Memorandum

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Re: Expert Panel Review of the Expansion and Update to the Ventura Regional Groundwater Flow Model (Ventura County, California)

Introduction

The United Water Conservation District (UWCD) has developed a numerical groundwater flow model of a series of interconnected groundwater basins in the southern portion of Ventura County, California where UWCD is charged with managing, protecting, conserving, and enhancing the region's water resources. This regional model initially was constructed for the four westernmost groundwater basins along the coast in southern Ventura County (the Oxnard, Pleasant Valley, West Las Posas, and Mound groundwater basins) and is referred to as the "Coastal Plain Model" in this memorandum and in a June 2021 report (UWCD, 2021a). The development and calibration of the Coastal Plain Model is documented and referred to as the VRGWFM in a report that also presented the underlying hydrogeologic conceptual model for those four groundwater basins (UWCD, 2018). The newest version of the numerical groundwater flow model (herein referred to as the Regional Model) expanded the Coastal Plain Model by adding three other groundwater basins (Piru, Fillmore, and Santa Paula) that occupy the alluvial valley of the Santa Clara River in the eastern portion of the county. The effort to expand and calibrate the model in the Piru, Fillmore, and Santa Paula groundwater basins was completed in August 2020 and documented in a June 2021 report (UWCD, 2021a). The report focuses on conceptual and numerical models for these three added groundwater basins but also discusses pertinent aspects of model development for the entire area simulated in the new Regional Model. The model's simulation period (originally calendar years 1985 through 2015) was later updated to include four more years of recent hydrologic and water use data (2016 through 2019) and is described in an August 2021 report (UWCD, 2021b).

The Regional Model has been developed to provide a new management tool to guide future policy decisions regarding groundwater management at wellfield to basin scales and potentially in various aquifers or groups of aquifers. The model initially has been used to support the development and implementation of Groundwater Sustainability Plans (GSPs) in several of these basins under the State of California's Sustainable Groundwater Management Act (SGMA). Aspects of GSP development and implementation that have made use of the model include (1) establishing sustainability goals and criteria in critical regions of the local groundwater basins, (2) developing numerical thresholds for evaluating compliance with the sustainability goals and criteria during the ensuing 20-year period for implementing each GSP, and (3) analyzing the hydrogeological impact of various projects and management actions intended to provide and/or maintain sustainability in a given groundwater basin.

UWCD has retained the services of an expert review panel consisting of the three groundwater modeling consultants who are the co-authors of this memorandum. Working individually and collectively, this panel has conducted a review of the Regional Model's construction, calibration, and simulation performance, with a focus on evaluating (1) the suitability of the overall modeling approach and model design to meet GSP objectives, (2) the conceptualization, construction, and simulation techniques by which the geologic and hydrologic attributes of the multi-aquifer groundwater system are represented in the model, and (3) the quality of the model's calibration. The panel also has considered the model's suitability for a variety of anticipated future uses, as well as potential limitations on its use. The panel conducted this work for the Coastal Plain Model from 2016 through 2018, and then resumed its efforts in 2020 once an initial version of the newly expanded Regional Model became available for review. UWCD has implemented many of the expert panel's suggestions and recommendations during the past five years and plans to further refine the model as needed to support future specific applications of the tool. Accordingly, this memorandum provides a summary of the panel's evaluation of the Regional Model as documented in UWCD's June 2021 model development report (UWCD, 2021a), with the recognition that the model is likely to evolve through a series of refinements as it is applied to specific projects and planning efforts in the region.

In summary, the expert review panel finds the model to be a well-designed and well-calibrated tool that is a substantial enhancement and upgrade over previously available models. The Regional Model provides a newer and more detailed representation of groundwater flow in the hydrostratigraphic units in these basins than was previously available. Accordingly, the Regional Model provides a sound platform for evaluating how the multiple aquifers in the region behave and how they might respond to the design and implementation of regional management programs in the seven groundwater basins that the model simulates in southern Ventura County. A detailed sensitivity analysis has been conducted on the model with regards to water levels in the various basins, the basin water budgets, and the inter-basin flows. The sensitivities are categorized as per ASTM guidelines (ASTM, 2016) which provide an overview of the significance of various parameters to model results. Use of the model for decision making can additionally use the sensitivity coefficients to evaluate impacts of parameter uncertainty to decision results. A future upgrade to an

unstructured-grid version of MODFLOW will allow this model to become a robust platform for evaluating projects and management actions in localized areas (i.e., at the land-parcel and wellfield scales).

