Hydromodification Software, Third Party Review

Prepared for

County of San Diego
Department of Public Works

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1 Introduction

1.1 PURPOSES OF THIS REPORT

The County of San Diego recently released their final Hydromodification Management Plan (HMP), developed by Brown & Caldwell (2011a). The HMP provides guidance on the management of changes to hydrology that have the potential to introduce instability.

In support of the HMP, Brown & Caldwell (2011b) has also developed the San Diego BMP Sizing Calculator. This uses simulations with the HSPF watershed model (Bicknell et al., 2001) implemented in the background, to develop sizing rules for BMPs consistent with the HMP. Clear Creek Solutions has released an alternative tool, the San Diego Hydrology Model, version 2011 (SDHM2011), which also allows users to analyze and develop BMP systems for consistency with the HMP.

This report provides an evaluation of the two alternative methods for satisfying the HMP, and is intended to provide the San Diego Copermittees with a clear understanding of the applicability, functions, and results of these tools. Both software tools are reviewed for compliance with the HMP and standard stormwater management methodology.

1.2 HMP SUMMARY

The San Diego Regional Water Board Order R9-2007-001, Provision D.1.g of California Regional Water Quality Control Board San Diego Region Order R9-2007-0001, requires the San Diego Stormwater Copermittees to implement a Hydromodification Management Plan (HMP) "…to manage increases in runoff discharge rates and durations from all Priority Development Projects, where such increased rates and durations are likely to cause increased erosion of channel beds and banks, sediment pollutant generation, or other impacts to beneficial uses and stream habitat due to increased erosive force." The Permit Order tasked the Copermittees to develop an HMP that addressed flows within geomorphologically-significant ranges for receiving channels, applied to all Priority Development Projects (PDPs). Copermittees must then incorporate the approved HMP into their local Standard Urban Storm Water Mitigation Plans (SUSMP) to implement the HMP. The permit Order also required continuous hydrologic simulation using long-term meteorological data to develop the range of hydrologic response needed to ensure that post-project runoff flows and durations would not exceed pre-project runoff flows and durations.

The County of San Diego, in concert with the Copermittees, hired a consultant team to assist them with the development of an HMP to meet the Permit Order (Brown and Caldwell, 2011a). The work was conducted over the course of 2007 – 2011, with input from work groups and a Technical Advisory Committee. The following flow criteria were developed during the process:

- The upper flow threshold was defined as the pre-project 10-year event (Q_{10}), and the lower flow threshold was defined as a fraction of the 2-year event (Q_2).
- The low flow threshold can be one of three values – $0.1Q_2$, $0.3Q_2$, or $0.5Q_2$ – depending on the results of a susceptibility analysis of the receiving channel. The HMP includes extensive background research and screening methodologies for selecting the lower threshold. In the absence of an analysis, the most conservative threshold ($0.1Q_2$) must be chosen.
- For flow rates between the two pre-project thresholds, the *"post-project discharge rates and durations shall not deviate above the pre-project rates and durations by more than 10 percent over and more than 10 percent of the length of the flow duration curve."*

- *"For flow rates ranging from the lower flow threshold to Q_5, the post-project peak flows shall not exceed pre-project peak flows. For flow rates from Q_5 to Q_{10}, post-project peak flows may exceed pre-project flows by up to 10 percent for a 1-year frequency interval. For example, post-project flows could exceed pre-project flows by up to 10 percent for the interval from Q_9 to Q_{10} or from $Q_{5.5}$ to $Q_{6.5}$, but not from Q_8 to Q_{10}."*

The HMP allows for project applicants to prepare their own continuous simulation hydrology model to demonstrate site-specific compliance with the HMP requirements. Alternatively, the HMP encourages applicants to use the San Diego BMP Sizing Calculator website (http://uknow.brwncald.com/wastewater/Welcome.aspx) to obtain sizing factors and outlet configurations for a variety of LID practices using prescriptive designs. The BMP Sizing Calculator also provides a routine for sizing extended detention ponds (or basins) and Self-Retaining/Self-Treating areas to meet the HMP requirements.

Brown and Caldwell was the lead consultant for the development of the continuous simulation modeling used to translate the HMP flow control criteria into BMP design criteria, discussed further in Section 2.1. The HMP and BMP Sizing Calculator technical report (Brown and Caldwell, 2011b) provides details of the development and application of the HSPF model, including the following:

- Development of the long-term precipitation input series.
- Review of existing applicable HSPF models and the selection of hydrology parameters for representative land covers.
- Selection and representation of the prescriptive designs for a set of LID practices.
- Sensitivity analysis to determine the most critical site descriptors for pre-development conditions, and justification for the simplification of the range of potential pre-project inputs.
- Analysis partial-duration flow series to develop BMP storage volume sizing factors to meet HMP flow requirements.

The sizing factors are presented as a series of tables relating pre-development land cover to the BMP sizing criteria. The table includes all iterations of five BMP types, the three low flow thresholds, four Hydrologic Soil Groups (HSG), three slope classes, and three rainfall zones. The portion of the County subject to the HMP requirements was simplified into three representative rainfall zones.

The HMP also covers many more topics, including exemptions from HMP requirements, determination of receiving channel susceptibility for the low-flow threshold, stream rehabilitation performance criteria, BMP selection, BMP inspection and maintenance, and BMP monitoring. However, the focus of this report is the application of continuous simulation hydrology to BMP design for meeting HMP flow control requirements, so other aspects of the HMP are not summarized here.

2 Methods Evaluated

2.1 BROWN & CALDWELL SIZING CALCULATOR

The San Diego BMP Sizing Calculator is a web application that assists designers with testing BMP configurations for meeting the San Diego County flow control HMP requirements. It allows for the representation of multiple land area types and BMPs on a site. The BMP Sizing Calculator is not a platform for running a continuous simulation model per se; rather, it provides an environment for implementing the *results* of the continuous simulation modeling for BMP design.

Brown and Caldwell provided Tetra Tech with the URL for accessing the BMP Sizing Calculator, as well as an updated draft of the BMP Sizing Calculator technical documentation (Brown and Caldwell, 2011b). Tetra Tech obtained other supporting documents from the Project Clean Water website for the Standard Urban Stormwater Management Plan (SUSMP) and Hydromodification Workgroup (http://www.projectcleanwater.org/html/wg_susmp.html), including the HMP, the San Diego County Model SUSMP, and training materials for the BMP Sizing Calculator. During review of the materials, Tetra Tech identified a need for reviewing supporting HSPF input (UCI) files, which Brown and Caldwell provided.

As noted in Section 1.2, the sizing factors for the LID BMPs depend on several factors:

- BMP type
- HSG
- Predevelopment slope class
- Rainfall zone in which the site is located
- Lower flow threshold

The BMP Sizing Calculator includes a mapping application to assist the user with determining the proper rainfall zone for a site. An HSG map layer is also provided for reference. The user defines and stores attributes for a project (the development site), and one or more basins (an area draining to a receiving water). Each basin has a Point of Compliance, the location used to determine the low flow threshold. The user enters data from a channel assessment conducted according to HMP method if available, and the Calculator assigns the low flow threshold. If no assessment was performed, the most restrictive threshold (0.1Q2) is assigned to the Basin.

Next, the user defines *drainage management areas* (DMAs) for a selected BMP type (LID, extended detention pond, or self-treating/self-retaining areas). Each DMA reflects land area with a specific set of properties – HSG, pre-project slope, pre-project land cover, and post-project land cover. The pre-project slope entry provides three slope classes – Flat (less than 5%), Moderate, (5% - 10%), and Steep (greater than 10%). A DMA ***must*** contain land area with only the assigned properties – for instance, one is not supposed to lump areas with both C and D soils into a single DMA. Multiple DMAs may be defined draining to a single practice. However, the output from one BMP cannot be linked as input to another BMP, so BMPs in series cannot be assessed. Each individual BMP is expected to meet HMP requirements for its contributing DMAs.

Finally, the user may review the results of the analysis. For LID BMPs, the applicable minimum sizing factors and maximum low flow orifice size are provided. For detention ponds, the user supplies some data (side slopes, invert head for the low and high flow threshold orifices, and spillway weir length and invert), and the Calculator provides orifice sizes and pond dimensions, or warns if the simulation cannot find a valid result. For self-treating/self-retaining areas, the Calculator simply warns if the contributing drainage area is too large.

Given that the HMP provides detailed sizing factors for each of the five LID BMPs and the self-treating/self-retaining areas, the BMP Sizing Calculator is simply a tool for automating sizing calculations. The pond sizing routine provides utility by performing internal flow routing calculations, but ultimately it is driven by HSPF unit-area hydrographs from the land cover of the assigned DMAs. As designed, the BMP Sizing Calculator is quite useful, but a review of its structure and methods does not provide insight into the underlying continuous simulation modeling required by the Regional Water Board Permit Order. The next section will provide some details about the HSPF modeling used to link the HMP flow control requirements to the HMP BMP designs.

2.1.1 HSPF Modeling Supporting the HMP and BMP Sizing Calculator

Simply stated, the HMP requires post-development peaks and durations of a range of storm event flows to not exceed (or rarely exceed) the pre-developed condition. This must be tested with a continuous simulation hydrology model, which is capable of examining a range of flow conditions using real long-term precipitation records, rather than just a set of synthetic design storms. Brown and Caldwell led the effort to develop an HSPF model that would adequately represent pre-development runoff, and post-development runoff routed through LID practices.

An HSPF model is typically developed for evaluating a single watershed. However, the goals of the HMP are different – evaluate unit area runoff from a development site (not a watershed) that could be located anywhere in the County where the HMP is in force. The HSPF model was therefore developed using regional, representative parameters. To that end, the parameters from several sources were reviewed, including local and regional models, HSPF technical guidance, and the Western Washington Hydrology Model.

The HSPF parameter selection are provided in Section 3.1. However, certain aspects of the HSPF model development process should be noted up front:

- Brown and Caldwell evaluated the runoff performance of several undeveloped land covers using the Southern California models noted previously. Their analysis indicated that runoff potential predicted by the most critical parameters influencing runoff (INFILT and LZSN) was highly correlated with differences in slope and HSG, but there was little difference between land covers for a given slope class and HSG. They elected to represent pre-developed land cover with a single vegetation class, but with variations in slope class and HSG.
- LID BMP sizing factors were developed by Brown & Caldwell assuming the post-developed land cover draining to BMPs was 100% impervious: “Consistent with the general design guidance in the Countywide Model SUSMP, designers are expected to minimize the amount of pervious surface that drains to BMPs. Post-project site runoff was therefore evaluated by simulating runoff from a unit area converted to 100% impervious surface. Comparing the pervious surface model output with the impervious surface model output shows the effects of development prior to adding a BMP.” BMP sizing was then developed iteratively to bring the post-project runoff to within 10 percent of the pre-development runoff over the range for flow duration control. Pervious areas are generally assumed to be “self treating”; however, there is a provision for adjusting the sizing factors if pervious areas are routed to the BMP.
- The automated pond sizing routine could not be reviewed in detail, because it is configured as a back-end program within the BMP Sizing Calculator website. Brown and Caldwell’s documentation states that unit area runoff time series for each land cover are scaled to land area and combined into one input series to the tool, which then runs sizing iterations until a best solution is achieved, or no solution can be found. A level-pool modified Puls computational routing routine is utilized for the sizing.

- The model UCI files provided by Brown and Caldwell contain a single post-developed "urban" land cover class, with variations in HSG but with slope specified as 10 percent. This class was not used for LID BMP sizing factors as the contributing area is assumed to be wholly impervious. This land class is assumed to be an input to the automated pond sizing routine, because ponds are expected to capture flow from a combination of pervious and impervious surfaces.

While the BMP sizing factors are based on contributing impervious area only, the BMP Sizing Calculator does account for pervious area draining to an LID BMP. During limited testing, it appeared that the sizing factor applied to pervious surface was equal to 10 percent of the impervious sizing factor. The HMP does state that an adjustment is used in the Calculator, but the 10 percent figure is neither discussed nor justified.

2.2 CLEAR CREEK SOLUTIONS SDHM2011

The San Diego Hydrology Model 2011 (SDHM2011) has been developed by Clear Creek Solutions as part of a commercial venture to create hydromodification analysis models throughout the west coast region. SDHM2011 is an update of an earlier SDHM (Clear Creek Solutions, 2008), and is closely related to the Bay Area Hydrology Model (BAHM; Clear Creek Solutions, 2007). All these models are based on the widely used Western Washington Hydrology Model (WWHM), now in version 4 (see http://www.clearcreeksolutions.com). The original versions of WWHM focused on hydromodification management by ponds. More recently, representations of LID components have been added. There have been numerous improvements to the suite of models over the last several years since BAHM was originally created which improve the ability to simulate LID components.

A fully functional version of SDHM2011 (single user license) was provided to Tetra Tech by Clear Creek Solutions. The install process proved a bit tricky on a system with network security as full user rights are required in certain Program File directories; however, Clear Creek Solutions provided quick responses to guide the process. They also provided several fixes to bugs in the user interface during this review process.

