A GIS based Water Demand Analysis for Municipal Application

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Introduction

There is an increasing awareness that water resources exist in limited quantities, and available supply varies considerably during the course of a year. As a result, there is an urgent need to find ways of saving, reusing and recycling water and to develop methodologies to improve water resource management. One long-term strategic goal advocated by several authorities is developing a stable supply of water throughout the year. This goal is consistent with a change in water resources management, which traditionally focused on supply-side policies. In fact, from the 1970s a movement toward demand-control policies has been challenging the expansion of supply capacity to meeting growing needs (Hiessel, 2002). The simultaneous emergence of these goals and paradigms of sustainable water management facilitates the development of constructive applications of new technologies to address these issues.

Demand Control Policies

Demand control policies, however, require that water supply agencies establish complete, accurate, and representative information about current water consumption patterns. A realistic assessment of regional water consumption is essential in understanding how water suppliers can accommodate variations in time and type of use. Consumption patterns include a number of water use characteristics representative of the individual users in space and time. These characteristics include, but are not limited to: the number of inhabitants to be supplied with water and their demographics; the consumption habits of the population; the type of development, property size; and property landscape. Each of these (and several other) parameters play a role in explaining overall demand. However data limitation have precluded analysis of the effects that these variables play. Municipalities have relied upon analysis of large-scale consumption patterns to evaluate management options (Forster, 1979; Martin, 1994; Gracia, et. al., 2001).

Municipal water managers today are attempting to understand better the general patterns associated to water use in the supply region. Once identified, municipal water suppliers can curtail demand by evaluating alternative demand-oriented management options tailored specifically to those areas. In this paper we propose a methodology that utilizes a Geographic Information System (GIS) and empirical data for analyzing spatial water consumption patterns with the objective of prioritizing water conservation areas within the City of Seattle, Washington (USA). While the proposed method is applicable to one city, namely, Seattle, we foresee application to any city that has the appropriate data. The raw data are publicly available, provided by the City of Seattle and the National Oceanic and Atmospheric Administration (NOAA).

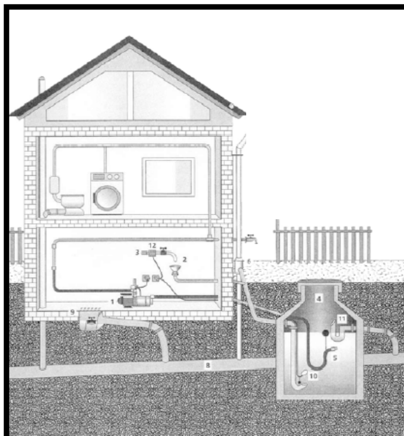

***Figure 1**: Proposed rain capture system and indoor water reuse system (Adapted from the German Federal Ministry for the Environment, Hiessel, 2002)*

Although Seattle is currently developing a comprehensive water supply plan for the coming decade, the City has been exploring conservation strategies aimed at curbing water demand in the near future. One of these strategies gaining considerable interest across the city involves the installation of rainwater capture systems that harvest rainwater from the roof, and channel it into a storage device (*Figure 1*). In essence, the proposal consists of capturing rainwater from rooftops during the winter months, storing through spring, and using for all non-potable purposes during high-demand summer months. While this technology is by no means new, the capital investment to install rainwater catchments at each household across the city is formidable. Therefore, there is widespread concern that such strategies need simultaneously to target areas with highest potential for conservation, keep costs minimal, and, ideally, reduce the ecological impacts associated to storm-water flows.

The following paper develops a spatially explicit methodology for assessing the potential application of rainwater catchments in the city of Seattle. The methodology aims to address the question, which parcels within the city have the highest overall potential for water conservation using rainwater capture systems? Seattle Public Utility (SPU), the primary water supplier in this region, expects to use the results of this study to begin a pilot rainwater capture project targeted at the highest conservation areas, and, subsequently assess the efficacy of the project. If successful, the Utility proposes applying rainwater-harvesting systems across all parcels in the city.

It is important to emphasize that this study does not examine the role of price or householder's characteristics on water demand; rather it examines water use patterns at a specific time in priority areas of the city. The intention of this paper is to develop a GIS based methodology upon which householder characteristics can later be incorporated. Moreover, this study is the first piece of the rainwater catchment assessment, namely, the identification of households within specified areas with highest potential for water conservation. There are three parts to this paper. The first section, describes the study area, data and methods; second, we use statistics and the GIS to evaluate results; and last, we provide recommendations for refining this analysis so that water managers can apply this methodology at the city scale.

