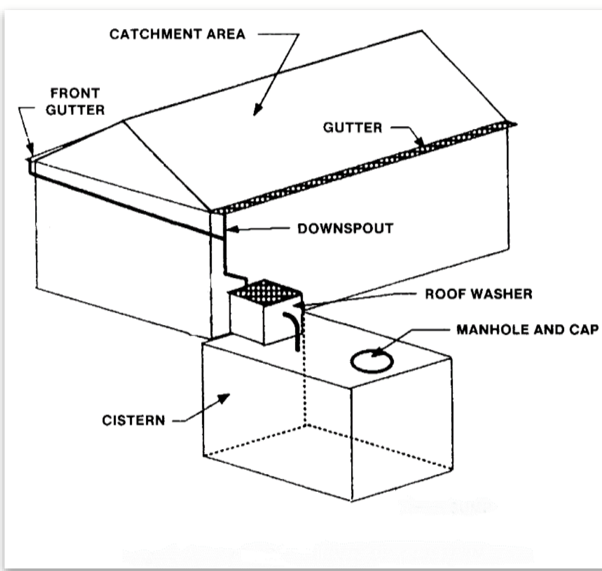

FIGURE 1: SCHEMATIC OF RAINWATER CATCHMENT SYSTEM [3]

Proper planning can help determine the kinds of materials needed in a rainwater harvesting system. This is particularly the case for new construction but it can also be important during renovation. First by looking at the catchment area, certain roofing materials can impact the quality and the quantity of the rainwater after it comes in contact with the roof. If feasible, picking non-absorptive roofing materials, such as steel, and not choosing porous materials containing potential contaminants is the best option. Having properly placed, sized and sloped gutters with an adequate number of downspouts can help the system collect the maximum amount of water [4].

In order to harvest, the water it needs to be collected and stored in a basin or storage container for future use. There are three major storage containers that are used the most in collecting rainwater: rain-barrels, cisterns and eco-retention ponds. Rain-barrels are used for small-scale outdoor uses, such as watering the garden. Their small capacity can be insignificant to the total runoff problem as they cannot collect very much, and since they merely store the untreated water they are susceptible to the growing of bacteria due to direct and indirect sunlight [5]. Cisterns are another method of storage that have a larger volume and can capture water runoff from roofs or surfaces that can direct the stormwater to a collection point. Cisterns can be made of materials such as wood, plastic, metal or concrete. They can also have an aesthetic appeal. Typically, cisterns are underground but in some cases they can be placed above ground [5].

Another effective runoff collection method is the utilization of slopes to collect runoff from parking lots and surrounding pavement. Parking lots are typically designed so that the rain flows in a specific direction to be collected or sent to a particular location or drain site. This is then connected to the stormwater system where all the water will flow.

FIGURE 2: PAVEMENT RAINWATER HARVESTING [6] [7]

Water would be collected from the pavement and a high enough grade on that pavement would allow the water to flow to a point. Gutter like structures and rims added to this pavement would assist in directing the water from the surface. Once the water reaches this point, which would be the drain, it would then be connected to piping that would flow the water to a pre-determined collection method, see Figure 2.

A final collection method is one in which excess water is extracted from the surface and in addition to this it collects the water that falls from the sky. A bio-retention pond is a logical system to use since flow can be directed into it from the ground using gravel and other man made means while also allowing an area that water can collect straight from the sky, holding it until a use for that water is needed. From this pond, a pump can be used to extract the water from the pond and direct the water to another collection basin or straight into the stormwater system depending on the needs of the situation, see Figures 3 and 4.

