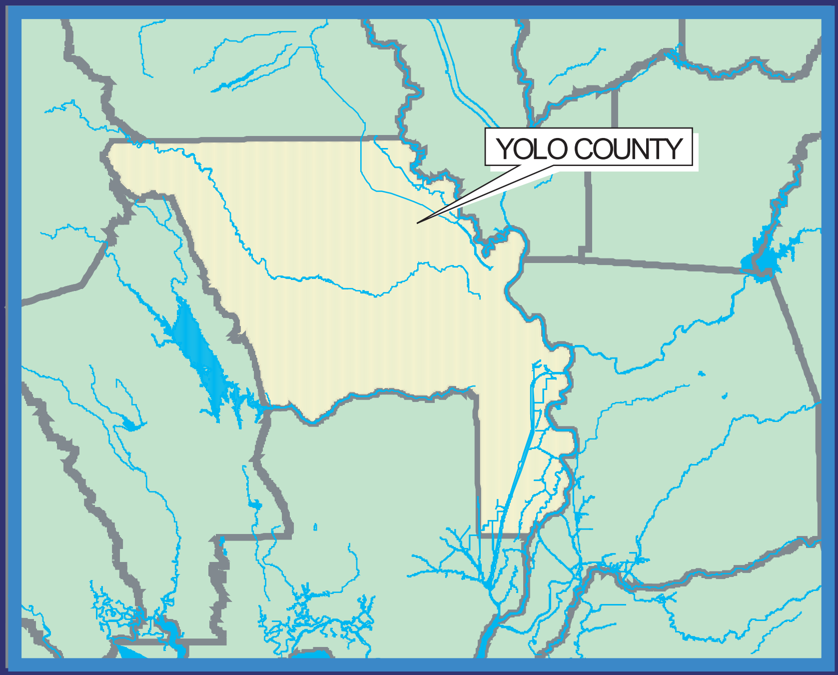
Hydrologic Modeling Goals and Objectives for

Yolo County



prepared for

Yolo County Water Resources Association

in coordination with

California Department of Water Resources
Division of Planning & Local Assistance
Conjunctive Water Management Branch

WRIME
Water Resources & Information Management Engineering, Inc.
May 2002

HYDROLOGIC MODELING GOALS AND OBJECTIVES FOR YOLO COUNTY

PROJECT PARTICIPANTS

WATER RESOURCES ASSOCIATION OF YOLO COUNTY
CALIFORNIA DEPARTMENT OF WATER RESOURCES

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SECTION 1 INTRODUCTION

The Water Resources Association of Yolo County (WRA) has entered into a Memorandum of Understanding (MOU) with the California Department of Water Resources (DWR) to cooperatively investigate conjunctive use opportunities in Yolo County. As part of the MOU, DWR is assisting the WRA to develop goals and objectives for a combined groundwater and surface water model of Yolo County, including a modeling strategy.

As DWR's contractor, WRIME, Inc., in collaboration with the DWR, WRA, and other consultants with modeling experience/knowledge about Yolo County, conducted the modeling assessment study. The study consists of four major tasks:

SCOPE OF WORK

TASK 1: MODELING GOALS AND OBJECTIVES – describe goals and objectives for a countywide model;

TASK 2: MODEL SELECTION – Evaluate potential tools, develop options, and recommend a model;

TASK 3: MODELING STRATEGY – Develop a data management plan and model development strategy;

TASK 4: MEETINGS AND COORDINATION – coordinate with DWR, WRA member agencies and their representatives.

The purpose of this report is to document the findings of the modeling assessment study and the modeling strategy for Yolo County.

This memorandum is organized into following sections:

1. Introduction;
2. Project Setting;
3. Previous Modeling Efforts and Data Status;
4. Modeling Needs and Goals;
5. Model Selection Criteria;
6. Comparison of Modeling Software;

7. Modeling Strategy;
8. Conclusions and Recommendations;
9. References.

As mentioned above, WRA and DWR signed a MOU to cooperatively investigate conjunctive use opportunities in Yolo County. The individual goals and the joint goals of WRA and DWR are described below.

WATER RESOURCES ASSOCIATION OF YOLO COUNTY

The WRA was formed in 1993 to coordinate the implementation of the 1992 Yolo County Water Plan Update, which was intended to be a planning instrument and educational tool for water resources management and protection; water use efficiency; consideration of and mitigation for environmental, economic, and social impacts; integration of water with other natural resources; and coordination with local governments and water users.

The WRA consists of representatives from the City Councils of Davis, West Sacramento, Winters, and Woodland; the County Board of Supervisors; the University of California at Davis; the Board of Directors of the Yolo County Flood Control and Water Conservation District; and the Board of Directors of the Dunnigan Water District. The WRA was organized in 1993 to coordinate the implementation of the 1992 Yolo County Water Plan Update.

Some of the continuing goals for the WRA and its members are to:

- Collaboratively assess the countywide water resources;
- Update the water resources water management plan;
- Identify and implement programs and projects to optimize water resources and increase the coordinated use of surface water and groundwater in Yolo County; and
- Serve as an open forum for cooperation, communication and collaboration on water management issues, which are, recognized prerequisites for implementing any preferred action or series of action.

CALIFORNIA DEPARTMENT OF WATER RESOURCES

For many years, the California Department of Water Resources has cooperated with local, State, and Federal agencies and other interested parties to manage and develop the water resources of California. One of the current efforts is the Surface and Ground Water Conjunctive Management Program (Conjunctive Management Program), major element of the CALFED Integrated Storage Investigation Program (ISI). Through the Conjunctive Management Program, DWR provides financial and technical assistance to local agencies to cooperatively identify conjunctive water management opportunities. Coordination between DWR and the local participants is developed through the signing of a Memorandum of Understanding.

MEMORANDUM OF UNDERSTANDING

The WRA and the DWR plan to work cooperatively to identify potentially feasible opportunities throughout Yolo County that will enable local authorities to:

- Enhance the water supply to reduce reliance on a particular water source;
- Improve reliability and quality of the water supply; and
- Utilize the water supply in a more efficient manner.

The specific tasks identified in the MOU include:

- Establish a County-wide Stakeholder Advisory Committee to provide technical expertise and recommendations to the WRA;
- Conduct Water Data Inventory and Future Water Needs Analysis;
- Establish Countywide Water Management and Basins Objectives;
- Identify potentially feasible future water management opportunities, initiatives, programs or projects for further review/ analysis/implementation.

The goal of the modeling assessment task described in this report is aligned with the overall program goals discussed above. The current effort is focused on identifying modeling goals and objectives and developing a modeling strategy for Yolo County to support the program goals. There are other projects and studies being conducted to also support the above-mentioned program goals, such as the Yolo County Integrated Water Management Plan.

YOLO COUNTY INTEGRATED WATER MANAGEMENT PLAN (IWMP)

In addition to the developing the Hydrologic Modeling Goals and Objectives for Yolo County, the ISI is participating in the Yolo County Integrated Water Management Plan (IWMP). Some of the goals of the IWMP include:

- Identify integrated water management goals and objectives for Yolo County
- Collect/Document/ Review Baseline Data
- Develop and adopt a County-wide Integrated Water Management Plan

The draft IWMP is scheduled for completion in April 2002. The draft report will include detailed information on the soils and land use; surface water conditions; groundwater conditions; water demands and supplies; legal and institutional issues, including data availability and data gaps.

The study area of this project is Yolo County. Yolo County is bounded by Lake County and Colusa County on the north, Sutter County and Sacramento County to the east, Solano County to the south, and Napa County to the west as shown on Figure 2-1. For the purpose of developing hydrologic models inclusive of the Yolo County, the project study area may include areas beyond the political boundaries of Yolo County but within the groundwater basins, which extend beyond Yolo County.

The WRA represents the water resources interests in Yolo County. The water resources management agencies located within Yolo County are shown in Figure 2-2. While not all the agencies shown on Figure 2-2 are members of WRA, they all have a stake in the water resources management of Yolo County.

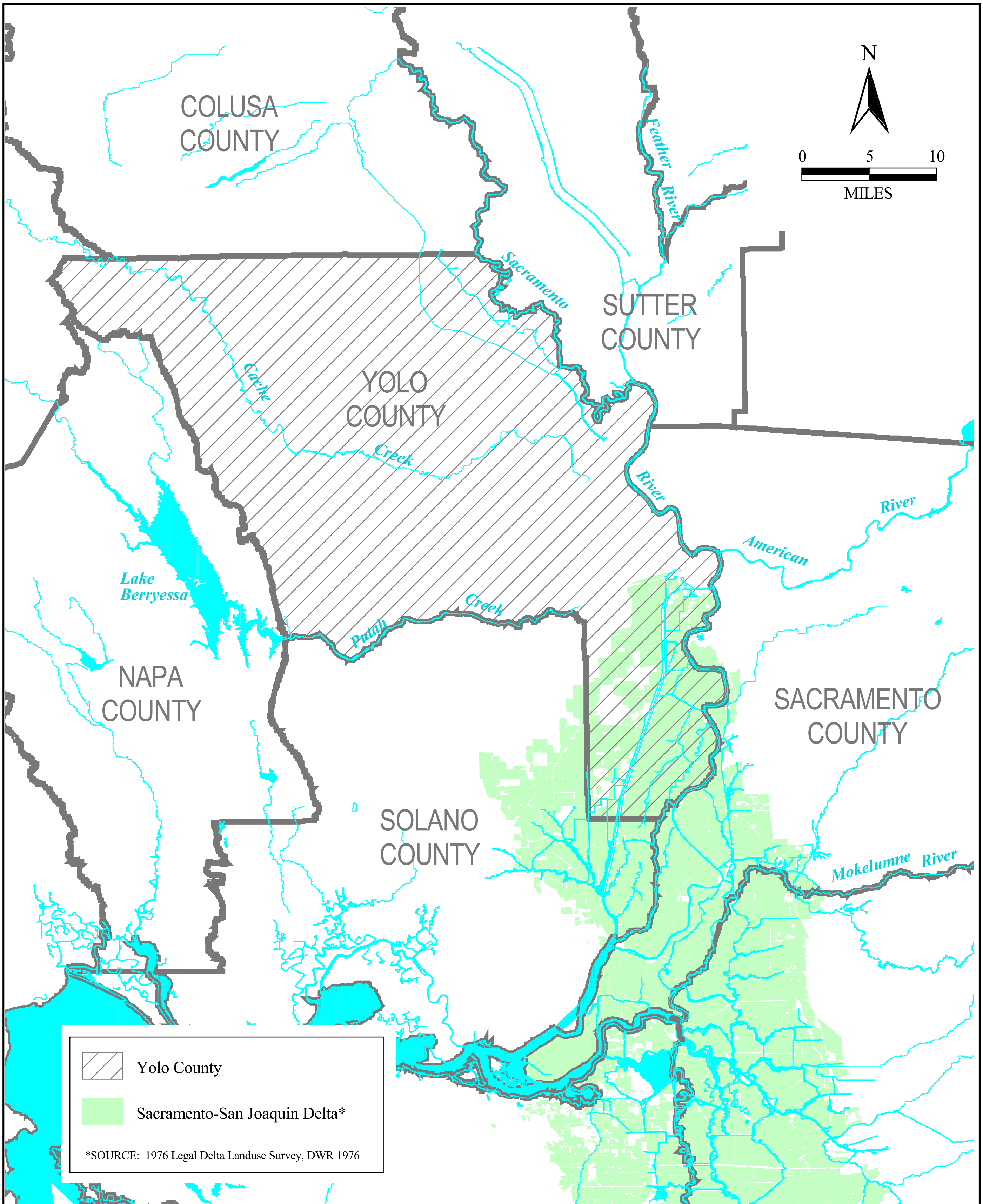
The water resources setting of Yolo County is being developed through the data collection and documentation included in the IWMP. A brief description of the physical features, surface water features and groundwater basins within Yolo County is provided here for reference purposes.

PHYSICAL FEATURES

Yolo County is located in the southwestern part of the Sacramento Valley, just north of the Sacramento-San Joaquin Delta. The ground surface ranges from near sea level in the southeast part of the County near the Delta to over 900 feet in the northwest corner of the County in the Blue Ridge Mountains of the Coast Range.

SURFACE WATER FEATURES

The two primary surface water rivers within Yolo County are Cache Creek and Putah Creek, which drain the eastern Coast Range. Cache Creek enters Yolo County above the Capay Valley and flows south through the valley before turning east and flowing onto the Putah Plain portion of the Sacramento Valley floor. It flows eastward past the City of Woodland, and then becomes channelized before it flows into the Yolo Bypass, which drains into the Sacramento-San Joaquin Delta.



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YOLO COUNTY HYDROLOGIC MODELING GOALS AND OBJECTIVES

Project Location

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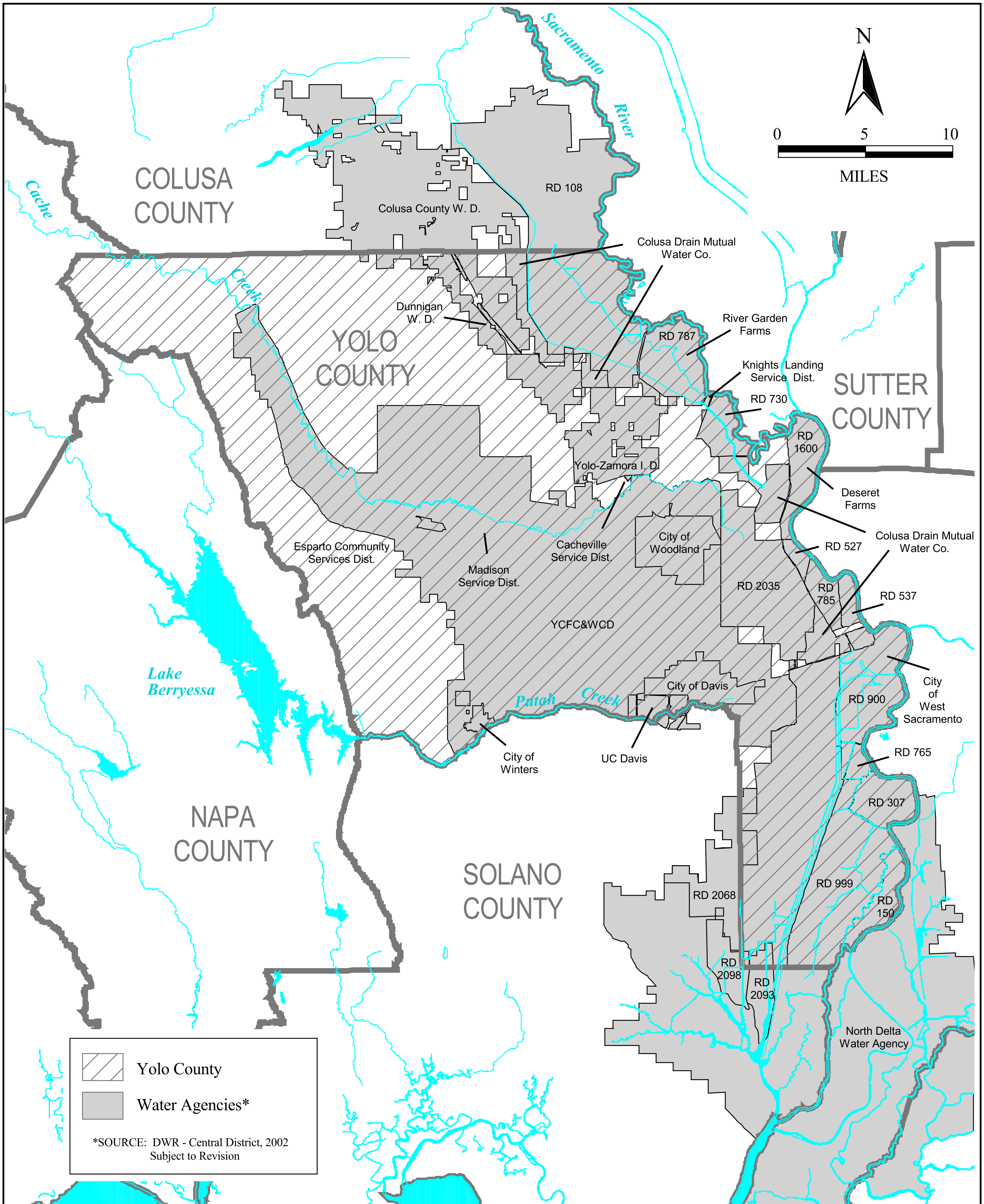
FIGURE 2-1



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YOLO COUNTY HYDROLOGIC MODELING GOALS AND OBJECTIVES

Water Agencies of Yolo County

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FIGURE 2-2

The headwaters of Putah Creek are located in Lake and Napa Counties. Monticello Dam impounds Lake Berryessa in Napa County just east of Yolo County. In Yolo County, Putah Creek flows east across the Putah Plain past the town of Winters and the City of Davis where it enters the Putah Creek Sinks in the Yolo Bypass.

