Date: March 7, 2013

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From: JERT-D Subcomittee:

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Subject: Alternatives to 1.963 Multiplier for Sizing Retention Volume

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Enclosed please find the results of our analysis of alternatives to using the 1.963 multiplier used in Attachment D of the PCRs.

This analysis was prepared by Valerie Huff and reviewed and approved by the JERT-D over a period of many weeks.

There are essentially two alternatives shown in this work. Both are recommended.

The first (Simple Sizing) follows the first step shown in Attachment D sizing for calculating runoff volume (Runoff Volume = C * 95^{th} Rainfall Depth * Tributary Area), but stops there, without applying the multiplier. The required retention volume (design volume) is the actual runoff produced from the design storm. The facility is sized as if it behaved like a bathtub, with all runoff entering and no outflow (discharge) from the design storm.

The second (Hydrograph Analysis) follows the same first step in calculating runoff volume, but routes that volume through the structure, accounting for the infiltration that will occur[1]. This provides an even

[1] One example of a computer model that performs the hydrograph analysis is HydroCad, a proprietary program that is commonly used for design of stormwater infrastructure. HydroCad is based on USDA's (Natural Resources Conservation Service) widely-used *TR-55 - Urban Hydrology for Small Watersheds*, developed in the 1980s. HydroCad is commonly specified by municipalities and is available for about $250. The important thing in the use of such analysis are the specified variables.

smaller sized facility, because the facility is assumed to behave like a reservoir, with inflow (runoff) and outflow (infiltration) being analyzed as they change over time.

In situations where the soil would not drain the design volume in 48 hours, the Hydrograph Analysis approach suggests a multiplier of 1.2 for the stormwater control measure storage capacity. This is different from the multiplier of 1.963 currently used in Attachment D, which is applied to the entire retention volume. Even with a volume multiplier of 1.2, the facility would still be smaller than the Simple Sizing method, and much smaller than what's currently used in Attachment D.

In order to be certain of these recommendations, we used actual rainfall data to verify that these sizing methods could accommodate back-to-back storms. We found that 1) the hydrograph method would accommodate multiple rainfall events, where soils infiltrated within 48 hours, 2) the hydrograph method with multiplier would accommodate multiple rainfall events where soils did not infiltrate in 48 hours, and 3) the Simple Sizing method would more than accommodate back-to-back, multiple-day events because the volume is larger than with the hydrograph method.

The JERT-D members would like to emphasize that this work focused only alternatives to the 1.963 multiplier. This analysis does not review the appropriateness nor justify the retention of a particular storm event. Some members of the JERT Attachment D Subcommittee believe that retention of the 95th percentile event could lead to reduced stormwater runoff compared to predevelopment conditions. Therefore, we encourage continued exploration of the best measures to protect and restore watershed processes.

Stormwater Control Measure Sizing:
Evaluation of Attachment D
to the Central Coast
Post Construction Requirements
(Resolution No. R3-2012-0025)

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April 8, 2013

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CERTIFICATION

In accordance with the provisions of Section 6735 of the Business and Professions Code of the State of California, this report was prepared by or under the direction of the following Civil Engineer, licensed in the State of California:

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PURPOSE

The purpose of this report is to document our work in reviewing the Central Coast Post-Construction Requirements (PCRs) Attachment D. Specifically, we have evaluated the stormwater control measure (SCM) sizing criteria in Attachment D of the PCRs, and identified retention SCM sizing methodologies that could be used in lieu of the criteria currently required in Attachment D (Resolution No. R3-2012-0025).

In response to stakeholder concerns, the Central Coast Water Board has acknowledged that the volume multiplier as currently presented in Attachment D requires revision. Also, Board Staff have expressed an intention to approve alternative sizing methodologies for SCMs, so long as the alternative methodologies meet the objectives of the PCRs.

We are currently participants in the Regional Board's reconvened Joint Effort Review Team (JERT), including the JERT Attachment D Subcommittee. This Subcommittee was formed to evaluate alternatives to the Attachment D multiplier, along with other reviewing other components of Attachment D.

Our focus of work to-date has been analyzing methods for calculating SCM storage capacity. For the purpose of this analysis, retention volume was calculated based on the WEF/ASCE formula presented in Attachment D, without the 1.963 multiplier. A review of methods for calculating retention volume may be undertaken by the Subcommittee at a later date.

This analysis does not review the appropriateness nor justify the retention of a particular storm event. Some members of the JERT Attachment D Subcommittee believe that retention of the 95th percentile event will in many cases lead to reduced stormwater runoff compared to predevelopment conditions.

RECOMMENDATIONS – EXECUTIVE SUMMARY

Based on our review of rainfall statistics for the Central Coast, post-construction criteria developed for other areas of California, and SCM sizing analysis using the Central Coast PCRs, we have the following recommendations for modifying the sizing criteria presented in Attachment D:

1. Eliminate the retention volume multiplier for projects using the simple sizing method (where storage capacity = retention volume)
2. Explicitly recognize hydrograph routing as an acceptable means for sizing retention based SCMs
3. Require a volume multiplier for facilities sized by a routing method that cannot drain within 48-hours. The recommended multiplier is 1.20.

Eliminate the volume multiplier for projects using the simple sizing method

For the purpose of this document, simple sizing refers to a design where SCM storage capacity is equal to the required retention volume. We have evaluated the PCRs based on simple sizing methodology, and results show that when the multiplier is included this method requires significant surface area or storage depth that would not be feasible on the majority of development sites. For comparison, we have also developed SCM capacity calculations using a hydrograph based routing analysis and found that a simple sizing approach with no multiplier results in SCMs that would capture back-to-back storms and still have room to spare. In other words, this simplified approach results in an oversized facility.

Also, when compared to post-construction criteria in other regions of California, a simple sizing approach based on the PCRs results in overly conservative volumes. For example, the Contra Costa C.3 guidebook includes minimum unit volumes for facilities that must provide water quality treatment AND 10-year peak flow control. With simple sizing and the 1.963 multiplier, the PCRs result in unit volumes 2 to 3 times that required to control a 10-year storm in Contra Costa.

The simple sizing approach may be reasonable for some projects, dependent on project size, complexity, rainfall, soil conditions, and other site specific factors. We recommend that the simple sizing approach is allowed as one sizing alternative, with no multiplier required for retention volume regardless of drawdown time.

Explicitly recognize hydrograph routing as an acceptable means for sizing retention and detention based SCMs

A hydrograph analysis has an advantage over a simple sizing analysis as it takes into account both rate of flow into a facility, and infiltration from a facility during the storm event. There can be two components to a hydrograph analysis: rainfall-runoff and storage routing. The rainfall-runoff portion of the analysis determines the site runoff over time, based on rainfall patterns and the site characteristics, including the infiltration capacity of the pervious surfaces. From this is derived the total runoff volume. For the purposes of the analyses presented in this report, the infiltration factors (CN values) are adjusted so that the runoff volume matches that calculated for the site based on the Attachment D method (WEF/ASCE formula). This produces a time based distribution of the Attachment D runoff volume. The hydrograph storage routing analysis considers the time-based runoff flowing into an SCM, along with the SCM infiltration capability, to determine the net storage over time. From this is derived the total storage capacity needed in the SCM.

We prepared SCM sizing calculations for three 95th percentile rainfall depths, evaluating required SCM capacity based on varying SCM infiltration rates. This analysis demonstrates that SCM capacities calculated by a routing method are more consistent with other criteria in California than results of simple sizing. For example, unit volumes developed by a hydrograph routing of the PCR criteria are generally equivalent to Contra Costa C.3 unit volumes required for water quality and peak flow control up to the 10-year storm event.

Hydrograph analysis for SCM sizing is referenced in the City of Santa Barbara LID BMP Manual. The City of Santa Barbara's program was recently approved by the Central Coast Water Board as an acceptable alternative to the PCRs. In addition, the City's LID Manual is referenced in Attachment D as a resource for design guidance. Also, the EPA guidance manual for federal hydromodification criteria (retention of the 95th percentile event) includes 9 case studies where SCMs were sized using a hydrograph analysis. Therefore, we conclude that hydrograph analysis is acceptable to the Central Coast Water Board for sizing calculations. However, we request that this method is explicitly stated to be acceptable in the PCRs, so there is no question of acceptability when hydrograph calculations are submitted to governing agencies.