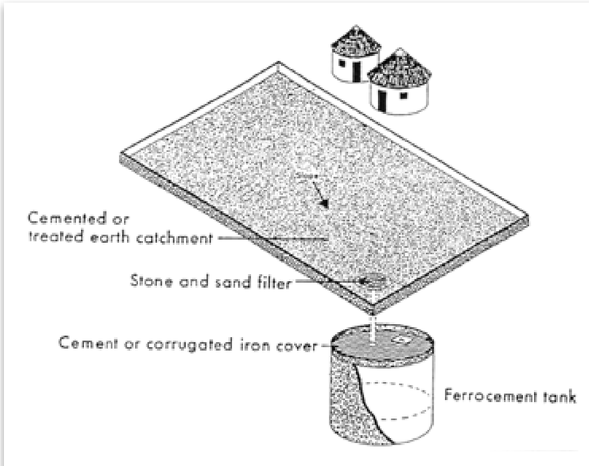

FIGURE 3: RAINWATER GROUND CATCHMENT [8]

FIGURE 4: RAINWATER GROUND CATCHMENT [9]

2.5 Patent Research

Patent research has provided insight into technologies that have been already developed, for potential uses in stormwater runoff applications. There are many patents related to the treatment of water and to the evaporation of untreated water. These technologies are able to provide alternate solutions working in conjunction with current methods. Permeable concrete, roof systems, corrugated pipe systems, and stormwater basin modifications to name a few, are available to facilitate the EPA's goal of providing alternative means to reduce the amount of stormwater runoff.

Of interest in the patent art are methods for direct water use and a variety of patents on sensors to control flow and retention. The most interesting are the patents that focus on the cooling potential through the utilization of evaporation technologies, where each have a slight difference in their method of application. The Evaporative Roof Cooling system patent (US Patent 4,761,965), the Roof Cooling System patent (US Patent 2,437,156), and the Method and Apparatus for Cooling by Evaporation patent (US Patent 2,506,936) all define how to apply water to a roof using spray technology to allow it to evaporate into the air for a cooling effect [10] [11] [12]. Another patent (US Patent 2,554,409) that could be used in junction with that patent is the Roof Cooling Device patent. This patent is for a device that restricts the flow of water sprayed onto the roof. It also has a self-flushing action to periodically clean itself [13].

Other patents (US Patent 5,342,144) are also available for use with stormwater evaporation technologies. The Stormwater Control System patent was for the control of stormwater basins using a sensor input device that controls the level of water in each basin according to the water runoff conditions at that time. A valve is controlled by this sensor that regulates the inflow and outflow of stormwater in each basin so that there is not an excess of flow to the treatment center at the end of the runoff [14].

The Stormwater Management System patent (US Patent 7,118,306) is for a corrugated pipe that would be in the ground. Water would be sent through the pipe and through its many holes water would seep into the ground surrounding the pipe and return to the environment [15]. The Green Roof Tile System patent (Us Patent 7,870,691) allows the accessibility of growing plants in channels where the water runs which in turn cause a plurality of positives including improved strength, reduced weight, reduced costs, increased life spans, reduced maintenance, easier installation, improved building energy conservation, reduced urban island heat effect, improved sound insulation, improved water retention, improved environmental aspects, improved irrigation, and reduced erosion of the growing medium [16].

The Traffic Bearing Structure with Permeable Pavement patent (US Patent 8,297,874) is for a traffic bearing structure that is made of many layers including a top layer of permeable pavement. It allows the stormwater to pass through the structure to reach the environment below while still maintaining usability [17]. The Bio Retention System with Internal High Flow Bypass patent (US Patent 8,911,626) is for a bio-retention system with multiple chambers and bypass system for water filtration and stormwater flow management. The system also inhibits flow of pollutants, debris, and other contaminants [18].

2.6 Law and Codes

There are many laws in place to address issues with stormwater runoff around the United States. Collection, storage, reuse, and pollution have each become issues in their own sense. All-encompassing laws such as the EPA's Clean Water Act sets limits to protect the quality of water and safety of those in contact with it [19]; however, beyond this, these laws vary by region.

