FINAL REPORT

PASO ROBLES GROUNDWATER BASIN STUDY
PHASE II

NUMERICAL MODEL
DEVELOPMENT, CALIBRATION, and APPLICATION

Prepared for:
COUNTY OF SAN LUIS OBISPO
PUBLIC WORKS DEPARTMENT

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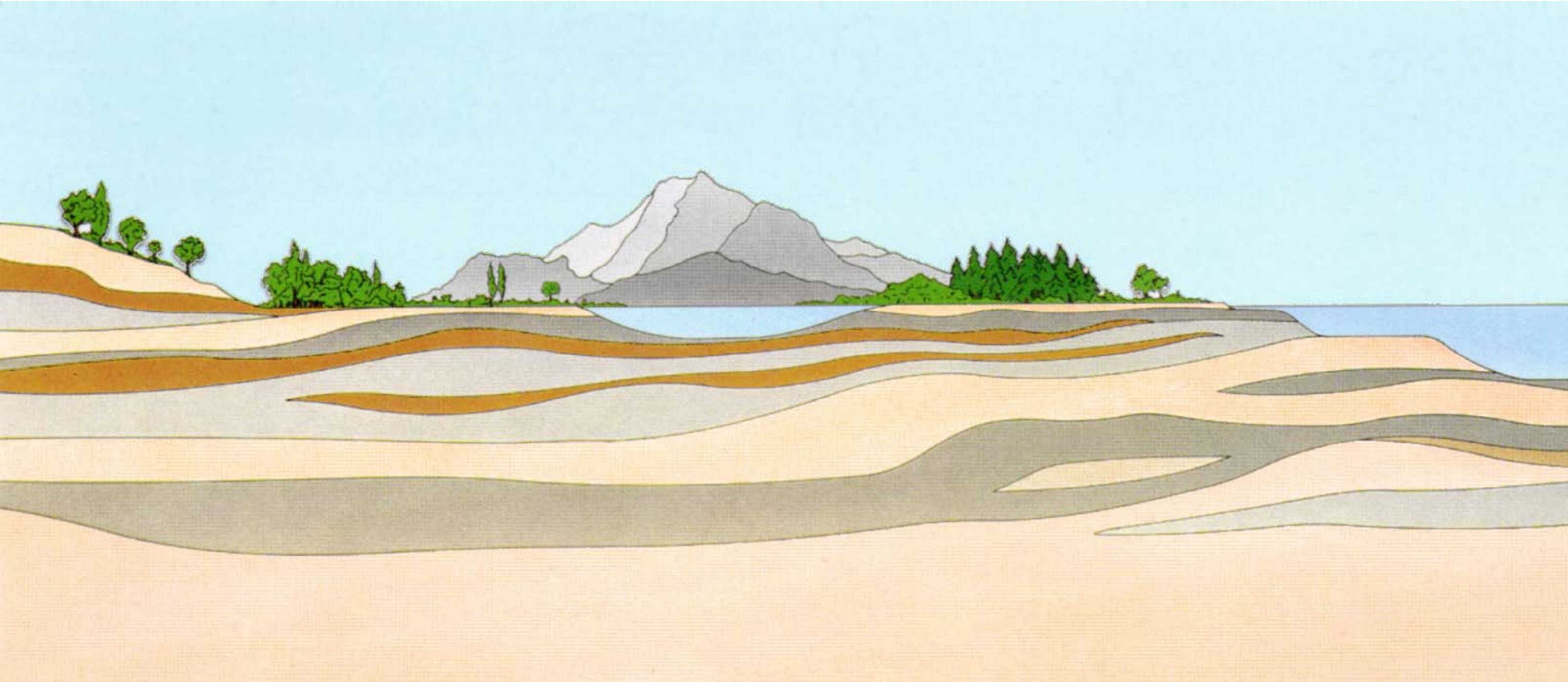
February 2005



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February 28, 2005
Project No. 3014.007.05

County of San Luis Obispo
Public Works Department
County Government Center, Room 207
San Luis Obispo, California 93408

Attention: Mr. Frank Honeycutt

FINAL REPORT
Paso Robles Groundwater Basin Study, Phase II

Dear Mr. Honeycutt:

Fugro West, Inc. and ETIC Engineering, Inc. are pleased to submit this FINAL REPORT of the Paso Robles Groundwater Basin Study, Phase II. The purpose of the project was to develop a numerical groundwater flow model as a quantitative tool to evaluate future basin hydraulic conditions. Using the model, the issues to be addressed in the Phase II efforts included an evaluation of the basin response to current and future water demands, with and without supplemental water, and an identification of areas of declining water levels.

Through the use of the model as a tool to refine our understanding of the dynamic flow conditions of the basin, the perennial yield is estimated to be 97,700 acre-feet per year (AFY) under current conditions. As of 2000, basin pumpage was approximately 82,600 acre-feet, under relatively stable conditions. However, concentrated pumping centers, particularly in the area along Highway 46 between Paso Robles and Whitley Gardens, have created localized pumping depressions and declining water levels.

The groundwater flow model was applied to simulate potential impacts to groundwater levels resulting from projected build-out conditions in the basin. With a projected basin pumpage of 108,300 AFY at build-out (without the importation of any supplemental water), groundwater storage would decline at a rate of approximately 3,800 acre-feet per year. Because of the concentration of pumping sources along Highway 46 east of Paso Robles, the localized pumping depressions developed over the past several years would be manifested by continued lowering of water levels.

Implementation of the Nacimiento water project would reduce the potential adverse impacts of build-out identified in the full build-out scenario. A direct in lieu exchange of Nacimiento water for a portion of the municipal pumpage would result in a general improvement of water levels relative to the projected build-out conditions. The water levels would not decline as much as would be the case without the water project; however, the currently contracted volume of Nacimiento water does not make up the entire deficit between build-out pumpage and perennial yield. With projected basin pumpage of 102,100 AFY at build-out (with importation of 6,250 AFY of Nacimiento water by Atascadero, Templeton, and Paso Robles), groundwater storage in the basin would still decline at a rate of approximately 1,200 AFY.

Comparison of the simulations of projected build-out conditions with and without the Nacimiento project indicates a net benefit of the Nacimiento water supply of about 2,600 AFY in the average annual change in groundwater storage. The benefits of the Nacimiento water project occur almost entirely along the Salinas River corridor.

Development of the model has increased our understanding of the dynamic flow processes of the basin. An increase in pumping does not result in an associated equivalent loss of groundwater storage because of complex interactions of groundwater and surface water, particularly along the Salinas River. This indicates that groundwater pumping locations and pumping volumes, particularly with respect to municipal supplies, can be optimized to manage groundwater levels.

In closing this phase of work for the San Luis Obispo County Public Works Department, we would like to express our appreciation to County staff, the Technical Review Committee, and the North County Water Resources Forum for their interest and cooperation throughout the study. It has been both a pleasure and a challenge to conduct the study. We will remain available at your convenience to discuss this report or to answer any questions.

Sincerely,

FUGRO WEST, INC.

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ACKNOWLEDGEMENTS

During the course of this investigation, both Phase I and Phase II which collectively transcended almost five years of time and effort, valuable information and assistance were obtained from a great number of individuals and agencies. It would be impossible to list all those that contributed to the effort, but all the contributions are gratefully acknowledged and truly appreciated.

Special mention is made of the Technical Review Committee (TRC), who met on a periodic basis to review and discuss the ongoing work efforts and the interim reports. The TRC participants are listed below.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This Final Report of Phase II of the Paso Robles Groundwater Basin Study presents the results of the development, calibration, and application of a numerical groundwater flow model of the basin. These Phase II efforts were designed to develop a sound, defensible flow model that will serve as a planning tool to quantitatively evaluate potential future trends in groundwater flow and water quality across the Paso Robles Groundwater Basin. The model was designed as a basin-wide model to evaluate long-term, regional trends and the overall inflow and outflow to and from the basin. Specific objectives for the model application during this Phase II work included refining uncertain components of the hydrologic budget for the basin, refining estimates of basin perennial yield, and evaluating potential impacts on groundwater levels and basin storage as a result of future build-out scenarios.

The overall purpose of the Phase I and II studies is intended to provide the San Luis Obispo County Public Works Department, North County public water agencies, and overlying landowners and water users with a better understanding of the basin by answering questions related to the quantity of groundwater in the basin, the hydraulic movement of groundwater through the aquifer, sources and volumes of natural recharge, and trends in water quality.

Through development and calibration of the model as a quantitative planning tool, there is now a tool capable of simulating groundwater trends over time across the entire basin. The calibration results indicate that the model accurately portrays previously measured groundwater flow conditions across the basin and is ready for use as a predictive tool to evaluate potential future trends in groundwater quantity and quality.

The groundwater flow model was applied to evaluate the perennial yield for the basin, and to simulate impacts to groundwater levels resulting from projected build-out conditions in the basin. General conclusions from these scenarios include:

- The model indicates that the perennial yield for the Paso Robles Groundwater Basin is 97,700 acre-feet per year (AFY).
- The perennial yield analysis shows that not all of the total volume of an increase in pumping comes out of groundwater storage. Because of the complex interaction of the groundwater with the surface water sources, increased basin pumping induces additional stream percolation as well as affecting other inflow and outflow components. Similarly, a decrease in pumping affects not only groundwater in storage, but concurrently reduces stream recharge and affects other inflows and outflows. Understanding this relationship suggests that groundwater pumping locations and amounts can be optimized to manage groundwater levels and protect beneficial uses.
- The Build-Out Scenario (Scenario 2) simulated the effects of urban build-out and maximum reasonable agricultural water demand (agricultural “build-out”). This scenario, reflecting basin pumpage of 108,300 AFY, results in an average annual decline in groundwater storage of 3,800 AFY. Declining groundwater storage would be manifested in a general lowering of water levels across much of the basin, particularly in the Estrella subarea and the northern part of the Atascadero Subbasin.
- The Build-Out Scenario with Nacimiento water (Scenario 3) simulated the impacts on basin storage and water levels by replacing a portion of municipal pumping with an equal portion of Nacimiento project water. The volume of applied Nacimiento water in this scenario was equal to the amounts presently contracted by Atascadero Mutual Water Company (2,000 AFY), Templeton Community Services District (250 AFY), and the City

of Paso Robles (4,000 AFY). This scenario, which simulated basin-wide annual pumping of 102,100 AFY, results in an average annual decline in groundwater storage of 1,200 AFY at full build-out.

- Comparison of Scenarios 2 and 3 indicates an overall positive net benefit of the Nacimiento project of 2,600 AFY in the average annual change in groundwater storage. Although a slight general lowering of water levels would still occur throughout the basin at build-out with implementation of the Nacimiento project, the benefits would be most apparent in the Estrella subarea and the Atascadero Subbasin, where all of the municipal pumping occurs.
- Municipal pumping is more significantly affected than agricultural pumping by groundwater-surface water interactions associated with the Salinas River. The hydraulic link between the groundwater and surface water indicates that municipal groundwater pumping locations and amounts can be optimized to manage the groundwater levels. Additional scenarios with alternative well locations and pumping rates in the vicinity of the Salinas River could be useful in managing groundwater storage, optimizing groundwater pumping, and maintaining beneficial river flows.
- The agricultural pumping component of the hydrologic budget is the single largest outflow of groundwater from the basin. It is also the single largest estimated parameter because the pumpage volumes are not metered but rather estimates based on land use and irrigation practices. Thus, minor variations of agricultural water demand estimates may have widespread impacts on groundwater storage and groundwater elevations.
- A sensitivity analysis was run on the Scenario 2 maximum reasonable agricultural water demand (simulating “agricultural build-out”). Agricultural pumpage was changed at each well to 90% of the projection for the first run and to 110% for the second run. The 90% run resulted in a small groundwater storage increase of 500 AFY, relative to the impacts simulated by the Scenario 2 conditions. The 110% run resulted in groundwater storage declines of 8,000 AFY. Because future agricultural trends are so problematic to forecast, slight misforecasts in agricultural demand predictions could have large implications relative to changes in groundwater storage and water levels. Given a perennial yield value of 97,700 AFY and estimated basin pumpage at 102,100 AFY at build-out (with Nacimiento water), it is clear a relatively slight adjustment in “build-out” agricultural pumping could make the difference between potential basin overdraft or not.
- Agricultural pumpage, by being more widespread across the basin and comprising much of the pumpage located away from the Salinas River, shows a more direct relationship with groundwater storage and less interaction with the Salinas River. Thus, basin-wide changes in agricultural trends that would result in changes in agricultural pumping would have a more direct effect on groundwater storage than would parallel changes in municipal pumping.

The computer model is a dynamic groundwater management tool that can be used by water resource managers and planners to analyze issues on a coordinated, basin-wide basis and to manage water resources for the long-term benefit of all overlying landowners. Specific recommendations include the following:

- Simulation of possible projects involving artificial recharge and/or provision of alternative irrigation supplies. These scenarios should involve simulation of impacts on groundwater levels and water quality. These scenarios also should involve simulation of the effect of turning off or resting wells with provision of an alternative water supply (e.g., reclaimed wastewater or surplus Nacimiento Water Project water). A particular focus for such possible projects would be the portion of the Estrella subarea that is characterized by groundwater level declines.

- Simulation of alternative well locations and pumping rates. The simulations documented in this report revealed the importance of the dynamic hydraulic interaction of groundwater and surface water, particularly along the Salinas River. Additional scenarios should focus on modifying the operation of municipal wells along the Salinas River to manage groundwater storage, optimize pumping, and preserve beneficial uses of river flow.
- Water quality modeling. Although the Phase 2 effort did not specifically include simulation of water quality trends, the model was developed with a water quality component that will allow for assessment of water quality trends and impacts. Particular areas of focus may include the areas with increasing TDS, chloride, and nitrate that were identified in the Atascadero Subbasin and in the Estrella subarea south of San Miguel.
- Update of the model on a regular basis. Annual compilation of data and update of the hydrologic budget is recommended; a full model update and recalibration of the model to current conditions is recommended every three to five years. This recommendation is particularly important because groundwater pumpage in the projected build-out scenarios is the result of many different decisions made by groundwater users and is close to the perennial yield value. Particular focus should be placed on agricultural pumping, and land use patterns, estimates of agricultural pumping, and distribution of agricultural pumping should be updated regularly.

CHAPTER 1 - INTRODUCTION

INTRODUCTION AND BACKGROUND

This Report presents the findings, conclusions, and recommendations of Phase II of a comprehensive investigation of the Paso Robles Groundwater Basin. These Phase II efforts, begun in April 2003, included the construction, calibration, and application of a numerical model of the basin. This work follows directly upon the heels of the Phase I investigation to conduct a detailed geologic and hydrogeologic investigation of the basin and to assess its perennial yield. The Phase I work developed the overall conceptual understanding of the basin, and served as the foundation for development of the numerical model in Phase II. The results of the Phase I study were presented in a Final Report dated August 2002 (Fugro and Cleath 2002).

The overall purpose of the Phase I and II studies is intended to provide the San Luis Obispo County Public Works Department, North County public water agencies, and overlying landowners and water users with a better understanding of the basin by answering questions related to the quantity of groundwater in the basin, the hydraulic movement of groundwater through the aquifer, sources and volumes of natural recharge, and trends in water quality. Specifically, the Phase II efforts were designed to develop a numerical groundwater flow model that will serve as a useful, quantitative tool to evaluate potential future trends in groundwater flow and water quality across the basin.

PURPOSE AND SCOPE

The Phase II hydrogeologic investigation of the Paso Robles Groundwater Basin was formally initiated in April 2003. The primary objectives for the model include:

- Refining uncertain components of the hydrologic budget for the basin,
- Refining estimates of perennial yield for the basin, and
- Evaluating potential impacts on groundwater levels and perennial yield as a result of continued and varied basin operations and hydraulic controls.

This Final Report presents a comprehensive and detailed description of the Paso Robles Groundwater Basin, through the development and use of the model as a tool. The scope of the Phase II project included:

- Task 1 presented the conceptual model developed in the Phase I work within the context of developing a numerical model, and documented the steps necessary to develop a basin-wide model of the basin;
- Task 2 documented the development and calibration of the numerical model;
- Task 3 reported on the results of model simulations of future build-out scenarios developed to provide insight into long-term conditions in the basin;
- Task 4 performed a sensitivity analysis of agricultural pumpage across the basin; and
- Task 5 consisted of preparation of a final report to document the results of each prior task.

The conclusion of each task was followed by presentation of an Interim Report (the results of Tasks 3 and 4 were combined into a single interim report), which presented the findings of each task and provided an opportunity for review and public comment throughout the process.

The Fugro team, coordinated by the San Luis Obispo County Public Works Department, conducted this Phase II investigation of the Paso Robles Groundwater Basin. An eight-member Technical Review Committee was appointed by the Public Works Department to provide guidance to the consultant team and provide oversight throughout the study through a regular series of meetings (usually by teleconference). An Oversight Committee, consisting of 23 members of the North County Water Resources Forum, provided review and critique of each Task Interim Report. The project team members include:

a. Prime Consultant:

- Fugro West, Inc. - Project Management, Hydrogeology, Geographic Information System (GIS), Admin. Support
  - Paul Sorensen, Associate Hydrogeologist, Project Manager
  - David Gardner, Principal Hydrogeologist
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b. Subconsultants:

- ETIC Engineering, Inc. - Groundwater Modeling, GIS, QA/QC
  - Mehrdad M. Javaherian, Ph.D., P.E., P.Hg., Vice President
  - Michael Maley, Senior Hydrogeologist
- Cleath & Associates - Hydrogeology, Hydrology, Water Quality
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  - David Williams, Staff Geologist

c. County Staff:

- Frank Honeycutt, P.E. - Project Manager, Senior Engineer, Utilities Division

d. Technical Review Committee:

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- Doug Filipponi, water well drilling contractor, agricultural representative
- Lynda Auchinachie, San Luis Obispo County Agricultural Commissioner's Office
- Michael Isensee, San Luis Obispo County Agricultural Commissioner's Office
- Steve Sinton, San Luis Obispo County Water Resource Advisory Committee, agricultural representative
- Frank Mecham, Mayor, City of Paso Robles
- Iris Priestaf, Ph.D., Todd Engineers
- Ken Weathers, CEO, Atascadero Mutual Water Co.

GENERAL BASIN SETTING

The Paso Robles Groundwater Basin is situated in the upper Salinas River drainage of San Luis Obispo and Monterey counties (Figure 1). The basin is located in the large inland valley bounded on the west by the Santa Lucia Range (which separates the North County area from the Pacific Ocean coastal region), on the south by the La Panza Range, and on the east by the Temblor and Diablo ranges. Although most of the basin is within San Luis Obispo County, the basin extends into Monterey County along the northern basin boundary. The basin overlies an area of approximately 505,000 acres (790 square miles); the total watershed area covers about 1,980 square miles.

Topographically, the main, central part of the basin is a large valley of minor relief. The Estrella River, which flows westerly from the Shandon area to north of Paso Robles where it merges with the Salinas River, has formed the broad plain that characterizes the central part of the region. The more significant creeks that flow into the Estrella River and contribute to its flow include Cholame, San Juan, Camatta, and Shedd creeks.

By contrast with the topography that characterizes the Estrella River area, the Salinas River, which drains the basin, flows northerly along the western edge of the basin through rolling hills. Numerous creeks are tributary to the Salinas River between its headwaters and its confluence with the Estrella River, including Santa Margarita, Paloma, Atascadero, Graves, and Paso Robles creeks.

Rolling hills and low ranging mountains surround the basin. To the north and northeast, the Gabilan Highlands and Cholame Hills form a broad range of hills with numerous small drainages and seasonal canyons. To the west and south, the basin is bounded by the Santa Lucia and La Panza ranges, both of which rise to elevations of 4,000 feet or more above the basin floor of about 700 to 900 feet MSL.

The climate of the study area is semiarid, with warm and dry summers accompanied by cool, wet winters. Virtually all rainfall is received in the rainy season from December through March, with precipitation averages ranging from 18 inches or more along the western edge of the basin, to as low as five to eight inches in the eastern portion of the basin.

Historically, development has concentrated along the Salinas River corridor, and somewhat along the Estrella River/Highway 46 East corridor from Paso Robles to Shandon. Although the Salinas River corridor is important for its population center, manufacturing, and commercial development, the historical economic base of the area has been the agricultural industry, both irrigated and non-irrigated, throughout the remaining portion of the basin.

CHAPTER 2 - APPROACH

A numerical model is a mathematical representation of a natural system. The approach to develop a numerical model capable of simulating historical and future conditions depends upon properly incorporating the hydrogeological data from the basin.

EVALUATION OF CONCEPTUAL MODEL

The first step towards developing a sound, defensible numerical model is to ensure that consistency is maintained with the hydrogeological understanding or conceptual model of the basin. The conceptual model describes the geological setting and hydraulic processes for the basin based on a compilation and evaluation of the available data. It serves as the basis for constructing a numerical model. These basic components of the conceptual model necessary to construct a numerical model include the hydrologic budget and aquifer properties. The hydrologic budget describes the amount and location where groundwater enters and exits the basin, and the aquifer properties describe the geologic factors that control the movement of groundwater within the basin. The Phase I Report (Fugro and Cleath 2002) compiled and analyzed the available hydrogeological data for the basin, thereby defining past and current conditions in the basin. The Phase I Report also included development of a conceptual understanding of hydrogeologic conditions, a water quality assessment, and a preliminary hydrologic budget across the basin (Table 1). The quality of the numerical model is highly dependent upon the accuracy of the conceptual model as well as the quality and quantity of the data. Therefore, a comprehensive data collection and conceptual model development, such as the Phase I Report (Fugro and Cleath 2002), is essential to successfully develop a numerical model of the Paso Robles Groundwater Basin.

Because of the complexity of a natural system, assumptions are necessary to define the aquifer properties and boundary conditions required for the numerical model. Although a model is a simplification of the natural system, the numerical model must be constructed in a manner that properly represents the key features of the groundwater basin in order to provide accurate and useful simulation results. In support of numerical model development, a range of reasonable values is defined for aquifer properties and the hydrologic budget based on measured field data and hydrogeological analysis. The general procedure for this process is to define values for a representative elementary volume (REV) as described by Bear and Verruijt (1987). These values represent the major physical features of the basin including surface water–groundwater interactions, recharge and discharge components, definition of model layers, and the distribution of hydraulic conductivity and storage coefficients. This report documents the assumptions that were applied to the development for the Paso Robles Groundwater Model.

DEVELOPMENT OF NUMERICAL MODEL

A numerical model is a mathematical description of the hydrogeological conceptual model. The input data for the numerical model mathematically describe the hydrogeological conceptual model. The advantage of a numerical model is that, once in a mathematical format, the model has the capability to solve the mass balance and motion equations that govern groundwater flow and chemical transport (Bear and Verruijt 1987) to simulate groundwater elevations and chemical concentrations. In this format, the numerical model can produce a quantitative analysis of the groundwater entering and exiting the basin and the rate of groundwater flow through the basin. The model also incorporates spatial distribution of groundwater features and is capable of calculating the combined interference effects of closely located wells or other features.

Model calibration is the next step towards developing a sound, defensible numerical model. Calibration is the process of comparing model simulation results to measured groundwater levels to evaluate the ability of the numerical model to accurately simulate historical conditions in the groundwater basin. The more extensive the calibration process, the more the potential uncertainty in the model simulation results is reduced and confidence in the model's ability to simulate historical and future conditions is improved. For the calibration process, aquifer properties and water balance data are varied within the range prescribed by the conceptual model until the best obtainable fit of simulated versus measured data is achieved. Areas where the numerical model is considered poorly calibrated may indicate locations where the initial estimates of input data were inadequate or that some key component of the hydrogeological conceptual model was not adequately recognized. The former serves as a valuable quality assurance check whereas the latter may provide guidance for future monitoring locations and frequencies where additional data evaluation is needed. Therefore, the numerical model can provide useful guidance on how to allocate resources for data collection.

APPLICATION OF MODEL RESULTS

The Paso Robles Groundwater Model is designed as a regional or basin-wide model to evaluate long-term, regional trends and the overall groundwater inflow and outflow to the basin. Within that scale, conditions are averaged. However, this model may not contain the site-specific details to evaluate some localized conditions that are due to geologic complexity or unique localized effects. For these areas, a more localized model may be required if such a detailed analysis is necessary. The regional model can provide a broader regional context for these localized models.

When evaluating model results, it is important to consider the strengths and limitations of the numerical model. The horizontal and vertical resolution used to construct the model dictates the range of scales that the model can evaluate. The results can be evaluated for overall trends and more localized effects. For example, a regional or basin-wide model will not likely contain the site-specific details of a more localized model, but a regional model will better evaluate a local area within the broader regional context.

Once calibration is achieved, the model is considered capable of simulating future conditions with reasonable accuracy. Input parameters can be set to simulate a wide range of potential future groundwater uses or hydrogeologic scenarios. By modifying the input data, the model provides the capability to simulate a wide range of potential future conditions. The types of future conditions can include natural or climatic variations such as variation in rainfall over time in a drought scenario. Future groundwater practices can also be evaluated such as changes in the amount and distribution of groundwater pumpage, the addition of groundwater recharge programs, or evaluating the benefits of water projects on groundwater conditions. The impact of water quality issues can also be addressed using the model. A numerical model provides another method to estimate perennial yield through balancing the amount of water entering and exiting the basin and the rate of groundwater flow through the basin.

CHAPTER 3 - CONCEPTUAL MODEL SUMMARY

As previously indicated, the conceptual understanding developed for the Phase I Report (Fugro and Cleath 2002) was adapted in support of constructing the numerical model of the basin. This conceptual model summary includes the understanding of geologic and hydrogeologic conditions in the basin, the hydrogeologic budget of the basin, and water quality throughout the basin.

SETTING

The Paso Robles Groundwater Basin is located in northern San Luis Obispo County and southern Monterey County in the Central Coast area of California (Figure 1). The groundwater basin lies within the Salinas River Valley and covers an area of about 505,000 acres or 790 square miles. The basin is asymmetrical. The long axis of the basin extends about 60 miles northwest-southeast roughly paralleling the Salinas River. At its maximum width, the basin is over 25 miles wide in the northeast-southwest direction. The basin is thickest at the center and tapers off to the northern and southern extents.

The Paso Robles Groundwater Basin is subdivided into eight basin areas designated as San Juan, Creston, Atascadero, Shandon, Estrella, South Gabilan, Bradley, and North Gabilan (Figure 1). Due to the presence of bedrock and fault boundaries, the Salinas River corridor area from Atascadero to Templeton is considered a distinct subbasin with restricted hydraulic interaction with the rest of the Paso Robles Groundwater Basin. The remaining basin areas are hydraulically interconnected, with their boundaries defined on the basis of recharge sources, groundwater movement, and the structure of the base of permeable sediments.

GEOLOGY

The boundaries of the groundwater basin are defined by the contact between water-bearing aquifer sediments and older geologic units or fault zones. The primary water-bearing formations are the recent alluvium and Paso Robles Formation. The alluvium consists primarily of sand and gravel and is located along stream channels. Thus, the alluvium occurs as a laterally discontinuous layer across the basin (Figure 2). The alluvium is up to 100 feet thick and typically has higher permeability than the adjacent Paso Robles Formation. Wells screened in alluvium have yields that may exceed 1,000 gallons per minute (gpm). The alluvium receives stream recharge as it is in direct contact with stream channels. Groundwater stored within the alluvium provides a ready source of recharge to the adjacent Paso Robles Formation.

The Paso Robles Formation is comprised of thin, discontinuous sand and gravel layers interbedded with thicker beds of silt and clay. The Paso Robles Formation is continuous across the basin except where offset occurs along fault zones. The thickness of the Paso Robles Formation typically ranges from 700 to 1,200 feet, although it reaches a maximum thickness of 2,500 feet near the junction of the Estrella and Salinas rivers north of Paso Robles (Figure 3). The Paso Robles Formation is unconsolidated with sufficient permeability and thickness to yield several hundred gpm to wells.

Several other geologic formations of low permeability lie adjacent to and beneath the Paso Robles Formation, including the Pancho Rico Formation, an unnamed clastic unit, the Santa Margarita Formation, the Monterey Formation, the Obispo Formation, and the Vaqueros Formation. These formations are considered non-water bearing for modeling purposes and will accordingly not be included in the model; however, it is understood that each of these formations is capable of yielding sufficient water to wells for domestic and other minor uses.

The limited groundwater contribution from these low permeability formations to the Paso Robles Groundwater Basin is accounted for through subsurface inflow calculations in the hydrogeologic conceptual model and via boundary conditions in the numerical model.

The geologic structure of the Paso Robles Groundwater Basin has important implications to the groundwater model. The Paso Robles Formation has been folded and faulted, resulting in significant variations in the base of aquifer sediments and creating abrupt basin boundaries along fault lines. Folding has produced anticlinal and synclinal structures that have created significant elevation differences in the base of the permeable sediments in the basin (Figure 3). The groundwater basin sediments are thickest north and east of Paso Robles and in the Shandon area. The combination of the White Canyon, Red Hills, and San Juan faults form the eastern boundary of the groundwater basin. The Rinconada Fault forms the eastern boundary of the Atascadero subbasin and causes its semi-isolation from the main Paso Robles Groundwater Basin.

To better understand the implications of the geologic structure, several geologic and hydrogeologic cross-sections were constructed across the basin to illustrate the vertical character of the basin. A set of eight hydrogeologic cross-sections was developed that extend across the entire basin (Figure 4). Six of these cross sections (sections A through F on Figure 4) are based on cross sections developed for the Phase I Report (Fugro and Cleath 2002). In addition, two new cross sections (sections G and H on Figure 4) were developed that extend along the long axis of the basin. The purpose of these cross-sections is to evaluate the key hydrogeological relationships in the basin in support of constructing the numerical model. These eight cross-sections are presented on Figures 5 through 12.

HYDROGEOLOGY

The hydrogeologic conceptual model addresses how groundwater flows through the subsurface. For this, the overall groundwater flow of the basin is characterized and the aquifer materials are subdivided into groundwater zones.

Groundwater Zones

To represent the vertical variation in groundwater conditions, groundwater zones were defined by grouping together multiple water-bearing zones. Importantly, rather than attempting to model individual sand and gravel zones which may exist, the separate groundwater zones define thicker intervals as illustrated on Figures 5 and 6. These groundwater zones are represented as separate layers in the numerical model. To represent the aquifer conditions for each groundwater zone, a range of aquifer properties was developed by basin area as representative of the overall hydraulic behavior (Table 2). For example, the hydraulic conductivity was representative of the overall transmissivity across the entire thickness of the aquifer system, rather than for a specific sand and gravel zone.

Four groundwater zones were defined for the Paso Robles Groundwater Basin for use in the numerical model. One groundwater zone represents the recent alluvium deposits and three zones represent vertical variations within the Paso Robles Formation. These groundwater zones are represented in the numerical model as separate model layers.

Model Layer 1 represents the saturated alluvial sediments located along the Salinas and Estrella Rivers. The alluvial deposits vary in thickness, but are generally about 100 feet thick in these main river valleys. The coarse nature of the alluvial sediments results in high permeability and storage capacity.

Groundwater conditions in the zones representing the Paso Robles Formation vary across the basin. For example, the shallow aquifer near Shandon (Figure 6) is considered to be under confined aquifer conditions. Historically, wells in this area have had flowing artesian conditions. To account for these observations, the numerical model defined the “shallow aquifer” as Model Layer 3. Model Layer 2 is defined to include the sediments above this Model Layer 3 including the confining layer. The vertical conductance between Model Layers 2 and 3 was assigned to reflect the observed confined conditions. Similarly, near Creston, the deeper zones are considered confined and have historically been under artesian conditions (Figures 5, 9, and 11). In this area, these deeper zones are defined as Model Layer 4. In this case, the vertical conductance between Model Layers 3 and 4 was assigned to reflect the observed confined conditions.

As recognized from the cross-sections, a key hydrogeologic relationship is the hydraulic connection between the Salinas River (and its many tributaries) with the underlying alluvium and Paso Robles Formation. Surface water flowing along the various streambeds readily percolates into the alluvium and provides a major source of recharge to the groundwater basin. The relationship between the alluvium and Paso Robles Formation is also somewhat complicated by folding of the Paso Robles Formation.

The geologic interpretation of the basin shows that folding of the Paso Robles Formation has brought deeper aquifer zone materials near the surface in parts of the basin. On Figure 5, the folding of the Paso Robles Formation brings the “sand and gravel zones” of the “Main Aquifer” in contact with the alluvium of Huer Huero Creek near Creston. Likewise, Figure 6 illustrates “mostly sand and gravel” of the “Deeper Aquifer Zone” near the center of the basin is in contact with the Salinas River alluvium near the City of Paso Robles. Locations where sand and gravel zones of the Paso Robles Formation have direct contact with the alluvium create enhanced groundwater recharge. These types of vertical relationships are accounted for in the numerical model by defining the deeper zone as Model Layer 4.

Groundwater Flow

In the Atascadero subbasin the alluvium along the Salinas River is generally about 100 feet thick. Groundwater is produced from both the alluvium and Paso Robles Formation (Figures 5 and 8). Hydrographs from alluvial wells typically show limited seasonal fluctuation (Fugro and Cleath 2002). Water levels in the deeper Paso Robles Formation often show seasonal fluctuations up to 100 feet or more. However, the water levels typically recover in the spring. Hydraulic gradients in the Atascadero subbasin typically vary from 0.0007 to 0.002.

In the Creston area the alluvium in Huer Huero Creek and its branches typically approximates 60 feet in thickness. In the Paso Robles Formation, the main water-producing zone is about 100 feet thick and appears to extend from Creston westward (Figures 5, 9, and 11). Near Creston, this zone appears to be in direct contact with the alluvial deposits of Huer Huero Creek providing an apparent direct recharge point. Water level elevations in the Creston area are typically shallow, and artesian conditions have occurred in wells that penetrate into the deeper zones (Figure 9). Water levels in the northern part of the Creston area have recovered more than 50 feet in recent years. In this area, hydraulic gradients are generally on the order of 0.009.

In the Estrella area the alluvium of the Salinas River, Estrella River, and Huer Huero Creek is typically up to 100 feet thick (Figures 6, 8, and 11). The Paso Robles Formation is up to 3,000 feet thick in the northern part of the Estrella area (Figure 8). The deeper aquifer zone has an average depth of 700 feet near Whitley Gardens, but rises to come into contact with the Salinas River alluvium along the western margin of the basin (Figure 6). The shallow aquifer zone is typically tapped by domestic wells up to 400 feet deep, whereas the deeper aquifer zone is tapped by municipal and irrigation wells. The hydraulic gradient in this area ranges from 0.003 to 0.01.

In the San Juan area the lower portion of the Paso Robles Formation, represented by Model Layer 4 (Figures 5, 10, and 12), rises to the surface. Groundwater is primarily produced from the deeper regions of the Paso Robles Formation (Figures 5, 10, and 12). In portions of this area, sand and gravel sequences of several hundred feet have been reported. Water levels have shown both rising and falling conditions over the hydrologic base period indicating the localized effects of heavy agricultural pumping and areas of significant stream recharge in this area. Hydraulic gradients range from 0.006 to 0.01.

In the Shandon area the basin thickens to approximately 2,000 feet (Figures 6, 10, and 12). Groundwater is typically produced from the upper parts of the Paso Robles Formation. Historically, flowing wells have been noted on the north flank of the Estrella River floodplain (Figure 6). The source of the artesian pressure is inferred to be from subsurface flow from the north along canyons draining the Cholame Hills (Figure 6). Poor water quality typically limits water production from the shallow alluvium.

In the North and South Gabilan areas, the Paso Robles Formation has been folded into a broad syncline with a thickness of approximately 1,000 feet (Figures 7, 9, and 12). Production zones are comprised of sand and gravel zones in the upper portion. In several of the canyons cutting across this area, groundwater rises to the surface and flows or ponds on the ground. Hydraulic gradients are on the order of 0.002.

The Bradley area is located near the confluence of the Nacimiento and San Antonio rivers with the Salinas River. This is the primary area of natural groundwater discharge from the basin. Alluvial deposits are generally 60 to 100 feet thick. The Paso Robles Formation thins to less than 500 feet thick at the northern basin margin (Figures 7 and 11). Evidence of confined to semi-confined aquifer conditions in the deeper zones exists based on pumping test results and electric logs. Much of the Bradley area is in southern Monterey County where only limited groundwater elevation data are available.

Groundwater elevation maps for Spring 1980, Fall 1990, Spring 1997, and average conditions for 1954 are shown on Figures 13 through 16. As shown, groundwater has historically flowed from the higher elevation areas along the basin margin and converges towards the Salinas River in the northwestern portion of the basin. The primary natural outflow of groundwater from the basin is discharge into the Salinas River and subsurface outflow through the northwestern margin of the basin. More specifically, in the southeastern portion of the basin, groundwater generally flows northwesterly from the San Juan area into the Shandon area and eventually into the Estrella area. In the southwestern portion of the basin, groundwater flows northerly from the Creston area into the Estrella area. In the northeastern portion of the basin, groundwater flows westerly through the North and South Gabilan areas towards the Bradley and Estrella areas. In the Bradley and Estrella areas, groundwater generally is converging towards the Salinas River and northwestern subsurface outflow discharge areas from the basin.

HYDROLOGIC BUDGET

The amount of yearly inflow and outflow for each budget component needs to be accounted for geographically within the model domain. A summary of the hydrologic budget prepared in the Phase I Report (Fugro and Cleath 2002) is provided in Table 1, and a summary of the various components is provided below.

The geographic distribution and acreages of various land uses is important to hydrologic budget calculations and to development of the numerical model. Hydrologic budget components such as precipitation recharge and irrigation return flow are based on land uses. The components represent the percolation of water areally distributed at the surface across all or portions of the groundwater basin.

- Average annual precipitation recharge amounted to 43,400 acre-feet per year (AFY) and was estimated to account for 44 percent of the total recharge into the Paso Robles Groundwater Basin.
- Average annual irrigation recharge amounted to 2,300 AFY and was estimated to account for 2 percent of the total recharge into the Paso Robles Groundwater Basin.

Surface water–groundwater interaction is a key element for this model. One of the primary hydrologic budget components is streambed percolation.

Treated wastewater effluent is discharged directly into streams or in recharge ponds adjacent to streams. Water loss due to evapotranspiration is also included as this is primarily related to riparian vegetation found adjacent to streams.

- Average annual percolation of stream flow is 41,800 AFY and was estimated to account for 43 percent of the total basin recharge.
- Average annual recharge from wastewater discharge amounted to 3,300 AFY and was estimated to account for 3 percent of the total basin recharge.
- Average annual evaporation amounted to 3,800 AFY and was estimated to account for 4 percent of the total basin outflow.

The groundwater pumpage represents groundwater extraction for consumptive use. Total groundwater pumpage amounts to an average annual rate of 93,200 AFY, which accounts for about 92% of the annual basin outflow. The pumpage consists of the combination of agricultural, municipal, community, and rural domestic pumpage.

- Agricultural wells account for an average annual basin outflow of 77,700 AFY and were estimated to account for 77 percent of the total basin outflow.
- Municipal wells account for an average annual basin outflow of 10,500 AFY and were estimated to account for 10 percent of the total basin outflow.
- Small commercial systems account for an average annual basin outflow of 900 AFY and were estimated to account for 1 percent of the total basin outflow.
- Rural domestic wells account for an average annual basin outflow of 7,400 AFY and were estimated to account for 7 percent of the total basin outflow.

The subsurface groundwater flow components account for the flow of groundwater to and from the surrounding “non-water bearing bedrock” and the basin sediments. The quantity of subsurface flow was computed by the slope area method using Darcy’s Law in which the rate of discharge through a given cross section of saturated material is proportional to the hydraulic gradient.

- Average annual subsurface inflow is 7,500 AFY and was estimated to account for 8 percent of the total basin recharge.
- Average annual subsurface inflow is 600 AFY and was estimated to account for 1 percent of the total basin outflow.

WATER QUALITY

The Phase I Report (Fugro and Cleath 2002) describes the general water quality of the groundwater basin with respect to general minerals and selected minor constituents. The Phase I Report analysis indicated generally good overall water quality, but noted some areas of rising concentrations of total dissolved solids (TDS), chloride, and nitrate. Potential sources of these three constituents include wastewater discharges, agricultural practices, and irrigation with recycled water.

The Salinas River is a major source of recharge to the Atascadero subbasin. Two surface water samples were analyzed (from 1954 and 1962) from the Salinas River in the Atascadero subbasin at Highway 58. One sample collected at a high stream flow rate and one at low flow showed TDS of about 200 parts per million (ppm) and chloride about 7 ppm. Groundwater samples from eleven wells had average concentrations of 550 ppm for TDS and 70 ppm for chloride. Nitrate concentrations ranged from not detected to 30 ppm.

In the Creston area five surface water samples from Huer Huero Creek from the 1950’s and 1960’s showed average concentrations of 150 ppm for TDS and 17 ppm for chloride. Average concentrations from ten groundwater samples were 490 ppm for TDS and 110 ppm for chloride. Nitrate concentrations ranged from 2 to 41 ppm.

In the San Juan area surface water samples were available from five creeks. Most data are from the 1950’s and 1960’s with one sample from 2001. The concentrations from these samples ranged from 63 to 968 ppm for TDS and from 3 to 58 ppm for chlorides. Eight groundwater samples had average concentrations of 750 ppm for TDS, 160 ppm for chlorides, and ranged from not detected to 56 ppm for nitrates.

In the Shandon area surface water samples were available from Cholame and San Juan Creeks. Concentrations ranged from 440 to 2,380 ppm for TDS, and from 57 to 550 ppm for chloride. Nine groundwater samples had average concentrations of 600 ppm for TDS and 110 ppm for chloride, and nitrate ranged from 6 to 35 ppm. Eight wells with times series data were available. Natural sources of high salinity in the basin include upwelling geothermal waters and groundwater inflow from the sandstone hills near the Shandon area (Fugro and Cleath 2002).

In the Estrella area surface water samples were available from three creeks. Concentrations ranged from 172 to 665 ppm for TDS, and from 6 to 130 ppm for chloride. Sixteen groundwater samples had a range from 350 to 1270 ppm for TDS, 32 to 572 ppm for chloride, and 11 to 71 ppm for nitrate. Evaluation of groundwater chemistry data suggests significant subsurface inflow from the Shandon area (Fugro and Cleath 2002).

In the Bradley area surface water samples were available from three creeks dated from 1954 to 1974. Concentrations from five of six samples were 300 ppm or less for TDS and 27 ppm or less for chloride.

No surface water samples were available for the North and South Gabilan areas. However, six groundwater samples had a range from 380 to 1,320 ppm TDS, 38 to 209 ppm chloride, and not detected to 30 ppm nitrate.

Paso Robles wastewater treatment plant effluent water quality data from 1994-1999 indicate an average TDS concentration of 1,000 ppm (Malcolm Pirnie 2003). A water quality sample collected in January 2000 indicated concentrations of 1,100 ppm for TDS and 320 ppm for chloride. Total nitrogen analyses in 1992 and 1993 ranged from 2.1 to 14 ppm.

CHAPTER 4 - NUMERICAL MODEL

The basic components of the conceptual model required to construct a numerical model describe how groundwater enters and exits a defined system and the geologic factors that control groundwater flow.

MODEL SETUP

The numerical model was constructed using the groundwater flow model MODFLOW 2000 (Harbaugh *et al* 2000), a finite-difference numerical model developed by the United States Geological Survey (USGS). To facilitate model development, the MODFLOW/MT3D processor Groundwater Vistas 3 (ESI 2001) was used. The use of the industry standard modeling code MODFLOW 2000 along with a commercial processor supports future usability of the model.

Model Domain

The model domain is the geographical area covered by the numerical model. The model domain for the Paso Robles Groundwater Model includes the entire Paso Robles Groundwater Basin; however, the area identified as unsaturated in the northeastern portion of the basin was excluded from the numerical model. Therefore, the active area of the groundwater model covers about 469,830 acres or 734 square miles (Figure 1).

The model grid provides the mathematical structure for developing and operating the numerical model. The Paso Robles Groundwater Model used a uniform grid spacing of 660 feet (Fugro, ETIC, and Cleath 2003). The model grid is comprised of 368 rows and 352 columns; therefore, each model layer is comprised of 129,536 model grid cells. The entire four-layer model contains a total of 518,144 model grid cells.

Model Layers

Model layers provide vertical resolution for the model to simulate variations in groundwater elevation, aquifer stresses, and water quality with depth. The Paso Robles Groundwater Model consists of four layers that simulate the primary water-bearing formations consisting of the recent alluvium and Paso Robles Formation. Because the alluvium has distinct aquifer properties and is closely linked with streamflow recharge, it is defined as a distinct model layer. The Paso Robles Formation was divided into three model layers. The primary purpose of this is to preserve the hydrologic relationships that were outlined in the preceding section on hydrogeology.

The upper surface of the model represents the basin topography (Figure 18) and is based on a Digital Elevation Model (DEM) file from the USGS. The top and bottom elevations of each model layer were derived from the basin-wide cross-sections (Figures 5 through 12). To create the model layers, a digital structure contour map was developed for each layer. These layers were terminated at the topographic surface. These maps were then directly imported into the numerical model.

Model Layer 1 represents the recent alluvium and was defined as a separate model layer due to its distinct aquifer properties. The distribution of this layer was primarily restricted to the Salinas and Estrella River valleys where the alluvium was sufficiently wide and thick (Figure 19). The thickness of Model Layer 1 was based on descriptions that the alluvial thickness along the Salinas and Estrella valleys was a maximum of about 100 feet thick (Fugro and Cleath 2002). Therefore, the bottom elevation of Model Layer 1 was defined as 100 feet below the river elevation based on the USGS DEM file.

The Paso Robles Formation was divided into three model layers. The general synclinal form of the Paso Robles Basin causes the younger portion of the sequence to be limited in distribution to the center of the basin. Model Layer 2 represents the upper portion of the Paso Robles Formation. Its distribution is limited to the center of the basin between Paso Robles and Shandon. Figure 20 shows the distribution of Model Layer 2 in the model and the total model thickness, which ranges up to approximately 800 feet in the Shandon area. However, Model Layer 2 is only partially saturated over much of its distribution. Therefore, the saturated thickness of Model Layer 2 would be less, ranging from near zero at the outer edge of its distribution to a maximum thickness of about 500 feet thick in the Estrella area. Saturated thicknesses generally range up to 100 feet over the active area of Model Layer 2.

Model Layers 3 and 4 are subdivisions of the main aquifer portion of the Paso Robles Formation. Defining two separate layers for this interval allows for more flexibility in simulating vertical differences including groundwater elevations, distribution of pumping, and other hydrologic budget components. Similarly, due to the synclinal form of the basin, Model Layer 3 extends over most of the model area, but generally does not extend to the outer edge of the basin (Figure 21). The saturated thickness of Model Layer 3 ranged from near zero at the outer edge of its distribution to a maximum thickness of about 750 feet in the Estrella area. Thicknesses generally range from 200 to 500 feet over most of the active area of Model Layer 3.

Model Layer 4 represents the deepest portion of the Paso Robles Formation and is interpreted as existing everywhere in the basin (Figure 22). The saturated thickness of Model Layer 4 ranged from about 100 feet in the Creston area to a maximum thickness of about 2,400 feet in the Estrella area. Thicknesses generally range from 200 to 700 feet over most of the active area of Model Layer 4.

The narrow extensions of Model Layers 2 and 3 along the Salinas and Estrella river valleys were input to allow for hydraulic connection between the alluvium and deeper model layers. A requirement of MODFLOW is that model layers must be continuous for groundwater flow between layers to occur. Therefore, in portions of the basin where the alluvium of Model Layer 1 is interpreted as setting directly on the deeper Paso Robles Formation represented by Model Layers 3 or 4, the missing intervening model layers had to be included to allow for groundwater exchange to properly occur within the model. In these cases, a thin layer was included directly beneath Model Layer 1. The aquifer properties were set to allow for groundwater flow to occur between the non-adjacent layers.

Stress Periods

To simulate changing conditions over time requires the definition of stress periods that represent the resolution of time into discrete intervals. For the Paso Robles Groundwater Model, six-month-long stress periods were used. These were designed to approximately correlate to the wet season/dry season character of the California climate and standard agricultural irrigation practices. In addition, groundwater elevation data are typically collected in the spring and fall. The stress periods run from October through March and April through September. These times typically also represent the times of highest and lowest groundwater elevations during a particular year. Therefore, a six-month stress period is considered an appropriate time length for long-term groundwater basin studies. To simulate the 17-year base period of 1981 to 1997 (Fugro and Cleath 2002), the model required 34 stress periods.

BOUNDARY CONDITIONS

Model boundary conditions represent the hydrologic budget by simulating where groundwater enters and exits the basin. Boundary condition data must be entered for each stress period at each model grid cell where a boundary condition is defined in the model. MODFLOW 2000 provides a number of boundary condition options to numerically represent the different physical processes included in the hydrologic budget.

The geographic distribution and acreages of various land uses is important to hydrologic budget calculations and to development of the numerical model. The amount of yearly inflow and outflow for each budget component needs to be accounted for geographically within the model domain. Some of the model input parameters involve hydrologic budget components that are based on the distribution of land uses, such as precipitation recharge, irrigation recharge, and agricultural groundwater pumping. A discussion of each component of the hydrologic budget is provided below.

Land-Use Dependent Components

Hydrologic budget estimates for precipitation recharge, agricultural pumpage, and irrigation return flows were based on land use data (Fugro and Cleath 2002). The geographical distribution of these components in the numerical model was based on the available land use mapping data. Land use mapping of San Luis Obispo County was conducted in 1977, 1985, and 1995. Land use mapping of Monterey County was conducted in 1989 and 1997. Land use data for 1995 (San Luis Obispo County) and 1997 (Monterey County) are already available in electronic form as a GIS coverage (Figure 23). Land use data for 1985 (San Luis Obispo County) and 1989 (Monterey County) were digitized as part of the Phase II Study into GIS files (Figure 24).

Numerical model input for the base period years of 1981 through 1989 was based on the 1980’s mapping data (Figure 24), and model input for the base period years of 1990 through 1997 was based on the 1990’s mapping data (Figure 23). The land use areas were held constant during these intervals; however, the volume of water applied through these boundary conditions was varied for each stress period based on the hydrologic budget data.

Precipitation Recharge

Precipitation recharge represents groundwater inflow resulting from the portion of rainfall that falls directly onto the basin sediments and percolates downward to the groundwater. Precipitation recharge is dependent upon multiple factors including amount of precipitation, land use, surface topography, and soil moisture conditions. The variability of precipitation across the Paso Robles Basin is minimal. The primary precipitation differential is between the upland and basin areas. The higher precipitation of the upland areas is represented by the streambed recharge. Conversely, there is high variability in land use across the basin. The distribution of precipitation recharge was primarily based on land use maps (Figures 23 and 24). The Phase I Report (Fugro and Cleath 2002) further refined these land use areas by type of crop and estimated the amount of groundwater recharge for each crop type.

Precipitation recharge was incorporated into the model using the MODFLOW recharge package. The amount of precipitation recharge was allowed to vary year by year based on measured rainfall data for the basin (Fugro and Cleath 2002). In the model, total precipitation recharge over the base period totaled 693,600 acre-feet for an annual average of 40,800 AFY. The annual precipitation was distributed as 85% in the winter stress period and 15% in the summer stress period to represent the typical seasonal precipitation pattern. The annual distribution of precipitation recharge applied to the model is shown in Table 3.

To adapt the land use data for model input, the land use data were totaled over one square mile areas of the model (Figure 25). The proportion of precipitation recharge was calculated for the different land use types within the square mile area. A recharge rate was then applied to all 64 model cells within the square mile area. Recharge from precipitation and irrigation return flows were incorporated together in the MODFLOW recharge package.

Irrigation Return Flow

Irrigation return flow represents the component of the hydrologic budget inflow that accounts for the portion of irrigation water that percolates back to the groundwater. Similar to precipitation recharge, the distribution of irrigation return flow was based on the land use data files for San Luis Obispo and Monterey Counties (Figure 23 and 24). The total irrigated acreages within one square mile areas were totaled (Figure 26), and the proportional amount of irrigation return flow was applied. In accordance with the methodology used in the Phase I Report for calculating irrigation recharge, the amount of calculated irrigation recharge for each year was divided by the total area of irrigated acreage. All irrigated acreages were assumed to receive the same yearly rate of irrigation recharge.

Irrigation return flow was input into the model using the MODFLOW recharge package. In the model, the recharge from irrigation return flow over the base period was 38,600 acre-feet for an annual average of 2,300 AFY. The annual irrigation return flow was distributed as 15% in the winter stress period and 85% in the summer stress period to reflect typical irrigation practices. The annual distribution of irrigation return flow is included in Table 3. Irrigation return flow accounts for about 2% of the total recharge in the model. Precipitation recharge and irrigation return flows were incorporated together in the MODFLOW recharge package.

Stream Recharge

Stream recharge represents the portion of streamflow that percolates to groundwater. This hydrologic budget component primarily accounts for water that falls as precipitation on the surrounding upland areas and enters the basin as surface water in a stream or river. The interaction of surface water and groundwater can result in either the percolation of streamflow through the streambed to the groundwater or the discharge of groundwater to the stream. This is primarily determined by the relative difference in elevation between the groundwater and the water surface of the stream. The amount of flow is also controlled by the hydraulic conductivity of the streambed materials and the amount of surface water flow in the stream itself.

For the Paso Robles Groundwater Model, the MODFLOW stream package was used to incorporate surface water–groundwater interaction into the model. The distribution of the stream network included in the model is shown on Figure 27. The MODFLOW stream package provides the capacity to input estimated streamflow data into the model to account for the widely varying streamflows that are observed in the Paso Robles Groundwater Basin. The stream package requires that stream discharge be entered at the uppermost stream boundary cell. The other required input data include streambed conductance and elevation. The streambed elevation was derived from USGS topographic contour maps. The streambed conductance was determined during calibration. The conductance term includes the depth, width, and length of the stream segment in a model cell, and the transmissivity of the streambed materials based on an estimate of the streambed thickness and hydraulic conductivity. MODFLOW will allow either gaining or losing stretches along the streams based on the relative difference between the stream stage and groundwater elevations to represent groundwater-surface water interactions.

The total estimated average annual percolation of stream flow in the model was 46,000 AFY. Recharge from streambed percolation is estimated to account for 39 percent of the total recharge into the Paso Robles Groundwater Basin. The annual distribution of stream recharge is included in Table 3.

Since many of the streams in this area are ephemeral, or only flow during periods of rain, the flow rates of these streams are highly variable. These can typically range from extended periods of no flow during the summer months to short periods of very high flow during high intensity rainfall events. An estimated amount of streamflow available for groundwater recharge is input at the first cell of a stream segment. The annual distribution of stream recharge by stream is included in Table 4. The MODFLOW stream package allows that surface water flow can be varied and provides a mechanism that limits the net recharge to the total streamflow into the model. If not all of the input water is recharged to the groundwater, then MODFLOW allows it to continue to flow downstream without impacting the groundwater basin. In addition, if a net discharge of groundwater to the stream occurs, then the MODFLOW stream package also acts as a groundwater outflow boundary.

Wastewater Discharge Percolation

Wastewater treatment plants are operated adjacent to the Salinas River by the cities of Atascadero and Paso Robles. Effluent from these plants is either discharged directly to the Salinas River or to recharge ponds in the alluvium adjacent to the river. Since these facilities are located along the Salinas River (Figure 27), they were incorporated into the model using the MODFLOW stream package. Recharge from wastewater discharge was input into the model using the same values as in the Phase I Report (Fugro and Cleath 2002) with a total discharge over the base period of about 55,600 acre-feet for an annual average of 3,300 AFY. The annual distribution of wastewater discharge is included in Table 3.

Implementation of wastewater discharges into the model requires assignment of discharge amounts by stress period. Review of monthly discharges indicates relatively constant monthly discharges for Paso Robles, whereas significant monthly variations in discharge are apparent for Atascadero. Atascadero wastewater treatment plant data indicate higher discharges in winter compared to summer. Most of this discrepancy is due to golf course irrigation with recycled water. Therefore, the amount of wastewater discharge is varied according to year and season. During the base period used for the model, wastewater from Templeton was discharged at the Paso Robles wastewater treatment plant, and was, therefore, incorporated into the Paso Robles data. Subsequently, Templeton has begun operation of a separate wastewater facility.

Groundwater Pumpage

Groundwater pumpage is the most significant groundwater outflow component for the basin. Groundwater pumpage is represented in the MODFLOW model using the well package. For the MODFLOW well package, the amount of pumping is specified for each well location. To import the pumpage data into the model, a GIS shapefile was developed that contained model layer and pumping rates for each 6-month stress period. Model layer assignments were based on well screen intervals for each individual well. In the model, pumpage includes a combination of municipal, small commercial and community, agricultural, and rural domestic pumpage. Below is a more detailed discussion of each.

Municipal Wells

The municipal groundwater pumpage category includes Atascadero Mutual Water Company, Templeton Community Services District, City of Paso Robles, and San Miguel. The locations of the municipal wells input into the model are shown on Figure 28. Monthly pumping amounts by well were available for most of the municipal wells. However, monthly pumping data were not available from City of Paso Robles wells prior to 1990 and for the San Miguel well(s). For wells with monthly pumping records, pumping amounts for each stress period were summed from existing data. For wells with at least some years of missing monthly data, estimates were made for each stress period based on available data. The pumping rates were based on the pumping records and were input as reported in the Phase I Report (Fugro and Cleath 2002) and were not changed during model calibration. The total municipal pumpage over the base period was about 177,500 acre-feet for an annual average of 10,440 AFY. Approximately 70 percent of the municipal pumping occurred during the summer stress period based on the monthly records.

Small Commercial and Community Pumpage

This groundwater pumpage category includes water demand from hospitals, golf courses, schools, and commercial entities not covered in the other categories. Of the list of small commercial water systems provided in the Phase I Report (Fugro and Cleath 2002), 15 systems could be specifically located on a map (Figure 28); these were located within the groundwater basin boundary, and had water production data available in project files.

The pumping rates were based on the pumping records and were input as reported in the Phase I Report (Fugro and Cleath 2002) and were not changed during model calibration. The small commercial system pumpage over the base period was about 15,300 acre-feet for an annual average of 900 AFY. The annual pumpage was distributed as 70 percent occurring during the summer stress period and 30 percent in the winter stress period based on the distribution of the municipal pumpage records.

Agricultural Pumpage

Agricultural pumpage includes groundwater extraction used for agricultural purposes with irrigation being the primary use. Since agricultural pumpage accounts for the largest portion of the total basin groundwater outflow (Table 3), the proper distribution of this pumpage over the model domain is a key element for calibrating the model. The distribution of agricultural pumpage was based on well location maps, land use maps, and a field reconnaissance.

The well location maps were produced by San Luis Obispo County Flood Control and Water Conservation District in 1990 on 7.5 minute topographic quadrangle maps. Thus, the well location maps are representative of active agricultural wells during the study period. Well location and land use maps were used during field reconnaissance to identify locations of agricultural wells associated with various irrigated agricultural land uses. For areas shown as irrigated agricultural areas on the land use map where no well was located, an agricultural well was assumed to exist approximately in the middle of the agricultural field shown on the land use map. Agricultural well characteristics were used to assign groundwater pumping to the most appropriate layer or layers for each well in the model (Figure 29). The Water Well Drillers Reports for agricultural wells were reviewed to compile characteristics of each well related to depth, screened interval, and formation screened.

Agricultural groundwater pumping is not metered in the basin; therefore, pumpage was calculated in the Phase I Report (Fugro and Cleath 2002) on the basis of crop types and other factors. The distribution of pumpage over time was based on two land use maps, one for the 1980's and the other for the 1990's. Each irrigated agricultural land use category was assigned an irrigation water application rate. These irrigation application rates were based generally on the crop type and acreage, and the monthly crop coefficients from the Phase I Report (Fugro and Cleath 2002). Agricultural pumpage over the base period was about 1,380,000 acre-feet for an annual average of 81,200 AFY (Table 3). The annual pumpage was distributed as 85 percent occurring during the summer stress period and 15 percent in the winter stress period.

Rural Domestic Pumpage

The rural domestic groundwater pumpage consists of the water demand for rural residential developments. The distribution of pumping for rural domestic wells was based on the distribution of Water Well Drillers Reports (wells with 6-inch diameter or less) by township. Since pumping records for rural domestic pumping do not exist, each township was assigned to have a percentage of the total rural domestic pumping based on the number of wells (6-inch diameter or less) contained in that township divided by the total number of wells in the basin (731). The total pumpage for each township in the model was assigned uniformly to the rural domestic pumping wells located in that township. The pumping was distributed uniformly across the township (Figure 30). The number of households for each year was estimated from population data, and the total number of households was multiplied by a water duty factor to obtain the total annual water use.

The total rural domestic pumpage was based on the Phase I Report (Fugro and Cleath 2002) and was not changed during model calibration. The rural domestic pumpage over the base period was about 126,000 acre-feet for an annual average of 7,400 AFY. The annual pumpage was distributed as 70 percent occurring during the summer stress period and 30 percent in the winter stress period based on the distribution of the municipal pumpage records. The wells were placed in the highest active model layer at each location (Figure 30). However, if Model Layer 2 was the highest active layer, then the well was placed in Model Layer 3 using the assumption that Model Layer 2 did not support significant pumpage.

Subsurface Inflow

The subsurface groundwater inflow accounts for groundwater inflow into the basin from the surrounding “non-water bearing bedrock”. Based on the Phase I Report, the amount of subsurface inflow was applied around the margin of the basin. This subsurface inflow was input into the model using the well package. The inflow was input as a region of recharge wells along the margin of the basin in Model Layer 4 (Figure 31). In the model, this general margin of subsurface inflow was kept the same with only minor exceptions to the data presented in the Phase I Report (Fugro and Cleath, 2002). Minor modifications were made during the calibration process to increase groundwater elevations in areas of the Atascadero subbasin, Creston, and San Juan areas. These changes accounted for less than a 400 AFY increase in recharge into the basin. The total recharge over the base period was about 134,300 acre-feet for an annual average of 7,900 AFY. The annual distribution of subsurface inflow is included in Table 3.

Areas of elevated local subsurface inflow were added where the groundwater model required significant additional recharge that was not accounted for in the Phase I Report hydrologic budget. These areas were identified during model calibration as areas where insufficient inflow was available to simulate the measured groundwater elevations. These areas of elevated local subsurface inflow are limited to three areas around the margins of the basin and are characterized by both high groundwater elevations and high topography. Because the annual groundwater inflow was not specified in the Phase I Report, these areas were simulated in the groundwater model using a head-dependent boundary condition (Figure 31). Specifically, these areas were simulated by:

- A MODFLOW constant head boundary with an elevation of 1,425 feet above mean sea level (amsl) in the Creston area.
- A MODFLOW constant head boundary with an elevation of 1,425 feet amsl in the area north of Paso Robles.
- A MODFLOW general head boundary with an elevation of 1,450 feet amsl in the South Gabilan area.

Subsurface Outflow

Subsurface outflow represents the flow of groundwater into the sediments and rocks adjacent to the groundwater basin. The only area of subsurface outflow specified in the model is located along the northwestern margin of the basin near San Ardo where the Salinas River exits the basin (Figure 31).

Subsurface outflow was simulated using the MODFLOW constant head package. The amount of groundwater flowing into or out of this boundary is influenced by the relative hydraulic gradient between the basin and the boundary condition. In Model Layer 1, a constant head boundary was input with an elevation of 425 feet amsl. This boundary simulates groundwater flow through the alluvium north out of the model domain. In Model Layer 4, another constant head boundary was input with an elevation of 430 feet amsl to represent the upward groundwater gradient assumed for this area. The majority of the flow is, therefore, designed to flow through Model Layer 1.

Evapotranspiration

Evapotranspiration represents the component of groundwater outflow from evaporation to the atmosphere and uptake by plants. The Phase I Report (Fugro and Cleath 2002) included evapotranspiration only for the riparian areas along the Salinas River. The model includes the capacity for evapotranspiration throughout the model. Two evapotranspiration rates were defined in the model (Figure 32). Evapotranspiration due to extraction by phreatophytes in riparian zones was included in the Phase I Report (Fugro and Cleath 2002). These riparian zones were primarily concentrated along the lower Salinas River north of San Miguel, and were therefore defined as a distinct zone in the model. Across the remainder of the model, evapotranspiration rates were estimated based on an average reference evapotranspiration rate of 49.0 inches per year for Paso Robles by the University of California (UC Publication 21426, Snyder *et al* 1992). An evapotranspiration rate of 14 inches was used for the winter stress period, and 35 inches was used for the summer stress period.

The MODFLOW evapotranspiration package was used to input these data into the model. Evapotranspiration is also a head dependent boundary condition. The ground surface elevation provided with the topographic data was used as the reference elevation. An evapotranspiration depth limit of 10 feet was used for the phreatophyte area, and 5 feet was used for the basin area. Because of this, evapotranspiration only impacts shallow groundwater and is most prominent in the alluvium (Model Layer 1) especially in the northern part of the basin, and in the summer after a heavy rainfall season.

AQUIFER PROPERTIES

Aquifer properties represent the hydrogeologic characteristics within the basin. Specifically, aquifer properties describe the physical characteristics of the aquifer and the hydraulic properties that control groundwater flow. As discussed in the conceptual model, the numerical model consists of four model layers that correlate with the geological formations and are representative of the hydrogeological conditions discussed in the Phase I Report. The numerical model requires that these properties are defined for every active cell in the model.

Aquifer properties must be assigned to each active grid cell in the model. The Phase I Report provides the data necessary to define aquifer properties. Extrapolation methods to define properties in areas with insufficient data have been performed using science-based assumptions based on the conceptual model. Reasonable value ranges for each have been defined and have been used to guide model calibration. Specific aquifer properties are summarized below.

Hydraulic Conductivity

For the numerical model, hydraulic conductivity is defined horizontally within a model layer and vertically between adjacent model layers. Rather than attempting to model individual sand and gravel zones, the model layers define thicker intervals that represent subdivisions of the basin aquifer system. The hydraulic conductivity for these layers represents an average value for the entire interval. For example, the hydraulic conductivity represents the overall transmissivity across the entire thickness of the aquifer system, rather than for a specific sand and gravel zone.

Hydraulic conductivity was defined in regionalized blocks per model layer. During the calibration process, the hydraulic conductivity values were varied within a reasonable range of values. Hydraulic conductivity data based on pumping test results compiled in the Phase I Report (Fugro and Cleath 2002) are summarized on Table 2 for each basin area and geologic formation. There are no pumping test results available for the Paso Robles Groundwater Basin to estimate the vertical hydraulic conductivity. Therefore, the vertical hydraulic conductivity was estimated based on lithologic descriptions. The vertical hydraulic conductivity was also used as a major model calibration parameter. Values were increased or decreased to allow more or less groundwater flow between model layers in order to better match groundwater elevation data in specific areas.

The hydraulic conductivity values used in the groundwater model are presented in Figures 33 through 36 for Model Layers 1 through 4, respectively. The highest hydraulic conductivities were used in Model Layer 1 (Figure 33). The hydraulic conductivities ranged from 50 to 500 feet per day (ft/d) with the highest values in the Salinas River alluvium. Vertical hydraulic conductivities ranged from 0.02 to 1 ft/d.

The main area of Model Layer 2 has lower hydraulic conductivities to represent lower permeability sediments (Figure 34). The horizontal hydraulic conductivity was 0.5 ft/d and the vertical hydraulic conductivity was set at 0.001 ft/d. Other areas in Model Layer 2 represent the interlayers where Model Layer 2 is physically absent, but needed by the model to allow groundwater interaction with the lower model layers. In these areas, the vertical hydraulic conductivity was increased so the interlayer did not inhibit flow between non-adjacent layers. Model Layer 3 interlayer areas were handled similarly.

Model Layers 3 and 4 represent the main aquifer zones of the Paso Robles Formation; therefore, a similar range of values of hydraulic conductivity was used (Figures 35 and 36). The hydraulic conductivities ranged from 0.5 to 20 ft/d, and vertical hydraulic conductivities ranged from 0.005 to 1 ft/d.

Storage Coefficient and Specific Yield

A limited amount of storage coefficient and specific yield data were available from aquifer test data. These data based on pumping test results compiled in the Phase I Report (Fugro and

Cleath 2002) are summarized on Table 2 for each basin area and geologic formation. The specific yield data were presented in the Phase I Report as average values per basin area.

The storage coefficient values used in the groundwater model are also presented in Figures 33 through 36 for Model Layers 1 through 4, respectively. Since Model Layer 1 was set as entirely unconfined, only the specific yield was required by the model. A specific yield of 0.17 was used for the alluvium throughout Model Layer 1 (Figure 33).

Model Layer 2 was set within MODFLOW as convertible between confined and unconfined conditions, so both a confined storage coefficient and specific yield value are required. In the main area of Model Layer 2, the storage coefficient was set to 0.00001 and the specific yield at 0.01 (Figure 34). The interlayer areas in Model Layer 2 used values similar to the alluvium with the storage coefficient set to 0.015 and the specific yield at 0.17.

Similarly, both a confined storage coefficient and specific yield value were defined for Model Layers 3 and 4 (Figures 35 and 36). The storage coefficient ranged from 0.0005 to 0.015, and the specific yield ranged from 0.05 to 0.17.

Rinconada Fault

The Rinconada Fault forms the eastern boundary of the Atascadero subbasin. This fault forms a leaky boundary between the Atascadero subbasin and the main part of the Paso Robles Groundwater Basin. The fault was simulated using the Horizontal Flow Boundary Package in MODFLOW that allows for a separate hydraulic conductivity to be placed between model cells. Since no hydraulic conductivity data exist for the Rinconada Fault zone, the hydraulic conductivity was estimated during model calibration. The fault was placed in Model Layers 3 and 4. The fault was simulated as a 10-foot wide zone with a hydraulic conductivity of 0.01 ft/d.

