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Plainfield Studies Summary Report

MBK ENGINEERS
455 UNIVERSITY AVE. SUITE 100
SACRAMENTO, CA 95825

Contents

Purpose

Due to the historical and frequent flooding of the region of Plainfield, the County of Yolo (County) has tasked MBK Engineers with summarizing reports and studies conducted in the Plainfield vicinity over the last 40 years. More specifically, Yolo County is interested in understanding if substantial and valid hydrologic and hydraulic analysis were completed that may eliminate the need to commission new studies and/or modelling.

A comprehensive list of relevant hydrologic and hydraulic studies was developed by MBK Engineers and reviewed and refined by the County and stakeholders within the Plainfield region. Of the 25 studies selected for review, three studies were not available and therefore were excluded from this review. In general, our review generally followed the following questions:

1. What is the purpose of the report?
2. What hydrologic and hydraulic models (i.e. software) were used, if any?
3. What are the extents of those H&H models?
4. What flow rates were computed or simulated in the hydraulic model?
5. What are the hydrologic standards used to compute the flow rates?
6. What are the conclusions or findings of the report?

This Summary Report summarizes the hydrologic and hydraulic analyses, as well as conclusions and recommendations on flood reduction strategies within the region discussed in the selected relevant studies.

Hydrologic and Hydraulic Models

For many of the studies reviewed, hydrologic and hydraulic models were developed and utilized to understand the flooding dynamics throughout each study's region. For many of these studies, a hydrologic model was developed using HEC-1 or HEC-HMS and simulated a variety of storm events. The resulting hydrology were then utilized with HEC-2 or HEC-RAS modeling to understand resulting floodplain and water surface elevations. Often the developed models are used to inform the design of new construction, analyze impacts of potential developments, or analyze potential flood reduction strategies or alternatives at the study site. The models used in the selected studies are documented in Table 1.

Of the studies reviewed, several contained models which covered watersheds relevant to the Plainfield region. These include the HEC-1 and HEC-2 models developed by Borcalli & Associates in their *Covell Drainage System Comprehensive Plan* (1993), the HEC-HMS and HEC-RAS 2D models developed by GEI in their *Drainage Study for Sacred Oaks Healing Center* (2016), the FLO-2D model developed by Wood Rodgers described in their *Combined Riverine and Overland Flow Hydraulic Models – Willow Slough Technical Memorandum* (2013), the HEC-HMS and HEC-RAS models developed in Mead and Hunt's *Yolo County Airport Drainage Plan Update* (2014) and the HEC-1 models developed in the City of Winters' *Putah Creek/Dry Creek and Moody Slough Subbasins Drainage Reports* (2005). The HEC-1 model developed by Borcalli & Associates was utilized in multiple subsequent studies of the area (Jones &

Stokes, 1996 and Wood Rodgers, 2013), and their HEC-1 model for the Willow Slough and Dry Slough areas was eventually reviewed and approved by the Flood Emergency Management Association (FEMA, 2012).

In addition to the relevant models mentioned above, several models covered larger regions, multiple watersheds or the entire county. These models include USACE's HEC-1 and HEC-2 models developed in their *Reconnaissance Report: Winters & Vicinity, California* (USACE, 1995) and *Winters and Vicinity, California, Final Feasibility Report and Environmental Assessment/Initial Study* (USACE, 1997). The peak discharges for Dry Creek developed in the USACE 1995 report, were eventually used by FEMA in the most recent *Flood Insurance Study Yolo County, California and Incorporated Areas* (FEMA, 2012). Additionally, an Integrated Groundwater and Surface Water Model was developed by Water Resources & Information Management Engineering, Inc. in their study *Yolo County Integrated Groundwater and Surface Water Model, Model Development and Calibration* (2013).

In addition to the models mentioned above, there were several models that focused on regions outside of the Plainfield vicinity, or were too localized to be substantially useful for the Plainfield region. These models include areas of Esparto, Maddison (Ensign & Buckley, 2000), areas within Davis (Mackay & Somps, 2012) and Winters (City of Winters, 2005), or small portions of Dry Creek (Quincy Engineering, 2016).

Selected Study Recommendations

Throughout the studies reviewed, there were many alternative flood mitigation and reduction strategies evaluated. Popular strategies included diversion channels, small-scale detention ponds, channel modification (clearing or widening), and construction of additional levees. The most common flood risk reduction feature evaluated that could have a larger effect on the Plainfield area is a diversion channel which could divert water from Moody/Dry Slough directly into Putah Creek. Variations of this alternative were evaluated in Moody Slough and Putah Creek/Dry Creek Subbasins Storm Drainage Report (City of Winters, 2005), Investigation of Flood Problems Chickahominy-Moody Slough Watershed, Yolo County, California (Soil Conservation Service 1982), Integrated Regional Water Management Plan (Water Resources Association of Yolo County, 2007), and Winters and Vicinity, California, Final Feasibility Report and Environmental Assessment/Initial Study (USACE, 1997).

Additionally, several non-structural (i.e. flood proofing, flood forecasting and warning, land use regulations, etc.) and policy recommendations have been made in the selected studies. These include the recommendation for increased public outreach on flood risk and management (Borcalli & Associates, 1997 and Water Resources Association of Yolo County, 2007) and updating Yolo County hydrologic methodology and design criteria (Borcalli & Associates, 1997). Regional watershed management programs (Water Resources Association of Yolo County, 2007) and changing agricultural practices to increase infiltration (Water Resources Association of Yolo County, 2007 and Jones & Stokes Associates, 1996) have been proposed as additional flood reduction strategies but would require further investigation to quantify flood impacts for the Plainfield region.

Findings

- Of the studies reviewed by MBK Engineers, most focused on reducing flood damages in the City of Winters or Cache Creek region. USACE (1997) investigated a flood alternative consisting of a levee at County Road 33 and a 300 or 1000 cfs diverting canal to Putah Creek. This alternative has the potential to reduce flows on Chickahominy-Moody Slough. However, USACE did not evaluate the change in flow, stage, or depth of flooding in the Plainfield region.

- In 2005, the City of Winters prepared Drainage Reports for the Moody Slough sub-basin and the Putah Creek/Dry Creek sub-basins. Those studies investigated drainage facilities to mitigate for any future development. A feature of the drainage plan relied on a 1000 cfs diversion into Putah Creek. These ultimate drainage facilities have the potential to change flows in Moody-Dry Creek but analysis was not performed to document changes in flow, stage, or depth of flooding in the Plainfield region.
- The Soil Conservation Service ("SCS") (1982) studied three diversions that would divert flood waters from Chickahominy-Moody Slough watershed to Putah Creek. SCS concluded that the three-diversion concept "…appear to be the most promising solution". The cost of the project was $2.4M (1982 dollars). However, SCS did not evaluate the change in flow, stage, or depth of flooding in the Plainfield Region.
- Of the studies reviewed by MBK Engineers, there were no specific studies identifying the cause of flooding in the Plainfield Region nor analysis of the frequency, depth, and duration of flooding specific to the Plainfield Region.
- Most of the hydrologic analysis prepared as part of these studies used outdated hydrologic standards and outdated hydrologic models of the region. The most up to date hydrologic models of the region were developed as part of CA DWR (2013) and could be a foundation hydrologic model moving forward for studies in the region.
- All hydraulic models developed as part of the studies reviewed relied on steady-state hydraulic models (i.e. HEC-2, XRATE). These steady-state hydraulic models are reach specific models and cannot take into account the attenuation of flows in the floodplain or flow splits in the system. Flows exceeding the channel capacity have the ability to reduce flows in the channel downstream thereby affecting the distribution of flow rates in the downstream channel. A steady-state hydraulic model cannot accurately simulate this floodplain condition. An unsteady regional hydraulic model should be utilized.
- Topography of the region is available from Wood Rodgers (2013) that could be the underlying topography for a new regional hydraulic model.

Recommendations

Prior to developing any structural or policy modifications intended to reduce flood risk in this particular region, the County, YCFCWCD, and impacted stakeholders need to consider that multiple factors have cumulatively resulted in the current condition and that no single flood risk reduction approach is immediately implementable at this time that would completely resolve flooding issues. Any substantial change to the hydrologic landscape in the form of re-routed runoff, berms, culverts, or other potential solutions would require an evaluation of pre-project and post-project changes and potential impacts to other interested parties both upstream and downstream of this region.

The ability to rely upon previous studies to initiate design and construction of flood risk reduction strategies is currently insufficient as they do not provide a defensible basis of fundamental hydrology and hydraulics upon which one may rely for design and implementation. Therefore, it is our opinion that the collective group of stakeholders consider the following:

- Studies to date provide concepts to explore, however stakeholders should commission an analysis documenting the extent, depth, and duration of flooding in the Plainfield region to establish an existing condition. This analysis will also help inform the source of flooding and potential causes of flooding. Funding for this analysis and concept development is unidentified at this time.

- Develop a new regional hydraulic model of the channels and floodplain using HEC-RAS that will be utilized to screen flood risk reduction options described below. The hydraulic model will have the ability to estimate water surface elevation, depth of flooding, extent of flooding, duration of flooding based on a flow rate in the channel.
- Review and refine the regional hydrologic model developed as part of CA DWR (2013) to ensure accuracy and that it meets the County's hydrologic standards. A hydrologic model is used to estimate the flow rates in the channel based on the amount of precipitation that falls in the watershed and basin soil characteristics and land use.
- Initiate a new reconnaissance/feasibility level flood risk reduction study to investigate flood risk reduction concepts, estimate cost and benefits, and identify potential environmental impacts. Hydrologic and hydraulic models recommended above will be used to develop and evaluate a flood risk reduction strategy on both a regional and local level.
  - Local Level – Engage with Plainfield stakeholders to identify flood risk reduction concepts to investigate. Options to reduce flood risk that require further investigation include a development of a berm system to redirect flows and development of an improved conveyance facilities upstream and downstream of impacted areas. The latter may include improving existing channels and/or developing new conveyance channels.
  - Regional Level – Revisit the concept of a diversion channel to Putah Creek. Additionally, consider developing various detention/retention options upstream of impacted areas. There may also be an opportunity to initiate a region-wide program to develop a comprehensive drainage plan for the area.
- Investigate options with state and federal entities that provide technical and financial support to areas in this region that are not currently addressed by flood risk reduction facilities and programs.

Table 1. Summary of Selected Study Models

Study	Model	Areas Covered	Notes
Covell Drainage System Comprehensive Study (Borcalli & Associates, 1993)	HEC-1	Covell Drain and Davis, north of I-80	• 2-, 10-, 50-, 100-year storm frequency events • Design Storm precipitation from James Goodridge • Unit hydrographs developed using SCS dimensionless unit hydrograph methodology
Covell Drainage System Comprehensive Study (Borcalli & Associates, 1993)	HEC-2	Willow Slough Bypass from the Yolo Bypass upstream to the confluence of Willow and Dry Sloughs	
Covell Drainage System Comprehensive Study (Borcalli & Associates, 1993)	HEC-2	Confluence with Willow Slough upstream to Road 95	
Covell Drainage System Comprehensive Study (Borcalli & Associates, 1993)	HEC-2	Confluence of Willow Slough Bypass to Highway 113	
Covell Drainage System Comprehensive Study (Borcalli & Associates, 1993)	HEC-2	North Davis Drain confluence with the Covell Drain west to the vicinity of Road 96	

Study	Model	Areas Covered	Notes
Putah Creek/Dry Creek Subbasins Drainage Report (City of Winters, 2005)	HEC-1	Putah Creek and Dry Creek	• 100-year 10-day, and 100-year 24-hour events • Additional modeling and rational method parameters in Tables 1-19 of report
Putah Creek/Dry Creek Subbasins Drainage Report (City of Winters, 2005) – Appendix E	HEC-HMS	Rancho Arroyo Subbasin (West Winters)	
Moody Slough Subbasin Drainage Report (City of Winters, 2005)	HEC-1	Moody Slough subbasin including portions of the Chickahominy Slough subbasin	• 100-year 10-day, 100-year 24-hour, 10-year 24-hour, and 2-year 24-hour events • Additional modeling and rational method parameters in Tables 1-19 of report
Evaluation of Flood Alternatives in Yolo County (Ensign & Buckley, 2000)	FEMA HEC-1 model	Esparto and Madison	• 2, 10, 50 and 100-year events
Evaluation of Flood Alternatives in Yolo County (Ensign & Buckley, 2000)	HEC-2	Esparto and Madison South Fork Willow Slough, Lamb Valley Slough and Madison Drain	• Included failed levees where FEMA criteria not met
Drainage Study for Sacred Oaks Healing Center (GEI, 2016)	HEC-HMS	Country Road 31 adjacent to Country Road 93A Willow Slough, Dry Slough and the Covell Drain watersheds	• NOAA 14 precipitation data • 100-year 10-day and 10-year 24-hour events • Utilized DWR's CVHS hydrologic model
Drainage Study for Sacred Oaks Healing Center (GEI, 2016)	HEC-RAS 2D	Country Road 31 adjacent to Country Road 93A Willow Slough, Dry Slough and the Covell Drain watersheds	• HEC-HMS hydrographs used for boundary conditions • Terrain based on CVFED LiDAR + field survey from RFE Engineering
Storm Water Resources Plan for Yolo County (Kennedy/Jenks, 2018)	HEC-HMS	Lamb Valley Slough, South Fork Slough, South Fork Willow Slough and Cottonwood Slough	• January 2017 and 100-year 24-hour design storms • Additional model inputs documented in table 2.1 (Appendix I)
Storm Water Resources Plan for Yolo County (Kennedy/Jenks, 2018)	WEAP	Cache Creek	• Immitted Application for Flood management • Additional model details in Appendix B
Flood Control Master Plan for The Cannery Davis, California (Mackay & Somps, 2012)	HEC-1	East of F Street and north of West Covell Blvd. in Davis	• 100-year 24-hour, 10-year 24-hour, 2-year 24-hour, 100-year 10-day, and 200-year 10-day events • Adapted from Mead and Hunt Covell Villages 2004 models • Hydrology was based on inputs established in 2010 Yolo County Drainage Manual for Covell Drain Watershed
Flood Control Master Plan for The Cannery Davis, California (Mackay & Somps, 2012)	HEC-RAS Unsteady	East of F Street and north of West Covell Blvd. in Davis	• Adapted from Mead and Hunt Covell Villages 2004 models
Yolo County Airport Drainage Plan Update (Mead and Hunt 2014)	HEC-HMS	Yolo County Airport area contributing runoff to the north-south drainage ditch on the eastern edge of the Airport	• 100-year 10-day, 10-year 10-day, 100-year 24-hour, 200-year 10-day, and 200-year 24-hour events • Model adapted from the 2005 Drainage Plan HEC-1 model

