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DRAFT SENSITIVITY ANALYSIS APPROACH MEMO FOR THE DEVELOPMENT OF THE GROUNDWATER-SURFACE WATER MODEL OF THE VENTURA RIVER WATERSHED

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LIST OF ACRONYMS AND ABBREVIATIONS

CIMIS	California Irrigation Management Information System
DBS&A	Daniel B. Stephens & Associates
DWR	Department of Water Resources
ET	Evapotranspiration
GHB	MODFLOW general-head boundary
GSFLOW	Groundwater and Surface-water Flow
HRU	Hydrologic response unit
HSPF	Hydrological Simulation Program in Fortran
ME	Mean error
MODFLOW	Modular Ground-Water Flow Model
OBGM	Ojai Valley Basin Groundwater Model
PAEE	Percent average estimation error
PRMS	Precipitation-Runoff Modeling System
RMSE	Root-mean-square error
USGS	U.S. Geological Survey
UWCD	United Water Conservation District
VCWPD	Ventura County Watershed Protection District
VRGFM	Ventura Regional Groundwater Flow Model
VSWHM	Ventura Surface Water Hydrology Model
WY	Water year

1. INTRODUCTION

A model sensitivity analysis is the systematic variation of model inputs[1] to enable quantitative evaluation of their effects on model outputs. This memorandum describes the methodology that will be used to conduct a sensitivity analysis of the Groundwater and Surface-water Flow (GSFLOW) model of the Ventura River Watershed that Geosyntec Consultants (Geosyntec) and Daniel B. Stephens & Associates, Inc. (DBS&A) are developing for the State Water Resources Control Board and the Los Angeles Regional Water Quality Control Board. Additional information on the GSFLOW and nitrogen transport models under development for this project are available in the project Final Study Plan (Geosyntec and DBS&A, 2019), Geologic Analysis (DBS&A, 2020), and Draft Data Compilation Report (Geosyntec and DBS&A, 2020). The sensitivity analysis approach described in this memo is limited to the GSFLOW model, but will inform the approach used for the nitrogen transport model.

A sensitivity analysis measures the effects of changing a model input on the outputs or performance of the model. In contrast, uncertainty analysis attempts to quantify the model uncertainty or error through systematic or random variation (e.g., a Monte-Carlo simulation) of multiple inputs concurrently over a specified range or distribution.

Results from the sensitivity analysis (e.g., identification of most sensitive inputs) should not necessarily be interpreted as a determination of the primary sources of model uncertainty. For example, a model may be sensitive to an input for which accurate and robust measurement data exists and contains relatively little uncertainty.

The goal of the sensitivity analysis is to understand the response of the model to adjustments in model inputs, parameters, and/or assumptions. Extensive informal sensitivity analysis is initially conducted as part of the model calibration process, whereby model inputs are varied to obtain match with observed streamflow volume and groundwater elevation data. The formal sensitivity analysis detailed herein will follow the completion of calibration. The sensitivity

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[1] Model inputs may include model input parameters (e.g., soil properties, rock and/or alluvium hydraulic conductivities), model input data (e.g., precipitation, air temperature), and key assumptions used to inform model input data (e.g., irrigation rates that may inform non-measured groundwater pumping volumes and/or surface water diversions).

analysis will not be an exhaustive study of all model inputs and will instead focus on the key inputs as determined through literature review of similar GSFLOW modeling studies, watershed-specific experience gained during the model development and preliminary calibration, and the current project's focus on low flow periods.

Section 2 summarizes sensitivity analysis approaches described in relevant literature, with an emphasis on GSFLOW models and other models developed for the Ventura River Watershed. The details of the approach that will be used in this study are presented in Section 3, including the model outputs that will be assessed and a table of model inputs that will be varied. Section 4 contains a brief summary of the approach, how it was developed, and how the results will be used.

