TECHNICAL MEMORANDUM

TO: Tom Dalziel, Contra Costa Clean Water Program

FROM: Chris Potter & Gary Palhegyi, GeoSyntec Consultants

DATE: April 20, 2005

SUBJECT: **Rainfall Data Analysis and Guidance for Sizing Treatment BMPs**

INTRODUCTION

Contra Costa Clean Water Program (CCCWP) contracted with GeoSyntec Consultants to conduct an analysis of local rainfall data and develop guidance that allow developers and their engineers to size flow or volume based BMPs. An analysis of local rainfall data is required because local rainfall patterns influence the water quality facilities sized for new development. Without local data, developers would rely on results published in the California Stormwater Quality Association Handbook (2003) using the closest gage in Oakland, California. A comparison of the Oakland gage to the gages in Contra Costa County believed to be similar show that rainfall patterns are influencing basin sizing and thus justifies the need for this project.

The CCCWP C3 Technical Work Group decided that developers should be able to use any of the appropriate sizing methods, but that the CCCWP would endorse one method in each category, and provide the guidance and technical data for the endorsed method. This Technical Memorandum summarizes the rainfall data analysis and design criteria for the following two endorsed methods.

Flow Based:

C.3.d(ii)(2) "the flow of runoff produced by a rain event equal to at least two times the 85th percentile hourly rainfall intensity for the applicable area, based on historical records of hourly rainfall depths".

Volume Based:

C.3.d(i)(2) "the volume of annual runoff required to achieve 80 percent or more capture determined in accordance with the methodology set forth in Appendix D of the California Stormwater Best Management Practices Handbook, (1993), using local rainfall data".

SELECTION OF RAINFALL GAGES FOR ANALYSIS

Rainfall data was obtained from the Contra Costa County Public Works Department, Flood Control Division. Gage locations were plotted on the County's Mean Seasonal Isohyetal Map (Drawing B-166) to select gages that cover the range of climatic conditions in the county. Selection factors considered location, elevation, mean annual precipitation (MAP), and the length and quality of the rainfall records. Eight gages were reviewed and six were selected for analysis. Table 1 summarizes pertinent information for the six gages selected. The Brentwood, Martinez and Walnut Creek gages are National Climatic Data Center (NCDC) gages; the remaining gages are operated by the Public Works Department. Although a number of factors affect rainfall in Contra Costa County, the effect of elevation on rainfall is pronounced in that the MAP at Orinda is about 27 inches per year (elevation 700 ft), compared to about 11 inches at Los Medanos (elevation 130 ft).

Table 1: Rainfall Station Information

	Rainfall Station						
	Brentwood	**Martinez**	**Walnut Creek**	**Los Medanos**	**Dublin Fire**	**Orinda Fire**	**Oakland**
Station ID.	NWS 1060	NWS 5321 2S	NWS 9426 2ENE	MED19	DBF20	ORF18	NWS 6335
Latitude	37:53	37:58	37:54	37.9983	37.7317	37.895	
Longitude	121:46	122:07	122:01	121.855	121.926	122.17	
Elevation (ft)*	325	230	220	130	355	700	
MAP (in)	16.1	21.5	17.7	11.2	16.9	27.1	18.2
Period of Record	1950 - 1986	1948 – 1999	1948 - 1983	1974 – 1999	1973 – 1999	1973 – 1999	1949 - 1980

* Relative to mean sea level

FLOW BASED DESIGN CRITERIA

This section describes the procedures used to analyze the rainfall records and the resulting rainfall statistics. EPA's Synoptic Rainfall Analysis Program (SYNOP), with some modifications added by GeoSyntec, was used to analyze the raw rainfall data and produce a set of storm event statistics.

Mean Storm Precipitation Depth: SYNOP aggregates hourly data into individual storm events, which are distinguished by an intervening dry period called an inter-event time. For this application, 6 hours was selected as the inter-event time. After the record was converted to a series of storm events, events smaller than 0.10 inches were deleted as such events are likely not to create runoff. Based on this record of storm events, storm event statistics, such as number of events per year, duration, volume and intensity for individual storms, as well as average annual statistics, were estimated using SYNOP.