SDHM2011 relies on a graphic user interface (GUI) that enables the user to quickly set up a simulation of a potential development site using the HSPF watershed model utilizing graphic objects. Typically, a user would simulate pre-development conditions, post-development conditions without mitigation, and post-development conditions with mitigation (BMPs). BMPs can be assigned with a drag-and-drop process and the user then has full control over a variety of sizing and outlet configuration options. The interface creates an HSPF input (UCI) file, runs it in the background, and analyzes results relative to HMP requirements for matching the pre-development hydrograph. These UCI files are visible to the user and provide a basis for rigorous examination and testing of the model.

SDHM2011 (and its related models) offers optimization routines for automatic sizing of ponds (and storage vaults that act like ponds) to meet HMP criteria. It does not conduct automated sizing of LID components like bioretention and the user must modify these through multiple iterations to ensure that HMP criteria are met. The online help file appears to encourage the user to add a storage vault to LID components and use the automatic sizing option to satisfy the HMP requirements.

With SDHM2011 the user can set up a potentially complex network of upland elements and BMP components and define one or more points of compliance for hydromodification analysis. The interface is thus very useful for the analysis of larger and more complex projects.

2.3 DIFFERENCES IN PHILOSOPHY

The Brown & Caldwell Sizing Calculator and the Clear Creek SDHM2011 represent different philosophies for hydromodification technical analysis. For the Sizing Calculator, a set of HSPF model runs has been completed in the background and used to develop sizing factors that meet HMP requirements. This results in an easy to use method with which a developer can easily plan appropriate BMPs and which can be easily reviewed. On the other hand, with this approach site planning is limited to the type and configurations of BMPs that have been used to develop the sizing factors. In addition, BMPs cannot be placed in series to derive incremental benefits – each BMP must fully meet HMP requirements for its contributing drainage area.

With SDHM2011 new site-specific simulations are undertaken, rather than relying on the results of a library of past model runs. Performance relative to HMP goals is evaluated through direct simulation. This allows much greater user flexibility. This in turn has the advantage of allowing for innovative designs beyond what has been considered by Brown & Caldwell. It also allows full evaluation of the interaction of multiple sources and management practices on large and complex sites. The disadvantage is that SDHM2011 is much more complex and time-consuming to apply, and submissions based on SDHM2011 will be more difficult and time-consuming to review.

Both approaches are technically valid within their range of applicability, and it is likely that both will be used in specific situations. The Brown & Caldwell Sizing Factor approach, which focuses on onsite controls and is easy to apply via pre-calculated sizing factors, appears best suited to smaller projects. Explicit simulation with SDHM2011 (or with another watershed model) appears most appropriate for larger projects where the combined effects of multiple onsite and offsite controls may need to be evaluated.

3 Simulation of Upland Flow

3.1 HSPF: TYPES OF LAND USE AND PARAMETER COMPARISON

Both Clear Creek Solutions and Brown & Caldwell use HSPF to simulate stormwater runoff in San Diego County. The model parameters in both modeling approaches are similar. Indeed, the Clear Creek SDHM2011 model appears to have been designed to intentionally mimic the parameter values selected by Brown & Caldwell; however, Clear Creek Solutions includes additional undeveloped pervious land uses that are not represented in the Brown & Caldwell model.

Model parameters are assigned based on land use, hydrologic soil group (HSG), and slope. The Brown & Caldwell model only has one general undeveloped pervious land use type for each soils class (defined as “grass” in the model files bur referred to as “scrub” in some of the documentation) while SDHM2011 has separate parameter sets defined for pervious grass, dirt, and gravel undeveloped areas. Interestingly, neither model attempts to explicitly represent the chaparral and scrub forest land covers that constitute much of the native vegetation of San Diego County and the Brown & Caldwell parameters are clearly derived from simulations of grass cover. Each model also has a developed pervious area (urban) land use that assumes a moderate (5-10 percent) slope for each soil class. As discussed above, Brown & Caldwell chose not to represent different slope categories for developed urban land, and Clear Creek Solutions has followed suit.

Table 2 through Table 5 summarize the HSPF model parameters by land use defined in the SDHM2011 model. Table 1 provides a description of the parameters. Model parameters in the Brown & Caldwell model are identical to those in SDHM2011, but represent only the “grass” and “urban” categories. Each model uses the same impervious land hydrologic parameters (Table 6).

Each model input file also included monthly varying model coefficients for pervious interception (MON-INTERCEP) and lower zone evapotranspiration (MON-LZETPARM) (Table 5). The Clear Creek Solutions model uses both of those model parameters to mimic vegetation effects on the soil moisture throughout the year. The Brown & Caldwell input file that was evaluated included both monthly varying parameters; however, the model was configured to only use the monthly varying interception and instead used a constant value of 0.5 as defined by the LZETP parameter (see Table 3). The reason that the model behaves in this manner is because the model flag (VLE) is not set to turn on the monthly varying LZETP. The documentation (Brown & Caldwell, 2011b) shows that this is intentional, although it may not be a wise choice as LZETP should vary seasonally as a function of canopy density. In any case, Clear Creek Solutions appears to have been misled by the presence of the MON-LZETPARM table and implemented the monthly values. If the flag for monthly varying LZETP was reconciled the parameters implemented by both models would be identical.

Table 1 HSPF Pervious Parameter Description

Parameter Name	Min	Max	Units	Description
FOREST	0	1	none	Fraction of the pervious land segment which is covered by forest
LZSN	0.01	100	in	Lower zone nominal storage
INFILT	0.0001	100	in/hr	Index to the infiltration capacity of the soil
LSUR	1	none	ft	Length of the assumed overland flow plane
SLSUR	0	1 10.	none	Slope of the overland flow plane
KVARY	0	none	1/in	Parameter which affects the behavior of groundwater recession flow
AGWRC	0.001	0.999	1/day	Basic groundwater recession rate
PETMAX	none	none	degF	Air temperature below which evapotranspiration will arbitrarily be reduced below the value obtained from the input time series
PETMIN	none	none	degF	Temperature below which evapotranspiration will be zero regardless of the value in the input time series
INFEXP	0	10	none	Exponent in the infiltration equation
INFILD	1	2	none	Ratio between the maximum and mean infiltration capacities over the PLS
DEEPFR	0	1	none	Fraction of groundwater inflow which will enter deep (inactive) groundwater
BASETP	0	1	none	Fraction of remaining potential evapotranspiration which can be satisfied from baseflow
AGWETP	0	1	none	Fraction of remaining potential evapotranspiration which can be satisfied from active groundwater
CEPSC	0	10	in	Interception storage capacity
UZSN	0.01	10	in	Upper zone nominal storage
NSUR	0.001	1	complex	Manning’s n for the overland flow plane
INTFW	0	none	none	Interflow inflow parameter
IRC	1.00E-03	0 0.999	1/day	Interflow recession parameter
LZETP	0	2	none	Lower zone evapotranspiration parameter

Table 2 HSPF Pervious Parameter Values

Soil Type	Land Use	Slope	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
A	Grass	0-5%	5.2	0.09	200	0.05	3	0.92
	Grass	5-10%	4.8	0.07	200	0.1	3	0.92
	Grass	10-20%	4.5	0.045	200	0.15	3	0.92
	Dirt	0-5%	5.2	0.09	400	0.05	0.8	0.955
	Dirt	5-10%	4.8	0.07	350	0.1	0.8	0.955
	Dirt	10-20%	4.5	0.045	300	0.15	0.8	0.955

Soil Type	**Land Use**	**Slope**	**LZSN**	**INFILT**	**LSUR**	**SLSUR**	**KVARY**	**AGWRC**
	Gravel	0-5%	2.6	0.045	400	0.05	0.8	0.955
	Gravel	5-10%	2.4	0.035	350	0.1	0.8	0.955
	Gravel	10-20%	2.2	0.022	300	0.15	0.8	0.955
B	Grass	0-5%	5	0.07	200	0.05	3	0.92
	Grass	5-10%	4.7	0.055	200	0.1	3	0.92
	Grass	10-20%	4.4	0.04	200	0.15	3	0.92
	Dirt	0-5%	5	0.07	400	0.05	1.2	0.95
	Dirt	5-10%	4.7	0.055	350	0.1	1.2	0.95
	Dirt	10-20%	4.4	0.04	300	0.15	1.2	0.95
	Gravel	0-5%	2.5	0.035	400	0.05	1.2	0.95
	Gravel	5-10%	2.3	0.028	350	0.1	1.2	0.95
	Gravel	10-20%	2.2	0.02	300	0.15	1.2	0.95
C	Grass	0-5%	4.8	0.05	200	0.05	3	0.92
	Grass	5-10%	4.5	0.04	200	0.1	3	0.92
	Grass	10-20%	4.2	0.03	200	0.15	3	0.92
	Dirt	0-5%	4.8	0.045	400	0.05	2	0.95
	Dirt	5-10%	4.5	0.04	350	0.1	2	0.95
	Dirt	10-20%	4.2	0.03	300	0.15	2	0.95
	Gravel	0-5%	2.4	0.022	400	0.05	2	0.95
	Gravel	5-10%	2.2	0.02	350	0.1	2	0.95
	Gravel	10-20%	2.1	0.015	300	0.15	2	0.95
D	Grass	0-5%	4.8	0.04	200	0.05	3	0.92
	Grass	5-10%	4.5	0.03	200	0.1	3	0.92
	Grass	10-20%	4.2	0.02	200	0.15	3	0.92
	Dirt	0-5%	4.8	0.045	400	0.05	2	0.95
	Dirt	5-10%	4.5	0.04	350	0.1	2	0.95
	Dirt	10-20%	4.2	0.03	300	0.15	2	0.95
	Gravel	0-5%	2.4	0.022	400	0.05	2	0.95
	Gravel	5-10%	2.2	0.02	350	0.1	2	0.95
	Gravel	10-20%	2.1	0.015	300	0.15	2	0.95
A	Urban	5-10%	4.6	0.05	200	0.1	3	0.92
B	Urban	5-10%	4.4	0.04	200	0.1	3	0.92
C	Urban	5-10%	4.3	0.03	200	0.1	3	0.92
D	Urban	5-10%	4.2	0.02	200	0.1	3	0.92

Note: Full set is from SDHM2011; Brown & Caldwell parameters use only the grass and urban categories.

Table 3 HSPF Pervious Parameter Values

Soil Type	Land Use	Slope	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
A	Grass	0-5%	0.08	0.6	0.2	1.5	0.7	0.5
	Grass	5-10%	0.08	0.6	0.2	1.5	0.7	0.5
	Grass	10-20%	0.08	0.6	0.2	1.5	0.7	0.5
	Dirt	0-5%	0.08	0.8	0.2	4	0.7	0.5
	Dirt	5-10%	0.08	0.7	0.2	3.2	0.45	0.5
	Dirt	10-20%	0.08	0.55	0.2	2.6	0.4	0.5
	Gravel	0-5%	0.08	1.6	0.35	0	0.7	0.5
	Gravel	5-10%	0.08	1.4	0.35	0	0.45	0.5
	Gravel	10-20%	0.08	1.1	0.35	0	0.4	0.5
B	Grass	0-5%	0.08	0.6	0.2	1.5	0.7	0.5
	Grass	5-10%	0.08	0.6	0.2	1.5	0.7	0.5
	Grass	10-20%	0.08	0.6	0.2	1.5	0.7	0.5
	Dirt	0-5%	0.08	0.8	0.2	3	0.7	0.5
	Dirt	5-10%	0.08	0.7	0.2	2.4	0.45	0.5
	Dirt	10-20%	0.08	0.55	0.2	1.6	0.4	0.5
	Gravel	0-5%	0.08	1.6	0.35	0	0.7	0.5
	Gravel	5-10%	0.08	1.4	0.35	0	0.45	0.5
	Gravel	10-20%	0.08	1.1	0.35	0	0.4	0.5
C	Grass	0-5%	0.08	0.6	0.2	1.5	0.7	0.5
	Grass	5-10%	0.08	0.6	0.2	1.5	0.7	0.5
	Grass	10-20%	0.08	0.6	0.2	1.5	0.7	0.5
	Dirt	0-5%	0.08	0.8	0.2	2	0.7	0.5
	Dirt	5-10%	0.08	0.7	0.2	1.2	0.45	0.5
	Dirt	10-20%	0.08	0.55	0.2	0.8	0.4	0.5
	Gravel	0-5%	0.08	1.6	0.35	0	0.7	0.5
	Gravel	5-10%	0.08	1.4	0.35	0	0.45	0.5
	Gravel	10-20%	0.08	1.1	0.35	0	0.4	0.5
D	Grass	0-5%	0.08	0.6	0.2	1.5	0.7	0.5
	Grass	5-10%	0.08	0.6	0.2	1.5	0.7	0.5
	Grass	10-20%	0.08	0.6	0.2	1.5	0.7	0.5
	Dirt	0-5%	0.08	0.8	0.2	2	0.7	0.5
	Dirt	5-10%	0.08	0.7	0.2	1.2	0.45	0.5
	Dirt	10-20%	0.08	0.55	0.2	0.8	0.4	0.5
	Gravel	0-5%	0.08	1.6	0.35	0	0.7	0.5
	Gravel	5-10%	0.08	1.4	0.35	0	0.45	0.5

Soil Type	Land Use	Slope	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
	Gravel	10-20%	0.08	1.1	0.35	0	0.4	0.5
A	Urban	5-10%	0.08	0.6	0.2	1.5	0.7	0.5
B	Urban	5-10%	0.08	0.6	0.2	1.5	0.7	0.5
C	Urban	5-10%	0.08	0.6	0.2	1.5	0.7	0.5
D	Urban	5-10%	0.08	0.6	0.2	1.5	0.7	0.5

Table 4 Constant HSPF Pervious Parameter Values across Land Uses and Soils

Slope	Clear Creek Land Use	FOREST	SLSUR	PETMAX	PETMIN	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
0-5%	Grass	0	0.05	35	30	2	2	0.4	0.05	0.05
5-10%	Grass & Urban	0	0.1	35	30	2	2	0.4	0.05	0.05
10-20%	Grass	0	0.15	35	30	2	2	0.4	0.05	0.05

Table 5 Monthly Varying Pervious HSPF Parameters

	MON-INTERCEP	MON-LZETPARM
January	0.1	0.4
February	0.1	0.4
March	0.1	0.4
April	0.1	0.4
May	0.06	0.6
June	0.06	0.6
July	0.06	0.6
August	0.06	0.6
September	0.06	0.6
October	0.1	0.4
November	0.1	0.4
December	0.1	0.4

Note: Brown & Caldwell does not set the flag to implement monthly variable LZETP, so the actual simulations use a constant value of 0.5.

