CALIFORNIA PHASE II LID SIZING TOOL DOCUMENTATION MANUAL

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Prepared by:
California State University Sacramento
Office of Water Programs
6000 J Street. Modoc Hall Room 1001
Sacramento, CA 95819-6025
www.owp.csus.edu

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APPENDICES

1.0 INTRODUCTION

This manual documents background information for the California Phase II Low Impact Development (LID) Sizing Tool. This is a web-based tool that assists stormwater practitioners in selecting and sizing LID Best Management Practices (BMPs) that meet the sizing requirements set forth in California's National Pollutant Discharge Elimination System (NPDES) permit for stormwater discharges from small municipal separate storm sewer systems (MS4s, SWRCB 2013). The tool allows users to input their location, soil type, and impervious areas, and then queries a database containing pre-solved sizing factors and design curves for a variety of BMP types, performs permit-based sizing calculations, and tabulates allowable sizes for each BMP type. Sizing results are provided based on three different sizing methods allowed by the Phase II permit: a Design Storm Method, a Percent Capture Method, and a Baseline Bioretention or Equivalent Performance Method. Sizing results are also provided for the Central Coast Regional Water Quality Control Board (RWQCB) simple sizing method adopted via resolution R3-2013-0032 (CA RWQCB Central Coast 2013). Users are also provided references for considering BMP feasibility factors beyond sizing, such as site topography and geometry and BMP maintenance requirements and costs. The tool includes training videos to visually instruct users on various aspects of the tool's interface, input, and output.

Development of this tool was funded by the California State Water Resources Control Board's (SWRCB) Proposition 84 Stormwater Grant Program (SWGP). The tool was developed by California State University, Sacramento's Office of Water Programs and is hosted on their website at: https://www.owp.csus.edu/specialized/tools.php.

2.0 PURPOSE AND NEED

Although a variety of LID BMP types are available, selecting and sizing them to meet permit requirements under site-specific conditions is difficult for many small MS4s due to the lack of an accurate and consistent means to compare their potential performance. Most tools that are available for statewide application simulate runoff based only on depth of precipitation for a single design storm and do not incorporate factors such as region-specific precipitation intensity, back-to-back storms (including antecedent moisture conditions), evaporation, etc. When these mechanisms are not simulated on a small (e.g., hourly), continuous time-step, it can result in inappropriate designs, which in the field either do not perform adequately or are oversized, and thus a waste of resources. The few continuous simulation models that do exist require extensive training and understanding of the base model, provide only conceptual methods for choosing and sizing BMPs, and/or apply only to fragmented locations and particular site conditions. These problems constitute a significant barrier to successful implementation of LID, particularly by small MS4s. The California Phase II LID Sizing Tool includes results from design storm calculations as well as continuous simulation. This improves the selection of cost-effective LID BMPs and increases LID implementation by supplying a simple and easily accessed application.

3.0 PHASE II NPDES REGULATORY CONTEXT

The Phase II permit requires implementation of LID standards for all new development and redevelopment projects that create and/or replace 5,000 square feet or more of impervious surface (regulated projects; with some exceptions for non-traditional permittees – see permit Section F.5.g.2.ii). All regulated projects must include LID BMPs that meet specific hydraulic sizing criteria.

The methods allowed for achieving permit criteria vary in complexity and can result in a wide variety of designs, and, as a result, costs. The CA Phase II LID Sizing Tool was developed to provide designers, planners, and regulators with a simplified process for selecting and sizing LID BMPs that comply with the permit sizing criteria. The tool includes relatively simple and land-intensive LID BMPs alongside more traditional and smaller-footprint designs so that the most cost-effective LID BMPs can be selected based on site-specific conditions such as land costs and topography.

The CA Phase II LID Sizing Tool provides three sizes (in area) for each LID BMP type based on the volumetric sizing criteria established in the Phase II permit. A fourth size is provided based on requirements adopted via resolution by the Central Coast RWQCB (Region 3): The four methods presented by the tool include the following:

1. Design Storm Method
2. Percent Capture Method
3. Baseline Bioretention or Equivalent Performance Method
4. Central Coast Simple Method

The Design Storm Method and Central Coast Simple Method are intended to allow easy sizing calculations, but may be a little conservative (i.e., result in over-sized LID BMPs). The Percent Capture Method requires continuous simulation – a much more complicated analysis – so a more precise (less conservative) result might be expected. As a backstop to these approaches, the Phase II permit also allows a very simple bioretention approach, where the size and other bioretention characteristics are pre-established without regard to local precipitation data. An equivalence criteria for this “permit-prescribed” bioretention approach is also allowed by the permit, but the method for determining equivalence is left up to the reader. The CA Phase II LID Sizing Tool’s Baseline Bioretention or Equivalent Performance Method addresses this additional permit sizing option.

The following subsections describe the specific permit or resolution sections from which the tool’s sizing methods were based. Section 4.2 of this manual describes the conceptual and mathematical derivations for these methods.

3.1 Design Storm Method

The Design Storm Method is based on Section E.12.e.ii.c.1.a of the permit, which allows LID stormwater retention and treatment facilities that evapotranspire, infiltrate, harvest/use, and biotreat stormwater to be designed as follows (SWRCB 2013):

> “The maximized capture storm water volume for the tributary area, on the basis of historical precipitation records, determined using the formula and volume capture coefficients in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87 (1998) pages 175-178 (that is, approximately the 85th percentile 24-hour storm runoff event)”.

3.2 Percent Capture Method

The Percent Capture Method is based on Section E.12.e.ii.c.1.b of the permit, which allows LID BMPs to be designed as follows (SWRCB 2013):

> “The volume of annual runoff required to achieve 80 percent or more capture, determined in accordance with the methodology in Section 5 of the CASQA’s Stormwater Best Management

Practice Handbook, New Development and Redevelopment (2003), using local precipitation data."

3.3 Baseline Bioretention or Equivalent Performance Method

The Baseline Bioretention or Equivalent Performance Method is based on Section E.12.e.ii.f of the Phase II permit. This permit section allows use of a stormwater treatment measure designed to: 1) infiltrate, evapotranspire, and/or bioretain runoff based on the sizing criteria from Section E.12.e.ii.c.1, and 2) be as effective as a bioretention system with the following permit-specified design parameters (SWRCB 2013):

1) Maximum surface loading rate of 5 inches per hour, based on the flow rates calculated. A sizing factor of 4% of tributary impervious area may be used.
2) Minimum surface reservoir volume equal to surface area times a depth of 6 inches.
3) Minimum planting medium depth of 18 inches. The planting medium must sustain a minimum infiltration rate of 5 inches per hour throughout the life of the project and must maximize runoff retention and pollutant removal. A mixture of sand (60%-70%) meeting the specifications of American Society for Testing and Materials (ASTM) C33 and compost (30%-40%) may be used.
4) Subsurface drainage/storage (gravel) layer with an area equal to the surface area and having a minimum depth of 12 inches.
5) Underdrain with discharge elevation at top of gravel layer.
6) No compaction of soils beneath the facility, or ripping/loosening of soils if compacted.
7) No liners or other barriers interfering with infiltration.
8) Appropriate plant palette for the specified soil mix and maximum available water use.

The equivalence standard is found in Section E.12.e.ii.g of the permit and allows designs to differ from the E.12.e.ii.f specification if all of the following may be demonstrated (SWRCB 2013):

1) Equal or greater amount of runoff infiltrated or evapotranspired.
2) Equal or lower pollutant concentrations in runoff that is discharged after biotreatment.
3) Equal or greater protection against shock loadings and spills.
4) Equal or greater accessibility and ease of inspection and maintenance.

The CA Phase II LID Sizing Tool's areas reported for the Baseline Bioretention or Equivalent Performance Method are based on a conservative interpretation of the second requirement concerning concentrations. Instead of quantifying the pollutant removal of any filtration or sedimentation mechanisms within an equivalent LID BMP, the tool only accounts for pollutant removal via evapotranspiration and infiltration losses. The assumption is that these latter mechanisms result in pollutant losses that are superior to the filtration mechanism in the permit-specified bioretention. This approach also means that all equivalent LID BMPs are sized to retain on site the same volume of runoff that would be discharged after biotreatment through the permit-specified bioretention.

3.4 Central Coast Simple Method

In lieu of adopting the methods listed in the Phase II permit, the Central Coast RWQCB has adopted other methods for sizing LID BMPs. One of the methods, the Simple Method, is included in the CA Phase II LID Sizing Tool. The Simple Method is similar to the Design Storm Method, except that for LID BMPs with an underdrain, any storage volume above the underdrain is not credited. The LID BMP areas resulting from the Central Coast Simple Method are therefore larger than those resulting from the Design Storm Method due to the decreased storage. Either the 85^{th} or 95^{th} percent, 24-hour storm is required depending on the project location within the Central Coast. The Central Coast Simple Method is documented in the post-construction requirements (Attachment 1, Appendix D) of Resolution R3-2013-0032 (CA RWQCB Central Coast 2013).

4.0 TOOL DEVELOPMENT

The tool consists of a website that is linked to a database through a server. The database stores precipitation and evaporation data for multiple geographic locations throughout California, pre-defined parameters for multiple LID BMP types and soil types, and pre-solved design curves. After the user enters project information into the tool's website, the server queries the database, performs calculations, and tabulates the areas required for various LID BMP types. LID BMP areas are provided for each of three sizing methods based on various sizing criteria specified in the Phase II permit as well as for the Central Coast Simple Method (see Section 3.0). Figure 1 provides graphical details of the tool's components and how they are linked.

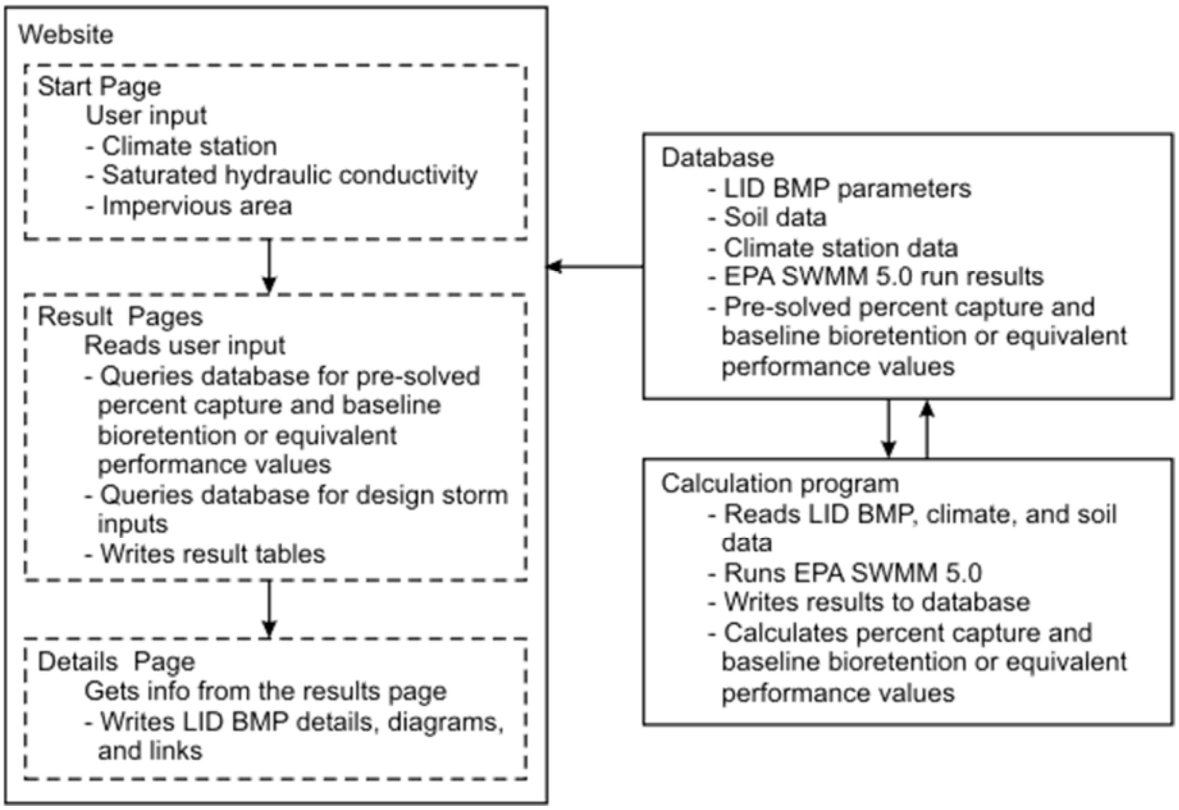


Figure 1. Components of the CA Phase II LID Sizing Tool

The following discussions present how the database parameters were selected, how the LID BMP sizing factors and design curves were derived, and how the tool calculates LID BMP areas for the user-defined project.

4.1 Parameter Selection

The tool results are dependent on the project location's climate and soil properties, as well as the design characteristics of the LID BMP types being assessed. The following subsections describe the climate locations, project sites soil properties, and LID BMP types represented by the tool.

4.1.1 Climate Locations

The tool currently provides sizing results based on precipitation and evaporation data from 92 climate stations located throughout California (Figure 2). These locations were chosen based on a variety of criteria, including: 1) statewide representation, 2) available climate data exceeding 30 years and 80% completeness, and 3) region-specific requests. Table 1 presents details about each climate station. Additional climate stations can be added to the tool in the future.

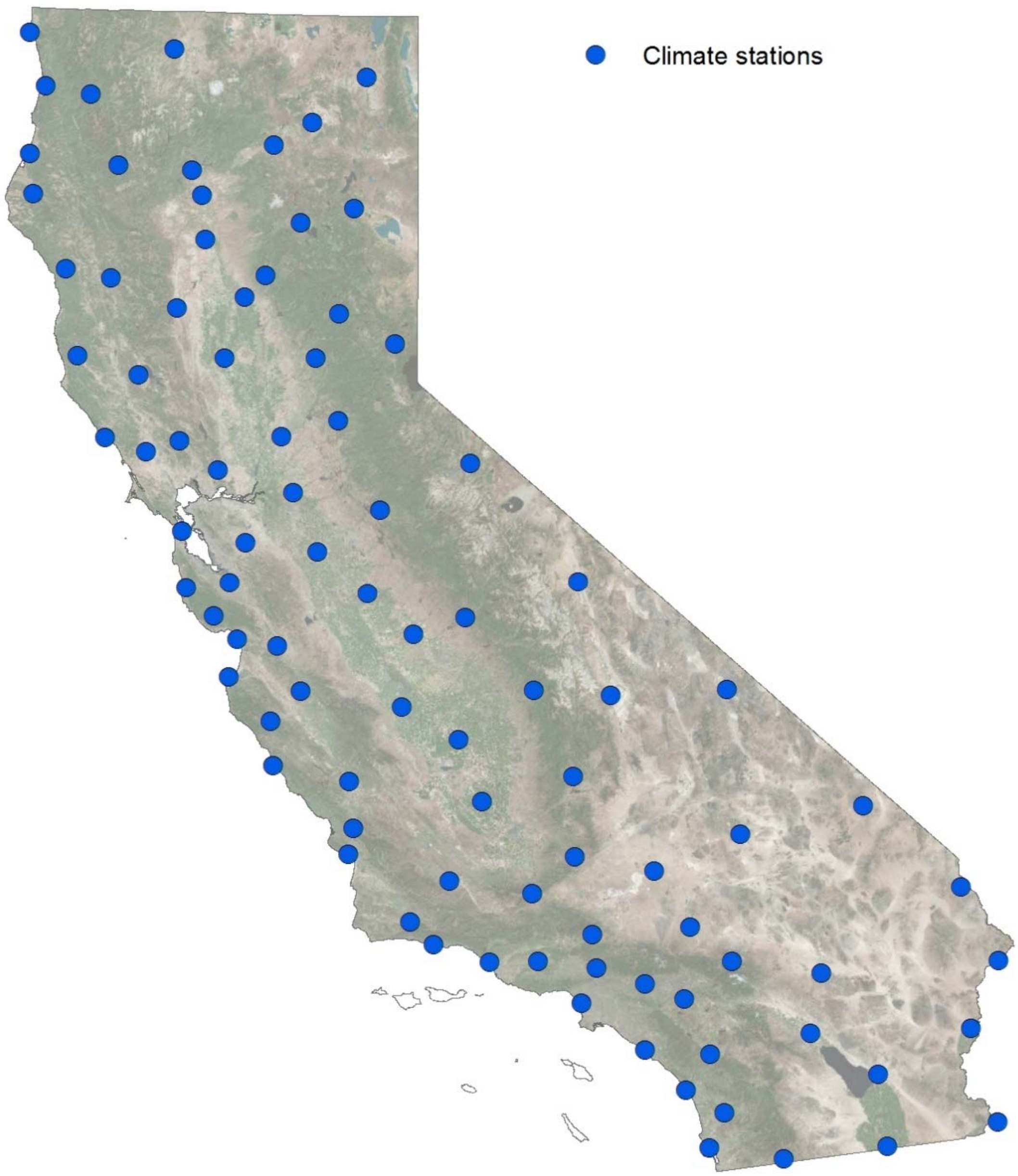


Figure 2. Climate Data Locations for the CA Phase II LID Sizing Tool

Table 1. Climate Station Information

Station Name	Coop ID	Latitude	Longitude	Elevation (ft)	Years on Record
ACTON ESCONDIDO FC261	040014	34.49389	-118.271	2833	37
ALTURAS	040161	41.49306	-120.553	4400	37
ARROYO SECO	040322	36.23556	-121.48	940	37
ASH MTN	040343	36.49139	-118.825	1708	37
AUBERRY 2 NW	040379	37.09194	-119.513	2090	37
BEN LOMOND #4	040673	37.08556	-122.08	420	34
BIEBER	040731	41.12083	-121.135	4125	36
BIG BAR 4 E	040738	40.74056	-123.208	1253	37
BIG BEAR LAKE	040741	34.24417	-116.904	6760	37
BISHOP AP	040822	37.37111	-118.358	4102	37
BLYTHE	040924	33.61306	-114.597	268	37
BORON	040979	35.00417	-117.65	2450	36
CALEXICO 2 NE	041288	32.68806	-115.464	12	37
CAMPO	041424	32.62333	-116.473	2630	37
CHESTER	041700	40.30333	-121.242	4530	37
CHICO UNIV FARM	041715	39.69111	-121.821	185	37
COLUSA 2 SSW	041948	39.1875	-122.027	50	37
CORCORAN IRRIG DIST	042012	36.0975	-119.582	200	37
COVELO	042081	39.81583	-123.244	1413	37
CRESCENT CITY 3 NNW	042147	41.79583	-124.215	43	37
DE SABLA	042402	39.87167	-121.611	2710	37
DEATH VALLEY	042319	36.46222	-116.867	-194	37
DONNER MEM SP	042467	39.32389	-120.233	5937	37
DOWNIEVILLE	042500	39.56333	-120.824	2915	37
EUREKA WFO WOODLEY IS	042910	40.80972	-124.16	20	37
FAIRFIELD	042934	38.27361	-122.068	40	37
FIVE POINTS 5 SSW	043083	36.36417	-120.156	285	37
FT ROSS	043191	38.515	-123.245	112	37
GOLDSTONE ECHO #2	043498	35.28139	-116.784	2950	32
GRASS VALLEY #2	043573	39.20417	-121.068	2400	37
HAT CREEK	043824	40.93167	-121.543	3015	37
HOLLISTER 2	044025	36.84833	-121.421	275	37
KERN RIVER PH 3	044523	35.78306	-118.439	2703	37
LA CRESCENTA FC251 C	044628	34.22222	-118.238	1545	37
LAGUNA BEACH	044647	33.54528	-117.781	44	37
LAKEPORT	044701	39.03333	-122.917	1315	31
LEBEC	044863	34.83278	-118.865	3585	37
LIVERMORE	044997	37.69222	-121.769	480	37