2. SENSITIVITY ANALYSIS APPROACHES

A model sensitivity analysis typically involves repeatedly running a calibrated model with systematic variation of model inputs, followed by graphical and statistical assessments of changes in model outputs. The specifics of the model and the characteristics of the watershed influence which model inputs are varied, and the variation magnitude. In addition, the outputs of focus or concern are also important to consider during a sensitivity analysis and will influence which input parameters are varied. If the model is focused on groundwater supplies for example, a different sensitivity analysis would be conducted compared to a model that is focused on surface water flows. To inform the current study, the following sections provide a summary of approaches used in previous studies, with an initial emphasis on GSFLOW models, followed by other coupled groundwater-surface water models. Additionally, discussions of sensitivity analysis conducted with existing surface water and groundwater models of, and within, the Ventura River Watershed are provided.

2.1 GSFLOW Models

GSFLOW is a coupled groundwater and surface water flow model based on integration of the U.S. Geological Survey (USGS) Precipitation-Runoff Modeling System (PRMS) and Modular Ground-Water Flow Model (MODFLOW). Additional details on the model and a description of how it was selected for this project are provided in the Final Study Plan (Geosyntec and DBS&A, 2019). Numerous studies have used GSFLOW to evaluate watershed processes, and several of those studies performed some degree of sensitivity analysis, as summarized below.

The GSFLOW manual (Markstrom et al., 2008) provides an example sensitivity analysis for the snow-dominated Sagehen Creek Watershed in the northern Sierra Nevada mountains in California. The analysis was limited to the evaluation of effect of five-fold increases and decreases in hydraulic conductivity on groundwater recharge and discharge.

More typically, GSFLOW studies vary several model inputs and assess their importance on a range of model outputs. For example, Allander et al. (2014) varied 11 GSFLOW input parameters for a model of the Lower Walker River Basin in West-Central Nevada. The selected model parameters were individually varied by factors of 0.8, 0.9, 1.1, and 1.2 to enable a detailed evaluation of the model sensitivity, including non-linear changes. The analysis was limited to a few key model outputs (i.e., the elevation of Walker Lake and loss rate in Walker River) that were of critical importance in their study. The parameters found to have the most impact on model outputs were streambed hydraulic conductivity (for river loss rate) and lake evaporation rate (for lake elevation).

Ely and Kahle (2012) calculated normalized scaled composite sensitivities for more than 40 inputs for a GSFLOW model of the Chamokane Creek Basin in Washington state. Notably, they identified the importance of calculating separate sensitivities for stream flows during low-flow and high-flow periods. Hydraulic conductivity of the glaciofluvial deposits that control the groundwater flow in the outwash aquifer toward the creek affected low flows the most. This is important for the current study, where much of the focus is on streamflow needs for anadromous fish during low-flow periods. In contrast, fast interflow from preferential flow reservoirs in the upper drainage basin and hydraulic conductivity of bedrock affected high flows the most. Hydraulic heads were mostly dependent on horizontal and vertical conductivities of the lower bedrock, and streambed conductivity of tributary streams.

Tian et al. (2015) performed a sensitivity analysis on a GSFLOW model[2] of the semi-arid Zhangye Basin in northern China. Nine GSFLOW inputs were independently varied using increases and decreases of 20% to assess effects on key model outputs. The nine model inputs were selected based upon understanding of the watershed and experience gained through the manual model calibration process. Results were presented in terms of “elasticities”. “Elasticities” were defined as percentage change of a model output variable divided by the percentage change of the model input variable. “Elasticities” were based on annual average conditions (i.e., low-flow and high-flow periods were not separated). The results indicated streamflows mostly depended upon precipitation inputs, lateral inflow boundary conditions in the groundwater model, maximum available capillary water-holding capacity of soil, and maximum possible area contributing to surface runoff. The hydraulic conductivity of the streambed strongly affected the two-way fluxes between groundwater and surface water. The lateral inflow boundary condition in the groundwater model strongly affected the flux from groundwater to surface

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[2] The GSFLOW model was coupled with the Storm Water Management Model to enable better representation of complex hydraulics and drainage networks (e.g., including backwater effects and hydraulic structures).

water, but only had minimal effect on the flux from surface water to groundwater. Tian et al. (2015) observed the groundwater elevations were relatively independent of model inputs. However, Tian et al. (2015) noted that “elasticity” is not an appropriate metric for variation in elevations since the percent change in absolute elevation is small. This illustrates the importance of using an appropriate metric. For example, the difference in groundwater elevations across the project area, rather than the absolute elevation, should be used to normalize the metric.

