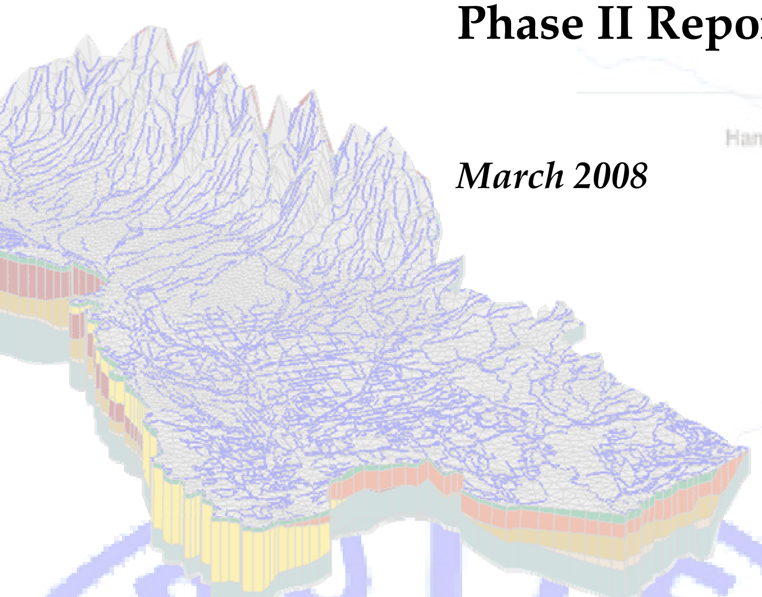
Butte County Department of Water and Resource Conservation

Butte Basin Groundwater Model Update
Phase II Report

March 2008



Technical Memorandum

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Introduction

1.1 Project Purpose and Scope

As part of the development of an Integrated Water Resource Plan the Butte County Department of Water and Resource Conservation (DW&RC) contracted with CDM to complete a review and update of the Butte Basin Water Users Association (BBWUA) Groundwater Model. The Updated Butte Basin Groundwater Model is an important water resource management tool for Butte County to complete local integrated water resource planning. Work on the model update was completed in two phases. Phase I consisted of:

- Reviewing the proposed use and application of an updated model,
- Assessing the suitability of the existing model,
- Recommending model modifications,
- And completing recommended updates and modifications.

The results of the Phase I efforts are documented in the report Butte Basin Groundwater Model Update Phase I Report (CDM 2004).

Phase II of this project encompassed the following items:

- Calibration of the model,
- Sensitivity analysis,
- Development of a Base Case, and
- Development of a water management scenario.

This document, the Butte Basin Groundwater Model Update Phase II Report, documents the final calibration and sensitivity analysis. It supersedes the Butte Basin Groundwater Model Update Phase II Interim Technical Memorandum (CDM 2005) which documented the model testing and initial calibration

Subsequent documentation will be developed to document the development and application of the Base Case and water management scenario.

1.2 Project Background

Following the drought period of the late 1980s and early 1990s, BBWUA funded the initial development of the BBWUA Groundwater Model to support water management activities. BBWUA subsequently entered into an agreement with Butte

County whereby model maintenance and updates would be completed by Butte County.

In the previous model, the hydrogeology of the Butte Basin was represented as generally undifferentiated sediment, resulting in a relatively simple stratigraphy of three basically horizontal layers. The California Department of Water Resources (DWR) Northern District Groundwater Section recently completed studies that provide a significantly improved interpretation of the basin's many stratigraphic units. As a result, the model stratigraphy needed to be completely restructured, and other model inputs updated to incorporate the latest land use and water management activities in the basin.

1.3 Proposed Groundwater Model Application

The original Butte Basin groundwater model, referred to as the BBWUA Groundwater Model in this report, was originally developed to assess the groundwater resources of the Butte Basin, develop a quantitative hydrologic understanding of the ground-water resources, and provide a tool for evaluating regional hydrologic impacts on the groundwater of alternative water policy decisions. These overall goals of the modeling have not changed. Specific objectives are listed below:

- Improve the understanding and characterization of the hydrogeology and groundwater hydrology of the Butte Basin.

- Support the periodic updates of the water inventory and analysis and annual groundwater status reports through the development of water budgets based on inventory units or other identified “zones”.

- Conduct project feasibility evaluations on water management alternatives identified during the IWRP.

- Assist in the screening of water transfer applications under Chapter 33 of the Butte County Code.

- Evaluate the potential regional impacts of droughts, or changes in surface water availability.

- Evaluate the benefits and impacts of recharge projects, and potential countywide conjunctive use programs.

- Provide the means through geographical and graphical interfaces to inform and educate stakeholders about the hydrogeology and hydrology of the basin.

The updated Butte Basin Groundwater Model documented in this report will provide DW&RC, BBWUA, and other stakeholders with a powerful resource management tool. It is important to emphasize that the objective of regional groundwater models is to achieve a representation of the basic hydrogeologic characteristics and controls of the groundwater flow system. Small-scale aquifer heterogeneities are represented by average, or bulk properties, for large volumes of aquifer material. As a regional model, the Updated Butte Basin Groundwater Model may not be capable of evaluating the potential yield or impacts of the operation of individual wells or recharge facilities. Such types of analyses require local-scale models which can represent small-scale heterogeneities in more detail. This regional model can be used as a starting point and guidance for the development of more localized models. Finally, no groundwater model, no matter how detailed, can eliminate the need for field measurement, or groundwater level and quality monitoring.

1.4 Acknowledgements

Funding and technical assistance in this project have been provided by: Butte County Department of Water & Resource Conservation, United States Bureau of Reclamation (USBR) Northern Area Office, Butte Basin Water Users Association, HCI Consultants, California DWR Northern District, and California DWR's Bay-Delta Office Modeling Support Branch.

1.5 Report Organization

This report is organized into five sections with three appendices. Figures are located at the end of each section. Tables are located within the text.

- Section 1 of the report introduces the project including the purpose, background, and proposed application of the calibrated groundwater model.

- Section 2 describes the groundwater model in general terms including the Integrated Water Flow Model (IWFM) modeling code and the model study area.

- Section 3 describes in detail model data and inputs, including numerous tables and figures.

- Section 4 evaluates the final calibration of the model. Appendix A provides comparisons of simulated and observed water levels for the 197 calibration wells discussed in Section 4. Appendix B provides graphs of annual budgets for agricultural applied water, stream flow, agricultural root zone moisture and groundwater by sub-region as discussed Section 4. Appendix A and B are provided in electronic format.

- Section 5 presents the results of sensitivity analysis using the final calibrated model.

- Section 6 lists references used in the text.

Section 2
Model Description

2.1 Introduction

The BBWUA Groundwater Model was developed using the FEMFLOW3D code (Durbin and Bond 1998). As part of the model update, CDM evaluated the capabilities of the FEMFLOW3D code to assess its suitability for application to the Updated Butte Basin Groundwater Model. Two other groundwater-surface water modeling codes were also reviewed and evaluated for this purpose: IWFM and DYNFLOW.

Based on the evaluation of the three codes, CDM recommended that the IWFM code be used for the updated model. DYNFLOW was also considered suitable for this project, but IWFM was selected because of California DWR's familiarity with the code and to expedite possible future merging of the Butte County model with the adjacent Stony Creek Fan model and other similar models in the region. FEMFLOW3D was not recommended because it is limited in some computational aspects.

2.2 Modeling Code

The Integrated Water Flow Model (IWFM) is a water resources management and planning model that simulates groundwater, surface water, surface-groundwater interaction as well as other components of the hydrologic cycle shown in Figure 2-1.

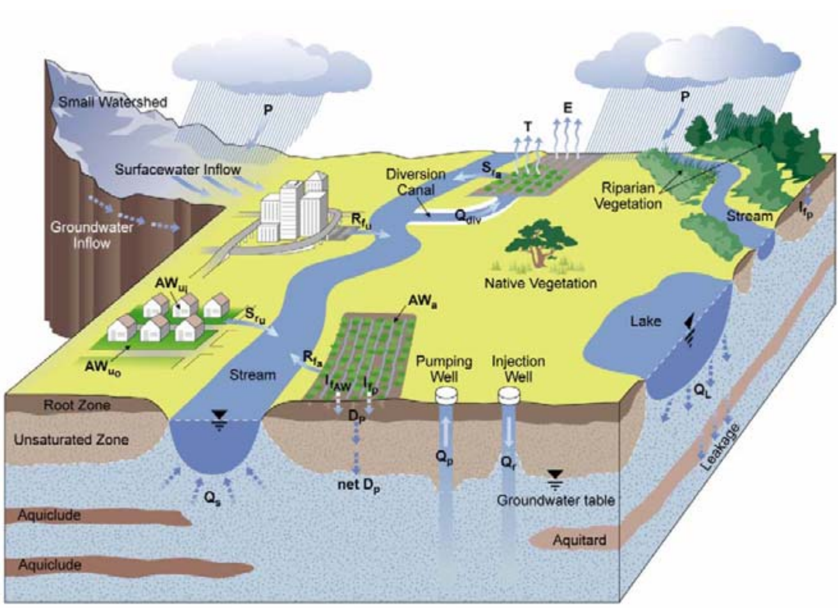

Figure 2-1: IWFM Hydrologic Components

IWFM was formerly known as IGSM2 (Integrated Groundwater and Surface water Model 2nd generation) with a name change taking place in September 2005.

IWFM was developed by staff in the Modeling Support Branch of California DWR's Bay-Delta Office. Technical support is also provided through this DWR office. IWFM was first released to the public as IGSM2 Version 1.0 in December 2002. Significant enhancements were made in 2003, and version 2.0 was released in December 2003.

The Butte County IWFM model uses IWFM v.2.4.1a and v. 2.4.1b for model computations. The original IGSM code, the precursor to IGSM2, was based on an earlier code called FEGW2, developed by researchers at the University of California at Los Angeles (UCLA) in late 1970s.

IWFM is a quasi-3 dimensional finite-element model that simulates, among other processes: groundwater flow, stream flow, reservoir operations, rainfall runoff processes, land use processes (crop consumptive use and evapotranspiration), unsaturated zone flow; and land subsidence.

2.2.1 Surface Water Hydrology

IWFM calculates flows and stages in streams based on a specified time series of stream inflows at the model area boundary and simulated flow additions and deletions within the model area. Modeled processes include agricultural surface runoff (Sr_a on Figure 2-1)) and return flow (Rf_a), urban return flow (Rf_u) and runoff (Sr_u), diversions (Q_{div}), and groundwater-surface water interactions (Q_s).

2.2.2 Land Surface and Root Zone Processes

Precipitation (P) and irrigation water applied to the land surface (AW) is routed to streams as runoff (Sr) and return flow (Rf) or to the root zone as infiltration(If). Root zone water is routed out of the system (to the atmosphere) as evapotranspiration (ET) and crop consumption or to the unsaturated (or vadose) zone as deep percolation (D_p). These computations depend primarily on land use, crop and soil characteristics assigned as model input.

2.2.3 Unsaturated Zone

Unsaturated zone hydraulic computations route deep percolation water (D_p) to the saturated zone water table (Net D_p). The thickness of the unsaturated zone is calculated each time step based on the water table elevation.

2.2.4 Saturated Zone

Modeled processes in the saturated zone include horizontal, vertical and boundary groundwater flow, interaction of surface water and groundwater (Q_s on Figure 2-1), recharge from deep percolation (net D_p), and extraction from groundwater pumping (Q_p).

2.3 Study Area

Butte County covers approximately 1,670 square miles, or 1.07 million acres and is located in the northern portion of the Central Valley (Figure 2-2), east of the Sacramento River. The County is bordered by Tehama County to the north, Plumas County to the east, Yuba and Sutter counties to the south, and Glenn and Colusa counties to the west.

2.3.1 Model Domain

The Updated Butte Basin Groundwater Model developed in this study was based on the original BBWUA Groundwater Model developed for the area. Figure 2-3 shows the domain of the previous BBWUA Groundwater Model. This model covered approximately 950 square miles focused mainly on the portion of Butte County that is within the Sacramento Valley Basin. The BBWUA Groundwater Model also extends north into Tehama County, west into Colusa and Glenn Counties, and south into Yuba and Sutter counties. The western boundary of the BBWUA Groundwater Model follows the Sacramento River.

The extent of the updated model is similar to that used in the BBWUA Groundwater Model in most areas. However, in the northeast, the Updated Butte Basin Groundwater Model domain was extended to incorporate areas hypothesized as the outcrop of the Tuscan Formation (CA DWR 2001) in the foothills as shown in Figure 2-3. This area was included in the Updated Butte Basin Groundwater Model in order to potentially assess the impacts of groundwater recharge to the Tuscan Formation through these outcrops. Additionally, the model was extended north to Deer Creek. The updated model domain encompasses 1,265 square miles.

2.3.2 Subregions

The model domain was been divided into 34 sub-areas for water balance accounting and to facilitate input and output of data from the model. The model subregions coincide with county inventory sub-units. The model subregions are shown in Figure 2-4.

2.3.3 Precipitation

Five precipitation stations were used to assign historical rainfall to the model. The name and location of these stations is shown in Figure 2-5. The distribution of average annual rainfall in the study area is shown in Figure 2-6, as published by the California Spatial Information Library (CaSIL).

2.3.4 Surface Water

Surface water features (e.g. streams and rivers) throughout the study area interact with the underlying groundwater. Depending on the relative elevations of the stream stage and the groundwater table, water may pass from the stream to the groundwater or may enter the stream from groundwater. The study area includes hundreds of small irrigation ditches and canals. However, only the larger, major streams and rivers are included in this model. Figure 2-7 illustrates the location of the major streams and water supply and drainage features incorporated in the model. The waterways explicitly incorporated into the model are the Sacramento River, Feather River, Yuba River, Singer Creek, Rock Creek, Pine Creek, Mud Creek, Big Chico Creek, Little Chico Creek, Little Dry Creek, Dry Creek, Butte Creek, N. Honcut Creek, S. Honcut Creek, and Deer Creek.

2.3.5 Land Use

Figure 2-8 shows the most current land use distribution for the revised model domain. The acreage within the revised model domain for each land use and crop-type in the DWR survey is listed in Table 2-1. Land use/crop assignments in the model for recent conditions are based on the most recent surveys completed by DWR at the time of the model construction. These land use surveys occurred between 1995 and 1999, depending on the county. The most recent DWR land use survey for Butte County occurred in 1999. To represent historic land use practices, land use for 1970 to 1994 were assigned based on data in the previous BBWUA Groundwater Model. The actual irrigated acreage for each irrigation district for each year (1970 – 1999) was assigned as specified in the BBWUA Groundwater Model.

Table 2-1
Model Crop Codes

DWR Code	*Description*	*Acres**	*Model Crop Number*
C	Subtropical	0	11
C-1	Grapefruit	0	11
C-2	Lemons	0	11
C-3	Oranges	59	11
C-4	Dates, subtropical fruits	0	11
C-5	Avocados	0	11
C-6	Olives	2,334	13
C-7	Miscellaneous	36	11
C-8	Kiwis	1,829	11
C-9	Jojoba	0	11
C-10	Eucalyptus	219	11
D	Deciduous Fruits and Nuts	1,285	8
D-1	Apples	434	8
D-2	Apricots	46	8
D-3	Cherries	262	8
D-5	Peaches & nectarines	11,538	8
D-6	Pears deciduous	8	8
D-7	Plums	0	8
D-8	Prunes	39,400	14
D-9	Figs	0	8
D-10	Miscellaneous	486	8
D-12	Almonds	47,368	2
D-13	Walnuts	38,913	21
D-14	Pistachios	441	8

Table 2-1 (continued)
Model Crop Codes

DWR Code	Description	Acres*	Model Crop Number
F	Field Crops	9	9
F-1	Cotton	20	9
F-2	Safflower	5,071	16
F-3	Flax	0	9
F-4	Hops	0	9
F-5	Sugar Beets	669	9
F-6	Corn (field)	5,539	5
F-7	Grain sorghum	61	9
F-8	Sudan	1,383	9
F-9	Castor Beans	0	9
F-10	Beans, dry (all types)	4,396	4
F-11	Miscellaneous Field	941	9
F-12	Sunflowers	4,788	18
G	Grain and Hay Crops	10,934	6
G-1	Barley	0	6
G-2	Wheat	51	6
G-3	Oats	349	6
G-6	Miscellaneous and mixed grain and hay	283	6
I	Idle	0	7
I-1	Land cropped within the past three years but not cultivated at the time of survey	9,609	7
I-2	New lands being prepared for crop production	1,029	7
NB	Barren And Wasteland	1,918	3
NB-1	Dry stream channels	0	3
NB-2	Mine tailing	1,929	3
NB-3	Barren land	0	3
NB-4	Salt flats	0	3
NB-5	Sand dunes	0	3
NC	Native Classes Unsegregated	0	23
NR	Riparian Vegetation	724	24
NR-1	Marsh Lands, tules and sedges	2,599	24
NR-2	Natural high water table meadow	554	24
NR-3	Trees, shrubs or other larger steam side or watercourse vegetation	16,221	24
NR-4	Seasonal duck marsh, dry or only partially wet during summer	30,324	24
NR-5	Permanent duck marsh, flooded during summer	5,294	24
NV	Native Vegetation	269,425	23
NV-1	Grass land	6,682	23
NV-2	Light brush	83	23
NV-3	Medium brush	4	23
NV-4	Heavy brush	280	23
NV-5	Brush and timber	895	23
NV-6	Forest	1,775	23

Table 2-1 (continued)
Model Crop Codes

DWR Code	Description	Acres*	Model Crop Number
NW	Water Surface	18,266	24
P	Pasture	143	10
P-1	Alfalfa & alfalfa mixtures	5,954	1
P-2	Clover	0	10
P-3	Mixed pasture	11,950	10
P-4	Improved native pasture	1,741	10
P-5	Induced high water native pasture	12	10
P-7	Turf farms	130	10
R	Rice	178,822	15
S	Semi-Agricultural	0	17
S-1	Farmsteads	4,032	17
S-2	Livestock feed lots	83	17
S-3	Dairies	30	17
S-4	Poultry farms	8	17
T	Truck and Berry Crops	29	12
T-1	Artichokes	0	12
T-2	Asparagus	0	12
T-3	Beans (green)	913	12
T-4	Cole crops	0	12
T-6	Carrots	0	12
T-7	Celery	0	12
T-8	Lettuce (all types)	11	12
T-9	Melons, squash, &cucumbers (all types)	3,857	19
T-10	Onions & garlic	6	12
T-11	Peas	0	12
T-12	Potatoes	0	12
T-13	Sweet Potatoes	0	12
T-14	Spinach	0	12
T-15	Tomatoes	445	19
T-16	Flowers, nursery, & Christmas tree farm	212	12
T-18	Misc. & mixed truck	352	12
T-19	Bushberries	0	12
T-20	Strawberries	36	12
T-21	Peppers (chili, bell, etc.)	0	12
T-22	Broccoli	0	12
T-23	Cabbage	0	12
T-24	Cauliflower	0	12
T-25	Brussels sprouts	0	12
U	Urban	11,006	22

CDM

Table 2-1 (continued)
Model Crop Codes

DWR Code	Description	Acres*	Model Crop Number
UC	Commercial	2,862	22
UC-1	Offices, retailers, etc	257	22
UC-2	Hotels	0	22
UC-3	Motels	6	22
UC-4	Recreation vehicle parking and camp sites	34	22
UC-5	Institutions (hospitals, prisons, etc.)	59	22
UC-6	Schools	748	22
UC-7	Municipal auditoriums, theaters, churches, stadiums, etc	96	22
UC-8	Misc. High water use	4	22
UI	Industrial	238	22
UI-1	Manufacturing	176	22
UI-2	Extractive industries	417	22
UI-3	Storage and distribution	2,100	22
UI-6	Saw mills	80	22
UI-7	Oil refineries	0	22
UI-8	Paper mills	0	22
UI-9	Meat packing plants	0	22
UI-10	Steel and aluminum mills	22	22
UI-11	Fruit and vegetable canneries	178	22
UI-12	Misc. High water use	239	22
UI-13	Sewage treatment plant, including ponds	393	22
UI-14	Waste accumulation sites	215	22
UL	Urban Landscape	141	22
UL-1	Lawn area-irrigated	379	22
UL-2	Golf course- irrigated	705	22
UL-3	Ornamental landscape (excluding lawns)- irrigated	0	22
UL-4	Cemeteries- irrigated	189	22
UL-5	Cemeteries - not irrigated	23	22
UR	Residential	13,238	22
UR-1	Single family dwellings with lot sizes greater than 1 acre up to 5 acres (ranchettes, etc.)	5,929	22
UR-2	Single family dwellings with a density of 1 unit/acre up to 8+ unit/acre	1,471	22
UR-3	Multiple family (apartments, condos, townhouses, barracks, bungalows, duplexes, etc.)	5	22
UR-4	Trailer courts	234	22
UV	Vacant	4,423	22
UV-1	Unpaved area (vacant lots, graveled surfaces, play yards, raw lands within metropolitan area, etc.)	4,928	22
UV-3	Railroad right of way	534	22
UV-4	Paved areas- (parking lots, oiled surfaces, flood control channels, tennis courts, auto sales lots, etc.)	2,080	22
UV-6	Airport Runways	259	22

Table 2-1 (continued) Model Crop Codes			
DWR Code	**Description**	**Acres***	**Model Crop Number**
V	Vineyards	155	20
V-1	Table grapes	1	20
V-2	Wine grapes	0	20
V-3	Raisin grapes	0	20

* Within model area, based on most recent land use survey (1995-1999).

2.3.6 Surficial Soil Classification

Soil classification information was obtained from the National Resources Conservation Service (NRCS, formerly Soil Conservation Service or SCS). Soil types were divided into four soil groups based primarily on runoff/infiltration properties. These four groups typically have the following characteristics:

- **Group A** (sands and gravels): These soils have high infiltration rates and low runoff potentials.
- **Group B** (mix of fine and coarse soils): These soils have moderate infiltration rates and low to moderated runoff potentials.
- **Group C** (fine soils): These soils have slow infiltration rates and moderate to high runoff potentials.
- **Group D** (clay soils): These soils have low infiltration rates and high runoff potentials.

Figure 2-9 shows the distribution of soil types in the model domain based on mapping complied by the NRCS. Within the model domain, the soils are predominantly Group D. Group C and Group B soils are predominately located near the major streams and rivers. There is no Group A soils in the model domain.

Basin Deposits, composed of shallow deposits of fine grained silt and clay, form the surficial layer in the primary rice growing area in Butte County (Figure 2-8). The Group D soils in the rice growing areas have a lower permeability than Group D soils in the hills and northern sections of the model domain.

2.3.7 Model Stratigraphy

The major groundwater bearing aquifers in Butte County lie within the larger Sacramento Valley groundwater basin. The domain of the updated model lies in portions of the Sacramento Valley groundwater basin (CA DWR 2003a). Figure 2-10 shows the location of the model domain with respect to the basin and sub-basins.

The principal hydrogeologic units of the Sacramento Valley groundwater basin in the study area consist of Pliocene sedimentary deposits, such as the Tuscan, Laguna and

Tehama Formations, and Quaternary terrace deposits, such as the Riverbank and Modesto Formations. The Tuscan, Laguna, and Tehama Formations are the source of water for deep irrigation and municipal wells, 90 percent of which are less than 750 feet deep. The Riverbank and Modesto Formations yield water to the shallower domestic wells, the majority of which are less than 200 feet deep. Deeper Miocene and Eocene Formations such as the Neroly, Lovejoy, and Upper Princeton Gorge formations are typically lower permeability deposits and are generally considered to be below the base of fresh water.

Table 2-2 lists each of the major geologic units within the study area along with a brief description. In the updated version of the model, the model is subdivided into nine layers, each layer representing a different aquifer unit as shown in Table 2-2. Each layer is bounded on the top and bottom by a level. Therefore, to create nine layers, the elevations of ten levels are defined.

Table 2-2 ***Model Layering & Hydrogeologic Description***		
Model Layer	***Aquifer Unit***	***Description***
1	Basin Deposits (Holocene)	Basin Deposits are shallow deposits of fine grained silt and clay with a thickness up to 200 feet. These silts and clays are from the erosion of the Cascade Ranges and the Sutter Buttes and were deposited in low-lying areas during flood events. The deposits have a low permeability and do not yield significant quantities of water. Areas of rice paddy agriculture in Butte County generally correspond with the occurrence of Basin deposits at the ground surface (DWR). Water in these deposits is often of poor quality.
2	Alluvium (Riverbank and Modesto Formations, Pleistocene)	Includes the Modesto Formation and the Riverbank Formation. Alluvium consists of surficial alluvium and stream channel deposits of gravel and cobbles with sand, silt, and clay. The deposits are from reworking of Tuscan and Laguna formations. Typically the maximum thickness is 200 feet. (DWR).
3	Sutter Formation (Pleistocene), Laguna Formation (Pliocene)	Exposure of the Laguna Formation is discontinuous and extends from Oroville southward to Lodi. Deposits are moderately consolidated alluvial sands, gravels and silts. Estimates of the Laguna's maximum thickness range from 180 feet (Helley and Harwood, 1985) to 1,000 feet (Olmsted and Davis, 1961). The Sutter Formation consists of alluvial fan deposits of gravel, sand, silt and clay derived from the Sutter Buttes. It has a maximum thickness of 980 feet (DWR).
4	Tehama Formation (Pliocene)	The Tehama Formation consists primarily of sandstone and siltstone with low to moderate permeability. It includes coarse grained lenses which create localized zones of high permeability. Well yields from the Tehama Formation are quite variable due to the varying permeability of the formation. The maximum thickness of the Tehama Formation is approximately 2,000 feet (DWR). Maximum thickness in Butte County is approximately 500 feet.
5	Tuscan C (Tuscan Formation, Pliocene)	The Tuscan Formation consists of layers of volcanic mudflows, tuff breccia, tuffaceous sandstone, and volcanic ash. It is described as four separate but lithologically similar units, Units A through D (Helley and Harwood, 1985). Unit A consists of the oldest deposits of the Tuscan Formation and has a maximum thickness of 400 feet. Units B and C have a maximum thickness of about 600 feet each and overly Unit A in most locations in Butte County. Unit D is the youngest unit and is not present in Butte County. Groundwater in the Sacramento Valley portion of Butte County is contained primarily within the two lower units of the Tuscan Formation, Units A and B (DWR).
6	Tuscan B (Tuscan Formation, Pliocene)	
7	Tuscan A (Tuscan Formation, Pliocene)	
8	Neroly, Upper Princeton Gorge, and Ione Formations (Miocene/Eocene)	Includes the Neroly, Upper Princeton Gorge, and Ione Formations. Marine to non-marine deposits of sandstone and conglomerate.
9	Base	Very low permeability layer included for numerical stability of the model.

The elevations of each of the layers at each model node, and therefore, the thicknesses and locations of each of the geologic units, were interpolated from surficial and cross-section geologic mapping developed by California DWR's Northern District (CA DWR 2001, 2002). DWR developed geologic cross-section through the study area. The locations of these cross-sections are shown in Figure 2-11.

Figures 2-12 and 2-13 show the cross-sections through the Updated Butte Basin Groundwater Model. The ground surface elevation was assigned to model nodes using a digital elevation model (DEM) provided by USEPA (USEPA 1998). Model layer 8, which represents marine deposits containing saline water, is included to evaluate potential saline water upwelling during simulation of increased pumping in the Tuscan A formation.

2.3.8 Water Supply

Both surface water and groundwater are used as water supply sources throughout the model domain. Urban water use is served primarily through groundwater pumping. Agricultural water needs are met by utilizing both surface water and groundwater sources.

Figure 2-14 shows the water source for areas within the model study area. Surface water is used predominately in rice-growing areas, groundwater in northern irrigated areas and a mix of both water sources in other areas.

The average annual surface water used for agriculture within the model domain is 1,240 thousand acre-feet (TAF). For urban uses the average annual surface water use is 5 TAF and the average annual groundwater use is 33 TAF.

Section 3
Model Input Data

3.1 Introduction

This section presents the model inputs including hydraulic parameters, boundary conditions, stratigraphy, land use data and pumping information.

3.2 Numerical Grid

The numerical model computations require that the model domain be divided, or discretized, into smaller units called elements and nodes. In this updated model these elements are represented by triangular areas. The vertices of the elements are termed nodes. Data is input to and output from IWFM at elements and/or nodes (depending on the data type). The finite-element grid used in the updated Butte Basin model is shown in Figure 3-1. The node spacing in this grid is approximately 5,000 feet over much of the model. The typical node spacing in the BBWUA Groundwater Model was approximately 8,000 feet. Finer node spacing, approximately 2,500 feet, was used in the vicinity of Chico and other areas where greater hydraulic gradients are expected in the groundwater flow field.

3.3 Hydrology

The precipitation and surface water inflow inputs to the model were based on historic measurements within the study area as discussed in Sections 2.3.3 and 2.3.4.

3.3.1 Precipitation

As discussed in section 2.3.3, there are 5 precipitation gages near the study area. Using Theissen polygons, each model element was assigned one of the precipitation stations as shown in Figure 3-2.

To ensure that the average simulated rainfall at each model element is consistent with this spatial distribution, a rainfall weighting factor was assigned to each element. This factor is a ratio of the average rainfall at each element based on the CaSIL data to the average rainfall at the corresponding rainfall gage. These ratios are multiplied by the gage precipitation value to determine the rainfall assigned to each element. The rainfall weighting factors are shown in Figure 3-2.

3.3.2 Surface Water Inflow

Each of the rivers that are modeled in this updated model originate in areas outside the model domain. River inflows are specified for the entire model period for each river at the point where the river enters the model domain.

These upstream inflow time series were developed based on daily streamflow gage data published by the United States Geologic Survey (USGS) and California DWR. The gage locations are shown in Figure 3-3. For streams where gage data is not available, inflow estimates developed for another similar stream was used, multiplied by an adjustment factor proportional to the ratio of the published long term average flows (Nady and Larragueta 1983) for the streams.

3.4 Stream Properties

In order for flow to be tracked in the streams and groundwater-surface water interaction calculated, the following physical properties of each river are required: channel profile, stage-discharge relationship, river bed thickness, and river bed hydraulic conductivity.

3.4.1 Stream Reaches

The rivers are divided into 25 reaches, and each reach is made up of a set of model nodes as shown in Figure 3-4. Some of the rivers are subdivided into reaches in order to facilitate the summarization and analysis of output data. River input data can also vary from reach to reach. Therefore, if one portion of a river has different properties (e.g. cross-sections) it may warrant the separation of the river into distinct reaches.

Each of the individual symbols in Figure 3-4 indicate a river node. The additional river parameters discussed below are actually specified at these nodes. In all, the updated model includes nearly 750 river nodes.

3.4.2 Channel Profiles

The elevation of the river bed is specified at each river node. River bed elevation assignments were made by interpolation from information in the BBWUA Groundwater Model. Adjustments to these elevations were based on data from DWR stream gages and ground surface datasets. Figures 3-5 through 3-8 show channel profiles for each river.

3.4.3 Rating Tables

IWFM requires the definition of a relationship between river depth and river discharge at each of the river nodes. Published stage-discharge data from DWR was used to make the initial assignments. Figure 3-3 shows the locations of the available depth-discharge data points. For streams where no DWR depth-discharge relationship was available, depth-discharge relationships were interpolated from other streams based on average streamflow. The depth-discharge relationships are shown in Figure 3-9 through Figure 3-11.

3.4.4 Streambed Properties

The physical characteristics of the streambed material were specified as follows to define the hydraulic resistance to flow between streams and groundwater. Model sensitivity to changes in streambed resistance is documented in Section 5.4.

- **Bed thickness**: Based on the BBWUA Groundwater Model and other models in the area, streambed thickness as set to 1 meter (3.28 feet) for all modeled streams and rivers.

- **Bed hydraulic conductivity**: Detailed estimates of streambed hydraulic conductivity were not available. The streambed hydraulic conductivity was therefore set to a value of 1 foot per day for all modeled streams and rivers.

- **Wetted Perimeter**: The average wetted perimeter of each reach was estimated from aerial photos and available topographic maps. Wetted perimeter values are shown in Table 3-1.

Table 3-1
Wetted Perimeter Values

Reach	*Reach Number*	*Wetted Perimeter (ft)*
Deer Creek	1	35
Singer Creek	2	25
Pine Creek above Singer Creek	3	40
Pine Creek below Singer Creek	4	30
Rock Creek	5	15
Mud Creek	6	20
Big Chico Creek	7	50
Little Chico Creek	8	15
Angel Slough	9	40
Little Butte Creek	10	15
Butte Creek above Durham Slough	11	65
Little Dry Creek	12	30
Dry Creek	13	30
Cherokee Canal	14	50
Butte Creek below Durham Slough	15	65
Feather River above Thermalito Afterbay	16	250
Feather River above S Honcut Creek	17	300
North Honcut Creek	18	25
South Honcut Creek	19	25
Yuba River	20	150
Feather River above Yuba River	21	300
Sacramento River above Glen-Colusa Irrigation District Pumping Plant	22	425
Sacramento River above Stony Creek	23	400
Sacramento River below Stony Creek	24	400
Sacramento River above Highway 20	25	375

3.4.5 Land Surface Drainage

Land surface drainage in IWFM consists of both surface runoff and return flow discussed in Section 3.5. Drainage from agricultural lands is directed to a specified stream node for each subregion. Colored polygons on Figure 3-12 represent drainage areas within the model. Surface flows from agriculture, native, and riparian land in these areas drain to a stream node, marked with an orange triangle on Figure 3-12, which is generally located in the southern or western edge of each drainage area.

Urban drainage can be specified to enter a stream at a specified node, leave the model, or be recharged to groundwater. This allows for accounting of urban wastewater discharged to streams or groundwater. Table 3-2 lists the drainage specification locations for urban areas within the model. These locations are based on the discharge locations for municipal wastewater. Locations are also shown with green pentagons on Figure 3-12.

Table 3-2
Urban Drainage

Subregion	City	Stream Node for Specified Return Flow	Wastewater Discharge Location
2	Chico	661	Sacramento River
5	Durham	661	Sacramento River
17	Oroville	520	Feather River
18	Biggs	456	Cherokee Canal
20	Gridley	534	Feather River
21	Oroville	520	Feather River
24	Live Oak	-2 (out of model)	Canal which drains out of model domain
34	Marysville	-2 (out of model)	Feather River, outside of model domain

3.4.6 Stream-Groundwater Interaction

Flow of water across the streambed in to or out of a river is computed for each river node by IWFM. The rate and direction of flow is computed based on the difference between the groundwater head and the river stage, and the river bed resistance defined by the bed thickness, hydraulic conductivity and wetted perimeter.

3.5 Land and Root Zone Processes

Land surface and root zone processes are simulated to calculate runoff and return flow to streams, infiltration to the root zone, evapotranspiration and deep percolation to the unsaturated zone. Land use type and surficial soil properties are specified in each model element.

3.5.1 Land Use

To maintain consistency with the land use data used in the BBWUA Groundwater Model, some of the individual crop types listed in Table 2-1 were combined with other similar crops into a single crop category for model input. Hence, a "model crop number" is also shown in Table 2-1 which indicates which crops are combined for model input. Table 3-3 summarizes the crops by categories assigned in the model along with associated acreage based on the most recent land use survey.

Table 3-3 Summary of Model Crop Codes		
Model Crop Number	**Description**	**Acres***
1	Alfalfa	5,954
2	Almonds	47,368
3	Barren/wasteland	3,847
4	Beans, dry	4,396
5	Corn	5,539
6	Grain(all)	11,618
7	Idle	10,638
8	Misc. Deciduous (all except almonds, prunes, walnuts)	14,499
9	Misc. Field(all except dry beans, corn, safflower, sunflower)	3,084
10	Misc. Pasture(all except alfalfa)	13,976
11	Misc. Subtropical(all except olives)	2,144
12	Misc. Truck(all except tomato, melon, squash, cucumber)	1,560
13	Olives	2,334
14	Prunes	39,400
15	Rice	178,822
16	Safflowers	5,071
17	Semi-agriculture	4,152
18	Sunflowers	4,788
19	Tomato, melon, squash, cucumber	4,302
20	Vineyards(all)	156
21	Walnuts	38,913
22	Urban	53,667
23	Native	279,143
24	Riparian	73,982

*Within model area, based on most recent land use survey (1995-1999).

3.5.2 Root Zone Properties

Calculations for evapotranspiration, return flow, infiltration, and deep percolation are based on processes in the root zone. The potential volume of water stored in the root zone depends on root zone depth, total porosity, and field capacity.

- **Root Zone Depth:** Root zone depths are specified for each crop type, native and riparian vegetation, and urban land. Depths used in the model are listed in Table 3-4.

Table 3-4 Root Zone Depths		
Model Crop Number	**Description**	**Crop Root Zone Depth (inches)**
1	Alfalfa	72
2	Almonds	72
3	Barren/wasteland	12
4	Beans, dry	36
5	Corn	42
6	Grain (all)	60
7	Idle	24
8	Misc. Deciduous (all except almonds, prunes, walnuts)	45.6
9	Misc. Field (all except dry beans, corn, safflower, sunflower)	60
10	Misc. Pasture (all except alfalfa)	36

Table 3-4 Root Zone Depths		
Model Crop Number	***Description***	***Crop Root Zone Depth (inches)***
11	Misc. Subtropical (all except olives)	24
12	Misc. Truck (all except tomato, melon, squash, cucumber)	36
13	Olives	24
14	Prunes	45.6
15	Rice	12
16	Safflowers	36
17	Semi-agriculture	6
18	Sunflowers	36
19	Tomato, melon, squash, cucumber	48
20	Vineyards (all)	72
21	Walnuts	72
22	Urban	12
23	Native	24
24	Riparian	72

- **Porosity:** The total porosity is the ratio of voids to total soil volume. For this model the total porosity of the root zone is set to 0.30.

- **Field Capacity:** Field capacity is the quantity of water retained by the soil when gravitation forces are balanced by surface tension and there is no drainage due to gravity. Field capacity is input as length/length in IWFM and converted to a depth by multiplying by the crop root zone depth for soil moisture calculations. Field capacities were assigned according to the surficial soil group as follows: Group A 0.04; Group B 0.06, Group C 0.07, and Group D 0.08.

3.5.3 NRCS Curve Number for Computing Runoff

The NRCS method for developing the relationship between rainfall and runoff is used to compute direct runoff from precipitation in IWFM. The relationship is based on a "curve number" indicating infiltration or runoff potential at each model element. Curve number is assigned based on local soil type and land use. When computing runoff, IWFM adjusts the assigned curve number for each element based on the antecedent moisture content of the soil. The NRCS method defines a relationship between daily rainfall and runoff. Therefore, it is appropriate for these calculations to run the model on a daily time step using daily rainfall data.

Curve numbers for each surficial soil type and land use in the model are shown in Table 3-5. These curve numbers are based on dry antecedent soil moisture conditions. IWFM adjusts runoff as antecedent soil moisture increases.

Table 3-5 Curve Numbers (CN / CN*) by Soil Group and Land Use				
Land Use	**Agriculture**	**Urban**	**Native Vegetation**	**Riparian Vegetation**
Soil Group A	67 / 96.1	70 / 96.6	65 / 95.7	65 / 95.7
Soil Group B	72 / 96.9	75 / 97.3	70 / 96.6	70 / 96.6
Soil Group C	80 / 98.0	82 / 98.2	78 / 97.7	75 / 97.3
Soil Group D	85 / 98.6	85 / 98.6	83 / 98.3	80 / 98.0
Curve numbers are generally developed based on rainfall, runoff and retention rates in inches. Because the model uses feet as the base unit of length, a modified curve number, CN*, was computed for use in the model as follows CN* = (12000 CN) / (110 CN + 1000).				

3.5.4 Runoff from Impervious Urban Land

All precipitation which falls on urban impervious land (e.g. rooftops and paved areas) becomes runoff. For this model, the percentage of impervious urban land is 60 percent for all sub-regions.

3.5.5 Return Flow

Runoff from agricultural and urban water application is termed "return flow" in IWFM. Return flow is calculated based on the applied water, the soil moisture content in the root zone, root zone depth (shown in Table 3-4), and the total porosity of the root zone. Return flow drains to streams or out of the model domain as discussed in section 3.4.5.

3.5.6 Infiltration

Precipitation which does not become surface runoff infiltrates the ground surface and enters the root zone. Irrigation and urban applied water which does not become return flow is also assumed to infiltrate. Return flow is discussed in Section 3.5.6. Water that infiltrates into the root zone is available to satisfy evapotranspiration needs or to percolate into deeper soil horizons.

3.5.7 ET and Consumptive Use

The monthly potential evapotranspiration (ET) rate is assigned in the model for each modeled crop/land use. The simulated ET at any given time may be less than potential ET, depending on the soil moisture level. In IWFM, the potential ET rate is applied if soil moisture exceeds one-half of field capacity. At lower soil moisture levels, the computed ET rate varies linearly with soil moisture from zero at the wilting point to the potential rate at one-half of field capacity. The potential ET rates for each modeled crop are shown in Figure 3-13 through Figure 3-17.

To account for the flooding of rice fields, the timing of ET/consumptive use assigned to rice in the model was adjusted to more closely match the timing of water application. In the process of shifting the ET pattern in time, the total amount of annual ET remained unchanged. IWFM does not explicitly represent storage of excess irrigation water in rice paddies and, therefore, this adjustment was made to prevent IWFM from erroneously computing too much runoff early in the growing season when irrigation water application exceeds crop needs. Most of the runoff should be computed near the end of the growing season to the degree that total application exceeds total rice ET and deep percolation.

3.5.8 Deep Percolation

Water which infiltrates the root zone is available to percolate to deeper soil horizons. In IWFM v.2.4.1, soil moisture is calculated for each time step based on infiltration and evapotranspiration. The volume of soil moisture in excess of field capacity (soil moisture not drainable by gravity) is available for deep percolation. At each computational time step, a fraction (K) of the excess soil moisture is assumed to enter the unsaturated zone as deep percolation. This parameter is used in the model instead of root zone hydraulic conductivity at the suggestion of the model developers at the CA DWR. Specified values of K in the model vary from 0.05 to 0.95 according to subregion and soil type. Values for this fraction are shown in Table 3-8 and subregion groups are shown in Figure 3-18.

Values for K were adjusted by subregion group to reflect the variations in soil properties within the A, B, C and D soil type groups. Subregions with predominantly Basin Deposits in the surface layer have slower infiltration rates and were assigned smaller K values. Subregions were also grouped along the Sacramento River, Feather River, and in the Tuscan outcrop area.

Table 3-6
Fraction of Excess Soil Moisture, K, to Deep Percolation by Soil Type

Subregions	***Soil Type Group***		
	B	***C***	***D***
1, 3, 7, 8, 9	0.8	0.7	0.25
2, 4, 5, 6	0.85	0.75	0.25
10, 11, 14, 22, 23	0.8	0.7	0.2
17, 20, 21, 27, 28, 29, 30, 31, 32, 33, 34	0.7	0.6	0.21
12, 13, 15, 16, 18, 19, 24, 25, 26	0.2	0.1	0.05

3.6 Subsurface Hydraulic Parameters

Water in the unsaturated zone is stored as soil moisture and routed to the saturated zone as net deep percolation. The saturated zone is composed of nine layers based on basin stratigraphy as presented in Section 2.3.7.

3.6.1 Unsaturated Zone

Recharge from the root zone to the unsaturated zone is termed "deep percolation" in IWFM. Recharge from the unsaturated zone to the groundwater table is termed "net deep percolation" in IWFM. The "net deep percolation" is the total volume of recharge which reaches the water table. "Deep percolation" and "net deep percolation" differ because of the travel time through, and storage in, the unsaturated zone. The unsaturated zone tends to damp and lag the simulated response of the saturated groundwater to changes in rainfall and applied irrigation water. However, the selected unsaturated zone parameters route water relatively quickly to the water table.

The thickness of the unsaturated zone is calculated in IWFM based on the elevation of the water table and ground surface. In the IWFM model the unsaturated zone was divided into two layers. Layer 1 includes the top of the unsaturated zone up to 50 feet deep. An effective porosity of 0.05 and hydraulic conductivity of 25 feet/day was assigned to layer 1. The remainder of the unsaturated zone where it is greater than 50 feet deep (Layer 2) was assigned an effective porosity of 0.1 and a hydraulic conductivity of 10 feet /day.

3.6.2 Model Layering

Vertically the domain of the model needs to encompass the geologic layers that are reasonably connected and will potentially be stressed during the conditions that will be simulated. Stratigraphy in the study area was represented with 8 layers plus a base layer.

- Basin Deposits (layer 1),
- Alluvium Formation (layer 2),
- Sutter Formation (layer 3),
- Laguna Formation (layer 3),
- Tehama Formation (layer 4),
- Tuscan Formation (layers 5, 6 and 7),
- and Neroly, Upper Princeton Gorge, and Ione Formations (layer 8).

Figure 3-19 is a plan view showing the extent and thickness of the Basin Deposits in model layer 1. Figure 3-20 shows the extent and thickness of the Alluvium Formation in model layer 2. Figure 3-21 shows the extent and thickness of model layer 3 which includes the Sutter Formation (in green on the figure) and the Laguna Formation (in pink on the figure). Figure 3-22 shows the extent and thickness of the Tehama Formation in model layer 4. Figures 3-23, 3-24 and 3-25 show the extent and thickness of the Tuscan Formation in layers 5, 6 and 7. Figure 3-26 shows the extent and thickness of the Neroly, Upper Princeton Gorge, and Ione Formations in model layer 8. Layer 9, included as a numerical “buffer” layer to prevent drying out of model layers as elevations increase into the foothills, is a uniform 1,500 feet thick.

3.6.3 Saturated Zone Hydraulic Properties

The key aquifer hydraulic properties specified in the groundwater flow model are saturated hydraulic conductivity in the horizontal and vertical directions, specific yield, and specific storativity. Table 3-7 lists the hydraulic conductivity values that are specified in the model for each of the layers. Model sensitivity to variations in hydraulic property assignments is documented in Section 5.2.

- **Horizontal Hydraulic Conductivity**: The horizontal hydraulic conductivity values assigned in the model are shown in Table 3-7 for each of model layer/formation. The initial assigned values for each of these parameters was developed based on information from previous studies, DWR pumping test results, and the previous models in the area (HCI 1996 and WRIME 2003). The assigned values were refined during the calibration process (discussed in Section 4).

Table 3-7
Calibrated Hydraulic Conductivity Values

Model Layer	*Aquifer Unit*	*Hydraulic Conductivity (feet/day)*	*Vertical Conductivity (feet/day)*
1	Basin Deposits	5	0.05
2	Alluvium (Riverbank and Modesto Formations)	130	1.3
3	Sutter Formation	80	0.8
	Laguna Formation	20	0.8
4	Tehama Formation	200	2
5	Tuscan C Formation	25	0.25
6	Tuscan B Formation	100	1
7	Tuscan A Formation	125	1.25
8	Miocene/Eocene Formations	2	0.02
9	Base Layer	0.01	0.0001

- **Vertical Hydraulic Conductivity**: The vertical hydraulic conductivity values are lower than corresponding horizontal hydraulic conductivity values by two orders of magnitude.

- **Specific Yield**: Specific yield was set to 0.1 for all layers based on previous modeling work in the study area. The specific yield parameter only applies at the water table, so the specific yield value assigned to lower model layers has little affect on the simulations.

- **Specific Storativity**: Specific storativity values were set to 0.00001 per foot for all layers based on previous modeling work in the study area.

3.7 Saturated Zone Boundary Conditions

Along the perimeter of the model domain, as well as the top and bottom of the model, the assigned boundary condition represents the physical process by which water crosses, or does not cross, the boundary. Boundary conditions for the model include no flow boundaries, specified flux boundaries, specified fixed head boundaries and head dependent flux (3rd type) boundary conditions. Locations of these boundaries are shown on Figure 3-27 and discussed below.

Inputs at the ground surface include precipitation, irrigation, and urban water application. As discussed in Sections 3.5 and 3.6, precipitation and applied water is routed through the root zone and unsaturated zone to streams in the form of runoff/return flow, to the atmosphere as evapotranspiration, to the unsaturated zone as deep percolation and (ultimately to the water table as net deep percolation).

3.7.1 Surface Water

The interaction of surface water features with groundwater is represented by both specified fixed flux and model calculated head dependent flux boundary conditions.

- **Rivers**: One of the important computational boundary conditions for the groundwater flow model is defined by computed groundwater discharge to and recharge from rivers. This includes all of the rivers listed in Section 2.3.5. The rate and direction of flow is computed based on the difference between the simulated groundwater head and simulated river stage, the river bed thickness, hydraulic conductivity and wetted perimeter.

- **Thermalito Afterbay**: A fixed rate of groundwater recharge from the Thermalito Afterbay was set in this model (green area on Figure 3-27). A rate of 10,000 acre-feet per year was assigned based on data in the BBWUA Groundwater Model. This rate was evaluated as part of calibration and sensitivity analysis.

3.7.2 Base of Model

A no-flow boundary condition is assigned at the base of the model (below layer 9), consistent with the relatively impermeable nature of the rock there. As noted above, the bottom layer is a very low permeability layer included for numerical stability of the model.

3.7.3 North Boundary

The north boundary of the model coincides with Deer Creek. The boundary condition in the top layer is defined by the groundwater-surface water interaction with Deer Creek.

Below the top layer, a no-flow boundary condition was assigned to the eastern portion of Deer Creek in the hills (black line on Figure 3-27). Groundwater elevation data is not available in the area. The boundary is approximately aligned with the direction of estimated regional groundwater flow and little groundwater is expected to cross the boundary.

Groundwater elevation data is available near the western portion of deer Creek which runs along the plain towards the Sacramento River. A specified fixed head boundary (purple line on Figure 3-27) was assigned in the Tuscan C Formation (layer 5) to the western portion of the Deer Creek based on average groundwater levels measured by DWR in nearby wells. This boundary condition allows for flow of water across the boundary due to urban and agricultural groundwater withdrawals.

3.7.4 East Boundary

A no-flow boundary condition was assigned along the east boundary of the model (black line on Figure 3-37). This eastern edge of the model coincides with the approximate limit of the groundwater basin and incorporates the Lower Tuscan outcrop/recharge area.

3.7.5 South Boundary

The southern model boundary is aligned with the Yuba River and the Sutter Buttes. A no-flow boundary condition is assigned along the perimeter of the Sutter Buttes (black line on Figure 3-37). Where the southern boundary of the model coincides with the Yuba River, the boundary condition in the top layer is defined by the groundwater-surface water interaction with the Yuba River. Below the top layer, a no flow boundary condition was assigned (black line on Figure 3-37) because the boundary is approximately aligned with the direction of estimated regional groundwater flow and little groundwater is expected to enter or leave the model domain.

East of the Buttes, a specified fixed head boundary was assigned to the southern boundary between the Sutter Buttes and Yuba River (purple line on Figure 3-37). Fixed head boundaries were assigned to the Sutter (layer 3), Tuscan B (layer 6), and the Miocene/Eocene (Layer 8) Formations based on average groundwater levels measured by DWR in nearby wells.

West of the Buttes, a fixed outward flux (green line on Figure 3-37) of 1,700 acre-feet per year was assigned in the Tehama Formation (layer 4) to the portion of the southern boundary between the Sutter Buttes and Sacramento River. These flux assignments were based on previous modeling work in the study area.

3.7.6 West Boundary

The western boundary of the model is aligned with the Sacramento River. Groundwater interaction with the Sacramento River defines the top layer boundary condition. Specified fluxes were assigned to the layers representing the Alluvium, Tehama, Tuscan C, and Tuscan B Formations (red line on Figure 3-27).

The specified fluxes are based on C2VSIM modeled fluxes under the Sacramento River (Brush 2007). C2VSIM is a three-layer integrated land surface-groundwater-surface water model of California's Central Valley developed using IWFM. The calibrated model is being used as the basis for the groundwater flow component of CALSIM-III, a water resources planning model for simulating operation of the California State Water Project and Federal Central Valley Project. C2VSIM modeled flux data from October 1970 to October 1999 for nodes underneath the Sacramento River was used to develop the specified fluxes for the Updated Butte Basin Groundwater Model.

Based on elevations and aquifer properties, the fluxes from layer 1 of the C2VSIM model were assigned to layer 2 (Alluvium) of the Updated Butte Basin Groundwater Butte Model. Fluxes from C2VSIM layer 2 were assigned to layer 4 (Tehama), layer 5 (Tuscan C) or layer 6 (Tuscan B) based on the thickness of each formation and elevation relative the C2VSIM layer 2 elevations. This resulted in three groups of nodes along the Sacramento River boundary as shown in Figure 3-27. Transient data was used from the C2VSIM model, so the boundary flows vary in size and flow direction with time.

"Group 1" is the southern section of the Sacramento River boundary. In this area layer 4, the Tehama Formation, is the thickest layer. Fluxes from layer 2 of the C2VSIM model were therefore assigned to layer 4. The average net flow under the Sacramento River boundary in this section is 18 percent in the Alluvium and 82 percent in the Tehama.

"Group 2" is the middle section of the Sacramento River boundary. In this section layer 5, the Tuscan C Formation, is the thickest layer. Fluxes from layer 2 of the C2VSIM model were therefore assigned to layer 5. The average net flow under the Sacramento River boundary in this section is 40 percent in the Alluvium and 60 percent in the Tuscan C.

"Group 3" is the northern section of the Sacramento River boundary. In this section layer 6, the Tuscan B Formation, is the thickest layer. Fluxes from layer 2 of the C2VSIM model were therefore assigned to layer 6. The average net flow under the Sacramento River boundary in this section is 64 percent in the Alluvium and 36 percent in the Tuscan B.

In addition to different layering, the Updated Butte Basin Groundwater Model has a finer discretization (i.e. smaller elements and more nodes) than C2VSIM. Nodes in the Updated Butte Basin Groundwater Model were grouped with the nearest corresponding C2VSIM node located along the same portion of the Sacramento River boundary. The C2VSIM flux at each node was then divided equally amongst the corresponding Updated Butte Basin Groundwater Model nodes.

3.8 Water Supply

Surface water diversions and urban groundwater pumping are specified for each subregion. Groundwater pumping to meet agricultural demanded is computed by IWFM.

3.8.1 Urban Groundwater Pumping

Historical monthly municipal and industrial (M&I) groundwater pumping is directly assigned in the model. Historical pumping rates were input to the model for the following cities: Chico, Biggs, Gridley, Oroville, Durham, Live Oak,; and Marysville on a well-by-well basis. The M&I well pumping data was compiled directly from the BBWUA Groundwater Model. Well locations were also developed from the BBWUA Groundwater Model data. Where well screens span multiple model layers, the assigned pumping flux is vertically distributed according to the relative layer transmissivities. The locations of M&I wells represented in the BBWUA Groundwater Model are shown in Figure 3-28. Annual urban groundwater pumping is shown in Figure 3-29.

3.8.2 Urban Water Use

Urban water is divided into indoor and outdoor water uses. The fraction of indoor water use varies monthly as shown in Table 3-8. Indoor water becomes return flow and is routed as specified in Section 3.4.5. Outdoor water use is treated like irrigation water; i.e. evapotranspiration, recharge, and return flow are calculated for outdoor water.

Table 3-8
Fraction Urban Indoor Water Used Indoors

Month	***Fraction of Urban Water Used Indoors***
October	0.44
November	0.54
December	0.67
January	0.66
February	0.47
March	0.31
April	0.25
May	0.29
June	0.32
July	0.40
August	0.44
September	0.42

3.8.3 Irrigation Requirements

IWFM calculates an agricultural supply requirement based on crop requirements and specified irrigation efficiency. This supply requirement can be met through surface water diversions or groundwater pumping. In this model, the monthly surface water diversion quantities applied to each agricultural area are specified based on data from the original BBWUA Groundwater Model. Irrigation requirements not met by application of surface water are met by groundwater pumping computed by IWFM in areas where groundwater pumping occurs as shown in Figure 3-28.

3.8.4 Water Reuse

IWFM allows for recapture and reuse of return flow for irrigation. This reuse is specified as a fraction of the calculated return flow. For this model, reuse water was specified as 10 percent of the return flow.

3.8.5 Surface Water Diversions

Surface water diversion data for water districts, unorganized areas, and urban water use in the model domain were compiled in the BBWUA Groundwater Model for the period from 1970 – 1999 (Figure 3-30 through Figure 3-33). Most of the surface water used for irrigation in Butte County is delivered in canals leading from the Thermalito Afterbay. This water is diverted into the Thermalito Afterbay from the Feather River outside (upstream) of the model domain, and therefore this diversion does not affect the river flow simulation within the model. Similarly, surface water used in the Wyandotte and North Yuba inventory sub-units is also diverted from the Feather River outside of the model domain. On the other hand, surface water used in Butte County taken from Butte Creek, Little Butte Creek, and Big Chico Creek is diverted within the model domain and was assigned as diversions from these rivers in the model.

In addition to the diversions from the Sacramento River that are delivered to areas east of the river, diversions that are delivered to the west side of the river are also included. The data to simulate these west-side diversions was obtained from the Stony Creek Fan IGSM model (WRIME, 2003).

A portion of the points of river diversion occur from portions of rivers and streams that are outside the model domain. In this case, the volume of water that is diverted is delivered to the agricultural areas, but is not directly diverted from the stream reaches within the model domain.

3.8.6 Agricultural Pumping

As mentioned previously, this updated model makes use of IWFM's capability to automatically compute estimated agricultural pumping based on crop requirements, soil moisture, and specified irrigation efficiency for a given crop. The required pumping is spread evenly over specified elements within the subregion. The locations where groundwater can be pumped are based on DWR's mapping of water source areas (Figure 2-14). Pumping is distributed between the layers by assigning fractions of the water pumped for each model layer based on the Butte County Groundwater Inventory Report (CA DWR 2000). Figure 3-28 shows the specific model elements that were available to be used for groundwater pumping.

Section 4
Model Calibration

4.1 Introduction

Model calibration is the process of adjusting model input parameters within a prescribed range until the output from the model reasonably matches a set of measured data and the observed transient behavior of the ground water flow system (e.g., seasonal head changes). The final calibration examined both synoptic and transient groundwater heads, as well as stream flow and stage and water budgets. In the groundwater synoptic calibrations, measured and model-computed heads (water levels) are compared, and the difference between the two (the residual) is calculated.

4.2 Calibration Simulation

The calibration simulation uses the input parameters discussed in Section 3. Rainfall, evapotranspiration, stream flows, diversions, and pumping are varied on a monthly basis during the calibration period. Land use and crop patterns were changed annually. Future simulations will be based on the calibration simulation and include changes to land use, urban and agricultural water use, and precipitation.

- **Simulation Time Period:** The model calibration simulation was constructed to simulate hydrologic conditions for a ten year period from water year 1971 through water year 1999 (October 1, 1970 to September 30, 1999) using a 1 day time step.

- **Initial Conditions:** Initial conditions were specified for groundwater heads, unsaturated zone soil moisture and root zone soil moisture. The input values for the calibration simulation were specified using reasonable values developed using an iterative approach.

4.3 Calibration Targets

Groundwater elevations were obtained for 197 DWR wells. These wells were selected because they were within in the model boundaries, had groundwater measurements during the calibration time period, and had available screen depth information. Locations of these wells are shown on Figure 4-1. Comparison of model results to this data is discussed in Section 4.4.2.

River stage and flow information was obtained for DWR and USGS gages. Five stream flow gages and seventeen stream stage gages used for calibration are shown on Figure 4-2.

