YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL
VOLUME 1 OF 2

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PREPARED FOR:

floodSAFE 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.

[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.

<u>FloodSAFE California</u>

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.

Federal

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.

Methodology

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.

Ti = 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:

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

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:

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

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:

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

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:

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

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

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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, mi^2	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

Source:
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

	CN			
Land Use	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 Channels With Available HEC-2 Storage-Discharge Information	Reach Length 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 Channels Represented by Eight-Point Cross Sections Channels With a Standard Cross Section, Trapezoidal, Rectangular or Circular	Channel Length Channel Slope Manning's Roughness for Overbanks and Channel Cross-Section Data
Muskingum	Channels With Limited Cross-Sectional Information	Number of Subreaches Muskingum "K" Coefficient, hrs Muskingum "X" Attenuation Coefficient

Source:
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 (ac)	C	CA (ac)	Sum CA (ac)	Time of Concentration																		Total L_c (min)	i (in/hr)	CiA	Q_{DESIGN} (cfs)	Pipe Capacity (cfs)	Remarks
						Overland Flow				Gutter Flow			Pipe Flow					Channel Flow											
From	To					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)						

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

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
Sum (Coeff X Area) 0.00
Weighted Subbasin

Runoff Coefficient
Sum (Coeff x Area)/Total Area

[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: $n_1 = \left(\frac{0.087d^{4/3}}{lg}\right)^{1/2}$

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

Where:

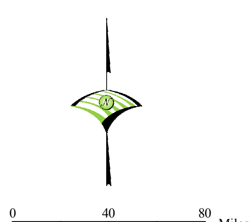
d = pipe diameter (ft.)
l = pipe length (ft.)
g = 32.2 ft./s^2

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

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

FIGURES

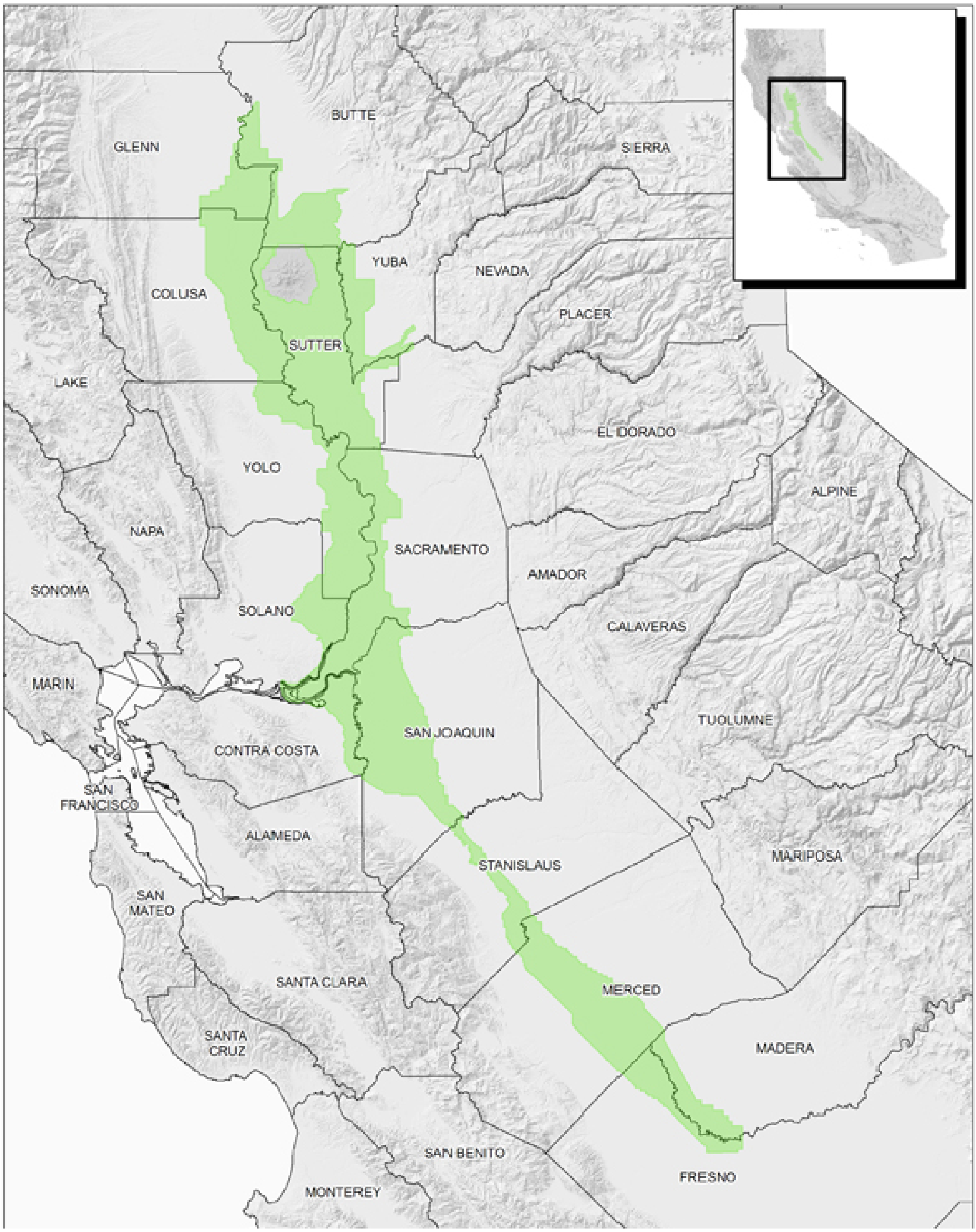
Yolo County
City/County Drainage Manual
Location Map
April 2009



