

Evaluating Low Impact Development Practices for Stormwater Management on an Industrial Site in Mississippi

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Abstract

Industrial site development can result in substantial impacts to water quality and quantity. While permitting requirements may reduce impacts, they are limited in addressing long-term cumulative and operational impacts from the changes in land uses and cover. Many of these developments occur within watersheds containing impaired waters across the Southeast. Approximately 25,000 acres of industrial sites are developed or expanded each year in the 201-county Tennessee Valley Authority (TVA) power service region. TVA's mission is to promote sustainable economic development, energy production, and environmental stewardship.

This paper describes methodologies used to perform stormwater evaluations at a TVA facility, including hydrologic and water quality modeling. The hydrologic and water quality modeling was accomplished with the use of the LIFE™ model, developed by CH2M HILL to simulate Low Impact Development (LID). The LIFE™ model is a continuous-simulation, physically based model that accounts for processes that occur in bioretention facilities, bioswales, green roofs, and infiltration devices, as well as the effects of site fingerprinting and soil compaction. Tennessee Valley Authority is in the process of installing several demonstration projects using LID designs.

Introduction

TVA selected four pilot projects to test and verify conservation design practices in a variety of environmental settings. The Golden Triangle Regional Airport Authority (GTRAA) near Columbus, Mississippi was one of the selected pilot project sites. GTRAA is developing an industrial site for American Eurocopter on an airport property near Columbus, Mississippi where conservation design practices will be implemented for the demonstration. The site will eventually require development of about 90 acres in several phases. TVA is investigating and evaluating various Low Impact Development (LID) practices for implementation and demonstration. Various alternatives, designed to reduce flow and water quality from the site using LID practices by controlling stormwater at its source rather than with end-of-pipe facilities, are being considered.

The GTRAA site is shown in Figure 1. The first phase of this development (south-west corner of the site) has already been completed. The LIFE™ model developed by CH2M HILL was used to evaluate the cost and benefits of various LID options for this Phase 1 development, including options for retrofitting the as-built site and new development scenarios. This paper presents the application of the LIFE™ model and the results obtained from the analysis in the following sections.

