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Using Stormwater Modeling in Iterative Site Design: An Integration of Techniques from Engineering and Landscape Architecture

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USING STORMWATER MODELING IN ITERATIVE SITE DESIGN: AN INTEGRATION OF TECHNIQUES FROM ENGINEERING AND LANDSCAPE ARCHITECTURE

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ABSTRACT

Landscape Architects currently do not have an efficient method for including stormwater quantities in early stages of their design process. With stormwater control infrastructure and theory rapidly shifting in favor of stormwater management with Green Infrastructure or Low Impact Development technologies (LIDs), landscape architects and planners are increasingly making layout and sizing decisions for stormwater design. Due to the development of modeling tools, it is now possible to rapidly produce quantifiable stormwater values for complex site designs at a range of scales. This paper proposes a methodology for the utilization of the EPA – Stormwater Management Model (SWMM), in conjunction with hand sketching, AutoCAD measured layouts and spreadsheet calculators, to quickly optimize stormwater detention based on spatial arrangements, sizing, and construction costs. Unlike available calculator-based methods, this model-centered methodology successfully simulates water quantity benefits of LIDs used in series. A twelve-acre development in Southeast Louisiana, broken into a 1.4-acre commercial site and 10.9-acre multi-family residential site, was designed using this multidisciplinary methodology. A total of fifty iterations were simulated, forty-one of which involved LIDs and twenty-nine of which included LIDs in sequence. Iterations were compared with pre-development flow rates and runoff volumes, and with each other in terms of stormwater performance and capital costs. The cumulative time required to set up and alter this thirty-eight subcatchment based model, run the almost instantaneous simulations, and track and cost the fifty iterations was less than 20 hours. Schematic and measured plan, section and

perspective sketches, as well as quick context analysis, were employed before modeling to determine appropriate type, sizing and layout of LIDs and after modeling to decide between the top quantifiably optimized designs. This integrated methodology provides the basis for more collaborative and quantitatively supported LID stormwater landscape designs by introducing efficient multidisciplinary modeling techniques at the beginning of the design process.

I. INTRODUCTION

Problems with Conventional Stormwater Design

The conventional view towards stormwater has been to remove it from development as fast as possible to prevent flooding. In urban areas, this approach has led to the installation of extensive underground pipe networks, pump stations, and concrete lined channels. However, more recently, scientists and designers have come to recognize the plethora of economic and environmental problems associated with the rapid concentration of stormwater (National Research Council 2008: 340). Generally, these are a result of (1) increases in the volume of runoff, (2) increases in the peak flow rates of runoff, and (3) increased pollutant loadings (EPA 2009: 5).

1. Increased volume of runoff

Trees, fallen leaves and branches, tall grasses and uneven ground catch rainwater and impede flow. When vegetated areas are converted to urban uses with impervious land cover, infiltration and evaporation transportation decreases. As a result, a significantly larger percentage of the rainfall becomes runoff (Ferguson 1998: 1-6). This increase in runoff volume increases flooding downstream. Conventional stormwater development can also cause upstream localized flooding when older infrastructure becomes overwhelmed. Overflow is especially foul and upgrades more costly for cities that have a combined sewer and stormwater infrastructure system.

2. Increased peak flow rate of runoff

In addition to infiltrating greater volumes of rainwater, natural systems impede flow, reducing the runoff flow rates. Conventional stormwater designs generally seek to provide the most direct removal of water in smooth straight channels and pipes. Therefore, increased urbanization and conventional stormwater designs, also known as gray infrastructure, increases stormwater flow rates and velocity, which in turn increases the runoff's potential for erosion and the water's ability to carry suspended solids and pollutants.

3. Increased pollutant loadings

Impervious surfaces collect oils, heavy metals, litter, bacteria and suspended solids with less decomposition and infiltration that vegetated areas (Ferguson 1998: 7). These pollutants easily wash off with even the small rainfall events and are carried downstream. The United States Environmental Protection Agency (EPA) considers stormwater runoff in urban areas as one the leading sources of water pollution in all water bodies in the United States (EPA 2009: i, EPA 2007: 1). Additionally, impervious cover absorbs and stores heat, which in turn increases the temperature of runoff (EPA 2009: 5). Temperature increases directly affect wildlife but it also indirectly decreases dissolved oxygen levels, which has a major impact on the health and abundance of fish and wildlife present in downstream waterways.

Benefits of Low Impact Development

In response to the negative effects of traditional stormwater infrastructure, designers in landscape architecture, engineering, architecture and planning, have looked to replicate the benefits of natural systems in storing, filtering and infiltrating stormwater through new stormwater interventions (ASLA et al: 4).

Green Infrastructure (GI) practices, low impact development controls (LIDs), best management practices (BMPs), sustainable urban drainage systems (SUSD), water sensitive urban design (WSUD) and low impact urban design and development (LIUDD) are different names for essentially the same technology and goals (Elliott and Trowsdale 2007: 394). These terms are used to describe interventions at a range of scales and types, from specific technologies to sustainable site practices but also an approach to regional planning (Benedict and McMahon 2006, 3). Structural GIs or LID devices include wetlands, ponds, swales, rainwater strips, rainwater tanks, green roofs, pervious pavement, planter boxes, cisterns, rain barrels and downspout disconnection. Non Structural GIs or LID approaches include designing building and road layouts to minimize imperviousness, improvement of infiltration ability of soils by amending the properties, maximizing vegetation land cover and selecting vegetation species that aid stormwater infiltration and pollutant uptake (Jayasooriya and Ng 2014: 2, Elliott and Trowsdale 2007: 395). Following the lead of Elliot and Trowsdale and most the EPA documents on the subject, this paper chooses to use the term LID because they particularly emphasize on site small-scale control of sources.

LID environmental benefits include the protection of downstream water resources, ground water recharge, pollution abatement, water quality improvements/ reduced treatment costs, reduced incidence of combined sewer overflows (CSOs), and habitat improvements. Land value and quality of life benefits include reduced downstream flooding and property damage, real estate value and property tax revenue, lot yield, aesthetic value, public spaces, regulatory compliance

credits and cost savings in regards to both installation and maintenance (EPA 2007: 6-10).

In addition to the direct benefits of better water management, LIDs have been credited with other ecological system services (ESS), including but not limited to energy savings, air quality improvement, mitigation of climate change by reducing greenhouse gases, reduction of urban heat island (UHI), healthier wildlife habitats and enhanced community livability with improved aesthetics, recreation, cultural resources and community character (Jayasooriya and Ng 2014: 2, Benedict and McMahon 2006: 118).

Need for LID Design Tools

There is considerable effort in academia, practice and many governmental bodies to produce case studies, design guidelines and regulations to promote the use of LIDs for stormwater management, ecological system services, and economic benefits. The United States Environmental Protection Agency (EPA), Water Environment Research Foundation (WERF), the American Society of Civil Engineers (ASCE), the American Society of Landscape Architects (ASLA), and local governments, particularly in the Pacific Northwest and Chesapeek Bay Area, are some of the most prolific of the public supporters of this literature.

One of the early guides was Prince George's County, Maryland's Low-Impact Development Design Strategies: An Integrated Design Approach report, published in 1999. The International Stormwater BMP Datatbase project began in 1996, and now features a database of over five hundred BMP studies, performance analysis results and costs. In 2007, the EPA provided a report on the stormwater retention

outcomes and cost savings of LID for seventeen case studies. More recently, the American Society of Landscape Architects collected 479 case studies provided by ASLA members to demonstrate to policymakers the value of promoting green infrastructure projects and how in many cases green infrastructure can be less costly than traditional gray infrastructure projects (ASLA, Stormwater Overview).

Unfortunately, despite the widespread knowledge of the benefits of LIDs by a range of professions, implementation has been slow. Some believe that it is because the benefits seem to good to be true and developers are skeptical, that there are lack of built case studies, or perhaps because there is a lack of design tools that operate efficiently or efficiently. According to Beecham (2002), the availability of effective LID modeling could encourage wider uptake of LID principles. Elliot and Thowsdale (2007) argue that the tools would make design and application of LID more efficient and that these could be used for education and policy development. This paper argues that though the design tools could certainly be improved, they do exist and can be used efficiently by a variety of design professions.

Approaches of Different Design Disciplines

Landscape architects are well equipped to contribute to the new paradigm of stormwater management design. "[Stormwater] is an environmental process, joining the atmosphere, the soil, vegetation, land use and streams to sustain landscapes (Ferguson 1998: 1)." Landscape architects are trained to harmonize biological processes and their ability to change and grow over time with the also changing cultural, social, and aesthetic goals of a site. All of these skills sets are essential as stormwater management shifts from underground pipes and hidden

canals to ecologically and socially functioning, accessible, visible spaces. For example, in the design of a rain garden, a landscape architect would locate the suitable place on site that fits with the overall aesthetic, doesn't interfere with circulation, works with existing hydrology, re-grade a portion of the site, remediate the soils so that they better infiltrate water, and specify water-loving vegetation. On a regional or municipality scale, landscape architects have typically assisted or been the lead on stormwater plans, which identify areas most sensitive to development and create incentives for the implementation of green infrastructure.

Engineers traditionally had professional jurisdiction over stormwater design projects because they were treated as a mechanical system. Gray infrastructure projects require extensive calculations to predict flow rates and optimize pipe sizing. The Rational Method for estimating peak flow rates has been a standard for stormwater design since modernization following World War II (National Research Council 2008: 340). The equation q=CIA correlates flow rate (q) with time based rainfall intensity (I), area of watershed (A), and the type of land cover represented by the runoff coefficient (C). This equation is run for each time step to produce hydrographs as shown in Figure 1. Values for rainfall intensity are based on hourly or twenty minute rain measurements for an actual storm or a hyetograph of a regionally relevant design storm. Time of concentration is also reflected in the time-based aspects of the equation. The time required to produce a hydrograph of a single design iteration with hand calculations can easily require upwards of eight hours. In addition to being time consuming, those trained in the rational method are typically only engineers. Web based and spreadsheet calculators have made

quantifying stormwater faster and more accessible to non-engineers. Software modeling packages allow for more user inputs and complex simulations than calculators. For example, the EPA – Stormwater Management Model (SWMM) can produce hydrographs for each component of a series of treatment systems for any user inputted rainfall distribution, whereas the EPA- National Stormwater Calculator, though downloads rainfall data, only provides a few annual runoff values as a reflection of the percentages of specific land covers.

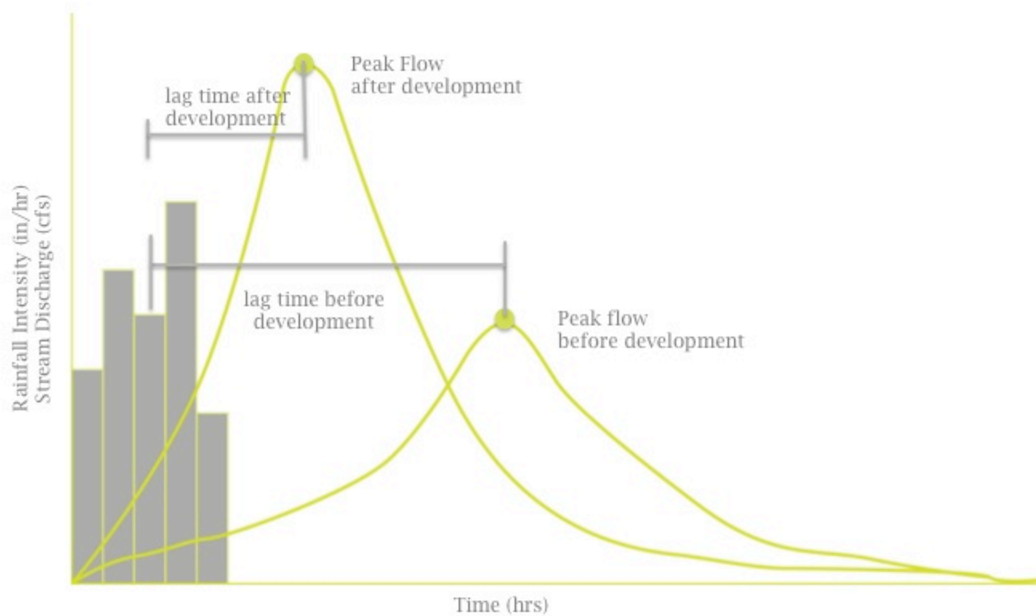


Figure 1: Typical Hydrograph. Hydrographs are used to illustrate volume and flow rates of rainfall events. Pre Development Conditions typically have more of a delay in time of concentration, smaller peak flow and smaller volume of water than Post Development Conditions.

Review of Stormwater and LID Modeling Tools

LIDs present a new challenge for stormwater modeling, as natural processes are complex and highly variable. Calculations and models are by definition a simplification of a phenomenon to a series of relationships. Therefore, LIDs are not as conducive to a computerized system or tool as gray infrastructure. Producing a

straightforward evaluation of LID drainage measures, especially when the tool needs to be applicable to a range of scales typical to urban stormwater management, is not an easy task (Elliot and Thowsdale 2007: 395).

In 2007, Elliot and Thowsdale published a review of models for low impact urban storage drainage, updating and building on an evaluation by Zoppou in 2001. Zoppou (2001) focused on the mathematical equations behind the modeling packages, whereas Elliot and Thowsdale (2007) focused on the suitability of software packages for designers. Jayasooriya and Ng (2014) further updated and built on Elliot and Thowsdale's review by looking at options for both stormwater modeling of LIDs and their economics. Other, less comprehensive evaluations of stormwater modeling tools with LIDs include Burton and Pitt (2001), McAlister et al. (2003), and Beecham (2002).

In Elliot and Thowsdale's review, ten models were compared in eight different ways to find that EPA – Stormwater Management Model (SWMM) and Model for Urban Sewers (MOUSE) were the most suitable to designers. SWMM and MOUSE showed the widest range of potential uses. Both were considered well suited for research, developing sizing rules for devices, planning of land use in catchments or cities, preliminary design or regional controls, and preliminary design of a subdivision or site. Both were marginally suited for detailed design of regional drainage systems, detailed design of subdivisions or sites, and site layout and materials selection. SWMM, MOUSE and MUSIC (Model for Urban Stormwater Improvement Conceptualization) have the finest temporal resolution, meaning they are best suited for small catchments. MOUSE used runoff coefficient and conceptual

rainfall-runoff in addition to SWMM's use of SCS Curve Number, Green-Ampt, and routing methods including, groundwater/baseflow, routing to drainage network, routing through devices, hydrologic routing in drainage network and hydraulic routing. MOUSE and SWMM were the only programs that included hydraulic routing. MOUSE is better suited for modeling BOD, dissolved oxygen and pathogens, but SWMM was deemed better suited for heavy metals. SWMM and MOUSE are both well-suited to model imperviousness reduction, ponds and wetlands, on site detention tanks, and swales. Both did not explicitly address soil protection, reduction of contaminant generation, infiltration trenches, rain tanks, bioretention, rain gardens, filtration devices and permeable paving (Elliot and Thowsdale 2007, 397- 402). Version 5.0 of SWMM has more features than the version evaluated in 2007. SWMM now has clear LID Controls for bioretention cells, rain gardens, green roofs, infiltration trenches, permeable pavement, rain barrels and vegetated swales. MOUSE's use is widespread outside of the USA, but the software costs approximately $5,000 (Elliot and Thowsdale 2007, 396). SWMM is widely used, especially in the USA, perhaps because it is free. Based on Elliot and Thowsdale's 2007 review and SWMM 5.0 LID Control updates, SWMM is the clear front contender for stormwater modeling with LIDs.

Jayasooriya and Ng (2014) expanded their review to tools that modeled the economics of green infrastructure as well stormwater management. Jayasooriya and Ng's 2014 paper is more useful to this paper's look at how economics could be integrated with stormwater modeling for multidisciplinary design decision-making.

They did not evaluate MOUSE, but like Elliot and Thowsdale, did analyze SWMM, MUSIC, and P8 UCM (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds). Benefits of MUSIC not included in Elliot and Thowsdale's review were centered around the propriety software's ability to evaluate cost effectiveness in addition to stormwater quantity reduction and quality improvement. The software has built in Australian costing and meteorological data (Jayasooriya and Ng 2014: 6). Like MUSIC, EPA –SUSTAIN (System for Urban Stormwater Treatment and Analysis Integration Model) interfaces with costing and meteorological data but from the United States. SUSTAIN is freely available to download and relatively new software. It has an ArcGIS based decision support system, several modules, Microsoft Access database and post-processor that uses Microsoft Excel. Due to additional software packages to run it, SUSTAIN was not used in this study but is recommended for consideration in future interdisciplinary methodology studies. The more accessible, free and spreadsheet based Water Environment Research Federation (WERF) BMP and LID whole life cycle cost modeling tools, reviewed by Jayasooriya and Ng (2014), were selected for cost estimation of LID practices.

II. PURPOSE

The purpose of this project is to provide a methodology to encourage landscape architects to use stormwater modeling and to apply it at early stages of the design process. The incorporation of quantitative and routing feedback early in the design process will enable spatial designers to optimize performance. The target audience is primarily landscape architects but the developed methodology is intended to be quickly applied by planners, architects and engineers for iterative site design. This methodology proposes a short hand way of modeling that lends itself to rapid changes and integrates the stormwater modeling with quantitative and qualitative design techniques and variables shown in Table 1.

