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Santa Clarita Valley Water Agency

Development of a Numerical Groundwater Flow Model for the Santa Clara River Valley East Groundwater Subbasin

Santa Clarita, California

September 22, 2020

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Abbreviations and Acronyms

AFY	acre-feet per year
ASR	aquifer storage and recovery
ASTM	American Society for Testing and Materials
BMPs	Best Management Practices
CGSTAB	Orthomin/stabilized conjugate-gradient package
CHD	time-variant specified head package
CIMIS	California Irrigation Management Information Service
CLN	Connected Linear Network
CVFD	control volume finite difference
DEM	digital elevation model
DWR	California Department of Water Resources
ET	evapotranspiration
EVT	Evapotranspiration package
EVT	Evapotranspiration package
FEIS	U.S. Forest Service Fire Effects Information System
ft/day	foot per day
ft^2/day	square feet per day
GAGE	Gage (GAGE) package
GHB	General Head Boundary package
GIS	geographic information systems
gpd	gallons per day
gpd/ft	gallons per day per foot
GSP	groundwater sustainability plan
GUI	graphical user interface
GV	Groundwater Vistas
HFB6	Horizontal Flow Barrier
I-5	Interstate 5
LACFCD	Los Angeles County Flood Control District
LACWWD36	Los Angeles County Waterworks District 36
NAVD88	North American Vertical Datum of 1988
NED	National Elevation Dataset
NWD	Newhall Water Division
RCH	Recharge package
regional model	Santa Clarita Valley Groundwater Flow Model
SCV Water	Santa Clarita Valley Water Agency
SCV-GSA	Santa Clarita Valley Groundwater Sustainability Agency
SCVGWFM	Santa Clarita Valley Groundwater Flow Model
SCWD	Santa Clarita Water Division
SFR7	Streamflow Routing package

SGMA	State of California’s Sustainable Groundwater Management Act
SMS	Sparse Matrix Solver package
TIB	Transient IBOUND package
TNC	The Nature Conservancy
USGS	U.S. Geological Survey
UWCD	United Water Conservation District
valley	Santa Clarita Valley (the valley),
VWD	Valencia Water Division
WRP	water reclamation plant
WEL	Well package

SECTION 1: **Introduction**

1.1 Background

This report describes the development of a three-dimensional numerical groundwater flow model for the Santa Clarita Valley (the valley), located in northwestern Los Angeles County, California. The model simulates conditions in the local groundwater basin, which is defined in California Department of Water Resources (DWR) Bulletin 118 as the Santa Clara River Valley East Subbasin (DWR Basin 4-4.07). As shown in Figure 1-1, the East Subbasin is the eastern-most and furthest upstream subbasin in the group of six subbasins that together comprise the Santa Clara River Valley Groundwater Basin.

The groundwater model simulates the occurrence and movement of groundwater flow in the East Subbasin, which contains two aquifers: a surficial aquifer called the Alluvial Aquifer and an underlying thick aquifer system that is present in a geologic unit called the Saugus Formation. The model simulates groundwater flow processes and groundwater budgets in both aquifers, as well as the connection of the local groundwater resources to the Santa Clara River and its tributaries. The model uses multiple layers to provide a three-dimensional representation of groundwater movement horizontally within individual model layers and vertical movement between layers. This model is called the Santa Clarita Valley Groundwater Flow Model, and is referred to in the remainder of this report as the SCVGWFM or the regional model. This model uses the U.S. Geological Survey (USGS) software MODFLOW-USG (Panday et al., 2013; Panday, 2019) and replaces a model that was first developed in 2004 (CH2M HILL, 2004a) using the European MicroFEM® finite-element software (Hemker and de Boer, 2003 and 2017). The model has been developed by GSI Water Solutions, Inc. (GSI), for the Santa Clarita Valley Water Agency (SCV Water) to use as its primary tool for analyzing groundwater management options in the context of future water demand and water supply conditions in the valley. Figure 1-2 is a map showing the locations of the service areas for SCV Water, its three retail divisions (the Newhall Water Division [NWD], the Santa Clarita Water Division [SCWD], and the Valencia Water Division [VWD]), and a fourth retailer (Los Angeles County Waterworks District 36 [LACWWD36]) that works cooperatively with SCV Water on groundwater basin management and planning activities. Figure 1-3 shows the locations of production wells that were present as of 2019, categorized by whether they are completed in the Alluvial Aquifer or the Saugus Formation.

1.2 Modeling Objectives

In accordance with the requirements of the State of California's Sustainable Groundwater Management Act (SGMA), the Santa Clarita Valley Groundwater Sustainability Agency (SCV-GSA) is developing a groundwater sustainability plan (GSP) for the East Subbasin. As the local wholesaler and supplier of municipal water supply in the Santa Clarita Valley, SCV Water is working cooperatively with the SCV-GSA to develop and implement the GSP. As part of supporting GSP development, and to facilitate future groundwater management activities, SCV Water commissioned the development of a MODFLOW-USG version of the regional model for the purposes of (1) using well known and widely used software that is in the public domain (MODFLOW-USG) and (2) providing detailed and sophisticated methods of simulating stream/aquifer interactions to support future water budget analyses and subsequent GSP planning and implementation activities. This new regional model (the SCVGWFM) has been designed and developed to support GSP development and implementation as follows:

1. The model will be used to develop historical, present, and future water budgets as required by SGMA and as described by DWR in two documents that provide Best Management Practices (BMPs) for groundwater modeling (2016a) and water budget development (DWR, 2016b). Climate change

effects on pumping sustainability will also be assessed using the model, as described in DWR's two climate change guidance documents (2018a and 2018b).

2. The model will be used to help develop minimum thresholds and measurable objectives for sustainability indicators.
3. The model will be used to assess the effectiveness and benefits of a range of programs and projects designed to maintain the sustainability of pumping in the basin and avoid undesirable results.
4. The model will be used to help evaluate the potential effects of groundwater management activities on surface water resources and groundwater-dependent ecosystems (GDEs), which is one sustainability indicator under SGMA.
5. The alternatives evaluation is anticipated to consider a variety of different strategies for groundwater pumping, banking of imported and/or treated water supplies, and discharges of treated water into the Santa Clara River.
6. The new regional model will be used to guide development of the GSP and support future implementation and monitoring programs, and, given the model's ability to simulate groundwater levels in pumping and non-pumping wells, provide detailed water budgets anywhere desired in the model domain, as well as calculate in-stream flow rates.
7. The model's simulation capabilities and its familiarity to the groundwater modeling community will support model review efforts and future refinements when needed—attributes that in turn are expected to support stakeholder communications and engagement.

1.3 Previous Hydrogeological, Water Use, and Modeling Studies

Groundwater level and pumping records in this groundwater basin have been maintained by the purveyors and certain private well owners for many years, in some cases dating back to the 1950s. Additionally, the basin's geology and hydrology have been the subject of several prior studies, and several other studies have used groundwater modeling to support planning efforts related to water supply sustainability and groundwater quality protection. Following is a list of the studies that are most pertinent to the development of the regional model:

- **Basin-Wide Hydrogeologic Characterization Studies (RCS, 1986, 1988, 2002).** Richard C. Slade & Associates (RCS) conducted studies to characterize the extent, thickness, and geologic structures in the Saugus Formation (RCS, 1988 and 2002) and the Alluvial Aquifer (RCS, 1986). These reports also summarize water well construction and testing information and basin-wide groundwater elevation and groundwater quality. These studies provide the basis for understanding geologic conditions regionally and in local sub-areas.
- **Geophysical and Hydrogeologic Characterization Study at the Los Angeles (LA)/Ventura County Line (Geomatrix, 2007).** As part of a study to develop Total Maximum Daily Loads (TMDLs) for the Santa Clara River, Geomatrix conducted a surface geophysics program to evaluate the total thickness and saturated thickness of the Alluvial Aquifer at and near the LA/Ventura County Line. The study was conducted to fill a data gap arising from the absence of wells in this area. The field program consisted of first drilling soil borings and conducting geophysical logging in each boring, followed by conducting seismic refraction sounding surveys along four profile lines totaling approximately 9,000 linear feet. Of the four profile lines, one was conducted along an access road located at the LA/Ventura County Line (County Line), and a second was conducted approximately 0.8 mile upstream of the County Line along an access road

leading to the mouth of Potrero Canyon. These two profiles provided critical data for defining the thickness of the Alluvial Aquifer in the new regional model for the East Subbasin.

- **Development of Prior Conceptual and Numerical Groundwater Models (CH2M HILL, 2004a and 2005; GSI and LSCE, 2013).** These reports document the initial development of—and refinements to—the local water purveyors' prior numerical model, which used the MicroFEM finite-element software (Hemker and de Boer, 2013 and 2017). The original model used seven layers to simulate the variability in aquifer thickness across the East Subbasin. As discussed by GSI and LSCE (2013), one of the model layers in the Saugus Formation later was subdivided to provide more vertical resolution in the model simulations, which resulted in the model using eight layers to simulate groundwater flow. Through the course of the three work efforts documented by the above-referenced reports, the model was calibrated to a 32-year record of monthly groundwater elevations and estimates of monthly groundwater discharges to the Santa Clara River (derived from streamflow and other records).
- **Annual Reports (such as LSCE, 2020).** These reports provide information annually about the water supply conditions for the Santa Clarita Valley, including the annual volumes of groundwater pumping and other water uses dating back to 1980. Each annual report describes the state of the local groundwater resources, as well as the state of water supply requirements and other sources of water supply to the valley. Each report reviews the sufficiency and reliability of water supplies to meet the prior year's demand, and then provides a short-term outlook of water supply and demand for the following year. These reports have been prepared annually since 1998 for the local wholesale and retail water purveyors to use for their internal future reference and for communications with local stakeholders.

The new regional model (using the MODFLOW-USG software) builds upon the capabilities of the original model (using the MicroFEM software). As such, the original model was an important starting point for development of the new regional model. The original model was developed as part of a Memorandum of Understanding (MOU) that was entered into in August 2001 by the local water purveyors and the United Water Conservation District (UWCD), located downstream in Ventura County.[1] The new regional model uses the original model's layering system to represent the two aquifers in the basin, uses similar techniques and tools to define groundwater recharge and discharge processes in the model, and relies on the historical records of groundwater levels and streamflows compiled over the years for prior model calibration purposes (with additional data for the years 2013 through 2019). The original model was used for several past studies, including the following:

- Evaluating the long-term sustainability, or operational yield, of the Alluvial Aquifer and the Saugus Formation for multi-decadal periods of fluctuating local hydrology and imported water availability (CH2M HILL and LSCE, 2005; LSCE and GSI, 2009) which has supported the development of the 2015 Urban Water Management Plan (UWMP; KJC et al., 2015) and prior UWMPs since 2005
- Evaluating offsite pumping strategies to capture, contain, and prevent further spreading of a perchlorate plume that is present in the Saugus Formation near the Whittaker-Bermite property (CH2M HILL, 2004b; GSI and LSCE, 2014)
- Developing time-varying groundwater budgets (GSI, 2014a) to support development of the basin's Salt Nutrient Management Plan
- Evaluating alternative locations and rates for recharge of the Alluvial Aquifer by infiltrating treated water and/or imported water supplies in spreading basins (Carollo, 2015; Kennedy/Jenks, 2016; GSI, 2017a)

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[1] Memorandum of Understanding Between the Santa Clara River Valley Upper Basin Water Purveyors and United Water Conservation District. August 2001.

- Evaluating aquifer storage and recovery (ASR) of imported water supplies as a method for augmenting pumping capacities from the Saugus Formation during curtailment years for imported water supplies (Carollo, 2015)
- Evaluating the potential rates and locations of temporary groundwater pumping redistribution to respond to short-term water level declines in certain Alluvial production wells at the east end of the basin during the middle of the recent drought that began in the latter half of 2011 (GSI, 2014b)
- Evaluating the potential range of effects of climate change on groundwater recharge rates and timing (from precipitation and streamflows) and on the basin pumping plan (LSCE and GSI, 2009; GSI, 2017b)

1.4 Conceptual Model Overview

A conceptual model of a groundwater basin's hydrogeology and water supply conditions is a descriptive construct that serves as the primary underlying basis for developing a numerical groundwater flow model. A conceptual model typically describes the basin's geographic setting and climate; its geology and the water-bearing potential of its various geologic units; groundwater occurrence and movement, including the connections that exist between multiple aquifers in a basin; the hydraulic properties of its aquifers; recharge and discharge processes for the basin's aquifers; the amounts and local uses of groundwater and other water supplies; and the temporal aspects of water use and the natural hydrologic system.

The East Subbasin lies within the relatively flat-lying Santa Clarita Valley and portions of the surrounding hills and mountains. Developable quantities of groundwater are present in the alluvium and in portions of the Saugus Formation. These units are underlain and laterally bounded by non-water-bearing bedrock units that are Miocene, Oligocene, and pre-Tertiary in geologic age and which do not contain significant quantities of water that can be developed for municipal purposes. Figure 1-4 shows the location of the groundwater basin within the local watershed, and Figure 1-5 identifies the tributaries and subwatersheds that extend upstream of the groundwater basin boundary and contribute surface flow into the groundwater basin area.