Groundwater models commonly contain a very large amount of data and can be extremely complex. This model is no exception, and in some respects is more complicated and detailed than other regional-scale or locally-focused groundwater models. While the review team has spent considerable time working with the model and discussing its underlying assumptions with UWCD, future reviews of the model's applications may turn up further recommendations and suggested changes to the model.

The expert review panel focused its review work during 2020 and 2021 on the model's expansion into the three eastern basins along the Santa Clara River (Piru, Fillmore, and Santa Paula) and the update of the model time period to include the years 2016 through 2019. The remainder of this memorandum discusses the following topics:

- The expert review panel's evaluation methods and activities
- A summary-level description of the model
- The panel's assessment of the model's calibration quality and representativeness of the hydrogeological conditions of the basins
- The model's uses and potential enhancements
- A list of the references cited in this memorandum

Expert Panel Evaluation Methods and Activities

The review process for the model expansion began with an online technical meeting hosted by UWCD in March 2020. UWCD staff presented details on the conceptual model of land uses, surface water hydrology (including water storage and releases into streams), the subsurface geology and hydrostratigraphy, and previous hydrogeologic investigations and water budget estimates for the Piru, Fillmore, and Santa Paula basins. UWCD's lead modeler then presented the construction and calibration status of the model in the expansion area. The numerical model and a write-up of the conceptual model for these three basins were then provided to the expert review panel for detailed review in March and April 2020, from which the panel provided an initial set of comments in June 2020. Later, newer versions of the model were provided to the panel for review in July 2020 (another draft version of the model) and in August 2020 (the final model that is described in the June 2021 documentation report). In April 2021, the panel also reviewed and provided comments on a draft version of the report. In July 2021, the panel reviewed a draft version of a second report issued in August 2021 that discusses the update of the model for the time period of calendar years 2016 through 2019 (UWCD, 2021b).

Model Summary

The original Coastal Plain Model developed by UWCD in 2018 was expanded during 2020 to include the Piru, Fillmore, and Santa Paula basins (from east to west), which are present in the lowland valley containing the reach of the Santa Clara River that extends from the Ventura/Los Angeles County Line downstream to the Mound basin and the Pacific Ocean. The expanded model used the same cell spacing for the model grid (2,000 feet) as was used in the Coastal Plain Model and simulates the same original time period (calendar years 1985 through 2015) for calibration purposes. The model update simulates four additional years (2016 through 2019) to serve as a further calibration check on the expanded model. The expanded model uses a daily stress period to capture the impacts of highly variable flows within the Santa Clara River and its tributaries; flow is otherwise more stable in the other streams that are located in the original model domain. (The Coastal Plain Model had used monthly stress periods.) In addition, the model domain for the expansion area (the Piru, Fillmore, and Santa Paula basins) has different hydrogeologic characteristics which are represented by 10 active model layers. (The portion of the model domain covering the four basins in the Ventura coastal plan has 13 active model layers). The expanded model domain interfaces with the original 2018 model domain across the Country Club fault, which distinctly divides the hydrogeology of the extended domain from the geological units further downstream in the Oxnard and Mound basins.

Boundary conditions for the expanded model domain represent similar features as in the original model, including similar conceptual representations for areal recharge, mountain front recharge, subsurface underflow, consumptive water use pumping, and streamflows entering the model (at the eastern end of the domain within the Santa Clara River and at model boundaries to various tributaries of the Santa Clara River). Riparian evapotranspiration is also included along the Santa Clara River corridor.

