Yolo County
City / County Drainage Manual
Volume 1 of 2

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Prepared For:

flood SAFE Yolo
Pilot Program

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DEVELOPING INNOVATIVE DESIGN SOLUTIONS

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I. INTRODUCTION

A. BACKGROUND

The Water Resources Association of Yolo County (WRA) and its member agencies[1] adopted the Yolo County Integrated Regional Water Management Plan (IRWMP) in June and July 2007. The IRWMP addressed water management issues for Yolo County that comprises approximately 1,013 square miles in the Sacramento Valley (Figure 1). One of several action items presented in the IRWMP and incorporated into one of eight Integrated Project—The Sloughs, Canals, and Creeks Integrated Project—was the preparation of a drainage manual to facilitate addressing storm drainage through rural and urban areas in a consistent manner.

In June 2007, as the IRWMP was being adopted, the City of Woodland, Yolo County, and the Yolo County Flood Control & Water Conservation District entered into a Memorandum of Understanding (MOU) to work on a pilot program aimed at: (1) developing solutions for reducing risks—a flood and management plan—while providing ecological and recreation benefits; and (2) establishing the administrative infrastructure to implement an on-going program in flood management. The parties to the MOU have named this flood management program the floodSAFE Yolo Pilot Program.

The work plan outlined by the parties to the MOU identified numerous tasks to implement to prepare a flood management program. Certain tasks are regarded as foundational or, in other words, a prerequisite to other tasks comprising the work plan. The task "Develop City-County Drainage Manual" is one of the foundational tasks. Accordingly, this City / County Drainage Manual (Manual) was prepared.

B. PURPOSE

The purpose of this Manual is to provide the guidelines for achieving consistency in criteria and methodology for hydrologic and hydraulic analyses associated with storm runoff between rural and urban areas in Yolo County. This Manual provides the following:

- Updated design rainfall (depth/duration/frequency and distribution patterns) for use throughout the County.

- Rainfall-runoff parameters and methodology, which are consistent between rural and urban areas.

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[1]Member agencies at the time of the IRWMP were: The Cities of Davis, West Sacramento, Winters, and Woodland; the Dunnigan Water District; Reclamation District No. 2035; Yolo County; and the Yolo County Flood Control & Water Conservation District.

- Criteria for addressing storm water quality in a consistent manner between urban and urbanizing areas.

- Criteria for sizing hydraulic structures associated with roads and other infrastructure affecting storm runoff.

- Hydrologic and hydraulic design criteria and guidelines for sloughs, creeks, and other anticipated types of storm drainage facilities, including direction for conveyance (peak) and storage (volume) design considerations.

- Tools for new development located in the unincorporated areas of the County to reduce pollutant discharge to the maximum extent practicable and to protect the beneficial uses of receiving waters.

In addition, the Manual will facilitate urban and urbanizing communities to comply with provisions of the "package" of legislation that became law on January 1, 2008. With that legislation, additional mandates were imposed on local agencies aimed at making more informed land use decisions with respect to flooding. The Manual will facilitate compliance of local agencies with the legislation, which requires amending general plans and zoning ordinances with the provision of 200-year flood protection for new development.

C. LOCAL/STATE/FEDERAL PLANS, POLICIES AND REGULATORY SETTING

It is the intent of this Manual to facilitate compliance and/or coordination with the requirements of local, state, and federal agencies with respect to reducing the risk of flooding to people and property in Yolo County. Accordingly, the relevance of the Manual with respect to the various levels of government is addressed below.

Local

The cities within Yolo County—Davis, West Sacramento, Winters, and Woodland—as well as the County, have design standards and guidelines for addressing flood issues and water quality issues, as well as drainage master plans within their respective areas of jurisdiction.

The information contained within this Manual provides criteria to use in sizing drainage facilities, although it remains the responsibility of each jurisdiction to determine how such issues are to be addressed. These criteria are for the benefit of all jurisdictions within Yolo County and are intended to facilitate coordinated planning to address the handling and management of storm water, particularly where multiple jurisdictions are affected. However, until the criteria or Manual is adopted by the jurisdictional entity, the existing City and County codes and ordinances will continue to govern.

Since there is not currently a comprehensive plan for addressing flooding or flood management within rural/agricultural areas, the criteria within this Manual will contribute to the future development of such a plan. Evaluating existing flooding conditions is the first step in identifying floodplains and problem areas. This step is key to developing alternatives for managing and avoiding adverse impacts, reducing flood risks along roadways, and protecting investments in property and infrastructure.

State

The Central Valley Flood Protection Board (CVFPB), formerly the State Reclamation Board, has jurisdiction of levees in the Central Valley and Yolo County that are part of the State Plan of Flood Control. In Yolo County this includes levees along the Sacramento River, Yolo Bypass, Colusa Basin Drain, Knights Landing Ridge Cut, Cache Creek, Willow Slough Bypass, and Putah Creek. The role of the CVFPB is to oversee any proposed project within the boundaries of the Sacramento-San Joaquin Drainage District (Figure 2) that will change the structural integrity or physical properties/dimensions of the levees under its jurisdiction or the watersheds affecting them, in an attempt to ensure that the existing levee integrity is not compromised. Most of the levees noted above were constructed by the U.S. Army Corps of Engineers (USACE); however, once completed the ownership and responsibility for inspection and maintenance is assumed by the CVFPB. The CVFPB in turn works with local agencies in some areas to have the inspection and maintenance performed.

In order to work on any levee under the CVFPB's jurisdiction, an encroachment permit must be obtained, defining the work to be done as well as the impacts of such work to the environment, to flood risk assessments, and increased risk to any affected properties.

Recent Senate and Assembly Bills – SB 5, SB 17, AB 5, AB 70, AB 156, and AB 162

With the overall heightened awareness of the risk to people and property protected by levees, the State Legislature passed a package of bills aimed at reducing the risks associated with flood protection levees. This package included: Senate Bill 5 (Mike Machado), Senate Bill 17 (Florez), Assembly Bill 5 (Lois Wolk), Assembly Bill 70 (Jones), Assembly Bill 156 (John Laird), and Assembly Bill 162 (Lois Wolk). These bills were all signed by Governor Schwarzenegger on October 10, 2007, and became law on January 1, 2008.

With the understanding that areas protected by levees are subject to risk, the legislation, Senate Bill 5 in particular, elevated the level of protection to be afforded by levees of the State Plan of Flood Control to urban or urbanizing areas. Although it is not the intent of this Manual to address levees per se, it is important to note that the legislation does not make a distinction between flooding associated with levees or flooding from other sources. Accordingly, excerpts are extracted from Senate Bill 5 to highlight the mandate for flood protection for urban and urbanizing areas that is greater than that associated with commonly used criteria of the Federal Emergency Management Agency (FEMA) for 100-year protection. Accordingly, the following are noted with respect to flood protection for urban areas:

- The bill imposes a state mandated local program. Each city and county within the Sacramento-San Joaquin Valley, within 24 months of the adoption of the Central Valley Flood Protection Plan by the CVFPB (not later than July 1, 2012) is to amend its general plan to include data and analysis contained in that flood protection plan; goals and policies for the protection of lives and property that will reduce the risk of flood damage; and related feasible implementation measures. Each city and county, within 36 months of the adoption of the flood protection plan, but not more than 12 months after the amendment of the general plan , is to amend its zoning ordinance so that it is consistent with the general plan, as amended.

- The Department of Water Resources (DWR) is to develop, for adoption and approval by the California Building Standards Commission, updated requirements to the California Building Standards Code for construction in areas protected by facilities of the Central Valley Flood Protection Plan, where levels are anticipated to exceed 3 feet for the 200-year event.

- Cities or counties are not to enter into a development agreement for any property that is located within a flood hazard zone unless the city or county finds, based upon substantial evidence in the record, that the facilities of the State Plan of Flood Control or other flood management facilities protect the property to the urban level of flood protection in urban and urbanizing areas or the standard of flood protection of the FEMA National Flood Insurance Program (NFIP) in non-urbanized areas.

FloodSAFE California

DWR is providing the leadership to implement FloodSAFE California and is to work with local, regional, state, tribal, and federal officials to improve flood management and emergency response systems throughout California. Funding for this effort is available through two bond measures, Proposition 1E and Proposition 84, which were passed by the electorate in 2007. Activities that are underway that are particularly relevant to Yolo County include:

- Central Valley Flood Protection Plan

  DWR is preparing the Central Valley Flood Protection Plan, which is to be presented to the CVFPB by January 1, 2012, and adopted by the CVFPB by July 1, 2012. DWR intends, in the preparation of the Plan, to obtain input from the local and regional communities. This provides an opportunity for the local and regional communities to help tailor the Plan to provide flood risk reduction and flood management projects and programs to best fit their needs.

- Central Valley Floodplain Evaluation & Delineation Project

  The Central Valley Floodplain Evaluation & Delineation Project (CVFED) will make available significant resources to communities in Yolo County. This will include: (1) detailed topographic data (equivalent accuracy for 1-foot contour interval); (2) new hydrologic and hydraulic models for Cache Creek, Willow Slough Bypass, Putah Creek, Yolo Bypass, and the Sacramento River; and (3) detailed floodplain mapping for the 10-, 50-, 100-, 200-, and 500-year events for areas protected by or influencing levees of the State Plan of Flood Control. This information should be available by January 31, 2011.

<u>Federal</u>

The Federal Government oversees the administration of flood insurance through the NFIP, administered by cooperative agreement between communities (cities and counties) and FEMA. FEMA agrees to provide mapping and flood insurance studies, develop Flood Insurance Rate Maps (FIRMs), and supportive assistance for communities, when funding is available, to identify flood hazards and to provide access to flood insurance for citizens living within communities participating in the NFIP. The community is responsible for administering the NFIP. Communities, as the building authority, agree to maintain control of changes to the floodplain within their jurisdictions by requiring studies and submittals for proposed development to mitigate negative impacts to flooding hazards where third-party properties are being impacted. Preventing injury or loss of life due to flooding is the priority for any local government.

For many decades there have been areas where levees were assumed to protect lands behind them, where FEMA "grandfathered" the integrity of levees if they were constructed by its sister agency, the USACE. Recently, the integrity of these levees has come into public question, particularly with the failure of levee systems designed by the USACE, such as in New Orleans during Hurricane Katrina, and with closer scrutiny of underseepage potentials.

Just prior to Hurricane Katrina, FEMA began addressing the issue of how much protection levee systems could reliably provide, and released a Procedural Memorandum #34 (FEMA 34), which requires levees to be re-evaluated before the structural integrity can be relied upon to help protect properties from damage. In order for such levees to be considered certified and mapped under the NFIP, they must be proven to provide protection in accordance with the latest standards, with all necessary structural testing and analysis to support such claims. FEMA 34 clearly lays out a procedure for communities to establish if the levees are certifiable. If the levees cannot be certified, it provides the opportunity for FEMA to return and remap areas with flood hazards where none were previously thought to exist. While there is no specific FEMA timeline for remapping flood hazards where levees should be treated as failed/removed, the procedural memorandum clearly defines this as imminent if communities cannot demonstrate the levees protecting them are certified. FEMA's focus will first fall on urbanized areas where there are large populations and significant inhabited properties potentially at risk. FEMA may not have a timeline for when it will reach all areas, mostly because the effort is so great and federal funding is cyclical, but Yolo County has received preliminary maps that will become effective in 2009. Of significance with the preliminary FIRMs is that FEMA, based upon information available from the USACE and local agencies, has determined that no levee in Yolo County qualifies as accredited. Thus, the new FIRMs will reflect flooding based upon this determination.

USACE Standards

Currently, the standards for evaluating the structural integrity of state/federal levees are established by the USACE. The process for establishing if a levee is certifiable is very involved. The interior (core) of the levee and subsurface (foundation) conditions must be tested by boring into the levee at specific intervals and examining/testing/classifying the material within the levee. The levee must be measured to determine its structural cross-section dimensions as well as the physical conditions and geometric cross sections of the river on one side, and the elevations of the landside toe outward for some distance. All the physical conditions affecting the levee's ability to withstand flooding stresses are quantified, such as determining the expected flow and erosive conditions within the river; reviewing the vegetative conditions on the levee slopes (waterside and landside) and levee crown; identifying/documenting the inspection, operation, and maintenance practices of a responsible overseeing entity; seismic conditions; underseepage and through seepage potential to boil and mobilize structural material out of the core and/or foundation of the levee; etc. Every aspect of potential failure must be examined and accounted for. Currently, the USACE takes all this information and performs a risk and uncertainty analysis to assert how much confidence can be placed in the levee to withstand adverse conditions. Formerly, levees were evaluated in a "deterministic" manner with design storm conditions and physical freeboard added to account for uncertainty. FEMA is considering the risk and uncertainty methodology, and both the USACE and

FEMA are working together to come to a mutual decision on how best to consider a levee certified.

The USACE can certify a levee and submit the technical documentation to FEMA, whereby FEMA will accredit the levee as certified on its mapping. Qualified and licensed civil and geotechnical engineers can also certify levees on behalf of their clients (public or private) and submit the certification to FEMA for accreditation. If levees cannot be certified and accredited, lands afforded protection by these levees will be analyzed and mapped by FEMA and placed into a special flood hazard area, as funding becomes available, potentially affecting some of the lower elevations of Yolo County.

II. DESCRIPTION OF PHYSICAL CONDITIONS

A. TOPOGRAPHY

Yolo County is located within the Sacramento Valley (Figure 1). The terrain generally slopes from west to east. The approximate ground elevations range from a maximum El. 3000 in the western portions of the County, to a minimum El. 0 (near the Sacramento Delta). Detailed topographic data was obtained by DWR in March/April 2008, under its CVFED Project. Additional data, having the same accuracy as that obtained by DWR, was obtained under the floodSAFE Yolo Pilot Program at the same time. Through this combined effort, the entire valley portion of Yolo County, including Capay Valley, will have new topographic data based on NAVD 88 datum. Once compiled, this data will be available to public agencies.

B. LAND USE

The proposed land use within the Cities of Winters, West Sacramento, Woodland, and Davis are contained within their respective General Plan documents. The County is in the process of revising its General Plan and anticipates completion in 2009. Any and all considerations for calculating/depicting drainage should account for known existing land use and future planning through the latest version of these respective documents. The guidelines presented in this Manual are intended to be used in conjunction with local standards and governing planning documents.

C. SOILS

Based upon data prepared by the U.S. Department of Agriculture, Natural Resource Conservation Service (NRCS), published (undated) over the internet at the California office of the NRCS, the soils within Yolo County are generally classified as Hydrologic Soil Type B, C, and D, except where Soil Type A is present within the Cache Creek channel areas. These general hydrologic soil group areas (derived from the NRCS studies) depict runoff characteristics for drainage considerations/ calculations. The soil types are defined as:

- Soil Type A – Soil that has a high infiltrative capacity, even when thoroughly wetted, and thus has the lowest potential for runoff.

- Soil Type B – Soil having a moderate infiltrative capacity when thoroughly wetted and a moderate runoff potential.

- Soil Type C – Soil having a slow infiltration rate when wetted and a high runoff potential.

- Soil Type D – Soil having a very slow infiltration rate and a very high potential for runoff.

Since this soil data is fully defined, free, and available (presumably indefinitely) each user should refer to the most up-to-date NRCS documentation for specific area delineations. Figure 3 is provided for illustrative purposes only as part of this Manual, with geo-referenced detail soil data available for the entire County to be used for design being readily available from its source. The following Website provides the link for obtaining Yolo County soil data:

http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm

D. GROUNDWATER ELEVATION

The WRA and its member agencies support a countywide groundwater monitoring program that is managed and maintained by the Yolo County Flood Control & Water Conservation District in cooperation with DWR. Groundwater elevations need to be considered when designing and constructing storm drainage facilities. From a review of historic groundwater information, Spring 1996 was selected to represent the groundwater conditions for general planning as it represents generally high groundwater levels. Presented on Figure 4 and Figure 5 are the groundwater levels as represented by contours for the Spring and Fall 1996, respectively. Since the groundwater table fluctuates from year to year and within the year, groundwater levels should be evaluated on a case-by-case basis, particularly in sizing, siting, and constructing storm drainage facilities.

E. DESIGN PRECIPITATION

Background

As part of the efforts to develop the Covell Drainage Study (1993), prepared by Borcalli & Associates on behalf of the Yolo County Flood Control & Water Conservation District, Mr. Jim Goodridge (former State Climatologist) was hired to develop design rainfall for Yolo County, as the basis for hydrologic and storm runoff analyses. Since its publication, this design rainfall has been utilized across the County and has been incorporated into the drainage design standards for the City of Woodland and the City of Winters, as well as the Yolo County Airport. Currently, the City of West Sacramento, due to its hydrologic proximity to Sacramento County, has adopted much of the Sacramento County drainage and precipitation standards to represent or otherwise approximate design rainfall within its city limits.

As part of the efforts of floodSAFE Yolo, originally developed as part of an IRWMP, it was identified that the 1991 design precipitation required updating, incorporating as much of the last two decades of data as possible as part of the evaluation. The efforts

under this Manual include updating the design precipitation for the entire County, carrying forward Goodridge's work in close consultation with him.

<u>Methodology</u>

Goodridge refined the statistical evaluation of rainfall gage data for Yolo County in a report published in 1991, by using the available gage data within the County to define the statistical relationships with Mean Annual Precipitation (MAP) and storm recurrence specific to the County. For this Manual, essentially all known individual rainfall gages within the County and within a 15-mile buffer outside of the County line have been evaluated both independently and collectively in order to determine the regional relationships between rainfall magnitudes, recurrence intervals (storm return periods), and storm durations. Following Goodridge's methodology, which is based upon accepted statistical methods, allows the user to review a map to obtain the average (mean) annual rainfall and the coefficient of variation (Cv) value for any location and to calculate the depth/duration/frequency for that location.

Each data gage's period of record is first processed to determine the maximum recorded increment of precipitation (different measured increments include 5-minute, 15-minute, 1-hour, and daily recordings) for each year of record, and then the average of all the annual maximum precipitations for each gage is calculated using all years of record. The pertinent statistical factors including the Skew (sk) and Coefficient of Variation (Cv) are then calculated for each gage. Before calculating the values for each recurrence interval and storm duration, the skew and coefficient of variation is regionally averaged and reintroduced at the individual gage level in performing the final depth/duration/frequency calculations.

With each gage's individual depth/duration/frequency relationship established, these values are statistically adjusted and averaged throughout the County to quantify the regional relationship between average annual maximum daily rainfall and MAP (also calculated independently at each gage). Gages with longer periods of records were utilized to establish this regional relationship since longer periods of record most accurately capture MAP and reflect this relationship. A second regional relationship between maximum annual data and storm duration was developed by utilizing all the maximum annual data for each gage, averaging them across the County, and plotting them in log form relative to the corresponding storm duration expressed in the log value of the duration (minutes). For example, if a particular gage measured rainfall in 1-hour increments, then the maximum recorded 1-hour rainfall for each year could be determined as well as the maximum 2-hour (consecutive) rainfall and subsequent longer storm durations. For each gage, the average of these annual maximums could be calculated, and the average of all the gages with 1-hour data could be averaged. Gages measured in daily increments cannot be used to express hourly maximums.

Data Sources

Goodridge has already accumulated most of the available rainfall data for California from the major sources, which include the California Data Exchange Center (CDEC - operated by DWR), the California Irrigation Management Information System (CIMIS - operated by DWR), the National Weather Service (NWS), the National Oceanic and Atmospheric Administration (NOAA) through the National Climatic Data Center, and the U.S. Forest Service Remote Automated Weather Stations System.

Goodridge developed a Coefficient of Variation (Cv) map at 0.1 degree (latitude/ longitude) grid intervals. The regional derived map is used as part of the location-specific calculation for rainfall depth/duration/frequency.

The MAP mapping has nationally been developed in gridded format through the PRISM (Parameter-elevation Regressions on Independent Slopes Model) system, developed in cooperation with the Oregon State University system, and is available through the internet. The MAP values generated through PRISM mapping are intended to account for orographic effects as well as other climatic processes in estimating the average rainfall for any location.

Statistical Methods

The individual gage level depth/duration/frequency evaluations utilize the statistical Pearson Type III distribution methods, as documented by G.W. Kite in his book entitled, "Frequency and Risk Analysis in Hydrology," published by Water Resources Publications, copyright 1988. Tables of precipitation depth can be calculated with different coefficients of skew and probability (return period) according to the following formula:

$$P_{ij} = (Q + F*MAP)*(1 + K_j*C_v)*Ti^M$$

Where:

P_{ij} = Design precipitation for return period j and storm duration i
Q = y intercept of the data trend line comparing
F = Slope of the trend line comparing the MAP of each long record gage to its respective average annual maximum daily rainfall.
MAP = Mean Annual Precipitation for the location being analyzed ($(Q + F*MAP)$ = Fraction of MAP occurring in the average maximum day)
K_j = Frequency factor for the Pearsons Type III distribution. Frequency factors represent the number of standard deviations in excess of the mean.

Return Period (Years)	K_j
2	-0.180
5	0.745
10	1.341
25	2.066

50	2.420
100	3.087
200	3.575
500	4.300
1000	4.673
10000	6.185

C_v = Design value of the Coefficient of Variation, derived from all the rainfall gage data in California and calculated by Goodridge for California at 0.1 degree resolution.

T_i = Time expressed in days of the storm duration being calculated.

M = Slope of the trend line relating the log value of the rainfall duration versus the log value of the corresponding adjusted average annual maximum rainfall.

Analysis

The list of rainfall gages utilized for the County's analysis is provided on Table 1. The data derived from these gages was used to develop the relationship between mean annual rainfall, as measured at each gage, and the average annual maximum daily rainfall at each gage (Figure 6). The slope (F) and intercept (Q) of the trend line from this figure is utilized in the regional formula, which translates the MAP values from PRISM to a predicted maximum rainfall/recurrence. The data from all the gages was also used to determine the general regional relationship of rainfall duration with correlating average maximum rainfall (Figure 7). The slope of the trend line from Figure 7 represents the factor M in the formula representing the County's design rainfall.

Figure 7 provides averages of all the gage values for the respective rainfall durations and plots the log value of each to the log value of the corresponding rainfall duration. Each gage that measures daily data will have a maximum daily value for each year of record. All maximum values from all the years of record of that gage can then be averaged to obtain the average annual maximum daily rainfall. As described above, this value is not necessarily accurate as 24-hour rainfall storms do not always fall from midnight to midnight, so they must be adjusted in accordance with DWR's Bulletin 195 for fixed interval corrections. In looking at all the gages as a whole, the rainfall characteristics specific to Yolo County are represented and can be applied to the prediction of rainfall as a fraction of the MAP for areas within Yolo County.

Results

The following formula represents the County's rainfall depth/duration/frequency:

$$P_{ij} = (-0.0974 + 0.1212*MAP)*(1 + K_j*C_v)*Ti^{0.4227}$$

A hard copy of the map representing the PRISM MAP values across Yolo County as well as the regional Cv values for the County is presented on Figure 8. This figure is a printout of an interactive GIS-based design precipitation tool developed by Wood Rodgers, Inc. Within ARC GIS (Version 9.2 – earlier versions available upon request), the County is geographically referenced (geo-referenced) in the Geographic Coordinate System GCS_North_American_1983 (degree units) and any user can locate their geo-referenced project drainage shed boundaries and obtain a completed design precipitation table that is location-specific and lists depth of rainfall for a range of design storm durations and corresponding storm recurrence intervals. With larger sheds, multiple tables may be necessary to represent the design rainfall. The interactive table linked within GIS utilizes the formula shown above and uses the location-specific PRISM MAP value and C_v value to populate the formula throughout the table. The interactive design precipitation GIS product is provided on the CD at the back of this Manual. If GIS software is not available to the user, an AutoCAD 2004 drawing is provided on the CD depicting gridded polygons representing the variable PRISM and C_v data across the County within the California State Plane Zone 2 coordinate system. Each user can then calculate the values for design precipitation (depth/duration/frequency) and create a table manually using the appropriate frequency factor (K_j above) and the storm duration desired.

F. STORM CENTERING

Substantial effort has been expended by hydrologic and meteorological experts to account for the effects of physical and temporal storm pattern variations in watershed response and, ultimately, in peak flow and flooding determinations. It is common when developing estimates of storm runoff, to attempt to account for the entire variability of the natural environment by defining a reasonable bounding limit. In doing so, design predictions are often conservative because of the unpredictability or complexity of a particular system. Rainfall measurements have been and continue to be physically measured at repetitive point (gage) locations, and these measurements are accumulated and analyzed locally and regionally. Even with detailed radar reflectivity, the veracity of radar measurements is adjusted based upon hard measurements of rainfall that are known to reach the ground (through gages), as radar can also measure storm moisture that stays in the air. Any future precipitation estimation will certainly use both point gage and radar information.

While specific rainfall amounts have been analyzed at point locations, the anticipated coverage area of a "storm" has been less studied. There are current efforts (nationally) being considered in using radar to help understand areal (based upon watershed "area") precipitation application using point rainfall measurements/ estimates. Experts and laymen agree there should be a maximum area and minimum area of consideration for rainfall when analyzing storms. It does not generally rain over the entire earth at one time or to any significant degree over very small areas. This section is intended to provide guidance regarding where storm centering may be considered and where/how it may be unrealistic to apply.

Storm centering is a modeling technique for modifying the application of rainfall within a watershed by focusing rainfall in some manner within a smaller portion of that same basin. Storm centering techniques are intended to account for the probability of higher intensity cells of precipitation that are present within larger storm systems. It is generally agreed upon by hydrologists that rainfall amounts can be very different depending upon elevation, proximity to a large water body, temperature, and proximity to adjacent higher elevations. These effects are referred to as "orographic" and are generally physical in nature, with respect to the watershed.

The concept of storm centering can be somewhat subjective in its application; however, it should not violate the basic physical limitations of a watershed. Storm centering should attempt to adjust for random variability within a storm and not for physical variability that is more predictable and tied to location. For example, if a watershed is large enough to have significant measured variation of rainfall, with much higher rainfall in upper elevations and lower precipitation in valley areas, then it is unreasonable to refocus rainfall volume from upland areas directly upon valley lands. Of course, the upland areas will contribute to flooding within valley areas via runoff through major streams and rivers, but the more intense rainfall of these upland areas cannot unilaterally be moved and forced to rain upon valley areas since the regional orographic mechanisms (physical constraints) will generally prevent this from occurring.

Consistent with jointly published HydroMeteorological Reports (HMR58 and HMR59) for probable maximum precipitation, published through the National Oceanographic and Atmospheric Administration (Department of Commerce) and the USACE (Department of Defense), these guidelines recommend that any watershed with less than 10 square miles of area is small enough that storm centering techniques of redistributing areal precipitation coverage are not necessary. Also, for watersheds of less than 10 square miles, no general areal reduction factor (watershed-wide) need be considered.

For watersheds between 10 square miles and 500 square miles in total area, hydrologic studies should evaluate the overall watershed by centering the rainfall for the entire watershed over each major tributary area greater than 20 percent of the watershed being evaluated, to determine if focusing the watershed's rainfall over one portion of the watershed yields a higher downstream result. It is important to note that "main stem" modeling should not be used to represent peak flow conditions for the tributary alone, but should only be used in evaluating the larger downstream watershed with its redistributed rainfall. Ideally, each tributary should also be evaluated in a "stand-alone" manner to determine the peak conditions along the reach of a tributary, with the appropriate areal reduction (based upon the tributary area only) factor applied from HMR 58. For example, if a watershed is 75 square miles, and has three tributaries, with 15 square miles, 25 square miles, and 35 square miles, then each tributary would have two different areal reduction factors, one for its inclusion in the 75-square-mile watershed, and one for its stand-alone watershed if the

tributary were also evaluated alone, using the tributary's area as the "total watershed area."

The method for centering the watershed precipitation should follow the procedure of developing elliptical isohyets as described in HMR 58, using the tables associated with a 6-hour to 1-hour storm ratio of 1.3 (HMR 58 Figure 2.24). However, the County evaluations should use the design precipitation values from these standards (Section II.E.) rather than the 1-hour Probable Maximum Precipitation values from HMR 58, as the procedures from HMR 58 were developed for establishing Probable Maximum Precipitation. The mathematical definition of the elliptical isohyets is not provided in HMR 58; however, the length (L) to width (W) ratio from HMR 58 is measured at approximately 2.023:1. With this relationship and the areas of each ellipse shown on HMR 58, Figure 2.20 (Figure 9 this report), the shape of each successive (expanded but with the same center point) ellipse can be calculated mathematically and developed utilizing the formula for the area of an ellipse:

$$(\text{Area} = 3.14159265ab, \text{ where } a = L/2 \text{ and } b = w/2).$$

The "A" isohyet should roughly be placed over the centroid of each tributary being evaluated as well as the centroid of the overall watershed for the larger watershed study. For watersheds with greater than a 6-hour time of concentration, utilize the values associated with a storm duration of 6 hours for adjusting the estimated precipitation previously mapped under Section II.E., within each respective isohyet. The HMR table providing these isohyet adjustment values (HMR Table 2.13 – current October 1998 edition) is copied and provided on Table 2 of this Manual.

For watersheds with greater than 500 square miles of area (Cache Creek watershed is approximately 1,110 square miles, but is located mostly outside of the County), only the general areal reduction factor from HMR 58 need be applied to the design precipitation (unreduced) derived from Section II.E., of this Manual. Most watersheds entirely within the County are between 10 and 200 square miles in size. The variability of design precipitation, accounting for orographic effects through the PRISM-adjusted design precipitation, should govern "centering" considerations in these cases. For larger watersheds, greater than 20 square miles, it is possible that storm centering will not produce a higher runoff rate since the centering isohyets actually reduce the volume of precipitation over the entire watershed as evidenced on Figure 10. As storm centering techniques become better understood and defined, possibly with the use of radar, these guidelines may be amended to refine or redefine how precipitation may be applied.

Areal reduction factors for the Valley Regions from HMR 58 are provided on Table 3. While a small portion of the western extents of Yolo County could be considered within the Mid-Coast Region, the vast majority of the County is within the Valley Region of HMR 58, thus only the values from Table 3 should apply. For evaluations of watersheds with major tributary areas outside of the County, the

proponents of such evaluations should utilize the described methodologies for centering, but utilize the best design precipitation available for said areas. Currently NOAA is planning on having its updated California-wide precipitation frequency published sometime in 2009/2010 under Atlas 14. It is assumed that NOAA will make this information available through its data server at the following Website:

http://hdsc.nws.noaa.gov/hdsc/pfds/

Solano County has developed similar design precipitation, using work also by Goodridge, as published in their Hydrology Manual available as a .pdf through the Solano County Water Agency Website:

http://www.scwa2.com

In other areas without any alternative precipitation frequency estimates available, the PRISM MAP values can be obtained (extended) into areas adjacent to Yolo County and the formulas specific to the County that derive frequency precipitation from the MAP may be applied.

G. REGIONAL FLOODING

The valley portion of Yolo County historically and even today experiences widespread flooding during moderate to high rainfall events. The extent of flooding is best illustrated by a composite of the effective FEMA FIRMs for the County (Figure 11).

As noted previously, FEMA is in the process of updating the FIRMs for Yolo County and new effective FIRMs are expected to be published late 2009.

III. STORM DRAINAGE DESIGN CRITERIA AND STANDARDS

Information regarding historic and current hydrologic methodologies, data, precipitation, and design standards used within the region were gathered and evaluated in development of this Manual. Based upon review of the available information, design criteria and standards for flood control and surface water quality treatment were developed for performing drainage/floodplain analyses and preparing flood risk reduction and storm drainage plans.

This Manual is to provide guidelines for the evaluation and design of storm drainage facilities throughout Yolo County. Accordingly, it is important to recognize the unique aspects of the storm drainage system within the County. A large part of the County outside the influence of the State Plan of Flood Control is characterized by sloughs, canals, and creeks. Some are in a near natural state, however, most have been influenced by development activities. For purposes of this Manual, a distinction is made between facilities or features in largely rural areas of the County and those within urban or urbanizing areas of the County. Both areas are addressed below.