WATER QUALITY MODEL COMPONENT

A water quality model was incorporated into the model using MT3D (Zheng and Wang 1999) to simulate water quality issues, particularly salinity (total dissolved solids (TDS) and chlorides) and nitrates. Although no scenarios were developed during this phase of the work that required simulations using the water quality model, the chemical parameters that can be used in the model were compiled from site-specific information and the model is available for simulation runs. The interaction of the flow model and water quality model component will allow for detailed evaluations of the water quality issues identified in the Phase I effort (Fugro and Cleath, 2002).

CHAPTER 5 - NUMERICAL MODEL CALIBRATION

Model calibration is the process of testing the accuracy of the model results by comparing the model simulated groundwater elevations to measured groundwater data from the basin. During the calibration process, the aquifer properties and boundary conditions are varied within an acceptable range until the closest fit of the simulated versus measured data is achieved. This comparison of observed versus simulated groundwater elevations is based on data from 180 wells. The locations of these wells are shown on Figure 37.

For the Paso Robles Groundwater Model, calibration consisted of an initial steady-state calibration that was followed by a more detailed transient calibration. This extensive calibration process was designed to better constrain the range of aquifer properties and boundary conditions for the model, thereby improving the accuracy and reliability of the model results.

STEADY-STATE CALIBRATION RESULTS

As an initial step, a steady-state groundwater flow model was constructed and calibrated for the Paso Robles Groundwater Basin. A steady-state simulation solves for groundwater elevations for a single stress period that is considered not to change over time. A steady-state calibration is typically evaluated using average conditions over a period of time. The primary purpose of the steady-state model was to serve as a time-effective process to develop the general spatial distribution of aquifer properties and boundary conditions. With such a large and complex numerical model, the time required to run the model was significantly shorter for the steady-state model. This is especially important during the early stages of model development. The steady-state calibration is considered as only one step in the model calibration process. Therefore, the discussion of the steady-state calibration is limited, and the transient calibration is considered the final model calibration.

The steady-state model was set up using a single stress period for the 17-year base period. The boundary conditions were based on an arithmetic average of the hydrologic budget components. The observed groundwater elevations used as calibration targets were also an arithmetic average for all water levels measured during the 17-year base period. The results of the model calibration are shown on Figure 38. This comparison of observed versus simulated groundwater elevations, based on data from 180 wells, shows a clear linear relationship indicating a strong correlation. Variations are attributed in part to averaging of groundwater elevations in parts of the basin where the range in groundwater elevations over the 17-year base period is quite large, exceeding 100 feet in some cases. The close overall fit indicated that the general groundwater flow pattern was being accurately simulated, and that the general spatial distribution of aquifer properties and boundary conditions were in order. The results of the steady-state model were used as the initial groundwater elevations for the transient model.

TRANSIENT CALIBRATION RESULTS

The transient calibration includes the simulation of changes in groundwater elevations over time. For the Paso Robles Groundwater Model, the period is the 17-year base period from 1981 to 1997. This aspect of the calibration is important to demonstrate that the model has the capability to simulate historical changes in groundwater elevations, and is therefore capable of forecasting future changes in groundwater elevations. This capability is necessary for the model to serve as a useful groundwater management tool.

Calibration Criteria

The Paso Robles Groundwater Model was calibrated using the developed calibration criteria to reduce uncertainty by matching model results to observed data. An extensive calibration process was designed to better constrain the range of aquifer properties and boundary conditions for the model, thereby reducing uncertainty in the results.

There are multiple combinations of aquifer properties and boundary conditions that can be used to match a single set of groundwater elevation data. Calibrating to multiple data sets under differing stresses (i.e. recharge and discharge rates) reduces this “non-uniqueness”, thereby reducing the uncertainty. Performing a comprehensive calibration over a 17-year base period infers the calibration has been performed over wet, dry, and normal years with varying degrees of pumping. To that end, the Paso Robles Groundwater Model was calibrated using three separate criteria. These criteria include:

- Groundwater Elevation Maps
- Statistical Analysis
- Hydrographs

It should be noted that some degree of difference or residual between the observed and simulated groundwater elevations is expected. Residuals may be due in part to localized effects or data quality issues. For example, residuals can result from using groundwater elevations from pumping wells as calibration targets. MODFLOW calculates the groundwater elevation for the center of a model cell rather than at the well location itself. MODFLOW also does not take into account the impact of well efficiency on groundwater elevations at pumping wells. In addition, the timing of the observed groundwater elevations does not exactly match the model stress periods.

Groundwater Elevation Map Calibration

The first and most basic model calibration criterion is a direct comparison of simulated versus measured groundwater elevation maps for select time periods. The primary purpose of this calibration is to compare hydraulic gradients for both magnitude and direction to ensure that the model is accurately simulating existing conditions. This visual comparison is a fast method to determine where additional model calibration efforts should be focused.

In the Phase I Report (Fugro and Cleath 2002), a series of hand-drawn groundwater elevation maps were developed based on the measured groundwater elevation data. Maps were constructed for 1954, Spring 1980, Fall 1990, Spring 1997, and Fall 1997 (Figures 13 through 16). These maps were developed for the Paso Robles Formation and did not separate the basin into separate depth intervals, thereby limiting the degree to which a direct comparison of model results to these hand-drawn maps can be made.

Figures 39 through 42 provide the simulated groundwater elevation maps for Fall 1997 for Model Layers 1, 2, 3, and 4, respectively. These figures show that the steeper hydraulic gradients are observed along the basin margin, and the gradients flatten toward the center of the basin. In general, groundwater flow is primarily toward the primary pumping areas in the center of the basin near Shandon and east of Paso Robles. The groundwater contours continue to converge towards the Salinas River in the area north of San Miguel to the basin boundary near San Ardo. The direction and magnitude of the hydraulic gradient as expressed by the contours is very similar to the maps from the Phase I Report. A comparison of the contour locations shows some variability, but the overall contour patterns compare favorably between model and hand-drawn maps. Therefore, this preliminary calibration suggests that the groundwater flow field generated by the model is reasonable.

Model results are also included for the Spring of 1983 and the Fall of 1990. These were chosen because they represent groundwater elevations at a very wet period in 1983 and near the end of the drought period in 1990. Figures 43 and 44 provide the simulated groundwater elevation maps for Spring 1983 for Model Layers 3 and 4, respectively. Figures 45 and 46 provide the simulated groundwater elevation maps for Fall 1990 for Model Layers 3 and 4, respectively. A comparison between these maps shows that the changes in groundwater elevation contours are most pronounced in the primary pumping areas near Shandon and east of Paso Robles. These maps are included to demonstrate that the model provides reasonable groundwater elevation maps during the more extreme climatic periods during the base period. This further demonstrates that the model is well calibrated and can accurately simulate wet and dry weather periods.

Statistical Calibration

Next, a more rigorous calibration was performed involving a statistical analysis to compare the difference or residual between measured and simulated groundwater elevations. A scatter plot of observed versus simulated groundwater elevations (Figure 47) depicts this relationship. As indicated on Figure 47, the scatter along the correlation line is minor in comparison to the range of the data. The correlation coefficient for the data on this graph is 0.996. The correlation coefficient ranges from 0 to 1 and is a measure of the closeness of fit of the data to a 1-to-1 correlation. A correlation of 1 is a perfect correlation. The correlation coefficient of 0.996 indicates a very strong correlation between simulated and observed groundwater elevations. This correlation is based on 4,290 groundwater elevation measurements over the 17-year base period from 180 basin wells (Figure 47).

Figure 47 also includes a list of other statistical measures of calibration. The residual mean is computed by dividing the sum of the residuals by the number of residual data values. The closer this value is to zero, the better the calibration. The residual mean for the model is 1.12 feet. The residual standard deviation evaluates the scatter of the data. A lower standard deviation indicates a closer fit between the simulated and observed data. The standard deviation for the calibrated model is 18.61 feet. The absolute residual mean is a measure of the overall error in the model. The absolute residual mean is computed by taking the square root of the square of the residuals and dividing that by the number of measurements. The absolute residual mean for the model is 13.98 feet. Another statistical measure of calibration is the ratio of the standard deviation of the mean error divided by the range of observed groundwater elevations. This ratio shows how the model error relates to the overall hydraulic gradient across the model. Typically, a calibration is considered good when this ratio is below 0.15 (ESI 2001). The ratio for the Paso Robles Groundwater Model is 0.017, which is about one order-of-magnitude better. Based on the statistical analysis, the model is well calibrated.

The statistical comparison is also consistent when evaluated by model layer. Table 5 provides the statistical calibration results for the Paso Robles Groundwater Model by layer. The residual mean varies from 0.63 in Model Layer 2 to 2.85 in Model Layer 3. The standard deviation ranges from 8.37 in Model Layer 1 to 24.17 in Model Layer 2. The absolute residual mean ranges from 6.17 in Model Layer 1 to 19.51 in Model Layer 2. More variability is indicated in Model Layers 3 and 4. This is primarily attributed to the higher levels of groundwater pumping in these layers, which increase the variability of the observed data. The statistical results are of high quality and indicate that each individual model layer is well calibrated.

Hydrograph Calibration

Hydrographs provide a detailed time history of groundwater elevations for specific wells. This time history data includes the impact of varying climatic and pumping stresses on the groundwater basin. Comparing hydrographs of model results versus observed data provides a measure of how well the model handles these changing conditions through time. Of the 180 wells with groundwater elevation data, 36 hydrographs from different parts of the basin are included on Figures 48 through 53 for the hydrograph evaluation. This representative sample includes about 20% of the total wells. For calibration purposes, the hydrographs were inspected to evaluate how well the model results matched the overall magnitude and trend of the observed groundwater elevation data over time. For the transient model, it was considered more important to honor the overall trend of the data. A hydrograph was considered a good match if the model simulated the trend, but the groundwater elevations were offset.

Model Layer 1 represents the alluvial sediments, and has distinct hydrogeological characteristics compared to the deeper Paso Robles Formation. Six hydrographs are presented from Model Layer 1 from the Atascadero, Estrella, and Shandon areas (Figure 48). Two distinct hydrograph responses are observed. One shows a significant decline in water levels during the drought period of the late 1980's whereas the other is very consistent over the entire base period.

In the Atascadero Subbasin, six hydrographs are presented for wells completed in the Paso Robles Formation (Figure 49). However, two wells (28S/12E-10B01 and 28S/12E-10H04) appear to be completed in both the alluvium and the Paso Robles Formation. The groundwater elevations in these appear to shift from being more representative of the alluvium and the Paso Robles Formation. When a well is screened across different hydrogeological units, the groundwater elevation is a composite of the different zones, yet is not truly representative of any of them. Since several wells used for the calibration have long well screens, a portion of the observed variability of the model calibration is attributed to this phenomenon. When the alluvial and Paso Robles Formation groundwater elevations are plotted on the measured data hydrograph, a much more consistent fit to the data is observed. The other four hydrographs are for wells completed in the Paso Robles Formation, and these also show strong correlation with the observed data. Two separate trends are observed, a declining trend in observed in the northern section whereas a more stable pattern is observed in the southern portion.

In the San Juan area, six hydrographs are presented for wells completed in the Paso Robles Formation (Figure 50). In the southern portion of the San Juan area, the groundwater elevations tend to decline during the late 1980's drought and then recover in the 1990's. Increased pumping near 28S/15E-14G01 is attributed for the ongoing declining trend in the area. To the north, the groundwater elevations remain more stable throughout the base period.

In the Shandon area, six hydrographs are presented for wells completed in the Paso Robles Formation (Figure 51). The groundwater elevations are highly variable in the Shandon area likely due to variations in groundwater extraction. However, the groundwater elevations tend to stay relatively stable during the base period. A decline in groundwater pumping during the 1990's is attributed for the rising groundwater elevations in portions of the Shandon area. In the southern portion of the Shandon area, the groundwater elevations tend to decline during the late 1980's drought and then recover in the 1990's. Increased pumping near 28S/16E-14G01 is attributed for the ongoing declining trend in the area. To the north, the groundwater elevations remain more stable throughout the base period.

In the Creston area, six hydrographs are presented for wells completed in the Paso Robles Formation (Figure 52). In most of the Creston area, the groundwater elevations tend to decline during the late 1980's drought and then recover in the 1990's. Groundwater elevations show a general decline on the order of 30 to 40 feet during the drought period. However, groundwater elevations did recover to pre-drought levels by the end of the base period. Part of that recovery is due to decreases in groundwater pumping in the 1990's. The groundwater elevations are highly variable in the Creston area due primarily to groundwater extraction.

In the Estrella area, six hydrographs are presented for wells completed in the Paso Robles Formation (Figure 53). The groundwater elevations are highly variable in the Estrella area due to high rates of groundwater extraction. The hydrographs for 26S/12E-14G01 and 25S/12E-24K01 show a reasonable agreement in overall groundwater elevation, but much of the variable character in the observed data is missing in the simulated results. This is considered a result of additional groundwater extraction near the well that is not included in the database developed for the model. This is in contrast to hydrographs for 26S/13E-10D01, 26S/12E-06B02, and 25S/12E-21G01 where the overall variabilities of the observed and simulated data are in good agreement. In these cases, the pumping well is located near the groundwater elevation data point. Therefore, the model is able to more accurately simulate these effects.

The model was able to match these separate responses in their appropriate areas. Overall, the results of the model calibration to the various criteria indicate that the model is well calibrated.

QUALITY ASSURANCE

The first step towards developing a sound, defensible numerical model is to ensure consistency with the hydrogeological conceptual model of the basin. The previous discussions regarding the model calibration and comparison of the hydrologic budget results demonstrate that the model is consistent with the conceptual model to produce these results. The calibration correlation coefficient of 0.996 demonstrates a strong comparison between measured and simulated groundwater elevations.

A numerical model mathematically describes the conceptual model by solving the mass balance and motion equations that govern groundwater flow and chemical transport (Bear and Verruijt 1987). To solve these equations, an iterative method is used to solve the matrix equations. For these iterative techniques, the procedure is repeated until the convergence criteria are met. The convergence criteria may be groundwater elevation change, mass balance difference, or both. Convergence defines whether the model is mathematically stable and capable of producing reliable results.

For this model, the MODFLOW preconditioned conjugate-gradient (PCG2) package was used (Hill 1990). The convergence criteria for PCG2 included both a maximum change in groundwater elevation and a maximum mass balance differential for a cell. For this model, the convergence parameter for groundwater elevation was set at 0.0001 feet and 10 cubic feet per day for mass balance differential. Convergence is evaluated at the grid cell level. If a single cell does not meet the requirement, then the solution procedure is repeated. The model was able to successfully converge using the set convergence parameters.

The primary method to check whether the model is numerically stable is to evaluate the differential in mass balance. Iterative techniques provide an approximate solution for the model; therefore, there is always a mass balance differential. This differential should be small, and typically a differential of less than 1% is considered as a good solution. The mass balance differential for the Paso Robles Groundwater Model is 0.0014%. Table 6 provides the mass balance for each year. The maximum mass differential is 0.0038% in 1988. These values further indicate that this is a high-quality numerical model that is accurately simulating the flow of groundwater in the Paso Robles Groundwater Basin.

CHAPTER 6 - MODEL RESULTS

The groundwater model quantitatively combines data on basin geometry, aquifer properties, recharge, and discharge to further evaluate the hydrologic budget. The mathematical solution includes solving the mass balance equation and these results are included as part of the model output. Once the model is calibrated, these data can be evaluated with respect to the hydrologic budget for the basin.

EVALUATION OF GROUNDWATER FLOW

The 1997 groundwater elevation maps for each model layer are presented on Figures 39 through 42. In Model Layer 1, groundwater elevations are strongly controlled by the Salinas and Estrella Rivers. In general, the groundwater is in near equilibrium with the river; however, there is an overall net recharge to groundwater in the Salinas and Estrella Rivers south of San Miguel, and a net discharge of groundwater to the river north of San Miguel. The hydraulic gradient is generally low, ranging from about 0.002 to 0.004.

Model Layer 2 represents the lower permeability sediments that were noted in the eastern Estrella and Shandon areas. The flow is primarily to the west with a hydraulic gradient ranging from about 0.003 to 0.012. Model Layer 2 intercepts part of the recharge over a large area of the central basin and limits the amount that recharges the deeper zone. A portion of the recharge flows towards the streams or alluvium (Model Layer 1).

Model Layers 3 and 4 are subdivisions of the major aquifer portion of the Paso Robles Groundwater Basin. As shown, groundwater generally flows from the higher elevation areas along the margin of the basin and converges towards the Salinas River in the northwestern portion of the basin. The primary natural outflow of groundwater from the basin is discharge into the Salinas River and subsurface outflow through the northwestern margin of the basin. More specifically, in the southeastern portion of the basin, groundwater generally flows northwesterly from the San Juan area into the Shandon area and eventually into the Estrella area. In the southwestern portion of the basin, groundwater flows northerly from the Creston area into the Estrella area. In the northeastern portion of the basin, groundwater flows westerly through the North and South Gabilan areas towards the Bradley and Estrella areas. In the Bradley and Estrella areas, groundwater generally is converging towards the Salinas River and northwestern subsurface outflow discharge areas from the basin.

Model Layer 1 represents the alluvial aquifer along the Salinas River. Stream recharge percolates into underlying alluvial aquifers that are typically of narrow width and less than 100 feet thick. The alluvial material is more permeable and of higher storage capacity compared to the underlying Paso Robles Formation, which is recharged via the alluvial zones. Hydrographs of wells completed within the alluvium typically show a narrow range of groundwater elevations that is likely due to the influence of the streams. The model sustained these relationships, thus indicating that the storage capacity of the alluvial aquifer is locally important along the Salinas River.

MODEL-BASED HYDROLOGIC BUDGET

A water balance or hydrologic budget is a quantitative statement of the balance of the total water gains and losses from the basin for a given time period. Groundwater recharge or inflow to the Paso Robles Groundwater Basin is derived from percolation precipitation, streamflow, wastewater discharge, irrigation return flows, and subsurface inflow. Groundwater discharge or outflow from the Paso Robles Groundwater Basin is derived from well pumpage, subsurface outflow, stream discharge, and evapotranspiration. The difference between inflow and outflow is balanced by the change of groundwater in storage. The major components of the hydrologic budget evaluated for the Paso Robles Groundwater Basin can be expressed by the following relationship:

$$\mathbf{P + S_i + PR + WW + Sb_i = Q + S_o + ET + Sb_o \pm \Delta S}$$

where: P = Percolation of Precipitation
S_i = Percolation of Stream Recharge
PR = Percolation of Irrigation Return Flow
WW = Percolation of Wastewater Discharge
Sb_i = Subsurface Inflow
Q = Gross Groundwater Pumpage
S_o = Groundwater Discharge to Streams
ET = Evapotranspiration
Sb_o = Subsurface Outflow
ΔS = Change in Groundwater Storage

The year-by-year hydrologic budget results from the calibrated model for recharge are presented in Table 3. The model results produce a total recharge of approximately 1,995,000 acre-feet over the 17-year base period for an average annual recharge rate of 117,400 AFY. The results show that 39 percent of the recharge was derived from percolation of streamflow from rivers, streams, and runoff from the smaller watersheds surrounding the basin. Percolation of precipitation is the other major recharge component, contributing about 35 percent of the total basin recharge. The recharge from streambed percolation was increased slightly for the groundwater model. The model had an average annual streambed recharge of 46,000 AFY whereas the Phase I Report had 41,800 AFY. Subsurface inflow accounted for another 22 percent of the total recharge. Of this subsurface inflow, 7 percent was attributed to general inflow along the margins of the basin whereas the other 15 percent was attributed to three areas of local elevated subsurface inflow. Of the remaining recharge, wastewater discharge accounts for 3 percent and irrigation return flow account for 2 percent. About 45 percent of the total recharge occurs in the three wettest years (1983, 1993, and 1995), and about 73 percent of the total recharge occurs in the eight wettest years (Table 3).

The year-by-year hydrologic budget results from the calibrated model for discharge are presented in Table 3. The model results produce a total discharge of 2,020,000 acre-feet over the 17-year base period for an average annual discharge rate of 118,900 AFY. Groundwater pumping accounts for the majority (84 percent) of the total groundwater discharge (Table 3). Agricultural pumping accounts for about 68 percent of the total discharge, and municipal, small community, and rural domestic (M&I) pumping accounted for about 16 percent. However, the ratio of agricultural to M&I pumping shifted over the base period. Agricultural pumpage declined from 90 percent of total pumpage in 1981 to 70 percent in 1997. Of the remaining discharge, groundwater discharge to the Salinas River accounted for 8 percent, evapotranspiration for 6 percent, and subsurface outflow for 1 percent (Table 3).

The hydrologic budget from the Phase I Report (Table 1) was compared to the model-based hydrologic budget (Table 3). Overall, the model-based hydrologic budget agrees well with the

Phase I Report. The model provides a higher estimate of inflow and outflow that is about 17 percent more than the Phase I Report. The changes in storage between the model and the Phase I Report are in good agreement. The model indicates a decrease of about 1,500 AFY in storage over the base period (Table 3). The two methods used by the Phase I Report ranged from a decrease of 2,700 AFY to an increase of 700 AFY (Table 1). The increase in the overall outflow calculated by the model is primarily due to the higher amounts of natural discharge through subsurface outflow, evapotranspiration, and discharge to the Salinas River. The overall increase in inflow is primarily accounted for by the local elevated subsurface inflow component. Other inflow parameters are in close agreement.

During the model calibration process, additional groundwater pumpage was added in areas where groundwater elevation data strongly suggested additional pumping was occurring. This additional pumpage was attributed to agricultural pumpage, but may possibly be due to other pumping activities. Overall, groundwater pumpage was increased by about 7 percent over the base period with most of the increases for the period 1990 to 1997.

The model included a higher percentage of outflow attributed to natural discharge of groundwater from the basin. Stream discharge was not included in the Phase I Report hydrologic budget (Table 1), but the model results indicate that stream discharge accounted for 9,700 AFY of outflow over the 17-year base period. Subsurface outflow increased slightly and accounted for about 1,600 AFY. Subsurface outflow primarily occurs as underflow through the alluvium north out of the basin. Groundwater outflow by evapotranspiration was increased to about 7,700 AFY.

Change in groundwater storage, as tracked by the model, ranged from a decrease of 85,300 acre-feet in 1984 to an increase of 201,500 acre-feet in 1993 (Table 3). The change in storage is primarily impacted by the amount of recharge. Groundwater pumping, the primary discharge component, tends to stay more consistent over time. The three wettest years (1983, 1993, and 1995) had the biggest increase in storage with an average increase of about 180,000 acre-feet. The seven driest years (1981, 1984, 1985, 1987, 1989, 1990, and 1994) had decreases in groundwater storage greater than 60,000 acre-feet. Over the 17-year base period, ten years had decreases in storage greater than 10,000 acre-feet whereas only four years had increases greater than 10,000 acre-feet (Table 3).

MODEL-BASED INSIGHTS TO THE CONCEPTUAL MODEL

One of the objectives of the Phase II Study was to provide insights into the hydrogeologic conceptual model for the Paso Robles Groundwater Basin. This section documents the conceptual model insights that were developed during the process of model development and calibration.

Precipitation Recharge

During model calibration, the distribution of precipitation rainfall was modified in order to better match the basin hydrographs (Figures 48 through 53). This modification shifted precipitation recharge from the two wettest years and redistributed to the remaining years. In the Phase I Report this range was more pronounced with annual precipitation recharge ranging from 0 acre-feet in the four driest years (1987, 1989, 1990, and 1994) to 346,400 acre-feet in 1995. This produced a distribution that concentrated 94% of the precipitation recharge into the high rainfall years of 1983, 1993, and 1995.

In the calibrated model, the total precipitation recharge over the base period was about 694,000 acre-feet for an annual average of 40,800 AFY. Precipitation recharge in the calibrated model ranged from 10,800 acre-feet in 1989 to 161,900 acre-feet in 1995. In comparison, 63% of the precipitation recharge was concentrated into the high rainfall years of 1983, 1993, and 1995; however, 7% of the precipitation recharge was applied in the low rainfall years of 1987, 1989, 1990, and 1994. The annual distribution of precipitation is included in Table 3.

This shift in the yearly distribution of precipitation recharge still maintains the concept of high recharge during high rainfall years; however, it does indicate that some recharge occurs even in the driest years. Conceptually, this dry year precipitation recharge is considered to be the result of continued downward percolation of residual moisture deeper within the vadose zone. In addition, a higher percentage of precipitation recharge was assumed to occur in these dry years in areas of higher soil moisture content such as the alluvium near the major rivers and irrigated lands. The distribution of precipitation recharge included:

- 457,000 acre-feet from the original precipitation distribution from the Phase I Report (Fugro and Cleath 2002) minus the 1983 and 1995 reductions.
- 120,000 acre-feet that was redistributed over the remaining 14 years proportional to the average annual precipitation for the Paso Robles Groundwater Basin. The recharge was distributed uniformly over the basin for each year.
- 64,000 acre-feet was distributed over the 17-year base period to the river alluvium using the assumption that a higher percentage of recharge would occur in these sediments.
- 23,000 acre-feet was distributed over the 17-year base period onto irrigated lands where a higher percentage of recharge was assumed to occur.
- 30,000 acre-feet was distributed over the 17-year base period to special areas needing additional recharge in the Creston and Bradley areas.

For this modification, precipitation recharge in 1983 and 1995 was reduced to near the 1993 levels. Approximately 280,000 acre-feet of recharge was shifted from 1983 and 1995 to the remaining years. For the model, annual precipitation recharge ranged from 10,800 acre-feet in 1989 to 161,900 acre-feet in 1995. However, the overall total for precipitation recharge was in close agreement with the model having about 5 percent less recharge from precipitation over the 1981 to 1997 base period.

Stream Recharge

In the Phase I Report (Fugro and Cleath 2002), the estimated stream recharge emphasized the major rivers and streams in the basin. In the model, the Salinas River and most of the Estrella River were placed in Model Layer 1. The groundwater levels in the alluvium of the Salinas and Estrella Rivers were generally in equilibrium with the rivers. Therefore, capacity for recharge from the streams was limited in the winter stress period and during wet years because much of the available storage capacity was filled.

During the model calibration, the annual average stream recharge was increased by approximately 10 percent from 41,800 to 46,000 AFY (Table 3). In addition, it was found that a significant amount of recharge was needed along the basin margins to match the observed groundwater elevations. This recharge was attributed to smaller streams along the basin margin. Therefore, a portion of the stream recharge was shifted to emphasize the recharge along the basin margin rather than along the major streams. Along the basin margins, the groundwater elevations tended to be well below the streambed elevations. Thus, even though the basin margin streams have lower total flow, there is typically available storage capacity throughout the year, including the wet years. Therefore, these streams have the capacity for a significantly higher percentage of the available flow going to groundwater recharge. The annual distribution of stream recharge by stream is presented in Table 4.

Discharge to Salinas River

Stream discharge was not included in the Phase I Report hydrologic budget (Table 1). However, the calibrated model results indicate that groundwater discharges into the Salinas River north of San Miguel, whereas upstream of San Miguel, the river typically recharges groundwater. This is supported by the groundwater elevation maps that show the convergence of groundwater elevation contours towards the Salinas River north of San Miguel, which is indicative of a groundwater discharge (Figures 13 through 16).

MODFLOW provides the capability to total the net recharge and/or discharge for portions of the stream package used to simulate streambed percolation. In evaluating the segments of the Salinas River north of San Miguel, the model results indicate that stream discharge accounted for 9,700 AFY of outflow over the 17-year base period. The estimated discharge to the Salinas in Table 3 was calculated from the model by summing the net inflow/outflow to the Salinas for the segments north of San Miguel. A comparison of stream gauge data for the Salinas River at Bradley (Fugro and Cleath 2002) shows that this groundwater discharge would account for between 1 and 3 percent of the total streamflow in the Salinas River. The exception is in 1990, which was a significantly low streamflow year near the end of an extended drought period. In 1990, the model groundwater discharge to the Salinas River nearly equals the streamflow measured at Bradley.

Subsurface Inflow

Subsurface inflow in the Phase I Report (Fugro and Cleath 2002) accounted for the flow of groundwater from the surrounding “non-water bearing bedrock” and into the basin sediments along the basin margin. In Table 3, this is represented by the general margin inflow subcomponent of subsurface inflow.

During calibration, three areas of elevated local subsurface inflow were added where the groundwater model required significant additional recharge that was not accounted for in the Phase I Report. On Figure 31, these three areas are identified as the Creston, Paso Robles, and South Gabilan elevated local subsurface inflow areas. These areas were defined during model calibration. Without this higher recharge rate, the difference between measured and simulated groundwater elevations was large. Therefore, to sustain these groundwater elevations over time, the groundwater model required the addition of significant additional recharge. The common feature of these areas is high groundwater elevations.

In the southwestern portion of the Creston area, high groundwater elevations are noted in several wells. The model required the addition of about 6,000 AFY to sustain recharge to the measured groundwater elevations (Figure 42). The Phase I Report (Fugro and Cleath 2002) noted that an area of artesian groundwater occurs in the Creston area, and that the likely source was inflow from the south where precipitation and runoff at higher elevations percolates into the basin along canyons draining the granitic rock of the La Panza Range. The Rinconada Fault also lies to the west of the area. Past activity along the fault may have increased fracturing in the upland areas that could enhance recharge. The Phase I Report (Fugro and Cleath 2002) also noted the occurrence of highly mineralized, sodium-chloride water found in the deeper zones in many parts of the Creston area. The source of the increased salinity was not known. However, saline groundwater flow associated with faults has been noted in several locations along the California Coast Ranges (Unruh *et al* 1992, Schaal *et al* 1994). The anomalously high chloride concentrations observed at depth in the Creston area (Fugro and Cleath 2002) may indicate the presence of a previously unknown water source entering the system along the fault at depth.

A similar area occurs northwest of Paso Robles in the Estrella area where high groundwater elevations are noted in several wells. This is noted on Figure 42 as an area with groundwater elevations greater than 800 ft amsl. The model also required the addition of about 6,000 AFY of recharge to sustain the measured groundwater elevations in this region. The upland area is composed of granite; however, the trace of the Rinconada Fault is mapped as leaving the basin and entering into the upland areas. Therefore, the primary source of this recharge is considered the result of increased groundwater inflow from the upland area due to higher fracturing related to the Rinconada Fault at this location.

In the South Gabilan area, high groundwater elevations have been mapped although fewer wells are present in this area. During model calibration, it was noted that sustaining groundwater levels in this area was important for calibrating the eastern Estrella area. Therefore, an increased level of recharge was necessary for the South Gabilan area. A portion of the stream recharge was shifted to the South Gabilan area (Table 3), but additional recharge was needed that also sustained water levels during the drier years. The model required the addition of about 5,000 AFY of recharge to sustain the measured groundwater elevations (Figure 42). This flow is distributed using a boundary condition that extends 15 miles along the northeastern boundary of the model. During review of the USGS topographic quadrangle maps for this area to obtain streambed elevations, it was noted that a zone of springs was mapped along this area. These springs consistently were located in a narrow elevation band that centered at an elevation of about 1,450 ft amsl. Since springs can be considered an outcrop of groundwater, this was another indication of high groundwater elevations in this area. The source of the spring water is speculated as subsurface inflow of precipitation that fell at higher elevations. These springs are considered to represent the additional subsurface inflow attributed to this area.

Agricultural Pumpage

During model calibration, groundwater elevation data indicated that pumping was underestimated in some areas and overestimated in other areas. Model calibration indicated that some modification to the pumpage was necessary to better match the hydrograph data. To account for this, modifications were made to the initial estimated distribution of agricultural pumpage. Agricultural groundwater pumping is not metered in the basin; therefore, it was estimated in the Phase I Report on the basis of crop types and other factors (Fugro and Cleath 2002). The average annual agricultural pumpage was estimated at 77,700 AFY and accounts for about 77% of the annual basin outflow. In the model, agricultural pumpage over the base period was about 1,380,000 acre-feet for an annual average of 81,200 AFY (Table 3). To summarize by area, agricultural pumpage was increased in the Atascadero, Bradley, Estrella, North Gabilan, and San Juan areas by about 15% whereas agricultural pumpage was decreased in the Creston and Shandon areas by about 8%. As a result of these modifications, groundwater pumpage was increased by about 7 percent over the base period with most of the increases for the period 1990 to 1997.

CHAPTER 7 - GROUNDWATER MODEL SCENARIOS

The model is a quantitative tool capable of evaluating the impact of potential future changes in pumping conditions on water levels in the groundwater basin. For this study, three case scenarios were defined to evaluate various groundwater-related issues and concerns in the basin. These three scenarios include:

> **Scenario 1 - Perennial Yield:** This scenario develops an estimate of perennial yield for the basin for the 1981 to 1997 base period using the groundwater model.
>
> **Scenario 2 - Build-Out:** This scenario evaluates long-term change in groundwater elevations based on projected agricultural, municipal, commercial, and domestic pumping. The groundwater pumping rates used in the model are designed to represent full build-out conditions based on long-term projections of future pumping from planning documents and other sources.
>
> **Scenario 3 - Build-Out with Nacimiento Water:** This scenario evaluates build-out conditions with the added effect of the Nacimiento water project. For Scenario 3, pumping rates for municipal wells were reduced to represent replacement of groundwater production with supplies from the Nacimiento water project. Other conditions remained unchanged from Scenario 2.

Based on the calibration to historical data and the quality assurance parameters, the Paso Robles Groundwater Model is capable of forecasting future case scenarios (Fugro, ETIC, and Cleath 2004b). However, these scenarios are necessarily based on assumptions of future conditions. Therefore, in evaluating the results of model scenarios, it is recommended to look more at the overall trends and the relative differences between the scenario to a base case or current conditions.

SCENARIO 1 – PERENNIAL YIELD ESTIMATE

The purpose of Scenario 1 is to develop a perennial or “safe” yield estimate for the Paso Robles Groundwater Basin using the calibrated groundwater flow model developed for Task 2 (Fugro, ETIC and Cleath 2004a). The perennial yield of a groundwater basin defines the rate at which water can be withdrawn perennially under specified operating conditions without producing an undesired result (Todd 1980).

For the Phase I Report (Fugro and Cleath 2002), the perennial yield of a groundwater basin was defined as the rate in which water can be pumped from wells year after year without decreasing the groundwater in storage. The change in groundwater storage was evaluated over the 1981 to 1997 base period. For Scenario 1, a definition for perennial yield similar to the Phase I Report (Fugro and Cleath 2002) was used to maintain consistency with previously reported perennial yield evaluations.

This definition of perennial yield focuses on generally balancing the overall historical groundwater levels in the basin, and does not include any implied management judgments specifying target groundwater elevations for particular areas. Modifying the definition of perennial yield to include further analysis made on water levels or quality for different areas of the basin may have an impact on the perennial yield.

The perennial yield is defined in terms of groundwater pumping. Scenario 1 was developed by uniformly varying the overall pumping in the calibrated groundwater model over the 1981 to 1997 base period. The change in groundwater storage varies from year to year primarily due to variations in annual precipitation. Therefore, the 17-year base period is considered an appropriate time-scale for this evaluation.

Scenario Conditions

Five separate runs were developed where total groundwater pumpage varied by 95%, 100%, 105%, 110%, and 115% of the total groundwater pumpage and related components relative to the calibrated groundwater model (Fugro, ETIC, and Cleath 2004b). Specifically, the changes for the input data for Scenario 1 include:

- Pumping rates for all existing wells (agricultural, M&I, and rural domestic) in the model were varied by a uniform percentage relative to the pumping rate data used in the calibrated model. Total pumpage applied to each run of Scenario 1 and a breakdown of pumping distribution by subarea is presented in Table 7.
- Irrigation return flows were modified proportionally to the agricultural pumpage.
- Wastewater discharge was modified proportionally to the municipal pumpage.
- All other conditions in the model remained unchanged.

Pumping was varied on a well-by-well basis for all wells in the model domain. The percentage change was applied to each stress period at each well location. Pumping was varied proportional to the historical pumping. Scenario 1 does not include any potential optimization by the spatial redistribution of pumping.

Irrigation return flows were based on the total agricultural pumpage and distributed using the same procedures used for the calibrated model. Wastewater discharge was varied by the appropriate percentage and directly entered into the model at the appropriate wastewater discharge location.

Results

The groundwater inflows, outflows, and change in storage were calculated by the model for the five model runs (Table 8). The change in groundwater storage was plotted relative to the groundwater pumpage, showing a linear relationship where increasing pumping produces a decrease in groundwater storage (Figure 54). A linear regression analysis was performed for these model results. Perennial yield is defined for Scenario 1 as the average annual pumping rate that can sustain a net zero change in aquifer storage (as calculated by the groundwater model) relative to the starting conditions used for the calibrated model representing Fall 1980. This is represented on Figure 54 as the pumping rate that represents the point on the linear regression line where the net groundwater storage for the basin is zero. Based on this analysis, the perennial yield for the Paso Robles Groundwater Basin is 97,700 AFY over the base period of 1981-1997 (Figure 54).

The change in groundwater storage was further calculated on a subarea basis. For Run 3, which includes 105% of the calibration total pumpage, positive change in groundwater storage is shown for the Shandon, Bradley, and Creston areas (Table 9). This is primarily due to significant decreases in agricultural pumpage over the base period, and because the Fall 1980 water levels for these areas had already experienced drawdown prior to the base period. However, it does suggest that additional pumping may be available in these areas.

In Run 1, only the San Juan area showed a decrease in the change in groundwater storage (Table 9). In part, this represents that the San Juan area has the highest groundwater elevations in the basin, indicating that the area does not receive groundwater inflow from other parts of the basin. Therefore, this area is dependent upon precipitation and stream runoff for groundwater recharge, thus making this area sensitive to annual variations in rainfall. Secondly, groundwater pumpage increased in the San Juan area over the base period. Therefore, the San Juan area did not have prior drawdown from historical pumping at the start of the base period as is the case in many other parts of the basin.

The results of the perennial yield scenario indicate that not all of the total pumpage volume comes completely out of groundwater storage. For the example where pumping is increased, the model results show a linear relationship where every 1,000 AFY increase in total pumpage results in an average 687 AFY decrease in basin storage (Table 10). The remaining 313 AFY indicate that the impact on groundwater from changes in pumping is complicated by other hydrogeologic processes operating in the basin. The majority of this remaining 313 AFY is due to increased streambed recharge, which accounts for 230 AFY (Table 10). Increases in wastewater recharge of 35 AFY and irrigation return flows of 23 AFY are specified in the model because they are directly related to the amount of pumping. The remainder is the result of increased recharge or decreased discharge due to lower groundwater elevations resulting from the increased pumping. The water balance (Table 10) shows that natural inflows increase by 10 AFY, whereas evapotranspiration decreases by 11 AFY and natural subsurface outflows decrease by 3 AFY. These results indicate that as groundwater elevations decline due to increased pumping, there is additional induced recharge that comes primarily from the Salinas River.

The model results show that the opposite case is also true when pumping is decreased. In this case, every 1,000 AFY decrease in pumpage results in an average 687 AFY increase in groundwater storage and a 230 AFY decrease in streambed recharge. The other water balance components vary in a consistent pattern but with groundwater flow in the opposite direction, as shown in comparing Runs 1 and 3 in Table 10. These results demonstrate that groundwater-surface water interactions, primarily associated with the Salinas River, have a significant impact on groundwater storage and affect the perennial yield of the basin.

In the Phase I Report, the Paso Robles Groundwater Basin perennial yield was estimated using three separate calculation methods. Similar results were obtained by each method. The established perennial yield of the Paso Robles Groundwater Basin ranged between 93,500 and 95,500 AFY. A value of 94,000 AFY was reported as being representative of this range of values (Fugro and Cleath 2002). The three percent difference in the model-based perennial yield of 97,700 AFY and the Phase I Report estimate of 94,000 AFY represents the model's capability to evaluate the complex groundwater-surface water interactions of the Salinas River over time.

SCENARIO 2 – BUILD-OUT SCENARIO

The purpose of Scenario 2 was to simulate the effects of urban growth build-out and maximum reasonable agricultural demand on groundwater elevations throughout the Paso Robles Groundwater Basin and to identify areas of special concern within the basin. The build-out conditions were based on projections from long-term planning documents and projected agricultural practices in the future. Projected climatological conditions correspond to conditions observed during the 1981-1997 base period.

Scenario Conditions

The objective of Scenario 2 is to evaluate the impact of estimated build-out pumpage on groundwater storage and levels in the basin. Scenario 2 consists of a single model run that includes significant modifications to the water balance components that are impacted by future population and land use trends in the basin. The primary component of Scenario 2 involved modifications to groundwater pumping and related changes to irrigation return flows and wastewater discharge. Groundwater pumping consists of four primary categories in the model: municipal, agricultural, small commercial, and rural domestic. As directed, the pumping rates for each well were uniformly applied throughout the scenario. This strategy was employed to eliminate the uncertainty in the timing of the projected growth from the evaluation. The model results evaluated the ultimate impact of the projected build-out scenario.

Agricultural pumpage includes groundwater extraction used for agricultural purposes with irrigation being the primary use. Overall agricultural pumpage has declined in the basin during the base period. Agricultural pumpage has shown a steady decline of approximately 55%, ranging from a maximum of 115,000 AFY in 1981 to 50,800 AFY in 1997. Agricultural pumping is not metered, so the volume and distribution of this pumping is necessarily based on estimates. The Phase I Report (Fugro and Cleath 2002) included a comprehensive analysis to estimate the volume of agricultural pumping in the basin.

For Scenario 2, the build-out condition was termed the projected maximum reasonable agricultural water use. The San Luis Obispo Agricultural Commissioner's Office (SLO ACO 2004a, 2004b) prepared an analysis of future groundwater demand based on projecting current trends in crop types and irrigation practices into the future. For example, production of alfalfa has decreased from 10,500 acres in 1982 to 3,240 acres in 2000. In contrast, production of wine grapes has increased from 4,500 acres to 27,000 acres over the same period (SLO ACO 2004a). Therefore, the SLO ACO (2004a, 2004b) developed the projected maximum reasonable agricultural water use based on an estimate of total irrigated acreage and assuming that much of the increase in agricultural water use will come from wine grapes. These estimates are the basis for the agricultural pumping input into the model. Because of the inherent uncertainty in forecasting future agricultural trends, agricultural pumpage was included in the sensitivity analysis (Chapter 8) to analyze the difference in groundwater levels resulting from variations in agricultural pumpage.

Using a variety of analytical techniques including linear regression and growth rate models, the SLO ACO projected a reasonable estimate of future irrigated farmland in the basin of 45,000 acres. Based on land use data, approximately 30% of the irrigated land lies in the "Shandon" area along the eastern portion of the basin and 70% in the "Salinas/Creston" area along the western half of the basin. For Scenario 2, the "Shandon" area for agricultural pumping is defined to include the San Juan, Shandon, South Gabilan, and North Gabilan areas. The "Salinas/Creston" area includes the Atascadero, Estrella, Creston, and Bradley areas.

The gross irrigation water requirement (GIWR) for the groundwater basin was estimated to range from 1.1 to 2.2 acre-feet per year per acre of irrigated farmland (SLO ACO 2004a). The GIWR for the groundwater basin was also evaluated primarily based on the calculated water use of Cabernet Sauvignon grapevines in Paso Robles during the 2000 growing season with evapotranspiration included. Based on this estimate, the GIWR of 1.25 acre-feet per year per acre of irrigated farmland was estimated for the Paso Robles area (Battany 2004). For the eastern portion of the basin, a higher evapotranspiration rate was assumed. Therefore, for Scenario 2, the GIWR for the Atascadero, Estrella, Creston, and Bradley areas was estimated at 1.25 acre-feet per year per acre of irrigated farmland, and 1.50 acre-feet per year per acre of irrigated farmland for the San Juan, Shandon, South Gabilan, and North Gabilan areas.

The projected maximum reasonable agricultural water use for the Paso Robles Groundwater Basin was estimated by applying the GIWR times the estimated irrigated acreage for the eastern and western portions of the basin. For the Atascadero, Estrella, Creston, and Bradley areas, a GIWR of 1.25 times a projected acreage of 31,500 produces an agricultural water use of 39,375 AFY. For the San Juan, Shandon, South Gabilan, and North Gabilan areas, a GIWR of 1.50 times a projected acreage of 13,500 produces an agricultural water use of 20,250 AFY.

This produces a total projected agricultural water use of 59,625 AFY that was rounded up in Scenario 2 to a total projected maximum reasonable agricultural pumpage of 60,000 AFY (Honeycutt 2004). The spatial distribution of the agricultural pumpage by area is presented in Table 11.

Irrigation return flow was adjusted in proportion to changes in agricultural pumpage. Irrigation return flows were distributed using the same procedures used for the calibrated model. Irrigation return flow assigned to Scenario 2 is shown in Table 12.

Municipal groundwater pumpage includes groundwater extraction by Atascadero Mutual Water Company, Templeton Community Services District, City of Paso Robles, and San Miguel. Municipal groundwater pumpage for these communities is projected at:

- 14,388 AFY from 20 wells for Paso Robles (Hand 2004 and Rincon Consultants 2003)
- 8,431 AFY from 16 wells for Atascadero (Atascadero Mutual Water Company 2004)
- 2,538 AFY from 9 wells for Templeton (pers. commun., William Van Orden, 6/15/04)
- 677 AFY from 1 well for San Miguel (Hand 2004)

The total municipal pumpage for Scenario 2 is 26,034 AFY. During the base period, municipal pumpage showed a steady increase of about 77%, ranging from a minimum of 7,598 AFY in 1981 to 13,513 AFY in 1997. The total municipal pumpage for the build-out scenario of 26,034 AFY is nearly double the 1997 total pumpage.

Pumpage was distributed to the existing municipal production wells in proportion to the percentage of pumping from the final year of the calibrated model. No new wells were assumed for Scenario 2. Minor redistribution of pumpage from some of the City of Paso Robles' wells was necessary because a uniform doubling of production capability was not possible (or likely) for some of the municipal wells.

Wastewater discharge was varied proportionally to municipal pumping for each community. A linear regression analysis was performed to develop a relationship between groundwater pumpage and wastewater discharge for each community over the 1981 to 1997 base period. The wastewater discharge was assigned to the model based on this analysis using the MODFLOW stream package. The Templeton wastewater system was added to the model for Scenario 2. During the base period, Templeton piped wastewater to Paso Robles for treatment and discharge at that location. Wastewater discharge for these communities is projected at:

- 5,100 AFY for Paso Robles
- 2,100 AFY for Atascadero
- 300 AFY for Templeton

Small commercial groundwater pumpage includes water demand from hospitals, golf courses, schools, and commercial entities not covered in the other categories. Fifteen systems are specifically input into the groundwater model. For Scenario 2, the 1997 water use from the calibrated model was projected into the future. The water use for these systems is projected to remain stable into the future with a combined total projected water demand of 958 AFY.

Rural domestic groundwater pumpage consists mostly of the water demand for rural residential developments. This type of development is projected to experience significant growth in the future. Total rural domestic demand in Scenario 2 is projected as 21,623 AFY (Hand 2004, Monterey County General Plan 1987). During the base period, rural domestic pumpage showed a steady increase from 4,700 AFY in 1981 to 9,400 AFY in 1997 (Fugro, ETIC, and Cleath 2004b). The total rural domestic pumpage for the build-out scenario of

21,623 AFY is more than double the 1997 pumpage. Also included in this category are small commercial systems where a specific well location was not known. A total of 812 acre-feet of water use was assigned to these types of systems and incorporated into the approximate location of the water system.

The rural domestic pumpage was distributed uniformly over each appropriate township using the same approach applied for the calibrated model (Fugro, ETIC, and Cleath 2004a). The wells were placed in the highest active model layer at each location.

Natural hydrology includes precipitation, streamflow, and subsurface inflow and outflow. For Scenario 2, the natural hydrology is equivalent to two repeated cycles of the natural hydrology of the calibrated, historical model representing the conditions over the 1981 to 1997 base period.

Aquifer properties such as hydraulic conductivity and storage coefficients are not considered time dependent. Therefore, no changes to these properties were made in any of the scenarios.

Initial groundwater elevations for Scenario 2 are the final groundwater elevations from the calibrated, historical model representing Fall 1997.

A summary of the changes in groundwater pumping from 1997 to the Scenario 2 build-out conditions is as follows:

	1997	Build-Out	Change
Agricultural	50,800 AFY	60,000 AFY	+ 9,200 AFY
Municipal	13,513 AFY	26,034 AFY	+ 12,521 AFY
Rural Domestic	9,400 AFY	21,623 AFY	+ 12,223 AFY
Small Commercial	958 AFY	958 AFY	No Change

Results

The results of Scenario 2 are presented in the form of simulated groundwater elevation maps representing the projected build-out conditions. Figures 55, 56, 57, and 58 represent build-out groundwater elevations for Model Layers 1, 2, 3, and 4, respectively. Along the Salinas River in Model Layer 1 (Figure 55), groundwater flow is toward the north. In the deeper layers, groundwater flow generally converges toward the Salinas River and toward the north (Figures 56, 57, and 58). In Model Layer 4 representing the deeper aquifer, a depression in the groundwater elevation surface around Paso Robles represents drawdown primarily from anticipated future municipal pumping, if that pumping were to occur from the City's current existing wells.

Future case model scenarios necessarily require assumptions of future conditions. Therefore, evaluating the relative difference in model results is generally considered more beneficial. For Scenario 2, the model results for each model layer are compared to the observed Fall 1997 conditions, which were used as the initial conditions for Scenario 2. Groundwater elevation differences maps comparing the observed Fall 1997 to the Scenario 2 results are presented in Figures 59, 60, 61, and 62 for Model Layers 1, 2, 3, and 4, respectively.

In Model Layer 1, water level declines greater than 20 feet occur near Paso Robles (Figure 59). In Model Layers 2, 3, and 4, water level declines in the southern Estrella area range from 20 to 100 feet (Figure 60, 61, and 62). Groundwater elevation declines are generally greater in Model Layer 4 than in Model Layer 3 (Figures 61 and 62). Water level declines in the Atascadero subbasin are highest in the northern portion near major pumping centers; however, the declines are much less in the southern portion of the subbasin relative to the calibrated model results representing Fall 1997 (Figures 61 and 62). Water level declines over a portion of the San Juan area range up to 20 feet relative to the calibrated model results representing Fall 1997 (Figures 61 and 62).

These differences result in an average annual decline in groundwater storage of 3,800 AFY compared to the calibrated model results representing Fall 1997 (Table 12). The change in groundwater storage was further calculated on a subarea basis. Table 13 shows that the Shandon area has an average annual increase in storage of 3,000 AFY per year; however, this primarily represents the continuation of historical reduction in agricultural pumpage in this area. An average annual decline in storage of 4,300 AFY is simulated in the Estrella area that is due to the large increase in pumping that is concentrated in this area for the build-out scenario (Table 12). The Bradley, Atascadero, and Creston areas show an average annual decline in storage of 400 to 1,000 AFY (Table 12).

A set of detailed groundwater elevation maps of the Paso Robles and Atascadero area is presented for Model Layers 1, 2, 3, and 4 in Figures 63, 64, 65, and 66, and accompanied by groundwater elevation differences maps in Figures 67, 68, 69, and 70, respectively. In Model Layer 1, water level declines greater than 20 feet occur near Paso Robles (Figure 67). In Model Layer 2, water levels declines are restricted to a small area northeast of Paso Robles (Figure 68). The limited area of saturation limits the impact to Layer 2 near Paso Robles.

The overall decline in groundwater levels and reduction in basin storage is attributed to the increased pumping. In summary:

- Agricultural pumpage was increased by 9,200 AFY from the 1997 rate of 50,800 AFY to the Scenario 2 rate of 60,000
- Municipal pumpage was increased by 12,521 AFY from the 1997 rate of 13,513 AFY to the Scenario 2 rate of 26,034
- Rural domestic pumpage was increased by 12,223 AFY from the 1997 rate of 9,400 AFY to the Scenario 2 rate of 21,623
- Small commercial pumpage was left unchanged from the 1997 rate of 958 AFY.

The most significant declines in water levels are simulated in Model Layers 3 and 4 (Figures 69 and 70). In Model Layer 4, significant localized water level declines would occur relative to the calibrated model results representing Fall 1997 (Figure 70) at locations near major pumping centers, based on increased pumping from existing municipal wells. Water level declines in Model Layer 3 are of a similar magnitude over the area (Figure 69); however, Model Layer 3 does not have the significant localized drawdowns simulated in Model Layer 4. It should be noted that the increased municipal pumpage was distributed to the existing production wells which would increase the drawdown at those specific locations, whereas the agricultural and rural domestic pumping was distributed uniformly across the basin. Future scenarios could look at optimizing the municipal production to minimize the impact on groundwater levels and basin storage.

SCENARIO 3 – BUILD-OUT SCENARIO WITH NACIMIENTO PROJECT

The purpose of Scenario 3 was to evaluate the impact on basin storage and water levels of replacing a portion of the municipal pumpage (at build-out) with an equal portion of Nacimiento project water. All other conditions were left the same as specified in Scenario 2.

Scenario Conditions

Municipal groundwater pumpage was reduced for Paso Robles, Templeton, and Atascadero municipal wells by 4,000, 250, and 2,000 AFY, respectively. For Scenario 3, municipal groundwater pumpage for these communities was projected at:

- 10,388 AFY from 20 wells for Paso Robles
- 6,431 AFY from 16 wells for Atascadero
- 2,288 AFY from 9 wells for Templeton

The spatial distribution of the groundwater pumpage by area is presented in Table 15. Note that only the three municipal agencies listed above receive Nacimiento water in lieu of groundwater; thus pumping estimates at build-out conditions for the rural domestic and small commercial components remained the same as specified in Scenario 2.

For Scenario 3, a redistribution of pumping relative to Scenario 2 was included. Municipal pumping was shifted to Model Layer 1 in the Atascadero subbasin to capture more groundwater flow in the alluvium. This shift included shifting all of the winter pumpage to Model Layer 1 to capture more flow in the alluvium.

Wastewater recharge remained the same in Scenario 3 because the Nacimiento water is assumed to replace groundwater pumpage; therefore, projected total municipal water use is not assumed to change.

Results

The results of Scenario 3 are presented in the form of simulated groundwater elevations for each model layer corresponding to the projected build-out conditions. Figures 71, 72, 73, and 74 represent build-out groundwater conditions for Model Layers 1, 2, 3, and 4, respectively. These results show a similar groundwater elevation pattern as those for Scenario 2.

The changes in groundwater elevations resulting from the conditions of Scenario 3 are best illustrated by maps showing the relative difference in groundwater elevation by comparing the observed Fall 1997 groundwater elevations to the Scenario 3 groundwater elevation results. The parameter that was varied for Scenario 3 was the municipal pumping rates for Paso Robles, Templeton, and Atascadero. To best illustrate the changes in Scenario 3 relative to Scenario 2, a set of groundwater elevation difference maps that detail the area of interest are presented in Figures 75, 76, 77, and 78 for Model Layers 1, 2, 3, and 4, respectively. As indicated on the figures, Scenario 3 results in recovery of groundwater elevations of approximately 20 to 40 feet relative to Scenario 2 over portions of the Estrella and Atascadero subareas. The most significant local increases in water levels occurred near the major pumping centers in the Estrella subarea (Figure 78).

Evaluating the change in groundwater elevations between Scenario 3, representing full build-out with the Nacimiento project, to the results of the calibrated model, representing Fall 1997 conditions, indicates an average annual decline in groundwater storage of 1,200 AFY (Table 12). This represents an improvement of 2,600 AFY in the average annual change in groundwater storage relative to Scenario 2, which does not include the Nacimiento project. The change in groundwater storage was further calculated on a subarea basis. Table 14 shows that increased groundwater storage is derived entirely from the Estrella and Atascadero areas.

Scenario 3 differs from Scenario 2 by decreasing municipal pumpage near Paso Robles, Templeton, and Atascadero to account for the Nacimiento project. Comparing the differences in the water balance results for Scenarios 2 and 3 indicates that every 1,000 AFY decrease in total pumpage in Scenario 3 results in only a 407 AFY increase in groundwater storage relative to

Scenario 2 (Table 14). These model results indicate that a lower percentage of the decreased pumping is going into groundwater storage. The remainder is accounted for by decreased recharge or increased discharge due to higher groundwater elevations. Further analysis indicates that decreased streambed recharge, primarily from the Salinas River, accounts for the majority (582 AFY) of the remaining 593 AFY (Table 14). The remainder is the result of minor decreases in natural inflows of 5 AFY and increases in evapotranspiration of 6 AFY due to the higher groundwater elevations (Table 14). This indicates that the portion of the basin closer to the Salinas River is more affected by the groundwater-surface water interactions due to either reduced recharge or increased discharge of groundwater to the river during high water-level periods.

CHAPTER 8 - SENSITIVITY ANALYSIS

A sensitivity analysis was run on key parameters that were considered to have the most significant impact on model results within their range of uncertainty. For the Paso Robles Groundwater Model, the selected parameter for sensitivity analysis was agricultural pumpage. Agricultural pumpage was not based on metered data, but rather on estimates based on land use and irrigation practices. As the single largest outflow of groundwater from the basin, minor variations in this estimate may have widespread impacts on groundwater storage and groundwater elevations thereby warranting further analysis.

Analysis Conditions

For this sensitivity analysis, the agricultural pumpage was varied at each well location in Scenario 2 by plus or minus 10 percent. The pumping rates for all agricultural wells was set at 90 percent of the Scenario 2 rates for the first sensitivity analysis (90% Run), and set at 110 percent of the Scenario 2 rates for the second sensitivity analysis (110% Run). Irrigation return flow was also modified by 10% for the respective model runs.

All other model conditions were left the same as specified in Scenario 2.

Results

The results of the 90% Run are in the form of simulated groundwater elevation maps for each model layer corresponding to projected build-out conditions. Groundwater elevation difference maps comparing the results of the 90% Run to the Scenario 2 results are presented in Figures 79, 80, 81, and 82 for Model Layers 1, 2, 3, and 4, respectively. At 90% of agricultural pumpage, water level increases of greater than 10 feet are simulated over portions of the Estrella subarea, whereas increases of 5 to 10 feet are simulated over portions of the Creston, Shandon, and San Juan areas relative to Scenario 2 (Figures 81 and 82).

The results of the 110% Run are in the form of groundwater elevation maps for each model layer corresponding to the projected build-out conditions. Groundwater elevation difference maps comparing the results of the 110% Run to the Scenario 2 results are presented in Figures 83, 84, 85, and 86 for Model Layers 1, 2, 3, and 4, respectively. At 110% of agricultural pumpage, water level declines of greater than 10 feet are simulated over portions of the Estrella subarea, and declines of 5 to 10 feet are simulated over portions of the Creston, Shandon, and San Juan areas relative to Scenario 2 (Figures 85 and 86).

Sensitivity analysis results show an average annual change in groundwater storage for the basin increases by 500 AFY for the 90% Run. For the 110% Run, the average annual change in groundwater storage in the basin decreases by 8,000 AFY. The change in groundwater storage is calculated in comparison to the calibrated model results representing Fall 1997 (Table 13).

The change in groundwater storage was further calculated on a subarea basis (Table 13). For the 90% Run, the average annual change in groundwater storage declines in the Estrella, Bradley, Atascadero, and Creston areas; however, all of these show improvement relative to Scenario 2. The largest total change in storage is simulated in the Estrella area, which also has the highest total agricultural pumpage (Table 11). The largest increase in groundwater storage was simulated in the Shandon and Estrella areas, where agricultural pumping is a more dominant percentage of the overall total pumpage (Table 11).

A similar, but opposite, response is simulated for the 110% Run (Table 13). For the 110% Run, the average annual change in groundwater storage was a decline in the Estrella, Bradley, Atascadero, Creston, San Juan, and South Gabilan areas as the result of the increased pumping. The Shandon and North Gabilan areas still show an increase in groundwater storage relative to the Fall 1997; however, they are both lower than the Scenario 2 results.

The water balance for sensitivity analysis indicates an inverse relationship between pumping and basin storage. For the 90% Run, every 1,000 AFY decrease in total pumpage results in a 696 AFY increase in basin storage relative to Scenario 2 (Table 14). The groundwater inflow component indicates that recharge from streams decreases by 215 AFY, irrigation return flow decreases by 54 AFY, and natural inflows decrease by 12 AFY. Similarly, for groundwater outflow components, natural subsurface outflows increase by 5 AFY and evapotranspiration increases by 18 AFY (Table 14). These changes are due to the higher water levels in the basin resulting from reduced pumping.

For the 110% Run, every 1,000 AFY decrease in total pumpage results in a 701 AFY increase in basin storage relative to Scenario 2 (Table 14). Similarly, this same comparison indicates that recharge from streams increases by 210 AFY, irrigation return flow increases by 55 AFY, and natural inflows increase by 12 AFY. For the groundwater outflow components, natural subsurface outflows decrease by 5 AFY and evapotranspiration decreases by 16 AFY (Table 14). These changes are due to the lower water levels in the basin resulting from increased pumping. Agricultural pumpage is more widely spread across the basin and comprises much of the total pumpage located farther away from the Salinas River. Therefore, uniform changes in agricultural pumpage show a more direct relationship with groundwater storage and less interaction with the Salinas River.

CHAPTER 9 - CONCLUSIONS

A numerical groundwater flow model was successfully developed for the Paso Robles Groundwater Basin. The model aquifer properties and boundary conditions are consistent with the hydrogeological conceptual model developed in the Phase I Report (Fugro and Cleath 2002). The model was calibrated using three separate criteria including groundwater elevation maps, statistical analysis, and hydrographs. More specifically, it was calibrated to 4,290 measured groundwater elevations from 180 wells completed in the basin. The calibration demonstrates that the model is capable of simulating previously observed groundwater trends over time across the entire model domain and provides the basis for using the model in a predictive manner. The model can serve as a useful tool to evaluate potential future trends in groundwater quantity and quality.

The process of developing and calibrating the groundwater model resulted in some refinements and modifications to the hydrologic budget for the basin. These refinements and modifications include:

- The overall water balance in the model was approximately 17 percent higher than calculated in the Phase I Report. The differences are primarily reflected in greater outflows through natural boundaries such as discharge to the Salinas River, evapotranspiration, and subsurface outflow.
- Recharge is greater than originally known along various portions of the basin boundary, apparently reflecting previously unidentified subsurface inflow.
- Significant recharge occurs in the smaller streams around the basin margins.
- Additional pumping is strongly indicated in specific areas and is assumed to be associated with agricultural use.
- The groundwater model agreed closely with the Phase I Report with respect to change in groundwater storage over the 17-year base period.

The calibrated groundwater model was applied to evaluate the perennial yield for the basin, and to simulate impacts to groundwater levels resulting from projected build-out conditions in the basin. General conclusions from these scenarios include:

- The model indicates that the perennial yield for the Paso Robles Groundwater Basin is 97,700 AFY.
- The perennial yield analysis shows that not all of the total volume of an increase in pumping comes out of groundwater storage. Because of the complex interaction of the groundwater with the surface water sources, increased basin pumping induces additional stream percolation as well as affecting other inflow and outflow components. Similarly, a decrease in pumping affects not only groundwater in storage, but concurrently reduces stream recharge and affects other inflows and outflows. Understanding this dynamic relationship suggests that groundwater pumping locations and amounts can be optimized to manage groundwater levels and protect beneficial uses.
- The Build-Out Scenario (Scenario 2) simulated the effects of urban and rural build-out as well as future maximum reasonable agricultural water demand. This scenario increased basin pumping to 108,300 AFY, which results in an average annual decline in

groundwater storage of 3,800 AFY. Under such a scenario, declining groundwater storage would result in a general lowering of water levels across much of the basin, particularly in the Estrella subarea and the northern part of the Atascadero Subbasin.

- The Build-Out Scenario with Nacimiento water (Scenario 3) simulated the impacts on basin storage and water levels by replacing a portion of municipal pumping with an equal portion of Nacimiento project water. The volume of applied Nacimiento water in this scenario was equal to the amounts contracted by Atascadero Mutual Water Company (2,000 AFY), Templeton Community Services District (250 AFY), and the City of Paso Robles (4,000 AFY). This scenario, which simulated basin-wide annual pumping of 102,100 AFY, results in an average annual decline in groundwater storage of 1,200 AFY.
- Comparison of Scenarios 2 and 3 indicate an overall positive net benefit of the Nacimiento project of 2,600 AFY in the average annual change in groundwater storage. Although a slight general lowering of water levels would still occur throughout the basin at build-out with implementation of the Nacimiento project, the benefits would be most dramatically apparent in the Estrella subarea and the Atascadero Subbasin, where all of the municipal pumping occurs.
- The municipal pumping, as opposed to agricultural water demand, is more significantly affected by groundwater-surface water interactions associated with the Salinas River by either reduced recharge from the river or induced discharge of groundwater to the river during high water periods. This relatively close link indicates that municipal groundwater pumping locations and amounts in particular can be optimized to manage the groundwater levels. Additional scenarios with alternative well locations and pumping rates in the vicinity of the Salinas River could be useful in managing groundwater storage, optimizing groundwater pumping, and maintaining beneficial river flows.
- The agricultural pumping component of the hydrologic budget reflects the largest groundwater outflow from the basin. It is also the single largest estimated parameter because the pumpage volumes are not metered but rather estimates based on land use and irrigation practices. Thus, minor variations of agricultural water demand estimates may have widespread impacts on groundwater storage and groundwater elevations.
- A sensitivity analysis was run on the Scenario 2 maximum reasonable agricultural water demand (simulating “agricultural build-out”). Agricultural pumpage was changed at each well to 90% of the projection for the first run and to 110% for the second run. The 90% run resulted in a small groundwater storage increase of 500 AFY, relative to the impacts simulated by the Scenario 2 conditions. The 110% run resulted in groundwater storage declines of 8,000 AFY. Because future agricultural trends are so problematic to forecast, slight misforecasts in agricultural demand predictions could have large implications relative to changes in groundwater storage and water levels. Given a perennial yield value of 97,700 AFY and estimated basin pumpage at 102,100 AFY at build-out (with Nacimiento water), it is clear a relatively slight adjustment in “build-out” agricultural pumping could make the difference between potential basin overdraft or non-overdraft conditions.
- Agricultural pumpage, by being more widespread across the basin and comprising much of the pumpage located away from the Salinas River, shows a more direct relationship with groundwater storage and less interaction with the Salinas River. Thus, basin-wide changes in agricultural trends that would result in changes in agricultural pumping would

have a more direct effect on groundwater storage than would parallel changes in municipal pumping.

It is important to note that short-term periods of groundwater extractions in excess of the perennial yield will not necessarily result in significant basin-wide negative economic impacts. Groundwater in storage in the basin is sufficiently large such that short-term storage declines may be acceptable to withstand temporary conditions such as droughts. The total estimated groundwater in storage in the basin approximates 30,500,000 acre feet (Fugro and Cleath 2002). At build-out with implementation of the Nacimiento project (Scenario 3), pumpage would exceed the perennial yield by approximately 4,400 AFY. This will result in a decline in groundwater storage of approximately 1,200 AFY, which represents a volume corresponding to approximately 0.004% of total groundwater in storage. This is not to underestimate the impacts or financial hardships of individuals affected by the localized water level drawdown in the Estrella subarea, but merely to state that the small percentage of decline in storage is well within the scientific margin of precision of the calculations and should be viewed as an indication of stable basin-wide conditions.

With the development of a sound, defensible model as a groundwater planning and management tool, the various issues and studies that previously would have been studied individually by different water purveyors and/or regulatory agencies can now be linked through the dynamic processes of the model. Actions proposed or taken in one part of the basin may have dramatic impacts elsewhere. The use of the model as a basin-wide tool to track local and regional projects will allow water resource managers and planners to proactively prepare for the future and manage the resource for the beneficial uses of all overlying landowners.

CHAPTER 10 - RECOMMENDATIONS

The computer model is a dynamic groundwater management tool that can be used by water resource managers and planners to analyze issues on a coordinated, basin-wide basis and to manage water resources for the long-term benefit of all overlying landowners. Specific recommendations include the following:

- Simulation of possible projects involving artificial recharge and/or provision of alternative irrigation supply. These scenarios should involve simulation of impacts on groundwater levels and water quality. These scenarios also should involve simulation of the effect of turning off or resting wells with provision of an alternative water supply (e.g., reclaimed wastewater or the remaining allocation of Nacimiento water). A particular focus for such possible projects would be the portion of the Estrella subarea that is characterized by groundwater level declines.
- Simulation of alternative well locations and pumping rates. The simulations documented in this report revealed the importance of the dynamic hydraulic interaction of groundwater and surface water, particularly along the Salinas River. Additional scenarios should focus on modifying the operation of municipal wells along the Salinas River to manage groundwater storage, optimize pumping, and preserve beneficial uses of river flow.
- Water quality modeling. Although the Phase 2 effort did not specifically include simulation of water quality trends, the model was developed with a water quality component that will allow for assessment of water quality trends and impacts. Particular areas of focus may include the areas with increasing TDS, chloride, and nitrate that were identified in the Atascadero Subbasin and in the Estrella subarea south of San Miguel.
- Update of the model on a regular basis. Annual compilation of data and update of the hydrologic budget is recommended; a full model update and recalibration of the model to current conditions is recommended every three to five years. This recommendation is particularly important because groundwater pumpage in the projected build-out scenarios is the result of many different decisions made by groundwater users and is close to the perennial yield value. Particular focus should be placed on agricultural pumping, and land use patterns, estimates of agricultural pumping, and distribution of agricultural pumping should be updated regularly.