Woolfenden and Nishikawa (2014) developed a GSFLOW model of the Santa Rosa Plain Watershed in northern California. A formal sensitivity analysis was not performed, but a qualitative assessment based on the calibration process was provided. The modeled hydraulic heads were generally sensitive to several inputs, including the hydraulic characteristic of horizontal-flow barriers, horizontal and vertical hydraulic conductivity, streambed conductance, general-head boundary conductance, and the quantity and distribution of pumping. The modeled hydraulic heads were less sensitive to the saturated vertical hydraulic conductivity of the unsaturated zone, specific yield, specific storage, and evapotranspiration (ET) extinction depth.

2.2 Other Models

In addition to GSFLOW, other hydrologic modeling platforms have previously been used to develop integrated groundwater-surface water models and test model sensitivity. Two relevant approaches are discussed below.

2.2.1 MODHMS Integrated Surface-Water/Groundwater Model

Panday and Huyakorn (2004) presented a fully coupled, physically based, spatially distributed surface/subsurface flow model using the MODFLOW-based MODHMS code. Sensitivity of the code was tested for an example watershed that was titled V-shaped Catchment. Changes in the discharge hydrograph of a stream draining the catchment and the watershed water budget components were evaluated by varying assorted model parameters. First, sensitivity of the discharge hydrograph to overland flow parameters was tested, including the presence of depressions and obstructions and the Manning friction coefficient. The presence of overland flow depressions was found to delay the rising-limb of the stormflow hydrograph. The delay increased with depression depth. In addition, the volume of water held within the depressions was unavailable for flow and therefore the area under the hydrograph decreased with increasing depression depth. The presence of obstructions within the streambed excludes storage at low flow-depths and therefore led to earlier arrival of water at the catchment outlet. Doubling the Manning’s friction coefficient caused delay in both the rising and receding limb of the hydrograph.

Inclusion of subsurface flow in the catchment model allowed for simulation of the discharge-hydrograph baseflow recession. Lowering the elevation of the groundwater table resulted in a depressed hydrograph (i.e., smaller discharge values) compared to the base-case due to additional pore-space filling before runoff occurs. Discharge results were also sensitive to the assumed soil-porosity and van-Genuchten (i.e., unsaturated flow) parameters.

2.2.2 Ventura Regional Groundwater Flow Model

Adjacent to the Ventura River Watershed, United Water Conservation District (UWCD) developed a numerical groundwater model of the Oxnard Plain, Oxnard Forebay, Pleasant Valley, West Las Posas, and Mound Groundwater Basins (UWCD, 2018) in Ventura County. The UWCD model, referred to as the Ventura Regional Groundwater Flow Model (VRGFM), was also used in preparation of Groundwater Sustainability Plans for these basins for the Fox Canyon Groundwater Management Agency. The VRGFM was developed using MODFLOW – Newton Formulation.

VRGFM model documentation (UWCD, 2018) included detailed sensitivity analyses. Each sensitivity analysis run represented variation of an input parameter for one simulation of the calibration period and a set of residual statistics (i.e., mean error (ME), absolute ME, and root-mean-square error (RMSE)). The model groundwater flow-budget (i.e., the fraction of each model simulated input such as precipitation recharge and output such as pumping) was also compared for each sensitivity run. For the purpose of the sensitivity analysis, spatially distributed parameters (e.g., hydraulic conductivity, specific yield) were assigned to specific zones within each model layer, and parameters were varied for each zone sequentially. Varied parameters included the following:

- Horizontal hydraulic conductivity (factors of 0.1, 0.5, 5, and 10).
- Vertical anisotropy (factors of 0.1, 0.5, 5, and 10).
- Storage coefficient (factors of 0.01, 0.1, 10, and 100).