Rural Areas

The waterways in the rural areas that convey storm drainage or runoff are not the product of design, but rather the results of the influences of man and hydrologic events or some combination thereof. In any case, what is there is there. As noted, flooding in the rural areas is widespread. The channels that convey storm runoff have limited capacity and overbank flooding due to limited conveyance capacity or limited capacity of structures or encroachment is common. As concluded in a report prepared by the Yolo County Floodplain Working Group on storm drainage and flooding in Yolo County in 1997, flooding in the rural areas of the County should be addressed with non-structural measures rather than seeking structural solutions, which would not be cost effective. Although some damage does occur, it was concluded that most "problems" appeared to be in the category of inconvenience resulting from flooded roads. There is no common design event that should be considered for "blanket" coverage in the rural areas. What is important is that widespread flooding is characteristic of the rural areas of the County and that maintaining and managing those floodplains is in the best long-term interest of the County.

Guidelines for addressing storm drainage and flooding in rural areas include the following:

- Evaluate the hydrology and hydraulics of the system/features of interest.

- Determine the existing conveyance capacity of the system and select a nominal design event for purposes of hydraulic continuity.

- Delineate the floodplain associated with "overbank" flows from the system or feature.

- Develop a management plan for the system that accommodates hydraulic conveyance, floodplain management, public safety, and gives full consideration to ecosystem benefits, recreation, and ongoing maintenance.

- Integrate elements, where appropriate, into the County's Local Hazard Mitigation Plan and Emergency Preparedness Plan.

In summary, it should be recognized that each waterway is unique and should be dealt with accordingly. The criteria and methodologies set forth in this Manual can be applied to hydrologic and hydraulic analyses appropriate for evaluating, planning, and designing facilities for storm/flood management in rural areas.

Urban and Urbanizing Areas

Within areas considered to be urban or urbanizing, there are different types of drainage facilities to serve different purposes. These may require design at different levels of performance or flood protection, water quality treatment, and/or maintenance and operation, and it is appropriate to define various types of drainage facilities. To be consistent with other drainage plans in the region, the definitions adopted for application in this Manual includes the following two categories:

- Regional Drainage Facilities – Runoff corridors, channels, culverts associated with channels, bridges, detention ponds, pump stations, and levees. Generally, these facilities serve as regional or "backbone" infrastructure for general or specific plan areas.

- Local Drainage Facilities – Roadside ditches, storm drainage pipe systems, and overland conveyance systems. Generally, these facilities serve as on-site facilities that are tributary to regional facilities.

The design standards and criteria developed for this Manual are intended to be acceptable and usable to all parties with jurisdiction over drainage and flood control for the area.

A. DESIGN CRITERIA FOR PUBLIC SAFETY

From the standpoint of public safety overriding criteria for the design of storm or flood management facilities, there are two criteria that dictate the level of flood protection to be afforded citizens of the County. These relate to FEMA's criteria under its NFIP and the State legislative mandate under Senate Bill 5, which became law on January 1, 2008. Both items are addressed below.

FEMA's NFIP

In addition to complying with the local cities and/or County standards, drainage facilities shall comply with FEMA criteria. Although FEMA's criteria is commonly accepted as a threshold for public safety, it should be noted that this criteria is for insurance purposes only. These criteria and standards include, but are not limited to:

- One foot of freeboard to existing ground in the 100-year storm event for open channels and ponds.

- Minimum three feet of freeboard in the 100-year storm event for levees with increases in freeboard adjacent to bridges and at the upstream and downstream ends. The geometry and structural integrity of levees must be certified for accreditation by FEMA in accordance with 44CFR 65.10.

- Back-up power and redundant pump capacity for pump stations.

- Finished floor elevations one foot above the base flood elevation (100-year storm event).

- The County is a participant in the National Flood Insurance Program and all development in the County shall comply with the regulations of FEMA. Amendments or revisions of FEMA flood maps will be required for all commercial and subdivision development located in Federal Special Flood Hazard Areas (Zones A, AO, A1-30, AH, A99, or AE) flood zone. Petitions for a Letter of Map Amendment (LOMA) or Letter of Map Revision (LOMR), including any fees required by FEMA, shall be submitted to the Yolo County Department of Planning and Public Works (Department) before improvement plans are approved. These regulations do not preclude the Department from requiring additional standards to protect the public from projected runoff.

- Fill for removing land from a designated FEMA 100-year floodplain, or a watercourse where building pads will be created, must be compacted to 95 percent of the maximum density obtainable with the modified proctor test method (ASTM Standard D-1557), or an equivalent test method.

State of California

For urban and urbanizing areas within the Central Valley, a 200-year level of flood protection is required. This criteria is applicable to communities that have 10,000 or more residents, or communities where it is planned or anticipated to have 10,000 residents or more within the next 10 years. The 10-year time frame is always a "look

ahead" time frame.   A jurisdiction has the discretion to apply this criteria to communities of less than 10,000.

Although DWR will be developing guidelines for 200-year criteria, the criteria is not available at this time.   Accordingly, 200-year design criteria as set forth in this Manual is similar to FEMA's, except as follows:

- One-half foot of freeboard to existing ground in the 200-year storm event for open channels and ponds.

- A minimum of two feet of freeboard in the 200-year event for levees.

- Finished floor elevations at least one-half foot above the 200-year flood elevation.

B.   REGIONAL DRAINAGE FACILITIES

Regional drainage facilities include conveyance, flood protection, water quality treatment, recreational, environmental, and aesthetic elements, which may consist of channels, culverts associated with channels, bridges, detention ponds, pump stations, and levees.

Regional drainage facilities should meet objectives consistent with the General Plan for each respective jurisdiction affected. In most cases, an analysis of the 10-year and 100-year storm events will provide the information necessary to design and evaluate the existing and proposed drainage system. The duration of the storms used in the analysis should represent the worst-case flooding scenarios with respect to peak flows and peak volume. The facility design should be evaluated under a 200-year storm to determine levels of protection are met under the 100-year and 200-year criteria as set forth in Section III A. As such, long duration storms (36-hour, 5- and 10-day) for 100-year and 200-year events, should be evaluated and compared with the 24-hour 100-year and 200-year events, to determine whether runoff volume or peak discharge is of the most importance.

Hydrology – Design Flow

Within the event, there have been hydrologic/hydraulic models developed for portions of the watershed including the Colusa Basin Drain, as well as Cache Creek, Willow Slough, the Yolo Bypass, and the Sacramento River.   There has not been one comprehensive hydrologic evaluation of the entire County to date, to include all rural flooded areas. Such a comprehensive evaluation is contemplated as part of the future planning and these criteria, or update thereof, shall be used to develop such hydrology in the future.   The proposed model will utilize HEC-HMS, a computer program developed by the USACE, which has been applied throughout the United States and other countries.   HEC-1, its predecessor, is also a valuable tool used to calculate, route, and combine runoff hydrographs and is acceptable under the proposed criteria.

Both methods are based upon accumulated applied rainfall, while applying infiltrative losses and routing flows to reflect volume and timing in the accumulation of runoff throughout the watershed.

For evaluation and design of Regional and Local drainage facilities within the County, the modeling methods presented in Table 4 shall apply.

Design Capacities

Drainage facilities shall be designed to accommodate future development consistent with adopted general plans. The future development shall be defined as full build out of the General Plan land use designations.

The capacity design criteria for Regional drainage facilities are as follows:

Water Quality Treatment Volume

Storm water runoff carries with it many pollutants in varying concentrations that are suspended and/or dissolved in runoff. As property is developed, Best Management Practices (BMPs), discussed in detail under Volume 2 of this manual, provide an opportunity to reduce the loading of pollutants to receiving waters.

Storm water runoff would normally convey a disproportionate loading of pollutants in the initial period of runoff during a storm event, under any urbanized setting, even if the population is not substantial enough to be classified as an MS4 Community. This initial period is usually the most critical and is commonly referred to as the "first flush." The "first flush" contaminants most frequently associated with storm water include sediment, nutrients, bacteria, oxygen demanding substances, oil and grease, other toxic chemicals, and floatables.

Detention ponds designed to address storm water quantity can include water quality treatment elements to minimize potential impacts to the quality of surface runoff entering receiving waters. Both dry and wet pond configurations can be used to provide water quality treatment and should be consistent with Volume 2 of 2 of this Manual.

Storage Facilities

Storage facilities, where volume rather than peak flow generally governs the size, shall be designed to contain or attenuate a 10-day 100-year storm event, while maintaining at least one foot of freeboard in the pond and attenuate a 10-day 200-year event while maintaining at least 0.5 foot of freeboard, and without creating excessive backwater effects on the tributary drainage storm system. Shorter duration 100-year and 200-year storms (24-hour, 36-hour, and 5-day) should also be evaluated to test the sensitivity of the system and to determine which storm duration shall govern the

design for a particular site. Basin outfall facilities shall be designed to restrict flow to the satisfaction of the respective jurisdiction.

Publicly-maintained regional detention basins/ponds shall include a minimum 20-foot perimeter buffer with an all-weather access road. The access road shall allow an adequate turning radius for maintenance vehicles. Ramps to the bottom of the pond with 10 percent maximum slope shall be provided. The side slopes of the pond shall be 4:1, or flatter. For detention ponds designed to fully drain, the bottom shall be sloped at 2% minimum, or as approved by the City/County Engineer. Steeper ramp and side slopes will only be allowed under special approval of the respective City or County Engineer or public works director having jurisdiction, and will require fencing for public safety.

For detention ponds that incorporate lake features, a lake/wetlands consultant shall be retained to provide detailed information regarding the operation and maintenance elements of the entire facility.

Pump Stations

To the extent possible, gravity systems are preferred over systems that rely on storm drainage pumping. Where pump stations are employed, they shall be designed to discharge the design capacity using a minimum of two equal-sized mixed-flow vertical pump and motor units. A redundant pump and motor unit of equal size shall be included as a backup. An attempt shall be made to control the outflow from pump stations for storm events equal to and less than the 100-year storm event by staggering the "set point" for initiating pump operation, to provide a reasonable downstream flow pattern similar to existing conditions. Pumps shall be designed to operate sequentially to prevent the continued use of a single pump unit under low-flow conditions.

The sump for each pump station will be sized according to the "Hydraulic Institute Standards for Centrifugal, Rotary, and Reciprocating Pumps." Storm water will be conveyed from the detention pond into the sump through an open inlet section. Before entering the pump vault, the storm water shall pass through a power-driven catenary trash rack system. The invert of each sump shall be lower than the invert of the pond or intake channel so the detention pond can be completely dewatered to facilitate maintenance.

Typically, each pump shall discharge into a separate pipe that includes a combined siphon breaker and air relief valve at the high point on the discharge pipe, and a flap gate with headwall at the terminal structure in the drain. Where discharge lines tend to be long (over 200 feet), or where the discharge line must cross under existing drains, roads, or railroads, the discharge line shall be manifolded to discharge through a single pipeline. Electrical control equipment shall be enclosed in a prefabricated metal or concrete block building on a concrete foundation with minimum outside

dimensions 8 feet wide by 20 feet long. The electrical equipment shall include pump controls, water-level detection system, float switch for sump high-water level alarm and low-level automatic shutoff, solenoid-controlled automatic pump motor oiler, and telemetry system. The type of pump controls and telemetry system should be uniform throughout the County and every effort should be made to coordinate with the County on such efforts. In addition, the building shall be equipped with two doors, wall louvers, rotary turbine roof vent, interior and exterior lighting, and a space heater.

Provision shall be made to accommodate a diesel generator to provide back-up power for each pump station. Each generator shall be sized to supply power to the drainage pumps running at design capacity, as well as to the electrical control equipment, lighting, and electrical building space heater. The generators shall be radiator-cooled and skid-mounted, and shall include a heater, batteries, battery charger, control panel with auto-start, critical silencer, and generator circuit breaker. The diesel generator and fuel storage tank shall be placed on a concrete pad. The fuel storage tank shall also be provided with the appropriate secondary containment feature.

As a minimum, and depending upon architectural or aesthetic considerations, the pump station site shall be enclosed with a 8-foot-high chain link fence with slats (material acceptable to the respective jurisdiction) topped with three strands of barbed wire. The fencing shall include a 16-foot to 20-foot-wide, double gate and a 4-foot-wide pedestrian gate. The pump station lot shall be sized and the sump, electrical control building, diesel generator, and transformer arranged to allow adequate operating space for vehicles, pump, and motor removal equipment, and maintenance of the trash rack system. The paved access yard shall be at a minimum elevation of two feet above the 100-year water surface elevation, and shall be sloped at 2% to provide adequate on-site drainage.

Open Channels, Culverts Associated with Open Channels, and Bridges

Open channels, including runoff corridors, shall have 3:1 side slopes, or flatter. For open channel design, a Manning's "n" roughness coefficient shall be used to account for vegetation to minimize maintenance requirements as presented in Table 5. Where open channels are proposed as new facilities or where rehabilitation of existing channels is proposed by either public or private efforts, every effort shall be made to coordinate with the County or respective governing agency to develop a planting plan for the channel that utilizes native plantings that are consistent with local growing soil and groundwater conditions. Recommendations for qualified consultants for vegetative planning specific to the County are available from the Yolo County Flood Control & Water Conservation District. A 20-foot buffer including a 15-foot-wide all-weather access road for maintenance shall be provided adjacent to open channels. A minimum of two feet of freeboard for the 100-year event and one foot of freeboard for the 200-year event shall be provided for unleveed open channels. These freeboard requirements shall be adhered to for open channels that utilize culverts or bridges at

crossings. In areas where fill is required to provide freeboard for open channels, three feet of freeboard shall be provided for the 100-year event

Hydraulic computations may be based upon the Manning's formula, as well as the USACE's computer program HEC-RAS. A more in-depth description of hydraulic computer modeling methodology is presented in a subsequent section of this Manual.

Seepage

The seepage of groundwater into or out of the detention ponds and open channels will be evaluated based upon available groundwater information and driller logs to determine if inflow of groundwater into the drainage facilities would affect the design capacities or operations. (Design seepage rates shall not exceed 50% of the lowest measured seepage value from field testing.)

Retention Storage

Retention ponds are discouraged within the County; however, under special circumstances may be considered with prior written authorization by the respective City or County Engineer having jurisdiction. If authorized, the retention ponds will be sized using the criteria provided below as well as dimensional side slope and bottom slope requirements stated above under *Storage Facilities*:

1. Configure all retention storage (effective flood control storage) above maximum groundwater elevation for the proposed retention pond site. Maximum groundwater elevations will be estimated using all the best available information, including actual seasonal groundwater measurements of monitoring wells, preferably within a one-mile radius. The maximum groundwater elevation shall be approximated using data from DWR's groundwater database for Yolo County, and the worst-case condition from either site-specific or regional estimations shall be used. Minimum allowable groundwater separation is 0' (from the highest recorded level) from a flood control perspective; however, as soil conditions may vary, separation shall be increased if groundwater contamination is a permit issue under federal, state, or local agencies.

2. Determine the pervious and impervious tributary areas within the directly contributing watershed. Include the retention pond site/area as an impervious surface.

3. Determine/verify that the surrounding (non-tributary) area 100-year and/or 200-year (worst-case) flood condition does not overflow and/or spill into or across the contributing watershed of the retention pond, utilizing these criteria in the absence of established City/County standards for assessing flooding impacts.

4. Determine the precipitation on the contributing watershed resulting from the 100-year storm and 200-year storm with a one-year duration from the Design Precipitation section of this Manual and the interactive GIS map (located on CD at back of Manual). Distribute the precipitation from this step according to the following distribution:

Month	Percent Total
October	0.8
November	10.1
December	6.9
January	30.9
February	20.7
March	23.1
April	3.4
May	1.6
June	1.7
July	0.8
August	0
September	0
TOTAL	**100**

5. Attribute no losses to impervious areas within the contributing watershed. Attribute losses to pervious areas differently each month using effective rainfall estimates (reaching retention storage) expressed as a percentage of the monthly rainfall below (for each month). Note the monthly effective rainfall for pervious areas varies due to varying saturation levels during the year:

Month	Effective Rainfall, (%) (% Monthly Rainfall as Runoff)
October	0
November	43.4
December	31.4
January	51.5
February	90.4
March	58.0
April	5.0
May	0
June	0
July	0
August	0
September	0

6.   Develop a table to calculate month-by-month water balance accounts to assess the impacts of infiltration (percolation into soil), evaporation, transpiration, rainfall (from Steps 4. and 5. above), total runoff volume, impervious area and runoff volume, pervious area and runoff volume, and incidental runoff volume (lawn over-watering). Monthly evaporation (pan) and transpiration estimates shall be estimated according to DWR's Bulletin 113 or other appropriate climatological station with each project location evaporation submitted to the appropriate City or County Engineer having jurisdiction for approval prior to proceeding. Full evaporation will only be allowed to deplete the storage volume if the operation and maintenance activities include annual removal/destruction of all vegetation within the water storage prism. Otherwise, transpiration values shall be used as if the pond is completely vegetated. On-site percolation tests shall be performed at a minimum of two tests per acre of pond footprint, at the elevation of the proposed soil interface. Infiltration rates used for calculations shall be reduced to 50% of observed/measured rates. This pond design calculation shall begin with an empty pond and leave no more than 25 percent of the total design volume in the pond at the end of a year's cycle.

7.   All retention ponds must be designed to be dewatered for a two-month period between September 1 and October 31 (or other period specified by the City or County Engineer) to an elevation at or below the invert of all connecting storm drain inlet pipes to allow for proper inspection and maintenance. If pumping becomes necessary to dewater the pond, installation and operation of dewatering pump(s) shall be provided at no additional cost to the local government agency having jurisdiction. If pumping is required to dewater the pond for five consecutive years, a permanent pump installation to effectively dewater the pond within a two-month period between September 1 and October 31 will be required.

8.   All retention ponds shall be designed with a minimum 15-foot-wide operating road around the perimeter of the pond that is a minimum of one foot above the maximum calculated (design) pond level. If overland release is considered, the overland release shall be at or above the maximum design pond level (based upon the 100-year annual volume calculations noted above). Overland release over the perimeter road shall include sufficient erosion control measures to armor the release path. All other applicable release criteria adopted by the respective City or County Engineer (agency) having jurisdiction shall still apply.

9.   Retention pond design shall include a staff gage for reliably monitoring the water level in the pond at all times. Retention pond design shall also include an access ramp and sump area to provide an emergency pumping/dewatering and discharge location that is easily accessible.

10. If the pond design is proven to be inadequate/incorrect after the operation of the pond, the tributary area to the pond will provide a permanent pump installation, or other reliable dewatering construction (i.e., channel or pipe, to the satisfaction of the respective City or County Engineer having jurisdiction). The pond design shall be considered inadequate if the water surface exceeds maximum design pond stage at any time unless the previous year's rainfall records indicate the design precipitation was exceeded. The pond design shall also be considered inadequate if greater than 25 percent of the design volume is present in the pond at the end of August of any year. The City or County Engineer shall require the developer to provide a back-up design of the pond with an outflow pumping system reflecting no infiltration and the pump station construction funding shall be provided to the City or County to hold for a minimum of 10 years.

Hybrid Retention/Detention Storage

1. If groundwater pumping is introduced as a means of gaining effective flood control storage, it shall be done only with the written approval of the City or County Engineer. If the groundwater table is invaded by design, the design shall include volume influences on the pond with groundwater permanently at maximum levels during the water balance calculations as previously defined under *Retention Storage, Item 6.,* of this Manual. The location of proposed flood control storage below the groundwater table will only be allowed with reliable pumping or gravity drainage that can effectively drain both rainfall and groundwater inflows.

2. If permanent pumping is introduced as a means of dewatering the pond (by design) during months where there is expected rainfall that reaches design storage (November 1–April 30), then such a pond will be considered a "Hybrid Retention/Detention" Pond, and pumping will be evaluated for downstream impacts during downstream design flood event analyses. Such pumping will be considered continually "on" for any such downstream impacts calculations. Such pumping shall not exceed 0.1 cfs/acre of tributary watershed area.

   Note: Existing conditions tributary areas will be utilized for determining peak pumping flow, as tributary areas to a designed storage pond are generally larger. All permanent pump installations shall be designed according to current adopted City/County standards with back-up power supply and pumping redundancies.

Levees

Levee systems and their design are currently under consideration for modifications by the State of California, together with FEMA and the USACE. The level of protection, the structural criteria for certification, and the assessment of the residual risk are

changing; therefore, it is difficult to set a standard locally in Yolo County when there is not any consensus regionally or nationally. The goal of the County is to protect its citizens from flooding. FEMA's current standard of the 100-year flood with vertical "freeboard" may be superseded in the future by state requirements for 200-year protection and/or using the evaluation of risk and uncertainty to determine certifiability. Any consideration of construction (or rehabilitation) of levees intended to protect property and people within the County should be made on a case-by-case basis in full consultation with the respective City and/or County staff, the City or County Engineer, DWR, the CVFPB, FEMA, and the USACE before proceeding with final design and construction.

Hydrologic Modeling

The HEC-1 or HEC-HMS computer programs developed by the USACE may be used to compute and route runoff hydrographs. The results may be used to design open channels, major road crossings, detention ponds, etc. The criteria that would be used to develop HEC-1 or HEC-HMS models are presented in this section.

Prepare Basic Information

Lay out the proposed storm sewer system and delineate the subbasins tributary to points of concentration for design of inlets, junctions, pipelines, etc. Delineate the land uses and hydrologic soil groups within each subbasin.

Storm Frequency

The frequency of the design storm used varies by the type and size of the facility.

Storm Duration

The storm duration shall be greater than the lag time or time of concentration for the entire watershed. Long-duration storms, 36-hour, 5-day, and 10-day events shall be evaluated, as appropriate, where runoff volume rather than peak discharge is of importance.

Rainfall (Precipitation) Depth-Duration-Frequency

The depth-duration-frequency information shall be obtained using the Design Precipitation section of this Manual and the interactive GIS map on the CD located at the end of this Manual.

Storm Distribution

The temporal distribution of rainfall, which varies with storm type, intensity, and duration, impacts the characteristics of the runoff hydrograph. There is no typical distribution that is applicable to all precipitation events. For design purposes, two different temporal distributions based upon the storm duration are presented below:

Short-Duration Storm – For short-duration storms, a symmetrical storm distribution is considered appropriate. This pattern is applicable for storms up to 24 hours in duration. For purposes of modeling a short-duration storm, a balanced storm distribution shall be modeled using the PH records in the HEC-1 model, or using the "Frequency Storm" method in HEC-HMS.

Long-Duration Storm – For storm durations greater than 24 hours, Sacramento City/County has prepared generalized storm distributions. Long-duration storms in the Sacramento region typically consist of several precipitation events separated by periods of either low-intensity precipitation or no precipitation. Sacramento City/County developed precipitation patterns for long-duration storm events based upon analyses of historical storms. The hourly precipitation records for the Downtown Sacramento NWS gage were examined to identify the 10 maximum depth storms for a duration of 36 hours, five days, and 10 days. From these storms, generalized temporal distributions of precipitation were derived. The resulting distributions are presented in Table 6, Table 7, and Table 8. Based upon review of the available gage data and long duration of storm patterns, the climate in Yolo County is considered very similar to that of the Sacramento region. The storm patterns (distributions) that were developed for Sacramento City/County are considered applicable and shall be used for purposes of modeling long-duration storms in Yolo County.

Computation Time Interval

The computation time interval, which is used in the IT records of the HEC-1 program, shall be computed by dividing the shortest subbasin lag time or time of concentration by 5.5. This calculated value shall be rounded down to the closest 5, 10, 15, or 30 minutes; or one, two, three, or six hours. If the calculated value is less than five minutes (a lag time of less than 33 minutes) it should be rounded down to the nearest minute.

HEC-1 uses a number of computation intervals in conjunction with a computation time interval to define the duration of simulation.

The number of computation intervals to use in the IT records of the HEC-1 program shall be computed as:

$$\text{Number of Computation Intervals} \geq \frac{\text{Storm Duration + Basin Lag or } T_c}{\text{Computation Interval}}$$

For design considerations where runoff rather than peak discharge is of importance, the number of computation intervals should be large enough so the final hydrograph ordinates on the receding limb of the hydrograph are close to zero.

Antecedent Moisture Content (AMC)

The AMC is based upon the condition of the soil prior to the modeled storm event occurring. Presented in Table 9 is the way AMC would vary with storm frequency.

Soil Conservation Service Curve Numbers

The SCS Curve Number (CN) is based upon land use soil type and AMC. The curve number model estimates precipitation excess as a function of cumulative precipitation, soil cover, land use, and antecedent moisture using the following equation:

$$P_e = \frac{(P - I_a)^2}{(P - I_a + S)}$$

Where:

P_e = accumulated precipitation at time *t*;
P = accumulated rainfall depth at time *t*; and
S = potential maximum retention, a measure of the ability of a watershed to abstract and retain storm precipitation.

From analysis of results from many small experimental watersheds, the SCS developed an empirical relationship of I_a and *S*:

$$I_a = 0.2S$$

Where:

$$S = \frac{(1000\text{-}10CN)}{CN}$$

For CN values between AMC I, AMC II, or AMC III, the CN shall be interpolated. Based upon SCS Technical Release 55 (June 1986), presented in Table 10 are the CNs for each land use type for a 24-hour storm for AMC II. Refer to Table 9, if necessary, for the storm recurrence/AMC correlation. The CN shall be adjusted for storm durations other than 24 hours in accordance with the National Engineering Handbook, Section 4 and SCS Technical Release 60. Presented in Table 11 is the

adjusted CNs for a 10-day storm. The CN shall be adjusted from AMC II values, if necessary, using Table 11.

Base Flow

Base flow is considered the normal day-to-day flow from groundwater, spring contributions, or even from landscaping runoff. In the vicinity of Yolo County, groundwater is typically 10 feet or more below ground and is not considered a significant contributing factor with respect to base flow. However, during the rainy season, some residual base flow is anticipated to be in the drainage system between storm events. To account for this, a base flow rate of one cfs/square mile of drainage area shall be included if more accurate site-specific base flow information is not available.

Lag Time

The temporal distribution of the unit hydrograph is a function of the basin lag time. The lag time shall be calculated by using one of two methods. Basin "n" lag method, or travel time component method. The Basin "n" method is typically used for planning-level analyses or in basins with limited conveyance systems. The travel time component method should be used for detailed conveyance system design and runoff analyses of existing conveyance systems. The calculation procedure for each method is outlined below:

Basin "n" Lag Time Method

The Basin "n" method of computing lag should be used for:

- Planning-level analyses.
- Basins with limited conveyance systems.

The Basin "n" lag equation, which was originally developed by Snyder and later revised by the USACE and the U.S. Bureau of Reclamation, is expressed as:

$$L_g = C \bullet n \ ([L \bullet L_c]/S^{\,0.5})^{\,0.33}$$

Where:
C = 1560 (174)
L_g = lag time, minutes (seconds)
L = length of longest watercourse, measured as approximately 90 percent of the distance from the point of interest to the headwater divide of the basin, miles (m)
L_c = length along the longest watercourse measured upstream from the point of interest to a point close to the centroid of the basin, miles (m)

S = overall slope of the longest watercourse between the headwaters and concentration point, ft/mile (m/m); and

n = basin "n" (Table 12)

The basin "n" value is dependent upon the basin land use and the condition of the main drainage course. For basins with mixed land use and/or varying characteristics of the main drainage course, the basin "n" should be weighted for the areas draining to each type of channel development. Presented in Table 12 are recommended basin "n" values. The shaded values in Table 12 are not normally used. However, these values may be used for planning purposes to estimate the effect of channelization, or to estimate composite "n" for large areas with mixed land use channelization.

Travel Time Component Lag Time Method

The travel time component method of computing basin lag should be used for the following applications:

- Detailed conveyance system design.
- Runoff analyses of existing conveyance systems.

The travel time is the time required for runoff to flow from the most upstream point of the drainage area through the conveyance system to the point of interest. The travel time is calculated by dividing the length of the conveyance system component by the corresponding velocity of flow. The travel time, T_c is computed as follows:

$$T_c = T_o + T_g + T_p + T_{ch}$$

Where:

T_o = overland flow time of concentration;

T_g = gutter flow travel time;

T_p = pipe flow travel time; and

T_{ch} = channel flow travel time.

The equation used to compute the travel time for each conveyance component is described below.

Overland Flow – The developed Kinematic wave empirical equation based upon available SCS, USACE, and the Federal Highways Administration (FHA) overland flow data (Sacramento City/County, 1996) is:

$$T_o = \frac{(0.66 L^{0.50} n^{0.52})}{S^{0.31} i^{0.38}}$$

Where:

T_o = overland flow time of concentration, min;

L = overland flow length, feet, should generally be in the range of those specified in Table 13;

n = roughness coefficient for overland flow (Table 13);

S = average slope of flow path, ft/ft; and

i = intensity of precipitation, i/hr (Table 14)

Use of the overland time of concentration equation requires an iterative approach: An initial estimate of time of concentration updated by successive estimates of precipitation intensity. In many cases, overland flow accounts for a large part of the lag time in a basin.

To assure that consistent and reasonable values are used to calculate the total time of concentration, the maximum times of concentration for commercial and residential areas and a range of times of concentration for open space are presented in Table 15.

Gutter Flow – The Manning's equation for a triangular channel cross section is used to determine the flow velocity and travel times for street gutter flow. The average distance from the overland flow surface to the nearest inlet is divided by flow velocity to obtain street gutter flow time. The gutter flow equation was derived using the following assumptions:

- The cross slope of the street is 0.02 ft/ft.
- The flow in the gutter is six inches deep and contained by the curb.
- The street surface is smooth asphalt or concrete.

$$V_g = \frac{1.12\ S_x^{0.67}\ S^{0.50}\ T^{0.67}}{n}$$

Where:

V_g = velocity of flow in the gutter, ft/s;

S_x = street cross slope, ft/ft, design value = 0.02

S. = street longitudinal slope, ft/ft;

T = spread of flow in gutter = d/S_x, ft;

D. = depth of flow in the gutter, ft, design value = 0.5 ft; and

N = Manning's "n" for pavement, design value = 0.02.

Pipe Flow – Manning's equation can also be used to determine travel time of flow through pipes. Travel time is usually calculated by assuming full pipe flow. Flow velocity is calculated with the equation:

$$V = \frac{1.49\ R^{0.67}\ S^{0.50}}{n}$$

Where:

V   =   velocity, ft/s;

R   =   hydraulic radius, D/4 for full pipe flow, ft;

D   =   diameter of pipe, ft;

S   =   slope, ft/ft.

n   =   Manning's "n" for channel flow (Table 5).

Trapezoidal Channels – A modified Manning's equation is used for open channel flow to derive the velocity for trapezoidal grass-lined channels. The following assumptions were made in the derivation of the modified equation:

- Channel side slopes are 3:1, horizontal: vertical.
- Channel bottom width equals depth.
- Top width is seven times the bottom width.

Flow velocity in trapezoidal channels is calculated using the following equation:

$$V = \frac{0.995\ b^{0.67}\ S^{0.50}}{n}$$

Where:

V   =   velocity, ft/s;

b   =   bottom width, ft;

n.   =   Manning's "n" for channel flow (Table 5); and

S   =   slope, ft/ft.

Lag Frequency Factors

Flow exceeding the storm drain capacity backs onto the streets; or if an overland release has been provided, flows in the streets.

Lag times, regardless of the method of calculation, should be adjusted to account for flows exceeding pipe capacities, causing temporary flooding in paved areas, and thereby increasing lag times. The multiplication factors presented in Table 16 are applied to the lag times for piped areas with overland release.

Synthetic Unit Hydrograph

The U.S Bureau of Reclamation's dimensionless urban unit hydrograph will be used to calculate runoff. The urban unit hydrograph was developed based upon many urban watersheds throughout the United States. The applicability of the unit hydrograph in Sacramento County was confirmed by successful comparisons of recorded runoff for several drainage basins and storms with the runoff calculated using the urban unit hydrograph. Due to similar hydrologic conditions, it is also applicable to Yolo County. The procedure below outlines the steps used to compute the urban unit hydrograph:

1. Determine basin lag time (hours) and area (square mi.).

2. Determine unit duration (hours).

3. Calculate Lag Time + Unit Duration/2.

4. Calculate volume of runoff resulting from one inch of rainfall on basin areas, in one-day cfs.

    V = Basin area x 26.89.

