GEO IMFROMATION SYSTEMS CERTIFICATE: UNIVERSITY OF WASHINGTON

Replicating Natural Hydrological Processes

Tacoma watersheds potential for producing and regulating non-point source pollution

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Introduction

Tacoma in the Pacific Northwest is blessed with bordering several water bodies such as Commencement Bay which is formed by the Puyallup River. Often cited for its aesthetic appeasement, this area is also characterized by industry and commercialization to support the population that resides in this region. Characteristically, these land uses degrade those natural assets which bless Tacoma and surrounding regions. Due to the Clean Water Act in 1972, the pollutants discharged from these areas are regulated under State and Federal Environmental Protection Acts, significantly reducing the post industrial pollution entering water bodies. Recently, concerns about pollutants entering water bodies outside of these land uses are being considered. These pollutants, identified as non-point source pollution, are typically entering water bodies via excess surface run-off from major storm events. Recently included into the Clean Water Act, these pollutants are difficult to regulate and mitigate. Regardless, municipalities such as Tacoma have begun to use different techniques to protect water assets; these mitigation techniques attempt to replicate natural hydrological processes which are eliminated by impervious human infrastructure such as pavement. This essay will discuss those characteristics which are indicative of non-point source pollution and discuss the possibilities of permeable concrete, a new technology attempting to replicate hydrologic processes, of reducing and mitigating this cause of environmental degradation. Furthermore, I will utilize Geo Informational Systems to provide a case study of non-point source pollution within Tacoma. I will then determine logical areas in which permeable concrete can be implemented within the city to help mitigate the effects of non-point source pollution.

Background Research

Non-Point Source (NPS) pollution is defined by the Environmental Protection Agency as any form of water pollution that is outside of the definition of point source pollution. Defined in section 502(14) of the 1972 Clean Water Act, point source pollution is:

> *… any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural storm water discharges and return flows from irrigated agriculture*.

Considering this definition, NPS pollution is difficult to track as it is diffused among a variety of different sources which are collected by rain or snow events. Typical pollutants collected by these storm events include: excess fertilizers, herbicides and insecticides from agricultural lands and residential areas; oil, grease, and toxic chemicals from urban land uses; sediments from bare land and construction sites; salt from irrigation practices and acid drainage from abandoned mines; bacteria and nutrients from livestock, pet wastes and faulty septic systems; and atmospheric decomposition and hydromodification (United States Envrionmental Protection Agency , 2012).

In particular, urban runoff as non-point source pollution is enhanced by the reduction of natural hydrologic processes that are limited by human infrastructure. Land uses and land cover are valuable indicators for distinguishing the human infrastructural impacts on the natural hydrological processes and the state of aquatic ecosystems (Allan, 2004). Natural vegetated landscapes allow rain fall to percolate through soils to replenish ground water aquifers and reenter the atmosphere through transpiration and evaporation (see figure one). However, impermeable surfaces limit the ability for these processes to occur. Impermeable surfaces and those land uses which characteristically contain large concentrations of roofs and concrete increase the amount of excess runoff by up to 45% of naturally occurring runoff causing a significant increase in the amount of NPS pollution entering bodies of water (Paul & Meyer, 2001). Due to this increased run-off, pollutants that collect on impervious surfaces are washed into water bodies with greater frequency. Furthermore, the transformation of vegetated landscapes to lawn also increases the potential NPS pollution that may enter water assets. Author Paul and Meyer acknowledge that urban uses account

