Exhibit 4.6

FINAL REPORT
GROUNDWATER MODELING STUDY
for the
CUMMINGS GROUNDWATER BASIN
KERN COUNTY, CALIFORNIA

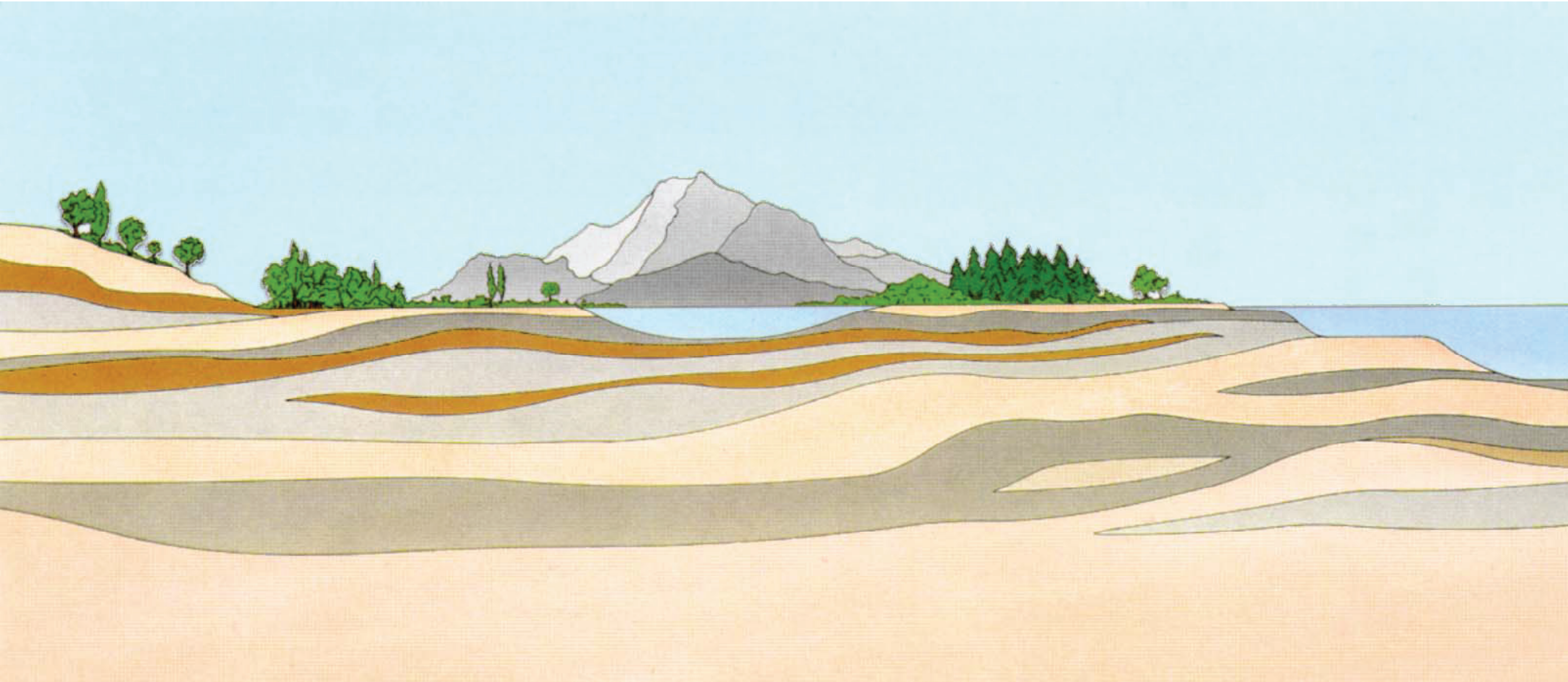
Prepared for:

TEHACHAPI-CUMMINGS COUNTY WATER DISTRICT
Tehachapi, California

Prepared by:

FUGRO WEST, INC.
ETIC ENGINEERING

March 2004



FUGRO WEST, INC.

660 Clarion Court, Suite A
San Luis Obispo, California 93401
Tel: (805) 542-0797
Fax: (805) 542-9311

March 2004
Project No. 3267.001

Tehachapi-Cummings County Water District
22901 Banducci Road
Tehachapi, California 93561

Attention: Mr. Robert Jasper

FINAL REPORT
Groundwater Modeling Study for the Cummings Groundwater Basin, Kern County, California

Dear Mr. Jasper:

Fugro West and ETIC Engineering, Inc. are pleased to submit this Final Report of the Cummings Groundwater Basin study. The objective of the overall study was to assess the hydrogeologic conditions of the basin, estimate the perennial yield, develop a numerical groundwater flow model to be used as a groundwater management tool, and evaluate future trends in groundwater levels and quality in response to current and future operations in the basin.

An updated water balance and estimated perennial yield was developed based on the calibrated model results. The investigation concluded that the perennial yield of the basin approximates 3,644 acre-feet per year under current conditions.

Five model scenarios were run for the study. Scenario 1 defined the baseline conditions that formed a basis of comparison for the other scenarios. Scenario 2 simulated an extended severe drought. Scenario 3 simulated the impact of the increased groundwater pumping in the basin by services districts in response to population growth. Scenario 4 simulated the reuse of CCI effluent for irrigation of nearby sod farm activities, and Scenario 5 evaluated the impact of CCI remediation of the methyl tert butyl ether (MTBE) plume on basin water supplies.

In closing this phase of work for the District, we would like to express our appreciation to the District staff and the Steering Committee for their interest and cooperation throughout the study. Robert Jasper, John Otto, and Glen Mueller were always willing to dedicate time and resources to assist us with data collection and to understand the details of the basin conditions and activities. Ernie Weber was a particular asset in reviewing technical issues. Lastly, the work could not have been done effectively without the willing cooperation of the growers in the valley.

It has been both a pleasure and a challenge to conduct this investigation, which we know is of utmost importance to the District and its constituents. If you have any questions, please do not hesitate to contact us. We will remain available at your convenience to discuss the report, answer any questions, or evaluate additional issues as they arise.

Sincerely,

FUGRO WEST, INC.

Paul Sorensen, RG, CHg
Associate Hydrogeologist

ETIC ENGINEERING, INC.

Mehrdad M. Javaherian, Ph.D.
Vice President

Michael Maley, RG, CHg
Senior Hydrogeologist

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The Cummings Groundwater Basin, located in Kern County about 7 miles west of Tehachapi, is a small alluvial basin (about 8,500 acres) situated between the Sierra Nevada and the Tehachapi Mountains. Agriculture is the primary water use. Other water users include the California Correctional Institution (CCI) and nearby residential developments. Prior to 1970, the basin was subject to groundwater overdraft resulting in basin adjudication and importation of supplemental surface water supplies. Groundwater levels have remained relatively stable as a result of management policies by the watermaster, the Tehachapi-Cummings County Water District (TCCWD). However, emerging water quality issues and increasing water demand by agricultural, municipal, and CCI interests will require basin-wide cooperation to resolve.

A numerical groundwater model was constructed for the Cummings Groundwater Basin using MODFLOW 2000 (Harbaugh et al 2000). Input data for the numerical model was based on hydrogeological and water budget data from the Task 1 Report (Fugro and ETIC 2003) over a base period from 1981 through 2001.

The model was calibrated to observed groundwater elevation data from 92 basin wells to reduce uncertainty in assigning aquifer properties. Modifications to the water balance were made to achieve model calibration. These changes included shifting more recharge from rainfall and stream flow from the dry years to the wet years and increasing the estimated amount of agricultural pumping. To match the hydrograph data, about 40 percent of the total base period recharge was shifted into the significantly wet years of 1983, 1995, and 1998. The model calibration showed good agreement between simulated and groundwater elevation data from 92 basin wells. Calibration criteria included comparison of groundwater elevation maps, statistical analysis, and hydrograph evaluations. The statistical calibration results showed a strong correlation coefficient of 0.976.

An updated water balance was developed based on the calibrated model results. The total water balance was calculated as 3,906 acre-feet per year (AFY). The water balance identified that 82 percent of the total net recharge was due to precipitation, runoff and subsurface inflow. The remaining 18 percent was attributed to return flows and artificial recharge operations. The primary discharge component was pumping which accounted for 87 percent of the total net discharge from the basin. The remaining 13 percent was attributed to natural outflow including subsurface outflow, evapotranspiration, and discharge to surface water. An average annual increase in storage over the 21-year base period was 510 AFY. A perennial yield of 3,644 AFY was estimated based on the calibrated numerical model results that excluded a portion of the natural outflow. This estimated perennial yield compares favorably with earlier estimates of 4,156 AFY by Tehachapi Soil Conservation District in 1969 (TSCD, 1969) and 3,560 AFY by Mann (1971).

The calibrated model is designed to provide TCCWD with a tool to assist with long-term planning of groundwater management issues for the basin. The calibration demonstrated that the numerical model could reasonably reproduce historical conditions in the Cummings Groundwater Basin over the 21-year base period. This provides the basis of confidence that the model can reasonably forecast future conditions.

Five model scenarios were run for this report based on the calibrated numerical model. Scenario 1 defined the baseline conditions that formed a basis of comparison for the other scenarios. This simulation assumes that the conditions during the 1981 to 2001 base period are repeated in the future. Scenario 2 simulated an extended severe drought. This simulation showed a general decrease in water levels across the basin that persisted even after the drought. Water levels declines were most pronounced near the stream recharge areas and least pronounced in the southwestern portion of the basin. Scenario 3 simulated the impact of increased groundwater pumping in the basin by service districts in response to increased demand due to population growth. This increased pumpage was balanced by recharge of imported water to maintain the water balance. However, the model suggests that there may be a physical limit to the amount of recharge that could be accepted at the Chanac Recharge Area. Scenario 4 simulated the reuse of CCI effluent for irrigation for nearby agriculture. Water levels increased in these areas as groundwater pumping was taken offline. Scenario 5 evaluated the impact of CCI remediation of an MTBE plume on basin water supplies. This scenario indicates that continuous groundwater pumping of about 50 gallons per minute (gpm) may be necessary for remediation resulting in a water demand of about 50 AFY.

One benefit of producing a numerical model is to identify areas where additional data collection would be most beneficial in understanding the basin system. A summary of the recommendations included in this report include:

- Compile and maintain a long-term database of groundwater pumpage data from metered agricultural and other wells in the basin.
- Perform a comprehensive watershed analysis to quantitatively evaluate the variable runoff between wet and dry years including the potential impact of single, high-intensity storms. This analysis should also identify the locations where runoff would most likely impact the groundwater basin.
- Evaluate the capacity of the Chanac Recharge Area to accept long-term intensive groundwater recharge.
- Closely observe Methyl tertiary Butyl Ether (MTBE) remediation activities in an effort to evaluate the potential impact on the perennial yield of the basin.

1.0 INTRODUCTION

The Cummings Groundwater Basin is located in Kern County about 7 miles west of Tehachapi, California. The Cummings Groundwater Basin lies in a small valley situated between the Sierra Nevada and the Tehachapi Mountains. The basin covers about 8,500 acres or 13.25 square miles. Agriculture is the dominant land and groundwater use in the basin. Other groundwater users include the California Correctional Institution (CCI), and nearby residential developments such as Bear Valley Community Services District (BVCSD) and Stallion Springs Community Services District (SSCSD).

Prior to 1970, the basin was subject to groundwater overdraft resulting in basin adjudication and importation of supplemental surface water supplies. Groundwater levels have remained relatively stable as a result of management policies by the watermaster, the Tehachapi-Cummings County Water District (TCCWD), involving the balancing of imported water with use of local groundwater supplies. However, increasing water demand by agricultural, municipal and CCI interests and emerging water quality issues will require basin-wide cooperation to resolve.

1.1 PURPOSE AND OBJECTIVES

The Groundwater Modeling Study consists of development of a numerical model to simulate groundwater flow and water quality in the Cummings Groundwater Basin. This numerical model was based upon the hydrogeologic data compiled in Task 1 of the project and documented in the Task 1 Interim Report: Data Collection and Conceptual Hydrogeologic Model, Cummings Groundwater Basin Study (Fugro and ETIC 2003). To this end, this report documents the development, calibration, and application of the groundwater model including:

- Adaptation of the hydrogeological data compiled in the Task 1 Report (Fugro and ETIC 2003) into aquifer properties and hydrogeologic boundary conditions required to construct a numerical model,
- Calibration of the groundwater flow model by matching model results to measured groundwater elevation data and the estimated water budget,
- Estimation of the perennial yield for the basin,
- Documentation of the results of five scenarios based on the calibrated model to evaluate basin conditions, and
- Conclusions and recommendations.

The primary objective of the Groundwater Modeling Study is to develop a calibrated basin-wide numerical model of the Cummings Groundwater Basin. The purpose of the model is to provide a tool to enhance the TCCWD's ability to manage and protect the groundwater resource in the Cummings Valley. To this end, the calibrated numerical model is used to calculate the basin perennial yield. To forecast future trends in groundwater levels and water quality, model runs or scenarios are developed by modifying specified sets of input parameters to simulate potential future conditions. In this way, the model can be used by TCCWD to evaluate the impacts of management practices on the long-term groundwater resource in the basin.

1.2 NUMERICAL MODEL

The first step towards developing a sound, defensible numerical model is to insure consistency with the hydrogeological understanding or conceptual model of the 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. Therefore, a model is a simplification of the natural system. The input data for the numerical model mathematically describe the hydrogeological conceptual model. The numerical model is a mathematical solution that solves the mass balance and motion equations that govern groundwater flow and chemical transport (Bear and Verruijt 1987).

Model calibration is the process to reduce uncertainty in the simulation by matching model results to observed data. The more extensive the calibration process, the more constrained the model becomes, thereby reducing uncertainty in the results. Typically, 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 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. The latter may provide guidance on nature and extent of future monitoring or identify locations where additional data evaluation is needed. A numerical model can provide useful guidance on how to allocate resources for data collection.

The primary advantage of a numerical model is that it requires a balance between the amount of water entering and exiting the basin and the rate of groundwater flow through the basin. In this way, a numerical model provides another method to estimate perennial yield.

Once calibration is achieved, the model is considered capable of forecasting future conditions with reasonable accuracy. Input parameters can be set to simulate a wide range of potential future groundwater use, water quality, or hydrogeologic scenarios. The results can be evaluated for overall trends and more localized effects. The horizontal and vertical resolution used to construct the model dictate the range of scales that the model can evaluate. 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.

When evaluating model results, it is important to consider the limitations of the model. The quality of a model is highly dependent upon the accuracy of the conceptual understanding of the hydrogeology and the quality and quantity of the data. A comprehensive data collection and conceptual model development are essential similar to those presented in the Task 1 Report (Fugro and ETIC 2003).

2.0 CUMMINGS GROUNDWATER BASIN CONCEPTUAL MODEL

A hydrogeologic conceptual model describes the geological setting and hydraulic processes for the basin and it serves as the basis for constructing a 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 the movement of groundwater within the area of interest. The Task 1 Report (Fugro and ETIC 2003) compiled and analyzed available hydrogeological data for the basin, thereby defining past and current conditions of the basin. The Task 1 Report also included development of a conceptual understanding of hydrogeologic conditions, a water quality assessment, and a preliminary hydrologic budget across the basin.

2.1 BASIN HYDROLOGY

The Cummings Groundwater Basin is composed of the water-bearing sediments that underlie the Cummings Valley (Figure 1). The Cummings Valley has a northeast-southwest orientation and is about 6 miles long by 2.5 miles wide (TSCD 1969). The valley floor is relatively flat but slopes gently towards the southwest. The valley floor elevation ranges from approximately 3,760 to 4,000 feet above Mean Sea Level (MSL). The valley is surrounded by highlands that are primarily composed of granitic rocks (Michael-McCann, 1962; TSCD, 1969). The highest mountains occur on the south side of the basin where Cummings Mountain reaches an elevation of 7,725 feet MSL.

Precipitation falls primarily as rain on the valley floor; however, a combination of rain and snow occurs at higher elevations in the surrounding mountains. Precipitation averages about 14 inches per year. Annual precipitation at the Tehachapi Precipitation Station has varied from 4.29 inches in 1959 to 28.48 inches in 1983 (Fugro and ETIC 2003). Typically, about 85 percent of the annual precipitation occurs during December through April. The remaining precipitation generally occurs as convection-type thunderstorms during the late summer and early fall. At the higher elevations, much of the precipitation occurs as snow with average snowfall totals of 65 to 70 inches. During high precipitation years, snow packs of 4 to 6 feet accumulate and remain on north-facing slopes until late spring.

Previous reports (Michael-McCann, 1962; TSCD, 1969) describe the Cummings Basin as a graben that settled along fault lines. The basin was subsequently filled with alluvial sediments that include alluvial fan deposits and finer-grained stream and floodplain deposits. Coarser materials are considered to occur closer to the mountain slopes at the apex of the major alluvial fans. The center of the basin is considered to be composed of finer-grained sediments. The basin is thought to consist of a heterogeneous sequence of sand, gravels, silts and clays in discontinuous layers of varying permeabilities with limited hydraulic continuity (Michael-McCann, 1962; TSCD, 1969). However, the basin is not considered to have any well-defined aquifers, but is instead considered a single aquifer system.

Historically, regional groundwater flow was toward the southwest corner of the basin. Prior to agricultural development, shallow groundwater levels and flowing wells were observed in the basin. Prior to 1950, groundwater discharged to stream channels. As groundwater pumpage increased, water levels in the basin declined. Currently, pumping is the primary groundwater discharge with only minor natural outflow, and groundwater flow tends to converge towards the major pumping locations in the center of the basin.

2.2 WATER BUDGET

The Task 1 Report (Fugro and ETIC 2003) provided a comprehensive data compilation and evaluation to identify and quantify the water balance components for the basin. The Task 1 Report includes a basin-wide water balance which was developed using the inventory method over the base period of 1981 through 2001 (Fugro and ETIC 2003). The water balance identified that 79 percent of the total net recharge was due to precipitation, stream flow and subsurface inflow. The remaining 21 percent was attributed to return flows and artificial recharge operations. The primary outflow component was pumping, which accounted for 98 percent of the total net outflow from the basin. The average annual contributions of each recharge and discharge component is summarized in Table 1 and 2.

The primary sources of recharge to the Cummings Basin include precipitation on mountainous areas to the south (main source of recharge), precipitation on other surrounding hills and mountains, surface inflow from Brite Valley during very wet years, percolation of precipitation on Cummings Basin alluvium, and irrigation return flows (Mann, 1970). Discharge or outflow from the basin is primarily from groundwater pumping with a limited amount of natural outflow. Surface outflow from Cummings Basin in Chanac Creek was said to occur only on rare occasions. Mann (1970) also stated that there was no groundwater flow into or out of Cummings Basin from adjacent alluvial areas.

Using the inventory method, the Task 1 Report calculated an average annual recharge to Cummings Basin of 3,171 acre-feet per year (AFY), whereas the total discharge from the basin approximates 2,254 AFY (Fugro and ETIC 2003). This comparison, however, yields a net excess of 917 AFY of recharge over discharge. This difference amounts to 19,257 AF over the course of the 21-year base period. Calculating the change in storage based on average changes in water levels and assuming a specific yield of eight percent yielded an increase in groundwater storage of 10,200 AF or 486 AFY for the base period. Importantly, this calculation suggests that the basin is not in overdraft.

For comparison purposes, the basin safe yield estimated by the Tehachapi Soil Conservation District (TCSD 1969) included 2,700 AFY of natural replenishment and 1,456 AFY of agricultural return flows (based on a return flows of 35 percent of applied water) for a total safe yield of 4,156 AFY. The major difference in these two estimates is the calculation of agricultural return flows (35 percent for TSCD study vs. 15 percent for current study). John Mann estimated a basin safe yield based on groundwater pumping and groundwater storage changes that amounts to 3,560 AFY. Determination of safe yield during the Cummings Basin adjudication process resulted in a basin safe yield estimate of 4,090 AFY.

3.0 NUMERICAL MODEL DEVELOPMENT

A numerical model was constructed for the entire Cummings Groundwater Basin. Initial input data for the numerical model were primarily based on the results of the Cummings Groundwater Basin Study (Fugro and ETIC 2003). Each component of the hydrogeologic conceptual model and hydrologic budget was mapped into the numerical model as either aquifer properties or boundary conditions as appropriate. The procedures used to mathematically represent each component of the Task 1 Report (Fugro and ETIC 2003) conceptual model in a numerical model is discussed below.

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 adapting the hydrogeological conceptual model in support of the numerical model, a range of reasonable values are 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.

3.1 MODEL SETUP

The Cummings Groundwater Basin numerical model was constructed using the groundwater flow model MODFLOW 2000 (Harbaugh et al 2000), a finite-difference numerical model developed by the U.S. Geological Survey. The water quality component of the modeling was constructed using MT3DMS (Zheng and Wang 1999) that was developed by the U.S. Environmental Protection Agency, and is designed to be used in conjunction with MODFLOW 2000. To facilitate the construction and operation of the numerical model, the MODFLOW 2000/MT3D processor Groundwater Vistas (ESI 2001) was used. In addition, the use of a commercial processor supports future usability of the model.

3.1.1 Model Domain

The model domain is the geographical area covered by the model. The model domain for the Cummings Groundwater Basin encompasses the entire Cummings Groundwater Basin. A requirement of MODFLOW 2000 is to define a rectangular model domain that encompasses the entire region to be actively modeled. The model domain extends 24,640 feet (4.67 miles) in the east-west direction and 26,400 feet (5 miles) in the north-south direction covering an area of 14,933 acres or 23.3 square miles (Figure 2). This represents the entire area included in the numerical model; however, water levels are only calculated within the basin region. This is called the active region of the model. The active area for the Cummings Basin Groundwater Model covers 8,500 acres or 13.25 square miles (Figure 2).

3.1.2 Model Layers

Model layers provide vertical resolution for the model to better simulate variations in aquifer stresses, groundwater elevation, and water quality with depth. Specifically, model layers can be defined to simulate separate aquifers or to subdivide a single aquifer. For the Cummings Groundwater Basin, three model layers were defined (Figure 3). The model layers were constructed continuously so that the bottom of one layer is the top of next layer. This is a requirement for running the MT3D code for water quality modeling.

For the Cummings Basin Groundwater Model, Model Layers 1 and 2 represent a large portion of the alluvial sediments within the basin (Figure 3). Model Layer 1 represents the uppermost alluvial sediments in the valley and was simulated as everywhere unconfined. The top of Model Layer 1 is set at the ground surface as based on a Digital Elevation Model (DEM) file from the USGS. Model Layer 1 varied in thickness from 10 feet near the edges to 230 feet in the thickest portion of the basin (Figure 3). Because Layer 1 is unconfined, the saturated thickness is less than the total thickness and is allowed to vary throughout the model period.

Model Layer 2 represents the deeper alluvial sediments that form the main groundwater pumping zone in the basin. The top of Model Layer 2 was derived from the basin-wide cross-sections discussed in the Task 1 Report (Fugro and ETIC 2003). From these cross-sections, a structure contour map was developed and converted into a gridded digital format that was imported directly into the numerical model. Model Layer 2 varied in thickness from 8 feet near the edges to 230 feet in the thickest portion (Figure 3).

Model Layer 3 represents the basal alluvial sediments and the upper weathered/fractured granite that is also water bearing. The geologic logs available from the basin were inconsistent regarding the base of the permeable sediments and a weathered or broken granite section was commonly noted on these logs. The bottom of Model Layer 3 is based on the “Base of Permeable Sediments” map (Figure 2) that was presented in the Task 1 Report (Fugro and ETIC 2003). However, the layer was deepened primarily along the model boundaries to limit desaturation of model cells that would lead to model instability. This deepening of Layer 3 is based on the on the assumption that groundwater flow also occurs in the upper weathered granite. The aquifer properties for Layer 3 represent the estimated mix of alluvial sediments and weathered granite at different locations around the basin. The top and bottom elevations of Model Layer 3 were derived from the basin-wide cross-sections (Fugro and ETIC 2003) and imported directly into the numerical model as a digital structure map. Model Layer 3 varied in thickness from 98 feet near the edges to 182 feet in the thickest portion (Figure 3). The maximum total model thickness (from the top of Layer 1 to the bottom of Layer 3) is 560 feet at the center of the basin, which is consistent with the previous interpretation (Figure 2).

3.1.3 Model Grid

To develop the numerical model, the model area is subdivided into a grid. An early technical decision was to select the appropriate model grid spacing. Adding more grid cells increases the model resolution, but it also increases the time required to manage and run the model. Transport modeling typically requires smaller grid spacing than groundwater flow alone because chemical concentrations typically vary by orders of magnitude over short distances. Since a future case scenario included evaluating the impact of a groundwater remediation at the CCI facility, a variable spacing grid was developed. This grid was designed to balance the need for higher model resolution in the CCI area versus developing an efficient groundwater flow model to evaluate groundwater resources in the rest of the basin. The grid size for the Cummings Basin Groundwater model ranged from 11 to 110 feet with the finer grid spacing centered over the CCI facility (Figure 4). The produces a model grid comprised of 397 rows and 381 columns. Therefore, the three-layer model will produce a total grid containing 453,771 total cells. Of these, 262,128 cells are in the active area of the model domain.

3.1.4 Stress Periods

In the numerical model, stress periods represent the resolution of time into discrete intervals. The stress periods are further subdivided into time steps, and a groundwater elevation is calculated at each time step. The stress periods should match both the physical nature and quality of the data. For the Cummings Basin numerical model, a six-month stress period was considered the appropriate time length. To correlate to the wet and dry seasonal character of the California climate and standard agricultural irrigation practices, the stress periods were set to run from October to March and April to September. In addition, the highest and lowest groundwater elevations during a typical year occur at the ends of these periods.

The base period of 1981 to 2001 used for the Task 1 Report (Fugro and ETIC 2003) was used for the total time interval for the numerical model. This 21-year period created 42 stress periods. Boundary conditions, which represent the components of the hydrologic budget, must be defined for each stress period.

3.2 AQUIFER PROPERTIES

Aquifer properties describe the physical characteristics of the aquifer materials that control groundwater flow. The numerical model requires that aquifer properties be defined for every active cell in the model. The data necessary to define aquifer properties are provided by the Task 1 Groundwater Basin Study. Extrapolation methods were used to define properties in areas with insufficient data using science-based assumptions based on the conceptual model. Reasonable value ranges were defined for each property. These ranges were used as guidance during model calibration. The necessary aquifer properties are summarized below.

For the numerical model, hydraulic conductivity must be defined horizontally within a model layer and vertically between adjacent model layers. The hydraulic conductivity was based on data presented in the Task 1 Report (Fugro and ETIC 2003); however, hydraulic conductivity was one of the major model calibration parameters. Hydraulic conductivity was defined in regionalized blocks per model layer that are shown in Figure 5 for each model layer. Overall, the hydraulic conductivities used in the calibrated model ranged as follows:

- Layer 1 – 1.2 to 5.0 feet/day
- Layer 2 – 1.2 to 5.0 feet/day

- Layer 3 – 0.8 to 5.0 feet/day

Typically, the higher hydraulic conductivities were used in Model Layers 1 and 2 since these represented the alluvial sediments and Model Layer 3 included a mixture of alluvium and weathered granite. The exception was the Cummings Creek Alluvial Fan which had higher values according to the conceptual model. Lower hydraulic conductivities were used along the basin margin for areas that were not the apex of major alluvial fans. A slightly lower hydraulic conductivity was used for the center of Layer 2 consistent with the conceptual model of more finer-grained material towards the center of the basin (Michael-McCann, 1962; TSCD, 1969). In the CCI area, the hydraulic conductivity was based on aquifer test results (AMEC 2003a).

Since no data were available for the Cummings Groundwater Basin, the vertical hydraulic conductivity was defined during model calibration. The vertical hydraulic conductivity can be allowed to vary independent of the horizontal hydraulic conductivity to allow more flexibility in simulating observed conditions. For the Cummings Basin a uniform vertical hydraulic conductivity of 0.05 feet/day was used everywhere in the model. In the geologically heterogeneous alluvial sediments within the Cummings Basin, the lower permeability sediments that restrict groundwater flow primarily control the vertical hydraulic conductivity. Conceptually, the vertical hydraulic conductivity represents the finer-grained silt and clay layers.