Station Name	Coop ID	Latitude	Longitude	Elevation (ft)	Years on Record
LODI	045032	38.10611	-121.288	40	37
LONE PINE COTTONWD PH	045067	36.44306	-118.043	3790	37
LOS ANGELES INTL AP	045114	33.93806	-118.389	97	37
LUCIA WILLOW SPRINGS	045184	35.87806	-121.45	355	37
MADERA	045233	36.95389	-120.038	270	37
MERCED	045532	37.28583	-120.512	153	37
MODESTO 2	045741	37.62556	-121.031	89	37
MONTEREY	045795	36.59028	-121.91	385	37
MTN PASS	045890	35.47028	-115.544	4730	37
NAVARRO 1 NW	046105	39.17361	-123.564	153	37
NEEDLES AP	046118	34.7675	-114.619	890	37
NEW CUYAMA FIRE STN	046154	34.94556	-119.683	2160	33
NILAND	046197	33.2775	-115.524	-60	37
OCEANSIDE MARINA	046377	33.20972	-117.395	10	37
ORICK PRAIRIE CREEK PK	046498	41.36194	-124.019	160	37
ORLEANS	046508	41.30889	-123.532	403	37
PARKER	026250	34.15472	-114.29	420	37
PINNACLES NM	046926	36.48194	-121.182	1307	37
PISMO BEACH	046943	35.15972	-120.683	39	36
PLACERVILLE	046960	38.69556	-120.824	1850	37
POMONA/FAIRPLEX	047050	34.08167	-117.766	999	37
POWAY VALLEY	047111	33.0175	-117.029	648	37
RED BLUFF MUNI AP	047292	40.15194	-122.254	353	37
REDDING AP	047304	40.5175	122.299	497	20
RIVERSIDE FIRE STN 3	047470	33.95111	-117.388	840	37
SACRAMENTO 5 ESE	047633	38.55556	-121.417	38	36
SAINT HELENA	047643	38.50667	-122.471	225	37
SAN DIEGO WSO AP	047740	32.73361	-117.183	15	37
SAN FRANCISCO DWTN	047772	37.77056	-122.427	150	36
SAN GREGORIO 2 SE	047807	37.31167	-122.362	275	37
SAN JOSE	047821	37.35917	-121.924	51	37
SAN MIGUEL WOLF RCH	047867	35.75278	-120.683	738	33
SANTA BARBARA MUNI AP	047905	34.42583	-119.843	9	37
SANTA MARGARITA BOOST	047933	35.37417	-120.638	1148	36
SANTA YNEZ	047976	34.60778	-120.069	600	37
SCOTIA	048045	40.48306	-124.104	136	37
SEBASTOPOL	048072	38.40861	-122.821	68	37

Station Name	Coop ID	Latitude	Longitude	Elevation (ft)	Years on Record
SHASTA DAM	048135	40.71417	-122.416	1075	37
SIMI SANITATION PLT	048261	34.28389	-118.812	660	31
SONORA	048353	37.96722	-120.387	1675	37
SONORA JUNCTION	048355	38.35111	-119.45	6886	37
STANDISH HICKEY SP	048490	39.87778	-123.728	853	37
STONY GORGE RSVR	048587	39.58611	-122.534	800	36
SUNSET STATE BEACH	048680	36.8975	-121.835	80	37
SUSANVILLE 1 WNW	048703	40.42389	-120.675	4555	37
TEHACHAPI AP	048832	35.13083	-118.433	3960	37
TEMECULA	048844	33.49722	-117.151	1020	34
THERMAL FS #39	048893	33.63583	-116.164	-115	33
TWENTYNINE PALMS	049099	34.12806	-116.037	1975	37
VENTURA	049285	34.2825	-119.292	105	37
VICTORVILLE PUMP PT	049325	34.535	-117.306	2858	36
WASCO	049452	35.58917	-119.352	291	37
YREKA	049866	41.70361	-122.641	2625	37
YUMA PROVING GROUND	029654	32.83556	-114.394	324	37

4.1.2 Project Site Soil Properties

The areas reported for the tool rely on soil characteristics for the project site. Six different soil types were modeled using the following soil parameters: suction head, saturated conductivity, and initial deficit. The tool's soil types are categorized by the Hydrologic Soil Groups established by the Department of Agriculture (USDA) National Resource Conservation Service (NRCS) as follows: one representing Hydrologic Soil Group A, one representing Soil Group B, two representing Soil Group C, and two representing Soil Group D. Table 2 presents the parameter values associated with each soil type modeled.

Table 1. Soil Parameter Values

Parameter	Unit	A	B	C_{high}	C_{low}	D_{high}	D_{low}
Suction Head	in	0.4	3.3	5.5	7.4	9.1	11.6
Saturated Conductivity	in/hr	5.0	1.0	0.3	0.1	0.04	0.01
Initial Deficit	fraction	0.45	0.39	0.34	0.30	0.26	0.21

The saturated conductivity values were selected based on the ranges established by the USDA NRCS for the different Hydrologic Soil Groups (Table 3).

Table 2. Soil Parameter Values

Soil Hydrologic Group	A	B	C	D
Saturated Conductivity (in/hr)	>1.42	0.57-1.42	0.06-0.57	<0.06

[1]USDA NRCS 2007

The suction head and initial deficit values were chosen based on regressions established from literature values (EPA 2010). The regressions are shown in Figures 3 and 4.

For soil types with characteristics other than those modeled, the tool allows the user to input a project-specific saturated conductivity value and interpolates between the results from the modeled values. Impacts from suction head and initial deficit values that differ from the modeled values are assumed to be negligible.

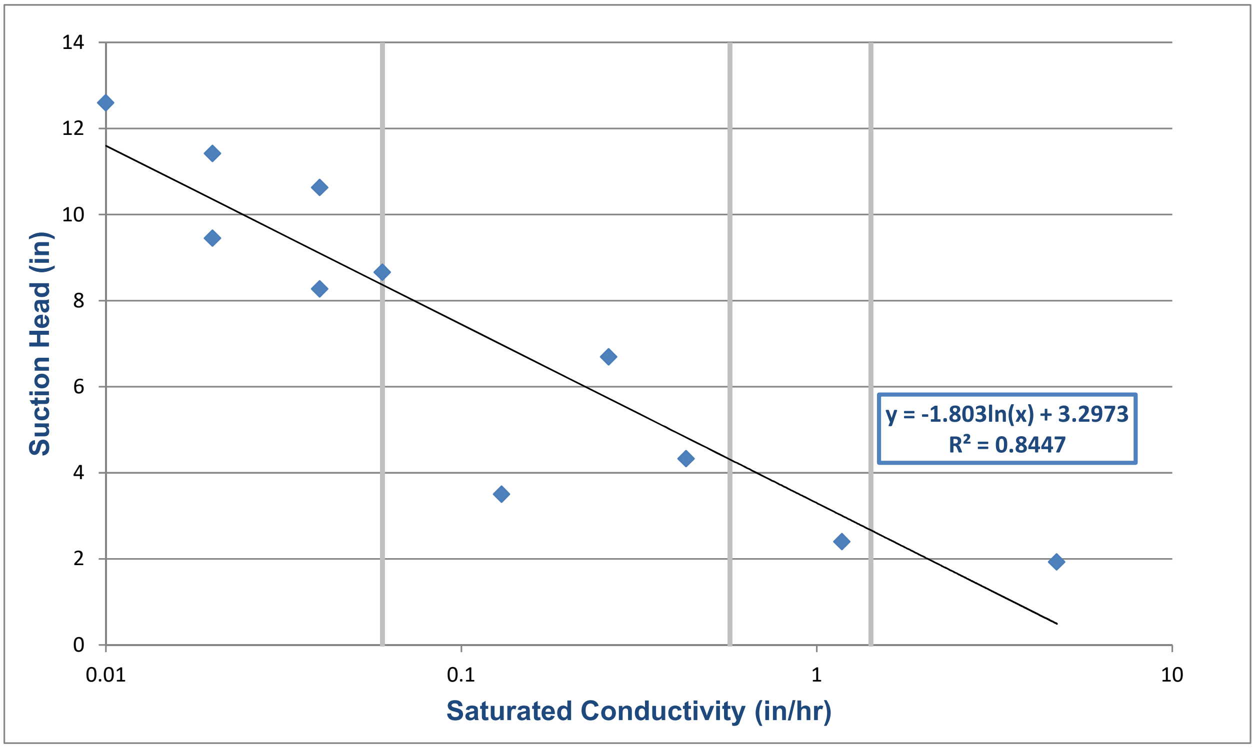


Figure 2. Saturated Conductivity and Suction Head Regression

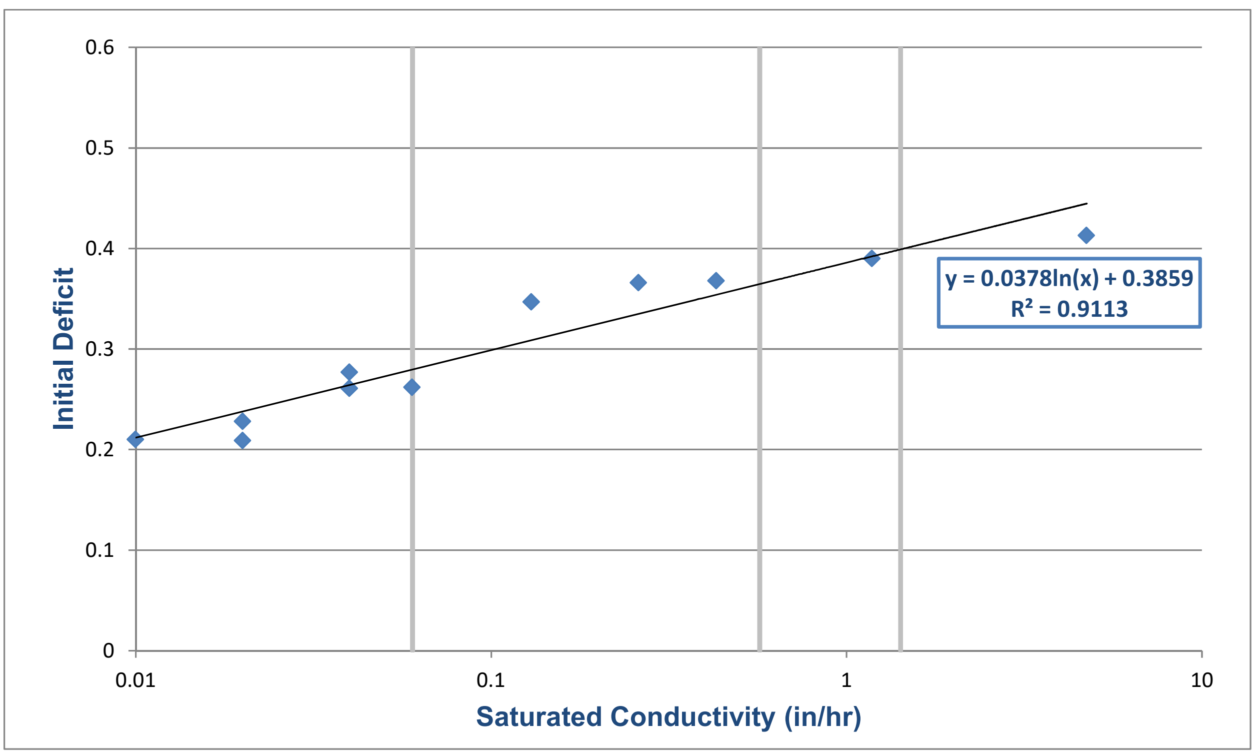


Figure 3. Saturated Conductivity and Initial Deficit Regression

4.1.3 LID BMP Types

The tool’s LID BMP types were selected based on the site design measures, stormwater treatment measures, and allowable alternative designs described in the Phase II permit. The tool’s LID BMP names are based on conventional terminology being adopted by practitioners statewide, as observed by the tool developers. Table 3 presents a list of the LID BMP types selected for the tool and the relevant permit-specified measures.

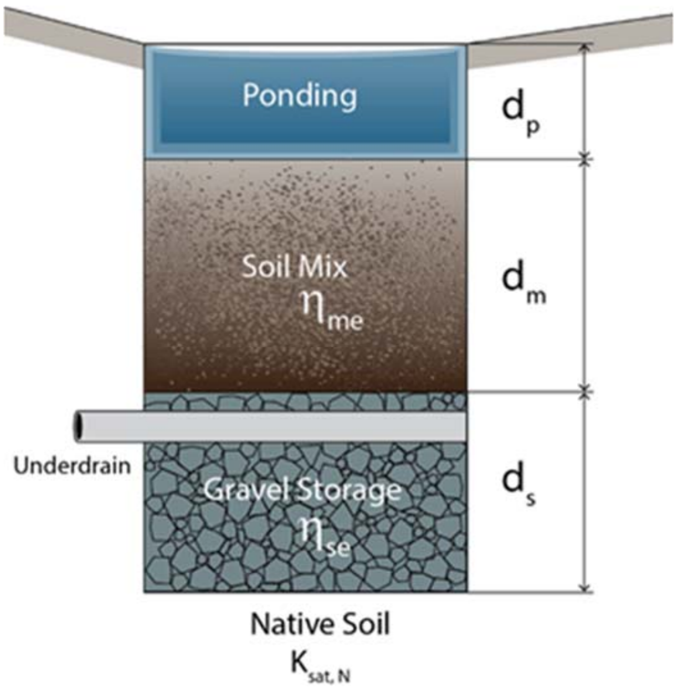
Table 3. Phase II Permit Measures and Sizing Tool LID BMP Types

Phase II Permit Measure	Phase II Permit BMP	CA Phase II LID Tool LID BMP Types
Site Design Measures (E.12.e.ii.d)	Soil Quality Improvement and Maintenance	Strip, Amended 6”
		Strip, Amended 12”
		Strip, Amended 18”
	Soil Quality Improvement and Maintenance; Vegetated Swales	Swale, Amended 6”
		Swale, Amended 12”
		Swale, Amended 18”
	Rain Barrels and Cisterns	Capture and Use Storage
	Porous Pavement	Porous Pavement
Storm Water Treatment Measures (E.12.e.ii.f)	Bioretention System	Bioretention Cell - 18” Soil - 12” Storage
		Bioretention Cell - 18” Soil - 24” Storage
		Bioretention Cell - 18” Soil - 36” Storage
		Bioretention Cell - 24” Soil - 12” Storage
		Bioretention Cell - 24” Soil - 24” Storage
		Bioretention Cell - 24” Soil - 36” Storage
		Bioretention Cell - Soil Depth Varies* - No Storage
Alternative Designs (E.12.e.ii.g)	Infiltration	Overland Flow (no amendment)
		Infiltration Trench
		Infiltration Gallery
		Vegetated Infiltration Basin

**Soil depth is a function of the underlying native soil’s saturated conductivity*

Figure 5 shows a conceptual profile template for the LID BMPs modeled by the tool. Each LID BMP includes up to four different components: 1) ponding, 2) soil mix/porous pavement, 3) gravel storage, and 4) underlying native soil. The ponding component provides temporary surface storage of precipitation and runoff intended to hold the water in place and promote infiltration into the lower components. The component directly beneath the ponding zone consists of a bioretention mix, amended soils, top soil, planting material, or porous pavement (collectively referred to as soil mix/porous pavement). This component allows for initial surface storage as well as treatment via filtration and, in some cases, volatilization, biological uptake, media adsorption, and/or vegetative transpiration. The third LID BMP component consists of an aggregate compartment that provides additional storage and promotes infiltration into the native soils below. The storage component may or may not include an underdrain, which allows discharge in the occasional case that the storage and volumetric losses (infiltration and evapotranspiration) are insufficient to retain all precipitation and runoff. The final component, which is included in every LID BMP modeled, is the underlying native soil. All LID BMPs are unlined to allow infiltration to whatever degree the underlying soil allows.

Appendix A provides fact sheets for each LID BMP. The fact sheets include profile schematics (including parameter values for each relevant component of the conceptual LID BMP shown in Figure 5), descriptions, and assumptions. These characteristics apply to all sizing methods provided by the tool.



d_p = max depth of ponding storage

d_m = depth of bioretention mix, planting mix, soil amendment, or porous pavement

η_{me} = effective porosity of bioretention mix, planting mix, soil amendment, or porous pavement (= total porosity – field capacity)

d_s = depth of gravel storage

η_{me} = effective porosity of gravel storage (= total porosity – field capacity)

$k_{sat,\,N}$ = saturated conductivity of native soil

Note: Some components may not be applicable to certain LID BMP types. For example, amended swales do not have gravel storage components and infiltration trenches do not have ponding or soil mix components.

Figure 4. Conceptual LID BMP Profile

4.2 Sizing Factor and Design Curve Derivation

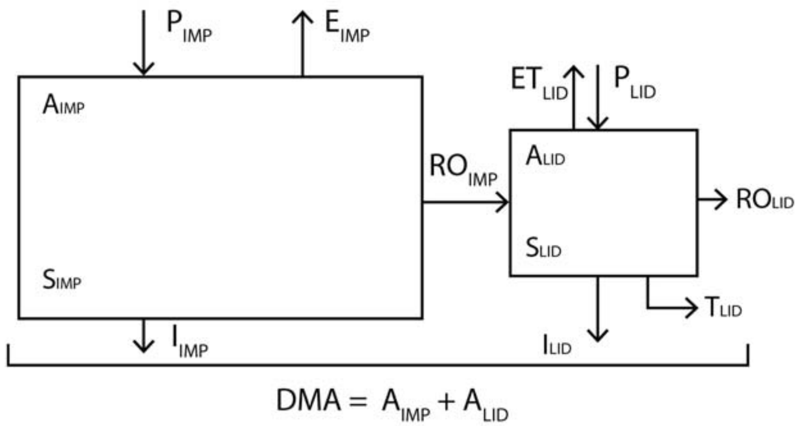
For each possible combination of climate location, soil type, and LID BMP type, the tool provides LID BMP areas based on the four different methods that meet the Phase II permit and Central Coast resolution sizing criteria: the Design Storm Method, the Percent Capture Method, the Baseline Bioretention or Equivalent Performance Method, and the Central Coast Simple Method.

Figure 6 presents the conceptual water balance associated with each of these sizing methods. The water balance consists of equating the total amount of rain that fell onto the drainage management area (DMA) with the total amount of water losses (including runoff discharge) from the DMA. The DMA consists of an impervious area and the area of the LID BMP. The water losses across the DMA include infiltration and evaporation from, and storage within the impervious area, as well as infiltration and evapotranspiration from, storage within, bypass of, and discharge from the LID BMP. The water balance for the DMA may be mathematically represented by two equations, one for the impervious area and one for the LID BMP area:

$$P_{IMP} = S_{IMP} + E_{IMP} + I_{IMP} + RO_{IMP} \qquad \text{EQN 1}$$

$$P_{LID} + RO_{IMP} = S_{LID} + ET_{LID} + I_{LID} + T_{LID} + RO_{LID} \qquad \text{EQN 2}$$

The following subsections present how these general equations were used to derive the specific calculations for each of the tool's sizing methods.



