IMPROVING HYDROLOGIC SUSTAINABILITY OF TEXAS A&M UNIVERSITY CAMPUS

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ABSTRACT

This research investigates the hydrologic sustainability of urban development and stormwater management for a watershed on the Texas A&M campus. The main Texas A&M campus has become increasingly urbanized, resulting in areas of imperviousness that generate higher rates of runoff. This growth has proceeded unchecked, and significant growth and development are planned for the future. Both increased rates of runoff from previous development and the impact of anticipated development should be addressed through mitigation efforts. This research provides a means to assess watershed health through biological indicators, water quality indicators, riparian ecosystems, the floodplain footprint, and the long term flow regime. A modeling framework is implemented to couple hydrologic and hydraulics models to simulate a set of watershed management plans that employ alternative best management practices. Development plans will be evaluated based on a set of comprehensive metrics that synthesize ecological, hydrologic, and environmental aspects of watershed health. The selection of management plans based on these metrics will enhance the environmental sustainability of further campus development.

INTRODUCTION

Urbanization of watersheds leads to an increase in peak flow and volumes of stormwater runoff and fundamentally alters the characteristics of the flow regime and therefore the health of the in-stream ecosystem. More sustainable development in a hydrologic context would enable the stream to maintain its natural variability and flow characteristics. Best Management Practices (BMP) are a range of technologies and methods for mitigating increased stormwater runoff and have provided an appropriate approach for controlling the volume of flow and limiting the amount of sediments and pollutants that would otherwise be washed into the stream. For example, detention ponds are typically designed to match pre-development peak flows (EPA 2004). While centralized BMP placement may reduce peak flows and may effectively remove pollutants, the natural hydrology may become dominated by inadequate base flow or flashy hydrology, which negatively affects the ecosystem (Coffman 2000). Alternatively, Low-Impact Development (LID) is a selected set of BMPs that enable the design of management strategies with the goal of either maintaining or replicated the pre-development hydrologic regime. LID principally uses the tactic of controlling stormwater at the source through the use of micro-scale stormwater retention areas, landscapes that act as stormwater facilities, and the protection of riparian buffers and other environmentally sensitive site features (EPA report 2000). LID strategies include permeable pavements, rainwater harvesting systems, green roofs, and vegetated swales.

The purpose of this paper is to explore through a simulation study the placement of LID strategies, including rainwater harvesting systems, permeable pavement, and riparian buffer systems, on a campus watershed for improvement of the hydrologic sustainability. The watershed has experienced development in recent years, through the construction of buildings, roadways, and parking lots. To simulate the pre-development flow regime, data from 1940 is incorporated into a hydrologic modeling framework. The flow regime for the current conditions and different LID placement scenarios are simulated and compared to the predevelopment flow regime to evaluate hydrologic sustainability.

TEXAS A&M UNIVERSITY CAMPS: PAST, PRESENT, AND FUTURE

The main Texas A&M University (TAMU) campus, located in College Station, Texas, covers an area of 5,280 acres (21.37 square kilometers), most of which are not densely developed. Since 1962, the campus witnessed unprecedented growth with a student population increasing from 7,500 to 45,000. The main campus consists of a mix of old and new structures which reflect the evolution of the university footprint over the past 130 years. Construction and development have led to degraded hydrologic conditions, especially during peak flow conditions, which lead to street flooding and in-stream erosion.