Table 6 Impervious HSPF Parameters

LSUR	SLSUR	NSUR	RETSC
100	0.035	0.05	0.1

Like other watershed models, HSPF requires calibration to local conditions to provide an accurate representation of hydrology. The Clear Creek Solutions model manual states that the "values used in SDHM are based on calibrated watersheds." However, no references are included to validate that statement, and the majority of the parameters appear to be selected to match the Brown & Caldwell model. The Brown & Caldwell work "compiled and assessed the similarities and variations among the PERLND parameters used for the Santa Monica Bay (SCCWRP), Calleguas Creek (Aqua Terra), and SDHM work efforts." Most of the parameters come from the earlier version of the SDHM (Clear Creek Solutions, 2008), which appears to use parameters (including a reduced range of INFILT) that were derived from BAHM model calibration to Ross Creek and Thompson Creek in Santa Clara County in the Bay Area (Beyerlein, 2007) for A, B, and C/D soils. These values in turn mostly come from the AQUA TERRA (2006) calibration of HSPF to Castro Valley Creek and Alameda Creek in Alameda and Santa Clara counties. None of these are calibrated and validated models specifically developed for the San Diego region.

The Castro Valley/Alameda Creek model was rigorously calibrated by AQUA TERRA and appears to provide a good to very good fit to gaged flows. That model, however, provides parameters for only A, B, and D soils and notes that, because the watersheds under study had very limited areas with B soils, a third watershed needed to be identified and calibrated to "help accurately assess model parameters for those soils." Results for C soils appear to have been subsequently determined by interpolation for use in SDHM. The extent to which these results from the southwestern side of San Francisco Bay are appropriate for use in San Diego County is unknown.

General guidance and acceptable ranges for hydrology parameters in HSPF are provided in BASINS Technical Note 8 (USEPA, 2000). In addition, Tetra Tech has recently developed detailed calibrated models for the Santa Margarita River (San Diego Co.), Los Peñasquitos (San Diego Co.), and Ventura River (Ventura Co.) that provide insights into potential parameter ranges for HSPF modeling in southern California. Many of the parameter values adopted for the Brown & Caldwell/SDHM2011 models appear reasonable in light of this experience. However, a few key parameter values appear questionable. In particular, the values assigned to the INFILT parameter, which is a major determinant of peak runoff, raise questions. The HMP models vary INFILT by both HSG and slope. The resulting infiltration values are compared to the USEPA Guidance in Table 7. It will be immediately noted that the HMP models have a compressed range for INFILT, with all values in the recommended ranges for C and D soils. The highest value assigned to A soils is 0.09, which would normally be typical of C soils. In contrast, Tetra Tech's Ventura River model achieves excellent calibration and validation with values of INFILT that fall within the range recommended by USEPA.

Table 7. Comparison of INFILT Parameters to USEPA Guidance

Soil HSG	Land Use	Slope	HMP Models	USEPA (2000)
A	Grass	0 – 5%	0.09	0.4 – 1.0
		5 – 10%	0.07	
		10 – 20%	0.045	
	Urban	5 – 10%	0.05	
B	Grass	0 – 5%	0.07	0.1 – 0.4
		5 – 10%	0.055	
		10 – 20%	0.04	
	Urban	5 – 10%	0.04	
C	Grass	0 – 5%	0.05	0.05 – 0.1
		5 – 10%	0.04	
		10 – 20%	0.03	
	Urban	5 – 10%	0.03	
D	Grass	0 – 5%	0.04	0.01 – 0.05
		5 – 10%	0.03	
		10 – 20%	0.02	
	Urban	5 – 10%	0.02	

The reduced range of INFILT across HSG suggests that the HMP models are likely to overestimate surface runoff from soils with higher infiltration capacity. If so, this is a conservative assumption that would tend to lead to over-sizing of BMPs. Note that this observation does not necessarily mean that the parameter values selected for the San Diego HMP models are incorrect; however, it does seem to demand further testing and justification through local calibration efforts.

Another parameter value that raises questions is the assignment of a value of 0.4 to DEEPFR (Table 4), indicating that 40 percent of the flow that percolates to groundwater is lost to the deep aquifer and does not reappear as stream flow. This parameter can be high in arid watersheds, but a value of 0.4 is outside the typical range of 0 to 0.2 recommended by USEPA (2000). In contrast, the detailed Santa Margarita and Los Peñasquitos models have DEEPFR of 0.10 or less. The detailed Ventura River model uses a value of DEEPFR in the 0.4 range in some high elevation watersheds, but most are characterized with values in the range of 0.05 – 0.20. DEEPFR in the AQUA TERRA (2006) calibrated models for Castro Valley and Alameda creeks ranges from 0.02 to 0.15 for grass cover. If DEEPFR is overestimated this will tend to decrease groundwater discharge and deplete the receding tail of the storm hydrograph in stream reaches. Ordinarily, this is not a major issue for stormwater management; however, for hydromodification management that addresses duration of flows above a fraction of the Q2 flow a noticeable difference could result. Note that this issue primarily affects estimates of pre-development flow. Brown & Caldwell assume infiltration from BMPs is lost from the system and indeed address pervious land areas only indirectly in developing sizing factors. This would be a potential issue for simulating compliance in larger stream networks with SDHM2011.

Also questionable is the decision in the SDHM2011 to assign identical monthly sets of values for interception and lower zone ET to all the pre-development (grass, dirt, gravel) land uses (Table 5). Both these factors reflect the influence of plants through canopy interception and withdrawal of moisture from roots in the lower soil zone. If the dirt and gravel land uses are intended to represent lower vegetative density they should have significantly lower values for both MON-INTERCEP and MON-LZETPARM or LZETP (depending on whether monthly values are used).

While the parameters are generally identical, a significant difference between the implementation of the SDHM2011 and Brown & Caldwell models is the representation irrigation on urban pervious lands. The Brown & Caldwell model does not include irrigation on any pervious areas. Irrigation in the Clear Creek Solutions model is included as a time series that is added to the urban pervious areas as a lateral inflow. The manner in which the irrigation time series was developed is not included in the documentation describing the San Diego model (Clear Creek Solutions, 2008) or the Western Washington Hydrology Model (Clear Creek Solutions, 2006). The addition of irrigation can have a major impact on stormflows because it increases the antecedent soil moisture, increasing runoff rates from a given amount of precipitation. As is described in Section 5, the inclusion of irrigation results in a significant increase in the simulated 2-year and 10-year runoff volumes. It is noted, however, that Brown & Caldwell does not use the simulation of pervious runoff from developed land in calculating BMP sizing for LID components, so there is no direct impact from this omission on the sizing factors for LID. It may have a direct impact on the automated sizing for ponds that are assumed to receive flow from both pervious and impervious areas.

In sum, the Brown & Caldwell model and SDHM2011 appear to be designed to have identical parameters for the land uses in common between the models (although SDHM2011 also adds other undeveloped land uses). This is not fully achieved due to confusion in the setting of the flag for monthly LZETP values, which needs to be resolved, but the difference is small. The two models should thus provide similar results. Whether those results provide a useful representation of reality is less clear as the parameter values have not been validated through testing on gaged flow records in San Diego County.

3.2 HSPF RUNOFF SIMULATION

Long-term simulations of both the Brown & Caldwell and Clear Creek Solutions models were made to assess differences in runoff across a wide variety of conditions. Simulations of each land use, on a unit acre basis, were made to quantify the amount of water leaving a given land use type. The two models were set up to use the same data for hourly rainfall and potential evapotranspiration (PET) at the Lake Wohlford rain gauge from October 1, 1959 through September 30, 2004. This is the maximum period allowed by the model setup: while precipitation records prior to 1959 are available, the PET series has not been developed.

3.2.1 Pre-development Flow

The simulation of pre-development flow from undeveloped lands in the “grass” category showed minimal differences between the SDHM2011 and Brown & Caldwell models. The first test examined total daily volumetric flow for pre-development land use. Each model showed greater runoff for the D soils than the A soils with daily runoff volume increases of about 45 percent for the 2-year return storms, 85 percent for the 5-year and doubling for the longer return periods (Figure 1). For both the A and D soils, the model outputs were within 10 percent of one another. The models were most similar for the 5- and 10-year return flows with differences less than 5 percent. The largest difference between the two models was in the 2-year return flows for D soils where the differences were 8 percent. The reasons for the difference in the model output was the utilization of the monthly varying lower zone evapotranspiration rate in SDHM2011. A test simulation of the Brown & Caldwell model was made using variable lower zone evapotranspiration and the results of the two models were then identical.

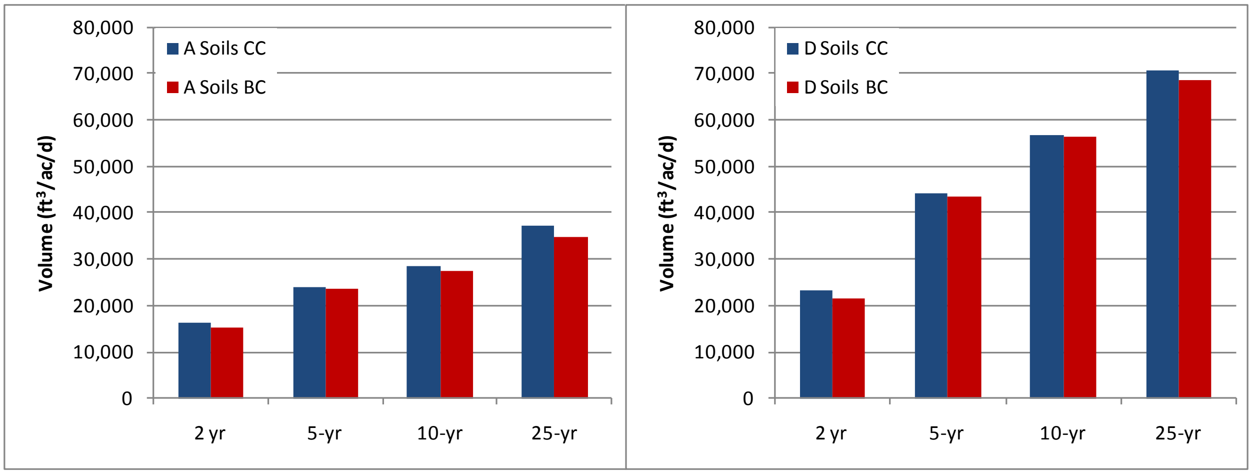

Figure 1 **Comparison of Clear Creek SDHM2011 and Brown & Caldwell Daily Flow Estimates for Pre-development Lands**

Note: CC: Clear Creek SDHM2011 model; BC: Brown & Caldwell Model

SDHM2011 adds user options to simulate pre-development conditions such as “dirt” or “gravel,” instead of “grass.” The ratios of simulated results for these land uses to the corresponding grass land use (i.e., same soil HSG and slope) for total volume and maximum hourly flow are summarized in Table 8 and Table 9.

Table 8 **Comparison of Total Volume for SDHM2011 Pre-development Land Covers (Ratio to Corresponding Grass Land Use, Lake Wohlford 1959-2004)**

Land Use	Average	Minimum	Maximum
Dirt	0.87	0.80	0.97
Gravel	1.03	0.86	1.22

Table 9 **Comparison of Maximum Hourly Flow Rate for SDHM2011 Pre-development Land Covers (Ratio to Corresponding Grass Land Use, Lake Wohlford 1959-2004)**

Land Use	Average	Minimum	Maximum
Dirt	0.69	0.06	1.19
Gravel	1.13	0.82	1.41

The dirt land use has lower runoff volumes than grass, which seems to be mostly due to assumption of higher values for upper zone storage (UZSN) and interflow inflow (INTFW) for the dirt land use. This seems counterintuitive. Dirt also generally has lower peak flows than grass – except for high slopes on B and C soils. In contrast, gravel is simulated as having, on average, somewhat higher total volume and peak flow than grass, with the highest values associated with steep slopes. The primary factor here would appear to be lower values of LZSN assigned to the gravel land use. It does not appear that the relationship between simulated flows from grass, dirt, and gravel has been validated.

