Introduction to Changing Site Design Standards for Stormwater Management

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A recent regulatory trend is to base storm water control requirements on the total volume of storm water runoff from a site rather than on runoff rates or a specific pollutant removal rate. This trend is based on a growing body of research which has concluded that volume-based controls accomplish the concurrent benefits of pollutant reduction, peak flow reduction, and base flow protection. The focus on runoff volume as the common currency for best management practices evaluation is gaining wider acceptance across the country. Current regulations in the region demand a high level of stormwater infrastructure to meet the total volume of detention storage required. Instead, the evolving volume based controls have been proving to be less cost intensive with distributed green technologies at the source level. The purpose of this paper is to provide an overview of new volume based standards and rainfall frequency analysis procedures for selecting the appropriate control matrix for an area. In addition, we have summarized commonly used green infrastructure practices, and outlined available computer models for designing and evaluating site level green infrastructure techniques.

INTRODUCTION

As the modern world continues to develop, stresses on the natural environment continue to increase as well. Urbanization and development in recent decades have escalated drastically which has only augmented these stresses on the natural environment. A major issue with urbanization is the increase in stormwater runoff and its negative effects on the natural surroundings. Stormwater runoff changes predevelopment hydrologic conditions and carries pollutants into the watershed which obviously is undesirable and negatively impact ecosystems, stream channels, and all aspects of the natural environment. Currently regulations are in place which primarily requires developers to design stormwater detention/retention such that the post-development runoff rate equals the pre-development runoff rate. Commonly detention/retention facilities are required to design for 25 year event with outlet structure or a spill way and emergency spill way for 100 year event. Removal of 80% of total suspended solids (TSS) from the post-development site runoff on an annual basis is commonly used as the water quality control requirement. However the changing approach is the use of Green Infrastructure (GI) at the site level. GI is a concept which implements natural elements to treat rainwater close to its source in an attempt to minimize and manage stormwater runoff volume, runoff pollution, and changes in natural hydrologic conditions. GI focuses on long term sustainability and affordable solutions to the issues presented by increasing urbanization.

Growing research and scientific development has proven that required runoff control of evolving regulations is possible through employment of systems and practices that use or mimic natural processes to; 1) infiltrate and recharge, 2) evapotranspire, and/or 3) harvest and use precipitation near to where it falls to earth. Best management practices (BMPs) that use low impact development (LID) techniques incorporated with GI are the most attractive control systems currently available for runoff control or treatment. Performance of LID/GI controls were demonstrated by several case studies and are reported elsewhere. The promise of runoff reduction is that the benefits go beyond water quality improvement.

New trends across the country, both at state and local community levels, for post development site design standards are requiring developers to retain the runoff volume at the site. Often these standards are implemented as a requirement to capture runoff resulting from a rainfall depth that is typically found at a frequency in their area i.e. events that occur 90% or 95% of the time, etc. Current Environmental Protection Agency (EPA) regulations require all new and re-development federal facilities to retain runoff volumes corresponding to rainfall events that occur 95% of the time. But in the case where the 95th percentile design is found not to provide sufficient protection to maintain or restore the pre-development site hydrology, site specific hydrology analysis needs to be conducted at federal facilities. Overall, the intent of the new approach for regulations in terms of runoff control is to maintain the pre-development hydrology at a development site to protect and preserve both the water resources onsite and those downstream. Figure 1 demonstrates the comparative site hydrology with runoff volume control requirements.

However, before any such new design standards are established for a community, as a first step, it is essential that long term representative rainfall data is reviewed and appropriate rainfall depth for site design standards be established that is both feasible for your area, for implementation, and is protective of public health and property. In this paper we have presented the approach recommended for analysis of rainfall data to determine percentile rainfall and the approach is demonstrated through analysis of long term rainfall data observed at Birmingham International Airport. There are also a number of computer modeling softwares which were developed for designing and evaluating LID/GI performance for a variety of site development scenarios. As part of this paper we have presented short descriptions of several common LID/GI techniques that are used for site hydrology control as well as presented basic information on the available LID/GI computers models.