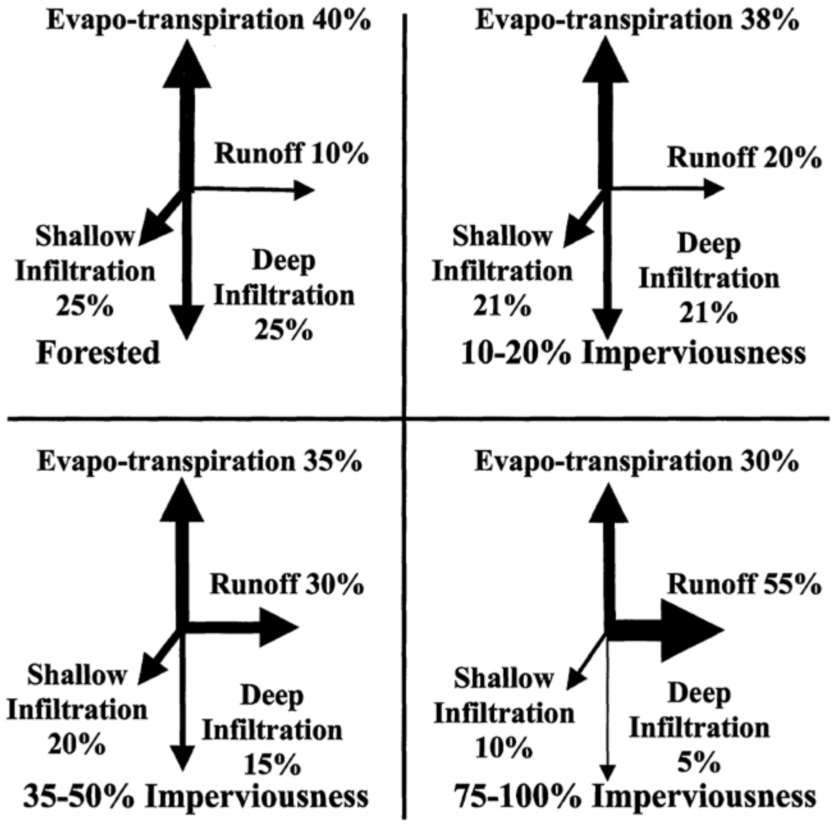


Figure 1: The correlations of human developed infrastructure and the increase in surface runoff (Paul & Myer 2001).

for more than 136,000kg of pesticide use, which are applied to residential lawns, commercial and industrial landscapes, and in recreational facilities such as golf courses and parks. This accounts for one third of the totally United States pesticide use (Paul & Meyer, 2001, p. 345). These pesticides are also washed away in storm events and contribute to pollutant discharge to water bodies.

With these aspects in mind, many scholars have attempted to track and identify areas within urban regions that are most likely to produce NPS pollution using land cover classifications such as lawns and impervious surface from satellite imagery ((Yin, Walcott, Kaplan, Cao, Chen, & Ning, 2005; Xian, Crane, & Su, 2007; Ventura & Kim, 1993; Qin, Khu, & Yu, 2010; Park & Stenstrom, 2008; Liu, Ke-Ming, Jing-Zhu, Xue, & Qing-hai, 2007). Variables of NPS pollution are dependent upon the locailty and scope of the study. In many areas,population density a critical factor in determining land uses which posses an increased liklihood of producing NPS pollution (Liu, Ke-Ming, Jing-Zhu, Xue, & Qing-hai, 2007; Qin, Khu, & Yu, 2010; Xian, Crane, & Su, 2007; Yin, Walcott, Kaplan, Cao, Chen, & Ning, 2005). Specifically, authors Yin et. Al, recognize population density as a contributing factor to non-point source pollution because of the unregulated disposal of trash and other pollutants on residential properties (Yin, Walcott, Kaplan, Cao, Chen, & Ning, 2005).

Due to the concerns about the quality of water assets due to increased exposure to NPS pollutants, there has been a significant attempt to reduce the amount of stormwater runoff coming from urban areas. These techniques, identified as low-impact developments attempt to replicate those hydrologic processes which occurred in a vegetated land cover. There are a variety of forms of low-impact developments; however for the purposes of this essay only permeable concrete will be considered. Permeable concrete is similar to regular concrete; however, the binding agent used in permeable concrete allows air bubbles to expand within the concrete to allow the percolation of water through the surface (Qingquan & Dongwei, 2009). Though the success of this technology is debated, proper management of the material can prevent clogging and can actually eliminate pollutants that may be present in stormwater. Authors Hunt and Bidelspach (2007) studied the success of permeable concrete in a case study of four sites in Eastern North Carolina; they found that permeable concrete actually possess the capabilities for reducing the pollutant loads of heavy metals such as Zinc and Copper. Furthermore, the surface runoff can replicate levels similar to that of a vegetated land use (Bean, Hunt, & & Bidelspach, 2007).

