

**APPENDIX D**

**GUIDANCE FOR SIZING GREEN INFRASTRUCTURE  
FACILITIES IN STREET PROJECTS**

***Guidance for Sizing Green Infrastructure  
Facilities in Street Projects***

with companion analysis:

***Green Infrastructure Facility Sizing for  
Non-Regulated Street Projects***



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## Introduction and Regulatory Background

Provision C.3.j. in the reissued Municipal Regional Stormwater Permit<sup>1</sup> (MRP) requires each Permittee to “complete and implement a Green Infrastructure (GI) Plan for the inclusion of low impact development drainage design into storm drain infrastructure on public and private lands, including streets, roads, storm drains, parking lots, building roofs, and other storm drain infrastructure elements.”

Provision C.3.j.i.(g) further mandates that these plans include:

*Requirements that projects be designed to meet the treatment and hydromodification sizing requirements in Provisions C.3.c. and C.3.d. For street projects not subject to Provision C.3.b.ii. (i.e., non-Regulated Projects) Permittees may collectively propose a single approach with their Green Infrastructure Plans for how to proceed should project constraints preclude fully meeting the C.3.d. sizing requirements. The single approach can include different options to address specific issues or scenarios. That is, the approach shall identify the specific constraints that would preclude meeting the sizing requirements and the design approach(es) to take in that situation. The approach should also consider whether a broad effort to incorporate hydromodification controls into green infrastructure, even where not otherwise required, could significantly improve creek health and whether such implementation may be appropriate, plus all other information as appropriate (e.g., how to account for load reduction for the PCBs or mercury TMDLs).*

This document represents the “single approach” collectively proposed by the Permittees for how to proceed when constraints on GI projects affect facility sizing in street projects. For other types of projects, information on hydraulic sizing is provided in the technical guidance manuals for Provision C.3 developed by each countywide stormwater program.

## Hydraulic Sizing Requirements

MRP Provision C.3.d contains criteria for sizing stormwater treatment facilities. Facilities may be sized on the basis of flow, volume, or a combination of flow and volume. With adoption of the 2009 MRP, a third option for sizing stormwater treatment facilities was added to Provision C.3.d. This option states that “treatment systems that use a combination of flow and volume capacity shall be sized to treat at least 80 percent of the total runoff over the life of the project, using local rainfall data.”

This option can also be used to develop sizing factors for facilities with a standard cross-section (i.e., where the volume available to detain runoff is proportional to facility surface area). To calculate sizing factors, inflows, storage, infiltration to groundwater, underdrain discharge, and overflows are tracked for each time-step during a long-term simulation. The continuous simulation is repeated, with variations in the treatment surface area, to determine the minimum area required for the facility to capture and treat 80% of the inflow during the simulation.

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<sup>1</sup> Order R2-2015-0049

Such an analysis was conducted for BASMAA by Dubin Environmental Consulting and is described in the attached Technical Report. The analysis shows that bioretention facilities with the current-standard cross-section can capture and treat the Provision C.3.d amount of runoff when sized to 1.5% - 3% of tributary equivalent impervious area, depending on location.

### **Hydromodification Management**

A principal objective of LID is to mimic natural hydrology in the post-development condition. This is accomplished by retaining and infiltrating runoff flows during small to medium events. Flows from larger events are detained and slowed.

MRP Provision C.3.g. includes requirements and criteria for implementing hydromodification management (HM). These HM requirements apply to Regulated Projects that create or replace an acre or more of impervious area, increase the amount of impervious area over the pre-project condition, and flow to creeks that are at risk of erosion. As such, the HM requirements do not apply to street projects that retrofit drainage systems that receive runoff from existing roofs and paving.

However, Provision C.3.j.i.(g) states that the Permittees' approach to sizing GI facilities "...should also consider whether a broad effort to incorporate hydromodification controls into green infrastructure, even where not otherwise required, could significantly improve creek health and whether such implementation may be appropriate..."

Various criteria for HM design have been used in California and throughout the U.S. These criteria have been based on one or more of the following principles:

- Maintaining watershed processes
- Maintaining a site-specific water balance
- Maintaining the value of the curve number used in the NRCS method of computing peak runoff
- Controlling increases in peak flows from a specified storm size
- Controlling increases in the duration of flows at each intensity within a specified range (flow duration control)
- Controlling the likelihood of downstream erosion in streams (erosion potential, or Ep)

Generally, for any HM criterion used, facilities with more storage and a larger infiltrative area will be more effective in meeting the criterion than facilities with less storage and a smaller infiltrative area.

In the statewide municipal stormwater NPDES permit for small MS4s, Provision E.12.f. includes the following HM standard applicable to Bay Area small MS4s: "Post-project runoff shall not exceed estimated pre-project flow rate for the 2-year, 24-hour storm..."

Dubin (2014) conducted modeling to evaluate whether this standard would be met in the San Francisco Phase II counties (Marin, Sonoma, Napa, and Solano) by a bioretention facility meeting the minimum requirements in that permit's Provision

E.12.f. Dubin's analysis found that a facility sized to 4% of tributary equivalent impervious area, and having a 6-inch deep reservoir with 2 inches of freeboard, 18 inches of treatment soil, and a 12-inch-deep "dead storage" gravel layer below the underdrain, would meet this standard, even in the wettest portions of the Bay Area.

### **Additional Considerations for Bioretention Sizing**

In summary, bioretention facilities for street projects sized to 1.5% - 3% of tributary equivalent impervious area (depending on their location in the Bay Area) can meet the criteria in Provision C.3.d., according to the modeling study documented in the attached Technical Memo.

There are many reasons to design and build facilities larger than the Provision C.3.d. minimum. Building larger facilities helps ensure the facilities perform to the minimum hydraulic capacity intended, despite minor flaws in design, construction, and maintenance, providing an engineering safety factor for the project. Further, larger-sized facilities may more effectively address objectives to maximize the removal of pollutants (particularly pollutants in dissolved form), to operate as full trash capture devices, and to manage hydromodification effects.

However, municipalities often face considerable challenges in retrofitting existing streetscapes with GI facilities. Constraints and design challenges typically encountered in the public right-of-way include:

- The presence of existing underground utilities (known and unknown during the design phase);
- The presence of existing above-ground fixtures such as street lights, fire hydrants, utility boxes, etc.;
- The presence of existing mature trees and root systems;
- The elevation of or lack of existing storm drains in the area to which to connect underdrains or overflow structures;
- Challenges of defining and controlling any catchment areas on adjacent private parcels that drain to the roadway surface;
- Low soil permeability and strength, and the need to protect the adjacent roadway structure;
- Competition with other assets & uses for limited right-of-way area; and
- Presence of archeologic/cultural deposits.

Use of the sizing factors in the attached Technical Memo will provide municipalities flexibility in design of bioretention facilities for street projects where constraints are present.

### **Recommendations for Sizing Approaches for Green Infrastructure Retrofit Facilities in Street Projects**

1. Bioretention facilities in street projects should be sized as large as feasible and meet the C.3.d criteria where possible. Constraints in the public right-of-way may affect the size of these facilities and warrant the use of smaller sizing factors.

Bioretention facilities in street projects may use the sizing curves in the attached memorandum to meet the C.3.d criteria. Local municipal staff involved with other assets in the public right of way should be consulted to provide further guidance to design teams as early in the process as possible.

2. Bioretention facilities in street projects smaller than what would be required to meet the Provision C.3.d criteria may be appropriate in some circumstances. As an example, it might be appropriate to construct a bioretention facility where a small proportion of runoff is diverted from a larger runoff stream. Where feasible, such facilities can be designed as “off-line” facilities, where the bypassed runoff is not treated or is treated in a different facility further downstream. In these cases, the proportion of total runoff captured and treated should be estimated using the results of the attached memorandum. In cases where “in-line” bioretention systems cannot meet the C.3.d criteria, the facilities should incorporate erosion control as needed to protect the facility from high flows. See Figures 1 and 2 below for illustration of the in-line and off-line concepts.
3. Pollutant reduction achieved by GI facilities in street projects will be estimated in accordance with the Interim Accounting Methodology<sup>i</sup> or the applicable Reasonable Assurance Analysis<sup>ii</sup>.



*Figure 1: Off-line system in El Cerrito where low flow is diverted to the sidewalk planter and high flows continue down the gutter.*



*Figure 2: In-line system in Berkeley/Albany where low and high flows enter the system and overflows exit through a drain within the system.*

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<sup>i</sup> The Interim Accounting Methodology for TMDL Loads Reduced Report (BASMAA 2017) describes the methodology that is being used to demonstrate progress towards achieving the PCB and mercury load reductions required during the term of MRP 2.0. The methodology is based on the conversion of land use from a higher to a lower PCB or mercury loading rate during the redevelopment of a parcel. See:

[www.waterboards.ca.gov/sanfranciscobay/water\\_issues/programs/stormwater/Municipal/POC/Final%20Interim%20Accounting%20Methodology%20Report%20v.1.1%20\(Revised%20March%202017\).pdf](http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/stormwater/Municipal/POC/Final%20Interim%20Accounting%20Methodology%20Report%20v.1.1%20(Revised%20March%202017).pdf)

<sup>ii</sup> A Reasonable Assurance Analysis (RAA) is a methodology used to demonstrate that implementation of pollutant control measures (such as GI facilities) over a specified time period will meet required pollutant load reductions associated with a TMDL. The Bay Area Reasonable Assurance Analysis Guidance Document (BASMAA 2017) establishes a regional framework and provides guidance for conducting PCBs and mercury RAAs in the San Francisco Bay Area. See: <http://basmaa.org/Announcements/bay-area-reasonable-assurance-analysis-guidance-document>



**BAY AREA  
STORMWATER MANAGEMENT AGENCIES  
ASSOCIATION**

**GREEN INFRASTRUCTURE  
FACILITY SIZING FOR NON-REGULATED STREET  
PROJECTS**

**Prepared by:  
Dubin Environmental  
December 13, 2017**



## 1. Introduction

The San Francisco Bay Regional Water Quality Control Board's reissued Phase I Municipal Regional Stormwater Permit (Order No. R2-2015-0049, issued 11/19/2015 and referred to as "MRP 2.0") includes a requirement that Permittees complete and implement green infrastructure plans to promote the increased use of green infrastructure in urban areas. These plans will guide the integration of green stormwater facilities into streets, parking lots, parks, building rooftops and similar places where there is an opportunity to retrofit traditional gray infrastructure systems and increase the removal of pollutants and improve water quality.

Provision C.3.j states:

*Over the long term, the (Green Infrastructure) Plan is intended to describe how the Permittees will shift their impervious surfaces and storm drain infrastructure from gray, or traditional storm drain infrastructure where runoff flows directly into the storm drain and then the receiving water, to green—that is, to a more-resilient, sustainable system that slows runoff by dispersing it to vegetated areas, harvests and uses runoff, promotes infiltration and evapotranspiration, and uses bioretention and other green infrastructure practices to clean stormwater runoff.*

Provision C.3.j.i.(2)(g) requires that projects be designed to meet the treatment and hydromodification sizing requirements in Provisions C.3.c. and C.3.d. However, the provision further states that for street projects that are not Regulated Projects:

*...Permittees may collectively propose a single approach with their Green Infrastructure Plans for how to proceed should project constraints preclude fully meeting the C.3.d sizing requirements. The single approach can include different options to address specific issues or scenarios. That is, the approach shall identify the specific constraints that would preclude meeting the sizing requirements and the design approach(es) to take in that situation.*

To address this provision and further define the C.3.d sizing requirements for green infrastructure projects, the Bay Area Stormwater Management Agencies Association (BASMAA) contracted with Dubin Environmental to conduct continuous simulation hydrologic modeling to evaluate relationships of facility size (e.g., area, depth, flow rate) to facility performance. The BASMAA Development Committee, and BASMAA member agencies, intend to use these relationships to develop and justify an approach, to be created by the Development Committee, for implementing green street projects when there are constraints on facility size.

This report describes the modeling analysis that was performed to better understand the relationship between bioretention configuration and annual runoff treatment across the different BASMAA stormwater agencies and their climate zones. Long-term continuous modeling was used to compute stormwater runoff, simulate bioretention hydraulics, and estimate the annual percentage of stormwater that is treated. The analysis was performed for 10 different rain gauges that together represent the full range of climate conditions across the BASMAA member agency area. The analysis also considered different bioretention configurations and treatment goals. BASMAA member agencies can use these results to help establish policies and design guidelines to include in their green infrastructure plans.

## 2. Project Approach

The performance of bioretention facilities was modeled using HSPF (Hydrologic Simulation Program Fortran), which is a physically based, hydrologic model that is maintained and distributed by the US EPA.

HSPF has been used since the 1970s to conduct hydrologic analyses and size stormwater and flood control facilities. For this project, an HSPF model was developed to simulate runoff from a fully paved, 1-acre reference site and route this flow through a bioretention facility. This section describes the rain gauge selection and the HSPF modeling approach. Section 3 describes the modeling results.