- Specific yield (factors of 0.33, 0.67, 1.33, 1.67, and 2).
- Recharge (factors of 0, 0.5, 1.5, 2, 2.5, and 3).
- Horizontal flow barrier (i.e., fault) conductance (factors of 0.01, 0.1, 10, and 100).
- Streambed conductance (factors of 0.01, 0.1, 10, and 100).
- General Head Boundary (GHB) conductance (factors of 0.01, 0.1, 10, and 100).
- Tile Drains (i.e., Drain Package) conductance (factors of 0.01, 0.1, 10, and 100).
- Evapotranspiration rate (factors of 0.01, 0.1, 10, and 100).
- Evapotranspiration extinction depth (default of 5 feet varied to 2.5 ft, 10 ft, 15 ft, and 20 ft).

In general, highly sensitive parameters included horizontal and vertical hydraulic conductivity, specific yield in a number of specific aquifer units within the model domain, recharge in agricultural areas, hydraulic conductivity along the Oak Ridge fault (which affects flow between the Oxnard Forebay and Mound Basin), streambed conductance of all streams, and certain GHB cell conductance values.

In addition, Tartakovsky and Dudek (2019) peer reviewed the VRGFM. The peer-review included conducting global sensitivity analyses based on Analysis of Variance (see Saltelli et al., 2008). The approach treated 28 highly sensitive parameters (UWCD, 2018) as mutually independent random variables distributed uniformly within a specified interval. The sensitivity analyses were conducted with the DAKOTA software, developed by the Department of Energy Sandia National Laboratories (Adams et al., 2013). The global sensitivity analysis indicated that horizontal hydraulic conductivity of specific aquifer units in the Oxnard Forebay accounted for a large portion of the total model variance in groundwater elevations. The peer review noted that this result instilled confidence in the model, as aquifer test data can independently constrain these parameters.

2.3 Models Specific to Ventura River Watershed

Results of sensitivity analysis inherently depend on the specific watershed and the dominant hydrological and hydrogeological processes therein. The following summarizes sensitivity analysis approaches and results for models specific to the Ventura River Watershed. Two numerical modeling efforts have previously been completed for parts of the Ventura River Watershed: (1) the Ventura Surface Water Hydrology Model (VSWHM); and (2) the Ojai Valley Basin Groundwater Model (OBGM). These models' sensitivity analyses are summarized below.

2.3.1 Ventura Surface Water Hydrology Model

Originally created in 2007, the VSWHM is a Hydrologic Simulation Program in Fortran model of the entire Ventura River Watershed (Tetra Tech, 2009). The model was calibrated to water year (WY[3]) 1996 through 2007 and validated to WY 1986 through 1996. In 2012, Ventura County Watershed Protection District (VCWPD) updated and simplified the model and calibrated it for 1996 through 2005 (VCWPD, 2012). The model uses sub-daily time steps and is geared towards predicting peak surface water flows from large storm events for hydraulic design of flood control infrastructure. The VSWHM is a lumped parameter model with sub-basin sizes ranging from approximately 100 acres to more than 6,000 acres. Groundwater inflows and outflows from the VSWHM were estimated, but no dynamic modeling or coupling of surface water flows with groundwater was included. This limited the accuracy of the model at low flows, which is of primary importance in the current study.

The VSWHM model calibration and validation report (Tetra Tech, 2009) describes a sensitivity analysis approach in which key model inputs were varied +/-10%. However, the report did not provide specific information on model inputs that were studied as part of the sensitivity analysis, nor results of the analysis. Discussion related to the calibration procedure noted that the water balance (i.e., fraction of precipitation that ends up as evapotranspiration, stream run-off, or deep groundwater) was most sensitive to the lower zone nominal storage and lower zone ET factor, both of which control the amount of water lost to evapotranspiration. The distribution of runoff between low- and high-

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[3] WY = water year, defined as October 1 through September 30. For example, WY1995 is from October 1, 1994 through September 30, 1995.

flows was most sensitive to the infiltration index and groundwater recession rate.