The expanded numerical model compares well with the descriptions of geology and hydrogeology that were developed from the data, in the conceptual model section of the model development report (UWCD, 2021a). Descriptions of soil material types or of semi-confined conditions, along with data from field tests and measurements, generally conform with values of hydraulic conductivities and water levels simulated by the numerical model. The expansion of the model domain into the Piru, Fillmore, and Santa Paula basins and the increased temporal resolution of the model's stress periods (from monthly to daily) did not affect the model results within the original model domain.

Assessment of Calibration Quality

During the process of reviewing and commenting on the expanded Regional Model, the expert review panel observed that the model's calibration quality was improved by several incremental changes made by UWCD during the spring and summer of 2020 within the expanded area. The incremental improvements arose from internal consultations among the members of the panel, panel member discussions with UWCD's lead groundwater modeler, and the internal review processes at UWCD (which included review of the simulated rates of surface water/groundwater exchanges and streamflows by UWCD's surface water hydrology team members). The incremental improvements and refinements within the expansion area included the following:

1. Splitting the San Pedro Formation aquifer system into three layers (rather than its original single layer) to obtain enhanced resolution of the hydrostratigraphic sequence within that model layer as shown in Table 2-10 of the model development report (UWCD, 2021a; Upper Saugus – Aquitard – Lower Saugus).

2. Incorporating ET processes from riparian plant communities into the model.

3. Resolving issues with dry cells and reduced pumping from certain wells, which were problems that occurred primarily along the model's edges.

4. Simulating storm flow components separately and discretely from conservation releases of water occurring from the Santa Felicia Dam.

5. Incorporating LIDAR elevation data sets into the definitions of the riverbed profiles and bed elevations.

6. Increasing the model's time resolution to daily, so that daily variations in stream flows could be simulated (which is critical to UWCD's groundwater resource management programs and water supply operations).

7. Coordinating the representation of hydraulic conductivity values and subsurface inflow at the east end of the Piru basin (at the Ventura/Los Angeles County Line) with the representations of these conditions in western Los Angeles County as contained in a numerical groundwater model that was concurrently being developed for the East Subbasin by the Santa Clarita Valley Water Agency (GSI Water Solutions, 2021). This coordination effort not only improved conditions at and near the county line, but also resolved the Regional Model's initial inability to simulate the dry gap that is present in the Santa Clara River upstream of the mouth of Piru Creek.

During the course of its review, the expert review panel observed that the process of calibrating the Regional Model was complicated by a number of factors. Specifically:

1. The multi-layered and faulted aquifer system is complex in structure, and the wells that penetrate these units commonly penetrate more than one aquifer system. Some wells penetrate 1, 2, or 3 layers in the model, while other wells penetrate as many as 7 or 8 model layers. Accordingly, the water level measured in a well is the result of not only its use at the time the water level is measured, but also the large ambient (natural) differences in groundwater elevations that are commonly present in the three primary aquifer systems that are present in the expansion area (identified by UWCD as Aquifer Systems A, B, and C which are represented in model layers 1 through 3, 4 through 7, and 8 through 10, respectively).

2. As discussed in Section 2.2 of the June 2021 model development report (UWCD, 2021a), the majority of the available groundwater elevation data are from production wells. The production wells are simulated as pumping wells in the model, in order to simulate this

important discharge term in the groundwater budget for each individual aquifer. Yet the water level data from these same wells consist almost exclusively of measurements that are made once a well has been off for a period of time that can range from (a) a few hours in the case of municipal wells (year-round) and agricultural wells (during the peak-pumping season) to (b) several days or weeks (primarily in the case of agricultural wells during the winter months). The use of these measurements in evaluating calibration quality is quite complicated and difficult to interpret because (a) the hourly and daily operations of each well are unknown, and (b) the duration of time a well has been off before a water level measurement is collected is unknown (and likely varies from well to well and over time at any individual well). Both factors affect the water level measurement and may be the cause of slight over-predictions in groundwater elevations at several well locations in the model (due to incomplete water level recovery and/or interference from nearby wells).