A_{IMP} = Impervious area of DMA

A_{LID} = LID BMP area of the DMA

P_{IMP} = Precipitation onto A_{IMP}

P_{LID} = Precipitation onto A_{LID}

E_{IMP} = Evaporation from A_{IMP}

ET_{LID} = Evapotranspiration from $A_{LID}S_{IMP}$ = Storage within A_{IMP}

S_{LID} = Storage within A_{LID}

I_{IMP} = Infiltration through A_{IMP}

I_{LID} = Infiltration through A_{LID}

RO_{IMP} = Runoff discharged from A_{IMP} to A_{LID}

RO_{LID} = Runoff bypassing A_{LID}

T_{LID} = Treated discharge from A_{LID} underdrain

Figure 5. Conceptual Plan View of Drainage Management Area Water Balance

4.2.1 Design Storm Method

The tool's Design Storm Method combines the infiltration, evaporation, and storage losses from the impervious area such that they are a fraction of the precipitation that fell onto the impervious area. The fraction is equivalent to one minus the impervious area's volumetric runoff coefficient, which is based on the percent of the DMA that is impervious. The resulting equation is:

$$S_{IMP} + E_{IMP} + I_{IMP} = (1 - R_v) * P_{IMP} \qquad \text{EQN 3}$$

where:

R_v = Volumetric runoff coefficient for the impervious area
= $0.858*(i)^3 - 0.78*(i)^2 + 0.774*(i) + 0.04$ (WEF and ASCE 1998)
(i = impervious fraction = 1.0)

Substituting EQN 3 into EQN 1 results in the following:

$$P_{IMP} = (1 - R_v) * P_{IMP} + RO_{IMP} \qquad \text{EQN 4}$$

EQN 4 can be rearranged to calculate the runoff discharged from the impervious area to the LID BMP area (RO_{IMP}):

$$RO_{IMP} = R_V * P_{IMP} \qquad \text{EQN 5}$$

The Design Storm Method assumes that this runoff, along with the rain that fell onto the LID BMP, must be stored within the LID BMP (losses due to infiltration, evapotranspiration, and discharge through an underdrain from the LID BMP are neglected):

$$RO_{IMP} + P_{LID} = S_{LID} \qquad \text{EQN 6}$$

Storage provided by the LID BMP may be calculated based on the depths and porosities of the LID BMP's ponding, soil mix/porous pavement, and gravel storage components (Figure 5) multiplied by the LID BMP area:

$$S_{LID} = A_{LID} * (d_p + d_m * n_{me} + d_s * n_{se}) \qquad \text{EQN 7}$$

Substituting EQN 5 and EQN 7 into EQN 6 results in the following:

$$R_V * P_{IMP} + P_{LID} = A_{LID} * \left(d_p + d_m * n_{me} + d_s * n_{se}\right) \qquad \text{EQN 8}$$

Precipitation onto the impervious and LID BMP areas may be represented by the design storm depth multiplied by the respective areas:

$$P_{IMP} = A_{IMP} * P_{DS} \qquad \text{EQN 9}$$

$$P_{LID} = A_{LID} * P_{DS} \qquad \text{EQN 10}$$

Substituting EQN 9 and EQN 10 into EQN 8 and rearranging the equation results in a sizing factor that represents the percentage of the LID BMP area relative to the impervious area:

$$\frac{A_{LID}}{A_{IMP}} = \frac{R_v * P_{DS}}{\left(d_p + d_m * n_{me} + d_s * n_{se} - P_{DS}\right)} \qquad \text{EQN 11}$$

EQN 11 is then used to calculate the LID BMP area based on the user-specified impervious area (see Section 4.3.1).

4.2.2 Percent Capture Method

For the tool's Percent Capture Method, design curves were developed for each location-soil type-LID BMP type scenario. The design curves correlate sizing factors (the percent of LID BMP area relative to the impervious area) with the amount of runoff infiltrated, captured, and/or biotreated by the LID BMP. The design curves were developed using the Environmental Protection Agency's (EPA) Storm Water Management Model Versions 5.0.022 and 5.1.007 (SWMM 5, EPA 2013). SWMM 5 is a dynamic, hydrologic model that can run long-term (continuous) simulations to estimate the quantity and quality of urban runoff over time. SWMM 5.0.022 was used for all LID BMPs except for porous pavement. Due to improvements in porous pavement calculations in version 5.1.007 that version was used for porous pavement.

A code was developed to load data into SWMM 5 and run simulations for all possible location-soil type-LID BMP type scenarios for a one acre impervious area and a variety of LID BMP areas. The uploaded data included hourly precipitation data, monthly evaporation data, LID BMP type characteristics, native soil properties, and various LID BMP areas. Appendix B provides the input parameter values used for SWMM 5 modeling to demonstrate how each LID BMP was modeled, including values for the impervious portion of the DMA. The SWMM 5 simulations were run at hourly time-steps across the entire time period of the climate data (30+ years). For each simulation, SWMM 5 tracked the hourly water balance across the DMA, including volumes associated with total precipitation onto the DMA, total abstraction within the impervious area, total infiltration through the LID BMP, total evapotranspiration from the DMA, total runoff that bypasses the LID BMP, and total runoff that was discharged through the LID BMP underdrain (where applicable). SWMM 5 then reported the total volumes associated with each of these elements across the 30+ year simulation, and the code was used to download these values into the tool's database. The values are used to calculate the percent of the runoff and precipitation that was captured by the LID BMP through infiltration, evapotranspiration, and discharge from an underdrain. The percent capture is derived from the water balance for the LID BMP area (EQN 2), where storage within the LID BMP is neglected:

$$RO_{IMP} + P_{LID} = ET_{LID} + I_{LID} + T_{LID} + RO_{LID} \qquad \text{EQN 12}$$

Both sides of EQN 12 can be divided by $RO_{IMP} + P_{LID}$. The resulting equation is:

$$\frac{RO_{IMP} + P_{LID}}{RO_{IMP} + P_{LID}} = \frac{ET_{LID} + I_{LID} + T_{LID} + RO_{LID}}{RO_{IMP} + P_{LID}} \qquad \text{EQN 13}$$

EQN 13 can be rearranged:

$$\frac{RO_{IMP} + P_{LID} - RO_{LID}}{RO_{IMP} + P_{LID}} = \frac{ET_{LID} + I_{LID} + T_{LID}}{RO_{IMP} + P_{LID}} \qquad \text{EQN 14}$$

EQN 14 therefore represents the percent of runoff from the impervious area and precipitation onto the LID BMP area that was capture (i.e., evapotranspired, infiltrated, and treated) by the LID BMP area and can be simplified to:

$$\%\,Capture = \frac{ET_{LID} + I_{LID} + T_{LID}}{RO_{IMP} + P_{LID}} \qquad \text{EQN 15}$$

For each location-soil type-LID BMP type scenario, the design curve stored in the tool's database consists of the calculated percent capture and its associated sizing factor (i.e., the fraction of LID BMP area to impervious area). The database stores the design curve in a tabular format. Figure 7 and Table 5 show an example curve and its tabulated values, respectively. These curves are then used to calculate the LID BMP area based on the user-specified impervious area (see Section 4.3.2).

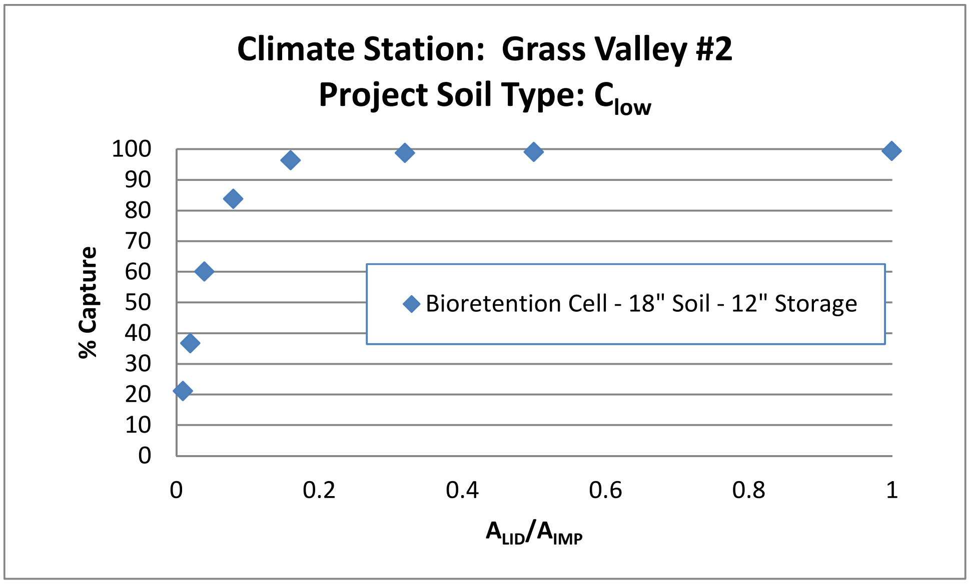


Figure 6. Example Design Curve

Table 4. Tabulated Data for Example Design Curve

Grass Valley #2, C_{low} Soils, Bioretention Cell – 18" Soil Mix – 12" Gravel Storage

A_{LID}/A_{IMP}	% Capture
0.01	21
0.02	36
0.04	60
0.08	84
0.16	96
0.32	99
0.5	99
1.0	99

4.2.3 Baseline Bioretention or Equivalent Performance Method

The tool's Baseline Bioretention or Equivalent Performance Method uses the same design curves that were developed for the Percent Capture Method (see Section 4.2.2). How the method uses these design curves to calculate LID BMP areas is presented in Section 4.3.3.

4.2.4 Central Coast Simple Method

The Central Coast Simple Method is similar to the Design Storm Method in that the infiltration, evaporation, and storage losses from the impervious area such that they are a fraction of the precipitation that fell onto the impervious area. The difference is that the Central Coast Simple Method does not allow for storage "credit" above an underdrain. Therefore, EQNs 1 through 6 apply to the Central Coast Simple Method, but EQN 7 is modified so that storage provided by the LID BMP is be calculated based on the depth and porosity of the LID BMP's gravel storage component (Figure 5) multiplied by the LID BMP area (depths and porosities of the ponding and soil mix/porous pavement components are omitted):

$$S_{LID} = A_{LID} * (d_s * n_{se}) \qquad \text{EQN 16}$$

EQN 8 therefore becomes:

$$R_V * P_{IMP} + P_{LID} = A_{LID} * (d_s * n_{se}) \quad \text{EQN 17}$$

EQN 11 becomes:

$$\frac{A_{LID}}{A_{IMP}} = \frac{R_v * P_{DS}}{(d_s * n_{se} - P_{DS})} \quad \text{EQN 18}$$

EQN 18 is then used to calculate the LID BMP area based on the user-specified impervious area (see Section 4.3.4).

4.3 LID BMP Area Calculations

To tabulate LID BMP areas, the tool queries the database for the sizing factor or design curve associated with the user-selected soil type and climate station for each LID BMP type, and then calculates the LID BMP area for each of the tool's sizing methods. The following subsections describe the area calculations for each method.

4.3.1 Design Storm Method

To calculate the LID BMP areas for the Design Storm Method, the tool queries the database for the sizing factors (A_{LID}/A_{IMP}) associated with the 85th percentile, 24-hour storm for each LID BMP type. The sizing factors are then multiplied by the user-defined impervious area and the LID BMP areas are tabulated.

Some regions are adopting design storm requirements based on criteria other than the 85th percentile design storm. For example, the Central Coast Regional Water Quality Control Board (RWQCB) includes design storm sizing requirements based on the 95th percentile storm. To accommodate these situations, the tool allows the user to input an alternate design storm depth. The tool queries the database for each LID BMP's characteristics and calculates sizing factors using EQN 11. These alternative sizing factors are then multiplied by the user-defined impervious area to determine the LID BMP area. Note that while the tool's database contains the 85th percentile design storm depth, it does not currently contain depths for other design storms, so users would need to check with their local resources to obtain them.

4.3.2 Percent Capture Method

To calculate the LID BMP areas for the Percent Capture Method, the tool queries the database for the design curves discussed in Section 4.2.2. The Phase II permit allows LID BMP sizing based on 80% capture, so the tool multiplies the sizing factor associated with this 80% capture by the user-defined impervious area to calculate the LID BMP area. In the case that 80% capture is not a defined point on the design curve, the tool interpolates to obtain the appropriate sizing factor.

4.3.3 Baseline Bioretention or Equivalent Performance Method

The Phase II permit allows implementation of LID BMPs that are designed to be at least as effective as a bioretention system with permit-specified characteristics, one of which is a sizing factor of 4% of the tributary impervious area. The tool's Baseline Bioretention or Equivalent Performance Method addresses this sizing option. For the user-defined climate station, the tool queries the percent capture database for the "permit-prescribed" bioretention LID BMP type having a sizing factor of 4%, and looks up the respective percent capture. The tool then determines the sizing factors for all other LID BMP types for the permit-prescribed bioretention percent capture, multiples the factors by the user-defined impervious area, and tabulates the resulting LID BMP areas for each LID BMP type.

4.3.4 Central Coast Simple Method

For the Central Coast Method, the tool queries the database for the sizing factors (ALID/AIMP) associated with the 85th percentile, 24-hour storm for each LID BMP type. Other, user-specified design storms may be used as is allowed for the Design Storm Method (see Section 4.3.1). The sizing factors are then multiplied by the user-defined impervious area and the LID BMP areas are tabulated.

5.0 TOOL INTERFACE

This section describes the interface of the tool, including the project information that the user must input and the results and output provided by the tool.

5.1 Tool Input

The tool's first seven steps allow the user to enter details of the project location, site design, and BMP information. Details regarding each entry are provided in the following subsections. Figures 8 to 15 provide screen shots of the tool's project input pages.

5.1.1 Climate Station

The first project input page includes an interactive Google Earth map that allows users to zoom to their project location as well as find summary information for each climate station by clicking each pin. On the left side of the page, the user can select which climate station best represents their project location from the drop down box. Below the drop down, the user may also enter a project name (Figure 7*)*. After selecting a climate station, the user clicks the *Next* button to move onto *Step 2 – Input a saturated hydraulic conductivity.*

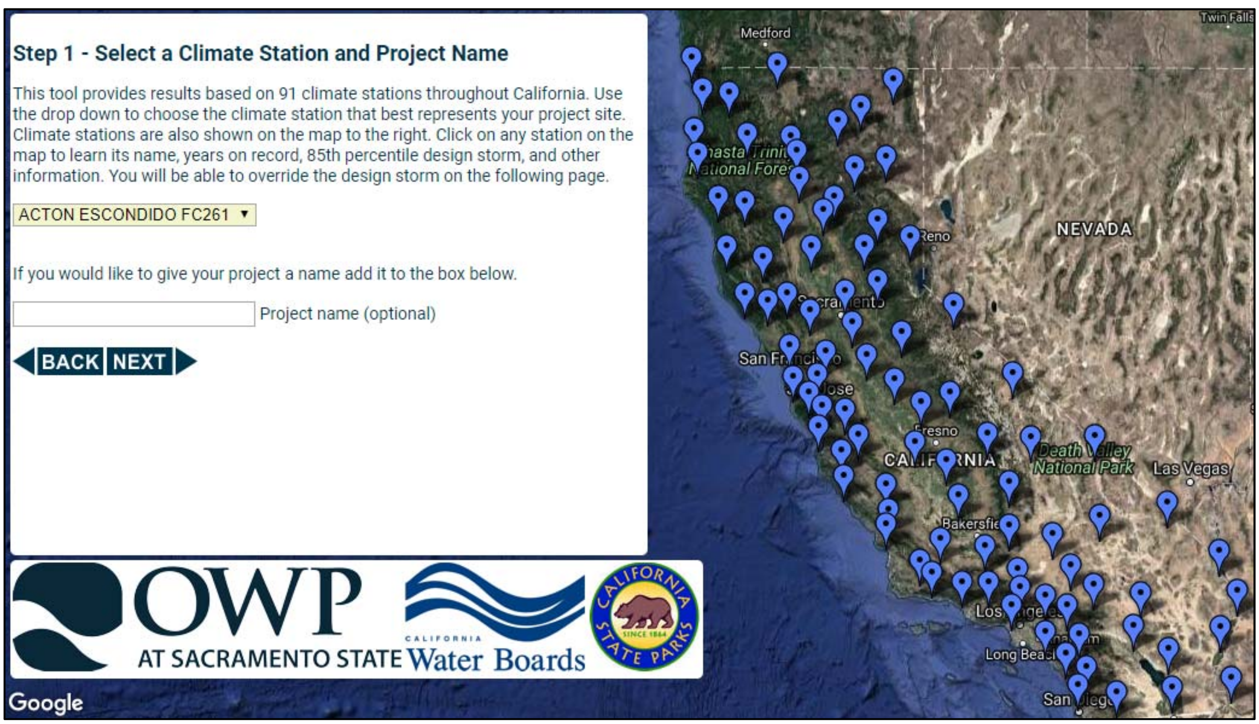


Figure 7. Step 1 of the CA Phase II LID Sizing Tool

5.1.2 Saturated Hydraulic Conductivity

The second project input page includes an interactive Google Earth map that allows users to zoom to their project location as well as find soil hydraulic summaries for given regions by clicking on each region of the map. On the left side of the page, the user must define the project site's native soil saturated hydraulic conductivity (Figure 8). If the saturated conductivity is not known, the user may select the region in which the project is located and/or open the Tables to determine the value (Table 5). The table provided come from the United States Department of Agriculture (USDA) National Resource Conservation Service (NRCS) and US Environmental Protection Agency (USEPA). After entering the saturated hydraulic conductivity, the user clicks the *Next* button to move onto *Step 3 – Input the impervious area*.

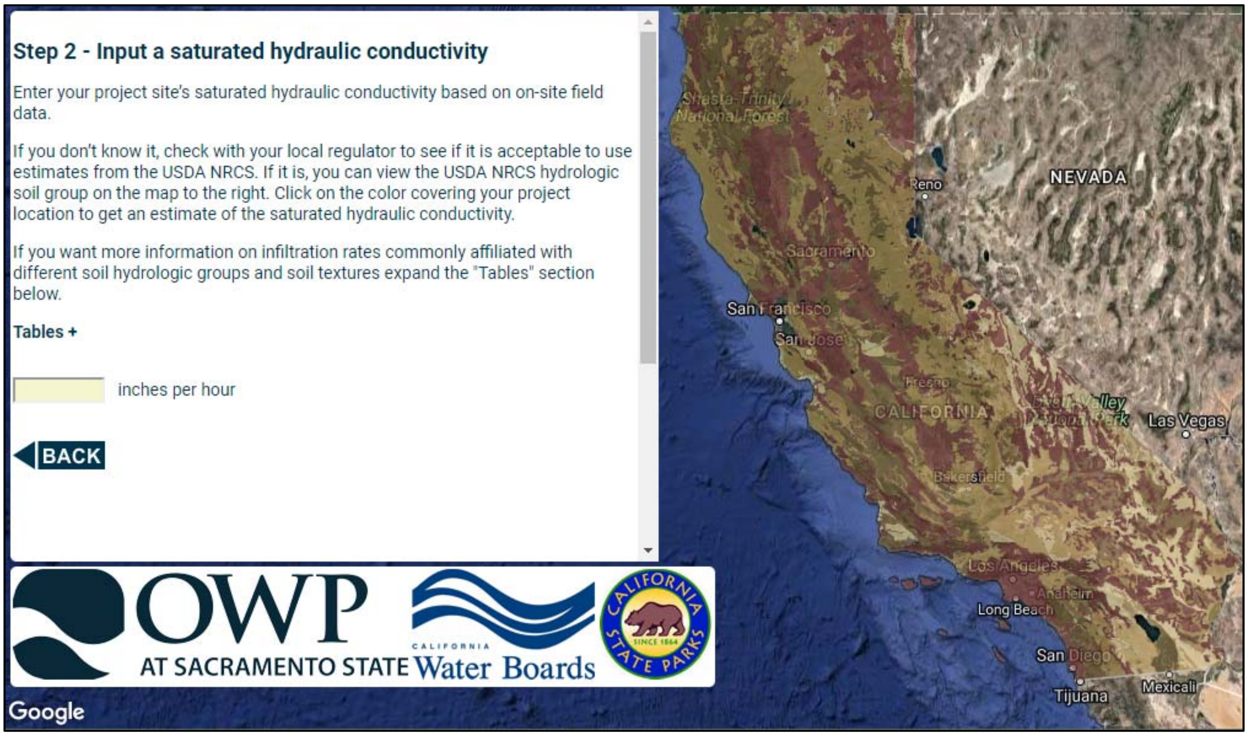


Figure 8. Step 2 of the CA Phase II LID Sizing Tool

Table 5. Suggested Saturated Hydraulic Conductivity rates

Soil Hydrologic Group	Typical Saturated Hydraulic Conductivity (in/hr)	Saturated Hydraulic Conductivity Range (in/hr)
A	1.5	5.67 - 1.42
B	1	1.42 - 0.57
C	0.32	0.57 - 0.06
D	0.03	0.06 - 0.01

USDA NRCS 2007

Soil Texture	Typical Saturated Hydraulic Conductivity (in/hr)
Sand	4.74
Loamy Sand	1.18
Sandy Loam	0.43
Silt Loam	0.26
Loam	0.13
Sandy Clay Loam	0.06
Clay Loam	0.04
Silty Clay Loam	0.04
Sandy Clay	0.02
Silty Clay	0.02
Clay	0.01

EPA 2010 (page 160)

5.1.3 Impervious Area

The user must enter the post-project impervious area in acres (Figure 9). After entering the impervious area, the user clicks the *Next* button to move onto *Step 4 – Input the Design Storm*.