2.3.2 Ojai Valley Basin Groundwater Model

The OBGM development included a sensitivity analysis that consisted of varying model inputs for the entire 39.5-year model calibration period (DBS&A, 2011). Sensitivity analyses tracked the model output as quantified by the RMSE between observed and simulated groundwater elevations.

Model sensitivity analysis was conducted using the model calibration period for 12 model inputs, including recharge, hydraulic conductivity, and storage parameters. For the purpose of model sensitivity analyses, hydraulic conductivity and storage parameters were generally varied within one order of magnitude. Recharge was varied 50 percent. The results of the model sensitivity analyses were presented in a spider plot displaying RMSE versus the scaling-factor of each parameter (reproduced as Figure 2-1).

DBS&A (2011) determined sensitive model inputs were recharge from precipitation and irrigation, hydraulic conductivity in aquifer units, and specific yield for aquifer units and semi-confining units. The most sensitive model input was recharge from precipitation and irrigation, indicating the importance of determining reliable estimates of these input values for the Ojai Valley Basin.

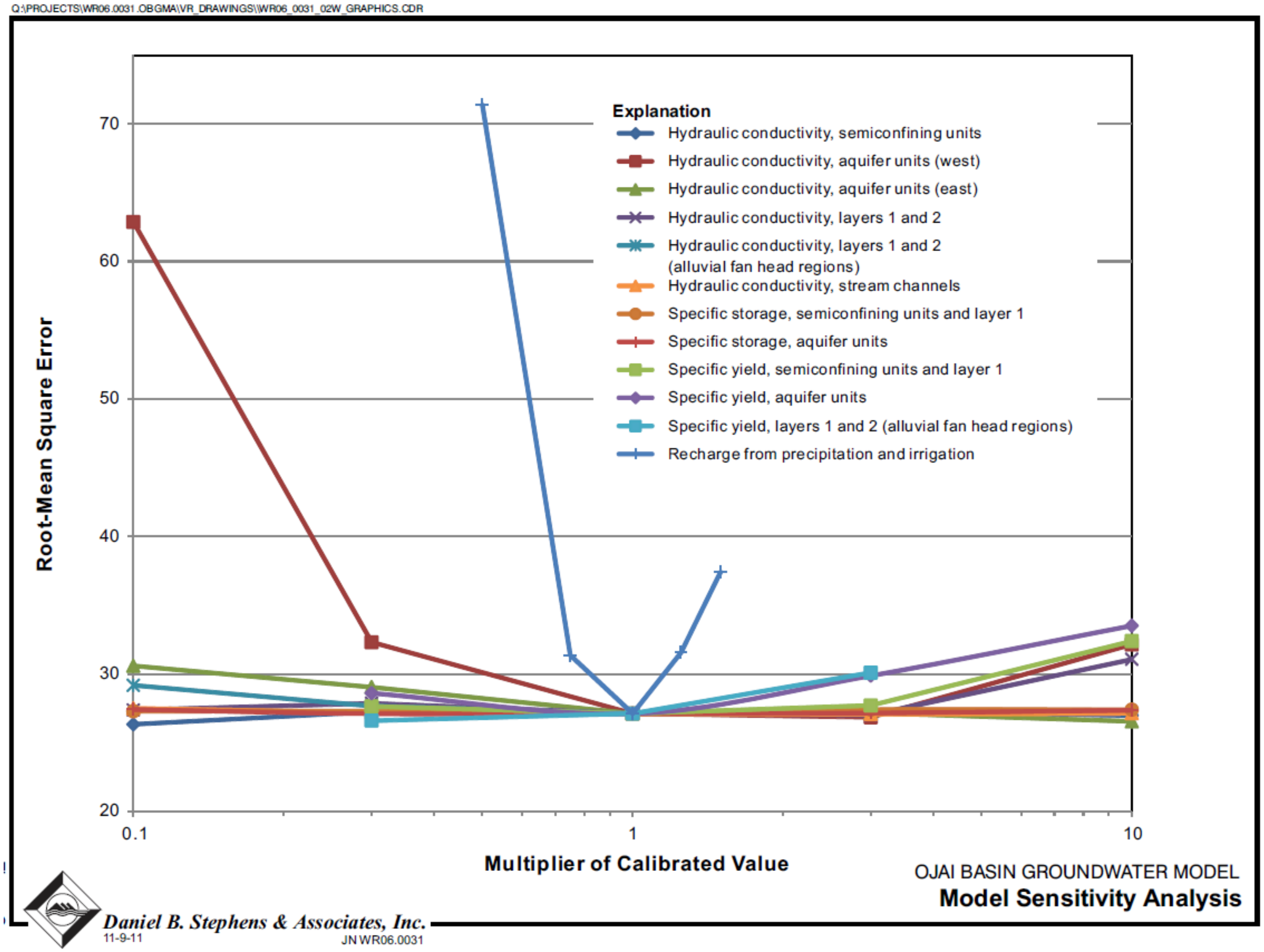

Figure 2-1 Spider-Plot of Model Sensitivity Analyses, Ojai Valley Basin Groundwater Model (DBS&A, 2011)

3. APPROACH FOR VENTURA RIVER WATERSHED MODEL

The following defines the approach that will be used to conduct sensitivity analysis for the Ventura River Watershed GSFLOW model. Descriptions of the key outputs and metrics that will be used to assess sensitivity and key model inputs that will be varied are provided.

3.1 Outputs to Evaluate

Key model outputs will be selected to assess and quantify the sensitivity. These include metrics related to the overall water balance, groundwater-surface water exchange, streamflow, and groundwater elevations.

3.1.1 Water Balance and Groundwater-Surface Water Exchange

For each sensitivity analysis simulation, the global watershed water budget will be calculated to quantify the total volumes of precipitation, ET, recharge to groundwater, groundwater discharge to surface water, and flow to the ocean. Results will be tabulated for the entire simulation period, as well as seasonal breakdowns into low- and high-flow periods. In addition, the groundwater-surface water exchange in the gaining and losing reaches of the mainstem Ventura River and San Antonio Creek will be calculated and tabulated.

