Hydrologic Evaluation of Low Impact Development

Using a Continuous, Spatially-Distributed Model

by

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ABSTRACT

Low Impact Development (LID) is gaining popularity as a solution to erosion, flooding, and water quality problems that stormwater ponds partially address. LID analysis takes a spatially lumped approach, based on maintaining the predevelopment Curve Number and time of concentration, precluding consideration of the spatial distribution of impervious areas and Integrated Management Practices (IMP's), runoff-runon processes, and the effects of land grading. Success is thus dependent on the accuracy of the assumption of watershed uniformity, applied to both land cover distribution and flow path length.

Considering the cost of long-term paired watershed monitoring, continuous, spatially-distributed hydrologic modeling was judged a better method to compare the response of LID, forest, and conventional development. Review of available models revealed EPA-SWMM 4.4H as the most applicable to the task. A 4.3-acre subwatershed of a local subdivision was adapted to LID using impervious surface disconnection, forest retention, and IMP's. SWMM was applied to the LID development at a fine spatial scale, yielding an 80-element SWMM model. The LID model was modified to reflect conventional development, with gutters, storm sewer, and detention. A predevelopment forest model was also developed. Two parameter sets were used, representing a range of assumptions characterized as favorable or unfavorable toward a particular development form. Modeled scenarios included favorable and unfavorable versions of Forest, LID, uncontrolled Conventional Development, and Conventional Development with Stormwater Management. SWMM was run in continuous mode using local rainfall data, and event mode using NRCS design storms. Runoff volumes, peak flows, and flow duration curves were compared.

DEDICATION

I dedicate this thesis to my father, Gene K. Bosley, who passed away in April, 2002, regrettably before I could share my thesis with him.

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LIST OF ABBREVIATIONS

AnnAGNPS	Annualized Agricultural Nonpoint Source Model
ANSWERS-2000	Areal Nonpoint Source Watershed Environmental Response Simulation
BMP	Best Management Practice
CAD	Computer Aided Design
CASC2D	Cascade 2-Dimensional
CN	Curve Number
DHSVM	Distributed Hydrology Soil Vegetation Model
DR3M	Distributed Routing Rainfall Runoff Model
EPA	Environmental Protection Agency
EPA-SWMM	EPA - Stormwater Management Model
G	Mean Capillary Drive (also Capillary Suction or Matric Potential)
GIS	Geographic Information System
HDPE	High Density Polyethylene
HEC-HMS	HEC-Hydrologic Modeling Software
HSPF	Hydrologic Simulation Program - Fortran
IFLOWS	Integrated Flood Observing and Warning System
IMP	Integrated Management Practice
KINEROS2	Kinematic Runoff and Erosion Model
K_{sat}	Saturated Hydraulic Conductivity
LID	Low Impact Development
LIFE	Low Impact Feasibility Evaluation
L-THIA NPS	Long-term Hydrologic Impact Assessment and Non Point Source Pollutant Model
MIKE-SHE	Systeme Hydrologique European
n	Manning’s roughness
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
P8	Program for Predicting Pollutant Particle Passage through Pits, Puddles, and Potholes
PET	Potential Evapotranspiration
PRMS	Precipitation-Runoff Modeling System
SWAT	Soil-Water Assessment Tool
SWM	Stormwater Management
T_c	Time of Concentration
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VT/PSUHM	Virginia Tech / Penn State Urban Hydrology Model
WEPP	Water Erosion Prediction Project
WinSLAMM	Source Loading and Management Model
WMS	Watershed Modeling System
WQ_V	Water Quality Volume
Θ	Moisture Content

1 INTRODUCTION

1.1 Problem Statement

Urban and suburban land development has long been known to have detrimental impacts on the hydrology, water quality, and ecology of developing watersheds, largely due to the increased imperviousness and drainage efficiency of the developed landscape. All aspects of the hydrologic cycle, both surface and subsurface, are affected. Peak flows and overall runoff volumes are increased, and the time from the start of rainfall to the runoff peak is reduced. Substantial runoff can occur in a developed watershed during many storms for which a forested watershed would produce little if any storm flow. The net result is increased magnitude and frequency of local and downstream flooding, increased channel erosion, decreased baseflow, and degraded instream habitat (Moglen & McCuen, 1988; Konrad et al. 1995; Booth 1991). The traditional engineering approach to the impacts of development has focused on stormwater conveyance, detention ponds, and other structural measures. It is now recognized that traditional stormwater ponds can exacerbate the channel erosion, flooding, and water quality problems that they sought to mitigate, because they do nothing to address the increased volume of runoff associated with development. In addition, stormwater ponds can introduce unique water temperature, water quality, stream stability, and stream habitat impacts of their own.

Low Impact Development (LID) is proposed as the solution to problems associated with traditional development patterns and stormwater best management practices (BMP's). The LID approach seeks to create a hydrologically functional landscape, which mimics predevelopment hydrologic functions in order to maintain ecosystem integrity. Stormwater runoff is reduced to predevelopment levels by minimizing imperviousness; using natural drainage courses in lieu of storm sewers, curbs, and gutters; minimizing grading and land disturbance; maintaining predevelopment time of concentration; and augmenting storage with detention, retention, and water reclamation practices distributed throughout the landscape (Prince George's County 2000a). Such an approach requires detailed knowledge and evaluation of distributed micro-scale hydrologic effects, yet present-day LID design practice takes a spatially lumped approach, based on NRCS hydrology methods (Prince George's County 2000b).

The LID site design and analysis approach, as presented by Prince George's County (Prince George's County 2000b) and summarized in Figure 1.1, begins with steps common to traditional development hydrologic analysis, such as determining the curve number and time of concentration:

- The LID approach begins with estimating the curve number (CN) and time of concentration (T_c) for the watershed under assumed forested pre-development conditions and existing soil types, using standard NRCS methods from TR-55 (NRCS 1986).
- The site layout is developed, and the post-development curve number computed, then adjusted to account for disconnected impervious areas such as roof drains.
- The site flow patterns are re-designed until the post-development T_c equals the pre-development T_c.
- The design storm is selected as the greater of the 1-year, 24-hour NRCS Type II storm, or 150% of the amount of rainfall that will initiate runoff for a forested site of the same Hydrologic Soil Group(s).

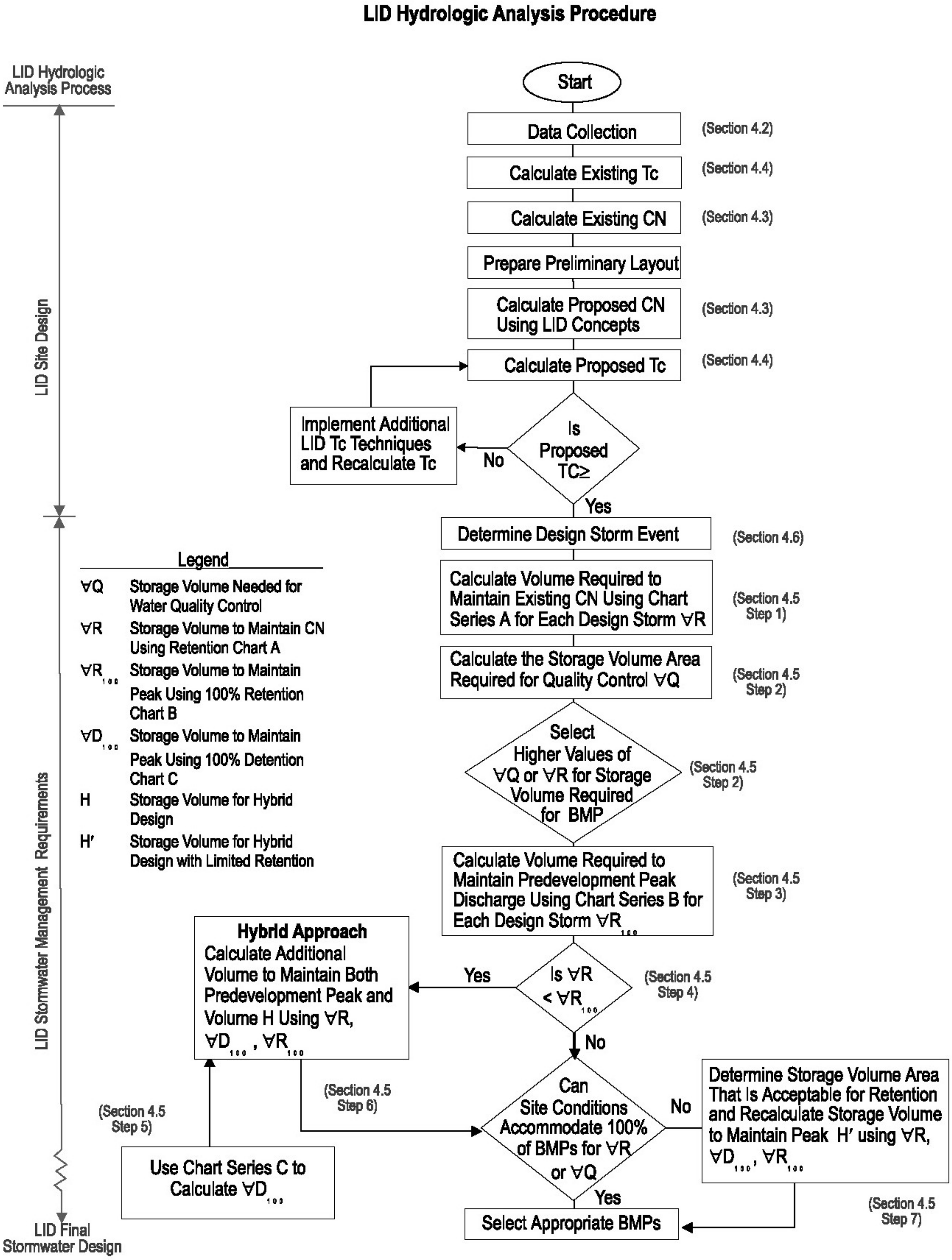


Figure 1.1: LID Flowchart

- Then, using design charts based on a 24-hour design storm, the retention volume required to match the pre- development curve number is determined. The larger of this volume and the volume required for water quality is provided in bioretention and infiltration Integrated Management Practices (IMP's). The computed Water Quality Volume varies with impervious percentage, but is roughly 1" of runoff from the impervious fraction under present Maryland criteria (MDE 2000); it was precisely ½" of runoff from the impervious fraction at the time LID was adopted in Prince George's County.
- Finally, the storage volume, if any, required for runoff peak control is determined, and provided by any combination of detention and retention.

The result is that, by definition, the pre- and post-development CN's and T_c's are equal. Equivalence between the pre- and post-development runoff volumes and peaks is thus guaranteed, and a true 'analysis' of the post-development condition is impossible. Success of the LID method is thus highly dependent on the adequacy of the lumped-model assumption of watershed uniformity, the practicality of maintaining the predevelopment time of concentration, and the applicability of NRCS methods to the small storms that account for most of the annual runoff volume.

In addition to its inherent inability to compare pre- and post-development hydrographs, the present-day LID approach has a few other potential difficulties, as listed below:

- The LID design storm is usually greater than two inches of rainfall, but in the Eastern/Mid-Atlantic states less than 10% of annual rainfall occurs during storms exceeding two inches of total volume. Using the present LID methods, it is impossible to evaluate LID design performance for the small storms that cause most of the annual runoff, especially from impervious surfaces directly connected to drainage pathways. Conventional 2-year/10-year peak control SWM can lead to under-management of smaller storms, but it is unclear whether LID suffers the same shortcoming. Given the storage and discharge characteristics of LID IMP's, it may even be that the smaller events are in fact over-managed, while larger events are under-managed.

- Second, and perhaps most importantly, the LID design and analysis approach precludes consideration of the spatial distribution of both impervious areas and infiltration or bioretention areas. The LID manual assumes that such areas will be distributed uniformly throughout the site, a practice probably difficult to apply in all but the most gently sloping landscapes. Use of the assumption prevents direct evaluation of runoff/run-on processes, interception of subsurface flows along cut slopes, and dynamic source areas near streams, all of which influence runoff production (Wemple et al. 1996, Wigmosta & Burges 1997).
- Finally, the LID manual does not require explicit consideration of the effects of grading and compaction on pervious land segments, other than a general directive to minimize disturbance of soils, and "footprint" sites to places impervious surfaces onto Group C or D soils. Residential lawns have been shown to be poor hydrologic substitutes for natural forest (Konrad et al. 1995), and possess generally thinner topsoil and more compacted subsoil than pasture or meadow. Beyond the admonishment to minimize soil disturbance, there is no design requirement to adjust the curve number of disturbed soils downward. The effects of disturbed soils can be mitigated by compost amendments (Kolsti et al. 1995), but their usage is not prescribed in the manual, or provided for in the LID analysis approach.

LID appears especially promising for gently sloping sites with permeable soils; indeed, it was developed in the eastern Piedmont and Coastal Plain regions. It is unknown to what extent and under what conditions the LID approach actually replicates natural hydrology, or whether the resulting designs are conservative. LID practices are relatively new, and not widely used, so little long-term hydrologic monitoring of LID had been completed at the time this research was undertaken (EPA, 2000). In light of the limitations of the lumped approach mentioned above, a more sophisticated and finer resolution modeling approach is needed to better quantify LID performance in lieu of conclusive monitoring results.

1.2 Research Objective

The primary objective of this research is to evaluate Low Impact Development and determine to what extent it replicates natural hydrology, especially that of an Appalachian watershed. Intermediate tasks were as follows:

- Review the capabilities of available hydrology models to identify those models appropriate to evaluation of LID. Since analysis of hypothetical future and assumed past conditions requires application to ungaged watersheds, the approach stresses use of physically-based models where parameters can be estimated *a priori*.
- Test likely models to examine parameter sensitivity and support selection of a model to evaluate LID.
- Redesign a segment of a local suburban development using LID practices.
- Apply the model to the development under conventional development conditions, predevelopment forest, and the LID redesign, attempting to capture the fine-scale effects of LID practices. Modeling incorporates a local rainfall time series, giving insight into LID’s impact over a wide range of possible storm sizes and antecedent conditions.

- Analyze the model results, and evaluate the hydrologic performance of LID versus predevelopment forest as well as conventional development.

1.3 Approach

Evaluation of Low Impact Development proceeded according to the following approach:

- In order to determine the best model for evaluating Low Impact Development, nineteen models were reviewed. Two (KINEROS2 and EPA-SWMM) were considered applicable to LID.
- In preliminary testing, KINEROS and EPA-SWMM were first applied to the 21.7-acre Virginia Tech Commuter Parking Lot, for which both rainfall and runoff data are available. Additional sensitivity analysis was performed by applying both models to a hypothetical 1-acre watershed. SWMM was selected for application to an LID site.
- The Village at Tom's Creek, a suburban development near the Virginia Tech campus, was selected for adaptation to LID because it was already designed as a cluster development with reduced street widths and grass swale drainage. A 4.3-acre subwatershed of the development was adapted to LID design.
- The site was modeled with continuous SWMM under predevelopment forested conditions, conventional development (with and without stormwater management), and the LID redesign. The model was applied over a range of typical parameter values, representing the wide potential site-to-site variation in soils and vegetation, and attempting to capture as many important hydrologic processes as possible. Over six years of mixed 5- and 15-minute resolution local rainfall data were used in the simulation, along with various 24-hour NRCS synthetic design storms.

- Comparisons of peak flow, runoff volume, and timing were made, providing insight into the apparent advantages and disadvantages of LID versus conventional development. Important issues in fine-scale continuous modeling were identified, and recommendations made for helping ensure that LID is applied effectively.

2 LITERATURE REVIEW

2.1 Hydrology of Forested and Urbanized Watersheds

A natural forested watershed only produces direct runoff for a small annual number of rainfall events compared to an urbanized watershed. For most events, much of the precipitation is intercepted by the tree canopy, stored in surface depressions, or infiltrated into the soil and lost to evapotranspiration. Some infiltrated moisture is percolated to groundwater and later discharged as baseflow. Increased streamflows following smaller rainstorms in a forested watershed are due largely to shallow subsurface flow of stormwater downslope (interflow), direct precipitation on the stream, and direct runoff from a relatively small proportion of the basin often located adjacent to the stream (Seybert 1996). Direct surface runoff may be either due to the rainfall intensity exceeding the infiltration capacity of the soil (Horton, or infiltration excess overland flow), or due to the water table rising to the soil surface (saturation excess overland flow). Additional overland flow (return flow) is produced where groundwater discharges directly to the face of a slope (Wigmosta & Burges 1997). For a typical eastern hardwood forest, 40% of the annual water budget is accounted for by evapotranspiration, 50% by subsurface flows, and less than 10% by surface runoff (Prince George's County 2000b).

Urbanization reduces natural watershed storage by creating impervious surfaces, increasing drainage density, reducing flow resistance, and reducing the infiltration capacity of many of the remaining pervious areas through compaction, filling, and grading. Both the surface and subsurface portions of the hydrologic cycle are affected. Peak flows and overall runoff volumes are increased, and the time from the start of rainfall to the runoff peak is reduced, resulting in negative impacts to stream stability, habitat, and flood-susceptible downstream development. The total volume of water available for evapotranspiration and groundwater recharge is reduced. Actual transpiration can be reduced as well due to the replacement of large trees and undergrowth with lawn and landscaping, leading to higher antecedent soil moisture content on the remaining pervious areas, in spite of a lower landscape-wide soil moisture storage volume.

In a typical developed watershed in the East, the overall annual water balance shifts to 25% evapotranspiration, 32% subsurface flows, and 43% surface runoff (Prince George's County 2000b). The effects are even more pronounced on an individual storm basis, with flood peak increases from twofold to tenfold, depending on storm intensity and watershed conditions (Booth 1991, Hollis 1975). While impervious surface runoff accounts for a large proportion of both the peak flow and total runoff volume in urbanized watersheds, pervious land runoff cannot be ignored, especially on less permeable soils experiencing high rainfall intensities (Boyd et al. 1993, Boyd et al. 1994).

Detention ponds may successfully control the flood peaks for which they were designed, but they have no provision to reduce the overall runoff volume, and may still result in increased peak flows downstream due to coinciding peaks from several ponds. One study (Traver & Chadderton 1983) determined that SWM peak control applied in each subwatershed still resulted in a 44 percent increase in 100-year peak flows at the watershed outlet when compared with existing natural conditions. For small storms, of a frequency lower than the pond's design frequency, ponds may provide no benefit at all. The effects are more dramatic for frequent storms where the ratios of post- to pre-development runoff are larger.

2.2 Required Model Characteristics

Models used to evaluate land use change must provide an accurate representation of conditions both before and after development, an especially important requirement for modeling LID because an LID site combines hydrologic features of both urban and rural land. Few available models can represent the profoundly different hydrology of undeveloped and urban lands equally well, a situation further complicated by the presence of various BMP's. Since analysis of future conditions precludes model calibration, physically-based models where parameters can be estimated *a priori* will be required.

In addition to having a physical basis, it is advantageous for an LID model to be capable of both continuous simulation, be applicable at a fine spatial scale, and successfully model transfer of water from one surface to another. The dominance of infiltration and subsurface processes in undeveloped and LID sites requires a continuous simulation model to improve estimates of antecedent moisture condition. Fixtures of the LID landscape such as disconnected impervious areas and distributed bioretention BMP's require spatially distributed modeling at a finer scale than is usual in modeling. Use of filter strips and impervious surface disconnection requires a model to allow runoff routing from one land use to another, commonly called a cascade.

Finally, the small spatial scale of LID features necessitates a small model time step to accurately compute runoff response. Fortunately, the small size of an LID site allows the modeler to dispense with issues such as detailed channel and floodplain routing, baseflow generation, and rainfall heterogeneity. It was believed that one or more of the above mentioned model requirements would have to be sacrificed to find a suitable existing model, so an extensive review of existing models was undertaken to find one with most of the required features.

Available hydrologic models are reviewed in the next section for their applicability in the modeling of the hydrologic effects of LID, as well as non-technical requirements such as documentation, user support, and current use in the engineering community. Models vary widely in their complexity and comprehensiveness, and are described by five basic model attributes, indicated below:

- *Watershed conceptualization* entails the model representation of the watershed, and fundamental modeling characteristics. Models generally represent a watershed as either a grid of interconnected cells, as a series of planes linked together by a channel network, or as a lumped response unit governed by empirical equations. Within each subgroup there are minor differences, for example in the permitted number of planes draining to a channel, or whether channels receive lateral inflow.
- *Overland flow* may be computed using the kinematic wave or diffusive wave approximations to the full dynamic equations, or using a non-linear reservoir formula usually based on Manning's equation. Possible numerical solution methods include the method of characteristics, finite difference, or Newton's method, each balancing accuracy with stability. A unit hydrograph may also be used to transform rainfall into runoff, but this precludes distributed modeling. Overland flow may be coupled with infiltration calculations, allowing infiltration during periods with no rainfall, or rainfall excess may be computed first and then routed as overland flow.

- *Infiltration and loss methods* range from simple empirical methods such as the NRCS Curve Number and Horton’s equation, to the physically based Green-Ampt method and Richards’ equation, with data requirements increasing accordingly. Models may also include canopy interception and surface depression storage.
- *Unsaturated zone* processes such as horizontal flow (interflow) and drainage (vertical redistribution) are included in a few models, usually with simple conceptual methods, empirical equations, or a one-dimensional form of Darcy’s law.
- *Saturated zone* moisture storage and movement is likewise often simplified to empirical or conceptual equations describing groundwater table fluctuations and groundwater discharge to streams (baseflow).
- *Evapotranspiration* may occur from the land surface, vegetation, or any of the soil layers, but not all models allow evapotranspiration from all possible sources. Potential evapotranspiration may be computed using the data-intensive but physically-based Penman-Monteith equations, the Ritchie equation, or can be user-supplied. Actual evapotranspiration is limited by moisture availability and potential evapotranspiration, and is removed from storage reservoirs in the order of priority specific to a particular model.
- *Channel and reservoir routing* may be computed using the storage indication method, the Muskingum method, the full dynamic (St. Venant) equations, or one of the simplifications thereof.

The features listed above are by no means the only ones available to each model, but they do represent the hydrologic processes considered important to modeling LID. Some models have significant other applications such as erosion and water quality prediction; these are ignored in the present discussion. With the increasing popularity of the LID approach, a few standard hydrologic models have been augmented to allow evaluation of LID practices (SWMM, HSPF, WinSLAMM), while one entirely new model has been developed solely to evaluate LID scenarios (LIFE model). Section 2.3 describes in detail the seven models that showed particular promise for LID modeling, two of which have recently been revised to accommodate LID practices. Their features are summarized in Table 2.1. Section 2.3.8 lists and describes briefly the twelve models that did not warrant detailed consideration due to unavailability/cost; or obvious shortcomings for the prescribed task of continuous modeling LID, forest, and conventional development at a fine spatial scale; even though three of those models were specifically developed or modified to evaluate urban BMP performance and/or LID practices. Their features are summarized in Table 2.2.

2.3 Model Review

Models described below exhibited enough of the desired model characteristics listed above to merit consideration for continuous simulation of LID at a fine spatial scale. Their features are summarized in Table 2.1.

Table 2.1: Features of Models Considered Applicable to Fine-Scale LID Simulation

Model Name	Watershed Conceptualization	Min. Time Step	Overland Flow Routing			Infiltration Routine(3)	Groundwater Routines		Evapo-transpiration	Channel Routing(2)	Pond Routing(2)
			Method(2)	Coupled?	Cascade?		Unsaturated	Saturated/ Baseflow			
ANSWERS	Grid	30 sec/ 24 hr	KW	Yes	Yes	G-A	Brooks-Corey	Crude	Ritchie	KW	None
CASC2D	Grid	1 sec/ 1 hr	DW	Yes	Yes	G-A	None		Penman-Monteith	DW, St.V	None
DR3M	Plane / channel	0.01 min/ 1 day	KW	No	No	G-A	Yes	Storage only (no outflow)	User-supplied	KW	Linear reservoir, Mod Puls
HEC-HMS	Plane / channel	1 min	UH, KW	Yes	No	CN, G-A, SMA	Yes, same as PRMS		User-supplied	M, M-C, mod Puls, lag, KW	Mod Puls
HSPF	Plane / channel	Any (typ. 1 hr)	Non-linear reservoir	Yes	Yes	Philip's	Yes, lumped		User-supplied	Rating curve	Rating curve
KINEROS2(1)	Plane / channel	1 sec	KW	Yes	Yes	G-A	None		None	KW	Mod Puls
EPA-SWMM	Plane / channel	1 sec	Non-linear reservoir	Yes	Yes	G-A, Horton	Yes, Darcy's law		User-supplied	Non-linear reservoir, KW, St. V	Mod Puls

Notes:

(1) KINEROS2 is a single-event model.

(2) KW = Kinematic wave, DW = Diffusive wave, UH = Unit hydrograph, GIUH = Geomorphological Instantaneous Unit Hydrograph, M = Muskingum, M-C = Muskingum-Cunge, St.V = Full St. Venant's equations.

(3) G-A = Green-Ampt, CN = NRCS Curve Number, SMA = Soil Moisture Accounting

2.3.1 ANSWERS-2000 – Areal Nonpoint Source Watershed Environmental Response Simulation

ANSWERS-2000 was originally developed as a distributed single-event model at Purdue University, and modified to accommodate continuous simulation by researchers at Virginia Tech. It was intended as a BMP planning model for ungaged rural catchments. ANSWERS is grid based, making it appropriate to distributed modeling. ANSWERS represents a watershed using an irregular matrix of equal-sized squares, each of which apportions runoff to neighboring cells or to its channel. The model operates with a dual time step: 30 seconds during days containing rainfall, and 24 hours required for non-storm days.

ANSWERS computes the net rainfall striking the soil surface by subtracting interception storage from the rainfall time series. The Mein-Larson formulation of the Green-Ampt method is used to compute infiltration, which is drawn from both surface detention and retention storage. Infiltration parameters are adjusted to account for the effects of surface crusting, macropores, canopy cover, coarse soil fragments, and entrapped air (Bouraoui 1994). Surface runoff is routed using an explicit backwards difference solution to the continuity and Manning's equations under the kinematic wave assumptions. Each grid cell is treated as an overland flow plane, where the inflow is the sum of the net rainfall and the outflow received from connected cells (Dillaha et al. 2001). Manning's equation is solved via a lookup table in the current version of the model, requiring an initial estimate of the 'expected' peak discharge value. Flow can be routed to multiple neighboring cells, rather than a single orthogonal direction. Owing to ANSWERS' original development as an agricultural model, impervious surfaces are not represented. It is possible to model them as bare clay soils, but some infiltration will occur because the user is only free to select soil type, not specific infiltration parameters.

Potential evapotranspiration is either user-input or computed using Ritchie's method, which requires inputs of daily air temperature and net solar radiation. Alternatively, an on-board climate generator, CLIGEN, can be used to synthesize weather inputs. Ritchie's method for actual evapotranspiration computes two-stage plant transpiration and soil evaporation separately, requiring inputs of leaf area index and root zone depth, which are tabulated for a variety of common crops. Actual ET is limited by available soil moisture present within the root zone. Upper zone soil moisture in excess of field capacity is drained according to the Brooks-Corey approach, and may percolate below the root zone. A parameter is provided which represents the fraction of moisture below the root zone that drains to a channel during each time step, providing an extremely crude approximation to baseflow generation. Use of the parameter is generally not recommended (Dillaha 2000, personal communication). Interflow is not simulated.

ANSWERS routes runoff through the channel network using an explicit backward difference solution to the kinematic wave equation. Runoff enters channels as lateral inflow from the grid cell containing the channel. Only rectangular channels are modeled, preventing the representation of either compound channels or circular storm sewers. Neither channel transmission losses nor reservoir routing are simulated in the current version of the model.

ANSWERS allows up to eight rain gages, which are Thiessen-weighted by grid cell, and up to 35,000 cells. Simulation times may be long for large numbers of cells and long simulations (about an hour for one year's data and 35,000 cells), but are usually favorable for models with fewer than 10,000 cells. Output is voluminous as well, because there is no option to forgo sediment and nutrient calculations (Nordberg 2000, personal communication). Unfortunately, hyetographs must be entered separately for each day, and only one hyetograph is permitted per day. The hydrology module is most sensitive to soil porosity, and slightly less sensitive to canopy area and clay content (Byne 2000). Considering its current inability to model impervious land, non-standard soils, or urban constructed channels, ANSWERS is not considered suitable for the LID modeling problem. The requirement for separate daily hyetograph entry, and limitation to 24 breakpoints, prevent effective use of the available high-resolution rainfall data as well. Planned improvements to the code in 2001 will increase versatility and applicability, but not in time to incorporate ANSWERS into the present LID research.

2.3.2 CASC2D – Cascade 2-Dimensional

CASC2D (Ogden 1998, DeBarry and Quimpo 1998) was originally developed at Colorado State University as a distributed, physically based, continuous, infiltration-excess watershed model intended for use where overland flow dominates the hydrology. It uses a matrix of square grid cells to represent a watershed, and allows spatial variation for all inputs. The Watershed Modeling System (WMS) provides a user interface for model setup and output visualization. Continuous simulation proceeds with an hourly time step for soil moisture accounting, and a 1 to 30 second time step during rainfall-runoff events, as required for numerical stability.

CASC2D accepts an unlimited number of point rainfall estimates, which can be distributed using either Thiessen polygons or inverse-distance squared interpolation. A two-parameter model is used to compute interception losses, with an additional fraction of rainfall intercepted each time step after the initial abstraction volume is filled. Infiltration is computed using either the traditional Green-Ampt method, or a modification allowing soil moisture redistribution during unsteady infiltration. Soil is assumed infinitely deep. A future version of the model will include solution of full Richards' equation, making that version of the model appropriate for areas of shallow groundwater tables. Overland flow is routed using a two-dimensional, finite difference solution to the diffusive wave equation, which accounts for backwater and allows flow on adverse slopes. Flow is routed to one of the eight neighboring cells only. No special consideration is given to impervious surfaces; they must be modeled as cells with zero infiltration and reduced roughness and depression storage.

Evapotranspiration is computed using the complex Penman-Monteith method, which requires inputs of five spatially varied plant cover parameters, and four hourly climate parameters. Radiation fluxes may be input directly or simulated by the model. Percolation is only simulated as part of the modified Green-Ampt soil moisture redistribution. Interflow and baseflow are not simulated.

Channel routing may be accomplished using an explicit, one-dimensional diffusive wave formulation, or a Preissmann 4-point implicit solution to the full one-dimensional St. Venant equations. The latter method is appropriate to extremely flat watersheds, and becomes unstable for near-critical or supercritical flow. The former method is appropriate to headwater catchments and is stable for all flow regimes at small time steps. A variety of channel cross sections are permitted, included free-flowing weirs. If channel routing is not considered important, the user may specify that water be removed from the model by treating a boundary as a channel with kinematic wave properties. Culvert and bridge-crossing hydraulics will be included in future versions of the model. Transmission losses and reservoir routing are not simulated.

CASC2D will operate at any spatial scale, assuming adequate digital datasets exist, but it is typically applied using 30 to 200 meter grid cells, too coarse for fine scale urban modeling. It is sensitive to input data quality, and becomes numerically unstable if input data errors are present. Considerable DEM pre-processing is thus essential for successful application. It also suffers from unnecessarily complex routines in some modules (e. g. evapotranspiration), while lacking any representation of other important hydrologic processes in others (i.e. subsurface flow, reservoir routing). The lack of subsurface and urban hydrology components is particularly troublesome, and limits application to semi-arid regions or large storms where overland flow dominates. The model is in the public domain, but its use is officially discouraged for users unfamiliar with distributed hydrology and numerical methods (Ogden 2007). In addition, the commercially available WMS interface required for efficient and effective model application is quite expensive. There is a freeware version of WMS, but it lacks important GIS and terrain modeling functionality that is needed to effectively build a model input dataset. These factors combine to make its use prohibitive for most users at this time.

2.3.3 DR3M – Distributed Routing Rainfall Runoff Model

The Distributed Routing Rainfall Runoff Model (DR3M) was developed by the USGS as a continuous or discrete event urban hydrology model, intended for watersheds up to 10 square miles (26 km^2) in size. It is similar to EPA SWMM (see below) in its watershed conceptualization and capabilities. Watershed elements are represented as a network of planes, channels, reservoirs, and nodes. DR3M assumes that planes contribute lateral inflow to their channels, unless otherwise specified. In continuous mode, DR3M computes daily evapotranspiration during interevent periods, and flow routing during ‘unit days,’ or those days that contain storms. Time steps as small as 0.01 minute can be used during unit days (Alley & Smith 1982).

DR3M computes rainfall excess from input gage data using a modification of the Green-Ampt method that eliminates having a single-valued threshold for infiltration. Rainfall striking ineffective impervious areas is assumed instantaneously distributed over the pervious area (without opportunity for infiltration). One-third of impervious surface rainfall is added to retention storage until the impervious retention storage capacity is filled. The remaining rainfall excess time series is then routed using the kinematic wave equations for either laminar or turbulent flow. DR3M uses the same conceptual overland flow ‘width’ of a plane as EPA SWMM, taken as the plane’s area divided by the average overland flow path length for a homogeneous rectangular plane. The user can choose one of three solutions to the kinematic wave equation: method of characteristics, implicit finite difference, or explicit finite difference (Alley & Smith, 1982).

DR3M operates with a user-input evaporation time series, to which it applies a user-input pan coefficient to obtain daily potential evapotranspiration. Both lower (saturated) zone and upper (unsaturated) zone groundwater storage are computed. During non-unit days, upper zone storage (derived from infiltration) may percolate to the lower zone at a rate based on the effective hydraulic conductivity of the upper zone. Any infiltrated water is effectively removed from the model, since groundwater discharge is not modeled. The program includes a Rosenbrock optimization procedure for infiltration and soil moisture parameters (Alley & Smith 1982).

DR3M routes runoff through the channel/pipe network using any of the three kinematic wave solution methods mentioned above. Runoff is assumed to enter channels as uniformly distributed lateral inflow, or as upstream inflow entering at a node. Channels may be specified as circular or triangular, or the user may specify the kinematic wave parameters alpha and m for other channel shapes. Compound channels may be simulated by entering a pair of kinematic wave parameter sets, one for the main channel, and one for the entire cross section during flows that exceed the main channel capacity. Reservoir routing is performed using either a linear reservoir model or the modified Puls method. Channel hydrograph attenuation may be simulated by changing the implicit finite difference method weighting factor (Alley & Smith 1982).

The most glaring limitation on DR3M is that only three rain gages and two soil types are permitted, making accurate representation of rainfall and soil heterogeneity over a large or highly discretized basin nearly impossible. It should remain applicable at the site scale only as long as soil parameters are relatively homogeneous. The decoupling of the infiltration and runoff equations, originally required to save computer time during optimization runs, prevents any infiltration from occurring during a rainfall hiatus or during the recession limb of the hydrograph, rendering simulation of small-scale BMP's difficult or impossible. The lack of a groundwater simulation limits DR3M's use to highly urbanized basins, or small basins where baseflow is negligible, but this alone wouldn't greatly impede its application to LID. Simulation duration is limited by a program limit of 60 storms occurring over no more than 120 unit days, with an additional overall maximum of 20 years of record (Alley & Smith 1982). A cascade can be represented in DR3M by using the unconnected impervious area option, but this approach will require an additional soil type beyond the two permitted, and may not be accurate for LID since runoff and infiltration calculations are decoupled. Given its above limitations and cumbersome FORTRAN input cards, it was not judged worth pursuing for LID modeling.

2.3.4 HEC-HMS – HEC-Hydrologic Modeling Software

While its predecessor, HEC-1, is not a continuous simulation model, the latest version of HEC-HMS includes a soil moisture accounting algorithm, thus qualifying it for consideration. HEC-HMS conceptualizes the watershed into a network of subareas connected by channel links. Basins of all sizes may be modeled. Automatic calibration algorithms are included with the new model version (Feldman 1995), and an ArcView extension, HEC-GeoHMS, expedites input file creation if proper GIS data layers are available. An urban hydrology option exists wherein each subarea contains two plane surfaces (one impervious, and one pervious), and two levels of collector channel. Another option allows each subarea to be represented as a raster grid, accounting for spatial variation of both rainfall and hydrologic parameters (Feldman 2000).

Rainfall excess is computed first, then routed by one of several unit hydrograph methods, or an explicit forward finite difference solution to the kinematic wave equation. The kinematic wave equation is solved using a variable distance step, with the solution approaching the characteristic solution (Kibler et al. 1987). Impervious surfaces are treated similarly, but without computing initial and infiltration losses. Only the ModClark or NRCS unit hydrograph methods may be used for runoff routing with the gridded watershed model, while the urban hydrology option requires that the kinematic wave be used. A variety of loss methods may be used for the pervious surfaces, including NRCS Curve Number, initial volume/constant rate, soil moisture accounting, and Green-Ampt. The gridded model may only use soil moisture accounting or Curve Number. The five-layer soil moisture accounting (SMA) is based on Leavesley's Precipitation-Runoff Modeling System (1983), and is described fully in Bennett (1998). Evapotranspiration is computed from the top three layers (canopy, surface, and upper soil zone), and percolation computed from the upper zone and the two groundwater layers. The groundwater layers discharge interflow to a linear reservoir for baseflow generation, or recharge a lower layer. Simple, conceptual equations are used for each flux, and the storage parameters require calibration. Groundwater flow and water table location is not computed. Several options are available for channel routing, including Muskingum, Muskingum-Cunge, modified Puls, lag, or kinematic wave. Reservoir routing uses the modified Puls (storage indication) method.

While HEC-HMS provides the hydrologist many options including reservoir routing, it is not quite versatile enough to tackle the LID problem. The model time step, which can be as small as one minute, is constant for storm and interevent periods, thereby limiting the length of any continuous simulation that would be attempted. The urban hydrology option mandates usage of two planes and three channels, and thus does not allow a cascade. The grid option appears promising in this regard, but unfortunately, the unit hydrograph flow routing precludes analyzing a cascade, and the SMA parameters require calibration. HEC-HMS was not further considered for LID modeling.

2.3.5 HSPF – Hydrologic Simulation Program - Fortran

HSPF was developed under EPA sponsorship as a comprehensive, watershed-scale model for both water quantity and water quality simulation in complex watersheds (Donigian et al. 1995, Bicknell et al. 1997). It has been applied successfully in a wide range of geographic regions and land uses. It continuously simulates all components of the hydrologic cycle with any user-defined single time step (usually hourly), over a simulation period of days to decades. The watershed is represented as a network of lumped planar flow elements, each having various surface and subsurface storage zones, which may contribute lateral inflows to each other and upstream inflows to river and reservoir reaches. No practical limits exist on the number of planes, reaches, or rain gages that may be included in an HSPF application.

Pervious HSPF flow elements receive rainfall input, which is initially directed into interception storage. From there it may either evaporate or overflow into surface detention storage. Water may then run off, enter interflow storage, enter upper zone storage, or infiltrate to deeper soil layers (lower zone and active groundwater). The surface detention and interflow storage zones may also receive lateral inflow from another flow element. The contents of upper and lower zone storage may percolate downward, eventually to active groundwater storage and possibly to inactive (deep) groundwater storage, where water is lost from the model. Evapotranspiration occurs from the interception, upper zone, lower zone, and active groundwater storages. For impervious land segments, interception and subsurface processes are not computed, and surface retention storage is the initial recipient of rainfall, from which water may either evaporate or overflow into surface detention storage. Methods of computing water fluxes are described in the following paragraphs.

Infiltration is computed using Philips' equation (1957), allowing for spatially variable infiltration over the land segment through use of a linear probability density function of the infiltration parameter. Infiltration capacity depends on three infiltration parameters and the lower zone storage to nominal storage ratio, thus accounting for soil moisture content as well. Interflow outflow depends on the current inflow and storage, and a recession parameter. The value of the recession parameter determines the timing and decay of interflow discharge, and thus whether interflow behaves more like surface runoff or groundwater discharge. Surface runoff is routed using a quasi-kinematic wave formulation (non-linear reservoir) similar to that used in the original Stanford Watershed Model. Each overland flow element is treated as a homogenous plane. The average overland flow length, roughness, and overland slope are required inputs. One of two equations may be used, depending on whether detention storage is above or below its equilibrium value at the current time step. The equilibrium value is determined by the current rate of moisture supply (rainfall less interception). Pervious and impervious land segment runoff are routed in the same manner.

HSPF computes evapotranspiration from available moisture in storage and a user-input time series of potential evapotranspiration (PET). Evaporation demand (PET) is first satisfied from baseflow, if it exists, and then sequentially from the following storages, as limited by availability: interception, upper zone soil, active groundwater, and lower zone soil. Upper zone ET depends on the actual/nominal storage ratio. Lower zone ET is determined by a lumped parameter describing plant growth stage characteristics. The parameter (LZETP) may vary seasonally, and is represented by a linear probability density function in a similar fashion as the infiltration parameter. Soil moisture is redistributed continuously through percolation, based on actual/nominal storage ratios. Water may be lost from the basin as deep percolation to inactive groundwater storage. Baseflow issues from the active groundwater storage at a rate proportional to the previous day's rate. An additional parameter allows for seasonal variation of this recession coefficient. The many conceptual parameters controlling HSPF water fluxes require estimation followed by calibration, and are impossible to determine *a priori*.

HSPF treats stream reaches and reservoirs alike, making no assumptions as to channel shape. A "RCHRES" segment receives upstream inflow from land segment elements or other reaches. Multiple outflows may be specified, representing river outflow and water withdrawals for irrigation, water supply, etc. For any reach, a table must be specified for depth vs. surface area, volume, and outflow. Volume (storage)-dependent outflows are specified in the table, or time-dependent outflows such as seasonal irrigation demands are entered as a time series. Channel transmission losses can only be represented as an outflow in a table, and thus can depend on stream stage, but not groundwater stage. Routing is performed based on continuity and a rating curve provided by the user. For river reaches, outflow rating curves are generally computed using Manning's equation. Backwater influence on upstream elements cannot be modeled; nor can flow reversals.

HSPF provides a very comprehensive treatment of hydrologic processes, but unfortunately few of the required parameters have a physically meaningful interpretation, and/or are not obtainable *a priori*. This is especially true of the infiltration and subsurface flow parameters. Careful calibration of parameters is thus a necessity, making HSPF applications limited to watersheds where good data sets exist. This is almost never the case with small, urbanizing watersheds. The antiquated FORTRAN card style input files also make application at a fine spatial scale extremely tedious for all but the smallest watersheds.

The Washington (State) Department of Ecology commissioned Clearwater Solutions, Inc., to develop an HSPF-based model, called the Western Washington Hydrologic Model (WWHM), to enable evaluation of BMP designs under continuous simulation (AQUA TERRA Consultants 2003). It is a GUI-based model, which simplifies input and output versus the standard version of HSPF. It was not originally developed specifically for LID, and suffers somewhat in that endeavor due to HSPF's poor routing algorithms, and the fact that its pervious land segment parameters were calibrated to larger-scale local USGS studies, rather than at the fine scales under which LID IMP's operate. The Puget Sound Action Team (Hinman 2005) developed guidelines for modeling LID practices in WWHM, but not until significantly after the modeling effort described in this paper was completed. The newest version of WWHM is now capable of simulating most LID-related processes, but is customized for the western Washington region. It was therefore inappropriate for use in the Appalachians, due to significant differences in rainfall patterns, vegetation, and soils.

2.3.6 KINEROS2 – A Kinematic Runoff and Erosion Model

KINEROS was developed by the USDA – Agriculture Research Service for the calculation of water and sediment runoff from arid and semiarid rural watersheds. KINEROS2, released in 2000, is the latest version. It is a physically-based, distributed, single-event model, but its potentially superior runoff physics made it worth considering an effort to devise a continuous simulation version using Visual Basic modules. KINEROS represents the watershed as a system of cascading planes and channels, with optional pond elements (Woolhiser et al. 1990). The user may specify any time step (typically seconds), and optionally the time step can be adjusted internally as needed to satisfy the Courant stability criteria. Up to 20 rain gages with up to 500 breakpoints each may be used, with gage weights for each plane and/or channel being computed internally given the coordinates of the elements and gages. Upland and channel sediment detachment and transport, as well as pond sedimentation, can be modeled if desired.

Rainfall input to both pervious and impervious KINEROS planes is reduced by the canopy cover fraction until the specified canopy interception storage is filled. Infiltration is computed for the pervious planes using the Green-Ampt method, modified to allow moisture redistribution during a rainfall hiatus. Two soil layers are modeled, but only for computing infiltration and redistribution. Infiltrated water is otherwise lost to the model. Surface runoff is computed using a four-point implicit kinematic wave solution, with either the Manning or Chezy roughness relation. Runoff routed from a plane can be input to a channel as either upstream or lateral inflow, or transferred to another downslope plane. The influence of microtopographic relief on infiltration during hydrograph recession can be simulated by specifying the microtopographic relief and spacing. Antecedent conditions can be varied for several storms without changing the watershed model if initial soil moisture is specified in the rainfall file instead of the watershed parameter file.

KINEROS uses the kinematic wave formulation to compute channel routing, and allows trapezoidal (including triangular and rectangular) or compound channels with up to 10 upstream contributing elements and 2 elements contributing lateral inflow. Direct rainfall to the channel and overbank can be computed, and the user can specify baseflow. Channel bed infiltration can be modeled similarly to pervious plane infiltration, with the wetted perimeter able to be adjusted to account for channel bed microtopography. Pond routing is accomplished using the modified Puls method, requiring a user-input rating table and stage-storage table.

Woolhiser et al. (1990) and Fu (1994) both indicate that KINEROS is highly sensitive to rainfall amount, saturated hydraulic conductivity, and mean capillary drive. Fu (1994) contended that the sensitivity to rainfall amount has more to do with intensity than with overall volume. He found that KINEROS overpredicted both peak discharge and runoff volume for smaller rainfall events, but questioned whether this was a result of poor rainfall gauge coverage and highly spatial variable rainfall rather than model bias. KINEROS is perhaps the most physically-based of any of the reviewed models, and shows promise in modeling LID. Because of the effort required to develop a continuous version, preliminary testing will be done comparing KINEROS and SWMM to determine if KINEROS provides enough of an advantage to warrant the additional effort. Chapter 3 describes the testing, comparing SWMM and KINEROS.

2.3.7 EPA-SWMM – Stormwater Management Model

EPA SWMM, originally developed for analysis of combined sewer overflows in urban watersheds, has found applications worldwide under hydrologic conditions ranging from rural to ultra-urban. Owing to its original application to urban storm sewers, SWMM conceptualizes the watershed as a system of overland flow planes, channel links, and nodes. It can be run in either continuous or event mode, though the difference between the two is merely semantic. Continuous SWMM operates with up to three time steps representing wet, transition, and dry periods, ranging from one second to 24 hours (Huber and Dickinson 1992). The Runoff, Transport, Storage/Treatment, and Extended Transport Blocks of the SWMM program are used to translate rainfall into runoff, and route the runoff to the basin outlet. Also included are several utility blocks (Rain, Temp, Combine, and Statistics) that allow climatic data file preparation, manipulation of output files, and statistical analysis of output.

The SWMM Runoff Block computes and routes rainfall excess, treating each overland flow plane as a non-linear reservoir with user-defined depression storage. Planes may contribute inflow to channels or to other planes (Oregon State University 2005). Either the integrated Horton method or Mein-Larson version of the Green-Ampt method may be used for infiltration calculation. A subcatchment ‘plane’ is divided into pervious and directly connected impervious fractions. The directly connected impervious fraction is further subdivided into sections with non-zero and zero depression storage. Slope and ‘width’ are assumed constant for the pervious and impervious portions of a subcatchment. The conceptual overland flow ‘width’ of a plane is typically taken as the plane’s area divided by the average overland flow path length, then calibrated to match simulated and observed hydrograph shapes (Huber 1995, Nix 1994). The non-linear reservoir model used for overland flow routing is essentially Manning’s equation modified to include depression storage, and solved by Newton-Raphson iteration. The numerical formulation averages the flow depth between the end of the previous time interval and the *midpoint* of the current one. Averaging of flow depth using the midpoint of a time step leads to a notoriously sluggish hydrograph peaking response, especially for long, narrow flow planes. The problem is typically remedied by adjusting the subcatchment width, impervious area depression storage, or less commonly, overland roughness, during calibration. The Runoff Block will also route the generated runoff through a limited channel network consisting only of trapezoidal (including triangular and rectangular) or circular channels, using a routine analogous to the non-linear reservoir used for planes, only without the depression storage parameter. From the input formatting, runoff would appear to enter the channel network at upstream nodes, but because a non-linear reservoir method is used, runoff is in fact distributed effectively uniformly over the channel length for calculations.

For continuous simulation, infiltration capacity recovers at a rate dependent on the hydraulic conductivity for Green-Ampt infiltration, or at a user-defined infiltration capacity recovery rate in the case of Horton infiltration. Evaporation is subtracted from rainfall and ponded water prior to the infiltration calculation, using a user-supplied potential evapotranspiration time series. If the groundwater routine is used, soil moisture is redistributed during light rainfall and during interevent periods using an approach based on Darcy's law, but surface infiltration capacity is still recovered using the method mentioned above rather than by the soil moisture accounting. For either infiltration model, infiltrated water may be routed through a lumped unsaturated zone storage, followed by a lumped saturated zone storage. Evapotranspiration is possible from either zone when surface storage has been depleted, but baseflow discharge is only from the lower zone. The only way that subsurface conditions can affect infiltration is if the computed groundwater table rises to the soil surface. Groundwater discharge to channels is computed utilizing the DuPuit-Forchheimer approximation for a rectangular reservoir. Water may also be lost to deep percolation. Relative or absolute elevations must be specified for the channel bed, aquifer bottom, groundwater table, and land surface. Fifteen other parameters are then required to describe soil properties, groundwater flow characteristics, and the influence of channel stages.

The Transport Block of SWMM routes runoff through a channel/pipe system using the kinematic wave equations. Runoff is injected into the channel system at nodes, rather than as lateral inflow. Fifteen standard channel cross sectional shapes are available, as well as user-defined irregular (natural) channels. Up to five subcatchments (planes) and up to three upstream channel elements may contribute to a given channel. Storage elements may also be included, for which Transport computes reservoir routing by the Modified Puls method. The Extended Transport

(Extran) Block performs hydraulic channel and pipe routing using the full St. Venant equations. It simulates backwater, looped networks, and dynamic boundary conditions.

SWMM has enjoyed a long history of use in urban hydrology, but it is relatively untested on urbanizing rural catchments. SWMM allows up to 10 rain gages, but requires that each plane be individually assigned a rain gage hyetograph. This becomes problematic for large watersheds where most planes are under the influence of multiple gages, but will not effect LID applications. The sluggish overland flow hydrograph response has already been noted above, as has the failure to simulate shallow subsurface flow (interflow). The groundwater routine has only a weak physical basis, and contains several unexplained parameters. The model is particularly sensitive to the subcatchment width and the amount of directly connected impervious area (DCIA), which if in error can result in incorrect calibration of infiltration parameters (Alley & Veenhuis 1983). GIS or CAD can prove useful in refining estimates of parameters. Overall, SWMM is one of the more promising LID models, and will be subjected to further testing to determine the final model selection. Chapter 3 describes the testing, comparing SWMM and KINEROS.

2.3.8 Other Models

Twelve other models were considered and quickly rejected due to obvious inapplicability to LID modeling. They are listed below, along with a brief description and explanation of the reasons for rejection. Their characteristics are summarized in Table 2.2.

Table 2.2: Features of Models Rejected for Fine-Scale LID Simulation

Model Name	Watershed Conceptualization	Min. Time Step	Overland Flow Routing			Infiltration Routine(3)	Groundwater Routines		Evapo-transpiration(4)	Channel Routing(1)	Pond Routing(1)
			Method(1)	Coupled?	Cascade?		Unsaturated	Saturated/ Baseflow			
AnnAGNPS	Lumped	1 day	Lumped travel time	No	No	CN	Brooks-Corey		Penman	Manning's	Constant-outflow
DHSVM	Grid	1 hour	Instant(2)	Yes	Yes	Darcy's law	Yes, Darcy's law		P-M	M-C	None
HYDROTEL	Grid or subwatershed	1 hour	KW or GIUH	Yes	Yes	CEQUEAU, BV3C	CEQUEAU, BV3C		Thornthwaite, H-Q, Linacre, P-M, P-T	KW, DW, Mod Puls	KW, DW, Mod Puls
LIFE Model	Plane / channel	Unknown - proprietary model									
L-THIA NPS	Lumped	1 day	None	N/A	N/A	CN	None		None	None	None
MIKE-SHE	Grid	Varies	DW	Yes	Yes	Richards'	Richards'	Darcy's, Linear res.	P-M, K-J	M, DW	None
P8	Lumped	1 hour	Rational / NRCS	No	No	CN	Unknown	Linear reservoir	Hamon's	Crude	Table inter-polation
PRMS	Plane / channel	1 min/ 1 day	KW, Linear or nonlinear reservoir	Yes	No	G-A	Linear and/or non-linear reservoirs		Hamon's	Mod Puls, Linear Reservoir	Mod Puls, Linear Reservoir
SWAT	Grid or subbasin/ channel	1 day	Mod. Rational	No	No	G-A, CN	Yes		P-M, P-T, Hargreaves	M, Manning's	Daily water balance
TOPMODEL	Grid	Varies	Time-delay histogram	No	No	G-A, Conceptual	Yes		User	Constant velocity	None
WEPP	Hillslope, subbasin/ channel	Varies/ 1 day	KW	Yes	No	G-A	Yes	Storage only	Ritchie, Penman, P-T	KW	Mod Puls
WinSLAMM	Lumped	6 min	None	No	No	Empirical	None		None	None	Mod Puls

Notes:

(1) KW = Kinematic wave, DW = Diffusive wave, UH = Unit hydrograph, GIUH = Geomorphological Instantaneous Unit Hydrograph, M = Muskingum, M-C = Muskingum-Cunge, St.V = Full St. Venant's equations.

(2) Transferred immediately to adjacent grid cell. Velocity is dependent on grid cell dimension and time step.

(3) G-A = Green-Ampt, CN = NRCS Curve Number, SMA = Soil Moisture Accounting

(4) H-Q = Hydro-Quebec, P-M = Penman-Monteith, P-T = Priestley-Taylor, K-J = Kristensen-Jensen, User = User-supplied data.

2.3.8.1 AnnAGNPS – Annualized Agricultural Nonpoint Source Model

AnnAGNPS is an updated, continuous simulation version of the water quality loading model AGNPS for computing water, sediment, and chemical runoff from agricultural watersheds. (ARS 2001). It is one of several companion models that comprise AGNPS 2001, which also includes a DEM utility (TopAGNPS), input and output processors, and CONCEPTS, a diffusion-wave based, one-dimensional, unsteady flow hydraulics and sediment transport routine. While AnnAGNPS accepts grid-based input, it takes a lumped approach to hydrologic computations. Daily rainfall data is either disaggregated into any of the four standard NRCS distributions, or assumed constant to represent irrigation or snowmelt. The NRCS curve number technique is used to compute runoff volume from each grid cell in the model. Peak flow is computed at any location in the stream network using the accumulated runoff volume and time of concentration to that point, and that average curve number which would convert the total precipitation to the total runoff volume at the point. The TopAGNPS model computes flow direction, path length and drainage area from DEM grids for use in AnnAGNPS. Channel travel times are computed using Manning's equation for bankfull conditions in a triangular or rectangular channel. AnnAGNPS assumes a two-layer soil profile for daily soil moisture accounting, using the Penman method for PET and the Brooks-Corey method for percolation. AET is a function of PET and the actual soil moisture content. Curve numbers vary by antecedent moisture condition according to a method also used in the SWRRB and EPIC models. Channel routing is only included implicitly in the time of concentration calculations, and only constant-outflow ponds can be modeled. Future versions will include channel losses and accretion, snowmelt, and the effects of frozen soil. Because of its lumped approach to surface hydrology, AnnAGNPS cannot be further considered for distributed LID analysis.

2.3.8.2 DHSVM – Distributed Hydrology Soil Vegetation Model

DSHVM was developed as a research tool for investigating the hydrology of forested, mountainous watersheds in the Pacific Northwest and Rockies (Wigmosta et al. 1994, Nijssen 1999). It is grid-based, and has a novel routine allowing the calculation of hillslope subsurface flows intercepted by an imposed network of roads or incised stream channels. Point or radar precipitation can be used. The soil-vegetation system is modeled in five layers: the vegetation canopy, soil surface, and three soil layers that contribute subsurface flow to neighboring grid cells. Surface runoff occurs if the upper soil layer is saturated or its infiltration capacity is exceeded, but is immediately routed to the downslope pixel during a single time step. Thus, overland flow velocity depends on the grid cell size and time step (typically 1 to 3 hours), rather than the usual overland flow routing parameters (Storck 2001 personal communication). Data requirements are intensive, and there is currently no GIS interface to automate input file construction. The GIS scripts that do exist for constructing stream and road networks are not user-friendly (Storck 2001 personal communication). Mainly due to the lack of an overland flow routing module, DHSVM falls short of the requirements for a LID model.

2.3.8.3 HYDROTEL

HYDROTEL is a continuous, distributed, grid-based hydrology model developed at the University of Quebec. It was designed for modeling flexibility, compatibility with GIS and remote sensing data, and applicability to a wide range of watershed conditions and sizes (Fortin et al. 2001). A variety of physically based and conceptual algorithms are available for modeling hydrologic processes, and the user may select an appropriately complex algorithm for each hydrologic process with due regard to the available data quality. Either individual grid cells or subwatersheds may be used as the elementary hydrologic response units. HYDROTEL calculates a vertical water budget based on up to three soil layers, including snowmelt but ignoring canopy interception and depression storage in the current version, and using any of several evapotranspiration methods. Soil thickness may not vary spatially in the current version, severely handicapping attempts at modeling LID BMP's. With grid cells as the computational unit, overland flow and baseflow are routed using kinematic wave theory. One hour is the minimum time step, presenting some difficulty for extremely small basins. If the subwatershed formulation is used, flow is routed using a geomorphological unit hydrograph. Channel and reservoir routing is accomplished using the kinematic wave, diffusion wave, or storage indication methods. Because channel networks are extracted from a DEM, storm sewer systems are not modeled. Despite several shortcomings, HYDROTEL's model physics, flexibility, and GIS-integrated design make it somewhat attractive as an LID evaluation tool. Unfortunately, the present model interface and manual are entirely in French. Spanish and English versions are under development but were not be available in time to complete the present research. Future versions of the model may be worth investigating for any future research into LID, if the model is downward-scaleable.

2.3.8.4 LIFE Model – Low Impact Feasibility Evaluation

CH2M HILL developed the Low Impact Feasibility Evaluation (LIFE) model specifically to evaluate LID performance (Patwardhan et al. 2005, Hinman 2005). The code and documentation are unfortunately proprietary, but limited information in the referenced articles indicates that is physically-based, distributed, and incorporates continuous simulation. It can evaluate runoff, interflow, infiltration, and baseflow; and model IMP's such as bioretention, infiltration systems, rainwater capture/reuse systems, permeable pavement, and green roofs, among others (Patwardhan et al. 2005). Outputs include runoff volumes, individual storm hydrographs, and flow-duration curves. It is not clear from the available literature what methods are used to model particular hydrologic processes, it has not been extensively calibrated (Hinman 2005), and is not available to users outside of CH2M HILL.

2.3.8.5 L-THIA NPS – Long-term Hydrologic Impact Assessment & Non Point Source Pollutant Model

L-THIA, as it was originally known, was developed as a simple, user-friendly, screening tool for evaluating the hydrologic impacts of land use change (Bhaduri et al. 2001). It computes average annual runoff and pollutant loads via the NRCS curve number method, given land use, soils data, and a long term daily rainfall time series (provided online). The program can be run from a web interface, which provides rainfall data for most of the U.S. at http://cobweb.ecn.purdue.edu/runoff/lthia/lthia_index.htm. The user therefore need only provide the land use and soils maps, or rather the land use-soil group complex breakdown derived from these maps. Up to eight different land use categories can be used. The defaults are: water/wetland, commercial, agricultural, high density residential, low density residential, grass/pasture, forest, or industrial. Unlike TR-55 (NRCS 1986), L-THIA first computes daily runoff separately for each unique area of the watershed, then determines the total watershed runoff depths. This provides a slightly higher degree of spatial distribution compared with TR-55, wherein curve numbers are averaged first, but still does not allow the study of detailed small scale hydrologic impacts (Engel 2001). L-THIA does provide a convenient hydrologic screening tool, but it does not, nor was it intended to, have the capability to model spatially distributed runoff process and BMP’s.

2.3.8.6 MIKE-SHE – Systeme Hydrologique European

MIKE-SHE, developed by the Danish Hydrologic Institute, now DHI Water and Environment, is possibly the most comprehensive and physically based model available today (DHI Water and Environment, 2001). Unfortunately, it is not in the public domain, is quite expensive, and requires an inordinate amount of data to apply successfully. It is a gridded model with capabilities similar to CASC2D, with the addition of unsaturated zone and groundwater flow modules. Precipitation gages are Thiessen-weighted. Interception and evapotranspiration may be computed using either the Rutter / Penman-Monteith method, or the Kristensen-Jensen method. Overland flow is routed using the kinematic wave equation, with infiltration computed using Richards' equation. An empirical bypass function is provided to account for macropore flow. Vertical flow in the unsaturated zone is computed using the one-dimensional Richards equation, with or without the tension term. A three-dimensional finite difference formulation of Darcy's law with stream-aquifer interactions is used for the saturated zone. At the user's option, subsurface flows may be simplified to a series of lumped linear reservoirs representing interflow and baseflow. Channel flow is routed using either the Muskingum method, or the one-dimensional diffusive wave approximation to the St. Venant's equations. Reservoir routing is not simulated. Alternatively, MIKE-SHE may be linked to MIKE-11 or MOUSE for analysis of complex channel hydraulics. MOUSE has capabilities similar to SWMM Extran for sewer routing, and contains modules for urban hydrology, real time control systems, and water quality. MIKE-11 provides a quasi-two-dimensional river hydraulics routine capable of handling bridges, weirs, and other hydraulic structures. MIKE-SHE is not commonly used in the United States, and the expense and data requirements prohibit its use in this research.

2.3.8.7 P8 – Program for Predicting Pollutant Particle Passage through Pits, Puddles, and Potholes

The P8 Urban Watershed Model (Walker 1990) was developed as a planning level model for the assessment of runoff quality and BMP particulate removal efficiencies in urban settings dominated by impervious surface runoff. P8 modeling was formerly restricted to 24 subwatersheds and 24 BMP's, limiting its use as a distributed model. Later updates in 1998 increased these limits to 192 and 48, respectively (Walker 2007). Runoff is computed by subwatershed from hourly rainfall data. Subwatershed runoff can be routed to any of seven devices (pond, infiltration basin, swale/buffer, pipe/manhole, splitter, aquifer, or user-defined), alone or in series. Impervious surface runoff begins as soon as depression storage is filled, and equals the rainfall rate times a runoff coefficient. Pervious surface runoff is computed using a continuous formulation of the NRCS Curve Number method. The modified method, described by Haith and Shoemaker (1987), adjusts the curve number based on the season and the five day antecedent rainfall. Evapotranspiration is computed using Hamon's (1961) method, and is constant for all vegetation types. Baseflow is computed using a linear reservoir model. Pipe routing is rudimentary and poorly documented, requiring only a time of concentration as input. The reservoir routing method first linearly interpolates the storage-outflow table, allowing an analytical solution to the facility flow balance. The P8 model's use of NRCS hydrology and unnecessarily simplified BMP routines make it inappropriate for detailed LID analysis, as it fails to capture important hydrologic processes at small scales.

2.3.8.8 PRMS – Precipitation-Runoff Modeling System

PRMS is a continuous, distributed model developed to evaluate the hydrologic effects of various combinations of precipitation, climate, and land use. It has also recently been used for stream flow forecasting (Leavesley & Stannard 1995). In daily mode, the watershed is separated into a number of homogenous hydrologic response units (HRUs), while in storm hydrograph mode each HRU is further subdivided into one or more kinematic flow planes draining to channels. Daily mode is used to compute daily runoff and snowmelt volumes, and includes a conceptual soil moisture accounting routine consisting of linear or non-linear reservoirs for upper and lower zone soil storage, each of which discharges to a subsurface (interflow) non-linear reservoir or a groundwater (baseflow) linear reservoir. Interception is included, and PET can be calculated by any of three methods, typically Hamon's. Actual evapotranspiration losses are computed as a function of soil moisture and soil type. Runoff in daily mode is a function of antecedent moisture and precipitation, and is routed using either a linear or nonlinear reservoir. Storm hydrograph mode allows detailed computation of storm hydrographs from high resolution rainfall data, with the model time step as low as one minute. Infiltration is computed using a version of the Green-Ampt method, and runoff is routed by kinematic wave. Each channel may receive upstream inflow from up to 3 other elements, and lateral inflow from 1 or 2 planes. Channel and reservoir routing is by linear reservoir or the modified Puls method. Cascading planes are not allowed. PRMS has been most commonly used on moderate sized watersheds in the mountainous western U.S. where snowmelt is an important process, and offers no discernable advantage over other models in the rain-dominated eastern U.S. Between the inability to model cascading planes, calibration requirements of its several conceptual modules, and general lack of use outside the Rockies, PRMS will not be appropriate for the present LID study.

2.3.8.9 SWAT – Soil-Water Assessment Tool

SWAT was developed to "predict the impact of land management practices on water, sediment, and agricultural yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time (Neitsch et al. 2001)." As such, it is a continuous, largely physically-based process model, yet is spatially lumped. It represents a watershed as either a grid or a number of uniform subbasins draining to a channel and reservoir network, preventing evaluation of processes on a hillslope scale. The model operates with a daily time step, though peak flows are computed for the purposes of erosion and sediment calculations. Climate inputs can be provided by the user, or generated synthetically with the on board WXGEN stochastic weather generator. Either NRCS methods or Green-Ampt may be used to compute infiltration, and peak flows are computed with the modified Rational method. Several physically based routines are available for computing PET: Penman-Monteith, Priestley-Taylor, and Hargreaves. Soil water and groundwater are modeled, with baseflow and interflow issuing from the appropriate model layer. Channel routing is by Manning's equation or the Muskingum methods with bank storage and transmission losses; reservoir routing is a daily water balance that includes seepage and evaporation as well as simplified outflow relations. Sediment, nutrient, and pesticide generation/entrainment, routing, and fate are all simulated. Overall, SWAT is a very comprehensive agricultural nonpoint source model, but its daily time step and large scale prevents consideration as a small-watershed LID model.

2.3.8.10 TOPMODEL

TOPMODEL was developed in the United Kingdom to provide both a continuous simulation/forecasting model and a research tool for investigating hydrologic processes and modeling scale, realism, and procedures. Its first applications were to small, upland watersheds in the U.K. with homogenous, shallow soils, and a humid temperate climate. Parameters were intentionally kept to a minimum, and each has a physical interpretation if not always a method for *a priori* determination (Beven et al. 1995). The model requires calibration of up to five essential parameters. Saturation excess is the principal modeled runoff mechanism wherein overland flow is generated by variable saturated source areas, usually near watercourses. As such, water table levels are computed using Kirkby's topographic index, and routing methods are coarse. The latest incarnations of TOPMODEL are grid-based, and amenable to the use of GIS for computing the topographic index and upslope contributing areas. The vertical water budget is computed based on three unsaturated reservoirs: root zone storage (which acts like interception storage), gravity drainage, and non-active moisture. Infiltration is computed either by simple conceptual methods or the Green-Ampt method. Evapotranspiration proceeds at the potential rate from the soil surface and gravity storage, then at a reduced rate from root zone storage. Overland flow (saturation or infiltration excess) is routed using a time delay histogram computed from pixel slope, distance from the stream, and a velocity parameter. Channel flow is translated at a constant wave speed because the TOPMODEL kinematic wave simplification for channels is often unstable. TOPMODEL does not compute interflow or evaluate runoff-runon, and requires a single soil layer with transmissivity distributed exponentially with depth. TOPMODEL's calibration requirements, inability to model a cascade, and weak overland flow routines prevent its consideration as an LID evaluation tool.

2.3.8.11 WEPP – Water Erosion Prediction Project

WEPP was developed by the USDA-ARS as a continuous, distributed, field- or watershed-scale hydrology and erosion model for agricultural areas. Submodels include hydrology, plant growth, soils, irrigation, and erosion (Novotny and Olem 1994). In ‘hillslope’ mode, it models a single agricultural field using a representative hillslope transect (overland flow profile) containing multiple segments of differing length, slope, soils, and management practices, and contributing lateral inflow to a single channel. In ‘watershed’ mode, WEPP models several such hillslopes as well as a network of channels and impoundments. A grid-based version of WEPP is planned, but its completion seemed unlikely when this research was underway (Theurer, personal communication 2001). A GIS-integrated version, GeoWEPP, was subsequently released (Renschler 2003), but it does not support cascading grid-based modeling. WEPP utilizes meteorological data (precipitation, wind speed, solar radiation, dew point, and temperature) from CLIGEN, a stochastic climate generator included with the modeling package. During simulation, WEPP disaggregates CLIGEN rainfall data, consisting of rainfall depth, duration, maximum intensity, and time to maximum intensity, into a single-peaked hyetograph. Alternately, WEPP can process up to 50 user-supplied rainfall breakpoint pairs per day (Flanagan and Livingston 1995). Infiltration is computed using the Green-Ampt method, and surface runoff is routed using the kinematic wave equations. Water balance calculations account for interception, depression storage, redistribution within and below the root zone, evapotranspiration, frost, and snowmelt using a modification of the SWRRB routines also used in AGNPS and SWAT. The hydrology results are refined by daily recalculation of soil properties and surface roughness based on rainfall and management practices. Channels are treated similarly to hillslopes, with properties changing with time according to the application of management practices. Peak flows are computed using either the CREAMS model empirical approach, or the modified rational method as utilized in EPIC. Input file requirements are quite intensive due to the plant growth and soils submodels, which also introduce an unmanageable excess of parameters needing estimation. WEPP was intended as an erosion prediction model, and as such is focused on obtaining accurate results for the several intense, short storms that cause the majority of annual erosion (Flanagan and Livingston 1995). Output is focused on an annual summary of erosion data. It is less accurate in determining annual runoff volumes under a wide range of storms, and the 50-breakpoint limitation prevents the use of much of the available 5-minute resolution rainfall data. Furthermore, each occurrence of concentrated flow necessitates a new channel element, likely requiring an excessively large number of both hillslopes and channels to model a complex, developed watershed with numerous roads, homes, and BMP's. Between the voluminous input required and inability to use much of the available rainfall record, WEPP is not appropriate for the present effort.

2.3.8.12 WinSLAMM – Source Loading and Management Model

WinSLAMM (Pitt and Vorhees, 2000) is a continuous, planning level model for evaluating the effects of alternative development types and BMP's on urban runoff quantity and quality. It is largely empirical, and emphasizes small storm hydrology and particulate washoff processes. Only runoff volume is computed, rather than the complete hydrograph. Only the rainfall depth, interevent time, and storm duration are required as meteorological inputs. To compute runoff and pollutant loadings, an urban watershed is first broken into six component land uses: residential, institutional, commercial, industrial, open space, and freeway. Each land use is associated with different proportions of source area types, including roofs/sidewalks, pavement, turf, landscaping, and other pervious areas. Other inputs include drainage system type (swale, gutter, etc.), effective NRCS Hydrologic Soil Group, building density, land use, presence of alleys, roof pitch, pavement texture, and traffic density for each source area. The WinSLAMM model computes runoff volume for each source area using empirical non-linear equations. The

WinSLAMM equations have parameters for the runoff coefficient, depression storage, and drainage efficiency factor of each combination of source area type and drainage system. WinSLAMM will simulate a variety of control measures, including wet detention basins, porous pavement, infiltration devices, street cleaning, catchbasin cleaning, grass swales, roof runoff disconnections, and paved parking/storage area runoff disconnections. Pond routing is performed using the Modified Puls method and assuming a triangular hydrograph with a peak flow of twice the average flow, and a time base of 1.2 times the rainfall duration. In addition to pollutant loadings, possible hydrologic outputs include the runoff volume and 6-, 15- or 60-minute resolution continuous hydrographs. The model's empirical approach requires calibration, making it a poor choice for ungaged sites. Furthermore, WinSLAMM does not explicitly consider the hydrologic processes of interest in LID analysis, rendering it unusable for truly distributed modeling.

3 PRELIMINARY MODEL TESTING

3.1 Introduction

It is apparent from the literature review of the previous chapter that no model optimally represents all of the hydrologic processes considered important in evaluating LID. In fact, only three models, EPA-SWMM, KINEROS, and HSPF/WWHM, can be expected to model distributed hydrologic processes in a mixed urban-natural watershed with BMP’s. As mentioned previously, even these models are deficient in certain areas. SWMM is handicapped by the formulation and solution method of its non-linear reservoir overland flow model, a rather crude soil moisture accounting routine, and rudimentary groundwater simulation ability. KINEROS takes a more physically-based approach to overland flow, yet is only a single-event model with no groundwater simulation ability at all. HSPF can model all aspects of surface and subsurface hydrology, but has only rudimentary channel and BMP routing capabilities, and requires calibration for its many conceptual parameters. WWHM was modified to allow LID processes after the work described in this chapter was completed, and in any case is based on HSPF model parameters calibrated to the Pacific Northwest.

HSPF and WWHM were not considered for further study, but SWMM and KINEROS both appeared to be viable choices, despite KINEROS’ limitations as a single-event model. Adapting KINEROS to continuous simulation could be accomplished with substantial effort using Visual Basic, but with unknown benefits over using continuous SWMM.

The preliminary work described in this chapter was undertaken to determine whether SWMM or KINEROS should ultimately be used in evaluating LID. Rainfall-runoff data was available for a parking lot on Virginia Tech's campus, so both models were first applied to the parking lot in an attempt to identify overland flow model accuracy and bias and to determine rainfall thresholds for pervious land runoff, all the while minimizing the confounding effects of infiltration. The parking lot study revealed both model inadequacies and data inaccuracies, which were used to guide further investigation into the comparability of SWMM and KINEROS and the sensitivity of both models to various parameters.

3.2 Study Site – Virginia Tech Parking Lot

Virginia Tech Commuter Parking Lot B (hereafter: Virginia Tech Parking Lot) occupies approximately 21.7 acres at the edge of the Virginia Tech campus (Figures 3.1 and 3.2). The 85 percent impervious site is drained by mostly curb-opening inlets to a storm sewer system with a single outlet at a 1.02 acre-foot extended detention water quality pond (Latham 1996, Hodges 1997). Appendix A-1 gives pertinent details of the storm sewer system. The bulk of the catchment is covered by asphalt pavement, interspersed with concrete sidewalks, lawn, and mulched and landscaped islands. Soils consist of approximately 65% Udorthents-Urban Land Complex, and 35% Groseclose-Urban Land Complex. The former consists of shallow to deep, well-drained to somewhat poorly drained, slow to moderately rapid permeability loam having a 5" to 15" thick surface layer and a 10" to several feet thick underlayer. The latter consists of deep, well-drained, slow permeability loam having a 10" surface layer over a 29" sticky, plastic clay underlayer. This Complex is extremely variable in disturbed areas, sometimes having a clayey surface layer (NRCS, 1985). Site inspection revealed that soils are intermixed with small rock fragments from the gravel parking lot that existed before the site was paved.

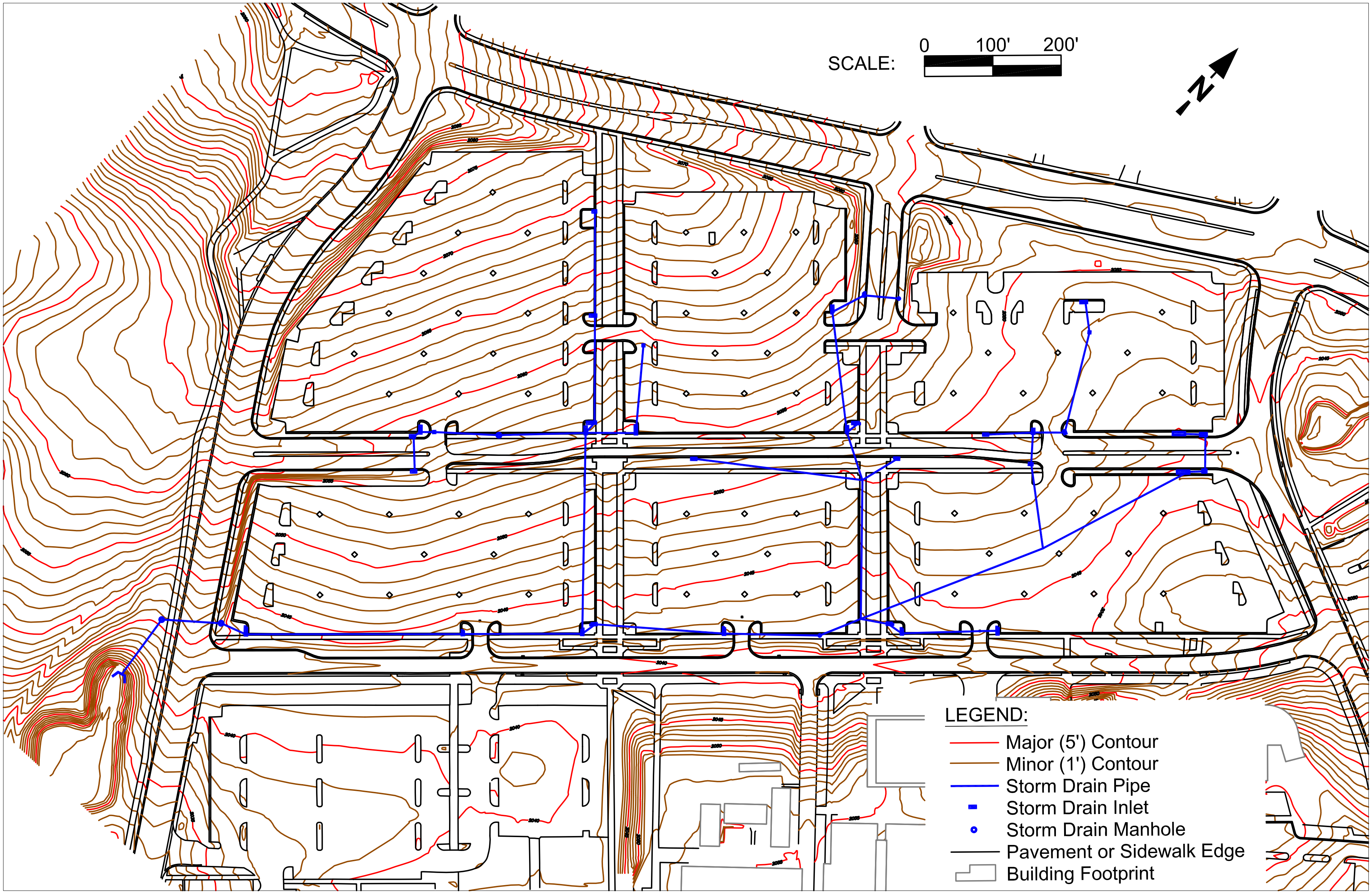


Figure 3.1: Virginia Tech Parking Lot Topography (Source: University Planning, Design, and Construction Services)

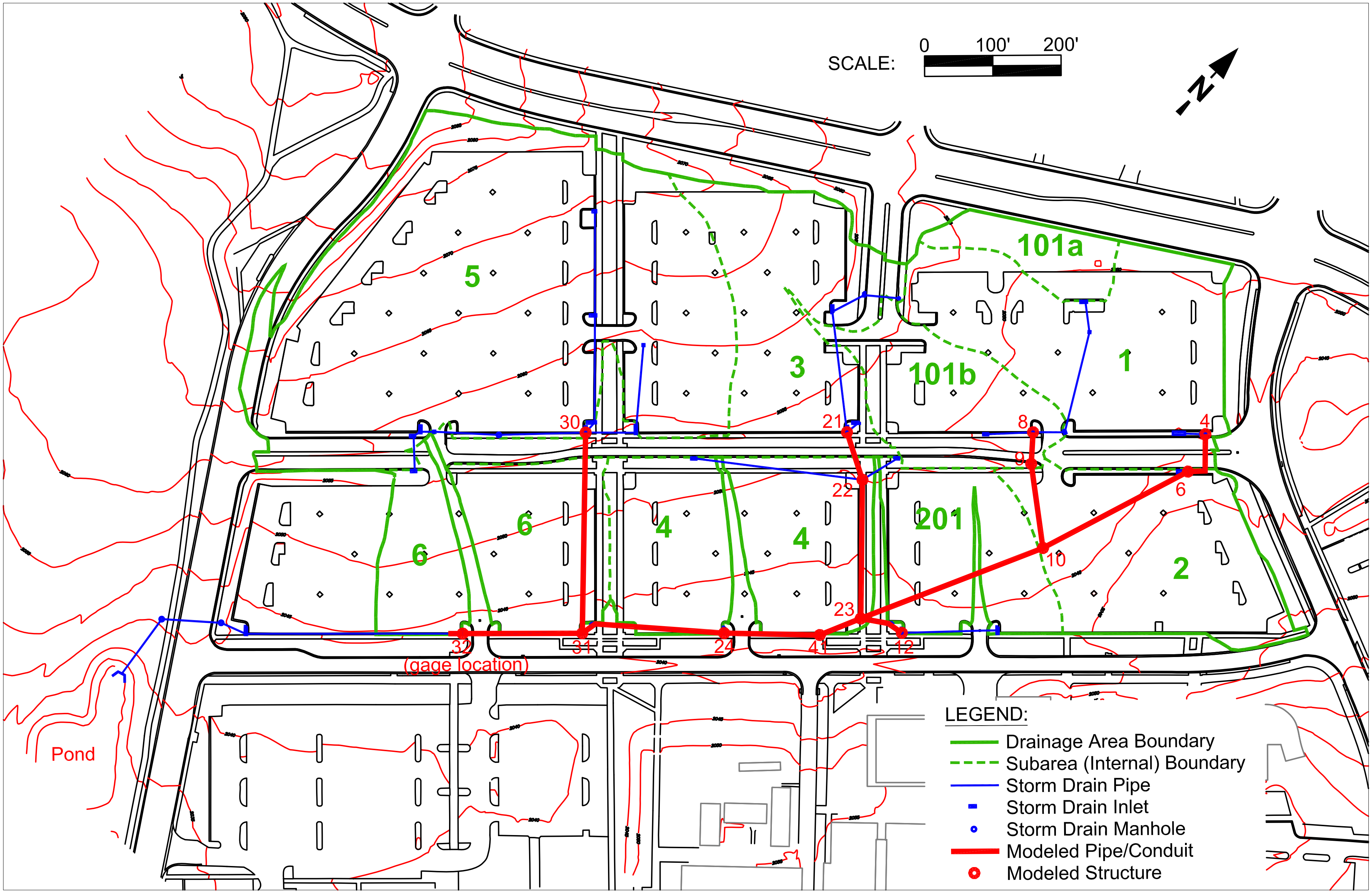


Figure 3.2: Virginia Tech Parking Lot Hydrologic Model Layout (Source: University Planning, Design, and Construction Services)

3.3 Available Rainfall Data

A water quality monitoring program was established for the Virginia Tech Parking Lot in 1995, in an attempt to determine the pollutant-removal effectiveness of the extended detention pond (Latham 1996, Hodges 1997). Storm sewer flow, pond outflow, pond stage, rainfall, and other variables were measured at 1-minute intervals, but recorded at 5-minute intervals during the monitoring period. Rainfall was measured by an 8-inch tipping bucket rain gage located on the embankment of the extended detention pond. Excluding two equipment malfunctions that totaled 3.84 days of downtime, the rain gage was in operation from May 5, 1995 to August 14, 1996. Hodges (1997) used the data from June 6, 1995 to May 31, 1996, during which there were 120 days with measurable rainfall. Due to freezing temperatures, errors are suspected in the 1995 data taken after November 22 as well as the January through March 1996 data.

Total rainfall for the monitoring period used by Hodges was 29.94 inches, with the highest rainfall day seeing 1.80 inches. 58 of the days with precipitation saw 0.10” or greater. From August 1, 1995 to May 31, 1996 (the period of overlap with NCDC records for Blacksburg), the Lot B gage recorded 23.14” of precipitation, while the Blacksburg NWS station recorded 30.58” (NCDC 2001). The 7.44” deficit resulted mostly from a late-1995 freeze, and other measurement errors during the winter months when snow and freezing rain are the dominant precipitation forms. The parking lot study did not utilize a heated rain gage. Daily rainfall totals can be found in Appendix A-2.

3.4 Available Runoff Data

Flow measurements taken during the Virginia Tech Parking Lot stormwater quality study (Latham 1996, Hodges 1997) provided data with which to attempt calibration and sensitivity analysis of the SWMM and KINEROS models. Flow measurements were accomplished using a Palmer-Bowlus flume (Kilpatrick et al. 1985) installed in the 48” pipe just downstream of Manhole #32. The drainage area to this point in the storm sewer is 19.497 acres. Approach flow depth was measured with a pressure transducer placed upstream of the flume, and the discharge computed from the flume rating curve (Hodges 1997). Because Hodges adjusted the hydrographs by an area ratio to reflect runoff from the entire parking lot entering the detention pond, the volumes had to be reduced by the inverse of her adjustment factor. Only the reduced (actual at-gage) volumes are reported here. Excluding obvious snowmelt events, 24 separate hydrographs were available from Hodges’ processed data. They are summarized in Table 3.1.

With the intention of determining thresholds for pervious land runoff, verifying connected impervious area measurements, and estimating depression storage, the runoff volume for each storm was plotted against the corresponding rainfall volume (Figure 3.3). Such a plot should exhibit two linear segments of differing slope, representing impervious-only and pervious/impervious runoff; and have an intercept representing impervious depression storage (Boyd et al. 1993), yet the figure exhibits none of these features. It is evident from both the table and figure that several storms have runoff coefficients exceeding one, indicating that the runoff data, rainfall data, or both must be in error. Hodges (1997) noted problems with the pressure transducer becoming buried under sediment, the high density of which would cause overestimation of stage. Improper flume calibration was another possibility that is investigated in the following paragraphs.