Estimated water budgets for Butte County sub-regions developed by the California Department of Water Resources, Northern District (CA DWR 2000b) were used to evaluate the specified diversions and groundwater pumping calculations performed by IWFM.

4.4 Groundwater Levels

As part of the final calibration of the model, a comparison of simulated and observed water levels across the model domain was made. For an acceptable groundwater model calibration, there should be no systematic head bias across the model domain. In other words, there should be no area or zone in the model with either consistently high, or consistent low simulated heads, compared to measured heads. Simulated transient groundwater levels should replicate the seasonal and long term trends indicated by the time history of historical data.

4.4.1 Transient Groundwater Level Comparisons

The simulated history for groundwater water levels at 69 wells across Butte County was compared to observed readings available during the transient calibration period. The 69 wells represent a spatial distribution across the county and vertically through the various hydrogeologic units. Figures 4-3 through 4-23 depict the simulated and measured groundwater levels for the 69 wells.

- **Basin Deposit/Formation Wells** - Figure 4-3 illustrates the simulated and observed groundwater head responses for three wells screened in the Basin Deposits (model layer 1). The measured groundwater levels show virtually no seasonal or long-term variation and this behavior is adequately reproduced by the model.

- **Alluvium Wells** - Figures 4-4 through 4-8 illustrate the simulated and observed groundwater head response for nineteen wells screened in the Alluvium Formation (model layer 2). These wells exhibit a moderate long-term variation. Some wells, for example, 21N01E25K001M and 20N01E10C002M show significant seasonal variation. The model is able to adequately reproduce the observed long-term and seasonal groundwater level behavior for wells in the Alluvium.

- **Sutter Formation Wells** - Figure 4-9 shows the simulated and observed response for two wells screened in the Sutter Formation (model layer 3). The simulated groundwater heads at these wells are adequately reproduced by the model.

- **Laguna Formation Wells** - Figure 4-10 shows the simulated and observed response for three wells screened in the Laguna Formation (mode layer 3). The two northern wells, 17N04E21Q001M and 17N04E22B001M, show moderate long-term and seasonal variation. The southern well, 16N04E22B001M, shows virtually no seasonal or long-term variation. The simulated groundwater heads at these wells are adequately reproduced by the model.

- **Tehama Formation Wells** - Figure 4-11 shows the simulated and observed response for three wells screened in the Tehama Formation (model layer 4). The measured groundwater levels show virtually no long-term variation and small seasonal variation. Measured groundwater levels in 19N01W13Q001M show occasional large decreases in groundwater levels for short periods. This response is likely due to local groundwater pumping and is not reproduced in the model due to lack of well specific data for agricultural pumping. The simulated long-term trend and seasonal variations are adequately reproduced by the model.

- **Tuscan C Formation Wells** - Figures 4-12 through 4-17 illustrate the simulated and observed groundwater heads for twenty-one wells screened in the Tuscan C Formation (model layer 5). Measured groundwater levels in wells along the northern boundary near Deer Creek show virtually no long-term or seasonal variation (Figures 4-12 and 4-13). Measured groundwater levels in wells in and near Chico and Durham (Figures 4-13 through 4-16) show small long-term and significant seasonal variability. Wells in the southern half of the model (Figure 4-15) show little long-term and seasonal variability. Measured groundwater levels in 19N01E09Q001M show occasional large decreases in groundwater levels for short periods. This response is likely due to local groundwater pumping and is not reproduced in the model. The simulated long-term trend and seasonal variations are adequately reproduced by the model.

- **Tuscan B Formation Wells** - Figures 4-18 through 4-21 illustrate the simulated and observed groundwater heads for fourteen wells screened in the Tuscan B Formation (model layer 6). Although simulated groundwater heads are higher than observed values in the initial years of the simulation, the model is able to reproduce the long-term and short-term variability in the latter half of the calibration period reasonably well.

- **Tuscan A Formation Wells** - Figure 4-22 illustrates the simulated and observed groundwater heads for two wells in the Tuscan A Formation (model layer 7). Long-term variability is simulated adequately for the well with a long-term record. Seasonal variations are simulated adequately for both wells.

- **Ione/UPG Formation Wells** - Figure 4-23 illustrates the simulated and observed groundwater heads for two wells in the Upper Princeton Gorge, & Ione Formations (model layer 8). Long-term and seasonal variability are reproduced adequately for well 19N03E22A001M. Simulated groundwater heads in well 18N04E08M01M are low and seasonal changes are not simulated, but long-term trends are reproduced.

4.4.2 Synoptic Groundwater Level Comparisons

For a larger number of wells, the simulated spring and fall groundwater levels for selected years were compared to the available measurements. Spring measurements represent a snapshot of simulated water levels on March 15 compared to average observed water levels from February 15 to May 15. Fall measurements represent a snapshot of simulated water levels on October 15 compared to average observed water levels from September 15 to December 15. Figures 4-24 through 4-27 show comparison of spring measurements for 1992 and 1997 and fall measurements for 1991 and 1996 for all hydrogeologic units. These times periods represent conditions during water years 1992 and 1997. Water year 1992 was classified as a “critical” year based on the DWR Water Year Hydrologic Classification Indices. Water year 1997 was classified as a “wet” year.

Figures 4-24 through 4-27 provide statistics to help compare the simulated and observed water levels. The "Mean Difference" is the mean of all model calculated heads minus the observed head at each well. The "Std. Deviation" is the standard deviation calculated from these comparisons.

Water table contours are also depicted on Figure 4-24 through 4-27. Ten-foot contours are depicted in red and 100 foot contours are shown in blue. In general, the hydraulic gradient is flat in the valley and rises steeply in the foothills. Influence of the rivers, particularly, the Sacramento River, Feather River and Butte Creek can be seen.

- Figure 4-24 compares simulated and observed water levels for spring 1992. The difference in simulated (i.e. "calculated") and observed water levels is generally within 5 feet. Notable differences include an area of both low and high simulated heads near the northern boundary.

- Figure 4-25 compares simulated and observed water levels for spring 1997. The difference in simulated (i.e. "calculated") and observed water levels is generally within 5 feet. Notable differences include an area of low and high simulated heads near the northern boundary and some low water level measurements in the area of the Durham/Dayton and Western Canal subregions.

- Figure 4-26 compares simulated and observed water levels for fall 1991. The difference in simulated (i.e. "calculated") and observed water levels is generally within 5 feet. Notable differences include an area of high simulated heads near the northern boundary and low simulated heads along Butte Creek and Little Dry Creek near the Esquon subregion.

- Figure 4-27 compares simulated and observed water levels for fall 1996. The difference in simulated (i.e. "calculated") and observed water levels is generally within 5 feet.

Appendix A contains comparison plots by hydrogeologic unit for the spring and fall time periods for Water Years 1992 and 1997.

4.4.3 All Measured Groundwater Levels

A comparison of all measured water levels with model results is shown in a 45 degree plot on Figure 4-28. In a 45 degree plot, observed water levels are plotted on the x-axis and simulated water levels on the y-axis. If all water levels matched, the plot would be a straight line at a 45 degree angle.

A total of 7406 observations were compared with model results. The mean difference between the simulated and observed heads is 2.43 feet and the standard deviation is 13.9 ft. There are a few outliers both where the model over or under simulates observed water levels. These mainly occur in the uplands east of the Sacramento Valley where groundwater head gradients are relatively steep. In general, the data lies close the 45 degree line indicating a good match.

4.5 Surface Water

Simulated surface water flows were compared with observed data at five USGS gauging stations shown on Figure 4-2. Figures 4-29 through 4-33 illustrate the comparison between the simulated and measured flow recorded at the Sacramento River near Hamilton City and at Colusa, Butte Creek near Chico, and the Feather River near Gridley and at Yuba City. The figures indicate that the model reproduces the observed flow in these rivers very well.

Simulated surface water stages were compared with observed data at seventeen DWR and USGS gauging stations shown on Figure 4-2. Figures 4-34 through 4-40 illustrate the comparison for one gage on Deer Creek, six gages on the Sacramento River, one gage on Big Chico Creek, five gages on Butte Creek, one gage on the Cherokee Canal, and three gages on the Feather and Yuba Rivers. The figures indicate that the model reproduces the changes in observed stages at these rivers very well.

4.6 Water Budgets

IWFM computes budgets based on specified time periods for land and water use, groundwater, streams, and the root zone moisture for each sub-region. Calculations of diversions and reductions due to streamflow shortage are also compiled by IFWM. Annual budgets for all sub-regions and the entire model are included in Appendix B.

4.6.1 Land and Water Use Budgets

Land and water use budgets show acreage, supply requirements, pumping, diversions, water re-use, water shortages, and regional imports and exports for agricultural and urban areas.

Figure 4-41 shows the model-wide applied water budget for agricultural areas. Positive bars represent available water through surface water diversions (blue bars on Figure 4-41) or groundwater pumping (green bars). Negative numbers represent water demand (yellow bars). Shortages or excesses of irrigation water are shown as brown bars. Shortages appear as positive bars and excess water is shown as a negative bars. Figure 4-41 shows that surface water is the primary source of irrigation water in the model domain. Demand, diversions, and groundwater pumping remain fairly constant throughout the model simulation time period. Overall, applied water exceeds demand by approximately 29 percent in the simulation. Graphs of the applied water budget for agricultural areas for each sub-region are included in Appendix B.

4.6.2 Stream and Reach Budgets

Stream and reach budgets include upstream inflow, downstream outflow, tributary inflows, runoff, return flow, gain from groundwater, and diversions. Stream budgets report values based on each sub-region. Reach budgets report values based on stream reaches illustrated in Figure 3-4.

Figure 4-42 shows the model wide streamflow budget for each water year. Stream inflow which enters the model domain is shown with color bars. Inflows to the streams within the model domain are shown as positive bars, including inflow into the model domain (yellow bars), runoff (red bars), return flow (brown bars), and gains from groundwater (green bars). Outflows include flow out of the model domain (salmon bars) and diversions (blue bars). Overall, the majority of water in the streams originates from outside of the model domain.

Figure 4-43 shows the changes in stream flow within the model domain for each water year. Inflows to the streams within the model domain are shown as positive bars, including runoff (red bars), return flow (brownish red bars), and gains from groundwater (green bars). Diversion outflows within the model domain are shown as negative blue bars. Positive yellow bars indicate that for the given year total simulated stream flows were reduced within the model area. Negative yellow bars indicate that simulated stream flows increased within the model area.

4.6.3 Root Zone Moisture Budgets

Root zone moisture budgets include acreage, precipitation, runoff, applied water, reused water, return flow, changes in storage, infiltration, evapotranspiration, and deep percolation for agricultural, urban and native/riparian areas.

Figure 4-44 shows the model wide soil moisture budget for the root zone for each year. Positive bars represent flow into the root zone and negative bars represent flow out of the root zone. Inflows are primarily from infiltration (blue bars on Figure 4-44) of applied water and precipitation. Outflows are primarily due to evapotranspiration (green bars) and secondarily to movement of water into the unsaturated zone as deep percolation (yellow bars). On average approximately 78 percent of water which infiltrates is removed by plants through evapotranspiration. The remaining approximately 22 percent percolates to the unsaturated zone.

4.6.4 Groundwater Budgets

Groundwater budgets include deep percolation and net deep percolation, changes in storage, gains from streams/lakes, boundary flow, pumping, and inflow from surrounding subregions.

Figure 4-45 shows the model wide groundwater budget for each water year. Positive bars represent flow into the groundwater and negative bars represent flow out of the groundwater. Deep percolation (yellow bars on Figure 4-45) is the primary source of recharge to the groundwater on a model-wide basis. Boundary inflow (purple bars) also contributes a small amount of water. Groundwater pumping (green bars) is the primary method of groundwater extraction. Overall, there is a net flow of water from groundwater to streams as shown by the blue bars. Graphs of the groundwater budget for each sub-region are also included in Appendix B.

4.6.5 Comparison With Butte County Estimated Budgets

Simulated annual water budgets were compared with estimated water budgets developed by the California Department of Water Resources, Northern District (CA

DWR 2000b). The budget estimates are based on the managed and measurable "applied" components of water budgets. Due to differences in water accounting methods, it is difficult to compare complete simulated versus estimated water budgets. Water budgets were compared for the simulated 1997 water year with the 1997 estimated budgets for inventory units which were contained within the model domain.

Figure 4-46 is a comparison of simulated water budgets and 1997 water budgets developed by the DWR (CA DWR 2000b). Bars represent agricultural surface water diversion (light green bars), agricultural groundwater pumping (dark green bars), urban surface water diversions (red bars), urban groundwater pumping (pink bars), and water re-use (blue bars). Water re-use in IWFM is a specified fraction of the model calculated return flow and runoff. Re-use in the DWR Water Budgets includes inflow drain water, drainage reuse, and reclaimed wastewater.

Overall, the simulated water budgets are reasonably consistent with the DWR estimated water budgets shown in Figure 4-46 with a few exceptions. For the Butte Sink inventory unit, the DWR budgets shows a large component of water re-use due to drains which route excess water from Biggs-West Gridley, Richvale, and Western Canal regions. The Butte County IWFM model does not explicitly model these drains. Instead water drains to the Cherokee Canal and other creeks explicitly included in the model. Water diverted from the Cherokee Canal and from outside the model is applied in Butte Sink. Overall the total volume of applied water is similar in both the simulated and estimated budgets.

Simulated agricultural water use is lower in the Butte (subregion 20) subregion than reported in the estimated DWR values. Review of applied water budgets (Appendix B) indicates that simulated water application for this subregion is more than sufficient to meet estimated demand.

4.7 Summary

The results of the calibration indicate that the overall structure of the model and model parameter assignments are appropriate, and that there are no significant errors or flaws in the input data. Overall, the model is able to reasonably reproduce observed groundwater gradients and flow directions. The simulated horizontal and vertical distribution of groundwater heads is consistent with the observed data, and simulated flows and depths in the major surface water features are consistent with measured data. The simulated transient or dynamic response of the groundwater levels reflects the measured short-term seasonal variation in groundwater levels, and trends driven by long-term hydrology are also simulated.

The final calibration represents the combination of streambed properties, recharge, boundary conditions, and aquifer properties which best reproduced calibration targets.

Section 5
Model Sensitivity

5.1 Introduction

Sensitivity analysis was conducted on major model parameters including saturated and unsaturated zone hydraulic properties, streambed resistance to groundwater-surface water interactions, agricultural diversion/irrigation and crop consumption rates, and boundary conditions. Metrics were developed to compare the variations in model simulation results due to changes to input parameters. The metrics are compared to the base calibration simulation in tables for each parameter group.

Metrics include comparison of mean and standard deviation in simulated versus observed head differences for spring 1992 and 1997. Simulated heads are for March 15 of the specified year and observed heads are average heads from February 15 to May 15 of the specified year. For the mean head differences, percentage differences are calculated as the sensitivity run simulated value minus the calibration run simulated value divided by the range of all observed head values within in the model domain. The range of observed head values for the entire calibration time period is 144.3 feet. Spring 1992 occurred during water year 1992, classified as a "critical" year based on the DWR Water Year Hydrologic Classification Indices. Spring 1997 occurred during water year 1997, classified as "wet."

In IWFM, "deep percolation" is defined as the water moving from the root zone to the unsaturated zone. "Net deep percolation" is the water flowing from the unsaturated zone to the saturated zone. The average annual net deep percolation (acre-feet/water year) is compared in the sensitivity simulations for root zone properties, surface water diversions, and evapotranspiration. Percentage differences are calculated as the change in value divided by the calibration value.

Average annual net groundwater flow to stream (acre-feet/water year) were compared for simulations of streambed properties. For surface water diversion sensitivity runs, average annual surface water diversions (acre-feet/water year) and groundwater pumping (acre-feet/water year) were compared for agricultural areas. For evapotranspiration sensitivity runs, evapotranspiration (acre-feet/water year) and groundwater pumping (acre-feet/water year) were compared for agricultural areas. Percentage differences are calculated as the change in value divided by the calibration value.

5.2 Saturated Zone Hydraulic Properties

Saturated zone parameters include horizontal and vertical hydraulic conductivity which impact groundwater flow gradients and specific storage and yield which relate to groundwater storage.

5.2.1 Horizontal Hydraulic Conductivity

Horizontal hydraulic conductivity was decreased and increased by 50 percent to evaluate the impact on groundwater heads and groundwater-surface water interactions. As expected, simulated groundwater heads increased as the hydraulic conductivity decreased because the ability of the aquifer to transmit groundwater was reduced (Table 5-1). An increase in hydraulic conductivity resulted in a decrease in heads.

Table 5-1
Saturated Zone - Hydraulic Conductivity, Horizontal

		Calibration Simulation	50% Decrease		Calibration Simulation	50% Increase	
			Value	% Diff*		Value	% Diff*
Spring 1992	Head difference - mean (ft)	-1.2	4.8	4.2%	-1.2	-5.1	-2.7%
	Head difference - std dev	6.9	10.0		6.9	8.0	
Spring 1997	Head difference - mean (ft)	-3.5	2.6	4.2%	-3.5	-6.3	-1.9%
	Head difference - std dev	6.2	10.0		6.2	6.7	

* % Difference for heads is compared to the range of measured water levels.

5.2.2 Vertical Hydraulic Conductivity

Vertical hydraulic conductivity was decreased to 10 percent of the original values and doubled. As expected groundwater heads increased as the hydraulic conductivity decreased because the resistance to groundwater flow vertically was reduced (Table 5-2). An increase in hydraulic conductivity resulted in a decrease in heads.

Table 5-2
Saturated Zone - Hydraulic Conductivity, Vertical

		Calibration Simulation	10% of Value		Calibration Simulation	Doubled Value	
			Value	% Diff*		Value	% Diff*
Spring 1992	Head difference - mean (ft)	-1.2	0.8	1.4%	-1.2	-1.5	-0.2%
	Head difference - std dev	6.9	9.6		6.9	6.9	
Spring 1997	Head difference - mean (ft)	-3.5	-2.1	1.0%	-3.5	-3.5	0.0%
	Head difference - std dev	6.2	7.9		6.2	6.3	

* % Difference for heads is compared to the range of measured water levels.

5.2.3 Specific Storage

Specific storage was decreased and increased by an order of magnitude to evaluate the sensitivity of overall storage on the modeled system. Small changes were observed in the simulated heads (Table 5-3). The specific storage term impacts the model simulation of seasonal and long term variations of groundwater heads. The range of modeled groundwater heads (maximum minus minimum) was compared in order to evaluate the sensitivity of the model to specific storage. The decrease in the specific storage term resulted in small changes in the range of simulated heads at calibration wells, generally small increases of less than 15 percent. An increase in the specific storage term resulted in larger changes in the range of simulated heads at calibration wells, generally decreases in the range of 15 to 50 percent.

Table 5-3
Saturated Zone - Specific Storage

		Calibration Simulation	10% of Value		Calibration Simulation	10 Times Value	
			Value	% Diff*		Value	% Diff*
Spring 1992	Head difference - mean (ft)	-1.2	-1.0	0.1%	-1.2	0.7	1.3%
	Head difference - std dev	6.9	7.0		6.9	7.1	
Spring 1997	Head difference - mean	-3.5	-2.8	0.5%	-3.5	-3.9	-0.3%
	Head difference - std dev	6.2	6.2		6.2	6.3	

* % Difference for heads is compared to the range of measured water levels. WY = Water Year

5.2.4 Specific Yield

This parameter describes the amount of water draining from or filling pore spaces as the water table fluctuates. This parameter was halved and doubled for sensitivity analysis. Small changes were observed in the heads (Table 5-4).

The specific yield term also impacts the model simulation of seasonal and long term variations in groundwater heads. The range of modeled groundwater heads (maximum minus minimum) was compared in order to evaluate the sensitivity of the model to specific yield. The decrease in the specific yield term resulted in large changes in the range of simulated heads at calibration wells, generally increases of 20 to 60 percent. An increase in the specific storage term resulted in changes in the range of simulated heads at calibration wells, generally decreases in the range of 15 to 40 percent.

Table 5-4
Saturated Zone - Specific Yield

		Calibration Simulation	50% of Value		Calibration Simulation	Doubled Value	
			Value	% Diff*		Value	% Diff*
Spring 1992	Head difference - mean (ft)	-1.2	-6.3	-3.5%	-1.2	-4.9	-2.5%
	Head difference - std dev	6.9	8.7		6.9	8.5	
Spring 1997	Head difference - mean (ft)	-3.5	-2.7	0.6%	-3.5	-0.1	2.3%
	Head difference - std dev	6.2	6.3		6.2	7.0	

* % Difference for heads is compared to the range of measured water levels. WY = Water Year

5.3 Root Zone Properties

The root zone parameter that most influences the recharge computations is the fraction of water in the root zone in excess of field capacity that is routed to deep percolation (K).

The fraction of excess deep percolation was decreased and increased by 5 percent. The 5 percent change in net deep percolation resulted in 1 percent change in groundwater head differences. (Table 5-5).

Table 5-5
Soil Moisture Routing - Fraction of Water to Deep Percolation

		Calibration Simulation	Decrease 5%		Calibration Simulation	Increase 5%	
			Value	% Diff*		Value	% Diff*
Spring 1992	Head difference - mean (ft)	-1.2	-2.8	-1.1%	-1.2	0.3	1.1%
	Head difference - std dev	6.9	7.0		6.9	7.0	
Spring 1997	Head difference - mean (ft)	-3.5	-5.4	-1.3%	-3.5	-1.7	1.3%
	Head difference - std dev	6.2	6.5		6.2	6.1	
Avg. Annual	Net deep percolation (ac-ft)	568,929	540,687	-5.0%	568,929	597,054	4.9%

* % Difference for heads is compared to the range of measured water levels. WY = Water Year

5.4 Streambed Conductivity

Streambed conductivity was selected as a representative parameter to evaluate the sensitivity of the model to changes in specified resistance to flow between the surface water and groundwater. Other parameters used in IWFM to define streambed resistance include wetted perimeter and streambed thickness.

Stream bed conductivity was halved and doubled. Impacts on groundwater heads were small. Stream-groundwater interaction showed more change (Table 5-6). Decreased conductivity values resulted in a reduction in flow of groundwater to the streams. Doubling of conductivity values resulted in increase of flow to the streams by 10 percent.

Table 5-6
Streambed - Streambed Conductivity

		Calibration Simulation	50% of Value		Calibration Simulation	Doubled Value	
			Value	% Diff*		Value	% Diff*
Spring 1992	Head difference - mean (ft)	-1.2	-3.5	-1.6%	-1.2	2.5	2.6%
	Head difference - std dev	6.9	7.2		6.9	7.5	
Spring 1997	Head difference - mean (ft)	-3.5	-6.4	-2.0%	-3.5	0.8	2.9%
	Head difference - std dev	6.2	7.3		6.2	6.8	
Avg. Annual	Net deep percolation (ac-ft)	150,104	160,182	6.7%	150,104	132,683	-11.6%

* % Difference for heads is compared to the range of measured water levels. % Difference for net groundwater flow to streams is compared to the calibration simulation.

5.5 Saturated Zone Boundary Conditions

Boundary conditions discussed in Section 3.7 were evaluated as part of sensitivity analysis. Model boundaries, shown on Figure 3-27 include no-flow, specified flux, and specified head boundaries.

5.5.1 Western Boundary Condition

Below the Sacramento River, the western model boundary condition is a specified flux based on flows calculated using the C2VSIM model. Sensitivity runs were conducted using a no-flow boundary condition, and ten times the C2VSIM flux. Overall, changes in simulated heads were small (Table 5-7).

Table 5-7
Boundary Conditions - Western Boundary under Sacramento River

		Calibration Simulation	No Flow		Calibration Simulation	10 times Flux	
			Value	% Diff*		Value	% Diff*
Spring 1992	Head difference - mean (ft)	-1.2	-1.3	-0.1%	-1.2	-0.7	0.4%
	Head difference - std dev	6.9	6.8		6.9	8.0	
Spring 1997	Head difference - mean (ft)	-3.5	-3.6	-0.1%	-3.5	-2.4	0.7%
	Head difference - std dev	6.2	6.1		6.2	6.8	

* % Difference for heads is compared to the range of measured water levels.

5.5.2 Northern and Southern Boundary Conditions

A sensitivity run was made replacing the fixed head boundary condition along the northern model boundary beneath Deer Creek, the fixed head boundary condition at the southern boundary east of the Sutter Buttes and the fixed flux boundary condition along the southern boundary west of the Sutter Buttes with a no-flow boundary condition. A second sensitivity run was made wherein the specified boundary heads were increased five feet and the specified flux along the southern boundary west of the Sutter Buttes was doubled. Overall, changes in simulated heads were small (Table 5-8).

Table 5-8
Boundary Conditions - Northern and Southern Boundaries

		Calibration Simulation	No Flow		Calibration Simulation	Doubled Flux or Increase Heads 5 ft.	
			Value	% Diff*		Value	% Diff*
Spring 1992	Head difference - mean (ft)	-1.2	-6.4	-3.6%	-1.2	-0.8	0.3%
	Head difference - std dev	6.9	15.4		6.9	7.1	
Spring 1997	Head difference - mean (ft)	-3.5	-7.9	-3.0%	-3.5	-3.2	0.2%
	Head difference - std dev	6.2	13.5		6.2	6.3	

* % Difference for heads is compared to the range of measured water levels.

5.5.3 Thermalito Afterbay

Sensitivity runs were conducted on the specified flux representing recharge to groundwater from the Thermalito Afterbay. This flux was halved and doubled. Changes in simulated heads were small as shown in Table 5-9.

Table 5-9
Boundary Conditions - Thermalito Afterbay

		Calibration Simulation	50% of Flux		Calibration Simulation	Doubled Flux	
			Value	% Diff*		Value	% Diff*
Spring 1992	Head difference - mean (ft)	-1.2	-1.4	-0.1%	-1.2	-0.8	0.3%
	Head difference - std dev	6.9	7.0		6.9	6.8	
Spring 1997	Head difference - mean (ft)	-3.5	-3.7	-0.1%	-3.5	-3.1	0.3%
	Head difference - std dev	6.2	6.2		6.2	6.2	

* % Difference for heads is compared to the range of measured water levels.

5.6 Applied Water and Evapotranspiration

Sensitivity simulations evaluated the impact of surface water diversions and evapotranspiration rates on simulated heads and flows. Changes in the applied water source and the agricultural water demand impacts groundwater levels through changes in model-calculated groundwater pumping and recharge.

5.6.1 Surface Water Diversions

Surface water diversions are primarily used for agricultural irrigation. Diversions, and the corresponding water application, were increased and decreased by 20 percent to evaluate the impact on groundwater heads, IFWM calculated groundwater pumping and net deep percolation (Table 5-10). Decreased diversions resulted in decreased recharge, increased groundwater pumping and decreased groundwater heads.

Table 5-10
Surface Water Diversions

		Calibration Simulation	Decrease 20%		Calibration Simulation	Increase 20%	
			Value	% Diff*		Value	% Diff*
Spring 1992	Head difference - mean (ft)	-1.2	-4.8	-2.5%	-1.2	0.4	1.1%
	Head difference - std dev	6.9	8.5		6.9	6.5	
Spring 1997	Head difference - mean (ft)	-3.5	-6.6	-2.2%	-3.5	-1.7	1.2%
	Head difference - std dev	6.2	7.0		6.2	6.0	
Avg. Annual	Agricultural surface water diversions (ac-ft)	1,240,106	997,440	-19.6%	1,240,106	1,481,773	19.5%
	Agricultural groundwater pumping (ac-ft)	464,516	506,518	9.0%	464,516	440,590	-5.2%
	Net deep percolation (ac-ft)	568,929	522,836	-8.1%	568,929	618,484	8.7%

* % Difference for heads is compared to the range of measured water levels. % Difference for agricultural surface water diversion, agricultural groundwater pumping, and net deep percolation is compared to the calibration simulation.

5.6.2 Evapotranspiration Rates

Evapotranspiration rates were increased and decreased by 20 percent as part of sensitivity analysis (Table 5-11). The reduction in evapotranspiration resulted in reduced groundwater pumping, increased recharge and an increase in simulated groundwater heads.

Table 5-11
Evapotranspiration Rate

		Calibration Simulation	Decrease 20%		Calibration Simulation	Increase 20%	
			Value	% Diff*		Value	% Diff*
Spring 1992	Head difference - mean (ft)	-1.2	4.9	4.2%	-1.2	-14.9	-9.5%
	Head difference - std dev	6.9	8.5		6.9	11.8	
Spring 1997	Head difference - mean (ft)	-3.5	5.8	6.4%	-3.5	-17.3	-9.5%
	Head difference - std dev	6.2	8.1		6.2	12.0	
Avg. Annual	Agricultural surface water diversions (ac-ft)	1,230,156	986,983	-19.8%	1,230,156	1,471,109	19.6%
	Agricultural groundwater pumping (ac-ft)	464,516	329,219	-29.1%	464,516	621,350	33.8%
	Net deep percolation (ac-ft)	568,929	612,063	7.6%	568,929	536,406	-5.7%

* % Difference for heads is compared to the range of measured water levels. % Difference for agricultural surface water diversion, agricultural groundwater pumping, and net deep percolation is compared to the calibration simulation.

5.7 Summary

Simulated groundwater heads are primarily sensitive to hydraulic conductivity values assigned in the model, groundwater pumping and calculated recharge. Calculated recharge is influenced by a number of model parameters including root zone properties (particularly the fraction of excess soil moisture that becomes deep percolation each time step), applied water volume and crop consumption (ET) rates. The sensitivity analysis indicated less sensitivity to variations in model boundary conditions that represent flows into and out of the model perimeter. The parameter set selected for the final calibration provided the best fit to the available data. Adjustments to hydraulic conductivity values and recharge may be indicated in the future based on continued collection of field data.

Model simulated net groundwater discharge to streams and to model boundaries was also sensitive to the same parameters that simulated heads are sensitive to. However, it is difficult to calibrate model parameters based on simulated flow rates to streams and boundaries because directly comparable field data are not available. Available flow data for the streams is not sufficient for this because groundwater flow to/from streams is very small compared to overall stream flow. However, additional water level data and aquifer performance tests adjacent to streams could provide useful data for model representation of groundwater-stream interactions.

Section 6
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Figures

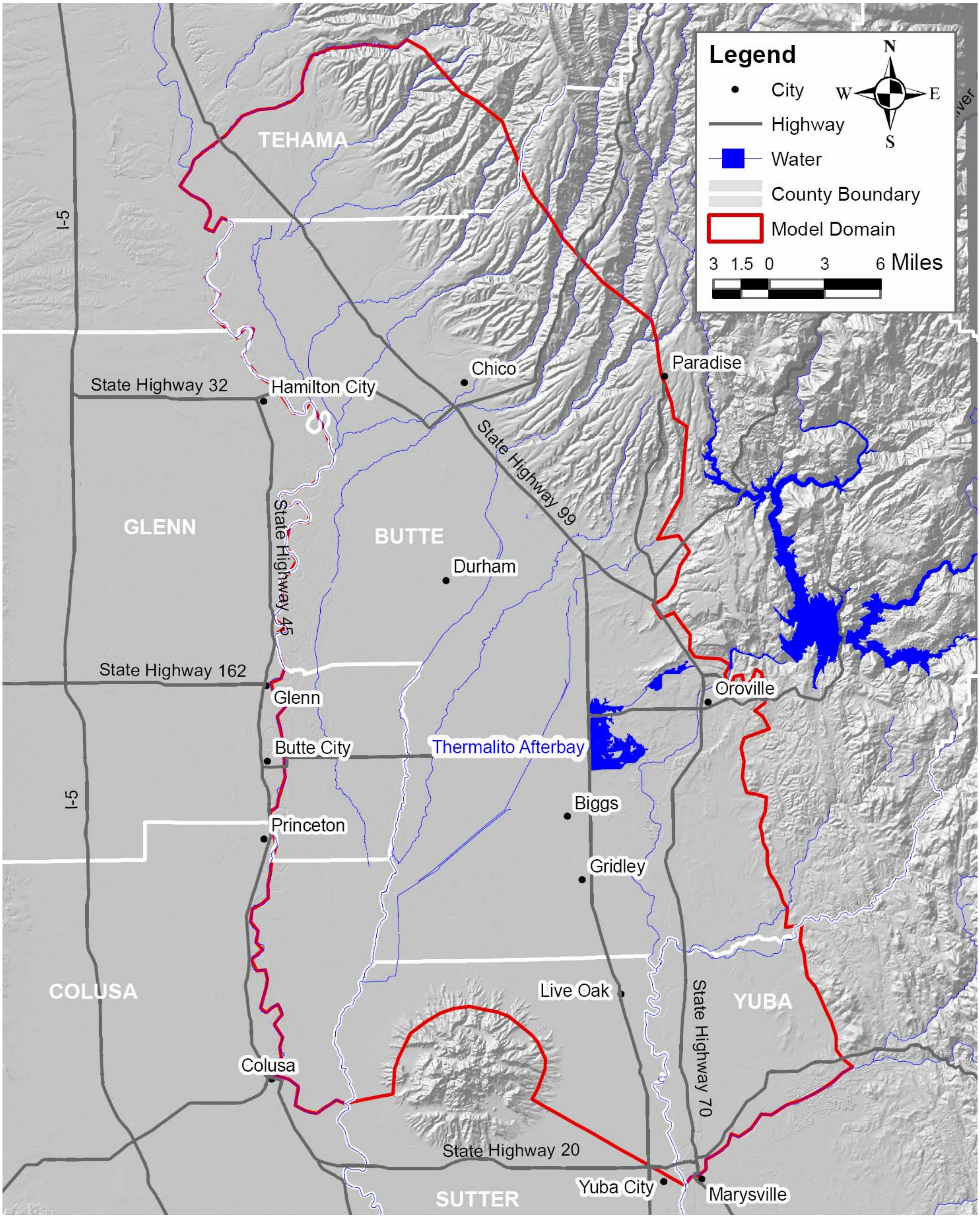

Figure 2-2
Study Area

CDM

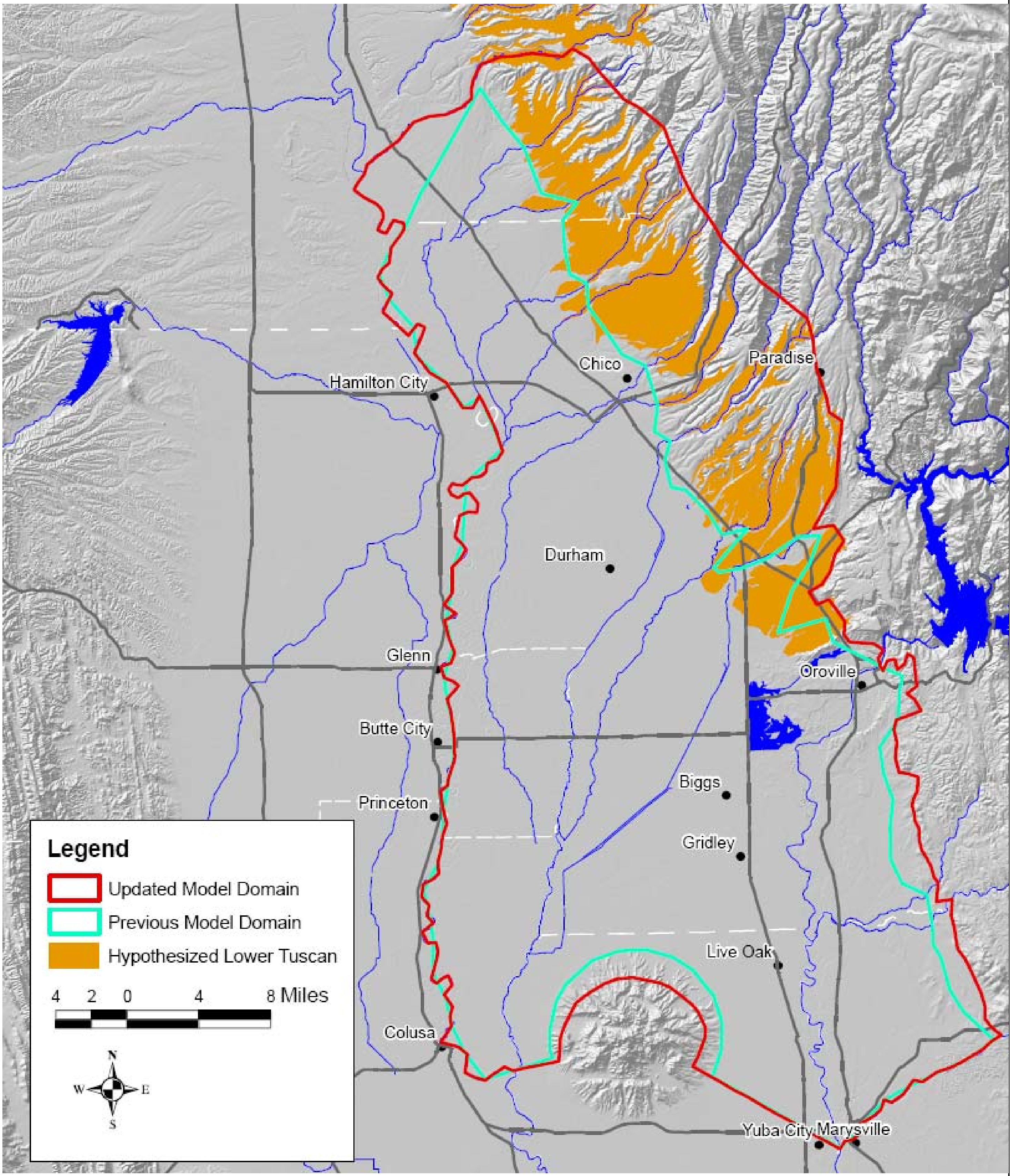

Figure 2-3
Model Domain and Hypothesized Tuscan Recharge Zone

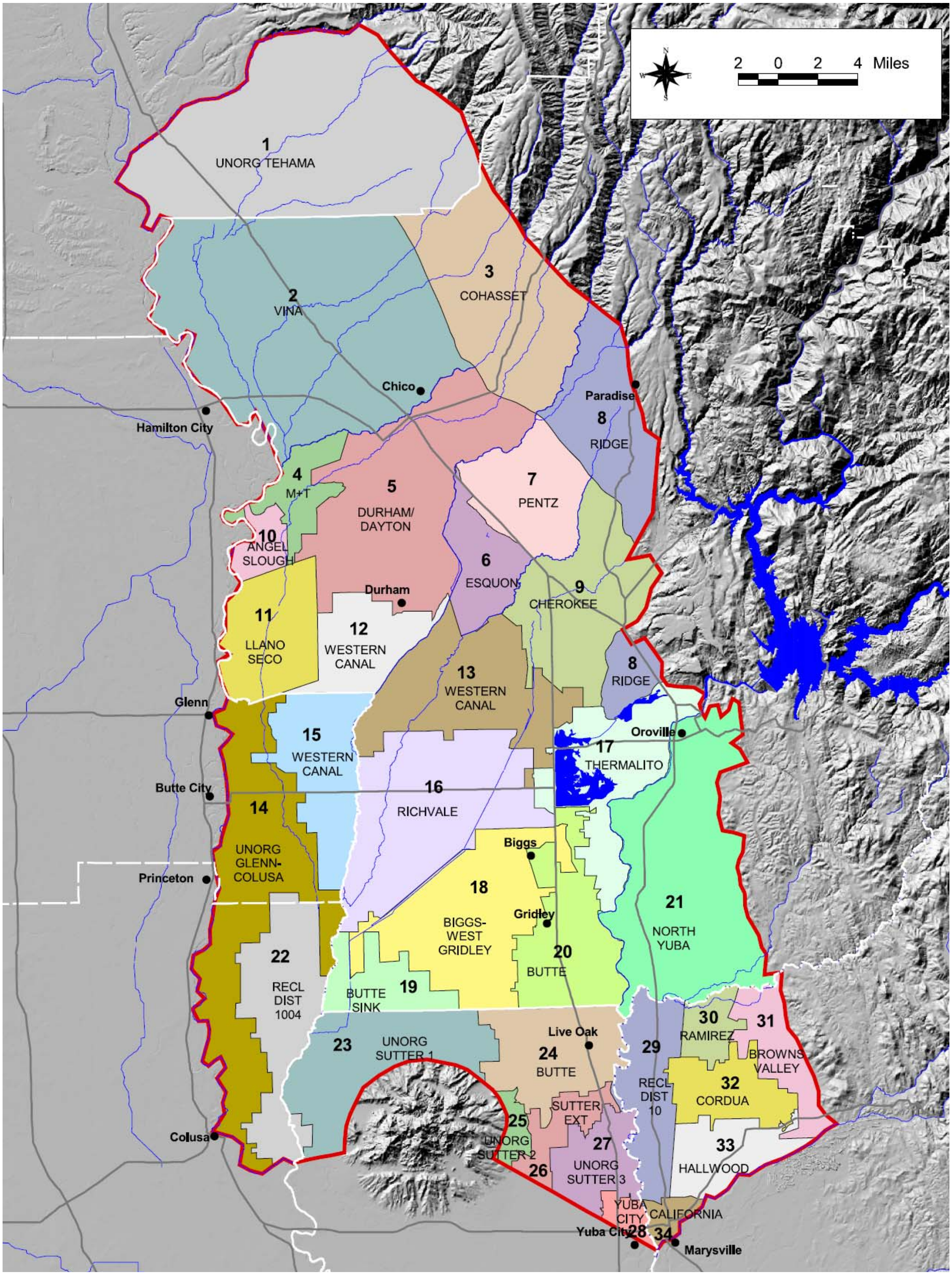

Figure 2-4
Model Subregions

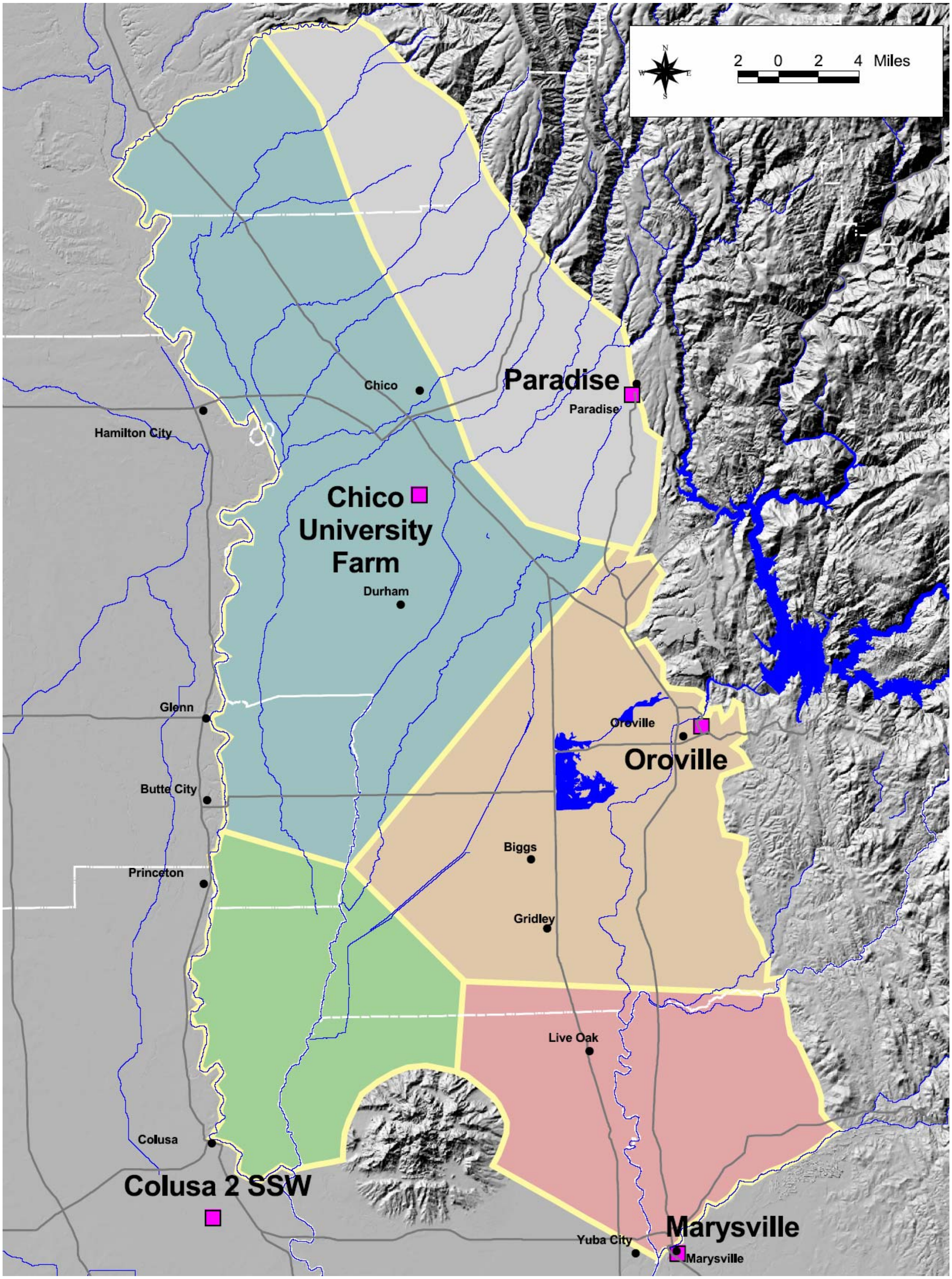

Figure 2-5
Precipitation Gages Assigned in the Model

CDM

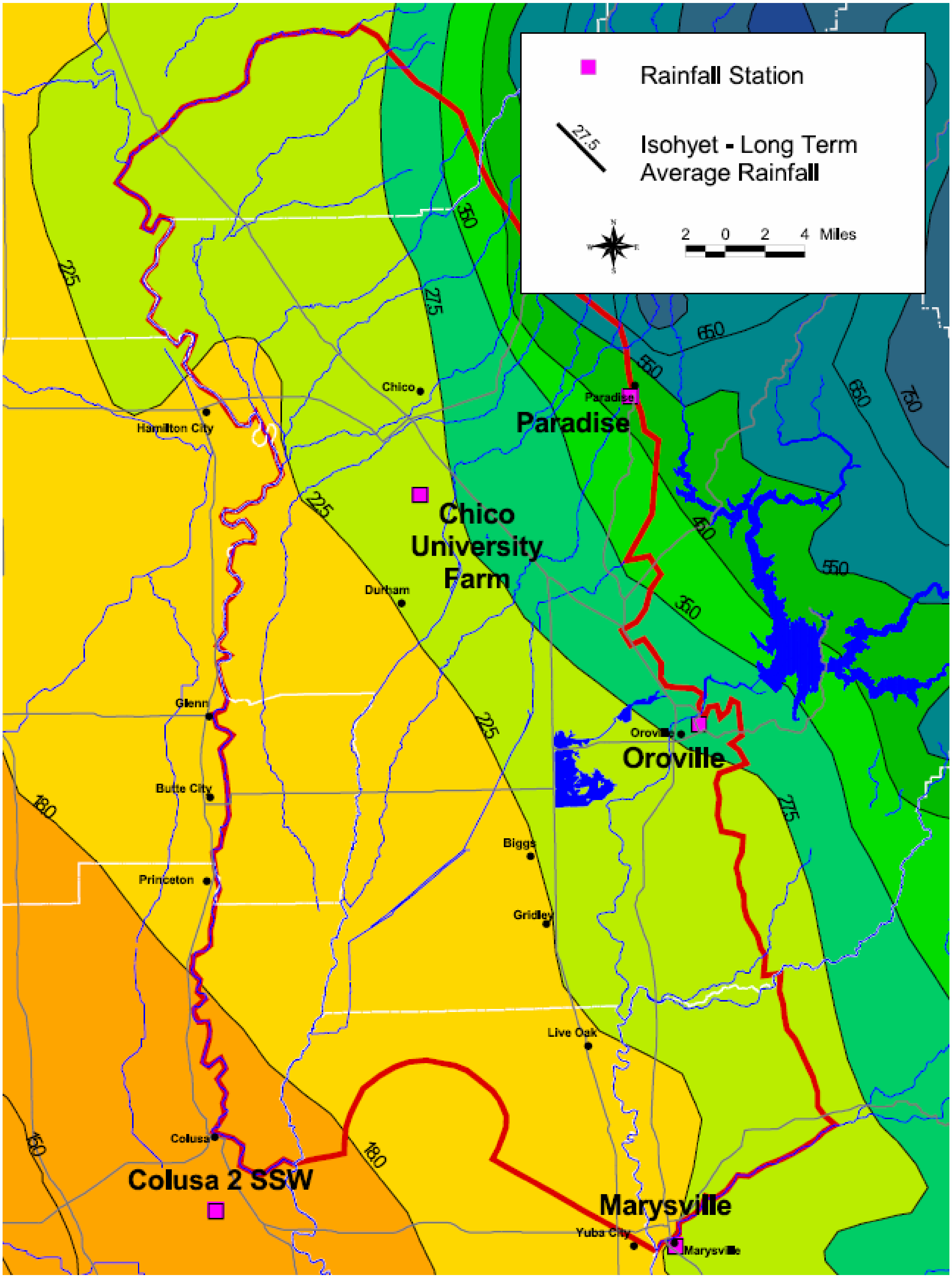

Figure 2-6
Long-Term Average Rainfall

CDM

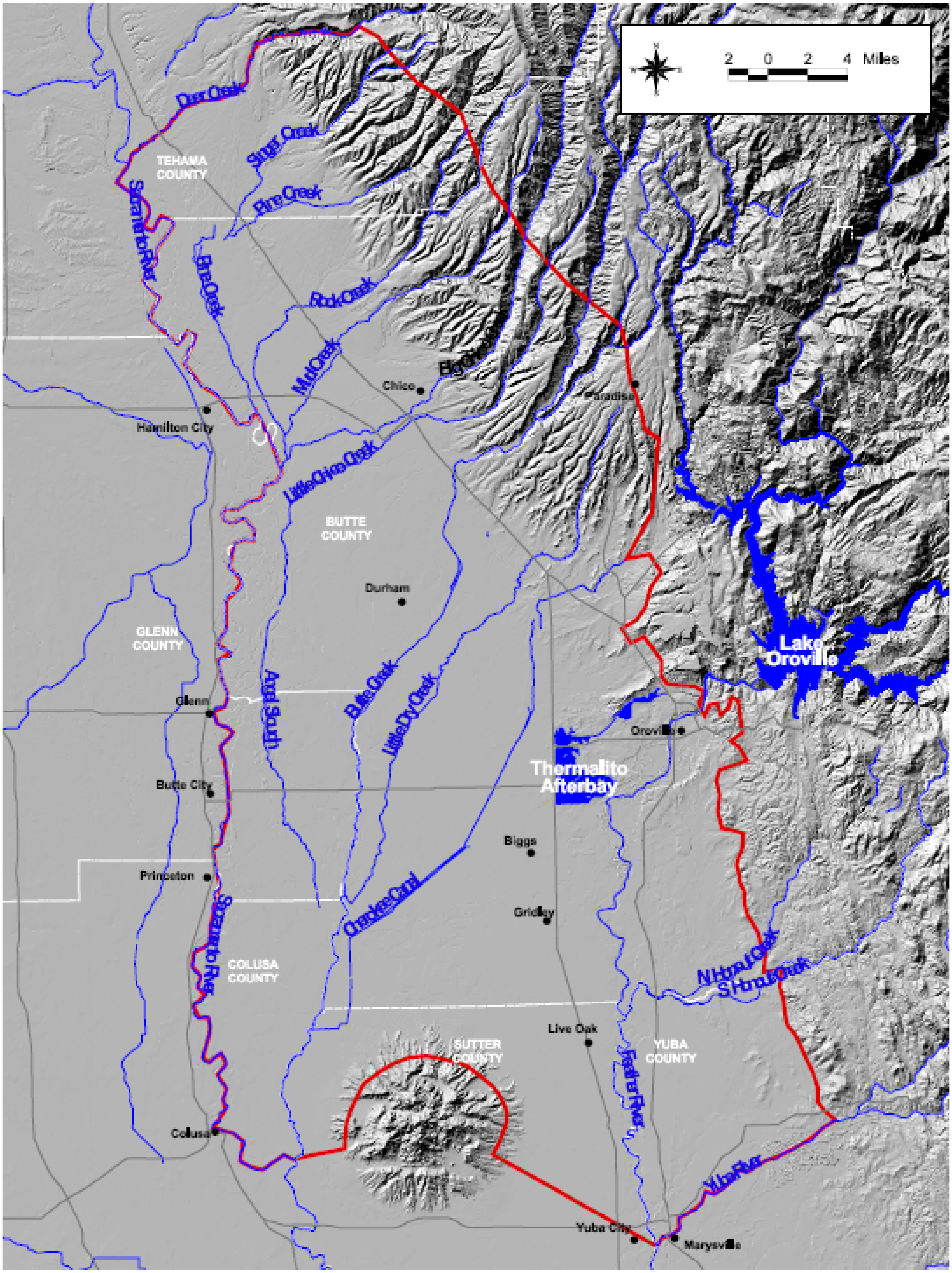

Figure 2-7
Major Streams, Water Supply, and Drainage Features

CDM

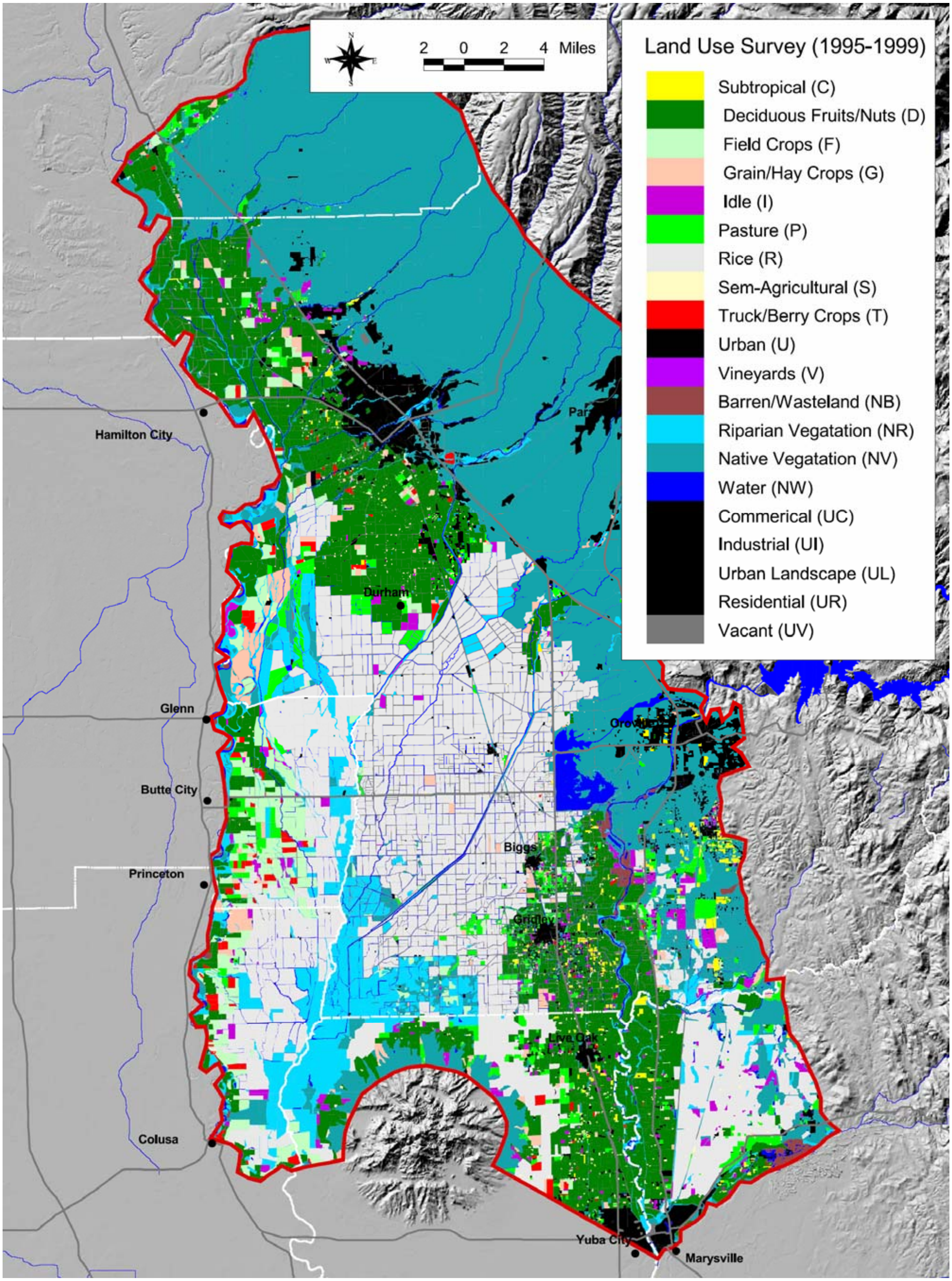

Figure 2-8
Land Use Map
Most Recent DWR Land Use Survey (1995-1999)

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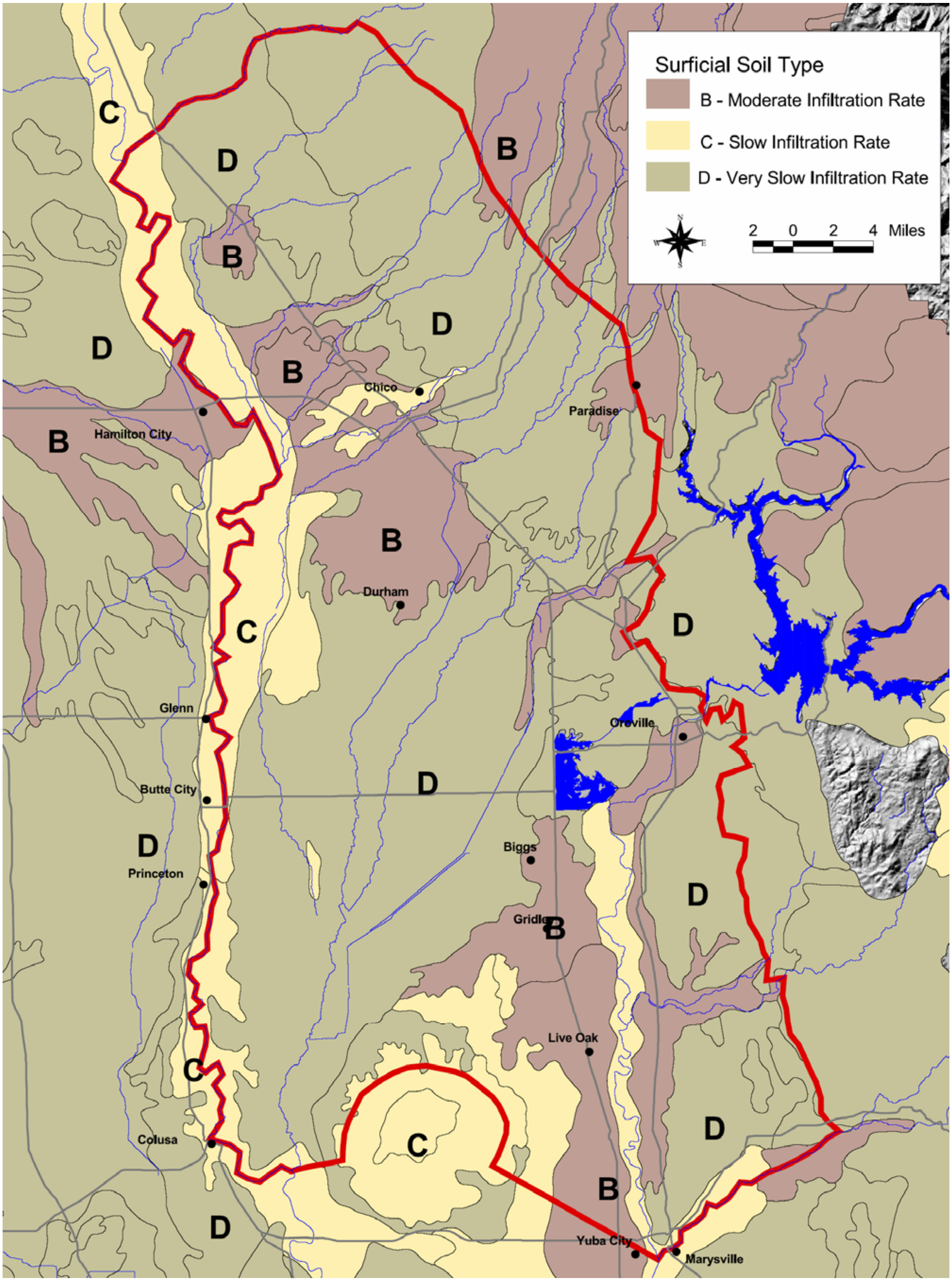