SOURCES
ESRI® Data & Maps, 2005.
California Department of Fish and Game, 2002.

Figure 1

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

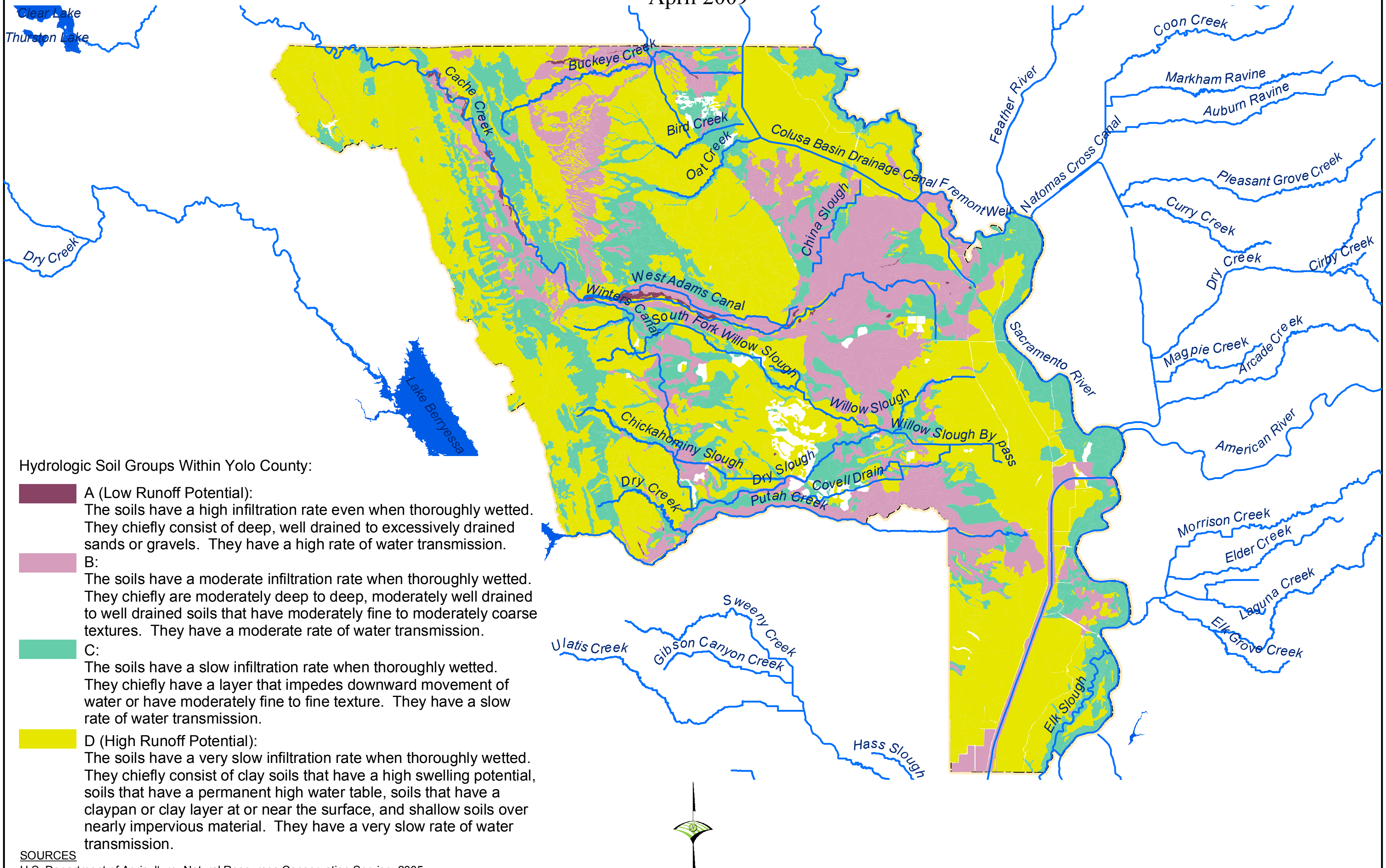


Sacramento-San Joaquin Drainage District Boundary

SOURCE
Central Valley Flood Protection Board, 2009.

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.