## 2.1 Rainfall and Evapotranspiration Data

There are more than two dozen rain gauges with long-term, hourly data located within the BASMAA area. A list of candidate gauges was prepared from the National Center for Environmental Information (NCEI; formerly the National Climate Data Center or NCDC) network and then evaluated for inclusion. The evaluation focused on gauge data that could be downloaded directly from EPA's National Stormwater Calculator, because these datasets have been reviewed and missing records filled with data from available nearby stations (similar to the data included with the EPA BASINS software). The list of candidate gauges was narrowed to 19 locations with 35+ years of data that are geographically distributed through the BASMAA area. The rain gauges were organized into tables that show a) mean annual precipitation (MAP) and b) 6-month, 1-year, and 2-year accumulations for 1-year and 24-hour durations. The different storm depth statistics were used to identify any outliers among the rain gauge data that could indicate problems that would hinder the effort to create regressions among the model results. The rain gauge locations were also plotted in ArcGIS.

The recommended sites were presented to the BASMAA project work group who provided helpful input about their preferences and experiences with different rain gauges. Based on this input, six stations were selected for inclusion in the modeling analysis. After developing the HSPF input and output routines, the number of gauges was increased to 10 by including higher rainfall locations to allow development of regression relationships that span the rainfall characteristics at any likely project location. Table 1 lists the candidate rain gauges included in the modeling analysis. For all gauges, a common 37 year period was used to eliminate the influence of drought and wet periods that occurred when some gauges were operational but not others. Figure 1 shows the mean annual rainfall and Figure 2 shows their locations. The 1-year and 24-hour storm durations are included in Appendix A.

TABLE 1. SELECTED RAIN GAUGES FOR GREEN INFRASTRUCTURE MODELING

2	Name	County/Agency	Years of Record	Mean Annual Rain (in)
049001	Tracy Pumping Plant	Contra Costa	37	12.7
047821	San Jose	Santa Clara	37	15.2
045378	Martinez Water Plant	Contra Costa	37	19.6
047769	SF Airport	San Francisco	37	20.4
047772	SF Downtown	San Francisco	37	21.9
046336	Oakland Museum	Alameda	37	22.8
042934	Fairfield	Fairfield-Suisun	37	24.1
043714	Half Moon Bay	San Mateo	37	28.6
047807	San Gregorio	San Mateo	37	30.0
044500	Kentfield	Marin	37	48.1

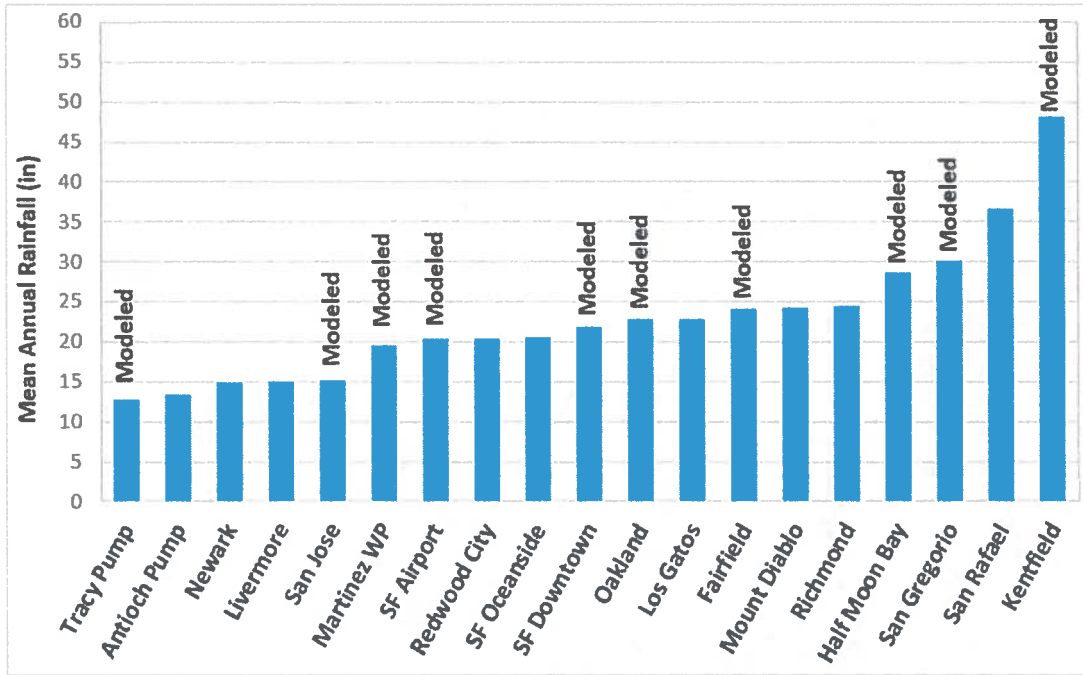


Figure 1. Candidate and selected rainfall sites with mean annual rainfall

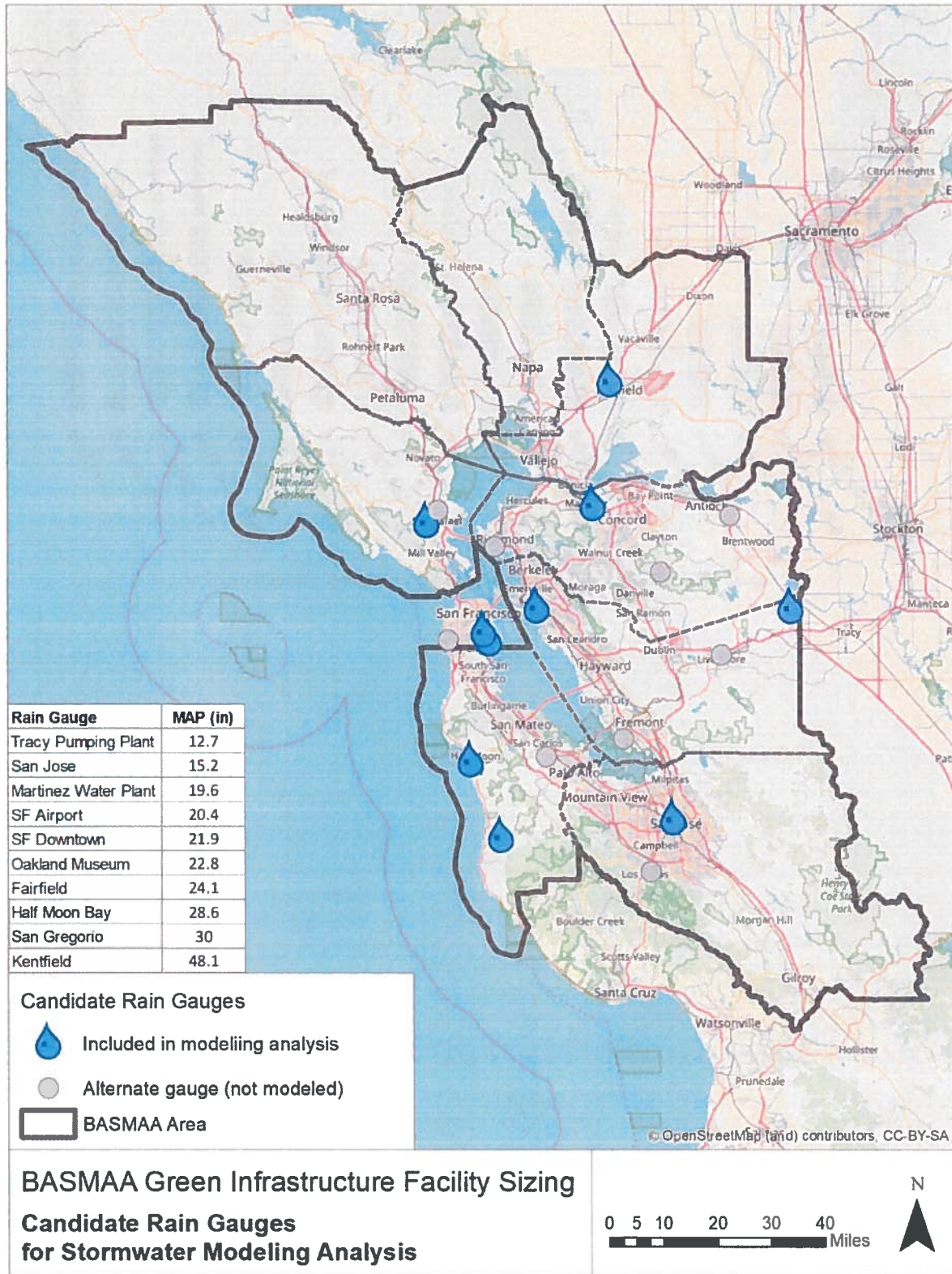


Figure 2. Location of rain gauges used in the modeling analysis

## 2.2 HSPF Model Setup

An HSPF model was developed to simulate runoff from a fully paved, 1-acre reference area and route this flow through a bioretention facility. The model outputs were then evaluated to determine the fraction of incoming stormwater receiving water quality treatment (defined as the fraction filtered through the bioretention media, evaporated or transpired). The HSPF model was developed with Excel/VBA-based code that enabled us to easily modify the rain gauge, bioretention area, and surface reservoir depth to determine how these watershed and configuration parameters affect the fraction of stormwater being treated.

The model parameters and approach to simulating bioretention hydraulics are discussed in detail below:

- Stormwater runoff flows across the reference 1-acre paved area and enters the bioretention facility. This water is initially detained in a shallow surface reservoir and then infiltrates to the bioretention media.
- Stormwater infiltrates through the bioretention media into an underlying gravel layer. The saturated soil permeability was set to 5 inches per hour (based on the media specification). For unsaturated soils, the relationship between soil moisture and permeability was based on monitoring data collected at three installations in Pittsburg (Contra Costa, 2013). The data showed very little infiltration occurs until the soil reaches about two-thirds saturation, and then infiltration increases roughly linearly until reaching 5 inches per hour at 90 percent saturation. Evapotranspiration also occurs in this layer.
- Stormwater within the gravel layer can move freely and infiltrate to surrounding soils, based on their capacity. If runoff enters the gravel layer more rapidly than it infiltrates, the saturation level in the gravel layer will rise until it reaches the elevation of a perforated pipe underdrain. When this occurs, water will flow through the underdrain to a downstream discharge point (typically the municipal storm drainage system).
- The surface reservoir is also equipped with an overflow structure that will become active if runoff enters the surface reservoir more rapidly than it infiltrates through the bioretention media and the surface reservoir fills to its maximum depth. Water discharged via the overflow relief structure does not receive treatment.

The bioretention configuration was based on the water quality treatment design criteria listed in the MRP 2.0 and accepted design practice in the Bay Area. Table 2 lists the dimensions of the bioretention layers as modeled in HPSF.

TABLE 2. BIORETENTION CHARACTERISTICS IN HSPF MODEL

Component	Characteristics
Surface reservoir	<ul style="list-style-type: none"> <li>• Area = bioretention area (varies from 0.5% to 5% of upstream impervious area)</li> <li>• Depth = 6 or 12 inches with overflow relief set 2 inches from top of reservoir</li> </ul>
Bioretention soil media	<ul style="list-style-type: none"> <li>• Area = bioretention area</li> <li>• Depth = 18 inches</li> <li>• Saturated permeability = 5 inches per hour</li> <li>• Unsaturated permeability = variable, based on Contra Costa's 2013 monitoring data</li> </ul>
Storage (gravel) layer	<ul style="list-style-type: none"> <li>• Area = bioretention area</li> <li>• Depth = 12 inches</li> <li>• Permeability of surrounding soils = 0.024 inches per hour</li> </ul>
Underdrain	<ul style="list-style-type: none"> <li>• Located at top of gravel layer</li> <li>• Assumed 4-in diameter pipe</li> </ul>

## 2.3 Model QA/QC Process

The HSPF input files and initial model results were carefully examined during the QA/QC process. Model errors and warnings were systematically eliminated and then the results were compared with the results generated from three independent calculation methods:

1. An Excel-based bioretention hydraulics calculator
2. A Matlab-based bioretention algorithm that was used for bioretention modeling in the Central Coast region
3. An EPA SWMM model using the LID module to represent bioretention hydraulics

The comparison was performed for the San Jose and Fairfield gauges with a bioretention sizing factor of 0.02 (i.e., bioretention surface area equal to 2 percent of the upstream impervious area). The estimated annual runoff treatment percentages agreed to within 3 percent, which confirmed the HSPF model was performing as intended.

## 3. Modeling Scenarios and Results

The HSPF modeling analysis was used to develop bioretention sizing criteria and support policy decisions. Working collaboratively with the BASMAA Development Committee, the modeling analysis addressed the following issues, which are presented in this section:

1. Bioretention area necessary to treat 80 percent of annual stormwater runoff
2. Relationships for estimating annual stormwater treatment percentage across a range of bioretention sizes and mean annual precipitation depths
3. Relationships for estimating annual stormwater treatment percentage for bioretention facilities without an underdrain
4. Bioretention treatment percentage for facilities with no infiltration to surrounding soils
5. Bioretention treatment percentage for facilities with lower bioretention media permeability

The results are summarized graphically here. The full set of results and underlying data were provided separately to the BASMAA Development Committee on 7/28/2017 and are available from BASMAA upon request.

