FINAL REPORT

GROUNDWATER MODELING STUDY
of the
SANTA MARGARITA GROUNDWATER BASIN

Prepared For:

Scotts Valley Water District
Two Civic Center Drive
Scotts Valley, California 95066

Prepared By:

ETIC Engineering, Inc.
1330 Broadway, Suite 600
Oakland, California 94612

May 2006

TABLE OF CONTENTS

FIGURES

TABLES

CHAPTER 1 – INTRODUCTION

PURPOSE AND SCOPE

In July 2004, the Scotts Valley Water District (SVWD) was awarded a $225,000 Local Groundwater Assistance Program (AB303) grant from the Department of Water Resources (DWR) to update the existing groundwater model for the Santa Margarita Groundwater Basin. The existing groundwater model was first developed in 1988 (Watkins-Johnson 1993) and had been updated periodically in subsequent years, including in 1997 and 2000. Previous independent modeling efforts in the basin have included academic (Jacobvitz, 1987) and localized studies (Johnson, 2003). Due to availability of additional data since its last update in 2000, the existing Santa Margarita Groundwater Basin model warranted both conceptual and numerical revisions.

ETIC Engineering, Inc. (ETIC) was selected as the consultant to perform the AB303 numerical model update. This report documents the approach and details of construction and calibration of the updated groundwater model; it also incorporates a sensitivity analysis and sample applications focused on quantifying the annual hydrologic budget for the basin and determining the relationship between groundwater pumpage and change in storage within the basin. The updated numerical model provides a more sound, defensible, and comprehensive tool to quantitatively evaluate and manage groundwater resources in the Scotts Valley area. Detailed model application to various groundwater management scenarios and/or comparisons to previous modeling efforts were not a part of this study's scope of work; however, such analyses may be performed in the future.

A key objective of the AB303 numerical model update and related scope of work included a fresh look at available data and a reevaluation of the hydrogeological conceptual model of the basin independent of previous studies. The updated hydrogeological conceptual model was incorporated into a revised numerical model that can proactively and efficiently support groundwater management practices. The types of basin management components that this model is intended to address include:

- Assessing the available aquifer storage volume;
- Defining the perennial yield for the aquifer, including effects of water quality; and
- Providing input regarding the impacts of land use decisions on water supply.

The DWR grant has been administered by SVWD, but the Technical Advisory Committee (TAC) is composed of members from SVWD, San Lorenzo Valley Water District (SLVWD), and Santa Cruz County. As a state-funded project, involvement by all the interested parties within the basin was considered a priority, recognizing that the goal of the AB303 numerical model update is to improve the understanding of groundwater resources throughout the basin and to develop an improved groundwater management tool.

BACKGROUND

Historical Groundwater Basin Management Activities

Beginning in 1994, the SVWD adopted an annual groundwater management plan, pursuant to Assembly Bill 3030 (AB3030). Management efforts have included monitoring of climatic, surface water, and groundwater conditions in the basin. Annual reports provide a source of reference for public and agency input, as well as establishing monitoring and reporting procedures. Currently the twelfth annual Groundwater Management Report (for water year 2005) is in production as part of the SVWD's groundwater management plan.

Basin Management Objectives

The concept of Basin Management Objectives (Dudley 2001) was developed by DWR as a systematic process to support groundwater basin management. Originally developed for groundwater basins in the Sacramento Valley, the Basin Management Objectives have been adapted to Scotts Valley. The SVWD GWM Plan (Todd Engineers 1994) incorporates a series of objectives that include:

- Encouraging public participation through annual reporting at one or more public meetings;
- Coordinating with other local agencies for hydrogeologic studies, cooperative monitoring, potential development of replenishment and water recycling projects, investigation and remediation of contamination sites, and prevention of groundwater contamination;
- Implementing groundwater replenishment and water recycling;
- Investigating groundwater quality and prevention of groundwater contamination; and
- Continuing monitoring and evaluation of hydrogeology, climatic and surface water conditions, groundwater levels and storage, perennial yield, and groundwater pumping and use, and updating of the computer model.

To this end, the MODFLOW-based numerical groundwater model for the Santa Margarita Groundwater Basin has been updated and improved through application of the AB303-awarded resources, and a comprehensive update of the conceptual and numerical representations of the groundwater basin.

Local Agency Cooperation in the Technical Advisory Committee (TAC)

The AB303 grant encourages the participation of other agencies in the groundwater basin to work cooperatively. To this end, a TAC for the groundwater modeling project was established. As previously indicated, this committee, which met regularly throughout the model development process, included representatives of SVWD, the SVWD Board of Directors, DWR, the SLVWD, and the County of Santa Cruz.

Regular interaction and cooperation among local agencies was provided through establishment of the TAC, and input from TAC members was essential to the collection and interpretation of geologic and hydrologic data within the Santa Margarita Groundwater Basin model domain established as part of the updated numerical model. TAC contributions included:

- Information on historical performance of SVWD, SLVWD, and other private water supply wells with regards to annual operational data, seasonal production rates, and observed groundwater elevations at these wells;
- Information on annual groundwater pumping well production data for areas outside of SVWD boundaries;
- Assistance in providing data characterizing water use from rural area private wells and potential recharge due private septic systems;
- Assistance in interpretation of geologic boring logs during reassessment of basin geology for the conceptual hydrogeologic model; and
- Information regarding typical seasonal streamflow patterns in the basin, with the goal of more accurately representing streamflow losses and gains in the numerical model.

Public Participation

The SVWD encourages public participation in the development and revisions to its Groundwater Management Plan and the application of the AB303 funded numerical model as part of this management program. This report will be made available to the general public upon its final publication.

In addition to the regular meetings of the TAC, the updated numerical model and this report will be presented at a future SVWD Board of Directors meeting, which will be open to the public. At this meeting, both Board members and the public may present questions and comments regarding the efforts documented herein to update the model.

CHAPTER 2 – APPROACH

A numerical model is a mathematical representation of a natural system. The approach to developing a numerical model capable of simulating historical conditions and predicting future conditions depends in large part on developing a sound conceptual hydrogeologic model, mathematically representing this conceptual model within the numerical model, and calibrating the numerical model to historically-observed conditions throughout the basin. The approach to evaluation of the conceptual model, model development (including calibration), and model application is summarized below.

EVALUATION OF CONCEPTUAL MODEL

The first step toward developing a sound, defensible numerical model is to ensure that consistency is maintained between the hydrogeological understanding or conceptual model of the basin and the numerical model. The conceptual model describes the geological setting and hydraulic processes for the basin based on a compilation and evaluation of the available data. It serves as the foundation and basis for constructing a numerical model. Basic components of the conceptual model necessary to construct a numerical model include the hydrologic budget and aquifer properties. The hydrologic budget describes the flow volumes and locations where groundwater enters and exits the basin. The aquifer properties describe the geologic factors that control the movement of groundwater within the basin. The quality of the numerical model is highly dependent upon the accuracy of the conceptual model, as well as on the quality and quantity of available data. Therefore, a comprehensive data collection and conceptual model development is essential to the successful development of a numerical model of the Santa Margarita Groundwater Basin. The updated conceptual model documented herein incorporates data made available to this study through the model development process.

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

DEVELOPMENT OF NUMERICAL MODEL

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

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

APPLICATION OF MODEL AND INTERPRETATION OF RESULTS

Once calibrated, the model provides a dynamic tool to manage groundwater resources, a tool capable of comprehensively evaluating a wide range of interrelated hydrogeologic conditions (e.g., changes in rainfall/recharge and well pumpage) simultaneously, and temporally and spatially across the entire basin. Correspondingly, its application is highly effective in managing typical groundwater management issues within the basin.

For example, input parameters can be set to simulate a wide range of potential future conditions, groundwater uses, or hydrogeologic scenarios. The types of future conditions can include natural or climatic variations such as variation in rainfall over time in a drought scenario. Future groundwater practices can also be evaluated, including changes in the amount and/or distribution of groundwater pumpage, the addition of groundwater recharge programs, or the benefits of water augmentation projects on groundwater conditions. The impact of water quality issues can also be addressed using the model. Lastly, a numerical model provides a robust and dynamic method to estimate perennial yield through balancing the amount of water entering and exiting the basin and the rate of groundwater flow through the basin.

The Santa Margarita Groundwater Model is designed as a regional or basin-wide model to evaluate long-term regional trends and the overall groundwater inflow and outflow associated with the basin. To the extent where data are available to characterize localized conditions that may exist due to geologic complexity or unique localized effects, these data have been incorporated into the model and the model results may be characterized with a high degree of certainty. For areas where information of a regional nature is available, the model can provide a broader regional context for hydrogeologic conditions.

When evaluating model results, the certainty and uncertainty of the numerical model is taken into consideration.

CHAPTER 3 – STUDY AREA

LOCATION

For this report, the study area covers the Santa Margarita Groundwater Basin. Specifically, the active model domain for this Scotts Valley study area is defined as the portion of the Santa Margarita Groundwater Basin that is south of the Zayante fault, east of Ben Lomond fault, and north of the steeply rising granitic crystalline rock in the area of the Carbonera Creek drainage (Figure 3-1).

PHYSICAL SETTING

Topography

The Santa Margarita Groundwater Basin is situated on the southwestern slope of the central Santa Cruz Mountains in Santa Cruz County (US Geologic Survey [USGS] 1998). The Santa Cruz Mountains comprise a portion of the California Coast Ranges physiographic province (Clark 1966). The relief in the Scotts Valley area is moderately rugged, with elevations ranging from less than 300 feet along the San Lorenzo River to over 1,800 feet on Ben Lomond Mountain.

The general topography of the area consists of north-south trending, elongated steep-sided ridges alternating with V-shaped valleys (Figure 3-1). Scotts Valley is among the largest of these valleys and is contiguous with Camp Evers, a broad bench on the south side of Scotts Valley that straddles the divide between the Carbonera and Bean Creek watersheds. Within Scotts Valley, which is situated along the Carbonera Creek, ground surface elevations range from 550 feet along Carbonera Creek to over 800 feet on the ridges north of the city, and over 1,000 feet on the ridges east of the city (USGS 1998).

Climate

The Santa Margarita Groundwater Basin has warm summers and mild winters. In the inland areas that have a sunny exposure, the mean maximum daily temperature is often more than 80 degrees. The elevated inland areas are approximately 3 to 5 degrees cooler per 1,000-foot rise above sea level (US Department of Agriculture [USDA] 1980). Precipitation varies across Santa Cruz County primarily due to the orographic effects of topography. Precipitation is heaviest in the mountains, such as Ben Lomond Mountain, where seasonal precipitation totals average 60 inches, whereas mean annual precipitation along the coast is approximately 30 inches. In the driest years, which occur every 20 years on average, the Santa Cruz Mountains receive only 30 to 35 inches of precipitation. In the wettest years, precipitation totals more than 90 inches in parts of the Santa Cruz Mountains (USDA 1980).

WATER USAGE

Water Districts

The SVWD serves water to most of the City of Scotts Valley and parts of the surrounding area. SVWD is a County Water District formed in 1961 in accordance with the County Water District Law, California Water Code Section 30,000, et seq.

The SLVWD also serves water to part of the southwestern portion of the City of Scotts Valley and adjacent areas to the west. Two nearby areas outside the Scotts Valley city limits receive water through private water purveyors, the Mt. Hermon Association and the Mañana Woods Mutual Water Company. Figure 3-2 shows the jurisdiction of these water districts and other private water purveyors considered in this document.

Land Use

Within the City of Scotts Valley, much of the land has been developed for residential, commercial, and industrial uses. Much of the land along Scotts Valley Drive and Mt. Hermon Road, which form the primary corridors through the city, has been developed and covered with asphalt parking areas, roads, and buildings. A study based on satellite image analysis approximated that more than 60% of the City of Scotts Valley is covered with impervious areas (Basic 2001). Residential development has occurred over much of the City of Scotts Valley and several parts of the surrounding area. Undeveloped parts of the Scotts Valley area are typically covered by redwood or pine forests.

A large sand quarry was operated by Hansen Aggregates in the South Scotts Valley area, southwest of the City of Scotts Valley. Operations at the quarry have ceased and no further mining activity is anticipated at the site, which is currently undergoing closure procedures. Similarly, the nearby Olympia Quarry is also in the process of closing. Smaller, older closed quarries are also located throughout the area, including the Mandarino Development (former Bergstrom Pit) site.

CHAPTER 4 – BASIN CONCEPTUAL MODEL

GEOLOGY

Regional Setting

The Santa Margarita Groundwater Basin is located on the southwestern slope of the Santa Cruz Mountains in western Santa Cruz County. The Santa Cruz Mountains comprise a portion of the California Coast Ranges. The area lies within a major tectonic block defined by the San Andreas Fault to the northeast and the San Gregorio Fault to the southwest. The geology of this tectonic block is characterized by Cenozoic clastic sedimentary and volcanic rocks with a composite thickness of over 30,000 feet that rest upon the crystalline basement rocks.

Geologic Units

The geology of the Scotts Valley area has primarily been mapped by Clark (1966, 1981), Clark and others (1989), Brabb (1997), and McLaughlin and others (2001). The stratigraphic column for the study area consists of a crystalline basement rock overlain by a Tertiary-aged sedimentary sequence (Figure 4-1). The geologic map (Figure 4-2), from Brabb (1997), shows surface outcrop distribution of these units in the Scotts Valley area.

The stratigraphic column for the Santa Margarita Groundwater Basin (Figure 4-1) includes several geologic units in the Tertiary sedimentary sequence above the crystalline basement rock that range from Paleocene to Pliocene in age. The geologic units found within the Santa Margarita Groundwater Basin include:

- Crystalline Rock (oldest)
- Locatelli Formation
- Butano Formation
- Lompico Sandstone
- Monterey Formation
- Santa Margarita Sandstone
- Santa Cruz Mudstone
- Purisima Formation
- Terrace Deposits and Alluvium (youngest)

The crystalline basement rock that underlies the Santa Margarita Groundwater Basin is primarily composed of granite and quartz diorite of Cretaceous age (Figure 4-1). This granitic rock is best exposed upon Ben Lomond Mountain, to the west of the Ben Lomond Fault, where it is primarily composed of granite. In the Scotts Valley area, the granitic rock is exposed along the lower portions of Carbonera Creek. The depth to the granitic crystalline basement rock varies less than 30 feet in the southern parts of the study area to over 1,000 feet north of Scotts Valley (Clark 1981).