Figure 2-9
Distribution of Surficial Soil Types

CDM

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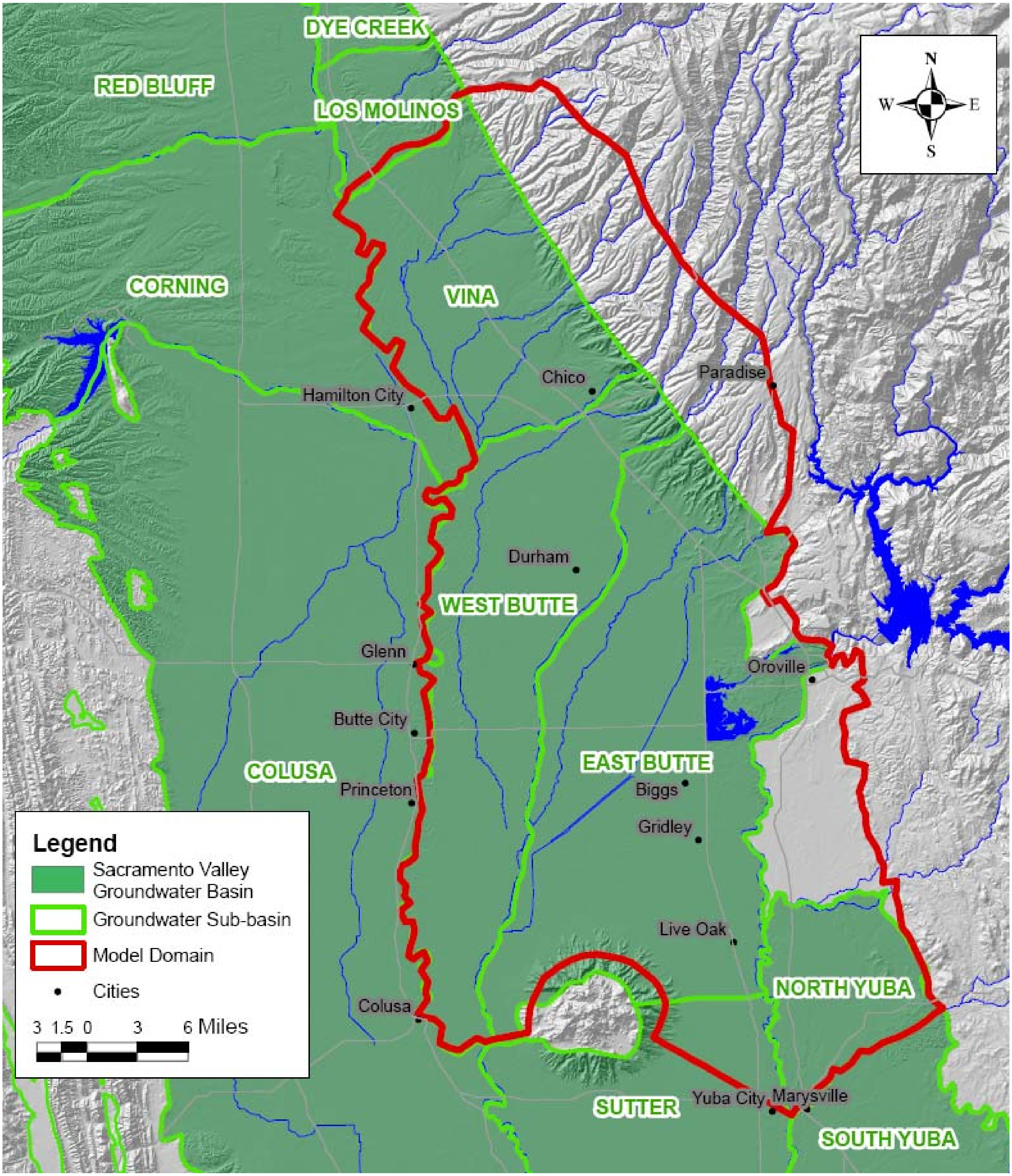


Figure 2-10
California DWR Groundwater Sub-Basins and Model Domain

CDM

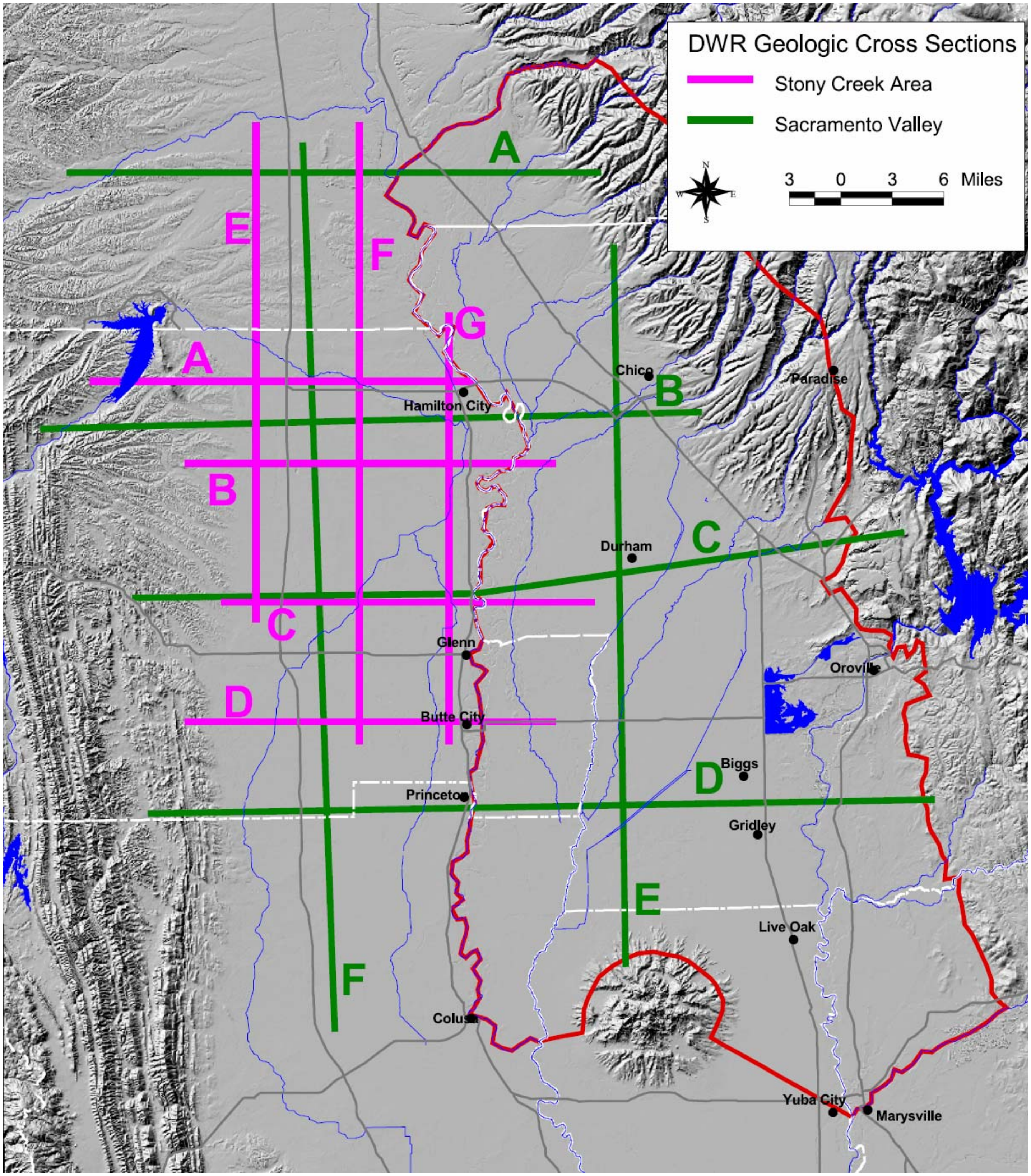


Figure 2-11
Location of DWR Cross-Sections used to Develop Model Stratigraphy

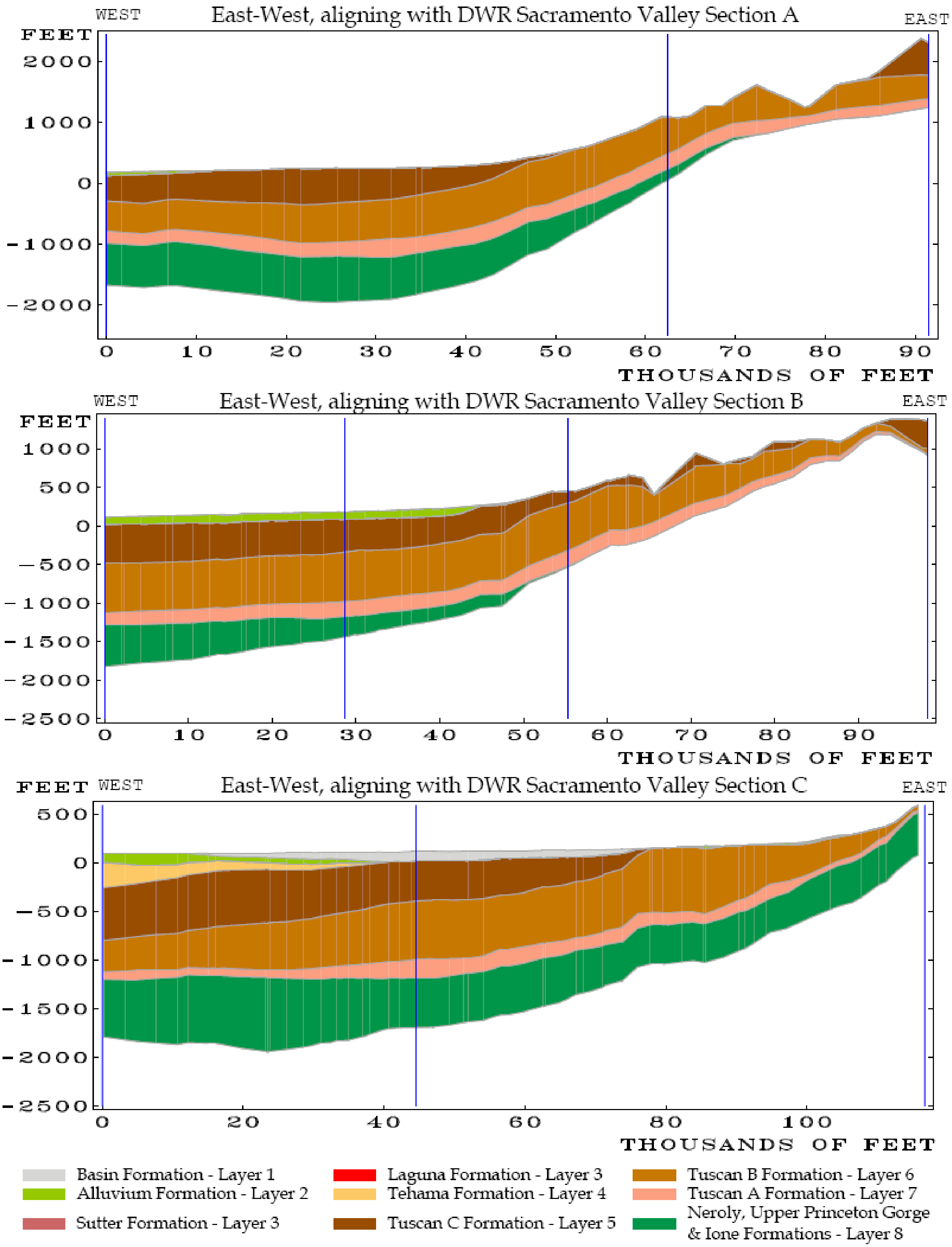


Figure 2-12
Cross-Sections A, B and C through Model

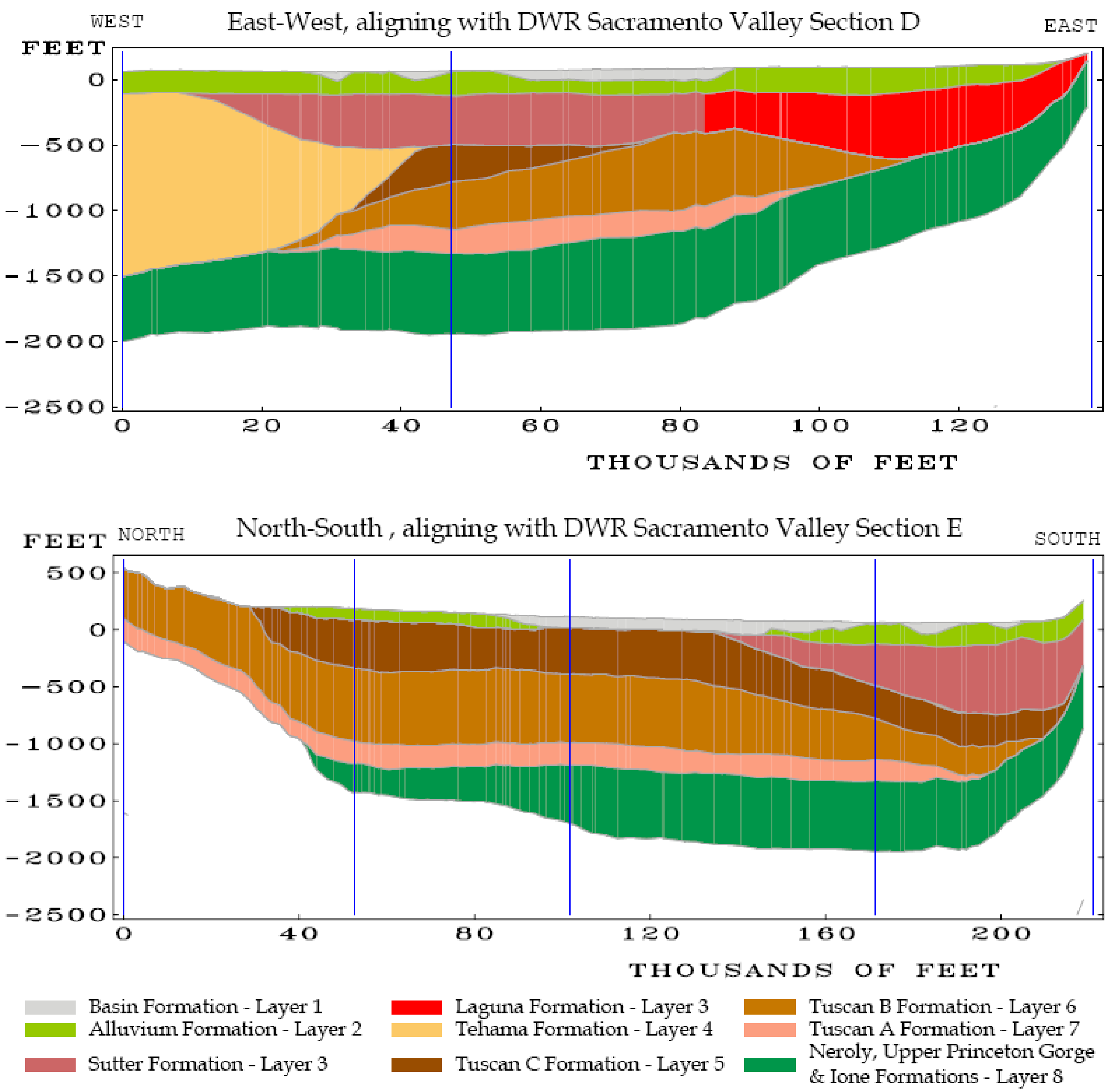
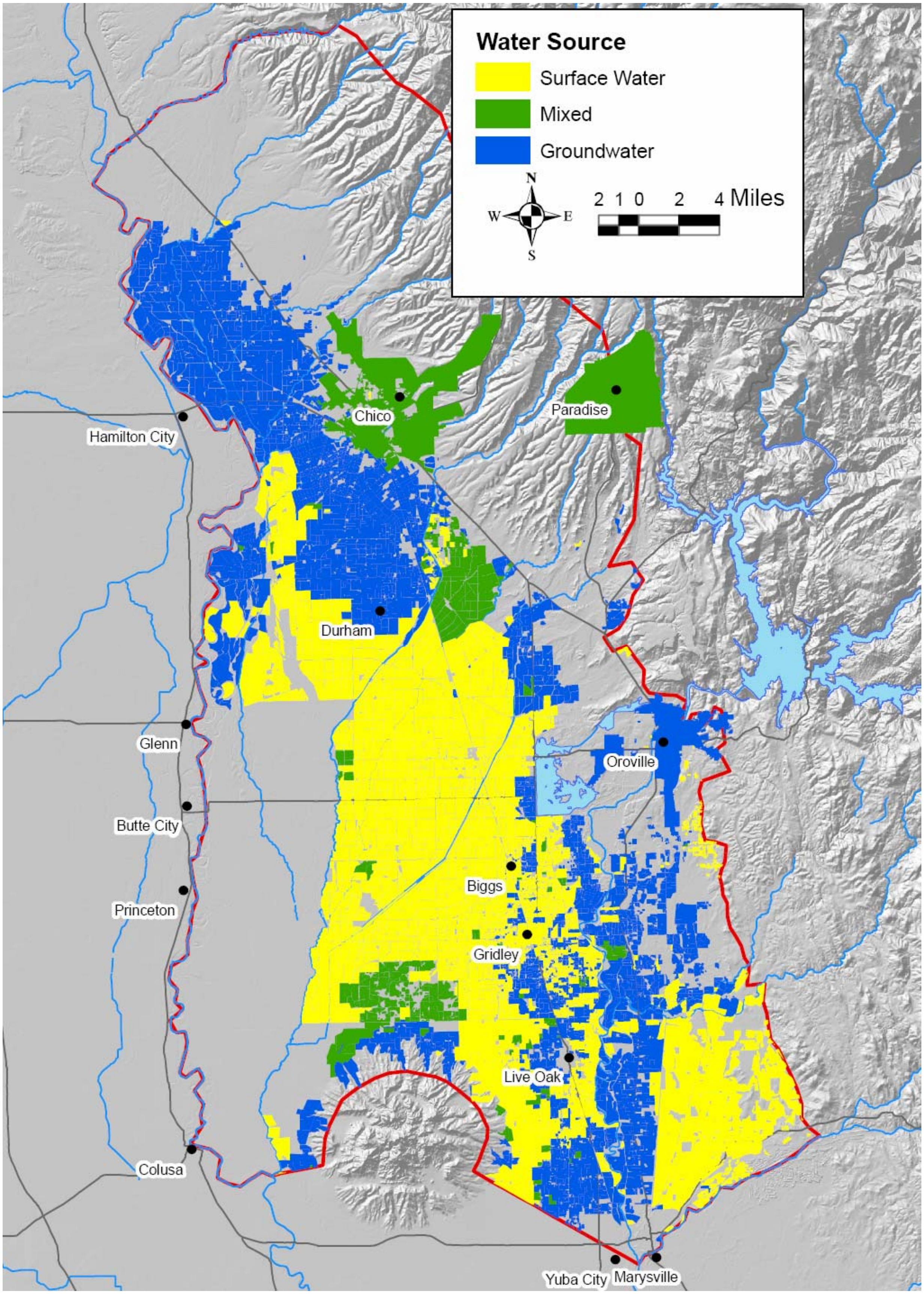


Figure 2-13
Cross-Sections D and E through Model

CDM



Water source data is not available for Glenn, Colusa, and Tehama counties.

Figure 2-14
Water Source Types

CDM

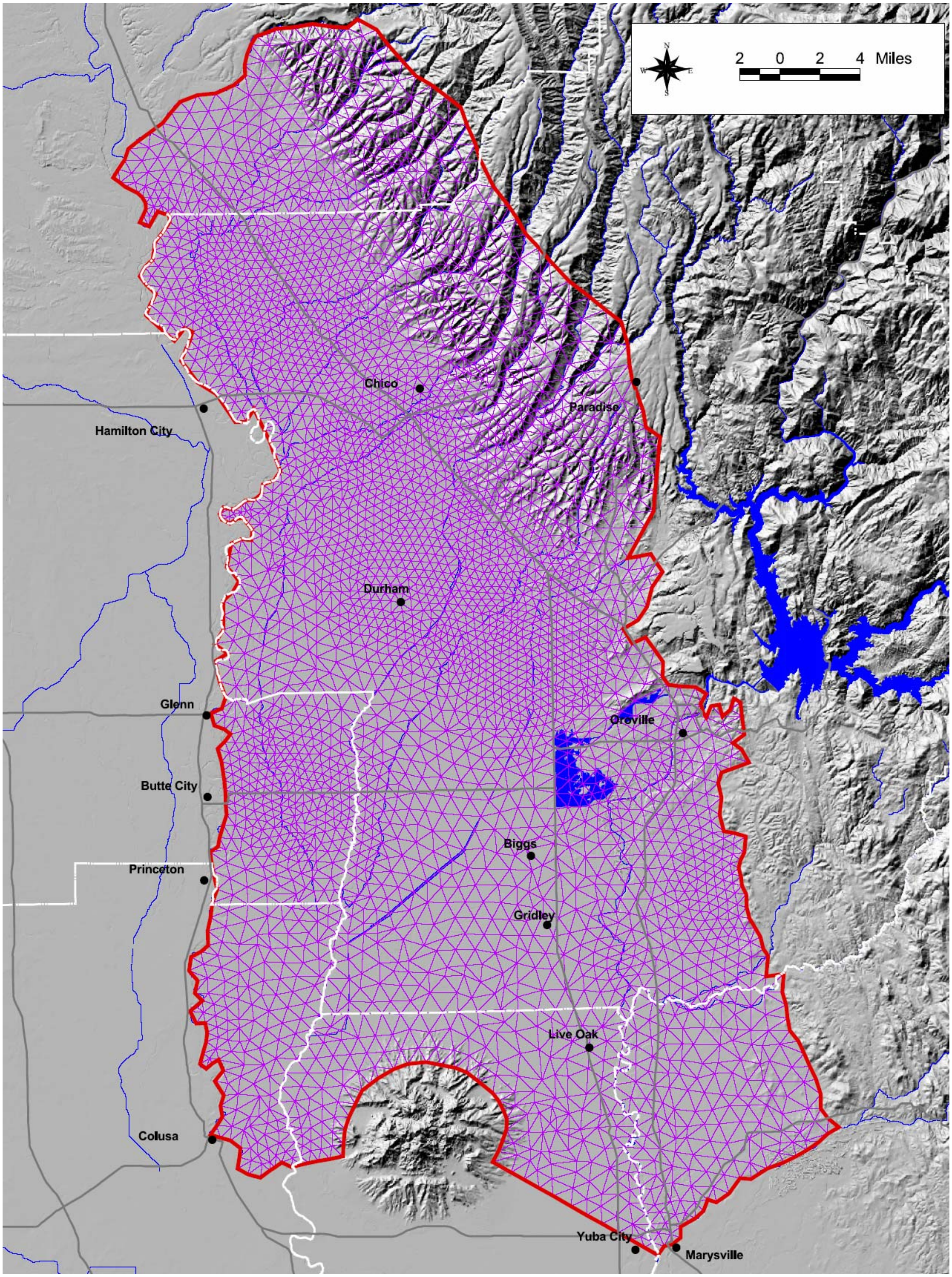


Figure 3-1
Model Domain and Finite Element Grid

CDM

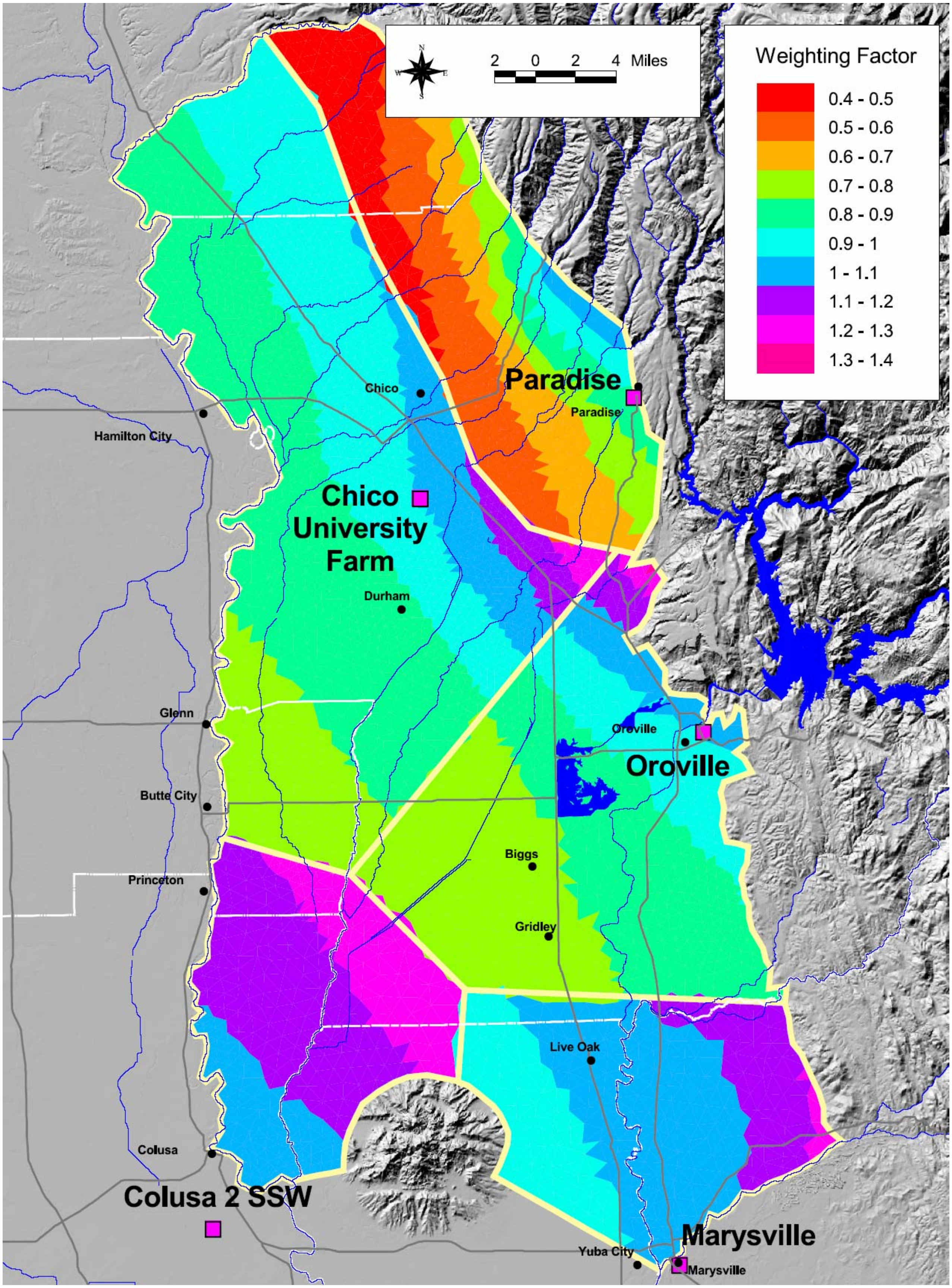
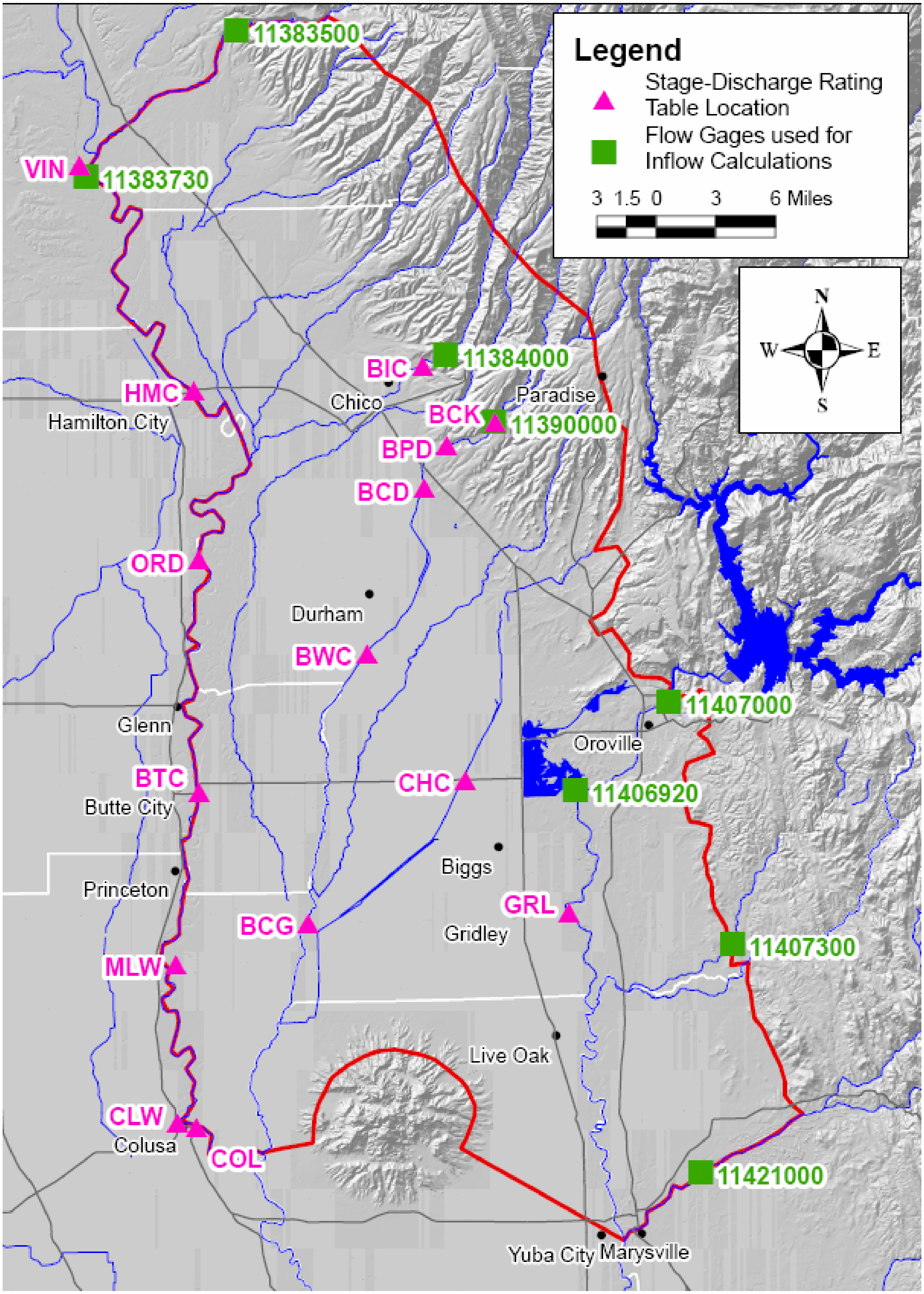


Figure 3-2
Precipitation Gage Weighting Factors



Note: Gages designated with 3 letters are CA DWR gages.
Gages designated with 8 numbers are UGGS gages.

Figure 3-3
Location of Stage-Discharge Data Sites and USGS Gauging Stations

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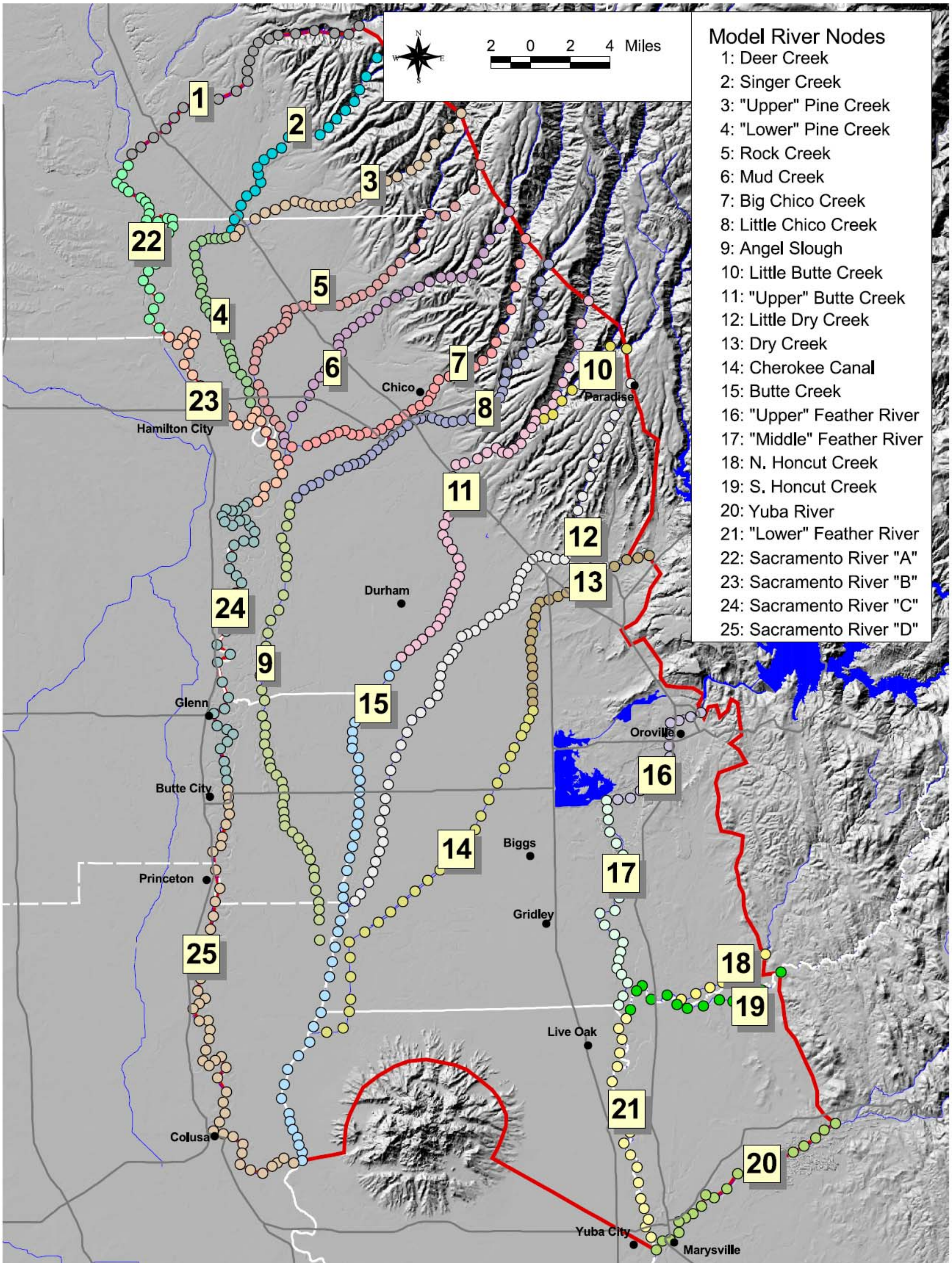

Figure 3-4
Location of Model River Nodes and Reaches

CDM

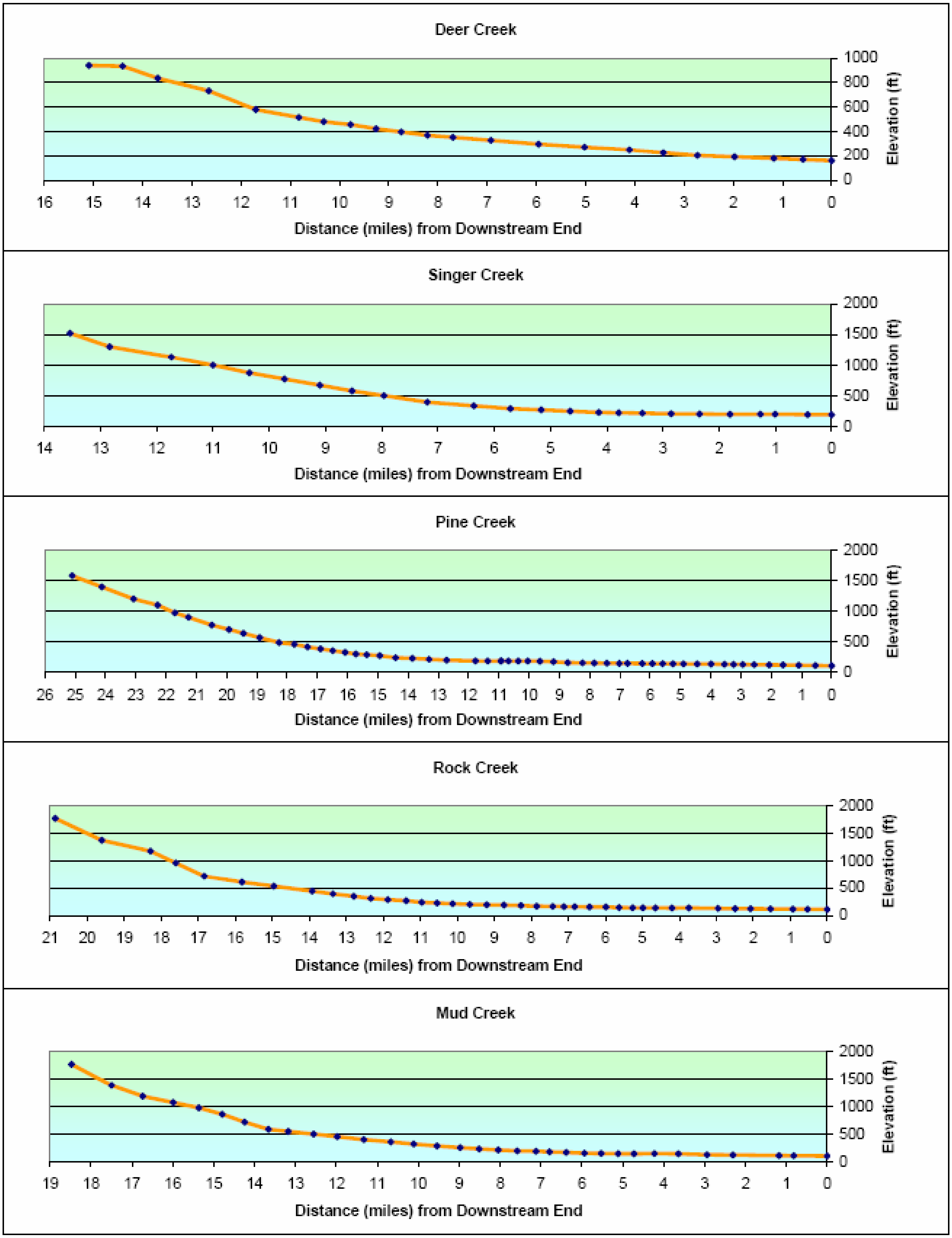

Figure 3-5
Stream Channel Profiles

Each blue point represents the elevation at a stream node in the model.
Distances are measured from the farthest downstream point with in the model domain.

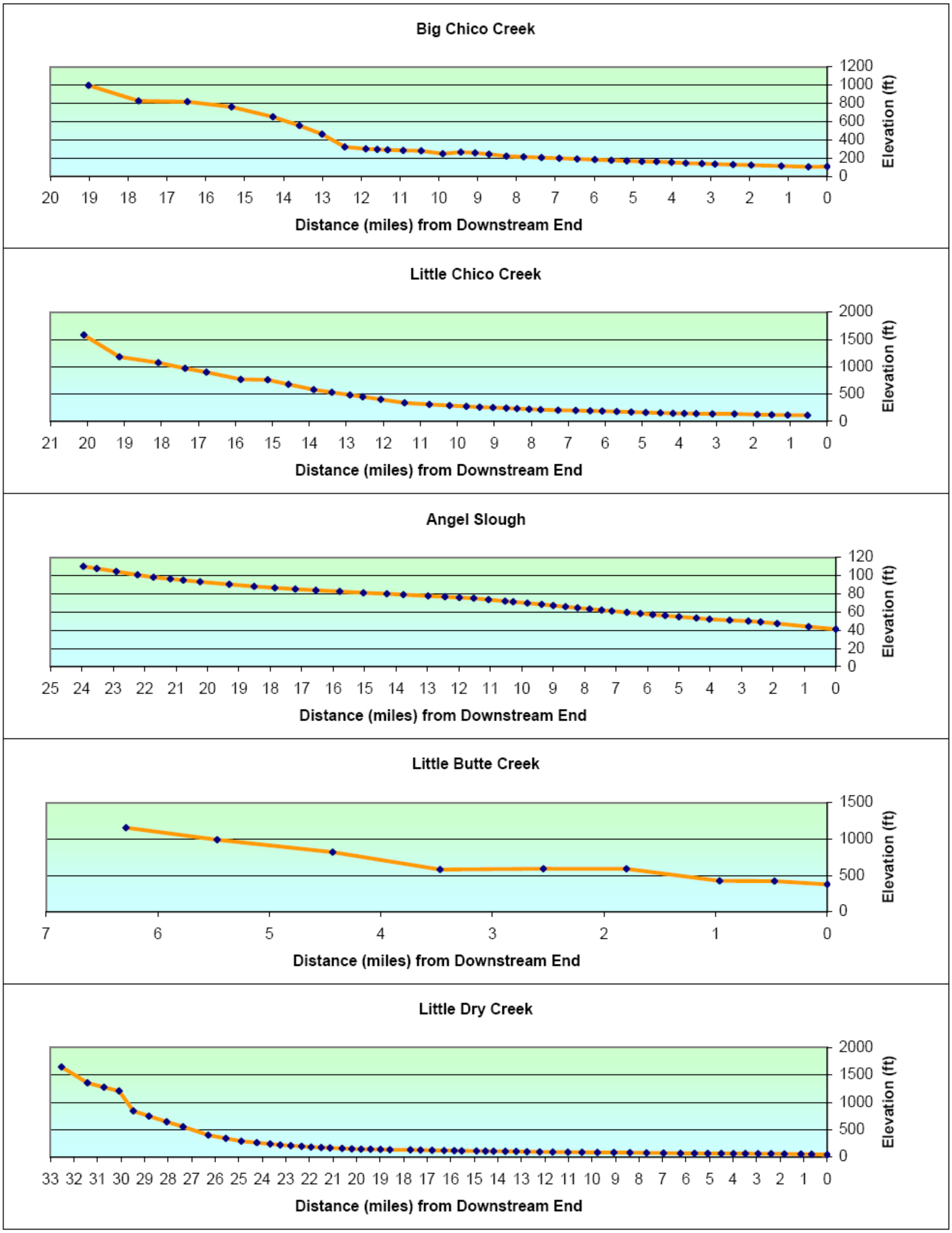

Figure 3-6
Stream Channel Profiles

Each blue point represents the elevation at a stream node in the model.
Distances are measured from the farthest downstream point with in the model domain.

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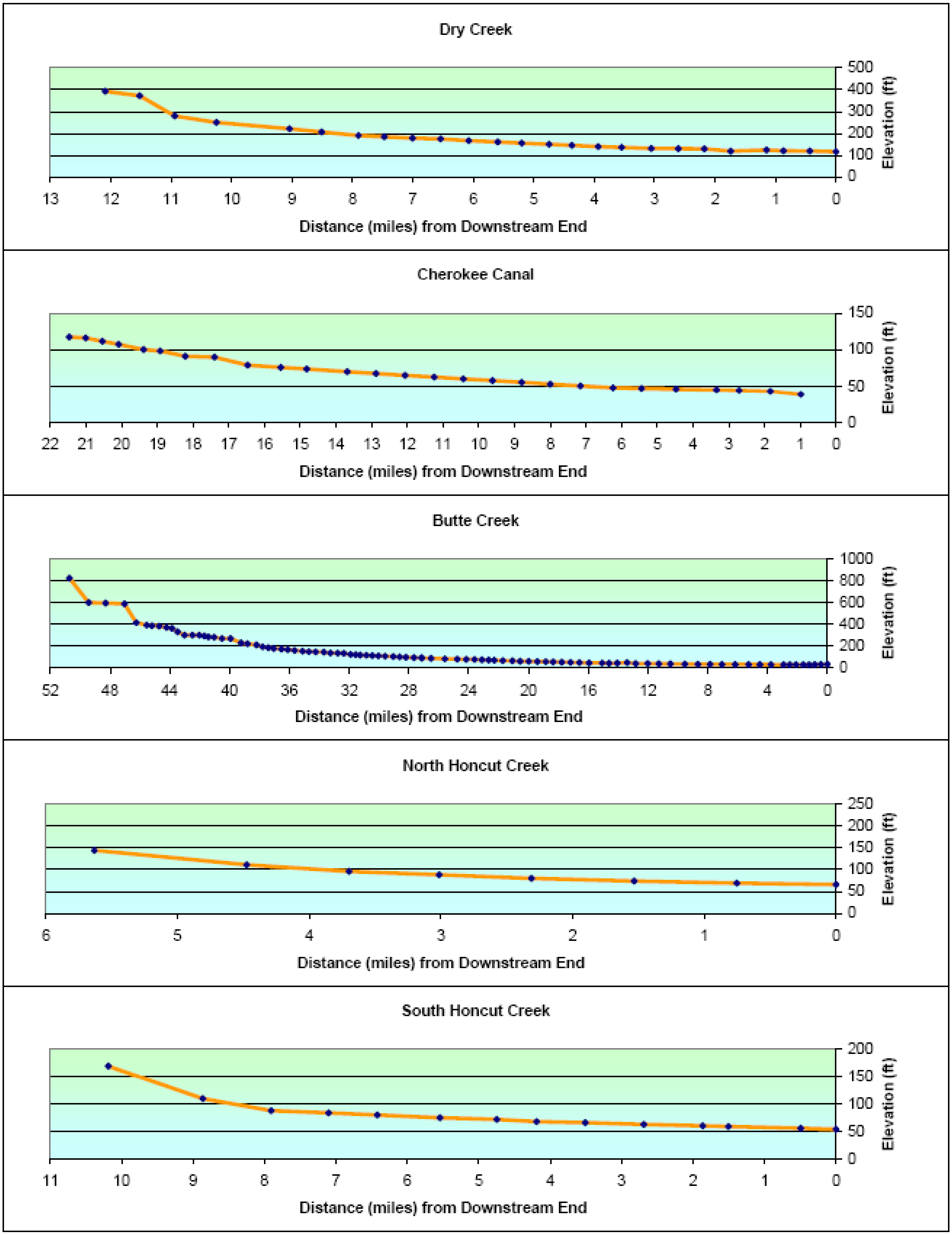


Each blue point represents the elevation at a stream node in the model.
Distances are measured from the farthest downstream point with in the model domain.

Figure 3-7
Stream Channel Profiles

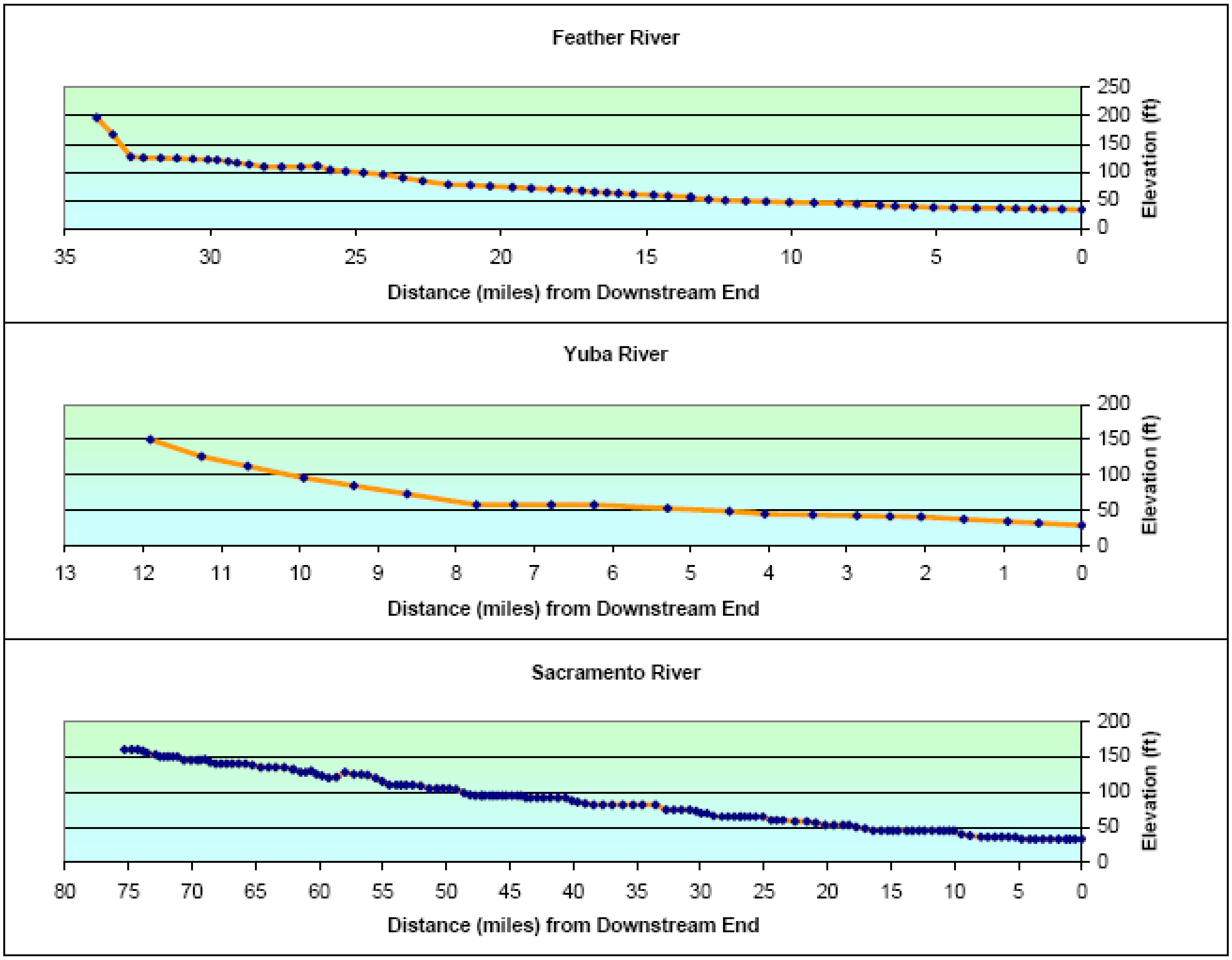


Figure 3-8
Stream Channel Profiles

Each blue point represents the elevation at a stream node in the model.
Distances are measured from the farthest downstream point with in the model domain.

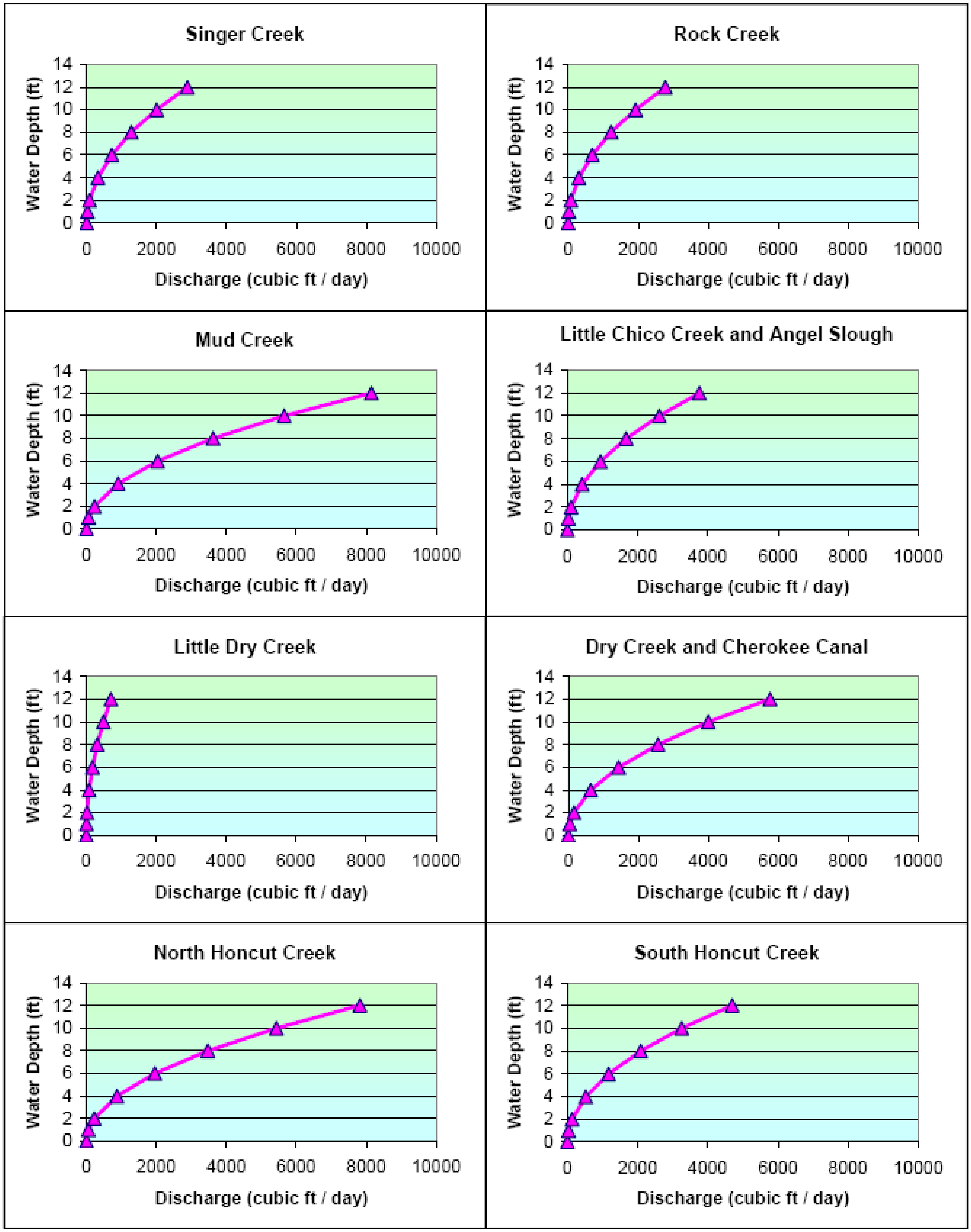


Figure 3-9
River Depth-Discharge Plots

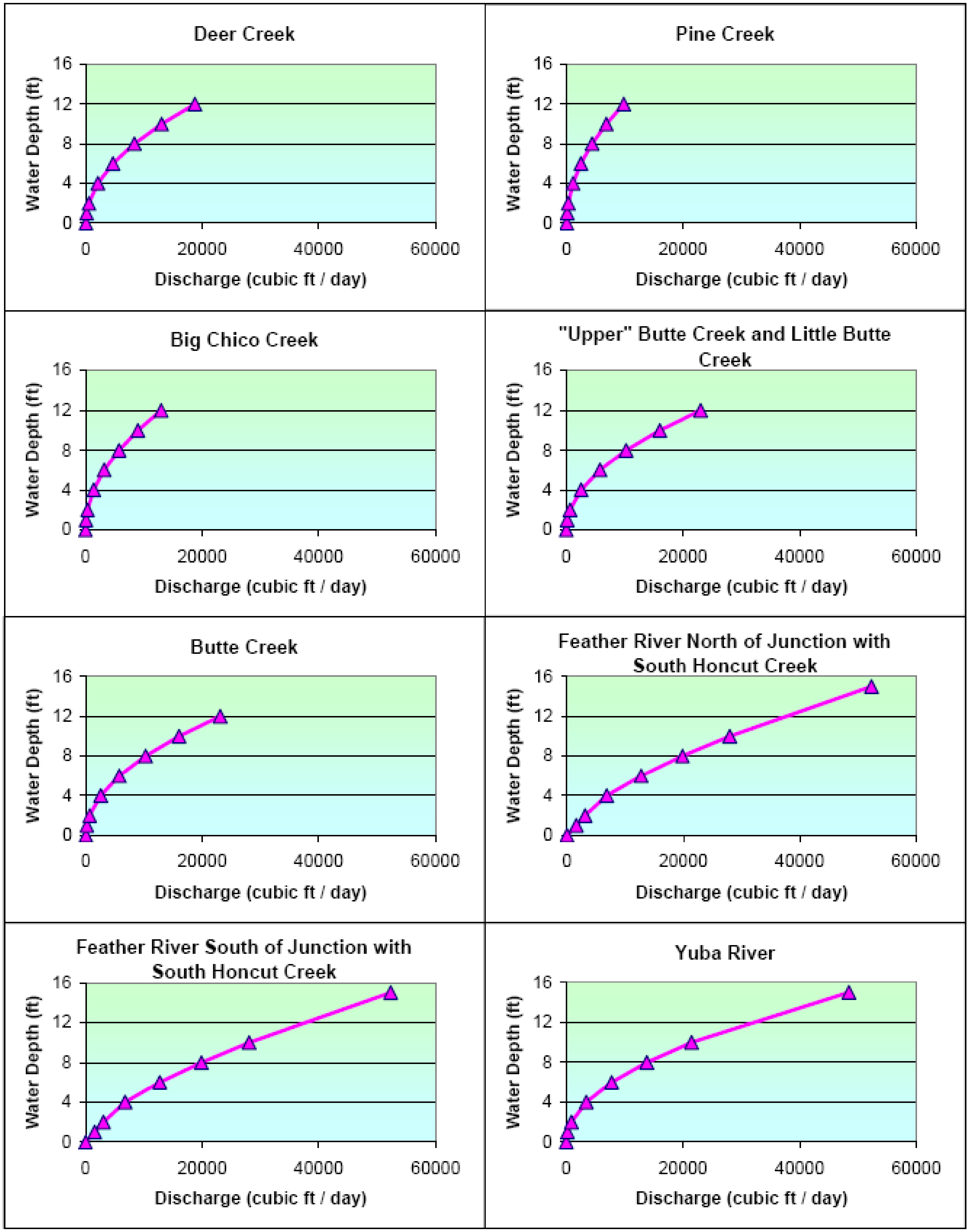
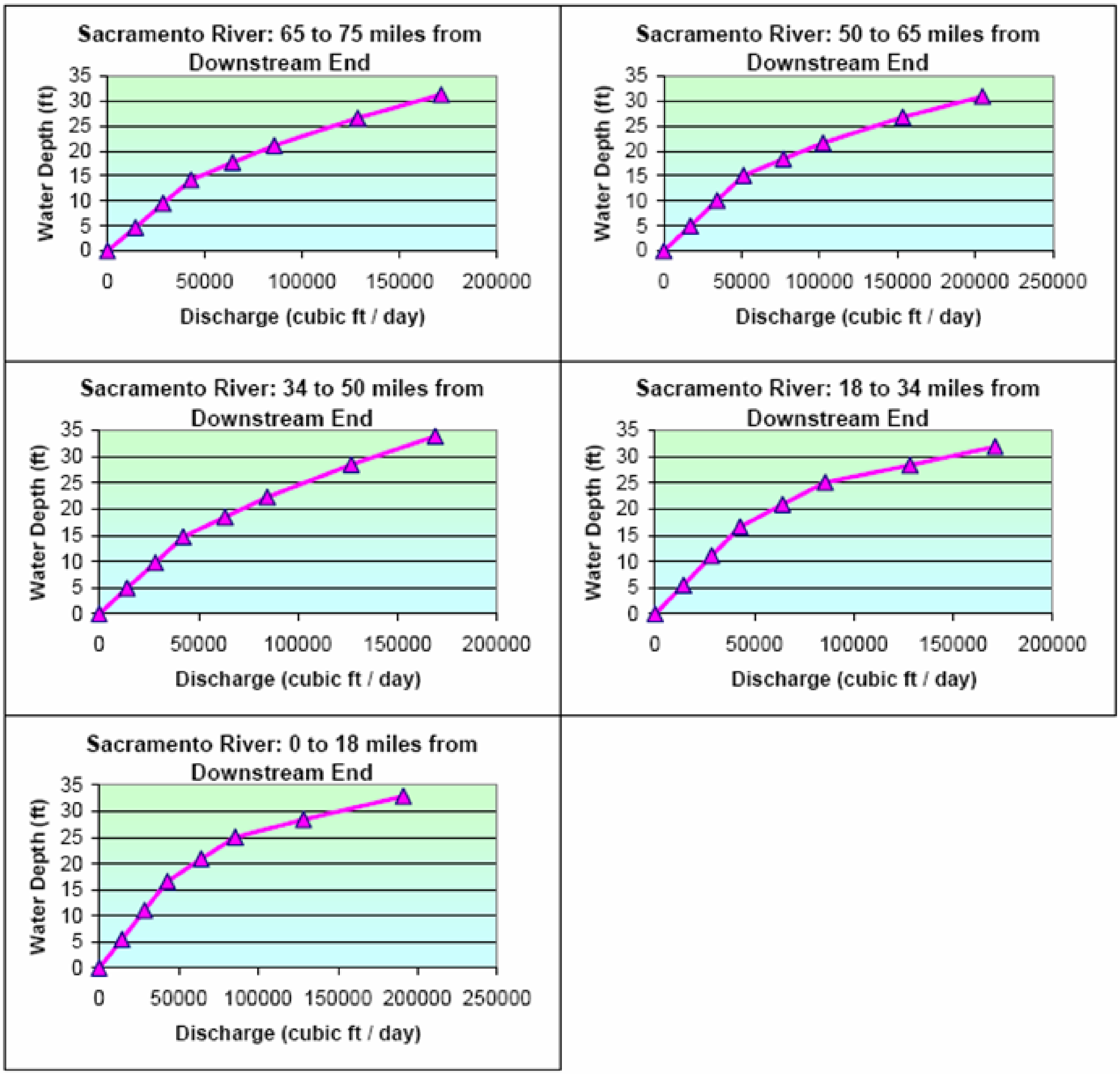
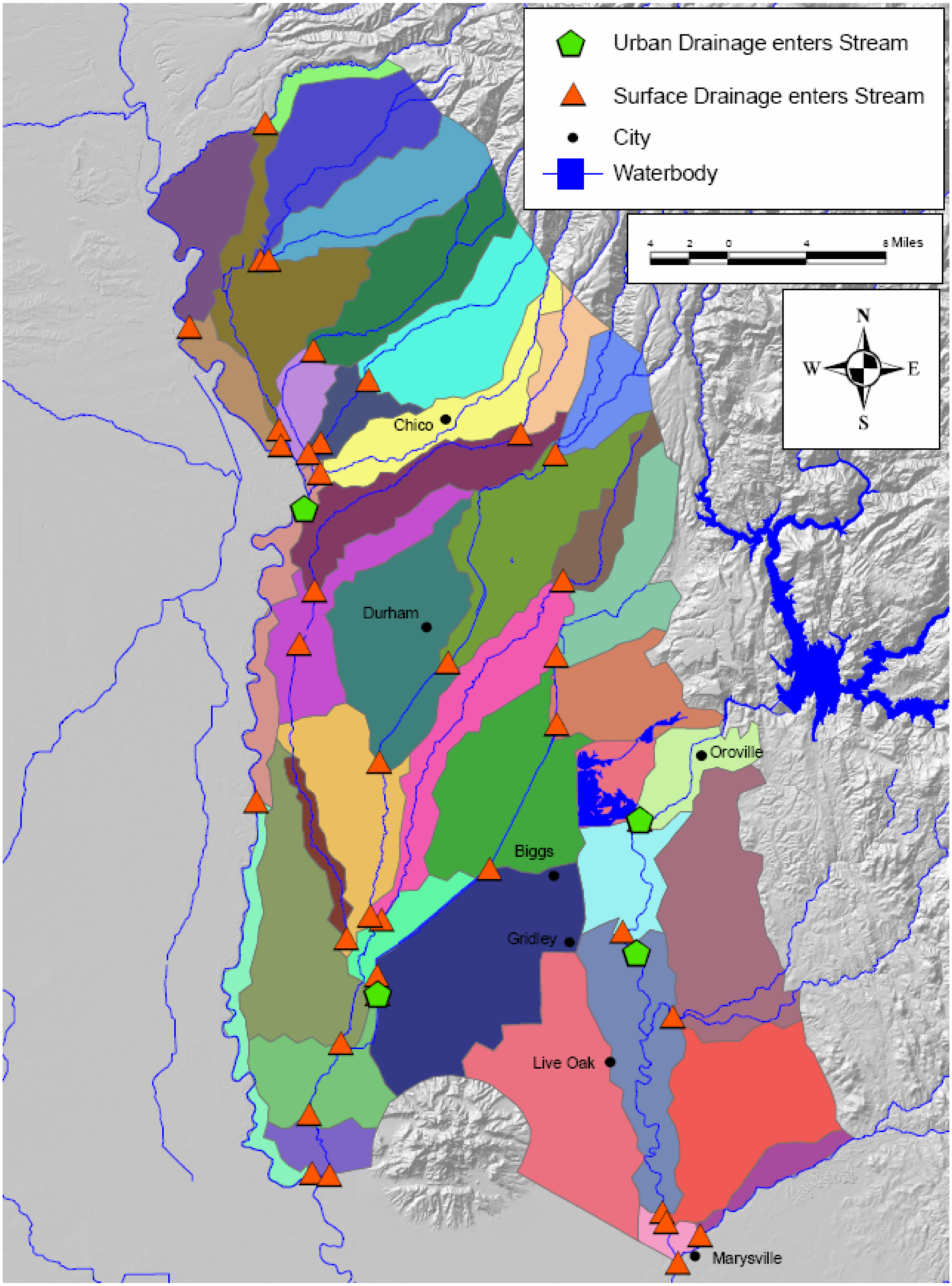


Figure 3-10
River Depth-Discharge Plots



The downstream end of the Sacramento River refers to the point the river flows out of the model at the confluence of the Sacramento River and Butte Creek.