The eastern boundary of Yolo County is defined by the Sacramento River, which drains much of the Sacramento Valley and flows into Sacramento-San Joaquin Delta near the southeast corner of Yolo County. Most of the surface water used in Yolo County originates from the Sacramento River, Cache Creek or Putah Creek.

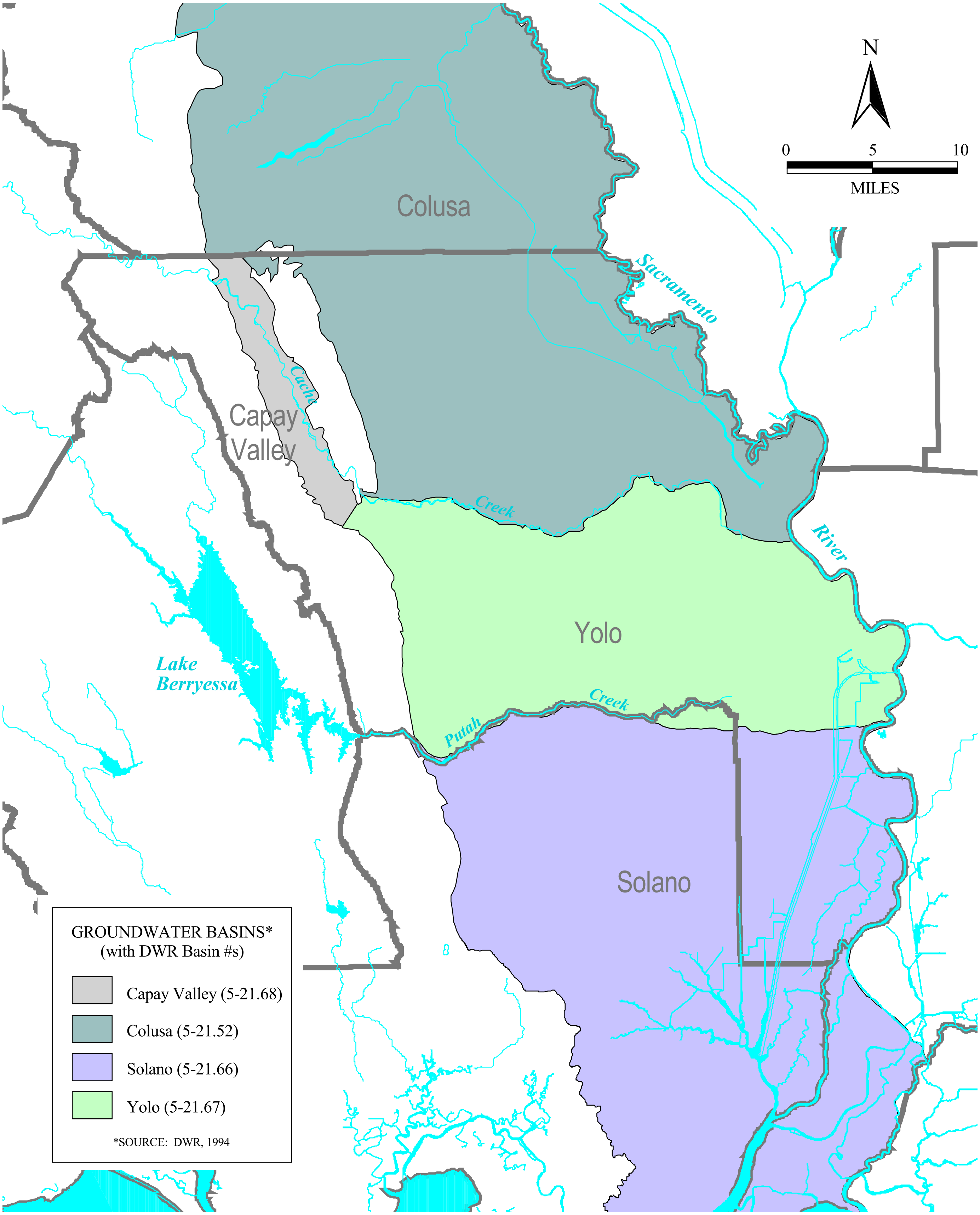
It should be noted that the boundaries of the watersheds in the Central Valley floor are currently being refined as part of the IWMP.

GROUNDWATER BASINS

The California Department of Water Resources Bulletin 118-80 identifies four separate groundwater basins within Yolo County, as shown in Figure 2-3. The Capay groundwater basin (DWR basin number 5-21.68) is located in the Capay Valley and is separated from the Central Valley by the Capay Hills. The Yolo groundwater basin (DWR basin number 5-21.67) is located almost entirely within the Yolo County portion of the Central Valley groundwater basin. The Colusa groundwater basin (DWR basin number 5-21.52) extends from Yolo County north into Colusa County. The Solano groundwater basin (DWR basin number 5-21.66) includes the southern panhandle portion of Yolo County and portions of Solano County. The primary water-bearing units within the Central Valley groundwater basins are the alluvium, Red Bluff Formation and the Tehama Formation.

These groundwater basin definitions are currently being refined as part of the IWMP.

An investigative study of the Yolo County groundwater resources (Clendenen and Associates, 1976) concluded that the groundwater basin can be subdivided into several smaller sub-basins as depicted in Figure 2-4.



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Groundwater Basins

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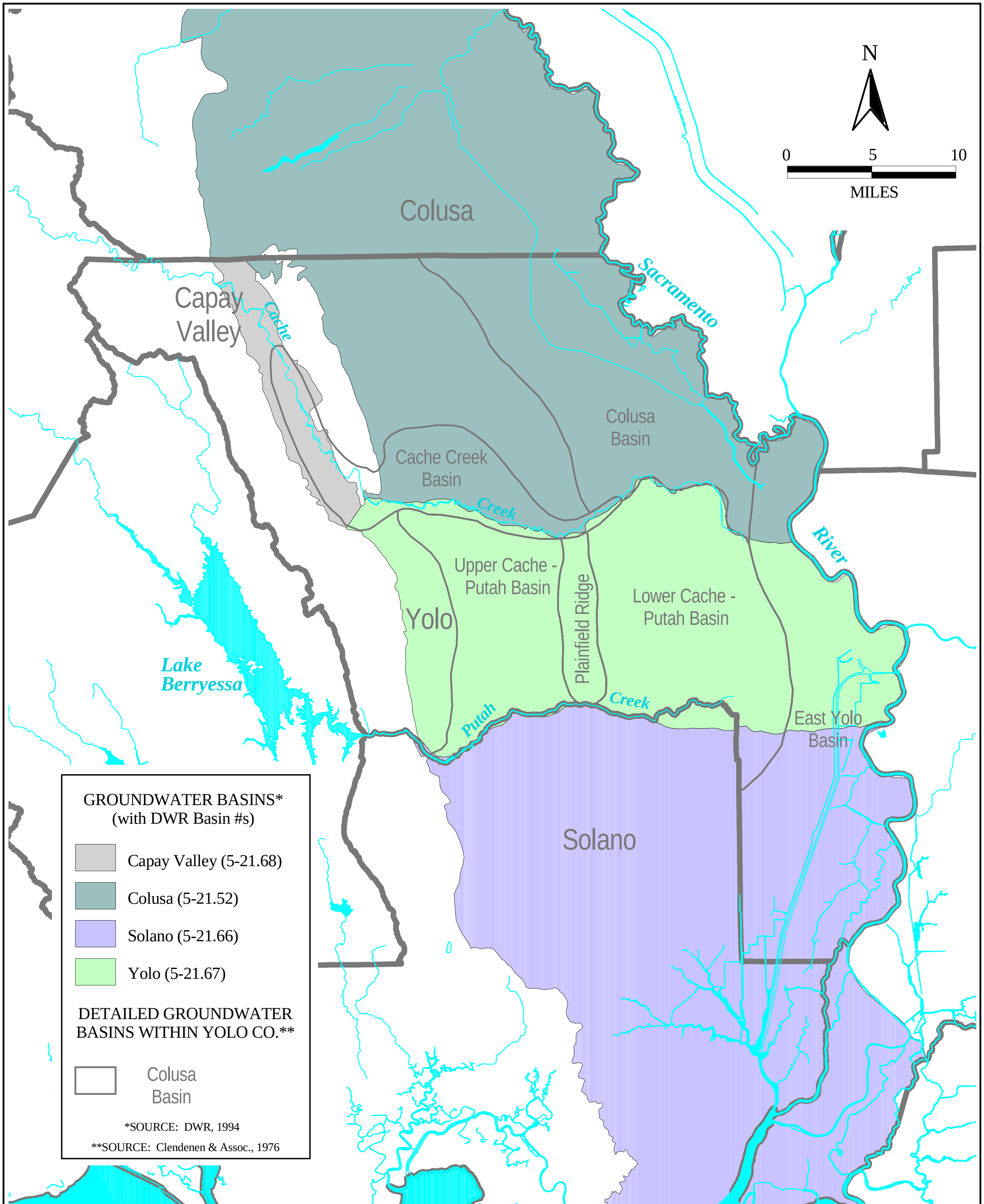
FIGURE 2-3



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YOLO COUNTY HYDROLOGIC MODELING GOALS AND OBJECTIVES

Detailed Groundwater Basins

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FIGURE 2-4

SECTION 3 PREVIOUS MODELING EFFORTS AND DATA STATUS

As mentioned above, the purpose of the current effort is to develop modeling goals and objectives for the Yolo County-wide hydrologic model development. In order to develop a strategy to meet future modeling needs in Yolo County, it is essential to evaluate previous modeling efforts applied to water resources issues in and near Yolo County. Additionally, an evaluation of the previous efforts:

- Provide insight regarding assumptions, algorithms, and software programs that have been successful in the past,
- Provide certain types of already compiled and reviewed data for modeling purposes, thereby saving time for future modeling efforts,
- Provide an indication of agency satisfaction with selected modeling tools and studies, and
- Reveal which parts of the hydrologic system have not yet been modeled.

INVENTORY OF WATER RESOURCES MODELS

Previous models related to the water resources of Yolo County were inventoried as part of this study. This inventory was based on literature review, discussions with DWR, WRA, and member agencies of WRA, Gus Yates, Fran Borcalli, and other consultants with modeling experience/knowledge about Yolo County. The WRA Technical Committee reviewed the model inventory and identified additional models to be included. The code and input data were not obtained for each of the models inventoried, but it is assumed that they would be available from the agency that sponsored the original modeling work. The available models in Yolo County are categorized into four groups and presented in Tables 3-1, 3-2, 3-3, and 3-4, as listed below:

- Table 3-1 Flood Hydraulic and Storm Drain Models
- Table 3-2 Operations and Distribution Models
- Table 3-3 Groundwater and Hydrologic Models
- Table 3-4 Water Quality, Economic, and Other Models

Table 3-1: Inventory of Flood Hydraulic and Storm Drain Models near Yolo County

Model Name	Year Developed	Study Area	Study Period	Responsible Agency	Model Purpose	Geographic Scale	Time Scale	Model Applicability to Hydrologic Model
UNET	1995	Sacramento River System		USCOE		River system		
HEC-2		Putah Creek	N/A	USCOE	Flood impacts of habitat restoration at City of Davis proposed Putah Creek South Fork Preserve	Diversion Dam to Bypass	Steady-state	Evaluate opportunities/constraints for diverting floodwaters to Putah Creek and for riparian habitat restoration.
HEC-2	1995/2001	Cache Creek	N/A	USCOE	100-year flood water surface profile and floodplain.	Capay to settling basin	Steady-state	Evaluate opportunities/constraints for diverting floodwaters to Cache Creek and for riparian habitat restoration.
HEC-2		Putah Creek	N/A	USFWS	Simulate water surface profiles for 100-year floods and low flows for alternative vegetation	Diversion Dam to Bypass	Steady-state	Evaluate opportunities/constraints for diverting floodwaters to Putah Creek and for riparian habitat restoration.
XRATE		Winters area	N/A	USCOE	10- to 500-year flood water surface elevations and floodplain	Moody and Chickahominy Sloughs	Hourly	Evaluate effects of land use changes on flooding near Winters
HEC-1 and HEC-2	1992	Willow Slough, Dry Slough, Covell Drain	N/A	YCFCWCD	2- to 100-year peak flood flows, elevations, and floodplains	Foothills to Yolo Bypass	HEC-2: steady-state	Simulate effects of land use changes or channel modifications on local flooding.
UNET	1995	Southport/West Sacramento	NA	West Sacramento	Storm Drainage Master Plan	Southport	Unsteady State	Simulate impact of changed land use on drainage and flooding
SWMM	1996	City of Woodland	NA	City of Woodland	Storm Drainage Master Plan	City of Woodland	Unsteady State	Simulate impact of changed land use on drainage and flooding

Table 3-2: Inventory of Operations and Distribution Models near Yolo County

Model Name	Year Developed	Study Area	Study Period	Responsible Agency	Model Purpose	Geographic Scale	Time Scale	Model Applicability to Hydrologic Model
Surface Water Operational Models								
PROSIM		CVP/SWP system	1922 to 1993	USBR	Simulate surface water supply availability on monthly time-step based on various operational scenarios.	State-wide	monthly	Provide estimated monthly flow data along simulated rivers (Sacramento River) for alternatives analysis.
DWRSIM		CVP/SWP system	1922 to 1993	DWR	Simulate surface water supply availability on monthly time-step based on various operational scenarios.	State-wide	monthly	Provide estimated monthly flow data along simulated rivers (Sacramento River) for alternatives analysis.
CALSIM		CVP/SWP system	1922 to 1993	USBR/DWR	Simulate surface water supply availability on monthly time-step based on various operational scenarios.	State-wide	monthly	Provide estimated monthly flow data along simulated rivers (Sacramento River) for alternatives analysis.
Clear Lake/Indian Valley/Cache Creek System Operation Model	1975	Cache Creek Watershed above Capay	1928 to 1976	YCFCWCD	Simulations for dispute resolution in Clear Lake.		monthly	May provide simulated flow data for Cache Creek.
Water Supply Distribution Models								
City of Davis H20Net		City of Davis water supply distribution system.	N/A	City of Davis		City-wide		May provide estimates of local groundwater extraction and system losses.
City of Woodland H20Net		City of Woodland water supply distribution system	N/A	City of Woodland	Simulates pipe netowrk response to hourly fire flow and customer water demand.	City-wide	hourly	May provide estimates of local groundwater extraction and system losses.

Table 3-3: Inventory of Groundwater Models and Hydrologic Models for Yolo County Conjunctive Use Study

Model Name	Year Developed	Study Area	Study Period	Responsible Agency	Model Purpose	Geographic Scale	Time Scale	Model Applicability to Hydrologic Model
Groundwater Models								
CCRR MODFLOW	1995	Portions of the groundwater basin related to the Cache Creek Recharge and Recovery Project (CCRR).	1961 to 1977	Yolo County Flood Control and Water Conservation District	Evaluate the feasibility of the CCRR Project and is impact on the groundwater resources of the area.	Yolo County	monthly	Data sets may be utilized in an expanded hydrologic model.
Yolo County MODFLOW		900 square mile area including portions of Yolo, Solano, Sutter, and Sacramento Counties.		DWR	Explore regional conjunctive use possibilities in Yolo County.	Yolo County		
Yolo County Finite Element Model		Yolo County between Putak Creek and Cache Creek			Part of a Masters Project as UCDavis. Limited information is available at this time.	Yolo County		
Hydrologic Models								
Central Valley Groundwater Surface Water Model (CVGSM)	1991/1995	Central Valley	1922 to 1993	DWR/USBR	Analyze impacts of surface water supply scenarios on groundwater conditions in basin	Central Valley	monthly	Provide regional geologic/hydrogeologic data
Sacramento County Integrated Groundwater and Surface Water Model (IGSM)	1993	Sacramento County	1922 to 1995	Sacramento County	Analyze impacts of surface water supply scenarios on groundwater conditions in basin	Sacramento County	monthly	Integrate hydrogeology near Sacramento River and define boundary conditions along river.
South Sutter and Western Placer County IGSM	1994	South Sutter County and Western Placer County	1922 to 1995	DWR		Sutter and Placer County	monthly	Integrate hydrogeology near Sacramento River and define boundary conditions along river.
Lower Colusa Basin IGSM	1999	Lower Colusa Basin area		DWR	Evaluate conjunctive use opportunities in the Lower Colusa Basin.		monthly	Depending on Yolo County model area, may be able to provide hydrogeologic continuity, and boundary conditions.