Table 1 provides a summary of our recommendations for the variables that are included in a routing method sizing analysis. These recommendations and the relative effect these variables are expected to have on calculation results are discussed in more detail in subsequent sections of this Report.

Table 1. Summary of Recommended Routing Method Variables

Variable	Recommendation
SCM Infiltration	Onsite testing per standardized procedure being developed by Earth Systems Pacific
Rainfall Distribution	NRCS Type I or based on local rainfall data
Time of Concentration	Agency's current drainage and flood control standard
Hydrograph Method	Either NRCS or SBUH
Time Increment	0.10 hour, unless otherwise justified to be more correct based on rainfall distribution
Storage (SCM) Routing Method	Storage-indication, unless otherwise justified to be more correct based on site and storage conditions.

Require a volume multiplier for facilities sized by a routing method that cannot drain within 48-hours. The recommended multiplier is 1.20.

The PCRs currently include a retention volume multiplier, described by Water Board Staff as a means to account for additional storage that may be required to capture runoff from back to back storms, for those facilities that do not drain within 24 hours. We evaluated the need for a multiplier by compiling and analyzing the following:

- Rainfall records for the Central Coast
- NOAA Atlas 14 rainfall frequency estimates
- Multipliers derived from the ASCE/WEF Manual of Practice referenced in the PCRs
- Continuous simulation data available through the program Basin Sizer
- Preparing SCM sizing calculations using hydrograph routing to identify storage capacity required to meet the PCR volume criteria, with varying facility drawdown times and back-to-back storms.

Based on our sizing calculations, facilities that are sized to manage the 95th percentile event can accommodate back-to-back storms with no increase in storage capacity, so long as the facility drains within 48 hours. Facilities that could not drain within 48-hours did require an increase in capacity to capture back-to-back storms. Therefore, we recommend a multiplier is applied only to those facilities that cannot drain within 48-hours. Regarding the value of the multiplier, we identified the following values based on our analysis and review of guidance documents:

Table 2. Summary of Volume Multipliers

Method	Volume Multiplier
ASCE/WEF Manual of Practice	1.19
Analysis of continuous rainfall records	1.10
Basin Sizer	1.30
SCM Sizing Calculations	1.02 – 1.12*

*Multiplier value for 2-day (back-to-back) storm event. Multiplier may increase for 3-day or longer storm event (continuous simulation) compared to our results.

Based on the multiplier values listed above, we recommend a multiplier of 1.20 is applied to facilities that cannot drain within 48-hours, in absence of project specific continuous simulation. This multiplier would be applied to the storage capacity calculated to manage a single 95th percentile event.

EXAMPLE CALCULATIONS

This section provides example calculations comparing results of a simple sizing and hydrograph routing approach, to design a bioretention area for a one-acre commercial development.

Project Details

- 1-acre Commercial Site
- 85% impervious
- Required to infiltrate the 95th percentile storm (2-inches)

Step 1: Calculate Required Retention Volume, Using Attachment D

- Fraction impervious, i = 0.85
- C = 0.66
- A = 43,560 sf
- Rainfall depth = 2 inches (.167 ft)
- Retention Volume = 4,801 cubic feet

Step 2: Calculate Required Storage Capacity, Either Simple Sizing or Routing Method

<u>Simple Sizing: Size Bioretention Capacity Equal to the Retention Volume</u>

- Assume surface area = 10% of impervious
- Bioretention surface area = 3,703 sf
- Required water depth = retention volume ÷ surface area = 1.29 feet
- Surface ponding depth = 0.5 feet, therefore subsurface depth required = 1.29 – 0.5 = 0.79 feet (9.5 inches) of water holding capacity
- Soil depth = 24 inches, with 25% porosity. Soil holds 6 inches.
- Gravel required to store remaining water. Water depth in gravel = 9.5 – 6 = 3.5 inches.
- Gravel porosity of 35%. Total required gravel depth = 3.5 inches ÷ 0.35 = 10 inches.

Results Summary:

- Ponding depth = 6 inches
- Soil depth = 24 inches
- Gravel depth = 10 inches

<u>Routing Method Sizing: Determine Required Storage Capacity to Retain and Infiltrate the Retention Volume</u>

- Set the subcatchment area to the project area (1 acre)
- Assign runoff method (NRCS or SBUH)
- Set the curve number (CN) value such that the volume of runoff from the subcatchment is equal to that calculated in Step 1 (CN = 93 for this example)
- Assign time of concentration (10 minutes used for this example)
- Route subcatchment to a retention pond
- For this example the ponding, soil, and gravel depth was matched to the dimensions found through simple sizing.
- The pond outlet is through soil infiltration. Set infiltration rate based on tested soil conditions (or, in this example case, based on average for HSG soil type). Set infiltration to occur from surface area only (lateral infiltration assumed to be negligible).
- Determine storage capacity needed to manage runoff volume (no overflow).

Results of the routing method example calculations are summarized in Table 3.

Table 3. Routing Method Results for Example Project

Soil Type	SCM Infiltration Rate (in/hr)	Required Storage Capacity (cubic feet)	Required Surface Area (square feet)	SCM Size as Percent of Retention Volume	Drawdown Time
A	5.0	800	1,600	17%	24 hours
B	1.0	2,394	1,850	50%	32 hours
B/C	0.6	2,912	2,250	61%	48 hours
C	0.23	3,818	2,950	80%	94 hours
D	0.06	4,529	3,500	95%	12 days

Results – Comparison of Simple Sizing to Routing Method

The comparison of simple sizing to the routing method shows that the needed storage capacity for a retention based SCM is significantly less than the retention volume, for an SCM with soils that infiltrate well. As SCM infiltration rate decreases, the needed storage capacity increases. The Type D soil modeled illustrates that because the infiltration rate is very low, the needed storage capacity is nearly the full retention volume. The resulting drawdown time for this type of soil also illustrates the need for a subsurface drain to avoid creating a perched water condition, where water is stored subsurface for long periods of time before infiltrating.

TECHNICAL DETAILS: DATA REVIEW AND SIZING ANALYSIS

The following is a more in depth summary of the data we have reviewed and the calculations developed for this analysis.

EPA Stormwater Guidance

The EPA developed technical guidance for implementing the stormwater runoff requirements for federal projects (Section 438 EISA). The guidance manual includes nine case studies for applying the requirements to project sites. A method called "direct determination" was used in the guidance manual, to evaluate the case studies for runoff volume and SCM sizing. The direct determination method assumes a constant rainfall and SCM infiltration rate for a 24-hour storm duration. SCM storage capacities were calculated based on the physical storage in the SCM, in addition to the SCM infiltration that would occur over a 24-hour period. This is basically a simplified version of a hydrograph analysis, where the rainfall distribution would be constant over time with a relatively low intensity. This method has the potential to under-size a facility, as more storage is typically needed for a shorter more intense storm event. Also, the SCM infiltration volume could be overestimated, because if inflow to the facility is occurring at a rate lower than the soil's infiltrative capacity (which is likely prior to the peak of the storm), it is physically impossible to infiltrate the maximum possible volume over the storm duration. Regardless, the important take-away from the guidance is that the EPA recognized the necessity of including the infiltrative capacity of soil for both the determination of runoff volume and SCM outflow, and a simplified hydrograph analysis was used for SCM sizing.

ASCE/WEF Manual of Practice Volume Multiplier

We reviewed the ASCE/WEF Manual of Practice "Design of Urban Stormwater Controls" to evaluate the drawdown multiplier, as this manual is referenced in the PCRs for the use of the

1.963 multiplier. The intended use of the 1.963 multiplier is to calculate water quality volume based on mean annual precipitation, not to provide buffer storage as is done in the PCRs. However, the ASCE/WEF Manual can be used to ascertain volume multipliers, by comparing the water quality volume calculated for a 24-hour drawdown period to that calculated for a 48-hour drawdown period. Based on the Manual, a **volume multiplier of 1.19** is calculated for event based sizing, for a 48-hour drawdown period.

Rain Gauge Statistics

As the purpose of the Attachment D retention volume multiplier is to provide capacity for back-to-back storms, we prepared an analysis of the frequency of multiple day storms on the Central Coast, and the potential affect on retention feasibility. We reviewed in detail daily rainfall records for a CIMIS rain gauge in San Luis Obispo and a NOAA NCDC rain gauge in Paso Robles. For both gauges, we found that an SCM sized for the 95th percentile storm (with no volume multiplier) would capture at least 98% of one day storms, 80% of two day storms, and nearly 50% of all 3-day storms. This is based on total storm depth compared to the 95th percentile, and actual capture would likely be much higher due to infiltration occurring over the course of the multi-day storms (and therefore the ability to capture depths greater than the 95th).

