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DRAFT TECHNICAL MEMORANDUM

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WMA/CMA NUMERICAL MODEL DOCUMENTATION

1.0. INTRODUCTION

A numerical groundwater model was constructed to support the Groundwater Sustainability Plan for the Western Management Area (WMA) and Central Management Area (CMA) of the Santa Ynez River Groundwater Basin (basin) located in Santa Barbara County. The model was developed as a tool for the sustainable management of groundwater resources within the basin. This Technical Memorandum documents the construction and calibration of the WMA/CMA Model.

The areal extents of the WMA/CMA Model (Figure 1) cover about 110 square miles (72,000 acres) from east of Buellton (upstream) to the Pacific Ocean (downstream). Seven groundwater subareas (Figure 2) are represented within the model: CMA Santa Ynez River alluvium, Buellton Upland, WMA Santa Ynez River alluvium, Santa Rita Upland, Lompoc Plain, Lompoc Upland, and Lompoc Terrace).

Two subareas, the Burton Mesa and south Lompoc Terrace, are uplifted marine terraces and not included in the WMA groundwater model because they are disconnected from the principal aquifers in the WMA. Groundwater in these two subareas is perched, and therefore not representative or correlative to the principal groundwater aquifers of the WMA. The water budget for these subareas has been incorporated as recharge for the active cells in the WMA/CMA Model.

2.0. MODEL DEVELOPMENT

The Model was developed based on the antecedent groundwater salinity finite element model in the Lompoc WMA developed by Durbin and others (1997) and was expanded to cover the CMA and additional areas within the WMA. The hydrogeologic framework of the model was built upon the Hydrogeologic Conceptual Model (HCM) developed for the GSP (Stetson, 2020) which include important aspects of geologic and hydrogeologic framework, groundwater movements, sources of recharge and discharge, and water budget components.

The numerical code selected for the WMA/CMA Model is the U. S. Geological Survey (USGS) unstructured grid groundwater flow model, MODFLOW-USG (Panday and others, 2017). Unlike the finite element and finite difference numerical solving approximations, the MODFLOW-USG code solves for three-dimensional saturated groundwater flow based on the control volume finite difference (CVFD) approach. Formulation and solution of the CVFD equations are available in the MODFLOW-USG report

(Panday and others, 2017) and are not repeated in this report. Details of model construction and calibration are discussed in the subsequent sections.

2.1 *MODEL GRID*

The WMA/CMA Model grid system is constructed with uniform rectilinear 4-acre model cells. The unstructured model grid was developed with eight layers to represent the regional hydrostratigraphic system. The thickness and lateral extent of each layer was based on the geologic framework model developed by Geosyntec (2020) and discussed in the HCM developed for the GSP (Stetson, 2020). More detailed layering for the Upper (Layer 3), Middle (Layer 4), and Lower (Layer 5) Aquifers within the Lompoc area were incorporated from the Finite Element Model developed by Durbin and others (1997). The detailed model grid layering and the corresponding geologic framework for each model layer is demonstrated in Figure 3. With an unstructured grid, the outcropping of different geologic units can occur at land surface. Figure 4 shows how the different model layers are 'exposed' on the model surface. This is important for distributing areal recharge, surface water (river and tributaries), and evapotranspiration within the model domain.

The different geologic units and aquifers included in each model layer are summarized in Table 1 and shown on Figure 5 through Figure 8. Model layers one (1) through eight (8) represent geologic units including shallow river channel deposits and young alluvium, relatively deeper older alluvium and Orcutt sand, and the deepest Paso Robles and Careaga formations.

TABLE 1 MODEL LAYERS BY GEOLOGIC UNIT AND AQUIFER

MODEL LAYER	MANAGEMENT AREA	GEOLOGIC UNIT	AQUIFER
1	CMA / WMA	Qr, River Gravels	Santa Ynez River Alluvium (CMA, WMA)
2	CMA / WMA	Qa, Younger Alluvium	Santa Ynez River Alluvium (CMA,WMA), Upper Aquifer (WMA)
3	WMA	Qo, Older Alluvium	Upper Aquifer
4	WMA	Qo, Older Alluvium	Upper Aquifer
5	WMA	Qo, Alluvium deep	Upper Aquifer
6	CMA / WMA	Orcutt Sand, and Paso Robles Formation	Buellton Aquifer (CMA), Lower Aquifer (WMA)
7	CMA / WMA	Graciosa Member of the Careaga Formation	Buellton Aquifer (CMA), Lower Aquifer (WMA)
8	CMA / WMA	Cebada Member of the Careaga Formation	Buellton Aquifer (CMA), Lower Aquifer (WMA)

The upper two (2) model layers represent the river gravels and younger alluvium (Figure 5). Model layer 1 simulates the high permeability river channel deposits and the underlying model layer 2 represents the younger alluvium. In both the WMA and CMA, the younger alluvium is a main water bearing formation in the Lompoc Plain. The following three (3) model layers represent the relatively deeper alluvium in the Lompoc plain. Model Layer 3 is thin and transmits insignificant quantities of groundwater, and model layer 4 is mainly clay or non-porous sediment that restricts groundwater flow (Figure 6). Model layer 5 (Figure 7) is the main groundwater source zone beneath the Lompoc Plain, and layer 6 represents the Orcutt Sand, and the Paso Robles formation. The Orcutt Sand and Paso Robles formations are major water-bearing units and are comprised of approximately 1,000 to 3,000 feet of consolidated to unconsolidated gravels, sands, silts, and clays. The bottom two layers represent the Careaga sandstone: Graciosa member (relatively more productive) is represented by Layer 7, and Cebada member (relatively less productive) is represented by Layer 8 (Figure 8). Layer7 and Layer 8 have the same areal extent but represented by different hydraulic properties.