### 3.1 Bioretention Sizing for Treatment of 80 Percent of Annual Runoff

The performance of bioretention facilities was modeled for 10 different rain gauges and bioretention footprint areas, ranging from 0.5 to 5.0 percent of the upstream tributary area, using the approach described in Section 2. Bioretention configurations with 6-inch and 12-inch deep surface reservoirs were modeled. For each of the model runs, the runoff treatment percentage was computed, and the results were plotted. Figure 3 shows an example for the San Jose gauge. Appendix B shows results for the other rain gauges.



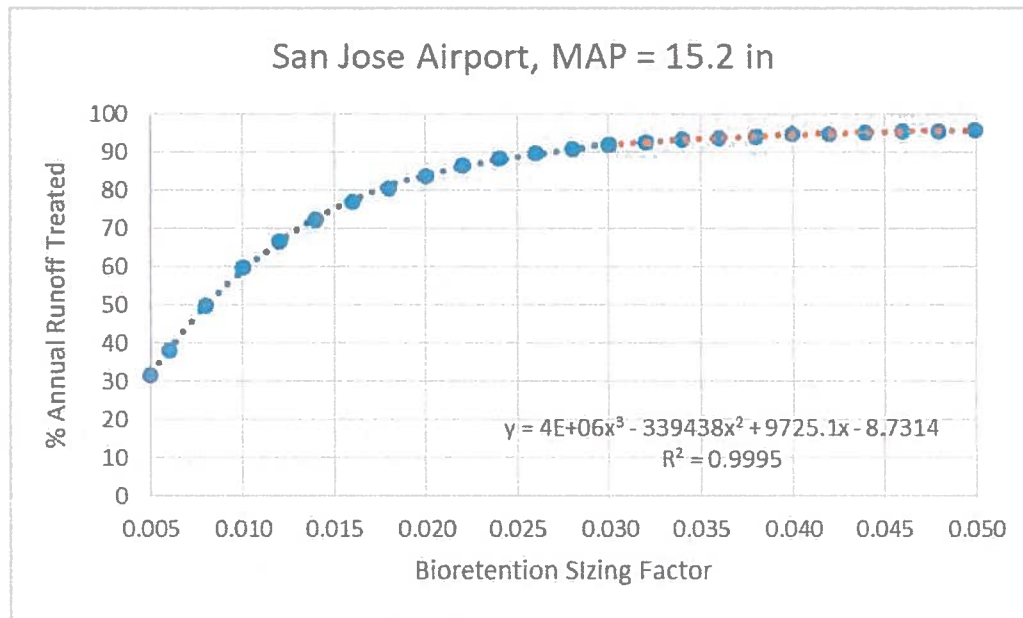


Figure 3. Percent of annual runoff treated for range of bioretention facility sizes using San Jose rain gauge

Using a polynomial regression equation, the model results for each rain gauge/surface reservoir depth scenario were interpolated to estimate the bioretention sizing factor needed to provide 80 percent annual runoff treatment, which is the treatment criterion for regulated water quality projects in the MRP 2.0. The results across the 10 rain gauges showed a clear linear relationship between mean annual rainfall and the bioretention footprint needed for 80 percent annual runoff treatment. Figure 4 and Figure 5 show the results for the 6-inch and 12-inch surface reservoir configurations, respectively.

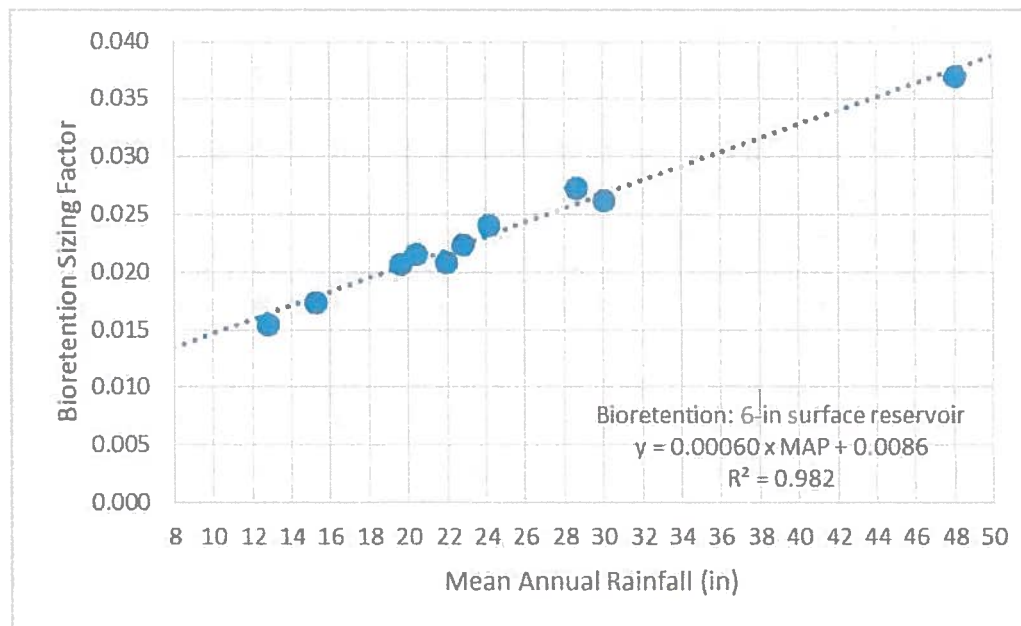


Figure 4. Bioretention size needed to provide treatment of 80 percent of annual runoff; 6-in surface reservoir



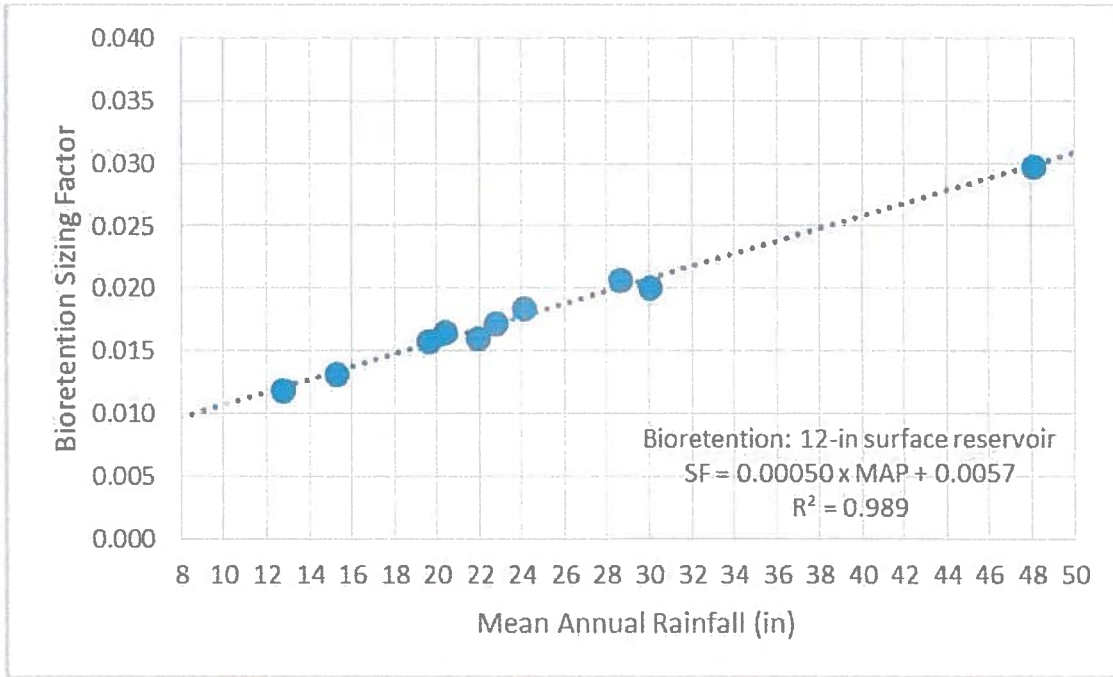


Figure 5. Bioretention size needed to provide treatment of 80 percent of annual runoff; 12-in surface reservoir

The results shown above could be used by BASMAA agencies to set minimum bioretention sizing criteria for projects that must provide treatment of 80 percent of annual runoff. The following equations could be included in BASMAA guidance for green infrastructure manuals.

For bioretention with 6-in surface reservoir configuration:

$$SizingFactor = 0.00060 \times MAP(in) + 0.0086$$

For bioretention with 12-in surface reservoir configuration:

$$SizingFactor = 0.00050 \times MAP(in) + 0.0057$$

### 3.2 Relationship Among Bioretention Sizing, Annual Precipitation, and Percent of Annual Runoff Treated

The modeling results generated in the previous section were then further evaluated to develop more general relationships among a) bioretention sizing factor, b) mean annual rainfall, and c) annual runoff treatment percentages. The following steps were used for the 6-inch and 12-inch reservoir depth configurations:

1. A polynomial regression was fit to the annual runoff treatment results for each of the 10 rain gauges (see example in Figure 3 above) and surface reservoir depths of 6 and 12 inches.
2. For each rain gauge/surface reservoir depth combination, the regression equation was used to estimate the sizing factors needed to provide 50, 60, 70, 80, 90, and 95 percent annual runoff treatment. This step generated 10 pairs of mean annual rainfall/bioretention sizing factor data for each rain gauge/surface reservoir depth combination (120 pairs in total). Excel’s solver function was used for these calculations.

3. For each runoff treatment percentage level (50 percent, 60 percent, etc.), the mean annual rainfall (x-axis) and computed sizing factor (y-axis) were plotted and a linear regression was fit to the data in a manner similar to Figure 4 and Figure 5 above.
4. The linear regressions created for each runoff treatment level (50 percent, 60 percent, etc.) and surface reservoir depth were then plotted together to create a nomograph. Figure 6 and Figure 7 show nomographs for the 6-inch and 12-inch reservoir depths, respectively.

These nomographs are simple but powerful tools that municipal planners can use to estimate the annual treatment percentage for any bioretention facility within the BASMAA member agency area that uses the standard bioretention configuration (i.e., 6-in or 12-in reservoir, 18-in soil media, 12-in gravel layer, underdrain at top of gravel layer). The nomographs should be read as follows:

**Step 1:** Find the mean annual rainfall for the project location along the horizontal axis

**Step 2:** Move vertically up the chart to the bioretention sizing factor for the project/installation (note: this step assumes the tributary impervious area and bioretention area have already been planned)

**Step 3:** Visually interpolate between the closest two “treatment lines” to estimate the percent of annual runoff treated for this location/project.

These nomographs and instructions could be included in BASMAA guidance for green infrastructure manuals and used to a) evaluate the water quality benefits of proposed projects or b) evaluate the treatment provided by existing facilities with the layer depths described above.

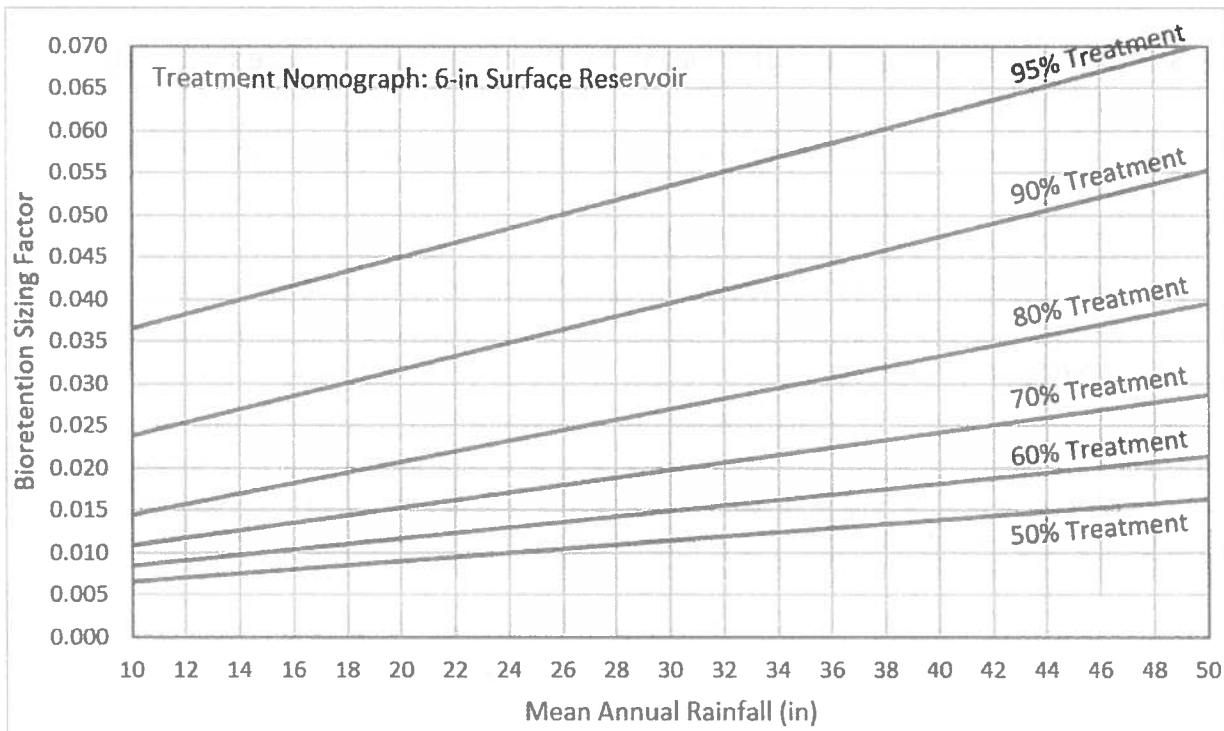


Figure 6. Percent of annual runoff treatment nomograph for bioretention facility with 6-in surface reservoir