Table 3-4: Inventory of Water Quality, Economic, and Other Models near Yolo County

Model Name	Year Developed	Study Area	Study Period	Responsible Agency	Model Purpose	Geographic Scale	Time Scale	Model Applicability to Hydrologic Model
Water Quality Models								
Spreadsheet stream temperature model	1994	Lower Putah Creek	1993-1994	UCD	Simulates stream temperature by applying mass and energy balance equations to 25 reaches. Similar to SNTEMP and QUAL2E	Putah Diversion Dam to Yolo Bypass	Hourly	Simulates temperature effects of changes in vegetation or flow regime
Crop Rotation Economic & Environmental Impact Decision Aid (CREEDA) and Soil & Water Assessment Tool (SWAT)		Union School Slough Watershed, Yolo County	2001-2004	Yolo Co. RCD & USDA ARS	Estimation of farm run-off water quality improvement associated with farm practices and conservation techniques	<30 sq mi		potentially useful in assessing impacts on surface and groundwater quality
Economic Models								
Central Valley Production Model (CVPM)		Central Valley		DWR	Evaluate economic impacts related to different water supply scenarios.			May be needed to assess impacts to agricultural industry.
		City of Woodland			Evaluate benefit/cost ratios of surface water systems.			
Other Models								
Sediment transport model		Cache Creek	N/A	Yolo Co.	Calculate sediment transport rates and aggradation/degradation by reach	Capay to Yolo	N/A	Simulate changes in gravel mining activity or sediment input to Cache Creek
Sediment transport model		Cache Creek	N/A	USACE	Calculate sediment transport rates and aggradation/degradation by reach	Rumsey to Madison	N/A	Simulate changes in gravel mining activity or sediment input to Cache Creek
Sediment transport model		Cache Creek	N/A	Yolo Co.	Calculate sediment transport rates and aggradation/degradation by reach	Capay to Yolo	N/A	Simulate changes in gravel mining activity or sediment input to Cache Creek

PREVIOUS GROUNDWATER/HYDROLOGIC MODELS

Groundwater and surface water flow and related aspects of land use and water use are central aspects of any water planning effort for Yolo County. Some models simulate more of these parts of the hydrologic system than others, and any comparison of modeling options must consider these differences. Accordingly, a distinction is made in this analysis between groundwater models and hydrologic models that simulate more than just groundwater. These terms are defined below and are followed by in-depth descriptions of some of the models listed in Table 3-3.

GROUNDWATER MODELS

Groundwater models are those models that simulate the movement of groundwater only, with limited representation of surface water processes (generally only seepage to and from channels). Typically, however, groundwater models do not simulate many important aspects of surface hydrology, including land and water use, stream diversions, rainfall runoff, recharge from rainfall and applied water, and evapotranspiration. Many of these processes affect input to a groundwater model, and groundwater modelers usually evaluate them using one or more third party and custom-made programs, spreadsheets, or Geographic Information Systems.

HYDROLOGIC MODELS

Hydrologic models are those models that -- in addition to groundwater flow -- simulate most or all of the hydrologic processes that are closely connected to the land and water use conditions in the basin. These additional processes and variables might include land and water use, rainfall-runoff; recharge calculation from rainfall and applied water, soil moisture accounting, stream-aquifer interactions, and subsurface flow in the unsaturated zone. Many of these processes are interdependent. For example, the changes in surface water supply from a river may affect groundwater-pumping requirements to meet the agricultural and/or urban water needs. At the same time, changes in the groundwater pumping may affect the groundwater levels, which in turn, may affect seepage losses from the river, and ultimately, the surface water available for diversion. The advantage of a hydrologic model is that it is capable of simulating these dynamic interactions among variables and processes.

PREVIOUS GROUNDWATER MODELS IN YOLO COUNTY

Cache Creek Recharge and Recovery (CCRR) MODFLOW Model

This MODFLOW application was developed for YCFCWCD and covers most of the county. In some areas, the boundaries extend beyond Yolo County as shown on Figure 3-1.

The purpose of this model is to evaluate the feasibility of the Cache Creek Recharge and Recovery Project and its impact on the groundwater resources of the area. The simulation period for this model is from 1961 to 1977. This model has a monthly stress period. The model data is generally based on the Central Valley wide CVAP model. The geologic units and hydrologic data are interpolated from the regional model. As such, the database is not refined based on the local geologic and hydrologic data available. In 1996, the City of Woodland refined the pumping data in the City area, and used the model for evaluation of several conjunctive use projects.

DWR Yolo County MODFLOW Model

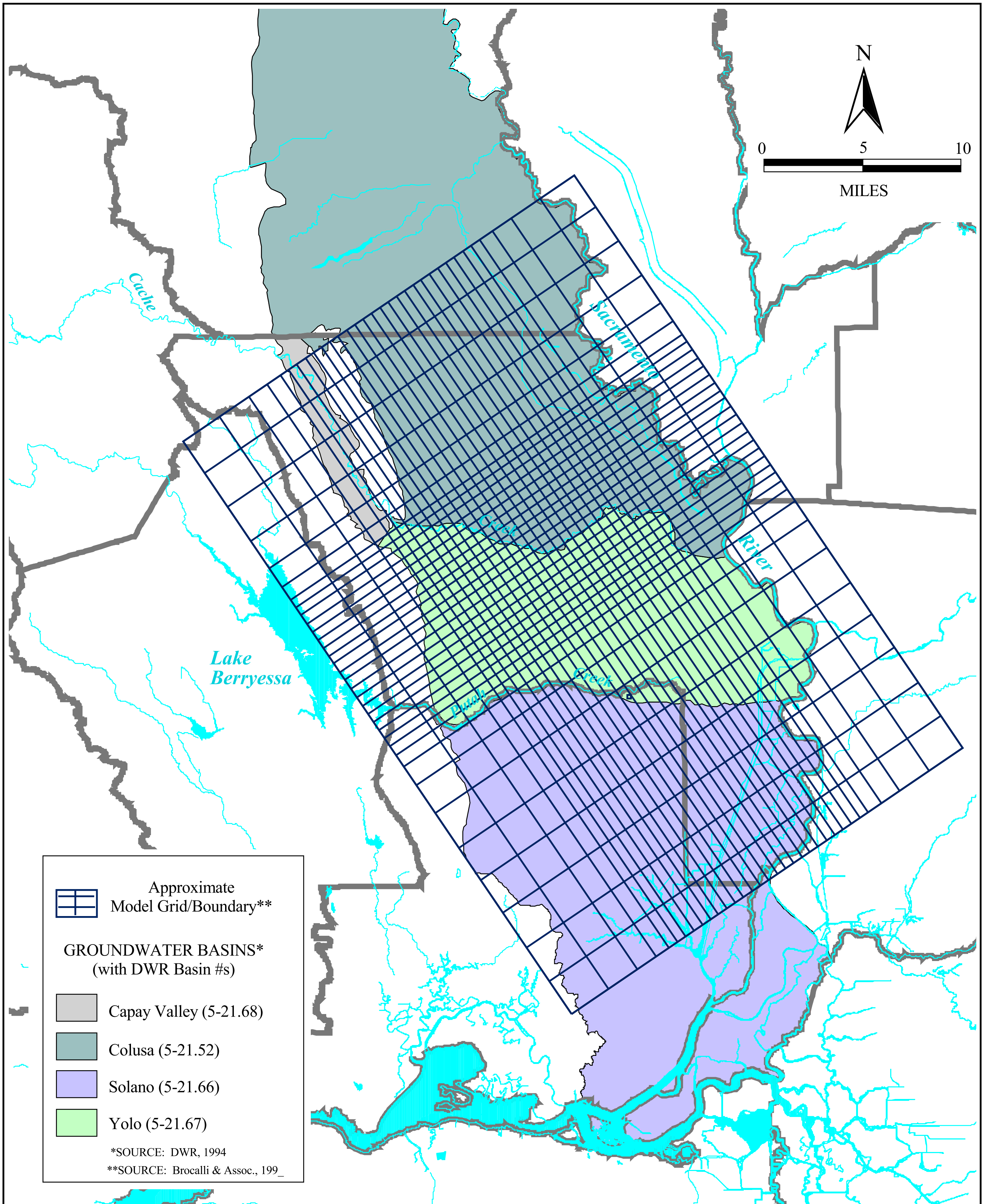
This is a MODFLOW application in the Yolo County, covering about 900 square miles. The boundaries of this model are shown on Figure 3-2.

This model includes portions of Yolo, Solano, Sutter and Sacramento counties. The purpose of this model is to explore and evaluate regional conjunctive use possibilities in Yolo County. It is four-layer model of the aquifer system. It is calibrated to approximate the groundwater contours shown on the 1912 groundwater level map published in Bulletin 118-6.

UCD YOLO COUNTY FINITE ELEMENT MODEL

This is a finite element transient groundwater flow model developed as part of a Master's thesis at the University of California at Davis. The boundary of this model is Putah Creek on the south, the Sacramento River on the east, the Mountain Front in the west and Cache Creek on the north as shown in Figure 3-3. The model area is about 236,000 acres, about half the total aquifer area in Yolo County.

The purpose of this model is to identify some of the sources and magnitudes of recharge that contribute to, and that might explain, the apparent rapid recovery of groundwater levels in



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YOLO COUNTY HYDROLOGIC MODELING GOALS AND OBJECTIVES

CCRR MODFLOW Model Network

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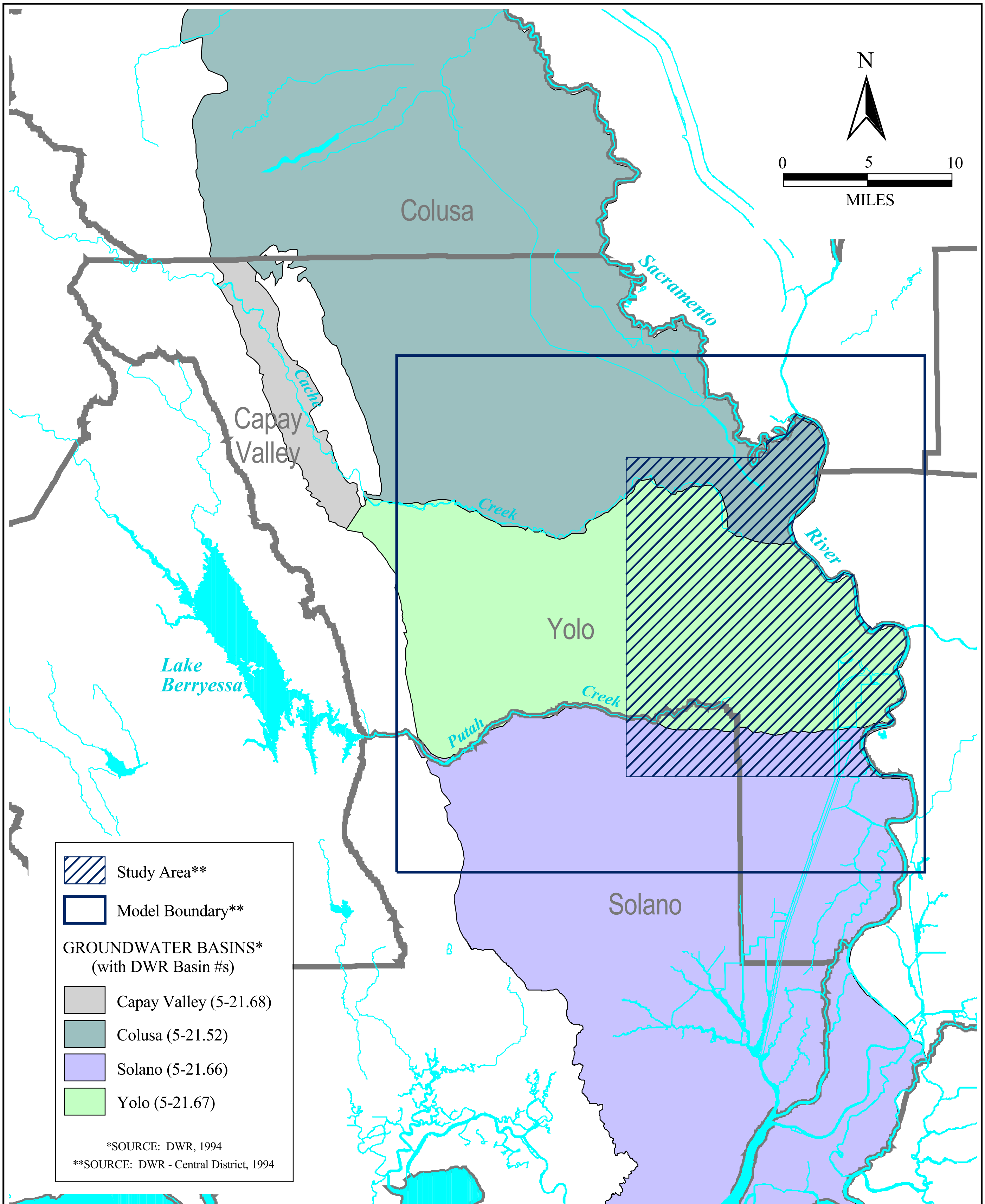
FIGURE 3-1



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YOLO COUNTY HYDROLOGIC MODELING GOALS AND OBJECTIVES

Yolo County Groundwater Model within Yolo County

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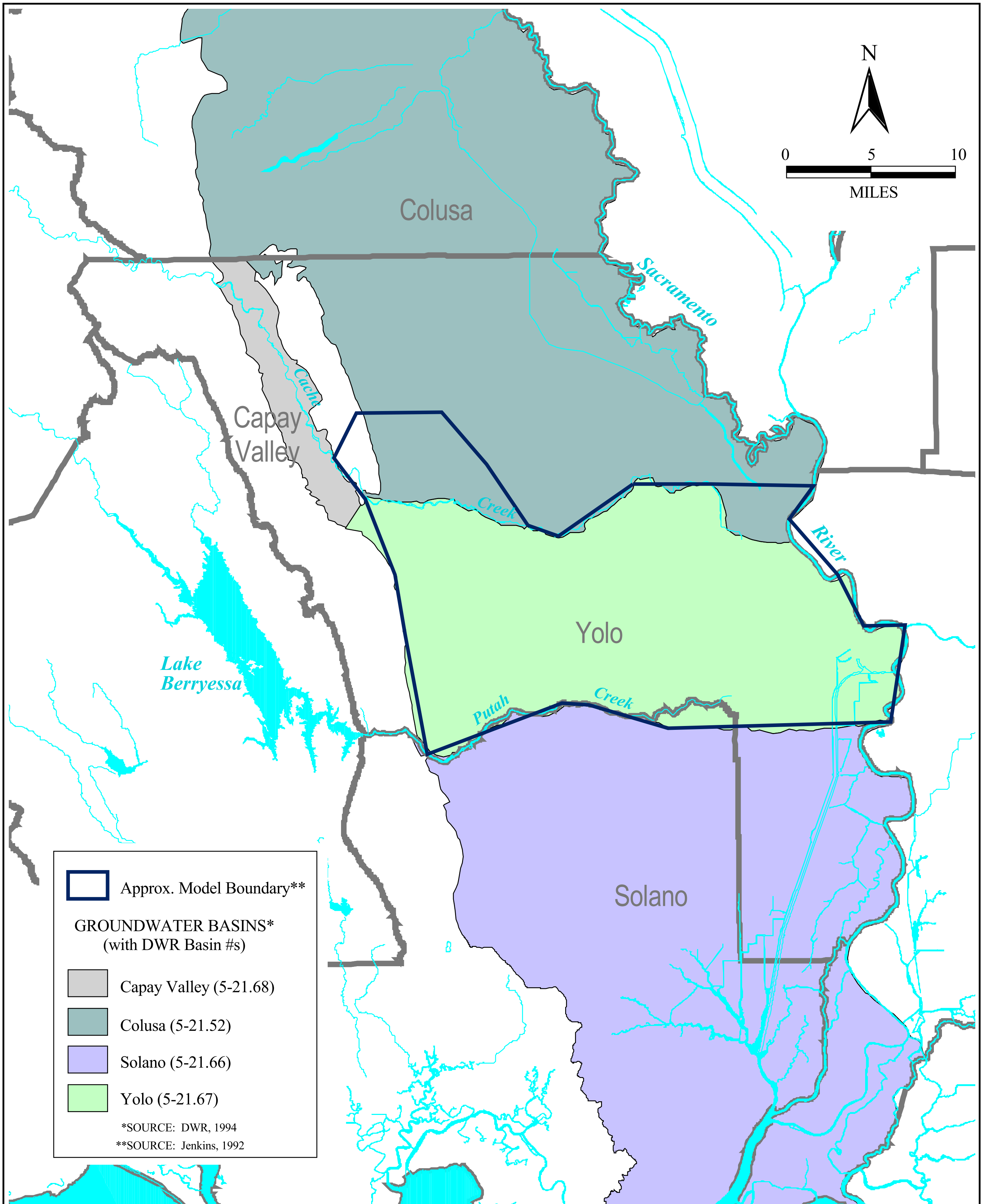
FIGURE 3-2