Study	Model	Areas Covered	Notes
Yolo County Airport Drainage Plan Update (Mead and Hunt 2014)	HEC-RAS	Yolo County Airport main north-south airport drainage ditch from northern end to just upstream of the confluence with Airport Slough	• Model adapted from the 2005 Drainage Plan HEC-RAS model
Reconnaissance Report: Westside Tributaries to Yolo Bypass California (USACE, 1994)	HEC-1	Cache Creek basin	• 50-, 100-, 200-, and 500-year hydrographs were developed
Reconnaissance Report: Westside Tributaries to Yolo Bypass California (USACE, 1994)	HEC-2	Cache Creek basin	• Included estimated existing levee failure locations
Combined Riverine and Overland Flow Hydraulic Models – Willow Slough Technical Memorandum (Wood Rodgers, 2013)	FLO-2D	Esparto, Madison, Woodland, Winters, and Davis	• Used B&A HEC-1 (1992) model to develop test flow for 500-year design storm • HEC-RAS 1D components embedded in the final FLO-2D model
Willow Slough Watershed Integrated Resources Management Plan (Jones & Stokes, 1996)	HEC-1	Willow Slough Watershed	• Modified version of B&A HEC-1 model (1992) • 2, 10, 50, and 100-years events with a duration of 4 days
Willow Slough Watershed Integrated Resources Management Plan (Jones & Stokes, 1996)	HEC-2	Dry Slough	
Reconnaissance Report: Winters & Vicinity, California (USACE 1995)/ Winters and Vicinity, California, Final Feasibility Report and Environmental Assessment/Initial Study (USACE, 1997)	HEC-1	Winters streams	• Developed using 72-hour rainfall data • Winters area model calibrated with January 1995 storm • 10-, 50-, 100-, and 500-year floods
Reconnaissance Report: Winters & Vicinity, California (USACE 1995)/ Winters and Vicinity, California, Final Feasibility Report and Environmental Assessment/Initial Study (USACE, 1997)	HEC-1	Dry Creek	• Developed using 72-hour rainfall data • Recon level of detail
Reconnaissance Report: Winters & Vicinity, California (USACE 1995)/ Winters and Vicinity, California, Final Feasibility Report and Environmental Assessment/Initial Study (USACE, 1997)	HEC-1	Putah Creek Monticello Dam to the Yolo Bypass	
Reconnaissance Report: Winters & Vicinity, California (USACE 1995)/ Winters and Vicinity, California, Final Feasibility Report and Environmental Assessment/Initial Study (USACE, 1997)	HEC-2	Putah Creek	
Reconnaissance Report: Winters & Vicinity, California (USACE 1995)/ Winters and Vicinity, California, Final Feasibility Report and Environmental Assessment/Initial Study (USACE, 1997)	XRATE	Winters Area	• Uses input data of normal depth stage flow tables at cross sections • Used 10-, 50-, 100-, and 500-year rain floods

Study	Model	Areas Covered	Notes
Yolo County Integrated Groundwater and Surface Water Model, Model Development and Calibration (Water Resources & Information Management Engineering, Inc., 2006)	Integrated Groundwater and Surface Water Model	Emphasis on Cache Creek, expanded over entire County	• Rainfall data at 22 gages • Streamflow data from 25 gages throughout model area • Gages at boundaries were used for model inflows • Simulates groundwater and stream flow on daily time step for 30-year record from 1971-2000
Bridge Design Hydraulic Study Report – County Road 95 Bridge Replacement at Dry Slough (Quincy Engineering, 2016)/ Floodplain Evaluation Report – Country Road 95 Bridge Replacement at Dry Slough (Quincy Engineering, 2016)	HEC-RAS (1D)	4,500 ft downstream and 1,000 ft upstream of County Road 95 along Dry Slough	• Used FEMA 100-year flows and 50-year flows derived using the USGS regional regression equations • Survey data from Quincy Engineering was included in model
Central Valley Hydrology Study: Willow Slough watershed hydrologic analysis (DRAFT) (California DWR, 2013)	HEC-HMS	Willow Slough Watershed	• Calculated flow frequency curves at CVHS analysis locations • Modeling inputs and sources of data extensively documented

1. Borcalli & Associates. *Covell Drainage System Comprehensive Drainage Plan.* WMP-93-01-3. September 1993.

The primary purpose of this study is to address drainage and flooding problems associated with the Covell Drain and Davis north of I-80 and create a comprehensive drainage plan which would facilitate development of the Northwestern Quadrant and lands in the vicinity of the City of Davis.

Items included in the scope of this study include identifying risks associated with deficiencies in the SRFCP, establish baseline hydrologic and hydraulic conditions for Covell Drainage System, determine hydrologic and hydraulic impacts of future and use proposals in Northwestern Quadrant and North of I-80 (including mitigation alternatives), and evaluate alternatives for handling of runoff from the Covell Drainage System. This study uses the 100-year storm frequency event for evaluating risk of flooding and alternatives.

HEC-1 and HEC-2 modeling programs were used to complete the modeling effort of this study. Precipitation data used for the design storm was prepared by James Goodridge (included in Appendix B). The time of concentration of the design storm was estimated at 18 hours, with a minimum duration of 72 hours to estimate peak discharges. Due to significant ponding considerations, a storm duration of 10 days was adopted. Aerial adjustment factors were applied to the precipitation data using "NOAA Atlas 2, Precipitation Frequency Atlas of the Western United States, Volume XI – California" (National Weather Service). Rainfall was based on a symmetrical distribution with maximum depth occurring at the center of the storm. Storms with a recurrence interval of 2-, 10-, 50-, and 100-years were evaluated. A base flow of 1 cubic foot per second per square mile of drainage area was assumed. Table 3 includes curve numbers adjusted for the 10-day duration by land use types used for the study. Synthetic unit hydrographs were developed using SCS dimensionless unit hydrograph methodology. Data did not exist to calibrate the model, however, precipitation data from February 1986 and January 1993 was used to estimate discharges and adjust curve numbers to create results more comparable with observed flood conditions for those events. Results of the HEC-1 modeling were used with the HEC-2 modeling effort.

The HEC-2 model for Willow Slough Bypass included the portion of Willow Slough Bypass from the Yolo Bypass upstream to the confluence of Willow and Dry Sloughs. The HEC-2 model for Dry Slough extended form the confluence with Willow Slough upstream to Road 95. The HEC-2 model for the Covell Drain extended from the confluence of Willow Slough Bypass to Highway 113. The HEC-2 model developed for North Davis Drain extended from its confluence with the Covell Drain west to the vicinity of Road 96. The HEC-2 models are not calibrated due to lack of available data.

Estimated peak discharges of the existing conditions are described, with a summary of these discharges shown in Figure 1 below. A map showing the locations of these discharges is provided on Map 4. Comparisons of these modeling results are compared with the FEMA maps of the time (1988) and differences between the two floodplains are pointed out. Sensitivity of flow splits was evaluated, with only limited effects on floodplain extents. Map 5-8 shows estimated peak discharges and floodplain extents for the Improved North Davis Drain, the Improved Covell and North Davis Drains, the Chickahominy-Dry Slough Diversion, and the Improved Willow Slough Bypass Levees and Pumping Plant alternatives, respectively.

SUMMARY OF ESTIMATED PEAK DISCHARGES [1]

Recurrence Interval year	Dry Slough	Willow Slough	W.S. Bypass [2]	North Davis Drain					Covell Drain					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
100	3700	10600	10600	1100	930	960	950	1100	1500	1100	1100	1300	1400	2400
50	3100	7800	7800	700	630	710	700	910	660	620	640	900	950	1800
10	1400	4000	4000	190	190	230	220	310	150	180	200	320	320	550
2	230	1100	1100	30	30	30	30	50	30	40	50	100	100	130

[1] Discharges are in cubic feet per second.
[2] W.S. Bypass indicates Willow Slough Bypass.

Figure 1: Estimated Peak Discharges

Important findings of this study conclude that the volume of water reaching the East Davis area is of a magnitude that the increase in runoff from planned urbanization is nondetectable. Stormwater detention in the City for the purpose of reducing peak discharges is nominal. A specific drainage plan requires designation of lands which require flood protection, which is not currently available. It is recommended that Yolo County and the City of Davis continue to support a detailed Flood Insurance Study through FEMA and establish an approach for dealing with drainage and flooding in lands currently or potentially designated for development.

3. Borcalli & Associates. A Report on Storm Drainage and Flooding in Yolo County. February 1997.

After the storms of 1995, the Yolo County Board of Supervisors tasked the Yolo-Solano Flood Control Task Force with providing recommendations on methods to best deal with flooding problems within the county. The purpose of this document is to compile available information on existing storm drainage and flood control issues and formulate recommendations for the Yolo County Floodplain Management Working Group.

Flood issues that occurred due to the 1995 storms are listed, with the largest problem identified being the flooding of primary transportation corridors. Maps are included documenting roads typically flooded and their frequency. A map is also included that shows 50-year, 100-year, and 500-year flows and flood depths for areas North of Woodland (Map 4). Information from various agencies was collected on existing flood problems, damages, and possible solutions (summarized in Table 2 of report). A table summarizing 33 flood hazard mitigation projects and investigations from the previous 10 years is provided in Table 4 of the report. FEMA FIRM for Yolo County of the time were based on non-detailed studies, but FEMA is currently in the process of three detailed flood insurance studies, which will provide useful information to the communities they encompass.

The hydrologic/hydraulic design criteria are listed for the City of Davis, City of West Sacramento, and City of Woodland. The City of Yolo has a basic hydrology design procedure based on the Rational Method for rural watersheds and the Synthesized Hydrograph Method for larger watersheds. The Yolo County Flood Control and Water Conservation District has developed a hydrologic model for the Willow Slough/Dry Slough watershed using HEC-1. Models for the Willow Slough Bypass, Dry Slough, Covell Drain, and North Davis Drain were developed using HEC-2 and a 10-day, 100-year storm (modeling details not documented in this report).

Recommendations include establishing coordination agencies for planning and development, and post storm activities, as well as public information programs. A Priority Project Program is also recommended to mitigate damage done to residencies and businesses from the 1995 storms. Updating the Yolo County hydrologic methodology and design criteria using new tools and data, as well as establishing design criteria in the unincorporated areas is recommended. Finally, a Flood Management Funding Program is recommended to create additional funds to implement the above recommendations.

4. City of Winters. *Moody Slough and Putah Creek/Dry Creek Subbasins Storm Drainage Report*. August 2005

Putah Creek/Dry Creek Subbasins Drainage Report

This Drainage Report aims to identify facilities that can accommodate existing and planned development, while mitigating stormwater runoff and flooding impacts. This includes first evaluating the existing drainage and flooding conditions within the subbasins, developing design criteria and standards, identifying cumulative drainage and flooding impacts associated with development, and identifying facilities to mitigate increases to existing flooding problems. A map of the project site is shown in Figure 2 below.

HEC-1, HEC-HMS, and SWMM modeling program development criteria, methods and standards to be used are extensively documented within the report.

A HEC-1 model was developed using the 100-year storm event to represent drainage and flood conditions for Putah Creek and Dry Creek. Additionally, HEC-1 models were developed for the 100-year 10-day, and 100-year 24-hour storm events for the existing conditions, with the 10-day event resulting in the worst-case flooding. The analysis performed includes a proposed diversion channel, which would route overflow from proposed Moody Slough water quality ponds to Putah Creek, which could also receive overland releases and serve as a collection facility for overflow draining from water quality facilities. HEC-1 modeling for the 100-year 10-day and 100-year 24-hour were used to analyze the proposed drainage plan. The proposed drainage plan includes several water detention/water quality ponds, the Putah Creek diversion, a Grant Street Interceptor canal, and additional storm drains, to mitigate for proposed development.

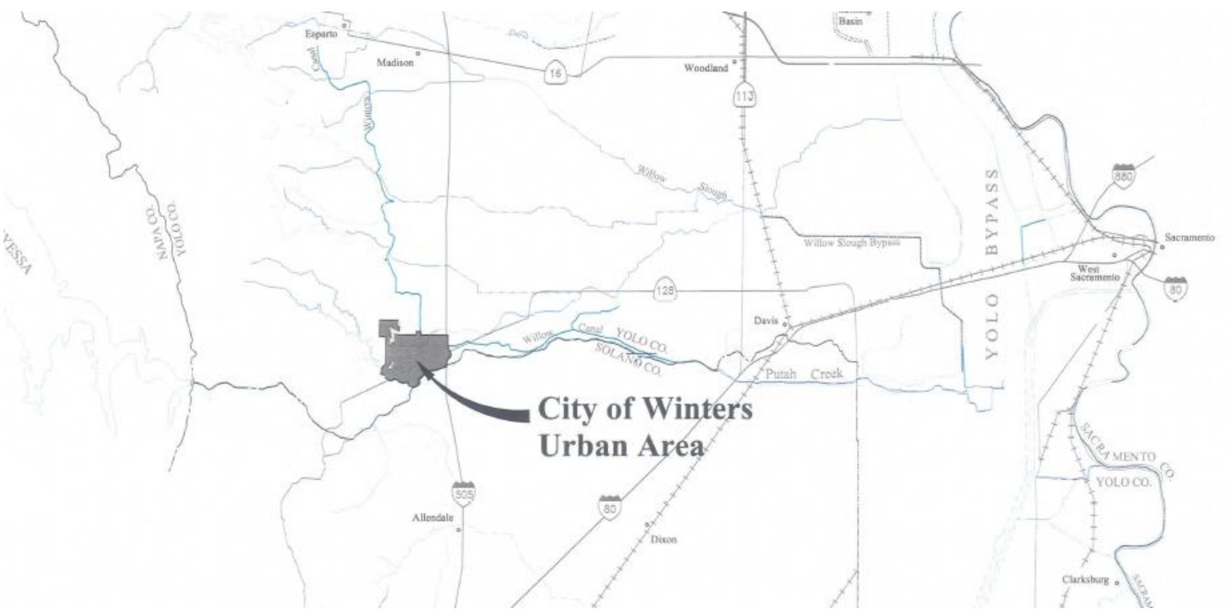

Figure 2: Project Area

Specific findings of the study confirm that the construction of proposed drainage facilities would significantly reduce the extent of the 100-year flood within the plan area. Recommendations include implementing storm drainage facilities to accommodate for new development within the subbasins and evaluate additional proposals for drainage infrastructure.

