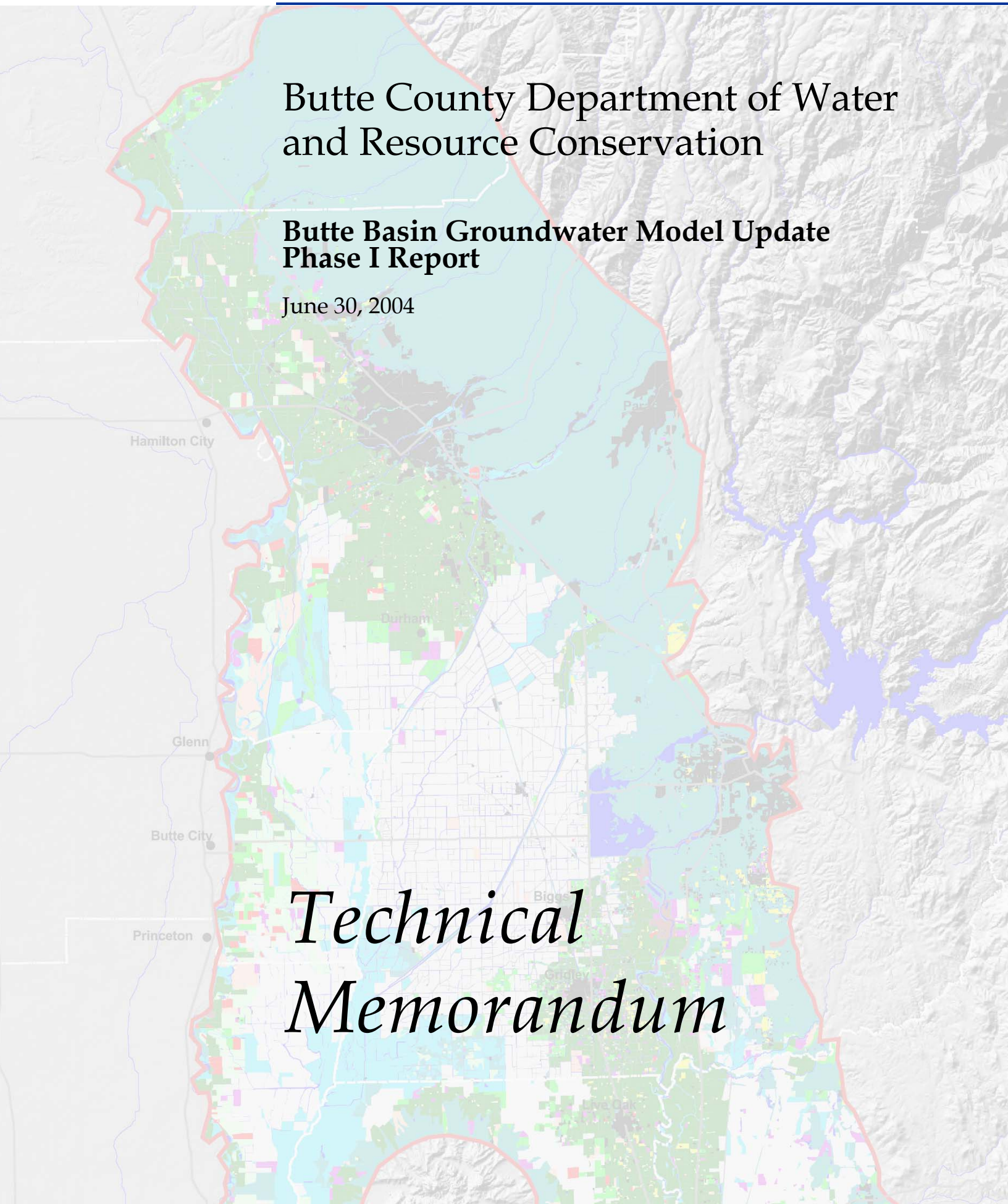
CDM

Butte County Department of Water and Resource Conservation

Butte Basin Groundwater Model Update Phase I Report

June 30, 2004



Technical Memorandum

Contents

Section 1 - Introduction

1.1 Project Purpose and Need 1-1
1.2 Proposed Groundwater Model Application 1-2

Section 2 – Assessment of Groundwater Modeling Codes

2.1 Introduction 2-1
2.2 Evaluation Criteria 2-1
2.3 Common Features of the Modeling Codes 2-2
2.4 Distinguishing Features of the Modeling Codes 2-2
2.5 FEMFLOW3D 2-3
2.5.1 Background 2-3
2.5.2 Differentiating Computational Features 2-3
2.5.3 Model Building, Interpretation and Presentation Features 2-4
2.5.4 Experience and Support 2-4
2.5.5 FEMFLOW3D Summary 2-4
2.6 IGSM2 2-5
2.6.1 Background 2-5
2.6.2 Differentiating Computational Features 2-5
2.6.3 Model Building, Interpretation and Presentation Features 2-6
2.6.4 Experience and Support 2-7
2.6.5 IGSM2 Summary 2-7
2.7 DYNFLOW 2-7
2.7.1 Background 2-7
2.7.2 Differentiating Computational Features 2-8
2.7.3 Model Building, Interpretation and Presentation Features 2-8
2.7.4 Experience and Support 2-9
2.7.5 Other Features and Considerations 2-9
2.7.6 DYNFLOW Summary 2-9
2.8 Summary and Conclusions 2-9

Section 3 – Recommended Features of the Updated Model

3.1 Introduction 3-1
3.2 Study Area and Model Domain 3-1
3.3 Conceptual Hydrogeology and Model Stratigraphy 3-2
3.3.1 Hydrogeology 3-2
3.3.2 Model Stratigraphy 3-4
3.4 Surface Water Hydrology 3-5
3.5 Model Boundary Conditions 3-8
3.6 Aquifer Hydraulic Properties 3-10

3.7 Land Use and Crop Patterns 3-11
3.8 Aquifer Recharge 3-12
3.9 Groundwater Pumping 3-14

Section 4 – Future Modeling Tasks
4.1 Phase II Scope of Work 4-1

Section 5 – References

Figures

3-1 Existing and Proposed Model Domains 3-20
3-2 Finite-Element Grid 3-21
3-3 Model Subregions 3-22
3-4 Location of Geologic Cross-Sections Used to Develop Model Stratigraphy 3-23
3-5 East-West Cross Section Through Northern Portion of Model 3-24
3-6 East-West Cross Section Through Central Portion of Model 3-25
3-7 East-West Cross Section Through Southern Portion of Model 3-26
3-8 North-South Cross Section Through Model 3-27
3-9 Major Streams, Water Supply and Drainage Features 3-28
3-10 Location of Model River Nodes 3-29
3-11 Location of Stage-Discharge Data Sites and USGS Gauging Stations 3-30
3-12 Land Use Map – Most Recent Land Use Survey (1995-1999) 3-31
3-13 Location of Rainfall Gauges used in Model and Areas of Model Assigned to Gages 3-32
3-14 Long-Term Average Rainfall 3-33
3-15 Rainfall Weighting Factors 3-34
3-16 Water Source Types 3-35
3-17 Distribution of Surficial Soil Types 3-36
3-18 Sample Evapotranspiration (ET) Rates 3-37
3-19 Location of Municipal Pumping Wells 3-38

Tables

Table 3-1 Proposed Model Layering 3-5
Table 3-2 Range of Hydraulic Conductivity Values 3-10
Table 3-3 Model Crop Codes 3-15
Table 3-4 Model Crop Acreages 3-19

Section 1
Introduction

1.1 Project Purpose and Need

The Butte County Department of Water and Resource Conservation (DW&RC) has initiated a program that will result in the integrated management of water resources to meet the current and future needs of agricultural, municipal and industrial users, and the environment in Butte County and recognizes regional water management needs. This program includes the development and implementation of integrated water resource management, including a countywide Water Inventory and Analysis, and an Integrated Water Resource Plan (IWRP).

As part of the IWRP, DW&RC contracted with CDM to complete a review and update of the Butte Basin Water Users Association (BBWUA) Groundwater Model. The groundwater model is a critical water resource management tool required for Butte County to complete local integrated water resource planning. Work on this project is to be completed in two phases. Phase I consists of the following components:

- Review of proposed use and application of updated model.
- Assessment of the existing model, including review of the underlying code.
- Recommendations for model modifications
- Complete recommended updates and modifications.

The results of the Phase I efforts are documented in this technical memorandum. In Phase II, the following tasks are to be completed:

- Model testing and calibration
- Sensitivity analysis
- Documentation of the calibrated model
- Model application, including the development of a base case for a proposed level of development in the County
- Documentation of the model application and base case

This project is supported with funding from the U.S. Bureau of Reclamation.

1.2 Proposed Groundwater Model Application

The BBWUA Groundwater Model 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 objectives of the modeling have not changed and are described in more detail below:

- Improve the understanding and characterization the hydrogeology and groundwater hydrology of the Butte Basin.
- Support the periodic update 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 graphic interfaces to inform and educate stakeholders about the hydrogeology and hydrology of the basin.

The updated Butte Basin Groundwater Model will provide DW&RC, BBWUA, and other stakeholders with a powerful resource management tool. However, it is important to also emphasize that regional groundwater models, such as the Butte Basin Groundwater Model are not capable of:

- Evaluate potential yield or impacts of the operation of individual wells or recharge facilities, and
- Finally, no groundwater model – no matter how detailed can be used as a replacement for field measurement, or groundwater level and quality monitoring.

Section 2
Assessment of Groundwater Modeling Codes

2.1 Introduction

The existing BBWUA Groundwater Model was developed using the FEMFLOW3D code. The capabilities of the FEMFLOW3D code were reviewed by CDM to assess its suitability for application to the updated Butte Model. Two other groundwater-surface water modeling codes were also reviewed and evaluated for this purpose: IGSM2 and DYNFLOW.

Other integrated groundwater-surface water codes are noted in modeling literature which may also have the capabilities required of the Butte Model update. However, the three codes selected for review, in addition to having most or all of the basic capabilities required, are well known either by Butte County, the California Department of Water Resources (DWR) or the CDM model development team and have been applied to similar model studies in the region.

2.2 Evaluation Criteria

The following criteria for evaluating modeling codes were listed in the Statement of Work (SOW) for this project.

- Technical acceptability of the modeling code, in particular the ability to simulate groundwater-surface water interaction, and handle surface water diversions, irrigation, and utilize crop patterns to determine agricultural pumping.
- Availability of adequate documentation, testing and technical support of the modeling code.
- Compatibility of data sets and modeling approach with other local and regional models, including watershed modeling anticipated by California Hydrologic Research Laboratory in Davis, California.
- Availability of appropriate graphical and geographic interfaces for both pre- and post-processing of input data and modeling results
- Cost, and access to future upgrades

Features of FEMFLOW3D, IGSM2 and DYNFLOW relevant to these criteria and common to all three codes, are summarized below followed by a summary of the distinguishing features each code.

2.3 Common Features of FEMFLOW3D, IGSM2 and DYNFLOW

All three of the codes reviewed have capabilities and features which make them potential candidates for development of the updated model:

- They have been successfully applied to similar studies in the Central Valley[1].
- They perform 3-dimensional (or quasi-3-dimensional) groundwater flow computations for multi-layered aquifers solving the same fundamental governing equation based on Darcy's Law and Conservation of Mass.
- They all feature the flexible and powerful finite element method for discretizing models and approximating the solution of the groundwater flow governing equation.
- All can account for surface water flow (including diversions) and stage in the basin simultaneously with groundwater flow, and simulate the interaction between surface water and groundwater.
- All have capabilities for computing the temporal and spatial distribution of groundwater recharge based on input specifications of landuse/cropping, agricultural practice, soil type, climate/season, irrigation and precipitation.
- All provide boundary conditions suitable for representing well pumping, spreading recharge and re-injection, and subsurface flows to or from adjacent basins.
- All three codes are well documented, including code-validation test results.
- All three codes are available without charge to the modeling team, Butte County and DWR reviewers.

2.4 Distinguishing Features of the Modeling Codes

As noted above, all three codes reviewed are considered to have adequate documentation, testing, and technical support. All three codes have been, or are currently being, applied to similar studies in the region[1], and no difficulty is anticipated related to cost or access to future upgrades. The evaluation therefore focuses on:

- Unique computational features of each code which could affect the technical ability of each code to perform the basic simulation functions listed in the first item of the SOW code criteria

[1] Groundwater water studies in the area have used previous versions of IGSM2 (specifically, IGSM v5.0). IGSM2 is being applied to the currently on-going revision of the Central Valley Groundwater-Surface Water Model (CVGSM).

- User features, including graphical/geographical interfaces as noted in the fourth item of the SOW criteria, which affect user efficiency and the ability to interpret and communicate simulation results, and

- Level of experience/familiarity of the modeling team, which can also affect the efficiency of the work. Familiarity of Butte County and DWR staff with the code is also considered.

Evaluations of FEMFLOW3D, IGSM2 and DYNFLOW are summarized below, along with a very brief introduction to the background and key features of each code. The summaries focus on features which are particular or unique to each code which may have a significant impact on the efficiency or quality of the model development.

2.5 FEMFLOW3D

2.5.1 Background

FEMFLOW3D was developed by the USGS to simulate regional groundwater systems. It is a relatively new code, published in 1998. The existing Butte Model was constructed using FEMFLOW3D. The FEMFLOW3D users manual (USGS, 1998) was the source of information for this review.

2.5.2 Differentiating Computational Features

- Agricultural pumping computation – No capability for computing agricultural groundwater pumping requirements. FEMFLOW3D therefore appears to be lacking one of the capabilities specifically identified in the SOW. This computation would have to be done externally using other tools, then translated to FEMFLOW3D input files defining the temporal and spatial distribution of groundwater pumping and irrigation.

- Fixed grid – The top of the computational grid does not move as the water table moves. FEMFLOW3D thus "disregards the effects of a change of (saturated) aquifer thickness on ground-water flow." The code therefore is "particularly applicable to ground-water systems for which the change in aquifer thickness is small relative to the overall aquifer thickness."(USGS, 1998) This may largely be the case for the Butte model. However, this feature would (at least) place restriction on the subdivision of the aquifer into model layers. It is not clear how the code reacts if a model layer is dry at some locations or periods of time.

- Unsaturated zone simulation – A specified portion of deep percolation from the root zone is assigned directly as saturated groundwater recharge. Unsaturated zone flow is not explicitly simulated. IGSM2 and DYNFLOW include capabilities for simulating unsaturated zone flow of percolating water from the root zone to the saturated groundwater, which typically results in some lag and damping of recharge fluctuations.

- Effective precipitation – A relationship between total monthly rainfall and effective precipitation (precipitation minus runoff and abstractions) is fixed in the code,

independent of soil type, land use and antecedent conditions (soil moisture). Computations of initial abstractions, runoff and infiltration in IGSM2 and DYNFLOW do account for soil type, land use and antecedent conditions. Also, it does not appear that FEMFLOW3D assigns estimated runoff from the land surface to flow in streams.

2.5.3 Model Building, Interpretation and Presentation Features

- Organization of nodes – Unlike most groundwater codes, FEMFLOW3D nodes are not organized or addressed by layer or level. CDM's experience with codes of this type indicates that visualization and modification of model inputs, as well as interpretation and diagnosis of model results, is significantly hampered.

- Data input structure – Numerous input data files are required which must be rigidly formatted with data supplied in a particular order in specified column positions. Each file has a unique layout and formatting. Time varying input data (e.g. stream inflows, boundary heads) must be supplied at prescribed time intervals which may not conform well to available records. These rigid requirements add to the burden of model building, modification, and application.

- Model building tools - There is no reference in the manual to any computational programs or tools, visual or otherwise, designed to expedite the building/modification of model input data files. With some effort it might be possible for the modeling team to create programs to transfer data between FEMFLOW3D and ArcView, GMS (a graphical groundwater model interface used with other modeling codes) and/or DYNPLOT (graphical user interface used with DYNFLOW).

- Visualization – None available at this time. Again, programs or procedures would have to be created to transfer data from FEMFLOW3D to ArcView, GMS, DYNPLOT or other visualization program.

2.5.4 Experience/Support

The CDM modeling team has no experience developing or running models using FEMFLOW3D. Availability of technical support is uncertain.

2.5.5 FEMFLOW3D Summary

FEMFLOW3D is not recommended for this project. It is lacking a key computational capability, i.e. computation of agricultural pumping needs, and is limited in some other computational aspects. Further, it will likely be relatively inefficient to use due to its grid structure, rigid data formatting requirements, lack of readily available model building/visualization interface, and lack of modeling team experience with this code. Though the existing Butte Model was developed using FEMFLOW3D, sufficient changes in model structure and hydrologic conditions simulated are anticipated such that a significant portion of the model data will need to be recreated no matter which code is used.