A second way that model results were compared for the grass land use was by analyzing the differences in the return periods of the higher flows that would have the greatest impact on stream hydromodification. The models had similar results on daily maximum flows from D soils, which were quadruple those of the A soils for the 2- and 5-year return periods (Figure 2 and Figure 3). The 10- and 25-year differences between soils groups were smaller. The daily maximum flows from each model were typically within 5 percent of one another, reflecting the similar parameterization.

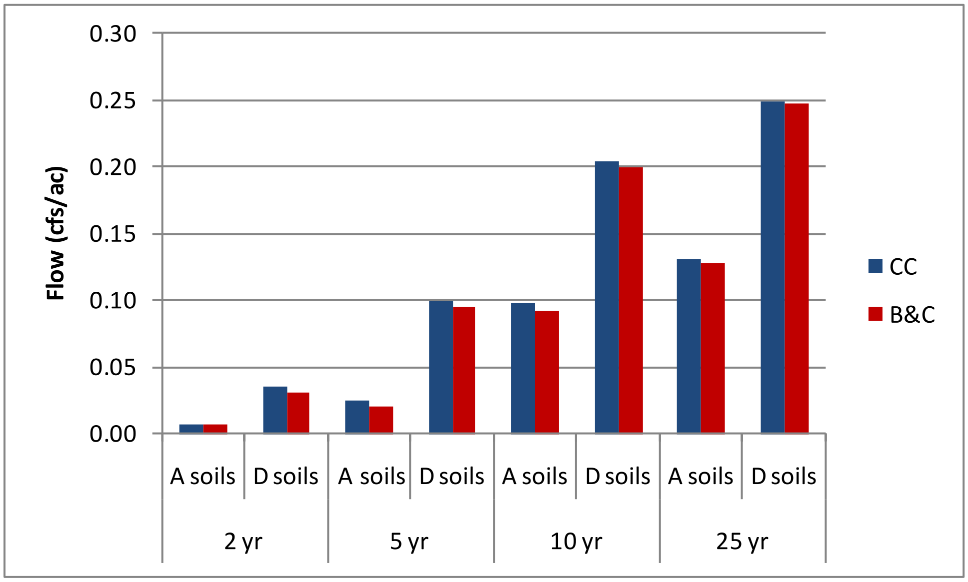

Figure 2 Comparison of Clear Creek SDHM2011 and Brown & Caldwell Daily Max Flow Recurrence Interval for Pre-Development Conditions

Note: CC: Clear Creek SDHM2011 model; CC- no irr: Clear Creek model without irrigation; B&C: Brown & Caldwell Model

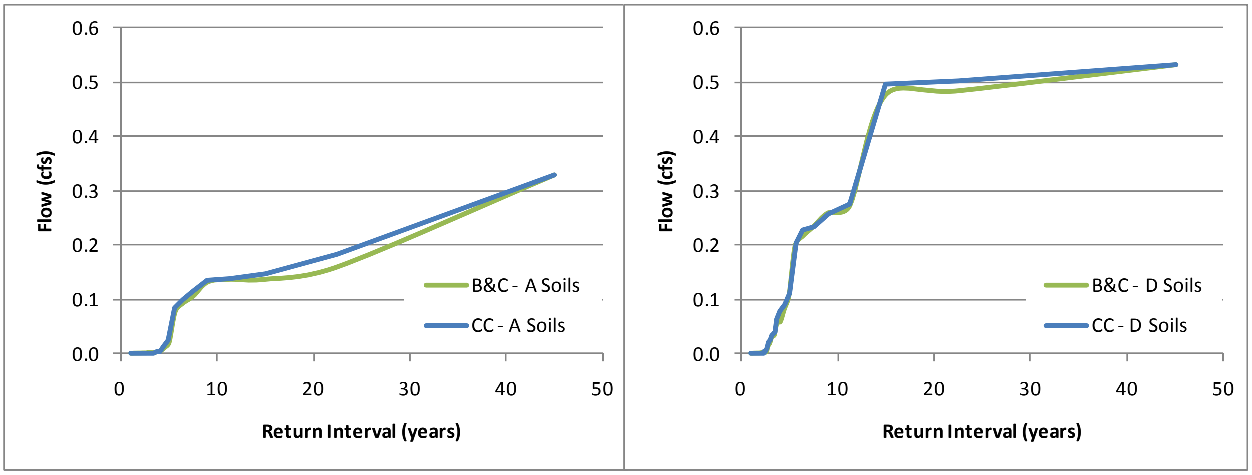

Figure 3 Flow-Duration Curves for Daily Maximum Flows for Undeveloped Pervious Lands

Note: CC: Clear Creek model; B&C: Brown & Caldwell Model

3.2.2 Developed Land Flow

There was considerably greater difference in the model output between the models for the developed pervious areas. With irrigation applied to the urban pervious areas in the Clear Creek model, the daily flows were between 50 and 20 percent greater than the Brown & Caldwell predicted flows (Figure 4), with the greatest difference in the more frequent return periods and A soils. When irrigation was removed from the model those differences reduced to less than 3 percent.

Irrigation had an impact on the daily runoff volume as compared across soil types. When irrigation was applied, that pattern was reversed. The greatest difference between the soil types was ~65 percent for the 2-year return periods and 36 percent for the 25-year flows. This shows the effect that maintaining soil moisture has on the runoff where a greater fraction of rainfall from the smaller storms runs off because the soil moisture storage capacity is already partially filled.

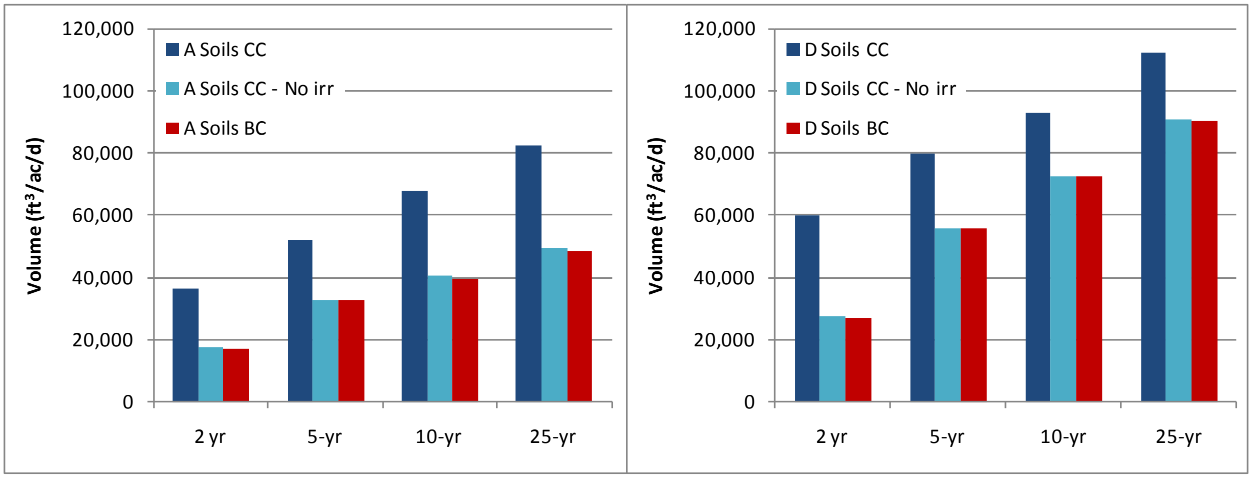

Figure 4 Comparison of Clear Creek SDHM2011 and Brown & Caldwell Daily Flow Estimates for Development Pervious Lands

Note: CC: Clear Creek SDHM2011 model; CC- no irr: Clear Creek model without irrigation; BC: Brown & Caldwell Model

The impact of irrigating developed lands had a more pronounced impact on the daily maximum flows (Figure 5 and Figure 6). The greatest impact can be seen on the 2-year return period storms where the irrigated A soils had flows more than 8 times greater than the non-irrigated Brown & Caldwell model. The D soils also had increased outflow but was 136 percent greater. As the runoff events became less frequent, the differences diminished with irrigated soils producing flows only 45 and 30 percent greater for A and D soils, respectively. The impact of irrigation reduced the storage potential of the irrigated developed pervious area, resulting in more surface runoff from those lands.

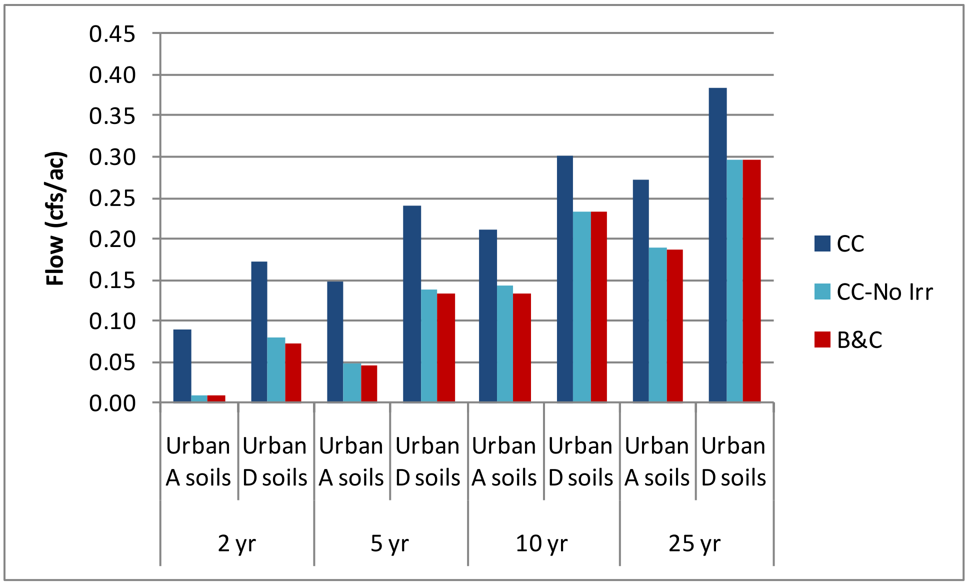

Figure 5 **Comparison of Clear Creek SDHM2011 and Brown & Caldwell Daily Max Flow Recurrence Interval for Developed Pervious Lands**

Note: CC: Clear Creek SDHM2011 model; CC- no irr: Clear Creek model without irrigation; BC: Brown & Caldwell Model

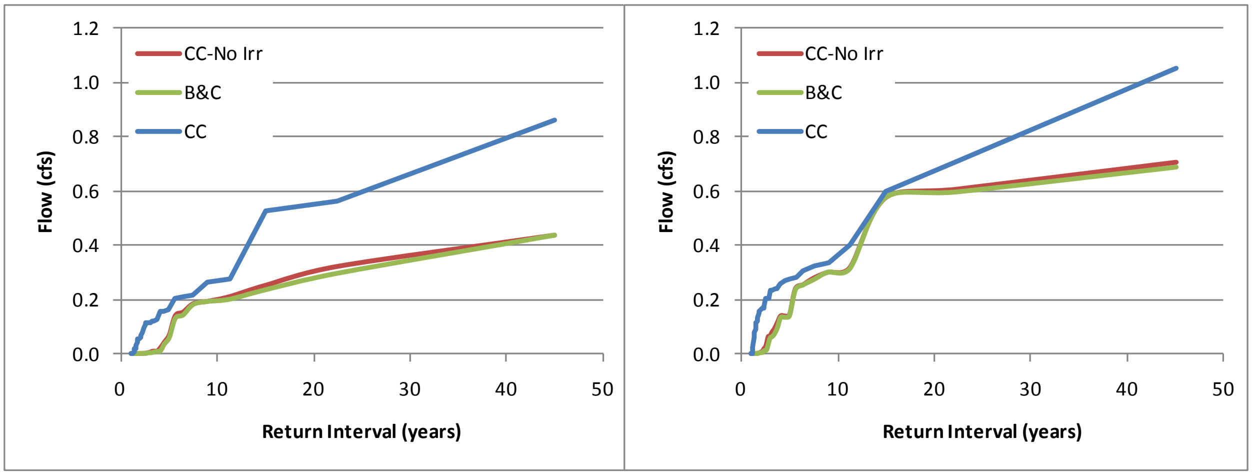

Figure 6 **Flow-Duration Curves for Daily Maximum Flows for Urban Developed Pervious Lands**

Note: CC: Clear Creek SDHM2011 model; CC- no irr: Clear Creek model without irrigation; BC: Brown & Caldwell Model

3.2.3 Impervious Area Flows

Impervious areas in both models were represented identically and, thus, had the same runoff. The daily runoff from impervious areas was 8 times that of undeveloped A soils for both modeling approaches and more than 5 times for D soils for the more frequently returning events (Figure 7). The less frequent, more intense events had a smaller increase in runoff volume but the 25-year return volumes were more than 5-fold and nearly triple for the A and D soils, respectively (Figure 8 and Figure 9).