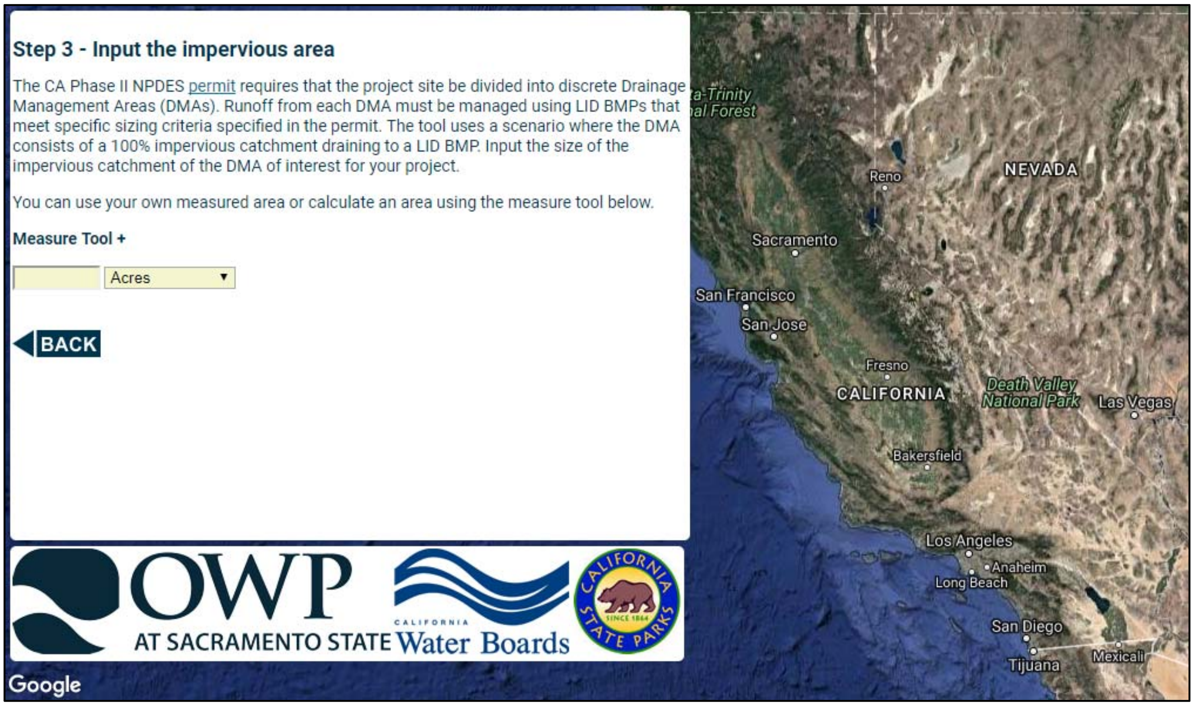


Figure 9. Step 3 of the CA Phase II LID Sizing Tool

5.1.4 Design Storm

The user must enter the desired design storm for the simulation. If the desired design storm is not known, the 85th percentile design storm for the project location is given below the project summary table. After entering the design storm, the user clicks the *Next* button to move onto *Step 5 – Site Design Measures*.

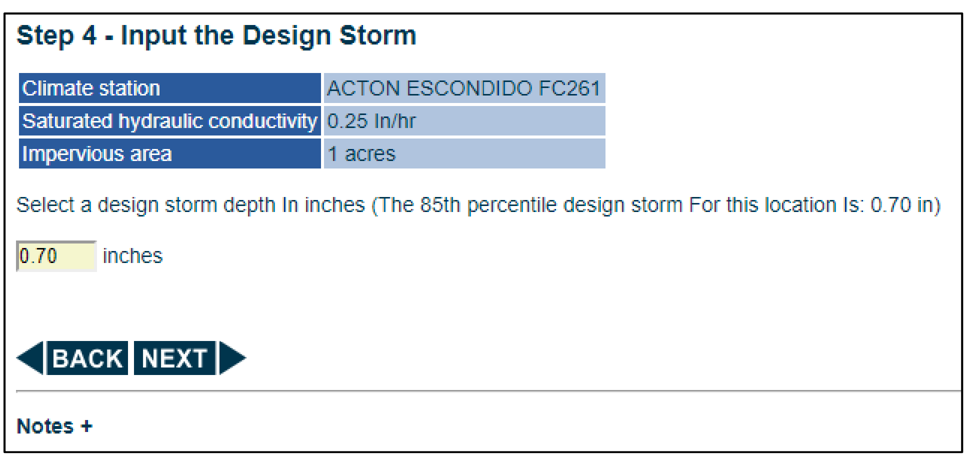


Figure 10. Step 4 of the CA Phase II LID Sizing Tool

5.1.5 Site Design Measures

Once the user has completed entering the project location information, they are then required to input the applicable Site Design Measures (SDMs). To comply with the Phase II permit, SDMs must first be implemented to the extent technically feasible before implementing Storm Water Treatment Measures (SWTMs). SDMs must be sized using the 85th percentile, 24-hour design storm, or other design storm as adopted by the local regulators. The following LID BMPs for the CA Phase II LID Sizing Tool are considered SDMs: porous pavement, amended strips and swales, and capture and use storage. Figure 11 presents a screenshot of tabulated areas for SDMs resulting from a 1.0 acre impervious catchment located near Sacramento, California on soils having an infiltration rate of 0.25 in/hr. The table provides LID BMP areas only for the Design Storm Method; this is the only method allowed by the permit for SDM sizing. The result is a suggested area based on a default 85th percentile design storm (the permit-specified design storm). The user must then enter the available or planned area in the *Area Available* column of the table.

If 100% of the design storm runoff cannot be reduced by a single SDM, a combination of SDMs should be considered. Directions for doing so are available by clicking *Instructions for Site Design Measures* below the table. If a combination of SDMs cannot achieve 100% reduction, SWTMs may be used. To view areas for SWTMs, the user clicks the *Next* button below the SDM table, selects the Storm Water Treatment Measure Method, and then clicks the *Next* button below the storm water treatment measure method options. After entering the site design measures, the user clicks the *Next* button to move onto *Step 6 – Select a Storm Water Treatment Measure Method*.

Step 5 - Site Design Measures

Climate station	SACRAMENTO 5 ESE
Saturated hydraulic conductivity	0.25 in/hr
Impervious area	1 acres
Design storm	0.64 in

Site Design Measures (SDMs) must first be implemented to the extent technically feasible before implementing Storm Water Treatment Measures (SWTMs). SDMs must be sized using the 85th percentile, 24-hour storm, or another design storm as adopted by local regulators.

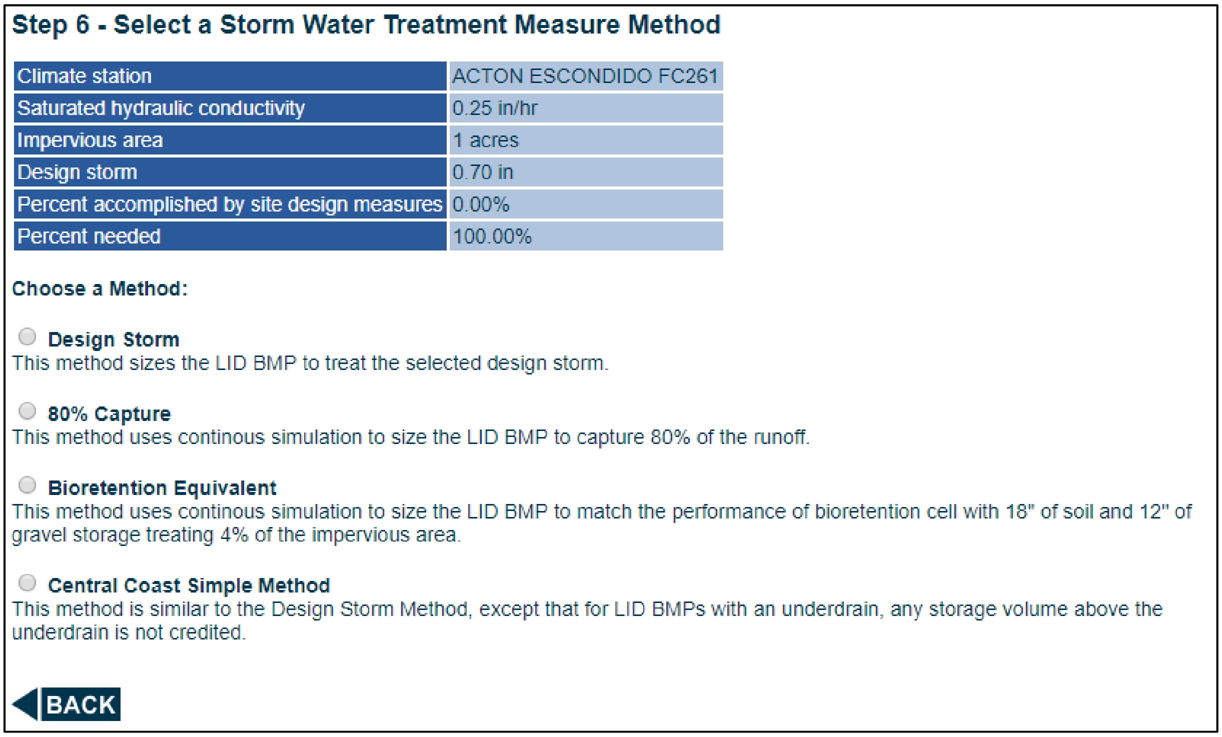
Site Design Measures Using a Design Storm of 0.64 Inches

LID BMP Types	Area Needed (acres)	Area Avaliable (acres)	Percent Accomplished
Porous Pavement	0.037	0.00	0.00
Strip, Amended 6"	0.490	0.00	0.00
Strip, Amended 12"	0.190	0.00	0.00
Strip, Amended 18"	0.120	0.00	0.00
Swale, Amended 6"[2]	0.490	0.00	0.00
Swale, Amended 12"[2]	0.190	0.00	0.00
Swale, Amended 18"[2]	0.120	0.00	0.00
Capture and Use Storage[3]	2110 cf	0.00 cf	0.00
	Totals	0.000	0.00

Figure 11. Step 5 of the CA Phase II LID Sizing Tool

5.1.6 Storm Water Treatment Measure Method

The user must enter the desired storm water treatment measure method by selecting one of the four options listed (see Figure 12). If the desired method is not known, comparisons between methods along with background information, and other notes are provided at the bottom of the page. After selecting the water treatment method, the user clicks the *Next* button to move onto *Step 7 – Use a Storm Water Treatment Measure*.



Step 6 - Select a Storm Water Treatment Measure Method

Climate station	ACTON ESCONDIDO FC261
Saturated hydraulic conductivity	0.25 in/hr
Impervious area	1 acres
Design storm	0.70 in
Percent accomplished by site design measures	0.00%
Percent needed	100.00%

Choose a Method:

Design Storm
This method sizes the LID BMP to treat the selected design storm.

80% Capture
This method uses continous simulation to size the LID BMP to capture 80% of the runoff.

Bioretention Equivalent
This method uses continous simulation to size the LID BMP to match the performance of bioretention cell with 18" of soil and 12" of gravel storage treating 4% of the impervious area.

Central Coast Simple Method
This method is similar to the Design Storm Method, except that for LID BMPs with an underdrain, any storage volume above the underdrain is not credited.

BACK

Figure 12. Step 6 of the CA Phase II LID Sizing Tool

5.1.7 Storm Water Treatment Measure

The final input requires the user to choose the Storm Water Treatment Measure (SWTM) to be implemented and enter the area in acres that will be covered by the SWTM. SWTMs may be sized using a variety of methods specified in the Phase II Permit. Any of the LID BMPs and sizing methods from the CA Phase II LID Sizing Tool may be used (subject to approval by local regulators). For more information on each available SWTM, click on the name of the SWTM and another page will open with detailed information about the selected measure. After entering the storm water treatment measure information, the user clicks the *Next* button to generate the output page.

Step 7 - Use a Storm Water Treatment Measure

Climate station	ACTON ESCONDIDO FC261
Saturated hydraulic conductivity	0.25 in/hr
Impervious area	1 acres
Method	80 Percent Capture

LID BMP Types	Area Needed (acres)	Area Avaliable (acres)	Percent Accomplished
Bioretention Cell - 18" Soil - 12" Gravel Storage	0.051	0.00	0.00
Bioretention Cell - 18" Soil - 24" Gravel Storage	0.044	0.00	0.00
Bioretention Cell - 18" Soil - 36" Gravel Storage	0.040	0.00	0.00
Bioretention Cell - 24" Soil - 12" Gravel Storage	0.047	0.00	0.00
Bioretention Cell - 24" Soil - 24" Gravel Storage	0.041	0.00	0.00
Bioretention Cell - 24" Soil - 36" Gravel Storage	0.038	0.00	0.00
Bioretention Cell - Soil Depth Varies[5] - No Gravel Storage	0.096	0.00	0.00
Infiltration Basin - Vegetated	0.090	0.00	0.00
Infiltration Gallery	0.054	0.00	0.00
Infiltration Trench	0.087	0.00	0.00
Overland Flow no amendment	N/A	N/A	N/A
Porous Pavement	0.140	0.00	0.00
Strip, Amended 6"	0.220	0.00	0.00
Strip, Amended 12"	0.160	0.00	0.00
Strip, Amended 18"	0.120	0.00	0.00
Swale, Amended 6"[6]	0.410	0.00	0.00
Swale, Amended 12"[6]	0.280	0.00	0.00
Swale, Amended 18"[6]	0.220	0.00	0.00
Capture and Use Storage[7]	8637 cf	0.00 cf	0.00
Site Design Measures		0.000	0.00
	Totals	0.000	0.00

BACK NEXT

Figure 13. Step 7 of the CA Phase II LID Sizing Tool

5.2 Tool Output

Tool results are provided on the LID BMP Summary Page. These outputs are intended to be used as an output package for pre-development meetings, applications, and discussions with local regulators.

This step shows a summary of any site design measure and storm water treatment measure LID BMPs you have chosen. If you selected a method that uses continuous simulation (80% Capture or Bioretention Equivalent) the volumes evaporated, infiltrated, passing through an underdrain, and untreated will be shown. The other methods do not calculate these volumes and a dash will be shown instead. The pre-project runoff volume is shown under the summary table. This is the volume that would have runoff the impervious area if the BMPs were not there.

To obtain more information regarding any particular LID BMP type, click the BMP name in the table.

You can print this page or copy and paste it into a document to save your work and to share it with others.

Step 8 - Summary

Climate station	ACTON ESCONDIDO FC261
Saturated hydraulic conductivity	0.25 in/hr
Design Storm	0.70 inches

Method	LID BMP Types	Area Needed (acres)	Area Avaliable (acres)	Percent Accomplished	Volume Evaporated (acre-ft/year)	Volume Infiltrated (acre-ft/year)	Volume of Passing Through the Underdrain (acre-ft/year)	Volume Untreated (acre-ft/year)
Percent Capture	Bioretention Cell - 18" Soil - 12" Gravel Storage	0.051	0.04	78.43	0.04	0.32	0.20	0.14
		Total LID BMP Area	0.04	78.43	0.04	0.32	0.20	0.14
		Total Impervious Area	1	0.00	-	-	-	-
		Totals	1.04	78.43	0.04	0.32	0.20	0.14

Pre-project runoff volume 0.84 acre-ft/year

Figure 14. CA Phase II LID Sizing Tool Summary Page

6.0 REFERENCES

California Regional Water Resources Control Board Central Coast Region (CA RWQCB Central Coast). Post-Construction Stormwater Management Requirements for Development Projects in the Central Coast Region. Attachment 1. Resolution No. R3-2013-0032. July 12, 2013.

Environmental Protection Agency (EPA). 2010. Storm Water Management Model User's Manual Version 5.0. EPA/600/R-05/040. Revised July 2010.

Environmental Protection Agency (EPA). 2013. Storm Water Management Model Version 5.0.022 with Low Impact Development (LID) Controls. Accessed April 2013. http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/

State Water Resources Control Board (SWRCB). 2013. State Water Resources Control Board Water Quality Order No. 2013-0001-DWQ National Pollutant Discharge Elimination System (NPDES) General Permit No. CAS000004 Waste Discharge Requirements (WDRS) for Storm Water Discharges From Municipal Separate Storm Sewer Systems (MS4s) (General Permit). February 2013.

United State Department of Agriculture National Resource Conservation Service (USDA NRSC). 2007. National Engineering Handbook. Part 630 Hydrology. Chapter 7 Hydrologic Soil Groups. May 2007.

Water Environment Federation and American Society of Civil Engineers (WEF and ASCE). 1998. Urban Runoff Quality Management. WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87. Pages 175-178.

Appendix A
CA Phase II LID Sizing Tool
LID BMP Fact Sheets

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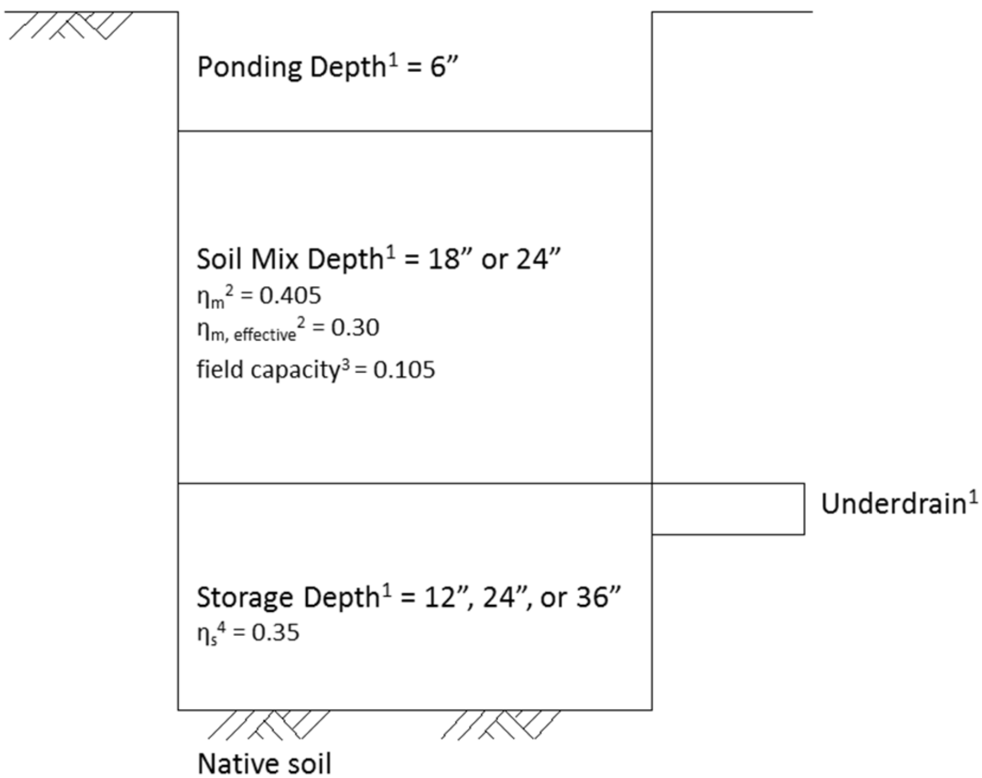
CA Phase II LID Sizing Tool
LID BMP Fact Sheet: Bioretention Cells

Description

Bioretention cells are depressed landscapes into which runoff is directed and allowed to pond, filter, and infiltrate. Some bioretention cells modeled by the CA Phase II LID Sizing Tool consist of the design parameters specified in Section E.12.e.ii.f.3 of the Phase II permit, including a 6" ponding depth underlain by 18" of bioretention soil mix and 12", 24", or 36" of gravel storage. (The Phase II permit requires a minimum storage depth of 12".) The ponding zone allows for temporary storage of runoff and promotes percolation into the bioretention mix. The runoff is also stored in the mix's pore structure, as well as being filtered and biotreated. It eventually drains into the gravel layer below which provides a third storage component. A perforated underdrain is located at the top of the gravel storage component to prevent overflow of the system. This system is unlined to allow infiltration into the underlying native soils. The Central Coast Regional Water Quality Control Board (Region 3) has adopted a variation on the permit-prescribed bioretention cell, where the soil mix depth is to be 24", and so the tool includes bioretention cells having 6" of ponding, 24" of soil mix, and 12", 24", or 36" of gravel storage (with an underdrain).