2.6 IGSM2

2.6.1 Background

The original basis for IGSM2 is a finite element groundwater flow code, FEGW2, developed in the 1970s at UCLA. Surface water and land surface processes were incorporated beginning in the late 1980s, and various enhancements and upgrades have been made during the 1990s. The current version of IGSM2 was released by the DWR in 2003.

IGSM (including IGSM2 and predecessor versions) has been applied in a number of groundwater/surface water model studies in central and southern California. Of particular significance to this study, IGSM was used for a regional model of the Central Valley (CVGSM) and the Stony Creek Fan Model which focuses on the basin immediately adjacent to Butte County.

Further information regarding IGSM2 can be accessed online at: http://modeling.water.ca.gov/hydro/model/indexigsm2.html.

Review of the IGSM2 Users Manual and Theoretical Documentation, plus attendance by CDM staff at an IGSM training course conducted by DWR, formed the basis for this assessment.

2.6.2 Differentiating Computational Features

- Overall – IGSM2 appears to include all of the fundamental soil, groundwater and surface water computational capabilities required for the Butte Model.

- Quasi 3D – Groundwater flow computations in IGSM2 are quasi-3dimensional, whereas FEMFLOW3D and DYNFLOW are fully 3-dimensional codes. As such, IGSM2 does not compute vertical flow within a model layer. Other simplifications, typical of quasi-3-dimensional codes, are that the vertical gradient/conductance from the water table layer to the layer below appears not to be adjusted for water table movement, and the water table elevation is approximated to be equal to the head at the midpoint of the water table layer. (IGSM2 does adjust transmissivity based on water table movement, which FEMFLOW3D does not.) These computational simplifications are not expected to have an adverse impact on the Butte model for the water management applications anticipated. However, the quasi-3D model structure could become a disadvantage if detailed local solute transport simulations or other local simulations requiring a detailed representation of vertical flow or water table response are anticipated in the future.

- Time step – The computational time step was fixed to 1 day in the previous version of IGSM2 (1.01). This is appropriate for the land surface computations which are based on the SCS curve number method. However, a 1 day time step is likely to be unnecessarily short for the groundwater flow computations, resulting in unnecessarily long simulation run times and large output files. The latest version of IGSM2(version 2.0) is not restricted to 1 day time steps, but there is still likely to

be a discrepancy between an appropriate time step length for soil computations and an appropriate time step length for groundwater computations. Ideally, different time step lengths would be applied to soil computations and saturated groundwater computations.

- Steady state simulations – There appears to be no easy way to do steady state simulations. While steady state simulations are not required to meet the objectives of the model development and application, they frequently provide a quick, convenient means of assessing the effect on simulation results of modifications to aquifer stresses, hydraulic properties or stratigraphy. This is a valuable capability for a groundwater modeling code.

- Evaporation – IGSM2 does not appear to simulate evapotranspiration directly from the water table (which is different from ET from the soil surface and root zone). Based on current knowledge, this is not an important process in Butte County.

IGSM can adjust either groundwater pumping, river diversions, or both to meet agricultural or urban water demand.

2.6.3 Model Building, Interpretation and Presentation Features

- Water budget output – IGSM includes a processor for quickly creating detailed water budget tables which effectively summarize the results of a simulation. Separate tables can be created for different hydrologic processes and different sub-regions of the model. Stream flow and groundwater level hydrographs can also be quickly created.

- Data exchange – Since the regional Central Valley model and the adjacent Stony Creek Fan model were developed with IGSM, it should be relatively simple to apply data and simulation results compiled for these models to an IGSM2-based Butte Model.

- Data input structure – Similar to FEMFLOW3D, numerous input data files are required which must be rigidly formatted with data supplied in a particular order in specified column positions. Each file has a unique layout and formatting. This can make the processing and debugging of input data cumbersome for the user.

- Time varying input data - Unlike FEMFLOW3D, time varying input data (e.g. stream inflows, boundary heads) need not be supplied at prescribed time intervals. This allows the input files to better conform to available records.

- Graphical interface – A graphical user interface is currently being developed for IGSM2. However, no comprehensive way of graphically displaying model inputs and results is currently available. In the meantime, informal linkages with other modeling interfaces such as DYNPLOT and GMS will have to be developed during the project. Similarly, linkages with ArcView GIS will need to be developed.

2.6.4 Experience/Support

CDM modeling team members recently attended an IGSM2 training workshop conducted by DWR. Additionally, the CDM modeling team has hands-on experience working with IGSM input datasets on previous projects (Pomona, San Joaquin County) where data from an existing IGSM model were converted for use in a new model. DWR obviously has extensive experience with IGSM.

Code support is available from DWR.

2.6.5 IGSM2 Summary

IGSM2 is generally well suited to the needs of this project. It has the required technical/computational capabilities. The CDM modeling team has reasonable familiarity with this code, and DWR is very familiar with it and can provide code support. The complexity of the data input structure can be overcome with a careful modeling approach and use of other database, spreadsheet and graphical tools. The lack of a graphical interface is still a deficiency.

2.7 DYNFLOW

2.7.1 Background

DYNFLOW was developed by CDM in 1982. It was based on a predecessor code, AQUIFEM, which was originally developed at MIT in the 1970s. DYNFLOW has been continually upgraded with new capabilities and streamlined data processing from 1982 to the present, and continues to be enhanced as new features are needed.

Such enhancements have included development of companion codes for simulating solute transport, sea water intrusion, two-phase (NAPL-groundwater) flow and development of a comprehensive graphical user interface which provides extensive model building capabilities and visualization of field data, model input data and simulation results. Integration of stream flow, land surface (agricultural practice) and unsaturated zone processes with the groundwater model was added in the late 1990s. Other recent enhancements have included streamlined processing of transient input and output data and extensive linkages with GIS and graphical programs such as ArcView, GMS, EVS and AutoCad.

DYNFLOW has been applied to over 150 modeling studies in the United States and abroad, including numerous projects in central and southern California. It was recently used in a San Joaquin County water management study to develop an integrated groundwater, surface water and agricultural/land use model similar to the Butte Model.

The DYNFLOW code has been reviewed and tested by the International Groundwater Modeling Center (IGWMC) (van der Heijde 1985, 1999). The code has been extensively tested and documented by CDM.

An introduction to DYNFLOW and example applications can be found at: http://www.dynsystem.com.

2.7.2 Differentiating Computational Features

- Overall – DYNFLOW includes all of the fundamental soil, groundwater and surface water computational capabilities required for the Butte Model. Aspects of runoff, infiltration, ET, unsaturated zone flow and river diversion processing in DYNFLOW were adapted from earlier versions of IGSM, and are therefore functionally similar in many ways to IGSM2.

- Fully 3-D - DYNFLOW is fully 3-dimensional, and (unlike FEMFLOW3D) automatically makes vertical grid adjustments which account for changes in transmissivity due to changes in water table elevation.

- Time step – Runoff, ET, infiltration and unsaturated zone computations are done with a fixed time step of 1 day. Simulation of saturated groundwater flow, which is computationally intensive, may be run with a longer time step to save computational time. The difference in time steps is handled automatically in the code.

- Steady state simulations – Steady state simulations may be easily run with DYNFLOW to provide a quick, convenient means of assessing the effect of changing aquifer stresses, hydraulic properties or stratigraphy.

- Land use distribution – A single representative set of land use characteristics is assigned to each DYNFLOW element. IGSM allows for a distribution of different land use types to be assigned to each element. Either approach is acceptable. A somewhat greater number of computational elements may to be required to adequately represent land use distributions using DYNFLOW.

- Backwater computations – DYNFLOW computes river stage by performing backwater computations based on the Manning equation and stream channel properties input to the model. This differs from IGSM2 which computes river stage based on user supplied rating tables at each river node. Each method has potential advantages in different conditions. Either method is probably acceptable for the Butte model.

- Agricultural water demand – DYNFLOW computes unmet agricultural water demand for each element based on soil moisture conditions. Additional groundwater pumping to meet this demand (supplementing irrigation application specified from other sources) may be automatically assigned for each element requiring it. DYNFLOW does not currently adjust river diversions automatically to meet agricultural demands.

- Urban water demand – DYNFLOW does not currently compute urban water demand or automatically assign pumping or diversions to meet such a demand.

2.7.3 Model Building, Interpretation and Presentation Features

- Graphical user interface – A comprehensive graphical user interface, DYNPLOT, has been created for DYNFLOW (and other DYN programs) which provides

extensive model building capabilities and visualization of field data, areal mapping, model input data, and simulation results.

- Linkages with GIS/graphics programs - Linkages with GIS and graphical programs such as ArcView, GMS, EVS and AutoCad have been developed for import/export of data to/from DYNFLOW and DYNPLOT. This is a significant asset for processing geologic, hydrologic, land use, agricultural and soil data which must be input to the model, and for creating enhanced displays of model results including 3-D projection and animation. Additionally, procedures and modules have been created for data transfer between DYNFLOW and other modeling codes, including IGSM.

- Data input structure – A free-format, command based structure makes the DYNFLOW model input specifications relatively easy to interpret, check and modify. The command structure also allows for interactive queries of specific details of model input or simulation results which greatly assists the refinement and trouble shooting of models.

Transient data (e.g., well pumping rates or river upstream inflow) can be input directly from available records, independent of model time step or the frequency of other data records.

2.7.4 Experience/Support

CDM modeling team members have extensive experience applying DYNFLOW, and also interpreting, maintaining, and updating the source code.

2.7.5 Other Features/Considerations

DYNTRACK, a particle tracking and solute transport model, links directly with DYNFLOW models and simulation results.

2.7.6 DYNFLOW Summary

DYNFLOW is also well suited to the needs of this project. It has the required technical/computational capabilities. It has superior user features, and the CDM modeling team is very experienced with this code.

2.8 Summary and Conclusions

Three integrated groundwater-surface water modeling codes were evaluated for application to the updated Butte Model: FEMFLOW3D, IGSM2, and DYNFLOW. The existing Butte Model was developed using FEMFLOW3D. IGSM2 and DYNFLOW were also selected for evaluation because they have the fundamental technical capabilities required, the CDM modeling team has experience with these codes, and they have been successfully applied to similar studies in the Central Valley.

Based on this evaluation, FEMFLOW3D is not recommended for this project. Compared with the other 2 codes it is limited in some computational aspects. It will also be relatively inefficient to use due to its data structure, lack of readily available

model building/visualization interface and lack of CDM modeling experience/training with this code.

IGSM2 and DYNFLOW are both suitable for this project. IGSM2 was particularly designed for this kind of regional water management study in California. It provides a water budget processing facility that will be very useful. DWR developed the latest version of this code and is, therefore, very familiar with IGSM2. IGSM2 has been used in studies of nearby areas[2]. DYNFLOW has also been extensively used in California, mostly in southern California and Bay area studies, and also in a similar study for San Joaquin County. DYNFLOW has superior user features, including a graphical user interface with extensive model building and visualization capabilities, which can significantly expedite the work.

CDM's approach to this project will be to take advantage of the strengths of both IGSM2 and DYNFLOW. The revised Butte Model will be an IGSM2-based model for consistency with neighboring models and because of the familiarity and acceptance of IGSM2 by DWR. However, linkages to DYNFLOW/DYNPLOT will be maintained to take advantage of the model building, interpretation and visualization capabilities provided by DYNFLOW/DYNPLOT.

[2] Groundwater water studies in the area have used previous versions of IGSM2 (specifically, IGSM v5.0). IGSM2 is being applied to the currently on-going revision of the Central Valley Groundwater-Surface Water Model (CVGSM).

Section 3
Recommended Features of the Updated Model

3.1 Introduction

Based on the recommendations detailed in Section 2, CDM will rebuild the BBWUA Groundwater Model using IGSM2. In addition to the modifications required by the change of modeling code from FEMFLOW3D to IGSM2, CDM recommends that a number of other conceptual and numerical model modifications be implemented in the revised model. Recommended features of the revised model are outlined in the following sections based on review by CDM of the BBWUA overall conceptual and numerical model.

3.2 Study Area and Model Domain

Butte County covers approximately 1,670 square miles, or 1.07 million acres and is located in the northern portion of the Central Valley, east of the Sacramento River. The County borders 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.

Figure 3-1 illustrates the domain of the existing BBWUA model, which covers approximately 950 square miles focused mainly on the portion of Butte County that is within the Sacramento Valley Basin. The BBWUA model also extends somewhat north into Tehama County, west into Colusa and Glenn Counties, and south into Yuba and Sutter counties. CDM recommends that the general model domain remains unchanged, with the exception of minor modifications in the north and northwest boundaries of the model. In this area, CDM recommends that the domain be extended to incorporate the estimated Tuscan Formation recharge areas (Reference, DWR GIS/Maps) in the foothills as shown in Figure 3-1. In the north, it is recommended that the model be extended to Deer Creek. The recommended model domain, also shown in Figure 3-1, encompasses 1,265 square miles.

The proposed finite element grid is shown in Figure 3-2. The proposed node spacing is approximately 5,000 feet over much of the model, compared with a typical node spacing of approximately 8,000 feet in the BBWUA model. Finer node spacing, approximately 2,500 feet, is proposed in the Chico vicinity and other areas where greater hydraulic gradients are expected in the groundwater flow field.

The revised model domain will be divided into sub-areas for water balance accounting. The model sub-areas will coincide with Butte County inventory sub-units. Proposed model sub-areas are shown in Figure 3-3.

3.3 Conceptual Hydrogeology and Model Stratigraphy

3.3.1 Hydrogeology

The groundwater conditions within Butte County have been comprehensively documented by DWR Northern District. The following data and descriptions are excerpted from the "Butte County Groundwater Inventory Analysis" (DWR, 2000) and the "Butte County Groundwater Inventory and Analysis" (CDM, 2001).

The major groundwater bearing aquifers in Butte County lie within the larger Sacramento Valley groundwater basin. The Sacramento Valley groundwater basin extends north to south from Red Bluff to the Sacramento-San Joaquin Delta, and is bordered by the Coast Ranges to the west and the Cascade Range and Sierra Nevada Mountains to the east. It covers an area of 4,900 square miles which includes all of Sutter county and part of Butte, Glenn, Tehama, Colusa, Yuba, Yolo, Solano, Placer and Sacramento counties.

The Sacramento Valley is a structural basin filled with up to five miles of sediment. Of these deposits, older sediments in the basin were emplaced in a marine environment and usually contain saline or brackish groundwater. Younger sediments were deposited under continental conditions and generally contain fresh groundwater. Sediments thin near the margins of the basin exposing the older metamorphic and granitic rocks underlying and bounding the Sacramento Valley sediments.

Principal hydrogeologic units of the Sacramento Valley groundwater basin 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% 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.

Tuscan Formation

The Tuscan Formation 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 is about 250 feet thick. Units B and C are about 600 feet thick each and overly Unit A in most locations in Butte County. Unit D is the youngest unit and is not exposed in Butte County. The total thickness of the Tuscan Formation is approximately 1,450 feet 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.

Much of the groundwater in the Tuscan Formation is confined under pressure by layers of impermeable clays, lahars or tuff breccia. The permeable layers of the Unit B

sediments compose the main aquifer material for groundwater storage in the valley. The fine-grained, consolidated lahars of Unit C form thick, low permeability confining layers for groundwater contained in the more permeable sediments of Unit B.

Pump test results revealed average well yield from a low of 976 gallons per minute (gpm) to a high of 1,395 gpm. Specific capacities for the valley inventory units ranged from 48 gpm per foot to 87 gpm per foot. Transmissivity values within the Butte Basin portion of the East and West Butte Inventory Units ranged from 97,000 to 182,000 gallons per day (gpd) per foot. Storativity values ranged from .0003 to .0015. Specific capacity measurements made for wells reported in a previous study provided a range of 45.7 to 104.7 gpm per foot of drawdown (DWR Memorandum Report, 1991).

Laguna Formation

Exposure of the Laguna Formation is discontinuous and extends from Oroville southward to Lodi. The thickness of the Laguna Formation is difficult to determine because the base of the unit is rarely exposed. Estimates of the maximum thickness range from 180 feet (Helley and Harwood, 1985) to 1,000 feet (Olmsted and Davis, 1961).

Quantitative water-bearing data for the Laguna is very limited, especially in the Butte County area. Wells completed in the finer-grained sediments of the Laguna Formation yield only moderate quantities of water. Well yield data from the Sacramento-American River area indicate yields as high as 1,000 gpm, with specific capacities values ranging between 24 and 42 gpm per foot of drawdown (Olmsted and Davis, 1961). In areas where soft, well-sorted granitic sand dominates, well yields are much higher. Some of the sand aquifers are highly permeable, but the average permeability is low to moderate. In the Gridley area, a sand unit that is stratigraphically equivalent to the Laguna Formation was reported to have a specific capacity of 60 gpm per foot of drawdown (Olmsted and Davis, 1961).

