MEASURING THE EFFECTIVENESS OF EDUCATIONAL TOOLS AND HYDROLOGIC METRICS IN RAISING AWARENESS ABOUT STORMWATER SUSTAINABILITY

A Thesis

by

TOMMI JO GRACE SCOTT

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2011

Major Subject: Civil Engineering

Measuring the Effectiveness of Educational Tools and Hydrologic Metrics in Raising Awareness about Stormwater Sustainability

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Approved by:

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Ralph Wurbs
Committee Member, Joshua Barbour
Head of Department, John Niedzwecki

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ABSTRACT

Measuring the Effectiveness of Educational Tools and Hydrologic Metrics in Raising Awareness about Stormwater Sustainability. (August 2011)

Tommi Jo Grace Scott, B.S., Texas A&M University

Co-Chairs of Advisory Committee: Dr. Emily Zechman
Dr. Ralph Wurbs

Urbanization of watersheds leads to the degradation of watershed health, as increased areas of imperviousness produce alterations in the flow regime of receiving water bodies. While centralized infrastructure improvements, such as detention ponds, are typically implemented to manage excess runoff, a more decentralized approach that utilizes Low Impact Development (LID) design principles may better preserve the pre-development flow regime. Peak flow is traditionally used to design both of these types of infrastructure, but this does not capture the changes in the flow regime, nor does it convey the importance of stormwater sustainability to the general public. To further the general public's understanding about stormwater sustainability, an educational tool was used to take a complicated issue and make it easier to understand by a layperson. The first purpose of this work was to explore the effectiveness of educational tools that may be developed to increase public awareness about issues of watershed sustainability and encourage adoption of sustainable stormwater controls. To increase knowledge about stormwater sustainability and encourage more sustainable practices, a new stormwater sustainability metric, the hydrologic footprint residence (HFR), was recently introduced to measure more holistically the impacts of urbanization on the downstream residence. HFR measures changes to the flow regime as the area of land inundated for one unit of time in response to one rainfall event, which is a more relatable metric than peak flow for the general public. It was the second purpose of this work is to explore the effectiveness of HFR in communicating the impacts of urbanization on watershed health, as compared to traditional stormwater metrics, such as peak flow. To test these different objectives, collaboration with the Communication and the Computer Engineering Departments at Texas A&M University was needed to create a survey, which helped evaluate the effectiveness of the educational tool in educating the general public about stormwater sustainability, and encouraging more sustainable practices. The survey was also used to evaluate and compare the use of HFR and peak flow within the quiz for communicating to the general public about stormwater sustainability. Results indicated the quiz was useful for educating the public about stormwater sustainability, encouraging more sustainable practices. In addition, results indicated the HFR was more effective than peak flow in educating the public about LIDs.

DEDICATION

This thesis is dedicated to my mother, Hilda Scott, who has been the best mother and best friend anyone could ask for. As a mother, she has taught me to be patient, work hard, and always do my best. As my best friend, she has always been there for moral support, given advice, and taught me how to be a better friend. This is, also, dedicated to both of my dads, Richard Scott and Tommy Grace, who have never failed to give moral support and advice when I may not have wanted to hear, but needed to.

ACKNOWLEDGEMENTS

I offer my sincerest thanks to my advisor and committee co-chair, Dr Emily Zechman, who has supported me throughout my thesis with her knowledge and guidance. While in her research group, I have been able to learn so much as student and person, and she has been crucial in helping me find my own path. I attribute the level of my Masters degree to her encouragement and effort, and without her, this thesis would not have been possible.

I would like to thank my committee co-chair, Dr. Ralph Wurbs, and my committee member, Dr. Joshua Barbour, for their guidance and support throughout the course of this research. I would like to include my thanks to my fellow P3 members, Alyssa Politte, Sean Saathoff, Sam Collard, Chandana Damadoram, Marcio Giacomoni, Jenna Kromann, and Dr. Alex Sprinston, who have all been instrumental in creating the *Stormwater Footprint Quiz.*

I also want to extend my gratitude to the Environmental Protection Agency and Texas A&M University, which provided the funding for the P3 project and my education, respectively. In addition, I would like to thank all the students at Texas A&M who were willing to participate in the study.

Finally, thanks to my parents for their moral and financial support.

NOMENCLATURE

BMP	Best Management Practices
CFS	Cubic Feet per Second
EPA	Environmental Protection Agency
GPM	Gallons per Minute
HEC-HMS	Hydrologic Modeling System
HFR	Hydrologic Footprint Residence
LID	Low Impact Development
RHS	Rain Harvesting Systems

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CHAPTER I

INTRODUCTION

Sustainable watershed management is an increasing concern for city planners as the conversion of natural land cover to impervious surfaces harms the environment and increases flooding. Municipal governments must invest in new infrastructure or channel rehabilitation projects due to the pronounced effects of urbanization on local water resources. Development leads to the transition from natural land cover to more impervious surfaces, causing alterations to the flow regime, including decreases in infiltration and shorter times of concentration. As a result, higher volumes of stormwater runoff are discharged to receiving streams, which leads to increased peak stream flow, increased flooding frequency, environmental degradation, and reduced stream flow during droughts (Roesner et al., 2001; Leopold, 1968; Hollis, 1977; US EPA, 2004a). Local ecosystems are dependent on the water levels and the timing of floods, and they become unstable under dramatic shifts in the hydrologic flow regime (Richter et al., 1996). Municipalities often rely on stormwater taxes to manage the impacts of flooding, water quality, and erosion, including property damage, increased costs of water during droughts, and water supply shortages (US EPA, 2004b).

Large infrastructure improvements, such as detention ponds, are typically implemented

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This thesis follows the style of *Journal of Water Resources Planning and Management.*

to manage excess runoff. These projects can be very expensive and are limited by the availability of land. In addition, centralized infrastructure systems are not typically efficient at sustaining the natural flow regime and health of the instream ecosystem habitats. Detention ponds are designed to store stormwater and release it slowly, sustaining high flows for a longer period than in pre-development conditions. More decentralized approaches that utilize Low Impact Development (LID) design principles may better preserve the pre-development hydrograph. LIDs can be placed flexibly and can be incorporated into pre-existing or planned development sites, which can make the LIDs relatively inexpensive when compared to centralized infrastructure. This flexibility allows excess stormwater runoff to be captured at the source, similar to pre-development conditions. Decentralized approaches, however, are more difficult to implement, as they must be adopted by homeowners and developers, who may be hesitant to bear the cost of expensive technologies for stormwater control. Through training and educational programs on how to implement LIDs and the benefits of their use, LIDs may become more widely accepted.

Scope of Research

The purpose of this work is to develop an educational tool, called the Stormwater Footprint Quiz that can be used to both increase public awareness about issues of watershed sustainability and encourage adoption of sustainable stormwater controls. The Stormwater Footprint Quiz is designed to instruct individuals on the significance of personal decisions regarding housing location, housing type, LID options, and on the collective impact that citizens might have to improve the health of a watershed. Players will learn how much stormwater they are generating in terms of a stormwater metric.

Traditionally, peak flow is used to design both centralized infrastructure and LID strategies, but does not capture the changes in the flow regime. In addition, it may not be useful for conveying the importance of stormwater sustainability to the lay person. To increase knowledge about stormwater sustainability and encourage more sustainable practices, a new stormwater sustainability metric, the hydrologic footprint residence (HFR), was recently introduced to measure more holistically the impacts of urbanization on the downstream residence (Giacomoni et al. in press). HFR measures changes to the flow regime as the area of land inundated for one unit of time in response to one rainfall event, which may be a more relatable metric than peak flow for the general public. The second purpose of this work is to explore the effectiveness of HFR in communicating the impacts of urbanization on watershed health, compared to traditional stormwater metrics, such as peak flow.

To test these different objectives, collaborations with the Communication and the Computer Engineering departments at Texas A&M University are utilized to create an online application of the Stormwater Footprint Quiz and a survey to evaluate the effectiveness of the quiz in educating the players about stormwater sustainability and encouraging more sustainable practices. The survey evaluates and compares the use of HFR and peak flow within the quiz for communicating to the lay person about stormwater sustainability. Preliminary results for this study have been reported by Scott et al. (2011a, b).

CHAPTER II

LITERATURE REVIEW

History of Stormwater Management

Civil engineers have historically been constrained by only few restrictions in designing stormwater systems. Stormwater management was designed to quickly and efficiently remove excess stormwater to prevent flooding and reduce property damage. This design process began to change when concerns over environmental degradation in the waterways led to the passing of the Clean Water Act in 1972. This act became the first national law that set out to restore and maintain the health of US waters. The act initially prohibited the discharge of pollutants into surface waters without a permit, but this was expanded in 1977 with the ruling in *NRDC v. Castle* to include stormwater discharge. These rulings are enforced by the Environmental Protection Agency (EPA) through the National Pollution Discharge Elimination System (NPDES) program. Since the passing of the Clean Water Act, the flood control design method has been expanded to control peak flows and removal of pollutants. This design method remained the norm until the late 1980s and 1990s, when concerns over the flow patterns in the waterways began to emerge. Amendments to the Clean Water Act and EPA's Phase I and Phase II Stormwater Permit Rules in 1987, 1990, and 1999, respectively, further restricted the stormwater discharges in urban and industrial areas. In 2007, finally, the Energy Independence and Security Act required all development sites over 5,000 sq. feet to meet pre-development hydrologic conditions.

Civil engineers are challenged by the design goals of minimizing projects costs and maximizing the sustainability of watershed and environmental health. Watershed sustainability has been defined as a balance between meeting the current developmental needs while reducing or having little to no impact on the natural processes of the environment (Baird, 2003; Patchett et. al, 1995; Patchett et. al, 2008). LID in combination with best management practices (BMPs) have been useful in meeting watershed sustainability goals. BMPs include several technologies and techniques for mitigating increased stormwater runoff. For example, detention ponds hold stormwater runoff for a length of time to prevent flooding when storm sewer systems are at capacity. LID is a selected set of BMPs that implement the design management strategies with the goal of either maintaining or replicating the pre-development hydrologic system (Prince George's County, 1999). LIDs, such as rain harvesting systems and green roofs, are not new, however, they did loose popularity as cities turned to more efficient means of controlling floodwaters. In the early 1990s, they were reintroduced in Prince George County, Maryland through a successful pilot program (Prince George County, 1999). Benefits from using an LID include pollutant removal, noise reduction, increased safety for drivers, decreased urban heating, replenishing groundwater, reduction in runoff, and reduction of larger on-site traditional stormwater detention or retention basins, pollutant reduction, sedimentation reduction, flow mitigation, decreased surface runoff volumes, decreased peak discharges, erosion, and restoration of infiltration rates through maintenance (US EPA, 2000; Koponen, 2006; Bean et. al, 2007a ,b). LIDs have been successful at capturing stormwater for smaller storms. (Kwiatkowski et al., 2007;

Haselbach et al., 2006) For smaller storms, it has also been found that LIDS performed better overall in comparison to the traditional materials or structures (Khedun et al, 2009, Damadoram et. al., 2010; Rushton, 2001).

Low Impact Development

This research focuses on the utilization of LID by single-family residences and multi-family housing. In these housing units, the main sources of impervious area are the roof and pavement areas. For this reason, permeable pavements, green roofs, rain harvesting systems are considered as LID options.