3. Large fluctuations in water levels occur in these wells because of changes in recharge and pumping. The magnitudes of both terms (recharge and pumping) can only be estimated from the available data sources, and therefore may contain large errors or may not be well represented by average conditions simulated by the model.

Even with these complexities, the expert review panel concludes that the model is generally well developed and well calibrated in the model expansion area, based on qualitative analyses (consisting of visual inspection of hydrographs) and quantitative statistical evaluations (consisting of tables, maps and scatter plots showing residual statistics for groundwater elevations, and groundwater elevation changes arising from pumping, changes in recharge, and controlled releases to streams). The expert review panel's specific observations regarding calibration quality are as follows:

1. The numerical model is well developed and consistent with the data and the conceptual model. Flow rates for model inputs were provided using the best information / estimates available for precipitation recharge; agricultural, domestic, and M&I return flows; recharge from WWTP discharges to streams or at recharge ponds; mountain-front recharge; inflow at streams; and groundwater pumping. Model parameters were estimated from various aquifer tests conducted in the region. The 2,000-foot grid-block size is appropriate for regional-scale simulations; monthly variations in pumping and recharge stresses are appropriate for seasonal planning purposes; and daily variation of streamflows in the Santa Clara River are appropriate for capturing groundwater responses to the flashy flow behavior of the river.

2. Some slight biases in the calibration are evident. For example, the residuals maps contained in the June 2021 model development report (UWCD, 2021a) show predominantly positive residuals (under-simulated) in the east and negative (over-simulated) residuals in the west for water levels in Aquifer System A (see report Figure 4-1), and predominantly negative residuals (over-simulated) in the west for Aquifer

System B (see report Figure 4-3). Scatter plots show that there is a tendency to overpredict water levels in the Santa Paula basin, primarily in Aquifer System B (see report Figure 4-61), whereas there is a tendency to underpredict water levels in Fillmore (see report Figure 4-60). Section 4.2.6 of the model development report mentions that natural baseflows are underpredicted in the Fillmore basin, which fits with our observation that heads have a tendency to be underpredicted in that basin as well.

3. However, in our opinion, none of these issues are critical enough to require revisions to the model because individual wells in these areas and certain aquifer systems show very robust calibration. For example, most of the simulated hydrographs in Aquifer Systems A and B in the Piru basin show an excellent fit to historical data, including good simulation of declining groundwater levels during drought periods. In the Fillmore basin where the statistics indicate a tendency to underpredict water levels, there are certain wells in the A and B aquifers that have only small to moderate underpredictions of groundwater elevations (see for example well 03N21W01P02S in Aquifer System A) while showing simulated fluctuations that are similar to historically observed fluctuations through multiple wet/dry hydrologic cycles (see wells 03N20W01C04S, 03N20W08A01S, and 04N19W30D01S, which are all screened within both the A and B aquifer systems, and wells 03N19W06D02S and 04N20W26C02S in Aquifer System B). In the Santa Paula basin, certain wells are quite well simulated – in particular, wells 03N21W32C01S and 03N21W29K02S in Aquifer System A and wells 03N21W11J02S and 03N21W02R02S in Aquifer System B. However, there are fewer wells in the Santa Paula basin that show as strong a match to groundwater elevations and elevation changes as are seen in Piru and Fillmore; in particular, the model has a tendency to predict too little seasonal fluctuation in Santa Paula groundwater levels and in some cases not enough of a decline in water levels during the two drought periods that are simulated (from 1988 through 1992, and from 2012 through 2016). This is a more frequent observation for wells in Aquifer System B than for wells in Aquifer System A. These observations are useful for evaluating prediction results within these basins when the model is being used for various analyses.

4. In our experience, scaled statistics less than 0.1 (i.e., 10 percent) are indicative of good calibration on an area-wide basis. Scaled statistics are defined as the statistic of interest divided by the range in values in the measured data set. The scaled groundwater elevation statistics for the absolute residual mean and the residual standard deviation are well below 10 percent, ranging between 2.5 and 6.0 percent during the calibration period (1985-2015) for the group of three basins along the Santa Clara River (Piru, Fillmore, and Santa Paula) and between 3.9 and 8.5 percent during the update period for these same three basins. When excluding outlier wells and wells with fewer than 10 water level records, these statistics range from 3.9 to 6.4 percent during the calibration period and 3.9 to 8.4 percent during the update period.