Table 1: Quantitative and qualitative variables and respective techniques

Variable	Technique for Determination
QUANTITATIVE	
Stormwater	
Volume of runoff	SWMM
Flow rate of runoff	SWMM
Time of peak concentration	SWMM
Land Use	
Parking Requirements	area specific regulations & Spreadsheet
Open Space Requirements	area specific regulations & Spreadsheet
Client/ Developer Requirements	
Cost	
Building Revenue	estimations & Spreadsheet
Construction Costs of Specific GI/LIDs	WERF
QUALITATIVE	
Layout & Placemaking	
Viewsheds	hand sketching plan & perspectives
Site Organization/ Wayfinding	hand sketching plan & perspectives
Efficiency of Circulation	hand sketching plan
Preservation of Existing Features	hand sketching plan & sections
Relevant LIDs	hand sketching sections, pulling precedent images
Watersheds & Grading	hand sketching & AutoCAD

The development of this methodology draws particularly from how landscape architects have historically derived tools and research from a plethora of other disciplines. For example, before landscape architects begin design, they typically have to research the topography (geology), the user groups (sociology) and how they play out spatially (geography), then diagram (graphic design) and map (land surveying) these phenomena. When landscape architects create a base plan they typically do concept sketches by hand (art), then measured drawings by hand or computer (engineering) and then scan or export these into Adobe Photoshop to color and shade (art) and finally export to Adobe Illustrator or InDesign to label (graphic design). This methodology will apply tools originally developed by engineering, soil science, hydrology, art, architecture, and economics, some of which already have been adopted by landscape architects.

III. METHODOLOGY

This paper proposes a methodology that integrates stormwater quantification techniques traditionally reserved for engineers with techniques already employed by landscape architects. These techniques produce quantitative and qualitative outputs and are summarized in Table 1. They include spreadsheets, hand sketching and AutoCAD with SWMM. The input and output connections between the techniques are illustrated in Figure 2, which highlights the cyclical nature of this methodology.

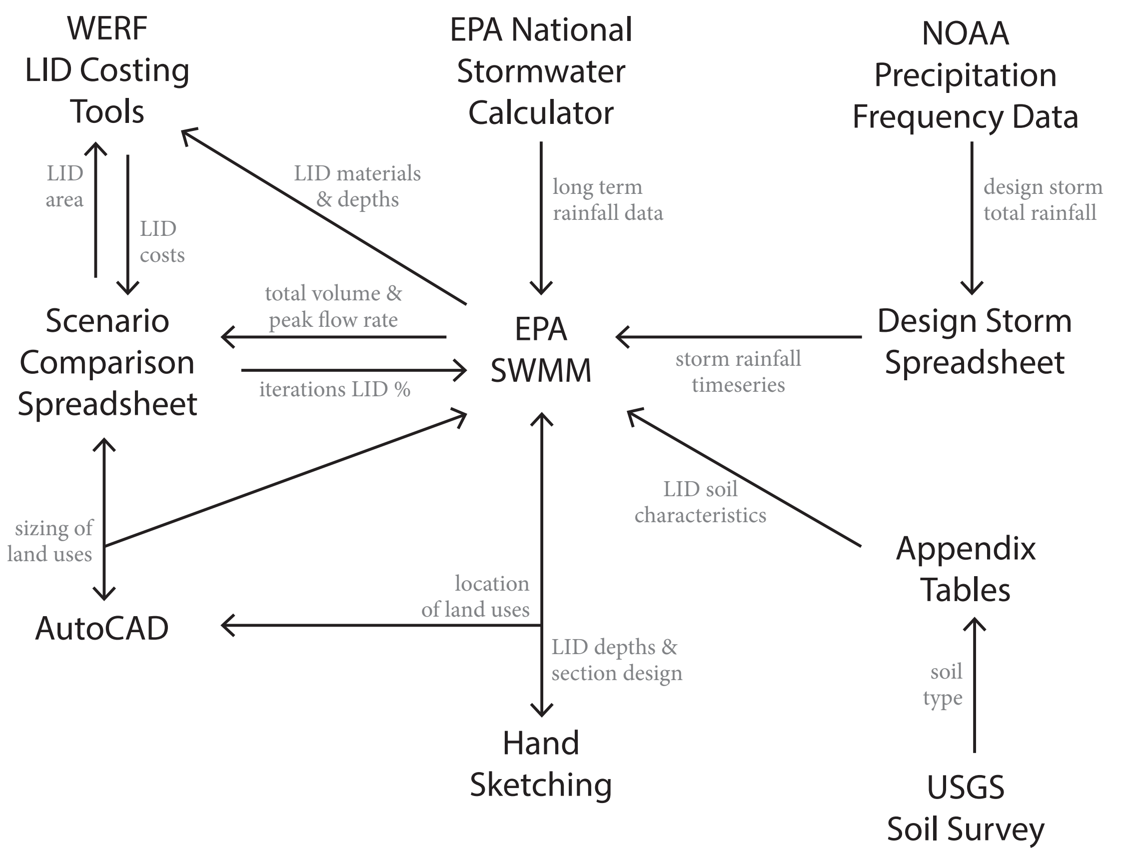


Figure 2: Input and Output Connections between Techniques in Proposed Methodology

Stormwater Modeling

Stormwater Management Model (SWMM) was developed in the late 1970s by the United States Environmental Protection agency for hydrologic and hydraulic water modeling. The hydrologic features include a required rainfall time series and subcatchments whos area, flow length, percent impervious, manning's roughness coefficients, and depression storages can be inputted. The hydraulic features include nodes (junctions, storage units and outfalls) and links (conduits, pumps, weirs, orifices and outlets) with required elevations and inputs available for length, roughness coefficient, and cross section size and shape. LID Controls were added to the most recent version of SWMM, but there are varying perspectives on the best way to use them (Rossman et al 2009, 74). These methods will be discussed in conjunction with routing and the selection of a shorthand method of homogeneous subcatchments based on land uses. Simulations can be run for a single event, or long-term daily rainfall data can be uploaded to run a continuous simulation. Simulations for a single event take usually less than a few seconds to run, but continuous simulations usually require a few minutes. The processing speed of one's computer and daily data for more than 20 years may increase the length of time required for simulations.

Rainfall Data & Simulation Set-Up

Design storms are manually inputted into SWMM as a time series. For this SCS distribution curves were selected and specifically SCS Type III because the application sites were in Louisiana. Figure 3 shows the fractional distribution of total rainfall for SCS Type III 24 hour storm in intervals used to create a time series

for SWMM.   The total rainfall for each design storm event for each location was selected using the NOAA's National Weather Service Hydrometerological Design Studies Center Precipitation Frequency Data Server interactive map (available at http://hdsc.nws.noaa.gov/hdsc/pfds/) and its outputted precipitation frequency chart. The design storms of interest were the 2 year 24 hour storm, 10 year 24 hour storm, and the 100 year 24 hour storm. The rainfall distributions for these design storms for the application site as they were inputed into SWMM time series are listed in Table A.1.

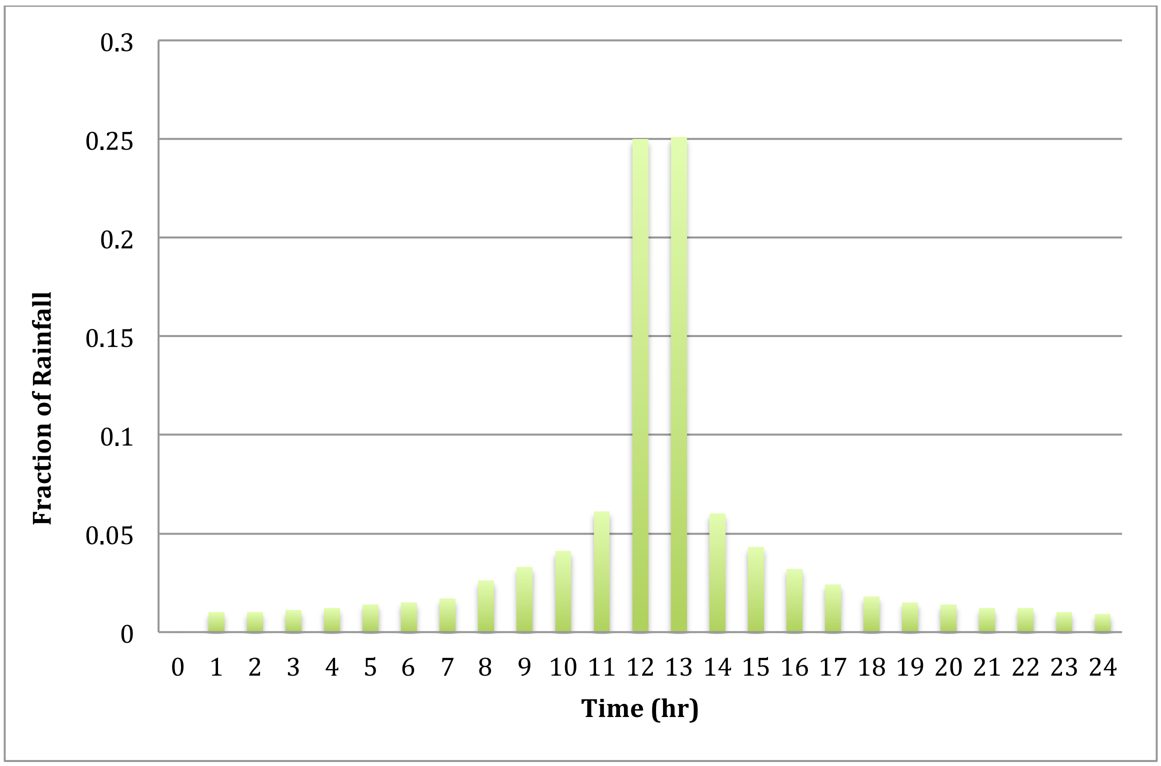


Figure 3: SCS Type III 24 hour design storm rainfall distribution

For the Application site in Hammond, 33 years worth of daily rainfall data was generously provided by the Southern Regional Climate Center for the Hammond 5 E location (Station ID: 164030) and plotted in Figure 6.   A new and easier way to obtain long-term rainfall data is to download the EPA National

Stormwater Calculator from http://www2.epa.gov/water-research/national-stormwater-calculator, navigate to your site, select a rain station and download the .dat file. Including time required to download the Stormwater Calculator, obtaining a site-specific .dat file from anywhere in the United States can be completed in under twenty minutes. The EPA National Stormwater Calculator, like EPA- SWMM, can only be run on a Windows operating system. The major advantage of downloading rainfall data downloaded from this source is that it is already formatted for SWMM use. To use it in SWMM, the rain gage to Data Source was changed to “File”, the Station ID number was provided, and the File uploaded in the File Name option. Simulation Date and Time Steps were altered to the fit the time period of the data. To find the dates, the .dat file was imported and read in Excel. For this project, roughly hourly data was available from December 2nd, 1983 to December 6th, 2006. When run through the SWMM model, the simulation took about five minutes to process and to retrieve a hydrograph (shown in Figure 4), another five minutes.

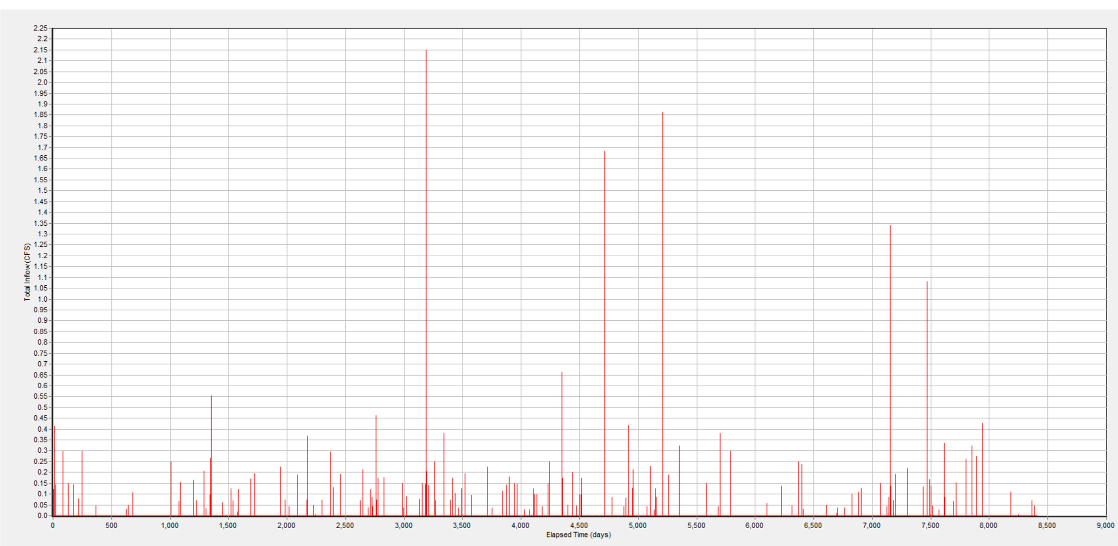


Figure 4: Hydrograph of Runoff with 23 years of Hourly Rainfall Data

In addition to showing the peak runoff values and hydrographs, SWMM can be used to create statistical reports on the rainfall itself as well as through different objects in the model (as shown in Figure 5). These capabilities showcase the power of SWMM for making arguments to stakeholders, but running simulations with design storms and actual events are more practical for the iterative design process.

Σ Statistics - System Precipitation

Summary | Events | Histogram | Frequency Plot

Rank	Start Date	Event Duration (hours)	Event Total (in)	Exceedance Frequency (percent)	Return Period (years)
1	08/26/1992	12.0	7.000	0.24	24.00
2	05/12/2004	7.0	5.600	0.49	12.00
3	10/26/1996	6.0	5.200	0.73	8.00
4	12/11/1983	4.0	5.163	0.97	6.00
5	06/30/2003	6.0	4.900	1.21	4.80
6	11/24/1986	6.0	4.000	1.46	4.00
7	04/04/1993	6.0	3.900	1.70	3.43
8	04/28/1998	3.0	3.800	1.94	3.00
9	08/12/1987	8.0	3.800	2.18	2.67
10	09/16/1994	5.0	3.700	2.43	2.40
11	03/07/1998	7.0	3.600	2.67	2.18
12	05/08/2001	6.0	3.500	2.91	2.00
13	10/26/1995	1.0	3.500	3.16	1.85
14	04/14/1996	3.0	3.300	3.40	1.71
15	06/06/2001	6.0	3.175	3.64	1.60
16	10/08/1999	3.0	3.000	3.88	1.50
17	03/15/1990	4.0	2.900	4.13	1.41
18	10/25/2002	3.0	2.825	4.37	1.33
19	01/20/1993	5.0	2.800	4.61	1.26
20	07/04/2003	2.0	2.800	4.85	1.20
21	01/05/1990	4.0	2.697	5.10	1.14
23	06/05/1994	2.0	2.600	5.58	1.04
23	06/29/1995	2.0	2.600	5.58	1.04
24	10/09/2004	2.0	2.575	5.83	1.00
25	06/24/1991	1.0	2.573	6.07	0.96
26	04/11/2004	2.0	2.501	6.31	0.92
27	05/19/1997	1.0	2.500	6.55	0.89
28	07/08/1999	1.0	2.400	6.80	0.86
30	03/05/1992	3.0	2.400	7.28	0.80
30	06/12/1987	2.0	2.400	7.28	0.80
31	11/16/1987	2.0	2.300	7.52	0.77
32	02/05/1991	3.0	2.300	7.77	0.75

Figure 5: Statistical Report showing Precipitation Events for Hammond. Hurricane Andrew is easy to find at the top of the list.

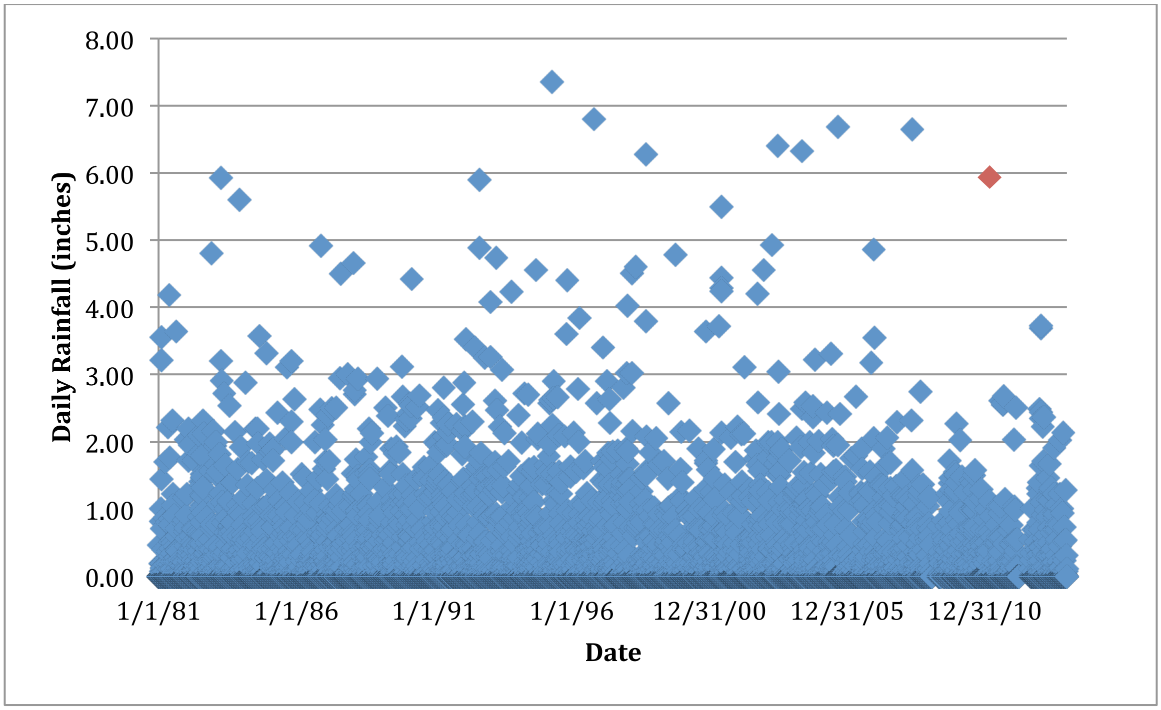


Figure 6: Daily Rainfall Totals for Hammond, LA (Station ID:164030) 1981 to 2014 based on data from the Southern Regional Climate Center

Long-term daily rainfall data can be used to select a real event. Figure 6 shows daily rainfall totals provided by the Southern Regional Climate Center and the selected 21 hour 6.77 inch rainfall event on March 4th and 5th, 2011. The roughly 20-minute data for this event was downloaded for the Hammond Airport weather station at NOAA's NNDC Climate Data Online and reformatted as hourly data and then manually inputted as an additional time series in SWMM. This date was selected because this source only had data for the Hammond Airport dating back to 2001 and hourly data sets for other large storms dates were incomplete.