CHAPTER 11 - REFERENCES

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TABLES

Table 1 – Hydrologic Budget Summary for the Paso Robles Groundwater Basin from the Phase I Report (Fugro and Cleath 2002)

(in thousands of acre-feet)

Year	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Total Extraction	Col. 10	Col. 11	Col. 12	Col. 13
	Subsurface Inflow	Percolation of Precipitation	Streambed Percolation	Percolation of Irrigation Water	Percolation of Wastewater Discharge	Total Inflow	Subsurface Outflow	Groundwater Pumpage			Extraction by Phreatophytes	Total Outflow	Inventory Method	Specific Yield Method
								Gross Agr.	M&I					
	IN	IN	IN	IN	IN	(1+2+3+4+5)	OUT	OUT	OUT		OUT	(7+8+9+10)	(6-11)	
1981	5.6	0.3	21.8	4.1	2.3	34.0	0.6	114.9	13.5	126.1	2.9	131.9	-97.9	40.2
1982	7.7	6.2	41.2	2.7	2.3	60.1	0.6	98.9	13.0	109.6	3.9	116.5	-56.4	-24.5
1983	12.7	223.0	88.8	1.5	2.6	328.6	0.6	87.5	13.7	98.6	6.4	108.3	220.3	184.5
1984	5.1	0.2	22.8	4.4	2.7	35.2	0.6	111.8	16.0	125.1	2.6	131.0	-95.8	-175.2
1985	4.6	0.1	19.9	3.9	2.9	31.4	0.6	103.0	16.5	116.6	2.3	122.5	-91.0	-116.6
1986	8.5	17.6	52.4	2.1	3.2	83.8	0.6	82.9	17.3	97.0	4.3	105.2	-21.4	249.8
1987	4.7	0.0	10.3	3.0	3.2	21.2	0.6	88.5	18.6	103.9	2.4	110.1	-88.9	-67.9
1988	7.5	2.1	16.9	2.2	3.4	32.1	0.6	78.3	19.2	94.1	3.8	101.9	-69.8	-206.7
1989	4.0	0.0	11.7	2.6	3.5	21.8	0.6	79.8	19.9	96.2	2.0	102.4	-80.6	-6.0
1990	5.0	0.0	2.8	2.8	3.4	14.1	0.6	79.8	20.2	96.6	2.6	103.2	-89.1	-45.0
1991	7.5	1.4	53.0	1.9	3.5	67.2	0.6	67.3	19.5	83.3	3.8	91.2	-24.0	185.0
1992	8.2	6.2	75.0	1.6	3.6	94.6	0.6	63.8	20.3	80.5	4.2	88.9	5.7	84.8
1993	11.7	125.8	127.6	1.2	3.8	270.1	0.6	56.8	20.9	73.9	5.9	84.3	185.8	37.7
1994	4.5	0.0	13.2	1.4	3.5	22.7	0.6	56.9	21.7	75.1	2.3	81.5	-58.9	-206.3
1995	14.9	346.4	75.2	1.0	4.0	441.6	0.6	49.8	21.6	67.4	7.6	79.6	362.0	205.6
1996	6.8	1.9	38.7	1.0	3.9	52.3	0.6	49.6	23.4	69.1	3.5	77.1	-24.8	-11.7
1997	8.1	6.3	39.8	1.1	3.9	59.2	0.6	50.8	24.4	71.3	4.1	79.9	-20.7	-115.4
17-Year Average:	7.5	43.4	41.8	2.3	3.3	98.2	0.6	77.7	18.8	93.2	3.8	100.9	-2.7	0.7
High	14.9	346.4	127.6	4.4	4.0	441.6	0.6	114.9	24.4	126.1	7.6	131.9	362.0	249.8
Low	4.0	0.0	2.8	1.0	2.3	14.1	0.6	49.6	13.0	67.4	2.0	77.1	-97.9	-206.7
Percentage of Total	8%	44%	43%	2%	3%	100%	1%	77%	19%	92%	4%	100%		

Table 2 – Summary of Transmissivity and Hydraulic Conductivity Data from the Phase I Report (Fugro and Cleath 2002)

Basin Area	Geologic Unit	Transmissivity (gpd/ft)			Hydraulic Conductivity (ft/day)		
		Min	Avg	Max	Min	Avg	Max
Atascadero	Alluvium (Salinas River)	101,106	376,000	650,000	450	1,963	3,476
	Alluvium (other Creeks)	15,840	20,020	24,200	161	187	212
	Alluvium and Paso Robles Fm.	22,000	38,120	52,800	16	42	146
	Paso Robles Fm.	1,700	5,305	8,250	1	4	11
Creston	Alluvium (Huer Huero Creek)	22,000	104,000	186,000	150	400	620
	Paso Robles Fm.	600	7,800	30,000	1	4	14
Estrella	Alluvium and Paso Robles Fm.	16,500	22,400	40,000	5	11	16
	Paso Robles Fm.	800	4,600	25,000	1	5	20
Shandon	Paso Robles Fm.	4,800	11,000	36,000	2	6	8
San Juan	Paso Robles Fm.	16,000	35,000	98,000	5	12	32
North and South Gabilan	Paso Robles Fm.	5,400	5,600	5,800	10	15	28

Table 3 – Hydrologic Budget Summary for the Paso Robles Groundwater Basin
Based on the Phase II Groundwater Model

(in thousands of acre-feet)

Year	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6		Col. 7	Col. 8	Col. 9	Col. 10	Col. 11		Col. 12	Col. 13	Col. 14
	Percolation of Precipitation	Percolation of Irrigation Water	Percolation of Stream Recharge	Percolation of Wastewater Discharge	Subsurface Inflow			Total Inflow	Subsurface Outflow	Groundwater Discharge to Salinas River	Groundwater Pumpage			Evapo-transpiration	Total Outflow	Change In Storage
					General Margin Inflow	Local Elevated Inflow	Total Subsurface Inflow				Gross Ag Pumpage	Gross M&I Pumpage	Total Extraction			
	IN	IN	IN	IN	IN	IN	IN	(1+2+3+4+5+6)	OUT	OUT	OUT	OUT	OUT	OUT	(8+9+10+11+12)	
1981	15.5	4.1	17.2	2.3	5.9	16.6	22.5	61.5	2.1	9.8	112.3	13.0	125.3	8.0	145.3	-83.7
1982	24.0	2.7	46.3	2.3	8.2	17.0	25.2	100.4	1.8	9.2	96.6	13.1	109.7	7.5	128.1	-27.7
1983	136.3	1.5	112.9	2.6	13.4	15.6	29.0	282.4	1.6	14.5	86.2	13.8	100.0	9.0	125.2	157.2
1984	13.8	4.4	16.4	2.7	5.4	16.3	21.7	58.9	1.5	8.7	109.6	16.0	125.6	8.4	144.2	-85.3
1985	12.4	3.9	18.4	2.9	4.8	17.2	22.0	59.6	1.5	7.7	100.6	16.4	117.0	7.5	133.7	-74.1
1986	37.2	2.1	56.3	3.2	9.0	17.2	26.2	125.0	1.6	8.7	80.9	17.3	98.2	7.5	116.0	9.0
1987	12.5	3.0	8.9	3.2	4.9	17.7	22.6	50.2	1.5	7.4	86.0	18.6	104.6	7.0	120.5	-70.3
1988	19.4	2.2	26.7	3.4	7.9	17.8	25.7	77.5	1.5	8.0	76.9	19.2	96.1	6.9	112.6	-35.1
1989	10.8	2.6	12.8	3.5	4.3	18.3	22.6	52.3	1.5	6.9	79.1	19.8	99.0	6.7	114.1	-61.8
1990	13.5	2.9	10.4	3.4	5.3	18.9	24.2	54.5	1.3	6.8	88.1	20.2	108.3	6.5	122.9	-68.5
1991	18.6	1.9	63.3	3.5	7.9	18.6	26.5	113.7	1.4	7.8	77.3	19.4	96.7	6.7	112.6	1.1
1992	25.2	1.6	74.9	3.6	8.7	18.1	26.8	132.0	1.5	8.3	73.6	20.2	93.8	7.0	110.6	21.5
1993	138.7	1.2	142.0	3.8	12.3	16.3	28.6	314.4	1.6	14.8	67.2	20.9	88.1	8.4	112.9	201.5
1994	12.0	1.4	6.4	3.5	4.7	17.0	21.7	45.1	1.5	8.8	66.7	21.6	88.3	7.8	106.5	-61.4
1995	161.9	1.0	96.0	4.0	15.7	15.4	31.1	294.1	1.7	16.5	59.9	21.6	81.5	9.1	108.8	185.3
1996	17.6	1.0	32.2	3.9	7.2	15.9	23.1	77.8	1.6	10.5	59.4	23.4	82.8	8.4	103.4	-25.5
1997	24.9	1.1	40.7	3.9	8.5	16.5	25.0	95.6	1.6	10.2	60.0	24.3	84.4	8.0	104.2	-8.5
17-Year Average:	40.8	2.3	46.0	3.3	7.9	17.1	25.0	117.4	1.6	9.7	81.2	18.8	100.0	7.7	118.9	-1.5
High	161.9	4.4	142.0	4.0	15.7	18.9	31.1	314.4	2.1	16.5	112.3	24.3	125.6	9.1	145.3	201.5
Low	10.8	1.0	6.4	2.3	4.3	15.4	21.7	45.1	1.3	6.8	59.4	13.0	81.5	6.5	103.4	-85.3
Percentage of Total	35%	2%	39%	3%	7%	14%	21%	100%	1%	8%	68%	16%	84%	6%	100%	

Table 4 – Streamflow Input Data for the Paso Robles Groundwater Model

(in thousands of acre-feet)

Stream Group	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**Total**
Salinas River	11.1	12.7	15.6	11.1	10.8	13.7	10.1	10.9	10.2	10.0	13.6	15.3	17.3	10.3	14.8	12.5	12.8	***212.9***
Santa Margarita Creek	0.7	2.3	5.7	0.8	0.6	3.0	0.1	0.8	0.2	0.1	3.0	4.4	7.4	0.3	4.9	2.1	2.3	***38.8***
Atascadero tributaries	1.4	2.4	4.6	1.5	1.3	2.9	0.8	1.3	0.8	0.7	2.9	3.9	5.7	0.9	4.0	2.2	2.4	***39.8***
Paso tributaries	0.7	1.7	4.3	0.8	0.6	2.3	0.1	0.7	0.2	0.1	2.3	3.3	5.6	0.3	3.7	1.6	1.8	***30.1***
Nacimiento River	1.3	1.6	5.8	1.3	1.0	2.0	0.3	0.7	0.4	0.2	2.0	2.9	7.5	0.5	5.0	1.5	1.6	***35.5***
San Antonio Creek	0.6	0.8	5.6	0.7	0.5	1.1	0.0	0.3	0.1	0.0	1.1	1.6	7.3	0.2	4.8	0.8	0.8	***26.4***
Hames Creek	0.5	0.9	7.2	0.6	0.4	1.2	0.1	0.4	0.2	0.1	1.2	1.7	9.2	0.2	6.1	0.9	0.9	***31.8***
Huer Huero Creek	1.3	3.3	7.7	1.4	1.1	4.3	0.4	1.3	0.5	0.3	4.3	6.1	9.9	0.6	6.6	3.1	3.4	***55.5***
Estrella River	1.1	2.6	7.5	1.1	0.9	3.3	0.5	1.1	0.5	0.4	3.3	4.7	9.5	0.6	6.4	2.4	2.6	***48.5***
San Juan Creek	3.5	4.8	10.9	3.7	3.0	6.1	1.2	2.3	1.5	1.0	6.1	8.4	13.8	1.7	9.4	4.5	4.9	***86.8***
North Gabilan creeks	0.3	0.9	1.6	0.3	0.2	1.2	0.0	0.3	0.0	0.0	1.2	1.7	2.0	0.1	1.3	0.8	0.9	***12.6***
South Gabilan creeks	0.3	1.1	1.8	0.3	0.2	1.5	0.0	0.4	0.1	0.0	1.4	2.1	2.3	0.1	1.5	1.0	1.1	***15.2***
Shandon creeks	0.1	0.2	1.4	0.1	0.1	0.2	0.0	0.1	0.0	0.0	0.2	0.4	1.8	0.0	1.2	0.2	0.2	***6.1***
San Juan Canyon group	1.1	3.0	6.4	1.1	0.8	4.0	0.1	1.0	0.2	0.0	4.0	5.8	8.2	0.3	5.4	2.8	3.1	***47.2***
Shedd Canyon group	0.6	1.5	3.5	0.7	0.5	2.0	0.0	0.5	0.1	0.0	2.0	2.9	4.6	0.2	3.0	1.4	1.5	***25.1***
Minor Tributary	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.5	0.0	0.0	***1.8***
Annual Total	***24.6***	***39.6***	***90.2***	***25.4***	***22.0***	***48.9***	***13.8***	***22.1***	***15.0***	***12.9***	***48.6***	***65.2***	***112.7***	***16.3***	***78.7***	***37.7***	***40.2***	***714.1***

Table 5 – Summary of Statistical Calibration Results for the Paso Robles Groundwater Model

Calibration Parameter	Model Layer 1	Model Layer 2	Model Layer 3	Model Layer 4	Full Model
Number of Observations	1,028	53	1,759	1,450	4,290
Residual Mean	-1.42	0.63	2.85	0.85	1.12
Standard Deviation of Residual Mean	8.37	24.17	19.80	21.69	18.61
Absolute Residual Mean	6.17	19.51	15.55	17.39	13.98
Ratio of Standard Deviation to Range of Groundwater Elevations	0.013	0.055	0.032	0.022	0.017

Table 6 – Summary of Total Groundwater Inflow and Outflow with Percent Mass Balance Differential

(in acre-feet)

Year	Total Groundwater Inflow	Total Groundwater Outflow	Change in Storage	Mass Balance Difference	Percent Mass Balance Difference
1981	61,543	145,278	-83,740	-3.86	-0.0027%
1982	100,443	128,147	-27,708	-3.21	-0.0025%
1983	282,389	125,159	157,229	-1.23	-0.0004%
1984	58,925	144,186	-85,263	-2.84	-0.0020%
1985	59,603	133,741	-74,140	-2.82	-0.0021%
1986	124,976	115,952	9,022	-1.15	-0.0009%
1987	50,204	120,461	-70,256	1.56	0.0013%
1988	77,473	112,560	-35,091	-4.31	-0.0038%
1989	52,255	114,070	-61,812	2.25	0.0020%
1990	54,469	122,943	-68,472	1.00	0.0008%
1991	113,713	112,564	1,146	-3.22	-0.0028%
1992	132,037	110,582	21,453	-2.01	-0.0015%
1993	314,372	112,880	201,487	-4.63	-0.0015%
1994	45,083	106,492	-61,410	-0.40	-0.0004%
1995	294,105	108,809	185,297	0.50	0.0002%
1996	77,842	103,368	-25,527	-0.27	-0.0003%
1997	95,630	104,163	-8,537	-4.07	-0.0039%
Total	**1,995,061**	**2,021,355**	**-26,322**	**-28.71**	**-0.0014%**

Table 7 – Scenario 1 Total Pumpage Summary

Subarea	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5
Shandon	17.6	18.5	19.4	20.4	21.3
San Juan	9.4	9.9	10.4	10.9	11.4
South Gabilan	0.4	0.4	0.4	0.4	0.4
Estrella	37.2	39.1	41.1	43.1	45.0
North Gabilan	1.7	1.8	1.9	2.0	2.0
Bradley	3.8	4.1	4.3	4.5	4.7
Atascadero	13.9	14.6	15.3	16.1	16.8
Creston	11.1	11.7	12.3	12.8	13.4
BASIN TOTAL	**95.1**	**100.1**	**105.1**	**110.1**	**115.1**

Note: Total pumpage presented as an annual average in thousand acre-feet per year

Table 8 – Scenario 1 Water Balance Summary

Subarea	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5
GROUNDWATER INFLOW					
Subsurface Inflow	25.0	25.0	25.1	25.1	25.2
Precipitation Recharge	40.8	40.8	40.8	40.8	40.8
Irrigation Return Flow	2.2	2.3	2.4	2.5	2.6
Net Stream Inflow	35.2	36.3	37.5	38.7	39.8
Wastewater	3.1	3.3	3.5	3.6	3.8
Net Inflow	**106.3**	**107.7**	**109.3**	**110.8**	**112.2**
GROUNDWATER OUTFLOW					
Subsurface Outflow	1.6	1.6	1.6	1.6	1.6
Agricultural Pumpage	77.1	81.2	85.3	89.3	93.4
M&I Pumpage	17.9	18.8	19.7	20.7	21.6
Evapotranspiration	7.8	7.7	7.6	7.6	7.5
Net Outflow	**104.5**	**109.3**	**114.3**	**119.3**	**124.2**
CHANGE IN GROUNDWATER STORAGE					
Change in Groundwater Storage	**1.8**	**-1.5**	**-5.0**	**-8.5**	**-12.0**

Note: Water balance presented as an annual average in thousand acre-feet per year

Table 9 – Scenario 1 Change in Groundwater Storage

Subarea	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5
Shandon	2.56	1.74	0.92	0.10	-0.73
San Juan	-2.62	-3.16	-3.70	-4.25	-4.79
South Gabilan	0.05	-0.05	-0.15	-0.24	-0.34
Estrella	0.38	-0.82	-2.04	-3.26	-4.51
North Gabilan	0.06	0.00	-0.06	-0.13	-0.19
Bradley	0.37	0.19	0.03	-0.14	-0.31
Atascadero	0.08	-0.02	-0.13	-0.25	-0.37
Creston	0.92	0.52	0.10	-0.32	-0.75
BASIN TOTAL	**1.80**	**-1.60**	**-5.03**	**-8.49**	**-11.99**

Note: Change in storage volumes presented as an annual average in thousand acre-feet per year

Table 10 – Scenario 1 Change in Water Balance Relative to Run 2

Subarea	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	AVERAGE
GROUNDWATER INFLOW						
Subsurface Inflow	-0.010	0	0.016	0.004	0.010	0.010[1]
Precipitation Recharge	0.000	0	0.000	0.000	0.000	0.000[1]
Irrigation Return Flow	-0.023	0	0.022	0.023	0.023	0.023[1]
Net Stream Inflow	-0.230	0	0.242	0.228	0.221	0.230[1]
Wastewater	-0.036	0	0.034	0.035	0.035	0.035[1]
Net Inflow	**-0.299**	**0**	**0.313**	**0.290**	**0.289**	**0.298**[1]
GROUNDWATER OUTFLOW						
Subsurface Outflow	0.004	0	-0.003	-0.003	-0.003	0.003[1]
Total Pumpage	-1.000	0	1.000	1.000	1.000	1.000[1]
Evapotranspiration	0.016	0	-0.010	-0.009	-0.009	0.011[1]
Net Outflow	**-0.980**	**0**	**0.987**	**0.987**	**0.987**	**0.985**[1]
CHANGE IN GROUNDWATER STORAGE						
Change in Groundwater Storage	**0.681**	**0**	**-0.673**	**-0.697**	**-0.698**	**0.687**[1]

Note: Relative change in water balance presented as an annual average in thousand acre-feet per year

[1] Average of absolute value relative to pumpage

Table 11 – Scenario 2 Total Pumpage Summary

Subarea	Agricultural Pumpage	M&I Pumpage**	Total Pumpage
Shandon	12.0	3.1	15.0
San Juan	7.3	1.4	8.7
South Gabilan	0.0	0.8	0.8
Estrella	26.1	21.1	47.2
North Gabilan	1.1	0.2	0.9
Bradley	4.7	1.2	6.0
Atascadero	3.9	15.8	19.7
Creston	4.9	5.1	9.9
BASIN TOTAL	**60.0**	**48.3**	**108.3**

Note: Total pumpage presented as an annual average in thousand acre-feet per year
**Note that M&I Pumpage includes municipal pumping (Atascadero, Templeton, Paso Robles, San Miguel), rural domestic, and small commercial systems

Table 12 – Scenario 2, 3 and Sensitivity Analysis Water Balance Summary

Subarea	Scenario 2	Scenario 3	Sensitivity Analysis 90%	Sensitivity Analysis 110%
GROUNDWATER INFLOW				
Subsurface Inflow	24.8	24.8	24.7	24.9
Precipitation Recharge	40.8	40.8	40.8	40.8
Irrigation Return Flow	1.3	1.3	1.0	1.7
Net Stream Inflow	39.5	35.8	38.1	40.7
Wastewater	7.5	7.5	7.5	7.5
Net Inflow	**113.9**	**110.2**	**112.2**	**115.6**
GROUNDWATER OUTFLOW				
Subsurface Outflow	1.6	1.6	1.7	1.6
Agricultural Pumpage	60.0	60.0	54.0	66.0
M&I Pumpage	48.3	42.1	48.3	48.3
Evapotranspiration	7.7	7.8	7.8	7.6
Net Outflow	**117.7**	**111.5**	**111.7**	**123.5**
CHANGE IN GROUNDWATER STORAGE				
Change in Groundwater Storage	**-3.8**	**-1.2**	**0.5**	**-8.0**

Note: Water balance presented as an annual average in thousand acre-feet per year

Table 13 – Scenario 2, 3 and Sensitivity Analysis Change in Groundwater Storage

Subarea	Scenario 2	Scenario 3	Sensitivity Analysis 90%	Sensitivity Analysis 110%
Shandon	3.0	3.0	3.9	2.0
San Juan	-0.6	-0.6	0.3	-1.4
South Gabilan	0.0	0.0	0.1	-0.2
Estrella	-4.3	-2.8	-2.9	-5.8
North Gabilan	0.3	0.3	0.4	0.3
Bradley	-1.0	-1.0	-0.6	-1.4
Atascadero	-0.7	0.0	-0.6	-0.8
Creston	-0.4	0.0	-0.1	-0.7
BASIN TOTAL	**-3.8**	**-1.2**	**0.5**	**-8.0**

Note: Change in storage volumes presented as an annual average in thousand acre-feet per year

Table 14 – Scenario 2, 3 and Sensitivity Analysis Change in Water Balance Relative to Scenario 2

Subarea	Scenario 2	Scenario 3	Sensitivity Analysis 90%	Sensitivity Analysis 110%
GROUNDWATER INFLOW				
Subsurface Inflow	0	-0.005	-0.012	0.012
Precipitation Recharge	0	0	0	0
Irrigation Return Flow	0	0.000	-0.054	0.055
Net Stream Inflow	0	-0.582	-0.215	0.210
Wastewater	0	0	0	0
Net Inflow	**0**	**-0.587**	**-0.281**	**0.278**
GROUNDWATER OUTFLOW				
Subsurface Outflow	0	0.000	0.005	-0.005
Total Pumpage	0	-1.000	-1.000	1.000
Evapotranspiration	0	0.006	0.018	-0.016
Net Outflow	**0**	**-0.994**	**-0.977**	**0.979**
CHANGE IN GROUNDWATER STORAGE				
Change in Groundwater Storage	**0**	**0.407**	**0.696**	**-0.701**

Note: Relative change in water balance presented as an annual average in thousand acre-feet per year

Table 15 – Scenario 3 Total Pumpage Summary

Subarea	Agricultural Pumpage	M&I Pumpage**	Total Pumpage
Shandon	12.0	3.1	15.0
San Juan	7.3	1.4	8.7
South Gabilan	0.0	0.8	0.8
Estrella	26.1	18.4	44.5
North Gabilan	1.1	0.2	0.9
Bradley	4.7	1.2	6.0
Atascadero	3.9	12.2	16.2
Creston	4.9	5.1	9.9
BASIN TOTAL	**60.0**	**42.1**	**102.1**

Note: Total pumpage presented as an annual average in thousand acre-feet per year

**Note that M&I Pumpage includes municipal pumping (Atascadero, Templeton, Paso Robles, San Miguel), rural domestic, and small commercial systems.

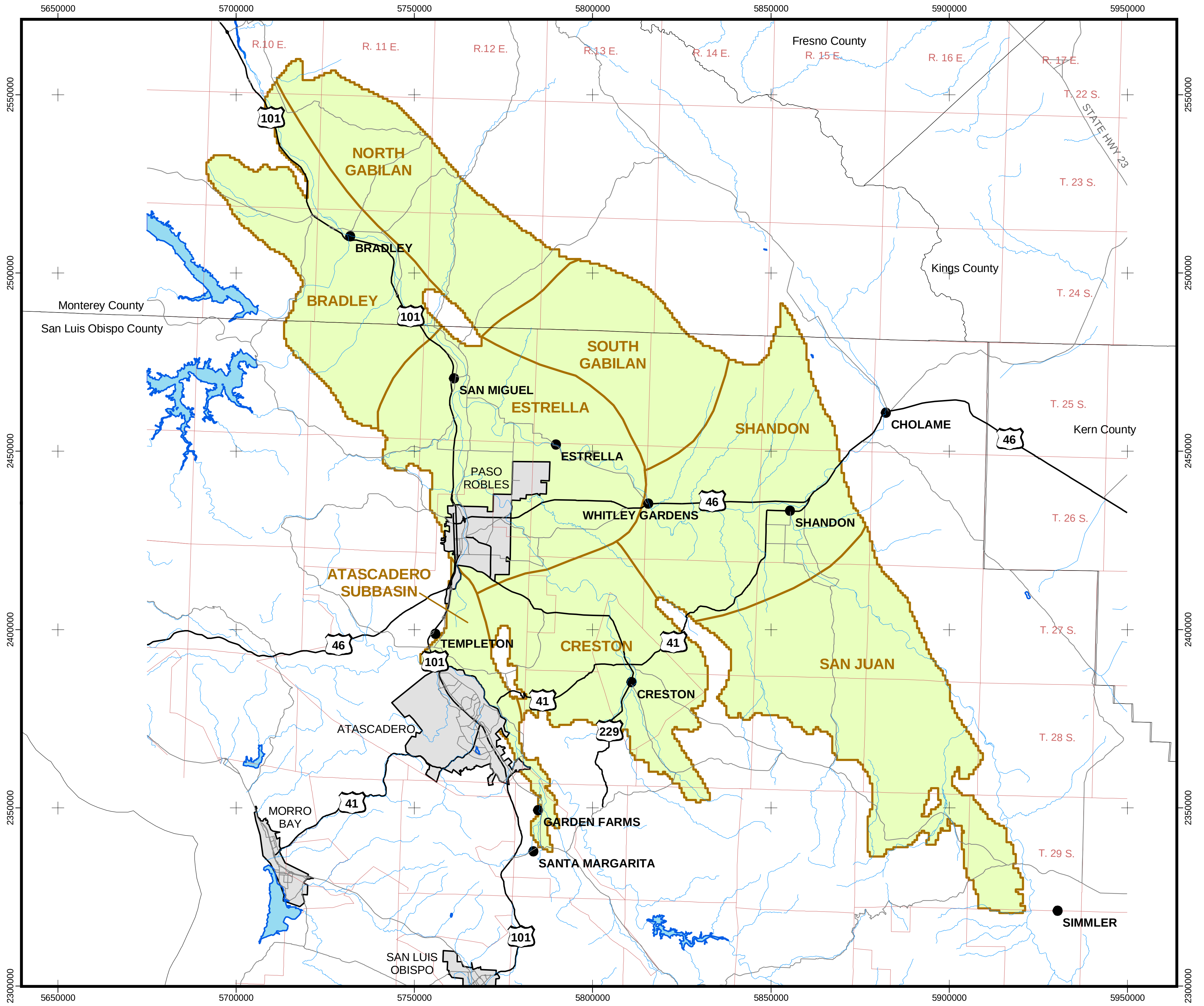
As noted in the text, only the municipal agencies (Atascadero, Templeton, and Paso Robles) receive Nacimiento water in lieu of groundwater. Other components of M&I Pumpage (rural domestic, small commercial systems) remain as specified in Scenario 2.

FIGURES

February 2005
Project No. 3014.007.05

ETIC ENGINEERING

FUGRO



LEGEND:

🟩 Paso Robles Groundwater Model Active Area
⬜ City Outlines
— Township and Range Grid

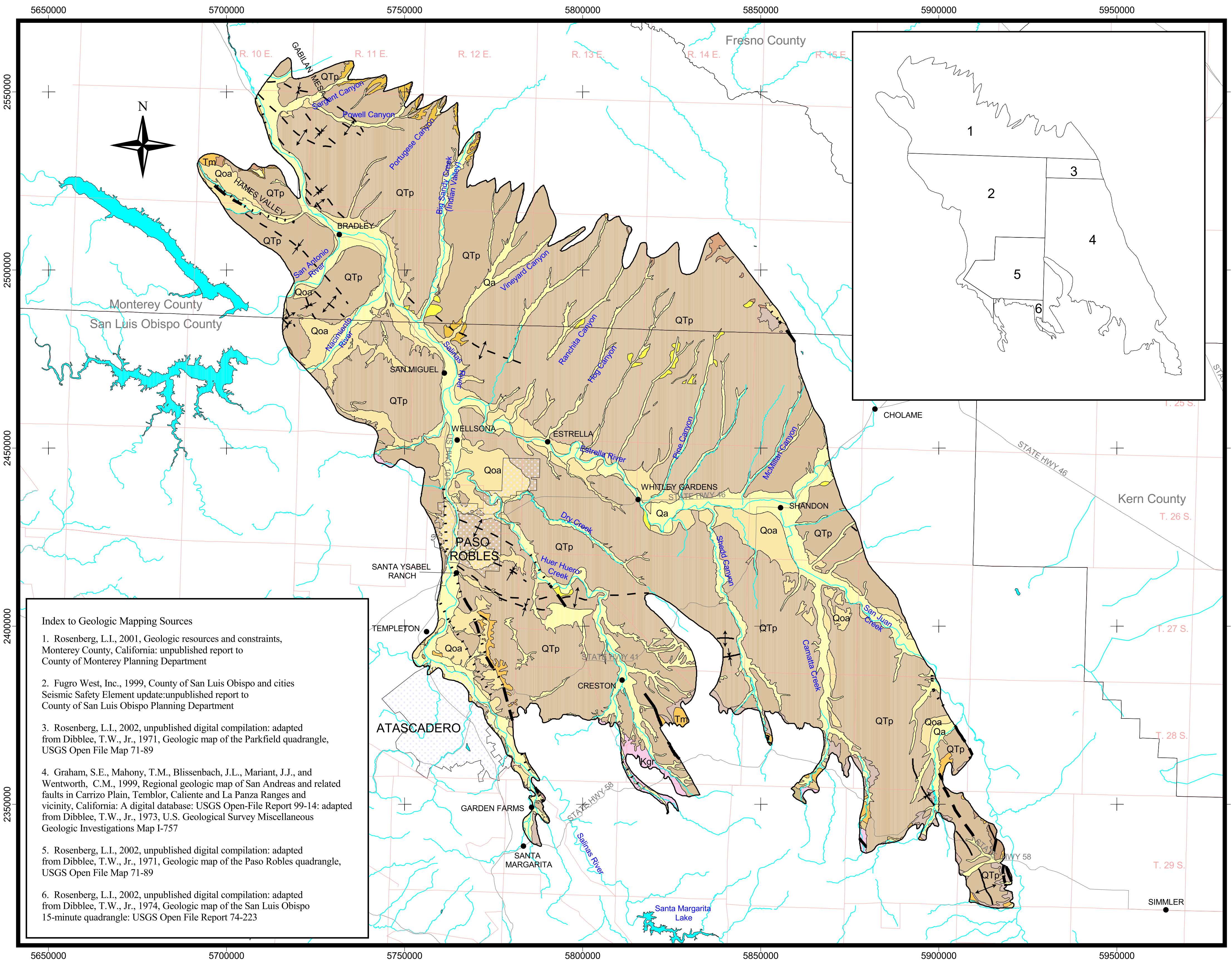
N

30000 0 30000
Feet

Paso Robles Groundwater Basin Location Map

Paso Robles Groundwater Basin Study, Phase II
Fugro West, Inc. and
ETIC Engineering

Figure 1



Index to Geologic Mapping Sources

1. Rosenberg, L.I., 2001, Geologic resources and constraints, Monterey County, California: unpublished report to County of Monterey Planning Department

2. Fugro West, Inc., 1999, County of San Luis Obispo and cities Seismic Safety Element update:unpublished report to County of San Luis Obispo Planning Department

3. Rosenberg, L.I., 2002, unpublished digital compilation: adapted from Dibblee, T.W., Jr., 1971, Geologic map of the Parkfield quadrangle, USGS Open File Map 71-89

4. Graham, S.E., Mahony, T.M., Blissenbach, J.L., Mariant, J.J., and Wentworth, C.M., 1999, Regional geologic map of San Andreas and related faults in Carrizo Plain, Temblor, Caliente and La Panza Ranges and vicinity, California: A digital database: USGS Open-File Report 99-14: adapted from Dibblee, T.W., Jr., 1973, U.S. Geological Survey Miscellaneous Geologic Investigations Map I-757

5. Rosenberg, L.I., 2002, unpublished digital compilation: adapted from Dibblee, T.W., Jr., 1971, Geologic map of the Paso Robles quadrangle, USGS Open File Map 71-89

6. Rosenberg, L.I., 2002, unpublished digital compilation: adapted from Dibblee, T.W., Jr., 1974, Geologic map of the San Luis Obispo 15-minute quadrangle: USGS Open File Report 74-223

Legend

Geologic Units

Paso Robles Groundwater Basin Sediments

Qa	Quaternary alluvium, undifferentiated (Holocene)
Qoa	Older alluvium, undifferentiated (Pleistocene)
Qls	Landslide deposits (Holocene-Pleistocene)
QTp	Paso Robles Formation, undifferentiated (Pliocene-Pleistocene)

Other Geologic Units

Tuc	Unnamed clastic sedimentary unit (probably Pliocene)
Tp	Pancho Rico Formation, undifferentiated (late Miocene to early Pliocene)
Tsm	Santa Margarita Sandstone (late Miocene)
Tbs	Branch Canyon Sandstone (middle to late Miocene)
Tm	Monterey Shale, undifferentiated (middle Miocene)
Tv	Vaqueros Formation, undifferentiated (Oligocene)
Ts	Simmler Formation, undifferentiated (Oligocene?)
Tsg	unnamed conglomerate (Oligocene or Miocene)
Kgr	Granitic rocks (Cretaceous)

━━	Fault, certain
━ ━	Fault, approximately located
· · · · ·	Fault, concealed
─┼─	Anticline, certain
─ ┼ ─	Anticline, approximately located
─┼─	Syncline, certain
─ ┼ ─	Syncline, approximately located
╱╲	Streams
╱╲	Highways
╱╲	County Line
╱╲	Township and Range Grid

Note:
1. Township and Range grid reference: Federal Township and Range System, Mt. Diablo Baseline and Meridian

30000 0 30000 Feet

Geologic Map of the Paso Robles Groundwater Basin

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

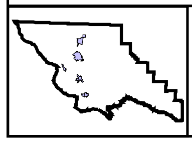
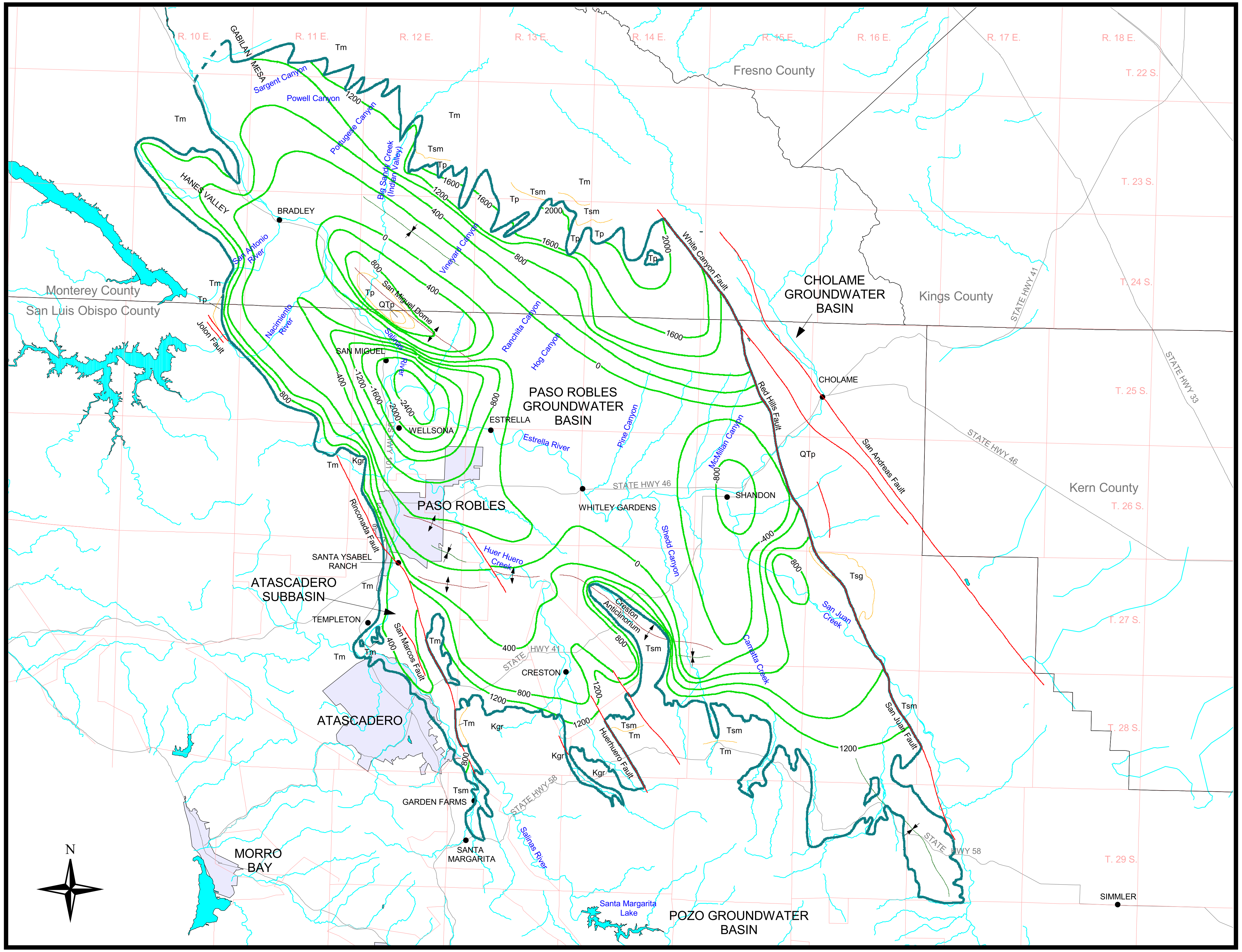


Figure 2



Legend

- City
- Elevation Contours on Base of Paso Robles Formation
  Contour interval = 400 feet
- Basin Outline
- Fault
- Anticline
- Syncline
- Streams
- Highways
- County Line
- Township and Range Grid

Geologic Units

Paso Robles Groundwater Basin Sediments	Qa	Alluvium
	Qoa	Older Alluvium
	Qls	Landslide
	QTp	Paso Robles Formation
Other Geologic Units	Tp	Pancho Rico Formation
	Tsm	Santa Margarita Sandstone
	Tm	Monterey Shale
	Tv	Vaqueros Formation
	Ts	Simmler Formation
	Tsg	unnamed (maroon) conglomerate
	Kgr	granite rocks

Notes:
1. Geologic units shown on base map around basin boundary are for reference only. For a geologic map of the basin see Figure 5.
2. Township and Range grid reference: Federal Township and Range System, Mt. Diablo Baseline and Meridian

30000 0 30000 Feet

Base of Permeable Sediments Map

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
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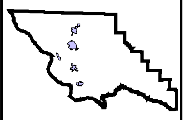
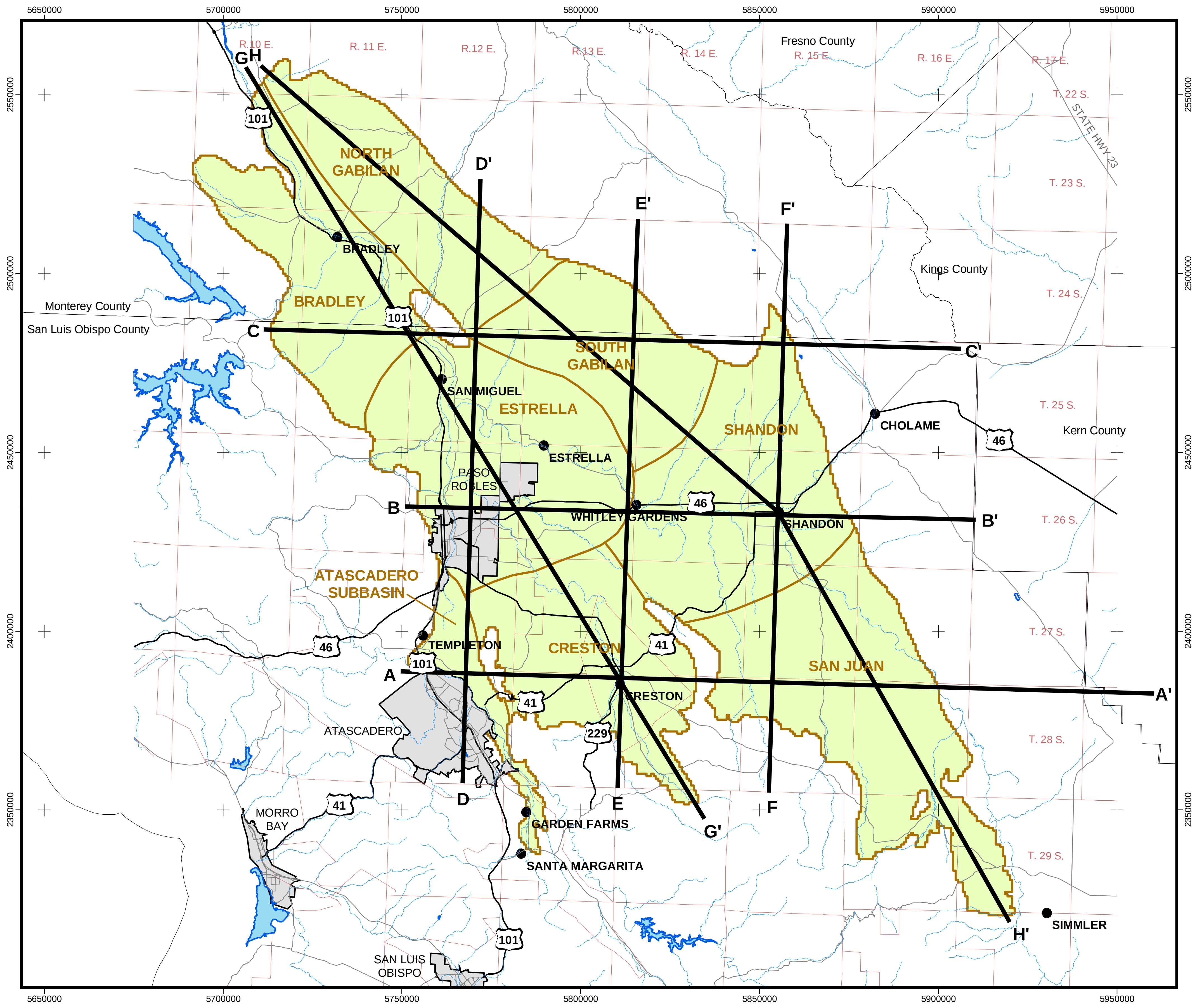
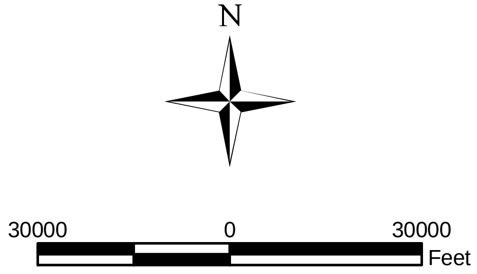


Figure 3



LEGEND:

- 🟩 Paso Robles Groundwater Model Active Area
- ▭ City Outlines
- — Township and Range Grid
- ━ Cross Section Location



Cross Section Location Map

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

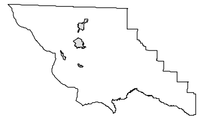
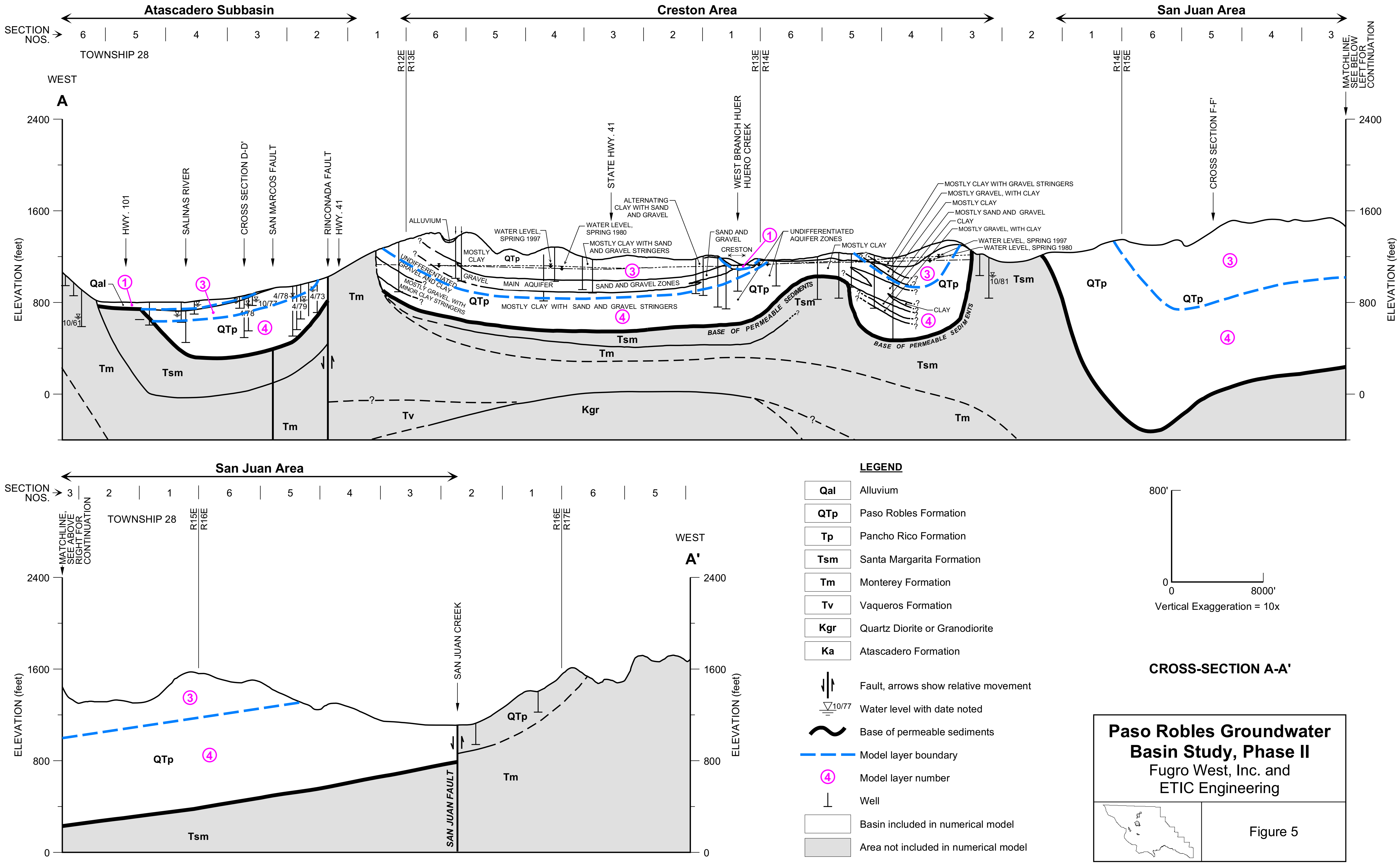


Figure 4



CROSS-SECTION A-A'

Paso Robles Groundwater Basin Study, Phase II
Fugro West, Inc. and
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Figure 5

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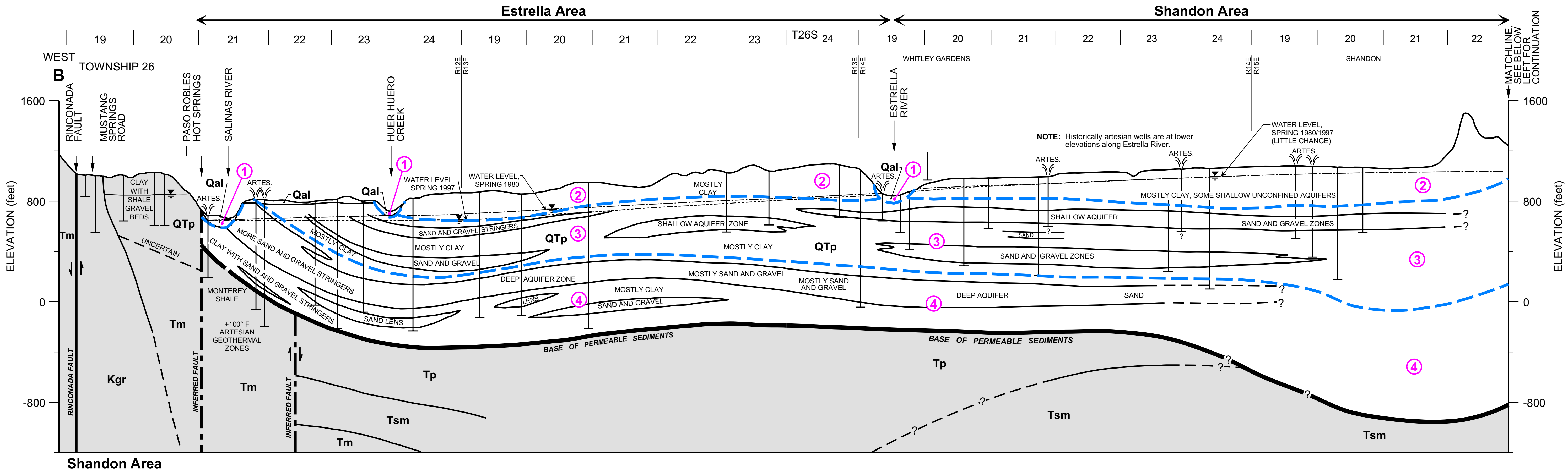
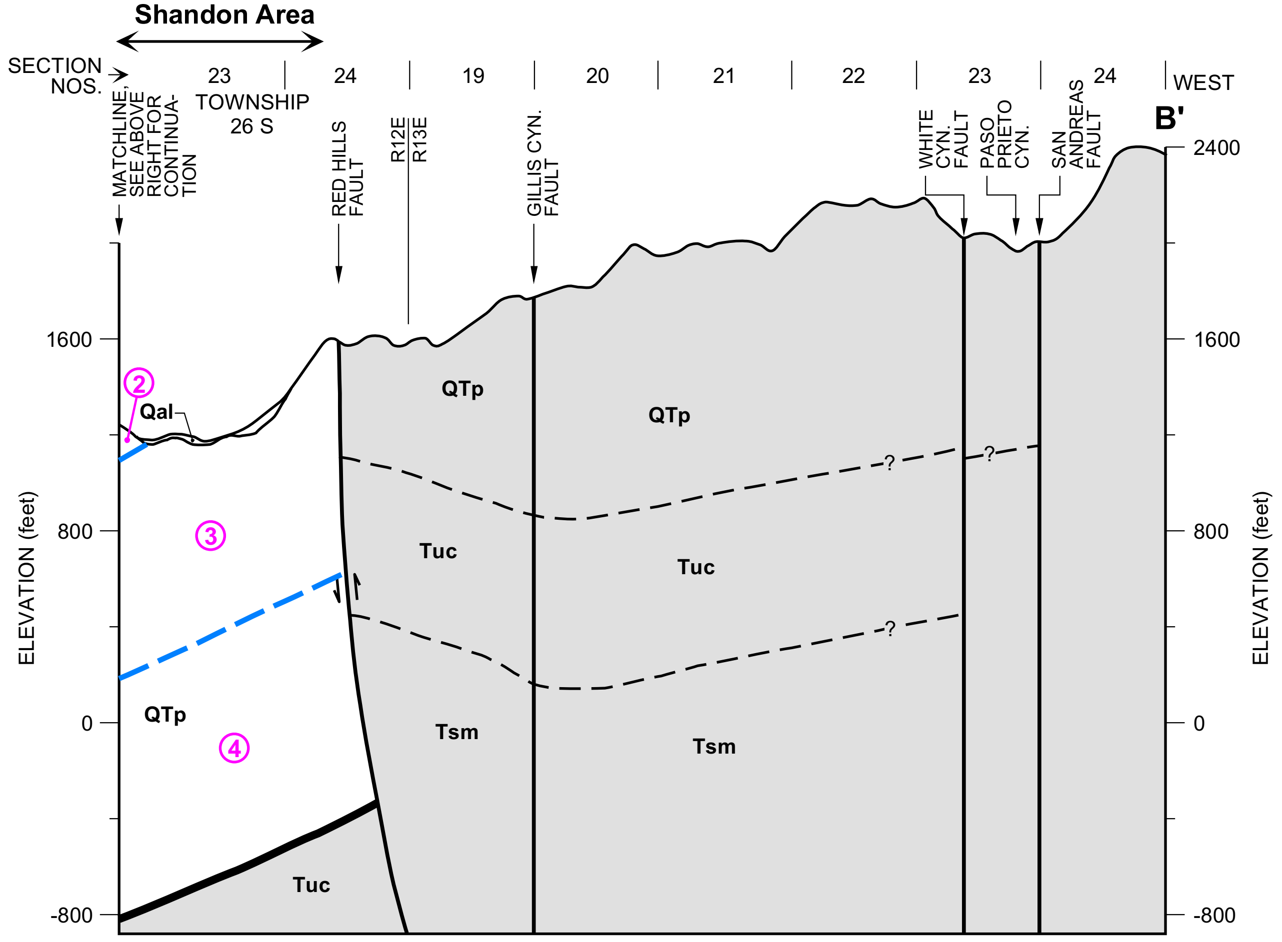
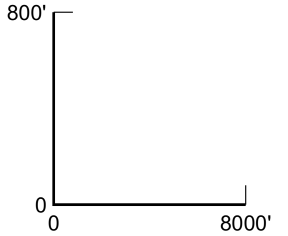




LEGEND

Qal	Alluvium
QTp	Paso Robles Formation
Tp	Pancho Rico Formation
Tsm	Santa Margarita Formation
Tm	Monterey Formation
Tv	Vaqueros Formation
Kgr	Quartz Diorite or Granodiorite
Ka	Atascadero Formation
⥮	Fault, arrows show relative movement
▽10/77	Water level with date noted
〜	Base of permeable sediments
— —	Model layer boundary
④	Model layer number
⊥	Well
☐	Basin included in numerical model
▨	Area not included in numerical model



Vertical Exaggeration = 10x

CROSS-SECTION B-B'

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

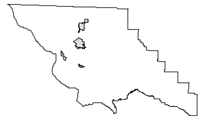
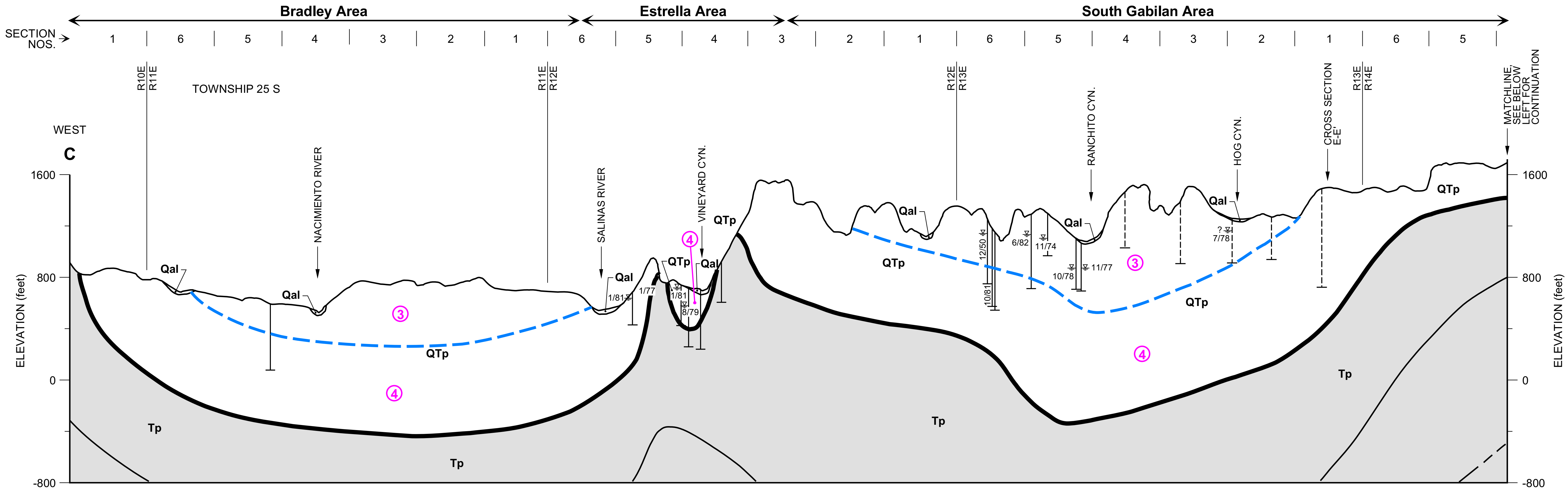
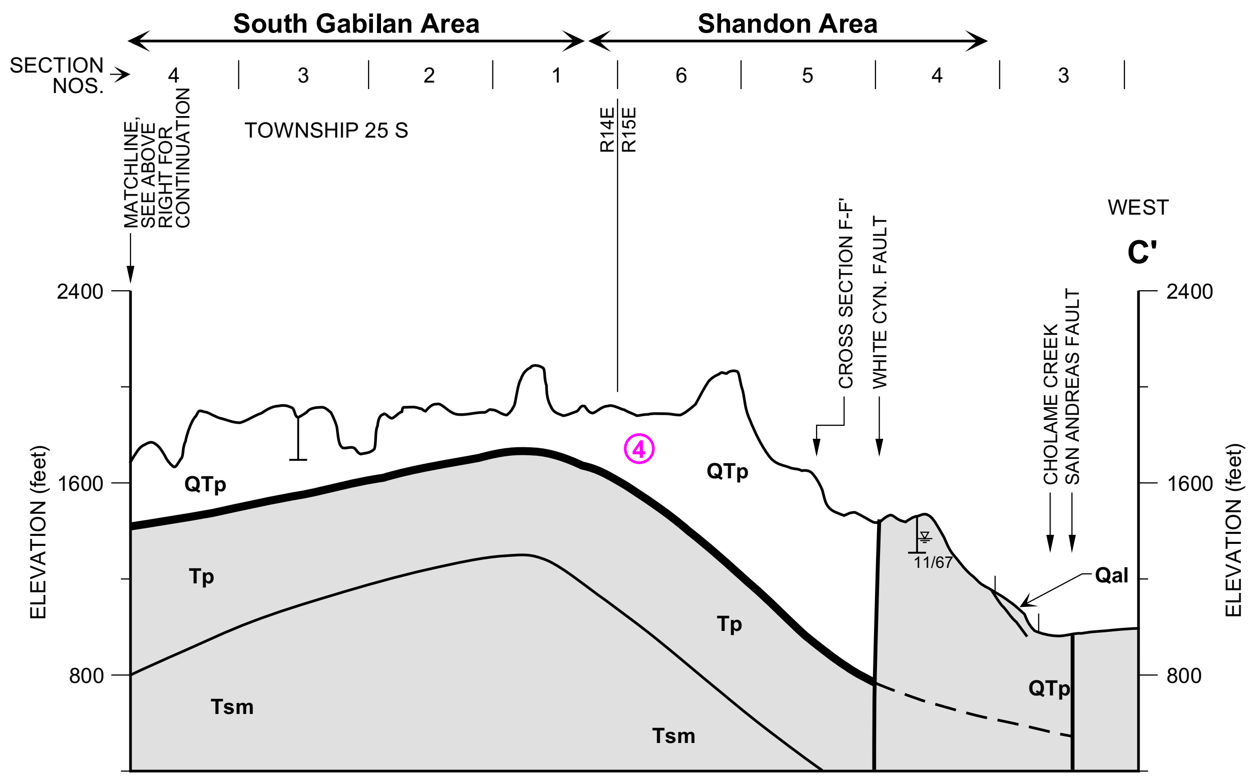


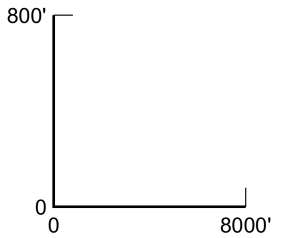
Figure 6





LEGEND

Qal	Alluvium
QTp	Paso Robles Formation
Tp	Pancho Rico Formation
Tsm	Santa Margarita Formation
Tm	Monterey Formation
Tv	Vaqueros Formation
Kgr	Quartz Diorite or Granodiorite
Ka	Atascadero Formation
⇅	Fault, arrows show relative movement
▽10/77	Water level with date noted
～	Base of permeable sediments
- -	Model layer boundary
④	Model layer number
⊥	Well
☐	Basin included in numerical model
▨	Area not included in numerical model



Vertical Exaggeration = 10x

CROSS-SECTION C-C'

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

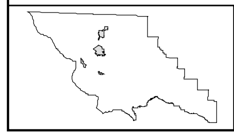
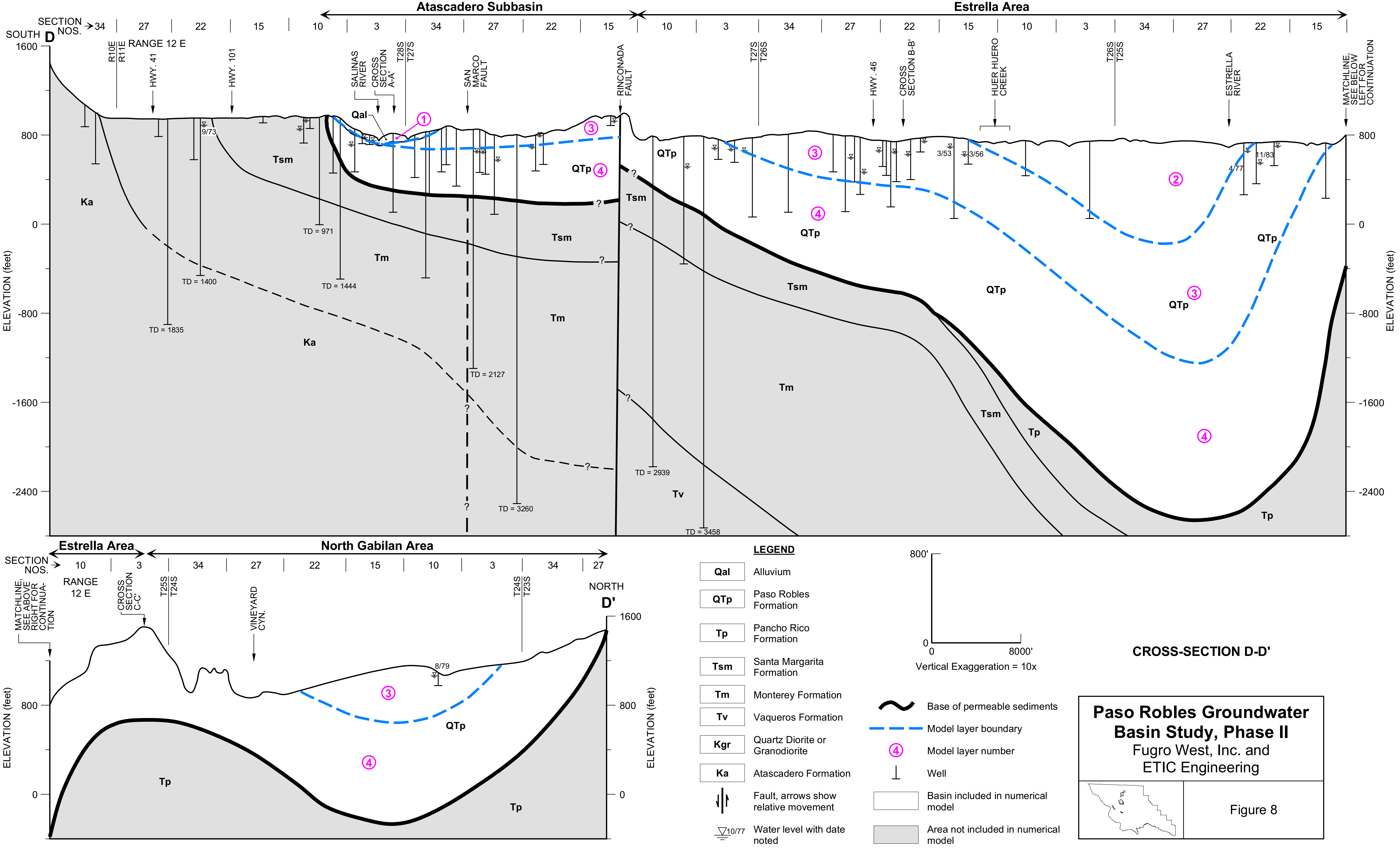


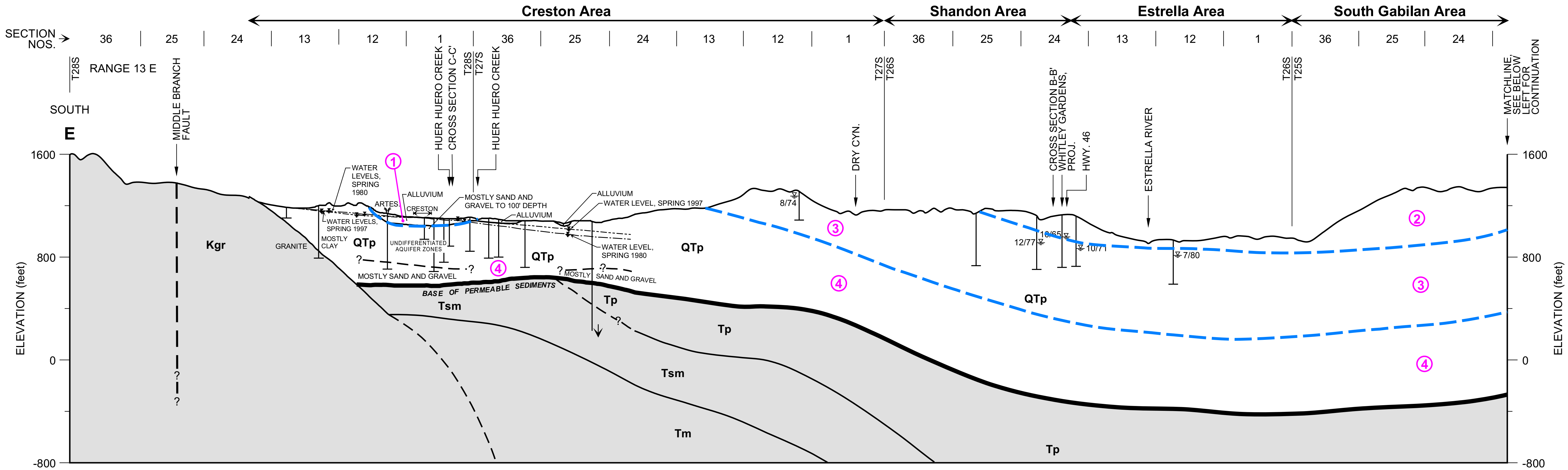
Figure 7

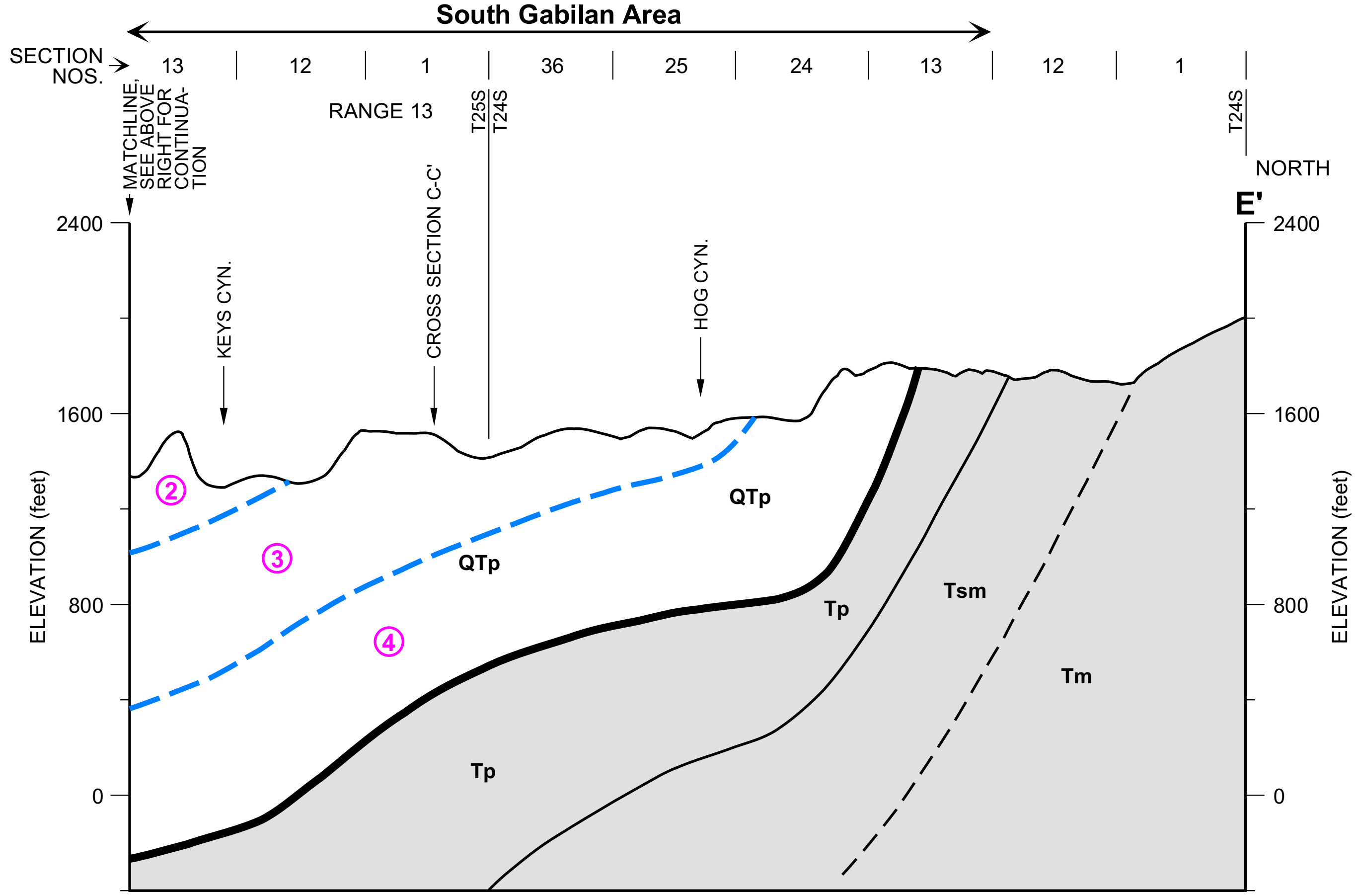


CROSS-SECTION D-D'