VOLUME CONTROL APPROACH

Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act has recommended two approaches to meet requirements. The two approaches for meeting requirements are as follows: Option 1 is to retain the 95th percentile rainfall event; Option 2 is site-specific hydrologic analysis. When Option 1 is not protective enough to maintain or restore the predevelopment hydrology of the project (for example, in some headwater streams), Option 2 could be used to determine the types of stormwater practices necessary to preserve the predevelopment runoff conditions. Option 2 could also be used if predevelopment runoff conditions can be maintained by retaining less than the 95th percentile rainfall event. Because a performance based approach was selected in lieu of a prescriptive requirement in order to provide site designers maximum flexibility in selecting control practices appropriate for the site, Option 2 was provided in recognition that there are established methodologies that can be utilized to estimate the volume of infiltration and evapotranspiration based on site-specific hydrology and thus establish the predevelopment hydrology performance design objectives (ESA 2009).

Calculating the 95th Percentile Rainfall Event

Section E of the Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act contains information on how to calculate the 95th percentile rainfall event for a specific area. A long-term record of daily rainfall amounts (ideally, at least 30 years) is needed to calculate the 95th percentile rainfall.

Designers opting to use Option 1 need to do the following:

Step 1: Obtain a long-term rainfall record from a nearby weather station (daily precipitation is fine, but try to obtain at least 30 years of daily record). Long-term rainfall records can be obtained from many sources, including NOAA at the following link: http://cdo.ncdc.noaa.gov/

pls/plclimprod/poemain.accessrouter?datasetabbv=SOD&countryabbv=&georegionabbv.

Step 2: Remove data for small rainfall events that are 0.1 inches or less and snowfall events that do not immediately melt from the data set. These events should be deleted since they do not typically cause runoff and could potentially cause the analyses of the 95th percentile storm runoff volume to be inaccurate.

Step 3: Using a spreadsheet or simple statistical package, sort the rainfall events from highest to lowest. In the next column, calculate the percentage of rainfall events that are less than each ranked event (event number/total number of events). Use the rainfall event at 95% as the 95th percentile storm event.

Designers opting to use Option 2 need to do the following:

Option 2 requires the designer to conduct a site-specific hydrologic analysis to determine the pre-development runoff conditions instead of using the estimated volume approach of Option 1. Under Option 2, the pre-development hydrology would be determined based on site-specific conditions and local meteorology by using continuous simulation modeling techniques, published data, studies, or other established tools.

If the designer elects to use Option 2, the designer would then identify the pre-development condition of the site (example, undistributed open lot) and quantify the post-development runoff volume and peak flow discharges that are equivalent to pre-development conditions. The post-construction rate, volume, duration and temperature of runoff should not exceed the pre-development rates and the predevelopment hydrology should be replicated through site design and other appropriate practices to the maximum extent technically feasible (ESA 2009).

Birmingham, AL Rainfall Analysis

Data Source: As mentioned earlier, long term rainfall data, at least a 30 year period, is required for percentile rainfall analysis such that the long period of data can account for temporal changes that may have occurred over the time. A weather station located at Birmingham International Airport has the continuous period of monitored rainfall data longer period that is geographically representative of the City's watershed area. This particular rain gauge is located within the City of Birmingham and use of monitored data from the gauge is believed to be a good representation of weather conditions in the city. The weather station is maintained by National Weather Services (NWS) and its latitude and longitude are 33.5656 and -86.745, respectively. For the purpose of current analysis, monitored hourly rainfall data from the station for the period of June 1948 – December 2010, excluding data for October 1978 – July 1987, was obtained as a download from the Environmental Protection Agency's Better Assessment Science Integrating point & Non-point Source (BASINS) modeling tool. The hourly data was converted to daily data for analytical purposes.