The hydrologic processes that affect groundwater conditions in the Alluvial Aquifer and the Saugus Formation are the following:

- Groundwater recharge processes, which consist of:
  - Deep percolation of precipitation directly over the basin
  - Streambed leakage of storm flows in ephemeral streams
  - Streambed leakage of water that is discharged into the Santa Clara River from two water reclamation plants (WRPs), the Saugus and Valencia WRPs; see Figure 1-2 for their locations
  - Streambed leakage of water that is discharged into Castaic Creek from periodic water releases out of Castaic Lagoon
  - Streambed leakage of water that is discharged into Bouquet Creek from periodic water releases out of Bouquet Reservoir
  - Deep percolation of water that is used for irrigation of certain agricultural lands
  - Deep percolation of water that is used outdoors in urban areas
  - Deep percolation from septic systems in certain rural areas where residential developments are served by public water supplies, but not sanitary storm sewers
  - Lateral subsurface inflow of groundwater into the Alluvial Aquifer (beneath Castaic Dam and where tributaries enter the groundwater basin)
- Groundwater discharge processes, which consist of:

  - Groundwater extraction (pumping) by agricultural, municipal, and private domestic well owners
  - Evapotranspiration by deep-rooted phreatophytes (withdrawing water from the water table, not just from the unsaturated zone)
  - Groundwater discharge to streams (primarily to portions of the Santa Clara River west of the mouth of Bouquet Canyon)
- Changes in the volume of groundwater in storage

The Alluvial Aquifer is present in the alluvial valley occupied by the Santa Clara River and also in alluvium that lies in each tributary valley. Development of agricultural and municipal groundwater supplies from this unconfined aquifer has occurred primarily along the Santa Clara River and Castaic Creek, and also in the lower reaches of Bouquet Canyon and San Francisquito Canyon. The Saugus Formation contains lenticular and interfingered beds of poorly to well-consolidated sandstone, conglomerate, and siltstone that are at least 7,500 feet thick in the deepest part of the basin. RCS (1988 and 2002) found that the groundwater-yielding capability of the Saugus Formation is likely limited north and east of the San Gabriel Fault compared with areas lying south and west of the fault (where all Saugus groundwater development has occurred to date).

See Appendix A for further discussions of the basin's geographic setting, climate, geology, and groundwater occurrence. Section 3 of this report contains more in-depth discussions and quantification of the hydrologic processes and historical water uses in the East Subbasin.

1.5 Report Organization

The remainder of this report is organized as follows:

- Section 2 discusses the selection of the groundwater flow model software code, then provides a description of the code's design, its input and output files, and other supporting software.
- Section 3 discusses the construction of the numerical model, including the modeling software; the extent of the model domain; the design of the model grid spatially and vertically; the model's boundary conditions and the modeling packages that represent them; the estimation of groundwater recharge rates to use in the model; the assignment of groundwater pumping rates and their allocation among layers; and initial estimates of the potential ranges in magnitude of aquifer hydraulic properties (transmissivity, horizontal and vertical hydraulic conductivity, storativity, and specific yield).
- Section 4 describes the calibration process for the numerical model; the historical data sets that were used to conduct calibration and their method of simulation in the model; the calibration results; observations of model parameter sensitivity that were made during calibration; and the outcome of the calibration process as it relates to the model's usefulness and limitations.
- Section 5 discusses the applicability of the numerical model for use in managing local groundwater resources, including a summary of certain key attributes that make it useful for these purposes.
- Section 6 is a list of references cited in this report.
- Appendices A through E provide supporting material.
  - Appendix A Summary of Physical Setting and Hydrogeology for the East Subbasin
  - Appendix B SCV Recharge Compiler
  - Appendix C 2007 Geophysical Study Report
  - Appendix D Published Groundwater Elevation Contour Maps for the Year 2000
  - Appendix E Stream Gage Sites

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SECTION 2: **Selection and Description of the Modeling Software**

The GSP regulations state the following regarding the software codes to be used under SGMA for groundwater and surface water models:

> *23 CCR §352.4(f) Groundwater and surface water models used for a Plan shall meet the following standards:*
> *(1) The model shall include publicly available supporting documentation.*
> *(2) The model shall be based on field or laboratory measurements, or equivalent methods that justify the selected values, and calibrated against site-specific field data.*
> *(3) Groundwater and surface water models developed in support of a Plan after the effective date of these regulations shall consist of public domain open-source software.*

As stated by DWR's BMP guidance document for groundwater resources modeling (DWR, 2016a), the public domain and open-source software requirement only applies to model codes that solve the equations for groundwater flow and transport, and does not apply to other supporting tools and software that are used to generate model input files or process model output data. The modeling BMP also discusses that it is highly likely that a groundwater model will be part of an ongoing long-term effort to support and provide for sustainable management of a groundwater basin; accordingly, the model must be able to be adapted to refined hydrogeologic interpretations and to incorporate additional data that are acquired over time from studies and monitoring programs.

In addition to the SGMA requirements for modeling software, SCV Water sought specific capabilities in a new groundwater model, particularly relating to estimating surface water flow rates in streams, interfacing with visualization software, and supporting peer-review and stakeholder engagement processes during GSP development. Accordingly, this section of the report discusses the process for selecting the software tools (Section 2.1), a description of the core groundwater modeling software and its input and output files (Sections 2.2 and 2.3), and a description of two other software tools that support the groundwater modeling software (Section 2.4).

2.1 Software Selection

Prior to development of the new regional model, SCV Water and GSI conducted an evaluation in early 2018 of multiple software codes that provide three-dimensional numerical solution capabilities for groundwater flow, capture-zone, and flowline analyses, and that can support water quality studies in some manner. Codes that were evaluated were the finite-element model MicroFEM; two groundwater flow models developed by the USGS (the structured finite-difference-grid model MODFLOW-NWT [Niswonger et al., 2011] and the unstructured-grid version of MODFLOW named MODFLOW-USG [Panday et al., 2013; Panday, 2019]), and an integrated watershed-groundwater model developed by the USGS (GSFLOW [Markstrom et al., 2008]), which uses an older version of the MODFLOW structured finite-difference-grid software for its groundwater simulations (MODFLOW-2005 [Harbaugh, 2005]). The comparison of these codes was conducted using an evaluation similar to, but more detailed than, that described by DWR in its BMP document for groundwater modeling under SGMA (see Figure 4 in the modeling BMP) (DWR, 2016a). Each model was evaluated using qualitative and quantitative ranking systems that evaluated each software code against 43 different capabilities and characteristics that were grouped into the following five categories:

- Methods for simulating surface water/groundwater exchanges and for simulating hydrologic processes in stream channels
- Methods for simulating surface hydrologic processes outside of stream channels

- Methods for simulating groundwater hydraulics, with particular emphasis on simulating well/aquifer interactions and drawdown in the long-screened production wells in the Saugus Formation (which span multiple model layers)
- Numerical implementation methods, such as flexibility in grid design; simulation of the drying and potential re-wetting of individual model grid cells over time; the types of solver algorithms and the ability to adjust solver parameters to increase run-time efficiency and solution accuracy; and other run-time logistical characteristics (such as memory requirements, file sizes, and file management)
- Other implementation considerations, including the availability of (and support by) commercially-or publicly available graphical user interfaces (GUIs); access to technical support and training; linkages to particle-tracking and solute-transport models and calibration software; data exchange with geographic information systems (GIS) and data visualization and animation software tools; and the familiarity of the groundwater modeling community outside of the USGS with each software code

The analysis resulted in MODFLOW-USG and MODFLOW-NWT scoring substantially higher than GSFLOW and MicroFEM because of their particularly robust groundwater simulation capabilities, the availability of well-supported GUIs, their detailed and flexible solvers, their ability to communicate with other software packages, the broad familiarity and support of the groundwater modeling community with the MODFLOW family of software codes and the GUIs that support them, and the subsequent benefits that are expected to accrue to SCV Water during peer reviews of the model and communication with external stakeholders. While the MicroFEM software has also provided robust simulation capabilities to date, the MODFLOW-USG model offers additional benefits as follows:

1. It is part of the MODFLOW family of software tools, which are the most widely known models in the groundwater and hydrologic modeling community. These tools are widely used and are supported by multiple GUIs and visualization programs that facilitate the pre-processing, post-processing, information management, and visualization aspects of groundwater modeling efforts. The USGS provides ongoing support and continued development of the MODFLOW family of modeling codes, and training programs and conferences are widely available through the USGS and other public and private entities.
2. MODFLOW-USG provides a variety of flexible gridding methods and grid types that allow a grid to have high spatial resolution where needed (such as the finite-element method built into MicroFEM®), without adding more grid nodes/cells in places where higher resolution is unnecessary. These gridding methods also provide the capability to simulate the thinning and pinching out of model layers/geologic units in a more robust manner than is available with the other software codes that were evaluated.
3. MODFLOW-USG provides more detailed and sophisticated methods of representing stream/aquifer interactions than are available in MicroFEM, including in particular the ability to calculate flow rates and instream channel hydraulics during the groundwater solution process.
4. MODFLOW-USG has a robust Connected Linear Network (CLN) package that greatly facilitates the process of simulating water levels in long-screened production wells, such as those in the Saugus Formation. This package is similar to the MNW2 package (Konikow et al., 2009) that is used for structured grids in MODFLOW-NWT (Niswonger et al., 2011) and MODFLOW-2005 (Harbaugh, 2005). However, the CLN package allows for specification of well efficiency values, whereas MNW2 makes use of empirical well-loss coefficients that are often unmeasured or are substantially harder to derive than well efficiency estimates.
5. Packages that are available in the structured version of MODFLOW (MODFLOW-NWT; Niswonger et al., 2011) are also supported by MODFLOW-USG, most importantly including:
    a. The Streamflow Routing (SFR7) package, which is based on the SFR2 package (Niswonger and Prudic, 2010) for structured grids and is used to simulate both the perennial and ephemeral

reaches of the Santa Clara River, as well as each of the ephemeral tributaries to the Santa Clara River;

   b. The Evapotranspiration (EVT) package, which simulates groundwater withdrawal by phreatophytes; and
   c. The Horizontal Flow Barrier (HFB6) package, which is based on the original HFB package of Hsieh and Freckleton (1993) and which simulates the flow-limiting influence of fault zones.

6. MODFLOW-USG provides the capability to simulate the movement and concentration of inorganic (geochemical) constituents and organic chemicals in groundwater, using the Block-Centered Transport process documented by Panday (2019).

Compared with the original model, SCV Water and GSI identified that the basin's groundwater modeling capabilities and local water resources management/planning activities would benefit from MODFLOW-USG having the following attributes and functionality:

- Substantially more sophisticated and direct simulation of the occurrence of dry cells and the time-dependent variability in dry compared with partially or fully saturated conditions in a given model cell
- Substantial gains in the flexibility to adjust solver parameters, which facilitates solution convergence and run-time efficiency (particularly when the model contains dry cells)
- Substantial efficiency gains and decreased time requirements for conducting detailed analyses of groundwater elevations, groundwater budgets, and stream/aquifer interactions;
- Increased flexibility to modify the spatial grid, the model's layering, and the various input terms that are needed to represent surface and subsurface hydrologic processes
- Increased efficiencies conducting sensitivity analyses, updating/checking model calibration, choosing efficient solver algorithms, minimizing model run times, streamlining file management, and linking to Cloud computing resources if warranted
- Substantially greater capabilities contained in commercial GUIs, which facilitates (1) visualizing and managing the modeling process real-time; (2) evaluating, displaying, and reporting model output; and (3) importing and exporting geologic and hydrologic data and simulation results with other commercial packages for 3D visualization and animation

2.2 MODFLOW-USG Code Description

As described by Panday et al. (2013), MODFLOW-USG was developed to support a variety of unstructured grid types that can provide a user with the ability to generate spatially irregular types of grids, in marked contrast to the rectangular (structured) grids that are common to finite-difference models such as MODFLOW-NWT and its predecessors. The types of irregular (unstructured) grids supported by MODFLOW-USG include local rectangular grids nested inside a structured regional model grid, and other grid types that do not require the use of a structured parent grid but instead can solely make use of prismatic triangles, rectangles, hexagons, and other cell shapes. The new regional model for the East Subbasin uses Quadtree gridding methods, which consist of high-resolution (small) rectangular cells that can be arranged in an irregular geometry within the lower-resolution (larger cells) parent grid. Rather than representing the three-dimensional groundwater flow equation using the traditional finite-difference formulation inherent to structured grids, MODFLOW-USG uses a control volume finite difference (CVFD) formulation, which allows a given model cell to be connected to an arbitrary number of adjacent cells, thereby providing significant capability to connect areas of low and high spatial resolution and to simulate the thinning and pinching out of individual model layers.

Like its predecessor code MODFLOW-NWT, the MODFLOW-USG code provides robust solution methods for solving the drying and rewetting of individual cells in the model grid. This is achieved using an upstream weighting approach for calculating inter-cell hydraulic conductance terms, and by addressing the nonlinearities of the unconfined groundwater-flow equation that arise during cell drying and rewetting by using a Newton-Raphson formulation for the nonlinear solver. The upstream weighting method treats the nonlinearities of cell drying and rewetting by using a continuous function of groundwater head, rather than discrete methods used in earlier versions of MODFLOW. This formulation creates an asymmetric matrix that must be solved, unlike the standard MODFLOW formulations for structured grids which solve a symmetric matrix. Accordingly, MODFLOW-USG contains a new solver package called the Sparse Matrix Solver (SMS) package, which for the linear solver includes an Orthomin/stabilized conjugate-gradient (CGSTAB) package called χMD (Ibaraki, 2005). As stated in the documentation for MODFLOW-USG, the SMS package provides several methods for resolving nonlinearities and supports multiple symmetric and asymmetric linear solution schemes to solve the matrix arising from the flow equations and the Newton-Raphson formulation, respectively. For the new regional model in the East Subbasin, GSI to date has primarily used the Delta-Bar-Delta/Newton-Raphson nonlinear solution method and the χMD Orthomin/linear solver for most simulations.

2.3 MODFLOW-USG Input and Output Files

The primary input and output files associated with a given MODFLOW-USG simulation of the new regional model for the East Subbasin are as follows.