Paso Robles Groundwater Basin Study, Phase II
Fugro West, Inc. and
ETIC Engineering

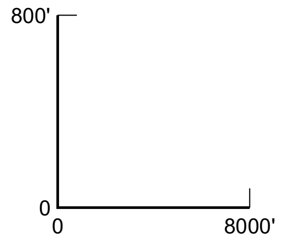
Figure 8





LEGEND

Qal	Alluvium
QTp	Paso Robles Formation
Tp	Pancho Rico Formation
Tsm	Santa Margarita Formation
Tm	Monterey Formation
Tv	Vaqueros Formation
Kgr	Quartz Diorite or Granodiorite
Ka	Atascadero Formation
⇅	Fault, arrows show relative movement
▽10/77	Water level with date noted
∼	Base of permeable sediments
- - -	Model layer boundary
④	Model layer number
⊥	Well
☐	Basin included in numerical model
▨	Area not included in numerical model



Vertical Exaggeration = 10x

CROSS-SECTION E-E'

Paso Robles Groundwater Basin Study, Phase II
Fugro West, Inc. and
ETIC Engineering

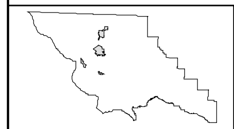
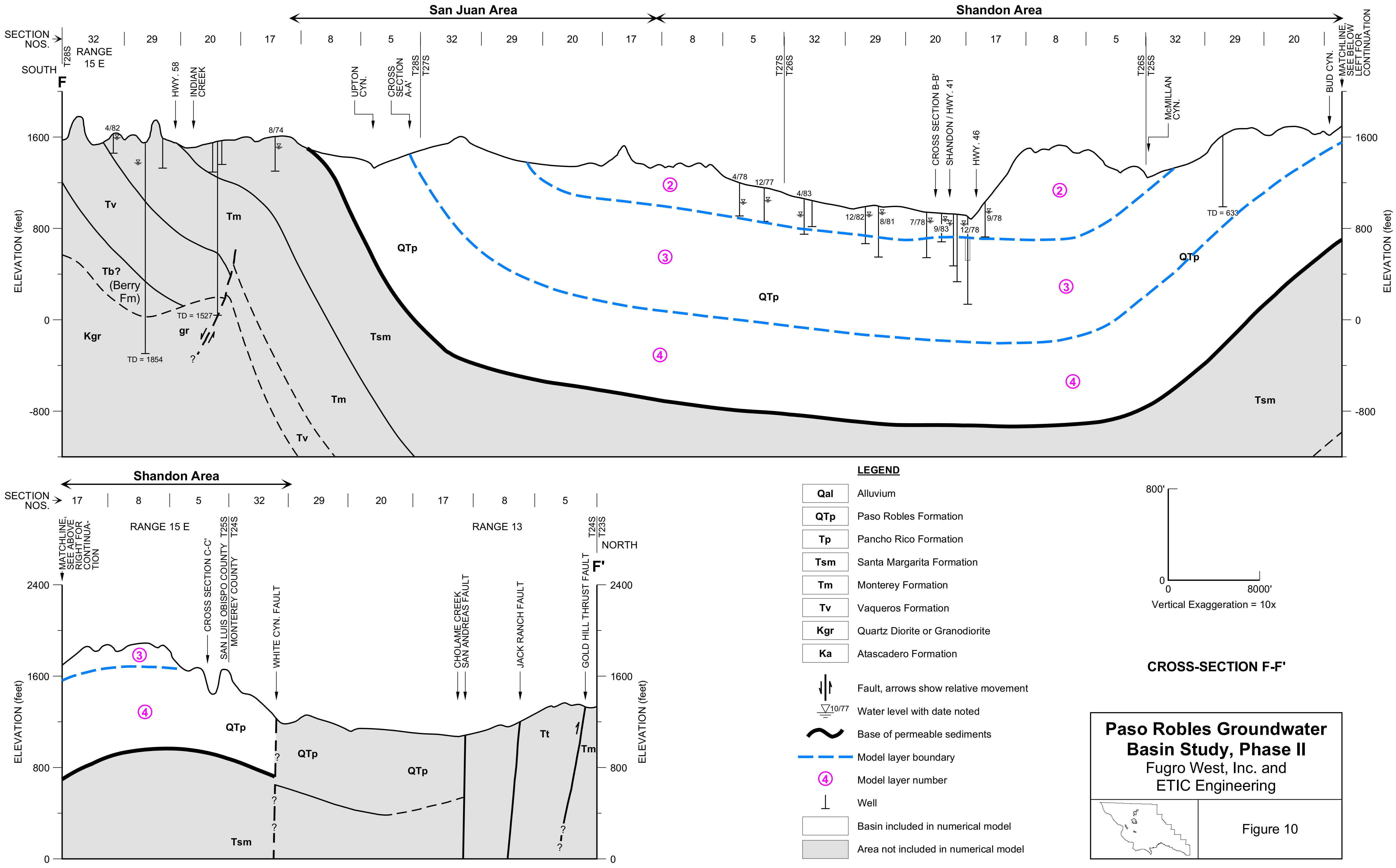


Figure 9

2004\3014.007.05\3014.007.05sec1.dsf.p5



LEGEND

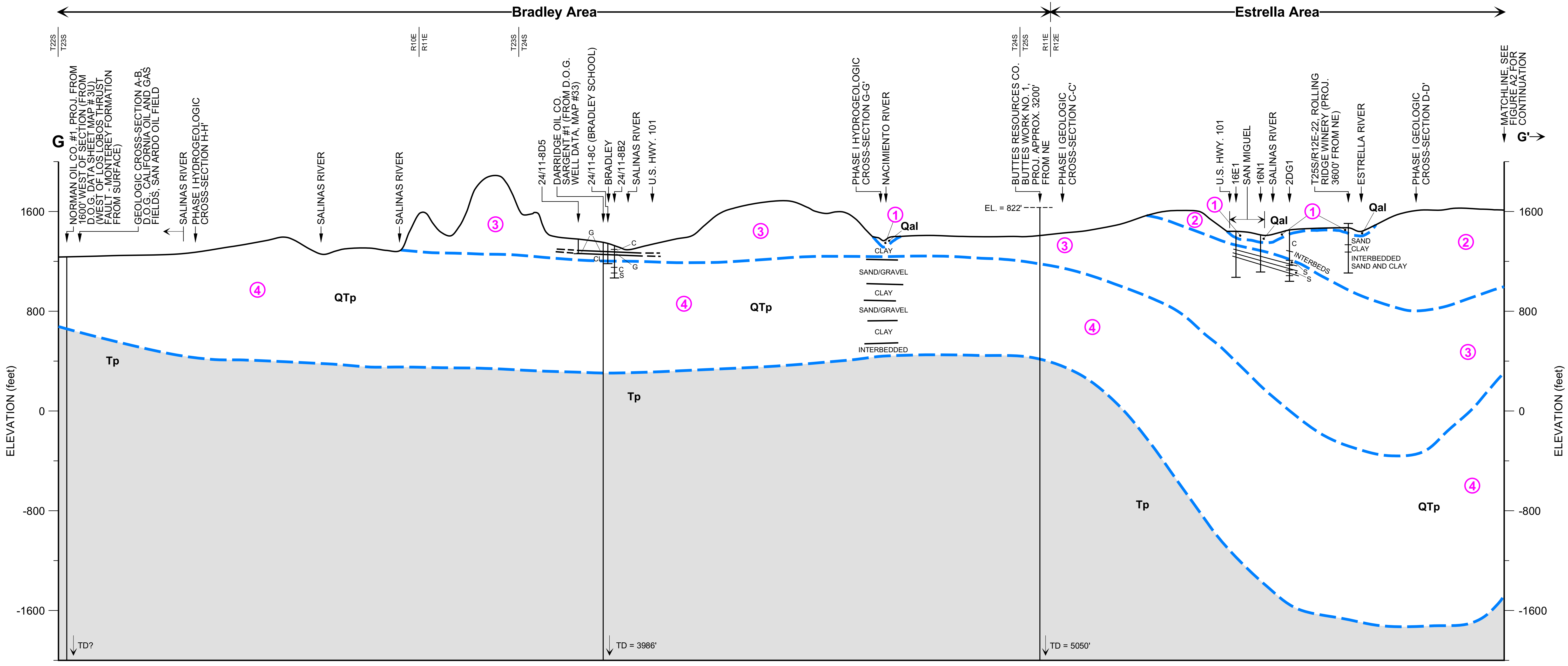
Qal	Alluvium
QTp	Paso Robles Formation
Tp	Pancho Rico Formation
Tsm	Santa Margarita Formation
Tm	Monterey Formation
Tv	Vaqueros Formation
Kgr	Quartz Diorite or Granodiorite
Ka	Atascadero Formation
⇅	Fault, arrows show relative movement
▽10/77	Water level with date noted
〜	Base of permeable sediments
– –	Model layer boundary
④	Model layer number
⊥	Well
☐	Basin included in numerical model
▨	Area not included in numerical model

CROSS-SECTION F-F'

Paso Robles Groundwater Basin Study, Phase II
Fugro West, Inc. and
ETIC Engineering

Figure 10

2004\3014.007.05\3014.007.05sec1.dsf.p6



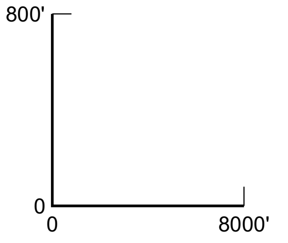
LEGEND

Qal	Alluvium
QTp	Paso Robles Formation
Tp	Pancho Rico Formation
Tsm	Santa Margarita Formation
– – – – –	Geologic contact
⊥	Well
← 1.5°	Geologic dip data

▽ 10/77	Water level with date noted
– – –	Model layer boundary
④	Numerical Model layer number
☐	Basin included in numerical model
▨	Area not included in numerical model

GEOLOGIC DESCRIPTION ABBREVIATIONS

S - Sand
CL - Clay
G - Gravel
S/G - Sand and Gravel



Vertical Exaggeration = 10x

CROSS-SECTION G-G'

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc., Cleath & Associates, and ETIC Engineering

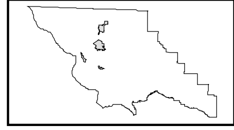
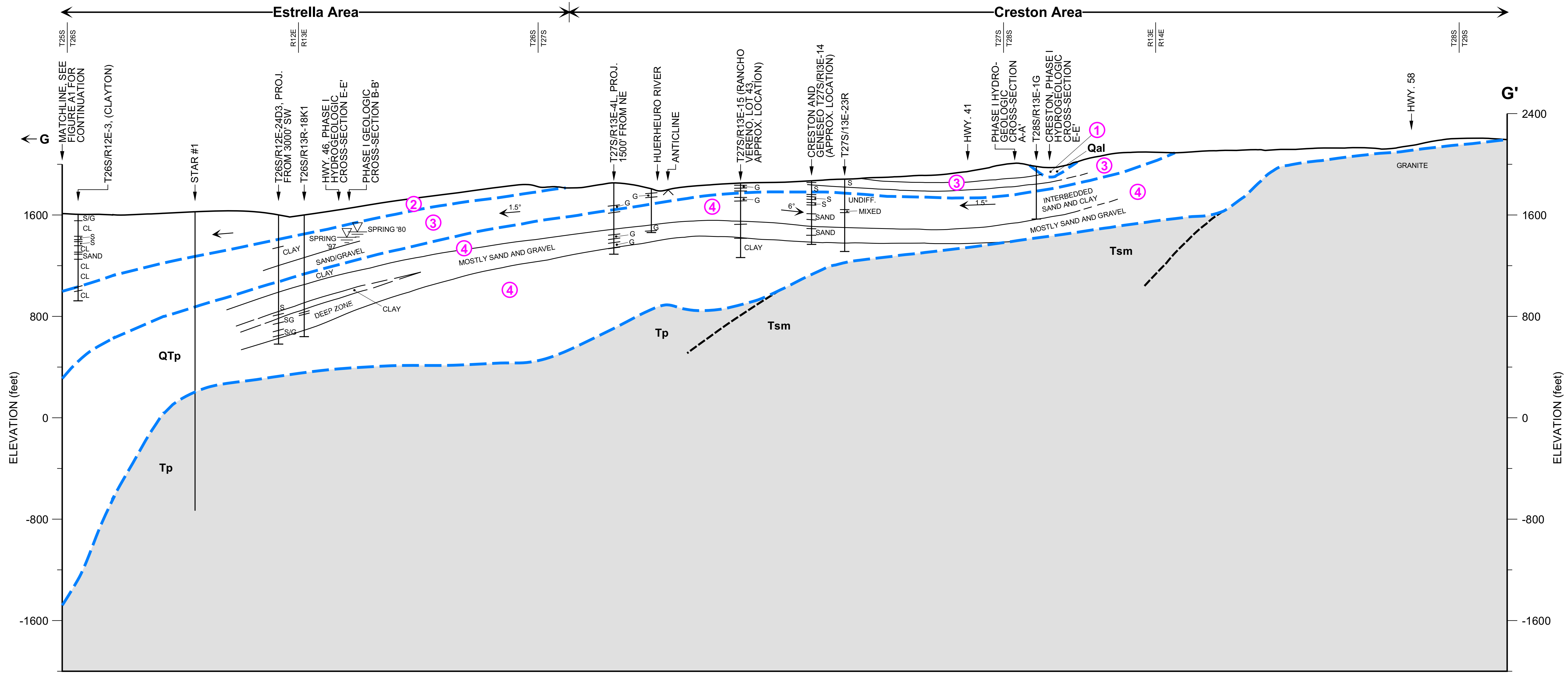


Figure 11A

2004\3014.007.05\3014.007.05sec2.dsf.p1

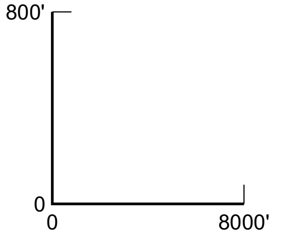


LEGEND

Qal	Alluvium
QTp	Paso Robles Formation
Tp	Pancho Rico Formation
Tsm	Santa Margarita Formation
- - - - - -	Geologic contact
⊥	Well
← 1.5°	Geologic dip data
▽ 10/77	Water level with date noted
– – –	Model layer boundary
④	Numerical Model layer number
☐	Basin included in numerical model
▨	Area not included in numerical model

GEOLOGIC DESCRIPTION ABBREVIATIONS

S - Sand
CL - Clay
G - Gravel
S/G - Sand and Gravel



Vertical Exaggeration = 10x

CROSS-SECTION G-G'
(continued)

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc., Cleath & Associates, and ETIC Engineering

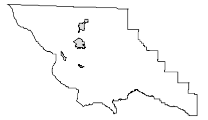
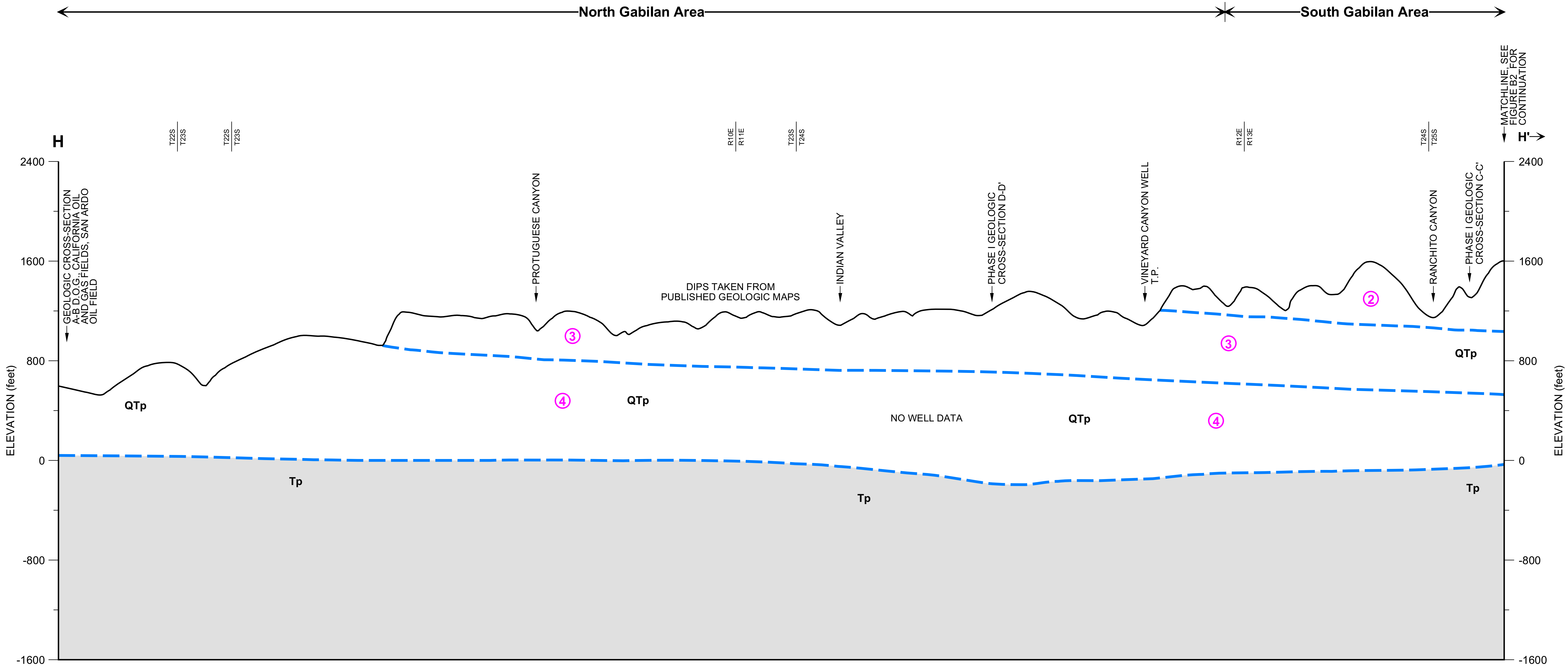


Figure 11B



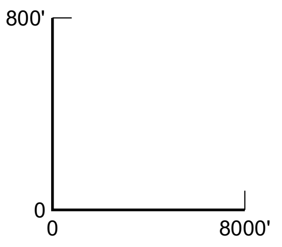
LEGEND

Qal	Alluvium
QTp	Paso Robles Formation
Tp	Pancho Rico Formation
Tsm	Santa Margarita Formation
- - - - - -	Geologic contact
⊥	Well
← 1.5°	Geologic dip data

▽10/77	Water level with date noted
— — —	Model layer boundary
④	Numerical Model layer number
☐	Basin included in numerical model
▨	Area not included in numerical model

GEOLOGIC DESCRIPTION ABBREVIATIONS

S - Sand
CL - Clay
G - Gravel
S/G - Sand and Gravel



Vertical Exaggeration = 10x

CROSS-SECTION H-H'

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc., Cleath & Associates, and ETIC Engineering

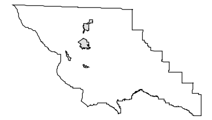
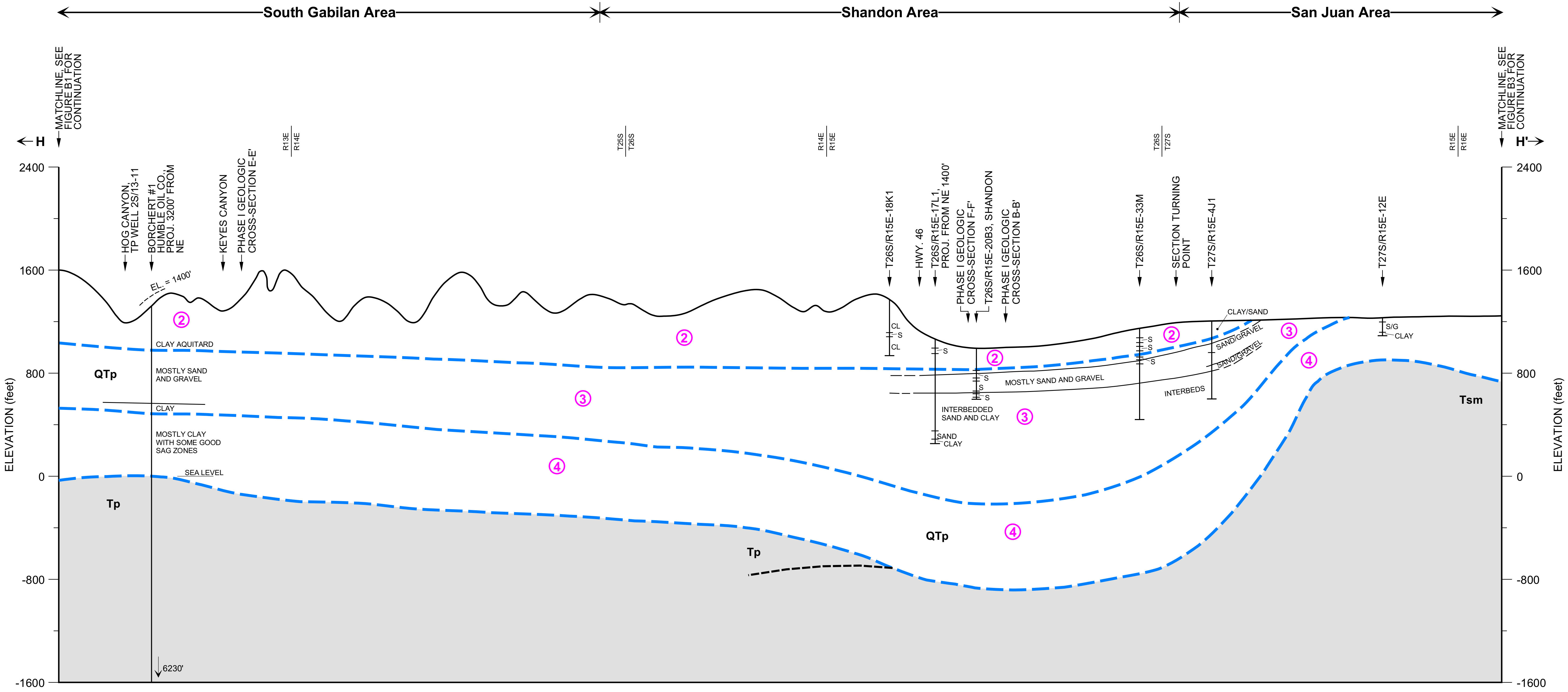


Figure 12A



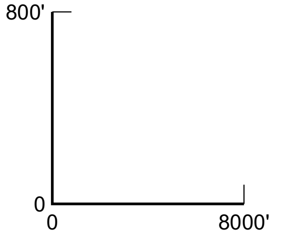
LEGEND

Qal	Alluvium
QTp	Paso Robles Formation
Tp	Pancho Rico Formation
Tsm	Santa Margarita Formation
- - - - -	Geologic contact
⊥	Well
↙ 1.5°	Geologic dip data

▽ 10/77	Water level with date noted
— — —	Model layer boundary
④	Numerical Model layer number
☐	Basin included in numerical model
▨	Area not included in numerical model

GEOLOGIC DESCRIPTION ABBREVIATIONS

S - Sand
CL - Clay
G - Gravel
S/G - Sand and Gravel



Vertical Exaggeration = 10x

CROSS-SECTION H-H'
(Continued)

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc., Cleath & Associates, and ETIC Engineering

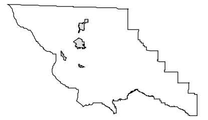
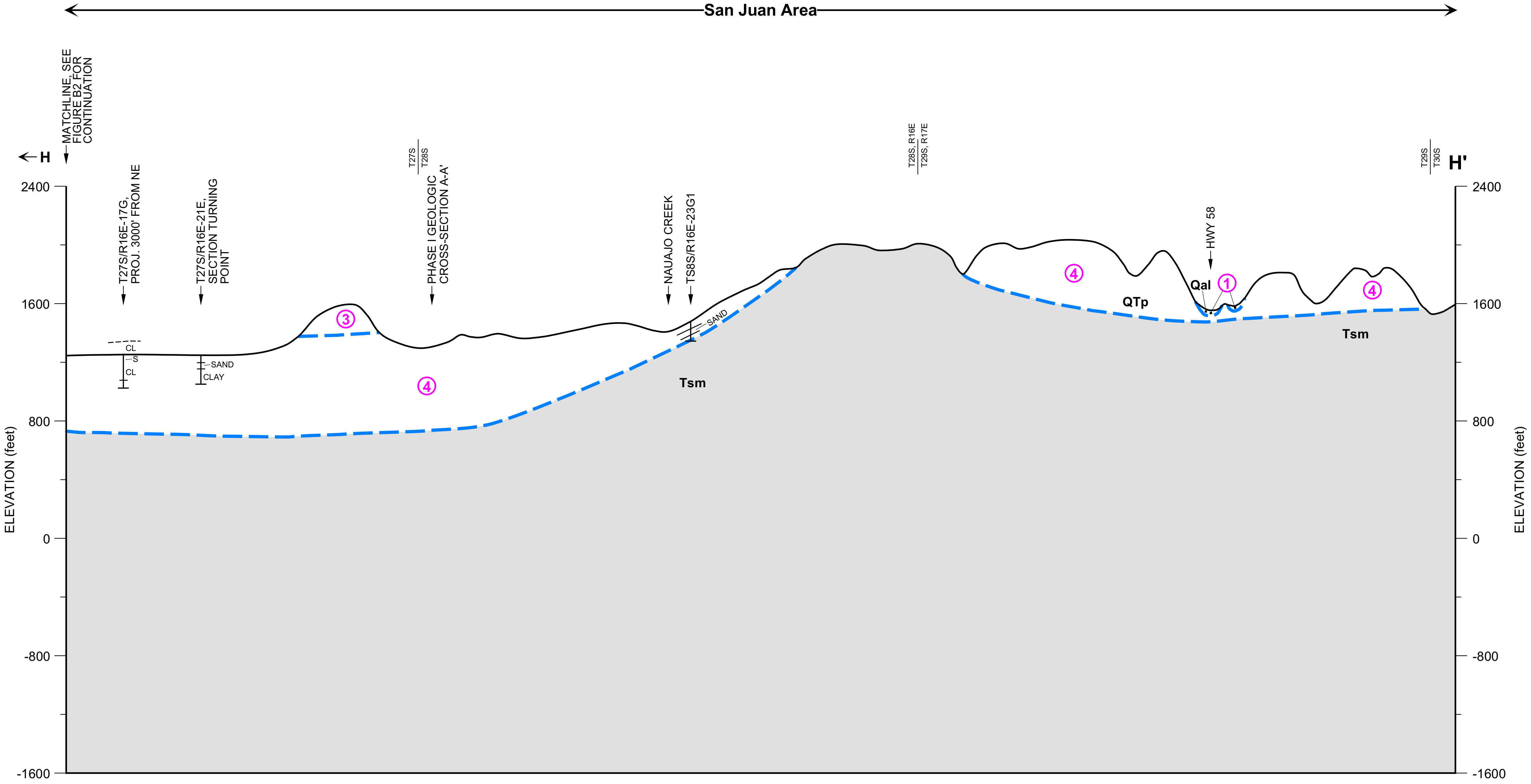


Figure 12B

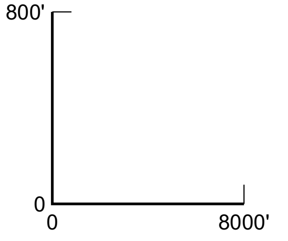


LEGEND

Qal	Alluvium
QTp	Paso Robles Formation
Tp	Pancho Rico Formation
Tsm	Santa Margarita Formation
------	Geologic contact
⊥	Well
← 1.5°	Geologic dip data
▽10/77	Water level with date noted
– – –	Model layer boundary
④	Numerical Model layer number
☐	Basin included in numerical model
▨	Area not included in numerical model

GEOLOGIC DESCRIPTION ABBREVIATIONS

S - Sand
CL - Clay
G - Gravel
S/G - Sand and Gravel



Vertical Exaggeration = 10x

CROSS-SECTION H-H'
(Continued)

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc., Cleath & Associates, and ETIC Engineering

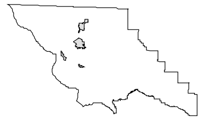
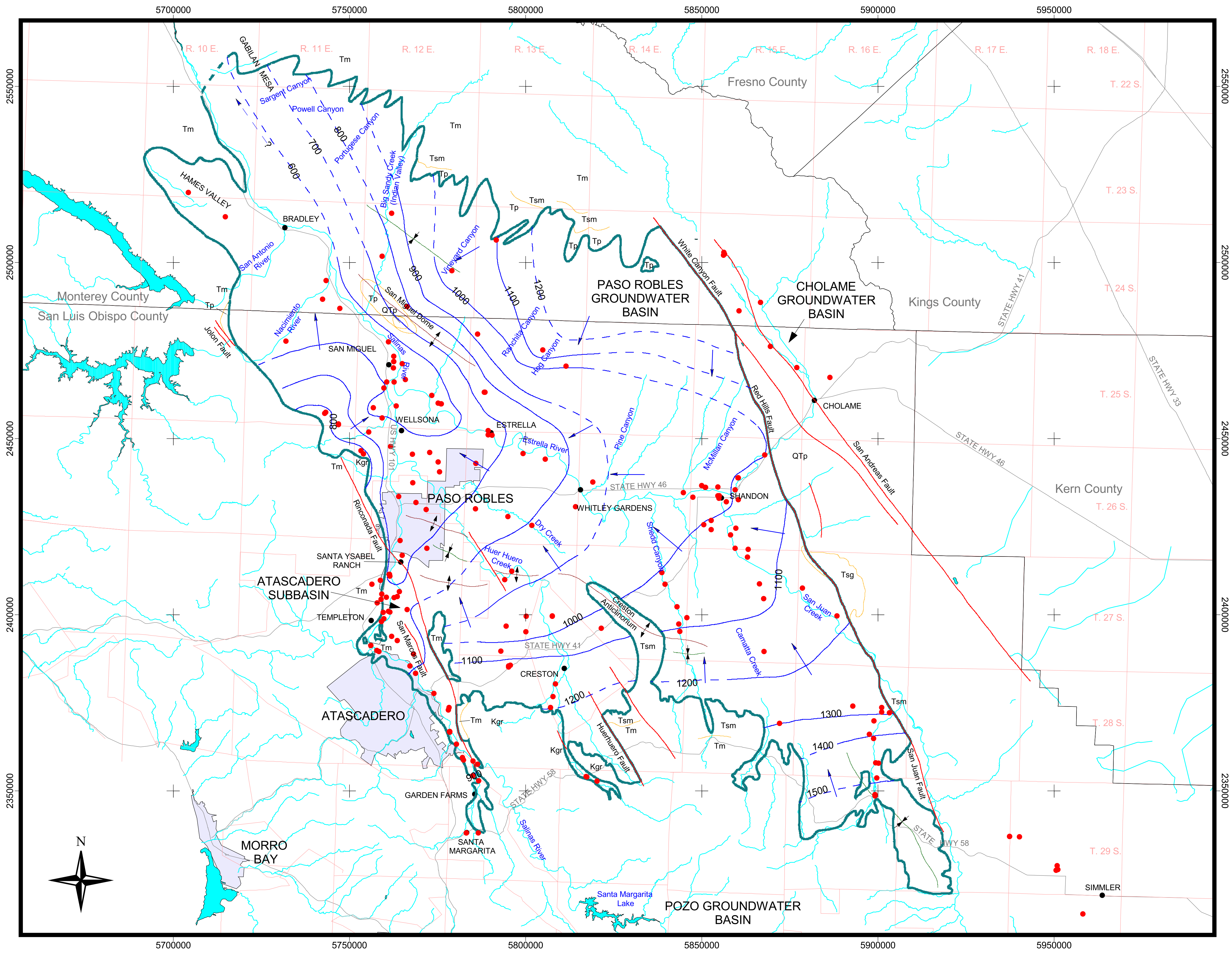


Figure 12C



Legend

- ▭ City
- ● Water Level Observation Well
- Spring 1980 Regional Water Surface Elevation (feet MSL) Querried where infered. Contour interval = 100 ft
- Direction of Regional Groundwater Flow
- Basin Outline
- Fault
- Anticline
- Syncline
- Streams
- Highways
- County Line
- Township and Range Grid

Geologic Units

Paso Robles Groundwater Basin Sediments	Qa	Alluvium
	Qoa	Older Alluvium
	Qls	Landslide
	QTp	Paso Robles Formation
Other Geologic Units	Tp	Pancho Rico Formation
	Tsm	Santa Margarita Sandstone
	Tm	Monterey Shale
	Tv	Vaqueros Formation
	Ts	Simmler Formation
	Tsg	unnamed (maroon) conglomerate
	Kgr	granite rocks

Notes:
1. Geologic units shown on base map around basin boundary are for reference only. For a geologic map of the basin see Figure 5.
2. Township and Range grid reference: Federal Township and Range System, Mt. Diablo Baseline and Meridian

30000 0 30000 Feet

Spring 1980 Regional Groundwater Elevation Map

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

Figure 13

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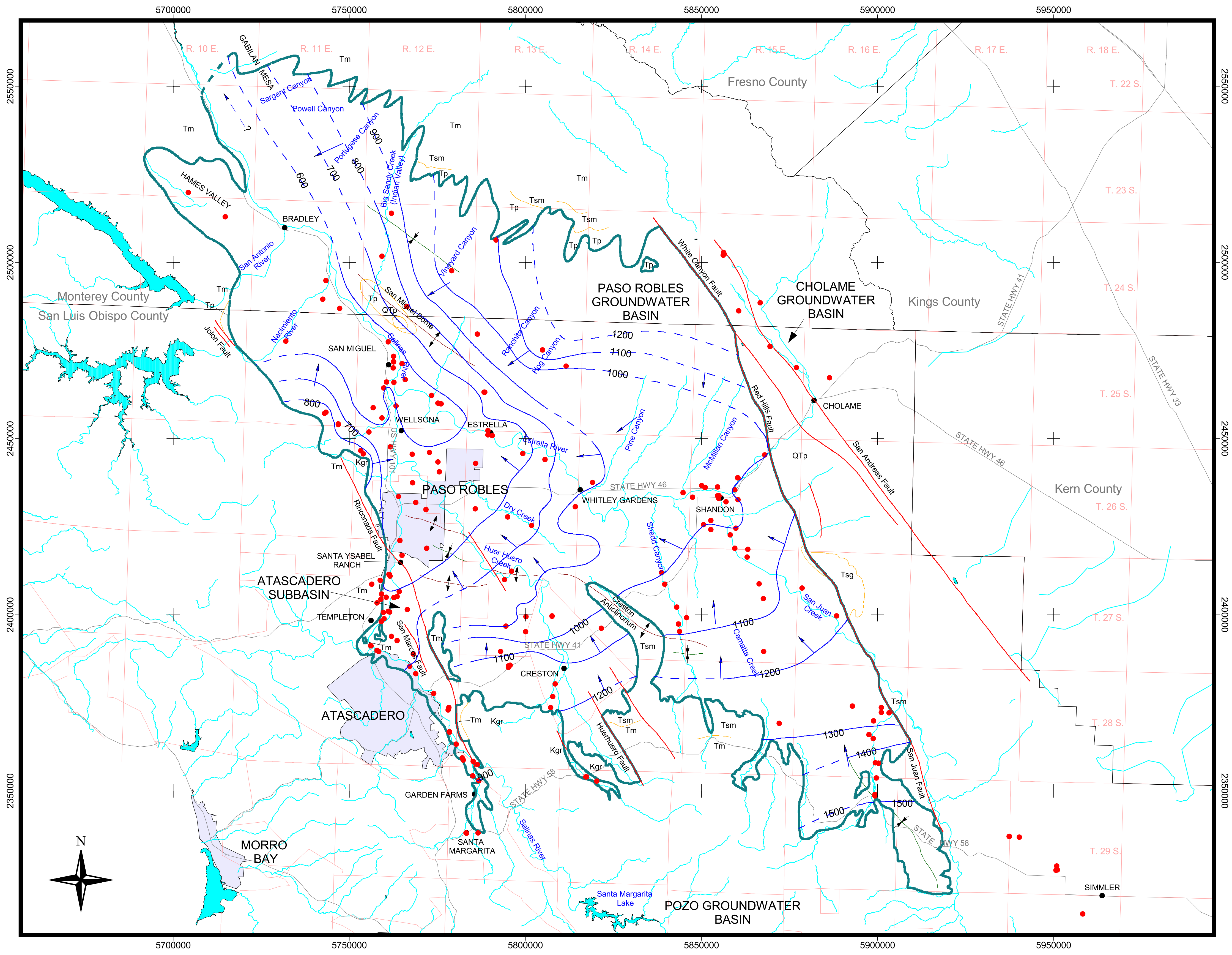


Legend

City

● Water Level Observation Well

Fall 1990 Regional Water Surface Elevation (feet MSL) Querried where infered. Contour interval = 100 ft

Direction of Regional Groundwater Flow

Basin Outline

Fault

Anticline

Syncline

Streams

Highways

County Line

Township and Range Grid

Geologic Units

Paso Robles Groundwater Basin Sediments	Qa	Alluvium
	Qoa	Older Alluvium
	Qls	Landslide
	QTp	Paso Robles Formation
Other Geologic Units	Tp	Pancho Rico Formation
	Tsm	Santa Margarita Sandstone
	Tm	Monterey Shale
	Tv	Vaqueros Formation
	Ts	Simmler Formation
	Tsg	unnamed (maroon) conglomerate
	Kgr	granite rocks

Notes:
1. Geologic units shown on base map around basin boundary are for reference only. For a geologic map of the basin see Figure 5.
2. Township and Range grid reference: Federal Township and Range System, Mt. Diablo Baseline and Meridian

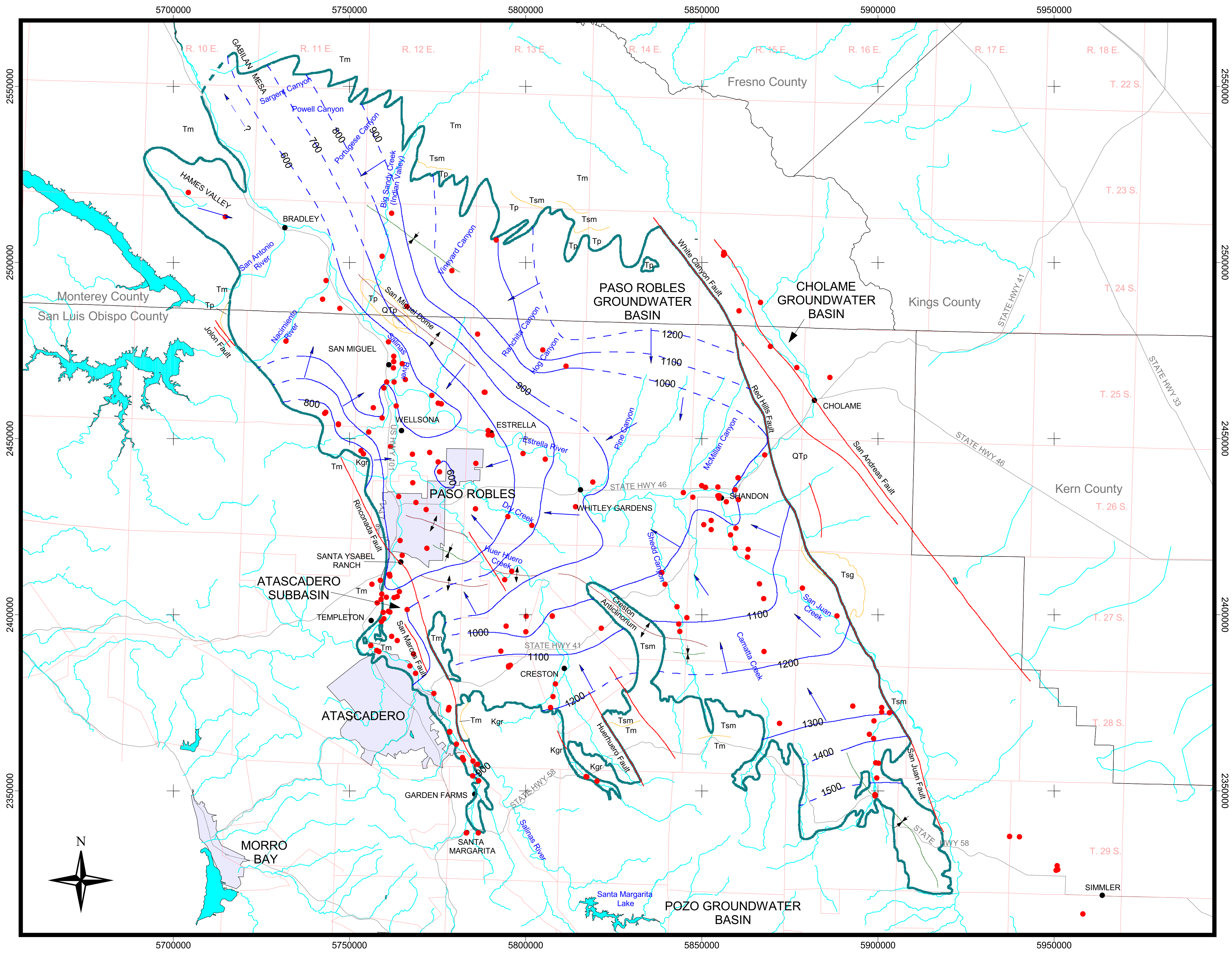
30000 0 30000 Feet

Fall 1990 Regional Water Surface

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

Figure 14



Legend

▭ City
● Water Level Observation Well
Spring 1997 Regional Water Surface Elevation (feet MSL) Querried where infered. Contour interval = 100 ft
← Direction of Regional Groundwater Flow
Basin Outline
Fault
Anticline
Syncline
Streams
Highways
County Line
Township and Range Grid

Geologic Units

Paso Robles Groundwater Basin Sediments	Qa	Alluvium
	Qoa	Older Alluvium
	Qls	Landslide
	QTp	Paso Robles Formation
Other Geologic Units	Tp	Pancho Rico Formation
	Tsm	Santa Margarita Sandstone
	Tm	Monterey Shale
	Tv	Vaqueros Formation
	Ts	Simmler Formation
	Tsg	unnamed (maroon) conglomerate
	Kgr	granite rocks

Notes:
1. Geologic units shown on base map around basin boundary are for reference only. For a geologic map of the basin see Figure 5.
2. Township and Range grid reference: Federal Township and Range System, Mt. Diablo Baseline and Meridian

30000 0 30000 Feet

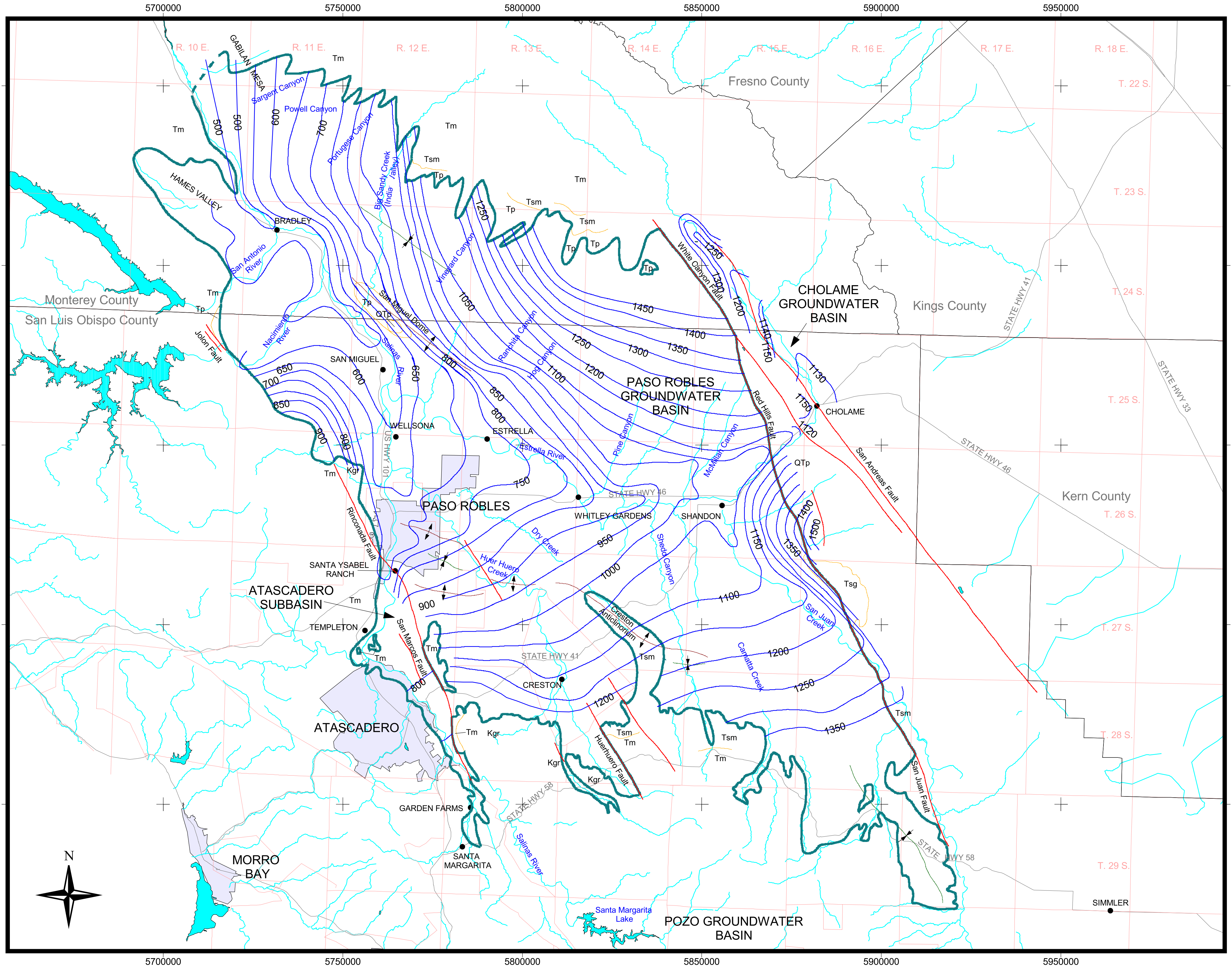
Spring 1997 Regional Groundwater Elevation Map

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

Figure 15

j:\gis\projects\slo\gis\odb\3014-007-05\fig-15_water1997.odb, tmcadam , 01/04/2005



Legend

- ▭ City
- 1954 Regional Water Surface Elevation (feet MSL) Contour interval = 50 ft
- Basin Outline
- Fault
- Anticline
- Syncline
- Streams
- Highways
- County Line
- Township and Range Grid

Geologic Units

Paso Robles Groundwater Basin Sediments	Qa	Alluvium
	Qoa	Older Alluvium
	Qls	Landslide
	QTp	Paso Robles Formation
Other Geologic Units	Tp	Pancho Rico Formation
	Tsm	Santa Margarita Sandstone
	Tm	Monterey Shale
	Tv	Vaqueros Formation
	Ts	Simmler Formation
	Tsg	unnamed (maroon) conglomerate
	Kgr	granite rocks

Notes:
1. Geologic units shown on base map around basin boundary are for reference only. For a geologic map of the basin see Figure 5.
2. Township and Range grid reference: Federal Township and Range System, Mt. Diablo Baseline and Meridian

30000 0 30000 Feet

1954 Regional Water Surface

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

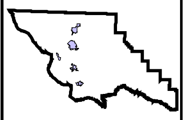
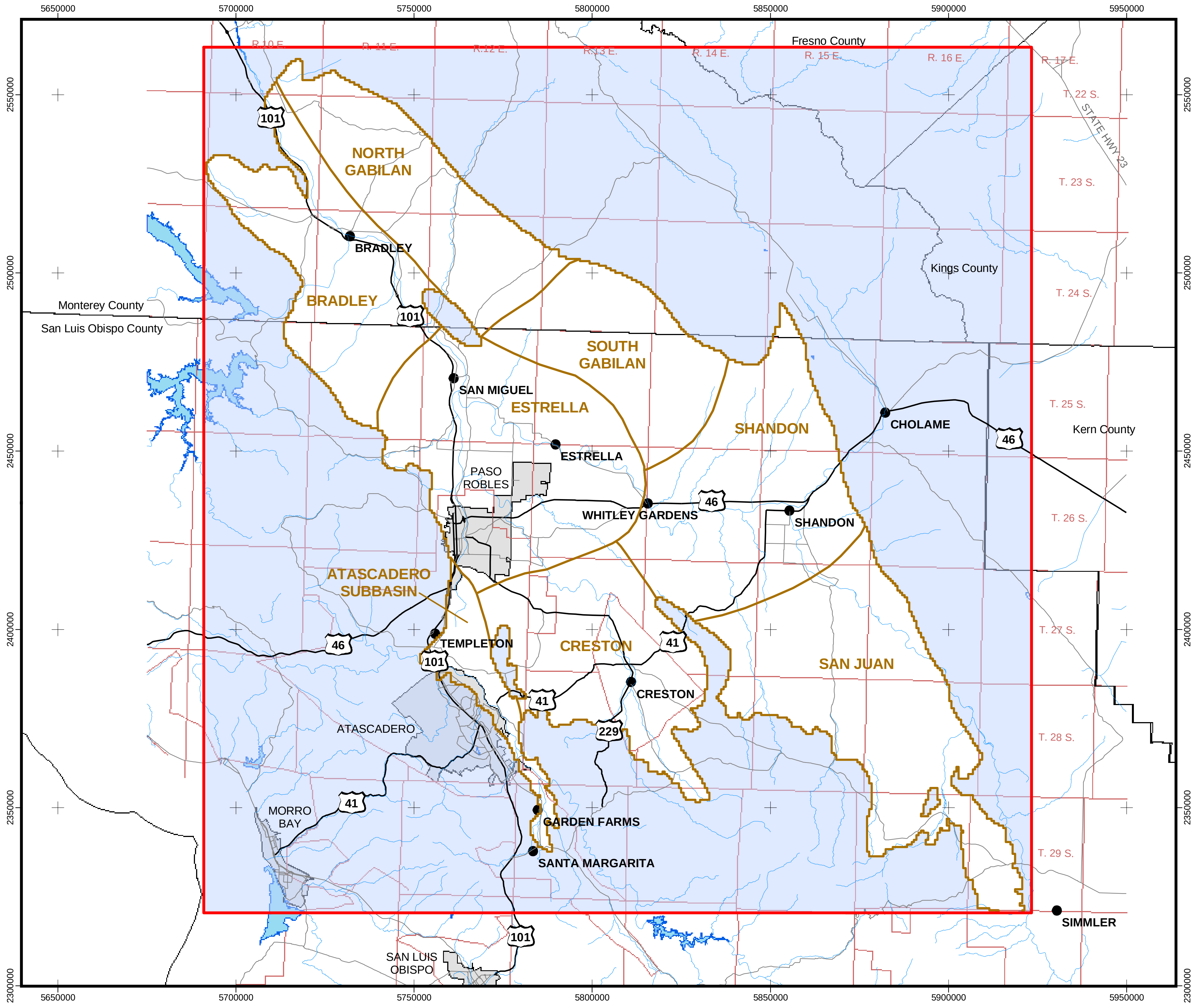


Figure 16



LEGEND:

- ▭ Paso Robles Groundwater Model Active Area
- 🟦 Non-Modeled Area
- — Model Domain Boundary
- ⬜ City Outlines
- — Township and Range Grid

Paso Robles Groundwater Basin Numerical Model Domain Location Map

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

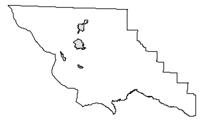
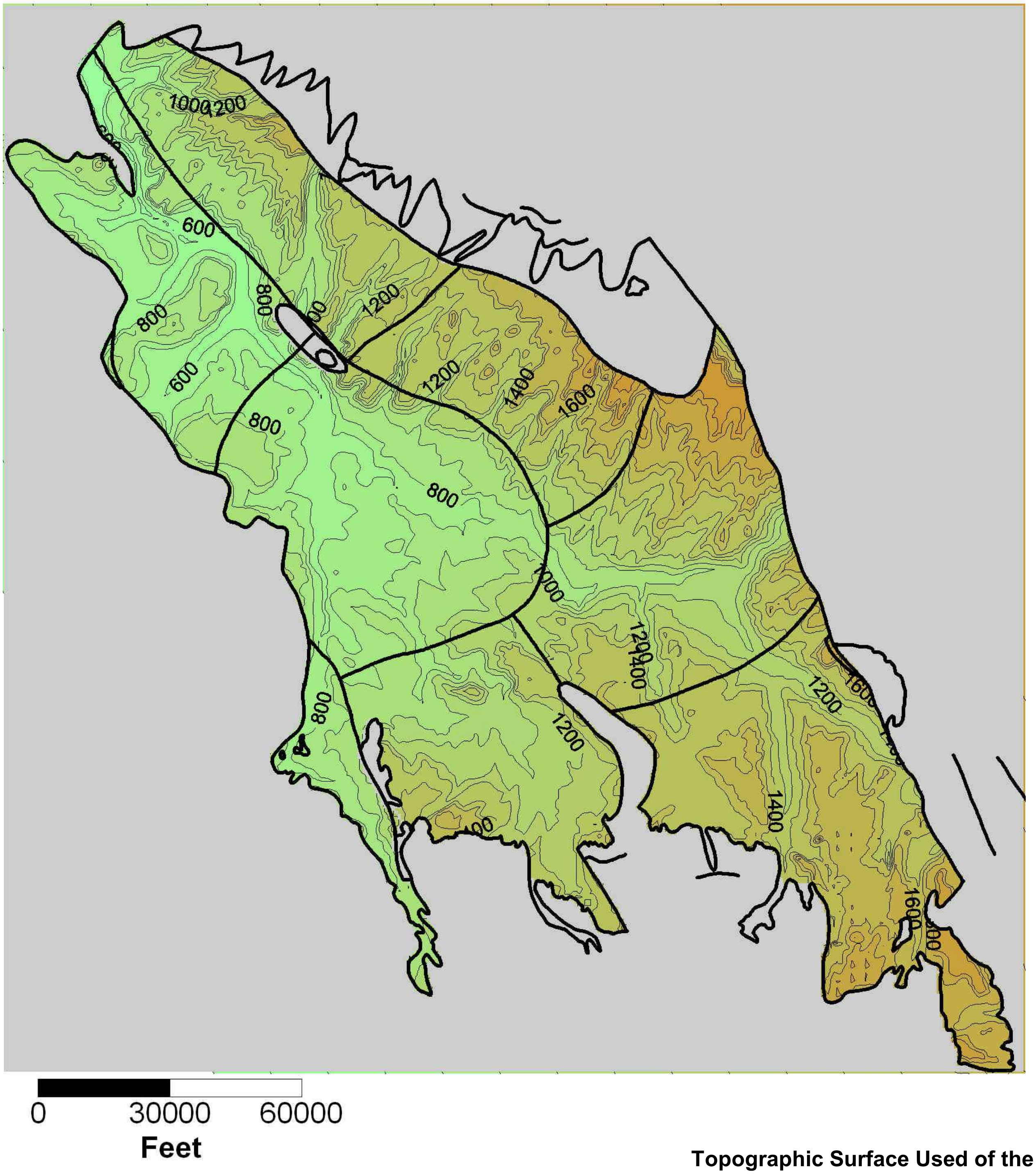


Figure 17



Topographic Surface Used of the Upper Model Surface

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

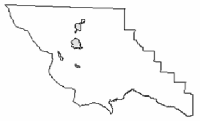
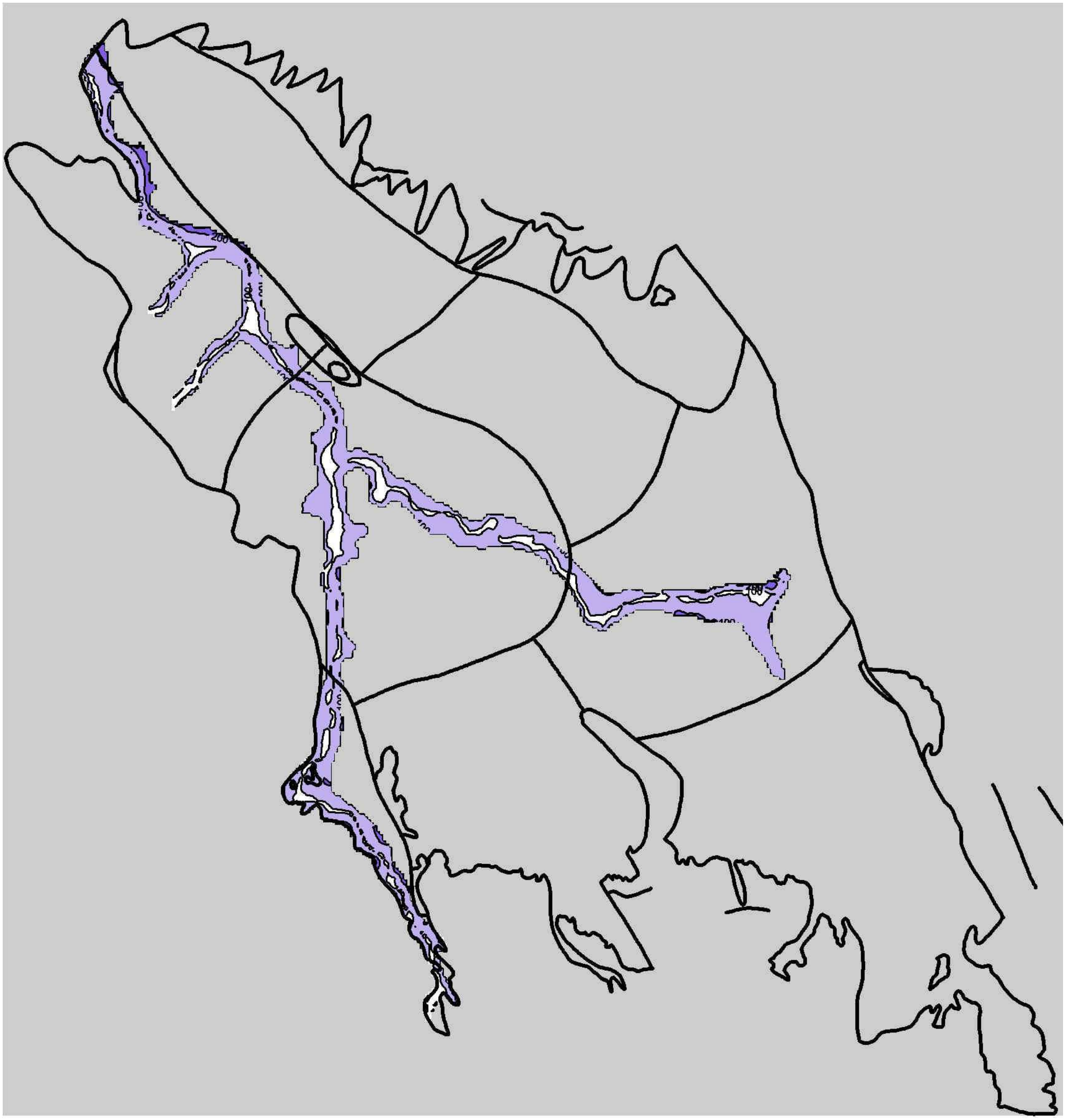


Figure 18

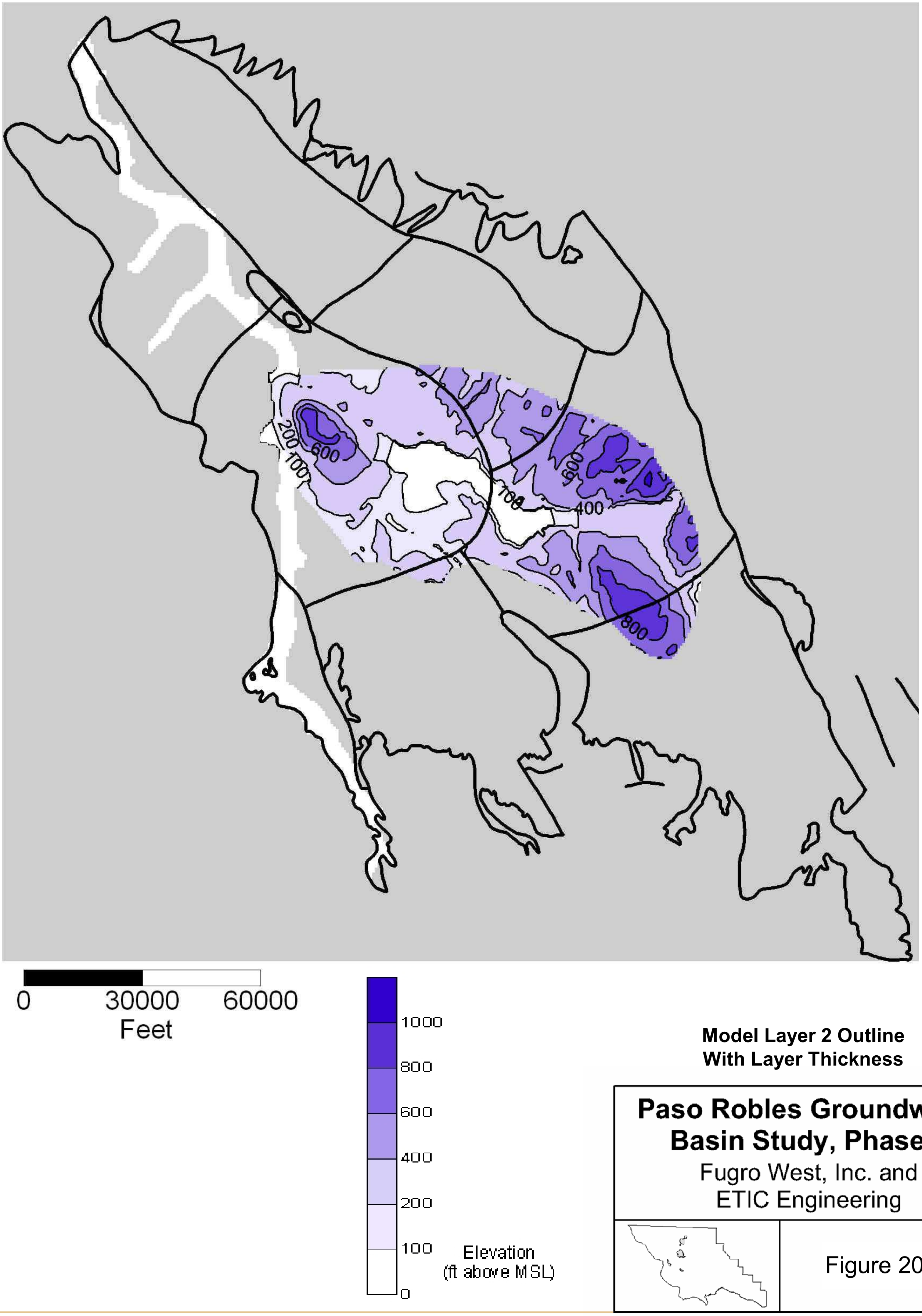


Model Layer 1 Outline
With Layer Thickness

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

Figure 19

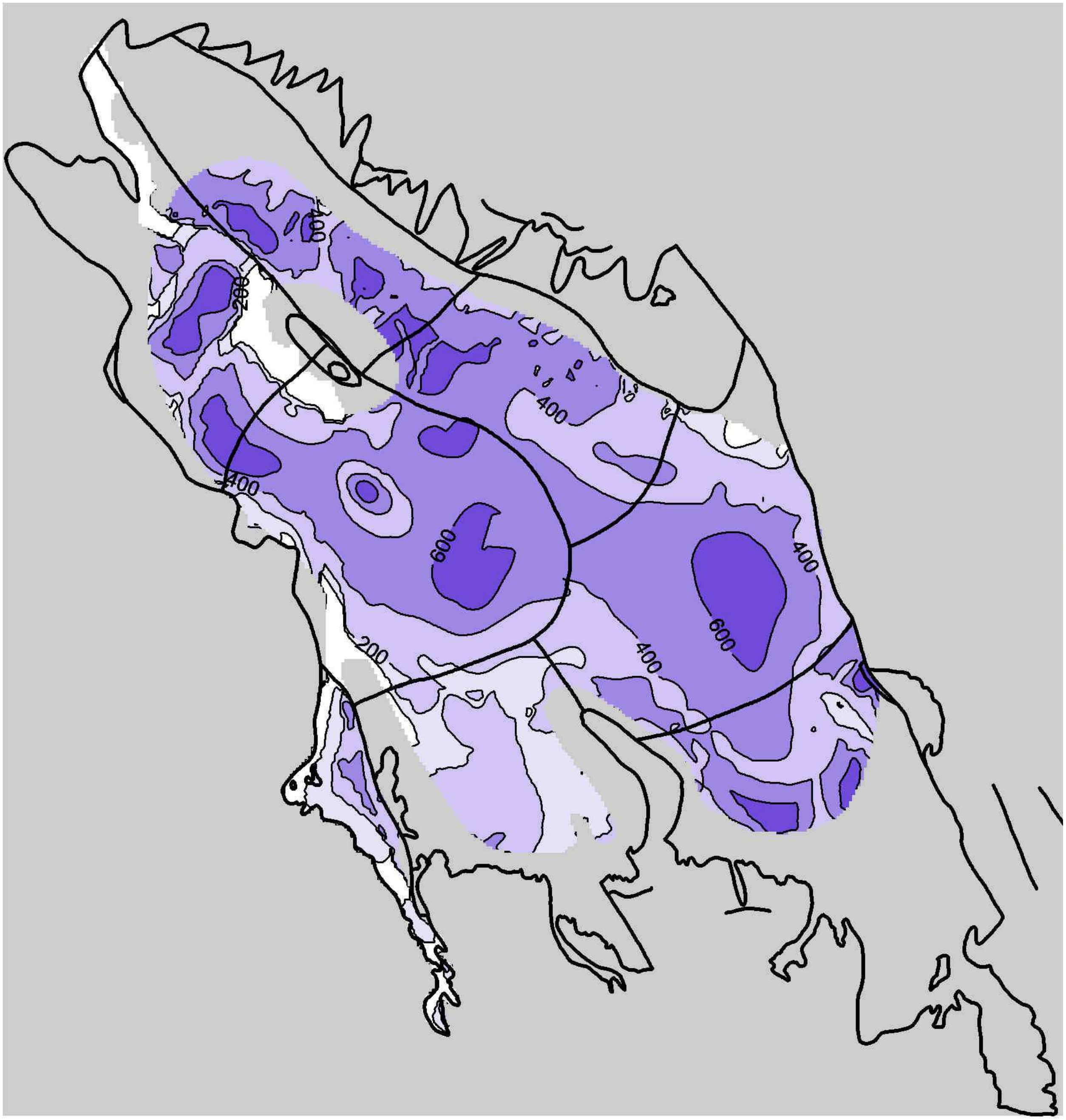


**Model Layer 2 Outline
With Layer Thickness**

**Paso Robles Groundwater
Basin Study, Phase II**

Fugro West, Inc. and
ETIC Engineering

Figure 20

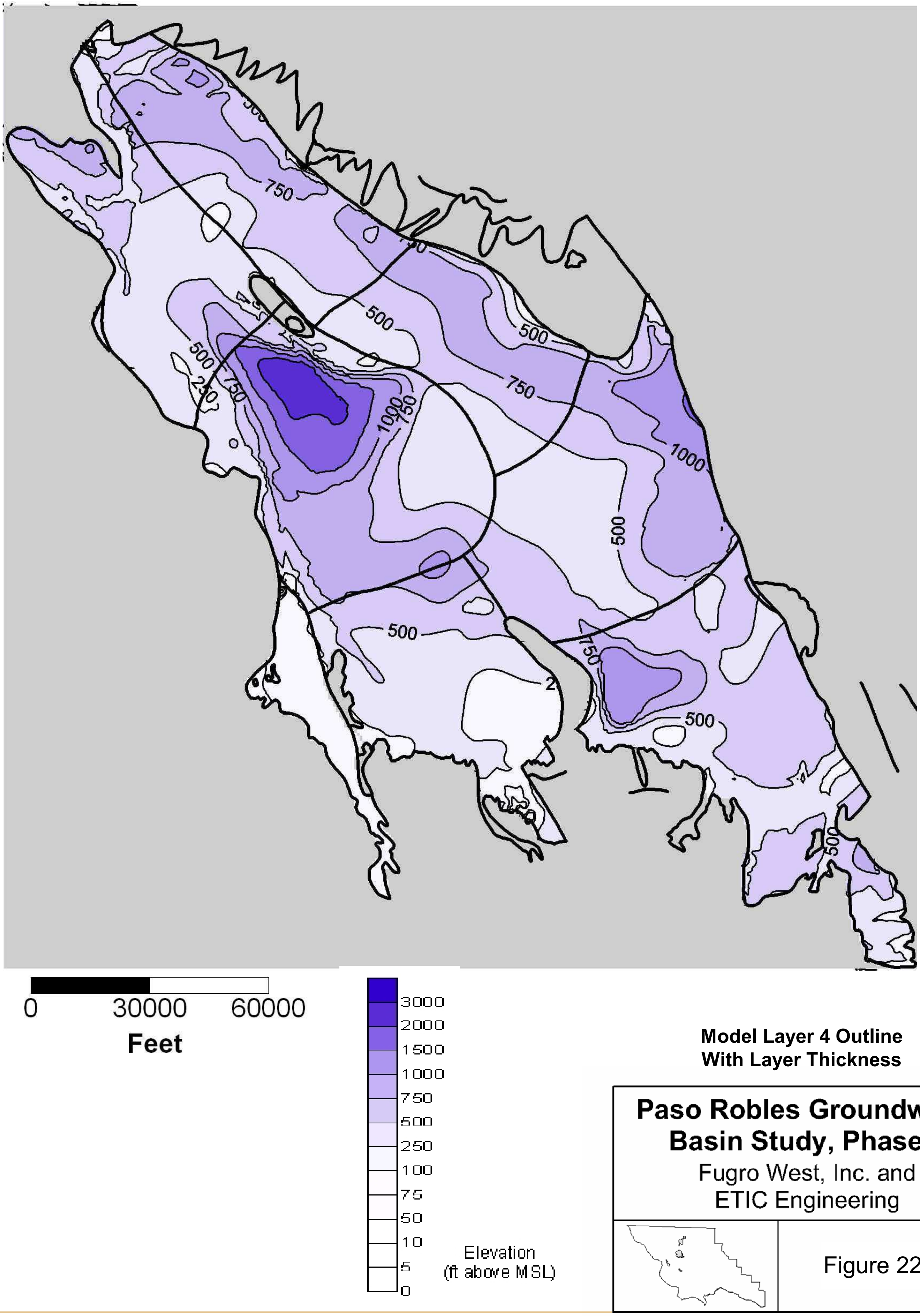


Model Layer 3 Outline
With Layer Thickness

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

Figure 21

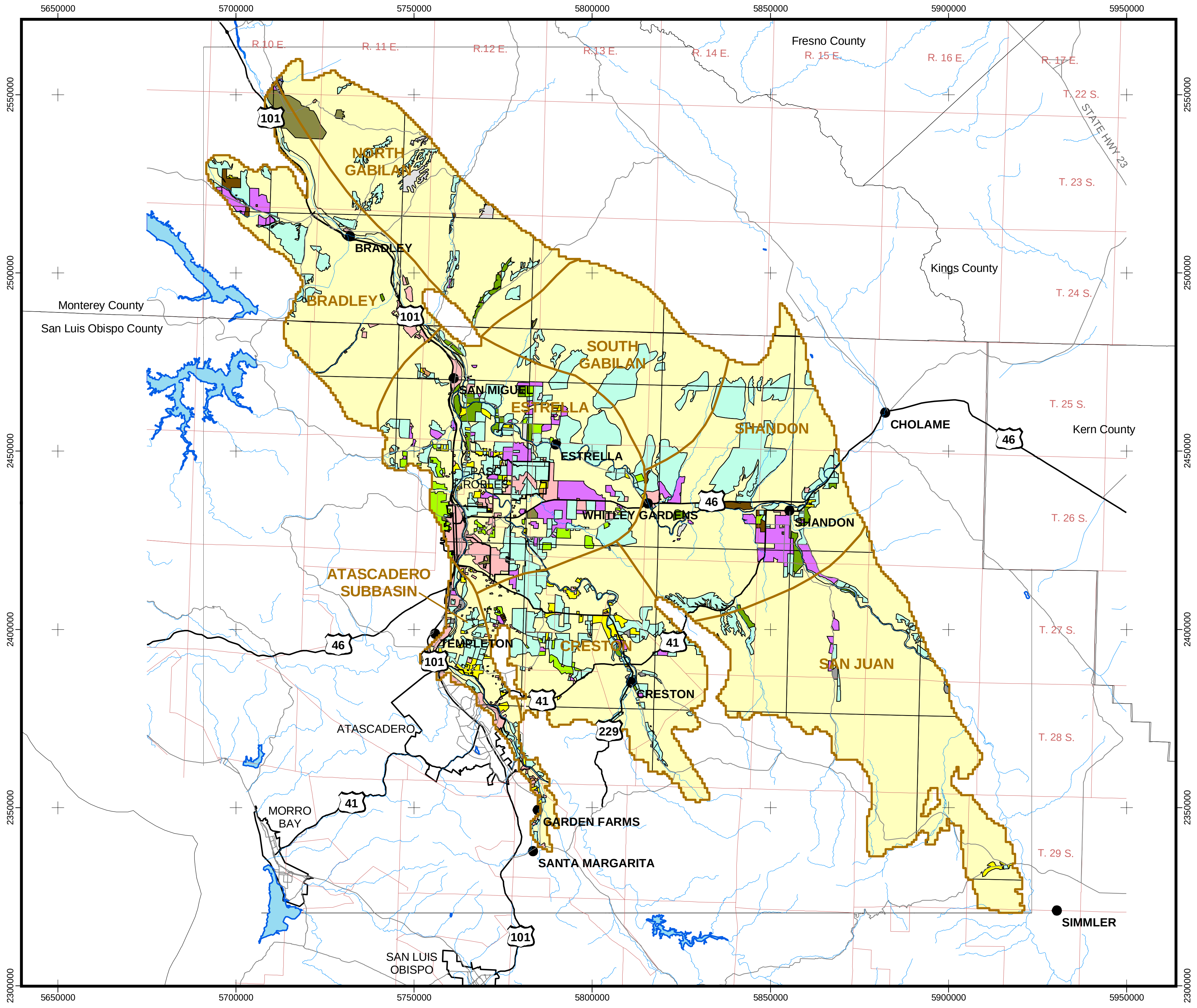


**Model Layer 4 Outline
With Layer Thickness**

**Paso Robles Groundwater
Basin Study, Phase II**

Fugro West, Inc. and
ETIC Engineering

Figure 22



LEGEND:

- ▭ Paso Robles Groundwater Model Active Area
- ☐ City Outlines
- — Township and Range Grid
- 🟩 Alfalfa
- 🟥 Citrus and Subtropical
- 🟩 Deciduous
- 🟫 Field
- ▨ Grain
- ▨ Idle
- ▨ Native
- 🟨 Pasture
- 🟧 Suburban
- ▨ Truck
- ▨ Urban
- 🟪 Vineyard
- ▨ Other

N

30000 0 30000
Feet

Land Use Map - 1995 data for San Luis Obispo County and 1997 data for Monterey County

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

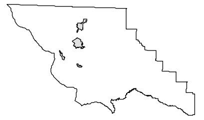
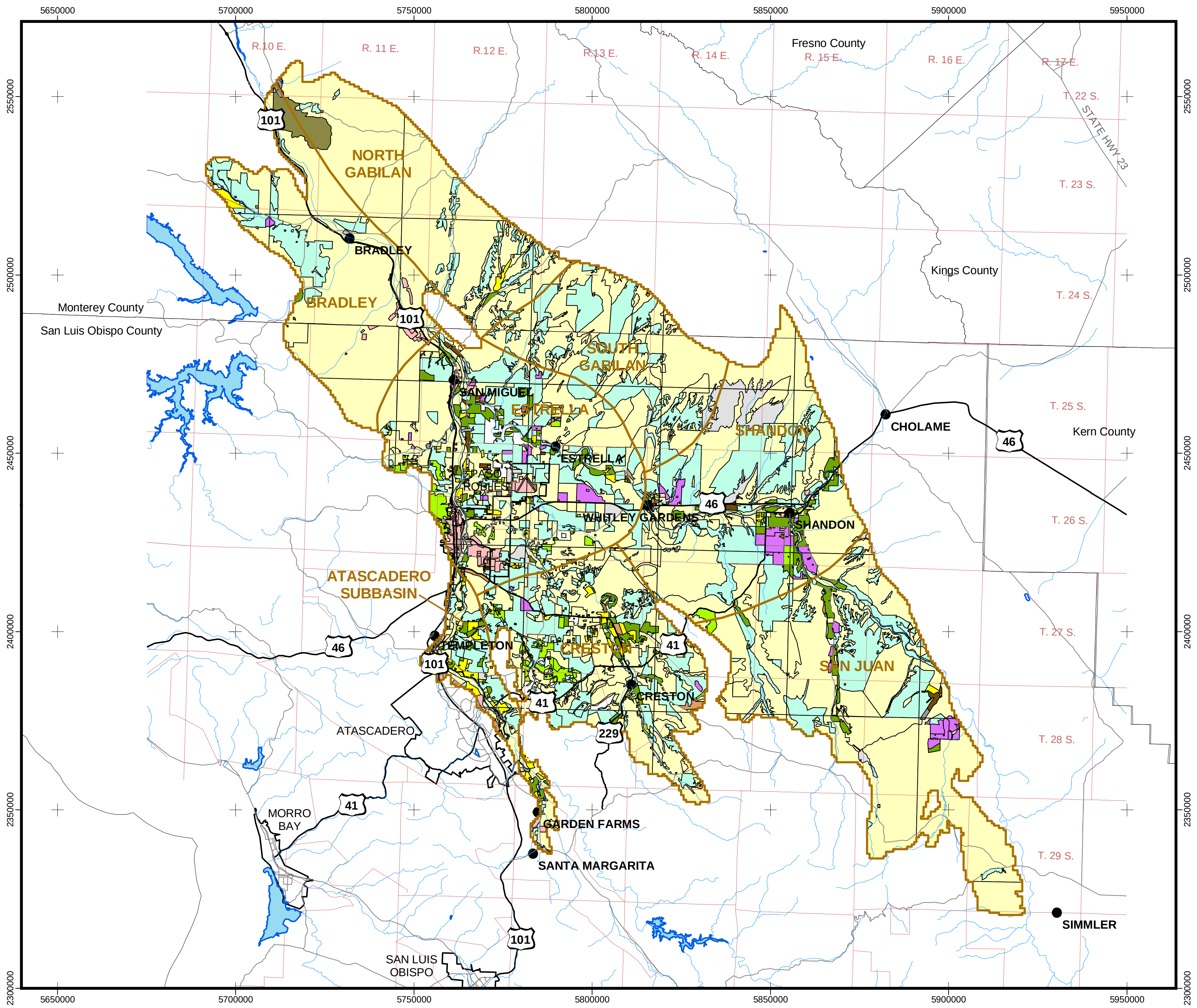
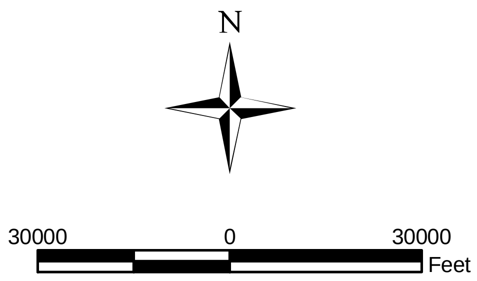


Figure 23



LEGEND:

- ▭ Paso Robles Groundwater Model Active Area
- ▭ City Outlines
- — Township and Range Grid
- 🟩 Alfalfa
- 🟧 Citrus and Subtropical
- 🟩 Deciduous
- 🟫 Field
- ▨ Grain
- ▨ Idle
- ▨ Native
- 🟨 Pasture
- 🟧 Suburban
- ▨ Truck
- ▨ Urban
- 🟪 Vineyard
- ▨ Other



Land Use Map - 1985 data for San Luis Obispo County and 1989 data for Monterey County

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

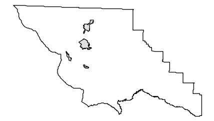
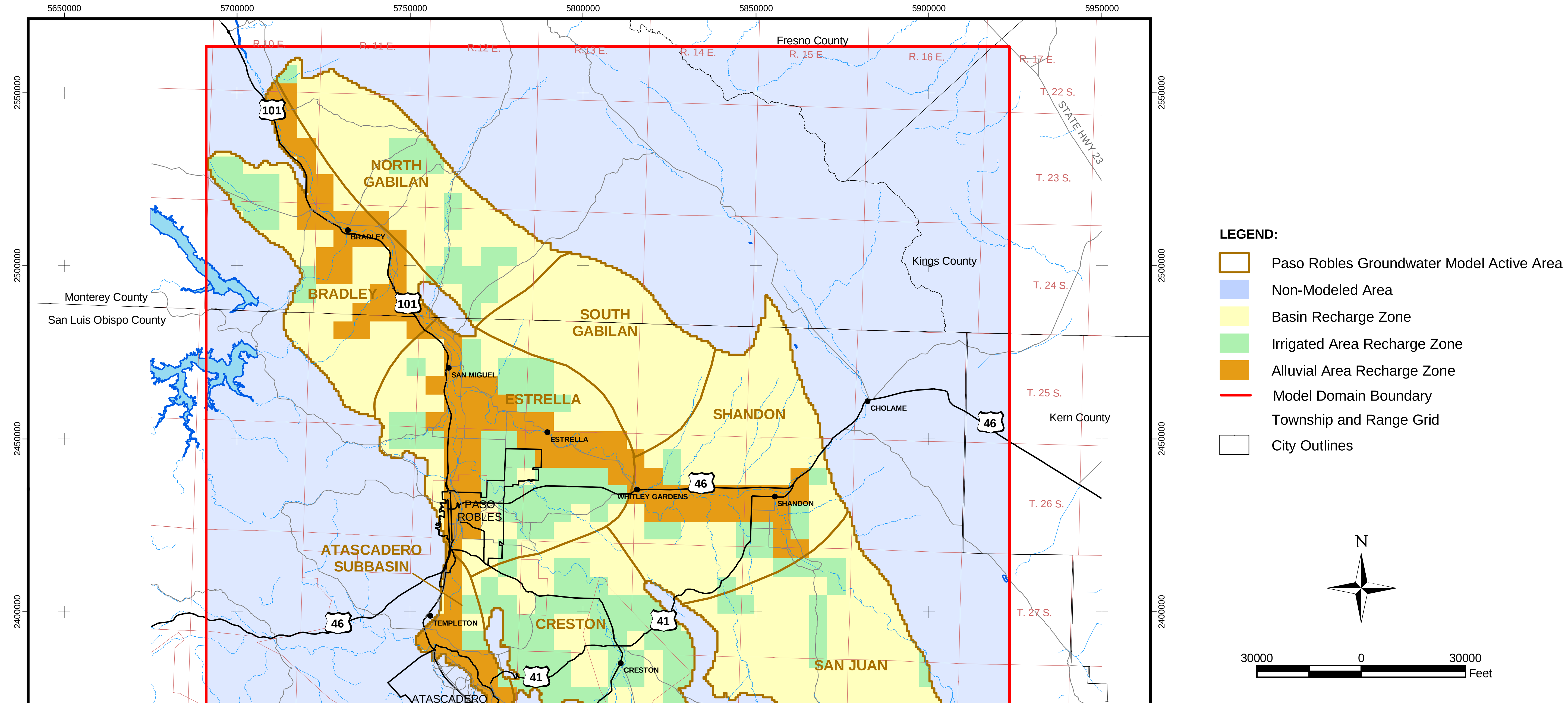


Figure 24



Distribution of Precipitation Recharge

Paso Robles Groundwater Basin Study, Phase II
Fugro West, Inc. and
ETIC Engineering

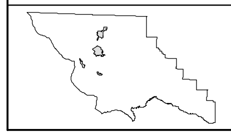
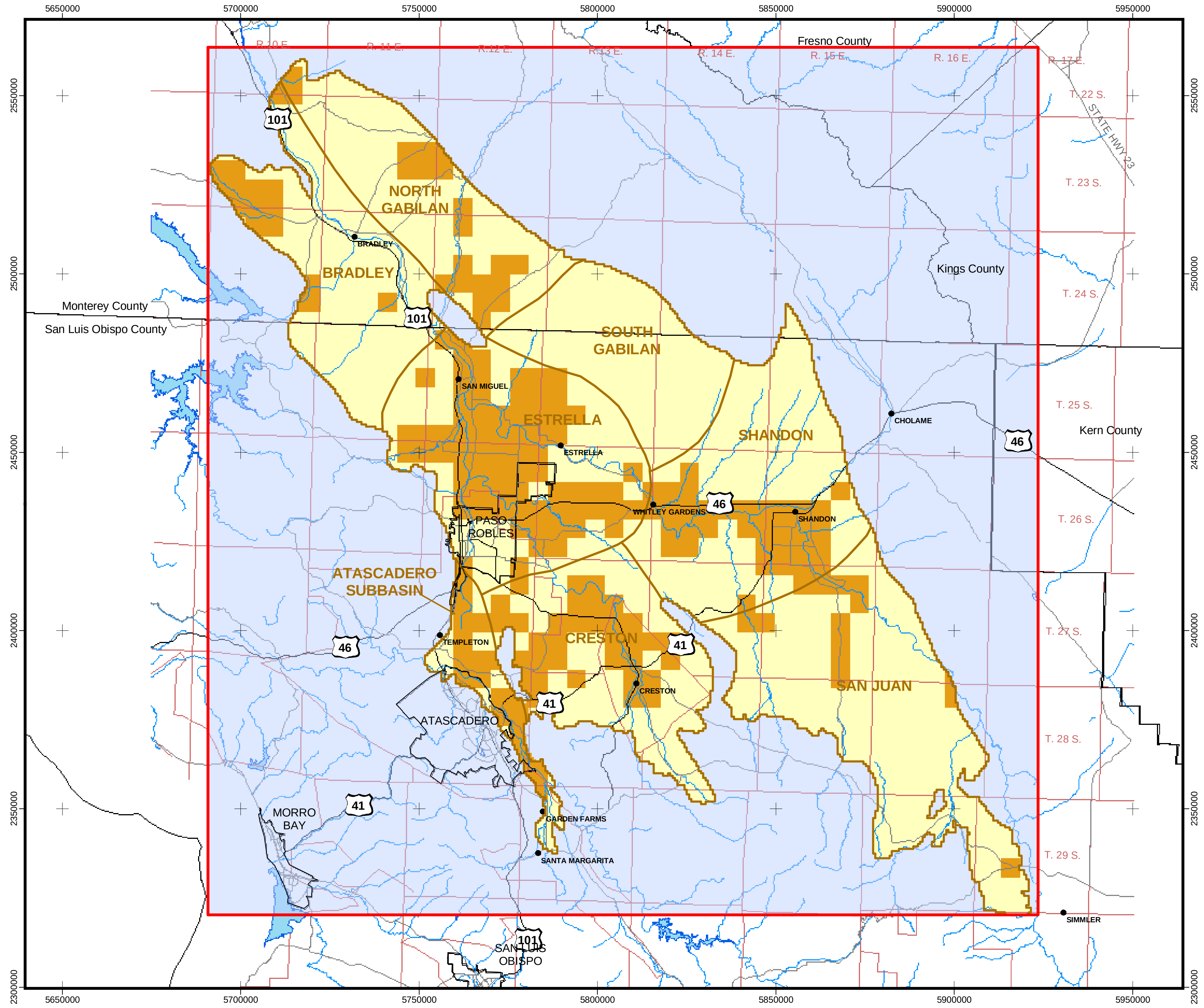
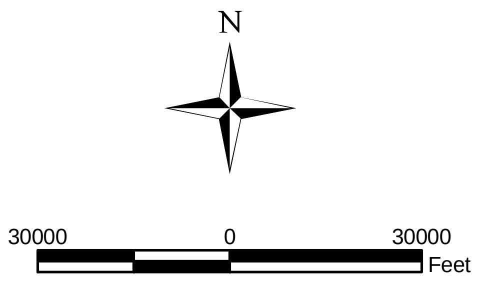


Figure 25



LEGEND:

▭ Paso Robles Groundwater Model Active Area
▨ Non-Modeled Area
▨ No Irrigation Return Flow Applied
▨ Irrigation Return Flow Applied
☐ City Outlines
— Model Domain Boundary
— Township and Range Grid



Distribution of Irrigation Return Flow Recharge

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

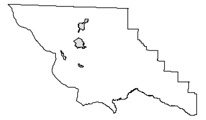
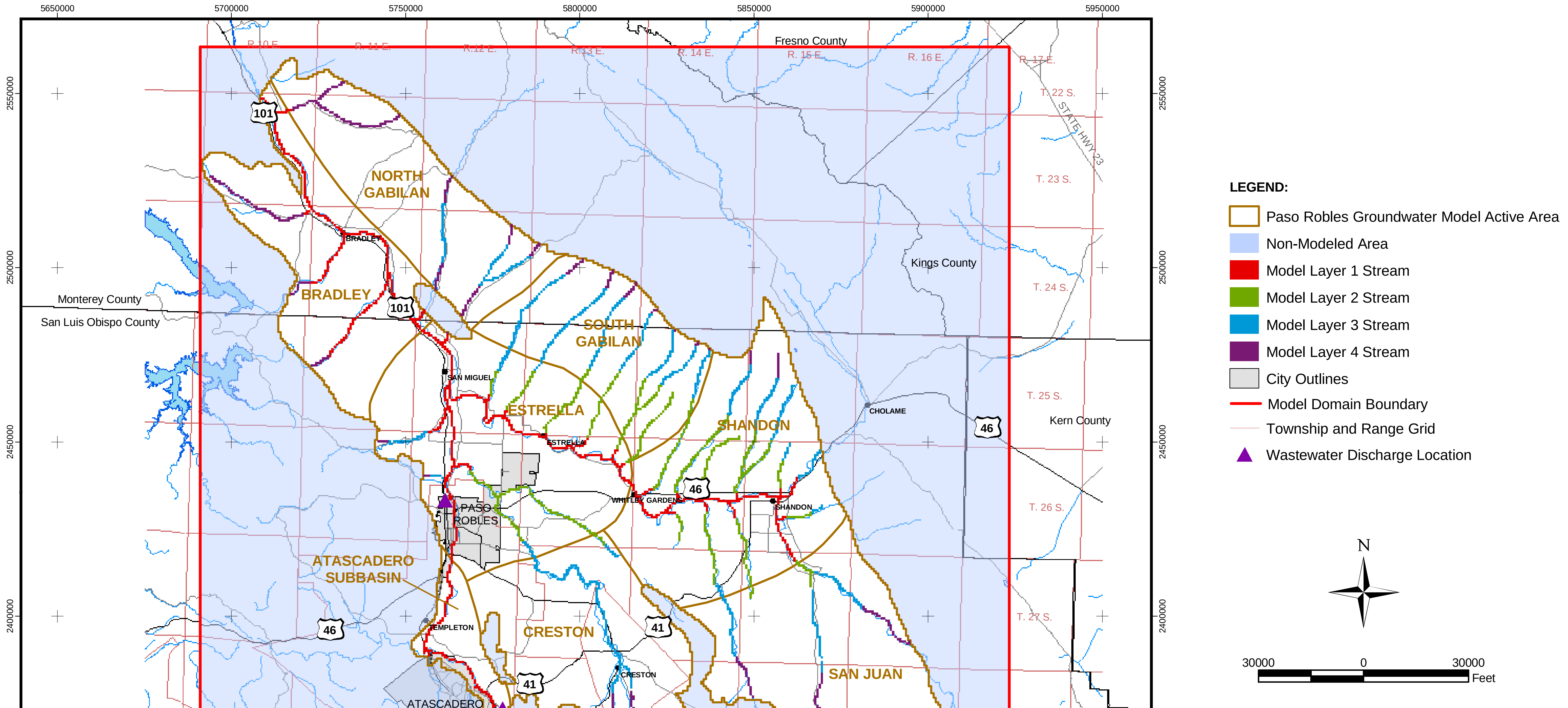


Figure 26



Numerical Model Stream Network and Wastewater Locations

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

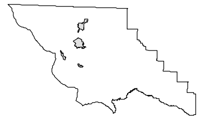
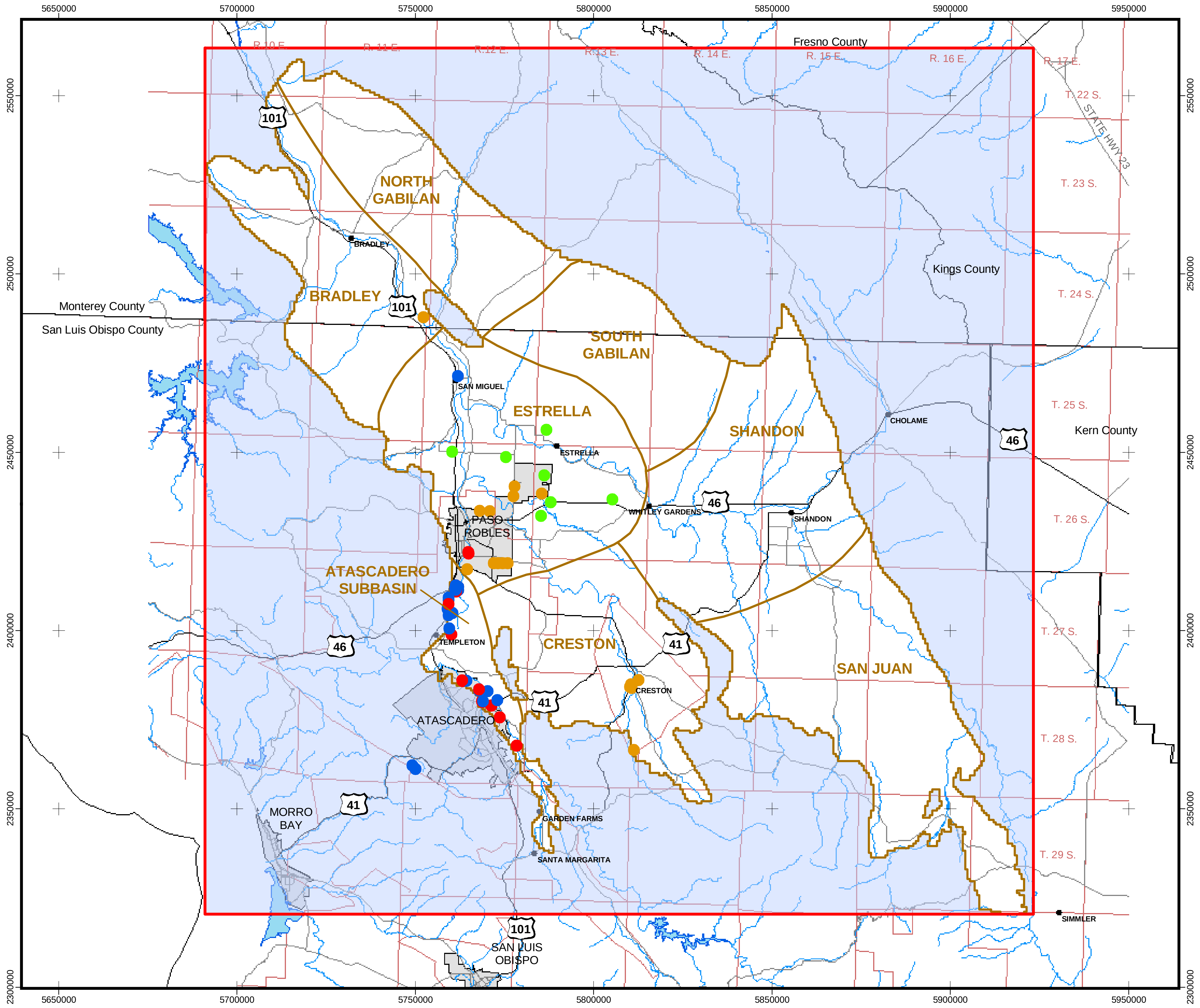


Figure 27



LEGEND:

- ▭ Paso Robles Groundwater Model Active Area
- 🟦 Non-Modeled Boundary
- ⬜ City Outlines
- — Model Domain Boundary
- — Township and Range Grid
- 🔴 Well Completed in Layer 1
- 🔵 Well Completed in Layers 3 and 4
- 🟢 Well Completed in Layer 3 only
- 🟠 Well Completed in Layer 4 only

N

30000 0 30000
Feet

Municipal and Small Commercial Well Locations

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

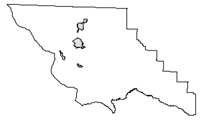
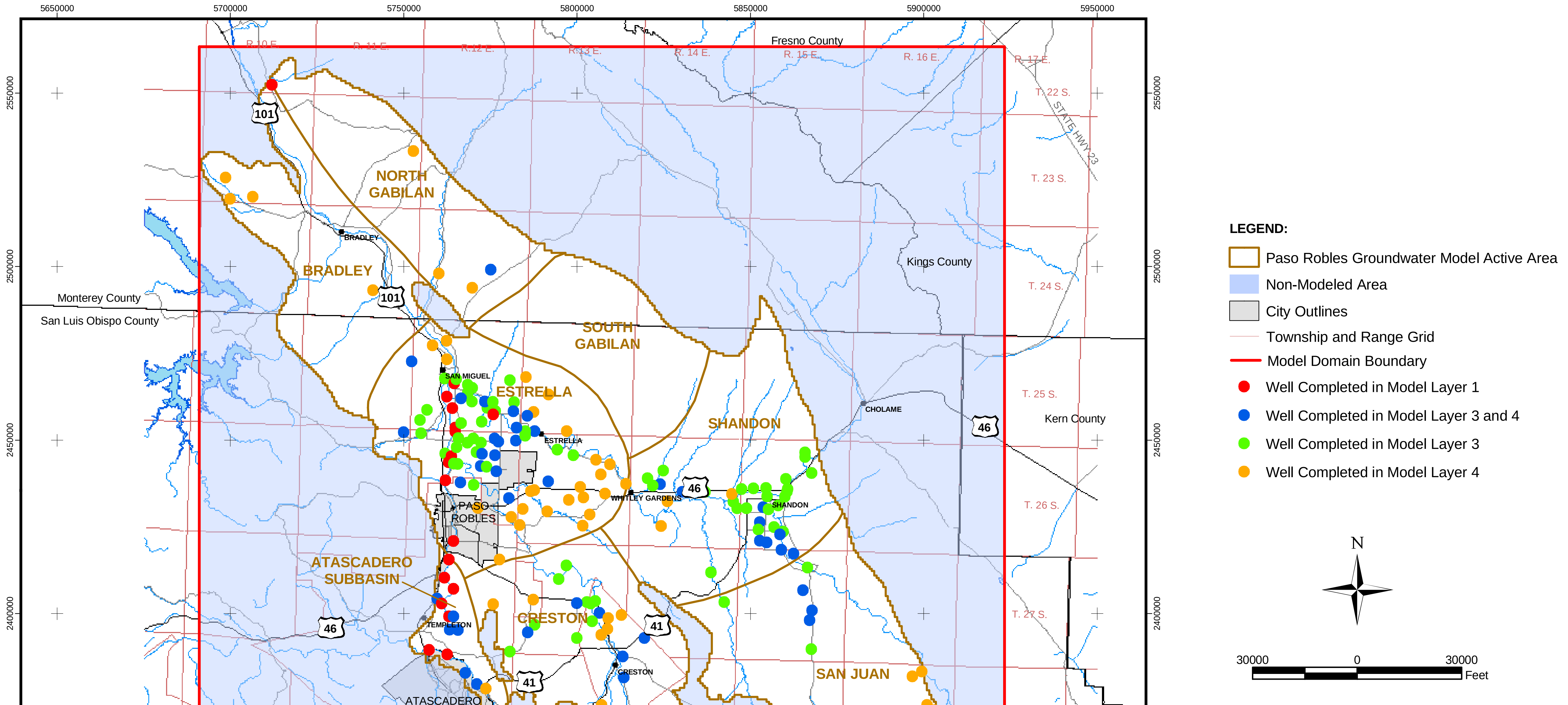


Figure 28



Agricultural Well Locations

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

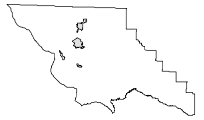
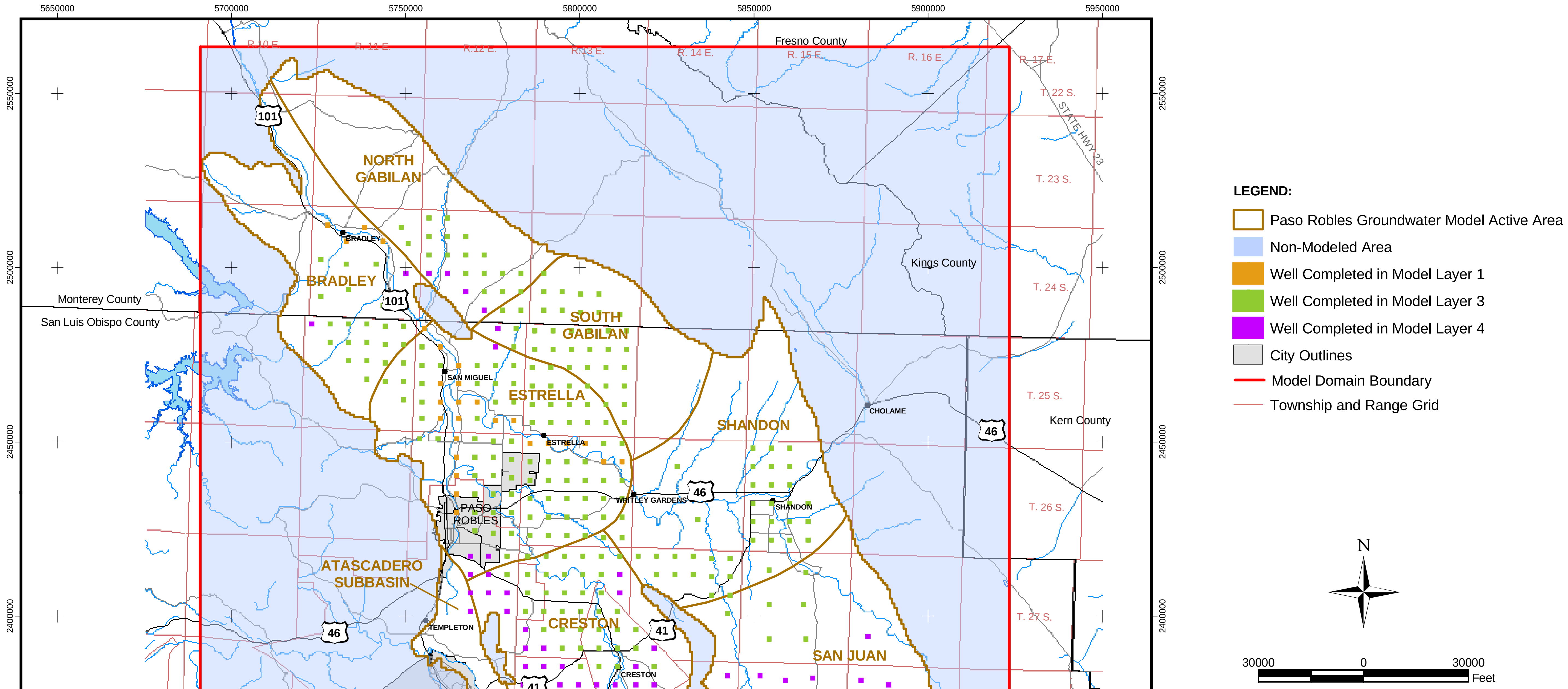


Figure 29



Distribution of Rural Domestic Pumping

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

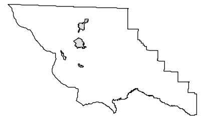
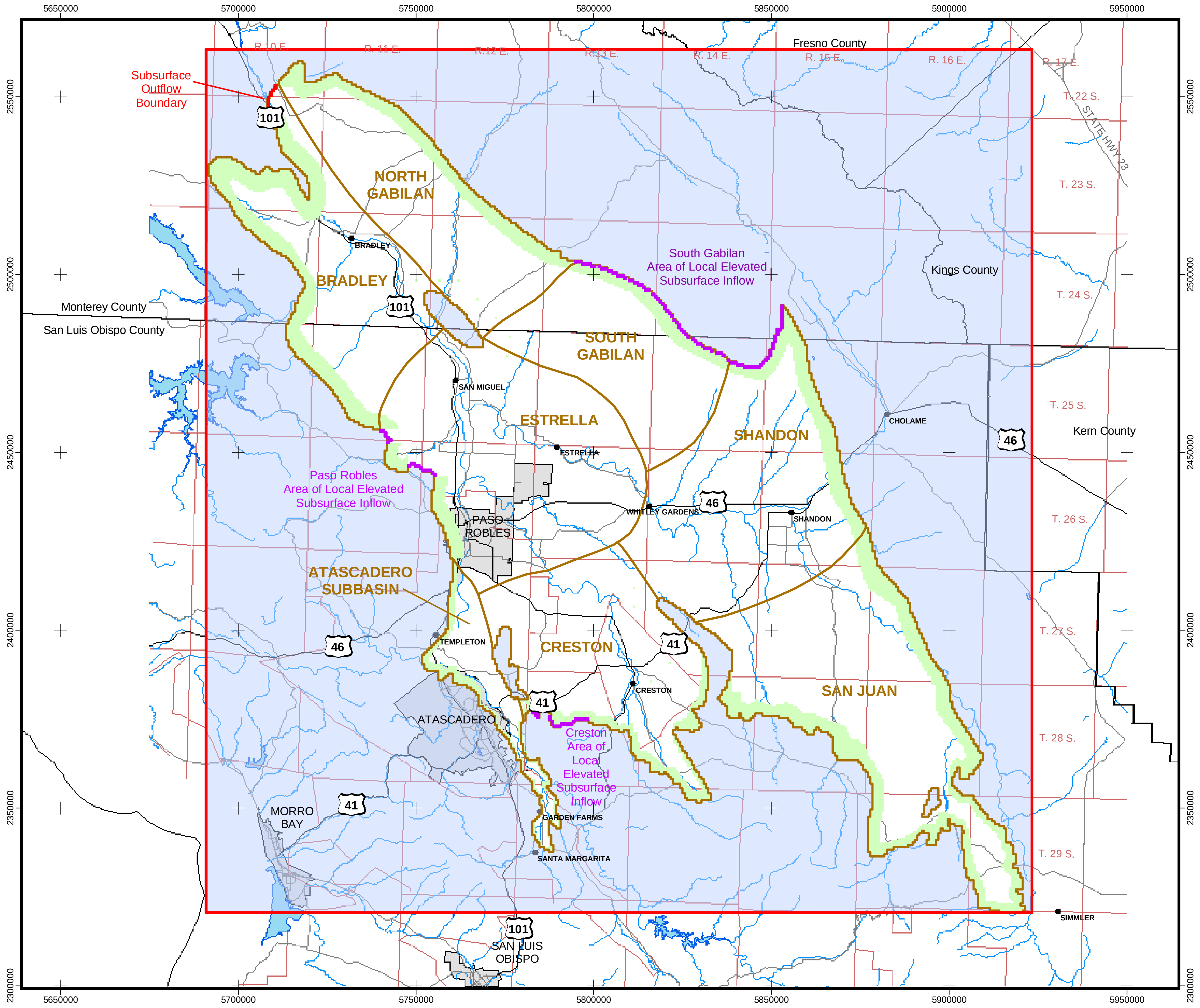


Figure 30



LEGEND:

- ▢ Paso Robles Groundwater Model Active Area
- ■ Non-Modeled Area
- ■ Area of Local Elevated Subsurface Inflow
- 🟥 Subsurface Outflow Boundary
- 🟩 Subsurface Inflow Area
- ■ City Outlines
- — Model Domain Boundary
- — Township and Range Grid

N

30000 0 30000 Feet

Distribution of Subsurface Inflow and Outflow

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

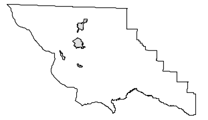
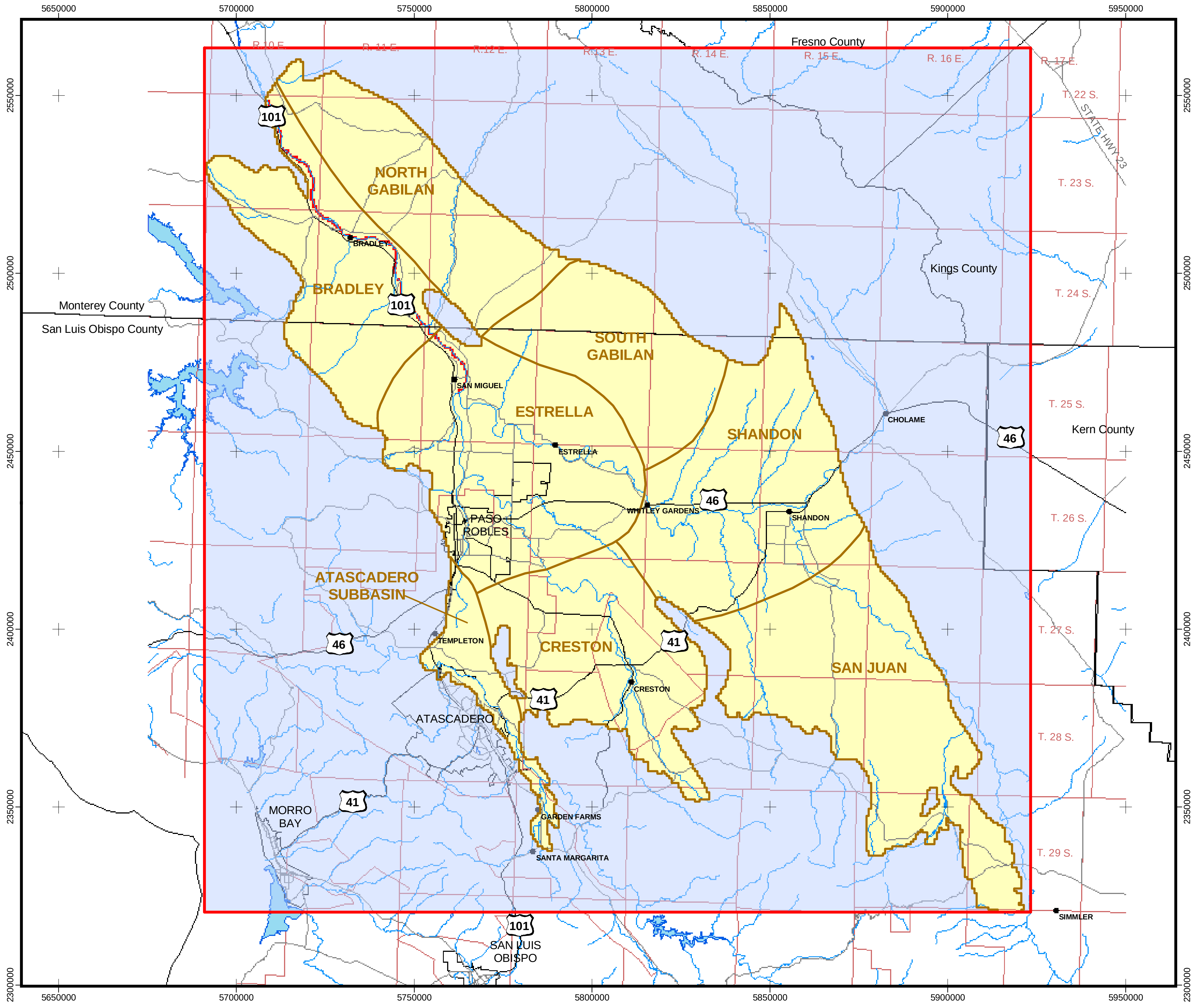


Figure 31



LEGEND:

- ☐ Paso Robles Groundwater Model Active Area
- 🟦 Non-Modeled Area
- 🟨 Basin Area
- 🟥 Riparian Area
- ☐ City Outlines
- — Model Domain Boundary
- — Township and Range Grid

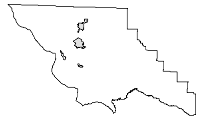
N

30000 0 30000
Feet

Distribution of Evapotranspiration

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering



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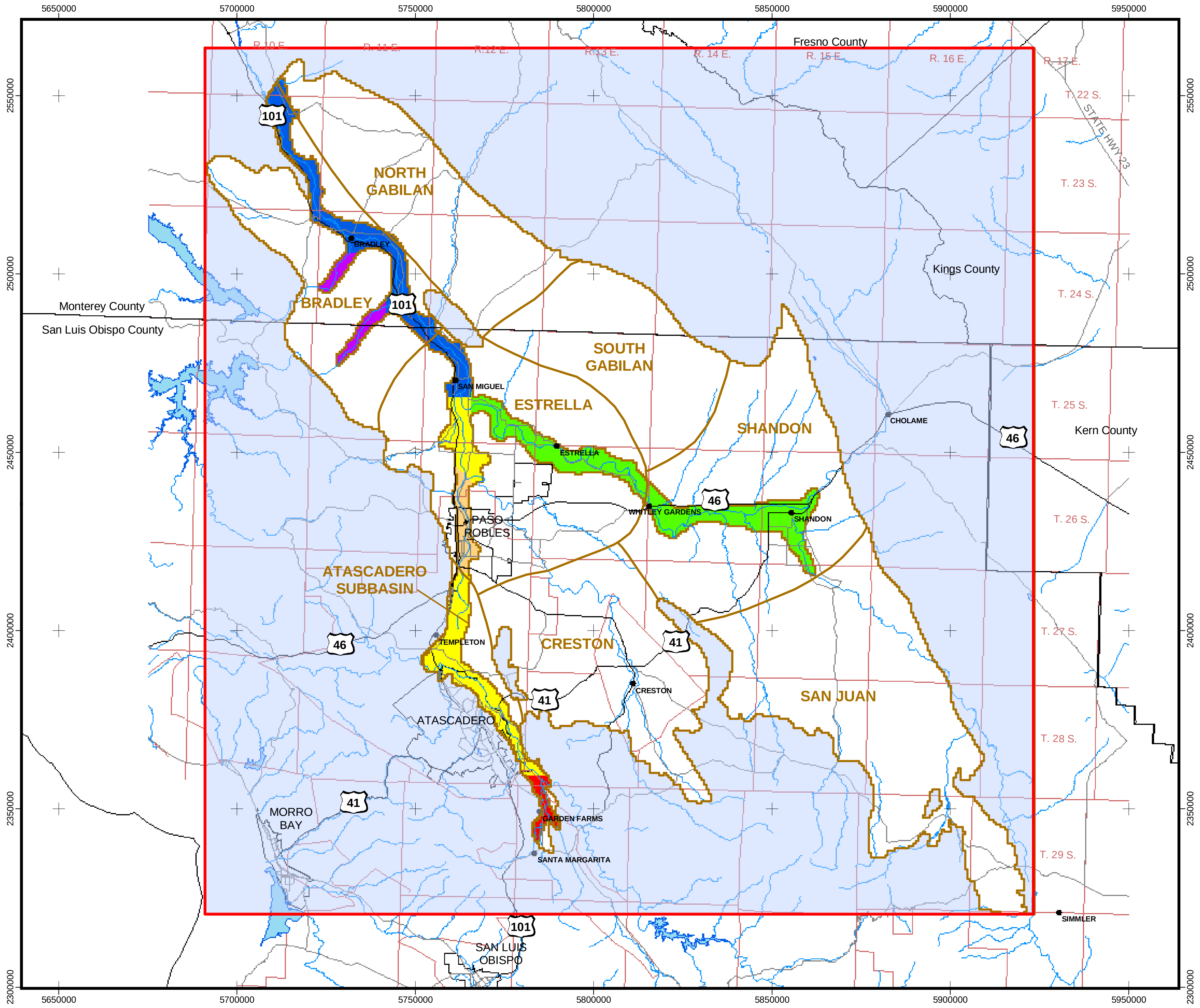
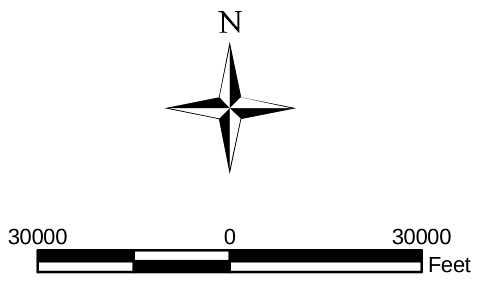


LEGEND:

- ▭ Paso Robles Groundwater Model Active Area
- 🟦 Non-Modeled Area
- ☐ City Outlines
- ━ Model Domain Boundary
- ― Township and Range Grid

			Hydraulic Conductivity		Storage	
	Zone	ID	Horizontal	Vertical	Storage Coefficient	Specific Yield
🟥	32	1	200	0.5	-	0.17
🟨	1	2	400	0.5	-	0.17
🟧	48	3	400	1	-	0.17
🟩	29	4	500	0.5	-	0.17
🟪	2	5	50	0.02	-	0.17
🟦	3	6	50	0.1	-	0.17



Model Layer 1
Hydraulic Conductivity and
Storage Coefficient Distribution

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

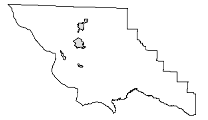
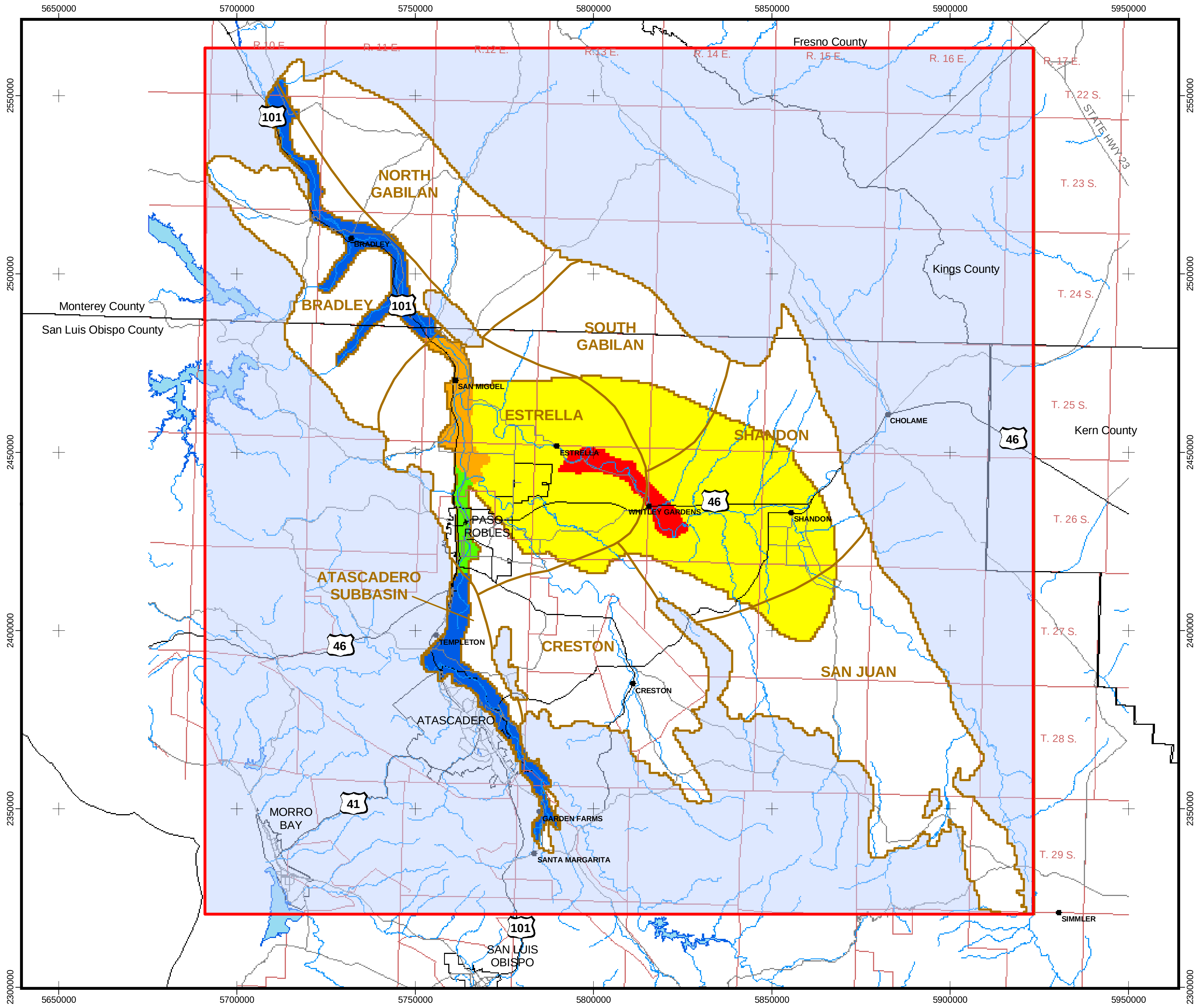


Figure 33



LEGEND:

- Paso Robles Groundwater Model Active Area
- City Outlines
- Non-Modeled Area
- Model Domain Boundary
- Township and Range Grid

			Hydraulic Conductivity		Storage	
	Zone	ID	Horizontal	Vertical	Storage Coefficient	Specific Yield
🟦	4	1	0.5	0.1	0.015	0.17
🟩	30	2	0.5	1	0.015	0.17
🟧	26	3	2	0.005	0.015	0.17
🟥	5	5	0.5	0.05	0.015	0.17
🟨	7	6	0.5	0.001	0.00001	0.01

N

30000 0 30000
Feet

Model Layer 2
Hydraulic Conductivity and
Storage Coefficient Distribution

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

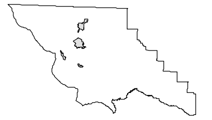
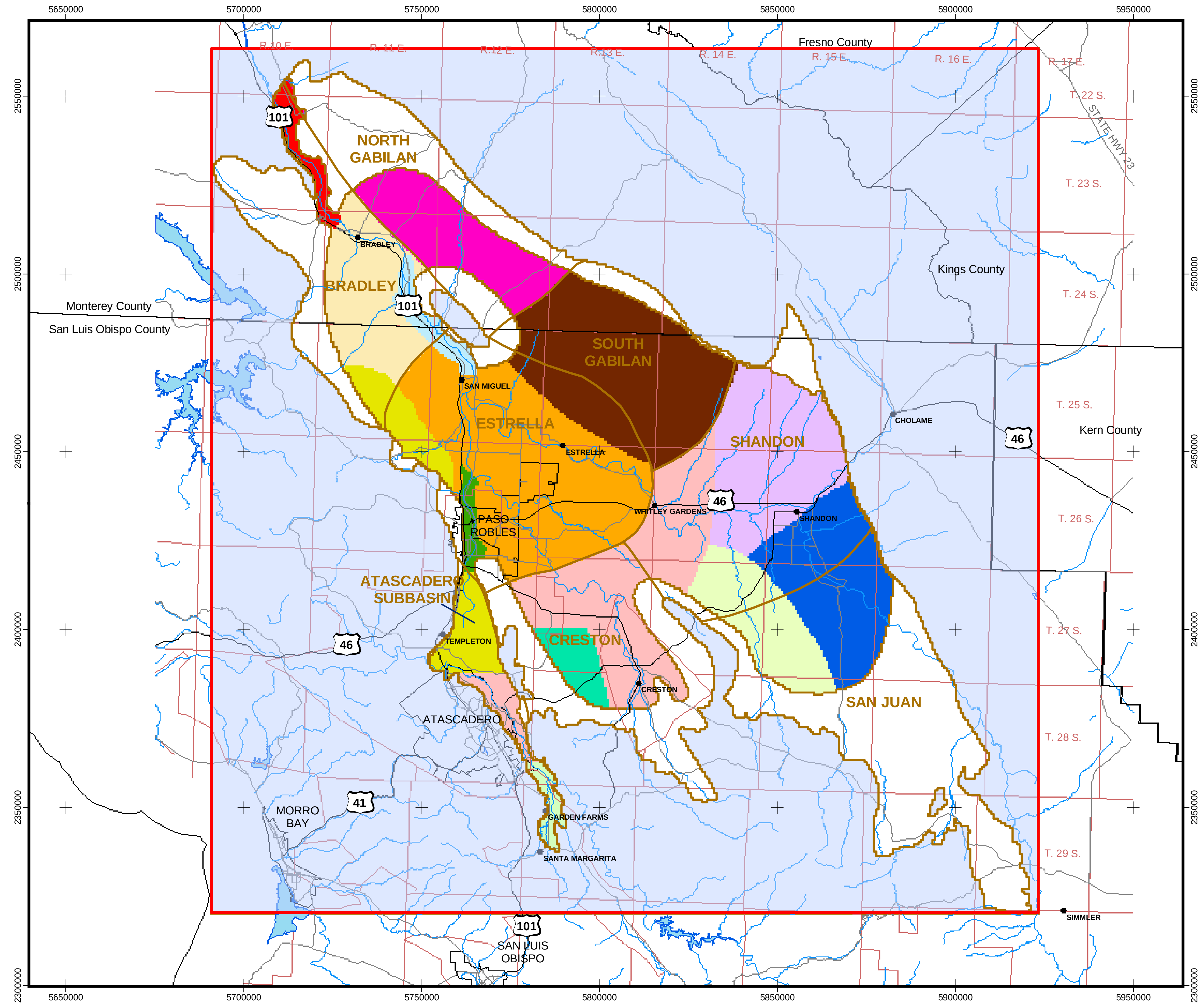


Figure 34



LEGEND:

☐ Paso Robles Groundwater Model Active Area

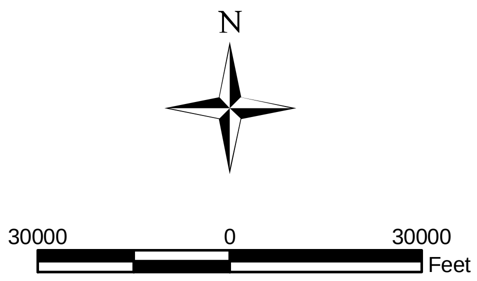
🟦 Non-Modeled Area

☐ City Outlines

— Model Domain Boundary

— Township and Range Grid

			Hydraulic Conductivity		Storage	
	Zone	ID	Horizontal	Vertical	Storage Coefficient	Specific Yield
🟩	35	1	6	0.01	0.00005	0.11
🟥	8	2	4	0.01	0.0001	0.11
🟦	45	3	2	0.005	0.00005	0.08
🟩	43	4	2	0.0001	0.0001	0.08
🟧	10	5	2.5	0.005	0.00005	0.08
🟨	11	6	5	0.01	0.00005	0.07
🟨	33	7	4	0.1	0.00005	0.11
🟩	39	8	4	0.005	0.00005	0.08
🟦	13	9	6	0.005	0.0001	0.08
🟫	41	10	4	0.01	0.00005	0.08
🟪	15	11	1.5	0.005	0.00005	0.09
🟪	14	12	1	0.005	0.00005	0.09
🟥	6	13	0.5	0.1	0.015	0.09
🟩	47	14	2	1	0.015	0.09



Model Layer 3
Hydraulic Conductivity and
Storage Coefficient Distribution

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

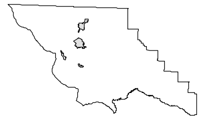
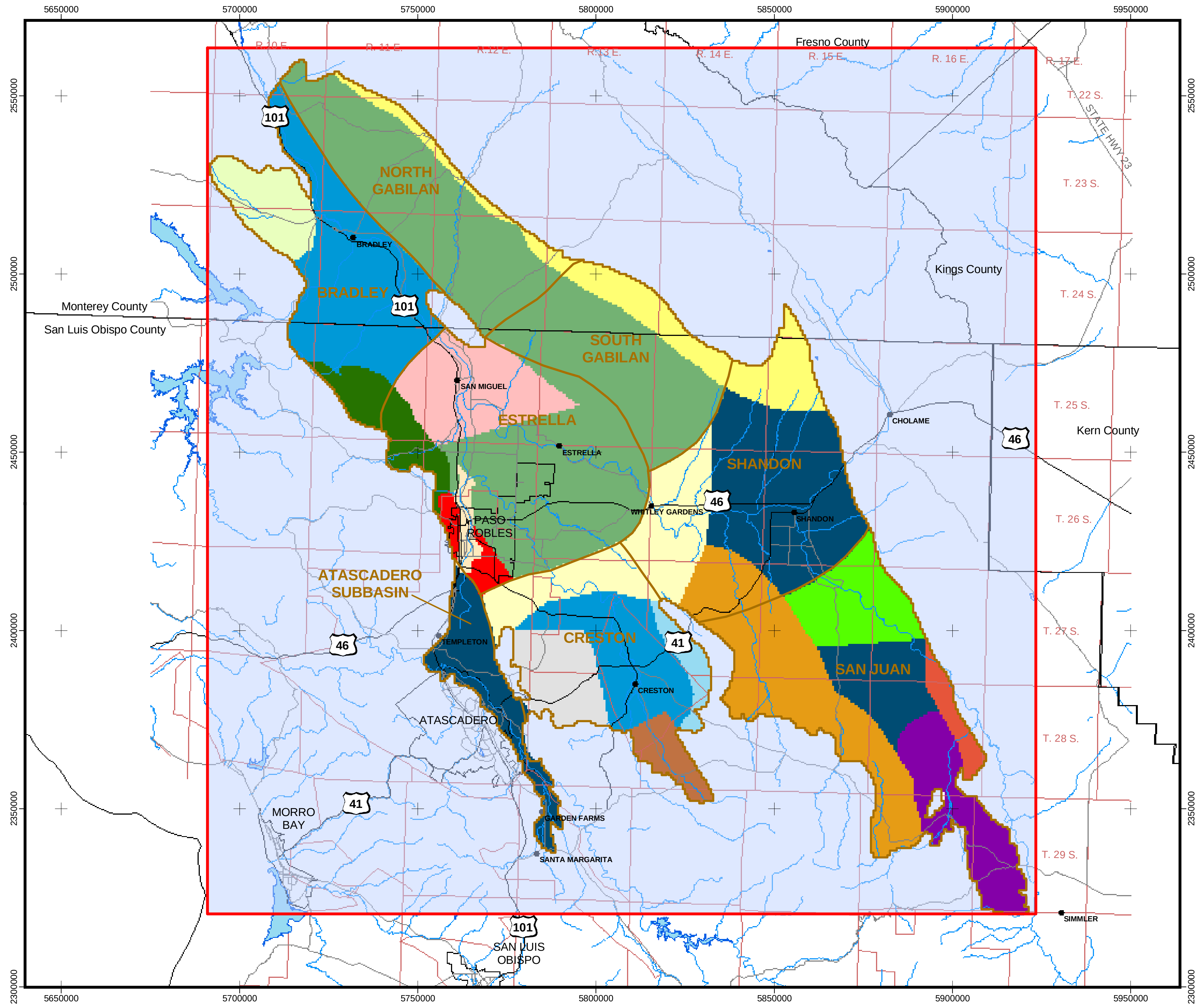


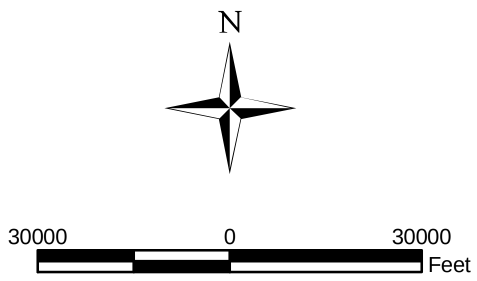
Figure 35



LEGEND:

▭	Paso Robles Groundwater Model Active Area
🟦	Non-Modeled Area
☐	City Outlines
━	Model Domain Boundary
─	Township and Range Grid

			Hydraulic Conductivity		Storage	
	Zone	ID	Horizontal	Vertical	Storage Coefficient	Specific Yield
🟦	35	1	6	0.01	0.00005	0.11
🟫	25	2	5	0.01	0.0001	0.09
⬜	42	3	3	0.0001	0.00005	0.08
🟦	17	4	4	0.01	0.0001	0.09
🟧	44	5	1	0.0001	0.00005	0.08
🟩	36	6	2	0.01	0.00005	0.08
🟨	37	7	1	0.05	0.0001	0.08
🟩	47	8	2	1	0.015	0.08
🟦	18	9	1	0.005	0.00005	0.08
🟥	28	10	2	0.005	0.00005	0.05
🟥	46	11	1	0.01	0.00005	0.08
🟥	34	12	6	0.005	0.0001	0.1
🟩	31	13	3	0.01	0.001	0.1
🟧	38	14	4	0.005	0.0001	0.08
🟪	20	15	12	0.01	0.0001	0.1
🟨	27	16	0.5	0.005	0.00005	0.05



Model Layer 4
Hydraulic Conductivity and
Storage Coefficient Distribution

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

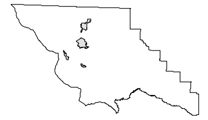
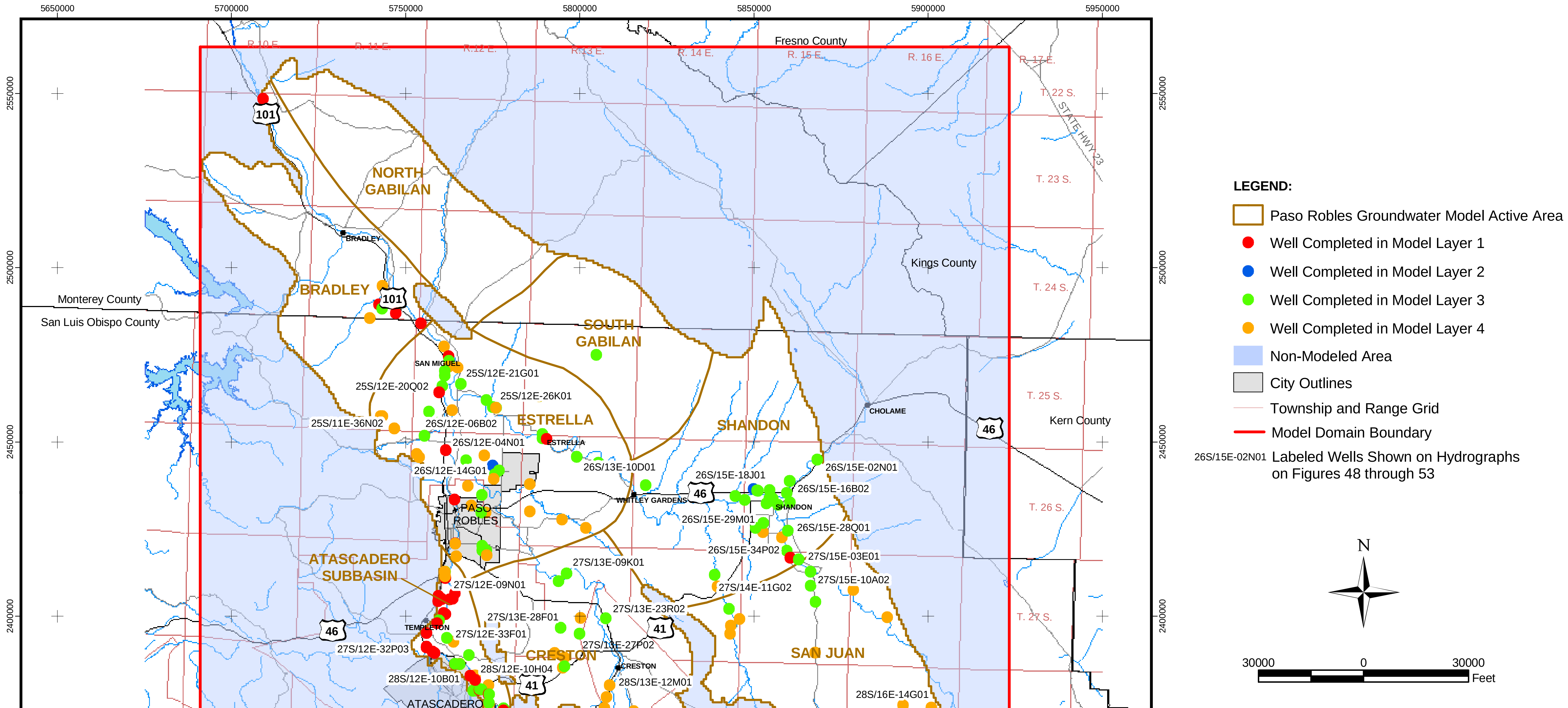