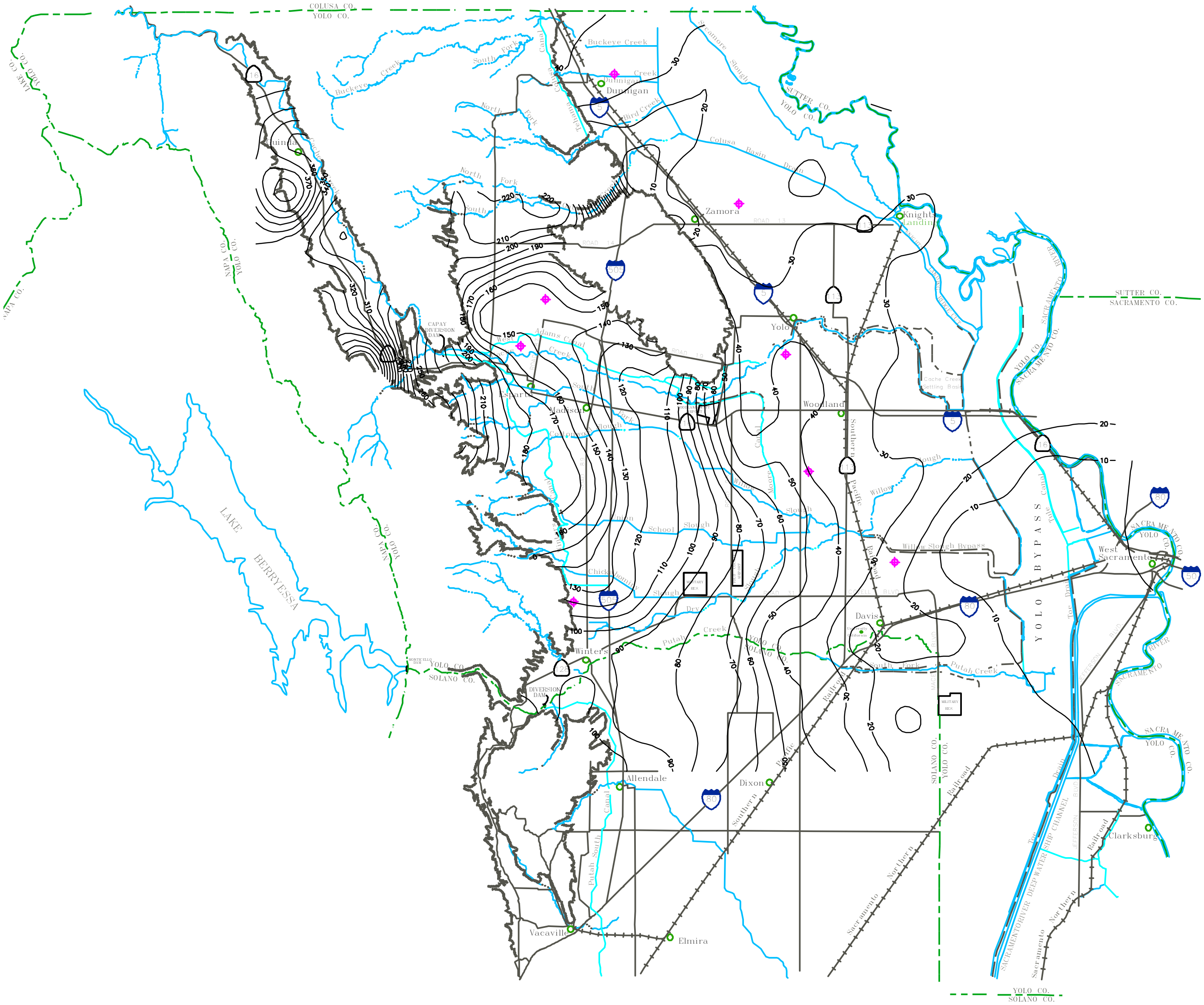
C:
The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. They have a slow rate of water transmission.

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.

Figure 3

Yolo County
City/County Drainage Manual
Groundwater Elevation - Spring 1996
April 2009