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YOLO COUNTY HYDROLOGIC MODELING GOALS AND OBJECTIVES

Jenkins' Finite Element Model for Yolo County

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FIGURE 3-3

Yolo County after a prolonged period of drought. The aquifer is treated as a horizontal two-dimensional confined aquifer. The model assumed that the surface sources and sinks, such as rain and pumping, are directly connected to this confined aquifer layer and are evenly distributed over the full grid area. Three possible recharge mechanisms are considered in this investigation:

1. Fluxes into the aquifer from stream flows in Cache Creek;
2. Fluxes along the western mountain front of the basin;
3. Fluxes entering the aquifer from stream flow in the Sacramento River.

The flow model grid is based on triangular two-dimensional elements.

USGS Regional Aquifer-System Analysis Central Valley Model

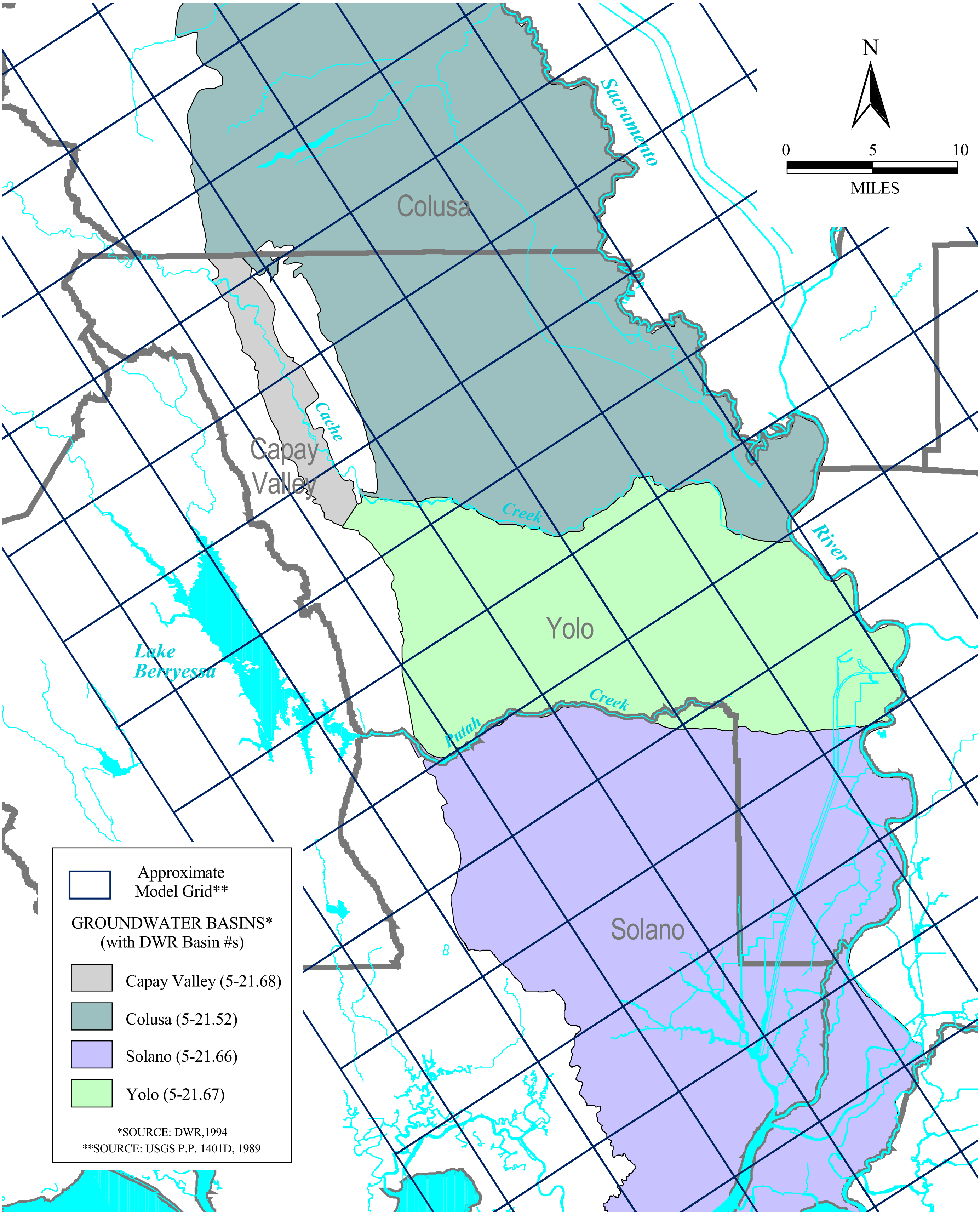
This is a finite-difference groundwater flow model of the entire Central Valley, covering about 20,000 square miles. The boundaries of this model as related to the Yolo County groundwater basin are shown on Figure 3-4. This model simulates the groundwater flow in the Central Valley groundwater basin within a four-layer aquifer system. The study period and calibration period for the model is the 1961 to 1977 period. Although, the model was developed for analysis of regional groundwater impacts, it was used for limited applications and alternatives evaluations.

HYDROLOGIC MODELS IN AND NEAR YOLO COUNTY

Four hydrologic models have been developed that cover all or part of Yolo County. All of them use the Integrated Groundwater and Surface Water Model (IGSM) code.

Central Valley Ground and Surface water Model

This application of the IGSM covers the entire Central Valley of California from Redding to Bakersfield, an area of about 20,000 square miles. The model was developed under the sponsorship of the U.S. Bureau of Reclamation, Department of Water Resources, State Water Resources Control Board and Contra Costa Water District. The model was originally developed and calibrated for the 1922-1980 period. USBR later extended the simulation



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YOLO COUNTY HYDROLOGIC MODELING GOALS AND OBJECTIVES

USGS RASA Model Network near Yolo Co.

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FIGURE 3-4

period through 1993. This is a comprehensive model that simulates the following processes in the entire Central Valley:

a) Groundwater Flow Simulation
b) Stream Flow Simulation
c) Rainfall Runoff Simulation
d) Soil Moisture Accounting
e) Unsaturated Flow Simulation
f) Stream - Aquifer Interaction
g) Land & Water Use Analysis
h) Land Subsidence

The model was used to evaluate groundwater resources, conjunctive use opportunities and impacts of water management scenarios.

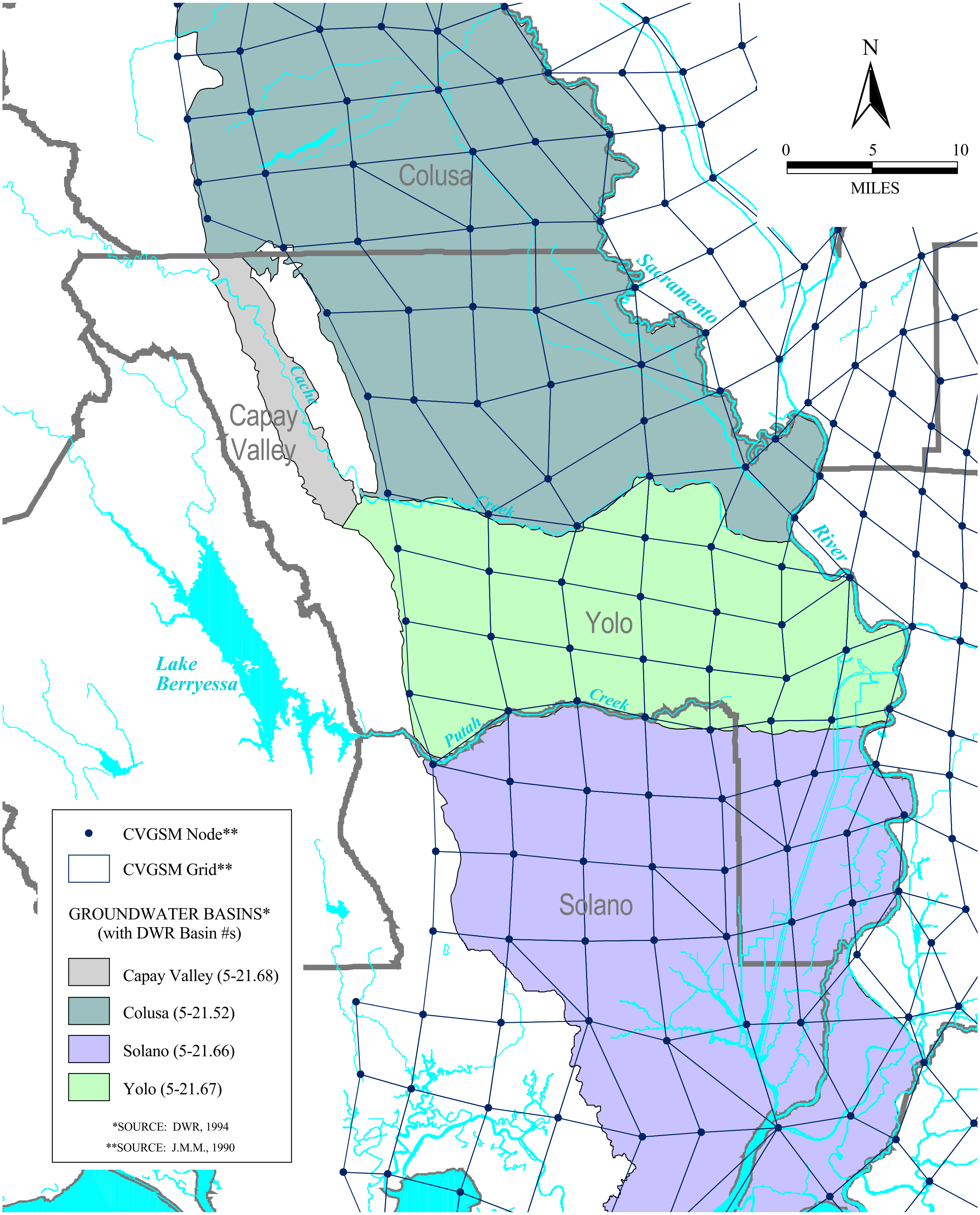
The CVGSM grid covers all of Yolo County, as shown in Figure 3-5. The CVGSM grid scale is quite coarse because of the scale of the entire model. In Yolo County, the average element size is about 14 square miles. CVGSM assumes a 3-layer aquifer system with the top layer being the unconfined aquifer. CVGSM simulates stream flow in Cache Creek, the Sacramento River and the Yolo Bypass.

Lower Colusa County IGSM

This IGSM application covers the southern part of Colusa County and the northeastern part of Yolo County. It could potentially be used to provide boundary conditions (groundwater levels and flow rates, and surface water flows) for a Yolo County hydrologic model. The part of the model area within Yolo County is shown on Figure 3-6.

Sacramento County IGSM

This IGSM application covers all of Sacramento County and borders Yolo County along the Sacramento River. The Sacramento County IGSM application has a finer finite element grid than that of the CVGSM and has more detailed data on aquifer stratigraphy. Therefore, this IGSM application might be useful than CVGSM for obtaining detailed boundary conditions



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YOLO COUNTY HYDROLOGIC MODELING GOALS AND OBJECTIVES

Central Valley Groundwater Surface Water Model (CVGSM) Model Network near Yolo County

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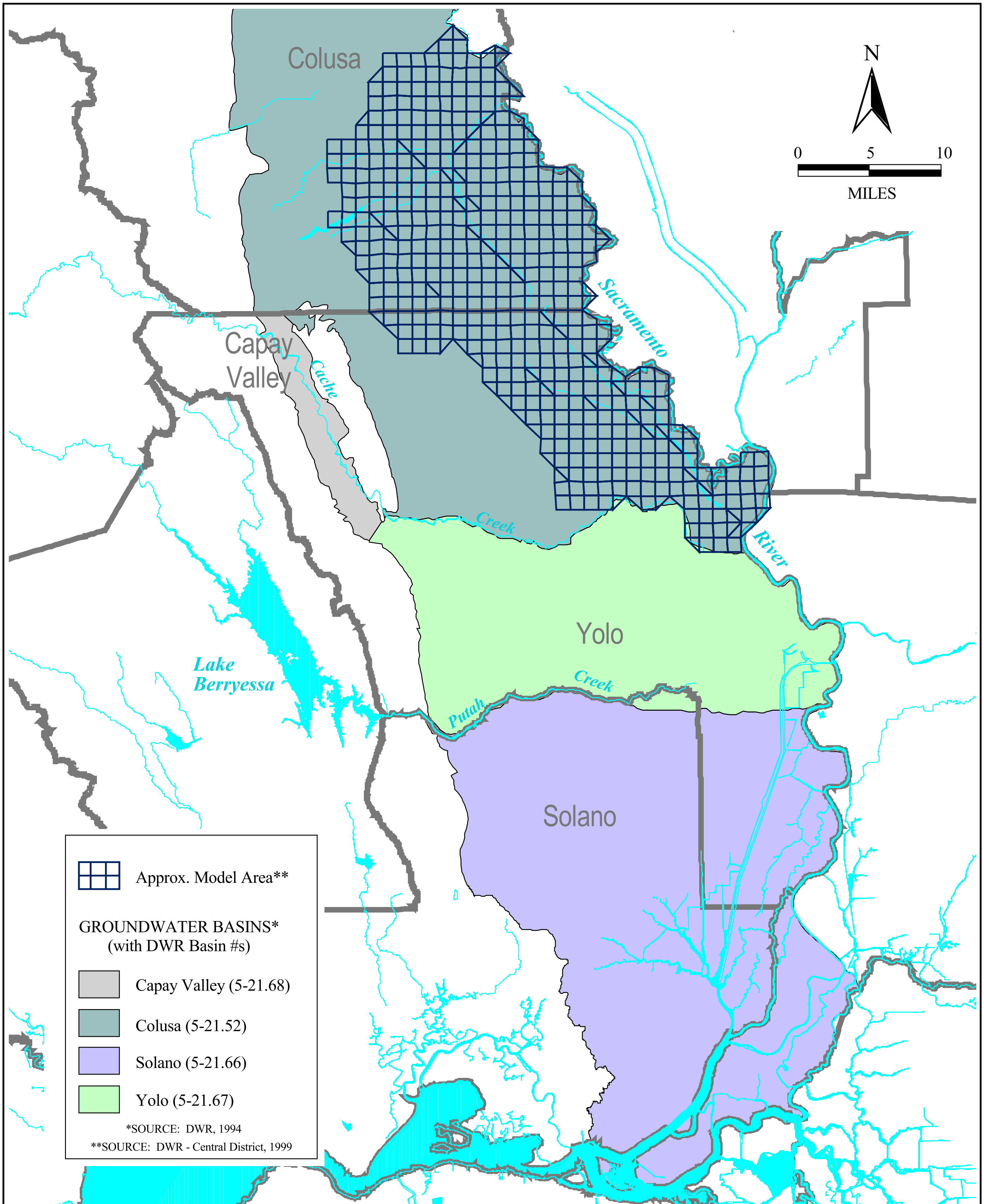
FIGURE 3-5



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YOLO COUNTY HYDROLOGIC MODELING GOALS AND OBJECTIVES

Lower Colusa Basin Drain - Integrated Groundwater Surface Water Model (IGSM) Model Area within Yolo County

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FIGURE 3-6

along the eastern border of Yolo County. It could also be used to evaluate the impacts of groundwater operations in Sacramento County on Yolo County, and vice versa. The simulation period for the Sacramento County IGSM model is 1961-1995.