The General Simulation Options were at Green Ampt as the Infiltration Model Option and Dynamic Wave for the Routing Model. Date Options were set up to allow 47 hours of simulation. Time Step Simulation Options were set up for one minute for Reporting, Runoff Dry Weather and Runoff Wet Weather. Routing was set at fifteen

seconds. A Rain Gage component was added and all iterations are run with the 10-yr 24 hour design storm time series selected unless otherwise stated. Monthly evaporation data from NOAA 1982 report was added under Climatology Editor. For the Hammond site, pan evaporation rates from a station in Baton Rouge were used and are summarized in Table 2.

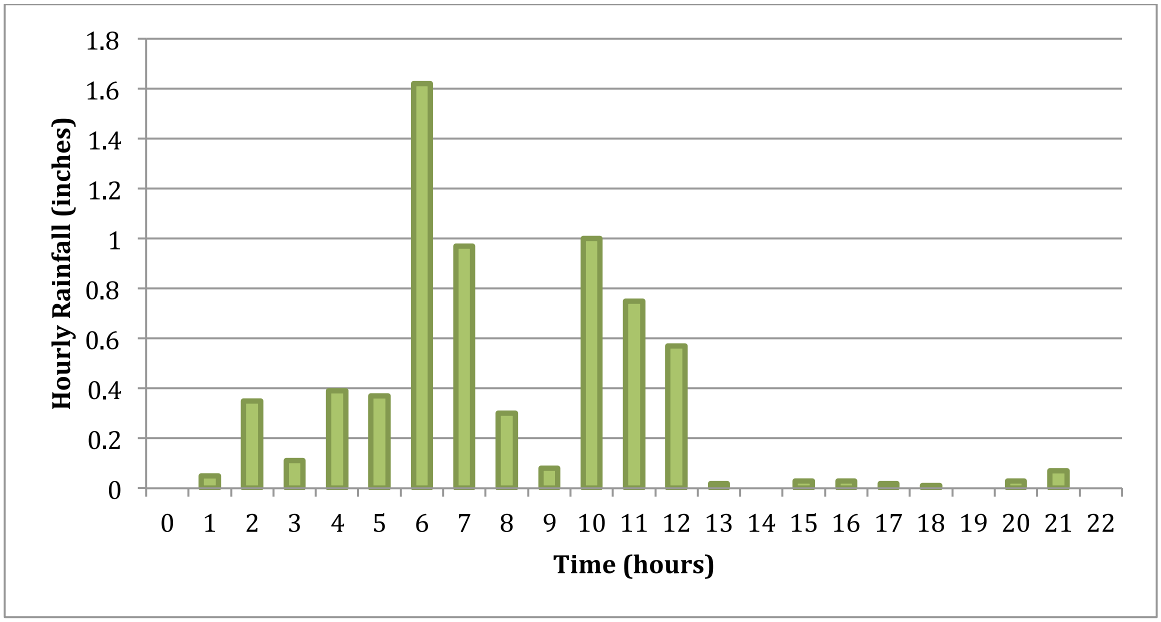


Figure 7: Rainfall Intervals for Actual Event in Hammond, LA on March 4th-5th, 2011

Table 2: Monthly Evaporation (in/day) for Baton Rouge: LSU Ben-Hur Exp station (NOAA 1982, 38).

Month	Monthly Evaporation (in/day)
January	0.075
February	0.119
March	0.156
April	0.214
May	0.232
June	0.257
July	0.216
August	0.205
September	0.182
October	0.169
November	0.114
December	0.082

Subcatchments

For this project, subcatchments and outfalls were the most popular components used to simulate hydrologic flow on site. Sample post development (PostD) subcatchment parameters are shown in column titled “PostD Value” of Table 3. The N and Dstore values represent the Manning’s n roughness coefficient and coefficient for Depression storage and are based on values from Tables A.2 and A. 3. Flow width, slope, percent impervious and the coefficients were different for predevelopment (PreD) conditions to simulate pasture or tree undergrowth as opposed to lawn, buildings and parking lots.

Table 3: Sample Subcatchment Parameter Values

Property	PreD Value	PostD Value
Name	S4PreD	S4
Rain Gage	Gage 1	Gage 1
Outlet	Out4PreD	Out4
Area (acres)	1.416	1.416
Width (ft)	300	134
% Slope	1	6.365
% Imperv	0	77.236
N-Imperv*	0.01	0.01
N-Perv*	0.4	0.1
Dstore-Imperv*	0.05	0.05
Dstore-Perv*	0.3	0.1

Area for the subcatchment is occasionally estimated with AutoLength On or was manually inputted into the list of parameters based on calculations in Excell or AutoCAD. To aid iterative site design, an Excel spreadsheet was developed to calculate and track sizing requirements for subcatchment inputs. A screenshot of this spreadsheet in use is shown in Figure 28 found on page 41. The outfalls for each subcatchment were set as another subcatchment or as a hydraulic outfall. Dotted lines showed up on the map when components were successfully connected.

Figure 8 shows a screenshot of the SWMM model with the Subcatchment Editor open.

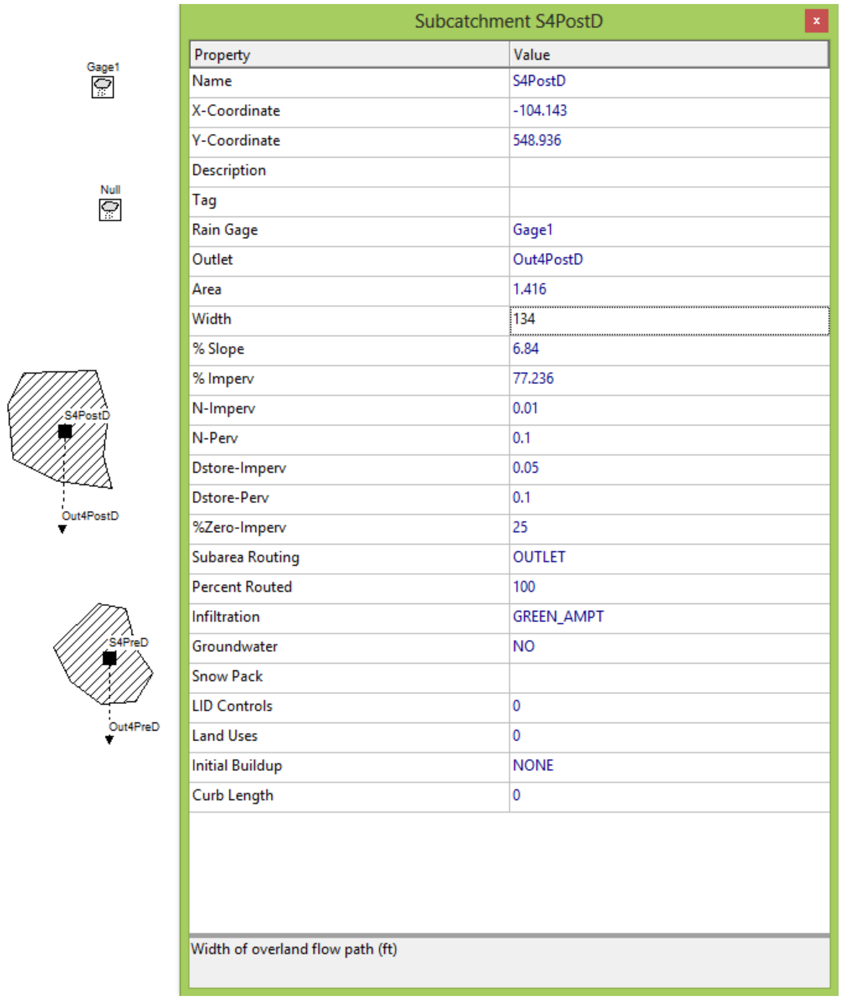


Figure 8: Screenshot of SWMM model PreD and PostD Subcatchments

LID Controls

In Version 5.0, LID Controls were added to SWMM. They are a hydrologic component that are applied to subcatchments to calculate infiltration and storage much like "Land Uses" are applied to calculate pollutant concentrations. Application of an LID to a subcatchment is shown in Figure 9, but before they can be applied, LID Controls have to be created and parameters defined with the LID Control Editor shown in Figure 10. USGS Soil Survey is used to determine the soil

type, then Table A.2 in EPA User Manual (or Table A.4 in this paper) is used to determine Porosity, Field Capacity, Wilting Point and Conductivity of that soil type and applied to the LID Control Parameters.

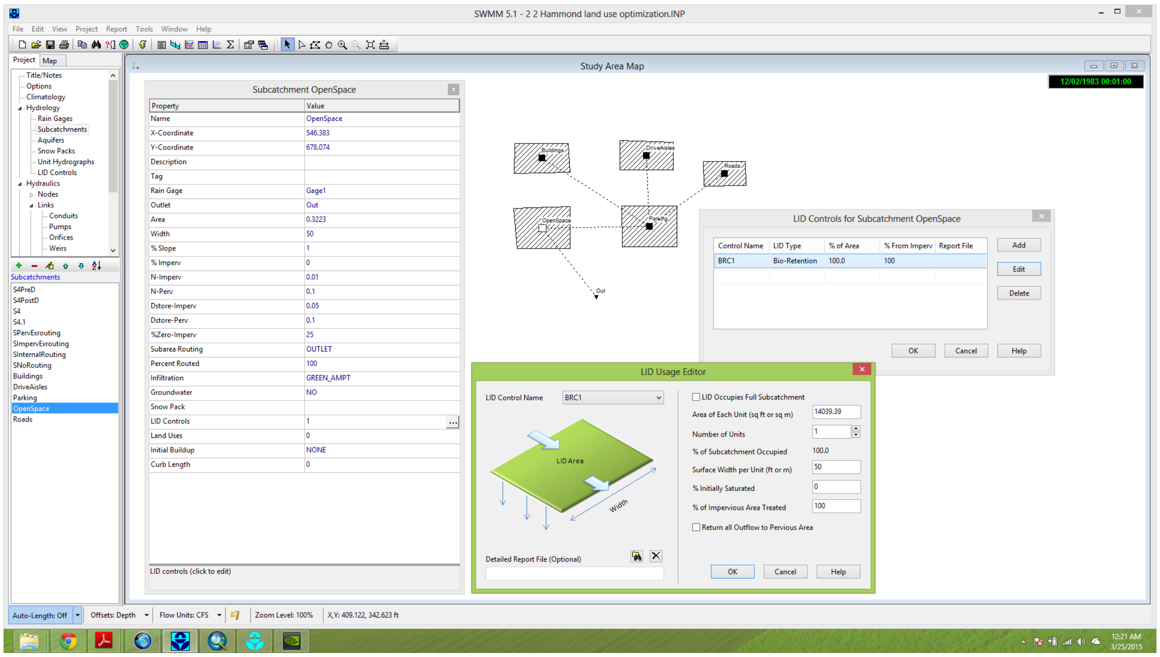


Figure 9: Application of LID Control to Subcatchment

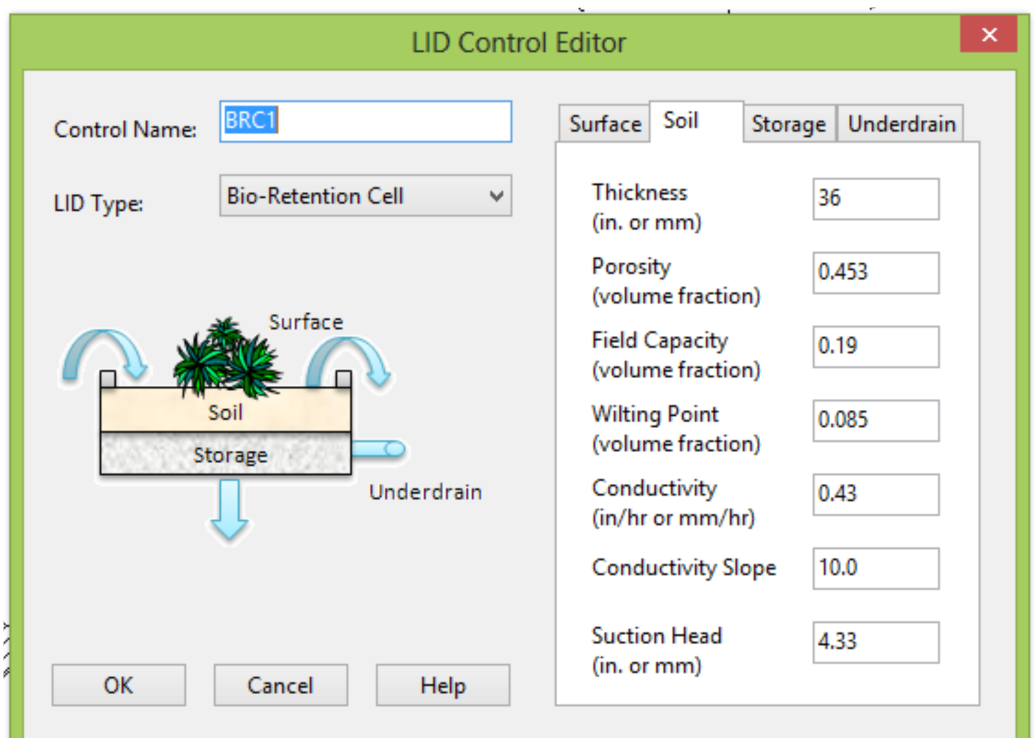


Figure 10: Setting up LID Control Parameters

Routing

In Chapter 4 of the SWMM Application Manual, Rossman et al. (2009) advise that when LIDs are inserted they are modeled as a separate subcatchment (Rossman et al. 2009: 74). This requires redrawing of the original subcatchment and drawing a second subcatchment. To avoid redrawing the original subcatchment, the LID subcatchment can drawn over the original subcatchment and be assigned a "Null Rain Gage." This rain gage is set with a time series with two points (0 hr, 0 inches of rainfall) and (24 hr, 0 inches of rainfall). This allows for two subcatchments to overlap without double counting the rainfall for the overlap area. Alternatively, the original subcatchment does not have to be redrawn, but the Sub-Area Routing option for a Subcatchment can be used to define that a percentage of the impervious area is routed to the pervious portion of the site and vis versa. A third option for routing is to indicate the percentage of impervious area routed to the LID when an LID Control is applied to a percentage of a subcatchment. The last two options are less flexible because they require that the LID must have the same slope and width as the rest of the subcatchment (Rossman et al. 2009: 74). Furthermore, Sub-Area routing can be more difficult to track and change as LIDs are switched out in different iterations.

Several experiments were conducted to compare the runoff of different routing methods. First, three different routing conditions were compared with no LIDs. The routing of pervious and impervious section for each of the three conditions is diagrammed in Figure 11. "No Routing" is created by allowing Sub-Area Routing option to remain as "Outlet". This input indicates for the SWMM

program to calculate the impervious and pervious portions of a single subcatchment separately and both portions of the subcatchment flow directly to the outlet. This approach does not allow for treatment of the impervious portion of the site through the pervious portion.

(a) No Routing

(b) Internal Routing

(c) External Routing

Figure 11: Routing Conditions Tested

The “Internal Routing” condition is created by setting the Sub-Area Routing option to “Pervious” and Percent Routed to “100”. This input routes 100% of the impervious portion of the site through the pervious portion, but the flow width and slope for each portion of the site can not be differentiated. The “External Routing” condition is created by setting up two subcatchments in series, each with Sub-Area Routing option remaining as “Outlet”. The first subcatchment is set with 100% impervious, its area is set to the area of the impervious area being modeled, and its

outlet being the pervious subcatchment. The second subcatchment is set with 0% impervious and its area is set to the area of the pervious area being modeled.

The results shown in Figure 12, indicate that the flow rate is similar for all three routing conditions but that “No Routing” has significantly more total runoff volume than the other two routing conditions tested. “No Routing” doesn’t allow for infiltration of the impervious portion via the pervious portion of the site, whereas both internal and external routing do. Internal Routing is less precise than External routing because the pervious area flow width and slope can not be different than the impervious portion, but this difference is marginal. The flow rates are the same for internal and external routing with an LID and the total volume difference is less than one percent.

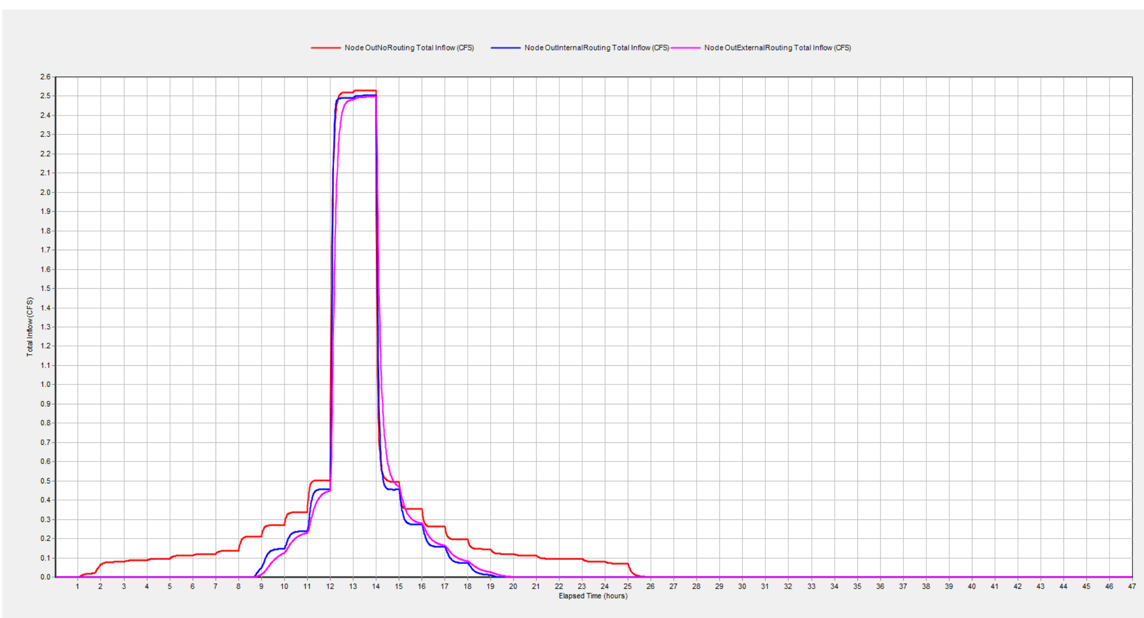


Figure 12: Hydrograph of Routing Conditions Tested

Internal and external routing do however have large differences in both flow rates and total runoff volume when LIDs are modeled. For all three conditions, an LID Control: BRC2, whose parameters are described in Table 6 on page 41, is

applied to the entire pervious portion of the site. In all three conditions, the flow width is set to 50’ and % of Impervious Area Treated is set to 100%. The results shown in Figure 13 and compared with Figure 12 , indicate that in Internal Routing, there is an overall approximately 1/5th reduction in flow rate and total volume, but the shape of the flow distribution is just a slightly squished version of the no LID version of Internal Routing.