Lines of Equal Groundwater Elevation, feet msl

Well Location

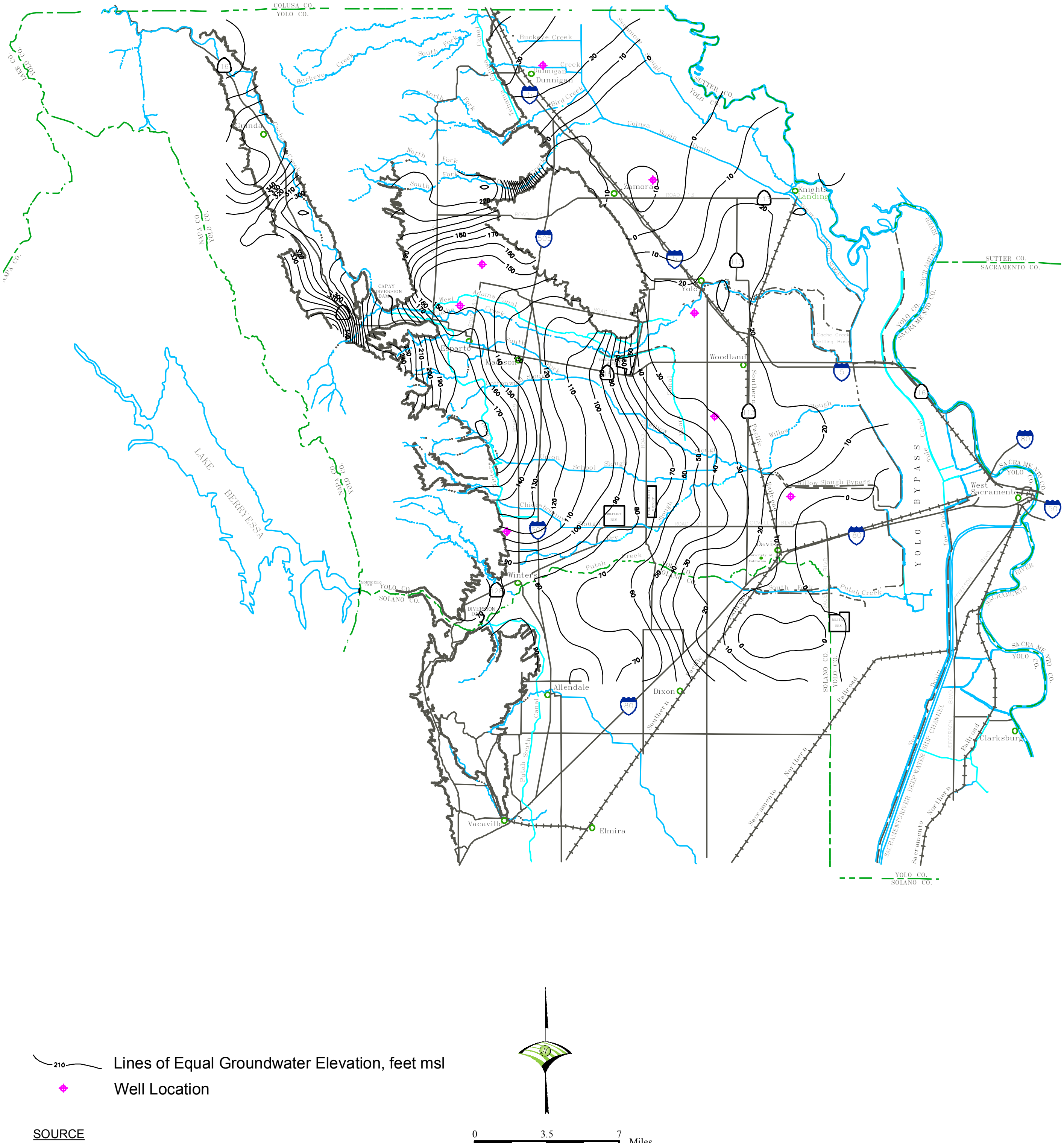
SOURCE
Borcalli & Associates, YCFC&WCD Engineer's Annual Report, December 1996.

0 3.5 7 Miles

J:\Jobs\8108.055_FloodSAFE_Yolo_Pilot_Prgm\FloodSAFE_Yolo_Pilot_Prgm-OA\GIS\Tasks\Figure4_Spring96_GWContours_20090904_V1.mxd 10/1/2009 9:41:18 AM jbuchanan

Figure 4

Yolo County
City/County Drainage Manual
Groundwater Elevation - Fall 1996
April 2009



SOURCE
Borcalli & Associates, YCFC&WCD Engineer's Annual Report, December 1996.

