Examination of Low Impact Development Design Strategies Applied to a Fictitious Land Development in Harris County, TX

Presented to the Department of Civil Engineering Faculty at the University of Houston in Partial Fulfillment of the Requirements for Master of Science in Civil Engineering

By:

Gareth J Young

December 2003

Examination of Low Impact Development Design Strategies Applied to a Fictitious Land Development in Harris County, TX

Gareth J Young

Project Advisor
Theodore G. Cleveland, Ph.D., P.E.
Associate Professor
Environmental Engineering Graduate Program Director
Department of Civil and Environmental Engineering

Jerry Rogers, Ph.D., P.E.
Associate Professor
Department of Civil and Environmental Engineering

Kye Han, Ph.D.
Associate Professor
Civil Engineering Graduate Program Director
Department of Civil and Environmental Engineering

Acknowledgements

I wish to express my sincere appreciation to the entire faculty and staff of the University of Houston's Department of Civil and Environmental Engineering who have made continuing my education both enlightening and enjoyable. I would especially like to recognize Dr. Ted Cleveland whose guidance and support have not only made this project possible, but also indeed guided my academic progress at the University. I would also like to express my gratitude to Dr. Jerry Rogers for taking the time to evaluate and critique this project. Dr. Han and Dr. Wang, who have supported my academic career by facilitating my transition between academic programs, also have my gratitude.

I would also like to thank several people at the firm of Walter P. Moore and Associates. I would like to especially thank Mr. Ted Vuong for making the collaboration possible. Special thanks also goes to Mr. Charles Penland, Principle, and Mr. David Finklea for taking time out of their busy schedule to meet with me on several occasions to discuss the possibility of a collaborative effort. Ms. Patricia Fraye also took time out of her schedule to provide guidance. It is deeply regrettable that a more collaborative effort was not possible, however, I sincerely appreciate the time and effort from everyone at Walter P Moore and I feel that the knowledge regarding real world engineering practices is invaluable.

Finally, I would like to express my deepest thanks to my family and friends for their love and support during my studies at the University. I would like to especially thank my fiancée, Tricia, whose support made the entire enterprise possible.

Table of Contents

List of Figures

List of Tables

1. Introduction to Low Impact Development

1.1 Introduction

Harris County, Texas, is a rapidly growing community that is experiencing rapid urbanization. This urbanization is significantly altering the hydrology of the watershed that the development occupies as well as the downstream watersheds. These effects are wide ranging, affecting both the quality and quantity of the stormwater runoff from the developed area.

Stormwater engineering practices have generally treated runoff as a nuisance that should be conveyed from the developed area as quickly and efficiently as possible. This philosophy resulted in massive changes to the hydrology of the receiving waters. As the amount of impervious area in the developed area is increased, the quantity of stormwater runoff from that area increases. Similarly when natural vegetation is replaced during development the surface roughness of the area is decreased. Decreased surface roughness results in faster translation of the stormwater. This effect is intensified with the introduction of traditional structural controls such as rain gutters and storm sewers. The net effect is a significant increase of the total quantity of runoff as well as a decrease in the amount of time it takes for this runoff to reach the receiving body. The combined effect of numerous developments within the same watershed result in a dramatic change to the flow characteristics of the stream during wet weather events.

The massive flooding that occurred in the Houston area in June of 2001as a result of Tropical Storm Allison illustrated the impacts of this extensive urbanization. Engineering practices could not have practically designed stormwater facilities to meet the massive deluge Tropical Storm Allison delivered that included local rainfall amounts of up to 16 inches per hour. The resulting flooding resulted in damage to over 700,000 homes, 22 lost lives, and $5 billion in economic damage. The huge scale of flooding in areas that had never previously flooded demonstrated the flaws in the philosophy of existing stormwater management techniques.

Recent approaches to stormwater management have been to decrease the effects of runoff conveyed to the receiving stream. Mitigation of urban development has typically been accomplished using stormwater detention facilities. Detention attempts to slow the rate that runoff from an area is delivered to the receiving stream. This delay is accomplished through the use of ponds to temporarily detain the stormwater and release it at a controlled rate. The rate at which the stormwater is released attempts to reflect the predevelopment runoff rate. Currently in Harris County, developments greater than a certain size are required to install stormwater detention facilities.

Stormwater detention increases the length of time that a given volume of water is discharged and thus the peak discharge rate. However, detention practices do nothing to control the quantity of excess runoff generated. Similarly, detention facilities do little to improve the quality of the stormwater. Similarly, conventional detention techniques treat stormwater on a site specific basis that ignores the cumulative impacts of stormwater management.

It has also been shown that traditional stormwater detention facilities may actually aversely affect the quality of the stormwater runoff. Some of these impacts include increased water temperature, groundwater contamination, and may increase the effects of stream erosion. (Clar, 8). Also, detention facilities tend to incur significant maintenance costs. Even though detention facilities do decrease the effects of the development on the rate of discharge, they rarely replicate the predevelopment hydrology resulting in a de facto alteration of the watershed.

More recent land development techniques have attempted to negate the effects of development on the hydrologic characteristics of an area. This approach, known as Low Impact Development, attempts to reproduce the predevelopment characteristics of an area. A major distinguishing feature of low impact development with traditional stormwater techniques is the use of decentralized, smaller facilities to mitigate the effects of development. This is in contract to traditional methods that convey stormwater to a central area to be stored and possibly treated.

1.2 Effects of Urbanization on Urban Watersheds

It is generally accepted that urbanization significantly affects the stormwater runoff characteristics. These changes arise from the increase in the amount of impervious area. The impervious area restricts abstraction of rainfall into the soil, resulting in an increase in the amount of runoff from a given rainfall. Increasing the amount of impervious area also has the effect of decreasing the surface roughness. The decreased surface roughness results in higher flow velocities, as there is less resistance to the flow.

The Harris County Flood Control District and the City of Houston began monitoring and documenting the magnitude and frequency of floods and monitoring the effects of urban development in a project known as the Houston Urban Runoff Program (HURP). A study by the United States Geological Survey in cooperation with the Harris County Flood Control District and the City of Houston examined the data collected in the HURP program and attempted to predict the effects of urbanization on stormwater runoff characteristics specifically for the Houston region.

The joint study examined effects of change on nine runoff characteristics. Three of the characteristics examined defined the magnitude of the stormwater runoff, including peak flow, peak yield, and direct runoff. The remaining six characteristics examined the durations of the storm hydrograph and its shape. These factors included direct runoff duration, time to peak flow, duration of flow that exceeded fifty and seventy-five percent of the peak flow, time of regression of peak flow to base flow, and basin lag.

Linear regression analysis was performed to correlate a relation between these stormwater runoff characteristics and five different basin characteristics along with five different factors that characterized the rainfall event. These basin characteristics included watershed area, ground slope, soil type, basin development factor, and degree of urban development. Several rainfall characteristics were also included in the analysis.

The study found significant effects on the runoff characteristics in areas with significant urbanization. In comparison, little change in the runoff characteristics of areas with little to moderate urbanization was noted.

Studies conducted by Robert Pitt at the University of Alabama suggest that covering soils with impervious cover is not the only impact of urbanization on the infiltration capacity of the soil. Studies show that soil compaction associated with construction activities significantly degrade a soil's ability is infiltrate stormwater. Also, the reductions in the organic content of the surface layers of the soil due to site grading reduce overall evapotranspiration losses and increases overall runoff. Runoff is also increased by the replacement of native grasses with shallow rooted decorative grasses. Similar studies conducted by Roger Bannerman at the University of Wisconsin show that loam soils may take several decades to recover their infiltration capacity after compaction.

1.3 Stormwater Pollutants

Urbanization has a marked effect on not only the quantity of stormwater generated from a rainfall event but also the quality of the stormwater. The combination of large volumes of low quality runoff can have significant adverse effects effect on the receiving body. While a receiving body can assimilate a limited amount of pollutants without significant adverse effects, the result of large scale urbanization results in unacceptable degradation of the quality of the receiving body. As a result, it is necessary to control the quality of the runoff at the source. Several types of common stormwater pollutants and their effects follow.

<u>Sediments</u> Sediments are a natural feature of streams and rivers. The natural sediment load in streams is dependent on a number of factors including the topography of its watershed, surface cover, soils, and climate. The removal of vegetation during development can significantly increase the amount erosion resulting in a marked increase of sediment load. Excessive sediment can result in highly turbid waters. Increased turbidity results in reduced light transmission through the water column that in turn decreases the amount of growth from photosynthetic organisms. Increased turbidity can also have the effect of clogging fish and invertebrate gills. The reduction in both plant and animal productivity and diversity reduce the ecological value of the stream. The decreased ecological values of the stream along with the increase turbidity of the water also produce negative aesthetic value.

Another impact on the stream from increased sediment load is an increase in the rate of sedimentation. The clay soils that dominate the Houston area have a low permeability that can result in higher volumes of runoff and increased velocities. However, the relatively flat topography encourages siltation and sedimentation. This process is especially marked in areas where water velocities decrease such as where a stream discharges into a lake.

Nutrients Nutrients are compounds required by plants for growth. The basic macronutrients limiting plant growth are nitrogen and phosphorus. Nitrogen in the form of ammonia and nitrate and phosphorus in the form of orthophosphate are readily available for uptake by plants and algae. Some nutrients that are generally required only in very small doses by plants and can be a limiting factor in their growth are known as micronutrients. Examples of essential plant micronutrients are boron, copper, iron, manganese, molybdenum and zinc.

As nutrients tend to accumulate on impervious surfaces, runoff during and after a storm event can have very high nutrient loads (Harris County 2-2). Runoff that occurs from areas that are extensively and improperly fertilized areas can have extremely high nutrient loads. The increase in nutrients available to aquatic plants can have the undesirable effect of a massive increase in plant productivity and growth. This growth can result in increased eutrophication in downstream areas. Eutrophication is the excessive growth of both attached plants and plants and algae that are free to move with the water. Short term effects of excessive plant and algae growth include surface algal scum, water discoloration, foul odors, and possibly toxic releases. Eutrophication can have significant long term effects on a water body including decreased aesthetic and recreational value, interference with navigation, large diurnal variations in dissolved oxygen levels, creation of a sediment oxygen demand from decaying plant matter, and the eventual filling of lakes by dead and decaying vegetation (Thoman 385).

Oxygen Demand The dissolved oxygen concentration of a body of water is a major indicator of the health of the water body as well as a measure of its ability to sustain life. As organic matter is oxidized, the dissolved oxygen concentration of a water body decreases. This depletion of the dissolved oxygen concentration in a water column becomes more pronounced in slow moving streams or other water bodies with little mixing or flushing such as stagnant lakes or estuaries. As the solubility of oxygen in water is inversely proportional to temperature, oxygen demand is even more pronounced in the warm water that is typical in the Houston area for most of the year. An oxygen concentration of approximately 4 mg/L is considered a minimum for good ecological health of a warm water stream (Thomann 265).

The methods used to determine the amount of oxidizable matter in water are known as the biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The BOD test is performed by measuring the depletion of the oxygen concentration in a water sample under controlled conditions over a specified length of time, typically five days. This test predicts the amount of oxygen required by microorganisms and is widely used to measure water quality. The test to determine the COD of a water sample determines the total amount of oxidizable matter in a water sample. A powerful oxidizer, typically potassium dichromate, is added to a water sample and allowed to react with the organic matter as shown in the following unbalanced equation:

$$(C_aH_bO_c) + Cr_2O_7^{-2} + H^+ \text{ -----> } Cr^{+3} + CO_2 + H_2O$$

Generally the COD of a water sample is higher than the BOD of a water sample since only the organic matter that is capable of being oxidized by microorganisms is measured in the latter test (Wastewater Engineering, 81).

<u>Oil and Grease</u> The term oil and grease can refer to a wide variety of hydrocarbon based compounds. Some of these compounds may be toxic to aquatic life even a very low concentrations. The primary source of hydrocarbons in stormwater runoff is crankcase oil and other lubricating agents that have leaked from automobiles. Oil and grease concentrations are therefore highest in stormwater runoff from paring lots and streets. Residential land uses tend to generate less hydrocarbon contamination in stormwater with the exception of illegal dumping of used motor oils into storm sewers (Harris County 2-2).

An oily sheen on the surface is generally the first indication of the presence of hydrocarbons. Oil and grease may also be part of an emulsion with the water as a result of the high concentrations of detergents in some oils, particularly engine crankcase oil. As hydrocarbons have a higher affinity to sediment than water, they tend adsorb onto sediment particles and settle out of the water column.

<u>Heavy Metals</u> A wide variety of heavy metals may be present in stormwater. Most metals are toxic to organisms at concentrations above some threshold limit. Common metals found in stormwater include: zinc, copper, lead, and cadmium. (Wanielista, 111) A primary source of lead has historically been from leaded fuels and paints. With the phase out of

these substances, lead contamination has become less common. Heavy metal contamination tends to be particulate and therefore unavailable for bioaccumulation (Wanielista, 111). Metals also tend to adsorb onto sediment particles and are removed from the water column through settling.

Microorganisms Microbial contamination of urban stormwater runoff can include bacteria, viruses, and protozoa. Common bacteria in runoff are coliform, fecal coliform, and pathogenic bacteria such as *Salmonella* and *Clostridium* (Wanielista, 111). Bacteria concentrations in undiluted stormwater runoff from urban areas usually exceed the public health criteria for contact recreation. However, as the public health criteria is based on total bacteria concentrations and not just the concentrations of pathogenic bacteria, the true impact on public health and safety are uncertain. While almost all runoff exceeds the allowable concentration of bacteria, the problem is especially prominent in older and more intensely developed areas. Very high concentrations of bacteria are possible in runoff from areas that experience overflows from sanitary sewer. (Harris County 2-3) Also, areas that have high occurrences of leaky or improperly maintained septic systems, such as parts of Brazoria County, will also result in high bacteria concentrations in stormwater.

Floatables The term floatables is used to describe pollutants that are relatively large, decompose slowly, and float. Examples of floatables include plastics, paper, tires, glass containers, aluminum cans, lawn clippings, and a host f other forms of debris. Floatables are generally introduced as litter or as otherwise improperly disposed of litter. Apart from the aesthetic degradation that this form of pollution generates, floatables also present a physical danger to flora and fauna in the ecosystem through entanglement, ingestions, and habitat congestion. Similarly, floatables may pose a significant problem to constructed engineering controls by clogging or obstructing pipes, values, or other controls.

Other Toxic Compounds Many other types of pollutants may be present in urban stormwater runoff. These compounds may include pesticides, herbicides, and other manufactured organic compounds. These substances may be very soluble in water resulting in spreading of the compound as well as increasing the possibility of it entering the food chain. Generally, concentrations of these pollutants found in runoff from residential and commercial areas tend to be low. However, relatively little sampling of stormwater runoff is conducted from heavy industrial areas, typical of east Harris County. Areas such as this may be a large source of toxic compounds. Other sources include improperly used or disposed of pesticides, paint thinners, herbicides, and preservatives (Harris County 2-3)

1.4 Project Overview

A fictitious land development project will be presented. The development will be designed using both traditional stormwater management techniques as well as low impact development techniques. Both methods will comply with all City of Houston and Harris County Flood Control District design criteria for both stormwater quality and flood control. The resulting detention requirements for both flood control and stormwater quality improvement will be examined.