A permeable pavement is similar to traditional concrete, however, in permeable pavements there are pores through which rainwater can infiltrate or voids are filled with high permeability materials. Porous pavement helps infiltrate precipitation through the pavement to the soil, when it is used in place of traditional pavements such as concrete or asphalt. Benefits from permeable pavement have included reductions in runoff volume, reductions in peak exfiltrate flow rate, removal of water from the surface of a road which reduces the risk of hydroplaning (Fitts, 2002; Collins et al., 2006, 2008; Booth and Leavitt, 1999; Brattebo and Booth, 2003; Legret and Colandini, 1999; Stenmark, 1995). Typically, permeable pavements are recommended on soils with low clay concentrations. The performance of permeable pavements can be improved for clay soils by installing additional drainage media over well-drained soils (Dreelin et al., 2006).

A green roof is installed on building rooftops, and vegetation is established on soil or other growing media, or a waterproof membrane. Green roofs help mitigate stormwater effects through rainwater storage in the media, evapotranspiration by plants, and rougher surfaces, which slow down the velocity of runoff. Benefits from green roof usage include increasing the time of concentration, decreasing the runoff peak, and reducing the volume of water running off a roof (Denardo et. al, 2007; Miller, 1998; Scholz, 2001; Hutchinson et al., 2003; Moran et al., 2004; VanWoert et al., 2005). On average, retention of stormwater is about 60-70%, through this varies for the type of green roof (Dietz, 2007). The types of green roof that can be installed on any structure is based on the allowable structural changes, especially for peaked roofs and considering the variability in the weight of the roof among growing and fallow seasons. Thin green roofs have been found to have little changes to stormwater storage, which is good for budget costs from structural changes, but if a roof is too thin the vegetation can become more sensitive to the seasonal changes and may not reduce stormwater impacts significantly (Boivin et al., 2001). The selection of roof plants is important since it provides shade, which reduces the roof surface temperatures, and increases rainfall absorption through its root system (Miller, 1998). Additional green roof benefits include improved air quality, reduction of the "heat-island effect," improved energy and sound insulation, building envelope protection, and aesthetic value (Denardo et. al, 2007, Peck et al., 1999; Liesecke, 1988; Niachaou et al., 2001).

Rainwater harvesting systems, or RHS, is an ancient water conservation technology that has been in use for 1000s of years. RHS is storage media, such as barrels or cisterns, which retains the stormwater runoff generated over rooftops. RHS collect the water from the roof by connecting the storage media to rain gutters, which are typically pre-installed. The stored rainwater can then be later used as water supply during drier periods. Of the three LIDs, this has had the widest spread of success due to its easy installation and low costs (TWDB, 2005; Lye, 2002). Benefits include decreased stormwater in waterways, decrease time of concentrations, increased groundwater recharge, and decreased water supply costs (Krishna, 2003).

Hydrologic Footprint Residence

Peak flow is often used to for infrastructure design but this not capture the changes to the flow regime as well as HFR. HFR is a sustainability metric that captures the extent of hydrologic change and the impact on downstream communities by measuring the inundation dynamics of the flow regime. As defined by Giacomoni et al. (in press), “the HFR associated with a rainfall-runoff event is the area of land that is inundated and the duration over which it is inundated as a storm wave passes through a specified reach of a receiving water body.” For any storm wave passing through a reach, the time series of the area that is inundated as the water surface elevation increases is called the inundated land curve. The value of the HFR is calculated as the definite integral of the inundated land curve, or the area under the inundated land curve. The HFR is designed to capture both temporal and spatial hydrological changes in the hydrograph, as it calculates the amount of land that was inundated and the duration of the flood. The HFR can be expressed in the amount of area flooded for one unit of time, which may make it more easily accessible by the lay person than a volumetric rate. Expressing the impact in units of area should be inherently easier to visualize than a flow rate. By using a time unit of one hour, HFR can be expressed as the number of acres flooded for one hour. Due to these characteristics, the HFR may increase the understanding of importance of stormwater and watershed sustainability and encourage more LID implementation. Furthermore, HFR can be used to facilitate a sense of ownership of the impact of urbanization on downstream communities.

Consider, for example, a rainfall event in a watershed that generates direct runoff. As the water drains into the receiving bodies and out of the watershed, water in the receiving bodies will rise and expand. This is represented as a water surface elevation time series and a time series of instantaneous discharge values, also known as a hydrograph. If proper topographical information of the waterways is available, the extent of inundated area of land for any given time can be calculated based on field measurements or hydrologic and hydraulic models, and represented as an inundated land curve. The value of the HFR is calculated by evaluating the integral of the inundated land curve in the waterways, or by summing the area under the inundated land response curve. The HFR has been demonstrated for a small watershed to study the impacts of urbanization and stormwater management techniques, including detention ponds, rainwater harvesting, permeable pavements, and green roofs, on the receiving water body sustainability (Giacomoni and Zechman, 2009; Damodaram et al., 2010). HFR was used to evaluate the change in the flow patterns compared to pre-development conditions and captured both changes in timing and flow volumes in the hydrograph better than using the peak flow criterion. The HFR was developed as a stormwater management tool through work funded by the United States Environmental Protection Agency Phase I P3 Grant #SU83394. “Improving Hydrologic Sustainability of Texas A&M University

Campus" was presented at the National Sustainable Design Expo in 2009 (Khedun et al., 2009; Giacomoni and Zechman, 2009; Giacomoni et al., in press; and Damodaram et al. 2009, 2010).

Games and Educational Tools

The public has not easily accepted LIDs due to misconceptions or limited understanding (Eadie, 2002; Mongard, 2002). Educational tools are needed for LIDs to gain more acceptance by the public (CASQA, 2007). Educational tools can be used to explain a complicated concept in a way that is easier to understand for a layperson or person who is not an expert in the field. In the past, educational tools such as games have been used to explain the importance of conserving natural resources (Barreteau et. al., 2007; Doucet, 2009). For example, the Carbon Footprint Calculator and the Water Footprint Calculator have both been important in showing the effect of personal decisions on the environment (Carbon Footprint, Ltd, 2011; National Geographic, 2011). The Carbon Footprint Calculator informs the player how much CO_2 he or she is producing based on his or her current lifestyle. The Water Footprint Calculator informs players about how many pounds of water they were consuming based on their current lifestyle. Both games increase the knowledge of players and encourage players to make changes to their lifestyle in order to reduce their impact.

Education tools, like quizzes, can be successful in garnering more support for LID usage through a grassroots approach, where the interest in new technologies or policies arises within the public, rather than imposed by governing agencies. A small population that actively supports a cause can influence the rest of the population in a domino-like effect. A grassroots effort works as word-of-mouth communication increases a population's likelihood to diversify in their openness to new technologies (Rogers, 1995). In Rogers' study of social diffusion, which is a study of how people learn or adapt to new concepts or technologies, he found 15% of the population are innovators, 34% are early adopters, 34% are late majority, and 16% are people who will never adopt the new technology. It was revealed in this study that once early adopters, or about 15% of the population, start to incorporate a new technology, then society will successfully adopt the new innovation. This means educational tools only need to target about 15% of the local population.

CHAPTER III

METHODOLOGY

The Stormwater Footprint Quiz is designed to determine, through a set of sequential questions, the land cover and land use in the player's neighborhood and return an associated stormwater impact, or footprint. Based on the responses of the participant, land use characteristics are applied for the entire area of a hypothetical watershed to simulate the hydrologic impacts that would occur if all residents in a watershed made similar land use and landscaping decisions. The participant receives information about the impacts on water sustainability and compares the impacts of land use decisions to the hydrologic conditions before urban development. The information about water sustainability is presented in one of two forms, either the peak flow, which is a conventional stormwater metric, or the HFR. To further the understanding of user's impact, the stormwater metric is compared to pre-development land use conditions and also the implementation of LID options including permeable pavements, rain harvesting systems, and green roof. The pre-development feedback conveys how much the player has affected the watershed and receiving water body, while the results associated with LID designs educates a player how his/her impact can be reduced.

Quiz Design

As the game begins, the first screen introduces players to the concept of stormwater runoff and the environmental impacts, including flooding, ecosystem degradation, and introduction of pollutants, of increased stormwater runoff due to increased urbanization. In addition, the player learns that land cover choices affect the amount of stormwater runoff. Throughout the quiz, the player answers a series of questions about the land cover at his or her residence and within his or her local neighborhood. Each of the questions includes example pictures for each selection choice. A housing model is displayed for the player to see how selections affect the land cover and is updated as the player selects options. An example of quiz layout for question given is shown in Figure 1. These visuals help the player answer the questions accurately.

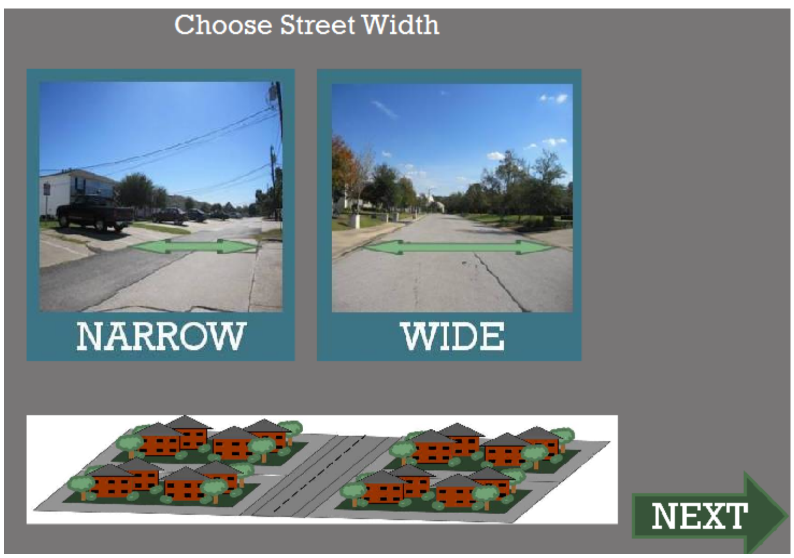

Figure 1: Sample question in the *Stormwater Footprint Quiz*

After a series of 2-3 questions, the player is introduced to a specific LID concept, including rain gardens and permeable pavement. For instance, when the player is asked about lot-level landscaping, then rain gardens are introduced. This placement of LID concepts is to enhance the connection between the benefits of LIDs and how the player could incorporate them within their home.

From the questions, the stormwater effect of the player's current land cover is given in either gallons per minute for peak flow or in acres flooded for one hour to represent HFR. Results are compared to a baseline case, which represents pre-development conditions. In addition, stormwater impacts are reported for LID options including permeable pavements, RHS, green roofs, and combinations thereof. The following steps summarize the quiz:

Step 1: The participant is introduced to the quiz.

The player first reads the introductory page, which reads as follows: "Every time it rains, some water runs off into the ground and some goes into the stream. Roofs and pavement replace vegetation and blanket the soil, causing less stormwater to soak into the ground and more to run off into streams. Even large streams cannot accommodate the increased water volume and flow that occur immediately following rainfall, leading to erosion, streams choked with mud, destroyed aquatic habitat, and increased flooding and property damage. In addition, stormwater carries a mix of bacteria, sediments, fertilizers, oil and grease to nearby streams. How are your choices affecting stormwater?"

Step 2: The participant answers quiz questions and reads information pages about LID.

Q1. Do you live in a residential home or in multifamily housing unit? (Residential/ Multifamily)

Info1. Rooftop Low Impact Development:

- Rain harvesting is the practice of storing rainwater in barrels or tanks for later use
- A green roof is a garden on top of a building
- If you choose to use rainwater harvesting or green roof instead of a typical roof, then the stormwater from your house will better mimic the stormwater before houses were built.