However, permeable concrete is less durable than traditional forms of concrete; thus it is ideally used in situations which do not expose the material to high loads and stress (Qingquan & Dongwei, 2009). Rather, an area with low traffic volume and vehicles with lower weights would be idea locations for this technology. Based on this conclusion, residential roads with low speed and weight limits, and low traffic flow would be ideal areas to implement this useful technology.

Methods and Implementation

Tacoma, recognizing its water bodies as valuable assets has expressed interest in protecting these resources. As a result, I decided use ArcGIS identify potential areas that the city of Tacoma could install permeable concrete to mitigate and reduce the amount of toxic runoff. Based on the examples of several other scholars, I began by obtaining a detailed 1 meter orthophoto from WAGDA to use classify land cover within Tacoma. Using the image classification toolset, I determined a training sample for the three land cover variables identified by my research: lawns, vegetation, and impervious surface. For each of these variables, I selected fifty polygons which contained pixels containing colors representing a certain land cover to ensure a distributed sample of colors. These polygons were then used in a Supervised Image Classification; resulting in a raster image which classified all of Tacoma as lawn, vegetation, or impervious surface (see figure two).


a) Orthophoto 1M Resolution

b) 1m Land Classifcation: lawn (light green); vegetation (green); impervious surface (gray)

Figure 2: The orthophoto (right) was used to determine the land cover classification (left) using the supervised image classification method in ArcGIS

Furthermore, as suggested by my research, population is also indicative of NPS pollution. I choose to download block group scale population data from the United States Census Bureau and American Fact Finder to identify population density. As well, the United States Environmental Protection Agency also has begun to include stormwater pollution into is regulatory portfolio. Using municipal issued stormwater discharge permits (NPDES) from the Washington State Department of Ecology, I could identify those areas which are already known to discharge polluted stormwater into the Puget Sound. I infer that these permits could act as indicators for areas which have a greater potential for generating NPS pollution.

After collecting and organizing the variables which contribute to NPS Pollution, the next step was to identify the scope of my analysis; I determined that watersheds would be the best possible scope for this analysis because they are indicative of natural hydrological flow. Using the hydrology toolset within spatial analyst, I began with a 10 meter Digital Elevation Model (DEM) obtained from the USGS seamless server. The first step of this procedure was to identify any areas which internally drained in Tacoma. Though there are potential areas within Tacoma that drain within the city boundaries, I eliminated these areas using the fill tool because I was mainly concerned about non-point source entering water-bodies entering into the Puget Sound. The next step was to create a flow accumulation raster; this file tracks the flow of water from one cell into another based on the filled DEM file. The flow direction raster can then be used to identify flow accumulation; those areas in which flow will be concentrated during a storm event. These areas of high flow are typically streams however, they are also low lying valleys which also collect water (see figure three). Pour Points are areas which two high flow accumulation items meet; these pour points are then combined with the flow direction raster to identify watersheds.