2. Development Site

2.1 Development

The site being developed is a fictitious satellite campus for the University of Houston. This campus is to be located on the north side of Houston inside of Houston city limits. The campus is to cover an area of approximately 360 acres and will include the following features:

- 60,000 square foot Library
- 750,000 square feet of classroom and laboratory space over two, two story buildings
- 100,000 square foot Administration Building (one two-story building)
- 3,000 square foot Physical Plant
- Parking for students and staff (12 acres primary/ 8 acres overflow)

The total area covered by buildings is 11.2 acres. Parking will cover 20 acres while sidewalks and entranceways will cover an additional 1 acre. Roads on the development will cover 1.5 acres.

2.2 Geographical Data

The North Campus will be located in North East Harris County and will be bounded by US Highway 59 on the west, Beltway 8 to the south, Bender Road to the north, and a Southern Pacific Railroad Line to the East. The approximate coordinates for the development site are 29°45' north and 95°15' west. The 7.5-minute quad outlining the area is shown in Figure 1.

As shown by the contours in Figure 1, the land development site has very little natural grade. There is a slight incline toward the northeast with a total difference in elevation of approximately 4 feet.

2.3 Land Use Data

The majority of the proposed development site is undeveloped lightly forested land. A business occupies a very small fraction of the property on the US 59 frontage road. Due to the relatively small size of this business, it will not be considered during the analysis.

A pipeline easement exists on the property that runs approximately north to south along the west side of the property. This area must be taken into consideration during the development phase in order to allow for maintenance access. Also, Harris County Flood Control District ditches run east to west along the north side of the proposed development as well as north to south along the east side of the property. An aerial photograph of the proposed development site is provided in Figure 2.

2.4 Soils

The area of the proposed development is dominated by Atasco soil. According to the NRCS Official Series Description, "The Atasco series consists of deep, moderately well drained, very slowly permeable soils on Coastal Plains. Atasco soils occupy nearly level to gently sloping convex ridges. Slope gradients are typically 1 through 5 percent, but range to 8 percent. The soil formed in thick beds of unconsolidated sediments of sandy clay loam and sandy clay of Pleistocene age. Moderately well drained; medium runoff; very slow permeability. The Atasco series was formerly included in the Acadia series." (NRCS OSD).

2.5 Pre-development Hydrology

2.5.1 City of Houston Method

The first step in the site development is determining the pre-development hydrology of the proposed site. As outlined in the City of Houston Department of Public Works and Engineering Infrastructure Design Manual, the rainfall duration for the proposed site shall be no less than six hours. There are several definitions presented for the time of concentration concept. Wanielista defines the time of concentration as the length of time required for the runoff rate to reach equilibrium and equal the rainfall rate (Wanielista, 72). McCuen, on the other hand provides two definitions of the time of concentration. The first definition is based on the hydrograph of a storm event where the time of concentration is time difference in time between the end of the rainfall excess and the inflection point on the recession. The other and most popular definition is the length of time required for a discrete particle of water to travel hydraulically to the watershed outlet from the most distant point in the watershed (McCuen, 140). The value of the time of concentration that will be used in the City of Houston method is given in the City of Houston Design Manual and is presented in Equation 2.1

Equation 2.1

$$Tc = 10A^{0.1761}+15$$

Where: Tc= Time of Concentration (minutes)
A = Area (acres)

For the proposed development that covers an area of 360 acres; the calculated TC is approximately 43 minutes.

The rainfall intensity for a 100-yr frequency is given from the City of Houston Intensity-Duration Frequency (IDF) Curve that in turn is taken from Hydro 35/TP-40. The City of Houston IDF Curve is shown in Figure 2.3. The rainfall intensity may also be obtained from the Equation 2.2 given in the City of Houston Infrastructure Design Manual.

Equation 2.2

$$I = (d+Tc)^{-e}\, b$$

Where: I= Rainfall Intensity (in/hr)
Tc = Time of Concentration (min)
d,b,e = Constants based on Rainfall Frequency

The constants for a 100 year design frequency are 215.4, 21.8, and 0.75 for b, d, and e, respectively. Using the value for Tc obtained using equation 2.1, the design intensity for a 100 year storm is 5.5 inches of rainfall per hour.

The method for calculating the peak runoff for a stormwater system is known as the Rational Formula, otherwise known as Mulvaney's equation. This basic formula was first developed by T.J Mulvaney in *On the Use of Self-registering Rain and Flood Gage sin Making Observations of the Relations of Rainfall and Flood Discharges in a Given Catchment* published in 1851 (Linsey et al, 58). The City of Houston utilizes the Rational Formula for developments up to 600 acres in size. The Rational Formula is given in Equation 2.3.

Equation 2.3

$$Q = I\,(CA)$$

Where C = Watershed Coefficient
I = Rainfall Intensity (in/hr)
A = Area (acres)
Q = Flow (cubic feet per second)

The watershed coefficient is given in the City of Houston Infrastructure Design Manual for several different land use type. The coefficient for Open Areas is given as 0.18. Using the rainfall intensity calculated in Equation 2.2 of 5.5 in/hr and the given area of 360 acres, the calculated peak flow for the 100 year rainfall event is 356 cubic feet per second (cfs).

The Rational Formula is based on several assumptions.

1. The watershed area is constant
2. The Watershed Coefficient remains constant over the entire Tc
3. Rainfall intensity is constant over the Tc

It is generally accepted that these assumptions are generally valid for watersheds with fairly low Tc. Wanielista states that the Tc should be less than 20 minutes for the assumptions to hold (Wanielista, 72). However, from the results of Equation 2.1, the Tc for this study area is 44 minutes, greater than the allowable 20 minutes. As the value of Tc is directly proportional to the area, a further increase in area would result in an even greater value for the Tc. It then follows that using equation 2.1 from the COH design manual and Wanilestia's criteria for this equation to be valid, the Rational Formula would only be valid for watersheds with an area of less than one acre. This is a significant contradiction of the City's position that the Rational Formula is valid for areas up to 600 acres.

2.5.2 TR55 Method

A potential flaw with the City's method of calculating runoff is the method used to determine the time of concentration. As shown in Equation 2.1, the Tc and hence the resultant flow is based entirely on the development area. As a result, the pre- and post-development hydrographs will be identical without regard to the amount of impervious area added to the site. As a result of the pre- and post-development hydrographs being identical and hence n, there is no incentive for a developer to utilize low impact development methods as the volume of runoff that must be detained will not be impacted.

For purposes of this analysis, an alternate method for calculating the Tc will also be used. The alternate method factors in variables other than the area, it also incorporates the surface over which the runoff is flowing. The alternate method is given in the United States Department of Agriculture's Technical Release 55 published in 1986 entitled Urban Hydrology for Small Watersheds (TR55). This method is currently used by several Houston area consulting firms and will be used for runoff analysis. TR55 calculates the Tc by:

Equation 2.4

$$Tc = Tt_1 + Tt_2 + \dots Tt_m$$

Where: Tc = Time of Concentration (hr)
Tt = Travel Time
m = number of flow segments

The Travel time is given by:

Equation 2.5

$$Tt = L/3600V$$

Where: Tt = Travel Time
L = Flow Path Length (ft)
V = Average Flow Velocity (ft/sec)

From Figure 2.1, the longest flow path occurs from the highest elevation located on the southwest corner of the property to the lowest elevation at the northeast corner giving a total flow length of 5600 feet. The average flow velocity is given in TR55 as 1.15 ft/sec for grades less than 0.5%. The pre-development time of concentration calculated from the TR55 equation, noted as Tc_2, is 1.35 hours, or 81 minutes. The resultant intensity from Equation 2.2 decreases to 3.88 inches/hour. The pre-development runoff similarly decreases to 251 cfs. The flow calculated using the TR55 method calculates forty percent less flow for the same 100 year event.

Table 2.1 – Summary of Pre-development Hydrology

Method	Tc (min)	Intensity of 100yr Event (in/hr)	Flow (cfs)
COH	43	5.5	356
TR55	81	3.9	251

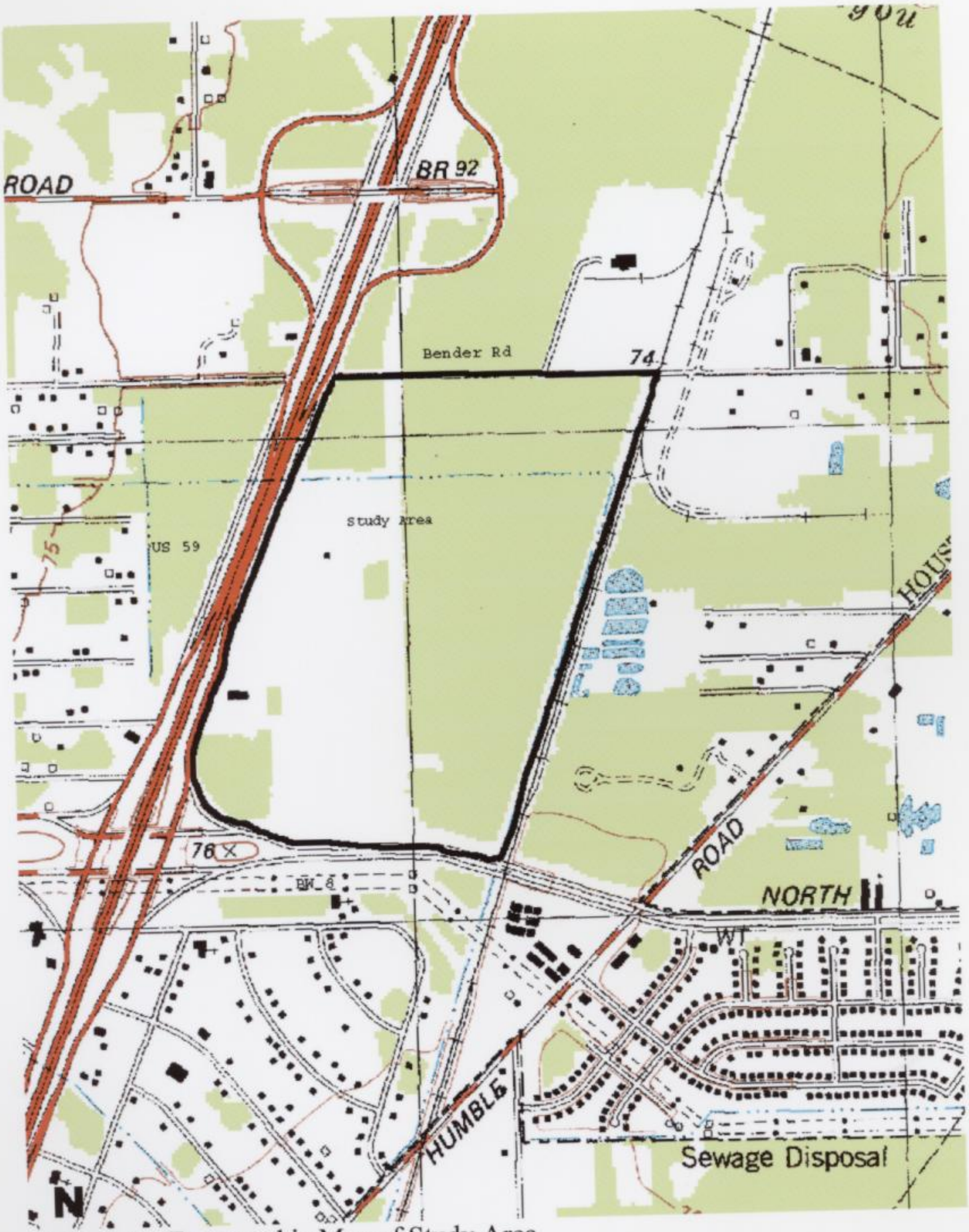

Figure 1 – Topographic Map of Study Area

Figure 2 – Aerial Map of Study Area

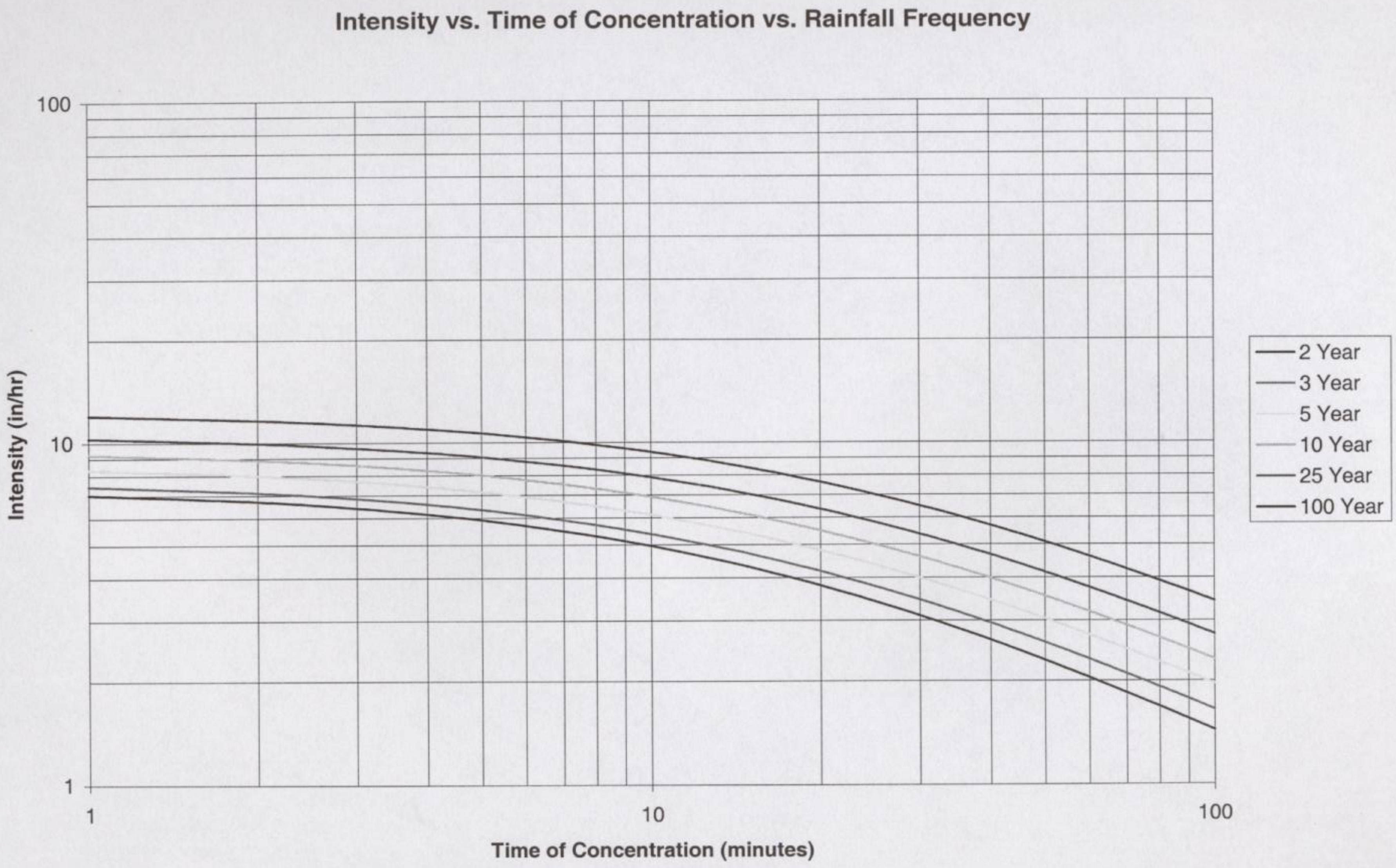

Figure 3 – City of Houston IDF Curves

3 Storm Water Quality Management Plan

3.1 Introduction

Any proposed development greater than five acres within the city limits of the City of Houston is required to submit a Storm Water Quality Management Plan (SWQMP). SWQMPs will propose structural, non-structural, and vegetative controls to ensure the water quality of stormwater runoff. This requirement is part of the city's Master Plan to meet the criteria of the National Pollutant Discharge Elimination System (NPDES). The city's Master Plan is actually titled the Proposed Comprehensive Master Plan for New Development and Significant Redevelopment in Harris County. The Harris County/Harris County Flood Control District Master Plan is applicable to unincorporated areas of the county and is titled the Proposed comprehensive Master Plan for New Development and Significant Redevelopment in Harris County (Unincorporated Areas).