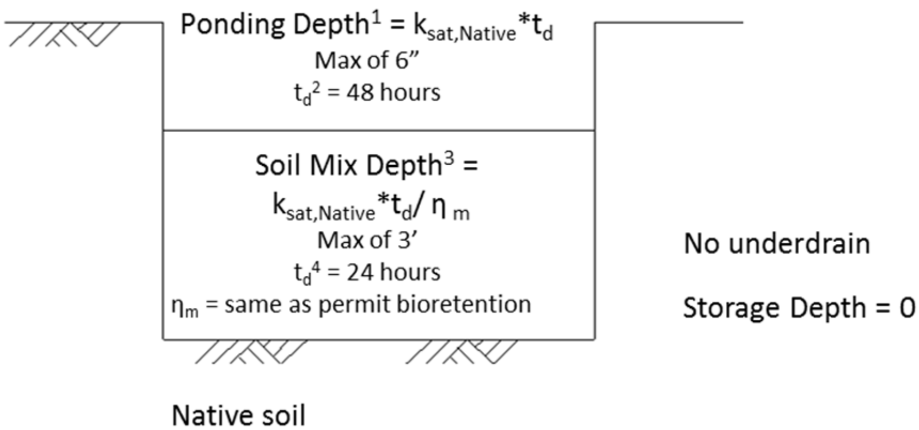


1. SWRCB 2013, LID standard for bioretention, p. 54; CCRWQCB 2013, post-construction requirement for water quality treatment, p. 4.
2. Effective porosity (total porosity – field capacity): VA DCR 2011, 25%; District DOE 2013, 30%; WI DNR 2010, 27%; Prince George 2013, 30%; NC Co-op 2009, 30%; LID Center 2010, 30%. Assume Total porosity = 30% + field capacity.
3. Caltrans 2010, 35% for infiltration trenches; City of Santa Barbara 2008, 30-40% commonly 32%; WI DNR 2010, 33%; NC Co-op 2009, effective porosity 25%. Assume field capacity = 0.
4. USEPA 2010. Field capacity for loamy sand = 0.105.

Note: Excavation depths should consider root uplift and expansion within the soil mix layer

Alternative Design

In cases where native soils are highly permeable and no underdrain is necessary, the tool includes an alternative bioretention cell consisting only of a ponding zone and soil (bioretention) mix zone, both having depths dependent on the native soil's saturated conductivity. These alternative bioretention cells do not have a gravel storage component or an underdrain.



1. City of Sacramento et al. 2007, used for design of infiltration trench depth
2. City of Sacramento et al. 2007, 72 hours. However, 48 hours provides a factor of safety for open-atmosphere ponding and vector issues.
3. Chosen as a more feasible alternative for well-draining soil.
4. 24 hours selected to avoid over ponding.

Note: Excavation depths should consider root uplift and expansion within the soil mix layer.

Design, Cost, Maintenance, and Other Resources

EPA Fact Sheet:

http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=72&minmeasure=5

Construction

http://www.lid-stormwater.net/bio_schedule.htm

Costs

http://www.lid-stormwater.net/bio_costs.htm

Maintenance

http://www.lid-stormwater.net/bio_maintain.htm

Specifications

http://www.lid-stormwater.net/biolowres_specs.htm
http://www.lid-stormwater.net/biohighres_specs.htm
http://www.lid-stormwater.net/biocomind_specs.htm
http://www.lid-stormwater.net/biotrans_specs.htm

Watershed Benefits

http://www.lid-stormwater.net/bio_benefits.htm

General References

LID Feasibility Screening Tool, Contech – coming soon

CASQA LID Portal

https://www.casqa.org/resources/california-lid-portal

Central Coast LID Initiative

http://centralcoastlidi.org/Central_Coast_LIDI/Technical_Guidance.html

EPA Low Impact Development

http://water.epa.gov/polwaste/green/

Low Impact Development (LID) Urban Design Tools Website

http://www.lid-stormwater.net/

EPA BMP Fact Sheets for Post-Construction Stormwater Management in New and Redevelopment

http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=81

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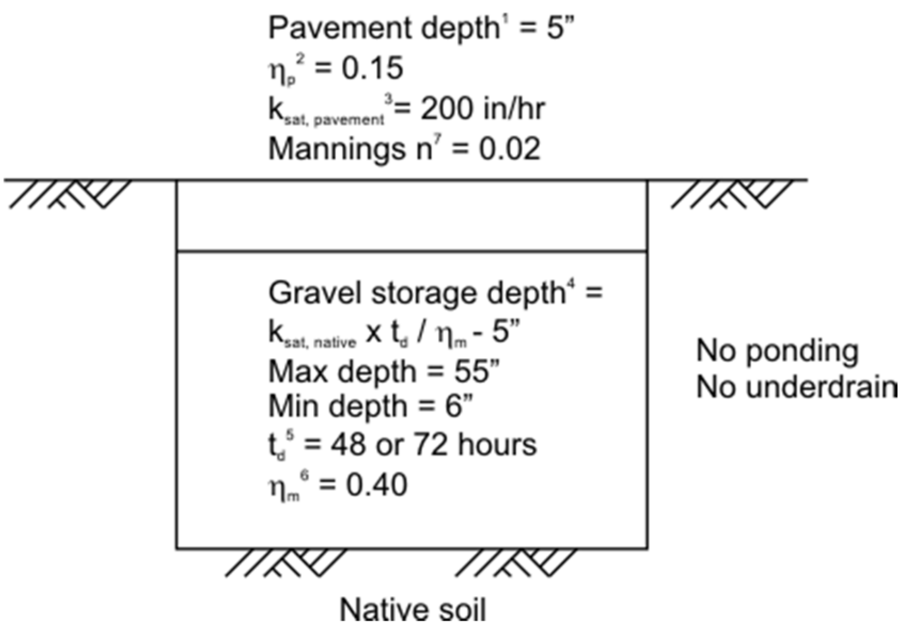
CA Phase II LID Sizing Tool
LID BMP Fact Sheet: Porous Pavement

Description

Porous pavement is a paved pervious surface underlain by a gravel storage zone. The pavement consists of less fine aggregates than traditional concrete or asphalt, and the larger pore spaces that result allow for temporary storage of runoff. The runoff eventually drains into the gravel layer below, which provides an additional storage component and allows infiltration into the underlying native soils. The porous pavement modeled by the CA Phase II LID Sizing Tool assumes a pavement thickness of 5" with a gravel storage depth dependent on the saturated conductivity of the underlying native soils.



1. City of Sacramento et al. 2007, 5" for personal vehicles or pickups, thicker for heavier vehicles.
2. NRMCA 2004, 15%; City of Sacramento et al. 2007, 15-21%; CA Sea Grant et al. 2009, 15-25% for pervious concrete and 30-40% for open graded aggregate; USEPA 2010, void ratios 12-21% ($\eta = e/(1+e)$); CO RMCA 2009, 15-25%.
3. NRMCA 2013, 270-450 in/hr; CA Sea Grant et al. 2009, 480 in/hr for pervious concrete and thousands of inches/hr for open graded aggregate.
4. City of Sacramento et al. 2007, used for design of infiltration trench depth. Add 6" freeboard.
5. Caltrans 2009, 72 hours; City of Santa Barbara 2008, 72 hours for infiltration BMPs. Storage is covered so not a vector concern. Use 72 hours for soils with a saturated conductivity less than 0.33 in/h (most C and D soils). Higher conductivity soils will result in gravel storage depths greater than the maximum, so use 55" of gravel storage for A and B soils.
6. NRMCA 2004, 40%; Cahill Associates 2006, 40%; CoRC 2013, 38-40%.
7. ASCE 2007, 0.013; Ramirez, A. 0.03

Note:Assumes overflow is accomplished at the surface. If a subsurface overflow is used under the pavement layer, the gravel storage depth should be increased by the vertical distance from the surface to the subsurface spill or underdrain.

Design, Cost, Maintenance, and Other Resources

EPA Factsheet for Pervious Concrete Pavement
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=137&minmeasure=5

EPA Factsheet for Pervious Asphalt Pavement
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=135&minmeasure=5

Construction
http://www.lid-stormwater.net/permpavers_schedule.htm

Costs
http://www.lid-stormwater.net/permpaver_costs.htm

Maintenance
http://www.lid-stormwater.net/permpavers_maintain.htm

Specifications
http://www.lid-stormwater.net/permpaver_specs.htm

Watershed Benefits
http://www.lid-stormwater.net/permpavers_benefits.htm

General References

LID Feasibility Screening Tool, Contech – coming soon

CASQA LID Portal
https://www.casqa.org/resources/california-lid-portal

Central Coast LID Initiative
http://centralcoastlidi.org/Central_Coast_LIDI/Technical_Guidance.html

EPA Low Impact Development
http://water.epa.gov/polwaste/green/

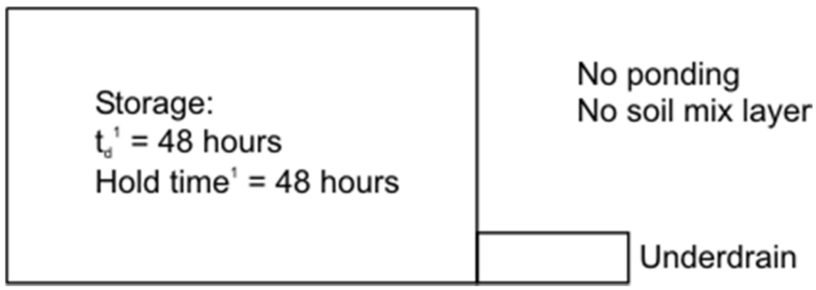
Low Impact Development (LID) Urban Design Tools Website
http://www.lid-stormwater.net/

EPA BMP Fact Sheets
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=81

CA Phase II LID Sizing Tool
LID BMP Fact Sheet: Capture and Use Storage

Description

Capture and Use Storage consists of rain barrels, cisterns, or other above- or below-grade containers that temporarily store runoff, which can in turn be used at a later time. The Capture and Use Storage modeled by the CA Phase II LID Sizing Tool assumes a hold time and drain time of 48 hours, which was selected with the intent of detaining flows, but not necessarily the practicality of when the stored runoff would be needed for later use such as irrigation. For this LID BMP type, the CA Phase II LID Sizing Tool provides the results as required volume capacity rather than areas.



1. Hold time and drain time based on goal of detention and not necessarily irrigation or reuse.

Note: Results are presents as required volume capacity.

Design, Cost, Maintenance, and Other Resources

Construction
http://www.lid-stormwater.net/raincist_construct.htm

Costs
http://www.lid-stormwater.net/raincist_cost.htm

Maintenance
http://www.lid-stormwater.net/raincist_maintain.htm

Specification
http://www.lid-stormwater.net/raincist_specs.htm

Watershed Benefits
http://www.lid-stormwater.net/raincist_benefits.htm

General References

LID Feasibility Screening Tool, Contech – coming soon

CASQA LID Portal
https://www.casqa.org/resources/california-lid-portal

Central Coast LID Initiative
http://centralcoastlidi.org/Central_Coast_LIDI/Technical_Guidance.html

EPA Low Impact Development
http://water.epa.gov/polwaste/green/

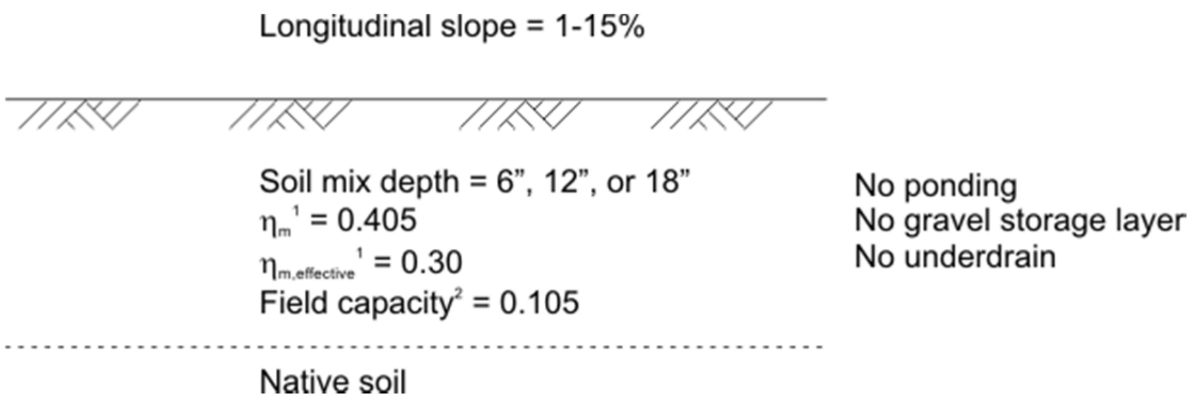
Low Impact Development (LID) Urban Design Tools Website
http://www.lid-stormwater.net/

EPA BMP Fact Sheets
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=81

CA Phase II LID Sizing Tool
LID BMP Fact Sheet: Amended Strip

Description

An amended strip consists of a gently sloped, vegetated surface over which runoff is allowed to move as sheet flow. The soil underlying the strip is amended with compost to increase its porosity and infiltration capacity, thereby increasing the storage volume within the underlying soils and the infiltration rates into the native soil below. The strips modeled by the CA Phase II LID Sizing Tool include amended depths of 6", 12", and 18", and apply for slopes ranging in grade from 1-15%.



1. SWRCB, 2013, LID standard for bioretention, p. 54; CCRWQCB 2013, post-construction requirement for water quality treatment, p. 4.
2. Effective porosity (total porosity – field capacity): VA DCR 2011, 25%; District DOE 2013, 30%; WI DNR 2010, 27%; Prince George 2013, 30%; NC Co-op 2009, 30%; LID Center 2010, 30%. Assume Total porosity = 30% + field capacity.

Notes: Soil amendment allows for enhanced infiltration into the native soil below. Assumes vegetation does not hinder infiltration into the amendment

Design, Cost, Maintenance, and Other Resources

EPA Factsheet
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=76

Construction
http://www.lid-stormwater.net/soilamend_construct.htm

Cost
http://www.lid-stormwater.net/soilamend_costs.htm

Maintenance
http://www.lid-stormwater.net/soilamend_maintain.htm

Specification
http://www.lid-stormwater.net/soilamend_specs.htm

Watershed Benefits
http://www.lid-stormwater.net/soilamend_benefits.htm

General References

LID Feasibility Screening Tool, Contech – coming soon

CASQA LID Portal
https://www.casqa.org/resources/california-lid-portal

Central Coast LID Initiative
http://centralcoastlidi.org/Central_Coast_LIDI/Technical_Guidance.html

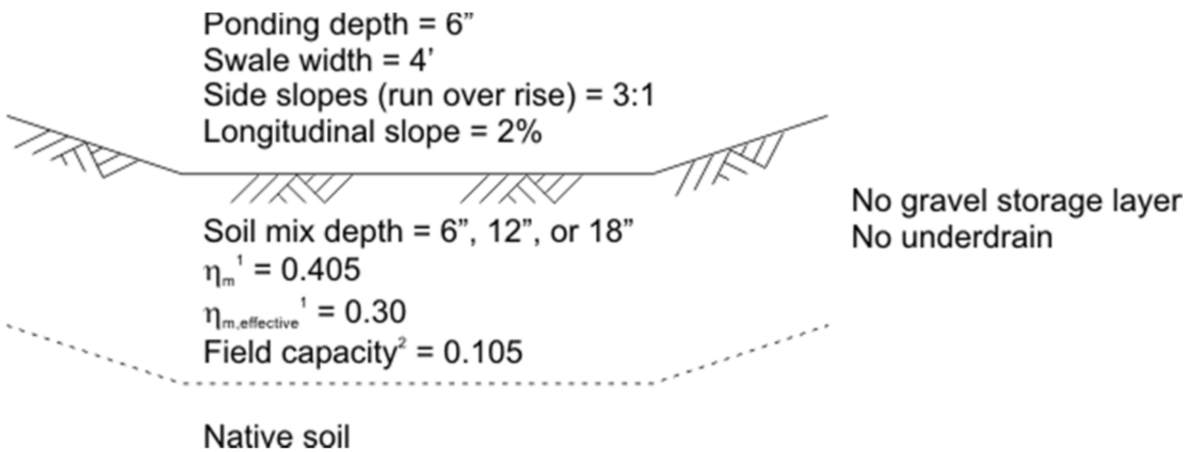
EPA Low Impact Development
http://water.epa.gov/polwaste/green/

Low Impact Development (LID) Urban Design Tools Website
http://www.lid-stormwater.net/

EPA BMP Fact Sheets for Post-Construction Stormwater Management in New and Redevelopment
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=81

Description

An amended swale consists of a gently sloped, vegetated channel through which runoff is allowed to move as sheet flow. The soil underlying the swale is amended with compost to increase its porosity and infiltration capacity, thereby increasing the storage volume within the underlying soils and the infiltration rates into the native soil below. The amended swales modeled by the CA Phase II LID Sizing Tool include amended depths of 6”, 12”, and 18” with a 2% longitudinal slope (in the direction of flow) and side slopes of 3:1 (run:rise).



1. SWRCB 2013, LID standard for bioretention, p. 54; CCRWQCB 2013, post-construction requirement for water quality treatment, p. 4.
2. Effective porosity (total porosity – field capacity): VA DCR 2011, 25%; District DOE 2013, 30%; WI DNR 2010, 27%; Prince George 2013, 30%; NC Co-op 2009, 30%; LID Center 2010, 30%. Assume Total porosity = 30% + field capacity.

Notes: Soil amendment allows for enhanced infiltration into the native soil below. Assumes vegetation does not hinder infiltration into the amendment.

Design, Cost, Maintenance, and Other Resources

EPA Factsheet
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=75&minmeasure=5

Construction
http://www.lid-stormwater.net/soilamend_construct.htm

Cost
http://www.lid-stormwater.net/soilamend_costs.htm

Maintenance
http://www.lid-stormwater.net/soilamend_maintain.htm

Specifications
http://www.lid-stormwater.net/soilamend_specs.htm

Watershed Benefits
http://www.lid-stormwater.net/soilamend_benefits.htm

General References

LID Feasibility Screening Tool, Contech – coming soon

CASQA LID Portal
https://www.casqa.org/resources/california-lid-portal

Central Coast LID Initiative
http://centralcoastlidi.org/Central_Coast_LIDI/Technical_Guidance.html

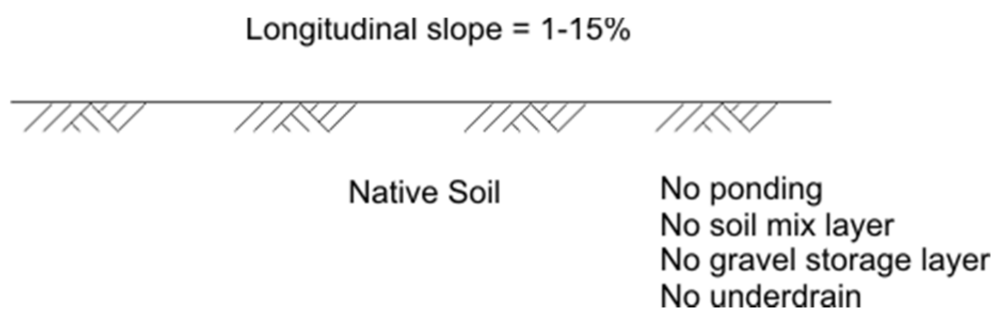
EPA Low Impact Development
http://water.epa.gov/polwaste/green/

Low Impact Development (LID) Urban Design Tools Website
http://www.lid-stormwater.net/

EPA BMP Fact Sheets for Post-Construction Stormwater Management in New and Redevelopment
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=81

Description

Overland flow consists of an existing vegetated strip with no soil amendment. Runoff is allowed to move as sheet flow across the strip, where the vegetation provides filtration and attenuation. The LID BMP type may be ideal where there is a large amount of available space or where the native soils are highly conductive. Overland flows modeled by the CA Phase II LID Sizing Tool apply to strips having 1-15% slopes.