Figure 3-11
River Depth-Discharge Plots



Colored polygons represent surface drainage areas.
Surface runoff drains to the orange triangle at the southern end of the drainage area. The drainage areas near the Thermalito Afterbay and west of Live Oak drain out of the model.

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Figure 3-12
Drainage Areas and Urban Return Flow

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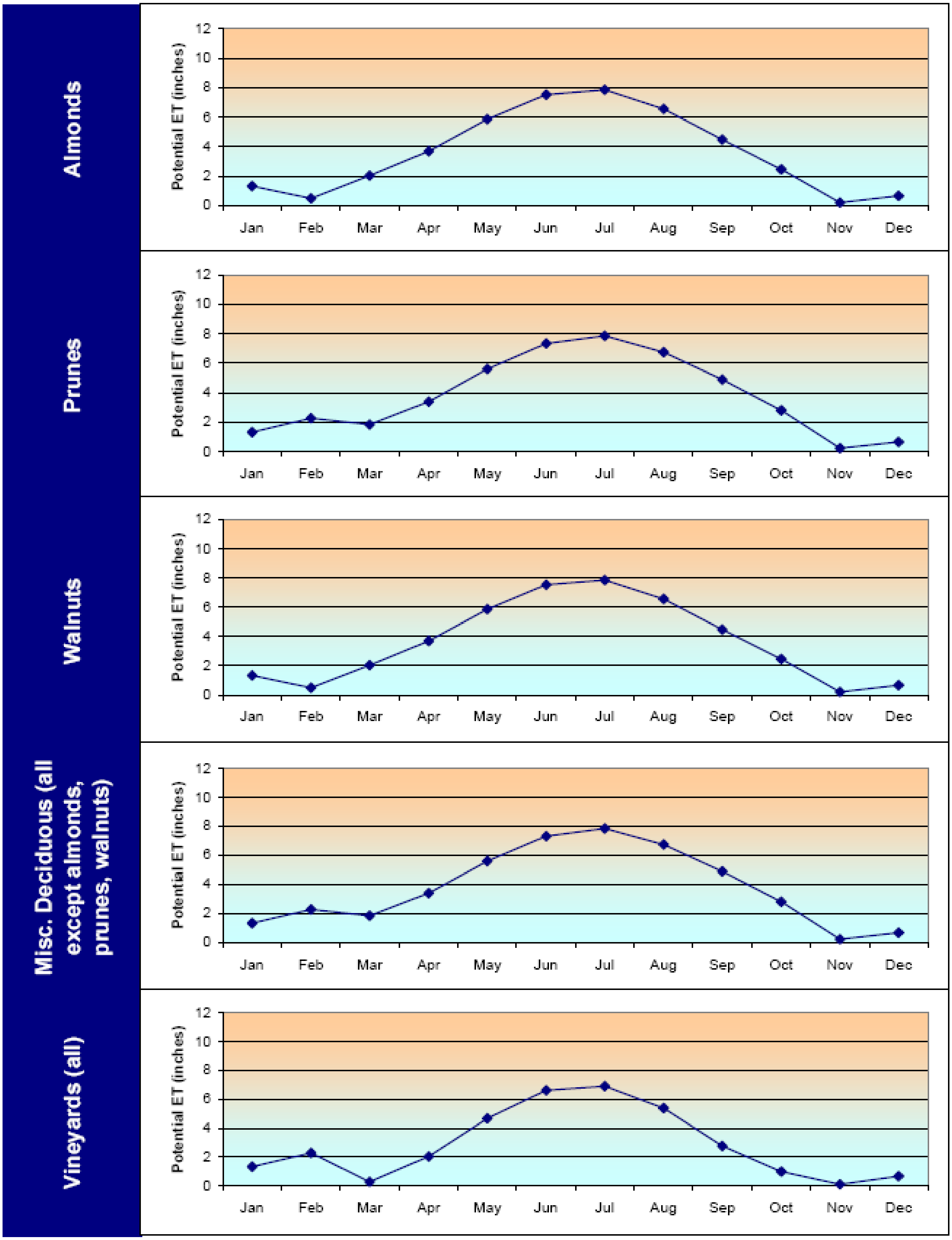

Figure 3-13
Evapotranspiration (ET) Rates for Deciduous Crops and Vineyards

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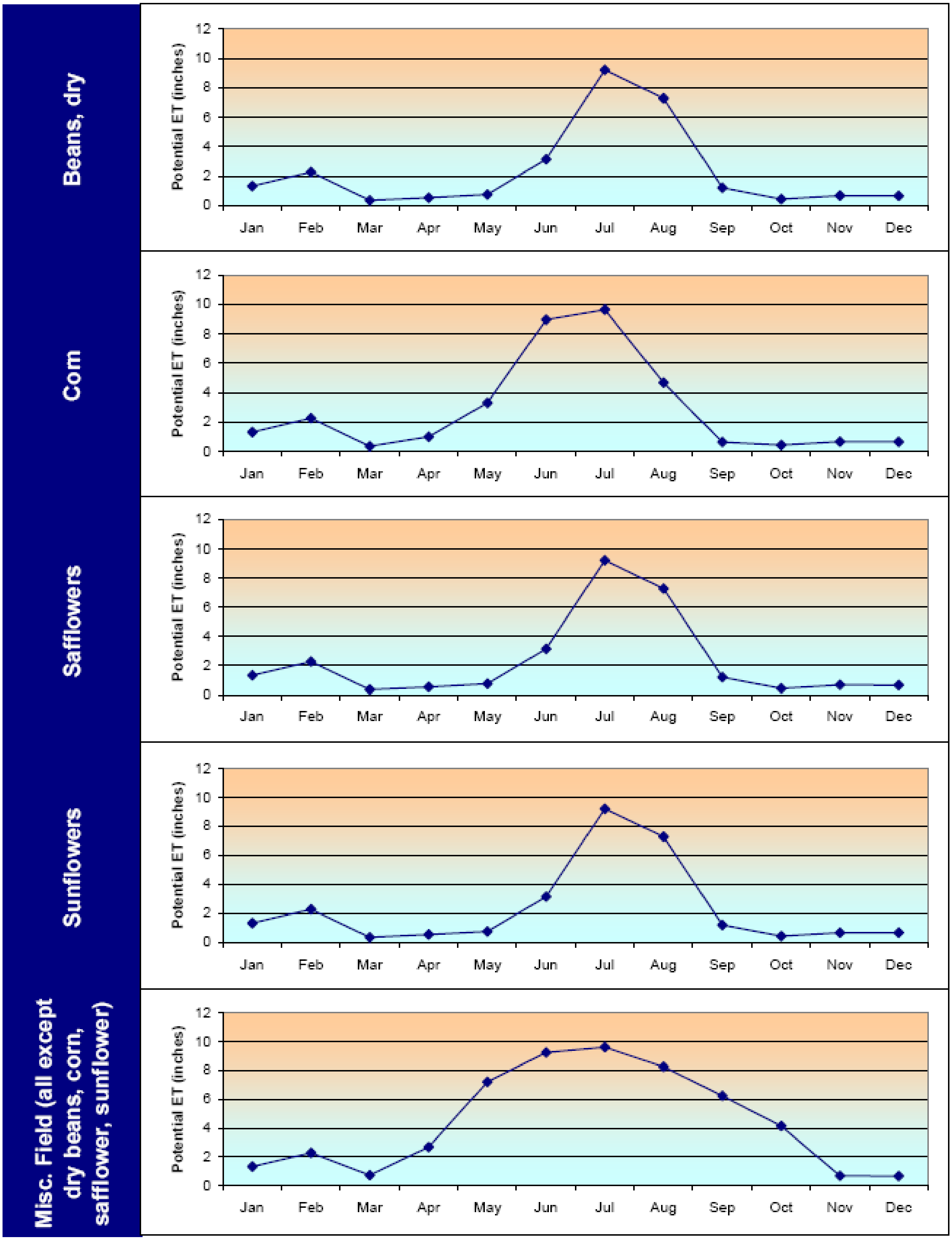

Figure 3-14
Evapotranspiration (ET) Rates for Field Crops

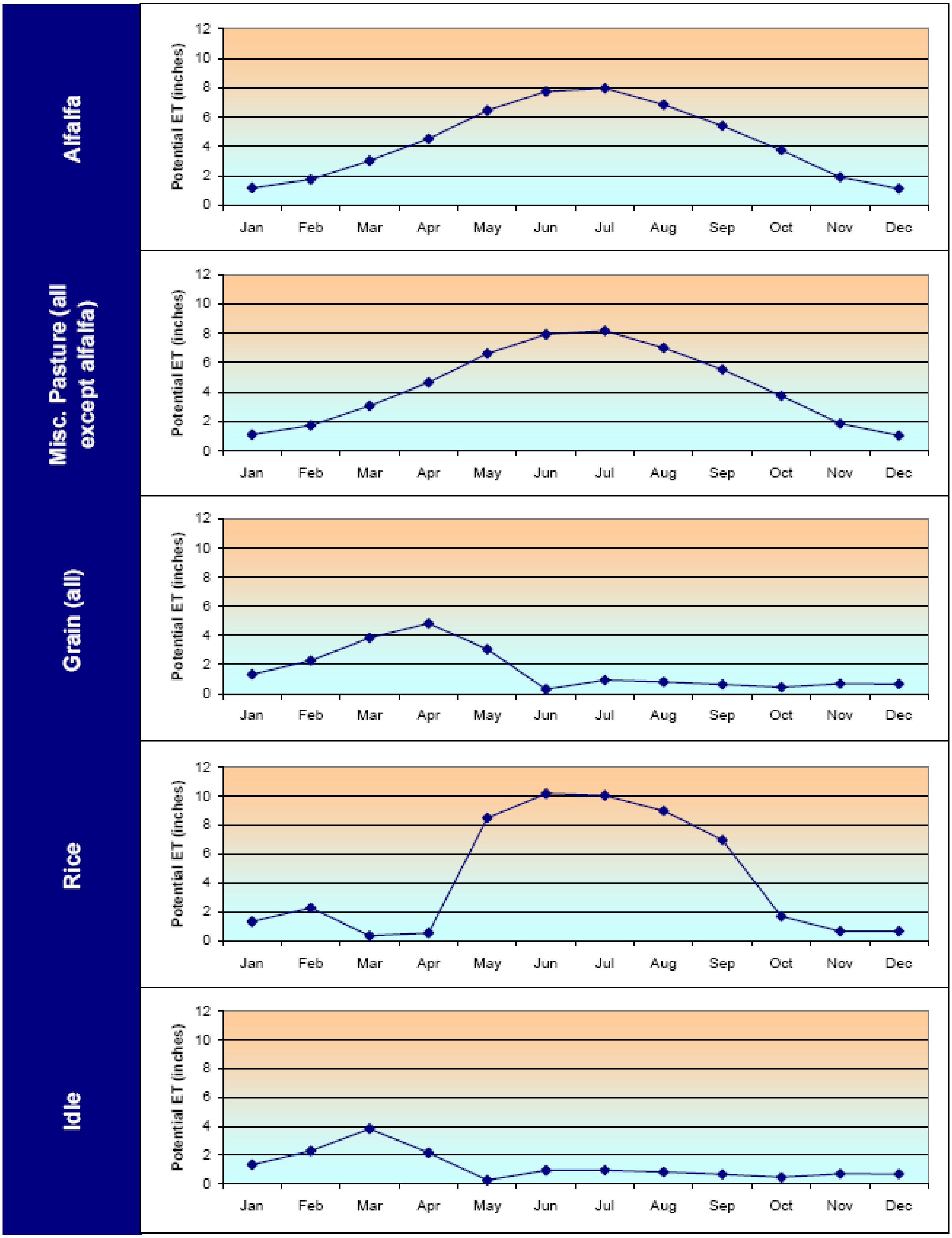

Figure 3-15
Evapotranspiration (ET) Rates for Pasture, Grain, Rice and Idle Land

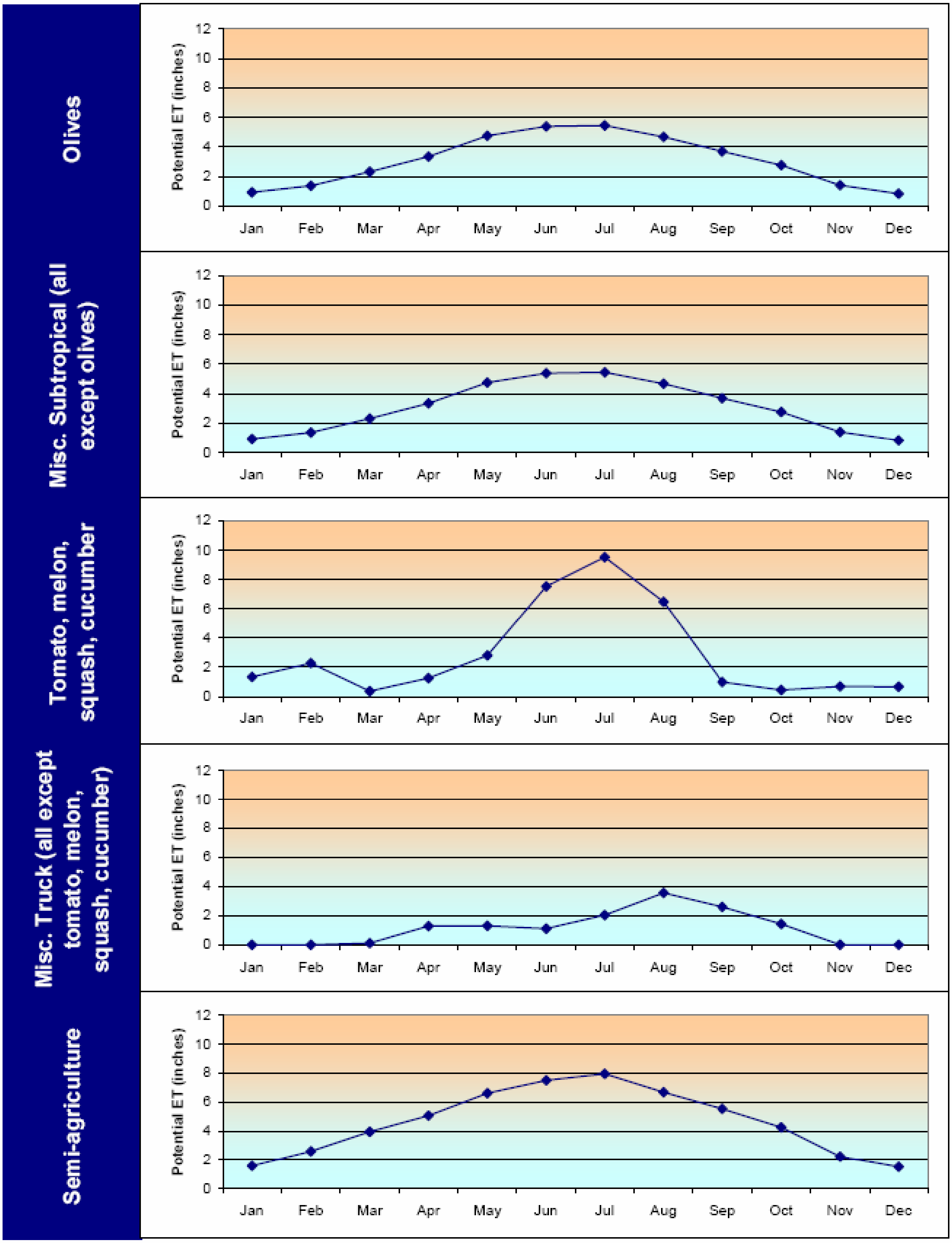

Figure 3-16
Evapotranspiration (ET) Rates for Subtropical and Truck Crops and Semi-agricultural Land

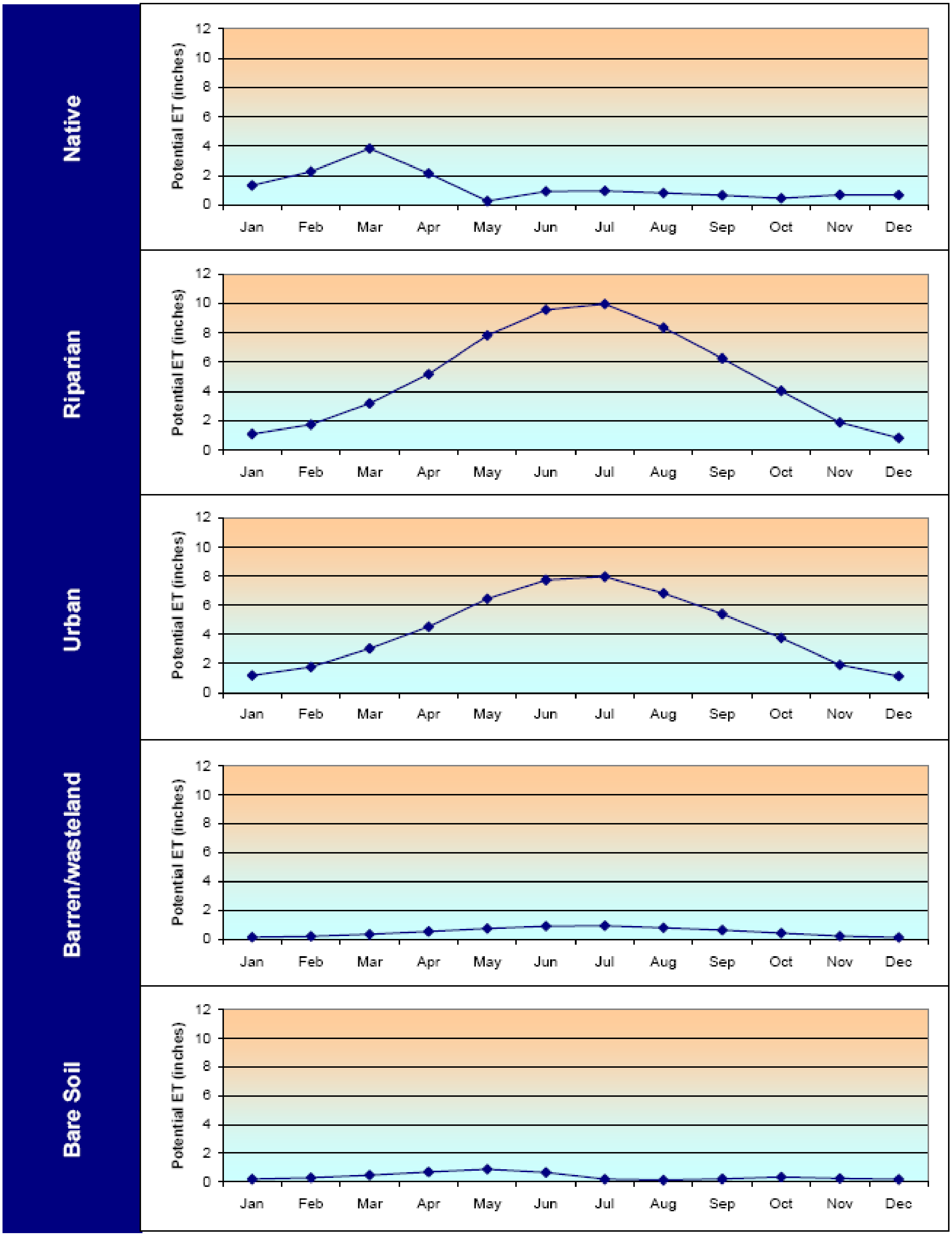

Figure 3-17
Evapotranspiration (ET) Rates for Native, Riparian, Urban, Barren/Wasteland, and Bare Soil

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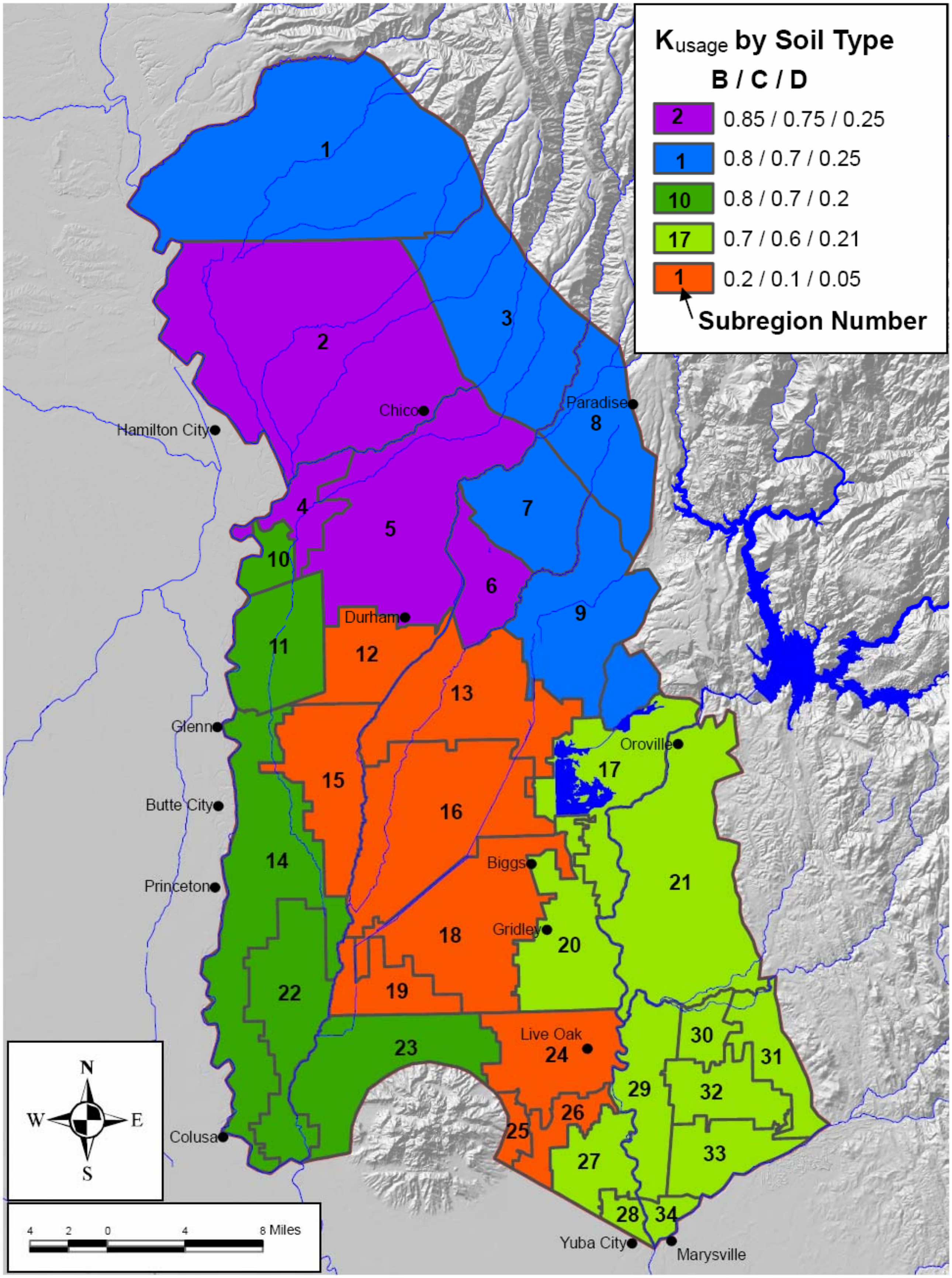

Figure 3-18
Deep Percolation – K_{usage} Terms

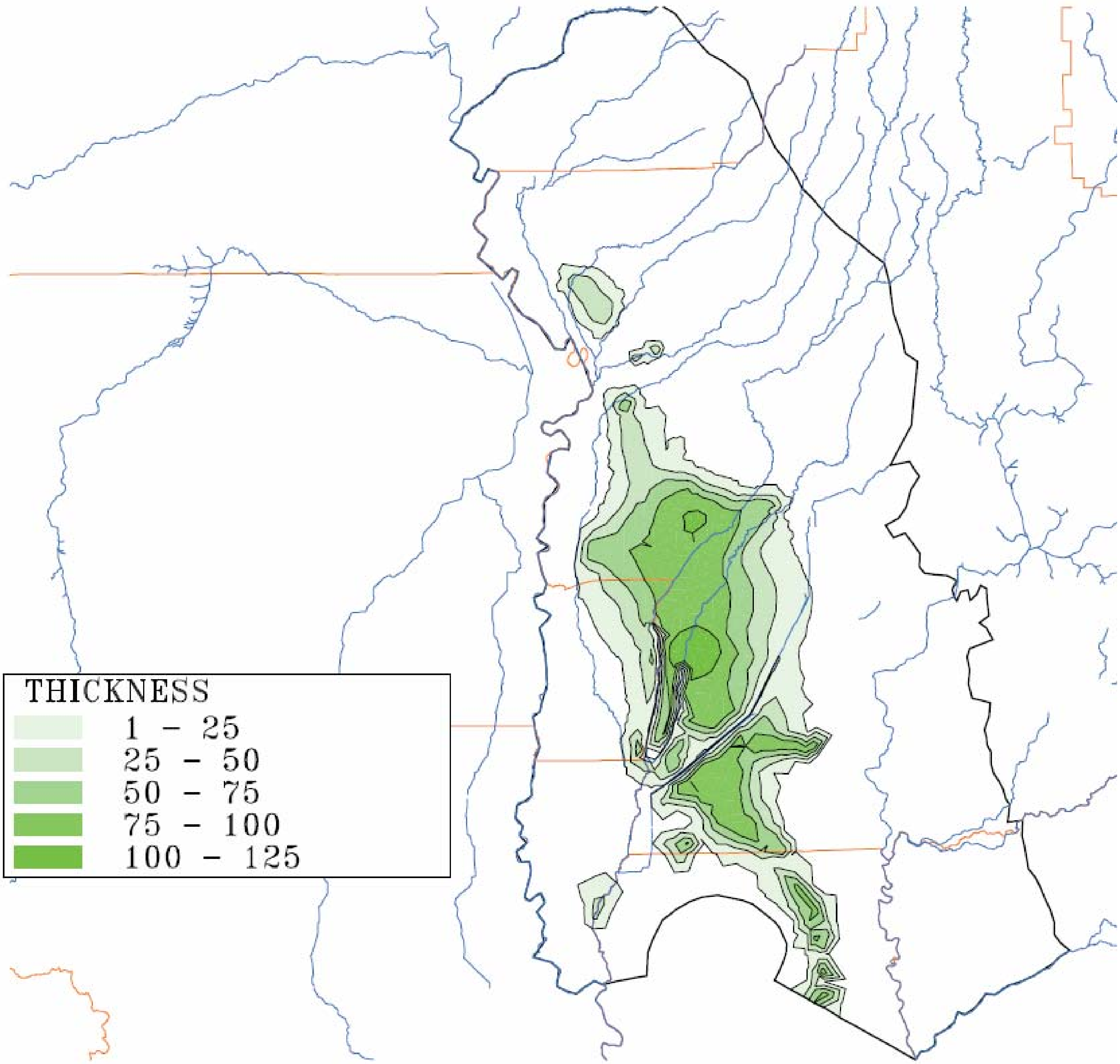

Figure 3-19
Basin Deposits
Model Layer Extent and Thickness

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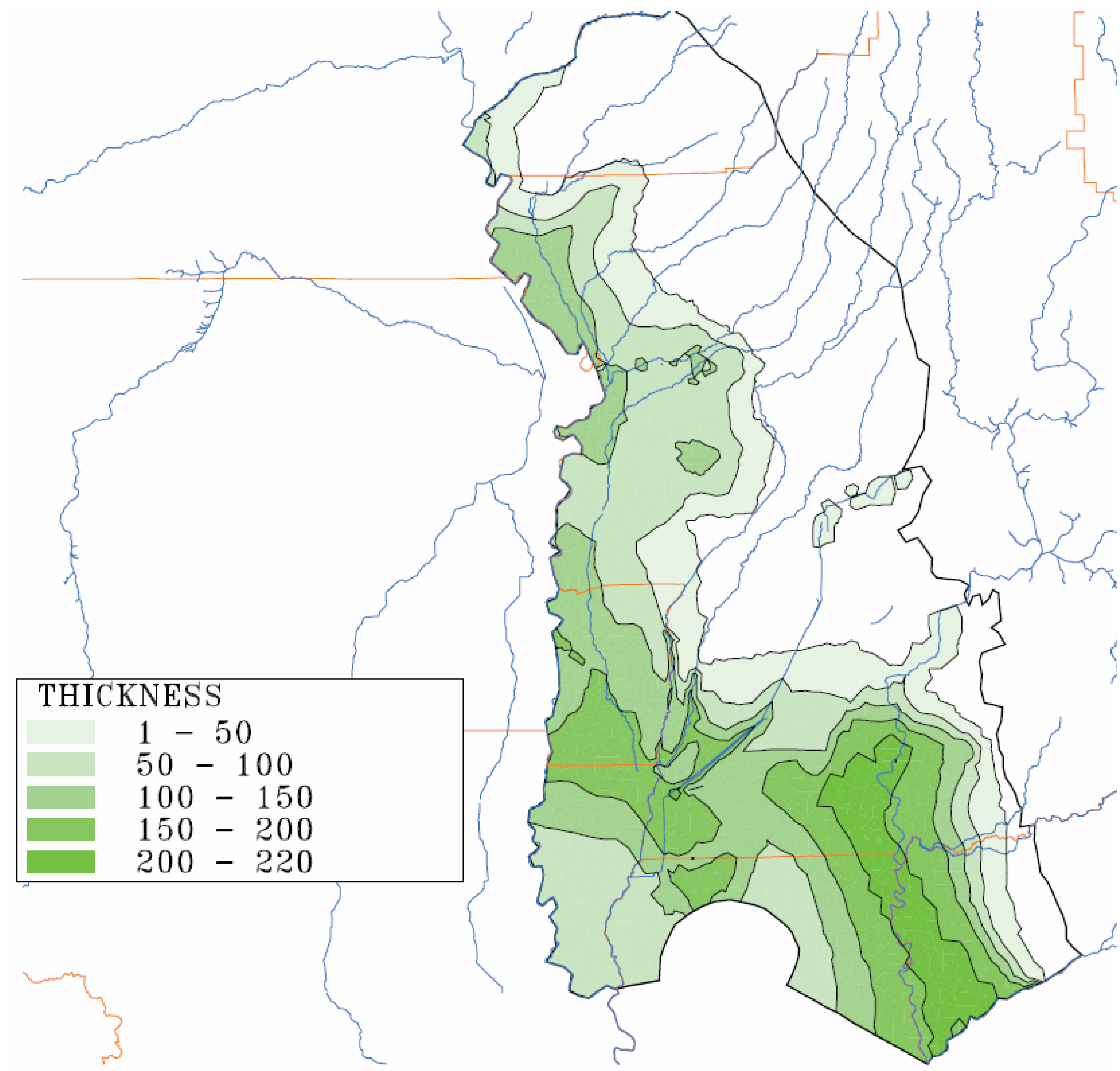

Figure 3-20
Alluvium Formation
Model Layer Extent and Thickness

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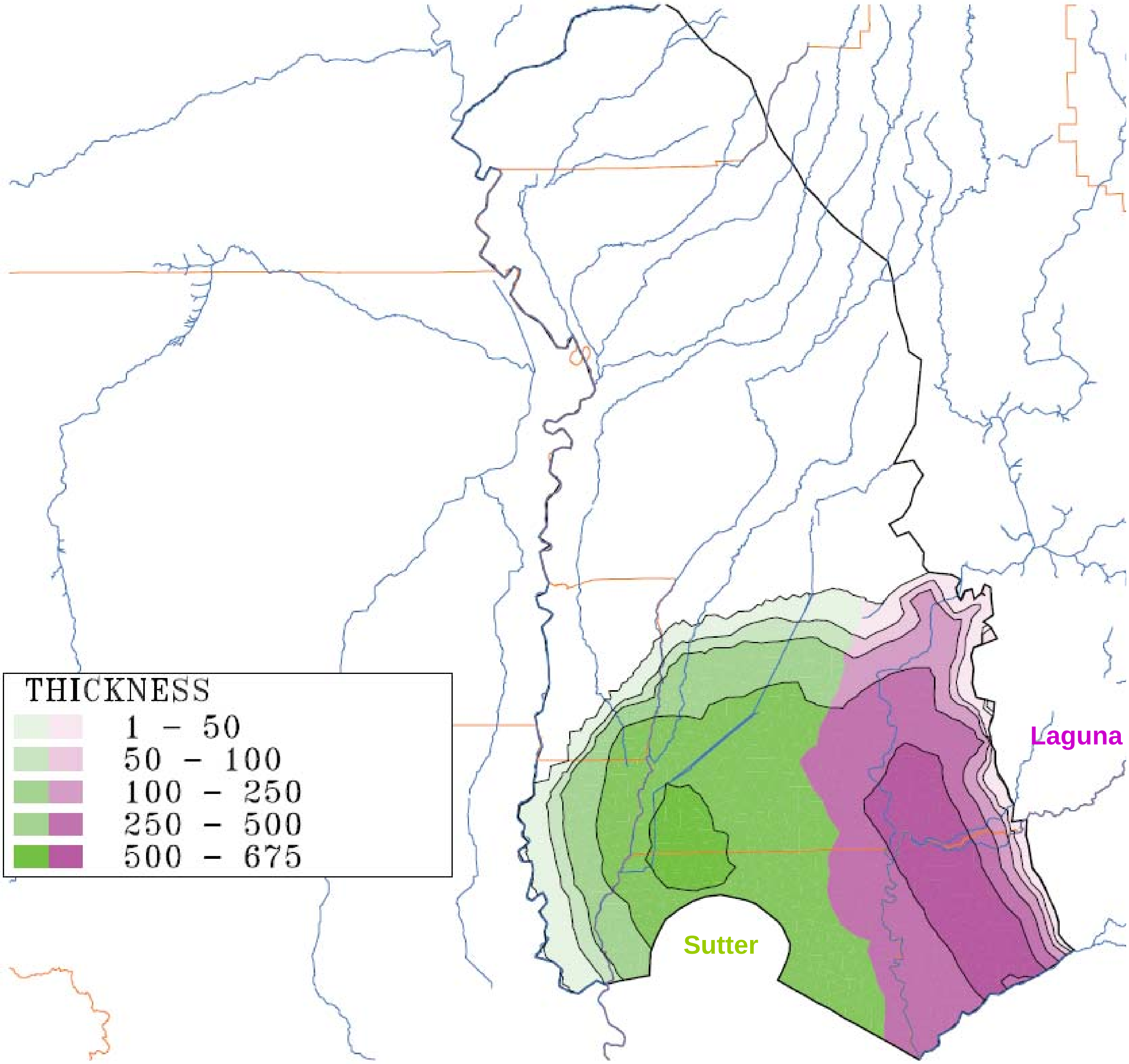

Figure 3-21
Sutter and Laguna Formations
Model Layer Extent and Thickness

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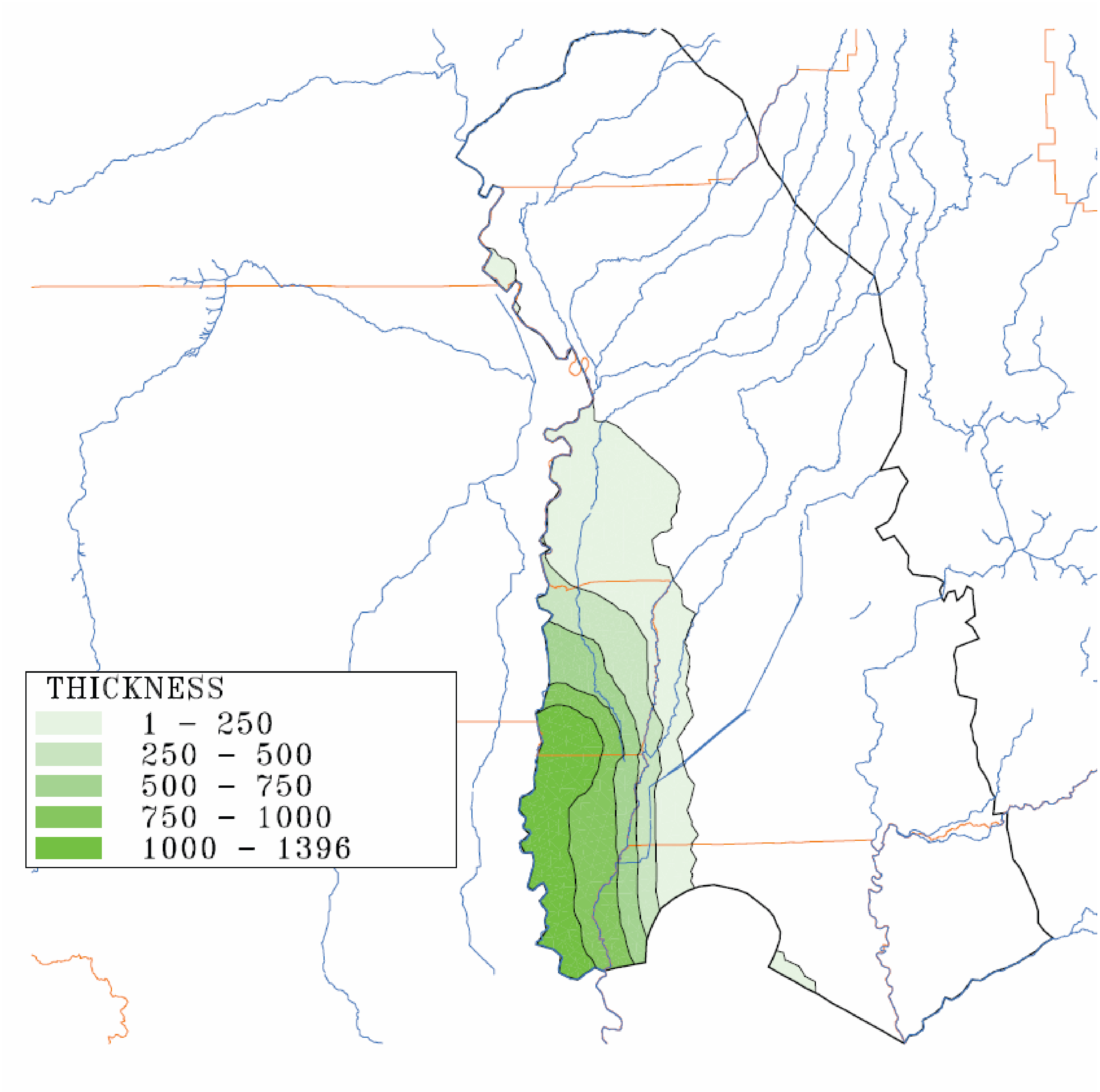

Figure 3-22
Tehama Formation
Model Layer Extent and Thickness

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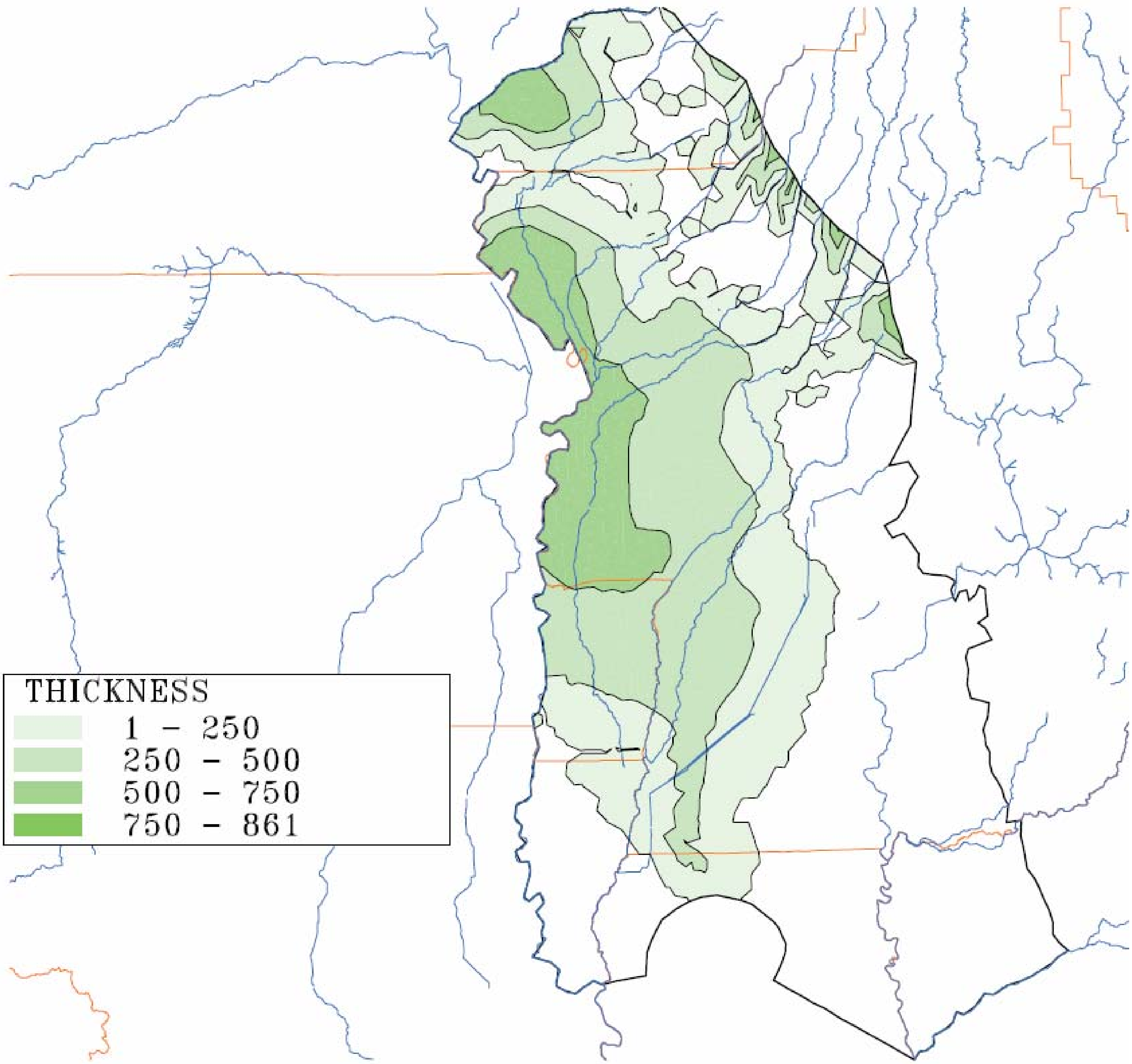

Figure 3-23
Tuscan C Formation
Model Layer Extent and Thickness

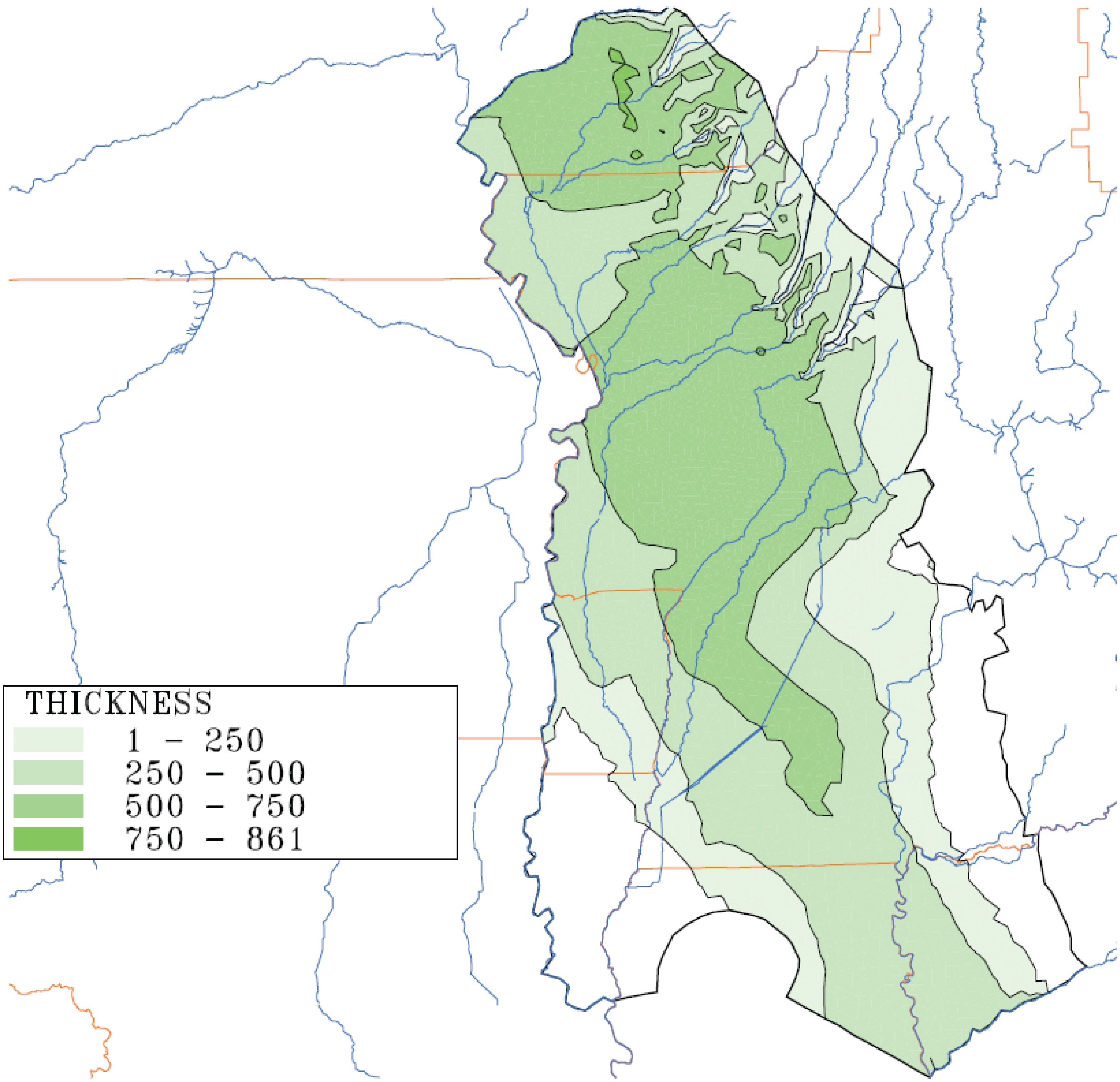

Figure 3-24
Tuscan B Formation
Model Layer Extent and Thickness

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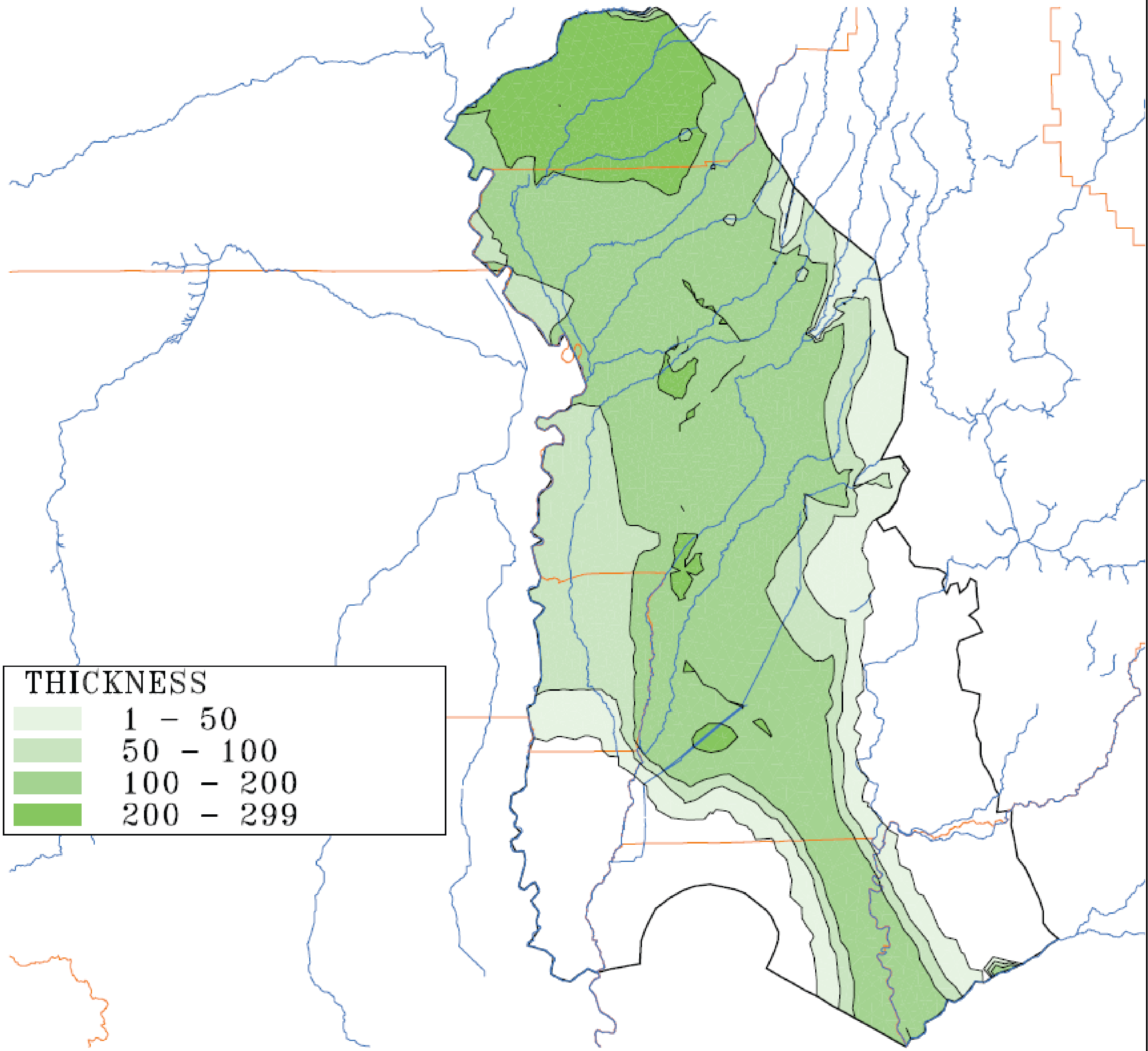

Figure 3-25
Tuscan A Formation
Model Layer Extent and Thickness

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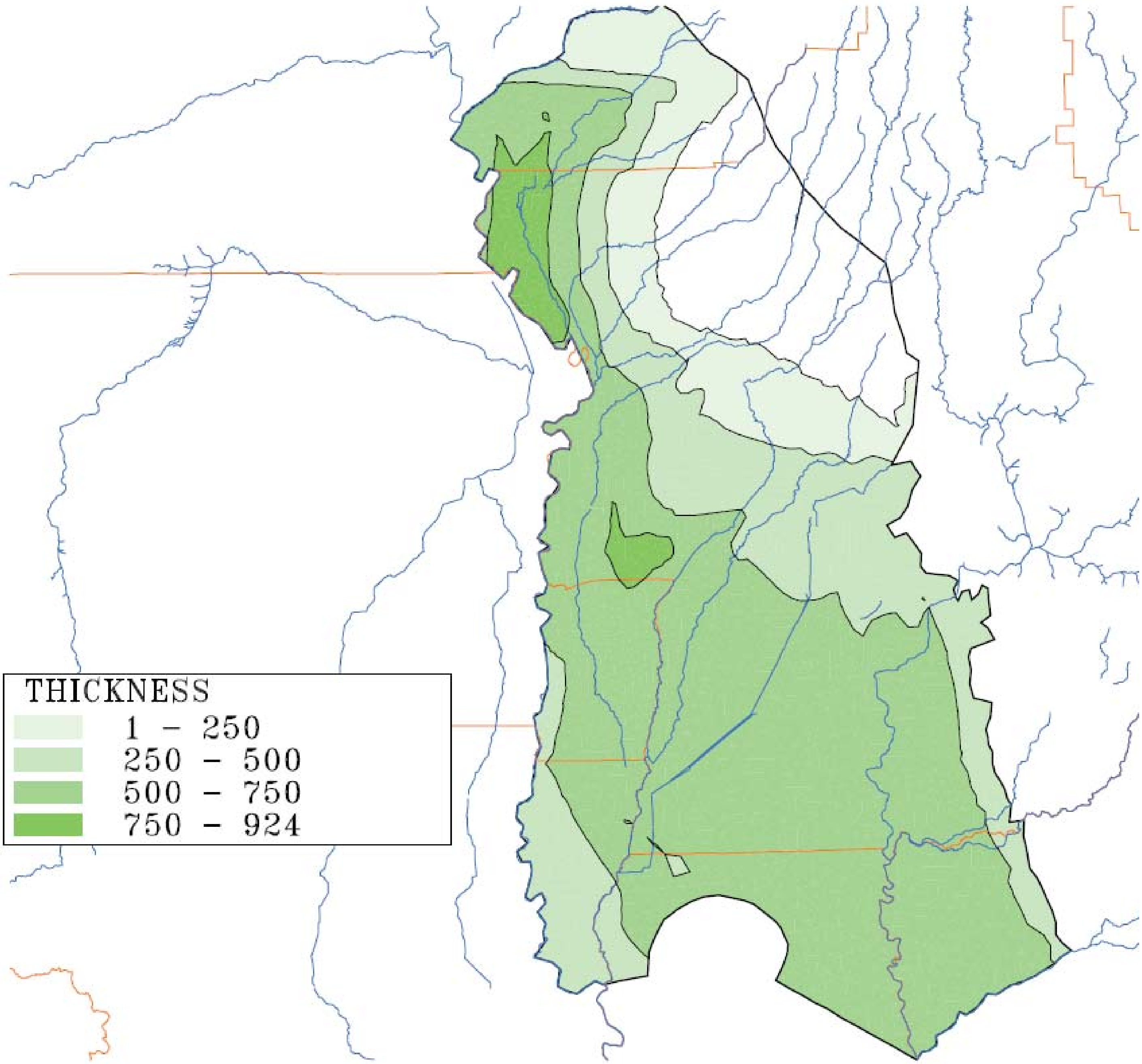

