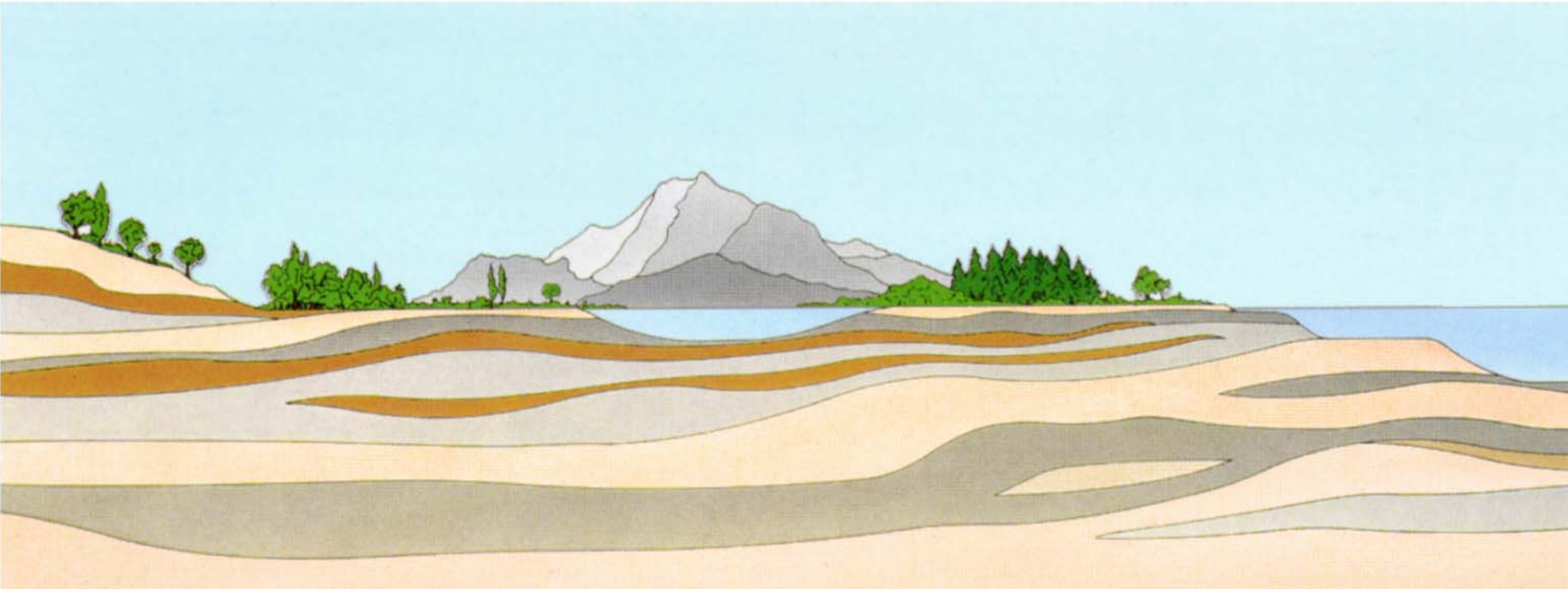
FUGRO CONSULTANTS, INC.

GROUNDWATER MODEL UPDATE, CUMMINGS GROUNDWATER BASIN

Prepared for:
TEHACHAPI-CUMMINGS COUNTY WATER DISTRICT

March 2015



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March 21, 2015
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Tehachapi-Cummings County Water District
22901 Banducci Road
Tehachapi, California 93561

Attention: Mr. John Martin

Subject: Groundwater Model Update, Cummings Groundwater Basin

Dear Mr. Martin:

Fugro Consultants, Inc., assisted by Kennedy/Jenks Consultants, is pleased to submit this report for a groundwater model update of Cummings Groundwater Basin. The objective of the overall study is to evaluate the updated hydrogeologic conditions in the basin, reevaluate the perennial yield, and update and recalibrate the groundwater model for use in evaluating future trends in groundwater levels in response to current and future operations in the basin.

It is important to understand that this Report is a compilation of our current understanding of the basin. It represents the results of our efforts to gather additional data since 2002 for use in the updating the numerical model. It can be anticipated that future model updates will be necessary as hydrogeologic and groundwater data continue to be collected over time. The updated groundwater model is now ready for evaluation of scenarios.

If you have any questions, please do not hesitate to contact us.

Sincerely,

FUGRO CONSULTANTS, INC.

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EXECUTIVE SUMMARY

This Report presents the findings of the Groundwater Model Update study for Cummings Groundwater Basin. The study is intended to provide the Tehachapi-Cummings County Water District, local municipal purveyors, and overlying agricultural users and landowners an updated understanding of the basin by evaluating recent changes in the quantity of groundwater storage in the basin, sources and volumes of recharge, sources and volumes of discharge, and an updated and recalibrated groundwater model.

The purpose of this report is to:

- Compile new data for the time period from 2002 to 2013;
- Assemble new data necessary for updating the conceptual and numerical models, including groundwater elevations, aquifer tests, drillers logs, precipitation records, well locations, land use, artificial recharge, groundwater production records, and the basin water balance;
- Update, run, and recalibrate the numerical model;
- Provide an updated estimate of basin perennial yield, and an assessment of basin pumping compared to perennial yield.

The original selected base period for the Cummings Basin study was water years 1981 through 2001 (Fugro and ETIC, 2003 and 2004). This report provides an update through 2013, and covers the entire period from 1981 to 2013. The update period of 2002 to 2013 was incorporated into the overall basin water balance and perennial yield calculations.

The perennial yield of the basin is defined to include all components of groundwater recharge and discharge from the basin, regardless of the source of the water (e.g., natural recharge, artificial recharge, return flows). Furthermore, the perennial yield of a basin is specific to a period of time (base period). As such, the perennial yield can change over time as cultural conditions change (e.g., the amount of agricultural irrigation affects return flows). Under current conditions, the basin is subject to and is being operated under conditions that include a significant volume of imported water recharge and return flows. This imported water source of supply has the effect of increasing the existing basin yield volume by artificially maintaining groundwater in storage that would not otherwise exist under “natural” conditions.

The components of recharge and discharge from the 2002 to 2013 update period were input to the original groundwater model. Slight modifications to the model basin geometry developed from review of new hydrogeologic data (e.g., DWR well logs) were incorporated into the updated model. In addition, groundwater elevation data from the 2002 to 2013 were added to model calibration targets.

On the basis of an updated water balance that is based on the calibrated model, the perennial yield of the Cummings Groundwater Basin, under current operating conditions, is 3,743 acre feet per year (AFY; rounded to 3,750 AFY).

For all considerations moving forward, a perennial yield of 3,750 AFY should be assumed. However, to illustrate the significance of the District’s artificial recharge operations on the basin, it is worthwhile to discuss what could be called the operational yield of the basin (or “native yield”). The operational yield of a basin is considered to be the amount of groundwater discharge that can occur (pumping and natural outflow) on an average annual basis while maintaining no net change in groundwater storage and not requiring any supplemental (artificial) recharge. The operational yield of the Cummings Basin accounts for natural recharge (precipitation recharge, streamflow infiltration, and bedrock inflow) and return flows (from agricultural irrigation from groundwater pumping and domestic water use). Thus, the operational yield (native yield) of the Cummings Basin is approximately 2,990 AFY (equivalent to the perennial yield of 3,750 AFY less 753 AFY of imported water recharge). Therefore, pumping in excess of 2,990 AFY must be compensated by the same amount of artificial recharge (after accounting for evaporative losses) to keep the basin in balance.

Groundwater hydrographs and groundwater level contour maps show relatively stable to rising trends in groundwater elevations over the portion of the base period from 1981 to 2001. However, the update period from 2002 to 2013 showed predominantly declining groundwater levels in wells, indicating that the previous 20-year period of stability (1981 to 2001) has been significantly nullified since 2001 by excessive groundwater pumping. With an average annual pumping rate of 5,084 AFY over the 2002 to 2013 period and an estimated perennial yield of 3,750 AFY, present groundwater production significantly exceeds the estimated perennial yield. If current production patterns continue, it is apparent that the excessive groundwater pumping at 2002 to 2013 rates will soon result in long-term basin overdraft. Measures should be implemented to reverse this trend.

1.0 INTRODUCTION

The Cummings Groundwater Basin is located west of Tehachapi, California at the junction of the Sierra Nevada and Tehachapi mountain ranges (Plate 1). Land use in the area is dominantly agriculture, but also includes the California Correctional Institute (CCI) and scattered residential areas. Prior to 1970, Cummings Basin was subject to groundwater overdraft, resulting in basin adjudication and importation of supplemental surface water supplies. The time from about 1974 to 2000 was characterized by a relatively stable period of groundwater levels due to groundwater management policies by the Tehachapi-Cummings County Water District (TCCWD) (basin water master) involving the balancing of imported water with use of local groundwater supplies. However, several groundwater related issues and concerns have arisen over the last 15 years that require basin-wide cooperation including:

- Significant increases in agricultural groundwater pumping,
- Continued growth in municipal water demands (Stallion Springs, Bear Valley, CCI), and
- Drier climatic conditions.

The impacts to groundwater levels over the last 15 years have been partially mitigated by significant increases in artificial recharge by TCCWD. However, it is apparent that basin groundwater levels have been declining over the past 10 to 15 years. Therefore, a better understanding of the groundwater basin response to these changes in groundwater pumping, natural recharge, and artificial recharge is needed in order for TCCWD to optimize management of the basin.

Previous studies have included data collection and development of a basin hydrogeologic conceptual model (Fugro and ETIC, 2003) and construction of a numerical groundwater flow and transport model (Fugro and ETIC, 2004). These two studies covered the time period from 1981 to 2001. As described above, since 2001 the Cummings Groundwater Basin has experienced drier climatic conditions, increased pumping, increased artificial recharge, and generally declining groundwater levels. The purpose of this report is to collect recent hydrogeologic data, provide an update to the hydrogeologic conceptual model, update the water balance, update and recalibrate the groundwater flow model for the basin, and provide an updated assessment of the perennial yield.

2.0 BACKGROUND

2.1 TOPOGRAPHY

Cummings Basin is a relatively flat valley that slopes gently towards the southwest, and is bounded on the north by the Sierra Nevada Mountains and on the south by the Tehachapi Mountains. Low-lying ridges connect the two ranges on the east and west sides of Cummings Basin. The valley floor elevation ranges from approximately 3,760 to 4,000 feet above Mean Sea Level (MSL). It is surrounded by hills and mountains, with the highest mountains on the south side of the basin reaching an elevation of 7,725 feet MSL. Cummings Valley has a northeast-southwest orientation and is about 6 miles long by 2.5 miles wide (Tehachapi Soil Conservation District [TSCD], 1969).

2.2 CLIMATE

Precipitation occurs primarily as rainfall on the valley floor and a combination of rain and snow at higher elevations in the surrounding hills and mountains. The majority of precipitation (85%) occurs between November and April in association with frontal storms. A portion of the remaining precipitation occurs as convection type thunderstorms of relatively high intensity-short duration during the late summer and early fall. In the upper watersheds, much of the precipitation occurs as snow, with average snowfall totals of 65 to 70 inches. During high precipitation years, snow packs of 4 to 6 feet accumulate and remain on north-facing slopes until late spring. Class A pan evaporation rates range from 80 to 90 inches per year. The typical growing season lasts 156 days, with the last freezing day in the spring being around April 28, and the first freezing day in the fall occurring around October 13 (TSCD, 1969).

2.3 PREVIOUS WATER BALANCE STUDIES

The Tehachapi Soil Conservation District (1969) estimated that the average annual natural replenishment for Cummings Basin was 2,700 acre-feet per year (AFY). The calculated agricultural return flows in Cummings Basin were 1,456 AFY, based on a standard (at that time) assumed average irrigation return flow of 35 percent of applied water percolating back to the water table. Therefore, the calculated safe yield was 4,156 AFY (TSCD, 1969).

Mann (1971) calculated a safe yield for Cummings Basin as the amount of groundwater that could be pumped with no net change in groundwater storage. The base hydrologic period used in Mann’s analysis was 1951-52 through 1969-70. Starting water levels were taken to be spring 1951, and ending water levels were spring 1970. Average annual pumping over the base period was estimated to be 4,890 AFY. Average water level conditions in Cummings Basin were represented by six key wells (T32S/R32E-20M1, 31A1, and T32S/R31E-24J2, 35N1, 36C1, and 36M2). The average drop in water levels in these six wells between spring 1951 and spring 1970 was 45.2 feet, assumed to apply over an effective basin area of 7,000 acres. Applying an average specific yield of 8 percent resulted in a total change in storage of 25,300 acre-feet over the base period or 1,330 AFY. Thus, safe yield was calculated to be average annual pumping (4,890 AFY) minus change in storage (1,330 AFY) or 3,560 AFY (Mann, 1971).

Ultimately, an average annual safe yield of 4,090 AFY was established in the Judgment of the Cummings Basin (TCCWD annual reports).

The previous study conducted by Fugro and ETIC (2003) concluded that average annual groundwater basin recharge over the 1981 to 2001 time period was 3,171 AFY, with the primary recharge sources being rainfall recharge, streamflow recharge, bedrock inflow, and irrigation return flow. Incorporation of the hydrogeologic conceptual model and water balance information into a calibrated groundwater model resulted in a perennial yield estimate of 3,644 AFY (Fugro and ETIC, 2004). It should be noted that the Fugro and ETIC (2004) perennial yield estimate was based on the volume of groundwater pumpage plus the change in groundwater storage, plus an additional estimated 200 AFY that could be added through the capture of subsurface outflow and stream discharge (which has not been realized). Subtracting the 200 AFY potential recharge capture volume from the perennial yield estimate would result in an effective perennial yield from that study of 3,444 AFY.

It should be noted that perennial yield estimates are based on climatic and cultural (e.g., land use) conditions over the base period for which the safe yield estimate is being prepared, and can change over time. Perennial yield estimates include natural recharge, return flows, and cultural activities such as artificial recharge. Sources of natural recharge for Cummings Groundwater Basin include infiltration of precipitation on the valley floor, streamflow percolation on the valley floor, and bedrock subsurface inflow from the watersheds in the mountains surrounding the valley floor. Return flows occur from excess irrigation water, CCI treated wastewater, and domestic (ranchette) irrigation and septic systems. As of 2013, artificial recharge operations were conducted at three facilities: Cummings Creek Ponds, Chanac Creek, and the 19-acre CV Loop site.

2.4 LAND USE

2.4.1 Agriculture

Land use in Cummings Basin has historically been and continues to be mostly agricultural. Irrigated cropland in Cummings Valley in 1968 included a total of 898 acres with alfalfa, potatoes, and apples comprising 691 acres or 77 percent of the total. Other irrigated crops in Cummings Valley in 1968 were grass seed/hay, onions, pears, mixed pasture, and ornamentals/flowers. Some grazing of sheep was also reported for Cummings Valley in the late 1960’s (TSCD, 1969).

Major crops grown in Cummings Basin over the 1981 to 2001 time period included alfalfa hay, apples, carrots, potatoes, and sod. Towards the end of the 1981-2001 time period, the major crop throughout the basin was sod. Annual irrigated acreages in Cummings Valley between 1981 and 2001 ranged from 385 to 1,828 acres.

For the model update period of 2002 to 2013, annual irrigated acreages ranged from 1,317 to 3,332 acres. The major crops in recent years have been vegetables and oats.

2.4.2 California Correctional Institute

The California Correctional Institute (CCI) is located in the eastern portion of Cummings Valley in T32E/R32E Section 29 (Plate 1). Water for the facility has historically been obtained from a combination of imported water and local groundwater. Groundwater is pumped from wells located in T32N/R32E Section 30. Treated wastewater ponds and a disposal spray field are also located within T32N/R32E Section 30 (Plate 1).

2.4.3 Residential

Residential areas of Cummings Valley include the Stallion Springs community and other scattered residences in the southwest portion of the valley, the northwest corner of the valley, and other residences throughout the valley. The water supply for the rural residential population is entirely derived from groundwater and is pumped from individual domestic wells scattered throughout the basin.

Stallion Springs pumps groundwater from various alluvial wells overlying the basin, and also pumps groundwater from bedrock wells outside the alluvial basin. Approximately 170 AFY of Stallion Springs production is produced from the basin and served directly to customers directly overlying the basin (that is, this amount is derived directly from the perennial yield of the basin and is not based on the imported water/conjunctive use supply). An additional portion of alluvial groundwater pumped by Stallion Springs and served to customers outside Cummings Basin alluvium boundaries is offset by an equivalent amount of artificial recharge of imported water by TCCWD.

The majority of Bear Valley residences are not located within Cummings Valley, but Bear Valley obtains a portion of their water supply via groundwater pumped from six wells in Cummings Basin in exchange for recharging an equivalent volume of imported water in Cummings Basin.

2.5 BASIN CHARACTERISTICS

2.5.1 Basin Geometry

Cummings Valley is located at the junction of the Sierra Nevada and Tehachapi mountains. It is a small alluvial basin comprised of approximately 8,500 acres, surrounded by bedrock watersheds comprising another 14,750 acres. The bedrock consists primarily of igneous rocks such as diorite, quartz diorite, granodiorite, and quartz monzonite. The alluvium consists of a mixture of clay, silt, sand, and gravel deposited by streams draining bedrock areas and flowing into the basin.

In a previous study (Fugro and ETIC, 2003), water well drillers reports obtained from TCCWD were evaluated to develop maps showing depth to unweathered and weathered bedrock. The thickness of alluvium ranged from a few feet at the edges of the basin to approximately 500 feet in the center of the basin. The boundary of alluvium shown on these maps was derived from Michael McCann Associates (1962) and a review of United States Geological Survey (USGS) topographic maps. The depth to bedrock maps were used in combination with surface elevation data to develop maps showing elevation (relative to Mean Sea Level) of the top of the unweathered and weathered bedrock surfaces. The elevations of the bedrock surfaces provided layer boundaries for the model (Fugro and ETIC, 2004).