2.3.1 Input Files

Twenty primary input files are used to construct and run the MODFLOW-USG flow model simulations for the new regional model in the East Subbasin. These are:

- The .NAM file, which lists the names of all input files to be read and all output files to be created (see also the .MFU file created by the GUI which runs the model)
- The .BAS file, which identifies which cells are active versus inactive in each model layer, and which also specifies the initial groundwater elevations to use at each active cell in the model
- The .LPF file, which specifies the layer type flag (which is set to a value of 4 for upstream weighting), the method of calculating interblock transmissivity, the values of aquifer properties (horizontal and vertical hydraulic conductivity and anisotropy, specific yield, and specific storage), and the head value to be specified for dry cells
- The .DIS file, which contains grid discretization information, including the number of grid nodes, the horizontal area of each grid cell/node, the number of layers, the top and bottom elevations of each grid cell/node, stress period and time step information, and the measurement units for length and time (see also the files *nodes.csv* and *nodes_xyz.csv* for other related grid information)
- The .SMS file, which contains the specifications for the linear and nonlinear solver routines
- The .OC file, which is the output control file specifying the writing of results to the model run log file (the .LST file) and to the various binary output files containing the model results
- Eleven separate files for flow processes:
  - The .RCH file for the recharge package
  - The .EVT package for evapotranspiration (by phreatophytes withdrawing water from the water table)
  - The .CHD file for time-variant specified heads
  - The .HFB file for faults

  - The .SFR file for groundwater/surface water interactions
  - The .GAG file for streamflow calculations
  - The .WEL file for specified subsurface inflows
  - The .GHB file for head-dependent subsurface inflows
  - The .CLN file for connected linear networks (wells spanning multiple model layers), along with the *well-info.csv* file containing basic data for each CLN well
  - The .TIB file for the transient IBOUND array (which specifies the periods that CLN wells are not physically present during a transient simulation, as documented by Panday [2019])

2.3.2 Output Files

Each simulation of the new regional model creates the following seven output files for each period during the simulation:

- The .HDS file, which is a binary file containing the computed heads (groundwater elevations) calculated at each node in the aquifer matrix
- The .CLN.HDS file, which is a binary file containing the computed heads inside each CLN well
- The .DDN file, which is a binary file containing the drawdowns (the changes in water levels since the beginning of the simulation) at each node in the aquifer matrix
- The .CBB file, which is a binary file containing the cell-by-cell flux terms in and out of each cell face in the aquifer matrix
- The .CBCLN file, which is a binary file containing the computed flux terms in and out of each CLN well
- The FLOWREDUTION.DAT file, which is a text file listing any reductions in pumping (due to dewatered cells) that might have occurred at one or more wells at any given period during the simulation
- The GAGE_STR.DAT file, which is a text file providing the streamflow and channel calculations from the SFR7 package for each period during the simulation

2.4 Supporting Software

In addition to using MODFLOW-USG, the new regional model relies on other two key companion codes for its successful operation.

2.4.1 Graphical User Interface

Version 7 of Groundwater Vistas (GV) is the GUI that was used to develop the model and manage the modeling process (ESI, 2017). GV is a popular and widely used program for managing model simulations and has an enhanced level of support for MODFLOW-USG. GV supports the entire family of MODFLOW codes for groundwater flow, particle-tracking, and solute transport. GV also supports certain codes developed by parties other than the USGS, including (1) the mod-PATH3DU particle-tracking code (Muffels et al., 2018) developed specifically for MODFLOW-USG and (2) the PEST suite of utilities for model calibration (Doherty and Hunt, 2010; Doherty et al., 2010a and 2010b). The new regional model was developed primarily using Version 7.24, Build 220 of GV, which was released in May 2020. The simulations developed to date with the new regional model (using GV Version 7) are expected to be readily usable in future versions of GV, based on its long record of compatibility importing existing models into newly upgraded versions of the GV software.

2.4.2 SCV Recharge Compiler

The SCV Recharge Compiler is a Visual Basic program developed in Microsoft Excel that was written by GSI to translate all recharge terms into the form that is needed by the Recharge (RCH) Package for MODFLOW-USG. This tool specifies the total amount of recharge occurring at each grid node in the uppermost model layer, and for each period during a given model simulation. The design of this tool also allows for calibration of various recharge terms, such as the relationship between rainfall and deep percolation outside of streambeds, and the infiltration rates (streambed hydraulic conductivity values) for ephemeral reaches of streams. This tool also estimates the surface flow entering the model in ungaged tributary streams from the upper reaches of their watersheds (i.e., the portion of the watershed upstream of the East Subbasin), and it provides mechanisms for tracking and infiltrating this flow as a given ephemeral stream enters the groundwater basin. Figure 2-1 shows the hydrologic processes that are implemented in the SCV Recharge Compiler, and shows the process flow chart for use of this tool during a given model simulation. See Appendix B for further details about the construction of this tool and the specification of input values for the various hydrologic processes that it evaluates.

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SECTION 3: **Model Construction**

Following are discussions of the new regional model's grid design (Section 3.1); its layering (Section 3.2), its boundary conditions (Section 3.3); the methods and data used to estimate groundwater recharge rates (Section 3.4); the assignment of historical pumping in the model, from both the Alluvial Aquifer and the Saugus Formation (Section 3.5); and the assignment of aquifer physical properties (Section 3.6).

3.1 Grid Design

The grid uses the California State Plane Zone 5, North American Datum of 1983 (NAD83) horizontal coordinate system. The grid consists of square cells having a 500-foot regular grid spacing regionally (in the parent grid), with a Quadtree grid consisting of square cells 250 feet on a side embedded in the parent grid to represent (1) the Alluvial Aquifer and (2) adjoining areas in the Saugus Formation where production wells and observation wells are present or are anticipated to be present in the future. The 250-foot cell size for the Quadtree grid was chosen to provide greater resolution than the parent grid, while avoiding smaller cell sizes that would have posed problems for simulating flow in the Santa Clara River under conditions other than drought periods or summer-season low-flow conditions.

Figure 3-1 shows the active portion of the grid in the uppermost model layer (Layer 1). The areal extent of this active grid largely conforms with DWR's Bulletin 118 basin boundary but has minor departures arising from (1) geologic mapping from prior local studies (RCS, 1988 and 2002) and (2) excluding the area where Castaic Lake is present (DWR, 2016c). The active portion of the grid contains 33,952 cells in the uppermost model layer, occupying an area of 60,762 acres (95 square miles [mi^2]). The grid includes a large surrounding area that is inactive in the model, including the location of the Piru Subbasin (DWR Basin 4-4.06). In total, the active and inactive portions of the grid contain 74,342 cells occupying an area of 246,550 acres (385 mi^2). The corner of the grid is inactive and is located at easting 6,296,583 feet and northing 1,947,887 feet. The grid is aligned with true north (i.e., is not rotated).

3.2 Layering

The model uses 8 layers to represent the East Subbasin's groundwater resources. The uppermost layer (Layer 1) contains the Alluvial Aquifer and (in adjoining areas) the Saugus Formation. Layers 2 through 8 represent just the Saugus Formation. The base of the Saugus Formation represents the bottom of the deepest member (the Sunshine Ranch Member) comprising the Saugus Formation, with its depth/elevation defined from mapping estimates developed by RCS (1988 and 2002). As shown by the grid maps presented in Figures 3-2 through 3-8, the areal extent of the Saugus Formation decreases with depth.

Figures 3-9 through 3-16 are maps showing the bottom elevations of each model layer, and Figures 3-17 through Figure 3-24 are maps showing the resulting layer thicknesses arising from the bottom elevation contours and the digital elevation model (DEM) that represents the ground surface elevation. The DEM that was used to construct the model's layers was obtained from the 2013 National Elevation Dataset (NED) published by the USGS and titled *USGS NED n35w119 1/3 arc-second 2013 1 x 1 degree ArcGrid*.[2] This DEM uses the North American Vertical Datum of 1988 (NAVD88) as its vertical datum. The use of 8 model layers and the definitions of the contact elevations for the top and bottom of each layer in the new regional model conform to the 8-layer design used in the MicroFEM model, as described by GSI and LSCE (2013). Further details regarding layering design are described below.

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[2] USGS online data source. Available at the USGS website https://catalog.data.gov/dataset/usgs-ned-n35w119-1-arc-second-2013-1-x-1-degree-arcgrid86566. (Accessed July 13, 2020.)

3.2.1 Alluvial Aquifer

The shape of the bottom elevation of the Alluvial Aquifer generally mimics the ground surface elevation changes within the alluvial valleys occupied by the river and its tributaries, and also incorporates estimates of alluvium thickness and saturated thickness developed in local geologic studies.

3.2.1.1 Elevation Gradient

The Santa Clara River occupies a valley that has an elevation change of approximately 1,050 feet over a distance of approximately 21 miles, for an average elevation gradient of approximately 50 feet per mile. However, this gradient changes significantly along the length of the river as follows:

- **Eastern Portion of the Valley.** The riverbed elevation drops 720 feet from where the river enters the Santa Clarita Valley at the Lang Gage to the mouth of Bouquet Canyon (a distance of approximately 12.2 miles), for an elevation gradient of nearly 60 feet per mile.
- **Central Portion of the Valley.** From the mouth of Bouquet Canyon to Interstate 5 (I-5) (a distance of approximately 2.5 miles), the elevation drops by approximately 80 feet, for an elevation gradient of 32 feet per mile (which is roughly half as large as the gradient in the reach upstream of Bouquet Canyon).
- **Western Portion of the Valley.** From I-5 to the mouth of Castaic Creek (a distance of approximately 3 miles), the elevation drops by approximately 125 feet, for an elevation gradient of 42 feet per mile, indicating that the river's gradient steepens slightly after passing along the south side of Round Mountain. From the mouth of Castaic Creek to the LA/Ventura County Line (a distance of approximately 3.5 miles), the gradient becomes gentler, as reflected by an elevation drop of approximately 110 feet and a resulting elevation gradient of approximately 31 feet per mile.

3.2.1.2 Variations in Saturated Thickness

In 2002, RCS compiled and geographically grouped hydrogeologic data from Alluvial Aquifer wells to estimate the aquifer's base elevation at each location and the range of aquifer saturated thickness values during various historical periods. RCS (2002) then categorized the different geographic areas of the Alluvial Aquifer for the purposes of defining variations in saturated thickness from one area to the next, which was necessary due to the need to extrapolate across areas with low densities of wells. For each of the 27 geographic areas (which were called "alluvial storage units" in the RCS studies), the saturated thickness was defined from the average base elevation of the aquifer and the water level elevations measured during 1945 (at the end of a period of high-rainfall years), 1965 (at the end of a long drought period), the fall of 1985, and the spring of 2000. The spatial distribution of the Alluvial Aquifer's thickness is shown in Figure 3-17 (with the Alluvial Aquifer present in the stippled area shown on the map). In tributaries to the Santa Clara River (which are displayed in Figure 1-5), saturated thicknesses for the Alluvial Aquifer ranged approximately as follows:

- **Sand Canyon:** Between 40 and 50 feet, except for 10 feet or less in 1965 (at the end of a drought) and 105 feet at the lower end of the canyon in 1945 (at the end of a high-rainfall period).
- **Mint Canyon:** Between 45 and 55 feet in the upper canyon and 55 to 75 feet in the lower canyon, but as low as 10 feet throughout the canyon in 1965.
- **Bouquet Canyon:** Between 85 and 95 feet, except for a slightly higher saturated thickness in the lower reaches of the canyon in 1945 (115 feet) and much lower saturated thicknesses throughout the canyon in 1965 (20 to 45 feet).
- **South Fork Santa Clara River:** Between 35 and 50 feet in the upper watershed and between 75 and 160 feet near the mouth of the canyon depending on local hydrologic conditions.

- **San Francisquito Canyon:** Increasing in the down-canyon direction from 40 feet to as much as 130 feet, except in 1965 when the saturated thickness was on the order of 15 feet in the upper reaches of the canyon, 35 feet in the middle reaches of the canyon, and 75 feet in the lower reaches of the canyon.
- **Castaic Valley:** Between 60 and 75 feet in the upper portion of the valley and 80 to 105 feet in the lower portion of the valley, except in 1945 when it was approximately 115 feet in both portions of the valley .

Along the Santa Clara River, RCS (2002) estimated the typical saturated thickness of the Alluvial Aquifer to range as follows:

- **Upstream of Mint Canyon:** Between 80 and 90 feet, but as little as 30 feet in 1965 and as much as 120 feet in 1945.
- **From the mouth of Mint Canyon to the mouth of Bouquet Canyon:** Between 105 and 120 feet, but as little as 40 to 55 feet in 1965 and as much as 130 feet in 1945. Geologic mapping and groundwater model calibration efforts also suggest that basement bedrock may underlie the alluvium at depths as shallow as 10 to 30 feet in the bend of the river where production wells are absent (between SCWD's North Oaks wellfield and its Honby and Santa Clara production wells; see Figure 1-3 for the locations of these wells).
- **From the mouth of Bouquet Canyon to I-5:** On the order of 170 feet, but as little as 110 feet in 1965. Along the south side of Round Mountain, the river is thought to possibly pass over a very thin veneer of alluvium, given the river's thin passageway between the Saugus Formation outcrop comprising Round Mountain on the north side of the river and terrace deposits on the south side of the river.
- **From I-5 to the mouth of Castaic Creek:** Between 115 to 135 feet, but as little as 100 feet in 1965 in the eastern portion of this area.
- **From the mouth of Castaic Creek to the LA/Ventura County Line:** However, a geophysical survey conducted in 2007 identified that the alluvium's total thickness at the western end of this area is as little as 30 feet at the County Line. See Appendix C for the report that documents this study (Geomatrix, 2007), which is the basis for defining the base elevation of the alluvium in this area in the new regional model.

3.2.2 Saugus Formation

The first (2004) version of the MicroFEM® model represented the Saugus Formation using 7 layers, with the 3rd through 6th layers being 500 feet thick (representing the Saugus Formation's freshwater-bearing deposits) and the 7th (deepest) layer representing the remaining thickness of the unit (corresponding to the brackish Sunshine Ranch Member, which is not a source of agricultural or municipal supply in the basin). In 2013, the third model layer (from depth 500 feet to depth 1,000 feet) was subdivided into two 250-foot-thick layers to reflect the differences in completion depths of certain production wells in the central portion of the basin. This layering system has been used to develop the new regional model. See Figure 3-25 for a schematic diagram of the model's layering and Table 3-1 for information regarding the relationship between the new model layering system and the open intervals of each production well in the Saugus Formation.

This 8-layer representation of the groundwater basin is also used in the new regional model. As shown in Figures 3-9 through 3-16, the Saugus Formation is present at progressively fewer model grid cells with depth, due to the bowl-shaped structure of this geologic unit and the underlying bedrock units. Figure 3-26 shows cross-sectional views of the model's layering along west-to-east lines passing through the northernmost reach of the river west of I-5 (parent grid row 66) and extending eastward from the LA/Ventura County Line (parent grid row 86). Figure 3-27 shows cross-sectional views of the model's layering along south-to-north lines passing through Castaic Valley (parent grid column 162) and the alluvial valley occupied by the South Fork Santa Clara River (parent grid column 205).