The oldest sedimentary sequence consists of erosional remnants of the Locatelli Formation of Paleocene age (Figure 4-1). The Locatelli Formation is characteristically a gray, sandy siltstone with a basal sandstone bed typically found at the base of the unit (Clark 1981). This formation lies nonconformably upon the crystalline basement rock. Within the study area, the Locatelli Formation is found only in the South Scotts Valley area where it outcrops in the hillside along Eagle Creek and the San Lorenzo River (Figure 4-2).

The Butano Formation consists largely of sandstone and interbeds of mudstone, shale, and siltstone of Eocene age (Figure 4-1). Specifically, the Butano Formation consists of three members that include the lower sandstone member, the middle siltstone member, and the upper sandstone member. The total estimated thickness of the Butano Formation is about 5,000 feet. The Butano Formation has been mapped as occurring along the southern margin of the Zayante Fault (Brabb 1997). The lower sandstone member consists of thick to very thick interbeds of conglomerate with clasts that range from well-rounded quartz pebbles to angular granitic boulders up to 8 feet across. The middle siltstone member is composed on this to medium-bedded siltstone that is exposed along Zayante Creek and Mountain Charlie Gulch. The upper sandstone member is more thinly bedded and finer-grained than the lower sandstone member that is exposed in the northwestern portion of the area from Ben Lomond Reservoir to Boulder Creek (Clark 1981).

The Lompico Sandstone is a thick sandstone unit that forms the base of the middle Miocene sequence (Figure 4-1). The lower third of the unit consists of thick beds of light-gray, medium-grained sandstone. The Lompico Sandstone ranges in thickness from 200 to 350 feet thick, with the thinner portions generally occurring as a result of overlying erosion by the Santa Margarita Sandstone (Cloud, 2001). The upper two-thirds of the unit are composed of massive yellowish-gray, fine-grained sandstone beds (Clark 1981). The Lompico Sandstone is found throughout much of the basin; however, the unit outcrops along the basin margins (Figure 4-2) as shown on the geologic map (Brabb 1997).

The Monterey Formation is primarily composed of mudstone, shale, and siltstone of middle Miocene age (Figure 4-1). A few thick sandstone interbeds have been noted within the Monterey Formation. The rock is generally light gray or olive gray to white. Upon weathering, the rock becomes highly fractured and individual pieces remain hard and firm. The upper surface of the Monterey Formation has been eroded, and the Monterey Formation is missing along the southern and eastern margins of the groundwater basin (Figure 4-2). The Monterey Formation thickens toward the center of the basin to over 2,000 feet thick (Clark 1981). The Monterey Formation is exposed at the surface over a large area within the northern and western portion of the study area (Figure 4-2)

The Santa Margarita Sandstone generally consists of massive, fine-to-medium-grained sandstone of upper Miocene age (Figure 4-1). The Santa Margarita Sandstone forms a distinctive formation of white sand that can be observed in cliffs around the area (Clarke 1981). Laboratory analyses of this sandstone indicate that it is 85 to 90 percent sand, 7 to 8 percent silt, and 4 percent clay (USDA 1980). The Santa Margarita Sandstone is a primary drinking water source for the area (Muir 1981) and occurs at the surface on the upland areas over a large portion of the area from south of Scotts Valley to the Quail Hollow area near Ben Lomond (Figure 4-2). In the northern Scotts Valley area the Santa Margarita Sandstone is overlain by either the Quaternary alluvium or the Santa Cruz Mudstone; however, the Santa Margarita Sandstone is exposed at the surface along the incised stream valleys (Brabb 1997).

The Santa Cruz Mudstone consists of organic mudstone beds of upper Miocene age that overlie the Santa Margarita Sandstone (Figure 4-1). The Santa Cruz Mudstone thickens westward from a featheredge along the eastern margin of the groundwater basin to more than 200 feet thick in the center of the basin. The Santa Cruz Mudstone conformably overlies the Santa Margarita Sandstone. In the Scotts Valley area, the Santa Cruz Mudstone underlies much of the northern portion of the City of Scotts Valley (Clark 1981). To the south and west, this unit forms a capping mudstone found along the higher elevations (Figure 4-2).

The rock of the Purisima Formation consists mostly of fine-grained sandstone, mudstone, and siltstone of Pliocene age (Clark 1981). The Purisima Formation forms a significant water producing horizon to the south in the Soquel Creek area. In the Scotts Valley area, it is locally present on the higher elevations overlying the Santa Cruz Mudstone (Figure 4-2).

The Pleistocene and Holocene-aged alluvial deposits are mapped in portions of the major stream valleys (Clark 1981). These deposits consist of unconsolidated sands and silts along the streambeds of the San Lorenzo River and the Carbonera and Bean Creeks. Much of the City of Scotts Valley is directly underlain by these unconsolidated sediments (Figure 4-2).

Geologic Structure

As mapped by the USGS (Brabb 1997), the Ben Lomond Fault trends north-northwest and forms the western boundary of the basin (Figure 4-2). Ben Lomond Mountain, which is primarily composed of granitic crystalline basement rock, is located west of the fault. The Zayante Fault forms the northern basin boundary. The area north of the Zayante Fault is composed of a sequence of Tertiary-aged sedimentary formations that are not present south of the Zayante Fault in the Scotts Valley Syncline (Figure 4-2).

Regional folding has produced a major syncline, or trough, termed the Scotts Valley Syncline, which crosses through the North Scotts Valley area (Figure 4-2). The axis of the syncline has a northwest-southeast trend that runs from near Ben Lomond to north of Scotts Valley (Clark 1981; Brabb 1997). The Scotts Valley Syncline was formed as a result of uplift along the Zayante Fault and, therefore, essentially parallels the fault (Figure 4-2).

The sediments in the basin have been folded during deformation associated with the development of the Coast Ranges (Clark 1981). A period of geologic deformation preceded the deposition of the Lompico Sandstone as evidenced by the Lompico unconformably overlying the crystalline basement and Locatelli and Butano Formations in different portions of the basin. Subsequent geologic deformation has caused the Lompico Sandstone to be steeply dipping in the Scotts Valley area. This subsequent deformation has caused the Lompico Sandstone to be directly overlain by the Monterey Formation, Santa Margarita Sandstone, and Santa Cruz Mudstone (Cloud, 2001). These complex relationships have significant impact on how groundwater flows into, out of, and through the Lompico Sandstone. Due to geologic deformation, the Santa Margarita Sandstone directly overlies, in different locations, the crystalline basement, and/or the Locatelli Formation, and/or Lompico Sandstone, and/or the Monterey Formation (Figure 4-2).

SANTA MARGARITA BASIN GEOLOGY

Definition of the Basin

The Santa Margarita Groundwater Basin is formed by the sedimentary sequence found within the Scotts Valley Syncline. The basin forms a roughly triangular area that is bounded by the two regional faults, the Ben Lomond Fault to the west and the Zayante Fault to the north (Figure 4-2). To the southeast, the basin is bounded by the granitic crystalline rock which rises steeply in this area. The depth to the granite varies from an elevation of approximately 1,000 feet below sea level to an elevation of approximately 500 feet above sea level over a distance of about one half mile. This marked change of the elevation of the top of the granite can be traced along the eastern side of Scotts Valley and marks the southeastern edge of the Santa Margarita Groundwater Basin.

Geologic Correlations

For this study, a series of hydrogeologic cross-sections have been constructed throughout the basin to reevaluate the geologic correlations within the Santa Margarita Groundwater Basin. These cross-sections provide support for developing the hydrogeological conceptual model by improving the understanding of geology, groundwater, and groundwater-surface water interactions based on data available to date.

Ten cross-sections representing the Santa Margarita Groundwater Basin (Figures 4-3 and 4-4) are depicted herein to show the geologic correlations across the entire basin. These cross- sections are based on geologic logs from wells in the area. Below is a discussion of updated interpretations of data key to the revised conceptualization of the hydrogeology.

<u>Cross-Section A-A'</u>

Cross-Section A-A' runs south of Scotts Valley northeast to north of Scotts Valley (Figure 4-3). This cross-section is representative of the geology in the Scotts Valley area. The depth to the granitic crystalline basement rock varies from a few hundred feet in the Blackburn Gulch area to over 2,000 feet in the area of SVWD wells #3B and #7A. This deepest part of the basin represents the axis of the Scotts Valley Syncline. In the west branch of Soquel Creek, granite is exposed at the bottom of the valley; however, this area is considered to be outside the Santa Margarita Groundwater Basin.

The Ben Lomond and Zayante Faults occur at the west and east ends of the cross-section, respectively. Three inferred faults with minimal offset are mapped based on water level data and model results.

The Locatelli Formation is restricted to the western portion of the cross-section. A small outcrop occurs near the San Lorenzo River; however, the Locatelli Formation is not mapped west of the Ben Lomond Fault. The Locatelli is absent east of Indian Springs Well #2 except for an interpreted remnant in the deepest part of the syncline that was encountered in SVWD Well #3B. The Butano Formation is found only in the northern portion of the basin. It forms a thick wedge that extends part way across the basin before pinching out on the west limb of the Scotts Valley Syncline. The Butano Formation ranges from 200 to approximately 1,000 feet in thickness (Figure 4-5).

The Lompico Sandstone unconformably overlies the Locatelli Formation in the west and the Butano Formation in the east (Figure 4-5). The Lompico Sandstone ranges in thickness from approximately 200 to 350 feet across this area and is highly folded. The Monterey Formation conformably overlies the Lompico Sandstone. It ranges in thickness from about 700 feet thick in SVWD #3B to absent in several areas. The Santa Margarita unconformably overlies the Monterey Formation, and has completely eroded the Monterey Formation along portions of this cross-section. In these areas, the Santa Margarita Sandstone is in direct contact with the Lompico Sandstone and results in reductions in the thickness of the underlying Lompico Sandstone (Cloud, 2001). The Santa Margarita Sandstone ranges from thin to over 400 feet thick in the Pasatiempo area to being absent at SVWD #7A.

The Santa Cruz Mudstone conformably overlies the Santa Margarita Sandstone, but is found only in the areas north of Scotts Valley. The Purisima Formation unconformably overlies the Santa Cruz Mudstone. The base of the Purisima dips uniformly toward the southeast and cuts into the Santa Cruz Mudstone, Monterey Formation, Lompico Sandstone and Butano Formation (Figure 4-5).

<u>Cross-Section B-B'</u>

Cross-Section B-B' runs from west to east across the Santa Margarita Groundwater Basin (Figure 4-3). The cross-section crosses the Ben Lomond Fault near Felton (Figure 4-5). The stratigraphic relationships are similar to those noted above. The cross-section line trends east across a syncline. This east limb of the syncline ends abruptly near the El Pueblo well field against granitic crystalline basement rocks. This area is interpreted to represent a paleotopographic high in the granitic crystalline basement rather than a structural feature (Clark 1981). The paleotopographic high would represent an erosional surface from prior to the deposition of the Miocene Lompico Sandstone. The large paleotopographic high in the granitic crystalline basement rocks forms the southeastern boundary to the Santa Margarita Groundwater Basin.

The cross-section also shows the geologic separation of the Lompico in the Blackburn Gulch area from those in the Santa Margarita Groundwater Basin (Figure 4-6). This relationship indicates the Blackburn Gulch area is hydrogeologically separate from the Santa Margarita Groundwater Basin.

<u>Cross-Section C-C'</u>

Cross-Section C-C' runs from west to east across the Santa Margarita Groundwater Basin (Figure 4-3). The cross-section crosses the Ben Lomond Fault south of the town of Ben Lomond (Figure 4-7). The cross-section shows that the Monterey Formation thickens to the north and the Lompico Sandstone is found at increasingly deeper depths in this area. The top of Lompico Sandstone is estimated to be approximately 1,000 feet below ground surface in parts of this area.

The Butano Formation is not interpreted to be present under much of this cross-section except for the areas under the City of Scotts Valley to the east. To the east, the cross-section crosses the Scotts Valley Syncline in the vicinity of SVWD #3B. The Blackburn Gulch area is separated from the Santa Margarita Groundwater Basin by a small anticline. The Lompico Sandstone has nearly been eroded through by downcutting by Blackburn Gulch.

Cross-Section D-D'

Cross-Section D-D' runs south to north across Scotts Valley (Figure 4-3). The cross-section crosses the Zayante Fault near Mountain Charlie Gulch and extends southward to the interpreted paleotopographic high in the granitic crystalline basement rocks (Figure 4-8). The cross-section crosses the Scotts Valley Syncline and shows an asymmetrical syncline. The northern limb of the syncline is mostly composed of the Butano Formation with the higher stratigraphic units having been eroded away. The southern limb of the syncline is composed of the sequence from the Butano Formation upward through the Santa Cruz Mudstone. The Butano Formation thins to the south. The Purisima Formation cuts through the syncline, indicating that it was deposited after the folding that formed the syncline.

Cross-Section E-E'

Cross-Section E-E' runs south of Scotts Valley northeast to north of Scotts Valley (Figure 4-3). This cross-section clearly shows the interpreted pinch-out of the Butano Formation at depth (Figure 4-9). The Lompico Sandstone unconformably overlies the Butano Formation and the stratigraphic relationship indicates the pinch-out of the Butano Formation is due to erosion. A thick sequence of Eocene to Miocene geologic units is present north of the Zayante Fault but is not present in the Santa Margarita Groundwater Basin. Therefore, a significant stratigraphic interval that is represented by the erosional contact between the Lompico Sandstone and Butano Formation is missing within the basin.