Q2. Do you have a yard? (Yes/No)

Q3. Do you have a garden and/or landscaping? (Yes/No)

Info2. Rain Gardens:

- A rain garden is a garden in a low spot where stormwater collects and seeps into the ground
- If you choose to use rain garden, then the stormwater from your yard will better mimic the stormwater before houses were build

Q4. Do you have a parking space? (Yes/No)

Q5. If so, is the parking space shared? (Yes/No)

Info3. Permeable Pavement:

- Permeable pavement is a material that water can flow through. It can be used in place of concrete or asphalt.

- If you choose to use permeable pavement, then rain will seep through the pavement and the stormwater from your driveway will better mimic the stormwater before houses were built.

Q6. Do you have a sidewalk? (Yes/No)

Q7. In your neighborhood, are sidewalks only on one side of the street? (Yes/No)

Q8. Are the streets wide or narrow? (Wide/Narrow)

Q9. In your neighborhood, are there parks and/or landscaping in the commons? (No/Parks/Landscaping/Both)

Model Development

The HFR and peak flow results for all scenarios are calculated using the curve number and initial abstraction. The curve numbers and initial abstractions are used for the rainfall-runoff and in-stream hydraulic routing. The curve number is used as input for the Hydrologic Modeling System (HEC-HMS) (US Army Corps of Engineers, 2008), which is used to model the entire watershed. For this case study, the weighted curve number is based on soil type C that ranges from 70 for pre-development levels to 98 for built-out levels. Time of concentrations was not included in this study due to a lack of topographical data. A baseline case is established to mimic the pre-development conditions in the watershed for a 2-yr 24-hr storm (4.4 inches) using an existing watershed, the Harris Gully sub-basin, which is a 5.7 sq. mi. watershed, located in Houston, TX as seen in Figure 2 (Harris County Flood Control District, 2010).

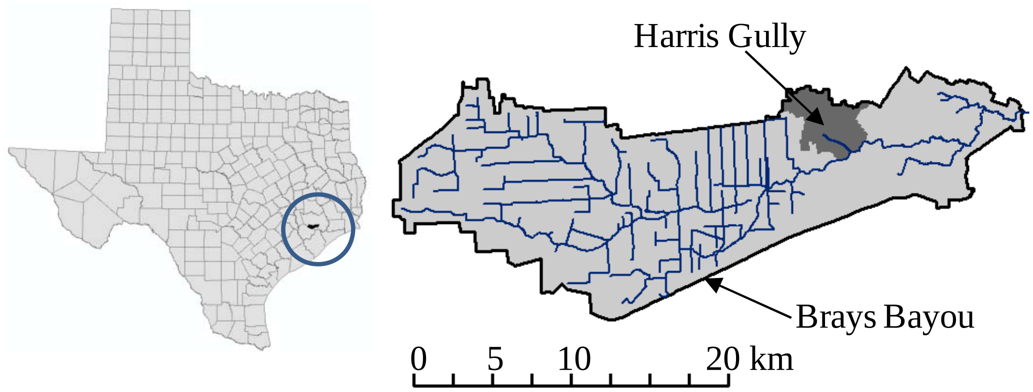

Figure 2: Location of Harris Gully

The HEC-HMS software converts rainfall into overland storm water runoff into a runoff hydrograph at the entering locations based on the Clark Unit hydrograph method. The hydrograph is then routed down the reaches to the outlet using the Modified Puls method, which creates a new hydrograph at the outlet of the sub-basin. Output from the model produces both the HFR and peak flow values. Peak flow is the highest volumetric rate at the outlet of the watershed. The HFR is calculated taking the hydrograph output from HEC-HMS at either end of simulated reaches and combining it with the topographic information given. A simplified channel, which is based on the high point, low points, and the average side slope, is used to represent the channel shape. The water surface elevations, WSEL, at each cross-section were calculated for each time step based on Manning's equation, which is the following equation:

Manning's Equation: $Q = (1.49 * A^{5/3} * S_0^{1/2}) / (n * P^{2/3})$ (1)

Q = Volumetric Rate (cfs)

A = Cross Sectional Area (ft^2)

S_0 = Channel Slope (ft/ft)

P = Wetted Perimeter (ft)

n = roughness coefficient.

The WSEL are converted to top water width with the following equation:

Top Width: $T = STN_{RB} - STN_{LB}$ (2)

STN_{RB} = Station at right bank

STN_{LB} = Station at left bank

For each reach, the top water width time series for each end cross-section is averaged and the multiplied times the length of the reach. This is represented by the following equation:

Inundated Area at time i: $IA = L*(T_{upstream} + T_{downstream})/2$ (3)

L = length of reach

$T_{upstream}$ = top width at upstream end of reach at time i

$T_{downstream}$ = top width at downstream end of reach at time i.

This produced the inundated response curve for each reach, which can be integrated over all time steps. The reach HFR is the integral, and the watershed HFR is the sum of all reach HFRs. For computational efficiency, a database is created to include all the feedback for every scenario.

Curve Number Calculation

Land use characteristics are calculated based on quiz responses to questions Q1-9. Land cover characteristics are used to calculate the corresponding curve number value and initial abstraction to model stormwater runoff using the curve number method (USDA 1986). Equations for the curve number method are:

Storage: $S_{CN} = 1000/CN - 10$ (4)

Initial Abstraction: $Ia_{CN} = 0.2S$ (5)

CN = Curve Number

The first question in the quiz (Q1) determines which housing distribution will be used, single-family or multi-family (assumed as apartments). The initial land cover distribution is based on the residential distribution from Table 1.

If a player selects both yard and landscaping options (Q2 and Q3), the area is split between the lawn and landscaping areas using a ratio of 0.8:0.2. The CN corresponding to landscaping and lawns is 70 and 74, respectively. For the multi-family scenario, if players select parking spaces but no sidewalks (Q4-Q6), the distribution is changed to 0% for sidewalks, and the area that would be attributed to sidewalks (3% for residential housing and 5% for multi-family housing) is used to increase the percentage of area covered by lawn.

Table 1: Regional decisions and impact on hydrologic modeling (Arnolds and Gibbons, 1996)

Regional Decisions	# of units/ ac.	Impervious Areas	Pervious Areas
Residential Housing	5	Streets: 16% Sidewalks: 3% Parking & Driveways: 6% Roofs: 15%	Lawns & Landscaping: 54%
Multifamily Housing	18	Streets: 11% Sidewalks: 5% Parking & Driveways: 15% Roofs: 17%	Lawns & Landscaping: 19% Open Space: 34%

The next step in the curve number calculation is to determine the new land cover distribution based any reduced impervious areas or increased green space made in the user's area (Q7-Q9). Reductions in the percentage of area dedicated to driveways, sidewalks, and streets are made based on information provided in Table 2. For this quiz, there is no exact width defined for narrow or wide street or wide. This is because many people do not know the exact width of their street but can relate this concept by using the visual aid. Instead, an example of a wide street and narrow street are shown, and the player chooses the option that best fits his or her neighborhood. Finally, if the player selects parks and landscaping, the impervious areas are reduced by 25% (Table 2). If the player selects either landscaping or parks, but not both, then all impervious areas are reduced by an additional 10% and the open space areas is increased by the total amount changed in the impervious areas.

Table 2: Neighborhood-level decisions and impact on hydrological modeling (Scheuler and Holland, 2000)

Neighborhood-level Decisions	Change in Land Use Characteristics
Increased green space	Reduce total impervious areas by 25%
Shared driveways	Decrease parking/driveway by 25%
Narrow streets	Decrease streets by 10%
One-sided sidewalks	Decrease sidewalk area by 50%

For all areas that are impervious, the curve number is 98, and the curve number for undeveloped areas is 70. The curve number for the player’s current impact levels is calculated by the following equation:

$$CN_{player} = 98*(\%Streets + \%Parking + \%Sidewalks + \%Roofs) + 70*\%Landscaping + 74*(\%\ Open\ Spaces + \%Lawns). \quad (6)$$

Once the player has answered all questions to describe the current land use patterns, the hydrologic model is updated to simulate LID options, which are implemented at every parking lot (driveway) and rooftop in the basin. Curve numbers and initial abstractions are reported by Damodaram et al (2010) that are used to represent the permeable pavement, RHS, and green roofs (Table 3).

Table 3: Lot-level decisions and impact on hydrological modeling (Damodaram et. al., 2009, 2010)

Lot-level Decisions	Change in Land Use Characteristics
Permeable pavement for driveways	Reduce curve number by 27 points for driveway areas
Rainwater harvesting system	Increase maximum potential rainwater retention up to 10 cm for roof areas
Green roofs	Reduce curve number by 12 points for roof areas

The permeable pavement for the quiz is on all pavement surfaces, which includes driveways, sidewalks, and streets. The curve number for the permeable pavement scenario is calculated by using the following equation:

$$CN_{PermeablePavement} = 71*(\%Streets + \%Parking + \%Sidewalks) + 98*\%Rooftop + 70*\%Landscaping + 74*(\%\ Open\ Spaces + \%Lawns). \qquad (7)$$

The RHS and green roofs for the quiz are applied to all rooftop areas. The curve number for the RHS scenario is calculated by using the following equation:

$$CN_{RHS} = 98*(\%Streets + \%Parking + \%Sidewalks + \%Roofs) + 70*\%Landscaping + 74*(\%\ Open\ Spaces + \%Lawns). \qquad (8)$$

The initial abstraction for the roof is changed to 3.94 inches and used to create a weighted initial abstraction using the following equation:

$$Ia_{RHS} = 3.94*\%Roof + Ia_{98}\,(\%Parking + \%Sidewalks + \%Streets) + Ia_{70}*\%Landscaping + Ia_{74}*(\%\ Open\ Spaces + \%Lawns). \qquad (9)$$

The curve number for the green roof scenario is calculated by using the following equation:

$$CN_{GreenRoof} = 98*(\%Streets + \%Parking + \%Sidewalks) + 86*\%Roofs + 70*\%Landscaping + 74*(\%\ Open\ Spaces + \%Lawns). \qquad (10)$$

For the combination options, the calculations are repeated from above using the following equations:

$$CN_{RHS\&Permeable\ Pavement} = 71*(\%Streets + \%Parking + \%Sidewalks) + 98*\%Rooftop + 70*\%Landscaping + 74*(\%\ Open\ Spaces + \%Lawns). \qquad (11)$$

$$Ia_{RHS\&PermeablePavement} = 3.94*\%Roof + Ia_{71}\,(\%Parking + \%Sidewalks + \%Streets) + Ia_{70}*\%Landscaping + Ia_{74}*(\%\ Open\ Spaces + \%Lawns). \qquad (12)$$

The curve number for the permeable pavement and RHS option is calculated by using the following equation:

$$CN_{GreenRoof\&PermeablePavement} = 71*(\%Streets + \%Parking + \%Sidewalks) + 86*\%Rooftop + 70*\%Landscaping + 74*(\%\ Open\ Spaces + \%Lawns). \quad (13)$$

All curve numbers are rounded to the 0.5 and if the initial abstraction is changed from the curve number method relationship, then all initial abstraction are rounded to the nearest hundredth decimal place.

CHAPTER IV

SIMULATION RESULTS

Based on the combinations of answers to quiz questions Q1-Q9, a total of 544 different scenarios can be generated. For each scenario generated, there are five LID scenarios (Eqns. 7-13), including rainwater harvesting; green roofs; permeable pavements; a combination of permeable pavements and rainwater harvesting; and a combination of permeable pavements and green roofs. Therefore, 3,264 hydrologic results are needed to account for any possible set of responses from a player. Due to rounding the curve number and initial abstraction, only 239 different hydrologic simulations are executed. To facilitate a quick response time, the HFR and peak flow values were computed *a priori* for each scenario, and these values are accessed from a data table during the quiz.