Riverbank Formation

The Riverbank Formation consists of gravel, sand, and silt eroded from the surrounding Coastal, Klamath, Cascade and Sierra Nevada Mountain Ranges and deposited in the Sacramento Valley. Exposures of the Riverbank Formation within Butte County are observed primarily west of Oroville and southward. Thickness of the Riverbank Formation ranges from less than one foot to over 200 feet depending on location.

The thickness of the Riverbank Formation can be a limiting factor to the water-bearing capabilities of the formation. The Riverbank Formation is moderately to highly permeable and yields moderate quantities of water to domestic and shallow irrigation wells. It also provides water to deeper irrigation wells that have multiple zones of perforation. Well yields are higher in areas where concentrations of gravel and sand are present. Groundwater occurs generally under unconfined conditions.

Modesto Formation

The Modesto Formation consists of gravel, sand, and silt. The most notable occurrences are found along the Sacramento and Feather Rivers. Similar to the Riverbank, the Modesto Formation ranges in thickness from less than ten feet in many of the terraces and along the margins of the valley to nearly two hundred feet across the valley floor (Helley and Harwood, 1985).

Like the Riverbank Formation, the thickness of the Modesto Formation limits the water-bearing capabilities of the formation. These deposits provide water to domestic and shallow irrigation wells as well as to deeper wells with multiple zones of perforations. In locations where gravel and sand predominate, groundwater yields are moderate. Lesser yields are found in areas with high silt and clay content. Groundwater occurs generally under unconfined conditions.

Tehama Formation

The Tehama Formation consists primarily of sandstone and siltstone with low to moderate permeability. It also 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.

Basin Deposits

These are shallow, Holocene deposits of fine grained silt and clay with a thickness up to 200 feet. The Basin deposits have low permeability and do not yield significant quantities of water, so this unit is not generally a source of well water supply. Areas of paddy rice agriculture Butte County generally correspond with the occurrence of Basin deposits at the ground surface.

3.3.2 Model Stratigraphy

It is proposed to include 8 layers in the revised model, each layer representing a different aquifer unit. This is a significant revision from the existing BBWUA model, which includes 3 layers. The proposed model layers are shown in Table 3-1, numbered from top to bottom.

Table 3-1: Proposed Model Layering

Model Layer	Aquifer Unit
1	Basin Deposits
2	Alluvium (Riverbank and Modesto Formations)
3	Laguna or Sutter Formation
4	Tehama Formation
5	Tuscan C Formation
6	Tuscan B Formation
7	Tuscan A Formation
8	Miocene/Eocene Formations

The vertical location of the model layers will be developed based on geologic cross-sections developed by DWR. The location of the DWR cross-sections used to develop the model stratigraphy is shown in Figure 3-4. Layer thickness and contact elevations are interpolated to each model node from these sections. DWR surficial geology mapping will also be used as a reference for developing model stratigraphy (DWR 2001, 2002). Example model cross-sections showing proposed stratigraphy are shown in Figures 3-5 through 3-8. Note that a model layer is inactive where the corresponding formation does not exist.

The ground surface elevation is assigned to model nodes using a digital elevation model (DEM) provided by USEPA (http://www.epa.gov/waterscience/basins/metadata/dem.htm), rather than geologic cross-sections, because the DEM provides complete coverage of the model domain.

3.4 Surface Water Hydrology

Figure 3-9 illustrates the location of the major streams and water supply and drainage features in the county. The major waterways originating outside the county are the Sacramento River, the Feather River, Big Chico Creek, Butte Creek and Pine Creek. Several tributaries and streams are formed within the county from runoff and groundwater discharge, these include the West Branch of the Feather River, Little Chico Creek, Rock Creek, Dry Creek, Little Dry Creek, Clear Creek, Angel Slough, Wyandotte Creek and Honcut Creek.

CDM recommends that the following rivers and streams be explicitly simulated in the model:

- 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.

This includes all of the rivers and streams represented in the BBWUA model plus Deer Creek, which will form the northern boundary of the revised model. The Sacramento River, Feather River and Yuba River were represented with specified head nodes in the BBWUA groundwater model. There was no accounting of flow and stage for these rivers. In the revised model, flow and stage will be computed for all of the rivers listed. The Feather River will be sub-divided computationally into two separate rivers: one upstream of the Thermalito Afterbay and one downstream of the afterbay.

The Thermalito Forebay and Afterbay and associated Oroville Dan operations will not be explicitly included in the surface water modeling. However, deliveries from the Afterbay to the various irrigation districts will be included in the recharge, runoff, and water budget computations for those districts. Infiltration of water from the Afterbay into the subsurface will be accounted for in the groundwater flow computations.

Computationally, the rivers will be divided into 25 reaches, and each reach is made up of a set of model nodes as shown in Figure 3-10. In all, the revised model will include nearly 750 river nodes.

To simulate rivers and streams in IGSM2, the following physical properties of each river are required: channel profile, stage-discharge relationship, river bed thickness and river bed hydraulic conductivity.

Channel profile

Initial river bed elevation assignments will be made to the revised model grid by interpolation from the BBWUA model bed elevations. Minor adjustments will be made based on ground surface elevation and DWR data at gage locations.

Stage-discharge relationship

The BBWUA model uses a single mathematical formula to define the stage-discharge relationship for all rivers. In the revised model, DWR published stage-discharge data will be used on streams where DWR data is available as shown in Figure 3-11. For streams with no DWR stage-discharge relation available, stage-discharge relations will be interpolated from DWR stage-discharge functions at other streams based on average streamflow.

Bed thickness

Based on the BBWUA model and other models in the area, streambed thickness parameter values are expected to be in the range of 1 to 10 feet. Adjustments will be made as needed during model calibration.

Bed Hydraulic Conductivity

Based on the BBWUA model and other models in the area, streambed hydraulic conductivity parameter values are expected to be in the range of 0.1 to 5 feet/day. Adjustments will be made as needed during model calibration.

A time series of upstream inflows must be specified for each river at the point where the river enters the model domain. Also, a time series of outflows must be specified at major points of diversion within the model domain. Local watershed inflow and groundwater inflows/outflows are computed by the model as part of each simulation.

Upstream Inflows

Upstream inflow time series will be input based on daily streamflow gage data published by the USGS or DWR for streams where this data is available. (See Figure 3-11). For streams where gage data is available, inflow time series developed for another similar stream will be used, multiplied by an adjustment factor proportional to the ratio of the published long term average flows (Nady 1983) for the streams. Minor adjustments to the specified upstream inflows may be made during calibration to ensure that measured and observed river flows are in reasonable agreement.

Diversions

Irrigation diversion data for water districts and unorganized areas in the model domain have been compiled in the BBWUA model for the period from 1970 – 1999. These data will be translated from FEMFLOW3D format to IGSM2.

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 so that the river flow simulation is not affected. 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 will be assigned as diversions from these rivers in the model. This includes a portion of the surface water used in the following inventory sub-units:

- Butte Sink
- Esquon

- Western Canal
- Ridge
- Durham/Dayton
- Llano Seco
- M&T

Diversions from the Sacramento River will also be assigned in the model. Monthly diversion data from the Sacramento River is available from the Bureau of Reclamation, and also is compiled in the Stony Creek Fan IGSM model (WRIME, 2003).

Some of the irrigation water used in areas south of Butte County, but within the model domain, is diverted from the Yuba River. However, the point of diversion is outside (to the east) of the model domain and therefore does not affect the simulation of the Yuba River in the model.

Local Watershed Inflow

Inflows to rivers from the local watershed are computed during model simulation. This includes direct runoff from precipitation computed by the SCS "Curve Number" method as part of the infiltration computations described in Section 3.8, irrigation losses, drain discharges and return flow from indoor urban water use.

Groundwater Inflow/Outflow

Flow from river to groundwater and groundwater to river is computed for each river node by IGSM2. The rate and direction of flow is computed based on the difference between the groundwater head and the river head, the river bed thickness and the river bed hydraulic conductivity.

3.5 Model Boundary Conditions

Perimeter boundary conditions in the revised model will be generally similar to the BBWUA model. Some differences are noted in the discussion below.

North Boundary

The north boundary of the revised model will coincide with Deer Creek. This is slightly north of BBWUA model north boundary. The revised model boundary condition in the top layer is defined by the groundwater interaction with Deer Creek (3rd type boundary condition). Below the top layer, a no-flow boundary condition will be assigned here because the boundary is approximately aligned with the direction of regional groundwater flow. A no-flow boundary condition was assigned to the BBWUA model north boundary for all layers.

East Boundary

A no-flow boundary condition will be assigned along the east boundary of the revised model, which coincides with the approximate limit of the groundwater basin. An inward flux was assigned along the northern part of this boundary in the BBWUA model; otherwise a no-flow boundary condition was assigned. This inward flux assignment should be unnecessary in the revised model because the revised model boundary has been extended farther east to incorporate the Lower Tuscan outcrop area.

South Boundary

The southern model boundary coincides with the Yuba River and Sutter Buttes in both the BBWUA and revised models, and it is anticipated that the same boundary conditions will be applied in both models. A no-flow boundary condition is assigned at Sutter Buttes. Interaction with the Yuba River defines the top layer boundary condition where the south model boundary coincides with the Yuba River. A no-flow boundary applies to the lower layers along the Yuba River. A specified outward flux is assigned to a portion of the southern boundary between the Sutter Buttes and Yuba River. The applied boundary conditions along the southern model boundary will be evaluated and tested during the modeling study.

West Boundary

The western boundary of both the BBWUA and revised models coincides with the Sacramento River. Groundwater interaction with the river defines the top layer boundary condition in both models. A no-flow boundary condition is assigned to the lower layers at the western boundary in the BBWUA model. A similar boundary condition will be assigned in initial simulations with the revised model. However, during calibration of the revised model consideration will be given to assigning a specified flux, or possibly a general head (3rd type) boundary condition, to lower layers of the western boundary to account for possible flow under the Sacramento River in the Tuscan aquifer.

Base of Model

A no-flow boundary condition is assigned at the base of the model, consistent with the relatively impermeable nature of the rock there.

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 3.4. The rate and direction of flow is computed based on the difference between the simulated groundwater head and river head, the river bed thickness and the river bed hydraulic conductivity.

Field Drains

In agricultural areas where a shallow water table is encountered, a drain boundary condition will be applied just below the ground surface. Application of this boundary condition depends on the simulated elevation of the water table. Where the water

table is less than the drain elevation, this boundary condition is not invoked and has no effect on the computations. However, if the water table tends to rise above the drain elevation, then the drain boundary condition is applied, the water table rise is limited, and discharge from the groundwater to a surface water feature is computed.

Thermalito Afterbay

A specified constant recharge to groundwater from the Thermalito Afterbay will be assigned. The specified inflow rate will be based on estimated hydraulic properties of the surficial soils and calibration to measured head at wells monitoring groundwater mounding from the afterbay. Approximately 10,000 afy recharge to groundwater was simulated in BBWUA model from the afterbay.

3.6 Aquifer 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. Ranges of expected values are listed below based on previous studies and models. Initial estimates will be near the midpoint of the expected range. Final selection of parameter values will be made based on the results of the model calibration process. Sensitivity analysis will quantify how much simulation results are affected by changes in parameter value assignments.

Horizontal Hydraulic Conductivity

The expected range of values is shown in Table 3-2 for each of the revised model layers/formations.

Table 3-2: Range of Hydraulic Conductivity Values

Model Layer	Aquifer Unit	Hydraulic Conductivity (feet/day)
1	Basin Deposits	0.5 - 10
2	Alluvium (Riverbank and Modesto Formations)	20 – 150
3	Laguna or Sutter Formation	20 - 80
4	Tehama Formation	50 – 300
5	Tuscan C Formation	10 – 50
6	Tuscan B Formation	40 – 125
7	Tuscan A Formation	40 – 125
8	Miocene/Eocene Formations	0.1 – 5

Note that previously published hydraulic conductivity values listed in Table 3-2 are not entirely consistent with more recent data and investigations. Hydraulic conductivity values will be further evaluated during the model calibration phase.

Vertical Hydraulic Conductivity

Vertical hydraulic conductivity values are expected to be lower than corresponding horizontal hydraulic conductivity values by 1 to 3 orders of magnitude. Initially, vertical hydraulic conductivity values will be assigned a value 100 times (2 orders of magnitude) lower than the horizontal conductivity values.

Specific Yield

Expected values of specific yield are in the 0.05 to 0.15 range. Specific yield values near the low end of the range are expected for the Basin Deposits due to the predominance of fine grained soil. Higher values are expected for the more conductive alluvium deposits. 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

Appropriate specific storativity values are expected to be in the 0.00001 per foot to 0.0001 per foot range.

3.7 Land Use and Cropping Patterns

Groundwater pumping and recharge computed by the model are closely related to water use associated with the different crops grown in the model area, plus urban consumption. Land use/crop assignments in the revised model for recent conditions will be based on the most current (1999) DWR land use survey for Butte County, plus similar data for the portions of adjoining counties which are within the model domain. For simulation of past conditions, land use for 1970 to 1994 will be assigned as currently incorporated into the BBWUA model. The actual irrigated acreage for each irrigation district for each year (1970 – 1999) will be assigned as currently input in the BBWUA model.

Figure 3-12 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 3-3. For consistency with the land use data incorporated in the BBWUA model, some of the individual crop types listed in Table 3-3 will be combined with other similar crops into a single crop category for model input. Hence, a "model crop number" is also shown in Table 3-3 which indicates which crops will be combined for model input. Table 3-4 lists all the proposed model input crop categories, with associated acreage within the revised model domain based on the most recent survey.

3.8 Aquifer Recharge

IGSM2 computes groundwater recharge every simulation time step based on:

- Rainfall
- Irrigation Application
- Runoff
- Infiltration
- E-T/Crop Consumptive Use
- Flooding of Rice Fields
- Deep Percolation
- Vadose Zone Flow and Storage
- Rainfall

Five precipitation stations will be used to assign historical rainfall to the model. The location and designation of these stations is shown in Figure 3-13. Using Theissen polygons, each model element will be associated with one of the precipitation stations. The zone associated with each station is also shown in Figure 3-13.

The distribution of average annual rainfall in the study area is shown in Figure 3-14, as published by the California Spatial Information Library (CASIL). To ensure that the average simulated rainfall at each model element is consistent with the distribution shown in Figure 3-14, a rainfall weighting factor is assigned to each model element. This factor is multiplied by the recorded value at the precipitation station designated for an element to determine the rainfall assigned to that element for a given time period. The distribution of rainfall weighting factors to be assigned is shown in Figure 3-15.

Irrigation

Surface water irrigation will be assigned according to irrigation district monthly water diversion records. This data is compiled in the BBWUA model and will be converted to IGSM2 format. In areas where groundwater or a mix of groundwater and surface water irrigation is applied, IGSM2 will compute irrigation volumes for each simulation time step based on crop requirements and specified irrigation efficiency. Figure 3-16 shows areas in Butte County which are served completely or partially by groundwater irrigation.

Runoff

The National Resources Conservation Service (NRCS, formerly SCS) method for developing a relation between rainfall and runoff is used to compute direct runoff in

IGSM. The relation is based on a "curve number" indicating infiltration or runoff potential which is assigned to each model element. Curve number is assigned based on local soil type and land use. Figure 3-17 shows the distribution of soil types (in terms of runoff potential) in the model domain based on mapping compiled by the NRCS. When computing runoff, IGSM2 adjusts the assigned curve number for each element based on the antecedent moisture content of the soil.

The NRCS method defines a relation between daily rainfall and runoff. Therefore it is appropriate that for these calculations the model be run on a daily time step using daily rainfall data.

A portion of applied irrigation water is simulated to run off to a stream or surface water body. A constant fraction of applied irrigation water is directly returned to a stream or surface water body. That fraction is specified for each sub-area in the model input. Additionally, if rainfall and irrigation application water exceeds deep percolation, ET and the root zone storage capacity, the excess applied water will also become runoff.

Infiltration

Irrigation and rain water which does not become surface runoff infiltrates the ground surface and enters the root zone. Water which infiltrates into the root zone is available to satisfy evapotranspiration needs and to percolate into deeper soil horizons.

Evapotranspiration/Consumptive Use

The monthly potential evapotranspiration (ET) rate is assigned in the model for each crop/land use. Sample plots showing monthly potential ET rates for selected crops are shown in Figure 3-18.