3.0. MODEL PARAMETERS

Aquifer properties vary spatially due to heterogeneous nature of the subsurface materials. Hydrogeologic parameters were assigned to each geologic unit (represented by 8 layers, Table 1) within the model area, and further subdivided into geographic subareas. This results in 35 hydrogeologic parameter zones in the WMA/CMA Model - 9 zones within the CMA and 26 zones within the WMA. A summary of this parameter zone distribution is provided in Table 2 showing the geologic layering and subareas within the Management Areas. The spatial distribution of each zone by subarea is displayed in Figures 5 through Figure 8.

TABLE 2 PARAMETER ZONES WITHIN THE MODEL DOMAIN

SUBAREA	HYDROGEOLOGIC PARAMETER ZONES FOR CALIBRATION	MANAGEMENT AREA	MODEL LAYERS (GEOLOGIC UNITS)
CMA SYR Alluvium	1, 7	CMA	1 and 2
CMA Lower Aquifer	19, 25, 31	CMA	6, 7 and 8
Buellton Tributary Alluvium	6	CMA	2
Buellton Upland	18, 24, 30	CMA	6, 7 and 8
WMA SYR Alluvium	5, 12, 23	WMA	1, 2 and 6
Lompoc Plain	2, 8, 13, 15, 16, 20, 26, 32, 34	WMA	1 through 8
Santa Rita Upland	4, 11, 22, 29, 35	WMA	1, 2, 6, 7 and 8
Lompoc Upland	3, 10, 14, 17, 21, 28	WMA	1, 2, 3, 5, 6, 7 and 8
Lompoc Terrace	9, 27, 33	WMA	2, 7 and 8

The Initial aquifer properties (hydraulic conductivity, specific storage and specific yield) assigned to the WMA/CMA Model were obtained from the groundwater salinity model (Durbin and others, 1993), and other limited aquifer test results. Aquifer properties were assigned to the model for each hydrogeologic parameter zone and adjusted within a reasonable range through model calibrations to ensure the model simulated heads respond reasonably close to measured groundwater conditions. The distributions of horizontal and vertical hydraulic conductivity, specific storage, and specific yield within each model layer varies by groundwater subzone as mapped in Figure 5 through Figure 8. Aquifer properties in each Management Area and Model Layer are tabulated below in Table 3 and Table 4.

TABLE 3 WMA/CMA MODEL CALIBRATED HYDRAULIC CONDUCTIVITY (K_{XY} / K_Z, FEET/DAY)

Layer	WMA SYR Alluvium	CMA SYR & Tributary Alluvium	Lompoc Plain	Lompoc Terrace	Lompoc Upland	Santa Rita Upland	Buellton Upland
1	600 / 30	750 / 37.5	600 / 30				
2	360 / 36	360 / 36	55 / 5.5	45 / 4.5	40 / 4	40 / 4	10 / 2
3			35 / 3.5				
4			5 / 0.5				
5			325 / 32.5				
6			55 / 5.5		40 / 4	40 / 4	1.5 / 0.075
7			40 / 4	40 / 4	40 / 4	40 / 4	1.5 / 0.075
8			4 / 0.4	1.5 / 0.15	2.5 / 0.25	1 / 0.1	1 / 0.1

TABLE 4 WMA/CMA MODEL CALIBRATED STORAGE PARAMETERS (SPECIFIC YIELD, SY (UNITLESS) / SPECIFIC STORAGE, S (1/FOOT)

Layer	WMA SYR Alluvium	CMA SYR & Tributary Alluvium	Lompoc Plain	Lompoc Terrace	Lompoc Upland	Santa Rita Upland	Buellton Upland
1	0.25 / 2.5E-05	0.25 / 2.5E-05	0.25 / 2.5E-05				
2	0.2 / 2.0E-05	0.2 / 2.0E-05	0.2 / 2.0E-05	0.2 / 2.0E-05	0.2 / 2.0E-05	0.2 / 2.0E-05	0.2 / 2.0E-05
3			0.15 / 1.5E-05				
4			0.05 / 5.0E-06				
5			0.15 / 1.5E-05				
6			0.1 / 1.0E-05		0.1 / 1.0E-05	0.1 / 1.0E-05	0.1 / 1.0E-05
7			0.15 / 1.5E-05	0.15 / 1.5E-05	0.15 / 1.5E-05	0.15 / 1.5E-05	0.15 / 1.5E-05
8			0.1 / 1.0E-05	0.1 / 1.0E-05	0.1 / 1.0E-05	0.1 / 1.0E-05	0.1 / 1E-05

3.1 *Temporal Discretization*

The WMA/CMA Model simulation period for the SGMA analysis is from Water Year (WY) 1982 to WY 2018. Water years are based on the 12 months from October 1st through September 30th to incorporate the major wet conditions within the same year. The model extends from October 1981 through September 2018 with a total of 444 monthly stress periods (37 years) and simulates the seasonal variations in recharge and discharge. Each stress period is subdivided into six time steps with a constant incremental time-multiplier of 1.12. During model construction, two additional years (24 monthly stress periods) were appended onto the SGMA time series with repeated monthly data from WY 2018 to make the model flexible for extending the analysis as future data become available.

3.2 *Model Boundary Conditions and Initial Groundwater Levels*

Model boundary conditions control the volume of water entering or leaving the model domain. All model cells are considered 'active' when using an unstructured grid. At the lateral and bottom edges of the model there is a 'no flow' condition, *i.e.* no groundwater flow is simulated from, or to, the bedrock surrounding or beneath the simulated aquifers. This assumption is consistent with the hydrogeologic conceptual model, which assumes the surrounding bedrock units are an insignificant source of water to the main groundwater basin.