As part of the groundwater model update study, a request was submitted to the California Department of Water Resources (DWR) to obtain water well drillers reports. Review of the well logs indicated several new logs were available since the time of the original model study. The new well logs were plotted on a map with previous well log data to update the depth to unweathered bedrock and unweathered bedrock elevation contour maps. In addition, a report prepared by GEI Consultants (2011) related to evaluation of potential surface recharge sites was reviewed. The new data generally confirmed the previous contours, although some minor modifications were made along the northeast, northwest, and southern margins of the basin (Plates 2 and 3).

The GEI report suggested that bedrock may be much shallower along the southern margin of the basin than indicated in the Fugro/ETIC contour maps in the area between new well logs E008696 and E024649. However, data from several available well logs (including new data obtained for this study) continue to show significant depths to bedrock in this area (greater than 400 feet in the case of new logs E008696 and E024649 – located 700 feet south and 1,500 feet north of the GEI borings, and 310 feet to bedrock in new log 510310 located 1,100 feet east of the GEI borings). Additional discussion of the thickness of alluvium in the area of the GEI borings is provided in the Geology section of this report.

2.5.2 Soils

Pertinent characteristics of the major soils in Cummings Valley are summarized in Table 1 and described in Fugro and ETIC (2003). Infiltration tests conducted on various soil types indicate relatively high infiltration rates of up to 10 inches per hour (TSCD, 1969). These tests indicate that the alluvial deposits are capable of absorbing large runoff volumes, and suggest that a major component of recharge to Cummings Basin occurs within alluvial fan and foothill areas along the perimeter of the basin (TSCD, 1969).

2.5.3 Geology

The geology of Cummings Valley and contributing watersheds was described in detail in Fugro and ETIC (2003). This previous study included preparation of several geologic cross-sections. Lithologic descriptions from water well drillers reports were used to develop those geologic cross sections, along with three geophysical logs that were available for wells in T32S/R32E-19. Results of the previous study indicated the distribution of alluvial sediments throughout the basin generally showed no consistent layering of fine-grained (clay and silt) versus coarse-grained (sand and gravel) materials from well to well, but rather a heterogeneous mixture of discontinuous layers. It was concluded that the basin could best be represented as a single, heterogeneous unconfined to semi-confined aquifer.

The wells logs received from DWR for this model update study were reviewed and new well logs plotted on a map (Plate 4). The previously developed geologic cross-section lines were reviewed in combination with new well locations to determine if updating of any of the cross-sections was warranted. Two of the five original geologic cross-sections were updated as follows:

Cross section C-C’ (Plate 5) shows the southeastern portion of the basin and incorporates the CCI area as well as the Cummings Creek alluvial fan. Two DWR well logs (314854 and 510344) were added between wells T12N/R16W-32G1 and T32S/T31E-36R1 on the Cummings Creek Alluvial Fan. The new logs generally show that the depth to bedrock in this area is greater than depicted on the original cross-section. Well log 510344 showed that depth to bedrock exceeds 300 feet at a location closer to the basin boundary than GEI boring B-4, which indicates an even greater depth to bedrock at B-4.

Cross section D-D’ (Plate 6) is oriented across the basin in the southwestern end of the valley. One DWR well log (E008696) and a GEI boring (B-4) were added to the southern portion of the cross-section in the Cummings Creek Alluvial Fan. The DWR log shows depth to bedrock exceeds 400 feet, in contrast to the nearby GEI boring B-4 that indicates decomposed granite at a depth of 35 feet. While the original cross-section showed depth to bedrock in this area on the order of 300 to 450 feet, the updated cross-section shows depth to bedrock to be in excess of 400 feet in this area.

2.6 SURFACE WATER

The major streams in Cummings Basin, Chanac Creek and Cummings Creek, are described in a previous report (Fugro and ETIC, 2003). There are also several minor streams flowing into the basin that drain several small watersheds. Basin outflow in terms of both surface water and groundwater occurs only along Chanac Creek at the southwestern end of the valley. No stream gauging data is available for Chanac Creek to document the amount of surface water flowing out of the basin, however surface water flows out of Cummings Valley in wet years (TSCD, 1969).

2.7 GROUNDWATER

Historic groundwater conditions are described in a previous report (Fugro and ETIC, 2003). To summarize: prior to extensive agricultural development, groundwater levels were within a few feet of ground surface with some flowing wells and groundwater discharged to stream channels (Michael-McCann Associates, 1962; TSCD, 1969). Water level declines likely began in the 1930s following increased agricultural activity, and accelerated in the 1950s and 1960s.

Groundwater level measurements have been collected by TCCWD in several wells from the 1950s until present. Groundwater levels encompassing the updated base period from 1981 to 2013 were tabulated for all available wells (Appendix A). The locations of wells with water level data are shown on Plate 7. Groundwater level hydrographs were constructed to show seasonal fluctuations and changes in levels during droughts, wet years, and due to variations in pumping (Appendix B). Groundwater contour maps were prepared for various years between 1981 and 2001 in a previous report (Fugro and ETIC, 2003), and for the years 2005, 2009, and 2013 in this report (Plates 8 through 13).

The groundwater hydrographs show relatively stable to rising trends in groundwater levels over the portion of the original base period from 1981 to 2001. The water level data indicate that the basin had accumulated groundwater storage over the time frame from 1981 to 2001. Fluctuations in water levels were typically in the range of 25 to 50 feet. For this time period, the following trends were noted:

- A modest long-term rising trend in water levels was observed in several wells located in T32S/R31E Sections 23, 24, 25, 26, and 36, and T32S/R32E Sections 20 and 30;
- Declining water levels occurred in T32S/R31E Section 34 and T32S/R32E Sections 18 and 19; and
- Water levels in other areas were generally stable.

The groundwater hydrographs show relatively stable to declining trends in groundwater levels over the portion of the base period from 2002 to 2013. The water level data indicate that the basin lost groundwater storage over this time frame. Fluctuations in water levels were typically in the range of 25 to 150 feet. For the 2002 to 2013 time period, the following trends were noted:

- A modest long-term rising trend in water levels was observed in T32S/R32E Section 20;
- Stable to modest declining trend in T32S/R32E-31 and 32;
- Generally declining water levels occurred in T32S/R31E Sections 23-26;
- Declining water levels that reached a low point in 2009 in T32S/R31E-35 and T32S/R32E-30;
- Declining water levels that reached a low point in 2006-2009 in T32S/R31E-36;

- Declining water levels until 2004-2005, followed by recovery to pre-2000 levels (T32S/R32E-19); and
- Water levels in other areas were generally stable (T32S/R31E-34; T32S/R32E-18).

Groundwater contour maps were previously constructed for several years including Fall 1980, Spring 1983, Spring 1990, Fall 1990, Spring 1995, Spring 2000, Fall 2000, Spring 2001, and Fall 2001 (Fugro and ETIC, 2003). Additional groundwater elevation contour maps prepared for this groundwater model update study included spring and fall of 2005, 2009, and 2013 (Plates 8 through 13).

In Spring 2005, groundwater depressions (Plate 8) were centered on wells in northeast portion of the basin (T32S/R32E-19; less than 3,680 feet MSL), and the southwest portion of the basin (T32S/R32E-35; less than 3,740 feet MSL and T32S/R31E-36; less than 3,720 feet MSL). In Fall 2005 (Plate 9), the major groundwater pumping troughs remained in the same locations.

In Spring 2009, groundwater depressions (Plate 10) were centered in the same areas as in 2005, with the addition of another pumping depression in the central part of the basin (T32S/R32E-30). The groundwater elevations at the center of all these pumping depressions were less than 3,700 feet MSL. In Fall 2009 (Plate 11), the major groundwater pumping troughs remained in the same locations.

In Spring 2013, groundwater depressions (Plate 12) were centered in the same areas as in 2009, with groundwater elevations at the center of these pumping depressions less than 3,720 feet MSL (or about the same levels as in 2009). In Fall 2013 (Plate 13), the major groundwater pumping troughs remained in the same locations, with the addition of another pumping depression in the southwest corner of the basin (T32S/R31E-35). Groundwater elevations in the center of these pumping depressions were less than 3,720 feet MSL, except in T32S/R32E-19 where it was less than 3,700 feet MSL.

Groundwater storage changes during the base period were calculated by comparing water level changes between Fall 1980 and Fall 2001, between Spring 1981 and Spring 2001, between Fall 2001 and Fall 2013, between Spring 2001 and Spring 2013, between Fall 1980 and Fall 2013, and between Spring 1981 and Spring 2013. Taking an average of all wells with available water level data indicates an overall increase in total groundwater storage of 10,300 AF for Fall 1980 to Fall 2001 and 9,400 AF for Spring 1981 to Spring 2001. These storage change values are based on average water level changes of 15.2 feet (Fall 1980 to Fall 2001) and 13.9 feet (Spring 1981 to Spring 2001), a basin area of 8,484 acres, and a specific yield of eight percent. These estimated volumes of change in groundwater storage are based on water level differences; the groundwater model results for the same period calculated an overall increase in groundwater storage of 10,708 AF, which compares well with the analytical results.

Similar calculations for the 2001 to 2013 and 1981 to 2013 time periods are shown in Table 2. These groundwater storage change calculations show a loss of 4,300 to 8,600 AF from 2002 to 2013, and a net gain of 1,800 to 5,100 AF from 1981 to 2013.

Groundwater storage change was also calculated by constructing a groundwater storage change map from the Fall 2001 and Fall 1980 groundwater contour maps (Plate 14), then using the Arc View GIS program to calculate the volumetric change, again assuming an overall basin specific yield of 8%. Using this method, an overall groundwater storage increase of 12,200 AF was calculated. Similar groundwater storage change maps were constructed between Fall 2013 and Fall 2001 (Plate 15), and between Fall 2013 and Fall 1980 (Plate 16). These calculations indicated a loss in groundwater storage of 9,120 AF from 2001 to 2013, and a net gain 3,000 AF throughout the entire period from 1980 to 2013. Review of the groundwater storage change maps indicates the major gains in storage from 1980 to 2001 were in the middle to northeastern portions of the basin (Plate 14); however, these same areas became the major zones of groundwater storage decline from 2001 to 2013 (Plate 15). For the entire study period from 1980 to 2013, the areas of greatest increase in storage were in the middle and southeastern portions of the basin (Plate 16).

2.7.1 Artificial Recharge Operations

The water supply for Cummings Basin consists of a combination of imported surface water and local groundwater supplies. Although most of the imported surface water is used directly for irrigation, an increasing portion has been recharged by the District since 1995 through streambed releases and artificial recharge ponds. The streambed release area is located at the head of Chanac Creek. The percolation pond recharge areas are located on the Cummings Creek alluvial fan in the southern portion of the basin and at the 19-acre CV Loop site (Plate 1). Active recharge of water at the 19 acre CV Loop site began in 2011.

2.7.2 Aquifer Parameters

Aquifer transmissivity (T) values are tabulated in Table 3 and shown on Plate 17. This table and plate were updated with new data that has become available since the previous report (Fugro and ETIC, 2003). Direct transmissivity values were obtained from aquifer tests on Bear Valley CSD wells in T32S/R32E-19, the CCI well (T32S/R32E-30C1), the Davis Trust well (T32S/R31E-25), San Benito Nursery well (T32S/R31E-35), and SSCSD Cummings Valley Well 1 (T32S/R31E-36) and Cummings Valley Well 2 (T32S/R32E-31). However, most of the T values were derived from specific capacity data taken from pump efficiency tests and DWR well logs. The pumping tests provided a direct calculation of transmissivity, whereas the specific capacity data were converted to transmissivity values using a method described by Driscoll (1986). Specific capacities were generally in the range of 1 to 20 gallons per minute per foot of drawdown (gpm/foot), with associated transmissivity values about 1,500 to 30,000 gallons per day per foot (gpd/foot) and hydraulic conductivity (K) values from 1 to 10 feet/day.

Transmissivity values were averaged by section using the geometric mean. As would be expected, the highest T values occur in the sections located in the middle of Cummings Valley where alluvium is thickest. The geometric mean T values ranged from about 6,000 to 21,000 gpd/ft with K values from 5 to 12 feet/day for sections in the middle of the basin. Other sections along the margins of the basin had T values from about 500 to 2,500 gpd/foot with K values of 0.6 to 3 feet/day. Vertical K values are considerably lower due to the presence of interbedded clay layers, and are probably in the range from 0.001 to 0.5 feet/day.

No aquifer tests with observation well data were available to evaluate aquifer storativity values. Specific yield values used in previous reports to calculate changes in groundwater storage ranged from seven to eight percent (TSCD, 1969; Mann, 1971).

3.0 WATER BALANCE INVENTORY

3.1 BASE PERIOD

Review of precipitation data and discussion of the original base period selection is described in a previous report (Fugro and ETIC, 2003). For the purposes of the model update study, it was desired to extend the original base period through the end of 2013, somewhat regardless of whether or not the 1981 to 2013 time period constitutes a representative base period in terms of climatic conditions. Nonetheless, it is useful to compare the average precipitation and climatic cycles over the 1981 to 2013 period to the longer term averages to provide some context for climatic conditions represented by the updated water balance.

Precipitation data for the Tehachapi and Cummings Valley stations are tabulated in Tables 4 and 5. The Tehachapi station is best used for comparisons as it has a long term record extending back to 1921. The average precipitation from 1921 to 2013 at Tehachapi is 11.24 inches/year versus an average of 11.79 inches per year from 1981 to 2013. Thus, it is apparent that the 1981 to 2013 study period is generally representative of slightly above average rainfall conditions. However, it is also important to note that 1981 to 2001 conditions were significantly wetter than average (12.44 inches per year), whereas 2002 to 2013 conditions were significantly drier than average (10.65 inches per year).

It is also important to examine the cumulative departure from mean over the study period relative to the long term record (Plate 18). This chart shows that the start of the model study period (1981) represented the end of a dry spell in the long term rainfall record. The subsequent period from 1981 to 1999 represented a relatively wet period, which was followed by a dry period from 1999 to 2013 punctuated by only two wet years in 2005 and 2011.

3.2 PRECIPITATION RECHARGE

Precipitation data were used to estimate the amount of water that recharges the basin from deep percolation of rainfall that falls on the valley floor. It was assumed as an initial gross estimate that 10% of total precipitation over the entire base period went to deep percolation. This assumption resulted in an average percolation of 1.31 inches per year (10 percent of 13.05 inches), which resulted in 896 AFY of average annual precipitation recharge (26% of net average annual recharge). However, the amount of deep percolation from precipitation on a year-to-year basis is not necessarily 10 percent of precipitation in that particular year. A previous report (Fugro and ETIC, 2003) described how precipitation recharge was calculated for each year from 1981 to 2001, and a similar methodology was applied for 2002 to 2013 (Appendix C). Table 6 provides yearly estimates of precipitation recharge based upon varying annual percentages of precipitation recharge.

3.3 STREAM FLOW RECHARGE

No stream flow records are available for Cummings Valley. The methodologies for calculation of streamflow from contributing watersheds and subsequent streamflow percolation in Cummings Basin for 1981 to 2001 were described in a previous report (Fugro and ETIC, 2003). A similar methodology was applied for streamflow recharge for 2002 to 2013 (Appendix D). The total stream flow occurring each year is provided in Table 6. Assuming that the basin is capable of absorbing up to 2,000 AFY of stream flow (1,000 AFY from Cummings Creek and 1,000 AFY from the remaining watersheds), and that stream flow in excess of that flows out of the basin, results in at least some surface outflow in six years of the base period. The use of a value of 2,000 AFY as the maximum stream flow absorption capacity of the basin is consistent with the observation in previous reports that significant stream flow out of the basin is limited to the wettest years. The resulting average annual percolation due to stream flow from all watersheds in Cummings Basin amounts to 727 AFY, or 21% of net average annual recharge (Table 6).

3.4 AGRICULTURAL IRRIGATION RETURN FLOWS

The calculation of irrigation return flows for the 1981 to 2001 time period is described in a previous report (Fugro and ETIC, 2003). In summary, aerial photos and crop surveys were reviewed to delineate irrigated acreage and crop type by sections (one mile by one mile). This same approach was maintained for the model update time period of 2002 to 2013. However, a major difference in methodology between the two time periods is that agricultural groundwater pumping for 2002 to 2013 was based on metered data instead of being estimated. Thus, the amount of imported water and groundwater pumping for agricultural irrigation are both metered and known quantities. The total applied irrigation water (imported water plus groundwater) was divided by total irrigated acreage to obtain water duty factors (Table 7). The total irrigated acres in each section were then multiplied by the water duty factor to obtain total applied irrigation water by section. The total applied irrigation water by section was multiplied by 15 percent (per TCCWD Annual Reports) to obtain total return flows for each section for each water year. The results are tabulated in Appendices E and F, and agricultural return flows are summarized in Table 6. Irrigation return flows from 1981 to 2001 and from 2002 to 2013 averaged 364 AFY and 887 AFY, respectively. Over the base period of 1981 to 2013, irrigation return flow amounts to an annual average of 554 AFY (16% of net recharge). Of the annual return flow volume of 554 AFY, 281 AFY of the return flow is from use of groundwater and 273 AFY is from applied imported water.