5. A detailed sensitivity analysis was conducted on every variable and stress within each of the modeled basins. The sensitivity analysis produced reasonable results in that the model's relative sensitivity or insensitivity to each type of parameter was consistent with what a modeler would expect to be the case in this type of setting. Specifically, the model showed sensitivity to horizontal hydraulic conductivity values, areal recharge rates, evapotranspiration rates, streambed conductance values in losing stream reaches, and certain other parameters in localized areas. The model was generally less sensitive to the vertical hydraulic conductivity, fault conductance terms, the dimensionless storage coefficient, and the specific yield – though there are localized areas where the choices of these terms are influential (for example, the fault conductance for the County Club fault, which controls the subsurface lateral flux term from the Santa Paula basin into the Mound basin).

6. In future model updates, we recommend comparing zone water budgets from the model (as presented in Section 4.3 of the June 2021 model development report) with estimates of groundwater inflow and outflow components from the conceptual model discussion that is presented in Section 2.6 of the model development report. Generally, the model compares well; however, some modeled water budget terms are beyond the conceptualized minimum or maximum values, so a discussion may help in this regard.

7. Inclusion of zone budget analyses for the Piru, Fillmore, and Santa Paula basins would be useful to conduct in future updates of the model, especially considering the hydrogeology of how one basin spills into the other. For example, we note that Figures 4-77A and 4-78A in the model development report indicate that groundwater elevation at the index wells underpredict flow across the basin boundary for high flows, while Figure 4-79 indicates that high flow rates in the stream are underpredicted at the Freeman Diversion. Therefore, it would be helpful in future model updates to see how total water budgets perform across basin boundaries in terms of cumulative volumes of water (against time) to see if total water budgets are as observed/conceptualized for measured or estimated components of the water budget.

8. The model was evaluated by comparing the original 1985-2015 calibration period to the extended model period 2016-2019. This update period exhibits the same type of calibration quality to the original calibration with just a few minor exceptions. In Piru basin, water levels over 600 ft in the 2016-2019 period were higher than in the original calibration. Water levels in the UAS/LAS of Oxnard Forebay were underestimated in the 2016-2019 period. The update period shows that the model calibration remains of good quality without having to change the conceptual model or aquifer properties even when simulating a different time period from the original calibration.

While there are uncertainties in this and any other groundwater model due to spatial variability or errors in data, model conceptualization, subsurface parameterization, and numerical representation, the expert review panel believes that the current model is a well-designed and well-calibrated tool that is a substantial enhancement and upgrade over previously available models and hence will be useful for understanding and managing the groundwater resources in southern Ventura County currently and in the future. This includes the influence of controlled surface water releases on groundwater levels, streamflow-derived groundwater recharge, and monthly streamflow volumes. However, UWCD has noted that the model currently does not have good calibration to daily streamflows and therefore should be used with caution for making daily streamflow predictions. Otherwise, the expert review panel sees no major problems with model development and calibration, and we understand that UWCD intends to continue evaluating whether improvements can be made to the simulation of streamflows arriving at the Freeman Diversion (which the groundwater model could not capture well, resulting in the use of a surface-water model to provide flows to the diversion and beyond in the Santa Clara River). Regardless of the refinements (if any) that arise from that effort, the three of us believe that the model replicates the historically observed conditions quite well during the calibration period. The model also shows similar behavior during the update period, providing consistent results to those of the calibration period. This is a very complicated and detailed modeling effort that has resulted in a model that will be useful for making regional management decisions within the UWCD jurisdiction. Accordingly, the UWCD team should feel proud of the current model.