A number of modeling and rational method parameters are included in Tables 1-19 of the report.

Appendices

Appendix A includes “Storm Drainage Master Plan”, CHM HILL 1992. Includes rainfall intensity curves, and depth-duration-frequency tables. 10-year frequency storms were used for analysis to analyze existing and proposed storm drainage infrastructure.

Appendix B includes “Solano & Yolo County Design Rainfall”, James D Goodridge.

Appendix C includes spreadsheets for hydrologic and hydraulic calculations but is missing from the document.

Appendix D contains the “Rancho Arroyo Subbasin Storm Drainage Evaluation” (project site in Figure 3). An HEC-HMS model was prepared using Goodridge’s 10-year, 10-day storm event. MIKE SWMM was used in conjunction with the HEC-HMS models’ routing inputs. Five drainage scenarios were evaluated.

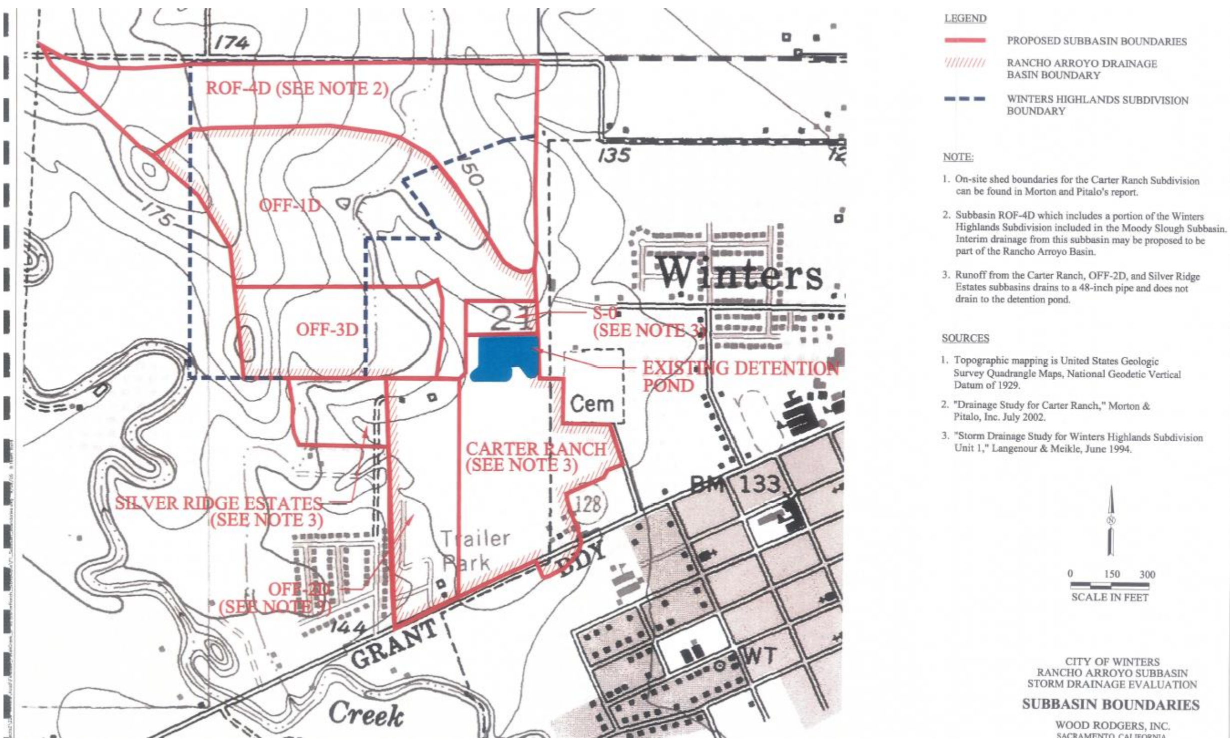

Figure 3: Rancho Arroyo Subbasin Storm Drainage Evaluation Project Location

Appendix E includes the Opinion of Probable Costs.

Moody Slough Subbasin Drainage Report

The purpose of this document was to identify facilities to accommodate existing and planned development to mitigate adverse impacts to stormwater runoff and flooding. This includes evaluating existing conditions, developing design criteria and standards, identifying cumulative drainage and flooding impacts associated with development, and identifying phased drainage planned facilities to mitigate flooding problems associated with proposed development.

HEC-1, HEC-HMS, and SWMM modeling program development criteria, methods and standards to be used are extensively documented.

HEC-1 models were developed for the Moody Slough subbasin including portions of the Chickahominy Slough subbasin, and analyzed the 100-year 10-day, 100-year 24-hour, 10-year 24-hour, and the 2-year 24-hour events (existing and proposed conditions, and for each proposed phase). During large events, the capacity of Chickahominy Slough is exceeded, spilling flows into the Moody Slough subbasin. A map of the project vicinity is provided in Figure 4 below. Proposed drainage facilities include the Putah Creek Diversion, five Detention/Water Quality Ponds, three Runoff Corridors, a Winters North Drain, and relocating the Willow Canal.

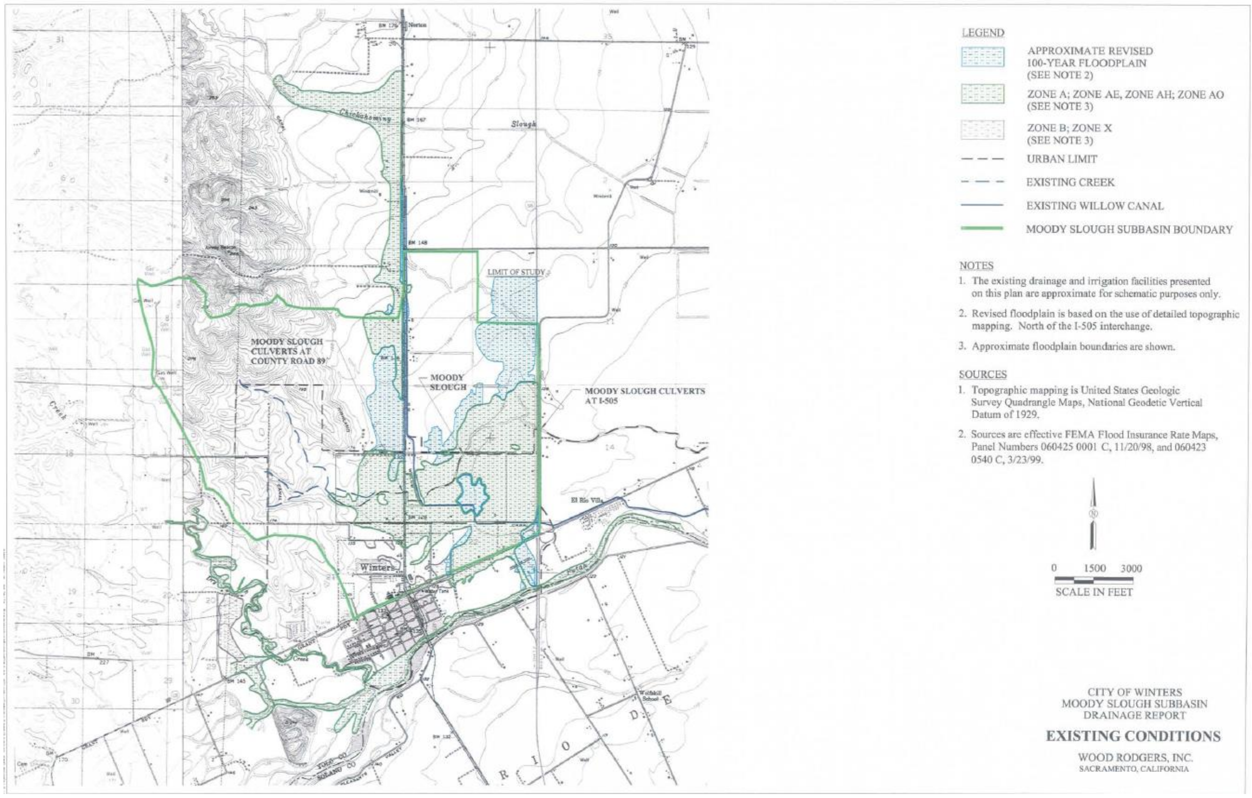

Figure 4: Project Location

Important findings conclude that the Putah Creek diversion is an effective means of mitigating existing floodplain upstream of Interstate 505, and the construction of the proposed facilities would facilitate removal of existing 100-year floodplain in portions of the project area. Recommendations include implementing storm drainage facilities to accommodate for development and phasing the development to ensure functional integrity of drainage facilities during development.

A number of modeling and rational method parameters are included in Tables 1-19 of the report.

Appendix A includes “Solano & Yolo County Design Rainfall”, James D Goodridge.

Appendix B includes spreadsheets for hydrologic and hydraulic calculations but is missing from the document.

Appendix C includes the “City of Winters General Plan Amendment”, 2003.

Appendix E includes the Opinion of Probable Costs.

5. Ensign & Buckley Consulting Engineers. Evaluation of Flood Control Alternatives in Yolo County. 2000.

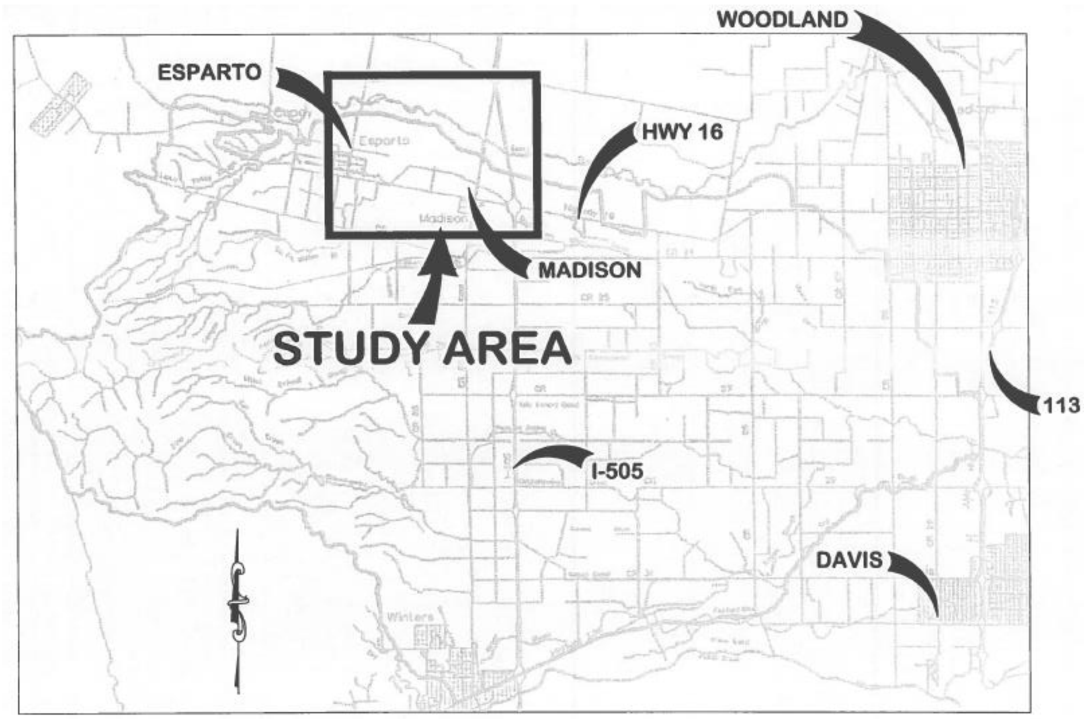

Figure 5: Study Area

The purpose of this report is to evaluate nine alternatives to relieve flooding problems in the areas of Esparto and Madison, approximately 10 and 13 miles west of Woodland. A map of the study area is shown in Figure 5. Flows were calculated for this study using a modified version of the FEMA HEC-1 model. Modifications included added detail to the vicinity of Madison and Esparto. HEC-2 modeling was conducted to model failed levees where FEMA criteria was not met, and water surface profiles were calculated in the South Fork Willow Slough, Lamb Valley Slough and Madison Drain.

A storm duration of 24 hours was used to compute the 2-, 10-, 50- and 100-year return period flows. The flows calculated with HEC-1 model and are provided in Table 1 of the report. The 100-year flows used with the HEC-2 model are shown in Table 2 of the report. Provided flows used in their simulation are for Lamb Valley Slough, South Fork Willow Slough, Madison Drain, and Cottonwood Slough.

6. Federal Emergency Management Agency. *Flood Insurance Study Yolo County, California and Incorporated Areas.* May 2012.

The purpose of this study is to develop flood risk data for the county that will be used to establish actuarial flood insurance rates. Several past studies of the area were used to compile relevant peak discharges throughout the area. These peak discharges are summarized in Table 4 of the report. Dry Slough locations contain 1% peak flows between 714 – 3659 cubic feet per second (cfs). Water surfaces are computed using HEC-2. Flooding patterns and flow splits surrounding the areas of County Road 31 and 95 are detailed for Dry Slough. Water surface elevation profiles are provided for all channels within the study area, including Dry Slough, Yolo County Airport Drainage Channel, Willow Slough and its tributaries, Union School Slough and others.