Table 3.1: Virginia Tech Parking Lot Rainfall-Runoff Data Summary

Storm Number	Year	Julian Date	Precip. (in)	Measured Runoff (ft^3)	Measured Runoff (in)	Apparent Runoff Coefficient
1	1995	179	1.21	412734	5.83	4.82
2	1995	198	1.38	74731	1.06	0.77
3	1995	230	1.80	120305	1.70	0.94
4	1995	239	0.52	28831	0.41	0.78
5	1995	256	0.14	7328	0.10	0.74
6	1995	259	1.13	73200	1.03	0.92
7	1995	265	0.06	507	0.01	0.12
8	1995	267	0.06	359	0.01	0.08
9	1995	269	0.20	9363	0.13	0.66
10	1995	277	1.58	101248	1.43	0.91
11	1995	286	0.36	16019	0.23	0.63
12	1995	293	0.67	43864	0.62	0.93
13	1995	300	0.14	2749	0.04	0.28
14	1995	304	0.07	1375	0.02	0.28
15	1995	306	0.33	12816	0.18	0.55
16	1995	311	0.89	54516	0.77	0.87
17	1995	315	0.42	22992	0.32	0.77
18	1996	13	0.02	257	0.00	0.18
19	1996	14	1.05	171064	2.42	2.30
20	1996	24	0.25	21073	0.30	1.19
21	1996	26	1.24	104326	1.47	1.19
22	1996	79	0.77	61265	0.87	1.12
23	1996	88	1.10	79270	1.12	1.02
24	1996	136	1.39	86392	1.22	0.88

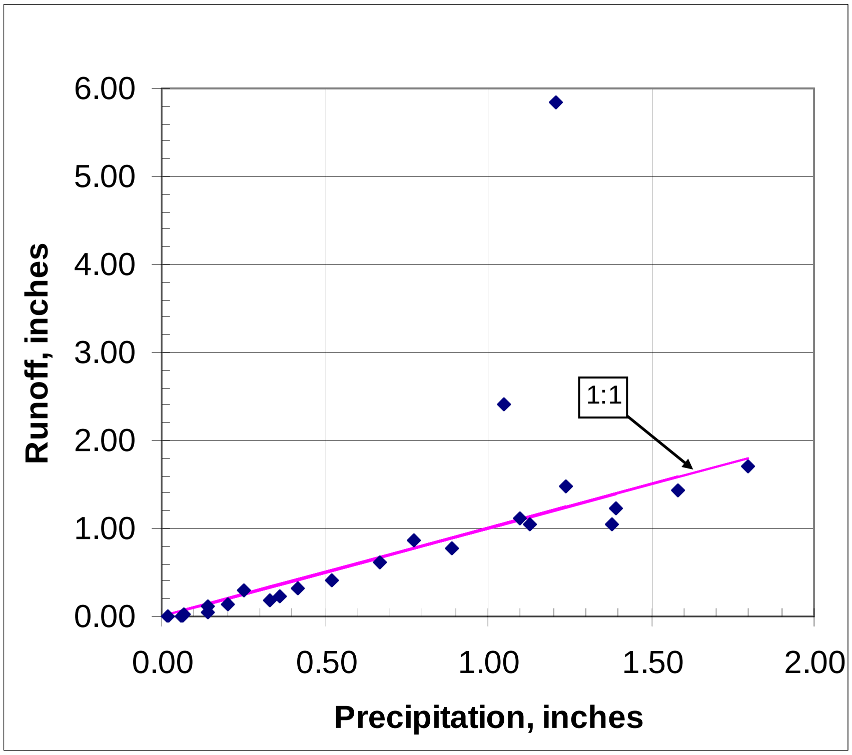


Figure 3.3: Rainfall-Runoff Relationship for Virginia Tech Parking Lot

The pipe in which the flume was installed has a slope of 0.5%, yet the flume rating curve uses generalized coefficients that were originally intended for slopes of 1% to 2%. Kilpatrick, et al. (1985) reported coefficients for pipe slopes of 0%, 1-2%, and 3%, but suggested that the 1-2% coefficients were applicable to pipe slopes as low as 0.5%. Given that the pipe in question is at this lower slope limit, and is also at the upper threshold of pipe diameter for Palmer-Bowlus flume usage (48”), it would be prudent to examine the flume rating coefficient selection more closely.

The Palmer-Bowlus rating curve is:

$$Q / D^{2.5} = a (H_a / D)^b$$

Where:

Q is discharge in cfs
D is the pipe diameter in feet
$H_a = d - D/6$ is the weir head in feet
d is the approach flow depth measured by the transducer, and
a and b are calibration coefficients dependant on pipe slope. For slopes ranging from 1% to 2%, a and b equal 3.685 and 1.868, respectively.

The coefficients of the flume rating curve are a possible source of bias in the flow monitoring results. Figure 3.4 reproduces Kilpatrick et al.'s calibration curves for various slopes, along with a best trial-and-error estimate of a possible curve for slopes of 0.5%. The estimated coefficients for 0.5% slope were used to recalculate flow from the raw stage data for three typical storm hydrographs. The recalculated flows were significantly lower than those computed using the original 1-2% coefficients, especially for small flows. As shown in Table 3.2, storm volumes computed with the alternate coefficients for 0.5% slope range between 86% and 95% of those computed with the 1-2% slope coefficients used by Latham and Hodges. It is therefore conceivable that the measured runoff data is biased up to 16% high, thereby rendering fine calibration of a runoff model meaningless.

The true extent of the bias cannot be known without independent verification in a laboratory flume. It may partially account for the observation that runoff volume exceeds rainfall volume for several of the recorded storms. Biased runoff data could easily result in erroneous estimates of directly connected impervious area and infiltration parameters if rainfall-runoff volume comparisons are used for such. Full details of the alternate volume calculations can be found in Appendix A-3.

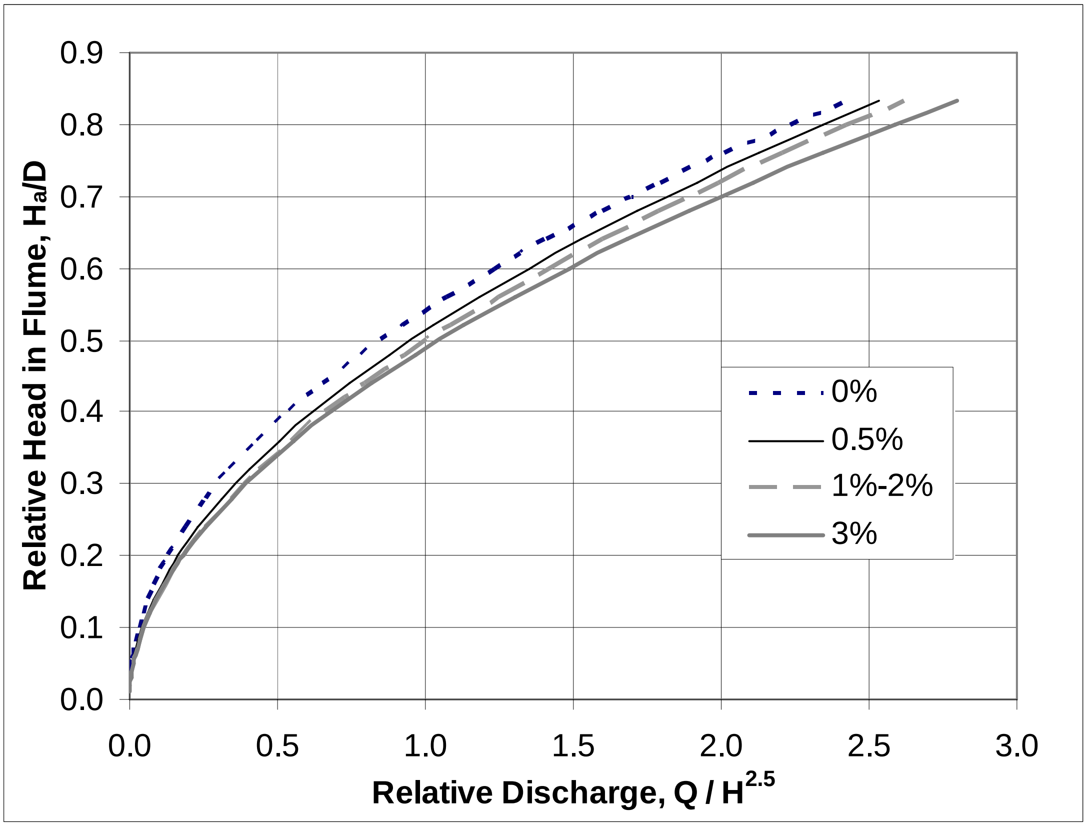


Figure 3.4: Palmer-Bowlus Flume Rating Curves

Table 3.2: Effect of Alternative Palmer-Bowlus Flume Coefficients on Computed Runoff

Approach Pipe Slope:	1-2%	<1%	>0.5%	~0.5%	<0.5%	>0%	0%
Flume coefficient, a:	3.685	3.650	3.640	3.600	3.550	3.540	3.536
Flume coefficient, b:	1.868	1.890	1.910	1.920	1.940	1.990	2.055
September 26, 1995 storm, P = 0.2"							
Runoff volume, ft^3:	9362	8790	8350	8061	7574	6695	5723
Runoff volume, in:	0.13	0.12	0.12	0.11	0.11	0.09	0.08
% of vol. using original coeffs:	100%	94%	89%	86%	81%	72%	61%
Potential % error in original est:	0.0%	6.5%	12.1%	16.1%	23.6%	39.8%	63.6%
October 20,1995 storm, P = 0.67"							
Runoff volume, ft^3:	43860	41542	39780	38553	36510	32914	28857
Runoff volume, in:	0.62	0.59	0.56	0.54	0.52	0.47	0.41
% of vol. using original coeffs:	100%	95%	91%	88%	83%	75%	66%
Potential % error in original est:	0.0%	5.6%	10.3%	13.8%	20.1%	33.3%	52.0%
July 17, 1995 storm, P = 1.38"							
Runoff volume, ft^3:	74732	73097	72075	70883	69120	67045	64650
Runoff volume, in:	1.06	1.03	1.02	1.00	0.98	0.95	0.91
% of vol. using original coeffs:	100%	98%	96%	95%	92%	90%	87%
Potential % error in original est:	0.0%	2.2%	3.7%	5.4%	8.1%	11.5%	15.6%

3.5 Storm Selection for Event Modeling

For preliminary event modeling using SWMM and KINEROS, rainfall-runoff data was desired with the widest possible range of intensity, volume, and duration among storms. Storms with less than 0.1” of rainfall, obvious snowmelt, or runoff coefficients larger than unity were all necessarily eliminated from consideration. Storms exceeding 16.5 hours duration were also eliminated because KINEROS rainfall data is limited to 200 breakpoints. This requirement also removed from consideration the later parts of multi-day storms, as it was not desired to change modeled antecedent moisture for each storm. After these steps, only 11 storms remained for which rainfall and runoff data were both available. Six additional rainfall data sets were retained for comparing SWMM to KINEROS, but due to lack of reliable corresponding runoff data they could not be used to compare the models to observed runoff. Both summer convective storms and spring and fall frontal storms were represented. Precipitation depths ranged from 0.1” to 1.8”, with observed peak flows ranging from approximately 1 cfs to 69 cfs. Table 3.3 summarizes the observed data used in the following sections.

Table 3.3: Observed Virginia Tech Parking Lot Rainfall-Runoff Data for 17 Storms Selected for Modeling

Year	Julian Date	Observed Rainfall Data							Observed Runoff Data			
		Precip. (in)	Maximum Intensity (in/hr) by duration		% of time raining	Storm Duration		Runoff Volume		Peak Discharge (cfs)	Time to Peak (min)
			5-min	15-min		(hr)	(min)	(ft^3)	(in)		
1995	186*	0.12	0.60	0.36	60.0	0.8	50	--	--	--	--
1995	187*	0.53	2.52	1.24	17.3	6.3	375	--	--	--	--
1995	198	1.38	5.76	4.40	81.8	0.9	55	74731	1.06	69.1	20
1995	230	1.80	4.68	3.72	69.4	3.0	180	120305	1.70	67.9	30
1995	239	0.52	0.24	0.20	30.7	12.8	765	28832	0.41	4.6	350
1995	259	0.57	0.36	0.20	31.4	14.3	860	35159	0.50	3.6	25
1995	269	0.20	0.24	0.20	40.5	3.1	185	9363	0.13	3.7	135
1995	277	0.26	0.12	0.08	26.5	8.2	490	12221	0.17	1.1	310
1995	278*	0.89	0.60	0.52	22.4	16.3	980	63218	0.89	11.5	220
1995	287	0.23	0.36	0.24	19.6	8.5	510	11671	0.16	3.6	200
1995	293	0.67	0.48	0.32	54.3	6.8	405	43863	0.62	6.4	65
1995	306	0.26	0.36	0.24	11.4	14.7	880	11475	0.16	3.6	65
1995	311	0.89	0.36	0.28	47.7	12.8	765	54516	0.77	6.0	190
1995	315	0.42	1.80	0.80	19.4	10.3	620	22992	0.32	17.2	515
1995	318*	0.30	0.24	0.20	21.6	9.7	580	--	--	--	--
1996	079*	0.77	0.48	0.40	41.5	11.3	675	61265	0.87	8.8	85
1996	143*	0.53	1.08	0.88	91.7	1.0	60	--	--	--	--

** Missing or unreliable (C>1.0) runoff data*

3.6 Model Application to Virginia Tech Parking Lot

Due to the uniformity and imperviousness of the parking lot site, it was initially hoped that just a few representative storms would provide an adequate model comparison. Thus, SWMM and KINEROS were first applied to the parking lot for storms of three representative sizes (0.20," 0.67," and 1.38"), occurring on September 26, October 20, and July 17, 1995, respectively. The latter was an intense, short-duration summer thunderstorm, while the former two were long-duration autumn frontal showers. Observed storm rainfall and runoff data for the three selected storm events are summarized in Table 3.4. The watershed covered by runoff measurements (that draining to the storm sewer down to manhole #32) was delineated in AutoCAD based on careful field inspection and CAD-generated one-foot contours. Eight subareas were delineated based on the storm drain network and the six main cells of the lot bounded by sidewalks (Figure 3.2, above). Latham (1996) demonstrated that six subareas were required for optimal discretization for SWMM modeling of the parking lot, so the current eight subarea model was deemed adequate.

Table 3.4: Summary of Three Storms Selected for Initial Model Testing

Julian Date:	198	269	293
Calendar date:	7/17/95	9/26/95	10/20/95
Precipitation, in:	1.38	0.20	0.67
Peak Flow, cfs:	69.13	3.68	6.40
Time to peak, min:	20	135	65
Runoff Volume, in:	1.056	0.132	0.620
Runoff Coefficient:	0.765	0.661	0.925

Model parameters were determined *a priori* where possible, with literature values used otherwise. Area, overland slope, flow path length, and impervious area of each subarea (Table 3.5) were measured using AutoCAD. Because of the dominance of impervious area, the impervious area flow path length was considered acceptable for general use, while in reality the pervious area flow path lengths varied widely, often being less than 10 feet. Values of Manning's n and depression storage were taken from the literature, and were set equal for all subareas. Median clay loam Green-Ampt infiltration parameters from Rawls and Brakensiek (1982) were used but adjusted slightly downward to reflect the compaction and reduced permeability typical of disturbed urban soils. Initial moisture content was estimated as approximately halfway between wilting point and field capacity, obtained from Novotny and Olem (1994).

The storm sewer system model was developed from the contractor's as-built drawings of the parking lot. Drainage from subareas was assumed to enter the system at the furthest downstream inlet for a particular subarea, eliminating the need to model most small laterals. Manning's n was taken as 0.013 for concrete pipe. Because the KINEROS2 circular conduit routine was considered a beta release for 2000, the storm sewer was approximated as a network of trapezoidal channels, with ½ :1 side slopes, and base widths equal to half the pipe diameter.

It was assumed that all of the modeled impervious area had depression storage, equating to 100% canopy coverage in KINEROS, and a PCTZERO of 0.001 in SWMM. In SWMM, the PCTZERO parameter is defined as the percent of the impervious area having zero depression storage. The effect of this assumption was tested by varying canopy coverage/PCTZERO over their full range of 0 to 100%.

To more accurately capture peak flows given the quick response of the system, both models were run with a one-minute time step, though KINEROS will use a shorter step as necessary to satisfy the Courant stability condition. Relevant SWMM and KINEROS hydrologic parameter values are listed in Table 3.6, and model input files can be found in Appendix B.

Table 3.5: Subcatchment Geometry for SWMM and KINEROS Models of Virginia Tech Parking Lot

Subarea I.D.	Drains to Inlet #	Flow Path Length (ft)	Slope (ft/ft)	Subcatch-ment Width (ft)	Area (acres)	Percent Impervious
1	46	264	0.0221	396	2.401	81.8
101	89	270	0.0260	254	1.577	77.5
2	610	171	0.0299	277	1.087	91.0
201	1223	222	0.0252	387	1.974	95.2
3	2122	308	0.0431	334	2.365	79.2
4	2431	232	0.0364	403	2.148	86.2
5	3031	356	0.0476	756	6.181	84.0
6	3299	235	0.0477	327	1.764	91.8

Table 3.6: Hydrologic Parameters for SWMM and KINEROS Models of Virginia Tech Parking Lot

Input Parameter Description	Value for Impervious Planes	Value for Pervious Planes
SWMM and KINEROS Parameters		
Overland roughness n:	0.015	0.25
Depression Storage:	0.02	0.1
Canopy cover fraction:	1	1
Moisture content, Θ:	N/A	0.18
Saturated Hydraulic Conductivity, K_{sat}:	N/A	0.2
Capillary Suction, G:	N/A	8
Porosity:	N/A	0.42
Channel roughness, n:	0.013	N/A
KINEROS-Only Parameters:		
C.V. of K_{sat}:	N/A	0
Thickness of soil layer:	N/A	3
Pore size distribution index:	N/A	0.24
Channel side slope:	0.5	N/A

Model results are compared to observed data in Table 3.7, and Figures 3.5, 3.6, and 3.7. Both models did passably well (usually less than 20% error) predicting both peaks and runoff volumes, no doubt because the high imperviousness of the site ensures that most rainfall becomes runoff. Runoff volume estimates were nearly identical for the two models, but SWMM consistently produced lower peaks than KINEROS. SWMM's underprediction of peaks was expected due to the numerical methods used in computing surface runoff, and the tendency of KINEROS to overpredict the peaks from small storms (Fu 1994). Notice also that the October 20 storm volume was underpredicted by both models, yet the storm has an exceedingly high observed runoff coefficient considering its maximum rainfall intensity was only 0.36 in/hr. This may be due to the above-mentioned bias in the observed runoff data, or reduced rain gage catch, rather than model error or incorrect assumption of antecedent moisture. Inspection of the hydrograph plots indicates that the observed peak for the July storm may have been larger but occurred between sampling intervals and was therefore truncated. Both models underpredicted the time to peak by several minutes, possibly attributable to the decision not to model gutter flow explicitly. The underprediction is especially evident from the time shift in the plotted observed and modeled hydrographs. The gutter flow velocity is approximately 1 ft/s for a wide range of flow depths and slopes, leading to a travel time of approximately 4 minutes in the 250 feet of gutter typical for the Lot B site. Thus, gutter flow at least partially accounts for the time shift of the hydrographs.

Table 3.7: Comparison of SWMM and KINEROS Results to Observed Data for Three Storms, Virginia Tech Parking Lot

Storm Date:	7/17/95	9/26/95	10/20/95	7/17/95	9/26/95	10/20/95
Absolute Error	SWMM - Observed			KINEROS - Observed		
Peak (cfs):	14.51	-0.41	-1.32	21.94	-0.06	-0.56
Time to peak (min):	-7.0	2.0	-6.0	-9	-2.9	-5.9
Runoff Volume (in):	0.183	0.021	-0.067	0.166	0.021	-0.066
Percent Error	(SWMM - Observed) / Observed			(KINEROS - Observed) / Observed		
Peak:	21.0%	-11.3%	-20.5%	31.7%	-1.7%	-8.8%
Time to peak:	-35.0%	1.5%	-9.2%	-45.0%	-2.1%	-9.1%
Runoff Volume:	17.3%	15.7%	-10.8%	15.7%	16.0%	-10.7%

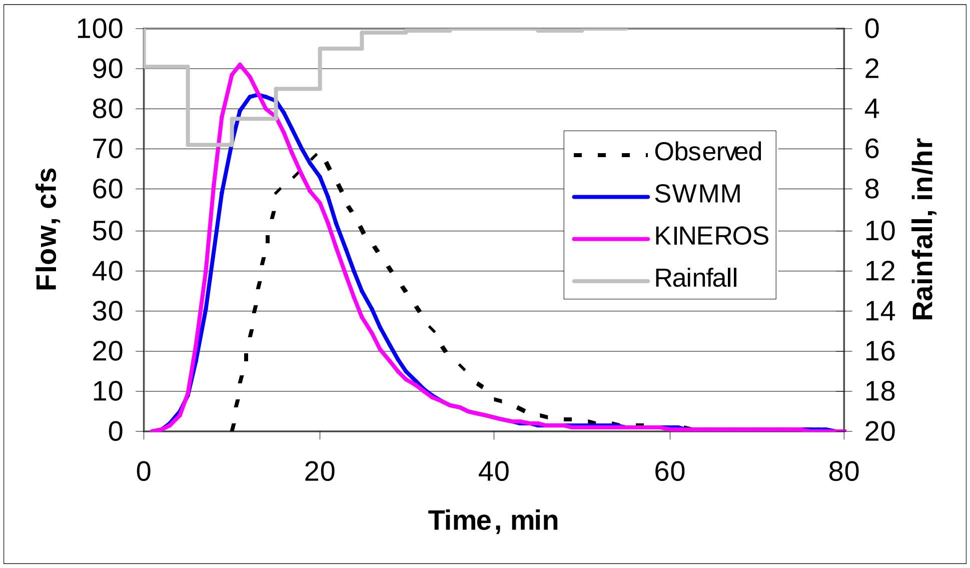


Figure 3.5: Simulated and Observed Hydrographs for July 17, 1995 Event, Virginia Tech Parking Lot

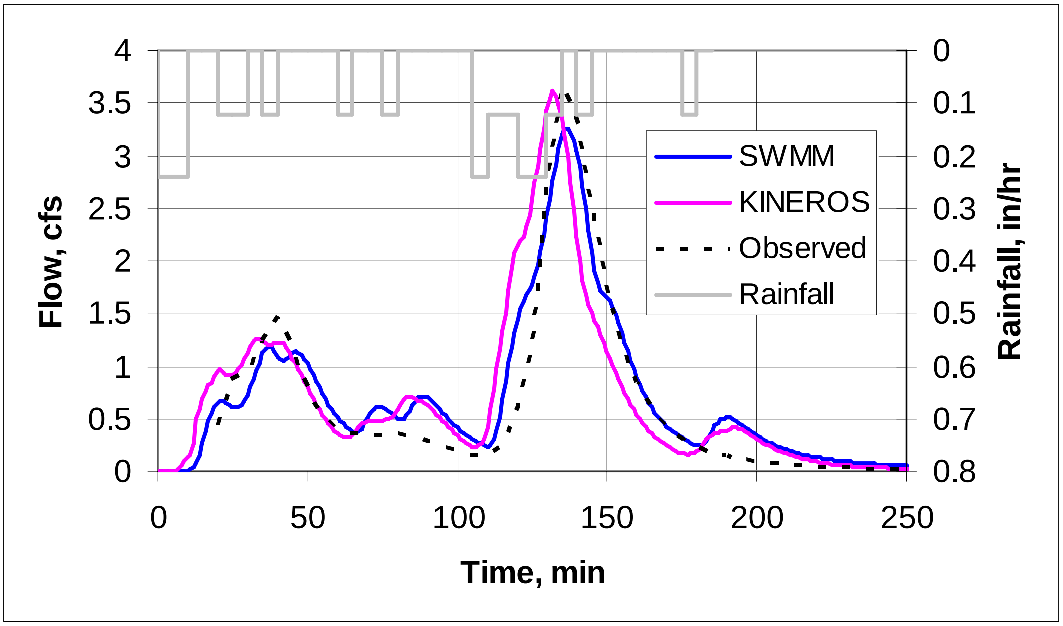


Figure 3.6: Simulated and Observed Hydrographs for September 26, 1995 Event, Virginia Tech Parking Lot

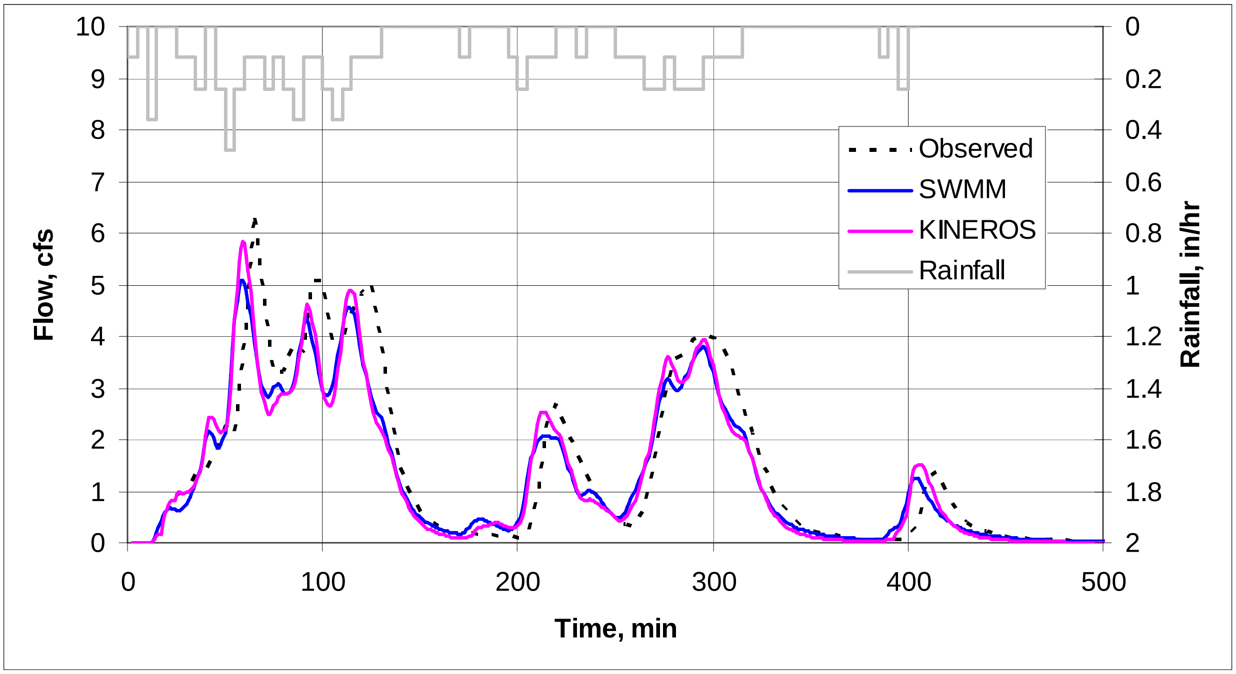


Figure 3.7: Simulated and Observed Hydrographs for October 20, 1995 Event, Virginia Tech Parking Lot

While model parameters were estimated *a priori* wherever possible, a few assumptions had to be made in model formulation. First among these was the decision not to utilize the SWMM PCTZERO parameter, which was designed to produce more rapid runoff and compensate for the slow response and low peaks of SWMM's overland flow numerical scheme. To test this assumption, the three storms were modeled using PCTZERO of 0.001, 25 (the SWMM default), and 100. The KINEROS parameter Canopy was modified accordingly as well. From the results in Table 3.8, it can be easily seen that the PCTZERO/Canopy parameters have very little effect on peak flows, with only a 0.26 cfs maximum variation in flow throughout the whole possible range of the parameter value.

Table 3.8: Effect of Modifying PCTZERO Parameter

Storm Date:	7/17/95	9/26/95	10/20/95	7/17/95	9/26/95	10/20/95
75% Coverage	SWMM @ PctZero = 25			KINEROS @ Canopy = 0.75		
Peak (cfs):	83.71	3.26	5.09	91.09	3.62	5.84
Time to peak (min):	13	137	59	11	132.1	59.1
Runoff Volume (in):	1.243	0.157	0.557	1.226	0.158	0.557
Infiltration (in):	0.126	0.030	0.100	0.128	0.015	0.085
Pervious Infilt. (in)*:	0.845	0.200	0.670	N/A	N/A	N/A
Full coverage**	SWMM @ PctZero = 0.001			KINEROS @ Canopy = 1.00		
Peak (cfs):	83.64	3.26	5.09	91.07	3.62	5.84
Time to peak (min):	13.0	137.0	59.0	11.0	132.1	59.1
Runoff Volume (in):	1.239	0.153	0.553	1.222	0.153	0.554
Infiltration (in):	0.126	0.030	0.100	0.128	0.015	0.085
No coverage	SWMM @ PctZero = 100			KINEROS @ Canopy = 0.001		
Peak (cfs):	83.90	3.26	5.10	91.13	3.62	5.84
Time to peak (min):	13.0	137.0	59.0	11.0	132.1	59.1
Runoff Volume (in):	1.256	0.170	0.570	1.239	0.171	0.571
Infiltration (in):	0.126	0.030	0.100	0.128	0.015	0.085
Range (Max - Min)	SWMM full range of PctZero			KINEROS full range of Canopy		
Peak (cfs):	0.258	0.000	0.016	0.057	0.000	0.000
Time to peak (min):	0.0	0.0	0.0	0.0	0.0	0.0
Runoff Volume (in):	0.017	0.017	0.017	0.017	0.017	0.017
Infiltration (in):	0.000	0.000	0.000	0.000	0.000	0.000

** Infiltration averaged over pervious land only. Unaffected by variation in PCTZERO.*

*** This result set used to compare vs. 15-min & observed data.*

The other major assumption regarded the use of 5 minute resolution rainfall data. Given the size and quick response of the Lot B catchment, and the existence of 5-minute rainfall data from Hodges (1997), there was initially no question about using it. In considering the limited 15-month series of available 5-minute data, it was realized that lower resolution National Weather Service Integrated Flood Observing and Warning System (IFLOWS) data might be needed to lengthen the time series for continuous simulation of LID. To determine the effect on model results, the models were rerun using the 3 storms with the rainfall input aggregated into 15-minute intervals. Results were as expected, with the 15-minute data producing a substantially lower peak discharge for the large storm in particular, and having a lesser effect on runoff and infiltration volumes. Times to peak were slightly delayed for each model. KINEROS results were generally more sensitive to rainfall resolution. In one instance, both models actually benefited from the lower resolution data, which produced a peak discharge much closer to the observed value for the July storm. Table 3.9 summarizes the results.

Table 3.9: Effect of Using 5-minute versus 15-minute Rainfall Data Resolution

Storm Date:	7/17/95	9/26/95	10/20/95	7/17/95	9/26/95	10/20/95
Computed Results	SWMM 15-min Results			KINEROS 15-min Results		
Peak (cfs):	71.67	3.14	4.84	68.98	3.31	5.28
Time to peak (min):	15	135	61	15	135.1	60.1
Runoff Volume (in):	1.228	0.153	0.553	1.215	0.153	0.553
Infiltration (in):	0.137	0.03	0.1	0.136	0.015	0.085
Pervious Infilt. (in)*:	0.917	0.20	0.67	N/A	N/A	N/A
Absolute Change	SWMM 15-min vs. 5-min			KINEROS 15-min vs. 5-min		
Peak (cfs):	-11.98	-0.13	-0.25	-22.09	-0.31	-0.56
Time to peak (min):	2.0	-2.0	2.0	4.0	3.0	1.0
Runoff Volume (in):	-0.011	0.000	0.000	-0.007	0.000	0.000
Infiltration (in):	0.011	0.000	0.000	0.009	0.000	0.000
Percent Change	SWMM 15-min vs. 5-min			KINEROS 15-min vs. 5-min		
Peak (cfs):	-14.3%	-3.9%	-4.8%	-24.3%	-8.5%	-9.5%
Time to peak (min):	15.4%	-1.5%	3.4%	36.4%	2.3%	1.7%
Runoff Volume (in):	-0.9%	0.0%	0.0%	-0.6%	0.0%	0.0%
Infiltration (in):	8.7%	0.0%	0.0%	6.8%	0.0%	0.0%

** Infiltration averaged over pervious land only.*

Modeling of only three storms failed to demonstrate significant distinctions between SWMM and KINEROS, beyond the expected SWMM underprediction and KINEROS overprediction of peak discharge. The models were run with the full data set of 11 rainfall-runoff sets, plus 6 storms with only rainfall data. Peak, volume, and time to peak results for each model can be found in Table 3.10, and model input files can be found in Appendix B.

Table 3.10: Summary of SWMM and KINEROS Model Results for 17 Storms, Virginia Tech Parking Lot

Year - Julian Date	Precip. (in)	Runoff Volume (in)		Peak Flow (cfs)		Time to Peak (min)		Infiltration Volume (in)	
		SWMM	KINEROS	SWMM	KINEROS	SWMM	KINEROS	SWMM	KINEROS
95 - 186	0.12	0.085	0.086	3.9	5.3	19	15	0.018	0.003
95 - 187	0.53	0.434	0.435	25.6	32.3	367	361	0.079	0.064
95 - 198	1.38	1.239	1.222	83.6	91.1	13	11	0.126	0.128
95 - 230	1.80	1.599	1.623	75.1	76.6	26	20	0.185	0.145
95 - 239	0.52	0.425	0.426	3.4	3.6	341	337	0.078	0.063
95 - 259	0.57	0.468	0.469	1.5	1.8	31	18	0.085	0.070
95 - 269	0.20	0.153	0.153	3.3	3.6	137	132	0.030	0.015
95 - 277	0.26	0.204	0.205	1.0	1.1	312	307	0.039	0.024
95 - 278	0.89	0.740	0.742	8.0	9.0	213	204	0.133	0.118
95 - 287	0.23	0.178	0.179	3.1	3.9	199	195	0.034	0.019
95 - 293	0.67	0.553	0.554	5.1	5.8	59	59	0.100	0.085
95 - 306	0.26	0.204	0.205	2.9	3.9	60	55	0.039	0.024
95 - 311	0.89	0.740	0.741	4.5	4.9	189	184	0.133	0.118
95 - 315	0.42	0.340	0.341	16.9	21.6	517	512	0.063	0.048
95 - 318	0.30	0.238	0.238	3.0	3.0	580	576	0.045	0.030
96 - 079	0.77	0.638	0.639	6.3	7.1	90	83	0.115	0.100
96 - 143	0.53	0.434	0.435	15.1	15.8	40	36	0.079	0.064

Paired t-tests were done on the results, comparing SWMM and KINEROS to the observed data and to each other. Average percent error for both models versus the observed data was mostly well below 15%, but SWMM had an average 26% error for peak discharge. The only statistically significant (at $\alpha = 0.05$) difference between model and observed was that of KINEROS and time to peak. KINEROS and SWMM were different from each other at $\alpha = 0.05$ for peak, time to peak, and infiltration volume. Calculations can be found in Appendix A-4.

SWMM had consistently lower peak discharges, and consistently later times to peak than KINEROS, along with slightly higher infiltration volumes, though not all differences were physically meaningful. The runoff and infiltration volume differences are due to the fact that SWMM allows pervious land depression storage to infiltrate, while KINEROS instead uses a canopy interception storage which cannot infiltrate. The amount of canopy interception is approximately 0.015" over the watershed, equal to the average absolute difference in modeled infiltration. Therefore, the volume differences between models, while statistically significant, are physically meaningless. Admittedly, having fewer than N=30 storms makes for a spurious statistical comparison. This illustrates the difficulty in drawing valid conclusions from the short-term hydrologic monitoring and modeling programs permitted by most project budgets. While SWMM conclusively produces lower peak discharges than KINEROS, more tests are required to compare the two models' infiltration routines and identify parameter sensitivity.

3.7 Sensitivity Analysis of SWMM and KINEROS

The above application of SWMM and KINEROS to Parking Lot B shed little light on the critical differences between the models, so it was decided to perform a relative sensitivity analysis on the two models using a simple hypothetical rectangular flow plane. The July 17, 1995 storm of 1.38", being most typical of those expected to cause frequent erosive flows and pollutant loading, was selected as rainfall input. Pervious planes of 1 acre were modeled in SWMM and KINEROS, testing soil and watershed parameters throughout their practical ranges. To ensure a valid comparison of runoff volumes, the depression storage and canopy interception parameters were set equal to zero for both models.

Table 3.11 shows the parameters tested, typical 'average' values, and the tested ranges. Soil parameters were obtained from Novotny and Olem (1994), Huber and Dickinson (1992), Pitt et al. (1999), and Rawls and Brakensiek (1982) for soil textures ranging from sand through clay. Where sources conflicted, parameter ranges were selected to encompass the highest and lowest values of a combination of sources. Watershed parameters (roughness, length, and slope) were varied through the range thought practical in a small Appalachian watershed. There were initial indications that response and parameter sensitivity varied with flow path length (or area divided by subcatchment width in SWMM), so length was included in each parameter analysis.

Using MATLAB, for each model, each hydrological output variable (infiltration volume, peak flow, and time to peak) was plotted versus length and the parameter being analyzed, resulting in a three-dimensional response surface. The following subsections discuss the results of this effort, and comment on the differing response of the two models to identical input parameters. A Visual Basic program was written to facilitate model creation, execution, and postprocessing of results. Source code can be found in Appendix C.

Table 3.11: Parameter Ranges for SWMM versus KINEROS Sensitivity Plots

Parameter:	Saturated Hydraulic Conductivity, Ksat (in/hr)	Mean Capillary Drive, G (in)	Moisture Content, Θ	Porosity	Length, L (ft)	Slope, S (ft/ft)	Roughness, n
Base Value:	0.20	8.0	0.250	0.450	40*	0.030	0.20
Minimum:	0.02	1.0	0.001	0.251	10*	0.002	0.01
Maximum:	1.00	18.0	0.449	0.600	300*	0.250	0.40

** Length was varied from 10 to 300, in steps of 10, 20, 40, 80, 160, 300 for all tests.*

3.7.1 Saturated Hydraulic Conductivity, K_{sat}

Saturated hydraulic conductivity was varied between 0.02 in/hr and 18 in/hr, while other parameters were held at the 'typical' values found in Table 3.11, above. Figure 3.8 (a) shows the impact that varying K_{sat} from 0.02 to 1.0 in/hr has on calculated infiltration volume for KINEROS; Figure 3.8 (b) shows the results for SWMM. Tests with hydraulic conductivity in excess of 1 in/hr are not included because they produced virtually zero runoff. The figures demonstrate that infiltration volume is quite sensitive to K_{sat}, ranging over an approximately 1 inch interval for both models. The surface is particularly steep for $K_{sat} < 0.5$ in/hr, the expected range for the soils of the LID site. Neither model is particularly sensitive to length for any value of K_{sat}, but SWMM exhibits slightly more change than KINEROS at small flow lengths. KINEROS produced negligibly higher infiltration depths for most parameter combinations.

Figure 3.9 (a) and (b) show the sensitivity of peak flow to K_{sat} and flow length for KINEROS and SWMM, respectively. KINEROS produces higher peak flows than SWMM over most of the parameter space. It is more sensitive than SWMM to variability of K_{sat}, though both plots have a similar trend. Because SWMM produces slightly higher runoff volume than KINEROS over most values of K_{sat} and length, their differences in predicting peak flow are obscured; SWMM (KINEROS) may be biased even lower (higher) than indicated on the plot. SWMM, however, is clearly more sensitive to flow length, with peak flows ranging over a 50% larger interval than KINEROS when K_{sat} equals 0.02 in/hr. This result was largely expected based on comments in the SWMM Manual (Huber and Dickinson 1992) regarding Runoff Block flow routing.

Plots of time to peak for KINEROS and SWMM (Figure 3.10 (a) and (b)) exhibited discontinuities at or near rainfall breakpoints times (10, 15, and 20 minutes), no doubt an artifact of the 5-minute rainfall resolution. Flow length significantly affected time to peak, with time to peak nearly coinciding with the end of the most intense rainfall period (t = 10 minutes) for the shortest, least permeable planes. Time to peak was only affected by K_{sat} insofar as infiltration affected the rainfall excess significantly enough to delay the maximum rainfall excess to t = 15 minutes.

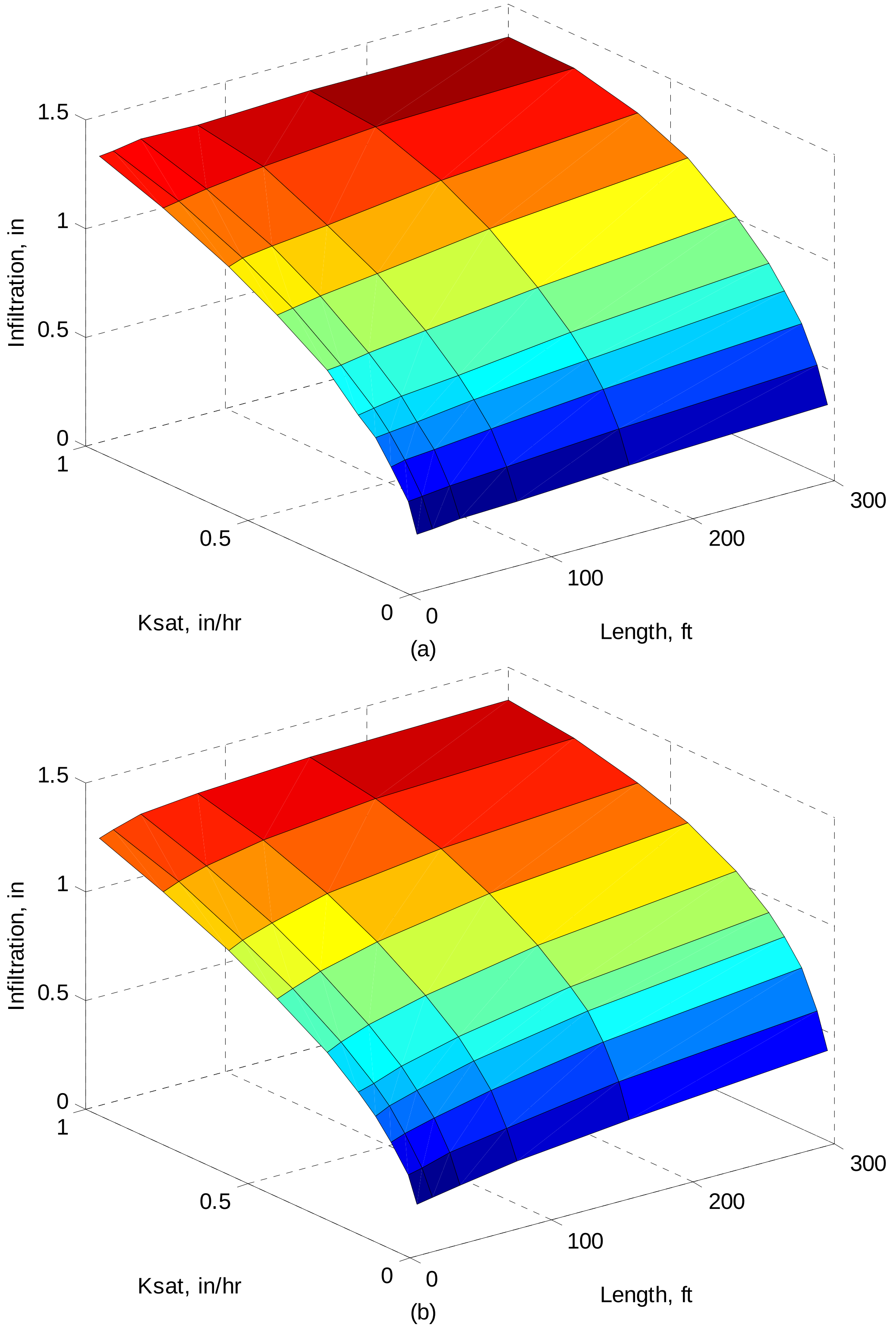


Figure 3.8: Sensitivity of KINEROS (a) and SWMM (b) Infiltration Estimates to K_{sat}

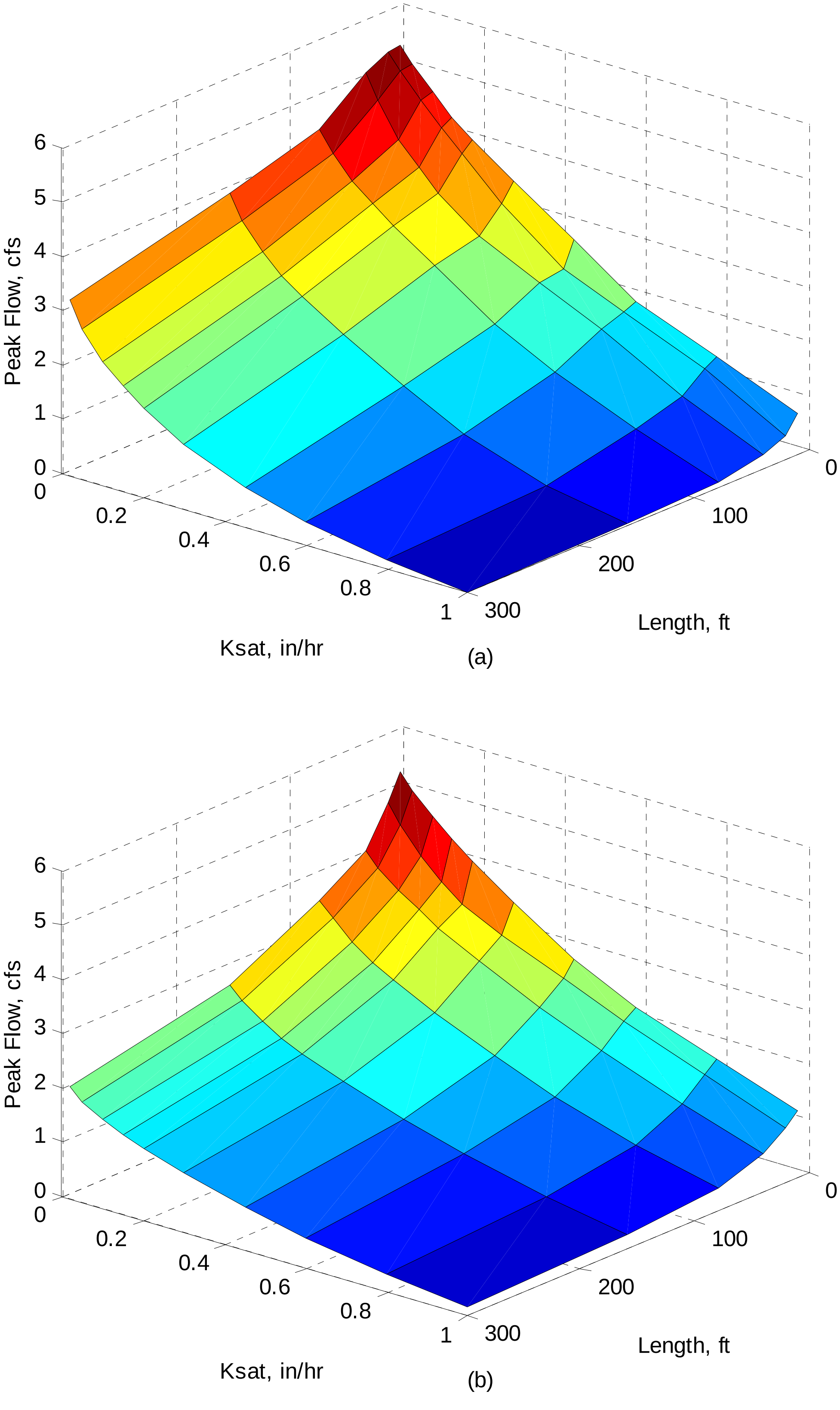
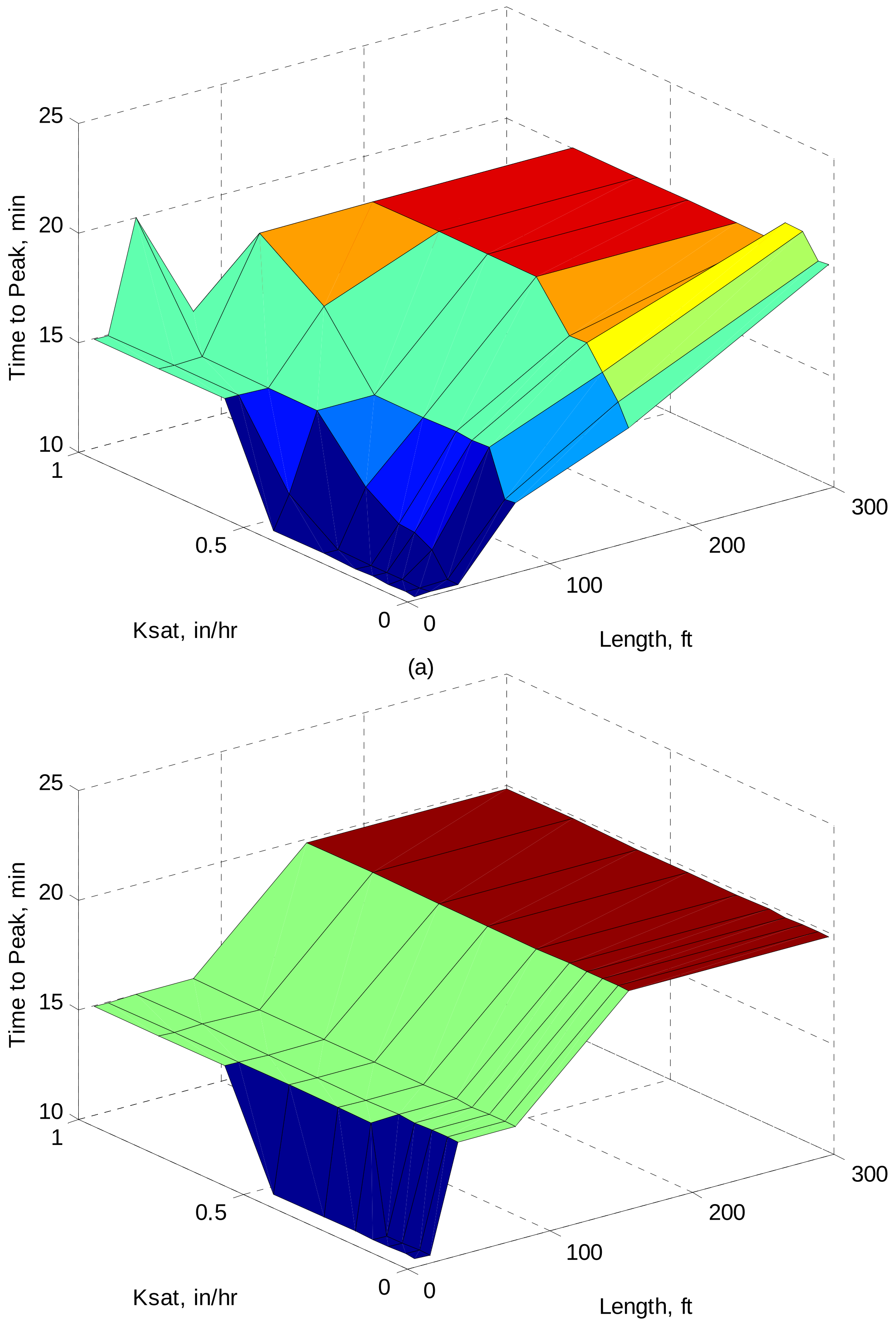


Figure 3.9: Sensitivity of KINEROS (a) and SWMM (b) Peak Flow Estimates to K_{sat}



(a)

(b)

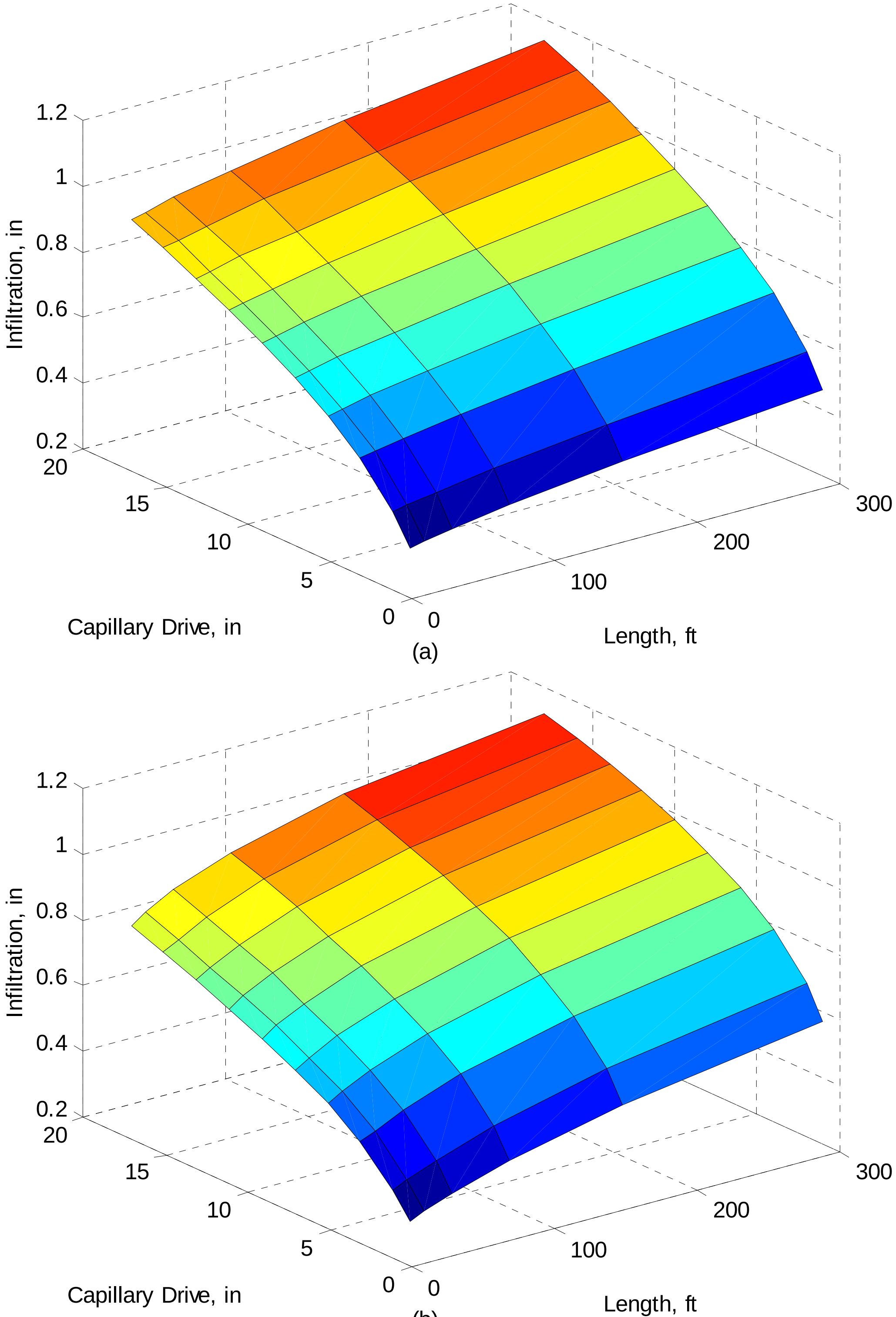
Figure 3.10: Sensitivity of KINEROS (a) and SWMM (b) Time to Peak Estimates to K_{sat}

3.7.2 Capillary Drive, G

The capillary drive (also matric potential, or capillary suction) was varied from 1 to 18 inches, with other parameters set to the 'typical' silt loam values found in Table 3.11. Figure 11 (a) and (b) indicates that both models' infiltration estimates are somewhat sensitive to capillary drive. KINEROS is more sensitive than SWMM, with response varying by nearly 0.7" throughout the tested range of G when L = 300 ft. SWMM infiltration generally varied by half an inch for most values of length. Neither model predicts consistently higher infiltration than the other, with SWMM predicting less infiltration at short lengths and high capillary suction, and KINEROS predicting less infiltration for long flow paths and low capillary suction. Despite the sensitivity over the full range of capillary suction values, both models were moderately well behaved over the middle range (8" to 14") encompassing most loam and silt loam soils, with infiltration estimates varying by up to 0.15".

Figure 3.12 (a) and (b) shows the response of the two models' peak flow estimates to capillary drive. KINEROS predicts higher peaks than SWMM for most values of capillary drive, except for the largest for which the models are approximately equal. Consequently, KINEROS predictions span a wider range, indicative of higher sensitivity. The sensitivity of both models may be due mostly to the influence of capillary drive on infiltration volume, discussed above.

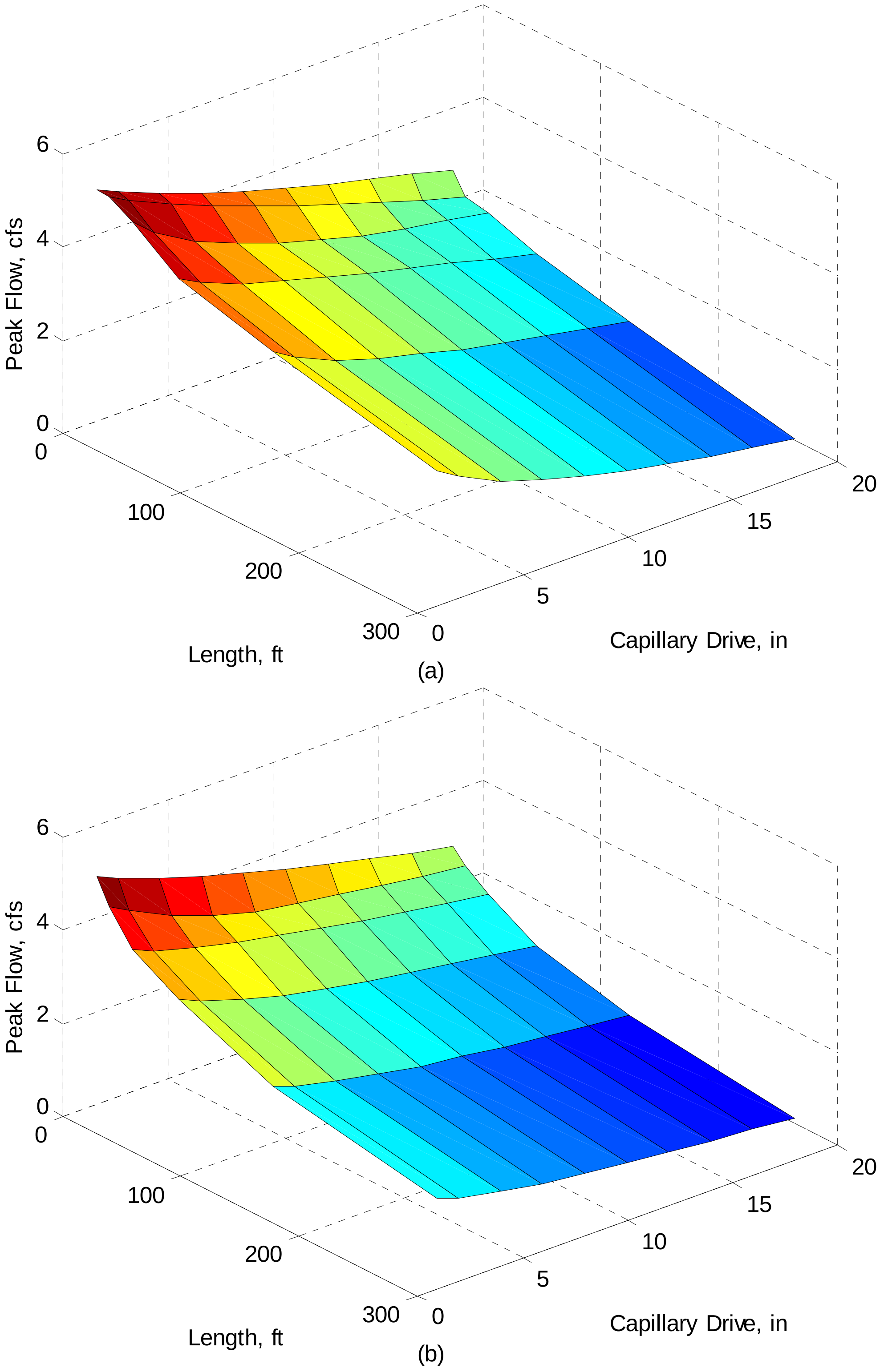
Capillary drive has a predictable effect on time to peak as well, comparable to that of K_{sat} above. The SWMM plot (Figure 3.13 (b)) is nearly identical to that for K_{sat} (Figure 3.10 (b)), while the KINEROS plot (Figure 3.13 (a)) is much smoother, and exhibits more influence of capillary drive on timing. The fixed 60-second time step used in SWMM simulations may contribute to this effect; KINEROS adjusts the time step internally to satisfy stability criteria. In any case, flow path length remains a very sensitive determinant of time to peak.



(a)

(b)

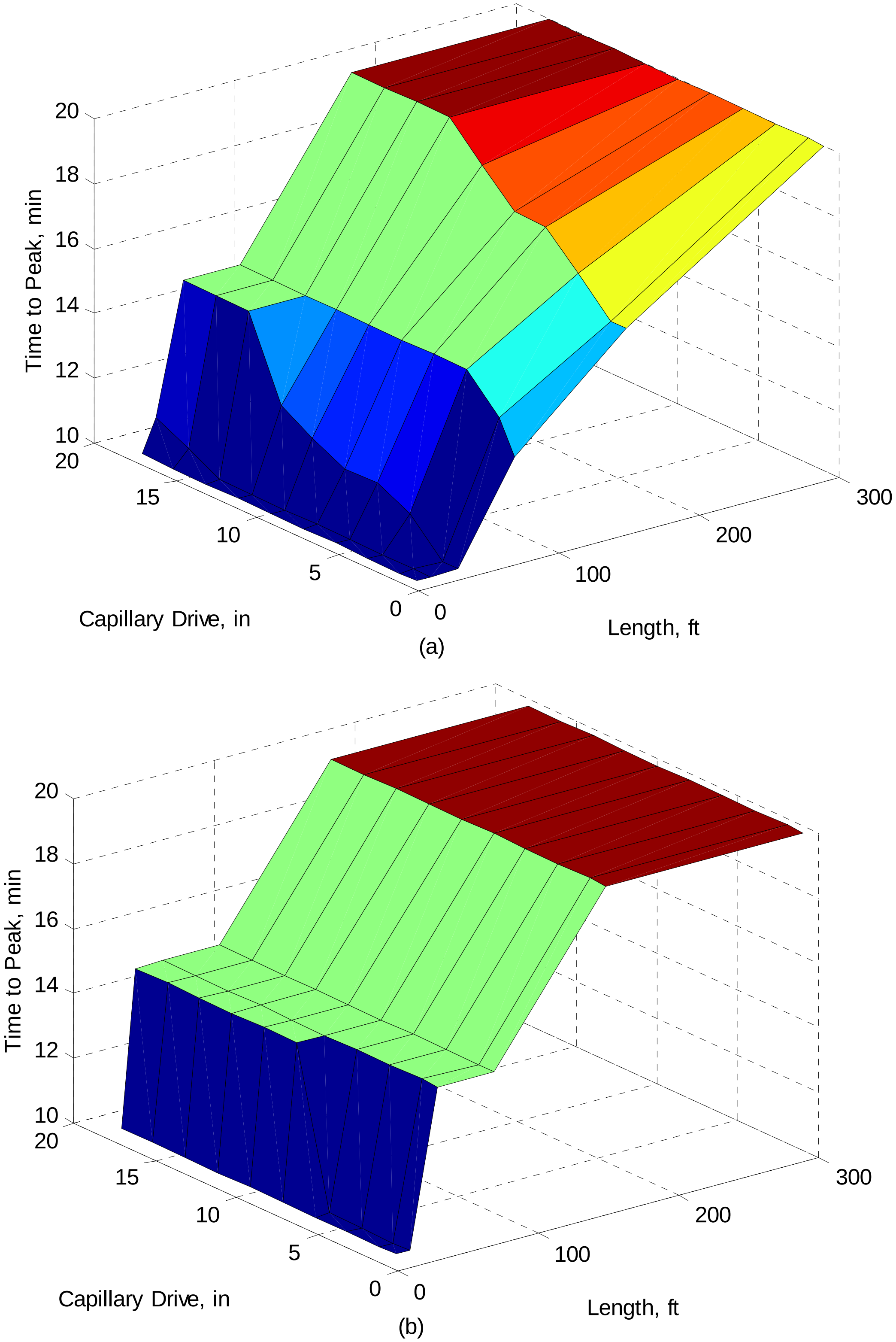
Figure 3.11: Sensitivity of KINEROS (a) and SWMM (b) Infiltration Estimates to Mean Capillary Drive



(a)

(b)

Figure 3.12: Sensitivity of KINEROS (a) and SWMM (b) Peak Flow Estimates to Mean Capillary Drive



(a)

(b)

Figure 3.13: Sensitivity of KINEROS (a) and SWMM (b) Time to Peak Estimates to Mean Capillary Drive

3.7.3 Moisture Content, Θ

Assuming a constant porosity of 0.45, moisture content was varied from nearly zero (0.001) through near saturation (0.449). The endpoints were selected to avoid zero values of moisture content (KINEROS) or moisture deficit (SWMM), which lead to division by zero errors in some model algorithms. Neither model considers wilting point, so values of moisture content below approximately 0.1 have little physical meaning. They were included nonetheless to discover any odd model behavior near extreme values of moisture content. Note that SWMM does not use porosity explicitly, rather, it requires the user to enter a soil moisture deficit (porosity minus moisture content) for each flow plane. The SWMM model does not update the moisture deficit for infiltration calculations during a surface water simulation; infiltration capacity is recovered as a function of saturated hydraulic conductivity.

Figure 3.14 (a) and (b) show the dramatically different infiltration predictions of KINEROS and SWMM versus moisture content. It can be seen that SWMM infiltration drops off sharply for $\Theta > 0.3$ (moisture deficit (SMDMAX) < 0.15 in model code), while KINEROS exhibits a planar, gently sloping response surface. SWMM predicts slightly higher infiltration in dry soils ($\Theta < 0.25$), but much lower infiltration in wet soils. KINEROS appeared more sensitive to slope length, and both models yielded similar results for the middle range of moisture contents from 0.1 to 0.3, with SWMM predicting slightly higher infiltration within this range for small lengths.

As shown in Figure 3.15 (a) and (b), neither model's peak flow predictions were greatly influenced by moisture content relative to other parameters. SWMM produced consistently lower peak discharges than KINEROS, except for extremely dry soils with short flow lengths, and was more sensitive for all values of moisture content. This effect is likely due to the increased runoff volume that SWMM predicts for wet soils. SWMM again showed a non-linear dependence on moisture content for wet soils, while KINEROS was linear over the entire range of values. Both models’ peak predictions were more influenced by flow length than moisture content. Time to peak was sensitive to flow length, but virtually unaffected by moisture content (Figure 3.16 (a) and (b)).

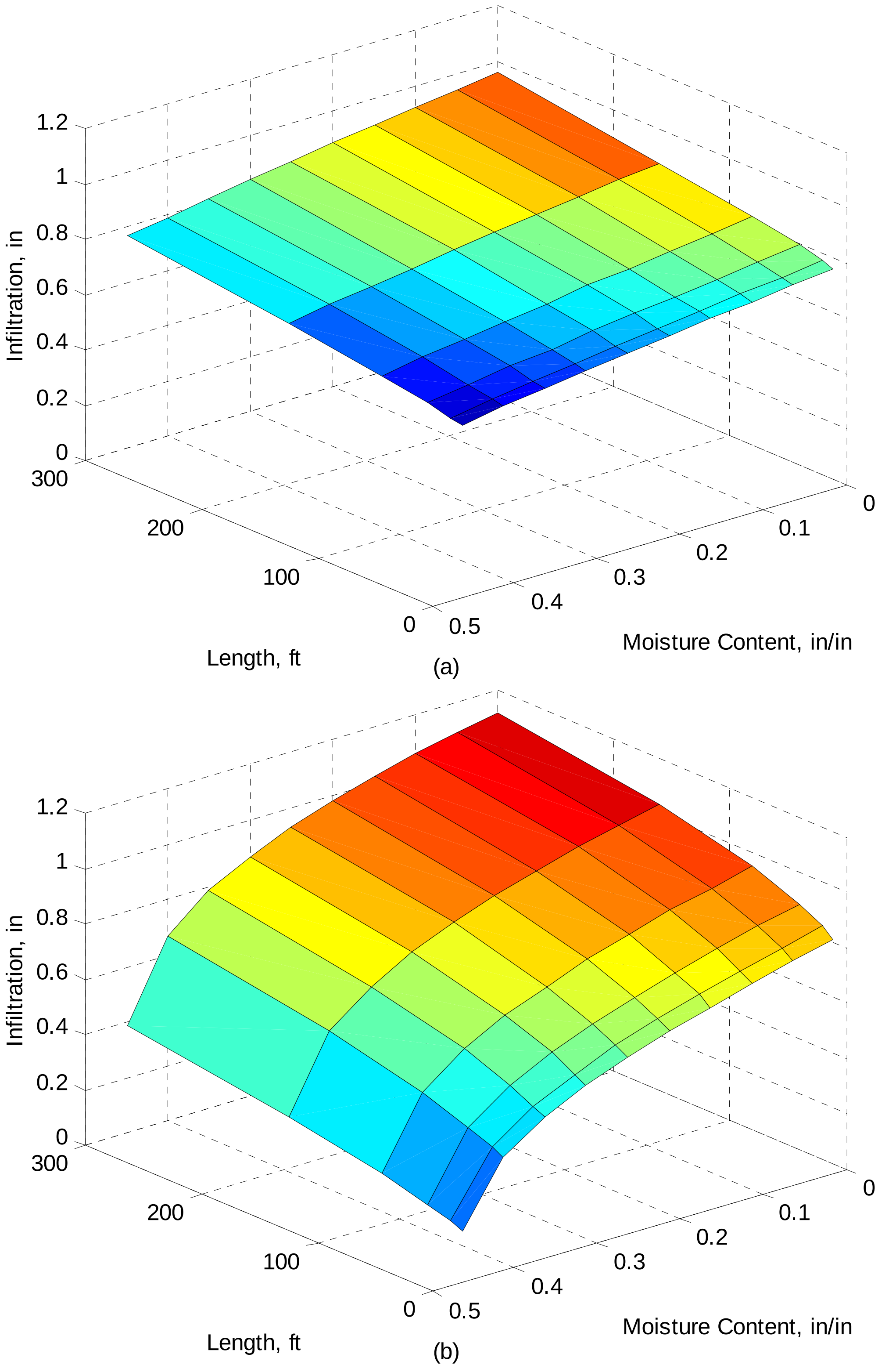
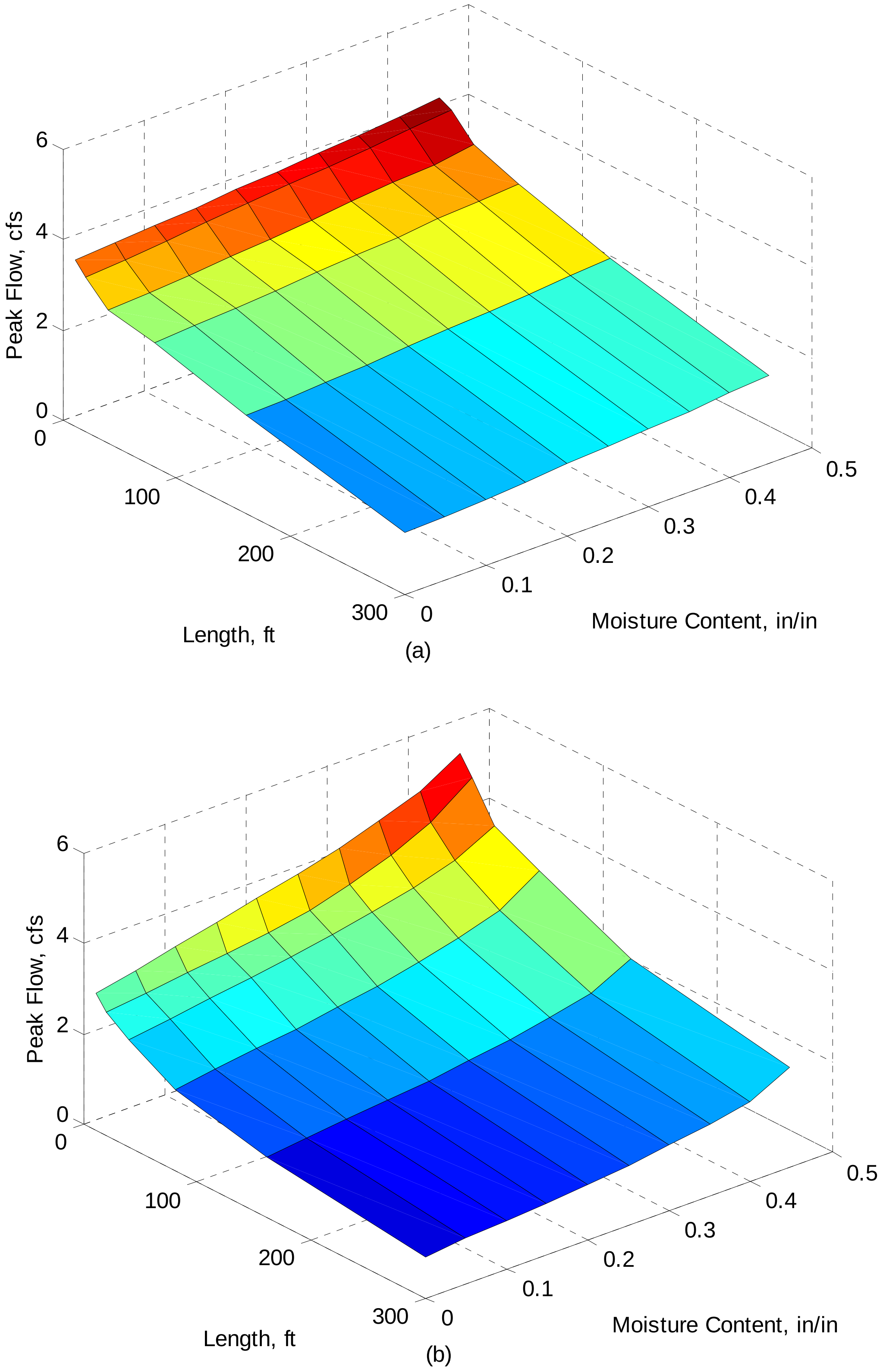


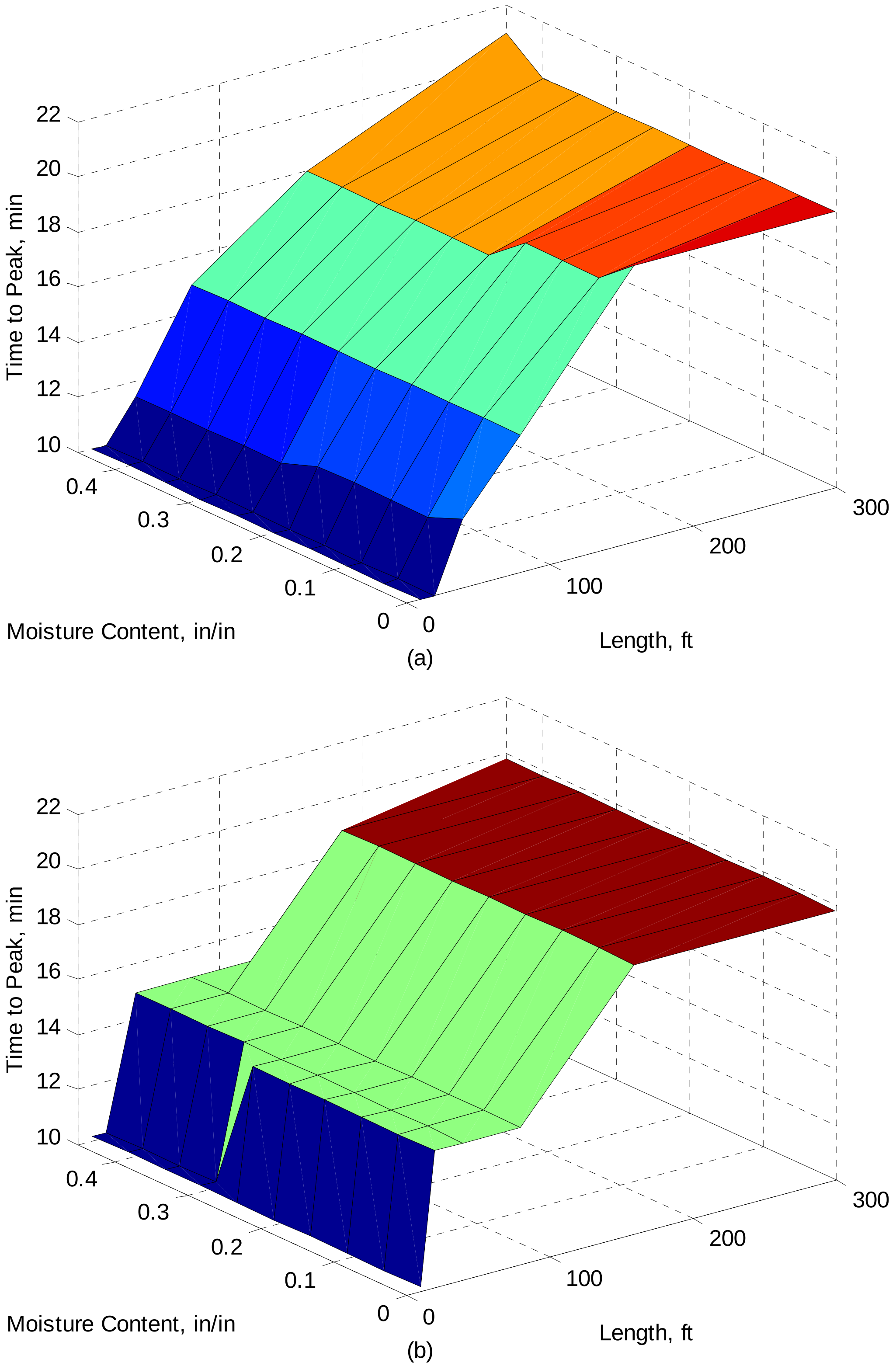
Figure 3.14: Sensitivity of KINEROS (a) and SWMM (b) Infiltration Estimates to Moisture Content



(a)

(b)

Figure 3.15: Sensitivity of KINEROS (a) and SWMM (b) Peak Flow Estimates to Moisture Content



(a)

(b)

Figure 3.16: Sensitivity of KINEROS (a) and SWMM (b) Time to Peak Estimates to Moisture Content

3.7.4 *Porosity*

Porosity was varied from 0.251 to 0.6, while holding moisture content at 0.25. Consequently, the soil moisture deficit ranged from near saturation to 0.35, less than the maximum tested above. The results of this section are thus redundant for SWMM, due to the fact that SWMM combines moisture content and porosity into a single moisture deficit term. The SWMM plots are included only to facilitate comparison between the models. Figures 3.17 (a,b), 3.18 (a,b), and 3.19 (a,b) show the effect of porosity on the infiltration, peak, and timing predictions of the two models. It can be seen that the relative response of the two models is nearly identical to that from varying moisture content, above. It is thus important to consider the *difference* between porosity and moisture content (the moisture deficit), rather than the particular values of each when modeling infiltration with the Green-Ampt method.

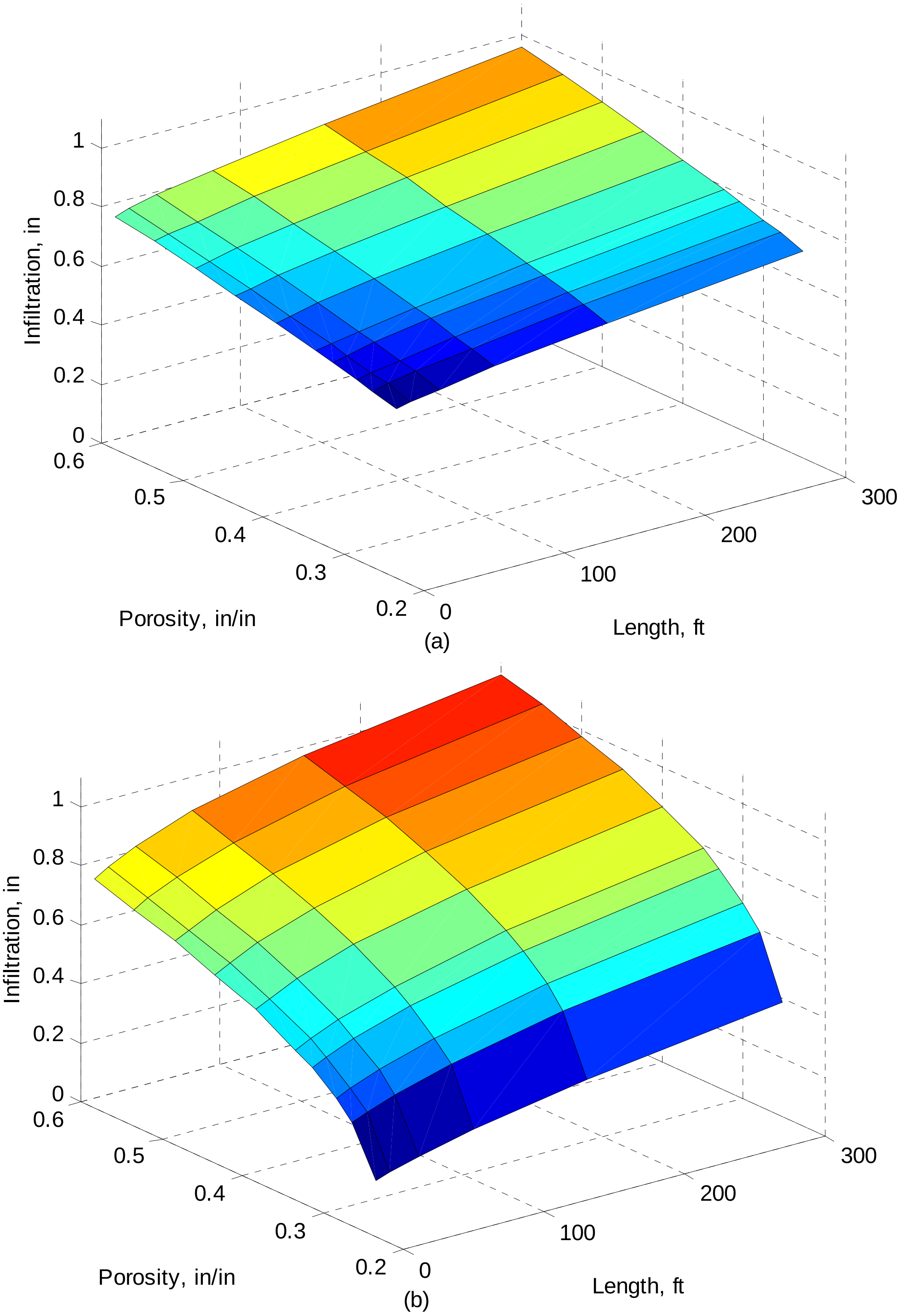


Figure 3.17: Sensitivity of KINEROS (a) and SWMM (b) Infiltration Estimates to Porosity

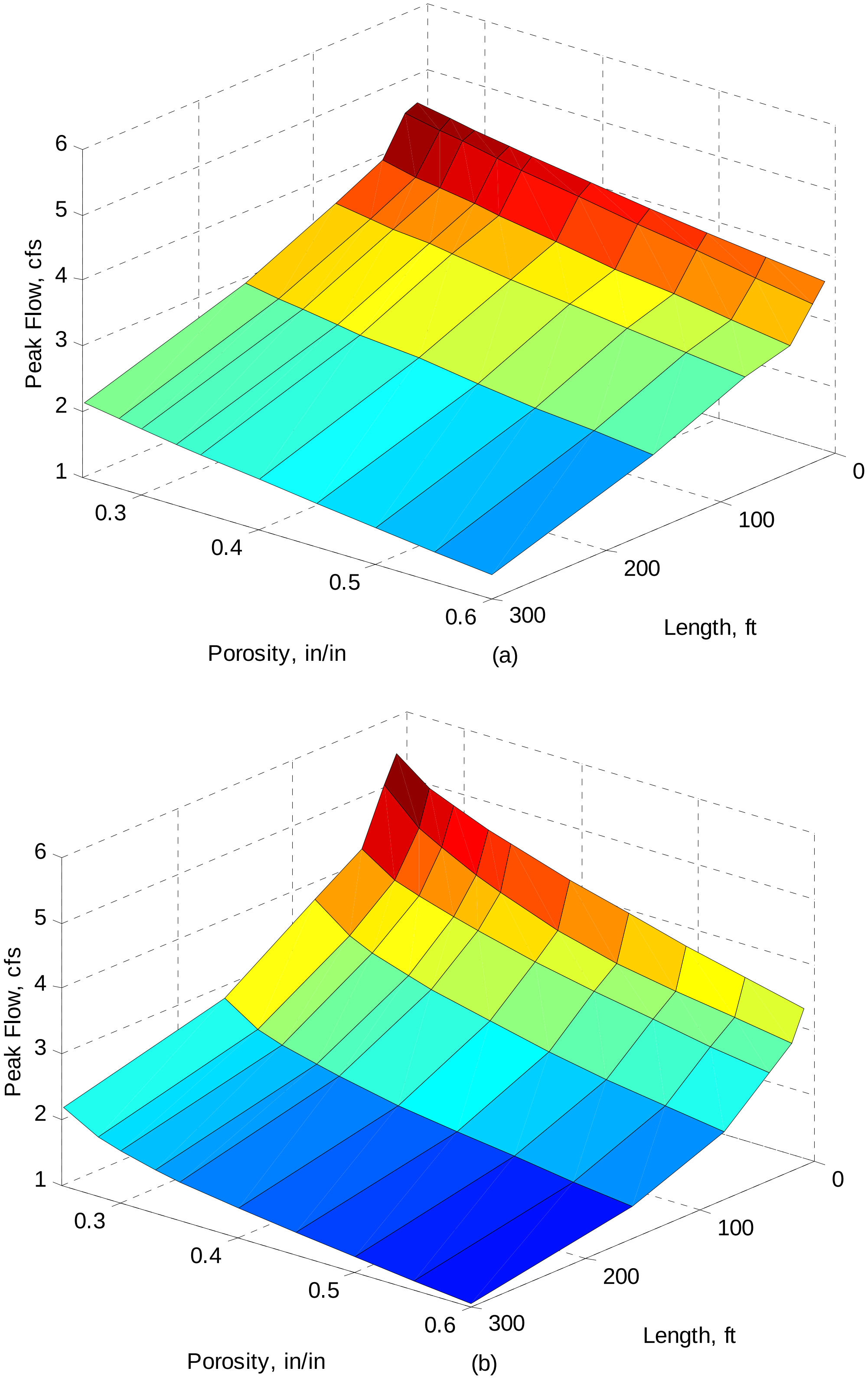


Figure 3.18: Sensitivity of KINEROS (a) and SWMM (b) Peak Flow Estimates to Porosity

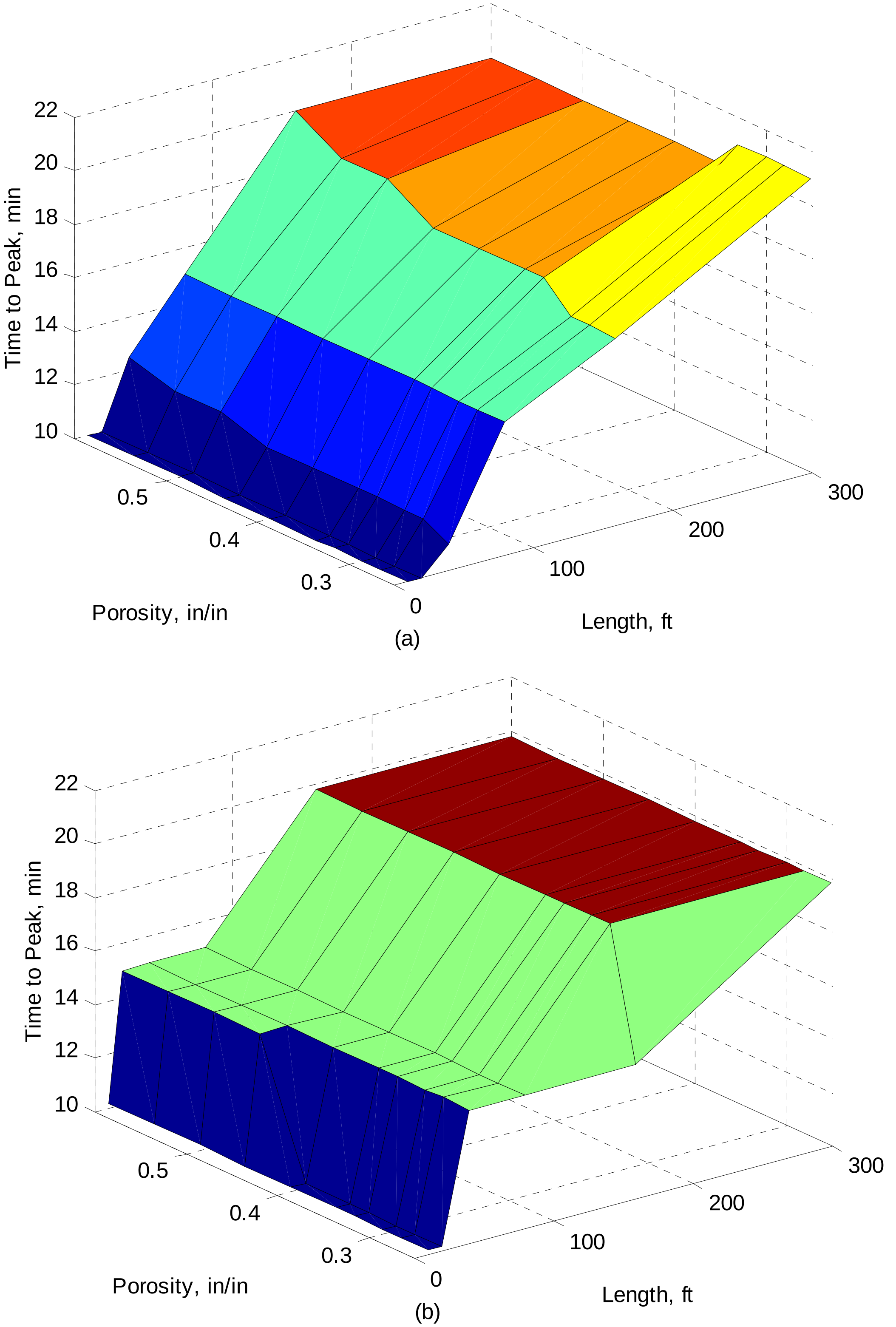


Figure 3.19: Sensitivity of KINEROS (a) and SWMM (b) Time to Peak Estimates to Porosity

3.7.5 Surface Roughness (Manning's n)

The overland flow surface roughness was varied from 0.01 to 0.40, representing a range from the smoothest conceivable pavement to woods with light underbrush. Again, SWMM's infiltration predictions proved more sensitive to both roughness and flow length, as demonstrated by Figure 3.20 (a,b). Peak flow predictions of both models were similar, with higher roughness predictably reducing peak discharges, and SWMM slightly more sensitive to length. Figure 3.21 (a,b) shows KINEROS predicting slightly higher peaks than SWMM for all but the smoothest, shortest flow planes. Time to peak was also predictably reduced by decreasing the roughness or length(Figure 3.22 (a,b)), with neither model being clearly more sensitive to either variable.

