Introduction

As the growing necessity and dependence on nature and its energy has been seen more clearly, so have the efforts on sustaining its life. New technologies have developed, from the hybrid automobiles to the re-useable shopping bag. Shifts in policy have also been environmentally conscious. Government on all scales push for sustainable living habits and for creating sustainable habitats.

Previous to the 1990s, storm water management practices largely focused on flood prevention. The United States Environmental Protection Agency legally recognized the need to monitor the quality of storm-water in 1990 through the introduction of the National Pollutant Discharge Elimination Systems (NPDES). BMP or best management practices were then adopted to treat storm water quality and flows in urban areas (Poirier, Champagne, Filion, 2010).

BMPs are used to mitigate the impacts of urban development on the quantity and quality of storm water runoff. BMPs can be either structural or non-structural. Non-structural BMPs include practices such as reducing litter, street sweeping, and educational programs to minimize polluting activities. Structural BMPs include detention basins, storage tanks, and wet ponds. The focus of my research will focus on structural BMPs, more specifically rain gardens.

The first structural additions to effective storm water monitoring help to reduce flooding during peak flows but minimally improved the quality of water. An emphasis on technology that has gained much attention in the past couple decade has been bioretention systems or rain gardens. “Bioretention systems consist of small areas which are excavated and backfilled with a mixture of high-permeability soil and organic matter designed to maximize infiltration and vegetative growth (Poirier,Champagne, Filion,2010)."

Rain gardens can help monitor peak flows to mitigate flooding as well as filter out pollutants and unwanted nutrients in storm water. It is important for cities and especially larger cities to think about BMPs so that storm water can be regulated effectively. Climate change is expected to modify the intensity and frequency of extreme rain falls making storm water management practices increasingly important (Mailhot, Duschense, 2010).

The natural hydrological landscape shifts when urbanization requires the transformation of open or natural space into residential, commercial, and industrial zones. As impervious surface area increases with constant urbanization, water infiltration on the surface decreases causing increased amounts of runoff and increased peak volumes of runoff. For every 10-20% increase in impervious surface cover, urban water runoff can double to 35-50%. This term is called "hydromodification" (Palhegyi, 2010) (Jenkins, Wadzuk, Welker, 2010). Hydromodification intensifies erosion and the sediment transport processes that can cause detrimental effects to the surrounding waters (Palhegyi, 2010). Storm-water is for the most part left untreated as it flows from our streets and sidewalks straight through urban storm drains into the surrounding waters. Although urban regions account for only 6% of the earth's surface, cities still output large amounts of waste (Paul, Meyer, 2001).

The advantages of rain gardens are that it is a technology that relies on natural ecological function in order for them to operate productively. Rain gardens are typically described as capable of mimicking the natural hydrological cycle (Palhegyi, 2010). Often rain gardens or bioretention systems include a selection of plants that are of the native variety making them sustainable in practice and in construction. This characteristic makes it popular for cities as urban water management favors sustainable practices and innovative technologies (Rodriguez, Andrieu, Morena, 2007).

Rain gardens can help to mitigate floods, filter water, sustain watersheds, as well as reduce the heat in the city. More importantly, rain gardens can do this naturally. Rain gardens filter polluted storm water through biologically active plants and soils thereby removing contaminants from the water (Trowsdale, Simcock, 2011). They can mitigate floods by delaying the initial time of runoff due to absorption of water; ii. Reducing total runoff, and iii. Distributing the runoff over longer periods of time (Mentens, Raes, Hermy, 2005). These are the primary reasons for implementation but there are also other advantages.

Rain gardens can help to reduce the heat island effect or UHE. UHE is typically an urban area that has a higher temperature than its surrounding area. This is caused by construction material's ability to retain heat (Eliasson,1999). Heat islands can be of any size. Moisture within rain gardens allows for the possibility for evapotranspiration to occur and consequently produce a cooling effect. Evapotranspiration is the process where water evaporation from soil as well as vegetation occurs. According to studies in Japan, Canada, and the United States, low evapotranspiration rates in urban areas are a major factor of increasing daytime temperatures (Taha,1997).

Effective storm water management has become a common goal for cities to combat the use and detriment of natural resources. The sustainable nature of rain gardens, their aesthetical enjoyment, and their many beneficial effects have made rain gardens a popular choice. For my research I attempted to evaluate Tacoma's need for increased storm-water practice.

Purpose

There is no correct way to measure storm water runoff and pollution. In one article six different studies were compared. Each had different results with different land uses assuming differing amounts of runoff. The existing studies had used land use zones as a major factor for determining the amount of storm water runoff produced and the pollution in them (Park, Swamikannu, Stenstrom, 2008) but, this method requires sample pollution data taken from the streets, which are then joined in an algorithm to come up with a value. Pollution data is unavailable for the City of Tacoma so I had to develop my own method for determining which areas in Tacoma had the most polluted storm water runoff. Once again there is no right or wrong way to measure storm-water runoff and pollutants.

The purpose of my project is to develop a strategy for deciding where to install rain gardens in Tacoma and to also understand where they would be most beneficial. Tacoma is an urbanized city with a large percentage of it covered by impermeable surfaces. Further, the industrial background of the city makes it appealing for sustainable and environmental improvement research. In my research project I attempt to coordinate a method for predicting storm water runoff and pollution without pollution data.

Methodology

My method considered 3 factors that I aggregated and created an index score for. Each factor was weighted equally. The 3 factors include for each basin, impermeable surface cover, road length, and population density.