<u>Study Area</u>

The city of Seattle is located in the Northwest of the United States and is a rain-fed landscape. Average annual rainfall is 39 inches (99.06 cm) with dry summers. The City serves drinking water to a population of 1.3 million people, of which there are 350 thousand single-family households. Total water consumption of the single-family households is 145 million gallons per day (MGD) and annual water budget of 53 billion gallons (200 billion liters). SPU provides direct retail water service to about 595,000 people in the City of Seattle and small areas adjacent to the city limits. SPU also sells water wholesale to 26 neighboring cities and water districts serving another 686,000 people. The average consumption per capita for the city of Seattle for the past 10 years is 114 gallons per day. Total water provided from SPU averages around 150 million gallons per day (MGD). The Cedar River provides about 70 percent of this supply, the Tolt River provides about 29 percent, and the remaining 1 percent comes from the Highline Wellfield.

Spurred in part by a yearlong drought Seattle reduced water demand by 39 percent from 1988 to 2002. SPU brought about these reductions through a combination of leak detection programs, domestic conservation programs featuring public education and retrofit low-flow fixtures, conservation services provided to industrial and commercial users, and rate increases for water supply and wastewater treatment. Seattle was also among the first major water utilities to treat

conservation and demand management as a potential water resource, rather than simply as a management tool. This conservation program, calling upon the strong environmental ethic of the Pacific Northwest, enabled the SPU system to
operate through the 1992 drought and to help reduce total water consumption levels despite population increases in the service area. Conservation continues to be the primary area for reductions in water demand.

Methods

We propose a parcel (or plot) based analysis of water use for Single Family Residents (SFR, N= 217,562) in the City of Seattle for the year 1999. Parcels are appropriate units for analysis because most land-use planning in the United States is done at this level, and the aim of this project entails installation of harvesting systems at a parcel scale. In addition, rather than calculating water consumption patterns for the whole city, we focus on 24 distinct 'priority' basins. The City defines priority basins according to information on the frequency and volume of overflows, proximity to public beaches, and other social and ecological criteria. Of the 24 priority basins we isolate four to test the applicability of this methodology, and report the findings here. The four priority basins are located next to each other, have ample area for assessment of water consumption patterns, and provide city officials with targeted information for application of the pilot project.

The analysis utilizes ARC View 3.2 GIS software and is structured around four major steps. First we recognize that seasonal variation in water consumption plays a very strong role in the Pacific Northwest with summer consumption orders of magnitude greater than winter—this is often one of the characteristics of a rain-fed landscape. Accordingly, we use Seattle land-use and seasonal water consumption data to identify all parcels (users) with high 'irrigation' rates. Irrigation rates are calculated by assuming no irrigation during winter months (base consumption), and subtracting total winter use from summer use. The marginal difference is the additional water consumption attributable to outdoor use or, in this case, non-potable use. We test the strength of this assumption prior to proceeding to the next step.

In the second step we perform a bivariate categorical comparison between the built area and nonbuilt area of each priority basin. The built area refers to the dwelling unit on the parcel, and the nonbuilt area encompasses the remaining non-dwelling area (i.e. property landscape). The built area and nonbuilt area are broken in sequences of square foot increments based on the capacity of the built area to capture and, thereby, irrigate nonbuilt area. In developing the increments we assume equal rainfall across all basins, complete rainfall capture on built area, requirement of irrigation to all of the nonbuilt property landscape, and equal irrigation rates. We also examine the correlation between summer use and nonbuilt area to test our assumption that the additional water use in summer is for irrigation. The second step is essential in identifying parcels within the priority basins that have adequate built area for capturing rainwater and, ultimately, for irrigation of nonbuilt areas. We develop a matrix based on the relationship between built and nonbuilt areas, and rank all parcels across the priority basins from highest to least conservation potential.

Third, we identify all parcels with the highest percentage of comparable built versus nonbuilt areas. We classify parcels based on specified built versus nonbuilt increments to allow city officials to assess highest conservation potential. In other words, when selecting which parcels to target within the basin for installation of rainwater harvesting systems, basins with the highest number of comparable parcel ratios are chosen. The City expects to target these dwellings for the pilot project.

In the fourth and final step, we use only those parcels with the highest conservation potential with building area and historic rainfall data to calculate potential for water capture for the four priority basins. By averaging rainfall data over the last 57 (1945-2002) years during winter months we calculate total runoff volumes from all SFR buildings in the four selected priority basins.