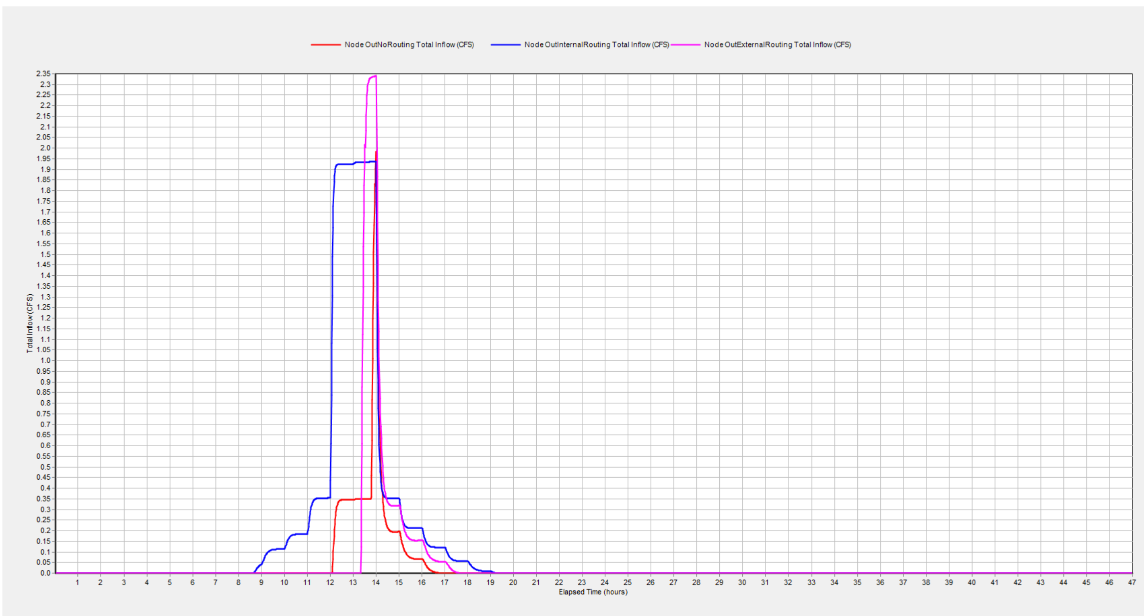


Figure 13: Hydrograph of Routing Conditions with LID Control applied to Pervious

The External and No Routing with LID conditions distributions tell more of a story. The No Routing conditions show that there is no flow, but after an increase in rainfall, there is some flow, then a sharp overflow of the LID that creates a brief high flow event. This no flow to slow flow is probably due to the pervious portion of the site being able to hold some of its own runoff for lower rainfall rates. This result indicates that the LID may treat the pervious portion of the model. This does not correlate to the real world because the LID would treat any rainfall that falls in an LID that takes up 100% of the pervious portion. The External Routing hydrograph

shows no flow then sudden but longer peak once the LID is filled and overflows. Because there is no flow before the overflow moment, it is known that the LID is treating 100% of the site.

More complexity can be added to the external routing with storage unit nodes and conduits to simulate drains from the ponds or bioretention cells. The addition of this form of modeling allows for dramatic decreases in flow rates and increases in time of concentration, both of which are major goals of green infrastructure and impossible to model with volume based calculators. The hydrograph in Figure 14 compares the simulation of Bioretention Cell being modeled as Storage Units and Conduits, shown in Figure 15, with simulation of Bioretention Cell as LID Controls to highlight the dramatic and powerful potential of using the hydraulic modeling of LIDs in SWMM.

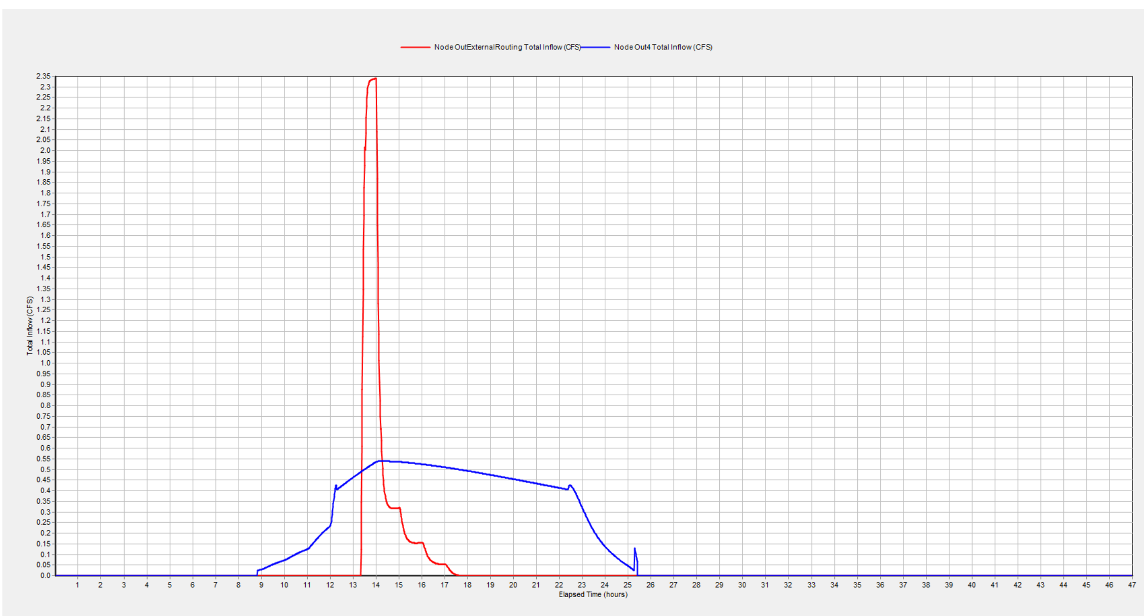


Figure 14: Hydrograph of External Routing with Storage Unit and Conduits simulating Bioretention Cell and External Routing with LID Control simulating Bioretention Cell

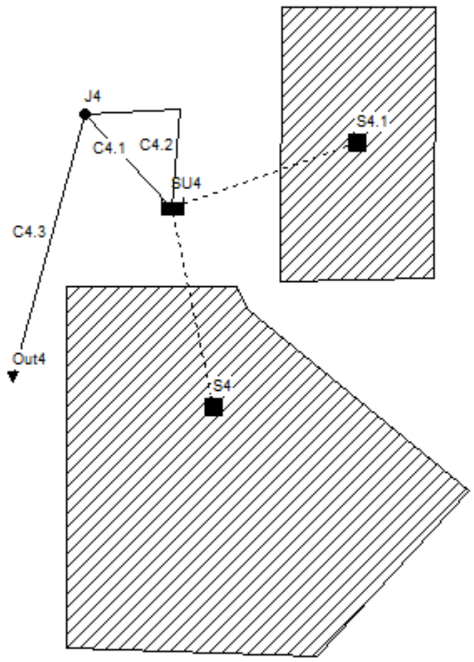


Figure 15: External Routing with Storage Unit and Conduits

Unfortunately, once flow has been channelized it cannot be dispersed once again in a subcatchment. Any treatments further in the treatment train will have to be modeled with hydraulic elements rather than hydrologic LID Controls. Due to the time it takes to model hydraulic elements, it is advisable to use only hydrologic elements (subcatchments with LID Controls that either flow to other subcatchments or final outlet) in early stages of design to compare differences in total runoff volume and add hydraulic elements when less spatial iteration are being considered to refine and reduce flow rates.

This paper proposes an extension of the External Routing method proposed by the SWMM Application Manual. Instead of just LIDs being modeled as separate subcatchments, this paper proposes that all land uses be drawn as a separate subcatchment. This approach is similar to the employment of homogeneous subcatchments based on land use by Joksimovic and Alam (2014) to test LID control

applications. However, the dramatic departure is that generalized subcatchments are drawn once for each land use for each sub-watershed and the subcatchment parameters may be quickly changed to reflect land use sizing and routing options in addition to LID application and sizing. The generalized subcatchments allow for use of SWMM early in the design process when sizing and layout decisions are made for the overall site. As a result, LID application can help direct the overall site layout and iterative site design can be better based on optimized LID performance.

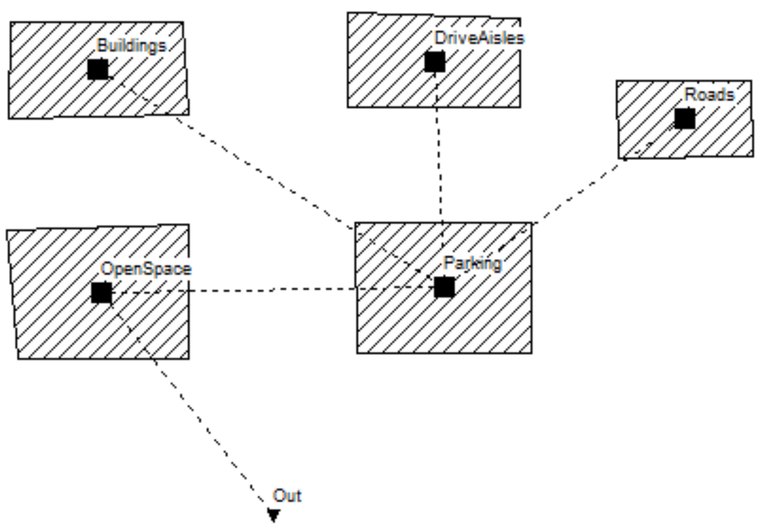


Figure 16: Screenshot of SWMM Subcatchments drawn based on Land Uses

Simulation Results

Whenever a scenario or iteration is drawn, with at least one subcatchment and outlet, a simulation can be run. For a time series with 26 inputs the simulation takes only a couple of seconds. The error was always usually less than 1% but sometimes increased if there was flooding at a node or surcharge in a conduit with more complicated hydraulic models. Summary results, shown in Figure 17, provided the peak rate of runoff, time of peak runoff and total runoff volume. These

three values are what engineers primarily use to compare to stormwater goals outlined in local stormwater codes. These codes are usually based on predevelopment conditions or volume detention requirements. Therefore, it is these values that are included in the Scenario Comparison Spreadsheet, shown in Figure 18.

Summary Results

Subcatchment Runoff — Click a column header to sort the column.

Subcatchment	Total Precip in	Total Runon in	Total Evap in	Total Infil in	Total Runoff in	Total Runoff 10^6 gal	Peak Runoff CFS	Runoff Coeff
S4PreD	7.53	0.00	0.02	5.08	2.43	0.09	1.92	0.322
S4PostD	7.53	0.00	0.10	1.11	6.32	0.24	2.53	0.839
S4	7.53	0.00	0.12	0.00	7.41	0.22	2.08	0.984
S4.1	7.53	0.00	0.01	4.99	2.52	0.02	0.45	0.335
SPervExrouting	7.53	25.13	0.16	12.34	6.67	0.06	2.34	0.204
SImpervExrouting	7.53	0.00	0.12	0.00	7.41	0.22	2.08	0.984
SInternalRouting	7.53	0.00	0.12	2.45	3.70	0.14	1.94	0.491
SNoRouting	7.53	0.00	0.11	3.59	0.95	0.04	1.98	0.127
Buildings	7.53	0.00	0.12	0.00	7.41	0.07	0.66	0.984
DriveAisles	7.53	0.00	0.12	0.00	7.41	0.04	0.39	0.984
Parking	7.53	12.47	0.12	0.00	19.87	0.22	2.08	0.994
OpenSpace	7.53	25.14	0.04	11.75	20.87	0.18	2.50	0.639
Roads	7.53	0.00	0.12	0.00	7.41	0.03	0.26	0.984

Figure 17: Summary Results

	A	B	C	D	E	F	G	H	I	J	K
77											
78		PP1 & BRC1	Name	Building	DriveAisles	Roads	Parking	Open Space			
79	Price:	$430,000	Outlet	Parking	Parking	Parking	Open Space	Out			
80			Area (acres)	0.344352617	0.203856749	0.137741047	0.407713499	0.322337006			
81			Width	50	20	25	20	20			
82			% Slope	25	1	1	1	1			
83			% Imperv	100	100	100	100	0			
84			LID Control	0	0	0 PP1		BRC1			
85											
86			Peak Flow (cfs)	0.66	0.39	0.26	1.09	1.56	-0.36	under	
87			Volume (gallons)	70,000	40,000	30,000	100,000	40,000	-50000	under	
88											
89											
90		only BRC1	Name	Building	DriveAisles	Roads	Parking	Open Space			
91	Price:	$240,000	Outlet	Parking	Parking	Parking	Open Space	Out			
92			Area (acres)	0.344352617	0.203856749	0.137741047	0.407713499	0.322337006			
93			Width	50	20	25	20	20			
94			% Slope	25	1	1	1	1			
95			% Imperv	100	100	100	100	0			
96			LID Control	0	0	0	0 BRC1				
97											
98			Peak Flow (cfs)	0.66	0.39	0.26	2.08	2.37	0.45	over	
99			Volume (gallons)	70,000	40,000	30,000	220,000	90,000	0	on target	
100											
101											
102		**only BRC2**	Name	Building	DriveAisles	Roads	Parking	Open Space			
103	Price:	$250,000	Outlet	Parking	Parking	Parking	Open Space	Out			
104			Area (acres)	0.344352617	0.203856749	0.137741047	0.407713499	0.322337006			
105			Width	50	20	25	20	20			
106			% Slope	25	1	1	1	1			
107			% Imperv	100	100	100	100	0			
108			LID Control	0	0	0	0 BRC2				
109											
110			Peak Flow (cfs)	0.66	0.39	0.26	2.08	2.31	0.39	over	
111			Volume (gallons)	70,000	40,000	30,000	220,000	60,000	-30000	on target	
112											
113											
114		only PP2	Name	Building	DriveAisles	Roads	Parking	Open Space			
115	Price:	$240,000	Outlet	Parking	Parking	Parking	Open Space	Out			
116			Area (acres)	0.344352617	0.203856749	0.137741047	0.407713499	0.322337006			

Senario 3 | Senario 2 | Senario 1

Normal View | Ready | Sum=0

Figure 18: Screen Shot of Excel file comparing iterations

Hydrographs are also available to track runoff rates and volumes against time for each component of the SWMM model. The ability to produce a hydrograph is what sets this software apart from stormwater calculators. When comparing iterations, the production of hydrographs may not be the primary focus, but it is extremely useful to have them as a resource to understand when flow rates and volumes change. When LIDs are used, hydrographs can show how much of the rainfall is being treated and at what point interventions fill and begin to overflow. Similarly, the cross section tool offers an animation of the depth of the water in hydraulic features.

LID Costing

Most firms have their own spreadsheets or rough costing methods, but for this project the Water Environment Research Foundation (WERF) LID Costing Tools were applied. These tools have the ability to compute capital, maintenance, and whole life cycle costs as well as more complex present value graphs useful for those with more extensive knowledge of economics (Jayassoriya and Ng 2014,8). For this project, only capital costs were used. The zip file can be downloaded from www.werg.org and contains a user manual and nine Excel files. There is a separate file for each different LID: Permeable Pavement, In-curb Planter Vaults, Retention Ponds, Extended Detention Basins, Swales, Curb Contained Bioretention, Rain Gardens and Green Roofs. For the application portion of this project, Permeable Pavement and In-curb Planter Vaults were applied.

Only the first two spreadsheets (shown in Figure 19 and 20) were used to determine the capital costs for the Porous Paving WERF LID Costing Tool. The

Simple Cost Estimation based on Drainage Area had four options for type of paving system. In this case, Option 2: Porous Concrete was selected. Because this Costing Tool has Asphalt listed, this tool could also be used to estimate conventional development costs. The LID Costing Tool estimates that Porous Paving costs $6.50 per square foot. Method A of Spreadsheet 2 adds additional implementation costs but doesn't specify gravel depth. This cost was added by adding a price per cubic foot of gravel ($0.93 derived from price per cubic foot of gravel cited in the In-Curb Planter Vault LID Costing Tool literature discussed later), adding a line for depth, linking the calculation to inputted area of porous paving, and adding that to Method A's capital cost calculation. Depth was modified from 1' to 2' for PP2 LID Control Costing.