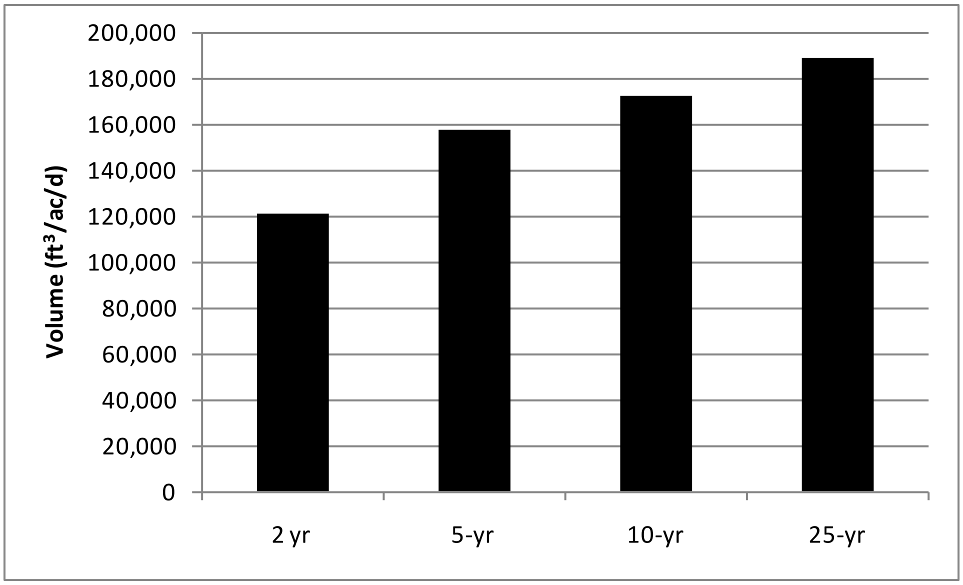

Figure 7 **Comparison of Clear Creek SDHM2011 and Brown & Caldwell Daily Flow Estimates for Impervious Lands**

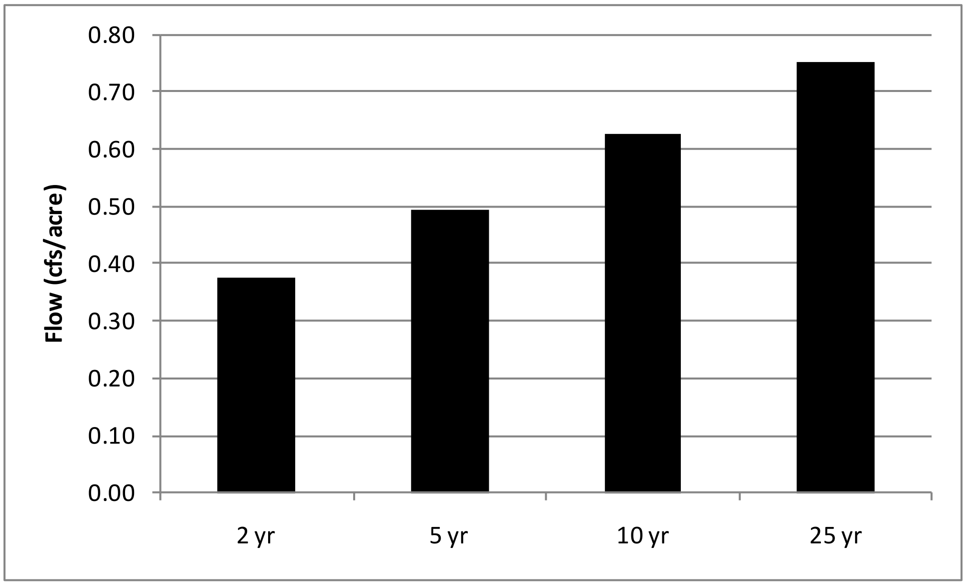

Figure 8 **Daily Max Flow Recurrence Interval for Impervious Lands**

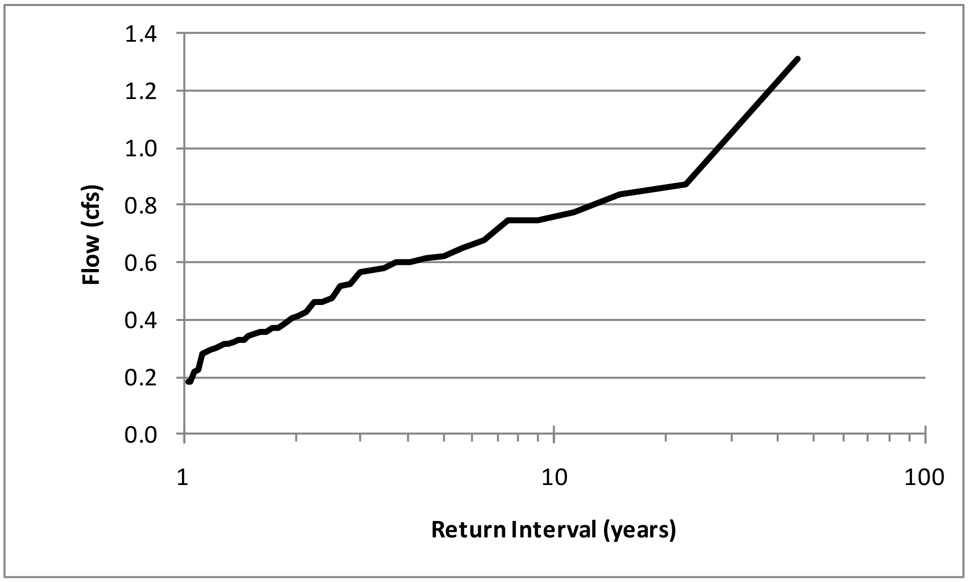

Figure 9 Flow-Duration Curve for Daily Maximum Flows for Impervious Lands

The conversion of undeveloped lands to impervious areas has greater impact on the daily maximum flows. The hourly-duration 2-year return flows for impervious lands was more than 50 times greater for A soils and 10 times that of D soils in both models. Those effects lessen as storms become less frequent and intense where a greater fraction of the flows from pervious areas were surface flows, but were still more than 5 times greater for A soils and 3 times greater for D soils in both models.

3.3 IMPLICATIONS FOR FACILITY SIZING

A hypothetical project was evaluated to determine the overall impact of the two model approaches on estimates of HMP control volumes and sizing. Following the methodology outlined in the San Diego Hydrology Manual (County of San Diego, 2003), a 1 acre, medium residential parcel with 4.3 dwelling units per acre is assumed to be 30 percent impervious. The remaining 70 percent of the parcel was assumed to be urban pervious area. The model implementation of the two approaches can then be used to evaluate the post-project runoff, and the control volume needed to match the pre-development hydrograph.

The post-project flows for the medium density residential development follows the same pattern observed in the previous results including irrigation increasing the runoff volumes significantly; the greatest increases were observed on the A soils (Figure 10).

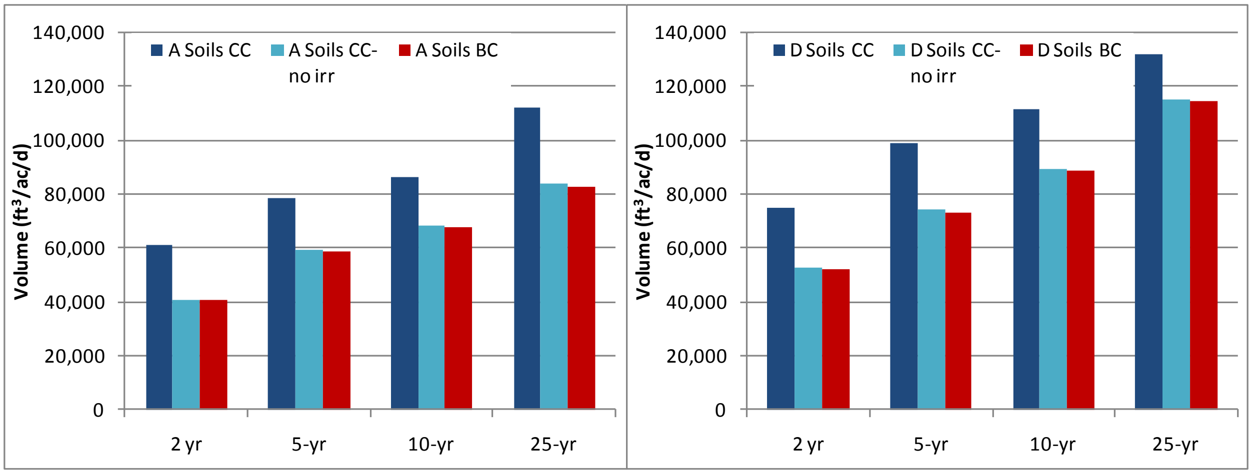

Figure 10 Comparison of Post-Project Flows for Hypothetical Development (30 Percent Impervious, Moderate Slopes)

Note: CC: Clear Creek SDHM2011 model; CC- no irr: Clear Creek model without irrigation;
BC: Brown & Caldwell Model

Subtracting the pre-project flows from the post-project flows yields an estimate of the volume of runoff that needs to be controlled to match the pre-development hydrograph. With irrigation included in the Clear Creek approach the estimated control volumes for urban land were much greater than calculated by the Brown & Caldwell methodology. The control volumes across all return frequencies were approximately 1.5 times greater for A soils and 1.7 times greater for D soils in the Clear Creek model than the Brown & Caldwell model (Figure 11). Without irrigation, model results from the two approaches were typically within 5 percent of each other. Note that the SDHM2011 tends to predict slightly larger pre-project flows, which result in slightly lower control volume requirements (for most recurrence intervals) when irrigation of urban land is not included.

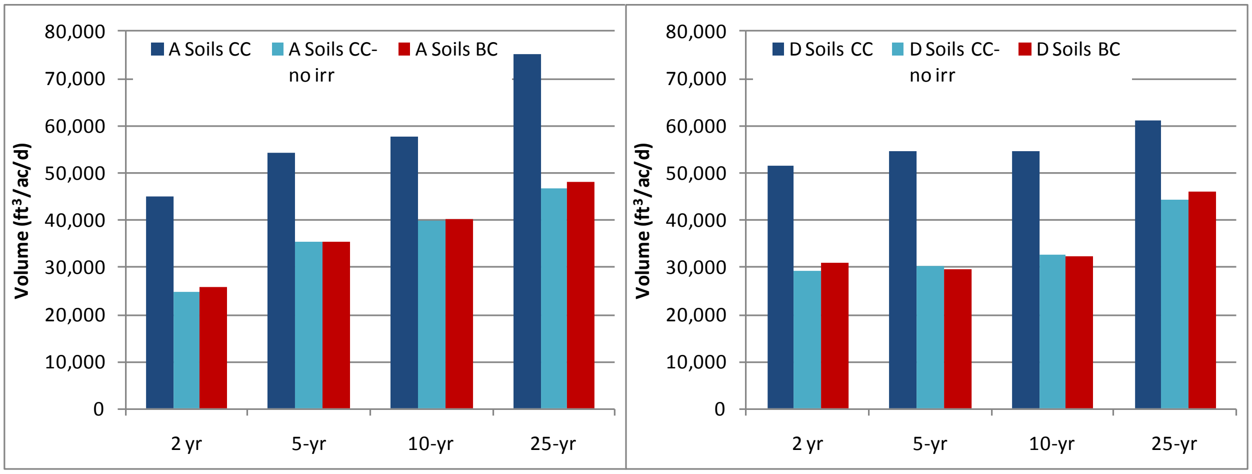

Figure 11 Comparison of Control Volumes for Hypothetical Development (30 Percent Impervious, Moderate Slopes)

Note: CC: Clear Creek SDHM2011 model; CC- no irr: Clear Creek model without irrigation;
BC: Brown & Caldwell Model

These results indicate that the SDHM2011 model will provide estimates of control volumes that are essentially identical to the Brown & Caldwell HSPF model – but only when irrigation of urban lands is not simulated and the pre-development land cover is specified as grass. Note, however, that the Brown & Caldwell Sizing Tool does not directly use the pervious land simulation for LID BMP sizing; rather, it applies a pervious sizing factor equivalent to 10 percent of the impervious sizing factor if the user specifies that any pervious area is routed to the practice. (The Pond sizing tool does include pervious area in its unit area hydrograph generation, but the time series used are stored internally and not available to the user.)

How well does the Brown & Caldwell sizing factor assumptions work relative to the full model simulation if a BMP receives flow from both pervious and impervious areas? For the case of 30 percent impervious development on D soils described above, the post-project flows estimated by the full model simulation and those estimated from the runoff from the impervious area plus 10 percent of the impervious runoff applied to the pervious area show good agreement up through a recurrence interval of approximately 1 year (Figure 12). For higher magnitude, less frequent recurrence flows the two curves diverge, which could lead to an underestimate of needed control volumes. However, the Brown & Caldwell approach assumes that pervious areas will generally not be routed to LID BMPs, and that pervious areas will generally be managed as self-retaining areas that have runoff characteristics similar or better than pre-development conditions. As shown above, this assumption seems suspect if urban irrigation occurs. In contrast, the SDHM2011 approach would enable the user more flexibility to tailor the design for the entire site directly to the HMP requirements.