Model Uses and Potential Enhancements

The Regional Model – the groundwater flow model that UWCD has developed for the Piru, Fillmore, Santa Paula, Mound, Oxnard (Forebay and Plain), Pleasant Valley, and (West) Las Posas Valley groundwater basins – is viewed by the expert review panel as an appropriate tool for meeting UWCD's stated objective of improving the understanding of key factors that affect the availability and usability of groundwater resources in the seven southern Ventura County basins that are simulated by this model. The spatial extent of the model, the use of monthly stress periods to simulate temporal variations in groundwater conditions, the use of daily stress periods to simulate streamflows, and the use of a calibration and update period spanning 35 years of fluctuating weather conditions (and changing land and water uses) together make the model suitable for assisting with long-term sustainable management of the groundwater resources in these seven groundwater basins. The Regional Model is viewed by the expert panel as being ready for use in regional and local planning efforts and is of sufficient quality to support the development and implementation of GSPs under SGMA. The model can facilitate GSP planning and implementation by simulating future potential changes in groundwater pumping, natural and artificial recharge, and future land and water uses.

The expert review panel has identified four potential enhancements to the model that warrant consideration in the future.

1. Local refinements to the representation of groundwater withdrawals by phreatophytes (riparian plant communities) may be warranted if projects are being considered in and near riparian habitats. Refinements to consider are (1) developing ET zones for

geographic areas to distinguish the types/mixtures of habitats/plant communities and their corresponding differences in ET rates and extinction depths; and (2) adding monthly/seasonal variations to the ET rates in each of these zones/geographics areas.

2. Local refinements in the magnitudes of irrigation recharge rates may be warranted for agricultural lands, based on differences in irrigation practices, crop types, and soil types.

3. The availability of tools such as MODFLOW-USG (Panday et al., 2013; Panday, 2021) allows for local-scale grid refinements to be made to the Regional Model, which can efficiently provide a representation of local-scale features and projects while also accounting for regional (basin-scale) processes and conditions. As recommended by the review panel, UWCD has stated that it is beginning to use the MODFLOW-USG software as it conducts applications with the model. MODFLOW-USG allows nested grids to be inserted into localized areas in the model which can be turned on and off as needed, according to the needs of future studies requiring predictive simulations with the model. This allows refined grids to be developed only where needed, which avoids creating finer grid spacing throughout the model and thereby reduces run-times and file sizes. Also, only one model needs to be maintained instead of separate models that have fine and coarse grid sizes. Additionally, the use of MODFLOW-USG allows multi-layer wells to be represented fully implicitly (as connected linear networks [CLNs]), allows lateral pinch-outs of hydrostratigraphic units to be explicitly modeled (to better honor the geology and provide more robustness to the simulation), and includes additional capabilities that may be of future use such as evaluations of seawater intrusion or agricultural return flow. Initial testing of the Regional Model by the panel indicates that model run times and file sizes may be improved by moving the model into the MODFLOW-USG environment in the future. UWCD can readily transfer the modeling software to MODFLOW-USG when refined simulations are required, because MODFLOW-USG uses similar numerical routines as the currently used software MODFLOW-NWT (Niswonger et al., 2011), and results should be similar.

4. The Regional Model is a complex model covering multiple basins and aquifers. The Regional Model simulates various stresses, parameters, and flows in the subsurface and in streams at a temporal resolution as fine as 1 day covering the hydrogeologic system for 35 years. This complexity does not affect the overall utility of the model if UWCD will be the sole user of the model (i.e., conducting all future predictive analyses). However, if this model were to be transferred outside UWCD, a user's guide would definitely be necessary. We also suggest providing users outside UWCD with a version of the model that uses a graphical user interface such as Groundwater Vistas (ESI, 2020) to promote usability and visualization. This would also allow the user to imbed local grids as desired, and it would provide the opportunity for other users of the model to make use of MODFLOW-USG as well. Providing outside users with a version of the MODFLOW-NWT model that is in Groundwater Vistas would allow UWCD to know that outside users have a version of the model that was correctly imported to (and

represented in) Groundwater Vistas. Furthermore, Groundwater Vistas keeps track of any changes made to a "final distributed" model, which helps maintain quality assurance and quality control of the model once other entities start modifying stresses or parameters and get different results.

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