Table 2 summarizes the results for the Mean Storm Precipitation Depth. Mean storm precipitation depths range from 0.43 inches at Los Medanos to 0.82 inches at Orinda. Other useful storm statistics, such as average number of storm events per year, average storm duration and average storm intensity are also provided in Table 2.

Table 2: Local Storm Event Statistics

Gage Location	Average No. of Storm Events per Year #	Mean Storm Precipitation Depth (in)	Average Storm Duration (hours)	Average Storm Intensity (in/hr)	Average No. of Dry Hours Between Storms (hours)
Walnut Creek	29	0.60	13.9	0.050	288
Martinez	36	0.58	10.5	0.069	229
Brentwood	26	0.59	13.2	0.048	314
Orinda	32	0.82	16.1	0.053	258
Dublin Fire	30	0.55	13.3	0.044	291
Los Medanos	24	0.43	11.3	0.047	371
Oakland Airport	31	0.56	13.1	0.047	269

Figure 1 shows the mean storm depth versus the MAP for each of the six gages, plus one additional gage at Saint Mary's College. The Saint Mary's College rain gage was added to improve the regression. This figure also provides the 80 percent confidence limits about the regression line.

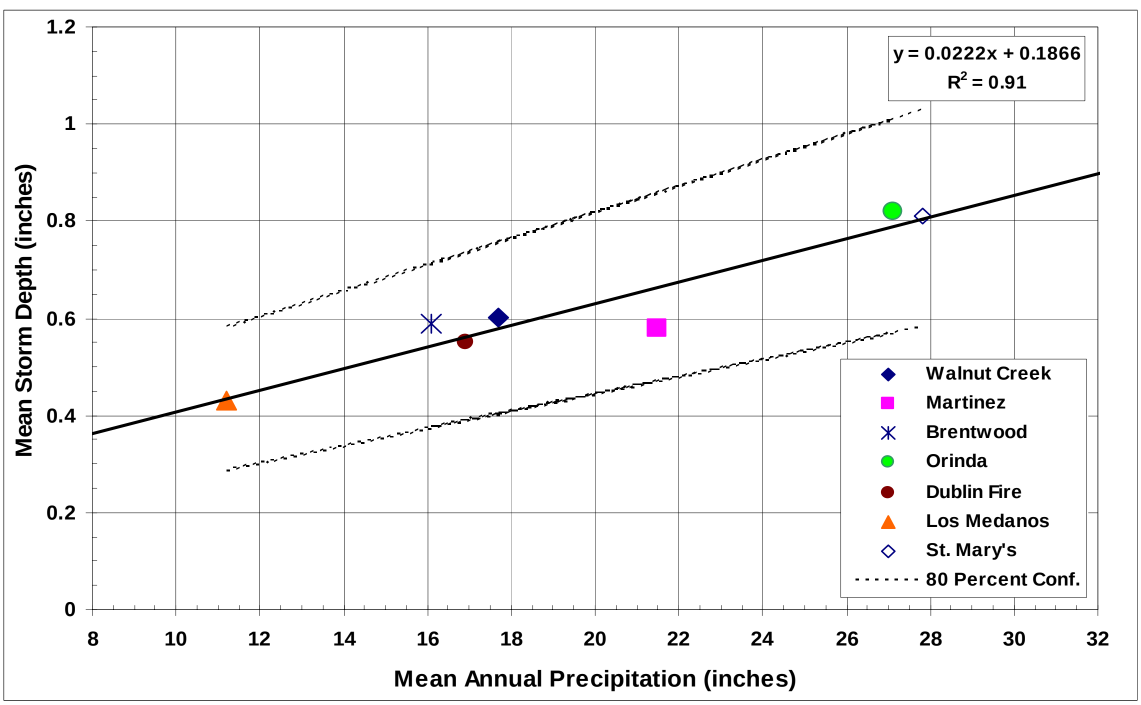

Figure 1 – Mean Storm Depth as a Function of MAP

85th Percentile Hourly Rainfall Intensity: The hourly rainfall records were converted to rainfall intensity. Each hour was then ranked to estimate the cumulative frequency distribution of the hourly rainfall intensity. Figures in Appendix A show the cumulative frequency distributions for intensity for each of the six gages.