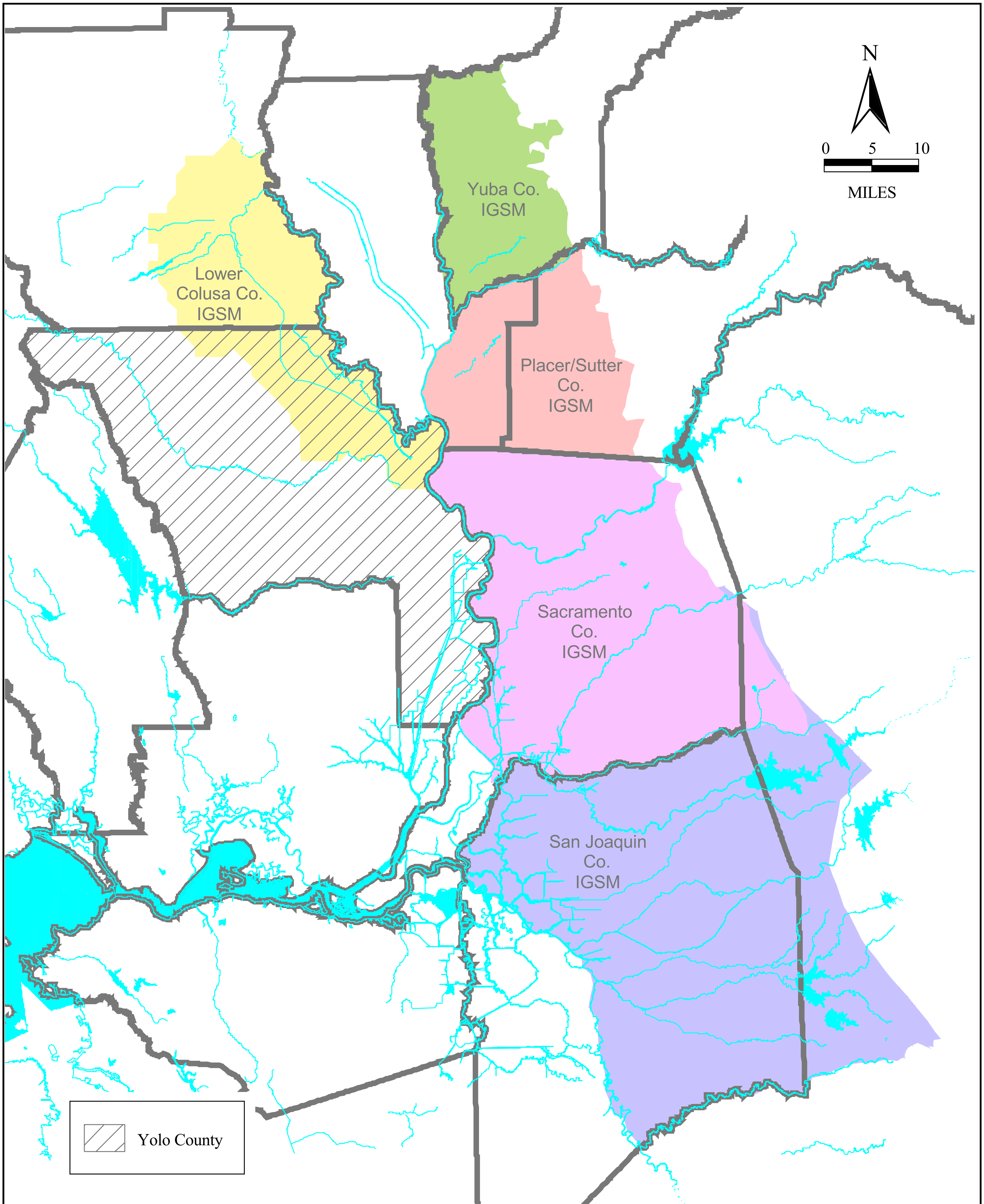
This model was used to evaluate groundwater resources, conjunctive use opportunities and impacts of water management scenarios. Figures 3-7 and 3-8 show the geographic extent of the model areas in relation to Yolo County.

North American River (South Sutter and Western Placer County) IGSM

This IGSM application is similar to the Sacramento County model. It covers the northern American River (NAR) watershed area in the southern part of Sutter County and the western part of Placer County. The grid size in this hydrologic model is approximately 1 mile. It borders part of Yolo County along the Sacramento River and could therefore be useful for providing boundary conditions for a Yolo County model. In addition, the NAR IGSM could be used to evaluate the impacts of groundwater operations in South Sutter groundwater basin on Yolo County, and vice versa. Figures 3-7 and 3-8 show the extent of the model grid in relation to Yolo County.

Yuba County IGSM

This is another IGSM application similar to the Sacramento County and North American River applications. It covers the Yuba County groundwater basin as defined by DWR. This model was developed by the Department of Water Resources, and has been applied to several groundwater management studies. Although, there are no geographic boundaries between Yolo and Yuba Counties, the model could potentially be used to evaluate the impacts of upstream groundwater operations on the Feather and Sacramento River systems, and the downstream water users. Figures 3-7 and 3-8 show the location of the Yuba County model grid.



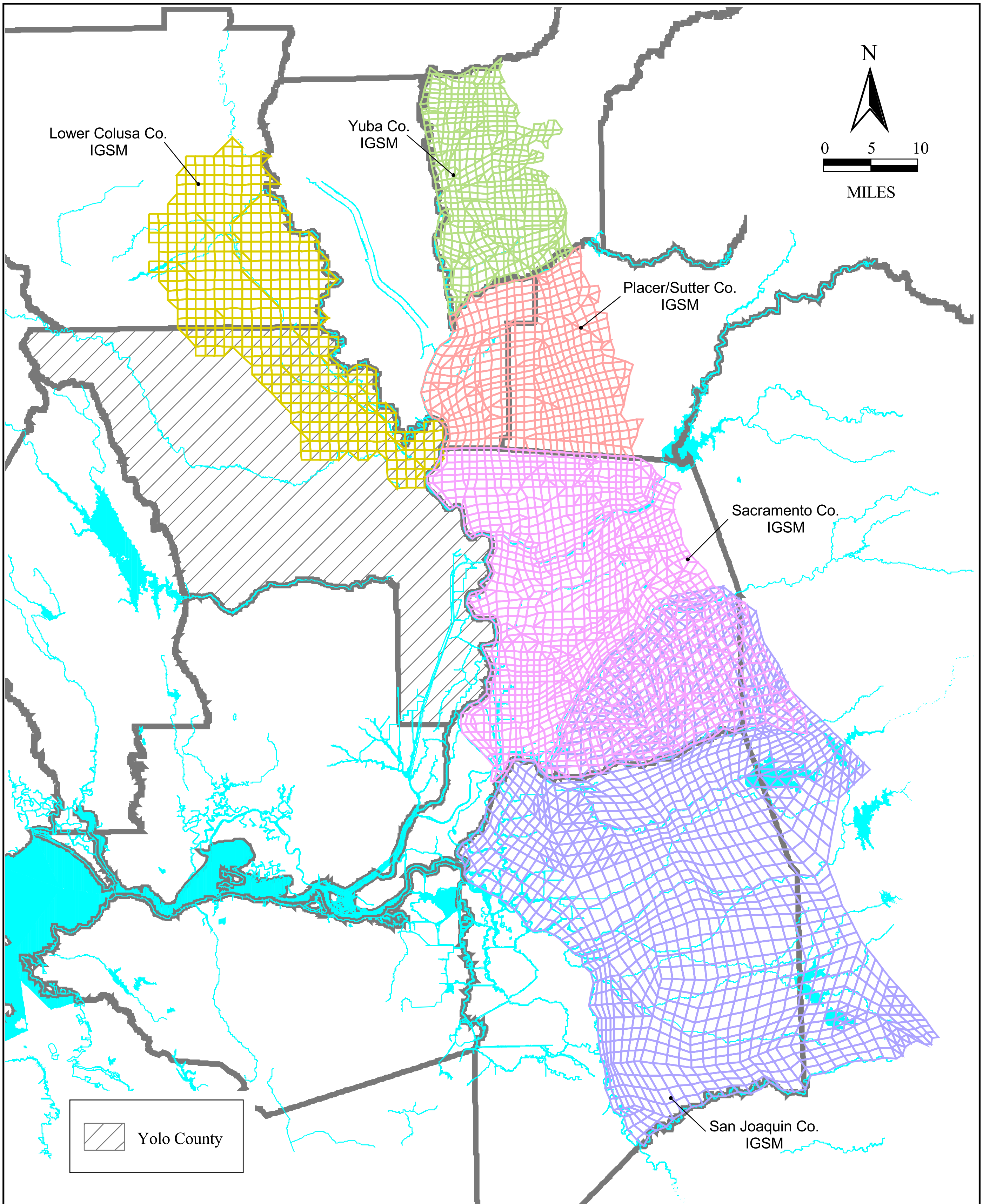
RIME

YOLO COUNTY HYDROLOGIC MODELING GOALS AND OBJECTIVES

Model Areas for IGSM Applications in the Vicinity of Yolo County

MAY 2002

FIGURE 3-7



YOLO COUNTY HYDROLOGIC MODELING GOALS AND OBJECTIVES

Model Networks for IGSM Applications in the Vicinity of Yolo County

MAY 2002

FIGURE 3-8

DATA STATUS

In 1998, the WRA conducted an inventory of hydrologic data available from 13 local, state and federal agencies (Data and Information Directory for Water Resources of Yolo County, WRAYC, 1998). This inventory was only for the surface water and groundwater data; no inventory was developed for other data related with the water management and planning. In 2001, Gus Yates, a consultant for WRA, published a report entitled *"Evaluation of Data Availability and Analysis Needs for Water Resources Management in Yolo County".* Three key conclusions reached by Yates are:

- Data are relatively abundant in urban areas compared to the rural areas;
- Agricultural groundwater production data is lacking throughout the County;
- Data on the recharge from deep percolation of rain and applied water is also lacking throughout the County.

In his report, Yates, categorized the data and analysis needs by six (6) water resources issues as shown below:

- Water supply yield and reliability;
- Water conservation;
- Water recycling;
- Floodwater management;
- Environmental water management;
- Water quality.

Yates also identified numerous surface water, groundwater, land and water use, soil, institutional, legal data items in his report. Currently, an effort is being undertaken as part of the Integrated Water Management Plan to collect, document, and review baseline data and determine the data gaps for water resources management.

SECTION 4 MODELING NEEDS AND GOALS

A joint WRA-DWR modeling committee[1] identified the modeling needs in the Yolo County as well as the short-term and long-term goals of water resources modeling in Yolo County. The process of identification of modeling needs and goals included meeting with WRA members, assessment of previous modeling efforts, evaluation of current and future analytical issues and needs, and technical sessions among the project team members.

The specific analytical/modeling needs of the Yolo County includes improved understanding of the following:

1) Local and regional groundwater flow system characteristics;
2) Local groundwater recharge capabilities;
3) Impacts of surface and groundwater supply alternatives on the groundwater basin conditions;
4) Impacts of changes in agricultural and urban land use conditions and cropping patterns on groundwater conditions;
5) Impacts of water urban conservation measures and irrigation practices on the groundwater conditions;
6) Interaction between surface water systems and groundwater system;
7) Response of the surface water and groundwater systems to different pumping and recharge programs;
8) Potential for conjunctive use to enhance the water supply reliability in the basin; and
9) Impacts of different management alternatives on hydrologic system.

These needs can be met by a combination of data collection and analysis, investigative field studies, monitoring programs, and water resources modeling activities. The current effort focused on identifying modeling goals of Yolo County in order to meet the above needs.

The short-term modeling goal is to have a reliable analytical tool that can meet the immediate need of YCFCWCD to evaluate conjunctive use possibilities in the Yolo-Zamora area.

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[1] Participants included Rich Juricich, Deborah Braver, Gus Yates, Fran Borcalli, Ali Taghavi, Mike Cornelius and Chris Barton.

The long-term modeling goal is to have a reliable analytical tool that can support the integrated water resources planning and management on an ongoing basis by simulating impacts of alternative water management actions, water development projects, land-use changes and other activities on groundwater and surface water flow and quality, habitat, and agricultural economics. The model area needs to include at a minimum the entire groundwater basin within Yolo County and may extend beyond Yolo County to reach logical hydrologic boundaries.

The specific long-term goals of water resources modeling in Yolo County are:

- Develop a model that covers the entire Yolo County along with appropriate model boundaries that may be within or outside the county boundary; this model should also represent the groundwater and surface water flow systems and their interactions in the Yolo County;
- Develop a model that can serve as the countywide water resources planning tool to assess impacts of different water management scenarios and projects, including land use changes, on both the groundwater and surface water systems.
- Develop a planning level analytical tool that can provide quantitative information on a comparative basis to help answer different questions on the groundwater and surface water system characteristics and to evaluate alternative conjunctive water management strategies.

It can be concluded from the above discussion that the hydrologic model for Yolo County will need to address a wide range of issues covering a broad set of hydrologic processes that include water quantity, water quality, sediment transport, land use, water use, and economics. Selection of one or more available software programs to implement the model must consider the technical capabilities of each software as well as key software characteristics, such as professional acceptability, availability, user-friendliness, and level of support. The WRA-DWR modeling committee compiled a list of technical capabilities and software characteristics to use as criteria for selecting a modeling software for Yolo County.

Technical capabilities of a model that can meet the modeling needs and goals of Yolo County include the ability to simulate:

1) Rainfall-runoff on tributary watersheds that feed streams and rivers crossing the groundwater basin;
2) Rainfall-runoff from lands overlying the groundwater basin;
3) Evaporation from open water surfaces;
4) Soil moisture budgets for lands overlying the groundwater basin, include evapotranspiration, irrigation, soil moisture storage, and deep percolation;
5) Irrigation demand based on crop type and current soil moisture and climate conditions;
6) Deep percolation through the unsaturated zone;
7) Three-dimensional, saturated groundwater flow;
8) Dynamic (head-dependent) interaction between surface water and groundwater flow, with conservation of mass applied to both;
9) Local reservoir operations, linked as appropriate to SWP/CVP reservoir operations models;
10) Local reservoir operations in conjunction with the groundwater and surface water simulation;
11) Changes in agricultural and urban water demand over a range of hydrologic conditions, from wet to very dry;

12) Changes in water supply availability;
13) Changes in water levels due to changes in hydrologic conditions and management actions;
14) Changes in yield at individual wells due to changes in water levels;
15) Impacts on wetlands or phreatophytic riparian vegetation by lowering or raising groundwater levels;
16) Increases in risk of subsidence during a critical drought;
17) Changes in the stream-aquifer interaction;
18) Changes in downstream flow regimes due to modified stream-aquifer interaction;
19) Changes in flood risk due to changing hydrologic conditions;
20) Changes in frequency and duration of flood flows and their impacts on riparian and wetland habitats;
21) Changes in the infiltration of groundwater contaminants from the soil surface (e.g. by increased inundation or irrigation of agricultural fields).
22) Changes in the rate and direction of any known groundwater contamination plume;
23) Changes in long-term concentrations of dissolved solids or particular solutes of concern in groundwater;
24) Changes in the economic viability of agriculture;
25) Changes in hydrologic systems due to land development or population growth;
26) Changes in estimates of water supply reliability by post processing model results.