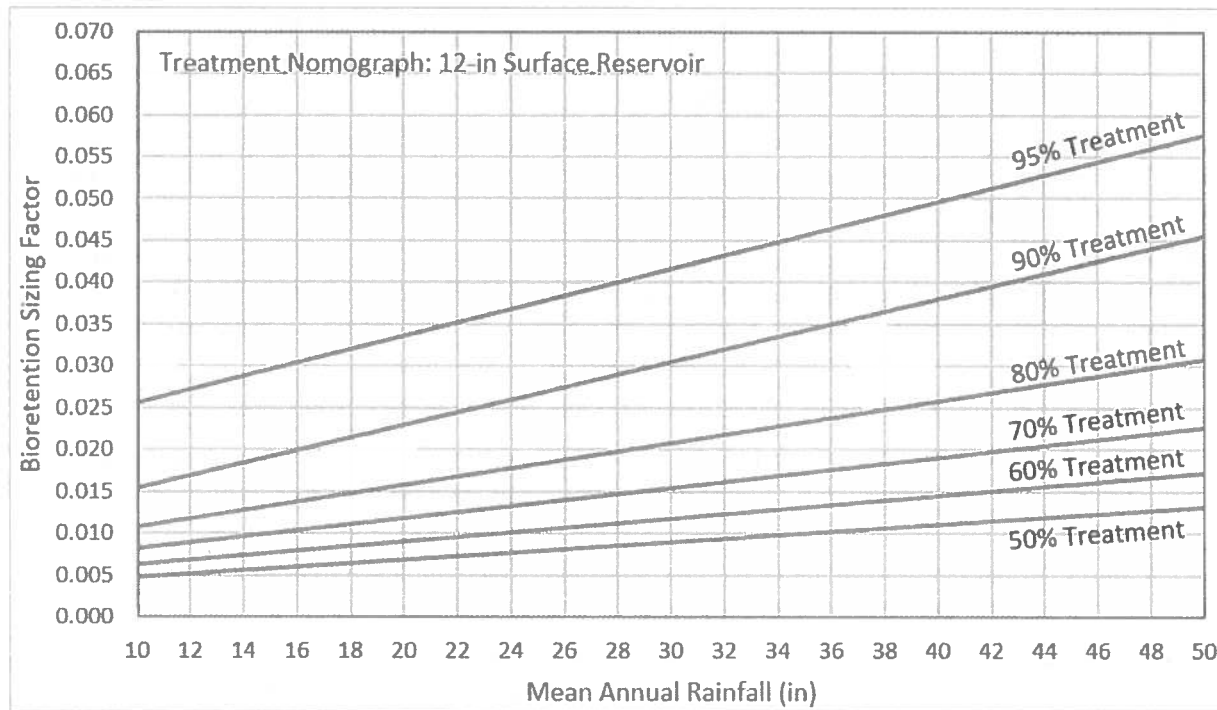


Figure 7. Percent of annual runoff treatment nomograph for bioretention facility with 12-in surface reservoir

### 3.3 Percent of Annual Runoff Treated by Bioretention Facilities with No Underdrain

Bioretention facilities are occasionally designed with no underdrain, including bioretention facilities in the following conditions:

- High permeability of surrounding (native) soils
- Isolated projects with no downstream drainage system for the underdrain connection
- Small projects that would not justify the additional design and construction costs associated with underdrains and cleanouts
- Projects that were designed and built prior to the development of the current standards

The HSPF model setup was modified to eliminate the underdrain outflows and allow the permeability of the surrounding soils to vary. The annual runoff treatment percentage was computed for a) three rain gauges representing drier, average and wetter than average conditions, b) six rates of permeability of surrounding soils, and c) two bioretention surface reservoir depths (Table 3).

TABLE 3. BIORETENTION WITH NO UNDERDRAIN SCENARIOS

Component	Characteristics
Rain gauges	<ul style="list-style-type: none"> <li>• San Jose (MAP = 15.2 in)</li> <li>• San Francisco Airport (MAP = 20.4 in)</li> <li>• Fairfield (MAP = 24.1 in)</li> </ul>
Permeability of surrounding (native) soils	<ul style="list-style-type: none"> <li>• 0.2, 0.5, 1.0, 2.0, 3.0, 4.0 inches per hour</li> <li>• Underdrain results also plotted</li> </ul>

TABLE 3. BIORETENTION WITH NO UNDERDRAIN SCENARIOS

Component	Characteristics
Surface reservoir depths	<ul style="list-style-type: none"> <li>• Depth = 6 inches</li> <li>• Depth = 12 inches</li> </ul>
Bioretention sizing factors	<ul style="list-style-type: none"> <li>• Area = 0.5% to 5.0% of upstream impervious acre</li> </ul>

Figure 8, Figure 9 and Figure 10 show the modeled annual runoff treatment results for the three rain gauges and a surface reservoir depth of 6 inches. Results for the 12-inch surface reservoir are shown in Appendix C. For rates of permeability of 4 inches per hour, there is little drop off in performance. The annual runoff treatment percentage declines gradually between rates of permeability of 2 to 4 inches per hour and then declines more rapidly for rates of permeability of 1 inch per hour or less. The reduction in performance is more pronounced in wetter areas (as seen in the Fairfield results). These results could be incorporated into the BASMAA guidance for green infrastructure manuals to assess the general performance of existing facilities that were installed with no underdrain.

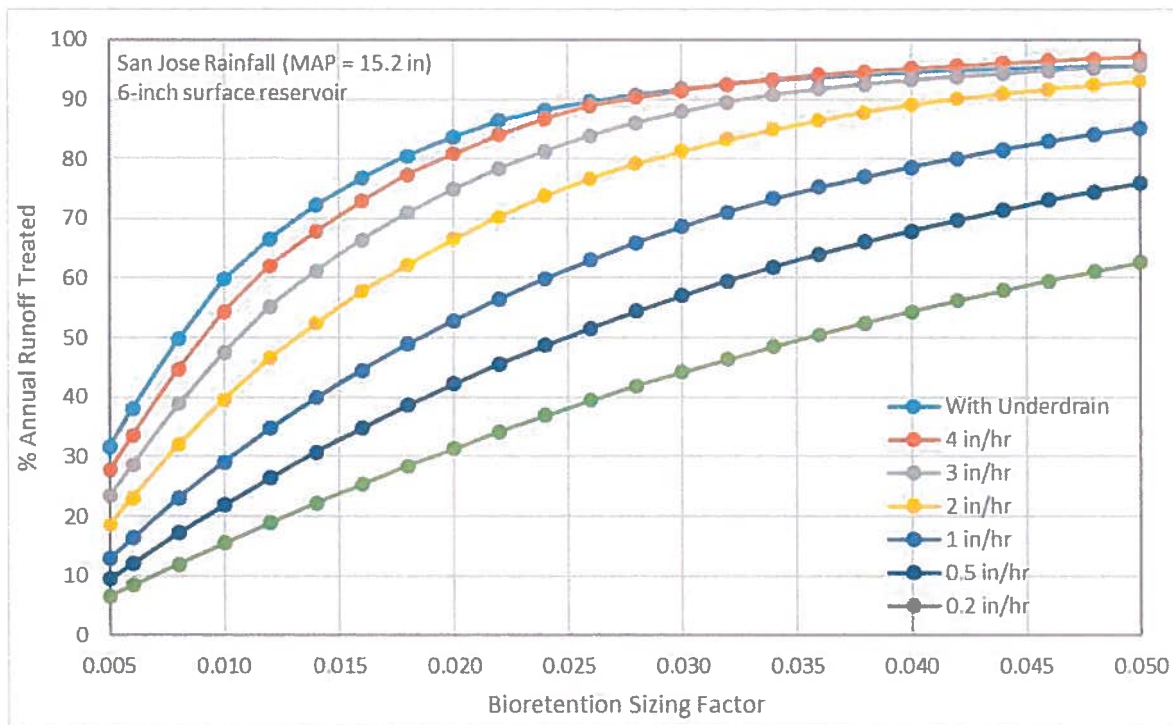


Figure 8. Treatment results for bioretention with no underdrain, San Jose gauge (MAP = 15.2 in), for varying rates of permeability of surrounding soils

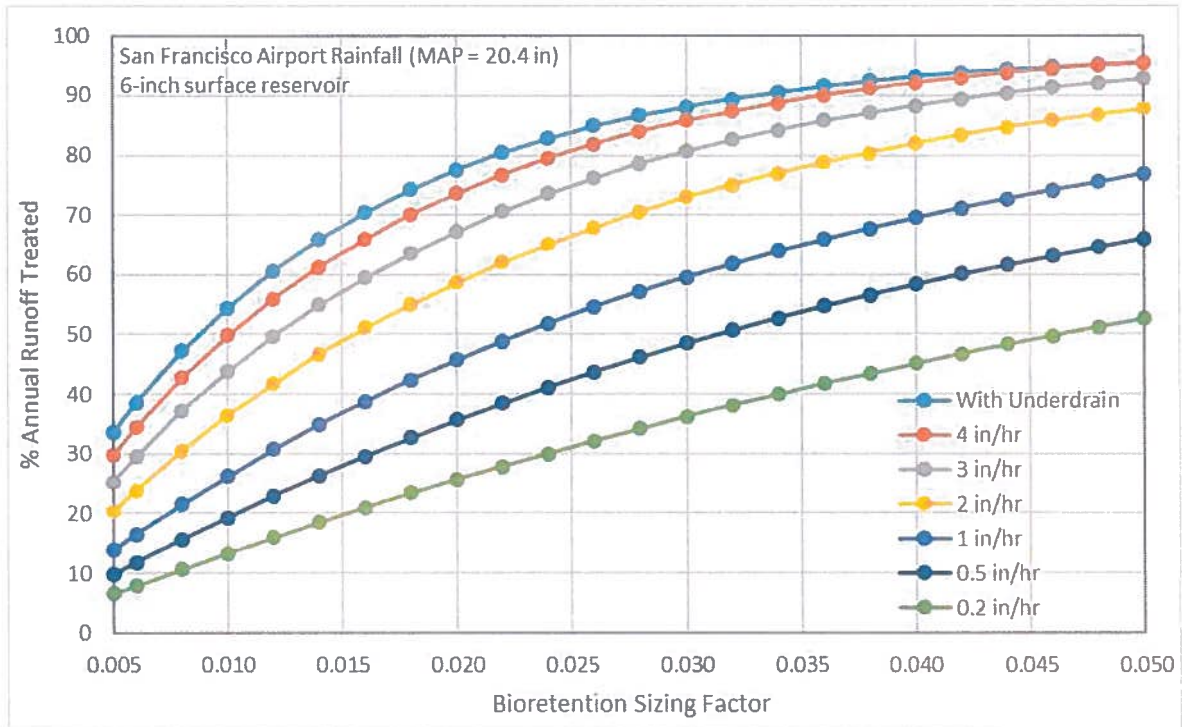


Figure 9. Treatment results for bioretention with no underdrain, San Francisco Airport gauge (MAP = 20.4 in), for varying rates of permeability of surrounding soils

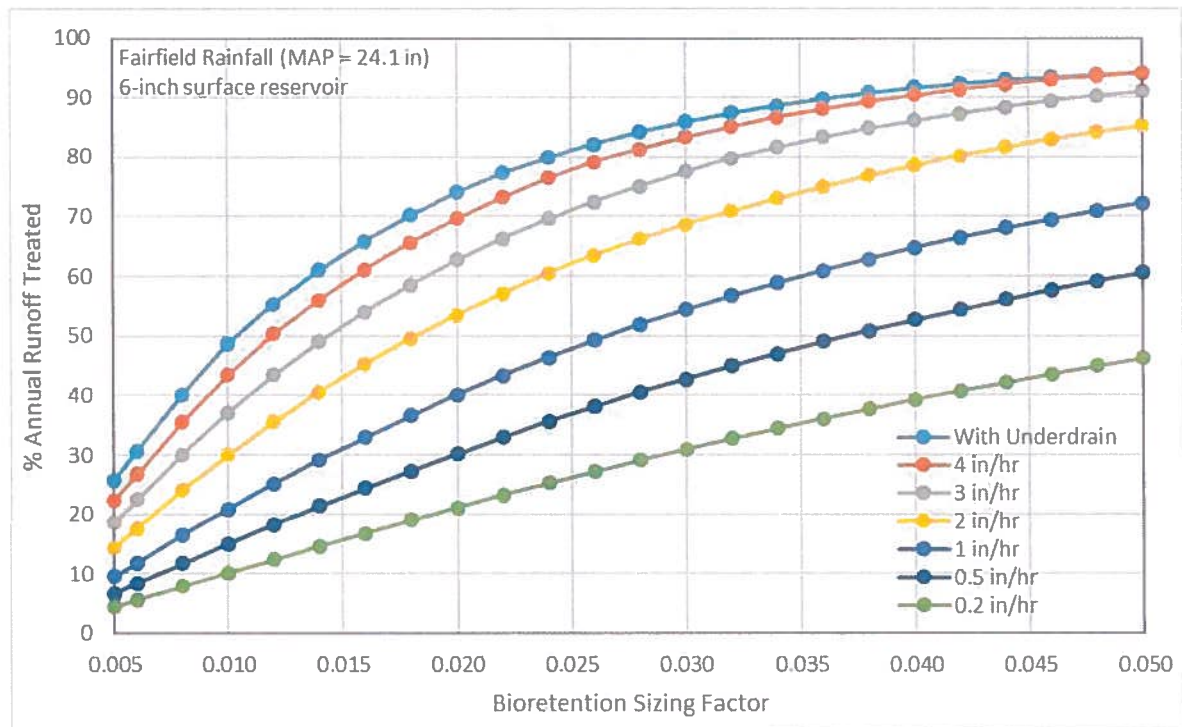


Figure 10. Treatment results for bioretention with no underdrain, Fairfield gauge (MAP = 24.1 in), for varying rates of permeability of surrounding soils

### 3.4 Percent of Annual Runoff Treated for Bioretention Facilities with No Infiltration to Surrounding Soils

The previous simulations described in Sections 3.1 and 3.2 were conducted for bioretention facilities located in NRCS hydrologic soil group D soils, which are low permeability soils, such as clays. These model simulations used a conservative permeability of 0.024 inches per hour from the bioretention gravel layer to surrounding soils. It was assumed the permeability of surrounding soils would have a negligible effect on the results because the hydraulic capacity of the underdrain is much higher than the permeability of D soils and that when the bioretention media becomes saturated, stormwater would exit mostly via the underdrain. If this assumption is correct, a lined bioretention facility or flow-through planter with no infiltration into surrounding soils should have similar performance.