The goal of the Master Plan and its associated regulations is to reduce to the Maximum Extent Practical (MEP) the discharge of pollutants in stormwater runoff. As such the goals of the SWQMP should seek the same goals as the Master Plan. An overview of requirements needed to complete a SWQMP as presented in the jointly published City of Houston/Harris County Storm Water Quality Guidance Manual will be presented.

3.2 SWQMP Requirements

The submitted SWQMP must contain a minimum amount of information to describe the site, the development, the engineering controls to be implemented, and the method by which the controls are to be inspected and maintained. The SWQMP should contain the entire mitigation plan to eliminate the potential impacts on stormwater runoff and the receiving body.

3.2.1 Site Description

The nature of the proposed development must be presented, including:

A. Site description including the precise location
B. Identification of the owners and responsible contact individual
C. The type of development or the nature of the redevelopment
D. Nature of the activities or business to be conducted on the site including the Standard Industrial Classification Code
E. Any existing NPDES storm water permits, applications, or notices of intent
F. Estimates of the total development area
G. Site maps to include:

1. A map of the vicinity of the development
2. Areas that will and will not be developed
3. Drainage areas, their acreage, and heir patterns
4. The grade of the land after the development is complete
5. Existing surface waters and wetlands
6. Identification of areas that may generate pollutants, including parking, loading areas, hazardous material storage areas, etc.
7. Identification and location of structural controls
8. Identification and location of non-structural controls
9. Locations where stormwater is to be discharged from the property.

3.2.2 Description of Controls

3.2.2.1 Structural Controls

Construction drawing should include all structural best management practices (BMPs). The operation of these BMPs should also be included. All supporting data including relevant calculations and specifications should be available for inspection.

3.2.2.2 Non-Structural Controls

Non-Structural control BMPs should similarly be presented on the submitted construction drawings. Descriptions of how these controls will be used should be submitted while supporting data and calculations should be available for inspection.

3.2.3 Inspections and Maintenance

Documentation outlining the means by which the control measures are to be inspected should be submitted along with acceptable reporting procedures. Similarly, requirements for maintenance of the engineering controls should be submitted. The parties responsible for conducting and overseeing the inspection and maintenance should be specified.

3.3 Preparation of the SWQMP

As the overall site plan must contain the planned provisions for stormwater quality, the SWQMP should be developed in the early stages of the proposed site development. However, preparation of the SWQMP is not possible until the preliminary site plan is complete. These seemingly conflicting requirements necessitate that the SWQMP be an integral part of the overall site plan, especially during the preliminary stages. This will insure that the best measures to protect stormwater quality are available. Measures to consider include

1. Minimization of the amount of land clearing and grading
2. Maximizing the use of native vegetation as a means to filter runoff
3. Minimizing disturbance of environmentally sensitive areas such as wetlands and areas with steep slopes
4. Incorporating the site's permanent BMPs with controls designed for the construction phase of the development
5. Minimize activities that will impact the quality of stormwater runoff

The actual basis for the minimization of the impact of the development of the quality of the stormwater will be both the structural and non-structural engineering controls.

Non-structural controls are defined as techniques or activities that will prevent or reduce the impact of the development on stormwater quality. The primary means of accomplishing this goal through non-structural controls in to minimize to the fullest extent possible the activities or practices that directly cause a detrimental impact to the quality of the stormwater. Non-structural controls can also be implemented by preventing contact between stormwater and the potentially harmful areas or activities. Non-structural controls are desirable as there is generally little cost associated with their implementation, operation, and maintenance.

Structural control BMPs are defined as constructed facilities or vegetative areas and practices specifically designed to reduce the impact of the development by reducing or eliminating pollutants in stormwater runoff. The most common stormwater pollutants are outlined in Section 1.3. The types of structural controls that are possible or practicable for a specific site are greatly dependant on the size f the development site. For example, vegetative controls may be acceptable or sites with a total area of les than 10 acres. For sites greater than 10 acres, vegetative controls may be incorporated into a more comprehensive set of structural controls.

The steps needed to successfully complete a SWQMP include:

1. Collection of pertinent site data
2. Development of a preliminary site map
3. Measurements of both the site area and the drainage area to determine the types of controls that are necessary.
4. Selection of appropriate structural and non-structural controls
5. Development of the final site plan
6. Preparation of a inspection and maintenance plan

A brief description of each phase of the development is presented.

3.3.1 Collection of Pertinent Site Data

Prior to making any decisions regarding the development, it is necessary to have all the information needed in order to make a well-informed choice. The first set of data should provide a through understanding of the existing conditions at the proposed development site. As such, a topographic map showing the predevelopment conditions at the site should be prepared. The map should include not only the existing activities at the site, but also any activities that may directly or indirectly impact the site. The map's scale should be appropriate in order to clearly resolve of significant features including but not limited to structural controls, swales, and existing impervious areas such as roads and buildings. All hydrologic features such as surface water ad wetlands should be clearly marked. At this time, determination of the locations of stormwater discharge points should be made.

3.3.2 Development of the Preliminary Site Map

The next phase in the preparation of the SWQMP is development of a preliminary site map. This may and probably should be revisited and the site map updated and revised and construction of the development progresses. Even as the site map is refined, it should retain its intent and the majority of its features.

The preliminary site map or maps should contain all of the features of the finished development. The proposed building outlines should be clearly defined as well as all of the impervious area. Any areas that have the potential of generating pollutants should be marked. Landscaping and areas should be noted along with areas that preserve the natural existing vegetation. The types and locations of drainage facilities should be noted including channels, ditches, pipes, and detention/retention basins as well as existing and proposed hydrological feature such as surface water and wetlands. Indicate the locations of outfalls and possible discharge locations. Also include any features or facilities to be implemented during construction of the site as part of the construction pollution prevention plan. These may include facilities such as sediment traps and sediment basins.

3.3.3 Site and Drainage Measurements

In order to predict the quantity of stormwater runoff generated, an accurate estimation of the area of the proposed development site should be made. An estimation of the drainage area that discharges to each discharge site will be necessary in a manner similar to watershed delineation. If the drainage area covers an area less than five acres, vegetative controls are acceptable. For drainage areas of greater than ten acres other structural controls are necessary to supplement or replace vegetative practices. Drainage areas that are between five and ten acres in area should be carefully examined on a case-by-case basis and a determination of the type of structural control made after detailed analysis.

3.3.4 Selection of Controls

The development site and drainage area should both be measured in order to determine both the minimum and most practical and desirable controls. The sources and locations of possible stormwater pollution identified in the previous step should be considered when determining what controls to implement. For certain types of developments, non-structural controls may be used in lieu of or supplementing structural controls. However, the site conditions should be very carefully evaluated prior top implementation of a BMP that only includes non-structural controls.

Bear in mind that many of these practices must be adapted or modified to meet the needs of the development site. Similarly, the following list of types of structural can non-structural controls is not exhaustive and constant innovation and improvement is made and indeed welcome with regard to storm water pollution management.

3.3.4.1 Examples of Common Structural Controls

A. Stormwater Quality Facilities
   1. Dry Basins
   2. Wet Basins
   3. Constructed Wetlands
   4. Other Site-Specific Alternatives

B. Catchment Facilities
   1. Catch Basins
   2. Oil/Grit Separators
   3. Other Site-Specific Alternatives

C. Vegetative Practices
   1. Vegetated Filter Strips
   2. Grassy Swales
   3. Other Site-Specific Alternatives

3.3.4.2 Examples of Common Non-Structural Controls

- Landscaping Practices
- Litter Control
- Fertilizer and Pesticide Use and Practices
- Hazardous Material Storage and Disposal
- Spill Prevention and Response
- Liquid Material Handling Practices
- Equipment Washing Practices
- Inlet Stenciling
- Other Site-Specific Alternatives

3.3.4.3 Selection of Structural Controls

As previously discussed, structural controls are facilities that are constructed to reduce or otherwise control pollutant levels on stormwater runoff. Structural controls may also include vegetative practices designed to reduce pollutant concentrations in stormwater runoff.

The necessary structural controls should have been previously estimated based on the area of the respective drainage areas. However, drainage area is but one of may factors that will ultimately determine the BMP most suitable for the site. Other relevant factors that need to be considered include soil type and permeability, vegetative cover and condition, land slope, the amount of impervious area, the type or types of pollutants expected, and other requirements for the facility specific to the site and area.

When planning structural controls, consideration should be given to the possible and probable need for stormwater detention in addition to stormwater quality facilities. It may be possible and desirable to combine the two necessary facilities into one dual-purpose facility. Specifications and design considerations for the various types of structural engineering controls and vegetative practices are available and should be consulted.

3.3.4.4 Selection of Non-Structural Controls

The use on Non-structural controls for the prevention of stormwater pollution prevention is attractive due to the general low cost is implementation and maintenance of the control. Care should be taken when planning to eliminate structural controls with non-structural controls. However any successful SWQMP will incorporate non-structural controls to the fullest extent practicable.

3.3.5 Development of the Final Site Plan

After both the structural and non-structural controls have been evaluated and the appropriate methods selected, prepare the final site map, The final site map should include all of the features of the preliminary site map in addition to the types and locations of any structural controls that are to be implemented. A narrative that details any non-structural controls that were selected for the site should be included. Incorporation of construction pollution prevention controls should also be included in the final site map where appropriate

3.3.6 Preparation of an Inspection and Maintenance Plan

Consideration of the long-term functionality of the structural controls requires that an inspection and maintenance program be established. Control measures will not perform the functions for which they were designed and implemented if not in proper working order. It is the direct responsibility of the owner of the controls to ensure that they be properly maintained.

A checklist that specifically details the needs of each of the structural controls be made and overseen by a responsible party. Similarly, an oversight and improvement plan of the non-structural controls should be implemented.

4. Low Impact Development

4.1 Introduction

Urbanization has a significant impact on both the quantity and the quality of stormwater runoff generated as a result on rainfall. In an attempt to reduce the impact of stormwater on the watershed and the environment as a whole, techniques have been developed to decrease the quantity of runoff while improving its quality. The previous chapter outlined conventional site planning for stormwater quality considerations in Harris County.

An alternate approach to site planning is to implement Low Impact Development techniques to all of the planning stages. Low impact development is defined as site design techniques that attempt to mimic pre-development runoff characteristics as well as replicating the natural hydrology of the area through methods that detain and retain or evaporate stormwater runoff. Low impact developments also reduce and compensate for the effect of the development on the environment by including pollution prevention measures. This is accomplished through the use of small, local, cost effective features.

LID emphasizes stormwater treatment at the source. This approach is in stark contrast to traditional techniques that place emphasis on end of pipe type technologies. The use of LID is also a sustainable technique meaning that it minimizes the effects on the environment. Several key considerations should be made when considering a Low Impact Development, including

1. Existing Site Development Regulations
2. Conservation of the pre-development Hydrologic Regime
3. Economic Restraints on Implementing LID techniques
4. Aesthetic Considerations
5. Ensuring Reasonable use of the Property
6. Safety and Legal Considerations
7. Time Restrictions

4.2 Low Impact Development Techniques

Many different means of designing a development using LID criteria are available. The following are some of the tools that are available to the engineer who desires to minimize the effects of the site development on the water resources of the environment:

1. Maximize opportunities for on site retention, detention, and storage.

2. Reduce impervious surfaces with special attention placed on the minimization of directly connected impervious surfaces.

3. Preserve areas that contain soils with high infiltration rates and selectively place impervious cover over soils with low infiltration rates.

4. Maximize flow path lengths.

5. Selectively grade the site in order to maintain the maximum amount of native vegetation.

6. Maximize the use of features such as grass filter strips, grassy swales, and biofilters.

7. Maximize surface roughness.

8. Encourage sheet flow as opposed to channeled flow.

9. Incorporate existing drainage paths and wetlands into design

10. Incorporate existing undisturbed vegetation into buffer strips.

11. Placing BMPs in areas with soils having higher permeability.

12. Replanting areas that must be graded with native vegetations.

A major hydrologic tool in developing sites utilizing LID strategies and techniques is through the use of the Soil Conservation Service Curve Number (CN). The CN is a means by which the amount of runoff from a given storm event is calculated. Developing a parcel of land generally results in an increase of the amount of runoff generated from a storm event and therefore an increase in the CN. One major goal of LID may be viewed as an overall attempt to reduce changes in the CN from its pre-development value to its post-development value.

Yet another vital tool in developing sites using LID techniques is the hydrologic concept of the Time of Concentration (Tc). The Tc is defined as the length of time required for runoff to travel from the most hydraulically distant point in the watershed to a point of interest within the watershed (TR55 3-1). As the amount of impervious area increases as a result of urbanization, the surface roughness of that area decreases. The decreased surface roughness results in faster flow velocities of the stormwater runoff. The faster flow velocities result in a decrease in the amount of time necessary for the runoff to reach the receiving body and thus a shortening of the time needed to reach a maximum flow rate. The goal of the engineer seeking to minimize the effects of a development on the receiving body should be to attempt to maximize the Tc.

4.3 LID Site Planning

The LID approach to site planning will be significantly different from traditional methods of handling stormwater runoff. While traditional approaches aim to remove stormwater from the development as quickly and efficiently as possible, the LID approach strives to mimic the pre-development hydrology of a site by incorporating small, cost effective controls throughout with the goal of controlling stormwater at its source. There are several concepts that while often overlooked, should be considered at every stage of the LID site planning. Included in these concepts are:

- Using site hydrology as the fundamental framework of the site development
- Micromanagement
- Controlling stormwater at its source
- Maximizing the use of simple, non-structural controls
- Creating multi-functional landscapes

These concepts should guide the engineer through each step of the design process. These fundamental concepts, while few and simple, can be easily overlooked. For example, the development engineer integrating site hydrology into framework of their site plan will begin by identifying hydrological sensitive areas such as wetlands, streams, steep slopes, permeable soils, and woodland conservation areas. By identifying the hydrological sensitive areas, the developer is then able to define a development envelope that results in the least impact on site hydrology. The development envelope is the total site area, both natural and manmade, that affects the hydrology of the area. The development envelope can then be incorporated into the overall site plan.

Similarly, another fundamental concept in a successful LID project is using the maximum amount of micromanagement tools practical. This requires a fundamental change in thinking as opposed to conventional site planning. Firstly, the site being developed should not be approach as a whole; rather it should be treated of microsubwatersheds. By subdividing the development as such, more flexible controls for managing stormwater are possible. This disaggregation also allows for distributed controls spread throughout the entire site.