Example Scenario

Consider, for example a set of answers returned by a player:

Q1. Do you live in a residential home or in multifamily housing unit? (Residential)

Q2. Do you have a yard? (Yes)

Q3. Do you have a garden and/or landscaping? (Yes)

Q4. Do you have a parking space? (Yes)

Q5. If so, is the parking space shared? (No)

Q6. Do you have a sidewalk? (No)

Q7. In your neighborhood, are sidewalks only on one side of the street? (No)

Q8. Are the streets wide or narrow? (Narrow)

Q9. In your neighborhood, are there parks and/or landscaping in the commons? (Parks)

The user's current stormwater effect is 7,114 gpm for peak flow and 233 acres for HFR (Figs 3 and 4). Of the five LID options, the combination of permeable pavement and RHS reduces the differences between pre-development levels the most with peak flow at 4,249 gpm and HFR at 176 acres. If the player is limited to only one type of LID, then RHS is the best option with peak flow at 5,506 gpm and HFR at 195 acres. Green roofs reduces the excess stormwater the least with the peak flow at 6,837 gpm and HFR at 225 acres. From these results, the player learns that RHS alone is a good LID option to implement into their home. If they are able to take a step further by either incorporating or supporting LID initiatives then permeable pavement and RHS would be the better option. The relationship among the LID options is consistent for all possible combinations of answers provided by the user to describe his or her current land use characteristics.

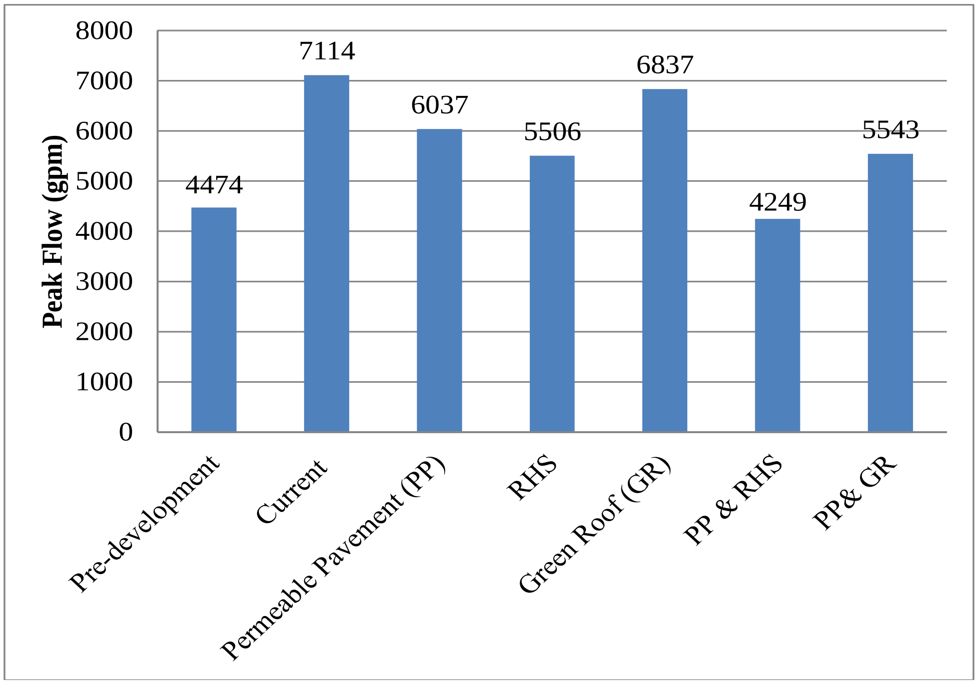

Figure 3: Range of peak flow values for example calculation

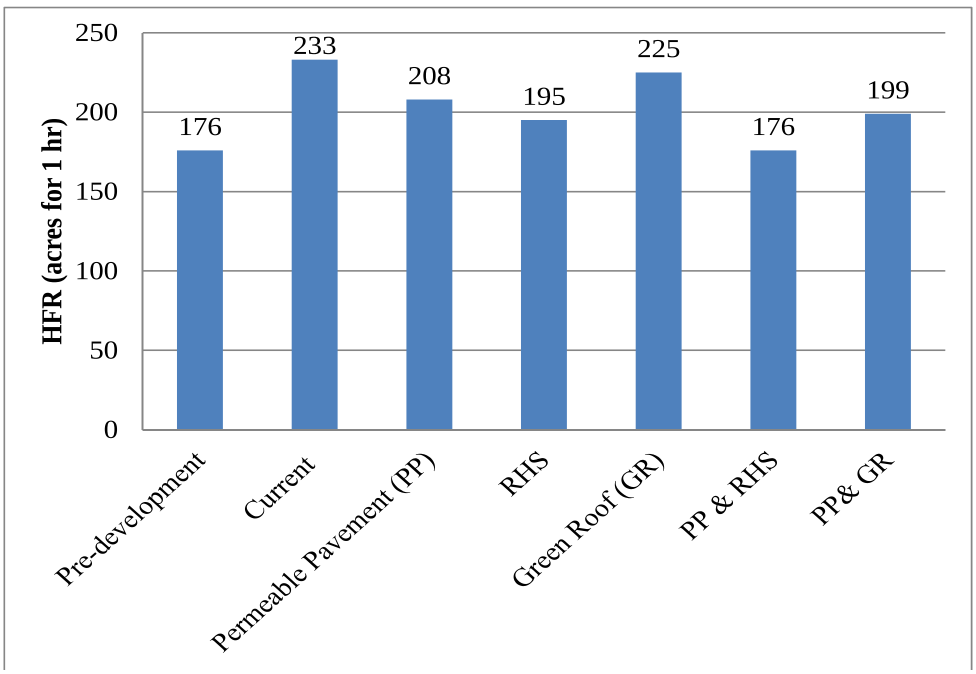

Figure 4: Range of the HFR values for example calculation

Simulation Data

For predevelopment conditions, the peak flow is calculated as 4,474 gallons per minute (gpm), and the HFR is calculated at 176 acres.

The player's current land use scenario is based on choices made by the user during the quiz. The average range for the current responses ranges from 6,516 gpm to 10,697 gpm for peak flow and 217 to 263 acres for the HFR. The cumulative distribution function for peak flow and the HFR results for the player's current landuse scenario can be seen in Figures 5 and 6.

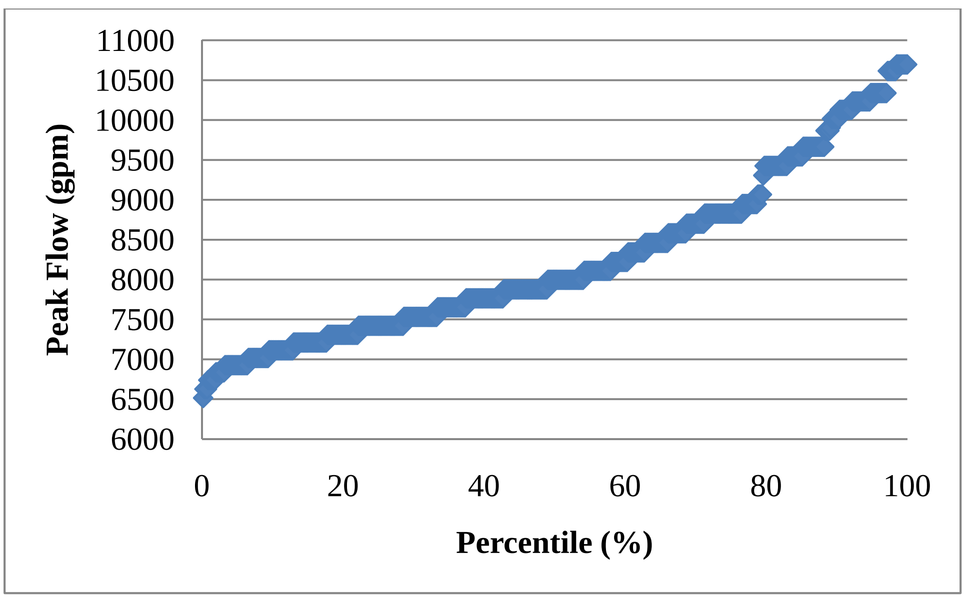

Figure 5: Cumulative distribution function of peak flow values for all user options

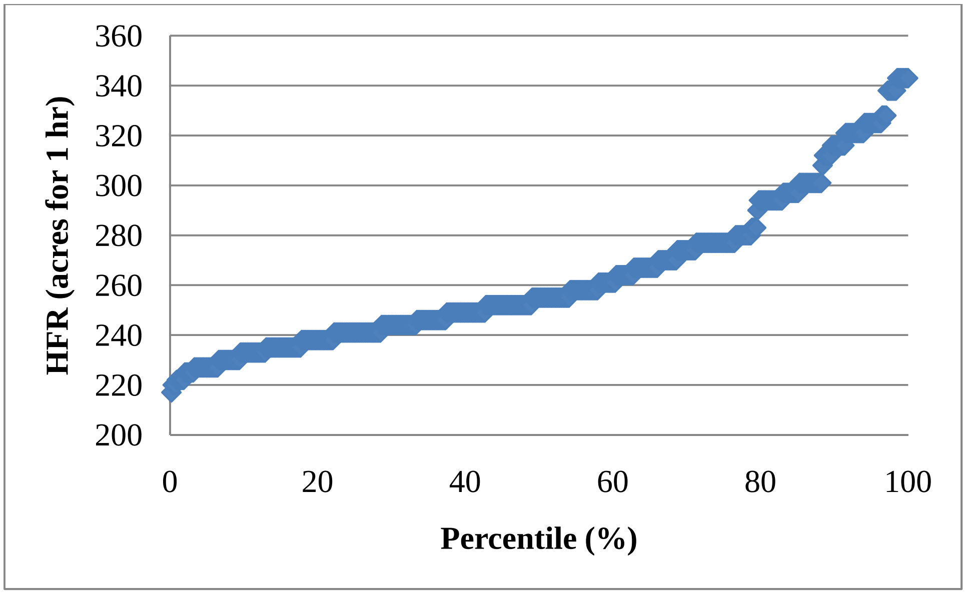

Figure 6: Cumulative distribution function of HFR values for all user options

The permeable pavement scenario replaces the player's pavement surfaces including street, sidewalk, and parking areas, with permeable pavement. The average range for the current responses ranges from 5,663 gpm to 6,269 gpm for peak flow and 201 to 212 acres for the HFR. The distributions of the peak flow and the HFR results are shown in Figures 7 and 8. For the rainwater harvesting scenario, the average range for the current responses ranges from 4,840 gpm to 10,166 gpm for peak flow and 185 to 267 acres for the HFR. Peak flow and the HFR results for the player's current response can be seen in Figures 9 and 10. For the green roof scenario, the average range for the current responses ranges from 6,157 gpm to 10,435 gpm for peak flow and 210 to 329 acres for the HFR. Peak flow and the HFR results for the player's current response can be seen in Figures 11 and 12. The sixth feedback response is the player's current stormwater effect with RHS for same rooftop areas and permeable pavement for the same pavement areas. The average range for the current responses ranges from 3,748 gpm to 4,601 gpm for peak flow and 158 to 181 acres for the HFR. Peak flow and the HFR results for the player's current response can be seen in Figures 13 and 14. The seventh feedback response is the player's current stormwater effect with green roofs for same rooftop areas and permeable pavement for the same pavement areas. The average range for the current responses ranges from 5,311 gpm to 5,783 gpm for peak flow and 194 to 203 acres for the HFR. Peak flow and the HFR results for the player's current response can be seen in Figures 15 and 16.