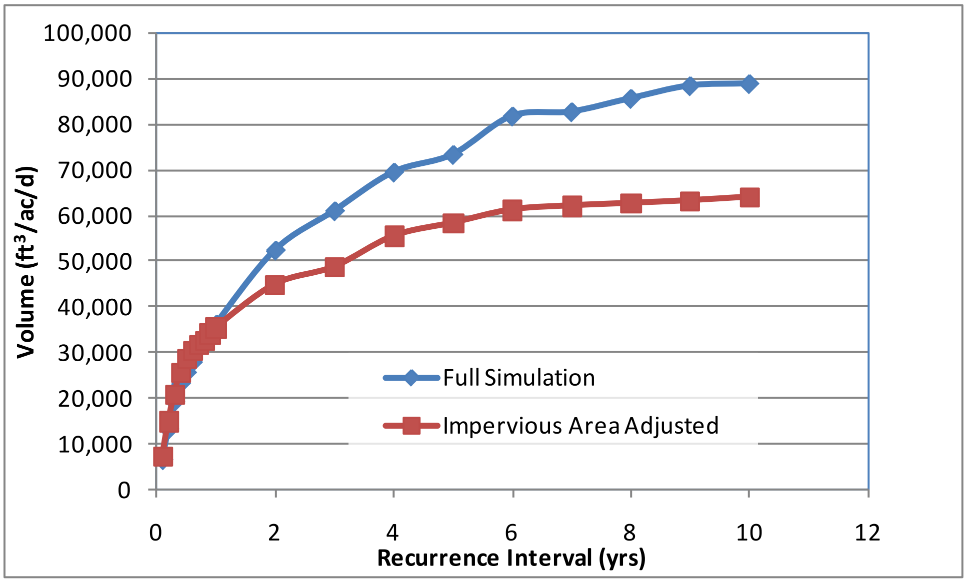

Figure 12 **Comparison of Post-project Flows Estimated from Brown & Caldwell HSPF Model (30 Percent Impervious, 70 Percent Pervious, D Soils, Moderate Slopes) and from Adjusted Impervious Runoff**

4 Simulation of BMP Hydrology

4.1 DIFFERENCES IN REPRESENTATION OF BMPS

Both SDHM2011 and the Brown & Caldwell Sizing Factors address a variety of flow control BMPs. Both use the HSPF model as the engine for analysis, but there are differences in the technical details of the approach used to simulate onsite BMPs, particularly those involving bioretention and infiltration.

Within SDHM2011, the onsite practices are simulated from a set of generic building blocks: The gravel bed trench element is used (with different parameters) to simulate porous pavement, dry wells, and infiltration trenches; the lateral flow basin element is used to simulate dispersion of runoff onto pervious surfaces; and the bioretention swale element is used to simulate green roofs, rain gardens, in-ground planters, flow-through planters, bioretention basins, and dry swales. This recycling of code elements makes practical sense; however, it can lead to unexpected results if not implemented carefully. The large number of practices simulated using the bioretention swale element and the many user options available may be particularly problematic. These have an upper (planted) soil layer, one or two lower soil or gravel layers, and an overflow device in common, and may or may not have an underdrain. The details of individual practices may differ greatly, however, and can present challenges for a generic setup. In contrast, explicit models were created for each of the BMPs used to develop the Brown & Caldwell sizing factors.

Both SDHM2011 and the Brown & Caldwell applications simulate the hydraulic performance of these practices using HSPF Functional Tables (FTables), expressing volume-stage-discharge relationships. For many of the practices, such as bioretention and planters, two FTables are linked, representing the upper and lower zones of the device. Percolation in the Brown & Caldwell applications is handled in a sophisticated way through application of Darcy’s law and the Van Genuchten relationships to account for soil water retention characteristics, including suction or matric head within the soil pores. This results in infiltration rates that increase with hydraulic head, and the values of discharge as a function of head are calculated external to the HSPF model. In early versions of Clear Creek Solutions’ models, the FTables were constructed based on a simple interpretation of soil properties including a fixed percolation rate, with the addition of a Special Actions control that ensures that the percolation rate into the lower soil layer does not exceed the available effective pore space. That resulted in differences from the Brown & Caldwell approach. In the current versions of the Clear Creek models (both SDHM2011 and other versions such as the Western Washington Hydrology Model) the infiltration routine has been upgraded to incorporate the Darcy and Van Genuchten equations, similar to the Brown & Caldwell approach. However, unlike the Brown & Caldwell models, SDHM2011 retains the Special Actions control that limits percolation to the available pore space.

The Brown & Caldwell HMP describes the setup for five LID BMP types in detail. Example UCI files were provided for two-layer bioretention on moderately sloped A soils and steep D soils, both with underdrains. A device of similar design was set up via the SDHM2011 interface which then generates HSPF UCI files that can be compared to the Brown & Caldwell model.

An important difference between the SDHM2011 and Brown & Caldwell models is the treatment of potential evapotranspiration (PET). Brown & Caldwell uses PET reduced by a crop factor of 0.78, which is applied only to the surface layer. SDHM2011 applies a factor of 0.5 to the surface soils, citing (but not referencing) information that amended soils typically exhibit a lower rate of ET than native soils, and a factor of 0.7 on the subsurface layer. Application of PET to the subsurface layer in bioretention suggests that roots are assumed to penetrate this layer, as this is certainly not a free water surface. However, testing shows that this does not make a significant impact on model results.

Earlier versions of the Clear Creek Solutions model (such as the Bay Area Hydrology Model) did not include a provision for including an orifice on the bioretention underdrain. This made it difficult to achieve HMP criteria with bioretention alone, but this shortcoming has now been rectified.

4.2 COMPARISON OF BMP SIMULATIONS

The performance of the two models was compared through a head-to-head comparison. To do this, an HSPF model was set up representing two 1-acre (unit) conversions to impervious roof from (1) grass/scrub on D soils on steep slopes and (2) grass/scrub on A soils on moderate slopes, treated with bioretention. The bioretention simulation was as provided by Brown & Caldwell, while the SDHM2011 interface was used to set up a similar bioretention unit, following the guidance in the HMP. Total outflows from each BMP were routed to nominal reaches for comparison of resulting flow durations.

The setup process highlights the difference in philosophies between the approaches. Using the Brown & Caldwell method, the conditions dictate a sizing factor that must be used for construction of a bioretention BMP that also conforms to other design specifications in the HMP (e.g., the one on D soils contains an underdrain, while the setup for A soils assumes that all excess moisture at the bottom of the bioretention cell can be infiltrated). With SDHM2011, the user has a wide range of possible configurations, and it takes some time and effort to construct a simulation that conforms to the HMP.

The example was run for the period 10/1/1959-9/30/2004, using Lake Wohlford precipitation and routing 1 acre of impervious surface to the BMP (thus providing unit area results). Results for the A soils are summarized in Figure 13. This is a portion of the (unit area) flow-duration curve for the high end of the hourly simulation results, plotting flow against the percent of time during which the flow is exceeded.

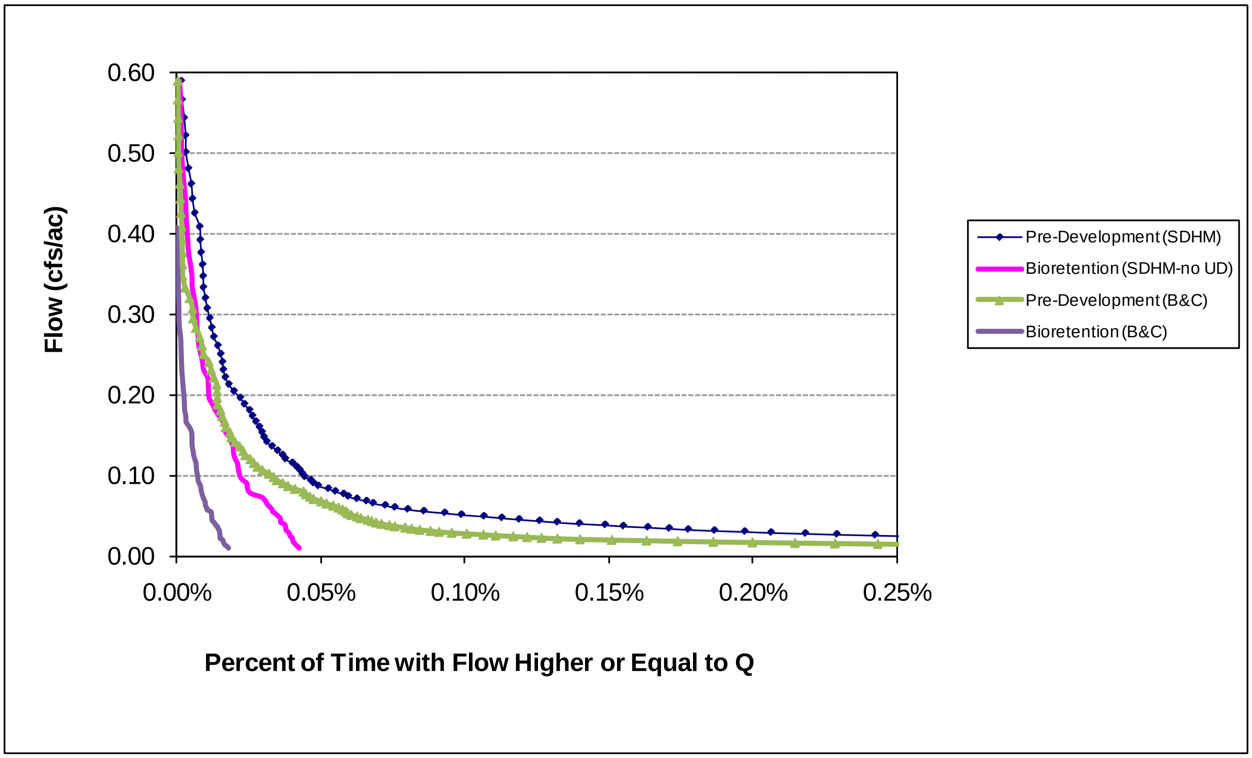

Figure 13 Bioretention Simulation on A Soils, Moderate Slopes

Pre-developments flow durations are shown by the blue line (SDHM) and the green line (Brown & Caldwell). As was seen above (Figure 3) SDHM2011 results in slightly higher flow volumes for flows of a given recurrence on A soils than does the Brown & Caldwell model, due to the treatment of lower zone evapotranspiration. For the 45-year record, the direct estimate of Q2 from the complete SDHM2011 results (the hourly flow that is exceeded is the fraction of 1/[2 x 365.25 x 24] of the time) is 0.442 cfs/ac, while the estimate from the Brown & Caldwell simulation results is 0.289 cfs/ac. In contrast, the partial duration analysis reported by Brown & Caldwell (2011b) in Table 1-6 yields a Q_2 of 0.351 cfs/ac.

The bioretention outflow (all overflow in this case) is shown in magenta for SDHM2011 and in purple for the Brown & Caldwell model. Each remains below the pre-development duration curve over its entire length and thus satisfies the HMP. The two bioretention cell model representations perform identically – the results differ primarily because of the differences in the pre-development simulation – because the dimensions of the bioretention cell and the overflow structure used in SDHM2011 were developed from the HMP specifications and thus yield an FTable that is essentially identical to that used by Brown & Caldwell.

For the D soils an underdrain is required in the design. This complicates achieving the HMP goals, as persistent flow from the underdrain extends the tail of the hydrograph, which must be controlled down to a flow equal to a specified fraction of Q_2. This is done by placing a restricting orifice on the underdrain. The Lake Wohlford example provided by Brown & Caldwell appears to use a rule of 0.5 Q_2 for the maximum flow from the underdrain orifice, which would be 0.1755 cfs/ac. However, the FTable for the lower layer of the bioretention facility supplied for this case had a maximum flow from the underdrain of 0.1861 cfs/ac:

```
  FTABLE      2
 rows cols                                          ***
   21    5
     Depth      Area    Volume    Q perc     Q out  ***
      (ft)   (acres) (acre-ft)     (cfs)     (cfs)  ***
      0.00      0.06    0.0000    0.0000    0.0000
      0.08      0.06    0.0019    0.0000    0.0416
      0.15      0.06    0.0037    0.0006    0.0589
      0.23      0.06    0.0056    0.0014    0.0721
      0.30      0.06    0.0075    0.0014    0.0832
      0.38      0.06    0.0093    0.0014    0.0931
      0.45      0.06    0.0112    0.0014    0.1020
      0.53      0.06    0.0131    0.0014    0.1101
      0.60      0.06    0.0149    0.0014    0.1177
      0.68      0.06    0.0168    0.0014    0.1249
      0.75      0.06    0.0187    0.0014    0.1316
      0.83      0.06    0.0205    0.0014    0.1381
      0.90      0.06    0.0224    0.0014    0.1442
      0.98      0.06    0.0243    0.0014    0.1501
      1.05      0.06    0.0261    0.0014    0.1557
      1.13      0.06    0.0280    0.0014    0.1612
      1.20      0.06    0.0299    0.0014    0.1665
      1.28      0.06    0.0317    0.0014    0.1716
      1.35      0.06    0.0336    0.0014    0.1766
      1.43      0.06    0.0355    0.0014    0.1814
      1.50      0.06    0.0374    0.0014    0.1861
  END FTABLE2
```

Simulation using this FTable shows that the crossover point between the pre-development and bioretention flow-duration curves does indeed occur at approximately 0.1755 cfs/ac (e.g., $0.5Q_2$). It appears that iterative adjustments to the FTable were likely made to achieve this result. Note that the FTable also specifies a non-zero infiltration rate of 0.0014 cfs/ac despite the presence of D soils. This seems inappropriate, as the HMP only allows accounting for infiltration to such soils after consultation with a geotechnical engineer, and native infiltration rates on compacted clay (D) soils are likely to be near zero.