Figure 3-26
Neroly, Upper Princeton Gorge & Ione Formations
Model Layer Extent and Thickness

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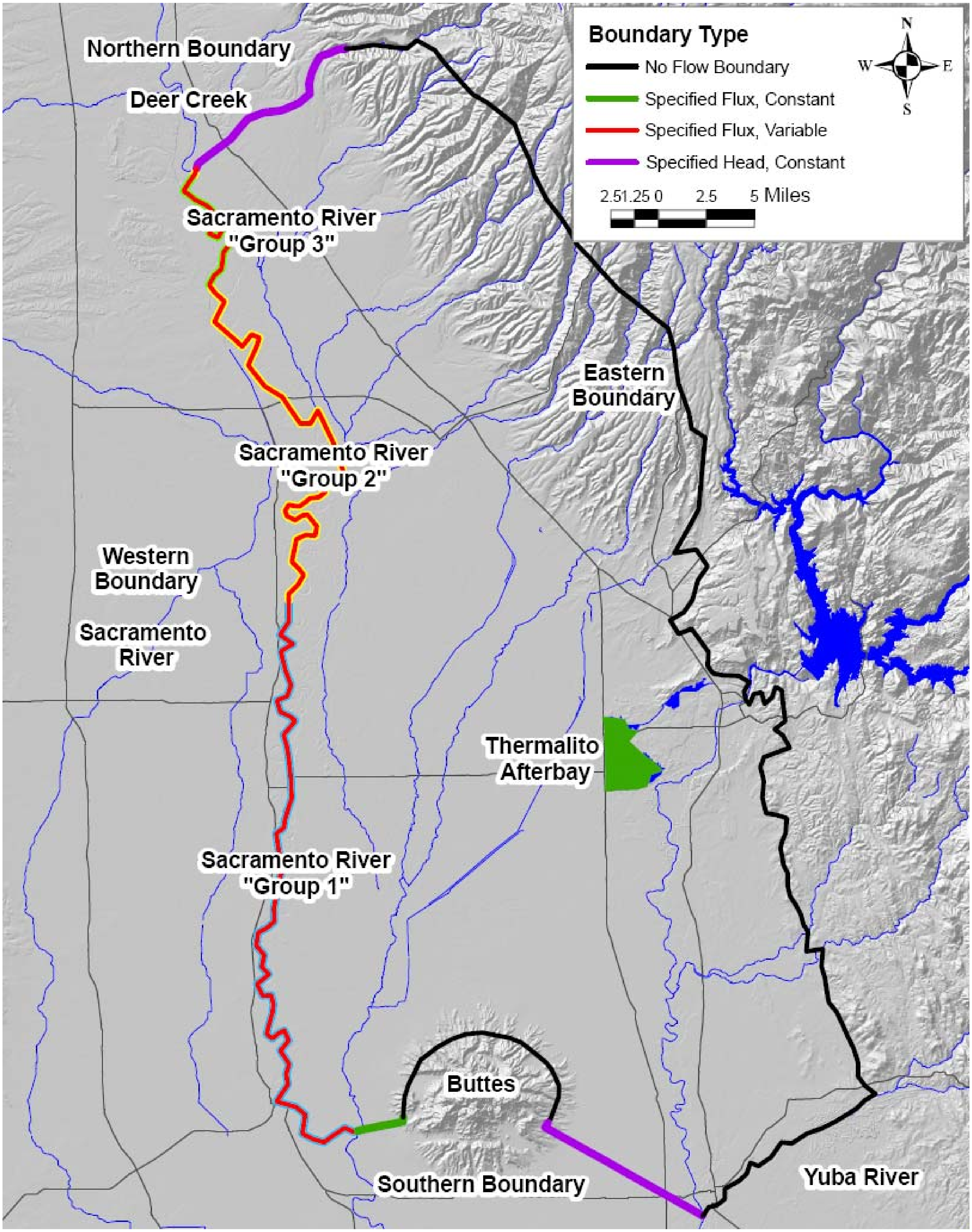

Figure 3-27
Boundary Conditions

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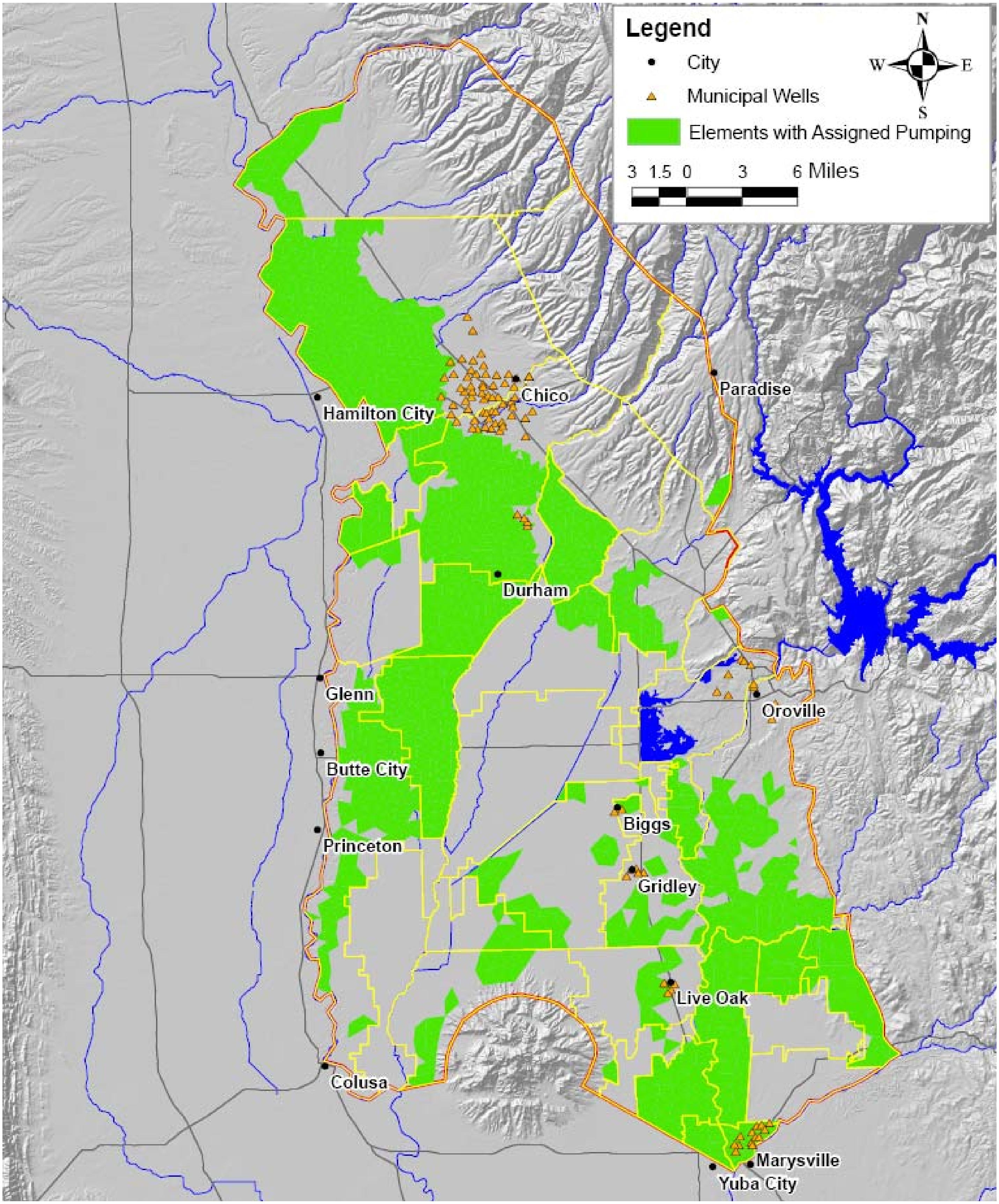

Figure 3-28
Municipal Wells and Agricultural (Elements) Pumping

CDM

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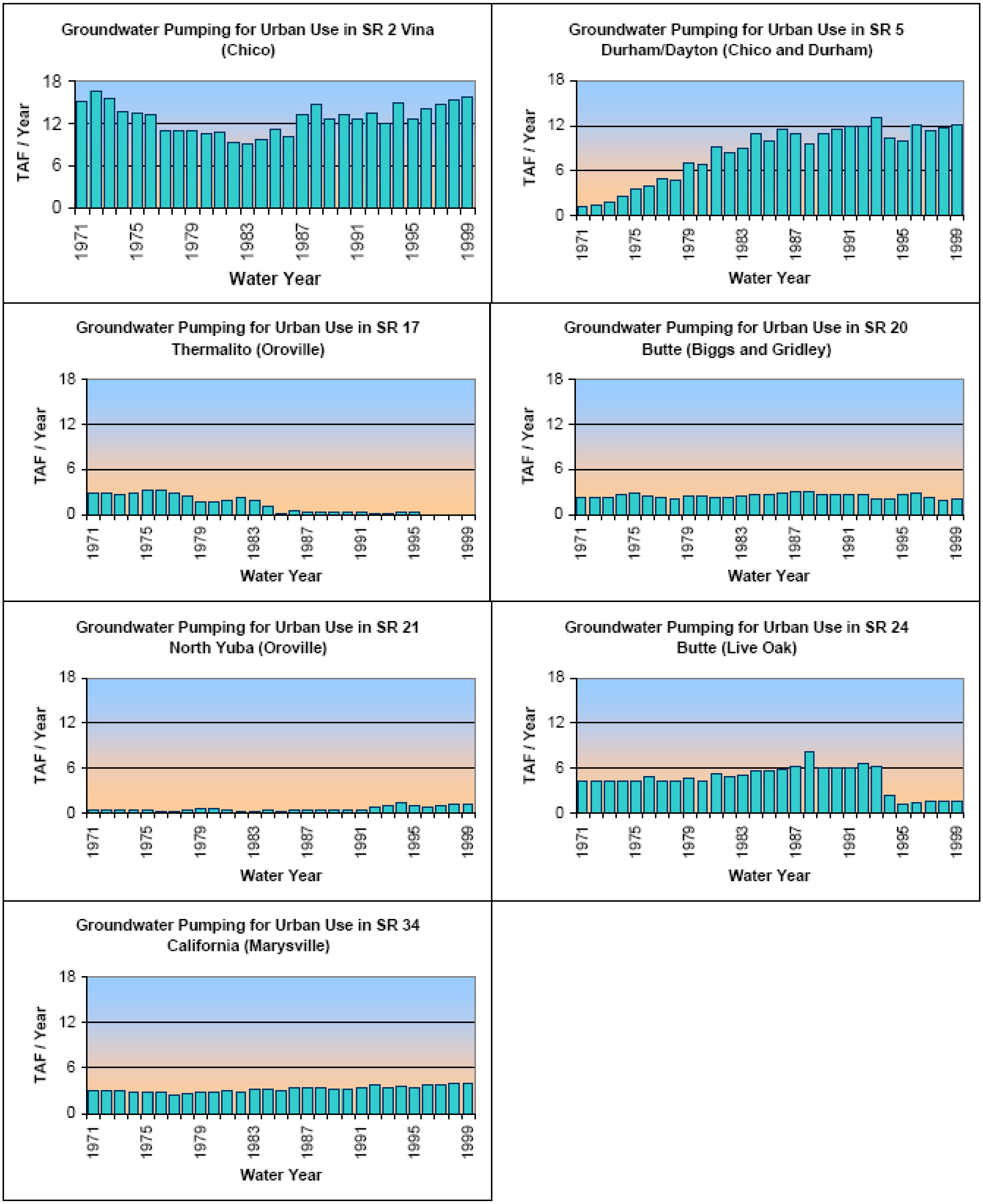
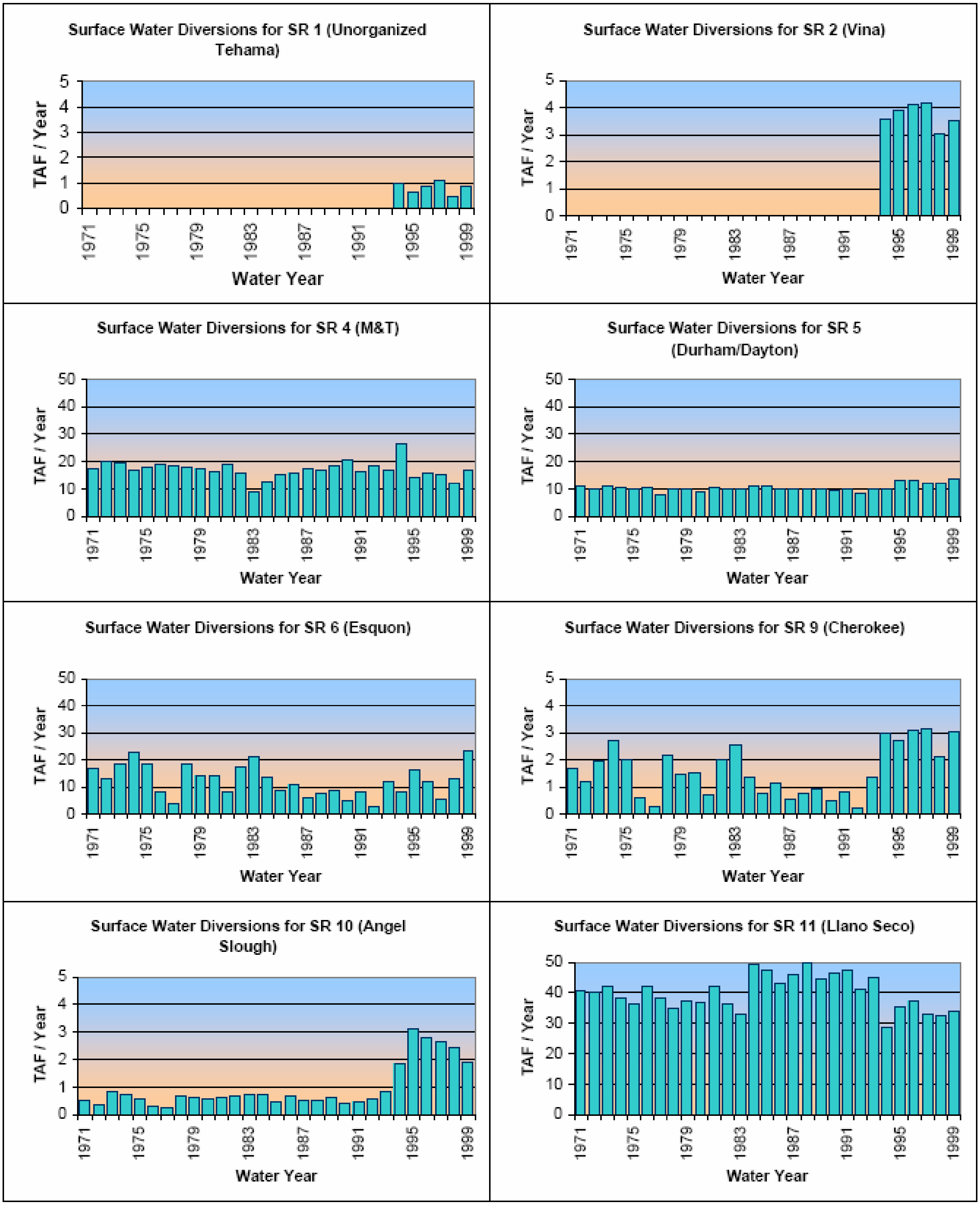


Figure 3-29
Urban Groundwater Pumping by Sub-Region



Sub-Regions 3 (Cohasset), 7 (Pentz) and 8 (Ridge) do not have assigned surface water diversions.

Figure 3-30
Surface Water Diversions: Sub-Regions 1 to 11

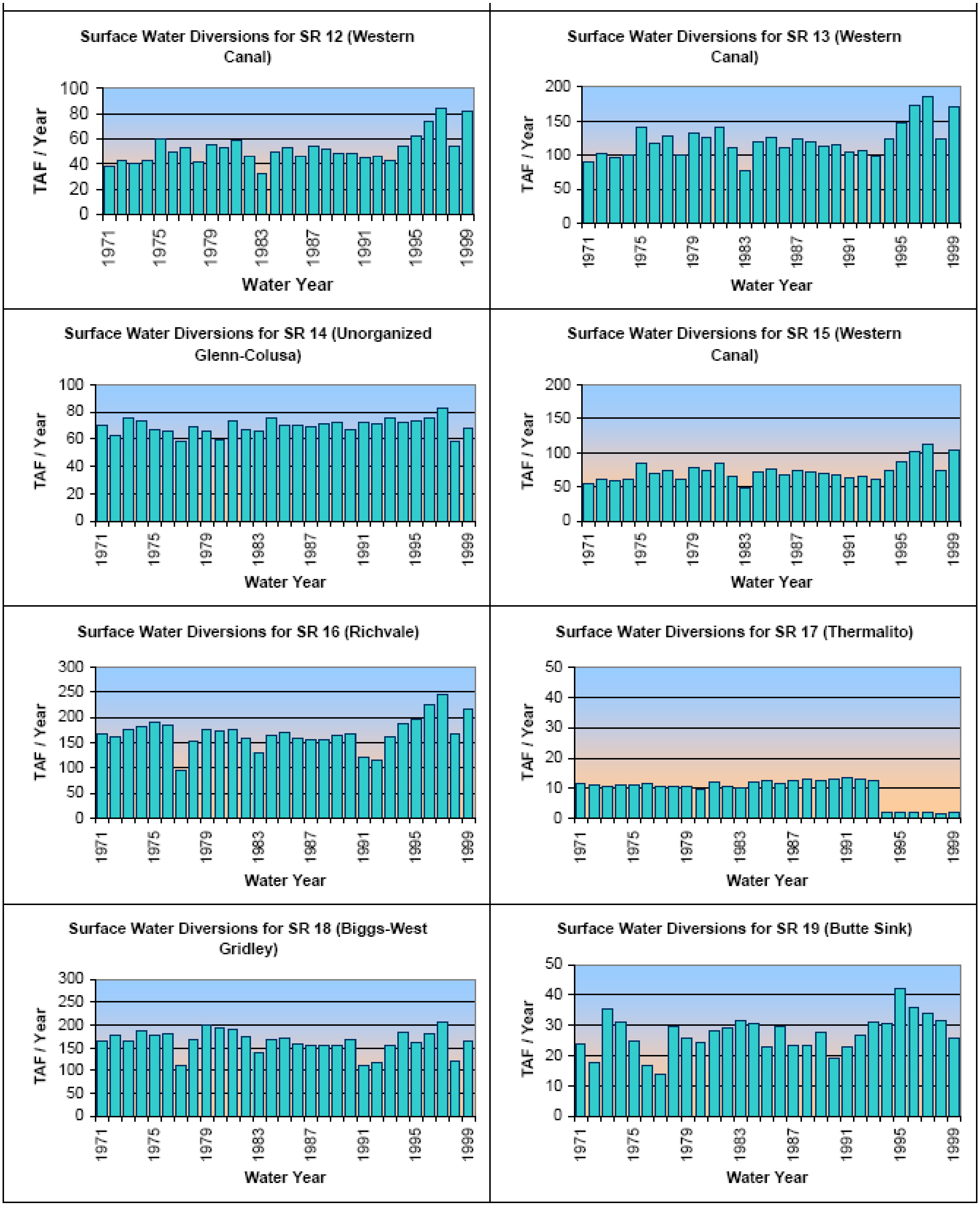


Figure 3-31
Surface Water Diversions: Sub-Regions 12 to 19

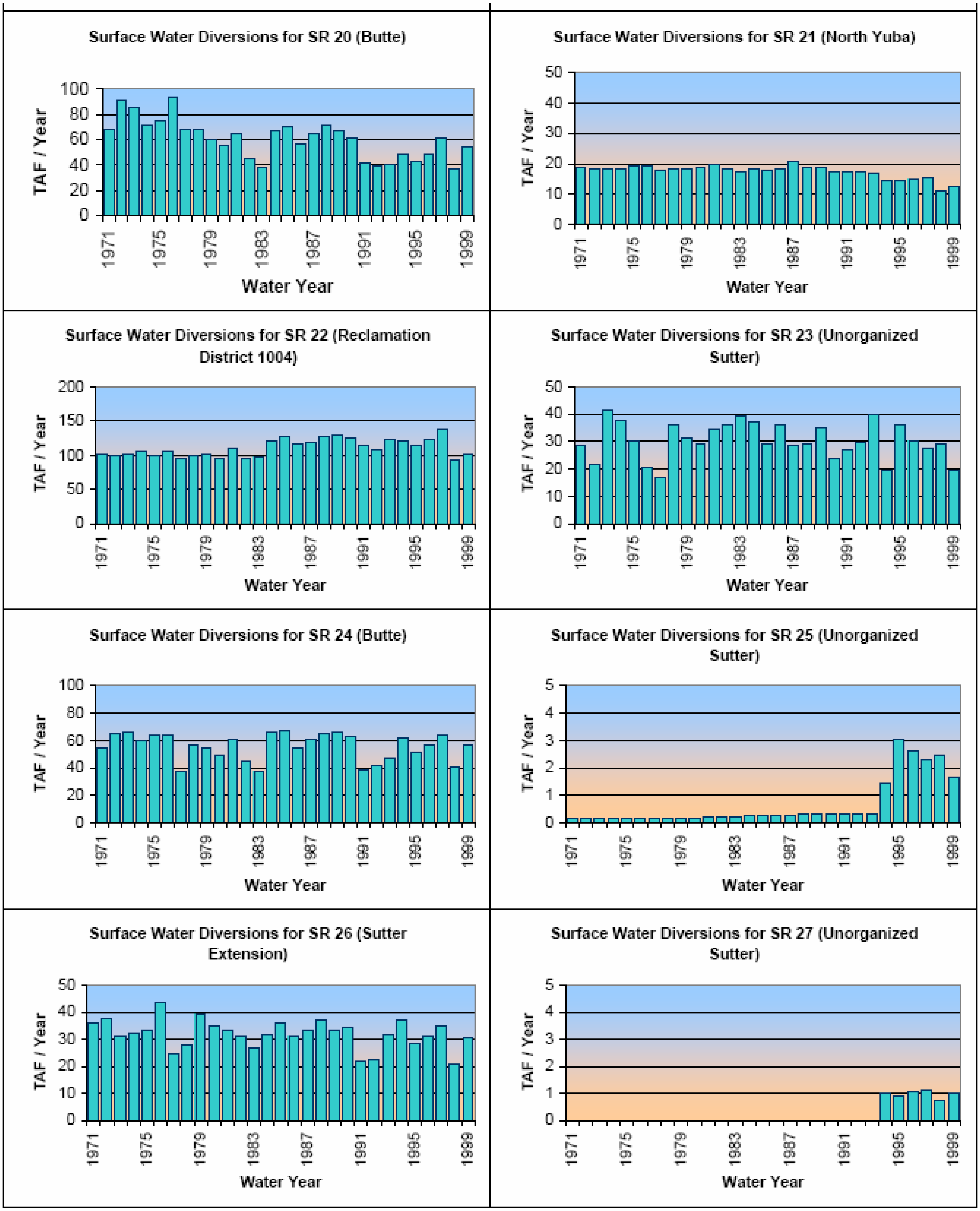
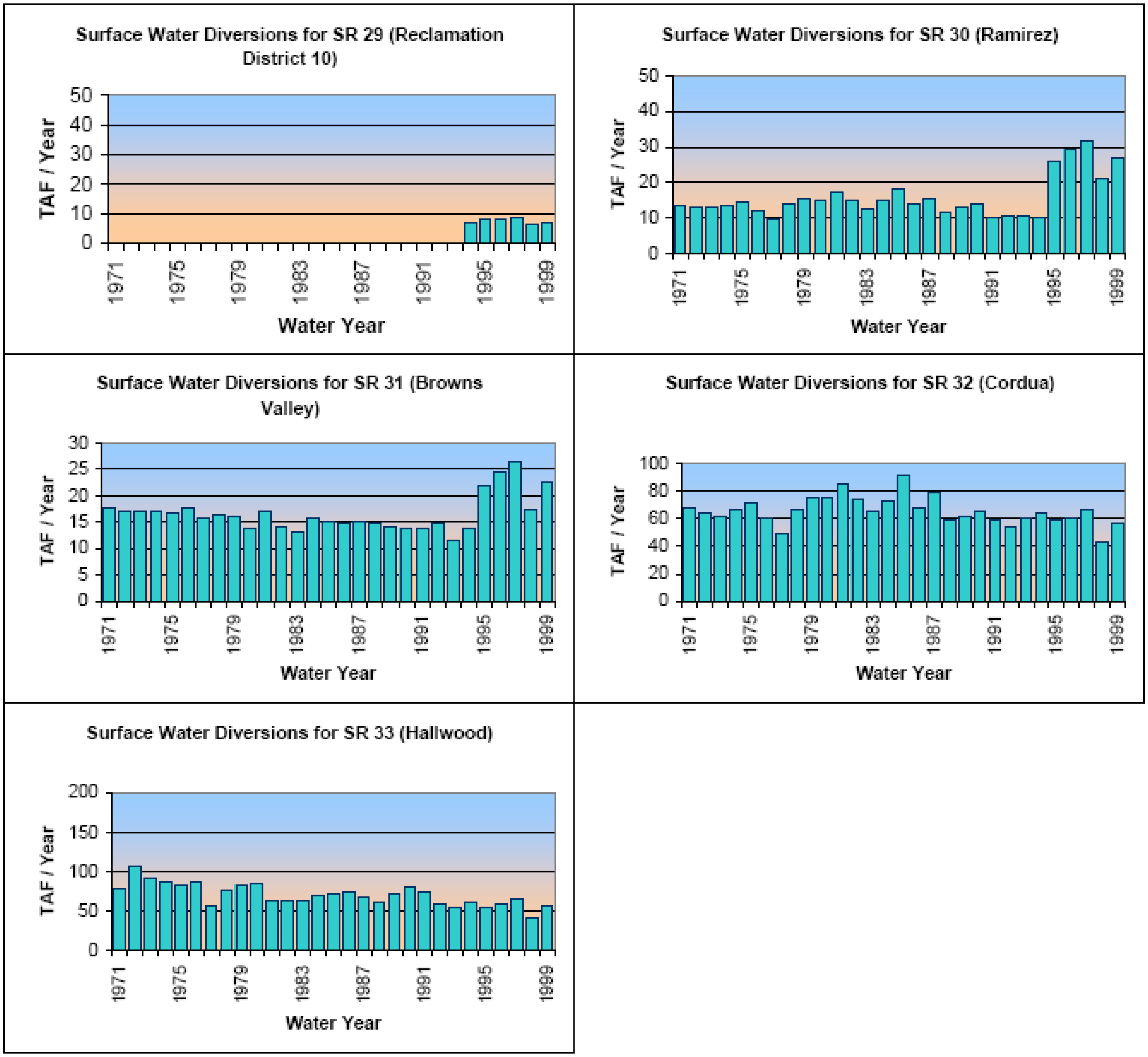


Figure 3-32
Surface Water Diversions: Sub-Regions 20 to 27



Sub-Regions 28 (Yuba City) and 34 (California) do not have assigned surface water diversions.

Figure 3-33
Surface Water Diversions: Sub-Regions 28 to 34

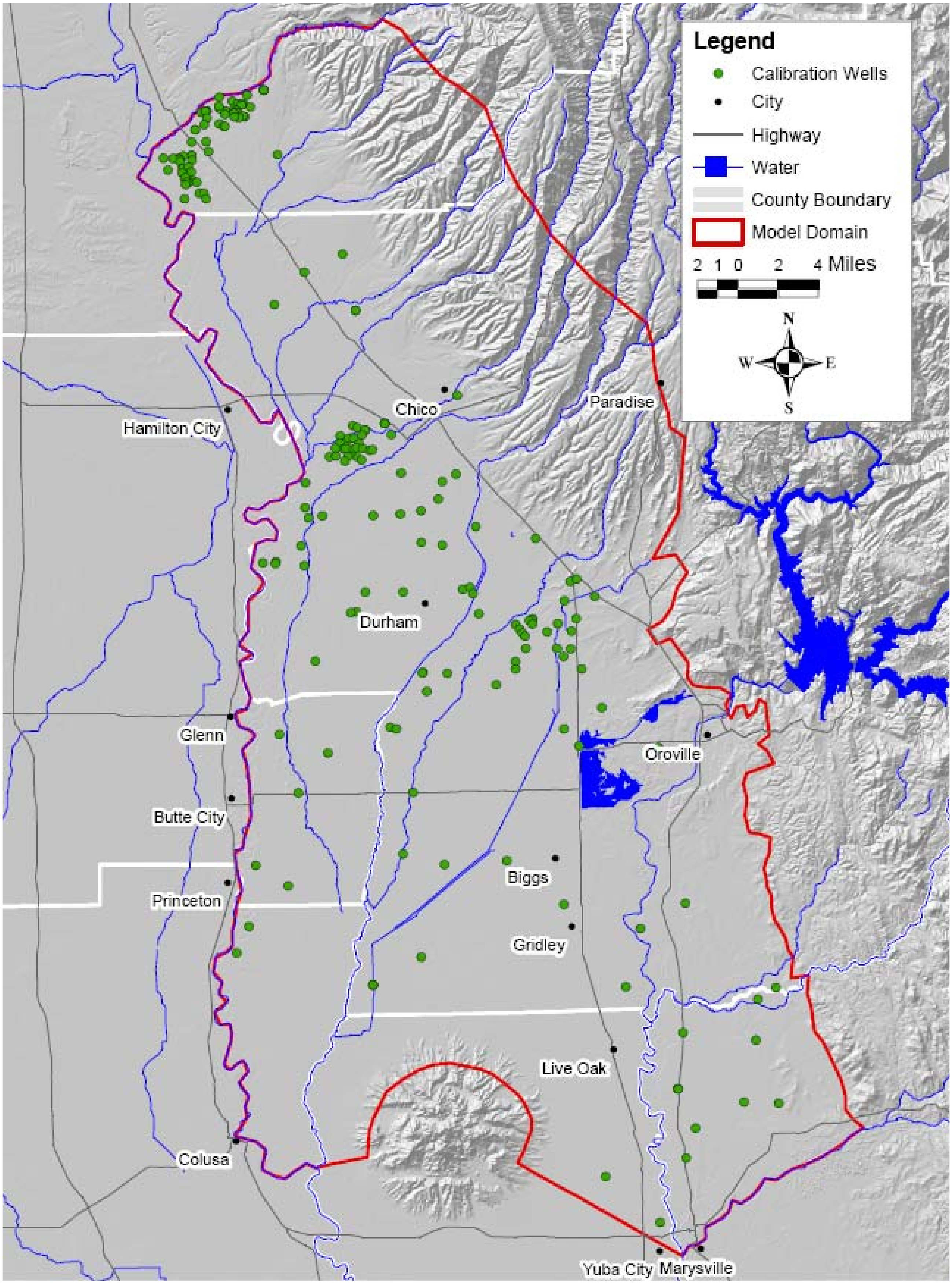


Figure 4-1
Calibration Wells

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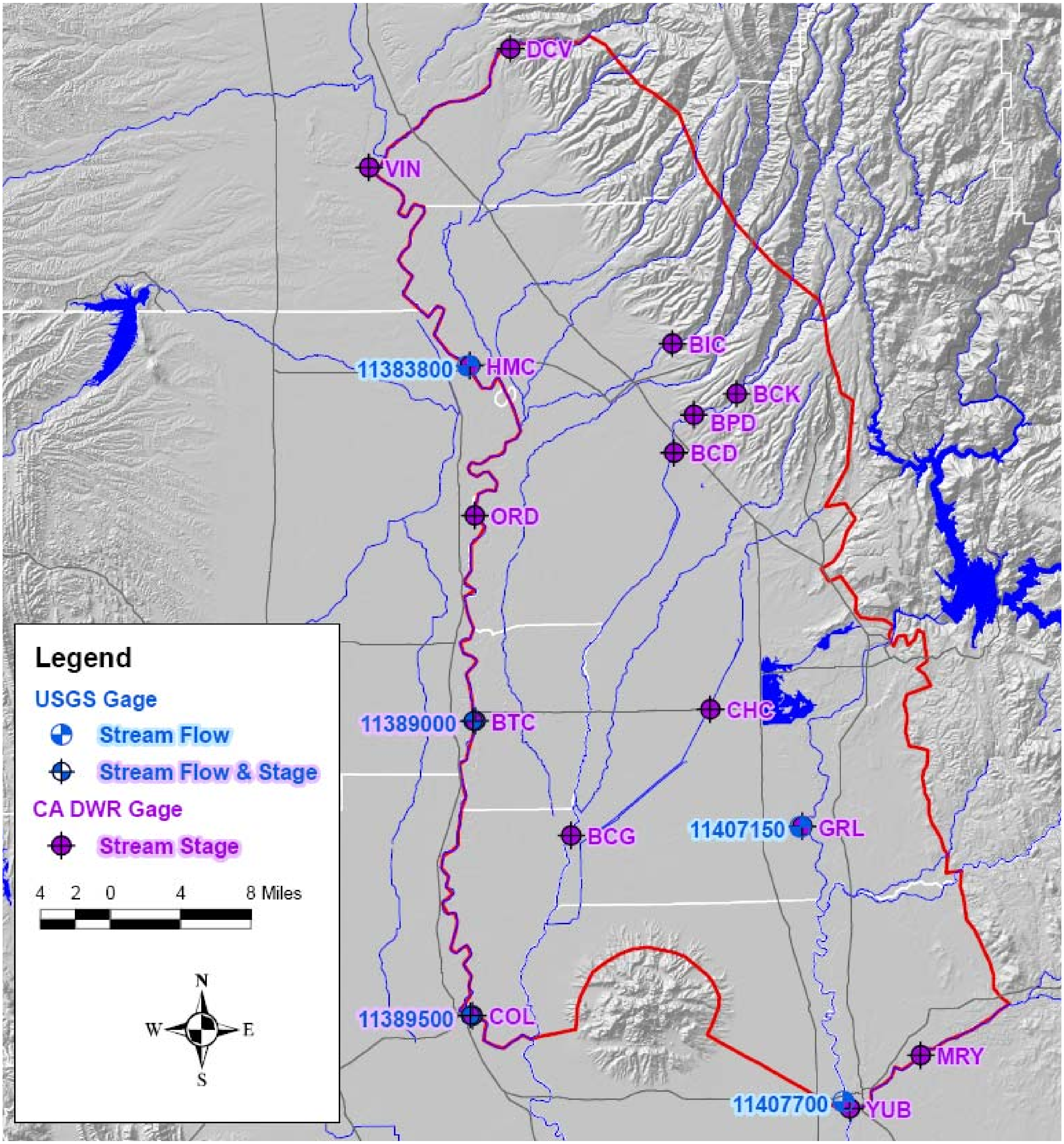
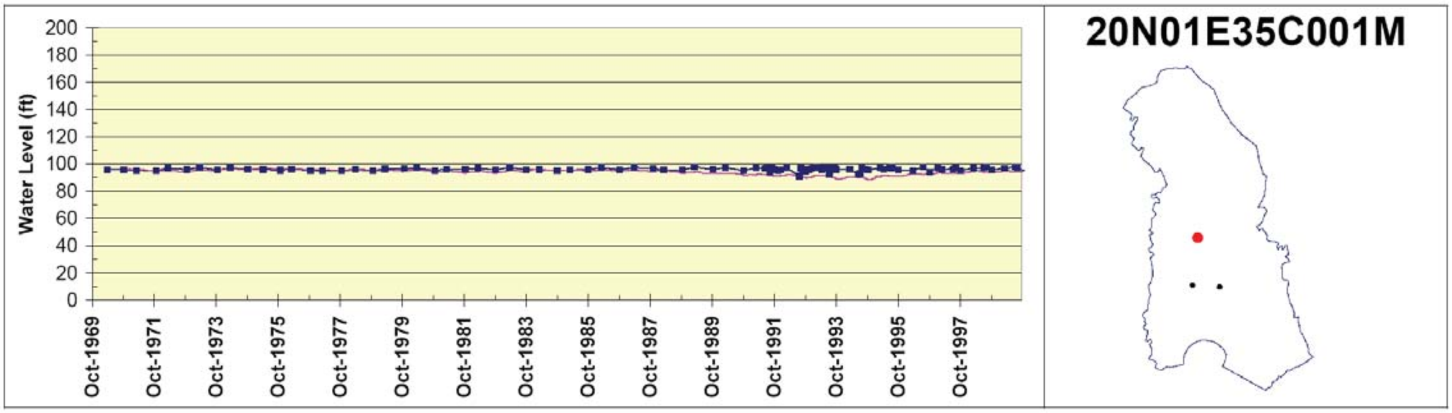
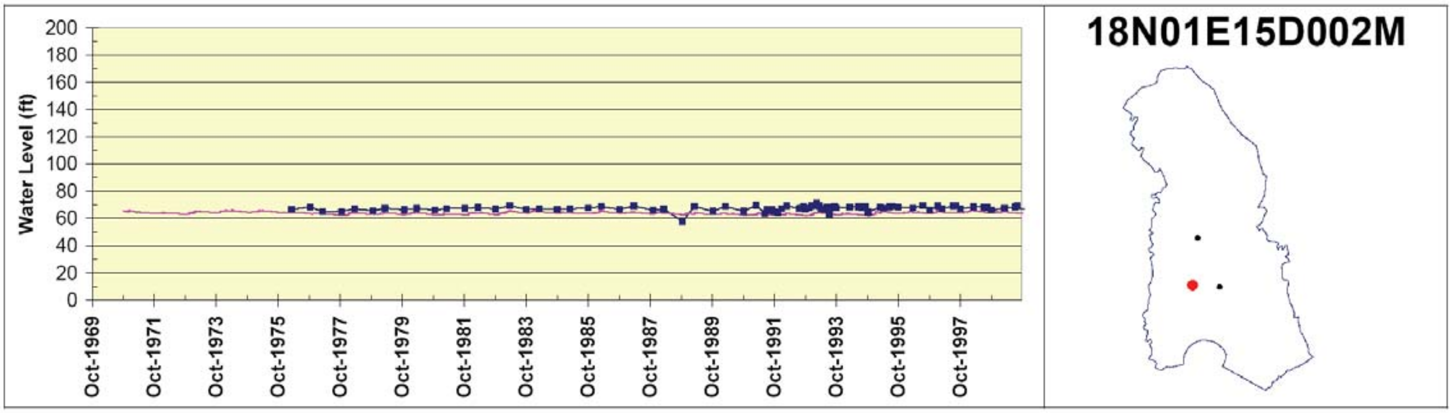
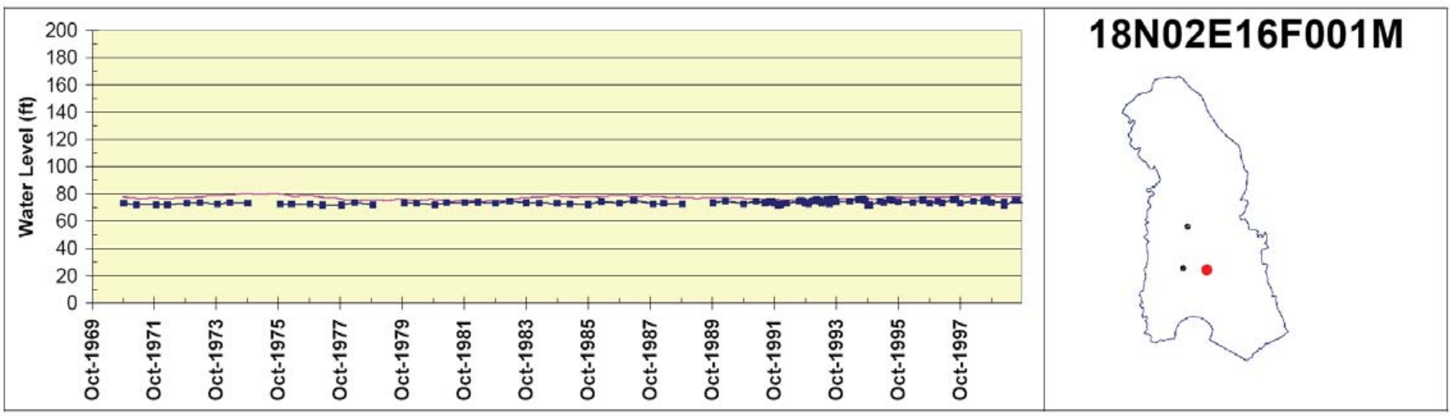


Figure 4-2
Stream Flow and Stage Gage Locations for Calibration

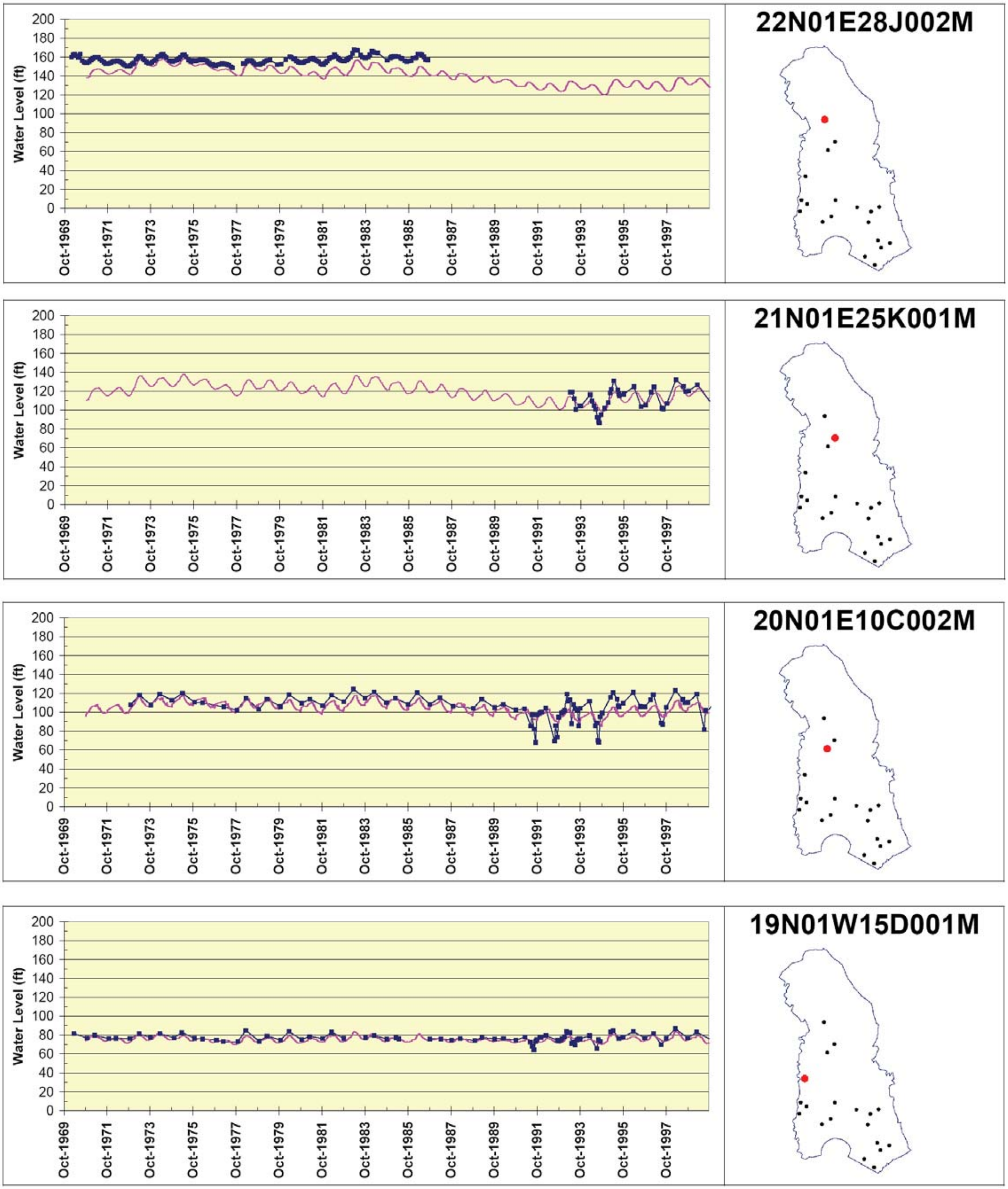






Observed Simulated

Figure 4-3
Simulated vs. Observed Water Levels
Wells Screened in **Basin** Formation



Observed　　Simulated

Figure 4-4
Simulated vs. Observed Water Levels
Wells Screened in **Alluvium** Formation

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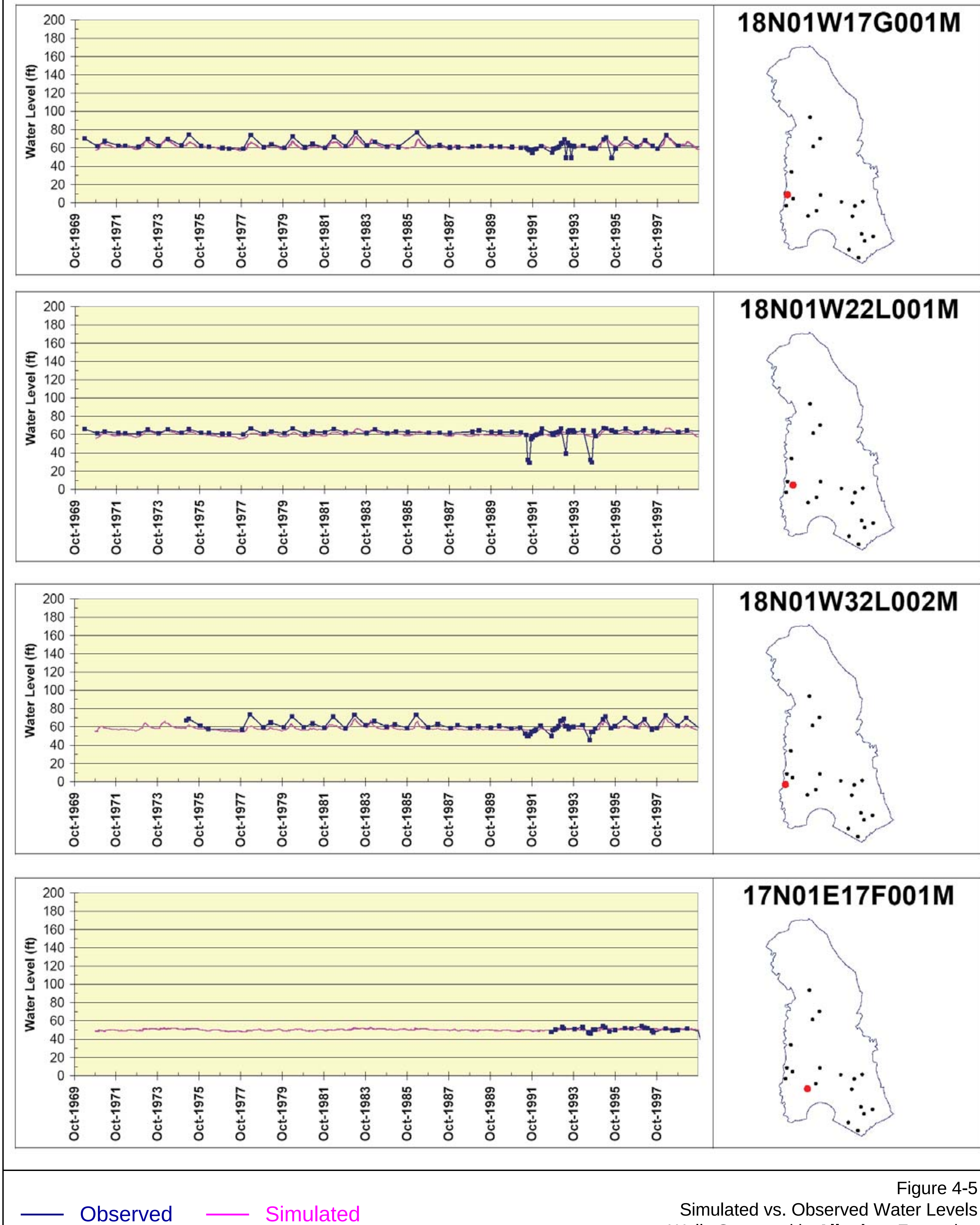
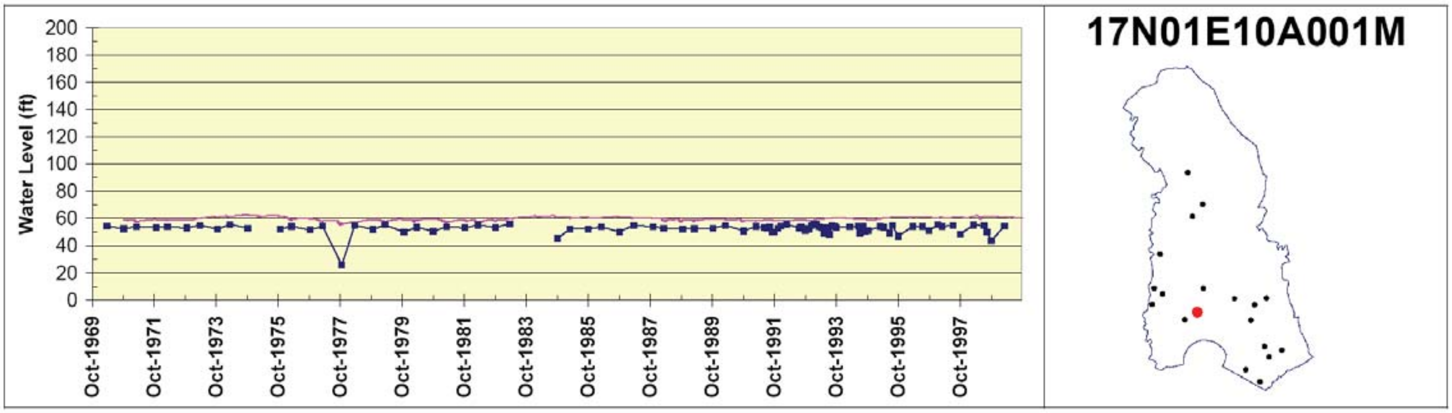
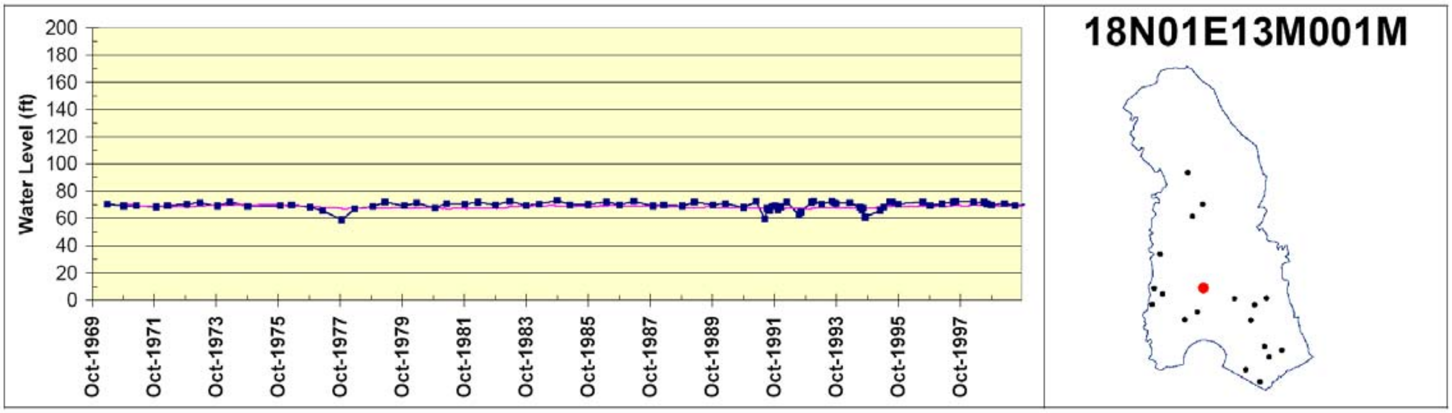
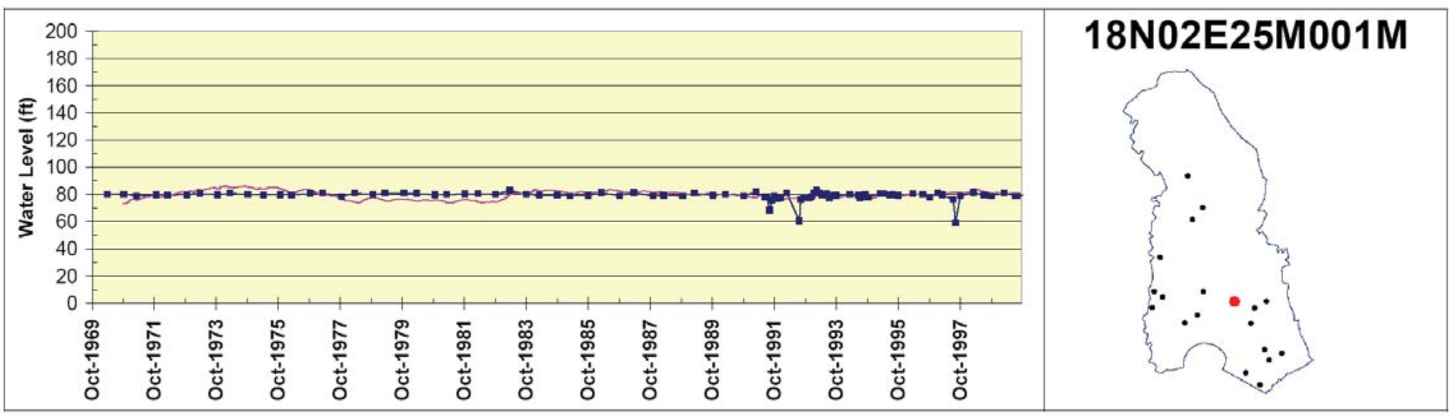


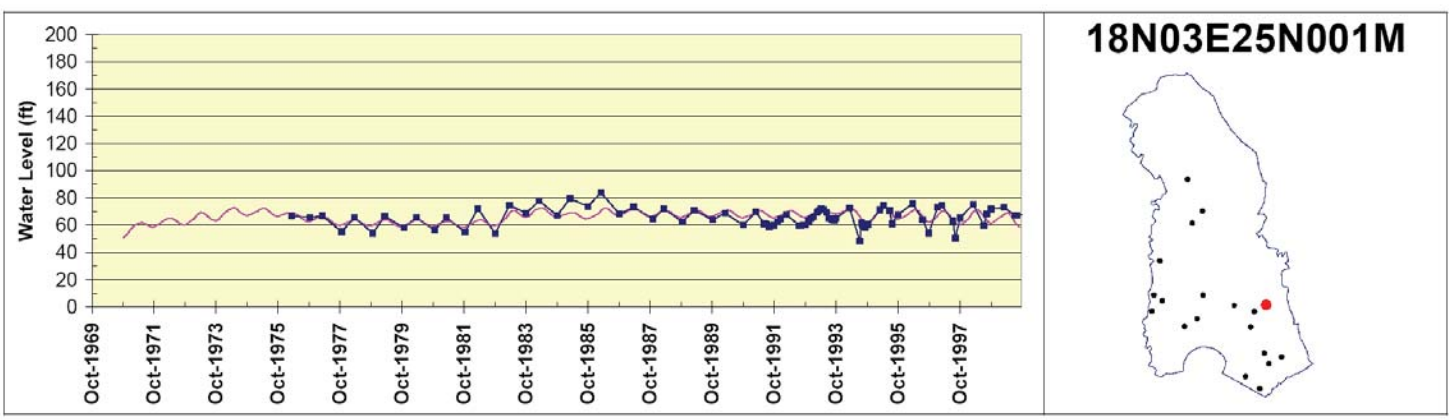
Figure 4-5
Simulated vs. Observed Water Levels
Wells Screened in **Alluvium** Formation

CDM









Observed   Simulated

Figure 4-6
Simulated vs. Observed Water Levels
Wells Screened in **Alluvium** Formation

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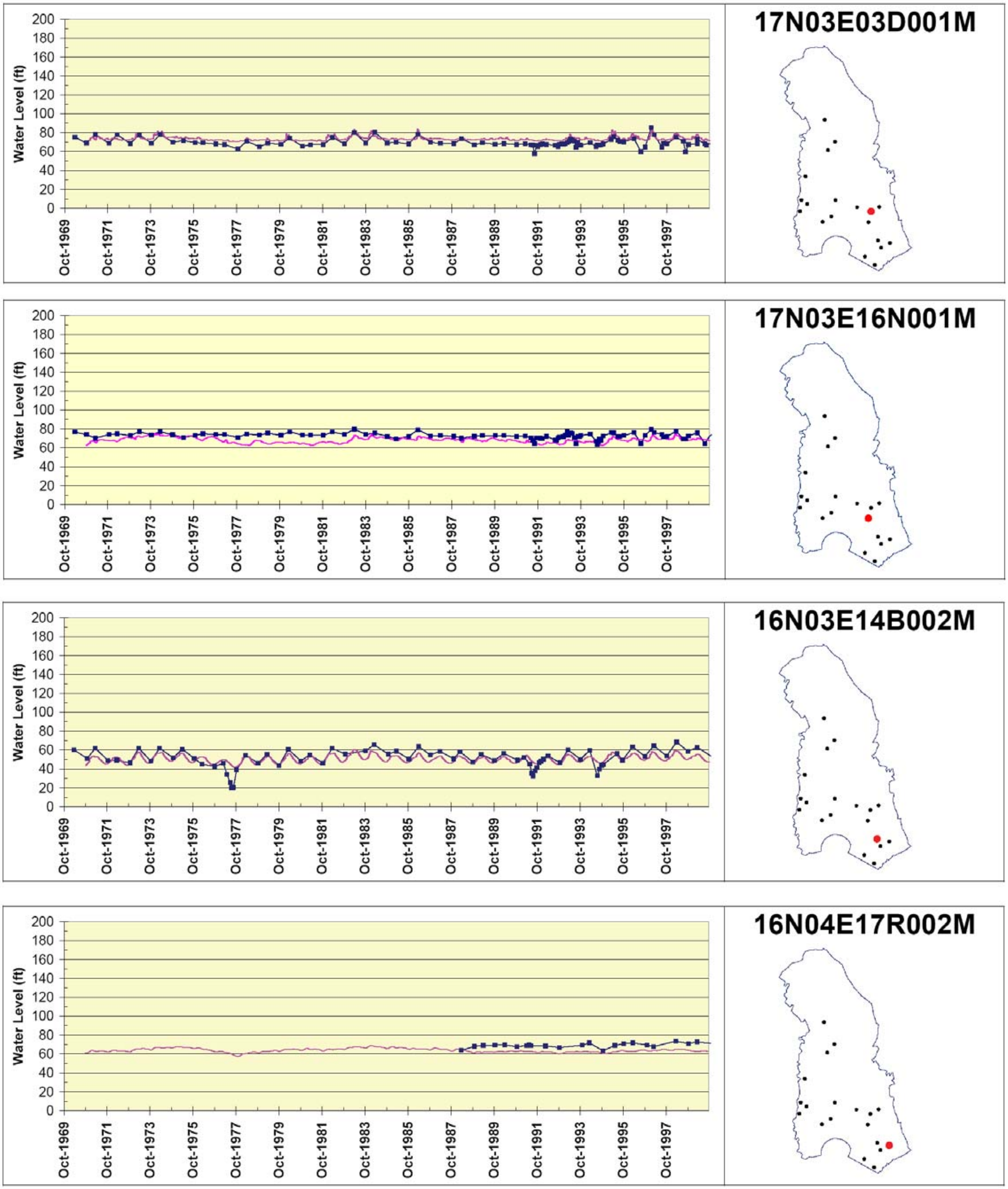