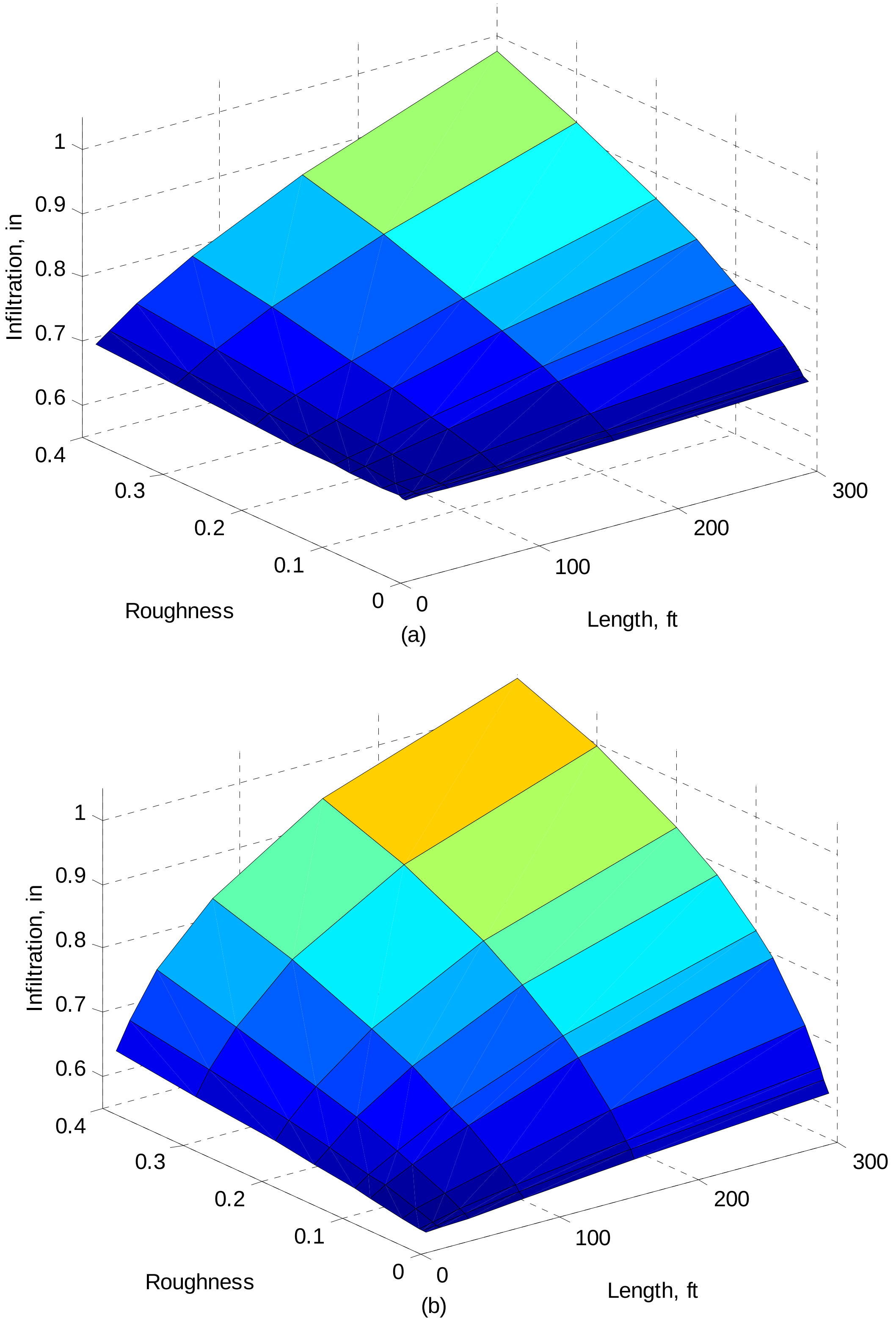


Figure 3.20: Sensitivity of KINEROS (a) and SWMM (b) Infiltration Estimates to Roughness

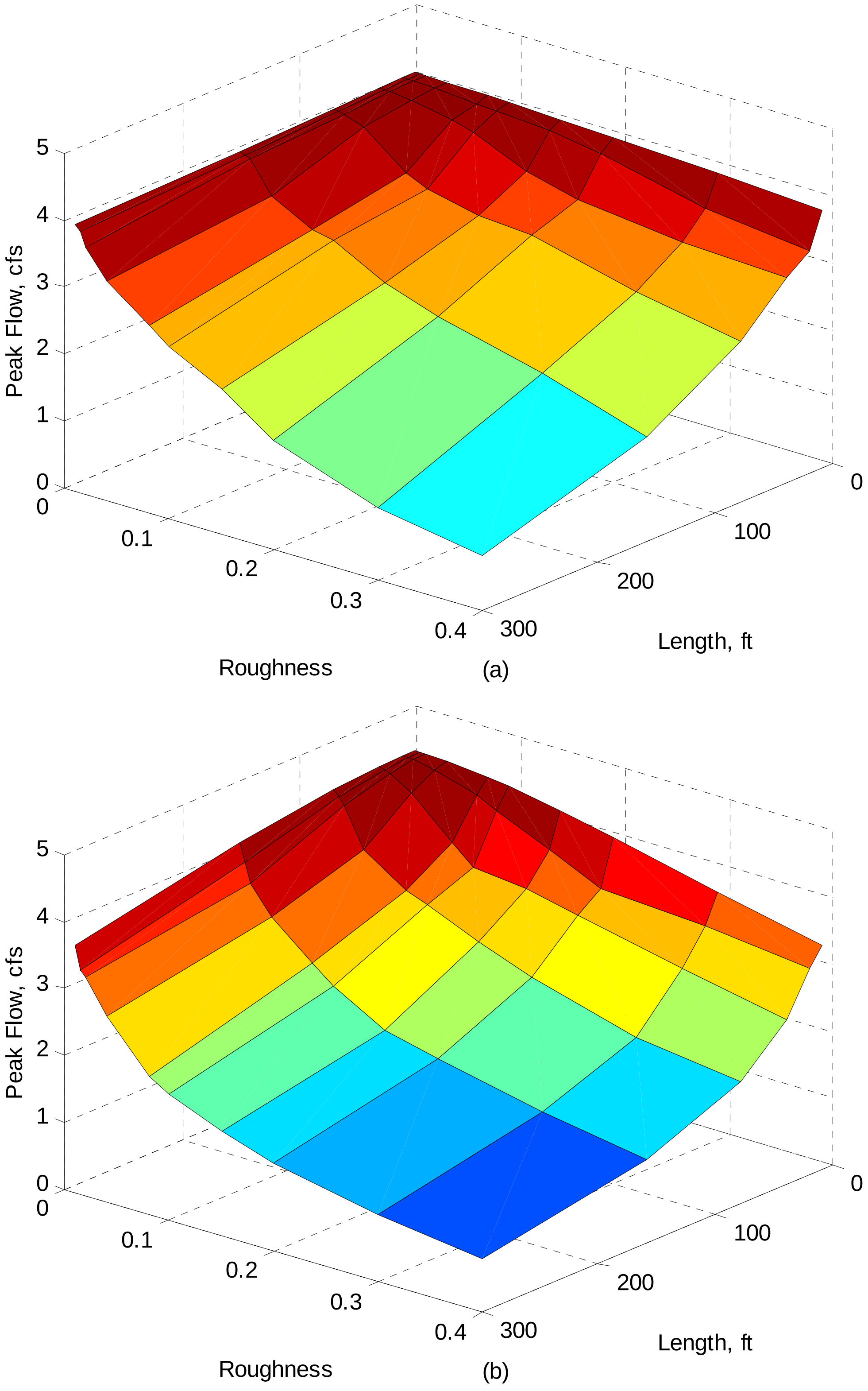
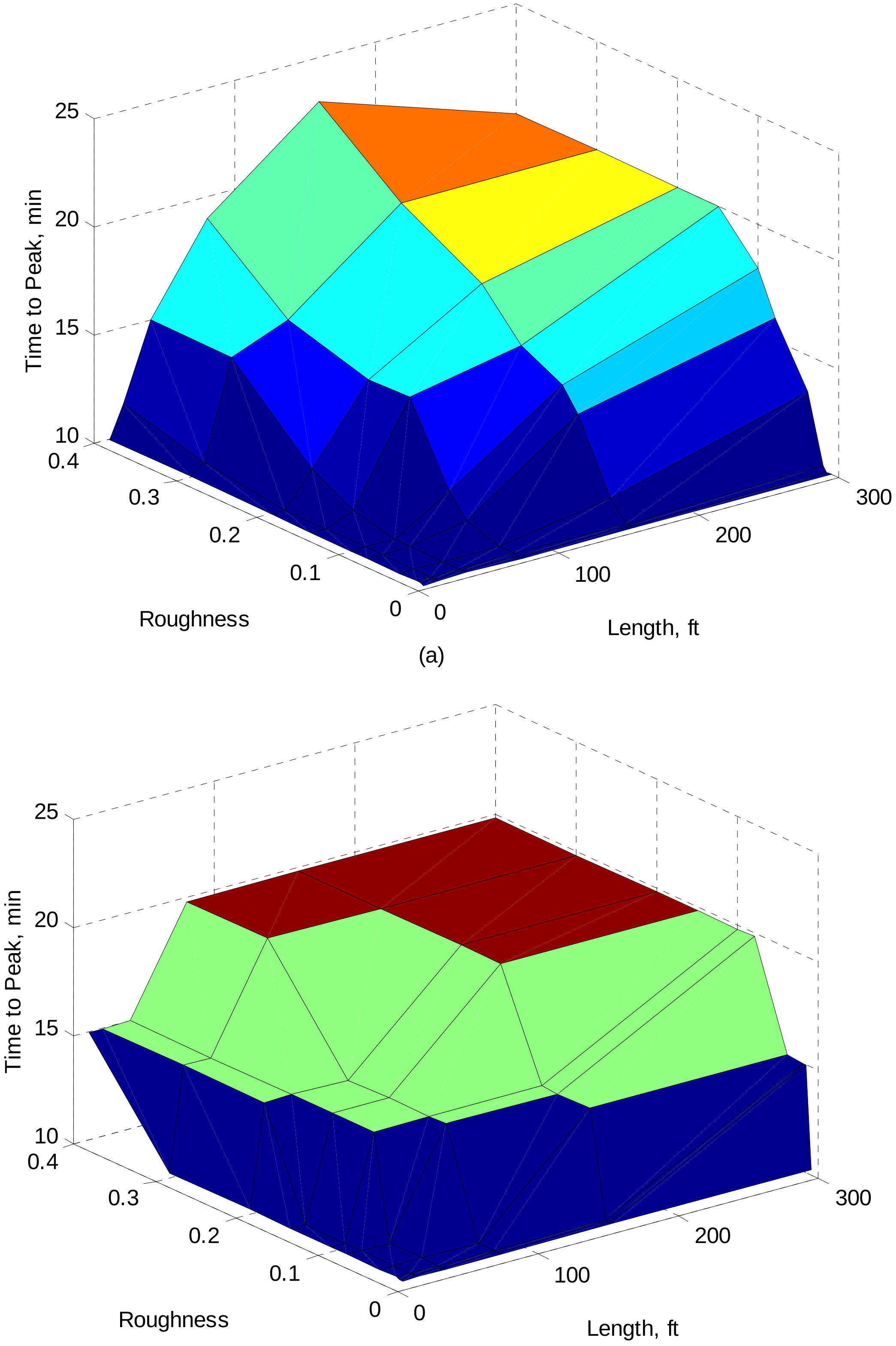


Figure 3.21: Sensitivity of KINEROS (a) and SWMM (b) Peak Flow Estimates to Roughness



(a)

(b)

Figure 3.22: Sensitivity of KINEROS (a) and SWMM (b) Time to Peak Estimates to Roughness

3.7.6 Surface Slope

Flow plane slope was varied from 0.002 to 0.25, a range which includes the flattest probable swale or bioretention area, up to the steepest typical rooftop or slope. As Figure 3.23 (a,b) shows, both models are rather insensitive to slope and length for slopes greater than 0.05. For slopes less than 0.05, SWMM appears to be slightly more sensitive. KINEROS again generally predicts higher peak flows than SWMM, except for very short flow lengths on steep slopes. SWMM peaks are slightly more sensitive to length and slope for lengths up to roughly 50 feet, while the opposite is true for lengths above 50 feet (Figure 3.24 (a,b)). Figure 3.25 (a,b) shows once again that SWMM and KINEROS produce similarly sensitive predictions of time to peak. The highest slopes included in the test are notably outside the range for which Manning's equation applies.

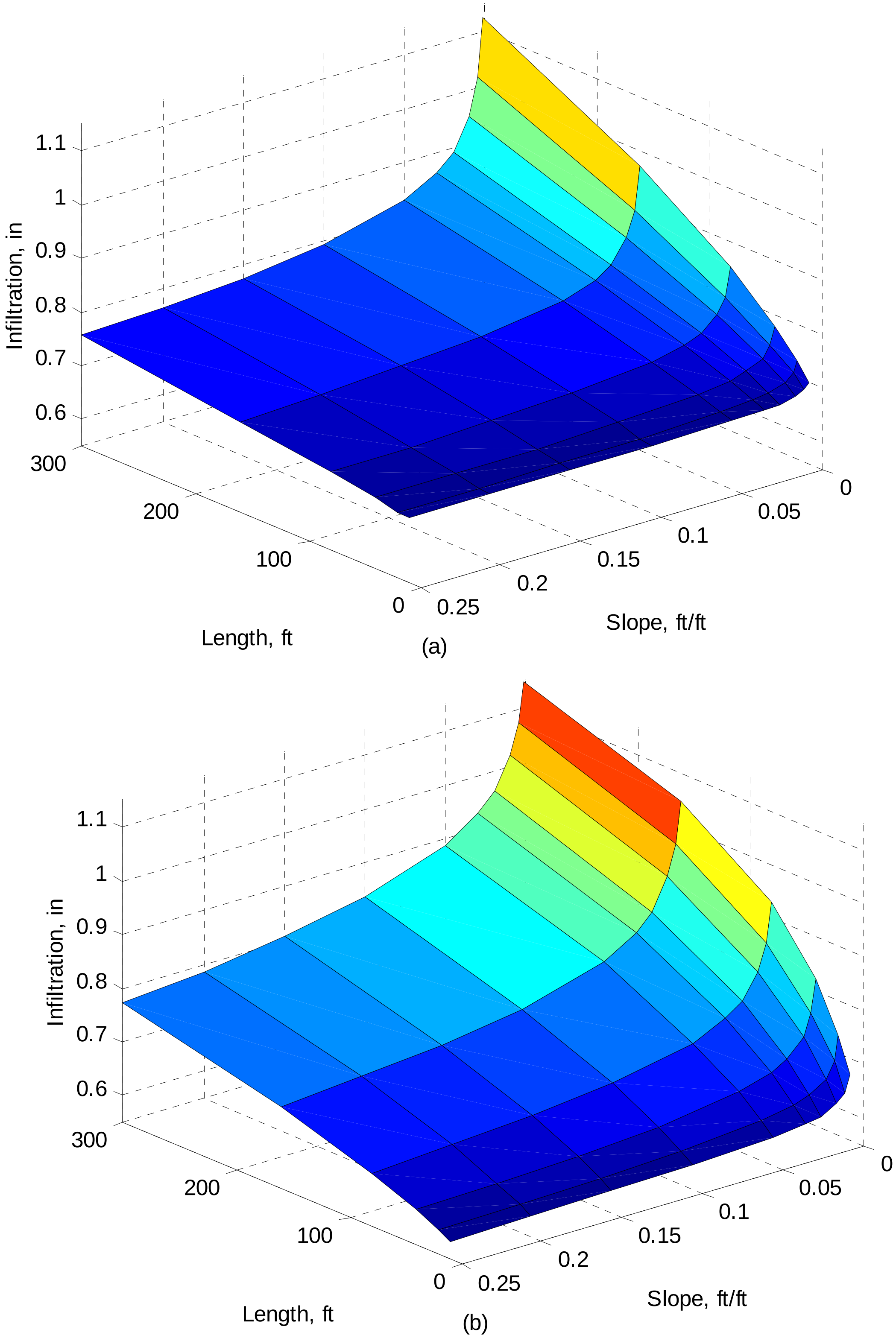


Figure 3.23: Sensitivity of KINEROS (a) and SWMM (b) Infiltration Estimates to Slope

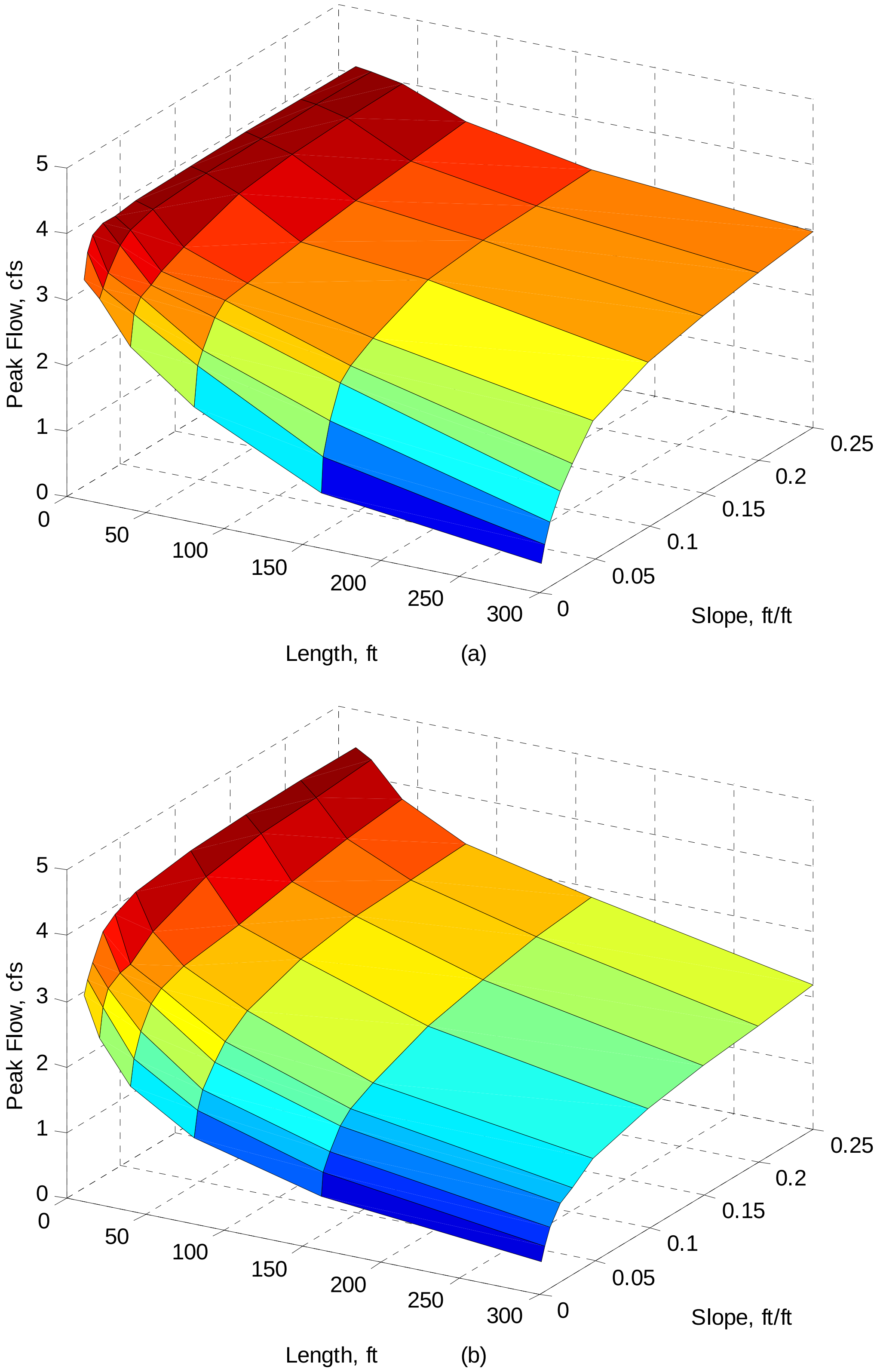


Figure 3.24: Sensitivity of KINEROS (a) and SWMM (b) Peak Flow Estimates to Slope

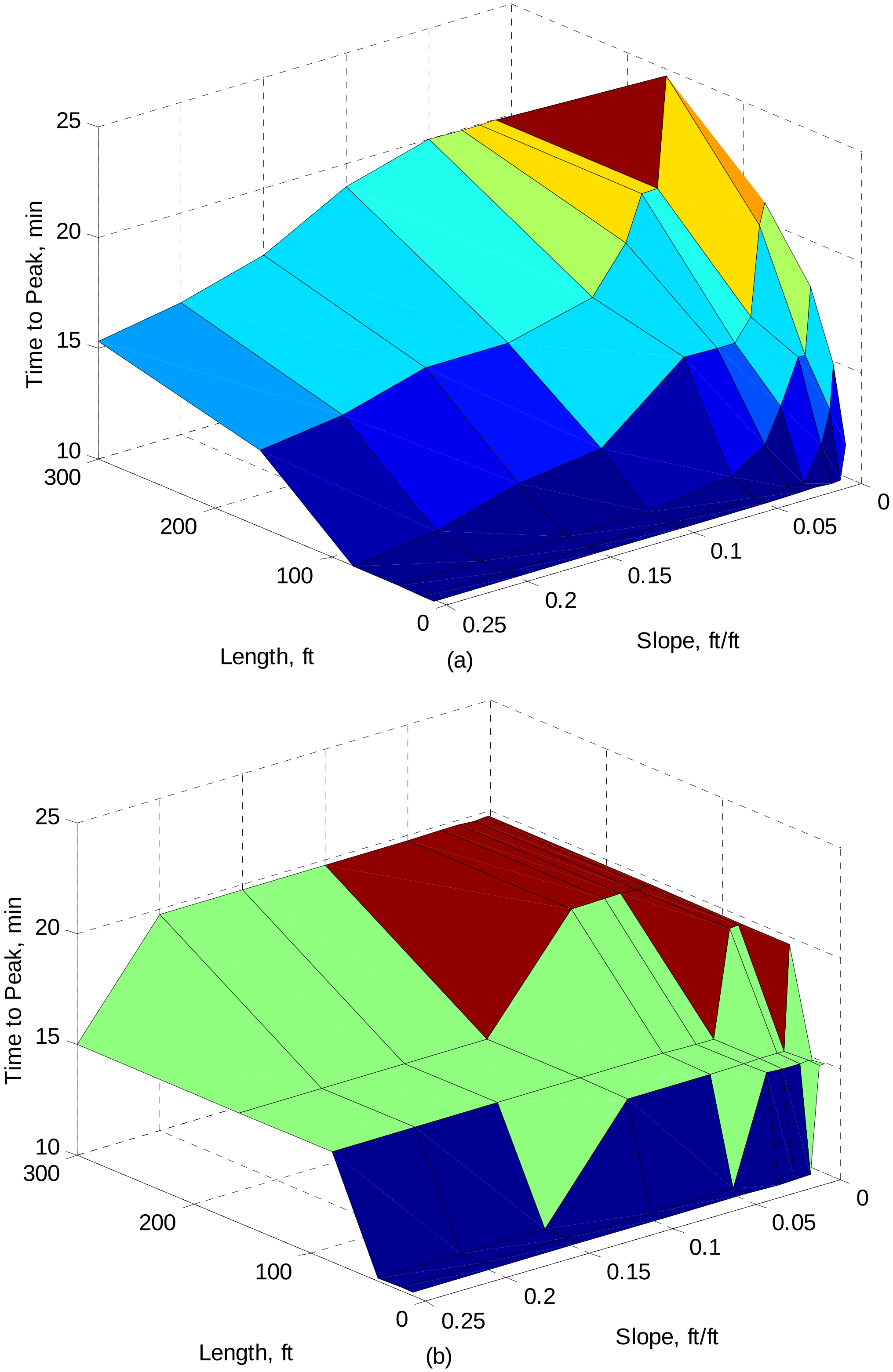


Figure 3.25: Sensitivity of KINEROS (a) and SWMM (b) Time to Peak Estimates to Slope

3.8 Summary of Preliminary Model Testing

This chapter focused on comparing KINEROS and SWMM in order to determine which was best suited for modeling LID. The models were first applied to the Virginia Tech Commuter Lot B, for which there were approximately 14.5 months of rainfall-runoff data. Due to equipment malfunctions, freezing weather, and uncertainties in the data, only 11 storms were identified that had both rainfall and somewhat accurate runoff data. These 11 storms were modeled with both SWMM and KINEROS, and the results compared with the observed data using a t-test. The only statistically significant difference (at $\alpha = 0.05$) was that between KINEROS predictions and the observed time to peak. Using the 11 storms plus an additional 6 for which there were only rainfall data, the models were compared to each other. SWMM consistently produced lower peaks and later time to peak compared with KINEROS, an effect that was significant at $\alpha = 0.05$. Other efforts at modeling 3 representative storms indicated that the SWMM PCTZERO parameter has negligible effect on peak discharge, but use of a lower, 15-minute, rainfall data resolution has dramatic effects on time to peak, significant effects on peak flow, and little effect on volume predictions. Perhaps the most important result of the comparison was to illustrate the difficulty in achieving meaningful results with a short term monitoring program.

Given the lack of conclusive results in the parking lot modeling, the relative sensitivity of SWMM and KINEROS to input parameters was investigated by modeling hypothetical one-acre planes in both models using a range of identical input parameters. Results indicated that both SWMM and KINEROS infiltration volume predictions are sensitive to saturated hydraulic conductivity and mean capillary drive, with KINEROS showing slightly greater sensitivity. Neither model gave consistently higher or lower predictions than the other over the tested range of these two variables. SWMM predictions of infiltration and peak flow were generally more sensitive than KINEROS for the remaining tested variables, including porosity, roughness, slope, and especially moisture content. Time to peak predictions were not sensitive to any variable except flow plane length. Flow plane length influenced SWMM infiltration calculations significantly, and dominated SWMM peak flow calculations as well as both models' time to peak results. Overall, SWMM and KINEROS results were similar over the middle range of parameters most likely to apply to LID modeling. Because infiltration volume results were so similar between the models, SWMM was selected for modeling LID. SWMM's weaknesses in peak flow and timing predictions can be overcome by considering relative, rather than absolute, differences between model results.

4 METHODOLOGY

4.1 Introduction

This chapter describes the research approach taken in hydrologic modeling of Low Impact Development. The following sections first describe the study site and the available meteorological data, then explain the steps used to design and model the site under four conditions: pre-development forest; low impact development; and conventional development, with and without stormwater management. The final section outlines the methods of comparing the four conditions.

4.2 Site Description

The selected site is the Village at Tom's Creek, a 175-acre mixed-use subdivision in Blacksburg, Virginia, designed by Gay and Kessee, Inc. for Tom's Creek Investors, L.C. The subdivision will include town homes, commercial sites, and detached houses on lots in a variety of sizes up to one-half acre. The site was designed using cluster development and some LID principles, such as slightly reduced pavement widths, limited swale drainage, and open space preservation. Due to topographic, zoning, and permitting constraints, the site remains largely conventional in its treatment of stormwater via rock-lined ditches, curb and gutter, storm sewer, and detention ponds. Selecting a local site allowed for plausible usage of the available local rainfall data, as well as allowing efforts to focus on modeling rather than detailed original site design. Given the fine watershed discretization required, and the complexity of the developed watershed, a small (4.3 acres) subwatershed within Phase II of the Village at Tom's Creek was selected for modeling.

The selected subwatershed feeds a single swale, which discharges to a perennial stream that flows through the site on its way to Tom's Creek. The site has dissected and rolling topography, with slopes exceeding 20% in steep areas near streams. The predevelopment land use is hay field interspersed with wooded fencerows, but it will be treated as forest for the purposes of this study, in accordance with LID design criteria. The topsoil is largely silt loam, underlain by sticky, plastic clay, over limestone and shale bedrock (NRCS 1985). Soils are mostly deep, and rated as Hydrologic Soil Group B or C according to the thickness of the silt loam topsoil, which varies from zero to 12 inches. Table 4.1 summarizes the soil properties and their prevalence on the site. Figure 4.1 shows the predevelopment topography, along with soil type boundaries, digitized from the county soil survey. SSURGO GIS soil mapping was not yet available for Montgomery County at the time of the analysis.

Table 4.1: Soil Types at the Village at Tom's Creek

Map Symbol	Soil Name	Hydrol. Soil Group	Topsoil	Subsoil	Drainage Status	Location
16B	Groseclose & Poplimento, 2 to 7% slopes	C	Loam / silt loam	Clay	Well-drained	Ridgetops
12B* & 12C	Frederick & Vertrees, 2 to 7% & 7 to 15% slopes	B	Silt loam	Clay loam / clay	Well-drained	Ridgetops
9D	Carbo & Chilhowie, 15 to 25% slopes	C	Silty clay loam / silty clay	Clay	Well-drained	Side slopes
8D	Caneyville-Opequon-Rock Outcrop Complex, 7 to 25% slopes	C	Silt loam / silty clay loam	Clay	Well-drained	Ridgetops and side slopes
11B* & 11C	Duffield-Ernest Complex, 2 to 7% & 7 to 15% slopes	B-C	Silt loam	Silt loam / silty clay loam	Well-drained / moderately well-drained	Intermittent drainageways, foot slopes, saddles, sinkholes

** Present on development site, but not present within 4.3-acre study watershed.*

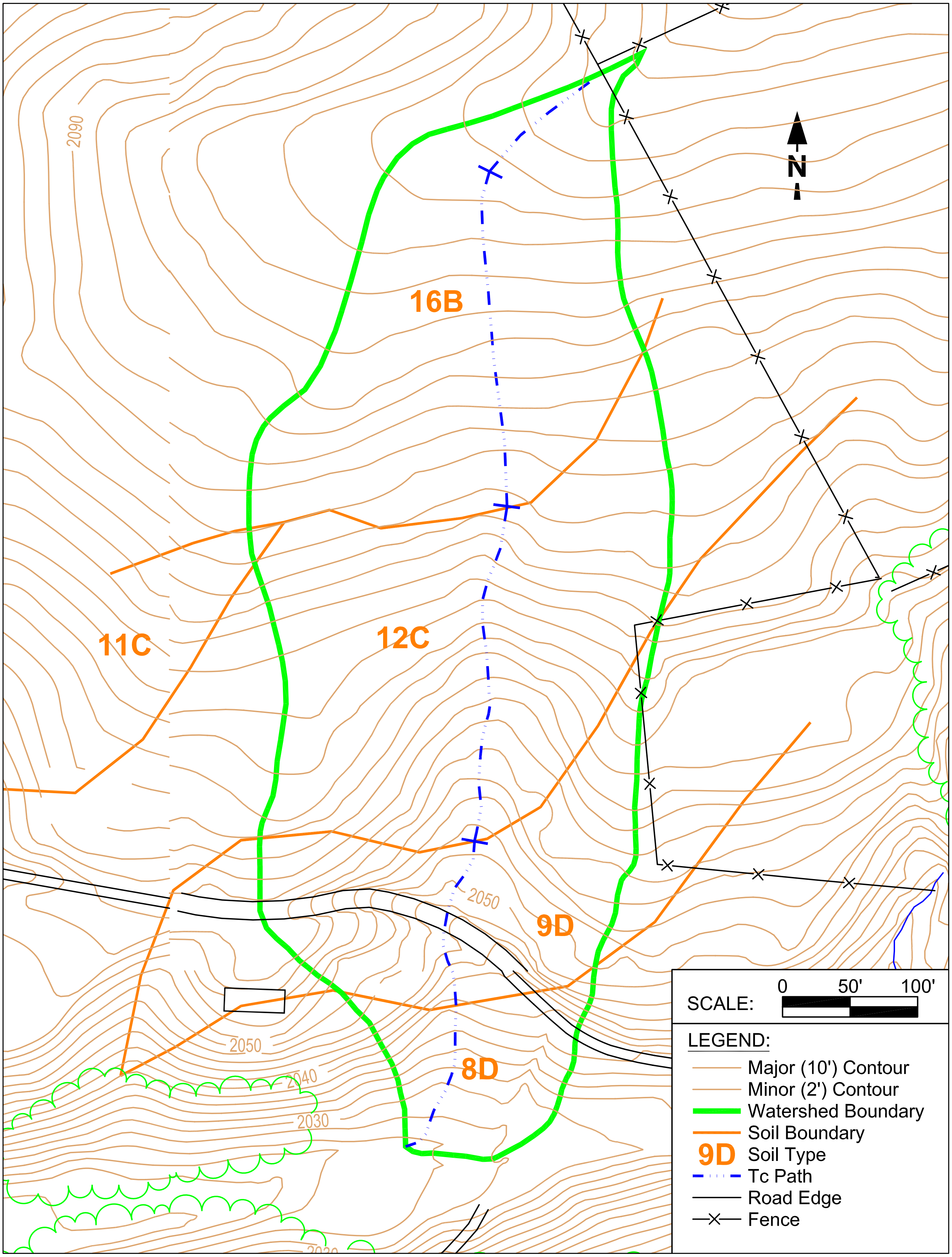


Figure 4.1: Village at Tom's Creek Predevelopment Topography and Soils

4.3 Climate Data

Continuous SWMM modeling requires a rainfall time series and an estimate of evaporation rates. A rainfall time series was created from available 5- and 15-minute resolution local rainfall data. Local temperature data was used to estimate evaporation using the Thornthwaite method. NRCS design storms were developed for single-event modeling.

4.3.1 Rainfall Data

Fourteen and a half months of rainfall data were available in 5-minute resolution from the parking lot stormwater pond study mentioned in Chapter 3, representing 120 days with measurable rainfall from May 1995 through August 1996. This data was supplemented with 15-minute resolution data from the National Weather Service's Integrated Flood Observation and Warning System (IFLOWS) gage network. The available IFLOWS data spans the period from April 1991 to May 2003, but monthly archives dated before May 1998 cannot be exported from the database in a suitable format. April 1998 data was obtained from the May 1998 archive. This was possible because the IFLOWS database is written in First-In, First-Out format, and monthly archives typically contain data from the previous month(s), depending on how many hours of rainfall data was recorded in a given month. A Visual Basic program entitled RainPro was created to process both the IFLOWS and datalogger data into a format readable by SWMM's Rain Block. See Appendix C for the source code. Because of the differing time periods for which rainfall data was available, the following approach was taken for collating the data:

1. Datalogger output from the parking lot was relabeled as May 2003 through August 2004 from the original May 1995 through August 1996.
2. IFLOWS data from April 1998 to April 2003 was used as it was obtained from the archive.
3. IFLOWS data from May 2003 was dropped in favor of the higher-resolution datalogger data.
4. The relabeled datalogger series was appended to the IFLOWS series, yielding a continuous record of 77 months (6.42 years / 2345 days), from April 1, 1998 through August 31, 2004, containing 239.80 inches of rainfall.

Table 4.2 gives the monthly rainfall totals. SWMM's Rain Block was used to create a rainfall interface file for use in continuous simulation.

Table 4.2: Monthly Rainfall Totals for mixed IFLOWS-datalogger record (datalogger May 2003 through August 2004; remainder IFLOWS)

Year	Month	Rainfall (0.01")
1998	4	168
1998	5	552
1998	6	453
1998	7	199
1998	8	462
1998	9	99
1998	10	292
1998	11	96
1998	12	304
1999	1	404
1999	2	308
1999	3	364
1999	4	340
1999	5	280
1999	6	160
1999	7	500
1999	8	319
1999	9	508
1999	10	176
1999	11	128
1999	12	216
2000	1	184
2000	2	312
2000	3	204
2000	4	556
2000	5	144
2000	6	571
2000	7	228
2000	8	644
2000	9	344
2000	10	0
2000	11	192
2000	12	116
2001	1	196
2001	2	180
2001	3	372
2001	4	80
2001	5	1036
2001	6	340
2001	12	208
2001	7	476
2001	8	269
2001	9	204
2001	10	208
2001	11	32
2002	1	192
2002	2	92
2002	3	376
2002	4	324
2002	5	538
2002	6	547
2002	7	270
2002	8	124
2002	9	416
2002	10	416
2002	11	448
2002	12	256
2003	1	104
2003	2	556
2003	3	252
2003	4	504
2003	5	269
2003	6	677
2003	7	368
2003	8	255
2003	9	180
2003	10	288
2003	11	296
2003	12	154
2004	1	326
2004	2	133
2004	3	311
2004	4	187
2004	5	461
2004	6	271
2004	7	527
2004	8	440

In addition to the continuous rainfall record, 24-hour NRCS Type II synthetic design storms were produced using VT/PSUHM, for the 1, 2, 10, and 100-year events. The synthetic storms were used in single-event modeling of the four scenarios, described below. The 1-year rainfall depth was also used to determine the required storage volume of LID Integrated Management Practices. Table 4.3 presents the rainfall volumes and peak rainfall intensities for the design storms to be used in the modeling.

Table 4.3: NRCS Type II Design Storm Depths

Approximate Recurrence Interval (yr)	Precipitation Depth (in)	Maximum Intensity (in/hr)
1	2.50	2.76
2	3.10	3.42
10	5.00	5.51
100	7.00	7.72

4.3.2 Evaporation Data

Evapotranspiration was computed using temperature data from the Roanoke Regional Airport / Woodrum Field, which is approximately 40 miles east and 940 feet in elevation below the site. The Thornthwaite method was applied to the 30-year average temperatures to arrive at a single average year of monthly evapotranspiration estimates, listed in Table 4.4. The evaporation rate does not directly affect SWMM's computation of infiltration rates, so the coarseness of the Thornthwaite method was considered acceptable. Relevant calculations can be found in Appendix D-1.

Table 4.4: Monthly Potential Evapotranspiration, Roanoke Regional Airport, VA

Month	Mean Temperature (^oF)	Potential Evapotranspiration (in/mo)
Jan	34.5	0.06
Feb	37.4	0.21
Mar	46.7	0.98
Apr	55.7	2.15
May	64.2	3.63
Jun	71.8	5.11
Jul	75.8	5.76
Aug	74.6	5.18
Sep	67.7	3.64
Oct	56.6	1.92
Nov	47.5	0.89
Dec	38.3	0.23

4.4 Land Development Scenario Design

To evaluate the effectiveness of LID, the site was designed and modeled using continuous simulation under four scenarios, developed based on topography and site plans for the Village at Tom’s Creek community:

1. Pre-development Forest, requiring no design.
2. Low Impact Development, adapted from the original site plans by a reduction in impervious surface and the addition of LID Integrated Management Practices (IMP’s). Recognizing that LID IMP’s were developed and applied largely in Maryland rather than Virginia, Maryland stormwater guidelines were used in their design where applicable.
3. Conventional Development (without Stormwater Management), using the same land cover developed for the LID case, but with runoff directed to gutters and storm drains rather than bioretention and other LID IMP’s. The approach provides a comparison of LID versus conventional development at the same impervious fraction.

4. Conventional Development with Stormwater Management, identical to uncontrolled conventional development, but with the addition of a stormwater management pond located at the watershed outlet.

This section describes the design approach for the LID and conventional development scenarios; Section 4.5 describes the modeling approach for all four scenarios.

4.4.1 Predevelopment Forest

The predevelopment condition, by definition, did not require design. However, LID design requires that the predevelopment curve number and time of concentration be established in order to set storage and timing targets for the LID watershed and select the LID design storm. The drainage area (4.33 acres) and time of concentration path were delineated based on the 2-foot contour mapping provided by the Town of Blacksburg. The length of overland (sheet) flow was limited to 100 feet for the purposes of time of concentration calculations. The curve number was computed for woods in good condition corresponding to the breakdown of hydrologic soil groups on the site. The predevelopment curve number was computed as 64.4 (rounded up to 65 in common design practice); the predevelopment time of concentration was 18.3 minutes (0.304 hr). Time of concentration calculations can be found in Appendix D-2.

4.4.2 Low Impact Development

The Village at Tom's Creek plans, provided by Gay and Kessee, were redesigned by the application of LID principles and integrated management practices, using the iterative process described below. The drainage area was delineated based on the proposed grading shown in the original plans, along with assumed rooftop discharge locations. Figure 4.2 presents the original site design for the test watershed, before application of LID practices, with the drainage area delineation shown. The lot numbers shown on the figure will be used throughout this document as part of the hydrologic unit naming convention, more fully described in Section 4.5. Note that the original plans provided by the developer include limited use of LID-related practices such as swale drainage, limited curb and cutter, reduced setback distances, clustering of dwellings to reduce overall roadway length, and open space preservation.

The following changes were made to the site in order to reduce impervious area, maintain runoff timing, and preserve infiltration areas:

1. The proposed site contours were modified to minimize land disturbance and grading, and facilitate runoff redirection and bioretention. Roadway cross-slopes and superelevation rates were adjusted in a similar fashion.
2. Existing forest cover was maintained wherever possible, and to a greater extent than the original plans.
3. Town homes along the main boulevard were grouped into attached rows of three to four units wide, with shared back parking areas. One unit was eliminated in lieu of forest preservation area and bioretention.
4. Shared driveways were used for the ¼ acre lot single-family houses with attached garages (Lot numbers 67 through 70).
5. Alley, sidewalk, driveway, and roadway widths were reduced.
6. Curb and gutter was replaced with swale drainage. Sidewalks were relocated, and slope grading changed to facilitate the swale drainage. Check dams were used to reduce swale slopes.

7. Rooftop and pavement runoff was redirected to lawns or open space rather than directly into the drainage system.
8. Storm sewers were largely eliminated, except for required cross drainage, and smooth-walled HDPE pipes were replaced with corrugated HDPE to increase roughness and travel time. Pipes were sized to convey 110% of the 10-year NRCS discharge.
9. For analysis, it was assumed that grading activities either would not reduce the permeability of disturbed soils; or that disturbed soils would be amended with compost in sufficient quantity to mitigate the effects of grading and compaction.

Figure 4.3 depicts the redesigned landscape, with the time of concentration path shown. The curve number and time of concentration were computed as 77.2 (rounded up to 78 in common design practice), and 18.7 minutes (0.312 hr), respectively. The curve number did not match that of the predevelopment condition (64.4, rounded up to 65), thereby requiring additional storage to bring the curve numbers into agreement. Use of swales in lieu of curb and gutter, impervious area disconnection, increased pipe roughness, and in-swale check dams successfully increased the time of concentration to match predevelopment conditions. Calculations can be found in Appendix D-2.

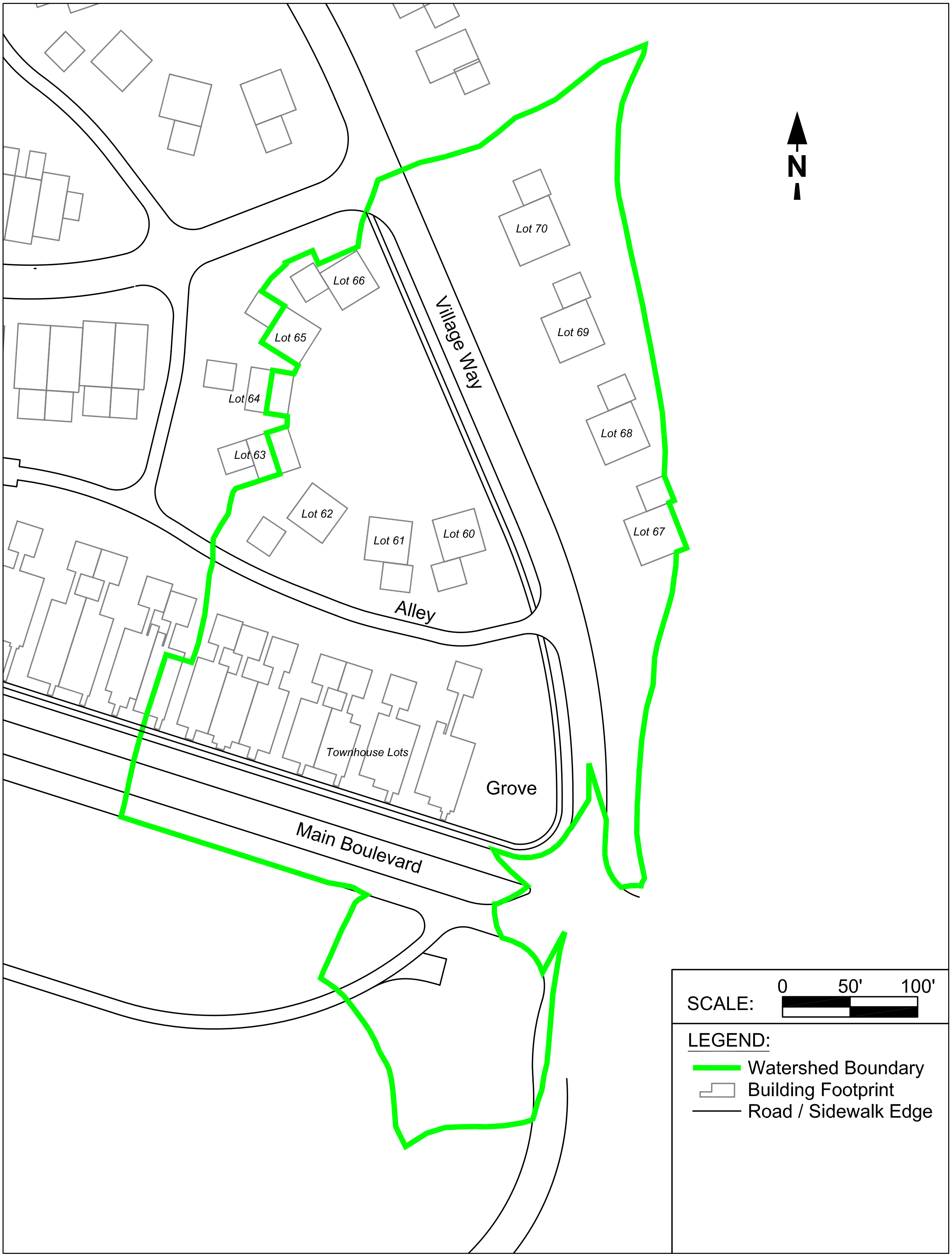


Figure 4.2: Village at Tom's Creek Initial (non-LID) Site Layout

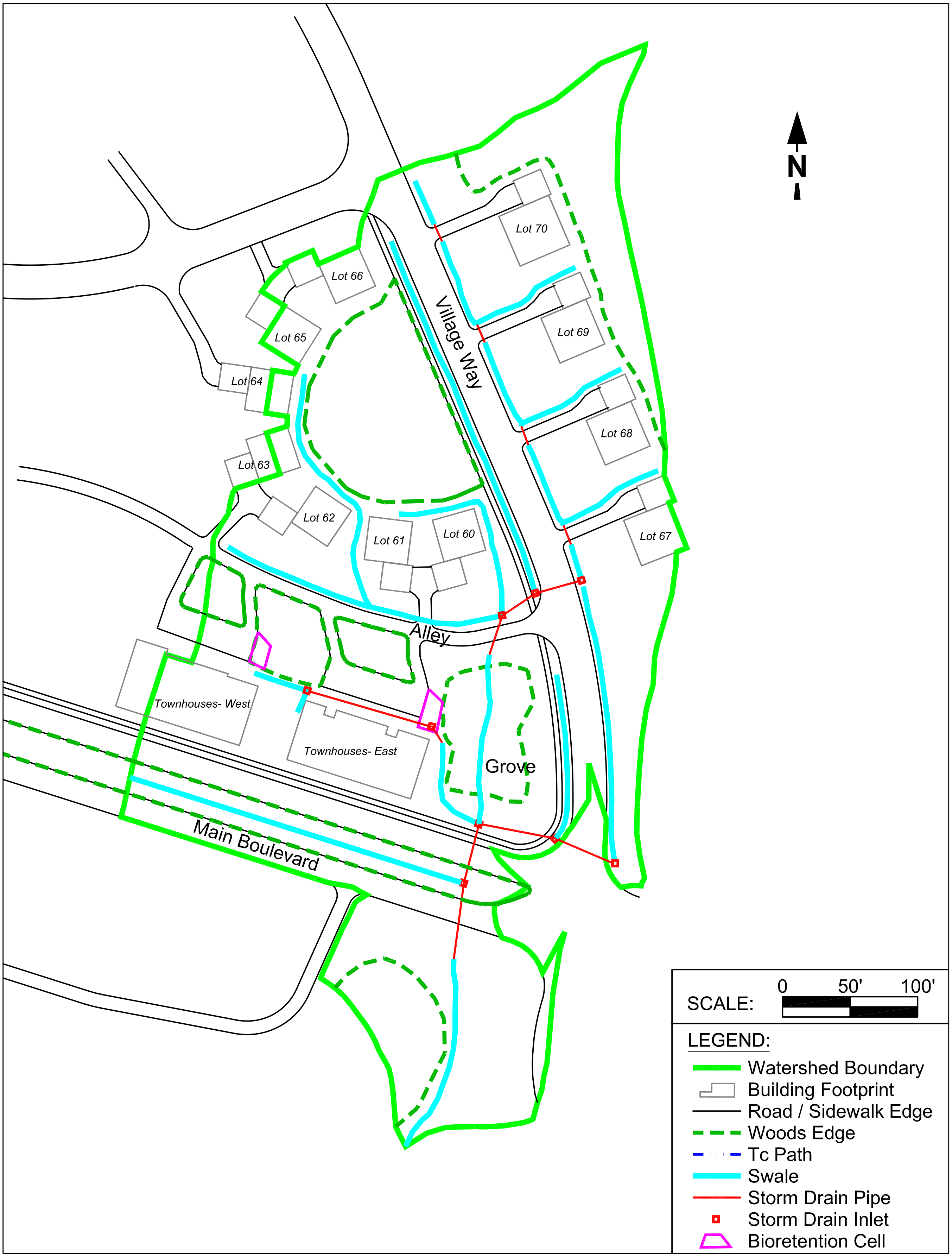


Figure 4.3: Village at Tom's Creek LID Site Design

4.4.2.1 LID Design Storm and Required Storage

The LID design storm was determined to be the 1-year, 24-hour rainfall of 2.5”, as it exceeded 1.5 times the minimum rainfall depth to initiate runoff for woods in good hydrologic condition, following the recommendations in the LID Hydrologic Analysis Manual (Prince George’s County 2000b). Given the predevelopment curve number of 65 and using the standard NRCS definitions of initial abstraction and runoff volume, a minimum of only 1.08” of rainfall is required to produce runoff from the predevelopment forested site. 150% of 1.08” is only 1.6”, less than the 1-year depth of 2.5”.

The LID site is 32.4% impervious, including 11.6% due to rooftops, and has a rounded Curve Number of 78 before inclusion of retention practices. Using the charts in the LID design manual and reproduced in Appendix D-3, it was determined that 0.485” of storage was required for management of the post-development runoff volume using only retention. Storage of 0.480” was required to manage peak discharges using retention while 0.325” was required to manage peak discharges using detention. Therefore, the volume-control retention depth of 0.485” controlled the design. Providing 0.485 inches (7630 cubic feet / 0.18 ac-ft) of storage was required to match the predevelopment Curve Number, maintain predevelopment runoff volumes and maintain predevelopment peak discharges in accordance with the methods outlined in the Low Impact Development design manual (Prince George’s County 2000a). At a higher imperviousness and/or lower predevelopment Curve Number, peak-control retention and/or detention would likely control the design.

In addition to increasing storage to meet the predevelopment curve number, the time of concentration was increased to match that of the predevelopment forested condition. Efforts to increase the time of concentration are described in the previous section.

Integrated management practices (IMP's) were applied iteratively to both increase runoff storage and increase time of concentration, until the time of concentration and curve number matched those for the predevelopment forested condition. Pavement runoff was captured in dry swales or bioretention cells, while rooftop runoff was managed using green roofs and rain barrels. Design methods are described below.

4.4.2.2 Pavement Runoff Control IMP's

A **dry swale** consists of a flat-bottomed ditch with highly permeable bottom soils, and temporary retention (prior to infiltration) provided using check dams. All dry swales were designed to convey a 10-year design discharge, determined using the TR-55 Graphical Method (NRCS 1986). Storage was provided using a series of check dams in each swale, which also served to flatten the effective swale slope and increase the travel time. The 10-year velocity was limited to 2 feet per second. Storage was computed based on the depth midway between check dams, in accordance with the Maryland Stormwater Design Manual (MDE 2000). Due to the clay subsoil of the site, perforated underdrains would generally be required for dry swales and bioretention cells that extended vertically to the clay layer in order to ensure a maximum 48-hour drawdown time.

A **bioretention** area consists of a shallow depression where stormwater is allowed to pond prior to infiltration. The bioretention area is underlain by approximately four feet of highly permeable manmade topsoil, and planted with drought- and flood-tolerant native vegetation. Stormwater volume is controlled through infiltration, followed by seepage into underlying soils or an underdrain, if provided. Bioretention areas were sized to provide for storage of at least one inch of runoff from contributing impervious areas, assuming an average six-inch ponding depth in the basin, in accordance with MDE (2000).

The final LID design incorporated 1265 linear feet of dry swales, at seven locations, containing a total of 5516 cubic feet of storage. In addition, there were two bioretention cells with a combined surface area of 618 square feet, containing a total of 309 cubic feet of surface storage.

4.4.2.3 Rooftop Runoff Control IMP's

A **green roof** is a general term describing a variety of practices involving placement of vegetation on rooftops to reduce stormwater runoff and pollutant loads. "Extensive" green roofs are those involving rooftop gardens with potted shrubs and trees, and typically applied to industrial or institutional buildings having large, flat roofs. They require considerable investment and care. "Intensive" green roofs consist of a series of geomembrane layers covering a pitched or flat roof, culminating in a layer of low-growing drought-tolerant grass or sedums. The required layers include a water barrier, a drainage media, and a soil substitute / growth media, with a combined thickness of four to eight inches. The growth media itself is typically two to four inches and may retain up to three inches of runoff within its void space following a storm. Intensive green roofs were considered more appropriate to residential buildings.

Rain barrels consist of plastic barrels into which downspout runoff is redirected. The stored runoff may then be infiltrated using a dry well, disposed of on pervious areas, or used for landscape maintenance/watering. Typical rooftops at the site range from 1200 to 2000 square feet. Rain barrels were provided to augment on-roof storage capacity in the event of a prolonged storm or successive storms filling the roof growth media pore space.

For the LID design, rooftop runoff storage was provided at a rate of 1.09 inch of storage over the roof area. A 3.5-inch thick intensive green roof growth media of wilting point 0.05 (volume fraction) and field capacity 0.30 (volume fraction) provides one-quarter inch of storage per inch of media, or 0.875 inches of subsurface storage. A canopy interception storage of 0.04 inches, equal to bluegrass, was assumed to apply to the green roof surface. One 55-gallon rain barrel per 500 square feet of roof area provided an additional 0.176 inches of storage, for a total of 1.09 inches over the watershed roof area of 0.526 acres. The watershed-wide total of 2079 cubic feet of rooftop runoff storage could alternatively be provided in any combination of methods, including rain barrels, dry wells, or underground cisterns.

4.4.2.4 LID Design Summary

Through a combination of dry swales, bioretention, rain barrels, and vegetated roofs, a total of 0.502 inches (7905 cubic feet) of storage was added to the LID landscape, slightly more than required to match the predevelopment curve number. The ultimate design represents a 3.6% overdesign, based on LID criteria. The storage provided greatly exceeded Maryland's Water Quality Volume (WQ_V) requirements (MDE 2000) because of the selection of the larger 2.5 inch design storm for LID. The WQ_V roughly approximates one inch of runoff over the watershed impervious area, and amounts to 0.31" for the subject site. The final LID time of concentration was 0.312 hour, slightly longer than the predevelopment time of concentration of 0.304 hours. Together with runoff redirection and swale drainage, the IMP's represent a redundant system for management of stormwater runoff wherein runoff from a particular location must often pass through multiple IMP’s or drainage features with multiple opportunities for infiltration. The following section describes how the conventional development design was adapted from the LID design.

4.4.3 Conventional Development Design

The conventional development watershed retained the same impervious surface footprint as the LID watershed to maintain a valid comparison of LID runoff treatment methods and practices versus those for conventional development. It was felt that usage of a wholly conventional development footprint would result in such a highly impervious landscape that the effects of runoff treatment practices would be overshadowed by the increased runoff peaks and volume associated with the impervious surface. The resulting comparison would lead to the trivial result that higher imperviousness causes higher runoff volumes and peaks. The approach taken will however tend to favor conventional development; e.g., conventional development hydrologic impacts are likely to be understated using the methods herein. A finding of lower runoff for the LID watershed would then be even more convincing of LID’s effectiveness, considering the comparison occurred at identical imperviousness. Though the impervious land cover remained the same, the following changes were made to the LID watershed to reflect a conventional development form:

1. IMP’s such as dry swales and bioretention were eliminated and no infiltration was permitted through channel or swale bottoms.

2. Rain barrels and green roofs were eliminated. Only a nominal surface depression storage was included for rooftops. Where physically reasonable (based on topography), rooftops were reconnected to driveways and gutters rather than lawns.
3. Roadside swales were replaced with curb and gutter.
4. Inlets and storm sewers were added to collect and convey gutter flow.
5. Smooth-walled pipes were substituted for the corrugated pipes used for the LID case.
6. Grading was revised to reflect a normal street crown and eliminate most runoff redirection, increasing impervious area connectivity.
7. LID forest preservation areas were converted to lawn.

Figure 4.4 shows the conventional development watershed along with the time of concentration path. The conventional development curve number was 77.17 (rounded up to 78 in common practice); the conventional development time of concentration was computed as 12.18 minutes (0.203 hour). Calculations can be found in Appendix D-2.

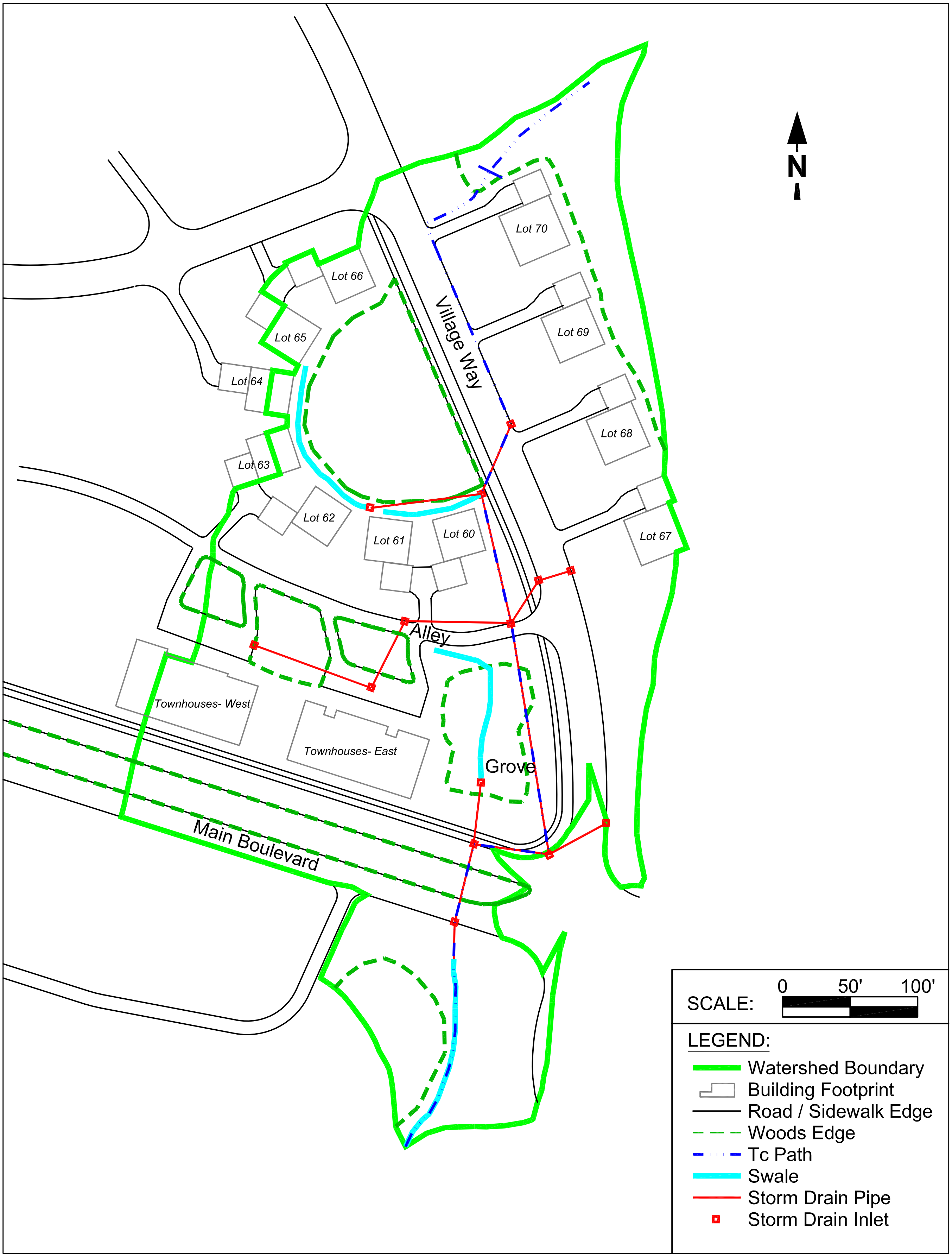


Figure 4.4: Village at Tom's Creek Conventional Development Site Design

For the conventional development with stormwater management scenario, a dry detention pond was designed for installation at the outlet of the conventional development watershed. A multistage stormwater detention pond was designed to provided 2-year and 10-year peak control, a common conventional stormwater standard at the time of the analysis. An initial estimate of pond volume was obtained from the charts in Chapter 6 of TR-55. This estimate was then refined and a riser design developed by trial and error application of the VT/PSUHM (version 7.1) Multi-Stage Routing Model, and HEC-HMS (version 3.1.0).

The final pond design consists of a basin with a bottom surface area of roughly 35 feet wide by 45 feet long (1575 square feet), 2:1 (horizontal: vertical) side slopes, and an 8-foot high embankment. The outlet structure consists of a closed-top inlet, with a 7" diameter low-flow (2-year peak control) orifice located at the pond bottom, and a 6" high by 18" wide rectangular orifice (10-year peak control) located 2.75 feet above the pond bottom. The outlet structure is drained by an 18" diameter reinforced concrete pipe set at a slope of 2.0%. A 5.0-foot wide grassed emergency spillway was provided, located 5.0 feet above the pond bottom (3.0 feet below the embankment crest). Table 4.5 shows the stage-volume-discharge rating for the facility, used in HEC-HMS and SWMM modeling. The VT/PSUHM input file can be found in Appendix D-4.

Figure 4.5 depicts the facility rating curves graphically, showing the slight difference between the 16-point rating curve used for modeling, and the 40-point rating curve (0.25-foot resolution) initially generated by VTPSUHM. SWMM's Transport Block can only process a 16-point rating curve. Therefore, 16 data points were chosen selectively from the rating curve generated in

VTPSUHM, with an eye toward best representing the principal inflection points that lie within the operating range of the SWM facility. The 100-year water surface elevation in the pond did not exceed 6 feet in the HEC-HMS analysis, so the departure of the modeled rating curve from the VTPSUHM curve above elevation 6.0 was considered acceptable.

Table 4.5: Stormwater Management Facility Rating Table

Stage* (ft)	Storage Volume (ac-ft)	Discharge (cfs)
0.00	0.000	0.00
0.25	0.009	0.14
0.50	0.019	0.51
1.00	0.040	1.08
2.00	0.088	1.68
2.75	0.130	2.02
3.00	0.145	2.68
3.25	0.161	3.80
3.50	0.177	4.78
4.00	0.211	6.00
4.50	0.248	6.97
5.00	0.288	7.79
5.25	0.309	10.04
5.50	0.330	13.74
6.00	0.376	24.09
8.00	0.588	89.27

** Stage measured from pond bottom*

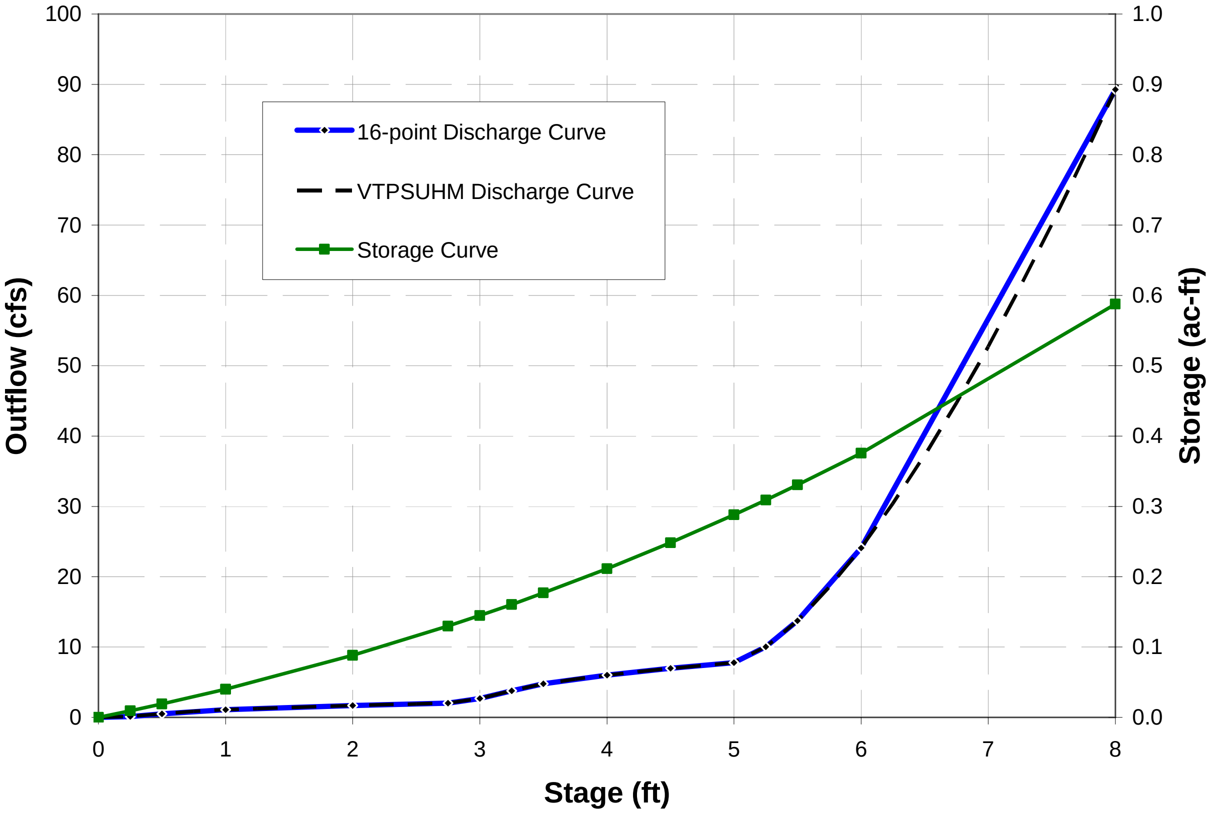


Figure 4.5: Stormwater Management Facility Rating Curve

4.5 Model Formulation

Continuous and event modeling of the scenarios was performed using the July 1, 2003 update of SWMM version 4.4H. Version 4.4H underwent its final update in October 2005, but that update did not include any substantive changes so the 2003 model runs were retained. All surface and channel hydrology was modeled using solely the Runoff Block. Use of the Runoff Block allowed the modeling of infiltration through channel bottoms (used for grass swales, dry swales, and bioretention cells) and redirection of runoff from one plane to another, rather than into a channel (e.g., a cascade of planes). The Transport Block was used for modeling of the conventional development stormwater management pond. SWMM was applied at the micro-scale with discrete hydrologic features such as rooftops, gutters, swales, and lawns each modeled individually.

Each land development scenario was modeled using both Favorable and Unfavorable sets of assumptions and model parameters, yielding an envelope of ‘best’ and ‘worst’ results for each. The Favorable parameter set, representing the best-case conditions, was selected to *minimize* runoff for the particular development form. The Unfavorable set, representing the worst-case conditions, tended to *maximize* runoff for each development form. Favorable and Unfavorable parameters were selected from the literature, and reflect the best judgment of the likely range of possible values for forest, LID, and conventional development on group B and C soils. Use of a such a range of parameters, and comparing the resulting envelope of results, facilitates a comparison between uncalibrated models of the development scenarios, with less bias and uncertainty than would be possible by comparing a single model of each. This section describes the modeling approach for the forest, low impact, and conventional development scenarios, and the selection of Favorable/Unfavorable parameter sets.

4.5.1 Parameter Description

SWMM’s Runoff Block requires 15 parameters to define the hydrologic response of overland flow planes, 13 of which were used in this study. Eleven parameters define channel response. Parameters were selected based on site topography or estimates in the literature, as appropriate. Parameter values are discussed in a following section.

Overland flow parameters used by SWMM are described below:

- NAMEW is the name of the SWMM flow plane. Plane naming convention is discussed below under the individual scenarios.
- NGTO is the destination of runoff produced by a flow plane. NGTO can identify a channel, or in conjunction with the newly implemented IFLOWP parameter, another plane.
- WIDTH is the subcatchment width. For the present micro-scale modeling, the subcatchment width is defined as the physical width of the overland flow plane, equal to area divided by flow path length. Flow path lengths were measured in CAD along the fall line of a plane.
- AREA is the plan-view surface area of a plane.
- %IMP is the percent imperviousness of the flow plane. For this study, all planes were modeled as either 100% impervious, or 100% pervious (0% impervious).
- S is the slope of the plane, herein measured along the longest flow path as the elevation difference divided by path length. Both the length and elevation difference were measured in CAD.
- IMPN and PERVN are the Manning's roughness coefficients of the impervious and pervious areas, respectively. Roughness coefficients for the various land cover types were taken from the literature.
- IDS and PDS are the depression storage depths for the impervious and pervious areas, respectively. Depression storage estimates were taken from the literature for traditional flow planes, but were increased significantly for the modeling of certain LID IMP's as described below.

- G represents the mean capillary drive, or capillary suction, used in the Green-Ampt infiltration equation. Because of the wide variability of soil infiltration parameters even among very similar soils, it was decided to model soils as either ‘B’ or ‘C’, making no further distinctions in parameters despite the differing permeabilities reported in the soil survey. Values of G were estimated from Rawls and Brakensiek (1982), Huber and Dickinson (1992) for silt loam soils.
- KSAT is the saturated hydraulic conductivity, used in the used in the Green-Ampt infiltration equation. Values of KSAT were estimated from Rawls and Brakensiek (1982), Huber and Dickinson (1992), and NRCS (1986). The KSAT values were adjusted based on engineering judgment for the modeling of IMP’s, described below. Note that KSAT is the limiting value of the infiltration rate.
- SMDMAX is the soil moisture deficit, used in the used in the Green-Ampt infiltration equation. For continuous SWMM, SMDMAX is represented as the different between the soil effective porosity, and the soil wilting point. SMDMAX was calculated from porosity and wilting point estimates for silt loam, and adjusted for modeling IMP’s.
- RMAXINF is the maximum infiltration volume for a storm event. It was not used in the simulations.
- IFLOWP is a flag for runoff redirection. A value of “0” indicates the plane’s runoff is directed to a channel in the normal fashion. A value of “3” indicates that all of a plane’s runoff (pervious and impervious) is directed to another plane. Other values provide for individual redirection of impervious or pervious runoff volumes, but were not needed in this study because all planes were considered either wholly impervious or wholly pervious.

Parameter values were estimated for best-case conditions, considering the most optimistic (lowest runoff-producing) range of conditions and maintenance level, and for worst-case conditions, considering pessimistic conditions and possible failure to maintain the infiltration properties of IMP's. The two variations are denoted Favorable and Unfavorable within each development scenario. Numerical values of the parameters are discussed in the next section.

Channel parameters for the SWMM Runoff Block are as typically defined:

- NAMEG is the channel name.
- NGTO is the destination of the channel's outflow. NGTO must be another Runoff Block channel, or a Transport Block node. SWMM cannot route flows from channels onto overland flow planes.
- TYPE denotes the channel type, "2" for circular, and "1" for trapezoidal. Other channel types are available, but were not used in this study. Triangular channels are a special case of the trapezoidal channel, defined by setting the bottom width to zero.
- GWIDTH is the diameter of a circular channel, or the bottom width of a trapezoidal channel.
- L is the channel length.
- S is the channel slope.
- Z1 and Z2 are the left and right side slopes of a trapezoidal channel.
- N is the channel Manning's roughness, determined using standard literature values.
- DFULL is the full depth of the channel, equal to the diameter for circular conduits.
- DINIT is the initial flow depth of the channel, set to zero for the present study.

Numerical values of the channel parameters discussed in the following section.

4.5.2 Overland Flow and Channel Parameter Values

Overland flow planes were used to model overland flow segments, and in some cases LID features, in order to account for infiltration losses in the IMP's. Eight different land cover types were modeled, with three land cover types subdivided according to Hydrologic Soil Group, leading to a total of 11 distinct land cover types in the LID model. Not all land cover types were present for the Conventional and Forest scenarios. The following describes the land cover types and the selection of Runoff Block parameters used to model them. Except where noted otherwise, identical parameters were used for each land use within the various Forested, Conventional, and LID scenarios. Table 4.6 lists the range of parameters used for overland flow planes in both the Favorable and Unfavorable scenarios.

- **Woods** was present in all of the scenarios except the Conventional Unfavorable scenario, where it was considered Lawn, representing traditional development with whole-site clearing. The category was subdivided according to Hydrologic Soil Group (B or C). Depression storage (PDS), hydraulic conductivity (KSAT), and soil moisture storage (SMDMAX) were varied between Favorable and Unfavorable conditions to reflect possible soil compaction as well as data uncertainty for those parameters. Roughness (PERVN) and capillary drive (G) were considered constant.
- **Meadow** was likewise present in the Conventional Favorable and both LID scenarios, and subject to variation of PDS, KSAT, and SMDMAX to reflect data uncertainty. PERVN and G were held constant. The meadow category was subdivided according to Hydrologic Soil Group (B or C).

- **Lawn** was present in all developed scenarios, and subject to similar variations of PDS, KSAT, and SMDMAX as meadow and woods. The variations can also reflect the possible addition of compost amendments under the LID scenario. The lawn category was subdivided according to Hydrologic Soil Group (B or C).
- The **Paved** land cover was present in the developed scenarios, and its parameters were held constant across all scenarios, considering that pavement hydrologic response is well-modeled in SWMM.
- The **Roof** land cover was subject to changes in depression storage (PDS) for the LID scenarios, to represent the presence and effectiveness of green roofs and rain barrels. It was modeled similarly to paved land in other scenarios, but at a slightly higher roughness and depression storage.
- **Swales** were used to represent natural or constructed grass channels, that were subject to infiltration but not designed as a IMP's. Use of an overland flow plane rather than a channel was required, because the swales drained to infiltrating IMP's such as bioretention or dry swales. KSAT was set lower than that for surface soils or IMP's, and varied to reflect possible soil compaction and clogging for the Unfavorable condition.
- **Dry swales** and **bioretention** cells were used to represent IMP's designed for infiltration, and using made soils to enhance infiltration and pollutant removal. KSAT was varied to reflect possible soil compaction and clogging associated with either poor initial construction, or lack of long term maintenance. They are more fully described in the LID section below.

Table 4.6: Range of Overland Flow Parameter Values

Land Use / Hydrologic Soil Group	Curve Number	Surface Roughness		Depression Storage		Capillary Drive, G (in)	Saturated Hydraulic Conductivity, Ksat (in/hr)	Soil Moisture Deficit, Smdmax
		Impervious, ImpN	Pervious, PervN	Impervious, IDS (in)	Pervious, PDS (in)			
Bioretention	N/A	0.06	0.06	0.02	6.0	6	0.50 - 0.05	0.33
Dry Swale	N/A	0.06	0.06	0.02	Midpt. depth	6	0.50 - 0.05	0.33
Lawn, B	61	0.24	0.24	9.9	0.20 - 0.10	9	0.25 - 0.15	0.33 - 0.22
Lawn, C	74	0.24	0.24	9.9	0.20 - 0.10	12	0.15 - 0.08	0.31 - 0.20
Meadow, B	58	0.30	0.30	9.9	0.25 - 0.15	9	0.25 - 0.15	0.33 - 0.28
Meadow, C	71	0.30	0.30	9.9	0.25 - 0.15	12	0.15 - 0.08	0.31 - 0.26
Paved	98	0.014	0.014	0.02	9.9	99	99	0.99
Rooftop	98	0.02	0.02	1.09 - 0.20	9.9	99	99	0.99
Swale	N/A	0.06	0.06	0.10	0.10	12	0.10 - 0.05	0.26 - 0.26
Woods, B	55	0.4	0.4	9.9	0.35 - 0.20	9	0.30 - 0.20	0.33 - 0.28
Woods, C	70	0.4	0.4	9.9	0.35 - 0.20	12	0.20 - 0.10	0.31 - 0.26

In addition to overland flow planes, three conduit types were defined:

- **Pipes** represented storm drain conduits and culverts. Manning's roughness (n) was chosen to reflect either smooth-walled (n=0.012) or corrugated (n=0.022) pipes for the Conventional and LID scenarios, respectively, but was *not* differentiated between Favorable and Unfavorable conditions.
- **Gutters** were only used in the Conventional model scenarios, with a Manning's roughness of 0.015, undifferentiated for Favorable and Unfavorable conditions.
- **Channels** were those constructed channels that were either riprap-lined, or otherwise considered unlikely to allow infiltration, and the natural channels along the main natural watercourse, that were expected to be saturated under existing conditions. Trapezoidal channel dimensions were as-designed or estimated in the field. Parameters were only differentiated between Favorable and Unfavorable values for the Predevelopment Forest scenario, where channel roughness (N) ranged from 0.08 to 0.15. Roughness varied from 0.06 to 0.08 for the other scenarios, according to channel size and flow depth.

Determination of conduit dimensions is discussed under the individual scenarios below.

4.5.3 Model Connectivity and Naming Convention

4.5.3.1 Forest

Modeling was straightforward for the predevelopment forested condition. The watershed was subdivided according to soil boundaries and topography, yielding eight planes and two channel segments, pictured in Figure 4.6. The measured predevelopment watershed area of 4.1243 acres differed from the LID and conventional development watershed area by 0.2095 acres; therefore the areas of the predevelopment model planes were adjusted by the ratio 1.0508 to yield a model having a comparable area to the LID watershed and ensuring an exact peak flow and volume comparison between scenarios.

Though it was deemed likely to occur, especially on the steep slopes adjacent to streams, interflow was not modeled because SWMM cannot effectively consider it. The required assumption is then that interflow behaves similarly to surface flow with a high roughness. The reader will also notice the excessive flow path lengths, especially when planes are connected in a cascade. Such lengths, exceeding 400 feet for the two plane-to-plane cascades in the Favorable conditions model, are much greater than the 100 to 150 foot rule of thumb often applied to overland sheet flow, yet no evidence of concentrated flow is present at the site. The Favorable model of this scenario considered the full apparent flow length, based on topography. The Unfavorable model limited flow lengths to 100 feet, and eliminated plane-to-plane cascades. For the Unfavorable condition, two planes (9Dwest and 16Bnorth) were rerouted to drain into the main channel, rather than cascading across the lower hillslope, thereby reducing the opportunities for reinfiltration of surface runoff. The natural channel is so ill-defined as to defy measurement, so it was modeled assuming a 2 foot wide trapezoidal cross section. For the predevelopment condition model, overland flow planes were named based on their underlying soil map unit, and geographic position (east, west, middle, etc.). Figure 4.6 shows the predevelopment model layout. SWMM input files can be found in Appendices E and F.

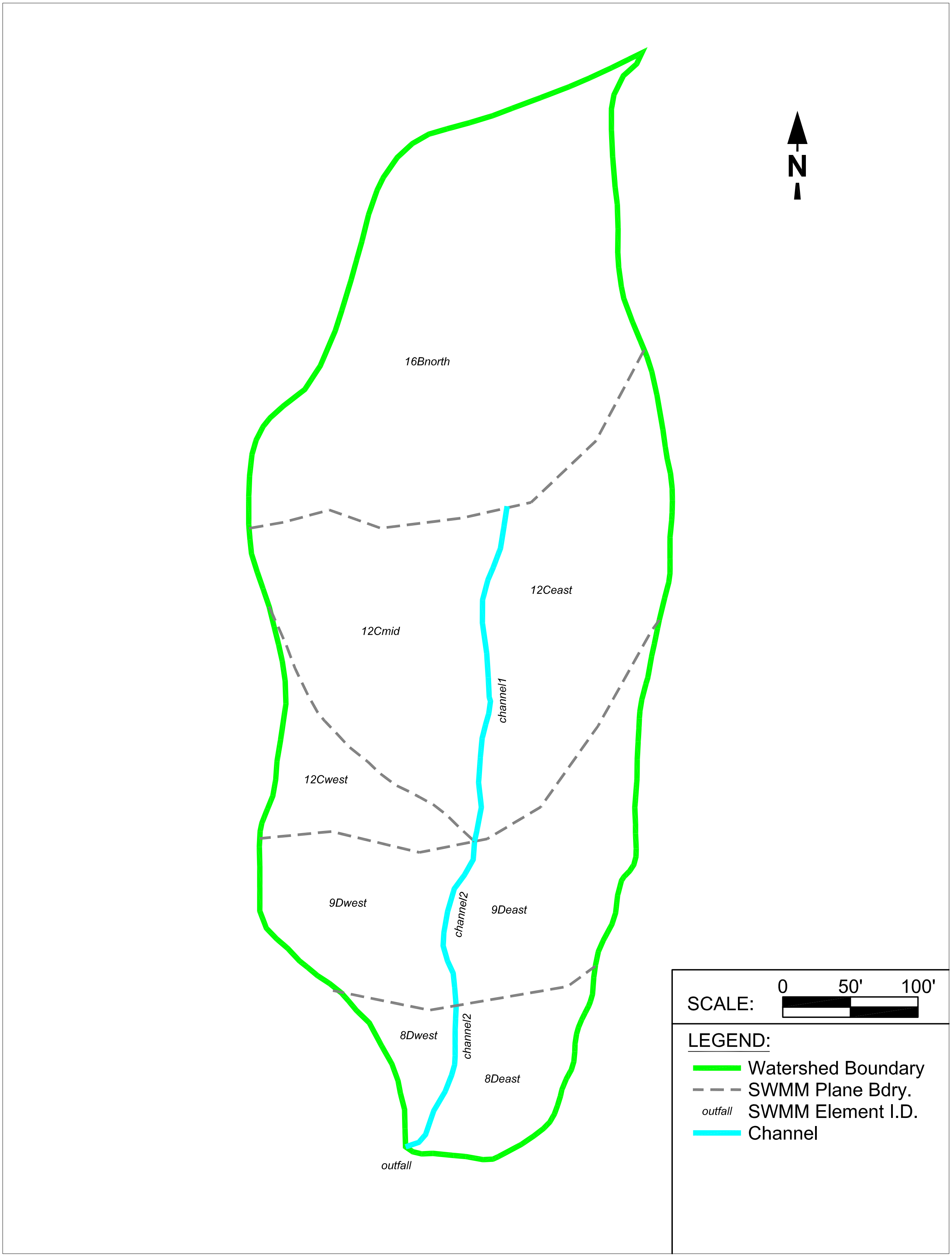


Figure 4.6: Predevelopment Forest Model Layout

4.5.3.2 Low Impact Development

The Low Impact Development scenario model was created at a finer scale than the forested model, with the intention of explicitly modeling the distributed hydrologic processes in the LID watershed. Each rooftop, pavement facet, and lawn surface was modeled as a single overland flow plane. Each drainage feature was likewise modeled individually. This led to a model containing 67 planes and 13 channel segments. Impervious area disconnection was modeled using SWMM4.4H's new runoff redirection feature, producing a cascade of planes and channels. LID Integrated Management Practices were modeled as follows:

- Vegetated swales were modeled as pervious planes, with roughness, infiltration, and depression storage values appropriate to a grassed channel in Group C soils. Length was set equal to the actual swale length, and width was set to one foot. Swale slope was the designed longitudinal slope of the swale flowline. Saturated hydraulic conductivity was reduced for the Unfavorable condition, reflecting compaction and clogging of soil pore space with fine sediment.
- Dry swales were modeled as pervious planes, but with infiltration parameters reflective of sandy loam "made" soil having a saturated hydraulic conductivity as high as 0.5 in/hr for Favorable conditions, and 0.05 in/hr for Unfavorable conditions. Dry swale depression storage was assigned according to the designed midpoint water depth, halfway between check dams. The modeled width was the average of the designed trapezoidal top and bottom widths. Dry swale slope was assigned according to the effective slope between check dams.

- Bioretention cells were modeled as pervious planes, but with infiltration parameters reflective of sandy loam “made” soil having a saturated hydraulic conductivity as high as 0.5 in/hr for Favorable conditions, and 0.05 in/hr for Unfavorable conditions. Length and width were assigned as the actual rectangular dimensions of the cell. Depression storage was taken as 6 inches for bioretention cells, reflective of the average temporary inundation depth above the ground surface. Though technically constructed as sumps, bioretention cells were modeled with a nominal slope of one percent to enable overflow downstream.
- Rooftops were modeled as impervious planes, with depression storage set equal to the combined storage provided in rooftop vegetation and rain barrels. Storage capacity was thus regenerated by evaporation at the monthly average potential evapotranspiration rate, which had the side effect of neglecting diurnal variations in evapotranspiration. For the Unfavorable condition, green roofs were ignored and only rain barrels were assumed to be operating, reflected in a reduction in modeled depression storage.

Both planes and channels were assigned six- to eight-character names based on their location and type. Location was identified using either lot numbers, where applicable, or an abbreviation of one of the segments of the development. Where appropriate, additional letters denoting upslope, downslope, soil type, or compass direction were included. Location abbreviations for model elements, and their descriptions, are listed in Table 4.7. Figure 4.7 shows the LID landscape, divided into modeled planes, with key areas labeled. SWMM input files can be found in Appendices E and F.