One study has given a “runoff coefficient” to areas depending on their zoned purpose. For example, a residential area might receive a runoff coefficient of .25 and a commercial will receive a .60. This means they estimate that 25% and 60% of the runoff from those areas will run through the storm water system and back to the water. This method attempted to predict the average amount of impermeable surface cover for each zoning type (Park, Swamikannu, Stenstrom, 2009). The zoning for land uses in Tacoma are densely aggregated not allowing for more site specific analysis so, hoping for more precision I decided to use impermeable surface data to be used for my runoff coefficient. Each sub basin in Tacoma (67 in total) received an impermeable surface score through a zonal statistics. The score being the average impermeable surface cover for that area. From this I was able to determine which sub basins of Tacoma had the most impermeable surface cover and thus completed the creation of my first factor of analysis.

Population density was another factor that was included in the analysis. I first downloaded Census 2000 block group population data. In order to determine the density I needed to attach the population data to the each of the 67 sub basins. I did this by doing a spatial join of each sub basin to all block groups that reside within it. I then needed to dissolve the population fields for all the block groups into one working number. Each sub basin consisted of all attributes from every block that resided within it. Once I had a single population number for each sub basin I was able to divide that number by the area of the sub basin resulting in my population density for that particular area thus creating the second factor of my analysis.

Much pollution that ends up in storm water runoff comes from automobiles (Park, Swamikannu, Stenstrom, 2008). Though the impermeable surface data includes roads I thought that the amount of roads within a sub basin is an important factor to consider. I did much the same with the first two factors. I joined the road length data that resides within each sub basin, then dissolved the length field quantities into one number for each basin much like the previous two steps. This concluded the creation of the variables for my analysis.

The analysis includes 3 factors that contribute to surface water pollution. Impermeable surface coverage, population density, and road length data. . I aggregated all of these into one table. These too were joined according to the sub basin they were contained in.

The next step in my process was to add all 3 attributes into one working number that could be symbolized. The 3 data sets were given an index score that were attached to each sub basin. If x = one sub basin's factor score, then ([x] – (Average of all[x's] ∕StdDev of all [x's]. = the sub basin's index score. The highest score out of all sub basins being a 3 and the lowest being a -4. The sub basins with the highest index score were the areas that I focused on for my analysis. Sub basins were symbolized according to index score.

There were four areas that resulted with a score of three (the highest score). Two out of the four were in the downtown core, one was north of the core and the other was at the very south side of Tacoma.

When determining suitable locations for rain gardens, the possibility of placement was of concern. I ended up removing two of the sub basins with a score of 3 and replacing them with two other sub basins that I felt required further analysis. The two that I did remove were ones that were away from the central business district and were primarily residential. I decided to include the two sub basins that reside within the central downtown core. The motivation behind doing this is because of the availability of land and the interest in aesthetic additions to down town.

With those four basins I attached parcel data and selected those parcels with land use type: commercial vacant, residential vacant, vacant land with problems, and parking. These parcels were selected as available land for placement of rain gardens.

The next step was to determine which parcels that were available would be most effective. Rain gardens must be 20% of the supporting area's size in order to be optimally effective (Palhegyi, 2010). The parking lots or vacant parcels were buffered individually each to its own size. I first created a field that represented 80% of the parcel's land area ($\sqrt{[\text{Parcel Area}\cdot 4]}$), I then used that number as the basis for the buffer. This would result in parcels that consisted of 20% of the area of the entire contents of the buffered zone and would represent the drainage area. This would prepare me for the concluding step. In order to find the parcels where rain gardens would be most needed I conducted a zonal statistics of the buffered area on the amount of impermeable surface within them. Those parcels with 80% or more impermeable surface cover within the buffer that surround the parcels were chosen as the most beneficial areas to locate rain gardens.

Results

Downtown Tacoma has the highest amount of overall impermeable surface coverage, population density, and road networks. Further, this is a highly commercialized zone allowing the rain gardens to have a greater aesthetic impact. I decided to extend my analysis to two sub basins below to include all of downtown. The reason the sub basins extending into downtown were included in the analysis is because of the commercial and high traffic characteristics making it suitable for a rain garden's purpose and aesthetic appeal. Also, the basins located in downtown are at the bottom of a slope. Though I did not include slope data in my analysis, my general knowledge of Tacoma has allowed me to determine that the nearby geography funnels its runoff to this area. The lack of population living down town also leads me to believe that this may be the reason for its exclusion in the original top 4.

The final result shows the parcels which have 80% or more impervious surface cover within a buffer that is 80% of the parcel's size. The total containment of the buffer includes the parcel, which is 20% of the area. In theory, if the entire parcel were to be a rain garden the buffered area would be the drainage coverage area of that parcel.

Critique and Conclusion

The methods for measuring storm water runoff can come in multiple styles leading to ambiguities about the complete accuracy of such data. Once again, there is no exact way to measure storm water runoff. My method must not be taken as fact but as one way to understand the process. The variables that I used, population density, road length, and impermeable surface coverage, come from trustable sources but the aggregation of data may be done in multiple ways, also multiple factors that were not included in my original analysis could lead to different results.

Pollution comes from multiple sources and to decide the weight behind each source was difficult to determine. Giving them equal weight assumes they all must equally contribute to polluted runoff.

As climate change has contributed to more rain fall and dramatic weather (Mailhot, Duschense, 2010) and as cities continue to implement sustainable and innovative strategies (Rodriguez, Andrieu, Morena, 2007) to suppress consequences of urbanization, city planners will continue to look to rain gardens in a double speared effort to represent their efforts in a aesthetically pleasing fashion as well as to combat the detrimental effects that storm water has on surrounding hydrological ecosystems.

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