Table 3. Summary of Storm Totals Compared to the 95th Percentile Event

Storm Duration (Days)	Paso Robles Rain Gauge		San Luis Obispo Rain Gauge	
	Percent of Rain Days	Percent of Storm Totals Less Than the 95th Percentile	Percent of Rain Days	Percent of Storm Totals Less Than the 95th Percentile
1	36%	98%	35%	98%
2	30%	81%	28%	84%
3	15%	43%	18%	45%
4	8%	19%	9%	6%
5+	11%	0%	10%	0%

Rain Gauge Statistics: Analysis for Volume Multiplier

We also used the rain gauge data we compiled for San Luis Obispo and Paso Robles to evaluate the need for increased SCM volume to capture back-to-back storms. We used continuous rainfall records, 26-years for San Luis Obispo and 59-years for Paso Robles, and compared daily rainfall depths to the 95th percentile storm depth. We determined the difference in SCM storage required for capture of the 95th percentile storm depth, comparing a 24-hour drawdown time to 48-hour drawdown time. This approximate analysis demonstrates that a **volume multiplier of 1.10**, for facilities with a 48-hour drawdown, would result in an equivalent volume capture compared to facilities with a 24-hour (or shorter) drawdown time.

This analysis was simple in approach, and was meant to provide a “reality check” in lieu of full continuous simulation modeling. The analysis was performed in a spreadsheet using the continuous rainfall records for each rain gauge. For the analysis we assumed a retention-based SCM was sized to retain the 95th percentile event, with either a 24-hour or 48-hour drawdown period. We further assumed that with a 48-hour drawdown, half of the SCM capacity would be infiltrated prior to the subsequent day of rain (or the storm total would infiltrate, whichever is less). For example, if the 95th percentile event is 2.0 inches, and the first day of rain was 1.6 inches, we assumed that 1.0 inch (half of the 95th percentile) would infiltrate prior to the 2nd day of rain. Or, if the first day of rain was 0.7 inches, we assumed the full 0.7 inches would infiltrate prior to the 2nd day of rain. Lastly, to be conservative, we assumed that any daily rainfall total that exceeded the 95th percentile event resulted in runoff. That is, if the rainfall total was 2.25 inches with a facility sized for a 2.0 inch event, then 0.25 inches was not retained.

Volume Multiplier Derived through Basin Sizer Program

We previously prepared an analysis of water quality volumes and volume multipliers using the program Basin Sizer. This analysis resulted in a recommended **volume multiplier of 1.30**.

NOAA Atlas 14 Rainfall Frequency Estimates

Rainfall statistics available through NOAA Atlas 14 were referenced to help answer the question "**what is an appropriate back-to-back storm to consider for SCM design?**" For the rain gauges we've analyzed, the 95th percentile 24-hour event is generally equivalent to the 1-year 24-hour event per the NOAA frequency estimates. Therefore, to maintain consistency with the 95th percentile requirement, the appropriate storm to analyze for back-to-back events is the 1-year 2-day storm. For the locations reviewed the 1-year 2-day storm was found to be an approximate 25% increase from the 1-day event. By comparison, a back-to-back 95th percentile event is between a 2 to 5-year storm.

SCM Sizing Calculations: Hydrograph Routing Analysis

We prepared an SCM sizing analysis using the PCRs retention volume criteria and the computer program HydroCAD. HydroCAD is a commonly used and widely accepted program for calculating runoff and sizing stormwater management features. We used the Santa Barbara Unit Hydrograph (SBUH) method, in conjunction with various storm distributions, to calculate required SCM storage capacity to fully retain the Attachment D volume, with varying storm events including the 95th percentile and back-to-back storms, and with varying SCM infiltration rates. We used average infiltration rates corresponding to hydrologic soil group (HSG), as presented in the Ventura County Stormwater Manual. We also derived the SCM infiltration rate that would result in a drawdown time of 48-hours, and included this infiltration rate as one sizing example.

Based on this analysis, an SCM sized for the 95th percentile event could also retain the back-to-back storm identified through the NOAA rainfall statistics, with no volume multiplier, for draw-down times up to 48 hours. Drawdown times longer than 48 hours were associated with HSG C and D soils, where SCM infiltration rate limits the capacity for site retention even with undeveloped conditions. For example, drawdown time for the 95th percentile event is 92 hours and 12 Days, for soil types HSG C and D, respectively. This analysis resulted in the volume multipliers listed in Table 4.

Table 4. Volume Multiplier for Drawdown Time Greater than 48 Hours

95th Percentile Rainfall Depth	Volume Multiplier	Location
1.4 inches	1.12	Paso Robles
2.0 inches	1.11	San Luis Obispo
2.5 inches	1.02 – 1.12	Goleta

It is important to note that the multipliers developed through this analysis are representative of a two-day storm event. The required multiplier for SCMs with low infiltration may increase compared to the results in Table 4 with a longer duration storm event (3-days or more), analyzed through continuous simulation modeling.

Summary of Variables Used in This Analysis

The following variables were used to calculate the tabulated SCM capacities for varying rainfall depths and soil conditions.

- SCM Infiltration: based on average value for HSG soil types A through D, as presented in the Ventura County Stormwater Manual
- Rainfall distribution: varies, listed in tabulated results
- Time of concentration: 10 minutes
- Hydrograph method: SBUH
- Time increment: 0.10 hours
- Storage (SCM) routing: storage-indication

Unit Storage Volume Comparison (Simple Sizing and Routing Method)

Another way to evaluate feasibility of the PCRs is to look at retention requirements in terms of unit storage volume, that is, cubic feet of storage required per square foot of impervious surface. Multiple agencies in California have developed design criteria for peak flow control based on local continuous simulation modeling, which includes a minimum unit storage volume. For example, the Contra Costa C.3 Guidebook provides minimum unit volume for peak flow control of the 2-year through 10-year storm. Contra Costa unit volumes range from 0.058 to 0.116. In comparison, by the simple sizing approach the PCRs require a unit retention volume ranging from 0.146 to 0.364, for storms between 1-inch and 2.5-inches. This retention volume is 2 to 3 times greater than what Contra Costa requires to control the 10-year storm event. These values are based on the current Attachment D multiplier of 1.963. Dropping the multiplier results in unit retention volumes ranging from 0.074 to 0.185, still over 50% greater than the Contra Costa 10-year peak flow control standard. By comparison, a hydrograph routing approach to SCM sizing with the PCR retention volume results in unit volumes ranging between 0.03 to 0.162, generally equivalent to the Contra Costa criteria.

SCM SIZING: VARIABLES FOR ROUTING METHOD CALCULATION

The purpose of this section is to address the variables that are involved in our routing method calculations for SCM sizing. In particular, Regional Board Staff requested information on rainfall distribution and intensity, and how this may affect SCM sizing in areas with high 85^{th} and 95^{th} percentile rainfall depths.

The following variables are included in an event based routing calculation for SCM sizing, listed in order of relative effect on calculated storage capacity:

- SCM Infiltration capacity.
- Rainfall distribution.
- Time of concentration.
  - o Sensitivity: Doubled time of concentration to 20 min, volume reduces by 5%.
- Hydrograph Method - SBUH or SCS. SCS produces slightly higher intensity, therefore slightly higher retention capacity.
  - o Sensitivity: Expected to be at most 5% difference between methods.
- Time increment. Typically set to 0.10 hour with SBUH method.
  - o Sensitivity: Doubled time increment, volume reduction approximately 1%.
  - o Difference may be greater if storm distributions other than NRCS are used.
- Pond Routing Method. Storage-indication typical for detention routing.

SCM Infiltration Capacity

Geotechnical Engineers at Earth Systems Pacific are currently working under contract with the Central Coast Low Impact Development Initiative to develop standard testing procedures and recommendations for identifying soil infiltration capacity. Therefore, testing for infiltration capacity will not be discussed further as part of this document.

For the purpose of this analysis infiltration capacity was modeled based on average values for HSG soil types A through D, as presented in the Ventura County Stormwater Manual.