3.5 CCI AND DOMESTIC RETURN FLOWS

CCI operates wastewater treatment facilities in T32S/R32E-30 that include percolation ponds and a disposal spray field. The water supply for CCI ranged from a combination of imported water and groundwater prior to 2004 to strictly groundwater pumping after 2004. Return flows from the disposal of treated wastewater at CCI were assumed to average 20% of water use and are tabulated by year in Appendix G. CCI return flows averaged 204 AFY from 1981 to 2001, 210 AFY from 2002 to 2013, and 207 AFY from 1981 to 2013.

Except for residences in the Stallion Springs community, which are primarily served by the District’s wastewater treatment facility, most domestic water users overlying the basin are on private individual septic systems. Return flows from domestic water uses resulting from a combination of outdoor irrigation and indoor flows to septic systems were assumed to average 50% of total water use. Yearly domestic return flow amounts are summarized in Appendix G. Domestic return flows averaged 43 AFY from 1981 to 2001, 114 AFY from 2002 to 2013, and 69 AFY from 1981 to 2013. CCI and domestic return flows are combined in Table 6. The combined return flows amount to 275 AFY over the 1981 to 2013 time period, which amount to 8% of net average annual recharge.

3.6 ARTIFICIAL RECHARGE

Since 1995, TCCWD has used imported water to conduct artificial recharge operations in the streambed of upper Chanac Creek and in ponds on the Cummings Creek alluvial fan. An additional artificial recharge facility, known as 19-acres/CV Loop, began operations in 2011. Recharge volumes have ranged from 41 to 1,951 AFY (Table 6). Artificial recharge operations were a relatively minor component of the water balance prior to 2002. However, during the time period from 2002 to 2013 artificial recharge operations have been a major addition to the water budget with an average annual recharge volume of 1,189 AFY from 2002 to 2013. Chanac Creek was the primary recharge facility until 2012, when the 19 acres/CV Loop received the most water for artificial recharge (Appendix H). Artificial recharge averaged 472 AFY over the 1981 to 2013 time period (14% of net average annual recharge). A previous study (Fugro, 2009) determined that artificial recharge operations have an average evaporative loss of about five percent. TCCWD data accounts for the evaporative losses at a rate of six percent beginning in 2010.

3.7 BEDROCK GROUNDWATER INFLOW

Additional study of bedrock groundwater flow was conducted for this Model Update Study by reviewing DWR well log data for wells screened in bedrock surrounding Cummings Basin. In particular, well logs with specific capacity data were compiled and tabulated (Appendix I). Based on these additional data, it was determined that prior assumptions documented in a previous report (Fugro and ETIC, 2003) were sufficiently accurate for water balance calculations. Thus, bedrock groundwater inflow for the 2002 to 2013 time period was maintained at a value consistent with the original 1981 to 2001 time period at 530 AFY, which amounts to 15% of average annual net recharge (Table 6).

3.8 GROUNDWATER PUMPING

The amount of agricultural groundwater pumping for each well during the 1981 to 2001 time period in the original study was estimated because agricultural pumping was not metered during that time frame. The methodology applied to assign the amount of agricultural pumping for each well for each year and model stress period is described in previous reports (Fugro and ETIC, 2003 and 2004). Beginning in 2002, agricultural groundwater pumping has been metered and recorded on a monthly basis for each well in Cummings Basin (Appendix J). Therefore, the amount of groundwater pumping for each agricultural well for each model stress period from 2002 to 2013 was assigned directly from the metered data. However, it should be noted that use of water years in this study (October 1 to September 30) required estimation of agricultural pumping for the three month period from October 1 to December 31, 2001. This pumping was estimated based on the percentage of total annual agricultural pumping that occurs from October to December. Agricultural groundwater pumping amounts are summarized in Tables 7 and 8.

The average annual agricultural groundwater pumping over the 1981 to 2001 period was 1,229 AFY, compared to the 2002 to 2013 average annual agricultural groundwater pumping of 2,870 AFY. The average annual agricultural groundwater pumping over the entire study period of 1981 to 2013 was 1,826 AFY. Over the entire 1981 to 2013 period, the greatest volume of agricultural groundwater pumping (3,594 AF) occurred in 2002, and the second highest total was 3,522 AF in 2009.

Tables 7 and 8 also show the amount of groundwater pumped per year for municipal/industrial and domestic uses. Additional detail on monthly municipal/industrial pumping amounts by well is provided in Appendix K. Municipal groundwater pumping includes CCI, Stallion Springs CSD, and Bear Valley CSD. Municipal and industrial groundwater uses averaged 866 AFY from 1981 to 2001, and 1,985 AFY from 2002 to 2013. The overall average from 1981 to 2013 was 1,274 AFY. Plate 19 shows the location of groundwater production wells used for agricultural and municipal/industrial purposes.

Domestic groundwater pumping from 1981 to 2001 was based on data in TCCWD annual reports. Domestic pumping from 2002 to 2013 was estimated based on both TCCWD annual reports and a more specific 2013 water demand analysis for developed rural parcels (Appendix L). Domestic groundwater pumping ranged from 159 AFY to 277 AFY with an overall average of 228 AFY from 2002 to 2013. Plate 20 shows the location of known wells used for domestic purposes from 2002 to 2013.

Tables 7 and 8 provide a yearly summary of the total average annual groundwater pumping from Cummings Basin over the updated base period, which amounted to 3,254 AFY. Total groundwater pumping increased substantially over the update period of 2002 to 2013 with an annual average of 5,084 AFY compared to the 1981 to 2001 annual average of 2,208 AFY. Total groundwater use in the basin ranged from a low of 1,606 AFY (1999) to a high of 5,644 AFY (2006).

3.9 BEDROCK GROUNDWATER OUTFLOW

The methodology for calculation of bedrock groundwater outflow is described in a previous report (Fugro and ETIC, 2003). The basic assumptions for this calculation have been maintained for the 2002 to 2013 time period. This calculation results in an average annual bedrock groundwater outflow of 44 AFY.

3.10 SUMMARY OF RECHARGE AND DISCHARGE COMPONENTS (BASIN INVENTORY)

Groundwater recharge in Cummings Basin is derived from several different sources, including precipitation, stream flows, return flows, bedrock inflow, and artificial recharge. The majority of groundwater discharge from Cummings Basin is via pumping with a minor component of groundwater outflow through the bedrock. The average annual contribution of each component based on the basin water balance inventory is summarized in Table 9.

The data summary shown on Table 9 shows that basin recharge exceeded basin discharge by approximately 917 AFY during the original base period from 1981 to 2001. However, during the update period from 2002 to 2013, basin discharge exceeded basin recharge by an average of 1,179 AFY. Over the entire 1981 to 2013 time period, basin recharge exceeded basin discharge by an average of approximately 156 AFY. It is important to note, however, that this seeming stability over the course of the 33-year period must be compared against the intensive demands on the basin over the past 12-year period of the update. Clearly, the basin demands over the most recent 12-year period are significantly higher than the previous 21-year period. Furthermore, the District’s return flow inventory (which claims 9,633 AF of artificial recharge return flow water) has partially offset what would otherwise be a more serious basin decline since 2002.

4.0 NUMERICAL GROUNDWATER MODEL UPDATE

The Cummings Basin groundwater model was originally developed and calibrated using a base period from 1981 to 2001 (Fugro and ETIC, 2004). Several scenarios were run related to perennial yield, basin water management, and groundwater quality. Many changes have occurred in the basin since 2001, related primarily to groundwater pumping and drier climatic conditions that have resulted in declining groundwater levels and storage. This model update is intended to incorporate water balance data from 2002 to 2013, run the model from 1981 to 2013, review calibration data, and recalibrate the updated flow model as necessary.

4.1 PURPOSE AND OBJECTIVES

The Groundwater Model Update Study consists of an update and refinement of the existing numerical model to simulate groundwater flow in the Cummings Groundwater Basin. This numerical model update was based upon the 2002 to 2013 hydrogeologic data. This section of the report documents the update and recalibration of the groundwater model, including:

- Incorporation of the hydrogeological and water balance data compiled in the study to update and refine the numerical model,
- Recalibration of the groundwater flow model by matching model results to measured groundwater elevation data and the estimated water budget,
- Estimation of the perennial yield for the basin, and
- Conclusions and recommendations.

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

4.2 CUMMINGS GROUNDWATER BASIN HYDROGEOLOGIC CONCEPTUAL MODEL UPDATE

A hydrogeologic conceptual model describes the geological setting and hydraulic processes for the basin and serves as the basis for constructing a numerical model. The basic components of the conceptual model required to construct a numerical model describe how groundwater enters and exits a defined system and the geologic factors that control the movement of groundwater within the area of interest. The hydrogeologic conceptual model for the basin was originally developed in a previous study (Fugro and ETIC, 2003). The tasks for this model update study included compilation and analysis of available hydrogeological data for the basin from 2002 to 2013, thereby defining recent past and current conditions of the basin. This work led to development of a conceptual understanding of recent hydrogeologic conditions, and a preliminary update of the hydrologic budget across the basin.

4.2.1 Basin Hydrology

The basin hydrology is described in previous reports (Fugro and ETIC, 2003 and 2004), and an abbreviated summary is provided below. The Cummings Groundwater Basin is composed of the water-bearing sediments that underlie the Cummings Valley. The valley is surrounded by highlands that are primarily composed of granitic rocks (Michael-McCann, 1962; TSCD, 1969). Precipitation falls primarily as rain on the valley floor; however, a combination of rain and snow occurs at higher elevations in the surrounding mountains. Typically, about 85 percent of the annual precipitation occurs during December through April. At the higher elevations, much of the precipitation occurs as snow with average snowfall totals of 65 to 70 inches.

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

4.2.2 Water Budget Update

Earlier sections of this report provide a comprehensive data compilation and evaluation to quantify the water balance components for the basin from 2002 to 2013. These sections include a basin-wide water balance that was developed using the inventory method over the updated base period of 1981 through 2013. The water balance identified that 62 percent of the total net recharge was due to precipitation, stream flow and subsurface inflow. The remaining 38 percent was attributed to return flows and artificial recharge operations. The primary outflow component was pumping, which accounted for 99 percent of the total net outflow from the basin. The average annual contributions of each recharge and discharge component are summarized in Table 9.

Using the inventory method, previous sections of this report provide the calculated average annual recharge to Cummings Basin of 3,454 acre-feet per year (AFY), whereas the total discharge from the basin approximates 3,298 AFY. This comparison yields a net excess of 156 AFY of recharge over discharge.

Calculating the change in storage based on average changes in water levels and assuming a specific yield of eight percent yielded an increase in groundwater storage of 1,765 to 5,090 acre-feet or 53 to 154 AFY (depending on use of fall or spring water levels) for the updated base period. Comparison of groundwater contour maps for Fall 1980 and Fall 2013 results in a change in groundwater level map (Plate 16). The change in groundwater storage computed from this map is 2,984 acre-feet, or an annual average gain of 90 AFY (Table 2), which compares well with the basin inventory method as well as, as will be described in later sections of this report, the updated model-based water budget.

The recharge and discharge amounts calculated for this study and cited above are for the 33-year period of 1981-2013. Examination of the model update period (2002 to 2013) shows basin discharge (5,128 AFY) far in excess of basin recharge (3,949 AFY). Thus, the method of estimating basin overdraft through calculation of the inventory of various basin recharge and discharge components results in an overdraft rate of approximately 1,179 AFY over the past 12 years (from 2002 to 2013). Note that this method of calculating basin yield and overdraft is one means of doing so, and compares well with the results of the modeling methodology (as described, below). The purpose of calculating basin yield by the basin inventory method is to provide an independent and alternative methodology; the results of the modeling calculations are considered to be more representative of actual conditions.

4.3 CUMMINGS GROUNDWATER BASIN NUMERICAL MODEL UPDATE

This model update is intended to collect and review new data not available during construction of the existing model (that was constructed in 2003-04), and update the existing model with new data. The existing model covered the time frame from 1981 to 2001, and the model update period is 2002 to 2013. The updated model now covers the entire time period from 1981 to 2013.

4.3.1 Numerical Model Framework

The numerical model framework is comprised of model geometry, model domain, model grid, model layers, boundary conditions, stress periods, and various input parameters (e.g., aquifer properties). The development and framework of the numerical model was described in detail in a previous report (Fugro and ETIC, 2004), and a brief summary is provided below.

The Cummings Groundwater Basin numerical model was originally constructed using the groundwater flow model MODFLOW 2000 (Harbaugh, et. al., 2000). The model update included changes to incorporate recent MODFLOW code advancements. The advanced features incorporated into the updated model include the following:

- The model was updated from MODFLOW 2000 to MODFLOW NWT to take advantage of new advanced features. MODFLOW-NWT (Niswonger, Panday and Ibaraki, 2011) is a stand-alone version of MODFLOW-2005 that includes an advanced mathematical solver that provides a more robust solution to complex conditions such as rewetting of dry model cells, unconfined conditions and groundwater-surface water interactions. These features improve the ability of the model to evaluate potential conjunctive use and recharge projects to increase groundwater levels in the basin.
- The simulation of surface streams was simulated using the Streamflow Routing (SFR) package (Prudic, et. al., 2004) that includes improved calculation methods for improved simulation of groundwater-surface water interactions.
- The MODFLOW processor used to facilitate the operation and data processing for the updated numerical model was upgraded to Groundwater Vistas Version 6 (ESI 2011).
- MODFLOW-NWT requires the input of specific storage rather than storage coefficient. Groundwater Vistas Version 6 includes a feature to automatically convert storage coefficient data, which is easier to work with, to specific storage required by MODFLOW. Therefore, storage coefficient is discussed below, but the data are properly entered into MODFLOW.

The model domain, layers, grid, and stress periods were described in a previous report (Fugro and ETIC, 2004) and were not modified, except that 24 additional 6-month stress periods were added for the 2002 to 2013 update period. The elevation for the bottom of the model representing the bedrock-basin boundary was modified to represent the updated interpretation of the bedrock contact shown on Plates 2 and 3. The original model was set up using the space and time dimensions in feet and years. For the updated numerical model, the time dimension was changed to days because this provided for more convenient units for assessing aquifer properties and pumping volumes.

4.3.2 Aquifer Properties

The data used to define aquifer properties were provided in a previous report (Fugro and ETIC, 2003), with supplemental data summarized in an earlier section of this report and in Table 3. Reasonable value ranges were defined for each property. These ranges were used as guidance during the original model calibration (Fugro and ETIC, 2004). Hydraulic conductivity was defined in regionalized zones that are shown in Plate 21 for each model layer. Overall, the horizontal hydraulic conductivities used in the recalibrated model were modified from a range of 0.8 to 5.0 feet/day to a range of 0.4 to 4.0 feet/day distributed as shown in Plate 21. During the recalibration process, the hydraulic conductivity was modified to improve the calibration; however, the values remained within a similar range as used in the original model. In general the horizontal hydraulic conductivity values in the central areas of the basin were reduced from either 4 or 5 feet/day to a maximum of 3 feet/day throughout the model. In Model Layer 3, the horizontal hydraulic conductivity in the basin margin areas along the southeastern portion of the basin were increased 0.5 and 0.8 feet/day to 1.0 and 1.25 feet/day.

Since no vertical hydraulic conductivity data were available for the Cummings Groundwater Basin, the vertical hydraulic conductivity was defined during the original model calibration. For the Cummings Basin a uniform vertical hydraulic conductivity of 0.05 feet/day was used throughout the original model. No changes to the vertical hydraulic conductivity were made during the recalibration.

A limited amount of storage coefficient and specific yield data were presented in a previous report (Fugro and ETIC, 2003) as average values in the basin. For Model Layer 1, which was simulated as entirely unconfined, a specific yield of 0.085 was applied uniformly in the original model. For Model Layer 2 the storage coefficients ranged from $1.5\text{x}10^{-3}$ to $2.5\text{x}10^{-4}$ and a specific yield of 0.08 was used in the original model. For Model Layer 3 the storage coefficients ranged from $1.5\text{x}10^{-3}$ to $2.5\text{x}10^{-4}$ and the specific yields varied from 0.01 in lower hydraulic conductivity areas to 0.08 in the Cummings Creek area in the original model (Fugro and ETIC, 2004). During the recalibration process, the storage coefficient and specific storage were modified to improve the calibration. In the center of the basin in Model Layer 3, the storage coefficient was decreased from $2.5\text{x}10^{-4}$ to $7.5\text{x}10^{-5}$; however, in Model Layers 1 and 2, the specific storage was increased from $2.5\text{x}10^{-4}$ to $5.0\text{x}10^{-4}$; and from $1.0\text{x}10^{-4}$ to $2.5\text{x}10^{-4}$. These changes were made to improve the overall calibration in these areas. In Model Layer 3, the distribution of the storage coefficient zones was modified resulting in an increase in storage coefficient along the western basin margin.

4.3.3 Boundary Conditions

Model boundary conditions simulate water entering and exiting the model domain and are based on the components of the hydrologic budget. A previous report describes how boundary conditions were implemented in the Cummings Basin MODFLOW model (Fugro and ETIC, 2004). To summarize, the primary mechanisms for groundwater to enter the model are from precipitation recharge, streamflow infiltration, return flows, artificial recharge, and subsurface inflow. The primary mechanism for groundwater to exit the model is from pumping wells, with minor basin discharge from subsurface outflow, and evapotranspiration. The implementation of these boundary conditions in the model update is described in subsequent paragraphs.