Observed Simulated

Figure 4-7
Simulated vs. Observed Water Levels
Wells Screened in **Alluvium** Formation

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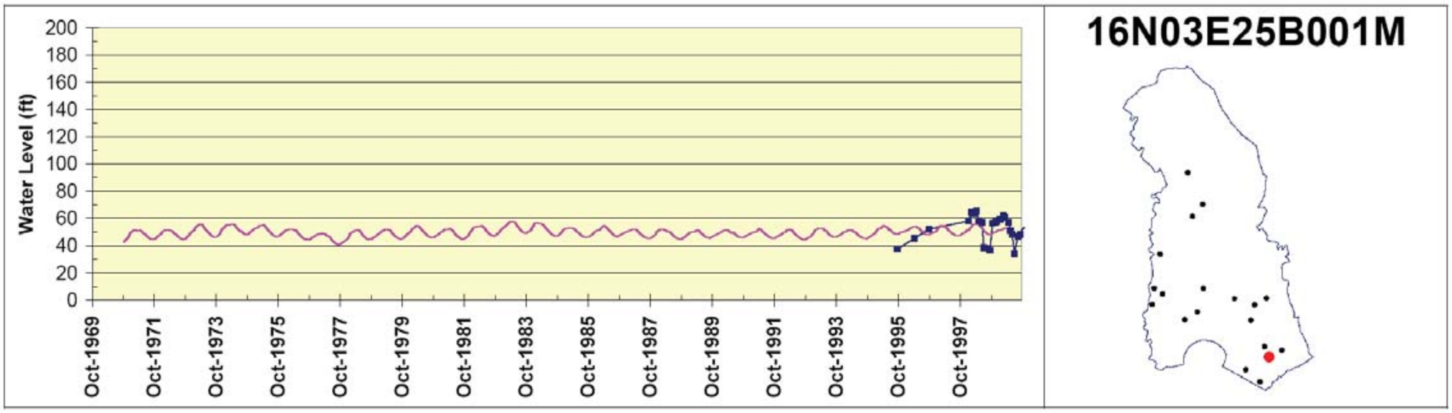
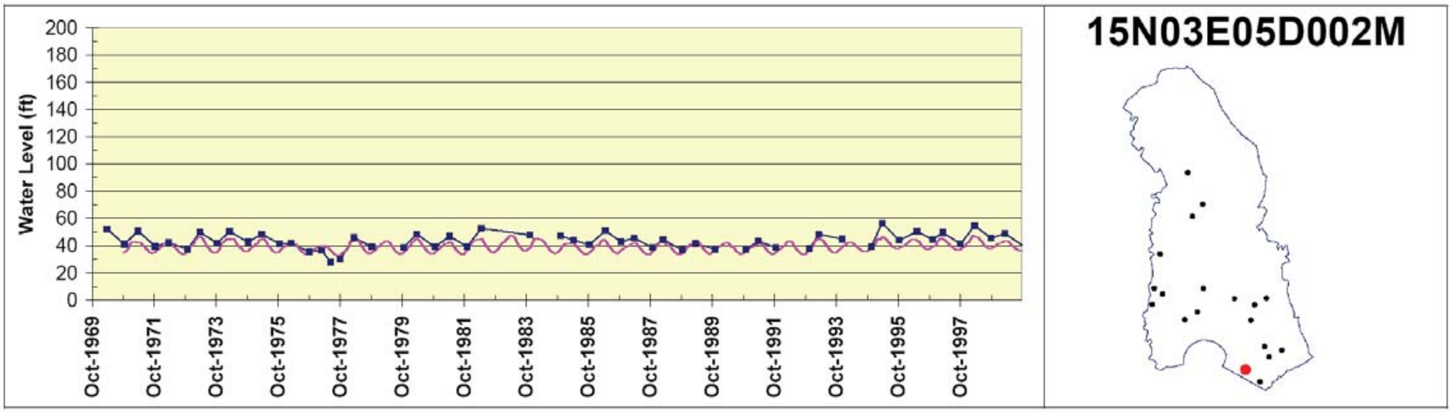
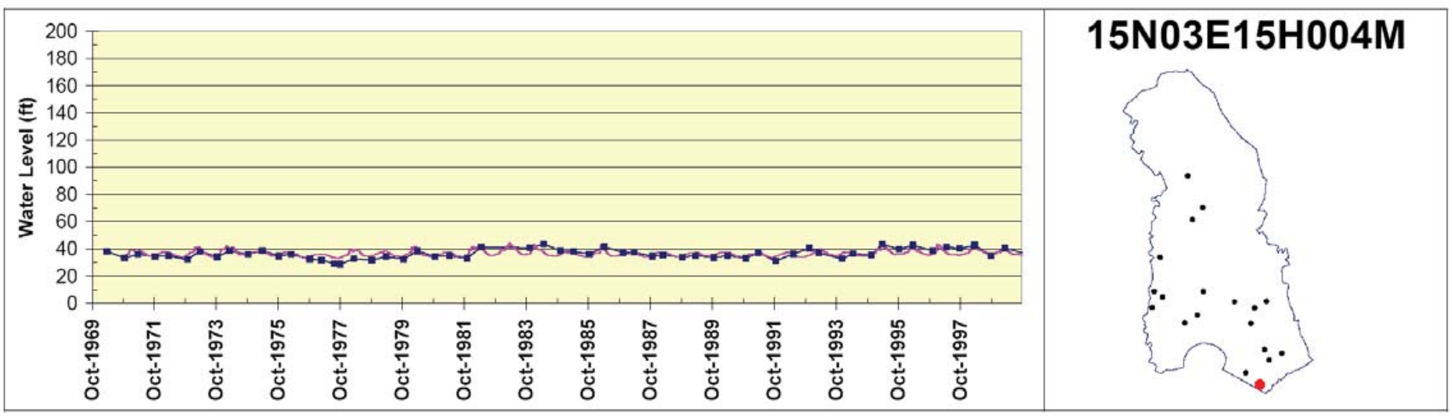
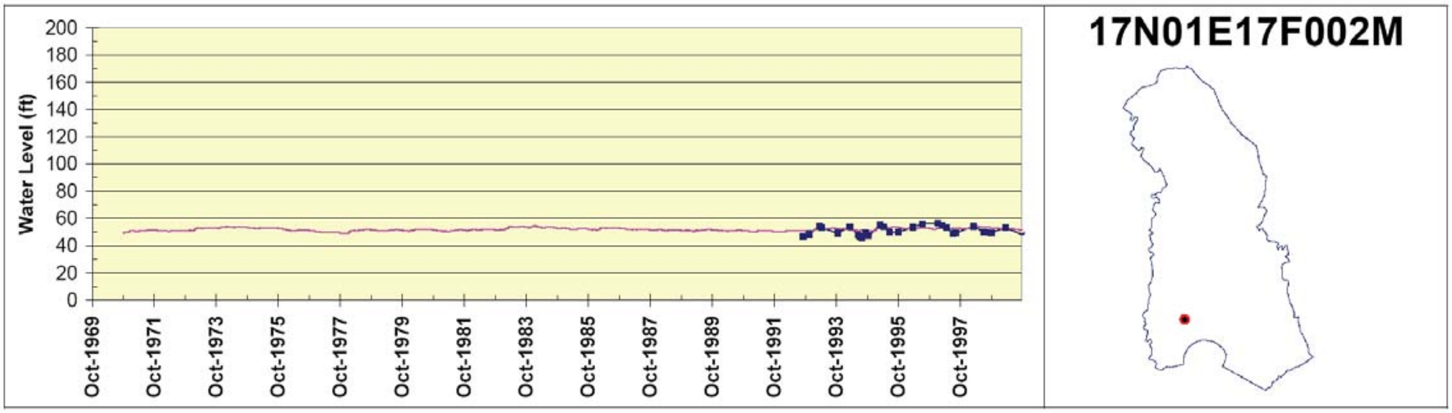


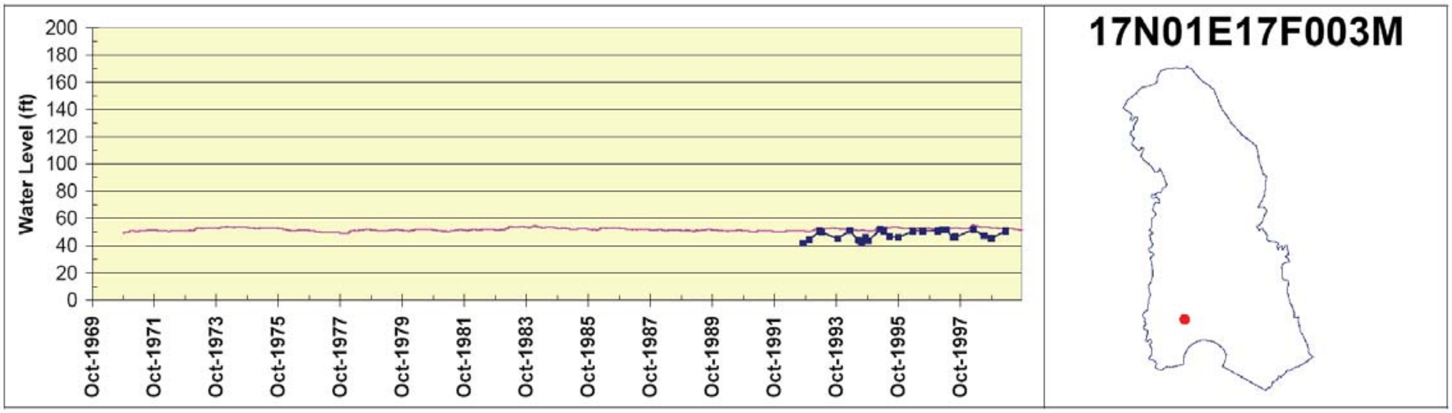




Observed Simulated

Figure 4-8
Simulated vs. Observed Water Levels
Wells Screened in **Alluvium** Formation





Observed Simulated

Figure 4-9
Simulated vs. Observed Water Levels
Wells Screened in **Sutter** Formation

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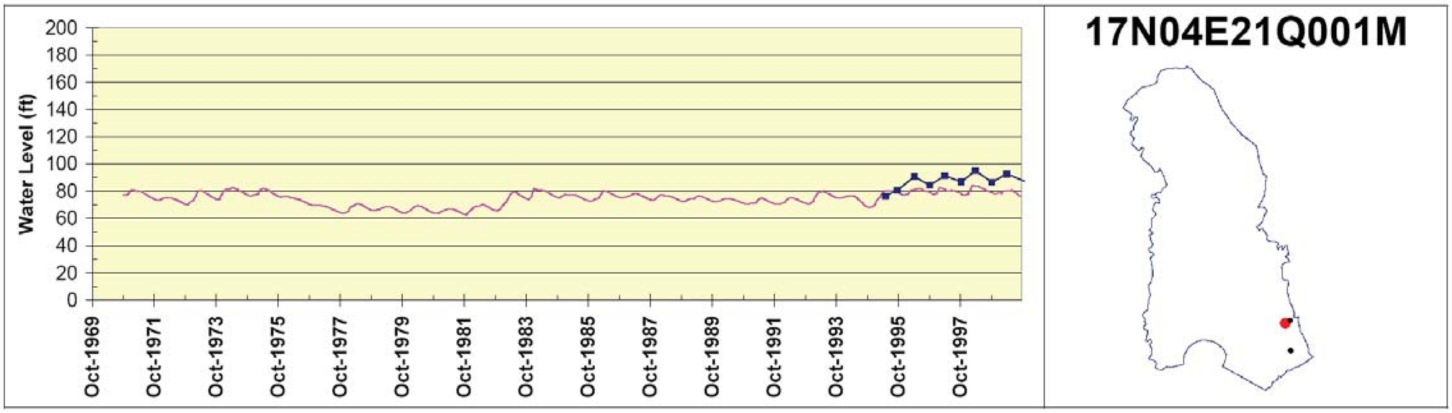
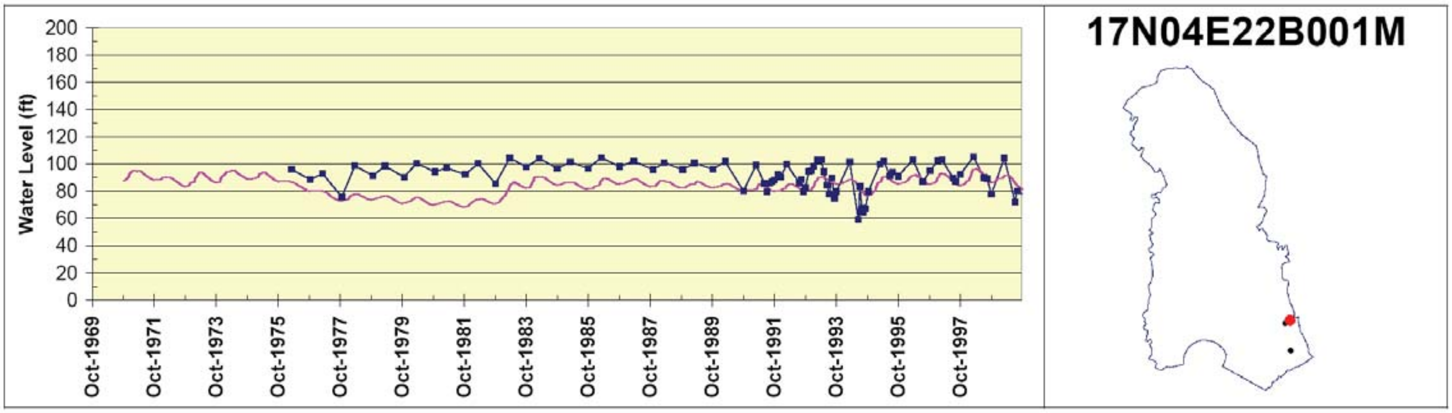
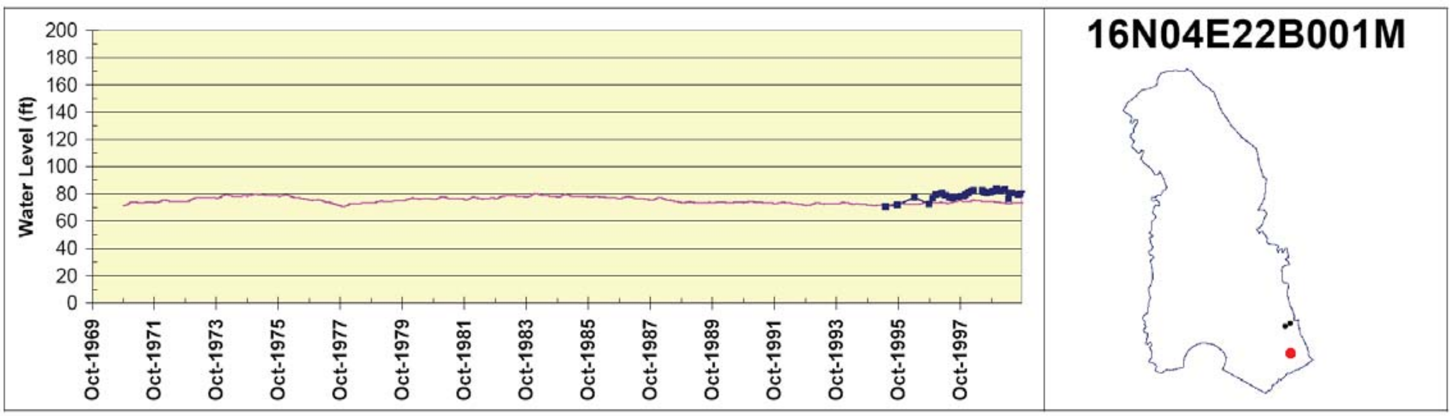


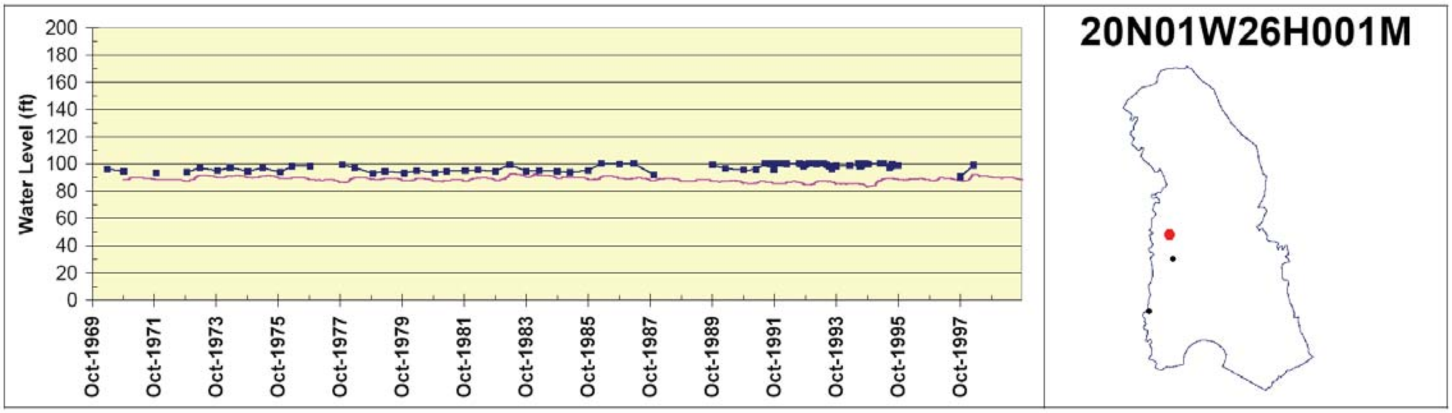


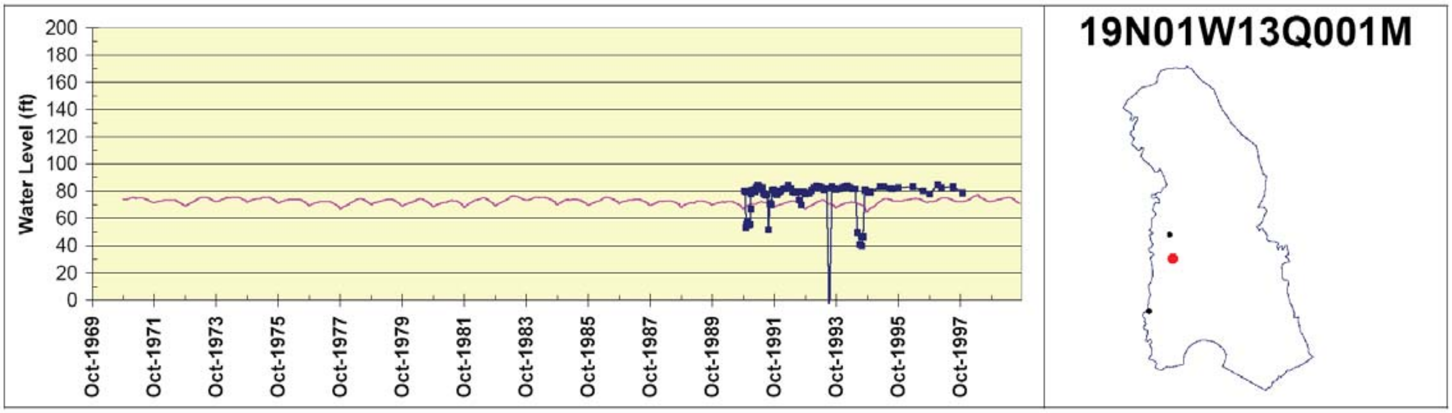


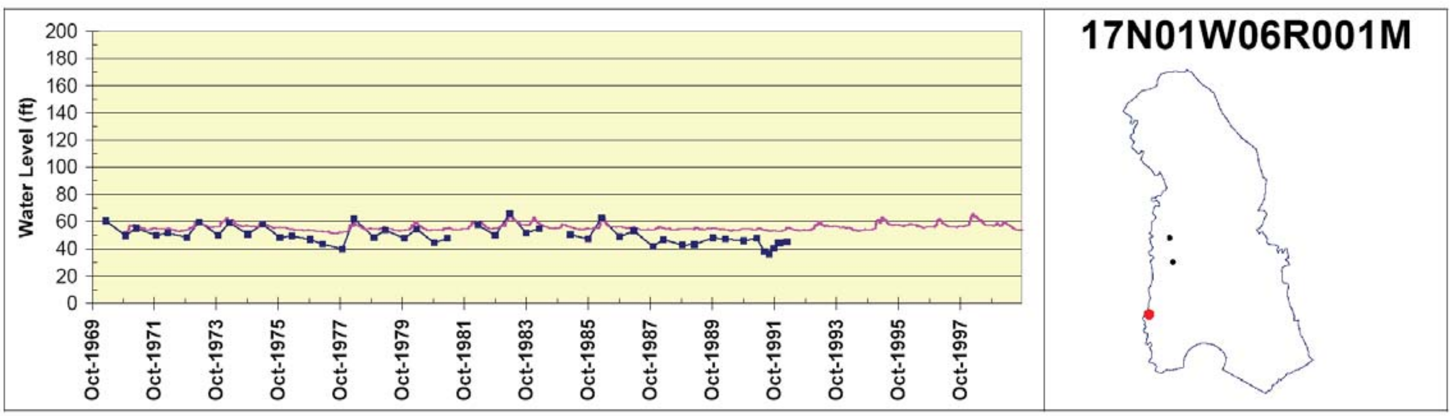
—— Observed —— Simulated

Figure 4-10
Simulated vs. Observed Water Levels
Wells Screened in **Laguna** Formation

CDM







Observed Simulated

Figure 4-11
Simulated vs. Observed Water Levels
Wells Screened in **Tehama** Formation

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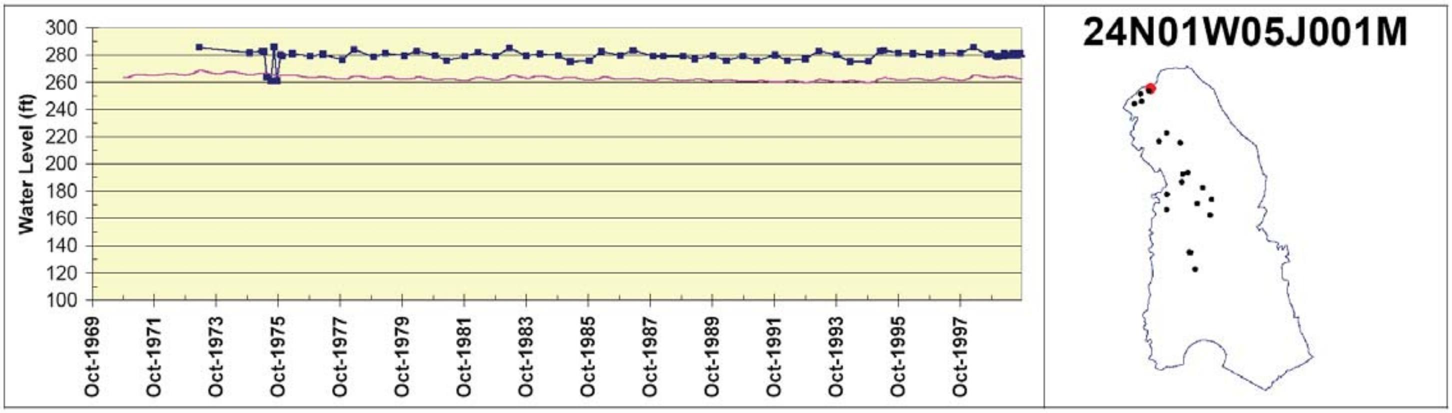
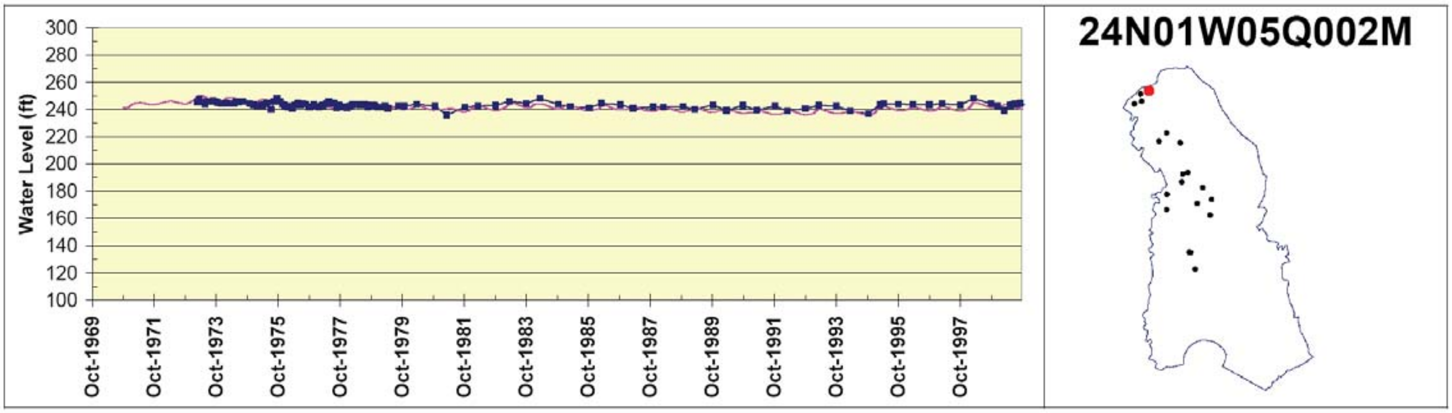
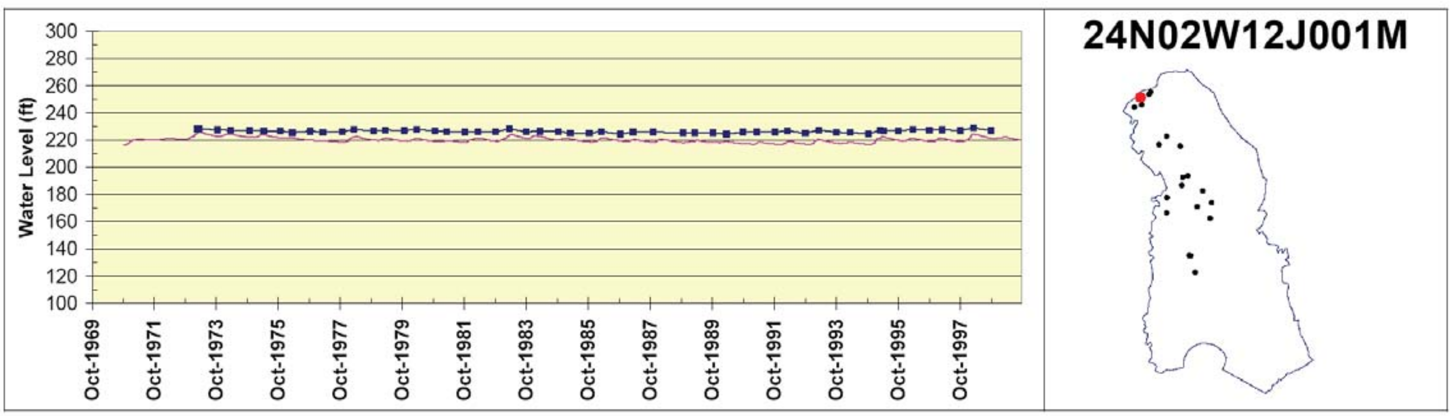
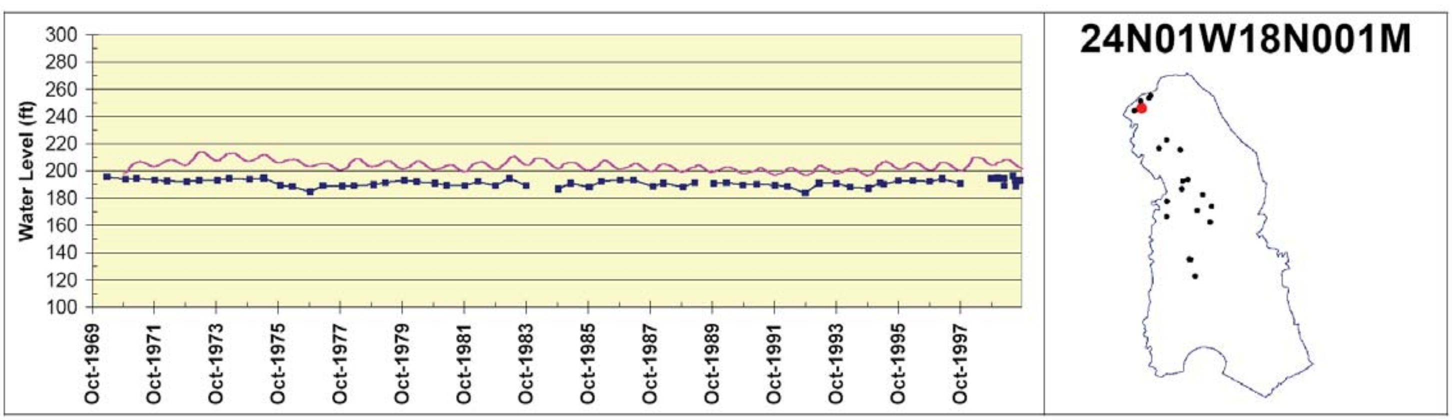


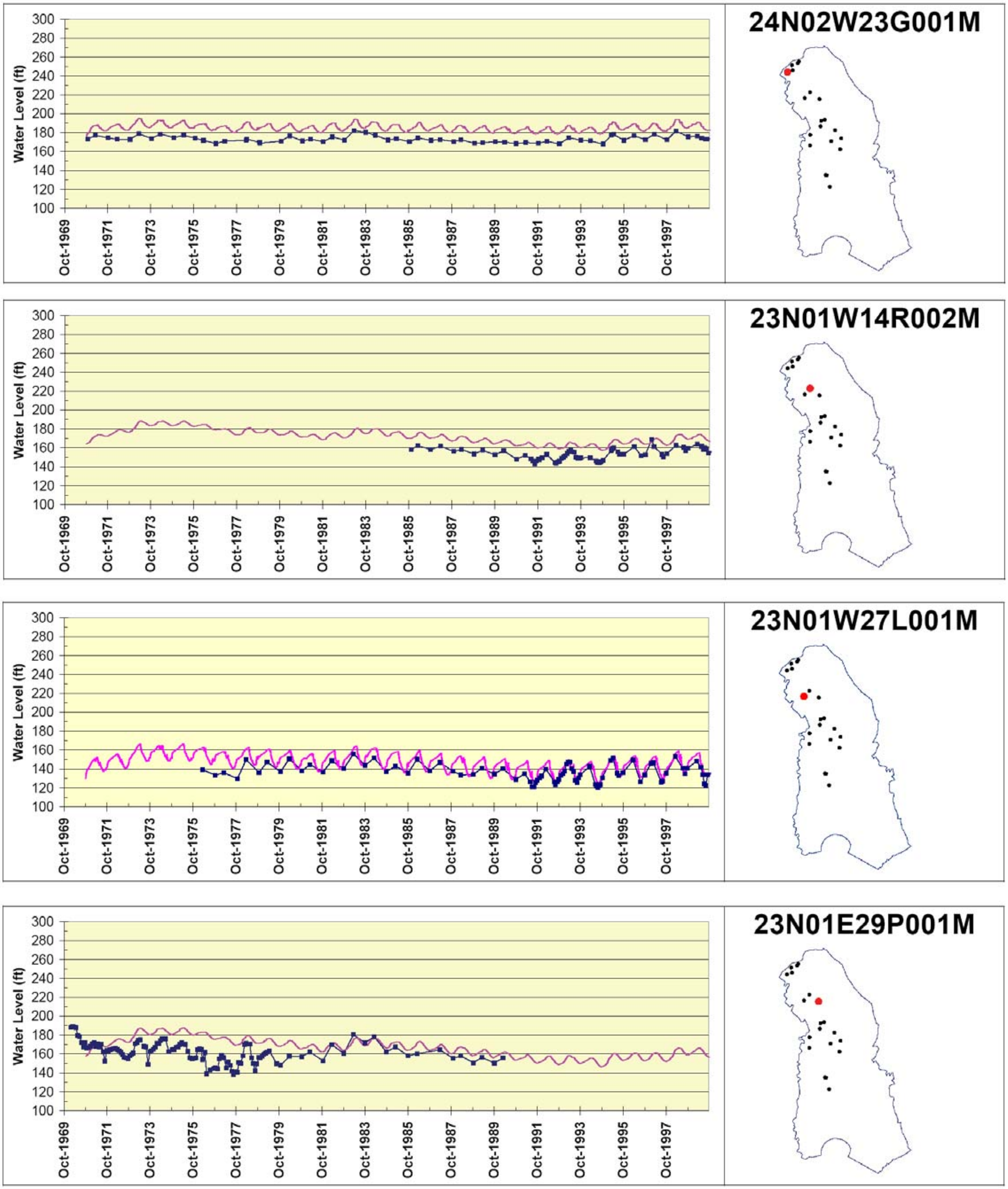






Observed Simulated

Figure 4-12
Simulated vs. Observed Water Levels
Wells Screened in **Tuscan C** Formation



Observed Simulated

Figure 4-13
Simulated vs. Observed Water Levels
Wells Screened in **Tuscan C** Formation

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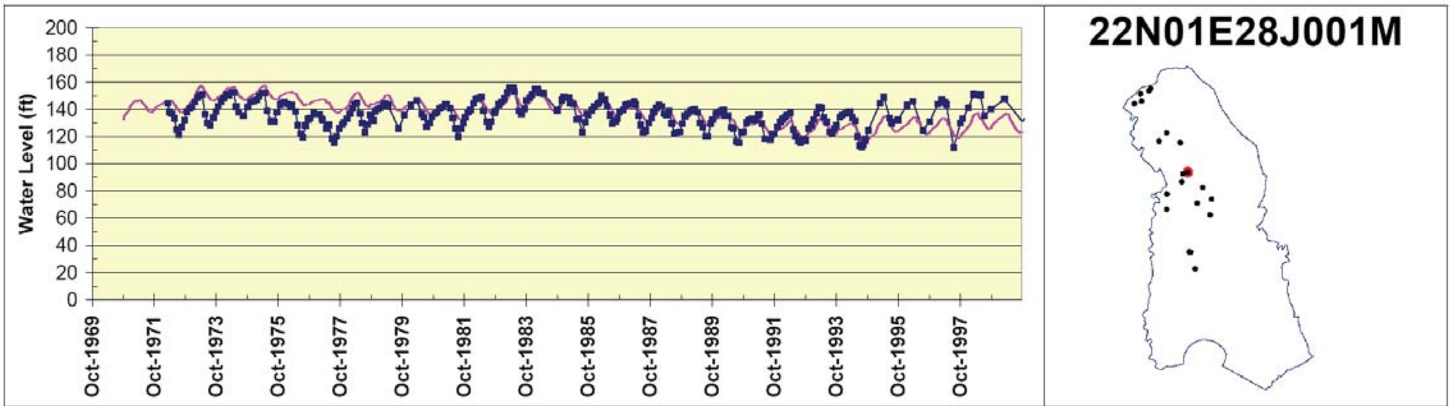

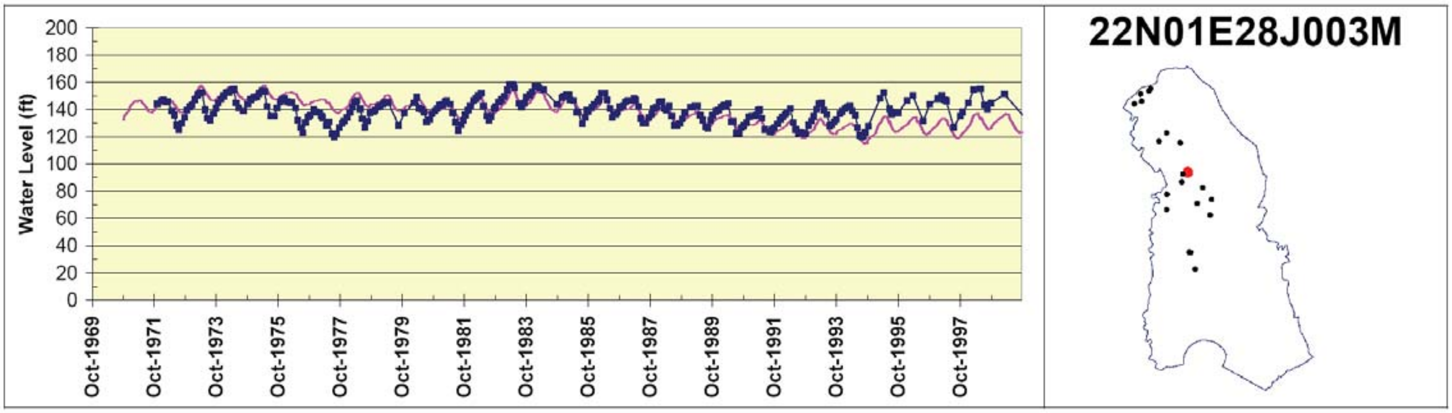

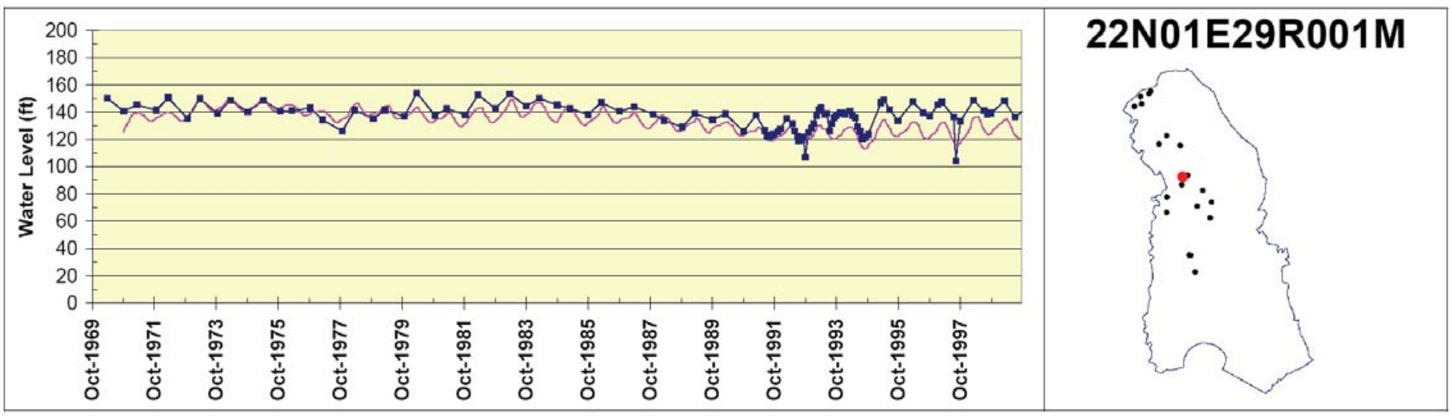

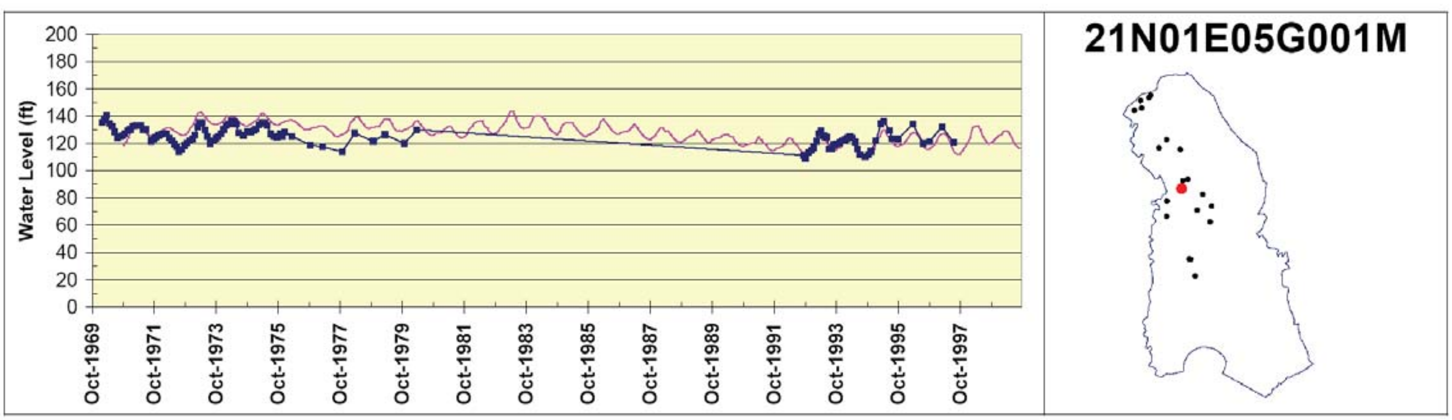

—— Observed —— Simulated

Figure 4-14
Simulated vs. Observed Water Levels
Wells Screened in **Tuscan C** Formation

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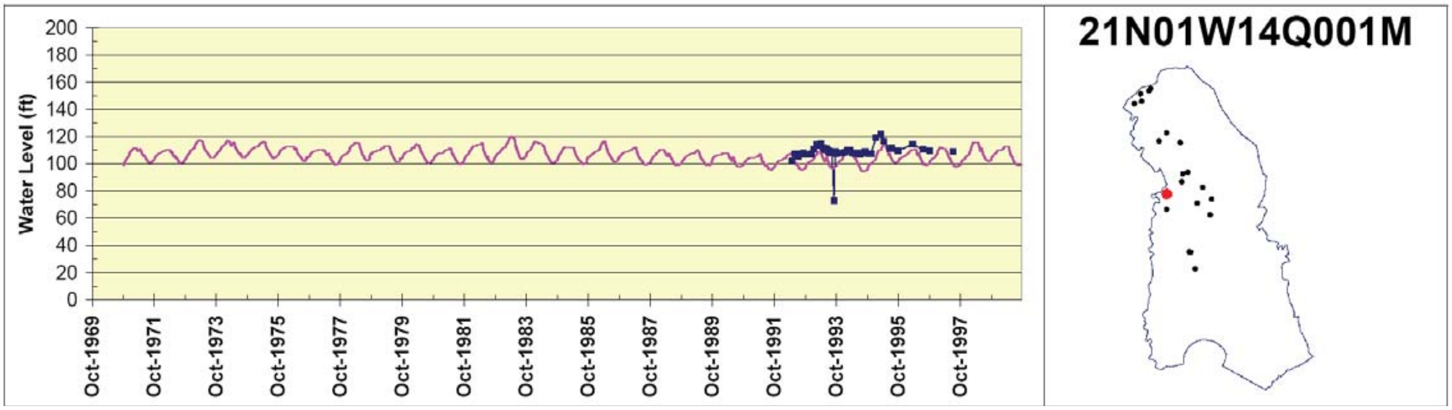
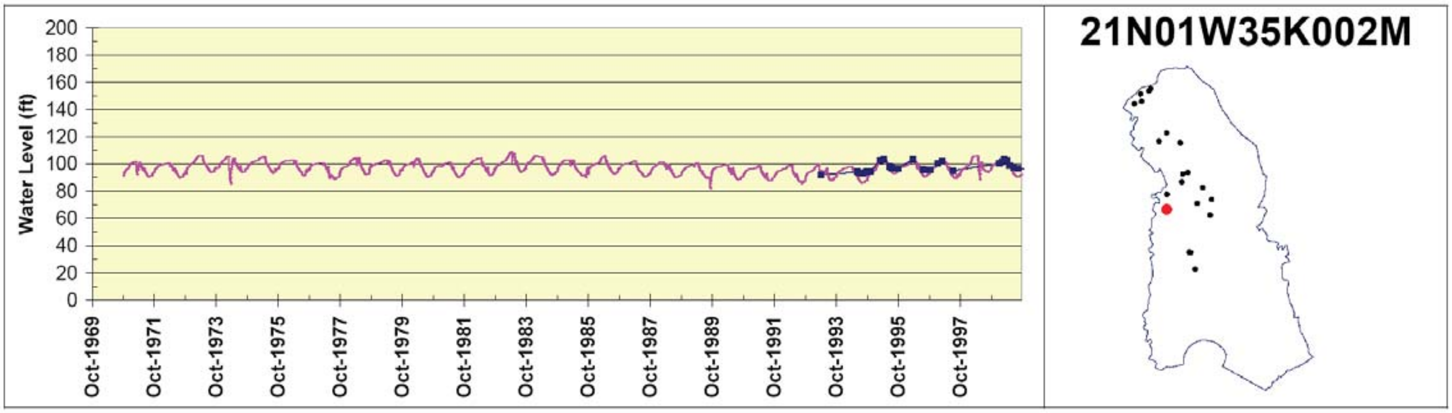
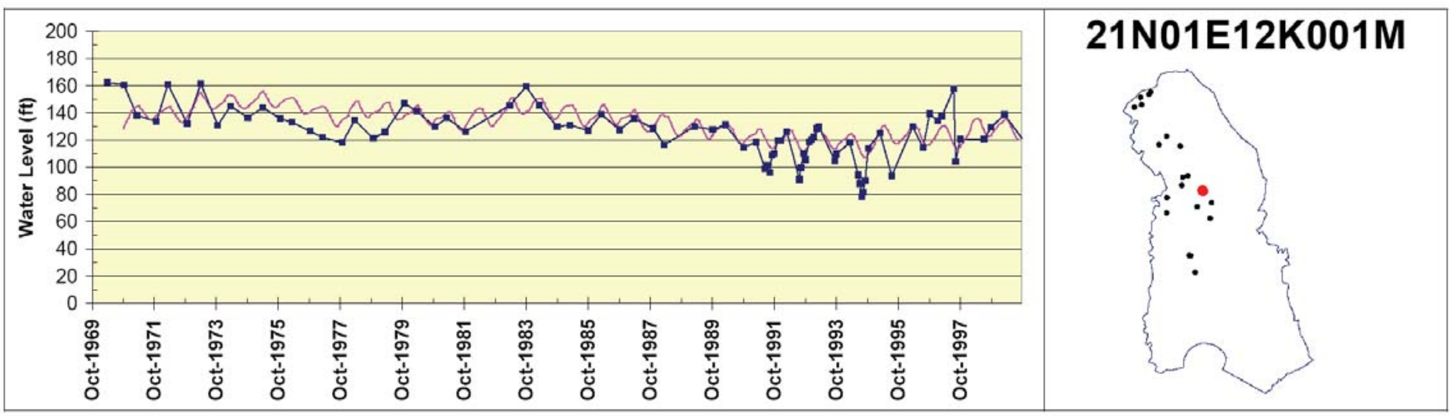


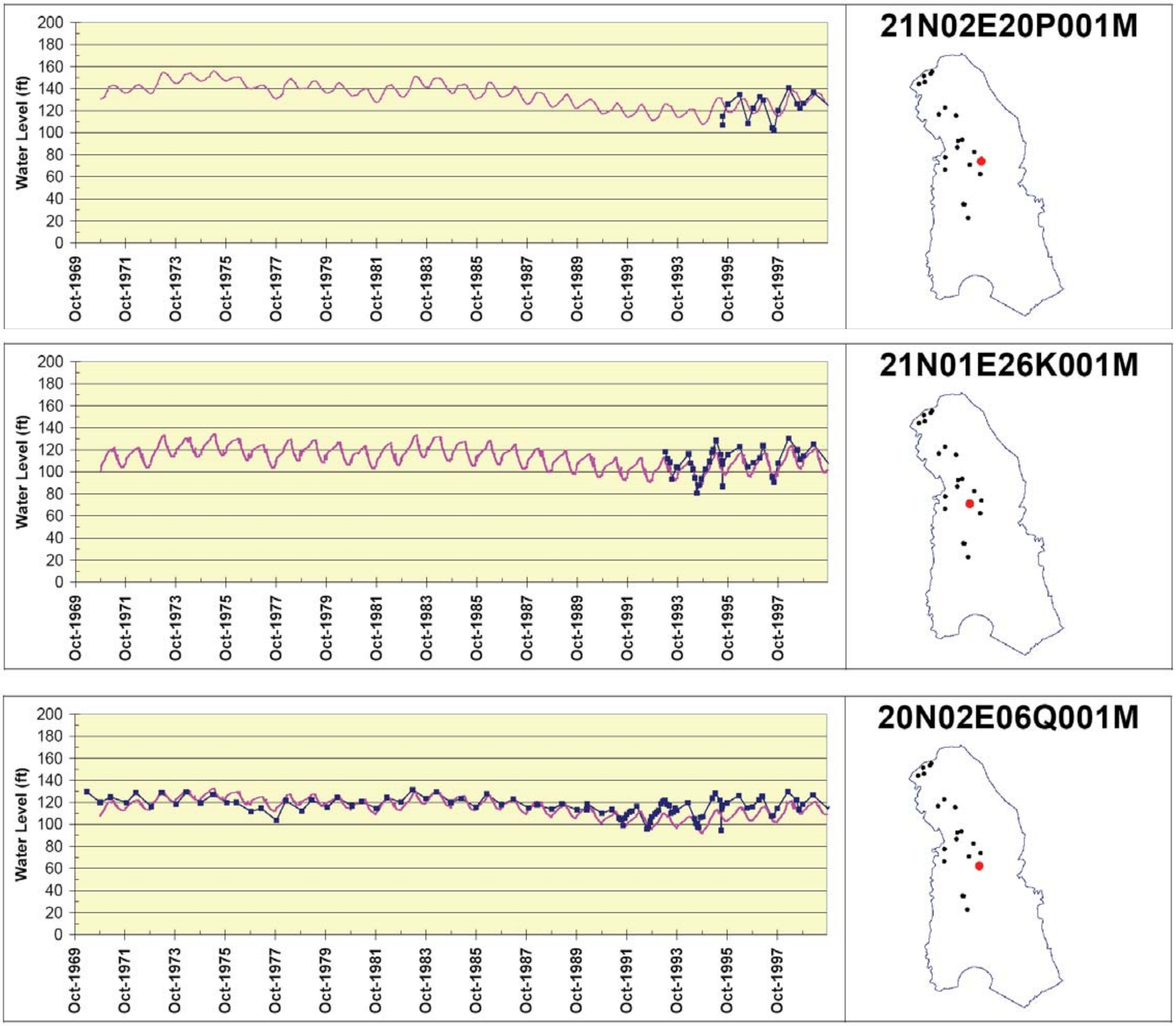




—— Observed —— Simulated

Figure 4-15
Simulated vs. Observed Water Levels
Wells Screened in **Tuscan C** Formation

CDM



Observed Simulated

Figure 4-16
Simulated vs. Observed Water Levels
Wells Screened in **Tuscan C** Formation

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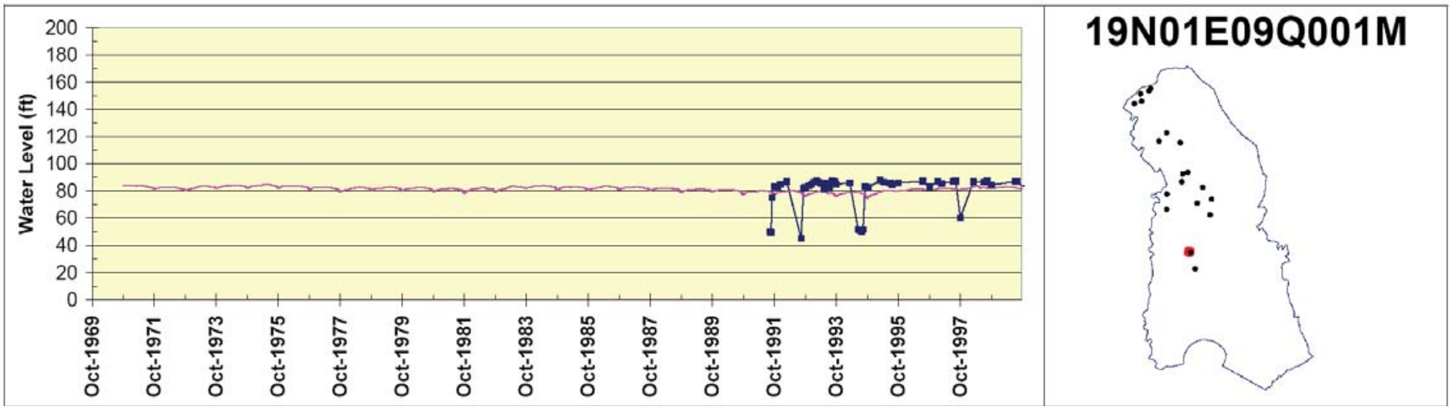

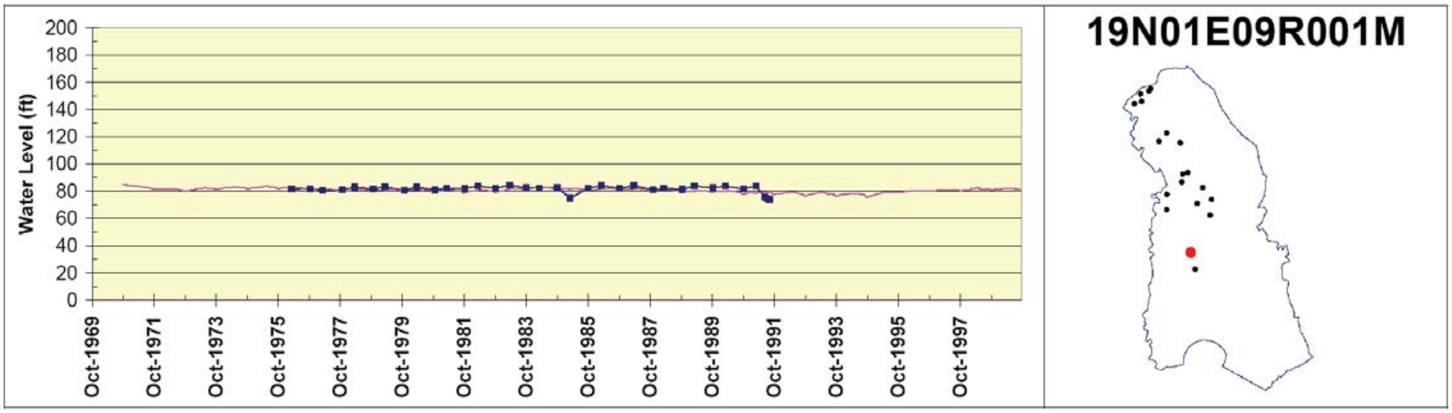

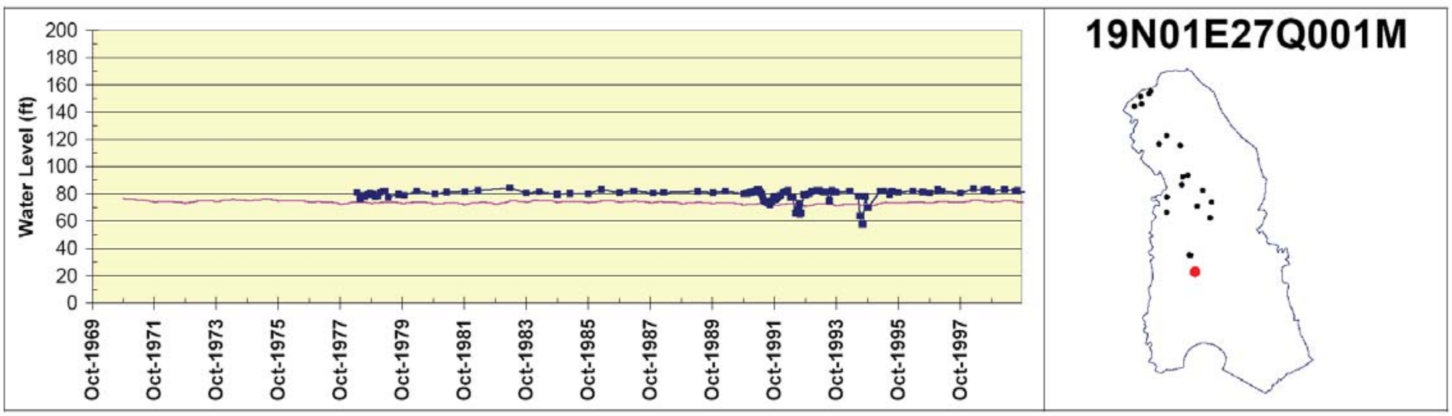

Observed Simulated

Figure 4-17
Simulated vs. Observed Water Levels
Wells Screened in **Tuscan C** Formation

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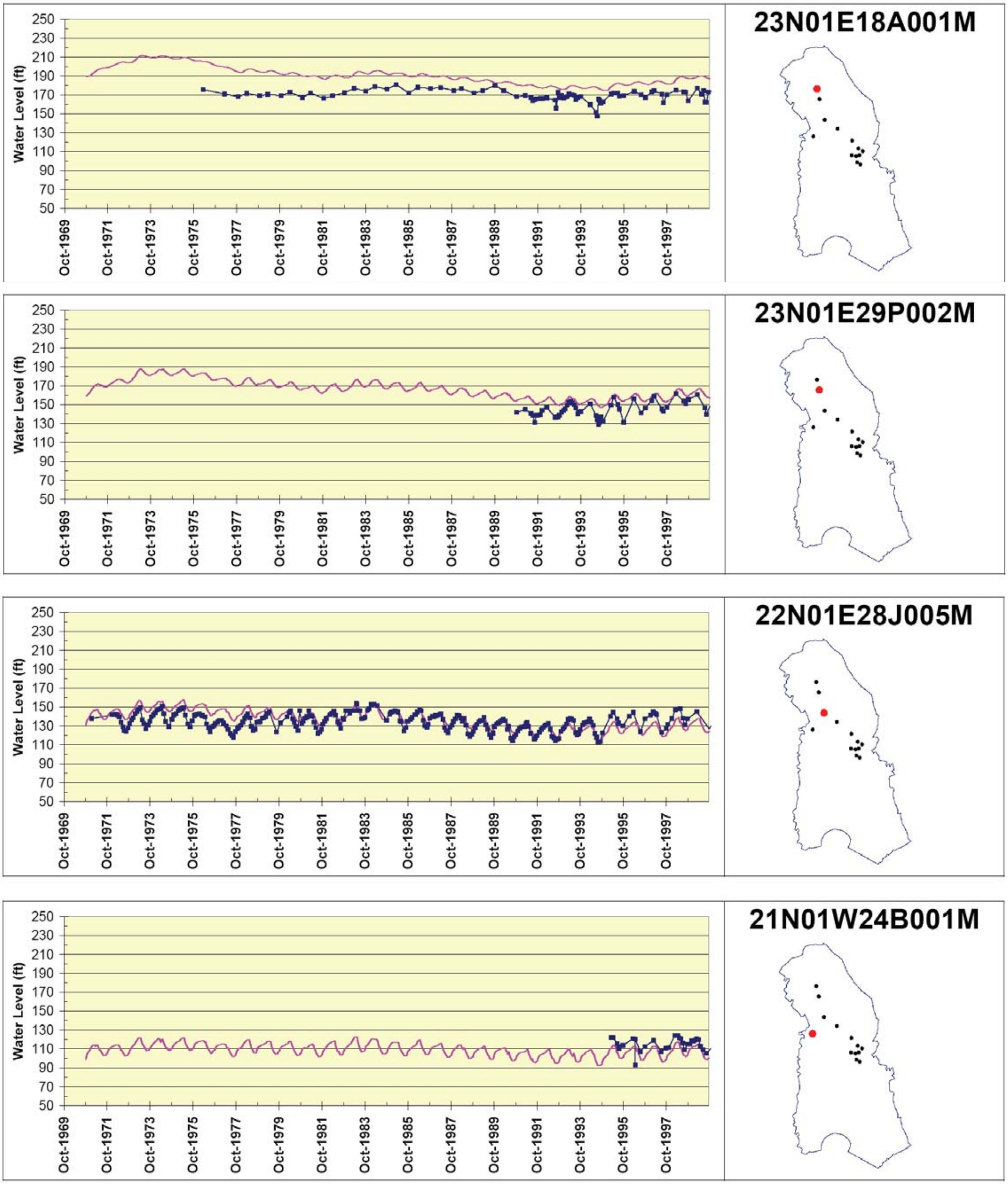