7. GEI Consultants. Drainage Study for Sacred Oaks Healing Center. December 2016

This report documents the drainage studies and models developed to be used to determine the 100-year base flood elevations at the site of the proposed construction of the Youth Regional Treatment Center, 7 miles west of Davis, California. The proposed location is on Country Road 31 adjacent to Country Road 93A (Figure 6 below).

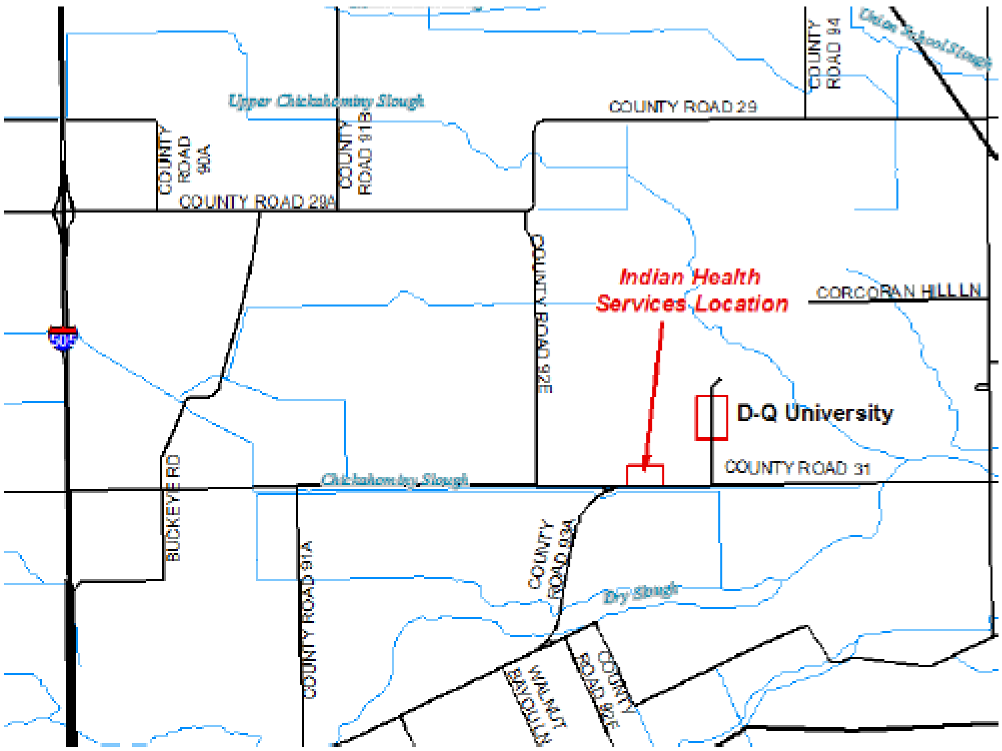

Figure 6: Project Area

A design storm hyetograph from the Yolo County manual was used for the two adjacent watersheds to the project site. NOAA 14 precipitation data was also compared to Yolo County data for four locations and found to be reasonably close. GEI decided that NOAA 14 precipitation data would be used for the 100-year 24-hour and 10-day models, as it was the most up-to-date data available. NOAA 14 and Yolo County precipitation duration/recurrence interval data is available in Table 3 of the report.

Flows through Willow Slough, Dry Slough and the Covell Drain watersheds were established using HEC-1 and findings from YCFCWCD, 2002. Flow hydrographs from the DWR CVFED (2013) project were extracted from watersheds that drain into Dry Slough and utilized as the upstream boundary conditions for the projects HEC-RAS 2D model.

A HEC-HMS model was developed for the project site using a symmetrical storm distribution (“Frequency Storm” method) for storms up to a duration of 24 hours. DWR’s CVHS hydrologic model was utilized, with adjusted precipitation data (NOAA 14) for Chickahominy Slough and Dry Creek watersheds from the frequency storm method. Although the CVHS model includes several basins for the Willow Slough basin, due to the project location, only precipitation data for the Chickahominy Slough and Dry Creek areas were utilized. Three design storms were modeled – CVHS 100-year 10-day, Yolo County 100-year 10-day, and Yolo County 10-year 24-hour events. Output hydrographs and hyetographs were used in the HEC-RAS 2D model. The HEC-HMS boundary hydrograph for Chickahominy Slough was split, with Dry Slough receiving 40% (3,476 cfs) and Chickahominy Slough receiving 60% (2,317 cfs) of sub basin flow for the HEC-RAS 2D model boundary conditions (Figure 7 below).

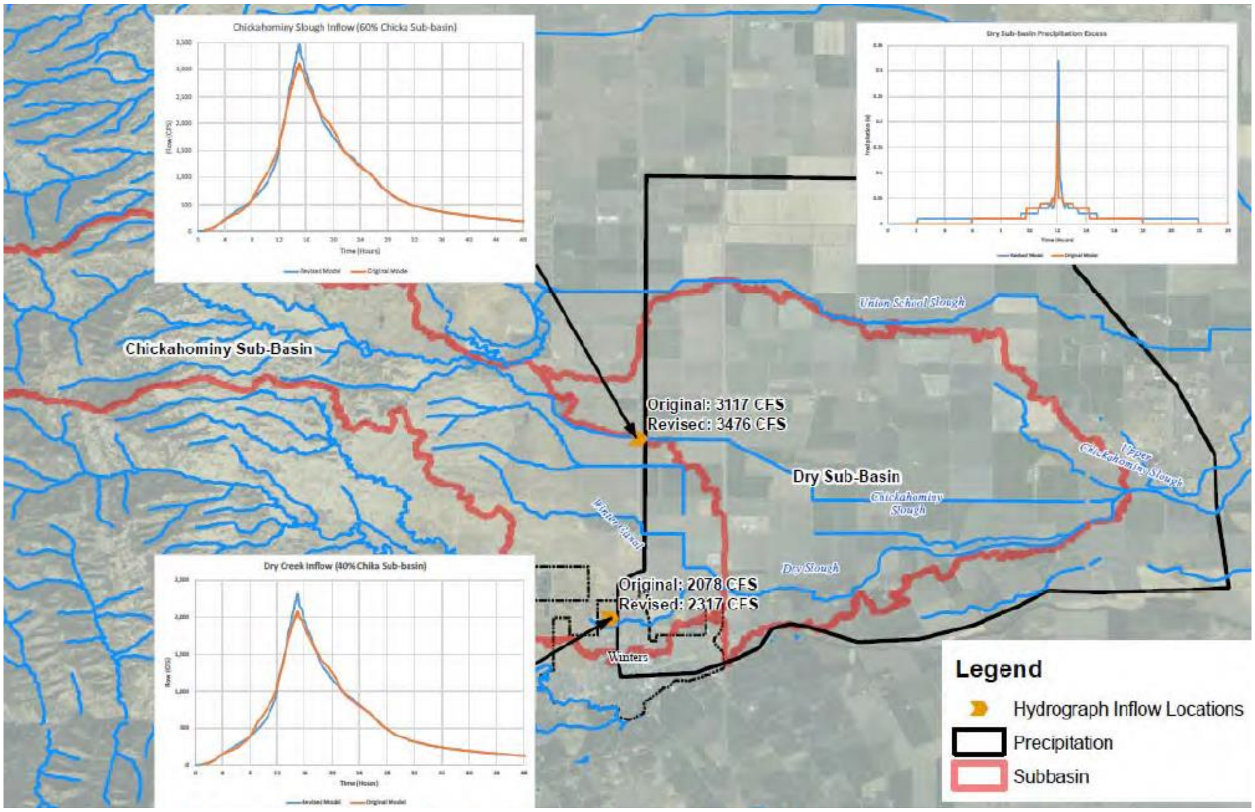

Figure 7: HEC-HMS Basins and HEC-RAS Boundary Conditions

Terrain data utilized for the HEC-RAS 2D model was based on the CVFED LiDAR (2008) and supplemented by a field survey from RFE Engineering. The with-project terrain included raising Buildings A, B, and C above existing grade.

The final 100-year water surface elevation at the project site was 104.99 feet NAVD 88. The flood depth at the project site for the 100-year 24-hour storms was approximately 0.5 feet. The with-project simulation increased the base flood elevation 0.01 feet within the project limits and had negligible impacts to the floodplain compared with the existing condition. The proposed building and parking lot elevations of the Youth Regional Treatment Center is a foot above the base flood elevation (106.0 feet NAVD 88). There were no significant differences in results between the 100-year 24-hour and 100-year 10-day simulations.

Note: There seemed to be HEC-HMS and HEC-RAS model files submitted with the report which may be useful for future hydraulic modeling, if available.

8. Kennedy/Jenks Consultants. *Storm Water Resource Plan for Yolo County*. May 2018

This study covers the entirety of Yolo County, and seeks to inform future water management decisions and promote effective conjunctive use and alleviate flooding, groundwater, and water quality issues through storm water management throughout the county. 24 of the 28 proposed projects have potential flood management benefits and are listed in Table 5-3 of the report, by either reducing runoff rate or volume, and/or reducing sanitary sewer overflows.

Appendix I

Several models were used to inform the analysis of flood management projects. A HEC-HMS model was developed (covering the Western Yolo Sloughs areas) and simulated the January 2017 and 100-year, 24-hour design storm. This model covered Lamb Valley Slough, South Fork Slough, South Fork Willow Slough and Cottonwood Slough. Two Water Evaluation and Planning (WEAP) models were developed for Cache Creek and Yolo County and simulated with a daily timestamp. The WEAP models were used to for two alternatives that involved capturing precipitation on farm fields. The storm water management measures explore only small and medium storms, and suggested measures would be too small to handle big storms.

The HEC-HMS model inputs are documented in Table 2.1 of the report, and include the sources of the data. Peak flows and modeled hydrographs are contained in Table/Figure 2.3/2.4 of the report. There are no flow measurements for these sloughs, so it is difficult to tell how reasonable these results are. Results of the HEC-HMS model led to the recommendations of establishing flow monitoring stations, upstream mitigation efforts (such as diversions), on-farm mitigation efforts, and canal gate operations upstream of the sloughs be explored.

The Cache Creek WEAP model was used to further explore groundwater recharge by diversions to the district's unlined canal systems, however there is limited application of this alternative for flood management. A second alternative of capturing precipitation on farm fields was explored using a modified version of the WEAP model. More details on the WEAP model development are contained in Appendix B.

10. Mackay & Somps. *Flood Control Master Plan for The Cannery Davis, California.* November 2012.

The purpose of this document is to evaluate drainage impacts from the proposed redevelopment project, The Cannery, in support of a CEQA analysis. The Cannery site is east of F Street and north of West Covell Blvd. in Davis, CA, shown in the Figure 8 below.

Figure 8: The Cannery Project Site

The storm events analyzed for this project include the 100-year 24-hour, 10-year 24-hour, 2-year 24-hour, 100-year 10-day, and 200-year 10-day events. HEC-1 modeling was used for the hydrology, and unsteady-state HEC-RAS modeling was used for hydraulics. The models used for this study were adapted from Mead and Hunt Models used for their Covell Villages analysis in 2004. Hydrology for the model was based on inputs established in the 2010 Yolo County Drainage Manual for the Covell Drain Watershed. Various specific modifications made to the HEC-1 and HEC-RAS models are listed in Appendix C. Modeled flow rates and WSEs for 8 channels at the project site are listed in Table 3A of the report, however listed channels are likely not relevant for modeling needed in the West Plainfield area due to the limited project area.

11. Mead & Hunt. *Yolo County Airport Drainage Plan Update.* September 2014.

An original Yolo County Airport Drainage Plan was prepared in October 1984 by Borcalli, Ensign, and Buckley, and was updated in 2005. Proposed developments add impervious areas to the watershed, and as part of the planning effort, this study was conducted to update the Yolo Country Airport Drainage Plan.

The Hydrologic and Hydraulic Design Criteria used for this study are summarized in Table 1 of the report and are derived from the Yolo County City/County Drainage Manual (2009). Models used in the 2005 Drainage Plan were updated and utilized for this study. A 10-day duration was used for the 100-year, 10-year events for storage facility design, and the 100-year 24-hour event was used for conveyance facility design. Additionally, the 200-year 10-day and 200-year 24-hour storms were included in this update. Table 3 of the report summarizes the design precipitation data used for this study.

HEC-HMS was used for hydrologic modeling and HEC-RAS was used for hydraulic modeling. Output hydrographs from the HEC-HMS model were used as input hydrographs for the HEC-RAS model. The HEC-HMS model was adapted from the 2005 HEC-1 model, while the 2005 Drainage Plan Update HEC-RAS model was modified to include dry detention basins and updated inflow hydrographs. The domain of the HEC-HMS model included the entire area contributing runoff to the north-south drainage ditch on the eastern edge of the Airport. The domain of the HEC-RAS model included the main north-south airport drainage ditch from its northern end to just upstream of the confluence with Airport Slough. Exhibit B includes Max WSE profiles and a flow hydrograph; however, no map of model extent and locations is provided. Specific recommendations of this study include several drainage design recommendations, and the recommendation to consider a regional drainage solution.

12. Soil Conservation Service. *Flood Hazard Analyses City of Winters, Including Portions of Putah Creek, Dry Creek and Moody (Dry) Slough, Yolo County, California*. July 1976.

The purpose of this report is to document information about frequency, depth, and other related information on potential flooding around the City of Winters. The study area includes the Putah Creek south of Winters, east to Interstate 505, and Monticello Dam to the west. It includes areas in the Putah Creek, Dry Creek, and Moody Slough Watersheds (Figure 9 below). Descriptions of each watershed’s vegetation, soils, average elevations, land uses, and channel geometry are included.