This assumption was tested directly by running a limited number of simulations with the permeability of the surrounding soils set to a value of zero (i.e., an impervious layer directly below the bioretention facility). The annual treatment percentages were then compared to the previous modeling results (with D soil permeability set to 0.024 inches per hour). These simulations were performed for the Fairfield rain gauge and a bioretention facility with a 6-inch surface reservoir for sizing factors ranging from 0.005 to 0.050.

Figure 11 shows the two sets of model results. For the impermeable bottom scenario, the annual treatment percentage was on average 0.8 percent less the scenarios with a D soil permeability of 0.024 inches per hour (minimum difference = 0.4 percent; maximum difference = 1.5 percent). Therefore, the sizing curves and nomographs in Figure 4 through Figure 7 can be used for lined facilities with no infiltration.

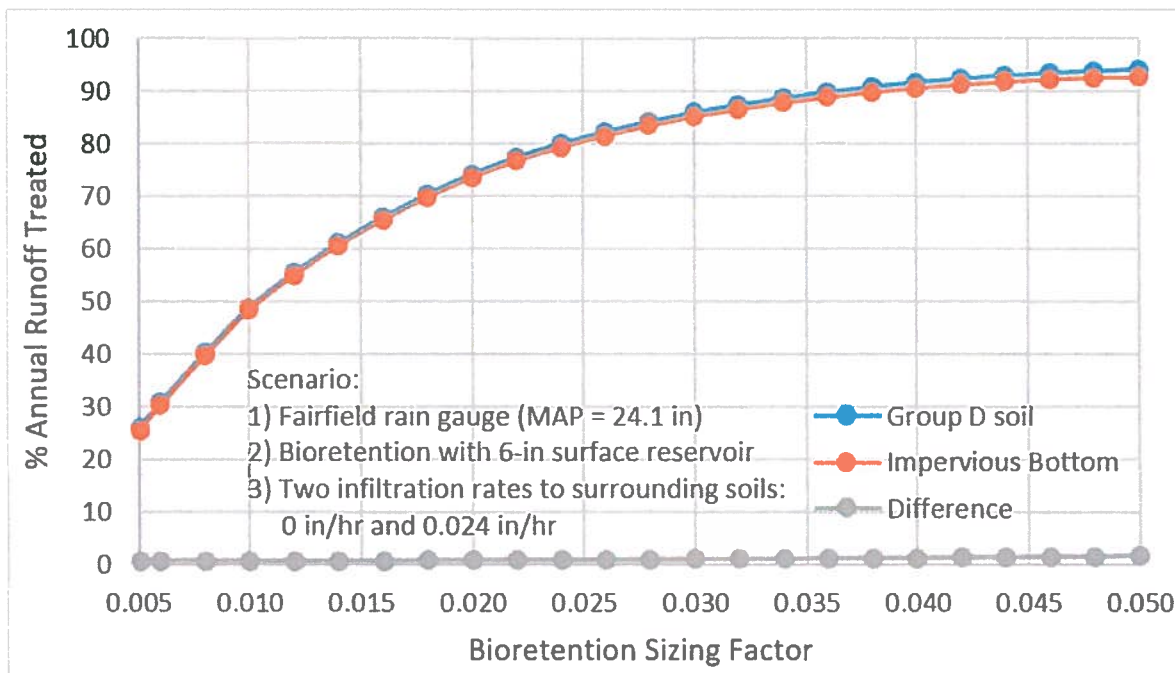


Figure 11. Comparison of model results for Group D soils and impermeable bottom scenarios



### 3.5 Percent of Annual Runoff Treated for Bioretention Facilities with Lower Media Permeability

The final modeling analysis examined the effect of modifying the bioretention media properties to reduce its saturated permeability from 5 inches per hour to 2 or 3 inches per hour. A lower permeability media would expand the list of available plantings and provide additional flexibility for landscape designers. However, the lower permeability would also reduce the bioretention’s capacity for treating runoff during intense storms.

Due to budgetary constraints, this modeling analysis was limited to two scenarios: San Jose rain gauge, 6-inch surface reservoir depth, sizing factors ranging from 0.005 to 0.05, and saturated bioretention media permeability of 2 and 3 inches per hour. Figure 12 shows the percentage of annual runoff treated across the range of bioretention sizing factors and permeability rates. All of the scenarios include an underdrain, so the media permeability is the facility characteristic that controls the treatment percentage (i.e., the rate limiting step). The reduction in treatment percentage could be significant, particularly for smaller facilities. For example, the percent of annual runoff treated for a bioretention facility with a sizing factor of 0.02 would be reduced from 84 percent to 74 or 65 percent (for media permeability rates of 3 and 2 inches per hour, respectively).

Another way to consider the effect of lower media permeability is to estimate *how much larger a facility would need to be* to treat 80 percent of annual runoff. For the San Jose gauge, a sizing factor of 0.017 is needed with the standard bioretention media specification. If the media permeability were reduced to 3 or 2 inches per hour, the sizing factor needed to treat 80 percent of annual runoff would be 0.024 or 0.030, respectively, which represents a 37 to 75 percent increase in the facility footprint.

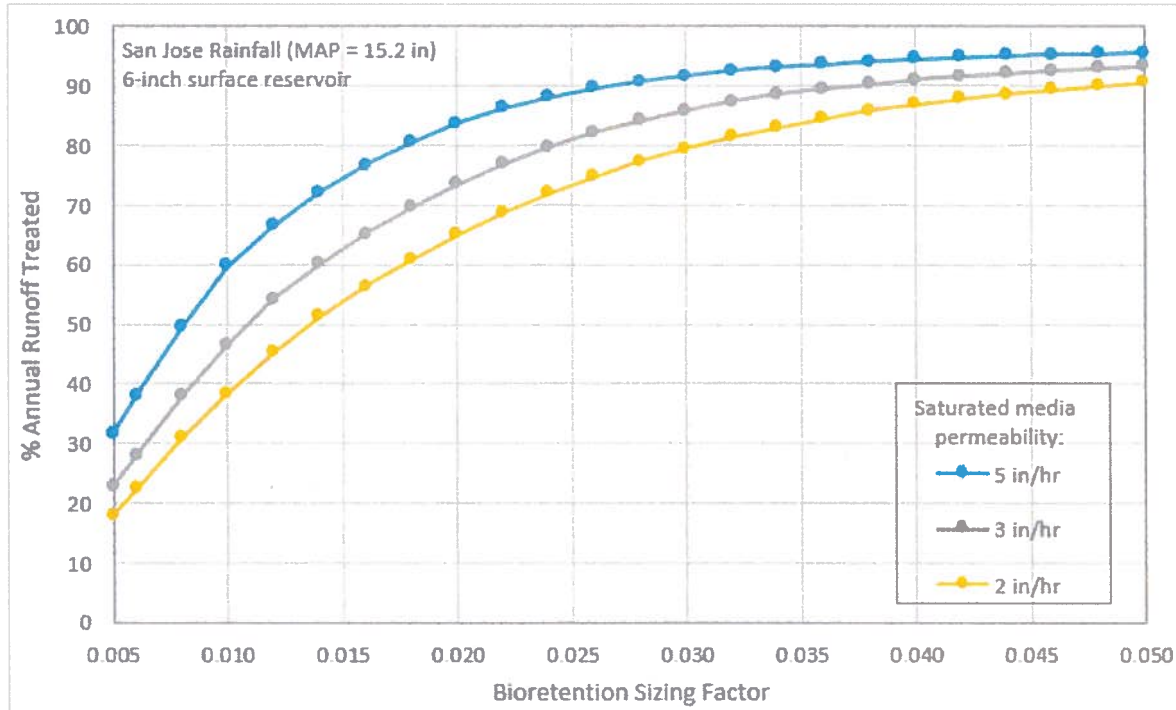


Figure 12. Treatment results for bioretention with variable media permeability, San Jose gauge (MAP = 15.2 in)

As a final note, the media permeability modeling was limited to two scenarios (one rain gauge, one facility configuration, two permeability rates). However, these results could be extended by noting that they are

generally similar to the “no underdrain” results shown in Section 3.3 (e.g., comparing the results for a media permeability of 2 inches per hour to a 2-inch per hour permeability of surrounding soil). When comparing the two sets of results, the percent of annual runoff treated for the lower media permeability is a little lower (0.5 to 2.5 percent) than the corresponding “no underdrain” scenario and the shape of the curve in Figure 12 is similar to the Figure 8 in Section 3.3.

## 4. Summary and Conclusions

Bioretention facilities are a useful and flexible approach for improving stormwater quality in urban areas. This project developed a set of useful tools that will help municipal staff plan green infrastructure projects in constrained public rights-of-way and assess the effectiveness of existing facilities.

### 1. Bioretention Sizing Criteria for 80 Percent Annual Runoff Treatment

The modeling analysis in Section 3.1 showed that bioretention facility performance is closely related to mean annual rainfall. For most locations, the bioretention area necessary to treat 80 percent of annual stormwater ranges from 1.5 to 2.5 percent of the connected upstream impervious area. The precise bioretention area necessary for any project within the BASMAA area (under the guidelines to be developed by BASMAA) can be calculated using the regression equations in Section 3.1.

### 2. General Sizing Relationships that Apply Throughout the BASMAA Area

The modeling analysis in Section 3.2 developed nomographs that estimate the annual stormwater treatment percentage across a range of bioretention facility sizes and mean annual rainfall depths. These nomographs can be used to estimate the annual treatment percentages for retrofit projects with space constraints and will enable municipal staff to compare bioretention with other treatment technologies. These nomographs can also be used to assess the effectiveness of existing facilities.

### 3. Performance of Bioretention Facilities with No Underdrain and Varying Rates of Permeability of Surrounding Soils

The modeling analysis in Section 3.3 demonstrated the relationship between stormwater treatment percentage and level of permeability of surrounding soils for bioretention facilities without an underdrain. Graphics were developed for rain gauges in wetter and drier areas. The results of this analysis can help assess existing installations and also inform designers about the benefits and tradeoffs of constructing bioretention with no underdrain.

### 4. Performance of Bioretention Facilities with No Infiltration

The modeling analysis in Sections 3.1 and 3.2 included the conservative assumption that bioretention facilities were installed in NRCS Group D soils with a very low permeability. The modeling analysis in Section 3.4 compared these results to bioretention facilities with no infiltration to surrounding soils (e.g., facilities with a liner or concrete bottom). The results were very similar, which confirms that the sizing guidance developed in Sections 3.1 and 3.2 can apply to flow-through planters or similar facilities that do not infiltrate to surrounding soils.



## 5. Sizing Criteria for Facilities with Lower Permeability Soil Media

The modeling analysis in Section 3.5 demonstrated the relationship between percent of annual runoff treated and bioretention soil media permeability. Reducing media permeability would allow for a wider range of bioretention plantings but would also result in a reduction in the percent of annual runoff treated for the same size drainage area. The reduction would be particularly notable for bioretention facilities with smaller sizing factors. The results of the bioretention media permeability analysis were similar to the no underdrain scenarios in Section 3.3. The Section 3.3 results could be used to estimate how reducing media permeability would influence treatment percentages across a wider range of scenarios.

In general, the bioretention surface area sizing criteria for treating 80% of the annual runoff derived from the modeling analyses described herein are significantly lower than the sizing factors that municipalities in the Bay Area have been requiring regulated projects to meet for compliance with permit requirements for some time. As stated in the Introduction (Section 1), the BASMAA Development Committee and BASMAA member agencies intend to use these sizing relationships to develop and justify a “single approach” for implementing non-regulated green street projects when there are constraints on facility size. A work group of the Development Committee was formed to develop policies and guidelines for implementing the new sizing criteria and addressing other related issues. These include defining the conditions, constraints, and types of projects for which the reduced sizing factors can be used; the method for applying the sizing factors; guidelines for when dimensions of other components such as media depths can be adjusted; how the design of other types of green infrastructure measures may be modified; the effectiveness of smaller or modified green infrastructure facilities in terms of pollutant load reduction; and other considerations.