Table 4.7: LID and Conventional Development Model Naming Convention

Basis	Description	Abbreviation
Land Cover	Woods	wood/woods
	Lawn	lawn
	Grass	gras
	Rooftop	roof
	Alley	alyW
	Driveway	drive/driv
	Pavement	pave/pav
	Sidewalk	side
	Parking lot	lot
	Inlet	inlt
	Cut slope	cut
	Fill slope	fill
	Median	medn
	Gutter	gutr
	Swale (dry swale or vegetated channel)	swale/swal/swl
	Bioretention cell	bior
	Channel	chan
Geographic Location	Lot numbers from original site plan	60-62, 67-70
	Upper section (in elevation)	up
	Lower section (in elevation)	lo
	Upper Village Way (East or West)	uvwE/W
	Circle (East or West)	cirW/E
	Townhomes (East or West segment)	thE/W
	The Grove section of neighborhood	grv
	Main boulevard (North or South side)	blvd/bvd N/S

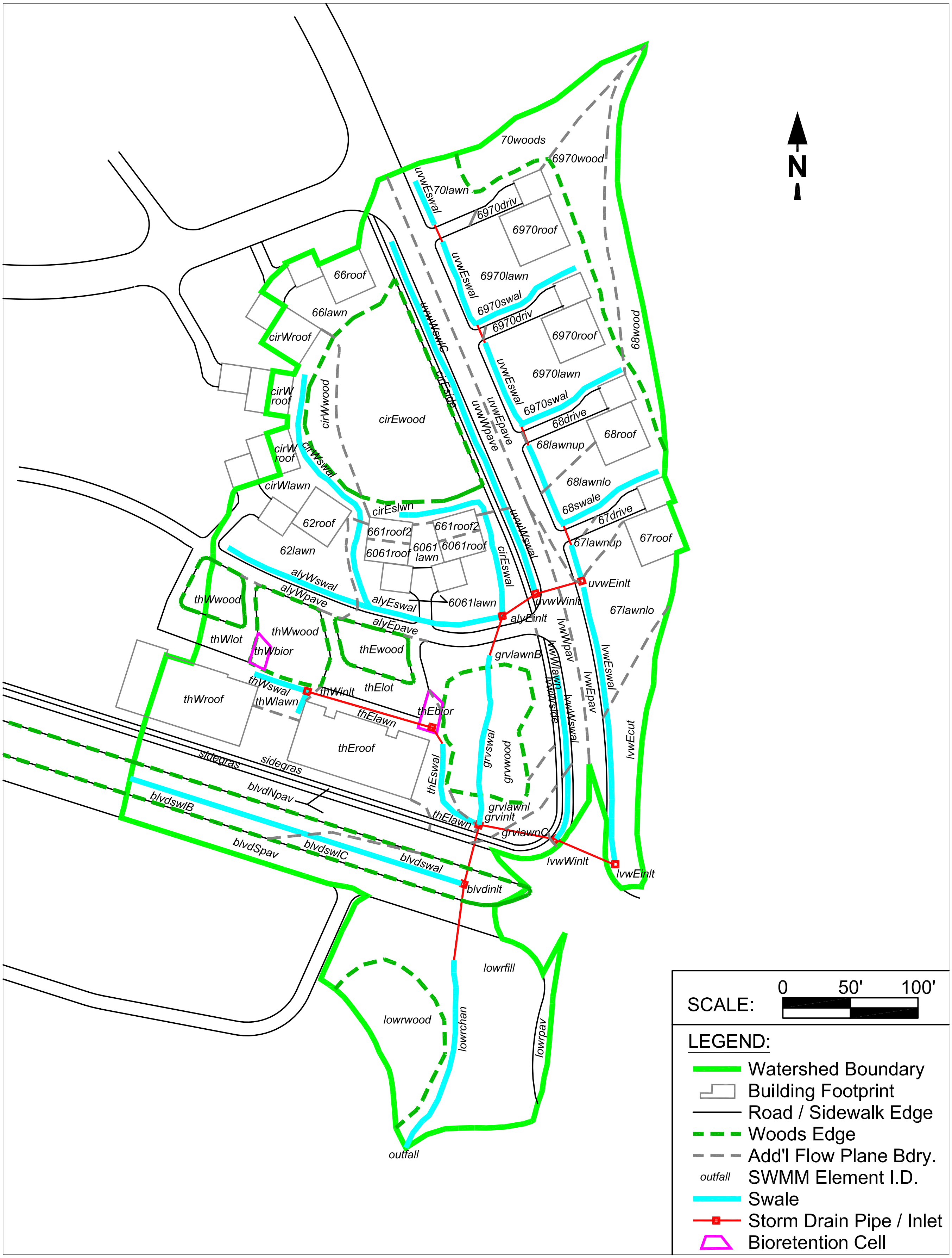


Figure 4.7: Low Impact Development Model Layout

4.5.3.3 Conventional Development, with and without Stormwater Management

Modeling of Conventional Development was more straightforward than LID, owing to the lack of integrated management practices, and less use of runoff redirection. With the conversion of infiltration practices to impervious conduits, the conventional development model featured 53 planes and 27 channels, versus the 67 planes and 13 channels of the LID model. The Conventional Favorable scenario utilized the same surface land cover coverage and parameters as the LID Favorable scenario. The Conventional Unfavorable scenario utilized the same parameter set from the LID Unfavorable scenario, with the added handicap of converting all forest and meadow land uses to lawn. For the Conventional with SWM scenarios, the detention pond was modeled using the SWMM Transport Block implementation of Modified Puls (Storage Indication) routing.

The naming convention for model elements was similar to that for the LID scenario. Both planes and channels were assigned six- to eight-character names based on their location and type. Location was identified using either lot numbers, where applicable, or an abbreviation of one of the segments of the development. Where appropriate, additional letters denoting upslope, downslope, soil type, or compass direction were included. Location abbreviations for planes, and their descriptions, are listed in Table 4.7. Figure 4.8 shows the conventional development landscape with the key areas labeled. SWMM input files can be found in Appendices E and F.

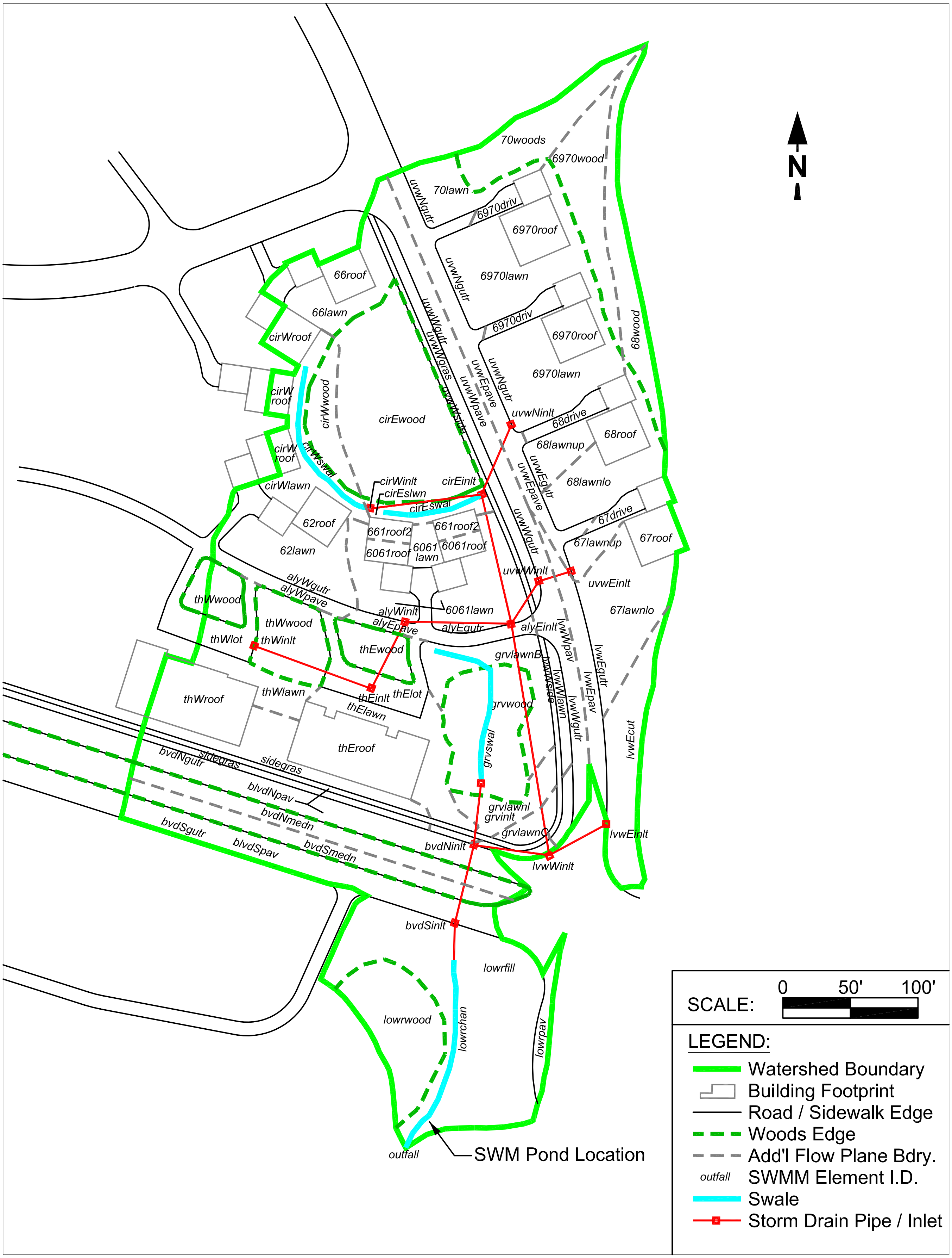


Figure 4.8: Conventional Development Model Layout

4.6 Model Simulations

The above-described development scenarios were modeled in SWMM under two parameter sets: a Favorable set, representing the best-case conditions, tending to minimize runoff for the particular development form; and an Unfavorable set, representing the worst-case conditions, and tending to maximize runoff for the development form. Between forest, LID, conventional development without stormwater management (SWM), and conventional development with SWM, this led to eight distinct SWMM models.

Each of the eight models were run in continuous simulation mode, using the rainfall data described previously, and event mode, using NRCS design storms. The ‘with SWM’ runs involved only a Transport Block run using the ‘without SWM’ Runoff Block output interface file as input to the Transport Block stormwater pond routing. The single-event mode runs included the 1-year, 2-year, 10-year, and 100-year NRCS Type II storms. The event models for a particular scenario were run in a single input file. In all, sixteen SWMM input files were constructed (eight continuous and eight event). Input files can be found in Appendices E and F.

Due to the small drainage area, small scale of model elements, high rainfall data resolution, and quick response time of urban land uses, the model time step was set to one minute for times when rainfall is occurring (Wet time step) or surface storage is present (WetDry time step). For interevent periods, a Dry time step of 24 hours was used. The model was found to be insensitive to the time step, through the practical range of time steps. The PCTZERO parameter, describing the percent of impervious land that has zero depression storage, was set to 0.001 (zero is not allowed) in order to allow a valid water budget comparison between scenarios. Postprocessing of the model data, including use of the SWMM Statistics and Combine Blocks, is described in the next section.

4.7 Model Postprocessing

Continuous SWMM modeling produces a massive time series of hydrograph output, which is unwieldy to process and difficult to compare visually. To facilitate comparison between development scenarios, the SWMM model output was postprocessed and summarized in a variety of ways, using the SWMM Combine and Statistics Blocks, as well as Microsoft Excel and FORTRAN utility programs. The event model output required less postprocessing, but Excel nonetheless proved useful for graphing. The following sections describe the data processing approach, and the bases of the resulting comparisons to be discussed in the next chapter.

4.7.1 Continuous Model

The continuous SWMM model output was summarized for each development scenario according to runoff volume, flow duration, and flood frequency. Total runoff volume provided the simplest and coarsest comparison between scenarios, while flow duration and flood frequency curves represented the peak, volume, and timing of runoff for the various scenarios. Calculation and graphing methods are summarized for each below.

4.7.1.1 Runoff Volume

SWMM's output files, by default, include monthly and annual runoff and precipitation volume summaries. The total runoff from the continuous simulation was computed from SWMM's monthly and annual totals, and compared with the total precipitation volume. Both total volume and the runoff coefficient were compared. Implicit in the volume comparison is the pervious infiltration rate and losses due to evaporation. Graphics were produced using Excel.

4.7.1.2 Ranked Events

Using SWMM's Statistics Block, each output time series was separated into discrete events, assuming a minimum inter-event time (MIT) of 12 hours and minimum runoff depth of 0.02 inches. Both peak flows and volumes were ranked based on Cunnane's (1978) plotting position, with parameter A = 0.40. Ranked output was compared graphically, to determine if the hydrologic response of the LID, forest, and conventional scenarios overlapped. The number of runoff-producing events for each scenario was tallied, providing a further point of comparison.

4.7.1.3 Frequency Analysis

Annual flood frequency was computed using the Log-Pearson 3 distribution, according to methods outlined in USGS Bulletin 17-B (U.S. Interagency Advisory Committee on Water Data 1982). The SWMM output time series was constructed in ASCII text format using the Combine Block. Water Year annual peaks were extracted from the ASCII time series using a FORTRAN utility program, HYDPRO.exe. The LP3 analysis of annual peaks was conducted in Excel for return periods ranging from 1.001 years to 500 years, a map skew of 0.50, and beta of 0.950. Only the results from 10-year and lesser return periods were presented, as the short duration of the output time series cannot justify estimating lower frequency events. Flood frequency curves were compared for the various development scenarios.

4.7.1.4 Flow Duration

Flow duration tables (discharge versus percent of time exceeded) were constructed from the full output time series using the HYDPRO FORTRAN utility, and graphed in Excel. The resulting flow duration curves were overlaid to compare development scenarios.

4.7.2 Event / NRCS Design Storms

Event-mode model results were compared based on peak flows, runoff volume, and hydrograph shape, including time-to-peak. As with the continuous simulation runs, use of Excel charts facilitated graphical comparisons. Peak flows and volumes from the 1-year, 2-year, 10-year, and 100-year NRCS Type II storms were computed with HEC-HMS (version 3.1.0), and compared to the SWMM results.

5 RESULTS AND DISCUSSION

5.1 Introduction

This chapter describes the results of the hydrologic modeling effort, comparing Low Impact Development with both natural forest and conventional residential development. The first section describes the continuous simulation results; the next section describes the results obtained with NRCS single-event storms. The final section discusses both the continuous simulation and single-event results.

5.2 Continuous Model Results

The continuous SWMM model output was summarized for each development scenario according to runoff volume, flow duration, and flood frequency, as described in the previous chapter. Model results are presented and discussed below.

5.2.1 Runoff Volume

Figure 5.1 shows the runoff volumes from each scenario, alongside the rainfall total for the 77-month simulation period. Table 5.1 presents the annual runoff volumes, and Table 5.2 presents the computed runoff coefficients. The Conventional w/ SWM scenario was not compared, as it produces the same runoff volume as the Conventional scenario, albeit with different timing. On a runoff volume basis, LID compares favorably to traditional development, but LID does not achieve quite as low a runoff volume as forest. Comparing the averages of the Favorable and Unfavorable conditions, over the entire simulation period, LID produces 3.1 times the runoff of Forest. Conventional development produces 10.6 times the runoff of Forest. The Favorable-to-Unfavorable range for the LID results overlaps with that of the Forested condition, albeit slightly; while the Conventional Development results overlap with neither of the other scenarios. Year-to-year variability in runoff coefficient (Table 5.2) appeared to be relatively low, at least partially owing to the use of the same average monthly potential evapotranspiration rate for all simulation years.

It is also instructive to compare overall runoff coefficients with the impervious percentage, which illustrates distinct advantages of the impervious surface disconnection and IMP's used in LID. Forested land, with zero imperviousness, converted 1% to 5% of rainfall to runoff. LID and conventional development, both at 32.3% total imperviousness, produced 4% to 13% and 25% to 31% runoff, respectively. As noted above, the LID range overlaps that of Forest, while the Conventional range lies significantly above both Forest and LID. Conventional development, with a high proportion (73%) of its imperviousness directly connected to a curb & gutter drainage system, produces runoff at a nearly 1:1 rate from its impervious fraction. LID, with only 14% of its imperviousness directly connected to rough, vegetated swales rather than gutters/storm drains, retains more runoff onsite more often than conventional development, producing a lower runoff coefficient at the same total impervious fraction.

Table 5.1: Annual runoff volumes for continuous simulation

Year	Rainfall (in)	Runoff Volume (in) by land use & condition					
		Forest		LID		Conventional	
		Fav.	Unfav.	Fav.	Unfav.	Fav.	Unfav.
1998	26.25	0.02	1.42	1.07	3.96	6.91	8.74
1999	37.03	0.00	0.34	0.93	2.69	8.80	9.76
2000	34.94	0.10	1.86	1.45	4.86	8.72	10.86
2001	36.01	0.24	2.20	1.71	6.01	9.43	11.93
2002	39.99	0.79	2.62	2.32	4.76	10.72	12.45
2003	39.02	0.16	2.12	1.54	4.67	9.93	11.80
2004	26.56	0.00	0.89	1.08	3.05	6.59	7.88
Total	239.80	1.30	11.44	10.08	30.00	61.10	73.43
Ratio Unfav./Fav.		8.8		3.0		1.2	

Table 5.2: Annual runoff coefficients for continuous simulation

Year	Rainfall (in)	Runoff Coefficient by land use & condition					
		Forest		LID		Conventional	
		Fav.	Unfav.	Fav.	Unfav.	Fav.	Unfav.
1998	26.25	0.001	0.054	0.041	0.151	0.263	0.333
1999	37.03	0.000	0.009	0.025	0.073	0.238	0.264
2000	34.94	0.003	0.053	0.041	0.139	0.249	0.311
2001	36.01	0.007	0.061	0.048	0.167	0.262	0.331
2002	39.99	0.020	0.065	0.058	0.119	0.268	0.311
2003	39.02	0.004	0.054	0.039	0.120	0.255	0.302
2004	26.56	0.000	0.033	0.041	0.115	0.248	0.297
Total	239.80	0.005	0.048	0.042	0.125	0.255	0.306
Ratio Unfav./Fav.		8.8		3.0		1.2	

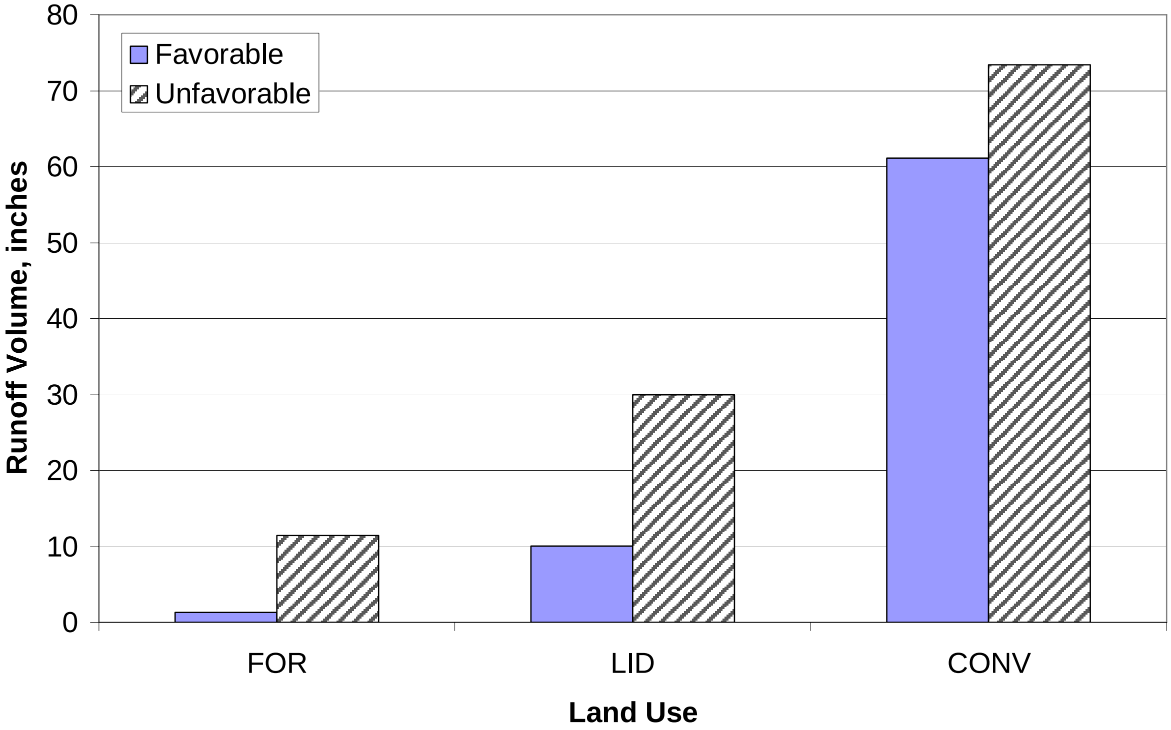


Figure 5.1: Runoff Volume for 77-month continuous simulation (239.8” rainfall)

5.2.2 Ranked Events

The developed scenarios, including LID, produced an order of magnitude more discernible events than the Forested condition (Table 5.3). The number of events followed a predictable order, with Forest having the fewest events, and Conventional development producing the most. Due to its large proportion of directly connected impervious area, the Conventional scenario produced runoff for nearly all rainfall events. The Favorable-Unfavorable range for number of events did not overlap for any combination of scenarios, clearly differentiating LID as producing consistently fewer runoff events than Conventional development, but more runoff events than Forest. The lack of overlap between Forest and LID can be attributed to the lack of any impervious fraction in the Forest model, resulting in zero runoff for many small rainfall events. Similarly, the high percentage of directly connected imperviousness, unmitigated by IMP's, caused the Conventional scenarios to produce runoff for nearly all rainfall events, no matter how small.

The reduction in the number of ranked events between the uncontrolled Conventional and Conventional with SWM scenarios is due to the tendency of the stormwater pond to flow continuously during successive storms that occur too close together to allow complete drawdown of the pond. A single pond discharge event may thus encompass several separate runoff-generating events. The ranked-event and flow-duration curves which follow will better show the magnitude of the additional runoff events for the LID versus Forested scenarios. Surcharge did not occur for any of the continuous simulation scenarios.

Table 5.3: Number of ranked events by scenario (77-month continuous simulation)

Land Use	Forest		LID		Conventional		Conv. w/ SWM	
Condition	Fav.	Unfav.	Fav.	Unfav.	Fav.	Unfav.	Fav.	Unfav.
Number of Ranked Events	7	37	94	153	358	358	319	318

Figure 5.2 presents the event flow volumes (total flow), with return periods determined based on Cunnane’s (1978) plotting position, for the four scenarios. For total flow, the Favorable-to-Unfavorable envelope for LID overlaps that for Forest for events less frequent than approximately 2.5 months. Lesser events produce near-zero runoff for the Forested condition, due to the lack of any imperviousness in the forested watershed. As would be expected, the Conventional and Conventional with SWM results are very similar for volume, and lie significantly above the Forest results. The conventional development range overlaps the LID range near the LID-Unfavorable limit for return periods exceeding 8 months, and exceeds the LID range by increasing amounts at lesser return periods, where ultimately Conventional development is the only scenario producing any runoff at all. The SWM results diverge from the Conventional results, especially near the ends of the distribution, due to multiple watershed runoff events, separated by 12 hours or more, being lumped into a single pond outflow event with the pond discharging continuously during what would have been the interevent period for watershed runoff. The effect is to generate fewer pond discharge events, with higher event volumes, than those for uncontrolled Conventional development, shifting the plotting position for all events.

Figure 5.3 presents the event peak flows, with return periods determined in the same fashion as those for volumes above. Similar to the result for event volumes, the LID envelope overlaps that of Forest for events exceeding a 2.1-month recurrence interval, and is starting to diverge from

Forest near the limits of data at 100 months. The Conventional with SWM alternative range lies within or below the LID results over a similar range of frequencies (1.6 months and above), and actually better replicates the Forest hydrology within most of this range (above 4.5 months), where “better” replication is taken as having results more centered within the Forest envelope. For return periods of less than 1.8 months, the Conventional with SWM alternative produces higher peaks than LID or forest, both of which have zero runoff for many of the smaller events that do produce runoff for the Conventional scenarios. The Conventional without SWM alternative is predictably above all of the other scenarios for peak flow, with minimal overlap.

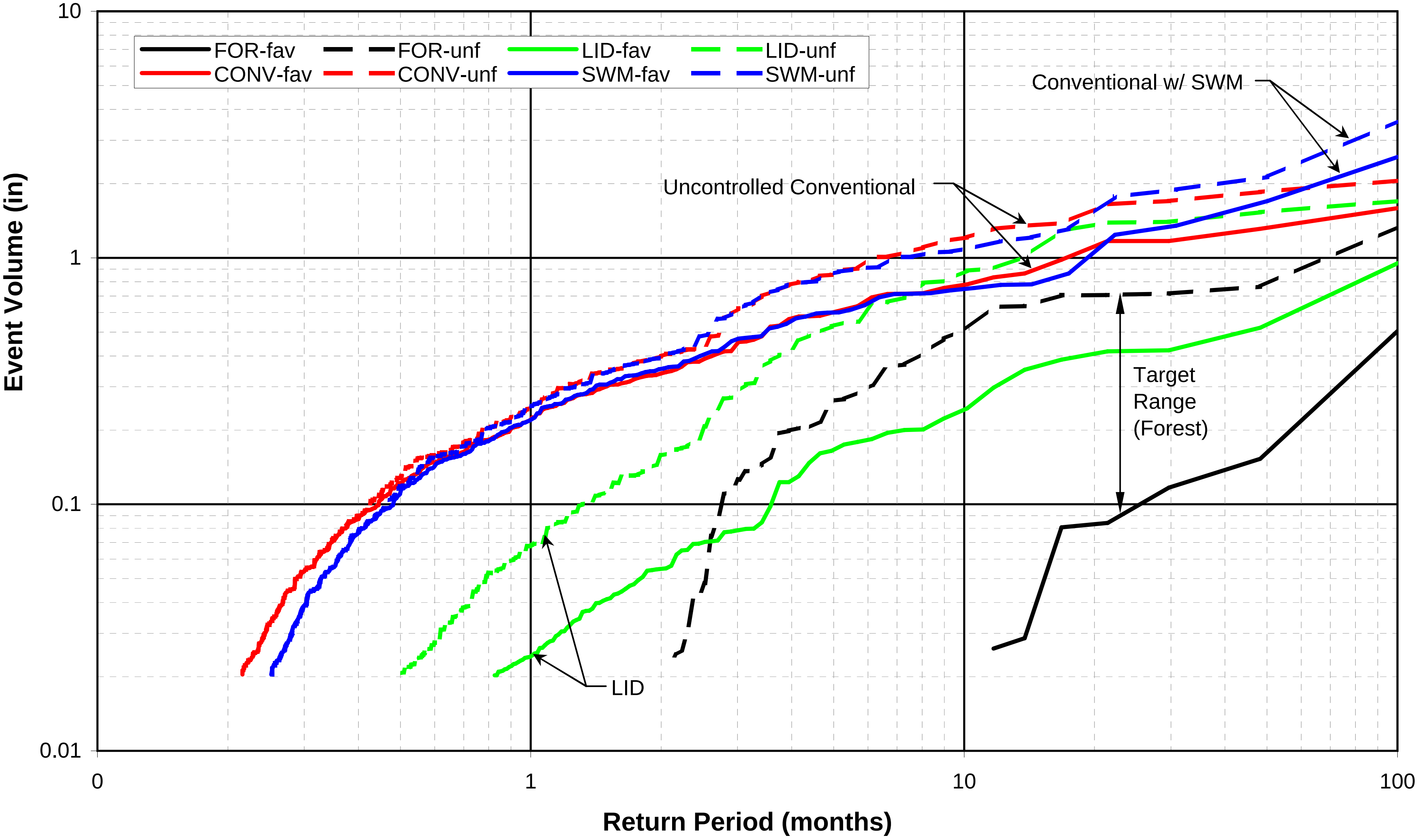


Figure 5.2: Frequency Analysis of Event Volume using SWMM Statistics Block and Cunnane's Plotting Position

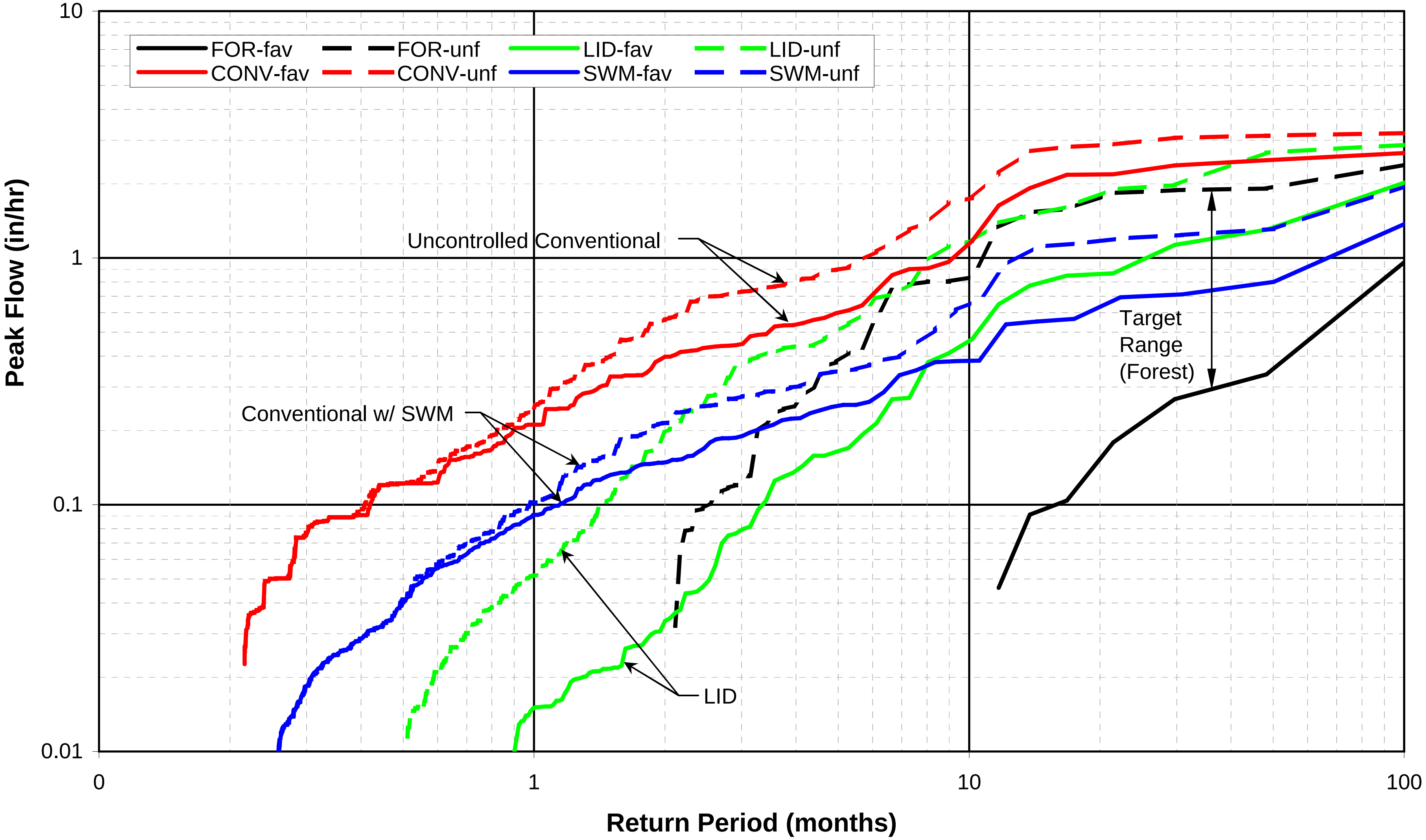


Figure 5.3: Frequency Analysis of Event Peak Flow using SWMM Statistics Block and Cunnane's Plotting Position

5.2.3 Frequency Analysis by Log-Pearson 3 (LP3)

Figure 5.4 presents the results of a Log-Pearson 3 (LP3) analysis, applied to the annual peaks of the output time series using a map skew of 0.5. Due to the short output series (77 months; 6.4 years), only return periods up to 10 years are shown. For computed return periods of 1.2 to 1.4 years (depending on scenario) or less, the Unfavorable result was unexpectedly lower than the Favorable result for the three developed scenarios. The odd finding resulted from the properties of the LP3 distribution, in which discharges are computed as $Q = 10^{X_T}$, where X_T equals the mean plus K_T times the standard deviation. The parameter K_T is negative for return periods of 2 years or less. Where the means are similar, as is the case for the developed scenarios, the equation for X_T is sensitive to the standard deviation. All else being equal, the value of X_T is more negative for datasets with a higher standard deviation, which to be expected given the small sample size in the present study. The modeled annual peaks had a higher standard deviation for the Unfavorable condition, which led to the larger negative X_T's up to approximately 1.3 years, after which the higher mean of the Unfavorable condition controlled, and the result was in line with expectations. For the Forested scenarios, the mean values of the Favorable and Unfavorable conditions were so significantly different that the results were insensitive to standard deviation.

Ignoring the results for return periods less than approximately 1.3 years, and the trivial case of uncontrolled Conventional development, the flow frequency curves of the other scenarios overlap each other within most of the pictured range. Conventional with SWM produces lower discharges than any other scenario for return periods exceeding 4.5 years. LID Favorable-to-Unfavorable envelope overlaps that of Forest, but at a higher average value than that of Conventional with SWM. The Conventional with SWM envelope overlaps the lower LID values for most of the valid output range, and diverges from the LID envelope further at high return periods. The Conventional without SWM results predictably fall above the rest of the data, with no overlap. In general, the differences between the scenarios do not appear to be substantial except for those between uncontrolled Conventional development (without SWM) and the others.

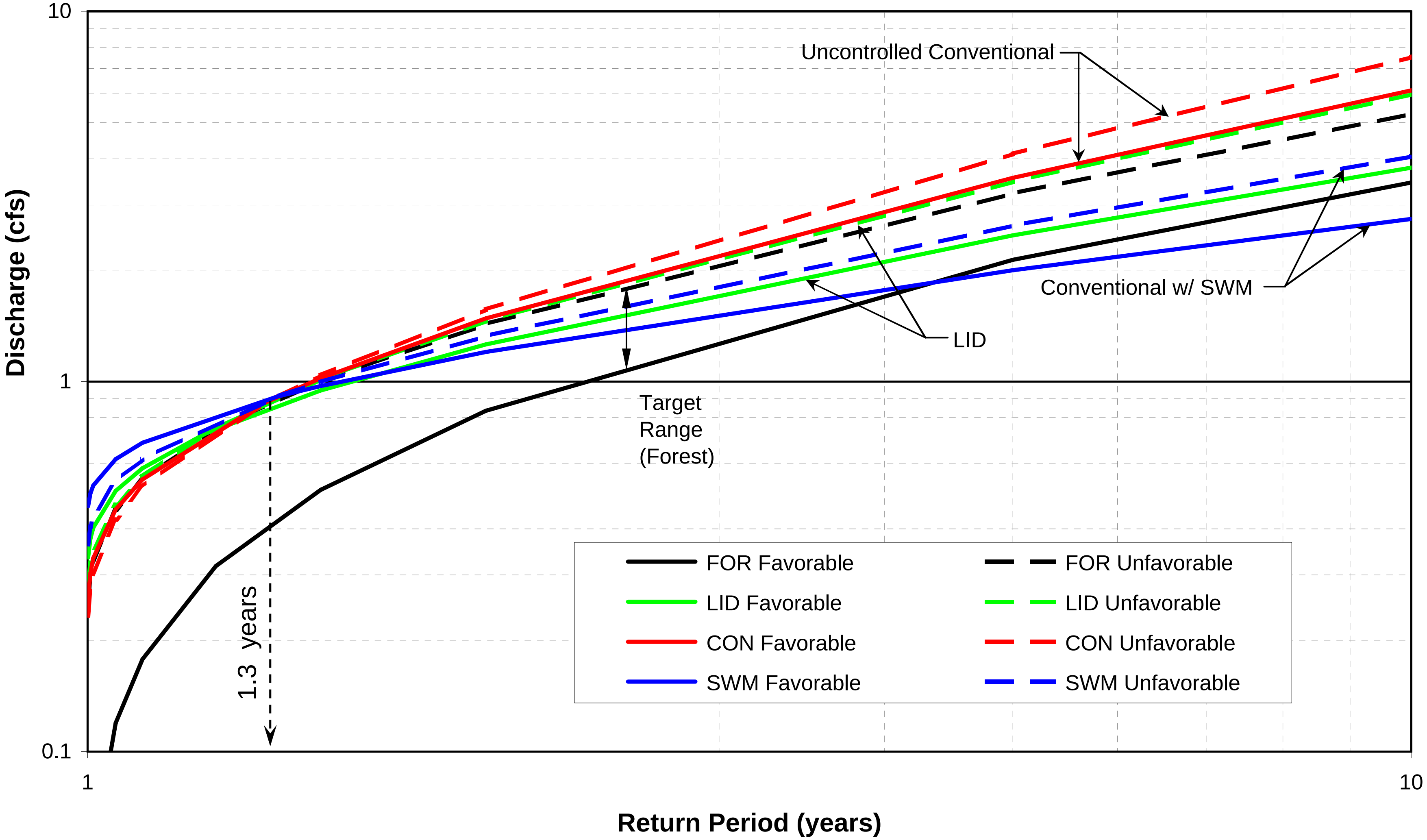


Figure 5.4: Log Pearson III Flood Frequency Analysis for All Scenarios

5.2.4 Flow Duration

The flow duration curves shown in Figure 5.5 provide a variation on the output presented for the ranked events, demonstrating a similar pattern wherein LID and Conventional development with SWM often successfully approximate the upper range Forest discharges, while uncontrolled Conventional development produces the highest discharges. As with the ranked events and LP3 analysis, the LID result envelope overlaps that for Forest, and the overlap occurs for less common flows (exceeded 0.4% or less of the time). The Conventional with SWM envelope lies within or below the Forest envelope for events exceeded 0.15% or less of the time, and lies entirely below the LID envelope for discharges less common than 0.03% exceedance. Conventional development without SWM, predictably, lies above the other result envelopes, with very little overlap.

At high frequencies, all of the Favorable-Unfavorable envelopes for developed land uses tend to collapse upon themselves, owing to the dominance of impervious surface runoff in small events. The LID curves do not fully collapse due to the modeling decision to eliminate rooftop storage for the Unfavorable case, effectively increasing the impervious area. For the Conventional scenarios, the effective impervious area is equal for both cases, and the two curves are identical for flows less than approximately 0.14 cfs (exceeded 2% of the time).

The SWM facility attenuates peak flows for the entire range of discharges, compared to the Conventional scenario, and over-manages peak flows (versus Forest) for larger events, roughly 0.01% or less in frequency. For common events (2% exceedance) the LID result lies between the two collapsed Conventional ranges, while the Forested conditions produce no runoff at all.

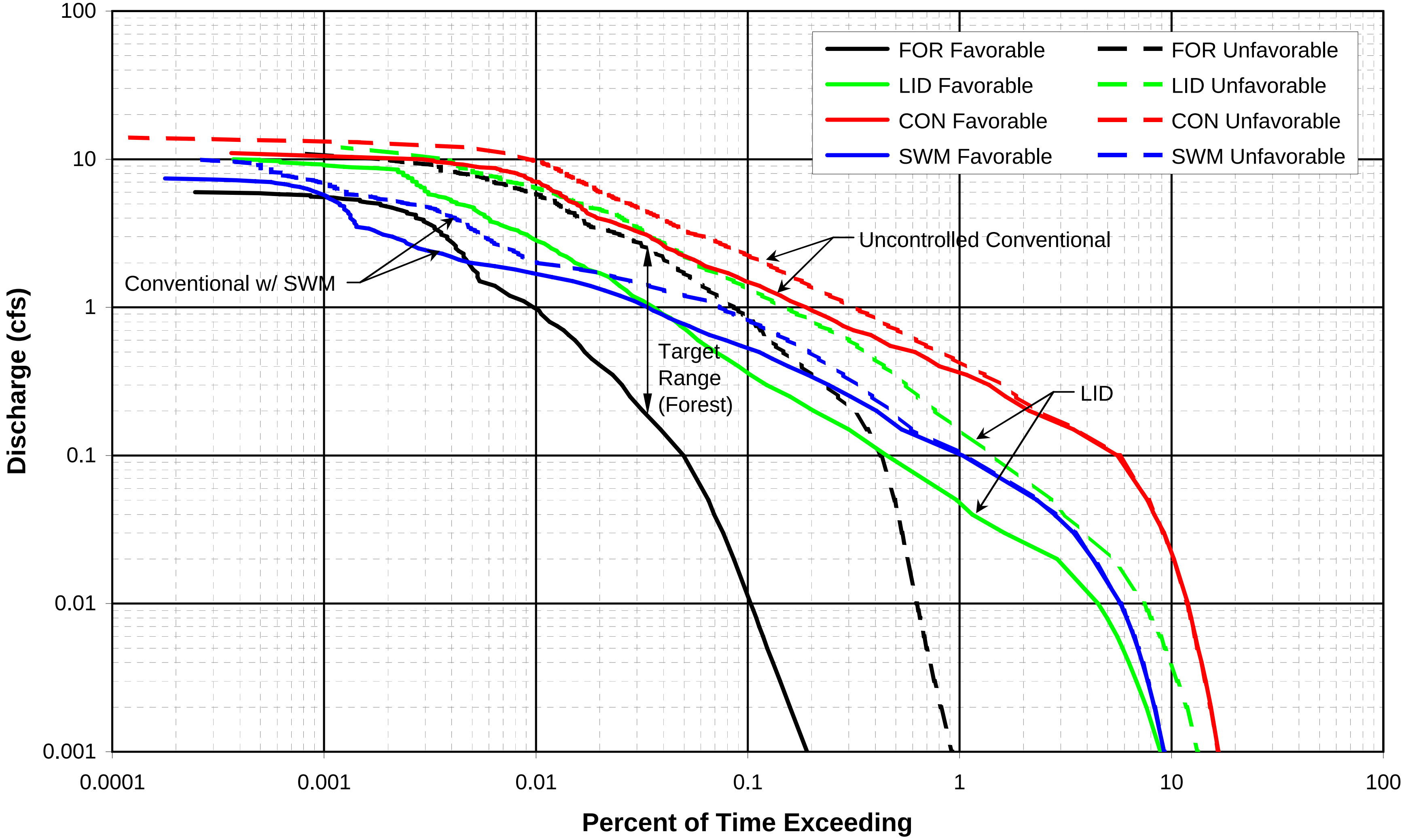


Figure 5.5: Discharge Duration Curves for All Scenarios

5.3 Single-Event Model Results

Single-event-mode model results are compared below based on runoff volume, peak flow, and hydrograph timing.

5.3.1 Runoff Volume

Single-event rainfall and runoff volumes, arranged by return period, are depicted in Figure 5.6. The Conventional with SWM scenario was not presented, as it produces the same runoff volume as the Conventional without SWM scenario, except for minimal evaporation occurring from the SWM pond surface. Natural Forest produced the least runoff across all events, while LID produced nearly as little runoff as Forest for the 1-year event. LID's Favorable-to-Unfavorable range overlapped that of Forest for all events, but overlapped less for larger events. The Conventional development results only slightly overlapped the LID results for the 10-year and 100-year events, and were notably higher than the other scenarios for all events.

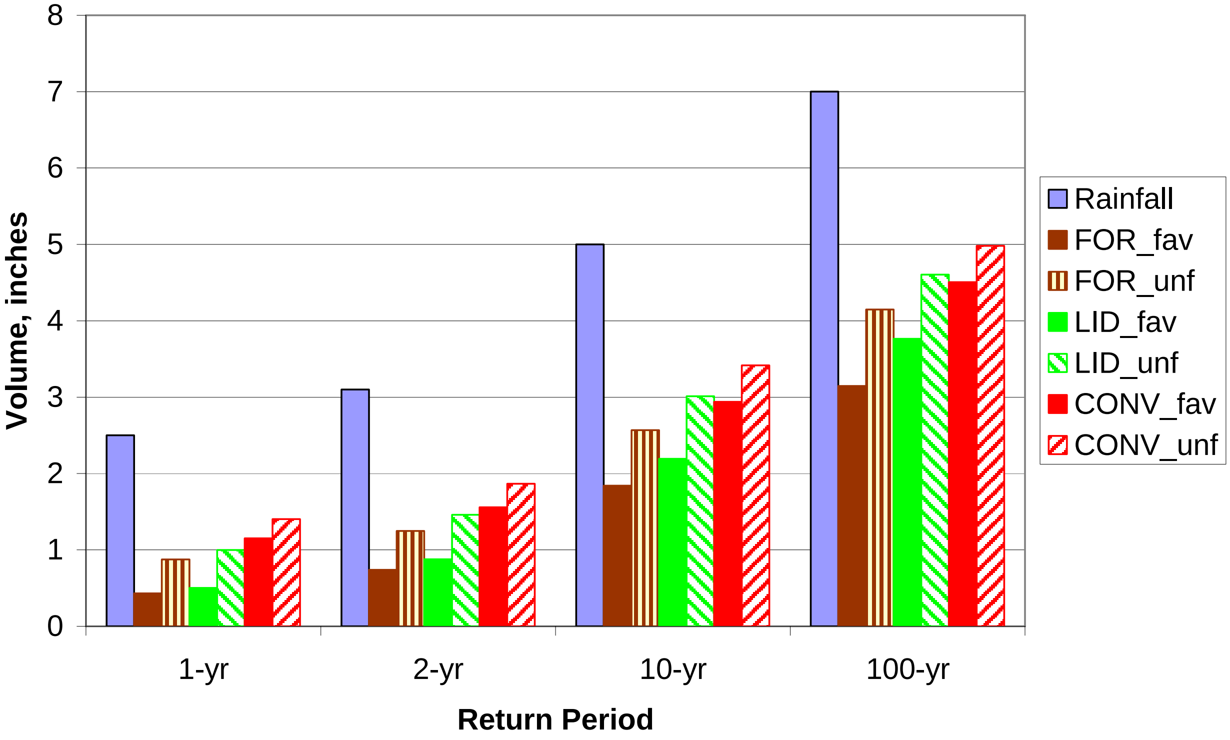


Figure 5.6: Single-event simulation volumes

5.3.2 Peak Flow

Event peak flows, arranged by return period, are depicted in Figure 5.7. The 10-year and 100-year events produced the surprising result that the peak flow range for Forest approached or enveloped that of uncontrolled Conventional development. The result is spurious, however, because the non-Forest scenarios were all affected by pipe surcharging for high flow events. Recall that storm drains are generally designed for the 10-year Rational Method discharge, and were modeled in SWMM as closed circular conduits. When a closed conduit surcharges, SWMM's Runoff Block retains the runoff at the upstream node, only releasing it at the pipe's full-flow capacity. No alternative overflow pathways are permitted, leading to an overestimate of the attenuation provided by pipe surcharging, and therefore an underestimate of the peak discharge. Surcharge occurred for all non-Forest land uses for the 100-year event, and for the

LID case for the 10-year event. The Conventional case did not surcharge for the 10-year event due to the use of smooth-walled pipe versus LID's corrugated pipe, selected in an effort to maintain the time of concentration. Single-event peak flow and hydrograph results are therefore invalid for the 100-year event across all non-Forest land uses, and for the 10-year event for the LID case.

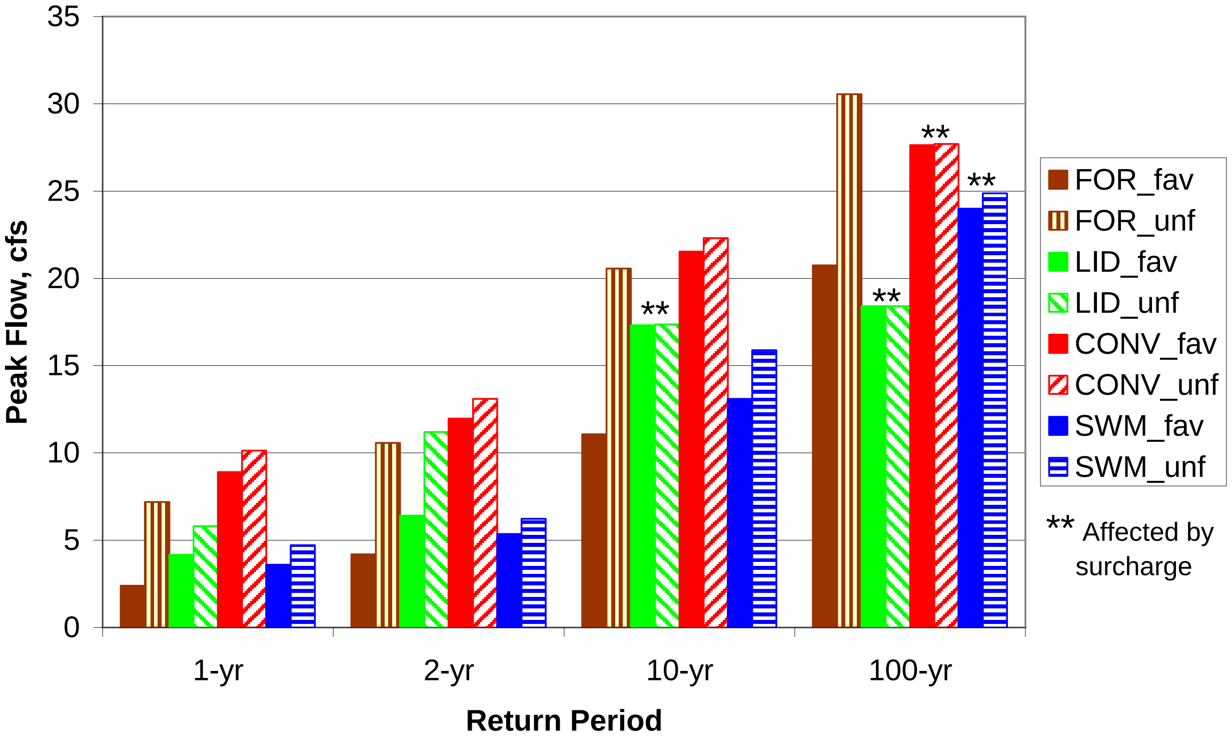


Figure 5.7: Single-event simulation peaks

For the 1-year and 2-year event, LID and Forest produced similar peak flow ranges, both of them lower than uncontrolled Conventional development. Conventional development with SWM, however, produced discharges in the lower range of Forest, due to the fact that the SWM facility was designed for the 2-year event, and has some residual ability to control smaller events. For the 10-year event, also a SWM facility design event, the SWM facility again provided significant attenuation, producing lower discharges than even the lowest Forest discharge. No comparison can be made versus the LID case at the 10-year event, due to the effects of surcharge. It will be noted, however, that for scenarios subject to surcharge the Favorable and Unfavorable peak discharges tend to coincide, or vary only slightly, because the overall peak discharge tends to be dominated by the full flow capacity of the surcharged conduits, rather than the overall watershed response.

5.3.3 Hydrograph Shape and Timing

Figures 5.8(a) through 5.8(d) show the outflow hydrographs for the 1-year through 100-year NRCS design storms. Peak flows were discussed above; hydrograph shape and timing are of interest in this section. For the 1-year and 2-year events, the LID and uncontrolled Conventional land use produce nearly bimodal hydrographs, with an early, high peak at hour 12.00, and a later “hump” at hour 12.25. The early peak appears to be caused by direct runoff from impervious surfaces and quickly saturated pervious planes, while the later “hump” represents delayed discharge from pervious land and IMP’s. The Forest-Unfavorable condition exhibits a similar phenomenon, but entirely due to saturated pervious land segments, in the absence of an impervious fraction. The Conventional with SWM scenario exhibits the typical low, delayed peak discharge, lying directly on the recession limb of the pond’s inflow hydrograph (the uncontrolled Conventional outflow). For the 1, 2, and 10-year events, the SWM outflow peak occurs slightly later than the Forest-Favorable peak discharge. For the 1 and 2-year events, the LID, Conventional, and Forest-Unfavorable peaks all roughly coincide in time, owing to the small watershed’s quick response time. The additional runoff volume from the Conventional scenarios is clearly evident from the area under the respective hydrographs, in particular the long tail of the SWM alternative. The 100-year hydrographs are shown only to demonstrate the effects of surcharge, also visible for the 10-year LID hydrographs.

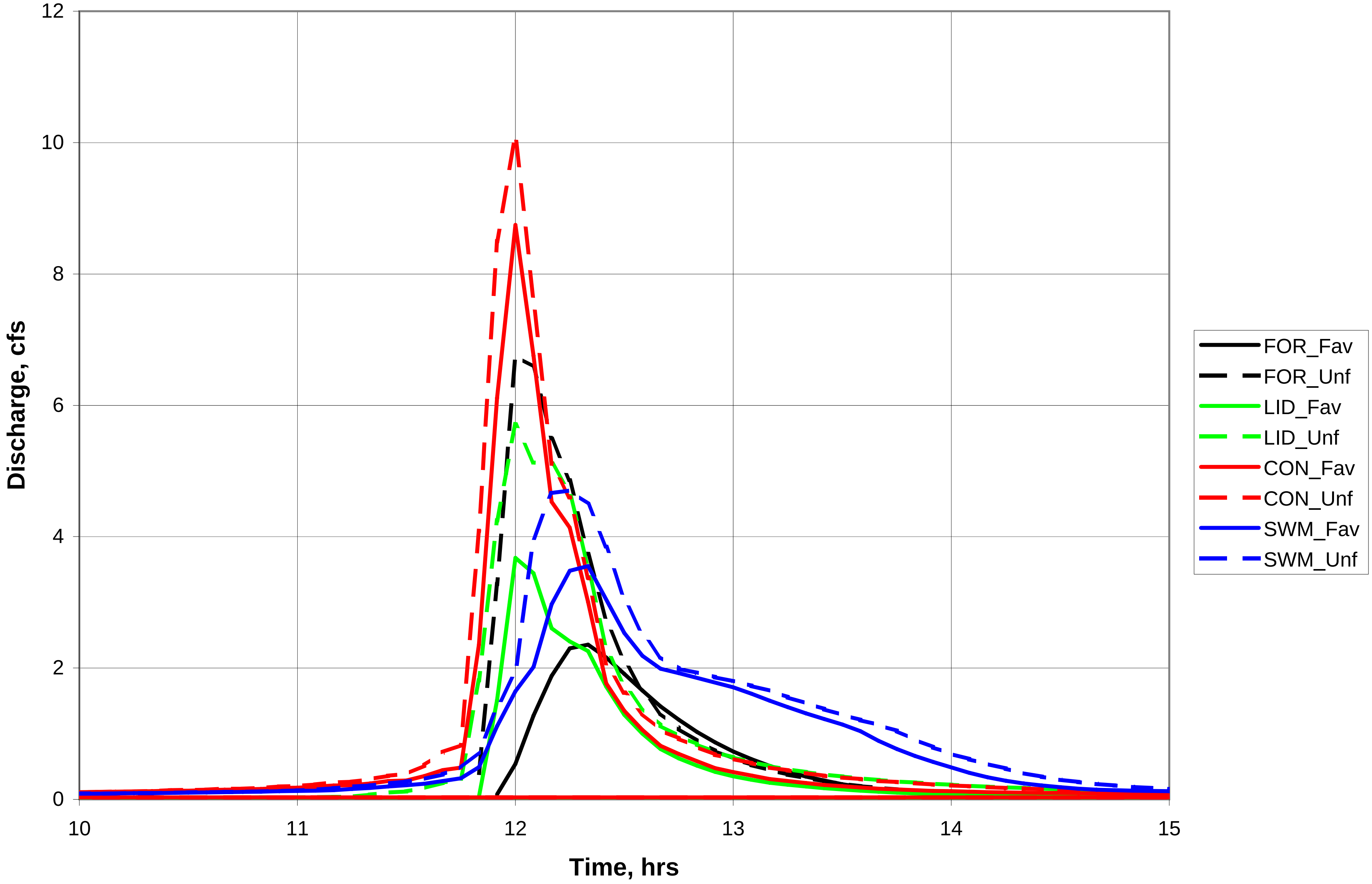


Figure 5.8(a): Event Model Results for 1-year, 24-hour NRCS Type II Storm

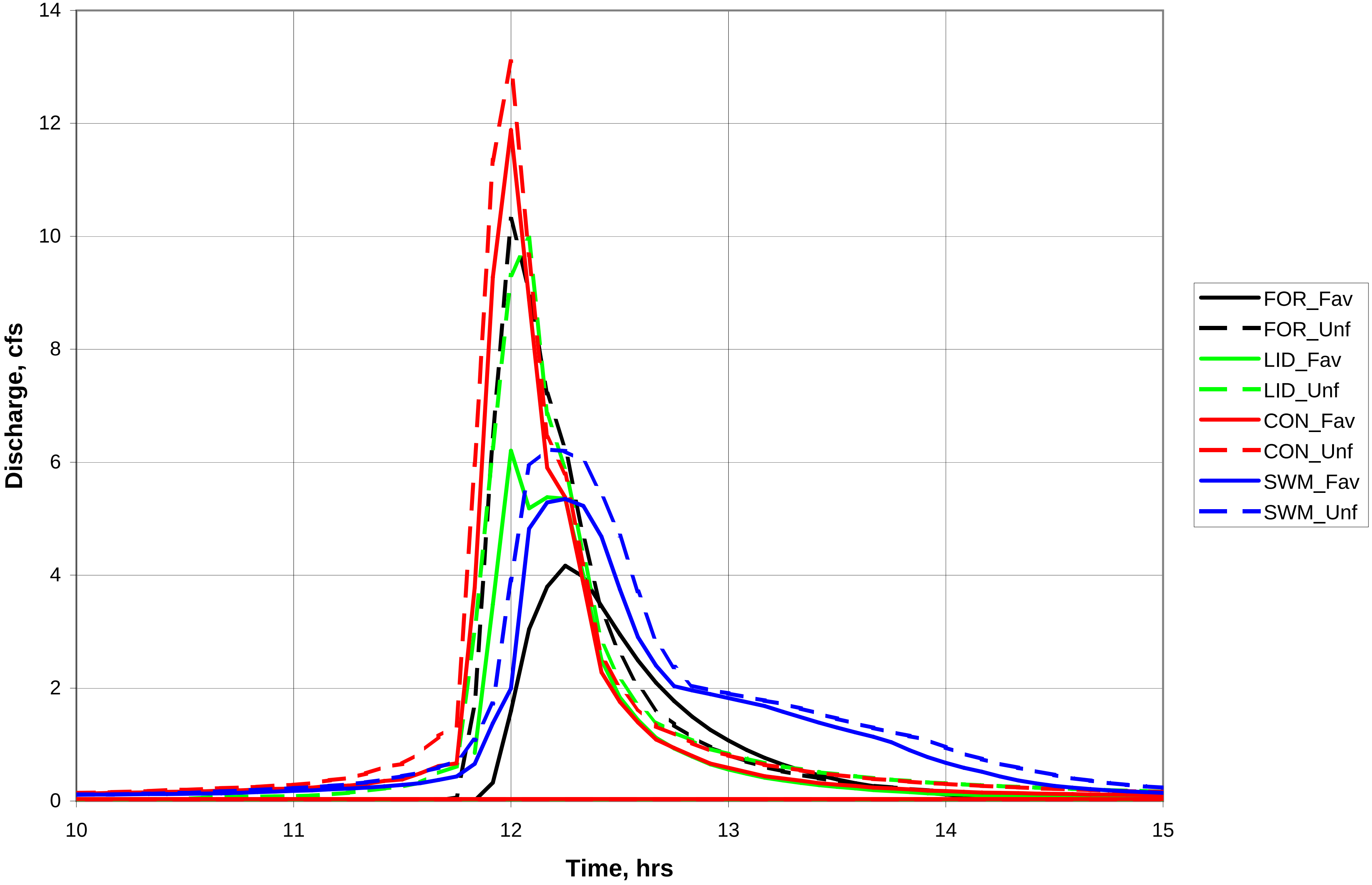


Figure 5.8(b): Event Model Results for 2-year, 24-hour NRCS Type II Storm

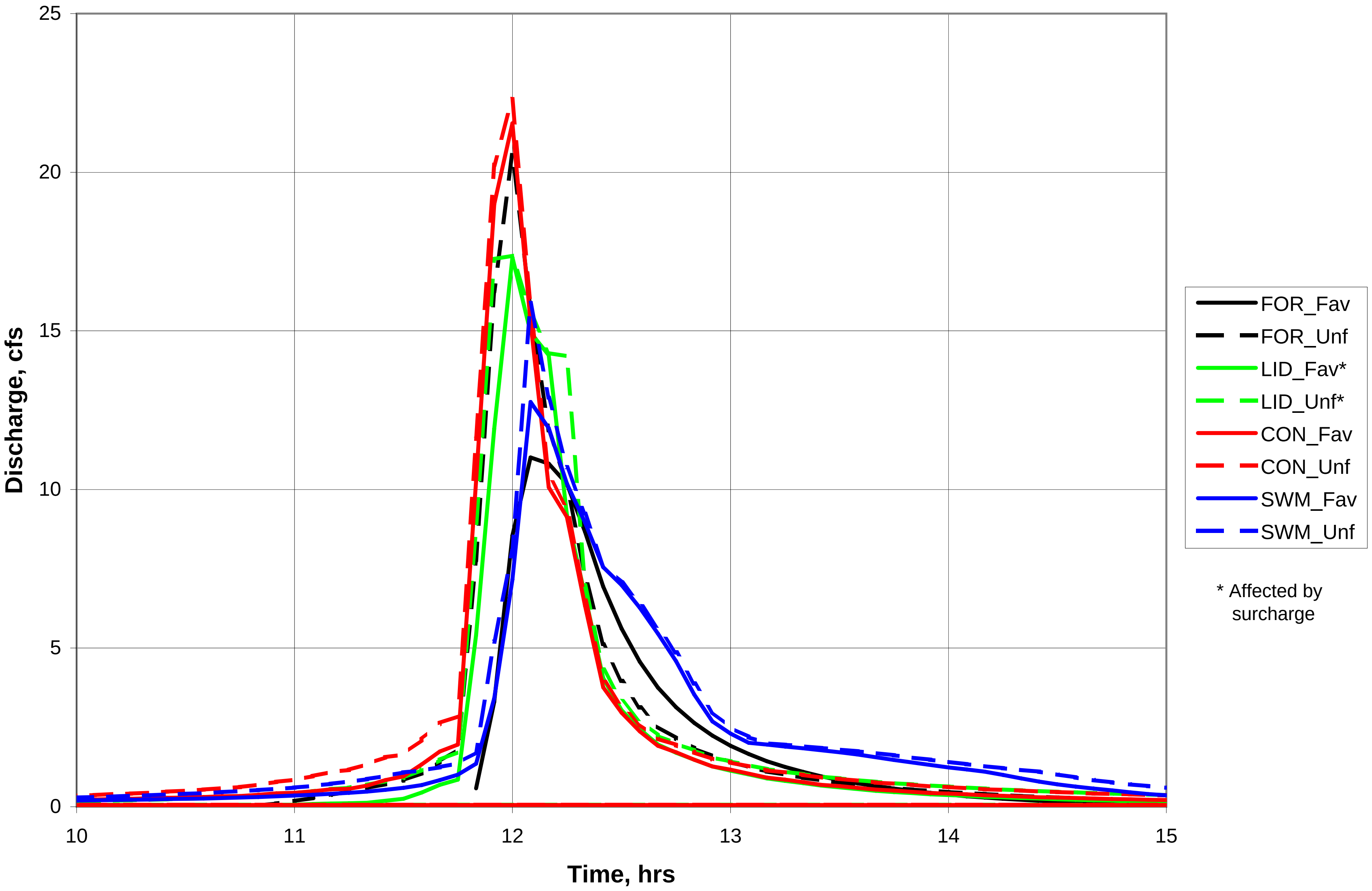


Figure 5.8(c): Event Model Results for 10-year, 24-hour NRCS Type II Storm

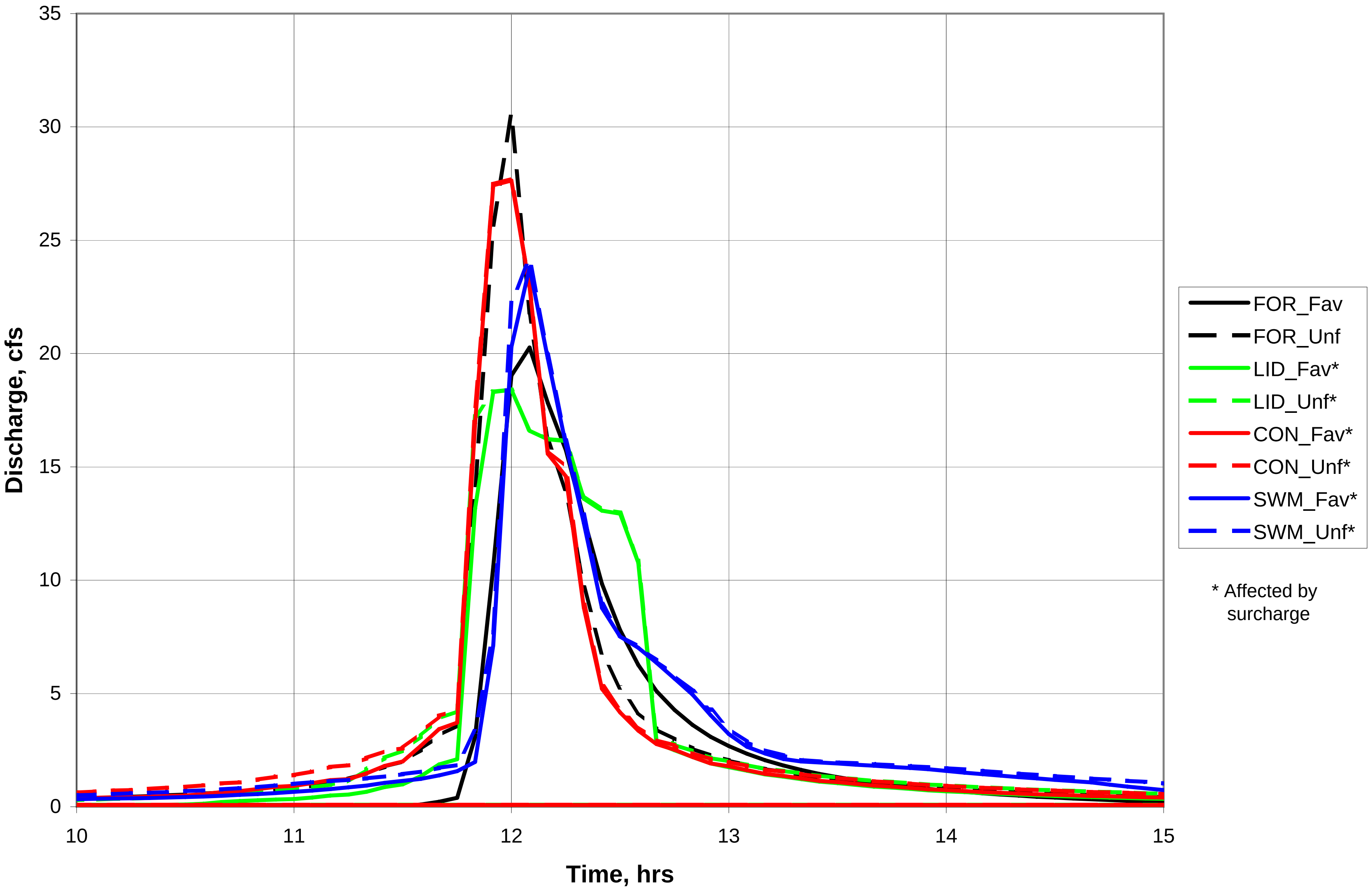


Figure 5.8(d): Event Model Results for 100-year, 24-hour NRCS Type II Storm

5.3.4 Comparison with NRCS Unit Hydrograph Methods

NRCS Unit Hydrograph methods were used to compute the peak flow for the Forested and both Conventional scenarios, using HEC-HMS, version 3.1.0. The LID scenarios were not analyzed because, as discussed previously, the LID design and analysis method assumes that the LID curve number and time of concentration are equal to that of the Forested condition, precluding meaningful modeling with NRCS methods. As with the continuous simulation runs, use of Excel facilitated comparisons between and among HEC-HMS and SWMM results.

Table 5.4 lists the peak discharge and runoff volume for the NRCS design storms for each scenario, from HEC-HMS. The HEC-HMS results predictably showed that the Forested scenario produced a lower runoff volume than either of the Conventional development scenarios. The Conventional with SWM scenario predictably produced lower peaks at the same runoff volumes as the uncontrolled Conventional scenario, and somewhat lower than the Forested peaks for the 2- through 100-year events. The Conventional with SWM scenario produced somewhat higher peaks than Forest for the 1-year event, and only slightly reduced the 100-year peak discharge, as would be expected for a SWM facility design targeted at the 2-year and 10-year events.

Table 5.4: HEC-HMS/NRCS Method Event Model Results

Scenario	Runoff volume (in)				Peak flow (cfs)			
	1-yr	2-yr	10-yr	100-yr	1-yr	2-yr	10-yr	100-yr
Forest	0.28	0.53	1.61	3.04	0.9	2.1	8.0	15.6
Conventional	0.75	1.15	2.64	4.38	4.3	6.9	16.0	26.3
Conv. w/ SWM	0.75	1.15	2.64	4.38	1.5	2.0	7.4	21.2

Table 5.5 presents the ratios of HEC-HMS-computed runoff volumes to those of the single-event SWMM runs. The HEC-HMS results lie below both the SWMM Favorable and Unfavorable

results for all return periods, but become increasingly close to the SWMM results at higher return periods. For the smaller events, SWMM's Green-Ampt infiltration routine, combined with depression storage, allows a larger runoff volume than that computed by HEC-HMS using the NRCS Curve Number method.

Table 5.5: Comparison of HEC-HMS vs. SWMM Runoff Volumes

Scenario	Percentage of SWMM Runoff Volume by Return Period			
	1-yr	2-yr	10-yr	100-yr
FOR_fav	65%	72%	87%	97%
FOR_unf	32%	43%	63%	73%
CONV_fav	65%	74%	90%	97%
CONV_unf	53%	62%	77%	88%

Table 5.6 compares the peak flows from both HEC-HMS and SWMM single-event analysis. As with runoff volumes, the HEC-HMS results tend to be lower than the SWMM results. For the Forested scenarios, HEC-HMS predicts much lower peaks than SWMM, subject to the same increasing trend versus return period as with volume, above. The uncontrolled Conventional scenario follows the trend as well, though the above-mentioned surcharge occurring in the SWMM model for the 10-year and 100-year events distorts and possibly artificially magnifies the trend. For the Conventional with SWM scenario, the trend does not hold because the 1-year event is slightly under-controlled by the SWM pond, while the 2-year and 10-year events are slightly over-controlled. The disparity between SWMM and HEC-HMS for the same design storm is unsurprising, given the substantial conceptual differences (curve number versus Green-Ampt infiltration for volume, lumped/unit hydrograph versus discrete/quasi-physically-based for routing) between the two models.

Table 5.6: Comparison of HEC-HMS vs. SWMM Peaks

Scenario	Percentage of SWMM Peak Flow by Return Period			
	1-yr	2-yr	10-yr	100-yr
FOR_fav	38%	50%	72%	75%
FOR_unf	13%	20%	39%	51%
CONV_fav	48%	58%	74%	95%
CONV_unf	42%	53%	72%	95%
SWM_fav	42%	37%	56%	88%
SWM_unf	32%	32%	47%	85%

5.4 Discussion

Examining the results of the SWMM modeling, we can see three key trends:

- LID tends to produce lower runoff volumes than conventional development with or without SWM, and approaches the runoff volume of forest land for a range of events. The LID volume results overlap those of Forest for all but the extremely low-flow events, for which Forest produces zero or near-zero runoff. This trend is consistent across both event and continuous simulation model results, including flow-duration analysis. On a long-term basis, Forest produced the lowest runoff volumes and fewest detectable runoff events, while Conventional development volumes exceeded both Forest and LID by wide margins.
- Both LID and Conventional SWM succeeded at their stated management goals, for their specified design storms. LID results overlapped Forest for continuous simulation peaks and volumes near the 12-month recurrence interval; and produced similar peaks and volumes as Forest for the 1-year and 2-year NRCS storms. Conventional development with SWM replicated or over-managed predevelopment peaks for events of 2-year through 10-year recurrence interval. For storms higher or lower than the specified design events, IMP/BMP performance varied, as discussed in the next point.

- While LID does reduce peak flow rates versus uncontrolled conventional development, Conventional SWM is often more successful at reducing peak discharges to levels below LID, and at or below those of forest, especially for low-frequency events. Conventional SWM, designed for 2-year/10-year peak control, reduces peak discharges over a range of flows well beyond its design intent. The flow duration analysis supports this conclusion as well.

The trends identified above have important implications for the adoption of LID as a regulatory policy for new development. It appears clear that LID, if maintained properly, offers substantial benefits towards reducing overall runoff volume, and by extension total pollutant loads, even without considering the water quality treatment benefits of the LID Integrated Management Practices. Conventional development with traditional Stormwater Management, on the other hand, more effectively controls peak discharges than LID at a given impervious fraction. A return to fully traditional development practices, with wider streets, more driveways, and total forest clearance would of course provide an even more stark comparison in favor of LID. Clearly, reducing the impervious fraction can effectively reduce runoff volume and peak, and improve water quality.

LID structural practices such as bioretention, dry swales, and green roofs can reduce pollution loads, runoff volume, and to some extent peak flows even further than what is obtainable by imperviousness reduction and disconnection alone. Taken together, IMP’s and imperviousness reduction produce an overall hydrologic response that approaches that of forested conditions for frequent events, especially when runoff volume is considered. What is not clear is whether LID can successfully manage damaging flood peaks due to large, low-frequency events; or, in the absence of effective local peak control, how far downstream any volume-reduction benefits persist. The results of this modeling effort suggest an optimal, hybrid strategy that combines LID, detention (regional or local), and effective floodplain management towards goals of protecting water quality, promoting and preserving stream stability, and preventing downstream flood damage.

The results above strictly apply to the conditions analyzed. Based on the modeling results, and the difficulty experienced in fitting the required IMP's into the developed landscape, it appears there may be an upper limit to the housing density that LID can support. At a minimum, at sites with impervious fractions higher than the 32% analyzed herein, and/or less permeable soil conditions, it appears that additional onsite detention would be needed to manage peak flows for both channel stability and flood protection. This fact is acknowledged in the LID Design Manual, which requires detention in addition to retention above a certain post-development Curve Number and Time of Concentration range. Conversely, at lower densities LID may be more effective at managing peak flows than shown in this study with its relatively high density (32% impervious, average ½-acre lot size).

6 SUMMARY AND CONCLUSIONS

6.1 Summary

Urban and suburban development has well-known detrimental impacts to the hydrology, water quality, and ecology of developing watersheds, largely due to the increased imperviousness and drainage efficiency of the developed landscape. Common results are increased magnitude and frequency of local and downstream flooding, increased channel erosion, decreased baseflow, and degraded instream habitat. Traditionally, stormwater impacts were managed through the use of structural measures such as stormwater conveyance and detention ponds, increasingly recognized as exacerbating the channel erosion, flooding, and water quality problems that they sought to mitigate. Low Impact Development (LID) is proposed as the solution to problems associated with traditional development patterns and stormwater best management practices (BMP's), caused by traditional SWM's failure to manage the additional runoff volume produced by the more impervious suburban landscape.

The LID approach seeks to create a hydrologically functional landscape, which mimics predevelopment (forested) hydrologic response. In LID, runoff is reduced to predevelopment levels by minimizing imperviousness; using natural drainage courses; minimizing land disturbance; maintaining the predevelopment time of concentration; and augmenting storage with detention, retention, and water reclamation practices distributed throughout the landscape. Such an approach requires detailed knowledge and evaluation of distributed micro-scale hydrologic effects, yet present-day LID design practice takes a spatially lumped approach, based on NRCS hydrology methods. The LID design approach precludes an analysis of the post-development condition from within the LID design framework. Success of the LID method is thus highly dependent on the adequacy of the lumped-model assumption of watershed uniformity, the practicality of maintaining the predevelopment time of concentration, and the applicability of NRCS methods to the small storms that account for most of the annual runoff volume. In light of the limitations of the lumped approach, a more sophisticated and finer resolution modeling approach is needed to better quantify LID performance in lieu of conclusive monitoring results.

The primary goal of this research was to evaluate LID and determine to what extent it replicates natural hydrology. The objective was achieved by application of a continuous-simulation hydrologic model to a segment of a local suburban development. The modeling effort attempted to capture the fine-scale effects of LID practices, and evaluate the hydrologic performance of an LID site under an actual rainfall time series, giving insight into LID's impact over a wide range of possible storm sizes and antecedent conditions. Since LID analysis of future and assumed past conditions obviously requires application to ungaged watersheds, the approach stressed use of physically-based models where parameters can be estimated *a priori*.

Initially, nineteen alternative computer models were investigated for analysis of LID, forest, and conventional development. Based on a literature review, and comparison of model features and applicability, it was determined that both EPA SWMM and KINEROS held promise for the task. Preliminary trials and sensitivity analysis were conducted using data from a previous study of the Virginia Tech commuter parking lot. The preliminary work led to the selection of EPA SWMM as the most appropriate model for analysis of the hydrologic effects of LID as compared to forest and conventional development. A 4.3 acre subwatershed of a local residential development site, the Village at Tom’s Creek, was redesigned using LID techniques. The site was modeled in EPA-SWMM at a fine spatial scale under LID, predevelopment forest, and conventional development (with and without stormwater management) conditions. Each scenario was modeled under both favorable (tending to decrease runoff) and unfavorable (tending to increase runoff) conditions via variation of runoff characteristics such as depression storage, hydraulic conductivity, and soil moisture capacity. Model results for each scenario would thus reflect a range or envelope of likely outcomes. Each scenario and condition combination was run in SWMM’s continuous simulation mode, using 6.4 years of local rainfall data. SWMM was then run in event mode, using various NRCS 24-hour design storms (1, 2, 10, and 100-year) as rainfall input. NRCS design storm hydrographs were computed in HEC-HMS, using NRCS hydrologic methods, for comparison to the single-event SWMM results.

Continuous simulation output was analyzed using SWMM’s Statistics Block, spreadsheets, and FORTRAN utilities to develop tables and charts for comparison between development scenarios. Event-mode SWMM results were plotted using spreadsheets, and also compared with HEC-HMS results. Continuous simulation comparisons included the number of runoff-producing events, runoff volume, peak flow, and flow duration. Event models were compared on the bases of runoff volume, peak flow, timing, and hydrograph shape.

Both event and continuous simulation results indicated that LID produces a lower runoff volume than conventional development, and approaches the runoff volume of predevelopment forest. Forest produced the lowest runoff volume over all flood frequencies. The LID results overlapped those of forest for both total simulated runoff volume, and for event runoff volume for most flood frequencies, indicating that LID plausibly replicates forest hydrology for those events, which include those for which it was specifically designed. The only exception was for trivially small events wherein LID produced some minimal runoff from its impervious fraction, while forest produced none.

Peak flow performance of LID was more complex than that for runoff volume. For small events (less than 2 months recurrence interval); the flow-frequency envelope curves for Forest, LID, Conventional with SWM, and Conventional without SWM scenarios did not overlap. For medium-frequency events (2 to 8 months recurrence interval), peak flow results overlapped in a complex fashion, with LID producing slightly higher peak flows than SWM, and both LID and SWM lying within the upper range of Forested conditions. For larger events (exceeding 8 months recurrence interval), including the synthetic storms studied using single-event modeling, SWM outperformed LID and often produced lower peaks than forest. Log Pearson 3 frequency analysis of the annual peak time series showed SWM outperforming LID, but both overlapping the range of forest results. Single-event analysis, which focused on NRCS design storms of 1-year or greater frequency, produced the lowest peak flows for SWM, followed by Forest conditions, and then LID. Unsurprisingly, conventional development produced higher peaks than forest, LID, or SWM across the range of frequencies and analysis methods.

Flow duration results were similarly complex as those for peak flow. For common (high-frequency) flows, SWM outperformed LID, but neither matched forest hydrology, as no overlap occurred between any of the scenarios. For medium-frequency flows, both LID and SWM overlapped the Forest results envelope, and LID produced slightly lower average flows. For large, low-frequency flows that represent the peaks of many of the larger storm events in the time series, SWM produced lower runoff than Forest, which in turn produced less runoff than LID. Uncontrolled conventional development again produced higher runoff for all scenarios and conditions, with negligible overlap.

Examining the results of the SWMM modeling, three trends were apparent:

- LID tends to produce lower runoff volumes than conventional development with or without SWM, and approaches the runoff volume of forest land for a range of events. On a long-term basis, Forest produced the lowest runoff volumes and fewest detectable runoff events, while Conventional development volumes exceeded both Forest and LID by wide margins. This trend is consistent across both event and continuous simulation model results, including flow-duration analysis.
- Both LID and Conventional SWM succeeded at their stated management goals, for their specified design storms. LID results overlapped Forest for continuous simulation peak flows and runoff volumes near the 12-month recurrence interval; and produced similar peak flows and runoff volumes as Forest for the 1-year and 2-year NRCS storms. Conventional development with SWM replicated or over-managed predevelopment peak flows for events of 2-year through 10-year recurrence interval.
- While LID does reduce peak flow rates versus uncontrolled conventional development, Conventional SWM is often more successful at reducing peak discharges to levels below LID, and at or below those of forest, especially for low-frequency events. Conventional SWM, designed for 2-year/10-year peak control, reduces peak discharges over a range of flows well beyond its design intent.

LID site design offers substantial benefits towards reducing overall runoff volume, and by extension pollutant loads. LID structural practices such as bioretention, dry swales, and green roofs can reduce pollutant loads, runoff volume, and peak flows even further than what is obtainable by imperviousness reduction and disconnection alone. Taken together, IMP's and imperviousness reduction produce an overall hydrologic response that approaches that of forested conditions for frequent events, especially when runoff volume is considered. However, conventional development with traditional Stormwater Management more effectively controls peak discharges than LID at a given impervious fraction.

Based on the modeling results, it is not clear that LID can successfully manage damaging flood peaks due to large, low-frequency events; or, in the absence of effective local peak control, how far downstream the reduction in runoff provides stream stability benefits or flood risk reduction. The differential performance of volume and peak-based controls would suggest a hybrid approach, wherein LID IMP's would provide water quality and runoff volume reduction benefits, while traditional stormwater management detention would augment flood control routing storage. If LID storage volumes are sufficient to provide channel protection, as they appear to be based on LID's performance in replicating predevelopment peak flows for events of approximately 1-year recurrence interval, flood control could be addressed by regional detention facilities or floodplain management/land use planning.

6.2 Conclusion & Recommendations

Based on continuous and single-event modeling at a fine spatial scale, it appears that, while LID succeeds in reducing overall stormwater volumes to levels approaching those of forest, LID does not fully replicate forest hydrology with respect to peak flows and flow duration, and is outperformed by conventional stormwater detention with respect to peak control. LID predictably compares favorably to traditional development without stormwater management controls under a wide range of discharges. Despite its inability to mitigate runoff volume, conventional stormwater detention appears to be more effective than LID at mitigating peak flows across the possible spectrum of flood frequencies, especially the low-frequency events responsible for flooding.

The results of this effort suggest an optimal, hybrid strategy that combines LID, detention (regional or local), and effective floodplain management towards goals of protecting water quality, promoting and preserving stream stability, and preventing downstream flood damage.

6.3 Suggestions for Further Research

There are several unanswered questions with regard to the larger-scale effects of implementing LID practices over a large watershed. The following avenues could be investigated to extend the present research:

1. Modeling of downstream effects of runoff volume reduction, especially for a larger watershed where timing effects are more notable.
2. Evaluate the effectiveness of LID in conjunction with regional detention or on-site detention for flood control.
3. Integrate flow-duration results with sediment transport relationships to determine effective discharge and likely channel stability effects.

4. Utilize a longer simulation period (20+ years), capturing more significant storms within the continuous record. This might prove problematic for small, flashy watersheds, as typical long-term datasets are of a 1-hour resolution.
5. Investigate the appropriateness of using pre-colonial forest as the “predevelopment” land use condition, given the legacy of erosion and sedimentation, and differing climate and hydrologic regime that now controls channel form.