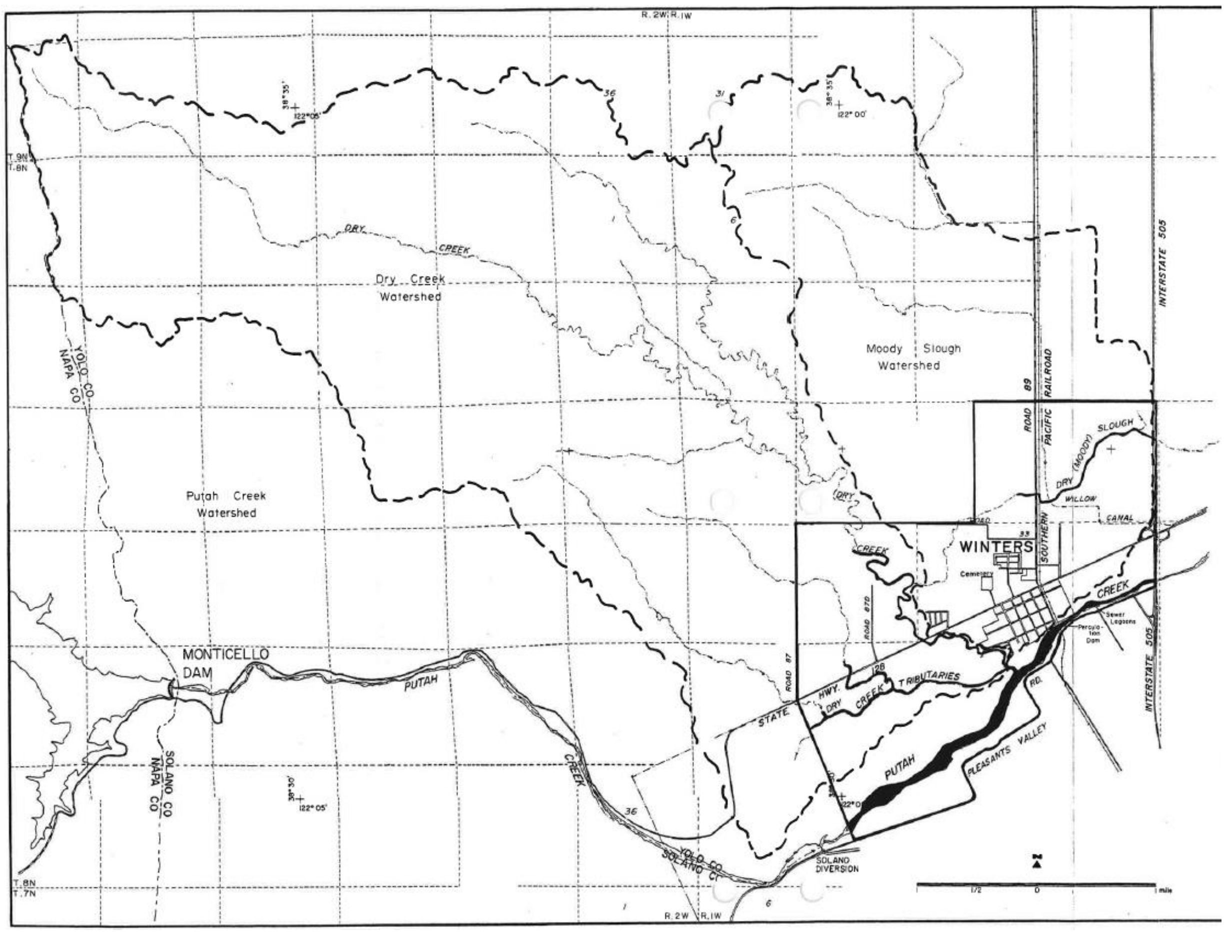

Figure 9: Study Area

The main source of flooding in the study area is caused by runoff from the Moody Slough watershed. Several descriptions of flooding at various intervals are described for each watershed. It is estimated that any storm greater than the 2-year storm would exceed the existing storm sewer system capacity in Winters. Floods greater than the 25-year flood would exceed capacity of Moddy Slough.

Flood Area maps, water surface profiles, and water surface elevations for selected return periods, are included in the appendices for the area surrounding Winters. Discharges are tabulated for return periods of 2-, 5-, 10-, 25-, 50-, 100-, and 500-year periods at selected locations along Putah Creek, Moody Dry Slough, Dry Creek, and its Tributaries. For Putah Creek watershed, peaks for various return periods were estimated using stream gage records (Figure 10 below). Peaks for Dry Creek watershed were developed using methods of Hydrologic Evaluation computer analysis. Hydraulic analysis was developed using WSPIN (standard SCS Water Surface Profile computer program).

Tabulation of Discharges for Selected Points and Reaches

Stream	Point or Reach	Drainage Area (sq. mi.)	500 Yr. (cfs)	100 Yr. (cfs)	Return Period 50 Yr. (cfs)	25 Yr. (cfs)	10 Yr. (cfs)	5 Yr. (cfs)	2 Yr. (cfs)
Dry Creek	Section 30 just above Hwy 128	16.7	6,500	4,780	4,160	3,450	2,670	2,020	1,150
	Section 21 just above junction with Trib.	16.8	6,490	4,770	4,150	3,440	2,660	2,010	1,150
	Section 20 just above junction w/Putah Creek	22.7	8,090	5,950	5,160	4,290	3,300	2,490	1,420
Dry Creek Tributaries	Section 61.1 just above Road 87A	2.8	1,690	1,240	1,070	890	680	510	280
	Section 49.1 just above Road 87A	2.1	820	610	510	420	310	230	110
	Section 45 just above Road 87E	5.7	2,990	2,200	1,880	1,570	1,150	860	420
	Section 40 just above junction with Dry Creek	5.9	3,060	2,250	1,920	1,590	1,180	880	440

E-10

Figure 10: Peak flows for Dry Creek and Tributaries

13. Soil Conservation Service. *Investigation of Flood Problems Chickahominy-Moody Slough Watershed, Yolo County, California.* January 1982.

This report provides a summary of flood problems in the Chickahominy-Moody Slough Watershed. The purpose was to develop a plan that could be installed with federal financial assistance. Of the alternatives examined, the most economical way to achieve substantial reductions in flooding within the watershed was the construction of three diversion channels, which would benefit only part of the flood-prone area. Once a cost benefit analysis was performed on this alternative, the benefits appeared about equal to slightly less than the cost. With significant opposition to the project from the landowners, the study of this alternative was discontinued. This report summarizes engineering phases of the study of the various alternatives.

The study area included the Chickahominy-Moody Slough Watershed, which is bounded by Putah Creek in the south, highway 113 in the east, Yolo Central Canal in the north, and the Vaca Mountains in the west, and includes Union School Slough, Chickahominy Slough, and Moody (Dry) Slough. Descriptions of the watershed (vegetation, land use, elevation slope) are included in the report. Estimations of the area inundated for various return period floods are also included. Additionally, a map of the estimated flood plain for a 10-year event is included.

Three flood reduction alternatives were studied, which include floodwater retarding structures, channel clearing, diversion channels, and channel enlargement. Estimated costs of these alternatives are provided in Tables 1-3 of the report. Details on the three-diversion alternative (Winters, DQU, and

Airport Diversions) are provided, along with expected WSEs, design discharges, and n values, however no modeling documentation is included.

14. US Army Corps of Engineers. *Reconnaissance Report: Westside Tributaries to Yolo Bypass California.* June 1994.

The purpose of this report is to investigate flooding and water resource problems associated with the westside tributaries to the Yolo Bypass. The study area includes sub-basins Cache Creek, Willow Slough, and Putah Creek. There were two structural alternatives found to be economically feasible on Cache Creek to reduce flood damages. The results of this report indicate that there is interest in pursuing feasibility-phase studies of flood improvements and environmental restoration along Cache Creek.

Several flood control measures were identified including non-structural, upstream storage, upstream detention storage, levee modification/new levees, channel improvements, and combinations of the measures. The two economically feasible flood control plans consisted of a setback levee and channel improvement (along Cache Creek).

Existing hydrologic data was reviewed and updated (included in Appendix B). A HEC-1 model was used for the Cache Creek basin, and 50-, 100-, 200-, and 500-year hydrographs were developed. HEC-2 was used to model Cache Creek and water surface profiles were developed for existing and project alternatives. Hydraulic analysis included estimated existing levee failure locations on the Cache Creek levee system.

Conclusions of the report include that there is serious flood threat to Woodland and Yolo from the Cache Creek overflow, and there are economically justified alternatives that would increase levels of flood protection and provide reductions to flood damage.

Appendix B – Hydrology Report

Appendix B contains relevant information used in the HEC-1 model. Various details of the data used is included for Cache Creek, Willow Slough, and Putah Creek. This information includes details on methods used to compute the Unit Hydrograph, loss analysis, and routing parameters. Flows at various locations for the 10-year and 100-year recurrence intervals are shown on Chart 3 but are illegible. Flood hydrographs for Cache Creek at Capay are included for the 100-, 200-, and 500-year recurrence intervals in charts 7-9. Graphical analysis was used to determine the 100-year peak flows on Putah Creek using annual peak flows and Weibull plotting positions. The peak flow frequency curve for Putah Creek at Winters is shown in Chart 6. It was determined that the Putah Creek has at least a 100-year channel capacity. The HEC-1 model for the Willow Slough Basin, developed by Brocalli and Associates, was reviewed and deemed appropriate.

15. Water Resources Association of Yolo County. *Integrated Regional Water Management Plan.* April 2007.

This document contains the vision of future water management in Yolo County. High priority water management actions are identified to improve water management throughout the county.

Flood management issues are generally documented, and include items such as levee inadequacies, lack of public outreach, erosion and seepage risks, and general inadequate flood protection in the various communities. Table 5-4 of the report documents 48 potential flood management actions. These 48 actions include several levee improvement and enhancement projects (addressing erosion and seepage), increasing public outreach and flood risk awareness, storm drainage detention projects, and vegetation and sediment clearing of existing channels and sloughs, conducting additional hydraulic capacity assessments (country roads, highways, and bridges), and integrated watershed management programs. Projects that have larger potential to impact the Plainfield area include; the Putah Creek Integrated Project, which includes the Storm Drainage Diversion to Putah Creek Project, Putah Creek Diversion Dam Vegetation Removal Project, and the Mace Boulevard Bridge Improvement Project (flood management), as well as two bank stabilization projects; and the Yolo County Sloughs, Canals, and Creeks Management Program, which includes several flood management projects to improve storm drainage management throughout Willow Slough and it's tributary sloughs, and throughout the county. Tasks, and estimated budget for each task, for each project are outlined in section 7 of the report.

16. Water Resources Association of Yolo County. *Integrated Regional Water Management Plan. Background Data and Information Appendix. Hydrology of Yolo County.* May 2005.

The intent of this report is to provide information on the surface water resources within or potentially available to Yolo County to meet and sustain the water needs of the county. This document contains descriptions of watersheds within Yolo County, including the Sacramento River, Yolo Bypass, Colusa Basin Drain, Cache Creek, Willow Slough, Putah Creek, and Wetlands Watersheds, as well as various Channels for Water Distribution and Storm Drainage. Descriptions generally include information on the watershed, water availability and water quality, with additional information on gauging stations, erosion and sedimentation, flow regime, and flooding available in some watersheds.

Information on the Willow Slough watershed indicates that drainage in the watershed continues to be altered by land-leveling operations, farm cultural practices, maintenance (or lack of) sloughs, and construction of berms and dikes.

Table 4-1 includes all gages in the County, with information on what data they collect and their period of records. Figures 4-1 and 4-2 contain information on mean precipitation, Figures 4-16 – 4-18 contain figures of average flows at various locations along the Sacramento River, Figures 4-26 and 4-27 contain information on Peak Flows at Cache Creek and Putah Creek from the gauging record. Map 4-15 contains gaged peak flood flows (the closest peak flow available to Plainfield is Cache Creek near Yolo).

17. Wood Rodgers, Inc. *Combined Riverine and Overland Flow Hydraulic Models – Willow Slough Technical Memorandum.* 2013.

This report serves to document methodology used to develop the Willow Slough hydraulic model under the CVFED TO23 and TO25 program. The purpose of TO23 was to develop FLO-2D models of areas identified in TO21, while TO25 served to finalize the models developed in TO23 and incorporate features for use in floodplain delineation for a future task order. The developed FLO-2D model incudes Esparto, Madison, Woodland, Winters, and Davis (domain shown in Figure 11 below). As part of their data collection, Wood Rodgers reviewed the Comprehensive Study FLO-2D model developed by USACE of the Willow Slough domain.

The HEC-1 model developed by Borcalli and Associates in 1992 for the "Covell Drainage System – Comprehensive Drainage Plan" was used to develop a test flow scenario for the 500-year design storm. Test flows used are summarized in Table 1 and Figure 4 and the associated hydrographs are available in Figure 5. FLO-2D outflow nodes at Cache Creek and Putah Creek were used to allow water to leave the model domain. The downstream boundary condition at the Willow Slough bypass utilized a stage time series with a fixed water surface elevation at the downstream end of Covell Drain and the downstream end of the 1D channel representing Willow Slough Bypass. Extensive documentation exists on methods used to develop the model elements, terrain, and parameters. Several HECRAS 1D components were eventually embedded in the final model (streams and rating curves for inline structures). The 1D elements incorporated from the HEC-RAS model were calibrated in the FLO-2D model to match water surfaces in the HEC-RAS model. Multiple quality control reviews were performed and documented.

Conclusions of the report indicate that the FLO-2D model developed is complete and suitable for CVFED floodplain mapping. It is also recommended that consideration be given to developing a more accurate dataset that identifies building footprints.