To the south, the pinch-out of the Monterey Formation is clearly shown based on geologic borehole data. These data indicate that the Monterey Formation has been eroded by the overlying Santa Margarita Sandstone. As shown, where the Monterey Formation is missing, the Lompico Sandstone is in direct contact with the Santa Margarita Sandstone. To the north, the Monterey Formation thickens to over 1,000 feet thick and forms a prominent ridge. Mountain Charlie Gulch has eroded through the Monterey Formation and Lompico Sandstone, and rests on the Butano Formation (Figure 4-9).

The northern portions of Bean Creek have eroded into the Santa Cruz Mudstone (Figure 4-9). To the south, the creek has eroded deeper until it has intersected the Santa Margarita Sandstone. The formation that underlies Bean Creek strongly influences the groundwater-surface water interaction.

Cross-Section F-F'

Cross-Section F-F' runs toward the northeast from south of Scotts Valley to north of Scotts Valley (Figure 4-4). This cross-section indicates that the paleotopographic high in the granitic crystalline basement rocks forms the southeastern boundary to the Santa Margarita Groundwater Basin (Figure 4-10). As discussed above, the pinch-outs of the Butano and Monterey Formations are observed on this cross-section. Bean Creek flows over outcrops of the Butano Formation and forms a likely recharge area for the Butano Formation. To the south, the remnant of the Locatelli Formation is shown as occurring in a depression or fold in the granitic crystalline basement rocks.

Cross-Section G-G'

Cross-Section G-G' runs from Boulder Creek in the northwest to north of Scotts Valley to the southeast (Figure 4-4). This cross-section shows the relationship of geologic units across the basin in the Boulder Creek area. In this cross-section, the Butano Formation is conceptualized as having a relatively uniform thickness across the basin; however, no wells have penetrated to this depth to conform this interpretation. The Lompico Sandstone occurs across the basin at a relatively uniform thickness of 200 to 300 feet. Several wells penetrate the Lompico Sandstone in the northern part of the basin. Most of the surface exposures reflect the Monterey Formation, with streams which have incised into the Monterey Formation forming a steep topographic profile. The Santa Margarita Sandstone and Santa Cruz Mudstone are typically found capping the tops of the higher elevations (Figure 4-11).

Cross-Section H-H'

Cross-Section H-H' runs from south of Scotts Valley northwest toward areas north of Boulder Creek (Figure 4-4). This cross-section indicates that the large paleotopographic high in the granitic crystalline basement rocks forms the southeastern boundary to the Santa Margarita Groundwater Basin (Figure 4-12). The Butano Formation is interpreted as existing only in the northern parts of the basin near Boulder Creek. The pinch-out of the Monterey Formation is observed in the Scotts Valley area. South and east of the paleotopographic high, only a thin remnant of the Santa Margarita Sandstone and Purisima Formation occur; this remnant is typically less than 30 feet thick. The Santa Margarita Sandstone has become increasingly incised by streams to the north until it has been eroded away, with only remnants found capping the tops of the higher elevations.

Cross-Section I-I'

Cross-Section I-I' runs south of Scotts Valley northeast to near Boulder Creek (Figure 4-4). This cross-section shows the remnant Locatelli Formation south of Scotts Valley that is terminated by the Lompico Sandstone, likely in the vicinity of the confluence of Bean and Zayante Creeks. The Lompico Sandstone is interpreted to cross the basin with a relatively uniform thickness. An anticline brings the Lompico Sandstone up higher in elevation to where it is incised by the San Lorenzo River between Boulder Creek and Ben Lomond. The Monterey Formation thickens northward from the southern pinch-out. North of Love Creek, the Monterey is increasingly incised by creeks to where it is less than 100 feet thick in most places along the northern extent of this cross-section. A syncline in Newell Creek area provides a thicker section of Santa Margarita Sandstone in the Quail Hollow area. Further to the north, the Santa Margarita Sandstone is entirely absent (Figure 4-13).

<u>Cross-Section J-J'</u>

Cross-Section J-J' runs from near Felton northward to Loch Lomond Reservoir (Figure 4-4). This cross-section runs across the Scotts Valley Syncline in the western portion of the basin, showing the syncline to be asymmetrical with a steep northern limb relative to the southern limb, which has been cut by the Ben Lomond Fault. To the south, the Monterey Formation thickens to over 1,000 feet thick. To the north, it also forms a prominent high point over Loch Lomond reservoir. Newell Creek has eroded through the Monterey Formation and Lompico Sandstone and rests on the Butano Formation (Figure 4-14).

GROUNDWATER AQUIFERS

Definition of Aquifers

The primary aquifers in the Scotts Valley area are the Santa Margarita Sandstone, the Lompico Sandstone, and the Butano Formation. The Santa Margarita and Lompico Sandstones have long been recognized as primary aquifers in the Scotts Valley area. The Santa Margarita Sandstone has a long groundwater production history, with several production wells completed within this unit in the Scotts Valley area (Muir 1981). Similarly, the Lompico Sandstone is currently the primary groundwater producing horizon in the Scotts Valley area, with several large production wells completed in this unit. Other units are of local importance for water supply needs. Additional information about the water bearing characteristics of these units is provided below.

Purisima Formation, Santa Cruz Mudstone, and Quaternary Alluvium

The Purisima Formation is a significant groundwater producing horizon farther to the southeast in the Soquel Creek area. Within the Santa Margarita Sandstone, the Purisima Formation is limited in lateral extent and is typically found capping topographic highs. Because of this, the Purisima Formation is not a significant water producing unit in the Santa Margarita Groundwater Basin.

The underlying Santa Cruz Mudstone is a lower permeability unit that primarily acts as an aquitard. However, it also is typically found capping topographic highs in the Santa Margarita Groundwater Basin. Numerous wet-weather springs are found near outcrops of the Santa Cruz Mudstone and drain precipitation recharge captured by the Purisima Formation.

The Quaternary alluvium located along Carbonera Creek is not considered a significant water producer in the Scotts Valley area because of its limited saturated thickness and lateral distribution. Where the alluvium overlies the Santa Margarita Sandstone, precipitation recharge can percolate down to the lower aquifer. Thicker Quaternary alluvium deposits are located along the San Lorenzo River and Zayante and Bean Creeks. Few water supply wells are completed solely within the alluvium. The alluvium collects precipitation recharge that can percolate down to the lower aquifer.

Santa Margarita Sandstone

The Santa Margarita Sandstone has widespread surface exposures primarily in the South Scotts Valley area, north of Bean Creek, and the Quail Hollow area near Ben Lomond. Where the Santa Margarita Sandstone is exposed at the surface, higher infiltration rates of precipitation relative to runoff are anticipated due to the development of high-permeability sandy soils in these areas (USDA 1980). These areas will form significant groundwater recharge locations (Figure 4-2). In the South Scotts Valley area, the Santa Margarita Sandstone forms upland areas that are covered by over 300 feet of sandstone (Figure 4-4).

The Santa Margarita Sandstone is a major source of groundwater for the SLVWD from their wells near Olympia and Quail Hollow. The SVWD has decreased pumpage from the Santa Margarita Sandstone as water levels in those units have declined (ETIC 2004). Numerous domestic, industrial, and small private water systems rely on the Santa Margarita Sandstone for their water supply.

North and west of Scotts Valley, the Santa Margarita Sandstone is found at depth below the Santa Cruz Mudstone. Based on the available geologic log data from wells drilled in the area, the thickness of the Santa Margarita Sandstone diminishes to the north. Where the Santa Margarita Sandstone is overlain by the Santa Cruz Mudstone in the North Scotts Valley area, however, groundwater recharge will be significantly limited due to the low-permeability clayey soils that develop over the Santa Cruz Mudstone (USDA 1980).

Thin, dense, lower permeability layers have been identified within the Santa Margarita Sandstone. These layers have been known to form perching horizons as was noted at the Watkins-Johnson site in Scotts Valley (R.L. Stollar 1988). The perched aquifer formed above this horizon has been noted to have a significantly higher groundwater elevation than the regional Santa Margarita Sandstone below it. However, these horizons are not considered to be continuous. Identification of these perching horizons is important for properly evaluating the impact of contamination to the regional aquifer, and for properly understanding and mapping groundwater elevations within the Santa Margarita Sandstone.

Monterey Formation

Numerous domestic wells and smaller water supply wells are completed within sandstone interbeds within the Monterey Formation. The sandstone interbeds and the fractured siltstones in the Monterey Formation can locally produce groundwater; this is mostly used for domestic wells. The SVWD Well #9 is currently producing from the lower well screen that is completed within the Monterey Formation. The Lompico County Water District obtains its groundwater from wells completed within the Monterey Formation.

The thickness of the Monterey Formation varies widely across the area as a result of geologic deformation and erosion. The Monterey Formation is considered to act as an aquitard that significantly limits groundwater flow between the Santa Margarita and Lompico Sandstones. Along the eastern rim of the Santa Margarita Groundwater Basin, the Santa Margarita Sandstone directly overlies the Lompico Sandstone. In this area, the Monterey Formation is absent, thus leaving the Santa Margarita and Lompico Sandstones in direct contact (Figure 4-4). The distribution of this contact forms a strip along the southern and eastern portions of the basin (Figure 4-4). This relationship is important in understanding the groundwater interactions between these two primary aquifers. Where present, the intervening Monterey Formation forms a significant aquitard that limits groundwater movement between the Santa Margarita and the Lompico. Where the Monterey Formation is absent is considered to form an area of significant groundwater recharge to the Lompico Sandstone from the overlying Santa Margarita Sandstone

Lompico Sandstone

In the Scotts Valley area, the Lompico Sandstone is primarily recharged from the Santa Margarita Sandstone. The limited amount of surface exposure of the Lompico Sandstone within the groundwater basin significantly limits the potential for groundwater recharge from surface sources such as precipitation and streambed percolation. The overlying low-permeability Monterey Formation also significantly limits groundwater recharge by vertical flow from overlying units. Therefore, a portion of the groundwater recharge for the Lompico Sandstone likely comes from the northern portion of the basin at a distance of several miles from the Scotts Valley area. Recharge can also occur where the Lompico is overlain directly by saturated Santa Margarita Sandstone. Groundwater outflow from the Lompico Sandstone is primarily from groundwater pumpage. Due to the limited surface exposures of the Lompico Sandstone, it appears that there are few natural discharge points within the Lompico Sandstone. Improving the understanding of groundwater inflow and outflow from the Lompico Sandstone will be addressed by the AB303 numerical model update presented herein.

The Lompico Sandstone is a major source of groundwater for both the SVWD and SLVWD in the Scotts Valley area. Other domestic, industrial, and small private water system wells are completed in the Lompico Sandstone in the Scotts Valley area. Elsewhere in the basin, the Lompico Sandstone occurs at significant depths below the ground surface. Few, if any, wells are drilled to those depths.

The Lompico Sandstone outcrops along Bear Creek and the San Lorenzo River in the Boulder Creek area. These areas are primarily discharge points for groundwater to the surface water.

The Lompico Sandstone is recharged by groundwater outflow from the Santa Margarita Sandstone where it is directly overlain by the Santa Margarita Sandstone (Figure 4-4). The amount of groundwater flow from the Santa Margarita to the Lompico Sandstone is considered to have increased as the result of decreasing groundwater levels in the Lompico Sandstone due to increased pumping. Importantly, portions of the Santa Margarita have also been dewatered. Groundwater pumping is another major component of groundwater outflow from the Santa Margarita Sandstone. Evapotranspiration, the uptake of groundwater by trees and vegetation, is considered to be locally significant where groundwater levels are shallow enough to exist within the root zone, which is no longer as prevalent as it may have been in the 1970s.

Butano Formation

Prior to this study, the significance of the Butano Formation as a major water-bearing unit had not been recognized. As a result of this study, the SVWD Wells #3B and #7A have been reinterpreted as being completed entirely or partially within the lower sandstone member of the Butano Formation (Figure 4-2). The production history of these wells indicates that the Butano Formation is capable of producing significant volumes of groundwater.

The Butano Formation forms a wedge along the northern portion of the basin (Clark 1981). Groundwater recharge is most likely from infiltration of precipitation and from the streams that flow over the Butano Formation in these exposure areas north of Scotts Valley. Correspondingly, the Butano Formation appears to have few natural discharge points.

The Butano Formation had been mapped in surface outcrop by Clark (1966, 1981), Brabb (1997), and McLaughlin and others (2001). These investigations noted that the Butano Formation extends beneath a portion of the Scotts Valley area. By constructing cross-sections that extended to these outcrop areas, the Butano was extended beneath the overlying layers. Through this analysis, it was recognized that SVWD production Well #3B was screened completely within the Butano Formation and Well #7A was screened across both the Lompico Sandstone and Butano Formation. Wells #3B and #7A have total depths of 1,067 and 981 feet, respectively. These wells have a significantly thicker sequence of sedimentary rock than other wells in the vicinity. The correlation of the lower section encountered in these wells with the Butano Formation provides a more realistic and logical geologic interpretation.

The Butano Formation has become a major source of groundwater for the Scotts Valley Water District. Elsewhere in the basin, the Butano Formation occurs at significant depths below the ground surface and few, if any, wells have been drilled to those depths.

Locatelli Formation and Fractured Crystalline Rock

The Locatelli Formation is primarily a dense, fine-grained geologic unit that is restricted to a small area south of Scotts Valley. However, a basal sandstone has been encountered overlying the granitic crystalline basement rock in most areas. A few wells in the South Scotts Valley area have also been completed within the basal sandstone layer in the Locatelli Formation. Groundwater in the basal Locatelli sandstone has water levels that are distinct from those in the overlying aquifers. This suggests that this unit is hydrologically separated from the rest of the Santa Margarita Groundwater Basin, and is likely more closely related to the underlying granitic crystalline basement rock.

Some local domestic wells, primarily south of Scotts Valley and west of Ben Lomond and Boulder Creek, are completed within fractures in the granitic crystalline basement rock. These wells are, for the most part, considered to be outside the Santa Margarita Groundwater Basin. South of Scotts Valley, there are areas where the Santa Margarita Sandstone overlies the granitic crystalline basement rock and likely provides recharge to fractures in the granitic rock.