	A	B	C	D	E
1	**Permeable Pavement**				
2	**Site Name:**				
3	**Site Location:**				
4					
5	**Design & Maintenance Options**				
6					
7	**WATERSHED CHARACTERISTICS**	**Unit**	**Model Default**	**User**	**Chosen option**
8	Surface Area of Permeable Pavement System	ft2	21,780	17,760	17,760
9	Drainage Area (DA)	ft2	21,780		21,780
10	Drainage Area Impervious Cover (IC)*	pct	100%		100%
11	Watershed Land Use Type *("R"-Residential; "C"-Commercial; "Ro"-Roads; "I"-Industrial)*		R		R
12	* Included since frequently used to calculate facility sizing.				
13					
14	**DESIGN & MAINTENANCE OPTIONS**	**Unit**	**Model Default**	**User**	**Chosen Option**
15	Choose among the following (affects default cost calcs):	-	1	2	2
16	1. Asphalt				
17	2. Porous Concrete	User Selected Pavement Type =			
18	3. Grass / Gravel Pavers	**Porous Concrete**			
19	4. Interlocking Concrete Paving Blocks				
20	5. Other				
21	Choose Capital Cost Level *("H"=high; "L"=low)*	-	H		H
22	Choose Level of Maintenance *("H"=high; "M"=medium; "L"=low)*	-	M		M
23					
24	**WHOLE LIFE COST OPTIONS**	**Unit**	**Model Default**	**User**	**Chosen Option**
25	Discount Rate	%	5.50		5.5

1.Design & Maintenance Options | 2.Capital Costs | 3.Maintenance Costs | 4.Cost Summary | 5.Whole Life Costs | 6.NPV Graph

Figure 19: Spreadsheet 1 of Permeable Pavement WERF LID Costing Tool

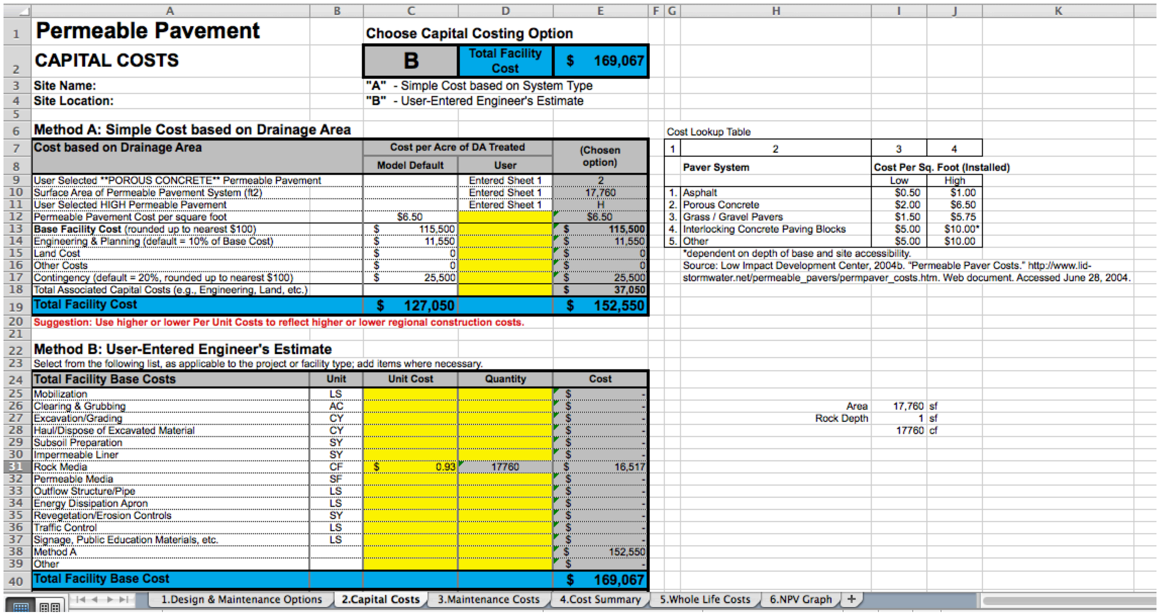


Figure 20: Spreadsheet 2 of Permeable Pavement WERF LID Costing Tool

Table 4: In curb Planter Vault specifications adapted from WERF LID Costing Tool's estimated cost of one In-curb Planter Vault Conforming to Specifications cited in Portland (2005) and using Cost data for Portland derived from RS Means 100 (2008).

Total Facility Base Costs	Unit	Unit Cost
Mobilization	LS	$650.00
Clearing & Grubbing	SF	$1.25
Excavation	CF	$0.30
Grading	SF	$0.59
Haul/Dispose of Excavated Material	SF	$0.30
Subsoil Preparation	CF	$0.93
Impermeable Liner	SF	$0.52
Rock Media	CF	$0.93
Permeable Media	CF	$1.75
Re-surface Sidewalk/Walkway	SF	$4.65
Replace Curbing	LF	$19.68
Outflow Structure/Pipe	LS	$35.00
Vault Grates and Screens	LS	$840.00
Shrubs	SF	$19.44
Trees	SF	$7.50
Traffic Control	LS	$650.00
Signage, Public Education Materials, etc.	LS	
Vault wall	SF	$19.68

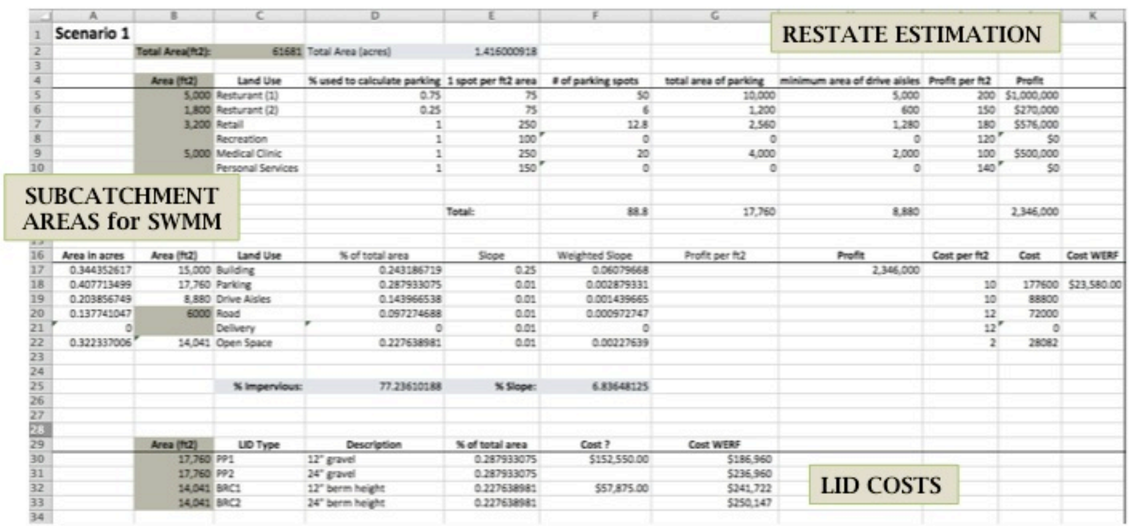
The second spreadsheet of the In curb Planter Vaults WERF LID Costing Tool was used in more detail with engineering specifications supplied from the reference tab. The engineering specifications applied were from City of Portland's 2005 SW 12th Avenue Green Street Project and are shown in Table 4.

The best time in process to set up the costing spreadsheets is when the LID parameters are being determined so that LID parameters can reflect any discoveries or changes made during the cost specification process. The WERF spreadsheets will then be used while simulations are being tested and to provide costing feedback of different sizing iterations of the LIDs. It maybe useful to have several screens so that the SWMM modeling software, WERF spreadsheets and scenario comparison spreadsheets may all be open at once.

Landscape Architecture Techniques

Landscape architects use precedent images, diagraming, and hand sketches of perspectives, plans and sections or 3D computer modeling and rendering to make decisions on site character, viewsheds, circulation, organizational or way-finding structure, vegetation, the preservation of existing features, and selection of relevant LIDs. These methods plus spreadsheets and vector based computer drawing, such as AutoCAD, are typically used for quantitative and spatial design tasks including grading, sizing land use requirements, and costing. Organization of many different design considerations and stakeholder participation, is a fundamental part of the landscape architecture design process so the outputs for different techniques and steps in the design process by landscape architects are meant to be understood by a broad audience.

This project is similar to typical landscape architecture in its use of hand sketching and AutoCAD to draw site plans, diagrams, and sections, but differed from them with the heavy use of an Excel spreadsheet for the organization of the inputs and outputs of different disciplines in a comparable quantitative manner. The Scenario Comparison spreadsheet is used to organize inputs and outputs of the land use requirements, costing, and stormwater simulation outcomes in a similar but separate sheet for each spatial scenario. Microsoft Excel is a program that is accessible to many professions and uses simple and well-known commands.



Scenario 1

Total Area(ft2): 61681 Total Area (acres) 1.416000918

Area (ft2)	Land Use	% used to calculate parking	1 spot per ft2 area	# of parking spots	total area of parking	minimum area of drive aisles	Profit per ft2	Profit
5,000	Resturant (1)	0.75	75	50	10,000	5,000	200	$1,000,000
1,800	Resturant (2)	0.25	75	6	1,200	600	150	$270,000
3,200	Retail	1	250	12.8	2,560	1,280	180	$576,000
	Recreation	1	100	0	0	0	120	$0
5,000	Medical Clinic	1	250	20	4,000	2,000	100	$500,000
	Personal Services	1	150	0	0	0	140	$0
			Total:	88.8	17,760	8,880		2,346,000

Area in acres	Area (ft2)	Land Use	% of total area	Slope	Weighted Slope	Profit per ft2	Profit	Cost per ft2	Cost	Cost WERF
0.344352617	15,000	Building	0.243186719	0.25	0.06079668		2,346,000			
0.407713499	17,760	Parking	0.287933075	0.01	0.002879331			10	177600	$23,580.00
0.203856749	8,880	Drive Aisles	0.143966538	0.01	0.001439665			10	88800	
0.137741047	6000	Road	0.097274688	0.01	0.000972747			12	72000	
0		Delivery	0	0.01	0			12	0	
0.322337006	14,041	Open Space	0.227638981	0.01	0.00227639			2	28082	
		% Impervious:	77.23610188	% Slope:	6.83648125					

Area (ft2)	LID Type	Description	% of total area	Cost ?	Cost WERF
17,760	PP1	12" gravel	0.287933075	$152,550.00	$186,960
17,760	PP2	24" gravel	0.287933075		$236,960
14,041	BRC1	12" berm height	0.227638981	$57,875.00	$241,722
14,041	BRC2	24" berm height	0.227638981		$250,147

Figure 21: Screenshot of Excel spreadsheet used to organize inputs

The simplicity of the Excel spreadsheet to organize quantitative aspects of multiple disciplines allows for cleaner integration of quantitative and qualitative aspects of spatial scenarios. This approach allows for easier to follow comparison between spatial options.

IV. CASE STUDY APPLICATION & RESULTS

A 12-acre site in southeast Louisiana illustrates the methodology for optimizing different layouts and LID choices in the earliest stages of design. The site sits on the northwest edge of Hammond, Louisiana city limits. It consists of two parcels separated by a segment of the Yellow Water River and was purchased by a developer to construct a mixed-use development catered towards Southeastern University students. Parcel One was previously a plant nursery and borders Highway 51 with almost 400 ft of road frontage whereas Parcel Two is wooded with pines and extends up to 1300 ft back from the river to a recreational and forested park.

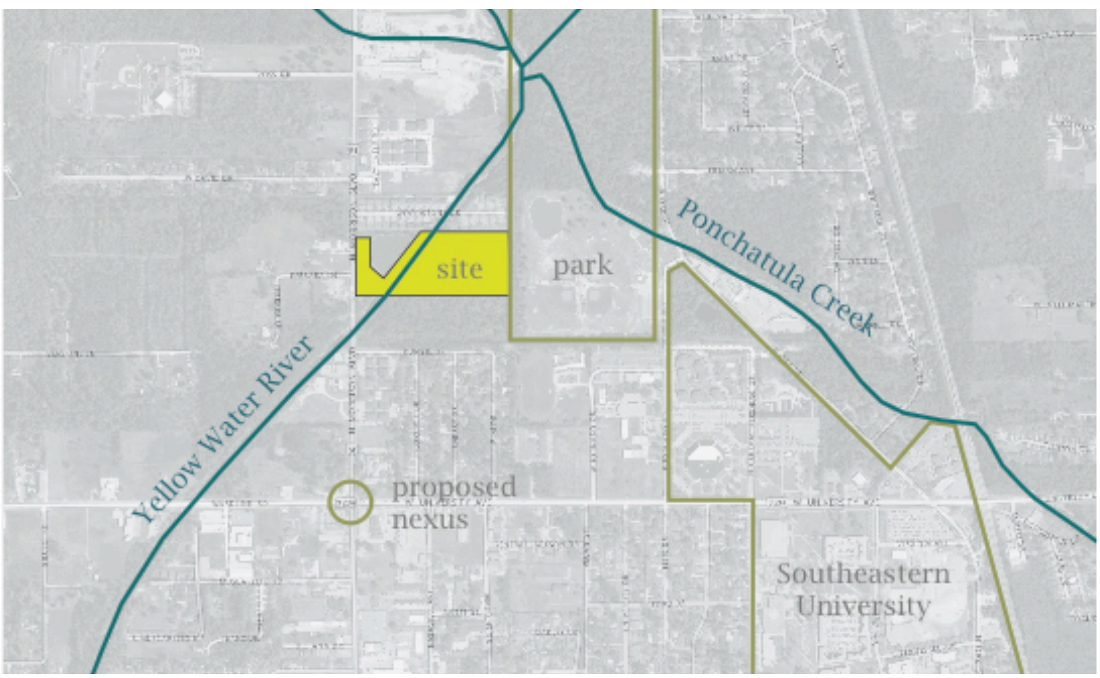


Figure 22: Northwest Hammond context map

The developer wanted approximately 15,000 sq ft of commercial space and at least 120 residential units with a 2,500 sq ft residential space. The City of

Hammond Unified Development Code requires new developments be able to accommodate a 10 year storm but does not indicate how much of that stormwater should be held on site (UDC , 12-2). A more stringent and increasingly popular requirement that is used increasingly by other municipalities is to design the post development runoff to match predevelopment conditions in terms of peak runoff rate and total runoff volume. This more stringent standard was used as the stormwater goals for this project.

Subcatchments with a flow length of less than 500 feet were drawn to simulate predevelopment conditions, shown in Figure 23. Simulation was run with the 10-year design storm in order to determine the design goals. With AutoLength turned off, the subcatchments corners were relocated so that PreD subcatchments were present but out of the way of future modeling. With AutoLength turned back on, sketching of land uses could be applied to the site.

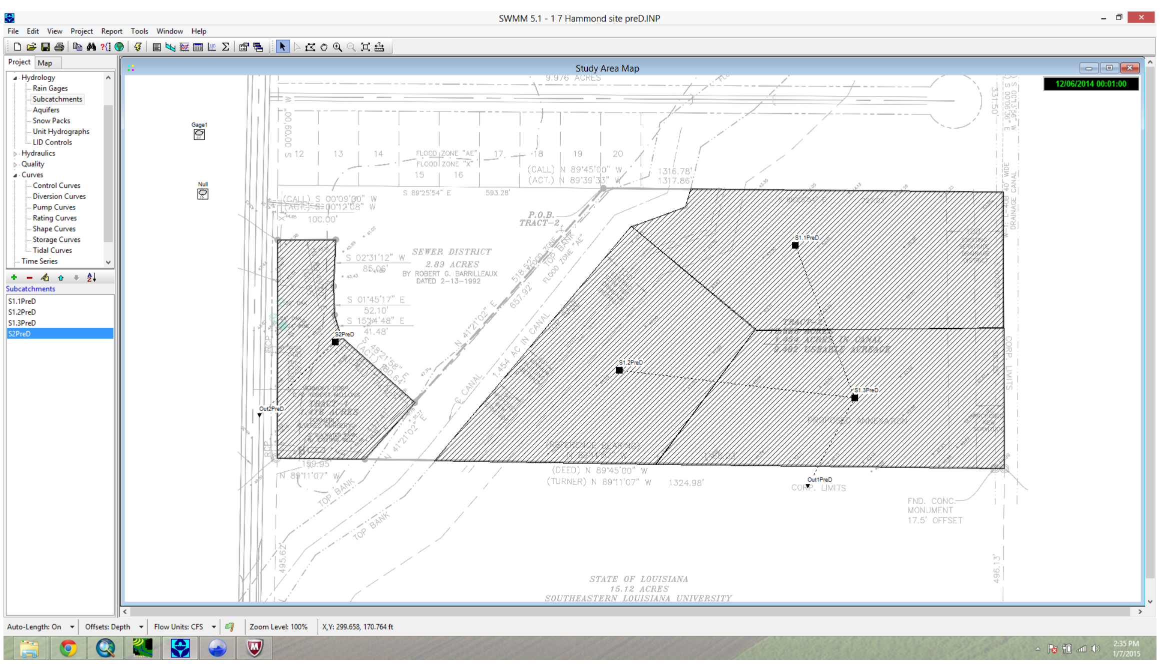


Figure 23: PreDevelopment (PreD) Subcatchments

From a landscape architecture and planning perspective, initial placement decisions were made.

1. Commercial should be located ideally entirely on Parcel 1 to optimize road frontage. Residential on Parcel 2 would provide more privacy and access to the park.
2. There will have to be road through Parcel 1 and a bridge to connect Parcel 2, the residential portion, to the highway.
3. The former sewage pond should be screened from view

The residential and commercial are therefore on different watersheds of the site and are essentially only co-constrained by the entrance road. As a result, scenarios could be run separately.