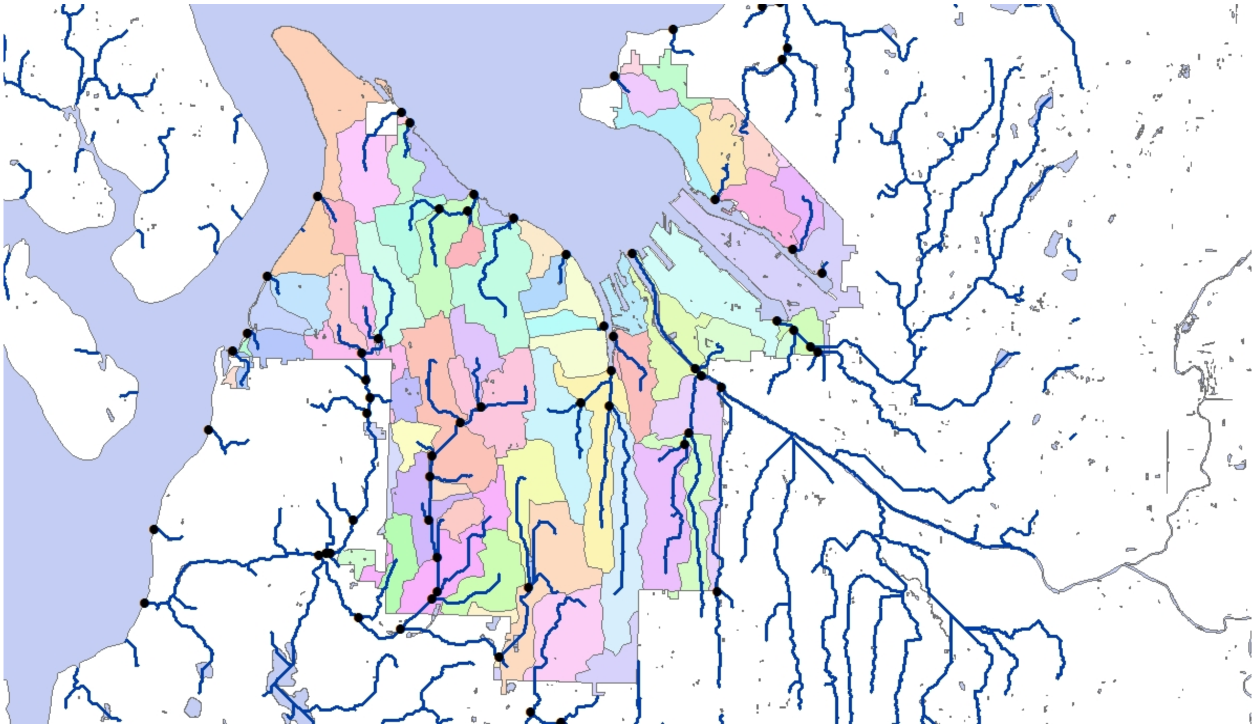
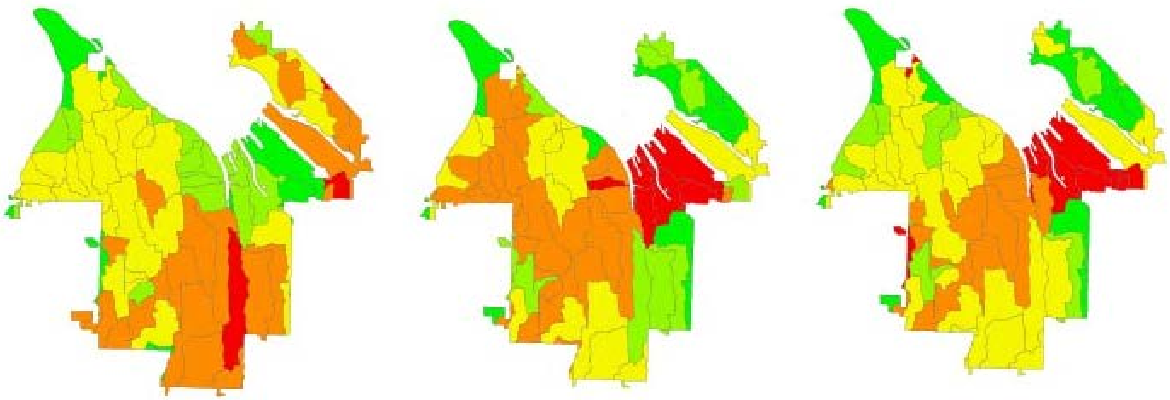