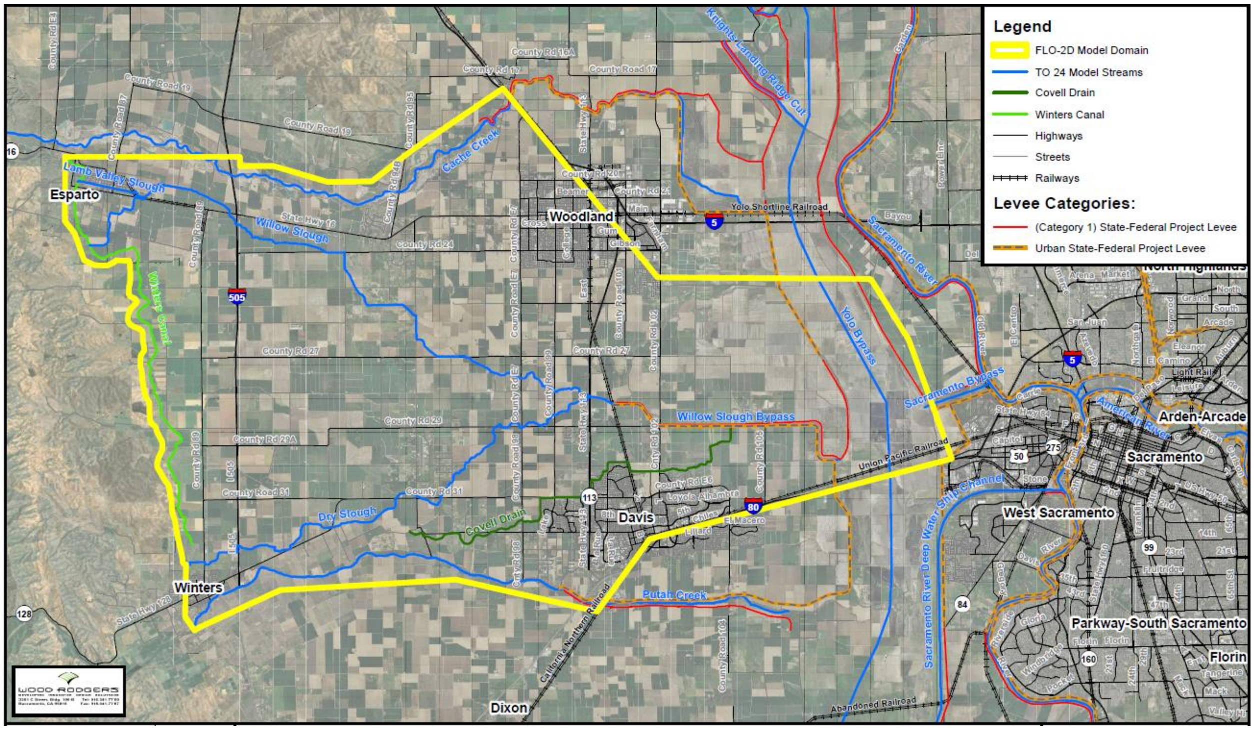

Figure 11: FLO-2D Area Domain

18. Western Yolo Regional Watershed Task Force. *Solicitation for Funds Proposal for Flood Control and Ecosystem Restoration*.

This document solicits funds for a feasibility and development phase to evaluate proposed solutions and determine which are the most suitable, update costs of implementation of proposed solutions, perform environmental reviews and prepare engineering plans for construction of flooding in the Chickahominy and Moody Slough Watersheds. Flooding issues in this area cause significant flood damage to agricultural lands. Proposed solutions include three components: diversions, small-scale containment ponds, and increasing infiltration rates due to changing agricultural practices. The three proposed diversions include: Chickahominy Slough at DQU to Putah Creek, Winters diversion and Airport Slough to Dry Slough. Seven basins have been selected as sites for containment ponds.

20. Jones & Stokes Associates. *Willow Slough Watershed Integrated Resources Management Plan*. May 1996.

The purpose of this document is to plan the enhancement of natural resources through integrated management. For flood control purposes, a HEC-1 model was used to simulate several small stormwater detention ponds and channel enhancement scenarios. Generally, small stormwater detention ponds did not provide significant flood benefits. However, channel enlargement could provide an increase in flood conveyance capacity while creating riparian habitat within the channel. The terrain and hydrology of the watershed are conducive to frequent and widespread flooding, as flooding was common under predevelopment conditions. A recommended strategy would be to divert floodwaters to areas where it creates the least impacts.

Appendix A contains the Hydrologic and Hydraulic Analysis. This analysis was an effort to develop a conceptual level assessment of the impacts of detention storage and channel improvements for flooding conditions in the Willow Slough watershed to be used in developing the Willow Slough Watershed Integrated Resources Management Plan. Peak flows of existing conditions were estimated using a modified version of the HEC-1 model developed in the Covell Drainage System Comprehensive Drainage Plan (Borcalli & Associates, 1993). The HEC-1 model nodes are identified in Figure 12 below. The events selected for modeling were the 2-, 10-, 50-, and 100-years events with a duration of 4 days.

Several potential flood control improvements are discussed, including rangeland improvements (decreasing grazing intensity), altering cultivation practices, detention of peak flows, and increased channel capacity. Seven pilot project concepts and designs are identified.

Three storage conditions were evaluated: detention upstream of Winters Canal, detention downstream of Winters Canal, and detention both upstream and downstream of Winters Canal. Storage was reflected as retention in the storage scenarios and the storage volume is removed from the watershed runoff volume with this approach. Therefore, the modeling results may overstate the impact of the small storage ponds. Based on the results it is not recommended to construct the detention ponds for the purpose of flood control. The ponds have little impact on reducing flows for the 10-, 50-, and 100-year events.

Three improved slough channel conditions were evaluated: removing vegetation within existing channels, modifying channels to reflect benching for habitat, and modifying channels for channelization and containment of flow. The HEC-1 channel routing parameters were adjusted to reflect these project conditions. Generally, channel improvements increase flows downstream and reduce overflows between sloughs. A HEC-2 model of Dry Slough was used to assess the relative impact of removing slough vegetation and creating habitat benching. The full bank capacities of Dry Slough below the confluence of Chickahominy Slough were estimated at 8-year level of protection at the existing conditions, 10-year protection for benched, and 21-year protection for cleaned channel conditions.

Tables 1-6 contain peak flows of existing conditions and with storage/vegetation/bench/channelization for sloughs throughout the region (Dry, Willow, Chickahominy, Union School, etc.) for the 2-, 10-, 50-, and 100-year events. Figure 13 below shows the peak flows of a 10-year event at selected node locations. Figures 1 and 2 of the report show the existing and with storage hydrographs at Cottonwood and Willow Sloughs for the 2- and 100-year events.

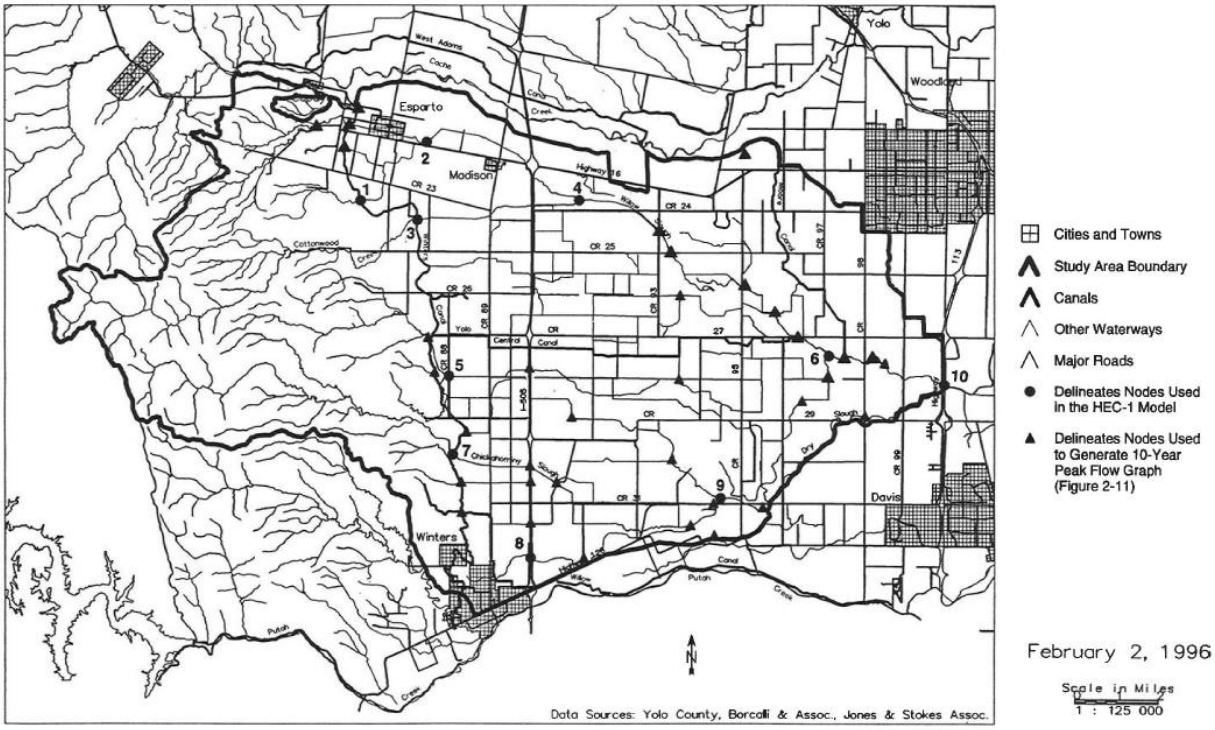

Figure 12: HEC-1 Model Nodes

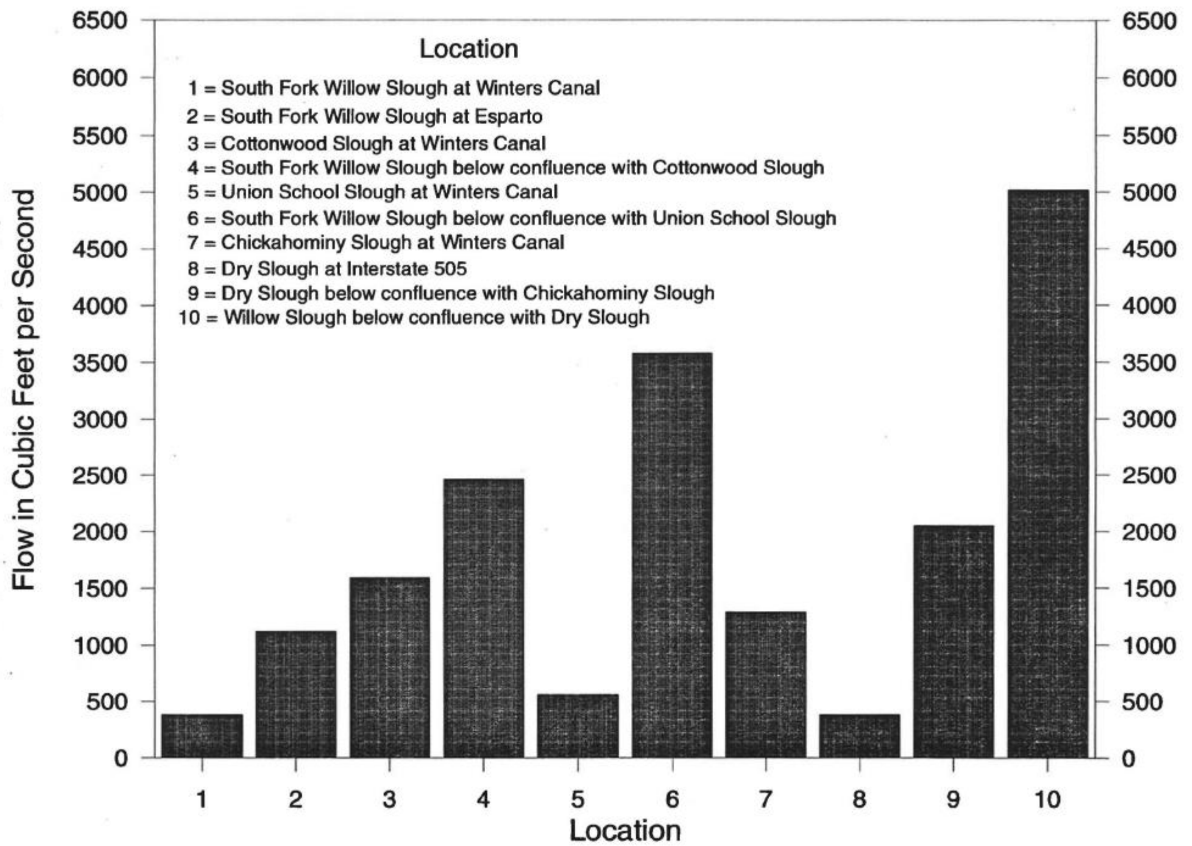

Figure 13: Peak Flows for the 10-Year Event at Node Locations

21. US Army Corps of Engineers. *Reconnaissance Report: Winters & Vicinity, California*. April 1995.

The purpose of this study was to investigate flooding and water resource problems in Winters and vicinity and develop solutions to address these problems. The study area includes portions of the Willow Slough and Putah Creek drainage basins. Of the alternatives evaluated, three were found to be economically feasible and provide 100-year level of protection, which included channel modifications, culvert enlargements, and levees. Flood control improvements to agriculture lands north of Winters are not economically feasible, however non-structural measures in certain areas may be feasible. Studies on hydrology, hydraulic analysis, and economic analysis were conducted in the study area following the flood of January 1995. Results of the study conclude that a feasibility study is needed for the study area, shown in Figure 14 below.

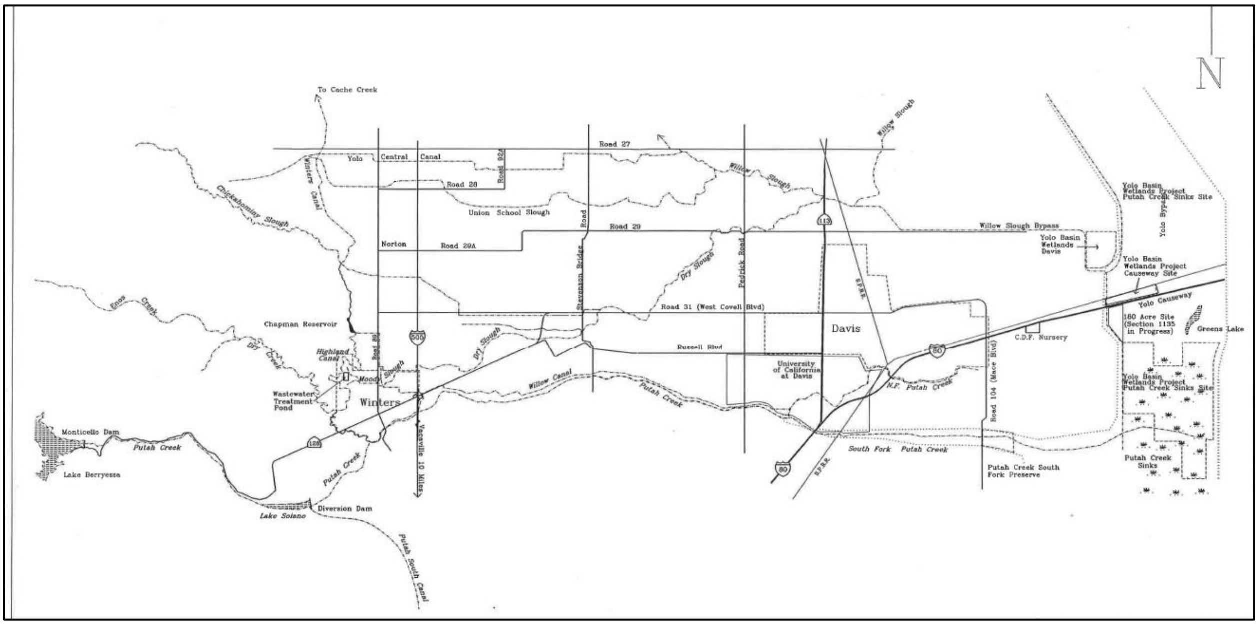

Figure 14: Study Area

Non-structural flood control measures identified included flood warning and evaluation plans, temporary closures using floodshields, ring levees and floodwalls for individual structures, raising existing structures, and relocations. Structural flood control measures identified include upstream storage, detention basins, channel improvements, levees, and culvert improvements.