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APPENDIX A

SUPPORTING CALCULATIONS FOR MODEL TESTING

- **A-1: Storm Drain Details for Commuter Lot B Modeling**
- **A-2: Daily Rainfall at Commuter Parking Lot B Gage**
- **A-3: Effects of Alternative Palmer-Bowlus Flume Coefficients on Computed Runoff**
- **A-4: T-Test Results Comparing SWMM, KINEROS, and Observations**

Appendix A-1: Storm Drain Details for Commuter Lot B Modeling

From Inlet Number	To Inlet Number	Pipe Diameter (in)	Pipe Length (ft)	Pipe Slope (ft/ft)
46	610	21	75	0.0053
610	1023	24	235	0.0051
89	910	21	54	0.005
910	1023	15	100	0.005
1023	2341	30	282	0.005
1223	2341	21	66	0.0076
2122	2223	15	70	0.0286
2223	2341	24	206	0.0335
2341	4124	36	55	0.0051
4124	2431	42	145	0.0054
2431	3132	42	213	0.0052
3031	3132	24	295	0.0305
3132	3299	48	178	0.0051
3299	9999	48	20	0.0052

Appendix A-2: Daily Rainfall at Commuter Parking Lot B Gage

Year	Julian Date	Rainfall (0.01")
1995	172	53
1995	177	99
1995	178	6
1995	179	115
1995	180	6
1995	181	2
1995	182	2
1995	186	12
1995	187	53
1995	188	1
1995	193	5
1995	198	138
1995	205	39
1995	206	109
1995	207	1
1995	208	8
1995	218	9
1995	219	1
1995	220	8
1995	223	4
1995	224	1
1995	230	180
1995	239	52
1995	244	14
1995	245	1
1995	256	14
1995	259	64
1995	260	49
1995	265	6
1995	266	3
1995	267	6
1995	268	2
1995	269	20
1995	272	1
1995	276	4
1995	277	69
1995	278	89
1995	279	1
1995	285	1
1995	286	5
1995	287	31
1995	293	64
1995	294	3
1995	300	9
1995	301	5
1995	304	7
1995	306	26
1995	307	7
1995	311	89
1995	313	1
1995	315	42
1995	317	9
1995	318	30
1996	1	3
1996	2	55
1996	12	1
1996	13	2
1996	14	11
1996	17	1
1996	18	28
1996	19	65
1996	21	1
1996	24	25
1996	26	39
1996	27	85
1996	30	1
1996	31	9
1996	36	1
1996	37	14
1996	38	5
1996	39	48
1996	40	13
1996	46	8
1996	51	9
1996	53	13
1996	59	22
1996	65	6
1996	66	7
1996	67	33
1996	75	40
1996	76	27
1996	77	3
1996	79	77
1996	81	1
1996	85	2
1996	88	104
1996	89	6
1996	91	5
1996	92	14
1996	95	1
1996	97	1
1996	99	9
1996	100	1
1996	104	9
1996	106	10
1996	107	19
1996	110	9
1996	111	17
1996	112	1
1996	114	16
1996	117	15
1996	120	1
1996	121	64
1996	122	2
1996	126	64
1996	127	1
1996	128	27
1996	129	6
1996	132	3
1996	133	1
1996	136	54
1996	137	85
1996	142	11
1996	143	53
1996	145	23
1996	146	23
1996	147	28
1996	148	60
1996	149	1
1996	150	19

Appendix A-3: Effects of Alternative Palmer-Bowlus Flume Coefficients on Computed Runoff

Palmer-Bowlus flume rating: $Q / D^{2.5} = a (H_a / D)^b$ Where: $H_a = d - D/6$, $D = 4.0$ ft

Alternative flume coefficients: *(close to 1%)* *(midrange, about 0.5%)* *(close to 0%)*

Slope	1-2%	<1%	>0.5%	~0.5%	<0.5%	>0%	0%
a	3.685	3.65	3.64	3.6	3.55	3.54	3.536
b	1.868	1.89	1.91	1.92	1.94	1.99	2.055

Julian Date	Time	H_a (ft)	$Q_{1-2\%}$	$Q_{<1\%}$	$Q_{>0.5\%}$	$Q_{\sim0.5\%}$	$Q_{<0.5\%}$	$Q_{>0\%}$	$Q_{0\%}$
198	1815	0.1114	0.15	0.13	0.12	0.12	0.11	0.09	0.07
198	1820	2.7574	58.86	57.82	57.24	56.40	55.20	54.03	52.68
198	1825	3.0054	69.13	68.04	67.47	66.54	65.24	64.13	62.88
198	1830	2.5234	49.87	48.90	48.32	47.57	46.48	45.29	43.90
198	1835	2.0604	34.15	33.34	32.81	32.23	31.37	30.26	28.95
198	1840	1.4544	17.82	17.26	16.87	16.51	15.96	15.13	14.15
198	1845	0.9554	8.13	7.80	7.56	7.37	7.06	6.56	5.97
198	1850	0.6734	4.23	4.03	3.88	3.77	3.58	3.27	2.91
198	1855	0.4944	2.37	2.25	2.15	2.08	1.97	1.77	1.54
198	1900	0.3684	1.37	1.29	1.22	1.18	1.11	0.98	0.84
198	1905	0.2844	0.85	0.79	0.75	0.72	0.67	0.59	0.49
198	1910	0.2254	0.55	0.51	0.48	0.46	0.43	0.37	0.31
198	1915	0.1844	0.38	0.35	0.33	0.31	0.29	0.25	0.20
198	1920	0.1554	0.27	0.25	0.24	0.23	0.21	0.18	0.14
198	1925	0.1334	0.21	0.19	0.18	0.17	0.15	0.13	0.10
198	1930	0.1164	0.16	0.15	0.14	0.13	0.12	0.10	0.08
198	1935	0.1014	0.12	0.11	0.10	0.10	0.09	0.08	0.06
198	1940	0.0894	0.10	0.09	0.08	0.08	0.07	0.06	0.05
198	1945	0.0804	0.08	0.07	0.07	0.06	0.06	0.05	0.04
198	1950	0.0714	0.06	0.06	0.05	0.05	0.05	0.04	0.03
198	1955	0.0634	0.05	0.05	0.04	0.04	0.04	0.03	0.02
198	2000	0.0574	0.04	0.04	0.04	0.03	0.03	0.02	0.02
198	2005	0.0494	0.03	0.03	0.03	0.02	0.02	0.02	0.01
198	2010	0.0444	0.03	0.02	0.02	0.02	0.02	0.01	0.01
198	2015	0.0414	0.02	0.02	0.02	0.02	0.02	0.01	0.01
198	2020	0.0354	0.02	0.02	0.01	0.01	0.01	0.01	0.01
198	2025	0.0324	0.01	0.01	0.01	0.01	0.01	0.01	0.01
198	2030	0.0294	0.01	0.01	0.01	0.01	0.01	0.01	0.00
198	2035	0.0264	0.01	0.01	0.01	0.01	0.01	0.01	0.00
198	2040	0.0224	0.01	0.01	0.01	0.01	0.00	0.00	0.00
198	2045	0.0214	0.01	0.01	0.01	0.01	0.00	0.00	0.00
198	2050	0.0174	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix A-3: Effects of Alternative Palmer-Bowlus Flume Coefficients on Computed Runoff

Palmer-Bowlus flume rating: $Q / D^{2.5} = a (H_a / D)^b$ Where: $H_a = d - D/6$, $D = 4.0$ ft

Alternative flume coefficients: *(close to 1%)* *(midrange, about 0.5%)* *(close to 0%)*

Slope	1-2%	<1%	>0.5%	~0.5%	<0.5%	>0%	0%
a	3.685	3.65	3.64	3.6	3.55	3.54	3.536
b	1.868	1.89	1.91	1.92	1.94	1.99	2.055

Julian Date	Time	H_a (ft)	$Q_{1\text{-}2\%}$	$Q_{<1\%}$	$Q_{>0.5\%}$	$Q_{\sim 0.5\%}$	$Q_{<0.5\%}$	$Q_{>0\%}$	$Q_{0\%}$
198	2055	0.0164	0.00	0.00	0.00	0.00	0.00	0.00	0.00
198	2100	0.0144	0.00	0.00	0.00	0.00	0.00	0.00	0.00
198	2105	0.0124	0.00	0.00	0.00	0.00	0.00	0.00	0.00
198	2110	0.0114	0.00	0.00	0.00	0.00	0.00	0.00	0.00
198	2115	0.0094	0.00	0.00	0.00	0.00	0.00	0.00	0.00
198	2120	0.0074	0.00	0.00	0.00	0.00	0.00	0.00	0.00
198	2125	0.0064	0.00	0.00	0.00	0.00	0.00	0.00	0.00
198	2130	0.0064	0.00	0.00	0.00	0.00	0.00	0.00	0.00
198	2135	0.0034	0.00	0.00	0.00	0.00	0.00	0.00	0.00
198	2140	0.0024	0.00	0.00	0.00	0.00	0.00	0.00	0.00
198	2145	0.0024	0.00	0.00	0.00	0.00	0.00	0.00	0.00
198	2150	0.0024	0.00	0.00	0.00	0.00	0.00	0.00	0.00
198	2155	0.0004	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Storm measured volume (ft^3):			74732	73097	72075	70883	69120	67045	64650
Adj. to original gaged area (ft^3):			79173	77441	76359	75096	73228	71030	68493
Adj. to original gaged area (in):			1.006	0.984	0.970	0.954	0.931	0.903	0.870
Adj. to 19.497 ac gaged area (in):			1.056	1.033	1.018	1.002	0.977	0.947	0.913
Percent of 1-2% basis volume:			100%	98%	96%	95%	92%	90%	87%

Appendix A-3: Effects of Alternative Palmer-Bowlus Flume Coefficients on Computed Runoff

Palmer-Bowlus flume rating: $Q / D^{2.5} = a (H_a / D)^b$ Where: $H_a = d - D/6$, $D = 4.0$ ft

Alternative flume coefficients: *(close to 1%)* *(midrange, about 0.5%)* *(close to 0%)*

Slope	1-2%	<1%	>0.5%	~0.5%	<0.5%	>0%	0%
a	3.685	3.65	3.64	3.6	3.55	3.54	3.536
b	1.868	1.89	1.91	1.92	1.94	1.99	2.055

Julian Date	Time	H_a (ft)	$Q_{1-2\%}$	$Q_{<1\%}$	$Q_{>0.5\%}$	$Q_{\sim 0.5\%}$	$Q_{<0.5\%}$	$Q_{>0\%}$	$Q_{0\%}$
293	1840	0.2949	0.90	0.85	0.80	0.77	0.72	0.63	0.53
293	1845	0.3215	1.06	1.00	0.94	0.91	0.85	0.75	0.64
293	1850	0.3593	1.31	1.23	1.17	1.13	1.06	0.94	0.80
293	1855	0.3681	1.37	1.29	1.22	1.18	1.11	0.98	0.84
293	1900	0.4196	1.75	1.65	1.57	1.52	1.43	1.28	1.10
293	1905	0.4800	2.25	2.12	2.03	1.97	1.86	1.67	1.45
293	1910	0.4619	2.09	1.98	1.89	1.83	1.72	1.54	1.34
293	1915	0.6437	3.89	3.70	3.56	3.45	3.28	2.99	2.65
293	1920	0.8406	6.40	6.12	5.92	5.76	5.51	5.08	4.59
293	1925	0.7054	4.61	4.40	4.23	4.12	3.92	3.58	3.20
293	1930	0.5886	3.29	3.12	3.00	2.91	2.76	2.50	2.20
293	1935	0.5915	3.32	3.15	3.03	2.94	2.79	2.53	2.23
293	1940	0.6424	3.87	3.68	3.54	3.44	3.27	2.98	2.64
293	1945	0.6250	3.68	3.50	3.36	3.26	3.10	2.82	2.49
293	1950	0.7431	5.08	4.85	4.68	4.55	4.34	3.98	3.56
293	1955	0.7418	5.07	4.83	4.66	4.53	4.32	3.96	3.55
293	2000	0.6486	3.94	3.75	3.61	3.50	3.33	3.03	2.69
293	2005	0.6516	3.98	3.78	3.64	3.53	3.36	3.06	2.72
293	2010	0.6903	4.43	4.22	4.06	3.95	3.76	3.43	3.06
293	2015	0.7221	4.82	4.60	4.43	4.31	4.10	3.76	3.36
293	2020	0.7395	5.04	4.81	4.63	4.51	4.30	3.94	3.52
293	2025	0.6355	3.79	3.61	3.47	3.37	3.20	2.91	2.58
293	2030	0.4997	2.42	2.29	2.19	2.12	2.01	1.80	1.57
293	2035	0.3832	1.47	1.39	1.32	1.28	1.20	1.06	0.91
293	2040	0.2999	0.93	0.87	0.83	0.80	0.75	0.65	0.55
293	2045	0.2356	0.59	0.55	0.52	0.50	0.47	0.40	0.34
293	2050	0.1940	0.41	0.38	0.36	0.35	0.32	0.27	0.23
293	2055	0.1594	0.29	0.26	0.25	0.24	0.22	0.19	0.15
293	2100	0.1344	0.21	0.19	0.18	0.17	0.16	0.13	0.11
293	2105	0.1250	0.18	0.17	0.16	0.15	0.14	0.11	0.09
293	2110	0.1250	0.18	0.17	0.16	0.15	0.14	0.11	0.09
293	2115	0.1224	0.17	0.16	0.15	0.14	0.13	0.11	0.09
293	2120	0.1162	0.16	0.15	0.14	0.13	0.12	0.10	0.08
293	2125	0.1090	0.14	0.13	0.12	0.11	0.10	0.09	0.07
293	2130	0.1035	0.13	0.12	0.11	0.10	0.09	0.08	0.06
293	2135	0.0955	0.11	0.10	0.09	0.09	0.08	0.07	0.05
293	2140	0.1177	0.16	0.15	0.14	0.13	0.12	0.10	0.08
293	2145	0.2864	0.86	0.80	0.76	0.73	0.68	0.60	0.50
293	2150	0.4911	2.34	2.22	2.12	2.05	1.94	1.74	1.52
293	2155	0.5282	2.69	2.54	2.44	2.36	2.24	2.02	1.77
293	2200	0.4708	2.17	2.05	1.96	1.89	1.79	1.60	1.39
293	2205	0.4213	1.76	1.66	1.58	1.53	1.44	1.29	1.11
293	2210	0.3648	1.35	1.26	1.20	1.16	1.09	0.97	0.83

Appendix A-3: Effects of Alternative Palmer-Bowlus Flume Coefficients on Computed Runoff

Palmer-Bowlus flume rating: $Q / D^{2.5} = a (H_a / D)^b$ Where: $H_a = d - D/6$, D = 4.0 ft

Alternative flume coefficients: *(close to 1%)* *(midrange, about 0.5%)* *(close to 0%)*

Slope	1-2%	<1%	>0.5%	~0.5%	<0.5%	>0%	0%
a	3.685	3.65	3.64	3.6	3.55	3.54	3.536
b	1.868	1.89	1.91	1.92	1.94	1.99	2.055

Julian Date	Time	H_a (ft)	$Q_{1-2\%}$	$Q_{<1\%}$	$Q_{>0.5\%}$	$Q_{\sim 0.5\%}$	$Q_{<0.5\%}$	$Q_{>0\%}$	$Q_{0\%}$
293	2215	0.3051	0.96	0.90	0.85	0.82	0.77	0.68	0.57
293	2220	0.2520	0.67	0.63	0.59	0.57	0.53	0.46	0.39
293	2225	0.2090	0.48	0.44	0.41	0.40	0.37	0.32	0.26
293	2230	0.1792	0.36	0.33	0.31	0.30	0.27	0.23	0.19
293	2235	0.1712	0.33	0.30	0.28	0.27	0.25	0.21	0.17
293	2240	0.2480	0.65	0.61	0.58	0.55	0.52	0.45	0.37
293	2245	0.3924	1.54	1.45	1.38	1.33	1.26	1.12	0.96
293	2250	0.5410	2.81	2.66	2.55	2.47	2.34	2.11	1.85
293	2255	0.6158	3.58	3.40	3.27	3.17	3.01	2.74	2.42
293	2300	0.6214	3.64	3.46	3.32	3.23	3.07	2.79	2.46
293	2305	0.6476	3.93	3.74	3.60	3.49	3.32	3.02	2.68
293	2310	0.6585	4.05	3.86	3.71	3.61	3.43	3.13	2.78
293	2315	0.6506	3.96	3.77	3.63	3.52	3.35	3.05	2.71
293	2320	0.6394	3.84	3.65	3.51	3.41	3.24	2.95	2.61
293	2325	0.6010	3.42	3.25	3.12	3.03	2.87	2.61	2.30
293	2330	0.5243	2.65	2.51	2.40	2.33	2.20	1.99	1.74
293	2335	0.4682	2.14	2.03	1.94	1.87	1.77	1.59	1.38
293	2340	0.4049	1.63	1.54	1.47	1.42	1.34	1.19	1.02
293	2345	0.3278	1.10	1.03	0.98	0.94	0.89	0.78	0.66
293	2350	0.2608	0.72	0.67	0.63	0.61	0.57	0.49	0.41
293	2355	0.2094	0.48	0.44	0.42	0.40	0.37	0.32	0.26
294	0	0.1723	0.33	0.31	0.29	0.28	0.25	0.22	0.18
294	5	0.1458	0.24	0.22	0.21	0.20	0.18	0.16	0.13
294	10	0.1265	0.19	0.17	0.16	0.15	0.14	0.12	0.09
294	15	0.1135	0.15	0.14	0.13	0.12	0.11	0.09	0.07
294	20	0.1033	0.13	0.12	0.11	0.10	0.09	0.08	0.06
294	25	0.0931	0.11	0.10	0.09	0.08	0.08	0.06	0.05
294	30	0.0801	0.08	0.07	0.07	0.06	0.06	0.05	0.04
294	35	0.0782	0.08	0.07	0.06	0.06	0.06	0.05	0.03
294	40	0.0710	0.06	0.06	0.05	0.05	0.05	0.04	0.03
294	45	0.0677	0.06	0.05	0.05	0.05	0.04	0.03	0.03
294	50	0.0670	0.06	0.05	0.05	0.04	0.04	0.03	0.03
294	55	0.0877	0.09	0.09	0.08	0.08	0.07	0.06	0.04
294	100	0.1840	0.37	0.35	0.33	0.31	0.29	0.25	0.20
294	105	0.3507	1.25	1.17	1.11	1.08	1.01	0.89	0.76
294	110	0.3691	1.38	1.29	1.23	1.19	1.12	0.99	0.85
294	115	0.3048	0.96	0.90	0.85	0.82	0.77	0.67	0.57
294	120	0.2379	0.61	0.56	0.53	0.51	0.48	0.41	0.34
294	125	0.1924	0.41	0.38	0.35	0.34	0.32	0.27	0.22
294	130	0.1582	0.28	0.26	0.24	0.23	0.22	0.18	0.15
294	135	0.1368	0.22	0.20	0.18	0.18	0.16	0.14	0.11
294	140	0.1175	0.16	0.15	0.14	0.13	0.12	0.10	0.08
294	145	0.1023	0.13	0.11	0.11	0.10	0.09	0.08	0.06

Appendix A-3: Effects of Alternative Palmer-Bowlus Flume Coefficients on Computed Runoff

Palmer-Bowlus flume rating: $Q / D^{2.5} = a (H_a / D)^b$ Where: $H_a = d - D/6$, $D = 4.0$ ft

Alternative flume coefficients: *(close to 1%)* *(midrange, about 0.5%)* *(close to 0%)*

Slope	1-2%	<1%	>0.5%	~0.5%	<0.5%	>0%	0%
a	3.685	3.65	3.64	3.6	3.55	3.54	3.536
b	1.868	1.89	1.91	1.92	1.94	1.99	2.055

Julian Date	Time	H_a (ft)	$Q_{1-2\%}$	$Q_{<1\%}$	$Q_{>0.5\%}$	$Q_{\sim 0.5\%}$	$Q_{<0.5\%}$	$Q_{>0\%}$	$Q_{0\%}$
294	150	0.0936	0.11	0.10	0.09	0.09	0.08	0.06	0.05
294	155	0.0845	0.09	0.08	0.07	0.07	0.06	0.05	0.04
294	200	0.0783	0.08	0.07	0.06	0.06	0.06	0.05	0.03
294	205	0.0721	0.07	0.06	0.05	0.05	0.05	0.04	0.03
294	210	0.0689	0.06	0.05	0.05	0.05	0.04	0.03	0.03
294	215	0.0630	0.05	0.05	0.04	0.04	0.04	0.03	0.02
294	220	0.0594	0.05	0.04	0.04	0.04	0.03	0.03	0.02
294	225	0.0554	0.04	0.04	0.03	0.03	0.03	0.02	0.02
294	230	0.0551	0.04	0.04	0.03	0.03	0.03	0.02	0.02
294	235	0.0510	0.03	0.03	0.03	0.03	0.02	0.02	0.01
294	240	0.0485	0.03	0.03	0.03	0.02	0.02	0.02	0.01
294	245	0.0449	0.03	0.02	0.02	0.02	0.02	0.01	0.01
294	250	0.0452	0.03	0.02	0.02	0.02	0.02	0.02	0.01
294	255	0.0445	0.03	0.02	0.02	0.02	0.02	0.01	0.01
294	300	0.0416	0.02	0.02	0.02	0.02	0.02	0.01	0.01
294	305	0.0394	0.02	0.02	0.02	0.02	0.01	0.01	0.01
294	310	0.0390	0.02	0.02	0.02	0.02	0.01	0.01	0.01
294	315	0.0398	0.02	0.02	0.02	0.02	0.01	0.01	0.01
294	320	0.0398	0.02	0.02	0.02	0.02	0.01	0.01	0.01
294	325	0.0398	0.02	0.02	0.02	0.02	0.01	0.01	0.01
294	330	0.0358	0.02	0.02	0.01	0.01	0.01	0.01	0.01
294	335	0.0329	0.02	0.01	0.01	0.01	0.01	0.01	0.01
294	340	0.0340	0.02	0.01	0.01	0.01	0.01	0.01	0.01
294	345	0.0347	0.02	0.01	0.01	0.01	0.01	0.01	0.01
294	350	0.0336	0.02	0.01	0.01	0.01	0.01	0.01	0.01
294	355	0.0329	0.02	0.01	0.01	0.01	0.01	0.01	0.01
294	400	0.0332	0.02	0.01	0.01	0.01	0.01	0.01	0.01
294	405	0.0325	0.01	0.01	0.01	0.01	0.01	0.01	0.01
294	410	0.0336	0.02	0.01	0.01	0.01	0.01	0.01	0.01
294	415	0.0325	0.01	0.01	0.01	0.01	0.01	0.01	0.01
294	420	0.0322	0.01	0.01	0.01	0.01	0.01	0.01	0.01
294	425	0.0311	0.01	0.01	0.01	0.01	0.01	0.01	0.01
294	430	0.0318	0.01	0.01	0.01	0.01	0.01	0.01	0.01
294	435	0.0311	0.01	0.01	0.01	0.01	0.01	0.01	0.01
294	440	0.0314	0.01	0.01	0.01	0.01	0.01	0.01	0.01
294	445	0.0322	0.01	0.01	0.01	0.01	0.01	0.01	0.01
294	450	0.0300	0.01	0.01	0.01	0.01	0.01	0.01	0.00
294	455	0.0307	0.01	0.01	0.01	0.01	0.01	0.01	0.01
294	500	0.0297	0.01	0.01	0.01	0.01	0.01	0.01	0.00
294	505	0.0289	0.01	0.01	0.01	0.01	0.01	0.01	0.00
294	510	0.0289	0.01	0.01	0.01	0.01	0.01	0.01	0.00
294	515	0.0250	0.01	0.01	0.01	0.01	0.01	0.00	0.00
294	520	0.0257	0.01	0.01	0.01	0.01	0.01	0.00	0.00

Appendix A-3: Effects of Alternative Palmer-Bowlus Flume Coefficients on Computed Runoff

Palmer-Bowlus flume rating: $Q / D^{2.5} = a (H_a / D)^b$ Where: $H_a = d - D/6$, $D = 4.0$ ft

Alternative flume coefficients: *(close to 1%)* *(midrange, about 0.5%)* *(close to 0%)*

Slope	1-2%	<1%	>0.5%	~0.5%	<0.5%	>0%	0%
a	3.685	3.65	3.64	3.6	3.55	3.54	3.536
b	1.868	1.89	1.91	1.92	1.94	1.99	2.055

Julian Date	Time	H_a (ft)	$Q_{1-2\%}$	$Q_{<1\%}$	$Q_{>0.5\%}$	$Q_{\sim0.5\%}$	$Q_{<0.5\%}$	$Q_{>0\%}$	$Q_{0\%}$
294	525	0.0264	0.01	0.01	0.01	0.01	0.01	0.01	0.00
294	530	0.0257	0.01	0.01	0.01	0.01	0.01	0.00	0.00
294	535	0.0279	0.01	0.01	0.01	0.01	0.01	0.01	0.00
294	540	0.0253	0.01	0.01	0.01	0.01	0.01	0.00	0.00
294	545	0.0250	0.01	0.01	0.01	0.01	0.01	0.00	0.00
294	550	0.0239	0.01	0.01	0.01	0.01	0.01	0.00	0.00
294	555	0.0217	0.01	0.01	0.01	0.01	0.00	0.00	0.00
294	600	0.0184	0.01	0.00	0.00	0.00	0.00	0.00	0.00
294	605	0.0217	0.01	0.01	0.01	0.01	0.00	0.00	0.00
294	610	0.0181	0.00	0.00	0.00	0.00	0.00	0.00	0.00
294	615	0.0170	0.00	0.00	0.00	0.00	0.00	0.00	0.00
294	620	0.0159	0.00	0.00	0.00	0.00	0.00	0.00	0.00
294	625	0.0141	0.00	0.00	0.00	0.00	0.00	0.00	0.00
294	630	0.0123	0.00	0.00	0.00	0.00	0.00	0.00	0.00
294	635	0.0101	0.00	0.00	0.00	0.00	0.00	0.00	0.00
294	640	0.0072	0.00	0.00	0.00	0.00	0.00	0.00	0.00
294	645	0.0061	0.00	0.00	0.00	0.00	0.00	0.00	0.00
294	650	0.0029	0.00	0.00	0.00	0.00	0.00	0.00	0.00
294	655	0.0011	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Storm measured volume (ft^3):	43859.84	41541.92	39779.93	38553.42	36509.87	32914.42	28857.31
Adj. to original gaged area (ft^3):	46467	44011	42144	40845	38680	34871	30572
Adj. to original gaged area (in):	0.591	0.559	0.536	0.519	0.492	0.443	0.389
Adj. to 19.497 ac gaged area (in):	0.620	0.587	0.562	0.545	0.516	0.465	0.408
Percent of 1-2% basis volume:	100%	95%	91%	88%	83%	75%	66%

Appendix A-3: Effects of Alternative Palmer-Bowlus Flume Coefficients on Computed Runoff

Palmer-Bowlus flume rating: $Q / D^{2.5} = a (H_a / D)^b$ Where: $H_a = d - D/6$, $D = 4.0$ ft

Alternative flume coefficients: *(close to 1%)* *(midrange, about 0.5%)* *(close to 0%)*

Slope	1-2%	<1%	>0.5%	~0.5%	<0.5%	>0%	0%
a	3.685	3.65	3.64	3.6	3.55	3.54	3.536
b	1.868	1.89	1.91	1.92	1.94	1.99	2.055

Julian Date	Time	H_a (ft)	$Q_{1-2\%}$	$Q_{<1\%}$	$Q_{>0.5\%}$	$Q_{\sim0.5\%}$	$Q_{<0.5\%}$	$Q_{>0\%}$	$Q_{0\%}$
269	710	0.2023	0.45	0.41	0.39	0.37	0.35	0.30	0.25
269	715	0.2913	0.88	0.83	0.78	0.75	0.71	0.62	0.52
269	720	0.2999	0.93	0.87	0.83	0.80	0.75	0.65	0.55
269	725	0.3494	1.24	1.17	1.11	1.07	1.00	0.89	0.76
269	730	0.3822	1.47	1.38	1.31	1.27	1.19	1.06	0.91
269	735	0.3402	1.18	1.11	1.05	1.02	0.95	0.84	0.71
269	740	0.2726	0.78	0.73	0.69	0.66	0.62	0.54	0.45
269	745	0.2179	0.51	0.48	0.45	0.43	0.40	0.35	0.29
269	750	0.1907	0.40	0.37	0.35	0.33	0.31	0.27	0.22
269	755	0.1820	0.37	0.34	0.32	0.31	0.28	0.24	0.20
269	800	0.1762	0.35	0.32	0.30	0.29	0.27	0.23	0.18
269	805	0.1758	0.34	0.32	0.30	0.29	0.26	0.23	0.18
269	810	0.1784	0.35	0.33	0.31	0.29	0.27	0.23	0.19
269	815	0.1729	0.33	0.31	0.29	0.28	0.26	0.22	0.18
269	820	0.1591	0.29	0.26	0.25	0.24	0.22	0.19	0.15
269	825	0.1457	0.24	0.22	0.21	0.20	0.18	0.16	0.13
269	830	0.1308	0.20	0.18	0.17	0.16	0.15	0.13	0.10
269	835	0.1170	0.16	0.15	0.14	0.13	0.12	0.10	0.08
269	840	0.1163	0.16	0.15	0.14	0.13	0.12	0.10	0.08
269	845	0.1413	0.23	0.21	0.20	0.19	0.17	0.15	0.12
269	850	0.2405	0.62	0.58	0.54	0.52	0.49	0.42	0.35
269	855	0.3369	1.16	1.09	1.03	1.00	0.94	0.82	0.70
269	900	0.5308	2.71	2.57	2.46	2.38	2.26	2.04	1.78
269	905	0.6250	3.68	3.50	3.36	3.26	3.10	2.82	2.49
269	910	0.5945	3.35	3.18	3.05	2.96	2.81	2.55	2.25
269	915	0.5108	2.52	2.39	2.29	2.22	2.10	1.89	1.65
269	920	0.4239	1.78	1.68	1.60	1.55	1.46	1.30	1.12
269	925	0.3468	1.22	1.15	1.09	1.05	0.99	0.87	0.74
269	930	0.2822	0.83	0.78	0.74	0.71	0.66	0.58	0.49
269	935	0.2306	0.57	0.53	0.50	0.48	0.45	0.39	0.32
269	940	0.1911	0.40	0.37	0.35	0.34	0.31	0.27	0.22
269	945	0.1642	0.30	0.28	0.26	0.25	0.23	0.20	0.16
269	950	0.1403	0.23	0.21	0.19	0.19	0.17	0.14	0.12
269	955	0.1232	0.18	0.16	0.15	0.14	0.13	0.11	0.09
269	1000	0.1108	0.15	0.13	0.12	0.12	0.11	0.09	0.07
269	1005	0.1003	0.12	0.11	0.10	0.10	0.09	0.07	0.06

Appendix A-3: Effects of Alternative Palmer-Bowlus Flume Coefficients on Computed Runoff

Palmer-Bowlus flume rating: $Q / D^{2.5} = a (H_a / D)^b$ Where: $H_a = d - D/6$, $D = 4.0$ ft

Alternative flume coefficients: *(close to 1%)* *(midrange, about 0.5%)* *(close to 0%)*

Slope	1-2%	<1%	>0.5%	~0.5%	<0.5%	>0%	0%
a	3.685	3.65	3.64	3.6	3.55	3.54	3.536
b	1.868	1.89	1.91	1.92	1.94	1.99	2.055

Julian Date	Time	H_a (ft)	$Q_{1-2\%}$	$Q_{<1\%}$	$Q_{>0.5\%}$	$Q_{\sim 0.5\%}$	$Q_{<0.5\%}$	$Q_{>0\%}$	$Q_{0\%}$
269	1010	0.0887	0.10	0.09	0.08	0.08	0.07	0.06	0.05
269	1015	0.0796	0.08	0.07	0.07	0.06	0.06	0.05	0.04
269	1020	0.0716	0.06	0.06	0.05	0.05	0.05	0.04	0.03
269	1025	0.0658	0.05	0.05	0.05	0.04	0.04	0.03	0.02
269	1030	0.0589	0.04	0.04	0.04	0.03	0.03	0.03	0.02
269	1035	0.0538	0.04	0.03	0.03	0.03	0.03	0.02	0.02
269	1040	0.0476	0.03	0.03	0.02	0.02	0.02	0.02	0.01
269	1045	0.0440	0.03	0.02	0.02	0.02	0.02	0.01	0.01
269	1050	0.0389	0.02	0.02	0.02	0.02	0.01	0.01	0.01
269	1055	0.0364	0.02	0.02	0.01	0.01	0.01	0.01	0.01
269	1100	0.0320	0.01	0.01	0.01	0.01	0.01	0.01	0.01
269	1105	0.0295	0.01	0.01	0.01	0.01	0.01	0.01	0.00
269	1110	0.0233	0.01	0.01	0.01	0.01	0.01	0.00	0.00
269	1115	0.0186	0.01	0.00	0.00	0.00	0.00	0.00	0.00
269	1120	0.0146	0.00	0.00	0.00	0.00	0.00	0.00	0.00
269	1125	0.0088	0.00	0.00	0.00	0.00	0.00	0.00	0.00
269	1130	0.0033	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Storm measured volume (ft^3):	9361.81	8789.69	8350.31	8060.86	7573.50	6694.90	5723.21
Adj. to original gaged area (ft^3):	9918	9312	8847	8540	8024	7093	6063
Adj. to original gaged area (in):	0.126	0.118	0.112	0.109	0.102	0.090	0.077
Adj. to 19.497 ac gaged area (in):	0.132	0.124	0.118	0.114	0.107	0.095	0.081
Percent of 1-2% basis volume:	100%	94%	89%	86%	81%	72%	61%

Appendix A-4: T-Test Results Comparing SWMM, KINEROS, and Observations

Storm Event ID			Rainfall Summary Information					Observed Runoff Data			
#	Julian Date	Precip. (in)	max I-5 (in/hr)	max I-15 (in/hr)	% of time raining	Rain Duration		Runoff volume		Qpeak (cfs)	Tp (min)
						(hr)	(min)	(ft3)	(in)		
1	186	0.12	0.6	0.36	60.0	0.83	50		0		
2	187	0.53	2.52	1.24	17.3	6.25	375		0.000		
3	198	1.38	5.76	4.4	81.8	0.92	55	74731	1.056	69.13	20
4	230	1.8	4.68	3.72	69.4	3.00	180	120305	1.700	67.93	30
5	239	0.52	0.24	0.2	30.7	12.75	765	28832	0.407	4.56	350
6	259	0.57	0.36	0.2	31.4	14.33	860	35159	0.497	3.56	25
7	269	0.2	0.24	0.2	40.5	3.08	185	9363	0.132	3.68	135
8	277	0.26	0.12	0.08	26.5	8.17	490	12221	0.173	1.05	310
9	278	0.89	0.6	0.52	22.4	16.33	980	63218	0.893	11.46	220
10	287	0.23	0.36	0.24	19.6	8.50	510	11671	0.165	3.55	200
11	293	0.67	0.48	0.32	54.3	6.75	405	43863	0.620	6.40	65
12	306	0.26	0.36	0.24	11.4	14.67	880	11475	0.162	3.64	65
13	311	0.89	0.36	0.28	47.7	12.75	765	54516	0.770	5.96	190
14	315	0.42	1.8	0.8	19.4	10.33	620	22992	0.325	17.16	515
15	318	0.3	0.24	0.2	21.6	9.67	580		0.000		
16	79	0.77	0.48	0.4	41.5	11.25	675	61265	0.866	8.75	85
17	143	0.53	1.08	0.88	91.7	1.00	60		0.000		
Range:		1.68	5.64	4.32	80.30	15.50	930	110942	1.70	68.08	495
Min:		0.12	0.12	0.08	11.36	0.83	50	9363	0.00	1.05	20
Max:		1.80	5.76	4.40	91.67	16.33	980	120305	1.70	69.13	515
Avg:		0.61	1.19	0.84	40.43	8.27	496	42278	0.46	15.91	170

Appendix A-4: T-Test Results Comparing SWMM, KINEROS, and Observations

Storm Event ID			Computed SWMM Results				SWMM minus Observed			%Error in SWMM		
#	Julian Date	Precip. (in)	Volume (in)	Qpeak (cfs)	Tp (min)	Infilt (in)	Volume (in)	Qpeak (cfs)	Tp (min)	Volume (in)	Qpeak (cfs)	Tp (min)
1	186	0.12	0.085	3.90	19	0.018						
2	187	0.53	0.434	25.58	367	0.079						
3	198	1.38	1.239	83.64	13	0.126	0.183	14.51	-7	15%	17%	-54%
4	230	1.8	1.599	75.14	26	0.185	-0.101	7.22	-4	-6%	10%	-15%
5	239	0.52	0.425	3.35	341	0.078	0.018	-1.21	-9	4%	-36%	-3%
6	259	0.57	0.468	1.54	31	0.085	-0.029	-2.02	6	-6%	-131%	19%
7	269	0.2	0.153	3.26	137	0.03	0.021	-0.41	2	14%	-13%	1%
8	277	0.26	0.204	1.02	312	0.039	0.031	-0.03	2	15%	-3%	1%
9	278	0.89	0.74	8.05	213	0.133	-0.153	-3.41	-7	-21%	-42%	-3%
10	287	0.23	0.178	3.06	199	0.034	0.013	-0.49	-1	7%	-16%	-1%
11	293	0.67	0.553	5.09	59	0.1	-0.067	-1.32	-6	-12%	-26%	-10%
12	306	0.26	0.204	2.90	60	0.039	0.042	-0.74	-5	21%	-25%	-8%
13	311	0.89	0.74	4.46	189	0.133	-0.030	-1.50	-1	-4%	-34%	-1%
14	315	0.42	0.34	16.95	517	0.063	0.015	-0.21	2	4%	-1%	0%
15	318	0.3	0.238	3.00	580	0.045						
16	79	0.77	0.638	6.34	90	0.115	-0.228	-2.42	5	-36%	-38%	6%
17	143	0.53	0.434	15.11	40	0.079						
Range:		1.68	1.51	82.62	567	0.17	0.411	17.93	15.00	56%	148%	73%
Min:		0.12	0.09	1.02	13	0.02	-0.228	-3.41	-9.00	-36%	-131%	-54%
Max:		1.80	1.60	83.64	580	0.19	0.183	14.51	6.00	21%	17%	19%
Avg:		0.61	0.51	15.44	188	0.08	-0.022	0.61	-1.77	0%	-26%	-5%

d =	-0.022	0.614	-1.77
s_D =	0.101	4.880	4.92
Δ_0 =	0	0	0
α =	0.05	0.05	0.05
n =	13	13	13
$t_{\alpha,n-1}$ =	1.782	1.782	1.782
Test t =	-0.780	0.454	-1.297
Result:	Equal	Equal	Equal

Appendix A-4: T-Test Results Comparing SWMM, KINEROS, and Observations

Storm Event ID			Computed KINEROS Results				KINEROS minus Observed			%Error in KINEROS		
#	Julian Date	Precip. (in)	Volume (in)	Qpeak (cfs)	Tp (min)	Infilt (in)	Volume (in)	Qpeak (cfs)	Tp (min)	Volume (in)	Qpeak (cfs)	Tp (min)
1	186	0.12	0.09	5.34	15.1	0.003						
2	187	0.53	0.44	32.28	361.1	0.064						
3	198	1.38	1.22	91.07	11	0.128	0.17	21.94	-9.0	16%	32%	-45%
4	230	1.8	1.62	76.55	20.1	0.145	-0.08	8.63	-9.9	-4%	13%	-33%
5	239	0.52	0.43	3.61	337.1	0.063	0.02	-0.95	-12.9	5%	-21%	-4%
6	259	0.57	0.47	1.80	18.1	0.070	-0.03	-1.76	-6.9	-6%	-49%	-28%
7	269	0.2	0.15	3.62	132.1	0.015	0.02	-0.06	-2.9	16%	-2%	-2%
8	277	0.26	0.20	1.06	307.1	0.024	0.03	0.01	-2.9	19%	1%	-1%
9	278	0.89	0.74	8.97	204.1	0.118	-0.15	-2.49	-15.9	-17%	-22%	-7%
10	287	0.23	0.18	3.94	195.1	0.019	0.01	0.38	-4.9	9%	11%	-2%
11	293	0.67	0.55	5.84	59.1	0.085	-0.07	-0.56	-5.9	-11%	-9%	-9%
12	306	0.26	0.20	3.90	55.1	0.024	0.04	0.26	-9.9	26%	7%	-15%
13	311	0.89	0.74	4.90	184.2	0.118	-0.03	-1.06	-5.8	-4%	-18%	-3%
14	315	0.42	0.34	21.62	512	0.048	0.02	4.46	-3.0	5%	26%	-1%
15	318	0.3	0.24	3.03	576.1	0.030						
16	79	0.77	0.64	7.06	83.1	0.100	-0.23	-1.69	-1.9	-26%	-19%	-2%
17	143	0.53	0.43	15.75	36	0.064						
Range:		1.68	1.54	90.01	565	0.14	0.39	24.43	14.0	53%	81%	44%
Min:		0.12	0.09	1.06	11	0.00	-0.23	-2.49	-15.9	-26%	-49%	-45%
Max:		1.80	1.62	91.07	576	0.14	0.17	21.94	-1.9	26%	32%	-1%
Avg:		0.61	0.51	17.08	183	0.07	-0.02	2.08	-7.1	2%	-4%	-12%

d =	-0.020	2.085	-7.06
s_D =	0.097	6.671	4.26
Δ_0 =	0	0	0
α =	0.05	0.05	0.05
n =	13	13	13
$t_{\alpha,n-1}$ =	1.782	1.782	1.782
Test t =	-0.762	1.127	-5.981
Result:	Equal	Equal	Not Eq.

Appendix A-4: T-Test Results Comparing SWMM, KINEROS, and Observations

Storm Event ID			SWMM minus KINEROS				(SWMM - KINEROS) / KINEROS			
#	Julian Date	Precip. (in)	Volume (in)	Qpeak (cfs)	Tp (min)	Infilt (in)	Volume (in)	Qpeak (cfs)	Tp (min)	Infilt (in)
1	186	0.12	-0.0006	-1.44	3.9	0.015	-0.7%	-27.0%	25.8%	503.4%
2	187	0.53	-0.0014	-6.70	5.9	0.015	-0.3%	-20.8%	1.6%	24.4%
3	198	1.38	0.0169	-7.43	2	-0.002	1.4%	-8.2%	18.2%	-1.4%
4	230	1.8	-0.0245	-1.41	5.9	0.040	-1.5%	-1.8%	29.4%	27.9%
5	239	0.52	-0.0011	-0.26	3.9	0.015	-0.3%	-7.2%	1.2%	24.5%
6	259	0.57	-0.0010	-0.26	12.9	0.015	-0.2%	-14.4%	71.3%	21.3%
7	269	0.2	-0.0005	-0.35	4.9	0.015	-0.3%	-9.8%	3.7%	101.1%
8	277	0.26	-0.0007	-0.04	4.9	0.015	-0.4%	-3.6%	1.6%	63.4%
9	278	0.89	-0.0020	-0.92	8.9	0.015	-0.3%	-10.3%	4.4%	12.9%
10	287	0.23	-0.0011	-0.87	3.9	0.015	-0.6%	-22.2%	2.0%	75.3%
11	293	0.67	-0.0005	-0.75	-0.1	0.015	-0.1%	-12.9%	-0.2%	17.6%
12	306	0.26	-0.0009	-1.00	4.9	0.015	-0.4%	-25.6%	8.9%	63.4%
13	311	0.89	-0.0011	-0.44	4.8	0.015	-0.1%	-9.0%	2.6%	12.9%
14	315	0.42	-0.0014	-4.67	5	0.015	-0.4%	-21.6%	1.0%	32.0%
15	318	0.3	-0.0004	-0.03	3.9	0.015	-0.1%	-1.0%	0.7%	50.9%
16	79	0.77	-0.0010	-0.72	6.9	0.015	-0.2%	-10.2%	8.3%	15.1%
17	143	0.53	-0.0006	-0.64	4	0.015	-0.1%	-4.1%	11.1%	23.2%
Range:		1.68	0.04	7.40	13.00	0.04	2.9%	26.0%	71.4%	504.8%
Min:		0.12	-0.02	-7.43	-0.10	0.00	-1.5%	-27.0%	-0.2%	-1.4%
Max:		1.80	0.02	-0.03	12.90	0.04	1.4%	-1.0%	71.3%	503.4%
Avg:		0.61	0.00	-1.64	5.09	0.02	-0.3%	-12.3%	11.3%	62.8%

d =	-0.001	-1.643	5.088	0.016
s_D =	0.007	2.299	2.780	0.008
Δ_0 =	0	0	0	0
α =	0.05	0.05	0.05	0.05
n =	17	17	17	17
$t_{\alpha,n-1}$ =	1.746	1.746	1.746	1.746
Test t =	-0.714	-2.946	7.547	8.487
Result:	Equal	Not Eq.	Not Eq.	Not Eq.

APPENDIX B

INPUT FILES FOR MODEL TESTING

- **B-1: SWMM Parameter Input for Model Testing**
- **B-2: SWMM Rainfall Input for Model Testing**
- **B-3: KINEROS Parameter Input for Model Testing**
- **B-4: KINEROS Rainfall Input for Model Testing**

Appendix B-1: SWMM Parameter Input for Model Testing

Note: The input file below models a single storm event. Replace the B3, E1, and E3 lines with the appropriate storm from Appendix B-2 to model other events.

```
SW      1       0       10
MM      7       1       2       3       4       12      13      14
@  10  'RUNOFF.INT'
$ANUM
$NOQUOTE
$RUNOFF
A1 'COMMUTER PARKING LOT SWMM MODEL'
A1 'EVENT MODE SIMULATION - SWMM vs. K2'
*       METRIC ISNOW NRGAG INFILM KWALTY IVAP NHR   NMN NDAY MONTH IYRSTR
B1      0       0       1       1       0       1       0       0       1       1       95
*       1inpt 2graf 3out  gwerr   nohed   landupr (Print control IPRN(1-3))
B2      1       1       2       1       1       0
*   !!Change LONG to reflect modeled storm
*       Wet     WtDry Dry       Lunit   Long
B3      60      60      60      1       500
*       PctZer Regen(N/R)
B4      0.001    0.01
*       ROPT
D1      0
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
*
E1      0       10      0       0       0       1       10      5.0     0
*
E3      0.16    0.48    0.37    0.25    0.08    0.02    0.01    0.00    0.00    0.01
*
*       MONTHLY EVAPORATION DATA (used in lieu of IVAP=0, 0.1"/day default)
F1      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
*CHANNEL/PIPE DATA
*       NameG   Ngto    Type    W       L       Slope   GS1     GS2     N       Dfull   Gdepth
G1      46      610     2       1.75    75      0.0053  0       0       0.013   0       0
G1      610     1023    2       2       235     0.0051  0       0       0.013   0       0
G1      89      910     2       1.75    54      0.0050  0       0       0.013   0       0
G1      910     1023    2       1.25    100     0.0050  0       0       0.013   0       0
G1      1023    2341    2       2.5     282     0.0050  0       0       0.013   0       0
G1      1223    2341    2       1.75    66      0.0076  0       0       0.013   0       0
G1      2122    2223    2       1.25    70      0.0286  0       0       0.013   0       0
G1      2223    2341    2       2       206     0.0335  0       0       0.013   0       0
G1      2341    4124    2       3       55      0.0051  0       0       0.013   0       0
G1      4124    2431    2       3.5     145     0.0054  0       0       0.013   0       0
G1      2431    3132    2       3.5     213     0.0052  0       0       0.013   0       0
G1      3031    3132    2       2       295     0.0305  0       0       0.013   0       0
G1      3132    3299    2       4       178     0.0051  0       0       0.013   0       0
G1      3299    9999    2       4       20      0.0052  0       0       0.013   0       0
* SUBCATCHMENT DATA
*       JK      NameW Ngto      Wid     Area    %Imp    S       ImpN    PervN   IDS     PDS     G
        Ksat    Smdmax RmaxInf IflowP PZ
H1      1       1       46      396     2.401   81.8    0.0221  0.015   0.25    0.02    0.1     8
        0.2     0.24
H1      1       101     89      254     1.577   77.48   0.0260  0.015   0.25    0.02    0.1     8
        0.2     0.24
H1      1       2       610     277     1.087   90.96   0.0299  0.015   0.25    0.02    0.1     8
        0.2     0.24
```

Appendix B-1: SWMM Parameter Input for Model Testing

```
H1      1       201     1223    387     1.974   95.24   0.0252  0.015   0.25    0.02    0.1     8
        0.2     0.24
H1      1       3       2122    334     2.365   79.24   0.0431  0.015   0.25    0.02    0.1     8
        0.2     0.24
H1      1       4       2431    403     2.148   86.17   0.0364  0.015   0.25    0.02    0.1     8
        0.2     0.24
H1      1       5       3031    756     6.181   83.97   0.0476  0.015   0.25    0.02    0.1     8
        0.2     0.24
H1      1       6       3299    327     1.764   91.78   0.0477  0.015   0.25    0.02    0.1     8
        0.2     0.24
* PRINT CONTROL
*       Nprnt   Interv(every K time steps)
M1      1       1
*       Ndet    StartP(1)       StopP(1)
M2      1       0       0
*       IPRNT(1)
M3      3299
$ENDPROGRAM
```

Appendix B-2: SWMM Rainfall Input for Model Testing

Note: Insert the B3, E1, and E3 lines below at the appropriate locations in the SWMM input file in Appendix B-1 to model each design storm. 15-minute resolution hyetographs are located at the end of this section. Storm names combine the Julian date with the two-digit year.

186_95 Storm

```
*         Wet       WtDry Dry           Lunit     Long
B3        60        60        60        1         500
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1  0  10  1  0  0  1         11        5.0  0
E3        0         0.03      0.05      0.01      0.01      0         0         0.01      0         0.01
E3        0
*
```

187_95 Storm

```
*         Wet       WtDry Dry           Lunit     Long
B3        60        60        60        1         580
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1  0  10  1  0  0  1         76        5.0  0
E3        0         0.01      0         0.01      0.06      0.05      0.02      0.01      0         0.01
E3        0         0         0         0         0         0.01      0         0.01      0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0.03      0.21      0.07      0.03      0
*
```

198_95 Storm

```
*         Wet       WtDry Dry           Lunit     Long
B3        60        60        60        1         500
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1        0         10        0         0         0         1         10        5.0       0
E3        0.16      0.48      0.37      0.25      0.08      0.02      0.01      0.00      0.00      0.01
*
```

230_95 Storm

```
*         Wet       WtDry Dry           Lunit     Long
B3        60        60        60        1         500
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1  0  10  1  0  0  1         37        5.0  0
E3        0         0.08      0.2       0.27      0.39      0.27      0.11      0.05      0.09      0.06
E3        0.05      0.05      0.04      0.01      0.01      0.01      0.02      0.01      0.01      0.01
E3        0         0.01      0         0         0         0         0         0         0         0
E3        0.01      0         0.01      0.01      0.01      0.01      0
*
```

Appendix B-2: SWMM Rainfall Input for Model Testing

239_95 Storm

```
*       Wet     WtDry Dry       Lunit   Long
B3      60      60      60      1       970
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1  0  10  1  0  0  1           154     5.0  0
E3      0       0.01    0       0       0       0       0       0.01    0       0
E3      0       0       0       0       0.01    0       0       0       0.01    0
E3      0       0       0       0       0       0       0.01    0       0       0
E3      0       0       0       0       0       0       0       0       0       0.01
E3      0       0.01    0       0.01    0       0.01    0.01    0       0.01    0.01
E3      0       0.01    0.01    0       0.01    0.01    0.01    0.01    0.01    0.01
E3      0.02    0.02    0.01    0.01    0.01    0.01    0.02    0.02    0.01    0.02
E3      0       0.01    0       0.01    0       0       0.01    0       0       0.01
E3      0       0.01    0       0.01    0       0       0       0.01    0       0
E3      0       0       0       0       0       0.01    0       0       0       0
E3      0       0.01    0       0       0       0.01    0       0       0.01    0
E3      0       0       0       0.01    0       0       0.01    0       0       0
E3      0       0       0       0       0       0       0       0.01    0       0
E3      0       0       0.01    0       0       0       0       0       0       0
E3      0       0       0       0.01    0       0       0       0       0       0
E3      0       0       0.01    0
*
```

259_95 Storm

```
*       Wet     WtDry Dry       Lunit   Long
B3      60      60      60      1       1060
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1  0  10  1  0  0  1           173     5.0  0
E3      0       0.03    0.02    0       0.01    0.01    0       0       0       0.01
E3      0       0       0.01    0       0       0.01    0       0.01    0.01    0
E3      0.01    0       0.01    0.01    0       0       0.01    0       0       0.01
E3      0       0       0       0       0.01    0       0       0.01    0       0
E3      0.01    0       0       0.01    0       0       0       0.01    0       0
E3      0.01    0       0       0       0.01    0       0.01    0       0.01    0
E3      0       0       0.01    0       0       0.01    0       0       0.01    0
E3      0       0       0       0       0       0.01    0       0       0.01    0
E3      0       0       0.01    0.01    0       0.01    0       0.01    0       0.01
E3      0       0.01    0       0.01    0       0       0       0.01    0       0
E3      0.01    0.01    0       0.01    0.01    0       0       0.01    0       0
E3      0.01    0       0       0.01    0       0       0       0.01    0       0
E3      0       0       0.01    0       0       0.01    0       0       0.01    0
E3      0.01    0       0.01    0       0.01    0       0       0       0       0
E3      0       0       0       0.01    0       0       0       0       0       0
E3      0       0       0       0       0       0       0       0       0.01    0
E3      0       0       0.01    0       0       0       0       0       0       0
E3      0       0.01    0
*
```

Appendix B-2: SWMM Rainfall Input for Model Testing

269_95 Storm

```
*         Wet       WtDry Dry           Lunit     Long
B3        60        60        60        1         500
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1  0  10  1  0  0  1         38        5.0  0
E3        0         0.02      0.02      0         0         0.01      0.01      0         0.01      0
E3        0         0         0         0.01      0         0         0.01      0         0         0
E3        0         0         0.02      0.01      0.01      0.02      0.02      0.01      0         0.01
E3        0         0         0         0         0         0         0.01      0
*
```

277_95 Storm

```
*         Wet       WtDry Dry           Lunit     Long
B3        60        60        60        1         700
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1  0  10  1  0  0  1         99        5.0  0
E3        0         0.01      0         0         0         0         0         0.01      0         0.01
E3        0         0         0.01      0         0         0         0         0         0.01      0
E3        0         0         0         0         0         0         0.01      0         0         0.01
E3        0         0         0         0.01      0         0.01      0         0         0         0.01
E3        0         0.01      0         0         0.01      0         0         0.01      0         0.01
E3        0         0         0.01      0         0.01      0         0         0.01      0         0.01
E3        0         0.01      0         0         0.01      0         0         0         0         0
E3        0         0         0         0         0.01      0         0.01      0         0         0.01
E3        0         0         0         0         0         0         0.01      0         0         0
E3        0         0         0         0.01      0         0         0         0.01      0
*
```

278_95 Storm

```
*         Wet       WtDry Dry           Lunit     Long
B3        60        60        60        1         1190
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1  0  10  1  0  0  1         197       5.0  0
E3        0         0.01      0         0         0         0.01      0         0         0.01      0.01
E3        0         0.01      0.03      0.01      0         0.01      0         0         0         0
E3        0         0.01      0         0.01      0         0         0.01      0         0         0
E3        0.01      0.01      0         0.01      0.01      0         0.01      0.01      0         0.04
E3        0.05      0.04      0.04      0.04      0.01      0         0.01      0         0.01      0
E3        0.01      0         0.01      0         0         0.04      0.05      0.02      0.01      0.02
E3        0.05      0.02      0.01      0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0.03      0.03      0.01      0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0.05      0.02
E3        0         0         0         0.01      0.01      0.05      0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0.01      0
```

Appendix B-2: SWMM Rainfall Input for Model Testing

```
*
```

287_95 Storm

```
*         Wet       WtDry Dry           Lunit     Long
B3        60        60        60        1         710
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1  0  10  1  0  0  1         103       5.0  0
E3        0         0.01      0         0         0         0         0         0         0         0
E3        0         0.01      0         0         0         0.01      0         0         0         0
E3        0         0.01      0         0.01      0         0         0.01      0         0         0
E3        0         0         0         0         0         0         0         0.02      0.03      0.01
E3        0.01      0         0.01      0         0.01      0.01      0         0.01      0.01      0.01
E3        0         0         0.01      0         0         0         0.01      0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0.01      0         0         0
E3        0         0.01      0
*
```

293_95 Storm

```
*         Wet       WtDry Dry           Lunit     Long
B3        60        60        60        1         610
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1        0         13        0         0         0         1         81        5.0       0
E3        0.01      0         0.03      0         0         0.01      0.01      0.02      0         0.02      0.04      0.02
          0.01
E3        0.01      0.02      0.01      0.02      0.03      0.01      0.01      0.02      0.03      0.02      0.01      0.01
          0.01
E3        0         0         0         0         0         0         0         0         0.01      0         0         0
          0
E3        0.01      0.02      0.01      0.01      0.01      0         0         0.01      0         0         0         0.01
          0.01
E3        0.01      0.02      0.02      0.01      0.02      0.02      0.02      0.01      0.01      0.01      0.01      0
          0
E3        0         0         0         0         0         0         0         0         0         0         0         0
          0.01
E3        0         0.02      0
*
```

306_95 Storm

```
*         Wet       WtDry Dry           Lunit     Long
B3        60        60        60        1         1090
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1  0  10  1  0  0  1         177       5.0  0
E3        0         0.01      0         0         0         0         0         0.01      0         0.02
E3        0.03      0.01      0.01      0.01      0.01      0.01      0.01      0         0.01      0.02
E3        0         0         0         0         0.01      0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0.01      0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
```

Appendix B-2: SWMM Rainfall Input for Model Testing

```
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0.01      0
E3        0         0         0         0         0         0         0         0.01      0         0
E3        0         0         0         0         0         0         0.01      0         0         0
E3        0         0         0.01      0         0.03      0         0         0         0         0
E3        0         0         0         0         0         0.01      0
*
```

311_95 Storm

```
*         Wet       WtDry Dry         Lunit     Long
B3        60        60        60        1         970
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1  0  10  1  0  0  1         154       5.0  0
E3        0         0.01      0         0         0         0.01      0         0         0         0
E3        0.01      0         0.01      0.01      0         0.01      0         0         0         0.01
E3        0         0.01      0.01      0         0.01      0         0         0.01      0.03      0.01
E3        0.01      0.02      0.01      0.01      0.01      0.02      0.03      0.02      0.02      0.02
E3        0.02      0.02      0.01      0.01      0.02      0.02      0.01      0.01      0         0.02
E3        0.01      0         0.01      0         0.01      0         0.01      0         0.01      0
E3        0.01      0         0.01      0.01      0.01      0         0.01      0.01      0.01      0.01
E3        0.01      0.01      0.01      0.01      0         0.01      0.01      0         0.01      0
E3        0         0.01      0         0.01      0         0         0         0.01      0         0
E3        0         0         0         0         0         0.01      0         0         0.01      0
E3        0         0         0         0         0.01      0         0         0         0         0.01
E3        0.02      0.02      0.01      0.01      0.01      0         0.01      0         0         0.01
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0.01      0         0         0         0.01
E3        0         0.01      0         0.01      0         0.01      0         0.01      0         0
E3        0         0         0.01      0
*
```

315_95 Storm

```
*         Wet       WtDry Dry         Lunit     Long
B3        60        60        60        1         820
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1  0  10  1  0  0  1         125       5.0  0
E3        0         0.01      0         0         0         0         0         0         0         0.01
E3        0         0         0         0         0         0         0         0         0         0.01
E3        0         0.01      0         0         0         0.01      0.01      0         0.01      0
E3        0         0         0         0         0.01      0         0.01      0         0.01      0
E3        0.01      0         0         0         0         0         0         0.01      0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0         0         0
E3        0         0         0         0         0         0         0         0.01      0         0
E3        0         0         0.01      0         0         0.01      0.01      0         0         0
E3        0         0.03      0.15      0.02      0.02      0         0         0.01      0         0
E3        0.01      0.01      0         0         0         0         0         0         0         0
```

Appendix B-2: SWMM Rainfall Input for Model Testing

```
E3      0       0       0       0.01    0
*
```

318_95 Storm

```
*       Wet     WtDry Dry       Lunit   Long
B3      60      60      60      1       790
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1  0  10  1  0  0  1           117     5.0  0
E3      0       0.01    0       0       0       0       0       0       0       0
E3      0       0       0       0       0       0       0       0       0       0
E3      0       0       0       0       0       0       0       0       0       0
E3      0       0       0       0       0       0       0       0       0       0
E3      0       0       0       0.01    0       0       0       0       0       0
E3      0       0       0       0       0       0       0       0       0       0
E3      0       0       0       0       0       0       0       0       0       0
E3      0       0       0       0       0       0       0       0       0       0.01
E3      0       0       0       0       0       0       0       0       0       0
E3      0       0       0       0.01    0.02    0.01    0.01    0.01    0.01    0.01
E3      0.02    0.01    0.01    0.01    0.01    0.01    0       0.01    0.01    0.01
E3      0.02    0.01    0.01    0.02    0.01    0.02    0
*
```

079_96 Storm

```
*       Wet     WtDry Dry       Lunit   Long
B3      60      60      60      1       880
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1  0  10  1  0  0  1           136     5.0  0
E3      0       0.01    0.02    0.02    0       0       0       0.01    0       0
E3      0.01    0       0       0.01    0.02    0.03    0.04    0.03    0.02    0.02
E3      0.02    0.02    0.01    0.02    0.02    0.03    0.02    0.01    0.01    0
E3      0.01    0       0.01    0.01    0       0.01    0       0       0       0
E3      0       0.01    0       0.01    0.02    0       0.01    0       0.01    0
E3      0       0.01    0.01    0       0       0.01    0       0       0.01    0.01
E3      0.01    0       0.01    0       0.01    0       0       0.01    0.01    0
E3      0.01    0       0       0       0       0       0       0       0       0.01
E3      0       0       0       0       0       0       0       0       0       0.01
E3      0       0.02    0.01    0.01    0.01    0       0       0.01    0       0.01
E3      0       0.01    0.01    0       0       0.01    0       0       0       0
E3      0       0       0       0       0       0       0       0       0       0
E3      0       0       0       0       0       0.01    0.01    0       0       0.01
E3      0       0       0       0       0.01    0
*
```

143_96 Storm

```
*       Wet     WtDry Dry       Lunit   Long
B3      60      60      60      1       500
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1  0  10  1  0  0  1           13      5.0  0
E3      0       0.07    0.03    0.05    0.04    0.07    0.06    0.09    0.02    0.04
E3      0.05    0.01    0
*
```

Appendix B-2: SWMM Rainfall Input for Model Testing

198_95 Storm, 15-minute rainfall data resolution

```
*      Wet    WtDry Dry    Lunit  Long
B3     60     60    60     1      500
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1     0      10     1      0      0      1      5      15     0
E3     1.01   0.35   0.01   0.01   0.00
*
```

268_95 Storm, 15-minute rainfall data resolution

```
*      Wet    WtDry Dry    Lunit  Long
B3     60     60    60     1      500
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1     0      10     1      0      0      1      13     15.0   0
E3     0.04   0.02   0.01   0.00   0.01   0.01   0.00   0.04   0.05   0.01
E3     0.00   0.01   0.00
*
```

293_95 Storm, 15-minute rainfall data resolution

```
*      Wet    WtDry Dry    Lunit  Long
B3     60     60    60     1      610
*
*  KTYPE  KINC  KPRINT  KTHIS  KTIME   KPREP   NHISTO  THISTO  TZRAIN
E1     0      10     1      0      0      1      28     15     0
E3     0.04   0.01   0.03   0.08   0.04   0.06   0.04   0.06   0.02   0.00
E3     0.00   0.01   0.00   0.04   0.02   0.01   0.01   0.04   0.05   0.05
E3     0.03   0.00   0.00   0.00   0.00   0.01   0.02   0.00
*
```

Appendix B-3: KINEROS Parameter Input for Model Testing

Note: Run the KINEROS parameter input file (.par suffix) below, with the appropriate rainfall file (.pre suffix) from Appendix B-4.

```
Begin Global
Units = English, Clen = 356.143
Nele = 22
End Global

Begin Plane
Id        Pr        Len       Acr       Slp       Man       Int       Can
1         0         264.11    1.964     0.0221    0.015     0.02      1
End Plane

Begin Plane
Id        Pr        Len       Acr       Slp       Man       Int       Can
21        0         264.11    0.437     0.0221    0.25      0.1       1
Sat       CV        Thick     Ksat      G         Dist      Poros
0.18      0         3         0.2       8         0.24      0.42
End Plane

Begin Channel
Id        Pr        Len       Wid       Slp       Man       SS1       SS2
46        0         75        0.875     0.0053    0.013     0.5       0.5
Up =      1,21
End Channel

Begin Plane
Id        Pr        Len       Acr       Slp       Man       Int       Can
2         0         170.938   0.989     0.0299    0.015     0.02      1
End Plane

Begin Plane
Id        Pr        Len       Acr       Slp       Man       Int       Can
22        0         170.938   0.098     0.0299    0.25      0.1       1
Sat       CV        Thick     Ksat      G         Dist      Poros
0.18      0         3         0.2       8         0.24      0.42
End Plane

Begin Channel
Id        Pr        Len       Wid       Slp       Man       SS1       SS2
610       0         235       1         0.0051    0.013     0.5       0.5
Up =      2,22,46
End Channel

Begin Plane
Id        Pr        Len       Acr       Slp       Man       Int       Can
101       0         270.449   1.222     0.026     0.015     0.02      1
End Plane

Begin Plane
Id        Pr        Len       Acr       Slp       Man       Int       Can
121       0         270.449   0.355     0.026     0.25      0.1       1
Sat       CV        Thick     Ksat      G         Dist      Poros
0.18      0         3         0.2       8         0.24      0.42
End Plane
```

Appendix B-3: KINEROS Parameter Input for Model Testing

```
Begin Channel
Id      Pr      Len     Wid     Slp     Man     SS1     SS2
89      0       54      0.875   0.005   0.013   0.5     0.5
Up =    101,121
End Channel

Begin Channel
Id      Pr      Len     Wid     Slp     Man     SS1     SS2
910     0       100     0.625   0.005   0.013   0.5     0.5
Up =    89
End Channel

Begin Channel
Id      Pr      Len     Wid     Slp     Man     SS1     SS2
1023    0       282     1.25    0.005   0.013   0.5     0.5
Up =    610,910
End Channel

Begin Plane
Id      Pr      Len     Acr     Slp     Man     Int     Can
201     0       222.19  1.88    0.0252  0.015   0.02    1
End Plane

Begin Plane
Id      Pr      Len     Acr     Slp     Man     Int     Can
221     0       222.19  0.094   0.0252  0.25    0.1     1
Sat     CV      Thick   Ksat    G       Dist    Poros
0.18    0       3       0.2     8       0.24    0.42
End Plane

Begin Channel
Id      Pr      Len     Wid     Slp     Man     SS1     SS2
1223    0       66      0.875   0.0076  0.013   0.5     0.5
Up =    201,221
End Channel

Begin Plane
Id      Pr      Len     Acr     Slp     Man     Int     Can
3       0       308.441 1.874   0.0431  0.015   0.02    1
End Plane

Begin Plane
Id      Pr      Len     Acr     Slp     Man     Int     Can
23      0       308.441 0.491   0.0431  0.25    0.1     1
Sat     CV      Thick   Ksat    G       Dist    Poros
0.18    0       3       0.2     8       0.24    0.42
End Plane

Begin Channel
Id      Pr      Len     Wid     Slp     Man     SS1     SS2
2122    0       70      0.625   0.0286  0.013   0.5     0.5
Up =    3,23
End Channel
```

Appendix B-3: KINEROS Parameter Input for Model Testing

```
Begin Channel
Id       Pr       Len      Wid      Slp      Man      SS1      SS2
2223     0        206      1        0.0335   0.013    0.5      0.5
Up =     2122
End Channel

Begin Channel
Id       Pr       Len      Wid      Slp      Man      SS1      SS2
2341     0        55       1.5      0.0051   0.013    0.5      0.5
Up =     1023,1223,2223
End Channel

Begin Channel
Id       Pr       Len      Wid      Slp      Man      SS1      SS2
4124     0        145      1.75     0.0054   0.013    0.5      0.5
Up =     2341
End Channel

Begin Plane
Id       Pr       Len      Acr      Slp      Man      Int      Can
4        0        232.176  1.851    0.0364   0.015    0.02     1
End Plane

Begin Plane
Id       Pr       Len      Acr      Slp      Man      Int      Can
24       0        232.176  0.297    0.0364   0.25     0.1      1
Sat      CV       Thick    Ksat     G        Dist     Poros
0.18     0        3        0.2      8        0.24     0.42
End Plane

Begin Channel
Id       Pr       Len      Wid      Slp      Man      SS1      SS2
2431     0        213      1.75     0.0052   0.013    0.5      0.5
Up =     4124,4,24
End Channel

Begin Plane
Id       Pr       Len      Acr      Slp      Man      Int      Can
5        0        356.143  5.19     0.0476   0.015    0.02     1
End Plane

Begin Plane
Id       Pr       Len      Acr      Slp      Man      Int      Can
25       0        356.143  0.991    0.0476   0.25     0.1      1
Sat      CV       Thick    Ksat     G        Dist     Poros
0.18     0        3        0.2      8        0.24     0.42
End Plane

Begin Channel
Id       Pr       Len      Wid      Slp      Man      SS1      SS2
3031     0        295      1        0.0305   0.013    0.5      0.5
Up =     5,25
End Channel

Begin Channel
```

Appendix B-3: KINEROS Parameter Input for Model Testing

```
Id      Pr      Len     Wid     Slp     Man     SS1     SS2
3132    0       178     2       0.0051  0.013   0.5     0.5
Up =    3031,2431
End Channel

Begin Plane
Id      Pr      Len     Acr     Slp     Man     Int     Can
6       0       234.984 1.619   0.0477  0.015   0.02    1
End Plane

Begin Plane
Id      Pr      Len     Acr     Slp     Man     Int     Can
26      0       234.984 0.145   0.0477  0.25    0.1     1
Sat     CV      Thick   Ksat    G       Dist    Poros
0.18    0       3       0.2     8       0.24    0.42
End Plane

Begin Channel
Id      Pr      Len     Wid     Slp     Man     SS1     SS2
3299    1       20      2       0.0052  0.013   0.5     0.5
Up =    3132,6,26
End Channel
```

Appendix B-4: KINEROS Rainfall Input for Model Testing

Note: Run the appropriate storm event below (.pre suffix) with the parameter file (.par suffix) from Appendix B-3. 15-minute resolution hyetographs are located at the end of this section. Storm names combine the Julian date with the two-digit year.

186_95 Storm
Begin 186
N = 11

Time	Depth
0	0
5	0.03
10	0.08
15	0.09
20	0.1
25	0.1
30	0.1
35	0.11
40	0.11
45	0.12
50	0.12

End

187_95 Storm
Begin 187
N = 76

Time	Depth
0	0
5	0.01
10	0.01
15	0.02
20	0.08
25	0.13
30	0.15
35	0.16
40	0.16
45	0.17
50	0.17
55	0.17
60	0.17
65	0.17
70	0.17
75	0.18
80	0.18
85	0.19
90	0.19
95	0.19
100	0.19
105	0.19
110	0.19
115	0.19
120	0.19
125	0.19
130	0.19
135	0.19
140	0.19
145	0.19

Appendix B-4: KINEROS Rainfall Input for Model Testing

150	0.19
155	0.19
160	0.19
165	0.19
170	0.19
175	0.19
180	0.19
185	0.19
190	0.19
195	0.19
200	0.19
205	0.19
210	0.19
215	0.19
220	0.19
225	0.19
230	0.19
235	0.19
240	0.19
245	0.19
250	0.19
255	0.19
260	0.19
265	0.19
270	0.19
275	0.19
280	0.19
285	0.19
290	0.19
295	0.19
300	0.19
305	0.19
310	0.19
315	0.19
320	0.19
325	0.19
330	0.19
335	0.19
340	0.19
345	0.19
350	0.19
355	0.22
360	0.43
365	0.5
370	0.53
375	0.53

End

<u>198_95 Storm</u>
Begin 198
N = 12

Time	Depth
0.0	0.00
5.0	0.16
10.0	0.64

Appendix B-4: KINEROS Rainfall Input for Model Testing

15.0	1.01
20.0	1.26
25.0	1.34
30.0	1.36
35.0	1.37
40.0	1.37
45.0	1.37
50.0	1.38
55.0	1.38

End

230_95 Storm

Begin	230
N=	37
Time	Depth
0	0
5	0.08
10	0.28
15	0.55
20	0.94
25	1.21
30	1.32
35	1.37
40	1.46
45	1.52
50	1.57
55	1.62
60	1.66
65	1.67
70	1.68
75	1.69
80	1.71
85	1.72
90	1.73
95	1.74
100	1.74
105	1.75
110	1.75
115	1.75
120	1.75
125	1.75
130	1.75
135	1.75
140	1.75
145	1.75
150	1.76
155	1.76
160	1.77
165	1.78
170	1.79
175	1.8
180	1.8

End

Appendix B-4: KINEROS Rainfall Input for Model Testing

<u>239_95 Storm</u>

Begin 239
N= 154

Time	Depth
0	0
5	0.01
10	0.01
15	0.01
20	0.01
25	0.01
30	0.01
35	0.02
40	0.02
45	0.02
50	0.02
55	0.02
60	0.02
65	0.02
70	0.03
75	0.03
80	0.03
85	0.03
90	0.04
95	0.04
100	0.04
105	0.04
110	0.04
115	0.04
120	0.04
125	0.04
130	0.05
135	0.05
140	0.05
145	0.05
150	0.05
155	0.05
160	0.05
165	0.05
170	0.05
175	0.05
180	0.05
185	0.05
190	0.05
195	0.06
200	0.06
205	0.07
210	0.07
215	0.08
220	0.08
225	0.09
230	0.1
235	0.1
240	0.11
245	0.12

Appendix B-4: KINEROS Rainfall Input for Model Testing

250	0.12
255	0.13
260	0.14
265	0.14
270	0.15
275	0.16
280	0.17
285	0.18
290	0.19
295	0.2
300	0.22
305	0.24
310	0.25
315	0.26
320	0.27
325	0.28
330	0.3
335	0.32
340	0.33
345	0.35
350	0.35
355	0.36
360	0.36
365	0.37
370	0.37
375	0.37
380	0.38
385	0.38
390	0.38
395	0.39
400	0.39
405	0.4
410	0.4
415	0.41
420	0.41
425	0.41
430	0.41
435	0.42
440	0.42
445	0.42
450	0.42
455	0.42
460	0.42
465	0.42
470	0.42
475	0.43
480	0.43
485	0.43
490	0.43
495	0.43
500	0.43
505	0.44
510	0.44
515	0.44
520	0.44

Appendix B-4: KINEROS Rainfall Input for Model Testing

525	0.45
530	0.45
535	0.45
540	0.46
545	0.46
550	0.46
555	0.46
560	0.46
565	0.47
570	0.47
575	0.47
580	0.48
585	0.48
590	0.48
595	0.48
600	0.48
605	0.48
610	0.48
615	0.48
620	0.48
625	0.48
630	0.48
635	0.49
640	0.49
645	0.49
650	0.49
655	0.49
660	0.5
665	0.5
670	0.5
675	0.5
680	0.5
685	0.5
690	0.5
695	0.5
700	0.5
705	0.5
710	0.5
715	0.51
720	0.51
725	0.51
730	0.51
735	0.51
740	0.51
745	0.51
750	0.51
755	0.51
760	0.52
765	0.52

End

Appendix B-4: KINEROS Rainfall Input for Model Testing

259_95 Storm

Begin	259
N=	173
Time	Depth
0	0
5	0.03
10	0.05
15	0.05
20	0.06
25	0.07
30	0.07
35	0.07
40	0.07
45	0.08
50	0.08
55	0.08
60	0.09
65	0.09
70	0.09
75	0.1
80	0.1
85	0.11
90	0.12
95	0.12
100	0.13
105	0.13
110	0.14
115	0.15
120	0.15
125	0.15
130	0.16
135	0.16
140	0.16
145	0.17
150	0.17
155	0.17
160	0.17
165	0.17
170	0.18
175	0.18
180	0.18
185	0.19
190	0.19
195	0.19
200	0.2
205	0.2
210	0.2
215	0.21
220	0.21
225	0.21
230	0.21
235	0.22
240	0.22
245	0.22
250	0.23

Appendix B-4: KINEROS Rainfall Input for Model Testing

255	0.23
260	0.23
265	0.23
270	0.24
275	0.24
280	0.25
285	0.25
290	0.26
295	0.26
300	0.26
305	0.26
310	0.27
315	0.27
320	0.27
325	0.28
330	0.28
335	0.28
340	0.29
345	0.29
350	0.29
355	0.29
360	0.29
365	0.29
370	0.29
375	0.3
380	0.3
385	0.3
390	0.31
395	0.31
400	0.31
405	0.31
410	0.32
415	0.33
420	0.33
425	0.34
430	0.34
435	0.35
440	0.35
445	0.36
450	0.36
455	0.37
460	0.37
465	0.38
470	0.38
475	0.38
480	0.38
485	0.39
490	0.39
495	0.39
500	0.4
505	0.41
510	0.41
515	0.42
520	0.43
525	0.43

Appendix B-4: KINEROS Rainfall Input for Model Testing

530	0.43
535	0.44
540	0.44
545	0.44
550	0.45
555	0.45
560	0.45
565	0.46
570	0.46
575	0.46
580	0.46
585	0.47
590	0.47
595	0.47
600	0.47
605	0.47
610	0.48
615	0.48
620	0.48
625	0.49
630	0.49
635	0.49
640	0.5
645	0.5
650	0.51
655	0.51
660	0.52
665	0.52
670	0.53
675	0.53
680	0.53
685	0.53
690	0.53
695	0.53
700	0.53
705	0.53
710	0.53
715	0.54
720	0.54
725	0.54
730	0.54
735	0.54
740	0.54
745	0.54
750	0.54
755	0.54
760	0.54
765	0.54
770	0.54
775	0.54
780	0.54
785	0.54
790	0.55
795	0.55
800	0.55

Appendix B-4: KINEROS Rainfall Input for Model Testing

805	0.55
810	0.56
815	0.56
820	0.56
825	0.56
830	0.56
835	0.56
840	0.56
845	0.56
850	0.56
855	0.57
860	0.57

End

269_95 Storm

Begin	269
N=	38
Time	Depth
0	0
5	0.02
10	0.04
15	0.04
20	0.04
25	0.05
30	0.06
35	0.06
40	0.07
45	0.07
50	0.07
55	0.07
60	0.07
65	0.08
70	0.08
75	0.08
80	0.09
85	0.09
90	0.09
95	0.09
100	0.09
105	0.09
110	0.11
115	0.12
120	0.13
125	0.15
130	0.17
135	0.18
140	0.18
145	0.19
150	0.19
155	0.19
160	0.19
165	0.19
170	0.19
175	0.19
180	0.2

Appendix B-4: KINEROS Rainfall Input for Model Testing

185	0.2

End

<u>277_95 Storm</u>

Begin 277
N= 99

Time	Depth
0	0
5	0.01
10	0.01
15	0.01
20	0.01
25	0.01
30	0.01
35	0.02
40	0.02
45	0.03
50	0.03
55	0.03
60	0.04
65	0.04
70	0.04
75	0.04
80	0.04
85	0.04
90	0.05
95	0.05
100	0.05
105	0.05
110	0.05
115	0.05
120	0.05
125	0.05
130	0.06
135	0.06
140	0.06
145	0.07
150	0.07
155	0.07
160	0.07
165	0.08
170	0.08
175	0.09
180	0.09
185	0.09
190	0.09
195	0.1
200	0.1
205	0.11
210	0.11
215	0.11
220	0.12
225	0.12
230	0.12
235	0.13

Appendix B-4: KINEROS Rainfall Input for Model Testing

```
240     0.13
245     0.14
250     0.14
255     0.14
260     0.15
265     0.15
270     0.16
275     0.16
280     0.16
285     0.17
290     0.17
295     0.18
300     0.18
305     0.19
310     0.19
315     0.19
320     0.2
325     0.2
330     0.2
335     0.2
340     0.2
345     0.2
350     0.2
355     0.2
360     0.2
365     0.2
370     0.21
375     0.21
380     0.22
385     0.22
390     0.22
395     0.23
400     0.23
405     0.23
410     0.23
415     0.23
420     0.23
425     0.23
430     0.24
435     0.24
440     0.24
445     0.24
450     0.24
455     0.24
460     0.24
465     0.25
470     0.25
475     0.25
480     0.25
485     0.26
490     0.26
End
```

Appendix B-4: KINEROS Rainfall Input for Model Testing

278_95 Storm

Begin	278
N=	197
Time	Depth
0	0
5	0.01
10	0.01
15	0.01
20	0.01
25	0.02
30	0.02
35	0.02
40	0.03
45	0.04
50	0.04
55	0.05
60	0.08
65	0.09
70	0.09
75	0.1
80	0.1
85	0.1
90	0.1
95	0.1
100	0.1
105	0.11
110	0.11
115	0.12
120	0.12
125	0.12
130	0.13
135	0.13
140	0.13
145	0.13
150	0.14
155	0.15
160	0.15
165	0.16
170	0.17
175	0.17
180	0.18
185	0.19
190	0.19
195	0.23
200	0.28
205	0.32
210	0.36
215	0.4
220	0.41
225	0.41
230	0.42
235	0.42
240	0.43
245	0.43
250	0.44

Appendix B-4: KINEROS Rainfall Input for Model Testing

255	0.44
260	0.45
265	0.45
270	0.45
275	0.49
280	0.54
285	0.56
290	0.57
295	0.59
300	0.64
305	0.66
310	0.67
315	0.67
320	0.67
325	0.67
330	0.67
335	0.67
340	0.67
345	0.67
350	0.67
355	0.67
360	0.67
365	0.67
370	0.67
375	0.67
380	0.67
385	0.67
390	0.67
395	0.67
400	0.67
405	0.67
410	0.67
415	0.67
420	0.67
425	0.67
430	0.67
435	0.67
440	0.67
445	0.67
450	0.67
455	0.67
460	0.67
465	0.67
470	0.67
475	0.67
480	0.67
485	0.67
490	0.67
495	0.67
500	0.67
505	0.67
510	0.67
515	0.67
520	0.67
525	0.67

Appendix B-4: KINEROS Rainfall Input for Model Testing

530	0.67
535	0.67
540	0.67
545	0.67
550	0.7
555	0.73
560	0.74
565	0.74
570	0.74
575	0.74
580	0.74
585	0.74
590	0.74
595	0.74
600	0.74
605	0.74
610	0.74
615	0.74
620	0.74
625	0.74
630	0.74
635	0.74
640	0.74
645	0.74
650	0.74
655	0.74
660	0.74
665	0.74
670	0.74
675	0.74
680	0.74
685	0.74
690	0.74
695	0.74
700	0.74
705	0.74
710	0.74
715	0.74
720	0.74
725	0.74
730	0.74
735	0.74
740	0.74
745	0.74
750	0.74
755	0.74
760	0.74
765	0.74
770	0.74
775	0.74
780	0.74
785	0.74
790	0.74
795	0.74
800	0.74

Appendix B-4: KINEROS Rainfall Input for Model Testing

805	0.74
810	0.74
815	0.74
820	0.74
825	0.74
830	0.74
835	0.74
840	0.79
845	0.81
850	0.81
855	0.81
860	0.81
865	0.82
870	0.83
875	0.88
880	0.88
885	0.88
890	0.88
895	0.88
900	0.88
905	0.88
910	0.88
915	0.88
920	0.88
925	0.88
930	0.88
935	0.88
940	0.88
945	0.88
950	0.88
955	0.88
960	0.88
965	0.88
970	0.88
975	0.89
980	0.89

End

287_95 Storm

Begin 287
N= 103

Time	Depth
0	0
5	0.01
10	0.01
15	0.01
20	0.01
25	0.01
30	0.01
35	0.01
40	0.01
45	0.01
50	0.01
55	0.02
60	0.02

Appendix B-4: KINEROS Rainfall Input for Model Testing

65	0.02
70	0.02
75	0.03
80	0.03
85	0.03
90	0.03
95	0.03
100	0.03
105	0.04
110	0.04
115	0.05
120	0.05
125	0.05
130	0.06
135	0.06
140	0.06
145	0.06
150	0.06
155	0.06
160	0.06
165	0.06
170	0.06
175	0.06
180	0.06
185	0.08
190	0.11
195	0.12
200	0.13
205	0.13
210	0.14
215	0.14
220	0.15
225	0.16
230	0.16
235	0.17
240	0.18
245	0.19
250	0.19
255	0.19
260	0.2
265	0.2
270	0.2
275	0.2
280	0.21
285	0.21
290	0.21
295	0.21
300	0.21
305	0.21
310	0.21
315	0.21
320	0.21
325	0.21
330	0.21
335	0.21

Appendix B-4: KINEROS Rainfall Input for Model Testing

340	0.21
345	0.21
350	0.21
355	0.21
360	0.21
365	0.21
370	0.21
375	0.21
380	0.21
385	0.21
390	0.21
395	0.21
400	0.21
405	0.21
410	0.21
415	0.21
420	0.21
425	0.21
430	0.21
435	0.21
440	0.21
445	0.21
450	0.21
455	0.21
460	0.21
465	0.21
470	0.21
475	0.21
480	0.22
485	0.22
490	0.22
495	0.22
500	0.22
505	0.23
510	0.23

End

293_95 Storm
Begin 293_95
N = 82

Time	Depth
0	0
5	0.01
10	0.01
15	0.04
20	0.04
25	0.04
30	0.05
35	0.06
40	0.08
45	0.08
50	0.1
55	0.14
60	0.16
65	0.17

Appendix B-4: KINEROS Rainfall Input for Model Testing

70	0.18
75	0.2
80	0.21
85	0.23
90	0.26
95	0.27
100	0.28
105	0.3
110	0.33
115	0.35
120	0.36
125	0.37
130	0.38
135	0.38
140	0.38
145	0.38
150	0.38
155	0.38
160	0.38
165	0.38
170	0.38
175	0.39
180	0.39
185	0.39
190	0.39
195	0.39
200	0.4
205	0.42
210	0.43
215	0.44
220	0.45
225	0.45
230	0.45
235	0.46
240	0.46
245	0.46
250	0.46
255	0.47
260	0.48
265	0.49
270	0.51
275	0.53
280	0.54
285	0.56
290	0.58
295	0.6
300	0.61
305	0.62
310	0.63
315	0.64
320	0.64
325	0.64
330	0.64
335	0.64
340	0.64

Appendix B-4: KINEROS Rainfall Input for Model Testing

345	0.64
350	0.64
355	0.64
360	0.64
365	0.64
370	0.64
375	0.64
380	0.64
385	0.64
390	0.65
395	0.65
400	0.67
405	0.67
End	

306_95 Storm

Begin	306
N=	177
Time	Depth
0	0
5	0.01
10	0.01
15	0.01
20	0.01
25	0.01
30	0.01
35	0.02
40	0.02
45	0.04
50	0.07
55	0.08
60	0.09
65	0.1
70	0.11
75	0.12
80	0.13
85	0.13
90	0.14
95	0.16
100	0.16
105	0.16
110	0.16
115	0.16
120	0.17
125	0.17
130	0.17
135	0.17
140	0.17
145	0.17
150	0.17
155	0.17
160	0.17
165	0.17
170	0.17
175	0.17

Appendix B-4: KINEROS Rainfall Input for Model Testing

180	0.17
185	0.17
190	0.17
195	0.17
200	0.17
205	0.17
210	0.17
215	0.18
220	0.18
225	0.18
230	0.18
235	0.18
240	0.18
245	0.18
250	0.18
255	0.18
260	0.18
265	0.18
270	0.18
275	0.18
280	0.18
285	0.18
290	0.18
295	0.18
300	0.18
305	0.18
310	0.18
315	0.18
320	0.18
325	0.18
330	0.18
335	0.18
340	0.18
345	0.18
350	0.18
355	0.18
360	0.18
365	0.18
370	0.18
375	0.18
380	0.18
385	0.18
390	0.18
395	0.18
400	0.18
405	0.18
410	0.18
415	0.18
420	0.18
425	0.18
430	0.18
435	0.18
440	0.18
445	0.18
450	0.18

Appendix B-4: KINEROS Rainfall Input for Model Testing

455	0.18
460	0.18
465	0.18
470	0.18
475	0.18
480	0.18
485	0.18
490	0.18
495	0.18
500	0.18
505	0.18
510	0.18
515	0.18
520	0.18
525	0.18
530	0.18
535	0.18
540	0.18
545	0.18
550	0.18
555	0.18
560	0.18
565	0.18
570	0.18
575	0.18
580	0.18
585	0.18
590	0.18
595	0.18
600	0.18
605	0.18
610	0.18
615	0.18
620	0.18
625	0.18
630	0.18
635	0.18
640	0.18
645	0.18
650	0.18
655	0.18
660	0.18
665	0.18
670	0.18
675	0.18
680	0.18
685	0.18
690	0.19
695	0.19
700	0.19
705	0.19
710	0.19
715	0.19
720	0.19
725	0.19

Appendix B-4: KINEROS Rainfall Input for Model Testing

730	0.19
735	0.2
740	0.2
745	0.2
750	0.2
755	0.2
760	0.2
765	0.2
770	0.2
775	0.2
780	0.21
785	0.21
790	0.21
795	0.21
800	0.21
805	0.21
810	0.22
815	0.22
820	0.25
825	0.25
830	0.25
835	0.25
840	0.25
845	0.25
850	0.25
855	0.25
860	0.25
865	0.25
870	0.25
875	0.26
880	0.26

End

311_95 Storm

Begin	311
N=	154

Time	Depth
0	0
5	0.01
10	0.01
15	0.01
20	0.01
25	0.02
30	0.02
35	0.02
40	0.02
45	0.02
50	0.03
55	0.03
60	0.04
65	0.05
70	0.05
75	0.06
80	0.06
85	0.06

Appendix B-4: KINEROS Rainfall Input for Model Testing

90	0.06
95	0.07
100	0.07
105	0.08
110	0.09
115	0.09
120	0.1
125	0.1
130	0.1
135	0.11
140	0.14
145	0.15
150	0.16
155	0.18
160	0.19
165	0.2
170	0.21
175	0.23
180	0.26
185	0.28
190	0.3
195	0.32
200	0.34
205	0.36
210	0.37
215	0.38
220	0.4
225	0.42
230	0.43
235	0.44
240	0.44
245	0.46
250	0.47
255	0.47
260	0.48
265	0.48
270	0.49
275	0.49
280	0.5
285	0.5
290	0.51
295	0.51
300	0.52
305	0.52
310	0.53
315	0.54
320	0.55
325	0.55
330	0.56
335	0.57
340	0.58
345	0.59
350	0.6
355	0.61
360	0.62

Appendix B-4: KINEROS Rainfall Input for Model Testing

365	0.63
370	0.63
375	0.64
380	0.65
385	0.65
390	0.66
395	0.66
400	0.66
405	0.67
410	0.67
415	0.68
420	0.68
425	0.68
430	0.68
435	0.69
440	0.69
445	0.69
450	0.69
455	0.69
460	0.69
465	0.69
470	0.69
475	0.7
480	0.7
485	0.7
490	0.71
495	0.71
500	0.71
505	0.71
510	0.71
515	0.71
520	0.72
525	0.72
530	0.72
535	0.72
540	0.72
545	0.73
550	0.75
555	0.77
560	0.78
565	0.79
570	0.8
575	0.8
580	0.81
585	0.81
590	0.81
595	0.82
600	0.82
605	0.82
610	0.82
615	0.82
620	0.82
625	0.82
630	0.82
635	0.82