Figure 36



Location of Wells with Groundwater Elevation Data

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

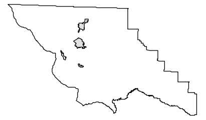
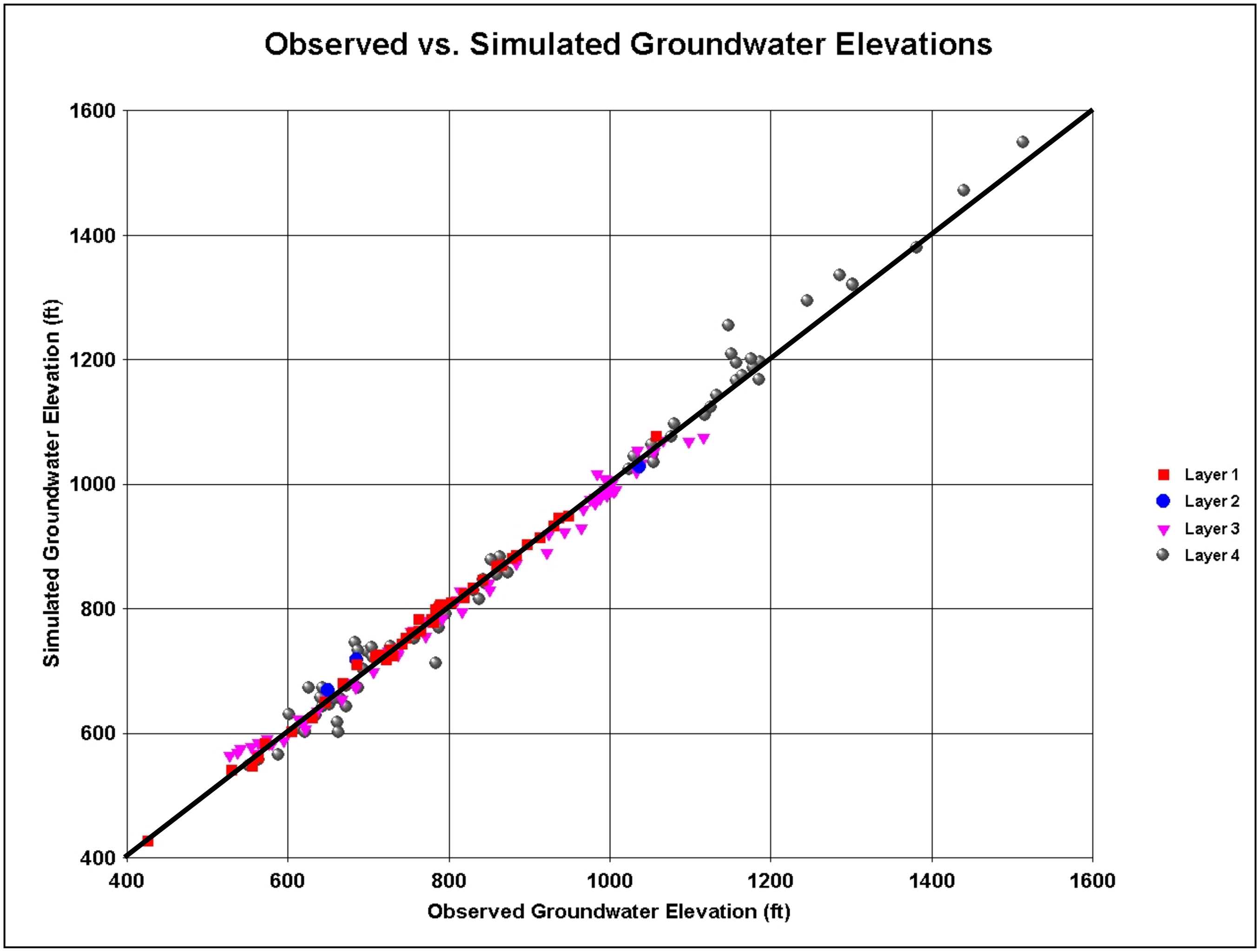


Figure 37

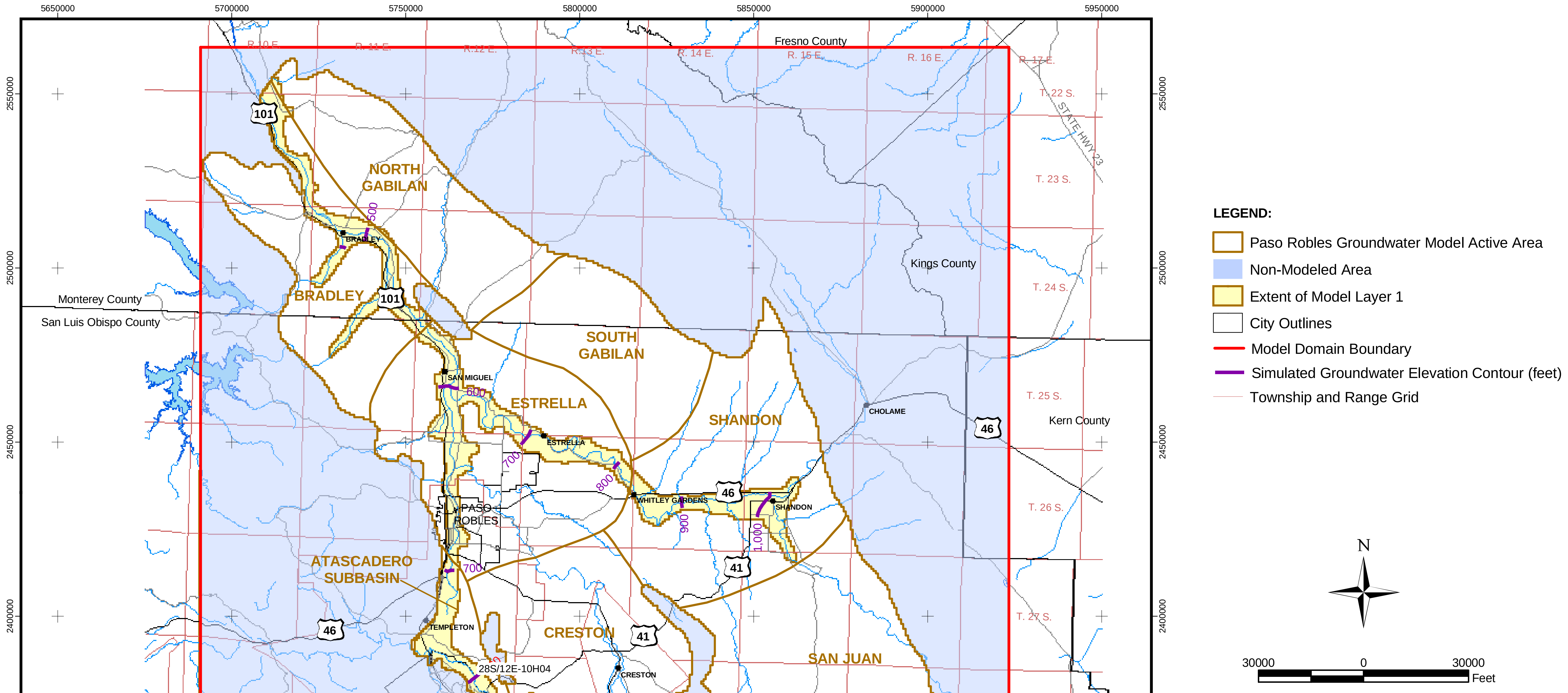


**STEADY-STATE MODEL CALIBRATION
SUMMARY PLOT**

**Paso Robles Groundwater
Basin Study, Phase II**

Fugro West, Inc. and
ETIC Engineering

Figure 38



Simulated Groundwater Elevations in Model Layer 1 for Fall 1997

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

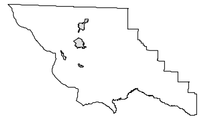
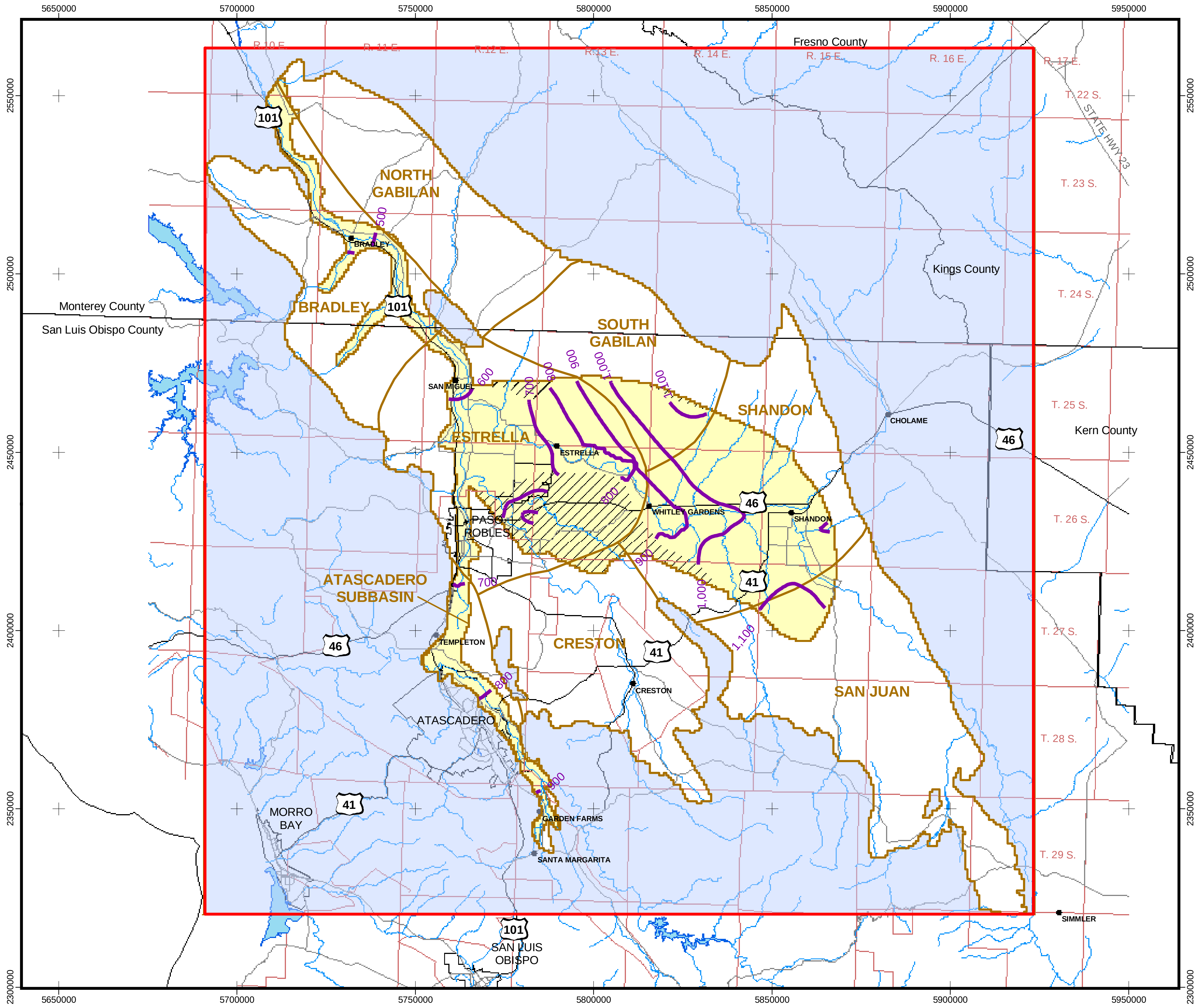


Figure 39



LEGEND:

□ Paso Robles Groundwater Model Active Area
□ City Outlines
🟦 Non-Modeled Area
🟨 Extent of Model Layer 2
▨ Area of Limited Saturation
— Model Domain Boundary
— Simulated Groundwater Elevation Contour (feet)
— Township and Range Grid

N

30000 0 30000
Feet

Simulated Groundwater Elevations in Model Layer 2 for Fall 1997

Paso Robles Groundwater Basin Study, Phase II
Fugro West, Inc. and
ETIC Engineering

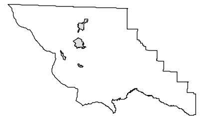
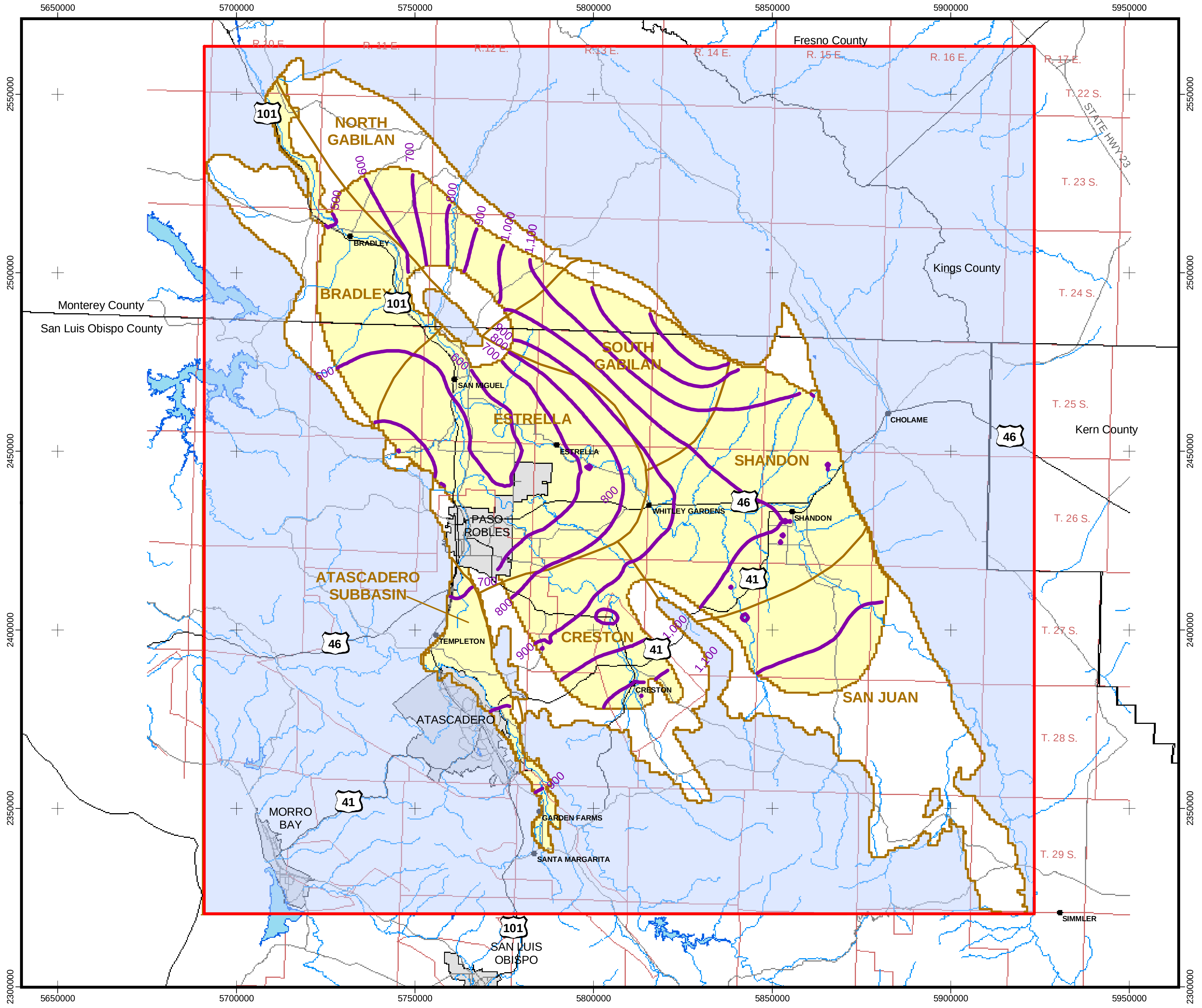


Figure 40



Simulated Groundwater Elevations in Model Layer 3 for Fall 1997

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

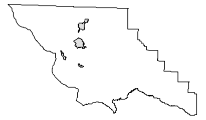
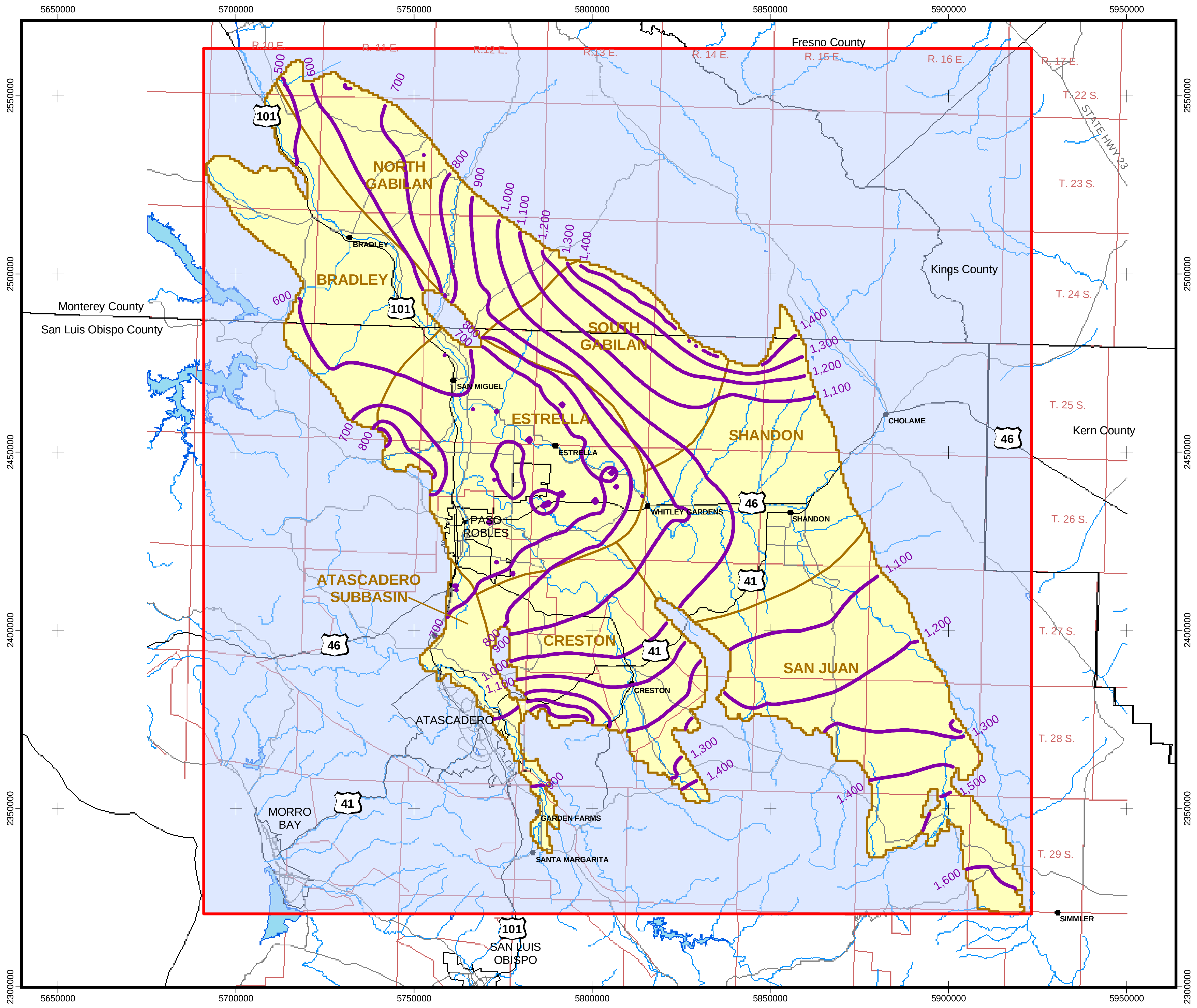


Figure 41



LEGEND:

▭ Paso Robles Groundwater Model Active Area
🟦 Non-Modeled Area
🟨 Extent of Model Layer 4
☐ City Outlines
— Model Domain Boundary
— Simulated Groundwater Elevation Contour (feet)
— Township and Range Grid

N

30000 0 30000
Feet

Simulated Groundwater Elevations in Model Layer 4 for Fall 1997

Paso Robles Groundwater Basin Study, Phase II
Fugro West, Inc. and
ETIC Engineering

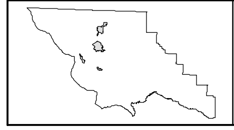
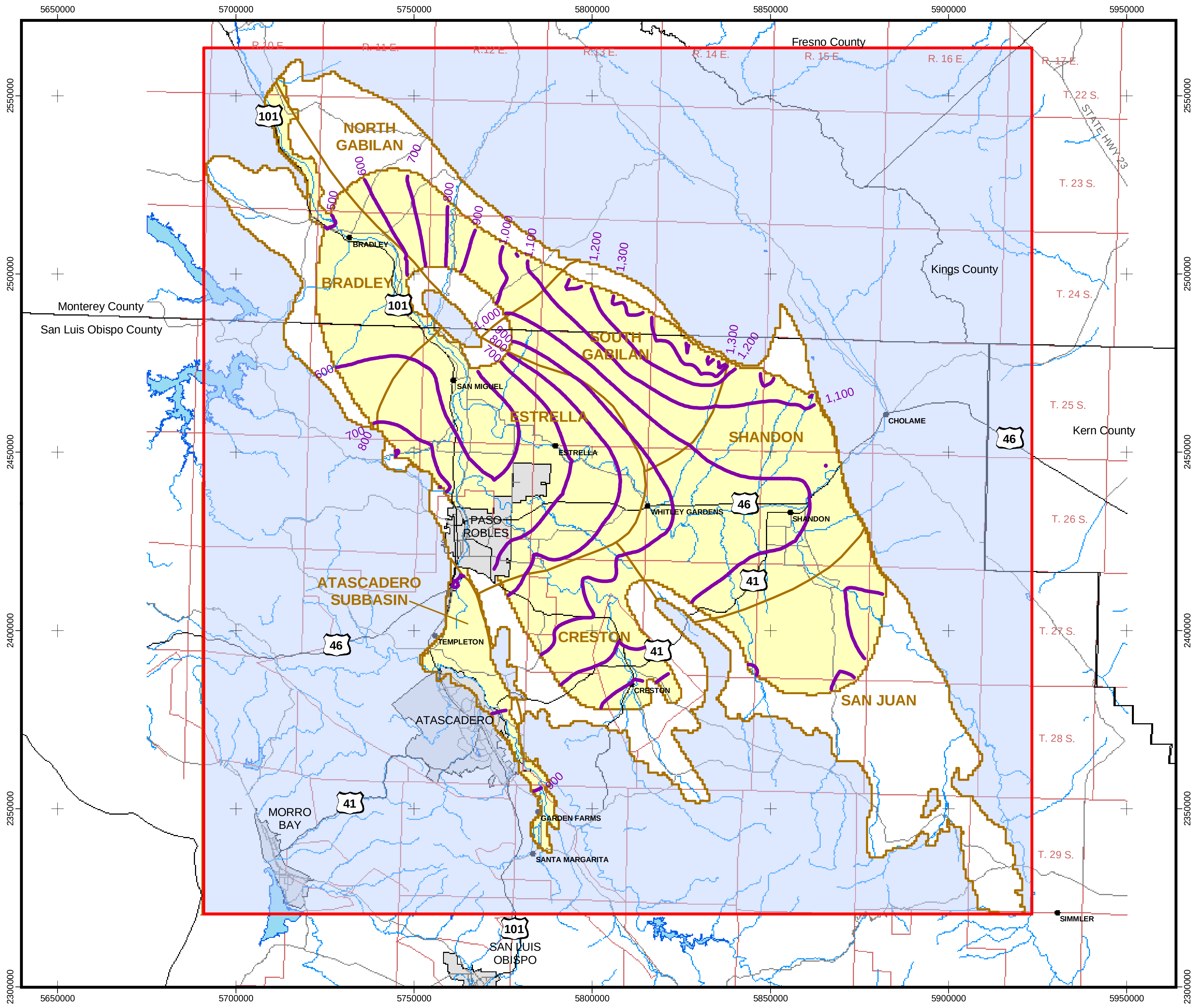


Figure 42



LEGEND:

▭ Paso Robles Groundwater Model Active Area
🟦 Non-Modeled Area
🟨 Extent of Model Layer 3
⬜ City Outlines
— Model Domain Boundary
— Simulated Groundwater Elevation Contour (feet)
— Township and Range Grid

N

30000 0 30000
Feet

Simulated Groundwater Elevations in Model Layer 3 for Spring 1983

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

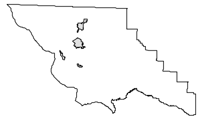
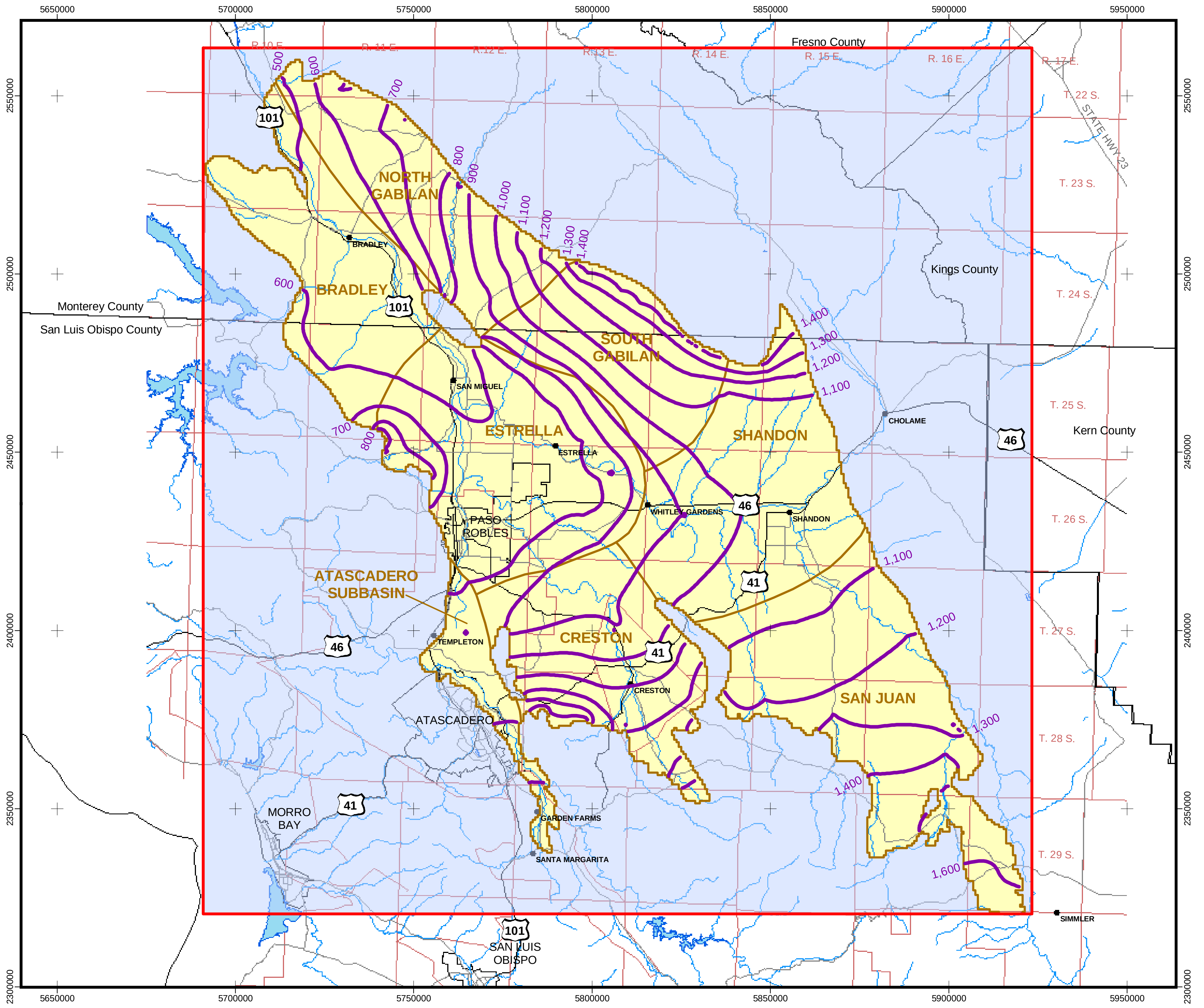


Figure 43



LEGEND:

- ▭ Paso Robles Groundwater Model Active Area
- 🟦 Non-Modeled Area
- 🟨 Extent of Model Layer 4
- ☐ City Outlines
- 🟥 Model Domain Boundary
- ▬ Simulated Groundwater Elevation Contour (feet)
- ─ Township and Range Grid

N

30000 0 30000 Feet

Simulated Groundwater Elevations in Model Layer 4 for Spring 1983

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

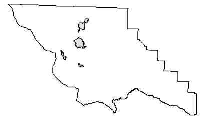
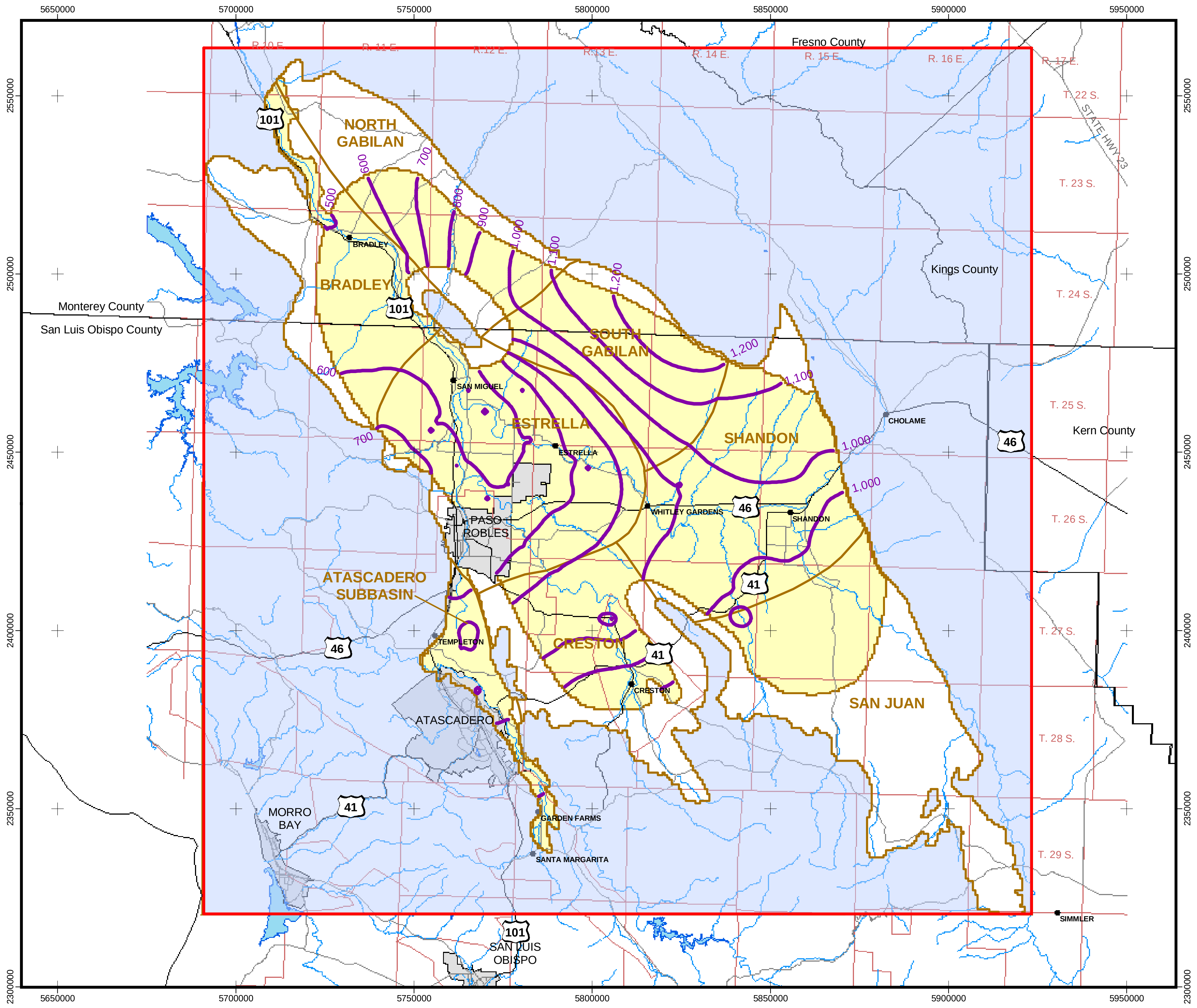
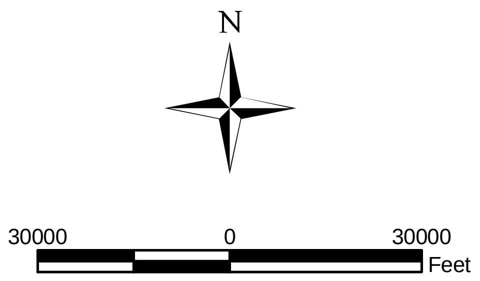


Figure 44



LEGEND:

▭ Paso Robles Groundwater Model Active Area
🟦 Non-Modeled Area
🟨 Extent of Model Layer 3
⬜ City Outlines
— Model Domain Boundary
— Simulated Groundwater Elevation Contour (feet)
— Township and Range Grid



Simulated Groundwater Elevations in Model Layer 3 for Fall 1990

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

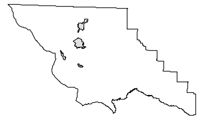
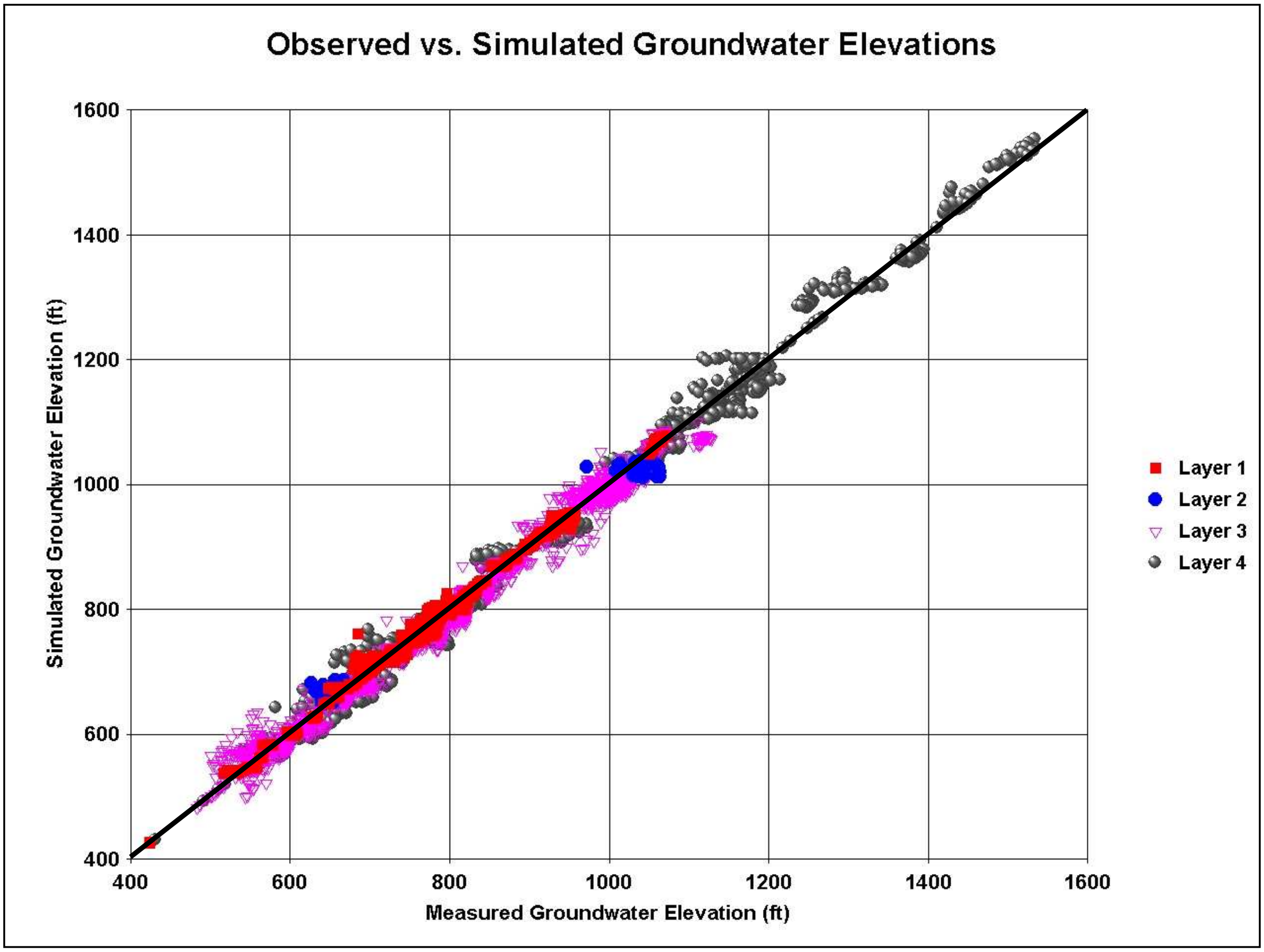


Figure 45



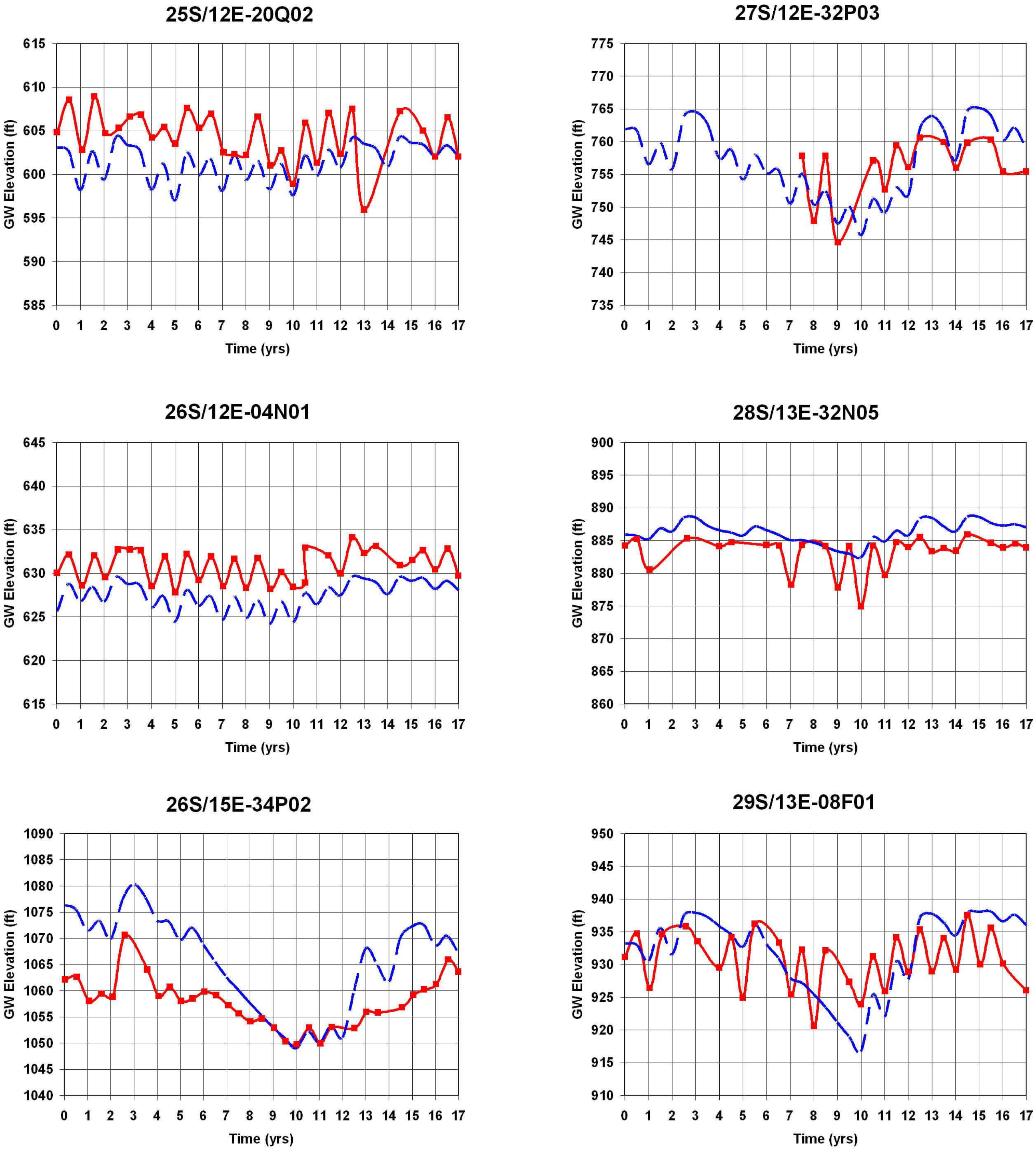
Correlation Coefficient	**=**	**0.996**
Residual Mean	**=**	**1.12**
Residual Std. Deviation	**=**	**18.61**
Absolute Residual Mean	**=**	**13.98**
Minimum Residual	**=**	**-83.02**
Maximum Residual	**=**	**70.95**
Observed Range in Head	**=**	**1110.7**
Residual Std. Dev / Range	**=**	**0.017**

**TRANSIENT MODEL CALIBRATION
SUMMARY PLOT AND STATISTICS**

**Paso Robles Groundwater
Basin Study, Phase II**

Fugro West, Inc. and
ETIC Engineering

Figure 47



LEGEND

━━━ Measured Data

┅┅┅ Simulated Data

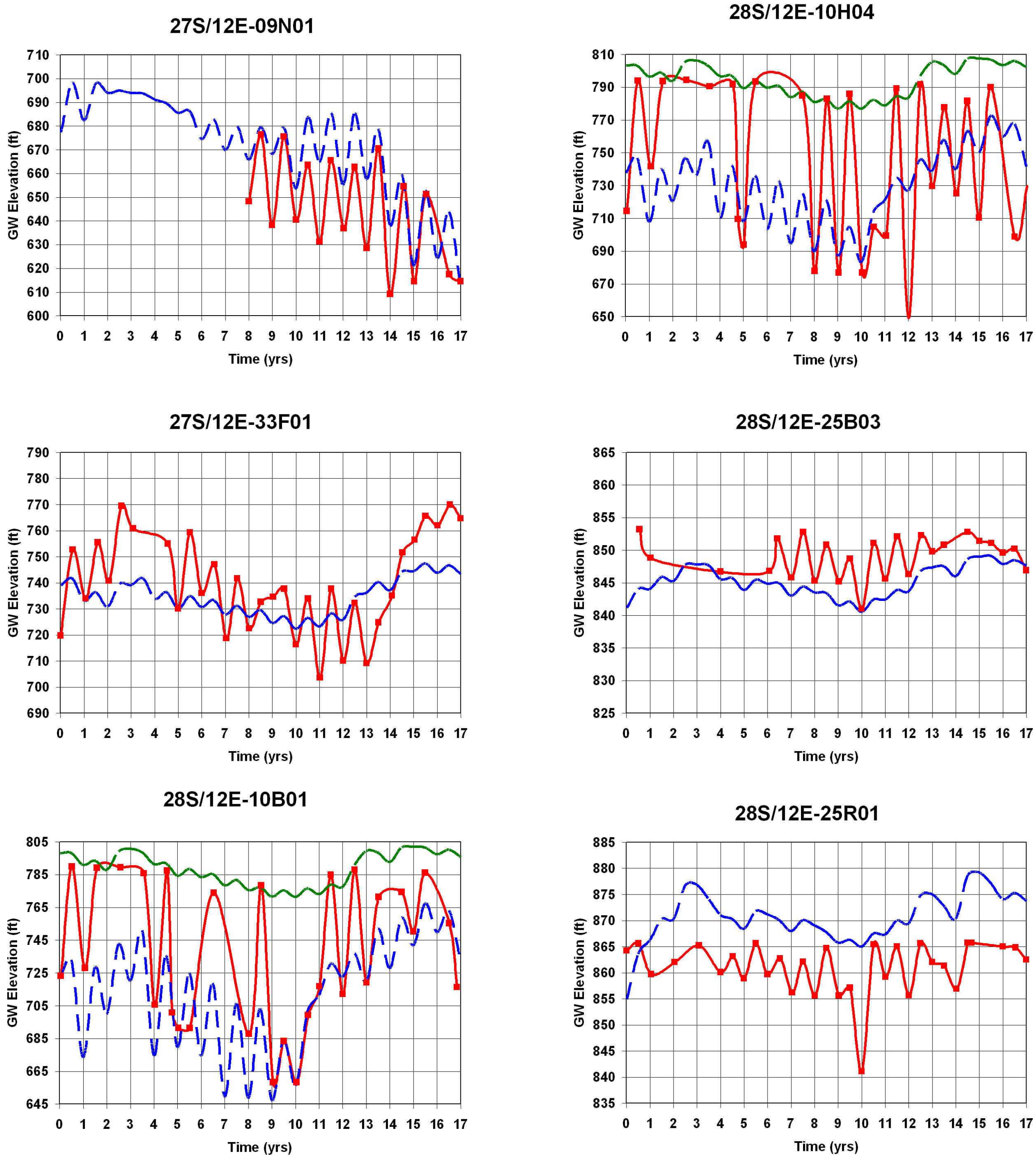
**MODEL CALIBRATION
INDIVIDUAL HYDROGRAPHS
FOR MODEL LAYER 1
ALLUVIUM**

**Note: Model calibration results cover the
17-year base period from 1981 through 1997**

**Paso Robles Groundwater
Basin Study, Phase II**

Fugro West, Inc. and
ETIC Engineering

Figure 48



LEGEND

🟥 Measured Data

······ Simulated Data

······ Second Simulated Data

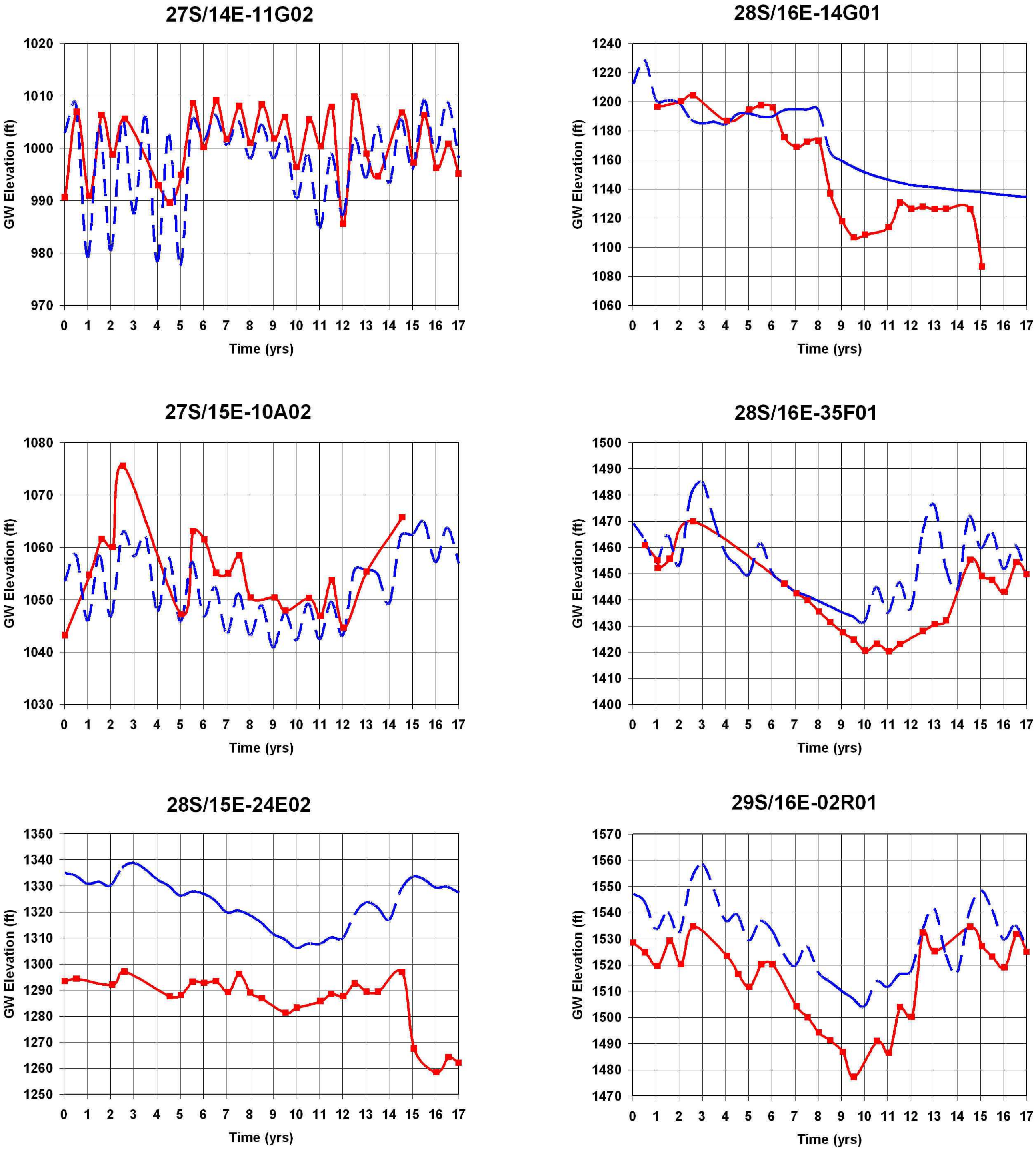
Note: Model calibration results cover the 17-year base period from 1981 through 1997

**MODEL CALIBRATION
INDIVIDUAL HYDROGRAPHS
FOR MODEL LAYERS 3 AND 4
ATASCADERO SUBBASIN**

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

Figure 49



LEGEND

━━━━ Measured Data

┅┅┅┅ Simulated Data

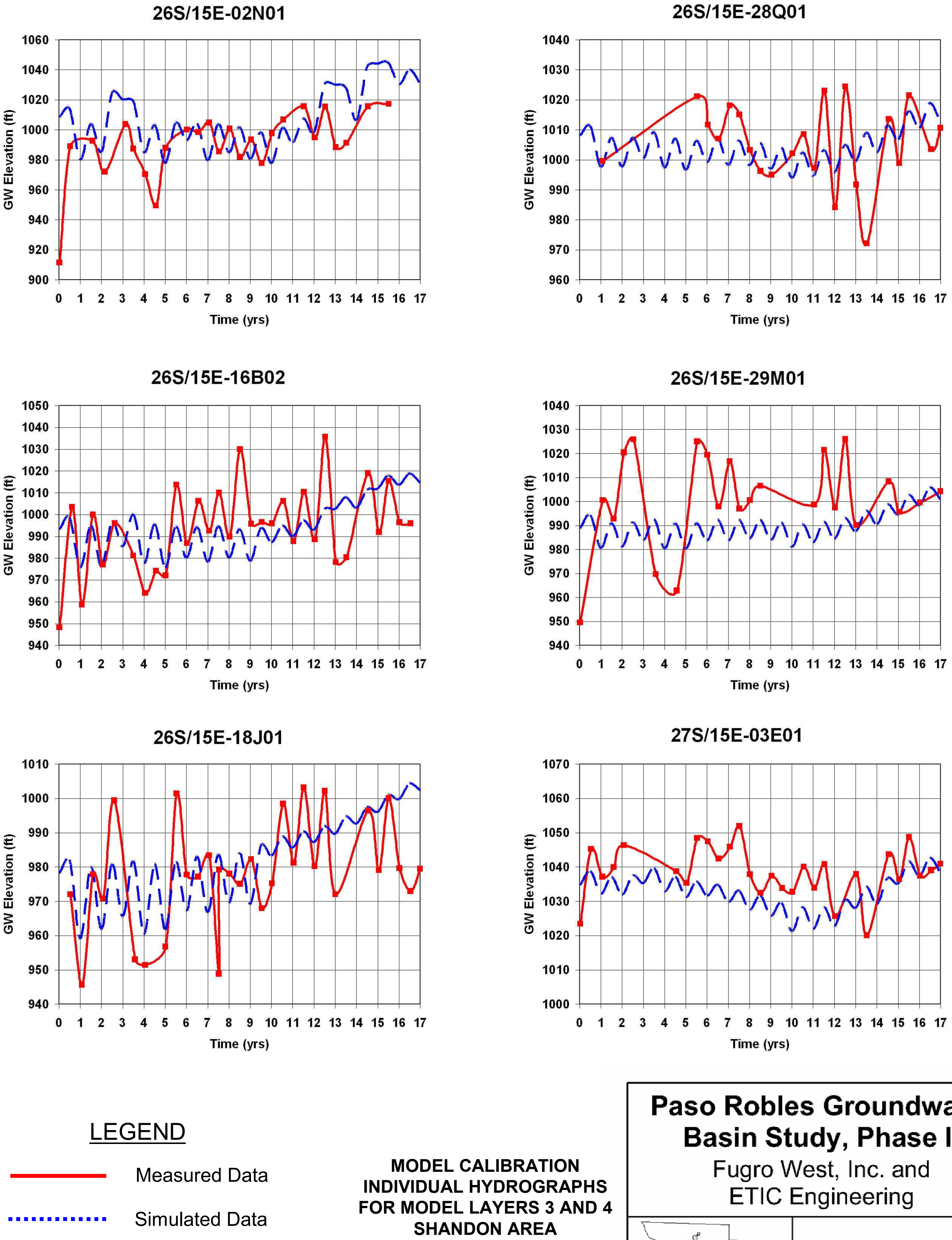
Note: Model calibration results cover the 17-year base period from 1981 through 1997

**MODEL CALIBRATION
INDIVIDUAL HYDROGRAPHS
FOR MODEL LAYERS 3 AND 4
SAN JUAN AREA**

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

Figure 50



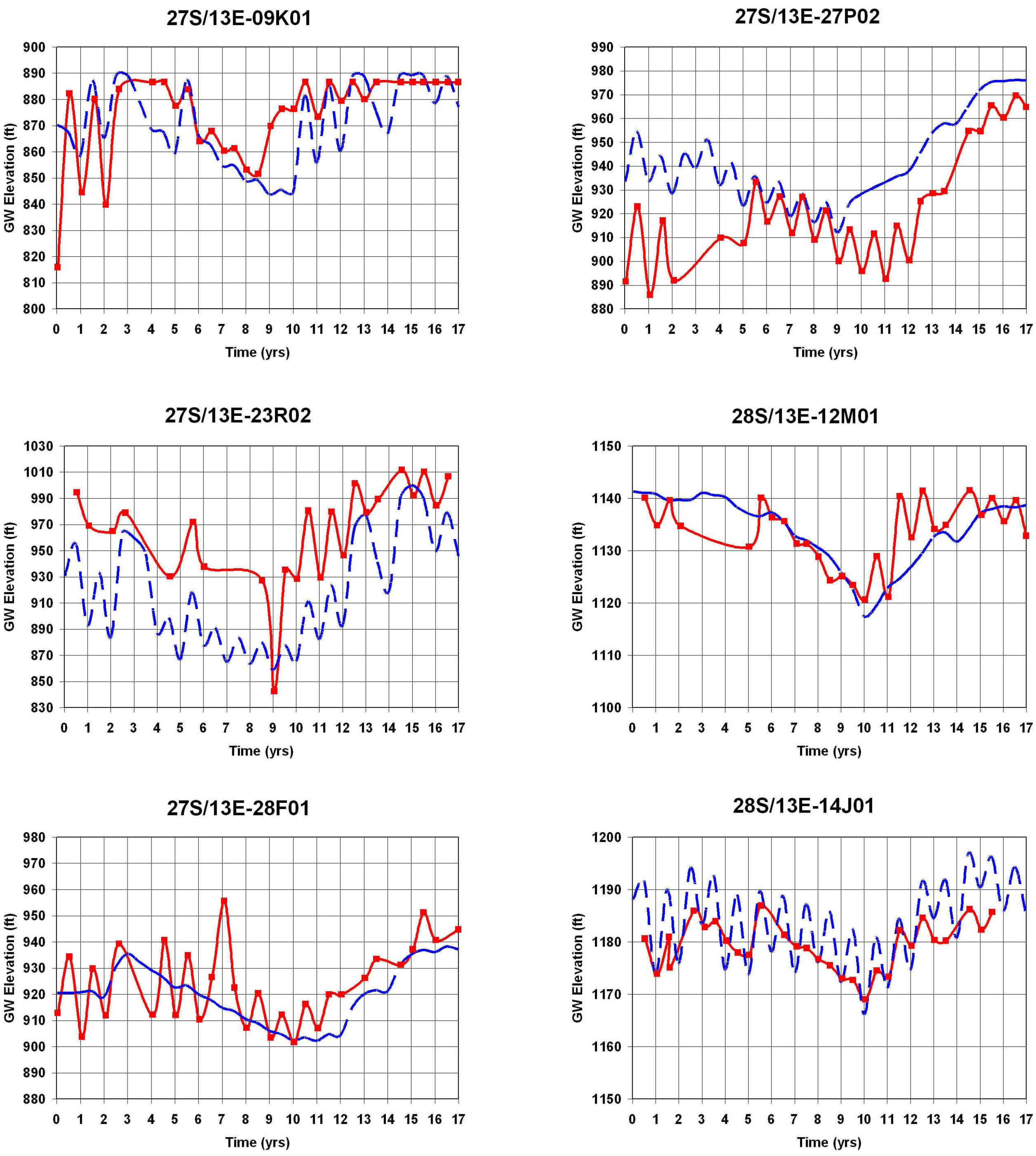
**MODEL CALIBRATION
INDIVIDUAL HYDROGRAPHS
FOR MODEL LAYERS 3 AND 4
SHANDON AREA**

Note: Model calibration results cover the 17-year base period from 1981 through 1997

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

Figure 51



LEGEND

━━━ Measured Data

┅┅┅ Simulated Data

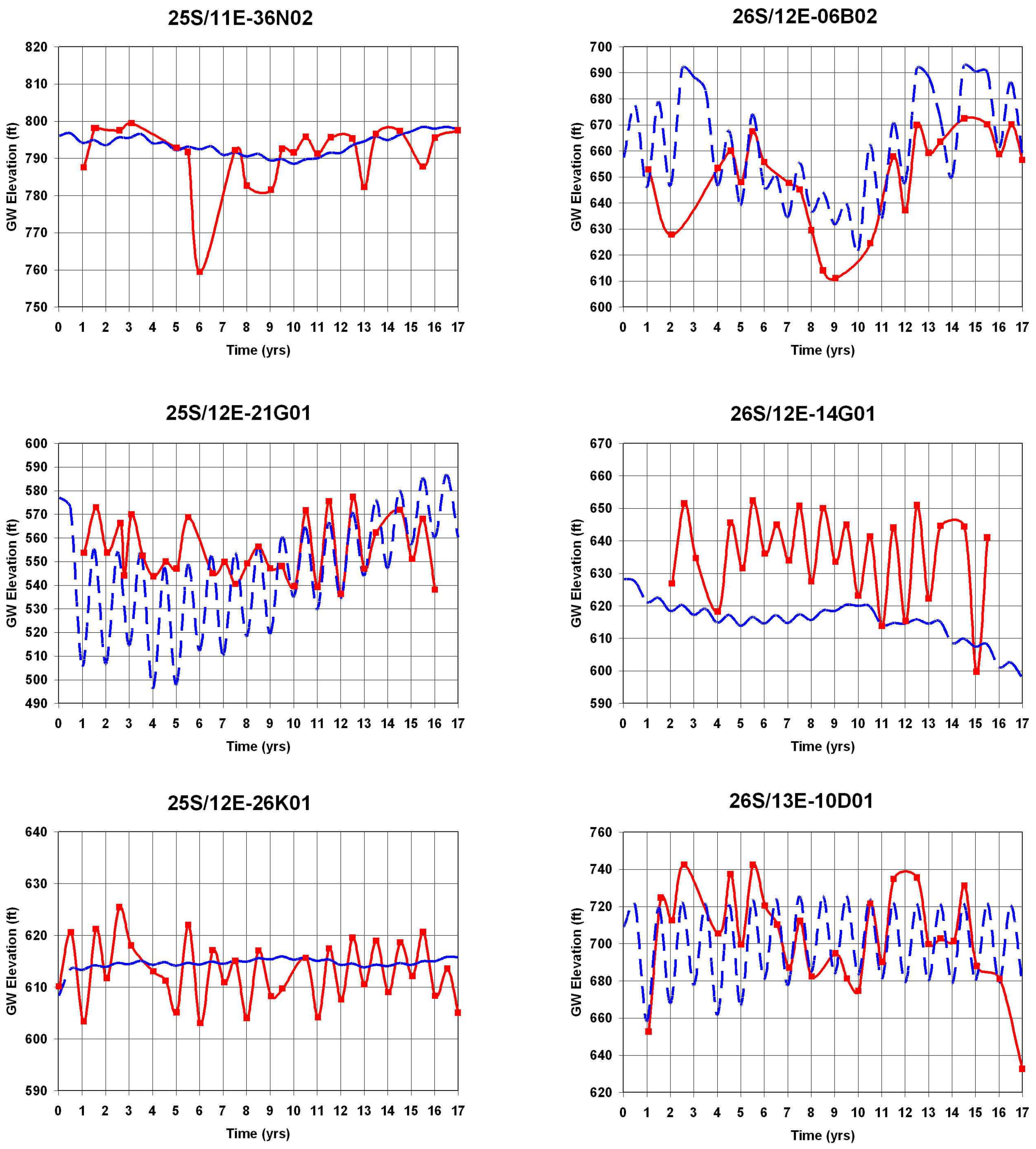
Note: Model calibration results cover the 17-year base period from 1981 through 1997

MODEL CALIBRATION
INDIVIDUAL HYDROGRAPHS
FOR MODEL LAYERS 3 AND 4
CRESTON AREA

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

Figure 52



LEGEND

🟥 Measured Data

┅ Simulated Data

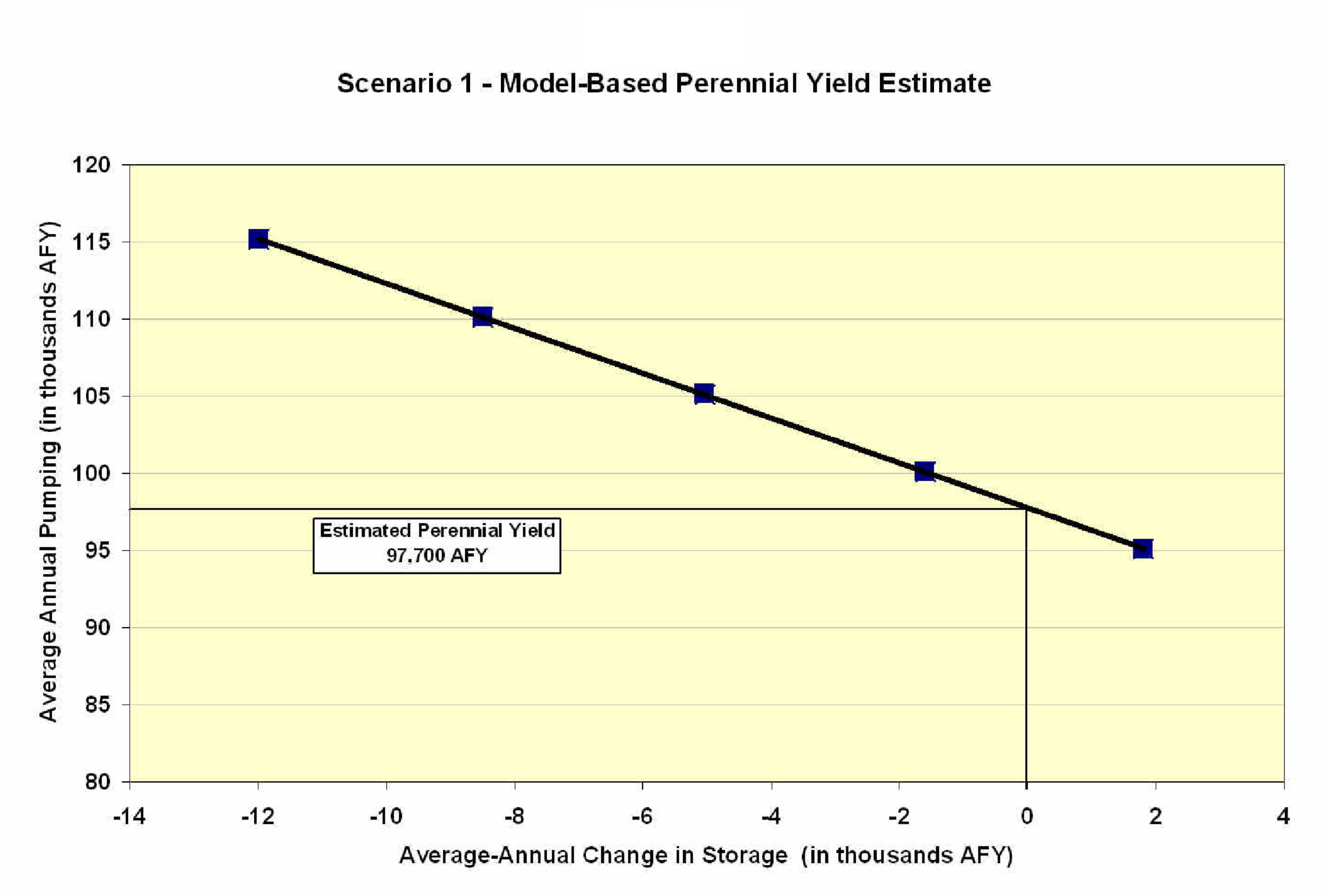
Note: Model calibration results cover the 17-year base period from 1981 through 1997

**MODEL CALIBRATION
INDIVIDUAL HYDROGRAPHS
FOR MODEL LAYERS 3 AND 4
ESTRELLA AREA**

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

Figure 53



Scenario 1 Perennial Yield
Linear Regression Analysis

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

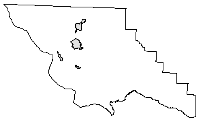
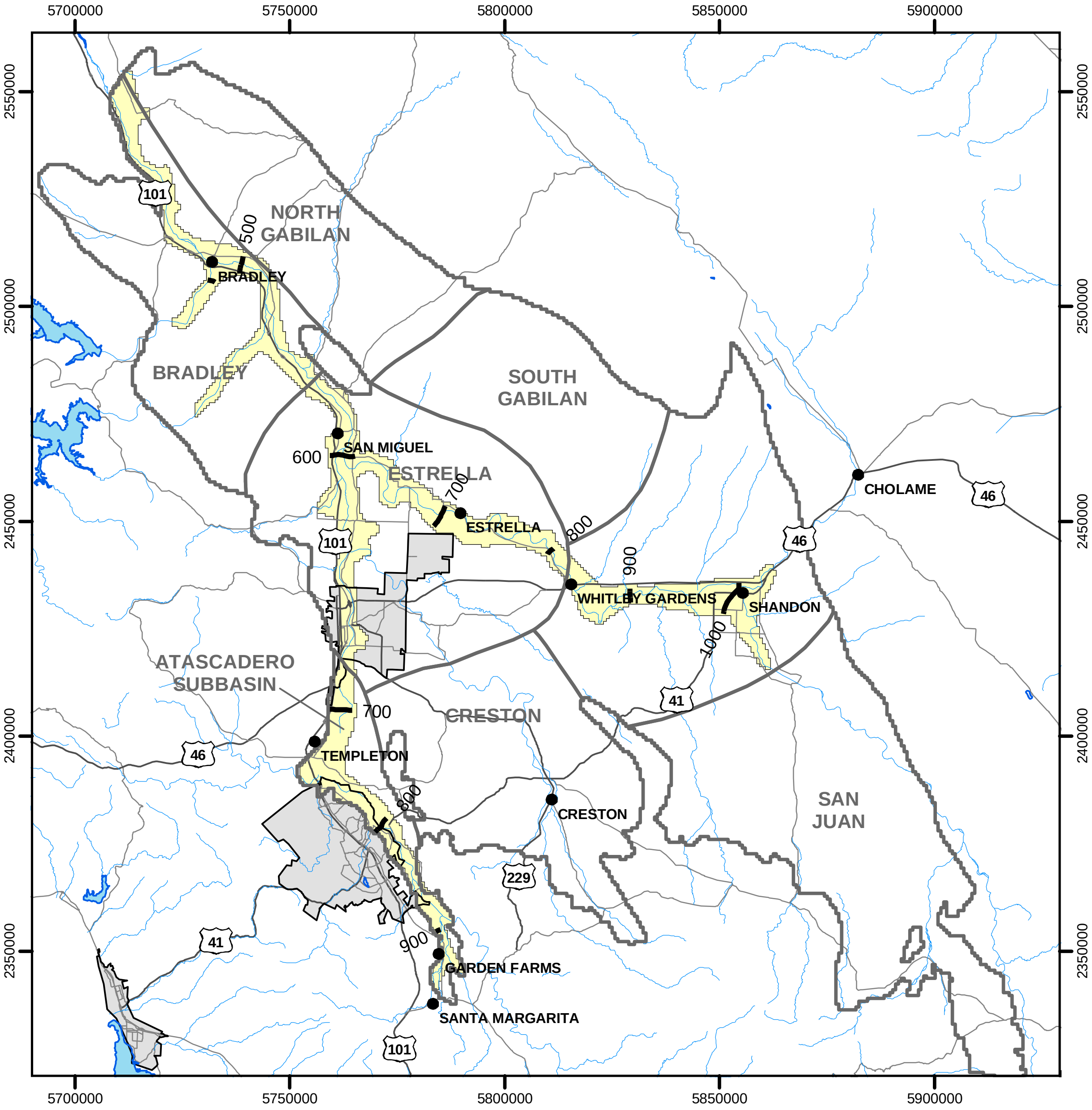


Figure 54



Legend

▬ Groundwater Elevation Contour (feet)

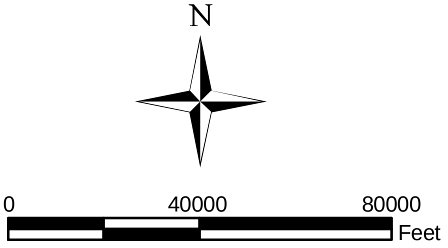
☐ Paso Robles Groundwater Model Active Area