Figure 3: A raster Image of Tacoma Watersheds; flow accumulation is shown in blue; black dots represent pour points

The next step was to identify those watersheds which have the highest potential for generating NPS pollution. To do so, I calculated the density of each variable (lawn, vegetation, impervious surface, population, and NPDES sites) within each individual watershed. This was done using the intersect of each variable with the watershed layer converted to a feature dataset. Then these polygons were dissolved by the watershed id. The mean and standard deviation was then calculated for each variable and used to calculate the z score:

$$\text{Z-score} = \frac{(\text{variable density} - \text{mean variable density})}{\text{standard deviation variable density}}$$

This z score was then reclassified any $z \leq -2 = -2$; $-0.5 > z \geq -2 = -1$; $0.5 > z \geq -0.5 = 0$; $2 > z \geq 0.5 = 1$; and $z > 2 = 2$. All variables besides vegetation were classified as a positive z score contributing to a higher potential of generating NPS pollution (see figure four). Vegetation was classified on an opposite scale with a higher density of vegetation reducing the potential of NPS pollution being generated. Following the reclassification of these variables, their scores were added. Since there were five variables, the highest potential score was a 10 and the lowest -10; a score of 10 indicates a high potential



a) Lawn Classification b) Vegetation Classification c) Impervious Classification

d) Municipal Issued NPDES Permits e) Population Density

Figure 4: The Z-scores of each variable; red signifying a higher potential (high Z-score) for generating NPS Pollution and Green a lower potential (lower Z-score)

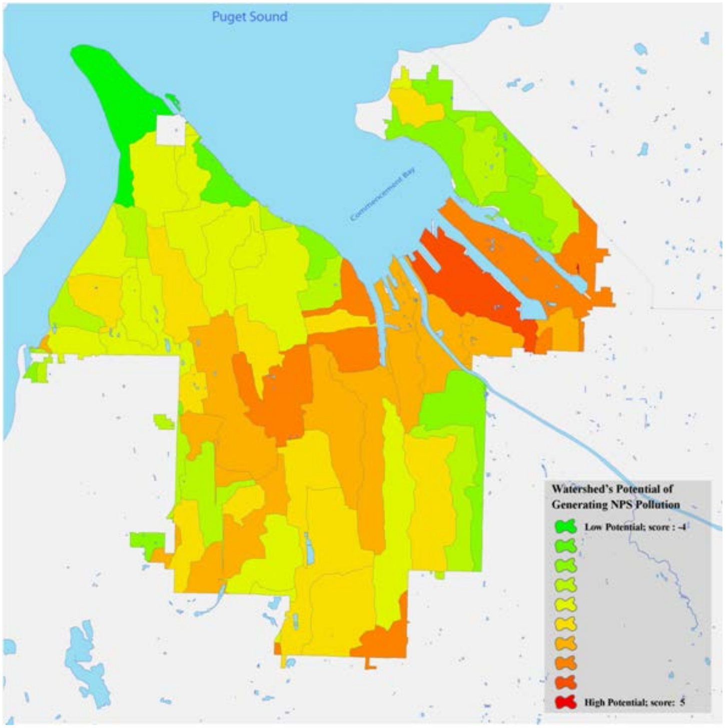


Figure 5: The areas within the Port area were found to have the highest concentration of impervious surface and Municipal issued NPDES sites

for NPS and -10 a low potential. However, for this map, the highest potential for any watershed was 5 and the lowest was -4 (see figure five).