## 5. References

- Contra Costa Clean Water Program (CCCWP). 2006. Hydrograph Modification Management Plan. April 16, 2006.
- Contra Costa Clean Water Program (CCCWP). 2013. IMP Monitoring Report, IMP Model Calibration and Validation Report. September 20, 2013.

### Appendix A: Storm Depths for 1-Hour and 24-Hour Durations

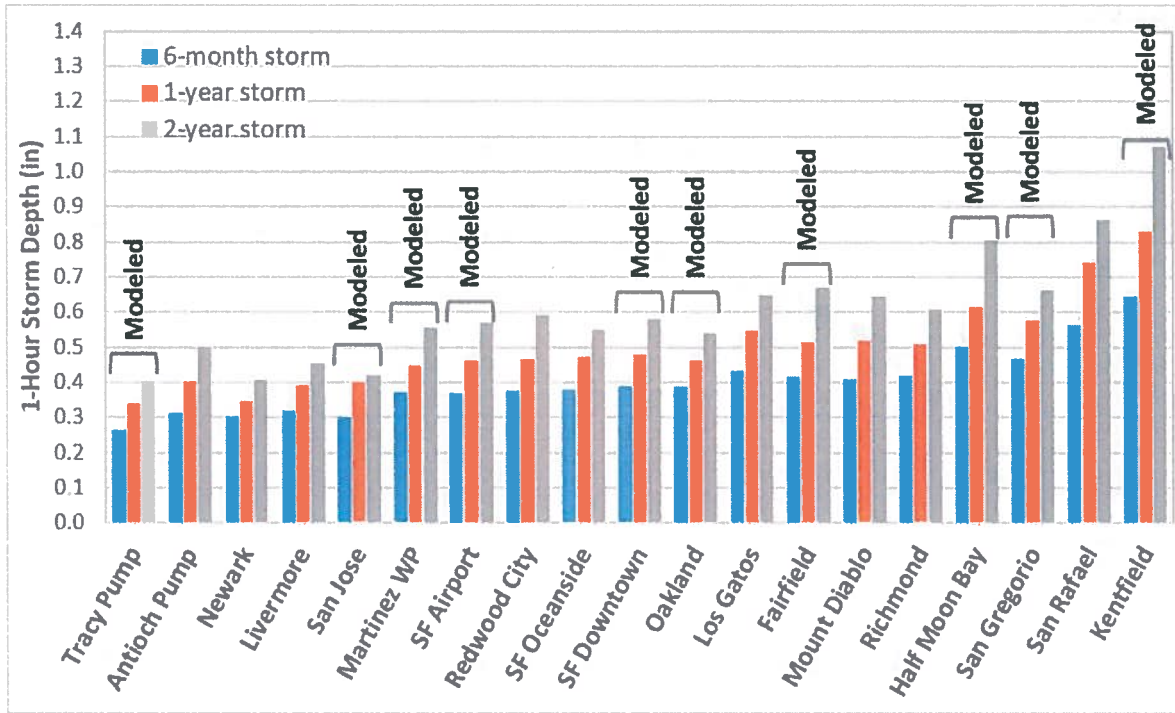


Figure 13. Storm depths for 1-hour duration

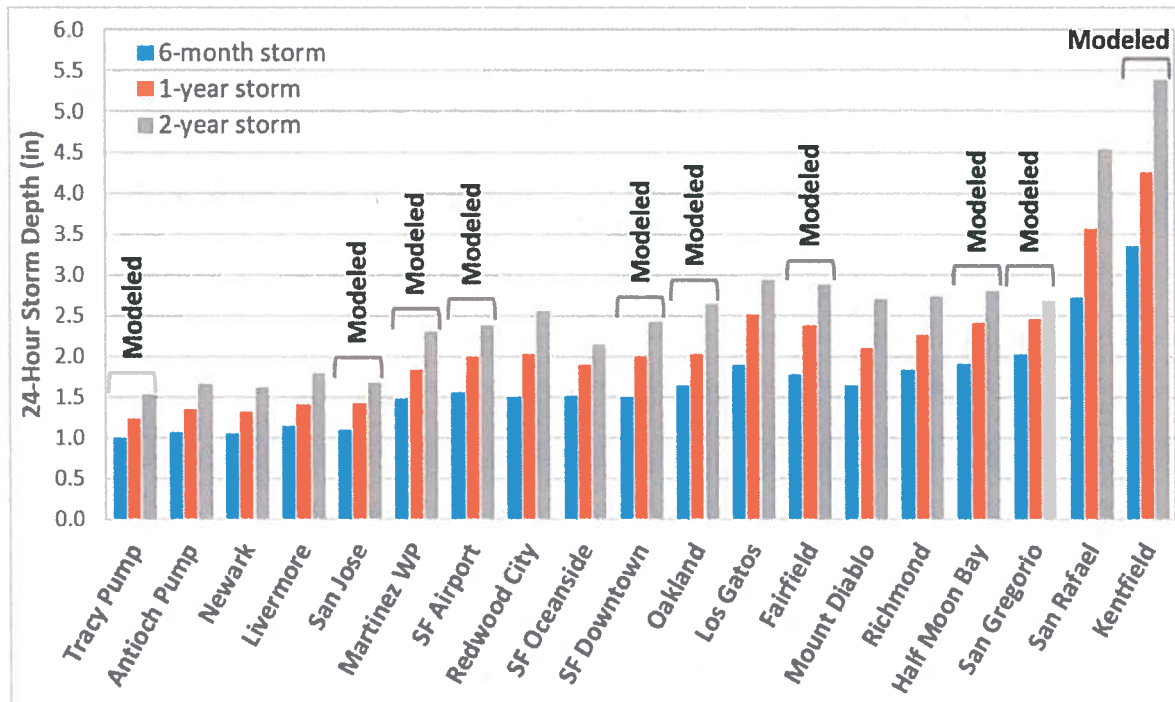


Figure 14. Storm depths for 24-hour duration

## Appendix B: Treatment Percentage Results Graphics for All Rain Gauges

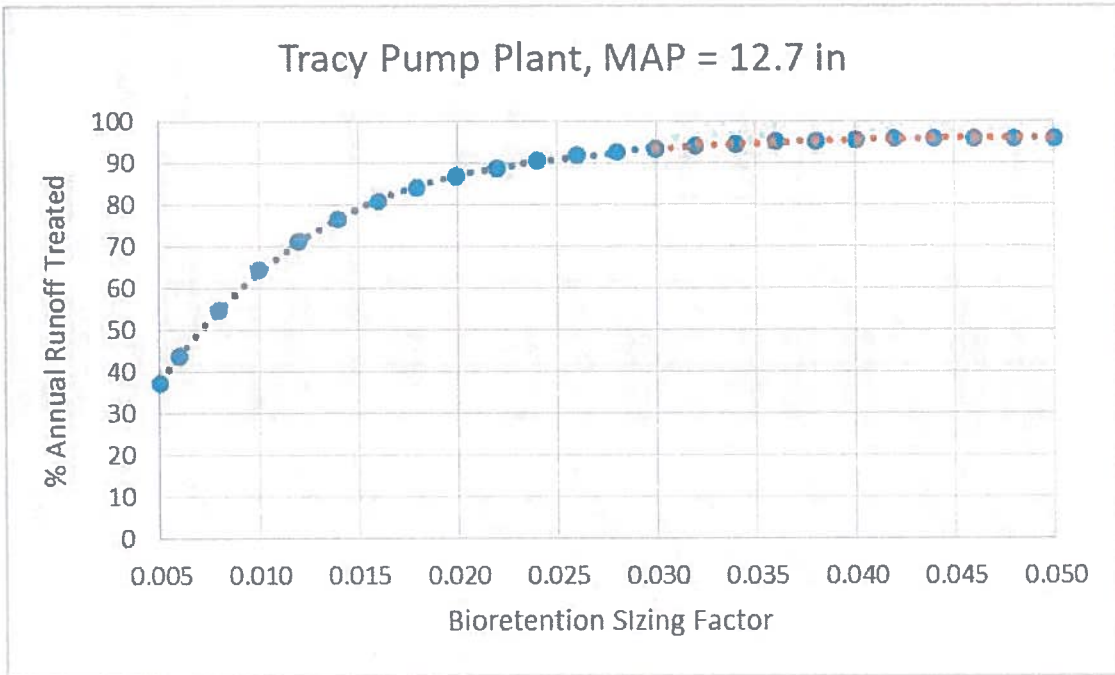


Figure 15. Annual treatment percentage for the Tracy Pump Plant rain gauge

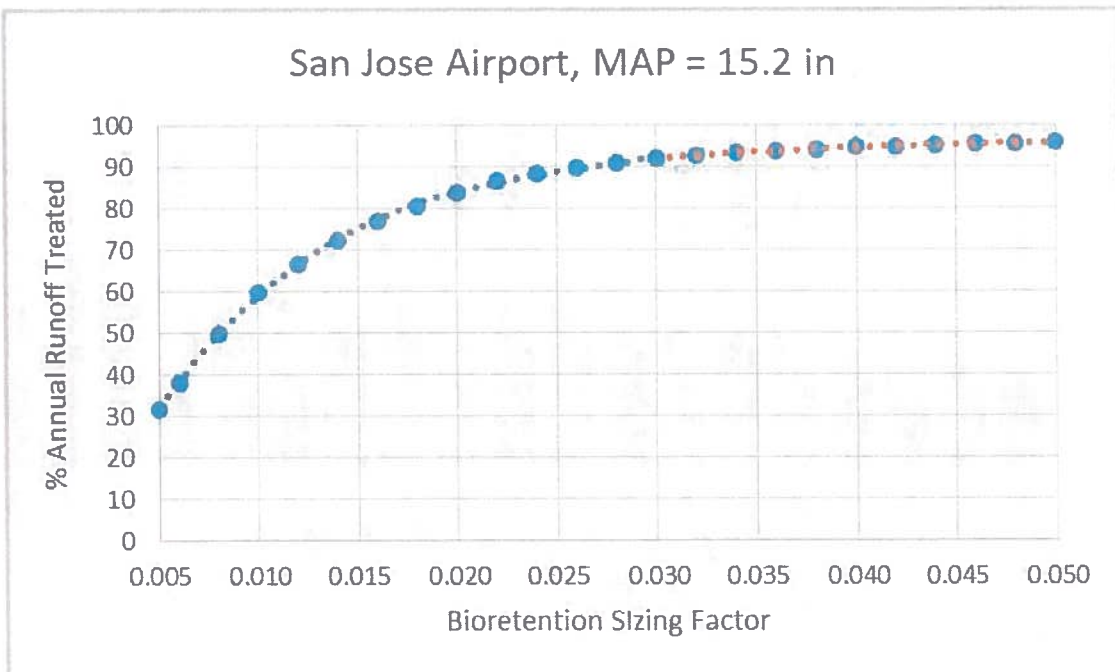