    The conversion factor, 26.89, is used to convert one inch of rainfall excess to over one square mile in 24 hours to runoff expressed in one-day cfs.

5. Calculate unit hydrograph time steps as percent of Lag + Unit Duration/2, up to 600 percent.

6. Determine dimensionless synthetic unit hydrograph ordinates from Table 17.

7. Calculate unit hydrograph ordinates by multiplying V from Step 4 by dimensionless synthetic unit graph ordinates in Step 6.

The ordinates in Step 7 are in cubic feet per second as a result of one inch of rainfall over the basin. To obtain ordinates as a result of any other rainfall depth, multiply by the rainfall depth, in inches.

The unit hydrograph ordinates are entered on the UI records in HEC-1, which calculates runoff hydrographs based upon the effective precipitation over the basin.

Hydrograph Routing

Hydrograph routing in HEC-1 can be used to represent hydrograph movement in a channel or through a storage facility. The hydrograph is routed based upon the characteristics of the channel or the storage-outflow characteristics of the storage facility. The following section lists the routing methods that would be permitted using HEC-1. It also describes techniques for modeling two types of detention basins.

Routing Methods

The HEC-1 program contains several methods to route runoff hydrographs. Three of the methods, Modified Puls, Muskingham-Cunge, and Muskingham are recommended for use in the County. The methods, applications, and required parameters are summarized in Table 18 in order of preference. In most cases, Modified Puls routing is required where HEC-2 or HEC-RAS models are available.

Additional information on these routing methods is available in the HEC-1 User's Manual.

Modified Puls Routing – The Modified Puls routing method is used for channels with available HEC-2 storage discharge information. The number of steps (NSTPS) is calculated from reach length and velocity with the following equation:

$$\text{NSTPS} = \frac{\text{(reach length/average velocity)}}{2 \times \text{NMIN}}$$

Where:

NMIN is the time interval. The factor of 2 in the denominator was added to reflect hydrograph attenuation typical of developed channels in Sacramento County and the valley areas. This is considered applicable to Yolo County drainage as well. The maximum NSTPS has been set to five, and is usually set to 1 for a reservoir.

Muskingham Routing – The Muskingham routing method is used for channels where limited cross-sectional information is available.

The number of subreaches is chosen to satisfy stability criteria, as described in the HEC-1 User's Manual. The Muskingham "K" value may be approximated as the travel time in hours for the reach based upon the flow velocity at normal depth. Typical ranges for the Muskingham "X" value are given below:

Channel Description	Muskingham "X" Range
Most Channel Flow is in the Floodplain	0.00 - 0.15
Natural Channels	0.20 – 0.35
Excavated Earth or Concrete Channels	0.40 – 0.50

Muskingham-Cunge Routing – The Muskingham-Cunge routing method is used for channels with standard cross sections.

Reservoir Routing – Reservoir routing is used to route a hydrograph through a storage facility such as a detention basin.

Off-Channel Detention Routing – Off-channel detention basins are usually the most effective means of reducing peak flow in a channel for a given storage volume. Off-channel detention basins are located adjacent to, but separate from, a channel. Peak flows in the channel are diverted into the detention basin over a weir in the side of the channel. Off-channel detention can be conceptually modeled using the diversion option in HEC-1. The diversion option allows diverting a flow from a channel based upon the total flow in the channel. The typical steps for modeling off-channel detention are:

- Divert flow to limit flow in the channel to the desired design flow.

- Determine the required channel overflow structure and off-channel storage based upon diverted hydrograph (in some cases, the detention volume is known and the reduction of flow in the channel is determined).

- Route the diverted flow through the off-channel detention basin.

- Return the routed detention basin flow to the channel.

On-Channel Detention Routing

On-channel detention includes using the excess storage capacity of a channel by building a berm across the channel and/or expanding the storage in a reach of the channel (e.g., through excavation). Another example of on-channel detention is an "end-of-pipe" basin that collects runoff from a subdivision before entering the channel. With on-channel detention, the entire runoff hydrograph is routed through the detention facility.

On-channel detention can be modeled in HEC-1 by using the Modified Puls routing methods for reservoirs. In cases where detention storage is provided predominantly by the natural floodplain of the channel, it may be more appropriate to use the Modified Puls routing method for channels.

Hydraulic Modeling

Hydraulic computations may be based upon the Manning's formula, as well as the USACE computer program HEC-RAS or EPA SWMM 5.0, or equivalent. HEC-RAS is used throughout the United States and other countries for evaluation of dynamic open channel flow. HEC-RAS was released by the USACE with the intention of replacing HEC-2, a steady-state flow predecessor program. Generally speaking, HEC-RAS is preferable in terms of its ability to model unsteady state flow, which provides a more accurate representation of routing and timing with respect to peak flows in a drainage system. SWMM analyses are typically more robust in urban environments containing large networks of pipe flow, overland flow, detention and pumping.

Manning's "n" values should be obtained from Table 5, but may be calculated using other widely practiced engineering methods if circumstances dictate.

Open channel contraction and expansion loss coefficients for gradual transitions will be 0.1 and 0.3, respectively. Contraction and expansion coefficients of 0.3 and 0.5, respectively, shall be used for losses between bridge or culvert cross sections.

C. LOCAL DRAINAGE FACILITIES

Local drainage facilities include conveyance, flood protection, water quality treatment, and recreational, environmental, and aesthetic elements, which may consist of roadside ditches, storm drainage pipe systems, and overland conveyance systems. It is important to note that emphasis should be placed upon the appropriate design of the overland conveyance system for the on-site development of the land so designated by the respective City or County plan governing a particular area. If the overland conveyance system is appropriately designed, the capacity of the storm drainage pipe systems, roadside ditches, and culverts would have little effect on the risk of property damage or threat to public safety from flooding.

It is not known at this time as to how the land will be planned and developed. Accordingly, traditional methodology is presented herein for the design of on-site drainage facilities. To the extent development is planned for respective Development Areas, consideration could be given to the application of Low Impact Development (LID) features discussed in Volume 2 of this Manual.

Hydrology – Design Flow

The Modified Rational Method shall be used to design local drainage facilities of limited size. The Modified Rational Method calculates flow based upon storm intensity, time of concentration, imperviousness, and basin size. The Modified Rational Method has been widely used and tested throughout the United States.

The Modified Rational Method for the 10-year storm event shall be used to calculate the peak design flow for storm drainage pipe systems and roadside ditches.

When the design capacity of a storm drainage pipe system is exceeded, overland conveyance systems, generally streets, are relied upon to safely convey flow downstream to detention ponds or other receiving waters. The 100-year storm event would be used for evaluating and designing overland conveyance systems and generally should coordinate with more regional rainfall/runoff methods consistent with Table 4, except for determining street flooding capacity in areas with less than 10 acres of tributary area.

Rational Method

The Rational method may be used for peak flow calculations to design street drainage, storm sewers, and culverts not associated with channels. The application of the Rational method would be limited to watersheds up to 10 acres.

The Rational method equation is expressed as:

$$Q = CiA$$

Where:

Q = rate of runoff, acre-inches per hour or cubic feet per second (acre inch per hour = 1.008 cubic feet per second, a negligible difference)

C = runoff coefficient, which is the ratio of peak runoff to average rainfall intensity;

i = average rainfall intensity, inches per hour; and

A = drainage area, acres.

The Rational method shall be applied using the procedure outlined below and the sample computation form presented in Table 19. A digital copy of Table 19 is also included on the CD at the back of this Manual.

Prepare Basic Information – Lay out the proposed storm sewer system and delineate the subbasins tributary to the points of concentration for the design of inlets, junctions, pipelines, etc. Delineate the land uses and hydrologic soil groups within each subbasin.

Determine Runoff Coefficient – The runoff coefficients, represented as "C," for a storm having a 10-year recurrence interval are presented in Table 20 by land use designation and hydrologic soil group. The 10-year runoff coefficients are to be used with the frequency factors presented in Table 21 for design storm frequencies other than the 10-year. The frequency factor adjusts the 10-year C for changes in infiltration and other losses with a change in storm frequency. The C value used in Table 19 is the weighted average of the C values for the subareas within the system being designed. Presented in Table 22 is a sample calculation for weighted average C computations for a basin.

Determine Time of Concentration – The time of concentration, or the travel time, is the time required for runoff to flow from the most upstream point of the drainage area through the conveyance system to the point of interest. The travel time is calculated by dividing the length of the conveyance system component by the corresponding velocity of flow. The "Travel Time Component Lag Time Method" outlined in the design criteria for regional facilities shall be used to determine the time of concentration.

Determine Intensity – As part of the design precipitation effort, Goodridge assisted in preparing design storm information for Yolo County. Location-specific design intensity can be extracted from design precipitation depth and duration values described under Design Precipitation of this Manual (Section II. E.).

Storm Drainage Pipe Systems

The invert of any storm drainage pipe outfall at ponds shall be designed to prevent standing water within the pipe systems, which can cause sedimentation that could affect the conveyance capacity and longevity of the pipes.

The storm drainage pipe systems shall be designed using the 10-year storm event design flow and the 10-year storm event peak water surface elevation in the downstream pond or other receiving water. Hydraulic grade lines shall be computed using the Manning's formula with an "n" value to account for friction and minor losses, in accordance with the information presented in Table 23. The minimum pipe slope shall be equal to or greater than the hydraulic slope, which shall be set by the local jurisdictional requirements. To the extent practical, the hydraulic grade line shall be within the pipe. The hydraulic grade line shall be at least one foot below the flow line of inlet grates and manhole covers. The minimum velocity in closed conduits shall be 2.5 feet per second when flowing full (94%), unless approved by the respective City or County Engineer.

The minimum drainage inlet elevation shall be one foot above the 100-year water surface elevation in the downstream detention pond or other receiving water.

Pipe inverts shall be designed to provide minimum cover at the upstream areas of the drainage. The minimum allowable pipe diameter is 18 inches.

Once flow at a point in a storm drain system exceeds the capacity of a 72-inch pipe, the facility must be designed as a Regional facility and cannot be placed inside parallel pipes to avoid sizing for a 100-year frequency. Additionally, downstream components within a drainage system cannot revert back to a local facility once a regional designation is reached (i.e., pipes draining detention ponds).

Manholes

Standard pre-cast concrete or saddle-type manholes shall be used where required. Maximum spacing between manholes shall be 400 feet for pipe sizes of 48 inches and under, and 800 feet for pipes of 54 inches and larger.

Manholes shall be located at junction points, angle points greater than 20 degrees, and changes in conduit size. On curved pipes with a radius of 200 feet to 400 feet, manholes shall be placed at the beginning of curve (B.C.) and ending of curve (E.C.) and at 200 feet maximum intervals along the curve. On curves with a radius exceeding 400 feet, manholes shall be placed at the B.C. and E.C. and at 400 feet maximum intervals along the curve for pipes 24 inches and less in diameter, and 500 feet maximum intervals along the curve for pipes greater than 24 inches in diameter.

Inlets

The spacing of storm water drainage inlets shall not exceed a maximum of 300 feet. Storm water drainage inlets shall be located to prevent surface flow through street intersections.

Pipes

Storm water drainage pipes shall be reinforced concrete pipe, non-reinforced concrete pipe, or cast-in-place concrete pipe, and as accepted in the respective City or County improvement standards. All pipes shall be constructed with a minimum cover of two feet. The minimum velocity in closed conduits shall be 2.5 feet per second when flowing full.

Flowage Easements

Where the flooding of land serves to attenuate the peak runoff similar to a detention pond, a flowage easement is recommended to be acquired to ensure the functional integrity of the land as a component of the any designed storm drainage system relying on the preservation of storage upstream.

Pipe Discharges into Water Quality Ponds

The location of pipe discharges at a pond shall be designed to enhance water quality treatment within the pond and to prevent the "short-circuiting" flow through the pond.

Overland Conveyance Systems

All new development within the County shall include the design of street systems or other suitable release paths to convey flow in excess of pipe capacity, in an unobstructed manner, to the detention pond or other receiving waters. The overland conveyance facilities shall provide water surface elevations below the pad elevations in the 100-year storm event with a minimum freeboard of one foot and shall provide a minimum of 0.5 foot of freeboard for the 200-year storm event. The street system would be designed to minimize flooding depths within the street.

Roadside Ditches

Roadside ditches shall be designed to minimize safety hazards and emphasize water quality treatment by implementing BMPs. Roadside ditch design shall conform to the applicable City or County improvement standards.

Non-Regional Water Quality Treatment

Refer to Volume 2 of 2 of this Manual for water quality treatment BMPs.

D. FLOODPLAIN ANALYSIS

Many areas within Yolo County are subject to overland (floodplain) flooding whereby creek and slough channel capacities are frequently exceeded and floodwaters spread out and inundate large areas, sometimes redirecting flow from one drainage shed into another. Due to the generally flat nature of the valley part of the County, and the many man-made roadways, railroads, canals, and other overland obstructions, the complexity of determining where flooding is occurring sometimes requires the use of detailed modeling tools. Currently, there are numerous software programs available for calculating two-dimensional flow in floodplains. DWR has selected FLO-2D software for application in its Central Valley Floodplain Evaluation & Delineation Project. Other modeling developed for areas within the County for Cache Creek flooding through Woodland have utilized MIKE FLOOD software, developed and distributed by the Danish Hydraulic Institute, Inc. (DHI).

Before any project is fully approved it must satisfy the City and/or County Engineer that all flooding sources have been identified and quantified with sufficient certainty to understand existing floodplains and the extent to which proposed changes in land use may affect it. For example, all flow must be accounted for when defining new facilities, such as diversion structures or detention ponds. If limited upstream channel capacities force water to leave the channel and divert around new (planned) facilities, this should be identified and accounted for as part of future design, as necessary.

Currently, roughness coefficients are recommended within the published FLO-2D Manual for general floodplain flow conditions and land use types when developing a two-dimensional floodplain model. The FLO-2D program will require input of normal flow conditions roughness, and will internally adjust "n" values under shallow flow conditions to reflect "low-flow" increases. Careful consideration should be given to determine roughness conditions for expected flow depths. For instance, roughness through a well maintained and widely spaced orchard will be different if the flow depth is two feet versus ten feet. Roughness conditions may also be different if tree rows are aligned with flow direction or are skewed in relation to flow. The latest edition of published floodplain roughness parameters developed through the CVFED program for use in two-dimensional floodplain modeling in the Central Valley areas should supersede any other published standards, whether from FLO-2D or other sources, unless specifically directed by the City and/or County Engineer. Additional consideration can be given to utilizing published USGS technical papers related to floodplain roughness, if CVFED and/or FLO-2D published standards are insufficient. Currently, two publications are acceptable for use under such circumstances. The first technical paper entitled, "USGS Water-Supply Paper 2339 – Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains," by George J. Arcement, Jr. and Verne R. Schneider, can be used to establish base estimates of floodplain roughness.

Buildings and structures that will create obstructions to overland flow can be represented several ways. If selected model grid element dimensions are small enough, buildings can be designated to have conveyance shut off through assigned grid elevations. The FLO-2D program also allows for an "area reduction factor" to be applied, which will reduce the cross-sectional conveyance capacity of any grid cell by a designated percentage in order to reflect the effect of regular measurable obstructions such as houses within a subdivision. The second USGS Technical Paper entitled, "A Method for Adjusting Values of Manning's Roughness Coefficient for Flooded Urban Areas," by H.R. Hejl, Jr. 1977, also provides an acceptable method for reflecting building obstructions through roughness coefficient adjustment. Careful consideration should be given to not double count the effects of such obstructions. All two-dimensional modeling efforts should be coordinated through the County and/or City Engineer during all stages of model development to ensure the acceptability of methods, procedures, and parameters, as these procedures are continually being updated as new information becomes available.

E. Additional Criteria

While the cities and County exercise respective authority over drainage in so much as providing storm drainage design criteria for drainage within their jurisdictions, it is also recognized that there may be other overarching criteria that will govern drainage design in certain circumstances, which are more stringent than the local requirements. These guidelines in no way prohibit exceeding the recommendations contained herein and all future development interests are encouraged to make sure that more stringent requirements are identified and adhered to.

F. Interim Conditions

As development progresses within a given jurisdiction, interim drainage conditions must be evaluated. Some flexibility in criteria and standards may be considered for interim conditions, but in no case would the following be allowed as a result of new development:

- Jeopardizing public safety.

- Increasing risk of property damage from flooding.

- Increasing floodplain elevations to surrounding lands, unless property owner approval is acquired in writing.

- Creating significant impacts to surface or groundwater quality.

Impacting the facilities and operation of downstream canal and ditch operations on surrounding land requires close coordination with downstream landowners and will require prior written legal permission granted by all affected property owners resulting from adverse impacts.

IV. REFERENCES

1. Arcement, G. J., and V. R. Schneider, USGS Water-Supply Paper 2339, "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains," 1989.

2. Borcalli & Associates, Inc., Yolo County Floodplain Management Working Group, "A Report on Storm Drainage and Flooding in Yolo County," February 1997.

3. Federal Emergency Management Agency, "Guidelines and Specifications for Flood Hazard Mapping Partners," February 2002.

4. Federal Emergency Management Agency, "Flood Insurance Study, Yolo County, California, Unincorporated Area," Revised.

5. Frequency and Risk Analyses in Hydrology, G.W. Kite, 1988

6. Hejl, H.R., Jr., USGS Technical Paper, "A Method for Adjusting Values of Manning's Roughness Coefficient for Flooded Urban Areas," 1977.

7. Sacramento City/County, "Drainage Manual Volume 2: Hydrology Standards," December 1996.

8. Solano and Yolo County Design Rainfall, James D. Goodridge, 1992

9. U.S. Department of Agriculture, NRCS, "Soil Survey of Yolo County, California," no date.

10. U.S. Department of Agriculture, Soil Conservation Service, "Technical Release 55," June 1986.

11. U.S. Department of Commerce; National Oceanic and Atmospheric Administration; U.S. Department of the Army; and U.S. Department of the Army, Corps of Engineers; Hydrometeorological Report No. 58 "Probable Maximum Precipitation for California," Calculation Procedures, October 1998.

12. U.S. Department of Commerce; National Oceanic and Atmospheric Administration; U.S. Department of the Army; and U.S. Department of the Army, Corps of Engineers; Hydrometeorological Report No. 59 "Probable Maximum Precipitation for California," February 1999.

13. U.S. Department of Defense, "Unified Facilities Criteria, Design: Low Impact Development Manual," October 24, 2004.

TABLES

TABLE 1

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

PRECIPITATION GAGES

Station Name	Station ID	County	Latitude	Longitude
American River College	A00 0179 55	Sacramento	38.645	-121.347
Arcade Greiner	A00 0249 34	Sacramento	38.628	-121.384
Arden Way	A00 0255 00	Sacramento	38.596	-121.412
Arden Way	A00 0255 00	Sacramento	38.596	-121.412
Ardentown 1 E	A00 0257 34	Sacramento	38.582	-121.380
Beach Lake	A00 0559 00	Sacramento	38.439	-121.499
Branch Center	A00 1041 34	Sacramento	38.537	-121.338
Browns Valley Res	A00 1117 25	Solano	38.383	-121.986
Bryte CIMIS	A00 1135 40	Yolo	38.599	-121.540
Bryte	A00 1145 30	Yolo	38.599	-121.540
Capay 5 WNW	A00 1507 00	Yolo	38.733	-122.133
Carmichael 2.4 W Hereth	A00 1540 22	Sacramento	38.628	-121.371
Carmichael 1 ENE Innes	A00 1540 26	Sacramento	38.612	-121.318
Carmichael 2.7 N Janssen	A00 1540 36	Sacramento	38.656	-121.322
Carmichael Winston	A00 1540 90	Sacramento	38.621	-121.311
Chicago Ave	A00 1714 20	Sacramento	38.660	-121.254
Citrus Heights JDG	A00 1773 00	Sacramento	38.708	-121.297
Citrus Heights	A00 1773 36	Sacramento	38.669	-121.274
Corabel	A00 2006 30	Sacramento	38.614	-121.397
Correctional Center	A00 2053 34	Sacramento	38.306	-121.424
Davis State Nursery	A00 2094 02	Yolo	38.558	-121.682
Davis CIMIS 6	A00 2094 60	Yolo	38.535	-121.775
Cresta Park	A00 2160 00	Sacramento	38.593	-121.368
Eagles Nest	A00 2160 34	Sacramento	38.485	-121.260
D05/Am Riv	A00 2253 74	Sacramento	38.584	-121.422
Dan Best Ranch	A00 2274 00	Yolo	38.780	-121.760
Davis 2 WSW	A00 2294 00	Yolo	38.535	-121.775
Davis 2 WSW	A00 2294 00	Yolo	38.525	-121.775
Davis 6	A00 2294 50	Yolo	38.536	-121.776
Dunnigan 3 NW	A00 2568 05	Yolo	38.917	-122.003
Dunnigan 5 WSW	A00 2568 09	Yolo	38.867	-122.050
Dunnigan Powers	A00 2569 00	Yolo	38.888	-121.989
Elkhorn Blvd	A00 2744 00	Sacramento	38.684	-121.448
Elkhorn Blvd	A00 2744 00	Sacramento	38.684	-121.448
Fair Oaks Johnson	A00 2948 65	Sacramento	38.667	-121.257
Fair Oaks CIMIS 130	A00 2948 67	Sacramento	38.677	-121.257
Gerber Road	A00 3387 34	Sacramento	38.481	-121.402
Gibson WTP	A00 3506 50	Solano	38.408	-121.925

TABLE 1

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

PRECIPITATION GAGES

Station Name	Station ID	County	Latitude	Longitude
Jan Drive	A00 4339 00	Sacramento	38.647	-121.318
Johns School	A00 4390 00	Colusa	38.957	-121.970
Karnak	A00 4449 00	Sutter	38.787	-121.655
Kirkville	A00 4574 00	Sutter	38.908	-121.805
Knights Landing	A00 4591 00	Yolo	38.802	-121.716
Lake Solano	A00 4712 00	Solano	38.493	-122.005
Lake Solano	A00 4712 00	Solano	38.493	-122.005
Mather AFB	A00 5403 00	Sacramento	38.567	-121.300
McClellan AFB	A00 5447 00	Sacramento	38.661	-121.391
Meridian Pumps	A00 5555 11	Sutter	39.148	-121.918
Sacramento Metro AP	A00 5569 90	Sacramento	38.698	-121.594
Mt Vaca	A00 6000 40	Solano	38.400	-122.100
Mt Vaca	A00 6000 40	Solano	38.400	-122.100
Navion	A00 6105 50	Sacramento	38.705	-121.309
Newhall L&F	A00 6159 02	Sutter	39.127	-121.817
Nicolaus	A00 6193 00	Sutter	38.900	-121.583
Nicolaus 30	A00 6194 32	Sutter	38.871	-121.545
Nicolaus 30	A00 6194 32	Sutter	38.871	-121.545
Plainfield Heinz	A00 6966 00	Yolo	38.588	-121.795
Plainfield 1 NNW	A00 6966 01	Yolo	38.598	-121.806
Rancho Cordova	A00 7247 00	Sacramento	38.592	-121.333
Rancho Cordova	A00 7247 01	Sacramento	38.603	-121.312
Rancho Cordova WTP	A00 7247 02	Sacramento	38.644	-121.394
Rancho Cordova Danley	A00 7247 03	Sacramento	38.604	-121.282
Rio Linda	A00 7443 34	Sacramento	38.700	-121.448
Rio Linda	A00 7443 34	Sacramento	38.700	-121.448
Robbins	A00 7477 00	Sutter	38.867	-121.717
Sacramento Executive AP	A00 7630 00	Sacramento	38.517	-121.500
Sacramento	A00 7633 00	Sacramento	38.583	-121.483
Sacramento PO	A00 7633 00	Sacramento	38.583	-121.483
Sacramento Dolislager	A00 7633 34	Sacramento	38.619	-121.478
Sacramento Waller	A00 7636 34	Sacramento	38.600	-121.370
Sacramento Metro AP	A00 7639 34	Sacramento	38.686	-121.587
Stonemead	A00 8575 34	Sacramento	38.509	-121.293
Stonemead	A00 8575 35	Sacramento	38.509	-121.293
Strong Ranch	A00 8607 00	Sacramento	38.602	-121.395
Sunrise Blvd	A00 8677 34	Sacramento	38.684	-121.271
Tisdale Weir	A00 8933 00	Sutter	39.022	-121.820

TABLE 1

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

PRECIPITATION GAGES

Station Name	Station ID	County	Latitude	Longitude
Tisdale Bypass	A00 8933 01	Sutter	39.028	-121.780
Vacaville	A00 9200 00	Solano	38.400	-121.967
Vacaville Well 9	A00 9200 30	Solano	38.356	-121.293
Van Maren	A00 9258 34	Sacramento	38.698	-121.308
Verona	A00 9307 00	Sutter	38.791	-121.596
Williams	A00 9677 00	Colusa	39.150	-122.150
Williams	A00 9677 00	Colusa	39.150	-122.150
Winters 139	A00 9742 00	Yolo	38.538	-121.978
Winters 139	A00 9742 00	Yolo	38.538	-121.978
Winters 3 NE	A00 9742 12	Yolo	38.540	-121.925
Winters 4 N	A00 9742 13	Yolo	38.586	-121.926
Winters Lewis Ranch	A00 9742 16	Yolo	38.558	-121.891
Winters 139	A00 9742 39	Solano	38.501	-121.973
Winters Wolfskill Rch	A00 9744 00	Solano	38.500	-121.968
Woodland 1WNW	A00 9781 00	Yolo	38.683	-121.793
Woodland 3W	A00 9783 00	Yolo	38.683	-121.833
Yolo	A00 9837 00	Yolo	38.733	-121.804
Yolo 2 NE	A00 9837 03	Yolo	38.765	-121.783
Zamora CIMIS 27	A00 9920 27	Yolo	38.808	-121.908
Zamora CIMIS 27	A00 9920 27	Yolo	38.808	-121.908
Brooks	A80 1112 00	Yolo	38.765	-122.155
Brooks	A80 1112 00	Yolo	38.765	-122.155
Brooks BSS	A80 1112 20	Yolo	38.719	-122.142
Capay 4W	A80 1500 00	Yolo	38.705	-122.117
Clear Lake Highlands	A80 1806 00	Lake	38.967	-122.650
Clearlake 4 SE	A80 1807 00	Lake	38.900	-122.600
H Bar H Ranch	A80 3872 00	Lake	38.848	-122.605
Indian Valley INV	A80 4249 00	Yolo	39.083	-122.533
Knoxville Creek	A80 4595 20	Lake	38.883	-122.417
Leesville Keegan	A80 4880 00	Colusa	39.153	-122.436
Lower Lake	A80 5161 01	Lake	38.913	-122.608
Mahnke	A80 5258 00	Lake	38.850	-122.483
Mahnke	A80 5258 00	Lake	38.850	-122.483
Morgan Valley Stanley	A80 5858 01	Lake	38.883	-122.475
Morgan Valley Stanley	A80 5858 01	Lake	38.883	-122.475
Aetna Springs	A90 0039 00	Napa	38.653	-122.483
Guenoc Ranch	A90 3683 50	Lake	38.752	-122.513
Harbin Hot Springs	A90 3771 50	Lake	38.783	-122.650

TABLE 1

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

PRECIPITATION GAGES

Station Name	Station ID	County	Latitude	Longitude
Markley Cove	A90 5360 00	Napa	38.500	-122.117
Middletown	A90 5598 00	Lake	38.748	-122.618
Monticello 1.5 N	A90 5816 00	Napa	38.633	-122.217
Monticello Dam	A90 5818 00	Napa	38.500	-122.117
Pope Valley 2 E	A90 7058 00	Napa	38.616	-122.389
Pope Valley 6.5 E	A90 7058 10	Napa	38.579	-122.350
Saint Helena 7NE	A90 7649 00	Napa	38.566	-122.382
Central Valley Hatchery	B00 1635 01	Sacramento	38.417	-121.367
Elk Grove	B00 2742 00	Sacramento	38.421	-121.374
Elk Grove Lorenzen	B00 2742 02	Sacramento	38.403	-121.379
Galt	B00 3301 00	Sacramento	38.254	-121.303
Shelton IPM	B00 8155 50	Solano	38.417	-121.753
Beaver BVE	B20 0720 20	Amador	38.483	-121.317
Bensons Ferry	B90 0682 00	San Joaquin	38.250	-121.433
Brannan Island SP	B90 1043 00	Sacramento	38.109	-121.697
Clarksburg	B90 1784 00	Yolo	38.417	-121.533
Dixon	B90 2451 01	Solano	38.448	-121.824
Dixon 121	B90 2451 50	Solano	38.415	-121.787
Dixon 121	B90 2451 50	Solano	38.415	-121.787
Grand Island	B90 3541 00	Sacramento	38.196	-121.619
Hastings Tract 122	B90 3813 50	Solano	38.283	-121.790
Hastings Tract 122	B90 3813 50	Solano	38.283	-121.790
Liberty Island	B90 4924 20	Solano	38.327	-121.693
Liberty Island	B90 4924 20	Solano	38.327	-121.693
Rio Vista	B90 7446 00	Solano	38.149	-121.693
Rio Vista4NW	B90 7446 02	Solano	38.200	-121.750
Twitchell Island 140	B90 9112 20	Sacramento	38.117	-121.658
Twitchell Island 140	B90 9112 20	Sacramento	38.117	-121.658
Georgiana Slough	B90 9429 00	Sacramento	38.237	-121.517
Georgiana Slough	B90 9429 00	Sacramento	38.237	-121.517
Jack London SP	E20 4319 19	Napa	38.545	-122.372
Angwin PUC	E30 0212 00	Napa	38.571	-122.435
Angwin PUC	E30 0212 00	Napa	38.571	-122.435
Angwin ANG	E30 0212 50	Napa	38.571	-122.434
Angwin ANG	E30 0212 50	Napa	38.571	-122.434
Angwin CIMIS	E30 0212 52	Napa	38.550	-122.417
Angwin 79	E30 0212 79	Napa	38.549	-122.421
Atlas Road	E30 0368 00	Napa	38.433	-122.250

TABLE 1

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

PRECIPITATION GAGES

Station Name	Station ID	County	Latitude	Longitude
Atlas Road	E30 0368 00	Napa	38.433	-122.250
Atlas Peak	E30 0372 20	Napa	38.432	-122.250
Conn Dam	E30 1976 00	Napa	38.481	-122.382
Deverton 1S	E30 2399 48	Solano	38.206	-121.891
Fairfield	E30 2933 00	Solano	38.283	-122.033
Fairfield FS	E30 2933 00	Solano	38.283	-122.033
Green Valley	E30 3612 01	Napa	38.357	-122.124
Grizzley Island	E30 3650 00	Solano	38.283	-121.967
Lake Curry	E30 4677 00	Napa	38.355	-122.122
Lake Milliken	E30 4691 20	Napa	38.379	-122.227
Saint Helena 6NE	E30 7649 00	Napa	38.550	-122.383
Travis AFB	E30 9012 00	Solano	38.250	-121.917
Hedgepath Ranch	F80 3889 50	Napa	38.606	-122.294

TABLE 2

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

ISOHYETAL LABEL VALUES
Duration (hrs)

Isohyet	1/4	1/2	3/4	1	2	3	4	5	6
A	55	79	91	100	114	120	125	128	130
B	44	66	77.6	86	100	106	111	114	116
C	26	44	53.6	61	74	81	86	89	91
D	17	31	40.2	46.5	58	65	70	73	75
E	11	20	26.8	32.5	42	49	54	57	59
F	6.6	13	19	24	32	38	43	46	48
G	6.5	11	14	16	23	28	33	36	38
H	5	8	10.5	12	17.5	21.5	25.5	29	31
I	3	6	8.5	10.5	16	20	24	27.5	30
J	2.5	5.5	8	10	15	19	23	26.5	29

Source:
Hydro Meteorological Reports (HMR58 and HMR59) for Probable Maximum Precipitation, published through the National Oceanographic and Atmospheric Administration (Department of Commerce) and the U.S. Army Corps of Engineers (Department of Defense).