3.3 Boundary Conditions

The new regional model uses no-flow boundary conditions to define inactive cells within the model grid. The model also uses the following MODFLOW-USG packages for boundary conditions that relate to specific hydrologic processes. These packages are the following:

- **The Recharge (RCH) package**, which uses specified-flux boundary conditions to represent deep percolation of rainfall, river storm flows, and land-applied water (discussed in Section 3.4 below)
- **The Well (WEL) package**, which uses specified-flux boundary conditions to specify the rate of subsurface inflow to the Alluvial Aquifer beneath Castaic Dam (at the upper end of Castaic Valley)
- **The General-Head Boundary (GHB) package**, which uses head-dependent boundary conditions to compute subsurface inflows in the Alluvial Aquifer beneath each tributary stream where it crosses into the groundwater basin
- **The Connected Linear Network (CLN) package**, which uses head-dependent boundary conditions to simulate flow exchanges between the aquifer matrix and groundwater production wells that span multiple model layers
- **The Transient IBOUND (TIB) package**, which is unique to MODFLOW-USG and specifies the periods that CLN wells are not physically present during a transient simulation
- **The Evapotranspiration (EVT) package**, which uses head-dependent boundary conditions to represent evapotranspiration from the Alluvial Aquifer by phreatophytes withdrawing water from the water table
- **The time-variant specified head (CHD) package**, which uses specified-head boundary conditions to hold steady the groundwater elevation in the Alluvial Aquifer at the LA/Ventura County Line (the downgradient end of the model), which thereby also holds steady the saturated thickness of the Alluvial Aquifer at that location
- **The Horizontal Flow Barrier (HFB) package**, which uses specified-flux boundary conditions to control the rate of groundwater movement across the San Gabriel Fault zone in the Saugus Formation
- **The Streamflow Routing (SFR7) package**, which uses head-dependent boundary conditions for computing groundwater/surface water exchanges in the Santa Clara River and its tributaries, specifying inflows to the river from the two WRPs, and routing streamflow from cell-to-cell for water-balance tracking purposes
- **The Gage (GAGE) package** for calculating streamflow rates from SFR7

The Recharge (RCH) package is discussed in Section 3.4. Following are descriptions of how the other boundary condition packages are implemented in the new regional model.

3.3.1 WELL Package (Subsurface Inflow into the Alluvial Aquifer in Castaic Valley)

The grid contains four model cells across the width of Castaic Valley at the location of Castaic Dam. Subsurface inflow rates are specified and held steady over time throughout the model calibration period. The rate of subsurface inflow to the Alluvial Aquifer at this location was examined during model calibration and was ultimately specified to be 1,675 acre-feet per year (AFY).

3.3.2 GHB Package (Subsurface Inflows to the Alluvial Aquifer in Tributary Valleys)

Table 3-2 provides information on the setup of GHBs in each tributary valley other than Castaic Valley. GHBs were used to simulate the subsurface flows of water that likely occur from the thin surficial alluvium just outside the model (groundwater basin) boundary. The GHBs were also used to help guide the model on groundwater elevations in the upper ends of these tributaries, and were checked during model construction and calibration to ensure that flow is predominantly (if not exclusively) into the model domain (i.e., inflow to the model) rather than flowing out of (discharge from) the model. As shown in Table 3-2, a total of 149 cells use GHBs in the model.

3.3.3 CLN Package (Multi-Layer Wells)

Table 3-3 lists the layer assignments, CLN node numbers, aquifer matrix numbers, and well-loss properties for each of the 18 Saugus Formation wells that have operated at one time or another during the 1980–2019 model calibration period. Each of these wells span multiple layers in the model. Each well was represented as a single node in the model, rather than using multiple CLN nodes for a given well (one node per model layer). During model calibration, each CLN well was initially assumed to have a well efficiency of 70 percent; as calibration progressed, this assumed value was deemed not worth varying because of the potential for changing well efficiencies over time and the limited amount of data on actual historical well efficiencies.

3.3.4 TIB Package (Timing of Installing or Abandoning Multi-Layer Wells)

The TIB package in MODFLOW-USG provides the capability of not simulating the exchange of groundwater between the aquifer matrix and a CLN well during those periods when the well is not in the ground. This prevents the well from being simulated as a conduit for flow between model layers during the periods when it is not present. Table 3-3 lists the periods that each Saugus Formation production well is present, compared with absent, in the model. Note that if a well is in the ground but is not pumping, it is treated as being present, which allows water to move between the well and the aquifer matrix and also potentially between model layers within the CLN well itself.

3.3.5 EVT Package (Groundwater Withdrawal by Phreatophytes)

The EVT package was used to specify groundwater withdrawals of shallow groundwater by phreatophytes within riparian corridors along streams, and in upland areas. The locations of two types of communities (riparian mixed hardwood forests and coast live oak woodlands) identified as potential GDEs in a recent mapping study (ESA, 2020). See Figure 3-28 for a map showing the geographic distribution of these two types of potential GDE communities. As shown on the map, the riparian mixed hardwood forests are located the Santa Clara River from Bouquet Canyon downstream to the LA/Ventura County Line, in the lower and upper reaches of Castaic Valley, in the central and lower portions of San Francisquito Canyon, and at the downstream end of the South Fork Santa Clara River. ESA (2020) indicates that the predominant species that are present in these riparian corridors are Fremont Cottonwood, willow trees and shrubs, and non-native grasses (such as *Arundo donax [Arundo]*).

The EVT package requires the specification of the evapotranspiration (ET) surface, the ET extinction depth, and the potential ET demand. The EVT package sets actual ET withdrawals to be equal to the potential ET demand rate when groundwater is at or above the ET surface. When the water table is below the ET extinction depth, phreatophytes are no longer able to withdraw groundwater. For water table depths between the ET surface and the ET extinction depth, the actual ET withdrawal rate follows a linear function between the maximum rate at the ET surface elevation and no withdrawal at the elevation corresponding to the extinction depth.

- The ET surface was set at a depth of 5 feet below ground surface, on the rationale that *Arundo* (a significant water user) can have root mats as deep as 3 feet below ground surface (Alden et al., 1998; Mackenzie, 2004; California Invasive Plant Council, 2011) and therefore could likely withdraw groundwater from a somewhat greater depth than the depths of the roots. Cottonwoods and willows would be expected to readily withdraw shallow groundwater.

- The ET extinction depth is the water table depth below which phreatophytes would no longer be able to withdraw groundwater. The U.S. Forest Service Fire Effects Information System (FEIS) website (https://www.fs.fed.us/database/feis/plants/tree/popfre/all.html) reports that rooting depths in mature stands of Fremont Cottonwood range between 3 and 5 meters (9.8 to 16.4 feet), based on studies by Zimmerman (1969) and Braatne et al. (1996). Given that deep-rooted trees can withdraw groundwater from depths greater than the depths of their root systems, the ET extinction depth was set at 25 feet. For comparison, as part of its preliminary screening and mapping process for GDEs, The Nature Conservancy (TNC) uses a depth of 30 feet as the cutoff depth for distinguishing where GDEs may be present compared with absent (Rohde et al., 2018).
- The ET demand rate was specified as follows:
    - **Riparian Mixed Hardwood Forests.** In support of the model development effort, ESA estimated monthly riparian demands for a mixture of 40 percent Fremont Cottonwood, 30 percent willow, and 30 percent *Arundo*. Average monthly reference ET rates for a well-irrigated grass cover were downloaded from the Santa Clarita California Irrigation Management Information Service (CIMIS) station No. 204 and were multiplied by vegetation coefficients for cottonwoods and willows (published by Howes et al., 2015). For *Arundo*, ESA developed monthly demand curves by adjusting the crop coefficient for large-stand permanent wetlands to make annual ET demands match mean and median results from *Arundo* studies by TNC. Table 3-4 presents the annual and monthly demands for these species, including the reference grass cover and the large-stand permanent wetland, followed by the aggregate demand for the mixture of cottonwood (40 percent), willow (30 percent), and Arundo (30 percent) that is representative of current conditions along the Santa Clara River's riparian corridor (ESA, 2020). As shown in Table 3-4 and Figure 3-29, the annual ET demand is estimated to be nearly 6 feet per year when using TNC's median demand for *Arundo*, with the monthly demand ranging from 0.21 to 0.87 feet per month (64 to 264 millimeters per month). These monthly values were programmed directly into the model and were assumed to be representative of potential ET demands in all years throughout the 1980–2019 calibration period.
    - **Coast Live Oak Woodlands.** The ET demand rates for these potential GDEs were set equal to the values for rain-fed oak grassland mix shown in Table 3-4 (as published by Howes et al., 2015).
    - **Other Locations.** A low value of 0.0001 foot per day (ft/day) was used in all other areas throughout the model simulation period, to allow for possible ET in other locations where groundwater potentially could be present close to the ground surface during and after high-rainfall years.

3.3.6 CHD Package (Specified Heads at County Line)

The time-variant specified head (CHD) package is used to specify the groundwater elevation in the Alluvial Aquifer at the LA/Ventura County Line (the downgradient end of the model). A groundwater elevation value of 823 feet is used in Layer 1 of the model at the 13 grid cells that span the width of the Alluvial Aquifer at the County Line. The elevation of 823 feet is based on a groundwater elevation contour map published by RCS (2002) for Spring 2000; see Appendix D, which presents this map (which is Plate 4.3 in the RCS, 2002 report). This groundwater elevation value at the County Line is approximately 18 feet higher than the groundwater level displayed in a geophysical cross section at the County Line (Geomatrix, 2007; see Appendix C). The groundwater elevation contour map was chosen as the source for the modeled groundwater elevation at the County Line because (1) the map shows contours and groundwater elevation measurements at nearby observation wells that were accessible at that time, and (2) the 823-foot groundwater elevation at the County Line produces a horizontal gradient from Potrero Canyon to the County Line that is similar to the hydraulic gradient occurring upgradient of Potrero Canyon. (In contrast, the cross sections displayed in the geophysical study show a much steeper head gradient below versus above Potrero Canyon—a steepening that cannot be correlated with local geologic conditions, which show no reason for such a significant change in gradient to occur in this area).

3.3.7 HFB Package (Flow Across the San Gabriel Fault)

The HFB package was used to limit the groundwater flow rate across the San Gabriel Fault. HFBs were established at 1,606 cells, mostly in Layers 2 through 8, but also in Layer 1 where the Saugus Formation is present at the ground surface (i.e., where the alluvium is absent). The hydraulic conductivity across each HFB was specified as $1x10^{-8}$ ft/day; this value was found to have similar influences on groundwater elevations in the Saugus Formation whenever the hydraulic conductivity for the HFB cell was less than approximately $1x10^{-5}$ ft/day.

3.3.8 SFR7 and GAGE Packages (Santa Clara River and Tributaries)

GSI (2020) presents the conceptual understanding of groundwater/surface water interactions along the central and western portions of the alluvial valley occupied by the Santa Clara River. The SFR7 and GAGE packages are used to simulate these interactions in the model. A total of 139 stream segments containing 2,367 stream reaches were programmed into the SFR7 package to allow for simulation of non-storm (dry-weather) flows in the Santa Clara River and its tributaries. See Table 3-5 for an index of the streams corresponding to each stream segment. Storm flows and controlled releases from upstream reservoirs outside the basin boundary were not directly tracked in the SFR package, but instead were accounted for in terms of their influence on groundwater recharge by using the SCV Recharge Compiler. This approach of using different tools to simulate the influences of storm flows compared with dry-weather flows allowed the role of the SFR7 package to be focused on simulating the influence of dry-weather flows in the Santa Clara River, which are the flow conditions that influence species and habitat management for conservation efforts in the perennial reach of the river (below the mouth of San Francisquito Canyon). Although the topic of dry-weather flows is of primary interest in the western portion of the basin, the SFR7 package was applied to all model cells containing the Santa Clara River and its tributaries, so that groundwater drainage into these stream systems (under high water tables) could be simulated and tracked from cell-to-cell to account for their contribution to streamflow along each stream system and the potential for reinfiltration within the basin.

Consistent with the approach of using the SFR7 package to evaluate dry-weather flows, the monthly and annual releases of water from Castaic Dam/Lagoon (into Castaic Creek) and from Bouquet Reservoir (into Bouquet Creek) were handled by the SCV Recharge Compiler, as described in Section 3.4 below. Inflows to the Santa Clara River occurring internally within the groundwater basin boundary (discharges from the Saugus and Valencia WRPs; see Figure 1-2) were programmed into the SFR7 package, because they are not of a storm-flow nature and have an important influence on dry-weather flows. See Tables 3-6 through 3-8 for the monthly and annual values of these flows since 1980. Additionally, periodic short-duration discharges to the river occur from outfalls conveying treated water from perchlorate-treatment programs at certain wells pumping from the Saugus Formation; these discharges were assigned to the same location as the outfall for the Saugus WRP because of their close proximity and their small discharge volumes. These discharges are estimated to be as follows:

- Outfall for wells SCWD-Saugus1 and SCWD-Saugus2, discharging into Segment 41, just upstream of the Saugus WRP: 1,792 acre-feet from May 2010 through January 2011

- Outfall for well VWD-201, discharging into Segment 79, just downstream of the Saugus WRP:
  Approximately 6,500 AF from January 2018 through December 2019 (and continuing at this time)
- Outfall for onsite extraction wells at the Whittaker-Bermite property, discharging into Segment 40, about 1 mile upstream of the Saugus WRP:
  Approximately 500 AF from August 2017 through December 2019 (and continuing at this time)

The GAGE package (a companion to SFR7) was used to write out streamflows from the SFR7 computations at each time during the simulation. Streamflow rates were written at the end of each of the 139 reaches and were evaluated during model calibration at specific locations where stream conditions are of interest. A generic cross-sectional profile designed to help simulate dry-weather flow conditions was defined in each stream segment using a low-flow channel 10 feet wide and 3 feet deep for the channel invert, with an adjoining 40-foot wide area for braided streamflow near the invert. The remainder of the 250-foot wide model grid cell containing an SFR boundary condition provided further flow capacity, with the top of the streambed being 8 feet above the channel invert at the edges of each SFR grid cell.