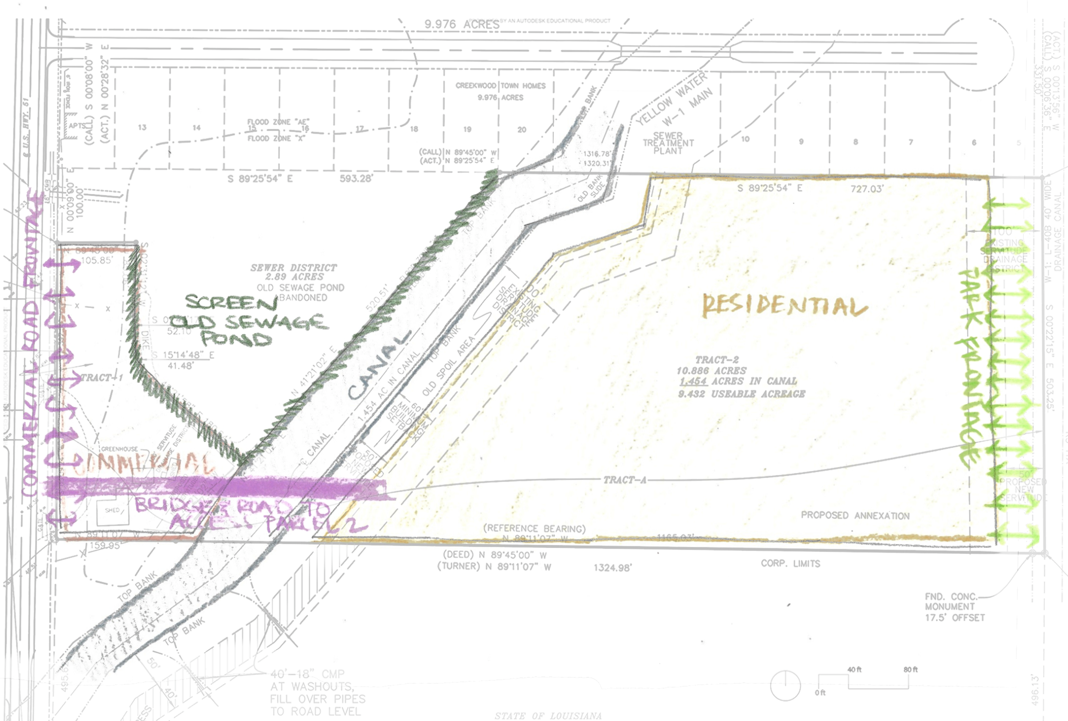


Figure 24: Sketch of early design decisions

Single Watershed

The spreadsheet shown in Figure 25 was created to represent the spatial requirements for different types of commercial land use. For the first scenario, a variety of commercial uses were selected based on what might be appealing to university students. Parking requirements based on the City of Hammond Unified Development Code (included in Table A.5 in the Appendix) were included to calculate required parking and estimated drive aisle areas. The spreadsheet calculated the area inputs for the different land use SWMM subcatchments, which were then mapped out based on concept rather than spatial location. The land use subcatchments shown in Figure 16 were set with parameters shown in Table 5.

	A	B	C	D	E	F	G	H	I	J	K
1	Scenario 1										
2		Total Area(ft2):	61681	Total Area (acres)	1.416000918						
3											
4		Area (ft2)	Land Use	% used to calculate parking	1 spot per ft2 area	# of parking spots	total area of parking	minimum area of drive aisles	Profit per ft2	Profit	
5		5,000	Resturant (1)	0.75	75	50	10,000	5,000	200	$1,000,000	
6		1,800	Resturant (2)	0.25	75	6	1,200	600	150	$270,000	
7		3,200	Retail	1	250	12.8	2,560	1,280	180	$576,000	
8			Recreation	1	100	0	0	0	120	$0	
9		5,000	Medical Clinic	1	250	20	4,000	2,000	100	$500,000	
10			Personal Services	1	150	0	0	0	140	$0	
11											
12											
13		15,000			Total:	88.8	17,760	8,880		2,346,000	
14											
15											
16	Area in acres	Area (ft2)	Land Use	% of total area	Slope	Weighted Slope	Profit per ft2	Profit	Cost per ft2	Cost	Cost WERF
17	0.344352617	15,000	Building	0.243186719	0.25	0.06079668		2,346,000			
18	0.407713499	17,760	Parking	0.287933075	0.01	0.002879331			10	177600	$23,580.00
19	0.203856749	8,880	Drive Aisles	0.143966538	0.01	0.001439665			10	88800	
20	0.137741047	6000	Road	0.097274688	0.01	0.000972747			12	72000	
21	0		Delivery	0	0.01	0			12	0	
22	0.322337006	14,041	Open Space	0.227638981	0.01	0.00227639			2	28082	
23											
24											
25			% Impervious:	77.23610188	% Slope:	6.83648125					
26											
27											
28											
29		Area (ft2)	LID Type	Description	% of total area	Cost ?	Cost WERF				
30		17,760	PP1	12" gravel	0.287933075	$152,550.00	$186,960				
31		17,760	PP2	24" gravel	0.287933075		$236,960				
32		14,041	BRC1	12" berm height	0.227638981	$57,875.00	$241,722				
33		14,041	BRC2	24" berm height	0.227638981		$250,147				
34											
35											
36											
37											
38											

Senario 3 | Senario 2 | Senario 1

Figure 25: Screenshot of Excel workbook for Scenario 1

The summary results indicated that the peak flow rate for PreD is 1.92 cfs and PostD 2.49 cfs and the volume of runoff is 90,000 gallons for PreD and 180,000 gallons for PostD. This result indicates that interventions need to be implemented to reduce the flow rate by 23% and the total runoff volume by half.

Table 5: Land Use Subcatchment Parameters and Results

Name	Building	DriveAisles	Roads	Parking	Open Space
Outlet	Parking	Parking	Parking	Open Space	Out
Area (acres)	0.3443526	0.2038567	0.1377410	0.4077135	0.3223370
Width	50	20	25	20	20
% Slope	25	1	1	1	1
% Imperv	100	100	100	100	0
LID Control	0	0	0	0	0
Peak Flow (cfs)	0.66	0.39	0.26	2.08	2.49
Volume (gallons)	70,000	40,000	30,000	22,000	180,000

Landscape architecture design decisions are used to select the relevant low impact development (LID) controls. For this commercial area, there is little open space to be converted into bioretention and what open space there is will likely need to also function as planted screens and buffers. Therefore, large retention and detention ponds are not likely relevant. Planter vaults with vertical edges can take up less space than vegetated swales and rain gardens. Porous pavement would allow the required parking to serve stormwater management function. In defining and sketching the site character, sketched in Figure 26, it was decided that the commercial buildings were to have sloped roofs, which rules out green roof options.

For this site, two versions of two different types of LID controls were considered. A Bioretention Cell with 12 " between the curb and soil is shorthanded as BRC1. A second Bioretention Cell 24" deep is shorthanded as BRC2. Pervious Paving with 12" of gravel beneath the porous layer is called PP1 and a Pervious Paving with 24" of gravel is called PP2. They are modeled as LID Controls with their parameters shown in Table 6. USGS Soil Survey used to determine that site contains Myatt fine sandy loam. Table A.2 in EPA User Manual (replicated as Table A.2 in

Appendix) was used to determine Porosity, Field Capacity, Wilting Point and Conductivity of the Sandy Loam in the Bioretention Cells.

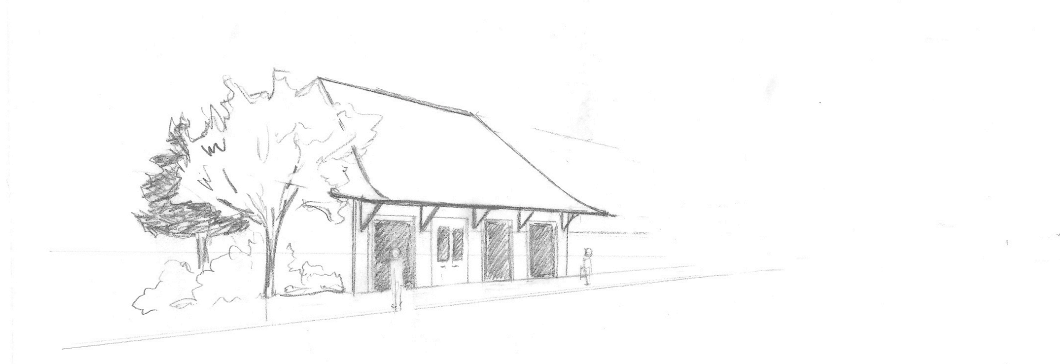


Figure 26: Sketch of site character

Table 6: Input Parameters for LID Controls

Control Name	BRC1	BRC2	PP1	PP2
LID Type	Bioretention Cell	Bioretention Cell	Permeable Pavement	Permeable Pavement
Berm Height	12 inches	24 inches	0.0	0.0
Vegetation Volume Fraction	0.5	0.5	0.0	0.0
Surface Roughness (Manning's n)	0.1	0.1	0.01	0.01
Surface Slope	1%	1%	0.1%	0.1%
Soil or Paving Thickness	36 inches	36 inches	4 inches	4 inches
Porosity	0.453	0.453	0.15	0.15
Field Capacity	0.19	0.19	0	0
Wilting Point	0.085	0.085	100 in/hr	100 in/hr
Conductivity	0.43 in/hr	0.43 in/hr	N/A	N/A
Conductivity Slope	10.0	10.0	N/A	N/A
Suction Head	4.33 in	4.33 in	N/A	N/A
Storage Thickness	12 inches	12 inches	12 inches	24 inches
Storage Voids Ratio	0.333	0.333**	0.333	0.333
Seepage Rate	0.43 in/hr	0.43 in/hr	0.43 in/hr	0.43 in/hr
Clogging Factor	0	0	0	0
Underdrain	No	No	No	No

While determining the LID parameters, it is best to also determine how much each LID costs. At this time, some of the LID parameters may be changed to produce a more monetarily effective design. In Scenario 1, there was 14,041 square feet of

open space and 17,760 of parking. In all six of the iterations for Scenario 1, the LIDs occupy 100% of their respective land uses. Their capital costs as determined by WERF LID Costing Tool are summarized in Table 7.

Table 7: Capital Costs of LIDs in Scenario 1

Area (ft2)	LID Type	Description	WERF Cost
17,760	PP1	12" gravel	$186,960
17,760	PP2	24" gravel	$236,960
14,041	BRC1	12" berm height	$241,722
14,041	BRC2	24" berm height	$250,147

Simulations were run with different combinations of the LID Controls. The peak flow rate and total runoff volume for each scenario were compared to the PreD conditions and the capital costs in the excel spreadsheet. The capital costs and stormwater performance were categorized as red, yellow, and green, with red being high cost or poor performance and are shown in Tables 8, 10 and 12.

Table 8: Scenario 1 simulation and costing results summarized

Iteration	LID Cost	Flow Rate (cfs) compared to PreD	Runoff Volume (gallons) compared to PreD
No LID	N/A	0.57 over	90,000 over
Only PP1	$190,000	0.42 over	20,000 over
PP1 & BRC2	$440,000	1.65 under	80,000 under
PP1 & BRC1	$430,000	0.36 under	50,000 under
Only BRC1	$240,000	0.45 over	equal to PreD
Only BRC2	**$250,000**	**0.39 over**	30,000 under
Only PP2	$240,000	0.42 over	20,000 over

The optimized iteration for Scenario 1 was the use of BRC2 in 100% of the open space for a total cost of $250,000. This iteration's flow rate was 0.39 CFS over the desired goal, but detains 30,000 gallons more than predevelopment conditions. For site schematic design, this is close enough. In design development, orifices that release the water at lower volumes can reduce the peak flow rate. This will reduce

the overall detention volume, but this iteration without the orifices holds 30,000 gallons more than necessary, providing plenty of flexibility in orifice design. This iteration was 58 % of the cost of the next better performing iteration.

For Scenario 2, restaurant space was maximized. The same LIDs were selected, but the changes in open space and parking area altered the prices and performance of 100% implementation of each LID. The results for five iterations are shown in Figure 10. The optimal iteration for Scenario 2 cost only 4% more than the LID implementation for the optimal iteration for Scenario 1, but they were two very different types of LIDs.

Table 9: Capital Costs of LIDs in Scenario 2

Area (ft2)	LID Type	Description	WERF Cost
24,500	PP1	12" gravel	$233,115
24,500	PP2	24" gravel	$255,900
6,681	BRC1	12" berm height	$115,498
6,681	BRC2	24" berm height	$119,507

Table 10: Scenario 2 simulation and costing results summarized

Iteration	LID Cost	Flow Rate (cfs) compared to PreD	Runoff Volume (gallons) compared to PreD
No LID	N/A	0.68 over	140,000 over
Only PP1	$230,000	0.44 over	10,000 over
Only PP2	**$260,000**	1.03 under	40,000 under
Only BRC1	$120,000	0.65 over	70,000 over
Only BRC2	$120,000	0.62 over	70,000 over
PP1 & BRC2	$350,000	0.43 over	40,000 under

For Scenario 3, retail space was maximized. Of the three scenarios, this one produced the largest revenue and required the fewest parking spaces. The same LIDs were selected, but iteration that showed implementation of BRC1 in 50% and 25% of the open space were also considered as well as pervious paving in the Drive Aisle land use.

Table 11: Capital Costs of LIDs in Scenario 3

Area (ft2)	LID Type	Description	WERF Cost
12,000	PP1	12" gravel	$114,160
12,000	PP2	24" gravel	$125,320
22,681	BRC1	12" berm height	$389,898
22,681	BRC2	24" berm height	$403,507
11340.5	BRC1	12" berm height	$195,400
6,000	PP2	24" gravel	$62,660
5670.25	BRC1	12" berm height	$98,160

Table 12: Scenario 3 simulation and costing results summarized

Iteration	LID Cost	Flow Rate (cfs) compared to PreD	Runoff Volume (gallons) compared to PreD
No LID	N/A	0.62 over	80,000 over
Only PP1	$110,000	0.47 over	40,000 over
PP1 & BRC2	$510,000	no runoff	no runoff
PP2 & BRC1	$500,000	1.76 under	80,000 under
Only BRC1	$390,000	0.51 over	10,000 over
Only BRC2	$400,000	0.95 under	10,000 under
Only PP2	$130,000	0.26 over	10,000 under
PP1 & 50% BRC1	**$310,000**	0.70 under	20,000 under
Only PP2 also Drive Aisles	$190,000	0.41 under	20,000 under
Only PP1 also Drive Aisles	$170,000	0.04 over	equal to PreD
PP1 & 25% BRC1	$210,000	0.11 under	10,000 over

Of the optimized iterations for each of the three scenarios, Scenario 3 produced the most revenue and had the lowest LID implementation costs. This, however, does not mean it is the optimal solution aesthetically and circulation wise. Landscape architecture drawings of character, circulation, viewsheds and way finding would help designers and clients choose right solution for this site. This process, however, narrowed down 21 iterations to three based on performance allowing for design development of a few successful schemes. Figures 27 - 29 represent some of the work that follows.