Furthermore, I decided that because the potential of stormwater to contain pollutants, and I was attempting to identify areas which will replicate the infiltration of water into aquifers; I choose to eliminate watersheds that fell within aquifer recharge areas. Using a shapefile obtained from WAGDA, I intersected this file and my watershed file and found that those watersheds with the two highest scores were within this boundary (see figure six). However, three watersheds with the third highest potential for generating NPS

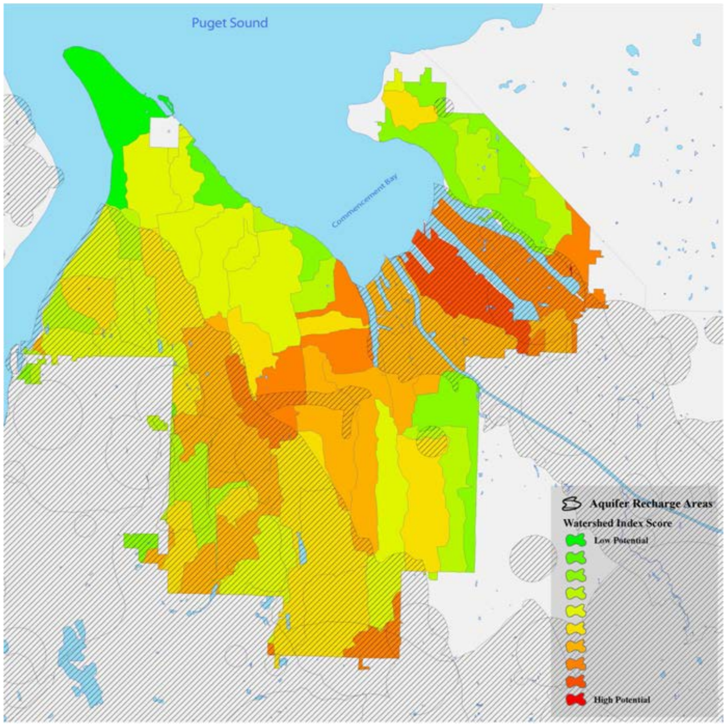


Figure 6: Three watersheds (orange) with the highest potential for generating NPS Pollution (score of 3) were found to be outside the aquifer recharge area

pollution had parts of their boundaries; which I choose used to identify roads which could be used to replace with permeable concrete.

After identifying these watersheds, roads within this watershed were visualized based on their appropriateness for the installation of permeable concrete. Based on a street layer of Pierce County obtained from WAGDA, roads with a speed limit of 25 mph and that were classified as residential roads were selected. To narrow the selection of roads that were classified, I determined that only roads that were in severe condition should be considered for this technology, as it would be less cost effective to replace an existing function road when other roads need to be fixed. I found that the City of Tacoma has developed a Road Condition Index, which is street classifying all the roads in Tacoma from failed to excellent. I was unable to obtain this data; however, I took a screen shot of this with the extent of my analysis in the window frame and georeferenced this image to the street network that I had obtained from WAGDA. I then