The two sections of campus, Main Campus and West Campus (3.03 and 4.39 square kilometers, respectively), are separated by a four-lane road and railway track (Fig. 1). The campus straddles two watersheds, and the Main campus drains southeast toward the Navasota River while West campus drains southwest through White Creek into the Brazos River. While West Campus is less developed than Main Campus, development that has taken place over the last 50 years on West Campus has greatly increased the impervious surface and volume of storm water draining into White Creek, subsequently degrading the structure of the creek and the ecosystem. Tributaries C and D that contribute to White Creek have undergone a transformation from small and slow moving creeks to large creeks that move large amounts of storm water during a typical 2-5 year rainfall event. The TAMU Physical Plant Utilities commissioned a study to assess the extent of erosion within the watershed and to propose the most effective engineering solutions (JF Thompson, 2005). The study documented the erosion and massive slope failure that has occurred throughout the extent of the creek's channel, and predicted that, if left unmitigated, erosion would likely undermine adjoining structures including buildings, roads, bridges, and ponds. As a result of this study, immediate protection of critical locations was recommended, and riprap and gabions with vegetation were implemented to decrease velocities in stream.

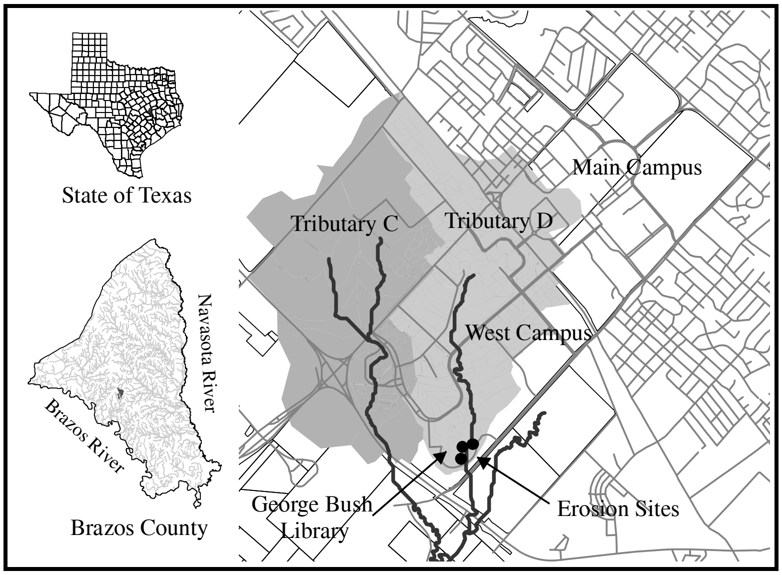

Figure 1. Location of Texas A&M campus; West Campus Watersheds C and D; Tributaries C and D; and the location of erosion problems

To prevent further damage and improve the aesthetics of the campus as a whole, a master plan was commissioned and was released in July 2004 (Barnes Gromatzky Kosarek Architects and Micheal Denis & Associates, 2004). It assesses the present strength and weaknesses of the campus and sets the tone for future construction and landscape development as the university enhances its physical environment. The master plan proposes an extension of the civic structure and landscape that exists on Main Campus into West Campus. As the number of buildings on West Campus is expected to approximately double, the replacement of parking areas with green spaces, buildings, and garages is suggested to mitigate environmental implications of increased impervious areas. Thompson (2005) suggests that a more comprehensive stream restoration plan is required to address erosion and hydrologic problems in the long term and plan for the further development of West Campus as proposed in the master plan.

LOW IMPACT DEVELOPMENT STRATEGIES

Three LID strategies, including a riparian buffer system, permeable pavement, and rainwater harvesting systems, are considered for mitigating the impacts of development in the campus watershed.

Riparian Buffer System. The campus master plan suggests that Tributary D should be developed as a greenway. The area can be restored to its natural state by encouraging the use of native Texas riparian landscape. A 300 feet (approximately 90 meter) wide riparian buffer, divided into three cores (inner, middle and outer) is proposed (Fig. 2). It is expected to act the backbone of the natural enhancement around which other segments will be organized.