Table 3 summarizes the results for the 85th percentile hourly intensity. The 85th percentile rainfall intensity ranges from 0.08 in/hr at Los Medanos to 0.13 in/hr at Orinda. The design criteria of 2 times the 85th percentile is also shown.

Table 3: Flow Based Design Criteria

Gage Location	85th Percentile Hourly Rainfall Intensity (in/hr)	Design Rainfall Intensity (2 * 85th Percentile) (in/hr)
Walnut Creek	0.10	0.20
Martinez	0.11	0.22
Brentwood	0.10	0.20
Orinda	0.13	0.26
Dublin Fire	0.10	0.20
Los Medanos	0.08	0.16

Figure 2 plots the 2*85% storm intensity as a function of the MAP for each of the six gages, plus one additional gage at Saint Mary's College. This figure also provides the 80 percent confidence limits about the regression line.

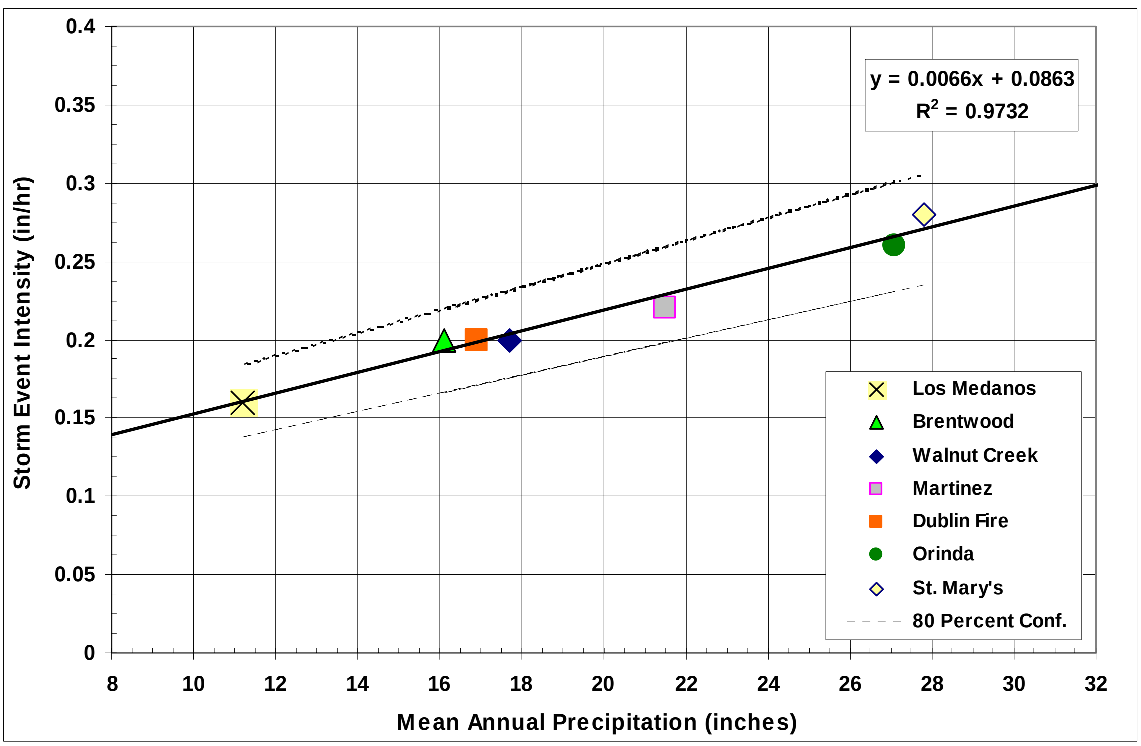

Figure 2 – Design Rainfall Intensity (2x the 85th Percentile) as a Function of MAP

Based on the results shown in Table 3, the CCCWP C.3 Technical Work Group selected 0.2 inches per hour as the recommended countywide criterion for the design of flow-based treatment BMPs, as allowed by NPDES Permit Provision C.3.d(ii)(3).