Because LiDAR data indicate that the low-flow channel is much narrower than the model grid cells where the SFR boundary condition is being used, the streambed elevations chosen were slightly above the absolute lowest invert elevation, but below the levels of the adjoining flow areas where wide streams or numerous braided channels could be present under flows that exceed the capacity of the low-flow channel. The thickness of the streambed was set at 1 foot, and the hydraulic conductivity of the streambed was varied during model calibration to improve the simulation of (1) observed groundwater levels in wells near the Santa Clara River and (2) measured dry-weather streamflows at the former County Line Gage (which was located approximately three-fourths of a mile west of the County Line during water years 1953 through 1996).

3.4 Estimation of Groundwater Recharge Rates

Groundwater recharge was defined on a month-by-month basis for the full calibration period (January 1980 through December 2019). Groundwater recharge rates were specified at each grid cell using a Visual Basic tool in Microsoft Excel that was developed by GSI to accompany the new regional model. A primary purpose of this tool was to compile the recharge rates from multiple hydrologic processes into the form required by the numerical model; specifically, the model's recharge (RCH) package (like most groundwater modeling software) requires that a single value for recharge be provided at any given time and location, rather than inputting the recharge rates corresponding to each individual hydrologic process. This tool (named the SCV Recharge Compiler) was therefore used to assemble the multiple recharge processes into the form required for input to the RCH package for MODFLOW-USG.

See Appendix B for a detailed description of the SCV Recharge Compiler. As shown in Figure 2-1, this tool specifies the monthly volumes/rates of groundwater recharge (deep percolation) resulting from the combined influences of the following hydrologic processes:

- Direct precipitation within the model grid area
- Seepage from streambeds to the underlying water table (a process that occurs exclusively over the Alluvial Aquifer, along the Santa Clara River and its tributaries); this includes not only stormwater, but controlled releases of water from Castaic Dam (into Castaic Creek) and Bouquet Reservoir (into Bouquet Creek)
- Irrigation on agricultural lands
- Irrigation in urban areas (residential, commercial, golf courses, parks/recreational areas)

- Septic systems in residential developments that are served by public water supplies, but not sanitary storm sewers

For tributaries of the Santa Clara River, the SCV Recharge Compiler estimates surface water inflows from ungaged upstream contributing watersheds, based on the basin size and regional isohyetal maps of annual precipitation. The SCV Recharge Compiler uses these surface inflow estimates plus the gaged inflows on the Santa Clara River itself (at the Lang Gage) to track the amount of stormwater that is available to infiltrate from one node to the next in the downstream direction on each ephemeral stream reach lying within the groundwater model domain. This process also makes use of streambed conductance values that are specified in the SCV Recharge Compiler in each ephemeral stream to control the rate of groundwater recharge, which allowed these conductance terms to be adjusted during model calibration.

No diversions of water are known to occur from the Santa Clara River or its tributaries within the East Subbasin. Water is discharged into the Santa Clara River within the interior of the basin and in two tributaries along or upstream of the basin. Table 3-9 lists monthly and annual releases from Castaic Dam/Lagoon into Castaic Creek. Table 3-10 lists monthly and annual releases from Bouquet Reservoir into Bouquet Creek. Even though the releases from Bouquet Reservoir occur well upstream of the groundwater basin boundary, they were simulated as being fully present in Bouquet Creek where it enters the groundwater basin in order to provide a more direct means of accounting for this flow in water budget analyses (rather than simulating this flow contribution as being strictly subsurface inflow).

The SCV Recharge Compiler also includes the capability to simulate future surface spreading basins, future changes in land use, and climate change factors that have been published by DWR for use during the preparation of GSPs.

3.5 Assignment of Groundwater Pumping Rates and Depths

Pumping rates from agricultural and municipal production wells were assigned in the model at wells that operated at any time during the period January 1980 through December 2019. The locations of these wells are shown on Figure 3-30. Pumping rates were assigned using the following information:

- Water use records maintained by the local water purveyors. These records were available as annual and monthly volumes of groundwater production from each well. For some wells, only annual data were available for the 1980s and 1990s, and in a few cases extending into the early 2000s.
- Annual water use records for agricultural wells. Monthly records were not available.
- Well construction records, which were needed to determine which model layers each Saugus Formation production well should be assumed to be pumping from.

For the period of 1980 through 2019, Tables 3-11 and 3-12 summarize the annual pumping volumes from each agricultural and municipal well in the Alluvial Aquifer and the Saugus Formation, respectively. Small domestic wells are not inventoried in this basin and hence are not represented in the model. As discussed in prior annual reports for the basin (see LSCE, 2020), small domestic wells are estimated to pump 500 AFY in and near the groundwater basin, with some of this production potentially occurring from older bedrock units underlying and surrounding the Alluvial Aquifer and Saugus Formation. As shown in the last row of Tables 3-11 and 3-12, total pumping since 1980 has ranged between 20,286 and 43,406 AFY from the Alluvial Aquifer and between 3,716 and 14,917 AFY from the Saugus Formation.

Table 3-13 summarizes the monthly distribution of pumping that was applied to production data for wells and periods for which only annual data were available. Separate distributions of monthly demand were used for agricultural compared with municipal wells, given that agricultural wells are used exclusively for outdoor water demands whereas municipal wells are used to meet indoor and outdoor demands. These monthly distributions are the same as those that were developed during construction of the original model (CH2M HILL, 2004a) and were developed at that time from crop consumptive use requirements published by CIMIS. The monthly distribution of urban demand was determined at that time by examining monthly flow records for the two WRP and monthly demand distributions recorded by one of the former retail water providers (Valencia Water Company) over a period of several years.

3.6 Assignment of Aquifer Physical Properties

The hydraulic conductivity distribution used in the model is shown in Figures 3-31 through 3-37 and in Table 3-14. This distribution is based on model calibration results and on data collected from a small number of controlled aquifer tests and from specific capacity measurements in individual pumping wells across the groundwater basin.

3.6.1 Alluvial Aquifer

Available groundwater elevation data and aquifer test data indicate that the Alluvial Aquifer is unconfined (i.e., is under water table conditions). RCS (1986 and 2002) reported transmissivity values to range between 4,700 square feet per day (ft^2/day), or 35,000 gallons per day (gpd) per foot (gpd/ft) and more than 100,000 ft^2/day, or 750,000 gpd/ft (CH2M HILL, 2004a). The specific yield of the Alluvial Aquifer has been estimated in past studies to range from about 0.09 to 0.16 (RCS, 1986 and 2002; CH2M HILL, 2004a); efforts to calibrate the numerical model to hydrographs throughout the alluvium indicate that the specific yield is on the order of 0.10 in much of the Alluvial Aquifer, with the exception of higher values (on the order of 0.20) in the upper portion of Castaic Valley and the lower portion of Bouquet Canyon. Based on interpretations of aquifer tests, specific capacity tests, and groundwater model calibration results, the hydraulic conductivity of the Alluvial Aquifer is estimated to range from 250 to 1,500 feet per day (ft/day) in the alluvial valley occupied by the Santa Clara River, and 75 to 700 ft/day in the alluvium that occupies the various tributary valleys.

During the multiple efforts since 2004 to build the original MicroFEM® model, update its calibration with new data, build the new regional model, incorporate the geophysical study at the LA/Ventura County Line (which changed the understanding of the Alluvial Aquifer's thickness at that location), and calibrate the model to the significant drought that occurred from 2011 through 2016, it has become apparent that a large percentage of the specific capacity data collected in Alluvial Aquifer wells result in underestimation of the hydraulic conductivity of this aquifer. This observation and conclusion became particularly apparent during the effort to calibrate the new regional model to (1) the 1980–1996 record of gaged flows near the County Line (after incorporating the geophysical study results) and (2) the groundwater level responses in the eastern third of the basin to the first-ever year-long (and in several cases multi-year) period of not operating wells at the far east end of the alluvium (during and after the 2011–2016 drought). Repeated testing with the model indicated that calibration quality was markedly improved by relying on the tests that had the highest reported specific capacity values while pumping at rates similar to or higher than most tests. The same tests that were evaluated during construction of the original model (see Appendix B of CH2M HILL, 2004a) were reviewed during construction of the new model to find tests that meet these criteria, and to reevaluate those test results with respect to the water level data that were collected at the time of each test, rather than relying solely on previously published summaries of average saturated thickness values in alluvial subareas (RCS, 1980 and 2002). Table 3-15 shows test results and hydraulic conductivity calculations for 13 wells that were identified as having been pumped at high rates while recording high specific capacity values. Water level data were recorded on or near the day of testing at 9 of these wells, while the water levels at 4 wells had to be estimated from the previously published estimates of saturated thickness. Calculations of transmissivity and hydraulic conductivity were conducted using methods described by Driscoll (1986) for unconfined aquifers and by assuming that well efficiencies range between

60 and 80 percent (to bracket the likely effect of well losses on the drawdown measurements during each field test). As shown in Table 3-15, these calculations indicate that hydraulic conductivity values for the Alluvial Aquifer range from about 700 ft/day to nearly 1,500 ft/day along the Santa Clara River, between 500 and 1,200 ft/day in Bouquet Canyon, and between 550 and 850 ft/day in Castaic Valley.

3.6.2 Saugus Formation

Available groundwater elevation data and aquifer test data indicate that the groundwater resources in the Saugus Formation are present under semi-confined to confined conditions (i.e., under pressure rather than being a water table aquifer). In areas where the Saugus crops out at the ground surface, the uppermost saturated zones are partially unconfined because the permeable beds are folded upwards. In the highlands, the Saugus beds are exposed at the ground surface, and in the valley, the uppermost Saugus beds are in contact with the Alluvial Aquifer.

RCS (1988 and 2002) estimated that transmissivity values in the Saugus Formation range between about 400 and 25,000 ft^2/day (3,000 to 180,000 gpd/ft), but with a more typical range of between 5,500 and 11,000 ft^2/day (40,000 and 80,000 gpd/ft). RCS (1988 and 2002) estimated that storativity values are on the order of 10^{-3} to 10^{-4}. Later, in March 2004, separate 72-hour constant-rate aquifer tests were conducted at production wells VWD-205 and NWD-13, from which the transmissivity of the Saugus Formation at these two locations was estimated to range from approximately 5,700 to 47,500 ft^2/day, corresponding to bulk hydraulic conductivity values estimated to range from 4 to nearly 35 ft/day. (See Table 4-2 and Appendix G.2 in CH2M HILL [2005] for details regarding these tests.)

The estimates of aquifer parameter values by RCS are based on data from well performance tests (summarized in Table 3-16) and from an ASR pump test and study that was conducted in the Saugus Formation (RCS, 2001 and 2002). Analyses of the ASR test data and subsequent numerical modeling analyses indicated that the bulk hydraulic conductivity of the Saugus Formation at Wells VWD-201 and VWD-205 is approximately 6.5 ft/day (CH2M HILL, 2004a). Specific capacity values at these two wells (10 to 20 gpm/ft) were found to be higher than in NWD's production wells to the south (2 to 10 gpm/ft) and similar to, if not slightly less than, those observed in other VWD and SCWD Saugus Formation wells to the immediate west and northeast (which reported values between 25 and 50 gpm/ft; see CH2M HILL, 2004a). Based on these data and on model calibration evaluations, the hydraulic conductivity of the Saugus Formation in the primary area that has historically been targeted for groundwater development (the area south of the Holser Fault and extending southward nearly to the mouth of Placerita Canyon [just north of the town center for the Town of Newhall]) is represented in the new regional model as gradually decreasing with depth, from values of 6.5 to 30 ft/day in the upper hydrostratigraphic units to values of 0.1 to 4 ft/day in deeper hydrostratigraphic units.

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SECTION 4: **Model Calibration and Parameter Sensitivity**

Before a model is used for predictive purposes, it must be demonstrated that the model provides a reasonable representation of historically observed conditions in the groundwater basin that it represents. This section of the report describes the process and results of calibrating the new regional model for the East Subbasin. Following are discussions of the calibration process (Section 4.1), a summary of the calibration data sets (Section 4.2), calibration results (Section 4.3), parameter sensitivity observations that were made during calibration (Section 4.4), and a summary of the resulting model's simulation capabilities from the standpoint of the calibration effort (Section 4.5).

4.1 Calibration Process

After constructing the model, a calibration process was conducted in which the model's hydrogeologic and streambed parameters were adjusted until the model was able to reasonably replicate two aspects of the historically observed conditions: (1) the general physical characteristics of the system (e.g., groundwater flow directions and locations of gaining compared with losing stream reaches), and (2) the quantifiable aspects of the system (groundwater elevations, the changes in groundwater levels that occur in response to variations in natural system conditions and groundwater pumping, and fluctuations in non-storm streamflows in the Santa Clara River at the LA/Ventura County Line). The model's parameters are inputs to the model that consist of values or coefficients describing the spatial distribution of hydrogeologic and streambed properties and the spatial and temporal distribution of model boundary conditions. The calibration process made use of three separate types of data sets: (1) groundwater elevation records in production wells, (2) groundwater elevation records in non-pumping observation wells, and (3) stream gaging records near the County Line. Each of the three data sets are affected by how the aquifer responds to short- and long-term changes in ambient background (natural) hydrology, groundwater pumping, and changing land uses and water uses (including changes in WRP discharges to the Santa Clara River and reservoir releases into two of the river's tributaries).

4.1.1 Time Period

The calibration runs consisted of transient (time-varying) simulations for calendar years 1980 through 2019. The transient simulations varied the hydrologic processes on a monthly basis, and calculations were conducted three times each month (i.e., once every approximately 10 days throughout the 40-year simulation period), The purpose of using transient simulations was to create a model capable of simulating seasonal and long-term variations in groundwater elevations, groundwater recharge, and groundwater discharge for a historical period characterized by variable rainfall and recharge and changing land use and water use patterns. This 40-year period was chosen for the following reasons:

- The volume of data is greater during this period than in years prior to 1980. In particular, SCWD and VWD installed several production wells in the Saugus Formation during this period. Also, regular monitoring of groundwater levels was performed at more wells during this period than before. Stream gaging records are also available near the County Line during the first 17 years of this period (through water year 1996), after which the gage was moved downstream to a location 3.5 miles west of the County Line.
- Annual pumping volumes are well known and well documented during this period, but are not as well known in prior years. Hence, it would be more difficult to calibrate a model prior to the 1980s because of the uncertainties in pumping volumes in earlier decades. (Robson [1972] provides brief discussions of the early years of groundwater usage in the basin.)