DATA GAP ANALYSIS

In developing a numerical groundwater flow model based on the basin conceptual model that has been developed and described for the Santa Margarita Groundwater Basin, areas where insufficient historical and/or field measured data exist have been identified. Where such data gaps exist with regard to developing a numerical model of the basin, interpretation and interpolation using nearby data sources has been used to estimate model input parameters as accurately as possible with the available data. In particular, where data was not consistently available across time or space for the model, the development of model inputs such as recharge from rainfall and stream flow across the domain was developed using correlations and interpolation amongst the available data. The correlations and interpolations used to estimate input parameters where directly measured values were not available are discussed in the proceeding chapter. In addition, spatial data gaps within the model domain for aquifer characteristics such as hydraulic conductivity and storage parameters were further adjusted and established through the model calibration process.

In developing the numerical model of the Santa Margarita basin and addressing the limitations of available data for characterizing geologic and hydraulic features within the basin, areas which would most benefit from possible future data collection efforts have been identified. These areas include:

- Local field recharge studies which could be designed to provide direct measurements of surface to groundwater recharge for a range of land surface conditions.
- The location and installation of additional streamflow monitoring gauges, particularly on the more significant tributaries to larger steams (Zayante, Carbonera, and Bean creeks) in the basin.
- Additional groundwater elevation monitoring points, particularly in the North Scotts Valley area, and at depths which contact the deeper Butano Formation.
- Studies which examine the local effects of (shallow) perching horizons within the Santa Margarita may improve the understanding of recharge and streamflow exchanges with the groundwater basin.

CHAPTER 5 – NUMERICAL GROUNDWATER MODEL

The conceptual model described above provides the basis for development of the numerical groundwater flow model. Specifically, it defines the occurrence and movement of groundwater within and through various hydrogeologic strata known to exist in the basin and includes interaction with surface water. Mathematical representation of the conceptual model within the numerical model is described below.

MODEL SETUP

The numerical model was constructed using the groundwater flow model MODFLOW 2000 (Harbaugh *et al* 2000), a finite-difference numerical model developed by the USGS. To facilitate model development, the MODFLOW processor Groundwater Vistas 4 (ESI 2004) was used. MODFLOW is a widely used, industry standard model with many documented uses in support of basin management. It is also consistent with the original code serving as the basis for the previous versions of the Santa Margarita Groundwater Basin model.

Model Domain

The model domain is the geographical area covered by the numerical model. The model domain for the Santa Margarita Groundwater Basin includes the previously defined triangular area bounded by the Ben Lomond Fault to the west, the Zayante Fault to the north, and the steeply rising granitic crystalline rock to the southeast (Figure 5-1). This area covers approximately 18,410 acres or 28.8 square miles.

The model grid provides the mathematical structure for developing and operating the numerical model. The Santa Margarita Groundwater Basin model used a uniform grid spacing of 110 feet by 110 feet. The model grid is comprised of 346 rows and 383 columns; therefore, each model layer is comprised of 132,518 model grid cells. The entire four-layer model contains a total of 530,072 model grid cells. Due to changes in the plan view area of the various hydrogeologic formations within the model domain and with depth, the number of active model cells within each layer varies, never exceeding a maximum of 56,100 cells in any one layer.

Model Layers

Model layers provide vertical resolution for the model to simulate variations in groundwater elevation, aquifer stresses, and water quality with depth. The Santa Margarita Groundwater Basin model consists of four layers that simulate the primary water-bearing formations within the basin. The simulated geologic layers, as occurring from shallowest to deepest and as previously described in the conceptual model portion of this report, consist of the following formations:

Model Layer 1: Santa Margarita Sandstone

Model Layer 2: Monterey formation

Model Layer 3: Lompico Sandstone

Model Layer 4: Butano Formation (northern portion of model domain) /
Locatelli Formation (southern portion of model domain)

Figure 5-2 illustrates the vertical layering configuration as it is represented in the MODFLOW model for a typical cross section. As indicated in the above layering configuration, the deepest layer in the basin model is used to model the presence of either the Butano or Locatelli Formation, depending on their occurrence (or lack thereof) across the model domain. With the exception of a very deep and thin occurrence of the Locatelli Formation beneath the Butano Formation in the north Scotts Valley area (Figure 4-4), these two formations do not occur simultaneously within the model domain; therefore, they may be simulated using the same Layer 4 in the model. The bottom of the vertical extent of the model domain is simulated using the contact between the deepest of the above-referenced layers and the underlying and relatively impervious granite beneath the Santa Margarita Groundwater Basin.

The three dimensional structure of each of these distinct layers in the numerical model is established using the formation depths and thicknesses, as established through the geologic interpretation of available soil boring and well logs documented in the conceptual model of the basin (see Chapter 4). Using the geologic structure established in the conceptual model, data files which reflect the top and bottom of each of the four model layers are generated. These data files are then imported into MODFLOW in order to provide the layout and structure for the model layers.

Stress and Base Periods

To simulate temporal changes within the model, definition of stress periods representing the resolution of time into discrete intervals is warranted. For the Santa Margarita Groundwater Basin model, seasonal, or 3-month, stress periods were used. Use of 3-month, seasonally-aligned, stress periods was prompted by the availability of historical data, which allow for input of rainfall, streamflow, and groundwater pumping at a temporal scale which captures changes in these data over observed climatological seasons. After transforming all time-dependant input data into 3-month long seasonal intervals, these data were input into the model in discrete intervals which conformed to a standard water year (October through December, January through March, April through June, and July through September).

An important chronological aspect of model development (and calibration as discussed in detail in later sections) is the identification and application of the base period upon which the model is built and calibrated. Specifically, water years 1985 through 2004 were selected as the base period for the updated Santa Margarita Groundwater Basin model. As discussed in more detail herein, this period reflects a period within which data characterizing key model components (e.g., rainfall, recharge, water level fluctuations, and well pumpage) were consistently measured and collected. Moreover, this period spans a representative range of hydrogeological and climatological conditions, including various average, dry, and wet years with respect to rainfall. As discussed in later sections, this period was used as the basis for constructing and calibrating the model prior to use for predictive conditions.

Correspondingly, to simulate the 20-year base period defined by water year 1985 through water year 2004, the model required eighty 3-month long stress periods.

BOUNDARY CONDITIONS AND HYDROGEOLOGIC BUDGET COMPONENTS

Model boundary conditions correspond directly to various components of the hydrologic budget through simulating the extent which groundwater enters and exits the model domain (and the basin). Boundary conditions reflecting the side boundaries of the model domain (e.g., subsurface inflow into the model), the top boundary of the model domain (e.g., rainfall-recharge), and within the model domain (e.g., well pumpage and surface-water groundwater interaction) were defined for each relevant model layer. Specifically, related data were entered for each stress period at each model grid cell where a boundary condition is defined with the model domain. MODFLOW 2000 provides a number of boundary condition options to numerically represent the different physical processes included in the hydrologic budget.

The amount of yearly inflow and outflow for each budget component was accounted for geographically within the model domain. Some model input parameters involve hydrologic budget components that are based on the distribution of land use, such as precipitation recharge, irrigation recharge, and agricultural groundwater pumping. A discussion of each component of the hydrologic budget and related boundary conditions is provided below.

Precipitation Recharge

Precipitation recharge represents groundwater inflow resulting from the portion of rainfall that falls directly onto the basin sediments and percolates downward to the water table. The variability of precipitation across the Santa Margarita Basin is primarily influenced by land surface elevation, land use, and surface geology. The spatial distribution of precipitation recharge in the model was based primarily on an isoheytal map of rainfall variation across the model domain and the time-dependent variations in rainfall indicated through rain gauge data at the El Pueblo Yard and Scotts Valley Water District Wastewater Treatment Plant stations (see Tables 2 and 3). Figure 5-3 shows the distribution of average annual precipitation across the model domain. This isoheytal plot, developed from historical rain gauge data from within the model study area (Ben Lomond, SVWD Wastewater Treatment Plant, El Pueblo stations) and nearby gauges (Boulder Creek and the CA Dept. of Forestry Ben Lomond stations), is used to simulate the differences in rainfall for model cells which can not be associated directly with a rainfall measurement location.

Further spatial variation for recharge was implemented based on surface geology (Figure 4-2) and was incorporated through generation of 11 zones of similar geologic material and associating unique reductions in infiltration with each of these zones. Similarly, the effects of land use on recharge across the basin was incorporated through creation of 5 land use zones of similar characteristics and associating effects on infiltration with reach of those zones. Figure 5-4 illustrates the land use designations applied to development of recharge data for the model. The reductions in rainfall infiltration associated with each land use category are also shown. Changes over time during the model base period (water year 1985 through water year 2004) due to residential or industrial development were incorporated through adjusting the land use zoning over time for recharge input into the model.

After incorporating the effects of rainfall distribution, surface geology and land use, a resulting transient recharge distribution was generated. A snapshot of the values associated with recharge applied to the model area for one of the 80 three-month long stress periods used in model base period is shown in Figure 5-5. These recharge values vary across the spatial extent of the domain (as shown in Figure 5-5), and over time as rainfall various both seasonally and annually.

Return Flow

Recharge due to septic system return flows was also incorporated in the MODFLOW recharge package. Using available county databases, the number of septic-related return flows within each of the over 600 recharge zones were summed. Subsequently, using an estimated return flow rate (to groundwater from septic systems) of 100 gallons per day per private system, recharge as a result of cumulative return flow within each zone was represented through the MODLFOW recharge package.

Stream Recharge

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

For the Santa Margarita Groundwater Basin model, the MODFLOW stream package was used to incorporate surface water–groundwater interaction into the model. The distribution of the stream network used in the model is shown on Figure 5-6. Correlations between streamflow and rainfall were developed for areas of the model where direct historical streamflow data was not available. Examples of the correlations used for the Zayante Creek and Carbonera Creek drainage basins are also shown in Figure 5-6. The temporal changes in streamflow suggested by these correlations to rainfall must also be delayed in time when developing the streamflow package depending on the distance a particular stream reach is located from the correlated rain gauge.

The MODFLOW stream package provides the capacity to input estimated streamflow data into the model to account for the wide spatial and temporal variation in streamflows that are observed in the Santa Margarita Groundwater Basin. The stream package requires that stream discharge be entered at the uppermost stream boundary cell. The other required input data include streambed conductance and elevation. The streambed elevation was derived from USGS topographic contour maps. The streambed conductance was determined during calibration. The conductance term includes the depth, width, and length of the stream segment in a model cell, and the transmissivity of the streambed materials based on an estimate of the streambed thickness and hydraulic conductivity. MODFLOW will allow either gaining or losing stretches along the streams based on the relative difference between the stream stage and groundwater elevations to represent groundwater-surface water interaction.

Since various streams in this area are ephemeral, or flow only during periods of rain, the flow rates of these streams are highly variable. These can typically range from periods of no-flow during the summer months to short periods of high-flow during high-intensity rainfall events. Through use of data from streamflow gauges on Bean Creek, Carbonera Creek, Newell Creek, and Zayante Creek, estimated amounts of streamflow available for groundwater recharge is input at the first cell of a stream segment (USGS, 2004). These streamflow values are varied for each time across the model base period. The annual distribution of stream recharge by stream is included in Table 1. The MODFLOW stream package allows that surface water flow can be varied and provides a mechanism that limits the net recharge to the total streamflow into the model. Where only a portion of the input water is recharged to groundwater, MODFLOW allows the remaining water to be available downstream without impacting the groundwater basin. In addition, where a net discharge occurs to groundwater, then the MODFLOW stream package acts as a groundwater outflow boundary.

The total estimated average annual percolation of stream flow into the groundwater model for the 20-year model base period was approximately 69,000 acre-feet. Recharge from streambed percolation is estimated to account for approximately 16 percent of the total recharge into the Santa Margarita Groundwater Basin. The annual distribution of stream recharge is included in Table 1.

Groundwater Pumpage

Groundwater pumpage is the most significant groundwater outflow component for the basin. Groundwater pumpage is represented in the MODFLOW model using the well package. For the MODFLOW well package, the amount of pumping is specified for each well location. To import the pumpage data into the model, pumping records for all pumping wells within the domain were analyzed to produce pumping rates for each well for each of the 80 seasonal (3-month) stress periods. Model layer assignments were based on well screen intervals for each individual well. In the model, pumpage includes a combination of municipal, small commercial and community, and rural domestic pumping wells. Below is a more detailed discussion of each.

<u>Municipal Wells</u>

The municipal groundwater pumpage category includes wells associated with SVWD and SLVWD. The locations of the municipal wells input into the model are shown on Figure 5-7. Municipal pumping rates were generally available on a monthly basis for the model base period. These data were organized into seasonal, three-month intervals for input into the 80 stress periods comprising the model base period. Through use of these monthly pumping records for municipal pumping wells, typical seasonal changes in municipal supply well pumping rates can be accurately represented in the model. The total municipal well pumpage over the base period was approximately 39,600 acre-feet for an annual average of 1,980 AFY.

Small Commercial and Community Pumpage

This groundwater pumpage category includes water demand from golf courses, small industrial, remediation, and other commercial entities not covered in the other categories. These categories include small community water suppliers such as Mt. Hermon Association, Mañana Woods Mutual Water Company, and the Lompico County Water District. Wells used for irrigation and landscaping purposes such as wells pumped for Spring Lakes Mobile Home Park, Vista del Lago, Montevalle Mobile Home Park, and Interdesign are also included in this category.

Groundwater pumping at large environmental remediation sites, such as Watkins-Johnson and Camp Evers, is also included in this category. Quarterly summaries of groundwater pumping are obtained from regulatory reports for these wells and organized into the necessary 3-month stress periods for input into the transient model.

Records for other small commercial and industrial pumpage (Harmony Foods, Interdesign, etc.) are also included in this category.