— River

— Main Road

— Minor Road

🟨 Model Layer 1



Scenario 2 Basin-wide Groundwater Elevation Map for Model Layer 1

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

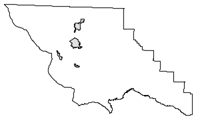
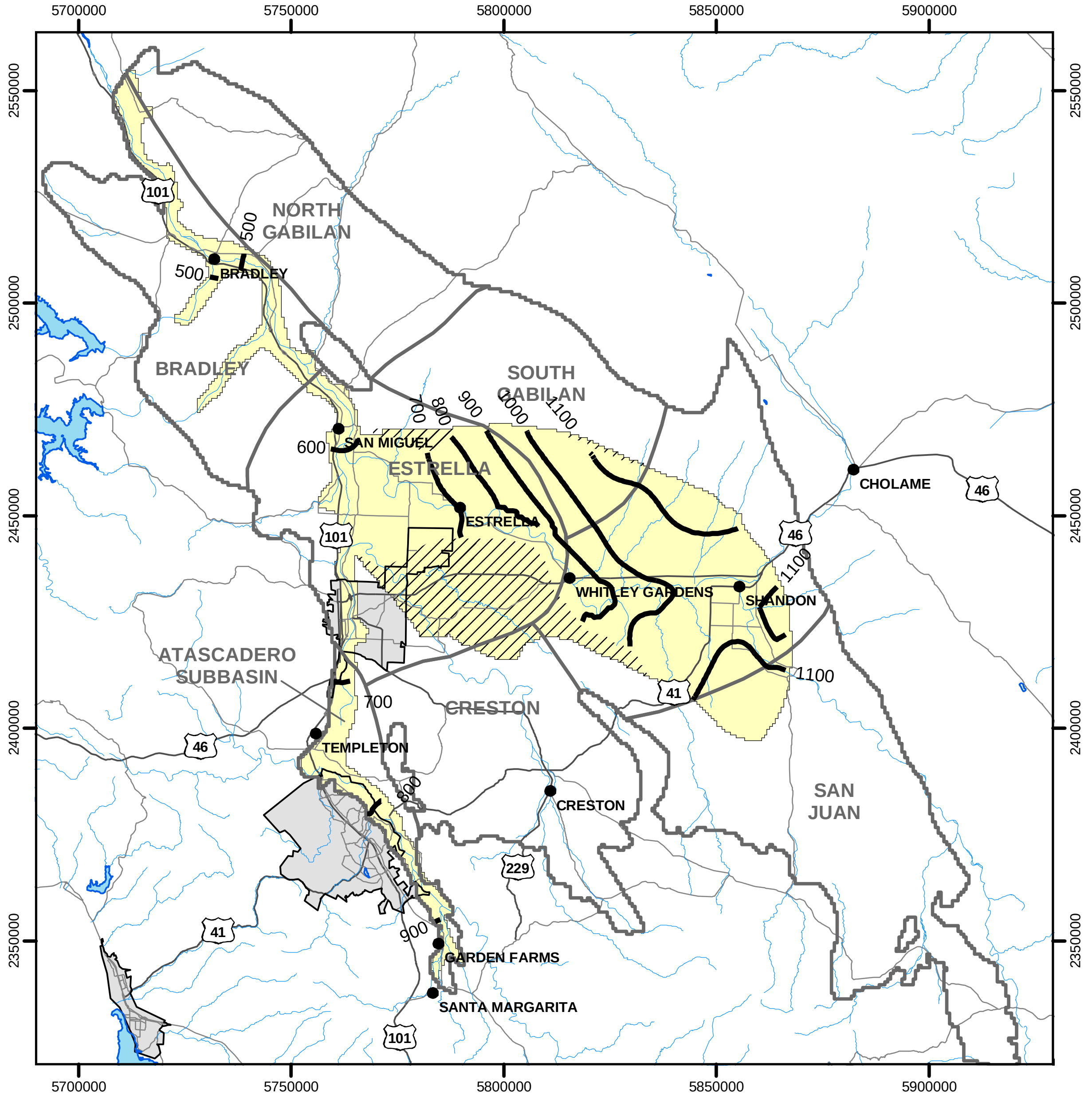


Figure 55



Legend

▬ Groundwater Elevation Contour (feet)

☐ Paso Robles Groundwater Model Active Area

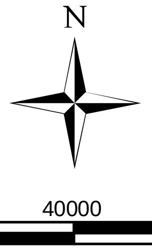
— River

— Main Road

— Minor Road

🟨 Model Layer 2

▨ Area of Limited Saturation



Scenario 2 Basin-wide Groundwater Elevation Map for Model Layer 2

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

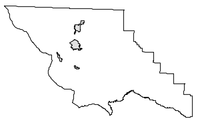
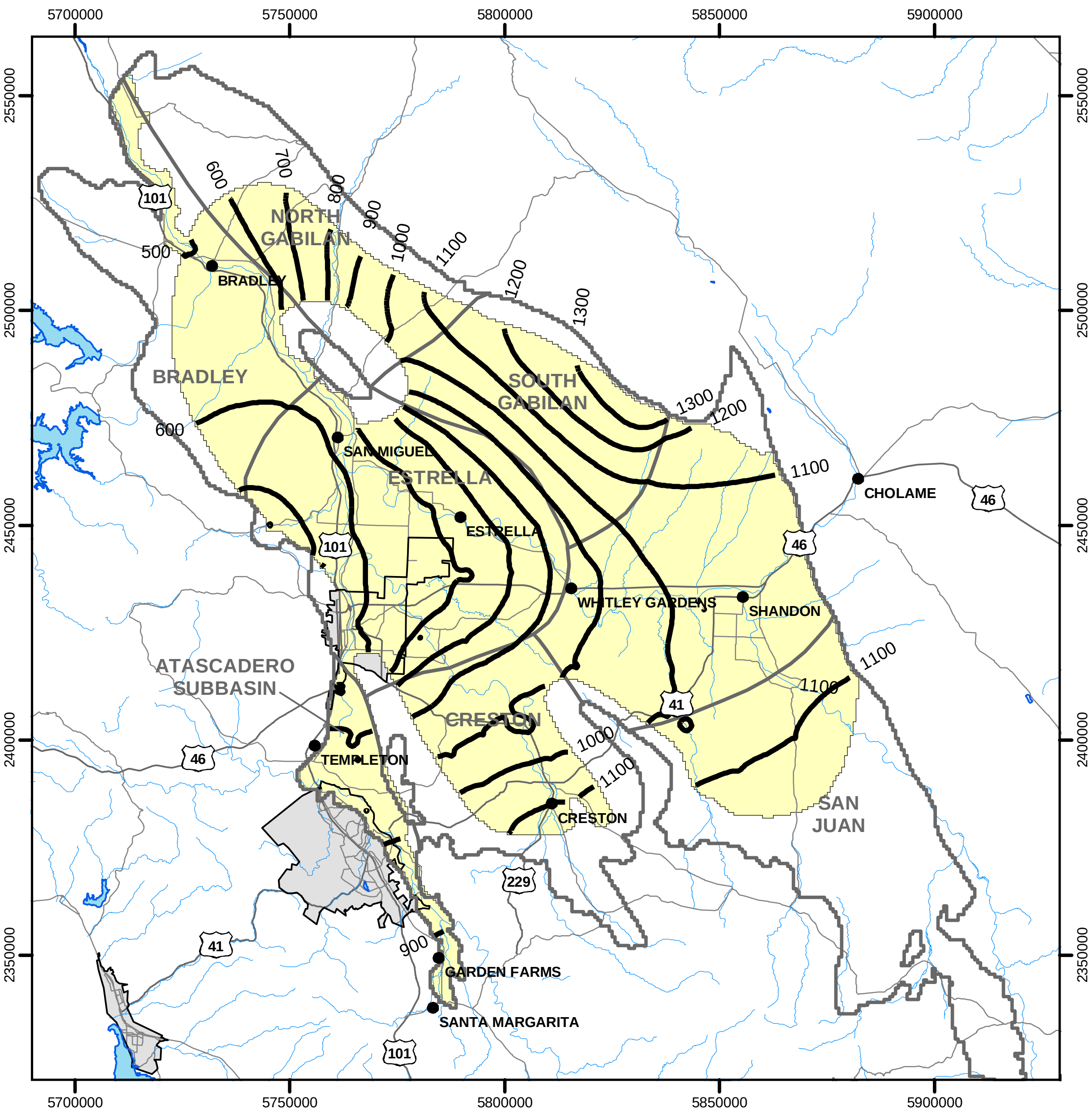
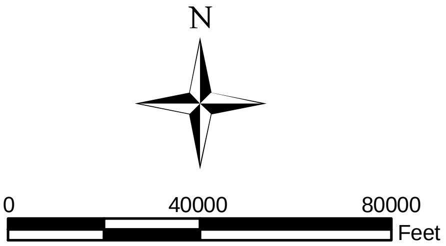


Figure 56



Legend

- Groundwater Elevation Contour (feet)
- Paso Robles Groundwater Model Active Area
- River
- Main Road
- Minor Road
- Model Layer 3



Scenario 2 Basin-wide Groundwater Elevation Map for Model Layer 3

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

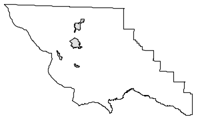
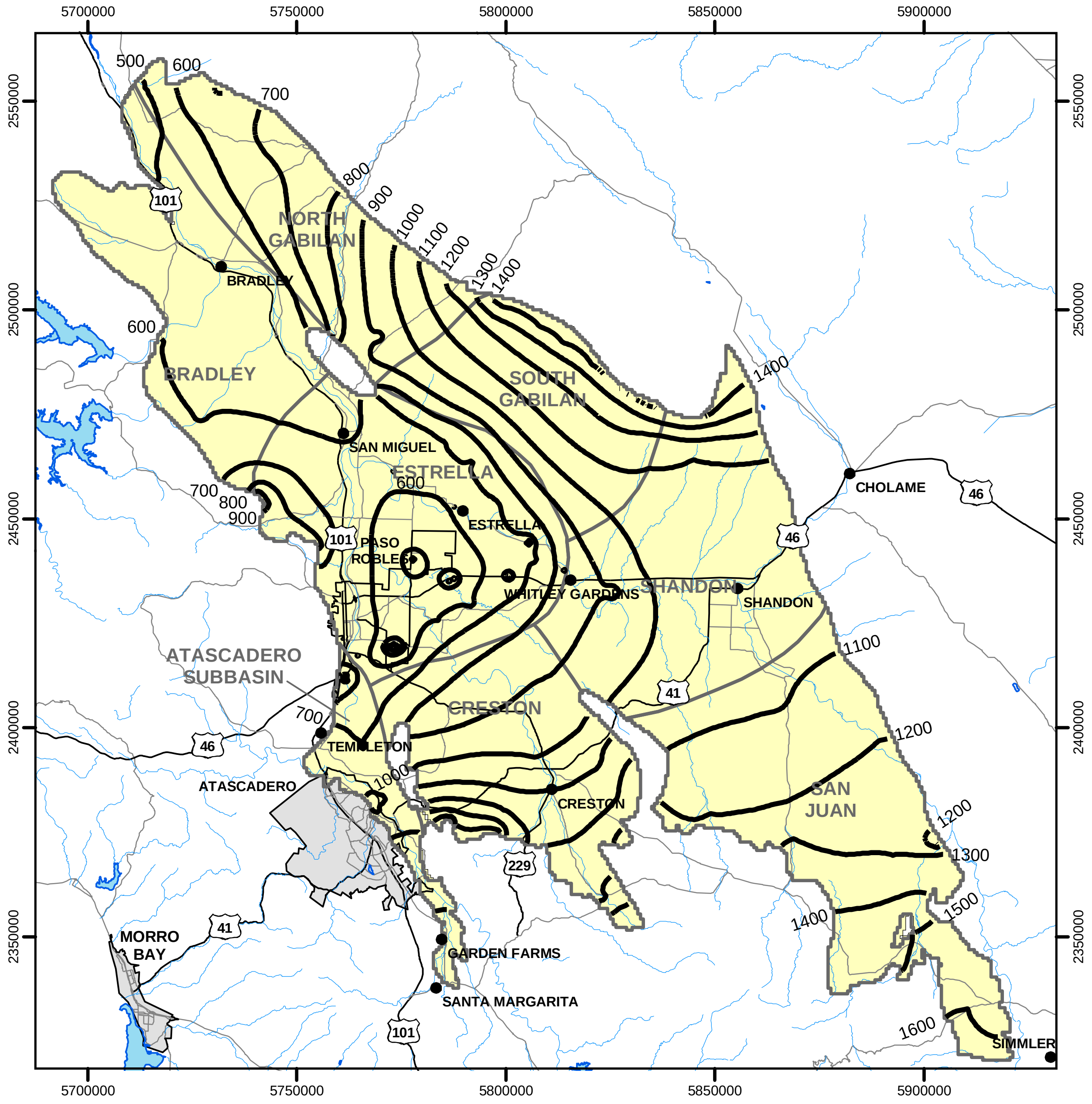


Figure 57



Legend

▬ Groundwater Elevation Contour (feet)

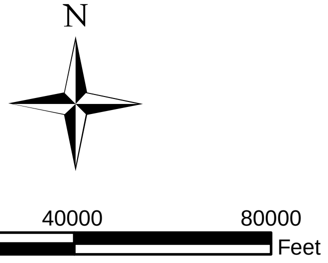
▢ Paso Robles Groundwater Model Active Area

— River

— Main Road

— Minor Road

🟨 Model Layer 4



Scenario 2 Basin-wide Groundwater Elevation Map for Model Layer 4

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

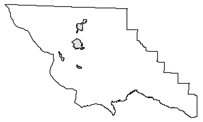
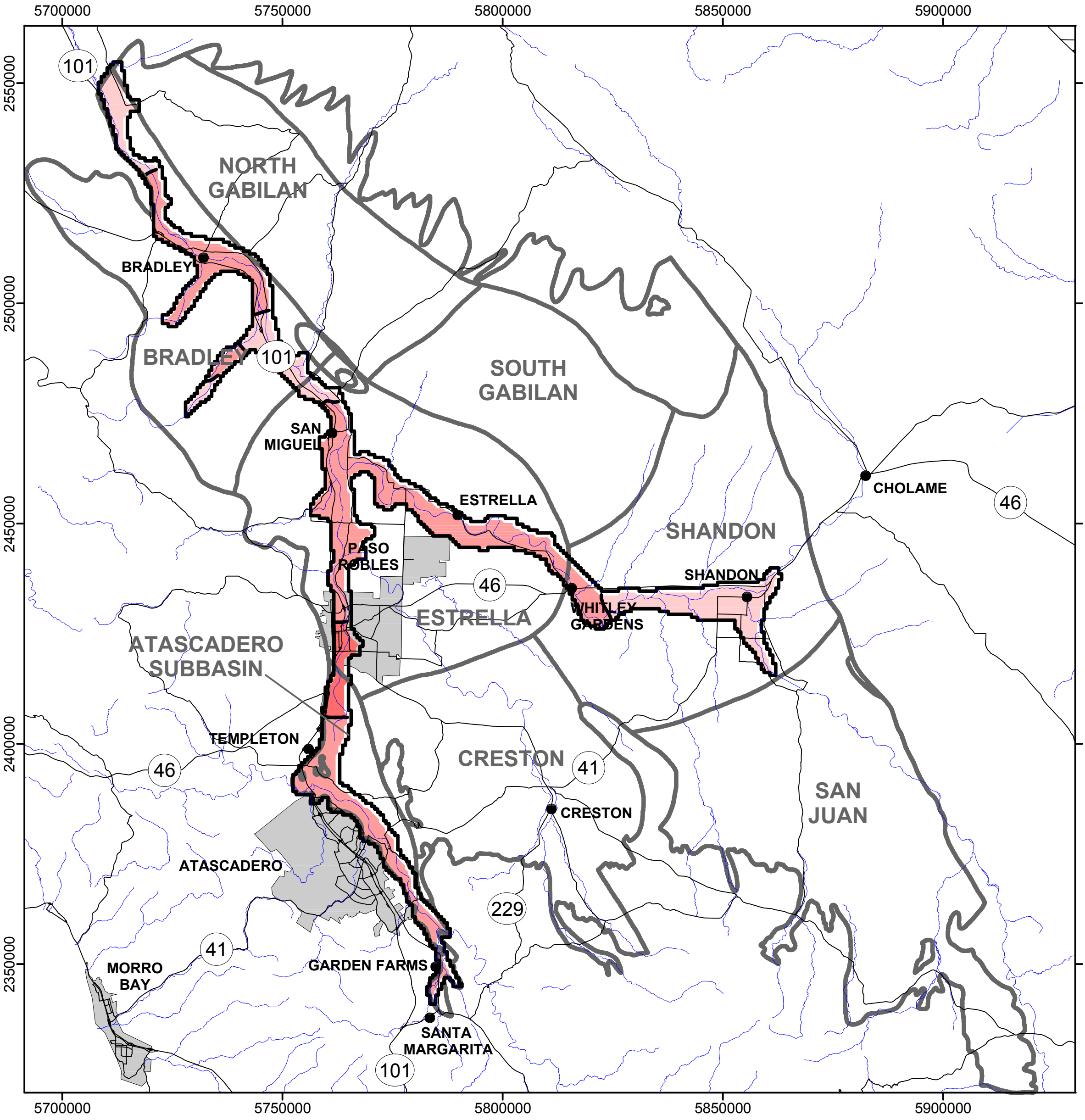


Figure 58



Legend

- 🟥 <-100
- 🟥 -80
- 🟥 -60
- 🟥 -40
- 🟥 -20
- 🟥 0
- Groundwater Elevation Contour (feet)
- Paso Robles Groundwater Model Active Area
- River
- Main Road
- Minor Road

N

0 40,000 80,000
Feet

Scenario 2 Basin-wide Change in Groundwater Elevation Map for Model Layer 1 Relative to Fall 1997

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

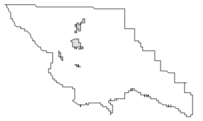
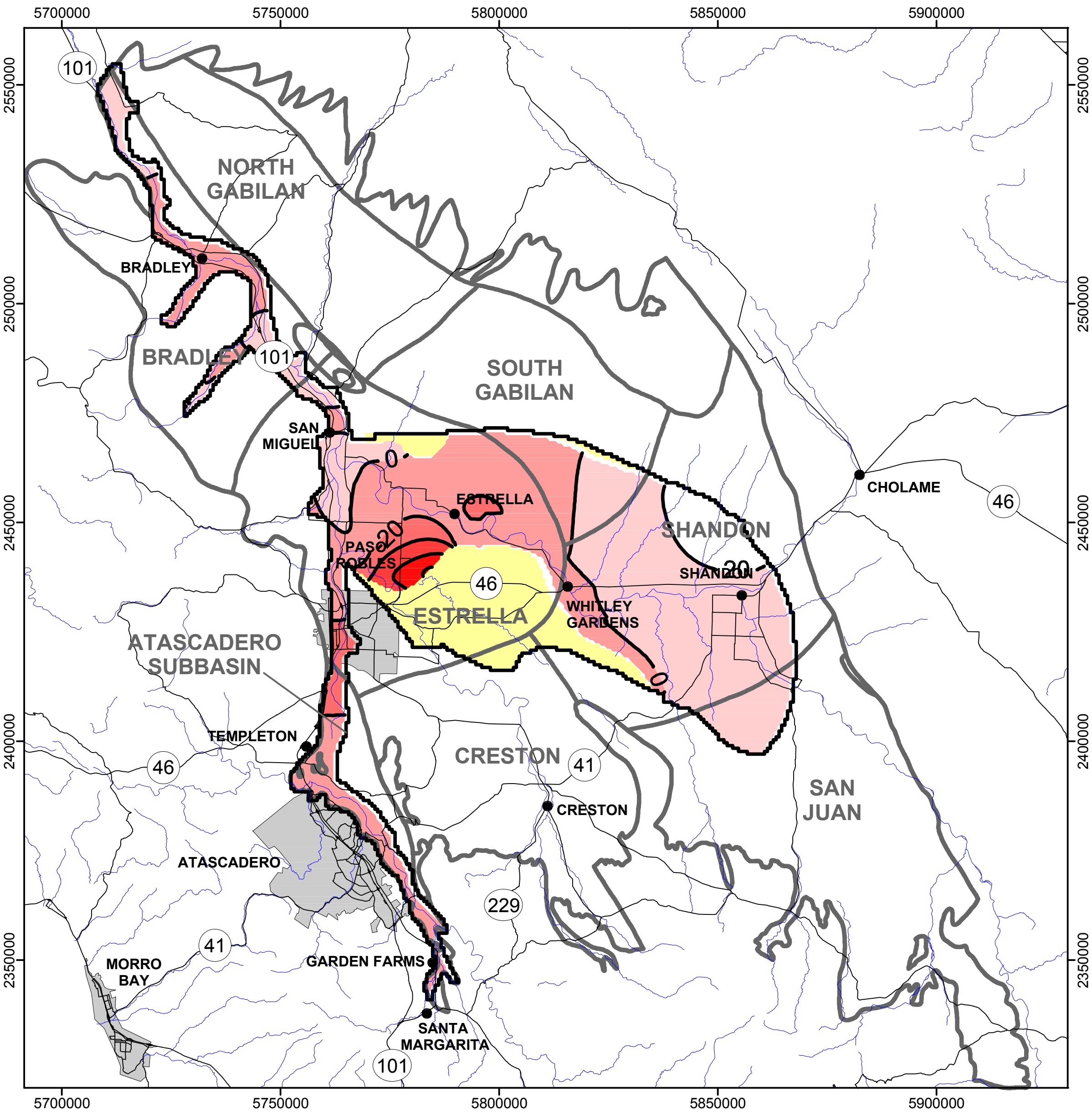
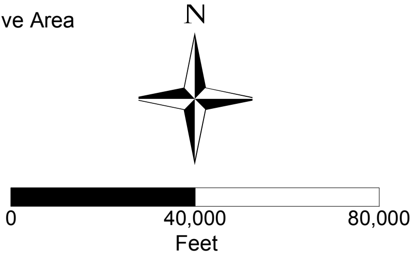


Figure 59



Legend

- 🟥 <-100
- 🟥 -80
- 🟥 -60
- 🟥 -40
- 🟥 -20
- 🟥 0
- — Groundwater Elevation Contour (feet)
- ▭ Paso Robles Groundwater Model Active Area
- — River
- — Main Road
- — Minor Road
- 🟨 Area of Limited Saturation



Scenario 2 Basin-wide Change in Groundwater Elevation Map for Model Layer 2 Relative to Fall 1997

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

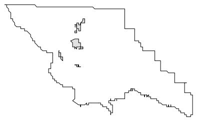
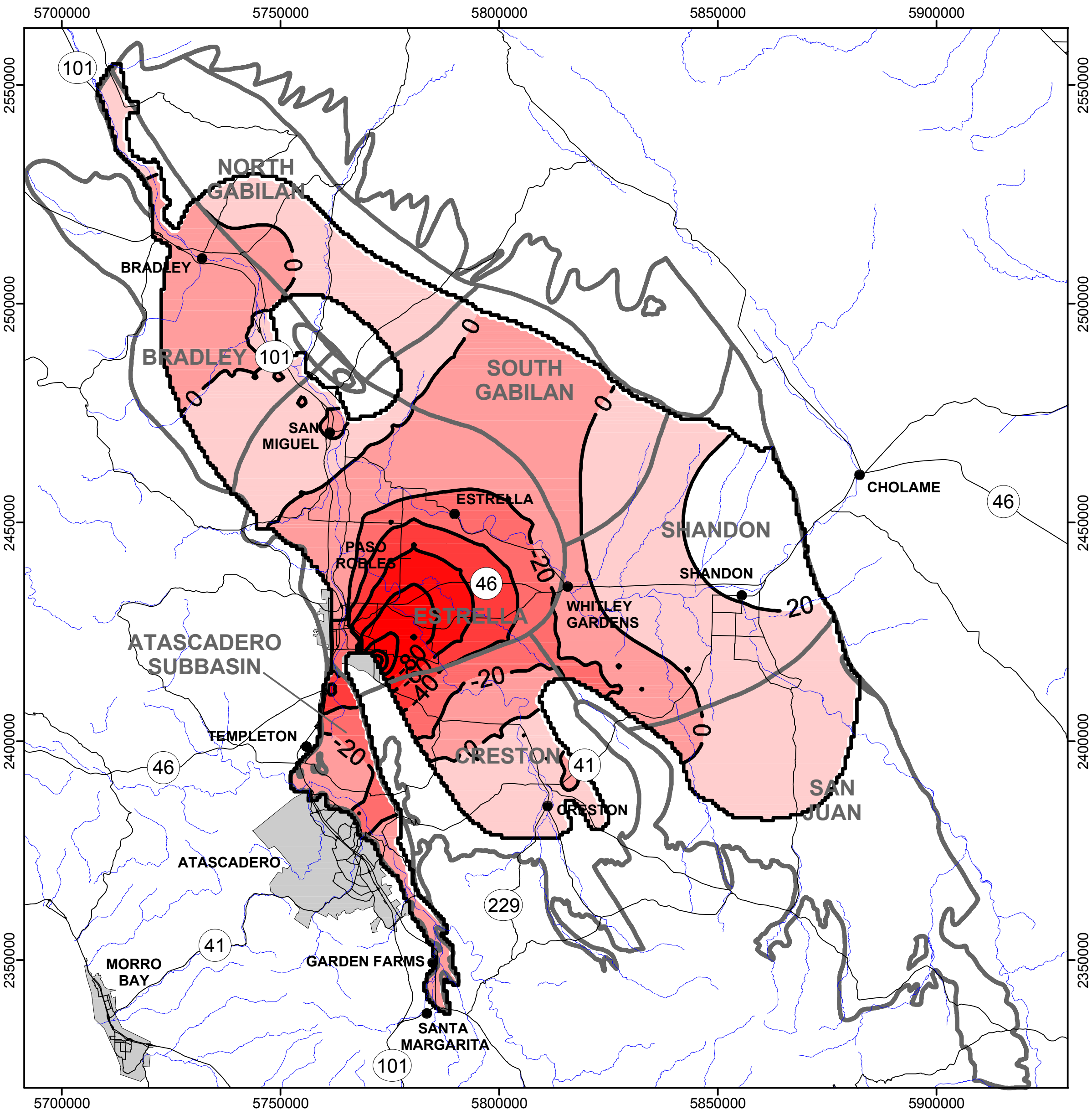


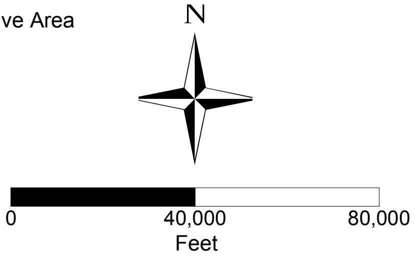
Figure 60



Legend

🟥 <-100
🟥 -80
🟥 -60
🟥 -40
🟥 -20
🟥 0

Groundwater Elevation Contour (feet)
Paso Robles Groundwater Model Active Area
River
Main Road
Minor Road



Scenario 2 Basin-wide Change in Groundwater Elevation Map for Model Layer 3 Relative to Fall 1997

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

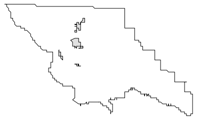
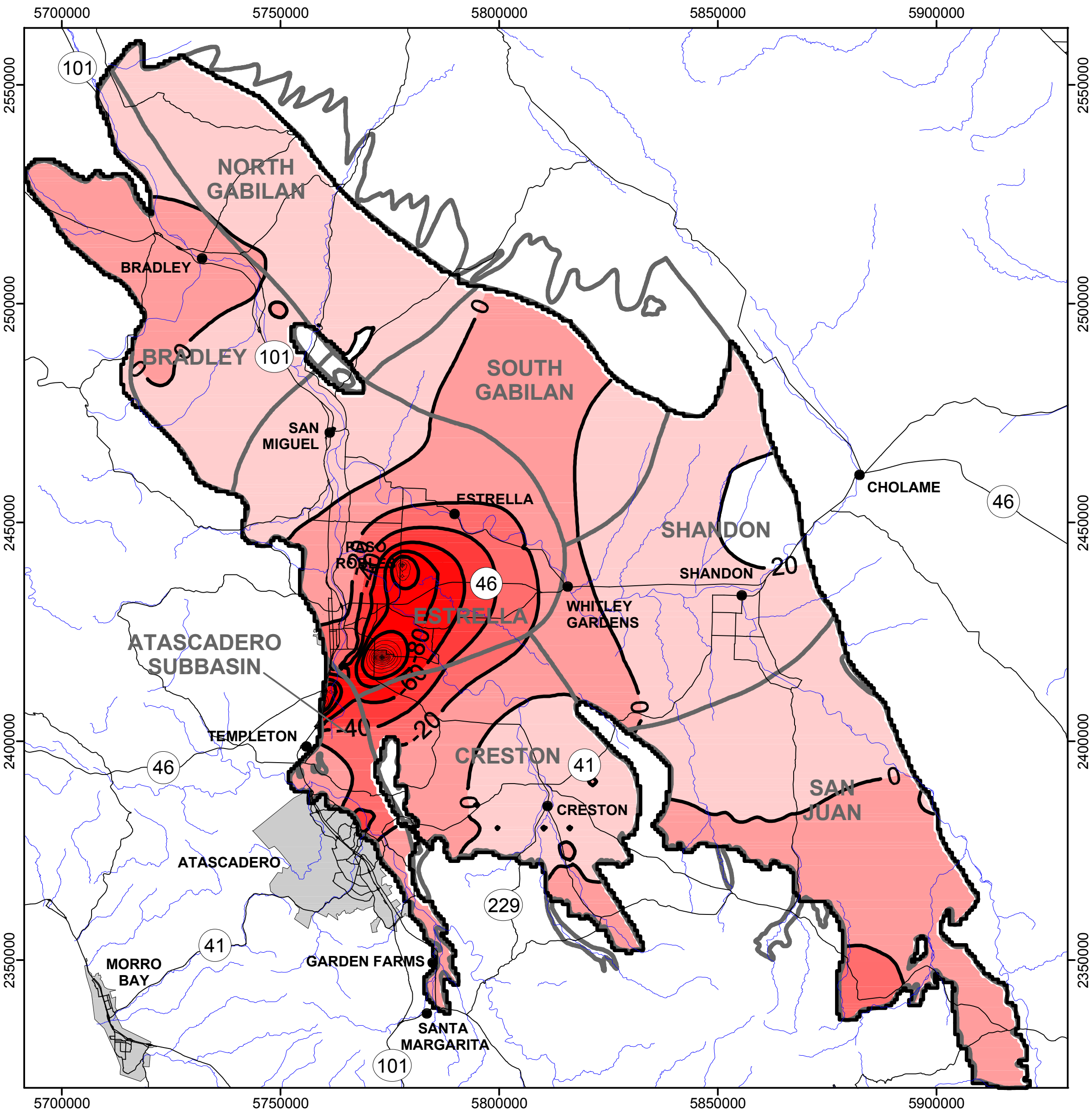


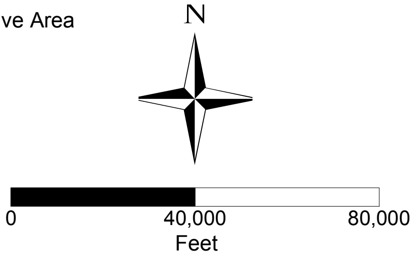
Figure 61



Legend

🟥 <-100
🟥 -80
🟥 -60
🟥 -40
🟥 -20
🟥 0

Groundwater Elevation Contour (feet)
Paso Robles Groundwater Model Active Area
River
Main Road
Minor Road



Scenario 2 Basin-wide Change in Groundwater Elevation Map for Model Layer 4 Relative to Fall 1997

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

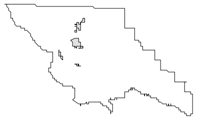
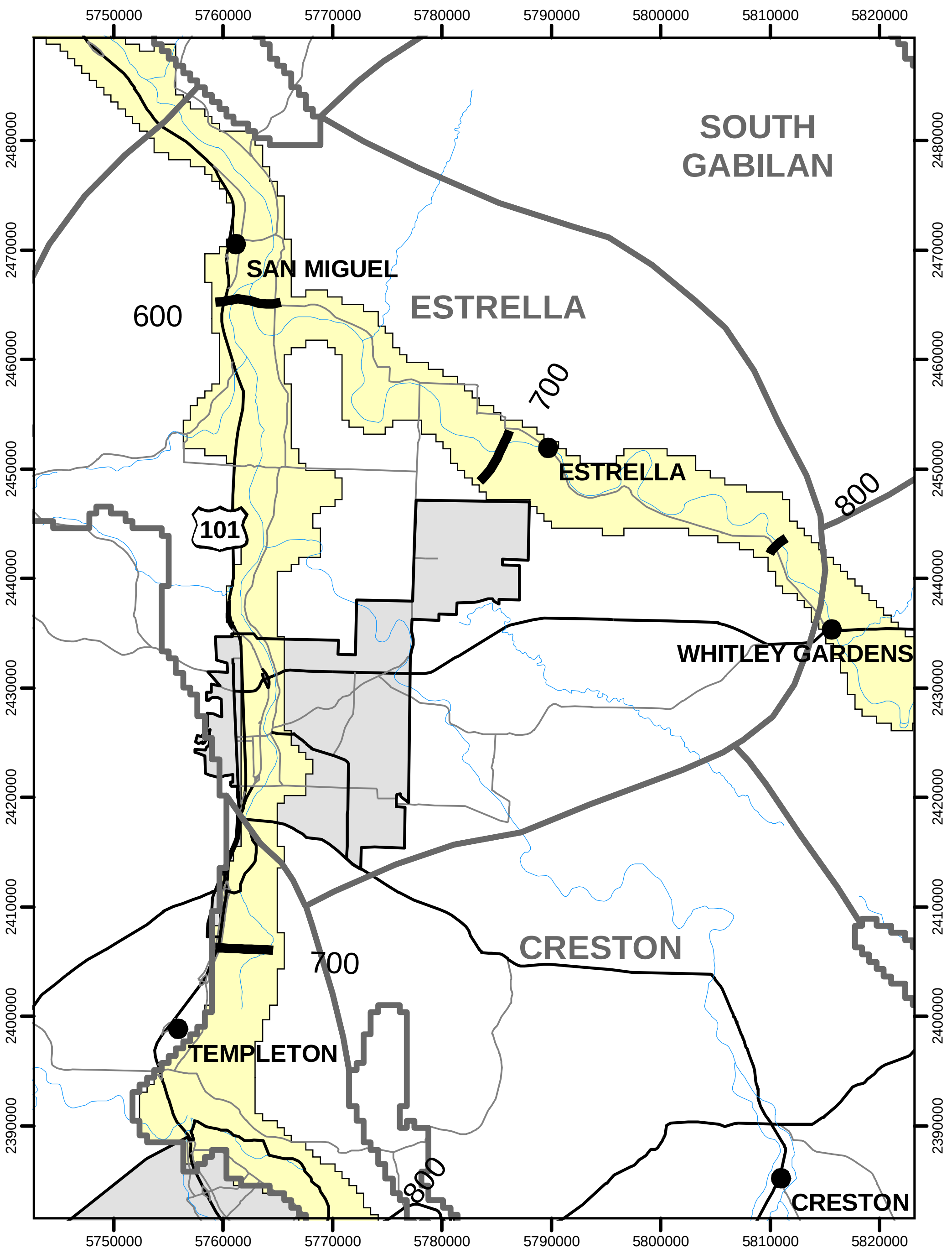
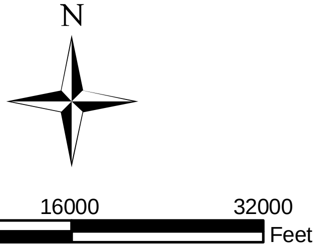


Figure 62



Legend

▬	Groundwater Elevation Contour (feet)
▭	Paso Robles Groundwater Model Active Area
—	River
—	Main Road
—	Minor Road
▨	Model Layer 1



Scenario 2 Detailed Groundwater Elevation Map for Model Layer 1

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

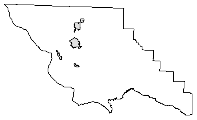
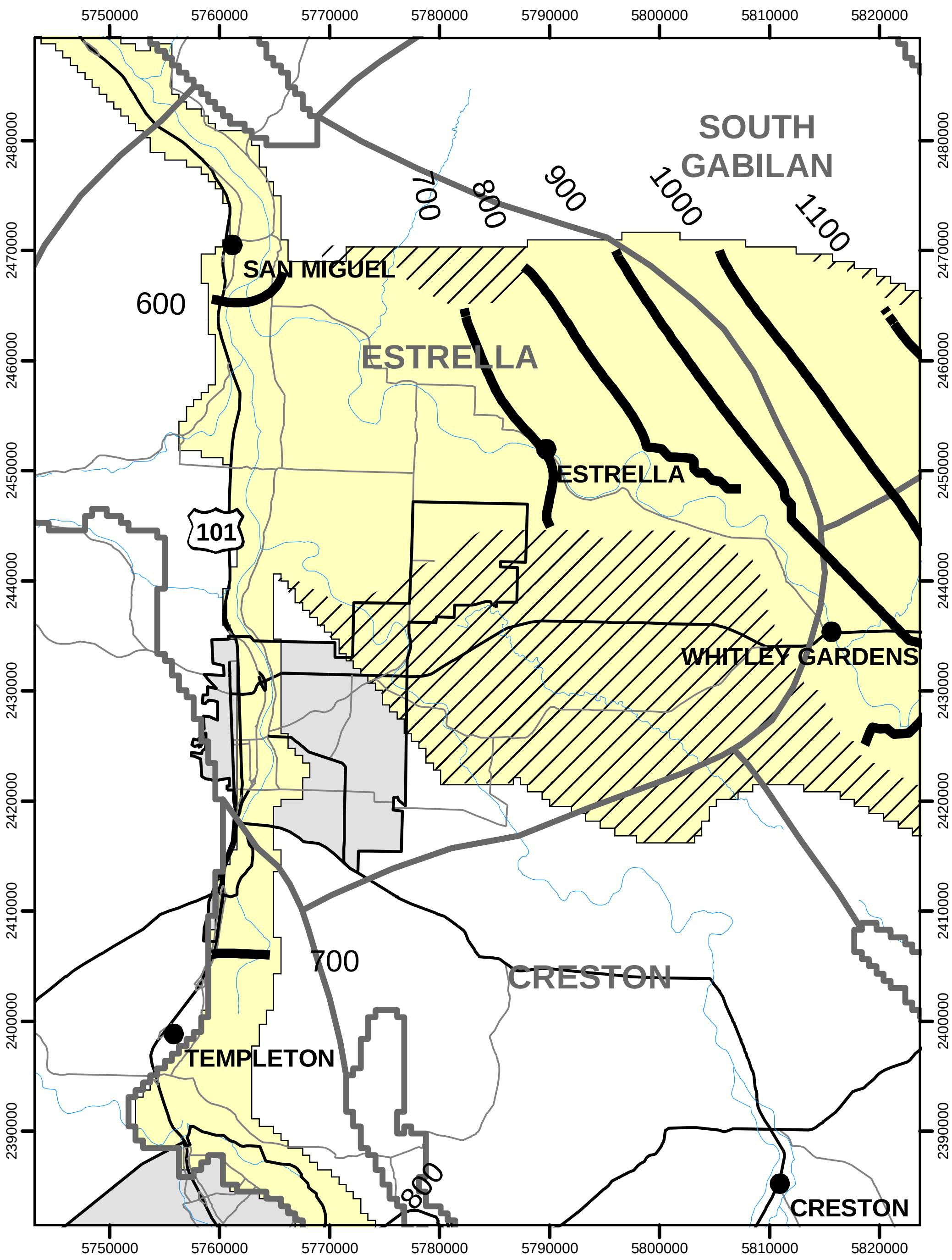


Figure 63



Legend

▬ Groundwater Elevation Contour (feet)

☐ Paso Robles Groundwater Model Active Area

— River

— Main Road

— Minor Road

🟨 Model Layer 2

▨ Area of Limited Saturation

N

0 16000 32000
Feet

Scenario 2 Detailed Groundwater Elevation Map for Model Layer 2

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

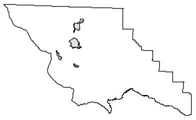
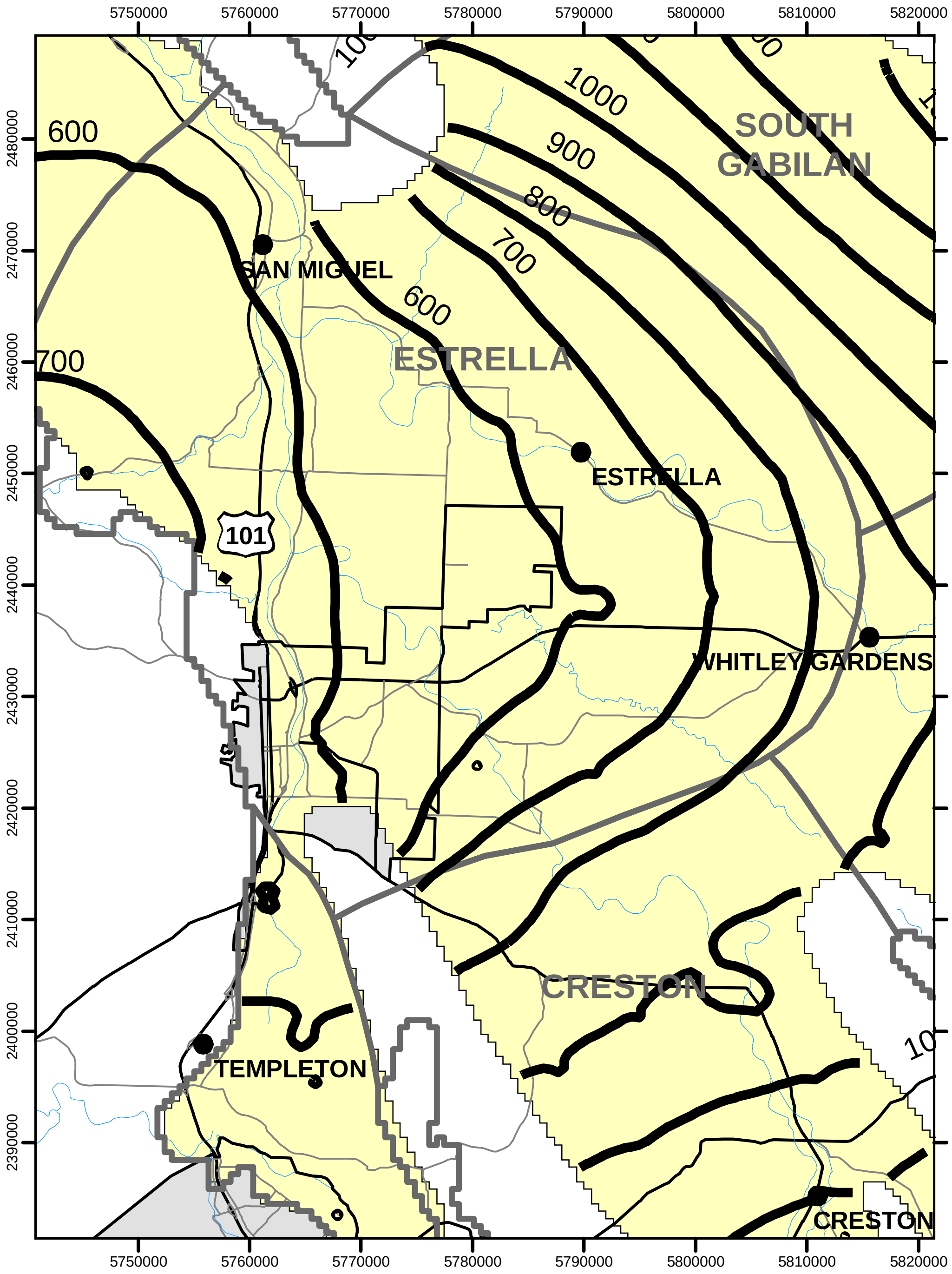


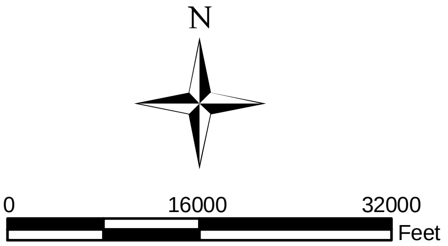
Figure 64



Scenario 2 Detailed Groundwater Elevation Map for Model Layer 3

Legend

▬	Groundwater Elevation Contour (feet)
☐	Paso Robles Groundwater Model Active Area
—	River
—	Main Road
—	Minor Road
🟨	Model Layer 3



Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

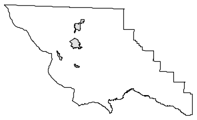
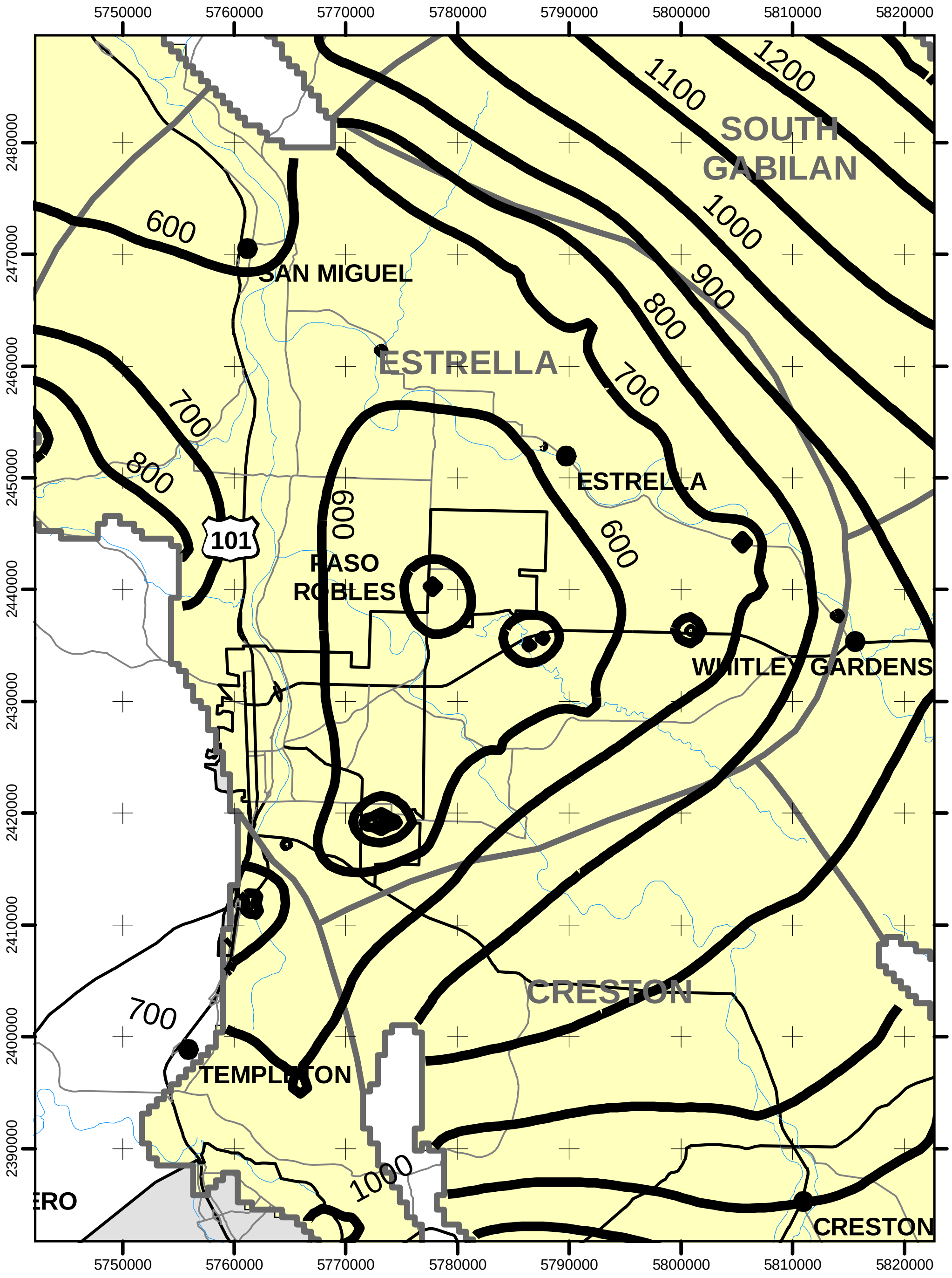


Figure 65



Legend

▬ Groundwater Elevation Contour (feet)

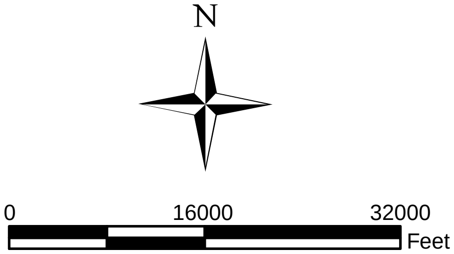
☐ Paso Robles Groundwater Model Active Area

River

Main Road

Minor Road

🟨 Model Layer 4



Scenario 2 Detailed Groundwater Elevation Map for Model Layer 4

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

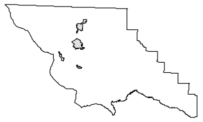
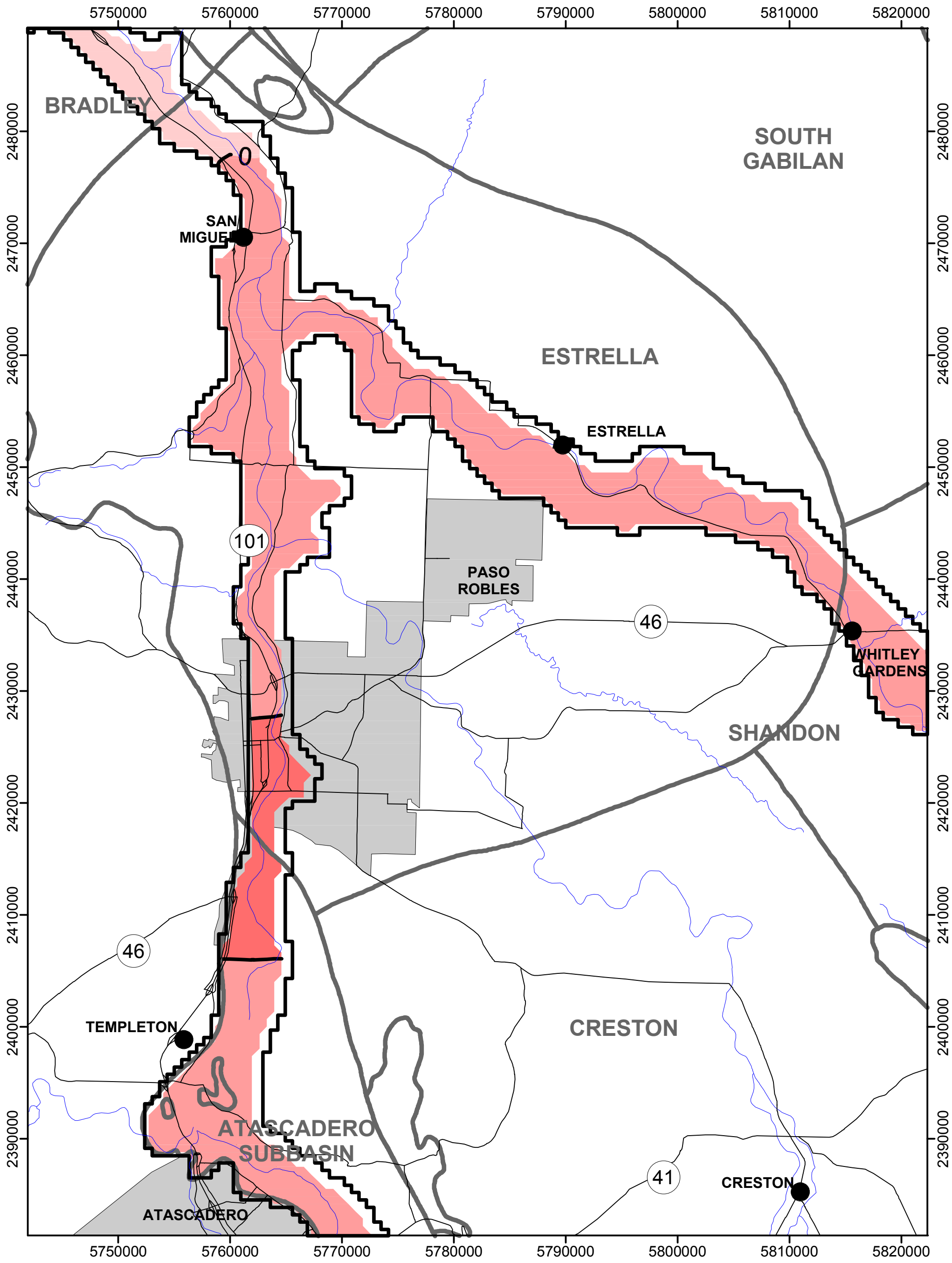


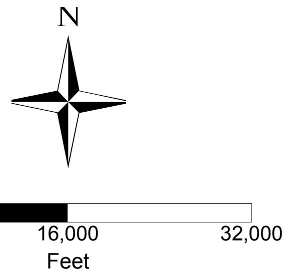
Figure 66



Scenario 2 Detailed Change in Groundwater Elevation Map for Model Layer 1 Relative to Fall 1997

Legend

🟥	<-100
🟥	-80
🟥	-60
🟥	-40
🟥	-20
🟥	0
━	Groundwater Elevation Contour (feet)
☐	Paso Robles Groundwater Model Active Area
─	River
─	Main Road
─	Minor Road



Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

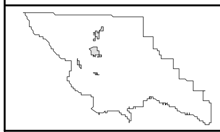
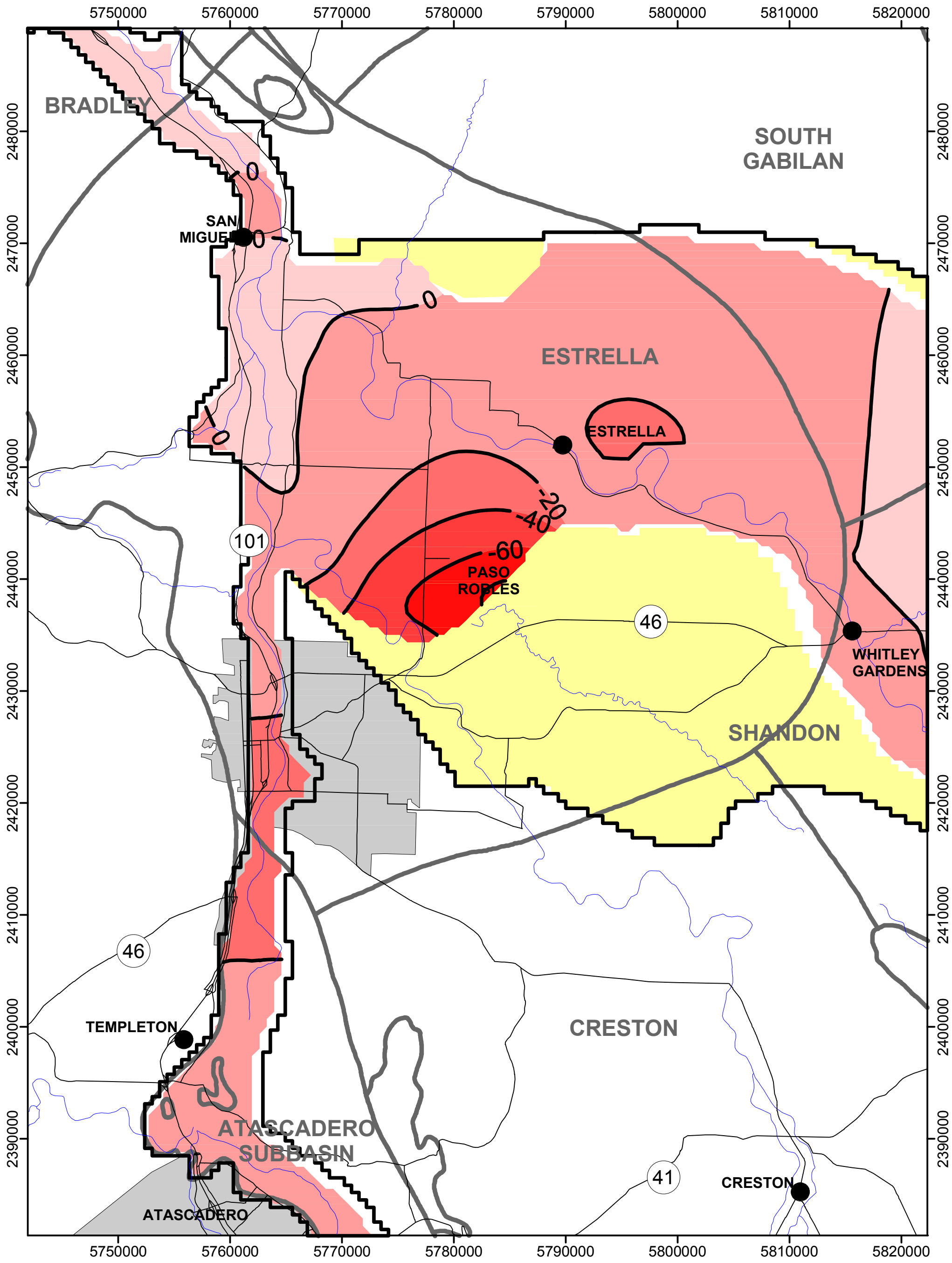
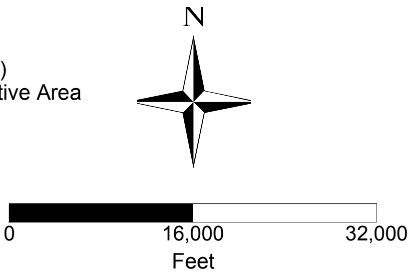


Figure 67



Legend

- 🟥 <-100
- 🟥 -80
- 🟥 -60
- 🟥 -40
- 🟥 -20
- 🟥 0
- Groundwater Elevation Contour (feet)
- Paso Robles Groundwater Model Active Area
- River
- Main Road
- Minor Road
- 🟨 Area of Limited Saturation



Scenario 2 Detailed Change in Groundwater Elevation Map for Model Layer 2 Relative to Fall 1997

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

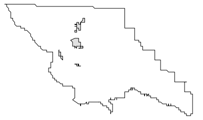
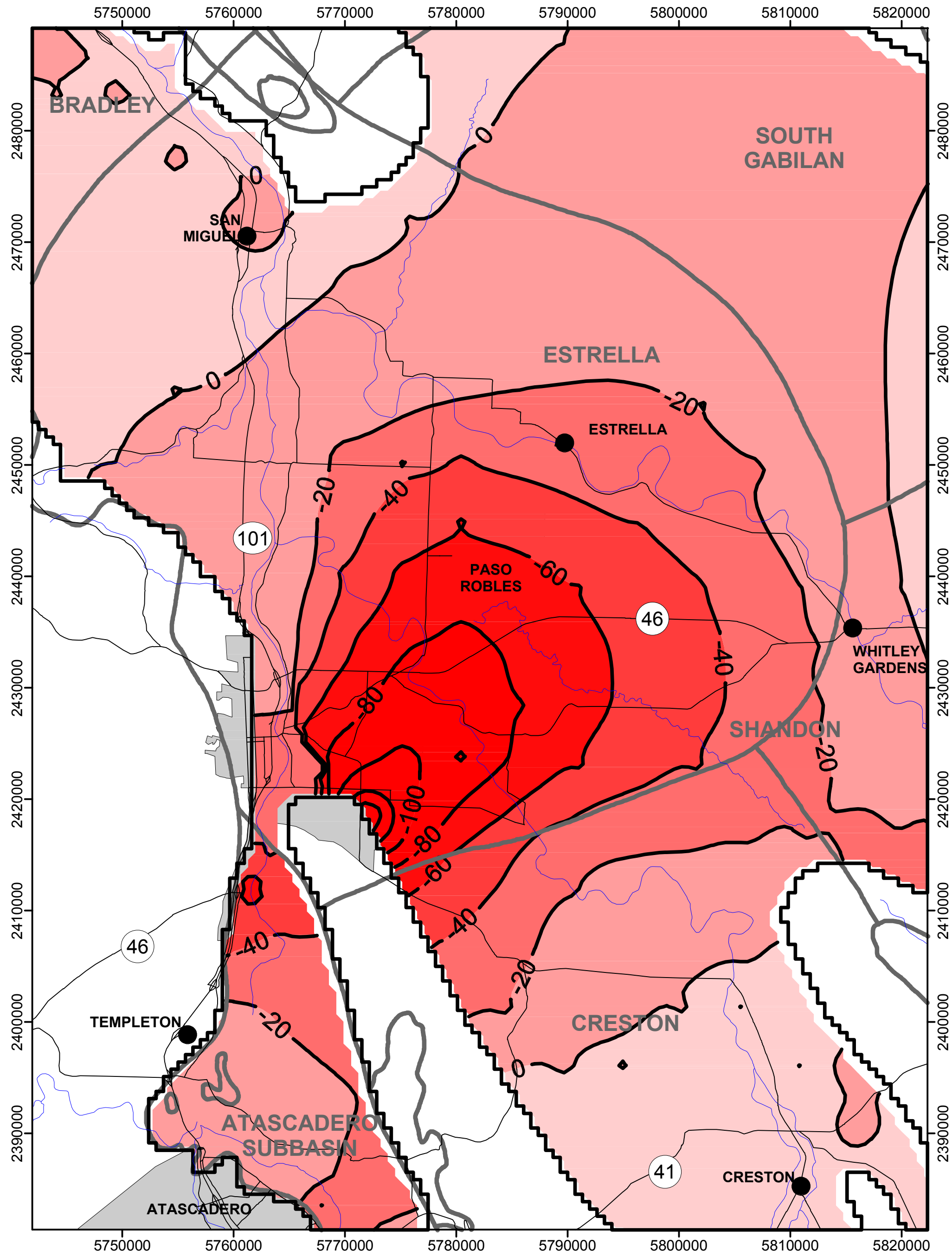


Figure 68



Legend

🟥 <-100
🟥 -80
🟥 -60
🟥 -40
🟥 -20
🟥 0
— Groundwater Elevation Contour (feet)
▭ Paso Robles Groundwater Model Active Area
— River
— Main Road
— Minor Road

N

0 16,000 32,000
Feet

Scenario 2 Detailed Change in Groundwater Elevation Map for Model Layer 3 Relative to Fall 1997

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

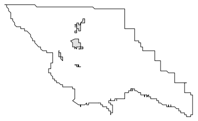
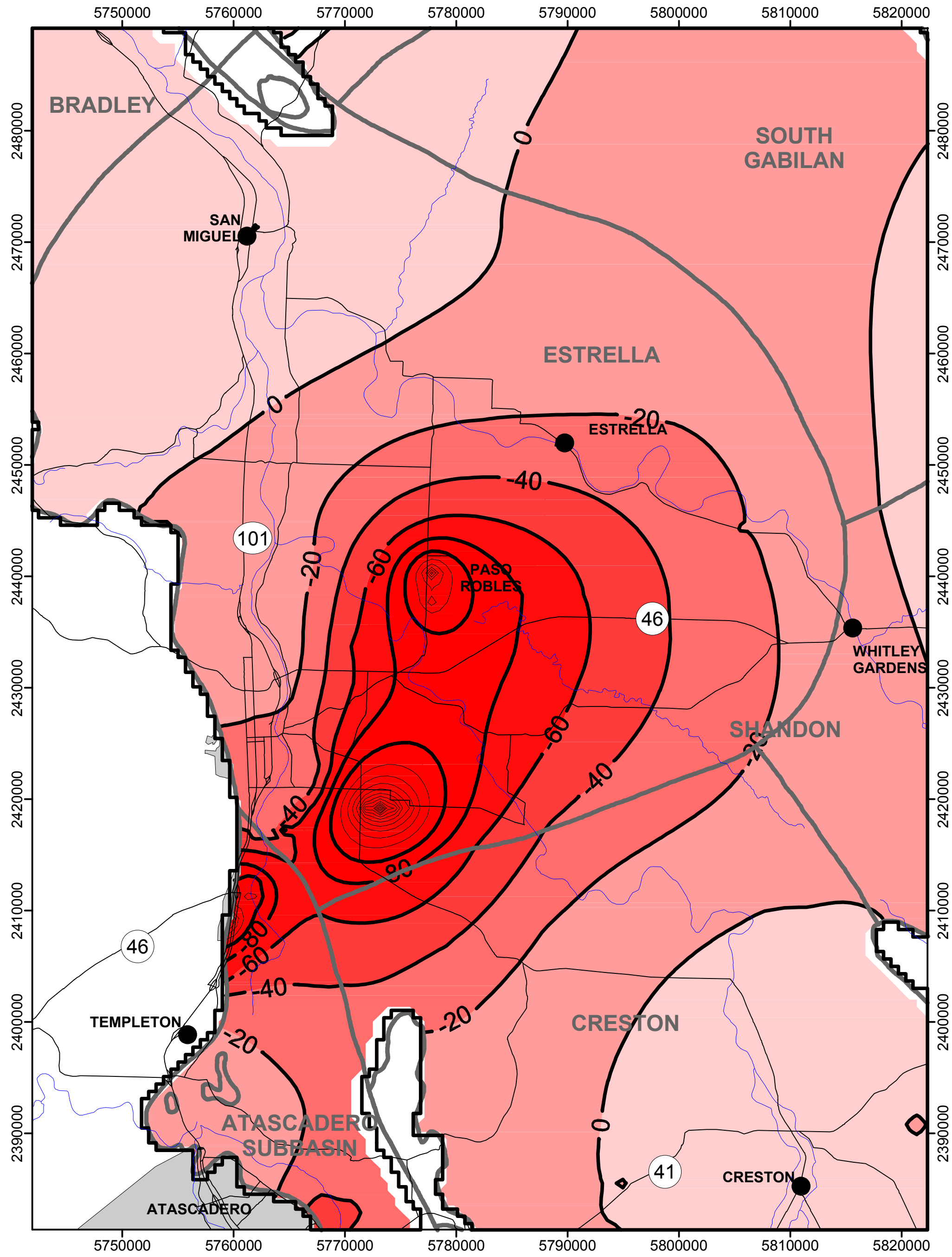
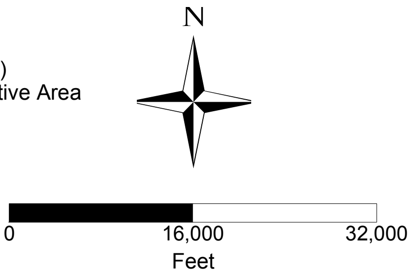


Figure 69



Legend

🟥	<-100
🟥	-80
🟥	-60
🟥	-40
🟥	-20
🟥	0
▬	Groundwater Elevation Contour (feet)
☐	Paso Robles Groundwater Model Active Area
—	River
—	Main Road
—	Minor Road



Scenario 2 Detailed Change in
Groundwater Elevation Map
for Model Layer 4 Relative to Fall 1997

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

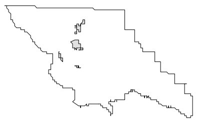
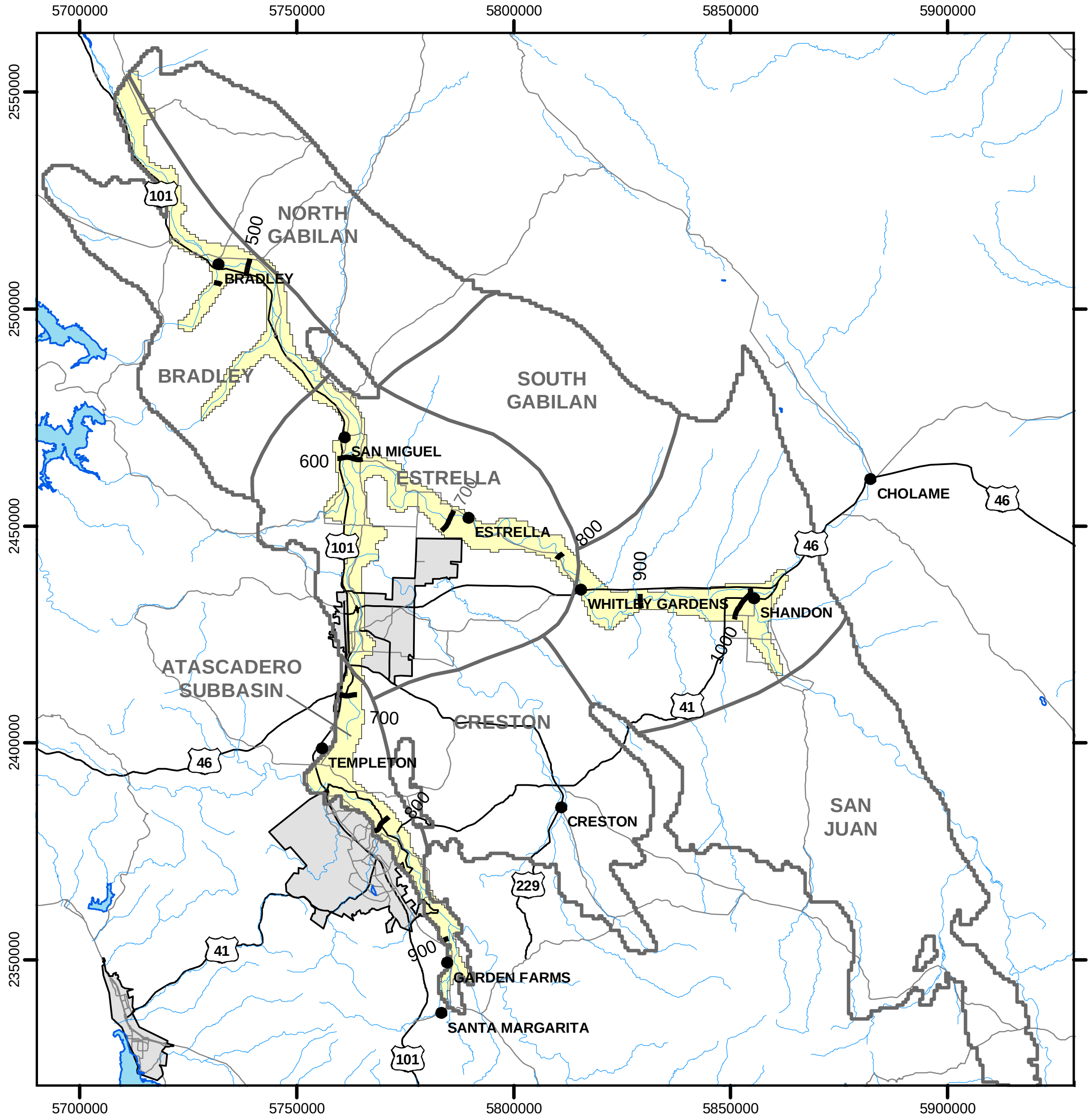
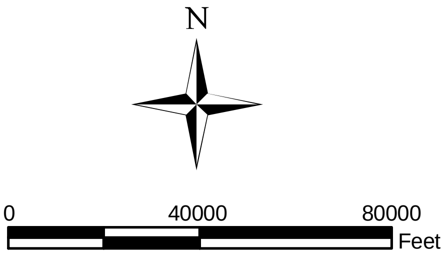