A limited amount of storage coefficient and specific yield were presented in the Task 1 Report (Fugro and ETIC 2003) as average values in the basin. For Model Layer 1, which was simulated as entirely unconfined, a specific yield of 0.085 was applied uniformly. For Model Layer 2 the storage coefficients ranged from 1.5x10-3 to 2.5x10-4 and a specific yield of 0.08 was used. For Model Layer 3 the storage coefficients ranged from 1.5x10-3 to 2.5x10-4 and the specific yields varied from 0.01 in lower hydraulic conductivity areas to 0.08 in the Cummings Creek area. These are typical storage coefficient values for the type of sediments found in the Cummings Groundwater Basin (Freeze and Cherry 1979).

3.3 BOUNDARY CONDITIONS

Model boundary conditions simulate water entering and exiting the model domain and are based on the components of the hydrologic budget. Boundary condition data must be entered for each stress period at each boundary condition cell, other than no-flow cells, in the model. From the Task 1 Groundwater Basin Study, the primary mechanisms for groundwater to enter the model are from precipitation recharge, stream flow, return flows and subsurface inflow. The primary mechanisms for groundwater to exit the model are from pumping wells, subsurface outflow, discharge to streams, and evapotranspiration. MODFLOW 2000 provides a number of boundary condition options to numerically represent these physical processes.

3.3.1 Precipitation Recharge

Precipitation recharge is an estimate of the amount of deep percolation occurring from rainfall on the valley floor. The estimate assumed ten percent of total rainfall went to deep percolation. The Task 1 Report (Fugro and ETIC 2003) used an average percolation rate of 1.49 inches per year (10 percent of 14.86 inches). This produced an estimated recharge of 22,063 acre-feet of precipitation recharge over the base period for an average rate of 1,051 AFY. The initial annual distribution of this recharge developed in the Task 1 Report (Fugro and ETIC 2003) are shown in Table 1. The distribution was based on an assumption that a higher percentage of recharge would occur in wet years over dry.

The precipitation recharge was input to the MODFLOW model using the recharge package. The data are input as recharge rates per unit area. MODFLOW then calculates the volume of recharge over the area of the model cell. The precipitation recharge was combined with the irrigation and domestic return flows in the MODFLOW recharge package. The precipitation recharge rate was applied uniformly across the basin, but was varied by stress period to reflect annual differences in precipitation. The general assumption used was that 85 percent of precipitation recharge occurred during the winter stress period and the remaining 15 percent occurred in the summer stress period.

During the model calibration, the precipitation recharge rates were modified as shown in Table 3. This distribution was developed to better match hydrograph data from basin wells. This distribution uses a similar assumption but applies an even higher percentage of recharge in wet years than in dry years. Subsequently, an increase was added to 1982, 1983, 1992, 1993, 1995, 1998, and 2001 total rainfall recharge for model calibration. Decreased rainfall recharge was used for drier years. The net result increased the total precipitation recharge to 23,049 acre-feet over the base period with an average annual recharge rate of 1,098 AFY.

3.3.2 Streams

Most streams within the Cummings Basin are ephemeral that rarely flow except during wet weather. However, streamflow recharge is a major component to the overall water balance that accounts for about 40 percent of the total groundwater recharge for the basin (Table 3). Streams also have complex interactions with groundwater that include both recharge and discharge. Stream recharge is the result of surface water flow from the surrounding watersheds entering the basin and percolating through the streambed to recharge groundwater as a losing stream reach. Stream discharge is the result of groundwater flowing into a stream as a gaining stream reach. Groundwater interactions with surface water were input into the MODFLOW model using the stream, drain and well packages (Figure 6).

In the Task 1 Report (Fugro and ETIC 2003), stream runoff was calculated for the 14,750-acre watershed that drains into the Cummings Groundwater Basin. Cummings Creek is the primary drainage into the basin, but several other minor drainages are also found around the basin. A higher annual runoff rate (2.1 inches/year) was applied at Cummings Creek than the other drainage areas (1.2 inches/year) because of its large size and the assumption of higher precipitation rates at the higher elevations included in this watershed area. Integrating these rates over the watershed area produced 40,698 acre-feet of recharge over the base period for an average rate of 1,939 AFY. A second estimate that capped wet year recharge produced 19,266 acre-feet of recharge over the base period for an average rate of 917 AFY (Table 1). This was considered as the reasonable range of stream flow recharge.

Cummings Creek was represented in the model using the stream package (Figure 6). The stream is a head-dependent boundary condition, allowing the model to calculate the amount of streambed percolation (losing reach) and groundwater outflow (gaining reach) to each stream reach. The MODFLOW stream package provides the capacity to incorporate streamflow data into the model to account for the widely varying stream flows that are observed in Cummings Creek. The stream package requires that a 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 contours from the site. The streambed conductance was established during model calibration to match groundwater recharge estimates and groundwater elevations from wells located near the stream.

Recharge related to smaller watersheds was input into the MODFLOW model using the well package (Figure 6). Using the well package, a specified volume of water is added to the model cells that is not head dependent. This eliminates the streambed conductance and elevation requirements. The recharge was spread over a wide area rather than in a stream channel to better represent areal distribution assuming more sheet flow in these areas.

Groundwater discharge to streams is very low in the Cummings Basin due to the depth of groundwater and is generally limited to the highest rainfall years. However, this capacity was added so that the model could accommodate this issue if necessary for future case scenarios. Minor surface drainages were added to the model using the MODFLOW drain package to allow for groundwater to exit the model domain (Figure 6). The other required input data included streambed conductance and elevation that were derived in a similar manner used for the stream package.

During the model calibration, the stream recharge was modified as shown in Table 3. This distribution was developed to better match hydrograph data from basin wells. This distribution uses a similar assumption as precipitation recharge that a higher percentage of recharge occurs in wet years than in dry years. Likewise, the general assumption used was that 85 percent of stream recharge occurred during the winter stress period and the remaining 15 percent occurred in the summer stress period. The total stream recharge was increased to 32,676 acre-feet over the base period with an average annual recharge rate of 1,556 AFY.

3.3.3 Well Pumpage

Groundwater pumpage is the major component that accounts for about 87 percent of total groundwater outflow from the Cummings Basin. Groundwater pumpage data were compiled to the Task 1 Report (Fugro and ETIC 2003). The locations of the groundwater extraction wells included in the model are included in Figure 7.

TCCWD estimates of annual agricultural pumpage were distributed to specific wells based on an aerial photo analysis of land use and water importation records from TCCWD. The agricultural water use was calculated by multiplying the total irrigated acreage for each square mile by a crop water duty factor for each section. Groundwater use was assumed as the difference with the imported water records. The calculated groundwater pumpage was assigned to the associated agricultural wells at that location. This method produced an estimate of 25,923 acre-feet of pumping over the base period for an average rate of 1,234 AFY (Table 2).

The water balance components based on land use data were tabulated per square mile (Figure 8). The distribution of agricultural pumpage assumed 15 percent of water use in the winter stress period and 85 percent of the summer stress period.

Municipal and industrial pumpage records show 18,142 acre-feet of pumping over the base period for an average rate of 864 AFY (Fugro and ETIC 2003) that is mostly attributed to CCI and service districts. Other domestic pumping was estimated at 1,776 acre-feet for an average rate of 85 AFY (Fugro and ETIC 2003). The distribution of municipal, industrial and domestic pumpage assumed 40 percent of water use in the winter stress period and 60 percent of the summer stress period.

The MODFLOW well package provides the capability to specify the amount of water pumped per stress period. Each individual well was input as an analytical element using the Groundwater Vistas (ESI 2001) interface that allows for better tracking of input for each individual well. Groundwater Vistas then automatically converts this data into the MODFLOW well input file for the model run. During calibration, additional pumping was added to better match hydrographs of wells located primarily in the center of the basin. These are assumed to represent underestimation of groundwater pumpage for agricultural use as developed in the Task 1 Report (Fugro and ETIC 2003). With these additions, the total groundwater pumpage was increased to 41,122 acre-feet of pumping over the base period for an average rate of 1,958 AFY (Table 4). The tabulated additional pumpage per section is included in Table 5.

3.3.4 Return Flows

Return flows represent the component of irrigation or wastewater disposal that percolates back to the groundwater. Therefore, this component of groundwater recharge is dependent upon water usage. Irrigation return was based on agricultural water usage including both groundwater and imported water that was developed for the Task 1 Report (Fugro and ETIC 2003). The estimation of irrigation return flow was assumed as 15 percent of total agricultural water use. This produced an estimate of 7,651 acre-feet of return flow over the base period for an average rate of 364 AFY. These data were tabulated per square mile and input into the model using the MODFLOW recharge package (Figure 8). The increased agricultural pumpage input during model calibration was also incorporated in the irrigation return flow calculation and added to the recharge package. The general assumption used to distribute the agricultural return flow recharge was that 15 percent occurred during the winter stress period and 85 percent occurred in the summer stress period.

Return flows from CCI wastewater disposal were based on specific records of wastewater discharge. CCI disposes of wastewater at sewage disposal ponds and spray fields. Return flows were estimated as 20 percent for the CCI wastewater treatment flow. The disposal ponds were simulated using the MODFLOW well package and the spray fields were incorporated into the MODFLOW recharge package. Return flows from domestic septic systems were assumed as 50 percent of the estimated domestic water use. This produced an estimate of 5,170 acre-feet of return flow over the base period for an average rate of 247 AFY. The estimation of CCI and domestic return flow assumed 40 percent of water use in the winter stress period and 60 percent of the summer stress period.

The total return flow recharge for the calibrated model was 13,782 acre-feet over the base period with an average annual recharge rate of 656 AFY. This accounted for about 17 percent of the total groundwater recharge over the base period.

3.3.5 Artificial Recharge

Artificial recharge includes imported water applied at recharge areas for the purpose of groundwater recharge. This water is typically applied at the Chanac Recharge Area in the northeastern portion of the basin; however, the Cummings Recharge Area, consisting of three separate areas located southeastern portion of the basin, is also available. Since 1995, TCCWD has utilized some imported water to conduct artificial recharge operations in the streambed of upper Chanac Creek and in ponds along the Cummings Creek alluvial fan. The annual amounts have ranged from 41 to 701 AFY (Table 3). All of the artificial recharge has occurred along Chanac Creek except for 200 AF of recharge in 2001 at the Cummings Creek pond area (the remaining 501 AF was recharged along Chanac Creek in 2001).

Artificial recharge data were input into the model using the well package. The artificial recharge component of 1,305 acre-feet was applied over the final six years of the base period based on TCCWD records (Table 3).

3.3.6 Subsurface Inflow and Outflow

Subsurface inflow and outflow estimates the amount of water that enters or exits the basin as groundwater. In the Task 1 Report (Fugro and ETIC 2003) this flow was based on a Darcy's Law calculation that assumed an average hydraulic gradient of 0.1 and hydraulic conductivity of 0.1 feet/day. Inflow was assumed to occur along 12 miles of the basin periphery and outflow along 1 mile. Inflow was calculated at 11,130 acre-feet over the base period with an average annual recharge rate of 530 AFY. Outflow was calculated as 924 acre-feet with an average annual discharge rate of 44 AFY (Table 1).

Subsurface inflow was implemented in the model using the MODFLOW well package. This inflow was distributed evenly along the basin margin in Model Layer 3 (Figure 9). The subsurface inflow values were based on data from the Task 1 Report (Fugro and ETIC 2003) calculations and these values were not varied during model calibration (Table 4).

Subsurface outflow was simulated using the MODFLOW general head package. Subsurface outflow represents the flow of groundwater into the low-permeability rocks adjacent to the groundwater subbasin. The general head boundary is a head dependent boundary condition. The amount of groundwater flowing into or out of this boundary was influenced by the relative hydraulic gradient between the basin and the boundary condition. The general head boundary was applied along the southwest corner of the basin near where Chanac Creek exits the valley. The conductance and elevation input data were established during model calibration to match groundwater elevations from wells located in the area. The result was a higher estimate of subsurface discharge of 6,193 acre-feet over the base period with an average annual discharge rate of 295 AFY. This accounted for about 9 percent of the total groundwater outflow from the basin.

3.3.7 Evapotranspiration

Evapotranspiration (ET) was not included in the Task 1 Report (Fugro and ETIC 2003). However, it was noted that depth to groundwater is relatively shallow in some areas. This occurs primarily in the southeastern corner of the basin where the ground surface elevations drop off. The annual reference ET rate for Tehachapi of 52.9 inches per year was based on University of California Publication 21426 (Snyder et al 1992). Class A pan evaporation ranges from 80 to 90 inches per year.

Therefore, the MODFLOW evapotranspiration package was included in the model. The input data were based on an arithmetic average of the monthly ET data (Snyder et al 1992) to develop input data for the winter and summer stress period. For the 6-month winter stress period, 13.1 inches of ET were assumed, and 39.8 inches of ET were attributed to the 6-month summer stress period. The evapotranspiration was applied to the highest active model layer in the model. ET was determined using the ground surface elevation as the reference. The ET rate was set to decrease linearly with an extinction depth of 10 feet.

Evapotranspiration from the calibrated model was 3,309 acre-feet over the base period with an average annual discharge rate of 158 AFY. This accounted for about 4 percent of the total groundwater outflow from the basin (Table 4).

4.0 NUMERICAL MODEL CALIBRATION

Model calibration consists of comparing simulation results from the numerical model to observed measurements collected in the groundwater basin over the base period. During calibration, aquifer properties and boundary conditions may be varied within an acceptable range until a close fit is achieved between model-simulated versus field-measured data. The calibration may require multiple adjustments to the model input data. It is possible that during the model calibration process, the model input parameters may require significant adjustment to match the observed groundwater elevations. Such a result may indicate a data gap that may require future investigation to resolve.

4.1 CALIBRATION CRITERIA

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 21-year base period infers the calibration has been performed over wet, dry, and normal years with varying degrees of pumping. To that end, the Cummings Basin 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.

4.2 CALIBRATION RESULTS

The Cummings Basin Groundwater Model was calibrated using the developed calibration criteria to reduce uncertainty by matching model results to observed data. The 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.

4.2.1 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 insure 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. Figure 10 provides a simulated groundwater elevation map for May 1990 and Figure 11 provides a simulated groundwater elevation map for October 2001. These figures show that the groundwater flow is primarily toward the heavy pumping areas in the center of the basin, as described in the conceptual model. Steeper hydraulic gradients are observed in the Cummings Creek area in the southeast and along other parts of the basin margin. Gradients flatten toward the center of the basin. This is similar to groundwater elevation maps presented in the Task 1 Report (Fugro and ETIC 2003); however, these maps are based on more limited data and were only contoured in the center of the basin. Notwithstanding this, this preliminary calibration suggests that the groundwater flow field generated by the model is reasonable.

4.2.2 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 12) depict this relationship. As indicated on Figure 12, 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 0.976. 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 0.976 indicates a very strong correlation between simulated and observed groundwater elevations. This correlation is based on 1,699 groundwater elevation measurements over the 21-year base period from 92 basin wells (Figure 13).

Figure 12 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 -2.82 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 15.40 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 residuals. The absolute residual mean for the model is 11.55 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 Cummings Basin Model is 0.019, which is about one order-of-magnitude better. This is another indicator that the model is well calibrated.

4.2.3 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 92 wells with groundwater elevation data, 50 had sufficient long-term data for the hydrograph evaluation. Included on Figure 14, 15 and 16 are eighteen representative hydrographs from different parts of the basin. 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.

The typical trend observed in the hydrograph data for the main part of the basin is a significant increase in water levels after 1983, followed by a general decline that lasted until about 1992. Water levels then began to slowly rise in response to increasing rainfall and changing pumping activities. Other types of trends are observed along the basin margins that are more strongly influenced by precipitation and less by pumping. Interestingly, a reverse trend is observed in two locations. Groundwater elevations at wells 32S/31E-18H2 in the far northern part of the basin and at 12N/16W-33B1 in the Cummings Creek alluvial fan area reflect these declines, albeit based on limited data. The model also produced these similar declines (Figures 14 and 16).

The hydrograph calibration was the basis for modifications to the water budget. The initial annual distribution of precipitation and stream recharge produced a more linear increase in groundwater elevations over time. To improve the match with the basin hydrographs, the precipitation and stream recharge was shifted into the wetter rainfall years and out of the low rainfall years (Table 3). This resulted in approximately 50 percent of the total rainfall and stream recharge being placed into the three wet years of 1983, 1995, and 1998. In contrast, rainfall and stream recharge was reduced in dry periods to account for the observed water level declines. These calibration results indicate that recharge is more episodic in nature for the Cummings Groundwater Basin and that basin recharge is highly dependent on a few high rainfall years.

A second change to the water budget was based on the hydrograph analysis. Field data indicated that the increase in water levels after the wet year of 1983 was followed by a general decline in water levels. However, simply reducing the recharge during those times did not produce this effect. Using these parameters, water levels stayed high in the center of the basin after 1983 as groundwater drained towards the center from the basin margins. The assumption used to improve the calibration was that the agricultural pumpage was underestimated. Agricultural pumpage was estimated based on land use maps and crop duty factors rather than measured volumes of pumpage from extraction wells. Additional pumpage was added in areas where the model was not properly representing the decline in measured groundwater elevations. The added pumpage was based on past practices where possible. Table 5 summarizes the amount and location of added groundwater pumpage to the model. The results of this change are best seen on hydrographs 32S/31E-35F1 (Figure 15) and 32S/31E-25P1 (Figure 16).

Overall, the results of the model calibration to the various criteria indicate that the model is well calibrated within generally accepted standards. The model may be further calibrated and updated in the future, as additional data become available. Based on the model calibration results, a recommendation for future data collection should focus on developing a long-term database of measured groundwater pumping data from all wells in the basin, and a watershed analysis to better estimate precipitation and stream recharge.

5.0 WATER BALANCE

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. Recharge or inflow to Cummings Basin is derived from precipitation, stream flow, return flows (from irrigation, CCI and domestic uses), bedrock inflow, and artificial recharge. Discharge or outflow from Cummings Basin is derived from well pumpage, bedrock outflow, stream discharge, and evapotranspiration. The major components of the water balance evaluated for the Cummings Groundwater Basin can be expressed by the following relationship:

$$P + S_{in} + RF + B_{in} + AR = W + S_{out} + B_{out} + ET \pm \Delta S$$

where:

where:	P	=	Precipitation Percolation
	S_{in}	=	Stream Flow Percolation
	RF	=	Return Flow Percolation
	B_{in}	=	Bedrock Inflow
	AR	=	Artificial Recharge Percolation
	W	=	Well Pumpage
	S_{out}	=	Groundwater Discharge to Streams
	B_{out}	=	Bedrock Outflow
	ET	=	Evapotranspiration
	ΔS	=	Change in Groundwater Storage

The Task 1 Report (Fugro and ETIC 2003) water balance estimated the annual recharge and discharge over the base period at 3,171 and 2,254 AFY, respectively. This resulted in a difference between recharge and discharge of 19,257 acre-feet or an average of 917 AFY. The change in storage calculation produced an increase of storage of about 10,000 acre-feet. Because of this discrepancy, a recommendation of the Task 1 Report (Fugro and ETIC 2003) was to use the numerical model to further refine the basin water balance and help resolve the discrepancy in groundwater storage change.

5.1 MODEL-BASED WATER BALANCE

A groundwater model provides a useful quantitative tool to further evaluate the water balance. The model incorporates data on basin geometry, aquifer properties, recharge, and discharge. 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 water balance for the basin.

The year-by-year water balance results of the calibrated model for recharge is presented in Table 3. The model results produce a total recharge of 82,022 acre-feet over the 21-year base period for an average annual recharge rate of 3,906 AFY. The results show that 40 percent of the recharge was derived from percolation of stream flow from Cummings Creek and runoff from the smaller watersheds surrounding the basin. Of the remaining recharge, rainfall recharge accounted for 28 percent, return flows for 17 percent, bedrock inflow for 14 percent, and artificial recharge for 1 percent.

The year-by-year water balance results of the calibrated model for discharge are presented in Table 4. The model results produce a total discharge of 71,306 acre-feet over the 21-year base period for an average annual discharge rate of 3,396 AFY. Groundwater pumping accounts for the majority (86 percent) of the total groundwater discharge (Table 4). The model calibration process determined that TCCWD estimates of agricultural pumpage used in the Task 1 conceptual model were likely underestimated. Much of the discrepancy between the water balance equation reported in the Task 1 Report (Fugro and ETIC 2003) and the model water balance is attributed to the apparent underestimation of agricultural pumpage. Future water balance calculations will benefit from the collection of metered groundwater pumpage of agricultural wells in the basin into a long-term database.

The model included components of natural discharge of groundwater from the basin. Subsurface outflow was increased to 6,193 acre-feet from the Task 1 Report (Fugro and ETIC 2003) estimate of 924 acre-feet. The average annual subsurface flow of 295 AFY from the model was generally stable over the base period, and accounted for about 9 percent of the total basin discharge. The MODFLOW model also added discharge from evapotranspiration and surface drainage into water balance. Evapotranspiration accounted for about 4 percent totaling 3,309 acre-feet over the base period for an annual average of 158 AFY. This was primarily limited to the southwestern portions of the basin and along the basin margin in areas of shallow groundwater. Stream discharge was a minor component that accounted for only 184 acre-feet over the model period for an annual average of 9 AFY. However, both stream discharge and evapotranspiration increased in the later model years as groundwater elevations rose. This would indicate that these components, which have historically been insignificant, might become more prominent as water levels continue to rise.

Change in groundwater storage represents the volume of groundwater stored in the basin and is reflected by changes in water levels over time. Over the 21-year base period, rising groundwater levels indicate a net increase in storage. Based on the model results, the groundwater storage increased by 10,708 acre-feet over the model period, accounting for 13 percent of the total water budget (Table 6). However, year-to-year changes in groundwater storage were quite variable ranging from an increase of 7,820 acre-feet in 1983 to a decline of 2,852 acre-feet in 1989.

An interesting result of the model calibration was that much of the natural recharge from rainfall and streamflow needed to be shifted into the wetter years to match the basin hydrographs (Table 3). In particular, the most significant amount of recharge was concentrated into the highest rainfall years of 1983, 1995, and 1998. The final model resulted in 50 percent of the total rainfall and stream recharge being included into these three wet years. In contrast, rainfall and stream recharge was significantly reduced during the dry periods. For the seven driest years (1981, 1987, 1989, 1990, 1994, 1996, and 1997) only 1,747 acre-feet of recharge was included in the rainfall and stream recharge, which accounts for only 3 percent of this recharge. This observation is also reflected in the change in storage (Table 6) where groundwater storage increased by 21,187 acre-feet during the three wettest years; however, groundwater storage decreased by 14,353 acre-feet during the seven driest years.

These calibration results indicate that recharge is more episodic in nature for the Cummings Groundwater Basin and that basin recharge is highly dependent on a few high rainfall years. This suggests a conceptual model where groundwater recharge is significantly higher in wet years rather than in drier years. In the wet years, a higher percentage of surface water runoff from the surrounding watershed reaches the valley floor in wet years rather than in drier years, thus resulting in increased groundwater recharge. This may also be true of other high-intensity storms in the region that occur in otherwise low rainfall years.

5.2 ESTIMATE OF PERENNIAL YIELD

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 this estimate of perennial yield, the undesired result is defined as a long-term decline in water levels. As discussed above, the change in storage varies from year to year based on the annual precipitation. Therefore, the 21-year base period is considered an appropriate scale for this evaluation.

The overall water balance based on the calibrated MODFLOW model is 3,906 AFY (Table 6). The most basic form of perennial yield is to add groundwater pumpage plus the change in storage. Total groundwater pumpage is 2,934 AFY. During this time, groundwater storage increased by 510 AFY. Together, these two components contribute 3,444 AFY towards the perennial yield.

The estimated perennial yield can be increased if a portion of the natural groundwater discharge can be captured. The conceptual model for subsurface outflow is that groundwater exits the basin through the fractured granite in the southwestern portion of the basin. Most of this flow cannot be captured. Assuming that 20 percent of this groundwater discharge could be captured would result in an additional 65 AFY of yield. Similar assumptions could be applied to stream discharge and evapotranspiration, which are dependent on groundwater elevations. Assuming 80 percent of this amount is available for capture would produce an additional 135 AFY. Thus, the potential total discharge available for capture is estimated at 200 AFY.

By adding the groundwater pumpage, increase in storage, and potential discharge available for capture, the estimated perennial yield for the Cummings Groundwater Basin based on the MODFLOW 2000 groundwater model is 3,644 AFY. This estimate of perennial yield compares favorably with previous estimates of 4,156 AFY by Tehachapi Soil Conservation District (TSCD 1969) and 3,560 AFY by Mann (1971).

Recharge of imported water to the basin is a managed portion of the perennial yield. For the base period, irrigation return flows from imported water amounted to an average annual recharge of 180 AFY. In addition, artificial recharge applied at the Chanac and Cummings

Recharge Areas from 1995 through 2001. Averaged over the 21-year base period, the artificial recharge accounted for an additional 62 AFY. Therefore, imported water accounted for an average annual total over the 21-year base period of 242 AFY.

6.0 MODEL SCENARIOS

The numerical model can serve as a useful quantitative tool for future planning, management, and evaluation of technical issues. Once the model is calibrated to historical conditions, it is capable of providing realistic forecasts of future groundwater and water quality conditions. For this study, five case scenarios were defined to evaluate various groundwater-related issues and concerns in the basin. These five cases include:

- Scenario 1: Baseline Conditions
- Scenario 2: Extended Severe Drought
- Scenario 3: Population Growth
- Scenario 4: Reuse of CCI Effluent for Irrigation
- Scenario 5: Impact of CCI Groundwater Remediation

Each of these scenarios is discussed in more detail below.

6.1 SCENARIO 1: BASELINE CONDITIONS

The purpose of the first model scenario was to define a baseline case to serve as a basis of comparison for the other scenarios. For the baseline case, a realistic set of assumptions for the future water balance is required. An overall assumption is to repeat the base period conditions from the calibrated model as representative of future conditions. Therefore, the baseline condition was defined by the following:

- Specified recharge from precipitation, stream flows, return flows, bedrock inflow and artificial recharge used the same rates developed for the base period and included in the calibrated model. One exception was made as described below.
- Groundwater pumpage from agricultural, municipal, and domestic wells used the same rates developed for the base period and included in the calibrated model
- Natural discharge components (evapotranspiration, discharge to streams, and subsurface outflow) were set in the model as head dependent boundary conditions rather than specified flux. Therefore, the elevation and conductance values were kept the same; however, the groundwater discharge or outflow from these boundaries will vary with changing groundwater elevations.
- 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.
- The initial groundwater elevations used for the model were changed from the Fall 1980 to Fall 2000 to incorporate the changes in the water levels observed over the base period.

The one exception to the baseline conditions from the calibrated model involved reduction of groundwater recharge due to surface flow from Brite Valley at the upper Chanac

Creek for Model Year 3. In the calibrated model, Model Year 3 represents 1983 which was the highest recorded rainfall year in the 80 year precipitation records for the area. To match the increase in water levels observed in the wells in this area, the recharge was increased to 1,200 acre-feet. However, when running the future case, this amount of recharge caused water levels to reach the ground surface. The model was modified to decrease the recharge in Model Year 3 to 500 acre-feet, which is the value used for 1998 another wet year. This change was included as part of the baseline conditions for all other scenarios.

The results of the baseline scenario are shown on Figures 17 and 18. The groundwater elevation map for Model Year 21 of Scenario 1 (Figure 17) is highly similar to the same period in the calibrated model (Figure 11). Water levels are generally higher for Scenario 1 due to the same water budget being applied but with a higher starting groundwater elevation. Figure 18 provides a difference map comparing groundwater elevations in Layer 3 for Model Year 21 between the calibrated model and Scenario 1. The highest water level increase is in the northern portion of the basin. Modest water level increases occurred in the western portion of the basin. Subsurface outflow in the southwestern corner of the basin provides a limiting factor on water level increases in this portion of the basin. Two areas of lower groundwater elevations occur in the north and southeast. These are located in the same areas where the decreasing trends were observed during the model calibration. Therefore, these trends would continue during this scenario as well. These areas also have high hydraulic gradients and the magnitude of the decrease represents only a minor shift in the hydraulic gradient.

These increases also vary over time as shown by model hydrographs across the basin. Figure 19 presents 6 hydrographs that show a comparison of the simulated results of the calibration versus Scenario 1. This is primarily to illustrate that water levels follow the same trend, as they should considering how the scenario was set up. The primary difference is the difference in the initial groundwater elevation.