TABLE 3

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

AREAL REDUCTION FACTORS

Area, mi²	1 hr	2 hr	12 hr	24 hr	48 hr	72 hr
B	100.00	100.00	100.00	100.00	100.00	100.00
C	84.50	87.25	89.50	91.50	92.75	94.00
D	77.25	81.00	84.00	86.50	88.50	90.50
E	70.00	74.50	78.00	81.00	83.00	85.00
F	59.75	64.75	68.75	72.00	74.50	77.00
G	51.00	56.50	61.00	64.50	67.00	69.50
H	41.00	47.50	52.00	55.50	58.50	61.50
I	27.00	33.75	38.50	42.00	42.25	48.50
J	14.00	21.00	26.00	30.00	33.00	36.50

Source:
Hydro Meteorological Reports (HMR58 and HMR59) for Probable Maximum Precipitation, published through the National Oceanographic and Atmospheric Administration (Department of Commerce) and the U.S. Army Corps of Engineers (Department of Defense).

TABLE 4

**YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL**

ACCEPTABLE METHODS FOR ESTIMATING DESIGN FLOW

Application	Method	Maximum Watershed Size	Design Parameter	Reference
Design of: • Minor Street Drainage • Minor Storm Drains • Culverts	Rational	10 ac	Flow	Hydrology Standards, Section III.C. (this Manual)
Master Plans or Designs of: • Major Storm Drains • Major Street Drainage • Open Channels • Bridges and Culverts • Detention Basins	SWMM, HEC-1 or HEC-HMS	No Limit	Flow and Volume	Hydrology Standards, Section III.B. (this Manual)
Water Quality Detention Basins		No Limit	Volume	Appendix A

TABLE 5

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

MANNING'S "n" FOR CHANNEL FLOW

Land Use Description	Manning's "n"
Concrete Pipe	0.015
Corrugated Metal Pipe	0.024
Concrete-Lined Channels	0.015
Earth Channel – Straight/Smooth	0.022
Earth Channel – Dredged	0.028
Mowed Grass Lined Channel	0.035
Natural Channel – Clean/Some Pools	0.040
Natural Channel – Winding/Some Vegetation	0.048
Natural Channel – Winding/Stony/Partial Vegetation	0.060
Natural Channel – Debris/Pools/Rocks/Full Vegetation	0.070
Floodplain – Isolated Trees/Mowed Grass	0.040
Floodplain – Isolated Trees/High Grass	0.050
Floodplain – Few Trees/Shrubs/Weeds	0.080
Floodplain – Scattered Trees/Shrubs	0.120
Floodplain – Numerous Trees/Dense Vines	0.200

<u>Source</u>:
Sacramento City/County Drainage Manual, Volume 2, "Hydrology Standards," December 1996.

TABLE 6

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

36-HOUR LONG-DURATION STORM PRECIPITATION
AS A PERCENT OF TOTAL STORM DEPTH

Hour	%	Hour	%	Hour	%	Hour	%	Hour	%	Hour	%
1	1.3	7	1.4	13	2	19	3.5	25	2.8	31	1.6
2	1.4	8	1.4	14	2.3	20	3.7	26	1.7	32	1.4
3	1.4	9	1.4	15	2.5	21	3.9	27	6.1	33	1.4
4	1.4	10	1.4	16	2.7	22	4.2	28	7.8	34	1.4
5	1.4	11	1.7	17	3	23	4.6	29	9.7	35	1.4
6	1.4	12	1.8	18	3.1	24	3.8	30	6.6	36	1.4

TABLE 7

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

5-DAY LONG-DURATION STORM PRECIPITATION
AS A PERCENT OF TOTAL STORM DEPTH

Hour	%	Hour	%	Hour	%	Hour	%	Hour	%	Hour	%
1	0.2	21	0	41	1.6	61	0.4	81	2.4	101	0
2	2	22	0	42	0.8	62	0.5	82	2.2	102	0
3	4.2	23	0	43	0.6	63	0.6	83	1.7	103	0
4	2.9	24	0	44	0.4	64	0.7	84	1	104	0
5	1.1	25	0	45	0.3	65	0.8	85	3.6	105	0
6	0.2	26	0	46	0.2	66	0.8	86	4.6	106	0
7	0.1	27	0	47	0.1	67	0.9	87	7.8	107	0.1
8	0	28	0	48	0	68	1	88	3.2	108	0.2
9	0	29	0	49	0	69	1.1	89	0.9	109	0.4
10	0	30	0	50	0	70	1.2	90	0.8	110	0.5
11	0	31	0.1	51	0	71	1.3	91	0.7	111	0.7
12	0	32	0.2	52	0	72	1.4	92	0.5	112	0.9
13	0	33	0.3	53	0	73	1.5	93	0.4	113	2.1
14	0	34	0.4	54	0	74	1.6	94	0.3	114	5
15	0	35	0.5	55	0	75	1.7	95	0.2	115	1.4
16	0	36	0.7	56	0	76	1.8	96	0.1	116	0.8
17	0	37	0.9	57	0	77	1.9	97	0	117	0.5
18	0	38	2.5	58	0.1	78	2	98	0	118	0.4
19	0	39	6.2	59	0.2	79	2.1	99	0	119	0.2
20	0	40	3.5	60	0.3	80	2.3	100	0	120	0.1

TABLE 8

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

10-DAY LONG-DURATION STORM PRECIPITATION
AS A PERCENT OF TOTAL STORM DEPTH

Hour	%	Hour	%	Hour	%	Hour	%	Hour	%	Hour	%
1	0.3	41	0.5	81	0	121	0	161	0	201	0
2	1.1	42	0.7	82	0	122	0	162	0	202	0
3	2.7	43	0.9	83	0	123	0	163	0	203	0
4	1.5	44	1.3	84	0	124	0	164	0	204	0
5	0.5	45	3	85	0	125	0	165	0	205	0
6	0.3	46	1.9	86	0	126	0	166	0	206	0
7	0.1	47	1	87	0	127	0	167	0	207	0
8	0	48	0.8	88	0	128	0	168	0	208	0
9	0	49	0.6	89	0	129	0.1	169	0	209	0
10	0	50	0.5	90	0	130	0.1	170	0	210	0
11	0	51	0.4	91	0	131	0.2	171	0	211	0
12	0	52	0.3	92	0	132	0.2	172	0	212	0
13	0	53	0.2	93	0	133	0.2	173	0	213	0
14	0	54	0.1	94	0.1	134	0.3	174	0	214	0
15	0	55	0	95	0.2	135	0.5	175	0	215	0
16	0	56	0	96	0.3	136	0.6	176	0	216	0
17	0	57	0	97	0.4	137	0.7	177	0	217	0
18	0	58	0	98	0.5	138	0.9	178	0	218	0
19	0	59	0	99	0.6	139	1	179	0	219	0
20	0	60	0	100	0.7	140	1.1	180	0	220	0
21	0	61	0	101	0.9	141	1.3	181	0.1	221	0
22	0	62	0	102	1.5	142	1.4	182	0.2	222	0
23	0	63	0	103	5.3	143	1.6	183	0.3	223	0
24	0	64	0	104	2.2	144	1.7	184	0.4	224	0
25	0	65	0	105	1	145	1.8	185	0.5	225	0
26	0	66	0	106	0.8	146	1.9	186	0.7	226	0
27	0	67	0	107	0.6	147	2.1	187	0.9	227	0
28	0	68	0	108	0.5	148	1.5	188	1.3	228	0
29	0	69	0	109	0.4	149	1.2	189	3.9	229	0
30	0	70	0	110	0.3	150	0.9	190	2	230	0.1
31	0	71	0	111	0.3	151	3.1	191	1	231	0.2
32	0	72	0	112	0.2	152	3.9	192	0.8	232	0.5
33	0	73	0	113	0.2	153	6.7	193	0.7	233	0.7
34	0	74	0	114	0.1	154	3.3	194	0.6	234	1
35	0	75	0	115	0.1	155	0.5	195	0.5	235	2.9
36	0	76	0	116	0	156	0.3	196	0.4	236	1.6
37	0	77	0	117	0	157	0.2	197	0.3	237	0.8
38	0.1	78	0	118	0	158	0.1	198	0.2	238	0.6
39	0.2	79	0	119	0	159	0.1	199	0.1	239	0.4
40	0.3	80	0	120	0	160	0.1	200	0	240	0.2

TABLE 9

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

ADJUSTMENT RESULTS FOR HEC-1 MODELS

Recurrence Interval, yr	Antecedent Moisture Conditions
500	2.00 (II)
200	2.00 (II)
100	2.00 (II)
50	1.55
10	1.10
2	1.00 (I)

TABLE 10

**YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL**

24-HOUR RUNOFF CURVE NUMBERS BY LAND USE, AMC II

Land Use	CN			
	A	B	C	D
Fallow	69	78	83	87
Idle	39	61	74	80
Row Crop (Grown in Winter)	64	74	81	85
Grain	62	73	81	84
Pasture	39	61	74	80
Orchard	32	58	72	79
Lawn Areas	39	61	74	80
Farmstead	59	74	82	86
Oak Areas, Grass Understory		48	57	63
Native Grasses	49	69	79	84
Suburban Residential (Acre Lots)	51	68	79	84
Urban	75	83.5	88.5	91
Urban Residential (1/4 Acre Lots)	61	75	83	87
Urban Industrial	81	88	91	93
Urban Commercial	89	92	94	95
Paved Areas (IE Roadways)	98	98	98	98
Apartments, Duplex	77	85	90	92
Residential (6,000 foot^2 Lots)	73	82.5	88.25	90.75
Residential (8,000 foot^2 Lots)	65	77.5	84.75	88.25
Residential (1/2 Acre Lots)	54	70	80	85
School (Half Commercial, Half Open Space)	64	76.5	84	87.5
Park	39	61	74	80
Vacant	77	86	91	94

Source:
USDA, Soil Conservation Service, Urban Hydrology in Small Watersheds, TR-55, June 1986.

TABLE 11

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

10-DAY RUNOFF CURVE NUMBER ADJUSTMENT[1]

Runoff Curve Numbers					
1 Day	10 Days	1 Day	10 Days	1 Day	10 Days
100	100	80	65	60	41
99	98	79	64	59	40
98	96	78	62	58	39
97	94	77	61	57	38
96	92	76	60	56	37
95	90	75	58	55	36
94	88	74	57	54	35
93	86	73	56	53	34
92	84	72	54	52	33
91	82	71	53	51	33
90	81	70	52	50	32
89	79	69	51	49	31
88	77	68	50	48	30
87	76	67	49	47	29
86	74	66	47	46	28
85	72	65	46	45	28
84	71	64	45	44	27
83	69	63	44	43	26
82	68	62	43	42	25
81	66	61	42	41	24

[1]This table is used only if the 100-year frequency 10-day point rainfall is six or more inches. If it is less, the 10-day CN is the same as that for the 1-day CN.

Source:
USDA, Soil Conservation Service, Earth Dams and Reservoirs, TR-60, October 1985.

TABLE 12

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

BASIN "n" FOR UNIT HYDROGRAPH LAG EQUATION

Basin Land Use	Percent Impervious	Channelization Description	
		Developed Pipe/Channel	Undeveloped Natural
Highways, Parking	95	0.030	0.067
Commercial, Offices	90	0.031	0.070
Intensive Industrial	85	0.032	0.071
Apartments, High-Density Residential	80	0.033	0.072
Mobile Home Park	75	0.034	0.073
Condominiums, Medium-Density Residential	70	0.035	0.074
Residential 8-10 du/ac (20-25 du/ha), Ext Industrial	60	0.037	0.076
Residential 6-8 du/ac (15-20 du/ha), Low-Density Residential, School	50	0.040	0.080
Residential 4-6 du/ac (10-15 du/ha)	40	0.042	0.084
Residential 3-4 du/ac (7.5-10 du/ha)	30	0.046	0.088
Residential 2-3 du/ac (5-7.5 du/ha)	25	0.050	0.090
Residential 1-2 du/ac (2.5-5 du/ha)	20	0.053	0.093
Residential .5-1 du/ac (1-2.5 du/ha)	15	0.056	0.096
Residential .2-.5 du/ac (0.5-1 du/ha), Ag Res.	10	0.060	0.100
Residential <.2 du/ac (0.5 du/ha), Recreation	5	0.065	0.110
Open Space, Grassland, Agriculture	2	0.070	0.115
Open Space, Woodland, Natural	1	0.075	0.120
Dense Oak, Shrubs, Vines	1	0.080	0.150
Shaded values are normally not used.			

Source:
Sacramento City/County Drainage Manual, Volume 2, "Hydrology Standards," December 1996.

TABLE 13

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

PARAMETERS FOR OVERLAND FLOW
WITH FLOW DEPTHS LESS THAN TWO (2) INCHES (50 mm)

Surface	Overland "n"	Distance, Foot (m)
Pavement – Smooth	0.02	50 (15)
Pavement – Rough/Cracked	0.05	50 (15)
Bare Soil – Newly Graded Areas	0.10	100 (30)
Range – Heavily Grazed	0.15	100 (30)
Turf – 1-2"/Lawns/Golf Course	0.20	100 (30)
Turf – 2-4"/Parks/Medians/Pasture	0.30	200 (60)
Turf 4-6"/Natural Grassland	0.40	200 (60)
Few Trees – Grass Undergrowth	0.50	300 (90)
Scattered Trees – Weed/Shrub Undergrowth	0.60	300 (90)
Numerous Trees – Dense Undergrowth	0.80	300 (90)

Source:
Sacramento City/County Drainage Manual, Volume 2, "Hydrology Standards," December 1996.

TABLE 14

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

OVERLAND FLOW PRECIPITATION INTENSITY

Design Frequency (yr)	Precipitation Intensity in/hr (mm/hr)	C	Initial Estimates	
			T_O = 5 min in/hr (mm/hr)	T_O = 10 min in/hr (mm/hr)
2	$i = CT_O^{-0.519}$	3.8 (96.5)	1.65 (41.9)	1.15 (29.2)
5	$i = CT_O^{-0.558}$	6.3 (160)	2.57 (65.3)	1.74 (44.2)
10	$i = CT_O^{-0.576}$	8.13 (206.5)	3.22 (81.8)	2.16 (54.9)
25	$i = CT_O^{-0.601}$	16 (279.4)	4.18 (106.2)	2.76 (70.1)
50	$i = CT_O^{-0.620}$	13.6 (345)	4.84 (122.9)	3.12 (79.2)
100	$i = CT_O^{-0.627}$	15.8 (401)	5.76 (146.3)	3.73 (94.7)
200	$i = CT_O^{-0.642}$	18.4 (467)	6.55 (166.4)	4.20 (106.7)
500	$i = CT_O^{-0.652}$	22.1 (561)	7.74 (196.5)	4.92 (125.0)

Source:
Sacramento City/County Drainage Manual, Volume 2, "Hydrology Standards," December 1996.

TABLE 15

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

STANDARD OVERLAND FLOW PARAMETERS

Land Use	Overland Flow Time, min	Slope Foot/ Foot, m/m	Overland, "n"	Distance, ft
Commercial	3	-	-	-
Residential	9	-	-	-
Open Space	17-44[1]	.001-.01	0.30	200

[1]Computed Using Overland Flow Equation Depending Upon Slope.

Source:
Sacramento City/County Drainage Manual, Volume 2, "Hydrology Standards," December 1996.

TABLE 16

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

LAG MULTIPLICATION FACTORS FOR OVERLAND RELEASE

Frequency (Yrs)	2	5	10	25	50	100	200	500
Multiplication Factor	1.0	1.0	1.0	1.1	1.2	1.3	1.4	1.5

Source:

Sacramento City/County Drainage Manual, Volume 2, "Hydrology Standards," December 1996.

TABLE 17

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

USBR'S DIMENSIONLESS URBAN UNIT HYDROGRAPH

Ordinate Number	Time t in % of $L_g + 0.5D$	q
1	0	0.00
2	5	0.64
3	10	1.56
4	15	2.52
5	20	3.57
6	25	4.36
7	30	5.80
8	35	6.95
9	40	8.38
10	45	9.87
11	50	11.52
12	55	13.19
13	60	15.18
14	65	17.32
15	70	19.27
16	75	19.74
17	80	20.00
18	85	19.74
19	90	19.27
20	95	17.72
21	100	16.12
22	105	14.50
23	110	13.08
24	115	12.19
25	120	11.31

TABLE 17

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

USBR'S DIMENSIONLESS URBAN UNIT HYDROGRAPH

Ordinate Number	Time t in % of $L_g + 0.5D$	q
26	125	10.27
27	130	9.63
28	135	8.96
29	140	8.27
30	145	7.75
31	150	7.22
32	155	6.75
33	160	6.27
34	165	5.94
35	170	5.55
36	175	5.24
37	180	4.92
38	185	4.63
39	190	4.39
40	195	4.18
41	200	3.93
42	205	3.73
43	210	3.55
44	215	3.37
45	220	3.24
46	225	3.04
47	230	2.93
48	235	2.75
49	240	2.67
50	245	2.53

TABLE 17

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

USBR'S DIMENSIONLESS URBAN UNIT HYDROGRAPH

Ordinate Number	Time t in % of $L_g + 0.5D$	q
51	250	2.47
52	255	2.37
53	260	2.30
54	265	2.21
55	270	2.12
56	275	2.04
57	280	1.98
58	285	1.90
59	290	1.83
60	295	1.78
61	300	1.71
62	305	1.64
63	310	1.60
64	315	1.53
65	320	1.49
66	325	1.42
67	330	1.39
68	335	1.32
69	340	1.28
70	345	1.23
71	350	1.21
72	355	1.15
73	360	1.11
74	365	1.07
75	370	1.03

TABLE 17

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

USBR'S DIMENSIONLESS URBAN UNIT HYDROGRAPH

Ordinate Number	Time t in % of $L_g + 0.5D$	q
76	375	1.00
77	380	0.97
78	385	0.93
79	390	0.90
80	395	0.87
81	400	0.84
82	405	0.81
83	410	0.78
84	415	0.75
85	420	0.73
86	425	0.69
87	430	0.67
88	435	0.64
89	440	0.62
90	445	0.60
91	450	0.58
92	455	0.56
93	460	0.54
94	465	0.52
95	470	0.50
96	475	0.49
97	480	0.48
98	485	0.46
99	490	0.45
100	495	0.43

TABLE 17

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

USBR'S DIMENSIONLESS URBAN UNIT HYDROGRAPH

Ordinate Number	Time t in % of $L_g + 0.5D$	q
101	500	0.41
102	505	0.40
103	510	0.39
104	515	0.37
105	520	0.36
106	525	0.34
107	530	0.33
108	535	0.32
109	540	0.31
110	545	0.30
111	550	0.29
112	555	0.28
113	560	0.27
114	565	0.26
115	570	0.25
116	575	0.24
117	580	0.24
118	585	0.23
119	590	0.22
120	595	0.21
121	600	0.21

TABLE 18

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

HYDROGRAPH ROUTING OPTIONS

Method	Application	Required Parameters
Modified Puls	Channels Influenced by Backwater	Reach Length
	Channels With Available HEC-2 Storage-Discharge Information	Velocity in Reach
		Storage-Discharge Information
	Reservoir Routing	Storage-Elevation Information
		Elevation-Discharge Information or Orifice Data and Spillway Data
Muskingum-Cunge	Channels With Insignificant Backwater Effects	Channel Length
		Channel Slope
	Channels Represented by Eight-Point Cross Sections	Manning's Roughness for Overbanks and Channel
	Channels With a Standard Cross Section, Trapezoidal, Rectangular or Circular	Cross-Section Data
Muskingum	Channels With Limited Cross-Sectional Information	Number of Subreaches
		Muskingum "K" Coefficient, hrs
		Muskingum "X" Attenuation Coefficient

<u>Source</u>:
Sacramento City/County Drainage Manual, Volume 2, "Hydrology Standards," December 1996.

TABLE 19

YOLO COUNTY

CITY / COUNTY DRAINAGE MANUAL

RATIONAL METHOD CALCULATION SHEET

Inlet		Area A	C	CA	Sum CA	Time of Concentration																					Total L_c	i (in/hr)	CiA	Q_{DESIGN}	Pipe Capacity	Remarks
						Overland Flow				Gutter Flow			Pipe Flow					Channel Flow													
From	To	(ac)		(ac)	(ac)	L_o	S_o	Overland "n"	T_o	L_g	S_g	T_g	S_p	D (in)	V (fps)	L (ft)	T_p (min)	S_c	Bottom Width	Manning's "n"	Velocity (fps)	L_c (ft)	T_c (min)				(min)			(cfs)	(cfs)	

Note: A digital copy of Table 19 is located on the CD at the back of this Manual.

TABLE 20

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

LAND USE VS. EFFECTIVE PERCENT IMPERVIOUS AND
10-YEAR RUNOFF COEFFICIENTS FOR THE RATIONAL METHOD

Page 1 of 2

Land Use From Aerial Photography	Land Use Designation	Effective % Impervious	10-Year Runoff Coefficient By Hydrologic Soil Group		
			B	C	D
Highways, Parking	N/A	95	0.86	0.87	0.87
Commercial Heavy Industrial	Commercial Professional Industrial	90	0.82	0.84	0.85
Office/Industrial	Office Professional/Light Industrial	85	0.78	0.80	0.82
Apartments	High Density Residential Mixed Use	80	0.74	0.77	0.79
Mobile Home Park	Public Facility	75	0.70	0.74	0.76
Condominiums	Medium-Density Residential	70	0.66	0.71	0.74
Residential: 8-10 du/ac (20-25 du/ha)	Residential	60	0.58	0.64	0.68
Residential: 6-8 du/ac (15-20 du/ha)	Residential/Urban Reserve	50	0.50	0.58	0.63

TABLE 20

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

LAND USE VS. EFFECTIVE PERCENT IMPERVIOUS AND
10-YEAR RUNOFF COEFFICIENTS FOR THE RATIONAL METHOD

Land Use From Aerial Photography	Land Use Designation	Effective % Impervious	10-Year Runoff Coefficient By Hydrologic Soil Group		
			B	C	D
Residential: 3-4 du/ac (7.5-10 du/ha)	Residential	30	0.34	0.45	0.52
Residential: 2-3 du/ac (5-7.5 du/ha)	Residential	25	0.30	0.41	0.49
Residential: 1-2 du/ac (2.5-5 du/ha)	Residential	20	0.26	0.38	0.46
Residential: .5-1 du/ac (1-2.5 du/ha)	Residential	15	0.22	0.35	0.43
Residential: .2-.5 du/ac (0.5-1 du/ha)	Residential	10	0.18	0.32	0.41
Residential: <.2 du/ac (.05 du/ha)	Residential/Parks	5	0.14	0.28	0.38
Open Space, Grassland	Open Space	2	0.12	0.26	0.36
Agriculture	Agriculture	2	0.26	0.41	0.51

TABLE 21

**YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL**

**RATIONAL METHOD
RUNOFF COEFFICIENT FREQUENCY FACTORS**

Return Period, yrs	Frequency Factor "F"
2	0.83
5	0.90
10	1.00
25	1.08
50	1.15
100	1.24

TABLE 22

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

RATIONAL METHOD
SUBBASIN RUNOFF COEFFICIENT CALCULATION SHEET

Land Use	Effective Percent Impervious	Hydrologic Soil Group B			Hydrologic Soil Group C			Hydrologic Soil Group D		
		Runoff Coeff (C)	Area, ac	F X C X Area[1]	Runoff Coeff (C)	Area, ac	F X C X Area[1]	Runoff Coeff (C)	Area, ac	F X C X Area[1]
Commercial Professional (CP)	90	0.82			0.84			0.85		
Industrial (IND)	90	0.82			0.84			0.85		
Office Professional/Light Industrial (OP/LI)	85	0.78			0.80			0.82		
High Density Residential (HD) Mixed Use (MU)	80	0.74			0.77			0.79		
Public Facility	75	0.70			0.74			0.76		
Medium-Density Res. (MD)	70	0.66			0.71			0.74		
Low-Density Residential (LD)	60	0.58			0.64			0.68		
Urban Reserve (UR)	50	0.50			0.58			0.63		
Estate Residential (ER)	25	0.30			0.41			0.49		
Parks/Recreation/Open Space	5	0.14			0.28			0.38		
TOTALS			**0.00**	**0.00**		**0.00**	**0.00**		**0.00**	**0.00**

Total Area 0.00   Runoff Coefficient
Sum (Coeff X Area) 0.00   Sum (Coeff x Area)/Total Area
Weighted Subbasin

[1]Apply Runoff Coefficient Frequency F Factor of 0.83, 0.90, 1.00, 1.08, 1.15, and 1.24 to 10-Year Runoff Coefficient for Design Storm Return Periods of 2, 5, 10, 25, 50, and 100 years, respectively.

TABLE 23

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL

EQUIVALENT ROUGHNESS COEFFICIENT FOR CALCULATION
OF HYDRAULIC GRADE LINE FOR STORM DRAIN DESIGN

Pipe Material	Base Manning's Roughness Coefficient, n_{base}
Corrugated Metal	0.024
Concrete	0.015

Equivalent Entrance Loss Adjustment: $\qquad n_1 = \left(\dfrac{0.087d^{4/3}}{lg} \right)^{1/2}$

Equivalent Exit Loss Adjustment: $\qquad n_2 = \left(\dfrac{0.174d^{4/3}}{lg} \right)^{1/2}$

Where:

$\quad$ d = pipe diameter (ft.)
$\quad$ l = pipe length (ft.)
$\quad$ g = 32.2 ft./s^2

$\quad n_{total} = n_{base} + n_1 + n_2$

Source: Chow, Ven Te, *Open Channel Hydraulics*, 1959.

FIGURES

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL
APRIL 2009

Yolo County
City/County Drainage Manual
Location Map
April 2009

Yolo County

Redwood NP

Lassen Volcanic NP

80

Sacramento

680

5

Stockton

San Francisco

Yosemite NP

San Jose

Kings Canyon NP

Fresno

Sequoia NP

Death Valley NP

Las Vegas

Bakersfield

15

40

215

Channel Islands NP

Los Angeles

Riverside

Joshua Tree NP

Long Beach

10

0   40   80 Miles

Figure 1

Yolo County
City/County Drainage Manual
Sacramento-San Joaquin Drainage District
April 2009
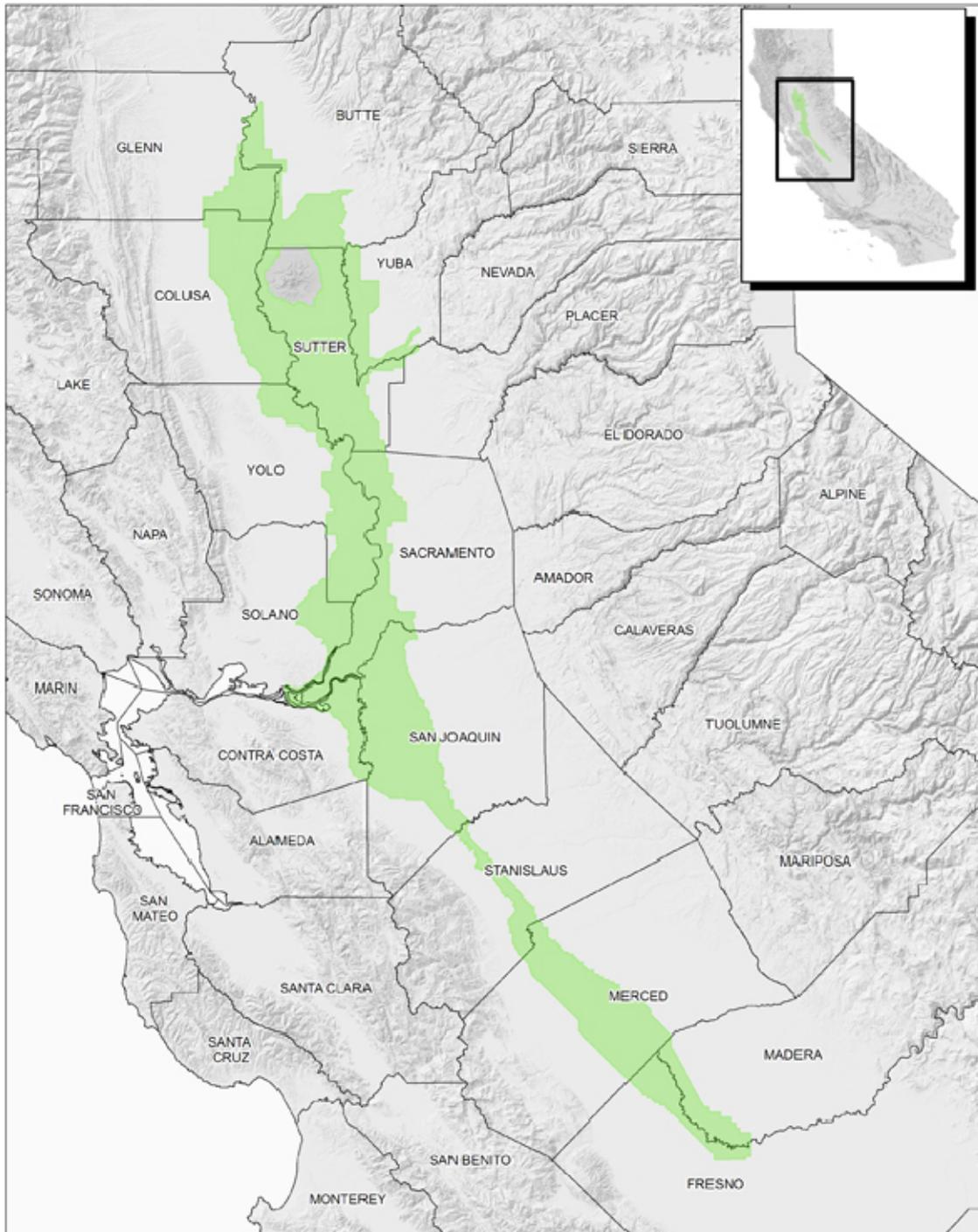
Sacramento-San Joaquin Drainage District Boundary

Figure 2

Yolo County
City/County Drainage Manual
Hydrologic Soil Groups
April 2009

Hydrologic Soil Groups Within Yolo County:

A (Low Runoff Potential):
The soils have a high infiltration rate even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels. They have a high rate of water transmission.

B:
The soils have a moderate infiltration rate when thoroughly wetted. They chiefly are moderately deep to deep, moderately well drained to well drained soils that have moderately fine to moderately coarse textures. They have a moderate rate of water transmission.

C:
The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. They have a slow rate of water transmission.

D (High Runoff Potential):
The soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have a high swelling potential, soils that have a permanent high water table, soils that have a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. They have a very slow rate of water transmission.

SOURCES
U.S. Department of Agriculture, Natural Resources Conservation Service, 2005.
http://websoilsurvey.nrcs.usda.gov/app/homepage.htm
Yolo County Integrated Regional Water Management Plan, May 2005.