Note: This LID BMP is an alternative to the more engineered LID BMPs.

Design, Cost, Maintenance, and Other Resources

EPA Factsheet

http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=76

General References

LID Feasibility Screening Tool, Contech – coming soon

CASQA LID Portal

https://www.casqa.org/resources/california-lid-portal

Central Coast LID Initiative

http://centralcoastlidi.org/Central_Coast_LIDI/Technical_Guidance.html

EPA Low Impact Development

http://water.epa.gov/polwaste/green/

Low Impact Development (LID) Urban Design Tools Website

http://www.lid-stormwater.net/

EPA BMP Fact Sheets for Post-Construction Stormwater Management in New and Redevelopment

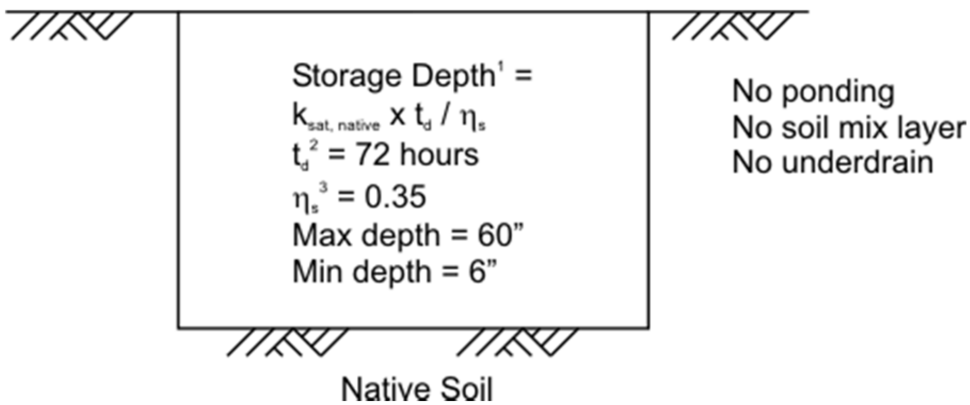
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5

http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=81

CA Phase II LID Sizing Tool
LID BMP Fact Sheet: Infiltration Trench

Description

Infiltration trenches are engineered structures that provide storage and facilitate infiltration of runoff into the subsurface. Infiltration trenches are typically long and narrow and filled with aggregate. The trenches modeled by the CA Phase II LID Sizing Tool were modeled having a depth dependent on the saturated conductivity of the underlying native soils.



1. City of Sacramento et al. 2007, used for design of infiltration trench depth.
2. City of Santa Barbara 2008, 72 hours for infiltration BMPs. Storage is covered so not a vector concern.
3. Caltrans 2010, 35% for infiltration trenches; City of Santa Barbara 2008, 30-40% commonly 32%; WA DOE 2012, 30-40%; WI DNR 2010, 33%; NC Co-op 2009, effective 25%. Assume field capacity = 0.

Design, Cost, Maintenance, and Other Resources

EPA Factsheet

http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=70&minmeasure=5

General References

LID Feasibility Screening Tool, Contech – coming soon

CASQA LID Portal

https://www.casqa.org/resources/california-lid-portal

Central Coast LID Initiative

http://centralcoastlidi.org/Central_Coast_LIDI/Technical_Guidance.html

EPA Low Impact Development

http://water.epa.gov/polwaste/green/

Low Impact Development (LID) Urban Design Tools Website

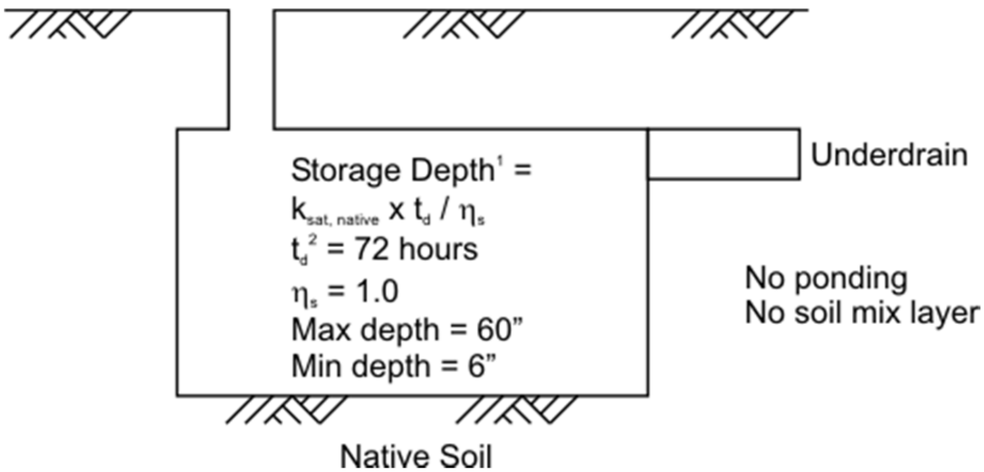
http://www.lid-stormwater.net/

EPA BMP Fact Sheets for Post-Construction Stormwater Management in New and Redevelopment

http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5

Description

Infiltration galleries are engineered structures that provide storage and facilitate infiltration of runoff into the subsurface. They consist of one or more horizontal or vertical perforated containers. The galleries modeled by the CA Phase II LID Sizing Tool were modeled having depths dependent on the saturated conductivity of the underlying native soils.



1. City of Sacramento et al. 2007, used for design of infiltration trench depth
2. City of Santa Barbara 2008, 72 hours for infiltration BMPs. Storage is covered so not a vector concern.

Design, Cost, Maintenance, and Other Resources

EPA Factsheet
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=70&minmeasure=5

General References

LID Feasibility Screening Tool, Contech – coming soon

CASQA LID Portal
https://www.casqa.org/resources/california-lid-portal

Central Coast LID Initiative
http://centralcoastlidi.org/Central_Coast_LIDI/Technical_Guidance.html

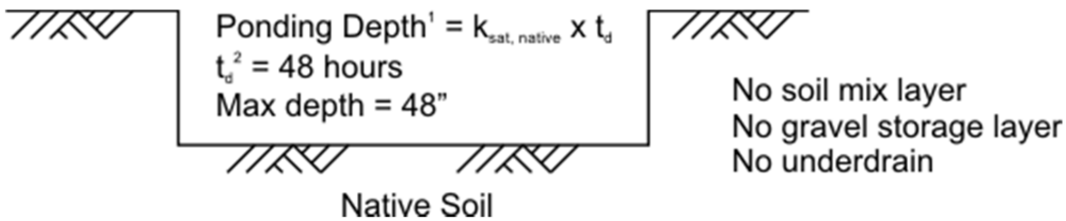
EPA Low Impact Development
http://water.epa.gov/polwaste/green/

Low Impact Development (LID) Urban Design Tools Website
http://www.lid-stormwater.net/

EPA BMP Fact Sheets for Post-Construction Stormwater Management in New and Redevelopment
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5

Description

Vegetated infiltration basins are shallow, vegetated basins designed to provide storage and promote infiltration of runoff into the underlying native soils. The basins modeled by the CA Phase II LID Sizing Tool assume a surface storage depth dependent on the saturated conductivity of the underlying native soils.



1. City of Sacramento et al. 2007, used for design of infiltration trench depth
2. City of Sacramento et al. 2007, could use 72 hours but 48 hours provides a factor of safety for open-atmosphere ponding and vector issues.

Note: Assumes vertical slopes. If slopes are laid back, areas must be recalculated manually.

Design, Cost, Maintenance, and Other Resources

EPA Factsheet
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=69&minmeasure=5

General References

LID Feasibility Screening Tool, Contech – coming soon

CASQA LID Portal
https://www.casqa.org/resources/california-lid-portal

Central Coast LID Initiative
http://centralcoastlidi.org/Central_Coast_LIDI/Technical_Guidance.html

EPA Low Impact Development
http://water.epa.gov/polwaste/green/

Low Impact Development (LID) Urban Design Tools Website
http://www.lid-stormwater.net/

EPA BMP Fact Sheets for Post-Construction Stormwater Management in New and Redevelopment
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5

CA Phase II LID Sizing Tool
LID BMP Fact Sheet References

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City of Sacramento, City of Citrus Heights, City of Elk Grove, City of Folsom, City of Galt, City of Rancho Cordova, City of Roseville, County of Sacramento 2007. Stormwater Quality Design Manual for the Sacramento and South Placer Regions. May 2007.

City of Santa Barbara 2008. Storm Water BMP Guidance Manual. June 2008.

District of Columbia Department of the Environment (District DOE) 2013. The River Smart Rain Garden Rebate. Retrieved November 2013. http://ddoe.dc.gov/sites/default/files/dc/sites/ddoe/publication/attachments/Rebate%20Rain%20Garden%20Design%20Specs.pdf.

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North Carolina Cooperative Extension (NC Co-op) 2009. Designing Bioretention with an Internal Water Storage (IWS) Layer: Design Guidance for an Innovative Bioretention Feature. November 2009.

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Prince George's County, Maryland 2013. Bioretention Design Specifications and Criteria. Retrieved November 2013.
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Ramirez, A. 2008. Untitled Presentation, with Objective to "Evaluate Various Surface Materials in Urban Parking Areas to Reduce Stormwater Runoff and Annual Pollutant Loads". Retrieved December 2013.
http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0CC4QFjAB&url=http%3A%2F%2Fwww.ce.utexas.edu%2Fprof%2Fmaidment%2FGradHydro2008%2FApr24%2FRamirez.ppt&ei=TCieUtmwIcXzoATZ94KwBA&usg=AFQjCNGjFqYyWMQPU6GD6AKlvEk-FoNtEQ&bvm=bv.57155469,d.cGU

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Appendix B
CA Phase II LID Sizing Tool
SWMM Input Parameters

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CA Phase II LID Sizing Tool
SWMM Input Parameters: Amended Strip, Overland Flow, Vegetated Swale

subcatchment input parameter	unit	paramenter description	sub-catchment			vegetated swale	
			LID BMP:		Notes	LID BMP:	Notes
			amended strip	overland flow w/no amendment		amended swale	
			SWMM LID:			SWMM LID:	
			sub-catchment			vegetated swale	
Rain gage	-	Name of the rain gage associated with the subcatchment.	Gage name	Gage name		Gage name	
Outlet	-	Name of the node or subcatchment that recieves the subcatchment's runoff.	outlet name	outlet name		outlet name	
Area	acre	Area of the subcatchment, including any LID controls (acres or hectares).	varies	varies		varies	
Width	ft	Characteristic width of the overland flow path for sheet flow runoff (feet or meters). (More)	area/100	area/100		area/100	
% slope	%	Average percent slope of the subcatchment.	5	2		2	
% impervious	%	Percent of the land area (not including any LIDs) which is impervious.	0	0		0	
N-imp	-	Manning's n for overland flow over the impervious portion of the subcatchment (Typical Values).	0.01	0.01		0.01	
N-perv	-	Manning's n for overland flow over the pervious portion of the subcatchment (Typical Values).	0.4	0.13	assume bermuda grass for amended strips, natural for overland flow	0.02	assume bermuda grass
Dstore-Imperv	in	Depth of depression storage on the impervious portion of the subcatchment (inches or millimeters) (Typical Values).	0.05	0.05		0.05	
Dstore-perv	in	Depth of depression storage on the pervious portion of the subcatchment (inches or millimeters) (Typical Values).	(6", 12", 18")*effective porosity of 0.30	0.2	For Amended strip, assume amended soil has same effective porosity as bioretention soil mix	(6", 12", 18")*effective porosity of 0.30	For Amended strip, assume amended soil has same effective porosity has bioretention soil mix
%Zero-Imperv	%	Percent of the impervious area with no depression storage.	0	0		0	
Subarea Routing	-	Choice of internal routing of runoff between pervious and impervious areas: imperv - runoff from pervious area flows to impervious area ; perv - runoff from impervious flows to pervious area ; outlet - runoff from both areas flows directly to outlet	outlet	outlet		outlet	
Percent Routed	%	Percent of runoff routed between subareas	100	100		100	
Infiltration	-	Click the ellipsis button (or press Enter) to edit infiltration parameters for the subcatchment	Green Ampt	Green Ampt		Green Ampt	
LID Controls	-	Click the ellipsis button (or press Enter) to edit the use of low impact development controls in the subcatchment.	NA	NA		vegetated swale	
GW	-	Click the ellipsis button (or press Enter) to edit groundwater flow parameters for the subcatchment.	NA	NA		NA	
SnowPack	-	Name of snow pack parameter set (if any) assigned to the subcatchment.	NA	NA		NA	
LandUses	-	Click the ellipsis button (or press Enter) to assign land uses to the subcatchment.	NA	NA		NA	
Initial Buildup	-	Click the ellipsis button (or press Enter) to specify initial quantities of pollutant buildup over the subcatchment.	NA	NA		NA	
Curb Length	-	Total length of curbs in the subcatchment (any length units). Used only when pollutant buildup is normalized to curb length.	NA	NA		NA	

CA Phase II LID Sizing Tool
SWMM Input Parameters: Amended Strip, Overland Flow, Vegetated Swale

LID input parameter	unit	paramenter description	amended strip	overland flow w/no amendment	Notes	amended swale	Notes
surface storage depth	in	When confining walls or berms are present this is the maximum depth to which water can pond above the surface of the unit before overflow occurs (in inches or mm). For LIDs that experience overland flow it is the height of any surface depression storage. For swales, it is the height of its trapezoidal cross section.	NA	NA	subcatchment is modeled as BMP	6	height of trapezoidal cross section
surface vegetation volume fraction	volume fraction	The fraction of the volume within the storage depth filled with vegetation. This is the volume occupied by stems and leaves, not their surface area coverage. Normally this volume can be ignored, but may be as high as 0.1 to 0.2 for very dense vegetative growth.	NA	NA	subcatchment is modeled as BMP	0.15	
surface roughness (Manning's n)	Manning's n	Manning's n for overland flow over the surface of porous pavement or a vegetative swale (see this table for suggested values). Use 0 for other types of LIDs	NA	NA	subcatchment is modeled as BMP	0.4	assume bermuda grass
surface slope	%	Slope of porous pavement surface or vegetative swale (percent). Use 0 for other types of LIDs.	NA	NA	subcatchment is modeled as BMP	2	
swale side slope	run/rise	Slope (run over rise) of the side walls of a vegetative swale's cross section. This value is ignored for other types of LIDs.	NA	NA	subcatchment is modeled as BMP	3	
top width of overland flow surface	in ft or m	width of the outflow face of each identical LID unit. Only applies to LID processes such as PP and veg swales that use overland flow to convery suface runoff off of the unit. (the other LID processes such as bioretention cells and infiltration trenches simply spill any excess captured runoff over thier berms	NA	NA	subcatchment is modeled as BMP	4	6" depth @ 3:1 (run:rise) - 1.5+1.5 = 3 feet; add 1 foot bottom width
soil thickness	in	The thickness of the soil layer (inches or mm). Typical values range from 18 to 36 inches (450 to 900 mm) for rain gardens, street planters and other types of land-based bio-retention units, but only 3 to 6 inches (75 to 150 mm) for green roofs.	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
soil porosity	volume fraction	The volume of pore space relative to total volume of soil (as a fraction).	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
soil field capacity	volume fraction	Volume of pore water relative to total volume after the soil has been allowed to drain fully (as a fraction). Below this level, vertical drainage of water through the soil layer does not occur.	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
soil wilting point	volume fraction	Volume of pore water relative to total volume for a well dried soil where only bound water remains (as a fraction). The moisture content of the soil cannot fall below this limit.	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
soil conductivity	in/hr	Hydraulic conductivity for the fully saturated soil (in/hr or mm/hr)	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
soil conductivity slope	-	Slope of the curve of log(conductivity) versus soil moisture content (dimensionless). Typical values range from 5 for sands to 15 for silty clay.	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
soil suction head	in	The average value of soil capillary suction along the wetting front (inches or mm). This is the same parameter as used in the Green-Ampt infiltration model.	NA	NA	subcatchment is modeled as BMP	NA	NA for swales

CA Phase II LID Sizing Tool

SWMM Input Parameters: Amended Strip, Overland Flow, Vegetated Swale

LID input parameter	unit	paramenter description	amended strip	overland flow w/no amendment	Notes	amended swale	Notes
storage height	**in**	This is the height of a rain barrel or thickness of a gravel layer (inches or mm). Crushed stone and gravel layers are typically 6 to 18 inches (150 to 450 mm) thick while single family home rain barrels range in height from 24 to 36 inches (600 to 900 mm).	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
storage void ratio	**voids/solids**	The volume of void space relative to the volume of solids in the layer. Typical values range from 0.5 to 0.75 for gravel beds. Note that porosity = void ratio / (1 + void ratio). Does not apply to rain barrels	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
storage conductivity	**in/hr**	The rate at which water infiltrates into the native soil below the layer (in inches/hour or mm/hour).This would typically be the Saturated Hydraulic Conductivity of the surrounding subcatchment if Green-Ampt infiltration is used or the Minimum Infiltration Rate for Horton infiltration. If there is an impermeable floor or liner below the layer then use a value of 0. does not apply to rain barrels	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
storage cloggin factor	**-**	Total volume of treated runoff it takes to completely clog the bottom of the layer divided by the void volume of the layer. Use a value of 0 to ignore clogging. Clogging progressively reduces the Infiltration Rate in direct proportion to the cumulative volume of runoff treated and may only be of concern for infiltration trenches with permeable bottoms and no under drains. Refer to the Pavement Layer page for more discussion of the Clogging Factor. Does not apply to rain barrels	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
underdrain coefficient	**in/hr**	Coefficient *C* and exponent *n* that determines the rate of flow through the underdrain as a function of height of stored water above the drain height. The following equation is used to compute this flow rate (per unit area of the LID unit): $q = C(h-Hd)^n$ where q is outflow (in/hr or mm/hr), h height of stored water (inches or mm), and Hd is the drain height. If the layer does not have an underdrain then set C to 0. A typical value for n would be 0.5 (making the drain act like an orifice). A rough estimate for C can be based on the time T required to drain a depth D of stored water. For n = 0.5, C = 2D1/2/T does not apply to rain barrels	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
underdrain exponent	**-**		NA	NA	subcatchment is modeled as BMP	NA	NA for swales
underdrain offset height	**in**	Height of any underdrain piping above the bottom of a storage layer or rain barrel (inches or mm).	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
underdrain delay	**hrs**	The number of dry weather hours that must elapse before the drain line in a rain barrel is opened (the line is assumed to be closed once rainfall begins). This parameter is ignored for other types of LIDs	NA	NA	subcatchment is modeled as BMP	NA	NA for swales