- Significant urban growth occurred in the valley between 1980 and 1999. This growth resulted in changes in land use and increased importation of water beginning in late 1979.
- The local hydrology varied considerably during this period, and included single-year and multi-year droughts (including the significantly below-normal rainfall period that began in late 2011 and lasted through late 2016). The Alluvial Aquifer showed multi-year periods of water level declines followed by multi-year periods of water level recovery. Additionally, water levels in the Saugus Formation fluctuated in response to changing pumping during this period (changes that arose from the installation of new wells plus temporary shut-downs of certain wells in response to groundwater contamination).

4.1.2 Calibration Goals

The success of the model calibration process was defined by its ability to satisfy a set of calibration goals that were developed from a review of the types and quality of the data sets that are available in the East Subbasin. As noted by Reilly and Harbaugh (2004) and DWR (2016a), it is important for groundwater modeling investigators to use the calibration process to evaluate the appropriateness of the conceptualization of the groundwater flow system and the model's representation of that system; focusing on quantitative measures of goodness-of-fit between measured and simulated values of groundwater elevations and changes in those elevations is insufficient by itself. Accordingly, a series of qualitative and quantitative calibration goals were developed for evaluating the calibration quality of the regional model, as described below.

4.1.2.1 Qualitative Calibration Goals

Two qualitative goals were identified:

- **Calibration Goal 1.** Simulate the general directions of groundwater flow and groundwater elevations on a long-term basis in both aquifer systems, as arising from natural hydrologic conditions and pumping operations from agricultural and municipal water supply wells. Regional groundwater elevation contour maps prepared by RCS (2002; see Appendix D) for the Alluvial Aquifer in Spring 2000 and the Saugus Formation in Fall 2000 were used to evaluate calibration quality.
- **Calibration Goal 2.** At nodes where streams are not present, maintain groundwater elevations below ground surface. At stream nodes, groundwater elevations should also be below ground surface in ephemeral reaches at most times, though this will not necessarily be the case during the periodic large rainfall/runoff events that are the largest natural sources of recharge to the aquifer system (particularly the Alluvial Aquifer). In perennial reaches of streams, the groundwater level should be higher than the channel bed elevation.

4.1.2.2 Quantitative Calibration Goals

Three qualitative goals were identified:

- **Calibration Goal 3.** Simulate seasonal and year-to-year variability in groundwater levels in production and observation wells, as arising from natural variability in rainfall recharge and stream gains/losses, as well as monthly and annual variations in production from water supply wells.
- **Calibration Goal 4.** Simulate seasonal low flows in the Santa Clara River at the County Line, near the site of the USGS' former County Line gaging station that operated through water year 1996.
- **Calibration Goal 5.** Obtain statistics for groundwater elevation residuals and groundwater elevation change residuals that are within reasonable limits for groundwater model calibration, in keeping with American Society for Testing and Materials (ASTM) guidelines (ASTM, 1996; Spitz and Moreno,

1996). In particular, achieve a relative error (as expressed by the scaled mean residual and the scaled standard deviation) of no greater than 10 percent. (The relative error, or scaled residual, equals the value of the statistic [the mean or standard deviation of all residuals] divided by the range in measured values.) Statistics were not calculated for streamflows because the calibration quality for streamflows is judged by visually examining the match to summer-season low-flow conditions (not to matching periods of higher flows), and because the data are somewhat limited in volume (i.e., data are available only near the model boundary and only prior to October 1996).

4.1.3 Model Parameters Adjusted During Calibration

Model parameters that were evaluated and adjusted during calibration of the numerical model were the following:

- Horizontal and vertical hydraulic conductivity
- Storage coefficients (specific storage and specific yield)
- The annual rainfall-runoff-recharge relationship that determines deep percolation of rainfall over the groundwater basin and streamflow coming into the basin from upstream watershed areas
- Streambed conductances

4.1.3.1 Horizontal and Vertical Hydraulic Conductivity

Figures 3-31 through 3-37 show the locations of zones of uniform hydraulic conductivity that were implemented into the new regional model during the course of constructing and calibrating the model. The model uses zones primarily to distinguish model layers and geographic areas on the basis of lithology and on the basis of differences in groundwater level fluctuations (such as spatial variability in the Alluvial Aquifer's responses to rainfall recharge events). Table 3-14 lists the horizontal and vertical hydraulic conductivity values that are used in the model, based on the results of the calibration process.

4.1.3.2 Storage Coefficients

Specific yield values are assigned to each model layer, including those below layer 1 to account for the unconfined flow conditions that would exist wherever layer 1 is simulated as being dry at a given time during the simulation. Specific yield values were allowed to range between 0.01 and 0.30 during model calibration. The Alluvial Aquifer is simulated with a value of 0.10 in most locations, except in the upper portion of Castaic Valley and the lower portion of Bouquet Canyon where the specific yield has been set at a value of 0.20 based on model calibration to production well hydrographs in those locations.

For all but the uppermost model layer, the storage coefficient for the Saugus Formation is equal to the product of the layer thickness and the user-specified value of specific storage (which has units of 1/ft, or ft^{-1}, in the regional model). Specific storage was set equal to 10^{-6} ft^{-1} throughout each model layer representing the Saugus Formation.

4.1.3.3 Rainfall-Runoff-Recharge Relationship

The two nonlinear coefficients in the rainfall-runoff-recharge relationship (see Appendix B and Turner, 1986) were varied during various model calibration tests to evaluate the sensitivity of the model's calibration quality to these coefficients. Tests were conducted that evaluated whether to raise or lower the threshold low value of annual rainfall at which deep percolation of rainfall can occur, and whether to allow more or less deep percolation to occur during the periodic "episodic rainfall" years (when rainfall is substantially above historical averages, resulting in recharge events that "refill" the Alluvial Aquifer in the central and eastern portion of the groundwater basin).

4.1.3.4 Bed Permeability in the Santa Clara River and its Tributaries

Streambed permeability terms control the volume of groundwater/surface water exchanges in both ephemeral reaches and perennial reaches of streams. For groundwater recharge processes in ephemeral stream reaches, the streambed permeability and bed conductance terms are controlled in the SCV Recharge Compiler, as described in Appendix B. These terms are specified in the SFR7 package of MODFLOW-USG in perennial reaches, and also in SFR7 stream cells that are present in ephemeral reaches to drain off groundwater when groundwater elevations exceed the streambed elevation.

4.2 Calibration Data Sets

As discussed previously in this section, the calibration process made use of three separate types of data sets: (1) groundwater elevation records in production wells, (2) groundwater elevation records in non-pumping observation wells, and (3) stream gaging records near the County Line.

4.2.1 Groundwater Levels in Production Wells

The local water purveyors have collected groundwater levels at their production wells on a generally monthly basis throughout the 40-year historical calibration period, and these data are maintained in a database that is used to generate annual reports on groundwater conditions in the East Subbasin. The model calibration effort evaluated groundwater elevations and fluctuations in 78 production wells which are listed in Table 4-1 and are as follows:

- 16 Saugus Formation production wells, which consist of 15 existing wells plus a former well (Well 157, owned by the former Valencia Water Company [now VWD]) that was taken out of service in 2005 and subsequently destroyed
- 62 production wells in the Alluvial Aquifer, which include 8 production wells that are not operating but are used for regular water level measurements (VWD's E14, E16, E17, and I wells, and Newhall Land & Farming Company's [NLF's] E, G3, X3, and W5 wells)

A report on water use and local groundwater basin conditions has been published annually through a cooperative effort between the local purveyors since the late 1990s. Since that time, greater attention has been given to the methodology for, and timing of, static water level measurements to minimize the influences of groundwater pumping on the well measured. In the Alluvial Aquifer, which is an unconfined aquifer, measurements that are reported to be static during the 1980s and into the 1990s in a few cases are similar to dynamic measurements collected in more recent years at certain wells—primarily in the eastern portion of the basin. In these cases, the model calibration effort focused more on the past 2 to 3 decades of water level data than on earlier years. These types of relationships are much less frequent in Saugus Formation production wells, most likely because the Saugus Formation is a confined aquifer system that has water levels that recover more quickly when a well stops pumping than is the case with wells constructed in the unconfined Alluvial Aquifer.

4.2.2 Groundwater Levels in Observation Wells

The model calibration effort evaluated groundwater elevations and fluctuations in 31 non-pumping observation wells situated at 11 different locations along the Santa Clara River and the South Fork Santa Clara River (Table 4-2).

- **Saugus Formation.** Seven nested observation wells/well clusters and one single observation well (together comprising a total of 28 observation wells) are used in the calibration process for the Saugus Formation. Three of these observation well groups lie along the eastern side of the lower reaches of the South Fork Santa Clara River (wells MP-1, MP-2, and SG-1), and the remaining five wells lie to the west and northwest of the South Fork Santa Clara River (MP-5, Library, Mall, DW-1, and DW-2) and south of the Santa Clara River. These wells use short screens to monitor water levels in discrete depth intervals within the Saugus Formation, and therefore in some cases may not measure groundwater elevations/pressures that are representative of the bulk aquifer formation or bulk thickness of a given model layer. Nonetheless, they are helpful for complementing the data sets that are available from production wells.

- **Alluvial Aquifer.** Three observation wells in this aquifer are used in the calibration process. Well AL-12a is located along the lower reaches of the South Fork Watershed. Wells LACFCD-7177B and LACFCD-7179D are located in the eastern end of the Alluvial Aquifer, along the Santa Clara River. While the Los Angeles County Flood Control District (LACFCD) measures water levels in other wells in the valley, most of the data from those other wells are unsuitable for calibration because of short durations, intermittent measurements with long data gaps in some cases, unknown/unconfirmed locations, poor estimates of ground surface elevations or reference point elevations (for converting depth measurements to elevations), or the data are known to be for production wells already accounted for in this analysis.

4.2.3 Streamflow in the Santa Clara River

Streamflow monitoring began in October 1952 at the former USGS stream gage Station 11108500, which was named Santa Clara River at LA/Ventura County Line and is locally referred to at times as the “County Line” stream gage. This gage was located 0.75 miles downstream of the County Line where the river turns southward as it enters a horseshoe bend in an area known locally as “Blue Cut.” This gage operated continuously through September 1996, but was subject to periods of missing data during and after extreme high flow events.

In October 1996, the County Line stream gage was decommissioned and a new USGS gage was put into operation at a bridge crossing on NLF’s Las Brisas property in Ventura County. This new gage (Station 11109000, Santa Clara River near Piru) is located 2.75 miles downstream of the former gage station and 3.5 miles downstream of the LA/Ventura County Line. This new gage is still in operation today and has provided a high-quality continuous record of streamflow since it was installed. However, because of this gage’s significant distance from the County Line and the western boundary of the East Subbasin, its data are slightly less reliable for use in model calibration than the earlier data from the County Line gage.

Appendix E provides more information on the locations of the two gages.

4.3 Calibration Results

Simulation results from the final calibrated model are presented in the form of groundwater elevation contour maps (Figures 4-1 through 4-8), time-series plots containing groundwater elevation hydrographs (Figures 4-9 through 4-12 for the Saugus Formation and Figures 4-13 through 4-23 for the Alluvial Aquifer), time-series plots of simulated compared with measured streamflows in the Santa Clara River at the LA/Ventura County Line (Figure 4-24), and calibration statistics presented in Table 4-3 and Figures 4-25 through 4-28.

Following are discussions of calibration quality with respect to historical groundwater conditions in the Saugus Formation (Section 4.3.1) and the Alluvial Aquifer (Section 4.3.2), the model’s ability to simulate historical streamflows at the LA/Ventura County Line (Section 4.3.3), and statistical measures of the model’s calibration quality (Section 4.3.4).

4.3.1 Saugus Formation

4.3.1.1 Groundwater Elevation Contour Maps

Figures 4-2 through 4-8 show that the model simulates Saugus Formation groundwater as flowing towards the center of the basin (towards the Santa Clara River in the areas west of the San Gabriel Fault), which is consistent with interpretations by RCS (2002; see Appendix D). South of the river, the hydraulic gradients in the upper portion of the Saugus Formation (model layers 2 through 4) are stronger (i.e., the contours are more closely spaced) than is the case in the deeper portions of the Saugus Formation (model layers 5 through 8).

Steep horizontal hydraulic gradients are observed in each unit across the San Gabriel Fault, but not across the Holser Fault—a result that is consistent with an aquifer testing study (CH2M HILL, 2005) which concluded that the Holser Fault likely does not act as a restriction or barrier to groundwater movement. Figures 4-2 through 4-8 also show a line of closely spaced contours north of the river, extending between the Holser and San Gabriel Faults; this is simulated to improve calibration to groundwater elevations at the LACWWD36-19 production well, which is the only well north of the Santa Clara River where groundwater levels are routinely measured.

4.3.1.2 Groundwater Elevation Hydrographs

Groundwater elevation hydrographs in the Saugus Formation are generally well matched, except in the southern periphery of the basin and in the northwest portion of the basin where only one well is present.

- Figure 4-9 shows that good calibration quality to groundwater elevations and elevation trends is achieved at NWD's two active production wells (NWD-12 and NWD-13) and at a former well (NWD-11) that is used for water level monitoring.
- Similar results occur further north at SCWD's two production wells and at four VWD production wells (Figure 4-10). The calibration quality is mixed at observation (monitoring) wells that are just east of these production wells (Figure 4-11a). The model appears to generally simulate the trends in groundwater elevations at the observation (monitoring) wells and in some cases the groundwater elevations in certain wells (such as the deepest wells at the SG-1 and MP-1 well clusters). However, the model has difficulty matching absolute groundwater elevations at several of the monitoring wells, possibly because their short screens measure head pressures in thin discrete zones in the aquifer, in contrast to the thick layers that are used in the model and are pumped by long-screened production wells constructed in the Saugus Formation. Further west, the model provides a reasonably close replication of the trends and groundwater elevations in the monitoring well locations west of the South Fork Santa Clara River (Figure 4-11b).
- In the western portion of the groundwater basin, the model simulates the historical groundwater elevations and trends at VWD's three production wells in this area, as shown in Figure 4-12. In contrast, in the northwest portion of the basin, simulated groundwater elevations at the LACWWD-36 production well are too low compared with both the static and pumping water levels.