3.1.2 Streamflow

Streamflow results will be analyzed at the following four gage locations:

1. Gage 604: North Fork Matilija Creek at Matilija Hot Springs.
2. Gage 607: Ventura River near Meiners Oaks (downstream of Robles diversion).
3. Gage 605/605A: San Antonio Creek at Old Creek Road/Highway 33 (upstream of confluence with Ventura River).
4. Gage 608: Ventura River near Ventura (Foster Park).

Time series plots of daily average and monthly average flows, and percent exceedance plots, will be made for each parameter variation. Each plot will have three lines: the calibrated model; an increase in parameter value; and a decrease in parameter value.

The percent average estimation error (PAEE) and the Nash-Sutcliff Model Efficiency, as defined in the project Final Study Plan (Geosyntec and DBS&A, 2019), will be calculated over the entire modeling period at each of the above gage locations. These results will be tabulated and plotted as “spider plots” (see Figure 2-1 for an example). In addition, the PAEE will be calculated separately for low- and high-flow periods, per recommendations of Ely and Kahle (2012).

3.1.3 Groundwater Elevations

Groundwater-related outputs that will be analyzed include statistical measures of the difference between the model simulated groundwater-elevation and observed results for all calibration wells. These error statistics will include the ME and RMSE for all groundwater wells used in model calibration, as given in the project Final Study Plan (Geosyntec and DBS&A, 2019) and Draft Data Compilation Report (Geosyntec and DBS&A, 2020).

3.2 Model Inputs to Vary

The key GSFLOW model inputs that will be varied are presented in Table 3-1. The inputs selected for sensitivity analysis will be multiplied by the factors presented in the table to increase and decrease from the original calibrated values. While these inputs generally vary spatially throughout the watershed, the adjustment factors will be applied uniformly. Results from the past studies discussed above guide the magnitude of the adjustment factors, while also maintaining parameter and input values within physically realistic bounds.