Distributed controls lend themselves to controlling stormwater at its source rather than at a centralized location. As hydrologic controls are distributed across a given area in a natural system, it becomes difficult if not impossible to reproduce the site hydrology using centralized end of pipe type controls. Significant cost savings can also be realized by using distributed controls as size and therefore cost of conveyance systems increase with increasing distance.

Distributed controls offer several other advantages over traditional end of pipe controls. One such advantage is that one or even several individual controls can fail without significantly impacting the overall function of the system. Distributed controls may also be safer than traditional detention facilities as they tend to be shallower and have flatter slopes. Non-traditional controls, such as bioretention cells, also tend to be aesthetically pleasing.

The use of non-traditional controls like bio-retention cells, which are small areas with slight depression containing permeable soils and natural vegetation, are but one example of incorporating stormwater management into a multifunctional landscape. Every infrastructure and landscape feature has the potential of being multifunctional with incorporation of detention, retention, filtration, or runoff use.

4.4 LID Site Planning Process

Many of the steps taken in the process of planning a LID project will resemble the planning stages in developing a SWQMP discussed in Chapter 3. One fundamental difference is that the LID plan will incorporate methods for controlling both the quality and quantity of stormwater at each stage of the development. The steps outlined in this chapter are taken primarily from Prince George's County, Maryland Department of Environmental Resources' (DER) publication Low-Impact Development Design Strategies. The Prince George's County DER has fully embraced the concept of LID and is on the forefront of LID strategies. The following steps are guidelines by which an engineer developing a site using LID techniques should take.

4.4.1 Identify Applicable Regulations

Local regulations are designed and developed with the intention of establishing the safest and most desirable neighborhoods possible. The LID process must recognize that the development process must adhere to local planning and zoning ordinances. However, it is not uncommon to find local planning and zoning ordinances that are rigid and inflexible. As a result, localities that desire the most environmentally sensitive development possible must consider the adoption of more flexible planning and zoning regulations that encourage LID technologies.

Non-traditional zoning options may facilitate the incorporation of LID into new site developments. Examples of non-traditional zoning regulations could include:

- Overlay Districts – Method that provides additional regulatory standards to existing zoning regulations

- Performance Zoning - Flexible zoning technique that aims to preserve the existing site functions by providing general goals of zoning

- Impervious Overlay Zoning – Zoning technique where allowable layouts of proposed sub-divisions are determined by the total amount of impervious area

- Incentive Zoning – Allows compromise on zoning regulations in order to give the developer more flexibility in meeting the goals of the regulations thus allowing for greater environmental protection

- Watershed-Based Zoning – Incorporates a combination of several of the zoning options outlined above in order to maintain watershed carrying and quality guidelines.

4.4.2 Development Envelope Design

The development envelope is designed by identifying environmental and hydrologic sensitive areas. Once these areas are identified, the portion of the site that will in fact be developed is known as the development envelope. These areas might include areas where development is not allowed, such as: wetlands, easements, riparian areas such as streams, and required setbacks. The development envelope should also include areas where development is not desirable, such as: stream buffer zones, steep slopes, permeable soils, floodplains, woodland conservation areas and other areas with significant topographic features.

4.4.3 Reduction of Limits of Clearing and Grading

Minimization of grading and clearing is first undertaken in the development envelope design stage. The areas that are identified as outside of the development envelope will not be graded at all. Of course, some areas within the development area must be graded. It is at this step where the areas that will eventually contain impervious areas, such as buildings, roofs, sidewalks, roads, will be identified. As mentioned, these areas should be selectively placed over soils that are the least permeable. The amount of extraneous grading and clearing should also be kept to a minimum during the construction phase.

4.4.4 Site-Fingerprinting

Site fingerprinting is the technique by which each development site is examined individually in order to develop techniques to minimize the disturbances. The use of site fingerprinting can further reduce the amount of site clearing and grading that is required. Site fingerprinting also minimizes the impacts on the CN. Minimizations of land cover impact techniques include but are not limited to:

- Minimizing site construction easements
- Placing all construction materials within the development envelope
- Reducing paving and compaction of permeable soils
- Placing building layout and selectively clearing and grading in order to minimize the amount of disturbance to existing vegetation
- Reducing overall site imperviousness by minimizing paved areas
- Disconnecting the impervious areas deemed necessary
- Maintaining existing topography to the extent practical
- Maintaining natural drainage patterns

4.4.5 Incorporate Hydrology and Drainage into Site Design

A pre-development site hydrology study is a vital phase not only in a LID site development, but also indeed in any development at all. For LID sites in particular, it would be all but impossible to implement controls that will recreate pre-development hydrology if the pre-development hydrology is not fully understood. As mentioned, urbanization greatly increases the amount of impervious area within a watershed. This increase in the total amount of impervious area changes the hydrology of the watershed where a development is located.

Increased impervious area also significantly changes the CN for the area. If LID techniques are incorporated at this early stage of the site plan, the overall impact on the CN. For example, a hydrologic study of the planned development area may reveal optimized placement of both impervious areas such as buildings and roads, but also the ideal placement of BMPs.

The hydrologic study should not only seek to reduce the impact on the CN by reduction of the amount of impervious area, but should also seek to maximize the Tc. The main component in maximizing the Tc other than reduction in the total amount of impervious area is to ensure that the impervious area is not continuous. Increased impervious area reduces the surface roughness of the area. This decreased surface roughness results in faster flow velocities of stormwater runoff and hence a decrease in the amount of time a receiving body will be flowing at peak flow.

Attention paid to the spatial layout of the development will not only reduce the overall impact on the Tc value, but will also increase the overall aesthetic appeal of the development. As opposed to traditional controls that use pipes that may not be visible, LID technologies often incorporate techniques that are not independent of the surface topography. As such, placing special attention to factors that influence the natural hydrology, such as site topography, will result in more aesthetically appealing implementation of the LID controls.

A detailed analysis of the steps taken in performing the hydrologic analysis for a LID site development is given in Section 4.5

4.4.6 Reduction/Minimization of Total Impervious Area

Concurrent to or after the completion of the layout of the development envelope, the traffic distribution layout pattern should be performed. This task is performed at this early stage since the combination of roads, driveways, parking lots, and sidewalks generally make up the majority of the total impervious area. As such, minimizing the amount of area dedicated ton these activities will greatly reduce the overall site imperviousness which in turn will reduce the impact on watershed hydrology and groundwater recharge. Methods useful in decreasing the amount of impervious area generated by the transportation distribution system include the following.

4.4.6.1 Alternate Road Layout

Roadway layout can have a very significant effect on the amount of impervious area generated. For example, implementation of a cul-de-sac type residential roadway layout as opposed to a classic grid layout can reduce the total amount of impervious area by 26 percent (Low Impact Development Design Strategies 2-11).

4.4.6.2 Narrow Road Sections

Narrowing of roadway sections will have a significant effect on the total impervious area. For example, by using a rural layout pattern system that reduces the width of residential roads from 36 to 24 feet and by using grassy swales as opposed to curb and gutters, the amount of impervious area is decreased by 33 percent. (Low Impact Development Design Strategies 2-12). The use of swales (open ditches) instead of curb and gutters also significantly reduces construction costs, maintains or decreases the CN, while increasing the Tc.

4.4.6.3 Sidewalks

Given the width of sidewalks at four feet, placing sidewalks on only one side of primary roads san have a significant effect on the total amount of impervious area. Also, eliminating sidewalks altogether from all but primary roads can significantly reduce the total amount of impervious area.

4.4.6.4 Driveways

Driveways contribute a significant portion to the total impervious area of developments, especially residential subdivisions. Several techniques are available to minimize this contribution. For example, the utilization of shared driveways where practical would reduce the total impervious area of the development. Limiting driveway width to a sensible nine feet would reduce the impervious area of an individual lot. Similarly, examining and shortening building setback requirements in local zoning ordinances would reduce the needed length of driveways. The use of different materials such as gravel and pervious pavement would decrease the impact of driveways.

4.4.6.4 On-Street Parking

Restricting on street parking to one side of the street or altogether eliminating on street parking has the potential of reducing the necessary width of the roadway and therefore reduces the total impervious area by up to 30%. This strategy of eliminating parking on one side of the road should not have any significant impact in residential areas. Sufficient residential parking will still be available as studies have shown that allowing parking on both sides of the street accommodates up to 6.5 cars per lot, which is excessive parking area for most residential areas (Low Impact Development Design Strategies 2-11).

4.4.6.6 Rooftops

Buildings placed on the site will contribute to the overall site imperviousness. The area of the rooftop rather that the square footage of the building will determine that amount of impervious area contributed by the building. With this in mind, is apparent that vertical construction will contribute less to the impervious area than one-story buildings with the same total square footage. However, techniques such as conveying rooftop runoff into retention cisterns and technologies such as green roofs will significantly reduce the impact of rooftop imperviousness.

4.4.7 Develop an Integrated Preliminary Site Plan

After the development envelope has been delineated and the amount of impervious area minimized, a preliminary integrated site development plan should be generated. This plan will provide a foundation for comparing the pre- and post-development hydrology of the development site. Later comparison of the two hydrologic profiles will ensure that the overall goals of minimizing the effects of the development are being met.

4.4.8 Minimize Directly Connected Impervious Areas

While its is desirable to minimize the total amount of impervious area, any urbanized area will contain a significant proportion of impervious area. However, eliminating continuous impervious areas and encouraging sheet flow can minimize the effects of this. Disconnecting impervious areas can be accomplished by the use of he following techniques:

- Directing flows from impervious areas toward stabilized vegetated areas
- Directing rooftop runoff into retention cisterns or onto vegetated areas
- Encouraging sheet flow through vegetated areas with maximum surface roughness
- Directing flows from large impervious areas in several different directions.
- Locating impervious areas so that runoff flows to natural systems or toward soils with high infiltration rates.

4.4.9 Maximize Flow Time

As discussed previously in this chapter, the time of concentration (Tc) is defined as . The Tc a primary factor in the shape of the discharge hydrograph resulting from a rainfall event. Urbanization decreases the Tc and results in the receiving body flowing at peak discharge sooner after the beginning of rainfall. This combined with increase runoff resulting from increased impervious area increase possibility of flooding. Factors affecting the Tc include flow length, ground slope, surface roughness, and channel geometry. The factors that should be incorporated to maximize flow path lengths and increase the Tc are described below.

4.4.9.1 Maximizing Overland Sheet Flow

The distance that stormwater runoff should travel should be lengthened to the maximum extent possible in order to increase travel time and thus increase the Tc. By increasing the Tc, the peak discharge resulting from a rainfall event will be reduced. This can be accomplished by grading the areas within the development envelope in a manner that maximizes overland sheet flow. Special care should also be given to minimize channeling of flows. Techniques to minimize channeled flow include limiting the use of curbs and gutters and reducing the use of directing runoff directly into swales.

Attention should be paid to minimizing the velocity of stormwater runoff flows. By encouraging overland sheet flow as opposed to channeled flow, the velocity of the runoff will be greatly reduced. Minimizing flow velocities even with overland sheet flow is highly desirable in order to reduce the occurrence of soil erosion. The velocity of flows in feet per second in an open channel is given by Manning's Equation as shown in Equation 4.1 where:

Equation 4.1

$$V = (1.486/n)\, R^{2/3} S^{1/2}$$

Where: V = flow velocity (ft/sec)
n = Manning's Roughness Coefficient
R = Hydraulic Radius (flow area/flow perimeter)
S_f = Slope (ground or friction)

Velocities in the range of 2-5 feet per second are generally recommended as maximum flow rates for overland flow. The City of Houston Infrastructure Design Manual, for example, specifies flow velocities of no greater than 3 feet per second for areas without special erosion control measures installed.

Several methods of slowing flows are available. As seen in the Manning's equation (Equation 4.1), increasing the surface roughness will reduce the resultant velocity. Flows may be slowed by installing a device known as a level spreader along the leading edge of a vegetated buffer. A level spreader is simply a stormwater outlet designed to convert concentrated channeled flows to sheet flow. This is accomplished by increasing the area that the flow is distributed over. A natural device can also be used to slow flows down. Installation of a grassy strip approximately 30 feet wide on the upward slope of the buffer will both spread flows out while slowing them down. It is not necessary to allocate land strictly to the creation of this natural spreader, rather in may easily be incorporated into the buffer itself.

4.4.9.2 Maximize Flow Path

As the design engineer seeks to maximize the Tc, attention should be placed on the distance that runoff must flow prior to reaching a discharge. As seen in the Manning's equation (Equation 4.1), the slope plays an important role in determining the velocity. By lengthening the horizontal distance, and thus the flow length, for a given change in vertical distance, in other words minimizing the slope, the resultant velocity will decrease. Also, it logically follows that at a given velocity, increasing the distance traveled will result in arrival at the destination at a later time. This logical concept applies to routing runoff flow and may be accomplished by strategic lot grading. Also, installation of bioretention and biodetention facilities will increase the distance that stormwater runoff flows must travel.

4.4.9.3 Ground Slope

As presented in Manning's equation, ground or friction slope play an important role in determining the resultant velocity. As discussed in the previous section, it was shown that decreasing the ground slope slowed the velocity of runoff flowing across it.

Ground slope should also be considered when planning the layout of a development. For example, avoid placing impervious structures such as roads along depressions. Rather roads should be strategically placed along ridgelines in order to reduce the impact on infiltration. As not all roads can feasibly be placed along ridgelines, roads should attempt to follow the natural grade of the land. Placing roads along step slopes increases the disturbance to the soil, which results in greater potential for erosion. Also, placing roads perpendicular to the natural grade results in greater construction costs from ground cut and fill.

4.4.9.4 Open Swales

LID designs should encourage the use of open grassy swales as opposed to curb and gutter type collection systems. Open drainage systems are favorable over pipe systems as they allow for infiltration along their length as well have a much higher degree of surface roughness. The use of swales as a primary means of conveying surface runoff off of roads and between lots as opposed to more conventional systems should minimize flooding problems for the entire watershed. This is due to the increased infiltration and the increased Tc.

The grade within the open drainage system should be minimized for the same reasons that site grades should be minimized as discussed in the previous section. However, a minimum grade of 2% along the swale should be considered to minimize the possibility of localized flooding.

Other measures may also be placed in open drainage systems such as swales to further reduce the velocity of stormwater runoff and encourage infiltration. These features include structures such as terraces and infiltration basins. Increasing the amount of vegetation within the swale will also further reduce the velocity of the flows.

4.4.9.5 Site Vegetation

Maximizing the prevalence of natural vegetation is a means of maintaining the pre-development hydrology of the site. Vegetation affects the stormwater discharge from by increasing the surface roughness and thus decreasing the travel time, increases potential for infiltration, and reduces the potential for rainfall to become runoff. Any areas within the development envelope that are graded should be replanted with natural vegetation. Vegetated buffer areas should be connected to natural, undisturbed vegetated areas in order to maximize the potential for natural retention and detention. Connected vegetated areas also greatly increase the aesthetic value of a development.

The vegetation selected to replenish and replant areas that have been graded should not only be vegetation native to the area, but should also be selected by maintenance requirement. For example, different types of vegetation may be selected for a specific area by fertilizer and herbicide application needs or by which types of plants are more susceptible to drought conditions. For the Houston area, different types of native vegetation that will thrive under different conditions are given in Storm Water Quality Management Guidance Manual jointly published by the Harris County Flood Control District and the City of Houston.