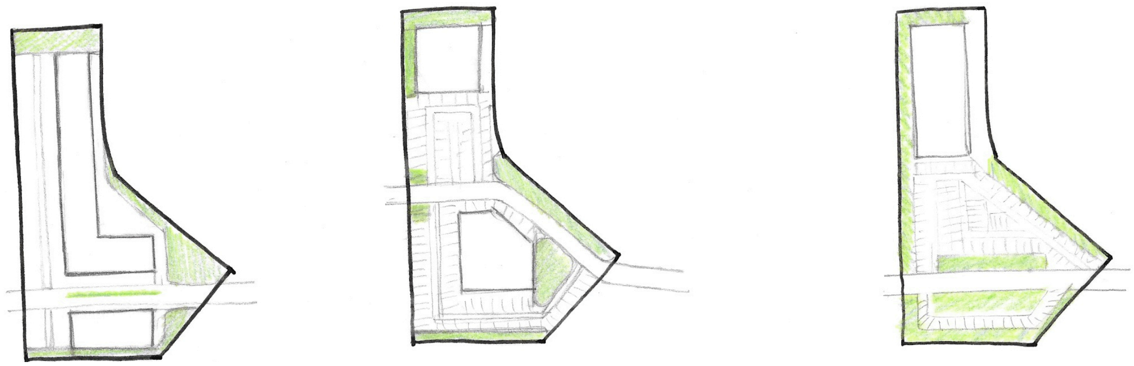


Figure 27: Sketches of Possible Layouts

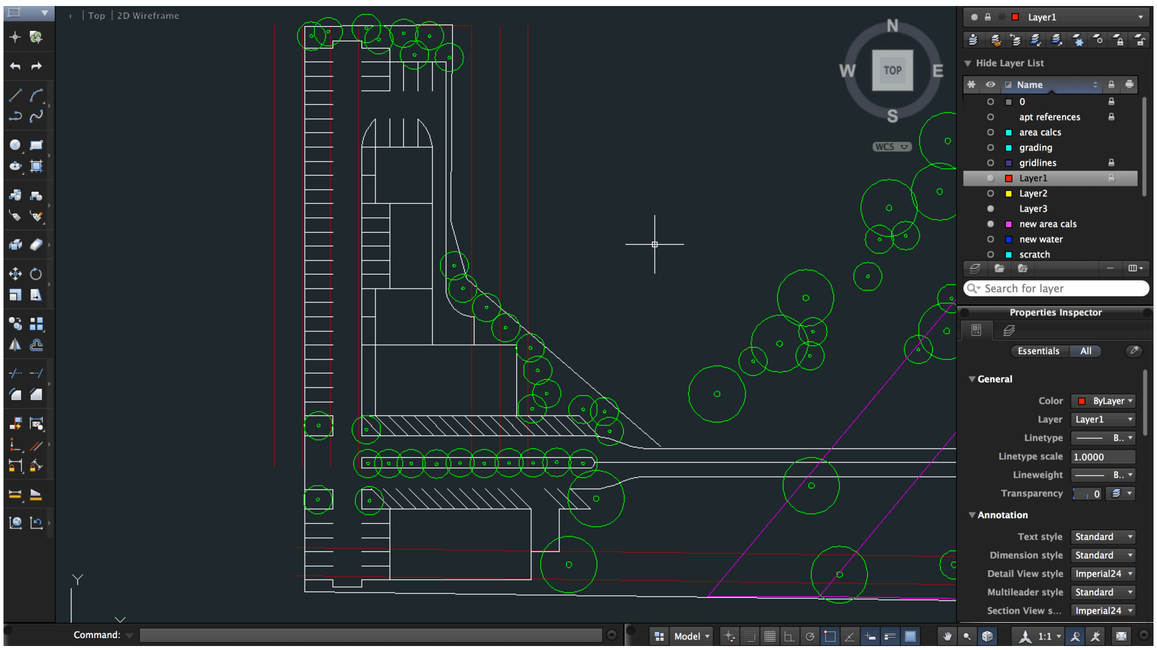


Figure 28: AutoCAD of Measured Design

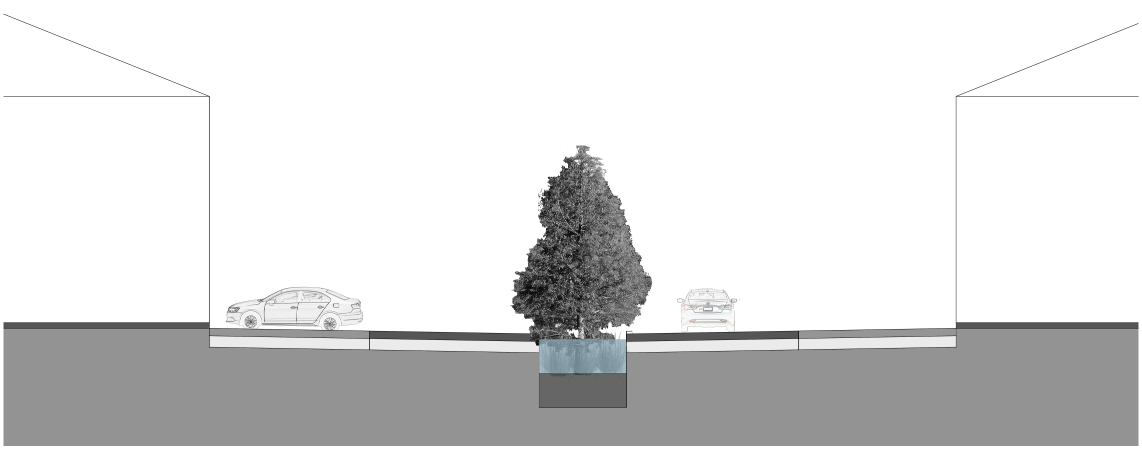


Figure 29: Measured Section of Entrance & Bioretention Cell

Watersheds in Sequence

The design process for the residential area included many more subcatchments and changing watersheds boundaries. The 10.88 acre parcel contained 9.432 usable acreage. Sixteen percent of that was in service easements. These easements were considered a part of the calculated watersheds, but buildings could not be constructed in these areas. LIDs were also not implemented in these areas, but these servitude areas were considered a part of the modeled watersheds. An adapted version of the spreadsheet used to determine commercial parking requirements and land use was utilized once for the residential site. It was determined that with four buildings, layouts pre-prescribed by the developer, 120 units would be provided and 237 parking spots would be required. This meant 12.8% of the site would be buildings, 11.5% would be parking, an estimated 5.8% of the site would be drive aisles and another 5.8% would be roads. This left 64.0% of the site or 6.03 acres as open space. With this scenario, there was far less concentrated development on the residential parcel than the commercial parcel. The simple land use routing method used for the commercial site was applied to this scenario for the commercial. The drive aisles and road routed to parking and parking and buildings routed to open space. The resulting flow rate was 2.26 cfs over and double the runoff volume of the PreDevelopment Conditions of 10.17 cfs and 500,000 gallons of runoff, shown in Table 13. The Pre Development Conditions for this parcel consisted of three subcatchments, shown in Figure 25, to keep the flow widths for any given subcatchment less than 500'. For a design project, it would be advisable for the designer to test more scenarios with an increased

number of buildings and to test further LID iterations, similar to what was done for the commercial site.

Table 13: Pre Development Conditions and Post Development Conditions of Residential Scenario 0

	Flow Rate	Final Runoff Volume
Pre Development	10.17 cfs	499,000 gallons
Scenario 0 - Post Development modeled as one watershed	12.43 cfs	1,000,000 gallons
Difference	2.26 over PreD	501,000 gallons over PreD
Percent Difference	22.2% over	50.1% over

For this project, however, the residential portion of the site was used to test the methodology for a more complex web of land uses and grading changes. Two spatial arrangements that approximately met the area calculations from the adapted land use spreadsheet were sketched. As part of the sketching, the routing of different land uses to each other was decided.

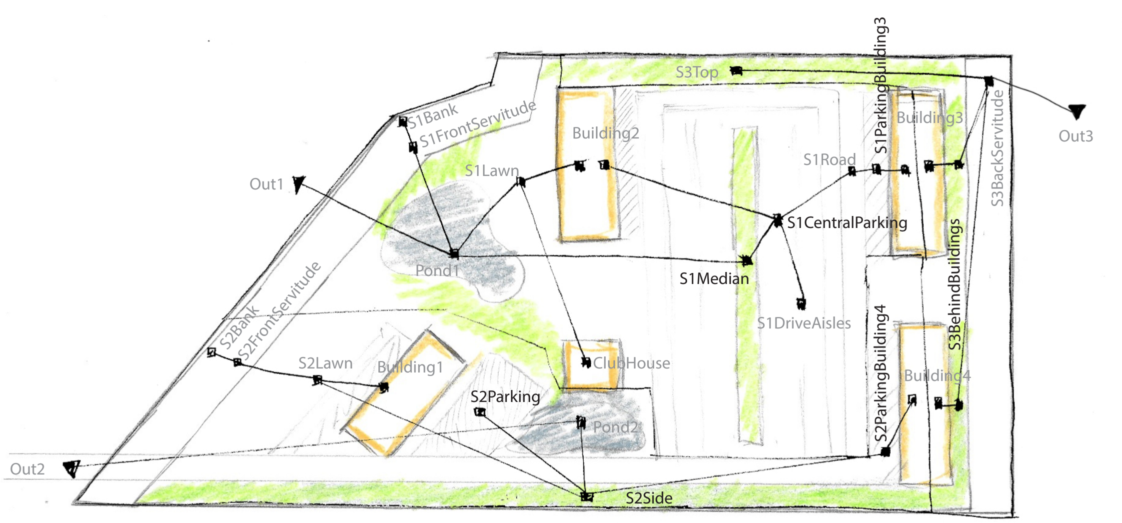


Figure 30: Routing Option A shown in Scenario 1

Scenario 1 spatial and routing arrangements (sketched in Figure 30) were mapped out in SWMM (shown in Figure 31) with a total of 30 subcatchments, 9 of which are

represent halves of the 4 residential building and one clubhouse, 4 parking, 14 open space, 2 roads and 1 drive aisle.

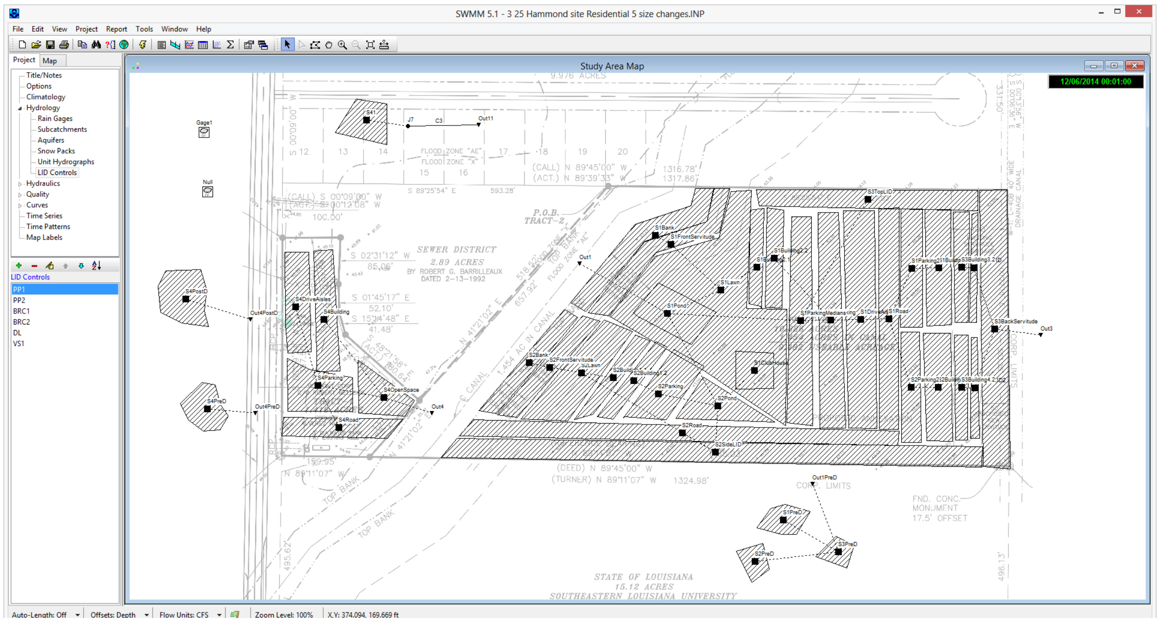


Figure 31: Screenshot of SWMM for Scenario 1

All of the subcatchments had parameters equal to the parameters of their classified land use. Instead of applying testing every combination of LIDs possible, applications were added and removed based on the results.

For Scenario 1, the model was run with no LIDs (Scenario 1, Iteration 1 or 1.1). Then, PP1 was added to all the parking (1.2), but flow rate and runoff volume was still far too high (flow rate only decreased 20% of goal reduction and runoff volume reduced 63%). For the third iteration (1.3), BRC1 was added to 100% of 5 subcatchments. This iteration reduced both flow rate and runoff volume far beyond the goal and cost 3.5 times the previous iteration. For the forth iteration (1.4), PP1 was removed. Runoff volume was just under the goal but flow rate was just over. In an effort to decrease the flow rate a bit, some of the PP1 was added back in just Watershed 2 (Iteration 1.5). This iteration caused a more dramatic decrease in flow

rate and runoff volume than anticipated. For the sixth iteration (1.6), BRC1 in Watershed 1 was removed and PP1 in Watershed 1 was added. Though this is a big move in LID implementation, it had an almost negligible effect on both pricing and stormwater performance. Finally in an effort to reduce cost, all LIDs were removed from Watershed 1 (Iteration 1.7). In this iteration, flow rate was well under the goal but runoff volume was above. The results including flow rates are color coded red(undesirable) to green (desirable) in Table 14.

Table 14: Scenario 1 simulation and costing results summarized

Iteration		LID Cost	Flow Rate (cfs) compared to PreD	Runoff Volume (gallons) compared to PreD
1	No LID	N/A	2.79 over	271,000 over
2	PP1 on all Parking	$390,000	2.23 over	110,000 over
3	PP1 on all Parking BRC1 in S1Median, S3BehindBuildings, S2Side	$1,360,000	1.75 under	178,800 under
4	BRC1 in S1Median, S3BehindBuildings, S2Side	$970,000	0.9 over	31,500 under
5	PP1 on all W2 Parking, BRC1 in S1Median, S3BehindBuildings, S2Side	$1,120,000	1.64 under	96,800 under
6	PP1 on all Parking, S3BehindBuildings, S2Side	$1,090,000	1.73 under	95,800 under
7	PP1 on all W2 Parking, S3BehindBuildings, S2Side	$850,000	1.48 under	2,200 over

Similar iterations were tested for routing changes in Scenarios 2 and 3, as shown in Tables 15 and 16, respectively. The routing for Scenario 2 illustrates how differences in spatial arrangements of structures on site can have little impact on the routing and results. Scenario 3 illustrates far bigger changes in routing, where Watershed 1 and 2 are combined, but without changes in the subcatchment sizes, routing has a marginal effect.

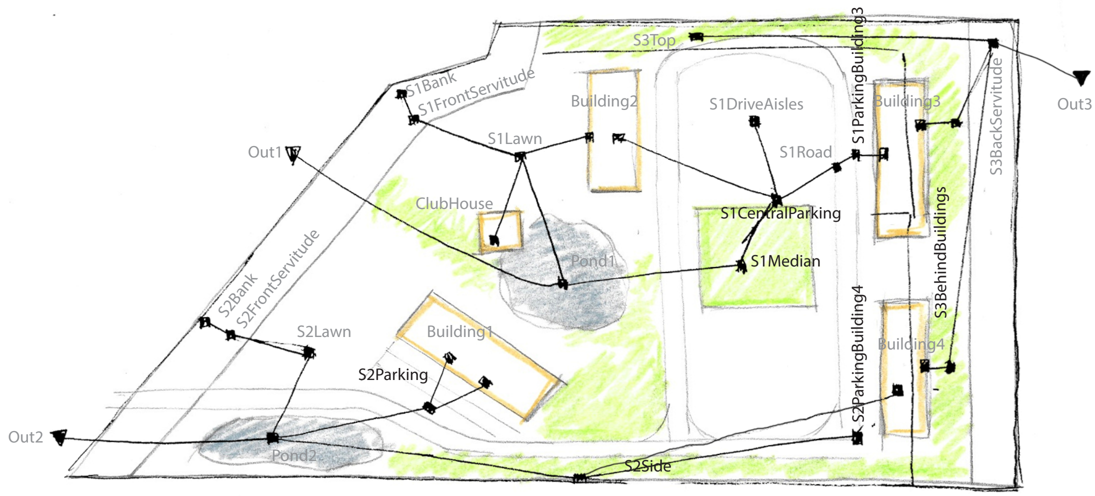


Figure 32: Routing Option B shown in Scenario 2

Table 15: Scenario 2 simulation and costing results summarized

Iteration		LID Cost	Flow Rate (cfs) compared to PreD	Runoff Volume (gallons) compared to PreD
1	No LID	N/A	2.80 over	271,000 over
2	BRC1 in S1Median, S3BehindBuildings, S2Side	$970,000	0.29 under	17,500 under

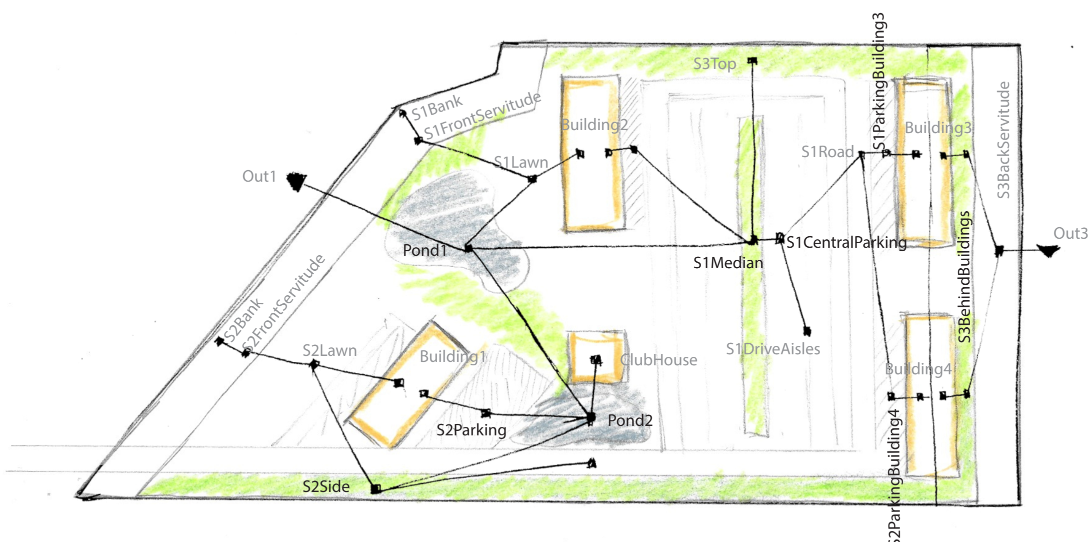


Figure 33: Routing Option C in Scenario 3 & 4

One LID combination that did not differ in size and therefore monetary costs but differed in stormwater performance for the three Scenarios was "BRC1 in S1 Median, S3BehindBuildings, S2Side." For 1.4, the flow rate was over PreD goals, for

2.2, the runoff volume was greater but both flow rate and runoff volume was under the PreD goals, and for 3.4, the runoff volume was even greater and flow rate lower than 2.2 but again runoff volume was still met the PreD goals. In all three Scenarios, this LID combination was one of the most, if not the only viable, LID iteration.

Table 16: Scenario 3 simulation and costing results summarized

Iteration		LID Cost	Flow Rate (cfs) compared to PreD	Runoff Volume (gallons) compared to PreD
1	No LID	N/A	2.78 over	281,000 over
2	PP1 on all Parking	$390,000	2.38 over	110,000 over
3	PP1 on all Parking, BRC1 in S1Median, S3BehindBuildings, S2Side	$1,360,000	0.87 under	162,400 under
4	BRC1 in S1Median, S3BehindBuildings, S2Side	$970,000	0.62 under	11,400 under
5	BRC1 in S1Median, S3BehindBuildings, 50% of S2Side	$660,000	0.96 over	75,600 over
6	BRC1 in S1Median, S3BehindBuildings, 75% of S2Side	$760,000	0.17 over	31,600 over
7	BRC2 in S1Median, BRC1 in S3BehindBuildings	$380,000	2.46 over	124,600 over

A closer look at the subcatchment runoff results of all iterations indicate that the reason this LID combination was so successful was largely due the success of the LID implemented in S2Side. In 3.4, BRC1 held all stormwater flowing into S2Side. Iterations 5 and 6 tried unsuccessfully to reduce the size of the S2Side LID and maintain overall achievement of meeting PreD conditions. In Iteration 7, BRC2 was added to the Median to see if that made up for the removal of the expensive the S2Side LID. It did not.

For Scenario 4, sizing changes to land uses were altered. S1Median was increased by 37% . S1CentralParking was increased by 29%. S1DriveAisles was reduced by 48%. The results for Scenario 4 are shown in Table 17.