The model inputs and their selection are discussed further in the following sections.

Table 3-1 GSFLOW Model Inputs to be Varied

Model Input	Description	Multipliers	Notes
soil_moist_max	Maximum available water holding capacity of capillary reservoir from land surface to rooting depth of the major vegetation type of each hydrologic response unit (HRU) [1]	0.8, 1.2	Affects Hortonian surface runoff, evapotranspiration (ET), direct recharge, and flow to gravity reservoir
sat_threshold	Water holding capacity of the gravity and preferential flow reservoirs [1]	0.8, 1.2	Difference between field capacity and total soil saturation for each HRU
slowcoef_sq	Non-linear coefficient in equation to route gravity reservoir storage downslope for each HRU [1]	0.8, 1.2	Controls slow interflow from gravity reservoir. The linear coefficient in the equation had less effect than the non-linear term and is not included in the sensitivity analysis.
jh_coef	Monthly (January to December) air temperature coefficient used in Jensen-Haise potential ET computations [1]	0.8, 1.2	Will directly affect ET and overall water balance

Model Input	Description	Multipliers	Notes
Streambed hydraulic conductivity	Hydraulic conductivity of streambed	0.1, 10	Affects groundwater-surface water exchange
Streambed width	Width of the tributaries	0.8, 1.2	Affects groundwater-surface water exchange and streamflow routing
Surface water diversion volumes	Diversions directly from creeks within the watershed	0.8, 1.2	Results in a direct reduction in streamflow
Horizontal Hydraulic conductivity	Hydraulic conductivity, broken out for each model layer within each basin and the bedrock areas	0.1, 10	Affects rate of groundwater movement
Specific yield	Broken out for each unconfined model layer within each basin and the bedrock areas	0.3, 2 (subject to specific yield not less than 0.02 or greater than 0.3)	Affects the amount of groundwater held in storage
Storage coefficient	Broken out for each model layer within each basin and the bedrock areas	0.1, 10	Affects the amount of groundwater held in storage
Vertical anisotropy	Broken out for each model layer within each basin and the bedrock areas	0.1, 3	Affects rate of vertical groundwater movement

Model Input	Description	Multipliers	Notes
Horizontal-flow barrier conductance	Hydraulic conductivity for faults that intersect alluvial basins	0.1, 10	Affects the rate of groundwater movement across fault zones
General-head boundary (GHB) conductance	GHB where assigned (e.g., at Pacific Ocean, at watershed boundary in Upper Ojai Valley Basin).	0.1, 10	Affects the rate of groundwater flow in cells assigned a GHB condition
Unsaturated-Zone Vertical Hydraulic Conductivity	Saturated vertical hydraulic conductivity of the vadose zone, broken out for each Basin and the bedrock areas	0.1, 10	Affects rate of subsurface water movement above the level of groundwater
Various	Assumptions used in the water supply/use calculations	Increase and decrease groundwater pumping volumes by up to 20%	Will affect groundwater elevations and low flows

ET = evapotranspiration
GHB = General-head boundary
HRU = hydrologic response unit
[1]PRMS-IV Techniques and Methods 6–B7 (Markstrom et al., 2015)

3.2.1 Soil and Surface Water Inputs

Soil and surface water inputs to be varied as part of the sensitivity analysis were selected based on observations during the initial PRMS calibration procedure, conclusions drawn from the existing literature, and prior experience. Soil zone storage parameter soil_moist_max affects multiple soil zone processes including Hortonian surface runoff, ET, direct recharge, and flow to the gravity reservoir. It is included in the sensitivity analysis along with another important soil zone parameter, sat_threshold. These parameters represent storage of water within the soil and are similar to the lower zone nominal storage parameter that was identified as being important in the VSWHM (see Section 2.3.1).