4.3.3.1 Precipitation Recharge

Precipitation recharge is an estimate of the amount of deep percolation occurring from rainfall on the valley floor. The estimate assumed ten percent of total rainfall went to deep percolation. The 2002-2013 update period was relatively dry and had an average annual precipitation of 9.89 inches per year (based on the Cummings Valley Station). In contrast, the average annual precipitation at the Cummings Valley Station over the 1981 to 2001 period was 14.86 inches. The Cummings Valley Station average over the entire base period from 1981 to 2013 was 13.05 inches per year. This produced an estimated recharge of 29,554 acre-feet of precipitation recharge over the update period for an average rate of 896 AFY. The initial annual distribution of this recharge developed in earlier sections of this report is shown in Table 6. The distribution was based on an assumption that a higher percentage of precipitation would become recharge in wet compared to dry years. The methodology for input of precipitation recharge to the MODFLOW model was based on use of the recharge package, and is described in more detail in a previous report (Fugro and ETIC, 2004).

During the original model calibration and subsequent recalibration for this study, the precipitation recharge rates were modified as shown in Table 10. This distribution was developed to better match hydrograph data from basin wells and uses a similar assumption but applies an even higher percentage of recharge in wet years than in dry years. Subsequently, an increase was added to 1982, 1983, 1992, 1993, 1995, 1998, 2001, and 2011 total rainfall recharge for model calibration. Decreased rainfall recharge was used for some of the drier years. The net result increased the total precipitation recharge to 30,539 acre-feet over the base period with an average annual recharge rate of 925 AFY (23 percent of total recharge).

4.3.3.2 Stream Recharge

Streamflow recharge is a major component to the overall water balance that accounts for about 32 percent of the total groundwater recharge for the basin (Table 10). Groundwater interactions with surface water were input into the MODFLOW model using the stream and well packages (Plate 22), and are described in more detail in a previous report (Fugro and ETIC, 2004).

In the original model, recharge from Chanac Creek employed the MODFLOW well package for recharge to specifically apply artificial recharge to the area of application. In addition, the drain package was used for simulating groundwater discharge in Chanac Creek.

For the updated model, the Chanac Creek drain package was converted to the SFR package to provide a more realistic simulation of groundwater-surface water interactions.

In a previous report (Fugro and ETIC 2003) and earlier sections of this report, stream runoff was calculated for the 14,750-acre watershed that drains into the Cummings Groundwater Basin. Cummings Creek is the largest drainage into the basin, but several other minor drainages are also found around the basin. This analysis of streamflow generated from the watershed area produced 47,986 acre-feet of streamflow over the base period for an average maximum potential recharge of 1,454 AFY. A second estimate that capped wet year streamflow infiltration at 2,000 AFY produced 23,995 acre-feet of recharge over the base period for an average annual recharge of 727 AFY (Table 6). This was considered as the reasonable range of stream flow recharge. The overall streamflow recharge for the update period of 2002 to 2013 was considerably less than the 1981 to 2001 due to drier climatic conditions over the recent time period.

During the model calibration, the stream recharge was modified as shown in Table 10. This distribution was developed to better match hydrograph data from basin wells. This distribution uses a similar assumption as precipitation recharge that a higher percentage of recharge occurs in wet years than in dry years. Likewise, the general assumption used was that 85 percent of stream recharge occurred during the winter stress period and the remaining 15 percent occurred in the summer stress period. The total stream recharge was increased to 42,732 acre-feet over the base period with an average annual recharge rate of 1,295 AFY.

4.3.3.3 Groundwater Pumping

Groundwater pumping is the major component that accounts for about 92 percent of total groundwater outflow from the Cummings Basin. Groundwater pumping data were compiled in a previous report (Fugro and ETIC 2003), and in previous sections of this report. The locations of the groundwater extraction wells included in the model are shown in Plate 23. The methodology used for implementation of pumping wells is described in a previous report (Fugro/ETIC, 2004).

The recent update time period from 2002 to 2013 had metered pumping data (with minor exceptions) for agricultural wells, which was not previously available. Total agricultural pumping in the calibrated model is 76,145 AF with an annual average of 2,307 AFY (Table 11). Municipal and industrial pumping has been metered over the entire base period, and shows 42,021 acre-feet of pumping with an annual average of 1,274 AFY. Other domestic pumping was estimated at 4,516 acre-feet for an average rate of 137 AFY (Table 8). The total metered municipal and industrial pumpage plus estimated domestic pumping equaled 46,537 AF (1,411 AFY); however, minor adjustments in domestic pumping during model implementation and calibration resulted in a model-based average annual municipal/industrial/domestic pumping estimate of 46,307 AF (1,403 AFY). The distribution of municipal, industrial and domestic pumping assumed 40 percent of water use in the winter stress period and 60 percent of water use in the summer stress period for the 1981 to 2001 period. For the period from 2002 to 2013, the municipal and industrial pumping was based on monthly metered data so the data was entered as provided (grouped into six-month time steps); however, domestic pumping for 2002-2013 used estimated annual volumes and the same 60%/40% assumption was applied.

During the original calibration time period (1981 to 2001), additional pumping was added to better match hydrographs of wells located primarily in the center of the basin. This was assumed to represent underestimation of groundwater pumping for agricultural use as developed in a previous report (Fugro and ETIC 2003). As agricultural pumping was metered for 2002 to 2013, no adjustments to agricultural pumping were made for the update period (2002 to 2013) during model recalibration. With these previous additions, the total groundwater pumping amounted to 122,452 acre-feet over the base period for an average rate of 3,710 AFY (Table 11).

4.3.3.4 Return Flows

Return flows represent the component of irrigation or wastewater disposal that percolates back to the groundwater. Therefore, this component of groundwater recharge is dependent upon water usage. Irrigation return was based on agricultural water usage including both groundwater and imported water that was developed in a previous report (Fugro and ETIC 2003), and in an earlier section of this report. The estimation of irrigation return flow was assumed as 15 percent of total agricultural water use. This produced an estimate of 18,298 acre-feet of return flow over the base period for an average rate of 554 AFY (equal to 281 AFY of return flow from groundwater and 273 AFY from applied imported water). These data were tabulated per square mile and input into the model using the MODFLOW recharge package (Plate 24).

The increased agricultural pumping input during the original model calibration period (1981 to 2001) was also incorporated in the irrigation return flow calculation and added to the recharge package. The general assumption used to distribute the agricultural return flow recharge was that 15 percent occurred during the winter stress period and 85 percent occurred in the summer stress period.

CCI disposes of wastewater at sewage disposal ponds and spray fields. Return flows were estimated as 20 percent of CCI water use. The disposal ponds were simulated using the MODFLOW well package and the spray fields were incorporated into the MODFLOW recharge package. Return flows from domestic septic systems were assumed as 50 percent of the estimated domestic water use. This produced an estimate of 9,073 acre-feet of return flow over the base period for an average rate of 275 AFY. Domestic return flow was input to MODFLOW using the recharge package. The estimation of CCI and domestic return flow assumed 40 percent of water use in the winter stress period and 60 percent of the summer stress period.

The total return flow recharge for the calibrated model was 28,136 acre-feet over the base period with an average annual recharge rate of 853 AFY. This accounted for about 21 percent of the total groundwater recharge over the base period.

4.3.3.5 Artificial Recharge

Artificial recharge includes imported water applied at recharge areas for the purpose of groundwater recharge. This water has been applied in three areas: at the Chanac Creek recharge area in the northeastern portion of the basin, the 19-acre/CV Loop recharge site, and the Cummings Creek recharge area. Since 1995, TCCWD has utilized varying amounts of imported water to conduct artificial recharge operations. The annual amounts ranged from 41 to 1,945 AFY (Table 10).

Artificial recharge data were input into the model using the well package. Note that the artificial recharge volume shown in Table 10 vary slightly from the totals shown in Table 6. The differences in the model-based results are a function of minor model input rounding that occurs over several grid square calculations. The artificial recharge component of 15,622 acre-feet was applied over the portion of the base period from 1995 to 2013 based on TCCWD records (Table 10 and Plate 23).

4.3.3.6 Subsurface Inflow and Outflow

Subsurface inflow and outflow represent the amount of water that enters or exits the basin as groundwater. The calculation methodology is presented in a previous report (Fugro and ETIC, 2003). Inflow was calculated at 17,490 acre-feet over the base period with an average annual recharge rate of 530 AFY. Outflow was calculated as 1,452 acre-feet with an average annual discharge rate of 44 AFY (Table 6). Implementation of subsurface inflow in the MODFLOW model is described in a previous report (Fugro and ETIC, 2004) (Plate 25). The model subsurface discharge was 9,092 acre-feet over the base period with an average annual discharge rate of 276 AFY (compared to the hydrologic inventory estimate of 44 AFY). This accounted for about 7 percent of total groundwater outflow from the basin.

Subsurface outflow was also described in a previous report (Fugro and ETIC, 2004). Minor changes were implemented in the updated model for the general head boundary (GHB) condition representing subsurface outflow. The distribution of the GHB cells was shifted slightly to avoid convergence issues. This involved moving 12 of the 796 GHB cells (1.5%) to a nearby location that provided better model simulation stability. This change was not considered to affect the model results.

4.3.3.7 Evapotranspiration

Evapotranspiration (ET) was originally not included in the basin inventory calculations of Fugro and ETIC (2003) because it was considered to be an insignificant component of the overall water balance. As described in Fugro and ETIC (2004), ET was subsequently incorporated into the model, and the use of ET estimates as part of the model-based water balance was maintained for the model update. Evapotranspiration from the calibrated model was 1,892 acre-feet over the base period with an average annual discharge rate of 57 AFY. This accounted for about 1.4 percent of the total groundwater outflow from the basin (Table 11).

4.4 NUMERICAL MODEL CALIBRATION

Model calibration consists of comparing simulation results from the numerical model to observed measurements collected in the groundwater basin over the base period. During calibration, aquifer properties and boundary conditions may be varied within an acceptable range until a close fit is achieved between model-simulated versus field-measured data. The Cummings Basin groundwater model was originally calibrated based on data from 1981 to 2001. The updated model documented in this report was recalibrated for the 1981 to 2013 time period. The original model calibration and basis for parameter adjustments are described in a previous report (Fugro and ETIC, 2004). The discussion below is focused on recalibration efforts for this study related to incorporation of the 2002 to 2013 update period into the groundwater model.

4.4.1 Calibration Criteria

There are multiple combinations of aquifer properties and boundary conditions that can be used to match a single set of groundwater elevation data. Calibrating to multiple data sets under differing stresses (i.e. recharge and discharge rates) reduces this “non-uniqueness”, thereby reducing the uncertainty. Performing a comprehensive calibration over a 33-year base period infers the calibration has been performed over wet, dry, and normal years with varying degrees of pumping. To that end, the Cummings Basin Groundwater Model was calibrated using three separate criteria. These criteria include:

- Groundwater Elevation Maps,
- Statistical Analysis, and
- Hydrographs.

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

4.4.2 Calibration Results

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

4.4.2.1 Groundwater Elevation Map Calibration

The first and most basic model calibration criterion is a direct comparison of simulated versus measured groundwater elevation maps for select time periods. The primary purpose of this calibration is to compare hydraulic gradients for both magnitude and direction to insure that the model is accurately simulating existing conditions. This visual comparison is a fast method to determine where additional model calibration efforts should be focused. Plate 26 provides a simulated groundwater elevation map for Spring 2009 and Plate 27 provides a simulated groundwater elevation map for Fall 2013. These figures show that the groundwater flow is primarily toward the heavy pumping areas in the center of the basin, as described in the conceptual model. Steeper hydraulic gradients are observed in the Cummings Creek area in the southeast and along other parts of the basin margin. Gradients flatten toward the center of the basin. This is similar to groundwater elevation maps presented in Plates 11 and 13; however, these maps are based on more limited data and were only contoured in the center of the basin. Notwithstanding this, this preliminary calibration suggests that the groundwater flow field generated by the model is reasonable.

4.4.2.2 Statistical Calibration

Next, a more rigorous calibration was performed involving a statistical analysis to compare the difference or residual between measured and simulated groundwater elevations. A scatter plot of observed versus simulated groundwater elevations (Plate 28) depict this relationship. As indicated on Plate 28, the scatter along the correlation line is minor in comparison to the range of the data. The correlation coefficient for the data on this graph is 0.96. The correlation coefficient ranges from 0 to 1 and is a measure of the closeness of fit of the data to a 1-to-1 correlation. A correlation of 1 is a perfect correlation. The correlation coefficient of 0.96 indicates a very strong correlation between simulated and observed groundwater elevations. This correlation is based on 2,439 groundwater elevation measurements over the 33-year base period from 92 basin wells (Plate 29).

Plate 28 also includes a list of other statistical measures of calibration. The residual mean is computed by dividing the sum of the residuals by the number of residual data values. The closer this value is to zero, the better the calibration. The residual mean for the model is -2.91 feet. The residual standard deviation evaluates the scatter of the data. A lower standard deviation indicates a closer fit between the simulated and observed data. The standard deviation for the calibrated model is 19.88 feet. The absolute residual mean is a measure of the overall error in the model. The absolute residual mean is computed by taking the square root of the square of the residuals and dividing that by the number of residuals. The absolute residual mean for the model is 14.28 feet. Another statistical measure of calibration is the ratio of the standard deviation of the mean error divided by the range of observed groundwater elevations. This ratio shows how the model error relates to the overall hydraulic gradient across the model. Typically, a calibration is considered good when this ratio is below 0.15 (ESI 2001). The ratio for the Cummings Basin Model is 0.024, which is about one order-of-magnitude better. This is another indicator that the model is well calibrated.

The calibration statistics increased slightly from the original model. This is considered to represent the effects of higher pumping in the Basin in the period from 2002 to 2013. Pumping introduces short-term variability in groundwater levels that are not well represented by the 6-month stress periods used in the model. However, the overall model calibration is still considered to be very good.

4.4.2.3 Hydrograph Calibration

Hydrographs provide a detailed time history of groundwater elevations for specific wells. This time history data includes the impact of varying climatic and pumping stresses on the groundwater basin. Comparing hydrographs of model results versus observed data provides a measure of how well the model handles these changing conditions through time. Of the 92 wells with groundwater elevation data, approximately 40 had sufficient long-term data for the hydrograph evaluation (Appendix M). Included on Plates 30, 31, and 32 are eighteen representative hydrographs from different parts of the basin. For calibration purposes, the hydrographs were inspected to evaluate how well the model results matched the overall magnitude and trend of the observed groundwater elevation data over time.

The typical trend observed in the hydrograph data for the main part of the basin is a significant increase in water levels after 1983, followed by a general decline that lasted until about 1992. Water levels then began to slowly rise until about 2001 in response to increasing rainfall and changing pumping activities. There was an overall decline from 2001 until about 2009, followed by some recovery and/or stabilization of groundwater levels through the end of the study period. Other types of trends are observed along the basin margins that are more strongly influenced by variations in recharge components and less by pumping.

A particular trend observed among a few hydrographs was an abrupt decline in observed groundwater levels between 2006 and 2009 below the modeled groundwater levels (by 20 to 100 feet), and then subsequent recovery of observed groundwater levels to match modeled groundwater levels from 2010 to 2013. This pattern was noted for wells 32S/31E-25R1, 32S/31E-26D1, 32S/31E-35H2, and 32S/31E-36F1/F2. These wells are not grouped together, and appear to represent relatively isolated deviations at specific well locations.

In addition, two wells in the vicinity of Bear Valley CSD Wells 1 through 4 had consistently lower observed water levels (compared to modeled water levels) for most of the 2002 to 2013 time period (32S/32E-19E1 and 32S/32E-19F2). However, other wells near the Bear Valley CSD wells show a much closer match of observed to modeled water levels (e.g., 32S/31E-24J1, 32S/32E-19E3, 32S/32E-19-L1, 32S/32E-20M1). These results do not indicate a regional deviation of observed vs. modeled groundwater levels, but rather a more isolated deviation of individual wells within a small area.

Overall, the results of the model calibration to the various criteria indicate that the model is well calibrated within generally accepted standards. The deviation of observed and modeled groundwater levels noted above may be due to a combination of model use of six-month stress periods (water level at the end of six month period) vs. individual daily water level measurements, use of model grid squares (average water level over area of up to 110 feet by 110 feet) vs. measured water levels at specific wells, and the possibility that some measured data may include the influence of actively pumping wells.

4.4.3 Water Balance

A water balance or hydrologic budget is a quantitative statement of the balance of the total water gains and losses from the basin for a given time period. Recharge (inflow) to Cummings Basin is derived from precipitation, stream flow, return flows (from irrigation, CCI and domestic uses), bedrock inflow, and artificial recharge. Discharge (outflow) from Cummings Basin is derived from well pumping, bedrock outflow, and evapotranspiration. The major components of the water balance evaluated for the Cummings Groundwater Basin can be expressed by the following relationship:

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

where: P = Precipitation Percolation
Sin = Stream Flow Percolation
RF = Return Flow Percolation
Bin = Bedrock Inflow
AR = Artificial Recharge Percolation
W = Well Pumping
Bout = Bedrock Outflow
ET = Evapotranspiration
ΔS = Change in Groundwater Storage

The basin inventory water balance estimated the annual recharge and discharge over the base period at 3,454 and 3,298 AFY, respectively (Table 9). This resulted in a difference between recharge and discharge of 5,148 acre-feet or an average of 156 AFY. The change in storage (specific yield method) calculation produced an increase of storage of about 3,000 acre-feet (Table 2). The numerical model was then used to modify the original pumping estimates from the 1981 to 2002 time period, refine the basin water balance, and to further evaluate groundwater storage change.

4.4.3.1 Model-Based Water Balance

A groundwater model provides a useful quantitative tool to further evaluate the water balance. The model incorporates data on basin geometry, aquifer properties, recharge, and discharge. The mathematical solution includes solving the mass balance equation and these results are included as part of the model output. Once the model is calibrated, these data can be evaluated with respect to the water balance for the basin.