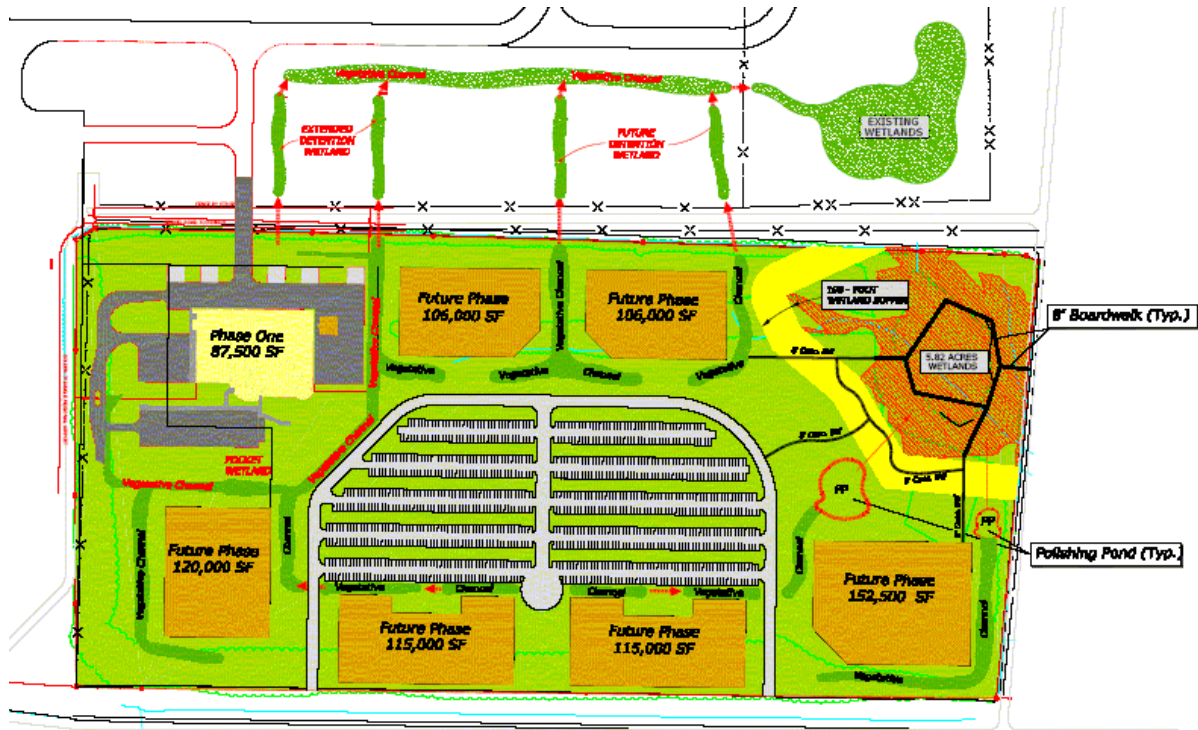


FIGURE 1
Overall Plan for American Eurocopter Site

LIFE™ Model Application

Model Overview

CH2M HILL's LIFE™ model was applied to test the performance of LID techniques for different land uses, rainfall patterns and soil characteristics. The LIFE™ model is a physically-based hydrologic and water quality simulation tool that was developed to evaluate the performance of various LID techniques (e.g., bioretention, infiltration systems, rainwater capture/reuse systems, permeable pavement, green roofs, etc). It is well suited to site-level analysis of spatially distributed stormwater source controls (i.e., LID techniques).

The LIFE™ model provides a continuous simulation of the runoff, interflow, infiltration, baseflow from a development (or re-development) area given the following inputs:

- *Continuous rainfall data* (typically in time increments of one hour or less) and *evapotranspiration data* (daily), typically for a time period of one year or more. Evapotranspiration (ET) can also be calculated from temperature data.
- *Site design parameters and land cover characteristics* for each land use type being modeled (e.g., road width, rooftop coverage, surface parking coverage).
- *Information on LID techniques* that are applied for each land use type, including:
 - Extent of source control application (e.g., fractions of road and of building coverage with a certain types of source controls)
 - Source control design parameters (e.g. area and depth of infiltration facilities, soil depth for green roofs or absorbent landscaping, volume of rainwater re-use cisterns)
- *Soils information, including:*
 - Surface soil parameters (e.g. maximum water content, vegetation rooting depth)
 - Sub-surface soil parameters (e.g. saturated hydraulic conductivity)

Descriptions of the model inputs, applications, and results obtained are provided in the sections below.

Model Inputs

Meteorological Data

The closest rainfall gauge to the project site with readily available data was located at Calhoun City, MS. Continuous rainfall data from January 1, 1992 to December 31, 2002 was used for model simulations. Maximum and minimum daily air temperature data was obtained from the climate station at Meridian WSO Airport for the same time period as the rainfall data (1992 – 2002). The temperature data was then used by the LIFE™ model to calculate a reference ET from vegetated surfaces using a modified Penman-Monteith equation. These reference ET values are then multiplied by a crop coefficient.

Soils Data

No site-specific soil data was available for the Eurocopter site. Therefore, soil parameters were estimated based on information from the STATSGO national soils database (USGS, 1999).

Site Drainage

A detailed drainage flow diagram for the site is shown in Figure 2. Runoff from the loading dock and south portion of the building roof (about two thirds) drains directly to the southern outlet swale, via a piped storm sewer system. Runoff from the remaining site area is captured in the large vegetated swales that carry flow around the perimeter of the site to the two outlet swales. Runoff from most of the paved surfaces flows over a portion of the on-site pervious area before being captured in the perimeter swales.