The software characteristics required for the Yolo County model for professional acceptability, availability, user-friendliness, and level of support can be represented by the following criteria:

27) The model has had thorough scientific peer-review for technical accuracy and a successful history of accurate results in a wide range of applications;
28) The model code is public domain software and can be readily obtained from a public agency or from standard technical software vendors;
29) The model code and documentation are supported by a public agency, institute or easily identifiable and accessible private firm in the event that problems are discovered in the code.

30) A graphical user interface is available to assist in preparing spatial datasets (parameter zones, land use zones, well locations, water district boundaries, etc.) and for post processing model results;
31) An automated preprocessor is available for prorating land use zones to model cells;
32) An automated preprocessor is available that allows the model grid to be easily constructed and modified;
33) Plotting hydrographs and contour maps of simulated water levels is easy;
34) Tabulating water budgets for user-specified sub areas within the model or for different hydrologic sub-systems (groundwater, soil zone, specific surface waterways) is easy;
35) Groundwater recharge contributions from operation of irrigation and surface water delivery projects can be easily tabulated;
36) The model is able to quantify induced seepage by wells near surface water bodies;
37) The model can evaluate groundwater storage capacity and banking potential for any sub area; and
38) The types and structure of model input variables readily allow simulation of a wide range of water management strategies.

SECTION 6 COMPARISON OF MODELING SOFTWARE

A review of available groundwater and hydrologic modeling software packages is conducted to explore the potential suitability of these models for application in Yolo County. These models are:

a) MODFLOW
b) FEMFLOW3D
c) MIKESHE
d) FEMWATER/FEMWASTE
e) IGSM

The result of comparison is provided in Table 6-1 in terms of model characteristics, features and capabilities. As explained in Section 3 of this report, it is noteworthy that these models are not necessarily comparable, as some only simulate the groundwater flow system, and others are comprehensive hydrologic models. The typical groundwater models can, of course, be used in conjunction with other programming tools to determine the effect of surface hydrologic processes on the groundwater basin.

These models are next compared against the selection criteria listed in Section 6. The results are presented in Table 6-2.

It can be seen that no single existing modeling software package meets all of the selection criteria. Therefore, a comprehensive hydrologic modeling tool often consists of multiple computer programs each covering a subset of the hydrologic system. To function in an integrated manner, it is necessary to pass output from one model to another, reformat certain types of data to meet the input requirements of different programs, and possibly to extract certain types of simulation results not included in the standard output of some programs. Typically, a certain amount of custom programming is needed to create these interfaces between different computer programs and component models.

Table 6-1- Features and Simulation Capabilities of Groundwater and Hydrologic Models for the Yolo County

MODEL CHARACTERISTICS	MODEL NAME				
	MODFLOW	FEMFLOW3D	MIKESHE	FEMWATER/ FEMWASTE	IGSM
Background, & Applications	Developed by the USGS, this model simulates three-dimensional flow in confined and unconfined aquifer systems. Division of the program into modules permits the user to examine specific hydrologic features of the model independently. The model provides output for use by several solute transport models. Third-party programs are sometimes available to simulate some of the hydrologic processes that affect the groundwater movement. It is noteworthy that these programs, however, do not simulate the two-way interaction between the processes, rather the one-way impact of these processes on the groundwater system.	Developed for the USGS, the model simulates three-dimensional flow in confined and unconfined groundwater systems using the finite-element method. Developed to simulate regional groundwater systems, but can be applied to small-scale problems as well.	Developed by the Danish Hydrologic Institute (DHI), the model uses finite difference method to simulate the three-dimensional flow in the subsurface system. The model program is grouped into four separate modules (Pre- and Post-Processing, Water Movement, Water Quality, and Agriculture) and offers the possibility of analyzing a number of hydrologic problems.	Originally developed by Oakridge National Laboratory, the model simulates three-dimensional flow and solute transport in the subsurface system. The model is designed for site-specific applications such as radioactive waste movement in the subsurface environment. The model code was upgraded to meet the U.S. Environmental Protection Agency coding conventions. The model is often used to delineate wellhead protection areas in agricultural regions using the assimilative capacity criterion.	Originally developed in 1976 at UCLA, was refined and updated through numerous model applications and reviews. Model provides psuedo-three dimensional simulation capability for comprehensive and integrated surface water and groundwater flow and solute transport under various hydrologic conditions through numerous options and routines. Model has been applied to numerous regional and local watersheds, in particular, to the Central Valley of California for the USBR, DWR, SWRCB, and CCWD.
Method of Simulation FE, FD, or Other	Finite-difference	Finite Element; Triangular elements only	Finite-difference	Finite-element	Finite Element; Quadrilateral and triangular elements
Timescale	Variable	Variable	Variable	Variable	Monthly. Surface water calculations (but not groundwater flow) can optionally be simulated daily
Groundwater	Layers can be simulated as confined, unconfined, or a combination of confined and unconfined. Can simulate subsidence.	Simulates linearized 3-dimensional flow in groundwater system with a fixed grid; Simulates both confined and water table aquifers; Land Subsidence	Simulates 3-dimensional groundwater flow in confined and unconfined aquifer system; various sources/sinks; time variable head boundaries and other types of boundary conditions;	Simulates flow and transport in three-dimensional variably-saturated porous media under transient conditions; Multiple distributed and point sources/sinks, and processes which retard the transport of contaminants	Simulates pseudo-three dimensional multi-layered confined and unconfined aquifer systems; Regional and site-specific aquifer parameters; Several boundary conditions; Land subsidence
Stream Flow and Stream-Aquifer Interaction	The River Package simulates the recharge from stream system to groundwater system, as a variable head boundary condition. The stream package simulates the flow in the river system and the interaction between the stream system and the groundwater system. The lake package simulates groundwater interaction with lakes, maintaining mass balance in both.	Simulates the stream-aquifer interaction, diversion, return flow, and rainfall runoff	One-dimensional river model (diffusion wave approximation of the Saint Venant equations); River/aquifer exchange.	No stream-aquifer ineraction	Integrated groundwater-surface water interactions; Rainfall runoff; Irrigation return flow; Water diversions; Daily streamflow gain or loss to the aquifer system; Mass balance in surface water bodies.

MODEL CHARACTERISTICS	MODEL NAME				
	MODFLOW	FEMFLOW3D	MIKESHE	FEMWATER/ FEMWASTE	IGSM
Rainfall/Runoff	No rainfall/runoff calculations. The Recharge Package is designed to simulate areally distributed direct recharge to the ground-water system; Net Recharge values are typically pre-processed and provided as input.	Runoff and Deep percolation are calculated based on fixed effective precipitation which is provided as a rating table input; Precipitation and evapotranspiration data are basin-wide.	Uses 3-D Boussinesq Equation for saturated flow; 2-D Saint Venant's Equation (diffusion wave approximation) for overland flow	No Rainfall-runoff and deep percolation simulation capability provided.	Rainfall is entered as data and the model calculates runoff using the SCS curve number method.
Landuse	Hydrologic processes at the land surface are not included within the model. Separate programs are typically used to estimate runoff, soil moisture budgets, irrigation demand, and deep percolation - all of which are affected by land use.	Surface processes affected by land use are simulated based on crop type, rooting depths and evapotranspiration.	Simulation of surface processes based on land use map, field surveys, aerial photos or satellite images are allowed	Not defined in model.	Simulation capability of surface processes based on various land use types cropping patterns, evapotranspiration and irrigation efficiency is provided. Model includes only four land use types (urban, native, agricultural, and riparian), although multiple crops can be simulated in agricultural areas.
Water Use	The model does not interactively calculate the water use and diversions from streams for delivery to water use areas. All water supply data are provided as pre-processed net recharge or groundwater pumping to the model. The surface water supply, applied water estimates, and resulting deep percolation may be calculated using third-party programming and input into the model as net recharge values.	Surface water diversion and Groundwater pumpage and recharge for an irrigated-agriculture system can be simulated; Data can be organized on basis of geographical or political boundaries, not restricted by layout of grid	The irrigation module supports: Automatic irrigation demand calculation or prescribed crop water demand; Sprinkler irrigation, drip irrigation or sheet irrigation; Different water sources; Priorities in water shortage situations	Only net pumping specified in model.	Surface water diversions, recoverable and non-recoverable losses, urban water use, agricultural water use, groundwater pumping by sub-basin or by wells, and surface water and/or groundwater imports and exports between basins can be specified
Snowmelt Runoff	Not simulated	Not simulated	Calculated on basis of the degree-day using a method that requires temperature, a degree-day factor (mm snow/s/Co) and a threshhold melting point temperature	Not simulated	Not simulated
Soil Moisture Accounting	Soil moisture accounting is not included. However, the Evapotranspiration Package simulates direct withdrawal of groundwater from shallow water-table areas by phreatophytic vegetation. Soil moisture accounting is typically done as a preprocessing step using separate software.	Soil moisture accounting is performed based on potential ET, effective rainfall, applied water, and soil moisture storage. Model allows for non-uniform application of applied water.	The ET component uses meteorological and vegetative input data to predict the total evapotranspiration and net rainfall amounts resulting from the processes of: Interception of rainfall by the canopy; Drainage from the canopy; Evaporation from the canopy surface; Evaporation from the soil surface; Uptake of water by plant roots and its transpiration.	Not available for soil zone processes.	The Soil Conservation Service methodology is used to simulate the soil moisture accounting effective precipitation; direct runoff; infiltration; and deep percolation. User enters monthly potential ET for each crop or vegetation type. Model allows for non-uniform application of applied water.

MODEL CHARACTERISTICS	MODEL NAME				
	MODFLOW	FEMFLOW3D	MIKESHE	FEMWATER/ FEMWASTE	IGSM
Unsaturated Zone Simulation	Not included. A third-party program can be used to simulate the flow in the unsaturaed zone. However, the interaction between the unsaturaed zone flow and the groundwater table can not be simulated with third-party programs.	Not included.	Described using a vertical flow model	Two methods of one-dimensional unsaturated flow simulation are provided; one based on an analytical solution and another based on a numerical solution.	One-dimensional flow through the unsaturated system and the resulting attenuation of recharge pulses is simulated.
Agricultural Drain Simulation	Simulates GW flow to agricultural drains when the elevation of the water table is above the drain invert elevation. If the water table is below drain inverts, no drain flows occur.	Not included.	Not included.	Not included.	Simulates groundwater flow to agricultural drains under various field conditions.
Reservoir Operations	Not included.	Not included.	The linear reservoir flow module includes: Linear reservoir flow routing accounting for interflow and baseflow components; dynamic coupling with MIKE SHE's infiltration, evapotranspiration and river models	Not included.	Simulates diversions and reservoir storage and releases. Utilizes specified water rights, physical data, and operational rules for each reservoir to compute diversions and reservoir releases
Water Quality Simulation	MODFLOW output links seamlessly to the MT3D solute transport model. Transport parameters are input directly to MT3D. MT3D is capable of modeling advection in complex steady-state and transient flow fields, anisotropic dispersion, first-order decay and production reactions, and linear and nonlinear sorption.	Not included.	The water quality simulation package includes the following modules: Advection-Dispersion Module; Particle Tracking Module; Sorption-Degradation Module; Geochemistry Module; Biodegradation	Simulates first-order contaminant decay; Includes three adsorption models--a linear isotherm, nonlinear Freundlich, or Langmuir isotherm.	Simulation for advective and dispersion movement of water quality constituents, chemical retardation and chemical decay; multilayered finite element technique; Inclusion of a pseudoviscosity term to minimize oscillation of water quality results; preservation of mass balance; Inclusion of special boundary condition to handle seawater intrusion; Transformation of chemicals in the soil zone including adsorption, desorption, immobilization, and mineralization.
Hydrogeologic Parameters	Thickness of aquifers, transmissivity and vertical hydraulic conductivities of aquifers; stream/river bed parameters.	Parameter estimation: Uses information on the expected value and variance of the expected value for hydraulic conductivity, specific storage, and specific yield, along with information on measured ground-water levels and variance of measurements to estimate max. likelihood values of hydraulic conductivity, specific storage, and specific yield	Saturated zone can be divided into a number of geologic layers; Vertical discretization can follow or be chosen independently of geologic layers; Soil physical characteristics must be specified; Vertical soil profiles defined; Spatial distribution of soil profiles	Data on the ranges of bulk density for various geologic material; Treats heterogeneous and anisotropic media consisting of as many geologic formations as desired.	Soil characteristics; Aquifer parameters (Specific storage or storage coefficient; Specific yield; Horizontal hydraulic conductivity; Vertical hydraulic conductivity or leakance parameters).
Language	FORTRAN77	FORTRAN	Not indicated	FORTRAN77	FORTRAN

MODEL CHARACTERISTICS	MODEL NAME				
	MODFLOW	**FEMFLOW3D**	**MIKESHE**	**FEMWATER/ FEMWASTE**	**IGSM**
Availability	Public Domain	A Public Domain code available from USGS, however, most updated features are available through specific licensing requirements	Licensed by the Danish Hydrologic Institute (DHI).	Public Domain	Public domain, but not routinely distributed by agencies and not available from standard commercial software vendors.
Graphical User Interface	Several powerful third-Party GUI programs available for preparing model input and viewing model output.	Not Available	A GUI is provided for MIKE SHE with a GIS environment	Not Available	A GUI for a recent version of IGSM is separately available but its capabilities are limited to viewing model output. The DWR version will not have a GUI in the near future.
Editing Method	ASCII-based data files, which can be edited by any text editor. Commercial preprocessing GUI software automatically writes input files but is more useful for time-independent data (grid, boundary locations, parameter zones, recharge zones, well locations, etc) than for transient input data.	ASCII-based data file, which can be edited by any text editor	GUI-based editting routines, as well as import/export options	ASCII-based data file, which can be editted by any text ediitor	ASCII-based data file, which can be edited by any text editor
Documentation	User Guide and documentation available	User Guide and documentation available	User Guide and documentation available	User Guide and documentation available	User Guide and documentation available
References	McDonald, M.G., A.W. Harbaugh, 1988. *Techniques of Water-Resource Investigations of the United States Geological Survey: A Modular Three-Dimensional Finite Difference Ground-water Flow Model.* US Geological Survey.	Durbin, T.J., L.D. Bond, 1998. *FEMFLOW3D: A Finite-Element Program for the Simulation of Three-Dimensional Aquifers. Version 1.0*, US Geological Survey.	Danish Hydrological Institute, 1999. *MIKE SHE Users Manual Edition 1.2*.	Yeh, G.T., S. Sharp, B. Lester, R.Strobl, J. Scarbrough, 1992. *3DFEMWATER/3DLEWASTE: Numerical Codes For Delineating Wellhead Protection Areas In Agricultural Regions Based On The Assimilative Capacity Criterion*. Environmental Research Laboratory, US EPA.	Montgomery Watson, 1993. *Documentation and Users Manual for Integrated Groundwater and Surface Water Model (IGSM)*

Table 6-2: Comparison of Available Model Codes Relative to Model Selection Criteria

		MODEL NAME				
Model Feature or Selection Criterion		IGSM	MODFLOW	FEMFLOW3D	MIKE SHE	FEMWATER
1	Rainfall-runoff on tributary watersheds that feed streams and rivers crossing the groundwater basin;	Yes	No*	No*	Yes	No
2	Rainfall-runoff from lands overlying the groundwater basin;	Yes	No*	No*	Yes	No
3	Evaporation from open water surfaces;	Yes	Yes (Lake package)	No	Yes	Not known
4	Soil moisture budgets for lands overlying the groundwater basin, include evapotranspiration, irrigation, soil moisture storage, and deep percolation;	Yes	No*	Yes	Yes	No
5	Irrigation demand based on crop type and current soil moisture and climate conditions;	Yes	No*	Yes	Yes	No
6	Deep percolation through the unsaturated zone;	Yes	No*	No	Yes	Yes
7	Three-dimensional, saturated groundwater flow;	Yes	Yes	Yes	Yes	Yes
8	Dynamic (head-dependent) interaction between surface water and groundwater flow, with conservation of mass applied to both;	Yes	Yes	Yes	Yes	No
9	Local reservoir operations, linked as appropriate to SWP/CVP reservoir operations models;	Yes	No	No	No	No
10	Local reservoir operations in conjunction with the groundwater and surface water simulation;	Yes	No*	No*	No*	No
11	Changes in agricultural and urban water demand over a range of hydrologic conditions, from wet to very dry;	Yes	No*	Yes	Yes	No*
12	Changes in water supply availability;	Yes	No*	No	Not Known	No*