Rainfall Distribution

The rainfall distribution tells us the amount of water that falls within a given period of time. Rainfall distribution has the greatest effect in sizing facilities for soils with high infiltration. In a high infiltrating soil, a low intensity storm may be fully infiltrated as it flows into the facility, in other words, no storage is required. As rainfall intensity increases relative to the infiltration capacity, the required storage also increases. The effect of varying rainfall intensity is negligible for calculating storage capacity for low infiltrating soils. This is because the infiltration capacity is typically much less than the inflow to the facility, regardless of storm intensity. For comparison, an average HSG Type A soil can infiltrate over 80 times faster than the average Type D soil.

We prepared a sensitivity analysis to evaluate the affect of rainfall intensity on required retention capacity. For the analysis we used the program HydroCAD to calculate required storage capacity with varying rainfall distributions, holding rainfall depth and all other variables constant. The following describes inputs and results for the sensitivity analysis.

<u>NRCS Storm Distributions</u>

NRCS has developed standard 24-hour rainfall distributions for hydrologic analysis, commonly used for design of detention and retention facilities. These rainfall distributions were intended to represent intensities associated with shorter duration storms, ranging from a 30 min to 12 hour duration. (*Ponce*).

The NRCS Type I storm applies to the west coast of California, including the Central Coast Region. The Type 1 rainfall distribution was derived using NOAA Atlas 2 rainfall statistics for the 1-year through 100-year storm. (*NRCS*)

> Benefits: Widely available, commonly used, conservative approach. For sites with flow control same method could be used for both retention and peak flow.
> Drawbacks: May be overly conservative in some cases

For comparison, the NRCS Type 1A distribution applies to the west coast of Northern California, Oregon and Washington. This rainfall distribution was also developed by NRCS using NOAA Atlas 2 statistics, but the peak intensity for this distribution is significantly lower than Type 1 due to the variation in rainfall patterns between the two regions. We used the Type 1A as an input to the sensitivity analysis to demonstrate the resulting difference in SCM sizing due to variation in storm intensity. The Type 1A storm distribution is not applicable to the Central Coast Region and is not recommended for design of stormwater facilities in our area.

<u>NOAA Atlas 14</u>

Rainfall intensity statistics available through NOAA Atlas 14 were reviewed for comparison to storm intensity associated with the NRCS storm distributions. The NOAA Atlas 14 statistics were compiled for locations throughout the Central Coast Region, and, the statistics were translated into 1-year storm distributions within HydroCAD for the three locations where we analyzed SCM sizing.

The peak intensity from the NRCS Type 1 storm distribution corresponds to a 5-minute to 10-minute intensity for the 1-year storm per NOAA Atlas 14. In comparison, the peak intensity for the Type 1A storm distribution corresponds to the 60-minute intensity for a 1-year storm. The NRCS Type 1 overestimates the peak intensity compared to NOAA Atlas 14 in three locations: Felton, Goleta, and Santa Barbara. All three of these locations also have relatively high rainfall depths for the 1-year storm.

Values for the 95th percentile storm depth are not yet readily available throughout the Region. However, we have found in the locations where we have calculated the 95th percentile storm depth it is generally equivalent to the 1-year 24-hour storm. Therefore, we used 1-year storm values to compare intensities for locations throughout the Central Coast Region. A summary table of the peak rainfall intensity statistics is attached at the end of this document.

<u>Results</u>

Rainfall intensity has the greatest effect on storage capacity for sites with high infiltrating soils. In a well draining soil, a low intensity storm may be fully infiltrated as it flows into the facility. As rainfall intensity increases relative to the infiltration capacity, the required storage also increases. The effect of varying rainfall intensity is negligible for calculating storage capacity for low infiltrating soils. This is because the infiltration capacity is typically much less than the inflow to the facility, regardless of storm intensity.

Results of the comparison illustrate that the effect of rainfall intensity is negligible for most soils. Type A soils have the greatest increase in required capacity with an increase in storm intensity. Soil types B and B/C had a minimal increase, and types C and D did not require any increase in capacity. Table 5 below summarizes results of the analysis for the 95th percentile storm event, comparing the NOAA Atlas 14 rainfall distribution for Goleta to the NRCS Type I distribution. In this location, NRCS Type I has the higher intensity.

Table 5: Capacity Increase Required for 30% Increase in Rainfall Intensity

HSG Soil Type	Infiltration Rate (in/hr)	Required Increase of Storage Capacity
A	5	28%
B	1	6%
B/C	0.6	4%
C	0.23	0%
D	0.06	0%

NOTE: This table represents a comparison of the NRCS Type I storm to the NOAA Atlas 14 1-year storm for Goleta

Results were similar comparing the NOAA rainfall distribution to the NRCS Type 1A, which has a lower peak intensity. The greatest affect occurred with Type A soils, with Types C and D showing no change in storage capacity required.

Also, even with the highest storm intensity modeled, required surface area for Type A soils was 4% of EISA, assuming 12-inches of surface ponding. This is the minimum surface area required for water quality treatment, based on the maximum loading rate required by the PCRs (5.0 inches/hour maximum loading for a 0.2 inch/hour rainfall intensity).

Recommendation
Allow applicants to use the NRCS Type I rainfall distribution, or, rainfall distribution based on local rainfall data for the 1-year or 95th percentile storm.

Time of Concentration

Agencies have typically already adopted time of concentration calculations to be used for drainage and flood control. The same calculations would apply for retention SCM sizing. A greater time of concentration equates to a lower peak runoff, and therefore a smaller SCM capacity for high infiltrating soils. As stated earlier, the effect of varying intensity on lower infiltrating soils is negligible. The overall effect of time of concentration is fairly low. We compared a Tc of 10 minutes to the same catchment with a Tc of 20 minutes and calculated a 5% reduction in SCM volume for Type A soils.

Recommendation
Allow agencies to continue use of time of concentration calculations as included in their current drainage and flood control standards.

Hydrograph Method

The two hydrograph methods evaluated as part of this analysis are the NRCS unit hydrograph and the Santa Barbara Urban Hydrograph (SBUH) method. The two methods are similar in approach. The main differences are:

1. The NRCS method utilizes a standard unit hydrograph to generate the runoff hydrograph. The SBUH method routes the rainfall through a reservoir with retention time equal to the time of concentration.
2. The SBUH method calculates runoff from pervious and impervious areas separately, where the NRCS method calculates runoff with a composite CN value. The separate pervious/impervious calculation in the SBUH method accounts for the non-linear relationship between CN and runoff.

The result of these two main differences is that the two methods produce different peak runoff values, even using the same rainfall distribution as an input. However, as discussed in more detail under the rainfall distribution section, the effect of peak runoff intensity is noteworthy only for the highest infiltrating soils. The difference in SCM sizing as a result of peak intensity differences between the two methods is anticipated to be in the range of 5 percent for Type A soils, and negligible for other soils.

Recommendation
Allow for either the NRCS or SBUH method to be used for hydrograph sizing analysis.

Calculation Time Increment

Hydrograph routing is an iterative procedure, that is, results for rainfall runoff, inflow, storage volume, and outflow are calculated for each time step to achieve mass balance. The time duration between calculations is referred to as the time increment. In general, a smaller time increment will provide a more precise result. The time increment can be set to a very small value when an automated program is used for the analysis, with little affect on computation time. If the calculation is done by hand than the time increment results in a lengthier computation.

Time increment for the SBUH method is typically set to 0.10 hour. The NRCS method does not have a standard time increment associated. However, rainfall distributions may also have a preferred time increment, based on the number of points in the curve. When evaluating a hydrograph, the time interval between points isn't specified directly, but is inferred from the storm duration and the number of points using the following equation: Interval = Duration / (#points-1). A hydrograph with a 0.10 increment will have 241 points (*HydroCAD Software Solutions*). Using the NRCS storm distributions, we found that time increment created negligible changes to the results of our analysis. However, using the NOAA rainfall distributions the peak intensity varied substantially with variation in time increment. The NOAA rainfall distributions contain 241 points, therefore a time increment of 0.10 hour is appropriate.

<u>Recommendation</u>
Require a time increment of 0.10 hour, unless otherwise justified to be more correct based on the input parameters for rainfall.