Computed actual ET at any given time may be less than potential ET, depending on soil moisture level. In IGSM2, 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 0 at wilting point to the potential rate at one-half of field capacity.

Flooding of Rice Fields

To account for the flooding of rice fields, the timing of rice ET/consumptive use assigned in the model may be adjusted to more closely match the timing of water application. (The total seasonal ET will not be changed.) Since IGSM2 does not explicitly represent storage of excess irrigation water in rice paddies, this adjustment will be designed to prevent IGSM2 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.

Deep Percolation

IGSM2 computes the rate of deep percolation each simulation time step based on the root zone soil moisture content and the saturated vertical hydraulic conductivity value assigned to the surface (root zone) soil. Hydraulic conductivity values assigned to the root zone and vadose zone in the model will be consistent with the hydraulic conductivity values assigned to the surficial deposits for saturated groundwater flow calculations. Hence, areas where Basin deposits are found at the surface will be assigned relatively low conductivity values, and this will tend to limit deep percolation in these areas.

Vadose Zone Flow and Storage

IGSM2 computes the flow and storage of deep percolation water from the root zone to the water table. This tends to damp and lag the simulated response of the saturated groundwater to changes in rainfall and infiltration. Hydraulic conductivity and storage parameters assigned to the vadose zone in the model will be consistent with the hydraulic parameters assigned to the different aquifer units for saturated groundwater flow simulation as discussed in Section 3.6.

3.9 Groundwater Pumping

Municipal

Historical monthly municipal/industrial pumping will be assigned in the model by well for the following cities:

- Chico; Biggs; Gridley; Oroville; Durham; Live Oak (Sutter County); and Marysville (Sutter County)

Municipal well pumping data compiled in the BBWUA model will be converted to IGSM2 input format. Figure 3-19 shows locations of municipal pumping wells assigned in the BBWUA model.

Well pumping fluxes will be assigned to the model nodes nearest the well. Where a well screen spans multiple model layers, the assigned flux will be vertically distributed according to the relative layer transmissivities.

Agricultural

In areas where groundwater is used for irrigation, IGSM2 automatically computes estimated agricultural pumping based on crop requirements, soil moisture and specified irrigation efficiency for a given crop. This capability is not included in the BBWUA model, so that estimates of agricultural pumping were previously made external to the model. Areas where groundwater is used as a source for irrigation are shown in Figure 3-16.

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
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

Table 3-3
Model Crop Codes
Butte Basin Groundwater Model

DWR Code	Description	Acres*	Model Crop Number
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
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

Table 3-3
Model Crop Codes
Butte Basin Groundwater Model

DWR Code	Description	Acres*	Model Crop Number
S	Semi-Agricultrual	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
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

Table 3-3
Model Crop Codes
Butte Basin Groundwater Model

DWR Code	Description	Acres*	Model Crop Number
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
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).

Table 3-3
Model Crop Codes
Butte Basin Groundwater Model

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).

Table 3-4
Summary of Model Crop Numbers
Butte Basin Groundwater Model

DWR_LU_Codes.xls: BCIGSM_CROPS
06/22/2004

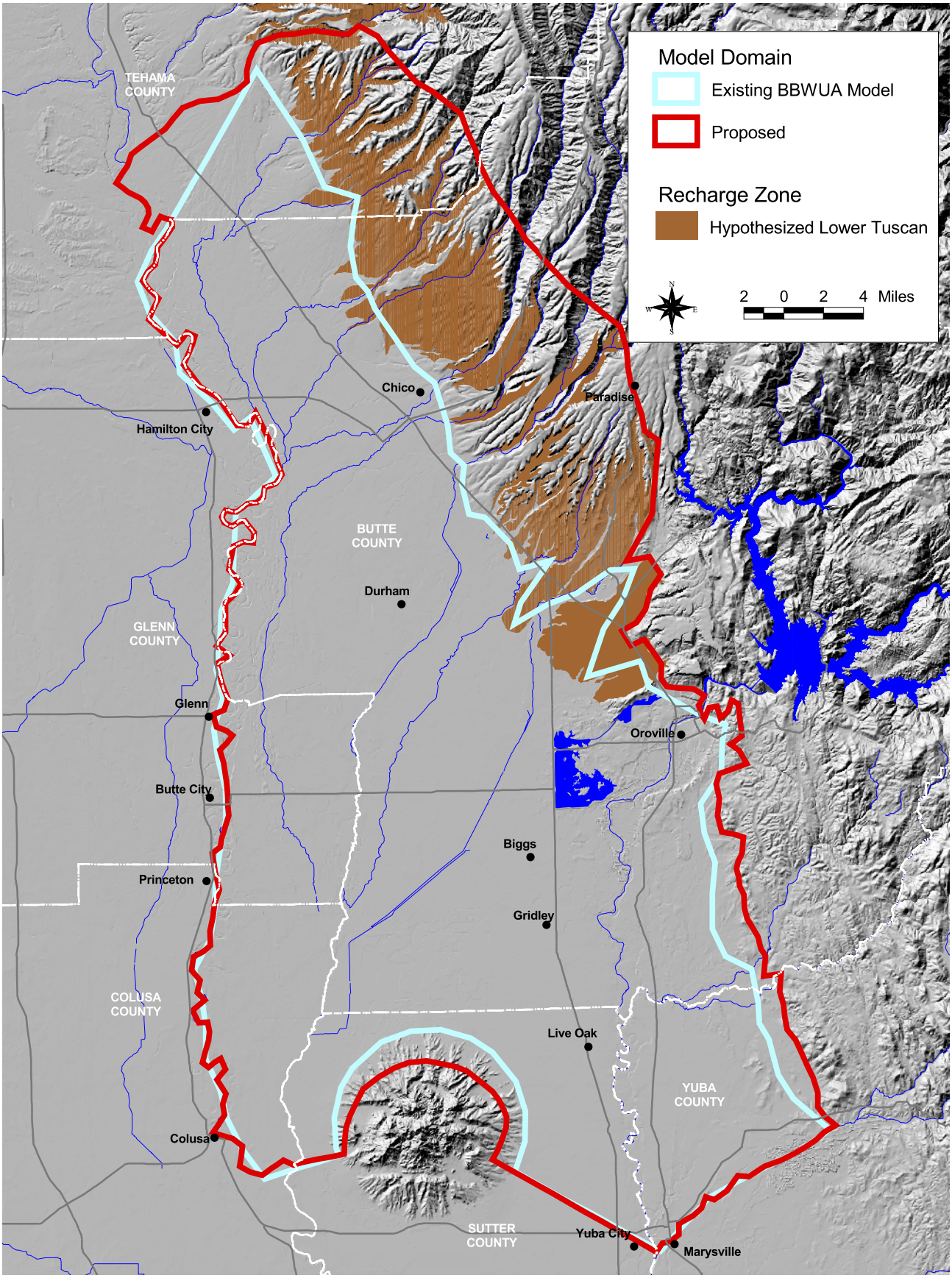


Figure 3-1
Existing BBWUA Model Domain
Proposed Butte County Model Domain
Butte Basin Groundwater Model