The proposed Greenway is a strip of riparian buffers and linear strips of vegetation between the aquatic ecosystem and the upland habitats. Such systems are usually located adjacent of streams, rivers, lakes, reservoirs, and other inland aquatic systems. They are different from riparian corridors, which primarily facilitate the movement of wildlife. Their purpose is to improve water quality (Fisher et al., 2000). Riparian buffer strips can reduce stream sedimentation in several ways. They trap terrestrial sediment in the surface runoff and reduce the velocity of the sediment bearing storm-water, allowing more time for the sediment to settle out. They also stabilize stream banks and prevent excessive channelization, they moderate flows during floods, and they contribute large wood to the stream, assisting stabilization by acting as soil rebar (Wenger, 1999).

The first five meters on the outer side of the strip is the most important as it screens out large particles. Smaller sized particles are more difficult to remove by filtering through grass, and generally require a zone of woody vegetation to intercept them (Garabaghi et al., 2001). Vegetation already existent along the riparian zone will be retained and protected and it must be ensured that drainage does not interfere with the hydrology of the buffer. The buffer tree canopy should be maintained to balance both understory and overstory vegetation. The buffer can also include sedimentation detention structure, such as depressions in the ground, vegetative filter strips, permeable barriers, and infiltration structures such as gravel trenches.

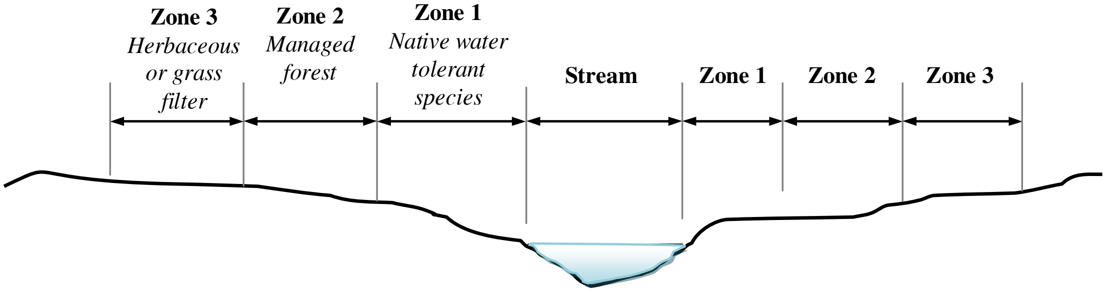

Figure 2. Schematic of riparian buffer system

Permeable Pavement. Permeable pavements systems generally consist of a matrix of concrete blocks or plastic web-type structure with voids that are filled with a material of high permeability (sand, gravel or even soil). The voids hold the precipitation, allows water to infiltrate and be retained within the highly permeable matrix as it slowly infiltrates into the underlying soil (Brattebo and Booth 2003). Permeable pavement may replace traditional pavement or concrete infrastructure for sidewalks, roads, and parking lots. A set of studies have documented the ability of permeable pavement to reduce the volume of stormwater runoff and the amount of contaminant washed from parking lots into surface water bodies (Braune and Wood 1999).

Rainwater Harvesting Systems. Rainwater harvesting is an ancient practice that has been receiving attention, fueled by water shortages from droughts, pollution and population growth (Nolde 2007). While originally used to collect water in depressions for irrigation, the practice of collecting rainfall from rooftops was later adapted for domestic water supply in rural areas and islands (Kahinda et al. 2007; Michaelides and Young 1983). More recently, environmental concerns have increased the appeal of green building practices, including rainwater harvesting systems, in urban areas. Rainwater harvesting is especially appealing as it combines the benefits of water reuse with runoff reduction and groundwater recharge, and has been proposed as a means to conserve rainwater and reuse it for landscaping (Porter et al. 2007).