Storage Routing Method

The routing method is the procedure for calculating storage and outflow for each time step. There are multiple standardized procedures for storage routing. The most common method for detention and retention facilities is the storage-indication method. This method is discussed in detail in the NRCS TR-55 and numerous other references, and will therefore not be described in more detail in this document.

<u>Recommendation</u>
Require the storage-indication method, unless another method is justified to be more correct based on site and storage conditions.

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8. Ventura County Watershed Protection District. Ventura County Hydrology Manual. 2006.

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ATTACHMENTS

Paso Robles, CA: NOAA Rain Gauge NCDC 6730
October 1951 - December 2010

Storm Duration Statistics

Storm Duration (Days)	Number of Occurances	Total Rain Days	Percent of Storms	Percent of Rain Days
1	564	564	60%	36%
2	238	476	25%	30%
3	79	237	8%	15%
4	31	124	3%	8%
5	17	85	2%	5%
6	11	66	1%	4%
7	2	14	0.2%	1%
8	2	16	0.2%	1%
9	0	0	0%	0%
Totals	944	1582		

Multi-Day Storm Totals

NOTE: 95th percentile 24-hour storm is 1.4 inches

Storm Duration (days)	Min Depth (in)	Ave Depth (in)	Max Depth (in)	Median (in)	Number of Storm Totals that Exceed the 95th	Percent of Storm Totals that Exceed the 95th
1	0.11	0.43	3.88	0.32	13	2%
2	0.22	1.00	7.10	0.86	45	19%
3	0.50	1.78	8.76	1.56	45	57%
4	0.71	2.52	7.31	2.13	25	81%
5	2.02	3.49	5.69	2.97	17	100%
6	1.54	4.22	6.44	4.16	11	100%
7	3.16	---	5.46	---	2	100%
8	6.50	---	7.84	---	2	100%

Approximate Volume Capture, by Drawdown Time and Design Volume Multiplier

Total Rainfall on Record: 830 inches

Design Storm: 95th percentile, 24-hour storm

Drawdown	No Multiplier		Multiplier = 1.963		Multiplier = 1.1	
	Runoff (inches)	Percent Capture	Runoff (inches)	Percent Capture	Runoff (inches)	Percent Capture
24 hours	52	94%	8	99%	42	95%
48 hours	72	91%	11	99%	57	93%

Definitions for purpose of this exhibit:

Rain Day: Greater than or equal to 0.10 inch of rainfall

Storm: 1 or more consecutive rain days

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January 2013

San Luis Obispo, CA: CIMIS Station 52
April 1986 - August 2012

Storm Duration Statistics

Storm Duration (Days)	Number of Occurances	Total Rain Days	Percent of Storms	Percent of Rain Days
1	263	263	60%	35%
2	103	206	24%	28%
3	44	132	10%	18%
4	16	64	4%	9%
5	4	20	1%	3%
6	3	18	1%	2%
7	1	7	0.2%	1%
8	3	24	0.7%	3%
9	1	9	0%	1%
10	0	0	0%	0%
Totals	438	743		

Multi-Day Storm Totals

NOTE: 95th percentile 24-hour storm is 1.97 inches

Storm Duration (days)	Min Depth (in)	Ave Depth (in)	Max Depth (in)	Median (in)	Number of Storm Totals that Exceed the 95th	Percent of Storm Totals that Exceed the 95th
1	0.10	0.50	2.98	0.35	5	2%
2	0.25	1.19	4.60	0.95	16	16%
3	0.56	2.41	10.65	2.17	24	55%
4	1.45	3.89	6.66	3.83	15	94%
5	2.37	3.68	5.40	3.48	4	100%
6	1.74	5.32	8.66	5.55	2	67%
7	6.28	---	6.28	---	1	100%
8	4.47	6.16	8.94	5.08	3	100%
9	5.28	---	5.28	---	1	100%

Approximate Volume Capture, by Drawdown Time and Design Volume Multiplier

Total Rainfall on Record: 483 inches

Design Event: 95th percentile, 24-hour storm

Drawdown	No Multiplier		Multiplier = 1.963		Multiplier = 1.1	
	Runoff (inches)	Percent Capture	Runoff (inches)	Percent Capture	Runoff (inches)	Percent Capture
24 hours	26	95%	3	99%	19	96%
48 hours	35	93%	4	99%	27	94%

Definitions for purpose of this exhibit:

Rain Day: Greater than or equal to 0.10 inch of rainfall

Storm: 1 or more consecutive rain days

Prepared by Wallace Group
January 2013

Table 5.4 **Values of coefficient a in Equation 5.2 for finding the maximized detention storage volume (Guo and Urbonas, 1995).[a]**

		Drain time of capture volume		
		12 hours	24 hours	48 hours
Event capture ratio	a =	1.109	1.299	1.545
	r^2 =	0.97	0.91	0.85
Volume capture ratio	a =	1.312	1.582	1.963
	r^2 =	0.80	0.93	0.85

[a] Approximately 85th percentile runoff event (range 82 to 88%).

Volume = a × C × P_6

48 hr drawdown multiplier = 48 hr volume / 24 hr volume

Event = 1.545 / 1.299 = 1.19

Volume = 1.963 / 1.582 = 1.24

a = regression constant from least-squares analysis;
C = watershed runoff coefficient; and
P_6 = mean storm precipitation volume, watershed in. (mm).

Table 5.4 lists the maximized detention volume/mean precipitation ratios based on either the ratio of the total number of storm runoff events captured or the fraction of the total stormwater runoff volume from a catchment. These can be used to estimate the annual average maximized detention volume at any given site. All that is needed is the watershed's runoff coefficient and its mean annual precipitation.

The actual size of the runoff event to target for water quality enhancement should be based on the evaluation of local hydrology and water quality needs. However, examination of Table 5.3 indicates that the use of larger detention volumes does not significantly improve the average annual removal of total suspended sediments or other settleable constituents. It is likely that an extended detention volume equal to a volume between the runoff from a mean precipitation event taken from Figure 5.3 and the maximized event obtained using Equation 5.2 will provide the optimum-sized and most cost-effective BMP facility. A BMP sized to capture such a volume will also capture the leading edge (that is, first flush) of the runoff hydrograph resulting from larger storms.

Runoff volumes that exceed the design detention volume either bypass the facility or receive less efficient treatment than do the smaller volume storms and have only a minimal net effect on the detention basin's performance. If, however, the design volume is larger and has an outlet to drain it in the same amount of time as the smaller basin, the smallest runoff events will be detained only for a brief interval by the larger outlet. Analysis of long-term precipitation records in the U.S. shows that small events always seem to have the greatest preponderance. As a result, oversizing the detention can cause the most frequent runoff events to receive less treatment than provided by properly designed smaller basins.

WEF MOP 23, 1st Ed (1998)

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MEMORANDUM

REVIEW OF VOLUME MULTIPLIER FOR THE CENTRAL COAST POST-CONSTRUCTION STORMWATER REQUIREMENTS

Date: 11 December 2012

To: Craig Campbell, PE

From: Valerie Huff, PE

Subject: Volume Multiplier Research

PURPOSE AND EXECUTIVE SUMMARY

The purpose of this memo is to address Central Coast RWQCB stakeholder concerns regarding the 48-hour drawdown multiplier of 1.963, as presented in the Post-Construction Requirements Attachment D. Additional resources have been reviewed to identify an appropriate volume multiplier for those stormwater facilities that do not drain with 24-hours. Based on review and research of available rain gauge information, a 48-hour drawdown volume multiplier of 1.30 is proposed. This multiplier was identified through the software program Basin Sizer, using the CASQA BMP method which incorporates results of continuous simulation modeling developed by the Army Corps of Engineers. Using Basin Sizer, a total of 14 rain gauge stations in the developed areas of the Central Coast Region were evaluated for 48-hour drawdown multipliers. The resulting multipliers range from 1.24 to 1.35, with an average of 1.30 and a standard deviation of 0.04. The multiplier of 1.30 is reasonable based on a comparison of Basin Sizer program results to design criteria developed for Bay Area municipalities through continuous simulation modeling.

BACKGROUND

The Central Coast Regional Water Quality Control Board adopted Post-Construction Stormwater Management Requirements for Development Projects in the Central Coast Region on September 6, 2012 (Resolution R3-2012-0025). Subsequent to adoption, stakeholders have expressed concerns regarding design guidelines for stormwater control measures as presented in Attachment D of the Post-Construction Requirements (PCRs).