CDM

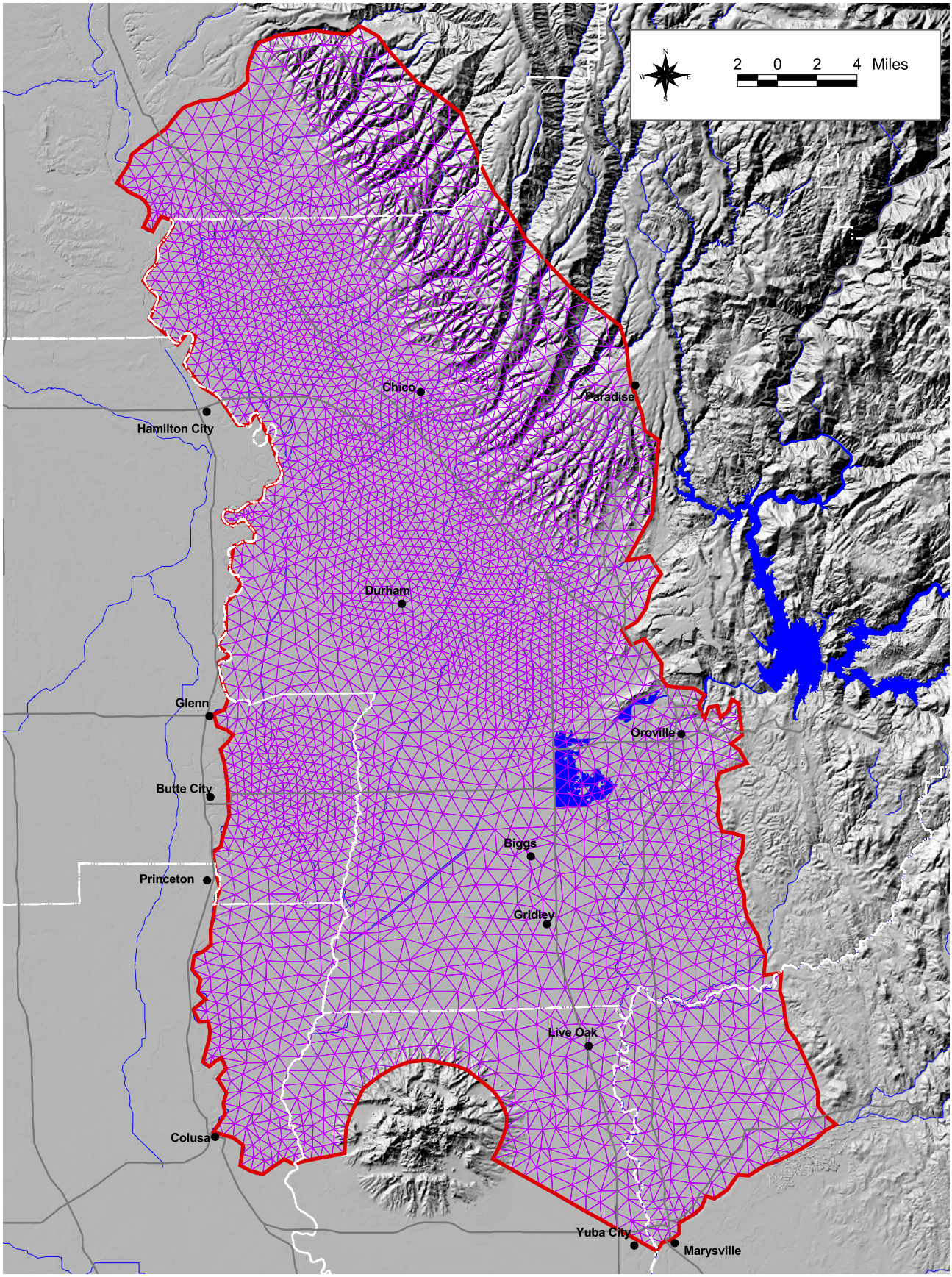


Figure 3-2
Finite-Element Grid
Butte Basin Groundwater Model

CDM

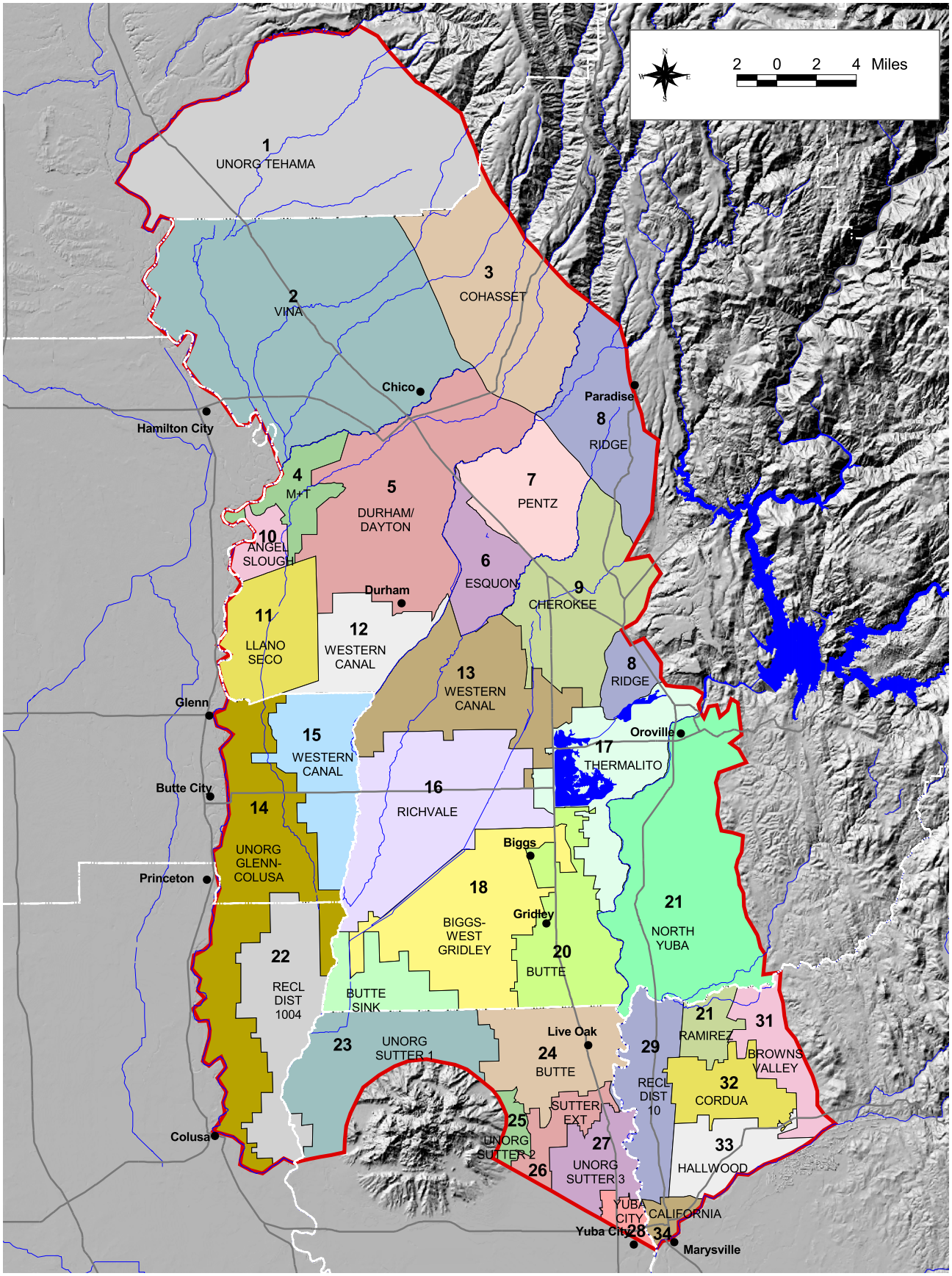


Figure 3-3
Model Subregions
Butte Basin Groundwater Model

CDM

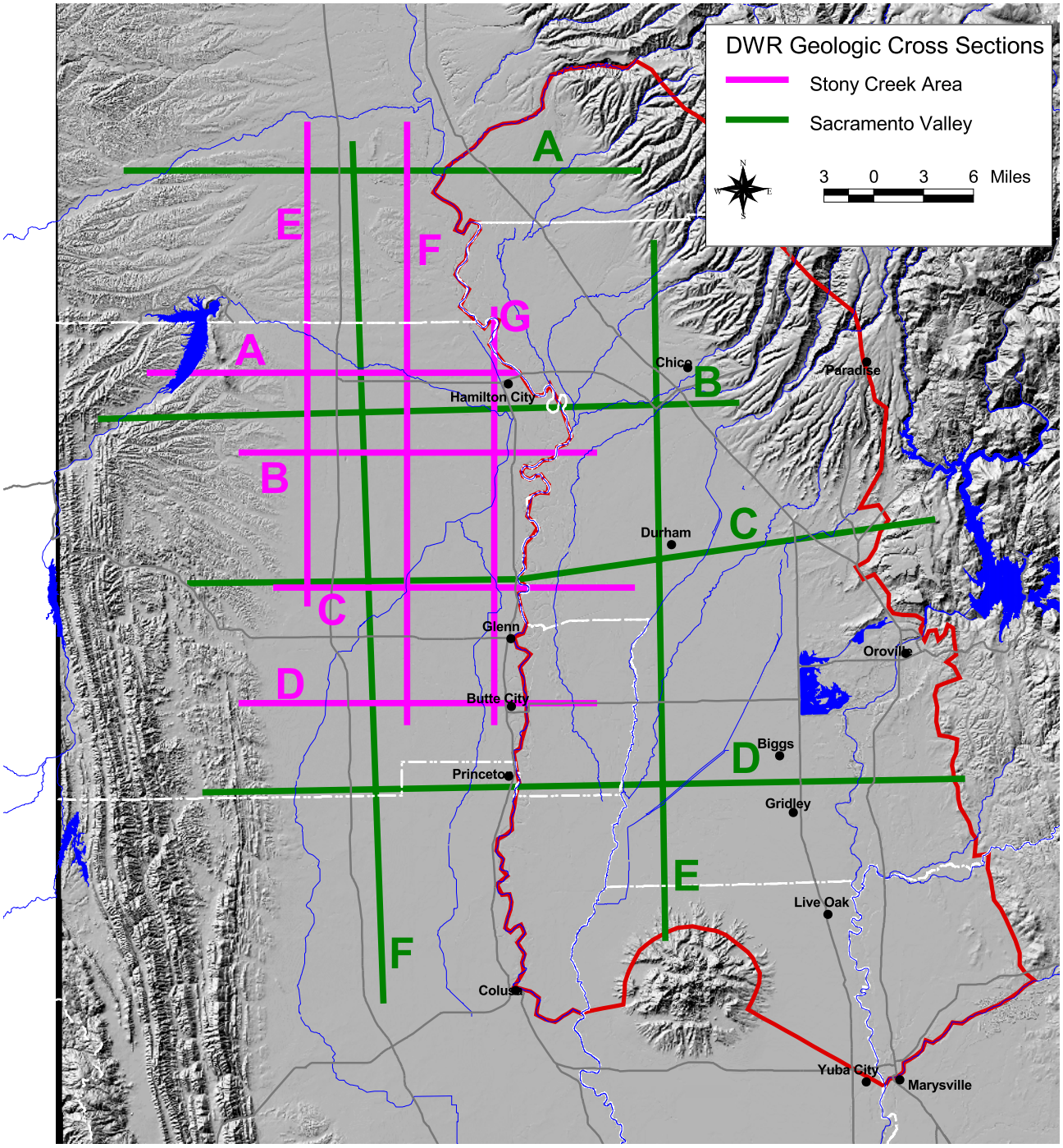
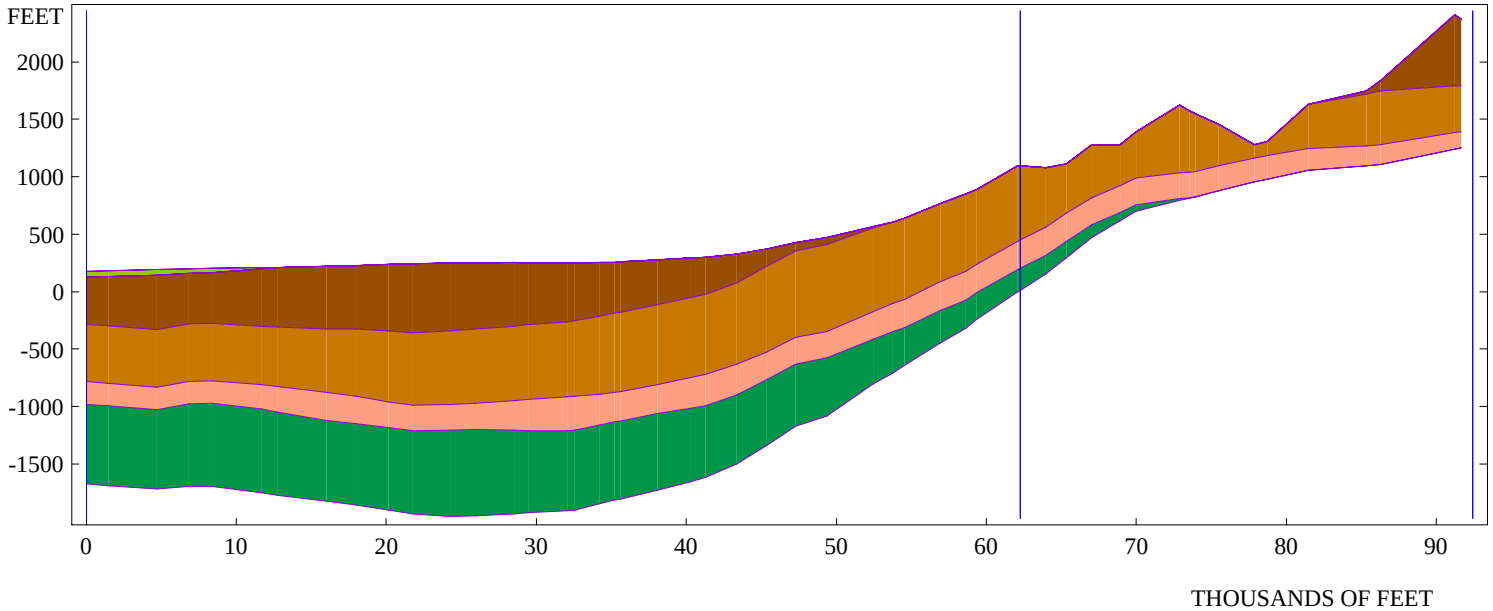


Figure 3-4
Location of CA DWR Geologic Cross-Sections
Used to Develop Model Stratigraphy
Butte Basin Groundwater Model

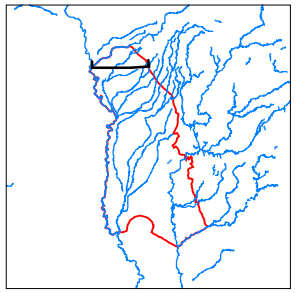
CDM



MATERIALS CROSS-SECTION AA

- Basin
- Alluvium
- Sutter
- Tehama
- Tuscan C
- Tuscan B
- Tuscan A
- Neroly/UPG/Ione

CROSS SECTION AA



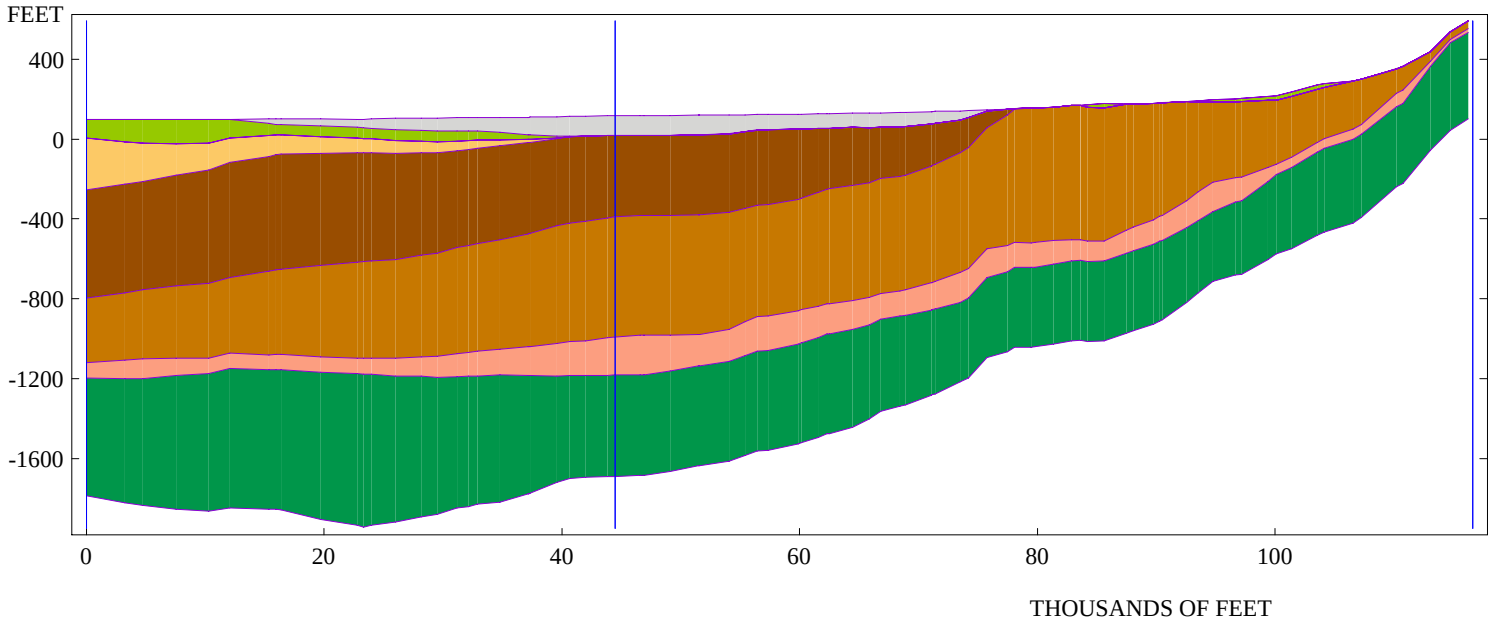
Jun18 04 sav/build03.sav

CDM

East-West Cross-Section Through Northern Portion of Model
Aligned with DWR Sacramento Valley Cross-Section A-A

Butte Basin Groundwater Model

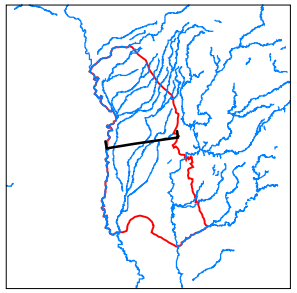
FIGURE
3-5



MATERIALS CROSS-SECTION CC

- Basin
- Alluvium
- Sutter
- Tehama
- Tuscan C
- Tuscan B
- Tuscan A
- Neroly/UPG/Ione

CROSS SECTION CC



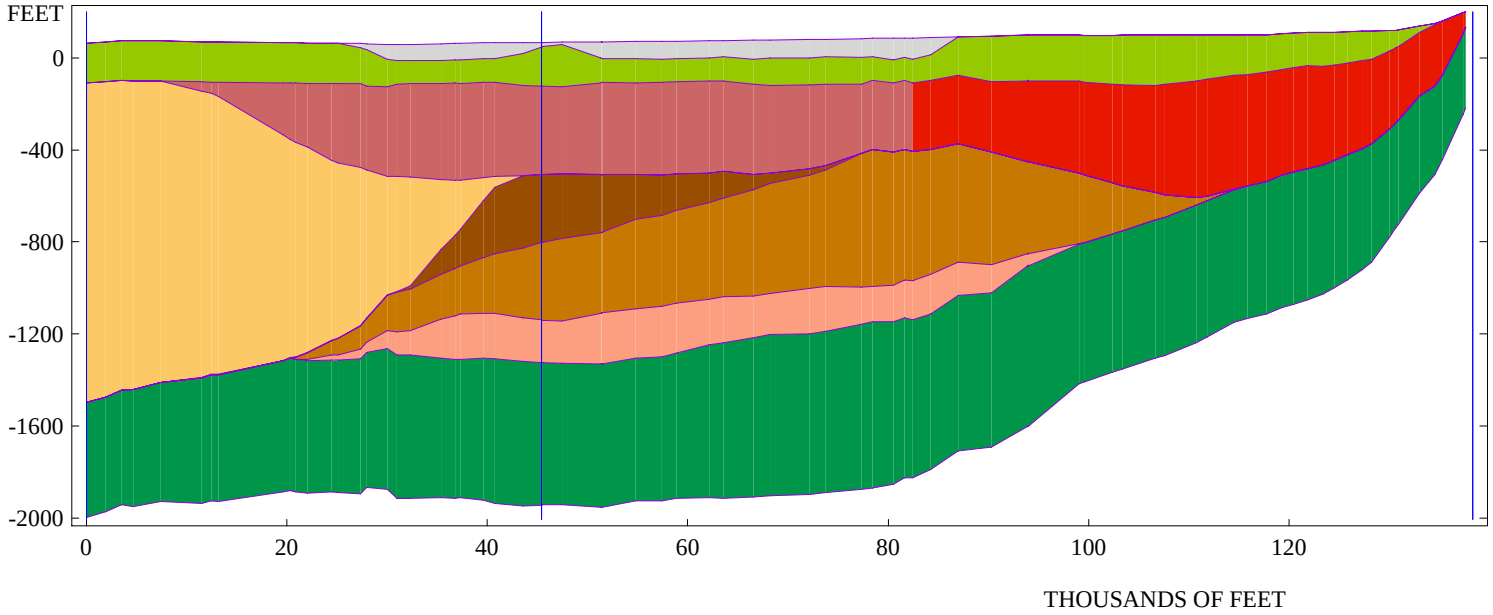
Jun18 04 sav/build03.sav

CDM

East-West Cross-Section Through Central Portion of Model
Aligned with DWR Sacramento Valley Cross-Section C-C

Butte Basin Groundwater Model

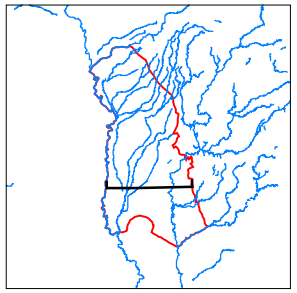
FIGURE
3-6



MATERIALS CROSS-SECTION DD

- Laguna
- Basin
- Alluvium
- Sutter
- Tehama
- Tuscan C
- Tuscan B
- Tuscan A
- Neroly/UPG/Ione

CROSS SECTION DD



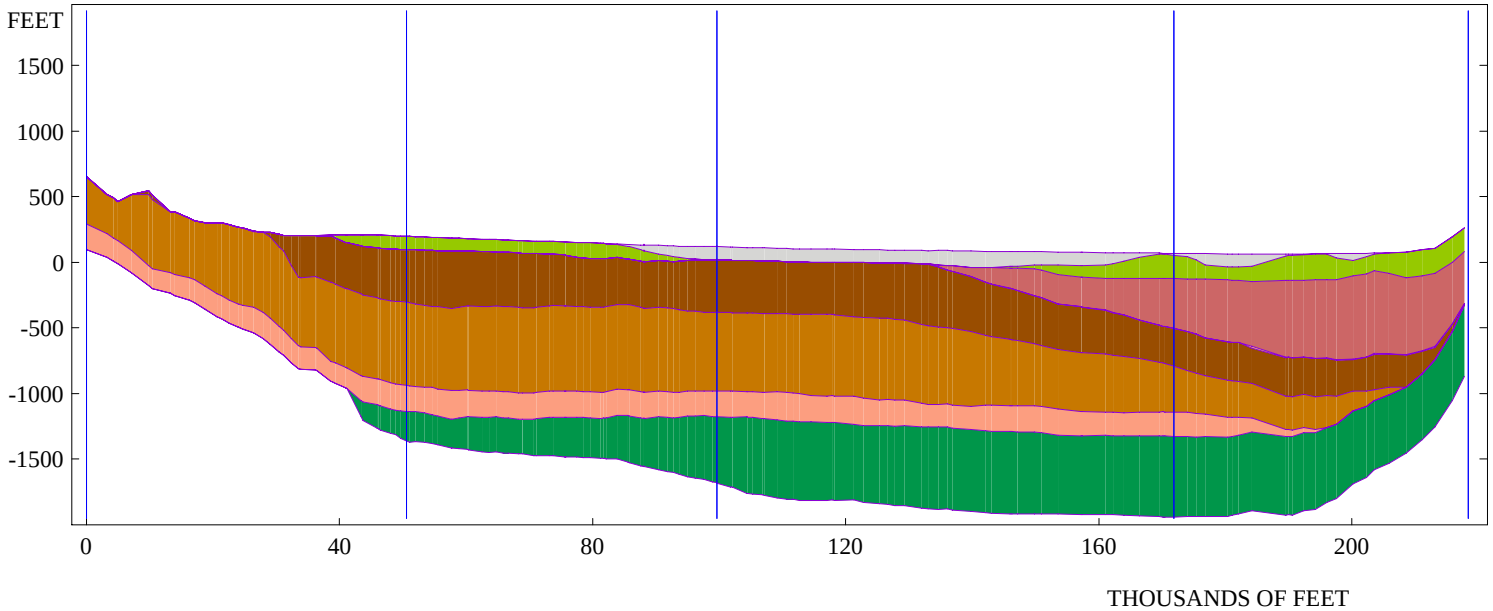
Jun18 04 sav/build03.sav

CDM

East-West Cross-Section Through Southern Portion of Model
Aligned with DWR Sacramento Valley Cross-Section D-D

Butte Basin Groundwater Model

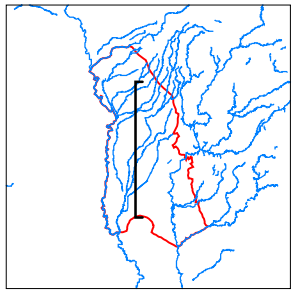
FIGURE
3-7



MATERIALS CROSS-SECTION EE

- Basin
- Alluvium
- Sutter
- Tehama
- Tuscan C
- Tuscan B
- Tuscan A
- Neroly/UPG/Ione