Table 17: Scenario 4 simulation and costing results summarized

Iteration		LID Cost	Flow Rate (cfs) compared to PreD	Runoff Volume (gallons) compared to PreD
1	No LID	N/A	2.69 over	254,000 over
2	BRC2 in S1Median, BRC1 in S3BehindBuildings	$470,000	2.36 over	97,600 under
3	PP2 in S1CentralParking, BRC2 in S1Median, BRC1 in S3BehindBuildings	$690,000	1.39 over	11,600 over
4	PP2 in S1CentralParking, PP2 in S2Parking, BRC2 in S1Median, BRC1 in S3BehindBuildings	$890,000	0.82 over	30,400 under
5	PP2 in S1CentralParking, PP1 in S2Parking & S2Building4Parking, BRC2 in S1Median, BRC1 in S3BehindBuildings	$840,000	1.14 under	54,400 under
6	BRC2 replacing both Ponds BRC1 in S3BehindBuildings	$360,000	2.41 over	98,600 over
7	BRC1 in S1Median, BRC2 replacing both Ponds BRC1 in S3BehindBuildings	$730,000	2.14 over	35,400 under
8	PP1 in S1CentralParking, BRC1 in S1Median, BRC2 replacing both Ponds, BRC1 in S3BehindBuildings	$940,000	2.16 over	85,400 under

Even with the increase in area of S1Median, BRC2 in S1Median and BRC1 in S3BehindBuildings fell very short of the predevelopment goals. The addition of PP2 in S1CentralParking also fell short. PP2 in S2Parking brought Iteration 4.4 closer to a feasible zone but the replacement of S2Parking with PP1 and adding PP1 to

Building4Parking was cheaper and better performing than Iteration 4.4. In addition to sizing changes, in Scenario 4, a dramatic character change was tested when the ponds were replaced with BRC2. This would have been beneficial for quality, but as for quantity, it struggled to reduce the flow rate.

Iteration 4.5 was the quantitatively optimized iteration of all 20 LID iterations tested for the residential site. It is also the only iteration that implemented all four LID options. The largest and deepest LIDs are implemented in the center of the site, which benefits stormwater performance and adds to the character of the development. In further design development, the BRC2 in S1Median could be broken into smaller subcatchments that act in sequence.

The 30-subcatchment model for this portion of the site required approximately four hours to construct and the running of various options took about 12 hours. Most of this time was spent tracking the runoff values of all 30 subcatchments for the four No LID iterations of each Scenario and the runoff of the subcatchments with LIDs applied in the other 20 iterations. Just looking at node inflow for each simulation would probably decrease the time spent simulating and comparing 26 iterations down to 4 hours. This is closer to the 4 hours required to simulate 25 iterations for the commercial site.

Presentation of Results

A big part of bridging multiple disciplines is finding a way for the results of each tool to communicate in a form that works for different audiences. In this project, color-coding tables were used predominantly to find optimal iterations based on three variables. It is more popular, however, to ignore the flow rate

variable and show stormwater runoff in volume alone. During a presentation at the National ASLA Convention in November 2014, Nicole Holmes from Nitsch Engineering presented the results from Nitsch's proprietary stormwater software RainUSE in terms of cost per cubic foot of reduction. Table 18 is set up similarly.

However, because her project was comparing different LIDs rather than iterations, Holmes' results were far more dramatic than the ones in this project. Furthermore, the results do not allow for comparison with stormwater performance goals. The results presented in this form indicate Iteration 3.2 is optimal based on cost per gallon performance, however, just because it was efficient does not mean it was relevant. This iteration had almost 50% more stormwater performance than the goal, costing 50% more than other adequate designs.

Joksimovic and Alam (2014) produced a more visual way that allows for selection based on performance goals. Their graph shows fifteen LID combinations with capital cost on the x axis and percentage of runoff reduction on the y-axis (Joksimovic and Alam 2014, 40). Figure 34 shows twenty LID combinations from the four residential routing scenarios shown as percentages of their respective No LID iteration runoff volume. Additionally a line was included to show the percent reduction necessary to meet predevelopment conditions. In such a graphic, the optimal iteration is in the top left right above the goal line. Figure 37 indicates Iteration 4.5 is the optimal quantifiable solution. This agrees with the results from the color coded tables.

Using quantifiable results for both stormwater performance benefits and LID costs, better inform the design process and provide clear reasoning for design

decisions that clients and collabortors understand and respect. A follow up project to this thesis would look at how stormwater modeling could be applied in an advocacy capacity at various stages of the design process. This would involve research quantitative visualization techniques applied spatially and could be applied back to this project in developing new methods for illustrating iteration comparisons.

Table 18: Results for Residential Site in LID Cost per Gallon Detained

Iteration	Iteration Description	Cost per gallon
	PP1 on all Parking	$2.42
1.3	PP1 on all Parking, BRC1 in S1Median, S3BehindBuildings, S2Side	$3.03
1.4	BRC1 in S1Median, S3BehindBuildings,S2Side	$3.21
1.5	PP1 on all W2 Parking,BRC1 in S1Median, S3BehindBuildings,S2Side	$3.05
1.6	PP1 on all Parking, S3BehindBuildings, S2Side	$2.97
1.7	PP1 on all W2 Parking, S3BehindBuildings, S2Side	$3.16
2.2	BRC1 in S1Median, S3BehindBuildings, S2Side	$3.36
3.2	PP1 on all Parking	$2.28
3.3	PP1 on all Parking BRC1 in S1Median, S3BehindBuildings, S2Side	$3.07
3.4	BRC1 in S1Median, S3BehindBuildings, S2Side	$3.32
3.5	BRC1 in S1Median, S3BehindBuildings, 50% of S2Side	$3.21
3.6	BRC1 in S1Median, S3BehindBuildings, 75% of S2Side	$3.05
3.7	BRC2 in S1Median, BRC1 in S3BehindBuildings	$2.43
4.2	BRC2 in S1Median, BRC1 in S3BehindBuildings	$3.01
4.3	PP2 in S1CentralParking, BRC2 in S1Median, BRC1 in S3BehindBuildings	$2.85
4.4	PP2 in S1CentralParking, PP2 in S2Parking, BRC2 in S1Median, BRC1 in S3BehindBuildings	$3.13
4.5	PP2 in S1CentralParking, PP1 in S2Parking & S2Building4Parking BRC2 in S1Median, BRC1 in S3BehindBuildings	$2.72
4.6	BRC2 replacing both Ponds BRC1 in S3BehindBuildings	$2.32
4.7	BRC1 in S1Median, BRC2 replacing both Ponds BRC1 in S3BehindBuildings	$2.52
4.8	PP1 in S1CentralParking, BRC1 in S1Median, BRC2 replacing both Ponds BRC1 in S3BehindBuildings BRC1 in S3BehindBuildings	$2.77

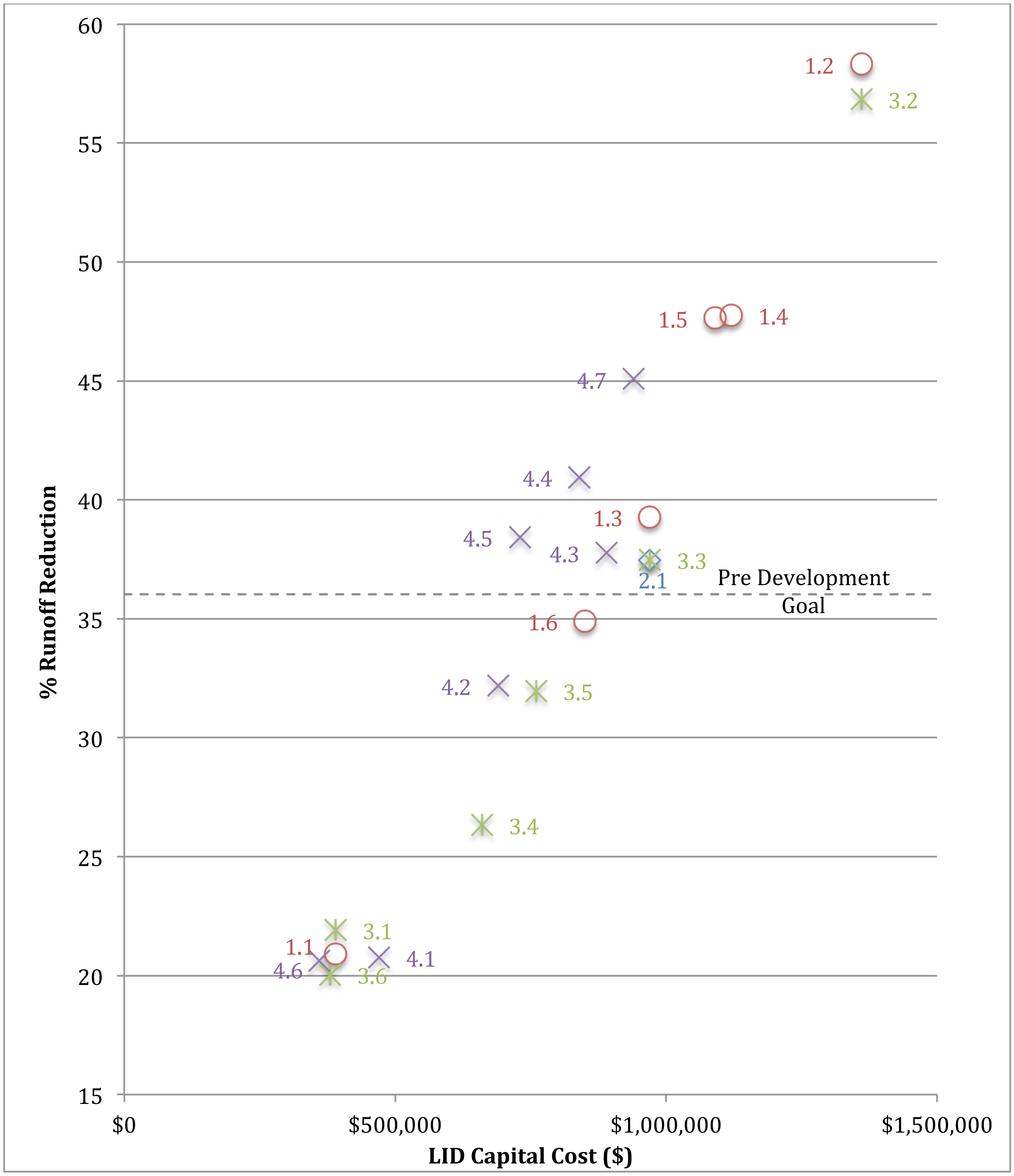


Figure 34: Graphed Results for Residential Site in terms of LID Cost and Percent Runoff Reduction

V. CONCLUSION

Stormwater modeling and landscape architect's role in stormwater management are both growing and with developments in both fields hopefully will grow towards the same goals. This project forms the basis for how stormwater modeling can be employed quickly to encourage uptake by landscape architects early in the design process.

The developed methodolgy allows for and application section explored routing changes, complex and changing watershed boundaries and layout changes, and the partial and full application of LIDs to homogenous land use based subcatchments. Other ways of diversifying the results were not included but could be easily applied. First, different design goals could have been considered. For example, the New Orleans new Comprehensive Zoning Ordinance will soon require the first 1.25" of rainfall on a newly developed site to be detained. In order to model this design goal, the design storm time series would be manipulated to only represent the first 1.25" of each storm event. Secondly, stormwater quality could have been analyzed. Thirdly, it would have been easy to include more LIDs types. SWMM has the abilty to model infiltration trenches, rain barels, rain gardens, and vegetated swales and WERF LID tools are avaliable for retention ponds, extended detetnion basins swales, rain gardens and green roofs but this project only applied bioretention cells and pervious pavement. Similiarly, pond modeling could have been included. Detention and retention ponds are common landscape techniques for stormwater detetention, but currently they are modeled by SWMM as storage units which act as nodes and require only hydraulic modeling to follow, meaning

LID Controls could not be modeled later in sequence. This conflict between hydraulic and hydrologic modeling in SWMM is a hangover from when the software was used soley for traditional gray stormwater infrastructure. Like real world LIDs, the LID Control features in SWMM are starting to bridge that gap between hydrologic and hydraulic modeling. Further software developments in SWMM will likely center around better LID modeling for both quantity and quality improvements.

As Zoopou, Elliot and Thowsdale, and Jayassoriya and Ng illustrated, the field of stormwater modeling is developing fast. This project could likely be replicated due to dramatic updates in modeling capabilities in less than ten years, if not five. EPA- SUSTAIN's model deserves particular attention in watching for updates as it is already ahead of EPA- SWMM in modeling LID quality benefits, interfaces with GIS for optimizing placement and links to costing databases. Landscape architects would be wise to not only stay abreast in stormwater modeling developments but to become a valuable user group so that they can direct the developments towards well rounded environmentally and people friendly goals. Landscape architects are intrinsically perfect to direct the dialogue on stormwater management, but need to step up and have a prominent role in how stormwater management is practiced. To do so, they need to do what they do best and integrate cutting edge techniques from other disciplines.

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APPENDIX

Table A.1: Design Storms for Fractional Distribution and Three Design Storm Time Series for Application Site in Hammond, Louisiana

Time (hrs)	Fraction of Total Rainfall	2 year storm (inches)	10 year storm (inches)	100 year storm (inches)
0	0	0	0	0
1	0.01	0.0511	0.0753	0.121
2	0.01	0.0511	0.0753	0.121
3	0.011	0.05621	0.08283	0.1331
4	0.012	0.06132	0.09036	0.1452
5	0.014	0.07154	0.10542	0.1694
6	0.015	0.07665	0.11295	0.1815
7	0.017	0.08687	0.12801	0.2057
8	0.026	0.13286	0.19578	0.3146
9	0.033	0.16863	0.24849	0.3993
10	0.041	0.20951	0.30873	0.4961
11	0.061	0.31171	0.45933	0.7381
12	0.25	1.2775	1.8825	3.025
13	0.251	1.28261	1.89003	3.0371
14	0.06	0.3066	0.4518	0.726
15	0.043	0.21973	0.32379	0.5203
16	0.032	0.16352	0.24096	0.3872
17	0.024	0.12264	0.18072	0.2904
18	0.018	0.09198	0.13554	0.2178
19	0.015	0.07665	0.11295	0.1815
20	0.014	0.07154	0.10542	0.1694
21	0.012	0.06132	0.09036	0.1452
22	0.012	0.06132	0.09036	0.1452
23	0.01	0.0511	0.0753	0.121
24	0.009	0.04599	0.06777	0.1089
Total	1	5.11	7.53	12.1

Table A.2: Manning's n Roughness Coefficient for Overland Flow. Based on values from SWMM User Manual Table A.6

Surface	n
Asphalt or concrete	0.01
Cement rubble surface	0.02
Fallow soils (no residue)	0.05
Cultivated soils	
Residue cover < 20%	0.06
Residue cover > 20%	0.17
Range (natural)	0.13
Grass	
Lawn	0.10
Short, prairie	0.15
Dense	0.24
Woods	
Light underbrush	0.40
Dense underbrush	0.80

Table A. 3: Depression Storage. Based on values from SWMM User Manual Table A.5

Surface	Dstore (inches)
Impervious surfaces	0.05 – 0.10
Lawns	0.10 – 0.20
Pasture	0.20
Forest litter	0.30

Table A.4: Soil Characteristics
Based on values from SWMM User Manual Table A.2

Soil Texture Class	Porosity (fraction)	Field Capacity (fraction)	Wilting Point (fraction)	Saturated hydraulic conductivity (in/hr)	Suction Head (in)
Sand	0.437	0.062	0.024	4.74	1.93
Loamy Sand	0.437	0.105	0.047	1.18	2.40
Sandy Loam	0.453	0.190	0.085	0.43	4.33
Loam	0.463	0.232	0.116	0.13	3.50
Silt Loam	0.501	0.284	0.135	0.26	6.69
Sandy Clay Loam	0.398	0.244	0.136	0.06	8.66
Clay Loam	0.464	0.310	0.187	0.04	8.27
Silty Clay Loam	0.471	0.342	0.210	0.04	10.63
Sandy Clay	0.430	0.321	0.221	0.02	9.45
Silty Clay	0.479	0.371	0.251	0.02	11.42
Clay	0.475	0.378	0.265	0.01	12.60

Table A. 5: Selected Hammond UDC parking requirements

Based on Table 12-2 in Hammond Unified Development Code (2014)

Use	Parking Requirement
Office	1.0 per 300 SF FA
Medical Clinics	1.0 per 250 SF FA
Retail Sales and Service	1.0 per 250 SF FA
Furniture sales	1.0 per 500 SF of Office and Display Area
Personal services, including barber shops, hair studios/ beauty salons, body piercing and adornment, message therapy and similar type services	1.0 per 150 SF FA
Restaurants	1.0 per 75 SF Dining Area
Drive –ins (Fast Food Establishments)	1.0 per 75 SF FA
Commercial recreational facilities	1.0 per 100 SF FA
Single Family Residential	2.0 spaces per unit
Two Family (Duplex) Residential	2.0 spaces per unit
Multi Family (1 bedroom) Residential	1.25 spaces per unit
Multi Family (2 bedrooms) Residential	2.5 spaces per unit
Multi Family (3 bedrooms) Residential	3.5 spaces per unit
Multi Family (4 bedrooms) Residential	4.0 spaces per unit + 10% additional spaces

VITA

Born in Florida, Brooke Morris grew up in Baton Rouge, Louisiana. She graduated Louisiana State University Laboratory School in 2007 with awards in science and visual arts and an International Baccalaureate Diploma. She immediately started her undergraduate studies at Louisiana State University with a LA-STEM Research Fellowship and worked under Dr. Monroe in Biological Engineering and Dr. Kousoulas at the School of Veterinary Medicine. In her sophomore year, she studied abroad in Brighton England at the University of Sussex and completed classes in Development Studies. Upon her return she joined the LSU Community Playground Project team and has since worked with over a dozen public schools in the Baton Rouge area to provide safe accessible play. At this time, she co-found and served as the first chapter president of Engineers Without Borders – LSU. She graduated in May 2011 with a Bachelors of Science in Biological Engineering, Distinguished Communicator Certification and cum laude honors.

After graduation Brooke worked on an organic farm and studied City and Regional Planning from the University of North Carolina in Chapel Hill for one semester and co-wrote a chapter on Reflection in *Service Learning: Engineering in Your Community*. In 2012, she began her master's studies at the Robert Reich School of Landscape Architecture. There she served as teaching and research assistant to Wes Michaels and interned with Spackman, Mossop and Michaels in New Orleans. After graduation, she plans to continue to combine problem-solving skill sets from multiple disciplines to better design urban systems, particuliarly stormwater.