Figure 5

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

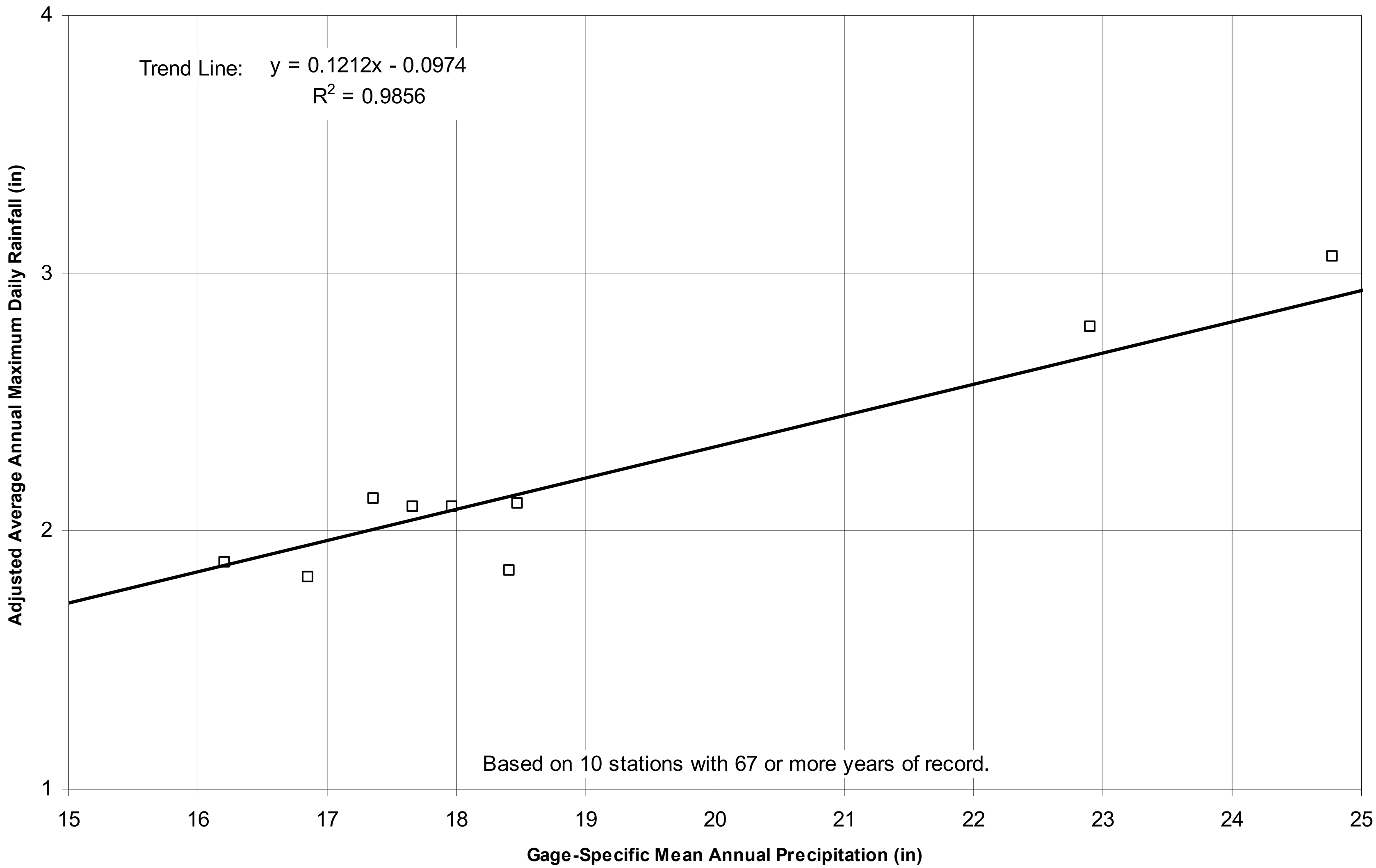


Figure 6

Yolo County
City/County Drainage Manual
Relationship of Rainfall Duration and Corresponding Maximum Rainfall
April 2009