Hydrologic studies included review of existing reports, and data/computer models of the study vicinity. A HEC-1 model of the contributory watersheds was updated for the study area and flow-frequency curves and hydrographs for contributory watersheds were developed. The hydrograph and peak flows were used with the XRATE program to develop floodplains for the Winters area. A HEC-2 model was developed for the Putah Creek to compute Water Surface Profiles.

Conclusions of the study indicate that there is severe flooding to the Winters and north of Winters areas. Channel and levee improvements and diversion channels to the north and west of Winters are the most cost-effective ways to increase flood protection for existing developments. Future studies are recommended for the Putah Creek and Dry Creek areas.

Appendix B – Hydrology

Excluding the Putah Creek, hydrographs for flood events were developed from 3-day rainfall depth-duration-frequency relationships and HEC-1 modeling. HEC-1 models were developed of the Winters streams area and Dry Creek. Rainfall-runoff analysis parameters are included, as well as 72-hour rainfall for the various subareas for various frequency events.

The winters area HEC-1 model was roughly calibrated using the observed rainfall and runoff data from the January 9, 1995 storm. There weas no observed peak flow data, so the modeled peak flows are uncalibrated. The Dry Creek HEC-1 model was developed using a recon-level of detail; the results corroborated the discharge frequency relationships developed by the Soil Conservation Service (Table 11 of study). A Putah Creek HEC-1 model was developed from Monticello Dam to the Yolo Bypass. Discharge-frequency relationships are recorded for Winters area subbasins for the 10-, 4-, 2-, 1-, and 0.2-% chance exceedance events (Figure 15 below). Peak flows for Putah Creek are also included in Table 12 of the report.

TABLE 10
WINTERS SUBAREA DISCHARGE-FREQUENCY RELATIONSHIPS

		Subbasin Peak Discharge (FT^3/S) Percent Chance Exceedance				
Subbasin	Area (MI^2)	10 %	4 %	2 %	1 %	0.2 %
UP-WC	0.39	120	150	170	190	230
CS1	0.73	310	380	440	490	590
CS2	1.50	380	480	560	620	770
CS3	13.90	2670	3410	4020	4520	5590
CS4	0.57	160	210	250	290	350
CS5	0.65	210	260	310	340	420
DS1	1.84	630	770	890	990	1210
DS2	0.43	140	180	200	230	280
DS3	1.19	310	390	450	500	620
Dry Cr. at Hwy 128	17.20	2780	3590	4270	4830	5990
CR1	1.17	430	530	600	670	820
WI	0.66	230	290	330	370	460
MS1	1.01	280	340	390	440	540
MS2	1.83	420	530	610	680	840
MS3	1.11	310	390	460	510	630
MS4A	0.37	160	200	220	250	300
MS4B	0.32	130	160	190	210	260
MS4C	1.25	380	490	580	670	820

Figure 15: Discharge Frequency Relationships

Appendix C – Hydraulics and Flood Plains

The hydraulic model for the study was developed using XRATE, which uses input data of normal depth stage flow tables at each cross section, storage stage-flow tables at ponding areas, and stage-flow relationships for overland flow areas, and local drainage inflow hydrographs. The 10-, 50-, 100-, and 500-year rain floods were used for this study. Products of this analysis include flooded area map, tables of flood stages, depths of flooding and duration of flooding, flow points and directions, and a table of peak flows.

22. U.S. Army Corp of Engineers. *Winters and Vicinity, California, Final Feasibility Report and Environmental Assessment/Initial Study*. February 1997.

The purpose of this study was to investigate flooding problems in the city of Winters and develop solutions to these flooding problems. Based on the economic analysis of the feasible alternatives, the natural economic development plan consists of constructing a new levee along future County Road 33 and a 300 cfs drainage channel that terminates into Putah Creek. The locally preferred plan included the construction of the levee and channel as well as increasing the size of the drainage channel to 1,000 cfs; this plan was selected for recommendation to Congress.

A HEC-1 model was developed for the hydrologic study. Flow-frequency curves were developed and the, frequency-flows were developed for the 10-, 50-, 100-, and 500-year floods. The XRATE program was used to model the accompanying floodplain in the Winters area. A HEC-2 model was developed for Putah Creek. (Same models as in study #21).

Attachment AA - Hydrology

Very similar information as in study #21. Additional sections are included on Winters Interior Drainage and Wind-Wave Runup. Discharge-frequency relationships are same as study #21.

Attachment BB – Hydraulic Design

The XRATE model developed in study #21 was used for this analysis. The existing conditions, the natural economic development alternative, and the locally preferred plan were modeled. “Northern Winters Flood Plain Routine – 100-YR FLD” is included, and includes Chickahominy Slough, Union School Slough, Winters Canal, Moody Slough and others.

23. Water Resources & Information Management Engineering, Inc. *Yolo County Integrated Groundwater and Surface Water Model, Model Development and Calibration.* May 2006.

The Yolo County Flood Control and Water Conservation District set out to develop an analytical tool to better understand the nature of groundwater flow in the County. The tool developed is documented in this report. The primary analytical tool selected was the Integrated Groundwater and Surface Water Model. The model was originally developed with emphasis on the Cache Creek vicinity but was later expanded to include refinements to the remaining portions of the model area. The model area is shown in Figure 16 below.

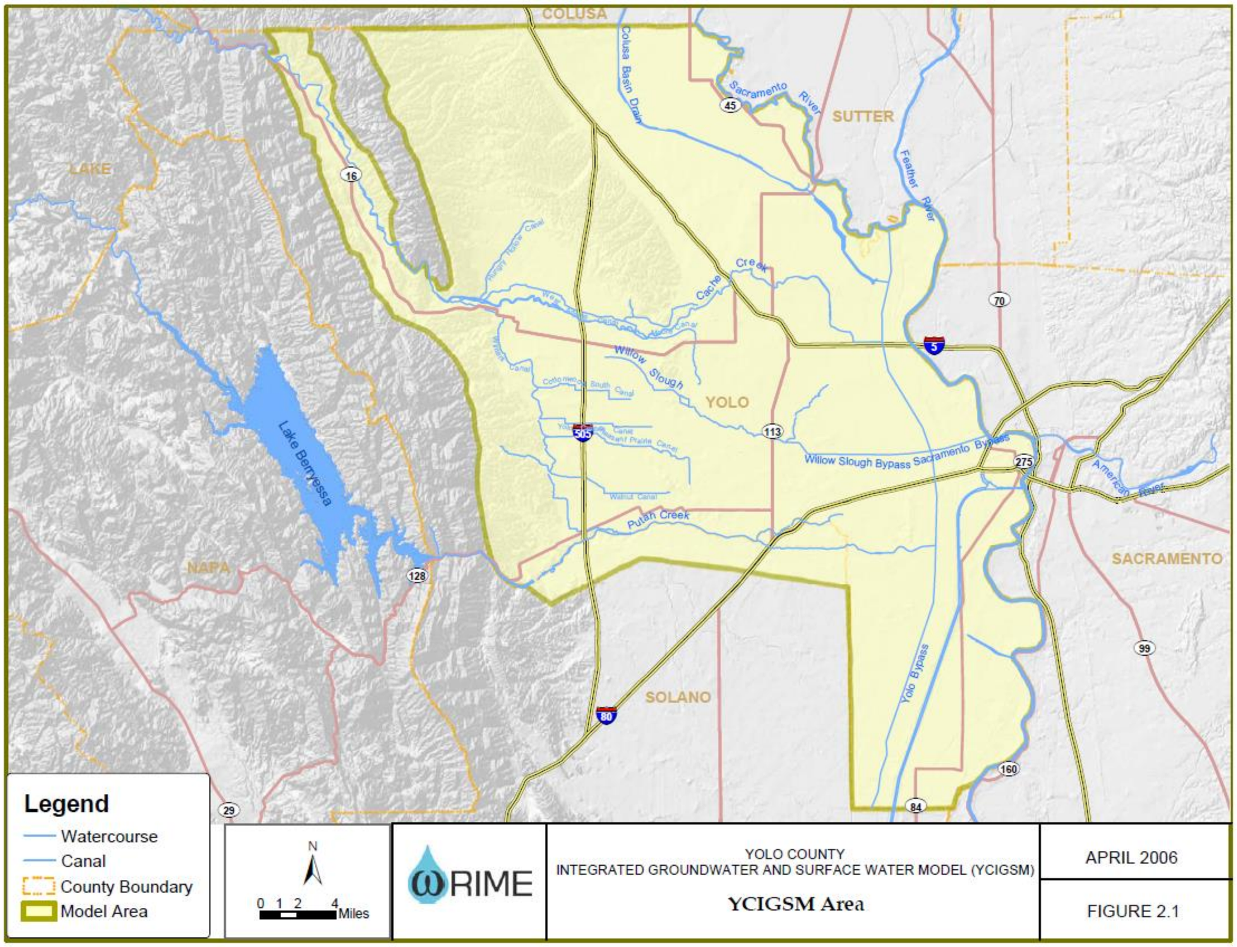

Figure 16: YCIGSM Model Area

Data collected for the study includes rainfall data at 22 rainfall gages throughout the project area. Streamflow data collected includes USGS, DWR and YCFCWCD gages (total of 25 gages) throughout the model area. There are also details of the hydrogeologic data of the model area contained in the report. Gages at the model boundaries were used for inflows into the model, while other gages were used during model calibration of stream flows. Calibration streamflow hydrographs are included in Appendix B.

The model was calibrated to the ensure calibration of water budgets, groundwater levels, and streamflows. A sensitivity analysis was also performed, and the models is considered stable. The Cache Creek Groundwater Recharge and Recovery Project alternative was evaluated and compared with baseline conditions.

The final model simulates groundwater and stream flow on a daily time step for a 30-year record from 1971-2000.

24. Quincy Engineering. *Bridge Design Hydraulic Study Report – Country Road 95 Bridge Replacement at Dry Slough.* August 2016

This report serves to analyze and document design flow characteristics, and calculated scour potential, associated with replacing an existing bridge on County Road 95 over Dry Slough with a new bridge. Peak design flows used for this study are derived from FEMA FIS report, which included a 100-year peak flow of 3,614 cfs. The 50-year peak flow was estimated by applying a 100-year to 50-year flow ratio from the USGS regional regression equations. Hydraulic analysis performed utilized HEC-RAS. Hydraulic analysis confirmed that the proposed bridge would be overtopped in both the 50-year and 100—year flows, however there would be minimal impacts to the WSE between the proposed and existing bridges.

The regression equations used to estimate peak flow are derived from the *Methods for Determining Magnitude and Frequency of Floods in California, Based on Data through Water Year 2006* (Gotvald et. Al. 2012) and are documented in the report. Calculated discharges at the project site were 7,000 cfs for the 100-year Recurrence Interval, and 5,910 cfs for the 50-year Recurrence Interval. Dry Slough 100-year peak discharge from the FIS report is 3,614 cfs approximately 2,500 ft upstream of County Road 95. The FIS report 100-year discharge was used for the hydraulic analysis, with a 50-year peak flow of 3,063 estimated using a ratio from the USGS regional regression equations.

Survey data from Quincy Engineering was incorporated into the HEC-RAS hydraulic model and included cross sections 4,500 ft downstream and 1,000 ft upstream of County Road 95 along Dry Slough, shown in Figure 17 below. Water Surface Elevations are documented for the existing and proposed bridges for the 100-year and 50-year flows.

Figure 17: HEC-RAS 1D Cross Sections

25. Quincy Engineering. *Floodplain Evaluation Report – Country Road 95 Bridge Replacement at Dry Slough.* August 2016

The purpose of this report is to analyze the existing floodplains withing the project area and document potential impacts or encroachments on the floodplain. The project site is located within FEMA special flood hazard area Zone AE. The designated 100-year water surface elevations is 94.5 feet NAVD 88. This water surface elevation is several feet below the calculated water surface elevations at the project site.

Modeling used for this project is documented and summarized in report #24.

The proposed bridge would increase the water surface elevation approximately 0.1 ft at the bridge during the 100-year event.

26. California Department of Water Resources. Central Valley Hydrology Study: Willow Slough watershed hydrologic analysis (DRAFT). March 2013.

The purpose of this report was to document California Department of Water Resources' (DWR) hydrologic analysis on the Willow Slough watershed. Th goal of this analysis was to develop flow-frequency curves at Central Valley Hydrology Study (CVHS) analysis points within the Willow Slough watershed using the *CVHS: Ungated watershed analysis procedures* (2011). The steps to complete this analysis included: delineating the watershed subbasins using the most recent digital elevation model, developing a HEC-HMS model using this updated watershed, selecting relevant modeling methods and parameters, obtaining precipitation-frequency estimates from *NOAA Atlas 14* (USDC-NOAA 2011), developing 10-day design storms based on the January 1995 event, and simulating 10 design storms in HEC-HMS model (two storm centerings and 5 exceedance probabilities). The exceedance probabilities evaluated were the 10%, 2%, 1%, 0.5% and 0.2% probabilities. A map of the watershed is included in Figure 18 below.