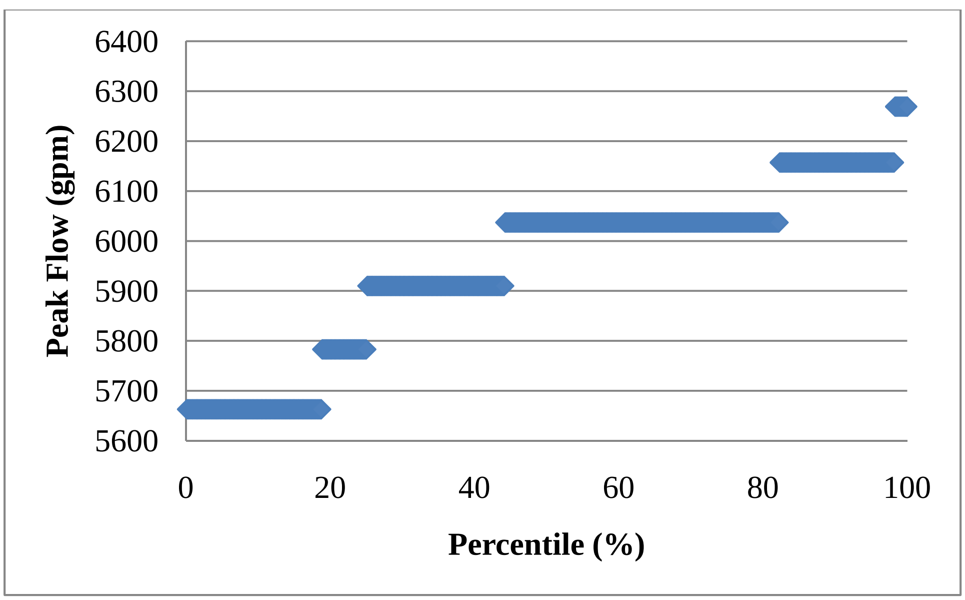

Figure 7: Cumulative distribution function of peak flow values for all user options with permeable pavement

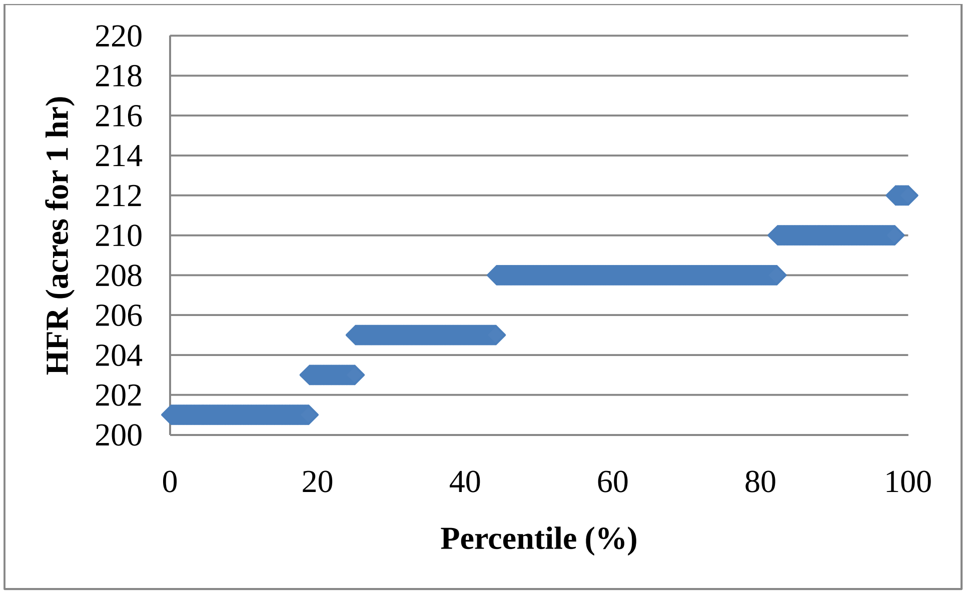

Figure 8: Cumulative distribution function of HFR values for all user options with permeable pavement

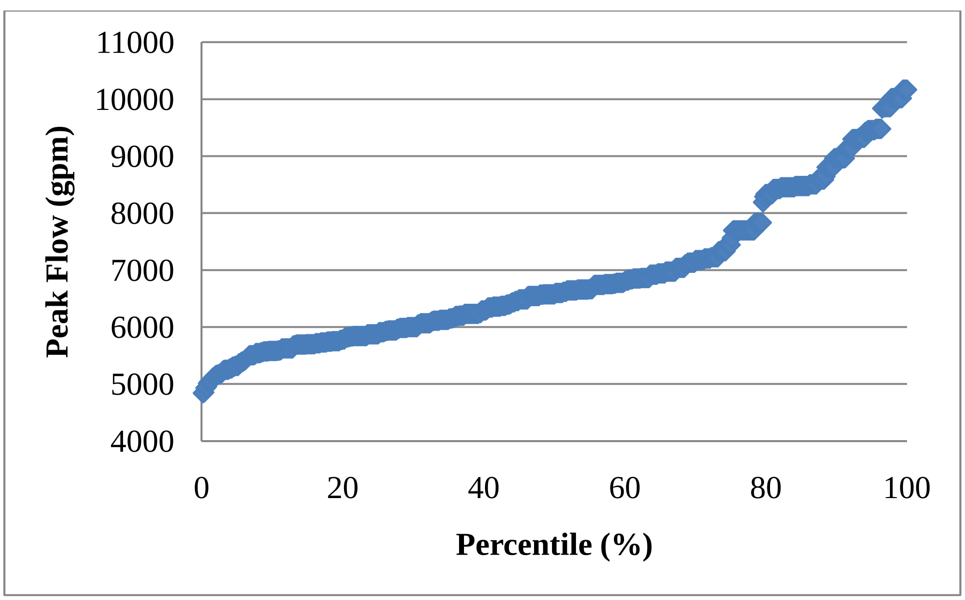

Figure 9: Cumulative distribution function of peak flow values for all user options with RHS

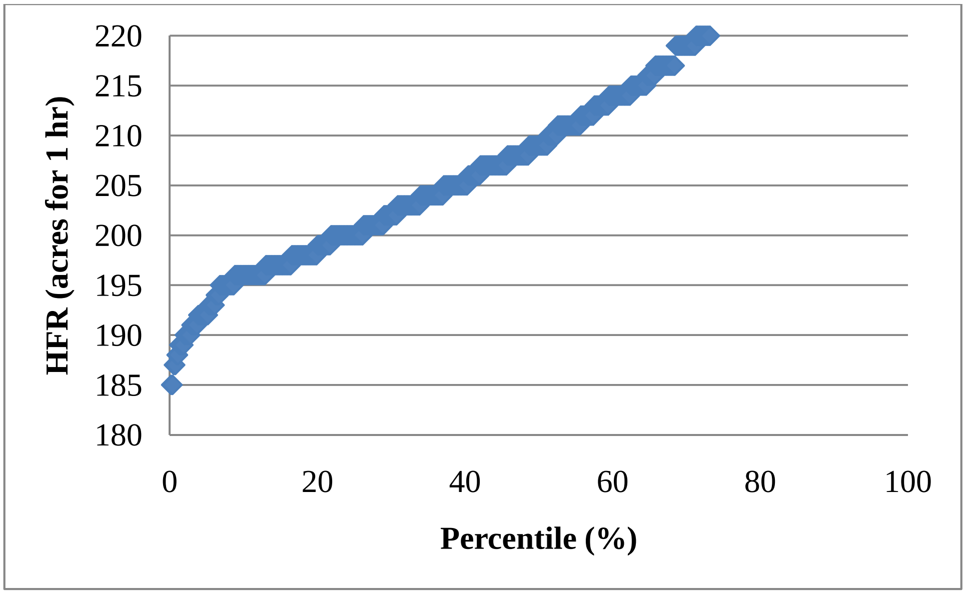

Figure 10: Cumulative distribution function of HFR values for all user options with RHS

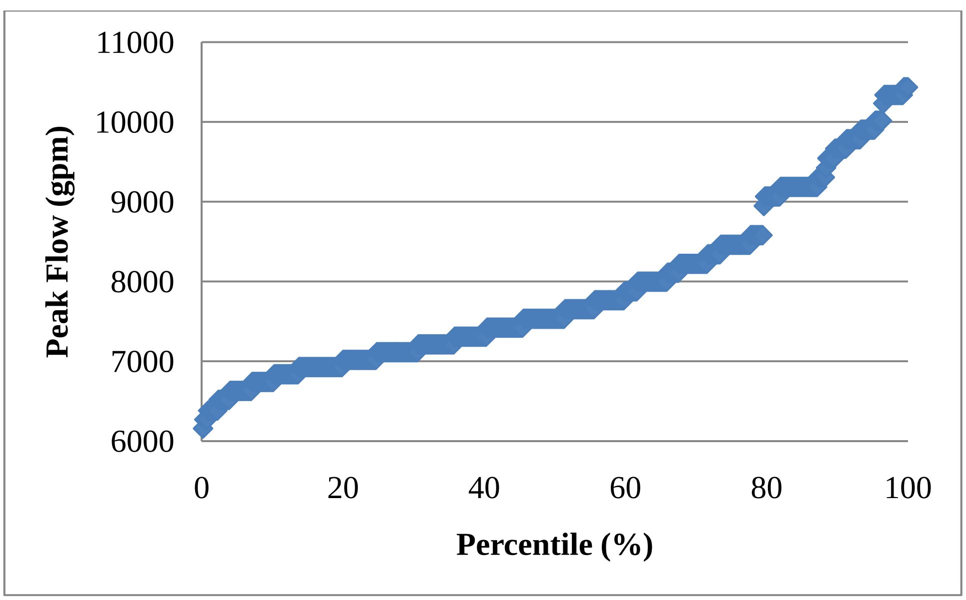

Figure 11: Cumulative distribution function of peak flow values for all user options with green roofs

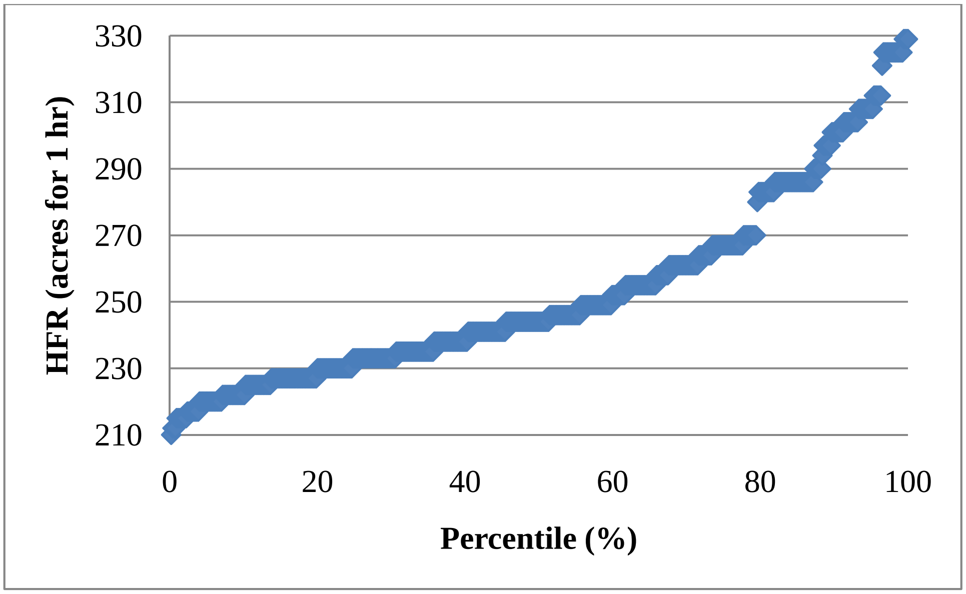

Figure 12: Cumulative distribution function of HFR values for all user options with green roofs