4.4.10 Comparison of Pre- and Post-development Hydrology

The hydrologic analysis at this stage will ensure that the overall goal of mimicking the pre-development hydrology of the site has been accomplished. Care must be taken to follow all applicable regulations with regard to stormwater quality and quantity. As the calculations required by the local regulatory agencies may differ from the technique used in the LID site development, additional calculations may be necessary in order to meet permitting requirements. This comparison will also dictate if any other BMPs or Integrated Management Practices (IMPs) must be installed.

4.4.11 Complete LID Site Plan

Completion of the LID site plan will require several iterative steps to be taken. After examining the comparison between pre- and post-development hydrology, the need for additional IMP will be identified. Additional IMPs will be installed across the site development and then another hydrologic evaluation is to be made. This process is repeated until all both the local regulations have been met and the pre-development hydrology has been reproduced. As it is not always possible to meet all stormwater requirements using IMPs, traditional management practices such as detention ponds should be employed. This use of both traditional and LID IMPs is known as a hybrid system.

4.5 LID Hydrologic Analysis Steps

The steps described are to be used in determining both the pre-development and post-development hydrology of the proposed development. The results of these analyses will determine if the steps taken to reduce the impact of the development are sufficient. If not, further controls must be implemented and the post-devolvement analysis repeated until all applicable regulations are met and the LID goal of mimicking the pre-development hydrology is also met. The steps listed below are meant as a guide and should be modified to meet the needs of a specific development.

1. Delineation of the Watershed and Sudwatershed areas

The areas that are to be included in the analysis must be determined prior to any analysis being performed. For LID delineation, delineations of sub and microwatersheds within the development site should also be performed. This is important for the placement of the small cost effective controls that are vital in a LID project.

2. Determine Appropriate Design Storm

The design storm to be used for calculations of runoff is normally determined by local ordinances. These ordinances may impede the implementation of LID techniques. For example, conventional stormwater management dictates that runoff quantity control is generally based on not exceeding the pre-development rate for the 2 and 10-year storm events. These amounts are selected in order to protect receiving streams from sedimentation and erosion in the case of the 2 year event and to provide adequate stormwater conveyance on the case of the 10 year event.

In comparison the criteria used to select a design storm for a LID development should attempt to maintain the pre-development hydrologic conditions for the site. In other words, the goal of LID is to retain the same amount of rainfall within the development site as would have been retained if the development did not exist. The design storm is then calculated by determining the amount of precipitation required to initiate direct runoff, given by:

Equation 4.2

$$P = 0.2 * (1000/CN_c - 10)$$

Where: P = precipitation required to initiate direct runoff
CN_c = Composite Curve Number

The value obtained in equation in Equation 4.2 is then multiplied by a factor of 1.5 to account for changes in the Tc value associated with the development.

3. Determine Modeling Technique to be Employed

Several different modeling techniques are available to the development engineer attempting to simulate the rainfall-runoff process. The model to be used is generally specified by local ordinances. For example, the rational formula is specified by the City of Houston for predicting flow. However there are many other models available that are capable of providing the engineer a more through analysis including: the Storm Water Management Model (SWMM), Hydrologic Simulation Program – FORTRAN (HSPF), HEC-1, and TR-55/TR-20.

4. Compile Information

All the data required to perform the analysis should be compiled. This data should include, but is not limited to: area, grade, soil types, existing imperviousness, and land use data.

5. Evaluate Pre-development Conditions and Develop Baseline

The results of the model selected are applied to the pre-development condition. This flow is then used to as a baseline value by which the post-development value is compared.

6. Evaluate Site Planning Benefits

The site planning tools described in detail in Section 4.4 provide the first level of mitigation against the impacts of site development. The post-development hydrology is then compared to the baseline and the need for additional controls are determined.

7. Evaluate IMPs

If possible, all additional controls that were deemed necessary after examining the site benefits will take the form of IMPs. The implementation of IMPs reflects a second means of mitigation, after proper site planning. Appropriate IMPs are determined and implemented. Another evaluation of the effectiveness of the IMPs is then conducted. The next iteration of determining whether additional IMPs are necessary is then performed. This iterative routine is repeated until the baseline hydrology is reproduced or no more IMPs are practical. A detailed description of different IMPs and methods of selecting appropriate IMPs is given in Section 4.6.

8. Evaluate Additional Needs

Many times, the implementation of site planning and IMPs will not be sufficient to meet the LID goal of reproducing the pre-development hydrology. Similarly, site planning and IMPs may not be sufficient to meet the regulations laid out by local ordinances. In this case, additional controls must be implemented. These additional controls often are traditional end-of pipe type controls such as large detention ponds or constructed wetlands. Often times these traditional techniques will be much smaller and more cost effective than if the same controls had been implemented without the use of LID.

4.6 Integrated Management Practices

One of the fundamental concepts of LID site development is the use of small, cost effective controls that are distributed across the development site. This is in stark opposition to traditional methods that concentrate stormwater runoff toward a few large controls, such as detention ponds. It has been shown how various site design techniques can be used to minimize the hydrologic effects of the development on the watershed. Utilizing such practices, while minimizing these effects, will rarely be enough to completely mitigate the effects of the development. As a result, further controls must generally be incorporated into the overall site plan. The engineer utilizing LID techniques must then determine what Integrated Management Practices (IMPs) are to be used in order to meet local regulations as well as the LID goal of reproducing pre-development hydrology and how they are to be employed.

4.6.1 Steps in implementing IMPs

1. Establish Hydraulic Controls Required

During the hydrologic analysis performed in the previous section, the total amount of runoff that was not controlled by site planning practices was determined. The magnitude of the volumes of runoff will be the primary indicator of the types and number of IMPs that will be necessary to mimic the pre-development baseline hydrology.

2. Evaluate Site Specific Opportunities and Constraints

Factors unique to area where the development site will determine which IMPs are most practical and most desirable. These may not be the same for two developments in the same local area, let alone developments in different region or parts of the country. As a result, the IMPs to be established will be unique to each site. Site characteristics that will determine what IMPs are most suited to it include soil type and permeability, land cover, maintenance requirements, available space, the depth of the water table, and the distance to the foundations of buildings.

3. Determine Candidate IMPs

Once site-specific opportunities and constraints are examined, IMPs that are deemed infeasible or impractical are eliminated from further consideration. It bears repeating that an overriding principle of LID is selection of small, cost-effective management practices. It is also important to realize that LID IMPs should not simply be selected from a list of possibilities, rather they should be tailored to fit ach individual development. LID stormwater management should remain an integral part of each step of the overall site development process.

4. Evaluate Candidate IMPs

After candidate IMPs have been identified, each individual candidate should be closely examined as to their potential placement on the site. After each of the candidate IMPs has been placed, the hydrologic control objectives should be reexamined as outlined in the previous section. Rarely will the first attempt at IMP placement meet the hydrologic control objectives. Rather, the first design attempt will tend to over or underestimate the amount of runoff to be controlled. Therefore, several iterations of IMP placement may be necessary before the final configuration is determined.

5. Select Preferred Design

Typically the iterative process described in Step 4 will identify the number of IMPs needed and layout several potential layouts. The final configuration must then be determined taking such factors as site aesthetics, space limitations, and construction and maintenance costs into account. The final configuration of IMPs should then provide the best compromise between functionality, aesthetics, and cost.

6. Supplement with Conventional Controls

Many times, the implementation of site planning and IMPs will not be sufficient to meet the LID goal of reproducing the pre-development hydrology. More often, site planning and IMPs may not be sufficient to meet the regulations for matching pre-development hydrologic characteristics that are laid out by local ordinances. In this case, additional controls must be implemented. These additional controls often are traditional end-of pipe type controls such as large detention ponds or constructed wetlands. Often times these traditional technologies will be much smaller and more cost effective than if the same controls had been implemented without the use of LID.

4.6.2 Common LID Integrated Management Practices (IMPs)

As mentioned, LID IMPs should focus on micromanagement of stormwater runoff. If the site planning process is correctly conducted, the volumes of stormwater runoff that each IMP must handle will be minimized. The IMPs should integrate the lot hydrology with the surrounding environment including existing riparian features. One challenge of implementing IMPs is the nature of IMPs themselves, that they should control not only the quantity of stormwater runoff, but should also significantly improve its quality as well. Some of the functions of IMPs include:

- Infiltration of runoff providing groundwater recharge
- Multi-Use Landscape Areas
- Pollutant removal
- Increased Aesthetic Value
- Runoff Retention
- Stormwater Detention

Several common IMPs will be presented along with considerations and limitations on their use.

4.6.2.1 Bioretention

Bioretention is the term used to describe stormwater treatment that uses conditioned planting soil beds and vegetation to treat stormwater runoff within a shallow depression. Bioretention is a practice originally developed by the Prince George's County DER during the 1990's. The bioretention concept was designed as an alternative to traditional BMPs by combining physical filtering, adsorption, and biological processes. Components of a bioretention system include a grassy pre-filter strip, a surface designed for shallow surface water ponding, a bioretention vegetation area, a soil zone, an underdrain, and an overflow structure.

Several considerations should be made prior to implementation of a bioretention system. For example, the ponding depth should generally be limited to six inches. The potting soil should be a permeable mix including sand, loamy sand, sandy loam, and should have maximum clay content of 10%. In areas where the permeability of the existing soil is less than 0.5 inches per hour, an underdrain should be installed. The depth of the area containing the potting soil should typically be about four feet with a covering of six inches of mature mulch covering the soil. Flow velocities into and out of the area should be limited to less than 0.5 feet per second in order to minimize the potential for erosion. Also, a minimum of three different species of native vegetation should be planted in the bioretention area. Maintenance needs requirements of the bioretention area will be comparable to any other landscaped area.

4.6.2.2 Dry Wells

Dry wells consist of a small pit filled with large diameter gravel such as pea gravel. The dry well is designed to function as an infiltration mechanism used to control runoff off of impervious areas such as rooftops. Dry wells are generally three to twelve feet deep and as wide as needed to retain the design discharge off of the neighboring impervious area. They are generally backfilled with homogenous gravel with a maximum diameter of three inches. Some sort of filter fabric generally surrounds the backfill. Also, An observation well consisting of 4 inch PVC must be included.

Dry wells are generally designed to discharge all of the runoff collected during a period not to exceed three days. As a result, they should be placed in permeable soils with infiltration rates of at least 0.5 inches per hour. Screens and oil and grit separators are generally placed upstream of the dry well in order to keep out undesirable material. Additional design guidance may be obtained from Maryland Standards and Specifications for Infiltration Practices (MDDNR, 1984).

4.6.2.3 Filter Strips

Filter strips are simply areas of dense vegetation, normally grasses, which are placed between impervious areas and receiving bodies or other IMPs such as bioretention areas. Generally filter strips are only considered as a single component in an integrated series of stormwater IMPs. Filter strips trap sediment and sediment bound pollutants, allow for infiltration, slow runoff velocities, and encourage overland sheet flow.

Filter strips should maintain a minimum slope of 1% to reduce chances of flooding on the upward side of the strip. A minimum length of 20 feet is generally recognized and should be increased depending on the volume of stormwater to be treated. Flows across filter strips should not exceed 3.5 cubic feet per second. The maximum drainage area flowing to a single filter strip is limited by the overland flow limit of 75 feet for pervious surfaces. Maintenance of filter strips is comparable to any other grassy area requiring mowing.

4.6.2.4 Vegetated Buffers

Vegetated buffers are similar to filter strips. They are strips of either natural or planted vegetation that surround environmentally sensitive areas. Vegetated buffers work in a similar manner to filter strips in that they trap sediment, allow for infiltration, slow runoff velocities, and encourage overland sheet flow. Design considerations for vegetated buffers are similar to filter strips.

4.6.2.5 Level Spreaders

A level spreader is designed to encourage overland sheet flow. Level spreaders are generally a trench that abuts to an impervious area filled with gravel or some other coarse material. The downstream side of the level spreader is at a uniform height. As runoff flows into the spreader at varying depths and velocities, it exits the downstream side as uniform shallow flow. Level spreaders prevent soil erosion by slowing flow velocities. They also discourage channel flow by spreading the runoff over a wide area. As the downstream lip of the level spreader must be completely level in order for the spreader to function, erosion resistant matting should be considered here depending on the flow rates expected.

Other measures that may be implemented to minimize erosion include stiff grass hedges, hardened structures downstream of the level spreader, and distributing flows into several, smaller level spreaders. The downstream side of the level spreader should have a uniform slope and should not be susceptible to erosion. This should include stabilized vegetated areas such as lawns. Directing outlet flow in this manner will further reduce the flow velocities and increase the Tc.

4.6.2.6 Grassy Swales

Modern grassy swales are designed to serve various hydraulic functions. Traditionally, grassy swales that merely served as stormwater conduits. Dry swales perform both water quality improvements while decreasing the quantity of stormwater by facilitating stormwater infiltration. Wet swales use the residence time of stormwater runoff and the growth of vegetation within the swale to improve stormwater quality and mitigate the quantity of runoff generated. It has been shown that swales surrounding paved areas reduce runoff from 30 percent to as much as 50 percent for swales with large gardens attached (Rushton, 16).

Swales should be designed to contain the flow specified by local ordinance. Generally, dry swales are preferred in areas having soils with permeability rates of at least 0.5 inches per hour. The bottom width of the swale should be between two and six feet with a maximum side slope of 3:1. Longitudinal slopes should be maintained between 1 and 6%. Flow velocities should be limited to 1 foot per second for water quality treatment purposes.

Maintenance of both dry and wet swales is similar to general landscape maintenance.

4.6.2.7 Rain Barrels

Rain barrels are designed to retain runoff from impervious surfaces, especially rooftops. They are simple to operate and maintain. Flow from downspouts is directed into the rain barrel where it is stored for later use. Rain barrels generally have a garden hose attachment near the bottom of the barrel that is connected to a drip irrigation system. Rain barrels should be equipped with some type of overflow device. The overflow device will make the rain barrel act as a detention device even after the designed retention volume is exceeded.

Rain barrels should be incorporate or hidden by landscaping in order to make them aesthetically pleasing. Screens should be placed over the gutters on the rooftop to eliminate debris from entering the rain barrel. The rain barrel should have a removable child-resistant top and a screen to exclude mosquitoes. The rooftop area should determine the size of the rain barrel needed.

4.6.2.8 Cisterns

Stormwater cisterns are similar to rain barrels in that they provide storage for runoff off of rooftops. Cisterns tend to be large containers and are generally buried underground. Stormwater is retained in the cistern for later irrigation use.

Cisterns should be placed in areas that allow easy routine maintenance. Runoff can be collected in small cisterns located at individual downspouts or may be collected in one large centralized cistern. The area of impervious rooftop determines total cistern volume.

4.6.2.9 Infiltration Trenches

An infiltration trench is a trench backfilled with large diameter gravel designed to allow stormwater to infiltrate into the soil. Stormwater runoff is diverted into the trench from impervious surfaces where it is allowed to percolate into the surrounding soil over a period of days. Infiltration trenches are generally preceded by either filter strips or vegetated buffers to remove fine sediment that may clog the gravel pore space. The use of such pretreatment greatly extends the useful life of the trench. Infiltration trenches are highly adaptable and are suitable for many different design configurations.