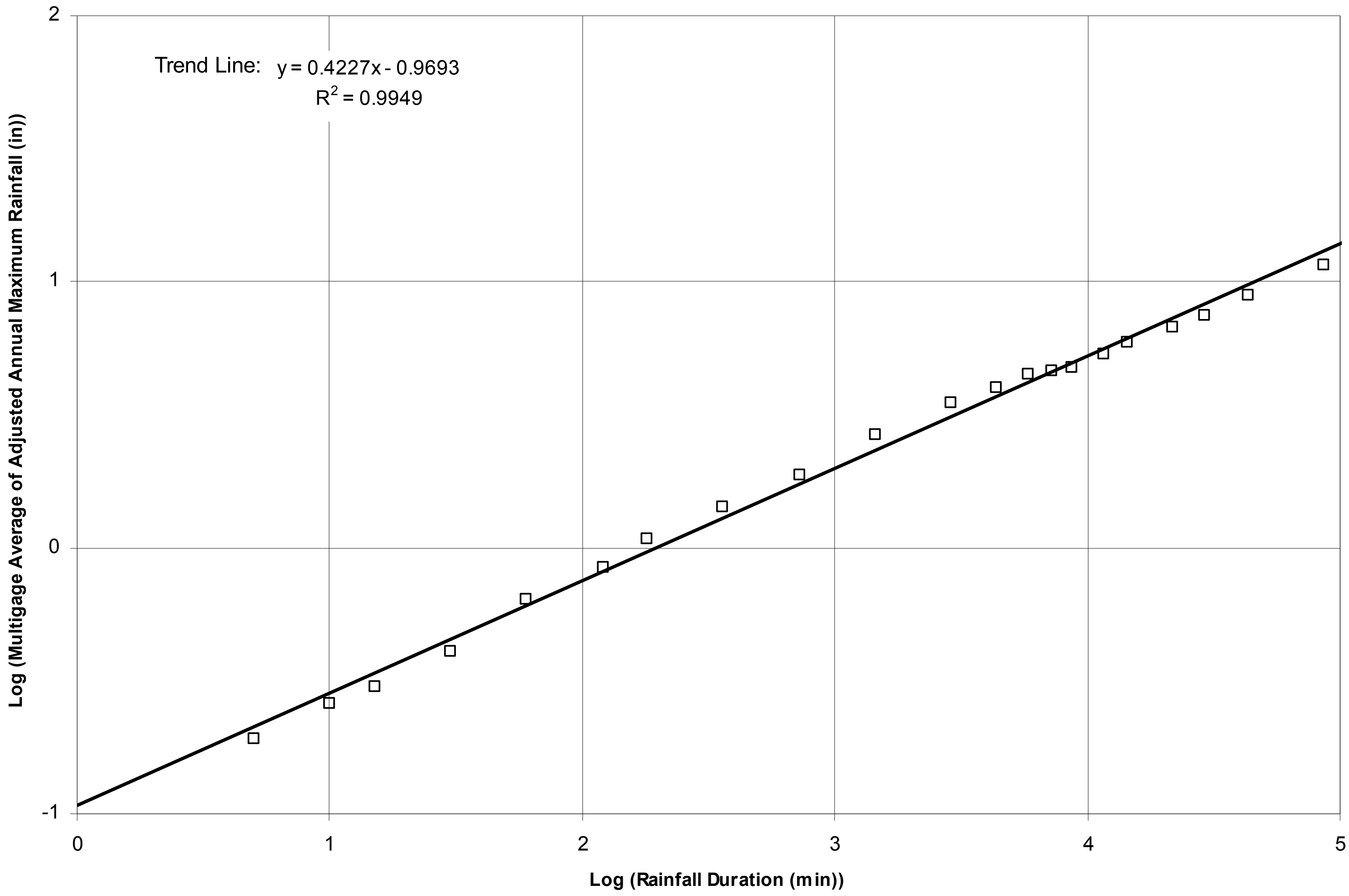
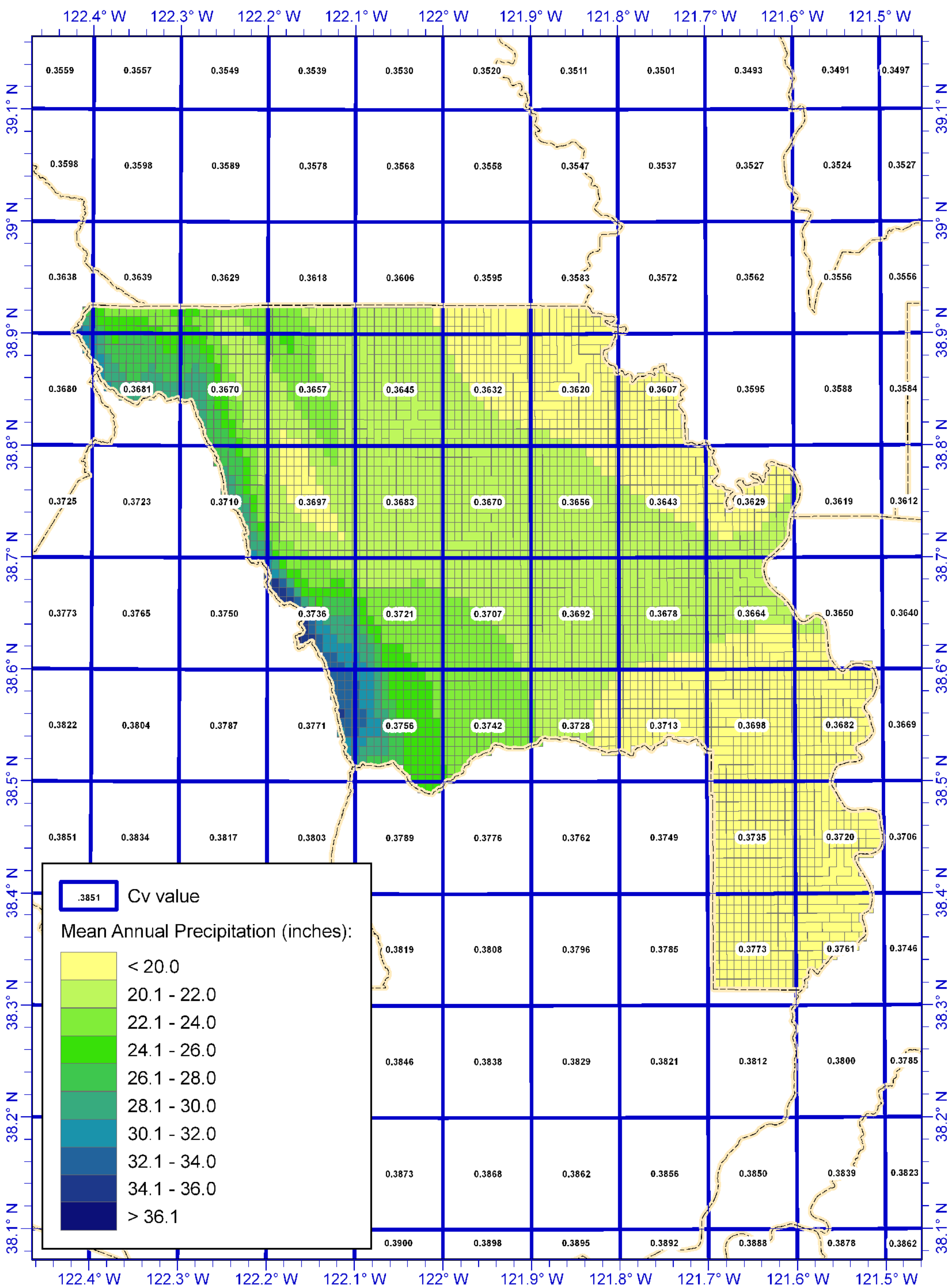


Figure 7

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



NOTES
1. Information relative to this figure is provided on the CD at the back of this Manual.
2. The interactive map requires a full version of ArcGIS 9.2 or newer.
3. Geodata features are available through ESRI ArcGISOnline Services: http://resources.esri.com/arcgisonlineservices.