		MODEL NAME				
Model Feature or Selection Criterion		**IGSM**	**MODFLOW**	**FEMFLOW3D**	**MIKE SHE**	**FEMWATER**
13	Changes in water levels due to changes in hydrologic conditions and management actions;	Yes	Yes	Yes	Yes	Yes
14	Changes in yield at individual wells due to changes in water levels;	Yes	Yes	Yes	Yes	Yes
15	Impacts on wetlands or phreatophytic riparian vegetation by lowering or raising groundwater levels;	Yes	No	No	Not Known	No
16	Increases in risk of subsidence during a critical drought;	Yes	Yes	Yes	Not Known	Not Known
17	Changes in the stream-aquifer interaction;	Yes	Yes	Yes	Yes	Not Known
18	Changes in downstream flow regimes due to modified stream-aquifer interaction;	Yes	Yes	Not Known	Yes	Not Known
19	Changes in flood risk due to changing hydrologic conditions;	No	No	No	Not Known	Not Known
20	Changes in frequency and duration of flood flows and their impacts on riparian and wetland habitats;	No	No	No	No	No
21	Changes in the infiltration of groundwater contaminants from the soil surface (e.g. by increased inundation or irrigation of agricultural fields).	Yes	No	Yes	Yes	No
22	Changes in the rate and direction of any known groundwater contamination plume;	Yes	Yes	Not Known	Yes	No
23	Changes in long-term concentrations of dissolved solids or particular solutes of concern in groundwater;	Yes	Yes	Not Known	Yes	No
24	Changes in the economic viability of agriculture;	Yes	No	Limited	Limited	No

		MODEL NAME				
Model Feature or Selection Criterion		IGSM	MODFLOW	FEMFLOW3D	MIKE SHE	FEMWATER
25	Changes in hydrologic systems due to land development or population growth;	Yes	No	Limited	Limited	No
26	Changes in estimates of water supply reliability by post-processing model results;	Yes	GW Only	Limited	Limited	GW Only
27	The model has had thorough scientific peer-review for technical accuracy and a successful history of accurate results in a wide range of applications;	In progress	Yes	Yes	Yes	Limited
28	The model code is public domain software and can be readily obtained from a public agency or from standard technical software vendors;	Public domain but not yet readily available	Yes	Public domain but limited availability	Proprietary but readily available	Yes
29	The model code and documentation are supported by a public agency, institute or easily identifiable and accessible private firm in the event that problems are discovered in the code.	DWR is assuming this role	Yes	Limited	Yes	Limited
30	A graphical user interface is available to assist in preparing spatial datasets (parameter zones, land use zones, well locations, water district boundaries, etc.) and for postprocessing model results;	Limited	Yes	No	Yes	Yes
31	An automated preprocessor is available for prorating land use zones to model cells;	3rd party add-on	No	Not known	Yes	Not known
32	An automated preprocessor is available that allows the model grid to be easily constructed and modified;	No	Yes	No	Yes	Yes
33	Plotting hydrographs and contour maps of simulated water levels is easy;	Yes	Yes	Limited	Yes	Yes
34	Tabulating water budgets for user-specified subareas within the model or for for different hydrologic sub-systems (groundwater, soil zone, specific surface waterways) is easy;	Yes	GW Budget Only	Limited	Yes	GW Budget Only

		MODEL NAME				
Model Feature or Selection Criterion		IGSM	MODFLOW	FEMFLOW3D	MIKE SHE	FEMWATER
35	Groundwater recharge contributions from operation of irrigation and surface water delivery projects can be easily tabulated;	Yes	No*	Yes	Limited	No*
36	The model is able to quantify induced seepage by wells near surface water bodies;	Yes	Limited	Limited	Limited	No
37	The model can evaluate groundwater storage capacity and banking potential for any subarea;	Yes	Yes; MODFLOW 2000	Yes	Limited	No
38	The types and structure of model input variables readily allow simulation of a wide range of water management strategies;	Yes	Limited	Limited	Yes	Limited

* These features can be simulated using third-party and custom-written programs and input into the groundwater model

** Other reservoir operation models such as HEC-5 can be used in conjunction with these groundwater models

Members of the WRA Technical Advisory Committee expressed a desire to minimize the amount of custom programming (e.g. modifications to standard model codes and new utility programs that link different component models) because it is difficult to ensure that the custom programs are documented well enough to be used by other hydrologists/modelers. Previously, many WRA agencies have paid for modeling studies only to find that the modeling tools became unusable when the individual who developed them changed employers or moved away from the area. The TAC members emphasized the desire in this case for a long-lived tool, not a one-time study. Thus, it would be preferable to create the overall hydrologic model with as few software programs as possible. In other words, existing programs that already cover a large part of the system are preferable to ones that focus on only a small part of the system.

Groundwater flow and interactions between surface water and groundwater will be central to any water management scenario for Yolo County. Also, the formulation and solution of the equations describing groundwater flow (and transport) requires very sophisticated mathematics and programming and would be the most difficult part of the hydrologic model to customize for Yolo County. Thus, it is reasonable to begin by selecting a groundwater model that will be a main element of the larger hydrologic model.

After reviewing the characteristics of the five models discussed above, the modeling committee narrowed the choice down to two modeling software's: IGSM and MODFLOW. Additional investigation of the capabilities and status of the IGSM was deemed necessary before it could be fairly compared with MODFLOW.

The principal advantage of IGSM is the large number of hydrologic processes included within the model. In particular, IGSM simulates the effects of land use overlying the groundwater basin and calculates rainfall runoff, crop ET, soil moisture budgets, irrigation demand and deep percolation of rainfall and irrigation water. Thus, the simulation of these aspects of the hydrologic system are "standardized" for all IGSM-based studies. MODFLOW does not simulate these processes, and there are no widely used software packages that simulate these processes and can be linked with MODFLOW. As a result, MODFLOW users typically develop their own spreadsheet or FORTRAN programs that perform calculations similar to those in IGSM for the purpose of preparing the recharge data set for MODFLOW. However, none of these programs are widely available or standardized, and few are peer-reviewed or thoroughly documented.

Another advantage of IGSM is that it can track flows through a complex system of reservoirs, streams and canals consistent with a user-specified set of operating rules, although the options for specifying operating rules might need customizing for Yolo County. In the context of an overall hydrologic model, IGSM would avoid a considerable amount of custom programming that would be needed if MODFLOW were selected as the central program.

Another minor advantage of IGSM is that it has already been used in several neighboring counties (Sacramento, Sutter, Placer, Yuba and Colusa). If IGSM were also used in Yolo County, comparisons of water use patterns and hydrologic processes among the counties would be more reliable.

However, the advantages of IGSM must be weighed against its disadvantages. These include concerns regarding its scientific acceptability and availability given its history as an evolving code that had not undergone formal and comprehensive peer review. The WRA-DWR modeling committee was also aware of a number of alleged flaws or weaknesses in IGSM's internal calculations. Each of these concerns was investigated, and the findings are summarized below:

PEER REVIEW AND PUBLIC AVAILABILITY

IGSM has evolved over a 15-20 year period of continuous upgrades and enhancements and was primarily used for many years by only a single consulting firm (now Montgomery Watson Harza Consulting Engineers). Although it has theoretically been a public domain model since it was used by USBR for several applications in the early 1990s, it is not widely distributed or readily available from a public agency, the International Groundwater Modeling Center or software vendors. However, DWR has made a commitment to become the official agency sponsor of the model and to begin distributing a public-domain version for free as a website download in summer 2002.

IGSM is currently undergoing comprehensive peer-review by a modeling group within DWR and by a committee of the California Water and Environmental Modeling Forum (CWEMF -- formerly the Bay-Delta Modeling Forum). The DWR team has identified several limitations/weaknesses in IGSM that may affect its desired application and are currently in the process of enhancing IGSM to overcome these modeling limitations/weaknesses. The CWEMF team has alleged that IGSM has some serious flaws, but preliminary review of the yet unpublished review report indicates that these alleged flaws are of more theoretical nature than of any practical significance. The principal technical concerns raised by CWEMF team are briefly described in the following sections. Both the DWR and CWEMF peer reviews are expected to be completed by Summer, 2002.

Assuming DWR follows through with its commitment to fix some of the key weaknesses of the IGSM code, prepare clear documentation, distribute the model via a readily-accessible website, offer training workshops, and dedicate staff to provide ongoing model support, many of the concerns in this area can be considered historical and not applicable to future modeling efforts.

METHOD FOR SOLVING NONLINEAR EQUATIONS

Unlike other major groundwater model codes, nonlinear boundary conditions and nonlinear unconfined flow equations are formulated and solved explicitly rather than implicitly in IGSM. This means that the solution of the set of groundwater flow equations for the current time step is partially dependent on the water levels from the previous time step, so the simulation is always partly out of phase with current inflows and outflows. The impetus for this approach was that it avoids computationally intensive iterative solution techniques. Computation time posed a significant constraint at the time IGSM was first developed because of the limited speed and capacity of personal computers in the 1970s and early 1980s. However, the CWEMF review team has reportedly demonstrated that IGSM's linearized solution method can lead to oscillating water levels or other incorrect results, particularly when there are highly nonlinear characteristics of the flow system, such as wells near streams or thin, unconfined surficial aquifers (LaBolle and Fogg 2001). Upon closer examination, however, some of those tests appear to have used unreasonable input parameters, such as streams with zero slope or wells pumping on the order of 100,000 gallons per minute. Full resolution of these issues will have to await the publication of the review teams findings, which is expected to occur this summer.

A second comparison of MODFLOW and IGSM has been completed by two of the three IGSM authors (Saquib Najmus and Ali Taghavi). A standard MODFLOW test data set provided with the GMS software package was simulated using IGSM and MODFLOW. The test basin (a small basin in Texas) included no-flow boundaries, constant-head boundaries, extraction wells and a stream that dynamically interacts with groundwater. Simulation results were similar for MODFLOW and IGSM, even when well pumping and aquifer characteristics were varied over a large range. Thus, it appeared that for typical stresses and hydrogeologic conditions, the groundwater flow component of IGSM functions correctly. No previous applications of IGSM to real study areas have reported questionable results stemming from the formulation and solution of the groundwater flow equations.

Errors associated with IGSM's linearized solution method also can be minimized by shortening the simulation time step, but IGSM presently uses a fixed monthly time step. DWR is addressing this problem by creating daily internal time steps within the model (invisible to the user), and this improvement will be included in the version released by DWR this summer.

EASE OF USE

The ease of preparing and modifying model input data and viewing and tabulating model output is an important consideration in selecting software for inclusion in the hydrologic model. These qualities affect the learning curve for using the model and the amount of time (i.e. labor cost) required to implement a simulation. The principal concerns for IGSM in this regard are the availability and capabilities of a graphical user interface (GUI) and the method of creating and modifying the finite-element grid. Several GUIs have been developed for IGSM over the years. The most capable of these in terms of preparing data input runs under DOS and was developed for a 1980s version of IGSM. More recent GUIs for IGSM use

Visual Basic but are primarily useful for viewing model output, especially well hydrographs, water budget tables, and water level contour plots. DWR would like to have a GUI for their improved version of IGSM but have no immediate plans to develop one. DWR's version of IGSM, like previous versions, runs under DOS, not Windows. Users must prepare the ASCII text input files using generic spreadsheet and text editor software.

The design of a finite-element grid can be tricky because elements with odd shapes (e.g. triangular elements with obtuse angles) can cause numerical instability in the model. Adding nodes to provide additional simulation detail in an area of interest is constrained by adhering to these same shape criteria. Automated mesh generation and modification routines are available for some commercial finite-element models (e.g. MicroFem and GMS), but none is included in IGSM. Thus, the ability of an IGSM-based hydrologic model to be modified in the future to focus in on an area of interest could be hampered by the effort required to modify the finite-element grid. However, it might be possible to construct the grid using one of these other commercial packages, and then import the node locations to IGSM. From a practical standpoint, questions involving a local area or short time periods (e.g. effects of pumping cycles in one well on water levels in nearby wells) might be more easily addressed using a separate local area model.

There are available Arc View routines that overlay the IGSM model grid and land use polygons for the purpose of elemental land use distribution, aggregating / disaggregating crop acreages, and assigning recharge zones to the groundwater model.

Clarity and documentation of the model code is important in the event that changes must be made to simulate a particular location or alternative. The IGSM code has evolved over many years of upgrades and enhancements. Although the code is organized into subroutines, it is approximately 17,000 lines long with few comment lines explaining what each segment of code is doing. The code authors have provided DWR with detailed theoretical documentation and code comments; DWR is incorporating those documentation and comments into the code file. This should facilitate implementing minor customizations of the code.

SUMMARY OF SELECTION RESULTS AND IMPLICATIONS

Most, but not all, of the drawbacks of using IGSM are being addressed by DWR through its development and distribution of an improved version of the code. If IGSM is selected as the central component of the hydrologic model, additional components that might need to be added to be able to address all issues of concern in water resources planning include programs to simulate erosion and deposition of sediment, flood flow magnitudes and probabilities, floodplain extent, terrestrial habitat (specifically, the relationship of wetland and riparian vegetation to soil type, depth to groundwater, and inundation timing, frequency and duration), aquatic habitat (water temperature and the relationship of flow depth, velocity and season to reproduction and survival of aquatic organisms), and agricultural economics (cost of water, price elasticity of water demand, cost of investments in irrigation efficiency, crop yield, etc.). A certain amount of custom programming would be needed to link IGSM with these additional components. Graphical user interfaces for IGSM are limited in their capabilities and may not be available for DWR's version of IGSM in the near future. Thus, a certain amount of custom programming will be needed to extract and display IGSM output.

If MODFLOW is selected as the central component of the hydrologic model, the number of additional programs needed would be considerably larger. In addition to the ones just mentioned for IGSM, it would be necessary to create or link programs that calculate rainfall runoff, urban water use, soil moisture budgets (land use, vegetation type, ET, moisture storage, irrigation demand, and deep percolation), surface water diversions and distribution (including water allocation rules), reservoir operation, and zone-specific operating rules and water budget subtotals.

Overall, the WRA-DWR modeling committee has concluded that the advantages of IGSM probably outweigh the disadvantages, assuming DWR follows through with its commitment to improve, distribute and support IGSM. Regardless of whether IGSM or MODFLOW is selected, a certain amount of customized programming will likely be necessary. Thorough documentation of that programming will be essential to ensure that a pool of capable model users is available in the future.

It is apparent from the above discussion that a single resource model, such as a groundwater model or a surface water model, by itself cannot meet Yolo County's need for integrated water management. As a result, an integrated groundwater and surface water model would be a preferable choice for the Yolo County in order to meet its long-term modeling needs. Obviously, no single model can meet all the needs identified in Section 5.0. Therefore, additional enhancements to an existing model may be necessary to meet certain needs. Therefore, Yolo County needs a long-term modeling strategy that will provide cost effectiveness while meeting the modeling goals and objectives.

Below, a modeling strategy is formulated for the successful development of an integrated hydrologic model for the entire Yolo County. The primary elements of this strategy are:

- Prioritization of required model features that are necessary for integrated water management in Yolo County;
- Selection of a proven model that can meet the feature requirements or can be easily enhanced to meet the feature requirements;
- Systematic approach to maximize the data utilization from the previously developed models;
- Cost effective approach to compile additional data that are necessary for new model application;
- Systematic data management plan to manage all model related data (raw and processed data), including background information on data and data processing notes;
- Systematic documentation/record keeping plan to help facilitate future review and modification of the model;
- Process based approach to model development with clearly defined milestones to ensure model quality;
- Process based approach to involve stakeholders to minimize disagreements about data, model selection, model calibration, and alternatives analysis;

- Process based approach to inform and educate the stakeholders about the limitations in both data and model and about applicability/inapplicability of the model for different sets of field conditions.