The calibrated model produced an increase in storage of 10,708 acre-feet over the model period resulting in a general increase in groundwater elevations across the basin. Scenario 1 produced an increase in storage of 7,815 acre-feet over the model period. Water levels increased across the basin (Figure 18). In parts of the model domain, water levels reached near the ground surface where higher groundwater discharge to surface water and evapotranspiration accounted for the difference in storage.

6.2 SCENARIO 2: EXTENDED SEVERE DROUGHT

The purpose of Scenario 2 was to evaluate the impact of a severe drought on groundwater elevations in the basin. For this analysis, a “severe” drought was assumed to constitute a rainfall pattern similar to that seen in the 5-year period from 1959-63, when rainfall averaged 7.77 inches per year. The rainfall data for the simulated drought was based on historical data of the five continuous years with the lowest recorded rainfall. These rainfall rates for these years are:

1959 – 4.29 inches
1960 – 8.73 inches

1961	–	7.29 inches
1962	–	10.45 inches
1963	–	8.09 inches

The five-year drought period was input in the model as Model Years 1 through 5. The recharge components that are dependent upon precipitation were reduced accordingly for those years. These components include:

- Direct percolation of precipitation on the valley floor was reduced from a base period value of 6,259 acre-feet to 660 acre-feet over the 5-year drought period.
- Streamflow recharge was reduced from a base period value of 5,090 acre-feet to 307 acre-feet over the 5-year drought period.
- Scenario 2 has an identical water balance as Scenario 1 for Model Years 6 through 21.
- All other conditions were unchanged from the baseline conditions.

The results of Scenario 2 are shown on Figures 20, 21 and 22. The groundwater elevation map at the end of Model Year 5 (Figure 20), which is the last year of the simulated drought period, shows changes in the groundwater elevation pattern when compared to Scenario 1 (Figure 17). The groundwater elevation difference map (Figure 21) for this same time period illustrates these changes more clearly. The greatest impact occurs along the basin margins near the stream recharge locations. The largest water level declines occurred along Cummings Creek, the northern basin along Chanac Creek and in the northwestern portion of the basin. Groundwater elevations declined by over 30 feet relative to the baseline scenario in these areas with declines over 50 feet occurring in localized areas near recharge areas (Figure 21). In the center of the basin, water level declines were generally between 10 to 30 feet below the baseline scenario (Figure 21). The least impact was found in the southwestern portion of the basin where water level declines were generally less than 10 feet (Figure 21). As a discharge point, groundwater continues to flow towards the subsurface discharge point and thus mitigates the impact.

The water balance for Scenario 2 has a net decrease in recharge of 14,788 acre-feet, which occurs only in Model Years 1 through 5. Groundwater discharge decreased accordingly. The subsurface outflow, discharge to streams, and evapotranspiration decreased 10, 90, and 70 percent, respectively, accounting for an approximately 7,220 acre-foot difference with Scenario 1. These changes also extended over the entire 21-year model period rather than restricted to the simulated drought period. The change in groundwater storage also shifted from an increase in storage to a decrease. The change in groundwater storage for Scenario 2 decreased by about 3,200 acre-feet, reflecting a 7,530 acre-foot change in storage relative to Scenario 1.

Hydrographs illustrate the impact of the drought over an extended period of time including the years after the drought period. In the northern and central portion of the basin, the groundwater elevations decline by about 30 feet. After the drought period in Model Years 1 through 5, the groundwater elevations tend to parallel the Scenario 1 results since Scenario 2 has an identical water balance as Scenario 1 for Model Years 6 through 21. This indicates that lost recharge is not recovered over time. The results of Scenario 2 support the conceptual model that basin recharge is strongly influenced by very high rainfall years.

6.3 SCENARIO 3: POPULATION GROWTH

Scenario 3 was developed to evaluate the potential impact of increased municipal pumping in Cummings Basin due to population growth in nearby residential areas and by the CCI facility. The conditions for this scenario include:

- Groundwater pumping by CCI was set at 1,150 acre-feet per year that was distributed evenly between two CCI wells. A total production of 650 acre-feet was applied only to the summer stress period and 500 acre-feet during the winter stress period.
- Total water production from five Bear Valley (BVCSD) wells was set at 1000 acre-feet per year. The BVCSD production was applied only to the summer stress period with no production from these wells during the winter stress period. The pumping rates were distributed as follows:

BVCSD Well #1	–	177 acre-feet
BVCSD Well #2	–	156 acre-feet
BVCSD Well #3	–	67 acre-feet
BVCSD Well #4	–	156 acre-feet
BVCSD Well #5	–	444 acre-feet

- One new well was added to the model to simulate future pumping by the Stallion Springs (SSCSD) in the center of the basin. A total production of 480 acre-feet was applied only to the summer stress period with no production during the winter stress period.
- Groundwater recharge was added to simulate the equivalent State Water Project (SWP) recharge applied by TCCWD. The total recharge was assumed as:
    - ❑ 1,000 acre-feet per year (100%) of BVCSD production
    - ❑ 312 acre-feet per year (65%) of SSCSD production
    - ❑ 350 acre-feet per year (30%) of the CCI production
- Recharge of SWP water was distributed between the Chanac Creek and the Cummings Recharge Areas.
- All others were left at the baseline conditions.

Scenario 3 results are shown on Figures 23, 24 and 25. The groundwater elevation map at the end of Model Year 21 (Figure 23) shows a similar pattern when compared to Scenario 1 (Figure 17). The groundwater elevation difference map (Figure 24) more clearly illustrates these changes. Water levels decline in excess of 10 feet over a wide area of the northern and central portion of the basin (Figure 24). This pattern of impact is as would be expected with the greatest decreases in water levels occurring in the vicinity of the increased pumping by CCI, BVCSD, and SSCSD. Only minor decreases in water levels occur in the southwestern portion of the basin.

Increases in water levels occur in the vicinity of the two recharge areas, Chanac Creek and Cummings Fan. In setting up Scenario 3, it was determined that the Chanac Recharge Area was not able to accept all of the recharge for this scenario, so the excess was shifted to the Cummings Recharge Area. This indicates that there may be a hydraulic limit to the amount of water that can be recharged at the Chanac Recharge Area. The relatively thin aquifer thickness and eroded channel of Chanac Creek limit the amount of groundwater that can flow through this area. Long-term sustained recharge causes the water to back up into the creek. The evaluation of whether Chanac Recharge Area has the capacity to accept large volumes of sustained recharge over long periods of time is dependent on localized conditions that are not necessarily reflected in the model. The model was constructed using available data. It is recommended that an additional site-specific evaluation be conducted before sustained recharge is planned for the Chanac Recharge Area.

The change in groundwater storage for Scenario 3 decreased by approximately 2,950 acre-feet, reflecting a 7,300 acre-foot change in storage relative to Scenario 1. In addition, groundwater discharge to streams increased. This increase primarily occurs near the Chanac Recharge Area. This observation further supports that there is a physical limit to the amount of recharge that can be applied at this location. Subsurface outflow and evapotranspiration is relatively unchanged relative to Scenario 1.

Hydrographs illustrate the changes in groundwater levels over time for Scenario 3 relative to the baseline scenario (Figure 25). Near the increased pumping areas, groundwater elevations show significant declines especially in the summer months when the high pumping rates are active. Outside the area of influence of these increased pumping wells, only minor changes in water levels are observed.

6.4 SCENARIO 4: REUSE OF CCI EFFLUENT FOR IRRIGATION

The purpose of Scenario 4 was to evaluate the benefit of using CCI treated wastewater effluent for irrigation water for nearby agricultural areas in lieu of either pumped groundwater or imported water. For this scenario, it was assumed that 1,000 AFY of treated wastewater is available from the CCI wastewater disposal facility. Instead of applying this water as recharge at the CCI spreading ponds and spray fields, the 1,000 AFY would be rerouted to nearby agricultural areas for irrigation of sod in Sections 25 and 30 (T32S/R32E). The input parameters applied for Scenario 4 included:

- Groundwater pumping by CCI was set at 1,150 acre-feet per year, which was distributed evenly between the two CCI wells. A total production of 650 acre-feet was applied only to the summer stress period and 500 acre-feet during the winter stress period.
- In Section 25, 580 AFY of wastewater was assumed to be used for irrigation and replacing the groundwater pumping and imported water. The irrigation return flow for this volume is 87 AFY, assuming 15 percent of this water recharges groundwater as irrigation return flow.
- In Section 30, 420 AFY of wastewater was assumed to be used for irrigation and replacing the groundwater pumping and imported water. The irrigation return flow for

this volume is 63 AFY, assuming 15 percent of this water recharges groundwater as irrigation return flow.

- Groundwater pumping wells were eliminated from Sections 25 and 30 (T32S/R32E) using the assumption that the reuse of CCI effluent was sufficient to meet the irrigation demand. A total of 8,464 acre-feet of agricultural pumpage was replaced.
- No imported water was included in the return flow recharge for Sections 25 and 30 (T32S/R32E) using the assumption that the CCI effluent was sufficient to meet the irrigation demand.
- Groundwater recharge of 350 acre-feet per year or 30 percent of the CCI production was added to the Chanac Recharge area to simulate the equivalent State Water Project (SWP) recharge applied by TCCWD. This recharge was added to the baseline conditions for Chanac Creek.
- All others conditions were left at the baseline conditions.

Scenario 3 results are shown on Figures 26, 27 and 28. The groundwater elevation map at the end of Model Year 21 (Figure 26) shows a similar pattern when compared to Scenario 1 (Figure 17). The groundwater elevation difference map (Figure 27) shows that the changes related to this scenario are localized. The primary change is a buildup of groundwater near the Chanac Recharge Area where water levels are shown to increase by up to 30 feet (Figure 27). This further illustrates (similar to Scenario 3) that there may be a physical limit to the recharge capacity at Chanac Creek. Another notable change reflects the distribution of pumping for CCI from two wells in Scenario 4 rather than one well in Scenario 1. The change in the drawdown pattern is reflected on Figure 27.

A 10-foot increase in water levels in the center of the basin in T32S/R31E section 25 is the result of taking groundwater extraction wells offline and replacing that agricultural pumpage with the treated CCI effluent water (Figure 27). However, a similar increase is not found in T32S/R32E section 30. This is because the land use calculations from the Task 1 Report (Fugro and ETIC 2003) had indicated that these areas had almost exclusive use of imported water at this time and little groundwater pumpage had occurred. The net impact then was to replace the return flow component from imported water with CCI effluent water.

The net groundwater pumpage for Scenario 4 was 1,182 acre-feet less than for Scenario 1. This represents the difference of the 8,464 acre-feet of agricultural pumpage taken offline versus the net 7,282 acre-foot increase over the Scenario 1 pumpage for the CCI, BVCSD and SSCSD water supply wells. From the water balance, Scenario 4 produced a net increase in the total groundwater recharge of approximately 6 percent, representing an approximately 4,900 acre-foot increase over the 21-year simulation period relative to Scenario 1. The majority of this water went towards increasing groundwater storage. Storage increased by 2,850 acre-feet in Scenario 4 relative to Scenario 1. Another 1,600 acre-feet were discharged to streams, primarily Chanac Creek. These increases were greatest toward the later model years and during high rainfall years. The net change in groundwater pumpage due to increased CCI pumping but lower agricultural pumping in the affected area was only a 56 acre-feet decrease over the 21-year base period.

Well hydrographs illustrate the changes in groundwater levels over time for Scenario 4 relative to the baseline scenario (Figure 28). Differences were more pronounced during the Model Years 8 through 19, when the CCI effluent recharge replaced a higher percentage of pumped groundwater rather than imported water (Figure 28). Water level increases of approximately 20 feet occurred at well 32S/32E-20M2 near the Chanac Recharge Area (Figure 28). Elsewhere in the basin only minor impacts, if any, were observed.

6.5 SCENARIO 5: IMPACT OF CCI GROUNDWATER REMEDIATION

Scenario 5 was developed to evaluate the potential impact to the overall groundwater resource in the basin from increased pumping due to the remediation of a Methyl tertiary Butyl Ether (MTBE) plume associated with the motor pool area at the CCI facility (AMEC 2001, 2003a, 2003b). The MODFLOW model was used to provide a reasonable estimate of the volume of water and time necessary to remediate the impacted groundwater at the CCI motor pool site. The scenario results were then evaluated to determine the impact of this added groundwater extraction to the perennial yield of the basin. The input parameters applied for Scenario 5 included:

- Development of an initial concentration distribution of MTBE based on reports of site data at the CCI facility (AMEC 2003c).
- Assumed a declining source area concentration based on a first order decay rate to represent non-groundwater source area remediation such as soil vapor extraction.
- Assumed groundwater pumping for the remediation equivalent to pumping at 50 gallons per minute (gpm) over the 21-year model period applied to all three model layers simultaneously.
- All others conditions were left at the baseline conditions.

Chemical transport modeling for compounds such as MTBE typically requires smaller grid spacing than for groundwater flow alone because MTBE concentrations vary significantly across short distances. Additional horizontal resolution was required to properly handle these large concentration gradients for the chemical transport model. Therefore, the variably spaced grid was developed for this scenario. This approach reduced the grid size from 110 to 11 feet with the smallest grid spacing centered over the MTBE plume in the CCI motor pool area.

To simulate the source area, a declining mass source term was used. The MTBE concentration at the source was decreased over time using a first order decay rate as shown in Figure 29. The MTBE source term was input as a specified mass flux based on a volumetric flux equivalent to approximately 0.02 gpm. This provided for a more realistic scenario with some remaining source impacting groundwater over time, but assumes that source area remediation measures are effectively implemented and that no new releases occur during the 21-year model period.

The transport simulation was performed using MT3D (Zheng and Wang, 1999) which is designed to work with MODFLOW. For the transport simulation, additional transport parameters are required. The model assumed a longitudinal dispersivity of 100 feet, a transverse dispersivity of 10 feet, and a vertical dispersivity of 1 foot. Dispersivity is the term that represents the spreading of the plume by microscale processes beyond the resolution of the model grid. No degradation of MTBE was assumed for Scenario 5. Retardation of MTBE transport relative to groundwater flow velocity was considered minimal because MTBE is considered a highly mobile solute with limited adsorption and degradation capacity. A retardation rate of 1.1 is assumed for Scenario 5.

Scenario 5 assumes that groundwater pumping for the MTBE remediation occurs at three separate well locations. The total pumping rate of 50 gpm to hydraulically control the MTBE plume was determined using the calibrated groundwater model. The extraction wells were located along the centerline of the plume (Figure 30). The well closest to the source represents source area remediation at 10 gpm, the location farthest from the source is for downgradient hydraulic control at 20 gpm, and the middle location is for mass removal of the existing plume at 20 gpm. This pumping was applied to the three model layers simultaneously using the analytical element option within Groundwater Vistas (ESI 2001). The model distributed the pumping at each location proportional to the transmissivity of each layer.

Figure 30 illustrates the resulting groundwater elevations and MTBE concentrations as a result of the simulated groundwater remediation of the MTBE plume for Model Year 21. Little impact in groundwater elevations is noted away from the CCI facility. The maximum MTBE concentration has fallen below 25 ug/L by this time. The groundwater pumping used for the remediation for this scenario is approximately 80 AFY, which results in 1,680 acre-feet of groundwater extraction over the 21-year model period. This represents 2 percent of the total perennial yield for the groundwater basin.

It is important to note that site-specific conditions are important to a local-scale remediation represented in Scenario 5. The available site-specific data has been represented in this model, but has necessarily been averaged. Site specific data such as the location of thin, high-permeability layers are important to local-scale remediation projects. Therefore, alternative remedial plans may be employed at the site. More aggressive remediation plans may use higher pumping rates for shorter time duration. For example, using 100 gpm over 10 years may be a more cost-effective option. This type of remediation plan would result in groundwater extraction of 4 percent of the total perennial yield for the groundwater basin. Therefore, changes in MTBE concentrations should be observed to evaluate the potential impact of the groundwater remediation on the perennial yield of the basin.

Scenario 5 assumes that groundwater remediation begins concurrent with the MTBE concentration distribution based on samples collected in June 2003 (AMEC 2003c). Delaying the implementation of the remediation may result in more downgradient spreading of the plume that requires a more extensive well field to capture the plume and meet similar regulatory requirements. Therefore, the results of Scenario 5 should be viewed as a reasonable estimate of the long-term pumping that will be required to reduce MTBE concentrations to within regulatory requirements.

7.0 CONCLUSION

The Groundwater Modeling Study for the Cummings Groundwater Basin documents the development, calibration, and application of a three-dimensional numerical groundwater model for the basin.

7.1 SUMMARY

A numerical groundwater model was constructed for the Cummings Groundwater Basin using MODFLOW 2000 (Harbaugh et al 2000). The numerical model was primarily based on hydrogeological and water budget data as part of the Task 1 Report (Fugro and ETIC 2003) over a base period from 1981 through 2001. The model was calibrated to observed groundwater elevation data from 92 basin wells to reduce uncertainty in assigning aquifer properties. The results of the calibration

- The year-to-year distribution of rainfall and stream flow recharge was shifted from the dry years to the wet years; however, the 21-year base period recharge total for these two components was within the range of the Task 1 Report (Fugro and ETIC 2003).
- The agricultural pumpage applied in the model was increased indicating that TCCWD's estimates of agricultural usage were low.
- The model calibration showed good agreement between simulated and observed data for groundwater elevation maps, statistical analysis, and well hydrographs. The calibration results showed a strong correlation coefficient of 0.976 (Figure 12).

Calibrating the model to historical data over a 21-year base period demonstrates the ability of the numerical model to accurately represent hydrogeological conditions observed in the field. Based on the model results, a water balance and perennial yield for the basin were calculated.

- The calibrated MODFLOW model produced an overall water balance with an average annual of 3,906 AFY (Table 6).
- A perennial yield of 3,644 AFY was estimated based on the calibrated numerical model results.

The calibration demonstrated that the numerical model could reasonably reproduce historical conditions in the Cummings Groundwater Basin for the 21-year base period. This provides the basis of confidence that the model can reasonably forecast future conditions. Five scenarios were run for the Groundwater Modeling Study. These included:

- Scenario 1 that defined the baseline conditions, which formed the basis of comparison for the other scenarios.
- Scenario 2 that simulated an extended severe drought. This simulation showed a general decrease in water levels across the basin that persisted even after the drought. Water levels declines were most pronounced near the stream recharge areas and least pronounced in the southwestern portion of the basin.

- Scenario 3 that simulated the impact of increased water demand by service districts due to population growth. Imported water was used as groundwater recharge to maintain the water balance; however, the model suggests that there may be a physical limit to the amount of recharge that could be accepted at the Chanac Recharge Area.
- Scenario 4 that simulated the reuse of CCI effluent for irrigation for nearby agriculture. Water levels increased in these areas as groundwater pumping was taken offline.
- Scenario 5 that evaluated the impact of the CCI groundwater remediation of an MTBE plume on basin water supplies. This scenario indicates that continuous groundwater pumping of about 50 gpm over 20 years may be necessary for remediation resulting in a water demand of about 80 AFY. Alternatively, groundwater extraction at 100 gpm (160 AFY) may be necessary to complete the remediation over a 10-year period.

7.2 REC0MMENDATIONS

The calibrated model is designed to provide TCCWD with a tool to assist with long-term planning of groundwater management issues for the basin. One benefit of producing a numerical model is to identify areas where additional data collection would be most beneficial in understanding the basin system. A summary of the recommendations included in this report include:

- Compile and maintain a long-term database of groundwater pumpage data from metered agricultural and other wells in the basin.
- Perform a comprehensive watershed analysis to quantitatively evaluate the variable runoff between wet and dry years including the potential impact of single, high-intensity storms. This analysis should also identify the locations where runoff would most likely impact the groundwater basin.
- Evaluate the capacity of the Chanac Recharge Area to accept long-term intensive groundwater recharge.
- Closely observe MTBE remediation activities in an effort to evaluate the potential impact on the perennial yield of the basin.

8.0 REFERENCES

AMEC Earth and Environmental, Inc. (2001), *Site Assessment Report, California Correctional Institution, 24900 State Highway 202, Tehachapi, California*, KCDEHS Case No. 600028, September 2001.

AMEC Earth and Environmental, Inc. (2003a), *Additional Site Assessment and Aquifer Testing Report, California Correctional Institution, 24900 State Highway 202, Tehachapi, California*, *KCDEHS Case No. 600028.* April 2003.

AMEC Earth and Environmental, Inc. (2003b), *Interim Remedial Action Plan, Tehachapi Motor Pool, California Correctional Institution, 24900 State Highway 202, Tehachapi, California*, *KCDEHS Case No. 600028.* July 2003.

AMEC Earth and Environmental, Inc. (2003c), *Quarterly Groundwater Monitoring and Treatment System Progress Report, Motor Pool Site, Fourth Quarter 2002, and First and Second Quarter 2003, KCDEHS Case No. 600028, California Correctional Institution, 24900 State Highway 202, Tehachapi, California*, August 13, 2003.

Bear, J. and A. Verruijt, 1987. Modeling Groundwater Flow and Pollution, D. Reidel Publishing Company, Boston, 414 p.

Environmental Simulations International (ESI), 2001. Guide to Using Groundwater Vistas Version 3, Environmental Simulations, Inc., Herndon, VA, 266 p.

Freeze, R. A. and J. A. Cherry, 1979. Groundwater, Prentice-Hall, Englewood Cliffs, New Jersey.

Fugro West and ETIC Engineering, 2003, Task 1 Interim Report, Data Collection and Conceptual Hydrogeological Model, Cummings Groundwater Basin Study. Report prepared for the Tehachapi-Cummings County Water District, July 2003, 20 pp, 9 apps, and 27 figs.

Harbaugh, A.W., E.R. Banta, M.C. Hill and M.G. McDonald, 2000. MODFLOW 2000, The U.S. Geological Survey Modular Ground-Water Model – User Guide to Modularization Concepts and the Ground-water Flow Process, U.S. Geological Survey Open-File Report 00-92, Reston, Virginia.

Mann, J.F., 1971, *Safe Yield – Cummings Basin*, Letter Report, June 9, 4 pp, 2 tabs.

Michael-McCann Associates, 1962, *Geology Ground-Water Survey, Tehachapi Soil Conservation District, Kern County, California*, report prepared for the Tehachapi Soil Conservation District (TSCD), November.

Snyder, R.L., W.O. Pruitt, and D.A. Shaw, 1992, Determining Daily Reference Evapotranspiration (ETo), U.C. Publication 21426, University of California Division of Agriculture and Natural Resources (ANR) Publications, Oakland, CA, 22 p.

Tehachapi Soil Conservation District (TSCD), 1969, *Tehachapi Comprehensive Soil and Water Conservation Planning Project Report* (Tehachapi Project Report).

Todd, D.K., 1980, Groundwater Hydrology, 2nd edition, John Wiley & Sons, New York, 535 p.

Zheng, C. and Wang, P., 1999. MT3DMS: A Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide. U.S. Army Corps of Engineers. December 1999.

TABLES

Table 1: Groundwater Recharge Components from Task 1 Report (Fugro and ETIC 2003)

Year	Rainfall Recharge (acre-feet)	Stream Recharge (acre-feet)	Return Flows (acre-feet)	Artificial Recharge (acre-feet)	Bedrock Inflow (acre-feet)	Recharge Total (acre-feet)
1981	1,302	1,629	364	0	530	**3,825**
1982	971	1,099	388	0	530	**2,988**
1983	1,522	2,000	320	0	530	**4,372**
1984	883	652	326	0	530	**2,391**
1985	927	1,018	332	0	530	**2,807**
1986	883	897	364	0	530	**2,674**
1987	905	937	407	0	530	**2,779**
1988	1,390	1,899	599	0	530	**4,418**
1989	728	407	641	0	530	**2,306**
1990	243	41	619	0	530	**1,433**
1991	530	81	559	0	530	**1,700**
1992	1,103	1,303	582	0	530	**3,518**
1993	1,721	2,000	593	0	530	**4,844**
1994	618	122	705	0	530	**1,975**
1995	1,897	2,000	713	0	530	**5,140**
1996	640	163	788	41	530	**2,162**
1997	662	143	847	41	530	**2,223**
1998	2,912	2,000	759	333	530	**6,534**
1999	684	244	870	108	530	**2,436**
2000	684	183	980	81	530	**2,458**
2001	860	448	1,074	701	530	**3,613**
Total (acre-feet)	**22,063**	**19,266**	**12,830**	**1,305**	**11,130**	**66,594**
21-Year Average (AFY)	**1,051**	**917**	**611**	**62**	**530**	**3,171**
Percent of Total	**33%**	**29%**	**19%**	**2%**	**17%**	**100%**

Table 2: Groundwater Discharge Components from Task 1 Report (Fugro and ETIC 2003)

Year	Ag Pumpage (acre-feet)	Other Pumpage (acre-feet)	Bedrock Outflow (acre-feet)	Stream Discharge (acre-feet)	Evapotran-spiration (acre-feet)	Discharge Total (acre-feet)
1981	1,441	625	44	0	0	**2,110**
1982	1,438	700	44	0	0	**2,182**
1983	1,250	590	44	0	0	**1,884**
1984	1,249	610	44	0	0	**1,903**
1985	1,253	625	44	0	0	**1,922**
1986	1,248	750	44	0	0	**2,042**
1987	1,251	750	44	0	0	**2,045**
1988	1,752	1,165	44	0	0	**2,961**
1989	1,904	1,071	44	0	0	**3,019**
1990	1,023	848	44	0	0	**1,915**
1991	1,028	933	44	0	0	**2,005**
1992	1,116	810	44	0	0	**1,970**
1993	1,024	820	44	0	0	**1,888**
1994	1,017	810	44	0	0	**1,871**
1995	1,584	610	44	0	0	**2,238**
1996	477	1,465	44	0	0	**1,986**
1997	484	1,624	44	0	0	**2,152**
1998	470	1,466	44	0	0	**1,980**
1999	467	1,131	44	0	0	**1,642**
2000	1,211	1,480	44	0	0	**2,735**
2001	3,236	1,614	44	0	0	**4,894**
Total (acre-feet)	**25,923**	**20,497**	**924**	**0**	**0**	**47,344**
21-Year Average (AFY)	**1,234**	**976**	**44**	**0**	**0**	**2,254**
Percent of Total	**55%**	**43%**	**2%**	**0%**	**0%**	**100%**

Table 3: Model-Based Groundwater Recharge Components

Year	Rainfall Recharge (acre-feet)	Stream Recharge (acre-feet)	Return Flows (acre-feet)	Artificial Recharge (acre-feet)	Bedrock Inflow (acre-feet)	Recharge Total (acre-feet)
1981	110	122	448	0	530	**1,210**
1982	1,296	3,807	473	0	530	**6,106**
1983	4,413	5,336	380	0	530	**10,659**
1984	220	907	337	0	530	**1,994**
1985	220	652	351	0	530	**1,753**
1986	330	1,218	384	0	530	**2,461**
1987	110	163	438	0	530	**1,241**
1988	1,296	1,803	704	0	530	**4,333**
1989	110	81	711	0	530	**1,432**
1990	110	41	717	0	530	**1,398**
1991	330	1,237	671	0	530	**2,768**
1992	1,296	1,836	672	0	530	**4,334**
1993	2,206	3,649	622	0	530	**7,007**
1994	110	143	676	0	530	**1,459**
1995	4,413	4,420	767	0	530	**10,129**
1996	110	183	794	41	530	**1,658**
1997	110	244	822	41	530	**1,747**
1998	4,413	4,370	776	333	530	**10,422**
1999	330	1,196	868	108	530	**3,031**
2000	220	448	890	81	530	**2,169**
2001	1,296	1,138	1,046	701	530	**4,712**
Total (acre-feet)	**23,049**	**32,676**	**13,782**	**1,305**	**11,130**	**82,022**
21-Year Average (AFY)	**1,098**	**1,556**	**656**	**62**	**530**	**3,906**
Percent of Total	**28%**	**40%**	**17%**	**1%**	**14%**	**100%**