CROSS SECTION EE



Jun18 04 sav/build03.sav

CDM

North-South Cross-Section Through Model
Aligned with DWR Sacramento Valley Cross-Section E-E

Butte Basin Groundwater Model

FIGURE
3-8

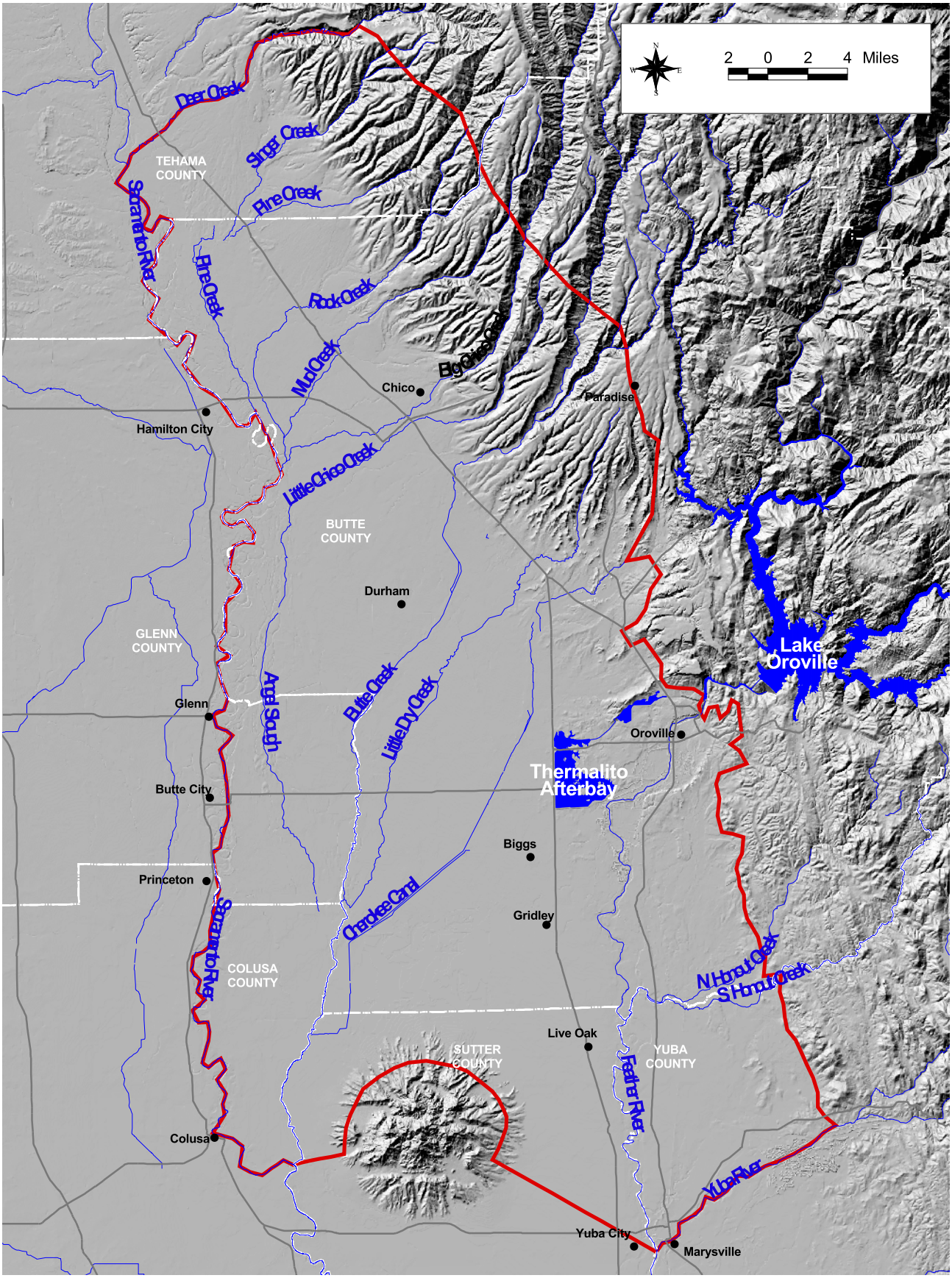


Figure 3-9
Major Streams, Water Supply, and Drainage Features
Butte Basin Groundwater Model

CDM

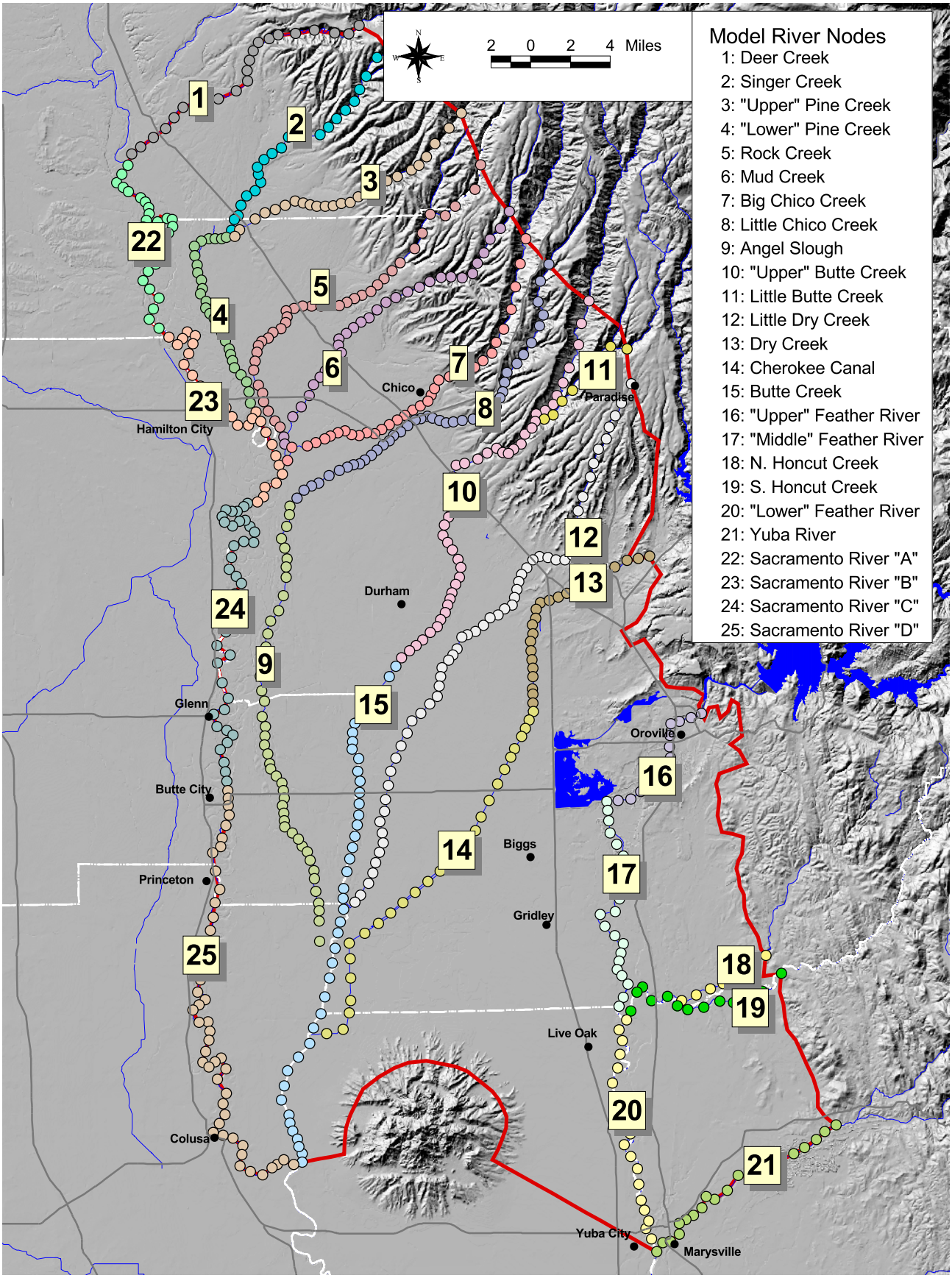


Figure 3-10
Locations of Model River Nodes
Butte Basin Groundwater Model

CDM

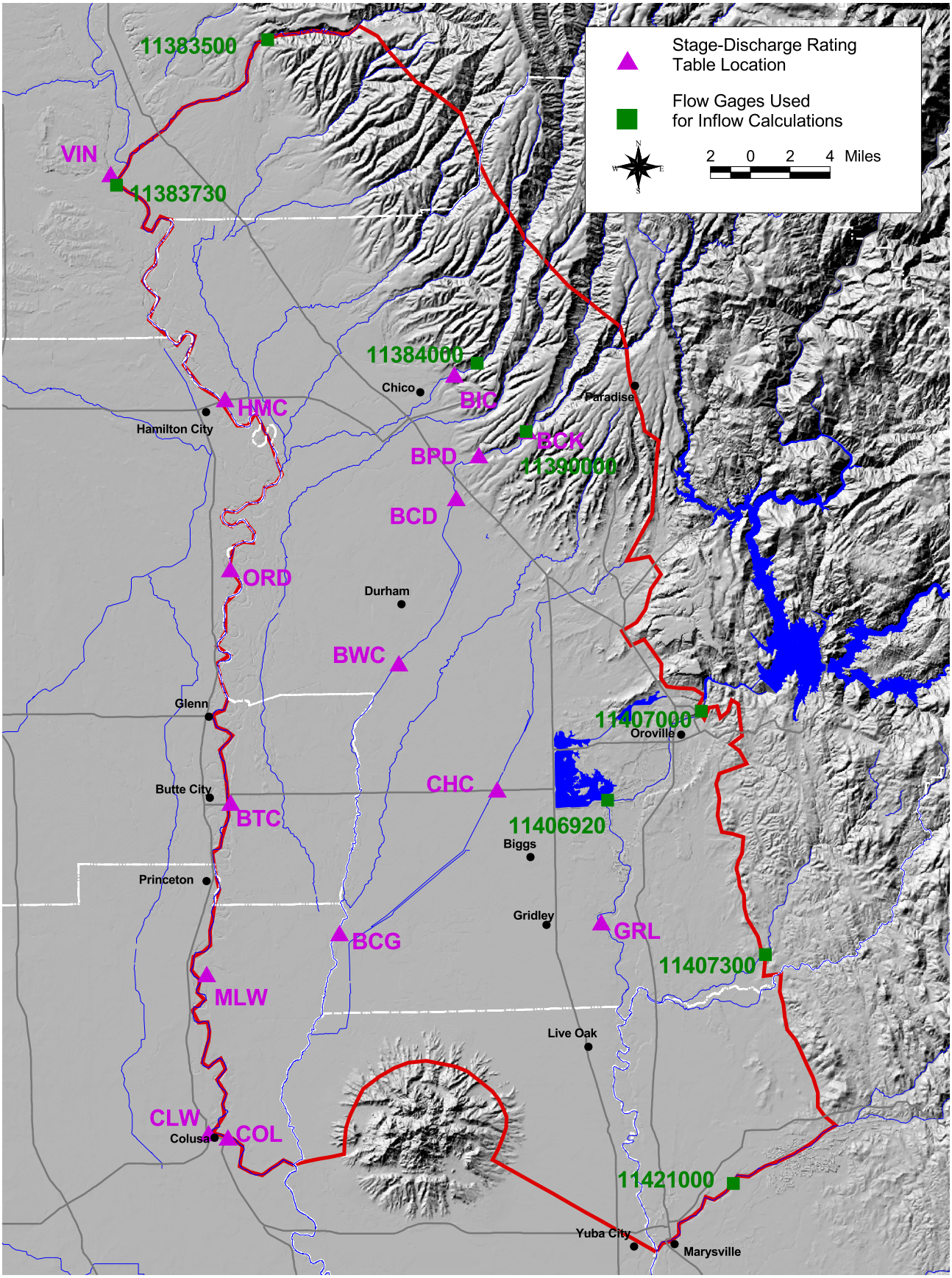


Figure 3-11
Location of Stage-Discharge Data Sites
Location of USGS Gauging Stations
Butte Basin Groundwater Model

CDM

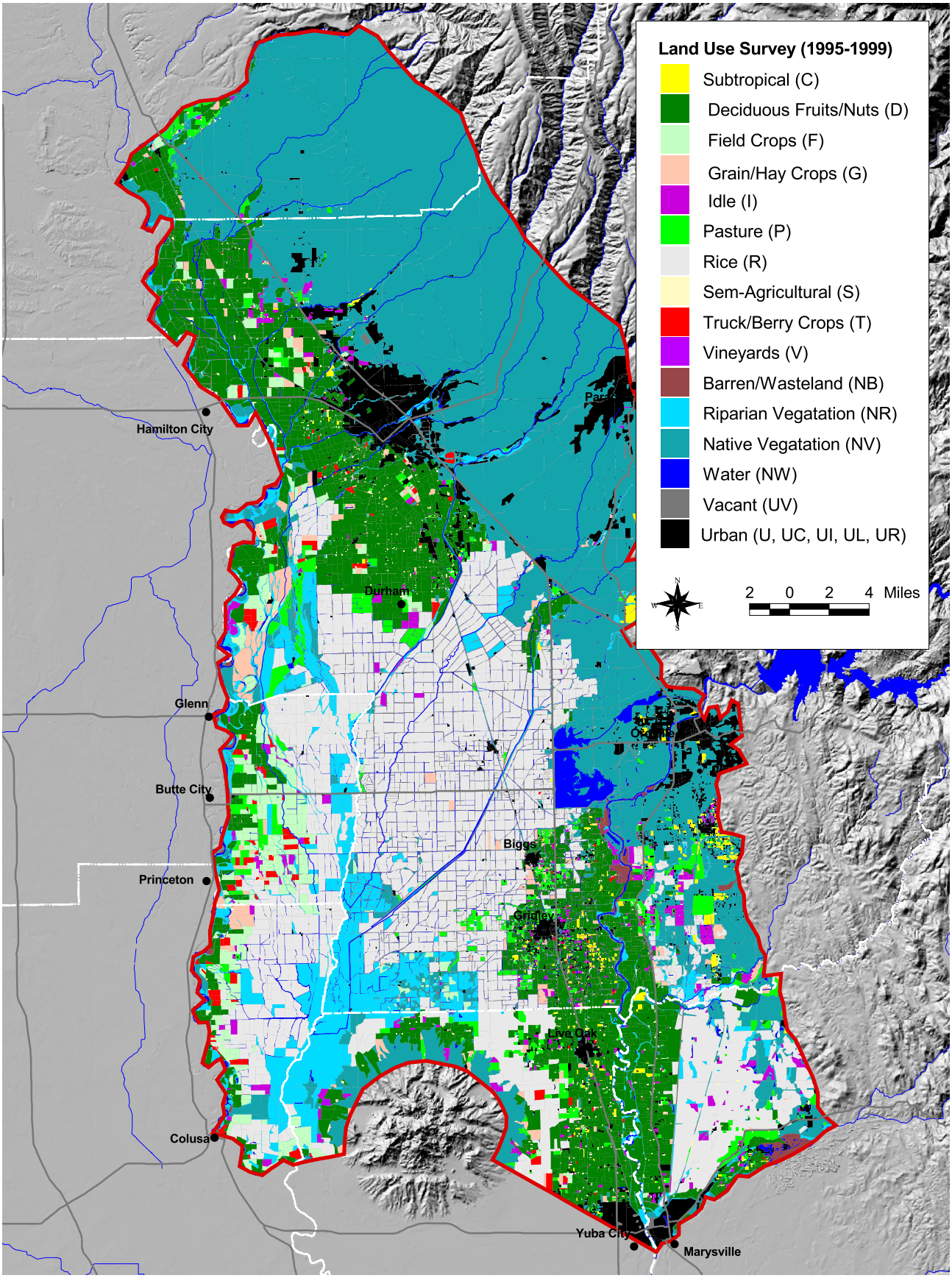


Figure 3-12
Land Use Across Model Area
Most Recent (1995-1999) Land Use Survey
Butte Basin Groundwater Model