Figure 16. Annual treatment percentage for the San Jose rain gauge

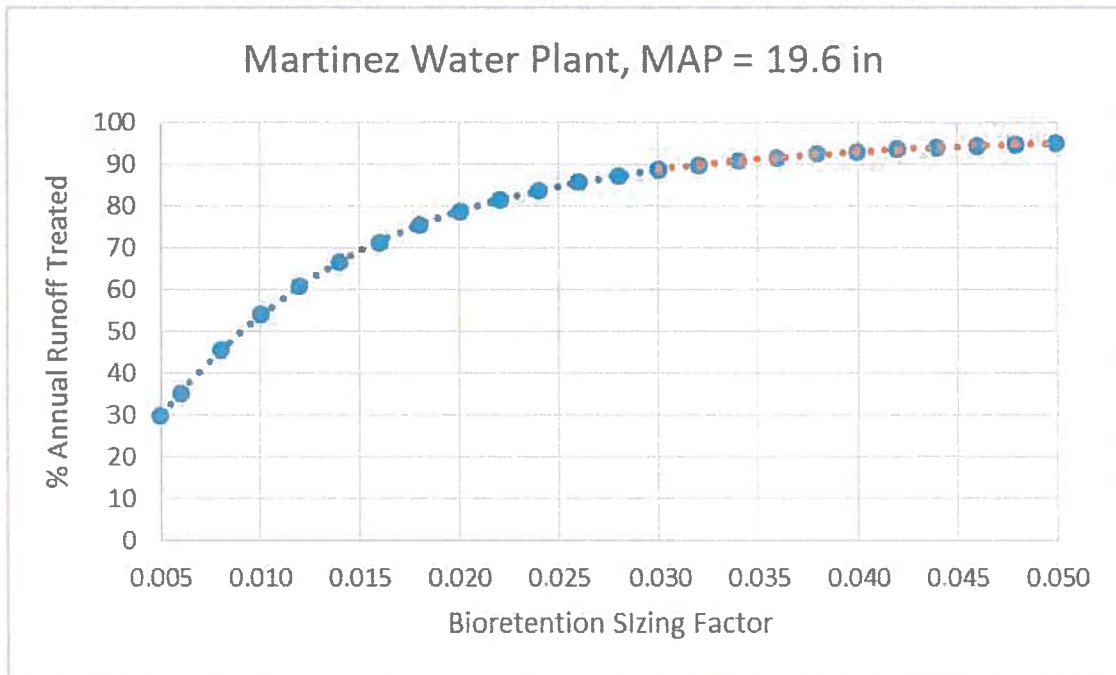


Figure 17. Annual treatment percentage for the Martinez Water Plant rain gauge

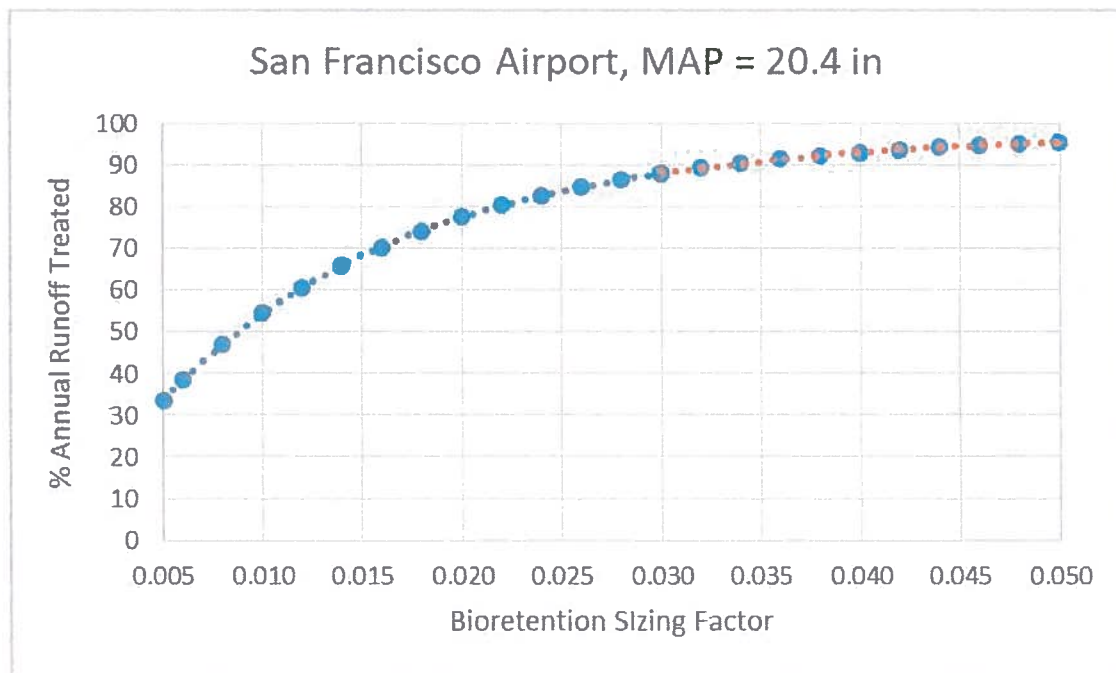


Figure 18. Annual treatment percentage for the San Francisco Airport rain gauge

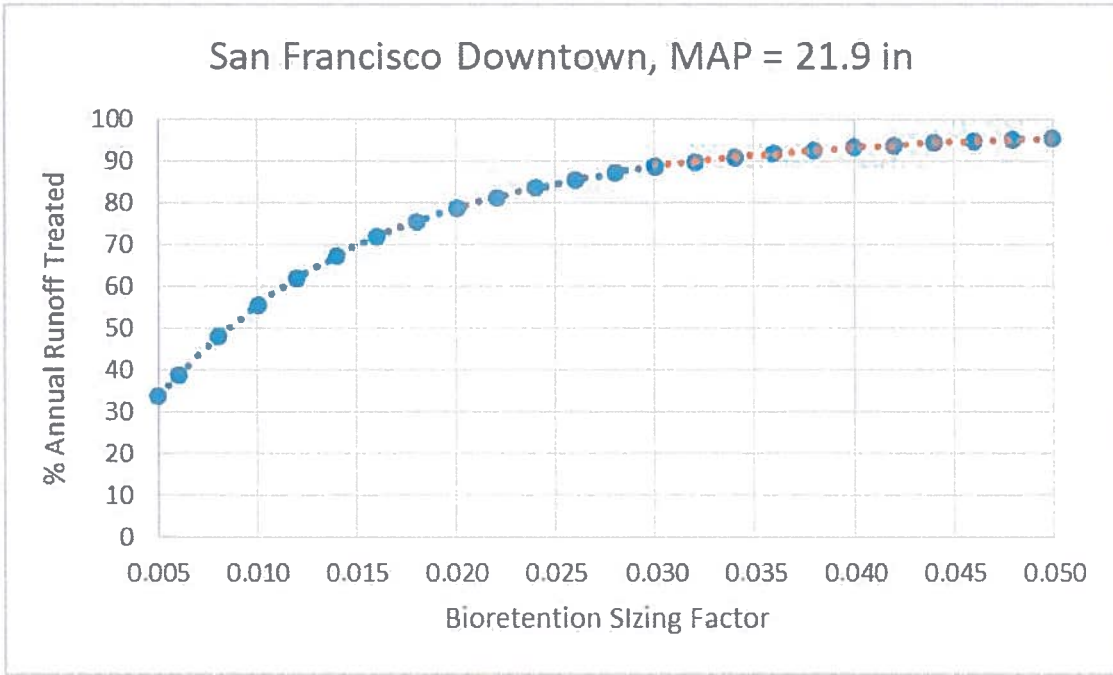


Figure 19. Annual treatment percentage for the San Francisco Downtown rain gauge

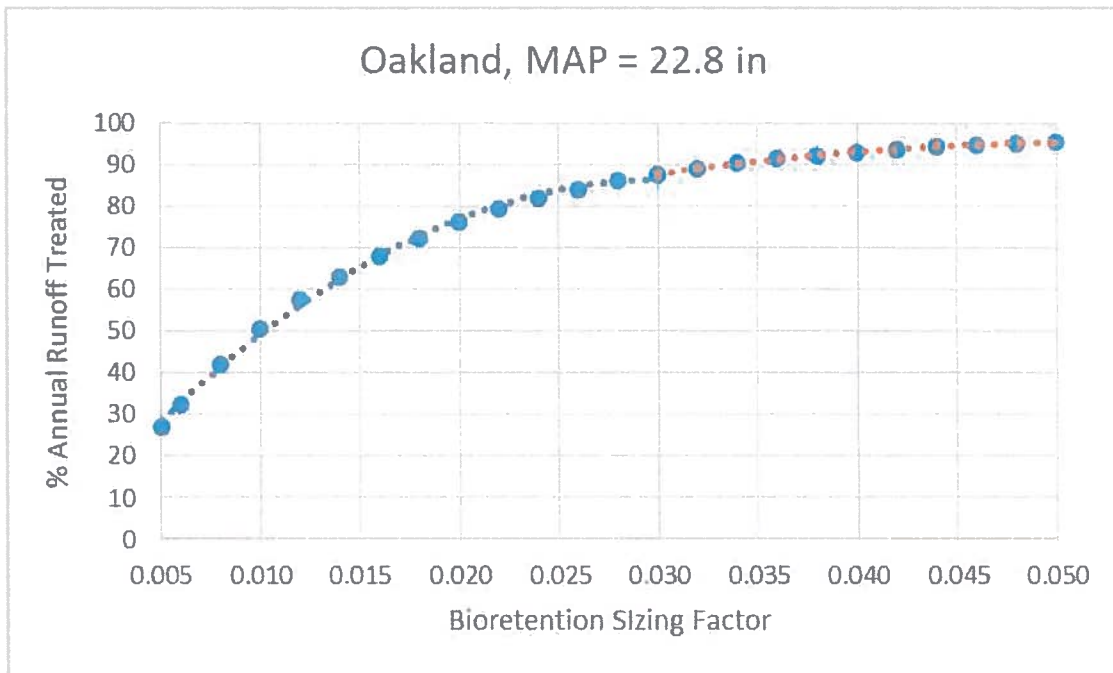


Figure 20. Annual treatment percentage for the Oakland rain gauge

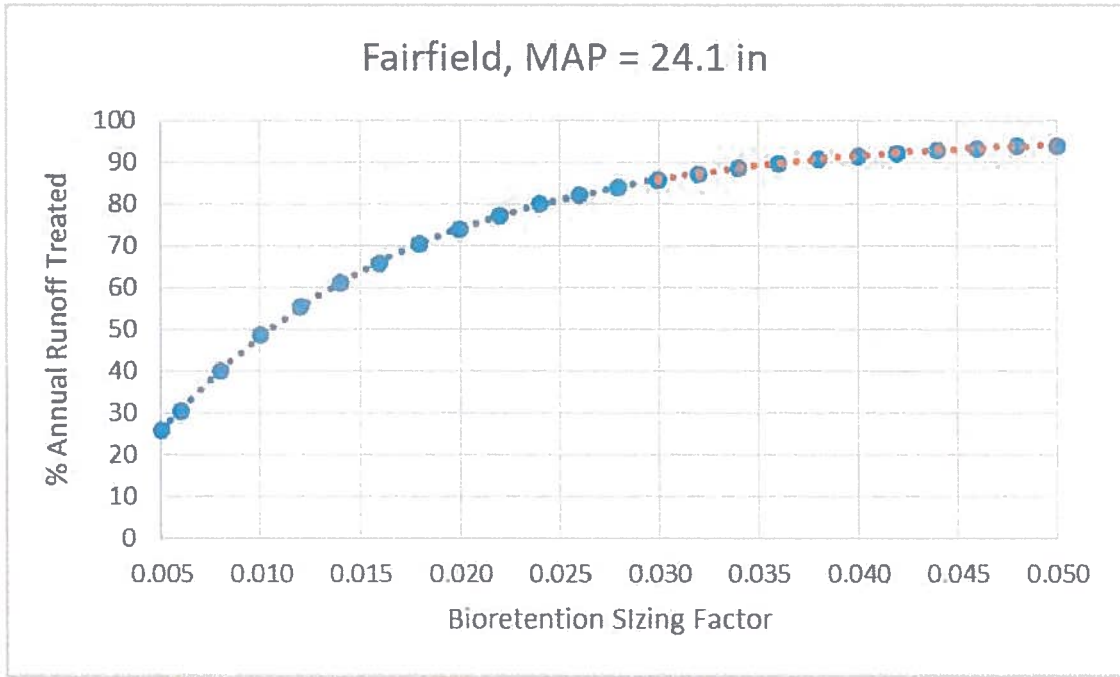


Figure 21. Annual treatment percentage for the Fairfield rain gauge

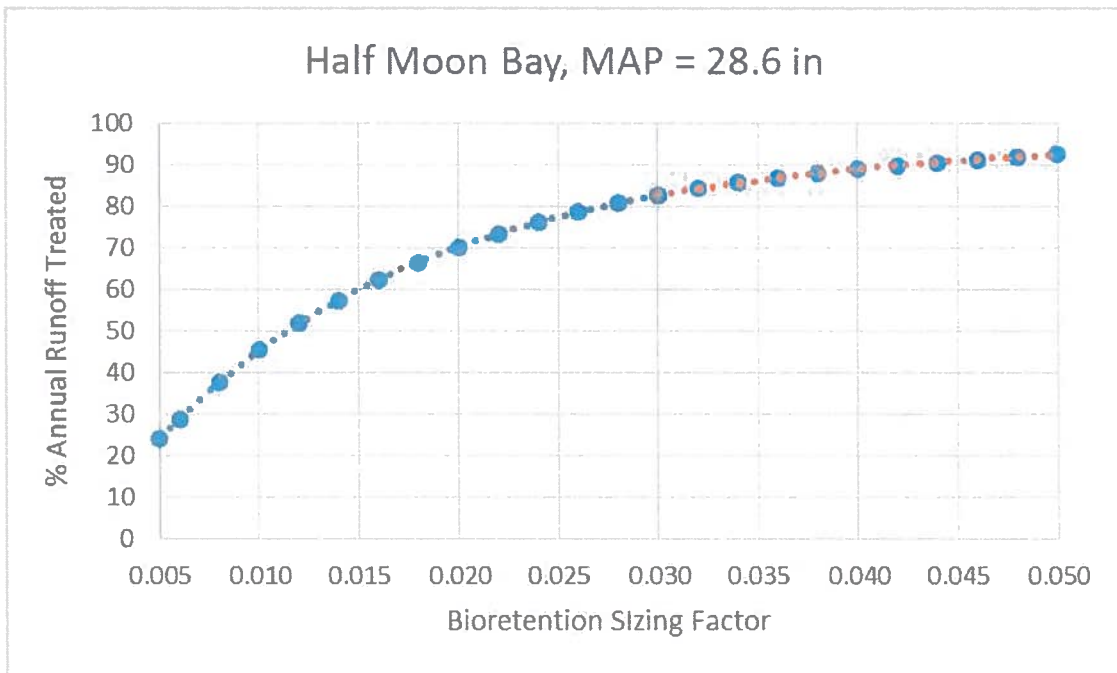


Figure 22. Annual treatment percentage for the Half Moon Bay rain gauge