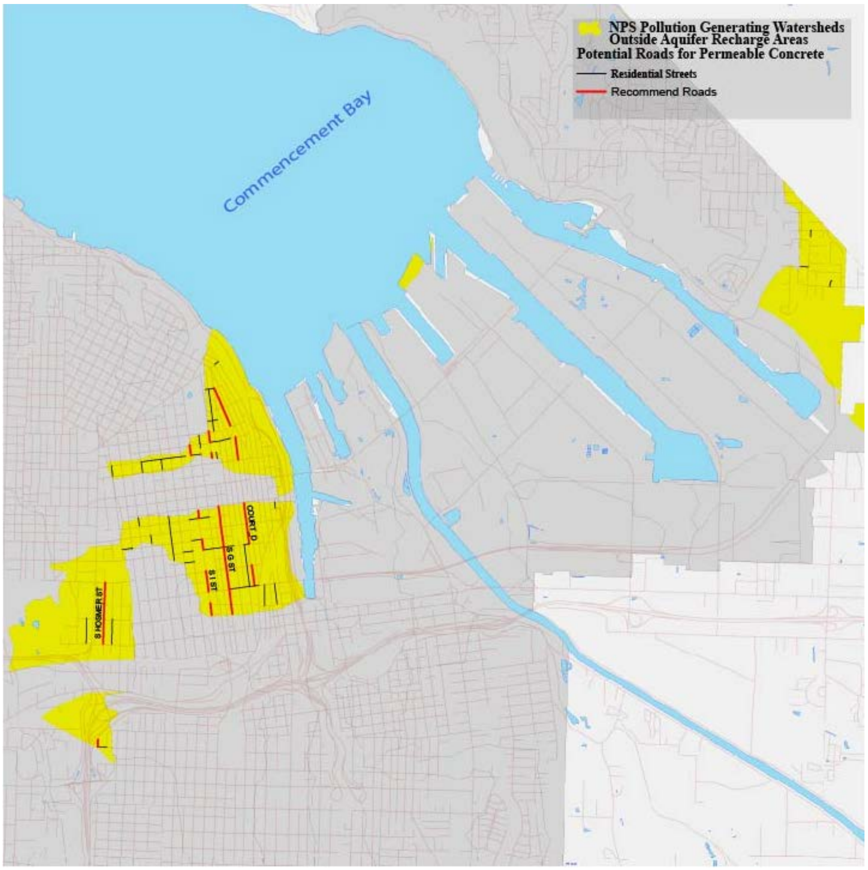


Figure 7: Critical Watersheds with thirty-one possible roads for permeable concrete

digitized the segments of roads which were classified as failed in the pavement condition index and were within the critical watersheds that I identified in previous steps. This procedure resulted in a total of thirty-one roads which were possible candidates for replacement with permeable concrete (see figure seven).

Results

Before proceeding to recommend roads for the city of Tacoma to install permeable concrete, I decided it would be best to look at road improvement projects happening within the city. Interestingly, the city is in the process of installing permeable concrete on Alaska Street. This project intends to replace 5,400 ft of roadway with complete street guidelines. These include bike lanes, sidewalks, pedestrian islands, the replacement of sewer line, sanitary sewer, and water mains, and porous asphalt and infiltration trenches (City of Tacoma 2012). With help from a grant of 5 Million dollars from the Washington State Department of Transportation (WSDOT), the city of Tacoma is committed to match 20% of the grant bringing the total cost of the project to 6 Million dollars.

Using this project as a guideline, I choose road segments which generally fit the criteria used for the Alaska Street project. The first of the limitations for the installation of an additional green infrastructure projects would be cost, which can be reflected in the amount of road needed to be replaced. Under the presumption that the city of Tacoma would invest in a similar project to that on Alaska Street, roads segments that were less than 5,000 ft would be ideal for additional green infrastructure improvements. I selected the four longest segments of roads from my recommended streets that were less than 5,000ft: Court D Avenue, South G Street, South I Street, and Hosmer Street (see figure eight). Of these roads, ideally the city of Tacoma would choose to replace South G Street (see figure nine). This road is the longest uninterrupted segment of road within the critical watershed area. Furthermore, it is a useful arterial that University of Washington Students and residents which typically use this road to navigate the lower parts of Hilltop and Downtown.