The small commercial and community pumpage over the base period was about 21,400 acre-feet for an annual average of 1,070 AFY. A summary of groundwater pumping for municipal, small commercial, and community pumping wells is include in Table 4.

Rural Domestic Pumpage

The rural domestic groundwater pumpage consists of the water demand as a result of pumpage at residential developments which are not serviced by a water district or municipal purveyor. The distribution of pumping for rural domestic wells was based on a survey of residential parcel records located areas outside water district service areas. As individual pumping records for rural domestic wells do not exist, each parcel identified as containing a residence without municipal potable water service was conservatively estimated to utilize an average of 250 gallons per day (USGS, 2000).

The rural domestic pumpage over the base period was approximately 19,400 acre-feet for an annual average of 980 AFY. The wells were placed in the highest active model layer at each location.

Subsurface Inflow

The subsurface groundwater inflow accounts for groundwater inflow into the basin from the surrounding non-water bearing bedrock, and were accordingly represented by lateral boundary conditions along the perimeter of the model domain. Based on the conceptual model, subsurface inflow was applied primarily to the northern edge of the Locatelli formation in layer 4 of the model. This subsurface inflow was input into the model using the well package. The inflow was input as a region of recharge wells along the margin of the basin in Model Layer 4. This subsurface inflow results in approximately 100 AFY increase in recharge into the basin. The annual distribution of subsurface inflow is included in Table 1.

Areas of elevated local subsurface inflow were added where the groundwater model required additional recharge that was not accounted for in the internal hydrologic budget. These areas were identified during model calibration as areas where insufficient inflow was available to simulate the measured groundwater elevations. These areas of elevated local subsurface inflow were generally limited to the western and eastern margins of the basin in layers 3 and 4 (Lompico and Butano formations). These areas were simulated in the groundwater model using a head-dependent boundary condition. Specifically, these areas were simulated by:

- A MODFLOW constant-head boundary with an elevation of approximately 600 feet above mean sea level (amsl) at the southern edge of Model Layer 1 (Santa Margarita formation),
- A MODFLOW constant-head boundary with an elevation of 505 feet above mean sea level (amsl) at the western edge of Model Layer 3 (Lompico formation),
- A MODFLOW constant-head boundary with an elevation of 505 feet amsl at the western edge of Model Layer 3 (Butano formation),
- A MODFLOW general-head boundary with elevations ranging from approximately 600 to 890 feet amsl along the eastern edge of Model Layer 3 (Butano formation), and
- A MODFLOW general-head boundary with elevations ranging from approximately 240 to 520 feet amsl along the eastern edge of Model Layer 4 (Butano formation).

Incorporated as described above, MODFLOW general-head boundaries result in an average annual net flux of 630 acre-feet of groundwater flowing from within the model domain to areas outside of the model domain. MODFLOW constant head boundary conditions result in an average annual net flux of 1,690 ac-ft flowing into the model domain. These values reflect average annual fluxes for the model base period (WY 1985 - WY 1004).

Drain and Seepage Outflows

Natural groundwater seepage and outflow was simulated using the MODFLOW drain package (Harbaugh et al 2000). The amount of groundwater flowing into or out of this boundary is influenced by the relative hydraulic gradient of the model at the location of the boundary condition. Exposed sandstone cliffs and other seepages at the margins of the Santa Margarita formation were input using the drain package. These seepages were set at elevations coincident with the lower extent of the Santa Margarita formation. Drains and seepage boundary conditions represented in the model result in an average annual flux of 4,850 acre-feet of groundwater flowing out of the groundwater model domain.

Evapotranspiration

Evapotranspiration represents the component of groundwater outflow from evaporation to the atmosphere and transpiration and uptake by plants. Across the model domain, evapotranspiration rates are estimated based on data collected at various pan evaporation measurement sites, in conjunction with GIS-based vegetation maps. Data provided by a network of Santa Cruz County weather stations is analyzed by the California Irrigation Management Information System (CIMIS) to assist in estimating evapotranspiration across the model domain (CIMIS, 2005). Use of these data sources resulted in seven distinct evapotranspiration zones across the model domain, which were varied over time according to the estimated changes in evapotranspiration throughout the model base period. Evapotranspiration rates estimated for the model domain ranged from an average of 6.5 inches for the winter stress period to 19.2 inches for the summer stress period.

The MODFLOW evapotranspiration package was used to represent these data into the model. Evapotranspiration is also a head-dependent boundary condition. The ground surface elevations accompanying the topographic data were used as the reference elevations. An evapotranspiration depth limit of 2.5 feet to 20 feet was used across the model domain, depending on the local surface geology and vegetation. Because of this, evapotranspiration impacts shallow groundwater most significantly and is most prominent in the Santa Margarita formation (Model Layer 1).

AQUIFER PROPERTIES

Aquifer properties represent the hydrogeologic characteristics within the basin. Specifically, aquifer properties describe the physical characteristics of the aquifer and the hydraulic properties that control groundwater flow. As discussed in the conceptual model, the numerical model consists of four model layers that correlate with the significant hydrogeologic formations.

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

Hydraulic Conductivity

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

Hydraulic conductivity was defined in regionalized blocks per model layer. During the calibration process, the hydraulic conductivity values were varied within a reasonable range of values. Hydraulic conductivity data based on pumping test results made available by SVWD were reviewed as part of the conceptual model. As vertical hydraulic conductivities were generally not estimated during these pumping tests, this parameter was estimated based on lithologic descriptions. Values were increased or decreased to allow more or less groundwater flow between model layers in order to better match groundwater elevation data in specific areas.

The horizontal hydraulic conductivity values used in the groundwater model are presented in Figures 5-8 through 5-11 for Model Layers 1 through 4, respectively.

The highest hydraulic conductivities were used in Model Layer 1 (Figure 5-8). Horizontal hydraulic conductivities in the model ranged from 2 to 50 feet per day (ft/d) for Model Layer 1

Model Layer 2 is represented with lower hydraulic conductivities to due to the lower permeability sediments associated with the Monterey Formation (Figure 5-9). The horizontal hydraulic conductivity in Layer 2 ranges from 0.001 to 0.75 ft/d.

Model Layers 3 represents the Lompico sandstone and ranges in horizontal hydraulic conductivity from 0.6 to 3.5 ft/d (Figure 5-10).

The Butano and Locatelli formations are represented in Layer 4 and are assigned horizontal conductivities ranging from 0.04 to 1.25 ft/d. The lower conductivity value of 0.04 ft/d in Layer 4 is isolated to a relatively narrow east-west oriented zone within the Butano formation, which tends to coincide with a steeper observed groundwater gradient in the area between Love Creek and Zayante Creek (Figure 5-11).

Vertical conductivities have also been established using the lithologic interpretations of the Santa Margarita Groundwater Basin as defined by the conceptual model, followed by adjustment during the model calibration process. The vertical conductivity values used in the model are shown in Figures 5-12 through 5-15 for Model Layers 1 through 4, respectively. Vertical conductivities used in the model ranged from 9×10^{-5} to 0.1 ft/d.

Storage Coefficient and Specific Yield

A limited amount of storage coefficient and specific yield data were available from historical aquifer test data. The storage coefficient values used in the groundwater model are also presented in Figures 5-16 through 5-19 for Model Layers 1 through 4, respectively.

Since Model Layer 1 is represented as entirely unconfined, only the specific yield was required by the model. Specific yield values ranging from 0.07 to 0.12 were used for the layer representing the Santa Margarita sandstone (Figure 5-16).

Model Layer 2, representing the Monterey formation, was set within MODFLOW as convertible between confined and unconfined conditions. Therefore, both confined storage coefficients and specific yield values were incorporated into the model. With the exception of a small area along the southern extent of Model Layer 2, the storage coefficient was set to 1×10^{-5} and the specific yield at 0.02 (Figure 5-17).

Similarly, both a confined storage coefficients and specific yield values were defined for Model Layers 3 and 4 as depicted in Figures 5-18 and 5-19, respectively. Model Layer 3, representing the Lompico formation, was assigned a uniform storage coefficient of 1×10^{-4} and a uniform specific yield of 0.06.

Model Layer 4 uses a storage coefficient of 1×10^{-5} associated with the existence of the Butano formation, a storage coefficient of 1×10^{-4} associated with the existence of the Locatelli Formation, and a uniform specific yield of 0.06 for both formations simulated within Layer 4 (Figure 5-19).

CHAPTER 6 – NUMERICAL MODEL CALIBRATION

Subsequent to model construction, model calibration is the process of refining the model and demonstrating its ability to simulate results which have already been measured under field conditions. The calibration process allows for its subsequent use as a predictive tool. The Santa Margarita Groundwater Basin model was calibrated by comparing and matching model simulated results to field-measured data. During model calibration, the aquifer properties and boundary conditions were varied within a reasonable range until a close fit was achieved between simulated versus measured data. The calibration consisted of an initial steady-state calibration that was followed by a more detailed transient calibration.

CALIBRATION CRITERIA

The Santa Margarita Groundwater Basin model was calibrated using calibration criteria developed to reduce model 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.

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" characteristic of the model, thereby reducing the uncertainty. Performing a comprehensive calibration over a 20-year base period infers the calibration has been performed over wet, dry, and normal rainfall years with varying degrees of pumping. To that end, the Santa Margarita Groundwater Basin Model was calibrated using three separate criteria including:

- Groundwater Elevation Maps
- Statistical Analysis
- Well Hydrographs

The model calibration process implemented is summarized in more detail below.

STEADY-STATE CALIBRATION

As an initial step, the groundwater flow model was run and calibrated in steady-state mode. The primary purpose of the steady-state model was to develop the general spatial distribution of aquifer properties and boundary conditions. The steady-state model was established using a single stress period utilizing average pumping and recharge conditions for the period from the period of water year 1976 through water year 1984.

The steady state run was calibrated using historical groundwater elevation measurements and contour plots, where available from water years 1976 to 1984.

The comparison of observed versus simulated groundwater elevations shows a strong correlation for the steady-state simulation. The close overall fit indicates that the general spatial distribution of aquifer properties and boundary conditions closely reflect field conditions. The results of the steady-state model were subsequently used as the initial starting groundwater elevations for the 20-year transient mode run.

TRANSIENT CALIBRATION

The transient calibration includes the simulation of changes in groundwater elevations over time. This aspect of the calibration is important to demonstrate that the model has the capability to simulate historical changes in groundwater elevations, and is therefore capable of forecasting future changes in groundwater elevations. The water year 1985 through 2004 base period was selected for the transient calibration to take advantage of the range or recharge and pumping conditions exhibited within the historical data for this period. A wide range of annual rainfall totals, along with changes in the spatial distribution of pumping, exists within the data available for this time period. These variations help ensure the final calibrated transient model is capable of simulating a wide range of hydraulic conditions observed within the basin.

Groundwater Elevation Contour (i.e., Hydraulic Gradient) 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 an efficient method to determine where additional model calibration efforts may be warranted.

A comparison of measured versus simulated groundwater elevation maps is presented for the end of water year 2004. These measured contours were chosen for comparison because they represent groundwater elevations after a full range of transient stresses have been applied to the model during the base period simulation.

Figures 6-1 presents a of groundwater elevations as predicted by the numerical model and as estimated through contouring of available groundwater elevation data for wells screened in the Santa Margarita formation. As indicated on this figures, the contour patterns compare favorably between model and the contoured groundwater elevations based on field data.

The minimal number of deeper monitoring wells in the Monterey, Lompico, and Butano Formations results in groundwater elevation data being available for small portions of the model domain in these formations. However, where specific elevation data are available in the form of hydrographs for pumping and/or monitoring wells in these model layers, this information allows for comparisons/calibration to model output across the 20-year base period at specific locations throughout the basin. This process involves analyzing all the available groundwater elevation observations in relation to model output in a model-wide statistical analysis as described below.

Further assessment of model output was performed by analyzing the flux either into or out of streams represented in the model. Figure 6-2 illustrates the magnitude and direction (a reach may be gaining from or losing water to the saturated zone) of this flux and allows for a comparison to historical streamflow data in terms of the model's representation of the exchange of water between streams and the underlying aquifer(s) across the model domain.

Statistical Calibration

Supplementing the hydraulic gradient calibration was a more rigorous calibration involving a statistical analysis to compare the difference or residual between measured and simulated groundwater elevations across a large number of points across the model domain. A scatter plot of observed versus simulated groundwater elevations (Figure 6-3) depicts this relationship. As indicated on Figure 6-3, the plot of observed versus simulated values reflects a strong correlation between simulated and field-measured levels. Importantly, this correlation is based on over 10,000 groundwater elevation measurements from over 200 wells during the period from water year 1985 through water year 2005.

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 more accurate the calibration. The residual mean for the model is 0.62 feet, well less than 1-foot across the entire model domain.

The absolute residual mean is a measure of the overall error in the model which is computed by taking the sum the absolute value of each of the residuals and dividing that by the number of residuals. The absolute residual mean for the model is 16.5 feet. This value is reasonable given the over 500 ft. range in observed groundwater elevation data used in model calibration.

Another key 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 favorable when this ratio is below 0.15 (ESI, 2001). The ratio for the Santa Margarita Groundwater Basin model is 0.046, which is approximately one-order-of-magnitude better than what is commonly considered as a well calibrated model. This is another indicator that the model is well calibrated.

Hydrograph Calibration

Groundwater level 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 aquifer. Comparing model simulated hydrographs versus observed field data provides a measure of how well the model reflects changing hydrogeologic conditions through time, including groundwater elevation changes in response to changes in recharge. Of the over 200 wells with groundwater elevation data, 6 hydrographs from different parts of the study area were compared with model output on Figures 6-4 through 6-6. 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. As can be observed in these figures, the significant changes in observed groundwater elevations over time are predicted by the model with reasonable accuracy.

QUALITY ASSURANCE AND CONVERGENCE CRITERIA

A critical component of developing a sound, defensible numerical model is to insure consistency with the hydrogeological conceptual model of the aquifer. The previous discussions regarding the model calibration and comparison of the hydrologic budget results demonstrate that the model is consistent with the conceptual model and is able to replicate observed field conditions.