VOLUME BASED DESIGN CRITERIA

Most water quality basins are designed to treat only a portion of the runoff from a given site, as it is not economically feasible to capture 100% of the runoff. The percent of the mean annual runoff treated by a basin is referred to as the "percent capture".

In the California Stormwater Best Management Practices Handbook (1993, updated 2003), a proprietary version of the Storage, Treatment, Overflow, Runoff Model – STORM – was used as the basis for the volume-based BMP sizing criteria. The model results were presented in the form of graphs showing the percent volume capture as a function of "unit basin storage volume" for a range of runoff coefficients. The "unit basin storage volume" would then be used to size the BMP, using the following equation:

$$BMP\ Volume = Unit\ Basin\ Storage\ Volume \cdot Drainage\ Area$$

This equation shows that the unit basin storage volume equals the basin volume (e.g., in acre-ft) divided by the area that drains to the basin (e.g., in acres). The units of unit basin storage are therefore units of length and are sometimes referred to as "watershed inches" or "watershed feet".

Herein, USEPA's Storm Water Management Model (SWMM) was used in place of STORM, as SWMM is a commercially available model that contains a more process based rainfall runoff algorithm. Comparison of the results from STORM and SWMM showed that the two models produced similar and consistent results.

Numeric sizing criteria for volume based controls are presented in the form of curves that plot the basin size, expressed as unit basin storage, corresponding to 80% capture as a function of site percent imperviousness, soil type, location (rain gage), and assumed slope. The 80% capture criterion stems from language in the CCCWP NPDES Permit, where the goal is to achieve "80 percent or more capture". Unit basin storage is expressed in watershed inches (or feet), which allows design curves to be developed that apply to a range of catchment sizes.

Factors that can affect the percent capture include:

- the rainfall characteristics at the site,
- the percent imperviousness of the site,
- the soil condition, slope, and associated infiltration rates (less important for highly impervious projects, or where grading compacts the soils),
- the design drain time for the volume based BMP

The following describes how each of these factors was taken into account in developing the design curves.

Site-Specific Precipitation: Rainfall amounts and characteristics vary across the County in response to orographic effects associated with the Mount Diablo Range, the directional patterns of storm fronts approaching the County, and other factors. These effects are illustrated in Table 2, which shows the distribution of local rainfall events in Contra Costa County. Obviously the location of the project site and the local rainfall patterns must be taken into account in developing the design sizing curves. For this purpose, rainfall records from several raingages that represented a range of climatic zones were analyzed.

Percent Imperviousness: The major factor affecting basin size is the percent imperviousness of the catchment. Impervious surfaces include paved highways, streets, sidewalks, rooftops, and parking lots. The percent of the drainage area covered by such surfaces is termed the "percent imperviousness" and will vary depending on each project. If the runoff from an impervious surface drains directly into the storm drain system, this area is termed the "directly connected imperviousness area" (DCIA). Values of percent imperviousness generally vary with the type and density of development. The numerical sizing curves shown in Figure 3 are for a range of directly connected percent imperviousness (15% to 100%) corresponding roughly with low density single family residential (30%) to commercial and/or industrial development (up to 90%).

Soil Infiltration: The pervious portions of a site can infiltrate some of the rainfall depending on the infiltration characteristic of the soils, the level of moisture in the soil, and the level of groundwater. The analysis was performed for one slope, one soil type and one infiltration rate: drainage area slope = 1% and a constant infiltration rate ranging from 0.17 in/hr to 0.18 in/hr for open space (pervious surfaces - M. Boucher Contra Costa County Public Works Department, personal communication data). The Green-Ampt infiltration parameters required for runoff analysis in the SWMM model were selected to provide a saturated hydraulic conductivity of 0.175 in/hr. Soil compaction due to grading and the resultant decrease in soil infiltration rates was not considered in the runoff analysis. Table 4 shows the values of the infiltration parameters used in the SWMM Model.