SDHM2011 does not do automated sizing of underdrains; this is left to the user. The orifice equation was used to size an orifice that yields a maximum outflow of $0.5Q_2$ = 0.1755 cfs/ac and no infiltration to native soils was assumed. Note that this yields a slightly different FTable than that used by Brown & Caldwell.

Results of the D soils simulation are shown in Figure 14. The Brown & Caldwell simulation behaves as intended: The flow duration curve for outflow from the Brown & Caldwell bioretention facility (purple line) remains below that for pre-development conditions (as estimated by the Brown & Caldwell model; green line) from the Q_{10} flow (0.538 cfs/ac) to the 0.5Q2 flow (0.1755 cfs/ac). Flows below $0.5Q_2$ are allowed to occur more frequently than under pre-development conditions because they are not within the range of flows that need to be controlled.

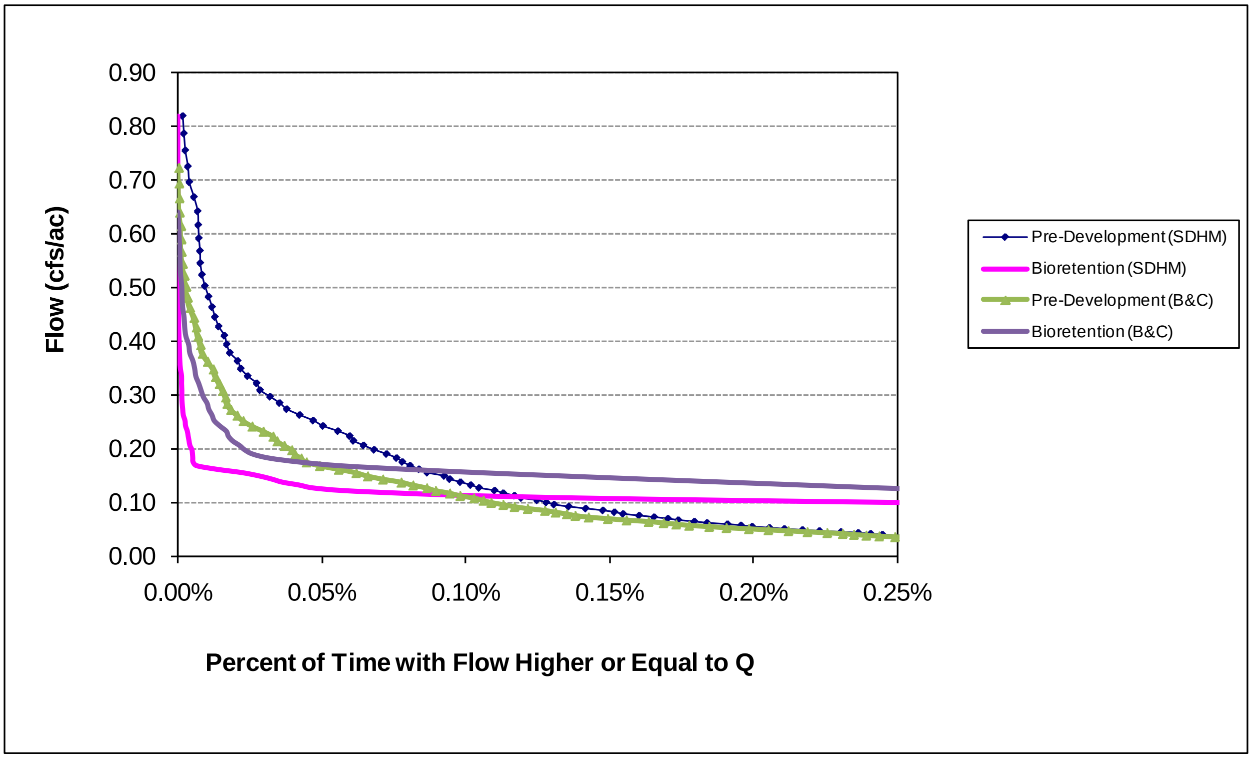

Figure 14 Bioretention Simulation on D soils, Steep Slopes

SDHM2011 results are shown by the blue line (pre-development) and magenta line (bioretention with underdrain). The shapes of these lines are similar to the Brown & Caldwell model, but the crossover (lower control) point is at a higher duration. Specifically, it occurs at about 0.11 cfs/ac and not, as intended, at the $0.5Q_2$ of 0.1755 cfs/ac (that instead yields the inflection point on the magenta line). Thus, use of SDHM2011 with the maximum underdrain orifice flow set equal to the lower control volume will yield overly conservative results that control a range of flows greater than intended.

A practical problem with the SDHM2011 model is that it does not do automatic sizing of the underdrain orifice. As shown by the simulations, setting the bottom row of the FTable to the intended lower flow criterion does not automatically guarantee that the intended control range will be exactly obtained. Thus, the user may need to pursue several iterations to hone in on an optimal design.

5 Ability to Simulate Event Volumes

HSPF models driving both the Brown & Caldwell Sizing Calculator and the Clear Creek SDHM2011 were developed without detailed local calibration. An important question is whether these models are consistent with the existing engineering methodologies established for calculating discharges of 2- and 10-year recurrence intervals in the Hydrology Manual (County of San Diego, 2003).

For the estimation of peak flows of a given recurrence, the Hydrology Manual recommends use of the Rational Method for analyzing the runoff response from drainage areas up to approximately 1 square mile in size. The Rational Method formula estimates the peak rate of runoff at any location in a watershed as a function of the drainage area (A), runoff coefficient (C), and rainfall intensity (I) for a duration equal to the time of concentration (Tc). San Diego has developed a procedure that converts the 6-hour and 24-hour precipitation isopluvial map data to an Intensity-Duration curve that can be used for the rainfall intensity in the Rational Method formula. A Modified Rational Method is also presented for use where there is a junction of independent drainage systems in watersheds up to 1 square mile in size, while the NRCS Hydrologic Method should be used for watersheds greater than approximately 1 square mile in size.

Direct application of the Rational Method yields (instantaneous) peak discharge for a given recurrence interval. A direct estimate of peak discharge is not provided by either the Sizing Calculator or the SDHM2011 because both these models operate at an hourly time step. For small watersheds and the maximum length of sheet flow assigned to both developed and natural areas (Table 3-2 in County of San Diego, 2003), the time of concentration will generally be well less than 1 hour. Therefore, a simulation model operating at an hourly time step will not yield the expected instantaneous peak discharge and a direct comparison cannot be made on this basis. Instead, comparison must be done on the basis of flows of an hourly duration and a specified recurrence.

The Rational Method does not directly create hydrographs, and thus does not directly provide an estimate of flows at a duration longer than Tc. However, such information is often needed for design and sizing of detention basins. To address this issue in small watersheds, Section 6 of the Hydrology Manual presents a Rational Method hydrograph procedure. This develops a hydrograph by convoluting a series of responses with length equal to Tc to determine the full hydrograph of runoff from a 6-hour storm event. The hydrograph for the entire 6-hour storm event is generated by creating a rainfall distribution consisting of blocks of rain, creating an incremental hydrograph for each block of rain, and adding the hydrographs from each block. The entire procedure is automated in a program (RATHYDRO) distributed by SD DPW. Analysis of the resulting hydrograph enables estimation of the maximum discharge over an approximately 1-hour interval (nearest integer multiple of Tc).

A comparison of the peak discharge estimates from the three methods (Rational Method hydrograph procedure, Sizing Calculator, and SDHM2011) was conducted using a simple example site, placed directly at the Lake Wohlford rain gauge. The example site is identical to that shown in WB.2 of the Hydrology Manual and used therein to demonstrate application of the Rational Method. This site consists of a 6-lot single-family medium density residential subdivision occupying 2.2 acres on D soils, as shown in Figure 15. Concentrated flow occurs through an open gutter on the adjoining residential street. As shown in the Hydrology Manual, initial calculations are done for overland flow in the subarea from nodes 0101 to 0102:

$C = 0.52$

$A_{0101\text{-}0102} = 0.4$ acres

$L = 220$ feet; reduced to 70-foot maximum per Table 3-2 of the Hydrology Manual

$s = 1.1\%$ slope.

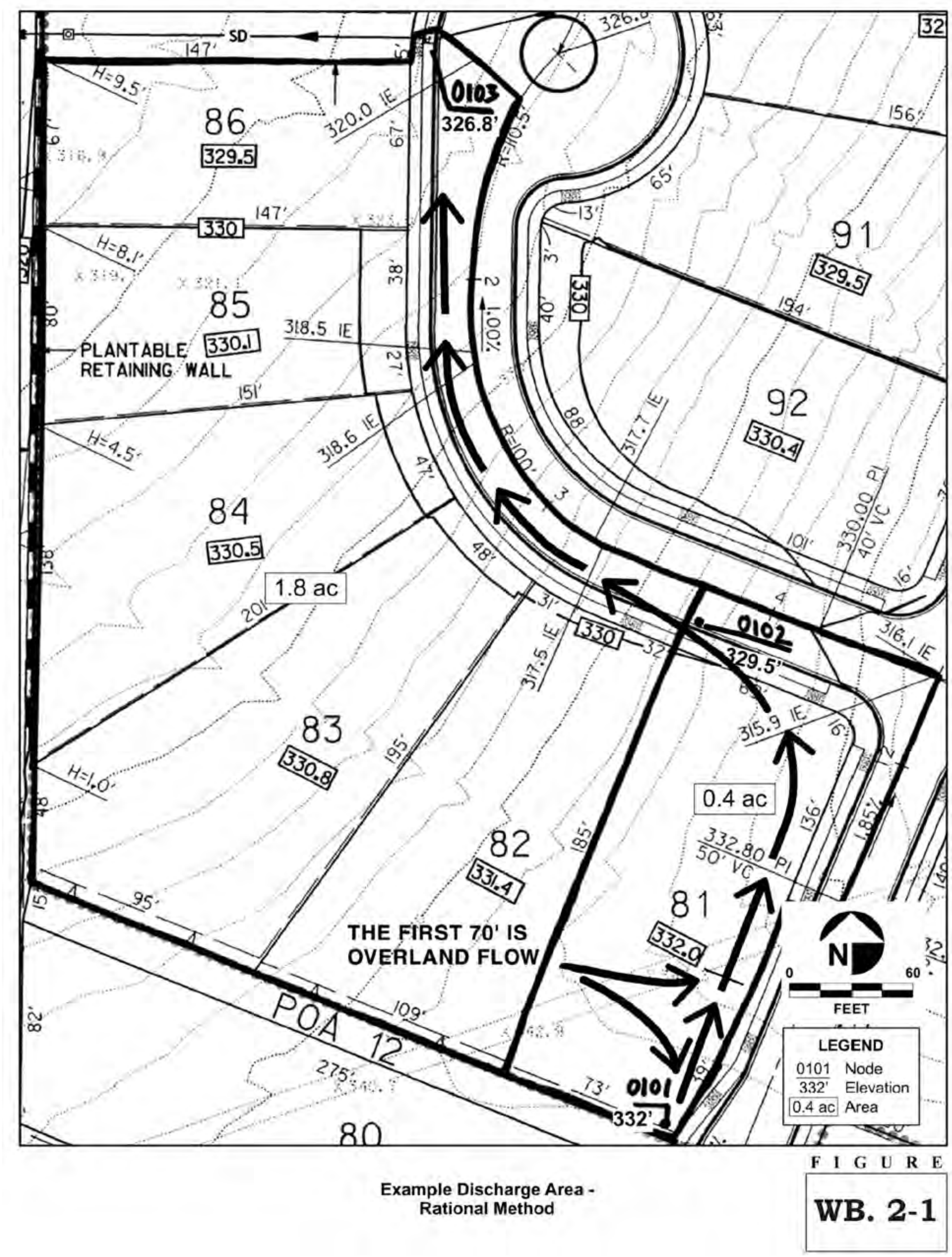

Figure 15 Example Development Site (County of San Diego, 2003, W.B.2)

In the example given in W.B.2.1, intensity for the 100-year event is determined from the isopluvial maps in Appendix B of the Hydrology Manual based on precipitation over a 6-hour period (P_6). This estimate is adjusted if P_6 is not within 45 percent to 65 percent of P_{24}. In the worked example, P_6 (not at Lake Wohlford) was 2.8 inches and required no adjustment.

Initial travel time is based on the maximum allowable distance of L = 70' (the travel time for the remaining 150' across the pad is neglected since it will be small with respect to T_i), yielding
T_i = 8.5 minutes.

Time of travel in the gutter, T_t, is then calculated from point 0102 to 0103. This is done iteratively by assuming an average Q over the drainage area (Q_{avg}), calculating velocity in the gutter, using this to determine T_t and $T_c = T_i + T_t$, redetermining the intensity based on T_c, recalculating the flow based on the revised intensity, and trying different values of Q_{avg} until the two estimates of flow from the watershed converge. For the case presented in W.B.2.1, analysis of a 100-year event resulted in the following results at node 0103:

$Q_{avg} = 3.2$ cfs

$Q_{0103} = 5.3$ cfs

$T_c = 10.5$ minutes

$I_{100} = 4.6$ inches/hr

For analysis of the 2-year and 10-year events at Wohlford, the relevant isopluvial data from the maps in Appendix B of the Hydrology Manual are shown in Table 10. The P_6 values do not require adjustment because they are within the acceptable range of P_{24}.