The prescribed head boundary (also known as time-variant specified-head [Harbaugh et al., 2000]) was defined at model cells to simulate flow along the eastern and western boundaries (Figure 9). The groundwater levels (heads) assigned to the boundary conditions were determined by linear interpolation and extrapolated from measured data from nearby wells[1]. The eastern head-dependent-model-flux boundary is located at the boundary between the CMA and Eastern Management Area (EMA). Measured groundwater levels from monitoring well 6N/31W-17D01 (USBR Node 16) were interpolated at the model cells along the boundary at Layers 2, 6, 7, and 8 to set the time-variant head vales for the CHD MODFLOW Package. Hydrographs are included in Attachment 5 showing the measured and simulated data at this location.

The hydrogeologic conceptual model of the western model boundary at the Pacific Ocean shows a connection to the lagoon or ocean at the river gravels (Qr, model layer 1) or young alluvium (Qal, model layer 2). Lower aquifer sediments (Layers 3 through 8) within the Santa Rita syncline encounter the Monterey formation (Tm) and are not connected to the ocean. Near the lagoon, measured groundwater elevations at monitoring wells 7N/35W-17K20 (surf, old barrier bridge), 7N/35W-18J02 (surf, s. side of lagoon), 7N/35W-21G02 (AFB) were interpolated at the model cells along the lagoon at Layers 1 and 2.

The initial groundwater level heads for the transient simulation were developed using 1981 and early 1982 contour data from historical USGS reports (Hamlin 1985, Berenbrock 1988), and supplemented with measured data. The available groundwater levels were interpolated and assigned to each model cell through

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[1] Measured groundwater level data and hydrographs for these wells are posted on sywater.com (DBID 1, 3, 39 and 1113).

kriging methods. The kriged groundwater levels are mapped in Figure 10 and considered to reasonably represent 1981 conditions within the model area.

3.3 *Groundwater Recharge and Discharge*

Water entering the groundwater basin includes recharge from precipitation, stormwater runoff, mountainfront recharge, municipal and irrigation return flow, water exchange between surface water and the aquifer, and subsurface inflows from the adjacent EMA located upstream of the WMA/CMA Model area. Similarly, groundwater leaving the model area includes groundwater withdraws (pumping), evapotranspiration, water exchanges between stream and aquifer, and subsurface outflow to the lagoon and Pacific Ocean.

3.3.1 Groundwater Recharge

Monthly recharge volume was incorporated into the WMA/CMA Model using the MODFLOW Recharge (RCH) package. The specified recharge rates include natural recharge from areal precipitation and mountainfront recharge; and return flow from municipal and agricultural[2] land use. Technical Memoranda written for the GSP Chapters on the Hydrogeologic Conceptual Model (HCM) and Water Budget for the WMA and CMA describe the development of natural recharge using the USGS Basin Characterization Model (Flint and Flint 2017). Monthly data were used for municipal return flow. Distribution of natural recharge and municipal return flow[3] are shown on Figure 11 (upper map).

A summary of annual recharge within the model are provided in Attachment 1 and summarized below in Table 5. The WY 1982 to 2018 average annual natural recharge simulated in the model was 19,680, with 13,090 acre-feet/year occurring within the WMA and 6,590 acre-feet/year occurring within the CMA. Recharge from precipitation ranged from 350 acre-feet in 2015 to 75,760 acre-feet in 1983. Municipal return flow was more constant than natural recharge and averaged 2,120 acre-feet during the model period. In the agricultural areas, irrigation return flow averaged about 17% of the pumped groundwater and net pumping was specified by subtracting the return flow from total pumping.

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[2] Agricultural return flows are accounted for by net irrigation pumping.

[3] ibid

TABLE 5 RECHARGE SUMMARY, WMA/CMA MODEL
(WY 1982-2018; 37-YEAR AVERAGE ANNUAL AFY)

RECHARGE COMPONENT	CMA AFY	WMA AFY	TOTAL RECHARGE AFY	MINIMUM AFY	MAXIMUM AFY
NATURAL RECHARGE:					
Precipitation Recharge	3,920	8,720	12,640	2015/ 350	1983/ 75,760
Mountainfront Recharge	1,430	3,490	4,920	2007/ 50	1983/ 14,030
ANTHROPOGENIC RECHARGE:					
Municipal Return Flow	1,240	880	2,120	1982/ 1,530	2004/ 2,470
Agricultural Return Flow[1]	860	4,680	5,540	1984/ 1,190	1997/ 6.085
TOTAL MODELED RECHARGE	6,590	13,090	19,680	2015/ 2,270	1983/ 91,350

1. Agricultural return flow is included in net agricultural pumping.

3.3.2 River and Tributary Streamflow

Santa Ynez River and the major tributaries flow through the WMA/CMA Model area. Quantification of the stream and groundwater exchange is performed using the Streamflow Routing Package (SFR) (Niswonger and Prudic, 2006). Figure 12 shows a schematic of the Santa Ynez River, tributaries, and tributary drainages with a corresponding map view of the modeled surface water features. Data required to quantify the stream and groundwater exchange include the locations of Santa Ynez River and tributaries, assigned stream segment and reach, and for each its specified length, streambed thalweg elevation, and streambed conductance. Additionally, the monthly river flow is specified where the Santa Ynez River enters the WMA/CMA Model area and for all tributaries upstream of the river. The streambed thalweg elevations were assigned and adjusted according to surface elevations derived from 10-meter Digital Elevation Models (DEMs) and comparisons with USGS topographical maps.