Table 4: Model-Based Groundwater Discharge Components

Year	Ag Pumpage (acre-feet)	Other Pumpage (acre-feet)	Bedrock Outflow (acre-feet)	Stream Discharge (acre-feet)	Evapotran-spiration (acre-feet)	Discharge Total (acre-feet)
1981	2,123	625	244	0	35	**3,027**
1982	2,005	700	241	0	104	**3,050**
1983	1,650	590	318	25	256	**2,839**
1984	1,449	610	303	18	135	**2,516**
1985	1,420	625	287	0	108	**2,439**
1986	1,464	750	279	0	107	**2,600**
1987	1,868	750	278	1	86	**2,982**
1988	2,892	1,165	295	5	109	**4,466**
1989	2,853	1,071	281	1	77	**4,283**
1990	2,172	848	266	0	55	**3,341**
1991	2,177	933	262	0	71	**3,443**
1992	2,265	810	274	0	86	**3,434**
1993	1,807	820	299	1	136	**3,063**
1994	1,634	810	285	1	97	**2,827**
1995	2,451	610	352	19	331	**3,764**
1996	2,123	1,465	324	13	181	**4,106**
1997	1,866	1,624	293	7	126	**3,916**
1998	1,191	1,466	355	21	389	**3,421**
1999	1,134	1,131	335	18	284	**2,901**
2000	1,211	1,480	312	16	250	**3,270**
2001	3,371	1,614	310	37	286	**5,618**
Total (acre-feet)	**41,122**	**20,497**	**6,193**	**184**	**3,309**	**71,306**
21-Year Average (AFY)	**1,958**	**976**	**295**	**9**	**158**	**3,396**
Percent of Total	**58%**	**29%**	**9%**	**0%**	**4%**	**100%**

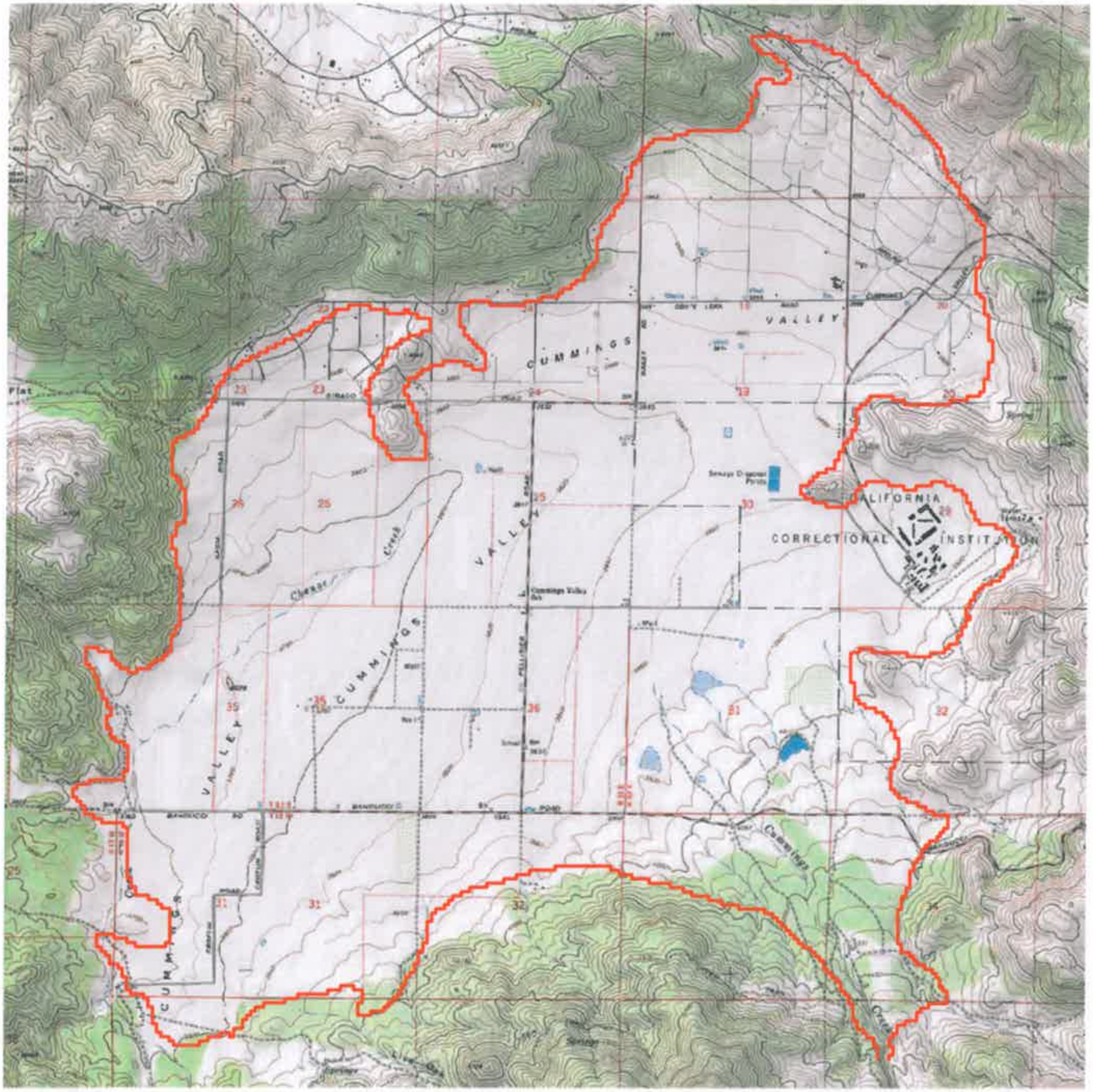
Table 5: Summary of Groundwater Pumpage by Section Added to Task 1 Report Water Balance (Fugro and ETIC 2003) for the Numerical Model

Year	T32S/R31E 25	T32S/R32E 30	T32S/R32E 31	T32S/R31E 35	T32S/R31E 36	Total
1981	0	167	200	0	315	**682**
1982	0	167	200	0	200	**567**
1983	0	0	200	0	200	**400**
1984	0	0	0	0	200	**200**
1985	0	167	0	0	0	**167**
1986	0	167	0	0	0	**167**
1987	0	167	0	135	315	**617**
1988	167	167	0	500	315	**1,149**
1989	167	167	0	500	115	**949**
1990	167	167	0	500	315	**1,149**
1991	167	167	0	500	315	**1,149**
1992	167	167	0	500	315	**1,149**
1993	167	167	0	135	315	**783**
1994	167	0	0	135	315	**617**
1995	417	0	0	135	315	**867**
1996	417	0	0	914	315	**1,646**
1997	417	0	0	851	115	**1,383**
1998	417	0	0	135	115	**667**
1999	417	0	0	135	115	**667**
2000	0	0	0	0	0	**0**
2001	0	0	0	135	0	**135**
Total (acre-feet)	**3,275**	**1,863**	**631**	**5,242**	**4,251**	**15,105**
Average (AFY)	**156**	**89**	**30**	**250**	**202**	**719**

Table 6: Model-Based Water Balance Summary

Year	Recharge Total (acre-feet)	Discharge Total (acre-feet)	Groundwater Storage Change (acre-feet)	Annual Water Balance (acre-feet)
1981	1,210	3,027	-1,815	1,211
1982	6,106	3,050	3,058	6,107
1983	10,659	2,839	7,820	10,659
1984	1,994	2,516	-524	1,993
1985	1,753	2,439	-685	1,754
1986	2,461	2,600	-138	2,462
1987	1,241	2,982	-1,741	1,241
1988	4,333	4,466	-133	4,333
1989	1,432	4,283	-2,852	1,432
1990	1,398	3,341	-1,940	1,400
1991	2,768	3,443	-674	2,768
1992	4,334	3,434	901	4,335
1993	7,007	3,063	3,949	7,010
1994	1,459	2,827	-1,383	1,452
1995	10,129	3,764	6,370	10,131
1996	1,658	4,106	-2,454	1,655
1997	1,747	3,916	-2,168	1,747
1998	10,422	3,421	6,997	10,420
1999	3,031	2,901	125	3,029
2000	2,169	3,270	-1,101	2,169
2001	4,712	5,618	-906	4,712
Total (acre-feet)	82,022	71,306	10,708	82,018
21-Year Average (AFY)	3,906	3,396	510	3,906

FIGURES



Legend

Basin Boundary

N
W E
S

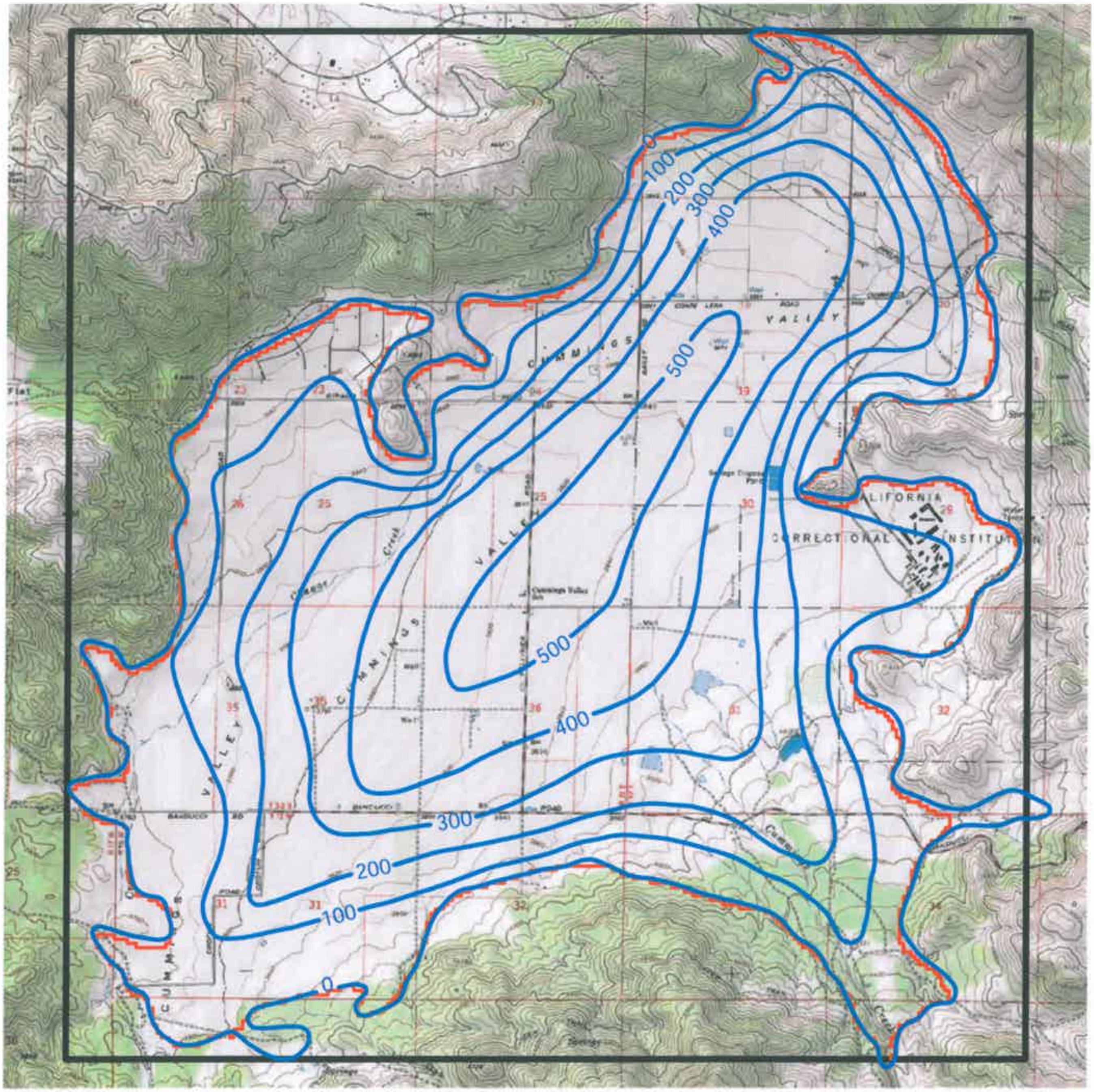
4,000
Feet

CUMMINGS GROUNDWATER BASIN LOCATION MAP

Cummings Basin Groundwater Modeling Study
December 2003

Filename: Figure 1.mxd	Project No.: 3267.001.01

ETIC ENGINEERING | FIGURE 1 | FUGRO



Legend

- Thickness of Alluvial Sediments Contour (feet)
- Model Domain Boundary
- Basin Boundary

N
W E
S

4,000
Feet

NUMERICAL MODEL DOMAIN WITH ALLUVIAL SEDIMENT THICKNESS

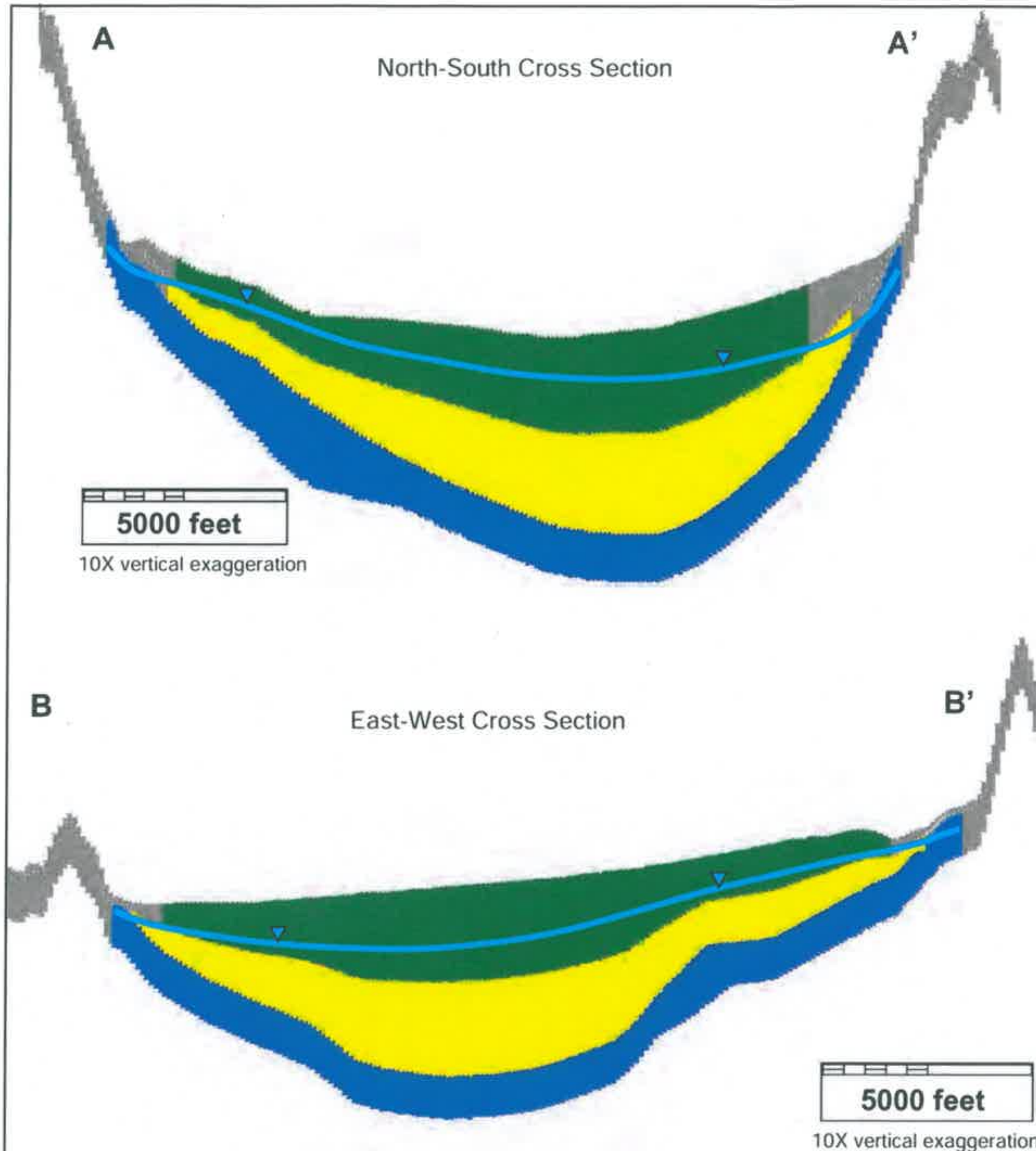
Cummings Basin Groundwater Modeling Study
December 2003

Filename: Figure 2.mxd | Project No.: 3267.001.01

ETIC ENGINEERING

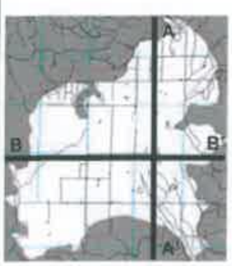
FIGURE 2

FUGRO



Legend

- Approximate Top of Groundwater
- Model Layer 1
- Model Layer 2
- Model Layer 3
- Inactive Cells



TYPICAL NUMERICAL MODEL CROSS SECTIONS SHOWING MODEL LAYERS

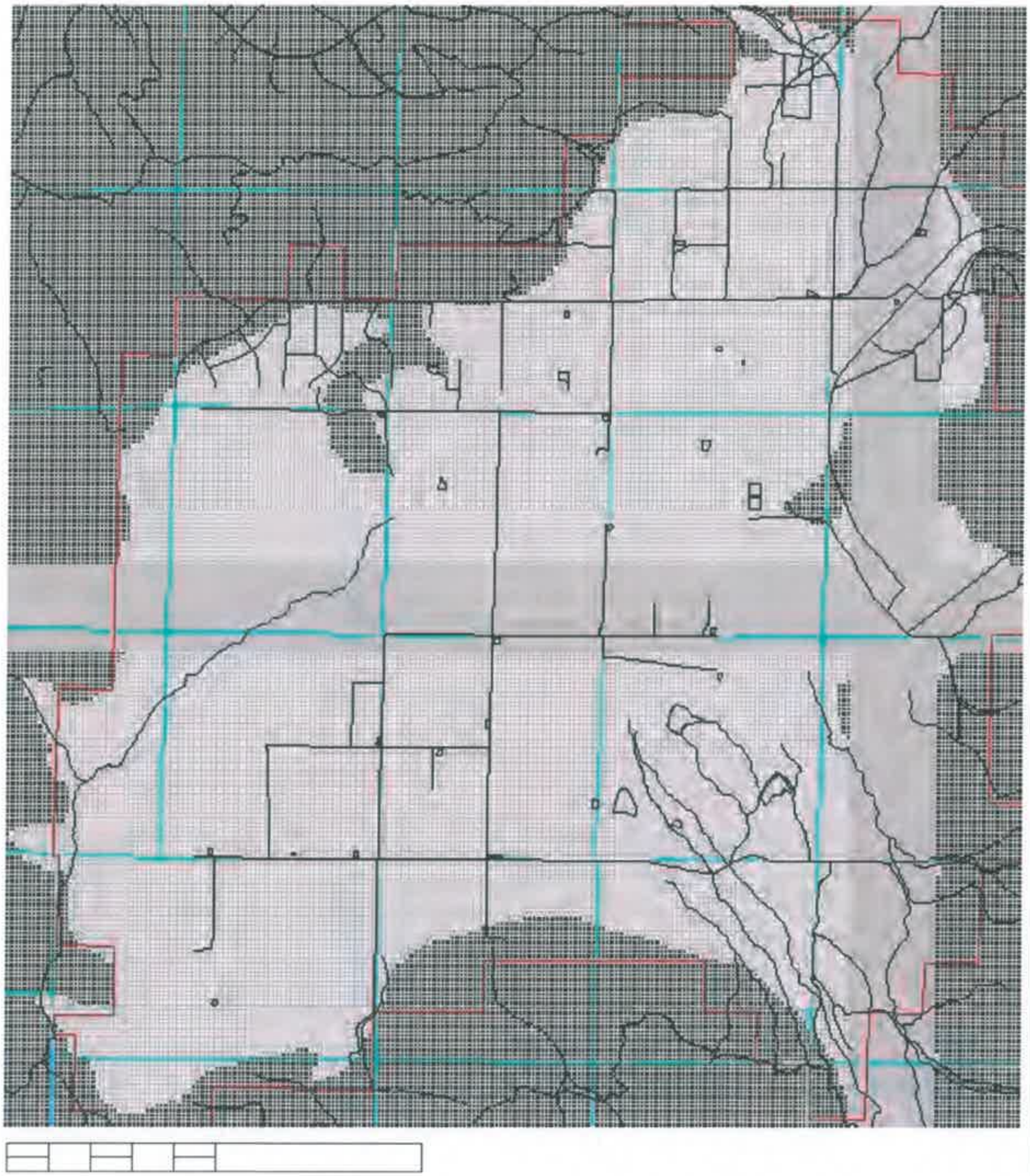
Cummings Basin Groundwater Modeling Study
December 2003

Filename: model maps.ppt	Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE
3

FUGRO



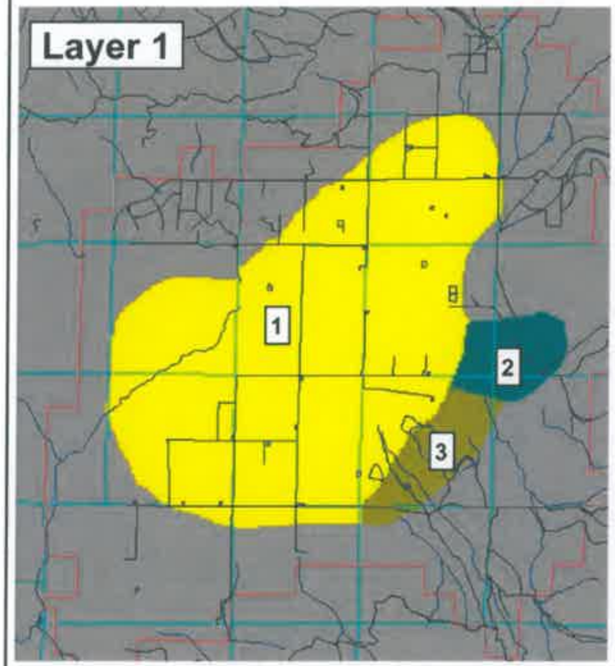
10,000 feet

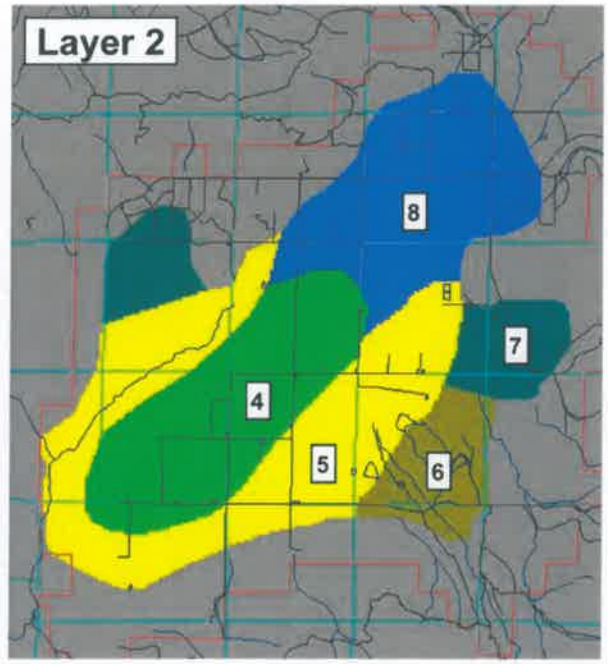
NUMERICAL MODEL GRID

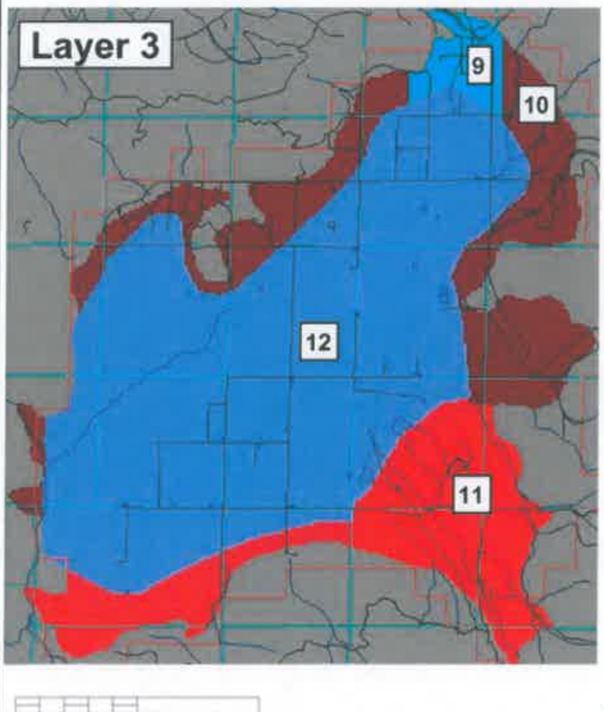
Cummings Basin Groundwater Modeling Study
December 2003

Filename: Diff Plots.ppt	Project No.: 3267.001.01

ETIC ENGINEERING	FIGURE 4	FUGRO







10000 feet

Zone	Horizontal Hydraulic Conductivity (ft/day)	Vertical Hydraulic Conductivity (ft/day)
1	5	.05
2	1.2	.05
3	3	.05
4	3.4	.05
5	5	.05
6	3	.05
7	1.2	.05
8	4	.05
9	4	.05
10	0.8	.05
11	5	.05
12	1.5	.05

HYDRAULIC CONDUCTIVITY DISTRIBUTION PER MODEL LAYER

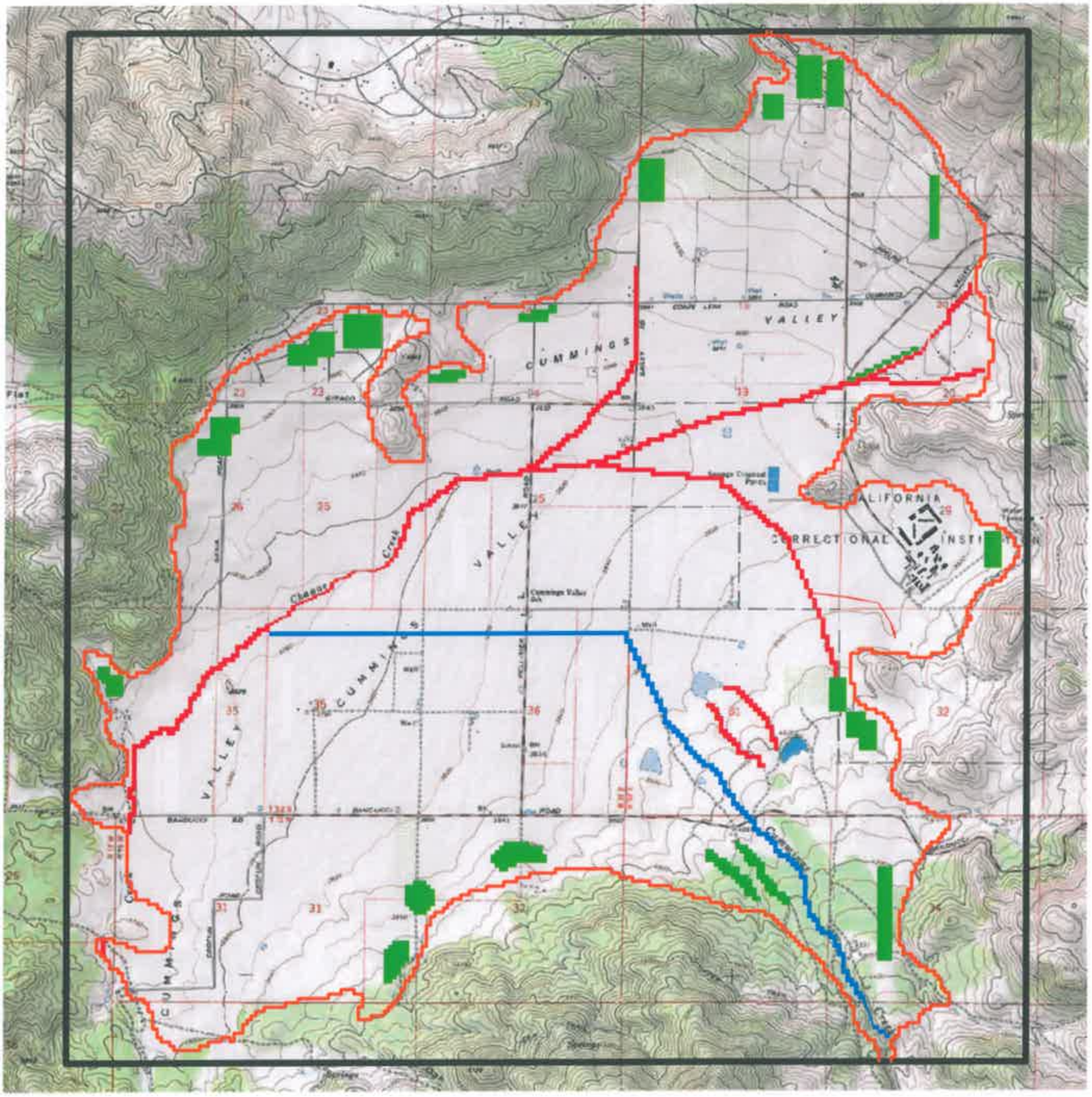
Cummings Basin Groundwater Modeling Study
December 2003