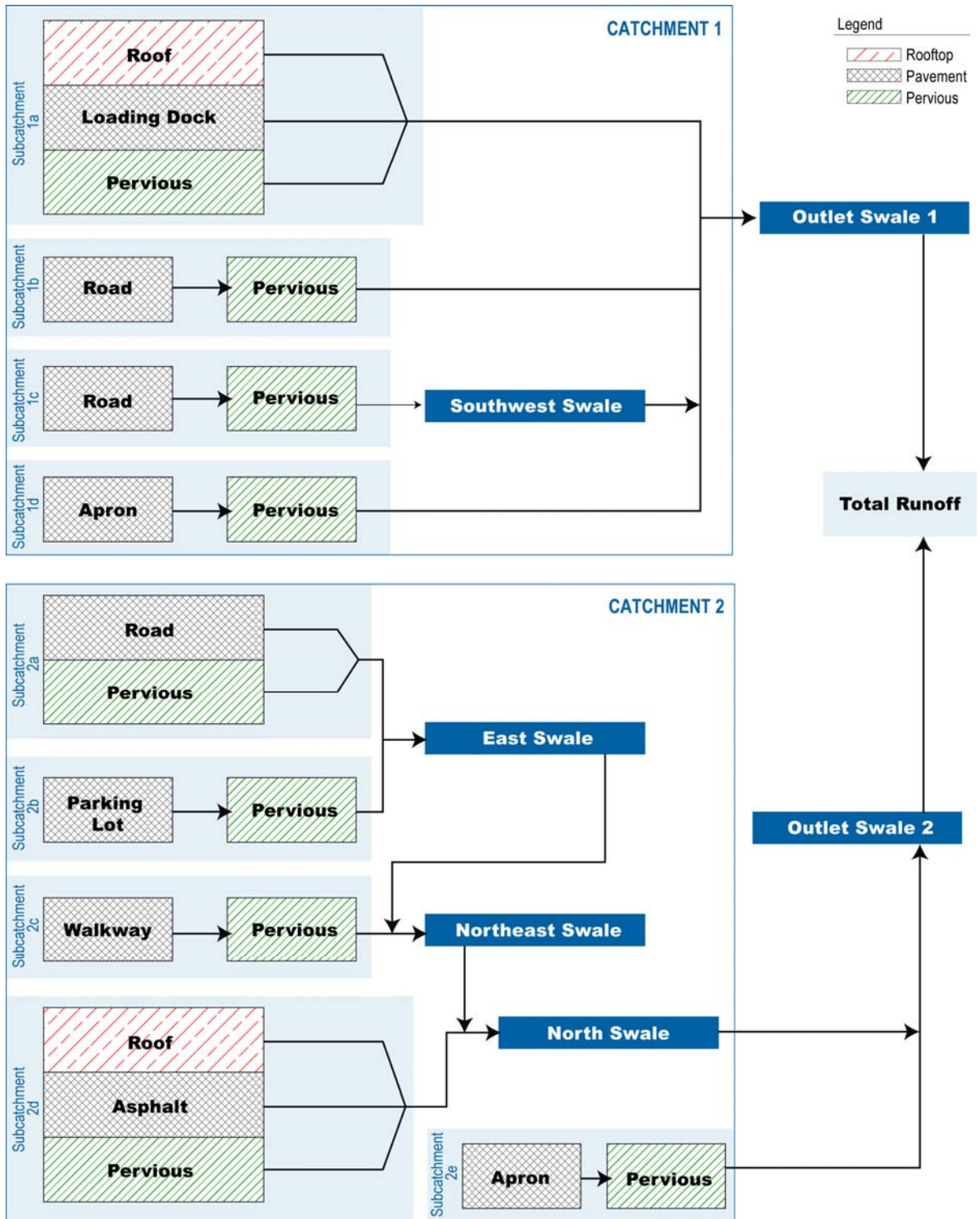


FIGURE 2
Drainage Flow Diagram of the Eurocopter Site

Performance Indicators

Changes in hydrology have been identified as the leading cause of channel instability and aquatic habitat degradation (Center for Watershed Protection, 2003). The ability of LID techniques to reduce runoff volume is a key indication of their effectiveness in protecting stream health. Hence, a primary measure of performance for the LID scenarios is the total volume of runoff over the 11-year modeled time period. These scenarios involve various configurations of LID controls.