Data Analysis: As described in the guidance document for federal facilities, a percentile rainfall event represents a precipitation amount which the given percent of all rainfall events for the period of record do not exceed. In more technical terms, the given percentile rainfall event is defined as the measured precipitation depth accumulated over a 24-hour period for the period of record that ranks as the given percentile rainfall depth based on the range of all daily event occurrences during this period. Percentile analysis presented in this memo determines a data value for a specified percentage. For example, if the 85th percentile rainfall depth is analyzed and a value of 1.00 inch is determined, 85 percent of all rainfall events produce 1.00 inch or less of precipitation. The analysis includes 24-hour periods with measurable rainfall and excludes all other 24-hour periods. In addition, Small rainfall events that are 0.1 of an inch or less are excluded from the percentile analysis because this rainfall generally does not result in any measureable runoff due to absorption, interception, and evaporation by permeable, impermeable, and vegetated surfaces. Also, for the purpose of analysis, the 24-hour period is typically defined as 12:00:00 am to 11:59:59 pm, hence the total rainfall occurring on a calendar day is considered as an event.

The compiled daily rainfall data was analyzed per the steps described in ESA 2009 for federal facilities. Results of analysis are illustrated in Figure 2 and data values for selected percentiles are presented in Table 1. The average 24-hour rainfall depth of the analyzed events was found to be 0.68 inches, which is equivalent to about the 64th percentile of the rainfall events for the area.

A time series plot of the rainfall data is illustrated in Figure 3. As expected and observed in the percentile rainfall depth analysis, most of the rain events had depth below average, which is also indicated by concentrated rainfall events close to the base in the Figure.

Overall, as expected most of the rainfall events had depths below average. It will be at the discretion of the regulators to choose the appropriate rainfall depth as their design standard for post-development site stormwater controls design such that post-development hydrology of the site is protected. At the same time the chosen rainfall depth should be such that the corresponding runoff will be technically feasible to control by established stormwater practices.

GI/LID TECHNIQUES

Previous methods for stormwater management have used methods that provide either costly BMPs such as large facilities located near the end of the drainage area, or "grey infrastructure" practices which show practically no stormwater control and include conventional stormwater piping networks that collect runoff from the impervious urban area and carry it into the local drainage basin or to a wastewater treatment plant. LIDs are practices used in the green infrastructure concept which can preserve or restore a watershed's natural hydrologic conditions through fashioning a landscape that imitates natural hydrologic processes. GI/LID has become increasingly important as stormwater control requirements have been trending towards greater regulation on runoff volume control at a site to accomplish pollutant reduction and to maintain natural hydrologic conditions. GI/LID techniques manage rainwater through infiltration, evapotranspiration, and re-use while providing additional benefits such as improved aesthetics, improved habitats, and increases in property value and lifestyle quality. In short, GI/LID practices are believed to be the present and future of stormwater control and can help offset the adverse effects of urbanization on watersheds through cost effective and environmentally sustainable means. Some of the most common and effective LID techniques include bioretention, green roofs, vegetated swales, permeable pavements, disconnected downspouts, and rain barrels or cisterns. A brief explanation of each practice is provided below.

Bioretention

Bioretention areas, sometimes referred to as rain gardens, are stormwater management systems which provide on-site treatment of stormwater runoff using vegetation and modified topsoil. These areas are located at the lowest point of a small drainage area, such as a parking lot, and have a concave shape. Grass buffers can be used around the rain garden to help reduce runoff velocity and to act as a filter for larger particulates. The concave shape helps to collect the runoff as it settles through the engineered soil layers which filter it to remove pollutants. Plants and shrubs in the garden function as pollutant removers by removing nutrients from the soil as well as removing water through evapotranspiration. The filtered water that has passed through the soil can then be collected by a filter under drain which returns it to the storm drain system or in some cases can be used for groundwater recharge. While bioretention areas are not designed for flood control, but they can reroute initial runoff which can help to maintain predevelopment hydrology for smaller high frequency rain events. It is suggested that these areas should be individually designed as to optimize their performance however overall they have proven quite effective as on-site treatment facilities.