LID input parameter	unit	paramenter description	amended strip	overland flow w/no amendment	Notes	amended swale	Notes
pavement thickness	in	The thickness of the pavement layer (inches or mm). Typical values are 4 to 6 inches (100 to 150 mm).	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
pavement void ratio	voids/solids	The volume of void space relative to the volume of solids in the pavement for continuous systems or for the fill material used in modular systems. Typical values for pavements are 0.12 to 0.21. Note that porosity = void ratio / (1 + void ratio).	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
pavement impervious surface fraction	-	Ratio of impervious paver material to total area for modular systems; 0 for continuous porous pavement systems.	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
pavement permeability	in/hr	Permeability of the concrete or asphalt used in continuous systems or hydraulic conductivity of the fill material (gravel or sand) used in modular systems (in/hr or mm/hr). The permeability of new porous concrete or asphalt is very high (e.g., hundreds of in/hr) but can drop off over time due to clogging by fine particulates in the runoff (see below).	NA	NA	subcatchment is modeled as BMP	NA	NA for swales
pavement clogging factor	-	Number of pavement layer void volumes of runoff treated it takes to completely clog the pavement. Use a value of 0 to ignore clogging. Clogging progressively reduces the pavement's permeability in direct proportion to the cumulative volume of runoff treated. If one has an estimate of the number of years it takes to fully clog the system (Yclog), the Clogging Factor can be computed as: Yclog * Pa * CR * (1 + VR) * (1 - ISF) / (T * VR) where Pa is the annual rainfall amount over the site, CR is the pavement's capture ratio (area that contributes runoff to the pavement divided by area of the pavement itself), VR is the system's Void Ratio, ISF is the Impervious Surface Fraction, and T is the pavement layer Thickness. As an example, suppose it takes 5 years to clog a continuous porous pavement system that serves an area where the annual rainfall is 36 inches/year. If the pavement is 6 inches thick, has a void ratio of 0.2 and captures runoff only from its own surface, then the Clogging Factor is 5 x 36 x (1 + 0.2) / 6 / 0.2 = 180.	NA	NA	subcatchment is modeled as BMP	NA	NA for swales

CA Phase II LID Sizing Tool
SWMM Input Parameters: Infiltration Trench, Infiltration Gallery, Rain Barrel

infiltration trench			
subcatchment input parameter	LID BMP:		Notes
	sand bed/infiltration trench	infiltration gallery	
	SWMM LID:		
	infiltration trench		
Rain gage	Gage name	Gage name	
Outlet	outlet name	outlet name	
Area	varies	varies	
Width	area/100		
% slope	2	2	
% impervious	0	0	
N-imp	0.01	0.01	
N-perv	0.02	0.02	
Dstore-Imperv	0.05	0.05	
Dstore-perv	0.2	0.2	
%Zero-Imperv	0	0	
Subarea Routing	outlet	outlet	
Percent Routed	100	100	
Infiltration	Green Ampt	Green Ampt	
LID Controls	infiltration trench	infiltration trench	
GW	NA	NA	
SnowPack	NA	NA	
LandUses	NA	NA	
Initial Buildup	NA	NA	
Curb Length	NA	NA	

rain barrel	
LID BMP:	Notes
reuse storage -> hold & release	
SWMM LID:	
rain barrel	
Gage name	
outlet name	
varies	
area/100	
2	
0	
0.01	
0.02	
0.05	
0.2	
0	
outlet	
100	
Green Ampt	
rain barrel	
NA	
NA	
NA	
NA	
NA	

CA Phase II LID Sizing Tool
SWMM Input Parameters: Infiltration Trench, Infiltration Gallery, Rain Barrel

LID input parameter	sand bed/infiltration trench	infiltration gallery	Notes
surface storage depth	0	0	No ponding for Infiltration trench or gallery
surface vegetation volume fraction	NA	NA	NA for infiltration trench
surface roughness (Manning's n)	0	0	0 for non porous pavement or swale
surface slope	0	0	0 for non porous pavement or swale
swale side slope	NA	NA	NA for infiltration trench
top width of overland flow surface	NA	NA	NA for infiltration trench
soil thickness	NA	NA	NA for infiltration trench
soil porosity	NA	NA	NA for infiltration trench
soil field capacity	NA	NA	NA for infiltration trench
soil wilting point	NA	NA	NA for infiltration trench
soil conductivity	NA	NA	NA for infiltration trench
soil conductivity slope	NA	NA	NA for infiltration trench
soil suction head	NA	NA	NA for infiltration trench

reuse storage -> hold & release	Notes
NA	NA for rain barrels
NA	NA for rain barrels
0	0 for non porous pavement or swale
0	0 for non porous pavement or swale
NA	NA for rain barrels
NA	NA for rain barrels
NA	NA for rain barrels
NA	NA for rain barrels
NA	NA for rain barrels
NA	NA for rain barrels
NA	NA for rain barrels
NA	NA for rain barrels
NA	NA for rain barrels

CA Phase II LID Sizing Tool
SWMM Input Parameters: Infiltration Trench, Infiltration Gallery, Rain Barrel

LID input parameter	sand bed/infiltration trench	infiltration gallery	Notes	reuse storage -> hold & release	Notes
storage height	$ksat_{(native)}*t_d/\eta_s$; min of 6"	$2*[ksat_{(native)}*t_d/\eta_s]$	for trench and gallery: td = 72 hours; for trench ns = 0.35; for gallery, ns = 1 and multiple depth by 2 to account for void ratio of 0.999	36	
storage void ratio	0.54	0.99	porosity of trench= 0.35 = e/(1+e) so e = 0.54; porosity of gallery = .75 so e = 3=n/(1-n) but SWMM doesn't take e>1, so Assumee= 0.99 multiply storage height by 2/3 to simulate	NA	NA for rain barrels
storage conductivity	varies depending on underlying soil	varies depending on underlying soil	native soil dependet	NA	NA for rain barrels
storage cloggin factor	0	0	Assume BMPs are well maintained with no clogging	NA	NA for rain barrels
underdrain coefficient	0	5.0000	no underdrain for trench	0.1	NA for rain barrels, but requires an input value
underdrain exponent	0	0.5	no underdrain for trench; for gallery, assume underdrain acts like orifice, so UD exp (n) = 0.5	0.1	NA for rain barrels, but requires an input value
underdrain offset height	0	storage height - 1"	no underdrain for trench; for gallery,SWMM doesn't let UD go at top of storage	0	
underdrain delay	NA	NA	NA for infiltration trench	48	

CA Phase II LID Sizing Tool
SWMM Input Parameters: Infiltration Trench, Infiltration Gallery, Rain Barrel

LID input parameter	sand bed/infiltration trench	infiltration gallery	Notes
pavement thickness	NA	NA	NA for infiltration trench
pavement void ratio	NA	NA	NA for infiltration trench
pavement impervious surface fraction	NA	NA	NA for infiltration trench
pavement permeability	NA	NA	NA for infiltration trench
pavement clogging factor	NA	NA	NA for infiltration trench

reuse storage -> hold & release	Notes
NA	NA for rain barrels
NA	NA for rain barrels
NA	NA for rain barrels
NA	NA for rain barrels
NA	NA for rain barrels

CA Phase II LID Sizing Tool
SWMM Input Parameters: Bioretention Cells, Vegetated Infiltration Basin, Porous Pavement

bioretention cell

subcatchment input parameter	LID BMP: Bioretention Cell 18 in. Soil Mix 12, 24, or 36 in. Gravel Storage	LID BMP: Bio Retention Cell 24 in. Soil Mix 12, 24, or 36 in. Gravel Storage	LID BMP: Bioretention Cell Soil Depth Varies No Gravel Storage	LID BMP: vegetated infiltration basin	Notes
SWMM LID:	bioretention cell				
Rain gage	Gage name	Gage name	Gage name	Gage name	
Outlet	outlet name	outlet name	outlet name	outlet name	
Area	varies	varies	varies	varies	
Width	area/100	area/100	area/100	area/100	
% slope	2	2	2	2	
% impervious	0	0	0	0	
N-imp	0.01	0.01	0.01	0.01	
N-perv	0.02	0.02	0.02	0.02	
Dstore-Imperv	0.05	0.05	0.05	0.05	
Dstore-perv	0.2	0.2	0.2	0.2	
%Zero-Imperv	0	0	0	0	
Subarea Routing	outlet	outlet	outlet	outlet	
Percent Routed	100	100	100	100	
Infiltration	Green Ampt	Green Ampt	Green Ampt	Green Ampt	
LID Controls	bioretention cell	bioretention cell	bioretention cell	bioretention cell	
GW	NA	NA	NA	NA	
SnowPack	NA	NA	NA	NA	
LandUses	NA	NA	NA	NA	
Initial Buildup	NA	NA	NA	NA	
Curb Length	NA	NA	NA	NA	

porous pavement

subcatchment input parameter	LID BMP: porous pavement	Notes
SWMM LID:	porous pavement	
Rain gage	Gage name	
Outlet	outlet name	
Area	varies	
Width	area/100	
% slope	0.5	
% impervious	0	
N-imp	0.01	
N-perv	0.02	
Dstore-Imperv	0.05	
Dstore-perv	0.1	
%Zero-Imperv	0	
Subarea Routing	outlet	
Percent Routed	100	
Infiltration	Green Ampt	
LID Controls	porous pavement	
GW	NA	
SnowPack	NA	
LandUses	NA	
Initial Buildup	NA	
Curb Length	NA	

CA Phase II LID Sizing Tool
SWMM Input Parameters: Bioretention Cells, Vegetated Infiltration Basin, Porous Pavement

LID input parameter	Bioretention Cell 18 in. Soil Mix 12, 24, or 36 in. Gravel Storage	Bio Retention Cell 24 in. Soil Mix 12, 24, or 36 in. Gravel Storage	Bioretention Cell Soil Depth Varies No Gravel Storage	vegetated infiltration basin	Notes
surface storage depth	6	6	ksat(native)*t_d; max of 6"	ksat(native)*t_d; max of 6"	For Alternative Bioretention and Veg. Infiltration Basin, t_d = 48 hours
surface vegetation volume fraction	0.05	0.05	0.05	0.05	
surface roughness (Manning's n)	0	0	0	0	0 for non porous pavement or swale
surface slope	0	0	0	0	0 for non porous pavement or swale
swale side slope	NA	NA	NA	NA	NA for bioretention cells
top width of overland flow surface	NA	NA	NA	NA	NA for bioretention cells
soil thickness	18	24	ksat(native)*t_d/$\eta_{meffective}$; max of 3'	1	For Alternative Bioretention, t_d = 24 hours; no mix for vegetated infiltration basin but SWMM requires a value so minimize it (1"); for Alternative BR use effective porosity $\eta_{meffective}$ = soil porosity-soil field capacity
soil porosity	0.405	0.405	0.405	0.405	no mix for vegetated infiltration basin but SWMM requires a value so use same as Prescribed Bioretention
soil field capacity	0.105	0.105	0.105	0.105	no mix for vegetated infiltration basin but SWMM requires a value so use same as Prescribed Bioretention
soil wilting point	0.047	0.047	0.047	0.047	no mix for vegetated infiltration basin but SWMM requires a value so use same as Prescribed Bioretention
soil conductivity	5	5	5	5	no mix for vegetated infiltration basin but SWMM requires a value so use same as Prescribed Bioretention
soil conductivity slope	8	8	8	8	no mix for vegetated infiltration basin but SWMM requires a value so use same as Prescribed Bioretention
soil suction head	2.4	2.4	2.4	2.4	no mix for vegetated infiltration basin but SWMM requires a value so use same as Prescribed Bioretention

porous pavement	Notes
0	NA for porous pavement
0	NA for porous pavement
0.02	
1	
NA	NA for porous pavement
sqrt(area)	
NA	NA for porous pavement
NA	NA for porous pavement
NA	NA for porous pavement
NA	NA for porous pavement
NA	NA for porous pavement
NA	NA for porous pavement
NA	NA for porous pavement

CA Phase II LID Sizing Tool
SWMM Input Parameters: Bioretention Cells, Vegetated Infiltration Basin, Porous Pavement

LID input parameter	Bioretention Cell 18 in. Soil Mix 12, 24, or 36 in. Gravel Storage	Bio Retention Cell 24 in. Soil Mix 12, 24, or 36 in. Gravel Storage	Bioretention Cell Soil Depth Varies No Gravel Storage	vegetated infiltration basin	Notes
storage height	12	12	0	1	Assume no storage or underdrain for alternative bioretention; For Veg. Infiltration Basin assume 1" to simulate infiltration below
storage void ratio	0.54	0.54	0	0.54	Assume no storage or underdrain for alternative bioretention; For Veg. Infiltration Basin assume Prescribed Bioretention to simulate infiltration below
storage conductivity	varies depending on underlying soil	varies depending on underlying soil	varies depending on underlying soil	varies depending on underlying soil	native soil dependet
storage cloggin factor	0	0	0	0	Assume no storage or underdrain for alternative bioretention or inf basin; assume BMPs are well maintained with no clogging
underdrain coefficient	1.021	1.021	0	0	Assume no storage or underdrain for alternative bioretention or inf basin
underdrain exponent	0.5	0.5	0	0	Assume no storage or underdrain for alternative bioretention or inf basin; assume underdrain acts like orifice, so UD exp (n) = 0.5
underdrain offset height	11	11	0	0	Assume no storage or underdrain for alternative bioretention or inf basin
underdrain delay	NA	NA	NA	NA	NA for bioretention cells

porous pavement	Notes
$Ksat_{(native)}$*td/ns+6, min of 6", Max of 5'	Assume ns = 0.40. td = 48 hours for A&B soils, 72 hours for C&D soils
0.67	
varies depending on underlying soil	native soil dependet
0	ignore
0	Assume no underdrain
0	Assume no underdrain
0	Assume no underdrain
NA	NA for porous pavement

CA Phase II LID Sizing Tool
SWMM Input Parameters: Bioretention Cells, Vegetated Infiltration Basin, Porous Pavement

LID input parameter	Bioretention Cell 18 in. Soil Mix 12, 24, or 36 in. Gravel Storage	Bio Retention Cell 24 in. Soil Mix 12, 24, or 36 in. Gravel Storage	Bioretention Cell Soil Depth Varies No Gravel Storage	vegetated infiltration basin	Notes
pavement thickness	NA	NA	NA	NA	NA for bioretention cells
pavement void ratio	NA	NA	NA	NA	NA for bioretention cells
pavement impervious surface fraction	NA	NA	NA	NA	NA for bioretention cells
pavement permeability	NA	NA	NA	NA	NA for bioretention cells
pavement clogging factor	NA	NA	NA	NA	NA for bioretention cells

porous pavement	Notes
5	
0.18	assume porosity of 0.15, e = n/(1-n)
0	
200	
0	Assume well maintained BMP with no clogging

CA Phase II LID Sizing Tool
SWMM Input Parameters: Impervious Catchment

Assume 100% impervious area running off to:

subcatchment input parameter	unit	LID BMP:									
		amended strip	amended swale	sand bed/infiltration trench	reuse storage -> hold & release	prescribed bioretention cell	alternative bioretention cell	overland flow w/no amendment	infiltration gallery	porous pavement	vegetated infiltration basin
		SWMM LID:									
		sub-catchment	vegetated swale	infiltration trench	rain barrel	bioretention cell	bioretention cell	sub-catchment	rain barrel	porous pavement	bioretention cell
Rain gage	-	Gage name	Gage name	Gage name	Gage name	Gage name	Gage name	Gage name	Gage name	Gage name	Gage name
Outlet	-	sub-catchment	sub-catchment	sub-catchment	sub-catchment	sub-catchment	sub-catchment	sub-catchment	sub-catchment	sub-catchment	sub-catchment
Area	acre	1	1	1	1	1	1	1	1	1	1
Width of overland flow	ft	435.6	435.6	435.6	435.6	435.6	435.6	435.6	435.6	435.6	435.6
% slope	%	2	2	2	2	2	2	2	2	2	2
% impervious	%	100	100	100	100	100	100	100	100	100	100
N-imp	-	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
N-perv	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Dstore-Imperv	in	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Dstore-perv	in	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
%Zero-Imperv	%	25	25	25	25	25	25	25	25	25	25
Subarea Routing	-	outlet	outlet	outlet	outlet	outlet	outlet	outlet	outlet	outlet	outlet
Percent Routed	%	100	100	100	100	100	100	100	100	100	100
Infiltration	-	Green Ampt	Green Ampt	Green Ampt	Green Ampt	Green Ampt	Green Ampt	Green Ampt	Green Ampt	Green Ampt	Green Ampt
LID Controls	-	sub-catchment	vegetated swale	infiltration trench	rain barrel	bioretention cell	bioretention cell	sub-catchment	rain barrel	porous pavement	bioretention cell
GW	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SnowPack	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
LandUses	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Initial Buildup	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Curb Length	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

N-perv will not be used - 100% imperv

Dstore-perv will not be used - 100% imperv

Appendix C
CA Phase II LID Sizing Tool
Results of Tool Testing

1.0 INTRODUCTION

This appendix presents the activities and findings for testing of the California Phase II LID Sizing Tool. The following activities were conducted to test the tool's output:

- Comparing the tool results and those from independent SWMM 5 runs
- Comparing tool results against those from other established models for three select locations
- Comparison of tool results for 85th percentile design storm and those for the tool's 80% capture requirement

2.0 COMPARISONS TO RESULTS FROM INDEPENDENT RUNS

Independent SWMM 5 runs were conducted for 11 different combinations of LID BMP types and site characteristics. The results from these independent runs were compared to the results obtained from the California Phase II LID Sizing Tool. Table 1 presents the 11 combinations that were tested, along with the volume reductions and differences between the two sources. The results for all combinations differed by less than 1 percent, indicating that the tool's code (including the input, output, and calculation components) is working properly.

Table 1. Comparisons of CA Phase II LID Tool and Independent SWMM 5 Runs

LID BMP Type	Native Soil K_{sat}[a] (in/hr)	Climate Station	A_{LID}/A_{IMP}[b]	Volume Reduction		Difference
				CA Phase II LID Sizing Tool	Independent SWMM 5 Simulation	
Bioretention Cell - 18" Soil - 12" Gravel Storage	0.3	Chico Univ Farm	4%	82.21%	82.21%	0%
Bioretention Cell - 24" Soil - 12" Gravel Storage	0.01	Santa Barbara Muni AP	32%	100%	100%	0%
Bioretention Cell - Soil Depth Varies[4] - No Gravel Storage	0.1	Eureka WFO	8%	56.32%	56.32%	0.00%
Infiltration Basin - Vegetated	0.04	Grass Valley #2	16%	88.39%	88.39%	0.00%
Infiltration Gallery	5.0	Modesto 2	50%	100%	100%	0.00%
Infiltration Trench	0.1	Sebastopol	16%	65.19%	65.22%	-0.03%
Overland Flow	1.0	Red Bluff Muni AP	50%	99.17%	99.17%	0.00%
Porous Pavement	1.0	Boron	2%	41.32%	41.34%	-0.02%
Strip, Amended 12"	0.01	Victorville Pump PT	4%	28.44%	28.40%	0.04%
Swale, Amended 12"	0.04	Tehachapi AP	8%	37.21%	37.18%	0.02%
Capture and Use Storage	0.3	San Miguel Wolf Ranch	32%	100%	100%	0%

[a] *Native soil's saturated hydraulic conductivity*

[b] *Ratio of LID BMP area to impervious area*

3.0 COMPARISONS TO RESULTS FROM OTHER MODELS

The tool's results were compared against those from the following models. These models are well-accepted in the stormwater design and planning industry:

- USEPA National Stormwater Calculator (SWC)
- Sacramento Area Hydrology Model (SAHM)

The following subsections present the activities and findings associated with comparisons to each model.

3.1 Comparisons to USEPA National SWC

The USEPA's National SWC is a desktop tool that estimates the annual rainfall and runoff from various locations throughout the United States (including Puerto Rico). Similar to the CA Phase II LID Sizing tool, the SWC estimates rainfall and runoff using local soil conditions, percent imperviousness, and historic rainfall records. The SWC can be accessed from the USEPA website:

http://www.epa.gov/nrmrl/wswrd/wq/models/swc/

Results from the CA Phase II LID Sizing Tool were compared against those obtained from the SWC for 24 different combinations of LID BMP types and site characteristics. Table 2 presents the combinations that were tested, along with the volume reductions and differences between the two sources. The results for all combinations differed by 4 percent or less, indicating that the tool has been developed and is performing appropriately.