0 5 10 Miles

SOURCES

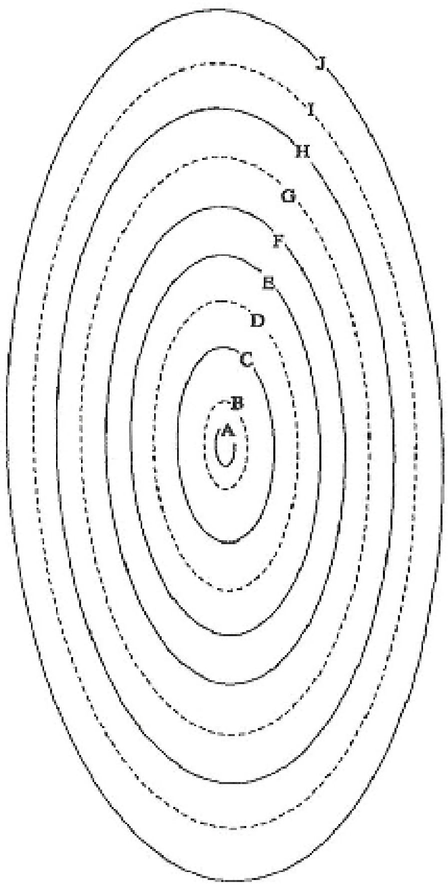
http://www.prismclimate.org Map created 17 Sept 2008.
James D. Goodridge, 2008.

J:\Jobs\8108.055_FloodSAFE_Yolo_Pilot_Prgm\FloodSAFE_Yolo_Pilot_Prgm-OA\GIS\Tasks\Figure8_PRISM_and_Cv_Map_20090904_V1.mxd 2/8/2010 3:26:01 PM jbuchanan

Figure 8

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

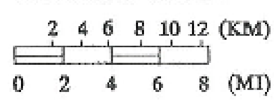
April 2009



ENCLOSED AREA

ISOHYET	AREA (MI^2)	AREA (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



SCALE
1:500,000

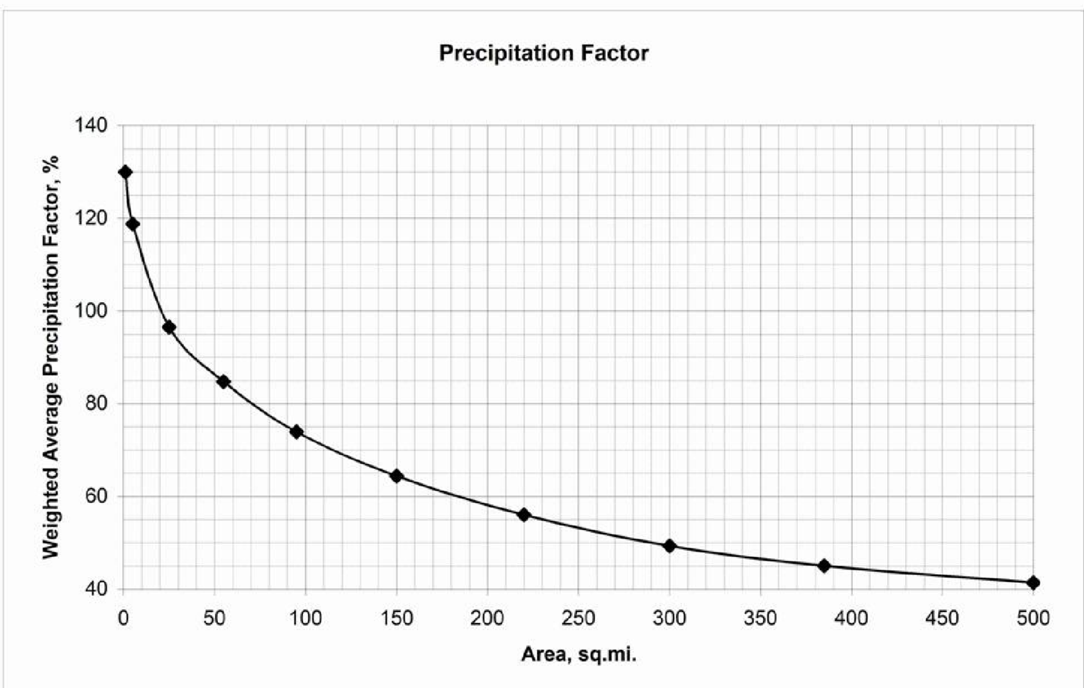
SOURCE
U.S. Department of Commerce, Hydrometeorological Report Number 58, Figure 2.20, October 1998.