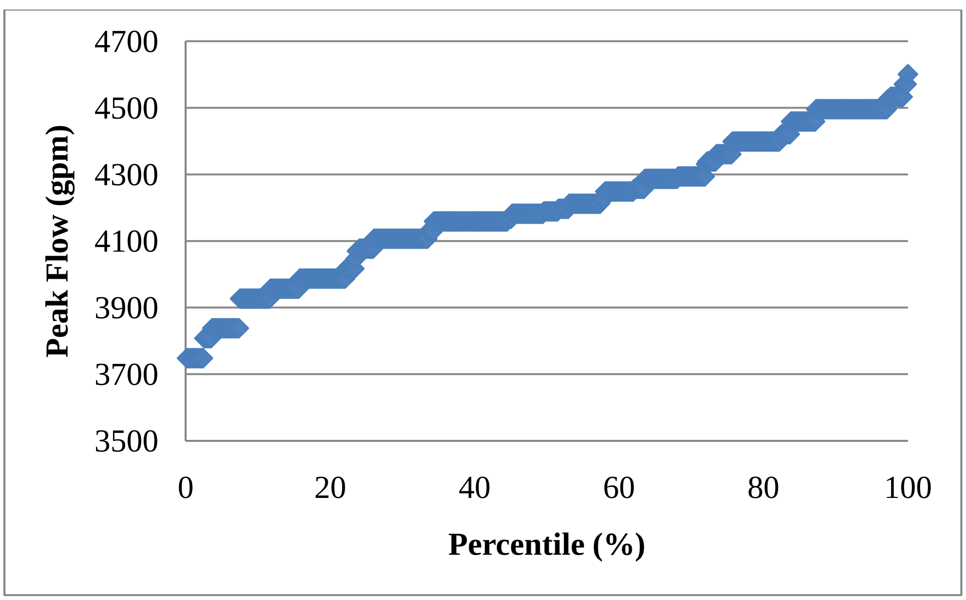

Figure 13: Cumulative distribution function of peak flow values for all user options with permeable pavement and RHS

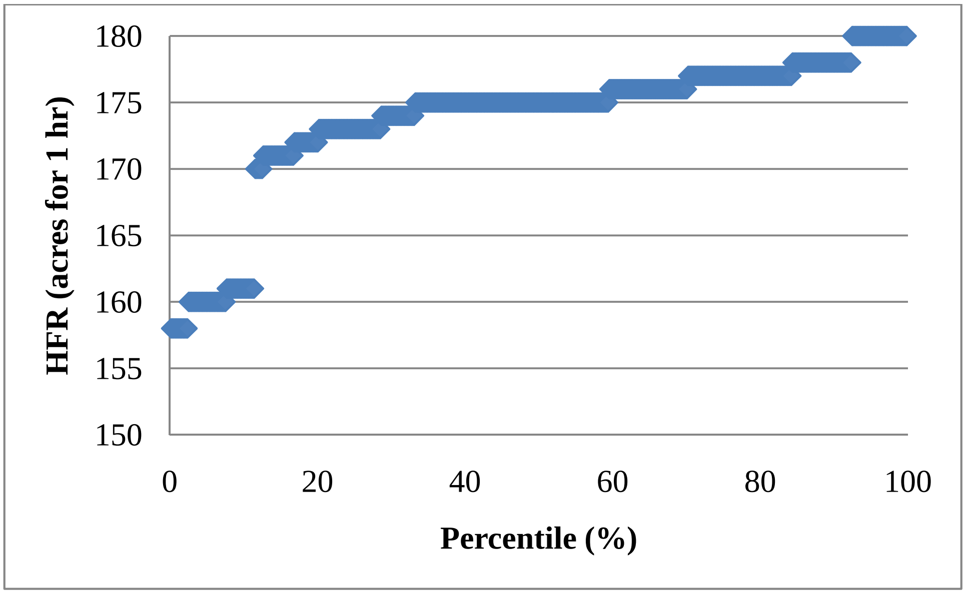

Figure 14: Cumulative distribution function of HFR values for all user options with permeable pavement and RHS

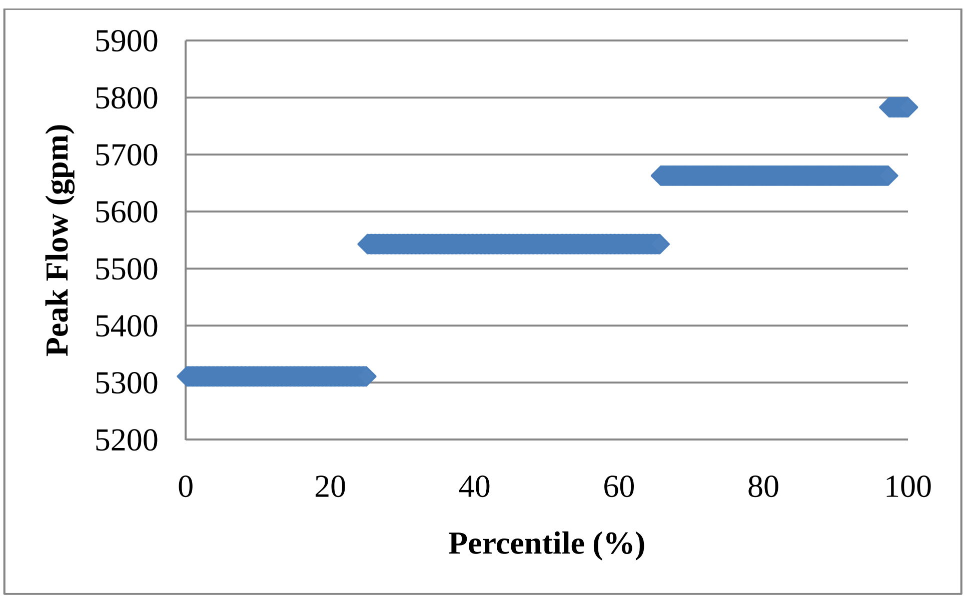

Figure 15: Cumulative distribution function of peak flow values for all user options with permeable pavement and green roofs

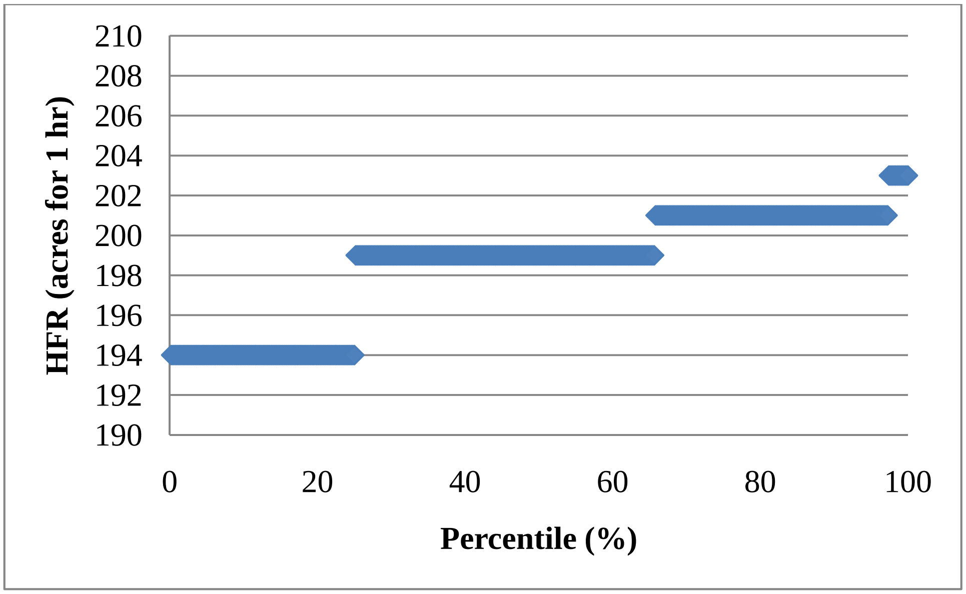

Figure 16: Cumulative distribution function of HFR values for all user options with permeable pavement and green roofs

CHAPTER V

SURVEY DEVELOPMENT

An initial version of the quiz was created in a data spreadsheet and presentation application that includes the layout, visuals, and results. The presentation file was used as mock up for how the game will be played out by the user, and the data spreadsheet will include a summary of all modeling computations. For ease of distribution and use for testing, this version was given to students from Computer Engineering department to code into an online flash application, iPhone application, and an iPad application. These formats are internet applications that deliver feedback from a server to the player based on the user's input (Adobe Systems Incorporated, 2011; Apple, Inc., 2011). These formats are selected in order to meet the widest range of online users. Online users are able to access the game for free at <https://ceprofs.civil.tamu.edu/ezechman/>.

An experiment was fielded to evaluate the effectiveness of such games for changing participants' knowledge and attitudes towards the effects of development on stormwater and about low impact developments. In addition, the experiment compared the effectiveness of different metrics in communicating the aforementioned concepts. Working with the Communication department, a testing package is developed on a survey collection site, which includes a pre- and post-survey, and the *Stormwater Footprint Quiz*. The experiment was conducted online to allow for participants to complete the study at a time and place convenient to them, and to allow participants to submit their answers anonymously. The players take a pre- and post-test to evaluate how well the information is being understood. The pre-test is taken before the quiz in order to determine how much the player knows before taking the quiz about stormwater and impacts of different development options. Post-quiz surveys are designed and administered to test how well participants learned about the concepts, and to discern how well the HFR and peak flow communicate hydrologic sustainability.

In the both surveys, the participants are asked three types of questions, which evaluated five different testing metrics. The first three metrics measure the participant's knowledge about stormwater management. The last two metrics measure the participant's attitudes towards stormwater management practices.

The first metric evaluates the participant's knowledge about effects excess stormwater based on true or false set of statements. The students were asked if the following statements were true or false: stormwater can cause flooding, stormwater can cause erosion, stormwater can cause damages to property, stormwater can cause loss of health of aquatic species, and stormwater can cause discoloration of tap water. The discoloration of tap water statement is to test if the participant is relating the concept correctly. The second testing metric measures the level of knowledge the participant has about what causes more stormwater runoff based on true or false set of statements. The students were asked if the following statements were true or false: excess volumes of stormwater can be caused by new parking lots; excess volumes of stormwater can be caused by new buildings; excess volumes of stormwater can be caused by new green space; excess volumes of stormwater can be caused by new parks; excess volumes of stormwater can be caused by rainwater harvesting; excess volumes of stormwater can be caused by green roofs. The third testing metric measures the participant's knowledge about the impacts of different development options on storm water generation. This is based a set of statements that the participant answered as follows: increases flooding; decreases flooding; no change; or I don't know. The students were asked about the following development options: wide sidewalks, shared driveways, permeable pavement, rainwater harvesting, green roofs, narrow streets, and new parking lots.

The third testing metric measures the participants' willingness to take action. Participants rated each statement using a 6-point Likert scale with 1=strongly disagree, 2=disagree, 3=somewhat disagree, 4=somewhat agree, 5=agree, and 6=strongly agree. Participants answered the following statements: my choices about where I live can affect flooding in my community; I am likely to tell my friends about low impact development; I am likely to vote for political candidates who support low impact development. The last testing metric evaluated the participants attitudes towards environmental and economic tradeoffs. This is based on the same Likert scale. Participants answered the following statements: in my neighborhood, the growth of new businesses is more important than having green space; environmental protection reduces economic development; private property rights must always trump conservation efforts.