MODELED SCENARIOS

A hydrologic and hydraulic model of Watersheds C and D in West Campus for current conditions was developed by AECOM (AECOM 2008). Geographical, hydrologic, and meteorological information were incorporated within HEC-HMS (Army Corps of Engineering 2006) for hydrologic simulation. Watersheds C and D were divided into sub-watersheds, delineated corresponding to storm sewer manholes, culverts, channel junctions, buildings, and streets. Curve numbers for the watershed, specified in the Bryan-College Station Unified Design Guidelines (2007), range between 75 for natural woodlands and natural grasslands and 77 for landscaped area. Streets, building roofs, and parking lots contribute to the percentage imperviousness for each sub-catchment. The Storm Water Management Model (SWMM) (EPA 2008) was used for hydraulic simulation. SWMM is a dynamic rainfall-runoff simulation model for both flow and water quality of a single storm event or a long-term continuous storm event. It extracts the flow hydrograph information from HEC-HMS at subbasins to route hydrographs through sewers, conduits, and open channels (AECOM 2008). As the storm water infrastructure on West Campus consists of box and circular storm sewers and two tributaries of White Creek, the hydraulic model consists of a combination of links and nodes representing the storm water infrastructure.

A set of scenarios were considered and compared to the Existing Conditions, which are represented in the current model. A 2-year 24-hour rain event with a cumulative depth of 4.42 inches (112.3 mm) (TxDOT 2004) was used to evaluate new scenarios, including Predevelopment Scenario, Riparian Buffer System, Permeable Pavement, and Rainwater Harvesting.

Predevelopment Scenario. An aerial photograph from 1940 is available (Texas A&M University Libraries Map & GIS Collection and Services) and was used to build the model of the predevelopment conditions. In 1940, most of the university infrastructure was concentrated on Main Campus, and West Campus was generally undeveloped and covered with natural grassland. A curve number of 75 was adopted for these areas (Bryan-College Station Unified Design Guidelines 2007).

In the current scenario, delineation of sub-watersheds was forced by curb gutters, inlets, conduits, and manholes. As the storm sewer infrastructure had not been implemented in 1940, the existing delineation of the sub-watersheds was restructured to reflect the natural topography of the watersheds for pre-development conditions. After this restructuring, the total number of sub-watersheds modeled in the predevelopment scenario is 52, compared to 327 in the existing conditions. The present channel configuration and cross section of the open channel in Tributaries C and D were adopted from the 2008 conditions.

Riparian Buffer System. The riparian buffer system is modeled using the recommendations of the campus master plan which proposes a riparian buffer along the creek. The buffer is divided into three zones; the outer zone being an herbaceous or grass filter strip, the middle zone consisting of managed forest of fast growing or native species, and the inner zone being native species that are water-loving or water-tolerant. A model of the buffer strip is incorporated within the HEC-HMS-SWMM model. Appropriate sub-catchments were delineated representing the buffer on both sides of the creek. While the standard design manual specifies a curve number of 75 for both natural grassland and natural forest (The Bryan-College Station Unified Design Guidelines 2007), other research suggest a wide range of curve numbers for grass, brush and woods based on hydrologic condition (e.g. McCuen, 1989). To simulate the presence of a buffer strip, a sub-catchment is created for each zone (outer, middle, and inner) with a curve number that reflects the type of vegetation.

Permeable Pavement. Few studies have investigated the mechanistic modeling of pervious pavements. Leming et al. (2007) identified a method for calculating a curve number for pervious pavement, which is implemented for this study. This method approximates the initial abstraction as the volume of water stored by the pervious pavement, based on the depth and porosity of the pavement. The following equations are used to calculate the corresponding curve number for a system of permeable pavement designed to store a 24-hr 2-yr storm, as demonstrated in Leming et al. (2007):

$$I_a = P_{24-hr,2-yr} \text{ (mm)} \qquad (1)$$

$$S = \frac{I_a}{0.2} \text{ (mm)} \qquad (2)$$

$$CN = \frac{100}{\left(\frac{S}{254}+1\right)} \qquad (3)$$

where $P_{24\text{-}hr,2\text{-}yr}$ is the depth of a 24-hr 2-yr storm (mm); I_a is the initial abstraction (mm); S is the maximum potential retention (mm); and CN is the curve number.