Infiltration trenches are preferred in permeable soils with infiltration rates in excess of 0.5 inches per hour. The trenches are generally three feet deep and are filled with homogenous material with an average diameter of less than 3 inches. Some sort of filter fabric generally surrounds the backfill. An observation well consisting of 4 inch PVC must be included.

4.6.2.10 Green Roof

Green roofs are vegetated coverings that are placed on the roof of a building. The surface of the roof is covered with a growing medium on which plants grow. Plant size and selection depends on the depth of the growing medium and local climate.

Green roofs can provide many benefits to the building on which they lie. Green roofs are aesthetically pleasing and reduce the amount of noise from exterior sources. The vegetation provides positive environmental impacts by eliminating carbon dioxide and particulate material from the atmosphere, eliminating nitrogen pollution from rain, and eliminating the effects of acid rain. Green roofs have also been shown to reduce the city heat island effect by absorbing solar radiation rather than reflecting it. Significant energy savings can be realized by incorporating green roofs including lower air condition expense in the summer and reduced heating cost in the winter. Green roofs may also lengthen roof life by two to three times.

The technology for green roofs has been pioneered in Germany. Between 1989 and 1999, German roofing companies installed nearly 350 million square feet of green roofs and the rate is increasing. Figures suggest that nearly 10% of German roofs are green. Little design data is available for green roofs and installation specifics are mostly proprietary. Performance data also tends to be largely subjective. In either case, little actual research information is currently available.

5. Conventional Site Design

5.1 Introduction

The conventional site design will incorporate the design requirements outlined in the City of Houston Infrastructure Design Manual and the Harris County Flood Control District's Stormwater Quality Management Regulations with the development techniques outlined in the McGraw Hill Land Development Handbook. A similar analysis will be performed using the TR55 method of estimating runoff. It should be noted that the criteria referenced are in effect at the time that this analysis was performed and does not reflect the updated criteria in the 2004 regulations. However, the conventional design still reflects current methodologies and technologies currently employed in land development.

Several aspects of the land development process will be examined. These aspects will include stormwater collection, water quality management, and flood control.

5.2 Regulations

As the development will reside within city limits, stormwater design must adhere to the guidelines detailed in the City of Houston Infrastructure Design manual. However, as the development is greater than 20 acres, the City design manual merely refers to the Harris County design criteria. Also, as stormwater runoff from the development area will make its way to the Harris County Flood Control District's ditch, the County requirements take precedent over the City's requirements. Existing developed land that is to be redeveloped requires additional stormwater management for only the areas that are made impervious that were once impervious. Conversely, the volumes of stormwater to be detained for both water quality improvement as well as flood control for new developments are based entirely on the total size of the development with the amount of total impervious area not considered in the calculations.

5.3 Stormwater Management

The county design manual offers and provides design specifications for several different BMP techniques that are acceptable for controlling stormwater quality, including: grassy swales, vegetated filter strips, dry detention, wet detention, and constructed wetlands. This development will utilize an inline dry detention for both water quality control as well as for flood control.

All of the other techniques were considered as part of the conventional design. Both the use of grassy swales and vegetated filter strips were eliminated due to the area of the development. The county design manual specifies that these BMPs are to be used only for developments less than ten acres or in conjunction with other BMPs. Wet detention was eliminated as a stormwater quality improvement technique due to maintenance requirements. Constructed wetlands were also eliminated due to both significant construction and maintenance costs.

5.3.1 Collection System

The development utilizes conventional curbs and gutters to convey stormwater to the detention basin. The curbs and gutters comply with county design requirements. The two year design storm is used to calculate the flow for the design of the storm sewers with resulting flow velocities between two and eight feet per second with velocities never exceeding twelve feet per second. Manholes are to be located at changes in sewer pipe diameter or cross section, changes in grade, street intersections, and inlet leads and conduit intersections. If none of these conditions exist, manholes will be placed at a minimum spacing of 700 feet.

Inlets to the storm sewer are placed at low points along the gutter. Inlets must also be placed at the end of the tracts of pavement. Otherwise, inlet spacing is a function of the grade of the gutter. As the development site has very little natural grade, the maximum spacing of inlets in possible. Inlets are placed at a spacing of 400 feet, the maximum allowable for a commercial development, with no more than 600 feet of pavement draining into a single inlet. The type of inlet used will depend on both its location as well as the design inflow.

Connections to the inlets are placed at the back of the inlet. Storm sewer leads will be at least 24 inches in diameter with no storm sewer pipe lowing into a pipe of smaller area. All inlet leads and storm sewers will be laid in straight lines according to City design requirements.

5.3.2 Stormwater Quality

The stormwater quality management plan (SWQMP) must adhere to the guidelines detailed in Chapter 3. As discussed, SWQMPs propose structural, non-structural, and vegetative controls to ensure the water quality of stormwater runoff. Necessary components such as site descriptions, location, and activities have been previously discussed and will not be reexamined here. Rather, structural and non-structural controls required to control the quality of the stormwater runoff will detailed.

As the amount of stormwater that must be treated for quality purposes in mandated, non-structural controls will not be utilized in the development of this site. Rather, if the final occupant desires, they may implement non-structural controls, such as fertilizer application practices, as they see fit. Theses practices, if implemented, will further improve the overall quality of the stormwater runoff.

The SWQMP will emphasize the use of structural controls. Specifically, a dry detention basin immediately adjacent to the flood control detention basin will be used to detain and treat the first 0.5 inch of runoff. The stormwater quality detention pond (SWQDP) will have a total volume of 65,340 cubic feet. The dimensions of the flood control detention basin will determine the SWQDP dimensions. Stormwater runoff will be collected by the storm sewer system and discharged to the SWQDB. Runoff in excess of the required 0.5 inch will be diverted to the flood control detention basin by means of an overflow weir.

5.3.3 Stormwater Detention

Two methods for determining the amount of stormwater detention for flood control will be examined. The method outlined in the City of Houston/Harris County design manuals specifies the amount of detention based entirely on the area of the development. This method does not lend itself for comparison with Low Impact Development techniques, as the amount of detention required will be the same regardless of the land development practice used. As a result, the detention requirements based upon the TR55 method will be used for analysis while the City of Houston/Harris County method is shown for comparative purposes.

5.3.3.1 City of Houston (COH) / Harris County Method

As stated in the Harris County Design Manual, regardless of the amount of impervious area added to a development site, the detention requirements are based entirely on the area being developed. The COH/Harris County requirements for detention specify 0.65 acre-ft of flood control detention per acre of development. For the 360 acre development being proposed, these requirements specify 234 acre-feet of stormwater detention. The design requirements specify side slopes no greater than 3:1 (V:H) with the length of the detention pond being three times its width. These requirements result in a trapezoidal pond 453 feet wide at its base, 543 feet wide at the crest, 1391 feet long, and 15 feet deep at capacity. This results in a relatively deep pond over 17 acres in area.

Due to the depth of the detention facility, it would be difficult to utilize this area for purposes other than stormwater detention. A shallow pond covering a larger area could be utilized for other purposes such as recreation during dry weather conditions.

A small detention facility large enough to accommodate frequent 2 year rainfall events will be placed within the larger 100 year detention facility. This will prevent shallow flooding of the entire area during frequent rainfall events that would prohibit other uses. The post development two year event runoff is calculated using the COH method of calculating rainfall intensity. Using the 43 minute Tc calculated in Equation 2.1, the intensity of a two year event is calculated by Equation 2.2 with the coefficients of b, d, and e, being 75.01, 16.2, and 0.8315, respectively. The resulting two year intensity is then calculated as 2.5 inches per hour. Using a Rational Formula coefficient of 0.65, the resulting flow is 585 cfs. As shown in Table 5.2, the two year event requires a flood detention volume of 24.63 acre-ft.

Keeping the COH criteria in mind, the dimensions of the two year trapezoidal flood control basin result pond 260 feet wide at its base, 290 feet wide at the crest, 780 feet long, 5 feet deep, with 3:1 side slopes. This reduces the larger detention pond to 209 acre-feet. Utilizing shallower side slopes and a depth of only 5 feet, the resulting pond is 772 feet wide at its base, 800 feet wide at the crest, and 2317 feet long. Despite having a larger area, the shallower depth and shallower side slopes will facilitate other uses of the basin during dry weather, such as sport and recreation. The addition of the smaller pond will further promote alternate uses by keeping the larger area dry for the vast majority of time.

The Harris County design manual specifies that the detention facility should completely drain within 24 to 48 hours after the rain event. An appropriate outflow device must be installed in order to meet these requirements. Sizing the outflow device is performed using the equation given in the Harris County design manual, given in Equation 5.1:

Equation 5.1

$$Q = CA\sqrt{2gh}$$

Where: Q = Outfall Flow (cfs)
A = Outfall Pipe Area (sq. ft)
g = gravitational constant
h = head/water surface differential
$C = 0.8$

A flow rate sufficient to completely drain the detention pond from capacity in 36 hours is used. The outfall pipe will be located close to the receiving water surface, so the minimum value of 2 feet that is allowable for h is used. At capacity, the pond contains 234 acre-ft of water, requiring a discharge rate of 78.7 cfs. These values result in a discharge pipe with an area of 8.67 square feet, equivalent to a pipe diameter of approximately 40 inches. Using the closest commercially available pipe diameter of 36 inches, the discharge rate becomes 64.17 cfs. At this rate, the pond will completely drain from capacity in approximately 45 hours, which is acceptable.

5.3.3.2 TR55 Method

As discussed in Chapter 2, the method of calculating the Tc using the TR55 method is a function of the composite travel times, Tt. The maximum flow path for the post development site will be divided into three segments, overland sheet flow, sheet flow across paved surfaces such as streets and parking lots, and pipe flow. The length of each of these segments is 300, 400, and 4900 feet, respectively. The average velocity for each of these flow regimes is given in TR55 as 1.15 ft/sec for unpaved surfaces, 1.41 ft/sec for paved surfaces, and between 3 and twelve feet per second for pipe flow. As specified in the City design manual, velocities should be in the range of 2 to 8 ft/sec. An average value of 5 ft/sec for pipe flow is used for the purposes of analysis.

The respective Travel Times are then calculated using Equation 2.5 and are, 4.34 minutes, 4.73 minutes, and 16.33 minutes for the overland, paved, and pipe flow segments respectively. The Tc calculated from Equation 2.4 then becomes 25.4 minutes. Using the non-composite runoff coefficient for light industrial area of 0.65, the post development flow calculated using Equation 2.3 is 1638 cfs. The required amount of storage for a 100 year storm having a one hour duration is 103.4 acre-ft. The calculations used for this determination are shown in Table 5.1.

The detention facility required for the calculated volume of storage required is determined using the same criteria as the City method. The side slopes of the detention facility are decreased to 4:1 (V:H) in order to facilitate alternate used of the area. Using the specified 3:1 length to width ratio with a depth of 5 feet at capacity, the detention facility is 538 feet wide at its base, 578 feet wide at its crest, and 1614 feet long. Due to the shallow depth and shallower side slopes, this detention facility is similar in size to the detention pond calculated using the COH method.

Equation 5.1 is again used to calculate the outfall pipe diameter necessary to completely drain the detention facility in 24 to 48 hours. Using the calculated volume of 103 acre-ft, the required flow rate requires to drain the pond in 36 hours is 34.6 cfs. This rate results in a pipe area of 3.8 square feet and a diameter of 26.4 inches. Using the closest commercially available pipe diameter of 24 inches, the pond will take just under 47 hours to drain. This is unacceptably close to the limit of 48 hours. The next larger pipe diameter of 36 inches results in the pond completely emptying in 20 hours, faster than the allowable limit. Several possible solutions exist. A flow restrictor could be placed on the 36 inch diameter pipe. Another possible solution is incorporating two 16 inch diameter pipes.

TABLE 5.1 : MODIFIED RATIONAL METHOD; 100 YEAR (TR55 Method)

INPUT:

Proposed Conditions			Equation Used
Area	360.00	acre	
Tc2	25.4	min	2.5
Intensity for Tc	7.0		2.2
Runoff Coefficient	0.65		
Peak Inflow	1638.00	cfs	2.3
Max. Outflow	251.4	cfs	
Existing Conditions			
Area	360.00	acre	
Tc2	81.0	min	2.5
Intensity for Tc	3.9		2.2
Runoff Coefficient	0.18		
Q-Max. Outflow	251.4	cfs	2.3

City of Houston Intensities (Equation 2.2)

Storm Event (yr)	100
Duration (min)	Intensity (in/hr)
5	10.65
10	9.36
15	8.39
20	7.63
25	7.01
30	6.49
35	6.06
40	5.69
45	5.37
50	5.08
55	4.83
60	4.61
70	4.23
80	3.91
90	3.65
100	3.42
110	3.22
120	3.05
130	2.90
140	2.76
150	2.64
160	2.53
170	2.43
180	2.34
190	2.26
200	2.18
210	2.11
220	2.05
230	1.98
240	1.93
250	1.87
260	1.82
270	1.78
280	1.73
290	1.69
300	1.65
310	1.61
320	1.58
330	1.54
340	1.51
350	1.48
360	1.45
370	1.42
380	1.40
390	1.37
400	1.35
410	1.32

OUTPUT:

Interval	Duration (min)	Intensity (in/hr)	Qin (cfs)	Volume (in) (cf)	Volume (out) (cf)	Volume (storage) (cf)	Ac-Ft
1	5	10.6	2491.2	747,366	229,299	**518,068**	**11.89**
2	10	9.4	2191.3	1,314,753	267,012	**1,047,741**	**24.05**
3	15	8.4	1963.9	1,767,543	304,726	**1,462,817**	**33.58**
4	20	7.6	1785.0	2,141,965	342,439	**1,799,526**	**41.31**
5	25	7.0	1639.9	2,459,916	380,153	**2,079,763**	**47.74**
6	30	6.5	1519.7	2,735,512	417,867	**2,317,645**	**53.21**
7	35	6.1	1418.2	2,978,321	455,580	**2,522,740**	**57.91**
8	40	5.7	1331.3	3,195,091	493,294	**2,701,797**	**62.02**
9	45	5.4	1255.8	3,390,743	531,007	**2,859,735**	**65.65**
10	50	5.1	1189.7	3,568,957	568,721	**3,000,236**	**68.88**
11	55	4.8	1131.1	3,732,557	606,435	**3,126,122**	**71.77**
12	60	4.6	1078.8	3,883,747	644,148	**3,239,599**	**74.37**
13	70	4.2	989.4	4,155,571	719,575	**3,435,995**	**78.88**
14	80	3.9	915.6	4,394,847	795,003	**3,599,845**	**82.64**
15	90	3.6	853.5	4,608,672	870,430	**3,738,242**	**85.82**
16	100	3.4	800.3	4,802,078	945,857	**3,856,221**	**88.53**
17	110	3.2	754.4	4,978,755	1,021,284	**3,957,471**	**90.85**
18	120	3.1	714.1	5,141,487	1,096,711	**4,044,775**	**92.86**
19	130	2.9	678.5	5,292,418	1,172,139	**4,120,280**	**94.59**
20	140	2.8	646.8	5,433,239	1,247,566	**4,185,673**	**96.09**
21	150	2.6	618.4	5,565,299	1,322,993	**4,242,306**	**97.39**
22	160	2.5	592.7	5,689,698	1,398,420	**4,291,278**	**98.51**
23	170	2.4	569.3	5,807,338	1,473,847	**4,333,491**	**99.48**
24	180	2.3	548.1	5,918,972	1,549,275	**4,369,697**	**100.31**
25	190	2.3	528.5	6,025,232	1,624,702	**4,400,530**	**101.02**
26	200	2.2	510.6	6,126,656	1,700,129	**4,426,527**	**101.62**
27	210	2.1	493.9	6,223,703	1,775,556	**4,448,147**	**102.12**
28	220	2.0	478.5	6,316,771	1,850,983	**4,465,787**	**102.52**
29	230	2.0	464.2	6,406,203	1,926,411	**4,479,792**	**102.84**
30	240	1.9	450.9	6,492,301	2,001,838	**4,490,463**	**103.09**
31	250	1.9	438.4	6,575,330	2,077,265	**4,498,065**	**103.26**
32	260	1.8	426.6	6,655,524	2,152,692	**4,502,832**	**103.37**
33	270	1.8	415.6	6,733,090	2,228,119	**4,504,971**	**103.42**
34	280	1.7	405.3	6,808,215	2,303,547	**4,504,668**	**103.41**
35	290	1.7	395.5	6,881,063	2,378,974	**4,502,090**	**103.35**
36	300	1.7	386.2	6,951,786	2,454,401	**4,497,385**	**103.25**
37	310	1.6	377.4	7,020,516	2,529,828	**4,490,688**	**103.09**
38	320	1.6	369.1	7,087,378	2,605,255	**4,482,122**	**102.90**
39	330	1.5	361.2	7,152,481	2,680,683	**4,471,798**	**102.66**
40	340	1.5	353.7	7,215,927	2,756,110	**4,459,817**	**102.38**
41	350	1.5	346.6	7,277,809	2,831,537	**4,446,272**	**102.07**
42	360	1.5	339.7	7,338,211	2,906,964	**4,431,247**	**101.73**
43	370	1.4	333.2	7,397,212	2,982,391	**4,414,820**	**101.35**
44	380	1.4	327.0	7,454,882	3,057,819	**4,397,064**	**100.94**
45	390	1.4	321.0	7,511,289	3,133,246	**4,378,044**	**100.51**
46	400	1.3	315.3	7,566,494	3,208,673	**4,357,821**	**100.04**
47	410	1.3	309.8	7,620,554	3,284,100	**4,336,453**	**99.55**

TABLE 5.2 : MODIFIED RATIONAL METHOD; 2-YEAR EVENT (TR55 Method)

INPUT:

Proposed Conditions		Equation Used
Area	360.00 acre	
Tc2	25.4 min	2.5
Intensity for Tc	7.0	2.2
Runoff Coefficient	0.65	
Peak Inflow	1638.00 cfs	2.3
Max. Outflow	251.4 cfs	
Existing Conditions		
Area	360.00 acre	
Tc2	81.0 min	2.5
Intensity for Tc	3.9	2.2
Runoff Coefficient	0.18	
Q-Max. Outflow	251.4 cfs	2.3

OUTPUT:

Interval	Duration (min)	Intensity (in/hr)	Qin (cfs)	Volume (in) (cf)	Volume (out) (cf)	Volume (storage) (cf)	Volume (storage) Ac-Ft
1	5	5.9	1374.0	412,186	229,299	**182,887**	**4.20**
2	10	4.9	1151.5	690,892	267,012	**423,880**	**9.73**
3	15	4.3	995.4	895,836	304,726	**591,110**	**13.57**
4	20	3.8	879.3	1,055,163	342,439	**712,723**	**16.36**
5	25	3.4	789.3	1,184,022	380,153	**803,869**	**18.45**
6	30	3.1	717.4	1,291,357	417,867	**873,491**	**20.05**
7	35	2.8	658.5	1,382,824	455,580	**927,243**	**21.29**
8	40	2.6	609.2	1,462,190	493,294	**968,896**	**22.24**
9	45	2.4	567.4	1,532,075	531,007	**1,001,068**	**22.98**
10	50	2.3	531.5	1,594,364	568,721	**1,025,643**	**23.55**
11	55	2.1	500.1	1,650,452	606,435	**1,044,017**	**23.97**
12	60	2.0	472.6	1,701,394	644,148	**1,057,245**	**24.27**
13	70	1.8	426.4	1,790,940	719,575	**1,071,364**	**24.60**
14	80	1.7	389.1	1,867,716	795,003	**1,072,713**	**24.63**
15	90	1.5	358.3	1,934,804	870,430	**1,064,374**	**24.43**
16	100	1.4	332.4	1,994,319	945,857	**1,048,462**	**24.07**
17	110	1.3	310.3	2,047,766	1,021,284	**1,026,482**	**23.56**
18	120	1.2	291.1	2,096,253	1,096,711	**999,541**	**22.95**
19	130	1.2	274.4	2,140,616	1,172,139	**968,477**	**22.23**
20	140	1.1	259.7	2,181,500	1,247,566	**933,934**	**21.44**
21	150	1.1	246.6	2,219,413	1,322,993	**896,420**	**20.58**
22	160	1.0	234.9	2,254,761	1,398,420	**856,340**	**19.66**
23	170	1.0	224.3	2,287,872	1,473,847	**814,024**	**18.69**
24	180	0.9	214.7	2,319,017	1,549,275	**769,742**	**17.67**
25	190	0.9	206.0	2,348,421	1,624,702	**723,719**	**16.61**
26	200	0.8	198.0	2,376,273	1,700,129	**676,144**	**15.52**
27	210	0.8	190.7	2,402,733	1,775,556	**627,177**	**14.40**
28	220	0.8	183.9	2,427,938	1,850,983	**576,954**	**13.25**
29	230	0.8	177.7	2,452,004	1,926,411	**525,593**	**12.07**
30	240	0.7	171.9	2,475,034	2,001,838	**473,197**	**10.86**
31	250	0.7	166.5	2,497,118	2,077,265	**419,852**	**9.64**
32	260	0.7	161.4	2,518,331	2,152,692	**365,639**	**8.39**
33	270	0.7	156.7	2,538,745	2,228,119	**310,625**	**7.13**
34	280	0.7	152.3	2,558,419	2,303,547	**254,872**	**5.85**
35	290	0.6	148.1	2,577,407	2,378,974	**198,433**	**4.56**
36	300	0.6	144.2	2,595,759	2,454,401	**141,358**	**3.25**
37	310	0.6	140.5	2,613,517	2,529,828	**83,689**	**1.92**
38	320	0.6	137.0	2,630,721	2,605,255	**25,465**	**0.58**

City of Houston Intensities (Equation 2.2)

Storm Event (yr)	2
Duration (min)	Intensity (in/hr)
5	5.87
10	4.92
15	4.25
20	3.76
25	3.37
30	3.07
35	2.81
40	2.60
45	2.42
50	2.27
55	2.14
60	2.02
70	1.82
80	1.66
90	1.53
100	1.42
110	1.33
120	1.24
130	1.17
140	1.11
150	1.05
160	1.00
170	0.96
180	0.92
190	0.88
200	0.85
210	0.81
220	0.79
230	0.76
240	0.73
250	0.71
260	0.69
270	0.67
280	0.65
290	0.63
300	0.62
310	0.60
320	0.59
330	0.57
340	0.56
350	0.55
360	0.53
370	0.52
380	0.51
390	0.50
400	0.49
410	0.48

6. LID Site Design

6.1 Introduction

The LID site design will attempt to incorporate the design requirements outlined in the City of Houston (COH) Infrastructure Design Manual and the Harris County Flood Control District's Stormwater Quality Management Regulations with the development techniques outlined in the Prince George's County, Maryland Department of Environmental Resources' (DER) publication Low-Impact Development Design Strategies. Unfortunately, the current COH requirements do not lend themselves to incorporating LID techniques into the stormwater management plan. This is particularly true of the flood control requirements, where no mention of LID practices is made. Current City and County stormwater quality regulations do, however, encourage the implementation of LID practices. However, neither set of criteria provides any economic incentive to the implementation of LID practices.

The same aspects of the land development process will be examined as in the case of the conventional site development. These aspects will include stormwater collection, water quality management, and flood control.

6.2 Regulations

As with the conventional site development procedure outlined in the previous section, the development will reside within city limits and the stormwater design must adhere to the guidelines detailed in the City of Houston Infrastructure Design manual. Again, as the development is greater than 20 acres and stormwater runoff from the development area will make its way to the Harris County Flood Control District's ditch, the County requirements supercede the City's requirements.

6.3 Stormwater Management

The county design manual offers and provides design specifications for several different BMP techniques that are acceptable for controlling stormwater quality. The LID development will focus on micromanagement of stormwater. Several small controls will be utilized with the focus on eliminating stormwater runoff at its source. An analysis of the amount of additional detention will then be performed. Traditional BMPs will then be examined and sized appropriately. The use of non-structural controls will then be reexamined and additional controls considered. Once the implementation of non-structural and source controls is no longer cost effective or provide limited returns, the remaining amount of runoff will be determined. A traditional BMP will hen be selected and sized appropriately.

6.3.1 Source Elimination

The most cost effective method to control both the quality and quantity of stormwater runoff is to minimize its occurrence. As discussed in Chapter 4, this begins with minimizing the disturbance caused by construction to the area. In order to accomplish this, a development envelope will be determined. After the development envelope is established, no construction or traffic will be allowed outside of this area.

6.3.1.1 Construction Techniques

As the development site has very little natural grade, less than 0.1%, the area will not need significant amounts of grading. Where possible, natural vegetation will be left undisturbed even within the development envelope. This is especially true of large trees that will not be removed unless absolutely necessary, such as located within the footprint of a building for example.

As the soil in the study area is uniformly nonpermeable, no limitation on the locations of impervious surfaces is made. Similarly, the development area does not contain any wetlands or otherwise ecologically sensitive areas.

6.3.1.2 Directly Connected Impervious Surfaces

Sidewalks: The primary means of eliminating runoff from rainfall is to reduce the overall amount of directly connected impervious area. One method of eliminating directly connected impervious areas is to examine the sidewalks. As mentioned in Chapter 2, the proposed site is to contain one acre of total sidewalk area. As opposed to using concrete sidewalks, gravel sidewalks will be implemented. The material will consist of fairly uniform porous media approximately two inches deep laid on a sand base contained within wood retainers. The permeability of the gravel and soil will be at least at great as the underlying soil, resulting in no increase in the total impermeable area from the sidewalks.

Overflow Parking: An even greater potential reduction in the amount of directly connected impervious area lies with the construction of the overflow parking area. As opposed to paving the overflow parking area with asphalt or concrete, lattice style concrete blocks are to be used. These lattice blocks, also know as modular porous pavement, are composed of relatively large blocks filled with crushed aggregate.

Research performed at Australia's Griffith University suggest that modular porous pavement has the advantage over porous asphalt as it is less susceptible of clogging and requires less maintenance. While it is recommended that modular porous pavement only be placed in areas with highly permeable soils, it seems apparent that modular porous pavement, in conjunction with other means of stormwater collection, would be much more desirable than traditional asphalt or concrete paving. The modular pavement reduces the amount of impervious area by 75%, the proportion of the block that is hollow and filled with gravel. Assuming that due to the impervious nature of the underlying soil, half of the rainfall falling on the pervious section of the modular pavement runs off. This is still an overall reduction in the amount of runoff of 37.5%.

Primary Parking: Primary parking areas have significantly higher traffic volume than overflow parking. As a result, modular porous pavement is not suitable for the entire primary parking area. Modular porous pavement would be suitable, however, for the actual parking spaces of the parking lot. The area where cars remain stationary will receive significantly lower traffic than the driveways feeding the parking area. As with the overflow parking area, means of collecting the runoff that does occur will still be necessary. Assuming that 70% of the entire primary parking lot area is designed for parking spaces and given that half of the rainfall falling on the porous section of the parking lot still results in runoff, a significant reduction on overall runoff is obtained.

Buildings: Building footprints comprise a significant fraction of the total area of the development and as such constitute a significant portion of total impervious area. Several methods are available to reduce or eliminate the amount of runoff generated from these structures. Green roofs are one such option. The use of green roof technology was eliminated from this development due to several factors, including a lack of performance data, installation costs, and maintenance costs. However, green roves could still provide significant environmental benefits such as eliminating carbon dioxide and particulate material from the atmosphere, eliminating nitrogen pollution from rain, and eliminating the effects of acid rain. Economic benefits of green roofs include lower air condition expense in the summer and reduced heating cost in the winter as well as lengthening roof life by two to three times. With this in mind, green roof technology may be incorporated at a future data as more data becomes available.

Runoff from building rooftops can be harnessed and utilized. This development will incorporate rain cisterns for collection of the runoff flowing from building rooftops. The total volume of storage required is equal to the runoff generated from one hour of precipitation resulting from the two year rainfall event. This is equal to 2.02 inches per hour for one hour over 11.2 acres, resulting in a total storage volume of 82,125 cubic feet. This storage volume is to be spread across the five buildings according to the area of the individual building. The cisterns are to be installed with overflow pipes to remove any excess runoff. The collected water can be used for a variety of purposes including irrigation and cooling water.

6.3.1.3 Result of Source Elimination on Runoff Calculations

The elimination of the sources will ultimately reduce the amount of runoff generated. A composite Rational Formula coefficient as given in the COH design manual will be used to determine the total amount of runoff generated according to Equation 6.1. Note that buildings are counted as completely impervious. The volume retained by the cisterns will be eliminated from the final detention requirements.

Equation 6.1

$$C = 0.6Ia + 0.2$$

Where C = watershed coefficient
Ia = impervious area/total area

The runoff coefficient for each area will then be weighted to determine the composite coefficient for the entire development. This calculation is given in Equation 6.2:

Equation 6.2

$$Cc = C_i\,(Area_i\,/\,Total\ Area) + C_j\,(Area_j\,/\,Total\ Area) + \ldots\ C_m\,(Area_m\,/\,Total\ Area)$$

Where C_x = area coefficient
Cc = composite coefficient

The results of the composite runoff coefficient values are presented in Table 6.1.

Table 6.1 – Composite Coefficient Values

Area	Total Area	% Impervious	Ia	Ci
Sidewalks	1	0	0	0.2
Overflow Parking	8	62.5	0.625	0.575
Primary Parking	12	77.5	0.775	0.665
Buildings	11.2	100	1	0.8
Roads	1.5	100	1	0.8
Open Areas	326.3	0	0	0.2
tal	360			

Cc = (0.2 *(1/360))+(0.575*(8/360))+(0.8(11.2/360))+(0.8*(1.5/360))+(0.2*(326.3/360))

Cc = 0.223

6.3.2 Runoff Collection

The conventional site plan incorporated traditional curb and gutter systems to collect stormwater runoff. The use of this method of collecting and conveying stormwater maximizes flow velocities. This is in contradiction with the goal of LID techniques that aim to maximize travel time by minimizing flow velocities. In order to accomplish this, curbs and gutters are eliminated in favor of other means of collecting and conveying stormwater runoff.