Table 4 Green-Ampt Infiltration Parameters used in SWMM

Soil Texture	Hydrologic Soil Group	SUCT (in)	HYDCON (in/hr)	SMDMAX
Silt Loam/Clay Loam	B/C	7.83	0.175	0.437

SUCT = average capillary suction at the wetting front
HYDCON = saturated hydraulic conductivity of soil
SMDMAX = initial moisture deficit
Source: Maidment, David R. (1993), *Handbook of Hydrology*

Drain Time: Drain time is the time required to drain a basin that has reached its design capacity; usually expressed in hours. Drain time is important as it affects residence time, which affects the range of particles (depending on size, shape, density, etc.) that could potentially be settled out in the basin. Estimates for design drain time vary, and ideally would be determined based on site-specific information on the size, shape, and density of suspended particulates in the runoff. This information is generally not available and estimates of appropriate ranges for drain time have relied on settling column information reported in the literature.

An important source of drain time information is settling column tests conducted by Grizzard et al. (1986) as part of the Nationwide Urban Runoff Program (NURP). He found that settling times of 48 hours resulted in removals of 80-90 % of total suspended solids (TSS). Rapid initial removal was also observed in stormwater samples with medium (100 to 215 mg/L) and high (721 mg/L) initial TSS concentrations. For example, at settling times of 24 hours, the 80-90% removals were already achieved in samples with medium and high initial TSS, whereas only 50-60% removal was achieved in those with low initial TSS.

Given the data provided above, a drain time of 48 hours has been used in developing the curves herein, consistent with the drain time used in developing curves in the California Stormwater BMP Handbooks (2003). This is also consistent with recommendations of the California Department of Health Services and the University of California, that structures be designed to drain in less than 72 hours to minimize mosquito production (Metzger, 2004).

Results: Figure 3 illustrates the unit basin storage volume required to achieve 80% capture for a range of imperviousness. Figure 4 illustrates the required unit basin storage volume as a function of the MAP, with the data grouped by %DCIA. This format allows designers to use the mean seasonal isohyetal map (D-166) provided by the County to estimate the MAP at their site. This information, combined with an estimate of the DCIA of the site, allows the designer to determine the required unit basin storage (ft). Then, by multiplying by the area of the site (acres), the designer can estimate the basin volume (e.g., in acre-ft) required to achieve 80% capture of the mean annual runoff.

Discussion of Storm Pattern and Effects on Basin Sizing:

The results presented in Table 2 summarize *storm statistics*. At first glance, one might be tempted to relate the results in Figure 3 to Mean Storm Depth or one might expect two gages with similar Mean Storm Depth to plot similarly on Figure 3. However, this is not entirely correct because of storm intensity, duration, and timing differs with rain gage location. Further examination of the statistics in Table 2 shows that Martinez tends to have higher intensity, shorter duration storms than other parts of the County. Martinez also has a shorter average period of dry weather between storms (229 hours vs. 269 hours) compared to the other gages; thus there is a greater chance the water quality basin is partially full when a second or third storm arrives. As a result, the basin sizes for new development near Martinez should be larger than what might be expected based on differences in mean annual precipitation alone (Figure 3). The point of this discussion is to recognize that storm pattern influences the results and that all the storm characteristics (e.g., Table 2) should be considered when comparing the results between gages and when sizing water quality basins.