CDM

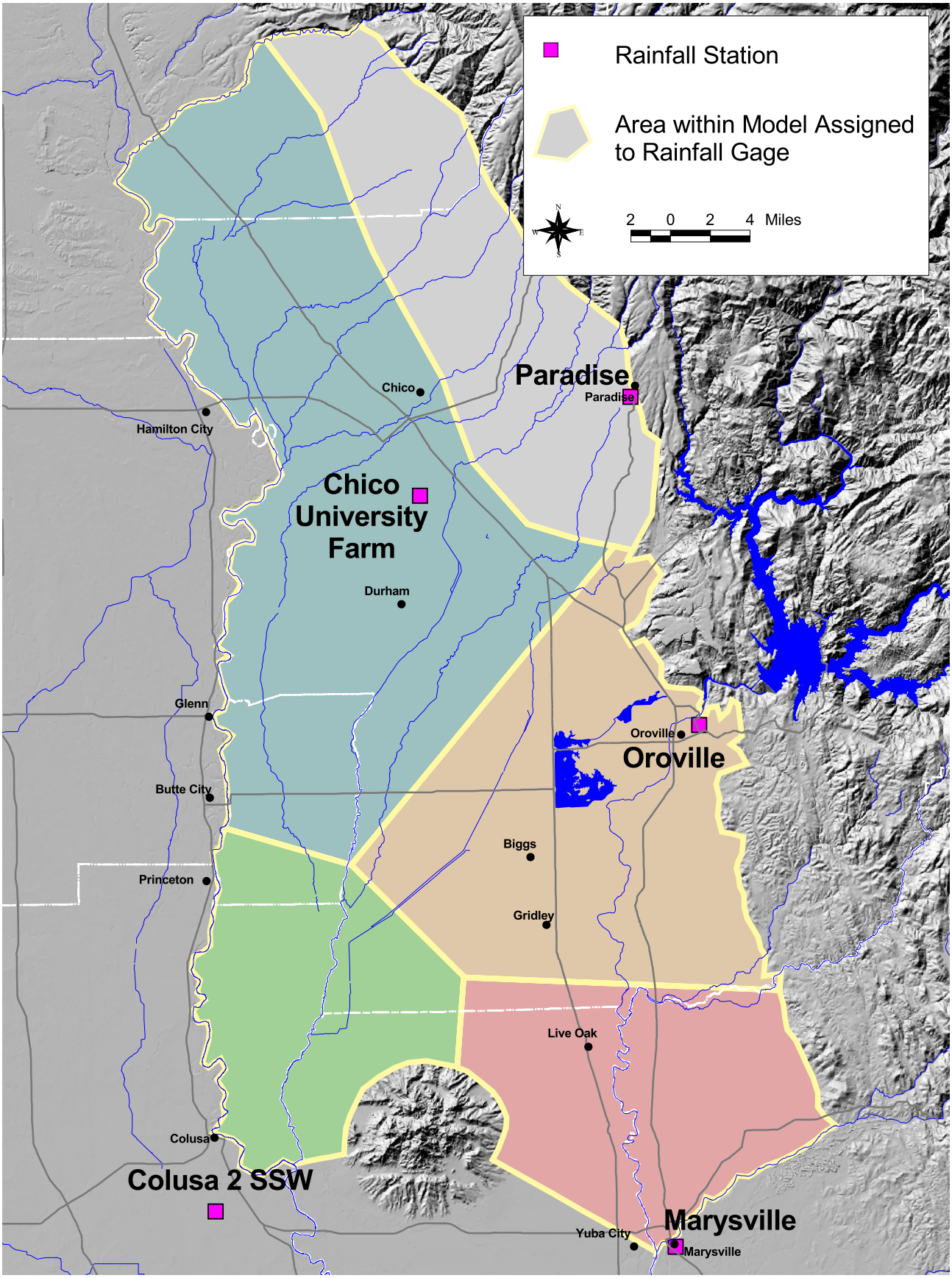


Figure 3-13
Location of Rainfall Gages used in Model
Areas of Model Assigned to Gages
Butte Basin Groundwater Model

CDM

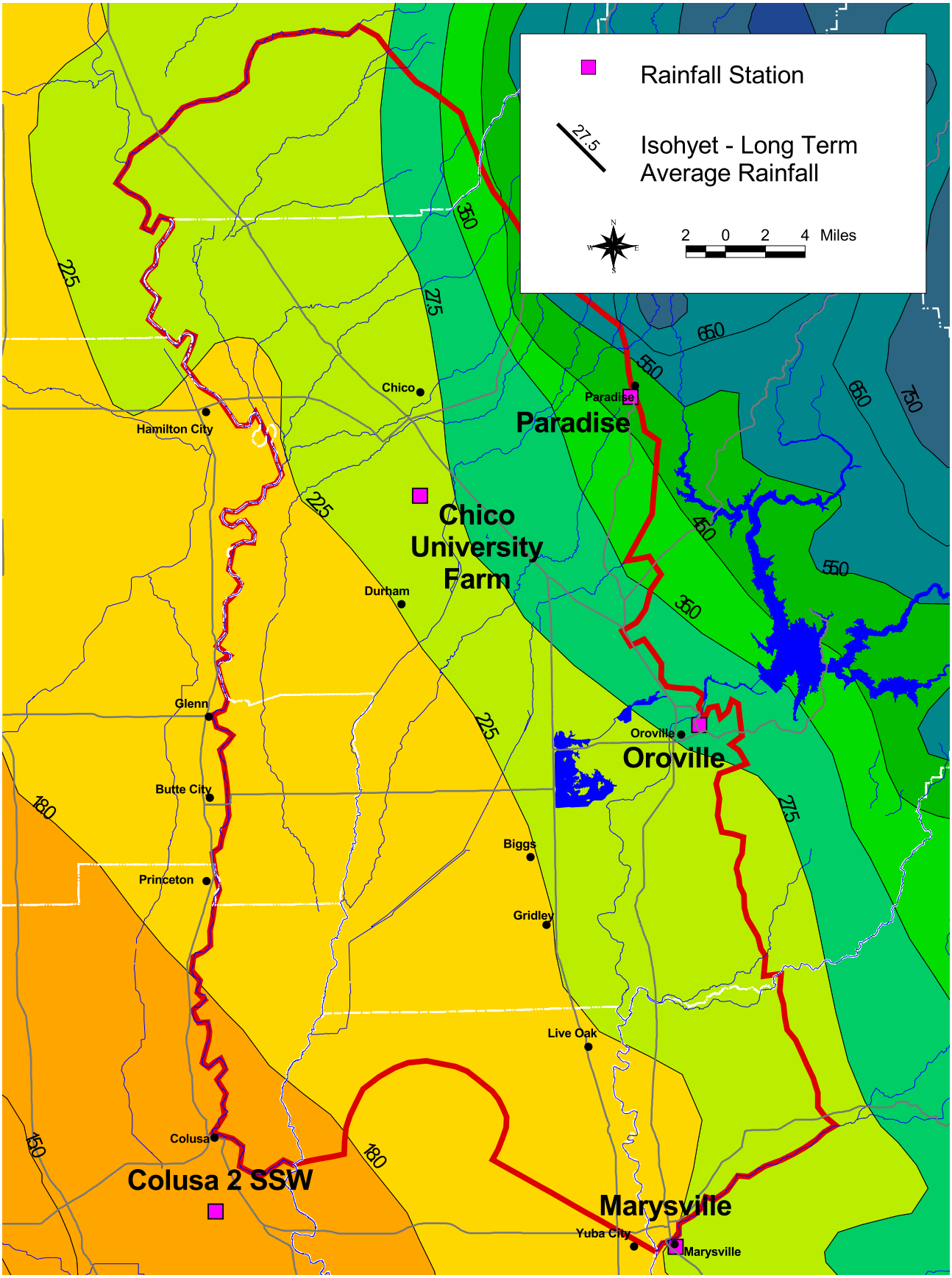


Figure 3-14
Long-Term Average Rainfall
Butte Basin Groundwater Model

CDM

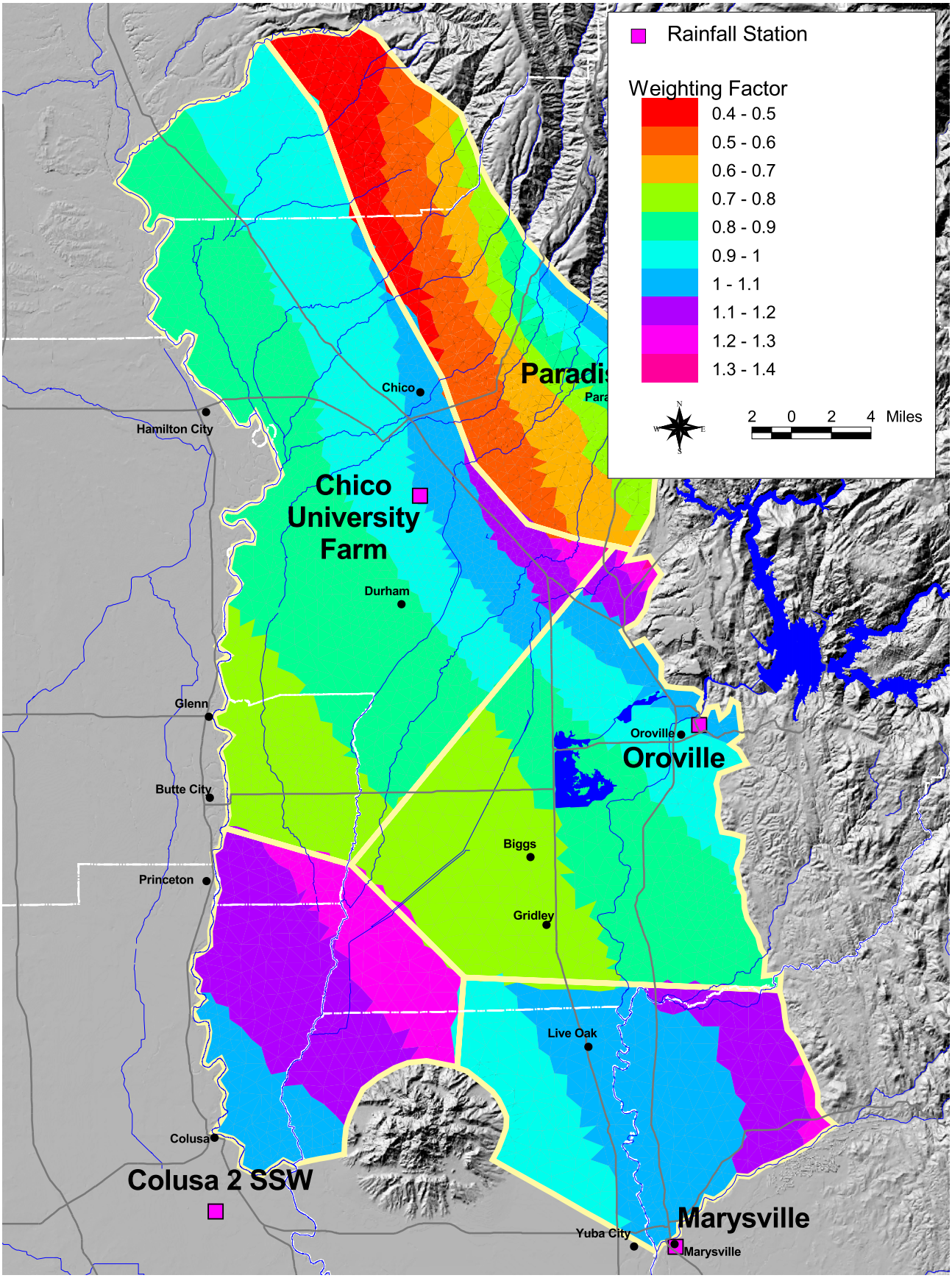


Figure 3-15
Rainfall Weighting Factor (Assigned by Element)
Butte Basin Groundwater Model