The rainwater capture from those parcels having highest conservation potential enables us to estimate the amount of water removed from the drainage system.

Results

Using standard statistical packages (i.e. SPSS and R) we diagnose the correlation between summer and winter consumption patterns to test the validity of our seasonal variation assumption. For the city of Seattle, there is a strong inverse relationship between season and consumption. In fact, during the summer months (June through October) water consumption is, on average, 30% greater. Comparisons with multiple years indicate average summer water consumption between 25-45% higher than winter months. While the relationship between summer use and nonbuilt area were not strong across the entire city, there were statistically significant correlations at the individual priority basin scale (adjusted R-Squared= 0.61, P-value<0.001). As evidenced by data about summer and winter uses, we are assured that seasonal variation plays an important role in Seattle's water consumption. In addition, we are certain that the increase in summer consumption is attributable to non-potable uses within the priority basins.

Built versus Nonbuilt Areas

In determining the amount of water required for irrigating nonbuilt areas in each basin we rely on historic meteorological data. We use the world's largest meteorological database from NOAA, and estimate the average rainfall for winter months from 1945 to 2002 to be 15.63 inches (39.7 cm). This average amount of rain if captured is 9.743 gallons per square foot. Given these figures we estimate the approximate amount of built area required to irrigate specific areas of land within each priority basin. The bivariate comparison indicates that, in general, the largest number of parcels fall between built area of 1500 to 2000 square feet and nonbuilt area of 4000 to 5000 square feet. We perform this analysis on each priority basin, and develop a coding scheme to reflect the rainwater harvest potential. Those parcels with the highest percentage of comparable areas are identified as having the greatest rainwater harvesting potential, while those with fewer comparable areas are assigned to 'medium', and those with the least into a 'low' category. As a result, all parcels within the priority basins will fall into a high, medium or low category. The indication of high, medium and low refers to both the conservation potential and a strategy to minimize the costs associated with the installation of rainwater harvesting system.

Table 1 illustrates the bivariate comparison between built and nonbuilt areas for priority basin number 14. In this example over 16.35 percent of parcels have

*Table 1: Total parcels and percentage in **priority basin 14** falling within specific built area and non-built area categories. The shaded cells represent those parcels with high and medium conservation potential. All non-shaded cells represent those parcels with low conservation potential.*

			Built Area (Sq. ft.)						
			0-1000	**1001-1500**	**1501-2000**	**2001-2500**	**2501-3000**	**3001 or more**	**Total**
Non-Built Area (Sq. ft)	**0-3000**	**33**	**1**	**13**	**7**	**7**	**3**	**2**	**33**
		16%	0.48%	6.25%	3.37%	3.37%	1.44%	0.96%	
	3001-4000	**56**	**2**	**18**	**22**	**12**	**1**	**1**	**56**
		27%	0.96%	8.65%	10.58%	5.77%	0.48%	0.48%	
	4001-8000	**80**	**2**	**13**	**34**	**16**	**4**	**11**	**80**
		38%	0.96%	6.25%	16.35%	7.69%	1.92%	5.29%	
	8001-10000	**11**	**0**	**0**	**2**	**4**	**1**	**4**	**11**
		5%	0.00%	0.00%	0.96%	1.92%	0.48%	1.92%	
	10001 or more	**28**	**3**	**0**	**3**	**3**	**5**	**14**	**28**
		13%	1.44%	0.00%	1.44%	1.44%	2.40%	6.73%	
	Total	**208**	**8**	**44**	**68**	**42**	**14**	**32**	**208**
		100%	3.85%	21.15%	32.69%	20.19%	6.73%	15.38%	

comparable built areas with non-built areas. That is, of the 208 parcels in this basin, 34 have a high potential for installation of rainwater capture systems, 56 (18+22+16) have a medium potential, and the remaining 118 have low potential. We use this procedure to select high, medium and low potential candidates across all the parcels within each priority basins.

The GIS is essential to investigate further the suitability of parcel selection. Across the four priority basins we examine here, 489 parcels are in the high category, 543 to the medium category, and 1807 to the low. Figure 2 illustrates all subcategories in a color map format. The yellow parcels indicate those areas with a high number of comparable built to nonbuilt areas, green indicates those areas with medium, navy blue with low, and gray are those parcels not in the four priority basins. These results indicate that only 5.8 percent (489) of the parcels within the four priority basins are likely to be considered for installation of the pilot rainwater harvesting system. The map also indicates geographic clustering of potentially high conservation areas. The next section describes the implications of these findings to urban drainage in specific areas of Seattle.