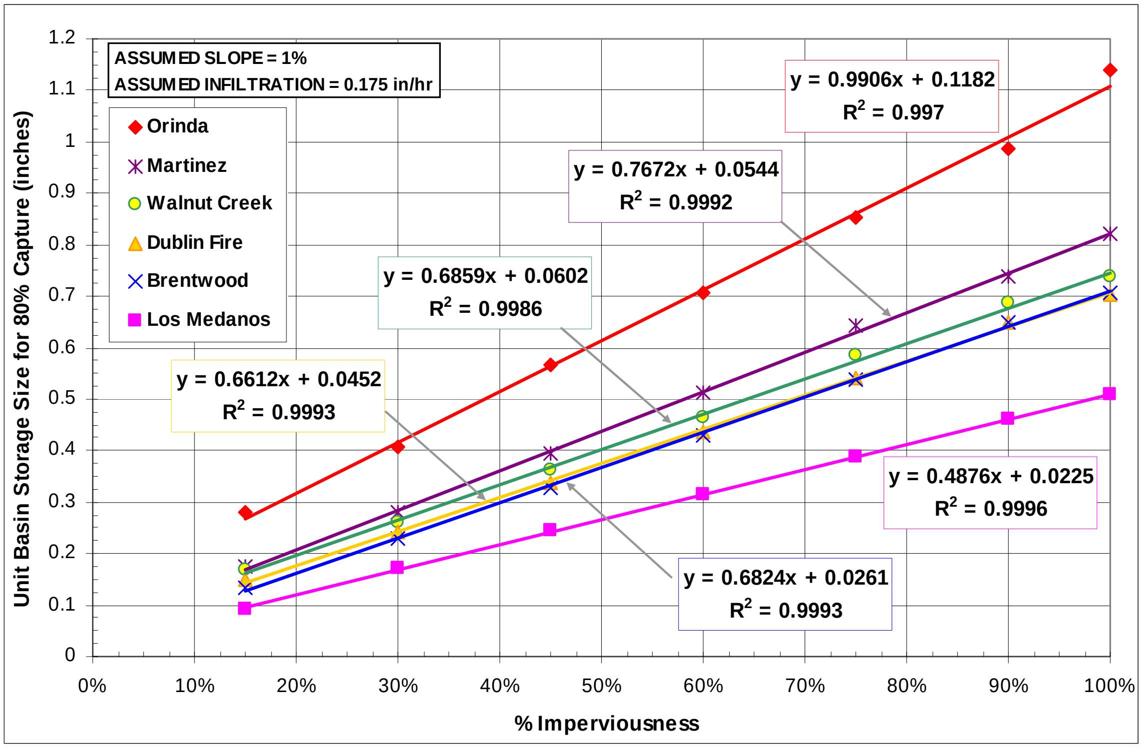

Figure 3 – Unit Basin Storage Volume as a Function of %DCIA

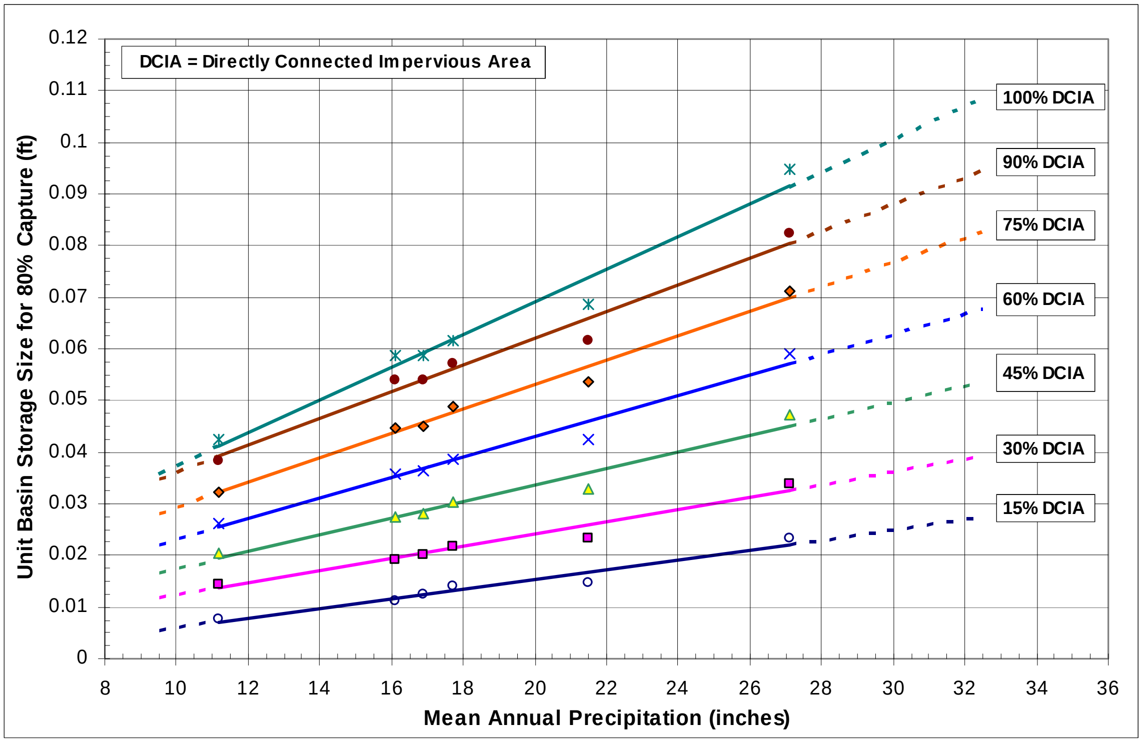

Figure 4 – Unit Basin Storage Volume as a Function of MAP

References:

California Stormwater Quality Association, 2003. Stormwater Best Management Practice Handbook, New Development and Redevelopment, January.

Grizzard T.J., C.W. Randall, B.L. Weand, and K.L. Ellis, 1986. *Effectiveness of Extended Detention Ponds in Urban Runoff Quality* – Impact and Quality Enhancement Technology: pp. 323-337.

Metzger, Marco E., 2004. *Managing Mosquitoes in Stormwater Treatment Devices*, University of California, Agriculture and Natural Resources, Publication 8125.

Maidment, David R., 1992, Handbook of Hydrology, McGraw-Hill, Inc.

RAINFALL ANALYSIS USING EPA'S SYNOP PROGRAM

The Synoptic Rainfall Data Analysis Program (SYNOP) was utilized to statistically analyze long-term precipitation data provided by the Contra Costa Clean Water Program (CCCWP). The program aggregates the hourly data into individual storm events and computes event descriptive statistics. The SYNOP program calculates the duration, volume and intensity for individual storms as well as average annual statistics. Reoccurrence interval and probability results are also available as output options. The SYNOP program allows the user to screen out storms that are not expected to result in runoff (see step 2 below).

Rainfall analysis conducted used in the sizing analysis consisted of running SYNOP to output storm event data in addition to average annual statistics. The individual storm event data can be ranked to give the 85th (or any other) percentile storm or averaged to give the mean storm size. An overview of the SYNOP rainfall analysis conducted for the sizing estimates follows:

1. Obtain the available hourly rainfall data for the gage of interest from the CCCWP or another source such as the National Climatic Data Center (NCDC).