0   4   8 Miles

Figure 3

Yolo County
City/County Drainage Manual
Groundwater Elevation - Spring 1996
April 2009
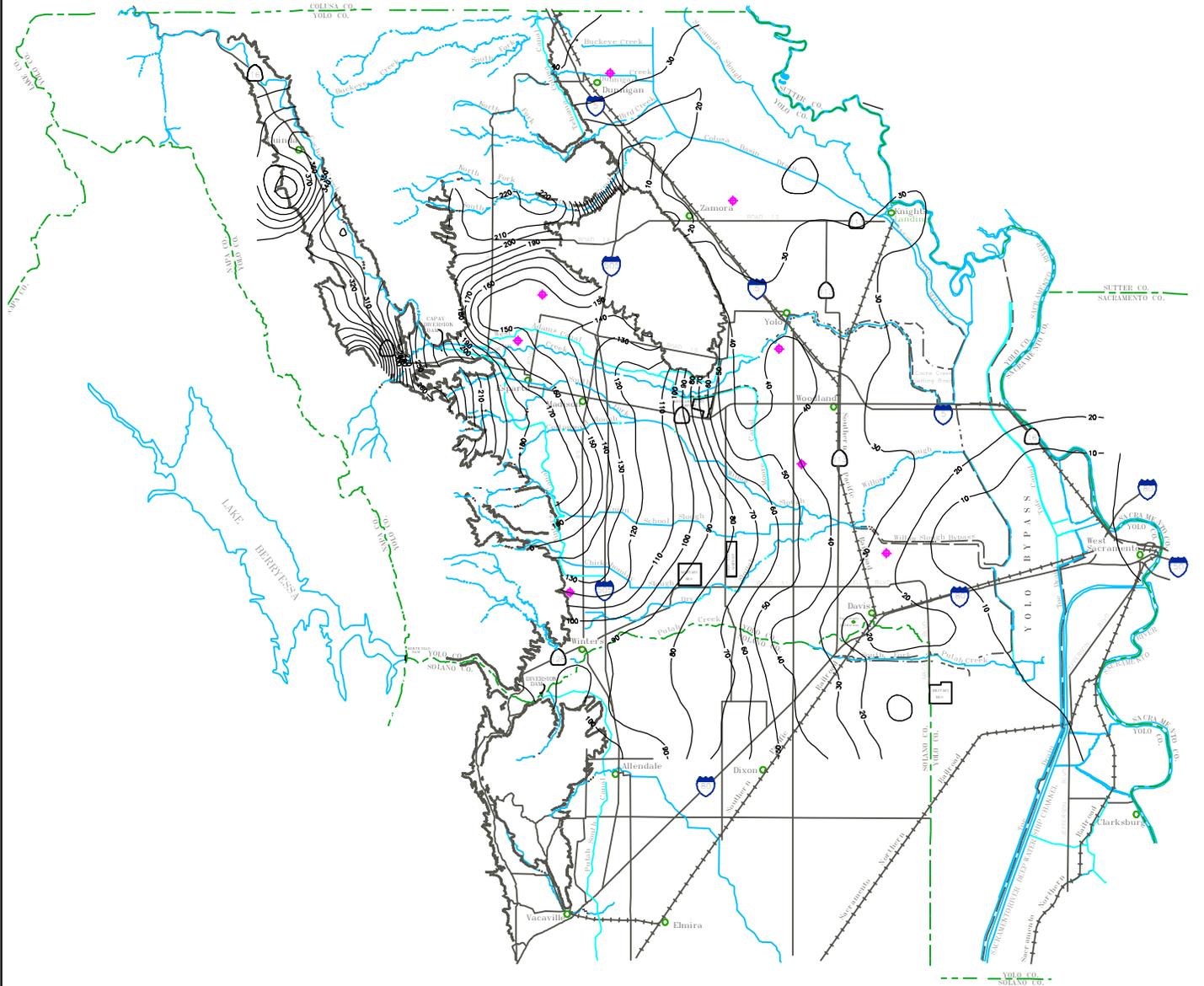
Lines of Equal Groundwater Elevation, feet msl

Well Location

0   3.5   7   Miles
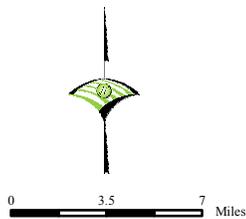
Figure 4

Yolo County
City/County Drainage Manual
Groundwater Elevation - Fall 1996
April 2009
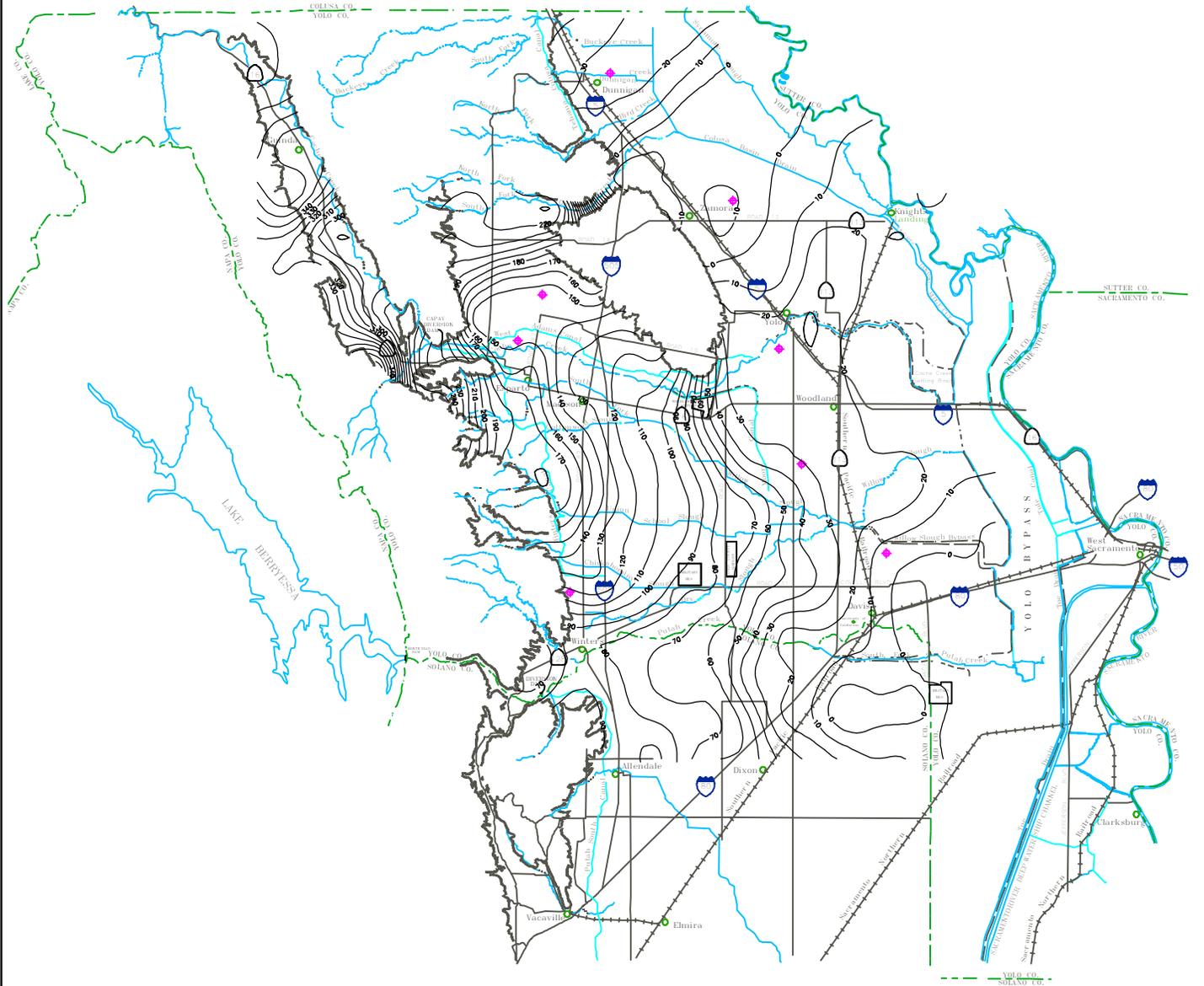
Lines of Equal Groundwater Elevation, feet msl

Well Location

0   3.5   7 Miles

Figure 5

Yolo County
City/County Drainage Manual
Relationship of Mean Precipitation to Maximum Daily Rainfall
April 2009

Trend Line: $y = 0.1212x - 0.0974$

$R^2 = 0.9856$

Based on 10 stations with 67 or more years of record.

Y-axis: Adjusted Average Annual Maximum Daily Rainfall (in)

X-axis: Gage-Specific Mean Annual Precipitation (in)
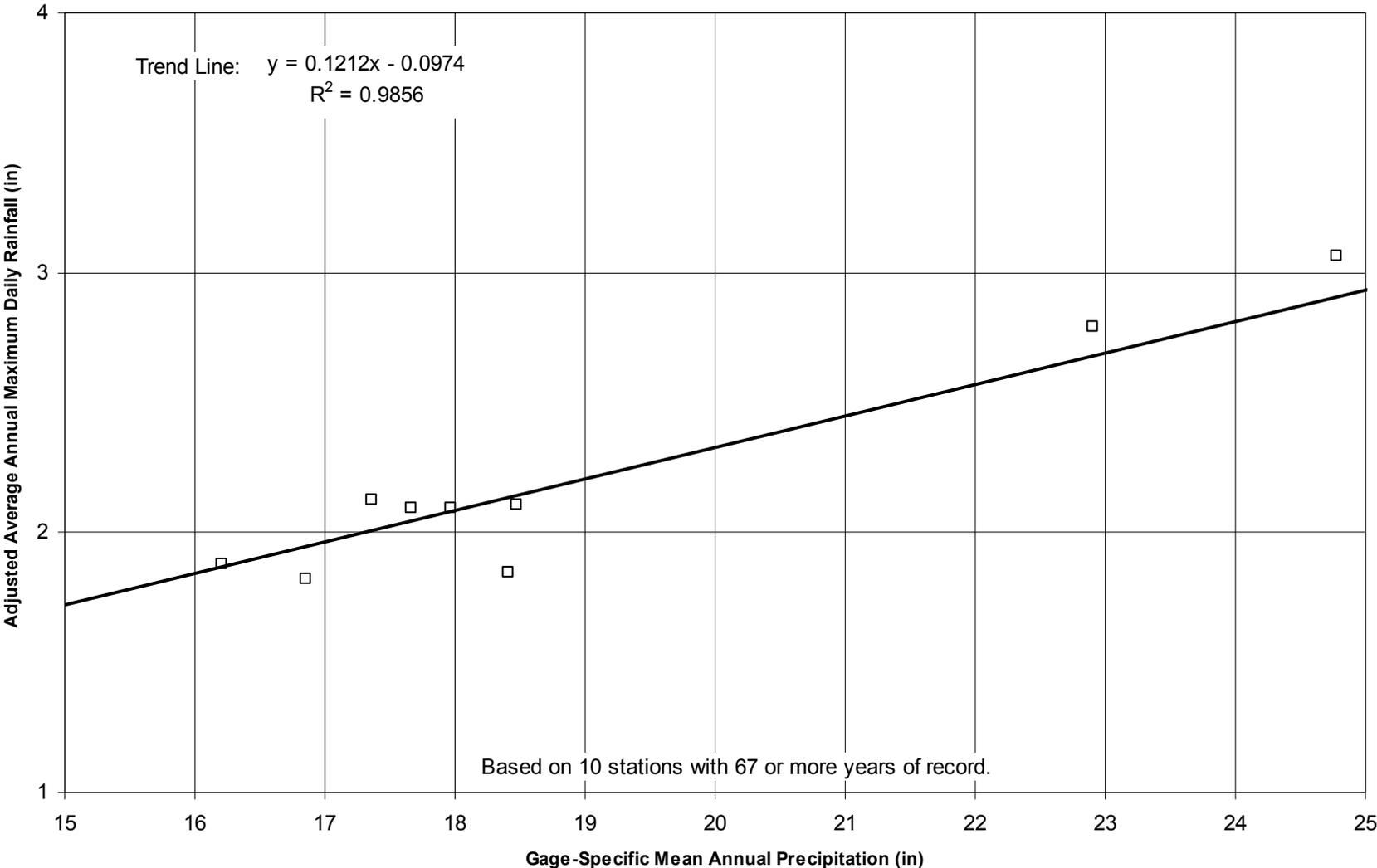
Figure 6

Yolo County
City/County Drainage Manual
Relationship of Rainfall Duration and Corresponding Maximum Rainfall

April 2009

Trend Line: $y = 0.4227x - 0.9693$

$R^2 = 0.9949$

X-axis: Log (Rainfall Duration (min))

Y-axis: Log (Multigage Average of Adjusted Annual Maximum Rainfall (in))
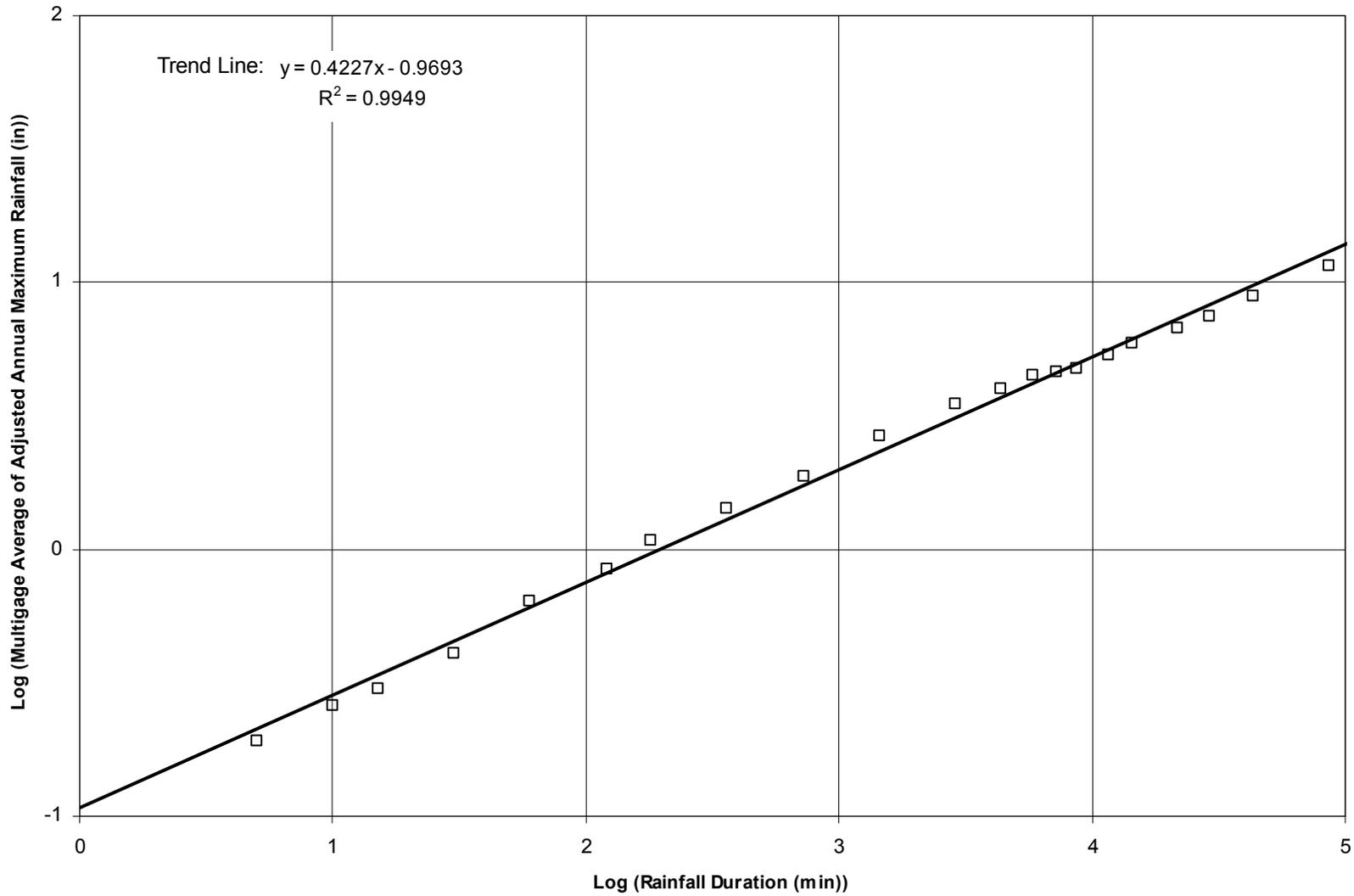
Figure 7

Yolo County
City/County Drainage Manual
Mean Annual Precipitation (1971-2000) and
Design Value of the Coefficient of Variation Interactive Map Calculator
April 2009

Figure 8

Yolo County
City/County Drainage Manual
Idealized Isohyetal Pattern for Local-Storm PMP Areas
up to 500 Square Miles

April 2009
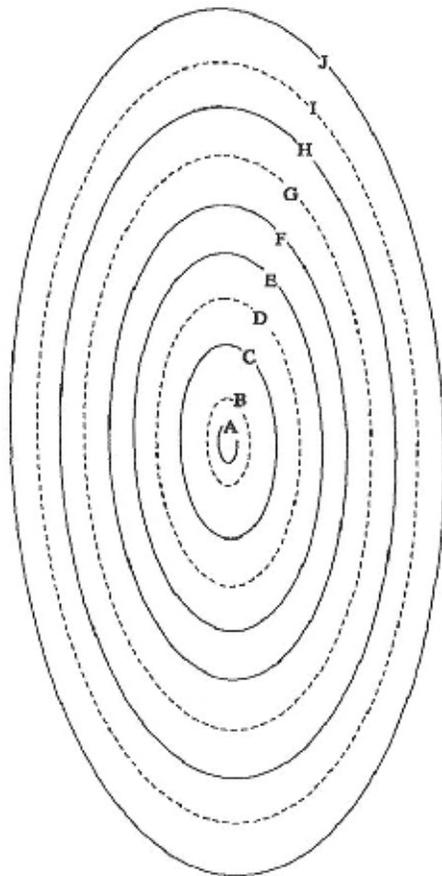
ENCLOSED AREA

	AREA	
ISOHYET	(MI^2)	(KM^2)
A	1	2.6
B	5	13
C	25	65
D	55	142
E	95	246
F	150	388
G	220	570
H	300	777
I	385	997
J	500	1295
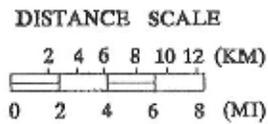
DISTANCE SCALE

2 4 6 8 10 12 (KM)

0   2   4   6   8 (MI)

SCALE
1:500,000

Figure 9

Yolo County
City/County Drainage Manual
Weighted Average Watershed Precipitation Factor
(HMR 58 Elliptical Storm Centering)
April 2009

Ellipse	Watershed Area in sq.mi. (A)	Effective Precipitation Factor Area in sq. mi. (EA)	Precipitation Factor in % (PF)	(EA) * (PF)	Cumulative Sum of (EA)*(PF)	Weighted Average Precipitation Factor in %
A	1	1	130	1.3	1.3	130
B	5	4	116	4.64	5.9	118.8
C	25	20	91	18.2	24.1	96.6
D	55	30	75	22.5	46.6	84.8
E	95	40	59	23.6	70.2	73.9
F	150	55	48	26.4	96.6	64.4
G	220	70	38	26.6	123.2	56.0
H	300	80	31	24.8	148.0	49.3
I	385	85	30	25.5	173.5	45.1
J	500	115	29	33.35	206.9	41.4
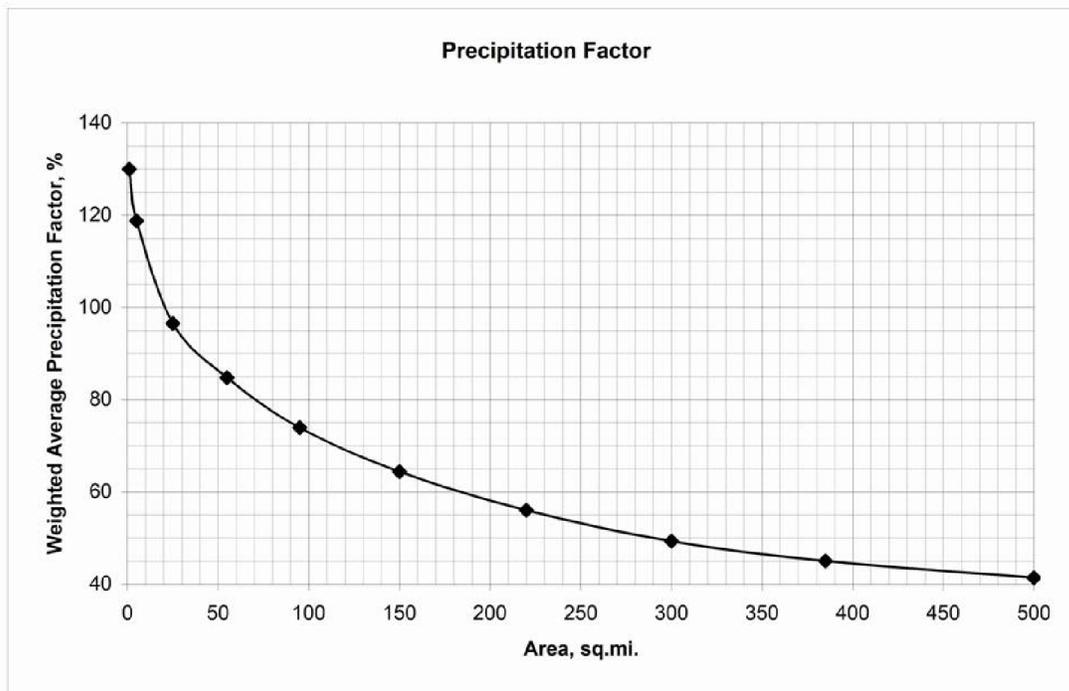
Precipitation Factor

Figure 10

Yolo County
City/County Drainage Manual
Effective Composite Flood Insurance Rate Maps
April 2009
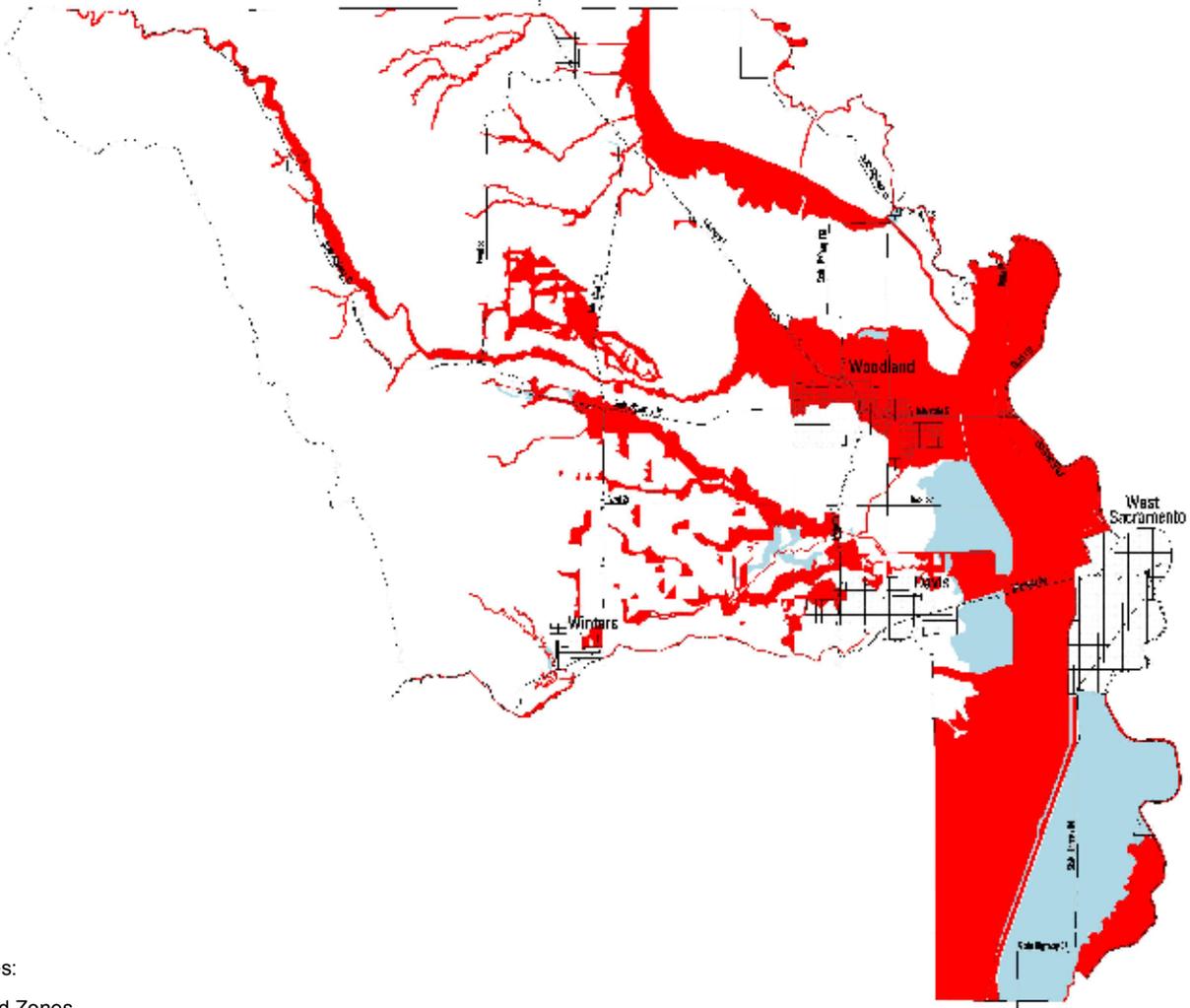
Yolo County Flood Zones:

100-Year Flood Zones

500-Year Flood Zones

<u>NOTE</u>
Refer to FEMA for latest FIRM updates.

<u>SOURCE</u>
Yolo County Integrated Regional Water Management Plan, May 2005.

0   4   8 Miles
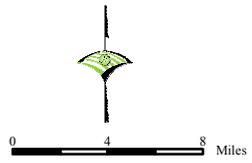
Figure 11

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL
STORM WATER QUALITY TREATMENT MEASURES
VOLUME 2 OF 2

APRIL 2009
(REV. FEBRUARY 2010)

PREPARED FOR:

floodSAFEYolo
Pilot Program

PREPARED BY:

WOOD RODGERS
DEVELOPING INNOVATIVE DESIGN SOLUTIONS

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE

1   Selection of Storm Water Quality Control Measures

EXHIBIT

Water Quality Flow (WQF) and Water Quality Volume (WQV)

VOLUME 1 of 2

City / County Drainage Manual

STORM WATER QUALITY MANAGEMENT

Purpose

This section of the Manual provides storm water related tools necessary for new development or development projects located in the unincorporated areas the County to reduce pollutant discharge to waters of the U.S., to the Maximum Extent Practicable (MEP), and to protect the beneficial uses of receiving waters, as required under the SWRCB, Small MS4 General Permit. This section of the Manual provides a description of storm water control measures and associated design criteria that are most appropriate for mitigating pollutants of concern originating from urbanized areas. Water control measures will be categorized within this Manual as the following BMPs: Source Control BMPs, Treatment BMPs, and Runoff Reduction BMPs. Each of the BMPs within this Manual will provide a varying degree of treatment for the following pollutants: sediment, nutrients, pathogens, oil and grease, metals, organic compounds, pesticides, and gross pollutants.

History and Applicability

The Federal Water Pollution Control Act, also referred to as the Clean Water Act (CWA), was amended in 1972 to prohibit point source storm water discharges unless the discharge is permitted under the National Pollutant Discharge Elimination System (NPDES) permitting program. In 1987, the CWA was further amended to include section 402 (p) which established NPDES requirements for municipal and industrial discharges. The municipal NPDES program was developed to be implemented in two phases, Phase I required urban areas with a population greater than 100,000 to obtain a NPDES permit for storm water discharges and Phase II, developed in 1999, required municipalities with a population less than 100,000. The storm water system operated by the County serves a population designated as a Phase II municipality and therefore the County was required to apply for coverage under the NPDES program.

In response to the 1987 Amendments to the CWA, USEPA developed Phase I of the NPDES Storm Water Program in 1990. Beginning at that time, municipalities with populations greater than 100,000 began to develop and implement storm water management programs. In California, Phase I municipalities now have individual NPDES permits, administered by Regional Water Quality Control Boards (RWQCB).

Phase II of the regulations require municipalities and contiguous areas with smaller – but still urban – communities to develop and implement storm water management programs. In California, the SWRCB has developed the *General Permit for Discharges of Storm Water From Small Municipal Separate Storm Sewer Systems* (hereafter the "Small MS4 General Permit"), to which all designated municipalities and contiguous jurisdictions must submit a Notice of Intent (NOI) to seek coverage under the General Permit. The nine Regional Water Quality Control Boards, as the designated regional authorities under the State Board, administer the Phase II permit program.

The County must implement BMPs that reduce pollutants in storm water to the MEP. MEP is the technology-based standard established by Congress in CWA §402(p)(3)(B)(iii). Technology-based standards establish the level of pollutant reductions that dischargers must achieve. MEP is generally a result of emphasizing pollution prevention and source control BMPs as the first lines of defense in combination with treatment methods serving as additional lines of defense, where appropriate.

In choosing control measures and the associated BMPs, the focus is on technical feasibility, but cost, effectiveness, and public acceptance are also relevant. If the County chooses only the most inexpensive control measures, it is likely that MEP has not been met. If the County utilizes all applicable control measures except those that are not technically feasible in the locality, or whose cost exceeds any benefit to be derived, it would meet the MEP standard. MEP requires the County to choose effective control measures, and to reject applicable control measures only where other effective control measures will serve the same purpose, the control measures are not technically feasible, or the cost is prohibitive.

Low Impact Development

Most pollution related to storm water runoff is the result of man-made hydraulic modifications that are usually associated with development. The addition of impervious surface, modification of existing topography, removal of vegetation, and concentration of drainage can result in the modification of the natural hydraulic patterns of a specific area, which can result in increased impacts to the quality of storm water runoff. One way to minimize potential storm water quality impacts is to implement traditional BMPs and LID techniques.

LID strategies and practices are an alternative comprehensive approach to help protect and restore water quality. LID techniques promote the use of natural systems, which can effectively remove nutrients, pathogens, sediments, trash, and metals from storm water runoff. LID is a storm water management approach and set of practices that can reduce runoff and pollutant loadings by managing runoff as close to the source as possible. This is achieved through a system of LID practices that, when linked together, promote infiltration, evapotranspiration, and the reuse of rainwater. In addition, LID also includes planning strategies that utilize land efficiently and in a manner which protects undisturbed natural lands and maintains the pre-construction hydraulic characteristics of a site while still allowing development to occur.

LID strategies can also result in a decrease in development costs by decreasing infrastructure requirements such as grading, paving, and storm drainage systems costs. This cost savings is also experienced post-construction due to a decrease in maintenance of a traditional storm drainage system. Considering LID early on in the project development process is a key factor to successful storm water management. The LID approach to site design promotes conservation practices and the use of small runoff reduction and treatment measures located at the lot level. Implementing smaller more frequent water quality measures will require the establishment of maintenance and monitoring programs at the local agency level to ensure these water quality measures remain established and operate properly.

Below are descriptions of LID strategies that can be considered for any project. Some of the strategies are planning in nature and other strategies are actual permanent storm water control measures. Specific design criteria for permanent measures are located either under Treatment BMPs or Runoff Reduction BMPs.

Conserve Natural Environments

Conservation designs can be used to minimize the generation of storm water runoff by reducing impervious surfaces. Each project site possesses unique topographic, hydrologic, and vegetative features, some of which are more suitable for development than others. Locating development on the least sensitive portion of a site and conserving naturally vegetated areas can minimize environmental impacts in general and storm water runoff impacts in particular.

If applicable and feasible for the given site conditions, the following site design features or elements are required and should be included in the project site layout, consistent with applicable General Plan and Local Area Plan policies:

- Concentrate or cluster development on least-sensitive (out of the riparian or wetland zone or on a naturally flat area) portions of a site, while leaving the remaining land in a natural undisturbed state.

- Limit clearing and grading of native vegetation at a site to the minimum amount needed to build lots, allow access, and provide fire protection.

- Maximize trees and other vegetation at each site by planting additional vegetation, clustering tree areas, and promoting the use of native and/or drought-tolerant plants.

- Reduce pavement widths (sidewalks and roadways) and reduce setbacks.

- Promote natural vegetation by using parking lot islands and other landscaped areas.

- Preserve open space areas.

Infiltration Measures

Infiltration practices are engineered landscape features designed to capture and infiltrate runoff. Infiltration reduces the discharge of pollutants by reducing or eliminating the discharge of storm water runoff. Prior to implementing infiltration measures within Yolo County, it is imperative that the soil type present either is defined as Type A or Type B. Refer to the Natural Resources Conservation soil surveys for more information (http://soils.usda.gov).

Infiltration can be used to reduce both the volume of storm water discharged from a specific site and the infrastructure needed to convey storm water runoff. Infiltration can also mitigate the temperature of storm water runoff by allowing the water to laterally transfer to surface water bodies, which typically will result in a lower temperature than overland flows that are subject to solar radiation. Examples of infiltration LID methods include:

- Infiltration basin and trenches (for the purposes of this manual, specific design requirements for basins and trenches are included under treatment BMPs).

- Porous pavement (specific design criteria is included under the runoff reduction BMP section).

- Disconnected downspouts.

- Rain gardens and other vegetated treatment systems.