Green Roofs

Green roofs are a LID practice that uses a vegetated roof cover to reduce stormwater runoff from buildings. These roofs manage stormwater without the necessity of utilizing additional land, making them ideal for dense urban areas where they can significantly reduce the overall percentage of impervious area. Along with reducing runoff, green roofs can provide further benefits including increased insulation and energy efficiency, a reduction of urban heat island effects, and increased durability and lifespan compared to conventional roofs. Green roofs can be applied to new and existing buildings and often only require minor modifications when applied to existing structures. In general these roofs consist of a waterproofing layer, a soil layer, and a plant layer, and can be easily and effectively constructed on roofs with slopes up to twenty percent. For building design the loading of the roof under fully saturated conditions must be considered. Many European countries, especially Germany, and several cities in the United States have been using green roofs for a number of decades and find them a very cost effective method in alleviating the impacts of development with applicability in almost every climate.

Vegetated Swales

Vegetated swales provide a method of reducing runoff velocity as well as providing some filtration and infiltration of stormwater. Due to their linear form these swales are good for highway and residential street runoff treatment. Stormwater that enters these channels is slowed down by the vegetation which allows sedimentation to occur. Although sedimentation is the primary treatment provided, infiltration and adsorption by the sub-soils also occurs. These channels are often used as a link in a treatment train that conveys the water to a downstream unit such as a detention pond. The channels should be mild in slope as the effectiveness of the pollutant removal is based on the vegetation, soil adsorption, and velocity of the water. Obviously steeper slopes account for higher velocities which yield lower infiltration and sedimentation rates. The use of vegetated swales can reduce the need for traditional curb and gutter systems which feed into large storm drain pipe networks. Thus, not only does the use of these swales reduce runoff velocity, but they also can eliminate costs associated with piping systems, curb construction, and maintenance. Maintenance required for swales would include sediment removal when necessary, and mowing of grass. As always there are different options for swale design and each location would need a specific design for optimum functionality.

Permeable Pavements

Permeable pavement is an operational practice used to reduce the amount of impervious area and therefore reduce the total runoff volume from a precipitation event. Included in this category of permeable pavement are porous asphalt, porous concrete, permeable pavers, and open grid pavers. Permeable pavements allow for water to infiltrate through the pavement into the subsoil which then promotes pollutant removal and some groundwater recharge. They are often placed on a base layer of crushed stone or uniform aggregates that are conducive to infiltration as well. Porous asphalt and porous concrete are achieved by reducing the amount of sand or fine aggregates in the mix leaving air pockets which water can drain through. Permeable pavements are most well suited for use in low traffic areas such as sidewalks and parking lots, they are not recommended for use in high speed-high traffic areas.

Disconnected Downspouts

A large portion of stormwater runoff in urban areas comes from the roofs of buildings. Traditionally this water is collected in gutters whose downspouts discharge directly into storm drain pipe systems. To mitigate this problem gutter downspouts can be disconnected from the systems and water can be directly discharged into vegetated swales, bioretention cells, or even into rain barrels or cisterns.

Rain barrels and Cisterns
Rain barrels and cisterns are methods of collecting and storing rainwater for reuse later. These simple storage facilities can be connected directly to gutter downspouts to capture all runoff from roofs. The water can then be reused for irrigation purposes during drier time periods. This is a very basic yet effective way to not only reduce runoff volume but to also reduce water demand and alleviate stress on the water table due to irrigation.

As indicated by the previous descriptions, one of the keys to a successful BMP which can reduce the impact of developed conditions on the predevelopment hydrology is the reduction of impervious area. Multiple other practices can be used to further reduce the impervious to pervious ratio. For example: vegetated center islands can be used in traffic circles or cul-de-sacs, on street parking can be implemented instead of individual parking in residential districts, streets can be designed for minimum width requirements, and so on. Innovative thinking is the basis of fruitful GI/LID strategies and could take any form. For example: re-vegetation or reuse of abandoned lots for gardens or parks could further reduce impervious area and provide functionality for community usage, or, flood prone areas near stream channels could be converted into parks or playing fields which, although they may be flooded at times, could provide recreation during dry periods. In general, lessening the impact of development needs to be forefront on the minds of developers at all times in order to protect our environment and our most precious resource, water.