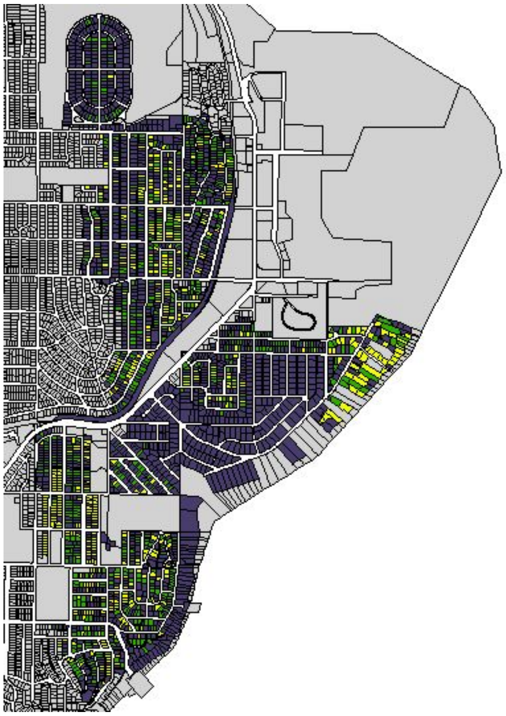

***Figure 2:** Four priority basins demarcated with high (yellow), medium (green), and low (navy blue) conservation potential.*

Impact on Drainage

Drainage has become an important consideration of urban regions. Plagued by damage to regional the economy, public health, and ecology municipalities are anxious to address citizen concerns. To begin addressing some of these issues, we estimated the amount of water removed from the drainage system in the four priority basins. This procedure estimates total reduction of flow into the combined sewage overflow system from installation of rainwater harvesting systems on parcels deemed with high conservation potential. Within the high category parcels, we found that a total of 8.85 million gallons (33.50 million liters) can be captured by installation of rainwater harvesting systems. As a result, the equivalent amount can be removed from the drainage system. While we recognize that all rainfall cannot be captured in these basins, these figures represent total potential, and should be regarded as such. Table 2 summarizes the calculation from each of the four priority basins with total parcel number and gallons of rainwater capture.

BASIN	Total Parcels in High Category	TOTAL CAPTURE (Gal)
NPDES 012	43	1625167.8
NPDES 013	231	3947647.14
NPDES 014	34	591818.48
NPDES 015	181	2685912.59
Total	**489**	**8850546.01**

***Table 2:** For each priority basin the summary of total parcels and gallons removed from drainage system.*

Discussion

The GIS analysis used in this study was essential to evaluate systematically the potential for installing rainwater-harvesting systems within the city of Seattle. The ability to overlay large varied datasets, and code for specific representations proved easy and effective. In fact, due to readily available geocoded data for the city of Seattle, we were able to complete this portion of the project in a timely and efficient manner. Through this analysis the City is able to prioritize parcels that could potentially be candidates for installation of such systems.

Clearly, some of our assumptions will need to be examined in greater detail when installation of a system is to occur. For example, we are comfortable with the assumptions of homogenous land cover, equal irrigation rates and total rainfall capture at the basin scale; however, at this point it is impossible to know if the specific parcel of interest is able to accommodate the installation of a rainwater harvesting system. There are many instances where landscaping or configuration of underground piping/wiring may prevent such installation. Therefore, we recommend ground-truthing all parcels of interest and evaluating the area for any circumstances not captured in this analysis.

With the success of applying this methodology to the four priority basins we expect to perform this analysis to the entire city of Seattle in the near future. As such, we expect to identify all regions with high conservation potential and use the GIS to present the findings to city officials. With limited resources to spend on innovative project at the city scale, this methodology enables us to identify specific parcels where investments can occur. The next phase of this study will examine the fiscal implications of installing these systems on selected parcels, and the willingness-to-pay of those households selected.

Conclusion

Water demand indicates both current and/or expected water consumption in any given area over a specific time period. Due to varying requirements and spatially explicit characteristics of individual users, water demand must be determined separately for individual user groups. Multiple uses of water can be differentiated according to the demand for potable water, industrial/commercial processes, as well as irrigation. The advantage of using a GIS for this analysis is that it helps with the initial identification of the parcels, visual cross checking with statistical data, and provides a platform for presenting the analysis to city officials for review. We hope that the study presented here establishes a basis upon which future research can examine fiscal and ecological implications of strategic water conservation strategies.

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