In addition, hydrographs for several individual storm events were modeled to evaluate the following performance criteria:

- **Runoff Quality:** A storm with 1.2 inches of rain. Capture of this storm is presumed to meet a water quality criterion to remove 80% of total suspended solids (TSS). An actual storm with these characteristics occurred on May 3, 1994.
- **Stream Channel Protection:** A 1-year, 24-hour storm (3.3 inches) that roughly matches a storm that occurred on March 7, 1995. Extended detention for a storm of this magnitude is presumed to provide channel protection.
- **Overbank Flood Protection:** A 25-year, 24-hour storm (6.1 inches) that approximates a storm that occurred on May 2, 1995. Matching pre- and post-development peaks for this storm event is assumed to provide overbank flood protection.

Flow duration curves for the period between 1992 and 2002 were derived for each LID scenario, alongside similar curves for as-built and pre-development conditions. The duration and magnitude of flows that exceed natural forested conditions is directly related to the level of stormwater related impacts on stream stability and aquatic habitat.

Model Application and Results

LID uses a variety of site planning and engineering techniques to control runoff. Under redevelopment, the applicability of these techniques depends on soil conditions, site usage and space constraints. Under new development conditions there is more flexibility as the hydrologic behavior can be included in planning the site and site features can be designed to be hydrologically functional.

For the American Eurocopter site, bioretention swales were examined as LID controls. This type of control was deemed to be appropriate based on available as-built drawings for existing swales and ongoing site construction.

Results of Modeled LID Scenarios

A series of scenarios were modeled to demonstrate the potential hydrologic effectiveness of a range of LID techniques for the Eurocopter site. These scenarios included:

Bioretention Swale Retrofits

- **Retrofit Option 1: Soil Amendments** – A portion of the existing swales are excavated and backfilled with amended soils to provide additional opportunities for infiltration.

The absorbent soil layer was about 15 feet wide and extends to a depth of 36 inches below the swale bottom.

The modeling results indicate that this retrofit could reduce total runoff volume by about 29 percent from as-built conditions, as shown in Figure 3.

- **Retrofit Option 2: Bioretention Swales with Check Dams** – In addition to the amended soil placement described above, a series of check dams are placed every 100 feet, thus creating a series of bioretention cells where surface ponding can occur. The ponding depth would be a maximum of 18 inches at the downstream end of each cell, with an average ponding depth of 8 inches over the entire bioretention area.

The modeling results indicate that this retrofit could reduce total runoff volume by about 43 percent (see Figure 3).

- **Retrofit Option 3: Two-Layer Bioretention Swales with Check Dams** – The bioretention swales (same as Retrofit Option 2) are underlain by a 28-inch thick gravel layer with a 6 inch perforated underdrain. Total flow out of these two-layer swales consists of surface runoff plus underdrain flow. The underdrain flow can be considered “clean runoff” since it has treated by the amended soil layer. In addition, the infiltration process attenuates peak flows.

The modeling results indicate that this retrofit reduced total surface runoff volume by about 79 percent (see Figure 3), which is actually below pre-development runoff volumes. However, the total runoff volume, including underdrain flow, is actually slightly higher than the single layer bioretention swale option (Retrofit Option 2).

Two-layer bioretention swales tend to have significantly lower durations of surface ponding, and to be an effective design option for sites where soils have relatively poor infiltration capacity, such as the Eurocopter site.

- **Retrofit Option 2 with Various LID BMPs** – In addition to Retrofit Option 2, all of the rooftop runoff was dispersed over the pervious area in the northeast corner of the lot, which was covered with 12 inches of landscaped amended soil. Similarly, amended soil layers were placed on pervious areas that drained paved surfaces. The east half of the parking area was covered by pervious paving, underlain by an 18-inch drain gravel layer. Similarly, the north half of the paved area on the north side of building was covered by pervious paving with a reservoir base course, which captures rainfall and runoff from the south half of this paved area. A lightweight extensive green roof with 4 inches of vegetated growing media covers the entire building rooftop, with a drainage layer underlying the growth media.