Currently there are few regulations in effect concerning runoff in the city of Pittsburgh for instances of heavy rainfall, and The Allegheny County Department (ALCOSAN) and other regional sewage treatment facilities have been threatened with upwards of $275 million in fines from the EPA [20]. When raining, just one-tenth of an inch of rainfall can cause an overflow of the system, and this problem must be solved by ALCOSAN in the near future [21]. Current ordinances and the sanitation department's Wet Weather Plan allow for steps of improvement to be taken and may benefit from adopting additional policies inspired from other areas. The legality of reusing water varies regionally. While most areas allow harvesting and reuse of rainwater, some limit uses based on where it is used such as indoors or outdoors, and some do not allow for any reuse. Currently Pennsylvania State law reads:

> "Ch. 73.71 governs Experimental Sewage Systems, which may be implemented upon submittal of a preliminary design plan. Experimental systems may be considered for individual or community systems in any of the following cases: 1) To solve existing pollution or public health problem; 2) To overcome specific site suitability deficiencies, or as a substitute for systems described in this chapter on suitable lots; 3) To overcome specific engineering problems related to the site or proposed uses; and 4) To evaluate new concepts or technologies applicable to on lot disposal [22]."

It is legal upon approval to use a water harvesting and storage system. In recent years, Pittsburgh has passed laws allowing for the disconnection of downspouts to the sewer system, and also requires the removal of any illegal connection to the sewer. A property cannot be sold without first verifying that there are no illegal connections [23]. Other ordinances require large properties, if possible, to retain the runoff from a 95th-percentile storm which is 1.5 inches [24]. The Leadership in Energy and Environmental Design or LEED rating system has also been adopted in the Pittsburgh region which provides incentives for green infrastructure. In Pittsburgh, LEED certified buildings are allowed to rise higher and contain a larger floor plan. Public buildings of a certain size and cost must also achieve a benchmark LEED rating [25].

Other states including Arizona, Rhode Island, Virginia, Texas, and more offer tax credits to provide incentive for individuals and businesses to install water collection systems. In Arizona, for example, a yearly credit is available for percent of a systems total cost up to $1,000. Incentives like these provide benefits that can often justify the installation costs of such a system [26].

2.7 Evaporation

The process in which water changes from the liquid state into the vapor state is referred to as evaporation. Evaporation plays a crucial role in the Earth's water cycle by taking water that has fallen as precipitation or condensation and returning it back into the atmosphere as water vapor. In addition to keeping the Earth's water cycle in balance, the effects of evaporation can be used as a mechanism to cool a surface, such as the roof of a hot building. The heat energy from the hot roof top surface can be absorbed by the molecules of the water and provide them with enough energy to break free from the surface of the liquid and carry away the heat energy as they enter the atmosphere as a vapor.

Several factors of the environment, such as the humidity, the air pressure, and the ambient temperature, affect the process and rate of evaporation [27]. Each gallon of water evaporated absorbs 8,652 BTU's [28]. Therefore, evaporating around 1.5 gallons of water an hour has the potential to absorb the equivalent of a one ton of air conditioning unit [28]. The reduction in electricity required to satisfy the cooling demands results in savings for the building owner.

Using a collection system to reduce the overflow of rain water appears to be the direction needed to reduce the overflow potential and to mitigate the environmental impact from excessive storm water. Finding a way through evaporation and percolation to return this water to the atmosphere is the next step. Using evaporation to reduce the quantity of collected and detained water while also cooling the building surfaces appears to represent an environmentally conscious solution and one that could prove to be financially advantageous.

3. Conclusion and Recommendations

Excess rain in the Pittsburgh region continues to put a large strain on local sanitation departments, which creates a host of other significant ecological issues. With this continued excess, and looming fines by the Environmental Protection Agency a solution needs to be established and executed. One proposed method is an evaporative roof spray system that utilizes stormwater runoff as the water source. It is recommended that a feasibility analysis be performed on a system of this type using modern sensor and modeling technologies through the development of a full-scale-test site, prior to consumer implementation.

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