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

For this model, the MODFLOW preconditioned conjugate-gradient (PCG2) package was used (Hill 1990). The convergence criteria for PCG2 included both a maximum change in groundwater elevation and a maximum mass balance differential for a cell. For this model, the convergence parameter for groundwater elevation was set at 0.5 feet. Convergence is evaluated at the grid cell level. If a single cell does not meet the requirement, then the solution procedure is repeated. The model was able to successfully converge using the set convergence parameters.

The primary method to check whether the model is numerically stable is to evaluate the differential in mass balance. Iterative techniques provide an approximate solution for the model; therefore, there is always a mass balance differential. This differential should be small, and typically a differential of less than 1% is considered as a good solution. Table 1 provides the mass balance for each year. The highest maximum yearly mass differential for the Santa Margarita Groundwater Basin model is 0.09%, occurring in water year 2003. Importantly, the overall mass balance differential for the 20-year base period run is only 0.02%. These values demonstrate that the MODFLOW model is accurately simulating the flow of groundwater in the Santa Margarita Groundwater Basin.

CHAPTER 7 - SENSITIVITY ANALYSIS

A sensitivity analysis was run on parameters that were identified to have the most significant impact on model results within their range of uncertainty. For the Santa Margarita Groundwater Basin Model, parameters identified as having the potential to significantly influence model output were horizontal hydraulic ($K_{x,y}$) conductivity, vertical leakance or conductivity (K_z), and the storage coefficient (S). A series of sensitivity model runs were performed for these three identified parameters.

Values for these key parameters were varied across the entire model domain by uniform multipliers (0.1, 0.5, 1.0, 2.0, 10.). For each of the three parameters (Kx,y, Kz, and S) five model runs were performed (multiplying the parameter by the range of multipliers using the previously described 20-year base

SENSITIVITY MODEL RUNS AND RESULTS

In order to assess the sensitivity of the model to these parameters, values for these key parameters were varied across the entire model domain by uniform multipliers (0.1, 0.5, 1.0, 2.0, 10.). For each of the three parameters ($K_{x,y}$, K_z, and S) five model runs were performed, multiplying a single parameter by a different factor for each model run and running the model under the conditions as previously described for the 20-year base period (water year 1985 to 2004).

Figures 7-1 and 7-2 illustrate the sensitivity of the model to the three parameters ($K_{x,y}$, K_z, and S) as measured by the effect on the overall model residual mean of altering the value of each parameter. As shown in Figure 7-1, altering the horizontal conductivity ($K_{x,y}$) by a factor of 0.1 to 10 results in a maximum change in the residual mean of up to 20%. Altering the vertical conductivity (K_z) by a factor of 0.1 to 10 results in a maximum change in the residual mean of up to 40%. Figure 7-2 illustrates the numerical model sensitivity to the storage coefficient (S) and indicates a maximum change in the residual mean of 45%.

While the results of these sensitivity analyses shows a potential increase of the residual mean from 20% to 45%, it is important to note the relative magnitude of the affects these parameters have on the residual mean is not large. The increase in residual mean in response to varying $K_{x,y}$, K_z, and S individually by a factor of 0.1 to 10 is typically less than 0.25 feet. The results of these sensitivity analyses suggest that the model is operationally robust with respect to varying these parameters across ranges that are reasonable across the model domain.

CHAPTER 8 – MODEL APPLICATION AND CONCLUSIONS

The calibrated model described in Chapter 5 is applicable to a wide range of groundwater management scenarios. Initial model applications documented herein focus on quantifying the annual hydrologic budget for the basin and determining the relationship between groundwater pumpage and change in storage within the basin. Model application for more detailed assessment of regional and local conditions will be performed through ongoing basin-wide groundwater management efforts. Results of the preliminary applications together with the overall conclusions of this study are outlined in the following sections.

SIMULATED HYDROLOGIC BUDGET

A water balance or hydrologic budget is a quantitative statement of the balance of the total water gains and losses to and from the basin over a defined period. As previously outlined in the conceptual model, groundwater recharge or inflow to the Santa Margarita Groundwater Basin is derived from percolation precipitation, streamflow, return flows, and subsurface inflow. Groundwater discharge or outflow from the Santa Margarita Groundwater Basin is derived from well pumpage, subsurface outflow, stream discharge, and evapotranspiration. The difference between inflow and outflow is balanced by the change of groundwater in storage. The major components of the hydrologic budget evaluated for the Santa Margarita Groundwater Basin may be expressed by the following relationship:

$$\mathbf{P + R_i + S_i + PR + Sb_i = Q + R_o + S_o + ET + DS \pm \Delta S}$$

where:

P	=	Percolation to Groundwater from Precipitation
R_i	=	Inflow to Groundwater from Rivers
S_i	=	Inflow to Groundwater from Streams
PR	=	Percolation to Groundwater from Return Flows
Sb_i	=	Subsurface Inflow to Groundwater
Q	=	Discharges due to Groundwater Pumpage
R_o	=	Discharges to Rivers from Groundwater
S_o	=	Discharges to Streams/Rivers from Groundwater
ET	=	Discharges from Groundwater due to Evapotranspiration
DS	=	Discharges to Drains and/or Surface Seepage Locations from Groundwater
ΔS	=	Change in Groundwater Storage

The annual hydrologic budget results from the calibrated model for water years 1985 through 2004 are presented in Table 1. As indicated in this table, the total recharge from precipitation and return flows (due to customers using septic systems) approximates 321,890 acre-ft over the 20-year base period, reflecting an average annual recharge rate of 16,090 AFY. Recharge to groundwater from streams and rivers approximates 75,560 acre-feet over the 20-year base period, corresponding to an average annual recharge rate of 3,790 AFY. Subsurface inflow accounted for 1,700 acre-ft of the total recharge over the 20-year base period.

The discharge components of the annual hydrologic budget estimated by the model are presented in Table 1. Losses to streams represent the largest component of total discharges from the groundwater basin, accounting for an average of 32 percent of the total average annual discharges in the model. Groundwater pumping accounts for an average of 17 percent of the total groundwater discharge (Table 1). Of the remaining discharge, 20 percent discharges to surface drains and seepages. Groundwater discharge to the San Lorenzo River in the south accounts for 18 percent of the total discharge, evapotranspiration accounts for 5 percent of the total discharge, and subsurface outflow accounts for 6 percent of the total discharge (Table1).

SIMULATED ANNUAL SUSTAINABLE YIELD

As a precursor to future model applications for groundwater management, the calibrated model was preliminarily applied for evaluating estimates of the sustainable yield and, more importantly, the underlying hydraulic relationship between groundwater pumpage and change in storage across the basin. This preliminary analysis also allows for a preliminary comparison between the sustainable yield and estimates of the safe yield previously developed for the basin. Importantly, these simulations were performed to demonstrate the potential applicability of the model as a tool to support future groundwater management efforts, which in turn will ultimately define groundwater management options for the basin.

In evaluating the preliminary model applications, a distinction should be made between the strict definitions and terminology used herein to reflect the overall basin safe yield and the sustainable yield of the basin. The overall basin safe yield reflects the total estimated amount of water considered available within the entire basin, which when drawn upon would not correspond to adverse impacts on groundwater quantity (storage), quality, and related costs of operations. This yield is independent of the locations of existing water supply wells and assumes no limits to the ability to access the water from wells. Comparatively, the sustainable basin yield is defined herein as the amount of water available to existing water supply wells currently present across the Santa Margarita Groundwater Basin and related sub-basins, without causing adverse impacts as previously defined.

Preliminary model application to evaluate basin-wide and sub-basin level sustainable yields is discussed in the following sections. These preliminary simulations were constructed and geared toward generating results in concert with the following specific objectives:

1. Quantifying the hydraulic relationship between average annual groundwater pumpage within the model base period and corresponding change in groundwater storage;
2. Estimating the average annual sustainable yield of the basin per the definition defined previously;
3. Estimating the net average annual change in streamflow as a result of pumpage at the sustainable yield level over a time frame characterized by the hydrologic conditions observed within the model base period; and
4. Providing estimates of sustainable pumpage within various portions of the basin defined by the TAC as sub-basin.

To the extent that model simulations inherently spawn other groundwater management questions and/or scenarios, such further analysis may be performed as part of ongoing groundwater management efforts.

Basin-wide Sustainable Yield

The most direct quantitative measurement of adverse affects on the basin is the change in storage induced by a particular groundwater extraction regime. Specifically, under anticipated recharge conditions, the sustainable yield corresponds to the total annual groundwater extraction quantity which results in no net loss in storage. To the extent that surface water-groundwater interaction in this basin is a known condition, then similar net effects on this interaction may also be considered within the definition of potentially adverse impacts. It is important to note that this exercise does not attempt to equate any exceedance of the no net loss in storage concept to an adverse impact. Rather, this definition of sustainable yield, developed collectively with input from the TAC, is considered a target number for helping direct future decision-making regarding various basin management options, including potential redistribution of pumpage, new well siting, and water augmentation efforts.

Previous water basin-wide safe yield estimates based on a water-balance approach have been estimated at approximately 4,200 acre-feet (Todd, 1998). These estimates are accurate within the limits of a water balance-based approach, but do not account for localized affects on storage. Additionally, this previous estimate of the basin-wide safe yield does not account for the actual spatial distribution of water supply wells within the basin.

Using the range of hydrologic conditions spanning the 20-year base period, the calibrated Santa Margarita Groundwater Basin model was used to develop estimates of sustainable yield corresponding to existing well locations, which may in turn be used to help provide the basis for future management of groundwater pumpage at existing and potential new well locations and help focus potential future water augmentation alternatives.

Sustainable Yield Model Runs

Five separate model runs were performed where total groundwater pumpage, relative to the original base period pumpage, was varied by 70 percent, 80 percent, 100 percent, and 110 percent. Specifically, input data for these sustainable yield focused model runs included:

- Pumping rates for all existing wells in the model, which were varied by a uniform percentage relative to the pumping rate data used in the calibrated model. Total pumpage applied to each run is presented in Figure 8-1.
- Irrigation return flows were modified proportionally to the municipal pumpage.
- All other conditions in the model remained unchanged.

The change in storage relative to the four distinct adjustments to pumping for the four model runs are shown in Figure 8-1. The change in groundwater storage is plotted relative to the groundwater pumpage, showing a linear relationship where increasing pumping produces a decrease in groundwater storage. A linear regression analysis was performed for these model results. The sustainable yield is then defined as the average annual pumping rate that can sustain a net zero change in aquifer storage (as calculated by the groundwater model) relative to the starting conditions used for the calibrated model representing the beginning of water year 1985. This is represented on Figure 8-1 as the pumping rate that corresponds to the point on the linear regression line where the net groundwater storage for the basin is zero. Based on this analysis, the current model-based sustainable yield for the Santa Margarita Basin is 3,320 AFY over the base period. Importantly, this yield also corresponds to no adverse impacts with respect to the surface water balance reflected by surface water-groundwater interaction.

This rate suggests that pumpage at 3,320 AFY from existing well locations across the basin will yield a zero net change in storage. Using the rates of total basin pumping estimated for 2004 (approximately 4,000 AFY) across the basin, this value is exceeded. While the current pumping remains below the overall safe yield of the basin (i.e., 4,200 AFY), this exercise allows for identification of management measures such as potential redistribution of pumpage across existing well locations and potential new well locations. These concepts were evaluated further through the subbasin analysis below and through ongoing work currently underway in support of the next Annual Groundwater Management Report published by the SVWD.

Sub-basin Sustainable Yield Model Runs

The concept of the basin-wide sustainable yield as previously defined was expanded further using the calibrated model, resulting in estimations of subbasin-specific sustainable yield values. The subject subbasins, as shown in Figure 8-2, were established jointly with the TAC and were identified so as to allow analysis of areas of local interest with regard to managing pumping within the basin. These five subbasins are considered hydraulically isolated from one another, to varying degrees, by features such as streamflow or geologic faults.

The approach to defining subbasin-specific sustainable yields focused on estimating changes in storage within each subbasin, using the model base period (WY 1985 – WY 2004). Analysis of the water budget data on a localized subbasin level, using the same linear regression procedure employed to estimate the overall basin sustainable yield (Figure 8-1), provides an improved understanding of storage changes within different hydraulic regions of the model. Based on this definition, the yield from San Lorenzo was not defined given the absence of major water supply wells in this subbasin.

Subbasin	Estimated Annual Subbasin Sustainable Yield (ac-ft)
South Scotts Valley	1,225
North Scotts Valley	1,376
Olympia	405
Quail Hollow	314
San Lorenzo	NA
TOTAL	***3,320***

The estimated sustainable yields for each subbasin help provide input toward future management of the subbasins, including the potential for redistribution of pumpage and potential for new well siting.

This analysis of subbasin sustainable yield may be further explored in future model applications. In particular, model runs designed to assess the yield of a single subbasin thought to be significantly isolated from neighboring subbasins may allow for an improved understanding of local relationships between groundwater extractions, streamflow, and changes in groundwater storage. Such model runs require a detailed understanding of fluxes between subbasins and might also involve the imposition of updated boundary conditions so as to more accurately assess fluxes into or out of a given subbasin. These local yield values may help guide future operational decisions both within any given subbasin, and in terms of the various subbasins influence on one another.

CONCLUSIONS

The previous version of the Santa Margarita Groundwater Basin groundwater model has been successfully updated to reflect the current conceptual understanding of the basin and reflect updated modeling tools and practices. The numerical model is based on a sound and defensible conceptual model, which has benefited from additional data, an independent hydrogeologic evaluation, and key input contributed to the study by the TAC. The model is well calibrated to a base period which reflects a time frame within which the necessary array of data is available. These data span a representative distribution of hydrologic conditions observed throughout the basin and over time.