It should be noted that this modeling strategy should serve as a guideline during the model development process. Necessary refinements and modification to this strategy should be made as required by the specific project needs and as new information becomes available.

PRIORITIZATION OF MODEL FEATURES

It should be noted that it will be very difficult, if not impossible, to find a single hydrologic model that can meet the required features developed on the basis of Yolo County's modeling goals and objectives. Therefore, the WRA needs to prioritize the required features with regards to its importance for the integrated water management in Yolo County and select a model that can meet the highest priority features of the model.

SELECTION OF A PROVEN MODEL

The WRA should consider the following factors in selecting a model as part of its modeling strategy:

- That a proven model, even though it may have some limitations, but which has been applied to Yolo County or to similar groundwater basins with similar geographic and temporal scales is often a wiser choice than an unproven model with many of features;
- A non-proprietary model is often a better choice because of ease of maintenance, distribution, peer review and upgrade capabilities.

UTILIZATION OF EXISTING MODELS AND DATA

The modeling strategy for Yolo County should include a systematic process to utilize the databases used in the existing models. Therefore, a systematic inventory and investigation of all existing hydrologic models should be made to ensure that current knowledge is used instead of developing data from scratch. This modeling step will provide both cost effectiveness and credibility to the new model application.

ADDITIONAL DATA COLLECTION AND COMPILATION

The data collection and compilation is a costly task. Therefore, Yolo County's modeling strategy should include developing partnership with agencies that collect and store data in the County so that existing data and knowledge among the agencies can be best utilized. Also, some preliminary sensitivity analysis can be done on determining the most sensitive input data for the model and then direct the data collection and compilation resources accordingly.

SYSTEMATIC DATA MANAGEMENT PLAN

Yolo County's modeling strategy must include a systematic data management plan. The purpose of the data management plan is to establish a process for managing large volume of different types of model related data. Often, there are other project tasks, aside from modeling, which also use substantial amounts of data. Therefore, Yolo County's modeling strategy should include a coordination plan with the other project task leaders to ensure the consistency of the model data management plan with other ongoing data collection and analysis efforts.

There are many benefits of a systematic data management plan, such as, it

- Helps data collection, processing, and documentation process;
- Ensures data quality and integrity;
- Helps identify data gaps and needs;
- Informs all project participants about the location, status, and source of data;
- Supports data collection processes for future efforts; and
- Helps retrieve the data easily for verification and evaluation purposes.

There are four primary aspects of data that are required to be carefully addressed as part of the modeling strategy:

1. **Quantity Aspect**: How much data is necessary to make a decision?
2. **Quality Aspect**: How accurate is the data and how representative does the data need to be?
3. **Time Scale Aspect**: What time intervals are essential for different types of data?
4. **Space Scale Aspect**: What geographic area is to be covered and what spatial scale of data is required?

The purpose and scope of the modeling study determines these four aspects of data. A systematic approach with proper recognition of these four aspects will help achieve the goal of focusing only on the data that is needed for the project.

It is also very important to document all sources of raw data as well as document the data processing steps taken to prepare the input data for the model. As part of Yolo County's modeling strategy, two tools can be used to accomplish these documentation goals:

1. Data Inventory Matrix – that will keep track of the basic information about the four primary aspects of major categories of data, including the source(s)/contact(s) names and phone numbers and status of the data request; and

2. Data Flow Diagram – a detailed record of individual data items, including all data processing and quality control steps associated with them (e.g. what was the format of the raw data; what data was missing; what data processing programs and steps are used to estimate the missing data and ensure data quality; who checked the data quality; etc.).

SYSTEMATIC DOCUMENTATION/RECORD KEEPING PLAN

This is another key element of Yolo County's modeling strategy because good record keeping on all aspects of model development, from data collection to calibration and application, is an essential element of a modeling project. It provides an objective basis for evaluating the validity and soundness of a model, which will become a crucial issue during the implementation phase of the conjunctive use projects.

The purpose of the documentation/record-keeping plan is to establish a standard procedure that would allow tracking of all related information on the model, including model assumptions, technical memoranda, modeling notes, etc. A logical computer directory structure should be followed to enable organization and storage of electronic documents. The paper documents should be filed in 3-ring binders according to the same hierarchy as the electronic documents. A catalogue of all documents should be maintained in a reference MS Word or Excel file.

MODEL DEVELOPMENT PROCESS

An effective model development process is the most important element of the modeling strategy for the Yolo County. A seven-step model development methodology is recommended on the basis of practical considerations and experience in developing field scale models. At every step of this seven-step model development process, there will be increased understanding of the hydrologic system being modeled. This value chain of the model development steps is depicted in Figure 7-1.

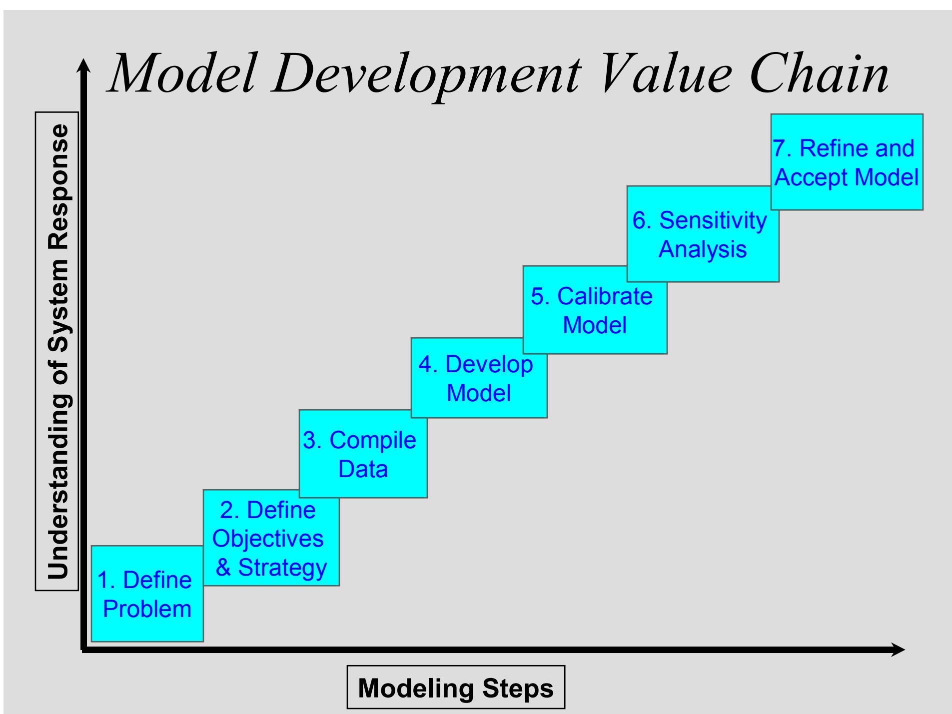

Figure 7-1: Modeling Steps and Model Development Value Chain

Stakeholder Involvement Process

The Yolo County modeling strategy should include a systematic stakeholder involvement process at different stages of model development to minimize disputes about data, mode assumptions, model calibration and alternatives analysis. The WRA Technical Committee should closely coordinate with the model development team with regular involvement and feedback from the broader stakeholder group and member agencies at different milestones of the modeling process.

Information about Model Limitations and Uses

Yolo County's modeling strategy should also include a process of informing the public and broader stakeholder group about the model limitations and potential uses, so that expectations about what the model can or cannot accomplish as an analytical tool are well placed. Typical model utilization pathways are shown in Figure 7-2.

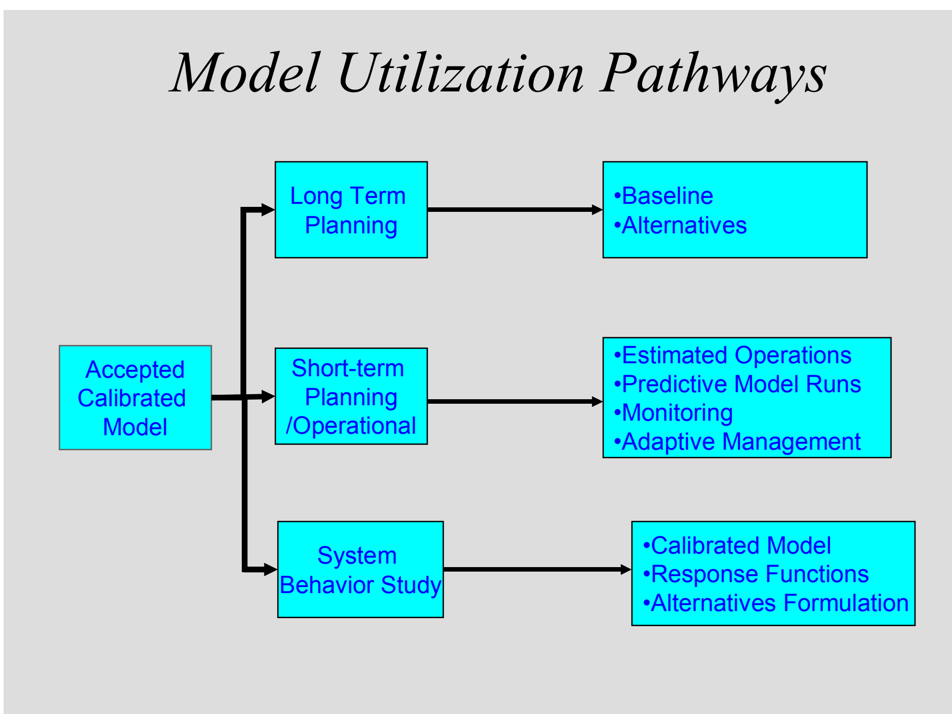

Figure 7-2: Different Uses of the Model

Several known limitations and potential uses of models are described below to serve as a guide for Yolo County modeling strategy.

USE OF MODELS FOR DEVELOPMENT AND/OR REFINEMENT OF BMOS

Basin Management Objectives (BMO) are basin operational criteria developed on the basis of historic measurements of well water levels, understanding and observations of groundwater basin behavior, and other field observations. A baseline model (with existing or 2030 conditions and historic hydrologic sequence as a surrogate for future hydrology) cannot be used to evaluate/ revise/implement BMOs, because the purpose of a baseline model is to give reference frame for analyses of alternative management plans, while BMOs are real-time operational guidelines. Furthermore, a model cannot tell whether BMOs are met or not met; the compliance with BMOs can be evaluated only through monitoring of the water levels in the area. Therefore, model should not be used for implementing the Glenn County Groundwater Management Ordinance.

However, a calibrated model can be used to (a) possibly re-examine the assumptions made during the development of the BMOs; (b) enhance the information background of an existing decision or a revised decision related to the Groundwater Management Ordinance or BMOs; (c) identify sensitive areas where additional monitoring may be required to check compliance with BMOs; (d) develop general response characteristics and/or sensitivity ranges among different physical and operational elements; and (e) enhance understanding of the groundwater system behaviors, characteristics, and constraints.

The use of the calibrated model for the above purposes is contingent upon how well the model matches the historical groundwater level observations and how well the model represents physical systems to provide insights (not exact answer) into the groundwater basin response characteristics and into the inter-relationships among different physical and operational elements.

USES AND LIMITATIONS OF MODELS IN MEETING THE PROJECT GOALS OF THE MEMBER AGENCIES

One of the goals of the project participants is to pursue conjunctive use opportunities to maximize program benefits through strategic, synergistic linkages with other regional water management activities and authorities. The model can help identify some opportunities or give some quantitative information to help formulate, understand, evaluate, and rank opportunities that can be specified in terms of model input data.

Another common goal of the project participants is to secure water supply reliability locally and provide opportunities for improved water supply reliability for water users' elsewhere in the state; the model can be used in a statistical mode to develop probabilistic measures of water supply reliability in the face of hydrologic uncertainties and different demand levels.

Another common goal is to seek ways to achieve environmental benefits that are compatible with project operations. A groundwater and surface water model cannot seek ways to achieve environmental benefits; also, a hydrologic model cannot determine whether environmental benefits are achieved or not. The model can provide information on the water levels and stream flows that can be used as an indicator or measure for evaluating environmental benefits of different alternative management plans.

A model will be able to assess on a comparative basis different alternative ways to manage surface water resources (e.g. reservoir re-operations, conjunctive use, water exchanges etc.). In addition, a calibrated model can provide general estimates of canal seepage loss ranges and help compare different alternatives of canal lining; a calibrated model also can help screen pumping well field sites or recharge sites on a preliminary basis. Both model input data and output data will be helpful in this regard.

GENERAL LIMITATIONS OF A MODEL

"Models are simplified mathematical representations of physical processes. Constructing a model that accounts for all the finest details of a process is not possible, nor is it useful or necessary." (Saquib Najmus in Water Resources Planning, AWWA Manual M50, AWWA, 2001, p.144). Thus no hydrologic model is an exact representation of the physical world.

Therefore, the simulated or predicted groundwater levels from a groundwater model should never be taken as absolute numbers to be compared against field measurements. Rather, the results of a calibrated groundwater model should be viewed as reasonable approximations of groundwater levels subject to the error ranges of history matching during calibration and also subject to the model assumptions, model set-up, and input data deficiencies.

However, it should be noted that a well-calibrated model could be used effectively in a comparative analysis mode to evaluate the relative impacts of different alternative scenarios.

SPECIFIC LIMITATIONS OF THE MODEL FOR YOLO COUNTY INTEGRATED HYDROLOGIC MODEL

The specific limitations of the model for the Yolo County Integrated Hydrologic Model cannot be determined a priori because they depend on (a) the model selection; (b) the conceptual model for the Yolo County model area; (c) the input data quality, level of accuracy, and deficiency; (c) necessary model assumptions; (d) necessary simplifications of physical system; (e) the specific performance of the calibration (history matching) for the Yolo County model application and the level of calibration, etc.

As part of the model development and documentation process the specific limitations of the Yolo County integrated hydrologic model should be evaluated and reported to help the project participants understand the modeling process as well as the model results and findings. It should also be noted that some potential uses of the model other than the specific purposes for which the model is developed, may require modifications of the Yolo County model application.

SECTION 8 CONCLUSIONS AND RECOMMENDATIONS

It can be concluded from the above discussion that none of the models that have previously been used in Yolo County is capable of meeting the full range of analysis capabilities needed for integrated water resources planning and management. In fact, no existing model code is capable of simulating all of the relevant processes and issues. A suite of software programs will need to be linked to create a truly comprehensive model. Creating new programs and linking existing ones requires a certain amount of customized programming, which can increase model development costs and increase the risk that future users will have difficulty using the model. Thus, it is desirable to minimize the number of individual software programs included in the model and to use well-documented existing programs to the extent possible. After comparing available modeling codes against 37 criteria identified as necessary or desirable for the Yolo County hydrologic model, it appears that IGSM is probably the best choice for the central component of the model. This recommendation is contingent on successful conclusion of DWR's review of IGSM and development of an improved version of the code, which are expected to be completed by summer 2002. The principal advantage of IGSM is its built-in capability to simulate many aspects of the hydrologic system, including land use and joint operation of surface water and groundwater resources.

On the basis of the above information, the following modeling approach is recommended:

1. Meet YCFCWCD's near-term modeling need by using the existing IGSM in the Lower Colusa Basin area to evaluate conjunctive use alternatives in the Yolo-Zamora area.
2. Extend the Lower Colusa Basin IGSM model to include the groundwater basin in Yolo County groundwater basin, with model boundaries possibly extended east and south of the county to coincide with more appropriate hydrologic boundaries.
3. Use data from previous models applied in Yolo County as much as possible to develop the aquifer stratigraphy and other groundwater related data for the IGSM application.
4. Extend the hydrologic simulation period up to year 2000 to capture most recent hydrology.

5. Calibrate the Yolo County IGSM application to local groundwater levels, stream flows, and water use based on historical data available from county and state agencies.

6. Link IGSM to the reservoir operations model of the Cache Creek system presently being developed by YCFCWCD, to obtain correct Cache Creek inflows and diversions at Capay Dam.

7. Use the County-wide IGSM application to simulate the effects of water resources management alternatives formulated by WRA and others pursuant to the integrated water management plan process.

Additional specific steps for model development and recommendations for data management are presented in Section 7, above. The recommended modeling strategy and approach represents a proven, systematic methodology that makes the most efficient use of previous models and available data.

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