Appendix B-4: KINEROS Rainfall Input for Model Testing

640	0.82
645	0.82
650	0.82
655	0.82
660	0.82
665	0.82
670	0.82
675	0.83
680	0.83
685	0.83
690	0.83
695	0.84
700	0.84
705	0.85
710	0.85
715	0.86
720	0.86
725	0.87
730	0.87
735	0.88
740	0.88
745	0.88
750	0.88
755	0.88
760	0.89
765	0.89

End

315_95 Storm

Begin	315
N=	125
Time	Depth
0	0
5	0.01
10	0.01
15	0.01
20	0.01
25	0.01
30	0.01
35	0.01
40	0.01
45	0.02
50	0.02
55	0.02
60	0.02
65	0.02
70	0.02
75	0.02
80	0.02
85	0.02
90	0.02
95	0.03
100	0.03
105	0.04
110	0.04

Appendix B-4: KINEROS Rainfall Input for Model Testing

115	0.04
120	0.04
125	0.05
130	0.06
135	0.06
140	0.07
145	0.07
150	0.07
155	0.07
160	0.07
165	0.07
170	0.08
175	0.08
180	0.09
185	0.09
190	0.1
195	0.1
200	0.11
205	0.11
210	0.11
215	0.11
220	0.11
225	0.11
230	0.11
235	0.12
240	0.12
245	0.12
250	0.12
255	0.12
260	0.12
265	0.12
270	0.12
275	0.12
280	0.12
285	0.12
290	0.12
295	0.12
300	0.12
305	0.12
310	0.12
315	0.12
320	0.12
325	0.12
330	0.12
335	0.12
340	0.12
345	0.12
350	0.12
355	0.12
360	0.12
365	0.12
370	0.12
375	0.12
380	0.12
385	0.12

Appendix B-4: KINEROS Rainfall Input for Model Testing

390	0.12
395	0.12
400	0.12
405	0.12
410	0.12
415	0.12
420	0.12
425	0.12
430	0.12
435	0.13
440	0.13
445	0.13
450	0.13
455	0.13
460	0.14
465	0.14
470	0.14
475	0.15
480	0.16
485	0.16
490	0.16
495	0.16
500	0.16
505	0.19
510	0.34
515	0.36
520	0.38
525	0.38
530	0.38
535	0.39
540	0.39
545	0.39
550	0.4
555	0.41
560	0.41
565	0.41
570	0.41
575	0.41
580	0.41
585	0.41
590	0.41
595	0.41
600	0.41
605	0.41
610	0.41
615	0.42
620	0.42

End

318_95 Storm

Begin	318
N=	117
Time	Depth
0	0
5	0.01

Appendix B-4: KINEROS Rainfall Input for Model Testing

10	0.01
15	0.01
20	0.01
25	0.01
30	0.01
35	0.01
40	0.01
45	0.01
50	0.01
55	0.01
60	0.01
65	0.01
70	0.01
75	0.01
80	0.01
85	0.01
90	0.01
95	0.01
100	0.01
105	0.01
110	0.01
115	0.01
120	0.01
125	0.01
130	0.01
135	0.01
140	0.01
145	0.01
150	0.01
155	0.01
160	0.01
165	0.01
170	0.01
175	0.01
180	0.01
185	0.01
190	0.01
195	0.01
200	0.01
205	0.01
210	0.01
215	0.02
220	0.02
225	0.02
230	0.02
235	0.02
240	0.02
245	0.02
250	0.02
255	0.02
260	0.02
265	0.02
270	0.02
275	0.02
280	0.02

Appendix B-4: KINEROS Rainfall Input for Model Testing

285	0.02
290	0.02
295	0.02
300	0.02
305	0.02
310	0.02
315	0.02
320	0.02
325	0.02
330	0.02
335	0.02
340	0.02
345	0.02
350	0.02
355	0.02
360	0.02
365	0.02
370	0.02
375	0.02
380	0.02
385	0.02
390	0.02
395	0.03
400	0.03
405	0.03
410	0.03
415	0.03
420	0.03
425	0.03
430	0.03
435	0.03
440	0.03
445	0.03
450	0.03
455	0.03
460	0.03
465	0.04
470	0.06
475	0.07
480	0.08
485	0.09
490	0.1
495	0.11
500	0.13
505	0.14
510	0.15
515	0.16
520	0.17
525	0.18
530	0.18
535	0.19
540	0.2
545	0.21
550	0.23
555	0.24

Appendix B-4: KINEROS Rainfall Input for Model Testing

560	0.25
565	0.27
570	0.28
575	0.3
580	0.3

End

079_96 Storm

Begin 79
N= 136

Time	Depth
0	0
5	0.01
10	0.03
15	0.05
20	0.05
25	0.05
30	0.05
35	0.06
40	0.06
45	0.06
50	0.07
55	0.07
60	0.07
65	0.08
70	0.1
75	0.13
80	0.17
85	0.2
90	0.22
95	0.24
100	0.26
105	0.28
110	0.29
115	0.31
120	0.33
125	0.36
130	0.38
135	0.39
140	0.4
145	0.4
150	0.41
155	0.41
160	0.42
165	0.43
170	0.43
175	0.44
180	0.44
185	0.44
190	0.44
195	0.44
200	0.44
205	0.45
210	0.45
215	0.46

Appendix B-4: KINEROS Rainfall Input for Model Testing

220	0.48
225	0.48
230	0.49
235	0.49
240	0.5
245	0.5
250	0.5
255	0.51
260	0.52
265	0.52
270	0.52
275	0.53
280	0.53
285	0.53
290	0.54
295	0.55
300	0.56
305	0.56
310	0.57
315	0.57
320	0.58
325	0.58
330	0.58
335	0.59
340	0.6
345	0.6
350	0.61
355	0.61
360	0.61
365	0.61
370	0.61
375	0.61
380	0.61
385	0.61
390	0.61
395	0.62
400	0.62
405	0.62
410	0.62
415	0.62
420	0.62
425	0.62
430	0.62
435	0.62
440	0.62
445	0.63
450	0.63
455	0.65
460	0.66
465	0.67
470	0.68
475	0.68
480	0.68
485	0.69
490	0.69

Appendix B-4: KINEROS Rainfall Input for Model Testing

495	0.7
500	0.7
505	0.71
510	0.72
515	0.72
520	0.72
525	0.73
530	0.73
535	0.73
540	0.73
545	0.73
550	0.73
555	0.73
560	0.73
565	0.73
570	0.73
575	0.73
580	0.73
585	0.73
590	0.73
595	0.73
600	0.73
605	0.73
610	0.73
615	0.73
620	0.73
625	0.74
630	0.75
635	0.75
640	0.75
645	0.76
650	0.76
655	0.76
660	0.76
665	0.76
670	0.77
675	0.77

End

143_96 Storm

Begin 143
N= 13

Time	Depth
0	0
5	0.07
10	0.1
15	0.15
20	0.19
25	0.26
30	0.32
35	0.41
40	0.43
45	0.47
50	0.52
55	0.53

60	0.53

End

198_95 Storm, 15-minute rainfall data resolution
Begin 7/17/95
N = 6

Time	Depth
0	0
15	1.01
30	1.36
45	1.37
60	1.38
75	1.38

End

269_95 Storm, 15-minute rainfall data resolution
Begin 09/26/95
N = 14

Time	Depth
0	0
15	0.04
30	0.06
45	0.07
60	0.07
75	0.08
90	0.09
105	0.09
120	0.13
135	0.18
150	0.19
165	0.19
180	0.2
195	0.2

End

293_95 Storm, 15-minute rainfall data resolution
Begin 10/20/95
N = 29

Time	Depth
0	0
15	0.04
30	0.05
45	0.08
60	0.16
75	0.2
90	0.26
105	0.3
120	0.36
135	0.38
150	0.38
165	0.38
180	0.39
195	0.39
210	0.43
225	0.45

Appendix B-4: KINEROS Rainfall Input for Model Testing

240	0.46
255	0.47
270	0.51
285	0.56
300	0.61
315	0.64
330	0.64
345	0.64
360	0.64
375	0.64
390	0.65
405	0.67
420	0.67

End

APPENDIX C

VISUAL BASIC SOURCE CODE

- **C-1: Gene VB Source Code: Gene.vbp & Gene.vbw**
- **C-2: Gene VB Source Code: MGlobals.bas**
- **C-3: Gene VB Source Code: Form1.frm**
- **C-4: RainPro VBSource Code: RainPro.vbp & RainPro.vbw**
- **C-5: RainPro VB Source Code: Module1.bas**
- **C-6: RainPro VB Source Code: frmMain.frm**

Appendix C-1: Gene VB Source Code: Gene.vbp & Gene.vbw

Gene.vbp:

```
Type=Exe
Reference=*\G{00020430-0000-0000-C000-000000000046}#2.0#0#C:\WINNT\System32\stdole2.tlb#OLE
Automation
Module=MGlobals; MGlobals.bas
Object={F9043C88-F6F2-101A-A3C9-08002B2F49FB}#1.2#0; COMDLG32.OCX
Form=Form1.frm
Startup="Form1"
HelpFile=""
ExeName32="GENE.exe"
Command32=""
Name="Project1"
HelpContextID="0"
CompatibleMode="0"
MajorVer=1
MinorVer=0
RevisionVer=0
AutoIncrementVer=0
ServerSupportFiles=0
VersionCompanyName="Virginia Tech"
CompilationType=0
OptimizationType=0
FavorPentiumPro(tm)=0
CodeViewDebugInfo=0
NoAliasing=0
BoundsCheck=0
OverflowCheck=0
FlPointCheck=0
FDIVCheck=0
UnroundedFP=0
StartMode=0
Unattended=0
Retained=0
ThreadPerObject=0
MaxNumberOfThreads=1

[MS Transaction Server]
AutoRefresh=1
```

Gene.vbw:

```
MGlobals = -201, 131, 715, 884,
Form1 = -183, 62, 733, 815, Z, -27, 41, 889, 794, C
```

Appendix C-2: Gene VB Source Code: MGlobals.bas

```
Attribute VB_Name = "MGlobals"
Option Explicit
Option Base 1

Public modflowloc As String
Public MODprojectfilename As String
Public mm, xx(), nn, yy(), xlab() As String, ylab() As String, zlab() As String, ff() As String, fin As String, fpre As String, fout() As String, com As String, dur As String, dt As String, adt As String, sed As String, mult As String, sf() As String, sipt As String, sout() As String

'Declare Function FindWindow Lib "user32" Alias _
'"FindWindowA" (ByVal lpClassName As String, _
'          ByVal lpWindowName As Long) As Long

'Declare Function SendMessage Lib "user32" Alias _
'"SendMessageA" (ByVal hWnd As Long, ByVal wMsg As Long, _
'          ByVal wParam As Long, _
'          ByVal lParam As Long) As Long


Global Const Black = &H0&
Global Const Red = &HFF&
Global Const Green = &H8000&
Global Const Yellow = &HFFFF&
Global Const Blue = &HFF0000
Global Const Magenta = &HFF00FF
Global Const Cyan = &HFFFF00
Global Const White = &HFFFFFF
Global Const Grey = &HC0C0C0
Global Const LBlue = &HFFFF00
Global Const PaleYellow = 14548991

Declare Function FindWindow Lib "user32" Alias "FindWindowA" (ByVal lpClassName As String, ByVal lpWindowName As String) As Long
Declare Function GetWindowTextLength Lib "user32" Alias "GetWindowTextLengthA" (ByVal hWnd As Long) As Long
Declare Function GetWindowText Lib "user32" Alias "GetWindowTextA" (ByVal hWnd As Long, ByVal lpString As String, ByVal nMaxCount As Long) As Long 'cch
Declare Function GetClassName Lib "user32" Alias "GetClassNameA" (ByVal hWnd As Long, ByVal lpClassName As String, ByVal nMaxCount As Long) As Long
Declare Function DestroyWindow Lib "user32" (ByVal hWnd As Long) As Long

Declare Function OpenProcess Lib "kernel32" (ByVal dwDesiredAccess As Long, ByVal bInheritHandle As Long, ByVal dwProcessId As Long) As Long
Declare Function WaitForSingleObject Lib "kernel32" (ByVal hHandle As Long, ByVal dwMilliseconds As Long) As Long
Declare Function CloseHandle Lib "kernel32" (ByVal hObject As Long) As Long
Const SYNCHRONIZE = &H100000
Const INFINITE = &HFFFFFFFF
Const WAIT_OBJECT_0 = 0
Const WAIT_TIMEOUT = &H102

Public ProcessID As Long
Public ProcessHandle As Long
```

Appendix C-2: Gene VB Source Code: MGlobals.bas

```
Declare Function SendMessage Lib "user32" Alias "SendMessageA" (ByVal hWnd As Long, ByVal wMsg As Long, ByVal wParam As Long, lParam As Any) As Long
Declare Function GetParent Lib "user32" (ByVal hWnd As Long) As Long
Declare Function GetWindowThreadProcessId Lib "user32" (ByVal hWnd As Long, lpdwProcessId As Long) As Long
Declare Function EnumWindows Lib "user32" (ByVal lpEnumFunc As Long, ByVal lParam As Long) As Long

Public Const INVALID_HANDLE_VALUE = -1
Public Const MAX_PATH = 260

  Type FILETIME
     dwLowDateTime As Long
     dwHighDateTime As Long
  End Type

  Type WIN32_FIND_DATA
     dwFileAttributes As Long
     ftCreationTime As FILETIME
     ftLastAccessTime As FILETIME
     ftLastWriteTime As FILETIME
     nFileSizeHigh As Long
     nFileSizeLow As Long
     dwReserved0 As Long
     dwReserved1 As Long
     cFileName As String * MAX_PATH
     cAlternate As String * 14
  End Type

Declare Function FindFirstFile Lib "kernel32" Alias "FindFirstFileA" (ByVal lpFileName As String, lpFindFileData As WIN32_FIND_DATA) As Long
Declare Function FindClose Lib "kernel32" (ByVal hFindFile As Long) As Long

Function SyncShell(ByVal pathname As String, ByVal windowstyle As Integer, ByVal program As Integer, ByVal arrnum As Integer) As Boolean
Dim winhand As Long
Dim val As Long
Dim clsname As Long
Dim wtitlelen, nMaxCount, lpClassName, hWnd, lresult, length As Long
Dim wtitle, wintxt, fromsim, sInput, T As String
Dim x, n
Dim s As String
x = 0
" In VB4, an error occurs if Shell
" fails to start the program
On Error GoTo SyncShell_Error3
' Shell the program, get its handle,
' and wait for it to terminate
ProcessID = Shell(pathname, windowstyle)
If ProcessID <> 0 Then
 "   AppActivate "seam3d"
    ProcessHandle = OpenProcess(SYNCHRONIZE, True, ProcessID)
rerunit3:
    val = WaitForSingleObject(ProcessHandle, 1000) '4000) ' INFINITE)'eduardo
    Select Case val
    Case WAIT_TIMEOUT
```

Appendix C-2: Gene VB Source Code: MGlobals.bas

```
        nMaxCount = 256
        lpClassName = Space(nMaxCount)
        sInput = "Finished - NASShell" '"[Inactive "  + CurDirPath + "NASShell.exe]"
        hWnd = FindWindow(vbNullString, sInput)
        lresult = GetClassName(hWnd, lpClassName, nMaxCount)
        length = GetWindowTextLength(hWnd)
        T = Space$(length + 1)              'Allocate buffer space
        length = GetWindowText(hWnd, T, length + 1)
        If Left(LCase(T), 10) = "finished -" Then  '
            AppActivate "finished - " + pathname
            'SendKeys "%{F4}", True
            'DestroyWindow (hWnd)
            GoTo allset3
        Else
            AppActivate pathname
            If program = 1 Then
                If x = 0 Then
                    SendKeys "y", True
                    SendKeys "{ENTER}", True
                    x = 1
                End If
            ElseIf program = 2 Then
                If x = 0 Then
                    For n = 1 To Len(Trim(sipt))
                        s = Mid(sipt, n, 1)
                        SendKeys s, True
                    Next n
                        SendKeys ".", True
                        SendKeys "i", True
                        SendKeys "p", True
                        SendKeys "t", True
                    SendKeys "{ENTER}", True
                    x = 1
                End If
                If x = 1 Then
                    For n = 1 To Len(Trim(sout(arrnum)))
                        s = Mid(sout(arrnum), n, 1)
                        SendKeys s, True
                    Next n
                        SendKeys ".", True
                        SendKeys "o", True
                        SendKeys "u", True
                        SendKeys "t", True
                    SendKeys "{ENTER}", True
                    x = 2
                End If
            End If
            GoTo rerunit3
        End If
    End Select
allset3:
    'CloseHandle (ProcessHandle) ""
    SyncShell = True
    Exit Function
Else
```

Appendix C-2: Gene VB Source Code: MGlobals.bas

```
    MsgBox " Simulation executable was not able to run. ", vbOKOnly + vbCritical
End If
SyncShell_Error3:
    On Error GoTo 0
    SyncShell = False
    Exit Function
End Function

Public Function FileExists(sSource As String) As Boolean

   Dim WFD As WIN32_FIND_DATA
   Dim hFile As Long

   hFile = FindFirstFile(sSource, WFD)
   FileExists = hFile <> INVALID_HANDLE_VALUE

   Call FindClose(hFile)

 End Function
```

Appendix C-3: Gene VB Source Code: Form1.frm

```
VERSION 5.00
Object = "{F9043C88-F6F2-101A-A3C9-08002B2F49FB}#1.2#0"; "COMDLG32.OCX"
Begin VB.Form Form1
   Caption         =   "Form1"
   ClientHeight    =   3180
   ClientLeft      =   60
   ClientTop       =   360
   ClientWidth     =   4680
   LinkTopic       =   "Form1"
   ScaleHeight     =   3180
   ScaleWidth      =   4680
   StartUpPosition =   3  'Windows Default
   Begin VB.CommandButton Command3
      Caption         =   "post"
      Height          =   1575
      Left            =   3360
      TabIndex        =   2
      Top             =   360
      Width           =   1095
   End
   Begin VB.CommandButton Command2
      Caption         =   "pre"
      Height          =   1455
      Left            =   240
      TabIndex        =   1
      Top             =   360
      Width           =   1095
   End
   Begin MSComDlg.CommonDialog dlgMain
      Left            =   3480
      Top             =   2640
      _ExtentX        =   847
      _ExtentY        =   847
      _Version        =   393216
   End
   Begin VB.CommandButton Command1
      Caption         =   "run"
      Height          =   1455
      Left            =   1920
      TabIndex        =   0
      Top             =   360
      Width           =   1095
   End
End
Attribute VB_Name = "Form1"
Attribute VB_GlobalNameSpace = False
Attribute VB_Creatable = False
Attribute VB_PredeclaredId = True
Attribute VB_Exposed = False
Public Nfiles

Sub Getfile()
Dim n As Long
Dim ErrorLine, x, y As Long
Dim fileline, allfileline As String
```

Appendix C-3: Gene VB Source Code: Form1.frm

```
Dim fnum, fnum1 As Long
fnum = FreeFile
dlgMain.CancelError = True
On Error GoTo ErrorLine
dlgMain.Filter = "All Files (*.*)|*.*"
dlgMain.FileName = ""
dlgMain.FilterIndex = 1
dlgMain.Action = 1
FromOpen = False
If CancelOpen = True Then GoTo ErrorLine
MODprojectfiletitle = dlgMain.FileTitle
MODprojectfilename = dlgMain.FileName
modflowloc = Left(dlgMain.FileName, Len(dlgMain.FileName) - Len(dlgMain.FileTitle))

Close
n = 0
Open MODprojectfilename For Input As fnum
x = 0
Do While Not EOF(fnum)
  Line Input #fnum, allfileline
  x = x + 1
Loop
Close #fnum
Nfiles = x - 1
ReDim mm(x + 1)
ReDim nn(x + 1)
ReDim xlab(x + 1)
ReDim ylab(x + 1)
ReDim zlab(x + 1)
ReDim ff(x + 1)
ReDim sf(x + 1)
ReDim fout(x + 1)
ReDim sout(x + 1)
Open MODprojectfilename For Input As fnum
fnum1 = fnum + 1
Line Input #fnum, allfileline
Do While Not EOF(fnum)
  n = n + 1
  Input #fnum, mm(n)
  ReDim Preserve xx(mm(n) + 1, n)
  For p = 1 To mm(n)
      Input #fnum, xx(p, n)
  Next p
  Input #fnum, nn(n)
  ReDim Preserve yy(nn(n) + 1, n)
  For p = 1 To nn(n)
      Input #fnum, yy(p, n)
  Next p
  Input #fnum, xlab(n), ylab(n), zlab(n), ff(n), fin, fpre, fout(n), com, dur, dt, adt, sed, mult, sf(n), sipt, sout(n)
    If LCase(ff(n)) = "t" Then
        For y = 1 To 3
            Open modflowloc + "kin.fil" For Output As fnum1
            Print #fnum1, fin + "_" + Trim(Str(y)) + ".par"
            Print #fnum1, fpre + ".pre"
            Print #fnum1, fout(n) + "_" + Trim(Str(y)) + ".out"
```

```
            Print #fnum1, com
            Print #fnum1, dur
            Print #fnum1, dt
            Print #fnum1, adt
            Print #fnum1, sed
            Print #fnum1, mult
            Close #fnum1
            Call SyncShell(modflowloc + "kineros2.exe", 1, 1, n)
        Next y
    End If
    If LCase(sf(n)) = "t" Then Call SyncShell(modflowloc + "swmm44h.exe", 1, 2, n)

Loop
Close #fnum
Exit Sub
' If user selects cancel button
ErrorLine:
MousePointer = 0
'File_Errors (Err)
Resume ErrorLine2
ErrorLine2:
End Sub

 Sub Command1_Click()
Call Getfile
'Call Run1
End Sub


Sub Command2_Click()
Call GetExcel
End Sub

Sub Command3_Click()
Dim n
For n = 1 To Nfiles
    If LCase(ff(n)) = "t" Then
        Call K2postpro(n)
        Call postpro(n, 1)
    End If
Next n
For n = 1 To Nfiles
    If LCase(sf(n)) = "t" Then
        Call Spostpro(n)
        Call postpro(n, 2)
    End If
Next n
End Sub

Sub K2postpro(ByVal filenum As Integer)
Dim fileline, allfileline As String
Dim fnum, fnum1 As Long
Dim lin As Integer
Dim plane As Integer, runoff As Single, infilt As Single, peak As Single, tim As Single
fnum1 = FreeFile
```

Appendix C-3: Gene VB Source Code: Form1.frm

```
On Error GoTo ErrorLine
Dim y
Close
plane = 0
Open modflowloc + fout(filenum) + "_" + "kin.txt" For Output As fnum1
fnum = fnum1 + 1
Print #fnum1, "Kineros Results:  " + fout(filenum)
Print #fnum1, ""
Print #fnum1, "     Plane     Runoff     Infilt       Peak       Time"
Print #fnum1, "        ID       (in)       (in)      (cfs)      (min)"
y = 0
nextfile1:
Close #fnum
y = y + 1
If y = 4 Then GoTo exitloop
Open modflowloc + fout(filenum) + "_" + Trim(Str(y)) + ".out" For Input As fnum
Line Input #fnum, allfileline
Line Input #fnum, allfileline
Line Input #fnum, allfileline
nextfile2:
For b = 1 To 5
   Line Input #fnum, allfileline
Next b
b = InStr(1, allfileline, "=", vbTextCompare)
plane = plane + 1
fileline = Mid(allfileline, b + 2)
b = InStr(1, fileline, " ", vbTextCompare)
peak = Mid(fileline, 1, b)
b = InStr(1, fileline, "at", vbTextCompare)
fileline = Mid(fileline, b + 3)
b = InStr(1, fileline, " ", vbTextCompare)
tim = Mid(fileline, 1, b)
For b = 1 To 6
   Line Input #fnum, allfileline
Next b
infilt = Mid(allfileline, 27, 11)
Line Input #fnum, allfileline
Line Input #fnum, allfileline
runoff = Mid(allfileline, 27, 11)
Print #fnum1, Format(plane, "@@@@@@@@@@@"); Format(runoff, "@@@@@@@@@@@");
Format(infilt, "@@@@@@@@@@@"); Format(peak, "@@@@@@@@@@@"); Format(tim,
"@@@@@@@@@@@")
For b = 1 To 4
   Line Input #fnum, allfileline
Next b
If (Mid(allfileline, 2, 5)) = "Input" Then GoTo nextfile1 Else GoTo nextfile2
exitloop:
Close #fnum1
Exit Sub
' If user selects cancel button
ErrorLine:
MousePointer = 0
'File_Errors (Err)
Resume ErrorLine2
ErrorLine2:
```

```
End Sub


Sub Spostpro(ByVal filenum As Integer)
Dim fileline, allfileline As String
Dim fnum, fnum1 As Long
Dim lin As Integer
Dim subc() As Integer, depth() As Single, loss() As Single, rate() As Single, tim() As Single
fnum1 = FreeFile
On Error GoTo ErrorLine
Dim y
Close
plane = 0
Open modflowloc + fout(filenum) + "_" + "swmm.txt" For Output As fnum1
fnum = fnum1 + 1
Print #fnum1, "SWMM Results:  " + fout(filenum)
Print #fnum1, ""
Print #fnum1, "      Plane     Runoff     Infilt       Peak       Time"
Print #fnum1, "         ID       (in)       (in)      (cfs)      (min)"

Close #fnum
Open modflowloc + fout(filenum) + ".out" For Input As fnum
allfileline = ""
Do Until Trim(allfileline) = "SUMMARY STATISTICS FOR SUBCATCHMENTS"
   Line Input #fnum, allfileline
Loop
For b = 1 To 9
   Line Input #fnum, allfileline
Next b
b = 0
Do Until (allfileline) = ""
   Line Input #fnum, allfileline
   If (allfileline) = "" Then Exit Do
   b = b + 1
   ReDim Preserve subc(b + 1)
   ReDim Preserve depth(b + 1)
   ReDim Preserve loss(b + 1)
   ReDim Preserve rate(b + 1)
   subc(b) = Mid(allfileline, 1, 12)
   depth(b) = Mid(allfileline, 51, 8)
   loss(b) = Mid(allfileline, 59, 8)
   rate(b) = Mid(allfileline, 68, 8)
Loop
ReDim tim(b + 1)
For s = 1 To 12
   Line Input #fnum, allfileline
Next s
s = 0
again:
Do Until (allfileline) = ""
   Line Input #fnum, allfileline
   If (allfileline) = "" Then Exit Do
   s = s + 1
   tim(s) = Mid(allfileline, 87, 6)
Loop
```

```
If s <> b Then
   For f = 1 To 9
      Line Input #fnum, allfileline
   Next f
   GoTo again
End If
For s = 1 To b
   Print #fnum1, Format(subc(s), "@@@@@@@@@@@"); Format(depth(s), "@@@@@@@@@@@");
Format(loss(s), "@@@@@@@@@@@"); ; Format(rate(s), "@@@@@@@@@@@"); Format(tim(b - s + 1) *
60, "@@@@@@@@@@@")
Next s
Close #fnum1
Close #fnum
Exit Sub
' If user selects cancel button
ErrorLine:
MousePointer = 0
'File_Errors (Err)
Resume ErrorLine2
ErrorLine2:
End Sub

Sub postpro(ByVal filenum As Integer, ByVal prog As Integer)
Dim fileline, allfileline As String
Dim fnum, fnum1 As Long
Dim lin As Integer
fnum1 = FreeFile
Dim tag(4) As String
Dim tag2(4) As String
tag(1) = "runoff"
tag(2) = "infilt"
tag(3) = "peak"
tag(4) = "time"
tag2(1) = "Runoff, in"
tag2(2) = "Infiltration, in"
tag2(3) = "Peak Flow, cfs"
tag2(4) = "Time to Peak, min"
On Error GoTo ErrorLine
Dim y
Close
For w = 1 To 4
   If prog = 1 Then
      Open modflowloc + fout(filenum) + "_" + "kin_" + tag(w) + ".m" For Output As fnum1
   ElseIf prog = 2 Then
      Open modflowloc + fout(filenum) + "_" + "swmm_" + tag(w) + ".m" For Output As fnum1
   End If
   fnum = fnum1 + 1
   fnum2 = fnum1 + 2
   Print #fnum1, "x = [   ";
   For s = 1 To mm(filenum) - 1
      Print #fnum1, xx(s, filenum);
   Next s
   Print #fnum1, xx(mm(filenum), filenum)
   Print #fnum1, "       ]"
   Print #fnum1, "y = [   "; yy(1, filenum)
```

Appendix C-3: Gene VB Source Code: Form1.frm

```
    For s = 2 To nn(filenum)
        Print #fnum1, yy(s, filenum)
    Next s
    Print #fnum1, "        ]"
    Print #fnum1, "Z = [   ";

    Close #fnum
    If prog = 1 Then
        Open modflowloc + fout(filenum) + "_" + "kin.txt" For Input As fnum
    ElseIf prog = 2 Then
        Open modflowloc + fout(filenum) + "_" + "swmm.txt" For Input As fnum
    End If
    Line Input #fnum, allfileline
    Line Input #fnum, allfileline
    Line Input #fnum, allfileline
    Line Input #fnum, allfileline
    d = 1
    k = 0
    ' COUNT IS INCORRECT....Z-MATRIX ENDS SORTED IN WRONG ORDER/DOESN'T MATCH X and
Y!!!!
Dim temp1() As String
    Do While Not EOF(fnum)
         Line Input #fnum, allfileline
         k = k + 1
        ReDim Preserve temp1(k)
        If w = 1 Then
        temp1(k) = Mid(allfileline, 12, 11)
        ElseIf w = 2 Then
        temp1(k) = Mid(allfileline, 23, 11)
        ElseIf w = 3 Then
        temp1(k) = Mid(allfileline, 34, 11)
        ElseIf w = 4 Then
        temp1(k) = Mid(allfileline, 45, 11)
        End If
    Loop
begagain:
            Print #fnum1, temp1(d);
            a = d
            For v = 1 To 4
                d = d + 10
                Print #fnum1, temp1(d);
            Next v
            d = d + 10
            Print #fnum1, temp1(d)
            If d = k Then GoTo finit
            Print #fnum1, "        ";
            d = a + 1
            GoTo begagain
finit:
    Print #fnum1, "        ]"
    Print #fnum1, "%Z = Z./";
    Close #fnum2
    Open modflowloc + "avg_results.txt" For Input As fnum2
    If prog = 1 Then
        Line Input #fnum2, allfileline
```

```
        Line Input #fnum2, allfileline
        Line Input #fnum2, allfileline
        If w = 1 Then
        temp = Mid(allfileline, 11, 10)
        ElseIf w = 2 Then
        temp = Mid(allfileline, 21, 10)
        ElseIf w = 3 Then
        temp = Mid(allfileline, 31, 10)
        ElseIf w = 4 Then
        temp = Mid(allfileline, 41, 10)
        End If
    ElseIf prog = 2 Then
        Line Input #fnum2, allfileline
        Line Input #fnum2, allfileline
        If w = 1 Then
        temp = Mid(allfileline, 11, 10)
        ElseIf w = 2 Then
        temp = Mid(allfileline, 21, 10)
        ElseIf w = 3 Then
        temp = Mid(allfileline, 31, 10)
        ElseIf w = 4 Then
        temp = Mid(allfileline, 41, 10)
        End If
    End If
    Print #fnum1, Trim(Str(temp))
    Print #fnum1, "surf(x,y,Z)"
    Print #fnum1, "xlabel('" + (xlab(filenum)) + "')"
    Print #fnum1, "ylabel('" + (ylab(filenum)) + "')"
    Print #fnum1, "zlabel('" + tag2(w) + "')"  '"zlabel('" + (zlab(filenum)) + "')"
    Close #fnum1
Next w
Close
Exit Sub
' If user selects cancel button
ErrorLine:
MousePointer = 0
'File_Errors (Err)
Resume ErrorLine2
ErrorLine2:
End Sub

Sub GetExcel()
   Dim MyXL As Object   ' Variable to hold reference
   Dim MyNP As Object   ' Variable to hold reference
                     ' to Microsoft Excel.
   Dim ExcelWasNotRunning As Boolean   ' Flag for final release.

' Test to see if there is a copy of Microsoft Excel already running.
   On Error Resume Next   ' Defer error trapping.
' Getobject function called without the first argument returns a
' reference to an instance of the application. If the application isn't
' running, an error occurs.
   Set MyXL = GetObject(, "Excel.Application")
 '  Set MyNP = GetObject(, "Notepad.Application")
   If Err.Number <> 0 Then ExcelWasNotRunning = True
```

Appendix C-3: Gene VB Source Code: Form1.frm

```
  Err.Clear   ' Clear Err object in case error occurred.

' Check for Microsoft Excel. If Microsoft Excel is running,
' enter it into the Running Object table.
  DetectExcel

' Set the object variable to reference the file you want to see.
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
Dim destination As String
Dim projectfilename As String
Dim outfile As String
Dim loc As String
Dim loc2 As String
Dim n As Long
Dim ErrorLine, x, y As Long
Dim fileline, allfileline As String
Dim fnum, fnum1 As Long
fnum = FreeFile
dlgMain.CancelError = True
dlgMain.Filter = "All Files (*.*)|*.*"
dlgMain.FileName = ""
dlgMain.FilterIndex = 1
dlgMain.Action = 1
If CancelOpen = True Then GoTo ErrorLine
projectfilename = dlgMain.FileName
loc = Left(dlgMain.FileName, Len(dlgMain.FileName) - Len(dlgMain.FileTitle))

dlgMain.Filter = "All Files (*.*)|*.*"
dlgMain.FileName = ""
dlgMain.FilterIndex = 1
dlgMain.Action = 2
If CancelOpen = True Then GoTo ErrorLine
outfile = dlgMain.FileName
loc2 = Left(dlgMain.FileName, Len(dlgMain.FileName) - Len(dlgMain.FileTitle))
Open outfile + ".ipt" For Output As fnum
Print #fnum, "SW  1   0   10"
Print #fnum, "MM  7   1   2   3   4   12  13  14"
Print #fnum, "@  10  'RUNOFF.INT'"
Print #fnum, "$ANUM"
Print #fnum, "$NOQUOTE"
Print #fnum, "$RUNOFF"
Print #fnum, "A1 'COMMUTER PARKING LOT SWMM MODEL'"
Print #fnum, "A1 'EVENT MODE SIMULATION - SWMM vs. K2'"
Print #fnum, "B1  0   0   1   1   0   1   0   0   1   1   95"
Print #fnum, "B2  1   1   2   1   1   0"
Print #fnum, "B3  60  60  60  1   500"
Print #fnum, "B4  0.001    0.01   "
Print #fnum, "D1  0"
Print #fnum, "E1  0   10  0   0   0   1   10  5.0 0"
Print #fnum, "E3  0.16    0.48    0.37    0.25    0.08    0.02    0.01    0.00    0.00    0.01    "
Print #fnum, "F1  0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0"

  Set MyXL = GetObject(projectfilename)

' Show Microsoft Excel through its Application property. Then
```

Appendix C-3: Gene VB Source Code: Form1.frm

```
' show the actual window containing the file using the Windows
' collection of the MyXL object reference.
   MyXL.Application.Visible = True
   MyXL.Parent.Windows(1).Visible = True
 """""""""""""""""""   Do manipulations of your  file here.
""""""""""""""""""""""""""""""""""""""""""""""""""""
   ' Fill the array with seven values from column B of
   ' the worksheet.
   MyXL.Worksheets(3).Range("K6:AA65").Select
   SendKeys "^(c)", True
   MyXL.Worksheets(3).Selection.Copy
destination = Clipboard.GetText()
Print #fnum, destination;
Clipboard.Clear
"""""""""""""""""""""""""""""""""""""""""""""""""""""""
Print #fnum, "M1  0   0"
Print #fnum, "$ENDPROGRAM"
Close #fnum
""""""""""""""""""""""""""""""""""""""""""""""""""""
'dlgMain.Filter = "All Files (*.*)|*.*"
'dlgMain.FileName = ""
'dlgMain.FilterIndex = 1
'dlgMain.Action = 2
'If CancelOpen = True Then GoTo ErrorLine
'outfile = dlgMain.FileName
'loc2 = Left(dlgMain.FileName, Len(dlgMain.FileName) - Len(dlgMain.FileTitle))
Open outfile + "_1.par" For Output As fnum
   MyXL.Worksheets(3).Range("B76:P159").Select
   SendKeys "^(c)", True
   MyXL.Worksheets(3).Selection.Copy
destination = Clipboard.GetText()
Print #fnum, destination;
Clipboard.Clear
Close #fnum

'dlgMain.Filter = "All Files (*.*)|*.*"
'dlgMain.FileName = ""
'dlgMain.FilterIndex = 1
'dlgMain.Action = 2
'If CancelOpen = True Then GoTo ErrorLine
'outfile = dlgMain.FileName
'loc2 = Left(dlgMain.FileName, Len(dlgMain.FileName) - Len(dlgMain.FileTitle))
Open outfile + "_2.par" For Output As fnum
   MyXL.Worksheets(3).Range("B161:P244").Select
   SendKeys "^(c)", True
   MyXL.Worksheets(3).Selection.Copy
destination = Clipboard.GetText()
Print #fnum, destination;
Clipboard.Clear
Close #fnum

'dlgMain.Filter = "All Files (*.*)|*.*"
'dlgMain.FileName = ""
'dlgMain.FilterIndex = 1
'dlgMain.Action = 2
```

Appendix C-3: Gene VB Source Code: Form1.frm

```
'If CancelOpen = True Then GoTo ErrorLine
'outfile = dlgMain.FileName
'loc2 = Left(dlgMain.FileName, Len(dlgMain.FileName) - Len(dlgMain.FileTitle))
Open outfile + "_3.par" For Output As fnum
  MyXL.Worksheets(3).Range("B246:P329").Select
  SendKeys "^(c)", True
  MyXL.Worksheets(3).Selection.Copy
destination = Clipboard.GetText()
Print #fnum, destination;
Clipboard.Clear
Close #fnum

  ' ...
' If this copy of Microsoft Excel was not running when you
' started, close it using the Application property's Quit method.
' Note that when you try to quit Microsoft Excel, the
' title bar blinks and a message is displayed asking if you
' want to save any loaded files.
  If ExcelWasNotRunning = True Then
    MyXL.Application.Quit
  End If

  Set MyXL = Nothing   ' Release reference to the
                  ' application and spreadsheet.
Close
Exit Sub
' If user selects cancel button
ErrorLine:
MousePointer = 0
'File_Errors (Err)
Resume ErrorLine2
ErrorLine2:
End Sub

Sub DetectExcel()
' Procedure dectects a running Excel and registers it.
  Const WM_USER = 1024
  Dim hWnd As Long
' If Excel is running this API call returns its handle.
  hWnd = FindWindow("XLMAIN", 0)
  If hWnd = 0 Then   ' 0 means Excel not running.
    Exit Sub
  Else
  ' Excel is running so use the SendMessage API
  ' function to enter it in the Running Object Table.
    SendMessage hWnd, WM_USER + 18, 0, 0
  End If
End Sub
```

Appendix C-4: RainPro VBSource Code: RainPro.vbp & RainPro.vbw

RainPro.vbp:

```
Type=Exe
Form=frmMain.frm
Reference=*\G{00020430-0000-0000-C000-000000000046}#2.0#0#..\..\..\WINDOWS\SYSTEM\stdole2.tlb#OLE Automation
Object={F9043C88-F6F2-101A-A3C9-08002B2F49FB}#1.2#0; COMDLG32.OCX
Module=Module1; Module1.bas
Reference=*\G{00025E01-0000-0000-C000-000000000046}#4.0#0#..\..\..\PROGRAM FILES\COMMON FILES\MICROSOFT SHARED\DAO\DAO350.DLL#Microsoft DAO 3.51 Object Library
IconForm="Form1"
Startup="Form1"
HelpFile=""
Title="RainPro"
ExeName32="RainPro.exe"
Path32="setup"
Command32=""
Name="Project1"
HelpContextID="0"
CompatibleMode="0"
MajorVer=1
MinorVer=0
RevisionVer=0
AutoIncrementVer=0
ServerSupportFiles=0
VersionCompanyName="Virginia Polytechnic Institute and State University"
CompilationType=0
OptimizationType=0
FavorPentiumPro(tm)=0
CodeViewDebugInfo=0
NoAliasing=0
BoundsCheck=0
OverflowCheck=0
FlPointCheck=0
FDIVCheck=0
UnroundedFP=0
StartMode=0
Unattended=0
Retained=0
ThreadPerObject=0
MaxNumberOfThreads=1
```

RainPro.vbw:

```
Form1 = 32, 67, 578, 507, C, 42, 42, 661, 483, C
Module1 = 1, 7, 767, 636,
```

Appendix C-5: RainPro VB Source Code: Module1.bas

```
Attribute VB_Name = "Module1"
Option Explicit
Option Base 1
Global JDate
Global Year
Global TotalRain
Global Month As String
Global Day As String
Global TimeHHMM
Global Hour As String
Global Minute As String
Global MasterFilePath As String
Global FileLocation As String
Global MasterFileTitle As String
Global CurrentFilePath As String
Global NLines As Long
Global NPoints As Long
Global DataFileList()
Global NDataFiles As Long
Global RainDataRaw()
Global LengthRainDataRaw As Long
Global RainDataCondensed() As String
Global LengthRainDataCondensed As Long
Const NumMetaDataChars = 71  'metadata identifying station & lat/lon. req'd
Const IflowsFieldWidth = 6   'field width for rainfall portion of file
Const NumCommentLines = 1    'comment lines in IFLOWS file.  can vary per user input during export
'GENERAL NOTES:
'text files MAY NOT CONTAIN any EOF characters, line returns, or blank lines,
'either at the beginning, end, or middle!!!

Sub ProcessDataLogger()
'Controls processing of multiple datalogger rainfall files into a single JIN file
'ready for conversion to a SWMM interface file.
Call GetMasterFilePath
If MasterFilePath = "" Then
  MsgBox "Cannot continue without master file....Returning to RainPro Main"
  Exit Sub
End If
Form1.MousePointer = 11
Call ReadMasterFile
Call ReadDataLoggerFiles
Call CondenseRainData
Form1.MousePointer = 1
MsgBox "Total Rainfall Depth = " & TotalRain & " inches"
Form1.MousePointer = 11
Call WriteSWMMFile
Form1.MousePointer = 1
MsgBox "SWMM rainfall file saved as rain_in.pre, length = " & LengthRainDataCondensed

End Sub
Sub GetMasterFilePath()
  'Reads the path and filename of a user-input master file listing the data files
  'to be used.  Data files are required to be in the same directory as the master file.
   Form1.CommonDialog1.DialogTitle = "Select Master File and File Path"
```

Appendix C-5: RainPro VB Source Code: Module1.bas

```
  Form1.CommonDialog1.InitDir = "c:\gene_thesis\VB Projects\RainPro\Data files"
  Form1.CommonDialog1.Filter = "Text files (*.txt)|*.txt|Data files (*.dat)|*.dat"
  Form1.CommonDialog1.ShowOpen
  'If Form1.CommonDialog1.CancelOpen = True Then GoTo ErrorLine
  MasterFilePath = Form1.CommonDialog1.FileName
  MasterFileTitle = Form1.CommonDialog1.FileTitle
  'If MasterFilePath = "" Then
   'GoTo ErrorLine
    'MsgBox "You must select a valid master file to continue!"
    'Form1.CommonDialog1.ShowOpen
  'End If
  FileLocation = Left(MasterFilePath, Len(MasterFilePath) - Len(MasterFileTitle))
'Exit Sub
' If user selects cancel button
'ErrorLine:

End Sub
Sub ReadMasterFile()
'Reads list of data files from master file that was read above
'Stores list in Global DataFileList(), of dimension Global NDataFiles.
Dim i As Integer
Dim fnum As Long
fnum = FreeFile

Close
CurrentFilePath = MasterFilePath
Call GetFileLength
NDataFiles = NLines

ReDim DataFileList(NDataFiles, 2)
Open MasterFilePath For Input As fnum
For i = 1 To NDataFiles
  Input #fnum, DataFileList(i, 1)
Next i
Close
'MsgBox " " & NDataFiles & DataFileList(1) & " " & DataFileList(2) & " " & DataFileList(3) & " "
End Sub
Sub GetFileLength()
'Determines number of lines in file Global CurrentFilePath;
'stores in Global NLines.  For comma-delimited datalogger files.
Dim allfileline As String
Dim fnum As Long
fnum = FreeFile

Close
Open CurrentFilePath For Input As fnum
NLines = 0
Do While Not EOF(fnum)
  Line Input #fnum, allfileline
  NLines = NLines + 1
Loop
Close #fnum

End Sub
Sub GetIflowsLength()
```

Appendix C-5: RainPro VB Source Code: Module1.bas

```
'Determines the length (number of rainfall data points) in an IFLOWS
'export file.  File is space-delimited, no line breaks, 6-character right-
'justified fields.  User-determined comment lines, plus 71 chars of metadata
'at the beginning of the first line of rain data.
Dim junk As String
Dim IflowsText
Dim NumChars
Dim fnum As Long
Dim i As Integer
fnum = FreeFile
Form1.MousePointer = 11
Close
Open CurrentFilePath For Input As fnum
For i = 1 To NumCommentLines
  Line Input #fnum, junk  'ignore comment lines
Next i
junk = 0
Line Input #fnum, IflowsText
NumChars = Len(IflowsText)
NPoints = (NumChars - NumMetaDataChars) / IflowsFieldWidth
Close #fnum
Form1.MousePointer = 1
'MsgBox "NPoints = " & NPoints

End Sub
Sub ReadDataLoggerFiles()
'Reads columns 1-4,6 from datalogger files into global array RainDataRaw()
Dim i As Long, m As Integer
Dim fnum1 As Long, j As Long, fnum2 As Long
Dim NLinesInFile As Long, NLinesInAllFiles As Long, NLinesUpToCurrentFile As Long
Dim junk
Dim RainSubTotal

fnum1 = FreeFile
fnum2 = fnum1 + 1
NLinesInAllFiles = 0

'get total number of lines for all data files
For i = 1 To NDataFiles
   Close
   CurrentFilePath = FileLocation & DataFileList(i, 1)
   Call GetFileLength
   NLinesInFile = NLines
   DataFileList(i, 2) = NLinesInFile
   NLinesInAllFiles = NLinesInFile + NLinesInAllFiles
Next i

ReDim RainDataRaw(NLinesInAllFiles, 5)
LengthRainDataRaw = NLinesInAllFiles

NLinesUpToCurrentFile = 0
For i = 1 To NDataFiles
   Close
   CurrentFilePath = FileLocation & DataFileList(i, 1)
   NLinesInFile = DataFileList(i, 2)
```

```
   NLinesUpToCurrentFile = NLinesInFile + NLinesUpToCurrentFile

   m = 0   'm is number of column in data file
   j = NLinesUpToCurrentFile - NLinesInFile + 1 'j is row of data file and array
   Open CurrentFilePath For Input As fnum1

   Do While j <= NLinesUpToCurrentFile
      m = m + 1
      Select Case m
      Case 1
        Input #fnum1, RainDataRaw(j, m)
        If RainDataRaw(j, m) > 113 Then
          Line Input #fnum1, junk
          junk = 0
          m = 0
          j = j + 1
        End If
      Case 2 To 4
        Input #fnum1, RainDataRaw(j, m)
      Case 5
        Input #fnum1, junk
        junk = 0
      Case 6
        Input #fnum1, RainDataRaw(j, m - 1)
        RainSubTotal = RainDataRaw(j, m - 1) + RainSubTotal
      Case Is > 6
        Line Input #fnum1, junk
        junk = 0
        m = 0
        j = j + 1
      End Select
    Loop
    Close #fnum1
    'Form1.MousePointer = 1
    'MsgBox "Inches of rain in file = " & RainSubTotal / 100
    'Form1.MousePointer = 11

Next i
Close

'print out RainDataRaw to text file for checking
CurrentFilePath = FileLocation & "test1.txt"
Open CurrentFilePath For Output As fnum2
For i = 1 To NLinesInAllFiles
  Print #fnum2, ""
  For j = 1 To 5
    Print #fnum2, RainDataRaw(i, j),
  Next j
  Print #fnum2, Chr(13)
Next i
Close #fnum2

End Sub
Sub CondenseRainData()
'Condenses RainDataRaw, eliminating dry time steps and WQ sampling
```

```
'(non-rainfall tip) events.  For datalogger rainfall.  See **** for
'condensing IFLOWS data.
Dim i As Long, j As Long, k As Long
Dim NoSkip As Long
Dim fnum3 As Long, fnum4 As Long
Dim RainDepth
fnum3 = FreeFile
fnum4 = fnum3 + 1

LengthRainDataCondensed = 0
'determine size of new matrix
For i = 1 To LengthRainDataRaw
  If (RainDataRaw(i, 1) <= 113) And (RainDataRaw(i, 5) > 0) Then
    NoSkip = 1
  Else
    NoSkip = 0
  End If
  LengthRainDataCondensed = LengthRainDataCondensed + NoSkip
Next i

ReDim RainDataCondensed(LengthRainDataCondensed, 6)
TotalRain = 0
j = 1
For k = 1 To LengthRainDataRaw
  If (RainDataRaw(k, 1) <= 113) And (RainDataRaw(k, 5) > 0) Then
       Year = RainDataRaw(k, 2)
       RainDataCondensed(j, 1) = Year
       JDate = RainDataRaw(k, 3)
       Call JDateConvert
       RainDataCondensed(j, 2) = Month
       RainDataCondensed(j, 3) = Day
       TimeHHMM = RainDataRaw(k, 4)
       Call TimeConvert
       RainDataCondensed(j, 4) = Hour
       RainDataCondensed(j, 5) = Minute
       RainDepth = RainDataRaw(k, 5)
       RainDataCondensed(j, 6) = RainDepth 'rainfall, hundredths of an inch
       TotalRain = TotalRain + RainDepth / 100 'total in inches
       j = j + 1
   End If
Next k

'print to text file for checking and SWMM JIN file
Close
CurrentFilePath = FileLocation & "test2.txt"
Open CurrentFilePath For Output As fnum4
For i = 1 To LengthRainDataCondensed
  For j = 1 To 6
    Print #fnum4, RainDataCondensed(i, j) & "  ";
  Next j
  Print #fnum4, ""
Next i
Close #fnum4

End Sub
```

Appendix C-5: RainPro VB Source Code: Module1.bas

```
Sub JDateConvert()
'Converts Julian Date to Month and Day
Dim LeapDay
Dim JDays
Dim TempDay

If Year Mod 4 = 0 Then
  LeapDay = 1
Else
  LeapDay = 0
End If

Select Case JDate
Case Is <= 31
  Month = "01"
  JDays = 0
Case Is <= 59 + LeapDay
  Month = "02"
  JDays = 31
Case Is <= 90 + LeapDay
  Month = "03"
  JDays = 59 + LeapDay
Case Is <= 120 + LeapDay
  Month = "04"
  JDays = 90 + LeapDay
Case Is <= 151 + LeapDay
  Month = "05"
  JDays = 120 + LeapDay
Case Is <= 181 + LeapDay
  Month = "06"
  JDays = 151 + LeapDay
Case Is <= 212 + LeapDay
  Month = "07"
  JDays = 181 + LeapDay
Case Is <= 243 + LeapDay
  Month = "08"
  JDays = 212 + LeapDay
Case Is <= 273 + LeapDay
  Month = "09"
  JDays = 243 + LeapDay
Case Is <= 304 + LeapDay
  Month = "10"
  JDays = 273 + LeapDay
Case Is <= 334 + LeapDay
  Month = "11"
  JDays = 304 + LeapDay
Case Is <= 365 + LeapDay
  Month = "12"
  JDays = 334 + LeapDay
End Select

TempDay = JDate - JDays
If Len(TempDay) = 1 Then
   Day = "0" & TempDay
ElseIf Len(TempDay) = 2 Then
```

```
   Day = TempDay
End If

End Sub
Sub TimeConvert()
'Converts time in HHMM to hours and minutes
Select Case TimeHHMM
   Case Is <= 9
      Hour = "00"
      Minute = "0" & TimeHHMM
   Case Is <= 55
      Hour = "00"
      Minute = TimeHHMM
   Case Is <= 955
      Hour = "0" & Left(TimeHHMM, 1)
      Minute = Right(TimeHHMM, 2)
   Case Is >= 1000
      Hour = Left(TimeHHMM, 2)
      Minute = Right(TimeHHMM, 2)
End Select

End Sub
Sub WriteSWMMFile()
'writes ASCII file for conversion to interface file using SWMM RAIN block
'ensures all columns are constant width throughout file (req'd for SWMM RAIN)
Dim fnum As Long, i As Long, j As Long
Dim GageNum As String
GageNum = "1135" 'Gage station number for Blacksburg - for IFLOWS
fnum = FreeFile

Close
CurrentFilePath = FileLocation & "rain_in.pre"
Open CurrentFilePath For Output As fnum
For i = 1 To LengthRainDataCondensed
  Print #fnum, GageNum & "  ";
  For j = 1 To 6
     Print #fnum, RainDataCondensed(i, j) & "  ";
  Next j
  Print #fnum, ""
Next i
Close #fnum

End Sub
Sub ProcessIFLOWS()

Call GetMasterFilePath
If MasterFilePath = "" Then
   MsgBox "Cannot continue without master file....Returning to RainPro Main"
   Exit Sub
End If
Form1.MousePointer = 11
Call ReadMasterFile
Call ReadIflowsFiles
Call ConvertIflowsToFiveMinute
Call AssignIflowsDateTime
```

Appendix C-5: RainPro VB Source Code: Module1.bas

```
Call CondenseIflows
Form1.MousePointer = 1
MsgBox "Total Rainfall Depth = " & TotalRain & " inches"
Form1.MousePointer = 11
Call WriteSWMMFile
Form1.MousePointer = 1
MsgBox "SWMM rainfall file saved as rain_in.pre, length = " & LengthRainDataCondensed

End Sub
Sub ReadIflowsFiles()
'Reads rain data from IFLOWS files into global array RainDataRaw(),
'data is listed in reverse chronological order, but read into array
'from back to front.  Note master file must list data files in reverse
'chronological order as well.  Done correctly, the array will be in forward
'chronological order.
Dim i As Long, j As Long, k As Long, m As Long
Dim fnum1 As Long, fnum2 As Long
Dim IflowsAsText
Dim NPointsInFile As Long, NPointsInAllFiles As Long
Dim junk, temp, RainSubTotal
Dim subtot As Long
Dim JStart() As Long
fnum1 = FreeFile
fnum2 = fnum1 + 1

'get total number of points for all data files
NPointsInAllFiles = 0
For i = 1 To NDataFiles
   Close
   CurrentFilePath = FileLocation & DataFileList(i, 1)
   Call GetIflowsLength
   NPointsInFile = NPoints
   DataFileList(i, 2) = NPointsInFile
   NPointsInAllFiles = NPointsInFile + NPointsInAllFiles
Next i
LengthRainDataRaw = NPointsInAllFiles
ReDim RainDataRaw(LengthRainDataRaw, 1)

'create array of starting index values of RainDataRaw array for each file number
ReDim JStart(NDataFiles)
For i = 1 To NDataFiles
   If i = 1 Then
     subtot = 0
   Else
     subtot = DataFileList(i - 1, 2) + subtot
   End If
   JStart(i) = NPointsInAllFiles - subtot
Next i

For i = 1 To NDataFiles
   CurrentFilePath = FileLocation & DataFileList(i, 1)
   Open CurrentFilePath For Input As fnum1
   For m = 1 To NumCommentLines
     Line Input #fnum1, junk    'ignore comment lines
   Next m
```

```
   Line Input #fnum1, IflowsAsText
   Close #fnum1
   NPointsInFile = DataFileList(i, 2)
   'trim off metadata
   IflowsAsText = Right(IflowsAsText, NPointsInFile * IflowsFieldWidth)
   j = JStart(i)
   RainSubTotal = 0
   For k = 1 To NPointsInFile
      'read 6 characters from array at a time
      temp = Mid(IflowsAsText, 1 + (k - 1) * IflowsFieldWidth, IflowsFieldWidth)
      'test for and eliminate '-'; replace with '0'
      If temp = "     -" Then
         temp = 0
      Else
         temp = Val(temp)
      End If
      RainDataRaw(j, 1) = temp * 100
      RainSubTotal = RainDataRaw(j, 1) + RainSubTotal
      j = j - 1
    Next k
    'Form1.MousePointer = 1
    'MsgBox "Inches of rain in file = " & RainSubTotal / 100
    'Form1.MousePointer = 11
Next i

'print out RainDataRaw to text file for checking
Close
CurrentFilePath = FileLocation & "test1.txt"
Open CurrentFilePath For Output As fnum2
For i = 1 To NPointsInAllFiles
  Print #fnum2, RainDataRaw(i, 1),
  Print #fnum2, Chr(13)
Next i
Close #fnum2
End Sub
Sub ConvertIflowsToFiveMinute()
'converts array of 15-minute resolution IFLOWS data to 5-minute resolution.
'distributes 15 min rainfall over 3-5 min periods such that the finest increment
'is 0.01" (i.e., '1' in array since storing inches*100 values).  Remainder of
'15 min rain / 3 is distributed to the first one or two 5-min periods as necessary.
Dim i As Long, j As Long, fnum2 As Long
Dim RainFifteenMin, Rain5min1, Rain5min2, Rain5min3, test, intDiv
Dim TempRainArray()
fnum2 = FreeFile

LengthRainDataRaw = 3 * LengthRainDataRaw
ReDim TempRainArray(LengthRainDataRaw)
For j = 3 To LengthRainDataRaw Step 3
   RainFifteenMin = RainDataRaw(Int(j / 3), 1)
   test = RainFifteenMin Mod 3
   intDiv = RainFifteenMin \ 3
   Select Case test
   Case Is = 0
      Rain5min1 = RainFifteenMin / 3
      Rain5min2 = Rain5min1
```

```
      Rain5min3 = Rain5min1
   Case Is = 1
      Rain5min1 = intDiv + 1
      Rain5min2 = intDiv
      Rain5min3 = Rain5min2
   Case Is = 2
      Rain5min1 = intDiv + 1
      Rain5min2 = Rain5min1
      Rain5min3 = intDiv
   Case Else    'in case of error
      Rain5min1 = 99999
      MsgBox "Error in raw rainfall data: non-integer value detected!"
      Rain5min2 = Rain5min1
      Rain5min3 = Rain5min1
   End Select
   TempRainArray(j - 2) = Rain5min1
   TempRainArray(j - 1) = Rain5min2
   TempRainArray(j) = Rain5min3
Next j

'Overwrite RainDataRaw with 5-min array, with space for JDate and Time
ReDim RainDataRaw(LengthRainDataRaw, 5)
For i = 1 To LengthRainDataRaw
  RainDataRaw(i, 5) = TempRainArray(i)
Next i

'print out RainDataRaw to text file for checking
Close
CurrentFilePath = FileLocation & "test2.txt"
Open CurrentFilePath For Output As fnum2
For i = 1 To LengthRainDataRaw
  Print #fnum2, RainDataRaw(i, 5),
  Print #fnum2, Chr(13)
Next i
Close #fnum2

End Sub
Sub AssignIflowsDateTime()
'Create date and time labels for 5-minute series of IFLOWS data,
'given the start and end dates/times.
Dim i As Long, k As Long, j As Long, fnum2 As Long
Dim yr As Long, jdy As Long, hr As Long, min As Long
Dim NDayInYr
fnum2 = FreeFile
'note global month, day, hour, and minute are all strings.  Year and JDate are not.
'input start and end
Dim StartYJHM, EndYJHM
Dim StartYr, StartJDay, StartHr, StartMin, EndYr, test
StartYJHM = InputBox("Enter start time, in format YYYYJJJHHMM, where JJJ=Julian date")
EndYr = InputBox("Enter ending year, YYYY")
'EndYJHM = InputBox("Enter end time, in format YYYYJJJHHMM")
'don't need EndYJHM separated, since will be used as string later in code to exit sub
'*******expect issues with string vs. variant format******
StartYr = Left(StartYJHM, 4)
StartJDay = Mid(StartYJHM, 5, 3)
```

```
StartHr = Mid(StartYJHM, 8, 2)
StartMin = Right(StartYJHM, 2)
'EndYr = Left(EndYJHM, 4)
'treat hour and minute as strings...merge hr*100+minute, then call TimeConvert

k = 1
For yr = StartYr To EndYr
  If yr Mod 4 = 0 Then
    NDayInYr = 366
  Else
    NDayInYr = 365
  End If
  If k > 1 Then
    StartJDay = 1
  End If
  For jdy = StartJDay To NDayInYr
    If k > 1 Then
      StartHr = 0
    End If
    For hr = StartHr To 23
      If k > 1 Then
        StartMin = 0
      End If
      For min = StartMin To 55 Step 5
        RainDataRaw(k, 1) = yr
        RainDataRaw(k, 2) = jdy
        RainDataRaw(k, 3) = hr
        RainDataRaw(k, 4) = min
        k = k + 1
        'test = 10000000 * yr + 10000 * jdy + 100 * hr + min
        If k > LengthRainDataRaw Then
          GoTo printloop
        End If
      Next min
    Next hr
  Next jdy
Next yr

'print out RainDataRaw to text file for checking
printloop:
Close
CurrentFilePath = FileLocation & "test3.txt"
Open CurrentFilePath For Output As fnum2
For i = 1 To LengthRainDataRaw
  For j = 1 To 5
    Print #fnum2, RainDataRaw(i, j) & "  ";
  Next j
  Print #fnum2, ""
Next i
Close #fnum2

End Sub
Sub CondenseIflows()
'eliminate zeros, convert JDate to month and day (strings), assure hour and minute are
'two-characters long.
```

Appendix C-5: RainPro VB Source Code: Module1.bas

```
Dim i As Long, j As Long, k As Long
Dim NoSkip As Long
Dim fnum3 As Long
Dim RainDepth
fnum3 = FreeFile

LengthRainDataCondensed = 0
'determine size of new matrix
For i = 1 To LengthRainDataRaw
  If RainDataRaw(i, 5) > 0 Then
    NoSkip = 1
  Else
    NoSkip = 0
  End If
  LengthRainDataCondensed = LengthRainDataCondensed + NoSkip
Next i

ReDim RainDataCondensed(LengthRainDataCondensed, 6)
TotalRain = 0
j = 1
For k = 1 To LengthRainDataRaw
  If RainDataRaw(k, 5) > 0 Then
       Year = RainDataRaw(k, 1)
       RainDataCondensed(j, 1) = Year
       JDate = RainDataRaw(k, 2)
       Call JDateConvert
       RainDataCondensed(j, 2) = Month
       RainDataCondensed(j, 3) = Day
       TimeHHMM = RainDataRaw(k, 3) * 100 + RainDataRaw(k, 4)
       Call TimeConvert
       RainDataCondensed(j, 4) = Hour
       RainDataCondensed(j, 5) = Minute
       RainDepth = RainDataRaw(k, 5)
       RainDataCondensed(j, 6) = RainDepth 'rainfall, hundredths of an inch
       TotalRain = TotalRain + RainDepth / 100 'total in inches
       j = j + 1
   End If
Next k

'print to text file for checking and SWMM JIN file
CurrentFilePath = FileLocation & "test4.txt"
Open CurrentFilePath For Output As fnum3
For i = 1 To LengthRainDataCondensed
  For j = 1 To 6
    Print #fnum3, RainDataCondensed(i, j) & "  ";
  Next j
  Print #fnum3, ""
Next i
Close #fnum3
End Sub
```

Appendix C-6: RainPro VB Source Code: frmMain.frm

```
VERSION 5.00
Object = "{F9043C88-F6F2-101A-A3C9-08002B2F49FB}#1.2#0"; "COMDLG32.OCX"
Begin VB.Form Form1
   Caption         =   "RainPro Main"
   ClientHeight    =   4500
   ClientLeft      =   60
   ClientTop       =   345
   ClientWidth     =   5940
   LinkTopic       =   "Form1"
   ScaleHeight     =   4500
   ScaleWidth      =   5940
   StartUpPosition =   3  'Windows Default
   Begin VB.CommandButton Command2
      Caption         =   "Quit"
      Height          =   375
      Left            =   4920
      TabIndex        =   6
      Top             =   3360
      Width           =   615
   End
   Begin VB.ComboBox Combo2
      Height          =   315
      Left            =   3000
      TabIndex        =   5
      Text            =   "<select resolution>"
      Top             =   1320
      Width           =   1695
   End
   Begin VB.ComboBox Combo1
      Height          =   315
      Left            =   600
      TabIndex        =   4
      Text            =   "<select source>"
      Top             =   1320
      Width           =   2295
   End
   Begin VB.CommandButton Command1
      Caption         =   "Process Data"
      Height          =   615
      Left            =   4560
      TabIndex        =   2
      Top             =   2160
      Width           =   1215
   End
   Begin MSComDlg.CommonDialog CommonDialog1
      Left            =   5160
      Top             =   240
      _ExtentX        =   847
      _ExtentY        =   847
      _Version        =   393216
      MaxFileSize     =   5000
   End
   Begin VB.Label Label3
      AutoSize        =   -1  'True
      Caption         =   "Data Source and Resolution:"
```

Appendix C-6: RainPro VB Source Code: frmMain.frm

```
      BeginProperty Font
         Name            =   "MS Sans Serif"
         Size            =   8.25
         Charset         =   0
         Weight          =   400
         Underline       =   0   'False
         Italic          =   -1  'True
         Strikethrough   =   0   'False
      EndProperty
      Height          =   195
      Left            =   480
      TabIndex        =   3
      Top             =   1080
      Width           =   2145
   End
   Begin VB.Label Label2
      Alignment       =   2  'Center
      AutoSize        =   -1  'True
      Caption         =   "SWMM Rainfall Data Pre-processor"
      Height          =   195
      Left            =   1560
      TabIndex        =   1
      Top             =   720
      Width           =   2520
   End
   Begin VB.Label Label1
      Alignment       =   2  'Center
      AutoSize        =   -1  'True
      Caption         =   "RainPro"
      BeginProperty Font
         Name            =   "MS Sans Serif"
         Size            =   13.5
         Charset         =   0
         Weight          =   700
         Underline       =   0   'False
         Italic          =   0   'False
         Strikethrough   =   0   'False
      EndProperty
      Height          =   360
      Left            =   2250
      TabIndex        =   0
      Top             =   360
      Width           =   1155
   End
End
Attribute VB_Name = "Form1"
Attribute VB_GlobalNameSpace = False
Attribute VB_Creatable = False
Attribute VB_PredeclaredId = True
Attribute VB_Exposed = False

Private Sub Command1_Click()

   If Combo1.Text = "Data logger" And _
      Combo2.Text = "5 minutes" Then
```

```
    Call ProcessDataLogger
  ElseIf Combo1.Text = "IFLOWS" And _
    Combo2.Text = "15 minutes" Then
    Call ProcessIFLOWS
  Else
    MsgBox "Unable to process this combination of data source and resolution."
  End If

End Sub

Private Sub Command2_Click()

End

End Sub

Private Sub Form_Load()

Combo1.AddItem "Data logger"
Combo1.AddItem "IFLOWS"

Combo2.AddItem "5 minutes"
Combo2.AddItem "15 minutes"

End Sub
```

APPENDIX D

SUPPORTING CALCULATIONS FOR LID DESIGN AND EVALUATION

- **D-1: Potential Evapotranspiration Calculations**
- **D-2: Time of Concentration Calculations**
- **D-3: LID Design Charts**
- **D-4: VT/PSUHM Input File for SWM Pond Outlet**

Appendix D-1: Potential Evapotranspiration Calculations

Thornthwaite PET Based on Mean Monthly Temperature

Month	# days	Temperature			I Factor	C Factor	PET		
		Mean F	Mean C	Mean >0	$(T/5)^{1.5}$	40 deg. N.	cm/mo	in/mo	in/day
Jan	31	34.5	1.4	1.4	0.1464	0.80	0.16	0.06	0.00206
Feb	28	37.4	3.0	3.0	0.4648	0.89	0.54	0.21	0.00759
Mar	31	46.7	8.2	8.2	2.0874	0.99	2.49	0.98	0.03168
Apr	30	55.7	13.2	13.2	4.2733	1.10	5.47	2.15	0.07173
May	31	64.2	17.9	17.9	6.7674	1.20	9.22	3.63	0.11707
Jun	30	71.8	22.1	22.1	9.2995	1.25	12.98	5.11	0.17032
Jul	31	75.8	24.3	24.3	10.7361	1.23	14.63	5.76	0.18584
Aug	31	74.6	23.7	23.7	10.2979	1.15	13.15	5.18	0.16703
Sep	30	67.7	19.8	19.8	7.9002	1.04	9.25	3.64	0.12141
Oct	31	56.6	13.7	13.7	4.5190	0.93	4.87	1.92	0.06188
Nov	30	47.5	8.6	8.6	2.2601	0.83	2.25	0.89	0.02959
Dec	31	38.3	3.5	3.5	0.5857	0.78	0.59	0.23	0.00748

I = 59.3
a = 1.4

Total Annual: 29.77 inches

Appendix D-2: Time of Concentration Calculations

Predevelopment Forested (FOR) Conditions Time of Concentration:

Seg-ment #	Location / Description	Flow Type	Length, L	Slope, S (ft/ft)	B (ft)	D (ft)	Side slope, z	n	A (ft^2)	P (ft)	R (ft)	V (ft/s)	Tt (hr)	Tt (hr)
1	Woods	Overland (sheet) flow *	100	0.0500	--	--	--	0.4	--	--	--	--	0.252	15.12
2	Woods	Shallow conc., unpaved	250	0.0800	--	--	--	0.05	--	--	0.40	4.57	0.015	0.91
3	Swale	Shallow conc., unpaved	252	0.1190	--	--	--	0.05	--	--	0.40	5.58	0.013	0.75
4	Swale	Trapezoidal channel	246	0.1077	2	0.5	6	0.08	2.5	8.08	0.31	2.79	0.024	1.47
		Total Length:	848										**0.304**	**18.25**
		* P_2 = 3.1 inches										**Lag time = 0.6*Tc =**		**10.95**

Appendix D-2: Time of Concentration Calculations

Low Impact Development (LID) Conditions Time of Concentration:

Seg-ment #	Location / Description	Flow Type	Length, L	Slope, S (ft/ft)	B (ft)	D (ft)	Side slope, z	n	A (ft^2)	P (ft)	R (ft)	V (ft/s)	Tt (hr)	Tt (min)
1	Woods behind lot 70 (70woods)	Overland (sheet) flow *	100	0.050	--	--	--	0.4	--	--	--	--	0.252	15.12
2	Lawn of lot 70 (70lawn)	Shallow conc., unpaved	57	0.092	--	--	--	0.05	--	--	0.40	4.91	0.003	0.19
3	Dry swale with check dams (east side of upper Village Way - uvwEswal)	Trapezoidal channel	230	0.075	7	0.25	2	0.06	1.88	8.12	0.23	2.56	0.025	1.50
4	Pipe from inlet (uvwEinlt)	Pipe (corrugated HDPE)	35	0.010	1.25	1.25	--	0.022	1.23	3.93	0.31	3.12	0.003	0.19
5	uvwWinlt	Pipe	30	0.042	1.25	1.25	--	0.022	1.23	3.93	0.31	6.39	0.001	0.08
6	alyEinlt	Pipe	30	0.017	1.5	1.5	--	0.022	1.77	4.71	0.38	4.59	0.002	0.11
7	grvswal	Trapezoidal channel	130	0.108	2	0.5	3	0.08	1.75	5.16	0.34	2.97	0.012	0.73
8	grvinlt	Pipe	50	0.033	1.5	1.5	--	0.022	1.77	4.71	0.38	6.40	0.002	0.13
9	blvdinlt	Pipe	57	0.049	1.5	1.5	--	0.022	1.77	4.71	0.38	7.79	0.002	0.12
10	lowrchan	Trapezoidal channel	150	0.120	2	1	3	0.08	5.00	8.32	0.60	4.59	0.009	0.54
		Total Length:	869										**0.312**	**18.71**

* P_2 = 3.1 inches

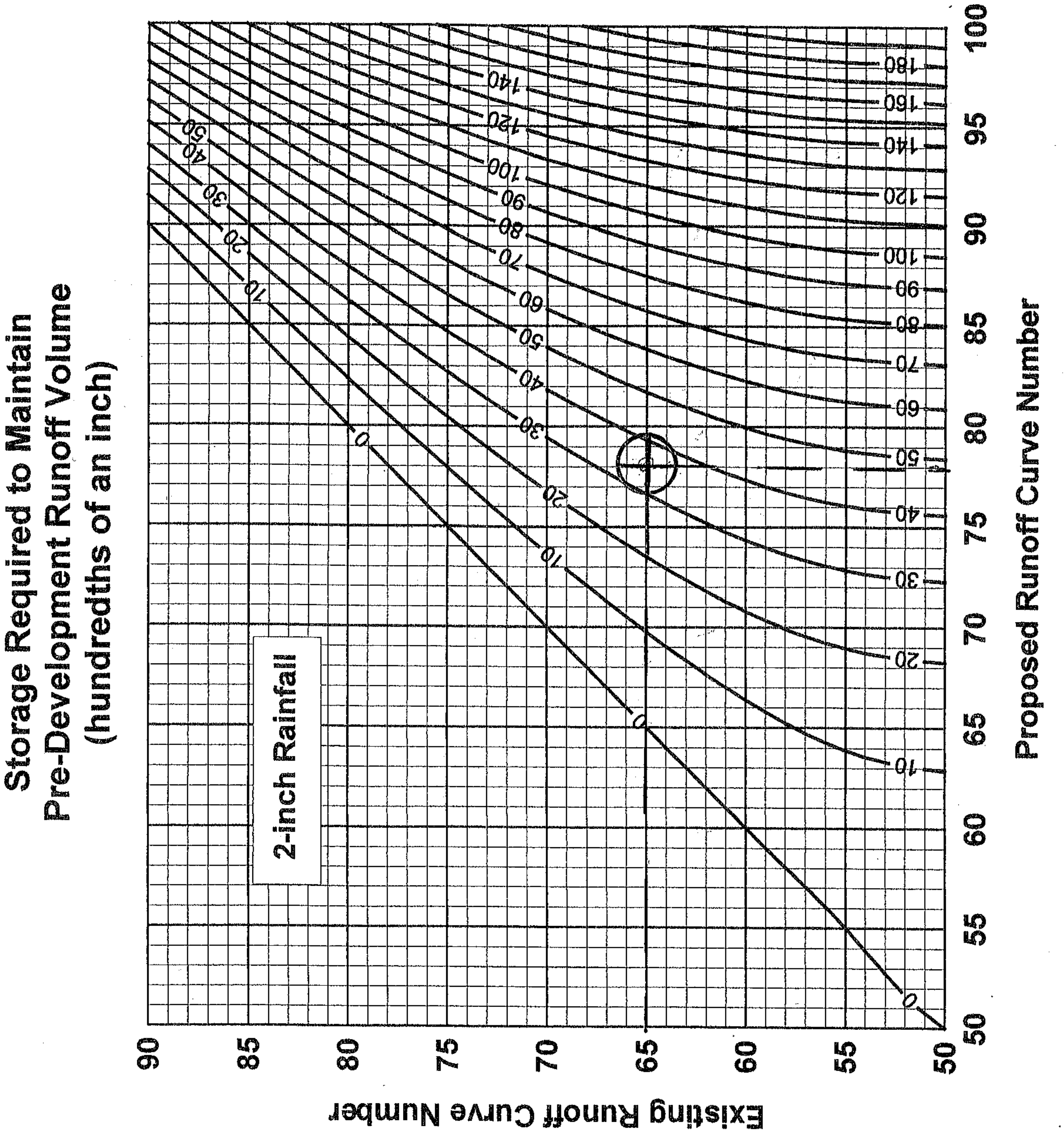
Lag time = 0.6*Tc = 11.23

Appendix D-2: Time of Concentration Calculations

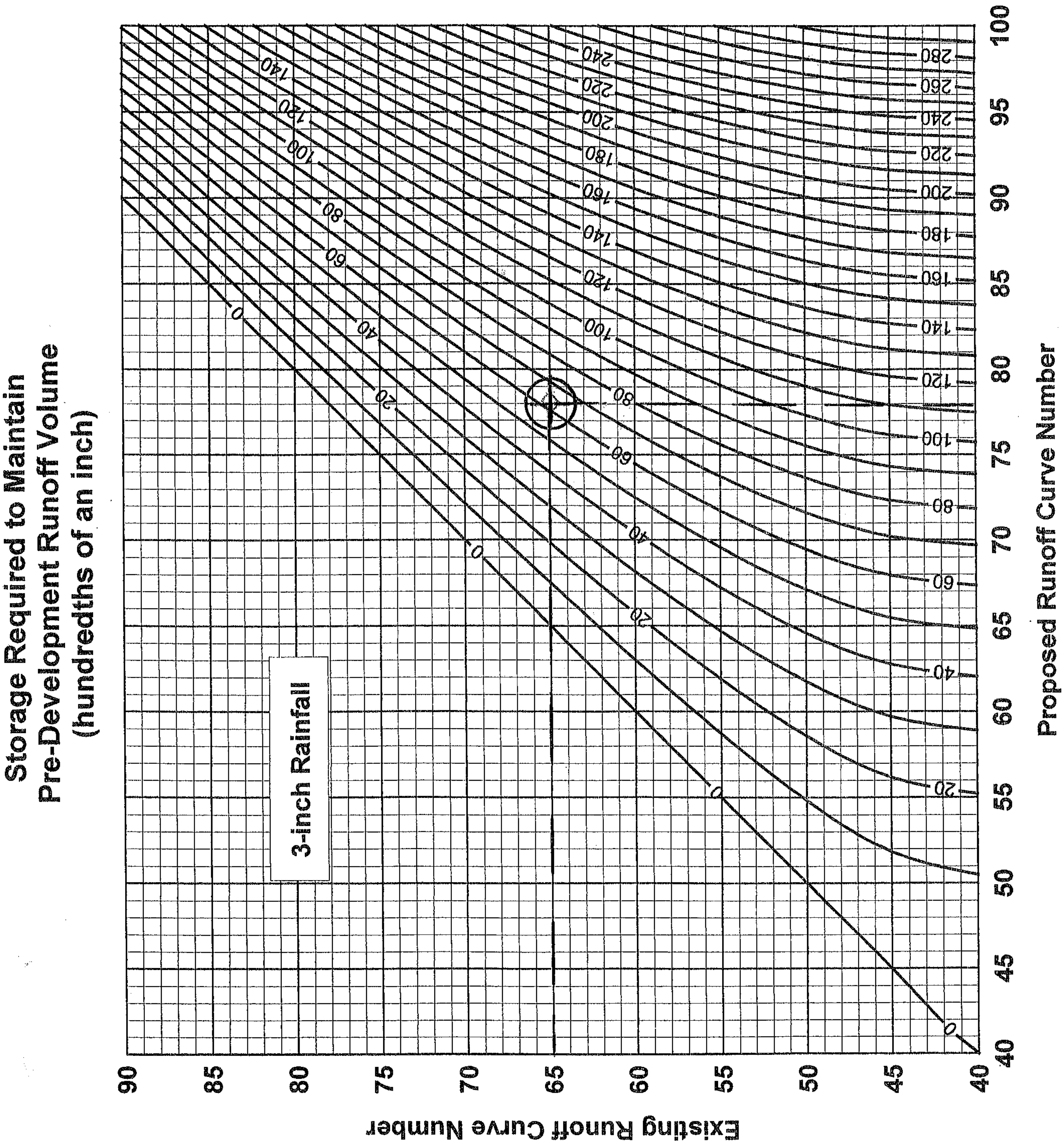
Conventional Development (CONV) Conditions Time of Concentration:

Seg-ment #	Location / Description	Flow Type	Length, L	Slope, S (ft/ft)	B (ft)	D (ft)	Side slope, z	n	A (ft^2)	P (ft)	R (ft)	V (ft/s)	Tt (hr)	Tt (min)
1	Woods behind lot 70 (70woods); assumed converted to lawn	Overland (sheet) flow *	100	0.050	--	--	--	0.24	--	--	--	--	0.167	10.05
2	Lawn of lot 70 (70lawn)	Shallow conc., unpaved	57	0.092	--	--	--	0.05	--	--	0.40	4.9	0.003	0.19
3	Gutter of upper Village Way (uvwNgutr)	Shallow conc., paved	170	0.075	--	--	--	0.025	--	--	0.20	5.6	0.008	0.51
4	Pipe from inlet (uvwNinlt)	Pipe (smooth HDPE)	45	0.005	1.25	1.25	--	0.012	1.23	3.93	0.31	4.0	0.003	0.19
5	cirEinlt	Pipe	85	0.005	1.25	1.25	--	0.012	1.23	3.93	0.31	4.0	0.006	0.35
6	uvwWinlt	Pipe	30	0.042	1.25	1.25	--	0.012	1.23	3.93	0.31	11.7	0.001	0.04
7	alyEinlt	Pipe	120	0.050	1.5	1.5	--	0.012	1.77	4.71	0.38	14.4	0.002	0.14
8	lvwWinlt	Pipe	52	0.058	1.5	1.5	--	0.012	1.77	4.71	0.38	15.5	0.001	0.06
9	bvdNinlt	Pipe	50	0.050	2	2	--	0.012	3.14	6.28	0.50	17.5	0.001	0.05
10	bvdSinlt	Pipe	57	0.050	1.5	1.5	--	0.012	1.77	4.71	0.38	14.4	0.001	0.07
11	lowrchan	Trapezoidal channel	150	0.120	2	1	3	0.08	5.00	8.32	0.60	4.6	0.009	0.54
		Total Length:	916										**0.203**	**12.18**
		* P_2 = 3.1 inches											**Lag time = 0.6*Tc =**	**7.308**

Appendix D-3: LID Design Charts

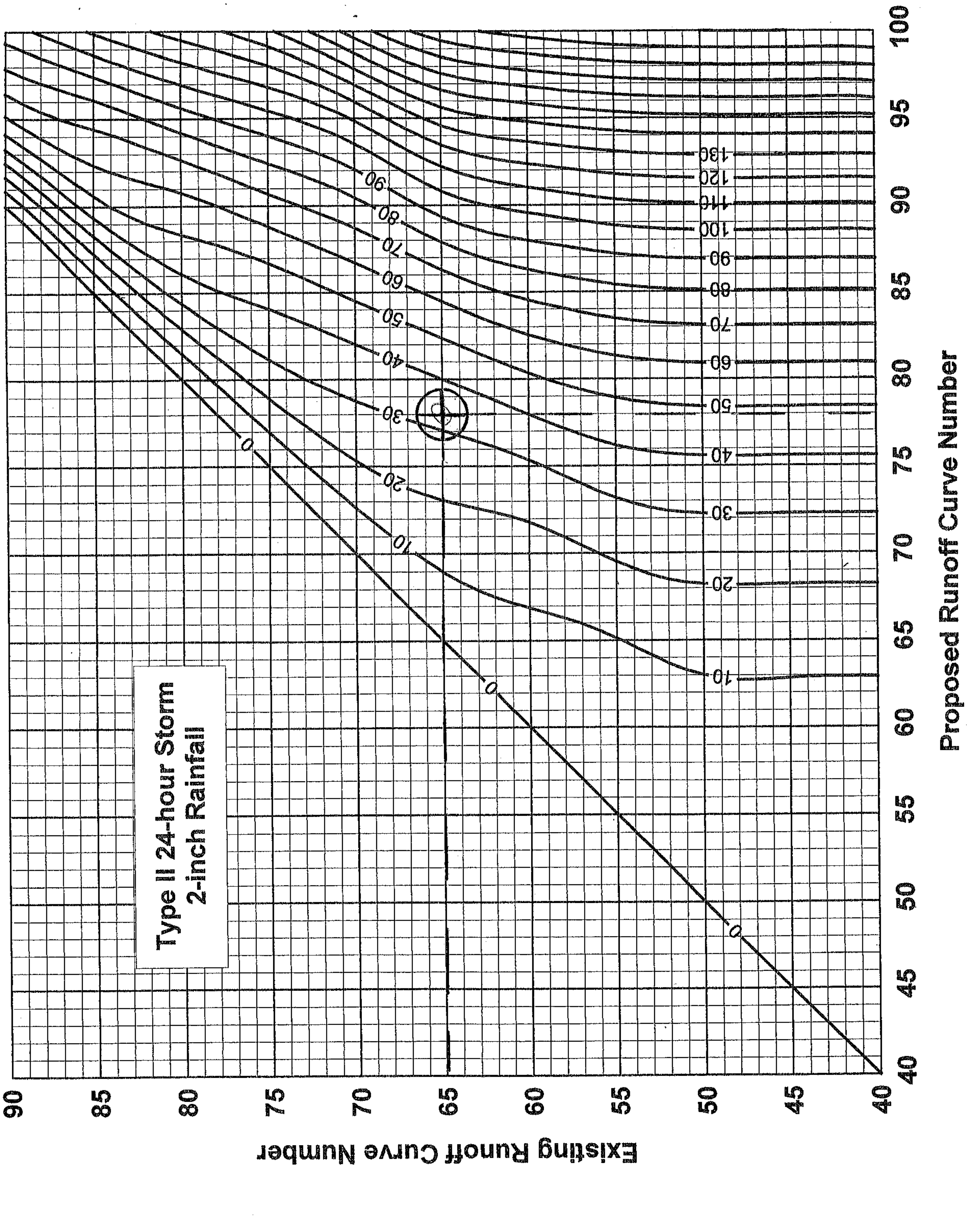


Appendix D-3: LID Design Charts

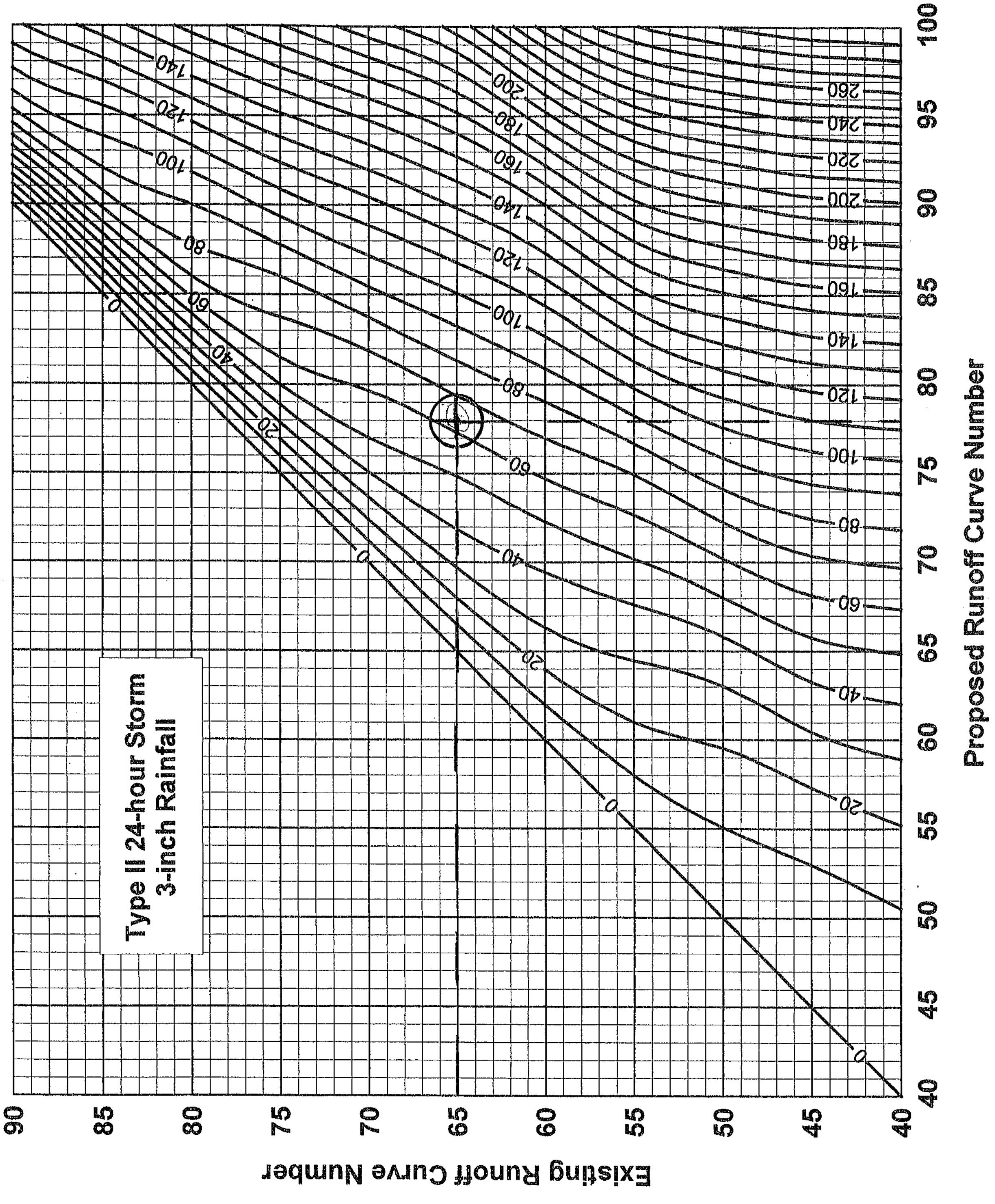


Appendix D-3: LID Design Charts

Storage Required to Maintain Pre-Development Peak Runoff Rate Using 100% Retention (hundredths of an inch)