GI/LID MODELING SOFTWARE
With the emerging regulations and interest for GI/LIDs, there are several stormwater GI/LID design and assessment models that are emerging, which are upgrades of existing models or new models. These models can range from scoping level simple models such as National Green Values Calculator, CityGreen, GreenSave Calculator to the more complex SWMM, SUSTAIN, WinSLAMM hydrological and hydraulic models. Some of these models are free domain and function as web-based models. In this section some of the most commonly used models are briefly discussed. As described in the EPA supplement on GI/LID modeling tools, depending on their structure, modeling tools can be used to inform a variety of green infrastructure planning and design decisions: from setting a green infrastructure target for an entire watershed to designing a green infrastructure practice for a particular site. Outputs that are particularly important in informing green infrastructure planning and design include runoff volume, runoff rate, pollutant loading, cost, and other environmental benefits. Table 2 is adopted from EPA supplement 3 and provides links to a series of models that can be used to predict the performance and/or cost of green infrastructure approaches. The table also identifies the model owner, model price, and model outputs.

Green Values® National Stormwater Management Calculator
The Green Values® calculator is a tool that was developed to help engineers and developers make quick evaluations and comparisons on the performance, costs, and benefits of GI/LID stormwater management practices. It is a free, web enabled tool which can be used and accessed by anyone at http://greenvalues.cnt.org/national/calculator.php . This calculator will take the user through a step by step process in order to help them find a combination of GI BMPs that can meet the needs of that area in a cost effective way. The calculator makes a number of different assumptions in order to arrive at the calculation and therefore often the information entered or used is not very specific. This tool is very useful in finding a quick evaluation and estimate of what costs can be saved and what practices could be used. That being said, this tool should only be used for this and not for design purposes as it does not provide sufficient information for specific design.

Bioretention, Permeable Pavement, Green Roof, and Rainwater Harvesting Models
These models were created by a group of faculty, graduate students, associates, and "off-campus

Extension Faculty" at North Carolina State University to help in evaluation and with design for the different stormwater management practices. The tools are free for download at this link: http://www.bae.ncsu.edu/stormwater/downloads.htm . The models available include a bioretention hydrologic performance model for hydrologic and water quality prediction of bioretention cells, a bioretention design model, a bioretention thermal model for thermal impact evaluation, a green roof hydrologic simulation model which can simulate how a green roof will attenuate a specific rainfall event, and a rainwater harvester design model to simulate and assist designers in sizing rainwater cisterns.

Source Loading and Management Model (WinSLAMM)

WinSLAMM capable of simulating and predicting flow and pollutant discharges that can reflect a number of different development conditions and combinations of urban runoff control practices. Some of the control practices which can be evaluated by WinSLAMM include detention ponds, infiltration devices, street sweeping, porous pavements and catch basin cleaning. These controls can be evaluated in various combinations at various sources. The program can also predict the relative contribution of different source areas such as roofs, landscaped areas, parking lots, and streets. Normally the software is used to predict source area contributions and outfall discharges however, it is also often used by planners to effectively gain a better understanding of the success of different control practices. The WinSLAMM software is available for purchase from www.winslamm.com for $320.

Stormwater Management Model (SWMM)

This model developed by and freely available from the EPA is used for planning, design, and analysis stormwater runoff and drainage systems in urban areas. This software uses a dynamic rainfall-runoff simulation process which can simulate runoff quantity and quality from primarily urban areas. Originally this software could only evaluate pipe systems, channels, storage/treatment devices, pumps, and regulators, now however, the software can also explicitly model hydrologic performance of certain LIDs including: porous pavement, green roofs, rain gardens, rain barrels, infiltration trenches, and vegetated swales. This model can now accurately represent any combination of LID practices in an area. The model is available for free download from the EPA website at the following link: http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/.