For the 24-hr 2-yr storm of 112.3 mm, the curve number is calculated as 31.2. Currently in West Campus, 41% of the watershed is total impervious area and 6.5% of the watershed is uncovered asphalt parking lots. A weighted curve number approach is taken to calculate the new curve number for each sub-watershed, based on the acreage of pavement in that subbasin.

Rainwater Harvesting Systems. The approach taken to simulate the rainwater harvesting is similar to the simulation procedure for the permeable pavement, employing the assumption that the precipitation from a 2-year 24-hour storm event will be collected from the roof of buildings within the watershed. The curve number is calculated as 31.2, based on Eqns. 1-3. Buildings on West Campus provide a total roof area of 227,150 square meters, or 3.2% of the total area.

PRELIMINARY RESULTS

Based on the modeling approaches described above, the characteristics for four scenarios as implemented in Watersheds C and D were calculated and summarized in Table 1.

Table 1. Scenario characteristics

Scenario	Total Pervious Area (%)	Total Impervious Area (%)	Area Represented as LID (%)	Weighted Curve Number
Pre-development	93%	7%	-	76.6
Existing Conditions	73%	27%	-	82.7
Permeable Pavement	73%	20.6%	6.4%	78.4
Rainwater Harvesting System	73%	23.8%	3.2%	80.5

A set of preliminary results have been generated to demonstrate the hydrologic differences between the existing and pre-development conditions. Four catchments in West campus were further examined (Fig. 3). The characteristics of these catchments under pre-development and existing conditions are summarized in Table 2. Values for curve numbers increase by 5-13% (Table 2) for these catchments. The hydrographs at the outlets are generated for existing and pre-development conditions for the 24-hr, 2-yr rainfall event (Fig. 4). The impact of increased imperviousness is seen clearly in both the increased peak flow and decreased time to peak.

Table 2. Physical characteristics of four selected sub-watersheds.

Catchment	Area (km^2)	Pre-development Conditions			Existing Conditions		
		CN (perm. areas)	% Imp.	Weighted CN	CN (perm. areas)	% Imp.	Weighted CN
C North	0.48	75	3%	75.6	77	11%	79.3
C South	0.15	75	0%	75.0	77	20%	81.1
D North	0.84	75	26%	81.0	77	51%	87.8
D South	0.36	75	16%	78.6	77	60%	89.5

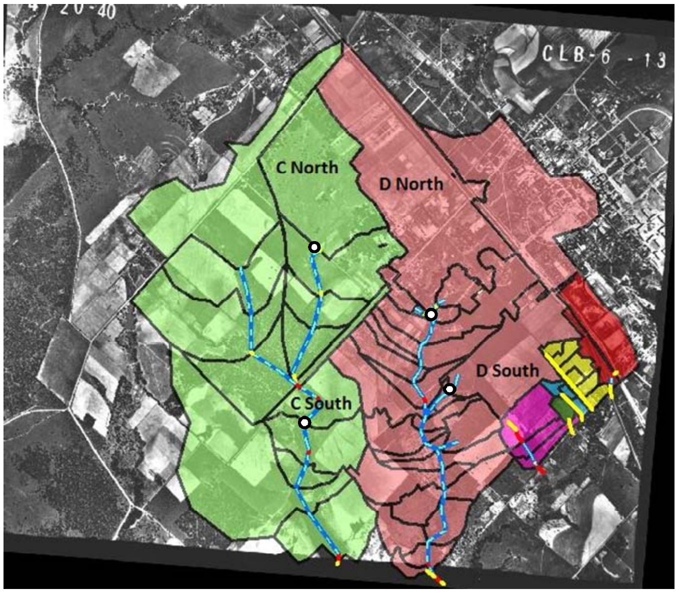

Figure 3. Location of four selected sub-watersheds on West Campus: C North, C South, D North, and D South, overlaying aerial photograph (Texas A&M University Libraries Map & GIS Collection and Services). Open circles show location of sub-watershed outlet.