Observed   Simulated

Figure 4-18
Simulated vs. Observed Water Levels
Wells Screened in **Tuscan B** Formation

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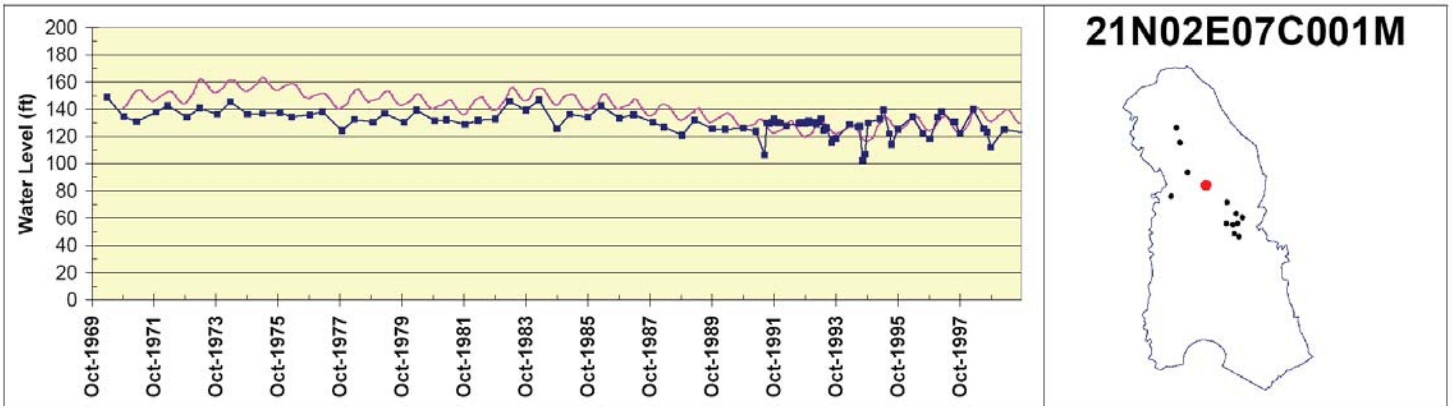

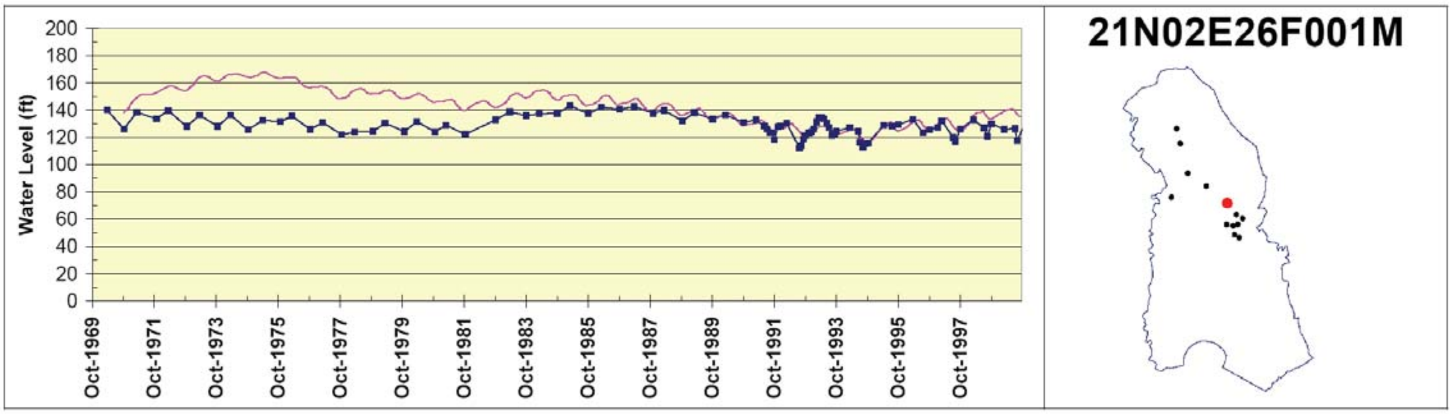

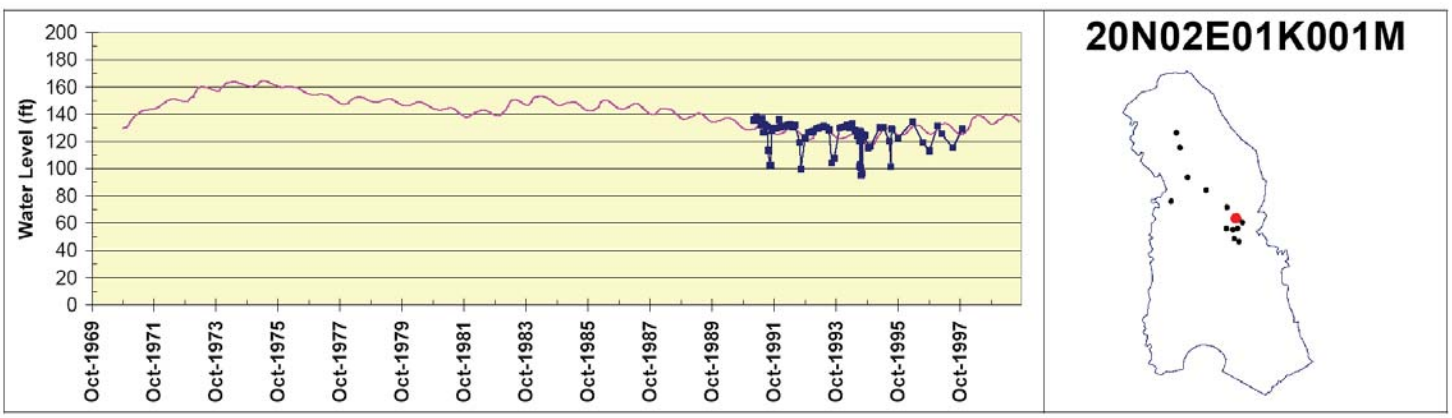

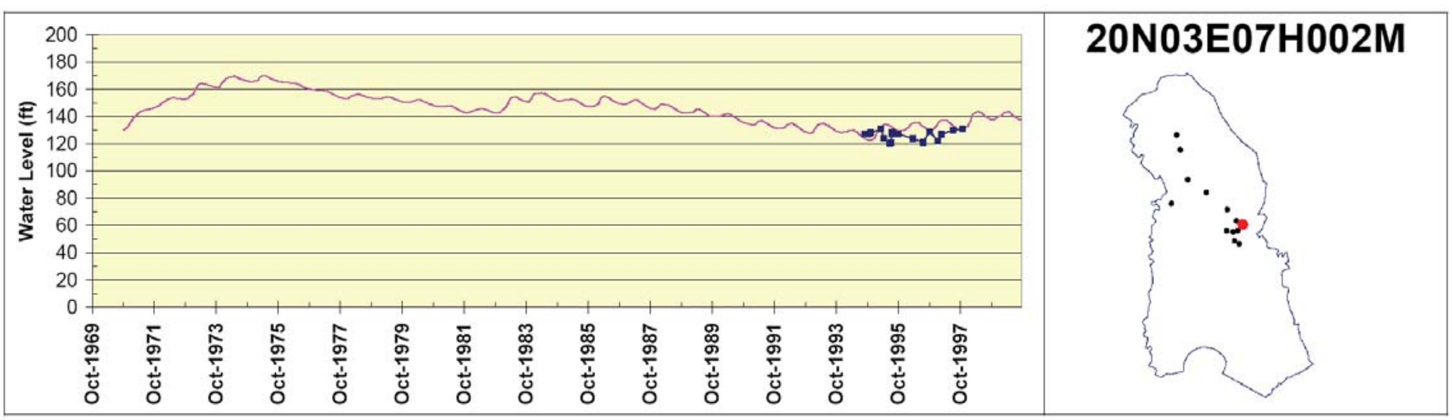

Observed   Simulated

Figure 4-19
Simulated vs. Observed Water Levels
Wells Screened in **Tuscan B** Formation

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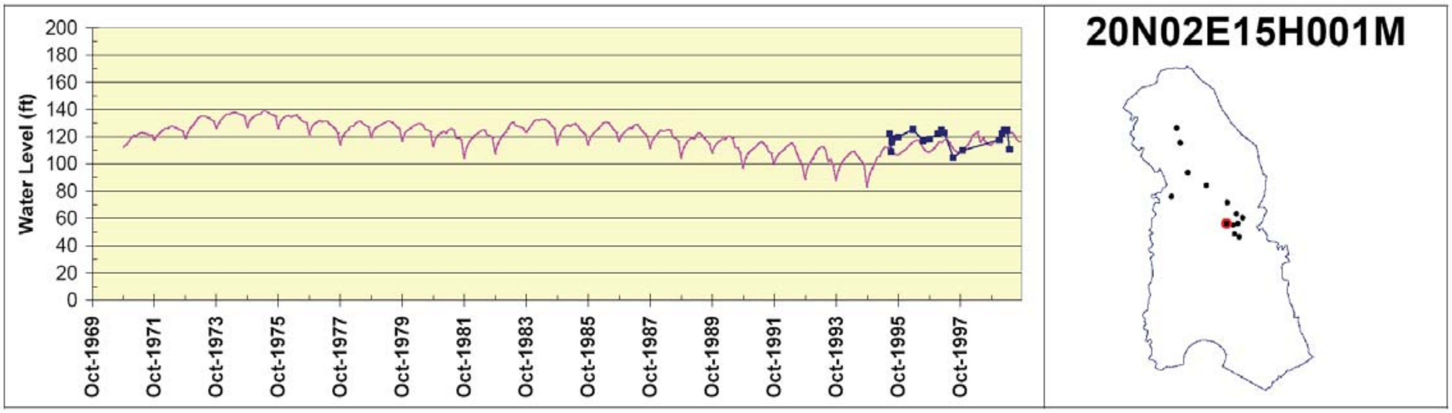
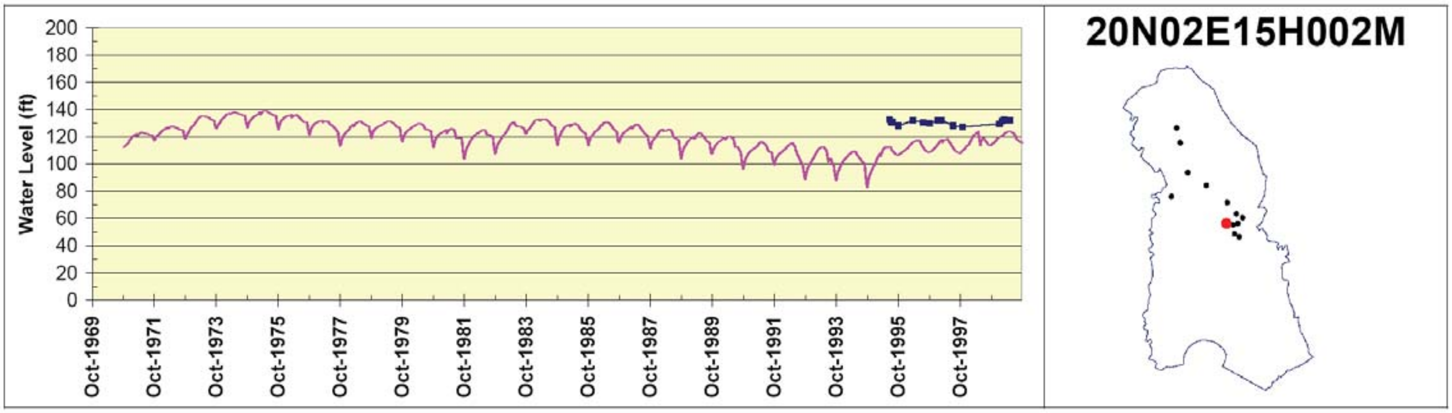
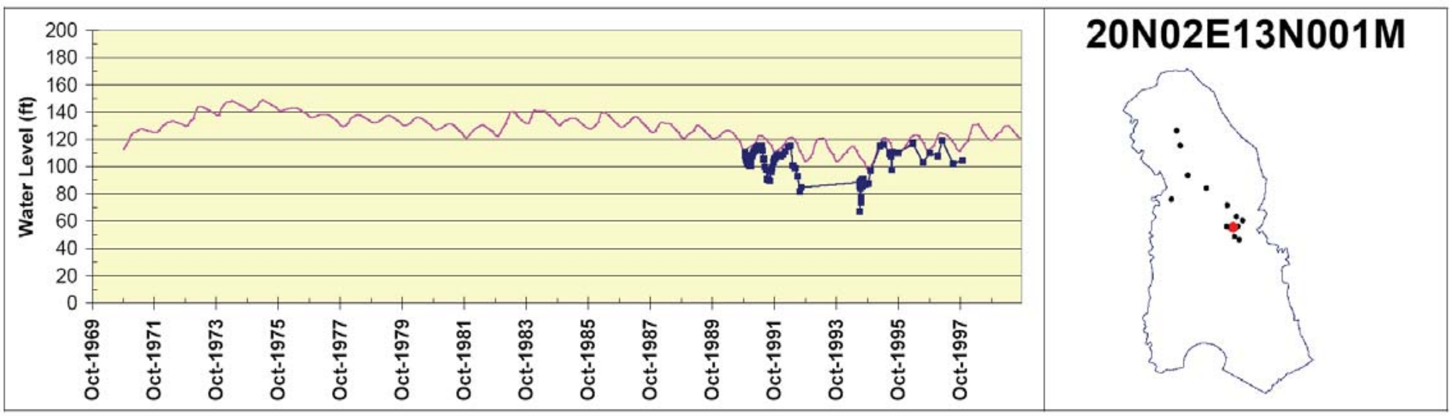
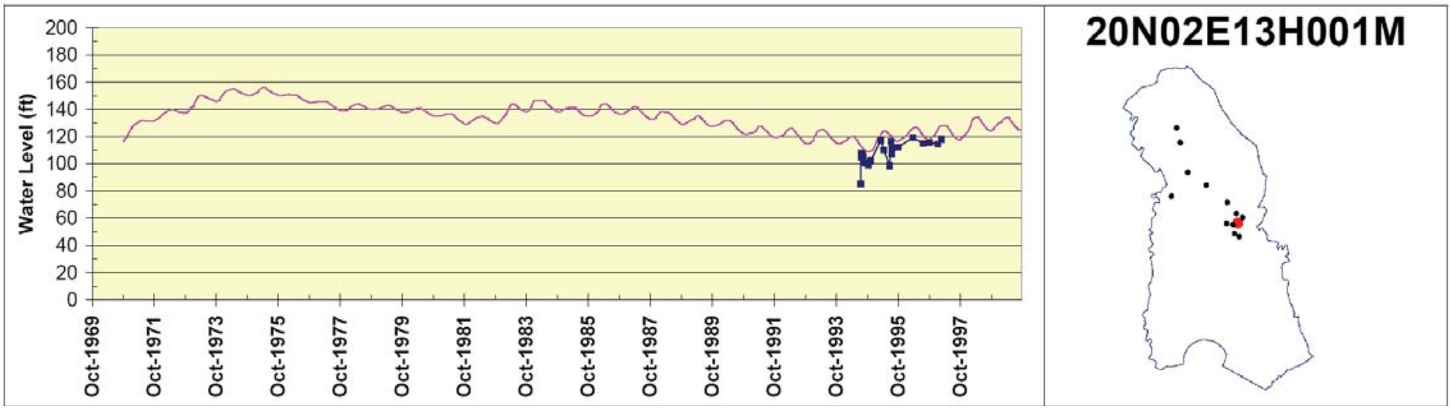


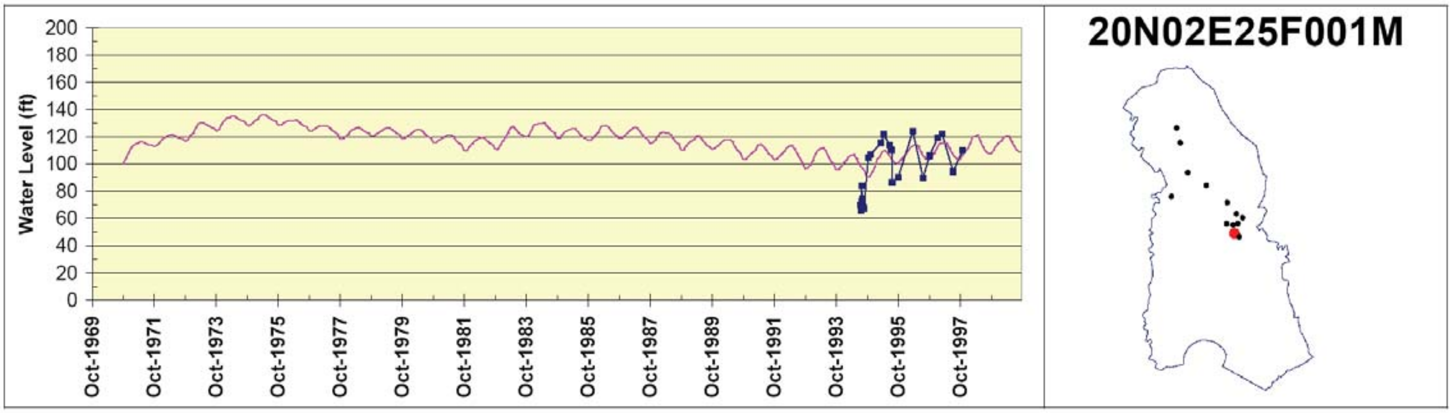


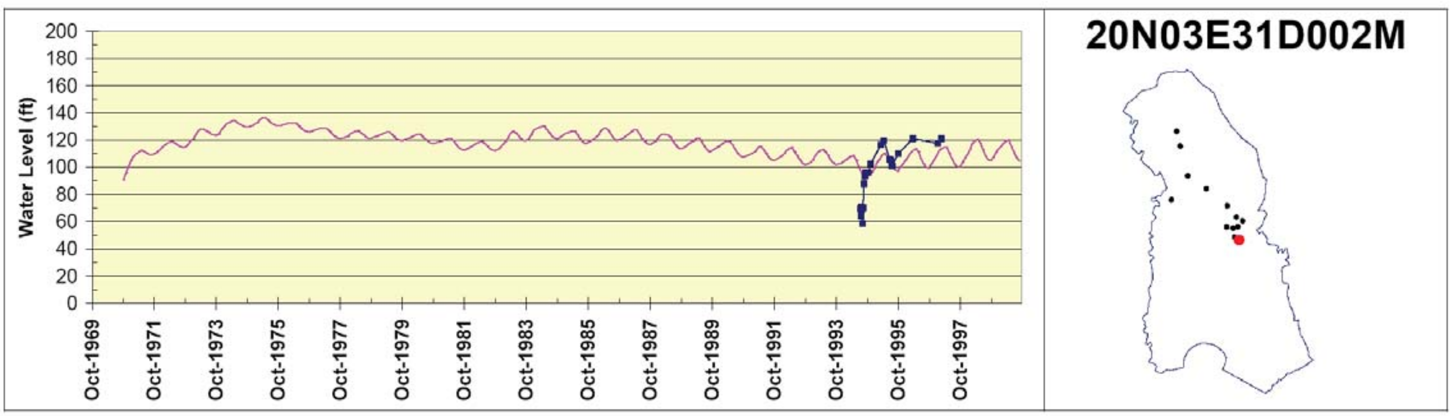


Observed — Simulated

Figure 4-20
Simulated vs. Observed Water Levels
Wells Screened in **Tuscan B** Formation







Observed Simulated

Figure 4-21
Simulated vs. Observed Water Levels
Wells Screened in **Tuscan B** Formation

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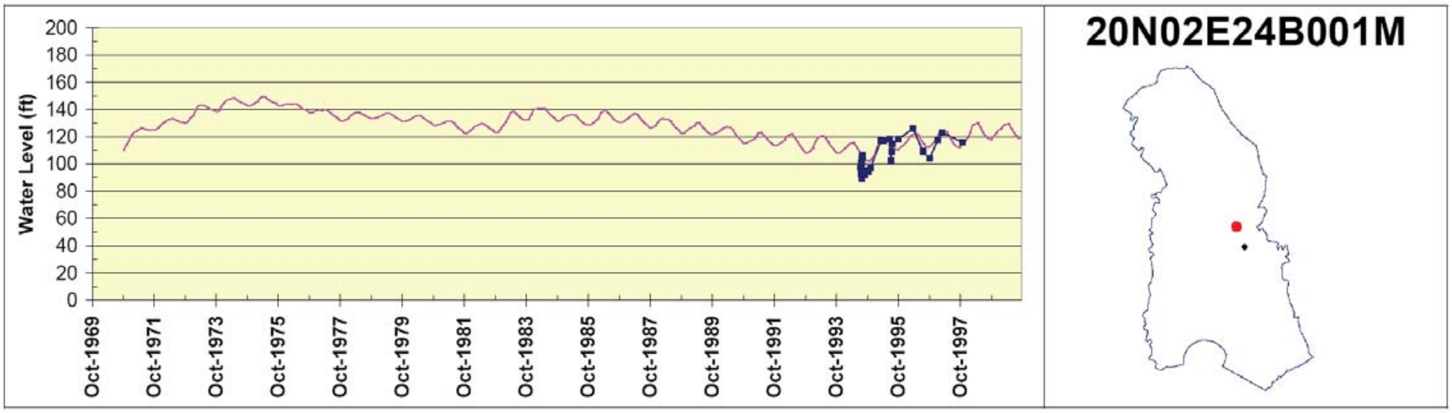
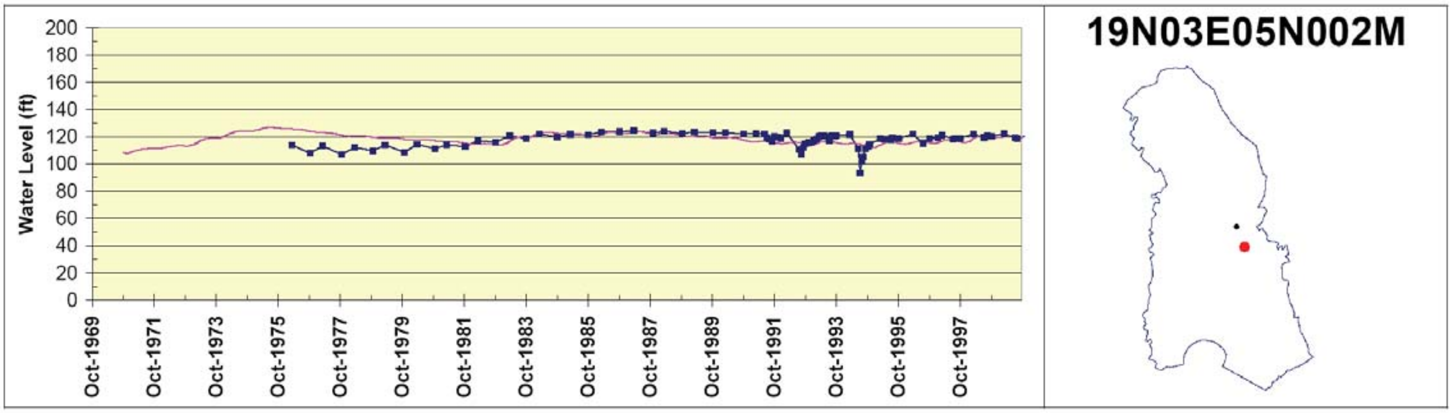
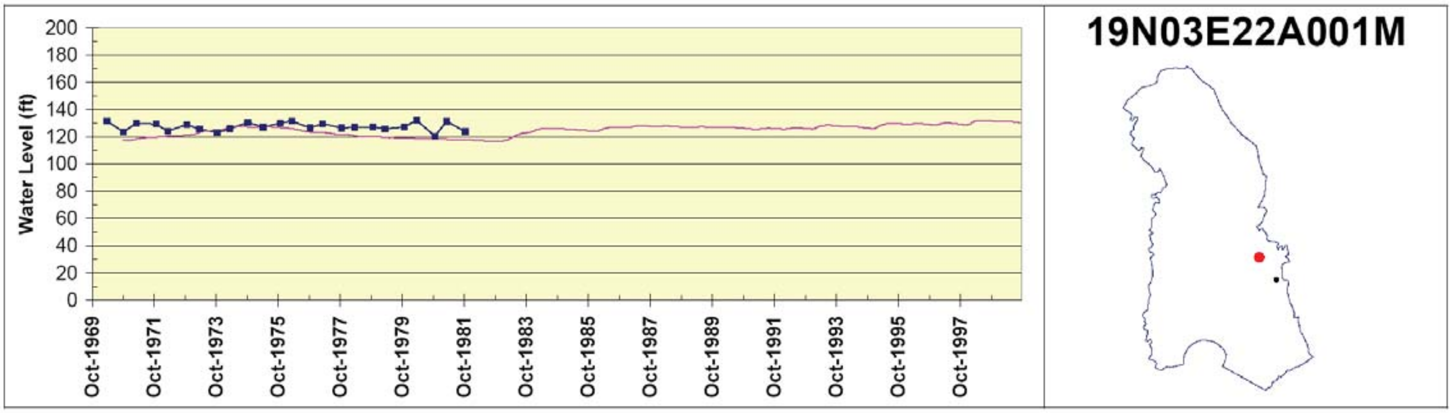
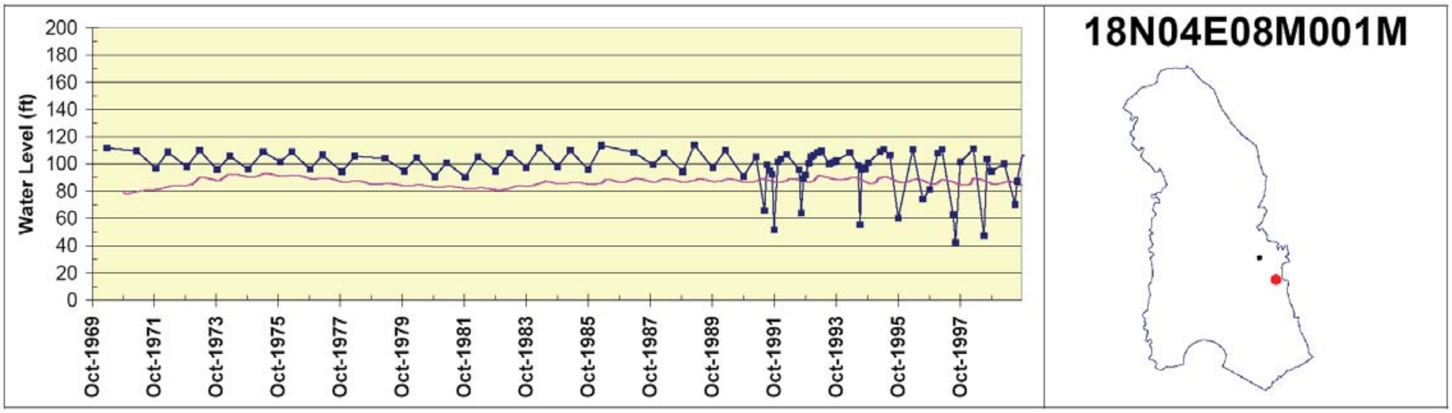




Observed — Simulated

Figure 4-22
Simulated vs. Observed Water Levels
Wells Screened in **Tuscan A** Formation





Observed
Simulated

Figure 4-23
Simulated vs. Observed Water Levels
Wells Screened in **Neroly, Upper Princeton Gorge & Ione** Formations

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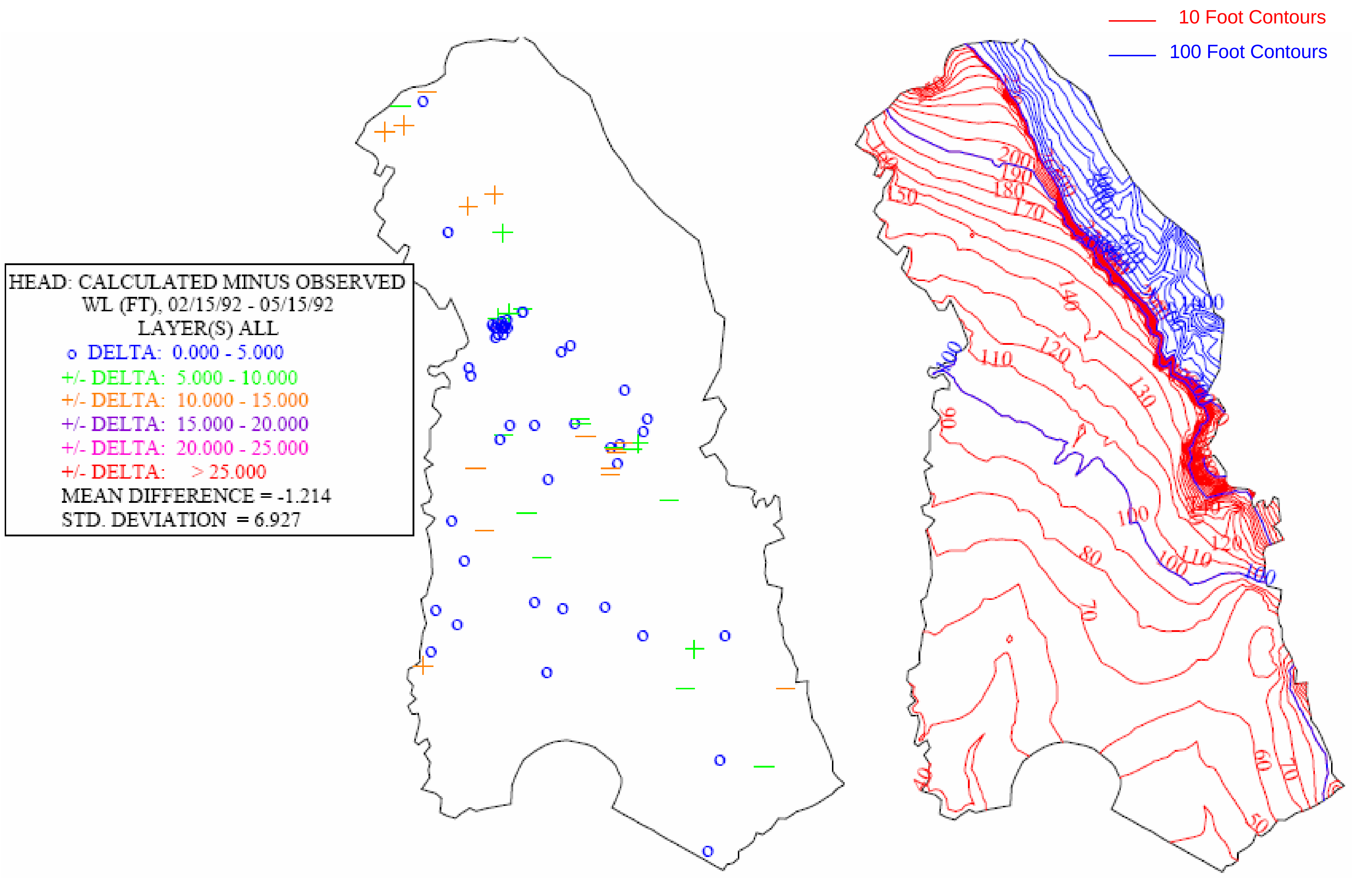

Simulated: March 15, 1992
Observed: Average Spring 1992

Figure 4-24
Simulated vs. Observed Water Levels and Groundwater Contours
Spring 1992

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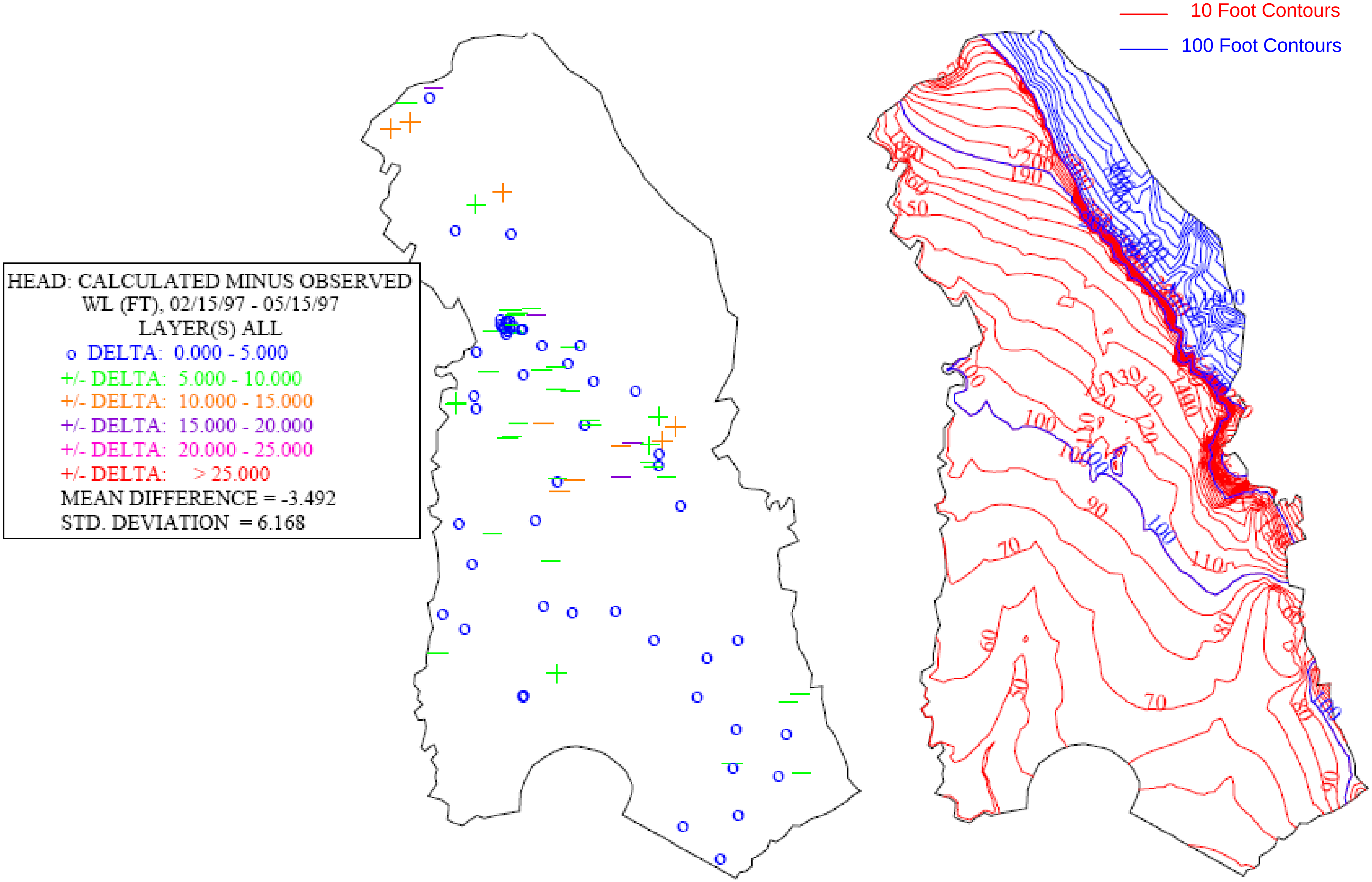
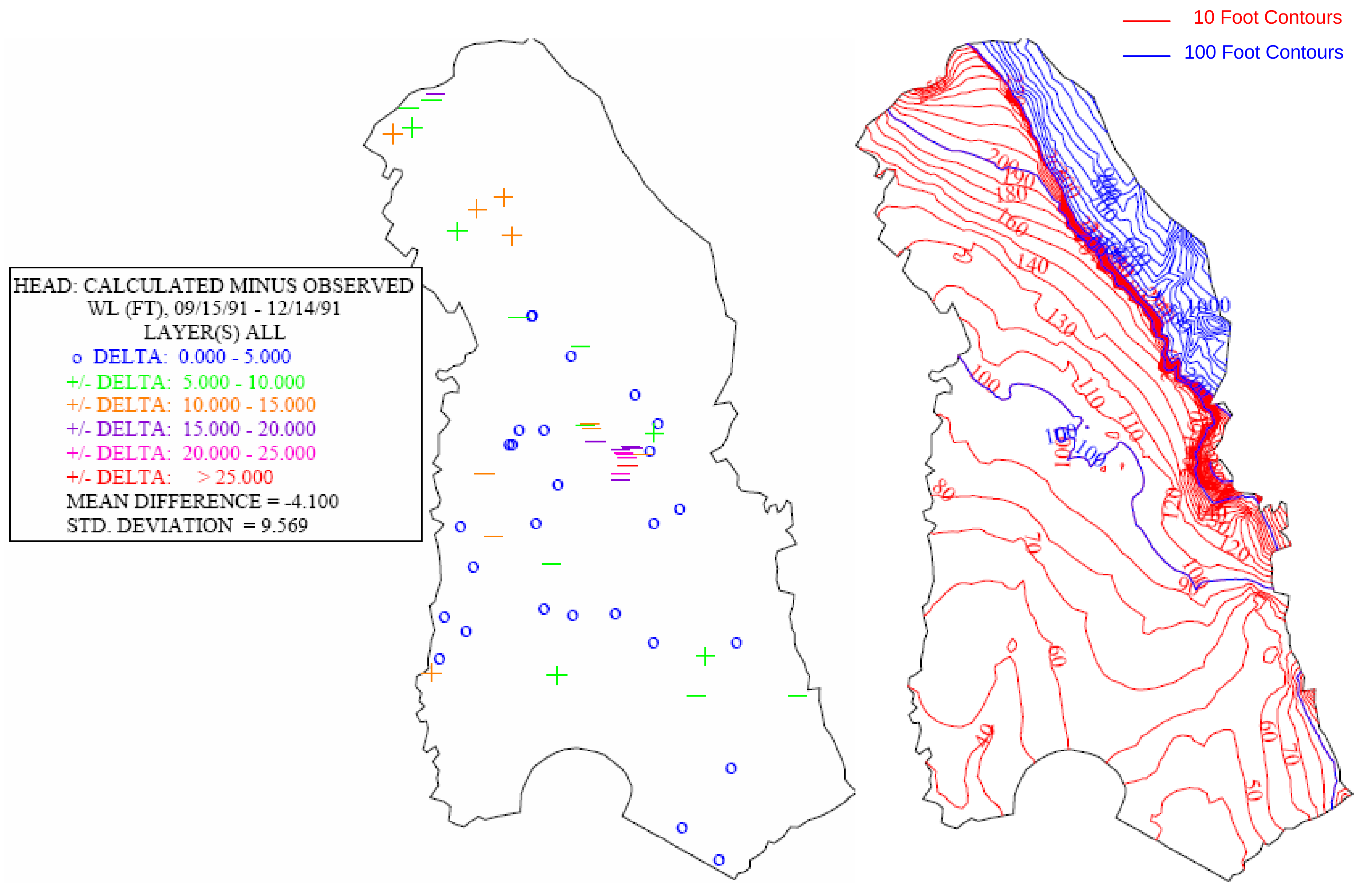


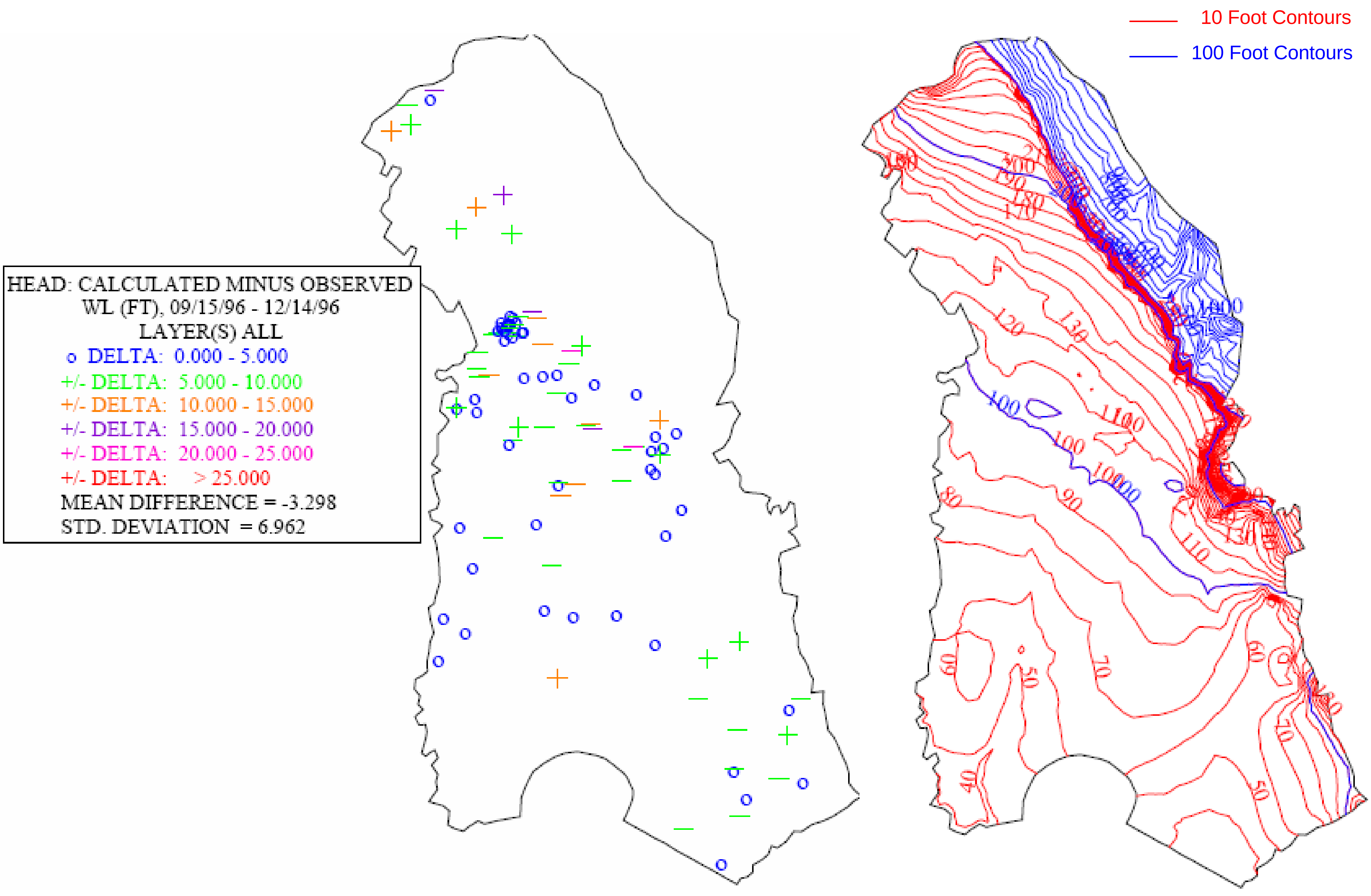
Simulated: March 15, 1997
Observed: Average Spring 1997

Figure 4-25
Simulated vs. Observed Water Levels and Groundwater Contours
Spring 1997



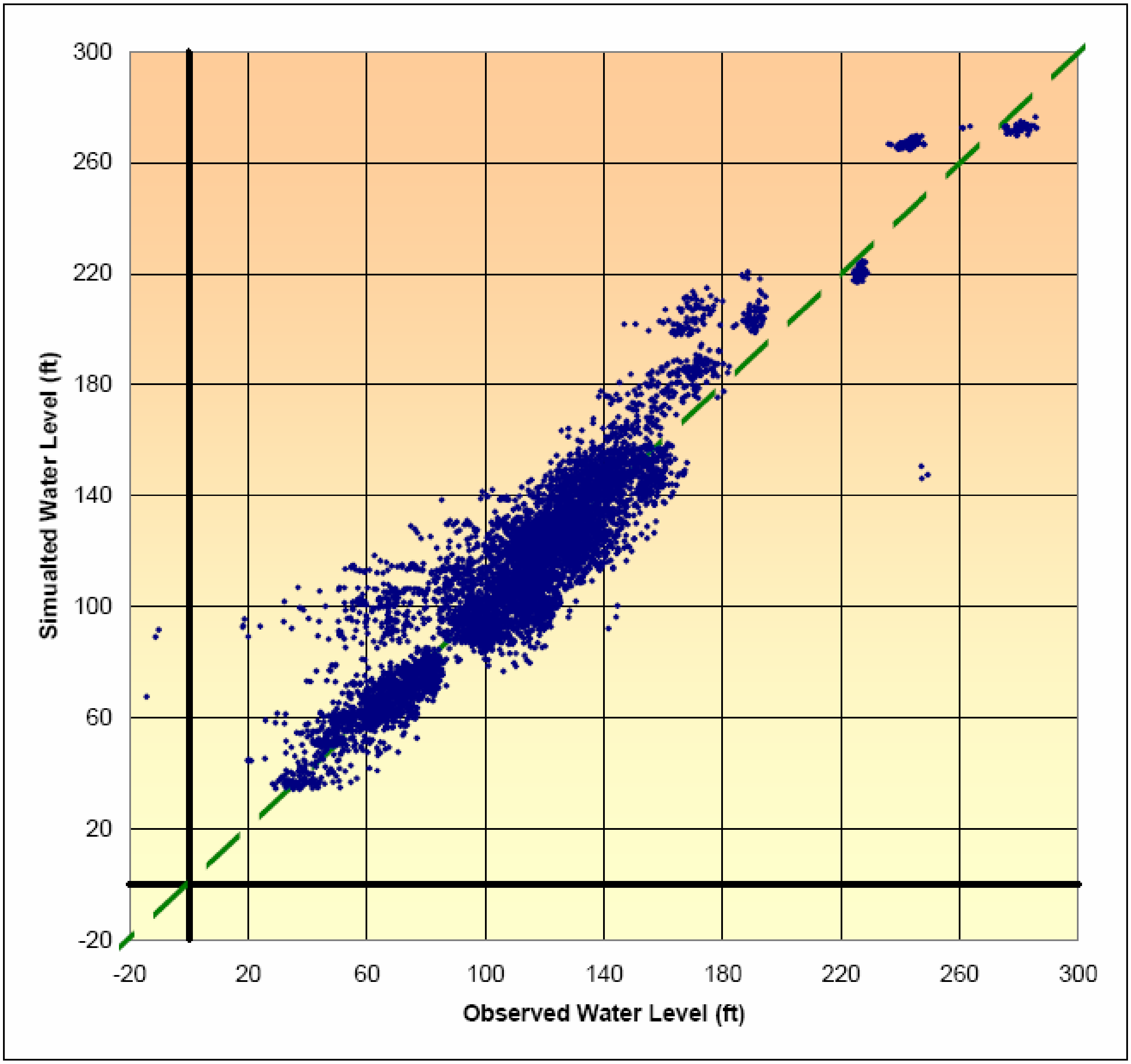
Simulated: October 15, 1991
Observed: Average Fall 1991

Figure 4-26
Simulated vs. Observed Water Levels and Groundwater Contours
Fall 1991



Simulated: October 15, 1996
Observed: Average Fall 1996

Figure 4-27
Simulated vs. Observed Water Levels and Groundwater Contours
Fall 1996



The 45 degree plot compares simulated and observed water levels for wells shown on Figure 4-1 during the simulation time period.

Figure 4-28
Simulated vs. Observed Water Levels
45 degree Plot

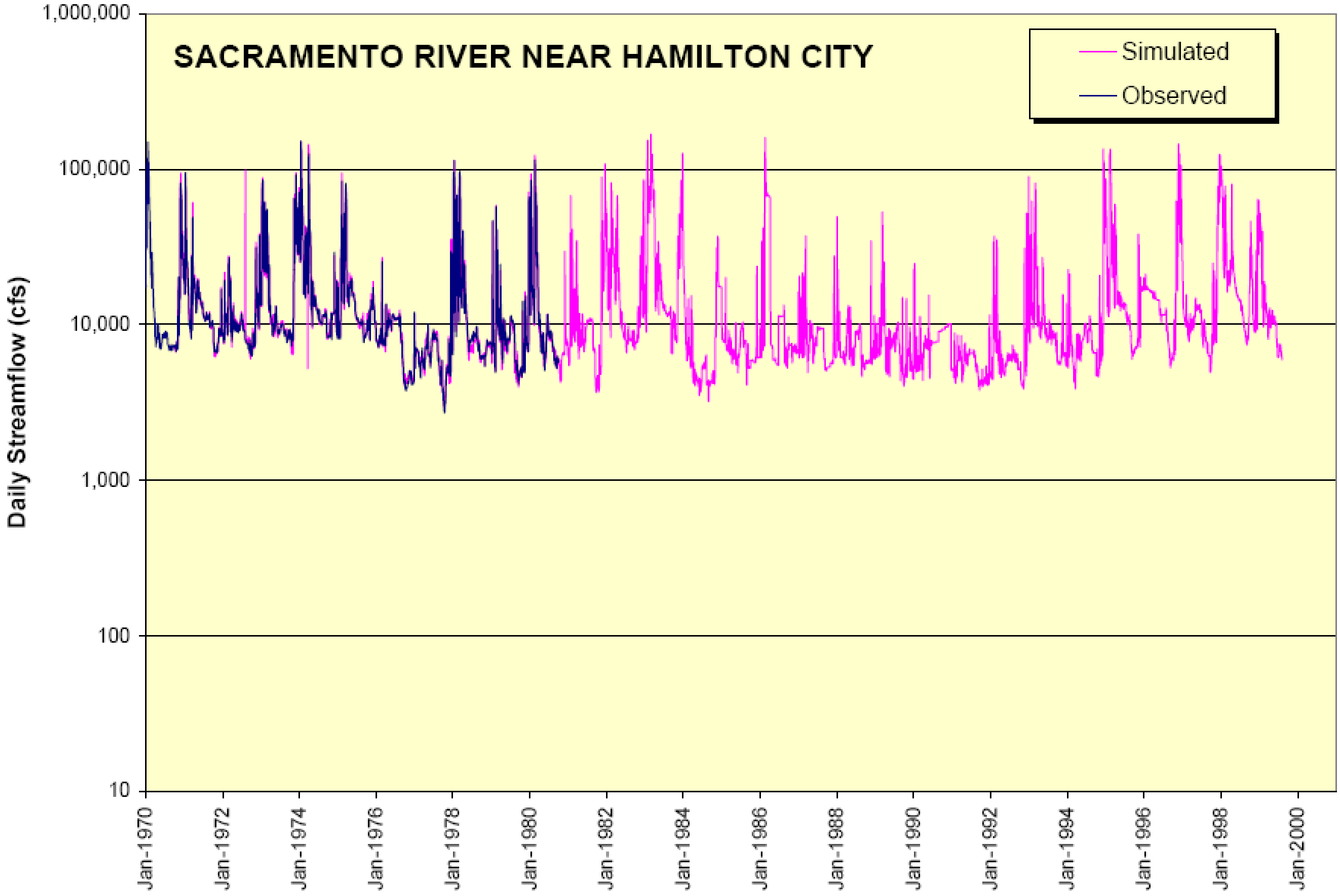


Figure 4-29
Simulated vs. Observed Streamflow
USGS Gage 11383800 (Sacramento River near Hamilton City)

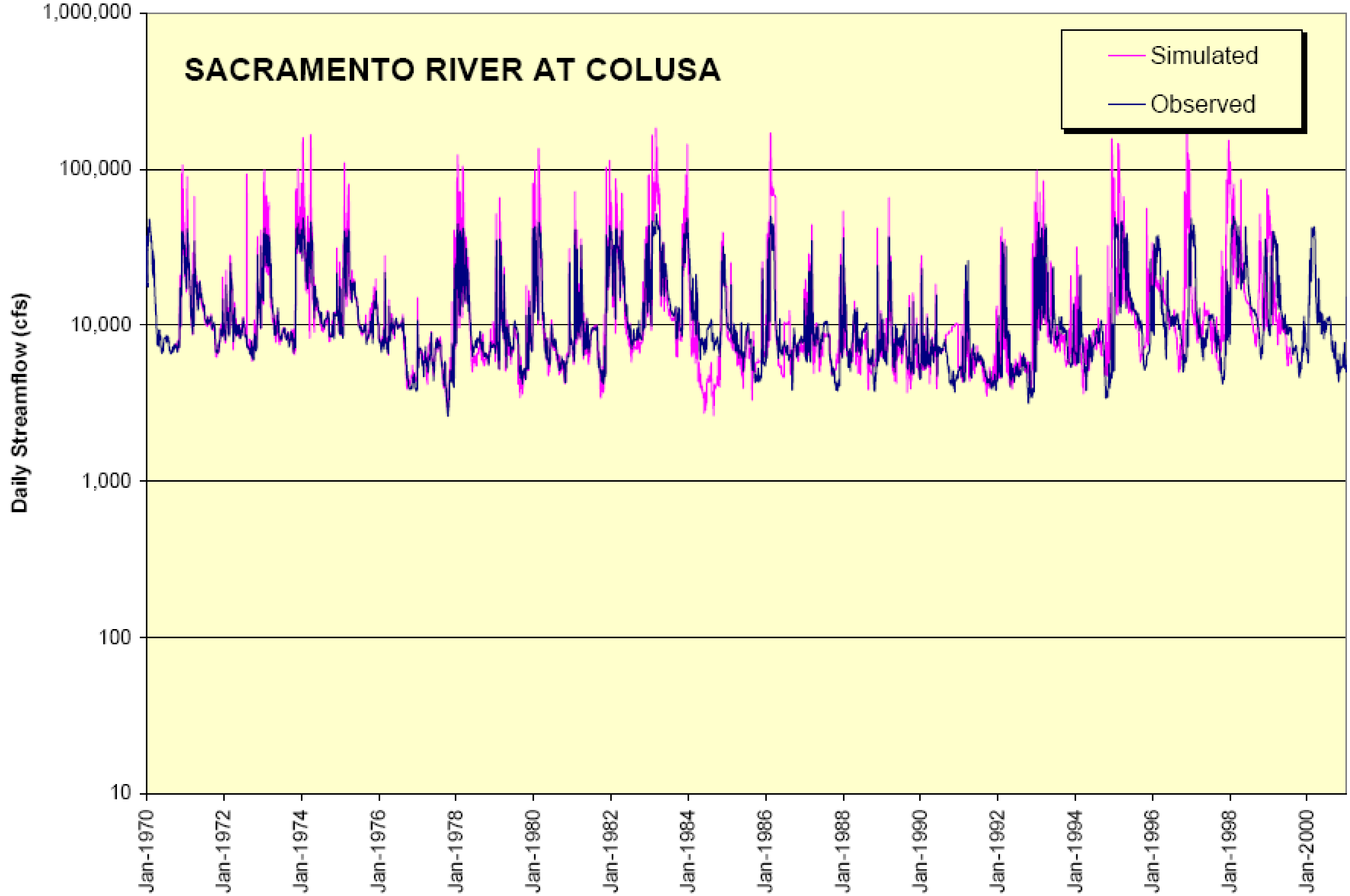


Figure 4-30
Simulated vs. Observed Streamflow
USGS Gage 11389500 (Sacramento River at Colusa)

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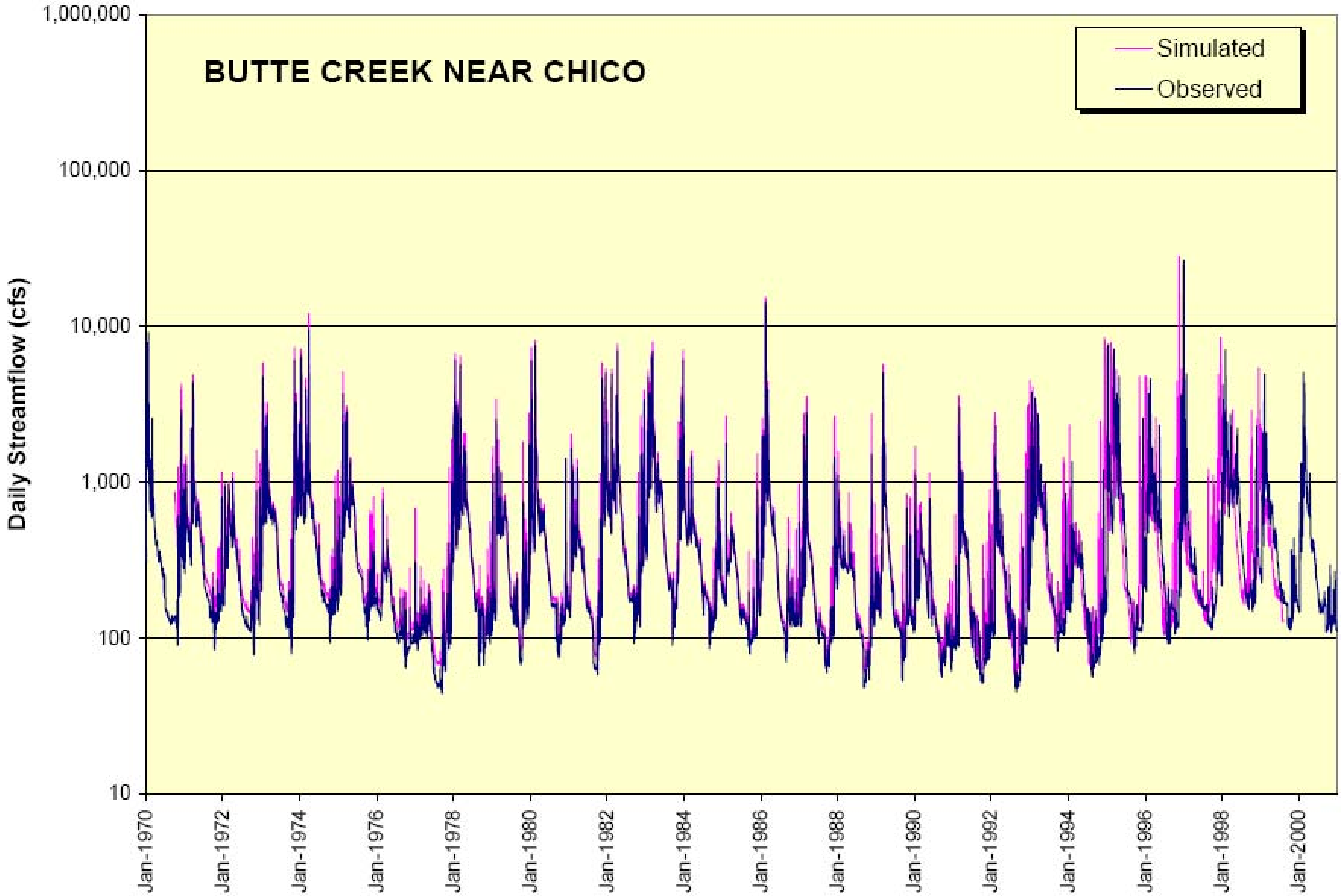