The entire Santa Ynez River network is divided into 68 segments and each segment consists of a set of model cells (reach). Details of the Santa Ynez River network are summarized in Attachment 2. Model-simulated stream stage and streamflow were calculated based on the channel hydraulics[4] at USGS gaging stations 11133000 (close to Lompoc Narrows), 11134000 (close to Lompoc H Street), 11129800 (Zaca Creek), and 11128500 (Solvang). The relationships of streamflow and corresponding width and depth at each gaging station are also summarized in Attachment 2. A summary of the annual streamflow entering the eastern model domain for the Santa Ynez River is about 3,500 feet downstream of the Solvang gage. Streamflow input to the model for the Santa Ynez River and all tributaries are tabulated in Attachment 3.

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[4] These stream values were similar to channel parameters used in the WMA Lompoc Plain finite element model (Durbin et al, 1993)

TABLE 6 SANTA YNEZ RIVER AND TRIBUTARY STREAMFLOW WMA/CMA MODEL (WY 1982-2018; 37-YEAR AVERAGE ANNUAL AFY)

STREAMFLOW INTO MODEL	CMA AFY	WMA AFY	TOTAL STREAMFLOW INTO MODEL DOMAIN[3] AFY	MINIMUM YEAR YEAR / AFY	MAXIMUM YEAR YEAR / AFY
Santa Ynez River	85,780[1]	94,190[2]	85,780[3]	1990/ 630	1998/ 655,820
Nojoqui Creek	3,260		3,260	2015/ 40	1995/ 21,980
Santa Rosa Creek	760		760	mult/ 0	1995/ 5,680
Santa Rita Creek		420	420	mult/ 0	1995/ 3,270
Salsipuedes Creek		9,440	9,440	2015/ 120	1995/ 63,690
San Miguelito Creek		1,310	1,310	2009/ 70	1995/ 9,960
Other Side Tributaries	3,820	3,730	7,550	mixed	mixed
Wastewater		3,790	3,790	2012/ 2,950	2000/ 4,720
Total Surface Water Inflow	93,610	112,870	112,300	1990/ 4,720	1998/ 776,650

Note: all numbers are rounded to the nearest 10 afy, sometimes causing a summation rounding error.

1. Simulated 3,500 feet downstream of USGS Gage 11128500 Solvang.
2. Simulated at USGS Gage 11133000 Narrows.
3 Flow from outside of the WMA/CMA Model domain does not include the ‘internal’ flow at the USGS Gage 11133000 Narrows.

During model calibration, simulation of the Santa Ynez River streamflow at the Lompoc Narrows was reset to the USGS gaging station 11133000 to remove any potential upstream errors that might have been introduced. The Santa Ynez River segment (stream segment 40) located immediate downgradient of the gaging station 11133000 became a new starting stream segment using the monthly recorded streamflow measurements at the gaging station 11133000 to complete the stream routing process. Both simulated and gaged streamflow are included in Attachment 3. Resetting flow at stream segment 40 was only part of model calibration. For the model simulation of future scenarios, the streamflow at the Lompoc Narrows is a simulated (not gaged) quantity. The comparison of simulated and gaged streamflow will be discussed in Section 4.2 discussing the results of model calibration.

3.3.3 Groundwater Pumping

Groundwater production is primarily pumped for agricultural, municipal, and domestic uses. Groundwater production required for the WMA/CMA Model was compiled from the pumping data obtained from the previous WMA Lompoc Plain finite element model[5] (Durbin et al, 1997) and pumping records obtain from the Santa Barbara County Water Agency. Locations of agricultural, municipal, and

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[5] This is also referred to as the “salinity finite element model in the Lompoc WMA developed by Durbin and others (1993).”

domestic wells are shown in Figure 13. An annual summary of the pumping data used in the model for WY 1982 through WY 2018 is provided as Attachment 4. Groundwater pumping was implemented in the WMA/CMA Model using the WEL package with the pumping reduction capability in the event of simulated water levels are approaching the well bottom.

TABLE 7 PRODUCTION WELL SUMMARY
WMA/CMA MODEL

PUMPING WELLS	WMA # WELLS	CMA # WELLS	TOTAL # WELLS
Agriculture/Irrigation	261	130	391
Municipal	18	4	22
Domestic	123	121	244
Total Wells Simulated	402	255	657

TABLE 8 PUMPING SUMMARY, WMA/CMA MODEL
(WY 1982-2018 AVERAGE ANNUAL AFY)

PUMPING TYPE	CMA PUMPING (AFY)	WMA PUMPING (AFY)	TOTAL PUMPING (AFY)
Net Agriculture/Irrigation	4,170	19,570	23,740
Municipal	850	7,000	7,840
Domestic	230	160	390
Total Volume Pumped	5,240	26,730	31,980

Note: all numbers are rounded to the nearest 10 afy, sometimes causing a summation rounding error.

1. Agricultural return flow is included in net agricultural pumping.

3.3.4 Evapotranspiration

Evapotranspiration was simulated in the model to estimate groundwater consumption from naturally occurring phreatophytic (roots tapping into the groundwater table) vegetation. Figure 14 shows the location of model cells simulating phreatophyte water use within the model area. These areas are primarily located along the Santa Ynez River and side tributary riparian areas and at the estuary. Evapotranspiration was assigned to the upper-most layer in the WMA/CMA Model. Groundwater loss through evapotranspiration (ET) within the model area was simulated based on the relationships between the surface elevations, simulated heads, potential ET rates, and root extinction depth using the MODFLOW Evapotranspiration (EVT) package. The ET surface was set to the average elevation within the 4-acre model cell based on land surface from Digital Elevation Models (DEM). The root extinction depth shown in Figure 14 ranges from 25 feet to 54 feet below the average 4-acre model cell land surface elevation. These values were established during model calibration using subarea water budget analysis during the WY 1982 to WY 2018 period estimated to average about 12,000 AFY (Table 9).