Prevent Slope Erosion

Erosion of slopes can be a major source of sediment and associated pollutants, such as nutrients, if not properly protected and stabilized. Slope protection practices must conform to design requirements set forth in the County's Improvement Standards. The LID strategies described below are intended to enhance and be consistent with these standards:

- Minimize construction on areas that are characterized by steep topography.

- Slopes must be protected from erosion by safely conveying runoff from the tops of slopes.

- Slopes must be vegetated (full-cover) with first consideration given to use of native or drought-tolerant species.

- Design slopes to be 4:1 or flatter.

Runoff Conveyance Practices

Large storm events are not conducive to infiltration and/or storage on site. In these situations conveyance systems are often designed to transport high storm flows off of a site as fast as possible. Increased velocity and frequency of high flows can cause impacts to the receiving water by degrading the channel geometries and causing pollutants to be suspended. LID techniques can be utilized to slow flow velocities, lengthen the time of runoff concentrations, and delay peak flows that are discharged off site. LID practices (vegetated swales, storm water planters, etc.) often have rougher surfaces, which slows runoff and increases evaporation and

settling of solids. Typically, they are permeable and vegetated, which promotes infiltration, filtration, and biological uptake of pollutants through absorption. The design of the LID strategies below must conform to the design criteria stated in the County's Improvement Standards and may be subject to other regulatory permits:

- Utilize natural drainage systems to the maximum extent practicable, but minimize runoff discharge **rate** and **volume** to the maximum extent practicable.

- Stabilize permanent channel crossings.

- Eliminate curb and gutters.

- Create grass-lined swales and channels in lieu of curb and gutters.

- Roughen surfaces by increase vegetation.

- Utilize check dams to slow the velocity of storm water runoff.

- Create longer flow paths through vegetated areas.

- Locate drain inlets necessary to convey high flows at the end of a vegetated area.

- In situations where beds and/or banks of receiving streams are fragile and particularly susceptible to erosion, special stabilization may be required: (1) a small-grade control structure (e.g., drop structure) may be used to reduce the slope of the channel; (2) severe bends or cut banks may need to be hardened by lining with grass or rock; or (3) rock-lined, low-flow channels may be appropriate to protect fragile beds.

- Install energy dissipaters, such as rock riprap, at the outlets of storm drains, culverts, conduits, or channels that discharge into unlined channels.

Minimize Impervious Area

The potential for discharge of pollutants in storm water runoff from a project site increases as the percentage of impervious area within the project site increases. Impervious areas increase the volume and rate of runoff flow. Pollutants deposited on impervious areas tend to be easily mobilized and transported by runoff flow. Minimizing impervious areas through site design is an important means of minimizing storm water pollutants of concern. In addition to the environmental and aesthetic benefits, a highly pervious site may allow reduction in the size of downstream conveyance and treatment systems, yielding savings in development costs.

This approach involves routing runoff from impervious areas over grassy areas or other pervious areas prior to discharge to the storm drainage system or receiving water to reduce peak flows, reduce total runoff volume and provide some degree of pollutant removal. Suggested strategies for minimizing imperviousness through site design include the following:

- Reduce the footprints of building and parking lots.

- Cluster buildings and paved areas to maximize pervious area.

- Use minimum allowable roadway and sidewalk cross-sections and parking stall widths.

- Include landscape islands in cul-de-sacs (where approved).

- Use pervious pavement materials, where appropriate, such as modular paving blocks, turf blocks, porous concrete and asphalt, brick, and gravel or cobbles. (Ref. BASMAA, 1999 for descriptions of pervious pavements options.)

- Use grass-lined channels or surface swales to convey runoff instead of paved gutters.

Low Impact Landscaping

Selection and distribution of plants is an important LID technique that can decrease storm water pollution through decreased water use for irrigation, decreased need for herbicides, pesticides and fertilizers, and decreased excess plant material. Properly preparing soils and selecting species adapted to the microclimate of a site will increase the success of plant establishment and can reduce the need for watering and long-term plant maintenance. In addition, interceptor trees uptake storm water, provide shade (decreasing the temperature of storm water runoff), and reduce erosion through their root structure. Examples of LID landscaping include:

- Planting native, drought tolerant plants.

- Converting turf areas to shrubs and trees.

- Re-vegetating areas where natural vegetation has been removed.

- Encouraging longer grass length.

- Planting wildflowers and native grasses rather than turf in medians and open spaces.

- Amending soil to improve infiltration and to enhance vegetation growth.

BMP Requirements

BMP requirements are project-specific and should be considered and/or reconsidered during each phase of project development. It is important that BMP requirements are re-evaluated and considered during initial site design, to ensure the initial site layout (the specific plan) allows for the implementation of required BMPs. In addition to LID techniques, there are three types of BMPs that shall be considered for all projects:

- Source Control BMPs – Post-construction pollution prevention measures that prohibit pollutants from coming into contact with storm water runoff.

- Treatment BMPs – Post-construction storm water devices, which physically or chemically remove pollutants from storm water runoff prior to discharge.

- Runoff Reduction BMPs – Reduce the amount of storm water runoff that is discharged by promoting infiltrations, absorption, and evapotranspiration.

All projects will require source control measures to address the proposed site activities. Specific runoff reduction measures may be acceptable, and treatment control measures may be required for your type of project. See Table 1 to identify the types of source control, runoff reduction, and treatment control measures that are required and acceptable.

SOURCE CONTROL BMPS

Introduction

Source control measures are designed to prevent pollutants from contacting site runoff, leaving the site, and entering the municipal storm drain system or local waterways. Development and redevelopment projects are required to employ source control measures appropriate to the planned site operations/activities as indicated in Table 1. Source control measures apply to both storm water and prohibited non-storm water discharges. Non-storm water discharges include anything not composed entirely of storm water (such as cooling water, process wastewater, irrigation water, etc.). Storm water that is mixed or commingled with other non-storm water flows is considered non-storm water. Local, state, or federal permits may be required for discharges of storm water and non-storm water to the storm drain system or a water body. To verify this, check with the local permitting agency.

Storm Drain Inlet Signage

Description

This section provides details about permanent "No dumping-drains to creek/river" messages at storm drain inlets and "No dumping" signs at public access points to channels and creeks on the development project site, where applicable. Storm drain markings are intended to help stop illegal dumping by alerting people that the drain leads directly to a water body and dumping is prohibited. Signs at access points to creeks and channels serve as reminders that dumping there is illegal.

Application

Permanent storm drain inlet markings are required on all new drain inlets (also known as catch basins) installed in development/redevelopment projects. Signs are also required at public access points to any creeks or drainage channels within or adjacent to the site.

Site and Design Considerations:

- Identify all storm drain inlets on the improvement plans and indicate if the need to be marked with the appropriate storm drain messages.

- Follow the message layout, content, and other specifications provided by the local permitting agency. Each agency may have its own design.

- For signs posted at access points to waterways, consult the local permitting agency for the required/preferred message and style.

- Alternatively, obtain approval from the local jurisdiction for a different layout/message that clearly prohibits dumping using words or graphical icons.

- Consider the use of bilingual messages, where appropriate, based upon local population.

Maintenance

The legibility of storm drain inlet messages and signs must be maintained to ensure effective pollution prevention over time.

Waste Management Areas

Description
This section specifies how to design waste and recycling storage areas so that they are not sources of pollutants to the storm drainage system and receiving waters. A properly designed waste/recycling storage area keeps rain, runoff, and other site water from leaching away pollutants; minimizes the chance of spills and leaks; and prevents any spilled or leaked wastes from entering the storm drainage system. Potential pollutants include fats/oils/greases (from food), particulates, organic matter, toxic chemicals, and more.

Application
The design requirements are primarily intended for new development. If applied to significant redevelopment, the requirements would only apply in the case of complete redesign of the portion of the facility involving the waste management/trash enclosure area(s).

Site and Design Considerations
The required design features need to be maintained and properly operated. This includes regular maintenance of the grease interceptor and handling and disposal of materials that accumulate in the interceptor and maintenance of covers and sanitary sewer connections, if applicable. Discuss any potential conflicts with the local permitting agency early in the planning process before proceeding with design. In addition, check with the appropriate waste hauler regarding design or access requirements.

Size and Location
- Design an enclosed area for waste and recycling storage and collection on the site so that containers cannot be knocked over and where unauthorized use or vandalism is unlikely. This will help keep debris from being blown off site and pollutants from entering the storm drain system.

- Provide adequate room for waste collection trucks to pick up and empty dumpsters to minimize the chance of accidents and spillage. Check with the local solid waste agency for access standards.

- In the absence of local standards, design the enclosure to have direct access for collection trucks, meaning the truck can drive directly at the bin and insert the forks into the sides of the bin.

- A minimum straight approach of 50-65 feet is recommended to line up directly with the bin.

Paving
- Pave the wash area with asphalt or concrete.

Coverage
- Provide a cover for the entire waste area, if acceptable to permitting agency. Some local waste haulers may not allow a cover due to vertical clearance/accessibility needs for front loading trucks.

- If a cover will be installed, check with local fire department about possible sprinkling requirements.

Drainage
- Direct runoff from roof downspouts away from the waste/recycling storage area.

- Locate the waste management area at least 35 feet from the nearest storm drain inlet. The intention is to deter employees/tenants/contractors from directing wash water to the storm drain system with a hose or pressure washer.

- Hydraulically isolate the area; this can be achieved by reverse grading at the perimeter, perimeter curbing or berming, or the use of perimeter or area drains to collect and divert runoff.

Sanitary Sewer Connections
- If acceptable to the permitting agency, connect the hydraulically-isolated area sewer via a trench drain at the back of the enclosure or similar, to facilitate proper disposal of polluted wash water. Check with the local solid waste agency for detail drawings if available.

- Provide pre-treatment with an approved grease interceptor prior to discharge to the sanitary sewer. Check with the local sanitary sewer permitting agency for specifics and approval. Note that the Plumbing Code limits the number of connections to a single grease interceptor at a facility.

Signage
- Post signs inside the enclosure and/or on the bins prohibiting the disposal of liquids and hazardous materials therein.

- Consider posting signs on the inside of the enclosure walls to educate employees and tenants about proper wash down procedures (procedures will vary depending upon whether or not the area is connected to the sanitary sewer system).

Maintenance
Proper maintenance of the waste management area design features is essential to its performance. Proper handling and disposal of materials will reduce the exposure of pollutants outside of designated areas. Drainage flow lines should be cleaned, as needed, to ensure adequate drainage. Site features may be subject to inspections by local fire and/or sanitary sewer agencies.

- If included on site, spill containment vaults should be cleaned on an as-needed basis.

- If included on site, roofs and covers should be inspected for leaks and structural integrity.

Outdoor Storage Areas

Description
This section specifies how to locate and design outdoor material storage areas so that materials do not get washed off-site with runoff and become sources of pollutants to the local municipal storm drain system, creeks, and rivers. Such materials, including raw, by-, and finished products, are not allowed in the storm drain system. Proper design of storage areas will also help ensure that storm water and other site water does not come into contact with the stored materials and leach out pollutants. Potential pollutants may include toxic compounds, heavy metals, nutrients, suspended solids, and more.

Site and Design Considerations
If possible, determine the types and quantities of materials likely to be stored prior to design. Design requirements in this section are intended to supplement (not supersede) those in other codes (such as the Building, Fire, and Zoning Codes and the hazardous waste requirements in Title 22, California Code of Regulations, as applicable). Discuss any potential conflicts with the local permitting agency early in the planning process before proceeding with design. In addition, certain industries are subject to the State's Industrial Storm Water General Permit, which is also intended to protect storm water quality: see http://www.waterboards.ca.gov/stormwtr/industrial.html regarding covered industries and applicable requirements.

The design features discussed in this section need to be maintained and properly operated. This includes proper handling and disposal of materials that accumulate in a secondary containment area, if applicable. In addition, features may be subject to inspections by local fire and/or sanitary sewer agencies, depending on the configuration.

Size and Location
- Size the storage area large enough for the expected materials and plan for segregation.

- Considering planned activities and traffic flow, locate the storage area where it will be convenient but not in the way of truck and vehicle traffic.

- Locate storage in a secure place to protect against vandalism and minimize accidents.

Paving
- Construct the storage area base with a material impervious to leaks and spills. Contact your local permitting agency to determine if gravel surfaces are acceptable under certain conditions (e.g., storage of inert bulk materials).

Coverage
- Install a roof or other cover acceptable to the local permitting agency that extends beyond the storage area (enough to keep rain out), or use a storage shed or cabinet.

- If solid bulk materials (such as wood chips and other landscaping materials, sand, lumber, scrap metal) will be stored and it is not feasible to cover the storage area, then omit the cover and follow the drainage requirements for uncovered storage areas (see the next section).

Drainage
- Direct runoff from downspouts/roofs away from storage areas.

- Hydraulically isolate the area using grades, berms, or interceptor drains to prevent run-on from surrounding areas or the runoff of spills.

Spill Control
- As a general rule, size the secondary containment to accommodate at least 110 percent of the volume of the largest container or 10 percent of the volume of all the containers.

- If liquids will be stored in tanks, UL-approved double-walled tanks can generally be used in lieu of other secondary containment. Verify this with the local permitting agency.

Maintenance

Proper maintenance of the Outdoor Storage design features included in this section are essential to its performance. Proper handling and disposal of materials will reduce the exposure of pollutants outside of designated areas. Drainage flow lines should be cleaned as needed to ensure adequate drainage. Site features may be subject to inspections by local fire and/or sanitary sewer agencies.

- If included on site, spill containment vaults should be cleaned on an as-needed basis.

- If included on site, roofs and covers should be inspected for leaks and structural integrity.

Loading Areas

Description

This section specifies how to design loading/ unloading areas to minimize the chance of spills and leaks and to keep any spilled/leaked materials out of the storm drain system and receiving waters. Potential pollutants addressed depend upon the operations and materials being handled, but may include toxic compounds, oil and grease, nutrients, suspended solids, fluids leaked from delivery vehicles, and/or other contaminants. Leaked fluids from delivery vehicles can also accumulate in the loading area.

Application

The design requirements provided in this section are primarily intended for new development. If applied to significant redevelopment, the requirements would only apply in the case of complete redesign of the loading area.

Site and Design Considerations

It is recognized that some land uses (e.g., food-handling, chemical distribution, hazardous materials) have a greater potential to pollute storm water than others, therefore the level of control needed varies. However, most times agency planners/reviewers will not know the use of the building at the time of plan approval. Further, warehouses and other buildings often have tenant turnover and use/materials handled will change over time. Therefore, a single set of design requirements is provided in order to address all anticipated land use types. The design features need to be maintained and properly operated. This includes proper handling and disposal of any materials that may accumulate in the spill containment vault. In addition, features may be subject to inspections by local fire and/or sanitary sewer agencies, depending on the configuration.

Paving
- Pave the loading area with an impervious paving material that is compatible with materials that will be loaded/unloaded. For example, use Portland Cement concrete if gasoline or other materials that react with asphalt will be loaded/unloaded.

Drainage
- Direct runoff from roof downspouts away from the loading/unloading areas.

- Design outdoor loading areas so the first 6 feet of pavement, as measured from the dock face (or from the building if there is no elevated loading dock), is hydraulically isolated to prevent runon/runoff. This can also be accomplished with berms, grading, or interceptor drains.

- Drain the hydraulically isolated area to a pre-treatment device (e.g., oil/water separator) then to the sanitary sewer. Equip the system with an emergency spill shut-off/diversion valve as described below. Verify that this is acceptable to the local permitting agency; the agency may require a cover on the entire area draining to the sanitary sewer.

Spill Control
- Equip the drainage system with an emergency spill shut-off/diversion valve.

- The bypass on the shut-off valve should flow to an adequately-sized spill containment vault located a safe distance away from structures due to potential for explosive/fire reaction. This is subject to approval of local permitting agency and fire department/district.

Signage
- Provide signage to identify the location and simple use instructions of any spill control/response design features (such as shutoff valves or spill response kits).

Maintenance
Proper maintenance of the loading area design features included in this section are essential to its performance. Proper handling and disposal of materials will reduce the exposure of pollutants outside of designated areas. Drainage flow lines should be cleaned, as needed, to ensure adequate drainage. Site features may be subject to inspections by local fire and/or sanitary sewer agencies.

If included on site, spill containment vaults should be cleaned on an as-needed basis.

Fueling Areas

Description

This section specifies how to locate and design
vehicle and equipment fueling areas so that pollutants
do not enter the storm drainage system and receiving
waters. Leaked engine fluids and spilled fuel
inevitably accumulate on the pavement around
fueling areas. They contain toxic materials and
heavy metals that are not easily removed by storm
water treatment devices. The design requirements in
this section are intended to prevent spilled fuel and
other potential pollutants (such as oil and grease,
solvents, car battery acid, and coolant) from
contacting storm water runoff or entering the storm
drainage system.

Application

The information in this section applies to design of fueling areas at new development or
significant redevelopment of retail or commercial gasoline outlets, automobile maintenance/
repair facilities, corporation yards, and any other facility incorporating a permanent fueling area.
This information is intended for use during facility design and therefore does not address mobile
fueling operations. It also does not include requirements for design of bulk fuel terminals (fuel
farms). Contact the local permitting agency for requirements applicable to that type of industrial
development.

Site and Design Considerations

To protect water quality, design vehicle or equipment fueling areas as explained below. Design
requirements in this section are intended to supplement (not supersede) those in Building, Fire,
and Zoning Codes. Discuss any potential conflicts with the local permitting agency early in the
planning process before proceeding with design.

Paving

- Use Portland cement concrete for the surface of the fuel dispensing area, which is
  defined as the entire area between adjacent fuel pumps and extending out at least
  six and one-half feet beyond the outer edges of the perimeter pumps. Asphalt is
  not permitted.

- Use Portland cement concrete for the surface of the fuel transfer area. Asphalt is
  not permitted.

- Check with local permitting agency on dimensions of this pavement for your
  project site.

- Use asphalt sealant to protect any asphalt paved areas surrounding the concrete fueling and transfer areas.

Cover

- Cover the fueling area with a roof structure or canopy unless the fueling area will be used routinely for oversized equipment or vehicles (such as cranes) that cannot be accommodated under cover. In such cases, special drainage requirements will apply. Check with local permitting agency.

- Design the cover height per the building code (CBC 311.2.3.2 minimum cover height is currently 13 feet, 6 inches).

- Extend the cover at least 5 feet beyond the fuel dispensing area.

Drainage

- Design drainage system so that uncontaminated runoff from the roof/canopy terminates underground in a connection to the storm drain system.

- If possible, design the fuel dispensing and transfer area pads with no slope (flat) to keep minor spills on the pad and encourage proper cleanup. Check this with the local permitting agency.

- Do not place a storm drain inlet in or near the fuel dispensing area. Check with local permitting agency to determine if there are minimum spacing requirements between fueling area and nearest inlet.

- Ensure that all grading, grade breaks and berms comply with applicable ADA requirements for disabled access.

Sanitary Sewer Connections

- If the sanitary sewer connection permitting agency allows inlets or interceptor drains that drain the fuel dispensing and/or transfer area(s) to connect to the sanitary sewer, equip such inlets and drains with a shutoff valve or spill control manhole (see below) to keep fuel out of the sanitary sewer in the event of a spill.

- Install manhole on the discharge line of the fueling pad (before the sanitary sewer line tie in); extend the tee section 18 inches below the outlet elevation and provide 60 cubic feet of dead storage volume (for oil, grease, and solids) below the outlet elevation.

Signage
- If not otherwise required, post signs that state, "Do not top off gas tanks" to prevent spills. Post sign(s) explaining the operation of any shut-off valves for facility employees, if applicable.

Maintenance
Proper maintenance of the fueling area design features included in this section is essential to its performance. Proper handling and disposal of materials will reduce the exposure of pollutants outside of designated areas. Drainage flow lines should be cleaned as needed to ensure adequate drainage. Site features may be subject to inspections by local fire and/or sanitary sewer agencies.

If included on site, spill containment vaults should be cleaned on an as needed basis.

Equipment Wash Areas

Description
This section specifies how to locate and design permanent wash areas for vehicles and equipment (including restaurant mats) so that wash water does not enter the storm drain system and receiving waters. Wash water typically carries an array of pollutants harmful to the aquatic environment. Typically pollutants include oil and grease, metals, suspended solids, soluble organics, food waste, fats/oils/greases from food, and/or detergents or other cleaning chemicals.

Application
If a permanent wash area (including steam cleaning) is planned for the development project, it must be designed according to the design requirements specified in this section. Some permitting agencies may require the inclusion of a permanent designated wash area for some land uses. Check with the local permitting agency for verification. Information in this section also pertains to the washing of equipment in outdoor areas, particularly restaurant mats and similar equipment, which can send food waste, fats, oils, and grease to the storm drain system.

Site and Design Considerations
Size and Location
- Locate the wash area so access is from paved areas only (to prevent tracking of sediment).

- Size vehicle and equipment wash areas to extend at least 4 feet in all directions around the largest piece of equipment/vehicle to be washed. For vehicle wash

areas where vehicle size is unknown, size the wash area to be at least 25 feet long and 15 feet wide.

Paving
- Pave the wash area with asphalt or concrete.

Coverage
- Cover the entire wash area with a roof or other type of approved permanent canopy.

- For covers 10 feet high or less, extend at least 3 feet beyond the perimeter of the hydraulically-isolated wash area.

- For covers higher than 10 feet, extend at least 5 feet beyond the wash area.

- A diversion valve is required for new development in infill areas, for redevelopment projects where there is no space to add a covered wash area, and for airport facilities. (Note: new facilities servicing oversize vehicles [bus, fire] can provide covered building or structure and redevelopment of such facilities should consider addition of diversion valve.)

Drainage
- Hydraulically isolate the wash area to contain the wash water and prevent runoff from leaving the area and run-on from surrounding areas from entering the wash area. Use grade breaks, berms, or interceptor drains (around the perimeter or in the entrance and exit zones) to accomplish this.

- Connect the covered wash area to an appropriate pretreatment device (e.g., oil/water separator), then to the sanitary sewer. Alternatively, install a zero-discharge water recycling system. For any of these options, first obtain approval from the applicable permitting agency.

- Connect the hydraulically isolated area to the storm drain system and equip the drainage system with a diversion valve that can temporarily redirect polluted wash water to the sanitary sewer when washing activities are taking place. Diversion valves could be triggered by a rain gage or by the water supply faucet.

- Check with the local permitting agency early in the planning process before proceeding with design of this type of system.

Signage

Post signs that clearly identify the facility's intended use for employees and tenants and that prohibit:

- The use of cleaning products that contain hazardous substances (hydrofluoric acid, muriatic acid, sodium hydroxide, bleach, etc.) and can turn wastewater into hazardous waste.

- The use of specific cleaning products incompatible with any pre-treatment device (check with local permitting agency).

- Dumping vehicle fluids in wash areas.

- Engine/car repair in the wash area.

- Dumping in storm drains.

Maintenance

Proper maintenance of the equipment area design features included in this section is essential to its performance. Proper handling and disposal of materials will reduce the exposure of pollutants outside of designated areas. Drainage flow lines should be cleaned as needed to ensure adequate drainage. Site features may be subject to inspections by local fire and/or sanitary sewer agencies.

If included on site, spill containment vaults should be cleaned on an as-needed basis.

RUNOFF REDUCTION BMPS

Introduction

Runoff reduction principles are aimed at balancing a site's runoff and infiltration rates. By integrating infiltration, evaporation, storage, and filter design techniques early in the site design process, a site can effectively mimic natural runoff characteristics.

Runoff reduction techniques are useful in lessen the volume of storm water runoff requiring treatment. Small-scale runoff controls integrated into site design, close to the source of water concentration and pollutants, can reduce the burden of treating larger volumes of water with conventional "end-of-pipe" treatment. A reduction in runoff volume can also help alleviate potential downstream habitat degradation.

The following strategies best describe the most common concepts used in designing runoff reduction control measures: Replace impervious surfaces with pervious surfaces, disconnect impervious surfaces, and plant more storm water interceptor trees.

Though runoff reduction measures may reduce the volume of water quality treatment needed on a site, flood control and drainage requirements specified by the permitting agency still apply.

Porous Pavement

Description

Porous pavement is a permeable pavement surface that allows surface runoff to infiltrate into the subsoil. Stone reservoirs are often constructed below pavement to temporarily store surface runoff prior to infiltration; or are used to collect storm water in underlying drain pipes prior to discharge off-site. Pollutants are removed by absorption onto soil particles and by bacterial decomposition in the reservoir or in surface soils. There are many types of porous pavement including: turf blocks (grass planted through load-bearing plastic or concrete frame), modular blocks (stone or concrete blocks interspersed with pervious material such as gravel or sand), granular pavement (crushed aggregrate with wood mulch and cobbles), porous asphalt, and pervious concrete.

Application

In developments where it is difficult to provide storm water treatment (e.g., small or redeveloping sites or high-density residential developments) porous pavement may provide the best or only opportunity to reduce site imperviousness.

All land uses contain potentially suitable locations for porous pavement. Consider porous pavement for:

- Residential driveways, patios, and walkways.

- Commercial plazas and courtyard overflow parking areas, parking stalls, some types of storage areas, walkways, and entryway features.

- Employee parking and entryway features at industrial sites.

- Fire lanes, maintenance access roads, and other roadways where infrequent or low traffic loads and volume are expected (check with fire department for minimum specifications).

- Within parks and open space for parking areas, sports courts, playgrounds, and pedestrian/bike trails.

- Porous pavement is not suitable for commercial drive aisles, loading and waste management areas, and other heavy traffic areas. It is also not appropriate where spills may occur, due to the potential for soil and groundwater contamination. Such areas include retail gas outlets, auto maintenance businesses, processing/manufacturing areas, food-handling businesses, and chemical handling/storage areas.

Site and Design Considerations
Consult a geotechnical engineer to determine what types of porous pavement are suitable for the expected traffic load and volume.

- Consult a geotechnical engineer to determine set back from building foundation, or use 10 feet.

- Determine site soil type and permeability before selecting porous pavement as a runoff reduction strategy; a soil permeability of 0.6-2.0 in/hr is required. The local permitting agencies will require a permeability soils test to verify infiltration capacity of native soils may be used over soils with lower permeability in selected situations if underdrain is provided (check with permitting agency to verify).

- Address seasonal shrink/swell in sites with expansive subgrade. Use the expansion index test (ASTM D 4828) to provide insight as to degree of surface deformation in choosing paving sections.

- Consider opportunities for directing runoff from impervious surfaces across porous pavement to achieve runoff reduction credits. See the section on Disconnected Pavement located elsewhere in this chapter.

- Select the porous pavement type based on the type of anticipated pedestrian traffic; most types of porous pavement can be designed to be Americans with Disabilities Act (ADA) compliant.

- A water barrier or interceptor drain will be required where porous material abuts regular asphalt/concrete pavement and there is concern about water infiltrating the regular pavement subbase. The water barrier should be 24-inch-wide thick visqueen run down the 12-inch-deep Interceptor drains should tie into an open landscape area or treatment control measure to quickly relieve the water pressure in the pavement section and prolong the pavement life. For manufactured products, check the manufacturer's specifications for any additional siting considerations.

Maintenance

Successful operation of porous pavement depends upon maintaining the percolation rate of the porous spaces in the pavement surface and in the underlying base and soils. Keys to assuring long-term performance are accurate estimation of the soil's percolation rate, proper construction, and regular maintenance. Porous pavements have a tendency to clog with fine particulate matter. Once clogged, it is very difficult and expensive to rehabilitate, often requiring complete replacement. The production and transport of fine particulate matter and debris from adjacent areas should be managed using pretreatment BMPs.

Porous asphalt and concrete should be regularly swept and/or vacuumed to maintain porosity. High pressure jet hosing should be used less frequently to "deep clean" voids and help restore permeability. If porous pavement continues to clog, rehabilitation (e.g., drilling holes through pavement) or replacement may be needed. Spills of gasoline or other potentially hazardous materials can lead to soil or groundwater contamination. Spills must be immediately vacuumed, followed by jet washing.

Disconnected Pavement

Description

Disconnected pavement is any impervious pavement designed to sheet flow runoff over adjoining vegetated areas or porous pavement before it reaches the storm drain system. It functions as a runoff reduction control measure because runoff slows and travels though vegetation or over a porous surface, water is infiltrated into the soil with some pollutant removal through filtration. An example of disconnected pavement is a sidewalk bordered on either side by lawn. The sidewalk in this case has no connectivity to the site's storm drainage system, and therefore reduces the amount of imperious surface area that can contribute to storm water runoff.
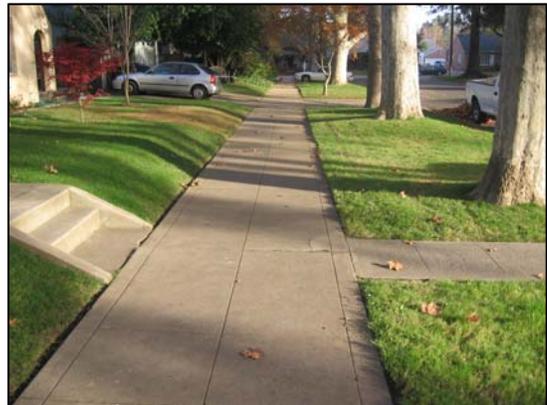
Application

Disconnected pavement area can be designed for residential, commercial, industrial, and roadway projects. Typical applications include driveways, patios, walkways, courtyards, parking lots and stalls, storage areas, walkways, and playgrounds. Disconnected pavement is not appropriate for areas where runoff may be an environmental or health concern, such as in a gas station or food preparation application.

Site and Design Considerations

When designing disconnected pavement areas, maximize the use of landscaping and natural areas that are already designed for the site. Design landscaping to sit below adjacent impervious surfaces. The width of the vegetation needed is dependent upon the area of contributing

pavement; the ratio of impervious to pervious surface should be 2:1 or less. Also consider the following when including disconnected pavement into site design:

- When draining pavement to open spaces, avoid environmentally-sensitive and protected wetlands areas.

- Check with the local permitting agency to determine if credit will be given for paved surfaces draining to vegetated creek buffer areas.

- Locate porous features in well drained soils (Type A or Type B) whenever possible. If porous pavement is used in Type C or Type D soils, an underdrain will be required.

- Eliminate curbs and slope pavement to sheet flow into vegetation where possible. Where curbs are required for safety or other reasons, use curb cutouts to convey flow into the vegetation.

- Maximize the use of porous pavement (as an alternative to conventional pavement) where it can double as a disconnected conveyance zone.

Maintenance
Pervious pavement systems do not require any special maintenance or care. Regular cleaning and landscaping maintenance is sufficient to maintain the functionality of these systems.

Alternative Driveway Design

Description
Alternative driveways are designed to reduce the volume and rate of runoff and increase localized infiltration. These driveways exhibit one or more of these features: they have permeable surfaces, drain to landscaping, provide access to more than one house, and/or limit concrete use to narrow driving strips.

Application
Alternative driveways reduce a development's total directly-connected impervious surface by using permeable materials, reducing the amount of pavement, paving area and/or by draining to landscaped areas. This effectively reduces runoff and may provide incidental pollutant removal. Alternative driveway designs are easily adopted into most residential construction projects, can improve the aesthetics, and may reduce the size and associated cost of treatment controls.

Site and Design Considerations
- Land use: Single-family residential development and redevelopment.

- Driveway slope: 10 percent maximum.

- Soils: Appropriate for all soil types but porous pavement requires an underdrain for Type C and Type D soil types.

- Consult a geotechnical engineer as to the suitability of each type of alternative driveway for specific load requirements.

Maintenance

Regular cleaning and landscaping maintenance is typically sufficient to maintain the functionality of these systems. Accumulations of sediment may need to be removed periodically to keep surface water flowing evenly into the porous areas.

Disconnected Roof Drains

Description

Roof drains can be disconnected from the storm drain system by directing the roof runoff across vegetation or into subsurface infiltration devices where it is filtered or infiltrates into the ground. The water may be directed across lawns, through dense groundcover, into devices such as a dispersal trench or dry well, if acceptable to the permitting agency. Roof runoff can also be directed into vegetated swales and storm water planters for storm water quality treatment.