System for Urban Stormwater Treatment and Analysis IntegratioN Model (SUSTAIN)

SUSTAIN was developed to assist stormwater management professionals in developing plans for flow and pollution control, meeting water quality goals, and protecting source waters. It was also designed for simulating developing, evaluating, and selecting optimal BMP combinations for various watersheds based on cost effectiveness. The model is very successful in determining how effective BMPs are, how big they should be, and what the most cost-effective solutions are for meeting water quality and quantity goals. SUSTAIN currently supports evaluation of the following structural BMPs: bioretention, cisterns, constructed wetlands, dry ponds, grass swales, green roofs, infiltration basins, infiltration trenches, porous pavement, rain barrels, sand filters, vegetated filter strips, and wet ponds. This module is free and available for download from the EPA website at the following link: http://www.epa.gov/nrmrl/wswrd/wq/models/sustain/ .

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Table 1. Observed Percentile Rainfall Depth for City of Birmingham.

Percentile	50	60	70	80	85	90	95	99
Rainfall Depth (inches)	0.48	0.6	0.8	1.03	1.2	1.44	1.9	3.14

Table 2. LID/GI Designing and Evaluation Modeling Tools (adopted from EPA Supplement 3)

Model/ Calculator	Owner	Freely Avail-able?	Runoff Volume	Runoff Rate	Cost	Pollutant Loading	Environmental Benefits	More Information
Bioretention, Permeable pavement, Green Roof, and Rainwater Harvesting	NC State Coop-erative Extension	Yes, down-loadable	x					http://www.bae.ncsu.edu/stormwater/downloads.htm
Delaware Urban Run-off Management Model (DURMM)	Delaware De-partment of Nat-ural Resources & Environmental Control	Yes, down-loadable	x	x		x		http://www.dnrec.state.de.us/dnrec2000/Divisions/Soil/Storm-water/New/DURMM%20Re-lease%201.0.xls (Spreadsheet) http://www.dnrec.state.de.us/dnrec2000/Divisions/Soil/Storm-water/New/DURMM_UsersMan-ual_01-04.pdf (User's Manual)
Green LTCP-EZ	EPA	Yes, down-loadable	x	x	x			http://www.epa.gov/npdes/pubs/final_form_green_ltcpez.xls (Spreadsheet) http://www.epa.gov/npdes/pubs/final_green_ltcpez_instructionswith-poecacomments.pdf (Manual)
Green Save Calculator	Green Roofs for Healthy Cities	No, members only	x		x		x	http://lcc.greenroofs.org/index.php?option=com_content&task=view&id=626&Itemid=116
Green Values National Stormwater Management Calculator	Center for Neighborhood Technology	Yes, web enabled	x		x		x	http://greenvalues.cnt.org/na-tional/calculator.php
Hydrologic Modeling Sys-tem (HEC-HMS)	US ACE	Yes, down-loadable	x					http://www.hec.usace.army.mil/software/hec-hms/

Table 2. LID/GI Designing and Evaluation Modeling Tools (adopted from EPA Supplement 3) (continued).

Model/ Calculator	Owner	Freely Available?	Runoff Volume	Runoff Rate	Cost	Pollutant Loading	Environmental Benefits	More Information
Hydrological Simulation Program – Fortran (HSPF)	USGS	Yes, downloadable	x			x		http://water.usgs.gov/software/HSPF/
i-Tree	USDA Forest Service	Yes, downloadable			x			http://www.itreetools.org/index.php
LID Quicksheet	Milwaukee Metropolitan Sewerage District	No, available on a CD for $25 fee	x					http://v2.mmsd.com/AssetsClient/Documents/stormwaterweb/PDFs/Appendix_L.pdf
Long-Term Hydrologic Impact Assessment Model	Local Government Environmental Assistance Network	Yes, downloadable	x			x		http://www.ecn.purdue.edu/runoff/lthia/lthia_index.htm
Program for Predicting Polluting Particle Passage through Pits, Puddles, and Ponds (P8)	William Walker	Yes, downloadable	x			x	x	http://wwwalker.net/p8/
RECARGA	University of Wisconsin – Madison, CEE Dept.	Yes, downloadable	x					http://dnr.wi.gov/topic/stormwater/standards/
Site Evaluation Tool (SET)	Tetra Tech	Yes, downloadable	x		x	x		http://www.unrba.org/set/index.shtml
Source Loading and Management Model (WinSLAMM)	PV & Associates	No, available for $320	x			x		http://www.winslamm.com/winslamm_overview.html
Stormulator	State Water Resources Control Board, UC Davis Extension, and the California Sea Grant Program	Yes, downloadable	x					http://www.stormulator.com/StormUlator/Welcome.html