The calibrated model is available for application to a wide range of groundwater management scenarios. As a precursor to future model applications for groundwater management, sample application of the calibrated model documented herein has focused on evaluating the hydraulic relationship between groundwater pumpage and change in groundwater storage across the basin and within preliminarily defined sub-basins. These simulations provide useful guidance toward future, more in depth analyses and decisions related to redistribution of pumpage, new well siting, and potential water augmentation alternatives. Evaluation of many such alternatives is underway as part of the Annual Groundwater Management reporting undertaken by the SVWD.

CHAPTER 9 – BIBLIOGRAPHY

Arcadis, G&M, Inc., 2003, *Fourth Quarter 2002 Monitoring Report (September, October, and November) and Annual Summary: Watkins-Johnson Superfund Site, 40 Kings Village Road, Scotts Valley, California,* report to US Environmental Protection Agency.

Arcadis, G&M, Inc., 2003, *First Quarter 2003 National Pollution Discharge Elimination System Operations Report, Permit #CA004907, Watkins-Johnson Superfund Site, 440 Kings Village Road, Scotts Valley, California,* report to Regional Water Quality Control Board.

Arcadis, G&M, Inc., 2005, *Fourth Quarter 2004 National Pollution Discharge Elimination System Operations Report, Permit #CA004907, Watkins-Johnson Superfund Site, 440 Kings Village Road, Scotts Valley, California,* report to Regional Water Quality Control Board.

Bay Area Shared Information Consortium (BASIC), 2001, *Identifying Potential Locations for Artificial Groundwater Recharge*, report to Santa Margarita Groundwater Basin Advisory Committee.

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

Brabb, E.E., S. Graham, C. Wentworth, D. Knifong, R. Graymer, and J. Blissenbach, 1997, Geologic Map of Santa Cruz County, California: A Digital Database, Open-File Report 97-489.

California Department of Health Services, 2005, Title 22 California Code of Regulations, Division 4 Environmental Health, Maximum Contaminant Levels, Received January 18, 2005.

California Department of Water Resources, 2003, *California's Groundwater*, Bulletin 118 Update 2003.

California Irrigation Management Information System (CIMIS), 2005, (web page interactive database), http://wwwcimis.water.ca.gov/cimis/welcome.jsp, Reference Evapotranspiration Data, Santa Cruz, California.

California Regional Water Quality Control Board, Central Coast Region, 2003, Staff report for Regular Meeting of February 7, 2003, letter dated January 7, 2003.

California Regional Water Quality Control Board, Central Coast Region, 2004, *SLIC: Scotts Valley Dry Cleaners, 272-A Mount Hermon Road, Scotts Valley, CA: Remedial Action and Groundwater Monitoring*, letter dated June 4, 2004.

California State Department of Finance, Demographic Research Unit, *Historical Census Populations of Places, Towns, and Cities in California, 1850-1990.* (Online) http://www.dof.ca.gov/html/Demograp/histtext.htm (visited March 2, 2005).

Center for Disease Control and Prevention, 1999, *Health Effects from Exposure to High Levels of Sulfate in Drinking Water Study*, CDC/USEPA Office of Water.

Clark, J.C., 1966, Tertiary Stratigraphy of the Felton-Santa Cruz Area, Santa Cruz Mountains, California, Ph.D. dissertation Stanford University, 1966, available from University Microfilms, Inc., Ann Arbor, Michigan.

Clark, J.C., 1981, *Stratigraphy, Paleontology, and Geology of the Central Santa Cruz Mountains, California Coast Ranges*, U.S. Geological Survey Professional Paper 1168, US Government Printing Office.

Clark, J.C., Brabb, E.E., and McLaughlin, R.J., 1989, Geologic map and structure sections of the Laurel 7 1/2' Quadrangle, Santa Clara and Santa Cruz counties, California, USGS Open File Report, OFR89-676.

Cloud, M., 2001, *Santa Margarita Groundwater Basin Structural Maps and Cross Sections*, Santa Cruz County Flood Control & Water Conservation District presentation to July 23rd Santa Margarita Groundwater Basin Advisory Committee

Delta Environmental Consultants, 2003, *Quarterly Monitoring Report-Third Quarter 2003, & Remediation Status Report, Shell-branded Service Station, 1 Hacienda Drive*, *Scotts Valley, California.*

Delta Environmental Consultants, 2005, *Quarterly Monitoring Report-Fourth Quarter 2004, Camp Evers Area*, Scotts Valley California.

Dudley, T., 2001, Chief of Groundwater Section, Northern District, Department of Water Resources, Basin Management Objective (BMO) Method of Groundwater Basin Management, Appendix A in BMO for Groundwater Surface Elevations in Glenn County, California, Glenn County.

Ellis, W., 1995, *Pasatiempo Subunit – Lompico Sandstone Aquifer, Preliminary Quantitative Assessment*, San Lorenzo Valley Water District.

ETIC Engineering, Inc., 2004, *Drinking Water Source Protection from Undefined Dichlorobenzene/Chorobenzene Plume, Santa Margarita Groundwater Basin, Scotts Valley, CA*, Memorandum to G. Duerig.

Geomatrix Consultants, March 1999, *Estimated Discharge of Surface Water Sources*, prepared for SLVWD.

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.

Jacobvitz, M., June 1987, A Comparison of Recharge Estimates Using a Numerical Model, Santa Margarita Aquifer, Scotts Valley, California, University of California, Santa Cruz (UCSC) Master Thesis.

Johnson, N.M., Water Resources Consultant, September 2001, *Conceptual Hydrogeologic Model of the Quail Hollow Area,* prepared for San Lorenzo Valley Water District.

Johnson, N.M., 2002*, Draft Conceptual Hydrogeologic Model of the Pasatiempo Area*, report to San Lorenzo Valley Water District.

Johnson, N.M., Water Resources Consultant, March 2003, *Quail Hollow Groundwater Flow Model Documentation*, prepared for SLVWD

McLaughlin, R.J., J.C. Clark, E.E. Brabb, E.J. Helley, C.J. Colon, 2001, Geologic maps and structure sections of the southwestern Santa Clara Valley and southern Santa Cruz Mountains, Santa Clara and Santa Cruz counties, California, USGS Miscellaneous Field Studies, MF-2373.

Muir, K.S., 1981, Assessment of the Santa Margarita Sandstone as a Source of Drinking Water for the Scotts Valley Area, California, USGS Water Resources Investigation WRI81-6.

Ramlit Associates, 2001, *The Lower San Lorenzo Valley Search for a Regionally Balanced Water Supplies Management*, Planning Department & Environmental Health Services, Santa Cruz County Water Resources Program.

R.L. Stoller & Associates Inc., 1988, *Characterization of Subsurface Conditions, Watkins Johnson Company, Scotts Valley, California*. Report submitted to Watkins-Johnson Company.

Santa Margarita Groundwater Basin Advisory Committee Member Agencies, 1995, *Memorandum of Understanding for the Santa Margarita Groundwater Basin Advisory Committee.*

Santa Margarita Groundwater Basin Advisory Committee Member Agencies, 2000*, White Paper*.

SECOR International Inc., 2003*, Remedial Action Performance Summary - First Quarter 2003,* Kings Village Shopping Center*,* Scotts Valley, California.

SECOR International Inc., 2003, *Initial Progress Report for Accelerated Bioremediation Pilot Testing, Scotts Valley Dry Cleaners, Scotts Valley, California*.

SECOR International Inc., 2004, *Revised Interim Remedial Action Plan*, Scotts Valley Dry Cleaners, Scotts Valley, California.

SECOR International Inc., 2004, *Monthly Status Report (July, 2004) and results of Third Quarter Sampling of Monitoring Wells MW-13A and MW-13B.* Scotts Valley Dry Cleaners, Scotts Valley, California.

SECOR International Inc., 2004, *Monthly Status Report for September 2004,* Scotts Valley Dry Cleaners, Scotts Valley, California.

SVWD, 2000, *Scotts Valley Water District Water Policy Statement*, revision January 7.

Todd Engineers, 1984, *Scotts Valley Water Resources Management Plan, Phase I,* report to Scotts Valley Water District.

Todd Engineers, 1994, *Scotts Valley Water District Groundwater Management Plan (AB3030),* report to Scotts Valley Water District.

Todd Engineers, 1996, *Scotts Valley Water District Groundwater Management Plan (AB3030),* report to Scotts Valley Water District.

Todd Engineers, 1997, Computer Modeling for Groundwater Management, Scotts Valley Groundwater Basin, Scotts Valley Water District.

Todd Engineers, 1998, *Reevaluation of the Water Balance*, report to Scotts Valley Water District.

Todd Engineers, 2003, *Scotts Valley Water District Groundwater Management Program, Annual Report (AB3030),* report to Scotts Valley Water District.

United States Geological Survey (USGS), 1998, Felton Quadrangle California-Santa Cruz Co. 7.5 Minute Series Topographic Map, USGS, Denver, CO.

United States Geological Survey (USGS), 2000, http://water.usgs.gov/ogs/pubs/fs00165/, received December 15, 2004, Land Subsidence in the United States, Fact Sheet FS-165-00.

United States Geological Survey (USGS), 2005 http://waterdata.usgs.gov/ca/nwis/rt, received December 21, 2004, Stream Flow Data for California.

United States Department of Agriculture (USDA), 1980, Soil Survey of Santa Cruz County, California.

WaterTrax Water Data, 2005, www.watertrax.com, received January 5, 2005, Water Quality Data for SVWD Production Wells.

TABLES

TABLE 1
Hydrologic Budget Summary Report
Santa Margarita Ground Water Basin Model
Transient Model Run (WY 1985 - WY 2004)
Units = acre-feet

Water Year	Constant Head Boundary	Wells	Drains	ET	General Head Boundary	Recharge	Rivers	Streams	**Total IN**	Constant Head Boundary	Wells	Drains	ET	General Head Boundary	Recharge	Rivers	Streams	**Total OUT**	Loss from Storage	Gain to Storage	Change in storage (Gain - Loss)	Residual Water Budget Error (in - out = change in storage)	Water Budget Error (%)
1985	1,740	85	0.00	0.00	618	15,438	560	2,458	20,899	0.02	3,211	5,809	3,691	1,727	0.00	4,556	9,453	28,448	10,989	3,470	-7,520	29.57	0.104%
1986	1,676	85	0.00	0.00	614	19,285	544	3,080	25,285	0.00	3,358	5,570	2,798	1,623	0.00	4,668	9,247	27,264	6,891	4,999	-1,892	87.40	0.321%
1987	1,715	85	0.00	0.00	642	11,056	647	2,009	16,154	0.00	4,240	4,580	2,193	1,531	0.00	4,016	7,427	23,987	9,400	1,649	-7,751	82.68	0.345%
1988	1,716	85	0.00	0.00	663	11,445	665	2,883	17,457	0.00	4,263	4,066	1,916	1,494	0.00	4,014	6,804	22,557	6,454	1,368	-5,085	15.08	0.067%
1989	1,714	85	0.00	0.00	660	13,409	647	3,548	20,063	0.00	3,955	4,046	1,856	1,492	0.00	4,015	6,909	22,274	5,415	3,204	-2,212	-1.14	-0.005%
1990	1,723	85	0.00	0.00	688	9,870	674	3,018	16,059	0.00	3,833	3,593	1,662	1,458	0.00	3,879	6,217	20,642	5,577	1,070	-4,507	76.85	0.372%
1991	1,711	85	0.00	0.00	700	12,096	688	2,850	18,130	0.00	4,138	3,616	1,640	1,434	0.00	4,066	6,101	20,995	5,892	3,069	-2,822	42.63	0.203%
1992	1,694	85	0.00	0.00	701	14,653	658	3,002	20,792	0.00	3,993	4,021	1,712	1,433	0.00	4,295	6,521	21,975	4,955	3,776	-1,179	3.56	0.016%
1993	1,669	85	0.00	0.00	686	19,125	608	3,388	25,560	0.01	3,610	4,782	1,910	1,456	0.00	4,670	7,543	23,970	4,232	5,848	1,616	25.35	0.099%
1994	1,697	85	0.00	0.00	703	12,791	634	2,939	18,850	0.00	4,215	4,313	1,732	1,427	0.00	4,172	6,944	22,804	5,388	1,560	-3,828	125.92	0.552%
1995	1,656	85	0.00	0.00	693	22,098	563	3,629	28,723	0.04	3,666	5,183	1,992	1,377	0.00	4,877	8,091	25,187	3,722	7,236	3,514	-21.59	-0.075%
1996	1,661	85	0.00	0.00	708	19,222	540	3,429	25,645	0.01	4,100	5,535	2,053	1,294	0.00	4,728	8,407	26,118	4,341	3,919	-422	51.69	0.198%
1997	1,656	85	0.00	0.00	721	19,264	520	3,435	25,680	0.01	4,506	5,794	2,104	1,224	0.00	4,783	8,773	27,185	5,760	4,242	-1,518	-14.17	-0.052%
1998	1,639	85	0.00	0.00	736	23,349	485	3,873	30,167	0.23	3,954	6,019	2,210	1,160	0.00	5,139	9,151	27,633	3,805	6,352	2,547	13.28	0.044%
1999	1,668	85	0.00	0.00	746	17,271	514	3,478	23,762	0.00	4,061	5,737	2,071	1,155	0.00	4,599	8,803	26,426	5,164	2,627	-2,538	126.15	0.477%
2000	1,672	85	0.00	0.00	760	17,422	529	3,505	23,973	0.00	4,442	5,282	1,945	1,120	0.00	4,595	8,296	25,680	5,501	3,922	-1,579	128.41	0.500%
2001	1,683	85	0.00	0.00	779	14,756	553	3,174	21,030	0.00	4,651	4,838	1,786	1,090	0.00	4,401	7,672	24,436	5,814	2,521	-3,292	114.10	0.467%
2002	1,680	85	0.00	0.00	774	16,280	555	3,397	22,772	0.00	4,639	4,840	1,767	1,092	0.00	4,435	7,758	24,531	5,578	3,798	-1,780	-21.39	-0.087%
2003	1,682	85	0.00	0.00	779	16,675	559	3,553	23,333	0.00	4,745	4,660	1,703	1,116	0.00	4,443	7,561	24,227	4,214	3,299	-916	-21.63	-0.089%
2004	1,678	85	0.00	0.00	786	16,378	563	3,212	22,702	0.00	4,314	4,734	1,708	1,113	0.00	4,493	7,536	23,898	5,394	4,100	-1,294	-97.11	-0.406%
Total	**33,733**	**1,694**	**0.00**	**0.00**	**14,157**	**321,885**	**11,706**	**63,859**	**447,034**	**0.32**	**81,895**	**97,018**	**40,450**	**26,816**	**0.00**	**88,844**	**155,215**	**490,237**	**114,488**	**72,030**	**-42,457**	**746**	**0.1521%**
Average	**1,687**	**85**	**0.00**	**0.00**	**708**	**16,094**	**585**	**3,193**	**22,352**	**0.02**	**4,095**	**4,851**	**2,022**	**1,341**	**0.00**	**4,442**	**7,761**	**24,512**	**5,724**	**3,602**	**-2,123**	**37**	**0.0076%**