2. Run SYNOP for the available rain gage data. Model parameters include the inter-event time and a minimum storm event size. The inter-event time specifies the minimum duration in which precipitation does not occur, used to define specific storm events, while the minimum storm event is the depth of precipitation generated by a storm below which runoff generally does not occur. For this analysis, an inter-event time of 6 hours (USEPA, 1989), and a minimum storm event size of 0.10 inches were used (i.e., storms of 0.10 inches or less are not considered to produce runoff on average). Model results include average annual statistic and storm events during the period of record analyzed.
3. Rank and average the storm events output by SYNOP (in Excel for example) to determine mean storm size.

SYNOP storm event data (for volume based BMPs) or hourly rainfall data (for flow based BMPs) are used to estimate the % capture for a range of sizing criteria as follows:

1. Import the storm event or hourly rainfall data into a single column in a spreadsheet program (e.g. Excel).
2. Input the sizing criteria in a row above the rainfall (or storm) data. The sizing criteria are typically volumes (acre-feet) or flows (rainfall intensities in inches per hour). The flow criteria are expressed as inches per hour for ease of analysis; the actual flow rate would be the flow expected to result from the given rainfall intensity.
3. Estimate the bypass for each storm or rainfall record in relation to the sizing criteria. For example, with flow based analysis, a rainfall intensity of 0.4

inches/hour and a sizing criteria of 0.3 inches per hour would be expected to results in 25% of the resulting flow bypassing the BMP and 75% of the flow captured and treated.

4. Sum the bypass flows for all given storm or rainfall data points and compare with the total precipitation depth to estimate the % bypass for a given design criteria.
5. Plot the estimated percent capture versus the design criteria to generate a curve.

References:

USEPA, Driscoll, E.D., E. Strecker, G. Palhegyi, 1989. *Analysis of Storm Events, Characteristics for Selected Rain Gauges throughout the United States*.