The year-by-year water balance results of the calibrated model for recharge are presented in Table 10. The model results produce a total recharge of 134,530 acre-feet over the 33-year base period for an average annual recharge rate of 4,077 AFY. The results show that 32 percent of the recharge was derived from percolation of stream flow from Cummings Creek and runoff from the smaller watersheds surrounding the basin. Of the remaining recharge, rainfall recharge accounted for 23 percent, return flows for 21 percent, bedrock inflow for 13 percent, and artificial recharge for 12 percent. The biggest change from the period of 1981-2001 to 2002-2013 is the increased volume of artificial recharge in the Basin that increased from an average of 62 to 1,193 AFY and now represents a significant portion of the total recharge in the Basin.

The year-by-year water balance results of the calibrated model for discharge are presented in Table 11. The model results produce a total discharge of 133,436 acre-feet over the 33-year base period for an average annual discharge rate of 4,044 AFY. Groundwater pumping accounts for the majority (92 percent) of the total groundwater discharge.

The model included components of natural discharge of groundwater from the basin. Subsurface outflow was increased to 9,092 acre-feet from the basin inventory estimate of 1,452 acre-feet. The average annual subsurface outflow of 276 AFY from the model was generally stable over the base period, and accounted for about 7 percent of the total basin discharge. The MODFLOW model also added discharge from evapotranspiration into the water balance. Evapotranspiration accounted for about 1 percent totaling 1,892 acre-feet over the base period for an annual average of 57 AFY. This was primarily limited to the southwestern portions of the basin and along the basin margin in areas of shallow groundwater. Stream discharge was a minor component in the original model that was limited to Chanac Creek. For the updated model, Chanac Creek was converted to the SFR package which allowed excess streamflow (e.g., from artificial recharge that discharged to adjacent stream channels) to continue downstream where it could percolate into the basin. This is considered a more appropriate simulation of the conditions for Chanac Creek. The result is that discharge of groundwater to surface water was no longer shown to occur in the Basin. This change also reduced the volume of groundwater lost to evapotranspiration in the Basin as well in the updated model.

Change in groundwater storage represents the volume of groundwater stored in the basin and is reflected by changes in water levels over time. Over the 33-year base period, rising groundwater levels indicate a net increase in storage. Based on the model results, the groundwater storage increased by 1,095 acre-feet over the model period (Table 12). However, year-to-year changes in groundwater storage were quite variable ranging from an increase of 8,004 acre-feet in 1983 to a decline of 2,811 acre-feet in 2002.

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

4.5 ESTIMATE OF PERENNIAL YIELD

The perennial yield of a groundwater basin defines the rate at which water can be withdrawn perennially under specified operating conditions without producing an undesired result (Todd, 1980). For this estimate of perennial yield, the undesired result is defined as a long-term decline in water levels. The 33-year base period is considered an appropriate scale for this evaluation.

The overall water balance based on the calibrated MODFLOW model is 4,077 AFY (Table 12). The most basic form of perennial yield is to add groundwater pumping plus the change in storage. Total groundwater pumping in the calibrated model was 3,710 AFY. During the 1981 to 2013 time period, groundwater storage increased by 33 AFY. Together, these two components result in a perennial yield of 3,743 AFY (rounded to 3,750 AFY).

This estimate of perennial yield is within the range of previous estimates, including estimates of 4,156 AFY by Tehachapi Soil Conservation District (TSCD 1969), 3,560 AFY by Mann (1971), 3,644 by Fugro and ETIC (2004), and the basin adjudication safe yield of 4,090 AFY.

It is important to note that implementation of the artificial recharge program has contributed towards a significant component (nearly 500 AFY) of the current perennial yield estimate presented in this study.

Recharge of imported water to the basin is a managed portion of the perennial yield. For the base period, irrigation return flows from imported water amounted to an average annual recharge of 273 AFY. In addition, artificial recharge was applied at the Chanac and Cummings Recharge Areas from 1995 through 2013. Averaged over the 33-year base period, the direct artificial recharge program accounted for an additional 473 AFY. Therefore, imported water accounted for an average annual recharge total over the 33-year base period of 753 AFY (this amount is embedded in the artificial recharge and return flow water balance components and was back-calculated here for purposes of illustration).

4.6 ADDITIONAL DISCUSSION OF PERENNIAL YIELD (OPERATIONAL YIELD)

The perennial yield of a groundwater basin is specific to a period of time (base period), and accounts for all sources of recharge to the basin (e.g., natural recharge, artificial recharge, return flows). The perennial yield of a groundwater basin can change over time as cultural conditions change (e.g., the amount of agricultural irrigation affects return flows). By the standard definition of perennial yield used herein and incorporated into the model update (described above in Section 4.5), the perennial yield of the Cummings Groundwater Basin, under current conditions and over the time period of 1981 to 2013, is 3,750 AFY.

The operational yield of a groundwater basin (or “native yield”) might be considered to be the amount of groundwater discharge that can occur (pumping and natural outflow) on an average annual basis while maintaining no net change in groundwater storage and not requiring any supplemental (artificial) recharge. The operational yield of the Cummings Basin accounts for natural recharge (precipitation recharge, streamflow infiltration, and bedrock inflow) and return flows (from agricultural irrigation from groundwater pumping and domestic water use). Thus, the operational yield (native yield) of the Cummings Basin is approximately 2,990 AFY (equivalent to the perennial yield of 3,750 AFY less 753 AFY of imported water recharge). Therefore, pumping in excess of 2,990 AFY must be compensated by the same amount of artificial recharge (after accounting for evaporative losses) to keep the basin in balance.

5.0 SUMMARY AND CONCLUSIONS

This report documents an update of the hydrogeologic conceptual model, water balance, and numerical groundwater model for the Cummings Groundwater Basin. The update period extends from 2002 to 2013, thus the complete revised base period is 1981 to 2013.

Well logs obtained from DWR were reviewed to plot locations of new well logs not available for the previous study (Fugro and ETIC, 2003). The new well logs were used to update the depth to unweathered bedrock map, and to update the tabulation of aquifer parameter data. Two hydrogeologic cross-sections developed in the previous study were updated with new well log data.

A variety of hydrogeologic and water balance data were obtained from TCCWD and others for the 2002 to 2013 update period. These data include precipitation, land use, groundwater levels, metered agricultural and municipal/industrial groundwater pumping, well locations, artificial recharge, well logs, aquifer test and pump efficiency test data, and estimates of domestic groundwater pumping. The new data were used to update the conceptual model, develop the basin water balance inventory for the update period, calculate groundwater storage changes, update and recalibrate the numerical groundwater model, and to reevaluate basin perennial yield.

5.1 GROUNDWATER STORAGE CHANGES

A key indicator of the status or health of a basin is through inspection of water level changes, which is a direct indication of changes in groundwater in storage. Based on a compilation of groundwater elevation data from wells throughout the basin over the base period of 1981 to 2013, the basin experienced a net increase in groundwater storage of approximately 3,000 AF. However, it is important to note the differences in groundwater storage changes from the original base period of 1981 to 2001 vs. the update period from 2002 to 2013. The 1981 to 2001 period had a net gain in groundwater storage of about 12,200 AF or an average gain of 580 AFY, whereas the 2002 to 2013 period shows a net decline in storage of 9,100 AF or an average loss of 760 AFY (based on changes in groundwater elevations and a specific yield of eight percent). Note that this method of estimating overdraft is one means of doing so (similar to use of the basin inventory method), and compares well with the results of the modeling methodology. The purpose of calculating basin yield by the change in groundwater storage method and the basin inventory method is to provide independent and alternative methodologies; the results of the modeling calculations are considered to be more representative of actual conditions.

The results of calculating changes in groundwater storage show that the basin has been in overdraft since 2002, and groundwater pumping must be reduced soon to avoid a long-term overdraft condition.

5.2 UPDATED GROUNDWATER MODEL

The basin water balance inventory data and updates to the basin geometry were input to the numerical groundwater model. The updated groundwater model was recalibrated based on new data input to the model and groundwater level data from 2002 to 2013. Some adjustments to the zonation and values of horizontal hydraulic conductivity and storage coefficient were made to improve model calibration. In addition, some additions to the precipitation and streamflow recharge components were made for the 2002 to 2013 time period during model recalibration.

The groundwater model was successfully updated and recalibrated for the entire 1981 to 2013 time period. The model calibration statistics are well within industry standards, with a relatively good match between simulated and measured groundwater elevations for most wells and years simulated in the model. It is now considered ready for future applications, such as simulation of various basin water management scenarios.

5.3 PERENNIAL YIELD ESTIMATE

Utilization of the calibrated numerical model results in an estimated perennial yield of the Cummings Basin of 3,743 AFY (rounded to 3,750 AFY). This perennial yield estimate is based on the modeled groundwater pumping average of 3,710 AFY plus the calibrated model water balance net storage gain of 33 AFY over the entire 1981 to 2013 period.

Model results showed that natural recharge comprises 73 percent and basin return flows plus artificial recharge comprise the remaining 27 percent of perennial yield. Thus, it is clear that return flows and artificial recharge have become very important components of overall basin recharge and a significant contribution to basin management efforts. The contribution of artificial recharge has been an even greater percentage of the overall water balance since 2002.

The operational yield of a groundwater basin (or “native yield”) is the amount of groundwater discharge that can occur (pumping and natural outflow) on an average annual basis while maintaining no net change in groundwater storage and not requiring any supplemental (artificial) recharge. For the Cummings Basin, an estimated operational yield is approximately 2,990 AFY. Therefore, pumping in excess of 2,990 AFY must be compensated by the same amount of artificial recharge (after accounting for evaporative losses) to keep the basin in balance.

5.4 CURRENT BASIN CONDITIONS

Groundwater hydrographs and groundwater level contour maps show relatively stable to rising trends in groundwater elevations over the portion of the base period from 1981 to 2001. However, the update period from 2002 to 2013 showed predominantly declining groundwater levels in wells, indicating that the previous 20-year period of stability (1981 to 2001) has been significantly nullified since 2001 by excessive groundwater pumping. With an average annual pumping rate of 5,084 AFY over the 2002 to 2013 period and an estimated perennial yield of 3,750 AFY, present groundwater production significantly exceeds the estimated perennial yield. If current production patterns continue, it is apparent that the excessive groundwater pumping at 2002 to 2013 rates will soon result in long-term basin overdraft.

5.5 RECOMMENDATIONS

- Groundwater pumping since 2002 has significantly exceeded basin recharge, resulting in declining groundwater levels and a loss of groundwater storage. If current rates of groundwater pumping continue, the basin will soon experience long-term basin overdraft. Measures should be implemented to reverse the current trends.

- One of the means of assisting in the design of mitigation measures to reduce groundwater pumping is through the use of the updated model. The recalibrated model is designed to provide TCCWD with a tool to assist with long-term planning of groundwater management issues for the basin. The calibration demonstrated that the numerical model could reasonably reproduce historical conditions in the Cummings Groundwater Basin over the 33-year base period. Thus, the recalibrated numerical model is now ready for use in evaluating basin water management scenarios.

- It will be important to continue taking steps to improve the hydrogeologic understanding of the basin in order to allow optimal future management of Cummings Groundwater Basin. The recommendations from this study include the following:
    - Continue to compile and maintain a long-term database of monthly groundwater pumping data from metered agricultural, municipal, industrial, and other wells in the basin.
    - Perform a comprehensive watershed analysis to quantitatively evaluate the variable runoff and streamflow infiltration in wet and dry years, including the potential impact of single, high-intensity storms. Such an analysis would require installation of permanent stream gauges at key locations for major streams entering and exiting Cummings Groundwater Basin, and installation of rain gauges at selected locations in the surrounding hills and mountains.
    - Perform periodic synoptic stream surveys (i.e., simultaneous measurement of streamflow at several locations along a stream channel) to identify locations and amounts of streamflow infiltration during or shortly after major rainfall events and during the late winter/early spring of years with major snow melt events.

- Continue to evaluate the capacity of designated artificial recharge areas to accept long-term intensive groundwater recharge.

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TABLES

Table 1. Cummings Basin Soil Characteristics

Soil Series	Physiographic Group	Hydrologic Group	Texture	SCS Permeability (inches/hour)	Infiltrometer K (inches/hour)
Visalia	Alluvial Fans Floodplains	C	Sandy Loam, Granite stones	2.5-5.0	1.48
Oakdale	Alluvial Fans Floodplains	C	Sandy Loam	0.8-5.0	0.77
Chino	Basin areas	C	Silt Loam, Clay Loam	0.2-0.8	0.21
Visalia Varient	Basin areas	-	-	-	-
Tehachapi	Low terraces	D	Loam, Sandy clay, clay pan	0.8-2.5	1.7
Chualar	Low terraces	-	-	-	-
Auberry	Uplands	B	Loam, Clay Loam	0.8-5.0	6.35
La Posta	Uplands	A	Gravelly loamy sand	5.0-10.0	7.95

Table 2. Cummings Basin Groundwater Storage Change Calculations

Time Period	Average GW Level Change (feet)	Total GW Storage Change (AF) – based on GW level data	Average GW Storage Change (AFY) – based on GW level data	Total GW Storage Change (AF) – based on GW Elevation Contour Maps	Average GW Storage Change (AF) – based on GW Elevation Contour Maps
Fall 1980 to Fall 2001	15.2	10,317	491	12,160	579
Spring 1981 to Spring 2001	13.9	9,434	472		
Fall 2001 to Fall 2013	-12.7	-8,620	-718	-9,120	-760
Spring 2001 to Spring 2013	-6.4	-4,344	-362		
Fall 1980 to Fall 2013	2.6	1,765	53	2,984	90
Spring 1981 to Spring 2013	7.5	5,090	159		

Positive value represents increased groundwater in storage
Negative value represents water level declines and declines in groundwater in storage
GW = groundwater
AF = acre feet
AFY = acre feet per year

Table 3. Summary of Aquifer Transmissivity Data

T/R-S	Date	Pump Rate (Q) (in gpm)	Drawdown (in feet)	Specific Capacity (Q/s) (in gpm/feet)	Transmissivity (Q/s x 1,500) in gpd/feet	Transmissivity (Aquifer Test) (in gpd/feet)	Representative Transmissivity (in gpd/ft)	Screen Length (in feet)	Hydraulic Conductivity (in feet/day)	Comments
32S/31E-21xx (1080971)	9/22/2006	10	100	0.1	150		150	100	0.20	From WWDR (airlift/bedrock)
32S/31E-23xx (E0087529)	11/7/2008	9	150	0.18	270		270	220	0.16	From WWDR (bedrock)
32S/31E-24F (438891)	4/6/1999	40	180	0.22	330		330	320	0.14	From WWDR (airlift/bedrock)
32S/31E-24R1	8/22/1946 9/20/1956 9/28/1961	537 283 148	15 31 193.2	35.8 9.1 0.8	53,700 13,694 1,149		22,850	?		
32S/31E-24R3 (715624)	7/8/2013	618	48	12.9	19,350		19,350	220	12	Efficiency Test
32S/31E-25xx (E073787)	3/7/2008 6/21/12 7/27/13	1,200 1,172 1,017	89 62 82	13.5 18.9 12.4	20,250 28,350 18,600		22,400	300	10	From WWDR Efficiency Test Efficiency Test
32S/31E-25xx (1084878)	2/4/2005	400	162	2.5	3,750	3,000	3,000	220	1.8	From WWDR
32S/31E-25A1	8/1/1961 3/21/1962	600 750	31 14	19.4 53.6	29,032 80,357		54,700	252	29	
32S/31E-25L1	9/10/1946 9/20/1956 9/28/1961	876 596 645	39 56 82.7	22.5 10.6 7.8	33,692 15,964 11,699		20,450	?		
32S/31E-25P1	9/20/1956 9/28/1961	508 259	84.3 171.8	6.0 1.5	9,039 2,261		5,650	?		
32S/31E-26G (529188)	7/15/99	100	70	1.4	2,100		2,100	100	2.8	From WWDR (airlift)
32S/31E-26	5/11/2001 8/29/2008	139 103	48 81	2.9 1.3	4,350 1,950		3,150			Giraudo Rd./Sasia Rd.
32S/31E-26	5/11/2001	260	86	3.0	4,500		4,500			Pegasus Rd./Giraudo Rd.
32S/31E-26	5/11/2001 8/29/2008	217 201	46 52	4.7 3.9	7,050 5,850		6,450			Pegasus Rd. S/O Giraudo Rd.