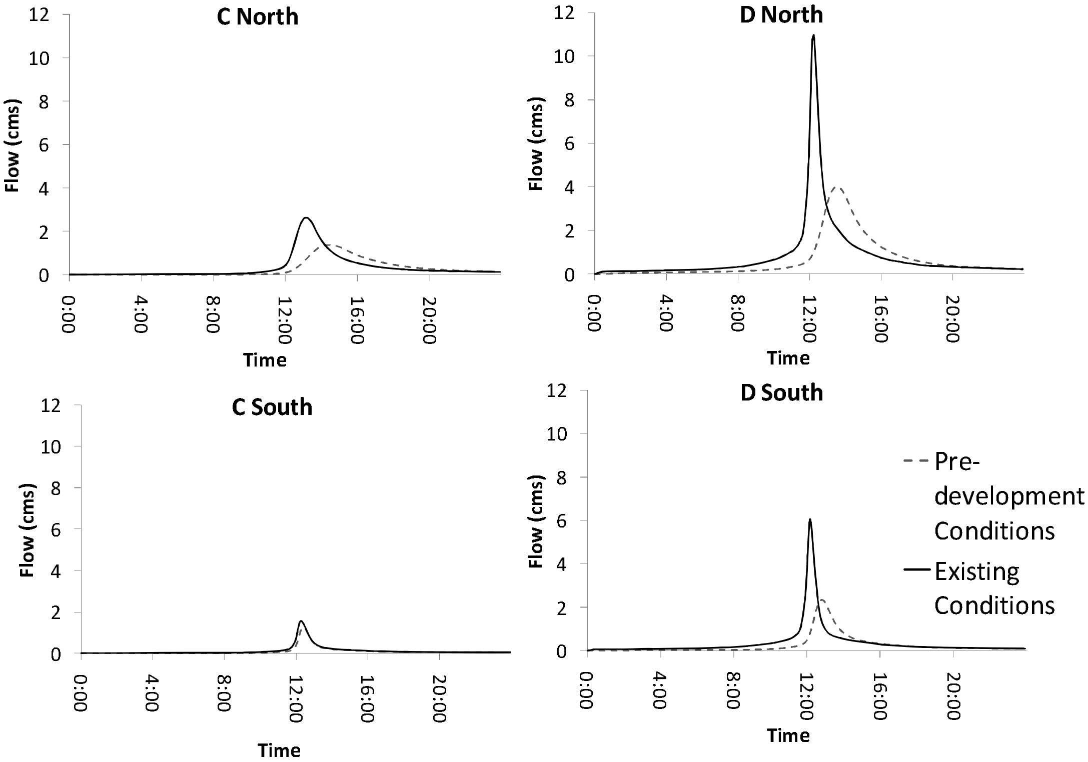

Figure 4. Hydrographs for pre-development and existing conditions at four selected sub-watersheds.

ONGOING WORK

This paper presents preliminary work to explore more hydrologically sustainable options for the current level and planned level of development in a campus watershed, as compared to pre-development conditions. LID strategies under consideration include both structural and ecological changes that may be designed and implemented to restore the creek to its predevelopment flow regime.

A Riparian Buffer System is suggested to improve both hydrological conditions and conditions for ecosystems. This system will be simulated to evaluate its contribution to hydrologic sustainability of the tributary. Two structural LID strategies, permeable pavement and rainwater harvesting systems, are designed to retain a 2-year 24-hour storm event so that there would be no runoff from these areas. Further modeling techniques will be explored to investigate the hydrologic performance of these LID strategies for 10-year and 100-year rainfall events. For larger events, rainfall that is not captured by the porous pavement will runoff as sheet flow. Rainfall that overflows the rainwater harvesting storage system will be discharged through the existing sewer system.

For future work, we will model the hydrologic effects of the development proposed in the master plan and investigate the effects of utilizing the three LID strategies described here.

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