Specifically, stakeholders have expressed concern regarding the use of a multiplier to calculate design volume. A multiplier of 1.963 is specified in Attachment D, to calculate both Retention Volume and Water Quality Volume. This multiplier is specified to account for additional volume that may be required in order to capture runoff from back to back storms, for those facilities that do not drain within 24 hours. This multiplier is meant to provide a simple approach to design, in lieu of continuous

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simulation modeling. However, the intended use of the 1.963 multiplier, as taken from a WEF/ASCE design manual, is to calculate water quality runoff volume based on average rainfall value, not to provide buffer storage as is done in the PCRs. Therefore, additional resources have been reviewed, in order to identify an appropriate volume multiplier and address stakeholder concerns.

PROPOSED SOLUTION

A multiplier of 1.30 is proposed for the Central Coast (RWQCB Region 3), to be used for design of stormwater facilities in lieu of continuous simulation modeling. This multiplier was derived based on a review of 14 rain gauge stations throughout the developed areas of the Central Coast. The software program Basin Sizer was used to evaluate water quality volumes corresponding to varying design drawdown times. Basin Sizer is a public domain software program developed for Caltrans by the Office of Water Programs at California State University Sacramento. Additional information on the program Basin Sizer is included as Attachment A.

Within Basin Sizer, the CASQA method for calculating water quality volume was used for both 80% and 90% runoff volume capture and a 24-hour and 48-hour drawdown time. The design volume for 24-hour drawdown was compared to the 48-hour drawdown volume to calculate the corresponding multiplier for each percent capture. Results of the analysis are summarized in Table 1.

Table 1: Unit Volume Based on Percent Capture and Drawdown Time

Rain Gauge Station	**80% Capture**			**90% Capture**		
	24 hrs	**48 hrs**	**Multiplier 24 hrs to 48 hrs**	**24 hrs**	**48 hrs**	**Multiplier 24 hrs to 48 hrs**
San Miguel	0.46	0.62	1.35	0.67	0.9	1.34
Santa Margarita	1.09	1.47	1.35	1.53	2.07	1.35
San Luis Obispo	0.79	1.04	1.32	1.13	1.45	1.28
King City	0.5	0.64	1.28	0.7	0.9	1.29
Santa Maria Airport	0.54	0.68	1.26	0.76	0.96	1.26
San Benito	0.47	0.61	1.30	0.66	0.84	1.27
Lompoc	0.5	0.63	1.26	0.76	0.94	1.24
Santa Ynez	0.73	0.95	1.30	1.09	1.39	1.28
San Juan Bautista	0.56	0.75	1.34	0.78	1.05	1.35
Santa Barbara	0.99	1.28	1.29	1.4	1.85	1.32

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Rain Gauge Station	80% Capture			90% Capture		
	24 hrs	48 hrs	Multiplier 24 hrs to 48 hrs	24 hrs	48 hrs	Multiplier 24 hrs to 48 hrs
Gilroy	0.58	0.78	1.34	0.8	1.08	1.35
Carpinteria	0.94	1.27	1.35	1.39	1.84	1.32
Del Monte	0.41	0.53	1.29	0.58	0.73	1.26
Sunset Beach (Mont Co)	0.57	0.74	1.30	0.8	1.04	1.30
		Average	**1.31**		**Average**	**1.30**
		Std Dev	**0.03**		**Std Dev**	**0.04**

In addition, to verify the validity of results from the Basin Sizer program, results from Basin Sizer were compared to design criteria included in the C.3 Handbook. The C.3 Stormwater Handbook was developed through the Santa Clara Valley Urban Runoff Pollution Prevention Program and last updated in 2012. The Handbook includes sizing criteria for stormwater facilities based on continuous simulation modeling. The C.3 Criteria reviewed was developed by Geosyntec Consultants for the Bay Area Stormwater Management Agencies Association (BASMAA), using the continuous simulation program SWMMM5.0. Results of this comparison and verification are provided in Tables 2 and 3.

Table 2: C.3 Stormwater Handbook Volume Multipliers

Location	Percent Capture	Multiplier 24 hrs to 48 hrs
Morgan Hill (Figure F-7)	80%	1.38
	90%	N/A
Palo Alto (Figure F-8)	80%	1.38
	90%	1.35
San Jose (Figure F-9)	80%	1.30
	90%	1.35

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Table 3: Comparison of Basin Sizer Results and C.3 Stormwater Handbook Criteria

80% Capture Volume per Acre Impervious, 48-hour drawdown				
C.3 Appendix I		Basin Sizer Results		
Location	Volume	Unit Volume	Volume	Percent Difference
Berkeley	23,000	0.85	23,080	0.3%
Brentwood	19,000	0.71	19,278	1.5%
Dublin	21,000	0.75	20,364	-3.0%
Hayward	23,500	0.89	24,166	2.8%
Lake Solano	29,000	1.08	29,325	1.1%
Martinez	23,000	0.81	21,993	-4.4%
Morgan Hill	25,500	0.97	26,338	3.3%
Palo Alto*	16,500	0.54	14,662	-11.1%
San Francisco	20,000	0.71	19,278	-3.6%
San Francisco Oceanside	19,000	0.69	18,735	-1.4%
San Jose	15,000	0.54	14,662	-2.3%

*The San Jose rain gauge in Basin Sizer is the nearest gauge to the C.3 Palo Alto gauge. The relatively high percent difference is likely due to weather variations between these two stations.

Based on the comparison to the C.3 continuous simulation modeling results, the volume multiplier obtained through the Basin Sizer program is reasonable and defensible.

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ATTACHMENT A
BASIN SIZER PROGRAM INFORMATION

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The Basin Sizer program was:

- Developed by the Office of Water Programs, California State University Sacramento.
- Developed for Caltrans. The program computes water quality volumes and water quality flows by methods approved for Caltrans use to meet the requirements of the State Water Quality Control Board.
- Updated in 2006 to include CASQA California Stormwater BMP Handbook methods.

California Stormwater BMP Handbook Approach

The CASQA California Stormwater BMP Handbook approach is based on results of a continuous simulation model, developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers. The Storage, Treatment, Overflow, Runoff Model (STORM) was applied to long-term hourly rainfall data at numerous sites throughout California. STORM translates rainfall into runoff, then routes the runoff through detention storage. The results of the STORM model are incorporated into the California Stormwater BMP Handbook approach.

Basin Sizer User Guide Excerpt

Basin Sizer is a software tool developed for the California Department of Transportation (Caltrans). This software computes water quality volumes (WQVs) and water quality flows (WQFs) by methods approved for Caltrans use to meet the requirements of the State Water Quality Control Board (SWQCB).

The software allows easy selection of rainfall stations through a graphical interface and displays results in US customary or metric units. The graphical map interface allows zooming and panning of a map of California, which shows rainfall stations, State and Federal highways and rivers.

Basin Sizer was developed to help engineers and designers who are often given a variety of methods to determine WQVs or WQFs. These methods vary by region and by regulator. Commonly WQVs are defined as “the 85^{th} percentile 24-hour runoff event determined as the maximized capture of stormwater volume for the area” or as “the 85^{th} percentile 24-hour storm rainfall depth”. In some areas WQVs are not calculated, instead a specific number is give by a regulator. For example, the Tahoe Basin has a WQV of 1”. WQFs are often determined to be “the 85^{th} percentile hourly rainfall depth” or a number determined by a regulator.