Table 3. Summary of Aquifer Transmissivity Data

T/R-S	Date	Pump Rate (Q) (in gpm)	Drawdown (in feet)	Specific Capacity (Q/s) (in gpm/feet)	Transmissivity (Q/s x 1,500) in gpd/feet	Transmissivity (Aquifer Test) (in gpd/feet)	Representative Transmissivity (in gpd/ft)	Screen Length (in feet)	Hydraulic Conductivity (in feet/day)	Comments
32S/31E-35xx (E0098029)	1/22/2009	1,200	129	9.3	13,950	10,800	10,800	320	4.5	Constant Rate
	11/24/2009	1,015	23	44.1	66,150					Efficiency Test
	7/23/2012	924	60	15.4	23,100					Efficiency Test
	7/29/2013	1,279	104	12.3	18,450					Efficiency Test
32S/31E-35xx (E052352)	3/17/2007	759	319	2.4	3,600		7,400	265	3.7	Efficiency Test
	6/13/2007	570	141	4.0	6,000					Efficiency Test
	8/1/2007	585	104	5.6	7,950					Efficiency Test
	8/5/2008	518	93	5.6	7,950					Efficiency Test
	8/17/2009	544	93	5.8	8,700					Efficiency Test
	7/30/2010	414	87	4.8	7,200					Efficiency Test
	10/10/2011	454	83	5.5	8,250					Efficiency Test
	6/11/2012	534	90	5.9	8,850					Efficiency Test
	7/29/2013	481	90	5.3	7,950					Efficiency Test
32S/31E-35xx (E052356)	5/29/2007	1,250	205	6.1	9,150		17,500	254	9.2	Efficiency Test
	8/1/2007	570	117	4.9	7,350					Efficiency Test
	8/5/2008	684	55	12.4	18,600					Efficiency Test
	8/17/2008	658	53	12.4	18,600					Efficiency Test
	7/60/2010	673	50	13.5	20,250					Efficiency Test
	10/10/2011	603	43	14.0	21,000					Efficiency Test
	6/21/2012	609	25	24.4	36,600					Efficiency Test
	7/29/2013	401	69	5.8	8,700					Efficiency Test
32S/31E-35H1	6/16/1955	323	58	5.6	8,353		9,000			
	6/28/1962	230	36	6.4	9,583			?		
32S/31E-35H2	8/22/1946	365	49	7.4	11,173		15,550	357	5.8	
	6/16/1955	593	44.6	13.3	19,944					

Table 3. Summary of Aquifer Transmissivity Data

T/R-S	Date	Pump Rate (Q) (in gpm)	Drawdown (in feet)	Specific Capacity (Q/s) (in gpm/feet)	Transmissivity (Q/s x 1,500) in gpd/feet	Transmissivity (Aquifer Test) (in gpd/feet)	Representative Transmissivity (in gpd/ft)	Screen Length (in feet)	Hydraulic Conductivity (in feet/day)	Comments
32S/31E-35Hx (542912)	8/1/2001	990	30	33	49,500		32,500	330	13	Efficiency Test
	9/30/2002	990	72	13.8	20,700					Efficiency Test
	9/2/2003	932	67	13.9	20,850					Efficiency Test
	1/6/2006	1,196	27	44	66,000					Efficiency Test
	7/31/2006	660	10	66	99,000					Efficiency Test
	5/3/2007	1,218	20	61	91,500					Efficiency Test
	6/13/2007	701	99	7.1	10,650					Efficiency Test
	8/5/2008	825	122	6.8	10,200					Efficiency Test
	8/17/2009	792	119	6.7	10,050					Efficiency Test
	7/30/2010	743	110	6.8	10,200					Efficiency Test
	10/10/2011	693	103	6.7	10,050					Efficiency Test
	6/21/2012	751	96	7.8	11,700					Efficiency Test
	7/29/2013	866	105	8.2	12,300					Efficiency Test
32S/31E-36xx (E02496 or E49407)	12/28/04	412	53	7.7	11,550	8,200	8,200	290	3.8	Step Test Data
	12/29/04	907	156	5.8	8,700					Constant Rate
	2/11/2008	629	116	5.4	8,100					Efficiency Test
	11/23/2009	598	160	3.7	5,550					Efficiency Test
	3/1/2011	352	86	4.1	6,150					Efficiency Test
32S/31E-36A1	9/28/1961	566	78.6	7.2	10,802		10,800	?		
32S/31E-36C1	8/21/1963	107	197.1	0.5	814		800	?		
32S/31E-36L1	7/29/1953	436	86.7	5.0	7,543		11,650	252	6.2	
	7/15/1959	353	31.6	11.2	16,756					
	10/10/1961	472	66.3	7.1	10,679					
32S/31E-36M1	10/10/1961	246	37.2	6.6	9,919		9,900	?		
32S/32E-18H	1971	210	132	1.6	2,386		2,400	?		From WWDR
32S/32E-19	6/29/1996	60	180	0.3	500		500	?		From WWDR
32S/32E-19E1	8/28/1946	294	8	36.8	55,125		8,800	?		
	8/8/1957	116	106.1	1.1	1,640					
	6/25/1959	68	97.6	0.7	1,045					
	8/4/1960	44	77.6	0.6	851					
	8/23/1961	139	106.4	1.3	1,960					
	9/16/1964	158	97.2	1.6	2,438					
	4/21/1966	186	79	2.4	3,532					
	5/11/1972	200	78	2.6	3,846					

Table 3. Summary of Aquifer Transmissivity Data

T/R-S	Date	Pump Rate (Q) (in gpm)	Drawdown (in feet)	Specific Capacity (Q/s) (in gpm/feet)	Transmissivity (Q/s x 1,500) in gpd/feet	Transmissivity (Aquifer Test) (in gpd/feet)	Representative Transmissivity (in gpd/ft)	Screen Length (in feet)	Hydraulic Conductivity (in feet/day)	Comments
32S/32E-19E2	8/28/1946	594	12.5	47.5	71,280		11,800			
	8/8/1957	196	80.5	2.4	3,652			?		
	6/25/1959	139	63.6	2.2	3,278					
	9/27/1961	68	95.5	0.7	1,068					
	9/16/1964	56	84	0.7	1,000					
	4/21/1966	45.7	59	0.8	1,162					
	5/11/1972	73.1	91	0.8	1,205					
32S/32E-19E3	8/7/1957	186	99	1.9	2,818					
	6/25/1959	149	49	3.0	4,561		2,700			
	8/4/1960	84	39.8	2.1	3,166			?		
	9/16/1964	55	75	0.7	1,100					
	4/21/1966	37.5	20.2	1.9	2,785					
	5/12/1972	65.3	51.2	1.3	1,913					
32S/32E-19E4	3/18/2001	350	133	2.6	3,947	3,100	3,100	?		
32S/32E-19F1	9/28/1946	560	18	31.1	46,667					
	6/24/1959	302	23.4	12.9	19,359		17,300	354	6.5	
	4/20/1966	408	66.6	6.1	9,189					
	7/20/1995	450	74	6.1	9,122	17,300				
32S/32E-19F2	5/11/1972	475	80.8	5.9	8,818		8,800	?		
32S/32E-19F3	4/6/1996	600	75	8.0	12,000	13,500	13,500	190	9.5	Efficiency Test
	7/9/2013	144	15	9.4	14,100					
32S/32E-19F	3/26/1996	500	86	5.8	8,721	12,000	12,000	190	8.4	Efficiency Test
	7/9/2013	92	18	5.3	7,950					
32S/32E-19E4 (715621)	3/17/2001	350	133	2.6	3,450		3,450	110	4.2	From WWDR
32S/32E-19G3	4/24/2001	475	73	6.5	9,760	12,000	12,000	140	11	Efficiency Test
	7/8/2013	284	35	8.2	12,300					
32S/32E-19P	7/8/2013	421	43	9.7	14,550		14,550	?		Efficiency Test
32S/32E-19Q3	10/31/1962	352	188.2	1.9	2,806		3,800	?		
	5/23/1963	475	148.7	3.2	4,792					
32S/32E-19J1	9/10/1946	451	149.1	3.0	4,537		3,900	?		
	4/25/1956	321	149.2	2.2	3,227					
32S/32E-19L1	9/28/1961	585	101.8	5.7	8,620		7,250	?		
	10/31/1962	580	147.7	3.9	5,890					
32S/32E-19Q1	9/28/1961	179	57.8	3.1	4,645		4,650	?		

Table 3. Summary of Aquifer Transmissivity Data

T/R-S	Date	Pump Rate (Q) (in gpm)	Drawdown (in feet)	Specific Capacity (Q/s) (in gpm/feet)	Transmissivity (Q/s x 1,500) in gpd/feet	Transmissivity (Aquifer Test) (in gpd/feet)	Representative Transmissivity (in gpd/ft)	Screen Length (in feet)	Hydraulic Conductivity (in feet/day)	Comments
32S/32E-19Q2	4/25/1956	503	147.1	3.4	5,129		4,250	294	1.9	
	9/27/1961	122	35.4	3.4	5,169					
	10/31/1962	292	179.6	1.6	2,439					
32S/32E-20xx (E046485)	6/12/2007	50	100	0.5	750		750	180	0.6	From WWDR (airlift – alluvium/granite)
32S/32E-20xx (739396)	4/2/2004	30	40	0.75	1,125		1,125	120	1.3	From WWDR
32S/32E-20xx (739400)	10/15/2004	20	100	0.2	300		300	140	0.3	From WWDR (airlift)
32S/32E-30xx (748854)	5/22/2001	1,500	100	15.0	22,500		25,950	260	13	From WWDR
	7/10/01	1,250	60	20.8	31,200					Efficiency Test
	6/29/04	932	44	21.2	21,800					Efficiency Test
	9/14/10	896	54	16.6	24,900					Efficiency Test
	10/19/11	972	50	19.4	29,100					Efficiency Test
	6/21/12	1,228	54	22.7	34,050					Efficiency Test
	7/27/13	1,202	99	12.1	18,150					Efficiency Test
32S/32E-30xx (788744)	10/11/2002	300	106	2.8	4,200		4,200	200	2.8	From WWDR
32S/32E-30xx (788743)	10/28/2002	1,200	90	13.3	19,950		19,950	230	12	From WWDR
32S/32E-30C1	10/2/1967	829	71.4	11.6	17,416	15,200	15,200	?		
	12/18/1968	819	60.1	13.6	20,441					
	10/29/1969	658	49	13.4	20,143					
	2/11/1999	845	106	8.0	11,958					
32S/32E-30D1	2/8/1956	797	37	21.5	32,311		30,800	?		
	5/9/1957	1006	53.9	18.7	27,996					
	7/25/1957	390	31	12.6	18,871					
	6/10/1959	892	47.8	18.7	27,992					
	8/24/1961	565	24.4	23.2	34,734					
	10/14/1964	627	26.6	23.6	35,357					
	10/2/1967	596	25.6	23.3	34,922					
	12/18/1968	316	13.6	23.2	34,853					
	10/29/1969	853	42.4	20.1	30,177					
32S/32E-30K2	10/3/1967	45.2	51.8	0.9	1,309		1,300	?		
	10/29/1969	44.3	54.2	0.8	1,226					

Table 3. Summary of Aquifer Transmissivity Data

T/R-S	Date	Pump Rate (Q) (in gpm)	Drawdown (in feet)	Specific Capacity (Q/s) (in gpm/feet)	Transmissivity (Q/s x 1,500) in gpd/feet	Transmissivity (Aquifer Test) (in gpd/feet)	Representative Transmissivity (in gpd/ft)	Screen Length (in feet)	Hydraulic Conductivity (in feet/day)	Comments
32S/32E-30K3	2/8/1956 6/10/1959 8/24/1961 10/14/1964 10/2/1967 12/18/1968 10/29/1969	456 327 361 326 334 336 348	55.4 105.7 83.8 108.6 86.4 85.7 100.6	8.2 3.1 4.3 3.0 3.9 3.9 3.5	12,347 4,640 6,462 4,503 5,799 5,881 5,189		6,400	?		
32S/32E-30M1	7/15/1959 10/20/1960 10/25/1961 11/28/1962	384 627 631 438	51.2 104.6 49.7 34.1	7.5 6.0 12.7 12.8	11,250 8,991 19,044 19,267		14,600	341	5.7	
32S/32E-30P1	6/25/1959 10/25/1961 11/28/1962	534 609 660	71 77.6 85.4	7.5 7.8 7.7	11,282 11,772 11,593		11,550	?		
32S/32E-31xx (E024649)	12/8/2005 12/13/2005 1/21/2008 6/3/2010	200 325 180 276	68 166 63 135	2.9 2.0 2.8 2.0	1,350 3,000 4,200 3,000	3,200	3,200	180	2.4	Step Test Data Constant Rate Efficiency Test Efficiency Test
32S/32E-31xx (510301)	12/29/1995	115	259	0.4	666		670	?		From WWDR
32S/32E-31D1	8/15/1969	740	28.5	26.0	38,947		38,950	?		
32S/32E-32P (775914)	11/12/2001	15	220	0.07	105		105	170	0.08	From WWDR (airlift/bedrock)
12N/16W-31xx	11/15/96	80	262	0.31	465		465			Efficiency Test
12N/16W-31xx	1/31/2008 6/3/2010	84 74	261 227	0.32 0.33	480 495		490			Efficiency Test
12N/16W-31xx	11/15/1996 1/21/2008 6/3/2010	253 245 184	45 36 28	5.2 6.0 5.3	7,800 9,000 7,950		8,250			Efficiency Test Efficiency Test Efficiency Test
32S/31E-24 Geometric Mean							21,030		12	Applies only to SE corner: 24R

Table 3. Summary of Aquifer Transmissivity Data

T/R-S	Date	Pump Rate (Q) (in gpm)	Drawdown (in feet)	Specific Capacity (Q/s) (in gpm/feet)	Transmissivity (Q/s x 1,500) in gpd/feet	Transmissivity (Aquifer Test) (in gpd/feet)	Representative Transmissivity (in gpd/ft)	Screen Length (in feet)	Hydraulic Conductivity (in feet/day)	Comments
32S/31E-25 Geometric Mean							13,350		8.1	
32S/31E-26 Geometric Mean							3,725		2.8	
32S/31E-35 Geometric Mean							13,600		6.5	
32S/31E-36 Geometric Mean							6,060		4.9	
32S/32E-18 Geometric Mean							2,400		?	
32S/32E-19 Geometric Mean							5,925		6.0	
32S/32E-20 Geometric Mean							580		0.6	
32S/32E-30 Geometric Mean							10,400		7.1	
32S/32E-31 Geometric Mean							4,370		2.4	
12N/16W-31 Geometric Mean							1,230		?	

Table 4. Monthly Precipitation at the Tehachapi Station (inches)

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
1921	0.40	0.25	0.65	2.50	1.16	0.54	0.69	1.40	0.07	0.00	0.00	0.15	7.81
1922	0.21	0.28	2.16	2.43	1.08	3.73	1.19	0.00	0.00	0.00	0.00	0.00	11.08
1923	0.51	0.71	3.04	0.54	0.58	0.00	2.37	0.00	0.00	0.00	0.00	2.61	10.36
1924	0.66	0.14	0.15	0.00	0.64	2.38	1.15	0.01	0.00	0.00	0.00	0.00	5.13
1925	0.92	0.92	2.60	0.50	1.59	2.45	1.30	0.90	0.00	0.00	0.00	0.00	11.18
1926	0.72	0.18	0.92	0.75	1.20	0.90	3.09	0.10	0.00	0.00	0.00	0.00	7.86
1927	0.00	3.25	1.01	0.72	2.92	1.28	0.48	0.28	0.00	0.17	0.00	0.00	10.11
1928	2.12	0.63	2.48	0.23	1.29	1.57	0.30	0.38	0.00	0.00	0.00	0.00	9.00
1929	0.00	1.89	1.32	0.95	0.60	2.04	1.53	0.05	0.55	0.00	0.10	0.05	9.08
1930	0.00	0.00	0.00	3.29	1.68	2.36	0.32	2.16	0.00	0.00	0.00	0.02	9.83
1931	0.03	1.63	0.00	1.77	4.02	0.10	0.79	0.05	0.37	0.14	2.42	0.01	11.33
1932	0.29	1.41	4.33	1.50	2.94	1.27	0.89	1.52	0.18	0.00	0.00	4.51	18.84
1933	2.60	0.00	2.24	4.17	0.68	0.34	0.17	0.94	0.49	0.00	0.00	0.00	11.63
1934	0.26	0.00	1.58	0.69	1.09	0.00	0.00	0.46	0.60	0.00	0.00	0.00	4.68
1935	1.15	2.19	1.78	3.19	2.17	2.11	2.90	0.18	0.00	0.00	0.23	0.41	16.31
1936	0.51	0.46	0.84	0.59	4.14	1.73	0.96	0.00	0.00	0.00	0.00	0.00	9.23
1937	0.63	0.08	3.17	2.50	3.00	4.30	1.70	0.30	0.00	0.00	0.00	0.00	15.68
1938	0.16	0.20	3.55	1.45	2.88	3.83	2.12	0.34	0.66	0.00	0.00	0.88	16.07
1939	0.00	0.00	2.74	3.79	3.28	2.17	0.72	0.95	0.26	0.00	0.00	1.61	15.52
1940	1.00	0.50	0.70	2.10	3.00	1.70	3.00	0.20	0.00	0.21	0.00	0.00	12.41
1941	1.10	0.23	3.66	1.99	5.79	4.10	3.56	0.00	0.00	0.00	0.12	0.00	20.55
1942	1.01	0.71	5.06	0.39	0.27	0.75	1.25	0.08	0.00	0.00	0.23	0.00	9.75
1943	0.35	0.64	2.04	5.65	2.07	3.25	1.52	0.03	0.00	0.00	0.00	0.00	15.55
1944	0.15	0.27	2.73	2.58	6.79	1.50	1.26	0.44	0.00	0.00	0.00	0.00	15.72
1945	0.04	2.71	1.23	1.23	4.14	4.12	0.22	0.87	0.18	0.04	0.46	0.79	16.03
1946	3.23	0.56	2.45	1.07	0.42	1.22	0.14	0.51	0.00	0.26	0.00	0.27	10.13
1947	0.44	3.62	1.97	1.07	0.55	0.37	0.80	0.26	0.00	0.00	0.03	0.00	9.11
1948	0.33	0.13	1.12	0.02	1.00	2.12	0.87	0.27	0.63	0.00	0.00	0.00	6.49
1949	0.03	0.16	1.06	3.02	2.06	2.24	0.08	0.71	0.00	0.00	0.00	0.00	9.36
1950	0.16	0.58	1.72	1.95	1.07	1.10	0.30	0.20	0.00	0.00	0.00	0.32	7.40
1951	0.20	1.37	0.73	1.62	0.67	0.42	3.02	0.43	0.00	0.00	0.00	0.00	8.46
1952	0.27	0.28	5.26	3.47	0.77	5.31	1.54	0.00	0.00	0.14	0.00	0.00	17.04
1953	0.00	3.12	3.10	1.85	0.40	0.95	1.35	1.07	0.00	0.00	0.16	0.00	12.00
1954	0.01	0.38	0.78	2.43	0.87	2.14	0.20	0.15	0.00	0.11	0.00	0.00	7.07
1955	0.00	1.12	0.65	2.82	0.97	0.00	0.71	0.32	0.00	0.00	0.00	0.00	6.59
1956	0.00	0.60	3.42	3.23	0.45	0.04	3.14	0.41	0.00	0.04	0.00	0.00	11.33
1957	0.32	0.00	0.17	2.90	1.22	1.20	1.16	0.98	0.22	0.00	0.00	0.00	8.17
1958	1.05	0.43	1.60	1.69	5.44	3.52	2.09	0.14	0.00	0.35	0.04	0.36	16.71
1959	0.27	0.75	0.12	0.00	1.83	0.02	0.28	0.23	0.00	0.00	0.00	0.79	4.29
1960	0.00	0.00	0.83	1.50	4.48	1.37	0.47	0.07	0.00	0.01	0.00	0.00	8.73
1961	0.07	3.01	0.13	0.62	0.30	1.56	0.20	0.32	0.00	0.00	1.08	0.00	7.29
1962	0.03	0.48	0.82	1.43	6.09	1.16	0.08	0.30	0.00	0.00	0.00	0.06	10.45
1963	0.13	0.00	0.00	0.27	1.29	1.49	1.46	0.09	0.66	0.00	1.36	1.34	8.09
1964	0.37	1.10	0.00	0.80	0.42	1.84	1.00	0.38	0.00	0.22	0.01	0.00	6.14
1965	0.29	1.02	4.43	0.78	0.19	1.28	2.68	0.00	0.00	0.44	1.18	0.00	12.29
1966	0.00	1.91	2.18	0.79	0.99	0.45	0.00	0.18	0.00	0.00	0.60	0.32	7.42