Application

Disconnected roof drains effectively disconnect the rooftop from the local storm system, which helps reduce runoff and provides incidental pollutant removal as the water travels over and through the vegetation and soil. In this approach, roof runoff is directed to a vegetated area (the conveyance zone), or into underground infiltration devices, if approved by the local permitting agency. Greater surface area and contact time within the conveyance zone promote greater runoff treatment efficiencies.

Site and Design Considerations

- Consult a geotechnical engineer about site suitability and other design considerations.

- Assess soil permeability to determine if infiltration option is viable for the type of system desired.

- Consult an engineer, if needed, particularly in areas adjacent to building foundations.

- Design buildings to take advantage of vegetated areas. Direct roof flow away from paved surfaces.

- Design site with a minimum of 2 percent positive slope away from building foundations.

- Maximize the length, and minimize the slope, of the conveyance zone. The land surrounding the downspout/emitter should be graded to spread and convey storm water (minimum 2 feet wide) and prevent concentration of flows.

- Integrate the disconnected roof drain system into the site landscaping plan.

- Consider using dry wells or dispersal trenches where the conveyance zone slope exceeds 25 percent and local permitting agency allows. Such devices must typically be located a minimum of 20 feet from any buildings, but verify with local permitting agency.

- Use of dispersal trenches and dry wells maybe restricted on commercial and industrial projects depending upon pollutant potential; check with local permitting agency.

Maintenance

Irrigate and maintain vegetated areas to maintain infiltration and filtering capacity. Periodically check for clogging of any subsurface pipes or infiltration systems and repair as needed.

Interceptor Trees

Description

Interceptor trees are used in residential and commercial settings as part of the storm water quality management plan to reduce runoff and pollution from the development project. Interceptor trees can be placed on residential lots, throughout landscape corridors, in commercial parking lots, and along street frontages. Trees installed in municipal right-of-ways may be protected through ordinances and can provide years of aesthetic benefit.

Application

Interceptor trees are ideal for projects in which trees can be placed along street frontages and in common space. Urban areas with higher numbers of trees exhibit hydrology more similar to natural conditions compared to urban areas without trees. Trees intercept storm water and retain water on their leaves and branches allowing for evaporation and providing runoff reduction. While the most effective interceptor trees are large evergreen trees, deciduous trees can also provide benefits. An added benefit of interceptor trees is that they keep the ground beneath them cooler, thereby reducing the amount of heat gained in runoff that flows over the surface under

the trees. This attenuation of heat in storm water helps control increases in stream temperatures. On slopes, tree roots hold soil in place and prevent erosion.

Site and Design Considerations
- Select trees from a list of approved species established by the permitting agency. Native species and those with a larger canopy at maturity are generally preferred, depending upon available space for root and canopy.

- Select tree species based on the soils found on the site, available water, and aesthetics. Soil in planter areas may be amended to satisfy species requirements. Consult a landscape architect or arborist to ensure suitability of species for site conditions and design intent.

- Do not plant monocultures of same family, genus and/or cultivar. Do not plant trees too close together.

- Interceptor trees should be incorporated into the site's general landscaping plan, but trees designated for storm water credits must be clearly labeled on plans submitted for local agency approval and other planning submittals.

- Do not place trees near structures that may be damaged by the growing root system. These include, but are not limited to, overhead utilities and lighting, underground utilities, signage, septic systems, curb/gutter and sidewalks, paved surfaces, building foundations and existing trees.

- Utilize approved root barriers (deflectors) when trees are planted close to infrastructure, per the local permitting agency standards.

- New landscaping under existing trees must be carefully planned to avoid any grade changes and any excess moisture in trunk area, depending on tree species. Existing plants which are compatible as to irrigation requirements and which compliment the trees as to color, texture and form are to be saved.

- Grade changes greater than 6 inches within the critical root zone should be avoided. Also, soil compaction and texture in the drip-line area greatly affect tree survival.

Maintenance
Pruning of trees may be required to maintain aesthetic value, ensure safety, and prevent damage to structures. Diseased or damaged trees and those with poor structure should be removed and replaced as soon as possible. Irrigation systems may be required and will require regular testing to ensure an adequate water supply.

Green Roof

Description
A green roof is a multi-layered, vegetated rooftop system designed for filtering, absorbing, and retaining storm water. Green roofs comprise lightweight growth media and a specialized mix of vegetation underlain by a root barrier, a drainage layer, and a waterproofing membrane that protects the building structure. A green roof captures storm water within the pore space of the growth medium and then releases the water slowly via evaporation, transpiration and discharge to the roof drains. There are two types of green roofs—extensive (shallow growth media, simple vegetation) and intensive (deeper growth media, complex vegetation).

Application
Green roofs reduce runoff volume and peak flow through several mechanisms. When it rains, the green roof's foliage, growth medium, and root uptake zone retain a substantial portion of the storm water that would otherwise flow from the roof to the storm drain system. The retention volume depends on many factors, including rainfall amount, depth and composition of the growth medium, and the type, diversity, and maturity of the vegetation. Some of the retained storm water is released to the atmosphere via evaporation and transpiration. The remainder slowly infiltrates through the growth medium to the roof underdrains and is discharged to the storm drain system with the volume and peak flow rate reduced.

Green roofs improve runoff water quality through a variety of biological, physical, and chemical processes within the plants and growth media. At the roof surface, airborne particulate matter (encompassing a range of organic and inorganic compounds) is intercepted and taken up by plant foliage. When it rains, storm water (and associated air pollutants) is retained within and filtered through the growth media and root uptake zone. Contaminants bind to clay and organic matter within the growth media. Further pollutant removal is achieved by bioremediation and phytoremediation, carried out by bacteria and fungi present within the root systems. Pollutant removal increases as the vegetation and root systems mature.

Site and Design Considerations
- No additional space is required for a green roof installation.

- Land Use: Most appropriate for commercial or multi-family land uses, particularly infill development and multi-story buildings in dense urban areas, parking garage and retail/warehouse roofs.

- Special structural design requirements to support green roof, irrigation needs and leak protection elements (due to roof irrigation) are likely to increase building costs.

- Erosion controls such as jute or cellulose netting and/or soil stabilizers will be required; additional controls such as cross-battens or steps may be required on sloped roofs.

Maintenance
Maintenance during the first two years of a green roof installation is very important to establish vegetation. Intensive attention to irrigation needs may be required. After becoming established, routine inspection and maintenance of the roof membrane, drainage layer flow paths will be required. Vegetation should be replaced, as needed, to maintain adequate cover.

TREATMENT BMPS

Introduction

Treatment control measures, if required, (Table 1) will address the removal of pollutants of concern in the storm water runoff before it leaves the site. Selecting appropriate treatment controls early in the site design is a key factor in successful water quality management. Table 1 is intended to be aid to designers in selecting the most applicable treatment control measure given the project location, size, and pollutants of concern. Once a preliminary treatment control BMP(s) has been identified, the treatment control information discussed below will dictate the proper design criteria to ensure your BMP(s) will function effectively and proper. All treatment control measures should be thoroughly reviewed with each respective City/County Engineer with respect to operation and maintenance requirements and agreement between all parties as to how operation and maintenance will be conducted and paid for will be made prior to acceptance, approval and construction of any such measures.

Bio-Swale

Description
Bio-swales are used specifically to treat and attenuate storm water runoff for a specified water quality volume (WQV). As storm water runoff flows along these channels, it is treated through vegetation slowing the water to allow sedimentation, filtering through a subsoil matrix, and/or absorption. Variations of the bio-swale include the grassed channel, dry swale, and wet swale. The specific design features and methods of treatment differ in each of these designs, but all are improvements on the traditional drainage ditch.

Application
Bio-swales can be applied in most situations with some restrictions. They are well suited for treating highway or residential road runoff because they are linear facilities. Bio-swales are also useful when combined in a series with detention ponds and filter strips, because bio-swales promote infiltration. Furthermore, bio-swales are also recommended by the proponents of design approaches such as LID, Better Site Design, and Other Green Designs.

Site and Design Considerations

In addition to the broad applicability concerns described above, designers need to consider site conditions. It is important to incorporate design features to improve the longevity and performance of the practice while minimizing the maintenance burden. Also considering the restrictions and adaptations of bio-swales to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question because some site conditions (i.e., steep slopes, highly impermeable soils) might restrict the effectiveness of grassed channels.

Siting Considerations

- Drainage area: 10 acres maximum per swale.

- Longitudinal Bottom Slope: 0.5-2.5 percent. Underdrains required for slopes less than 1 percent. For slopes up to 5 percent, check dams can be used to reduce slopes to 2.5 percent.

- Minimum Bottom width: 2 feet.

- Side slopes: 3:1 or flatter.

- Liners may be required in areas where swales may be impacted by hazardous materials or where spills may occur (e.g., retail gasoline outlets, auto maintenance businesses, processing/manufacturing areas).

- Surface flow into swale preferred instead of underground conveyance.

- Minimum contact time: 7 minutes

Drainage Area – Bio-swales should generally treat runoff from small drainage areas (less than 5 acres). If used to treat larger areas, the flows through the swale become too large to simultaneously treat storm water runoff and convey adequate flow.

Slope – Bio-swales should be used on sites with relatively flat slopes of less than four percent; one to two percent slope is recommended. When site conditions require installing the swales in areas with larger slopes, check dams can be used to reduce the influence of the slope. Runoff velocities within the channel become too high on steeper slopes. This can cause erosion and does not allow for infiltration or filtering in the swale.

Soils/Topography – Bio-swales can be used on most soils, with some restrictions on the most impermeable soils. In a dry swale, a fabricated soil bed replaces on-site soils in order to ensure that runoff is filtered as it travels through the soils of the swale.

<u>Groundwater</u> – The required depth to ground water depends on the type of swale used. In the dry swale and grassed channel options, the bottom of the swale should be constructed at least 2 feet above the ground water table to prevent a moist swale bottom or contamination of the ground water. In the wet swale option, treatment is provided by creating a standing or slow flowing wet pool, which is maintained by intersecting the ground water.

Design Criteria
    <u>Step 1 – Determine the Vegetated Swale's Function</u>
The vegetated swale can be designed to function as both a treatment control measure for the storm water quality design flow and as a conveyance system to pass the peak hydraulic design flows, if the swale is located "on-line."

    <u>Step 2 – Calculate Water Quality Flow (WQF)</u>
Using Exhibit 1 in this Manual, determine the contributing area and storm water quality design flow, WQF.

    <u>Step 3 – Provide for Peak Hydraulic Design Flows</u>
Using local hydrologic design criteria, calculate flows greater than WQF to be diverted around or flow through the swale. Design the diversion structure, if needed.

    <u>Step 4 – Design the Vegetated Swale Using Manning's Equation</u>
Swales can be trapezoidal or parabolic in shape. While trapezoidal channels are the most efficient for conveying flows, parabolic configurations provide good water quality treatment and may be easier to mow since they do not have sharp breaks in slope.

Use a roughness coefficient (n) of 0.20 with Manning's Equation to design the treatment area of a swale to account for the flow through the vegetation. To determine the capacity of the swale to convey peak hydraulic flows, use a roughness coefficient (n) of 0.10 with Manning's Equation.

Manning's Equation:

$$Q = (\frac{1.49}{n})A(\frac{A}{P})^{2/3}(s^{1/2})$$

    Where:
    Q =   WQF, (cfs)
    A =   Cross-sectional area of flow, (ft^2)
    P =   Wetted perimeter of flow, (ft)
    s =   Bottom slope in flow direction, (ft/ft)
    n =   Manning's n (roughness coefficient)

For treatment design, solve Manning's equation by trial and error to determine a bottom width that yields a flow depth of 3 to 5 inches at the design WQF and the swale geometry (i.e., side slope and s value) for the site under design.

Step 5 – Design Inlet Controls
For flow introduced along the length of the swale through curb cuts, provide minimum curb cut widths of 12 inches and avoid short-circuiting the swale by providing the minimum contact time of 7 minutes. For swales that receive direct concentrated runoff at the upstream end, provide an energy dissipater, as appropriate, and a flow spreader such as a pea gravel diaphragm flow spreader at the upstream end of the swale.

Step 6 – Select Vegetation
A full, dense cover of sod-forming vegetation is typically recommended for vegetated swales, since most pollutant removal performance studies are based on use of grass. Alternative vegetation such as shrubs and groundcovers may also be allowed; check with the local permitting agency.
Select vegetation that:

- Will be dense and strong enough to stay upright, even in flowing water and steep slopes.

- Has minimum need for fertilizers.

- Is not prone to pests and will not require a lot of pesticide/herbicide application, consistent with any integrated pest management (IPM) practices or policies of the local permitting agency.

- Will withstand being inundated for periods of time.

- Needs little supplemental water, consistent with local water conservation ordinances. Bunch-type grasses or grass mixes are preferred.

Check with the permitting agency for approved plant and tree lists. Do not use bark or similar buoyant material in the swale or around drain inlets or outlets.

Maintenance
Maintenance of bio-swales mostly involves litter control and maintaining the grass or wetland plant cover. Bio-swales require regular maintenance throughout the year to ensure effectiveness and preserve aesthetic values. Listed below are maintenance items that should be performed on an annual and as-needed basis.

Annual Maintenance Activities
Inspect pea gravel for clogging and correct the problem:

- Remove trash and debris accumulated in the inflow forebay.

- Based upon inspection, plant an alternative grass species if the original grass cover has not been successfully established.
- Inspect and correct grass along side slopes for erosion and formation of rills or gullies.

- Inspect and correct erosion problems in the sand/soil bed of dry swales.

As-Needed Maintenance Items
Rototill or cultivate the surface of the sand/soil bed of dry swales if the swale does not draw down within 48 hours.

- Remove sediment build-up within the bottom of the swale once it has accumulated to 25 percent of the original design volume.

- Mow grass to maintain a height of 3 to 4 inches.

Water Quality Detention Basin

Description
A storm water quality detention basin (also called a water quality basin or extended detention basin) is designed to hold storm water runoff from small storms and the initial runoff ("first flush") from larger storms for a regulated downstream release.

Pollutants are removed from storm water through gravitational settling and biological processes depending on the type of basin. There are three types of water quality detention basins:

- *Wet* storm water quality detention basins (wet basins) that store a permanent pond of water.

- *Dry* extended storm water quality detention basins (dry-extended basins) that temporarily store storm water runoff.

- *Combination* (wet/dry) storm water quality detention basins (combination basins) that combine the wet and dry basin treatment systems.

Storm water quality basins must incorporate features that treat dry-weather flows (such as irrigation runoff). Wet basins and combination basins treat the dry weather flows within the permanent pond (micropool); however, dry basin designs must include an additional feature such as a submerged gravel bed or other agency approved feature.

Application
Storm water quality detention basins allow particles and associated pollutants to settle out. Permanent ponds (micropools) may enhance pollutant removal through biological and chemical

processes. The volume of runoff may also be reduced through infiltration and evaporation. Dry basins fill up during a storm event and detain the WQV for a period of 48 hours. Wet basins allow storm water runoff to slowly pass through the pond displacing water from the permanent pond. Combination basins include both a permanent pond and additional storage for detaining a portion of the WQV for a period of 48 hours.

Site and Design Considerations
In addition to the restrictions and modifications to adapting detention basins to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question. The following are basic guidelines for designing detention basins.

- Plan water quality basins to be aesthetically-pleasing public amenities.

- Where possible, design water quality basins as a joint use with parks (passive recreation), open space, wildlife habitat, aesthetic amenities and/or flood control detention facilities with 2% minimum bottom slope or as approved by the City/County Engineer.

- Generally, the area within the WQV is not well suited for recreation facilities such as ballparks, picnic areas, and restrooms.

- Ponds present special design considerations such as the selection of appropriate vegetation and nuisance abatement in order to function properly as both a water quality control measure and a public amenity.

- Use dry basins if dry weather flows are not sufficient to maintain the permanent pond of wet and combination ponds.

- Wet and combination basins may require a supplemental water source to maintain the permanent pond until the entire drainage shed is built out.

- Wet and combination basins require submitting water balancing calculations to ensure that the permanent pond volume will be maintained in the dry season. Use an evaporation rate of 0.45 in/day for the Yolo County area.

- May be required to include aeration and/or fountains for permanent ponds with depths greater than 6 feet.

- Place top soil within the top 12 inches of the basin to support plant growth.

- Refer to the local agency drainage criteria for flood control design.

- Consider re-circulating dry-weather flows in a water feature or as irrigation water to conserve water and benefit water quality.

Design Procedure

Step 1 – Calculate WQV

The information in Exhibit 1 can be used to determine the storm water quality design volume, WQV, for the contributing area.

Step 2 – Design the Basin

Design the basin to:

- Provide the required volume as determined in Step 1.

- Incorporate a sediment forebay if required by the local agency (Step 3).

- Maximize residence time by placing the inlet and outlet on opposite ends of the basin. Ensure the length is at least three times the width, as measured down the center of the flow path. For permanent ponds, incorporate additional features to maximize residence time, such as:

  o using islands or peninsulas;
  o designing the deepest point to be at least 8 ft. deep, if possible, with appropriate fencing as directed by the City/County Engineer;
  o incorporating an access (Step 5);
  o incorporating a concrete low-flow channel in dry basins; or
  o considering an aquatic bench with emergent vegetation around the perimeter of wet ponds and permanent pools to help with water quality and to provide a safety feature, with a minimum 2% bottom slope or as directed by the City/County Engineer.

Step 3 – Sediment Forebay

A sediment forebay may be required (check with local permitting agency) at each inflow point in order to trap sediment where it can be easily cleaned out. The forebay size should be about 5 to 10 percent maximum of the total design volume and designed to release in 3-5 minutes.

For easy-maintenance, design the sediment forebay(s) to include:

- An access road (see Step 5 for detailed information).

- Concrete lining to prevent equipment from sinking during cleaning.

- A concrete wall to separate the forebay from the rest of the water quality basin. The concrete wall should include overflow weir allowing flows to exit at non-erosive velocities during the 2-year and 10-year frequency design storms.

Step 4 – Design the Inlet and Outlet
Inlet Design – Design the inlet structure to:
- Dissipate energy of incoming flows to prevent erosion and prevent re-suspension of previously deposited sediment.

- For permanent ponds, set pipe invert approximately 2 feet from pond bottom above sediment storage.

- Install trash/access control rack. Check with the local agencies details.

- Provide access in accordance with Step 5.

Outlet Design – The goal of the outlet design criteria is to detain flows for a sufficient period of time to permit the settling of smaller sized sediments while meeting the release criteria so that storage is available for subsequent storm events. Outlets should be approved by the local agency and shall include trash racks to keep debris from clogging the outlet without interfering with the hydraulic capacity. In addition, flap gates should be installed to avoid the effects of backwater in the downstream creek or channel. The release criteria for the basins are as follows:

Dry Basin – A dry basin is required to release 75 percent of the WQV in a minimum of 24 hours and the total design volume over an additional 24 hours for a total release time of 48 hours, to prevent mosquito breeding conditions unless otherwise directed by the City/County Engineer. The WQV should not be discharged too quickly or pollutant removal will be compromised.

Wet Basins – A wet basin is required to maintain the permanent pond volume while discharging based on the downstream drainage systems capacity.

Combination Basins – A combination basin is required to maintain the permanent pond volume while releasing 75 percent of the 0.5 WQV in a minimum of 24 hours and the remainder 25 percent of the 0.5 WQV over an additional 24 hours for a total release time of 48 hours.

Step 5 – Access Design
Provide a way for maintenance vehicles to access all structures and cells within the basin such as the basin bottom, sediment forebay, inlets and outlets, low-flow channels, and submerged gravel beds. Design access roads to have an all-weather access surface, a width of 15 to 20 feet (check with the local permitting agency for required width) and a minimum turning radius of 40 feet. Design access ramps to be concrete or other impervious surface (check with local permitting agency) to the basin bottom with a maximum slope of 10 percent and a minimum width of 15 feet. Place gates across all access ramps to discourage access.

Step 6 – Design for Safety
Incorporate features for safety:

- Consider fencing the facility with chain link security fencing or other approved fencing material to prevent access if maximum depth is greater than 4 feet.

- Hinge and lock gates on structures.

- Provide gates or removable bollards across access roads.

- If applicable, design the dam embankment for safety.

- Obtain approval from State Division of Safety of Dams, if required based on the size of the dam/storage volume. If that is not required, nonetheless design the embankment-spillway-outlet system to prevent catastrophic failure.

- Design the embankment not to fail during 100-year and larger storms.

- Create embankment slopes to be 3:1 or flatter for outside slopes and 4:1 or flatter for inside slopes and plant them with turf forming grasses.

- Compact embankment soils in accordance to geotechnical engineer's specifications.

- Design spillway structures and overflows in accordance with local drainage criteria.

Step 7 – Incorporate Treatment for Dry-Weather Flows

For wet and combination basins, the permanent pond provides treatment for dry-weather flows. For dry basins, it is necessary to provide dry-weather flow treatment such as a vegetated submerged gravel bed or other equal treatment that is approved by the local permitting agency. Dry-weather flows vary by land use, drainage basin size, soil types, and other factors. The local agency should be contacted for acceptable design criteria.

Vegetated Submerged Gravel Beds

Vegetated submerged gravel beds can be used to reduce contaminants in dry-weather flows within or outside of a dry basin. Design vegetated submerged gravel beds so that:

- Anticipated dry-weather flows pass through the gravel bed without overland flow or flooding.

- Anticipated dry-weather flows pass through the gravel bed without dry out (excessive dry headspace) at the inlet zone of the bed.

- The bed remains functional in the likely event of changing hydraulic conductivity (As the bed clogs with roots and sediment, it should not flood.)

- Water levels are fully controllable through the use of inlet and outlet structures.

- The system achieves desired removal of contaminants.

- The gravel bed shall be planted with emergent plants.

- The top 3 inches of the gravel bed shall be above the outlet flow line.

- Gravel shall be held to 2 inches below the outfall flow line within a 4-foot radius of the outfall pipe.

Basin Geometry

Choose a length-to-width ratio that results in a sufficient hydraulic gradient to push the water through the gravel bed. A length-to-width ratio of 5 to 10 is common, but other length-to width ratios can be used provided the hydraulic gradient is adequate. (As the length-to-width ratio is increased, the linear velocity of the water passing through the gravel bed increases, the pressure drop increases, and the hydraulic gradient decreases. At some point, the hydraulic gradient is not sufficient to push the water through the gravel bed, resulting in overland flow.)

Design Criteria
Design using the following criteria:

- The gravel media – 1 inch to 1-1/2 inches in size. The porosity of the gravel bed is approximately 0.4.

- The bed depth – d = 2 feet (the depth of media is selected by allowing consideration for bottom sediment buildup and rooting requirements of desired vegetation).

- The design porosity of the gravel bed - ε = 0.3.

- The effective hydraulic conductivity shall be less than 95,000 ft/day.

- Nominal hydraulic detention time through the gravel bed, τ = 2 days.

Surface Area = SA = L W = (τ Q) / (d ε) = (2 days)Q/(2 feet)(0.3)(86400 sec/day)

Where:
Q = dry weather design flow rate (cfs)

Step 8 – Prepare a Landscaping Plan
Retain a certified landscape architect or wetland specialist to prepare a landscaping plan that includes:

- A planting layout showing what species to plant where plant sizes (e.g., seed, plug, 1-gallon container, etc.), planting techniques, plant spacing, soil amendments hydroseed specifications, and irrigation specifications (which must conform to applicable local regulations).

- Do not plant trees within the basin (bottom or side slopes) or at the base of any access ramps, around any inlet, outlet or culvert, or within 5 to 10 feet of a concrete structure or channel.

- For any pre-approved tree placement by the City/County Engineer cluster trees and shrubs when possible to make mowing of basin and surrounding area easier.

- Trees may not be allowed on the basin floor (check with local permitting agency).

- Use native plants.

- Choose plants that are adapted to the site conditions, including the expected degree of inundation/soil moisture.

- Incorporate plants known to improve water quality.

- Where possible, specify an array of plant types, including emergent species (in channels/ponds), herbaceous species, and trees and shrubs (along the outer borders). T his results in a more natural system and enhances the aesthetic and wildlife value. However, shrubs and trees should not be used for clay-lined permanent ponds or basins.

Constructed Wetland Basin

Description

A constructed wetland basin is an earthen basin treatment system with a permanent pool of water that includes four zones: a forebay, an open-water zone, a wetland zone with aquatic plants, and an outlet zone. The basin contains an area above the permanent pool to retain runoff from the storm water quality design storm (water quality volume or WQV) and slowly release excess water over a specified drawdown period. Constructed wetland basins provide a significant natural amenity to a community.

Application

Constructed Wetland Basins shall not be permitted within areas under the jurisdiction of Yolo County, however, they may be considered as an option within City jurisdictions within the County and the discretion of the respective City Engineer. Permanent pools of water are located throughout the constructed wetland basin, within: the forebay (which allows settling out of larger particles); an open water zone and a wetland zone with emergent vegetation (providing desired biodiversity); and the outlet zone (from which water is discharged to the downstream storm drain system or receiving water). An area above the permanent pool is designed to retain the storm water quality design volume (WQV). The retained water mixes with and displaces water from the permanent pool, which drains to the downstream storm drain system or receiving water over the design drawdown period (48 hours for WQV). Much of the water discharged during and following a storm event is water displaced from the permanent pool which has previously been treated by natural processes.

Treatment of the runoff occurs through a variety of natural mechanisms that occur in the wetland, including sedimentation, filtration, adsorption, and biological uptake. The aquatic plants provide energy dissipation and pollutant removal by enhancing sedimentation and providing biological uptake. Supplemental water or perennial base flow is needed to maintain the permanent pool at all times.

<u>*Site and Design Considerations*</u>
- Integrate constructed wetland basins into open space, natural areas, and other planned landscaped areas when possible. Avoid placing features in open space and wetland preserves where future maintenance of the water quality facility will be restricted or prohibited.

- Provide aesthetic security fencing if required by the permitting agency.

<u>*Design Procedure*</u>

<u>Step 1 – Calculate WQV</u>
Using Exhibit 1 in this Manual, determine the tributary drainage area and storm water quality design volume (WQV) for 48-hour drawdown.

<u>Step 2 – Determine Basin Minimum Volume for Permanent Pool</u>
The volume of the permanent wetland pool (V_{pp}) shall be not less than 75 percent of the WQV.

$$V_{pp} \geq 0.75 \text{ x WQV}$$

<u>Step 3 – Determine Basin Depths and Surface Areas</u>
Distribution of the wetland area is needed to achieve desired biodiversity.

Estimate average depth of permanent pool (D_{avg}) including all zones.

Estimate the water surface area of the permanent pool (A_{pp}) based upon actual V_{pp}

$$A_{pp} = V_{pp} / D_{avg}$$

Estimate water surface elevation of the permanent pool (WS $Elev_{pp}$) based on site elevations.

<u>Step 4 – Determine Surcharge Depth of WQV Above Permanent Pool and Maximum Water Surface Elevation</u>
The surcharge depth of the WQV above the permanent pool's water surface (D_{WQV}) should be ≤ 2.0 feet.

Estimate WQV surcharge depth (D_{WQV}) based on A_{pp}.

$$D_{WQV} = WQV/A_{pp}$$

If $D_{WQV} > 2.0$ feet, adjust value of V_{pp} and/or D_{avg} to increase A_{pp} and yield $D_{WQV} \leq 2.0$.

The water surface of the basin will be greater than A_{pp} when the WQV is added to the permanent pool.

Estimate maximum water surface area (A_{WQV}) with WQV based on basin shape.

Recalculate Final D_{WQV} based on A_{WQV} and A_{pp}. Note: V_{pp} and/or D_{avg} can be adjusted to yield Final $D_{WQV} \leq 2.0$ feet.

$$\text{Final } D_{WQV} = WQV/((A_{WQV} + A_{pp})/2)$$

Calculate maximum water surface elevation in basin with WQV.

$$\text{WS Elev}_{WQV} = \text{WS Elev}_{pp} + \text{Final } D_{WQV}$$

Step 5 – Determine Inflow Requirement
A net inflow of water must be available at all times through a perennial base flow or supplemental water source. Use the following equation and parameters to estimate the quantity of monthly inflow required at various times of the year. The maximum monthly requirement will govern the design requirement.

$$Q_{inflow} = Q_{E\text{-}P} + Q_{seepage} + Q_{ET}$$

Where:

Q_{inflow}	=	Estimated base flow (acre-ft/mo.) (Estimate by seasonal measurements and/or comparison to similar watersheds)
$Q_{E\text{-}P}$	=	Loss due to evaporation minus the gain due to precipitation (acre-ft/mo.)
$Q_{seepage}$	=	Loss or gain due to seepage to groundwater (acre-ft/mo.)
Q_{ET}	=	Loss due to evapotranspiration (additional loss through plant area above water surface not including the water surface) (acre-ft/mo.)

Note that an impermeable liner may be required to maintain permanent pool level in areas with extremely permeable soils.

Step 6 – Design Basin Forebay
The forebay provides a location for sedimentation of larger particles and has a solid bottom surface to facilitate mechanical removal of accumulated sediment. The forebay is part of the permanent pool and has a water surface area comprising 5 to 10 percent of the permanent pool water surface area and a volume comprising 5 to 10 percent of the WQV. The depth of permanent pool in the forebay should be a minimum of 4 feet. Provide the forebay inlet with an energy dissipation structure and/or erosion protection. Trash screens at the inlet are recommended to keep trash out of the basin.

Step 7 – Design Outlet Works
Provide outlet works that limit the maximum water surface elevation to WS Elev$_{WQV}$. The outlet works are to be designed to release the WQV over a 48-hour period. Protect the outlet from clogging with a trash rack and a skimmer shield that extends below the outlet and above the maximum WQV depth.

For single orifice outlet control or single row of orifices at the permanent pool elevation (WS Elev$_{pp}$), use the orifice equation based on the WQV (ft^3) and depth of water above orifice centerline D (ft) to determine orifice area (ft^2):

Orifice Equation
$$Q = C \times A \times 2gD$$

Where:
Q = Flow rate, (cfs)
C = Orifice coefficient (use 0.61)
A = Area of orifice, (ft^2)
g = Acceleration due to gravity (32.2 ft/sec^2)
D = Depth of water above orifice centerline (DWQV)

The equation can be solved for A based on the WQV and using a design drawdown time (t) of 48 hours.

For perforated pipe outlets or vertical plates with multiple orifices, use the following equation to determine required area per row of perforations, based on the WQV (acre-ft) and depth of water above centerline of the bottom perforation D (ft).

$$\text{Area/row (in2)} = \text{WQV/K48}$$

Where:
$$K48 = 0.012D2 + 0.14D - 0.06 \text{ (from Denver UDFCD, 1999)}$$

Select appropriate perforation diameter and number of perforations per row (columns) with the objective of minimizing the number of columns and using a maximum perforation diameter of 2 inches. Rows are spaced at 4 inches on center from the bottom perforation. Thus, there will be 3 rows for each foot of depth plus the top row. The number of rows (nr) may be determined as follows:

$$nr = 1 + (D \times 3)$$

Calculate total outlet area by multiplying the area per row by number of rows.

$$\text{Total Orifice Area} = \text{area/row} \times nr$$

Step 8 – Design Basin Shape

Whenever possible, shape the basin with a gradual expansion from the inlet and a gradual contraction toward the outlet. The recommended length to width ratio is between 2:1 to 4:1, with 3:1 optimal. Internal baffling with berms or modification of inlet and outlet points may be necessary to achieve this ratio.

Step 9 – Design Basin Side Slopes
Side slopes should be stable and sufficiently gentle to limit rill erosion and to facilitate maintenance. Internal side slopes should be no steeper than 4:1; external side slopes should be no steeper than 3:1.

Step 10 – Design Maintenance Access
Provide for all-weather access for maintenance vehicles to the bottom and outlet works. Maximum grades of access ramps should be 10 percent and minimum width will vary according to local permitting agency requirements, but usually between 15-20 feet. Pave ramps with concrete or porous pavement, subject to the approval of the permitting agency.

Step 11 – Design Security Fencing
To protect habitat and for safety reasons, provide aesthetic security fencing approved by the permitting agency around the basin, except when specifically waived by the permitting agency.

Step 12 – Select Vegetation
Select wetland vegetation appropriate for planting in the wetland bottom. Consider the water fluctuations that are likely to occur. Consult a qualified wetland specialist regarding selection and establishment of plants. The shallow littoral bench should have a 4- to 6-inch layer of organic topsoil. Berms and side-sloping areas should be planted with native or irrigated turf grasses.