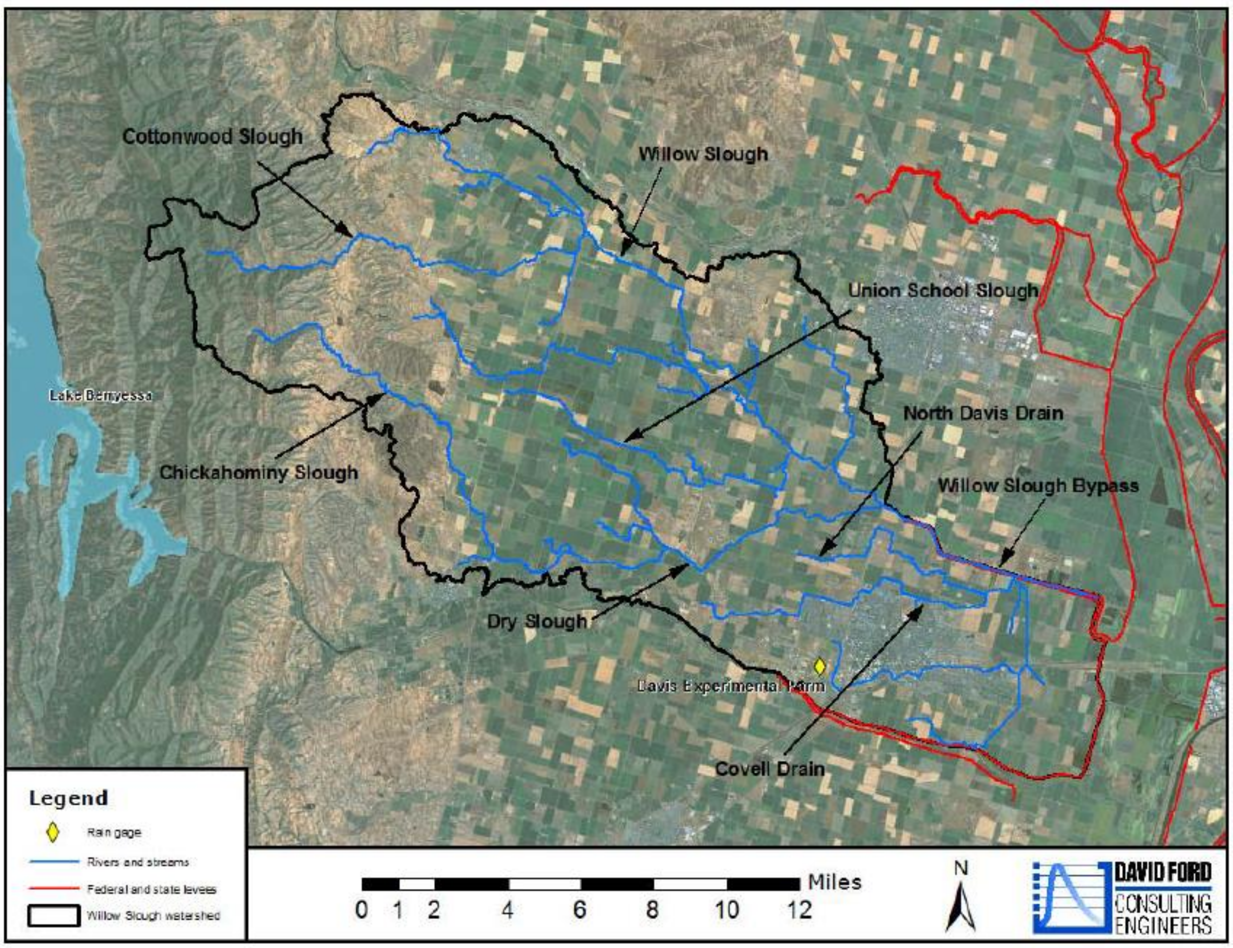

Figure 18: Willow Slough Watershed Boundaries

Table 1 of the report documents the peak flows for each annual exceedance probability at each of the CVHS analysis points (included in Figure 19 below). Figure 20 maps the location of the relevant CVHS analysis points.

Table 1. Analysis point descriptions and design storm runoff peaks[1] at each analysis point (flow, in cfs)

Stream (1)	Analysis point (2)	Location description (3)	Contributing area (mi^2) (4)	Annual exceedence probability				
				0.1 (5)	0.02 (6)	0.01 (7)	0.005 (8)	0.002 (9)
Willow Slough	WBY-11	Willow Slough at Union School Slough Junction	99.5	4,362	7,763	9,352	11,037	13,150
	WBY-7	Willow Slough at Willow Slough Bypass inlet	161.3	6,027	10,927	13,322	15,843	19,201
	WBY-6[2]	Willow Slough Bypass at Road 102	161.3	6,023	10,876	13,267	15,767	19,119
	WBY-2	Willow Slough Bypass at Yolo Bypass	196.6	6,705	11,999	14,640	17,540	21,347

1. The results do not reflect any cross-basin transfers, watershed transfers, or levee outflanking resulting from computed flows exceeding channel capacities. The impacts of these features on the peak flows will be evaluated in subsequent hydraulic studies being completed by DWR.
2. Flows decrease from those reported at WBY-7 as a result of hydrograph attenuation. No local flows are added to the system between these 2 analysis points.

Figure 19: Peak Flows at CVHS Analysis Locations

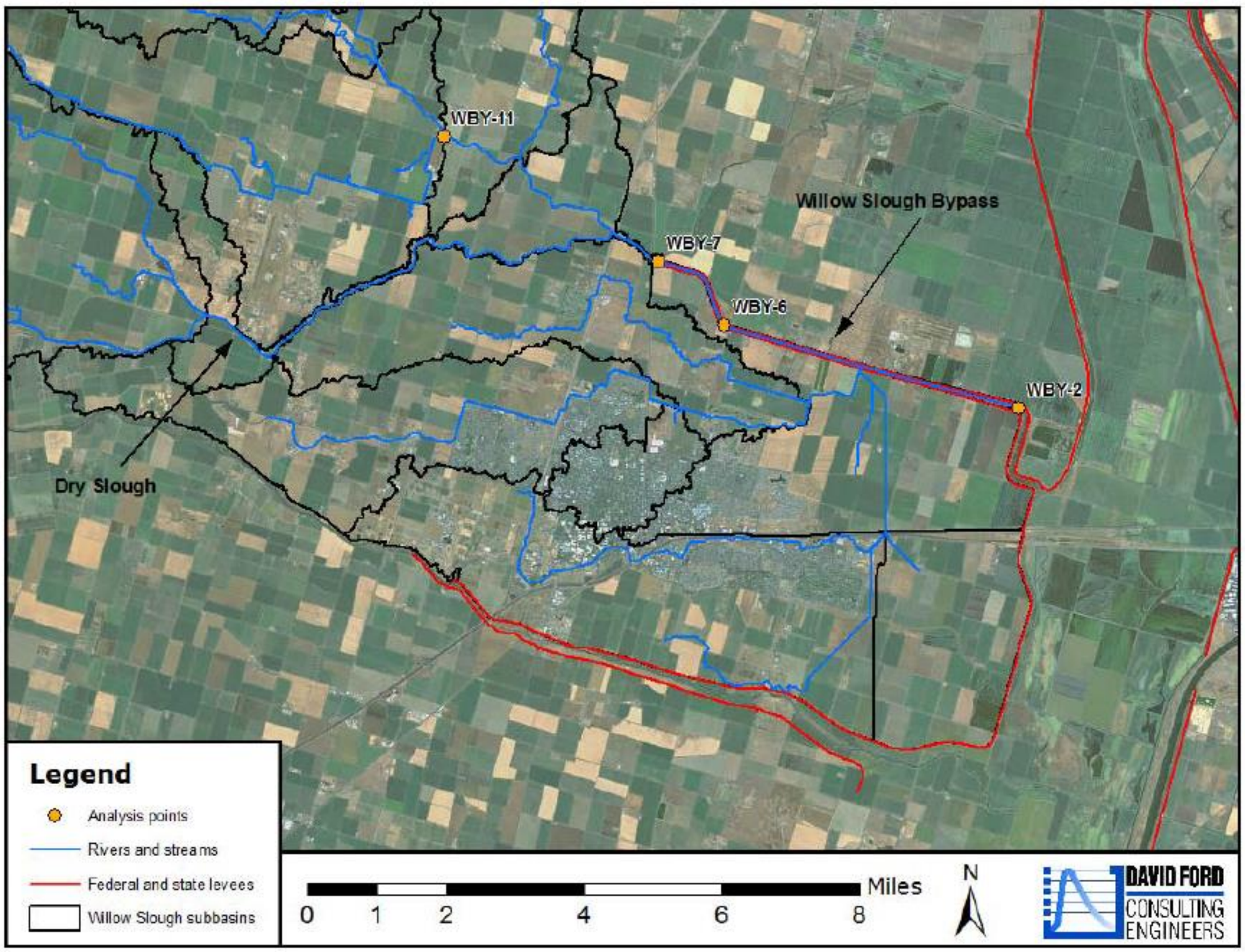

Figure 20: CVHS Analysis Points

The modeling complexities, and considerations, as well as the approaches taken to account for the complexities, are documented. The data sources for the HEC-HMS model and relevant details are listed in Table 5 of the report and include details on sources of topography, levee and stream alignments, streamgage locations, land cover, soil types, and watershed boundaries. HEC-HMS modeling details are also included and include methods for rainfall-runoff transform, lag time computation, runoff volume, baseflow, and routing. Details on the development of the design precipitation are also documented. The base hyetographs are included in Figures 4 and 5 of the report. Design storm hydrographs for each CVHS analysis point are plotted in Figures 6-9 of the report.

The result flow-frequency curves were compared to various previous studies. A comparison of results with the USGS regression equations concluded that the current study's peak flows are compare closely to the USGS estimate for the 1% exceedance probability event and are significantly less than the USGS estimate for the 10% exceedance probability event. A comparison of the current study's results with the USACE 1993 results showed significantly varied results, however since the USACE HEC-1 model is no longer available, a detailed comparison cannot be made. A comparison with the FEMA 2010 peak flows revealed that the current study's peak flows are typically significantly greater than the FEMA 2010 peak flows at the selected locations. This discrepancy is likely due to different precipitation-frequency estimates and modeled level of detail. In a comparison with other CVHS ungated watersheds, the current study peak flows appear consistent. Therefore, the flow-frequency curves from this study have been adopted and should be used as input into a detailed hydraulic model.

List of Selected Studies

Studies #2, 9 and 19 were unavailable and therefore omitted from the review.

1. Borcalli & Associates. *Covell Drainage System Comprehensive Drainage Plan.* WMP-93-01-3. September 1993.
2. Borcalli & Associates. *Covell Drain - Design Flow East of "F" Street and SP Railroad*. July 1990.
    - Report Unavailable
3. Borcalli & Associates. *A Report on Storm Drainage and Flooding in Yolo County.* February 1997.
4. City of Winters. *Moody Slough and Putah Creek/Dry Creek Subbasins Storm Drainage Report*. August 2005
5. Ensign & Buckley Consulting Engineers. *Evaluation of Flood Control Alternatives in Yolo County.* 2000.
6. Federal Emergency Management Agency. *Flood Insurance Study Yolo County, California and Incorporated Areas.* May 2012.
7. GEI Consultants. *Drainage Study for Sacred Oaks Healing Center.* December 2016
8. Kennedy/Jenks Consultants. *Storm Water Resource Plan for Yolo County*. May 2018.
9. Mansoubi, A., *Chickahominy-Moody Slough Watershed Flood Control Study Review for West Plainfield.* September 1999.
    - Report Unavailable.
10. Mackay & Somps. *Flood Control Master Plan for The Cannery Davis, California.* November 2012.
11. Mead & Hunt. *Yolo County Airport Drainage Plan Update.* September 2014.
12. Soil Conservation Service. *Flood Hazard Analyses City of Winters, Including Portions of Putah Creek, Dry Creek and Moody (Dry) Slough, Yolo County, California*. July 1976.

13. Soil Conservation Service. *Investigation of Flood Problems Chickahominy-Moody Slough Watershed, Yolo County, California.* January 1982.
14. US Army Corps of Engineers. *Reconnaissance Report: Westside Tributaries to Yolo Bypass California.* June 1994.
15. Water Resources Association of Yolo County. *Integrated Regional Water Management Plan.* April 2007.
16. Water Resources Association of Yolo County. *Integrated Regional Water Management Plan. Background Data and Information Appendix. Hydrology of Yolo County.* May 2005.
17. Wood Rodgers, Inc. *Two-Dimensional Overland Hydraulic Model Construction – Willow Slough Technical Memorandum.* 2013.
18. Western Yolo Regional Watershed Task Force. *Solicitation for Funds Proposal for Flood Control and Ecosystem Restoration*.
19. Yolo Engineers and Surveyors, Inc. *Drainage Report - Chickahominy-Dry Slough Drainage Complex.* March 1986.
    - Report Unavailable
20. Jones & Stokes Associates. *Willow Slough Watershed Integrated Resources Management Plan*. May 1996.
21. US Army Corps of Engineers*. Reconnaissance Report: Winters & Vicinity, California*. April 1995.
22. U.S. Army Corp of Engineers. *Winters and Vicinity, California, Final Feasibility Report and Environmental Assessment/Initial Study*. February 1997.
23. Water Resources & Information Management Engineering, Inc*. Yolo County Integrated Groundwater and Surface Water Model, Model Development and Calibration.* May 2006.
24. Quincy Engineering. *Bridge Design Hydraulic Study Report – Country Road 95 Bridge Replacement at Dry Slough.* August 2016
25. Quincy Engineering. *Floodplain Evaluation Report – Country Road 95 Bridge Replacement at Dry Slough.* August 2016
26. California Department of Water Resources. *Central Valley Hydrology Study: Willow Slough watershed hydrologic analysis (DRAFT).* March 2013.