Figure 4-31
Simulated vs. Observed Streamflow
USGS Gage 11389000 (Butte Creek near Chico)

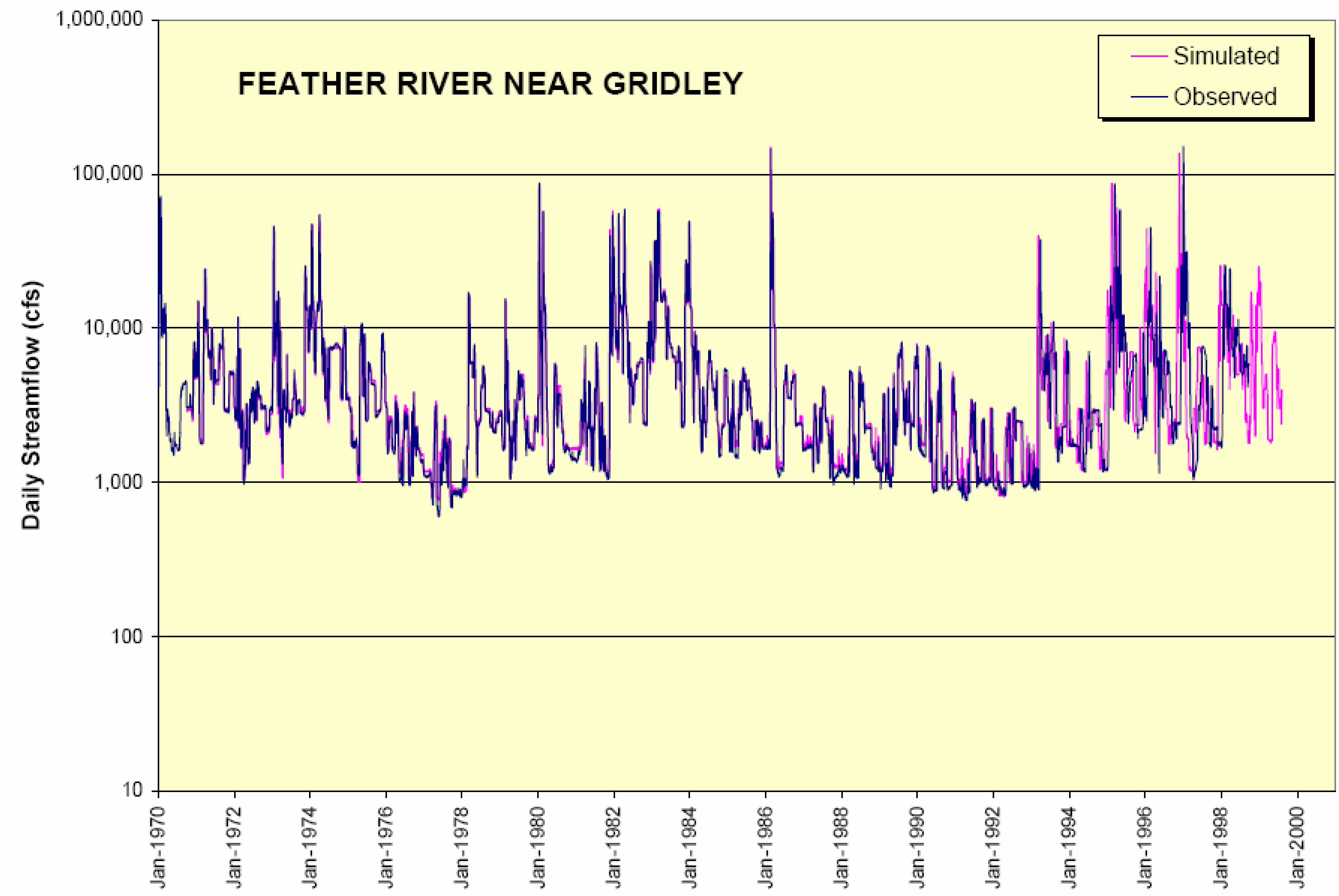

Figure 4-32
Simulated vs. Observed Streamflow
USGS Gage 11407150 (Feather River near Gridley)

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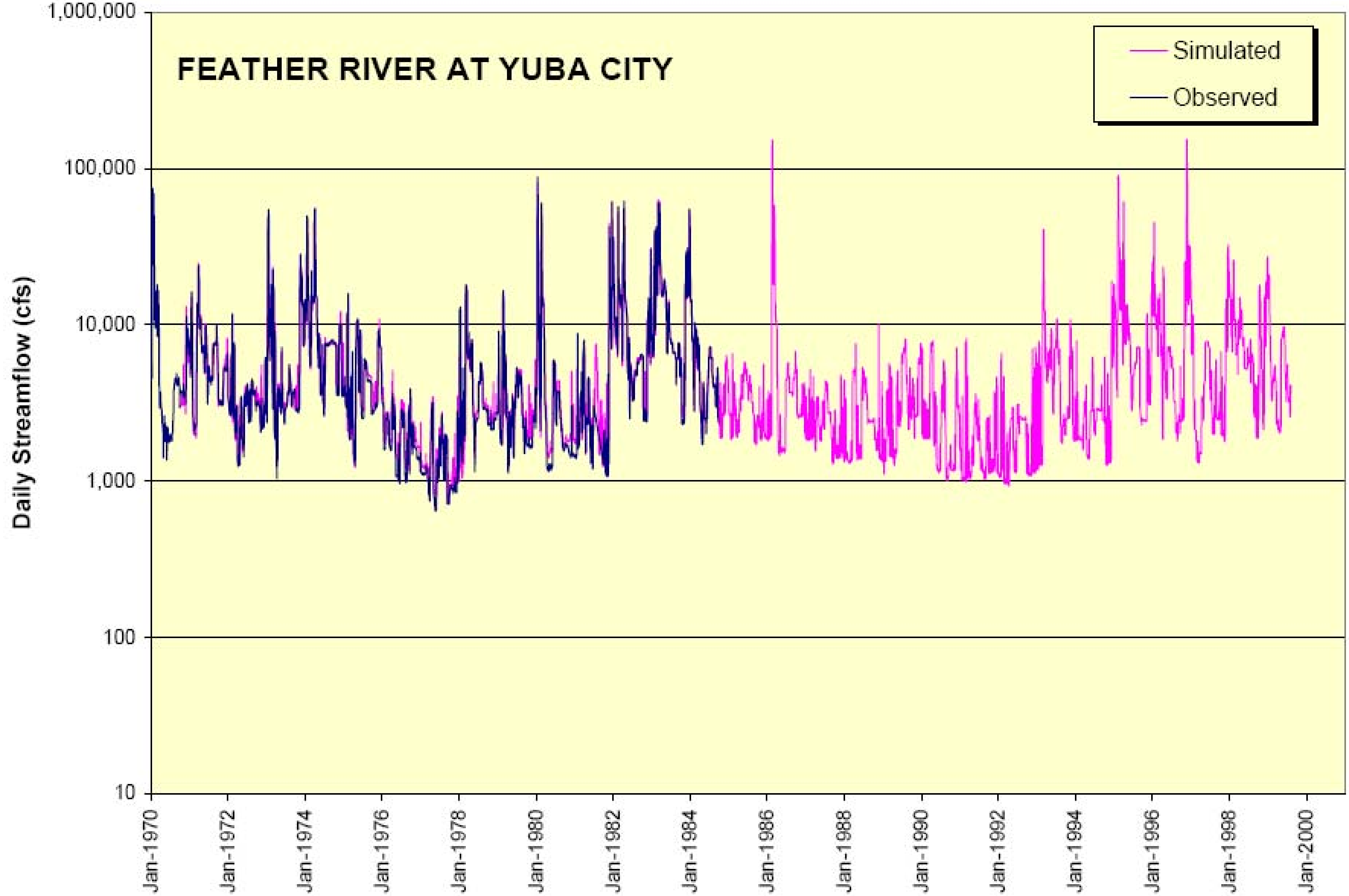
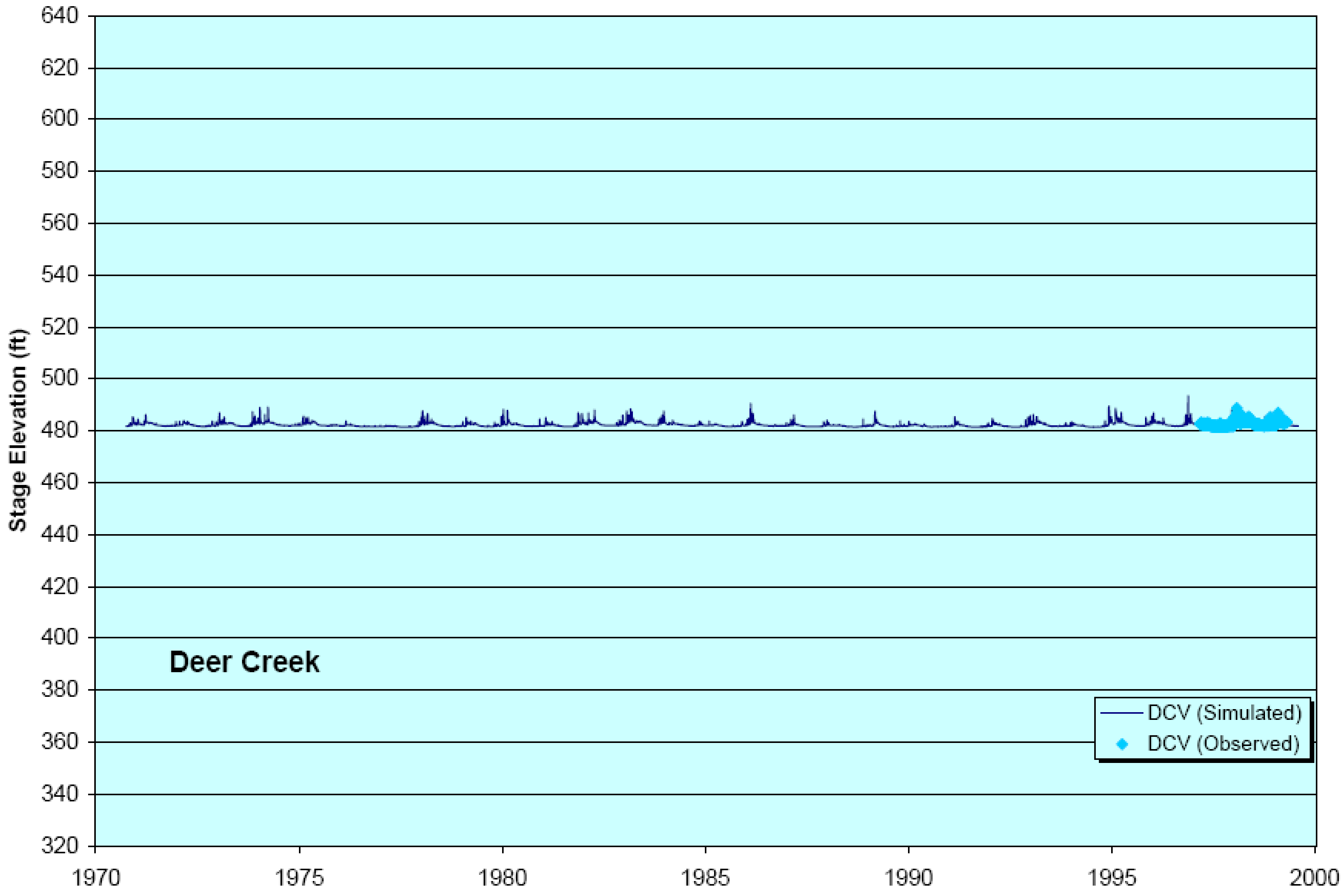


Figure 4-33
Simulated vs. Observed Streamflow
USGS Gage 11407700 (Feather River at Yuba City)



DVC – DWR Gage: Deer Creek near Vina

Figure 4-34
Simulated vs. Observed Stream Stage
Deer Creek

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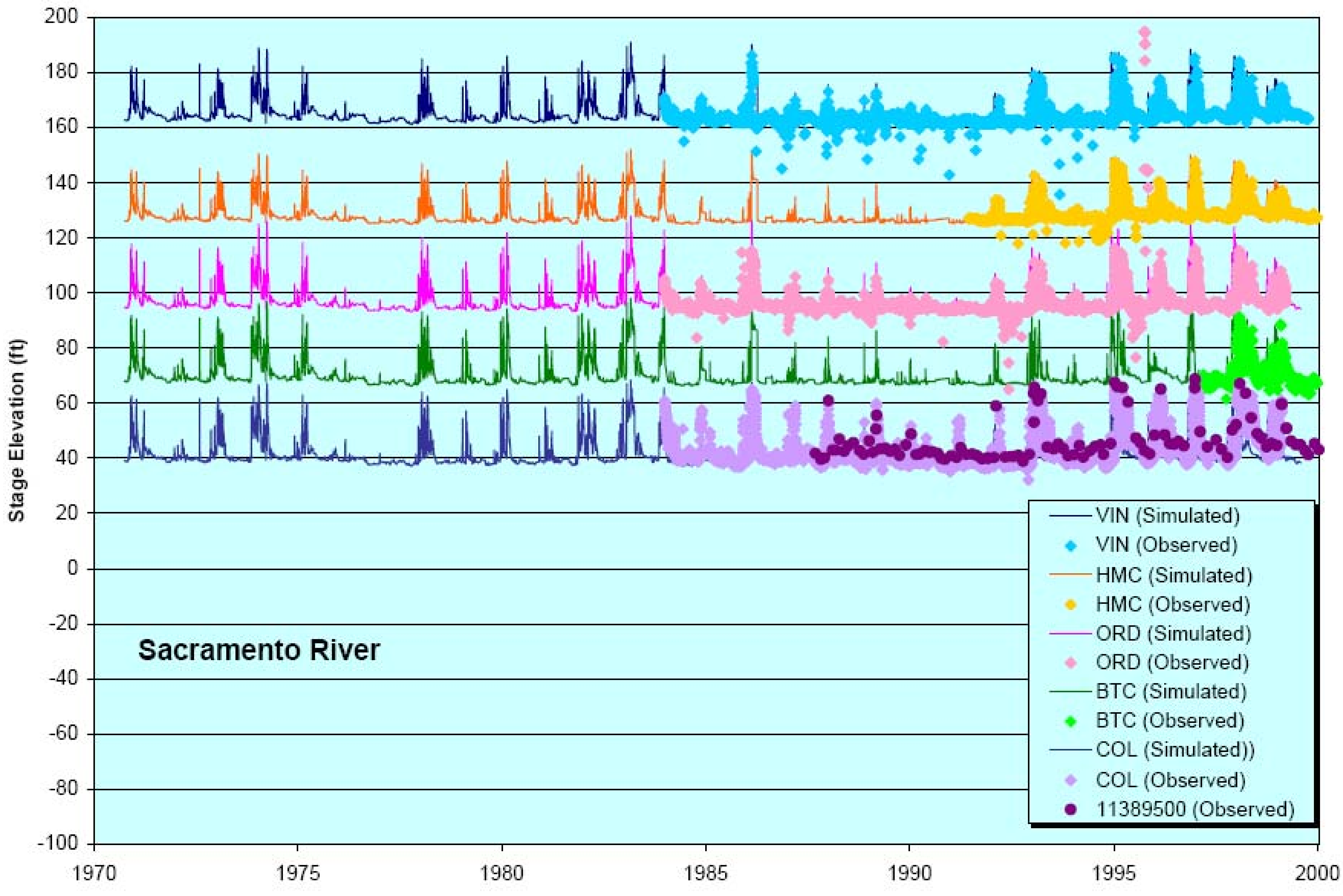
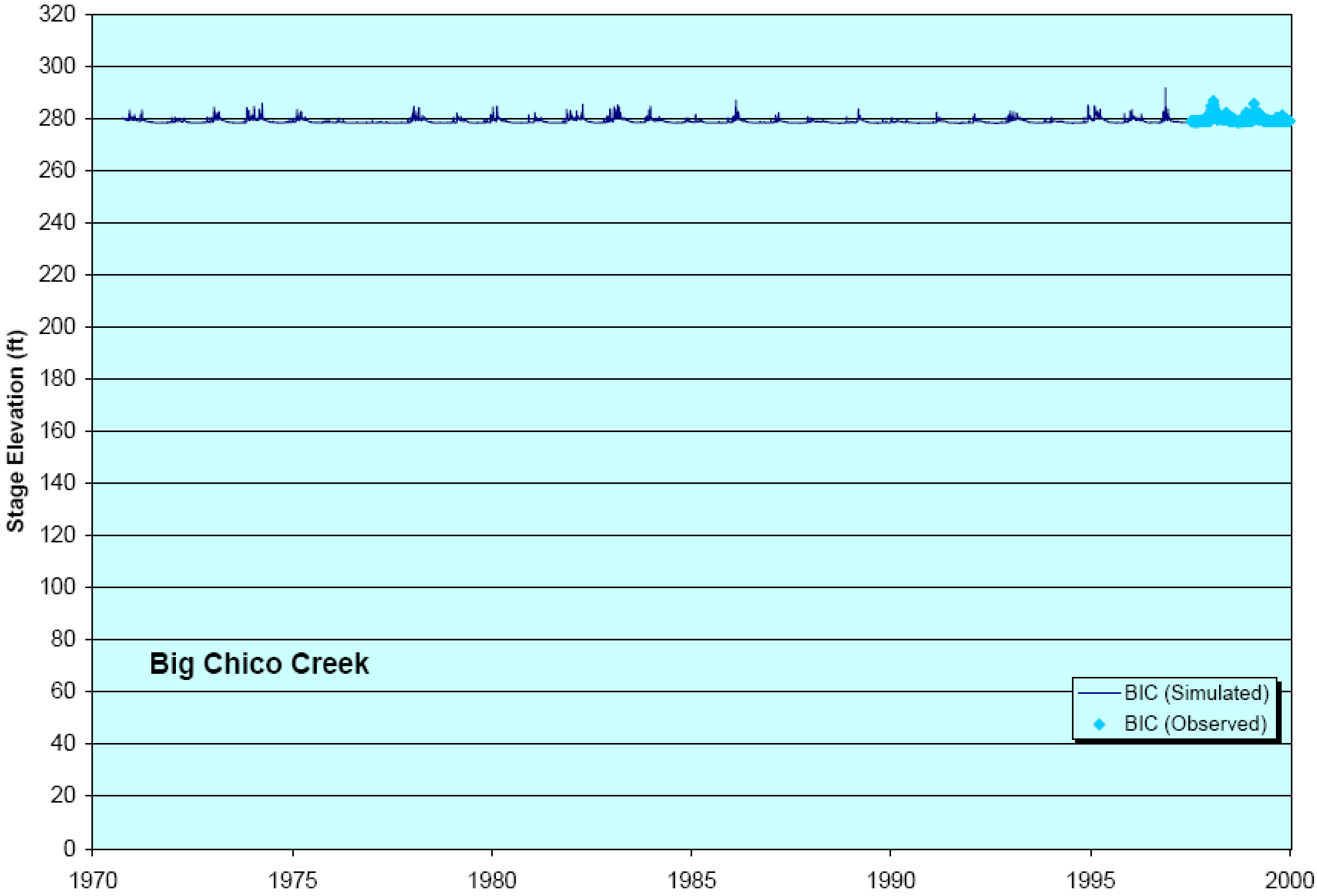


VIN – DWR Gage: Sacramento River near Vina Bridge near Vina
HMC – DWR Gage: Sacramento River near Hamilton City
ORD – DWR Gage: Sacramento River at Ord Ferry
BTC – DWR Gage: Sacramento River at Butte City
COL – DWR Gage, 11389500 – USGS Gage: Sacramento River at Colusa

Figure 4-35
Simulated vs. Observed Stream Stage
Sacramento River



BIC – DWR Gage: Big Chico Creek near Chico

Figure 4-36
Simulated vs. Observed Stream Stage
Big Chico Creek

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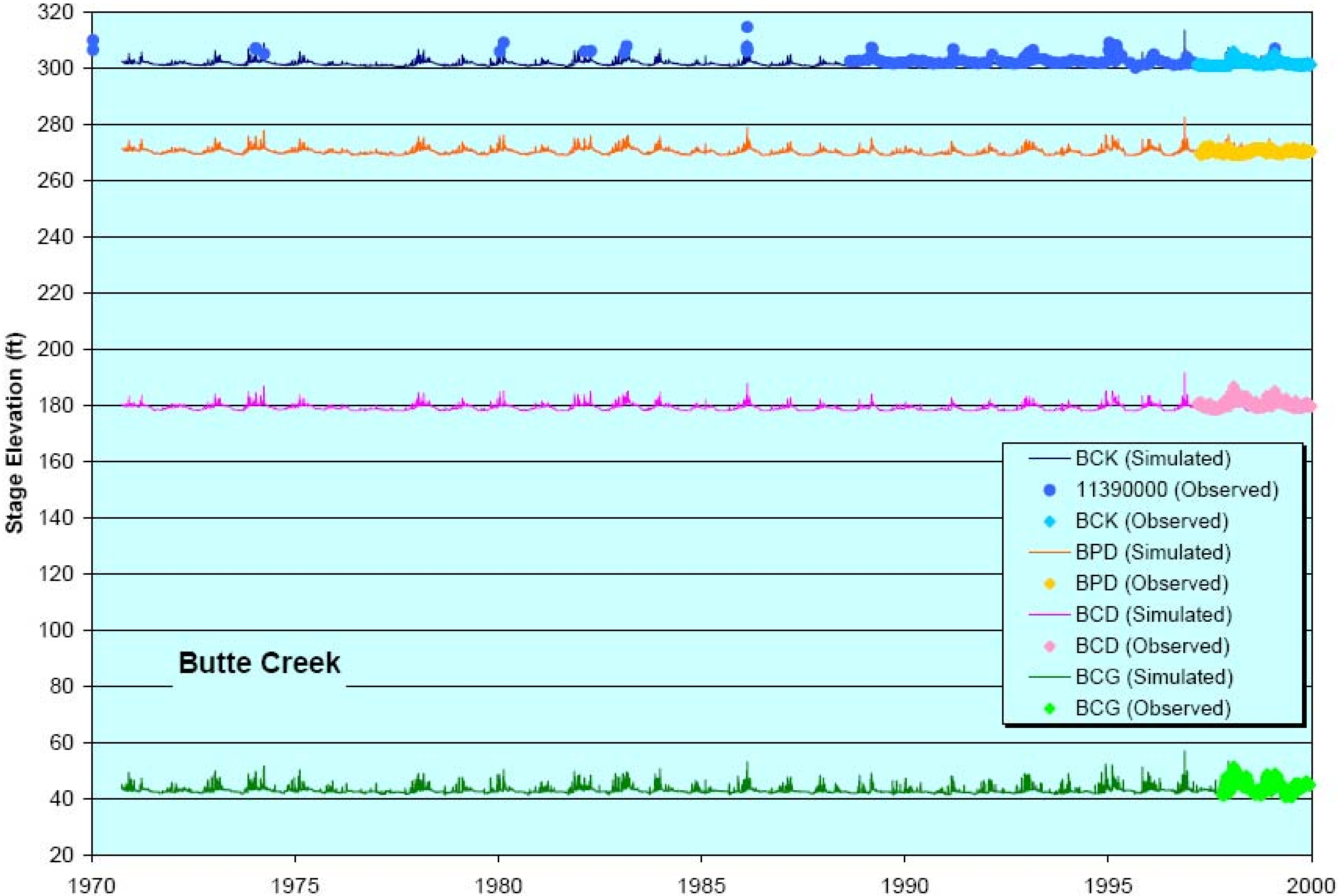

BCK – DWR Gage, 11390000 – USGS Gage: Butte Creek near Chico
BPD – DWR Gage: Parrot Diversion from Butte Creek
BCD – DWR Gage: Butte Creek near Durham
BCG – DWR Gage: Butte Creek near Gridley

Figure 4-37
Simulated vs. Observed Stream Stage
Butte Creek

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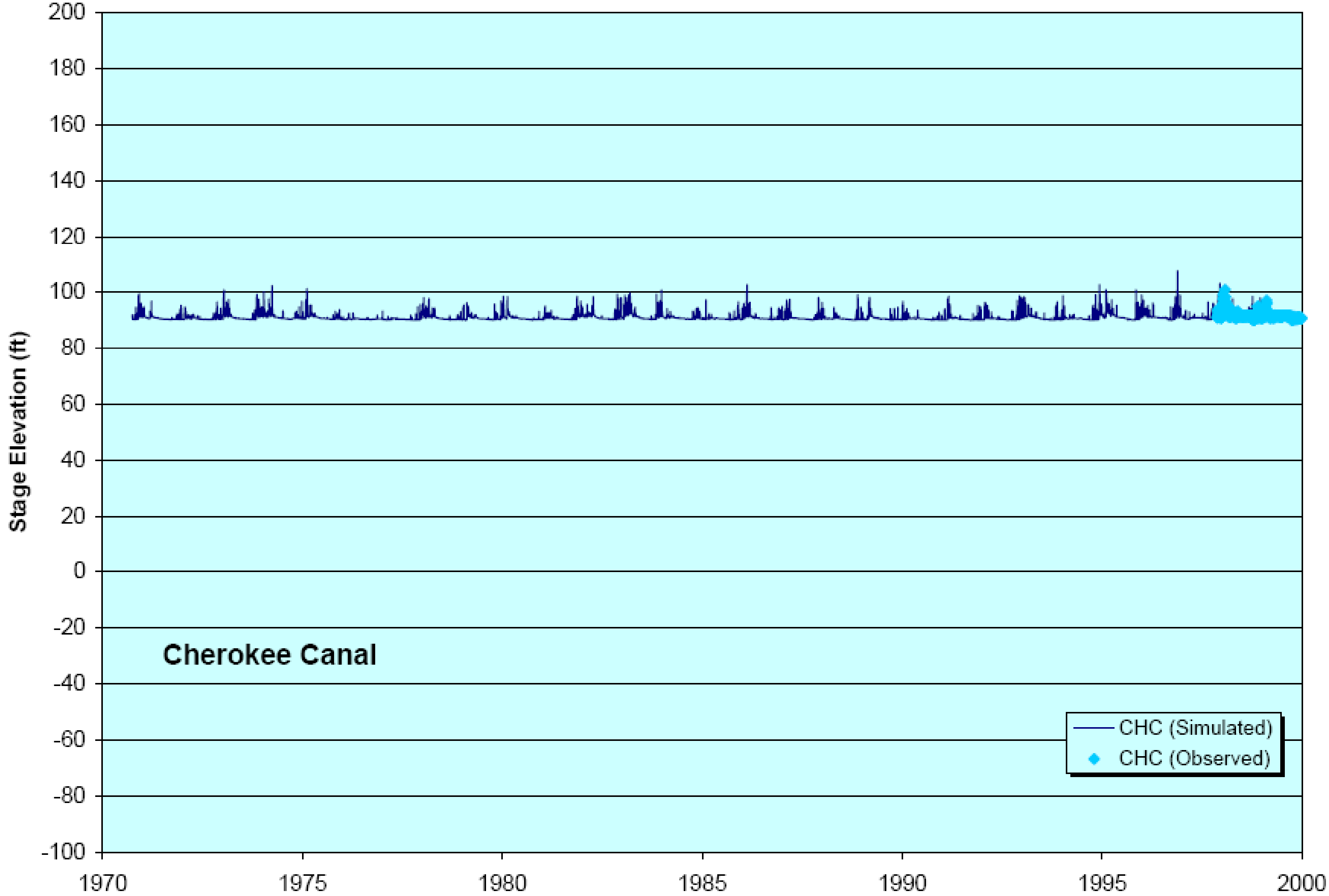

CHC – DWR Gage: Cherokee Canal near Richvale

Figure 4-38
Simulated vs. Observed Stream Stage
Cherokee Canal

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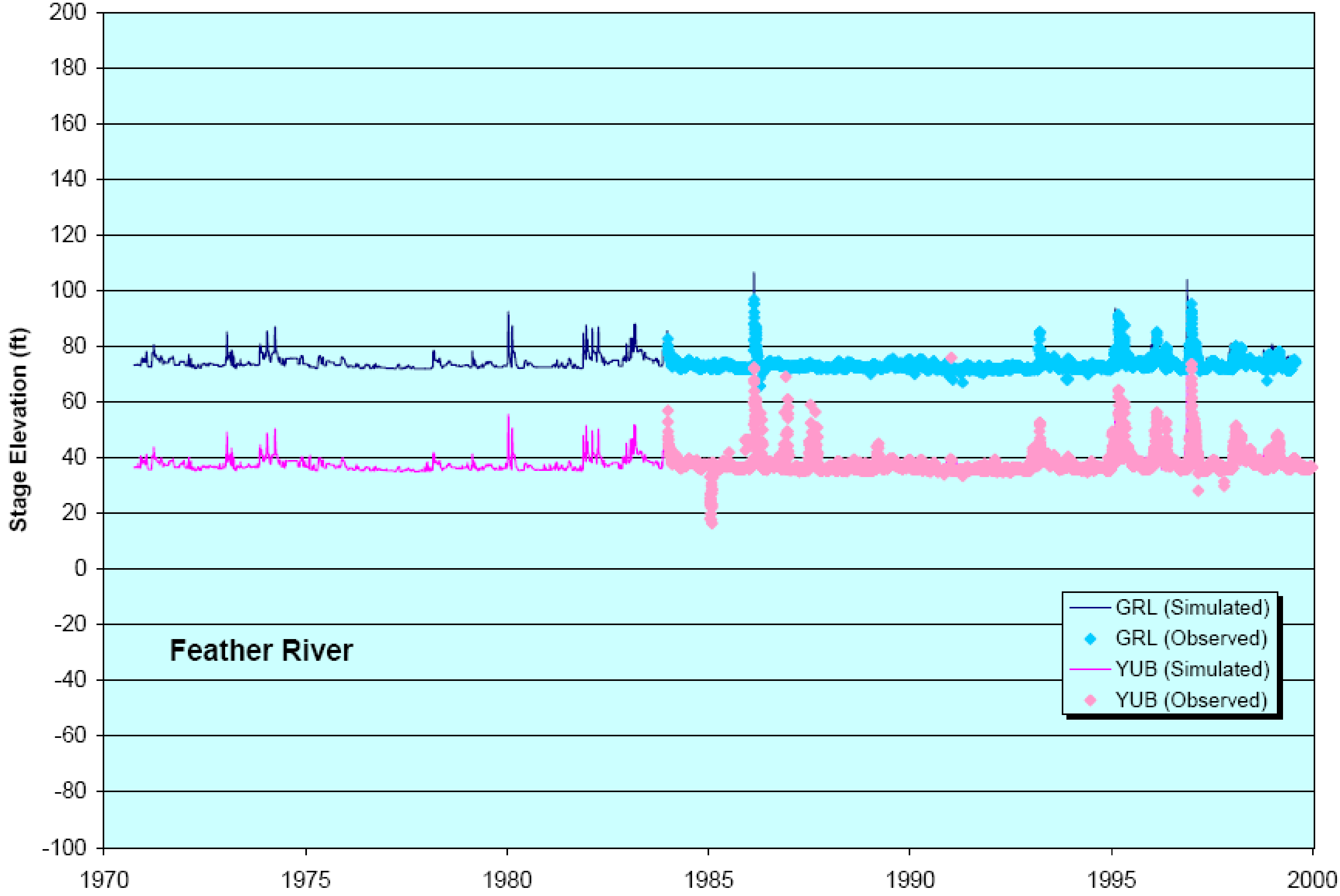

GRL – DWR Gage: Feather River near Gridley
YUB – DWR Gage: Feather River at Yuba City

Figure 4-39
Simulated vs. Observed Stream Stage
Feather River

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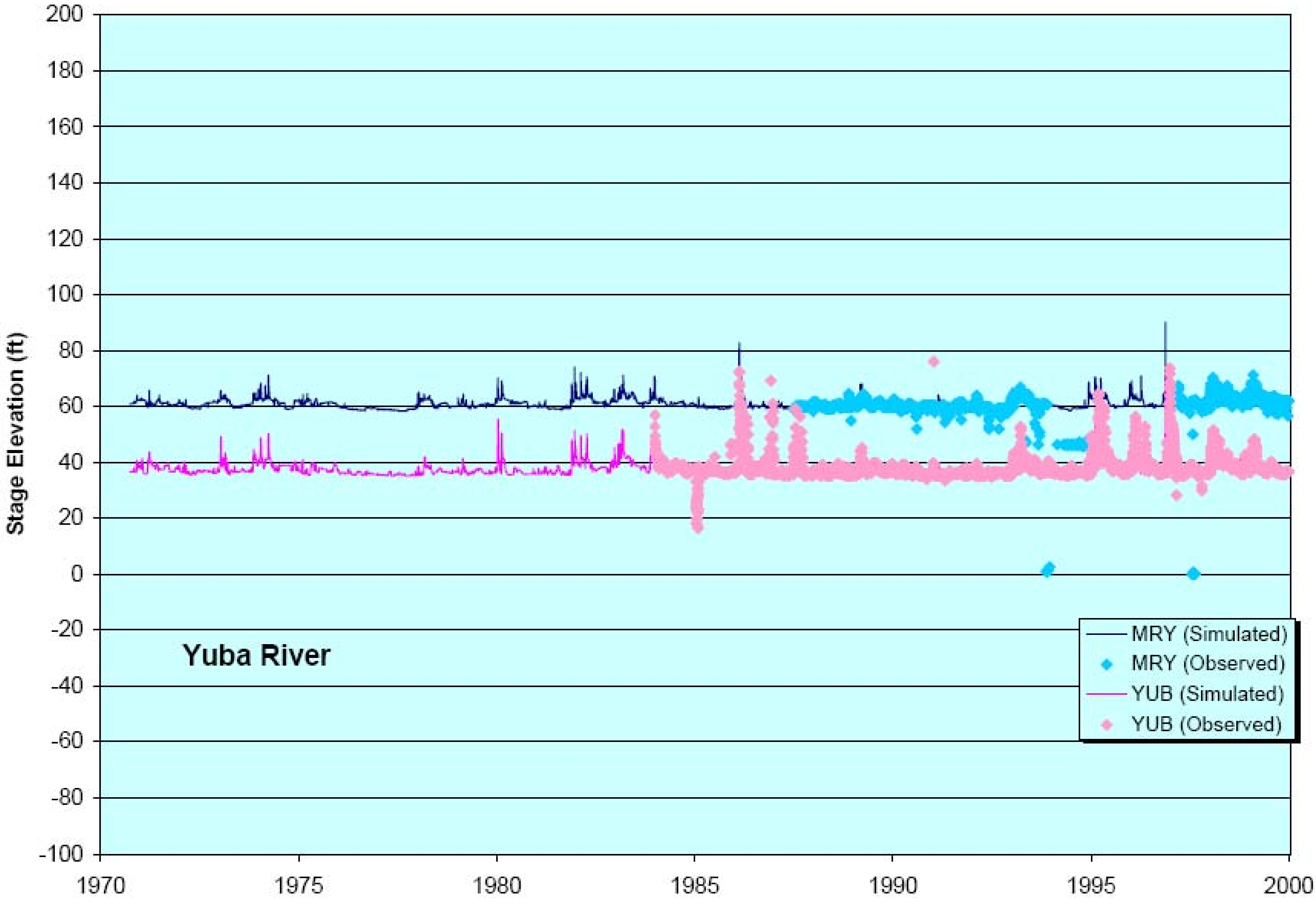

MRY – DWR Gage: Yuba River near Marysville
YUB – DWR Gage: Feather River at Yuba City (near Junction with Yuba River)

Figure 4-40
Simulated vs. Observed Stream Stage
Yuba River

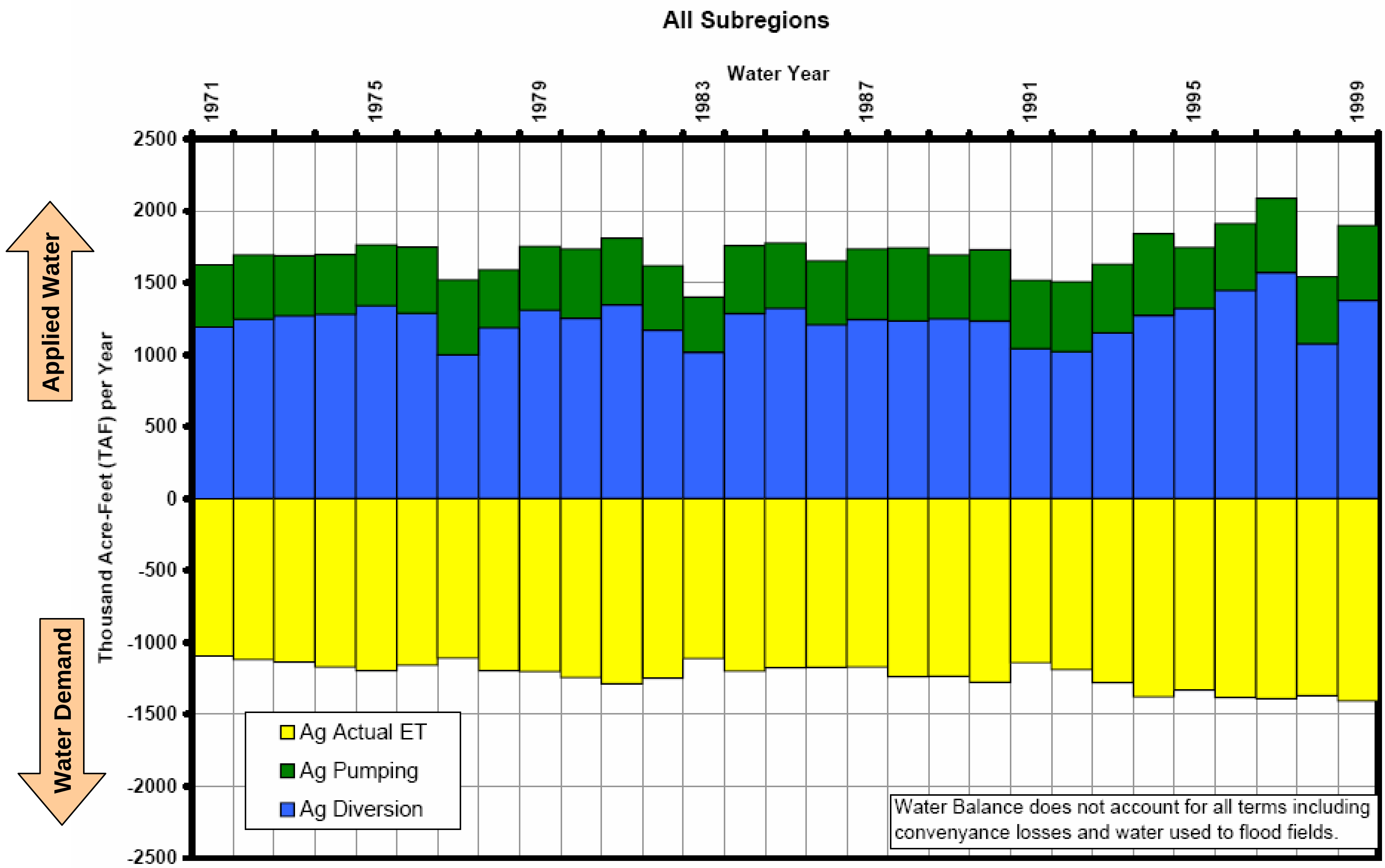

Figure 4-41
Annual Agricultural Applied Water Budget
Butte County Model

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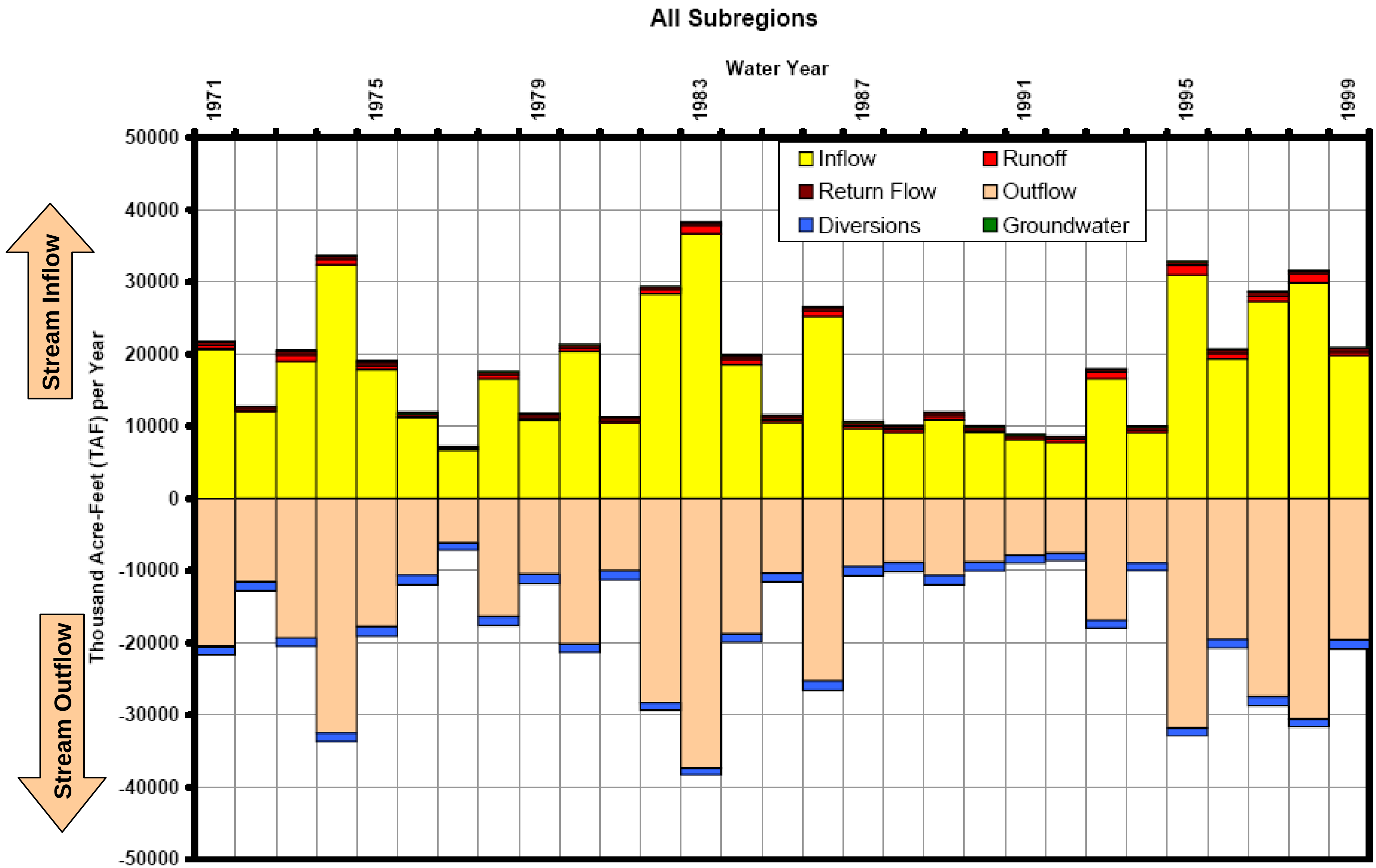

Surface water inflows (yellow bars) and outflows (salmon bars) represent surface water entering and leaving the model domain.

Figure 4-42
Annual Stream Inflow Budget
Butte County Model

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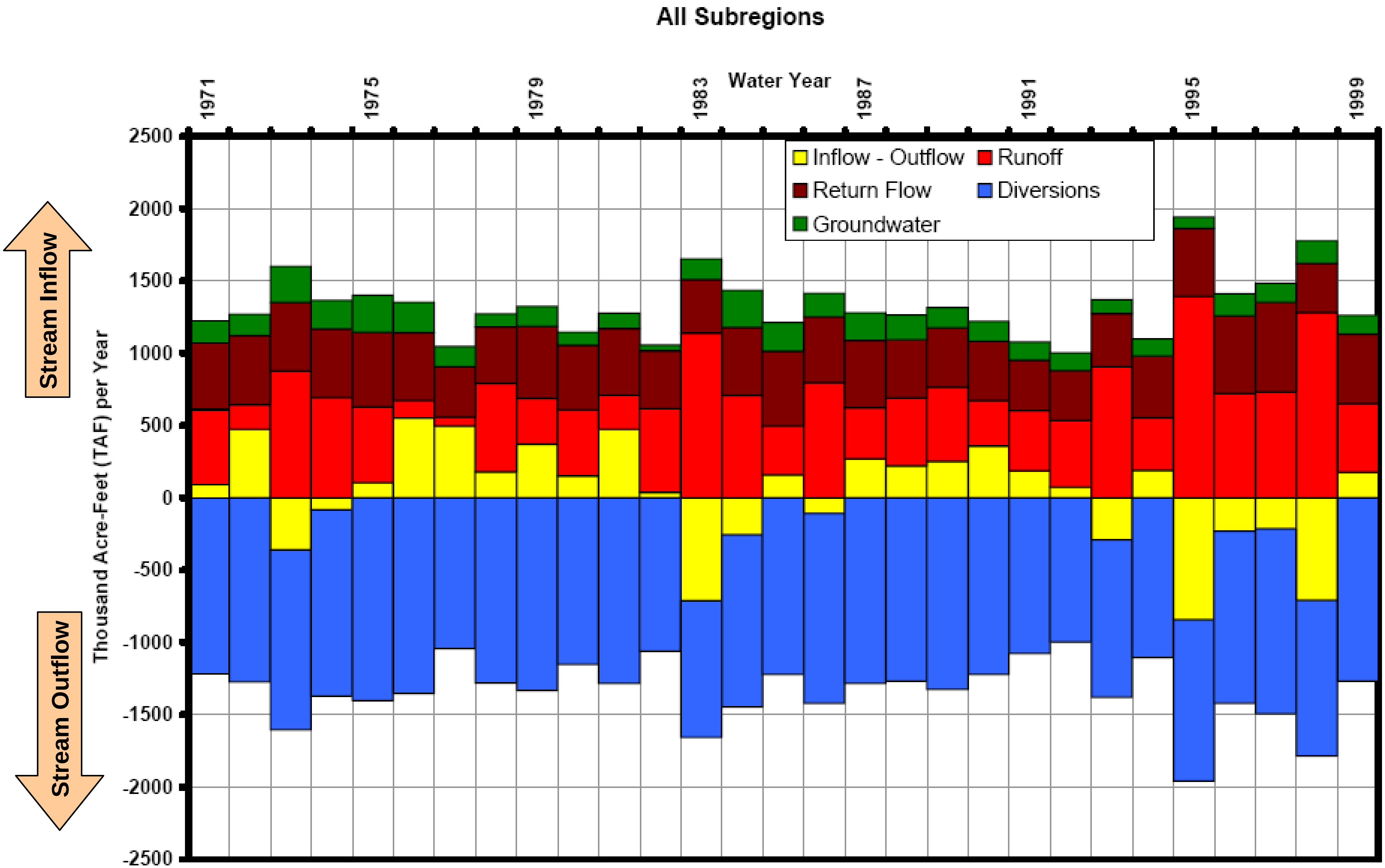

Figure 4-43
Annual Stream Flow Budget
Butte County Model

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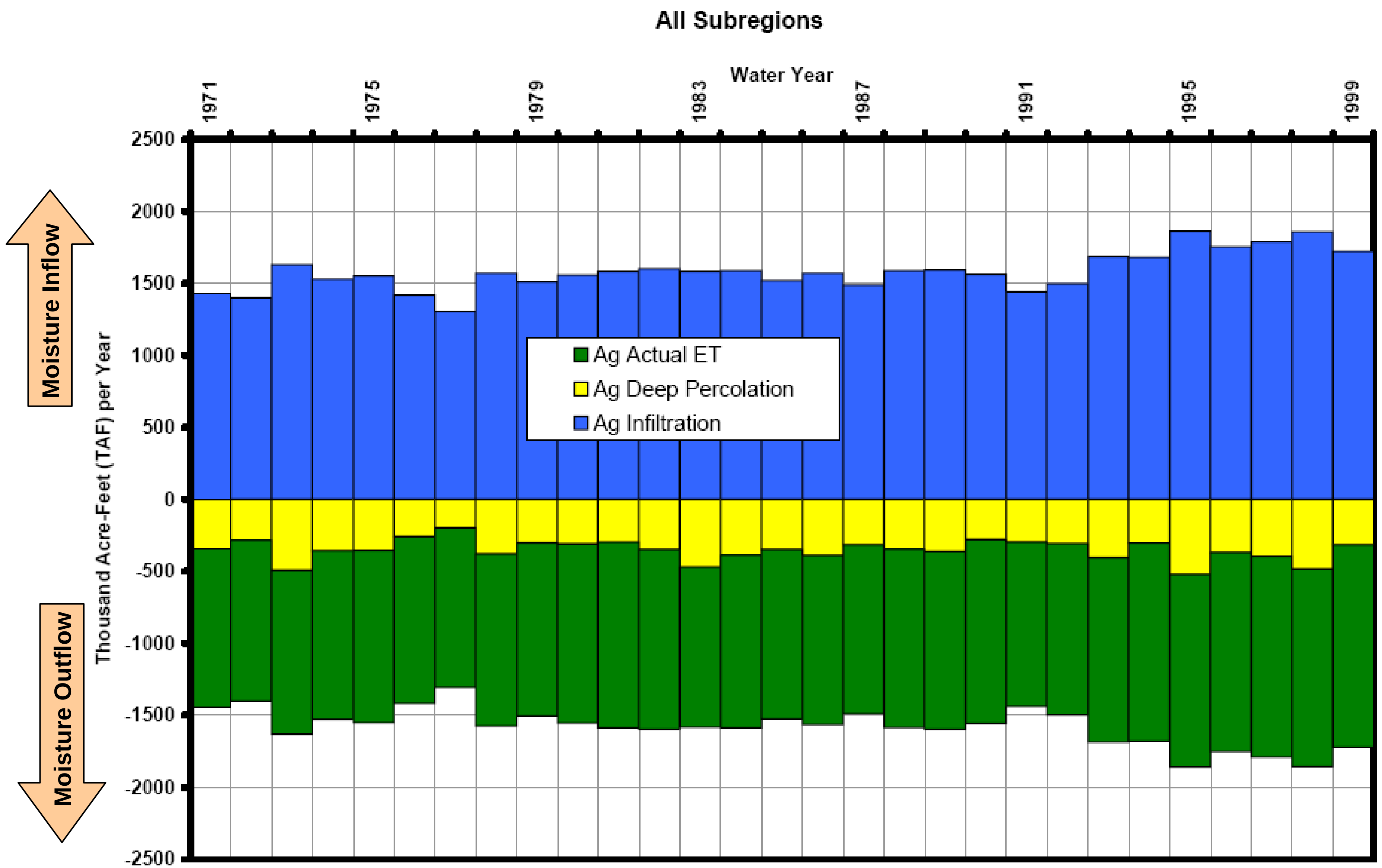

Figure 4-44
Annual Agricultural Root Zone Moisture Budget
Butte County Model

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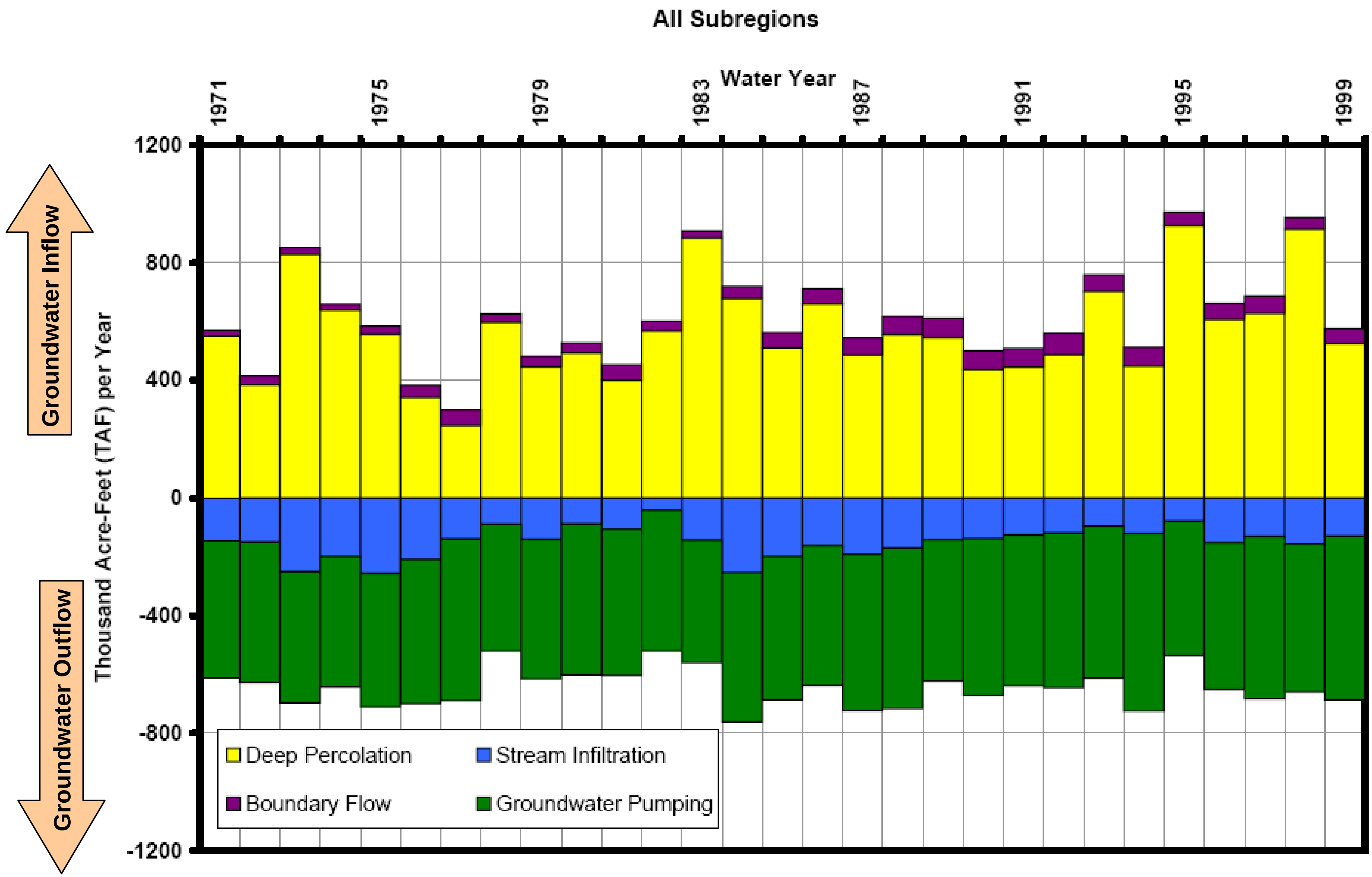

Figure 4-45
Annual Groundwater Budget
Butte County Model

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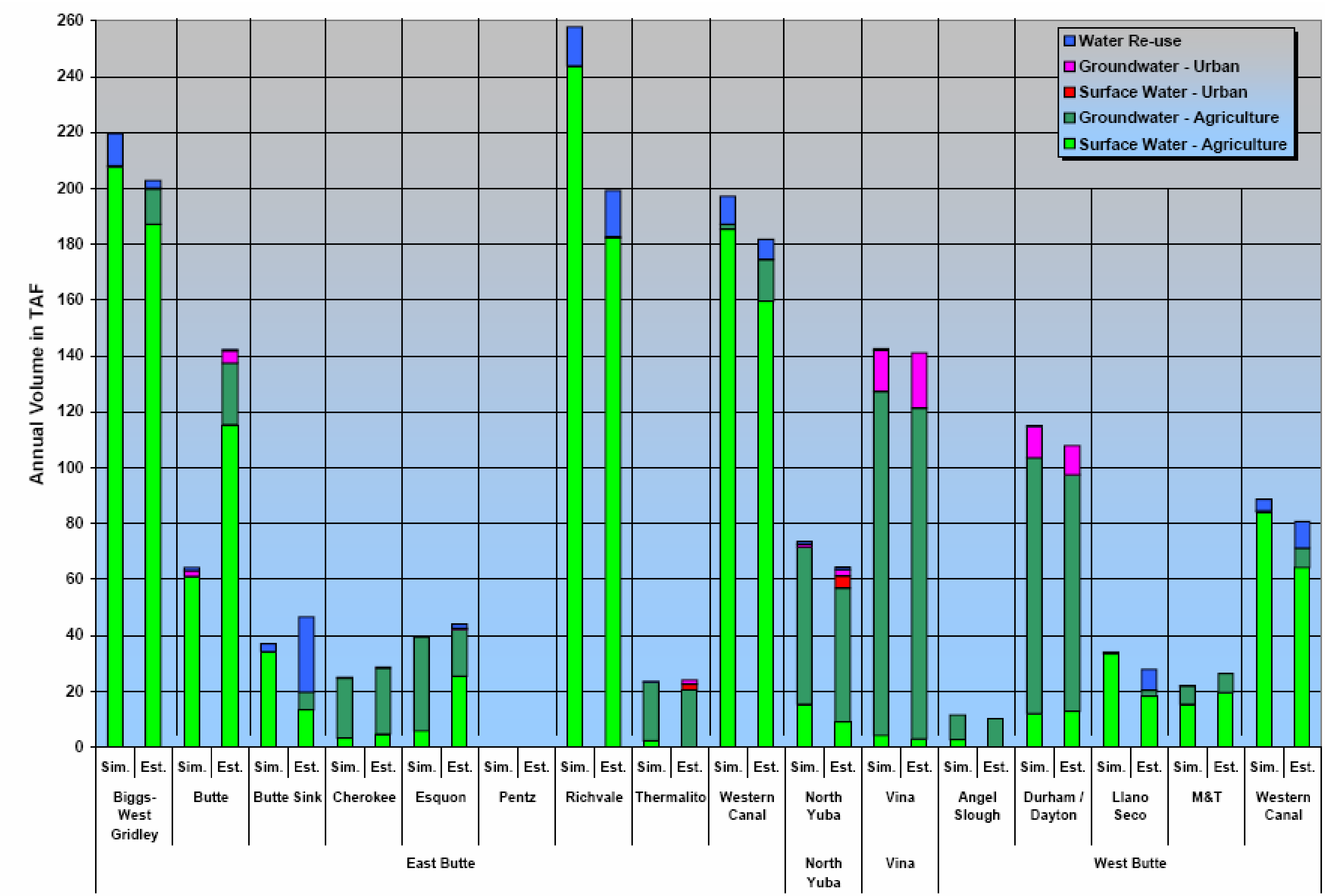

Sim. – Model Simulated Values for Water Year 1997
Est. – California DWR Estimated Budgets (CA DWR 2000b)

Figure 4-46
Comparison of Model Simulated and DWR Estimated Water Supplies by Inventory Unit

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