TABLE 2

Precipitation Summary For El Pueblo Yard Station

Santa Margarita Ground Water Basin Model

units = inches

	El Pueblo Yard Gauging Station												WATER YEAR
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1985	1.72	4.20	7.92	0.73	0.11	0.15	0.09	0.02	0.54	1.12	7.14	2.62	35.03
1986	7.38	22.40	15.00	0.48	0.83	0.00	0.00	0.00	1.30	0.03	0.05	2.74	58.27
1987	4.51	9.06	6.31	0.70	0.00	0.02	0.00	0.00	0.00	1.19	2.30	10.70	23.42
1988	4.58	0.68	0.00	3.13	1.07	0.16	0.00	0.00	0.00	0.19	5.90	8.89	23.81
1989	2.06	1.39	10.60	0.67	0.08	0.03	0.00	0.03	0.83	3.53	1.58	0.01	30.67
1990	3.42	3.69	2.13	0.16	5.79	0.00	0.00	0.12	0.15	0.50	0.24	1.65	20.58
1991	0.61	5.39	17.19	0.51	0.06	0.40	0.00	0.02	0.07	2.37	1.46	5.42	26.64
1992	3.01	15.32	4.65	0.45	0.00	0.82	0.00	0.05	0.00	3.41	0.20	11.54	33.55
1993	18.50	10.22	3.17	1.38	0.96	0.68	0.00	0.00	0.00	0.73	2.74	5.52	50.06
1994	3.51	9.72	0.68	2.75	2.10	0.01	0.00	0.00	0.05	1.79	8.29	4.78	27.81
1995	23.88	0.65	13.62	3.79	0.89	1.03	0.01	0.00	0.00	0.32	0.00	10.03	58.73
1996	13.52	11.35	5.14	2.38	4.31	0.03	0.00	0.00	0.00	2.89	7.13	22.25	47.08
1997	12.31	0.17	1.50	0.58	0.17	0.13	0.00	0.54	0.00	0.68	10.12	4.06	47.67
1998	14.21	21.81	6.17	2.85	3.65	0.01	0.00	0.01	0.17	1.02	9.11	1.85	63.74
1999	9.25	11.08	5.22	2.58	0.00	0.39	0.00	0.02	0.14	0.36	5.69	0.53	40.66
2000	16.84	18.74	2.77	2.69	1.01	0.18	0.00	0.2	0.4	5.14	1.38	0.94	49.41
2001	8.68	10.65	4.05	2.67	0.00	0.07	0.00	0.00	0.16	1.13	9.93	16.45	33.74
2002	4.97	2.69	4.66	0.52	0.90	0.00	0.00	0.05	0.00	0.00	5.80	21.40	41.30
2003	2.77	2.94	2.54	5.75	1.09	0.16	0.00	0.00	0.00	0.19	3.93	17.55	42.45
2004	4.44	9.69	0.35	0.65	0.07	0.00	0.06	0.00	0.11	7.24	3.25	14.39	37.04
Average	8.01	8.59	5.68	1.77	1.15	0.21	0.01	0.05	0.20	1.69	4.31	8.17	39.58

TABLE 3

Precipitation Data for Scotts Valley Wastewater Treatment Plant Gauging Station

Santa Margarita Ground Water Basin Model

units = inches

	Wastewater Treatment Plant Gauging Station												CALENDAR	WATER
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR TOTAL	YEAR TOTAL
1986*							0.00	0.00	1.78	0.00	0.03	2.61	--	--
1987	4.69	8.56	6.29	0.79	0.00	0.08	0.00	0.00	1.24	4.45	10.21	5.31	41.62	24.29
1988	0.96	0.01	3.23	1.48	0.07	0.00	0.00	0.00	0.00	0.00	7.76	10.42	23.93	25.72
1989	2.18	1.98	11.70	0.99	0.15	0.11	0.00	0.01	1.02	3.56	1.75	0.07	23.52	36.32
1990	4.06	3.79	2.79	0.29	6.10	0.03	0.00	0.11	0.29	0.39	0.37	2.81	21.03	22.84
1991	0.47	6.19	18.79	0.65	0.17	0.36	0.02	0.02	0.04	3.38	1.75	6.50	38.34	30.28
1992	3.47	16.74	5.83	0.53	0.00	1.15	0.00	0.05	0.00	3.73	0.26	13.55	45.31	39.40
1993	23.94	11.96	3.84	1.46	1.09	0.93	0.01	0.01	0.85	2.96	6.40	4.42	57.87	61.63
1994	11.14	0.85	3.83	3.36	0.02	0.00	0.00	0.00	0.05	2.18	8.96	5.63	36.02	33.03
1995	27.38	0.71	16.02	6.24	1.37	1.29	0.01	0.00	0.00	0.34	0.00	11.60	64.96	69.79
1996	17.62	13.45	6.40	2.94	5.00	0.03	0.00	0.00	0.01	3.42	6.03	26.10	81.00	57.39
1997	16.06	0.27	1.90	0.89	0.14	0.19	0.02	0.59	0.00	0.88	12.34	4.98	38.26	55.61
1998	18.35	27.16	7.56	4.09	5.44	0.03	0.00	0.01	0.22	1.17	10.22	2.13	76.38	81.06
1999	11.29	12.28	6.07	3.84	0.05	0.52	0.00	0.00	0.18	0.46	5.43	0.64	40.76	47.75
2000	17.45	20.47	2.89	3.15	0.96	0.16	0.00	0.19	0.45	5.91	1.66	1.19	54.48	52.25
2001	9.08	11.04	4.05	3.16	0.00	0.07	0.00	0.01	0.22	1.31	9.49	18.30	56.73	36.39
2002	5.44	3.41	5.02	0.39	1.00	0.00	0.00	0.03	0.00	0.00	6.25	23.70	45.24	44.39
2003	3.04	3.11	2.57	6.16	1.30	0.13	0.00	0.01	0.00	0.25	4.16	17.20	37.93	46.27
2004	4.64	11.28	1.4	0.93	0.07	0.00	0.06	0.00	0.11	7.24	3.25	14.39	43.37	40.10
Average	10.85	8.68	6.64	2.14	1.35	0.31	0.00	0.06	0.37	2.01	5.23	8.23	46.08	44.97

* Full precip data not available

Precip. data for WY 1985 and WY 1986 interpolated from other gauging stations within basin

TABLE 4

Groundwater Pumping Summary for Muncipal, Small Commercial, and Community Pumping Wells
Santa Margarita Ground Water Basin Model
Transient Model Run (WY 1985 - WY 2004)
units = Acre-Feet

	Water Year																			
Well ID	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
#3ELPUEBLO	60.0	73.8	16.0	32.9	24.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
#3AELPUEBLO	188.8	140.3	149.5	15.3	15.3	1.5	0.0	5.7	4.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
#6SCVWD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
#7ELPUEBLO	138.9	211.8	143.8	84.0	154.5	3.9	1.2	0.1	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
#9CITYHALL	423.5	292.6	277.3	342.0	226.6	183.2	205.8	160.6	210.6	210.5	251.0	134.0	149.2	132.0	109.1	77.7	110.5	122.0	85.2	44.1
#10BUSINESSMENS	108.1	425.3	383.6	397.8	397.8	585.6	547.0	475.0	445.1	354.5	143.4	389.5	450.2	370.9	340.1	263.9	220.5	373.1	399.9	331.5
#11LOMPICO	0.0	0.0	359.9	444.7	532.9	558.8	665.0	807.4	697.9	825.9	520.1	373.2	230.9	233.1	131.7	132.0	0.0	0.0	0.0	0.0
HIDDENOAKS	0.0	0.0	0.0	0.0	48.5	40.8	10.0	28.2	145.9	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
#7ASVWD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	335.8	658.9	1015.7	1032.0	893.5	905.2	849.3	757.3	771.0	631.5	605.1
#3BSVWD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.5	238.0	228.8	209.3	342.1	315.5	203.7	218.7	285.6
#11A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	90.0	153.9	45.7	68.1	53.6	54.5	101.9
#11B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	240.9	534.9	498.3	682.0	607.0
OlympiaNo.1	47.6	50.8	60.4	62.3	41.5	21.1	31.1	2.7	0.7	2.4	0.7	0.5	0.2	0.1	0.2	0.3	0.0	0.0	0.0	0.0
OlympiaNo.2	166.6	115.3	405.3	336.0	306.2	348.5	362.9	357.3	203.8	348.4	268.7	200.0	304.5	180.0	245.8	227.2	275.0	264.4	267.6	274.5
OlympiaNo.3	0.0	0.0	0.0	0.0	0.0	0.0	106.6	105.8	133.1	150.0	15.5	146.2	126.0	14.0	22.6	216.0	234.2	179.2	158.3	173.9
OldProbationP#1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pasatiempo#2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NewProbationP#5	154.9	178.8	243.2	179.2	170.7	140.6	115.1	36.1	10.2	16.1	9.3	0.2	0.1	0.1	0.5	0.0	0.0	0.0	0.0	0.0
ChampionP#4	0.0	0.0	0.0	15.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EstrellaP#3	0.0	0.0	0.0	15.2	26.1	6.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pasatiempo6	12.7	34.7	0.6	19.8	66.4	118.0	153.1	4.4	30.8	40.5	95.6	111.5	137.0	183.8	204.4	224.8	183.3	230.4	229.7	289.9
Pasatiempo7	0.0	0.0	0.0	0.0	0.0	0.0	6.2	260.1	268.6	251.7	271.1	274.8	270.2	152.3	200.9	209.3	263.8	203.0	206.7	138.2
Manana#2	0.0	0.0	0.0	0.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	73.0	64.5	68.2	66.1	58.7
Mt. Hermon#2	0.0	0.0	0.0	0.0	0.0	0.0	89.6	111.7	130.2	193.5	181.6	138.8	155.6	191.4	214.5	193.8	184.5	188.7	205.5	202.3
Mt.Hermon#1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QuailHollow3	87.7	64.4	80.6	90.1	65.2	50.5	32.4	16.3	26.2	52.5	12.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QuailHollow4	183.8	239.2	266.2	280.6	175.3	150.5	223.3	169.2	123.0	151.0	107.5	125.8	110.6	105.3	122.3	109.7	57.1	159.5	176.6	210.3
QuailHollow5/QuailHollow	120.8	105.5	170.6	130.7	91.1	64.7	88.9	56.9	39.0	87.2	41.4	55.0	76.1	31.6	1.1	37.1	157.5	123.5	155.1	159.1
QuailHollow7/QuailHollow	28.3	11.3	33.5	44.9	17.3	2.1	3.2	18.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kaiser#2	50.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	12.0	36.0	43.0	30.0	30.0	21.0	21.0	21.0	0.0
Kaiser#3	200.1	140.1	140.1	140.1	140.1	140.1	140.1	140.1	140.1	140.1	140.1	79.0	181.1	72.0	140.1	140.1	166.1	166.1	166.1	0.0
Kaiser#4	50.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	104.5	80.0	100.0	110.1	141.1	141.1	141.1	0.0
SpringLakes5	0.0	0.0	0.0	0.0	0.0	96.0	96.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0
VistadelLago	124.9	124.9	124.9	124.9	124.9	124.9	124.9	124.9	124.9	124.9	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1
SpringLakes2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SpringLakes1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SpringLakes4	96.0	96.0	96.0	96.0	96.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SpringLakes3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ValleyGardensGolfCourse	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0
MontevalleMobileHomePark	124.9	124.9	124.9	124.9	124.9	124.9	124.9	124.9	124.9	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
MissionSprings	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
FernGroveClub	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
Interdesign	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
HiddenMeadows	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
FernBrookWoods	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
SpringBrookPark	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lonestar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silverking	81.0	81.0	81.0	81.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MountainBrookTrailerPark	19.0	19.0	19.0	19.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HarmonyFoods	34.0	34.0	34.0	7.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LCWD1	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
LCWD3	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
LCWD5	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
LCWD7	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
WatkinsJohnsonRA-1	0.0	0.0	116.0	107.5	100.8	87.5	75.0	62.5	50.0	30.3	40.0	42.0	36.0	45.0	32.8	40.0	40.0	37.0	28.0	35.8
WatkinsJohnsonRA-2	0.0	0.0	116.0	107.5	100.8	87.5	75.0	62.5	50.0	30.3	40.0	42.0	36.0	45.0	32.8	40.0	40.0	37.0	28.0	35.8
WatkinsJohnsonRA-3	0.0	0.0	116.0	107.5	100.8	87.5	75.0	62.5	50.0	30.3	40.0	42.0	36.0	45.0	32.8	40.0	40.0	37.0	28.0	35.8
WatkinsJohnsonRA-4	0.0	0.0	116.0	107.5	100.8	87.5	75.0	62.5	50.0	30.3	40.0	42.0	36.0	45.0	32.8	40.0	40.0	37.0	28.0	35.8
Moon_Meadow_WS	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Manana#1	60.0	60.0	60.0	60.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEEW-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.0	17.0

FIGURES