Potential ET was estimated using the monthly average precipitation data collected from the California Irrigation Management Information System (CIMIS) during the period between 1983 and 2018. Based on the precipitation collected from the CIMIS, the average annual potential ET for the WMA and CMA are approximately 43.9 inches per year and 51.0 inches per year, respectively. The estimated monthly potential ET for the ET cells in the WMA and CMA areas are provided in Table 9. These ET rates vary monthly with the largest rate occurring during the summer months and the smallest rate occurring in the winter months).

The model calculates the groundwater consumed at the 4-acre model cell based on the simulated depth to water and the parameters assigned to the model cell. The maximum ET loss occurs when the simulated head is at or above the ET surface; on the contrary, the minimum ET loss (equal to zero) occurs when the simulated head drops at or below the root extinction depth.

TABLE 9 ESTIMATED AVERAGE MONTHLY POTENTIAL AND SIMULATED EVAPOTRANSPIRATION

Water Year Month	Western Management Area Potential ET (feet/day)	Central Management Area Potential ET (feet/day)	Simulated WY 1982-2018 Evapotranspiration (acre-feet/year)
October	0.00866	0.00989	845
November	0.00570	0.00629	533
December	0.00444	0.00475	431
January	0.00468	0.00511	469
February	0.00608	0.00672	574
March	0.00922	0.01035	976
April	0.01202	0.01366	1,227
May	0.01551	0.01789	1,610
June	0.01427	0.01707	1,421
July	0.01508	0.01833	1,531
August	0.01355	0.01648	1,358
September	0.01147	0.01353	1,091
		Total Average Annual AFY:	12,067

3.3.5 Groundwater Flow Barriers

Groundwater flow can be completely or partially restrained by geologic features. Figure 15 shows groundwater level measured during well installation near the boundary between the Santa Rita Upland and Buellton Upland. The observed water levels in the Buellton Upland are generally higher than water levels observed in the Santa Rita Upland. The measured data suggest the existence of a partial flow barrier located between the Santa Rita Upland and Buellton Upland due to the sharp differences in groundwater elevations. The characteristic of this partial barrier is uncertain; however, groundwater in the Buellton Upland area appears to also be restricted in the same area. To account for this inferred flow barrier, a line of model cells located between the Santa Rita Upland and Buellton Upland were assigned a relatively low hydraulic conductivity as shown on Figure 15. The hydrogeologic properties of these cells in this area of the model were set to limit groundwater flow -- decrease of five (5) orders of magnitude of the horizontal and vertical hydraulic conductivity (Kx and Kz) and a decrease of two (2) orders of magnitude of specific yield and specific storage (Sy, and Ss). This simulated partial barrier to flow restricts the movement of groundwater between the Buellton Upland and Santa Rita Upland, and maintains the relatively higher groundwater conditions observed in the Buellton Upland. The physical reasons for the hydraulic conductivity contrast between the Santa Rita Upland and Buellton Upland is unknown and will require additional geohydrologic data and investigation to better understand its mechanism.

3.4 *WMA/CMA Model Package Summary*

This section describes the different USGS MODFLOW-USG codes (packages) that were used to construct the unstructured grid model for the WMA/CMA Model. These unstructured grid packages were used to represent the hydrostratigraphic units, model discretization, recharge and discharge water components, and numerical solver. The MODFLOW-USG packages employed in the WMA/CMA Model are tabulated in Table 10 and summarized below.

TABLE 10 MODFLOW-USG PACKAGES USED IN THE WMA/CMA MODEL

MODFLOW-USG PACKAGE		PURPOSE
Basic	BAS	model cell status and initial starting heads
Discretization	DISC	model cell connection, size, and time discretization
Layer-Property Flow	LPF	aquifer properties
Time Varying Constant Head	CHD	specified heads at model domain boundary
Well	WEL	groundwater production
Evapotranspiration	EVT	evapotranspiration process
Recharge	RCH	natural recharge and anthropogenic return flow
Streamflow-Routing	SFR	Santa Ynez River and tributaries flow system
Output Control	OC	model output control
Solver	SMS	Sparse Matrix Solver
Gage	GAGE	output control for streamflow segments
Zone Budget		model post-processing

3.4.1 Basic Package (BAS)

The Basic Package is used to specify the model cell status, and initial water level conditions within the model domain. Because of the MODFLOW-USG's flexibility in model grid design, the WMA/CMA Model was constructed to efficiently represent pinch-outs between merging geologic structures and eliminate the need for inactive model cells when using a rectilinear finite-difference. There is a total of 53,265 active groundwater cells in the model, and includes 1,219 cells representing layer 1, 7,710 cells representing layer 2, 3,035 cells representing layer 3, 1,399 cells representing layer 4, 1,988 cells representing layer 5, 10,910 cells representing layer 6, 13,520 cells representing layer 7, and 13,520 cells representing layer 8. The initial heads employed in the WMA/CMA Model were determined based on historical reports and observed water level data.

3.4.2 Discretization Package (DICU)

The Discretization Package specifies model discretization information to define model geometry, model cell connection, and time stepping throughout the entire simulation period. The model domain was discretized using a constant grid-block size of approximately 4 acres (174240 feet). The entire model area is discretized into eight (8) model layers based on the geological map. Figure 3 through Figure 8 show the discretization of the groundwater domain. The WMA/CMA Model was constructed to simulate hydrologic conditions starting from October 1981 through September 2020 (total of 39 years) with a total of 468 monthly stress periods.