Filename: Diff Plots.ppt | Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE
5

FUGRO



Legend

- Model Domain Boundary
- Basin Boundary
- Surface Water Feature Simulated Using MODFLOW Drain Package
- Surface Water Feature Simulated Using MODFLOW Stream Package
- Surface Water Feature Simulated Using MODFLOW Well Package

N W E S

4,000 Feet

LOCATION OF SURFACE WATER FEATURES IN NUMERICAL MODEL

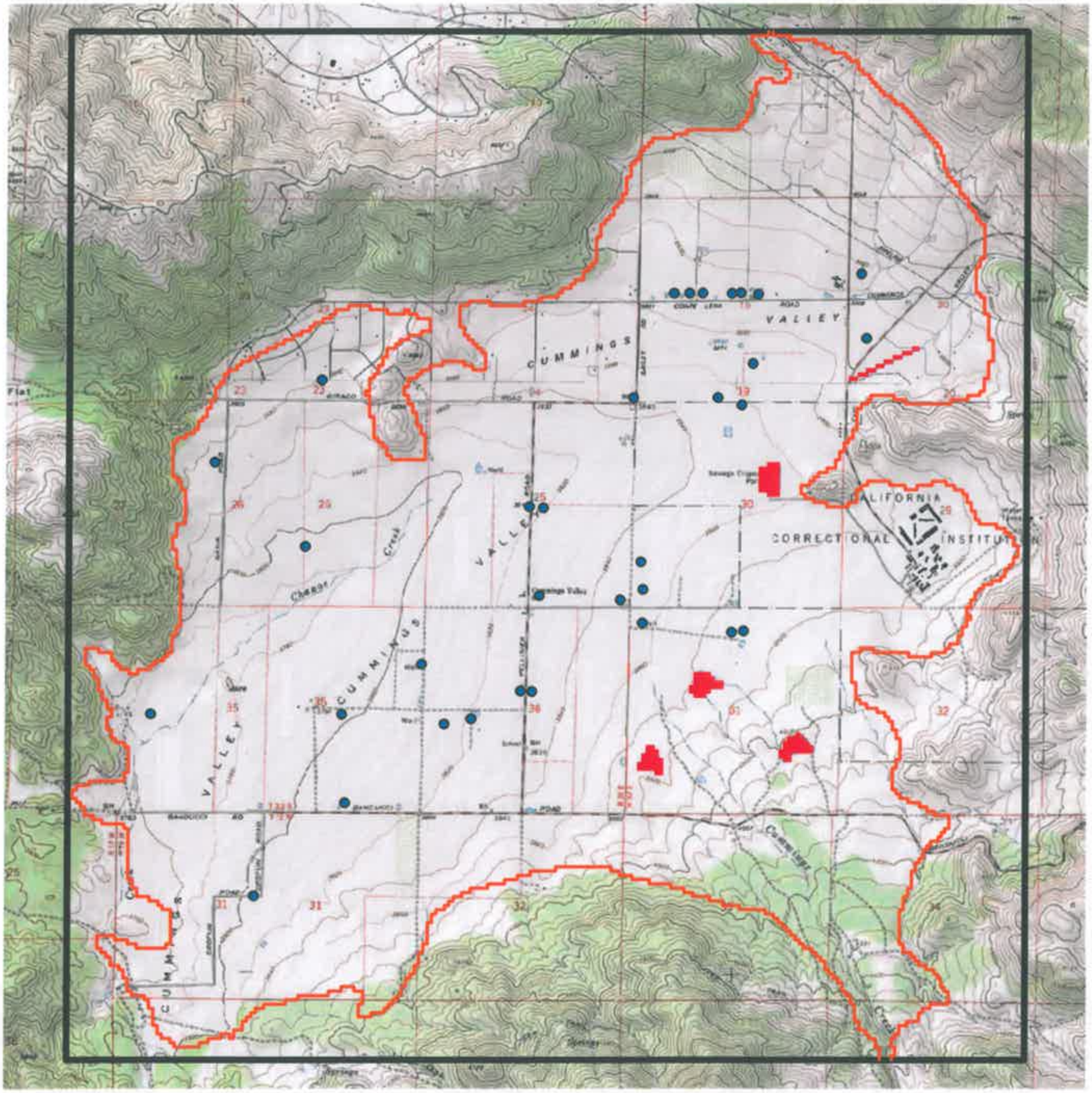
Cummings Basin Groundwater Modeling Study
December 2003

Filename: Figure 6.mxd | Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE 6

FUGRO



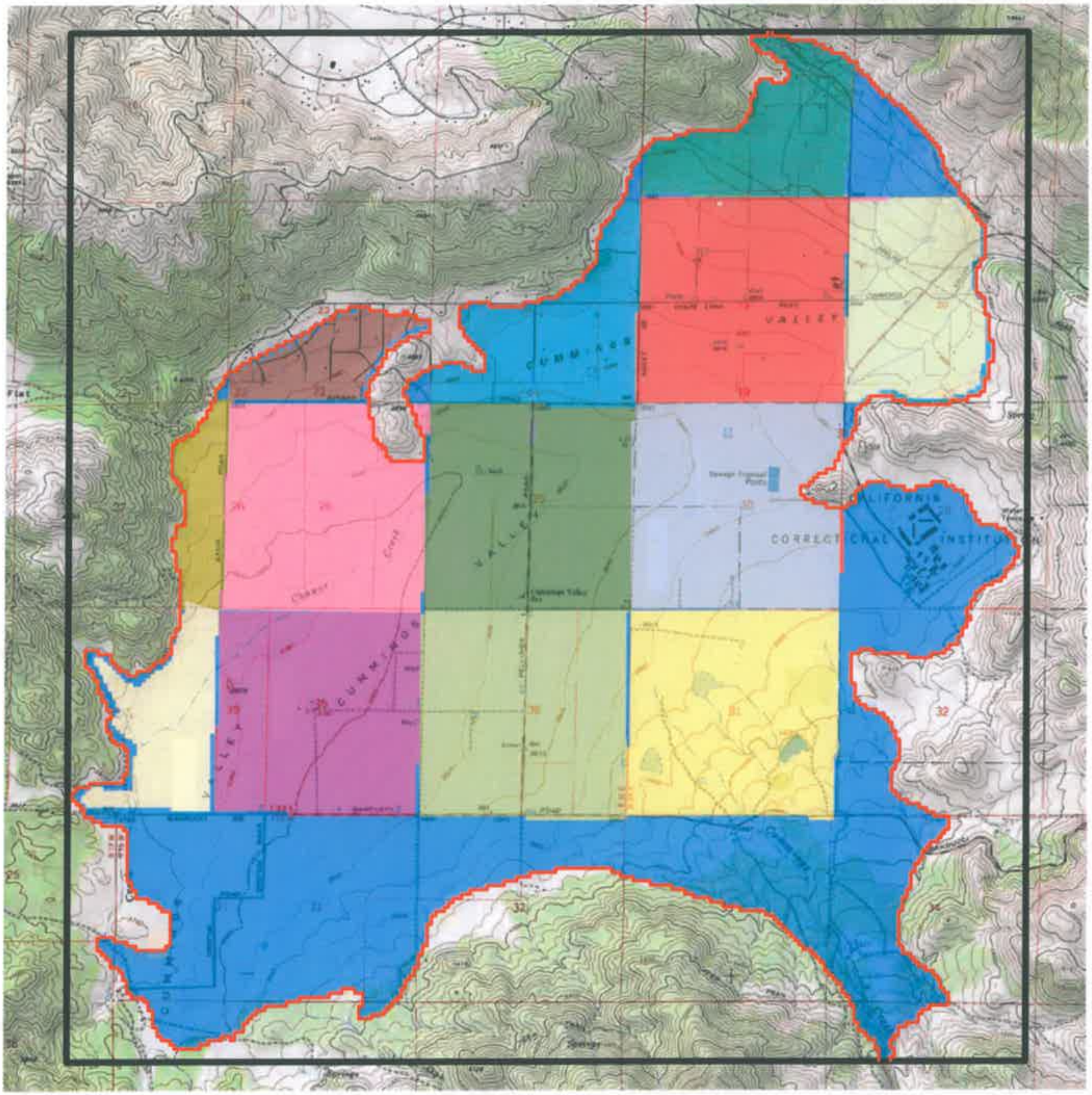
Legend

- ● Pumping Wells
- Model Domain Boundary
- Basin Boundary
- Artificial Recharge

N
W E
S

4,000
Feet

LOCATION OF WELLS AND ARTIFICIAL RECHARGE IN NUMERICAL MODEL	
Cummings Basin Groundwater Modeling Study December 2003	
Filename: Figure 1.mxd	Project No.: 3267.001.01
ETIC ENGINEERING	FIGURE 7	FUGRO



NOTE:
Different colors show areas of varying recharge rate

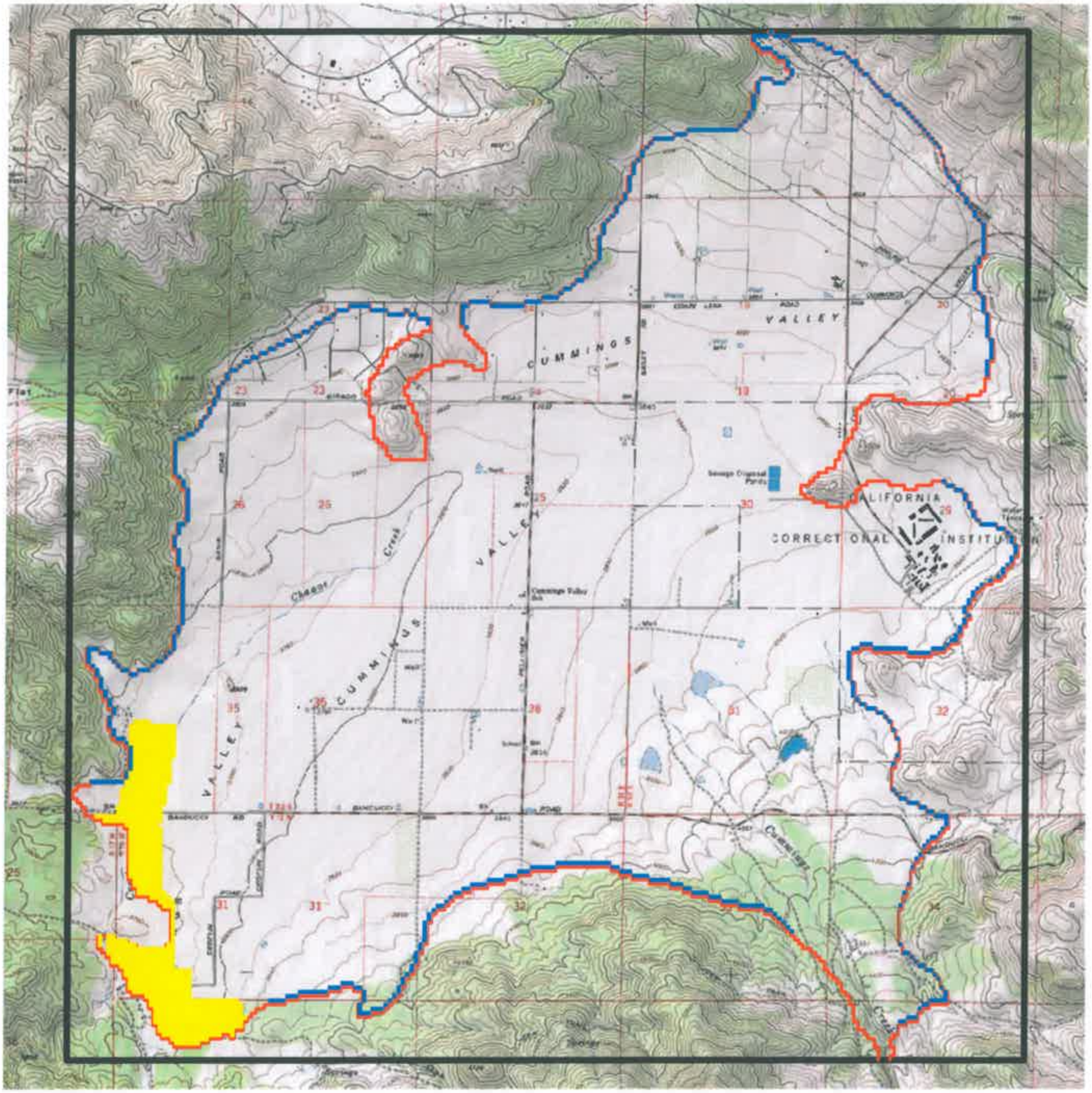
Legend

- Model Domain Boundary
- Basin Boundary

N
W E
S

4,000
Feet

DISTRIBUTION OF AGRICULTURAL PUMPAGE AND RETURN FLOW RECHARGE IN NUMERICAL MODEL	
Cummings Basin Groundwater Modeling Study December 2003	
Filename: Figure 8.mxd	Project No.: 3267.001.01
ETIC ENGINEERING	FIGURE 8	FUGRO



Legend

- Model Domain Boundary
- Basin Boundary
- Subsurface Inflow
- Subsurface Outflow

N
W E
S

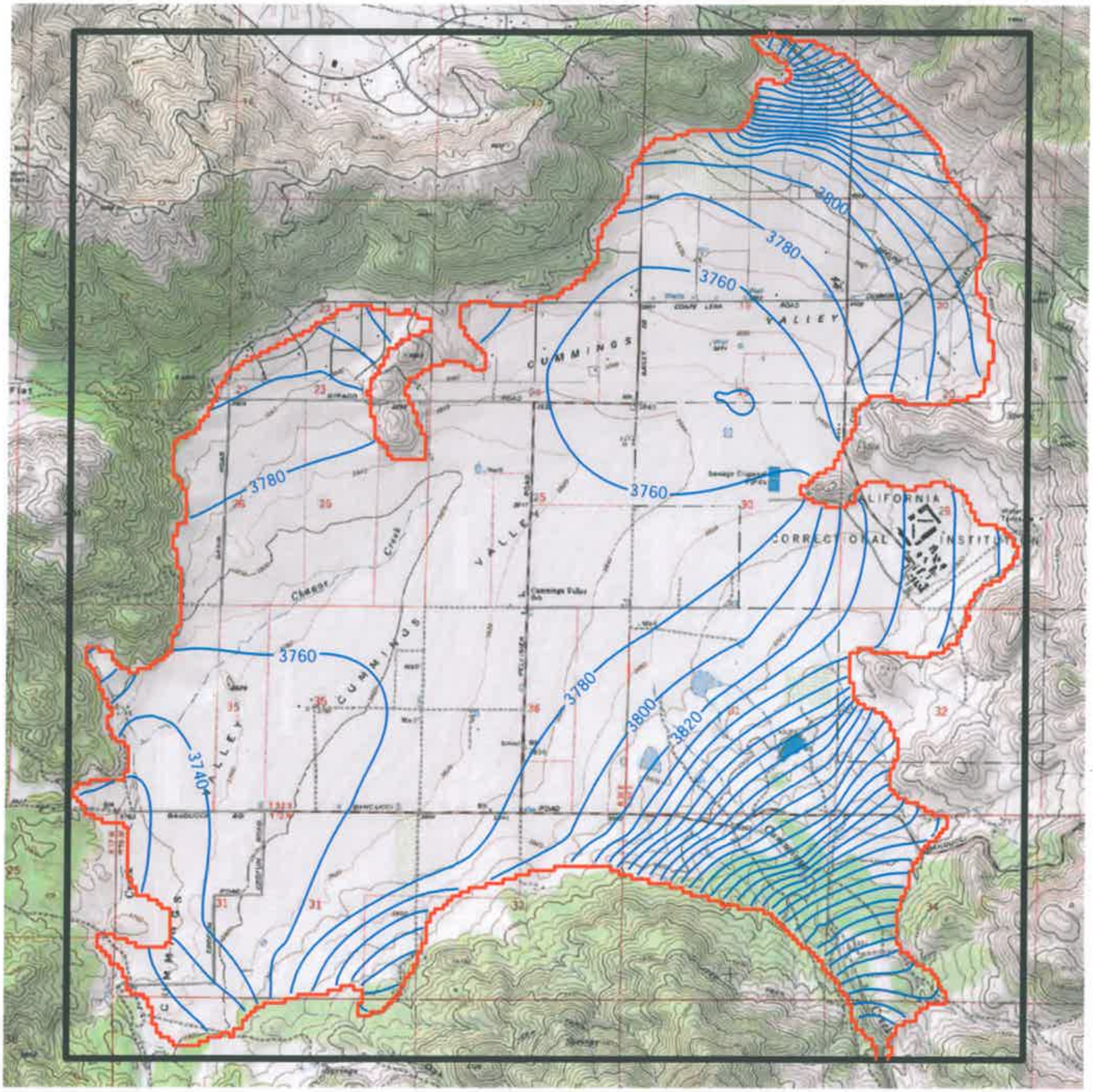
4,000
Feet

DISTRIBUTION OF SUBSURFACE INFLOW AND OUTFLOW IN NUMERICAL MODEL

Cummings Basin Groundwater Modeling Study
December 2003

Filename: Figure 9.mxd	Project No.: 3267.001.01

ETIC ENGINEERING | FIGURE 9 | FUGRO



Legend

- Model Domain Boundary
- Basin Boundary
- Groundwater Elevation Contour (feet)

N
W E
S

4,000
Feet

MODEL CALIBRATION
SIMULATED GROUNDWATER ELEVATIONS
FOR MAY 1990 - MODEL LAYER 3

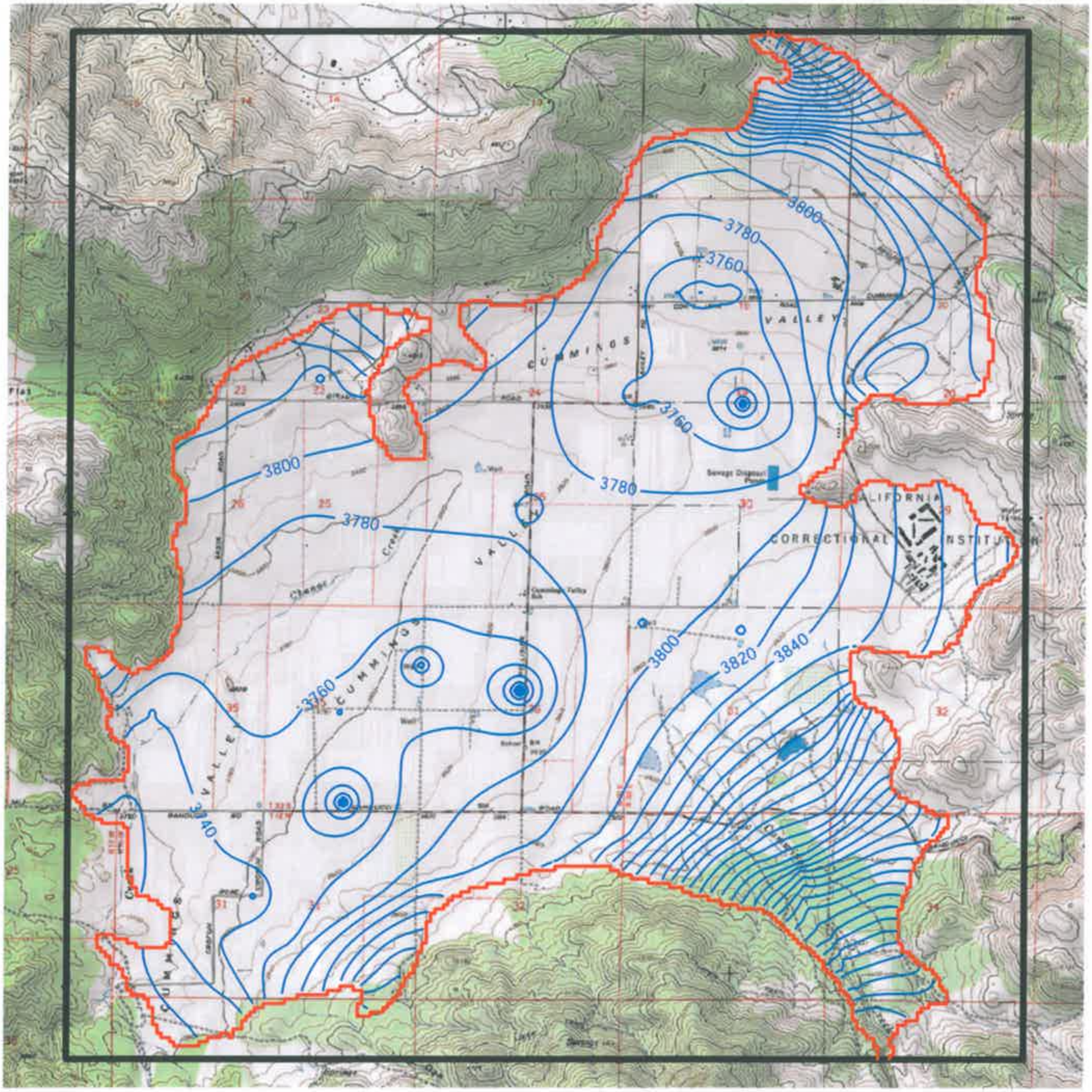
Cummings Basin Groundwater Modeling Study
December 2003

Filename: Figure 10.mxd	Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE
10

FUGRO



Legend

- Model Domain Boundary
- Basin Boundary
- Groundwater Elevation Contour (feet)

N
W E
S

4,000
Feet

MODEL CALIBRATION
SIMULATED GROUNDWATER ELEVATIONS
FOR OCTOBER 2001 - MODEL LAYER 3

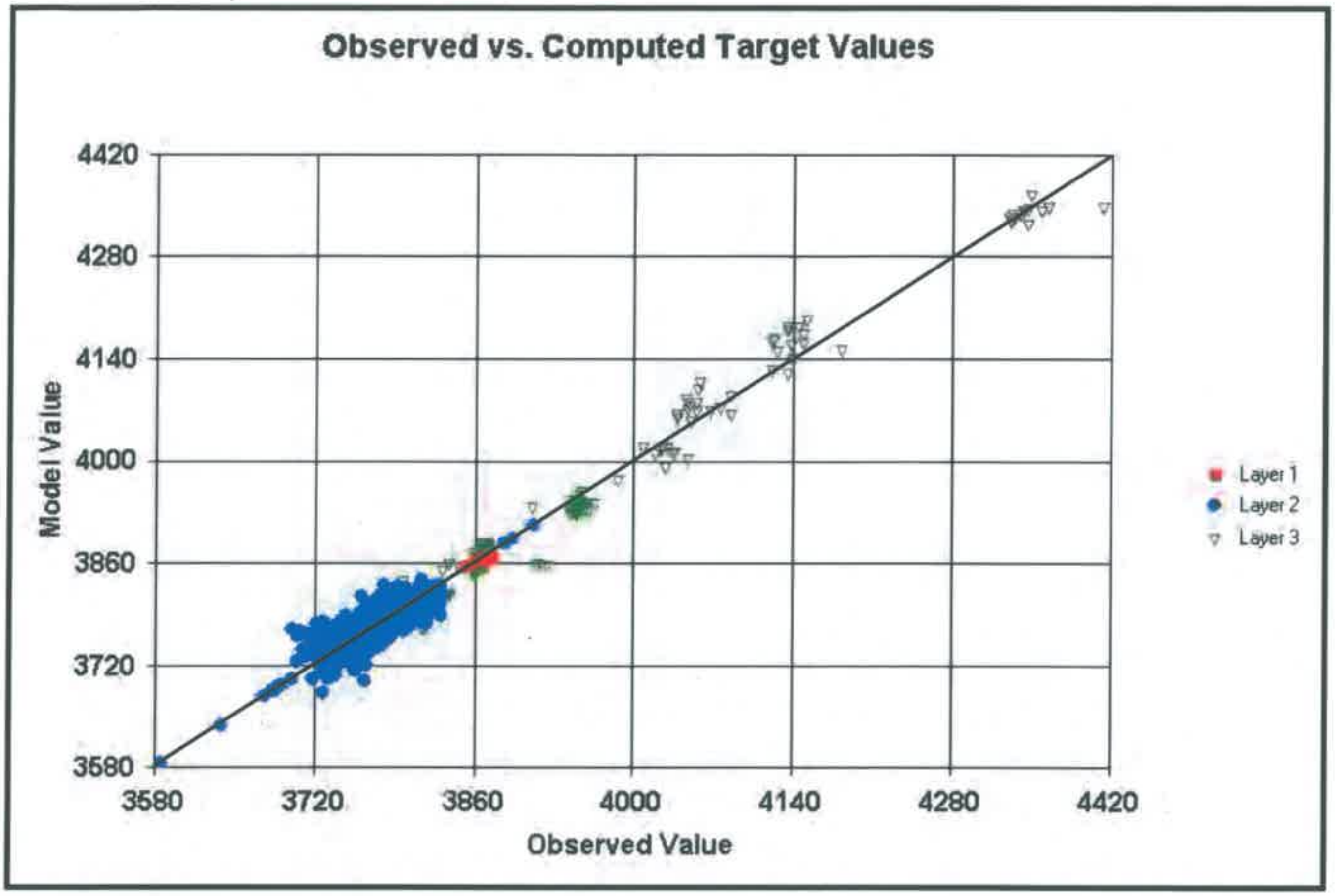
Cummings Basin Groundwater Modeling Study
December 2003

Filename: Figure 11.mxd	Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE
11

FUGRO



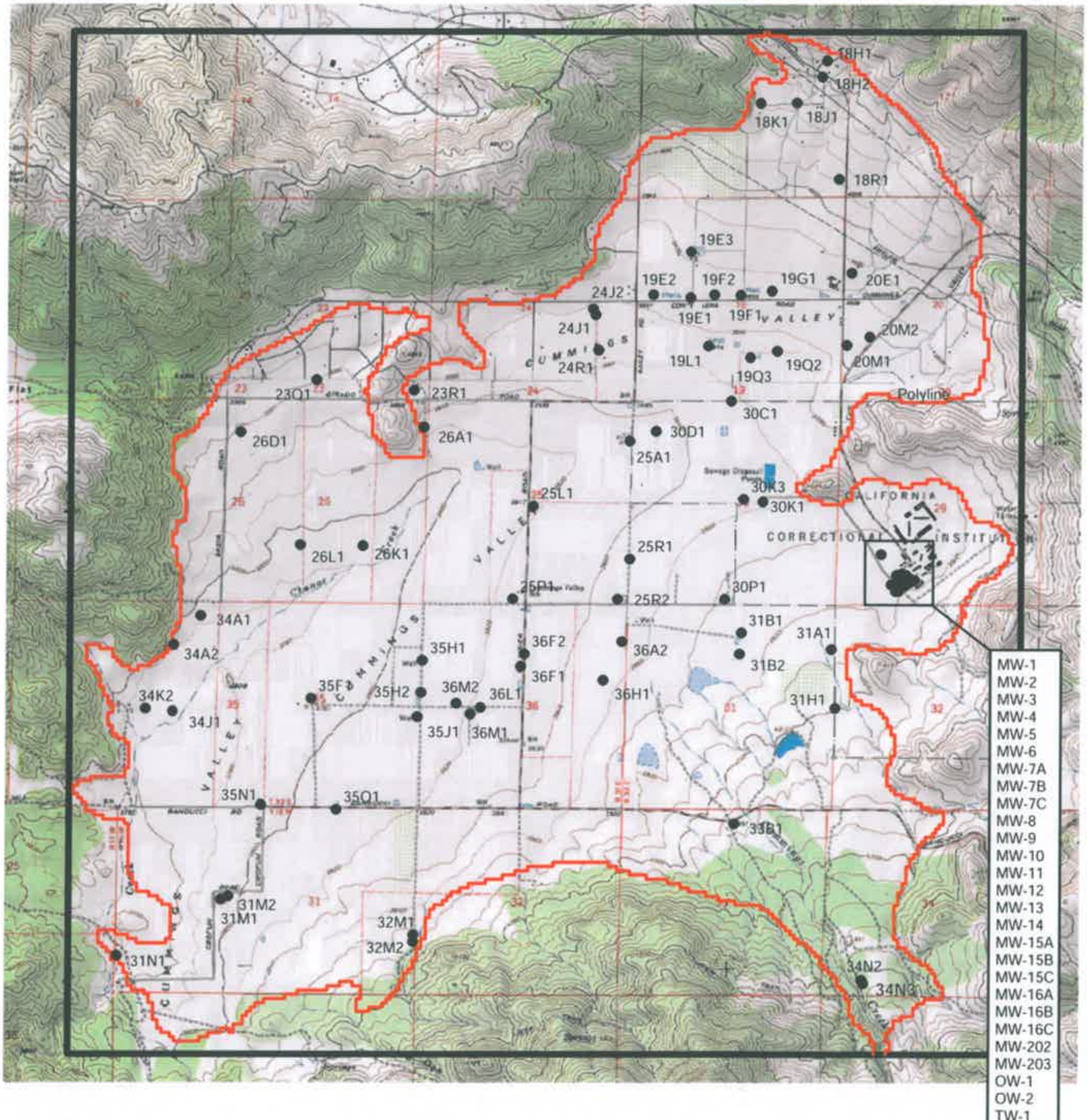
Correlation Coefficient	**=**	**0.976**
Residual Mean	**=**	**-2.82**
Residual Std. Deviation	**=**	**15.40**
Absolute Residual Mean	**=**	**11.55**
Minimum Residual	**=**	**-68.51**
Maximum Residual	**=**	**66.78**
Observed Range in Head	**=**	**826.10**
Residual Std. Dev / Range	**=**	**0.019**