4.3.2 Alluvial Aquifer

4.3.2.1 Groundwater Elevation Contour Maps

Figure 4-1 shows that the model simulates Alluvial Aquifer groundwater as flowing parallel with the geographic alignments and vertical gradients of the Santa Clara River and its tributaries, which is consistent with interpretations by RCS (2002; see Appendix D). Inspection of simulated groundwater elevations indicates that groundwater levels can lie above the bed elevation of the Santa Clara River at some locations between the mouth of San Francisquito Canyon and the County Line, which is consistent with the conceptual understanding of the occurrence of overall gaining streamflow conditions in this area, with a mixture of shorter reaches that are gaining and shorter reaches that are losing.

Simulated groundwater elevations at times are slightly above the ground surface beneath streams entering the groundwater basin in some tributary valleys, but drop below the streambed further downstream in the upper reaches of these valleys (well before entering the Santa Clara River). This observation indicates that, at the groundwater basin boundary, the alluvium’s thickness and/or hydraulic conductivity in some of these valleys may be too small.

4.3.2.2 Groundwater Elevation Hydrographs

Seasonal and year-to-year groundwater elevation fluctuations differ in magnitude across the length of the Alluvial Aquifer adjacent to the Santa Clara River, as well as in the tributary valleys. Previous studies have divided the Alluvial Aquifer into multiple subareas for the purposes of evaluating these differences, and also quantifying differences in groundwater production from various parts of the alluvium. See for example the annual reports for the basin, such as the 2019 annual report (LSCE, 2020). The alluvial subareas are shown in Figure 4-13 and are used to discuss the model’s calibration quality to groundwater elevation hydrographs in the Alluvial Aquifer.

The model generally simulates the historical groundwater elevations and their fluctuations throughout the Alluvial Aquifer. Specific observations about the model’s calibration quality in this regard follow, beginning upstream and including tributary valleys where production wells are present.

- **Mint Canyon Subarea.** The high and low groundwater elevations, recorded over the course of many years of variable rainfall, are well matched in the two observation wells (LACFCD-7177B and -7179D) that are present in the eastern portion of the basin (in the Mint Canyon subarea; see Figure 4-14). The fit of the high and low groundwater elevations is also good at NWD’s nearby production wells, particularly the Pinetree1 and Pinetree4 wells. However, in many of these wells, the model simulates too rapid of a decline in groundwater levels following major recharge events (i.e., after high groundwater elevations are observed). Also, during droughts, simulated groundwater levels are slightly higher than the levels measured at the two other Pinetree wells and also at two other production wells just to the west (SCWD’s Lost Canyon 2 and Lost Canyon 2A wells; see Figure 4-15). The remaining wells in the Mint Canyon area are well matched (see Figures 4-15 and 4-16), except for an upward trend in water levels at several wells during 2016 that appeared to precede the observed water level recovery. Several of these wells were shut off or pumped at very low rates/volumes as the drought progressed, causing their observed water levels to stop declining and, in some cases, to rise slightly, but at lower recovery rates than simulated by the model. Repeated testing of antecedent recharge rates and aquifer parameters resulted in a closer fit to measured water levels than the fit achieved in initial simulations during the calibration process; however, repeated testing could not fully replicate the actual timing of water level recovery rates during and after the latter part of the 2011–2016 drought.
- **Above Saugus WRP Subarea.** In this subarea, the high and low groundwater elevations are well-matched, along with general elevation trends. However, as was noted above for the Mint Canyon subarea, water levels at some wells in the Above Saugus WRP subarea decline too rapidly after major recharge events and rise somewhat faster in the model in 2016 and 2017 than was observed in these wells. (See Figure 4-17.)
- **San Francisquito Canyon and Bouquet Canyon.** In these two northern tributaries to the Santa Clara River, the groundwater elevations and elevation trends are generally well-matched, particularly in

San Francisquito Canyon where the trends are well-matched in all four production wells. (See Figure 4-18.) In Bouquet Canyon, the model tends to slightly or moderately under-predict groundwater elevations at many times, and the simulated trends occasionally are the opposite of those recorded by static water level measurements. Repeated testing in Bouquet Canyon could not resolve these discrepancies.

- **Below Saugus WRP Subarea.** Groundwater elevations and elevation trends are generally well-matched in this subarea, including at observation wells AL-12A and VWD-I, the latter of which is a former production well that has been out of service since late 1991 but has continued to be used for monthly water level measurements since that time. (See Figure 4-19.) While the drought and post-drought conditions of recent years are well-simulated at VWD-Q2, VWD's wells just to the west (N, N7, and S8) show simulated decreases in water levels during the drought that are less than the observed amounts of the decreases in water levels.
- **Castaic Valley Subarea.** Groundwater elevations and elevation trends are generally well-matched in NWD's Castaic wellfield, in the upper (northern) portion of Castaic Valley. (See Figure 4-20.) Groundwater elevations in the upper valley during the recent drought are somewhat below the measured static elevations but well above the measured pumping elevations. In the lower (southern portion) of Castaic Valley, Figure 4-21 shows that groundwater elevations and elevation trends are well-matched, except for a modest over-prediction of groundwater elevations at one of the six wells in this area (NLF-E).
- **Below Valencia WRP Subarea.** The groundwater model readily simulates the small seasonal fluctuations and the near absence of year-to-year changes in groundwater elevations that make this subarea unique compared with the rest of the Alluvial Aquifer. (See Figures 4-22 and 4-23.) Groundwater elevations are closely matched at some wells (such as NLF-B14) while differences are notable at other nearby wells (such as NLF-B10 and NLF-B16). Lack of survey control, uncertainties about water-level recovery rates prior to measuring static water levels, and a lack of information about nearby pumping creates considerable uncertainty in the interpretation of the water level data from agricultural wells in this subarea. This may explain why the model closely simulates groundwater elevations at some wells (such as NLF-C6) while appearing to notably overestimate groundwater elevations in other nearby wells (such as NLF-C4). Specifically, the model closely simulates the hydrograph for well NLF-C6 (which was not been pumped since 2004 and thereby is providing truly static water level data), whereas simulated water levels are higher than the reportedly "static" water levels at NLF-C4 (which is used each year to meet agricultural water demands and may not be showing water levels that represent static conditions in the well or the aquifer). This data quality issue is further indicated by the data at NLF-C10, which showed a 15- to 20-ft decline in its static water level readings during the first year of monitoring. While these data are uncertain with respect to absolute elevations of the water table, there are consistently small variations in water levels at each well throughout this area despite the increased urbanization and the variable nature of precipitation and streamflows during the 40-year calibration period; this is a strong indication of the importance of groundwater discharges from the Saugus Formation to the Alluvial Aquifer in this area.

4.3.3 Streamflows in the Santa Clara River at the LA/Ventura County Line

The historical dry-weather seasonal low streamflows of the Santa Clara River appear to be well simulated in the vicinity of the LA/Ventura County Line when compared with historical stream gaging records from the nearby former gaging station prior to October 1996. See Figure 4-24, which provides this comparison for the gaged flow in green, and the simulated flows in blue. Four plots are shown to illustrate how streamflows were extrapolated from the model boundary (at the County Line, which is also virtually coincident with the boundary of the East Subbasin) to the location of the former gaging station. The upper two charts on Figure

4-24 show that the model simulates the river as being a losing stream between the mouth of Potrero Canyon and the County Line (a distance of approximately 0.85 miles). The model's simulation of losing stream conditions near the County Line is consistent with the findings from the 2007 soil boring and geophysical survey program in this area (see Appendix C). The chart in the lower left corner of Figure 4-24 shows that streamflows at the former County Line gage station would be under-predicted if the rate of loss between Potrero Canyon and the County Line were to be extrapolated from the County Line to the former gage site. Between the County Line and the former gage site, a loss rate that is one-quarter of that between Potrero Canyon and the County Line provides a good fit to the measured data prior to October 1996 at the former gage site. Beginning in late 1996, this interpretation results in the appearance of simulated low flows that are slightly less than those at the new gage site at most times -- an observation that suggests that the river is receiving a small net influx of water between the County Line and the new gage site 3.5 miles further downstream.

4.3.4 Statistical Measures

Calibration statistics were calculated for the residuals of groundwater elevations and groundwater elevation changes over time. As defined by ASTM (1996), the residual is equal to the measured value minus the simulated value at any point in time for a given well that is used for model calibration. The calibration statistics were calculated for all times when static water levels measurements are available for a given well. Static water levels were used because they represent conditions in the aquifer, whereas pumping water levels are influenced by well losses and variability over many years in the condition of both the well and the well's pumps.

Statistics were calculated for all residual values during the 40-year simulation period and were calculated for the entire aquifer system (89 target wells, consisting of 78 production wells and 11 observation wells), the Alluvial Aquifer alone (65 target wells, consisting of 62 production wells and 3 observation wells), and the Saugus Formation alone (24 target wells consisting of 16 production wells and 8 observation wells). The target wells included each production well where a continuous or nearly-continuous water level record is available over multiple years or decades; three Alluvial Aquifer monitoring wells (AL-12A, LACFCD-7177B, and LACFCD-7179D) that could be located and verified as not coinciding with another well already being analyzed and also not being a bedrock well; and eight Saugus Formation observation/monitoring wells (DW-1B, DW-2, Library-A, Mall-A, SG1-HSU3a, SH1-HSU3c, MP1-08, and MP5-03) whose groundwater elevation hydrographs (discussed in Section 4.3.1.2) indicate that the well is monitoring the regional flow system rather than locally discrete water-bearing strata.

Table 4-3 presents summary statistics for groundwater elevations and groundwater elevation changes. Figures 4-25 and 4-26 present scatter diagrams that plot the modeled values (on the vertical axis) against the simulated values on the horizontal axis, and which include three diagonal lines: one showing a perfect fit, and the other two representing one standard deviation of residual values on each side of the perfect-fit line. For groundwater elevations, the table and plots show that the calibration goal of 10 percent or less for scaled statistics is met for the scaled residual mean (ranging from 0.7 percent to 3.5 percent) and the scaled standard deviation (ranging from 2.7 percent to 7.9 percent). The scaled statistics for groundwater elevation changes meet the 10 percent goal for the scaled residual mean (ranging from 0.5 percent to 5.9 percent) and for two of the three scaled standard deviations (2.3 percent for both aquifers combined and 3.1 percent for the Saugus Formation alone). However, the scaled standard deviation for groundwater elevation changes in the Alluvial Aquifer is 12.2 percent, which is slightly above the 10 percent goal. Inspection of the elevation-change statistics indicate that the residual error for the Alluvial Aquifer is caused by the wells in the eastern portion of the basin (in the Mint Canyon subarea and the Above Saugus WRP subarea) where groundwater levels (1) decline too quickly following high-rainfall/recharge events and, in some cases, (2) recover too quickly during the latter portion of the 2011–2016 drought (as discussed in Section 4.3.2.2).

After reviewing the statistics, the analysis was repeated without five Saugus Formation production wells that are near the perimeter of the model, away from the primary focus area in the central portion of the basin (wells LACWWD36-19, VWC-159, NCWD-7, NCWD-9, and NCWD-10). Even though the calibration statistics in the initial analysis met the calibration goal, this second analysis was of interest to understand (and quantify) the extent to which these five peripheral wells are affecting the statistics and the model's calibration quality, given the difficulties in improving the calibration in these peripheral areas where only limited data are available. These statistics are presented in Table 4-4 and Figures 4-27 and 4-28. As shown, the mean, standard deviation, and scaled statistics decreased in value in the case of groundwater elevations. For groundwater elevation changes, the absolute value of the mean residual increased slightly, the standard deviation decreased slightly, and the scaled statistics were similar or slightly lower in value than in the initial analysis.

4.4 Observations of Parameter Sensitivity During Calibration

Calibration and testing of the new regional model was conducted over an approximately 2-month period, and was conducted primarily using manual calibration methods because of the model's long run times. During this effort, observations were made about the general influences that adjusting certain model parameters would have on improving or degrading the model's ability to simulate historically measured groundwater elevations and groundwater elevation trends for the Alluvial Aquifer and the Saugus Formation as well as historically measured streamflows at the County Line. Following are some of the noteworthy observations from this process.

The following observations about model sensitivity were made regarding upgradient areas of the model.

- Groundwater elevations at the LACWWD36-19 production well were sensitive to the placement or absence of a low-permeability hydraulic conductivity zone south of the well and north of the Santa Clara River. Without such a feature, initial calibration simulations produced simulated static groundwater elevations that were more than 300 feet below the measured static elevations. Because no other production wells or observation wells are known to be present in the Saugus Formation in the area situated north of the river and west of the San Gabriel Fault, the nature of the geologic features supporting the high groundwater elevations at this well are unknown. However, the placement of a low-permeability hydraulic conductivity zone was deemed appropriate because of the presence of the high recorded groundwater elevations at this well.
- The selection of hydraulic conductivity values in the southern portion of the Saugus Formation (south of NWD's wells 10 through 13) was instrumental in calibrating groundwater elevations and groundwater elevation trends at NWD's active and inactive production wells. This zone (zone 18) uses a vertical hydraulic conductivity of 1 ft/day, compared with its horizontal hydraulic conductivity of 2 ft/day. The need for a relatively high vertical hydraulic conductivity in this zone is consistent with the understanding that groundwater recharge to the Saugus Formation at the southern edge of the groundwater basin is potentially an important recharge mechanism (in addition to leakage from the Alluvial Aquifer from the Santa Clara River east of I-5).
- In the eastern portion of the Alluvial Aquifer, tests were conducted to seek improvements in the too-early simulated onset of water level recovery towards the end of the 2011–2016 drought period. Because hydraulic conductivity values were already similar to those estimated from the highest specific-capacity wells in this area, further increases in hydraulic conductivity were deemed as unsupported by field data and were not tested as a means of reducing the magnitude and timing of water level recovery. Initial tests that raised the specific yield from 0.10 to 0.20 resulted in overall

poor matches to long-term hydrographs in this area. Further tests of lower streambed recharge rates, lower rainfall infiltration rates prior to the drought, and lower hydraulic conductivity values in the Alluvial Aquifer resulted in varying degrees of worsening of the match to observed groundwater elevation trends and, in some cases, observed groundwater elevations.