Figure 70



Legend

▬	Groundwater Elevation Contour (feet)
☐	Paso Robles Groundwater Model Active Area
—	River
—	Main Road
—	Minor Road
🟨	Model Layer 1



Scenario 3 Basin-wide Groundwater Elevation Map for Model Layer 1

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

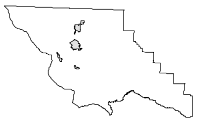
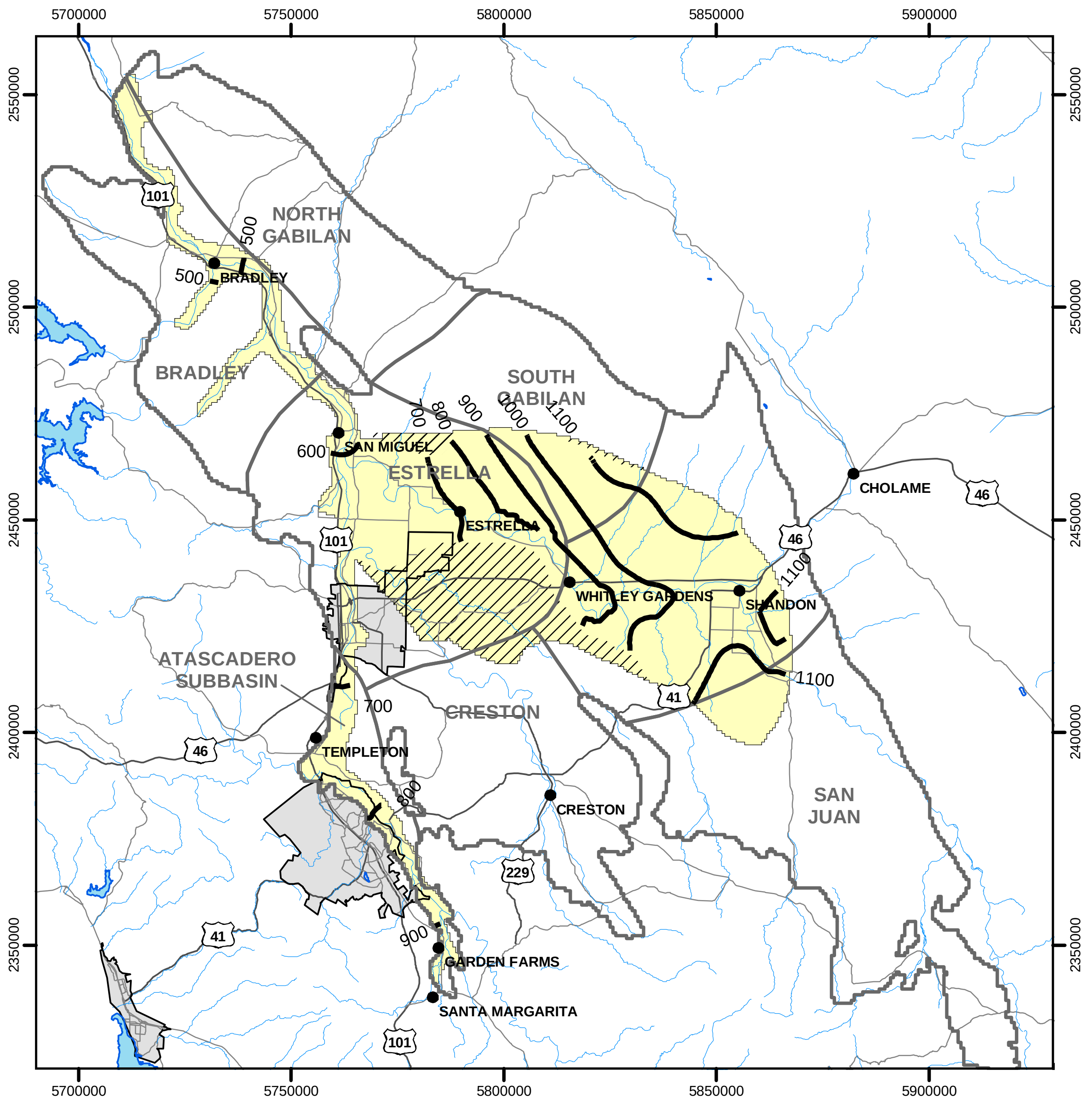


Figure 71



Legend

▬ Groundwater Elevation Contour (feet)

☐ Paso Robles Groundwater Model Active Area

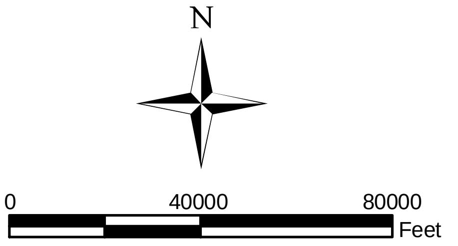
River

Main Road

Minor Road

🟨 Model Layer 2

▨ Area of Limited Saturation



Scenario 3 Basin-wide Groundwater Elevation Map for Model Layer 2

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

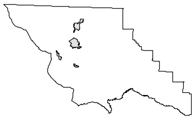
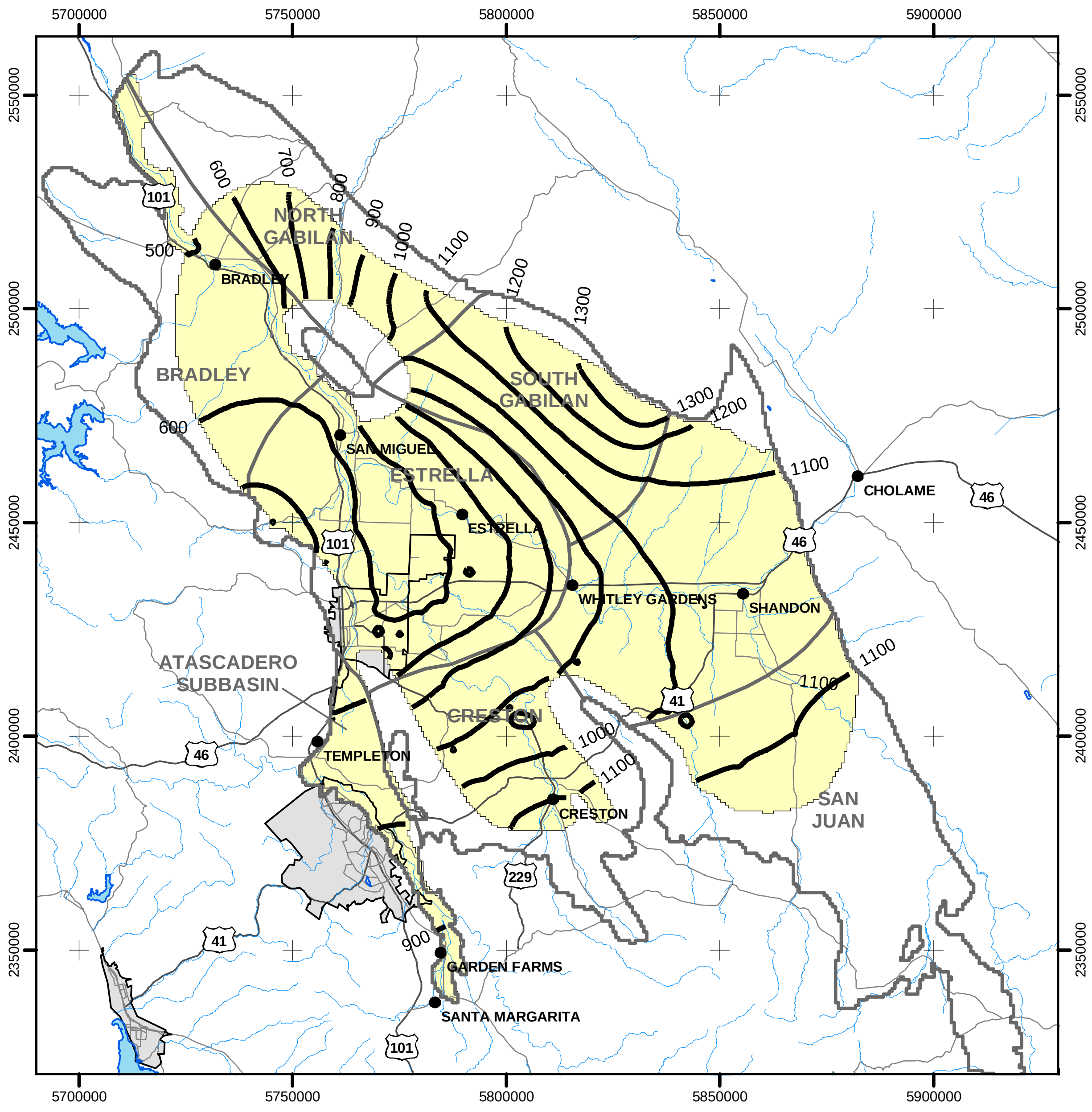


Figure 72



Legend

▬ Groundwater Elevation Contour (feet)

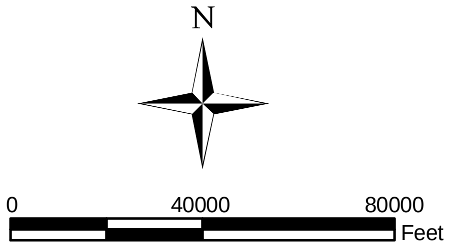
☐ Paso Robles Groundwater Model Active Area

— River

— Main Road

— Minor Road

🟨 Model Layer 3



Scenario 3 Basin-wide Groundwater Elevation Map for Model Layer 3

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

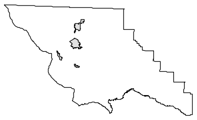
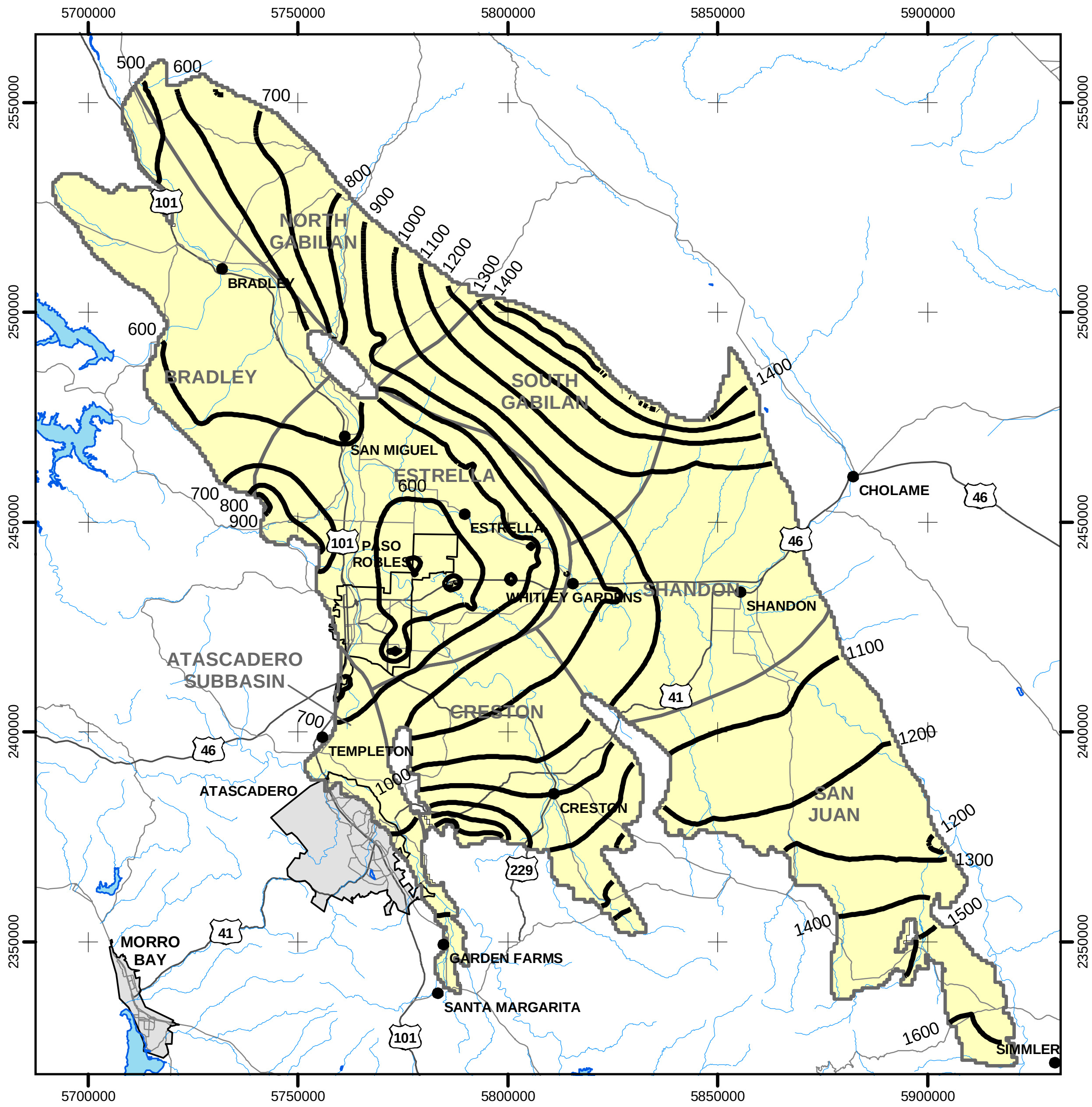


Figure 73



Legend

▬ Groundwater Elevation Contour (feet)

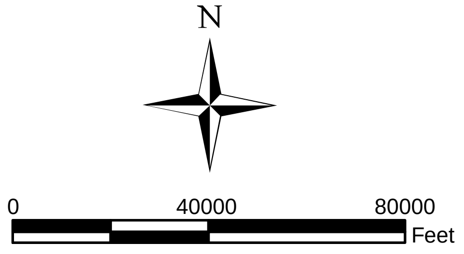
▭ Paso Robles Groundwater Model Active Area

— River

— Main Road

— Minor Road

🟨 Model Layer 4



Scenario 3 Basin-wide Groundwater Elevation Map for Model Layer 4

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

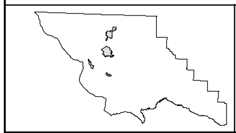
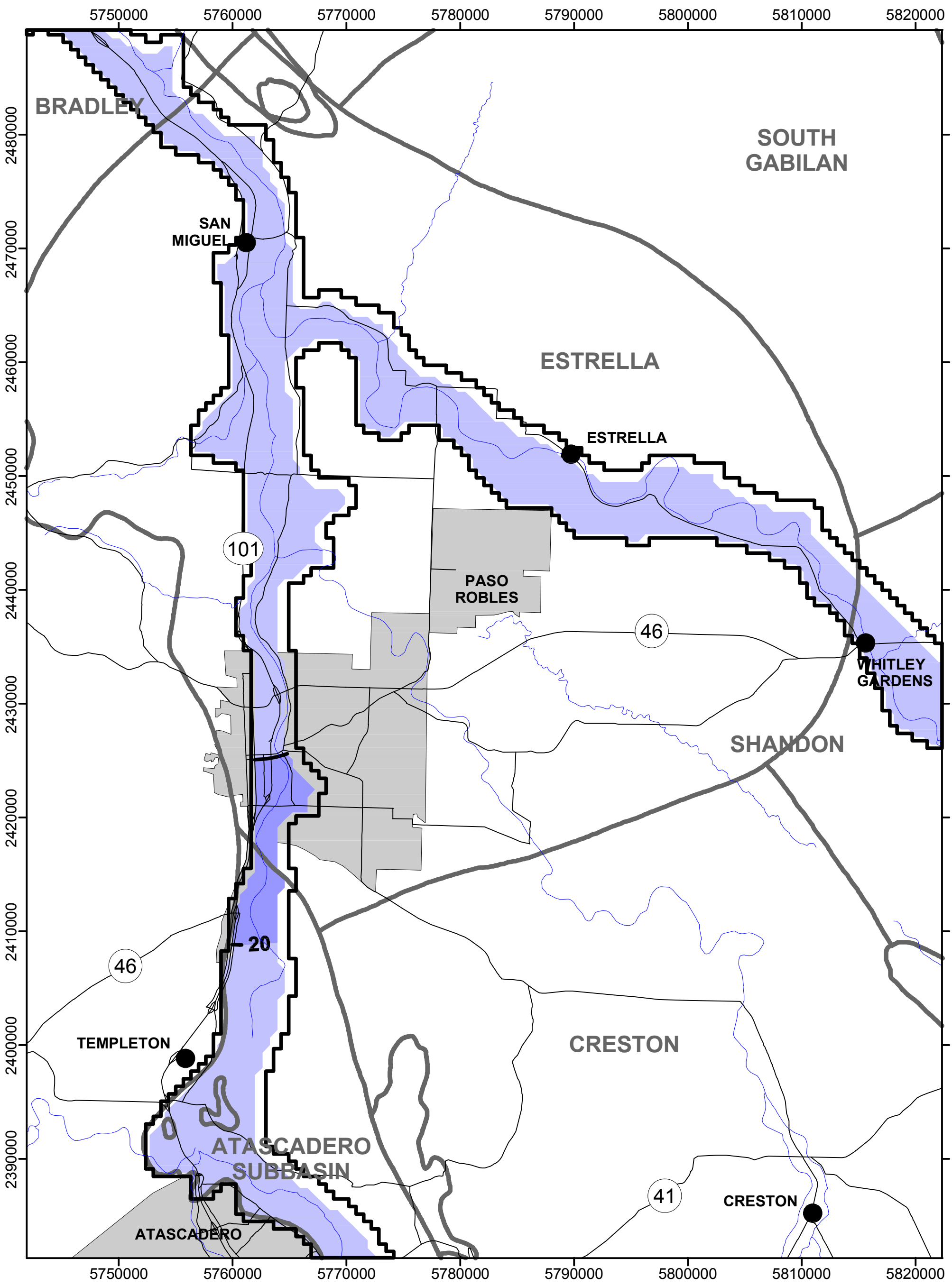
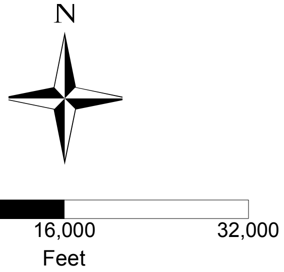


Figure 74



Legend

- 🟦 >100
- 🟦 80
- 🟦 60
- 🟦 40
- 🟦 20
- 🟦 0
- Groundwater Elevation Contour (feet)
- Paso Robles Groundwater Model Active Area
- River
- Main Road
- Minor Road



Scenario 3 Detailed Change in Groundwater Elevation Map for Model Layer 1 Relative to Scenario 2

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

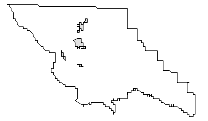
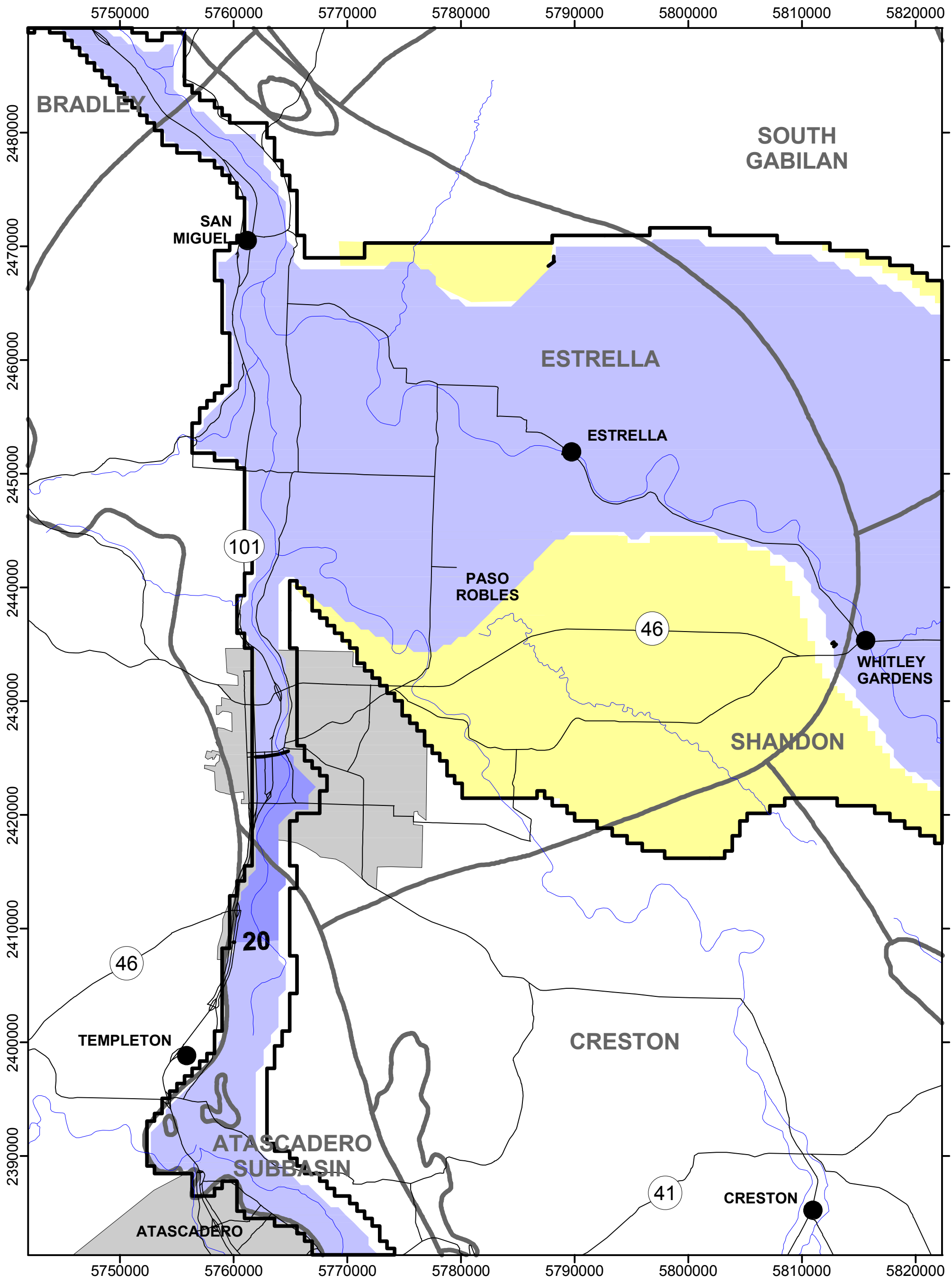
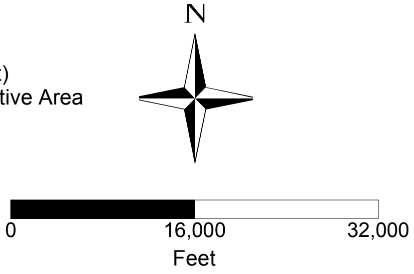


Figure 75



Legend

🟦 >100
🟦 80
🟦 60
🟦 40
🟦 20
🟦 0
━ Groundwater Elevation Contour (feet)
☐ Paso Robles Groundwater Model Active Area
— River
— Main Road
— Minor Road
🟨 Area of Limited Saturation

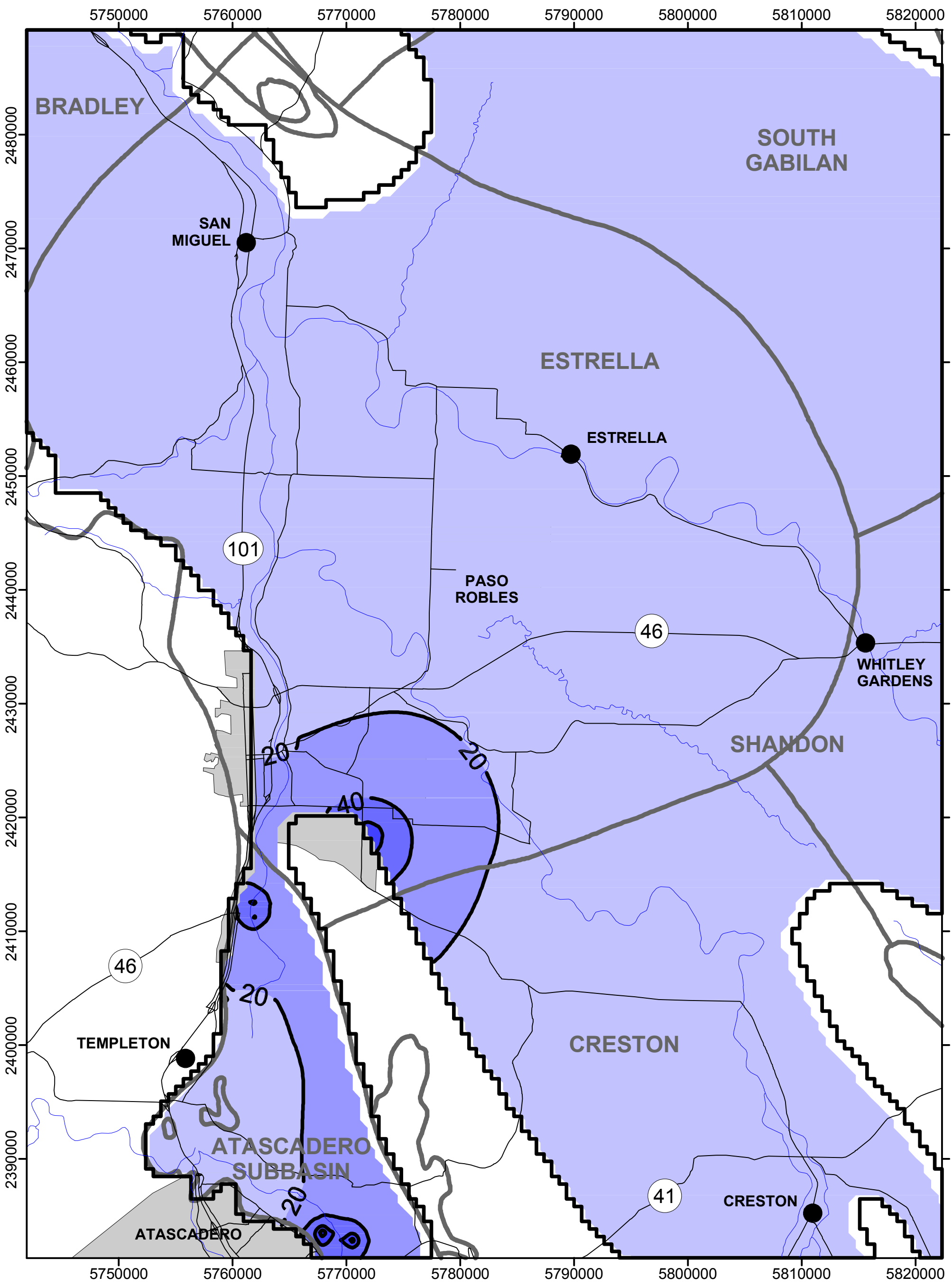


Scenario 3 Detailed Change in Groundwater Elevation Map for Model Layer 2 Relative to Scenario 2

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

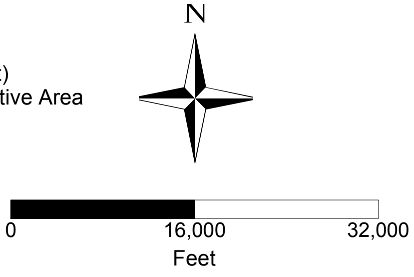
Figure 76



Scenario 3 Detailed Change in Groundwater Elevation Map for Model Layer 3 Relative to Scenario 2

Legend

- >100
- 80
- 60
- 40
- 20
- 0
- Groundwater Elevation Contour (feet)
- Paso Robles Groundwater Model Active Area
- River
- Main Road
- Minor Road



Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

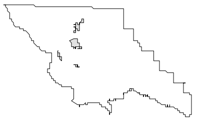
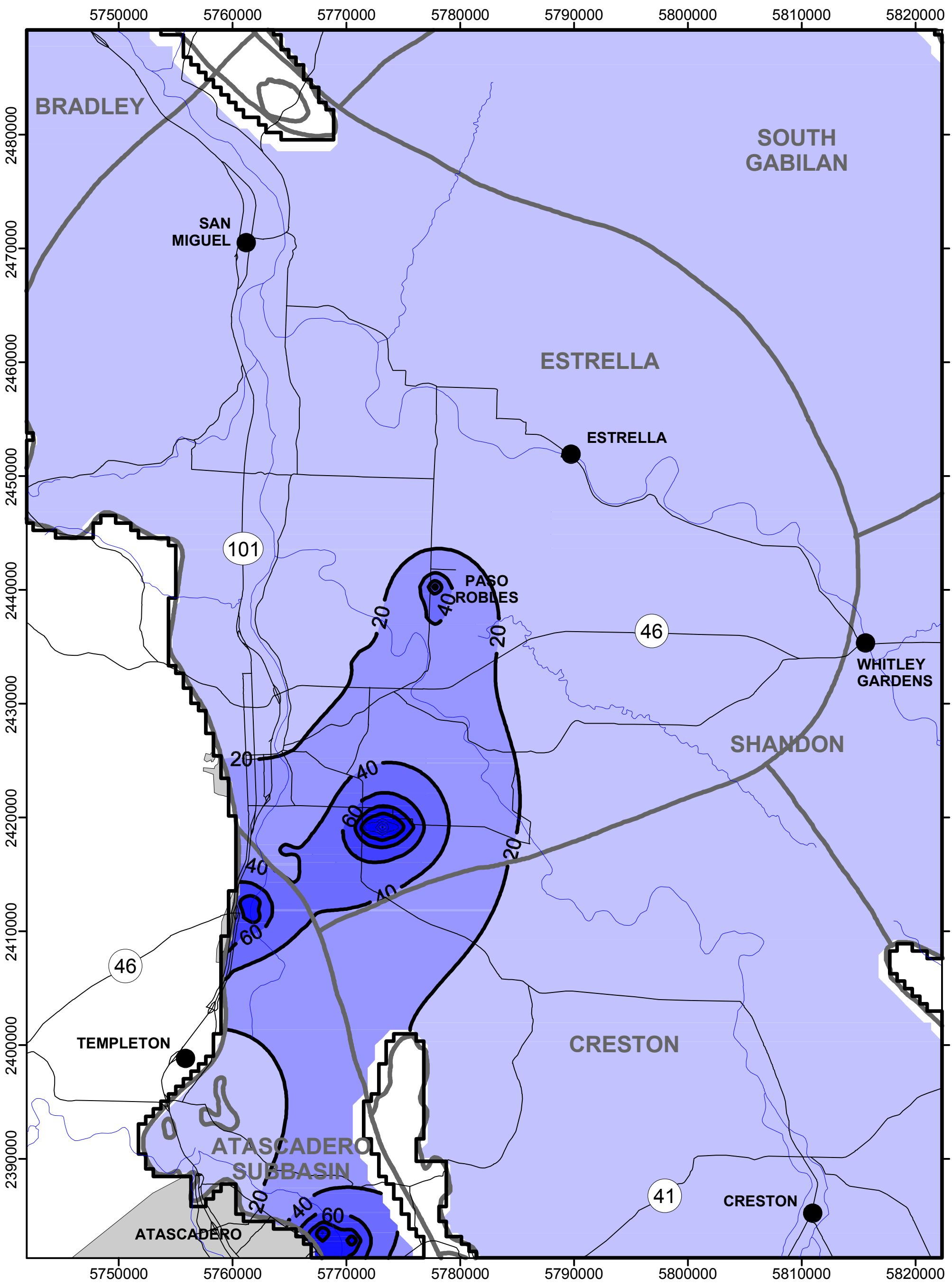


Figure 77



Legend

- >100
- 80
- 60
- 40
- 20
- 0
- Groundwater Elevation Contour (feet)
- Paso Robles Groundwater Model Active Area
- River
- Main Road
- Minor Road

N

0 16,000 32,000
Feet

Scenario 3 Detailed Change in Groundwater Elevation Map for Model Layer 4 Relative to Scenario 2

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

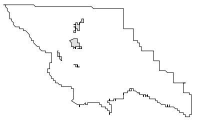
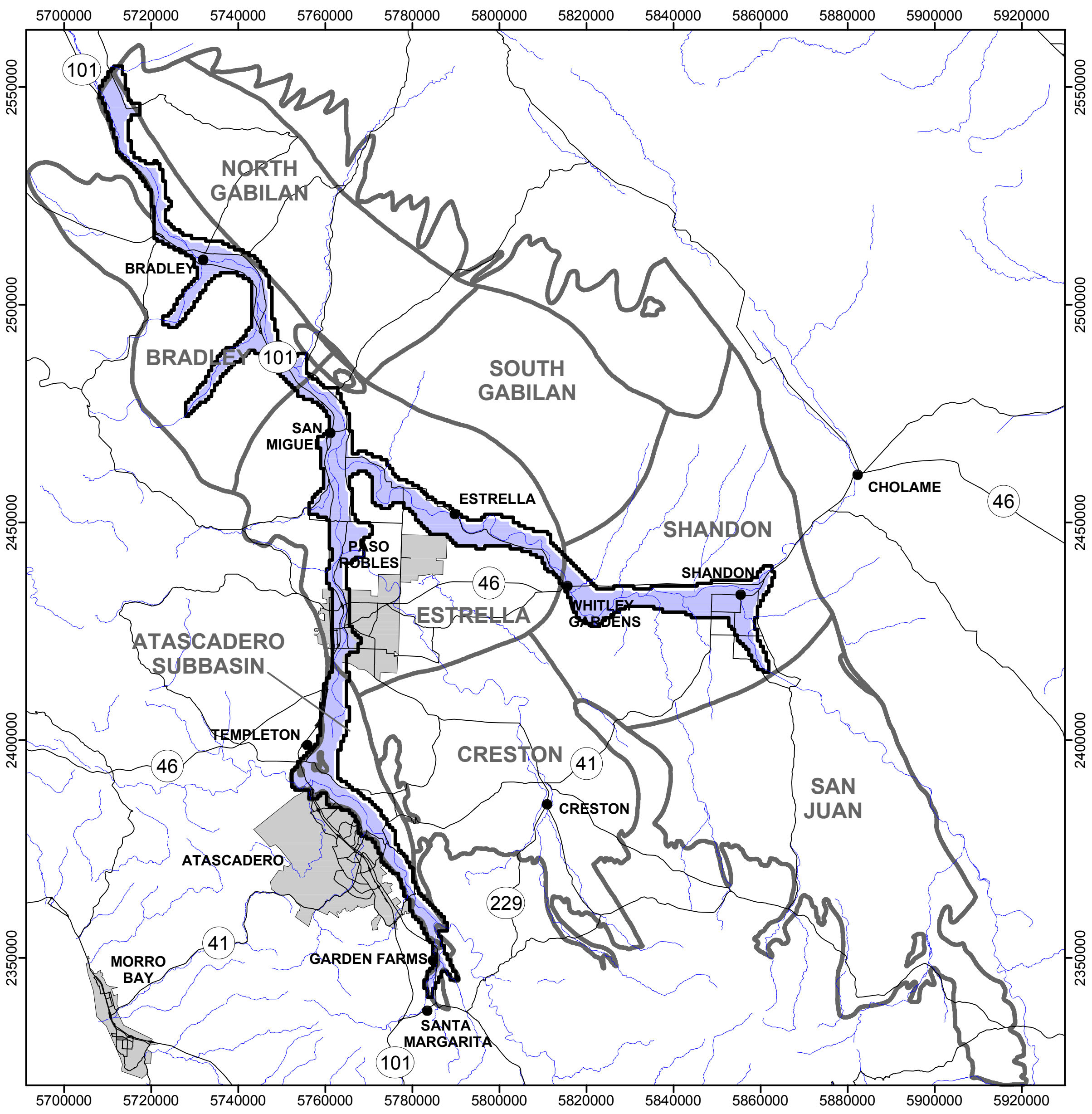


Figure 78



Legend

🟦	>25
🟦	20
🟦	15
🟦	10
🟦	5
🟦	0

━ Groundwater Elevation Contour (feet)
▭ Paso Robles Groundwater Model Active Area
— River
— Main Road
— Minor Road

N

0 40,000 80,000
Feet

Sensitivity Analysis of 90% Agricultural Pumpage Basin-wide Change in Groundwater Elevation Map Relative to Scenario 2 for Model Layer 1

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

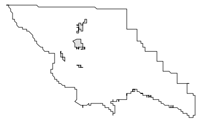
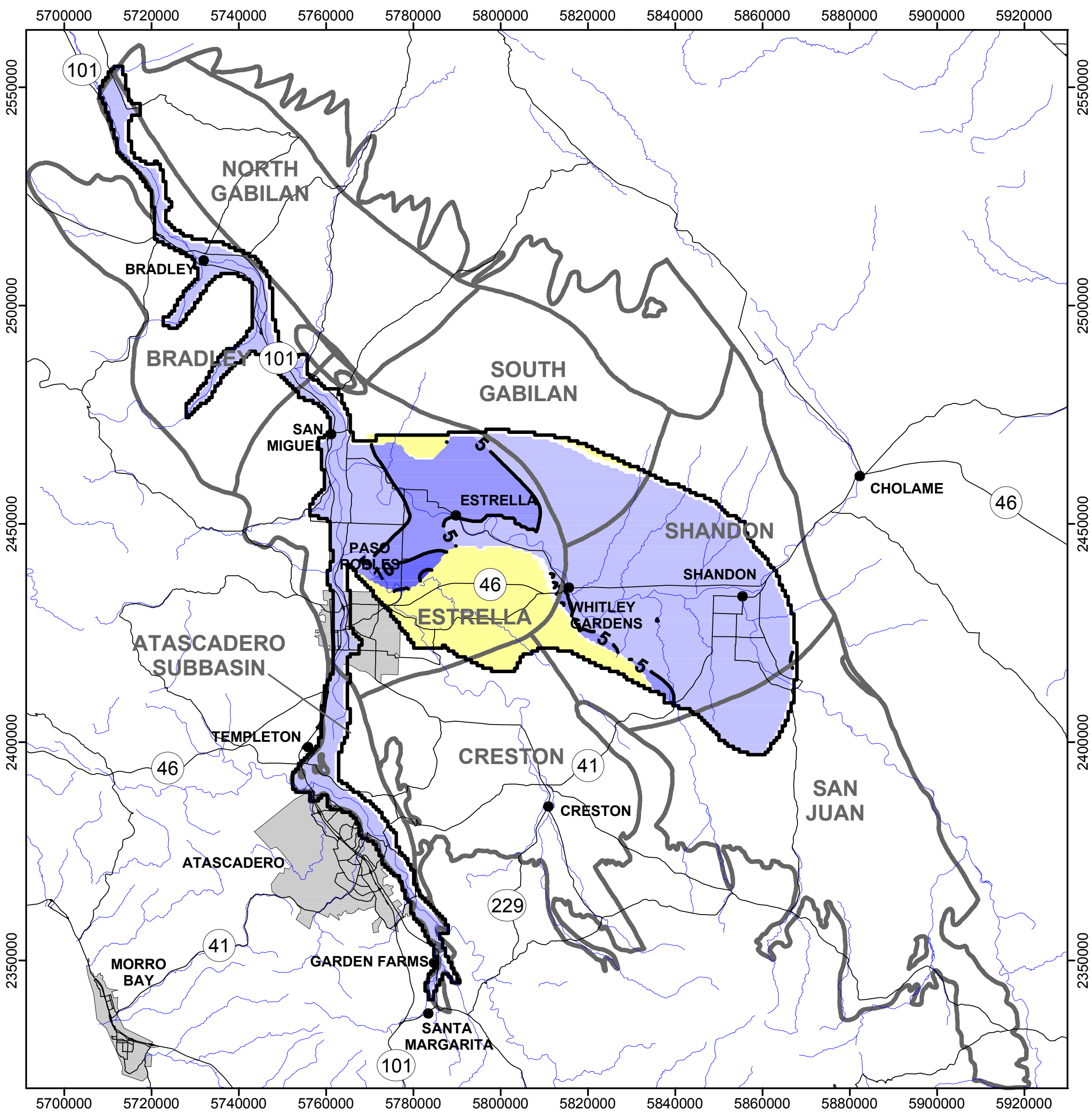


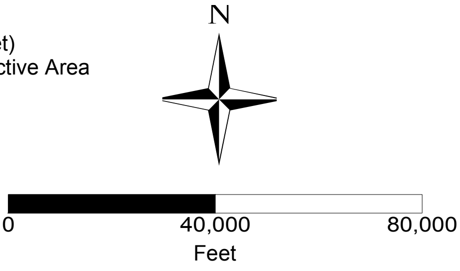
Figure 79



Legend

■	>25
■	20
■	15
■	10
■	5
■	0

— Groundwater Elevation Contour (feet)
☐ Paso Robles Groundwater Model Active Area
— River
— Main Road
— Minor Road
🟨 Area of Limited Saturation



Sensitivity Analysis of 90% Agricultural Pumpage Basin-wide Change in Groundwater Elevation Map for Model Layer 2 Relative to Scenario 2

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

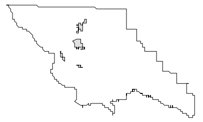
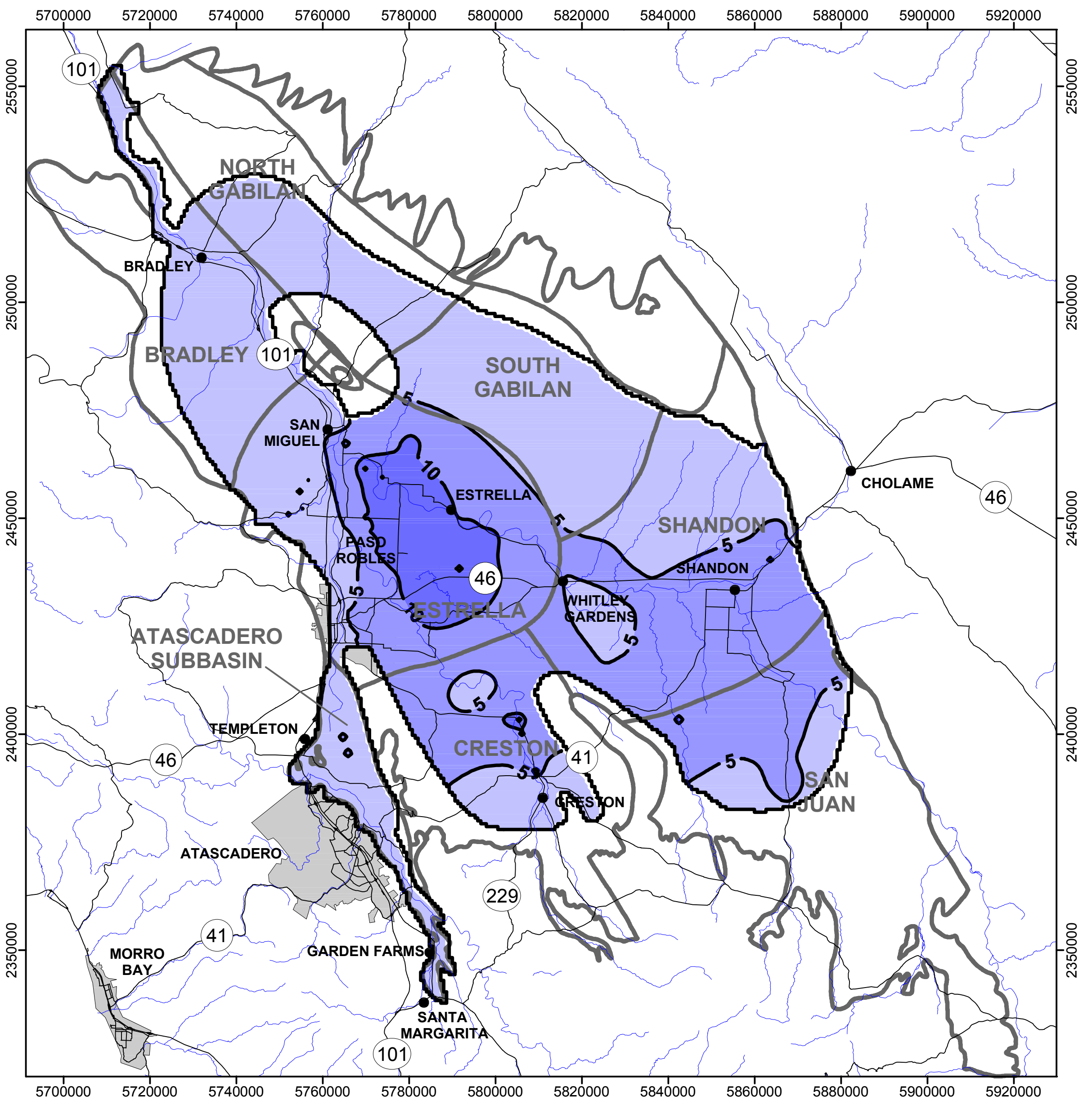


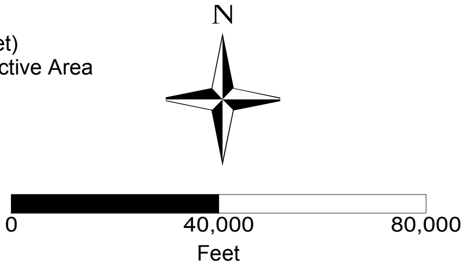
Figure 80



Legend

■	>25
■	20
■	15
■	10
■	5
■	0

- Groundwater Elevation Contour (feet)
- Paso Robles Groundwater Model Active Area
- River
- Main Road
- Minor Road



Sensitivity Analysis of 90% Agricultural Pumpage Basin-wide Change in Groundwater Elevation Map for Model Layer 3 Relative to Scenario 2

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

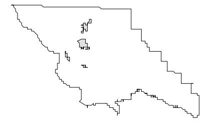
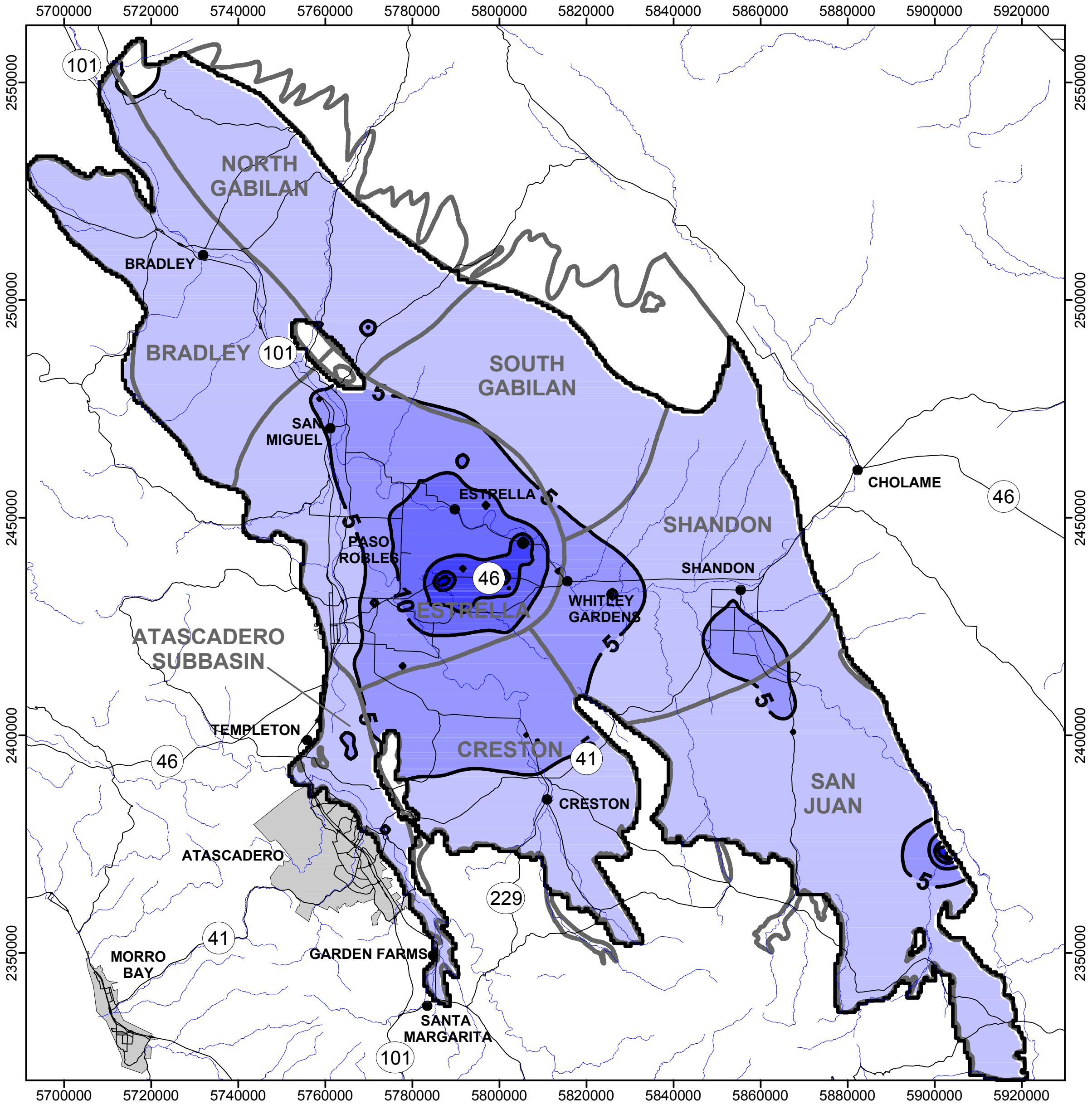


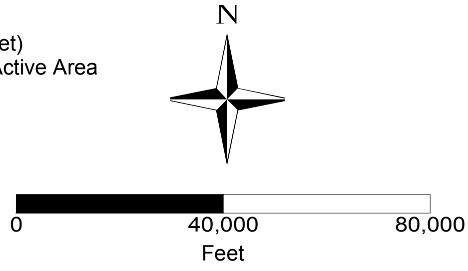
Figure 81



Legend

■	>25
■	20
■	15
■	10
■	5
■	0

Groundwater Elevation Contour (feet)
Paso Robles Groundwater Model Active Area
River
Main Road
Minor Road



Sensitivity Analysis of 90% Agricultural Pumpage Basin-wide Change in Groundwater Elevation Map for Model Layer 4 Relative to Scenario 2

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

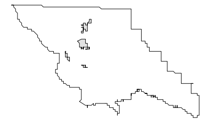
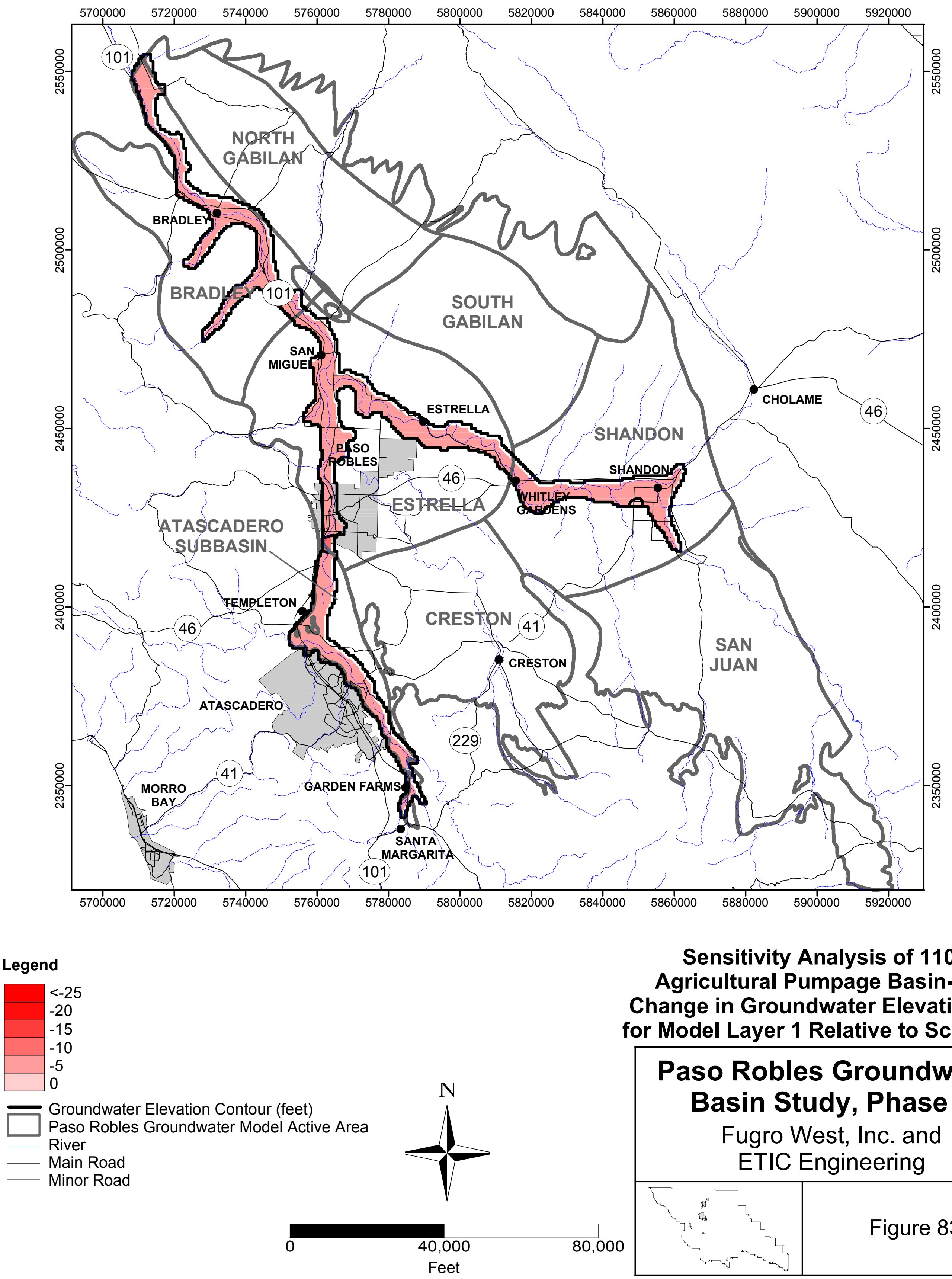


Figure 82

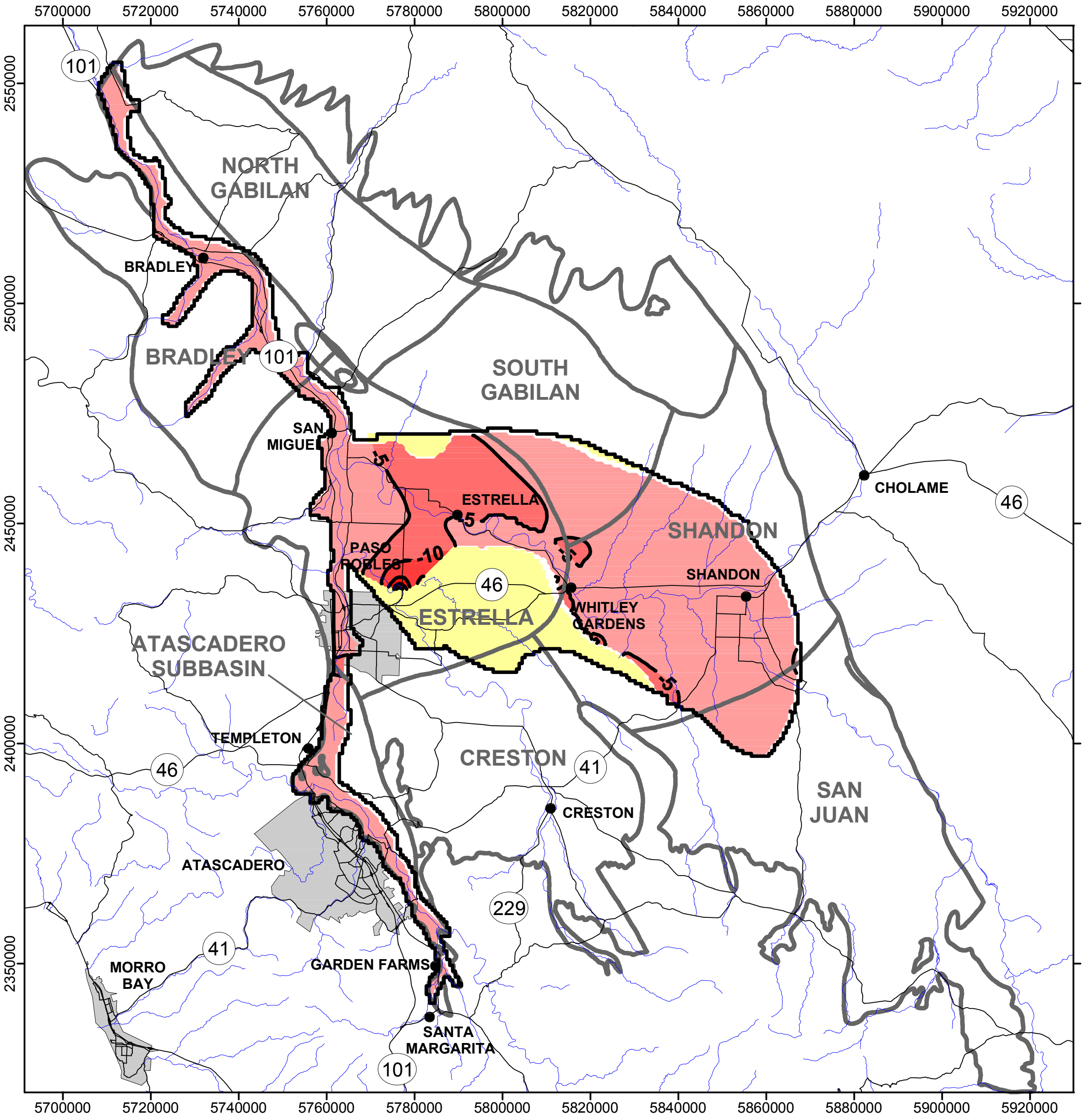


Sensitivity Analysis of 110% Agricultural Pumpage Basin-wide Change in Groundwater Elevation Map for Model Layer 1 Relative to Scenario 2

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

Figure 83



Legend

🟥	<-25
🟥	-20
🟥	-15
🟥	-10
🟥	-5
🟥	0

Groundwater Elevation Contour (feet)
Paso Robles Groundwater Model Active Area
River
Main Road
Minor Road
🟨 Area of Limited Saturation

N

0 40,000 80,000
Feet

Sensitivity Analysis of 110% Agricultural Pumpage Basin-wide Change in Groundwater Elevation Map for Model Layer 2 Relative to Scenario 2

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

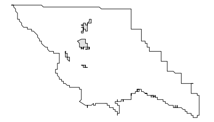
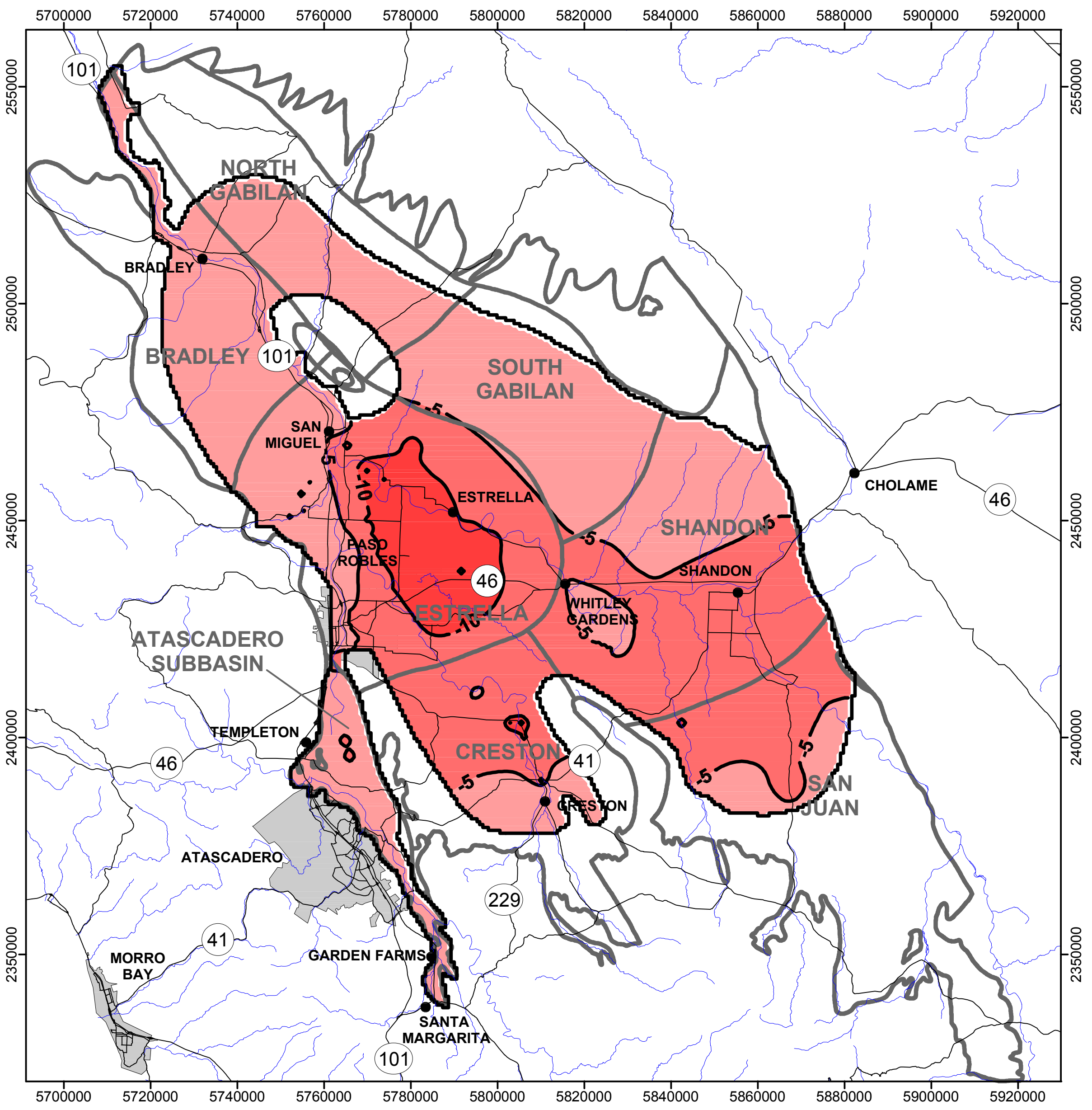


Figure 84



Legend

🟥 <-25
🟥 -20
🟥 -15
🟥 -10
🟥 -5
🟥 0

Groundwater Elevation Contour (feet)
Paso Robles Groundwater Model Active Area
River
Main Road
Minor Road

N

0 40,000 80,000
Feet

Sensitivity Analysis of 110% Agricultural Pumpage Basin-wide Change in Groundwater Elevation Map for Model Layer 3 Relative to Scenario 2

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

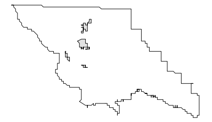
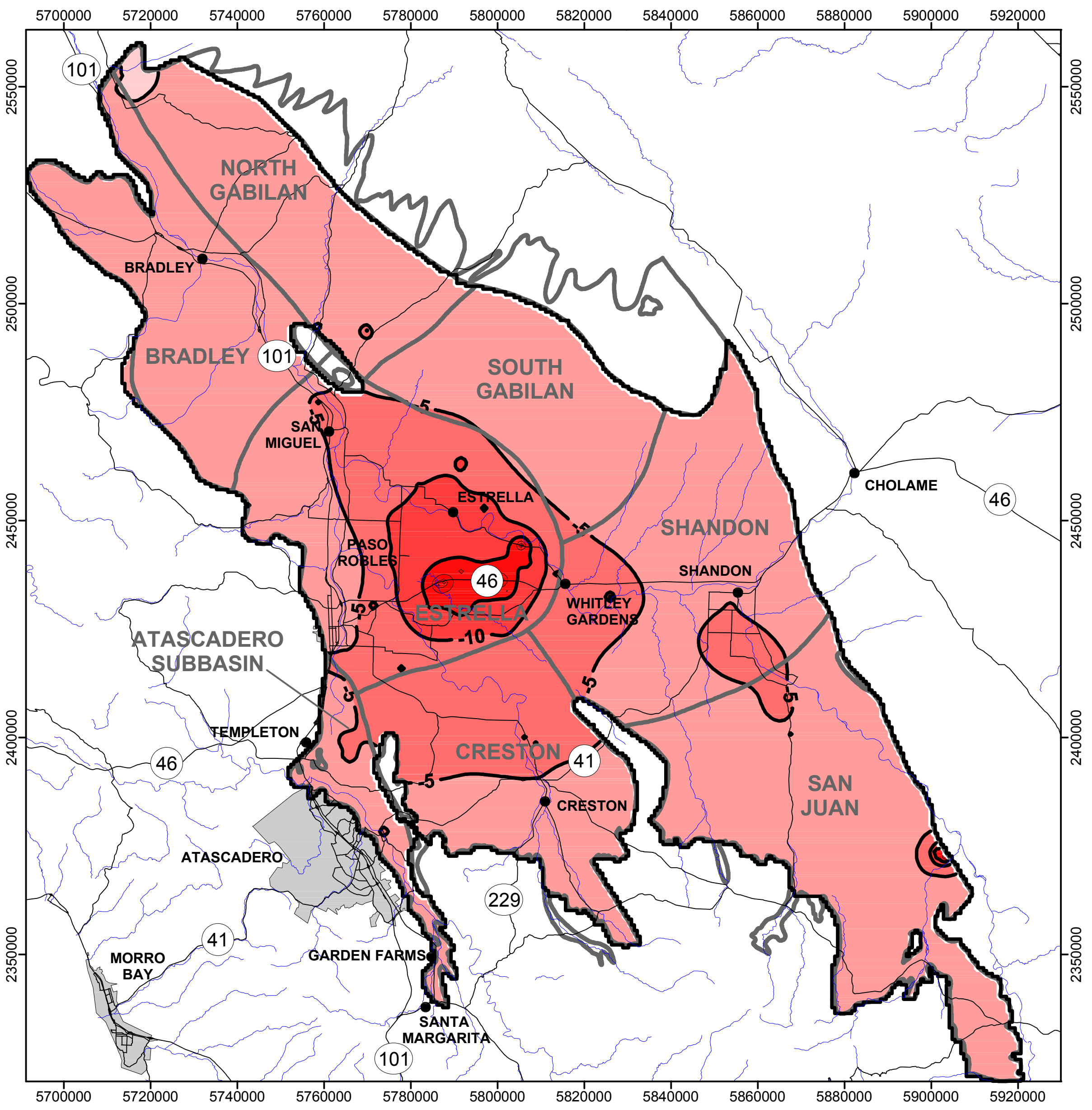


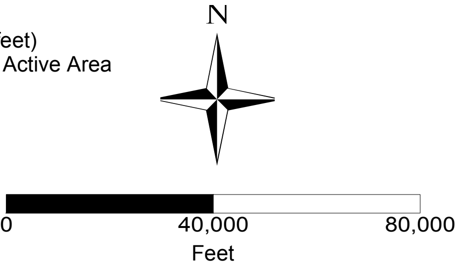
Figure 85



Legend

🟥	<-25
🟥	-20
🟥	-15
🟥	-10
🟥	-5
🟥	0

Groundwater Elevation Contour (feet)
Paso Robles Groundwater Model Active Area
River
Main Road
Minor Road



Sensitivity Analysis of 110% Agricultural Pumpage Basin-wide Change in Groundwater Elevation Map for Model Layer 4 Relative to Scenario 2

Paso Robles Groundwater Basin Study, Phase II

Fugro West, Inc. and
ETIC Engineering

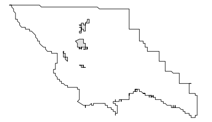


Figure 86