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Peak Rainfall Intensity Statistics

Location		NOAA Atlas 14 1-year 24-hour depth (in)	1-year Peak Storm Intensity by Rainfall Curve (in/hr)		NOAA Atlas 14 1-year Storm Intensity by Duration (in/hr)				
			NRCS 1	NRCS 1A	5-min	10-min	15-min	60-min	2-hr
Buellton	Hwy 246 / Hwy 101	2.36	1.77	0.57	1.74	1.25	0.99	0.56	0.43
Carmel	Ocean Ave / Junipero St	1.55	1.16	0.37	1.81	1.30	1.05	0.47	0.32
Carpinteria	Linden Ave / 5th Street	2.74	2.06	0.66	2.24	1.60	1.29	0.64	0.49
Felton	**Hwy 9 / Graham Hill Rd**	**4.55**	**3.41**	1.09	**2.99**	2.14	1.72	0.85	0.67
Gilroy	Hwy 152 / Hwy 101	1.83	1.37	0.44	1.51	1.08	0.87	0.42	0.32
Goleta	**Fire Station / Los Carneros**	**2.72**	**2.04**	0.65	**1.74**	1.25	1.02	0.59	0.43
Greenfield	Walnut Ave / Hwy 101	1.21	0.91	0.29	0.97	0.70	0.57	0.27	0.21
Grover Beach	Grand Ave / 4th St	1.73	1.30	0.42	1.39	0.99	0.80	0.40	0.31
Hollister	4th St / San Felipe Rd	1.27	0.95	0.30	1.15	0.82	0.66	0.32	0.24
Lompoc	H Street / Hwy 246	1.94	1.46	0.47	1.45	1.04	0.84	0.48	0.35
Morro Bay	Main St / Hwy 1	1.55	1.16	0.37	1.32	0.95	0.76	0.39	0.30
Pacific Grove	Lighthouse Ave / Forest Ave	1.41	1.06	0.34	1.74	1.25	1.00	0.44	0.30
Paso Robles	Union Rd / Golden Hill Rd	1.47	1.10	0.35	1.32	0.95	0.76	0.39	0.29
Salinas	N Main St / Laurel Dr	1.41	1.06	0.34	1.20	0.86	0.69	0.33	0.24
San Luis Obispo	Broad St / Orcutt Rd	2.06	1.55	0.49	1.80	1.29	1.04	0.51	0.39
Santa Barbara	**State / Anapamu**	**2.77**	**2.08**	0.66	**1.82**	1.30	1.05	0.63	0.45
Santa Cruz	17th Ave / Portola Dr	2.36	1.77	0.57	1.93	1.40	1.12	0.54	0.40
Santa Maria	Betteravia Rd / Hwy 135	1.70	1.28	0.41	1.67	1.19	0.96	0.47	0.34
Watsonville	Main St / Hwy 129	2.05	1.54	0.49	1.75	1.26	1.01	0.48	0.35

Prepared by Wallace Group
February 2013

Attachment D SCM Sizing Analysis
City of Goleta, per Acre of Impervious

PROJECT DATA				
	Impervious Area	1	acres	
		43,560	square feet	
	Pervious Area	0	square feet	
	Percent Impervious	100%		
	WMZ	4	retain 95th via infiltration	
	85th % storm	1.44	inches	
	95th % storm	2.4	inches	
Bioretention design parameters				
	Ponding Depth	6	inches	
	Engineered Soil Depth	24	inches	
	Engineered Soil Porosity	25%		
	Engineered Soil Storage	6	inches	
	Gravel Depth	12	inches	
	Gravel Porosity	35%		
	Gravel storage	4	inches	
	Available Storage Depth	16	inches	
	NOTE: Facility storage depth must be increased by storm depth, in order to capture rain that falls on bioretention feature			
	Gravel Depth to Capture design storm	7	inches	
	Total Facility Depth	49	inches	
	Total Underground Depth	43	inches	
Attachment D Calculations				
	Runoff Coefficient	0.89	unitless	
	95th Runoff Volume	7,771	cubic feet	
		0.178	acre-feet	
	Min. Surface Area for full volume	5,756	square feet, based on depth above	
	Percent of Surface Area	13%		
	85th Retention Volume	4,663	cubic feet	
		0.11	acre-feet	

Prepared by Wallace Group
January 2013

HYDROGRAPH ROUTING FOR SCM SIZING: SBUH METHOD WITH HYDROCAD PROGRAM

95th percentile, NOAA 1-year storm curve, AMC 2 — Peak intensity = 1.38 in/hr

Soil Condition	Req'd Surface Area	Percent of Imp Area	Drawdown (hrs)	Total Bioretention Volume	Percent of Ret. Volume	Volume as Percent of Imp Area	Infiltration Rate (in/hr)	Ponding Depth
HSG A	2,000	5%	24	2,000	26%	0.046	5	6 inches
HSG A	1,400	3%	25	1,458	19%	0.033	5	12 inches
HSG B	2,700	6%	38	3,645	47%	0.084	1	6 inches
HSG B/C	3,350	8%	48	4,523	58%	0.104	0.60	6 inches
HSG C	4,700	11%	92	6,345	82%	0.146	0.23	6 inches
HSG D	5,800	13%	12 days	7,830	101%	0.180	0.06	6 inches

95th percentile, Type 1 storm curve, AMC 2 — Peak intensity = 1.81 in/hr

Soil Condition	Req'd Surface Area	Percent of Imp Area	Total Bioretention Volume	Percent of Ret. Volume	Percent of NOAA storm curve	Percent of 1A storm curve	Volume as Percent of Imp Area	Ponding Depth
HSG A	2,550	6%	2,550	33%	128%	159%	0.059	6 inches
HSG A	1,750	4%	1,823	23%	125%	114%	0.042	12 inches
HSG B	2,850	7%	3,848	50%	106%	110%	0.088	6 inches
HSG B/C	3,500	8%	4,725	61%	104%	106%	0.108	6 inches
HSG C	4,700	11%	6,345	82%	100%	100%	0.146	6 inches
HSG D	5,800	13%	7,830	101%	100%	100%	0.180	6 inches

Back-to-back storms, 0.70 then 95th percentile, NOAA 1-year storm curve, both AMC 2

Soil Condition	Req'd Surface Area	Percent of Imp Area	Total Bioretention Volume	Percent of Ret. Volume	Back to Back Multiplier	Volume as Percent of Imp Area	Ponding Depth
HSG A	2,000	5%	2,000	26%	1.00	0.046	6 inches
HSG A	1,400	3%	1,400	18%	1.00	0.032	12 inches
HSG B	2,700	6%	3,645	47%	1.00	0.084	6 inches
HSG B/C	3,350	8%	4,523	58%	1.00	0.104	6 inches
HSG C	4,800	11%	6,480	83%	1.02	0.149	6 inches
HSG D	6,600	15%	8,910	115%	1.14	0.205	6 inches

Back-to-back storms, 0.70 then 95th percentile, Type 1 storm curve, both AMC 2

Soil Condition	Req'd Surface Area (sq ft)	Percent of Imp Area	Total Bioretention Volume (cu. Ft)	Percent of Ret. Volume	Back to Back Multiplier	Volume as Percent of Imp Area	Ponding Depth
HSG A	2,550	6%	2,550	33%	1.00	0.059	6 inches
HSG A	1,750	4%	1,750	23%	1.00	0.040	12 inches
HSG B	2,850	7%	3,848	50%	1.00	0.088	6 inches
HSG B/C	3,500	8%	4,725	61%	1.00	0.108	6 inches
HSG C	4,750	11%	6,413	83%	1.01	0.147	6 inches
HSG D	6,600	15%	8,910	115%	1.14	0.205	6 inches

85th percentile storm, NOAA 1-year curve, AMC 2 — Peak intensity = 0.83 in/hr

Soil Condition	Req'd Surface Area (sq ft)	Percent of Imp Area	Total Bioretention Volume (cu. Ft)	Percent of Ret. Volume	Volume as Percent of Imp Area
HSG A	1,150	3%	1,150	25%	0.026
HSG B	1,550	4%	2,093	45%	0.048
HSG B/C	1,950	4%	2,633	56%	0.060
HSG C	2,650	6%	3,578	77%	0.082
HSG D	3,250	7%	4,388	94%	0.101

85th percentile storm, Type 1 storm curve, AMC 2 — Peak intensity = 1.09 in/hr

Soil Condition	Req'd Surface Area (sq ft)	Percent of Imp Area	Total Bioretention Volume (cu. Ft)	Percent of Ret. Volume	Percent of NOAA Storm Curve	Volume as Percent of Imp Area
HSG A	1,450	3%	1,450	31%	126%	0.033
HSG B	1,650	4%	2,228	48%	106%	0.051
HSG B/C	2,000	5%	2,700	58%	103%	0.062
HSG C	2,700	6%	3,645	78%	102%	0.084
HSG D	3,250	7%	4,388	94%	100%	0.101

NOTES:
95th percentile storm = 2.40 inches — 85th percentile storm = 1.44 inches
AMC = Antecedent Moisture Condition