3.4.3 Layer Property Flow Package (LPF)

The Layer Property Flow Package specifies aquifer properties for all model cells and model layer type within the model. Aquifer parameters required by the WMA/CMA Model include horizontal and vertical hydraulic conductivities, specific storage, and specific yield. Aquifer properties assigned to the WMA/CMA Model were adjusted during model calibration. All model layers are assigned to be convertible between confined and unconfined conditions depending the layer thickness and water level conditions.

3.4.4 Well Package (WEL)

The well package simulates groundwater extraction within the model domain. The extraction wells include irrigation, domestic, and municipal wells. The MODFLOW-USG will reduce groundwater pumping rates when the simulated heads approach the specified bottom elevation of the cell, which prevents "dry" model cells from occurring during model computations. The perforated intervals of most wells in the model are unknown. It was therefore necessary to assume that wells extract groundwater primarily from the main water bearing formation represented by model layers 2, 5, 6, and 7. Well extractions were allocated between layers based on the following rule set:

If pumping well is located where:

model layers 1 and 2 are present	100% from layer 2
model layers 2 and 5 are present	40% / 60% from layers 2 and 5
model layers 2 and 6 and/or 7 are present	40% / 60% from layers 2 and 6 and/or 7
model layers 5 and 6 are present	50% / 50% from layers 5 and 6
model layers 2, 5 and 6 are present	20% / 40% / 40% from layers 2, 5, and 6

3.4.5 Time Variant Specified Head Package (CHD)

The CHD package was employed to provide constant head boundaries along the western and eastern perimeter of model boundary and the lagoon area (Figure 10 upper). A constant head value of zero is assigned to model cells in model layers 1 and 2 where model cells located adjacent to the ocean. In order to ensure the other CHD boundary cells can provide reasonable head gradients, the constant heads assigned to the eastern boundary and lagoon cells were determined based on the historical water levels observed in the nearby wells.

3.4.6 Evapotranspiration Package (EVT)

The ET package is used to apply ET rates to each ET cell in the WMA/CMA Model. The pertinent data required in the EVT package includes the potential ET rate, root extinction depth, ET surface elevation, and model simulated head. The MODFLOW-USG calculates the ET extraction over the model top active cells.

3.4.7 Recharge Package (RCH)

The Recharge Package is employed to simulate groundwater recharge as a result of water percolation over the uppermost layer of active model cells. The recharge applied to the WMA/CMA Model is the total precipitation recharge, drainage flow, mountain front flow, and municipal return flow.

3.4.8 Stream Routing Package (SFR)

The SFR Package defines the locations of the Santa Ynez River and all tributaries that will be simulated in the model. Required data for the SFR Package includes Stream location, stream identification, stream length, stream bed elevation and conductance, and streamflow. The SFR provides several options to calculate stream width and depth, the current setup is to calculate the stream width and depth using the channel hydraulics table (Attachment 2).

3.4.9 Gage Package (GAG)

The MODFLOW-USG Gage Package controls streamflow output at any stream cell of interest. The Gage Package in the WMA/CMA Model setup is to generate simulated time series streamflow at the USGS gage stations 11133000, 11134000, 11135000, and 11135250 where observed streamflow data are available for model calibration.

3.4.10 Sparse Matrix Solver Package (SMS)

The Sparse Matrix Solver (SMS) package provide groundwater flow equation solver for the MODFLOW-USG. The SMS package has several solver options and the Newton-Raphson linearization scheme was determined to be the most appropriate solver option for the WMA/CMA Model due to its good convergence and faster simulation time.

3.4.11 Output Control Package (OC)

The Output Control Package of MODFLOW-USG controls how water levels, fluxes and water budget information is saved during a simulation. The Output Control Package was set up to save the simulated groundwater levels (heads), volumetric budget, and cell-by-cell flow at the end of each stress period. The cell-by-cell flow output is used by the post processing Zone Budget program to calculate internal fluxes and subarea water budgets based on model simulated rates.

4.0. MODEL CALIBRATION

Model calibration is the process of iteratively adjusting aquifer parameters and boundary conditions with the intention to ensure the model simulated results match the conditions observed in the field or estimated by other approaches within acceptable errors. Calibration of the transient WMA/CMA Model was performed for the 37-year period from WY 1982-2018 (444 monthly stress periods) through a systematic adjustment of model parameters and comparisons of simulated results with measured data. The aquifer parameter adjustment in the calibration process represents the constant parameter adjustment over each management zone; that is, each model management zone has one constant set of aquifer parameters.

4.1 *GROUNDWATER LEVELS*

Although there are many wells located within the model area, many wells have one or few groundwater level measurements. For calibration purposes, 122 wells with longer-term water level measurements were considered as target wells for model calibration. The locations of the target wells are shown on Figure 16 and tabulated in Attachment 5. These water level measurements are the basis for groundwater level trend analysis and comparison to the model's simulated results. Review of observed water level measurements at these 122 wells indicates water level measurements at some wells may consist of both static and non-static measurements. The non-static measurements were collected either when a well was still pumping, or when the groundwater level was not fully recovered. In addition, some measurements may be considered as outliers when the data deviate significantly from the normal water level range. However, without knowing the exact causes of those abnormal water level measurements, all water measurements are considered and included in the model calibration statistics and comparison hydrographs (Attachment 5).