3.2 Comparisons to SAHM

SAHM is a tool that was established for designing LID BMPs in the greater Sacramento area. SAHM was used to simulate the bioretention systems modeled by the CA Phase II LID Sizing Tool and compare results. As with the USEPA National SWC and the CA Phase II LID Sizing Tool, SAHM estimates rainfall and runoff using LID BMP characteristics, local soil conditions, percent imperviousness, and historic rainfall records. SAHM may be accessed from the Sacramento Stormwater Quality Partnership website: http://www.beriverfriendly.net/Newdevelopment/

Results from the CA Phase II LID Sizing Tool Percent Capture sizing method were compared against those obtained from SAHM for multiple LID BMP bioretention facilities and sizes, and two soil types. Although the CA Phase II LID Sizing Tool does not include a Sacramento area climate station, climate data from a Sacramento rain gauge was temporarily uploaded into the tool to make these comparisons. Table 3 presents the combinations of LID BMPs, sizes, and soil types that were tested, along with the volume reductions and differences between the two sources. For all scenarios tested with well-draining soils (saturated hydraulic conductivity of 1.0 in/hr), the results differed by less than 10%. However, for poorer-draining soils (saturated hydraulic conductivity of 0.1 in/hr) the results differed by up to 24%. The larger differences are primarily attributed to the different ways the two models simulate discharge through an underdrain. In SWMM 5, the background model for the CA Phase II LID Tool's Percent Capture sizing method, discharge through an underdrain is calculated merely as a function of elevation head above the orifice using a form of the following equation:

$$Q = c * A * \sqrt{2 * g * z}$$

where:

Q = discharge through the orifice (cfs)

C = coefficient of discharge, representing friction and contraction through orifice (0.6)

A = cross section area of orifice (sf)

g = gravitational acceleration (32.2 ft/sec^2)

z = effective elevation head above orifice = elevation head * porosity (ft)

It is unclear exactly how discharge through an underdrain is calculated by SAHM, but it appears to be dependent on the depth of gravel storage below the underdrain. This is demonstrated by comparing the stage-discharge relationships reported by SAHM for two different bioretention cells. Figure A-1 presents a schematic of the cells. Both bioretention cells have 6 inches of ponding, 18 inches of bioretention media, and an underdrain at the top of the gravel storage layer, and runoff is allowed to infiltrate into underlying soils having a saturated conductivity of 0.1 in/hr. One cell has a gravel storage depth of 12 inches, while the other has a gravel storage depth of 36". Figure A-2 plots the height above the gravel storage layer (a surrogate of stage) against discharge through the underdrain based on SAHM modeling of each bioretention cell. For the cell having 12 inches of gravel storage, runoff does not discharge through the underdrain until the water within the cell is approximately 0.4 feet (4.8 inches) above the top of the gravel storage. For the 36-inch storage cell, runoff does not discharge until the water is approximately 1.2 feet (14.4 inches) above the top of the gravel storage. The fact that the stage-discharge relationships differ indicates that discharge through the underdrain dependent on the depth of the cell's gravel storage, and not merely the elevation head above the point of discharge.

Table 2. Comparisons of CA Phase II LID Tool and USEPA National SWC

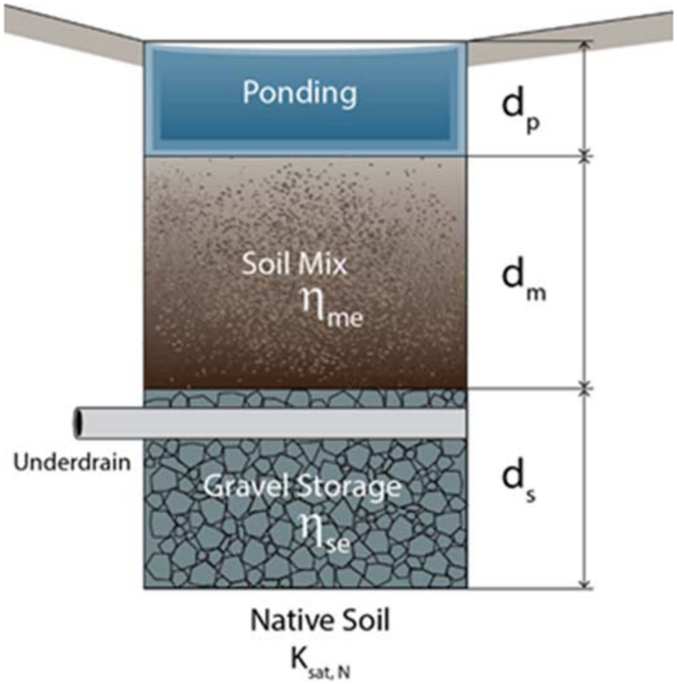
LID BMP Type	Native Soil K_{sat}[a] (in/hr)	Climate Station	A_{LID}/A_{IMP}[b]	Volume Reduction		Difference
				CA Phase II LID Sizing Tool	USEPA National SWC	
Bioretention Cell - Soil Depth Varies - No Gravel Storage	0.3	Eureka	0.08	86.0%	88.2%	2.2%
		Modesto		95.7%	97.3%	1.6%
		Boron		95.8%	96.9%	1.1%
		Los Angeles		83.3%	81.9%	-1.3%
		Sacramento		91.0%	89.9%	-1.1%
		Shasta Dam		55.3%	53.4%	-2.0%
	0.04	Eureka	0.08	29.4%	30.6%	1.2%
		Modesto		45.4%	48.0%	2.6%
		Boron		52.1%	54.6%	2.5%
		Los Angeles		31.3%	29.5%	-1.8%
		Sacramento		34.5%	32.4%	-2.1%
		Shasta Dam		14.6%	13.6%	-1.0%
Porous Pavement	0.1	Eureka	0.16	75.3%	79.3%	4.0%
		Modesto		89.0%	90.7%	1.7%
		Boron		88.9%	92.8%	3.9%
		Los Angeles		71.7%	72.4%	0.7%
		Sacramento		81.2%	81.5%	0.3%
		Shasta Dam		45.6%	43.3%	-2.3%
	0.04	Eureka	0.04	16.5%	17.7%	1.2%
		Modesto		27.3%	29.3%	2.0%
		Boron		32.5%	34.0%	1.5%
		Los Angeles		17.8%	18.3%	0.5%
		Sacramento		19.5%	20.1%	0.6%
		Shasta Dam		8.0%	8.3%	0.2%

[a] *Native soil's saturated hydraulic conductivity*
[b] *Ratio of LID BMP area to impervious area*

Table 3. Comparisons of CA Phase II LID Tool and SAHM

LID BMP Type	Native Soil K_{sat}[a] (in/hr)	Climate Station	A_{LID}/A_{IMP}[b]	Volume Infiltrated, Evaporated, and Treated		Difference
				CA Phase II LID Sizing Tool	SAHM	
Bioretention Cell - 18" Soil - 12" Gravel Storage	1.0	Sacramento 5 ESE	1%	42%	47%	4%
			2%	68%	74%	6%
			4%	90%	94%	4%
			8%	99%	99%	1%
			16%	100%	100%	0%
Bioretention Cell - 18" Soil - 36" Gravel Storage	1.0	Sacramento 5 ESE	1%	49%	46%	-3%
			2%	75%	75%	0%
			4%	94%	94%	0%
			8%	99%	100%	0%
			16%	100%	100%	0%
Bioretention Cell - 24" Soil - 12" Gravel Storage	1.0	Sacramento 5 ESE	1%	43%	49%	6%
			2%	69%	77%	8%
			4%	91%	95%	4%
			8%	99%	100%	1%
			16%	100%	100%	0%
Bioretention Cell - 24" Soil - 36" Gravel Storage	1.0	Sacramento 5 ESE	1%	50%	47%	-4%
			2%	76%	75%	-1%
			4%	95%	95%	0%
			8%	99%	100%	0%
			16%	100%	100%	0%
Bioretention Cell - 18" Soil - 12" Gravel Storage	0.1	Sacramento 5 ESE	1%	35%	43%	**8%**
			2%	59%	71%	**12%**
			4%	84%	92%	**9%**
			8%	97%	99%	2%
			16%	100%	100%	0%
Bioretention Cell - 18" Soil - 36" Gravel Storage	0.1	Sacramento 5 ESE	1%	39%	21%	**-18%**
			2%	63%	41%	**-22%**
			4%	87%	65%	**-22%**
			8%	98%	89%	-9%
			16%	100%	99%	-1%
Bioretention Cell - 24" Soil - 12" Gravel Storage	0.1	Sacramento 5 ESE	1%	37%	48%	**10%**
			2%	61%	75%	**14%**
			4%	85%	95%	**9%**
			8%	97%	99%	2%
			16%	100%	100%	0%
Bioretention Cell - 24" Soil - 36" Gravel Storage	0.1	Sacramento 5 ESE	1%	40%	21%	**-19%**
			2%	65%	41%	**-24%**
			4%	88%	66%	**-22%**
			8%	98%	89%	**-9%**
			16%	100%	99%	-1%

[a] *Native soil's saturated hydraulic conductivity*
[b] *Ratio of LID BMP area to impervious area*



d_p = 6”

d_m = 18”

d_s = 12” or 36”

$K_{sat,N}$ = 0.1 in/hr

Figure 1. Profile of Bioretention Cells Compared for Stage-Discharge Relationships

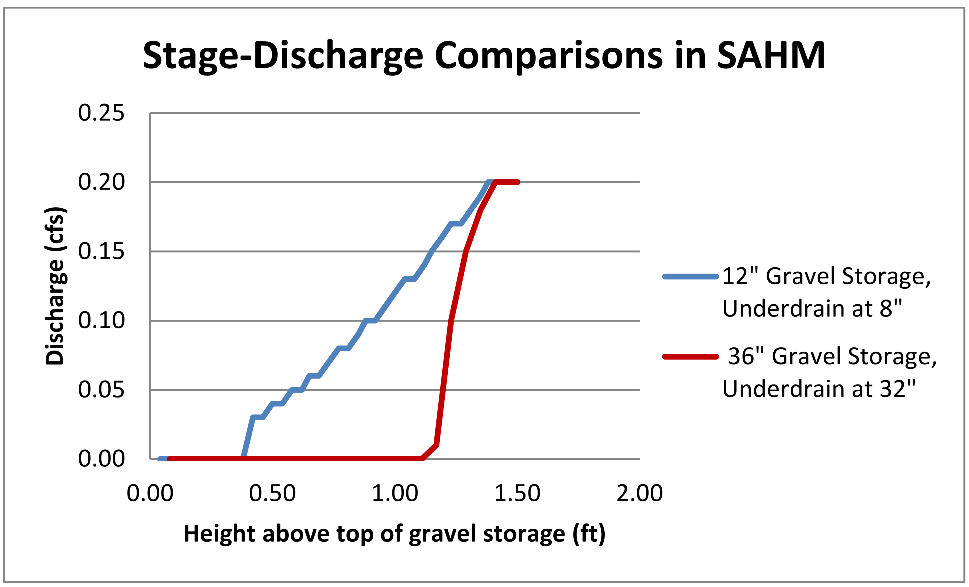


Figure 2. Comparison of SAHM Stage-Discharge Relationship for Bioretention, C Soils

4.0 COMPARISONS OF DESIGN STORM AND PERCENT CAPTURE RESULTS

The CA Phase II LID Sizing Tool’s results for 85th percentile design storm were compared against those for the tool’s 80% capture requirement. It was anticipated that the Percent Capture Sizing Method would generally result in smaller LID BMP areas than the Design Storm Sizing Method, particularly for well-draining soils (saturated hydraulic conductivity ≥ 1.0 in/hr). This is because the Percent Capture Sizing Method analyzes all storms, including the more frequent, smaller storms that account for most of the annual precipitation. The Percent Capture Sizing Method also accounts for volume reduction and treatment mechanisms through infiltration into the underlying soils, evapotranspiration, and filtration through bioretention media (if applicable) during and after a storm event. In contrast, the Design Storm Sizing Method is based solely on the storage of a static volume (i.e., there is no consideration of volume routing) within the LID BMP – the capacity of the underlying soils to provide any volume reduction is not included. For well-draining soils, a good amount of infiltration is anticipated, and so, for the Percent Capture Sizing Method, this allows for reduction in the LID BMP size. Table 4 presents the required areas for several types of LID BMPs for a 1-acre impervious catchment for a relatively wet, Northern California region (Chico). As was expected, the Percent Capture Method results in smaller LID BMP areas than the Design Storm Method for well- draining soils. This trend, however, does not hold for Southern California climates which tend to have storms of higher intensity (flash storms) even though the frequency is less. Table 5 presents the required areas for a Southern California region (Boron) subject to such storms. For poor-draining and even some well-draining soils (saturated hydraulic conductivity ≤ 5 in/hr), the Percent Capture Method results in LID BMP areas that are equivalent to or larger than those resulting from the Design Storm Method. This is primarily because the rainfall intensities often exceed 1.0 in/hr and exceed the infiltration rates of most soils.

Additional anomalies in the results, that are not immediately intuitive, are discussed below.

Strip vs. Swale: Design Storm Sizing Method

The design storm result is identical for strips and swales of the same amendment depth because infiltration into the side-slopes of the swale is not considered. The side slopes are not included because the flow depths along the swale change with distance along the swale, and simulating this requires a more sophisticated model than a design storm approach. In reality, some infiltration through the side slopes can occur on the influent side of the swale, thus making the swale design storm calculation conservative.

Strip vs. Swale: Percent Capture

The percent capture area values for swales are always larger than those strips of the same amendment depth. This is due to the tool's definition of capture for strips and swales. The capture mechanisms for these LID BMPs only include evapotranspiration, infiltration, and storage; any surface water discharge is not considered captured. For strips, 100% of the amended soil is available for evapotranspiration, infiltration, and/or storage as water sheet flows evenly across the strip. For swales, only a portion of the swale's amended surface area is available for capture because the runoff depths vary along the length of the swale. The swale cross section modeled by the tool includes a depth of 6 inches, width of 4 ft, and side slope of 3:1, which results in an invert width of 1 ft. For this cross-section, the side slopes dominate the surface area of the swale. To make 100% of the swale's amended surface area available for capture, the depth of runoff must be 6 inches throughout the entire length of the swale. However, an event that causes this amount of inundation would be quantified by the tool as having very little capture because of the predominance of surface flow. The swale and storm size combination that maximizes infiltration with no surface discharge is one that completely inundates the swale at the influent, but at the effluent the runoff depth approaches zero. In this idealized scenario, only a portion of the swale's total amended surface swale area is inundated. Therefore swales will require more area to accomplish the same percent capture as a strip.

Strip vs. Bioretention: Percent Capture at K_{sat} =5.0 in/h

At very high saturated conductivities (e.g. 5.0 in/hr), strips with a 12-inch amended depth require less area than bioretention cells. This is not intuitive, since bioretention cells have more dead storage below their underdrain than strips have in their amendment soil depth. The explanation is due to how SWMM models flow through media transitions. Bioretention has more media layers so those layers start to play a limiting factor when the native infiltration is very high.

Table 4. Comparison of Area Results for Different CA Phase II LID Tool Methods - Chico

LID BMP Type	Native Soil K_{sat}[a] (in/hr)	Climate Station	A_{LID}[b] (acres) Design Storm Method	A_{LID}[b] (acres) Percent Capture Method	Difference (acres)
Bioretention Cell - 18" Soil – 12" Gravel Storage	5.0	Chico	0.048	0.022	**+0.026**
	1.0		0.048	0.034	**+0.014**
	0.4		0.048	0.038	**+0.010**
	0.1		0.048	0.040	**+0.008**
	0.04		0.048	0.043	**+0.005**
	0.01		0.048	0.045	**+0.003**
Bioretention Cell - 18" Soil – 36" Gravel Storage	5.0	Chico	0.031	0.022	**+0.009**
	1.0		0.031	0.029	**+0.002**
	0.4		0.031	0.033	-0.002
	0.1		0.031	0.037	-0.006
	0.04		0.031	0.039	-0.008
	0.01		0.031	0.043	-0.012
Bioretention Cell - 24" Soil – 12" Gravel Storage	5.0	Chico	0.043	0.020	**+0.023**
	1.0		0.043	0.033	**+0.010**
	0.4		0.043	0.036	**+0.007**
	0.1		0.043	0.038	**+0.005**
	0.04		0.043	0.039	**+0.004**
	0.01		0.043	0.041	**+0.002**
Bioretention Cell - 24" Soil – 36" Gravel Storage	5.0	Chico	0.029	0.019	**+0.010**
	1.0		0.029	0.027	**+0.002**
	0.4		0.029	0.032	-0.003
	0.1		0.029	0.036	-0.007
	0.04		0.029	0.038	-0.009
	0.01		0.029	0.040	-0.011
Infiltration Trench	5.0	Chico	0.035	0.013	**+0.022**
	1.0		0.035	0.031	**+0.004**
	0.4		0.035	0.049	-0.014
	0.1		0.110	0.150	-0.040
	0.04		0.300	0.460	-0.160
	0.01		0.550	>1	<-0.450
Strip, Amended 12"	5.0	Chico	0.250	0.018	**+0.232**
	1.0		0.250	0.057	**+0.193**
	0.4		0.250	0.110	**+0.140**
	0.1		0.250	0.210	**+0.040**
	0.04		0.250	0.320	-0.070
	0.01		0.250	0.890	-0.640
Swale, Amended 12"	5.0	Chico	0.250	0.028	**+0.222**
	1.0		0.250	0.089	**+0.161**
	0.4		0.250	0.190	**+0.060**
	0.1		0.250	0.390	-0.140
	0.04		0.250	0.780	-0.530
	0.01		0.250	>1	<-0.750

[a] *Native soil's saturated hydraulic conductivity*
[b] *Required area of LID BMP area for a 1 acre impervious area*
[c] *Bold values indicate Design Storm Method area > Percent Capture Method area*

Table 5. Comparison of Area Results for Different CA Phase II LID Tool Methods - Boron

LID BMP Type	Native Soil K_{sat}[a] (in/hr)	Climate Station	A_{LID}[b] (acres) Design Storm Method	Percent Capture Method	Difference (acres)[c]
Bioretention Cell - 18" Soil – 12" Gravel Storage	5.0	Boron	0.026	0.019	**+0.007**
	1.0		0.026	0.026	0.000
	0.4		0.026	0.029	-0.003
	0.1		0.026	0.030	-0.004
	0.04		0.026	0.031	-0.005
	0.01		0.026	0.032	-0.006
Bioretention Cell - 18" Soil – 36" Gravel Storage	5.0	Boron	0.017	0.019	-0.002
	1.0		0.017	0.019	-0.002
	0.4		0.017	0.022	-0.005
	0.1		0.017	0.025	-0.008
	0.04		0.017	0.027	-0.010
	0.01		0.017	0.030	-0.013
Bioretention Cell - 24" Soil – 12" Gravel Storage	5.0	Boron	0.024	0.018	**+0.006**
	1.0		0.024	0.024	0.000
	0.4		0.024	0.026	-0.002
	0.1		0.024	0.028	-0.004
	0.04		0.024	0.029	-0.005
	0.01		0.024	0.030	-0.006
Bioretention Cell - 24" Soil – 36" Gravel Storage	5.0	Boron	0.016	0.018	-0.002
	1.0		0.016	0.019	-0.003
	0.4		0.016	0.020	-0.004
	0.1		0.016	0.022	-0.006
	0.04		0.016	0.025	-0.009
	0.01		0.016	0.028	-0.012
Infiltration Trench	5.0	Boron	0.020	0.011	**+0.009**
	1.0		0.020	0.020	0.000
	0.4		0.020	0.028	-0.008
	0.1		0.058	0.081	-0.023
	0.04		0.150	0.240	-0.090
	0.01		0.240	0.460	-0.220
Strip, Amended 12"	5.0	Boron	0.130	0.017	**+0.113**
	1.0		0.130	0.040	**+0.090**
	0.4		0.130	0.069	**+0.061**
	0.1		0.130	0.120	**+0.010**
	0.04		0.130	0.150	-0.020
	0.01		0.130	0.250	-0.120
Swale, Amended 12"	5.0	Boron	0.130	0.026	**+0.104**
	1.0		0.130	0.072	**+0.058**
	0.4		0.130	0.130	0.000
	0.1		0.130	0.230	-0.100
	0.04		0.130	0.310	-0.180
	0.01		0.130	0.570	-0.440

[a] *Native soil's saturated hydraulic conductivity*
[b] *Required area of LID BMP area for a 1 acre impervious catchment*
[c] *Bold values indicate Design Storm Method area > Percent Capture Method area*