Table 4. Monthly Precipitation at the Tehachapi Station (Continued)

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
1967	0.00	2.42	3.87	1.33	0.10	0.97	3.55	0.19	0.00	0.00	0.06	2.13	14.62
1968	0.00	2.73	1.89	0.59	0.63	1.36	0.40	0.00	0.00	0.00	0.00	0.00	7.60
1969	0.48	1.21	2.24	5.16	5.69	1.60	1.16	0.02	0.00	0.26	0.00	0.12	17.94
1970	0.06	0.75	0.50	2.37	3.24	0.25	0.71	0.00	0.00	0.00	0.00	0.00	7.88
1971	0.00	6.22	2.01	0.42	0.79	0.66	1.20	0.81	0.00	0.03	0.16	0.04	12.34
1972	0.00	0.35	3.45	0.09	0.12	0.00	0.22	0.00	0.77	0.00	0.25	0.04	5.29
1973	0.19	2.51	3.31	2.40	1.56	3.87	0.67	2.06	0.00	0.00	0.46	0.00	17.03
1974	0.09	1.80	1.89	2.55	0.11	1.67	2.01	0.56	0.00	0.04	0.35	0.00	11.07
1975	2.23	0.51	1.06	0.19	1.23	1.72	1.35	0.00	0.00	0.00	0.07	0.44	8.80
1976	0.86	0.18	0.21	0.07	1.87	0.80	0.58	0.14	0.00	0.04	0.00	1.80	6.55
1977	0.82	0.56	0.00	2.66	0.71	1.62	0.00	2.35	0.29	0.00	1.54	0.00	10.55
1978	0.02	0.00	2.75	2.29	6.09	5.21	1.51	0.04	0.00	0.00	0.00	0.90	18.81
1979	0.00	0.47	1.27	3.91	2.13	2.22	0.03	0.26	0.00	0.00	0.51	0.29	11.09
1980	0.49	0.34	0.38	3.46	3.17	1.71	0.78	0.46	0.00	0.43	0.00	0.07	11.29
1981	0.28	0.01	0.61	1.81	0.71	3.75	0.22	0.49	0.00	0.00	0.00	0.00	7.88
1982	2.19	1.29	1.12	2.49	0.59	3.93	1.89	0.00	0.20	0.00	0.42	0.36	14.48
1983	0.95	2.47	3.13	3.55	2.41	11.59	1.34	0.26	0.00	0.00	2.65	0.13	28.48
1984	0.79	2.98	2.07	0.00	0.64	0.09	0.55	0.01	0.09	1.10	1.02	0.01	9.35
1985	0.31	1.91	3.25	1.17	1.09	1.37	0.12	0.10	0.52	0.00	0.00	0.48	10.32
1986	0.33	2.98	0.30	1.87	2.24	2.53	0.31	0.08	0.00	0.02	0.00	0.06	10.72
1987	0.14	0.99	0.81	1.63	1.50	2.18	0.35	0.47	0.60	0.00	0.00	0.32	8.99
1988	0.47	4.24	1.26	1.39	1.02	0.59	1.20	0.90	0.13	0.00	0.03	0.02	11.25
1989	0.00	1.91	1.69	0.19	0.98	0.79	0.13	0.44	0.00	0.00	0.00	0.96	7.09
1990	0.51	0.30	0.00	1.63	0.79	1.22	0.24	1.39	0.04	0.00	0.00	0.25	6.37
1991	0.05	0.68	0.74	1.05	1.61	5.83	0.00	0.18	0.00	0.55	0.00	0.00	10.69
1992	0.63	0.57	1.55	1.54	4.53	3.17	0.66	0.06	0.00	0.10	0.00	0.00	12.81
1993	1.18	0.05	4.45	5.78	4.51	1.46	0.01	0.00	0.82	0.00	0.00	0.00	18.26
1994	0.38	1.19	1.67	0.41	1.85	0.55	1.51	0.61	0.00	0.00	0.00	0.05	8.22
1995	0.30	1.44	1.37	9.09	0.49	6.23	1.31	0.86	0.14	0.05	0.63	0.00	21.91
1996	0.00	0.05	1.06	2.78	3.79	1.20	0.36	0.00	0.00	0.00	0.00	0.00	9.24
1997	1.57	1.07	2.47	3.30	0.95	0.00	0.18	0.00	0.00	0.03	0.00	0.71	10.28
1998	0.24	1.98	2.98	3.29	9.37	3.15	1.60	1.31	0.00	0.00	0.76	1.44	26.12
1999	0.06	1.34	0.47	3.17	0.92	0.54	0.96	0.00	0.03	1.04	0.00	0.03	8.56
2000	0.00	0.22	0.00	1.37	4.11	1.46	0.61	0.79	0.08	0.00	0.30	0.00	8.94
2001	0.81	0.30	0.39	2.90	2.40	2.02	1.98	0.01	0.00	0.57	0.00	0.00	11.38
2002	0.52	1.96	1.63	0.42	0.08	1.33	0.08	0.39	0.00	0.00	0.00	0.00	6.41
2003	0.03	3.23	2.84	0.10	3.33	1.68	2.07	0.44	0.00	0.09	0.29	0.16	14.26
2004	0.00	0.96	1.89	0.86	4.07	0.83	0.20	0.00	0.00	0.00	0.01	0.00	8.82
2005	2.19	0.23	3.72	4.13	4.82	1.77	1.71	0.89	0.00	0.43	0.05	0.47	20.41
2006	1.81	0.40	1.54	1.87	0.67	2.29	1.84	0.09	0.00	0.42	0.00	0.00	10.93
2007	0.36	0.29	1.71	0.70	1.79	0.94	0.69	0.00	0.00	0.01	0.00	0.15	6.64
2008	0.23	0.27	1.14	4.32	2.68	0.03	0.25	0.52	0.00	0.84	0.00	0.00	10.28
2009	0.02	3.34	1.43	0.65	1.43	0.47	0.32	0.25	0.80	0.00	0.02	0.00	8.73
2010	0.04	0.61	0.72	3.51	1.88	2.38	1.27	0.81	0.00	0.00	0.00	0.00	11.22
2011	1.11	1.57	8.94	0.51	0.99	4.59	0.35	1.17	0.05	0.00	0.00	0.20	19.48
2012	0.90	1.68	0.16	0.82	0.52	1.30	2.09	0.20	0.17	0.00	0.30	0.00	8.14
2013	0.04	0.08	1.34	0.35	0.02	0.14	0.06	0.19	0.00	0.32	0.00	0.00	2.54

Table 4. Monthly Precipitation at the Tehachapi Station (Continued)

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Average 1921-2013	0.49	1.10	1.78	1.88	2.01	1.86	1.03	0.41	0.10	0.09	0.19	0.28	11.24
Average 1981-2001	0.53	1.33	1.49	2.40	2.21	2.55	0.74	0.38	0.13	0.16	0.28	0.23	12.44
Average 2002-2013	0.60	1.22	2.26	1.52	1.86	1.48	0.91	0.41	0.09	0.18	0.06	0.08	10.65
Average 1981-2013	0.56	1.29	1.77	2.08	2.08	2.16	0.80	0.39	0.11	0.17	0.20	0.18	11.79

Table 5. Monthly Precipitation at Cummings Valley Station (inches)

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
1969	0	1.98	1.33	3.88	4.25	0.5	0	0	0	0	0	0.05	11.99
1970	0.1	0.8	0.51	2.15	0.95	2.28	0.58	0	0.08	0.05	0	0	7.50
1971	0	4.67	1.23	0.18	0.49	0.52	0.72	1.1	0	0	1.02	0.05	9.98
1972	0.05	0.34	2.55	0	0	0	0.45	0	2.25	0	0.17	0	5.81
1973	0.45	2.16	2.35	2.49	2.05	5.18	1.6	0.54	0	0	0.05	0	16.87
1974	0	1.77	0.66	2.43	0.78	5.37	0.63	0.55	0	0.06	0	0	12.25
1975	2.9	0.89	1.74	0.76	2.07	2.7	1.75	0.1	0	0	0.14	0.05	13.10
1976	2.25	0.81	0.13	0.04	1.59	0.82	0.71	0.23	0.05	0	0	3.01	9.64
1977	0.13	0	1.3	2.87	0.7	1.49	0.12	2.46	0.45	0	1.25	0	10.77
1978	0	0.52	3.72	1.92	7.58	8.98	2.61	0	0	0	0	1.8	27.13
1979	0.41	0.5	1.57	4.03	3.05	3.34	0	0.61	0	0	0	0	13.51
1980	0	0.3	0.9	5.1	4.77	1.8	0.8	0.7	0	0	0.05	0.15	14.57
1981	0	0.55	0.8	7.65	2.45	4.33	1.08	1.40	0.00	0.00	0.00	0.30	18.56
1982	2.85	1.60	1.25	0.90	1.85	5.20	2.60	0.00	0.60	0.00	0.00	0.00	16.85
1983	0.65	0.55	4.55	6.25	1.40	7.00	0.00	0.00	0.00	0.00	1.30	0.30	22.00
1984	0.50	6.50	1.10	0.00	0.10	3.15	1.05	0.00	0.00	0.40	0.00	0.15	12.95
1985	0.05	3.30	3.95	0.95	3.50	2.04	0.25	0.20	0.60	0.00	0.00	0.78	15.62
1986	0.75	4.29	1.20	2.43	2.76	1.70	0.25	0.15	0.00	0.00	0.00	0.20	13.73
1987	0.45	2.05	1.28	2.15	2.30	2.95	0.80	1.33	0.87	0.10	0.00	0.40	14.68
1988	5.34	3.95	2.65	2.19	1.20	0.82	1.66	1.10	0.25	0.00	0.00	0.00	19.16
1989	0.10	1.85	3.10	0.95	1.95	1.19	0.30	0.35	0.00	0.00	0.00	1.10	10.89
1990	0.70	0.00	0.00	2.50	1.29	1.11	0.41	1.24	0.01	0.00	0.00	0.20	7.46
1991	0.00	0.70	0.30	1.63	2.62	1.97	0.00	0.00	0.00	0.93	0.00	0.00	8.15
1992	1.33	0.85	3.08	2.45	5.65	3.33	0.15	0.00	0.00	0.20	0.00	0.00	17.04
1993	1.45	0.13	5.42	9.55	5.30	1.90	0.00	0.00	1.10	0.00	0.00	0.00	24.85
1994	0.35	1.05	1.70	0.55	2.05	0.40	1.45	0.75	0.00	0.00	0.00	0.10	8.40
1995	0.35	1.50	1.55	10.88	0.75	5.98	1.35	1.20	0.20	0.00	1.10	0.00	24.86
1996	0.00	0.25	1.35	0.00	3.05	4.35	0.95	0.00	0.00	0.00	0.00	0.00	9.95
1997	1.60	1.25	2.10	3.13	0.78	0.00	0.20	0.00	0.00	0.00	0.00	0.20	9.26
1998	0.80	1.55	1.25	3.75	7.33	3.23	4.23	1.77	0.45	0.00	0.55	0.90	25.81
1999	0.81	2.03	1.38	2.91	1.67	0.55	1.00	0.05	0.05	0.00	0.00	0.00	10.45
2000	0.00	0.15	0.15	0.88	5.73	2.05	0.70	0.25	0.00	0.00	0.30	0.00	10.21
2001	1.74	0.05	0.45	3.95	1.46	1.10	2.36	0.00	0.00	0.00	0.00	0.00	11.11
2002	0.61	2.66	1.97	0.37	0.26	1.76	0.84	0.20	0.00	0.00	0.00	0.00	8.67
2003	0.00	0.00	0.00	0.20	2.87	1.13	1.97	0.40	0.00	0.52	0.17	0.20	7.36
2004	0.07	0.36	1.22	0.71	4.43	1.04	0.02	0.00	0.00	0.00	0.00	0.00	7.88
2005	2.90	0.10	2.62	3.33	2.96	2.35	2.15	1.55	0.00	0.00	0.05	0.10	18.11
2006	1.70	0.85	1.07	0.55	0.38	2.00	1.27	0.00	0.00	0.30	0.00	0.00	8.12
2007	0.02	0.70	0.84	1.73	2.32	0.98	1.74	0.00	0.00	0.00	0.00	0.45	8.78
2008	0.33	0.15	1.25	1.80	3.01	0.46	0.61	0.25	0.00	0.03	0.00	0.00	7.89
2009	0.20	2.32	1.72	0.95	0.90	0.60	0.30	0.10	1.35	0.00	0.02	0.00	8.46
2010	0.00	1.05	2.90	2.45	3.00	0.05	3.00	0.55	0.00	0.00	0.00	0.05	13.05
2011	2.71	1.65	3.91	0.71	3.05	4.90	0.21	1.28	0.01	1.22	0.00	0.02	19.67
2012	1.22	0.66	0.00	0.73	0.90	1.43	1.56	0.28	0.02	0.00	0.11	0.00	6.91
2013	0.13	0.25	2.29	0.51	0.03	0.17	0.06	0.21	0.00	0.01	0.10	0.00	3.76

Table 5. Monthly Precipitation at Cummings Valley Station (Continued)

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Average 1969-2013	0.80	1.33	1.70	2.34	2.39	2.31	0.99	0.47	0.18	0.08	0.14	0.24	12.97
Average 1981-2001	0.94	1.63	1.84	3.13	2.63	2.59	0.99	0.47	0.20	0.08	0.15	0.22	14.86
Average 2002-2013	0.82	0.90	1.65	1.17	2.01	1.41	1.14	0.40	0.12	0.17	0.04	0.07	9.89
Average 1981-2013	0.90	1.36	1.77	2.42	2.40	2.16	1.04	0.44	0.17	0.11	0.11	0.17	13.05

Table 6. Summary of Groundwater Recharge Components (acre-feet)

Year	Total Rainfall	Rainfall Recharge	Cummings Creek Streamflow	Cummings Creek Streamflow Recharge	Other Streamflow	Other Streamflow Recharge	Irrigation Return Flow	Artificial Recharge	Bedrock Inflow	CCI/Domestic Return Flow	Total Potential Recharge	Streamflow Out of Basin	Total Net Recharge
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10	Col. 11	Col. 12	Col. 13	Col. 14
											=3+4+6+8+9 +10+11	=(4+6)-(5+7)	=12-13
1981	18.56	1,302	909	909	720	720	227	0	530	137	3,825	0	3,825
1982	16.85	971	613	613	486	486	236	0	530	152	2,988	0	2,988
1983	22.00	1,522	2,272	1,000	1,799	1,000	193	0	530	127	6,443	2071	4,372
1984	12.95	883	364	364	288	288	189	0	530	137	2,390	0	2,391
1985	15.62	927	568	568	450	450	192	0	530	140	2,806	0	2,807
1986	13.73	883	500	500	396	396	199	0	530	165	2,672	0	2,674
1987	14.68	905	523	523	414	414	202	0	530	205	2,778	0	2,779
1988	19.16	1,390	1,136	1,000	899	899	325	0	530	274	4,554	136	4,418
1989	10.89	728	227	227	180	180	401	0	530	240	2,306	0	2,306
1990	7.46	243	23	23	18	18	378	0	530	241	1,432	0	1,433
1991	8.15	530	45	45	36	36	317	0	530	242	1,700	0	1,700
1992	17.04	1,103	727	727	576	576	333	0	530	249	3,518	0	3,518
1993	24.85	1,721	3,635	1,000	2,878	1,000	336	0	530	257	9,357	4513	4,844
1994	8.40	618	68	68	54	54	439	0	530	266	1,975	0	1,975
1995	24.86	1,897	3,635	1,000	2,878	1,000	480	0	530	233	9,654	4513	5,140
1996	9.95	640	91	91	72	72	383	41	530	405	2,162	0	2,162
1997	9.26	662	80	80	63	63	440	41	530	407	2,222	0	2,223
1998	25.81	2,912	6,816	1,000	5,397	1,000	349	333	530	410	16,747	10213	6,534
1999	10.45	684	136	136	108	108	568	108	530	302	2,436	0	2,436
2000	10.21	684	102	102	81	81	685	81	530	295	2,458	0	2,458
2001	11.11	860	250	250	198	198	779	701	530	295	3,613	0	3,613