The following observations about model sensitivity were made in the center of the basin (primarily the downgradient areas that are situated at and west of I-5).

- Streambed conductance has an influential role on simulation quality in the calibration model, including in the perennial reach of the river. Changes as small as a factor of 2 in streambed conductance west of I-5 were found to have a discernible effect on dry-weather flows downstream of the Valencia WRP, with the influence becoming pronounced when dividing or multiplying by a factor of 10. The model's current representation of Santa Clara River flows west of I-5 is based in part on careful adjustment of the conductance terms in Segments 85 through 107 (from the mouth of San Francisquito Canyon to the mouth of Castaic Creek), to reflect field observations of a small amount of net streamflow loss occurring between the outfall from the Valencia WRP and Castaic Creek.[3]
- The ET surface and the ET extinction depth have a noteworthy influence on the annual volume of ET that occurs from uptake of groundwater by deep-rooted vegetation along the riparian corridor of the Santa Clara River. Sensitivity tests indicated that lowering the ET surface to a depth of 5 feet (in contrast to placing it at the ground surface) caused a 23 to 28 percent increase in annual ET, which varied in accordance with year-to-year fluctuations in basin-wide rainfall and rainfall recharge. Lowering the ET extinction depth from 15 feet to 30 feet increased ET withdrawals by an additional 7 to 11 percent. The combined effect of these two model tests was a 32 to 43 percent increase in ET, depending on background hydrologic conditions. The calibrated model uses an ET surface placed 5 feet below ground surface, and an extinction depth 25 feet below ground surface.
- West of the Valencia WRP, the selection of the deep percolation rate beneath agricultural lands has little influence on simulated groundwater levels in the Alluvial Aquifer. The choice of the horizontal and vertical hydraulic conductivity in the upper layers of the Saugus Formation at and west of the Valencia WRP has a notable effect on groundwater elevations in the southern portion of the Saugus Formation, and also has enough of an effect on Alluvial Aquifer groundwater levels so as to sometimes cause notable effects on the rates at which groundwater discharges from the alluvium into the river west of the Valencia WRP.
- The selection of the hydraulic conductivity of the Alluvial Aquifer downstream of the Valencia WRP was crucial for calibrating the model's simulation of dry-weather flows in the Santa Clara River to measured streamflows, particularly after the thin nature of the alluvium in the vicinity of Potrero Canyon and the LA/Ventura County Line was programmed into the model using the results from a 2007 geophysical study. Initially low hydraulic conductivity values (on the order of 100 to 550 ft/day) produced unreasonably high simulated streamflow volumes. Reinspection of specific capacity data in this area revealed that one well (NLF-B5) has a specific capacity that produces hydraulic conductivity estimates of more than 1,000 ft/day, and potentially as high as 1,500 ft/day. The model calibration process has resulted in the use of hydraulic conductivity values of 1,000 ft/day at the County Line and the mouth of Potrero Canyon, and values as high as 1,400 ft/day extending upstream to and just east of NLF's C wellfield.

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[3] Personal communication, Andy Collison/ESA to John Porcello/GSI Water Solutions, December 6, 2016.

4.5 Calibration Outcome

DWR's modeling BMP (DWR, 2016a) states the following regarding the decision-making processes involved in assessing whether a model is sufficiently calibrated for its intended uses:

> No model is perfectly calibrated, and establishing desired calibration accuracy a priori is difficult. One criteria that could be considered is whether additional calibration would change a GSA's approach to achieving sustainability. If a more accurate model does not change the decision a GSA would make, then additional calibration is not necessary. [p. 28]

The process of calibrating the new regional model to a 40-year period of groundwater elevation and streamflow data has resulted in a model that is deemed by the authors of this report to be suitable for its intended applications, which include evaluating groundwater sustainability and potential projects that can improve sustainability if needed, evaluating groundwater pumping strategies between and during drought periods, and supporting water quality studies. The primary attributes of the model's calibration that makes this tool appropriate for its intended uses are:

- Its ability to simulate groundwater elevations and flow directions, as well as historical trends in groundwater elevations and river flows, during a 4-decade period that reflects (1) multiple cycles of rainfall and streamflows and (2) the effects of increased urbanization on changes in land use and water use, thereby meeting the goals established for the calibration process (calibration goals 1 through 5 as described in Section 4.1.2)
- Its ability to simulate these same characteristics in smaller geographic areas of interest within the valley (for example, in multiple subareas of the Alluvial Aquifer)
- The use of groundwater elevation and streamflow data to constrain the model's calibration (rather than relying solely on groundwater elevation data)
- The consistency of the calibration results with the conceptual models for the groundwater and river systems, which have been described in numerous prior reports (including RCS, 2002; CH2M HILL, 2004a; CH2M HILL, 2005; CH2M HILL and HGL, 2006 and 2008; Geomatrix, 2007; and basin annual reports, such as LSCE, 2020)
- The model's use of an integrated model of the watershed (the SCV Recharge Compiler) to define the amount of rainfall and stormwater that is potentially available to recharge the groundwater system
- The incorporation of a streamflow routing package that allows streamflows to be directly simulated in the model
- The use of MODFLOW-USG, which allows efficient simulation of local-scale conditions with a high-resolution grid that is efficiently integrated into the parent grid

The calibration process has resulted in a new regional model that reasonably replicates, on a monthly and annual basis, historically-observed groundwater elevation fluctuations and the dynamic and spatially variable nature of flows in the Santa Clara River and groundwater/surface water exchanges throughout the East Subbasin – capabilities that are necessary for evaluating and designing groundwater management strategies and monitoring and evaluating their effectiveness. Accordingly, as envisioned by DWR in its modeling BMP document (DWR, 2016a), the model can serve as a valuable tool for comparing the benefits and impacts of various management strategies with respect to one another, which in turn will facilitate an adaptive management approach to continuing the current management program and/or implementing new programs under the GSP.

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SECTION 5: **Model Applicability to Local Water Resource Management**

Following are a summary of the model's applicability to current and future groundwater management activities, a summary of the model's limitations, and recommendations for future maintenance of the model.

5.1 Model Applicability

The process of constructing and calibrating the SCVGWFM (the new MODFLOW-USG regional groundwater flow model) to a 40-year record of groundwater level and streamflow records has resulted in a model that is well-suited for its intended applications. As discussed in Section 1.2 of this report, the SCVGWFM was built to support GSP development and implementation by virtue of its use of widely known groundwater modeling software that (1) enables the use of unstructured grids, (2) provides rigorous numerical treatment of multi-layer production wells, and (3) allows for calculation of instream flow rates while simulating groundwater/ surface water exchanges—a combination of capabilities that does not exist in any other groundwater modeling code. The primary attributes that make the SCVGWFM appropriate for its intended uses are as follows:

- The model's boundaries extend outward to the groundwater basin boundary, thereby avoiding the introduction of artificial boundary influences on simulation results and their interpretations.
- The SCVGWFM simulates historical trends in groundwater elevations and streamflows across the basin, particularly in the Alluvial Aquifer where significant differences in these trends occur in different parts of the basin.
- The SCVGWFM has been calibrated to a 40-year period that was characterized by increased urbanization, variations in agricultural water use, increased State Water Project imports (which began in late 1979), associated changes in land use and water use, significant rainfall/recharge events during El Niño years, and periods of prevailing below-normal rainfall conditions (including a deep drought characterized by far-below-normal rainfall from late 2011 through 2016). The model's calibration includes periods of normal, above-normal, and below-normal rainfall years, which makes it useful for examining groundwater resource management topics under a variety of future climatic conditions.
- For the portion of the alluvial valley hosting the perennial reach of the Santa Clara River, the SCVGWFM can simulate the surface and shallow groundwater hydrologic processes that are of interest to the SCV-GSA, SCV Water, and local stakeholders. Specifically, the model simulates the discharge of treated water to the Santa Clara River from the Saugus and Valencia WRPs, the and the spatial changes in flow in the river arising from streambed seepage to the water table in losing reaches, and groundwater discharge to the river in gaining reaches. The model also simulates the seasonal variations in groundwater uptake by phreatophyte plant communities that are comprised of native species (predominantly Fremont Cottonwood and various species of willow trees and shrubs) and invasive species (predominantly *Arundo*).
- The SCVGWFM includes a companion code developed by GSI—named the SCV Recharge Compiler—that determines the monthly volume of rainfall that is available to streams that are tributaries to the Santa Clara River (from the portions of those tributaries that lie in the contributing watersheds situated upstream of the groundwater basin boundary). The SCV Recharge Compiler also computes how much of this runoff entering the groundwater basin can recharge the Alluvial Aquifer, and the locations of that recharge. Together, the SCV Recharge Compiler and the SCVGWFM allow for estimation of the time-varying magnitude of storm-driven groundwater recharge and the effects of that recharge on groundwater return flows to the Santa Clara River. In summary, the SCVGWFM is actually a groundwater

flow model coupled with an empirical tool that estimates stormwater generation from each watershed lying upstream of, and extending into, the East Subbasin.

5.2 Model Limitations

The SCVGWFM has been created through a detailed process of planning, construction, and calibration. Accordingly, the model is a viable and reliable tool for the SCV-GSA and SCV Water to use for development, implementation, and monitoring of the GSP for the East Subbasin, and for other groundwater resource planning and management programs. Nonetheless, despite its detail and the in-depth nature of the calibration and validation process, the numerical model is a simplification of a complex hydrogeologic system and has been designed with certain built-in assumptions. Like any model, it is not perfect and should be used with care. Predictive simulation results should be examined by qualified and experienced hydrogeologists and water resource managers. Future modeling analyses, interpretations, and conclusions should not be viewed as absolute results and could change as the model is refined in the future as new data become available.

As with any groundwater model, there are data limitations inherent in the use of the model, in particular because of the small number of wells in certain areas. This is particularly the case (1) in the Saugus Formation north of the Holser Fault, where only one deep production well is present (LACWWD36-19) and (2) in the Alluvial Aquifer along several tributaries to the Santa Clara River where few (if any) wells are present. The use of the model in these areas for in-depth predictive analyses would best be preceded by further study and modeling of the local groundwater system (including local calibration refinements wherever new data are sufficient in volume and quality to support such an effort).

5.3 Recommendations for Future Maintenance of the Model

The process of calibrating and validating the SCVGWFM has resulted in a tool that reasonably represents historically observed groundwater elevations, their seasonal and annual fluctuations, historical streamflow data near the LA/Ventura County Line, as well as the relative magnitudes of groundwater recharge and discharge mechanisms as understood by local hydrogeologists before the development of the SCVGWFM began. The model's reasonable representation of historical data, and its agreement with the conceptual model, make it a useful and important tool to support water supply planning and groundwater resource management in the East Subbasin.

Continued maintenance of the model is recommended, to ensure that it will continue to be ready for future groundwater resource planning and system evaluation needs. Maintenance activities should be determined by SCV Water based on how it plans to use the model to support long-term programs (water supply planning, groundwater supply augmentation, and groundwater resource protection) and to support near-term decision-making on matters such as wellfield operations, site development impacts on groundwater, or other specific resource management topics. Maintenance activities could include one or more of the following activities, to the extent deemed necessary and appropriate by SCV Water:

- **Extending the calibration period as new data become available.** This can be thought of as a "calibration check" process, for which the objective is to evaluate the model's ability to simulate more recent conditions than those for the pre-2020 period to which the model was calibrated. Events that could warrant an extension of the calibration period include the collection of data at new locations and the occurrence of different groundwater conditions than those experienced in the past (e.g., if the onset of an extended drought were to cause decreased pumping at some wells, the need to increase pumping elsewhere, lower recharge to the aquifer, and accordant changes in observed groundwater levels). Additionally, whenever new production wells are installed, long-term water level monitoring should commence in the well, and controlled pumping tests should be conducted to provide quantitative estimates of aquifer properties—particularly in areas where wells have not been previously constructed.

- **Upgrades to model software.** New versions of the MODFLOW family of software tools periodically become available that add/improve existing MODFLOW packages and/or improve solver capabilities and reduce model run times. These updates can occur every few years. Additionally, updates to the GUI (GV) occur frequently, although major upgrades in its features occur only every few years. Updates to MODFLOW and GV do not need to be conducted on a regular schedule for the model to remain functional and suitable for its intended uses. If SCV Water elects to use the model in an updated version of MODFLOW or under a major update of GV, the model should be run with the new software to confirm that it converges and runs properly, and to check that simulation results are similar to those obtained from the earlier software.
- **Model-sharing and cooperative efforts with local stakeholders and other government agencies.** When a municipality or water provider has developed a detailed numerical groundwater model of a regional aquifer system, it is common to receive requests for the model from local landowners/stakeholders or other government agencies. Keeping the model updated with recent software and a calibration that is not several years old is generally helpful for increasing the confidence of other stakeholders and for providing the model's owner (SCV Water) with opportunities to ensure that the model is being used correctly.

The thoroughness and completeness of much of the available groundwater and surface hydrologic data set has had a long history of greatly facilitating the ability to (1) construct and calibrate the original groundwater flow model and the new regional model described in this report, and (2) check the calibration of the model as new data become available from the monthly monitoring programs that are conducted across the basin. These activities should continue in order to support groundwater model maintenance and SCV Water's other monitoring and resource planning programs. Critical data for SCV Water and its retail water divisions to collect include well-by-well groundwater pumping volumes, routine groundwater level measurements under static and pumping conditions, and rainfall (at the former NWD office). These data—along with other critical hydrologic data (particularly stream gaging data) collected by city, county, state, and federal cooperating agencies—provide valuable information for identifying and understanding the changes that occur in the surface and groundwater systems, including the nature of the exchanges of water between groundwater and local streams.

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SECTION 6: **References**

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