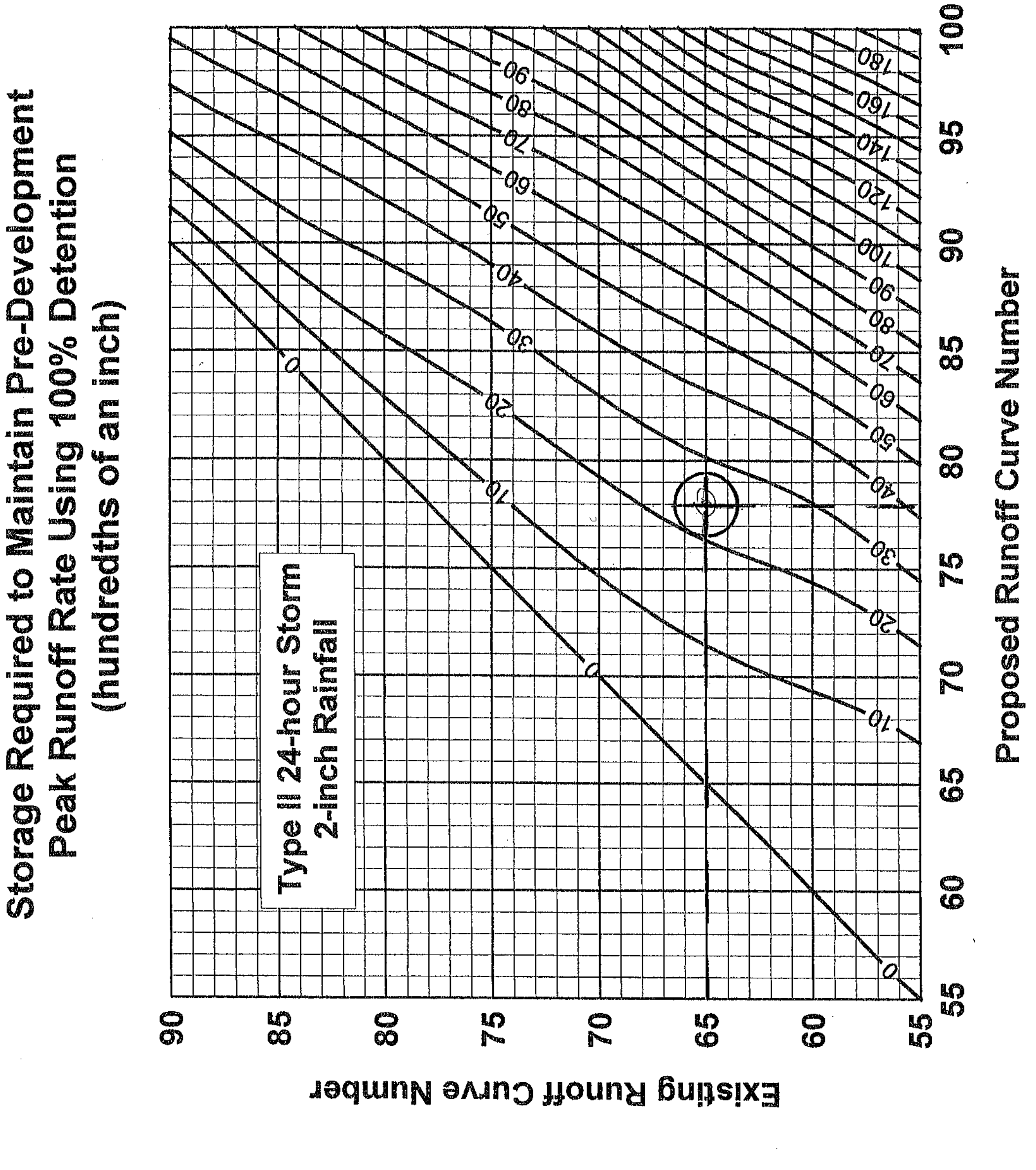


Appendix D-3: LID Design Charts



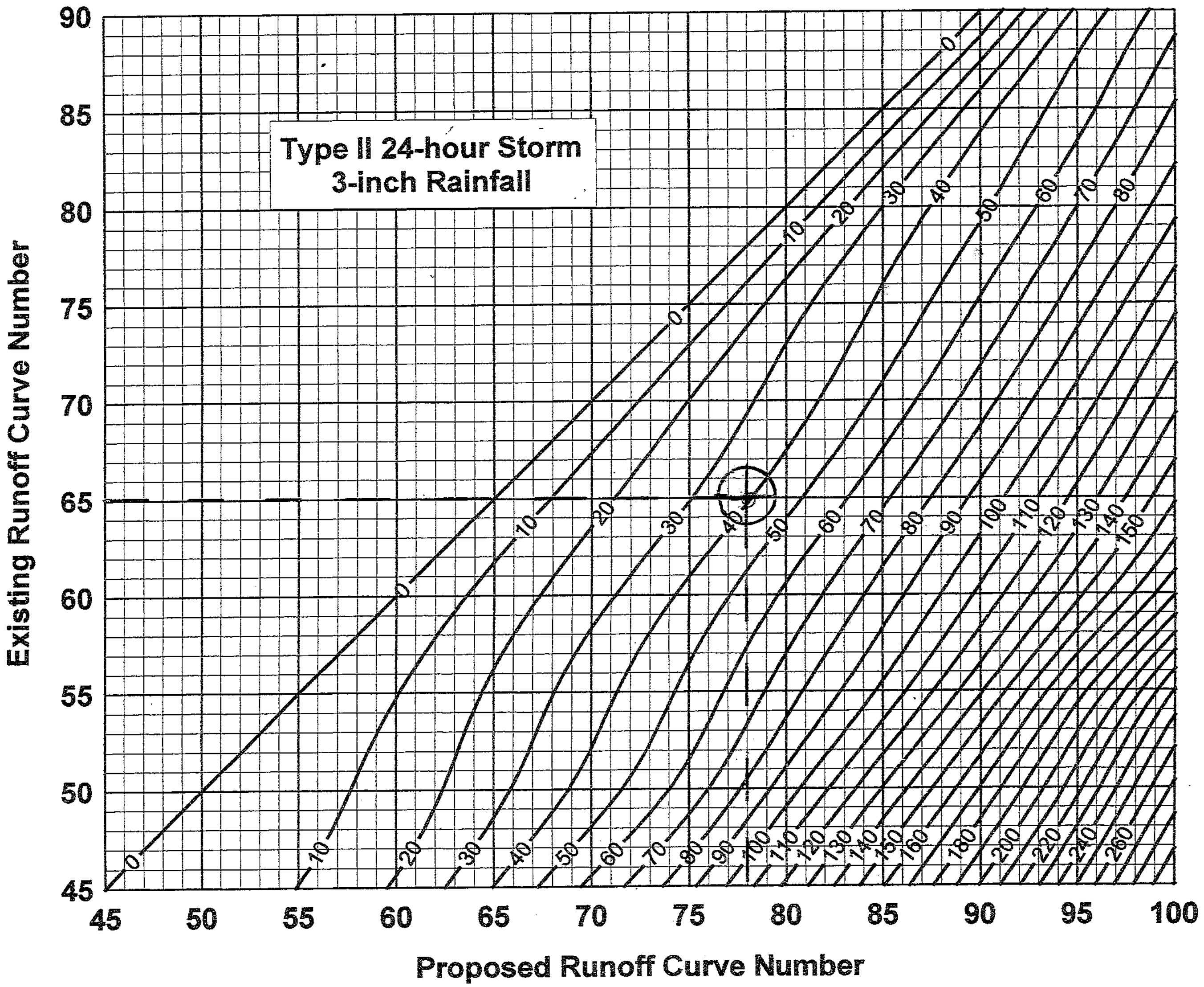
Storage Required to Maintain Pre-Development Peak Runoff Rate Using 100% Retention (hundredths of an inch)

Appendix D-3: LID Design Charts



Appendix D-3: LID Design Charts

Storage Required to Maintain Pre-Development Peak Runoff Using 100% Detention (hundredths of an inch)



Appendix D-4: VT/PSUHM Input File for SWM Pond Outlet

Elevations in NewRiser.OSC, below, are relative to the outlet pipe invert.

```
3
"CO"
.75,.5833,.6
"RO"
3.5,.5,1.5,.6
"SP"
5.75,5,3
3
0,0,0,0,0,0,0
0,1.5,35,.02,.013,"SOH",1
0,10,.25
```

APPENDIX E

CONTINUOUS SWMM INPUT FOR LID EVALUATION

- **E-1: Continuous SWMM Input: Forest, Favorable Conditions**
- **E-2: Continuous SWMM Input: Forest, Unfavorable Conditions**
- **E-3: Continuous SWMM Input: LID, Favorable Conditions**
- **E-4: Continuous SWMM Input: LID, Unfavorable Conditions**
- **E-5: Continuous SWMM Input: Conventional Development, Favorable Conditions**
- **E-6: Continuous SWMM Input: Conventional Development, Unfavorable Conditions**
- **E-7: Continuous SWMM Input: Conventional with Stormwater Management, Favorable Conditions**
- **E-8: Continuous SWMM Input: Conventional with Stormwater Management, Unfavorable Conditions**

Appendix E-1: Continuous SWMM Input: Forest, Favorable Conditions

```
SW  2  20 21 22 23
MM  6    1  2  3  4  12 13
@ 1 'rain_all.dnt'
@ 21 'for_fav.int'
@ 22 'for_fav.int'
*@ 21 'for_unf.int'
*@ 22 'for_unf.int'
*@ 21 'lid_fav.int'
*@ 22 'lid_fav.int'
*@ 21 'lid_unf.int'
*@ 22 'lid_unf.int'
*@ 21 'conv_fav.int'
*@ 22 'conv_fav.int'
*@ 21 'conv_unf.int'
*@ 22 'conv_unf.int'
$ANUM
$NOQUOTE
$RUNOFF
A1 'VTC Continuous SWMM Model'
*A1 'Runoff Block Template'
A1 'Predevelopment/Forest - Favorable Condition'
*A1 'Predevelopment/Forest - Unfavorable Condition'
*A1 'Low Impact Development - Favorable Condition'
*A1 'Low Impact Development - Unfavorable Condition'
*A1 'Conventional Development - Favorable Condition'
*A1 'Conventional Development - Unfavorable Condition'
*   METRIC ISNOW NRGAG INFILM KWALTY IVAP NHR NMN NDAY MONTH IYRSTR IVCHAN
* For continuous simulation using mixed IFLOWS and Datalogger rainfall record:
B1  0      0    1     1      0      -2   00  00  01  04     1998   0
*  Print Control
*  Input Graph Outpt GW NoHead Landupr
B2  0     1     1    0    1      0
*   Wet WetDry Dry   Lunit Long
* For continuous simulation (through August 31, 2004):
B3  60  60     86400 3     2345
*         PctZero  Regen(NR)
B4        0.0001   0
*         ROPT
D1        1
*         MONTHLY EVAPORATION (in/month) -turned off during rainfall for negative IVAP-
F1        0.064    0.213    0.982    2.152    3.629    5.110    5.761    5.178    3.642    1.918    0.888    0.232
*
*INSERT CHANNEL/PIPE DATA (G1 LINES), & SUBCATCHMENT DATA (H1 LINES) BELOW:
*         NameG  Ngto      Type      Gwidth   L        S        z1       z2       N        Dfull    Dinit
G1        channel1         channel2           1        2.00     244      0.1189   6        6        0.15     1.5
          0
G1        channel2         outfall   1        2.00     254      0.1102   6        6        0.15     1.5      0
*
*         JK       NameW   Ngto      Wid      Area     %Imp     S        ImpN     PervN    IDS      PDS      G
          Ksat     SmdmaxRmaxInfIflowP
H1        1        '8Deast'  'outfall'  79.602   0.24853 0        0.176    0.4      0.4      9.9      0.35     12
          0.2      0.31     0        0
H1        1        '9Deast'  'channel2'          89.031   0.47418 0        0.125    0.4      0.4      9.9      0.35
          12       0.2      0.31     0        0
```

Appendix E-1: Continuous SWMM Input: Forest, Favorable Conditions

```
H1        1         '9Dwest'  '8Dwest'  70.602    0.36792   0         0.167     0.4       0.4       9.9       0.35      12
          0.2       0.31      0         3
H1        1         '8Dwest'  'channel2'          21.679    0.11297   0         0.167     0.4       0.4       9.9       0.35
          12        0.2       0.31      0         0
H1        1         '12Cwest'           'channel2'          55.440    0.21636   0         0.118     0.4       0.4       9.9
          0.35      9         0.3       0.33      0         0
H1        1         '12Cmid''channel1'            142.595   0.68744   0         0.124     0.4       0.4       9.9       0.35
          9         0.3       0.33      0         0
H1        1         '12Ceast''channel1'           138.070   0.71317   0         0.116     0.4       0.4       9.9       0.35
          9         0.3       0.33      0         0
H1        1         '16Bnorth'          '12Cmid'323.114   1.51320   0         0.088     0.4       0.4       9.9       0.35
          12        0.2       0.31      0         3
*
*  PRINT CONTROL
*         NPrnt     Interv
M1        1         0
*   NDet StartP(1) StartP(2)
M2   0     0        0
*         IPRNT(1) Prints INflows to channels/pipes
M3        'outfall'
*Stats Block to Analyze Flow Output
$STATISTICS
* Istart Tstart Iend Tend InLog JCube JNeg
A1 0 0.0 0 0.0 1 0 0
*  MIT  Base Ebase LocQ      LocRn NPR Npnt Metric LRet A
B1 12.0 0.0  0.02  'outfall' ''    0   0    0      1    0.4
* Kseq Kterm Ktseqs
B2 1 0 0
C1 1001 1001 1001 1001 1001
$ENDPROGRAM
```

Appendix E-2: Continuous SWMM Input: Forest, Unfavorable Conditions

```
SW  2  20 21 22 23
MM  6    1  2  3  4  12 13
@ 1 'rain_all.dnt'
*@ 21 'for_fav.int'
*@ 22 'for_fav.int'
@ 21 'for_unf.int'
@ 22 'for_unf.int'
*@ 21 'lid_fav.int'
*@ 22 'lid_fav.int'
*@ 21 'lid_unf.int'
*@ 22 'lid_unf.int'
*@ 21 'conv_fav.int'
*@ 22 'conv_fav.int'
*@ 21 'conv_unf.int'
*@ 22 'conv_unf.int'
$ANUM
$NOQUOTE
$RUNOFF
A1 'VTC Continuous SWMM Model'
*A1 'Runoff Block Template'
*A1 'Predevelopment/Forest - Favorable Condition'
A1 'Predevelopment/Forest - Unfavorable Condition'
*A1 'Low Impact Development - Favorable Condition'
*A1 'Low Impact Development - Unfavorable Condition'
*A1 'Conventional Development - Favorable Condition'
*A1 'Conventional Development - Unfavorable Condition'
*   METRIC ISNOW NRGAG INFILM KWALTY IVAP NHR NMN NDAY MONTH IYRSTR IVCHAN
* For continuous simulation using mixed IFLOWS and Datalogger rainfall record:
B1  0      0    1     1      0      -2   00  00  01  04     1998   0
*  Print Control
*  Input Graph Outpt GW NoHead Landupr
B2  0    1    1    0    1      0
*   Wet WetDry Dry   Lunit Long
* For continuous simulation (through August 31, 2004):
B3  60  60     86400 3     2345
*         PctZero  Regen(NR)
B4        0.0001   0
*         ROPT
D1        1
*         MONTHLY EVAPORATION (in/month) -turned off during rainfall for negative IVAP-
F1        0.064    0.213    0.982    2.152    3.629    5.110    5.761    5.178    3.642    1.918    0.888    0.232
*
*INSERT CHANNEL/PIPE DATA (G1 LINES), & SUBCATCHMENT DATA (H1 LINES) BELOW:
*         NameG    Ngto     Type     Gwidth   L        S        z1       z2       N        Dfull    Dinit
G1        channel1          channel2          1        2.00     244      0.1189   6        6        0.08     1.5
          0
G1        channel2          outfall  1        2.00     254      0.1102   6        6        0.08     1.5      0
*
*         JK       NameW    Ngto     Wid      Area     %Imp     S        ImpN     PervN    IDS      PDS      G
          Ksat     SmdmaxRmaxInfIflowP
H1        1        '8Deast' 'outfall' 108.258 0.24853 0         0.176    0.4      0.4      9.9      0.2      12
          0.1      0.26     0        0
H1        1        '9Deast' 'channel2'        206.552 0.47418 0         0.125    0.4      0.4      9.9      0.2
          12       0.1      0.26     0        0
```

Appendix E-2: Continuous SWMM Input: Forest, Unfavorable Conditions

```
H1      1       '9Dwest' 'channel2'     160.266 0.36792 0       0.167   0.4     0.4     9.9     0.2
        12      0.1     0.26    0       0
H1      1       '8Dwest' 'channel2'     49.211  0.11297 0       0.167   0.4     0.4     9.9     0.2
        12      0.1     0.26    0       0
H1      1       '12Cwest'       'channel2'      94.248  0.21636 0       0.118   0.4     0.4     9.9
        0.2     9       0.2     0.28    0       0
H1      1       '12Cmid''channel1'      299.450 0.68744 0       0.124   0.4     0.4     9.9     0.2
        9       0.2     0.28    0       0
H1      1       '12Ceast''channel1'     310.657 0.71317 0       0.116   0.4     0.4     9.9     0.2
        9       0.2     0.28    0       0
H1      1       '16Bnorth'      'channel1'      659.152 1.51320 0       0.088   0.4     0.4     9.9
        0.2     12      0.1     0.26    0       0
*
*  PRINT CONTROL
*       NPrnt   Interv
M1      1       0
*   NDet StartP(1) StartP(2)
M2   0     0       0
*       IPRNT(1) Prints INflows to channels/pipes
M3      'outfall'
*Stats Block to Analyze Flow Output
$STATISTICS
* Istart Tstart Iend Tend InLog JCube JNeg
A1 0 0.0 0 0.0 1 0 0
*  MIT  Base Ebase LocQ      LocRn NPR Npnt Metric LRet A
B1 12.0 0.0  0.02  'outfall' ''    0   0    0      1    0.4
* Kseq Kterm Ktseqs
B2 1 0 0
C1 1001 1001 1001 1001 1001
$ENDPROGRAM
```

Appendix E-3: Continuous SWMM Input: LID, Favorable Conditions

```
SW  2  20 21 22 23
MM  6    1  2  3  4  12 13
@ 1 'rain_all.dnt'
*@ 21 'for_fav.int'
*@ 22 'for_fav.int'
*@ 21 'for_unf.int'
*@ 22 'for_unf.int'
@ 21 'lid_fav.int'
@ 22 'lid_fav.int'
*@ 21 'lid_unf.int'
*@ 22 'lid_unf.int'
*@ 21 'conv_fav.int'
*@ 22 'conv_fav.int'
*@ 21 'conv_unf.int'
*@ 22 'conv_unf.int'
$ANUM
$NOQUOTE
$RUNOFF
A1 'VTC Continuous SWMM Model'
*A1 'Runoff Block Template'
*A1 'Predevelopment/Forest - Favorable Condition'
*A1 'Predevelopment/Forest - Unfavorable Condition'
A1 'Low Impact Development - Favorable Condition'
*A1 'Low Impact Development - Unfavorable Condition'
*A1 'Conventional Development - Favorable Condition'
*A1 'Conventional Development - Unfavorable Condition'
*   METRIC ISNOW NRGAG INFILM KWALTY IVAP NHR NMN NDAY MONTH IYRSTR IVCHAN
* For continuous simulation using mixed IFLOWS and Datalogger rainfall record:
B1  0      0     1     1      0      -2   00  00  01  04     1998   0
*  Print Control
*  Input Graph Outpt GW NoHead Landupr
B2  0     1     1    0    1      0
*   Wet WetDry Dry   Lunit Long
* For continuous simulation (through August 31, 2004):
B3  60  60     86400 3     2345
*         PctZero  Regen(NR)
B4        0.0001   0
*         ROPT
D1        1
*         MONTHLY EVAPORATION (in/month) -turned off during rainfall for negative IVAP-
F1        0.064     0.213     0.982     2.152     3.629     5.110     5.761     5.178     3.642     1.918     0.888     0.232
*
*INSERT CHANNEL/PIPE DATA (G1 LINES), & SUBCATCHMENT DATA (H1 LINES) BELOW:
*         NameG  Ngto       Type      Gwidth  L         S         z1        z2        N         Dfull     Dinit
G1        'uvwEinlt'        'uvwWinlt'          2         1.25      35        0.01      0         0         0.022     1.5
          0
G1        'uvwWinlt'        'alyEinlt'2         1.25      30        0.04167 0         0         0.022     1.5       0
G1        'cirEswal'        'alyEinlt'1         1.00      150       0.093     4         4         0.06      2.1       0
G1        'alyEinlt''grvswal'2        1.50      30        0.01667 0         0         0.022     1.5       0
G1        'thWswal'         'thWinlt' 1         2.00      45        0.026     4         4         0.06      2.02      0
G1        'thWinlt' 'thEswal'2        1.25      90        0.01667 0         0         0.022     1.5       0
G1        'thEswal''grvinlt'  1       2.00      75        0.107     3         3         0.06      2.05      0
G1        'lvwWinlt'        'grvinlt'  2        1.25      52        0.058     0         0         0.022     1.5       0
G1        'lvwEinlt'        'lvwWinlt'          2         1.25      55        0.055     0         0         0.022     1.5
          0
```

Appendix E-3: Continuous SWMM Input: LID, Favorable Conditions

```
G1     'grvswal''grvinlt' 1     2.00     130      0.108    3        3        0.08     2.36     0
G1     'grvinlt' 'blvdinlt'2    1.50     50       0.033    0        0        0.022    1.5      0
G1     'blvdinlt''lowrchan'     2        1.50     57       0.049    0        0        0.022    1.5      0
G1     'lowrchan'      'outfall' 1       2.00     150      0.12     3        3        0.08     3        0
*
*      JK       NameW Ngto      Wid      Area     %Imp     S        ImpN     PervN    IDS      PDS      G
       Ksat     SmdmaxRmaxInfIflowP
H1     1        '70woods'       '70lawn' 29.547   0.08818 0         0.046    0.4      0.4      9.9      0.35
       12       0.2      0.31   0        3
H1     1        '70lawn' 'uvwEswal'      71.789   0.04944 0         0.170    0.24     0.24     9.9      0.2
       12       0.15     0.31   0        3
H1     1        '6970wood'      '6970swal'        29.328   0.09089 0         0.070    0.4      0.4      9.9
       0.35     12       0.2    0.31     0        3
H1     1        '6970roof'      '6970lawn'        188.816 0.08669 100        0.200    0.02     0.02     1.09
       9.9      99       99     0.99     0        3
H1     1        '6970driv'      '6970lawn'        58.954   0.02571 100       0.075    0.014    0.014    0.02
       9.9      99       99     0.99     0        3
H1     1        '6970lawn'      '6970swal'        171.263 0.21624 0          0.083    0.24     0.24     9.9
       0.2      12       0.15   0.31     0        3
H1     1        '6970swal'      'uvwEswal'        1.000    0.00207 0         0.038    0.06     0.06     0.1
       0.1      12       0.1    0.26     0        3
H1     1        '68drive''68lawnup'      69.578   0.01597 100       0.083    0.014    0.014    0.02     9.9
       99       99       0.99   0        3
H1     1        '68lawnup'      'uvwEswal'        27.864   0.02559 0         0.067    0.24     0.24     9.9
       0.2      12       0.15   0.31     0        3
H1     1        '68wood''68swale'       20.497   0.08470 0         0.089    0.4      0.4      9.9      0.35
       12       0.2      0.31   0        3
H1     1        '68roof' '68lawnlo'     86.875   0.03989 100       0.200    0.02     0.02     1.09     9.9
       99       99       0.99   0        3
H1     1        '68lawnlo'      '68swale'         79.949   0.08259 0         0.119    0.24     0.24     9.9
       0.2      9        0.25   0.33     0        3
H1     1        '68swale'       'uvwEswal'        1.000    0.00207 0         0.030    0.06     0.06     0.1
       0.1      12       0.1    0.26     0        3
H1     1        '67drive''67lawnup'      19.606   0.01170 100       0.087    0.014    0.014    0.02     9.9
       99       99       0.99   0        3
H1     1        '67lawnup'      'uvwEswal'        29.124   0.02139 0         0.125    0.24     0.24     9.9
       0.2      9        0.25   0.33     0        3
H1     1        'uvwEpave'      'uvwEswal'        73.776   0.10162 100       0.080    0.014    0.014    0.02
       9.9      99       99     0.99     0        3
H1     1        'uvwEswal'      'uvwEinlt'        8.500    0.04878 0         0.075    0.06     0.06     0.02
       10.5882 6        0.5    0.33     0        0
*

H1     1        'uvwWswlC'      'uvwWswal'        169.402 0.03889 0          0.350    0.24     0.24     9.9
       0.2      12       0.15   0.31     0        3
H1     1        'uvwWpave'      'uvwWswal'        74.357   0.10242 100       0.080    0.014    0.014    0.02
       9.9      99       99     0.99     0        3
H1     1        'uvwWswal'      'uvwWinlt'        2.900    0.01664 0         0.092    0.06     0.06     0.02
       4.7172   6        0.5    0.33     0        0
*

H1     1        'cirWroof'      'cirWswal'        128.000 0.05877 100        0.200    0.02     0.02     1.09
       9.9      99       99     0.99     0        3
H1     1        'cirWlawn'      'cirWswal'        185.548 0.06389 0          0.060    0.24     0.24     9.9
       0.2      12       0.15   0.31     0        3
```

Appendix E-3: Continuous SWMM Input: LID, Favorable Conditions

```
H1      1       'cirWwood'      'cirWswal'      20.061  0.04605 0       0.060   0.4     0.4     9.9
        0.35    12      0.2     0.31    0       3
H1      1       'cirWswal'      'alyEswal'      1.000   0.00344 0       0.082   0.06    0.06    0.1
        0.1     12      0.1     0.26    0       3
H1      1       '62roof' '62lawn' 47.823  0.02196 100     0.200   0.02    0.02    1.09    9.9     99
        99      0.99    0       3
H1      1       '62lawn' 'alyWswal'     96.321  0.07739 0       0.100   0.24    0.24    9.9     0.2
        9       0.25    0.33    0       3
H1      1       'alyWpave'      'alyWswal'      43.596  0.04103 100     0.068   0.014   0.014   0.02
        9.9     99      99      0.99    0       3
H1      1       'alyWswal'      'alyEswal'      3.500   0.00803 0       0.059   0.06    0.06    0.02
        8.5714  6       0.5     0.33    0       3
H1      1       '66roof' 'cirEwood'     73.200  0.03361 100     0.200   0.02    0.02    1.09    9.9
        99      99      0.99    0       3
H1      1       'cirEside'      'cirEwood'      120.212 0.03036 100     0.089   0.014   0.014   0.02
        9.9     99      99      0.99    0       3
H1      1       '66lawn' 'cirEwood'     116.060 0.05329 0       0.050   0.24    0.24    9.9     0.2
        12      0.15    0.31    0       3
H1      1       'cirEwood'      'cirEswal'      79.253  0.25471 0       0.086   0.4     0.4     9.9
        0.35    12      0.2     0.31    0       0
H1      1       'cirEslwn'      'cirEswal'      132.568 0.03043 0       0.150   0.24    0.24    9.9
        0.2     12      0.15    0.31    0       0
H1      1       '661roof2'      'cirEswal'      51.200  0.02351 100     0.200   0.02    0.02    1.09
        9.9     99      99      0.99    0       0
*

H1      1       '6061roof'      'alyEswal'      95.413  0.04381 100     0.200   0.02    0.02    1.09
        9.9     99      99      0.99    0       3
H1      1       'alyEpave'      'alyEswal'      25.091  0.04608 100     0.077   0.014   0.014   0.02
        9.9     99      99      0.99    0       3
H1      1       '6061lawn'      'alyEswal'      165.366 0.13287 0       0.130   0.24    0.24    9.9
        0.2     9       0.25    0.33    0       3
H1      1       'alyEswal'      'alyEinlt'3.500   0.00723 0       0.075   0.06    0.06    0.02    8.5714
        6       0.5     0.33    0       0
*

H1      1       'thWlawn'       'thWswal'       48.191  0.04093 0       0.064   0.24    0.24    9.9
        0.2     9       0.25    0.33    0       0
H1      1       'thWroof'       'thWswal'       170.519 0.07829 100     0.200   0.02    0.02    1.09
        9.9     99      99      0.99    0       0
H1      1       'thWwood'       'thWswal'       65.362  0.09003 0       0.084   0.4     0.4     9.9
        0.35    9       0.3     0.33    0       0
H1      1       'thWlot' 'thWbior'      33.247  0.02900 100     0.048   0.014   0.014   0.02    9.9
        99      99      0.99    0       3
H1      1       'thWbior'       'thWswal'       20.000  0.00551 0       0.010   0.06    0.06    0.02
        6       6       0.5     0.33    0       0
*

*

H1      1       'thEwood'       'thElot'  34.212  0.03927 0       0.115   0.4     0.4     9.9     0.35
        9       0.3     0.33    0       3
H1      1       'thElot' 'thEbior' 43.225  0.05458 100     0.119   0.014   0.014   0.02    9.9     99
        99      0.99    0       3
```

Appendix E-3: Continuous SWMM Input: LID, Favorable Conditions

```
H1        1         'thEbior' 'thEswal'27.000    0.00868   0         0.010     0.06      0.06      0.02      6         6
          0.5       0.33      0         0
H1        1         'thElawn'           'thEswal'160.005   0.07346   0         0.150     0.24      0.24      9.9       0.2
          9         0.25      0.33      0         0
H1        1         'thEroof' 'thEswal'215.998   0.09917   100       0.200     0.02      0.02      1.09      9.9       99
          99        0.99      0         0
*

H1        1         'lvwWlawn'          'lvwWswal'          121.491   0.02789   0         0.350     0.24      0.24      9.9
          0.2       12        0.15      0.31      0         3
H1        1         'lvwWside'          'lvwWswal'          22.385    0.01953   100       0.105     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'lvwWpav'           'lvwWswal'          72.263    0.05806   100       0.108     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'lvwWswal'          'lvwWinlt'          2.900     0.00832   0         0.100     0.06      0.06      0.02
          4.7172    6         0.5       0.33      0         0
*

H1        1         '67roof'  '67lawnlo'          86.729    0.03982   100       0.200     0.02      0.02      1.09      9.9
          99        99        0.99      0         3
H1        1         '67lawnlo'          'lvwEswal'          66.704    0.10719   0         0.138     0.24      0.24      9.9
          0.2       9         0.25      0.33      0         3
H1        1         'lvwecut''lvwEswal'           115.516   0.08751   0         0.210     0.3       0.3       9.9       0.25
          12        0.15      0.31      0         3
H1        1         'lvwepav'           'lvwEswal'          30.261    0.05419   100       0.102     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'lvwEswal'          'lvwEinlt'          5.900     0.02709   0         0.100     0.06      0.06      0.02
          7.8305    6         0.5       0.33      0         0
*

H1        1         'grvlawnB'          'grvwood'           106.585   0.05138   0         0.160     0.24      0.24      9.9
          0.2       9         0.25      0.33      0         3
H1        1         'grvwood'           'grvswal'110.655   0.12701   0         0.127     0.4       0.4       9.9       0.35
          9         0.3       0.33      0         0
*

H1        1         'grvlawnI'          'grvinlt' 124.585   0.06006   0         0.160     0.24      0.24      9.9       0.2
          9         0.25      0.33      0         0
H1        1         'grvlawnC'          'grvinlt' 27.649    0.01904   0         0.130     0.24      0.24      9.9       0.2
          12        0.15      0.31      0         0
*

H1        1         'sidegras'          'blvdNpav'          283.159   0.09751   0         0.091     0.24      0.24      9.9
          0.2       9         0.25      0.33      0         3
H1        1         'blvdNpav'          'blvdswal'          124.054   0.14239   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'blvdSpav'          'blvdswal'          104.192   0.11960   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'blvdswlB'          'blvdswal'          242.678   0.05571   0         0.340     0.24      0.24      9.9
          0.2       9         0.25      0.33      0         3
H1        1         'blvdswlC'          'blvdswal'          255.943   0.05876   0         0.340     0.24      0.24      9.9
          0.2       12        0.15      0.31      0         3
H1        1         'blvdswal'          'blvdinlt'8.250     0.04735   0         0.067     0.06      0.06      0.02      11.4545
          6         0.5       0.33      0         0
*
```

Appendix E-3: Continuous SWMM Input: LID, Favorable Conditions

```
H1        1         'lowrpav'           'lowrfill' 81.037    0.02232   100       0.020     0.014     0.014     0.02      9.9
          99        99        0.99      0         3
H1        1         'lowrfill' 'lowrchan'          245.822   0.33860   0         0.290     0.3       0.3       9.9       0.25
          12        0.15      0.31      0         0
H1        1         'lowrwood'          'lowrchan'          56.892    0.11754   0         0.250     0.4       0.4       9.9
          0.35      12        0.2       0.31      0         0
*
*
*  PRINT CONTROL
*         NPrnt     Interv
M1        1         0
*   NDet StartP(1) StartP(2)
M2   0     0       0
*         IPRNT(1) Prints INflows to channels/pipes
M3        'outfall'
*Stats Block to Analyze Flow Output
$STATISTICS
* Istart Tstart Iend Tend InLog JCube JNeg
A1 0 0.0 0 0.0 1 0 0
*  MIT  Base Ebase LocQ      LocRn NPR Npnt Metric LRet A
B1 12.0 0.0  0.02  'outfall' ''    0   0    0      1    0.4
* Kseq Kterm Ktseqs
B2 1 0 0
C1 1001 1001 1001 1001 1001
$ENDPROGRAM
```

Appendix E-4: Continuous SWMM Input: LID, Unfavorable Conditions

```
SW  2  20 21 22 23
MM  6    1  2  3  4  12 13
@ 1 'rain_all.dnt'
*@ 21 'for_fav.int'
*@ 22 'for_fav.int'
*@ 21 'for_unf.int'
*@ 22 'for_unf.int'
*@ 21 'lid_fav.int'
*@ 22 'lid_fav.int'
@ 21 'lid_unf.int'
@ 22 'lid_unf.int'
*@ 21 'conv_fav.int'
*@ 22 'conv_fav.int'
*@ 21 'conv_unf.int'
*@ 22 'conv_unf.int'
$ANUM
$NOQUOTE
$RUNOFF
A1 'VTC Continuous SWMM Model'
*A1 'Runoff Block Template'
*A1 'Predevelopment/Forest - Favorable Condition'
*A1 'Predevelopment/Forest - Unfavorable Condition'
*A1 'Low Impact Development - Favorable Condition'
A1 'Low Impact Development - Unfavorable Condition'
*A1 'Conventional Development - Favorable Condition'
*A1 'Conventional Development - Unfavorable Condition'
*   METRIC ISNOW NRGAG INFILM KWALTY IVAP NHR NMN NDAY MONTH IYRSTR IVCHAN
* For continuous simulation using mixed IFLOWS and Datalogger rainfall record:
B1  0     0    1     1     0     -2   00  00  01  04     1998   0
*  Print Control
*  Input Graph Outpt GW NoHead Landupr
B2  0    1    1    0    1     0
*   Wet WetDry Dry   Lunit Long
* For continuous simulation (through August 31, 2004):
B3  60  60    86400 3     2345
*         PctZero  Regen(NR)
B4        0.0001   0
*         ROPT
D1        1
*         MONTHLY EVAPORATION (in/month) -turned off during rainfall for negative IVAP-
F1        0.064    0.213    0.982    2.152    3.629    5.110    5.761    5.178    3.642    1.918    0.888    0.232
*
*INSERT CHANNEL/PIPE DATA (G1 LINES), & SUBCATCHMENT DATA (H1 LINES) BELOW:
*         NameG  Ngto       Type     Gwidth   L        S        z1       z2       N        Dfull    Dinit
G1        'uvwEinlt'        'uvwWinlt'        2        1.25     35       0.01     0        0        0.022    1.5
          0
G1        'uvwWinlt'        'alyEinlt'2       1.25     30       0.04167  0        0        0.022    1.5      0
G1        'cirEswal'        'alyEinlt'1       1.00     150      0.093    4        4        0.06     2.1      0
G1        'alyEinlt''grvswal'2       1.50     30       0.01667  0        0        0.022    1.5      0
G1        'thWswal'         'thWinlt' 1       2.00     45       0.026    4        4        0.06     2.02     0
G1        'thWinlt' 'thEswal'2       1.25     90       0.01667  0        0        0.022    1.5      0
G1        'thEswal''grvinlt'  1      2.00     75       0.107    3        3        0.06     2.05     0
G1        'lvwWinlt'        'grvinlt'  2       1.25     52       0.058    0        0        0.022    1.5      0
G1        'lvwEinlt'        'lvwWinlt'        2        1.25     55       0.055    0        0        0.022    1.5
          0
```

Appendix E-4: Continuous SWMM Input: LID, Unfavorable Conditions

```
G1      'grvswal''grvinlt'  1       2.00    130     0.108   3       3       0.08    2.36    0
G1      'grvinlt'  'blvdinlt'2      1.50    50      0.033   0       0       0.022   1.5     0
G1      'blvdinlt''lowrchan'        2       1.50    57      0.049   0       0       0.022   1.5     0
G1      'lowrchan'          'outfall'  1    2.00    150     0.12    3       3       0.08    3       0
*
*       JK      NameW Ngto  Wid     Area    %Imp    S       ImpN    PervN   IDS     PDS     G
        Ksat    SmdmaxRmaxInfIflowP
H1      1       '70woods'       '70lawn' 29.547 0.08818 0       0.046   0.4     0.4     9.9     0.2
        12      0.1     0.26    0       3
H1      1       '70lawn' 'uvwEswal'     71.789  0.04944 0       0.170   0.24    0.24    9.9     0.1
        12      0.08    0.2     0       3
H1      1       '6970wood'      '6970swal'      29.328  0.09089 0       0.070   0.4     0.4     9.9
        0.2     12      0.1     0.26    0       3
H1      1       '6970roof'      '6970lawn'      188.816 0.08669 100     0.200   0.02    0.02    0.2
        9.9     99      99      0.99    0       3
H1      1       '6970driv'      '6970lawn'      58.954  0.02571 100     0.075   0.014   0.014   0.02
        9.9     99      99      0.99    0       3
H1      1       '6970lawn'      '6970swal'      171.263 0.21624 0       0.083   0.24    0.24    9.9
        0.1     12      0.08    0.2     0       3
H1      1       '6970swal'      'uvwEswal'      1.000   0.00207 0       0.038   0.06    0.06    0.1
        0.1     12      0.05    0.26    0       3
H1      1       '68drive' '68lawnup'    69.578  0.01597 100     0.083   0.014   0.014   0.02    9.9
        99      99      0.99    0       3
H1      1       '68lawnup'      'uvwEswal'      27.864  0.02559 0       0.067   0.24    0.24    9.9
        0.1     12      0.08    0.2     0       3
H1      1       '68wood''68swale'       20.497  0.08470 0       0.089   0.4     0.4     9.9     0.2
        12      0.1     0.26    0       3
H1      1       '68roof'  '68lawnlo'    86.875  0.03989 100     0.200   0.02    0.02    0.2     9.9
        99      99      0.99    0       3
H1      1       '68lawnlo'      '68swale'       79.949  0.08259 0       0.119   0.24    0.24    9.9
        0.1     9       0.15    0.22    0       3
H1      1       '68swale'       'uvwEswal'      1.000   0.00207 0       0.030   0.06    0.06    0.1
        0.1     12      0.05    0.26    0       3
H1      1       '67drive' '67lawnup'    19.606  0.01170 100     0.087   0.014   0.014   0.02    9.9
        99      99      0.99    0       3
H1      1       '67lawnup'      'uvwEswal'      29.124  0.02139 0       0.125   0.24    0.24    9.9
        0.1     9       0.15    0.22    0       3
H1      1       'uvwEpave'      'uvwEswal'      73.776  0.10162 100     0.080   0.014   0.014   0.02
        9.9     99      99      0.99    0       3
H1      1       'uvwEswal'      'uvwEinlt'      8.500   0.04878 0       0.075   0.06    0.06    0.02
        10.5882 6       0.05    0.33    0       0

*
H1      1       'uvwWswlC'      'uvwWswal'      169.402 0.03889 0       0.350   0.24    0.24    9.9
        0.1     12      0.08    0.2     0       3
H1      1       'uvwWpave'      'uvwWswal'      74.357  0.10242 100     0.080   0.014   0.014   0.02
        9.9     99      99      0.99    0       3
H1      1       'uvwWswal'      'uvwWinlt'      2.900   0.01664 0       0.092   0.06    0.06    0.02
        4.7172  6       0.05    0.33    0       0
*

H1      1       'cirWroof'      'cirWswal'      128.000 0.05877 100     0.200   0.02    0.02    0.2
        9.9     99      99      0.99    0       3
H1      1       'cirWlawn'      'cirWswal'      185.548 0.06389 0       0.060   0.24    0.24    9.9
        0.1     12      0.08    0.2     0       3
```

Appendix E-4: Continuous SWMM Input: LID, Unfavorable Conditions

```
H1        1         'cirWwood'          'cirWswal'          20.061    0.04605   0         0.060     0.4       0.4       9.9
          0.2       12        0.1       0.26      0         3
H1        1         'cirWswal'          'alyEswal'          1.000     0.00344   0         0.082     0.06      0.06      0.1
          0.1       12        0.05      0.26      0         3
H1        1         '62roof'  '62lawn'  47.823    0.02196   100       0.200     0.02      0.02      0.2       9.9       99
          99        0.99      0         3
H1        1         '62lawn'  'alyWswal'          96.321    0.07739   0         0.100     0.24      0.24      9.9       0.1
          9         0.15      0.22      0         3
H1        1         'alyWpave'          'alyWswal'          43.596    0.04103   100       0.068     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'alyWswal'          'alyEswal'          3.500     0.00803   0         0.059     0.06      0.06      0.02
          8.5714    6         0.05      0.33      0         3
H1        1         '66roof'  'cirEwood'          73.200    0.03361   100       0.200     0.02      0.02      0.2       9.9
          99        99        0.99      0         3
H1        1         'cirEside'          'cirEwood'          120.212   0.03036   100       0.089     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         '66lawn'  'cirEwood'          116.060   0.05329   0         0.050     0.24      0.24      9.9       0.1
          12        0.08      0.2       0         3
H1        1         'cirEwood'          'cirEswal'          79.253    0.25471   0         0.086     0.4       0.4       9.9
          0.2       12        0.1       0.26      0         0
H1        1         'cirEslwn'          'cirEswal'          132.568   0.03043   0         0.150     0.24      0.24      9.9
          0.1       12        0.08      0.2       0         0
H1        1         '661roof2'          'cirEswal'          51.200    0.02351   100       0.200     0.02      0.02      0.2
          9.9       99        99        0.99      0         0
*

H1        1         '6061roof'          'alyEswal'          95.413    0.04381   100       0.200     0.02      0.02      0.2
          9.9       99        99        0.99      0         3
H1        1         'alyEpave'          'alyEswal'          25.091    0.04608   100       0.077     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         '6061lawn'          'alyEswal'          165.366   0.13287   0         0.130     0.24      0.24      9.9
          0.1       9         0.15      0.22      0         3
H1        1         'alyEswal'          'alyEinlt'3.500     0.00723   0         0.075     0.06      0.06      0.02      8.5714
          6         0.05      0.33      0         0
*

H1        1         'thWlawn'           'thWswal'           48.191    0.04093   0         0.064     0.24      0.24      9.9
          0.1       9         0.15      0.22      0         0
H1        1         'thWroof'           'thWswal'           170.519   0.07829   100       0.200     0.02      0.02      0.2
          9.9       99        99        0.99      0         0
H1        1         'thWwood'           'thWswal'           65.362    0.09003   0         0.084     0.4       0.4       9.9
          0.2       9         0.2       0.28      0         0
H1        1         'thWlot'  'thWbior'           33.247    0.02900   100       0.048     0.014     0.014     0.02      9.9
          99        99        0.99      0         3
H1        1         'thWbior'           'thWswal'           20.000    0.00551   0         0.010     0.06      0.06      0.02
          6         6         0.05      0.33      0         0
*

*

H1        1         'thEwood'           'thElot'  34.212    0.03927   0         0.115     0.4       0.4       9.9       0.2
          9         0.2       0.28      0         3
H1        1         'thElot'  'thEbior' 43.225    0.05458   100       0.119     0.014     0.014     0.02      9.9       99
          99        0.99      0         3
```

Appendix E-4: Continuous SWMM Input: LID, Unfavorable Conditions

```
H1        1         'thEbior' 'thEswal'27.000   0.00868   0         0.010     0.06      0.06      0.02      6         6
          0.05      0.33      0         0
H1        1         'thElawn'           'thEswal'160.005  0.07346   0         0.150     0.24      0.24      9.9       0.1
          9         0.15      0.22      0         0
H1        1         'thEroof' 'thEswal'215.998  0.09917   100       0.200     0.02      0.02      0.2       9.9       99
          99        0.99      0         0
*

H1        1         'lvwWlawn'          'lvwWswal'          121.491   0.02789   0         0.350     0.24      0.24      9.9
          0.1       12        0.08      0.2       0         3
H1        1         'lvwWside'          'lvwWswal'          22.385    0.01953   100       0.105     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'lvwWpav'           'lvwWswal'          72.263    0.05806   100       0.108     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'lvwWswal'          'lvwWinlt'          2.900     0.00832   0         0.100     0.06      0.06      0.02
          4.7172    6         0.05      0.33      0         0
*

H1        1         '67roof'  '67lawnlo'          86.729    0.03982   100       0.200     0.02      0.02      0.2       9.9
          99        99        0.99      0         3
H1        1         '67lawnlo'          'lvwEswal'          66.704    0.10719   0         0.138     0.24      0.24      9.9
          0.1       9         0.15      0.22      0         3
H1        1         'lvwecut''lvwEswal'           115.516   0.08751   0         0.210     0.3       0.3       9.9       0.15
          12        0.08      0.26      0         3
H1        1         'lvwepav'           'lvwEswal'          30.261    0.05419   100       0.102     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'lvwEswal'          'lvwEinlt'          5.900     0.02709   0         0.100     0.06      0.06      0.02
          7.8305    6         0.05      0.33      0         0
*

H1        1         'grvlawnB'          'grvwood'           106.585   0.05138   0         0.160     0.24      0.24      9.9
          0.1       9         0.15      0.22      0         3
H1        1         'grvwood'           'grvswal'110.655  0.12701   0         0.127     0.4       0.4       9.9       0.2
          9         0.2       0.28      0         0
*

H1        1         'grvlawnI'          'grvinlt' 124.585   0.06006   0         0.160     0.24      0.24      9.9       0.1
          9         0.15      0.22      0         0
H1        1         'grvlawnC'          'grvinlt' 27.649    0.01904   0         0.130     0.24      0.24      9.9       0.1
          12        0.08      0.2       0         0
*

H1        1         'sidegras'          'blvdNpav'          283.159   0.09751   0         0.091     0.24      0.24      9.9
          0.1       9         0.15      0.22      0         3
H1        1         'blvdNpav'          'blvdswal'          124.054   0.14239   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'blvdSpav'          'blvdswal'          104.192   0.11960   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'blvdswlB'          'blvdswal'          242.678   0.05571   0         0.340     0.24      0.24      9.9
          0.1       9         0.15      0.22      0         3
H1        1         'blvdswlC'          'blvdswal'          255.943   0.05876   0         0.340     0.24      0.24      9.9
          0.1       12        0.08      0.2       0         3
H1        1         'blvdswal'          'blvdinlt'8.250   0.04735   0         0.067     0.06      0.06      0.02      11.4545
          6         0.05      0.33      0         0
```

Appendix E-4: Continuous SWMM Input: LID, Unfavorable Conditions

```
*

H1      1       'lowrpav'       'lowrfill' 81.037   0.02232 100     0.020   0.014   0.014   0.02    9.9
        99      99      0.99    0       3
H1      1       'lowrfill' 'lowrchan'      245.822 0.33860 0       0.290   0.3     0.3     9.9     0.15
        12      0.08    0.26    0       0
H1      1       'lowrwood'      'lowrchan'      56.892  0.11754 0       0.250   0.4     0.4     9.9
        0.2     12      0.1     0.26    0       0
*
*
*  PRINT CONTROL
*       NPrnt   Interv
M1      1       0
*   NDet StartP(1) StartP(2)
M2   0    0      0
*       IPRNT(1) Prints INflows to channels/pipes
M3      'outfall'
*Stats Block to Analyze Flow Output
$STATISTICS
* Istart Tstart Iend Tend InLog JCube JNeg
A1 0 0.0 0 0.0 1 0 0
*  MIT  Base Ebase LocQ      LocRn NPR Npnt Metric LRet A
B1 12.0 0.0  0.02  'outfall' ''    0   0    0      1    0.4
* Kseq Kterm Ktseqs
B2 1 0 0
C1 1001 1001 1001 1001 1001
$ENDPROGRAM
```

Appendix E-5: Continuous SWMM Input: Conventional Development, Favorable Conditions

```
SW  2  20 21 22 23
MM  6    1  2  3  4  12 13
@ 1 'rain_all.dnt'
*@ 21 'for_fav.int'
*@ 22 'for_fav.int'
*@ 21 'for_unf.int'
*@ 22 'for_unf.int'
*@ 21 'lid_fav.int'
*@ 22 'lid_fav.int'
*@ 21 'lid_unf.int'
*@ 22 'lid_unf.int'
@ 21 'conv_fav.int'
@ 22 'conv_fav.int'
*@ 21 'conv_unf.int'
*@ 22 'conv_unf.int'
$ANUM
$NOQUOTE
$RUNOFF
A1 'VTC Continuous SWMM Model'
*A1 'Runoff Block Template'
*A1 'Predevelopment/Forest - Favorable Condition'
*A1 'Predevelopment/Forest - Unfavorable Condition'
*A1 'Low Impact Development - Favorable Condition'
*A1 'Low Impact Development - Unfavorable Condition'
A1 'Conventional Development - Favorable Condition'
*A1 'Conventional Development - Unfavorable Condition'
*   METRIC ISNOW NRGAG INFILM KWALTY IVAP NHR NMN NDAY MONTH IYRSTR IVCHAN
* For continuous simulation using mixed IFLOWS and Datalogger rainfall record:
B1  0     0    1     1      0      -2   00  00  01  04     1998   0
*  Print Control
*  Input Graph Outpt GW NoHead Landupr
B2  0    1     1    0    1      0
*   Wet WetDry Dry   Lunit Long
* For continuous simulation (through August 31, 2004):
B3  60  60     86400 3     2345
*         PctZero  Regen(NR)
B4        0.0001   0
*         ROPT
D1        1
*         MONTHLY EVAPORATION (in/month) -turned off during rainfall for negative IVAP-
F1        0.064     0.213     0.982     2.152     3.629     5.110     5.761     5.178     3.642     1.918     0.888     0.232
*
*INSERT CHANNEL/PIPE DATA (G1 LINES), & SUBCATCHMENT DATA (H1 LINES) BELOW:
*         NameG  Ngto       Type    Gwidth  L         S         z1        z2        N         Dfull     Dinit
G1        'uvwNgutr'        'uvwNinlt'        1         0.00      170       0.075     12        0.042     0.015     2
          0
G1        'uvwNinlt'        'cirEinlt' 2      1.25      45        0.005     0         0         0.012     1.25      0
G1        'uvwEgutr'        'uvwEinlt'        1         0.00      80        0.075     12        0.042     0.015     2
          0
G1        'uvwEinlt'        'uvwWinlt'        2         1.25      35        0.01      0         0         0.012     1.25
          0
G1        'uvwWgutr'        'uvwWinlt'        1         0.00      250       0.092     12        0.042     0.015     2
          0
G1        'uvwWinlt'        'alyEinlt'2       1.25      30        0.04167 0         0         0.012     1.25      0
```

Appendix E-5: Continuous SWMM Input: Conventional Development, Favorable Conditions

```
G1     'cirWswal'     'cirWinlt'     1      1.00   130    0.069  4      4      0.06   2
       0
G1     'cirWinlt'     'cirEinlt' 2   1.25   75     0.005  0      0      0.012  1.25   0
G1     'alyWgutr'     'alyWinlt'     1      0.00   120    0.059  12     12     0.015  2
       0
G1     'alyWinlt'     'alyEinlt'2    1.25   70     0.02   0      0      0.012  1.25   0
G1     'cirEswal'     'cirEinlt' 1   1.00   80     0.038  4      4      0.06   2.1    0
G1     'cirEinlt' 'uvwWinlt'   2     1.25   85     0.005  0      0      0.012  1.25   0
G1     'alyEgutr'     'alyEinlt'1    0.00   70     0.075  12     12     0.015  2      0
G1     'alyEinlt''lvwWinlt'    2     1.50   120    0.05   0      0      0.012  1.5    0
G1     'thWinlt' 'thEinlt'  2 1.25   90     0.01667 0     0      0.012  1.25   0
G1     'thEinlt'  'alyWinlt'   2     1.25   50     0.007  0      0      0.012  1.25   0
G1     'lvwWgutr'     'lvwWinlt'     1      0.00   125    0.1    12     0.042  0.015  2
       0
G1     'lvwWinlt'     'bvdNinlt'     2      1.25   52     0.058  0      0      0.012  1.25
       0
G1     'lvwEgutr'     'lvwEinlt'     1      0.00   200    0.1    12     0.042  0.015  2
       0
G1     'lvwEinlt'     'lvwWinlt'     2      1.25   55     0.055  0      0      0.012  1.25
       0
G1     'grvswal''grvinlt'  1    2.00   130    0.108  3      3      0.08   2.36   0
G1     'grvinlt'  'bvdNinlt'   2     1.50   50     0.033  0      0      0.012  1.5    0
G1     'bvdNgutr'     'bvdNinlt'     1      0.00   250    0.067  12     0.042  0.015  2
       0
G1     'bvdSgutr'     'bvdSinlt'     1      0.00   200    0.1    12     0.042  0.015  2
       0
G1     'bvdNinlt'     'bvdSinlt'     2      2.00   50     0.05   0      0      0.012  2
       0
G1     'bvdSinlt'     'lowrchan'     2      2.00   57     0.05   0      0      0.012  2
       0
G1     'lowrchan'     'outfall'  1   2.00   150    0.12   3      3      0.08   3      0
*
*      JK     NameW Ngto    Wid    Area   %Imp   S      ImpN   PervN  IDS    PDS    G
       Ksat   SmdmaxRmaxInfIflowP
H1     1      '70woods'     '70lawn' 29.547 0.08818 0     0.046  0.4    0.4    9.9    0.35
       12     0.2    0.31   0      3
H1     1      '70lawn' 'uvwEgutr'   78.872 0.05432 0      0.170  0.24   0.24   9.9    0.2
       12     0.15   0.31   0      0
H1     1      '6970wood'    '6970lawn'    29.328 0.09089 0     0.070  0.4    0.4    9.9
       0.35   12     0.2    0.31   0      3
H1     1      '6970roof'    '6970lawn'    188.816 0.08669 100  0.200  0.02   0.02   0.02
       9.9    99     99     0.99   0      3
H1     1      '6970driv'    'uvwNgutr'    58.954 0.02571 100   0.075  0.014  0.014  0.02
       9.9    99     99     0.99   0      0
H1     1      '6970lawn'    'uvwNgutr'    199.945 0.25246 0    0.083  0.24   0.24   9.9
       0.2    12     0.15   0.31   0      0
*

H1     1      '68drive' 'uvwNgutr'   69.578 0.01597 100   0.083  0.014  0.014  0.02   9.9
       99     99     0.99   0      0
*

H1     1      '68lawnup'    'uvwEgutr'    38.489 0.03534 0     0.067  0.24   0.24   9.9
       0.2    12     0.15   0.31   0      0
```

Appendix E-5: Continuous SWMM Input: Conventional Development, Favorable Conditions

```
H1        1         '68wood''68lawnlo'            20.497    0.08470   0         0.089     0.4       0.4       9.9       0.35
          12        0.2       0.31      0         3
H1        1         '68roof'  '68lawnlo'          86.875    0.03989   100       0.200     0.02      0.02      0.02      9.9
          99        99        0.99      0         3
H1        1         '68lawnlo'          'uvwEgutr'          81.949    0.08466   0         0.119     0.24      0.24      9.9
          0.2       9         0.25      0.33      0         0
*

H1        1         '67drive' 'uvwEgutr'          19.606    0.01170   100       0.087     0.014     0.014     0.02      9.9
          99        99        0.99      0         0
H1        1         '67lawnup'          'uvwEgutr'          29.124    0.02139   0         0.125     0.24      0.24      9.9
          0.2       9         0.25      0.33      0         0
H1        1         'uvwEpave'          'uvwEgutr'          73.776    0.10162   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
*

H1        1         'uvwWgras'          'uvwWgutr'          241.902   0.05553   0         0.350     0.24      0.24      9.9
          0.2       12        0.15      0.31      0         0
H1        1         'uvwWpave'          'uvwWgutr'          74.357    0.10242   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
*

H1        1         'cirWroof'          'cirWswal'          128.000   0.05877   100       0.200     0.02      0.02      0.02
          9.9       99        99        0.99      0         0
H1        1         'cirWlawn'          'cirWswal'          195.548   0.06734   0         0.060     0.24      0.24      9.9
          0.2       12        0.15      0.31      0         0
H1        1         'cirWwood'          'cirWswal'          20.061    0.04605   0         0.060     0.4       0.4       9.9
          0.35      12        0.2       0.31      0         0
*

H1        1         '62roof'  '62lawn'  47.823    0.02196   100       0.200     0.02      0.02      0.02      9.9       99
          99        0.99      0         3
H1        1         '62lawn'  'alyWgutr'          106.321   0.08543   0         0.100     0.24      0.24      9.9       0.2
          9         0.25      0.33      0         0
H1        1         'alyWpave'          'alyWgutr'          43.596    0.04103   100       0.068     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
*

H1        1         '66roof'  'cirEwood'          73.200    0.03361   100       0.200     0.02      0.02      0.02      9.9
          99        99        0.99      0         3
H1        1         'uvwWside'          'uvwWgras'          120.212   0.03036   100       0.089     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         '66lawn'  'cirEwood'          116.060   0.05329   0         0.050     0.24      0.24      9.9       0.2
          12        0.15      0.31      0         3
H1        1         'cirEwood'          'cirEswal'          79.253    0.25471   0         0.086     0.4       0.4       9.9
          0.35      12        0.2       0.31      0         0
H1        1         'cirEslwn'          'cirEswal'          132.568   0.03043   0         0.150     0.24      0.24      9.9
          0.2       12        0.15      0.31      0         0
H1        1         '661roof2'          'cirEswal'          51.200    0.02351   100       0.200     0.02      0.02      0.02
          9.9       99        99        0.99      0         0
*

H1        1         '6061roof'          'alyEgutr'          95.413    0.04381   100       0.200     0.02      0.02      0.02
          9.9       99        99        0.99      0         0
```

Appendix E-5: Continuous SWMM Input: Conventional Development, Favorable Conditions

```
H1        1         'alyEpave'          'alyEgutr'          25.091    0.04608   100       0.077     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
H1        1         '6061lawn'          'alyEgutr'          174.366   0.14010   0         0.130     0.24      0.24      9.9
          0.2       9         0.25      0.33      0         0
*

H1        1         'thWlawn'           'thWinlt' 48.191    0.04093   0         0.064     0.24      0.24      9.9       0.2
          9         0.25      0.33      0         0
H1        1         'thWroof'           'thWinlt' 170.519   0.07829   100       0.200     0.02      0.02      0.02      9.9
          99        99        0.99      0         0
H1        1         'thWwood'           'thWlot'  69.362    0.09554   0         0.084     0.4       0.4       9.9       0.35
          9         0.3       0.33      0         3
H1        1         'thWlot'  'thWinlt' 33.247    0.02900   100       0.048     0.014     0.014     0.02      9.9       99
          99        0.99      0         0
*

H1        1         'thEwood'           'thElot'  34.212    0.03927   0         0.115     0.4       0.4       9.9       0.35
          9         0.3       0.33      0         3
H1        1         'thElot'  'thEinlt' 43.225    0.05458   100       0.119     0.014     0.014     0.02      9.9       99
          99        0.99      0         0
*

H1        1         'thElawn'           'thEinlt' 160.005   0.07346   0         0.150     0.24      0.24      9.9       0.2
          9         0.25      0.33      0         0
H1        1         'thEroof' 'thEinlt' 215.998   0.09917   100       0.200     0.02      0.02      0.02      9.9       99
          99        0.99      0         0
*

H1        1         'lvwWlawn'          'lvwWgutr'          157.741   0.03621   0         0.350     0.24      0.24      9.9
          0.2       12        0.15      0.31      0         0
H1        1         'lvwWside'          'lvwWlawn'          22.385    0.01953   100       0.105     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'lvwWpav'           'lvwWgutr'          72.263    0.05806   100       0.108     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
*

H1        1         '67roof'  '67lawnlo'          86.729    0.03982   100       0.200     0.02      0.02      0.02      9.9
          99        99        0.99      0         3
H1        1         '67lawnlo'          'lvwEgutr'          75.132    0.12074   0         0.138     0.24      0.24      9.9
          0.2       9         0.25      0.33      0         0
H1        1         'lvwecut' 'lvwEgutr'          133.395   0.10106   0         0.210     0.3       0.3       9.9       0.25
          12        0.15      0.31      0         0
H1        1         'lvwepav'           'lvwEgutr'          30.261    0.05419   100       0.102     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
*

*

H1        1         'grvlawnB'          'grvwood'           106.585   0.05138   0         0.160     0.24      0.24      9.9
          0.2       9         0.25      0.33      0         3
H1        1         'grvwood'           'grvswal' 110.655   0.12701   0         0.127     0.4       0.4       9.9       0.35
          9         0.3       0.33      0         0
*
```

Appendix E-5: Continuous SWMM Input: Conventional Development, Favorable Conditions

```
H1        1         'grvlawnI'          'grvinlt' 124.585   0.06006   0         0.160     0.24      0.24      9.9       0.2
          9         0.25      0.33      0         0
H1        1         'grvlawnC'          'grvinlt' 27.649    0.01904   0         0.130     0.24      0.24      9.9       0.2
          12        0.15      0.31      0         0
*

H1        1         'sidegras'          'bvdNgutr'          283.159   0.09751   0         0.091     0.24      0.24      9.9
          0.2       9         0.25      0.33      0         0
H1        1         'blvdNpav'          'bvdNgutr'          124.054   0.14239   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
H1        1         'blvdSpav'          'bvdSgutr'          104.192   0.11960   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
H1        1         'bvdNmedn'          'blvdNpav'          352.436   0.08091   0         0.100     0.4       0.4       9.9
          0.35      12        0.2       0.31      0         3
H1        1         'bvdSmedn'          'blvdSpav'          352.436   0.08091   0         0.100     0.4       0.4       9.9
          0.35      12        0.2       0.31      0         3
*

H1        1         'lowrpav'           'lowrfill' 81.037   0.02232   100       0.020     0.014     0.014     0.02      9.9
          99        99        0.99      0         3
H1        1         'lowrfill' 'lowrchan'         245.822   0.33860   0         0.290     0.3       0.3       9.9       0.25
          12        0.15      0.31      0         0
H1        1         'lowrwood'          'lowrchan'          56.892    0.11754   0         0.250     0.4       0.4       9.9
          0.35      12        0.2       0.31      0         0
*
*
*  PRINT CONTROL
*         NPrnt     Interv
M1        1         0
*   NDet StartP(1) StartP(2)
M2   0     0        0
*         IPRNT(1) Prints INflows to channels/pipes
M3        'outfall'
*Stats Block to Analyze Flow Output
$STATISTICS
* Istart Tstart Iend Tend InLog JCube JNeg
A1 0 0.0 0 0.0 1 0 0
*  MIT  Base Ebase LocQ      LocRn NPR Npnt Metric LRet A
B1 12.0 0.0  0.02  'outfall' ''    0   0    0      1    0.4
* Kseq Kterm Ktseqs
B2 1 0 0
C1 1001 1001 1001 1001 1001
$ENDPROGRAM
```

Appendix E-6: Continuous SWMM Input: Conventional Development, Unfavorable Conditions

```
SW  2  20 21 22 23
MM  6    1  2  3  4  12 13
@ 1 'rain_all.dnt'
*@ 21 'for_fav.int'
*@ 22 'for_fav.int'
*@ 21 'for_unf.int'
*@ 22 'for_unf.int'
*@ 21 'lid_fav.int'
*@ 22 'lid_fav.int'
*@ 21 'lid_unf.int'
*@ 22 'lid_unf.int'
*@ 21 'conv_fav.int'
*@ 22 'conv_fav.int'
@ 21 'conv_unf.int'
@ 22 'conv_unf.int'
$ANUM
$NOQUOTE
$RUNOFF
A1 'VTC Continuous SWMM Model'
*A1 'Runoff Block Template'
*A1 'Predevelopment/Forest - Favorable Condition'
*A1 'Predevelopment/Forest - Unfavorable Condition'
*A1 'Low Impact Development - Favorable Condition'
*A1 'Low Impact Development - Unfavorable Condition'
*A1 'Conventional Development - Favorable Condition'
A1 'Conventional Development - Unfavorable Condition'
*   METRIC ISNOW NRGAG INFILM KWALTY IVAP NHR NMN NDAY MONTH IYRSTR IVCHAN
* For continuous simulation using mixed IFLOWS and Datalogger rainfall record:
B1  0      0     1     1      0      -2   00  00  01  04     1998   0
*  Print Control
*  Input Graph Outpt GW NoHead Landupr
B2  0     1     1    0    1      0
*   Wet WetDry Dry   Lunit Long
* For continuous simulation (through August 31, 2004):
B3  60  60     86400 3     2345
*          PctZero  Regen(NR)
B4         0.0001   0
*          ROPT
D1         1
*          MONTHLY EVAPORATION (in/month) -turned off during rainfall for negative IVAP-
F1         0.064      0.213      0.982      2.152      3.629      5.110      5.761      5.178      3.642      1.918      0.888      0.232
*
*INSERT CHANNEL/PIPE DATA (G1 LINES), & SUBCATCHMENT DATA (H1 LINES) BELOW:
*
*          NameG  Ngto        Type      Gwidth  L          S          z1         z2         N          Dfull      Dinit
G1         'uvwNgutr'         'uvwNinlt'        1          0.00       170        0.075      12         0.042      0.015      2
           0
G1         'uvwNinlt'         'cirEinlt' 2      1.25       45         0.005      0          0          0.012      1.25       0
G1         'uvwEgutr'         'uvwEinlt'        1          0.00       80         0.075      12         0.042      0.015      2
           0
G1         'uvwEinlt'         'uvwWinlt'        2          1.25       35         0.01       0          0          0.012      1.25
           0
G1         'uvwWgutr'         'uvwWinlt'        1          0.00       250        0.092      12         0.042      0.015      2
           0
```

Appendix E-6: Continuous SWMM Input: Conventional Development, Unfavorable Conditions

```
G1      'uvwWinlt'      'alyEinlt'2     1.25    30      0.04167 0       0       0.012   1.25    0
G1      'cirWswal'      'cirWinlt'      1       1.00    130     0.069   4       4       0.06    2
        0
G1      'cirWinlt'      'cirEinlt' 2    1.25    75      0.005   0       0       0.012   1.25    0
G1      'alyWgutr'      'alyWinlt'      1       0.00    120     0.059   12      12      0.015   2
        0
G1      'alyWinlt'      'alyEinlt'2     1.25    70      0.02    0       0       0.012   1.25    0
G1      'cirEswal'      'cirEinlt' 1    1.00    80      0.038   4       4       0.06    2.1     0
G1      'cirEinlt' 'uvwWinlt'   2       1.25    85      0.005   0       0       0.012   1.25    0
G1      'alyEgutr'      'alyEinlt'1     0.00    70      0.075   12      12      0.015   2       0
G1      'alyEinlt''lvwWinlt'    2       1.50    120     0.05    0       0       0.012   1.5     0
G1      'thWinlt' 'thEinlt'  2  1.25    90      0.01667 0       0       0.012   1.25    0
G1      'thEinlt'  'alyWinlt'   2       1.25    50      0.007   0       0       0.012   1.25    0
G1      'lvwWgutr'      'lvwWinlt'      1       0.00    125     0.1     12      0.042   0.015   2
        0
G1      'lvwWinlt'      'bvdNinlt'      2       1.25    52      0.058   0       0       0.012   1.25
        0
G1      'lvwEgutr'      'lvwEinlt'      1       0.00    200     0.1     12      0.042   0.015   2
        0
G1      'lvwEinlt'      'lvwWinlt'      2       1.25    55      0.055   0       0       0.012   1.25
        0
G1      'grvswal''grvinlt'  1   2.00    130     0.108   3       3       0.08    2.36    0
G1      'grvinlt'  'bvdNinlt'   2       1.50    50      0.033   0       0       0.012   1.5     0
G1      'bvdNgutr'      'bvdNinlt'      1       0.00    250     0.067   12      0.042   0.015   2
        0
G1      'bvdSgutr'      'bvdSinlt'      1       0.00    200     0.1     12      0.042   0.015   2
        0
G1      'bvdNinlt'      'bvdSinlt'      2       2.00    50      0.05    0       0       0.012   2
        0
G1      'bvdSinlt'      'lowrchan'      2       2.00    57      0.05    0       0       0.012   2
        0
G1      'lowrchan'      'outfall'  1    2.00    150     0.12    3       3       0.08    3       0
*
*       JK      NameW Ngto      Wid     Area    %Imp    S       ImpN    PervN   IDS     PDS     G
        Ksat    SmdmaxRmaxInfIflowP
H1      1       '70woods'       '70lawn' 29.547 0.08818 0       0.046   0.4     0.4     9.9     0.2
        12      0.1     0.26    0       3
H1      1       '70lawn' 'uvwEgutr'     78.872  0.05432 0       0.170   0.24    0.24    9.9     0.1
        12      0.08    0.2     0       0
H1      1       '6970wood'      '6970lawn'      29.328  0.09089 0       0.070   0.4     0.4     9.9
        0.2     12      0.1     0.26    0       3
H1      1       '6970roof'      '6970lawn'      188.816 0.08669 100     0.200   0.02    0.02    0.02
        9.9     99      99      0.99    0       3
H1      1       '6970driv'      'uvwNgutr'      58.954  0.02571 100     0.075   0.014   0.014   0.02
        9.9     99      99      0.99    0       0
H1      1       '6970lawn'      'uvwNgutr'      199.945 0.25246 0       0.083   0.24    0.24    9.9
        0.1     12      0.08    0.2     0       0
*

H1      1       '68drive' 'uvwNgutr'    69.578  0.01597 100     0.083   0.014   0.014   0.02    9.9
        99      99      0.99    0       0
*
```

Appendix E-6: Continuous SWMM Input: Conventional Development, Unfavorable Conditions

```
H1      1       '68lawnup'      'uvwEgutr'      38.489  0.03534 0       0.067   0.24    0.24    9.9
        0.1     12      0.08    0.2     0       0
H1      1       '68wood''68lawnlo'      20.497  0.08470 0       0.089   0.4     0.4     9.9     0.2
        12      0.1     0.26    0       3
H1      1       '68roof' '68lawnlo'     86.875  0.03989 100     0.200   0.02    0.02    0.02    9.9
        99      99      0.99    0       3
H1      1       '68lawnlo'      'uvwEgutr'      81.949  0.08466 0       0.119   0.24    0.24    9.9
        0.1     9       0.15    0.22    0       0
*

H1      1       '67drive' 'uvwEgutr'    19.606  0.01170 100     0.087   0.014   0.014   0.02    9.9
        99      99      0.99    0       0
H1      1       '67lawnup'      'uvwEgutr'      29.124  0.02139 0       0.125   0.24    0.24    9.9
        0.1     9       0.15    0.22    0       0
H1      1       'uvwEpave'      'uvwEgutr'      73.776  0.10162 100     0.080   0.014   0.014   0.02
        9.9     99      99      0.99    0       0
*

H1      1       'uvwWgras'      'uvwWgutr'      241.902 0.05553 0       0.350   0.24    0.24    9.9
        0.1     12      0.08    0.2     0       0
H1      1       'uvwWpave'      'uvwWgutr'      74.357  0.10242 100     0.080   0.014   0.014   0.02
        9.9     99      99      0.99    0       0
*

H1      1       'cirWroof'      'cirWswal'      128.000 0.05877 100     0.200   0.02    0.02    0.02
        9.9     99      99      0.99    0       0
H1      1       'cirWlawn'      'cirWswal'      195.548 0.06734 0       0.060   0.24    0.24    9.9
        0.1     12      0.08    0.2     0       0
H1      1       'cirWwood'      'cirWswal'      20.061  0.04605 0       0.060   0.4     0.4     9.9
        0.2     12      0.1     0.26    0       0
*

H1      1       '62roof' '62lawn' 47.823  0.02196 100     0.200   0.02    0.02    0.02    9.9     99
        99      0.99    0       3
H1      1       '62lawn' 'alyWgutr'     106.321 0.08543 0       0.100   0.24    0.24    9.9     0.1
        9       0.15    0.22    0       0
H1      1       'alyWpave'      'alyWgutr'      43.596  0.04103 100     0.068   0.014   0.014   0.02
        9.9     99      99      0.99    0       0
*

H1      1       '66roof' 'cirEwood'     73.200  0.03361 100     0.200   0.02    0.02    0.02    9.9
        99      99      0.99    0       3
H1      1       'uvwWside'      'uvwWgras'      120.212 0.03036 100     0.089   0.014   0.014   0.02
        9.9     99      99      0.99    0       3
H1      1       '66lawn' 'cirEwood'     116.060 0.05329 0       0.050   0.24    0.24    9.9     0.1
        12      0.08    0.2     0       3
H1      1       'cirEwood'      'cirEswal'      79.253  0.25471 0       0.086   0.4     0.4     9.9
        0.2     12      0.1     0.26    0       0
H1      1       'cirEslwn'      'cirEswal'      132.568 0.03043 0       0.150   0.24    0.24    9.9
        0.1     12      0.08    0.2     0       0
H1      1       '661roof2'      'cirEswal'      51.200  0.02351 100     0.200   0.02    0.02    0.02
        9.9     99      99      0.99    0       0
*
```

Appendix E-6: Continuous SWMM Input: Conventional Development, Unfavorable Conditions

```
H1        1         '6061roof'          'alyEgutr'          95.413    0.04381   100       0.200     0.02      0.02      0.02
          9.9       99        99        0.99      0         0
H1        1         'alyEpave'          'alyEgutr'          25.091    0.04608   100       0.077     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
H1        1         '6061lawn'          'alyEgutr'          174.366   0.14010   0         0.130     0.24      0.24      9.9
          0.1       9         0.15      0.22      0         0
*

H1        1         'thWlawn'           'thWinlt' 48.191    0.04093   0         0.064     0.24      0.24      9.9       0.1
          9         0.15      0.22      0         0
H1        1         'thWroof'           'thWinlt' 170.519   0.07829   100       0.200     0.02      0.02      0.02      9.9
          99        99        0.99      0         0
H1        1         'thWwood'           'thWlot'  69.362    0.09554   0         0.084     0.4       0.4       9.9       0.2
          9         0.2       0.28      0         3
H1        1         'thWlot'  'thWinlt' 33.247    0.02900   100       0.048     0.014     0.014     0.02      9.9       99
          99        0.99      0         0
*

H1        1         'thEwood'           'thElot'  34.212    0.03927   0         0.115     0.4       0.4       9.9       0.2
          9         0.2       0.28      0         3
H1        1         'thElot'  'thEinlt' 43.225    0.05458   100       0.119     0.014     0.014     0.02      9.9       99
          99        0.99      0         0
*

H1        1         'thElawn'           'thEinlt' 160.005   0.07346   0         0.150     0.24      0.24      9.9       0.1
          9         0.15      0.22      0         0
H1        1         'thEroof' 'thEinlt' 215.998   0.09917   100       0.200     0.02      0.02      0.02      9.9       99
          99        0.99      0         0
*

H1        1         'lvwWlawn'          'lvwWgutr'          157.741   0.03621   0         0.350     0.24      0.24      9.9
          0.1       12        0.08      0.2       0         0
H1        1         'lvwWside'          'lvwWlawn'          22.385    0.01953   100       0.105     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'lvwWpav'           'lvwWgutr'          72.263    0.05806   100       0.108     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
*

H1        1         '67roof'  '67lawnlo'          86.729    0.03982   100       0.200     0.02      0.02      0.02      9.9
          99        99        0.99      0         3
H1        1         '67lawnlo'          'lvwEgutr'          75.132    0.12074   0         0.138     0.24      0.24      9.9
          0.1       9         0.15      0.22      0         0
H1        1         'lvwecut''lvwEgutr'           133.395   0.10106   0         0.210     0.3       0.3       9.9       0.15
          12        0.08      0.26      0         0
H1        1         'lvwepav'           'lvwEgutr'          30.261    0.05419   100       0.102     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
*

*

H1        1         'grvlawnB'          'grvwood'           106.585   0.05138   0         0.160     0.24      0.24      9.9
          0.1       9         0.15      0.22      0         3
H1        1         'grvwood'           'grvswal' 110.655   0.12701   0         0.127     0.4       0.4       9.9       0.2
          9         0.2       0.28      0         0
```

Appendix E-6: Continuous SWMM Input: Conventional Development, Unfavorable Conditions

```
*

H1      1       'grvlawnI'      'grvinlt' 124.585 0.06006 0      0.160   0.24    0.24    9.9     0.1
        9       0.15    0.22    0       0
H1      1       'grvlawnC'      'grvinlt' 27.649  0.01904 0      0.130   0.24    0.24    9.9     0.1
        12      0.08    0.2     0       0
*

H1      1       'sidegras'      'bvdNgutr'        283.159 0.09751 0      0.091   0.24    0.24    9.9
        0.1     9       0.15    0.22    0         0
H1      1       'blvdNpav'      'bvdNgutr'        124.054 0.14239 100    0.080   0.014   0.014   0.02
        9.9     99      99      0.99    0         0
H1      1       'blvdSpav'      'bvdSgutr'        104.192 0.11960 100    0.080   0.014   0.014   0.02
        9.9     99      99      0.99    0         0
H1      1       'bvdNmedn'      'blvdNpav'        352.436 0.08091 0      0.100   0.4     0.4     9.9
        0.2     12      0.1     0.26    0         3
H1      1       'bvdSmedn'      'blvdSpav'        352.436 0.08091 0      0.100   0.4     0.4     9.9
        0.2     12      0.1     0.26    0         3
*

H1      1       'lowrpav'       'lowrfill' 81.037 0.02232 100    0.020   0.014   0.014   0.02    9.9
        99      99      0.99    0          3
H1      1       'lowrfill' 'lowrchan'     245.822 0.33860 0      0.290   0.3     0.3     9.9     0.15
        12      0.08    0.26    0         0
H1      1       'lowrwood'      'lowrchan'        56.892  0.11754 0      0.250   0.4     0.4     9.9
        0.2     12      0.1     0.26    0         0
*

*
*  PRINT CONTROL
*       NPrnt   Interv
M1      1       0
*   NDet StartP(1) StartP(2)
M2   0    0       0
*       IPRNT(1) Prints INflows to channels/pipes
M3      'outfall'
*Stats Block to Analyze Flow Output
$STATISTICS
* Istart Tstart Iend Tend InLog JCube JNeg
A1 0 0.0 0 0.0 1 0 0
*  MIT  Base Ebase LocQ      LocRn NPR Npnt Metric LRet A
B1 12.0 0.0  0.02  'outfall' ''   0   0    0      1    0.4
* Kseq Kterm Ktseqs
B2 1 0 0
C1 1001 1001 1001 1001 1001
$ENDPROGRAM
```

Appendix E-7: Continuous SWMM Input: Conventional with Stormwater Management, Favorable Conditions

```
SW  2  20 21 22 23
MM  6    1  2  3  4  12 13
@ 20 'conv_fav.int'
@ 21 'swm_fav.int'
@ 22 'swm_fav.int'
*@ 20 'conv_unf.int'
*@ 21 'swm_unf.int'
*@ 22 'swm_unf.int'
$ANUM
* $NOQUOTE
$TRANSPORT
A1  'VTC Continuous SWMM Model: Transport Block'
A1 'Conventional Development with SWM - Favorable Condition'
*A1 'Conventional Development with SWM - Unfavorable Condition'
*   NDT  NINPUT NNYN NNPE NOUTS NPRINT NPOLL NITER IDATEZ METRIC INTPRT
B1 3376800        0           0           0           1           0           0           6           0           0           0
*  DT EPSIL  DWDAYS TZERO GNU     TRIBA
B2 60 0.0001  0     0     0.00001 4.3338
* B3 & C1 lines all zeros for quantity-only WWF simulation
B3 0 0 0 0
C1 0 0
E1 'outfall' ' '        ' '           ' '           22 /
G1 0
*   DEPTH   AREA  VOL   OUTFLOW
G2        0           1575  0              0
G2        0.25        1656  403.9 0.14
G2        0.5         1739  828.3 0.51
G2        1           1911  1741  1.08
G2        2           2279  3836  1.68
G2        2.75        2576  5656  2.02
G2        3           2679  6313  2.68
G2        3.25        2784  6996  3.8
G2        3.5         2891  7706  4.78
G2        4           3111  9206  6
G2        4.5         3339  10819 6.97
G2        5           3575  12547 7.79
G2        5.25        3696  13456 10.04
G2        5.5         3819  14395 13.74
G2        6           4071  16368 24.09
G2        8           5159  25598 89.27
*
G5        0           /
*    JN(1)   .....  JN(NOUTS) To Subsequent Blocks
H1 'outfall'
*H1       'outfall'   'pond'
*    NYN(1)   .....  NYN(NNYN) Input Hydrographs
*J1       ''
*    NPE(1)   .....  NPE(NNPE) Routed Hydrographs
*J2       ''
*Stats Block to Analyze Flow Output
$STATISTICS
* Istart Tstart Iend Tend InLog JCube JNeg
A1 0 0.0 0 0.0 1 0 0
*  MIT  Base Ebase LocQ      LocRn NPR Npnt Metric LRet A
```

Appendix E-7: Continuous SWMM Input: Conventional with Stormwater Management, Favorable Conditions

```
B1 12.0 0.0  0.02  'outfall' ''    0   0    0      1    0.4
* Kseq Kterm Ktseqs
B2 1 0 0
C1 1001 1001 1001 1001 1001
$ENDPROGRAM
```

Appendix E-8: Continuous SWMM Input: Conventional with Stormwater Management, Unfavorable Conditions

```
SW  2  20 21 22 23
MM  6    1  2  3  4  12 13
*@ 20 'conv_fav.int'
*@ 21 'swm_fav.int'
*@ 22 'swm_fav.int'
@ 20 'conv_unf.int'
@ 21 'swm_unf.int'
@ 22 'swm_unf.int'
$ANUM
* $NOQUOTE
$TRANSPORT
A1  'VTC Continuous SWMM Model: Transport Block'
*A1 'Conventional Development with SWM - Favorable Condition'
A1 'Conventional Development with SWM - Unfavorable Condition'
*   NDT  NINPUT NNYN NNPE NOUTS NPRINT NPOLL NITER IDATEZ METRIC INTPRT
B1 3376800      0       0       0       1       0       0       6       0       0       0
*  DT EPSIL  DWDAYS TZERO GNU     TRIBA
B2 60 0.0001  0     0     0.00001 4.3338
* B3 & C1 lines all zeros for quantity-only WWF simulation
B3 0 0 0 0
C1 0 0
E1 'outfall' ' '       ' '         ' '         22 /
G1 0
*   DEPTH   AREA  VOL   OUTFLOW
G2       0          1575  0            0
G2       0.25       1656  403.9 0.14
G2       0.5        1739  828.3 0.51
G2       1          1911  1741  1.08
G2       2          2279  3836  1.68
G2       2.75       2576  5656  2.02
G2       3          2679  6313  2.68
G2       3.25       2784  6996  3.8
G2       3.5        2891  7706  4.78
G2       4          3111  9206  6
G2       4.5        3339  10819 6.97
G2       5          3575  12547 7.79
G2       5.25       3696  13456 10.04
G2       5.5        3819  14395 13.74
G2       6          4071  16368 24.09
G2       8          5159  25598 89.27
*
G5       0          /
*   JN(1)   .....  JN(NOUTS) To Subsequent Blocks
H1 'outfall'
*H1       'outfall'  'pond'
*   NYN(1)   .....  NYN(NNYN) Input Hydrographs
*J1       ''
*   NPE(1)   .....  NPE(NNPE) Routed Hydrographs
*J2       ''
*Stats Block to Analyze Flow Output
$STATISTICS
* Istart Tstart Iend Tend InLog JCube JNeg
A1 0 0.0 0 0.0 1 0 0
*  MIT  Base Ebase LocQ      LocRn NPR Npnt Metric LRet A
```

Appendix E-8: Continuous SWMM Input: Conventional with Stormwater Management, Unfavorable Conditions

```
B1 12.0 0.0  0.02  'outfall' ''    0   0    0      1    0.4
* Kseq Kterm Ktseqs
B2 1 0 0
C1 1001 1001 1001 1001 1001
$ENDPROGRAM
```

APPENDIX F

SINGLE-EVENT SWMM INPUT FOR LID EVALUATION

- **F-1: Single-Event SWMM Input: Forest, Favorable Conditions**
- **F-2: Single-Event SWMM Input: Forest, Unfavorable Conditions**
- **F-3: Single-Event SWMM Input: LID, Favorable Conditions**
- **F-4: Single-Event SWMM Input: LID, Unfavorable Conditions**
- **F-5: Single-Event SWMM Input: Conventional Development, Favorable Conditions**
- **F-6: Single-Event SWMM Input: Conventional Development, Unfavorable Conditions**
- **F-7: Single-Event SWMM Input: Conventional with Stormwater Management, Favorable Conditions**
- **F-8: Single-Event SWMM Input: Conventional with Stormwater Management, Unfavorable Conditions**
- **F-9: Single-Event SWMM Input: Rainfall Hyetographs (E3 lines)**