Four hypotheses were set up to evaluate effectiveness of the game and metrics using the statistical hypothesis testing method. The hypothesis testing is based on a two-directional t-test with an alpha level of 0.05. The hypotheses are as follows:

H1: Game play will improve participants' knowledge about sustainable stormwater management practices.

H2: Game play will encourage more sustainable stormwater management decisions.

H3: Game play feedback utilizing the HFR will have a greater effect on participants' knowledge about sustainable stormwater management practices than conventional stormwater metrics.

H4: Game play feedback utilizing the HFR will encourage more sustainable stormwater management decisions than feedback utilizing conventional stormwater metrics.

To investigate these hypotheses, four versions (two with the HFR metric and two with peak flow) were created based on Solomon four group experimental design testing guidelines. (Babbie, 1998; Campbell & Stanley, 1963) The guidelines are as follows: one HFR and one peak flow version included a pretest questionnaire to allow for the measurement of change in knowledge and attitudes; the other HFR and peak flow versions did not have a pretest questionnaire to control for the effects of taking the pretest itself (if any); all participants played a version of the game, and then completed a posttest questionnaire; all participants finished by answering various demographic questions; tests given to students must be based on random selection.

The testing site was distributed in Texas A&M University's classrooms. To encourage participation in the study, some classes offered extra credit to students. Students were able to receive credit by submitting their name, which was not associated with any data set submitted. The sample size of the experiment was 510 participants, which meets population size guidelines, in undergraduate classes in communication and engineering courses (Cohen, 1988). These courses were selected in order to get the widest range of background knowledge with participants coming from over 30 different majors. The complete survey given in this experiment is in Appendix A.

CHAPTER VI

RESULTS OF SURVEY

The first two hypotheses are based on the comparisons of pre and post test results for each of the knowledge and attitude testing metrics. The last two hypothesis are based the results on the posttest questionnaires between the HFR and peak-flow conditions. Hypotheses 1 and 3 evaluate the knowledge metrics and hypotheses 2 and 4 evaluate the attitude metrics. Hypotheses are tested based on correlation, which measures the size effect the quiz has on the participant knowledge or attitude. This is categorized as follows: small effect is r less than 0.1, medium effect is r between 0.1 and 0.3, and large effect is between 0.3 and 0.5 (Cohen, 1988).

Hypothesis 1 which postulates the game play will improve participants' knowledge about stormwater and sustainable stormwater management practices, received partial support. Participants' knowledge about the effects of stormwater was not improved by game play. The average scores increased from 92.6% to 93.2% and had no effect. This suggests the game did not have much influence on knowledge about the effects of stormwater, because participants already had a strong sense of these effects. Participants' knowledge about the causes of stormwater improved from 67.1% to 79.2% and the effect of game play on participants' knowledge of the causes of stormwater is a medium effect (r = 0.23). Participants' knowledge about the effects of different development options improved from 0.17 to 0.46 (on a -1.00 to 1.00 scale) and the effect of game play on participants' knowledge of development technologies is a large effect (r

= 0.33). Summary of the results are seen in Figures 17 and 18. These results indicate the game had large positive effects on participants' knowledge, which suggests games are useful education tools for communicating these complex ideas to the public.

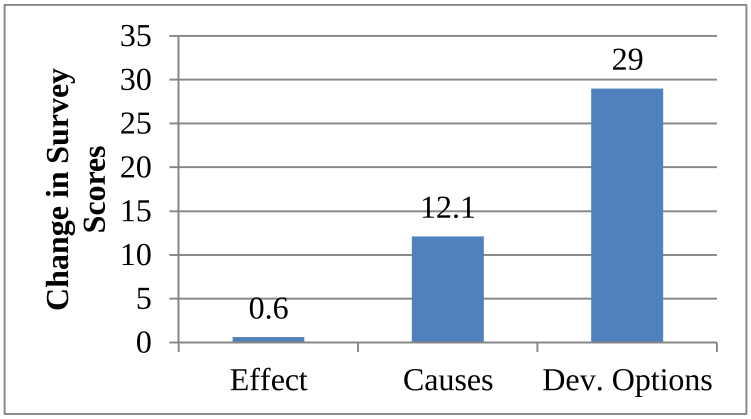

Figure 17: Summary of score changes for Hypothesis 1

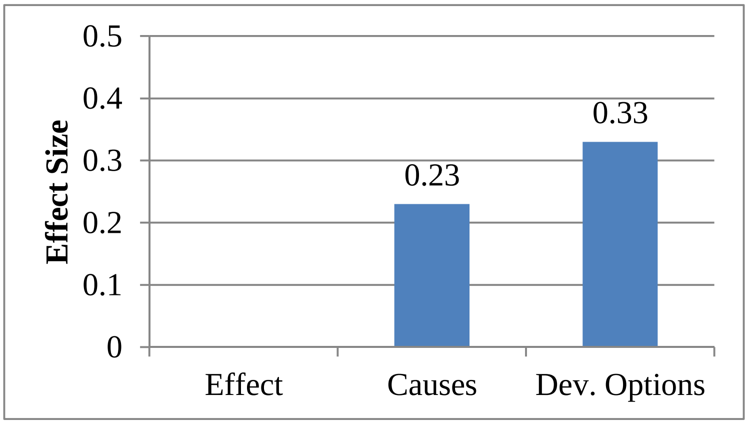

Figure 18: Summary of effect size for Hypothesis 1

Hypothesis 2, which postulates the game will encourage more sustainable stormwater management decisions, received partial support. Data from the economic and environmental metric revealed the participants' attitudes were more likely to respond economic development should trump environmental protection after playing the game, which is not unexpected because the economic benefits were not targeted within the quiz. The data did show the game did have a small effect on their attitude (r = 0.08), which suggests participants wanted to support the environment without sacrificing economic development. Data from the willingness to take action metric revealed participants were more likely to report a willingness to take action or support more sustainable stormwater management. The game had medium size effect on their attitude (r = 0.29). Summary of the results are seen in Figure 19. These results indicate game play had medium positive effects on participants' attitudes, which suggests games are useful education tools for changing the public attitude towards implementing more sustainable stormwater practices.

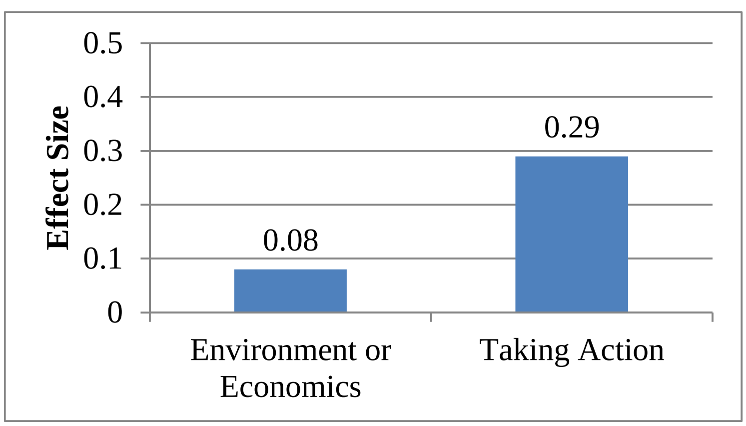

Figure 19: Summary of effect size for Hypothesis 2

The third hypothesis, which postulates the HFR will have a greater effect on participants' knowledge about stormwater and sustainable stormwater management practices than peak flow, received partial support. Data revealed participants receiving HFR feedback did not increase their knowledge about stormwater in comparison to peak flow. Furthermore, there was no effect size. Participants receiving HFR feedback did increase their knowledge about different development alternatives with the effect size being a medium effect (r = 0.12). Summary of the results are seen in Figure 20. These results indicate game play had small positive effects on participants' knowledge about development options, which suggests HFR is a useful metric for communicating the benefits of different sustainable stormwater management practices.

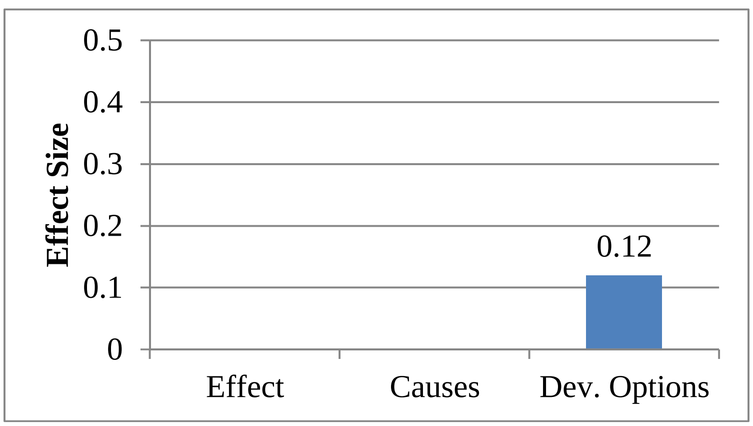

Figure 20: Summary of effect size for Hypothesis 3

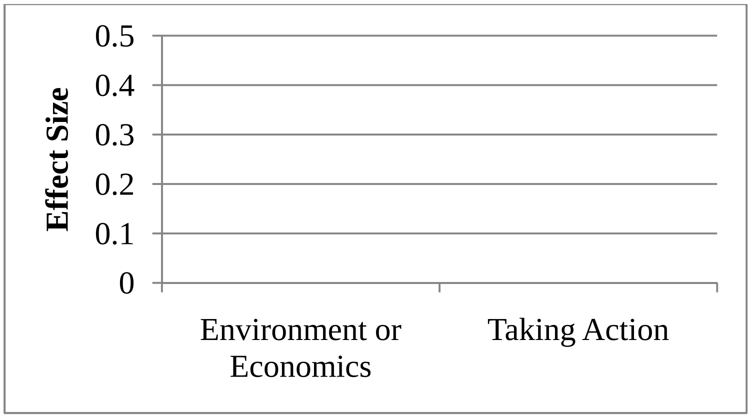

Figure 21: Summary of effect size for Hypothesis 4

The fourth hypothesis, which postulates that the HFR will encourage more sustainable stormwater management decisions than peak flow, was not supported. When comparing the attitude from the participants receiving HFR feedback and those receiving peak flow feedback, no differences in their attitudes about the economy and the environment or their willingness to take action were noted. This resulted in zero effect size for both testing metrics. Summary of the results are seen in Figure 21. These results indicate that either metric influence the participants attitudes about stormwater management just as well as the other.

CHAPTER VII

CONCLUSIONS

The purpose of this project was to create an educational tool for increasing awareness about watershed sustainability. The educational tool was simple to use but required extensive engineering calculation for it to work. Engineering calculations were required for each combination of the quiz, which included the latest curve number modeling for permeable pavements, rain harvesting systems, and green roofs. The HFR was calculated for the reach of the water body, and peak flow was calculated at the outlet. This research introduced the concept of relating stormwater to the general public by having the player's home land use characteristics be duplicated across the watershed. This provided information about the extent of their stormwater effect and created a sense of ownership and responsibility within the player. This further encourages homeowners to take initiative to reverse some of effects of development by incorporating more LIDs within their home and/or by supporting local LID initiatives.

The results from the field study provide support that this quiz can be effectively used for communicating stormwater concepts to the public and can be used as a tool for civil engineering research. Results showed that this quiz can influence attitudes and improve knowledge about stormwater management and low-impact development, which can lead to the public making more sustainable decisions about stormwater management. The results also indicate that the HFR offers a more understandable alternative to peak flow with regards to knowledge about low-impact developments.