MODEL CALIBRATION SUMMARY PLOT AND STATISTICS

Cummings Basin Groundwater Modeling Study
December 2003

Filename: graphs.ppt	Project No.: 3267.001.01

ETIC ENGINEERING | FIGURE **12** | FUGRO



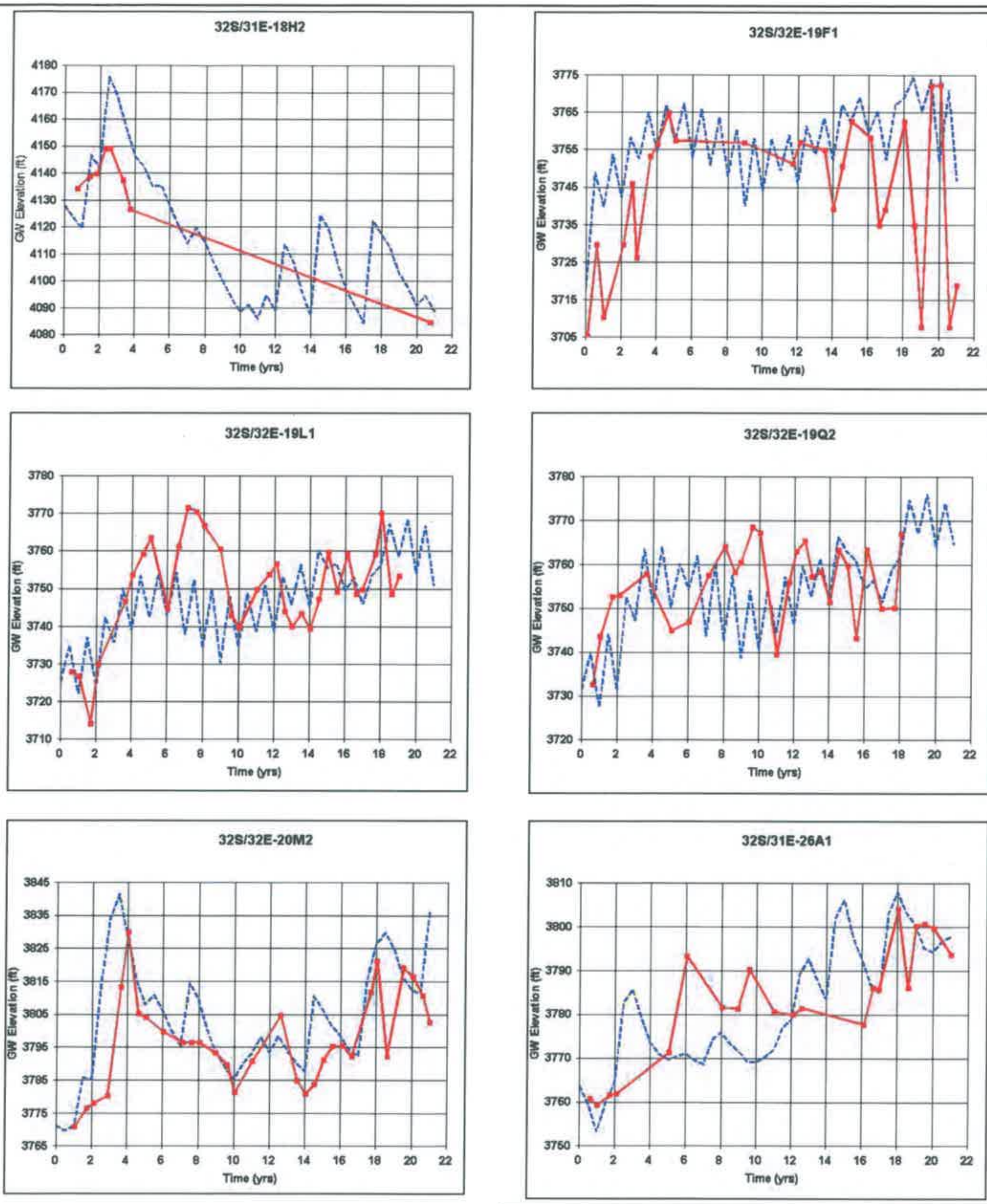
Legend

- ● Location of Well with Groundwater Elevation Used in Calibration
- Model Domain Boundary
- Basin Boundary

N
W E
S

4,000
Feet

LOCATION MAP FOR MODEL CALIBRATION DATA		
Cummings Basin Groundwater Modeling Study December 2003		
Filename: Figure 13.mxd	Project No.: 3267.001.01	
ETIC ENGINEERING	FIGURE 13	FUGRO



LEGEND

Measured Data

Simulated Data

MODEL CALIBRATION
INDIVIDUAL HYDROGRAPHS FOR NORTHERN BASIN

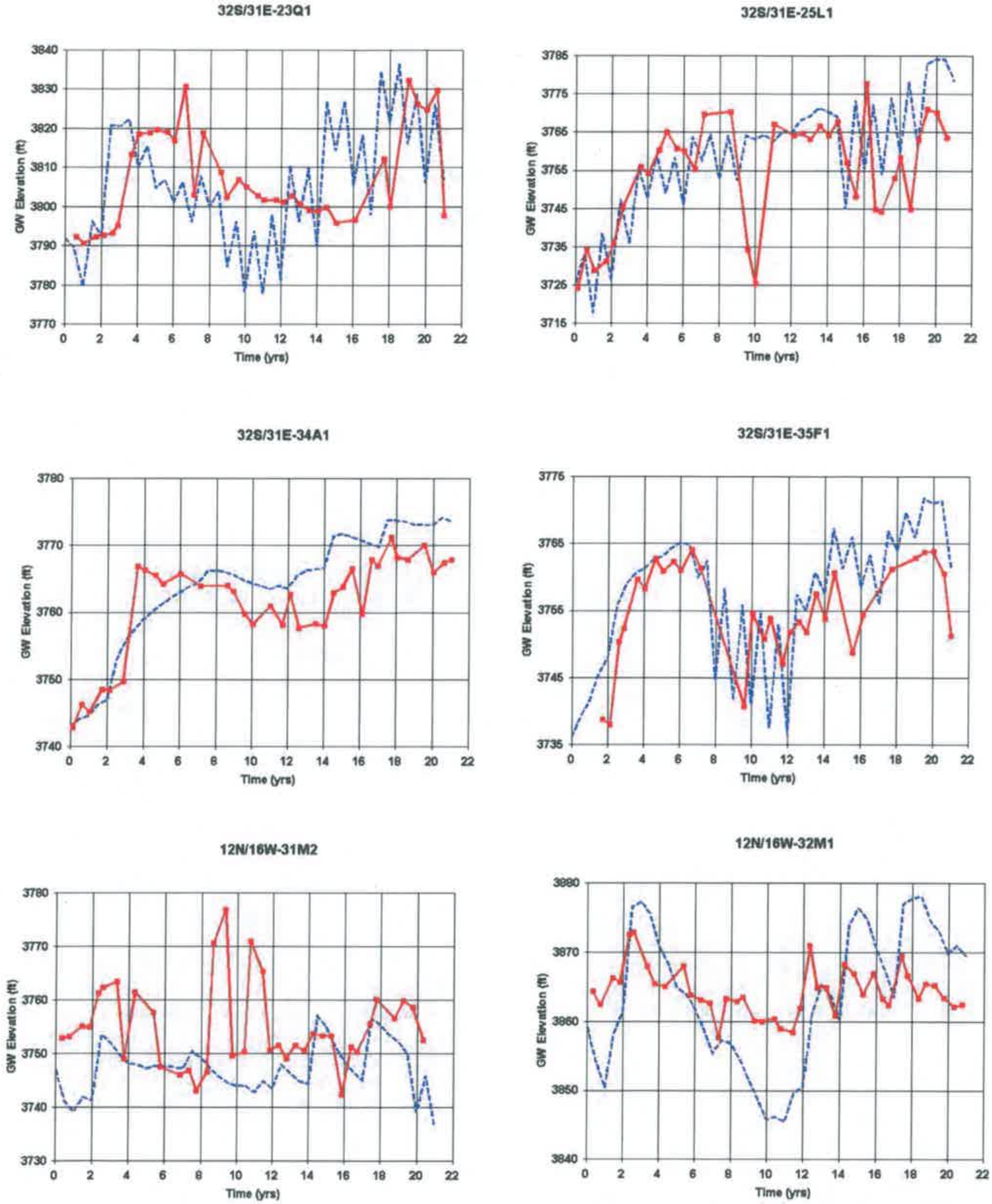
Cummings Basin Groundwater Modeling Study
December 2003

Filename: graphs.ppt	Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE
14

FUGRO



LEGEND

Measured Data

Simulated Data

MODEL CALIBRATION
INDIVIDUAL HYDROGRAPHS FOR WESTERN BASIN

Cummings Basin Groundwater Modeling Study
December 2003

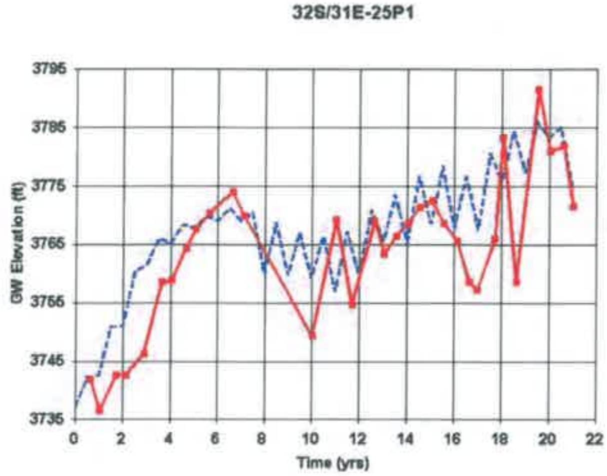
Filename: graphs.ppt

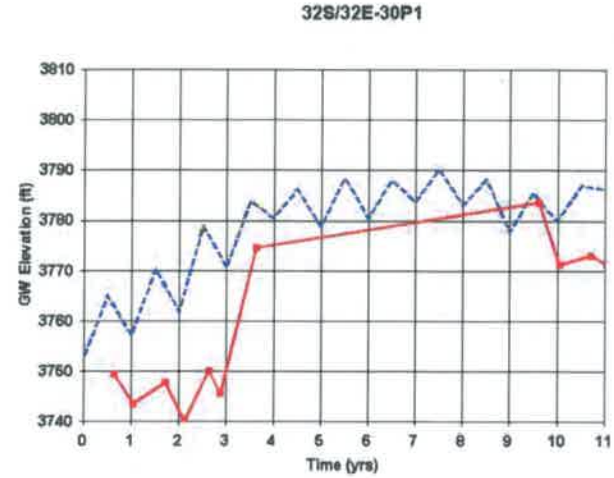
Project No.: 3267.001.01

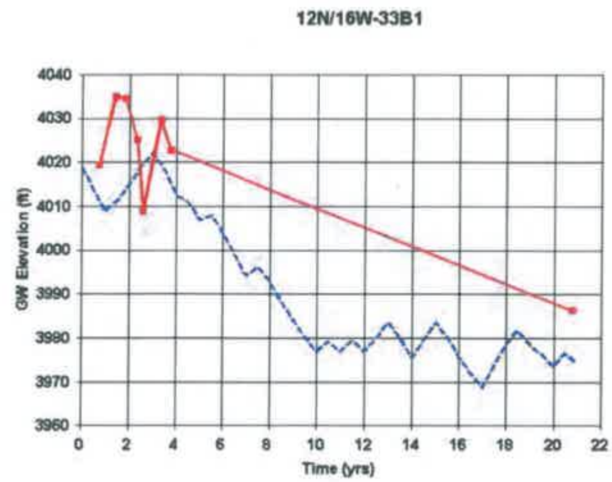
ETIC ENGINEERING

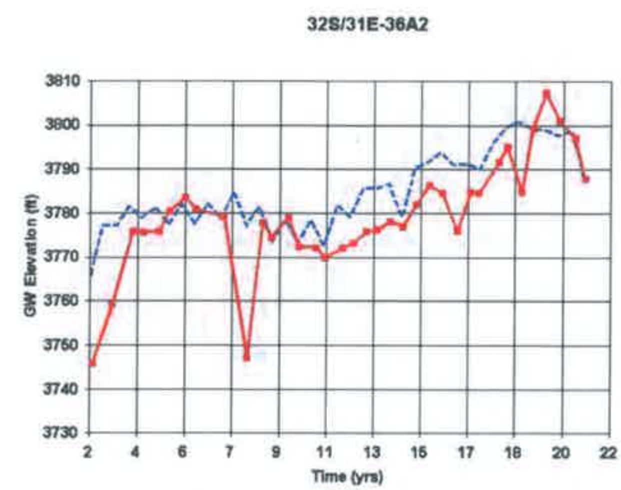
FIGURE
15

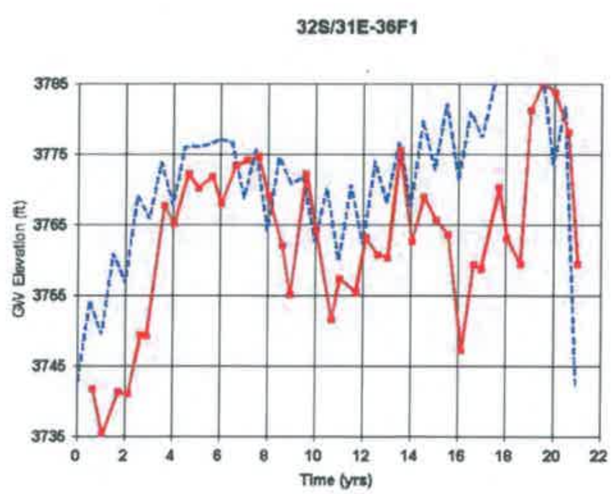
FUGRO

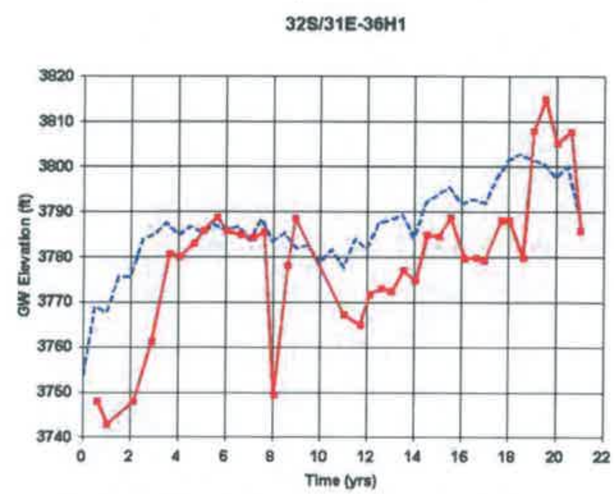












LEGEND

Measured Data

Simulated Data

MODEL CALIBRATION
INDIVIDUAL HYDROGRAPHS FOR SOUTHERN BASIN

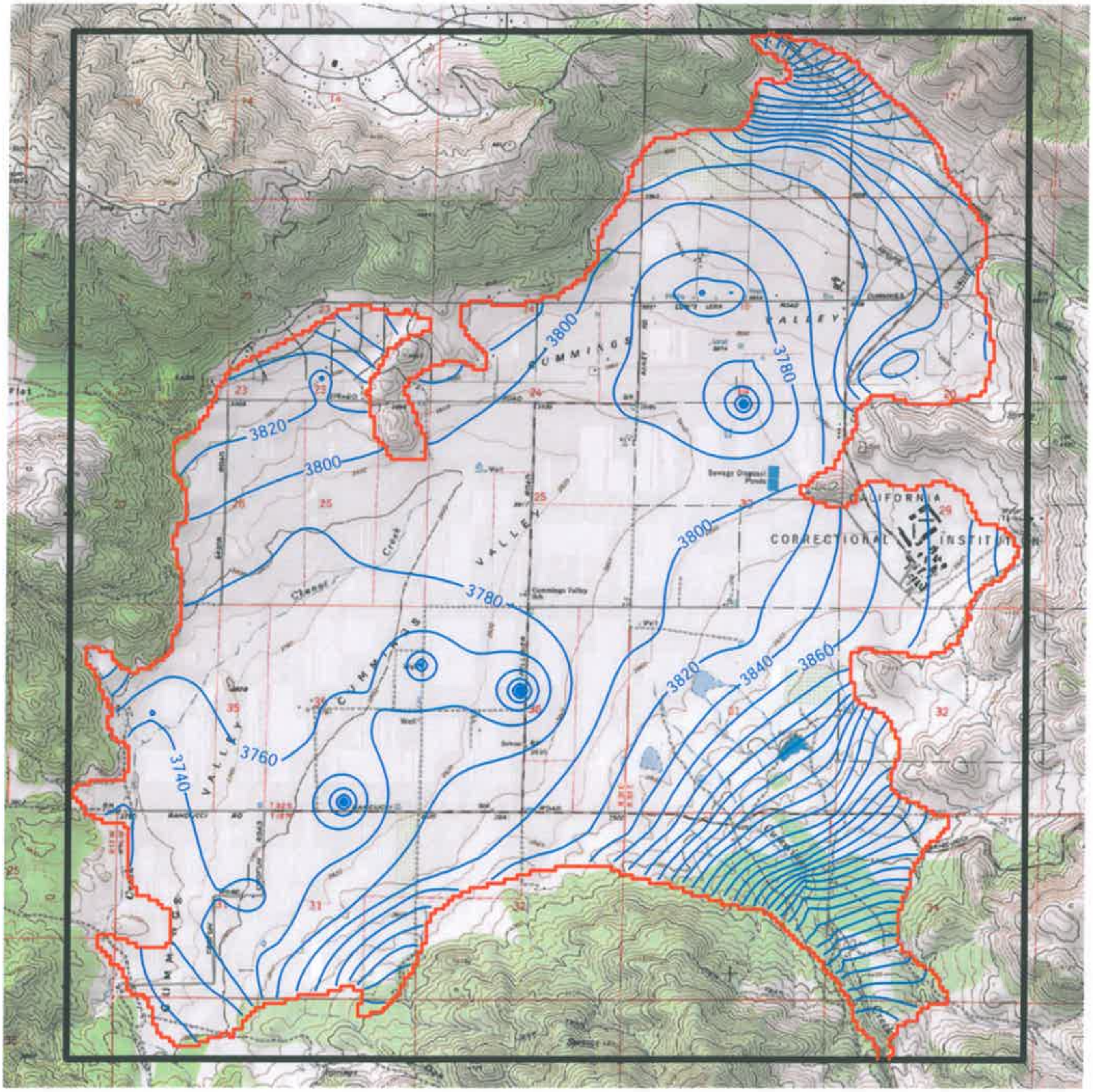
Cummings Basin Groundwater Modeling Study
December 2003

Filename: graphs.ppt	Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE
16

FUGRO



Legend

- Model Domain Boundary
- Basin Boundary
- Groundwater Elevation Contour (feet)

N W E S

4,000 Feet

SCENARIO 1 - SIMULATED GROUNDWATER ELEVATION MAP FOR MODEL YEAR 21 - MODEL LAYER 3

Cummings Basin Groundwater Modeling Study
December 2003

Filename: Figure 17.mxd | Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE 17

FUGRO

SCENARIO 1 - GROUNDWATER ELEVATION DIFFERENCE MAP BETWEEN SCENARIO 1 AND CALIBRATED MODEL FOR MODEL YEAR 21 - MODEL LAYER 3

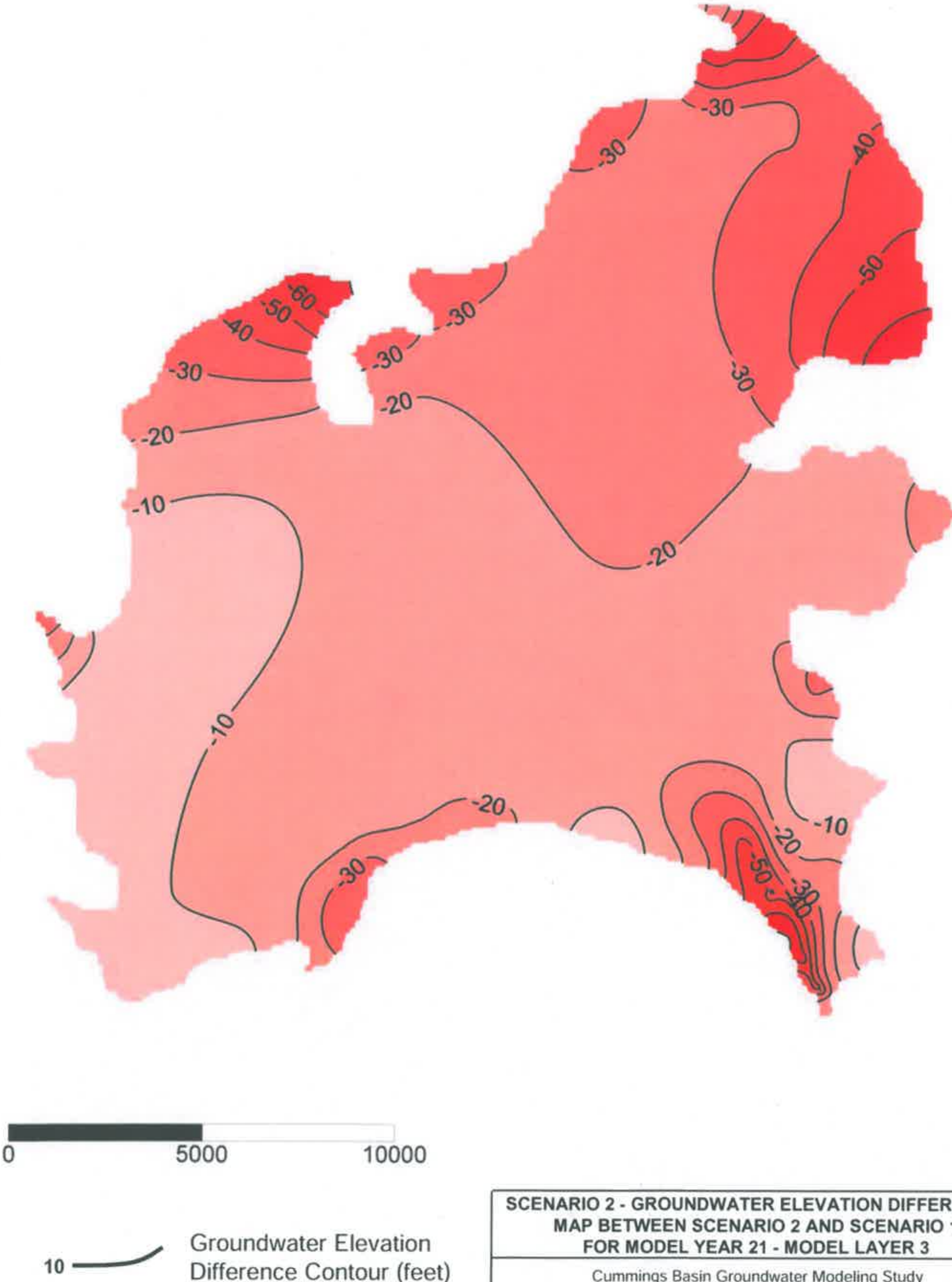
Cummings Basin Groundwater Modeling Study
December 2003

Filename: Diff Plots.ppt	Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE
18

FUGRO



SCENARIO 2 - GROUNDWATER ELEVATION DIFFERENCE MAP BETWEEN SCENARIO 2 AND SCENARIO 1 FOR MODEL YEAR 21 - MODEL LAYER 3

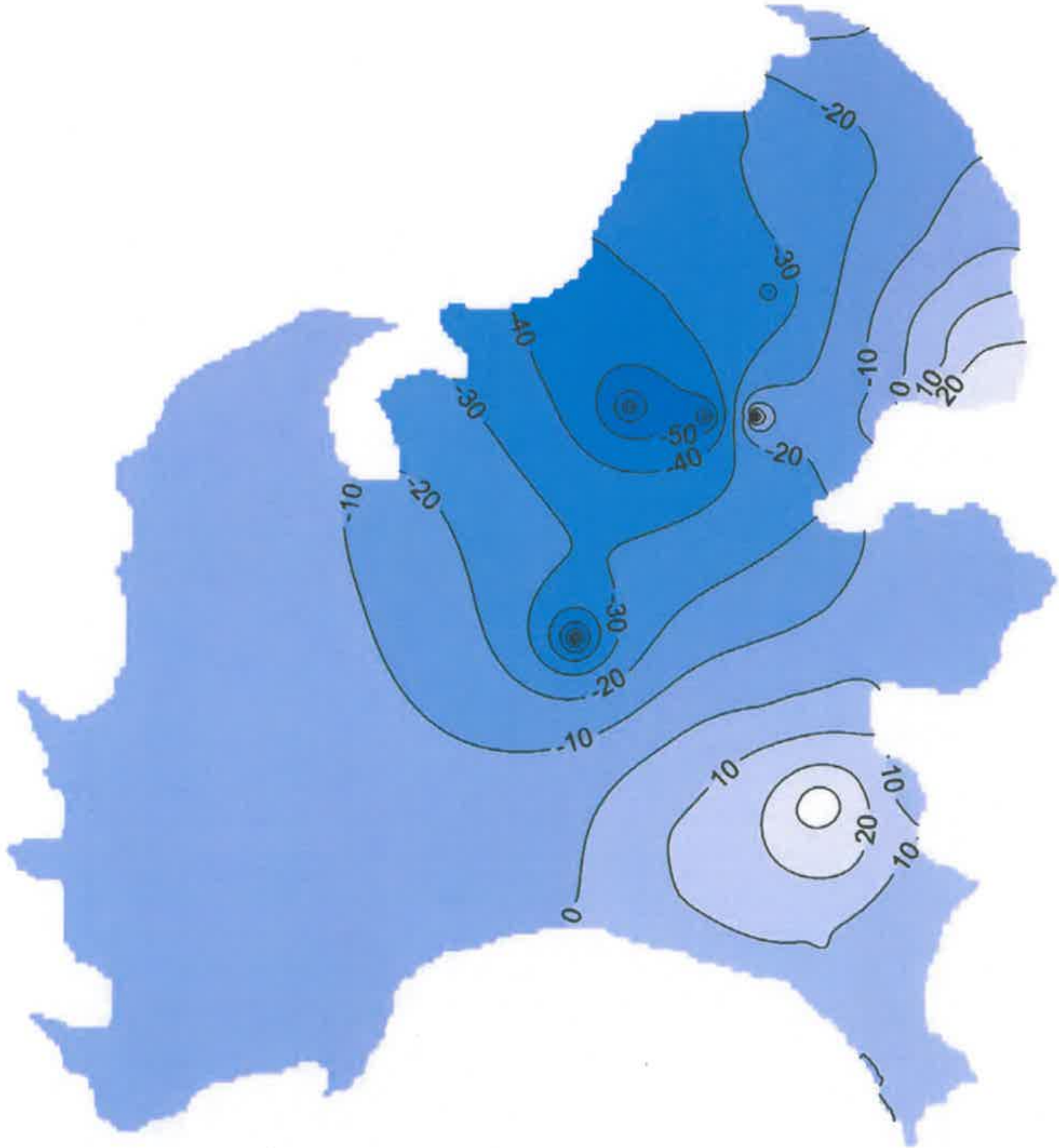
Cummings Basin Groundwater Modeling Study
December 2003