Table 6. Summary of Groundwater Recharge Components (Continued)
(acre-feet)

Year	Total Rainfall	Rainfall Recharge	Cummings Creek Streamflow	Cummings Creek Streamflow Recharge	Other Streamflow	Other Streamflow Recharge	Irrigation Return Flow	Artificial Recharge	Bedrock Inflow	CCI/Domestic Return Flow	Total Potential Recharge	Streamflow Out of Basin	Total Net Recharge
Col. 1	**Col. 2**	**Col. 3**	**Col. 4**	**Col. 5**	**Col. 6**	**Col. 7**	**Col. 8**	**Col. 9**	**Col. 10**	**Col. 11**	**Col. 12**	**Col. 13**	**Col. 14**
											=3+4+6+8+9 +10+11	**=(4+6)-(5+7)**	**=12-13**
2002	8.67	512	100	100	79	79	1,028	404	530	336	2,990	0	2,990
2003	7.36	424	25	25	20	20	1,028	1,056	530	335	3,418	0	3,418
2004	7.88	452	25	25	20	20	1,106	877	530	327	3,337	0	3,337
2005	18.11	1,297	718	718	568	568	969	940	530	345	5,367	0	5,367
2006	8.12	472	43	43	34	34	994	1,695	530	350	4,118	0	4,118
2007	8.78	520	107	107	85	85	1,034	1,193	530	337	3,806	0	3,806
2008	7.89	455	36	36	28	28	936	961	530	322	3,267	0	3,267
2009	8.46	497	57	57	45	45	755	1,634	530	301	3,820	0	3,820
2010	13.05	858	368	368	291	291	717	1,951	530	275	4,990	0	4,990
2011	19.67	1,439	2,540	1,000	2,010	1,000	423	1,459	530	329	8,730	2,549	6,180
2012	6.91	385	21	21	17	17	737	714	530	295	2,699	0	2,699
2013	3.76	179	21	21	17	17	921	1,389	530	340	3,397	0	3,397
Total	430.72	29,554	26,781	12,748	21,205	11,243	18,298	15,578	17,490	9,073	137,979	23,995	113,984
1981-01 Avg.	14.86	1,051	1,082	487	857	430	364	62	530	247	4,192	1,021	3,171
2002-13 Avg.	9.89	624	338	210	268	184	887	1,189	530	325	4,161	212	3,949
1981-13 Avg.	13.05	896	812	386	643	341	554	472	530	275	4,181	727	3,454

Table 7. Cummings Basin Water Use
(acre feet)

Year	Irrigated Crop (ac)	Imported Water (af)				Groundwater Pumped (af)						Total Ag Use (af)	Ag Duty Factor (af/ac)
		Ag	CCI	Other M&I	Total	Ag	CCI	Other M&I	Domestic	Other	Total		
1981	483	70	0	188	258	1,440	585	0	40	0	2,065	1,510	3.13
1982	510	133	0	179	312	1,440	660	0	40	0	2,140	1,573	3.08
1983	481	35	0	81	116	1,250	560	0	30	0	1,840	1,285	2.67
1984	407	12	0	103	115	1,250	560	0	50	0	1,860	1,262	3.10
1985	433	30	0	133	163	1,250	575	0	50	0	1,875	1,280	2.96
1986	385	79	0	166	245	1,250	700	0	50	0	2,000	1,329	3.45
1987	472	96	198	181	475	1,250	700	0	50	0	2,000	1,346	2.85
1988	871	415	258	183	856	1,750	986	0	50	129	2,915	2,165	2.49
1989	909	771	248	556	1,575	1,900	700	0	100	271	2,971	2,671	2.94
1990	1,267	1,500	256	574	2,330	1,021	700	0	100	48	1,869	2,521	1.99
1991	1,348	1,092	256	576	1,924	1,021	702	0	100	131	1,954	2,113	1.57
1992	945	1,196	270	560	2,026	1,021	700	0	110	0	1,831	2,217	2.35
1993	1,019	1,219	298	513	2,030	1,021	710	0	110	0	1,841	2,240	2.20
1994	1,149	1,914	357	550	2,821	1,021	700	0	110	0	1,831	2,935	2.55
1995	1,046	1,614	389	247	2,250	1,590	500	0	110	0	2,200	3,204	3.06
1996	1,284	2,074	393	426	2,893	475	1,355	0	110	0	1,940	2,549	1.99
1997	1,496	2,450	404	346	3,200	475	1,355	159	110	0	2,099	2,925	1.96
1998	1,582	1,856	419	200	2,475	475	1,355	55	110	0	1,995	2,331	1.47
1999	1,660	3,328	433	308	4,069	475	800	221	110	0	1,606	3,803	2.29
2000	1,586	3,358	347	332	4,037	1,206	821	537	122	0	2,686	4,564	2.88
2001	1,828	1,956	360	343	2,659	3,237	829	671	114	0	4,851	5,193	2.84

Table 7. Cummings Basin Water Use (Continued)
(acre feet)

Year	Irrigated Crop (ac)	Imported Water (af)				Groundwater Pumped (af)						Total Ag Use (af)	Ag Duty Factor (af/ac)
		Ag	CCI	Other M&I	Total	Ag	CCI	Other M&I	Domestic	Other	Total		
2002	2,321	3,259	343	377	3,979	3,594	942	852	159	0	5,615	6,853	2.95
2003	2,918	3,871	247	198	4,316	2,983	942	781	195	0	4,973	6,854	2.35
2004	2,507	4,304	19	331	4,654	3,072	1,128	908	195	0	5,384	7,376	2.94
2005	2,727	3,893	0	222	4,115	2,565	1,125	959	240	0	4,962	6,458	2.37
2006	2,741	3,594	0	200	3,794	3,034	1,155	1,144	239	0	5,644	6,628	2.42
2007	2,909	3,886	0	245	4,131	3,004	1,140	1,184	219	0	5,610	6,890	2.37
2008	2,062	3,083	0	254	3,337	3,154	1,058	1,262	220	0	5,719	6,237	3.02
2009	1,584	1,512	0	250	1,762	3,522	913	997	238	0	5,728	5,034	3.18
2010	1,317	1,707	0	198	1,905	3,072	799	907	231	0	5,041	4,779	3.63
2011	1,418	863	0	196	1,059	1,956	1,018	765	251	0	4,024	2,819	1.99
2012	3,332	2,937	0	34	2,971	1,977	784	946	277	0	4,008	4,914	1.47
2013	2,873	3,633	0	9	3,642	2,506	1,009	1,107	276	0	4,933	6,139	2.14
1981-01 Avg.	1,008	1,200	233	321	1,754	1,229	788	78	85	28	2,208	2,429	2.56
2002-13 Avg.	2,392	3,045	51	210	3,305	2,870	1,001	984	228	0	5,084	5,915	2.57
1981-13 Avg.	1,511	1,871	167	281	2,318	1,826	866	408	137	18	3,254	3,697	2.56

Table 8. Summary of Groundwater Pumping (acre feet)

Year	Ag	CCI, BVCSD, SSCSD	Private Domestic	Other	Total
1981	1,441	585	40	0	2,066
1982	1,438	660	40	0	2,138
1983	1,250	560	30	0	1,840
1984	1,249	560	50	0	1,859
1985	1,253	575	50	0	1,878
1986	1,248	700	50	0	1,998
1987	1,251	700	50	0	2,001
1988	1,752	986	50	129	2,917
1989	1,904	700	100	271	2,975
1990	1,023	700	100	48	1,871
1991	1,028	702	100	131	1,961
1992	1,116	700	110	0	1,926
1993	1,024	710	110	0	1,844
1994	1,017	700	110	0	1,827
1995	1,584	500	110	0	2,194
1996	477	1,355	110	0	1,942
1997	484	1,514	110	0	2,108
1998	470	1,356	110	0	1,936
1999	467	1,021	110	0	1,598
2000	1,211	1,358	122	0	2,691
2001	3,236	1,500	114	0	4,850
2002	3,594	1,794	159	0	5,615
2003	2,983	1,723	195	0	4,973
2004	3,072	2,036	195	0	5,384
2005	2,565	2,084	240	0	4,962
2006	3,034	2,299	239	0	5,644
2007	3,004	2,324	219	0	5,610
2008	3,154	2,320	220	0	5,719
2009	3,522	1,910	238	0	5,728
2010	3,072	1,706	231	0	5,041
2011	1,956	1,783	251	0	4,024
2012	1,977	1,730	277	0	4,008
2013	2,506	2,116	276	0	4,933
Total	60,257	42,021	4,516	579	107,373
1981-2001 Average	1,229	866	85	28	2,208
2002-2013 Average	2,870	1,985	228	0	5,084
1981-2013 Average	1,826	1,274	137	18	3,254

Table 9. Average Annual Groundwater Recharge and Discharge by Component, Basin Inventory Methodology

Water Balance Component	Calculation Method	21-Year Average Annual Amount 1981-2001 (AFY)	12-Year Average Annual Amount 2002-2013 (AFY)	33-Year Average Annual Amount 1981-2013 (AFY)	Comments
Precipitation Recharge	10% of precipitation	1,051	624	896	-
Cummings Creek Stream flow Recharge	2.1 inches over 6,182 acres minus excess stream flow	487	210	386	2.1 inches derived from Tehachapi Project Report
Other Stream flow Recharge	1.2 inches over 8,566 acres minus excess stream flow	430	184	341	1.2 inches derived from Tehachapi Project Report
Irrigation Return Flow	15% of applied irrigation water (sw and gw)	364	887	554	15% based on TCCWD value for return flow
Artificial Recharge	Per TCCWD records	62	1,189	472	Artificial recharge occurred from 1995-2013
Bedrock Inflow	Darcy's Law	530	530	530	-
CCI/Domestic Return Flow	20% and 50% of Total Use	247	325	275	Avg Ann Dom Use = 137 AFY (69 AFY return flow) Avg Ann CCI GW Pumping = 866 AFY (173 AFY return flow) Avg Ann CCI Import = 167 AFY (33 return flow)
Recharge Totals	**-**	**3,171**	**3,949**	**3,454**	**-**
Groundwater Pumping	District Records	2,208	5,084	3,254	Includes Agricultural, Municipal/Industrial, Domestic, and Other
Bedrock Outflow	Darcy's Law	44	44	44	-
Discharge Totals	**-**	**2,254**	**5,128**	**3,298**	**-**

Table 10. Summary of Model Based Recharge Components (acre feet)

Year	Rainfall Recharge	Stream Recharge	Return Flows	Artificial Recharge	Bedrock Inflow	Recharge Total
1981	110	125	462	0	530	1,227
1982	1,296	3,856	421	0	530	6,103
1983	4,413	5,551	204	0	530	10,698
1984	220	918	348	0	530	2,016
1985	220	670	348	0	530	1,769
1986	330	1,246	376	0	530	2,483
1987	110	167	475	0	530	1,282
1988	1,296	1,839	693	0	530	4,359
1989	110	83	753	0	530	1,477
1990	110	42	761	0	530	1,444
1991	330	1,263	692	0	530	2,815
1992	1,296	1,874	646	0	530	4,346
1993	2,206	3,653	562	0	530	6,951
1994	110	147	728	0	530	1,515
1995	4,413	4,097	628	0	530	9,668
1996	110	188	873	41	530	1,743
1997	110	251	901	41	530	1,833
1998	4,413	4,537	640	333	530	10,453
1999	330	1,221	912	108	530	3,101
2000	220	460	936	81	530	2,227
2001	1,296	1,129	987	702	530	4,644
2002	512	184	1,345	487	530	3,059
2003	424	46	1,349	1,053	530	3,402
2004	452	46	1,417	874	530	3,320
2005	1,297	3,594	1,264	937	530	7,622
2006	472	79	1,327	1,690	530	4,098
2007	520	197	1,352	1,190	530	3,789
2008	455	66	1,239	958	530	3,249
2009	497	105	1,036	1,629	530	3,798
2010	858	677	958	1,945	530	4,969
2011	1,439	4,342	1,233	1,455	530	8,998
2012	385	39	1,017	712	530	2,684
2013	179	39	1,255	1,385	530	3,388
Total	30,539	42,732	28,136	15,622	17,490	134,530

Table 10. Summary of Model Based Recharge Components (acre feet) (Continued)

Year	Rainfall Recharge	Stream Recharge	Return Flows	Artificial Recharge	Bedrock Inflow	Recharge Total
1981-2001 Average	1,098	1,587	635	62	530	3,912
2002-2013 Average	624	785	1,233	1,193	530	4,365
1981-2013 Average	925	1,295	853	473	530	4,077

Table 11. Summary of Model-Based Groundwater Discharge Components (acre feet)

Year	Ag Pumpage	Other Pumpage	Bedrock Outflow	Stream Discharge	ET	Discharge Total
1981	-2,124	-625	-206	0	-23	-2,978
1982	-2,006	-700	-232	0	-46	-2,984
1983	-1,651	-590	-322	0	-132	-2,694
1984	-1,450	-610	-282	0	-48	-2,389
1985	-1,421	-625	-263	0	-30	-2,338
1986	-1,521	-668	-255	0	-26	-2,470
1987	-1,869	-750	-249	0	-18	-2,885
1988	-3,022	-1,046	-259	0	-23	-4,350
1989	-3,126	-800	-250	0	-14	-4,189
1990	-2,222	-800	-241	0	-10	-3,273
1991	-2,310	-806	-237	0	-15	-3,368
1992	-2,267	-810	-246	0	-17	-3,339
1993	-1,810	-820	-313	0	-53	-2,995
1994	-1,636	-810	-275	0	-18	-2,739
1995	-2,453	-610	-353	0	-127	-3,544
1996	-2,125	-1,465	-309	0	-33	-3,932
1997	-1,868	-1,624	-284	0	-20	-3,796
1998	-1,139	-1,524	-369	0	-195	-3,227
1999	-1,136	-1,138	-328	0	-64	-2,666
2000	-1,214	-1,358	-302	0	-35	-2,909
2001	-3,332	-1,556	-302	0	-42	-5,232
2002	-3,598	-1,953	-290	0	-29	-5,870
2003	-2,987	-1,923	-279	0	-26	-5,214
2004	-3,077	-2,232	-269	0	-39	-5,617
2005	-2,570	-2,324	-284	0	-122	-5,301
2006	-3,039	-2,538	-270	0	-103	-5,950
2007	-3,008	-2,543	-261	0	-80	-5,893
2008	-3,159	-2,540	-254	0	-72	-6,024
2009	-3,527	-2,147	-248	0	-86	-6,008
2010	-3,077	-1,938	-247	0	-106	-5,368
2011	-1,957	-2,034	-306	0	-179	-4,476
2012	-1,934	-2,007	-266	0	-21	-4,229
2013	-2,512	-2,392	-243	0	-41	-5,187
Total	-76,145	-46,307	-9,092	0	-1,892	-133,436

Table 11. Summary of Model-Based Groundwater Discharge Components (acre feet) (Continued)

Year	Ag Pumpage	Other Pumpage	Bedrock Outflow	Stream Discharge	ET	Discharge Total
1981-2001 Average	-1,986	-940	-280	0	-47	-3,252
2002-2013 Average	-2,870	-2,214	-268	0	-75	-5,428
1981-2013 Average	-2,307	-1,403	-276	0	-57	-4,044

Table 12. Model-Based Water Balance Summary (acre feet)

Year	Recharge Total	Discharge Total	Groundwater Storage Change	Cumulative Storage Change
1981	1,227	-2,978	-1,751	-1,751
1982	6,103	-2,984	3,119	1,369
1983	10,698	-2,694	8,004	9,373
1984	2,016	-2,389	-373	9,000
1985	1,769	-2,338	-570	8,430
1986	2,483	-2,470	12	8,443
1987	1,282	-2,885	-1,603	6,840
1988	4,359	-4,350	8	6,848
1989	1,477	-4,189	-2,713	4,136
1990	1,444	-3,273	-1,830	2,306
1991	2,815	-3,368	-553	1,753
1992	4,346	-3,339	1,007	2,760
1993	6,951	-2,995	3,956	6,715
1994	1,515	-2,739	-1,224	5,492
1995	9,668	-3,544	6,124	11,616
1996	1,743	-3,932	-2,190	9,426
1997	1,833	-3,796	-1,963	7,463
1998	10,453	-3,227	7,226	14,689
1999	3,101	-2,666	436	15,125
2000	2,227	-2,909	-681	14,443
2001	4,644	-5,232	-587	13,856
2002	3,059	-5,870	-2,811	11,045
2003	3,402	-5,214	-1,813	9,233
2004	3,320	-5,617	-2,297	6,935
2005	7,622	-5,301	2,321	9,257
2006	4,098	-5,950	-1,852	7,405
2007	3,789	-5,893	-2,104	5,302
2008	3,249	-6,024	-2,775	2,526
2009	3,798	-6,008	-2,210	316
2010	4,969	-5,368	-399	-83
2011	8,998	-4,476	4,522	4,439
2012	2,684	-4,229	-1,545	2,893
2013	3,388	-5,187	-1,799	1,095
Total	134,530	-133,436	1,095	

Table 12. Model-Based Water Balance Summary (acre feet) (Continued)

Year	Recharge Total	Discharge Total	Groundwater Storage Change	Cumulative Storage Change
1981-2001 Average	3,912	-3,252	660	
2002-2013 Average	4,365	-5,428	-1,063	
1981-2013 Average	4,077	-4,044	33	