Application of the LID measures described above dramatically reduced the level of surface runoff from the site. Total runoff volume was reduced by about 90 percent compared with as-built conditions, and well below pre-development runoff volumes, as shown in Figure 3. Runoff from small frequent storms, such as the water quality storm, was eliminated (see Figure 4a), and peak runoff rates were significantly reduced during larger storms, such the 1-yr channel protection storm (see Figure 4b). The flow duration curve could be reduced below the curve for pre-development conditions for the complete spectrum of rainfall conditions, as shown in Figure 5. These findings indicate

that the LID measures described above would achieve the specified performance standards.

Modeled Runoff Volumes

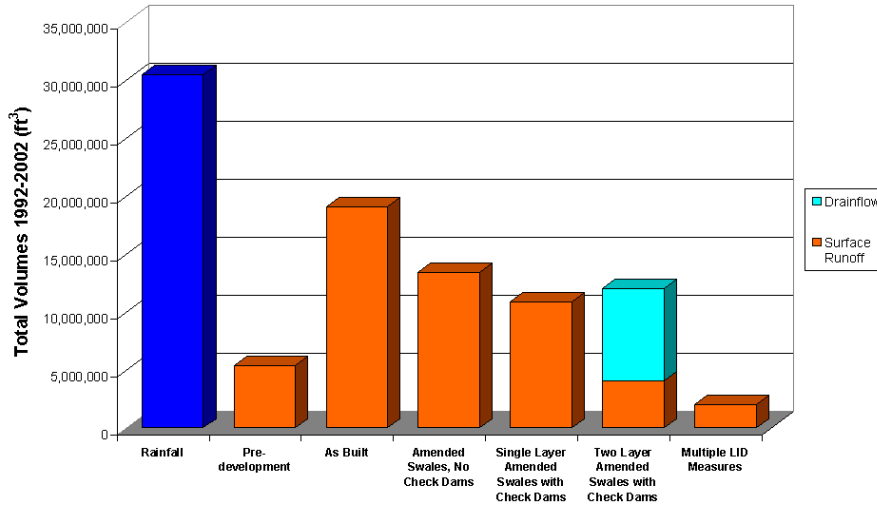


FIGURE 3
Runoff Volumes by Various LID Retrofit Scenarios for 1.2 inches of Storm (Water Quality Protection)

Modeled Flow Hydrographs - Water Quality Storm (1.2 inch)

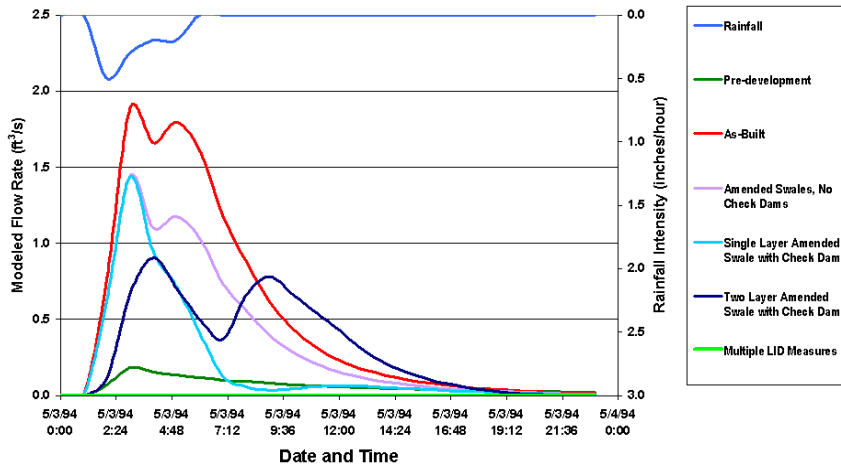


FIGURE 4A
Hydrographs for Various LID Retrofit Scenarios for 1.2 inches of Storm (Water Quality Protection)