Attachment D SCM Sizing Analysis
Commercial Project - Paso Robles

PROJECT DATA				
	Impervious Area	5.4	acres	
		235,224	square feet	
	Pervious Area	0	square feet	
	Percent Impervious	100%		
	WMZ	4	retain 95th via infiltration	
	85th % storm	0.9	inches	
	95th % storm	1.4	inches	
	Tested infiltration	6	inches/hour	
Bioretention design parameters				
	Ponding Depth	6	inches	
	Engineered Soil Depth	18	inches	
	Engineered Soil Porosity	25%		
	Engineered Soil Storage	5	inches	
	Gravel Depth	12	inches	
	Gravel Porosity	35%		
	Gravel storage	4	inches	
	Total Available Depth	15	inches	
	NOTE: Facility storage depth must be increased by storm depth, in order to capture rain that falls on bioretention feature			
	Gravel Depth to Capture design storm	4	inches	
	Total Facility Depth	40	inches	
Attachment D Calculations				
	Runoff Coefficient	0.89	unitless	
	95th Percentile Volume	24,479	cubic feet	
		0.56	acre-feet	
	Min. Surface Area for full volume	19,983	square feet, based ondepth above	
	Percent of Surface Area	8%		
	85th Percentile Volume	15,736	cubic feet	
		0.36	acre-feet	

Prepared by Wallace Group
January 2013

HYDROGRAPH ROUTING FOR SCM SIZING: SBUH METHOD WITH HYDROCAD PROGRAM

95th percentile, 2-year SLO storm distribution, AMC 2

Soil Condition	Req'd Surface Area (sq ft)	Percent of Imp Area	Drawdown (hrs)	Total Bioretention Volume (cu. Ft)	Percent of Ret. Volume	Volume as Percent of Imp Area
Actual	5,800	2%	24	5,075	21%	0.022
HSG A	5,800	2%	24	5,075	21%	0.022
HSG B	8,900	4%	38	10,903	45%	0.046
HSG B/C	11,000	5%	48	13,475	55%	0.057
HSG C	14,800	6%	92	18,130	74%	0.077
HSG D	18,000	8%	12 days	22,050	90%	0.094

95th percentile, NRCS Type 1 Storm distribution, AMC 2

Soil Condition	Req'd Surface Area (sq ft)	Percent of Imp Area	Drawdown (hrs)	Total Bioretention Volume (cu. Ft)	Percent of Ret. Volume	Volume as Percent of Imp Area
Actual	8,100	3%	24	7,088	29%	0.030
HSG A	8,100	3%	24	7,088	29%	0.030
HSG B	8,900	4%	38	10,903	45%	0.046
HSG B/C	11,100	5%	48	13,598	56%	0.058
HSG C	14,600	6%	92	17,885	73%	0.076
HSG D	18,000	8%	12 days	22,050	90%	0.094

Back-to-back storms, 0.4 then 95th percentile, 2-year SLO storm distribution, both AMC 2

Soil Condition	Req'd Surface Area (sq ft)	Percent of Imp Area	Total Bioretention Volume (cu. Ft)	Percent of Ret. Volume	Back to Back Multiplier	Volume as Percent of Imp Area
Actual	5,800	2%	5,075	21%	1.00	0.022
HSG A	5,800	2%	5,075	21%	1.00	0.022
HSG B	8,900	4%	10,903	45%	1.00	0.046
HSG B/C	11,000	5%	13,475	55%	1.00	0.057
HSG C	14,800	6%	18,130	74%	1.00	0.077
HSG D	20,200	9%	24,745	101%	1.12	0.105

85th percentile storm, 2-year SLO storm distribution, AMC 2

Soil Condition	Req'd Surface Area (sq ft)	Percent of Imp Area	Total Bioretention Volume (cu. Ft)	Percent of Ret. Volume	Volume as Percent of Imp Area
Actual	3,600	2%	3,150	20%	0.013
HSG A	3,600	2%	3,150	20%	0.013
HSG B	5,400	2%	6,615	42%	0.028
HSG B/C	6,600	3%	8,085	51%	0.034
HSG C	8,900	4%	10,903	69%	0.046
HSG D	10,800	5%	13,230	84%	0.056

NOTES:

95th percentile storm = 1.43 inches

85th percentile storm = 0.9 inches

AMC = Antecedent Moisture Condition

Attachment D SCM Sizing Analysis
City of San Luis Obispo, per Acre of Impervious

PROJECT DATA				
	Impervious Area	1	acres	
		43,560	square feet	
	Pervious Area	0	square feet	
	Percent Impervious	100%		
	WMZ	4	retain 95th via infiltration	
	85th % storm	1.18	inches	
	95th % storm	1.97	inches	
Bioretention design parameters				
	Ponding Depth	6	inches	
	Engineered Soil Depth	18	inches	
	Engineered Soil Porosity	25%		
	Engineered Soil Storage	5	inches	
	Gravel Depth	12	inches	
	Gravel Porosity	35%		
	Gravel storage	4	inches	
	Available Storage Depth	15	inches	
	NOTE: Facility storage depth must be increased by storm depth, in order to capture rain that falls on bioretention feature			
	Gravel Depth to Capture design storm	6	inches	
	Total Facility Depth	42	inches	
	Total Underground Depth	36	inches	
Attachment D Calculations				
	Runoff Coefficient	0.89	unitless	
	95th Retention Volume	6,379	cubic feet	
		0.15	acre-feet	
	Min. Surface Area for full volume	5,207	square feet, based on depth above	
	Percent of Surface Area	12%		
	85th Retention Volume	3,821	cubic feet	
		0.09	acre-feet	

Prepared by Wallace Group
January 2013

HYDROGRAPH ROUTING FOR SCM SIZING: SBUH METHOD WITH HYDROCAD PROGRAM						
95th percentile, 2-year SLO storm distribution, AMC 2						
Soil Condition	Req'd Surface Area (sq ft)	Percent of Imp Area	Drawdown (hrs)	Total Bioretention Volume (cu. Ft)	Percent of Ret. Volume	Volume as Percent of Imp Area
HSG A	1,500	3%	24	1,313	21%	0.030
HSG B	2,400	6%	38	2,940	46%	0.067
HSG B/C	2,850	7%	48	3,491	55%	0.080
HSG C	3,900	9%	92	4,778	75%	0.110
HSG D	4,700	11%	12 days	5,758	90%	0.132
95th percentile storm, NRCS Type 1 storm distribution, AMC 2						
Soil Condition	Req'd Surface Area (sq ft)	Percent of Imp Area	Total Bioretention Volume (cu. Ft)	Percent of Ret. Volume	Percent of SLO Curve Volume	Volume as Percent of Imp Area
HSG A	2,100	5%	1,838	29%	140%	0.042
HSG B	2,400	6%	2,940	46%	100%	0.067
HSG B/C	2,850	7%	3,491	55%	100%	0.080
HSG C	3,900	9%	4,778	75%	100%	0.110
HSG D	4,700	11%	5,758	90%	100%	0.132
Back-to-back storms, 0.50 then 95th percentile, 2-year SLO storm distribution, both AMC 2						
Soil Condition	Req'd Surface Area (sq ft)	Percent of Imp Area	Total Bioretention Volume (cu. Ft)	Percent of Ret. Volume	Back to Back Multiplier	Volume as Percent of Imp Area
HSG A	1,500	3%	1,313	21%	1.00	0.030
HSG B	2,400	6%	2,940	46%	1.00	0.067
HSG B/C	2,850	7%	3,491	55%	1.00	0.080
HSG C	3,900	9%	4,778	75%	1.00	0.110
HSG D	5,200	12%	6,370	100%	1.11	0.146
Back-to-back storms, 0.50 then 95th percentile, NRCS Type I storm distribution, both AMC 2						
Soil Condition	Req'd Surface Area (sq ft)	Percent of Imp Area	Total Bioretention Volume (cu. Ft)	Percent of Ret. Volume	Back to Back Multiplier	Volume as Percent of Imp Area
HSG A	2,100	5%	1,838	29%	1.00	0.042
HSG B	2,400	6%	2,940	46%	1.00	0.067
HSG B/C	2,850	7%	3,491	55%	1.00	0.080
HSG C	3,900	9%	4,778	75%	1.00	0.110
HSG D	5,200	12%	6,370	100%	1.11	0.146
NOTES:						
95th percentile storm = 1.97 inches			85th percentile storm = 1.18 inches			
AMC = Antecedent Moisture Condition						

Prepared by Wallace Group
February 2013