Figure 9

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

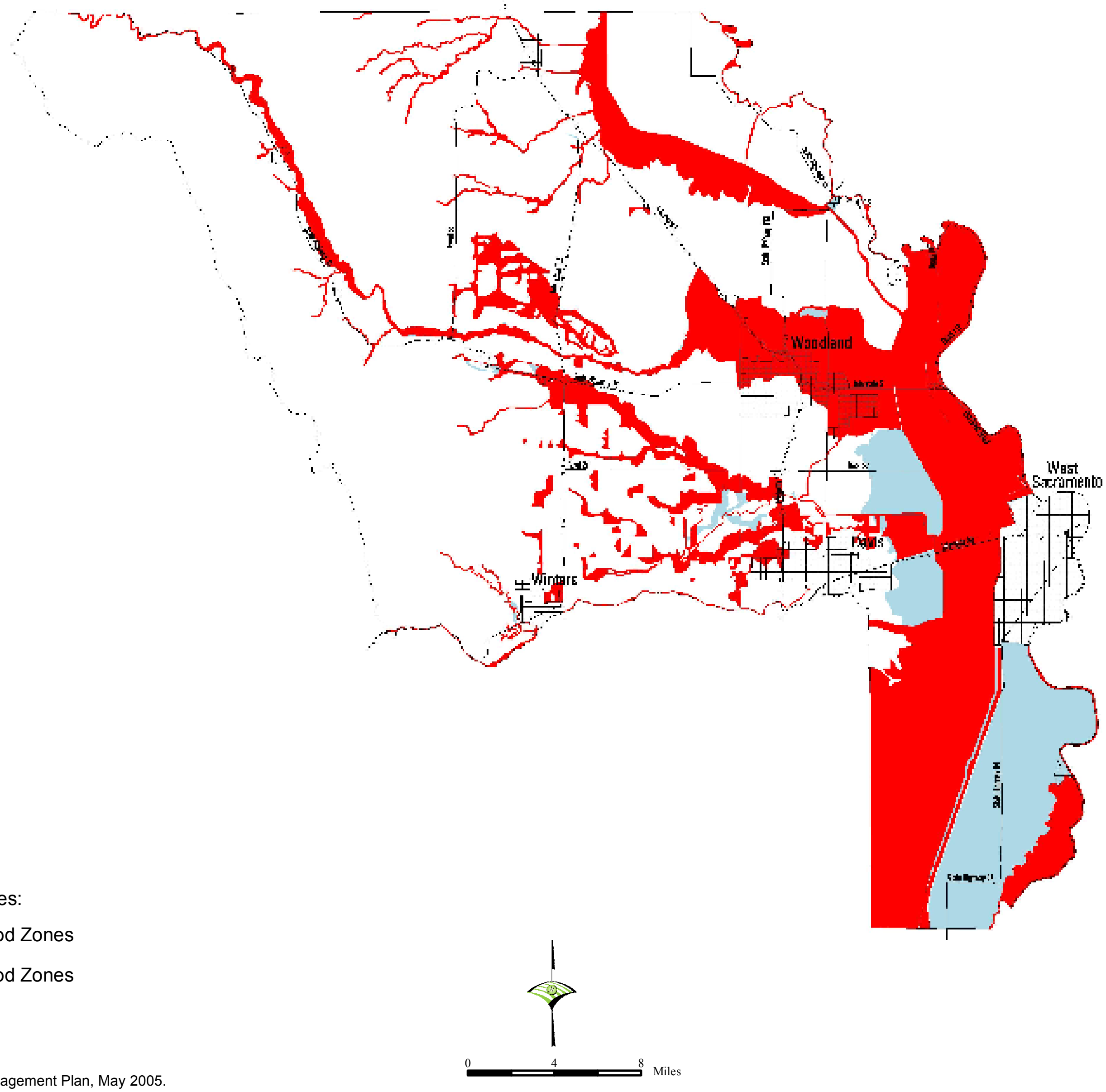
April 2009

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



SOURCE
U.S. Department of Commerce, Hydrometeorological Report Number 58, October 1998.

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



NOTE
Refer to FEMA for latest FIRM updates.

SOURCE
Yolo County Integrated Regional Water Management Plan, May 2005.

Figure 11

Yolo County

City / County Drainage Manual

Storm Water Quality Treatment Measures

Volume 2 of 2

April 2009

(Rev. February 2010)

Prepared For:

floodSAFE Yolo
Pilot Program

Prepared By:

WOOD RODGERS
DEVELOPING INNOVATIVE DESIGN SOLUTIONS

EXHIBIT

E
X
H
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B
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T

EXHIBIT

YOLO COUNTY
CITY / COUNTY DRAINAGE MANUAL
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

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.

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.