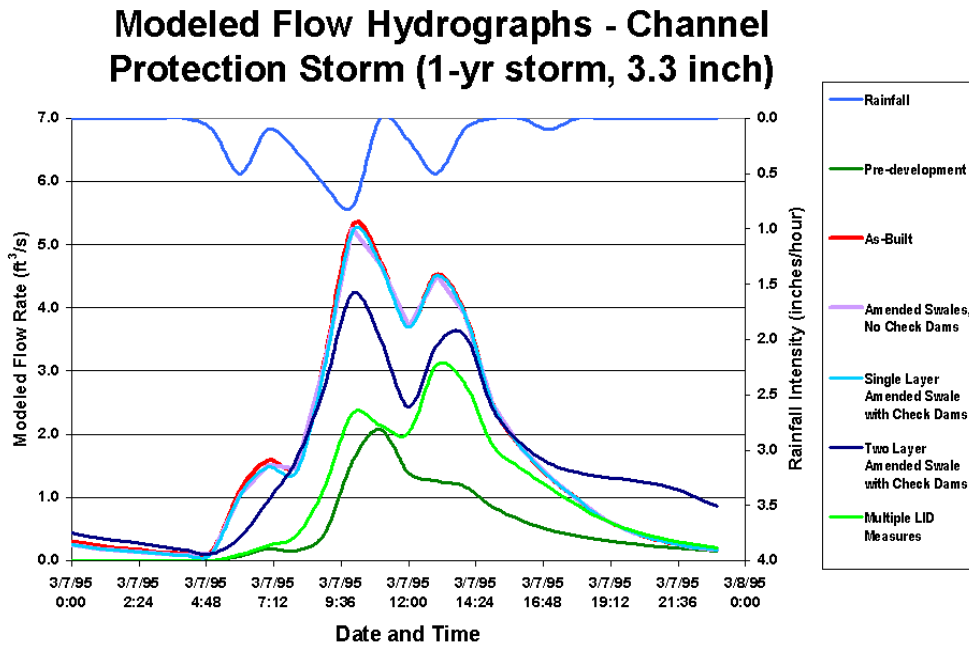


FIGURE 4B
Hydrographs for Various LID Retrofit Scenarios for 3.3 inches of Storm (Channel Protection)

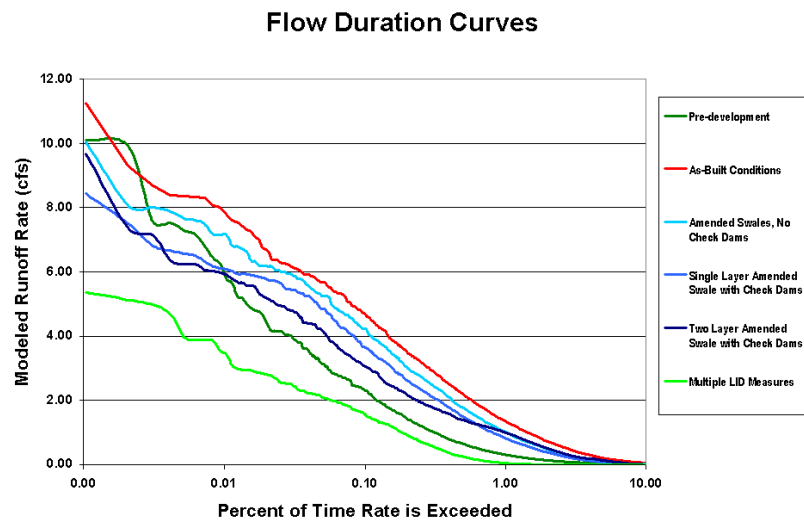


FIGURE 5
Flow Duration Curves for Various LID Retrofit Scenarios for 6.1 inches of Storm (Bank Protection)

Conclusions

The LIFE™ model has proven to be an effective tool to simulate LID hydrology. The model was built on basic hydrologic principles and its main advantage is the ability to simulate a wide array of site-planning measures as well as engineered BMPs.

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