In addition to its educational function, this research created a platform for testing the communicative effectiveness of different stormwater metrics, including HFR and peak flow. Stormwater metrics are useful to civil engineers in the design process but are difficult to translate to the general public. This testing platform allows for other metrics to be tested. The key to any metric is how the general public relates to the metric. This is important because the metric demonstrates to the general public how they are affecting stormwater through their home's current land use characteristics, which can later lead to more LID implementation.

The base model is limited by a number of factors, including simplification of watershed modeling and limited LID options. The hydrologic model is currently updated using curve number and initial abstraction parameters. This gives a rough estimate on the changes in excess runoff but fails to better represent the changes in the flow regime since time of concentration is left constant. In addition, the HFR is calculated using a simplified geometry data, which provides a rough estimate for the HFR. To better represent the hydraulic responses, an unsteady flow hydraulic model should be incorporated. This will provide a more accurate calculation of the HFR, however, for this testing platform only a rough estimate was needed to communicate the effects of urbanization on stormwater. Permeable pavements, rain harvesting systems, and green roofs are the only LIDs modeled for this educational tool, which is a very small selection in comparison to the range of LIDs available. In addition, only one type of each LID was modeled, which is a very small selection in comparison to the options for each type of LID available. For example, the RHS was modeled to capture roughly the first four inches of the storm, which is more than the average recommended 1” capture for rain barrels. Rain harvesting systems do range in size from the small rain barrels to large cisterns.

The model is currently based on the Harris Gully watershed model, but this quiz could be easily expanded or adapted to other watershed regions, which will better represent local responses. Players comprehensive knowledge about developmental stormwater effect are limited by the model because it only represents their current residential responses, which only represents a small portion on land use distribution. Future efforts should aim at developing a more complex gaming platform, where participants can not only input their current residence, but also make different changes to their home over time. Furthermore, this new tool should introduce different land use types, such as commercial and industrial sites. Players would be restricted to a select number of development options for each location in the playing field. This restriction would be based on the assessment made by the engineer before the game by evaluating hydrologic feedback from different placement scenarios. The engineer would recommend a range of options that would optimize the developmental costs with the level of environmental impact, and the player would select from these range of options that would better suit their needs. The new tool should also allow for more flexibility in testing stormwater management and concepts. Such a tool might not only make use of hydrologic models but provide the human response, which allows for models to better integrate environmental and human systems.

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APPENDIX A

P3 Questionnaire

A

* Please read the following statements. Indicate if you think they are true or false.

	True	False	Leave Blank/No Answer
Excess volumes of stormwater can be caused by new parking lots.			
Excess volumes of stormwater can be caused by new buildings.			
Excess volumes of stormwater can be caused by new green space.			
Excess volumes of stormwater can be caused by new parks.			
Excess volumes of stormwater can be caused by lots of rain.			
Excess volumes of stormwater can be caused by permeable pavements.			
Excess volumes of stormwater can be caused by solar fuel cells.			
Excess volumes of stormwater can be caused by rainwater harvesting			
Excess volumes of stormwater can be caused by green roofs.			
Stormwater can cause flooding.			
Stormwater can cause erosion.			
Stormwater can cause damages to property.			
Stormwater can cause loss of health of aquatic species.			
Stormwater can cause discoloration of tap water.			

* What effect (if any) would the following technologies have on flooding in your community?

	Increase flooding	Decrease flooding	No effect	I don't know	Leave Blank/No Answer
rainwater harvesting					
new parking lots					
narrow streets					
permeable pavement					
new parks					
wide streets					
wide side walks					
new green space					
green roofs					
shared driveways					
new buildings					

Figure 22: Page 1 of survey

*** How much do you agree or disagree with the following statements?**

	Strongly agree	Agree	Somewhat agree	Somewhat disagree	Disagree	Strongly disagree	Leave Blank/No Answer
Green spaces raise the value of my neighborhood.							
In my neighborhood, the growth of new businesses is more important than having green space.							
Environmental protection reduces economic development.							
My city government needs to invest more tax dollars in the maintenance of stormwater management.							
Private property rights must always trump conservation efforts.							
Green spaces are best served by environmentalists and business leaders working together.							
My choices about where I live can affect flooding in my community.							
I am likely to tell my friends about low impact development.							
Changes I make to my home to make it greener have little effect on flooding in my community.							
I am likely to vote for political candidates who support low impact development.							
I will tell my co-workers about how low impact development can help our community.							
The decisions my community makes about building influence flooding.							
Controlling flooding is a personal responsibility.							
Controlling flooding is a responsibility of the government.							
I am likely to install rain capture devices at my home.							
I am likely to install a green roof at my home.							
I am likely to try to use some flooding friendly technology at my home.							
I am likely to advocate with my local government for flooding friendly technologies.							

*** After a rainstorm of 4.4 inches, the flow in a stream that is near to your community is 4000 gallons per minute. A new apartment complex is built in your community, and now the flow after a rainstorm of 4.4 inches is increased. Rate each flow condition below.**

	No big deal	Could cause problems	Very big problem	I don't know	Leave Blank/No Answer
4040 gallons per minute					
4200 gallons per minute					
4400 gallons per minute					
5000 gallons per minute					
6000 gallons per minute					
8000 gallons per minute					

Figure 23: Page 2 of the peak flow version of survey

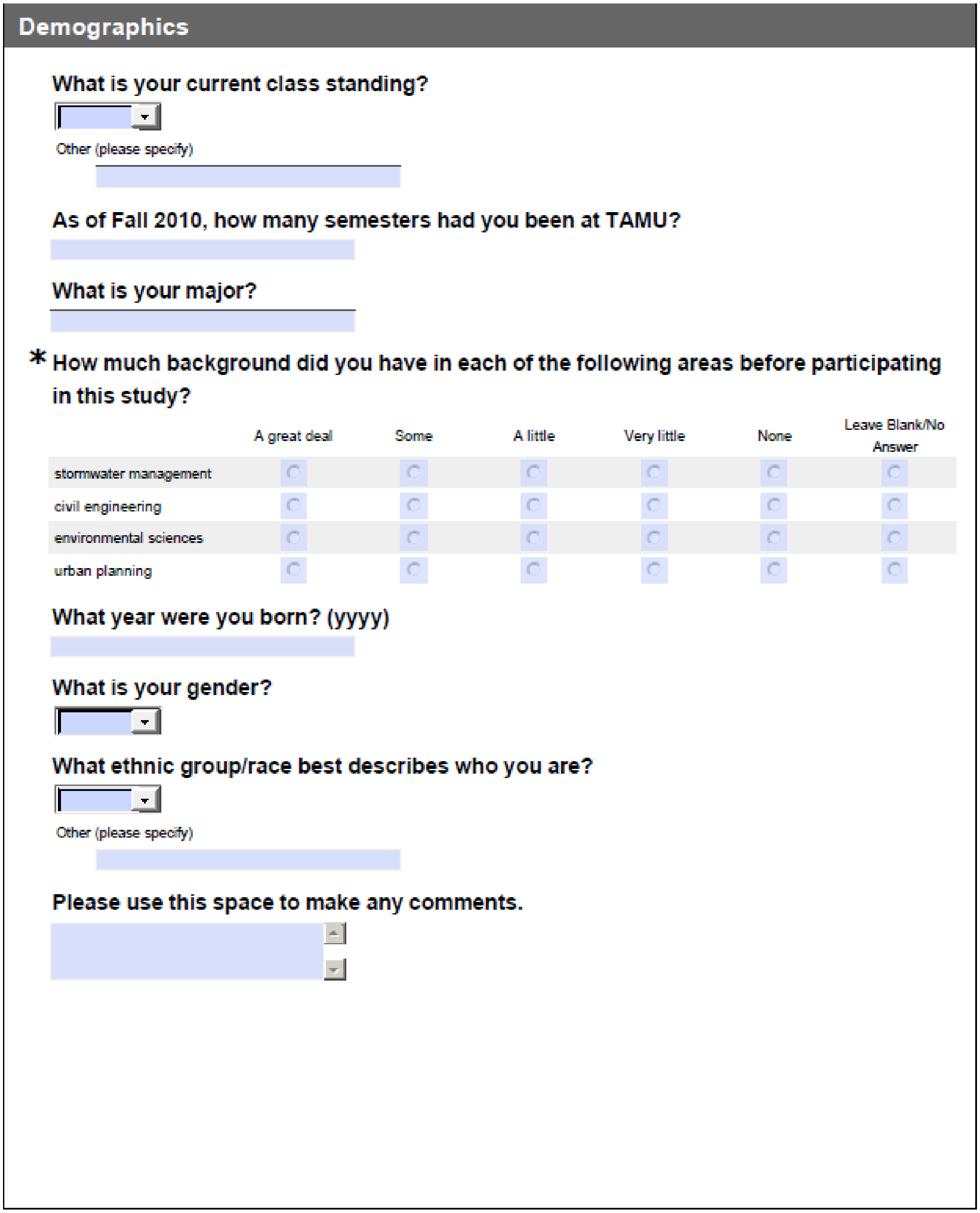
* How much do you agree or disagree with the following statements?

	Strongly agree	Agree	Somewhat agree	Somewhat disagree	Disagree	Strongly disagree	Leave Blank/No Answer
Green spaces raise the value of my neighborhood.							
In my neighborhood, the growth of new businesses is more important than having green space.							
Environmental protection reduces economic development.							
My city government needs to invest more tax dollars in the maintenance of stormwater management.							
Private property rights must always trump conservation efforts.							
Green spaces are best served by environmentalists and business leaders working together.							
My choices about where I live can affect flooding in my community.							
I am likely to tell my friends about low impact development.							
Changes I make to my home to make it greener have little effect on flooding in my community.							
I am likely to vote for political candidates who support low impact development.							
I will tell my co-workers about how low impact development can help our community.							
The decisions my community makes about building influence flooding.							
Controlling flooding is a personal responsibility.							
Controlling flooding is a responsibility of the government.							
I am likely to install rain capture devices at my home.							
I am likely to install a green roof at my home.							
I am likely to try to use some flooding friendly technology at my home.							
I am likely to advocate with my local government for flooding friendly technologies.							

* After a rainstorm of 4.4 inches in your community, the amount of land that is flooded for one hour is 200 acres. A new apartment complex is built in your community, and now the amount of land that is flooded for one hour is increased after a rainstorm of 4.4 inches is increased. Rate each flooding condition below.

	No big deal	Could cause problems	Very big problem	I don't know	Leave Blank/No Answer
202 acres					
210 acres					
220 acres					
250 acres					
300 acres					
400 acres					

Figure 24: Page 2 of the HFR version of survey



Demographics

What is your current class standing?

Other (please specify)

As of Fall 2010, how many semesters had you been at TAMU?

What is your major?

* How much background did you have in each of the following areas before participating in this study?

	A great deal	Some	A little	Very little	None	Leave Blank/No Answer
stormwater management						
civil engineering						
environmental sciences						
urban planning						

What year were you born? (yyyy)

What is your gender?

What ethnic group/race best describes who you are?

Other (please specify)

Please use this space to make any comments.

Figure 25: Page 3 of survey

VITA

Name: Tommi Jo Grace Scott

Address: Department of Civil Engineering
3136 TAMU
WERC 205R
College Station, TX 77843

Email Address: tjgscott1@gmail.com

Education: B.S. Civil Engineering, Texas A&M University, 2009
M.S. Civil Engineering, Texas A&M University, 2011