Table 2. LID/GI Designing and Evaluation Modeling Tools (adopted from EPA Supplement 3) (continued).

Model/ Calculator	Owner	Freely Avail-able?	Runoff Volume	Runoff Rate	Cost	Pollutant Loading	Environmental Benefits	More Information
Stormwater Management Model (SWMM)	EPA	Yes, down-loadable	x	x				http://www.epa.gov/nrmrl/ws-wrd/wq/models/swmm/index.htm
Watershed Treatment Model	Center for Watershed Protection	Yes, down-loadable	x			x		http://www.cwp.org/documents/cat_view/83-watershed-treatment-model.html
WinTR-55	Natural Resources Conservation Service	Yes, down-loadable	x	x				http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/alphabetical/water/hydrology/?&cid=stelprdb1042901

Figure1. Site Hydrology Scenarios for pre- and post-development conditions.

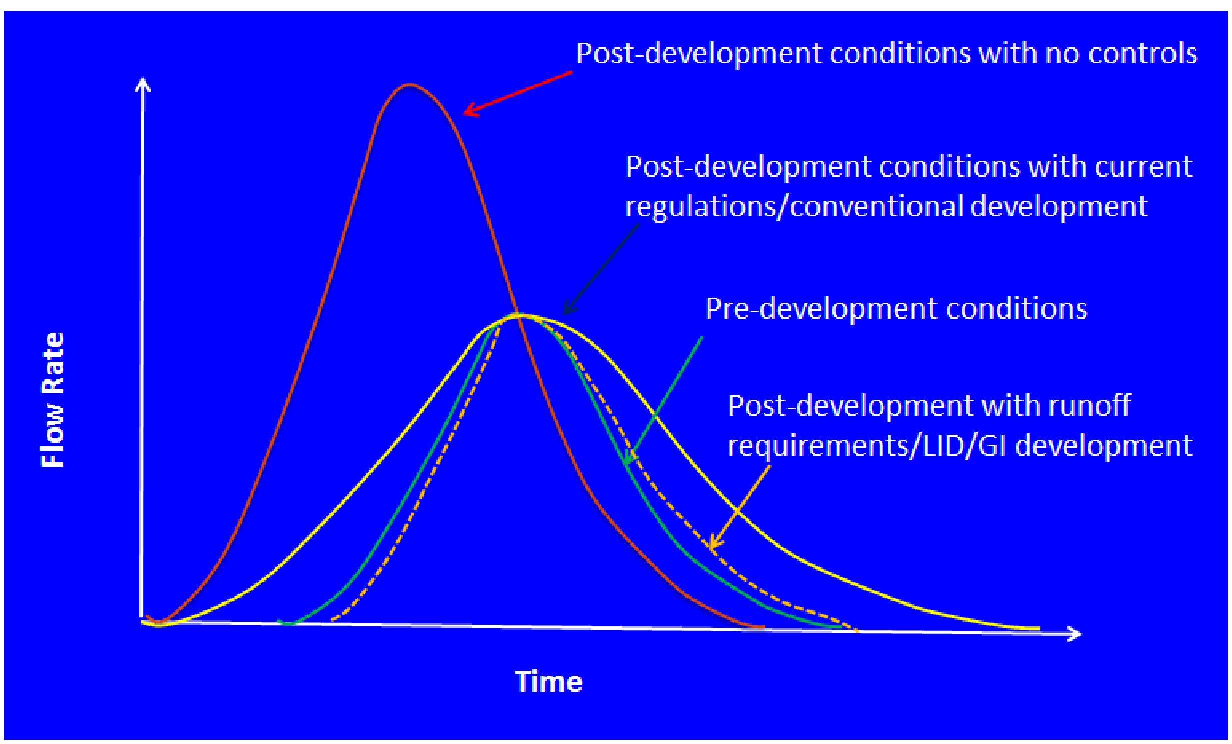

Figure 2. Rainfall Frequency Spectrum Rainfall Percentile and Corresponding Depths.