Table 10 Isopluvial Data for 2-year and 10-year Events at Lake Wohlford

Recurrence	P_6 (inches)	P_{24} (inches)	P_6/P_{24}
2-yr	1.6	2.7	59%
10-yr	2.4	4.5	53%

Rational Method calculations for the site yield the following results

2-yr Event

$Q_{avg} = 1.8$ cfs

$Q_{0103} = 2.9$ cfs

$T_c = 10.6$ minutes

$I_2 = 2.6$ inches/hr

10-yr Event

$Q_{avg} = 2.7$ cfs

$Q_{0103} = 4.5$ cfs

$T_c = 10.5$ minutes

$I_{10} = 3.9$ inches/hr

These results were taken into the RATHYDRO program and the resulting hydrograph was used to estimate the maximum average flow for intervals bracketing a duration of 1-hour over the storm hydrograph. (Note: The calculation is approximate due to the number of significant digits reported in RATHYDRO.)

For the Brown & Caldwell Sizing Calculator and the SDHM2011, flows of a given recurrence were estimated directly from the time series generated by a 45-year run (the maximum length for which the PET series are available). The run combines 30 percent urban impervious and 70 percent pervious on D soils. The pervious portion was represented in two variations: urban land use on D soils (for which only moderate slopes are simulated by both models) and grass on low-slope D soils (which accounts for low slope does not include irrigation). As HSPF simulates uplands on a unit area basis, the result is multiplied by 2.2 acres. Recurrence interval is then given by the plotting position formula (N+1)/*m*, where N is the total number in the series and *m* is the rank when sorted from the largest to smallest of the annual maxima (i.e., the 2-year recurrence 1-hour event is equal to the flow that is exceeded 1/(2 x 365.25 x 24) = 0.0057038 percent of the time). Results are shown in Table 11 (note that calculation from a series of annual maxima yields similar estimates for the 10-year event and a lower estimate for the 2-year event, as would be expected).

Table 11. Comparison of Estimated 1-hour Duration Peak Flows (cfs) from 2-year and 10-year Storms on 2.2-acre Medium Density Residential Development at Lake Wohlford

	RATHYDRO	Brown & Caldwell		SDHM2011	
		70% grass, low slope, D	70% Urban D	70% grass, low slope, D	70% Urban D
2-year Storm	0.87	0.440	0.513	0.445	0.654
10-year Storm	1.32	0.617	0.798	0.624	0.946

Results from the Brown & Caldwell and SDHM2011 models are similar to one another when the pervious land is specified as grass, but SDHM2011 gives substantially greater estimates when the urban category is used – because Clear Creek considers urban irrigation, while Brown & Caldwell does not. All the estimates from both the Brown & Caldwell and SDHM2011 models are only a fraction of the 1-hour duration peak predicted by RATHYDRO. This difference is primarily due to the rainfall series: Over the 1959 – 2004 simulation period the maximum reported 1-hr precipitation at Lake Wohlford is 1.36 in. However, the estimated 2-year and 10-year recurrence 1-hr precipitation amounts for this period from the Lake Wohlford time series are 0.534 and 0.795 in/hr. In contrast, the 2-year 1-hour intensity predicted from the 6-hour isopluvial map (using the formula $I_D = 7.44\ P_6\ D^{-0.645}$, where D is duration in minutes) is 0.849 in/yr, while the 10-year 1-hour intensity from the isopluvials is 1.27 in/hr. These are about 1.6 times greater than those estimated from the 1959 – 2004 time series. The remainder of the difference in results apparently comes from the Rational Method predicting a higher rate of discharge than the HSPF models.

In sum, the Brown & Caldwell Sizing Calculator and the SDHM2011 are not consistent with one another in predicting 2-year and 10-year 1-hour duration peak flows due to the treatment of irrigation – and can also differ considerably from calculations made with the Rational Method. For the example case at Lake Wohlford, the Rational Method calculations are much more conservative. This may reflect uncertainty in the 6-hour isopluvial map as well as the possibility that the selected 1959 – 2004 time period used in the HSPF model simulations may not be representative of long-term precipitation recurrence.

Finally, it should be repeated that both the Sizing Calculator and SDHM2011 operate on a 1-hour time step. This time step is much longer than the time of concentration expected for small developments (typically on the order of 10 to 15 minutes). Therefore, neither the Sizing Calculator nor SDHM2011, as currently configured, can provide accurate estimates of instantaneous peak discharge rates.

The HMP establishes a goal for peak flow control: “For flow rates ranging from the lower flow threshold to Q5, the post-project peak flows shall not exceed pre-project peak flows. For flow rates from Q5 to Q10, post-project peak flows may exceed pre-project flows by up to 10% for a 1-year frequency interval.” If “peak flow” is interpreted here as the instantaneous peak flow, neither the Brown & Caldwell approach nor the SDHM2011 is appropriate for estimating such peaks. Further, both models appear to underestimate hourly flow peaks calculated by the Rational Method. However, when both pre-development flows and post-mitigation flows are calculated by the same method (i.e., with HSPF simulation), controlling the modeled post-development hourly peaks to meet the HMP requirements relative to the modeled pre-development hourly peaks is likely sufficient to achieve a similar level of control on instantaneous peaks – although this is not proven. To better investigate these issues, both models could be improved through use of a 15-minute, rather than hourly time step. Brown & Caldwell (2011b) does report the results of some sensitivity analyses using 15-minute precipitation; however, these analyses focus on hydrograph matching and not on peak flow analysis.

6 Summary and Recommendations

6.1 ADEQUACY OF METHODS TO ADDRESS THE HMP

The HMP requires post-development flow peaks and durations of a range of storm event flows to not exceed (or rarely exceed) the pre-developed condition, using continuous simulation hydrology modeling. Brown and Caldwell developed an HSPF model assumed to be consistent with representative parameters for Southern California. Model pre-development hydrology allowed for variation in some of the most critical landscape characteristics – slope, HSG, and precipitation regime – which are carried through to the HMP requirements. Model post-development hydrology accounts for BMP influence on hydrology, and appears to successfully represent variations in LID BMP designs across a range of low to high runoff events. It is our opinion that the HSPF modeling as implemented in the HMP is likely to address the core HMP requirements for managing peak flows and durations, although uncertainty remains regarding adequacy to address instantaneous peak flows.

By incorporating the HMP BMP requirements for the LID sizing, and by using HSPF unit area runoff series for the pond sizing routine, the BMP Sizing Calculator *a priori* incorporates the HMP requirements and is adequate for site design evaluation. SDHM2011 is also capable of evaluating the HMP requirements, but requires appropriate user choices to do so.

6.2 ACCEPTABILITY OF SDHM2011

Tetra Tech conducted a rigorous evaluation of SDHM2011. The model is designed to use assumptions very similar to most of those used by Brown & Caldwell in the background modeling from which the Sizing Factor tool was derived. There are some differences, but these are not major and are within the realm of plausible alternatives. It is thus our considered opinion that SDHM2011 is technically acceptable for use in developing site plans to meet the requirements of the San Diego HMP, with the exception of potential issues with its compliance reporting methods.

Our review indicates that the SDHM2011 Project Report does not provide a complete set of statistics for assessing compliance with HMP criteria (listed in Section 1.2), and it is possible that the Q2 and Q10 values (which are the basis for determining the range for hydrograph matching) are not calculated in a manner consistent with the HMP. SDHM2011 is sound for modeling site discharge for pre- and post-developed conditions; however, the analysis and reporting must be tuned for San Diego County HMP requirements. The method used by SDHM2011 to estimate Q2 and Q10 is not fully documented and could not be determined during review. The help file states that a series of maxima are used, but the analysis screen reports considerably more peaks. These are apparently drawn from hourly output, and it is not stated if these have first been analyzed into discrete events as required in the HMP (the HMP defines a discrete event as separated from other events by a period of at least 24 hours below a specific threshold). Assurance needs to be provided that the SDHM2011 evaluates Q2 and Q10 consistent with the HMP before final certification given that the tool provides an acceptable alternative to the BMP Sizing Calculator.

There is a great degree of user freedom in the setup of the SDHM, and not all options that a user may select are compatible with the HMP and/or the San Diego Hydrology Manual or other local requirements. Therefore, submissions developed using SDHM2011 will require careful review and scrutiny. Tetra Tech will develop a separate checklist for staff review of SDHM2011 submissions. In most cases, the sizes of BMPs calculated through an SDHM2011 application to meet HMP requirements should be very similar to those calculated with the Brown & Caldwell sizing factors, so reference to those sizing factors will be the first level of cross-checking. If there are significant differences, more detailed review will be needed.

It should also be noted that in reviewing SDHM2011 we encountered a number of minor bugs in the user interface, some of which resulted in incorrect parameter settings being incorporated into the resulting simulation models. Clear Creek Solutions has been responsive and prompt in addressing such bugs; however, their existence does emphasize the need for careful review of SDHM-based submissions.

6.3 SUMMARY OF RECOMMENDATIONS

As described in the preceding sections, both Brown & Caldwell's Sizing Calculator and Clear Creek Solutions SDHM2011 appear to provide an adequate basis for evaluating site designs relative to the San Diego HMP. Results obtained by the two methods should generally be similar. The Sizing Calculator was created in conjunction with the HMP and will likely be the default method used in most cases. Submissions made using SDHM2011 should also be acceptable, but will require more extensive review.

Based on our review, Tetra Tech recommends a number of refinements to improve the performance and consistency of both HMP tools:

1. The HSPF models driving the two applications (which intentionally have the same hydrology parameters) need to be tested and calibrated against local conditions in San Diego County, preferably using a long period of hourly gage data in several small watersheds. As described in Section 3, some of the parameter assumptions appear suspect for San Diego County and may affect results.
2. The issue of using monthly LZETP values needs to be resolved. Turning off the monthly flag in SDHM2011 would ensure consistency between the modeling approaches; however, Tetra Tech is not convinced that an approach without monthly variability is appropriate.
3. Further review should be undertaken of the review of urban irrigation in determining post-development flow durations. Brown & Caldwell currently ignores urban irrigation, while the basis for Clear Creek Solutions' representation of irrigation is not documented. We suspect that irrigation does play a sufficient enough role in the distribution of flows within the HMP control range that it needs to be considered in HMP planning; however, this is open to further investigation and sensitivity analysis.
4. The period of record of meteorological data used by both approaches (1959-2004) appears to be inconsistent with assumptions incorporated in the County of San Diego isopluvial maps and may underestimate the long-term frequency of large flows. Further research on this topic is recommended.
5. Neither the Brown & Caldwell nor the Clear Creek Solutions HSPF model are appropriate for estimating instantaneous storm flow peaks at the development scale as the 1-hour model time step is substantially longer than the likely time of concentration. This could be remedied by modifying both models to use 15-minute data, if available. At a minimum, design components of BMPs that depend on peak discharge need to continue to be reviewed with the methods in the County of San Diego's (2003) Hydrology Manual.
6. The Brown and Caldwell automated pond sizing routine could not be reviewed in detail, since it resides as a back-end web-application within the BMP Sizing Calculator website. The pond sizing routine should be reviewed by a qualified entity fluent in both the programming environment used by the tool, as well as the underlying computational routing routine.
7. Clear Creek Solutions should validate or update SDHM2011 analyses for Q2 and Q10 to be consistent with the San Diego County HMP criteria. Without such assurance, the Project Report cannot be used to fully demonstrate compliance. The specific criteria and allowable exceedances discussed in Section 6.2, page 6-9 of the HMP should also be validated or updated.

7 References

AQUA TERRA. 2006. Hydrologic Modeling of the Castro Valley Creek and Alameda Creek Watersheds with the U.S. EPA Hydrologic Simulation Program – FORTRAN (HSPF). Prepared for Alameda Countywide Clean Water Program. AQUA TERRA Consultants, Mountain View, CA.

Beyerlein, D. 2007. Santa Clara HSPF Calibrations. Memorandum from Doug Beyerlein to Jill Bicknell, SCVURPPP, 5 May 2007. Clear Creek Solutions, Mill Creek, WA.

Bicknell, B.R., J.C. Imhoff , J.L. Kittle, Jr., T.H. Jobes , and A.S. Donigian, Jr. 2001. Hydrological Simulation Program – FORTRAN, HSPF, Version 12, User's Manual. National Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Athens, GA.

Brown & Caldwell. 2011a. Hydromodification Management Plan (Final). Prepared for County of San Diego. Brown & Caldwell, San Diego, CA.

Brown & Caldwell. 2011b. San Diego BMP Sizing Calculator Methodology (Draft, May 2011). Prepared for San Diego Copermittees. Brown & Caldwell, San Diego, CA.

Clear Creek Solutions. 2008. San Diego Hydrology Model, User Manual. Clear Creek Solutions, Mill Creek, WA.

Clear Creek Solutions. 2007. Bay Area Hydrology Model, User Manual. Clear Creek Solutions, Mill Creek, WA.

County of San Diego. 2003. San Diego County Hydrology Manual. Department of Public Works Flood Control Section

Project Clean Water. 2011. Countywide Model SUSMP - Standard Urban Stormwater Mitigation Plan Requirements for Development Applications (March 25, 2011).

USEPA. 2000. Estimating Hydrology and Hydraulic Parameters in HSPF. BASINS Technical Note 8. EPA-823-R00-012. Office of Water, U.S. Environmental Protection Agency, Washington, DC.