Filename: Diff Plots.ppt	Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE
21

FUGRO



0 5000 10000

10 Groundwater Elevation Difference Contour (feet)

SCENARIO 3 - GROUNDWATER ELEVATION DIFFERENCE MAP BETWEEN SCENARIO 1 AND CALIBRATED MODEL FOR MODEL YEAR 21 - MODEL LAYER 3

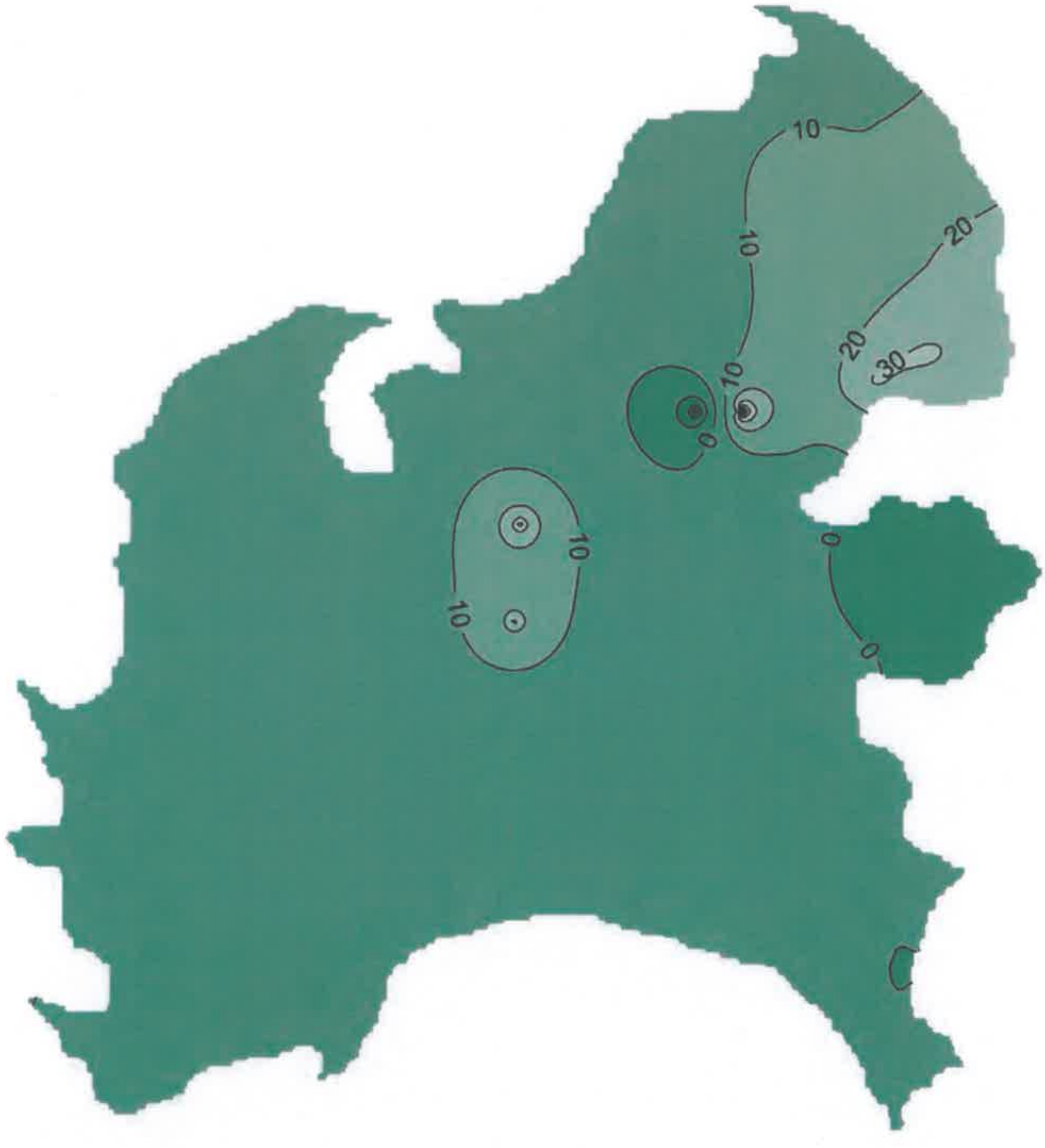
Cummings Basin Groundwater Modeling Study
December 2003

Filename: Diff Plots.ppt	Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE
24

FUGRO



0 5000 10000

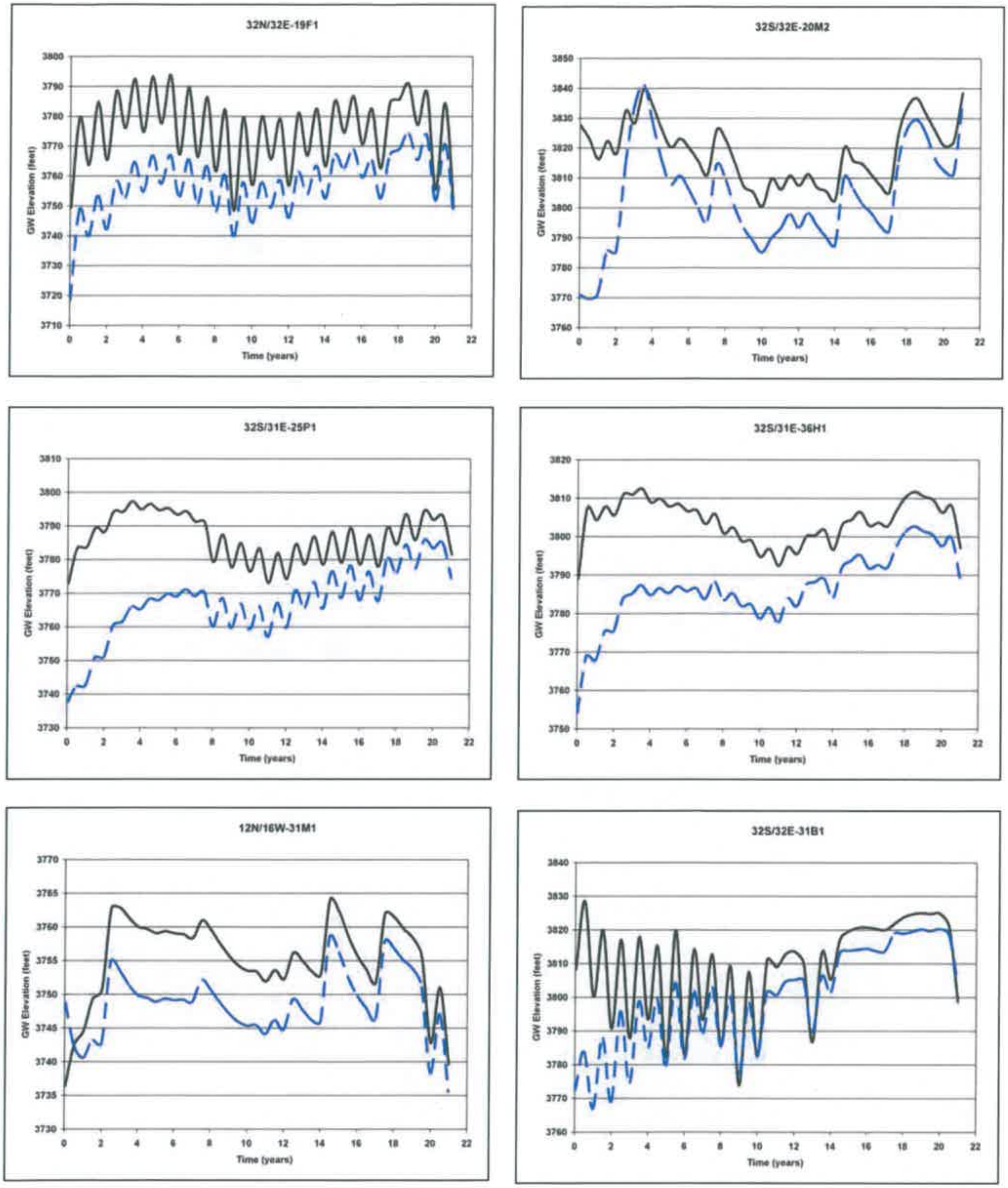
10 — Groundwater Elevation Difference Contour (feet)

SCENARIO 4 - GROUNDWATER ELEVATION DIFFERENCE MAP BETWEEN SCENARIO 1 AND CALIBRATED MODEL FOR MODEL YEAR 19 - MODEL LAYER 3

Cummings Basin Groundwater Modeling Study
December 2003

Filename: Diff Plots.ppt	Project No.: 3267.001.01

ETIC ENGINEERING	FIGURE 27	FUGRO



LEGEND

Scenario 1 Results

Calibrated Model Results

SCENARIO 1 - SIMULATED HYDROGRAPHS
COMPARING SCENARIO 1 TO CALIBRATED MODEL

Cummings Basin Groundwater Modeling Study
December 2003

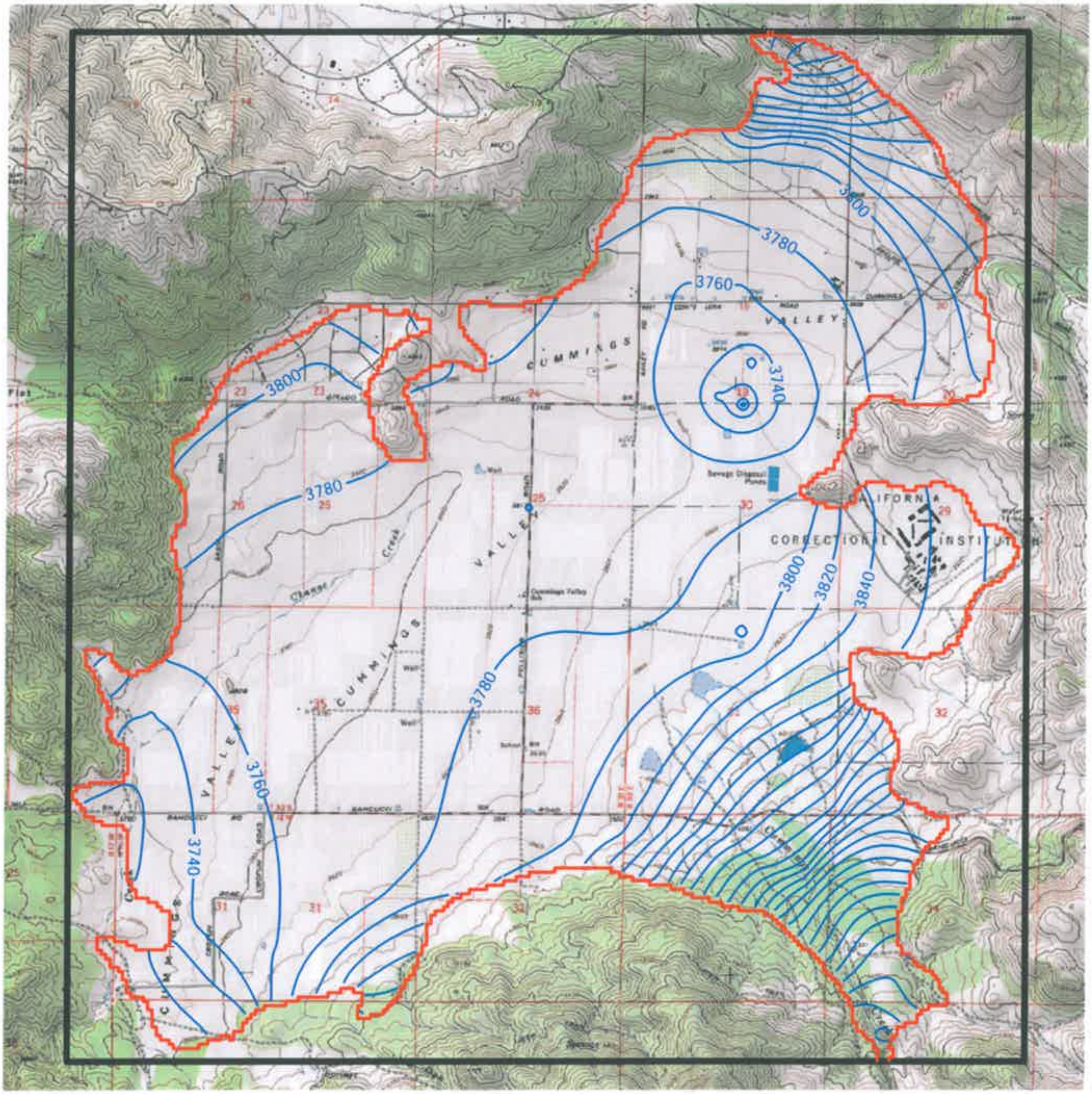
Filename: graphs.ppt

Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE
19

FUGRO



Legend

- Model Domain Boundary
- Basin Boundary
- Scenario 2 - Simulated Groundwater Elevation (feet)

N W E S

4,000

Feet

SCENARIO 2 - SIMULATED GROUNDWATER ELEVATION MAP FOR MODEL YEAR 5 (END OF SIMULATED DROUGHT) MODEL LAYER 3

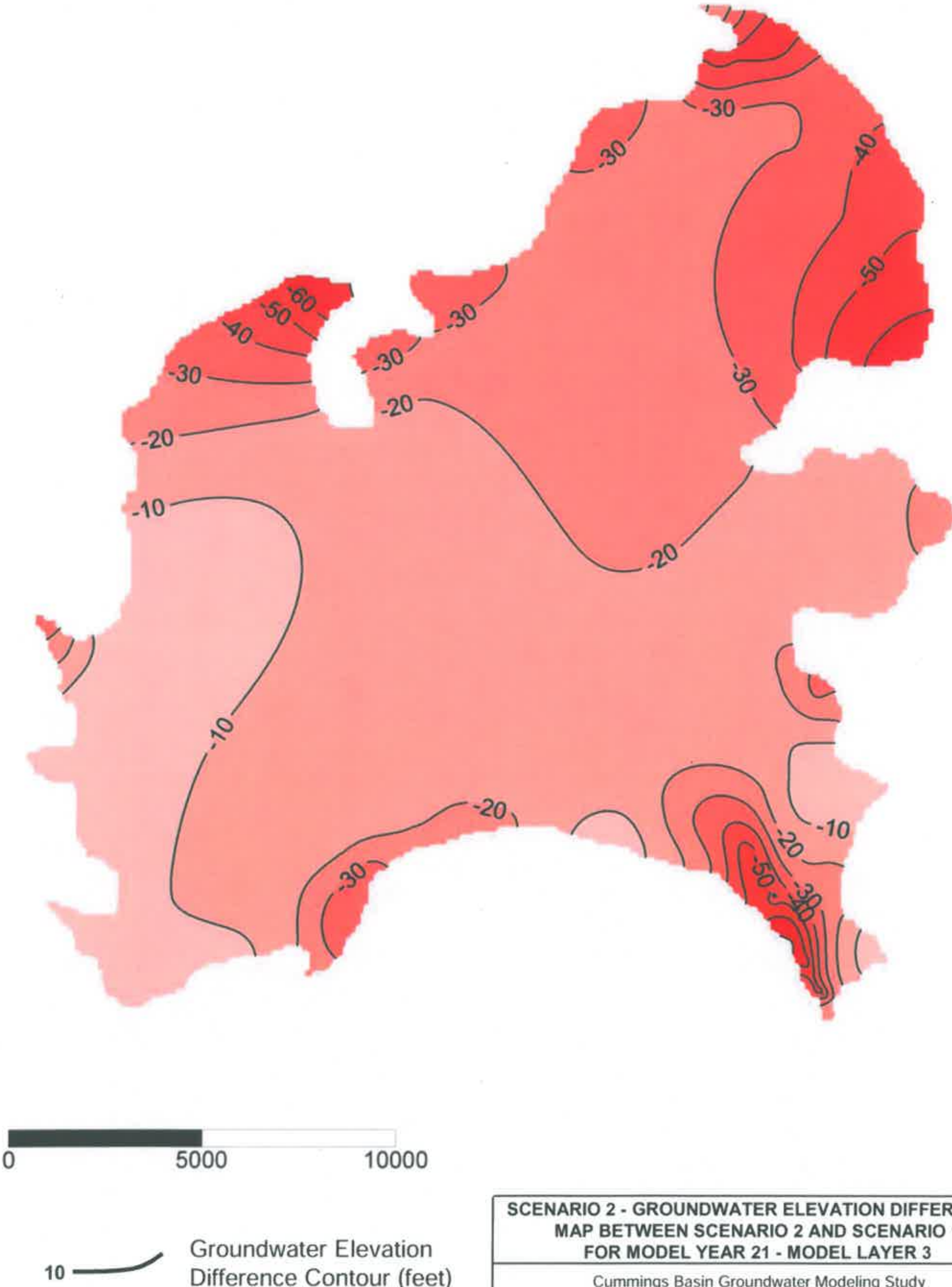
Cummings Basin Groundwater Modeling Study
December 2003

Filename: Figure 20.mxd | Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE **20**

FUGRO

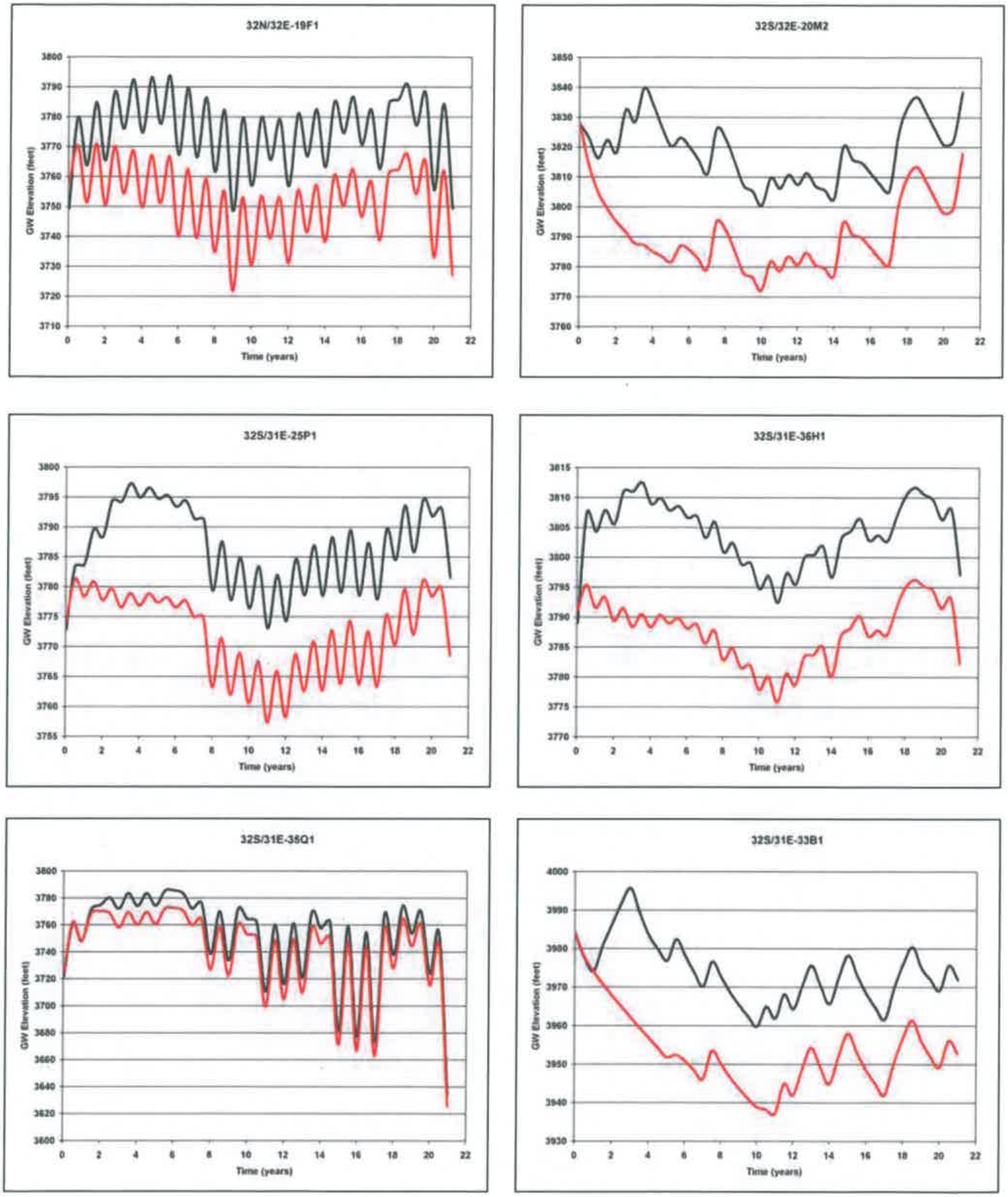


SCENARIO 2 - GROUNDWATER ELEVATION DIFFERENCE MAP BETWEEN SCENARIO 2 AND SCENARIO 1 FOR MODEL YEAR 21 - MODEL LAYER 3

Cummings Basin Groundwater Modeling Study
December 2003

Filename: Diff Plots.ppt	Project No.: 3267.001.01

ETIC ENGINEERING | FIGURE 21 | FUGRO



LEGEND

Scenario 1 Results

Scenario 2 Results

SCENARIO 2 - SIMULATED HYDROGRAPHS COMPARING SCENARIO 2 TO CALIBRATED MODEL

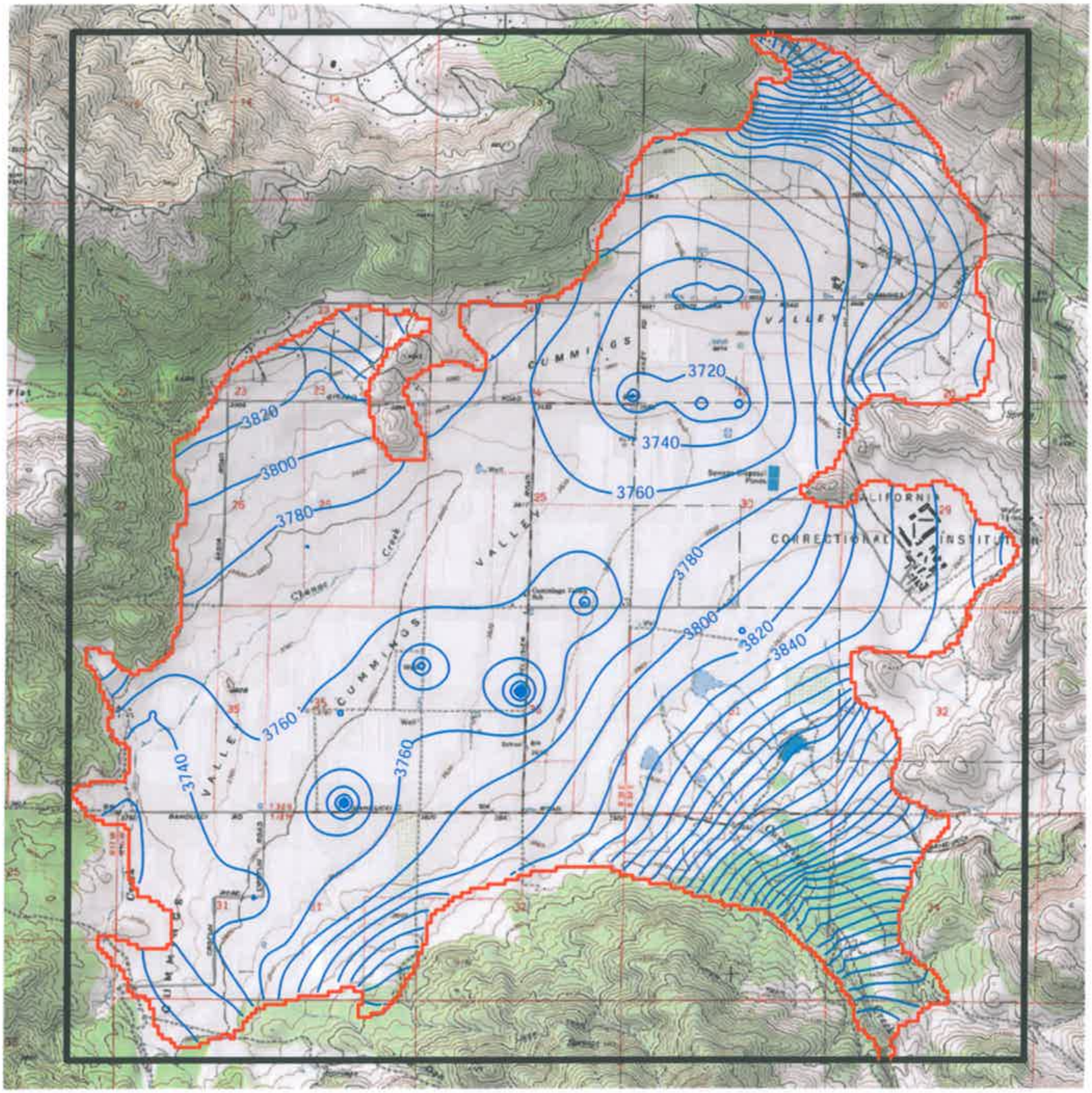
Cummings Basin Groundwater Modeling Study
December 2003

Filename: graphs.ppt	Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE
22

FUGRO



Legend

- Model Domain Boundary
- Basin Boundary
- Scenario 3 - Simulated Groundwater Elevation (feet)

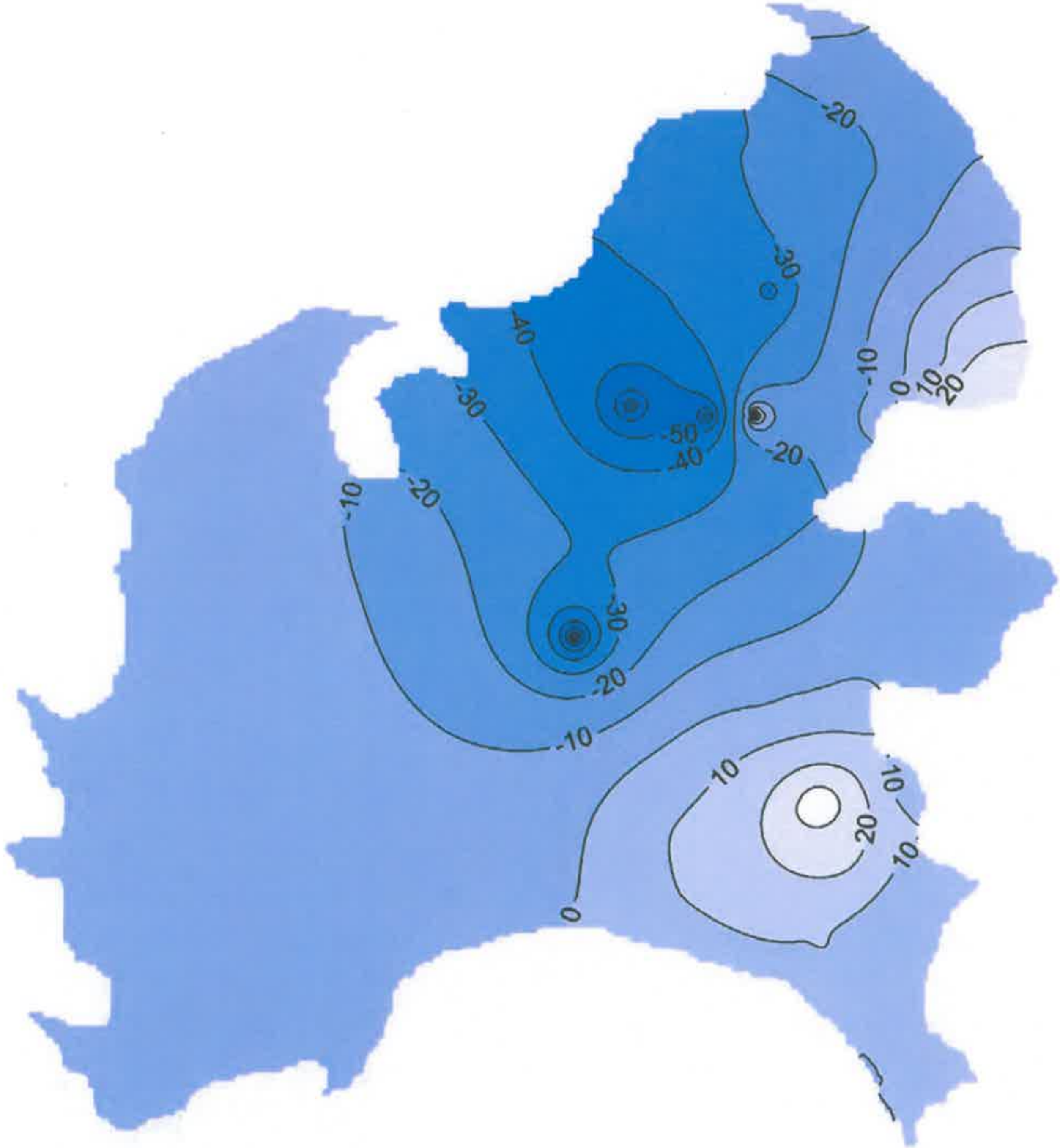
N W E S

4,000 Feet

SCENARIO 3 - SIMULATED GROUNDWATER ELEVATION MAP FOR MODEL YEAR 21 - MODEL LAYER 3

Cummings Basin Groundwater Modeling Study
December 2003

Filename: Figure 23.mxd	Project No.: 3267.001.01
ETIC ENGINEERING	FIGURE 23	FUGRO