6.3.2.1 Bioretention Areas

Stormwater runoff from parking area may be initially conveyed to bioretention areas. Bioretention is designed as an alternative to traditional BMPs by combining physical filtering, adsorption, and biological processes. Components of the bioretention system include a grassy pre-filter strip, a surface designed for shallow surface water ponding, a bioretention vegetation area, a soil zone, an underdrain, and an overflow structure. The maximum ponding depth is limited to six inches with an underdrain installed. Fifteen square feet of bioretention area will be designated for each 100 square feet of parking area. The area devoted to bioretention will not be included in the area allocated for parking, resulting in fifteen percent increase in total parking lot area. Bioretention areas are to be placed strategically throughout the parking area, between parking rows for example, in order to maximize stormwater retention as well as to provide aesthetic value. While the use of bioretention areas should eliminate runoff from the parking areas for all but the most severe rainfall, runoff will still be calculated for these areas as if they did not exist.

6.3.2.2 Grassy Swales

Grassy swales will line all roads on the development and also surround the parking areas to collect and convey stormwater originating in these areas. Due to the potential of harboring mosquitoes in standing water, dry swales will be utilized. Dry swales perform both water quality improvements while decreasing the quantity of stormwater by facilitating stormwater infiltration. As the area is not constrained by space requirements, the swales are to be relatively wide at 6 feet and have a shallow 1:5 (V:H) side slopes and depth of 5.5 feet at capacity. This size swale will accommodate runoff generated during the two year event as specified in the COH design manual.

For purposes of the calculations, it is assumed that all 20 acres of parking area are continuous. Placing the flow path of 1320 feet in Equation 2.5 and using the average velocity for overland street flow given in TR55 of 1.41 ft/sec, the resulting Tc_2 is 15.6 minutes. Using this value in Equation 2.2 yields an intensity of 4.8 inches/hour. Using the runoff coefficient calculated in Table 6.1 of 0.665 for primary parking areas, the resulting maximum inflow is 64.37 cfs. Assuming that this runoff is flowing uniformly into the swale, the

Given the dimensions of the swale, the total area is 184 square feet. Using Manning's Equation, the maximum velocity through the swale is 0.4 ft/sec, resulting in a maximum flow rate of 74.5 cfs. As the outflow significantly exceeds the inflow, the swales can easily accommodate the runoff from a two year event. Similar analysis should also be performed on the roadways in order to size them appropriately.

In order to further reduce quantity of stormwater runoff and improve its overall quality, vegetate filter strips are placed between the grassy swale and the impervious area they service. The strips will have a width of five feet, which also serve to distance the swale from the impervious area.

6.3.3 Detention Requirements

Despite the implementation of the preceding LID techniques, a portion of runoff from the 100 year event must still be detained. The volume of detention required is calculated in Table 6.2. The individual Tts are calculated using Equation 2.4. The maximum street flow is across the 20 acres of combined parking area and was previously calculated as 15.6 minutes. As all pipe flow is eliminated, the remaining Tt is for overland flow and results in a Tt of 62 minutes for a path flow length of 4280 feet. The resulting Tc is 77.6 minutes. The amount of detention required is 7.32 acre-ft. Subtracting the 1.88 acre-ft retained in the rain cisterns, the total required detention volume of 5.43 acre-ft. This value compares to 234 acre-ft of detention required by the City of Houston/ Harris County Method and 103 acre-ft required by the TR55 method. It should also be noted that this value overestimates the runoff volume generated by the parking areas.

6.3.4 Flood Control/ Water Quality Facilities

In order to maximize the improvement in the quality of the remaining runoff, a wet detention pond will be utilized. Similar to the requirements for dry detention ponds, the County requires a 3:1 length to width ratio. In the case of wet ponds this is to promote plug flow conditions. Plug flow is the theoretical condition where the runoff from a rainfall event will move through the pond as a unit.

The Harris County Stormwater quality design manual specifies the pond size required for water quality improvement. The minimal flood control volume will be added to the overall volumes.

The permanent pool volume should be equal to the amount of runoff generated from the first half inch of rainfall. This volume is equal to 15 acre-ft. This total area is to be divided between the forebay and the main pool with the forebay accounting for 20% of the volume and the main pool accounting for he remaining 80%. For analysis purposes, the pond will be assumed to be trapezoidal with 1:3 (V:H) side slopes and a depth of 5 feet. These criteria result in dimensions of 247 feet wide at its base, 277 feet wide at its crest, and 741 feet long for the combined water quality/flood control pond. Suitable vegetation should be planted along the pond banks in order to facilitate pollutant removal.

6.3.5 Storm Water Quality

The stormwater quality management plan (SWQMP) must adhere to the guidelines detailed in Chapter 3. As discussed, SWQMPs propose structural, non-structural, and vegetative controls to ensure the water quality of stormwater runoff. Necessary components such as site descriptions, location, and activities have been previously discussed and will not be reexamined here. Similarly, the SWQMP will cover the same structural controls aspects previously covered in this section.

Nonstructural controls that will be implemented as part of the LID site plan include:

- Landscaping Practices
- Litter Control
- Fertilizer and Pesticide Use and Practices
- Hazardous Material Storage and Disposal
- Spill Prevention and Response
- Liquid Material Handling Practices
- Equipment Washing Practices

TABLE 6.2 : MODIFIED RATIONAL METHOD; 100 YEAR LID (TR55 Method)

INPUT:

		Equation Used
Proposed Conditions		
Area	360.00 acre	
Tc2	77.6 min	2.5
Intensity for Tc	3.98	2.2
Runoff Coefficient	0.22	Table 6.1
Peak Inflow	319.51 cfs	2.3
Max. Outflow	251.4 cfs	
Existing Conditions		
Area	360.00 acre	
Tc2	81.0 min	2.5
Intensity for Tc	3.9	2.2
Runoff Coefficient	0.18	
Q-Max. Outflow	251.4 cfs	2.3

City of Houston Intensities (Equation 2.2)

Storm Event (yr) Duration (min)	100 Intensity (in/hr)
5	10.65
10	9.36
15	8.39
20	7.63
25	7.01
30	6.49
35	6.06
40	5.69
45	5.37
50	5.08
55	4.83
60	4.61
70	4.23
80	3.91
90	3.65
100	3.42
110	3.22
120	3.05
130	2.90
140	2.76
150	2.64
160	2.53
170	2.43
180	2.34
190	2.26
200	2.18
210	2.11
220	2.05
230	1.98
240	1.93
250	1.87
260	1.82
270	1.78
280	1.73
290	1.69
300	1.65
310	1.61
320	1.58
330	1.54
340	1.51
350	1.48
360	1.45
370	1.42
380	1.40
390	1.37
400	1.35
410	1.32

OUTPUT:

Interval	Duration (min)	Intensity (in/hr)	Qin (cfs)	Volume (in) (cf)	Volume (out) (cf)	Volume (storage) (cf)	Ac-Ft
1	5	10.6	854.7	256,404	623,029	**-366,625**	**(8.42)**
2	10	9.4	751.8	451,062	660,742	**-209,681**	**(4.81)**
3	15	8.4	673.8	606,403	698,456	**-92,053**	**(2.11)**
4	20	7.6	612.4	734,859	736,169	**-1,311**	**(0.03)**
5	25	7.0	562.6	843,940	773,883	**70,057**	**1.61**
6	30	6.5	521.4	938,491	811,597	**126,894**	**2.91**
7	35	6.1	486.6	1,021,793	849,310	**172,483**	**3.96**
8	40	5.7	456.7	1,096,162	887,024	**209,138**	**4.80**
9	45	5.4	430.8	1,163,286	924,737	**238,548**	**5.48**
10	50	5.1	408.1	1,224,427	962,451	**261,976**	**6.01**
11	55	4.8	388.0	1,280,554	1,000,165	**280,389**	**6.44**
12	60	4.6	370.1	1,332,424	1,037,878	**294,546**	**6.76**
13	70	4.2	339.4	1,425,680	1,113,305	**312,375**	**7.17**
14	80	3.9	314.1	1,507,771	1,188,733	**319,038**	**7.32**
15	90	3.6	292.8	1,581,129	1,264,160	**316,969**	**7.28**
16	100	3.4	274.6	1,647,482	1,339,587	**307,895**	**7.07**
17	110	3.2	258.8	1,708,096	1,415,014	**293,082**	**6.73**
18	120	3.1	245.0	1,763,925	1,490,441	**273,484**	**6.28**
19	130	2.9	232.8	1,815,707	1,565,869	**249,838**	**5.74**
20	140	2.8	221.9	1,864,019	1,641,296	**222,723**	**5.11**
21	150	2.6	212.1	1,909,326	1,716,723	**192,603**	**4.42**
22	160	2.5	203.3	1,952,004	1,792,150	**159,854**	**3.67**
23	170	2.4	195.3	1,992,364	1,867,577	**124,786**	**2.86**
24	180	2.3	188.0	2,030,663	1,943,005	**87,658**	**2.01**
25	190	2.3	181.3	2,067,118	2,018,432	**48,686**	**1.12**
26	200	2.2	175.2	2,101,914	2,093,859	**8,055**	**0.18**
27	210	2.1	169.5	2,135,209	2,169,286		
28	220	2.0	164.2	2,167,138	2,244,713		
29	230	2.0	159.3	2,197,820	2,320,141		
30	240	1.9	154.7	2,227,359	2,395,568		
31	250	1.9	150.4	2,255,844	2,470,995		
32	260	1.8	146.4	2,283,357	2,546,422		
33	270	1.8	142.6	2,309,968	2,621,849		
34	280	1.7	139.0	2,335,741	2,697,277		
35	290	1.7	135.7	2,360,734	2,772,704		
36	300	1.7	132.5	2,384,997	2,848,131		
37	310	1.6	129.5	2,408,577	2,923,558		
38	320	1.6	126.6	2,431,516	2,998,985		
39	330	1.5	123.9	2,453,851	3,074,413		
40	340	1.5	121.4	2,475,618	3,149,840		
41	350	1.5	118.9	2,496,848	3,225,267		
42	360	1.5	116.6	2,517,571	3,300,694		
43	370	1.4	114.3	2,537,813	3,376,121		
44	380	1.4	112.2	2,557,598	3,451,549		
45	390	1.4	110.1	2,576,950	3,526,976		
46	400	1.3	108.2	2,595,890	3,602,403		
47	410	1.3	106.3	2,614,436	3,677,830		

7 Conclusions

Recent approaches to stormwater management have been to decrease the effects of runoff conveyed to the receiving stream. These techniques have attempted to negate the effects of development on the hydrologic characteristics of an area. This approach, known as Low Impact Development (LID), attempts to reproduce the predevelopment characteristics of an area. A major distinguishing feature of low impact development with traditional stormwater techniques is the use of decentralized, smaller facilities to mitigate the effects of development. This is in contract to traditional methods that convey stormwater to a central area to be stored and possibly treated.

Comparisons of the volume of detention facilities required by City and County regulations clearly show the effects of incorporating LID techniques into site planning. As shown in Table 7.1, flood control detention requirements were decreased from 103 acre-ft to 234 acre-ft using conventional land development techniques, depending on the method of analysis, to 7.32 acre-ft. This dramatic decrease is a result of minimizing the occurrence of runoff and using small, cost effective measures to control the runoff that does occur.

Table 7.1 - Summary of Detention Requirements

Development Method	Detention Requirements (acre-ft)
COH Method	234
TR55 Method	103
LID Method	7.32

Although is difficult to show, the overall quality of the stormwater runoff is also dramatically improved. This is due to treating the stormwater at several points along its flow path rather than attempting to use end of pipe type approaches.

Another benefit of the LID site development is aesthetic value. The maximization of green space is generally appealing. Incorporating features such as bioretention areas in the parking lots and using wet detention greatly increases the visual appeal; of a site.

Unfortunately, the current City and County guidelines do not encourage incorporating LID techniques into the stormwater management plan. This is particularly true of the flood control requirements, where no mention of LID practices is made. Current City and County stormwater quality regulations do, however, encourage the implementation of LID practices. However, neither set of criteria provides any economic incentive to the implementation of LID practices.

Harris County is currently reviewing a new set of Criteria for stormwater management. Hopefully, more emphasis will be placed on incorporating LID techniques into site development than have been in the past.

Bibliography

City of Houston and Harris County Flood Control District, *Storm Water Quality Guidance Manual*, 2001 Edition

City of Houston Public Works and Engineering, *Infrastructure Design Manual*, Revision 1, 2002

Clar, Michael. "Stormwater BMP Technology Assessment Protocols – Preliminary Findings." 2001 American Society of Civil Engineers Low Impact Development Conference Proceedings

Hannan, Ataul. "Experience Gained from Analyzing Watersheds in Harris County, TX." 2003 American Society of Civil Engineers Proceedings

Harris County Flood Control District. *Minimum Design Criteria for Implementation of Certain Best Management Practices for Stormwater Runoff Treatment Options.*2001 Edition. Harris County, Texas, Department of Engineering, Public Infrastructure Department.

Harris County Flood Control District. *Regulations of Harris County, Texas for Stormwater Quality Management.*2001 Edition. Harris County, Texas, Department of Engineering, Public Infrastructure Department.

Harris County Flood Control District. *Standard Specifications Book* .2000 Edition. Harris County, Texas, Department of Engineering, Public Infrastructure Department.

Harris County Permit Office. *Unincorporated Harris County Draft Floodplain Management Plan.*2003 Edition. Harris County, Texas, Department of Engineering, Public Infrastructure Department.

Liscum, Fred, "Effects of Urban Development on Stormwater Runoff Characteristics for the Houston, Texas Metropolitan Area" Water-Resources Investigations Report 01-4071. US Geological Survey.

McCuen, Richard. *Hydrologic Analysis and Design*. Pretence Hall 1998

McGraw Hill, *Land Development Handbook*, 2nd Edition, 2002.

McGraw Hill, *Water Resources Engineering*, 4th Edition, 1992.

McGraw Hill, *Wastewater Engineering, Treatment, Disposal, and Reuse*, 3rd Edition, 1991.

Pitt, Robert, "Compacted Urban Soils Effects on Infiltration and Bioretention Stormwater Control Designs." 2003 American Society of Civil Engineers Urban Drainage Conference Proceedings

Prince George's County, MD, Department of Environmental Resources Programs and Planning Division. *Low-Impact Development Design Strategies An Integrated Design Approach.* 1999

Prince George's County, MD, Department of Environmental Resources Programs and Planning Division. *Low-Impact Development Hydrologic Analysis.* 1999

Rushton, Betty, "Enhanced Parking Lot Design for Stormwater Treatment" 2003 American Society of Civil Engineers Urban Drainage Conference Proceedings.

Soil Survey Division, Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions [Online WWW]. Available URL: " http://ortho.ftw.nrcs.usda.gov/osd/"

Texas Natural Resources Information System, Texas Water Development Board, [Online WWW]. Available URL: " http://www.tnris.state.tx.us/digital.htm/"

Thomann, Robert V., *Principles of Surface Water Quality Modeling and Control.* Harper Collins Publishers, 1987.

Natural Resources Conservation Service, TR55 Urban Hydrology for Small Watersheds United States Department of Agriculture, Conservation Engineering Division. Washington, 1986

United States Department of Agriculture, Soil Conservation Service (now NRCS). *Soil Survey of Harris County, TX*, Washington, 1978

United States Environmental Protection Agency, "Stormwater Technology Fact Sheet – Porous Pavement" US EPA Office of Water. Washington D.C.. 1999

Wanielista, Martin P., *Stormwater Management*, John Wiley and Sons, 1993.