CDM

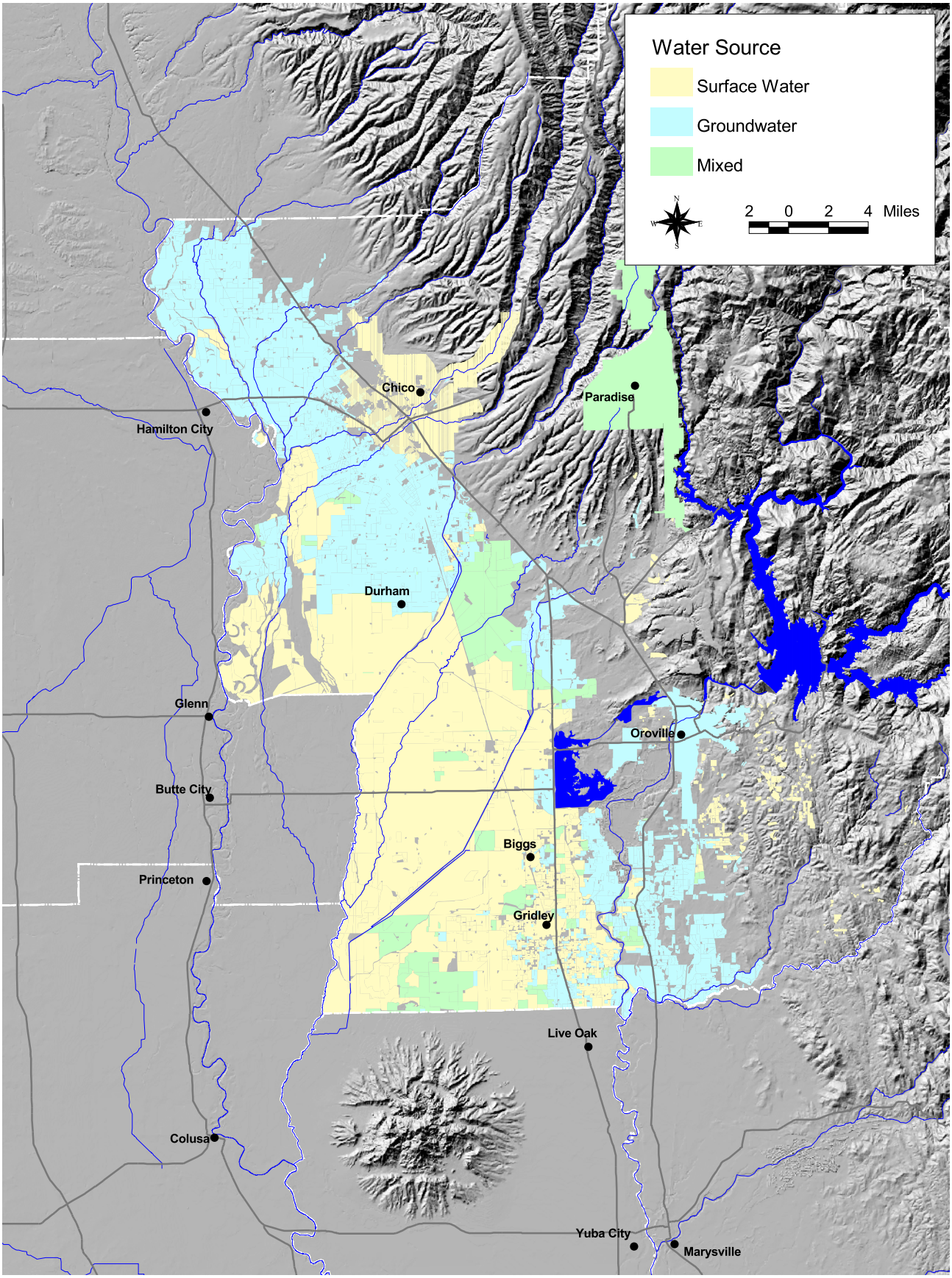


Figure 3-16
Water Source Types
Butte Basin Groundwater Model

CDM

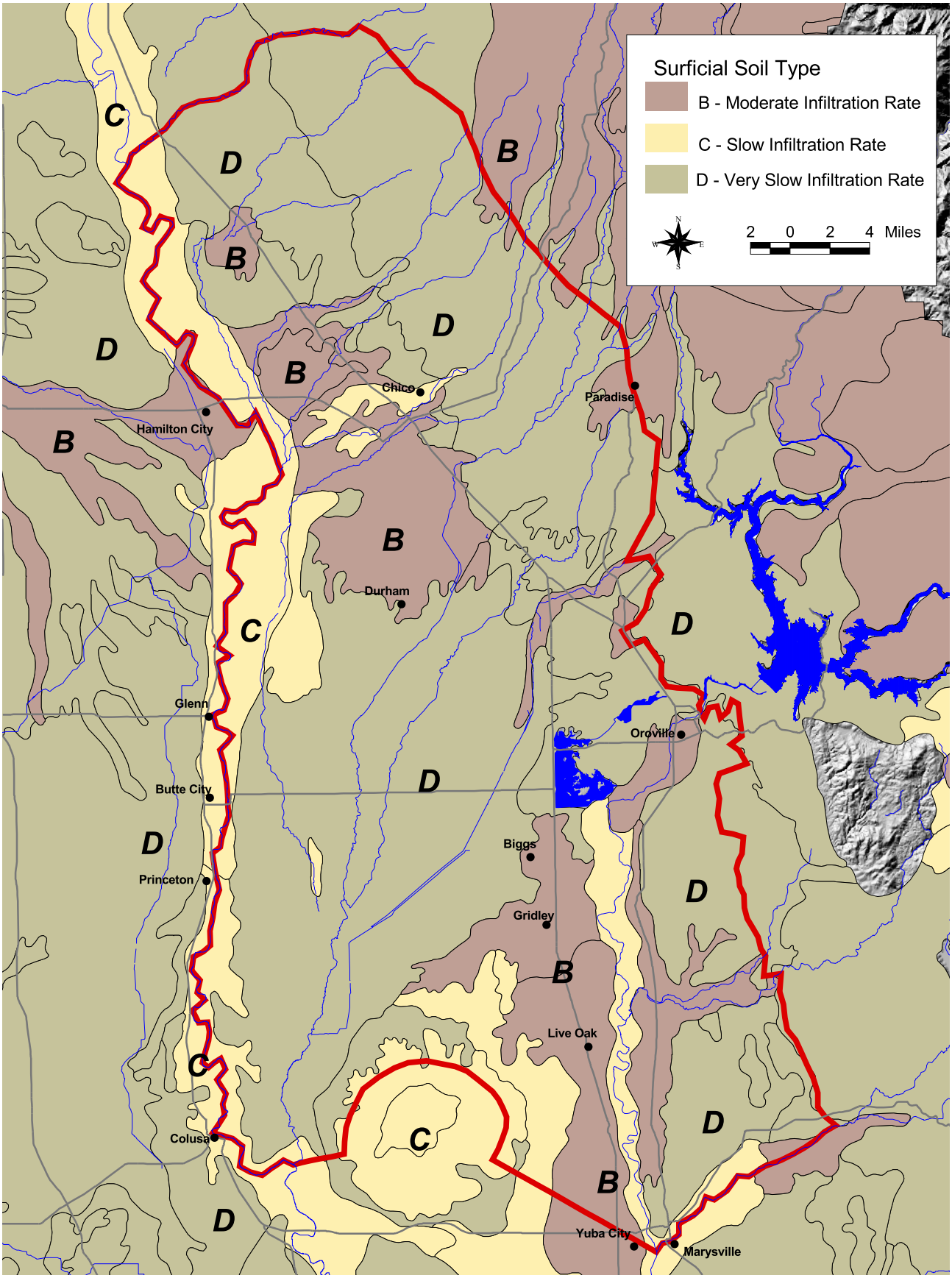


Figure 3-17
Distribution of Surficial Soil Types
Butte Basin Groundwater Model

CDM

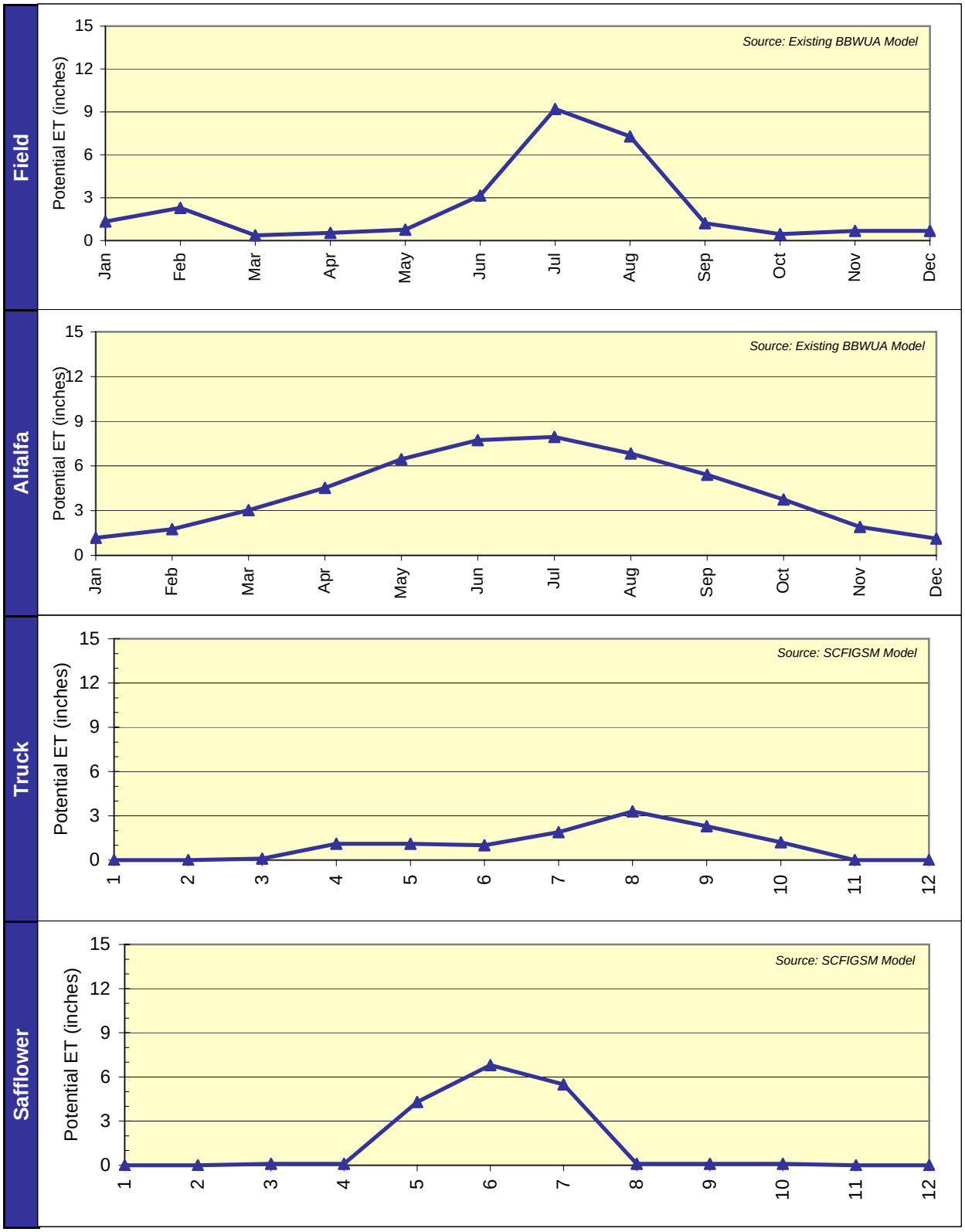


Figure 3-18
Sample Evapotranspiration (ET) Rates
Data from Existing BBWUA and SCFIGSM Models
Butte Basin Groundwater Model

ET_Charts.xls: Sheet1
06/21/2004

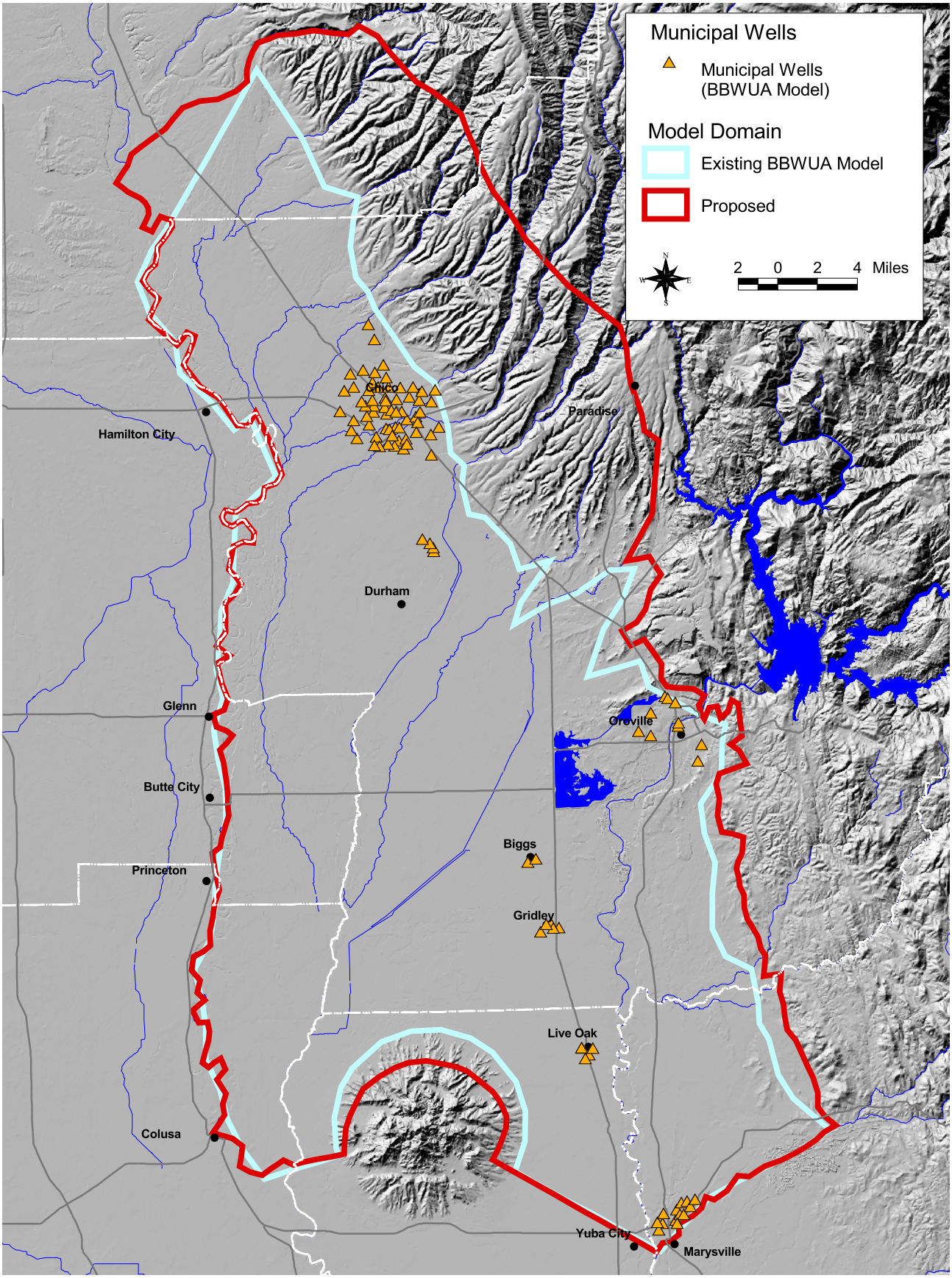


Figure 3-19
Location of Municipal Pumping Wells
In Existing BBWUA Model
Butte Basin Groundwater Model

CDM

Section 4
Future Modeling Tasks

4.1 Phase II Scope of Work

The Butte Basin groundwater model is an important water resource management tool required for Butte County to implement local integrated water resource planning. The recommendations and proposed model revisions documented in this technical memorandum were completed as part of Phase I work. For the next phase of work, the following tasks need to be funded and completed to finalize the update of the groundwater model.

Model testing and calibration

Calibration is the process of modifying model input parameters 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). It is common practice to calibrate groundwater models to both steady state and transient conditions. As part of Phase II, the most appropriate calibration periods for the steady state calibration and transient calibration will be determined. At a minimum the model calibration will include comparisons between model-simulated conditions and measured conditions for groundwater levels; groundwater-flow direction; hydraulic-head gradients and water mass balance, including groundwater-surface water interaction.

Sensitivity Analysis

Sensitivity analysis is the process of varying model input parameters over a reasonable range (range of uncertainty in values of model parameters) and observing the relative change in model response, such as groundwater levels. As part of the calibration process a sensitivity analysis will be performed to demonstrate the sensitivity of to uncertainty in input parameters, such as hydraulic conductivity.

Model Application

Once the model has been appropriately updated and calibrated the model application phase of the work will be initiated. This initially entails the development of a base case scenario. The purpose of developing a base case scenario is to create a tool that can be used to evaluate relative impacts to a groundwater basin caused by a proposed project, or a proposed change in basin hydrology, such as reservoir re-operation, conjunctive use project, cropping shift, or other.

A base case simulation in IGSM is typically constructed by replacing all the water demand and supply input data files in the calibrated model with files that represent a constant level of development. Aquifer parameter data and other parameter files that are used to define stratigraphy and streambeds remain unchanged. For the development of the base case, a proposed level of development will be selected. This is typically an average (typical) year at the current level of development or a projected level of development such as 2020 or 2030. Although a projected level of

development is desirable, the most recent calibration year may be the most practical level of development, due to data limitation. The latest reports and data with regarded to forecast demand and supplies will be reviewed to select the most appropriate level of development.

After the level of development is selected, a historic hydrologic period will be selected. The hydrologic period represents historic precipitation occurring in the model area. The precipitation data corresponds to stream flow and reservoir operation in the model. The longer the hydrologic period, the more comprehensive the assessment of the relative impacts of the proposed water management decisions. DWR usually uses the 1922 through 1995 hydrologic period. At a minimum it will be long enough to include a reasonable number of all year types in the order in which they naturally occurred (i.e. critical, dry, below normal, above normal, and wet water year types).

After all the data files are created, a simulation is made. The output from the model represents the base-case for Butte County. To evaluate a project, the base-case input data set is modified to represent the operation of a project and the simulation is run again. The project is then evaluated by comparing the output (heads) from the base case with the output (heads) from the modified base case. The relative changes in head (groundwater level) provide an estimate of how the proposed project will relatively impact groundwater levels in the basin.

Section 5
References

CDM. 1997, Revised 2004. DYNFLOW User's Manual.

CDM. March 30, 2001. Butte County Water Inventory and Analysis.

California Dept. of Water Resources Northern District. 1991. Western Canal groundwater test program. Memorandum Report. 71 p.

California Dept. of Water Resources Northern District. 1999. Land Use Survey of Butte County, California. Received electronically in ESRI® shapefile format.

California Dept. of Water Resources, Northern District. 2000. Butte County Groundwater Inventory Analysis.

California Dept. of Water Resources, Northern District. December 5, 2001. Geology and Hydrogeology of the Freshwater Bearing Aquifer Systems of the Northern Sacramento Valley, California. Revised. 2 Sheets.

California Dept. of Water Resources, Northern District. July 24, 2002. Geology of the Stony Creek Fan Area, Glenn, Tehama, Butte and Colusa Counties, California. Review Copy – Version 1.3. 1 Sheet.

California Dept. of Water Resources. December 2003. Integrated Groundwater-Surface Water Model 2 (IGSM2 v2.0), User's Manual.

California Dept. of Water Resources. Stage-discharge relationship data. Available from: http://cdec.water.ca.gov/

Durbin, T.J., and L.D. Bond. 1998. FEMFLOW3D: A Finite-Element Program for the Simulation of Three-Dimensional Aquifers. Version 1.0. U.S. Geological Survey Open-File Report 97-810.

Helley, E.J., and D.S. Harwood. 1985. Geographic map of the late Cenozoic deposits of the Sacramento Valley and northern Sierran foothills, California. U.S. Geological Survey Miscellaneous Field Studies Map MF-1790, Scale 1:250,000. 2 Sheets.

Hydrologic Consultants, Inc. (HCI). February 22,1996. Development of a Ground-Water Model, Butte Basin Area, California.

Nady, Paul and Larragueta, Lori L., 1983. Estimated average annual streamflow into the Central Valley of California: U.S. Geological Survey Hydrologic Investigations Atlas HA-657. Scale 1:500,000. 1 Sheet

Olmsted, F.H., and G.H. Davis. 1961. Geologic features and ground-water storage capacity of the Sacramento Valley, California. U.S. Geological Survey Water Supply Paper 1497, 241 p.

Teale GIS Solutions Group. 1997. Long Term Average Rainfall Isohyets. Available from: http://gis.ca.gov/meta.epl?oid=286

U.S. Dept. of Agriculture, Natural Resources Conservation Service. State Soil Geographic (STATSGO) Data Base. Miscellaneous Publication Number 1492.

U.S. Geological Survey. Historic gaged streamflow records. Available from: http://nwis.waterdata.usgs.gov/usa/nwis/discharge

U.S. Environmental Protection Agency. 1998. USGS 300 Meter Resolution, 1-Degree Digital Elevation Models (DEM) for CONUS, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands. http://www.epa.gov/waterscience/basins/metadata/dem.htm

van der Heijde, Paul K.M. 1985. "Review of DYNFLOW and DYNTRACK Ground Water Simulation Codes." International Ground Water Modeling Center (IGWMC) Report 85-15.

WRIME. May 2003. Stony Creek Fan Groundwater and Surface Water Model (SCFIGSM): Volume 1 of 4, Modeling Goals and Objections and Data Assessment.

WRIME. May 2003. Stony Creek Fan Groundwater and Surface Water Model (SCFIGSM): Volume 2 of 4, Hydrogeology and Conceptual Model.

WRIME. May 2003. Stony Creek Fan Groundwater and Surface Water Model (SCFIGSM): Volume 3 of 4, Model Development, Calibration and Analysis.