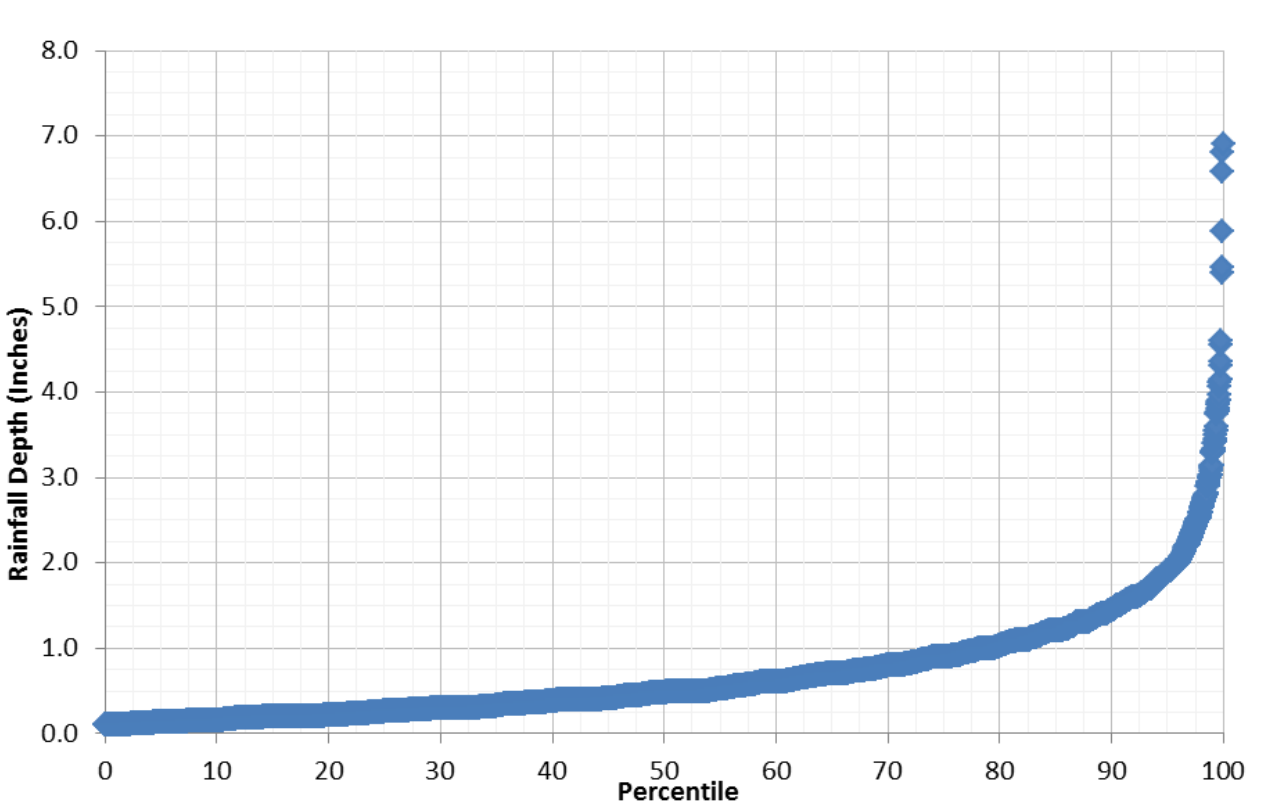

Figure 3. Time Series of Observed Daily Rainfall Data at Birmingham International Airport