Appendix F-1: Single-Event SWMM Input: Forest, Favorable Conditions

Note: For brevity, the input file below only runs the 1-year storm event. To model all events in a single input file, repeat lines $RUNOFF through M3 for each design storm, and substitute the appropriate hyetograph (E3 lines) from Appendix F-9. Use appropriate A1 lines for clarity.

```
SW  4  0 20 0 21 0 22 0 23
MM  6     1  2  3  4 12 13
@ 20 'for_fav_1.int'
@ 21 'for_fav_2.int'
@ 22 'for_fav_10.int'
@ 23 'for_fav_100.int'
* for_fav
* for_unf
* lid_fav
* lid_unf
* conv_fav
* conv_unf
$ANUM
$NOQUOTE
$RUNOFF
A1 'Event Model- 1-year Storm-Soils 1/2 way between F.C. and W.P.'
A1 'Predevelopment/Forest - Favorable Condition'
*A1 'Predevelopment/Forest - Unfavorable Condition'
*A1 'Low Impact Development - Favorable Condition'
*A1 'Low Impact Development - Unfavorable Condition'
*A1 'Conventional Development - Favorable Condition'
*A1 'Conventional Development - Unfavorable Condition'
*   METRIC ISNOW NRGAG INFILM KWALTY IVAP NHR NMN NDAY MONTH IYRSTR IVCHAN
* For event simulation of SCS Type II design storms:
B1  0      0     1     1      0      -2   00  00  01  05     2003   0
*  Print Control
*  Input Graph Outpt GW NoHead Landupr
B2  1     1     1    0    1      0
*   Wet WetDry Dry   Lunit Long
* For event mode (3 days to allow pond routing):
B3  60  60     86400 3     3
*   PctZero Regen(NR)
B4  0.0001  0
*   ROPT
D1  0
*  HYETOGRAPHS FOR EVENT MODE SIMULATION OF SCS DESIGN STORMS
*  Rainfall intensity in in/hr, at 15-minute intervals
*  time units of hours, 8 E3 lines required per hyetograph @ 12 per line
*  KType KInc Kprint KTHis KTime KPrep NHisto THisto TZRain
E1 0     12   1      0      1      0     96     0.25   0.0
*
* 1-year 24-hr SCS Type II Storm Distribution, 0.25 hour resolution, P = 2.5"
E3      0.026   0.027   0.027   0.028   0.028   0.029   0.029   0.03    0.03    0.031   0.031   0.032
E3      0.033   0.034   0.034   0.035   0.036   0.037   0.038   0.039   0.04    0.041   0.042   0.043
E3      0.045   0.046   0.048   0.05    0.052   0.054   0.056   0.059   0.062   0.065   0.068   0.073
E3      0.077   0.083   0.09    0.098   0.108   0.12    0.137   0.161   0.196   0.259   0.405   2.756
E3      1.043   0.314   0.223   0.176   0.148   0.128   0.113   0.102   0.093   0.086   0.08    0.075
E3      0.07    0.067   0.063   0.06    0.057   0.055   0.053   0.051   0.049   0.047   0.046   0.044
E3      0.043   0.042   0.04    0.039   0.038   0.037   0.036   0.036   0.035   0.034   0.033   0.032
E3      0.032   0.031   0.031   0.03    0.029   0.029   0.028   0.028   0.027   0.027   0.027   0.026
*
```

Appendix F-1: Single-Event SWMM Input: Forest, Favorable Conditions

```
*        MONTHLY EVAPORATION (in/month) -turned off during rainfall for negative IVAP-
F1       0.064    0.213    0.982    2.152    3.629    5.110    5.761    5.178    3.642    1.918    0.888    0.232
*
*INSERT CHANNEL/PIPE DATA (G1 LINES), & SUBCATCHMENT DATA (H1 LINES) BELOW:
*        NameG    Ngto     Type     Gwidth   L        S        z1       z2       N        Dfull    Dinit
G1       channel1          channel2          1        2.00     244      0.1189   6        6        0.15     1.5
         0
G1       channel2          outfall  1        2.00     254      0.1102   6        6        0.15     1.5      0
*
*        JK       NameW    Ngto     Wid      Area     %Imp     S        ImpN     PervN    IDS      PDS      G
         Ksat     SmdmaxRmaxInfIflowP
H1       1        '8Deast' 'outfall' 79.602  0.24853  0        0.176    0.4      0.4      9.9      0.35     12
         0.2      0.235    0        0
H1       1        '9Deast' 'channel2'        89.031   0.47418  0        0.125    0.4      0.4      9.9      0.35
         12       0.2      0.235    0        0
H1       1        '9Dwest''8Dwest'70.602     0.36792  0        0.167    0.4      0.4      9.9      0.35     12
         0.2      0.235    0        3
H1       1        '8Dwest''channel2'         21.679   0.11297  0        0.167    0.4      0.4      9.9      0.35
         12       0.2      0.235    0        0
H1       1        '12Cwest'         'channel2'        55.440   0.21636  0        0.118    0.4      0.4      9.9
         0.35     9        0.3      0.245    0        0
H1       1        '12Cmid''channel1'         142.595  0.68744  0        0.124    0.4      0.4      9.9      0.35
         9        0.3      0.245    0        0
H1       1        '12Ceast''channel1'        138.070  0.71317  0        0.116    0.4      0.4      9.9      0.35
         9        0.3      0.245    0        0
H1       1        '16Bnorth'        '12Cmid'323.114   1.51320  0        0.088    0.4      0.4      9.9      0.35
         12       0.2      0.235    0        3
*
*  PRINT CONTROL
*        NPrnt    Interv
M1       1        5
*   NDet StartP(1) StartP(2)
M2   1    0      0
*        IPRNT(1) Prints INflows to channels/pipes
M3       'outfall'
* Repeat lines $RUNOFF through M3 for each design event.
* Substitute appropriate E3 lines for desired design hyetograph.
* Change A1 (title) lines as appropriate.
$ENDPROGRAM
```

Appendix F-2: Single-Event SWMM Input: Forest, Unfavorable Conditions

Note: For brevity, the input file below only runs the 1-year storm event. To model all events in a single input file, repeat lines $RUNOFF through M3 for each design storm, and substitute the appropriate hyetograph (E3 lines) from Appendix F-9. Use appropriate A1 lines for clarity.

```
SW  4  0 20 0 21 0 22 0 23
MM  6     1  2  3  4 12 13
@ 20 'for_unf_1.int'
@ 21 'for_unf_2.int'
@ 22 'for_unf_10.int'
@ 23 'for_unf_100.int'
* for_fav
* for_unf
* lid_fav
* lid_unf
* conv_fav
* conv_unf
$ANUM
$NOQUOTE
$RUNOFF
A1 'Event Model- 1-year Storm-Soils 1/2 way between F.C. and W.P.'
*A1 'Predevelopment/Forest - Favorable Condition'
A1 'Predevelopment/Forest - Unfavorable Condition'
*A1 'Low Impact Development - Favorable Condition'
*A1 'Low Impact Development - Unfavorable Condition'
*A1 'Conventional Development - Favorable Condition'
*A1 'Conventional Development - Unfavorable Condition'
*   METRIC ISNOW NRGAG INFILM KWALTY IVAP NHR NMN NDAY MONTH IYRSTR IVCHAN
* For event simulation of SCS Type II design storms:
B1  0      0     1     1      0      -2   00  00  01  05     2003   0
*  Print Control
*  Input Graph Outpt GW NoHead Landupr
B2  1     1     1    0    1      0
*   Wet WetDry Dry   Lunit Long
* For event mode (3 days to allow pond routing):
B3  60  60     86400 3     3
*   PctZero Regen(NR)
B4  0.0001  0
*   ROPT
D1  0
*  HYETOGRAPHS FOR EVENT MODE SIMULATION OF SCS DESIGN STORMS
*  Rainfall intensity in in/hr, at 15-minute intervals
*  time units of hours, 8 E3 lines required per hyetograph @ 12 per line
*  KType KInc Kprint KTHis KTime KPrep NHisto THisto TZRain
E1 0     12   1      0     1      0     96     0.25   0.0
*
* 1-year 24-hr SCS Type II Storm Distribution, 0.25 hour resolution, P = 2.5"
E3      0.026   0.027   0.027   0.028   0.028   0.029   0.029   0.03    0.03    0.031   0.031   0.032
E3      0.033   0.034   0.034   0.035   0.036   0.037   0.038   0.039   0.04    0.041   0.042   0.043
E3      0.045   0.046   0.048   0.05    0.052   0.054   0.056   0.059   0.062   0.065   0.068   0.073
E3      0.077   0.083   0.09    0.098   0.108   0.12    0.137   0.161   0.196   0.259   0.405   2.756
E3      1.043   0.314   0.223   0.176   0.148   0.128   0.113   0.102   0.093   0.086   0.08    0.075
E3      0.07    0.067   0.063   0.06    0.057   0.055   0.053   0.051   0.049   0.047   0.046   0.044
E3      0.043   0.042   0.04    0.039   0.038   0.037   0.036   0.036   0.035   0.034   0.033   0.032
E3      0.032   0.031   0.031   0.03    0.029   0.029   0.028   0.028   0.027   0.027   0.027   0.026
*
```

Appendix F-2: Single-Event SWMM Input: Forest, Unfavorable Conditions

```
*         MONTHLY EVAPORATION (in/month) -turned off during rainfall for negative IVAP-
F1        0.064     0.213     0.982     2.152     3.629     5.110     5.761     5.178     3.642     1.918     0.888     0.232
*
*INSERT CHANNEL/PIPE DATA (G1 LINES), & SUBCATCHMENT DATA (H1 LINES) BELOW:
*         NameG     Ngto      Type      Gwidth    L         S         z1        z2        N         Dfull     Dinit
G1        channel1            channel2            1         2.00      244       0.1189    6         6         0.08      1.5
          0
G1        channel2            outfall   1         2.00      254       0.1102    6         6         0.08      1.5       0
*
*         JK        NameW     Ngto      Wid       Area      %Imp      S         ImpN      PervN     IDS       PDS       G
          Ksat      SmdmaxRmaxInfIflowP
H1        1         '8Deast'  'outfall' 108.258   0.24853   0         0.176     0.4       0.4       9.9       0.2       12
          0.1       0.185     0         0
H1        1         '9Deast'  'channel2'          206.552   0.47418   0         0.125     0.4       0.4       9.9       0.2
          12        0.1       0.185     0         0
H1        1         '9Dwest' 'channel2'           160.266   0.36792   0         0.167     0.4       0.4       9.9       0.2
          12        0.1       0.185     0         0
H1        1         '8Dwest' 'channel2'           49.211    0.11297   0         0.167     0.4       0.4       9.9       0.2
          12        0.1       0.185     0         0
H1        1         '12Cwest'           'channel2'          94.248    0.21636   0         0.118     0.4       0.4       9.9
          0.2       9         0.2       0.195     0         0
H1        1         '12Cmid''channel1'            299.450   0.68744   0         0.124     0.4       0.4       9.9       0.2
          9         0.2       0.195     0         0
H1        1         '12Ceast''channel1'           310.657   0.71317   0         0.116     0.4       0.4       9.9       0.2
          9         0.2       0.195     0         0
H1        1         '16Bnorth'          'channel1'          659.152   1.51320   0         0.088     0.4       0.4       9.9
          0.2       12        0.1       0.185     0         0
*
*  PRINT CONTROL
*         NPrnt     Interv
M1        1         5
*   NDet StartP(1) StartP(2)
M2   1    0       0
*         IPRNT(1) Prints INflows to channels/pipes
M3        'outfall'
* Repeat lines $RUNOFF through M3 for each design event.
* Substitute appropriate E3 lines for desired design hyetograph.
* Change A1 (title) lines as appropriate.
$ENDPROGRAM
```

Appendix F-3: Single-Event SWMM Input: LID, Favorable Conditions

Note: For brevity, the input file below only runs the 1-year storm event. To model all events in a single input file, repeat lines $RUNOFF through M3 for each design storm, and substitute the appropriate hyetograph (E3 lines) from Appendix F-9. Use appropriate A1 lines for clarity.

```
SW  4  0 20 0 21 0 22 0 23
MM  6     1  2  3  4 12 13
@ 20 'lid_fav_1.int'
@ 21 'lid_fav_2.int'
@ 22 'lid_fav_10.int'
@ 23 'lid_fav_100.int'
* for_fav
* for_unf
* lid_fav
* lid_unf
* conv_fav
* conv_unf
$ANUM
$NOQUOTE
$RUNOFF
A1 'Event Model- 1-year Storm-Soils 1/2 way between F.C. and W.P.'
*A1 'Predevelopment/Forest - Favorable Condition'
*A1 'Predevelopment/Forest - Unfavorable Condition'
A1 'Low Impact Development - Favorable Condition'
*A1 'Low Impact Development - Unfavorable Condition'
*A1 'Conventional Development - Favorable Condition'
*A1 'Conventional Development - Unfavorable Condition'
*   METRIC ISNOW NRGAG INFILM KWALTY IVAP NHR NMN NDAY MONTH IYRSTR IVCHAN
* For event simulation of SCS Type II design storms:
B1  0     0    1    1     0     -2   00  00  01  05     2003   0
*  Print Control
*  Input Graph Outpt GW NoHead Landupr
B2  1     1     1    0    1      0
*   Wet WetDry Dry   Lunit Long
* For event mode (3 days to allow pond routing):
B3  60  60    86400 3     3
*   PctZero Regen(NR)
B4  0.0001  0
*   ROPT
D1  0
*  HYETOGRAPHS FOR EVENT MODE SIMULATION OF SCS DESIGN STORMS
*  Rainfall intensity in in/hr, at 15-minute intervals
*  time units of hours, 8 E3 lines required per hyetograph @ 12 per line
*  KType KInc Kprint KTHis KTime KPrep NHisto THisto TZRain
E1 0     12   1      0     1     0     96     0.25   0.0
*
* 1-year 24-hr SCS Type II Storm Distribution, 0.25 hour resolution, P = 2.5"
E3      0.026   0.027   0.027   0.028   0.028   0.029   0.029   0.03    0.03    0.031   0.031   0.032
E3      0.033   0.034   0.034   0.035   0.036   0.037   0.038   0.039   0.04    0.041   0.042   0.043
E3      0.045   0.046   0.048   0.05    0.052   0.054   0.056   0.059   0.062   0.065   0.068   0.073
E3      0.077   0.083   0.09    0.098   0.108   0.12    0.137   0.161   0.196   0.259   0.405   2.756
E3      1.043   0.314   0.223   0.176   0.148   0.128   0.113   0.102   0.093   0.086   0.08    0.075
E3      0.07    0.067   0.063   0.06    0.057   0.055   0.053   0.051   0.049   0.047   0.046   0.044
E3      0.043   0.042   0.04    0.039   0.038   0.037   0.036   0.036   0.035   0.034   0.033   0.032
E3      0.032   0.031   0.031   0.03    0.029   0.029   0.028   0.028   0.027   0.027   0.027   0.026
*
```

Appendix F-3: Single-Event SWMM Input: LID, Favorable Conditions

```
*       MONTHLY EVAPORATION (in/month) -turned off during rainfall for negative IVAP-
F1      0.064   0.213   0.982   2.152   3.629   5.110   5.761   5.178   3.642   1.918   0.888   0.232
*
*INSERT CHANNEL/PIPE DATA (G1 LINES), & SUBCATCHMENT DATA (H1 LINES) BELOW:
*       NameG  Ngto     Type    Gwidth  L       S       z1      z2      N       Dfull   Dinit
G1      'uvwEinlt'      'uvwWinlt'      2       1.25    35      0.01    0       0       0.022   1.5
        0
G1      'uvwWinlt'      'alyEinlt'2     1.25    30      0.04167 0       0       0.022   1.5     0
G1      'cirEswal'      'alyEinlt'1     1.00    150     0.093   4       4       0.06    2.1     0
G1      'alyEinlt''grvswal'2    1.50    30      0.01667 0       0       0.022   1.5     0
G1      'thWswal'       'thWinlt' 1     2.00    45      0.026   4       4       0.06    2.02    0
G1      'thWinlt' 'thEswal'2    1.25    90      0.01667 0       0       0.022   1.5     0
G1      'thEswal''grvinlt'  1   2.00    75      0.107   3       3       0.06    2.05    0
G1      'lvwWinlt'      'grvinlt'  2    1.25    52      0.058   0       0       0.022   1.5     0
G1      'lvwEinlt'      'lvwWinlt'      2       1.25    55      0.055   0       0       0.022   1.5
        0
G1      'grvswal''grvinlt'  1   2.00    130     0.108   3       3       0.08    2.36    0
G1      'grvinlt'  'blvdinlt'2  1.50    50      0.033   0       0       0.022   1.5     0
G1      'blvdinlt' 'lowrchan'   2       1.50    57      0.049   0       0       0.022   1.5     0
G1      'lowrchan'      'outfall'  1    2.00    150     0.12    3       3       0.08    3       0
*
*       JK      NameW Ngto      Wid     Area    %Imp    S       ImpN    PervN   IDS     PDS     G
        Ksat    SmdmaxRmaxInfIflowP
H1      1       '70woods'       '70lawn' 29.547 0.08818 0       0.046   0.4     0.4     9.9     0.35
        12      0.2     0.235   0       3
H1      1       '70lawn' 'uvwEswal'     71.789  0.04944 0       0.170   0.24    0.24    9.9     0.2
        12      0.15    0.235   0       3
H1      1       '6970wood'      '6970swal'      29.328  0.09089 0       0.070   0.4     0.4     9.9
        0.35    12      0.2     0.235   0       3
H1      1       '6970roof'      '6970lawn'      188.816 0.08669 100     0.200   0.02    0.02    1.09
        9.9     99      99      0.99    0       3
H1      1       '6970driv'      '6970lawn'      58.954  0.02571 100     0.075   0.014   0.014   0.02
        9.9     99      99      0.99    0       3
H1      1       '6970lawn'      '6970swal'      171.263 0.21624 0       0.083   0.24    0.24    9.9
        0.2     12      0.15    0.235   0       3
H1      1       '6970swal'      'uvwEswal'      1.000   0.00207 0       0.038   0.06    0.06    0.1
        0.1     12      0.1     0.185   0       3
H1      1       '68drive' '68lawnup'    69.578  0.01597 100     0.083   0.014   0.014   0.02    9.9
        99      99      0.99    0       3
H1      1       '68lawnup'      'uvwEswal'      27.864  0.02559 0       0.067   0.24    0.24    9.9
        0.2     12      0.15    0.235   0       3
H1      1       '68wood''68swale'       20.497  0.08470 0       0.089   0.4     0.4     9.9     0.35
        12      0.2     0.235   0       3
H1      1       '68roof'  '68lawnlo'    86.875  0.03989 100     0.200   0.02    0.02    1.09    9.9
        99      99      0.99    0       3
H1      1       '68lawnlo'      '68swale'       79.949  0.08259 0       0.119   0.24    0.24    9.9
        0.2     9       0.25    0.245   0       3
H1      1       '68swale'       'uvwEswal'      1.000   0.00207 0       0.030   0.06    0.06    0.1
        0.1     12      0.1     0.185   0       3
H1      1       '67drive' '67lawnup'    19.606  0.01170 100     0.087   0.014   0.014   0.02    9.9
        99      99      0.99    0       3
H1      1       '67lawnup'      'uvwEswal'      29.124  0.02139 0       0.125   0.24    0.24    9.9
        0.2     9       0.25    0.245   0       3
H1      1       'uvwEpave'      'uvwEswal'      73.776  0.10162 100     0.080   0.014   0.014   0.02
        9.9     99      99      0.99    0       3
```

Appendix F-3: Single-Event SWMM Input: LID, Favorable Conditions

```
H1          1           'uvwEswal'              'uvwEinlt'              8.500       0.04878     0           0.075       0.06        0.06        0.02
            10.5882     6           0.5         0.24        0           0
*

H1          1           'uvwWswlC'              'uvwWswal'              169.402     0.03889     0           0.350       0.24        0.24        9.9
            0.2         12          0.15        0.235       0           3
H1          1           'uvwWpave'              'uvwWswal'              74.357      0.10242     100         0.080       0.014       0.014       0.02
            9.9         99          99          0.99        0           3
H1          1           'uvwWswal'              'uvwWinlt'              2.900       0.01664     0           0.092       0.06        0.06        0.02
            4.7172      6           0.5         0.24        0           0
*

H1          1           'cirWroof'              'cirWswal'              128.000     0.05877     100         0.200       0.02        0.02        1.09
            9.9         99          99          0.99        0           3
H1          1           'cirWlawn'              'cirWswal'              185.548     0.06389     0           0.060       0.24        0.24        9.9
            0.2         12          0.15        0.235       0           3
H1          1           'cirWwood'              'cirWswal'              20.061      0.04605     0           0.060       0.4         0.4         9.9
            0.35        12          0.2         0.235       0           3
H1          1           'cirWswal'              'alyEswal'              1.000       0.00344     0           0.082       0.06        0.06        0.1
            0.1         12          0.1         0.185       0           3
H1          1           '62roof'    '62lawn'    47.823      0.02196     100         0.200       0.02        0.02        1.09        9.9         99
            99          0.99        0           3
H1          1           '62lawn'    'alyWswal'              96.321      0.07739     0           0.100       0.24        0.24        9.9         0.2
            9           0.25        0.245       0           3
H1          1           'alyWpave'              'alyWswal'              43.596      0.04103     100         0.068       0.014       0.014       0.02
            9.9         99          99          0.99        0           3
H1          1           'alyWswal'              'alyEswal'              3.500       0.00803     0           0.059       0.06        0.06        0.02
            8.5714      6           0.5         0.24        0           3
H1          1           '66roof'    'cirEwood'              73.200      0.03361     100         0.200       0.02        0.02        1.09        9.9
            99          99          0.99        0           3
H1          1           'cirEside'              'cirEwood'              120.212     0.03036     100         0.089       0.014       0.014       0.02
            9.9         99          99          0.99        0           3
H1          1           '66lawn'    'cirEwood'              116.060     0.05329     0           0.050       0.24        0.24        9.9         0.2
            12          0.15        0.235       0           3
H1          1           'cirEwood'              'cirEswal'              79.253      0.25471     0           0.086       0.4         0.4         9.9
            0.35        12          0.2         0.235       0           0
H1          1           'cirEslwn'              'cirEswal'              132.568     0.03043     0           0.150       0.24        0.24        9.9
            0.2         12          0.15        0.235       0           0
H1          1           '661roof2'              'cirEswal'              51.200      0.02351     100         0.200       0.02        0.02        1.09
            9.9         99          99          0.99        0           0
*

H1          1           '6061roof'              'alyEswal'              95.413      0.04381     100         0.200       0.02        0.02        1.09
            9.9         99          99          0.99        0           3
H1          1           'alyEpave'              'alyEswal'              25.091      0.04608     100         0.077       0.014       0.014       0.02
            9.9         99          99          0.99        0           3
H1          1           '6061lawn'              'alyEswal'              165.366     0.13287     0           0.130       0.24        0.24        9.9
            0.2         9           0.25        0.245       0           3
H1          1           'alyEswal'              'alyEinlt'3.500         0.00723     0           0.075       0.06        0.06        0.02        8.5714
            6           0.5         0.24        0           0
*

H1          1           'thWlawn'               'thWswal'               48.191      0.04093     0           0.064       0.24        0.24        9.9
            0.2         9           0.25        0.245       0           0
```

Appendix F-3: Single-Event SWMM Input: LID, Favorable Conditions

```
H1          1           'thWroof'               'thWswal'               170.519     0.07829     100         0.200       0.02        0.02        1.09
            9.9         99          99          0.99        0           0
H1          1           'thWwood'               'thWswal'               65.362      0.09003     0           0.084       0.4         0.4         9.9
            0.35        9           0.3         0.245       0           0
H1          1           'thWlot'    'thWbior'                33.247      0.02900     100         0.048       0.014       0.014       0.02        9.9
            99          99          0.99        0           3
H1          1           'thWbior'               'thWswal'               20.000      0.00551     0           0.010       0.06        0.06        0.02
            6           6           0.5         0.24        0           0
*

*

H1          1           'thEwood'               'thElot'    34.212      0.03927     0           0.115       0.4         0.4         9.9         0.35
            9           0.3         0.245       0           3
H1          1           'thElot'    'thEbior'   43.225      0.05458     100         0.119       0.014       0.014       0.02        9.9         99
            99          0.99        0           3
H1          1           'thEbior'   'thEswal'27.000         0.00868     0           0.010       0.06        0.06        0.02        6           6
            0.5         0.24        0           0
H1          1           'thElawn'               'thEswal'160.005        0.07346     0           0.150       0.24        0.24        9.9         0.2
            9           0.25        0.245       0           0
H1          1           'thEroof'   'thEswal'215.998        0.09917     100         0.200       0.02        0.02        1.09        9.9         99
            99          0.99        0           0
*

H1          1           'lvwWlawn'              'lvwWswal'              121.491     0.02789     0           0.350       0.24        0.24        9.9
            0.2         12          0.15        0.235       0           3
H1          1           'lvwWside'              'lvwWswal'              22.385      0.01953     100         0.105       0.014       0.014       0.02
            9.9         99          99          0.99        0           3
H1          1           'lvwWpav'               'lvwWswal'              72.263      0.05806     100         0.108       0.014       0.014       0.02
            9.9         99          99          0.99        0           3
H1          1           'lvwWswal'              'lvwWinlt'              2.900       0.00832     0           0.100       0.06        0.06        0.02
            4.7172      6           0.5         0.24        0           0
*

H1          1           '67roof'    '67lawnlo'              86.729      0.03982     100         0.200       0.02        0.02        1.09        9.9
            99          99          0.99        0           3
H1          1           '67lawnlo'              'lvwEswal'              66.704      0.10719     0           0.138       0.24        0.24        9.9
            0.2         9           0.25        0.245       0           3
H1          1           'lvwecut''lvwEswal'                 115.516     0.08751     0           0.210       0.3         0.3         9.9         0.25
            12          0.15        0.235       0           3
H1          1           'lvwepav'               'lvwEswal'              30.261      0.05419     100         0.102       0.014       0.014       0.02
            9.9         99          99          0.99        0           3
H1          1           'lvwEswal'              'lvwEinlt'              5.900       0.02709     0           0.100       0.06        0.06        0.02
            7.8305      6           0.5         0.24        0           0
*

H1          1           'grvlawnB'              'grvwood'               106.585     0.05138     0           0.160       0.24        0.24        9.9
            0.2         9           0.25        0.245       0           3
H1          1           'grvwood'               'grvswal'110.655        0.12701     0           0.127       0.4         0.4         9.9         0.35
            9           0.3         0.245       0           0
*

H1          1           'grvlawnI'              'grvinlt'   124.585     0.06006     0           0.160       0.24        0.24        9.9         0.2
            9           0.25        0.245       0           0
```

Appendix F-3: Single-Event SWMM Input: LID, Favorable Conditions

```
H1        1         'grvlawnC'          'grvinlt' 27.649    0.01904   0         0.130     0.24      0.24      9.9       0.2
          12        0.15      0.235     0         0
*

H1        1         'sidegras'          'blvdNpav'          283.159   0.09751   0         0.091     0.24      0.24      9.9
          0.2       9         0.25      0.245     0         3
H1        1         'blvdNpav'          'blvdswal'          124.054   0.14239   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'blvdSpav'          'blvdswal'          104.192   0.11960   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'blvdswlB'          'blvdswal'          242.678   0.05571   0         0.340     0.24      0.24      9.9
          0.2       9         0.25      0.245     0         3
H1        1         'blvdswlC'          'blvdswal'          255.943   0.05876   0         0.340     0.24      0.24      9.9
          0.2       12        0.15      0.235     0         3
H1        1         'blvdswal'          'blvdinlt'8.250     0.04735   0         0.067     0.06      0.06      0.02      11.4545
          6         0.5       0.24      0         0
*

H1        1         'lowrpav'           'lowrfill' 81.037   0.02232   100       0.020     0.014     0.014     0.02      9.9
          99        99        0.99      0         3
H1        1         'lowrfill' 'lowrchan'           245.822   0.33860   0         0.290     0.3       0.3       9.9       0.25
          12        0.15      0.235     0         0
H1        1         'lowrwood'          'lowrchan'          56.892    0.11754   0         0.250     0.4       0.4       9.9
          0.35      12        0.2       0.235     0         0
*

*
*  PRINT CONTROL
*         NPrnt     Interv
M1        1         5
*   NDet StartP(1) StartP(2)
M2   1     0       0
*         IPRNT(1) Prints INflows to channels/pipes
M3        'outfall'
* Repeat lines $RUNOFF through M3 for each design event.
* Substitute appropriate E3 lines for desired design hyetograph.
* Change A1 (title) lines as appropriate.
$ENDPROGRAM
```

Appendix F-4: Single-Event SWMM Input: LID, Unfavorable Conditions

Note: For brevity, the input file below only runs the 1-year storm event. To model all events in a single input file, repeat lines $RUNOFF through M3 for each design storm, and substitute the appropriate hyetograph (E3 lines) from Appendix F-9. Use appropriate A1 lines for clarity.

```
SW  4  0 20 0 21 0 22 0 23
MM  6     1  2  3  4 12 13
@ 20 'lid_unf_1.int'
@ 21 'lid_unf_2.int'
@ 22 'lid_unf_10.int'
@ 23 'lid_unf_100.int'
* for_fav
* for_unf
* lid_fav
* lid_unf
* conv_fav
* conv_unf
$ANUM
$NOQUOTE
$RUNOFF
A1 'Event Model- 1-year Storm-Soils 1/2 way between F.C. and W.P.'
*A1 'Predevelopment/Forest - Favorable Condition'
*A1 'Predevelopment/Forest - Unfavorable Condition'
*A1 'Low Impact Development - Favorable Condition'
A1 'Low Impact Development - Unfavorable Condition'
*A1 'Conventional Development - Favorable Condition'
*A1 'Conventional Development - Unfavorable Condition'
*   METRIC ISNOW NRGAG INFILM KWALTY IVAP NHR NMN NDAY MONTH IYRSTR IVCHAN
* For event simulation of SCS Type II design storms:
B1  0      0     1     1      0      -2   00  00  01  05     2003   0
*  Print Control
*  Input Graph Outpt GW NoHead Landupr
B2  1     1     1    0    1      0
*   Wet WetDry Dry   Lunit Long
* For event mode (3 days to allow pond routing):
B3  60  60     86400 3     3
*   PctZero Regen(NR)
B4  0.0001  0
*   ROPT
D1  0
*  HYETOGRAPHS FOR EVENT MODE SIMULATION OF SCS DESIGN STORMS
*  Rainfall intensity in in/hr, at 15-minute intervals
*  time units of hours, 8 E3 lines required per hyetograph @ 12 per line
*  KType KInc Kprint KTHis KTime KPrep NHisto THisto TZRain
E1 0     12   1      0     1      0     96     0.25   0.0
*
* 1-year 24-hr SCS Type II Storm Distribution, 0.25 hour resolution, P = 2.5"
E3        0.026    0.027    0.027    0.028    0.028    0.029    0.029    0.03     0.03     0.031    0.031    0.032
E3        0.033    0.034    0.034    0.035    0.036    0.037    0.038    0.039    0.04     0.041    0.042    0.043
E3        0.045    0.046    0.048    0.05     0.052    0.054    0.056    0.059    0.062    0.065    0.068    0.073
E3        0.077    0.083    0.09     0.098    0.108    0.12     0.137    0.161    0.196    0.259    0.405    2.756
E3        1.043    0.314    0.223    0.176    0.148    0.128    0.113    0.102    0.093    0.086    0.08     0.075
E3        0.07     0.067    0.063    0.06     0.057    0.055    0.053    0.051    0.049    0.047    0.046    0.044
E3        0.043    0.042    0.04     0.039    0.038    0.037    0.036    0.036    0.035    0.034    0.033    0.032
E3        0.032    0.031    0.031    0.03     0.029    0.029    0.028    0.028    0.027    0.027    0.027    0.026
*
```

Appendix F-4: Single-Event SWMM Input: LID, Unfavorable Conditions

```
*       MONTHLY EVAPORATION (in/month) -turned off during rainfall for negative IVAP-
F1      0.064   0.213   0.982   2.152   3.629   5.110   5.761   5.178   3.642   1.918   0.888   0.232
*
*INSERT CHANNEL/PIPE DATA (G1 LINES), & SUBCATCHMENT DATA (H1 LINES) BELOW:
*       NameG  Ngto     Type    Gwidth  L       S       z1      z2      N       Dfull   Dinit
G1      'uvwEinlt'      'uvwWinlt'      2       1.25    35      0.01    0       0       0.022   1.5
        0
G1      'uvwWinlt'      'alyEinlt'2     1.25    30      0.04167 0       0       0.022   1.5     0
G1      'cirEswal'      'alyEinlt'1     1.00    150     0.093   4       4       0.06    2.1     0
G1      'alyEinlt''grvswal'2    1.50    30      0.01667 0       0       0.022   1.5     0
G1      'thWswal'       'thWinlt' 1     2.00    45      0.026   4       4       0.06    2.02    0
G1      'thWinlt' 'thEswal'2    1.25    90      0.01667 0       0       0.022   1.5     0
G1      'thEswal''grvinlt'  1   2.00    75      0.107   3       3       0.06    2.05    0
G1      'lvwWinlt'      'grvinlt'  2    1.25    52      0.058   0       0       0.022   1.5     0
G1      'lvwEinlt'      'lvwWinlt'      2       1.25    55      0.055   0       0       0.022   1.5
        0
G1      'grvswal''grvinlt'  1   2.00    130     0.108   3       3       0.08    2.36    0
G1      'grvinlt'  'blvdinlt'2  1.50    50      0.033   0       0       0.022   1.5     0
G1      'blvdinlt''lowrchan'    2       1.50    57      0.049   0       0       0.022   1.5     0
G1      'lowrchan'      'outfall'  1    2.00    150     0.12    3       3       0.08    3       0
*
*       JK      NameW Ngto      Wid     Area    %Imp    S       ImpN    PervN   IDS     PDS     G
        Ksat    SmdmaxRmaxInfIflowP
H1      1       '70woods'       '70lawn' 29.547 0.08818 0       0.046   0.4     0.4     9.9     0.2
        12      0.1     0.185   0       3
H1      1       '70lawn' 'uvwEswal'     71.789  0.04944 0       0.170   0.24    0.24    9.9     0.1
        12      0.08    0.125   0       3
H1      1       '6970wood'      '6970swal'      29.328  0.09089 0       0.070   0.4     0.4     9.9
        0.2     12      0.1     0.185   0       3
H1      1       '6970roof'      '6970lawn'      188.816 0.08669 100     0.200   0.02    0.02    0.2
        9.9     99      99      0.99    0       3
H1      1       '6970driv'      '6970lawn'      58.954  0.02571 100     0.075   0.014   0.014   0.02
        9.9     99      99      0.99    0       3
H1      1       '6970lawn'      '6970swal'      171.263 0.21624 0       0.083   0.24    0.24    9.9
        0.1     12      0.08    0.125   0       3
H1      1       '6970swal'      'uvwEswal'      1.000   0.00207 0       0.038   0.06    0.06    0.1
        0.1     12      0.05    0.185   0       3
H1      1       '68drive' '68lawnup'    69.578  0.01597 100     0.083   0.014   0.014   0.02    9.9
        99      99      0.99    0       3
H1      1       '68lawnup'      'uvwEswal'      27.864  0.02559 0       0.067   0.24    0.24    9.9
        0.1     12      0.08    0.125   0       3
H1      1       '68wood''68swale'       20.497  0.08470 0       0.089   0.4     0.4     9.9     0.2
        12      0.1     0.185   0       3
H1      1       '68roof'  '68lawnlo'    86.875  0.03989 100     0.200   0.02    0.02    0.2     9.9
        99      99      0.99    0       3
H1      1       '68lawnlo'      '68swale'       79.949  0.08259 0       0.119   0.24    0.24    9.9
        0.1     9       0.15    0.135   0       3
H1      1       '68swale'       'uvwEswal'      1.000   0.00207 0       0.030   0.06    0.06    0.1
        0.1     12      0.05    0.185   0       3
H1      1       '67drive' '67lawnup'    19.606  0.01170 100     0.087   0.014   0.014   0.02    9.9
        99      99      0.99    0       3
H1      1       '67lawnup'      'uvwEswal'      29.124  0.02139 0       0.125   0.24    0.24    9.9
        0.1     9       0.15    0.135   0       3
H1      1       'uvwEpave'      'uvwEswal'      73.776  0.10162 100     0.080   0.014   0.014   0.02
        9.9     99      99      0.99    0       3
```

Appendix F-4: Single-Event SWMM Input: LID, Unfavorable Conditions

```
H1        1         'uvwEswal'          'uvwEinlt'          8.500     0.04878   0         0.075     0.06      0.06      0.02
          10.5882   6         0.05      0.24      0         0
*

H1        1         'uvwWswlC'          'uvwWswal'          169.402   0.03889   0         0.350     0.24      0.24      9.9
          0.1       12        0.08      0.125     0         3
H1        1         'uvwWpave'          'uvwWswal'          74.357    0.10242   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'uvwWswal'          'uvwWinlt'          2.900     0.01664   0         0.092     0.06      0.06      0.02
          4.7172    6         0.05      0.24      0         0
*

H1        1         'cirWroof'          'cirWswal'          128.000   0.05877   100       0.200     0.02      0.02      0.2
          9.9       99        99        0.99      0         3
H1        1         'cirWlawn'          'cirWswal'          185.548   0.06389   0         0.060     0.24      0.24      9.9
          0.1       12        0.08      0.125     0         3
H1        1         'cirWwood'          'cirWswal'          20.061    0.04605   0         0.060     0.4       0.4       9.9
          0.2       12        0.1       0.185     0         3
H1        1         'cirWswal'          'alyEswal'          1.000     0.00344   0         0.082     0.06      0.06      0.1
          0.1       12        0.05      0.185     0         3
H1        1         '62roof'  '62lawn'  47.823    0.02196   100       0.200     0.02      0.02      0.2       9.9       99
          99        0.99      0         3
H1        1         '62lawn'  'alyWswal'          96.321    0.07739   0         0.100     0.24      0.24      9.9       0.1
          9         0.15      0.135     0         3
H1        1         'alyWpave'          'alyWswal'          43.596    0.04103   100       0.068     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'alyWswal'          'alyEswal'          3.500     0.00803   0         0.059     0.06      0.06      0.02
          8.5714    6         0.05      0.24      0         3
H1        1         '66roof'  'cirEwood'          73.200    0.03361   100       0.200     0.02      0.02      0.2       9.9
          99        99        0.99      0         3
H1        1         'cirEside'          'cirEwood'          120.212   0.03036   100       0.089     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         '66lawn'  'cirEwood'          116.060   0.05329   0         0.050     0.24      0.24      9.9       0.1
          12        0.08      0.125     0         3
H1        1         'cirEwood'          'cirEswal'          79.253    0.25471   0         0.086     0.4       0.4       9.9
          0.2       12        0.1       0.185     0         0
H1        1         'cirEslwn'          'cirEswal'          132.568   0.03043   0         0.150     0.24      0.24      9.9
          0.1       12        0.08      0.125     0         0
H1        1         '661roof2'          'cirEswal'          51.200    0.02351   100       0.200     0.02      0.02      0.2
          9.9       99        99        0.99      0         0
*

H1        1         '6061roof'          'alyEswal'          95.413    0.04381   100       0.200     0.02      0.02      0.2
          9.9       99        99        0.99      0         3
H1        1         'alyEpave'          'alyEswal'          25.091    0.04608   100       0.077     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         '6061lawn'          'alyEswal'          165.366   0.13287   0         0.130     0.24      0.24      9.9
          0.1       9         0.15      0.135     0         3
H1        1         'alyEswal'          'alyEinlt'3.500     0.00723   0         0.075     0.06      0.06      0.02      8.5714
          6         0.05      0.24      0         0
*

H1        1         'thWlawn'           'thWswal'           48.191    0.04093   0         0.064     0.24      0.24      9.9
          0.1       9         0.15      0.135     0         0
```

Appendix F-4: Single-Event SWMM Input: LID, Unfavorable Conditions

```
H1        1         'thWroof'           'thWswal'           170.519   0.07829   100       0.200     0.02      0.02      0.2
          9.9       99        99        0.99      0         0
H1        1         'thWwood'           'thWswal'           65.362    0.09003   0         0.084     0.4       0.4       9.9
          0.2       9         0.2       0.195     0         0
H1        1         'thWlot'  'thWbior'           33.247    0.02900   100       0.048     0.014     0.014     0.02      9.9
          99        99        0.99      0         3
H1        1         'thWbior'           'thWswal'           20.000    0.00551   0         0.010     0.06      0.06      0.02
          6         6         0.05      0.24      0         0
*

*

H1        1         'thEwood'           'thElot'  34.212    0.03927   0         0.115     0.4       0.4       9.9       0.2
          9         0.2       0.195     0         3
H1        1         'thElot'  'thEbior' 43.225    0.05458   100       0.119     0.014     0.014     0.02      9.9       99
          99        0.99      0         3
H1        1         'thEbior' 'thEswal'27.000     0.00868   0         0.010     0.06      0.06      0.02      6         6
          0.05      0.24      0         0
H1        1         'thElawn'           'thEswal'160.005    0.07346   0         0.150     0.24      0.24      9.9       0.1
          9         0.15      0.135     0         0
H1        1         'thEroof' 'thEswal'215.998    0.09917   100       0.200     0.02      0.02      0.2       9.9       99
          99        0.99      0         0
*

H1        1         'lvwWlawn'          'lvwWswal'          121.491   0.02789   0         0.350     0.24      0.24      9.9
          0.1       12        0.08      0.125     0         3
H1        1         'lvwWside'          'lvwWswal'          22.385    0.01953   100       0.105     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'lvwWpav'           'lvwWswal'          72.263    0.05806   100       0.108     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'lvwWswal'          'lvwWinlt'          2.900     0.00832   0         0.100     0.06      0.06      0.02
          4.7172    6         0.05      0.24      0         0
*

H1        1         '67roof'  '67lawnlo'          86.729    0.03982   100       0.200     0.02      0.02      0.2       9.9
          99        99        0.99      0         3
H1        1         '67lawnlo'          'lvwEswal'          66.704    0.10719   0         0.138     0.24      0.24      9.9
          0.1       9         0.15      0.135     0         3
H1        1         'lvwecut''lvwEswal'           115.516   0.08751   0         0.210     0.3       0.3       9.9       0.15
          12        0.08      0.185     0         3
H1        1         'lvwepav'           'lvwEswal'          30.261    0.05419   100       0.102     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'lvwEswal'          'lvwEinlt'          5.900     0.02709   0         0.100     0.06      0.06      0.02
          7.8305    6         0.05      0.24      0         0
*

H1        1         'grvlawnB'          'grvwood'           106.585   0.05138   0         0.160     0.24      0.24      9.9
          0.1       9         0.15      0.135     0         3
H1        1         'grvwood'           'grvswal'110.655    0.12701   0         0.127     0.4       0.4       9.9       0.2
          9         0.2       0.195     0         0
*

H1        1         'grvlawnI'          'grvinlt' 124.585   0.06006   0         0.160     0.24      0.24      9.9       0.1
          9         0.15      0.135     0         0
```

Appendix F-4: Single-Event SWMM Input: LID, Unfavorable Conditions

```
H1        1         'grvlawnC'          'grvinlt' 27.649    0.01904   0         0.130     0.24      0.24      9.9       0.1
          12        0.08      0.125     0         0
*

H1        1         'sidegras'          'blvdNpav'          283.159   0.09751   0         0.091     0.24      0.24      9.9
          0.1       9         0.15      0.135     0         3
H1        1         'blvdNpav'          'blvdswal'          124.054   0.14239   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'blvdSpav'          'blvdswal'          104.192   0.11960   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'blvdswlB'          'blvdswal'          242.678   0.05571   0         0.340     0.24      0.24      9.9
          0.1       9         0.15      0.135     0         3
H1        1         'blvdswlC'          'blvdswal'          255.943   0.05876   0         0.340     0.24      0.24      9.9
          0.1       12        0.08      0.125     0         3
H1        1         'blvdswal'          'blvdinlt'8.250     0.04735   0         0.067     0.06      0.06      0.02      11.4545
          6         0.05      0.24      0         0
*

H1        1         'lowrpav'           'lowrfill'81.037    0.02232   100       0.020     0.014     0.014     0.02      9.9
          99        99        0.99      0         3
H1        1         'lowrfill' 'lowrchan'         245.822   0.33860   0         0.290     0.3       0.3       9.9       0.15
          12        0.08      0.185     0         0
H1        1         'lowrwood'          'lowrchan'          56.892    0.11754   0         0.250     0.4       0.4       9.9
          0.2       12        0.1       0.185     0         0
*

*
*  PRINT CONTROL
*         NPrnt     Interv
M1        1         5
*   NDet StartP(1) StartP(2)
M2   1    0      0
*         IPRNT(1) Prints INflows to channels/pipes
M3        'outfall'
* Repeat lines $RUNOFF through M3 for each design event.
* Substitute appropriate E3 lines for desired design hyetograph.
* Change A1 (title) lines as appropriate.
$ENDPROGRAM
```

Appendix F-5: Single-Event SWMM Input: Conventional Development, Favorable Conditions

Note: For brevity, the input file below only runs the 1-year storm event. To model all events in a single input file, repeat lines $RUNOFF through M3 for each design storm, and substitute the appropriate hyetograph (E3 lines) from Appendix F-9. Use appropriate A1 lines for clarity.

```
SW  4  0 20 0 21 0 22 0 23
MM  6     1  2  3  4 12 13
@ 20 'conv_fav_1.int'
@ 21 'conv_fav_2.int'
@ 22 'conv_fav_10.int'
@ 23 'conv_fav_100.int'
* for_fav
* for_unf
* lid_fav
* lid_unf
* conv_fav
* conv_unf
$ANUM
$NOQUOTE
$RUNOFF
A1 'Event Model- 1-year Storm-Soils 1/2 way between F.C. and W.P.'
*A1 'Predevelopment/Forest - Favorable Condition'
*A1 'Predevelopment/Forest - Unfavorable Condition'
*A1 'Low Impact Development - Favorable Condition'
*A1 'Low Impact Development - Unfavorable Condition'
A1 'Conventional Development - Favorable Condition'
*A1 'Conventional Development - Unfavorable Condition'
*   METRIC ISNOW NRGAG INFILM KWALTY IVAP NHR NMN NDAY MONTH IYRSTR IVCHAN
* For event simulation of SCS Type II design storms:
B1  0      0     1     1      0      -2   00  00  01  05     2003   0
*  Print Control
*  Input Graph Outpt GW NoHead Landupr
B2  1     1     1    0    1      0
*   Wet WetDry Dry   Lunit Long
* For event mode (3 days to allow pond routing):
B3  60  60     86400 3     3
*   PctZero Regen(NR)
B4  0.0001  0
*   ROPT
D1  0
*  HYETOGRAPHS FOR EVENT MODE SIMULATION OF SCS DESIGN STORMS
*  Rainfall intensity in in/hr, at 15-minute intervals
*  time units of hours, 8 E3 lines required per hyetograph @ 12 per line
*  KType KInc Kprint KTHis KTime KPrep NHisto THisto TZRain
E1 0     12   1      0     1      0     96     0.25   0.0
*
* 1-year 24-hr SCS Type II Storm Distribution, 0.25 hour resolution, P = 2.5"
E3      0.026   0.027   0.027   0.028   0.028   0.029   0.029   0.03    0.03    0.031   0.031   0.032
E3      0.033   0.034   0.034   0.035   0.036   0.037   0.038   0.039   0.04    0.041   0.042   0.043
E3      0.045   0.046   0.048   0.05    0.052   0.054   0.056   0.059   0.062   0.065   0.068   0.073
E3      0.077   0.083   0.09    0.098   0.108   0.12    0.137   0.161   0.196   0.259   0.405   2.756
E3      1.043   0.314   0.223   0.176   0.148   0.128   0.113   0.102   0.093   0.086   0.08    0.075
E3      0.07    0.067   0.063   0.06    0.057   0.055   0.053   0.051   0.049   0.047   0.046   0.044
E3      0.043   0.042   0.04    0.039   0.038   0.037   0.036   0.036   0.035   0.034   0.033   0.032
E3      0.032   0.031   0.031   0.03    0.029   0.029   0.028   0.028   0.027   0.027   0.027   0.026
```

Appendix F-5: Single-Event SWMM Input: Conventional Development, Favorable Conditions

```
*
*         MONTHLY EVAPORATION (in/month) -turned off during rainfall for negative IVAP-
F1        0.064     0.213     0.982     2.152     3.629     5.110     5.761     5.178     3.642     1.918     0.888     0.232
*
*INSERT CHANNEL/PIPE DATA (G1 LINES), & SUBCATCHMENT DATA (H1 LINES) BELOW:
*         NameG     Ngto      Type      Gwidth    L         S         z1        z2        N         Dfull     Dinit
G1        'uvwNgutr'          'uvwNinlt'          1         0.00      170       0.075     12        0.042     0.015     2
          0
G1        'uvwNinlt'          'cirEinlt' 2        1.25      45        0.005     0         0         0.012     1.25      0
G1        'uvwEgutr'          'uvwEinlt'          1         0.00      80        0.075     12        0.042     0.015     2
          0
G1        'uvwEinlt'          'uvwWinlt'          2         1.25      35        0.01      0         0         0.012     1.25
          0
G1        'uvwWgutr'          'uvwWinlt'          1         0.00      250       0.092     12        0.042     0.015     2
          0
G1        'uvwWinlt'          'alyEinlt'2         1.25      30        0.04167   0         0         0.012     1.25      0
G1        'cirWswal'          'cirWinlt'          1         1.00      130       0.069     4         4         0.06      2
          0
G1        'cirWinlt'          'cirEinlt' 2        1.25      75        0.005     0         0         0.012     1.25      0
G1        'alyWgutr'          'alyWinlt'          1         0.00      120       0.059     12        12        0.015     2
          0
G1        'alyWinlt'          'alyEinlt'2         1.25      70        0.02      0         0         0.012     1.25      0
G1        'cirEswal'          'cirEinlt' 1        1.00      80        0.038     4         4         0.06      2.1       0
G1        'cirEinlt' 'uvwWinlt'         2         1.25      85        0.005     0         0         0.012     1.25      0
G1        'alyEgutr'          'alyEinlt'1         0.00      70        0.075     12        12        0.015     2         0
G1        'alyEinlt''lvwWinlt'          2         1.50      120       0.05      0         0         0.012     1.5       0
G1        'thWinlt' 'thEinlt' 2         1.25      90        0.01667   0         0         0.012     1.25      0
G1        'thEinlt'  'alyWinlt'         2         1.25      50        0.007     0         0         0.012     1.25      0
G1        'lvwWgutr'          'lvwWinlt'          1         0.00      125       0.1       12        0.042     0.015     2
          0
G1        'lvwWinlt'          'bvdNinlt'          2         1.25      52        0.058     0         0         0.012     1.25
          0
G1        'lvwEgutr'          'lvwEinlt'          1         0.00      200       0.1       12        0.042     0.015     2
          0
G1        'lvwEinlt'          'lvwWinlt'          2         1.25      55        0.055     0         0         0.012     1.25
          0
G1        'grvswal''grvinlt'  1         2.00      130       0.108     3         3         0.08      2.36      0
G1        'grvinlt'  'bvdNinlt'         2         1.50      50        0.033     0         0         0.012     1.5       0
G1        'bvdNgutr'          'bvdNinlt'          1         0.00      250       0.067     12        0.042     0.015     2
          0
G1        'bvdSgutr'          'bvdSinlt'          1         0.00      200       0.1       12        0.042     0.015     2
          0
G1        'bvdNinlt'          'bvdSinlt'          2         2.00      50        0.05      0         0         0.012     2
          0
G1        'bvdSinlt'          'lowrchan'          2         2.00      57        0.05      0         0         0.012     2
          0
G1        'lowrchan'          'outfall' 1         2.00      150       0.12      3         3         0.08      3         0
*
*         JK        NameW Ngto    Wid       Area      %Imp      S         ImpN      PervN     IDS       PDS       G
          Ksat      SmdmaxRmaxInfIflowP
H1        1         '70woods'           '70lawn'  29.547    0.08818   0         0.046     0.4       0.4       9.9       0.35
          12        0.2       0.235     0         3
H1        1         '70lawn'  'uvwEgutr'          78.872    0.05432   0         0.170     0.24      0.24      9.9       0.2
          12        0.15      0.235     0         0
```

Appendix F-5: Single-Event SWMM Input: Conventional Development, Favorable Conditions

```
H1      1       '6970wood'      '6970lawn'      29.328  0.09089 0       0.070   0.4     0.4     9.9
        0.35    12      0.2     0.235   0       3
H1      1       '6970roof'      '6970lawn'      188.816 0.08669 100     0.200   0.02    0.02    0.02
        9.9     99      99      0.99    0       3
H1      1       '6970driv'      'uvwNgutr'      58.954  0.02571 100     0.075   0.014   0.014   0.02
        9.9     99      99      0.99    0       0
H1      1       '6970lawn'      'uvwNgutr'      199.945 0.25246 0       0.083   0.24    0.24    9.9
        0.2     12      0.15    0.235   0       0
*

H1      1       '68drive' 'uvwNgutr'    69.578  0.01597 100     0.083   0.014   0.014   0.02    9.9
        99      99      0.99    0       0
*

*

H1      1       '68lawnup'      'uvwEgutr'      38.489  0.03534 0       0.067   0.24    0.24    9.9
        0.2     12      0.15    0.235   0       0
H1      1       '68wood''68lawnlo'      20.497  0.08470 0       0.089   0.4     0.4     9.9     0.35
        12      0.2     0.235   0       3
H1      1       '68roof'  '68lawnlo'    86.875  0.03989 100     0.200   0.02    0.02    0.02    9.9
        99      99      0.99    0       3
H1      1       '68lawnlo'      'uvwEgutr'      81.949  0.08466 0       0.119   0.24    0.24    9.9
        0.2     9       0.25    0.245   0       0
*

H1      1       '67drive' 'uvwEgutr'    19.606  0.01170 100     0.087   0.014   0.014   0.02    9.9
        99      99      0.99    0       0
H1      1       '67lawnup'      'uvwEgutr'      29.124  0.02139 0       0.125   0.24    0.24    9.9
        0.2     9       0.25    0.245   0       0
H1      1       'uvwEpave'      'uvwEgutr'      73.776  0.10162 100     0.080   0.014   0.014   0.02
        9.9     99      99      0.99    0       0
*

*

*

*

H1      1       'uvwWgras'      'uvwWgutr'      241.902 0.05553 0       0.350   0.24    0.24    9.9
        0.2     12      0.15    0.235   0       0
H1      1       'uvwWpave'      'uvwWgutr'      74.357  0.10242 100     0.080   0.014   0.014   0.02
        9.9     99      99      0.99    0       0
*

*

H1      1       'cirWroof'      'cirWswal'      128.000 0.05877 100     0.200   0.02    0.02    0.02
        9.9     99      99      0.99    0       0
H1      1       'cirWlawn'      'cirWswal'      195.548 0.06734 0       0.060   0.24    0.24    9.9
        0.2     12      0.15    0.235   0       0
H1      1       'cirWwood'      'cirWswal'      20.061  0.04605 0       0.060   0.4     0.4     9.9
        0.35    12      0.2     0.235   0       0
```

Appendix F-5: Single-Event SWMM Input: Conventional Development, Favorable Conditions

```
*

*

H1        1         '62roof'  '62lawn'  47.823    0.02196   100       0.200     0.02      0.02      0.02      9.9       99
          99        0.99      0         3
H1        1         '62lawn'  'alyWgutr'          106.321   0.08543   0         0.100     0.24      0.24      9.9       0.2
          9         0.25      0.245     0         0
H1        1         'alyWpave'          'alyWgutr'          43.596    0.04103   100       0.068     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
*

*

H1        1         '66roof'  'cirEwood'          73.200    0.03361   100       0.200     0.02      0.02      0.02      9.9
          99        99        0.99      0         3
H1        1         'uvwWside'          'uvwWgras'          120.212   0.03036   100       0.089     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         '66lawn'  'cirEwood'          116.060   0.05329   0         0.050     0.24      0.24      9.9       0.2
          12        0.15      0.235     0         3
H1        1         'cirEwood'          'cirEswal'          79.253    0.25471   0         0.086     0.4       0.4       9.9
          0.35      12        0.2       0.235     0         0
H1        1         'cirEslwn'          'cirEswal'          132.568   0.03043   0         0.150     0.24      0.24      9.9
          0.2       12        0.15      0.235     0         0
H1        1         '661roof2'          'cirEswal'          51.200    0.02351   100       0.200     0.02      0.02      0.02
          9.9       99        99        0.99      0         0
*

*

H1        1         '6061roof'          'alyEgutr'          95.413    0.04381   100       0.200     0.02      0.02      0.02
          9.9       99        99        0.99      0         0
H1        1         'alyEpave'          'alyEgutr'          25.091    0.04608   100       0.077     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
H1        1         '6061lawn'          'alyEgutr'          174.366   0.14010   0         0.130     0.24      0.24      9.9
          0.2       9         0.25      0.245     0         0
*

*

H1        1         'thWlawn'           'thWinlt' 48.191    0.04093   0         0.064     0.24      0.24      9.9       0.2
          9         0.25      0.245     0         0
H1        1         'thWroof'           'thWinlt' 170.519   0.07829   100       0.200     0.02      0.02      0.02      9.9
          99        99        0.99      0         0
H1        1         'thWwood'           'thWlot'  69.362    0.09554   0         0.084     0.4       0.4       9.9       0.35
          9         0.3       0.245     0         3
H1        1         'thWlot'  'thWinlt' 33.247    0.02900   100       0.048     0.014     0.014     0.02      9.9       99
          99        0.99      0         0
*

*

*
```

Appendix F-5: Single-Event SWMM Input: Conventional Development, Favorable Conditions

```
H1        1         'thEwood'           'thElot'  34.212    0.03927   0         0.115     0.4       0.4       9.9       0.35
          9         0.3       0.245     0         3
H1        1         'thElot'  'thEinlt' 43.225    0.05458   100       0.119     0.014     0.014     0.02      9.9       99
          99        0.99      0         0
*

H1        1         'thElawn'           'thEinlt' 160.005   0.07346   0         0.150     0.24      0.24      9.9       0.2
          9         0.25      0.245     0         0
H1        1         'thEroof' 'thEinlt' 215.998   0.09917   100       0.200     0.02      0.02      0.02      9.9       99
          99        0.99      0         0
*

*

H1        1         'lvwWlawn'          'lvwWgutr'          157.741   0.03621   0         0.350     0.24      0.24      9.9
          0.2       12        0.15      0.235     0         0
H1        1         'lvwWside'          'lvwWlawn'          22.385    0.01953   100       0.105     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         'lvwWpav'           'lvwWgutr'          72.263    0.05806   100       0.108     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
*

*

H1        1         '67roof'  '67lawnlo'          86.729    0.03982   100       0.200     0.02      0.02      0.02      9.9
          99        99        0.99      0         3
H1        1         '67lawnlo'          'lvwEgutr'          75.132    0.12074   0         0.138     0.24      0.24      9.9
          0.2       9         0.25      0.245     0         0
H1        1         'lvwecut''lvwEgutr'           133.395   0.10106   0         0.210     0.3       0.3       9.9       0.25
          12        0.15      0.235     0         0
H1        1         'lvwepav'           'lvwEgutr'          30.261    0.05419   100       0.102     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
*

*

H1        1         'grvlawnB'          'grvwood'           106.585   0.05138   0         0.160     0.24      0.24      9.9
          0.2       9         0.25      0.245     0         3
H1        1         'grvwood'           'grvswal'110.655    0.12701   0         0.127     0.4       0.4       9.9       0.35
          9         0.3       0.245     0         0
*

H1        1         'grvlawnI'          'grvinlt' 124.585   0.06006   0         0.160     0.24      0.24      9.9       0.2
          9         0.25      0.245     0         0
H1        1         'grvlawnC'          'grvinlt' 27.649    0.01904   0         0.130     0.24      0.24      9.9       0.2
          12        0.15      0.235     0         0
*

H1        1         'sidegras'          'bvdNgutr'          283.159   0.09751   0         0.091     0.24      0.24      9.9
          0.2       9         0.25      0.245     0         0
H1        1         'blvdNpav'          'bvdNgutr'          124.054   0.14239   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
H1        1         'blvdSpav'          'bvdSgutr'          104.192   0.11960   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
```

Appendix F-5: Single-Event SWMM Input: Conventional Development, Favorable Conditions

```
H1        1         'bvdNmedn'          'blvdNpav'          352.436   0.08091   0         0.100     0.4       0.4       9.9
          0.35      12        0.2       0.235     0         3
H1        1         'bvdSmedn'          'blvdSpav'          352.436   0.08091   0         0.100     0.4       0.4       9.9
          0.35      12        0.2       0.235     0         3
*

*

*

*

H1        1         'lowrpav'           'lowrfill' 81.037   0.02232   100       0.020     0.014     0.014     0.02      9.9
          99        99        0.99      0         3
H1        1         'lowrfill' 'lowrchan'         245.822   0.33860   0         0.290     0.3       0.3       9.9       0.25
          12        0.15      0.235     0         0
H1        1         'lowrwood'          'lowrchan'          56.892    0.11754   0         0.250     0.4       0.4       9.9
          0.35      12        0.2       0.235     0         0
*

*
*  PRINT CONTROL
*         NPrnt     Interv
M1        1         5
*   NDet StartP(1) StartP(2)
M2   1     0       0
*         IPRNT(1) Prints INflows to channels/pipes
M3        'outfall'
* Repeat lines $RUNOFF through M3 for each design event.
* Substitute appropriate E3 lines for desired design hyetograph.
* Change A1 (title) lines as appropriate.
$ENDPROGRAM
```

Appendix F-6: Single-Event SWMM Input: Conventional Development, Unfavorable Conditions

Note: For brevity, the input file below only runs the 1-year storm event. To model all events in a single input file, repeat lines $RUNOFF through M3 for each design storm, and substitute the appropriate hyetograph (E3 lines) from Appendix F-9. Use appropriate A1 lines for clarity.

```
SW  4  0 20 0 21 0 22 0 23
MM  6     1  2  3  4 12 13
@ 20 'conv_unf_1.int'
@ 21 'conv_unf_2.int'
@ 22 'conv_unf_10.int'
@ 23 'conv_unf_100.int'
* for_fav
* for_unf
* lid_fav
* lid_unf
* conv_fav
* conv_unf
$ANUM
$NOQUOTE
$RUNOFF
A1 'Event Model- 1-year Storm-Soils 1/2 way between F.C. and W.P.'
*A1 'Predevelopment/Forest - Favorable Condition'
*A1 'Predevelopment/Forest - Unfavorable Condition'
*A1 'Low Impact Development - Favorable Condition'
*A1 'Low Impact Development - Unfavorable Condition'
*A1 'Conventional Development - Favorable Condition'
A1 'Conventional Development - Unfavorable Condition'
*   METRIC ISNOW NRGAG INFILM KWALTY IVAP NHR NMN NDAY MONTH IYRSTR IVCHAN
* For event simulation of SCS Type II design storms:
B1  0      0     1     1      0      -2   00  00  01  05     2003   0
*  Print Control
*  Input Graph Outpt GW NoHead Landupr
B2  1     1     1    0    1      0
*   Wet WetDry Dry   Lunit Long
* For event mode (3 days to allow pond routing):
B3  60  60     86400 3     3
*   PctZero Regen(NR)
B4  0.0001  0
*   ROPT
D1  0
*  HYETOGRAPHS FOR EVENT MODE SIMULATION OF SCS DESIGN STORMS
*  Rainfall intensity in in/hr, at 15-minute intervals
*  time units of hours, 8 E3 lines required per hyetograph @ 12 per line
*  KType KInc Kprint KTHis KTime KPrep NHisto THisto TZRain
E1 0     12   1      0     1     0     96     0.25   0.0
*
* 1-year 24-hr SCS Type II Storm Distribution, 0.25 hour resolution, P = 2.5"
E3        0.026    0.027    0.027    0.028    0.028    0.029    0.029    0.03     0.03     0.031    0.031    0.032
E3        0.033    0.034    0.034    0.035    0.036    0.037    0.038    0.039    0.04     0.041    0.042    0.043
E3        0.045    0.046    0.048    0.05     0.052    0.054    0.056    0.059    0.062    0.065    0.068    0.073
E3        0.077    0.083    0.09     0.098    0.108    0.12     0.137    0.161    0.196    0.259    0.405    2.756
E3        1.043    0.314    0.223    0.176    0.148    0.128    0.113    0.102    0.093    0.086    0.08     0.075
E3        0.07     0.067    0.063    0.06     0.057    0.055    0.053    0.051    0.049    0.047    0.046    0.044
E3        0.043    0.042    0.04     0.039    0.038    0.037    0.036    0.036    0.035    0.034    0.033    0.032
E3        0.032    0.031    0.031    0.03     0.029    0.029    0.028    0.028    0.027    0.027    0.027    0.026
```

Appendix F-6: Single-Event SWMM Input: Conventional Development, Unfavorable Conditions

```
*
*           MONTHLY EVAPORATION (in/month) -turned off during rainfall for negative IVAP-
F1          0.064       0.213       0.982       2.152       3.629       5.110       5.761       5.178       3.642       1.918       0.888       0.232
*
*INSERT CHANNEL/PIPE DATA (G1 LINES), & SUBCATCHMENT DATA (H1 LINES) BELOW:
*
*           NameG  Ngto             Type        Gwidth      L           S           z1          z2          N           Dfull       Dinit
G1          'uvwNgutr'              'uvwNinlt'              1           0.00        170         0.075       12          0.042       0.015       2
            0
G1          'uvwNinlt'              'cirEinlt'  2           1.25        45          0.005       0           0           0.012       1.25        0
G1          'uvwEgutr'              'uvwEinlt'              1           0.00        80          0.075       12          0.042       0.015       2
            0
G1          'uvwEinlt'              'uvwWinlt'              2           1.25        35          0.01        0           0           0.012       1.25
            0
G1          'uvwWgutr'              'uvwWinlt'              1           0.00        250         0.092       12          0.042       0.015       2
            0
G1          'uvwWinlt'              'alyEinlt'  2           1.25        30          0.04167     0           0           0.012       1.25        0
G1          'cirWswal'              'cirWinlt'              1           1.00        130         0.069       4           4           0.06        2
            0
G1          'cirWinlt'              'cirEinlt'  2           1.25        75          0.005       0           0           0.012       1.25        0
G1          'alyWgutr'              'alyWinlt'              1           0.00        120         0.059       12          12          0.015       2
            0
G1          'alyWinlt'              'alyEinlt'  2           1.25        70          0.02        0           0           0.012       1.25        0
G1          'cirEswal'              'cirEinlt'  1           1.00        80          0.038       4           4           0.06        2.1         0
G1          'cirEinlt' 'uvwWinlt'               2           1.25        85          0.005       0           0           0.012       1.25        0
G1          'alyEgutr'              'alyEinlt'  1           0.00        70          0.075       12          12          0.015       2           0
G1          'alyEinlt''lvwWinlt'                2           1.50        120         0.05        0           0           0.012       1.5         0
G1          'thWinlt' 'thEinlt'     2           1.25        90          0.01667     0           0           0.012       1.25        0
G1          'thEinlt'  'alyWinlt'               2           1.25        50          0.007       0           0           0.012       1.25        0
G1          'lvwWgutr'              'lvwWinlt'              1           0.00        125         0.1         12          0.042       0.015       2
            0
G1          'lvwWinlt'              'bvdNinlt'              2           1.25        52          0.058       0           0           0.012       1.25
            0
G1          'lvwEgutr'              'lvwEinlt'              1           0.00        200         0.1         12          0.042       0.015       2
            0
G1          'lvwEinlt'              'lvwWinlt'              2           1.25        55          0.055       0           0           0.012       1.25
            0
G1          'grvswal''grvinlt'      1           2.00        130         0.108       3           3           0.08        2.36        0
G1          'grvinlt'  'bvdNinlt'               2           1.50        50          0.033       0           0           0.012       1.5         0
G1          'bvdNgutr'              'bvdNinlt'              1           0.00        250         0.067       12          0.042       0.015       2
            0
G1          'bvdSgutr'              'bvdSinlt'              1           0.00        200         0.1         12          0.042       0.015       2
            0
G1          'bvdNinlt'              'bvdSinlt'              2           2.00        50          0.05        0           0           0.012       2
            0
G1          'bvdSinlt'              'lowrchan'              2           2.00        57          0.05        0           0           0.012       2
            0
G1          'lowrchan'              'outfall'   1           2.00        150         0.12        3           3           0.08        3           0
*
*           JK          NameW Ngto              Wid         Area        %Imp        S           ImpN        PervN       IDS         PDS         G
            Ksat        SmdmaxRmaxInfIflowP
H1          1           '70woods'               '70lawn'    29.547      0.08818     0           0.046       0.4         0.4         9.9         0.2
            12          0.1         0.185       0           3
```

Appendix F-6: Single-Event SWMM Input: Conventional Development, Unfavorable Conditions

```
H1      1       '70lawn' 'uvwEgutr'     78.872  0.05432 0       0.170   0.24    0.24    9.9     0.1
        12      0.08    0.125   0       0
H1      1       '6970wood'      '6970lawn'      29.328  0.09089 0       0.070   0.4     0.4     9.9
        0.2     12      0.1     0.185   0       3
H1      1       '6970roof'      '6970lawn'      188.816 0.08669 100     0.200   0.02    0.02    0.02
        9.9     99      99      0.99    0       3
H1      1       '6970driv'      'uvwNgutr'      58.954  0.02571 100     0.075   0.014   0.014   0.02
        9.9     99      99      0.99    0       0
H1      1       '6970lawn'      'uvwNgutr'      199.945 0.25246 0       0.083   0.24    0.24    9.9
        0.1     12      0.08    0.125   0       0
*

H1      1       '68drive' 'uvwNgutr'    69.578  0.01597 100     0.083   0.014   0.014   0.02    9.9
        99      99      0.99    0       0
*

*

H1      1       '68lawnup'      'uvwEgutr'      38.489  0.03534 0       0.067   0.24    0.24    9.9
        0.1     12      0.08    0.125   0       0
H1      1       '68wood''68lawnlo'      20.497  0.08470 0       0.089   0.4     0.4     9.9     0.2
        12      0.1     0.185   0       3
H1      1       '68roof'  '68lawnlo'    86.875  0.03989 100     0.200   0.02    0.02    0.02    9.9
        99      99      0.99    0       3
H1      1       '68lawnlo'      'uvwEgutr'      81.949  0.08466 0       0.119   0.24    0.24    9.9
        0.1     9       0.15    0.135   0       0
*

H1      1       '67drive' 'uvwEgutr'    19.606  0.01170 100     0.087   0.014   0.014   0.02    9.9
        99      99      0.99    0       0
H1      1       '67lawnup'      'uvwEgutr'      29.124  0.02139 0       0.125   0.24    0.24    9.9
        0.1     9       0.15    0.135   0       0
H1      1       'uvwEpave'      'uvwEgutr'      73.776  0.10162 100     0.080   0.014   0.014   0.02
        9.9     99      99      0.99    0       0
*

*

*

*

H1      1       'uvwWgras'      'uvwWgutr'      241.902 0.05553 0       0.350   0.24    0.24    9.9
        0.1     12      0.08    0.125   0       0
H1      1       'uvwWpave'      'uvwWgutr'      74.357  0.10242 100     0.080   0.014   0.014   0.02
        9.9     99      99      0.99    0       0
*

*

H1      1       'cirWroof'      'cirWswal'      128.000 0.05877 100     0.200   0.02    0.02    0.02
        9.9     99      99      0.99    0       0
H1      1       'cirWlawn'      'cirWswal'      195.548 0.06734 0       0.060   0.24    0.24    9.9
        0.1     12      0.08    0.125   0       0
```

Appendix F-6: Single-Event SWMM Input: Conventional Development, Unfavorable Conditions

```
H1        1         'cirWwood'          'cirWswal'          20.061    0.04605   0         0.060     0.4       0.4       9.9
          0.2       12        0.1       0.185     0         0
*

*

H1        1         '62roof'  '62lawn'  47.823    0.02196   100       0.200     0.02      0.02      0.02      9.9       99
          99        0.99      0         3
H1        1         '62lawn'  'alyWgutr'            106.321   0.08543   0         0.100     0.24      0.24      9.9       0.1
          9         0.15      0.135     0         0
H1        1         'alyWpave'          'alyWgutr'          43.596    0.04103   100       0.068     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
*

*

H1        1         '66roof'  'cirEwood'            73.200    0.03361   100       0.200     0.02      0.02      0.02      9.9
          99        99        0.99      0         3
H1        1         'uvwWside'          'uvwWgras'          120.212   0.03036   100       0.089     0.014     0.014     0.02
          9.9       99        99        0.99      0         3
H1        1         '66lawn'  'cirEwood'            116.060   0.05329   0         0.050     0.24      0.24      9.9       0.1
          12        0.08      0.125     0         3
H1        1         'cirEwood'          'cirEswal'          79.253    0.25471   0         0.086     0.4       0.4       9.9
          0.2       12        0.1       0.185     0         0
H1        1         'cirEslwn'          'cirEswal'          132.568   0.03043   0         0.150     0.24      0.24      9.9
          0.1       12        0.08      0.125     0         0
H1        1         '661roof2'          'cirEswal'          51.200    0.02351   100       0.200     0.02      0.02      0.02
          9.9       99        99        0.99      0         0
*

*

H1        1         '6061roof'          'alyEgutr'          95.413    0.04381   100       0.200     0.02      0.02      0.02
          9.9       99        99        0.99      0         0
H1        1         'alyEpave'          'alyEgutr'          25.091    0.04608   100       0.077     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
H1        1         '6061lawn'          'alyEgutr'          174.366   0.14010   0         0.130     0.24      0.24      9.9
          0.1       9         0.15      0.135     0         0
*

*

H1        1         'thWlawn'           'thWinlt' 48.191    0.04093   0         0.064     0.24      0.24      9.9       0.1
          9         0.15      0.135     0         0
H1        1         'thWroof'           'thWinlt' 170.519   0.07829   100       0.200     0.02      0.02      0.02      9.9
          99        99        0.99      0         0
H1        1         'thWwood'           'thWlot'  69.362    0.09554   0         0.084     0.4       0.4       9.9       0.2
          9         0.2       0.195     0         3
H1        1         'thWlot'  'thWinlt' 33.247    0.02900   100       0.048     0.014     0.014     0.02      9.9       99
          99        0.99      0         0
*

*
```

Appendix F-6: Single-Event SWMM Input: Conventional Development, Unfavorable Conditions

```
*

H1       1        'thEwood'         'thElot'  34.212   0.03927  0        0.115    0.4      0.4      9.9      0.2
         9        0.2      0.195    0        3
H1       1        'thElot' 'thEinlt' 43.225   0.05458  100      0.119    0.014    0.014    0.02     9.9      99
         99       0.99     0        0
*

H1       1        'thElawn'         'thEinlt' 160.005  0.07346  0        0.150    0.24     0.24     9.9      0.1
         9        0.15     0.135    0        0
H1       1        'thEroof' 'thEinlt' 215.998 0.09917 100     0.200    0.02     0.02     0.02     9.9      99
         99       0.99     0        0
*

*

H1       1        'lvwWlawn'        'lvwWgutr'         157.741  0.03621  0        0.350    0.24     0.24     9.9
         0.1      12       0.08     0.125    0        0
H1       1        'lvwWside'        'lvwWlawn'         22.385   0.01953  100      0.105    0.014    0.014    0.02
         9.9      99       99       0.99     0        3
H1       1        'lvwWpav'         'lvwWgutr'         72.263   0.05806  100      0.108    0.014    0.014    0.02
         9.9      99       99       0.99     0        0
*

*

H1       1        '67roof' '67lawnlo'         86.729   0.03982  100      0.200    0.02     0.02     0.02     9.9
         99       99       0.99     0        3
H1       1        '67lawnlo'        'lvwEgutr'         75.132   0.12074  0        0.138    0.24     0.24     9.9
         0.1      9        0.15     0.135    0        0
H1       1        'lvwecut''lvwEgutr'         133.395  0.10106  0        0.210    0.3      0.3      9.9      0.15
         12       0.08     0.185    0        0
H1       1        'lvwepav'         'lvwEgutr'         30.261   0.05419  100      0.102    0.014    0.014    0.02
         9.9      99       99       0.99     0        0
*

*

H1       1        'grvlawnB'        'grvwood'          106.585  0.05138  0        0.160    0.24     0.24     9.9
         0.1      9        0.15     0.135    0        3
H1       1        'grvwood'         'grvswal'110.655   0.12701  0        0.127    0.4      0.4      9.9      0.2
         9        0.2      0.195    0        0
*

H1       1        'grvlawnI'        'grvinlt' 124.585  0.06006  0        0.160    0.24     0.24     9.9      0.1
         9        0.15     0.135    0        0
H1       1        'grvlawnC'        'grvinlt' 27.649   0.01904  0        0.130    0.24     0.24     9.9      0.1
         12       0.08     0.125    0        0
*

H1       1        'sidegras'        'bvdNgutr'         283.159  0.09751  0        0.091    0.24     0.24     9.9
         0.1      9        0.15     0.135    0        0
H1       1        'blvdNpav'        'bvdNgutr'         124.054  0.14239  100      0.080    0.014    0.014    0.02
         9.9      99       99       0.99     0        0
```

Appendix F-6: Single-Event SWMM Input: Conventional Development, Unfavorable Conditions

```
H1        1         'blvdSpav'          'bvdSgutr'          104.192   0.11960   100       0.080     0.014     0.014     0.02
          9.9       99        99        0.99      0         0
H1        1         'bvdNmedn'          'blvdNpav'          352.436   0.08091   0         0.100     0.4       0.4       9.9
          0.2       12        0.1       0.185     0         3
H1        1         'bvdSmedn'          'blvdSpav'          352.436   0.08091   0         0.100     0.4       0.4       9.9
          0.2       12        0.1       0.185     0         3
*

*

*

*

H1        1         'lowrpav'           'lowrfill' 81.037   0.02232   100       0.020     0.014     0.014     0.02      9.9
          99        99        0.99      0         3
H1        1         'lowrfill' 'lowrchan'         245.822   0.33860   0         0.290     0.3       0.3       9.9       0.15
          12        0.08      0.185     0         0
H1        1         'lowrwood'          'lowrchan'          56.892    0.11754   0         0.250     0.4       0.4       9.9
          0.2       12        0.1       0.185     0         0
*

*
*  PRINT CONTROL
*         NPrnt     Interv
M1        1         5
*   NDet StartP(1) StartP(2)
M2   1     0        0
*         IPRNT(1) Prints INflows to channels/pipes
M3        'outfall'
* Repeat lines $RUNOFF through M3 for each design event.
* Substitute appropriate E3 lines for desired design hyetograph.
* Change A1 (title) lines as appropriate.
$ENDPROGRAM
```

Appendix F-7: Single-Event SWMM Input: Conventional with Stormwater Management, Favorable Conditions

Note: For brevity, the input file below only runs the 1-year storm event. To model all events in a single input file, repeat lines $TRANSPORT through J2 for each design storm. Use appropriate A1 lines for clarity.

```
SW  4  20 0 21 0 22 0 23 0
MM  6    1  2  3  4  12 13
@ 20 'conv_fav_1.int'
@ 21 'conv_fav_2.int'
@ 22 'conv_fav_10.int'
@ 23 'conv_fav_100.int'
* conv_unf
$ANUM
* $NOQUOTE
$TRANSPORT
A1  'Event Model: 1-yr storm, Transport Block'
A1 'Conventional Development with SWM - Favorable Condition'
*A1 'Conventional Development with SWM - Unfavorable Condition'
*   NDT  NINPUT NNYN NNPE NOUTS NPRINT NPOLL NITER IDATEZ METRIC INTPRT
B1 4320    0     0    1    0     0     0     6     0    0     5
*  DT EPSIL  DWDAYS TZERO GNU     TRIBA
B2 60 0.0001  0     0     0.00001 4.3338
* B3 & C1 lines all zeros for quantity-only WWF simulation
B3 0 0 0 0
C1 0 0
E1 'outfall' ' '        ' '           ' '           22 /
G1 0
*   DEPTH   AREA  VOL   OUTFLOW
G2        0           1575  0               0
G2        0.25        1656  403.9 0.14
G2        0.5         1739  828.3 0.51
G2        1           1911  1741  1.08
G2        2           2279  3836  1.68
G2        2.75        2576  5656  2.02
G2        3           2679  6313  2.68
G2        3.25        2784  6996  3.8
G2        3.5         2891  7706  4.78
G2        4           3111  9206  6
G2        4.5         3339  10819 6.97
G2        5           3575  12547 7.79
G2        5.25        3696  13456 10.04
G2        5.5         3819  14395 13.74
G2        6           4071  16368 24.09
G2        8           5159  25598 89.27
*
G5        0           /
*    NPE(1)   .....  NPE(NNPE) Routed Hydrographs
J2          'outfall'
* Repeat lines $TRANSPORT through J2 for each design event.
* Change A1 (title) lines as appropriate.
$ENDPROGRAM
```

Appendix F-8: Single-Event SWMM Input: Conventional with Stormwater Management, Unfavorable Conditions

Note: For brevity, the input file below only runs the 1-year storm event. To model all events in a single input file, repeat lines $TRANSPORT through J2 for each design storm. Use appropriate A1 lines for clarity.

```
SW  4  20 0 21 0 22 0 23 0
MM  6    1  2  3  4  12 13
@ 20 'conv_unf_1.int'
@ 21 'conv_unf_2.int'
@ 22 'conv_unf_10.int'
@ 23 'conv_unf_100.int'
$ANUM
* $NOQUOTE
$TRANSPORT
A1  'Event Model: 1-yr storm, Transport Block'
*A1 'Conventional Development with SWM - Favorable Condition'
A1 'Conventional Development with SWM - Unfavorable Condition'
*   NDT  NINPUT NNYN NNPE NOUTS NPRINT NPOLL NITER IDATEZ METRIC INTPRT
B1 4320    0     0    1    0     0     0      6     0     0     5
*  DT EPSIL  DWDAYS TZERO GNU     TRIBA
B2 60 0.0001  0     0     0.00001 4.3338
* B3 & C1 lines all zeros for quantity-only WWF simulation
B3 0 0 0 0
C1 0 0
E1 'outfall' ' '        ' '           ' '           22 /
G1 0
*   DEPTH   AREA  VOL   OUTFLOW
G2        0           1575  0               0
G2        0.25        1656  403.9 0.14
G2        0.5         1739  828.3 0.51
G2        1           1911  1741  1.08
G2        2           2279  3836  1.68
G2        2.75        2576  5656  2.02
G2        3           2679  6313  2.68
G2        3.25        2784  6996  3.8
G2        3.5         2891  7706  4.78
G2        4           3111  9206  6
G2        4.5         3339  10819 6.97
G2        5           3575  12547 7.79
G2        5.25        3696  13456 10.04
G2        5.5         3819  14395 13.74
G2        6           4071  16368 24.09
G2        8           5159  25598 89.27
*
G5        0           /
*    NPE(1)   .....  NPE(NNPE) Routed Hydrographs
J2          'outfall'
* Repeat lines $TRANSPORT through J2 for each design event.
* Change A1 (title) lines as appropriate.
$ENDPROGRAM
```

Appendix F-9: Single-Event SWMM Input: Rainfall Hyetographs (E3 lines)

Substitute the appropriate set of E3 lines for each design storm run.

E3 lines for 1-year storm:

```
*
* 1-year 24-hr SCS Type II Storm Distribution, 0.25 hour resolution, P = 2.5"
E3      0.026   0.027   0.027   0.028   0.028   0.029   0.029   0.03    0.03    0.031   0.031   0.032
E3      0.033   0.034   0.034   0.035   0.036   0.037   0.038   0.039   0.04    0.041   0.042   0.043
E3      0.045   0.046   0.048   0.05    0.052   0.054   0.056   0.059   0.062   0.065   0.068   0.073
E3      0.077   0.083   0.09    0.098   0.108   0.12    0.137   0.161   0.196   0.259   0.405   2.756
E3      1.043   0.314   0.223   0.176   0.148   0.128   0.113   0.102   0.093   0.086   0.08    0.075
E3      0.07    0.067   0.063   0.06    0.057   0.055   0.053   0.051   0.049   0.047   0.046   0.044
E3      0.043   0.042   0.04    0.039   0.038   0.037   0.036   0.036   0.035   0.034   0.033   0.032
E3      0.032   0.031   0.031   0.03    0.029   0.029   0.028   0.028   0.027   0.027   0.027   0.026
*
```

E3 lines for 2-year storm:

```
*
* 2-year 24-hr SCS Type II Storm Distribution, 0.25 hour resolution, P = 3.1"
E3      0.033   0.033   0.034   0.034   0.035   0.036   0.036   0.037   0.038   0.038   0.039   0.04
E3      0.041   0.042   0.043   0.044   0.045   0.046   0.047   0.048   0.049   0.051   0.052   0.054
E3      0.056   0.057   0.059   0.062   0.064   0.067   0.07    0.073   0.076   0.08    0.085   0.09
E3      0.096   0.103   0.111   0.121   0.133   0.149   0.17    0.199   0.244   0.321   0.503   3.418
E3      1.293   0.389   0.276   0.219   0.183   0.159   0.141   0.127   0.116   0.107   0.099   0.093
E3      0.087   0.082   0.078   0.074   0.071   0.068   0.065   0.063   0.061   0.058   0.057   0.055
E3      0.053   0.052   0.05    0.049   0.047   0.046   0.045   0.044   0.043   0.042   0.041   0.04
E3      0.039   0.039   0.038   0.037   0.037   0.036   0.035   0.035   0.034   0.033   0.033   0.032
*
```

E3 lines for 10-year storm:

```
*
* 10-year 24-hr SCS Type II Storm Distribution, 0.25 hour resolution, P = 5.0"
E3      0.053   0.054   0.054   0.055   0.056   0.057   0.058   0.059   0.061   0.062   0.063   0.064
E3      0.066   0.067   0.069   0.07    0.072   0.074   0.076   0.078   0.08    0.082   0.084   0.087
E3      0.09    0.093   0.096   0.1     0.103   0.108   0.112   0.117   0.123   0.13    0.137   0.145
E3      0.155   0.166   0.179   0.195   0.215   0.24    0.274   0.321   0.393   0.518   0.811   5.513
E3      2.086   0.627   0.446   0.353   0.295   0.256   0.227   0.205   0.187   0.172   0.16    0.15
E3      0.141   0.133   0.126   0.12    0.115   0.11    0.105   0.101   0.098   0.094   0.091   0.088
E3      0.086   0.083   0.081   0.079   0.076   0.075   0.073   0.071   0.069   0.068   0.066   0.065
E3      0.064   0.062   0.061   0.06    0.059   0.058   0.057   0.056   0.055   0.054   0.053   0.052
*
```

E3 lines for 100-year storm:

```
*
* 100-year 24-hr SCS Type II Storm Distribution, 0.25 hour resolution, P = 7.0"
E3      0.074   0.075   0.076   0.078   0.079   0.08    0.082   0.083   0.085   0.086   0.088   0.09
E3      0.092   0.094   0.096   0.098   0.101   0.103   0.106   0.109   0.111   0.115   0.118   0.122
E3      0.126   0.13    0.134   0.139   0.145   0.151   0.157   0.164   0.172   0.181   0.191   0.203
E3      0.216   0.232   0.251   0.273   0.301   0.337   0.384   0.45    0.55    0.726   1.135   7.718
E3      2.92    0.878   0.624   0.494   0.414   0.358   0.318   0.286   0.261   0.241   0.224   0.21
E3      0.197   0.186   0.177   0.168   0.161   0.154   0.148   0.142   0.137   0.132   0.128   0.124
E3      0.12    0.116   0.113   0.11    0.107   0.104   0.102   0.099   0.097   0.095   0.093   0.091
E3      0.089   0.087   0.086   0.084   0.082   0.081   0.08    0.078   0.077   0.076   0.074   0.073
*
```