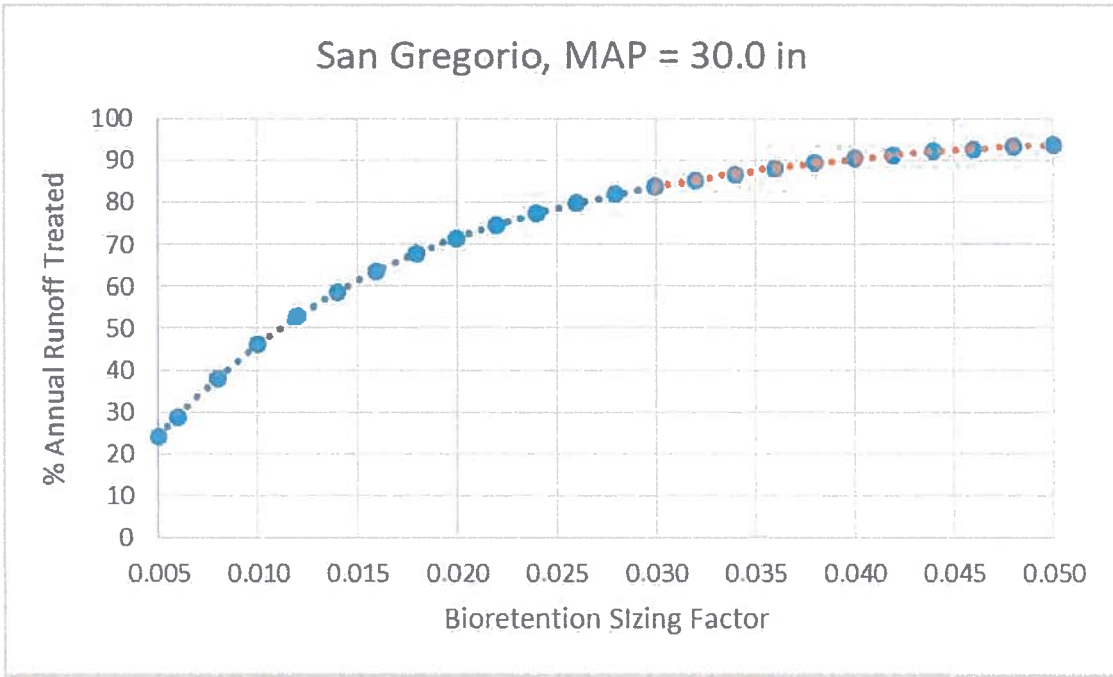


Figure 23. Annual treatment percentage for the San Gregorio rain gauge

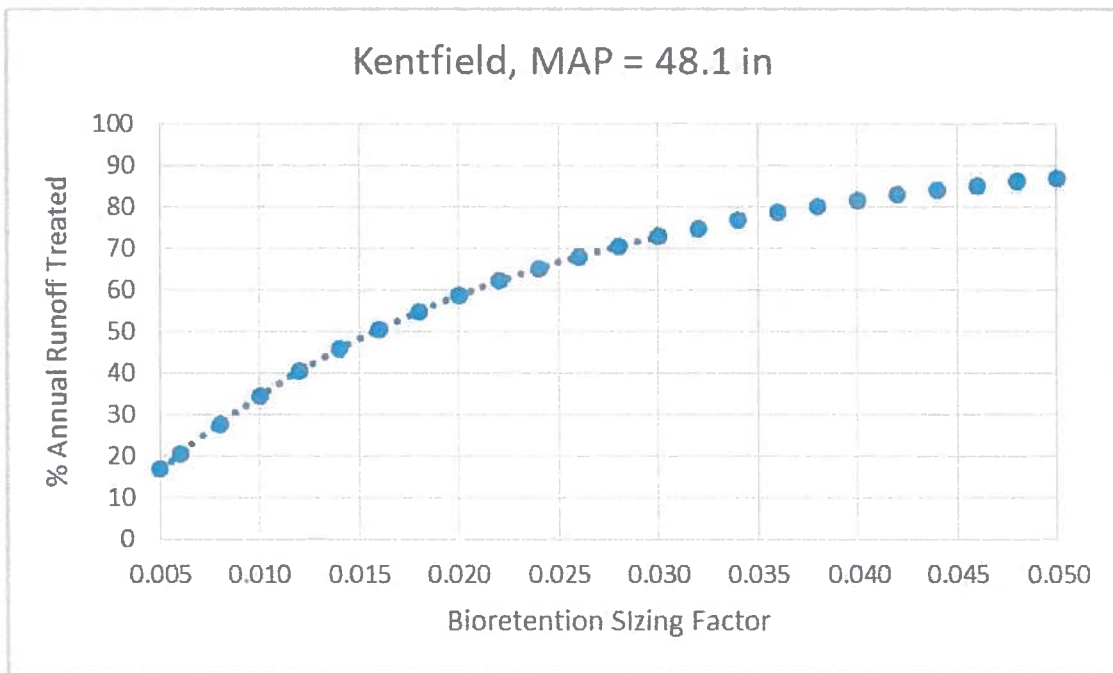


Figure 24. Annual treatment percentage for the Kentfield rain gauge



### Appendix C: Bioretention with No Underdrain, 12-inch Surface Reservoir Results

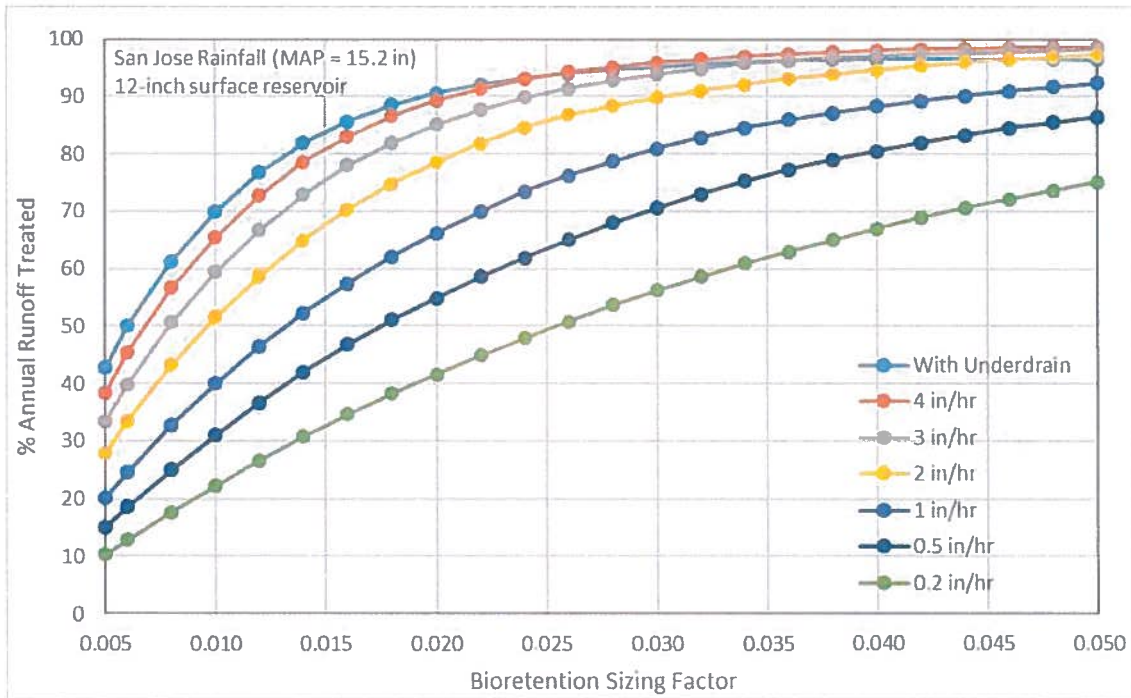


Figure 25. Treatment results for bioretention with no underdrain, San Jose gauge (MAP = 15.2 in)

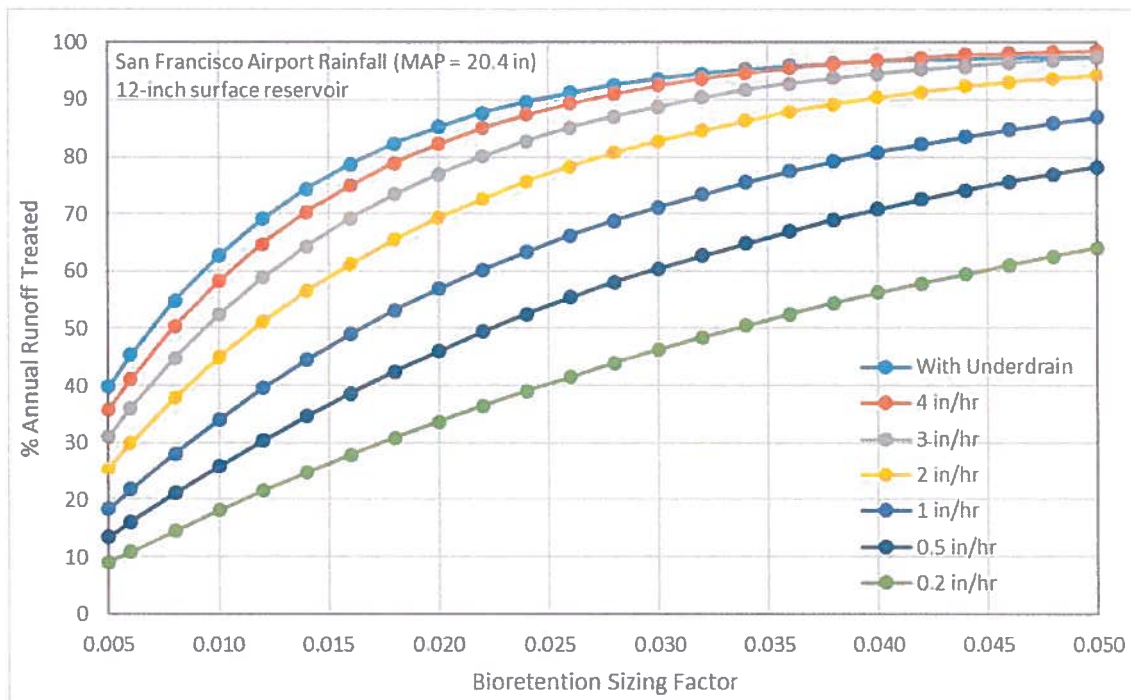


Figure 26. Treatment results for bioretention with no underdrain, San Jose gauge (MAP = 15.2 in)



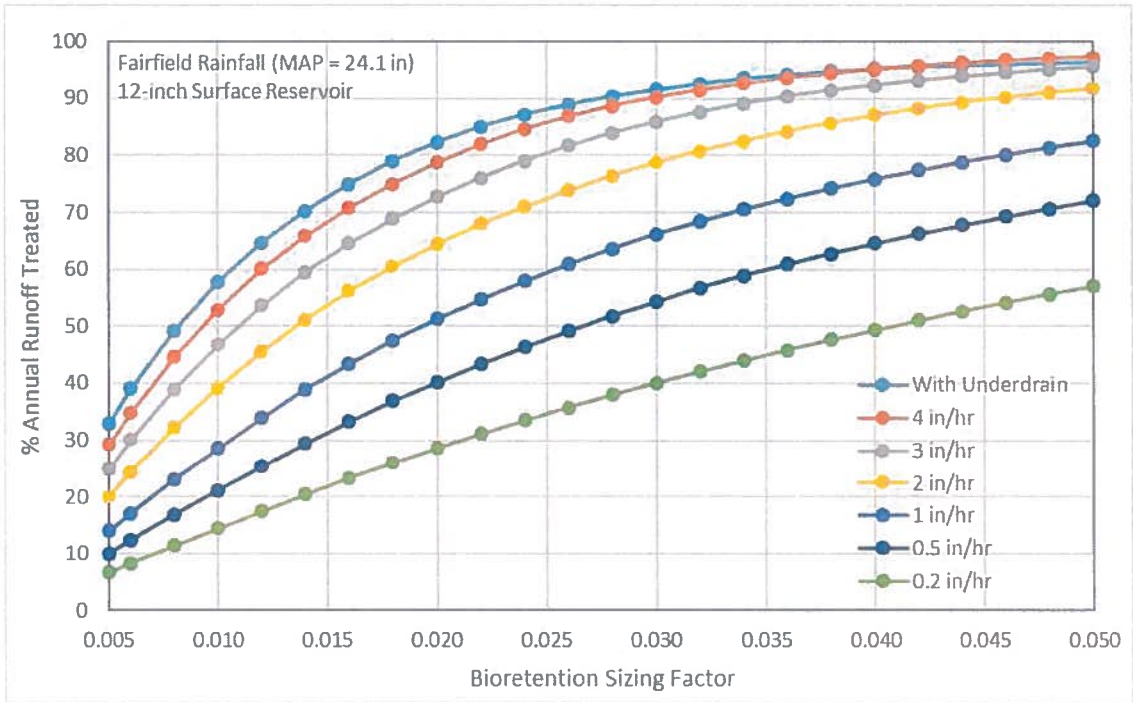


Figure 27. Treatment results for bioretention with no underdrain, San Jose gauge (MAP = 15.2 in)