Calibration statistics are shown on Figure 17 using a scatter plot of observed versus simulated water level, and a histogram (distribution) of the residual differences (measured - simulated) computed for 24,114 groundwater level measurements at the 122 target wells. The closely clustered data around the diagonal match-line shown in the scatter plot illustrates a good fit of the simulated groundwater levels to the observed data, with no trend or bias to the errors. Statistic evaluations of the simulated water levels are also presented in Figure 17. The calculated mean residual is 1.40 feet in the WMA and -0.62 feet in the CMA; with a Standard Deviation (σR) of 10.13 in the WMA and 7.10 feet in the CAM. These statistics indicate that on average, the WMA/CMA Model simulated results are slightly higher than the measured data (0.99 feet) and most of the residuals (differences) are generally less than 9.63 feet throughout the whole model area. The residual of histogram shown on Figure 17 shows a good bell shape distribution (normal distribution). The large discrepancy of -50 feet difference (to the left of the residual distribution) are mostly the differences between the model simulated heads and possible outliers. The statistics shown on Figure 17 suggest a good fit between the simulated and observed heads over the entire model area.

For discussion purposes, measured and model-calculated water levels are plotted for 30 select wells on Figures 18 through Figure 23 (all 122 hydrographs are included as Attachment 5). Hydrographs in the CMA (Figure 18) show close agreement between measured and simulated heads. Most of the simulated water levels were extracted from the main water bearing layers (model layers 2, 5, or 6) except for those wells located in areas where main water bearing formations do not exist or the water bearing formation is thin. Information of township and range, Stetson's database identification number, and the model layer where simulated heads were extracted from the WMA/CMA Model of all 122 target wells are summarized in Attachment 5. Closer comparisons occur in the alluvial areas of the CMA, compared to the relatively sparse data sites available in the Buellton Upland. Figure 19 shows simulated and measured data within the WMA river alluvium and Santa Rita Upland. Similar to the CMA, closer agreement between measured and model-calculated water levels in wells located in the alluvial aquifers compared to wells located in the upland aquifers. The hydrographs in Figure 20 show a very close match between simulated and measured groundwater level data in the Lompoc Plain and eastern edge of the Lompoc Upland – both in wet/dry seasonal trends and absolute values. Figure 21 continues west, showing target wells in the middle Lompoc Plain and along a tributary drainage in the Lompoc Upland. These wells show a very good match along the river, and a good match with distance from the river. Figure 22 and Figure 23 shows target wells in the western Lompoc Plain and near the Pacific coast where simulated groundwater levels are mostly within a few feet to about 10 feet of measured.

Review of the calibration results indicates that some observed measurements are significantly different from the simulated heads (i.e. at well 7N/33W-21N01 well located in the Santa Rita Upland with about 20 ft difference between the simulated and observed heads). These discrepancies may be the cause of large water level changes due to nearby pumping activities while measurements were taken or may be outliers. The larger discrepancies generally occur in the Lompoc Upland, Santa Rita Upland, and Buellton Upland areas where knowledge and water level measurements in those areas are fairly limited.

4.2 *SANTA YNEZ RIVER STREAMFLOW*

The SFR simulated streamflow at the of the USGS gaging stations 11133000, 11134000, 11135000, and 11135250 were also used during calibration of the model. Among these four (4) gaging stations, only the gaging station 11133000 (close to the Lompoc Narrows) has a complete monthly streamflow record between October 1981 and September 2018. Comparison of simulated versus measured streamflow at the

Lompoc Narrows gaging station 11133000 is presented monthly in Figure 24 and annually on Figure 25. The log-scaled scatter diagram (Figure 25) of simulated versus measured streamflow at the USGS gage near the Lompoc Narrows shows an R^2 value of 0.98. Figure 26 shows the limited measured data at USGS gage 11134000 at H Street compared with the simulated values from the WMA/CMA Model, with an R^2 value of 0.99. Figure 27 shows the limited measured data at USGS gage 11135000 at Pine Canyon compared with the simulated values from the WMA/CMA Model, with an R^2 value of 0.99. And Figure 28 shows the limited measured data at USGS gage 11135250 at 13th Street Bridge at VAFB compared with the simulated values from the WMA/CMA Model, with an R^2 value of 0.98.

5.0. Water Budgets

The model calculates a volumetric groundwater budget for each monthly stress period of all inflows and outflows throughout the model domain. Water Budget Technical Memoranda (Stetson, 2021) developed for the GSP give details of water budgets by subareas within the WMA and CMA. Figure 29 shows annual distribution of inflows, outflows, and changes of groundwater in storage simulated by the model from WY 1982 through WY 2018. The variability in natural recharge (inflow to the model) is typical of this semi-arid coastal region of California. Water demand from pumping and phreatophytic vegetation is fairly constant throughout this 37-year period. Groundwater in storage changes in response to the recharge variability, supplying groundwater to water demand during dry conditions (net storage change is negative) and replenishing the aquifer during wet conditions (net storage is positive).

6.0. MODEL SENSITIVITY

An analysis was conducted on the transient calibrated model to assess the sensitivity of the WMA/CMA Model input parameters. The sensitivity analysis results will assist in understanding and addressing uncertainties between the calibrated model and the predictive model. Input model parameters considered in the sensitivity analysis included:

- aquifer properties of horizontal and vertical hydraulic conductivity, specific yield, and specific storage,
- groundwater recharge from precipitation, drainage flow, mountain front flow, and municipal return flow,
- root extinction depth assigned in the Evapotranspiration Package, and
- effectiveness of the groundwater flow barrier located between the Santa Rita Upland and Buellton Upland as discussed in Section 3.3.5.

Evaluations of model changes due to model input parameters were performed by adjusting a single input parameter for each sensitivity run. Simultaneous adjustments of multiple model input parameters were not performed. The WMA/CMA Model's calibration run was used to assess comparative changes with each sensitivity analysis.