0 5000 10000

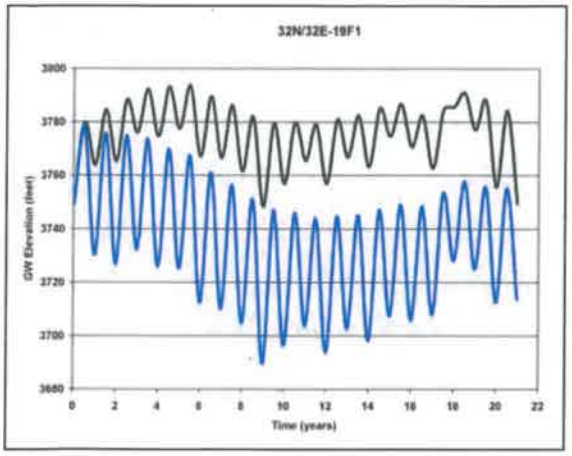
10 — Groundwater Elevation Difference Contour (feet)

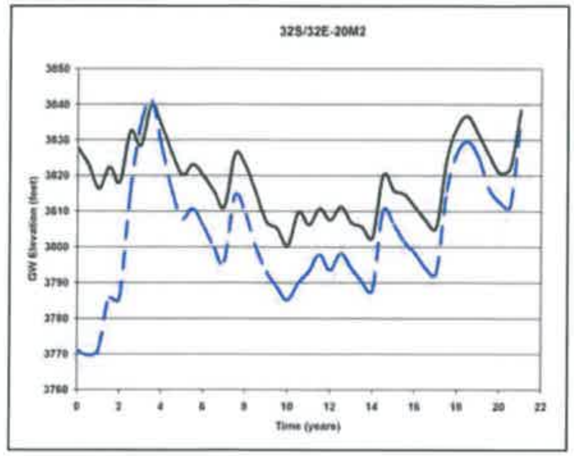
SCENARIO 3 - GROUNDWATER ELEVATION DIFFERENCE MAP BETWEEN SCENARIO 1 AND CALIBRATED MODEL FOR MODEL YEAR 21 - MODEL LAYER 3

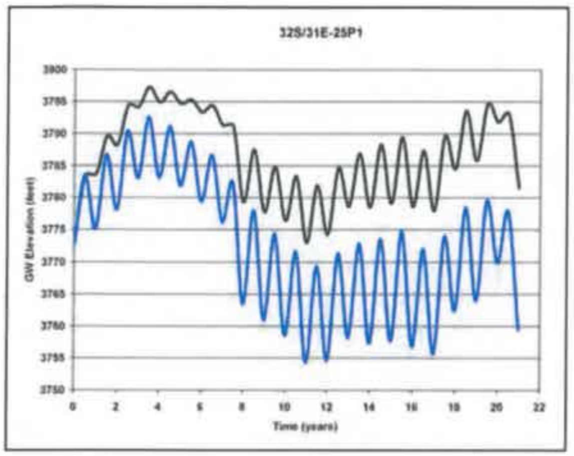
Cummings Basin Groundwater Modeling Study
December 2003

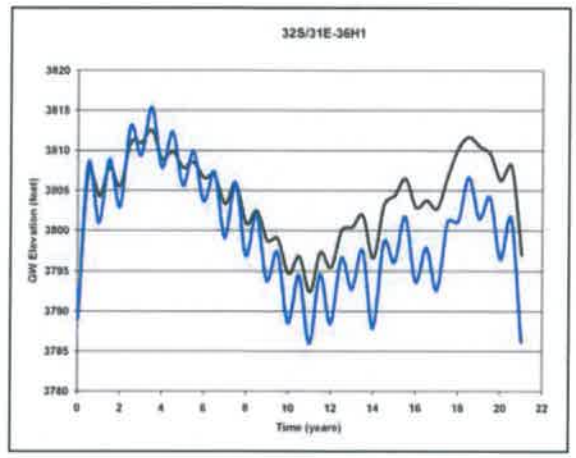
Filename: Diff Plots.ppt	Project No.: 3267.001.01

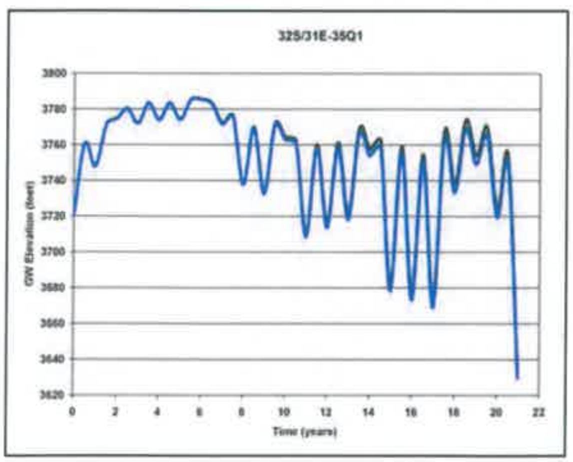
ETIC ENGINEERING | FIGURE 24 | FUGRO

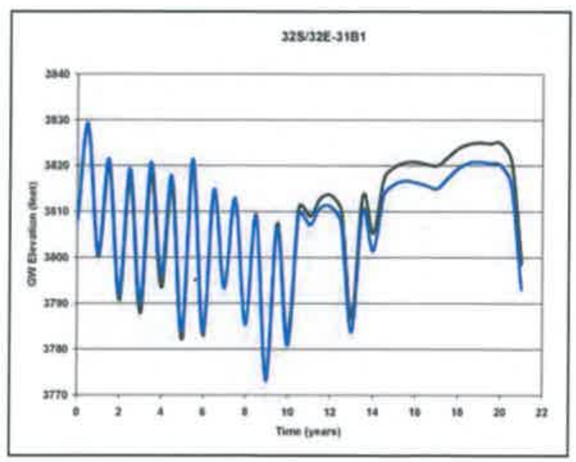












LEGEND

Scenario 1 Results

Scenario 3 Results

SCENARIO 3 - SIMULATED HYDROGRAPHS COMPARING SCENARIO 3 TO CALIBRATED MODEL

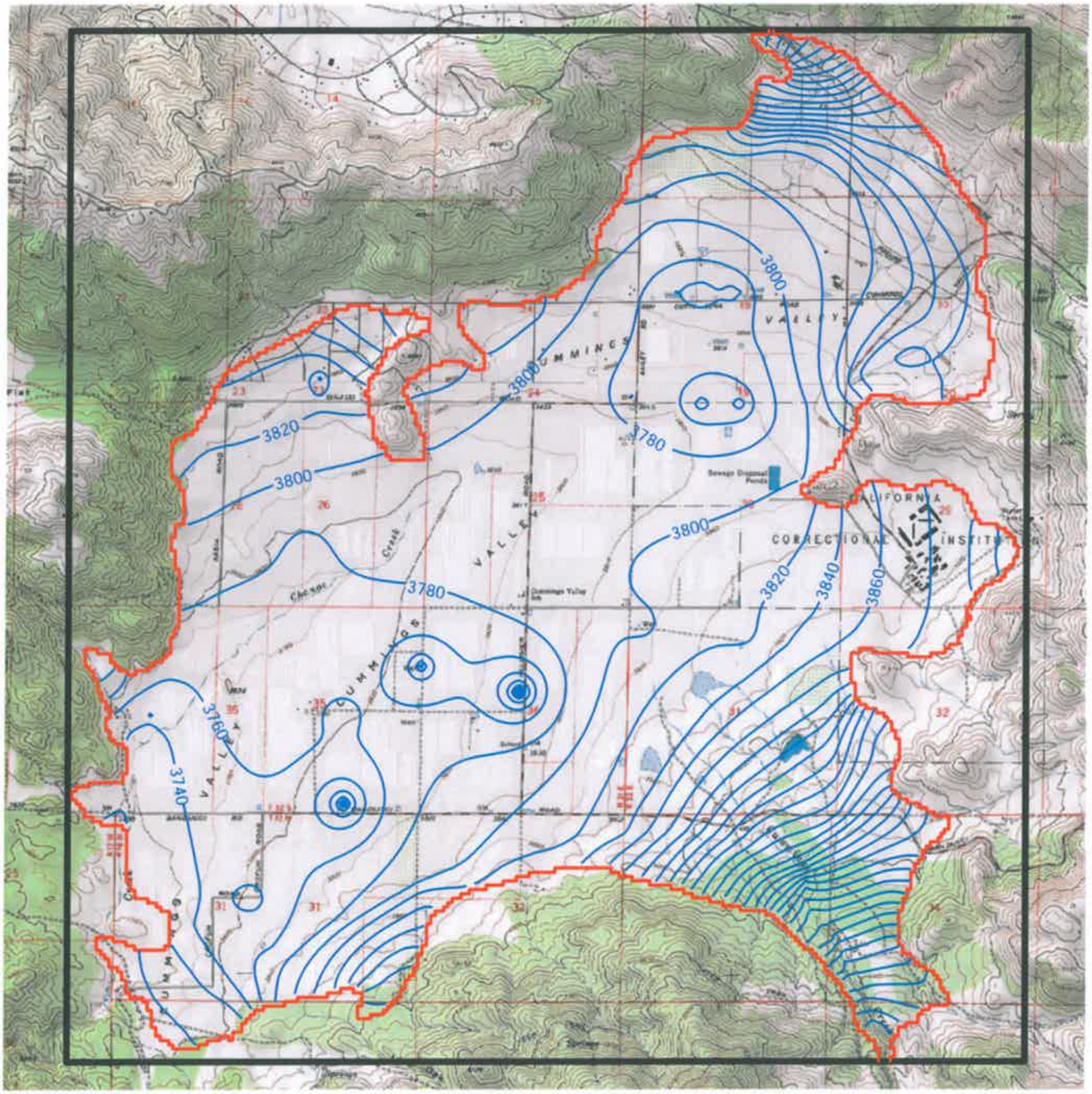
Cummings Basin Groundwater Modeling Study
December 2003

Filename: graphs.ppt | Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE **25**

FUGRO



Legend

- Model Domain Boundary
- Basin Boundary
- Scenario 4 - Simulated Groundwater Elevation (feet)

N
W E
S

4,000
Feet

SCENARIO 4 - SIMULATED GROUNDWATER ELEVATION MAP FOR MODEL YEAR 21 - MODEL LAYER 3

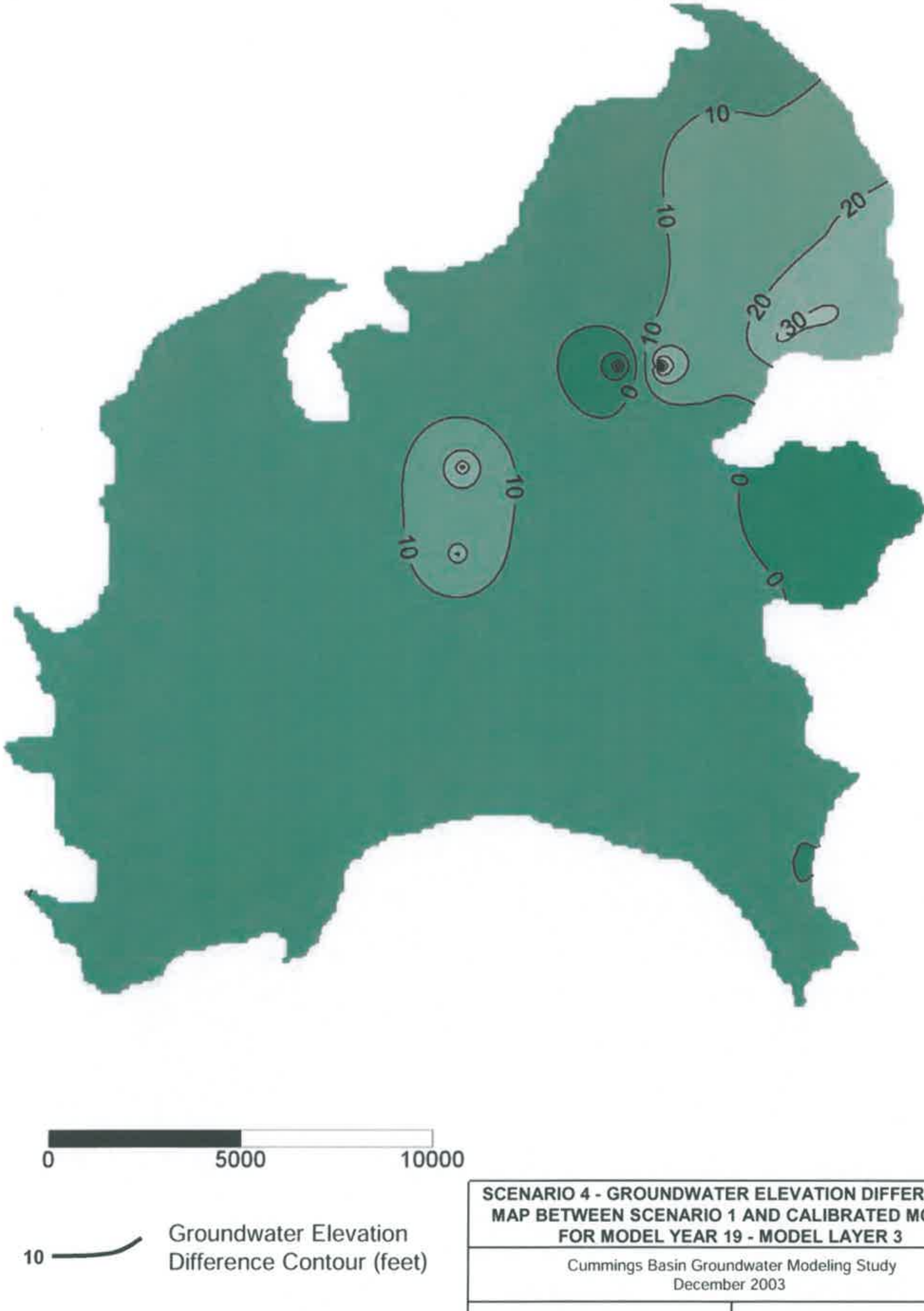
Cummings Basin Groundwater Modeling Study
December 2003

Filename: Figure 26.mxd	Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE
26

FUGRO



SCENARIO 4 - GROUNDWATER ELEVATION DIFFERENCE MAP BETWEEN SCENARIO 1 AND CALIBRATED MODEL FOR MODEL YEAR 19 - MODEL LAYER 3

Cummings Basin Groundwater Modeling Study
December 2003

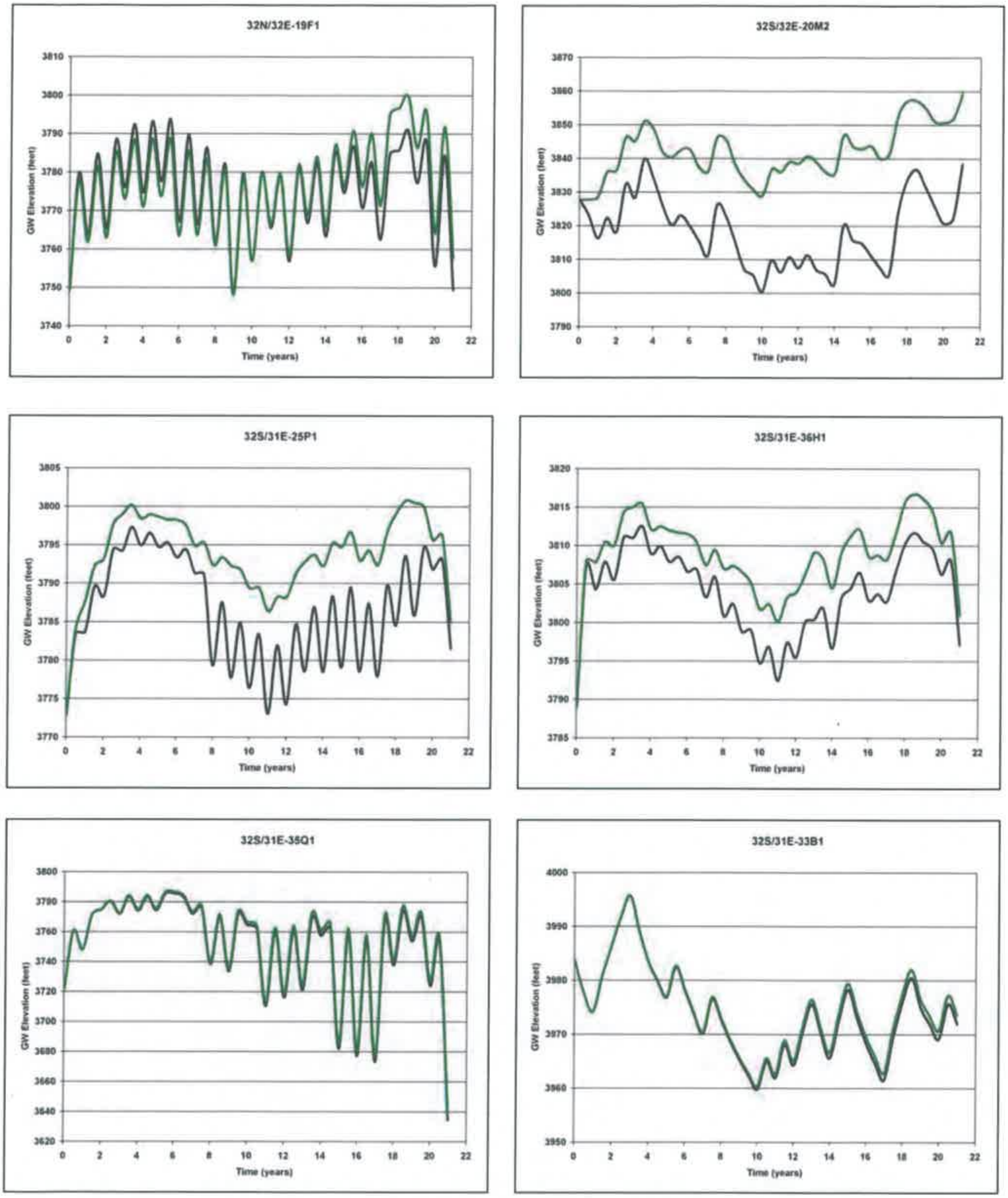
Filename: Diff Plots.ppt

Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE 27

FUGRO



LEGEND

Scenario 1 Results

Scenario 4 Results

SCENARIO 4 - SIMULATED HYDROGRAPHS COMPARING SCENARIO 4 TO CALIBRATED MODEL

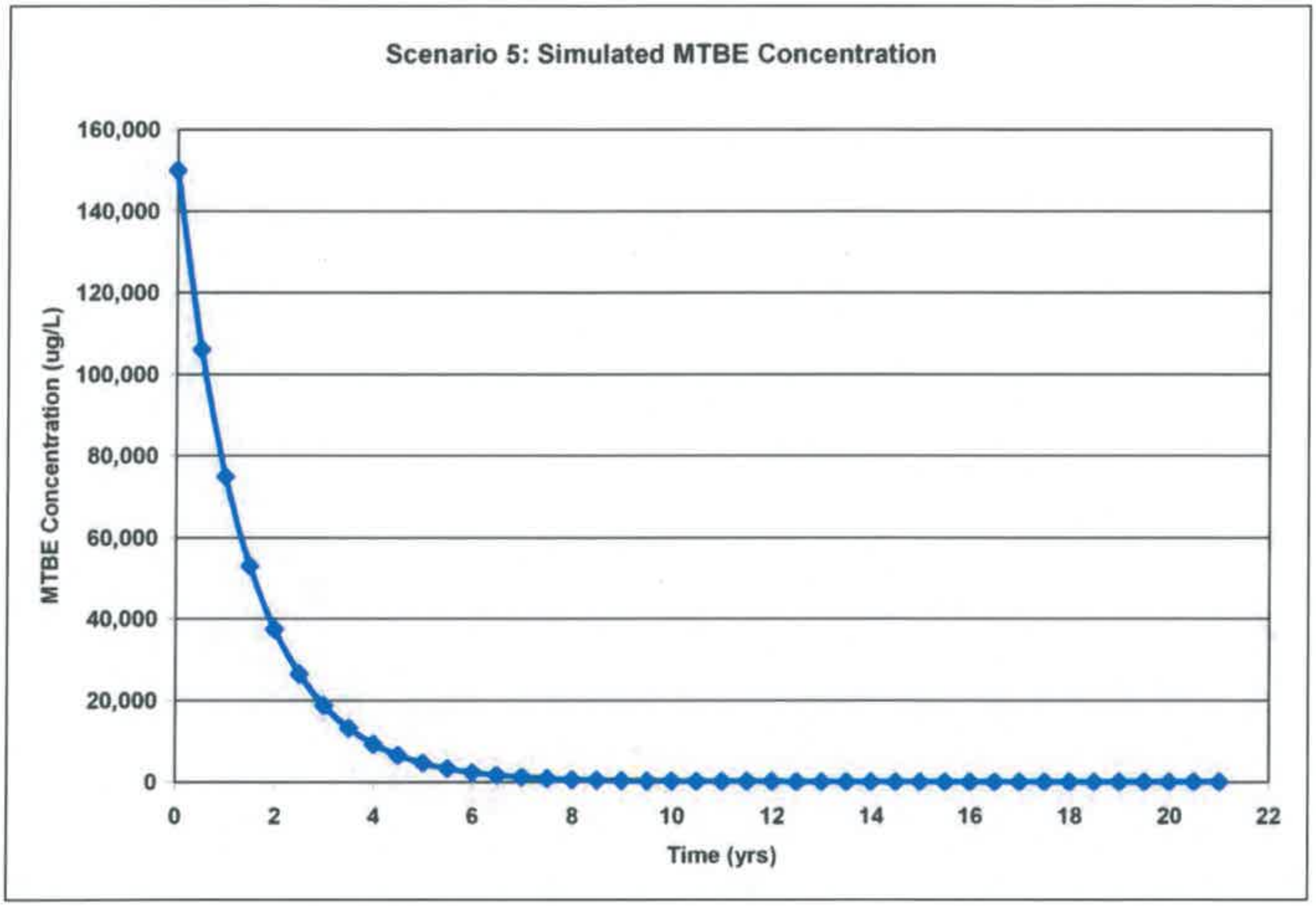
Cummings Basin Groundwater Modeling Study
December 2003

Filename: graphs.ppt	Project No.: 3267.001.01

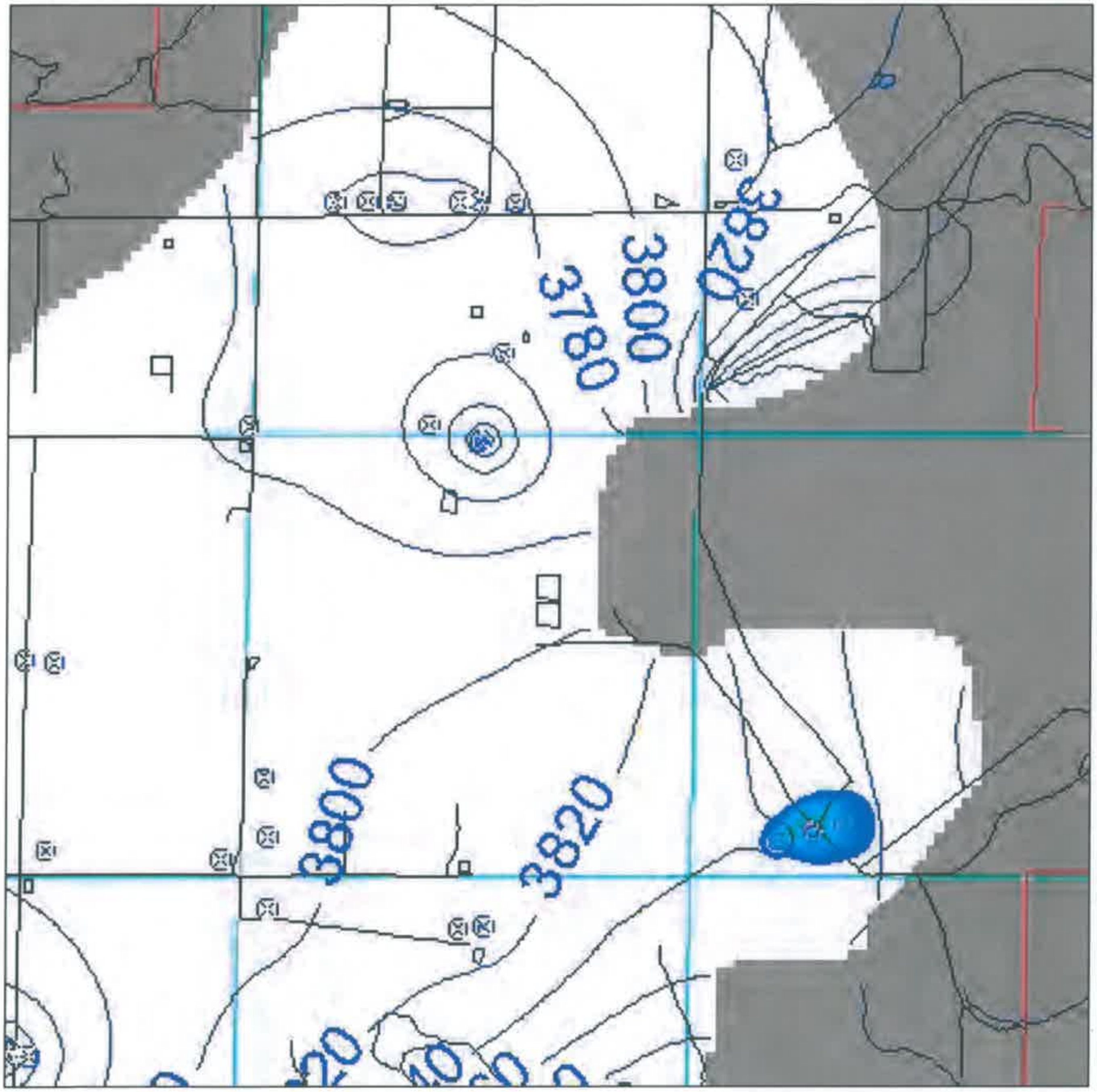
ETIC ENGINEERING

FIGURE
28

FUGRO



SCENARIO 5 - SIMULATED MTBE SOURCE CONCENTRATION	
Cummings Basin Groundwater Modeling Study December 2003	
Filename: graphs.ppt	Project No.: 3267.001.01
ETIC ENGINEERING	FIGURE 29	FUGRO



5000 feet

Groundwater Elevation Contour (feet)

25

1

MTBE Concentrations (ug/L)

SCENARIO 5: GROUNDWATER ELEVATION MAP AND SIMULATED MTBE PLUME FOR MODEL YEAR 21 IN LAYER 2

Cummings Basin Groundwater Modeling Study
December 2003

Filename: Diff Plots.ppt	Project No.: 3267.001.01

ETIC ENGINEERING

FIGURE
30

FUGRO