Maintenance
In addition to incorporating features into the pond design to minimize maintenance, some regular maintenance and inspection practices are needed.

Annual Maintenance Activities
- Note erosion of pond banks or bottom.

- Inspect for damage to the embankment.

- Monitor for sediment accumulation in the facility and forebay.

- Examine to ensure that inlet and outlet devices are free of debris and operational.

As-Needed Maintenance Items
- Note erosion of pond banks or bottom.

- Repair undercut or eroded area.

- Mow side slopes.

- Manage pesticide and nutrients.

- Inspect for invasive vegetation and remove where possible.

- Remove litter and debris.

- Seed or sod to restore dead or damaged ground cover.

- Remove sediment from the forebay.

- Monitor sediment accumulations and remove sediment when the pond volume has been reduced by 25 percent.

Infiltration Basin

Description
An infiltration basin is a shallow impoundment that is designed to infiltrate storm water into the soil. This practice has high pollutant removal efficiency and can also help recharge the ground water, thus increasing baseflow to stream systems. Infiltration basins recharge the ground water because runoff is treated for water quality by filtering through the soil and discharging to ground water. However, some studies have shown relatively high failure rates compared with other management practices.

Application
Infiltration basins are widely applicable storm water management practices. Infiltration basins recharge the ground water because runoff is treated for water quality by filtering through the soil and discharging to ground water. The two primary applications of infiltration basins are flood control and channel protection. They are also very useful storm water control retrofits. Infiltration basins should be used to treat small sites (less than five acres). However, when applied to small sites they generally have a high construction cost and require substantial maintenance. It is often difficult to find areas where soils are appropriate for infiltration in an already urban or suburban environment. Infiltration basins are only recommended for small sites in a flat, relatively continuous area.

Site and Design Considerations
In addition to the restrictions and modifications to adapting infiltration basins to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question. Designers need to ensure that the soils on the site are appropriate for infiltration and that designs minimize the potential for ground water contamination and long-term maintenance problems. Following are basic guidelines for siting infiltration basins.

Drainage Area – Infiltration basins have historically been used as regional facilities, serving for both quantity and quality control. In some regions of the country, this practice is feasible, particularly if the soils are mostly sandy. In most areas; however, infiltration basins experience high rates of failure when used in this manner. In general, the practice is best applied to relatively small drainage areas (i.e., less than 10 acres).

Slope – The bottom of infiltration basins needs to be completely flat to allow infiltration throughout the entire basin bottom.

Soils/Topography – Soils and topography are strongly limiting factors when locating infiltration practices. Soils must be significantly permeable to ensure that the practice can infiltrate quickly enough to reduce the potential for clogging. S oils that infiltrate too rapidly may not provide sufficient treatment, creating the potential for ground water contamination. The infiltration rate should range between 0.5 and 3 inches per hour. In addition, the soils should have no greater than 20 percent clay content, and less than 40 percent silt/clay content. Finally, infiltration basins may not be used in regions of karst topography, due to the potential for sinkhole formation or ground water contamination.

Ground Water – Designers always need to provide significant separation distance (2 to 5 feet) from the bottom of the infiltration basin and the seasonally high ground water table, to reduce the risk of contamination. Infiltration practices should also be separated from drinking water wells.

Design Procedures
    Step 1 – Calculate WQV
    Using Exhibit 1 in this Design Manual, determine the tributary drainage area and storm water quality design volume (WQV) for 48-hour drawdown.

    Step 2 – Calculate Design Depth of Water Surcharge in Infiltration Basin (D_{max})

$$D_{max} = \frac{t_{max}(I)}{12s}$$

Where:
t_{max} = Maximum drawdown time = 48 hrs
I = Site infiltration rate (soil permeability) (in/hr)
s = Safety factor

In the formula for maximum allowable depth, the safety factor accounts for the variability in soil permeability at the site and the relative uncertainty in the infiltration rate measurements. he more variable the soil conditions and the less certain the infiltration rate, the higher the safety factor should be. Safety factors typically range between two and ten and should be determined by a qualified geotechnical engineer or geologist based on field measurements of saturated vertical permeability at the proposed site. Note that soils with permeability greater than 2 inches per hour may be used if full pretreatment is provided using one of the approved treatment controls from this manual.

<u>Step 3 – Calculate Minimum Surface Area of Infiltration Basin Bottom (A_{min})</u>

$$A_{min} = WQV/D_{max}$$

Where:
A_{min} =   minimum area required (ft2)
D_{max} =   maximum allowable depth (ft)

<u>Step 4 – Design Forebay Settling Basin</u>
The forebay provides a zone for removal of course sediment by sedimentation. Design the forebay volume to be five (5) to ten (10) percent of the WQV. Separate the forebay from the basin by a berm or similar feature. Provide an outlet pipe connecting the bottom of the forebay and the basin and size it to allow the forebay volume to drain within 45 minutes.

<u>Step 5 – Design Embankments</u>
Interior slopes (H:V) should be no steeper than 4:1 and exterior slopes no steeper than 3:1. Flatter slopes are preferable.

<u>Step 6 – Design Maintenance Access</u>
Provide for all-weather access for maintenance vehicles to the bottom and outlet works. Maximum grades of access ramps should be 10 percent and minimum width will vary according to local permitting agency requirements, but usually between 15-20 feet. Pave ramps with concrete that is colored to blend with surroundings.

<u>Step 7 – Design Security Fencing</u>
To protect habitat and for safety reasons, provide aesthetic security fencing approved by the permitting agency around the infiltration basin, except when specifically waived by the permitting agency.

<u>Step 8 – Design Bypass</u>
Provide for bypass or overflow of runoff volumes in excess of the WQV. Provide spillway or overflow structures, as applicable.

Step 9 – Design Relief Drain
Provide 4-inch-diameter perforated plastic relief underdrain with a valved outlet to allow removal of standing water in the event of loss of soil infiltration capacity. Cutoff collars are recommended along drain pipes running under the embankment at 10- to 20-foot intervals to prevent the water from piping through the fill. The portion of the relief drain that is under the embankment should not be permeable.

Step 10 – Select Vegetation
Plant basin bottoms, berms, and side slopes with native grasses or with irrigated turf. Vegetation provides erosion protection and filters sediment out of the runoff.

Step 11 – Design Irrigation System
Provide an irrigation system to maintain viability of vegetation (short-term establishment and long-term needs).

Step 12 – Select Vegetation
Select wetland vegetation appropriate for planting in the wetland bottom. Consider the water fluctuations that are likely to occur. Consult a qualified wetland specialist regarding selection and establishment of plants. The shallow littoral bench should have a 4- to 6-inch layer of organic topsoil. Berms and side-sloping areas should be planted with native or irrigated turf grasses.

Maintenance
In addition to incorporating features into the pond design to minimize maintenance, some regular maintenance and inspection practices are needed.

Annual Maintenance Activities
- Note erosion of pond banks or bottom.

- Inspect for damage to the embankment.

- Monitor for sediment accumulation in the facility and forebay.

- Examine to ensure that inlet and outlet devices are free of debris and operational.

As-Needed Maintenance Items
- Note erosion of pond banks or bottom.

- Repair undercut or eroded area.

- Mow side slopes.

- Manage pesticide and nutrients.

- Inspect for invasive vegetation and remove where possible.

- Remove litter and debris.

- Seed or sod to restore dead or damaged ground cover.

Infiltration Trench

Description
An infiltration trench is a rock-filled trench with no outlet that receives storm water runoff. Storm water runoff passes through some combination of pretreatment measures, such as a swale and detention basin, and into the trench. Runoff is stored in the void space between the stones and infiltrates through the bottom and into the soil matrix. The primary pollutant removal mechanism of this practice is the filter effect as the water passes through the soil.

Application
Structural storm water management practices can be used to achieve four broad resource protection goals. These include flood control, channel protection, ground water recharge, and pollutant removal. Infiltration trenches can provide ground water recharge, pollutant control, and can help to provide channel protection.

Site and Design Considerations
Infiltration trenches should be placed in areas with a low susceptibility for sediment erosion (e.g., at the base of a long slope). The following items should also be considered prior to construction.

Drainage Area – Infiltration trenches generally can be applied to relatively small sites (less than five acres), with relatively high impervious cover. Application to larger sites generally causes clogging, resulting in a high maintenance burden.

Slope – Infiltration trenches should be placed on flat ground, but the slopes of the site draining to the practice can be as steep as 15 percent.

Soils/Topography – Soils and topography are strongly limiting factors when locating infiltration practices. Soils must be significantly permeable to ensure that the storm water can infiltrate quickly enough to reduce the potential for clogging. In addition, soils that infiltrate too rapidly may not provide sufficient treatment, creating the potential for ground water contamination. The infiltration rate should range between 0.5 and 3 inches per hour. In addition, the soils should have no greater than 20 percent clay content, and less than 40 percent silt/clay content. The infiltration rate and textural class of the soil need to be confirmed in the field; designers should not rely on more generic information such as a soil survey. Finally, infiltration trenches may not be used in regions of karst topography, due to the potential for sinkhole formation or ground water contamination.

Groundwater – Designers always need to provide significant separation (2 to 5 feet) from the bottom of the infiltration trench and the seasonally high ground water table, to reduce the risk of contamination. In addition, infiltration practices should be separated from drinking water wells.

Maintenance
In addition to incorporating features into the infiltration trench to minimize maintenance, some regular maintenance and inspection practices are needed.

Annual Maintenance Activities
- Following three days of dry weather check for failure to percolate, which would indicate clogging.

- Inspect pre-treatment devices for sediment build-up and structural damage.

As-Needed Maintenance Items
- Remove sediment and oil/grease from pretreatment devices and overflow structures.

- Total rehabilitation of the trench should be conducted to maintain storage capacity within two-thirds of the design treatment volume and 72-hour infiltration rate limit.
- Remove litter and debris.

- Seed or sod to restore dead or damaged ground cover.

Vegetated Filter Strip

Description
Vegetated filter strips (grassed filter strips, filter strips, and grassed filters) are vegetated surfaces that are designed to treat sheet flow from adjacent surfaces. Vegetated filter strips function by slowing runoff velocities, filtering out sediment and other pollutants, and by providing some infiltration into underlying soils. Vegetated filter strips were originally used as an agricultural treatment practice and have more recently evolved into an urban practice. With proper design and maintenance, filter strips can provide relatively high pollutant removal. One challenge associated with filter strips; however, is that it is difficult to maintain sheet flow, so the practice may be "short circuited" by concentrated flows, receiving little or no treatment.

Application
Filter strips are applicable in most regions, but are restricted in some situations because they consume a large amount of space relative to other practices. Filter strips are best suited to treating runoff from roads and highways, roof downspouts, small parking lots, and pervious surfaces. Filter strips are most effective when combined with another practice. Filter strips can be applied in most regions of the country.

Site and Design Considerations

In addition to the broad applicability concerns described above, designers need to consider site conditions. It is important to incorporate design features to improve the longevity and performance of the practice while minimizing the maintenance burden. While considering the restrictions and adaptations of vegetated filter strip with respect to land use, designers need to ensure that this management practice is feasible at the site in question because some site conditions (i.e., steep slopes, highly impermeable soils) might restrict the effectiveness of grassed strips.

- Drainage Area: 5 acres maximum per filter strip.

- Longitudinal Slope: 1- 4 percent.

- Terracing may be used for slopes > 4 percent.

- Minimum length in flow direction: 25 feet.

- Minimum depth to groundwater table: 2 feet.

- Maximum Ponding Depth: 1 foot.

- Type A and Type B soils only.

- Vegetation Height: 2 inches – 4 inches.

Drainage Area – Filter strips are used to treat very small drainage areas. The limiting design factor; however, is not the drainage area the strip treats, but the length of flow leading up to the strip. As storm water runoff flows over the ground's surface, it changes from sheet flow to concentrated flow. Rather than moving uniformly over the surface, the concentrated flow forms rivulets that are slightly deeper and cover less area than the sheet flow. When flow concentrates, it moves too rapidly to be effectively treated by a vegetated filter strip. The concentrated flow can lead to scouring. As a rule, flow concentrates within a maximum of 75 feet for impervious surfaces and 150 feet for pervious surfaces. Using this rule, a filter strip can treat one acre of impervious surface per 580-foot-length.

Slope – Filter strips should be designed on slopes between 2 and 6 percent. Greater slopes than this would encourage the formation of concentrated flow. Slopes flatter than two percent could pond runoff, creating a potential for vector.

Soils/Topography – Filter strips should not be used on soils with a high clay content because they require some infiltration for proper treatment. Very poor soils that cannot sustain a grass cover crop are also a limiting factor.

Groundwater – Filter strips should be separated from the ground water by between 2 to 4 feet to prevent contamination and to ensure that the filter strip does not remain wet between storms.

Design Procedures

Step 1 – Calculate WQF (Flow-Based Control Measure)
Using Exhibit 1 in this Design Manual, determine the contributing area and water quality design flow, WQF.

Step 2 – Calculate Minimum Width of Vegetated Filter Strip (W_{VFS})
The design minimum width of the Vegetated Filter Strip (W_{VFS}) normal to flow direction is a determined from the design WQF and the minimum application rate (q_a), as follows:

$$W_{VFS} = (WQF)/(q_a)$$

$$W_{VFS} = (WQF)/0.005 \text{ cfs/ft (minimum)}$$

Step 3 – Determine the Minimum Length of Vegetated Filter Strip in the Flow Direction
The length of the filter strip in the flow direction must be a minimum of 25 feet. Greater lengths are desirable, as somewhat better treatment performance can typically be expected.

Step 4 – Determine Design Slope
Slope of the filter strip surface in the direction of flow should be between one percent and four percent to avoid ponding and channeling of flow. Terracing may be used to maintain a slope of four percent in steeper terrain.

Step 5 – Design Inlet Flow Distribution
Incorporate a device such as slotted curbing, modular block porous pavement, or other spreader devices at the upstream end of the filter strip to evenly distribute flow along the top width. Concentrated flow delivered to the filter strip must be distributed evenly by means of a level spreader.

Step 6 – Select Vegetation
A full, dense cover of sod-forming vegetation is necessary for the filter strip to provide adequate treatment.

Select vegetation that:

• Will be dense and strong enough to stay upright, even in flowing water.

• Has minimum need for fertilizers.

• Is not prone to pests and is consistent with IPM practices.

• Will withstand being inundated for periods of time.

• Is consistent with local water conservation ordinance requirements.

Do not use bark or similar buoyant material in the filter strip or around drain inlets or outlets.

Step 7 – Design Outlet Flow Collection
Provide a means for outflow collection and conveyance (e.g., grass channel/swale, storm drain, gutter).

Step 8 – Design Irrigation System
Provide an irrigation system to maintain viability of filter strip grass.

Maintenance
Maintenance activities usually involve litter control and maintaining the grass or wetland plant cover. Vegetated filter strips require regular maintenance throughout the year to ensure effectiveness and preserve aesthetic values. Maintenance is very important for filter strips, particularly in terms of ensuring that flow does not short circuit the treatment measures. Listed below are maintenance items that should be performed on an annual and as-needed basis.

Annual Maintenance Activities
- Inspect pea gravel diaphragm for clogging and correct the problem.

- Remove trash and debris accumulated in the strip.

- Based on inspection, plant an alternative grass species if the original grass cover has not been successfully established.

- Inspect grass and correct for erosion and formation of rills or gullies.

- Inspect and correct erosion problems in the sand/soil bed of dry swales.

As-Needed Maintenance Items
- Remove sediment build-up within the bottom of the filter strip once it has accumulated to 25 percent of the original design volume.

- Mow grass to maintain a height of 3 to 4 inches.

Sand Filter

Description
Sand filters are usually designed as two-chambered facilities; the first is a settling chamber, and the second is a filter bed filled with sand or another filtering media. As storm water flows into the first chamber, large particles settle out, and then finer particles and other pollutants are removed as storm water flows through the filtering medium. There are several modifications of the basic sand filter design, including the surface sand filter, underground sand filter, perimeter sand filter, organic media filter, and multi-chamber treatment train. All of these filtering practices operate on the same basic principle. Modifications to the traditional surface sand filter were made primarily to fit sand filters into more challenging design sites (e.g., underground and perimeter filters) or to improve pollutant removal (e.g., organic media filter).

Application
Sand filters can be applied on most site types. Sand filters, in general, are good options in densely developed urban areas where space is limited. Underground and perimeter sand filters, in particular, are well suited to the ultra-urban setting because they consume no surface space.

Sand filters are also an excellent option to treat runoff from land use activities that generate highly contaminated runoff with concentrations of pollutants in excess of those typically found in urban storm water (e.g., commercial nurseries, auto recycle facilities, commercial parking lots, fueling stations, storage areas, industrial rooftops, marinas, outdoor container storage of liquids, outdoor loading/unloading facilities, public works storage areas, hazardous materials generators, vehicle service and maintenance areas, vehicle and equipment washing/steam cleaning facilities).

Sand filters are a good option for storm train retrofits because they consume very little surface space and have few site restrictions. It is important to note; however, that sand filters cannot treat a very large drainage area.

Site and Design Considerations
In addition to the broad applicability concerns described above, designers need to consider site conditions. It is important to incorporate design features to improve the longevity and performance of the practice while minimizing the maintenance burden. While considering the restrictions and adaptations of sand filters to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question because some site conditions (i.e., steep slopes, high groundwater, highly impermeable soils) might restrict the effectiveness of sand filters.

There are currently three manufacturers of storm water filter systems.

Filter System A – This system is similar in appearance to a slow-rate sand filter. However, the media is cellulose material treated to enhance its ability to remove hydrocarbons and other organic compounds. The media depth is 12 inches (30 cm). It operates at a very high rate, 20 gpm/ft^2 at peak flows. Normal operating rates are much lower assuming that the storm water

covers the entire bed at flows less than the peak rate. The system uses vortex separation for pretreatment. As the media is intended to remove sediments (with attached pollutants) and organic compounds, it would not be expected to remove dissolved pollutants such as nutrients and metals unless they are complex with the organic compounds that are removed.

Filter System B – It uses a simple vertical filter consisting of 3-inch-diameter, 30-inch-high-slotted plastic pipe wrapped with fabric. The standard fabric has nominal openings of 10 microns. The storm water flows into the vertical filter pipes and out through an underdrain system. Several units are placed vertically at 1 foot intervals to give the desired capacity. Pretreatment is typically a dry extended detention basin, with a detention time of about 30 hours. Storm water is retained in the basin by a bladder that is automatically inflated when rainfall begins. This action starts a timer which opens the bladder 30 hours later. The filter bay has an emptying time of 12 to 24 hours, or about 1 to 2 gpm/ft2 of filter area. This provides a total elapsed time of 42 to 54 hours. Given that the media is fabric, the system does not remove dissolved pollutants. It does remove pollutants attached to the sediment that is removed.

Filter System C – The system use vertical cartridges in which storm water enters radially to a center well within the filter unit, flowing downward to an underdrain system. Flow is controlled by a passive float valve system, which prevents water from passing through the cartridge until the water level in the vault rises to the top of the cartridge. Full use of the entire filter surface area and the volume of the cartridge is assured by a passive siphon mechanism as the water surface recedes below the top of the cartridge. A balance between hydrostatic forces assures a more or less equal flow potential across the vertical face of the filter surface. Hence, the filter surface receives suspended solids evenly. Absent the float valve and siphon systems, the amount of water treated over time per unit area in a vertical filter is not constant, decreasing with the filter height; furthermore, a filter would clog unevenly. Restriction of the flow using orifices ensures consistent hydraulic conductivity of the cartridge as a whole by allowing the orifice, rather than the media, whose hydraulic conductivity decreases over time, to control flow.

The manufacturer offers several media used singly or in combination (dual- or multi-media). Total media thickness is about 7 inches. Some media, such as fabric and perlite, remove only suspended solids (with attached pollutants). Media that also remove dissolved include compost, zeolite, and iron-infused polymer. Pretreatment occurs in an upstream unit and/or the vault within which the cartridges are located.

WQV or flow rate (depending upon the particular product) is determined by local governments or sized so that 85 percent of the annual runoff volume is treated.

Drainage Area – Sand filters are best applied on relatively small sites (up to 10 acres for surface sand filters and closer to two acres for perimeter or underground filters). Filters have been used on larger drainage areas of up to 50 acres, but these systems can clog when they treat larger drainage areas unless adequate measures are provided to prevent clogging, such as a larger sedimentation chamber or more intensive regular maintenance.

<u>Slope</u> – Sand filters can be used on sites with slopes up to 6 percent. It is challenging to use most sand filters in very flat terrain because they require a significant amount of elevation drop, or head (about 5 to 8 feet), to allow flow through the system. One exception is the perimeter sand filter, which can be applied with as little as 2 feet of head.

<u>Soils/Topography</u> – When sand filters are designed as a stand-alone practice, they can be used on almost any soil because they can be designed so that storm water never infiltrates into the soil or interacts with the ground water. Alternatively, sand filters can be designed as pretreatment for an infiltration device where soils do play a role.

<u>Ground Water</u> – Designers should provide at least 2 feet of separation between the bottom of the filter and the seasonally high ground water table. This design feature prevents both structural damage to the filter and possibly, though unlikely, ground water contamination.

Maintenance
Sand filters require regular maintenance throughout the year to ensure effectiveness. Maintenance of sand filters mostly involves maintaining the conveyance of storm water through the treatment measure. Listed below are maintenance items that should be performed on an annual basis.

Annual Maintenance Activities
- Check to see that the filter bed is clean of sediments and the sediment chamber is no more than one-half full of sediment; remove sediment if necessary.

- Make sure that there is no evidence of deterioration, sailing, or cracking of concrete.

- Inspect grates (if used).

- Inspect inlets, outlets, and overflow spillway to ensure good condition and no evidence of erosion.

- Repair or replace any damaged structural parts.

- Stabilize any eroded areas.

- Ensure that flow is not bypassing the treatment measure.

REFERENCES

California Stormwater Quality Association, "California Best Management Practices Handbook: New Development and Redevelopment Handbook," updated in September 2004.

TABLE

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL
STORM WATER QUALITY TREATMENT MEASURES
APRIL 2009
(REV. FEBRUARY 2010)

TABLE 1

CITY / COUNTY DRAINAGE MANUAL

SELECTION OF STORM WATER QUALITY CONTROL MEASURES

✓ Required * Optional • Acceptable Method NA Not Applicable or Allowed

Project Category	Residential		Commercial/Industrial							
	Single Family Residential *Greater Than 20 Acres*	Multi-Family Residential *Gross Area Greater Than 1 Acre*	Commercial *Impervious Area Greater Than or Equal to 1 Acre*	Auto Repair Shops *Impervious Area Greater Than or Equal to 1 Acre*	Retail Gasoline Outlets *Impervious Area Greater Than or Equal to 1 Acre*	Restaurants *Impervious Area Greater Than or Equal to 1 Acre*	Industrial *Impervious Area Greater Than or Equal to 1 Acre*	Hillside Developments *Greater Than or Equal to 25% Slope*	Parking Lots (a) *Greater Than or Equal to 5,000 SF or 25 Spaces*	Streets/Roads (b) *Impervious Area Greater Than or Equal to 5 Acres*
Control Measure										
Source Control	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Storm Drain Markings and Signs	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fueling Areas	NA	NA	✓	✓	✓	✓	✓	✓	NA	NA
Loading Areas	NA	NA	✓	✓	✓	✓	✓	✓	NA	NA
Outdoor Storage Areas	NA	NA	✓	✓	✓	✓	✓	✓	NA	NA
Outdoor Work Areas	NA	NA	✓	✓	✓	✓	✓	✓	NA	NA
Vehicle/Equipment Wash Areas	NA	NA	✓	✓	✓	✓	✓	✓	NA	NA
Waste Management Areas	NA	NA	✓	✓	✓	✓	✓	✓	✓	NA
Runoff Reduction	*	*	*	*	*	*	*	*	*	*
Porous Pavement	(c)	•	•	NA	NA	•	•	•	•	(c)
Disconnected Pavement	•	•	•	•	•	•	•	•	•	•
Alternative Driveways	•	•	NA	NA	NA	NA	NA	•	NA	NA
Disconnected Roof Drains	•	•	•	•	•	•	•	•	NA	NA
Interceptor Trees	•	•	•	•	•	•	•	•	•	•
Green Roof	NA	•	•	•	•	•	•	•	NA	NA
Treatment Control (d)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Constructed Wetland Basin	•	•	•	NA	NA	•	•	NA	•	•
Detention Basin	•	•	•	•	•	•	•	•	•	•
Infiltration Basin	•	•	•	NA	NA	•	•	NA	•	•
Infiltration Trench	•	•	•	NA	NA	•	•	NA	•	•
Sand Filter	•	•	•	•	•	•	•	•	•	•
Storm Water Planter (Flow-through)	•	•	•	•	•	•	•	•	•	•
Storm Water Planter (Infiltration)	•	•	•	NA	NA	•	•	•	•	•
Vegetated Swale	•	•	•	•	•	•	•	•	•	•
Vegetated Filter Strip	•	•	•	NA	NA	•	•	•	•	•
Proprietary Devices (e)	•	•	•	•	•	•	•	•	•	•

(a) Only applies to stand-alone parking lots exposed to rainfall. Parking lots associated with buildings/facilities need to meet requirements of associated land use (commercial, industrial, etc.).

(b) Public road capital projects and expansions that are not a part of new residential, commercial, and industrial developments.

(c) Consult local permitting agency to determine acceptability for use in public right-of-way.

(d) Alternative treatment controls may be proposed; subject to review and approval of Yolo County. The need for treatment may be reduced through runoff reduction measures; consult with Yolo County. If the project drains to an adequately sized/ designed regional treatment facility (e.g., detention basin), additional on-site treatment controls may not be needed.

(e) Consult Yolo County for a list of acceptable devices.

EXHIBIT

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL
STORM WATER QUALITY TREATMENT MEASURES
APRIL 2009

EXHIBIT

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STORM WATER QUALITY TREATMENT MEASURES

WATER QUALITY FLOW (WQF) AND WATER QUALITY VOLUME (WQV)

Treatment BMPs are designed to treat either a design volume or flow. The statewide Phase II Small Municipal MS4 permit sets the design standards for structural or treatment control BMPs as follows (excerpt taken from Attachment 4 of WQO 2003-0005-DWQ):

"........ i. Design Standards for Structural or Treatment Control BMPs

The Permittees shall require that post-construction treatment control BMPs incorporate, at a minimum, either a volumetric or flow based treatment control design standard, or both, as identified below to mitigate (infiltrate, filter or treat) storm water runoff:

1) Volumetric Treatment Control BMP

a) The 85th percentile 24-hour runoff event determined as the maximized capture storm water volume for the area, from the formula recommended in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ ASCE Manual of Practice No. 87, (1998); or

b) The volume of annual runoff based on unit basin storage water quality volume, to achieve 80 percent or more volume treatment by the method recommended in California Stormwater Best Management Practices Handbook – Industrial/ Commercial, (2003); or

c) The volume of runoff produced from a historical-record based reference 24-hour rainfall criterion for "treatment" that achieves approximately the same reduction in pollutant loads achieved by the 85th percentile 24-hour runoff event.

2) Flow Based Treatment Control BMP

a) The flow of runoff produced from a rain event equal to at least two times the 85th percentile hourly rainfall intensity for the area; or

b) The flow of runoff produced from a rain event that will result in treatment of the same portion of runoff as treated using volumetric standards above.

Limited Exclusion
Restaurants and Retail Gasoline Outlets, where the land area for development or redevelopment is less than 5,000 square feet, are excluded from the numerical
Structural or Treatment Control BMP design standard requirement only…"

WQF

Flow-based control measure design standards apply to control measures whose primary mode of pollutant removal depends on the rate of flow of runoff through the facility or device. Examples of control measures in this category include swales, sand filters, diversion structures for off-line control measures, and many proprietary products. Typically flow-based design criteria calls for the capture and infiltration or treatment of the flow runoff produced by rain events of a specified magnitude. For the local area, the intensity of such a storm event is 0.20 inches/hour for Yolo County. This method satisfies the provisions of the Yolo County NPDES Municipal Stormwater Permits, which requires that flow-based measures be designed for at least the maximum (peak) flow rate of runoff produced by the 85th percentile hourly precipitation intensity multiplied by a factor of two, referred to here as the flow-based 85th percentile method. (CDM, 2003).

The flow-based BMP design criteria should be used in conjunction with the Rational Formula, a simplified, easy to apply formula that predicts flow rates based on rainfall intensity and drainage area characteristics. The Rational Formula is as follows:

WQF (cfs) = C i A

Where:

WQF = flow in ft^3/s
i = rain intensity in inches/hr
A = drainage area in acres
C = rational runoff coefficient

Use the table below to estimate C:

Type of Drainage Area	Runoff Coefficient, C
Business:	
Downtown areas	0.95
Neighborhood areas	0.70
Residential:	
Single-family areas	0.50
Multi-units, detached	0.60
Multi-units, attached	0.75
Apartment dwelling areas	0.70
Industrial:	
Light areas	0.80
Heavy areas	0.90
Parks, cemeteries	0.25
Playgrounds	0.40

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Type of Drainage Area	Runoff Coefficient, C
Railroad yard areas	0.40
Unimproved area	0.30
Lawns:	
Sandy soil, flat, 2%	0.10
Sandy soil, average, 2 – 7%	0.15
Sandy soil, steep, 7%	0.20
Heavy soil, flat, 2%	0.17
Heavy soil, average 2 – 7%	0.22
Heavy soil, steep, 7%	0.35
Streets:	
Asphaltic	0.95
Concrete	0.95
Brick	0.85
Drives and Walks	0.85
Roofs	0.95

WQV

Volume-based design standards apply to control measures whose primary mode of pollutant removal depends on the volumetric capacity of the facility. Examples of control measures in this category include water quality detention basins, constructed wetlands, stormwater planters, and infiltration basins/trenches. Volume-based design criteria calls for the capture and infiltration or treatment of a certain percentage of the runoff from the project site, usually in the range of the 75th to 85th percentile average annual runoff volume.

For projects in Yolo County, volume-based control measures shall be designed to capture and treat stormwater runoff equal to eighty (80) percent of the volume of annual runoff, determined in accordance with the methodology set forth in the California BMP Handbook, using local rainfall data. Also referred to as the "CASQA approach", the approach is simple to apply, and relies largely on commonly available information about a project.

The following steps describe the use of the sizing curves contained in the California BMP Handbook.

1. Identify the drainage shed that drains to the proposed control measure. This includes all areas that will contribute runoff to the proposed facility, including pervious areas, impervious areas, and off-site areas, whether or not they are directly or indirectly connected to the control measure.

2. Calculate the composite runoff coefficient "C" for the area identified in Step 1.

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3. Select a capture curve representative of the site and the desired drain down time using Appendix D of the California BMP Handbook. Curves are presented for 24-hour and 48-hour draw down times. The 48-hour curve should be used in most areas of California. Use of the 24-hour curve should be limited to drainage areas with coarse soils that readily settle and to watersheds where warming may be detrimental to downstream fisheries. Draw down times in excess of 48 hours should be used with caution, as vector breeding can be a problem after water has stood in excess of 72 hours.

4. Determine the applicable requirement for capture of runoff (Capture, % of Runoff).

5. Enter the capture curve selected in Step 3 on the vertical axis at the "Capture, % Runoff" value identified in Step 4. Move horizontally to the right across capture curve until the curve corresponding to the drainage area's composite runoff coefficient "C" determined in Step 2 is intercepted. Interpolation between curves may be necessary. Move vertically down from this point until the horizontal axis is intercepted. Read the "Unit Basin Storage Volume" along the horizontal axis. If a local requirement for capture of runoff is not specified, enter the vertical axis at the "knee of the curve" for the curve representing composite runoff coefficient "C." The "knee of the curve" is typically in the range of 75 to 85% capture.

6. Calculate the required capture volume of the control measure by multiplying the drainage shed from Step 1 by the "Unit Basin Storage Volume" from Step 5 to give the design volume. Due to the mixed units that result (e.g., ac-in., ac-ft) it is recommended that the resulting volume be converted to cubic feet for use during design.