Because the change in groundwater elevation is a result of the change in groundwater storage, the goal of the sensitivity analysis is to measure the changes of groundwater storage as a result of adjustments of model input parameters. The significance level is quantified by calculating the change of simulated net groundwater storage between the sensitivity analysis model run and the calibration model run for the simulation period between October 1981 and September 2018. The sensitivity analysis focuses on the adjustments of aquifer properties of horizontal and vertical hydraulic conductivity (Kx and Kz), specific yield (Sy) and specific storage (Ss) and specific yield (Sy), groundwater recharge, root extinction depth, and horizontal hydraulic conductivity of the model flow barrier cells. A total of 18 sensitivity runs were performed. The tested parameters and range of adjustments, and the significance levels quantified for each simulation cases are summarized in Table 11.

Depending on the percentage changes in net groundwater storage with respect to the analyzed parameters, the significance level of the model to the tested parameters are generally classified into:

1) high sensitivity if the percentage change is generally greater than 20%,
2) moderate sensitivity if the percentage change is between 5% and 20%, and
3) low sensitivity if the percentage change is general less than 5%.

Based on the sensitivity classification discussed above, attention will focus on the high sensitivity parameters for future predictive simulations. Results of this analysis show that the WMA/CMA Model is highly sensitive to groundwater recharge and horizontal hydraulic, moderately sensitive to specific yield and root extinction depth, and least sensitive to vertical hydraulic conductivity and specific storage. Although the quantified significance level of the flow barrier located between the Santa Rita Upland and Buellton Upland is low, impacts from the flow barrier remain uncertain and will require further investigations as new geological information becomes available.

TABLE 11 PARAMETER ADJUSTMENTS IN THE WMA/CMA MODEL SENSITIVITY ANALYSIS

Analysis Run	Parameter	Parameter Adjustment	Storage Change (AFY)	%[1] Change	Significance Level
1	Kx	+ 100% in Model Layers 2, 5, 6	4,398	20.05%	High
2	Kx	- 50% in Model Layers 2, 5, 6	3,075	-16.07%	High
3	Kz	+100% in Model Layers 2, 5, 6	3,719	1.52%	Low
4	Kz	-50% in Model Layers 2, 5, 6	3,629	-0.93%	Low
5	Kx	+100% in Model Layers 1, 3, 4, 7, 8	4,777	30.39%	High
6	Kx	-50% in Model Layers 1, 3, 4, 7, 8	2,611	-28.74%	High
7	Kz	+100% in Model Layers 1, 3, 4, 7, 8	3,682	0.50%	Low
8	Kz	-50% in Model Layers 1, 3, 4, 7, 8	3,648	-0.41%	Low
9	Sy	+100% in Model Layers 2, 5, 6	3,917	6.91%	Moderate
10	Sy	-50% in Model Layers 2, 5, 6	3,439	-6.13%	Moderate
11	Ss	+1000% in Model Layers 2, 5, 6	3,735	1.94%	Low
12	Ss	-10% in Model Layers 2, 5, 6	3,655	-0.23%	Low
13	Recharge[2]	150% recharge increase	1,205	-67.10%	High
14	Recharge[2]	50% recharge decrease	6,319	72.48%	High
15	ET depth	150% root extinction depth increase	3,884	6.01%	Moderate
16	ET depth	50% root extinction depth decrease	3,306	-9.77%	Moderate
17	Kx	‘+1000% at flow barrier cells	3,721	1.57%	Low
18	Kx	‘-10% at flow barrier cells	3,659	-0.13%	Low
		Calibration Run	3,664		

Kx = horizontal hydraulic conductivity; Kz = vertical hydraulic conductivity; Sy = specific yield; Ss = specific storage; ET = evapotranspiration

1. % Change in Net Storage =
   [Sensitivity Run Net Storage Change – Calibration Run Net Storage Change] / Calibration Run Net Storage Change x 100%
2. Groundwater recharge consists of precipitation, drainage flow, mountain front flow, and municipal return flow.

7.0. Conclusions

The development of the WMA/CMA Model was primarily based on the WMA and CMA HCM (Stetson, 2020). The model was constructed to consist of eight (8) layers and 53,265 active cells to represent the geologic units including shallow river channel deposits and young alluvium, relatively deeper older alluvium and Orcutt sand, and the deepest Paso Robles and Careaga formations to evaluate groundwater conditions, surface water and groundwater communications, and streamflow of the Basin for the period between WY 1982 and WY 2018 (model calibration period). Results of the WMA/CMA Model simulations provide an improved understanding of the Basin’s groundwater conditions related to various stresses that have occurred in the Basin. In addition, the predictive model runs can assist in future management prioritization for the implantation of groundwater sustainability plan.

8.0. MODEL LIMITATIONS

The WMA/CMA Model is a regional groundwater flow model and constructed with simplifying assumptions and limited data. These include,

- Lack of observed groundwater elevations, particularly in the Lompoc Upland, Santa Rita Upland and Buellton Upland areas.
- Although aquifer properties assigned to the WMA/CMA Model are based on the general aquifer characteristics and limited aquifer tests and applied over relatively large areas.
- The evapotranspiration from phreatophytic riparian vegetation is simulated with monthly ET rates that do not vary year by year. This assumption does not address changes in vegetation over time.
- The low hydraulic conductivity cells assumed in areas between the Santa Rita Upland and Buellton Upland (Section 2.5.5) may restrict the westerly groundwater flow from the Buellton Upland to the Santa Rita Upland, mechanics of the flow barrier are not fully understood, consequently, quantification of the subsurface flow between the Santa Rita Upland and the Buellton Upland is estimated.
- The WMA/CMA Model was constructed as a regional groundwater flow model to assess large-scale groundwater conditions in the WMA and CMA. Caution is needed when considering its use for relatively smaller, more localized applications.

9.0. References

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