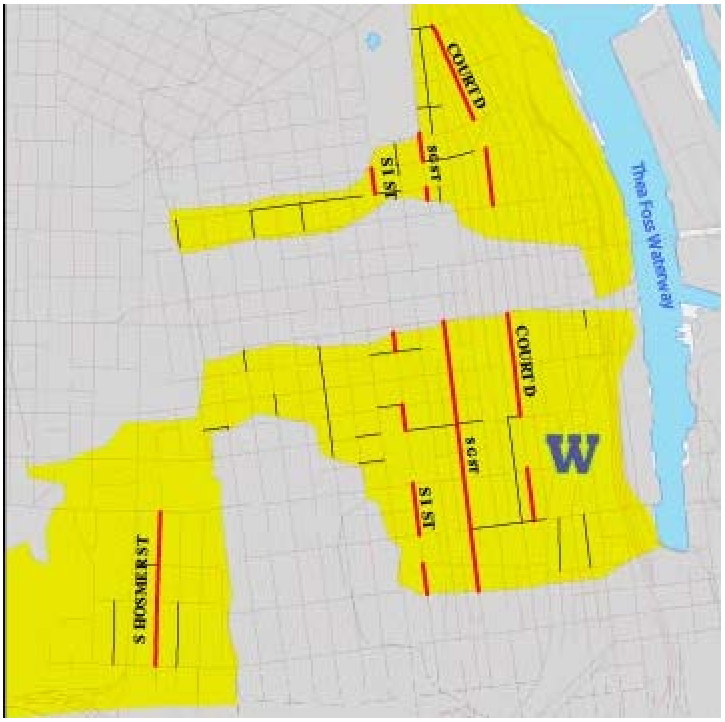


Figure 8: The four streets in red were recommended for permeable concrete based on length.

Figure 9: South G Street

Discussion

In retrospect of the methods that were used to perform the analysis of this project, I begin by questioning the reliability of the image classification which was used to index the watersheds in Tacoma. I distinguished three classes which were indicative of generating NPS Pollution; however, there were land uses within these classes which act as sinks for NPS pollution rather than generators; particularly open rural lands, quarries, and other similar land uses were found by Liu et Al. to be areas which collect and eliminate excessive stormwater runoff (Liu, Ke-Ming, Jing-Zhu, Xue, & Qing-hai, 2007). Furthermore, research has shown that not all land cover has the same potential for generating NPS pollution (Park & Stenstrom, 2008). For example, stormwater runoff from an impervious playground is less likely to contain contaminates than an industrial parking lot (Park & Stenstrom, 2008, p. 182). These extraneous variables could have been eliminated with the identification of additional land cover classes or by using Bayesian networks similar to those that Mi-Huyn Park and Michael K. Stenstrom, used in their article, *Classifying environmentally significant urban land uses with satellite imagery* (2008). However, I lacked the expertise to use these methods in my analysis.

Additionally, the population density also seemed to skew the results of my analysis of watersheds potential for generating NPS pollution. Several of Tacoma’s watersheds had a much smaller area than anticipated. The smallest scale of population data from American Fact Finder is at the block group level; which in some cases, block groups were much larger than those watersheds mentioned above. As a result, the population density of several of these smaller watersheds was significantly higher than reality. As a possible solution, it may have been better to dissolve these smaller watersheds into larger adjacent watersheds because the excess runoff from a smaller area would be negligible.

If this study was to be replicated or revisited, I would recommend that different boundaries be used to delineate possible hot-spots of non-point source pollution. Hydrologic flow in urban areas is less likely to follow the natural topography of the landscape, like the watersheds which were used in this project. Rather, stormwater is directed and collected through human infrastructure such as sewer lines. It would be interesting to examine how these delineations differ and if hot-spots of non-point source pollution would migrate.

Conclusion

Water quality has been in a deteriorating cycle as more impervious surfaces prevent natural hydrological process of infiltration and evaporation. Excess water from rainfall events collect non-point source pollution which can consist of debris, fertilizers, oil and grease, and other contaminants which are rushed into other various water bodies creating an array of ecosystem degradation. However, many civil engineers, environmental scientist, and urban scholars have been exploring development techniques which seek to replicate hydrological processes to eliminate stormwater runoff. Permeable concrete has proven to be an exceptional example of the Low Impact Development techniques capabilities to reduce non-point source pollution and the impacts it may have on water quality.

This essay shows the capabilities of using ArcGIS for identifying areas which potentially generate high amounts of non-point source pollution. Furthermore, ArcGIS can be utilized by engineers and city officials to guide development in localities to maximize the use of low impact development techniques. The methods used in this study in

Tacoma, Washington should be able to be applied in other regions of the United States. However, different boundaries reflecting the modified hydrologic flow of stormwater due to human infrastructure may be more useful in identifying potential hot-spots of non-point source pollution. If these techniques are practiced regularly in other regions and cities, managing non-point source pollution could possibly become increasingly feasible.

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