The interflow parameter slowcoef_sq controls slow interflow from the gravity reservoir and was important for post-storm recession flows during calibration. This parameter is similar to the groundwater recession rate that was identified as being important in the VSWHM (see Section 2.3.1). Therefore, slowcoef_sq is included in the sensitivity analysis.

The ET parameter jh_coef was calibrated using California Irrigation Management Information System (CIMIS) reference ET data (Geosyntec and DBS&A, 2019). Jh_coef is included in the sensitivity analysis due to the relative coarseness and potential uncertainty of the CIMIS data (CIMIS, 1999), and the importance of ET to the overall water balance. This parameter is similar to the lower zone ET factor that was identified as being important in the VSWHM (see Section 2.3.1). It is noted that the climate change scenario that will be evaluated with the GSFLOW model, as part of this study, will likely include increases in ET as a result of increased air temperatures. Additionally, the Post-Thomas Fire scenario will likely include decreases in ET due to loss of burned vegetation (see Geosyntec and DBS&A, 2019).

Streambed hydraulic conductivity is included in the sensitivity analysis. Streambed hydraulic conductivity is a key input in influencing the groundwater-surface water exchange, which is of critical importance in this study.

The width of the tributary streams will also affect the groundwater-surface water exchange, as well as the streamflow routing. The tributary stream widths used in the model are estimated based on regional regressions relating width to upstream catchment area as developed for the VSWHM (Tetra Tech, 2009) and verified with comparison to a nationwide study (Bieger et al., 2015). These relations include a certain degree of uncertainty and therefore the stream widths are included in the sensitivity analysis.

The channel widths and hydraulic properties of the mainstem Ventura River and San Antonio Creeks were determined from detailed and calibrated hydraulic models that the VCWPD developed for flood protection. These hydraulic models were run at a range of flow rates and used to develop rating tables at each stream reach within the GSFLOW model that relate water depth and wetted width to flow rate. This approach is considered sufficiently robust, compared with the more approximate approach used in the tributary streams, and therefore variation of these rating tables is not included in the sensitivity analysis.

There are approximately 30 known surface water diversions within the Ventura River Watershed that directly remove water from streams. Since 2010, monthly diversion volumes are annually self-reported to the State Water Resources Control Board through the Electronic Water Rights Information and Management System. It is understood that these volumes may be estimates, rather than direct measurements, and therefore there is inherent uncertainty in the data. Due to the direct impact of the diversions on streamflow, the surface water diversion volumes are included in the sensitivity analysis.

3.2.2 PRMS Input Parameters that will not be Evaluated

Some PRMS parameters identified in literature as important are not included in the approach. For example, precipitation inputs are included as sensitivity parameters in some studies (e.g., Tian et al., 2015) that have limited meteorological stations. The Ventura River Watershed has more than 20 precipitation measurement stations, and Parameter-elevation Relationships on Independent Slopes Model data were used to augment the observed precipitation data (Geosyntec and DBS&A, 2019). Therefore, it is expected that resultant precipitation inputs are reliable and therefore are not included in the sensitivity analysis.

Other parameters are not included due to relatively small effects being noted during calibration processes. The surface runoff parameter carea_max, the maximum possible fractional area contributing to surface runoff, is varied in some sensitivity studies (Tian et al., 2015; Markstrom et al., 2016). However, during initial calibration of the Ventura River Watershed GSFLOW model in PRMS-only mode (i.e., not coupled to groundwater) for this study, carea_max showed very small impacts on output variables. Many of the prior PRMS sensitivity studies utilized PRMS models were developed using a lumped parameter approach, whereas the Ventura River Watershed GSFLOW model is a gridded parameter model. For example, the Regan et al. (2018) PRMS model for the Continental U.S. has approximately 50 hydrologic response units (HRUs) in the Ventura River Watershed. In comparison, the Ventura River Watershed GSFLOW model has over 100,000 smaller gridded HRUs

(Geosyntec and DBS&A, 2019). Responses of the empirical equations for model parameters assigned on a much finer scale may be different to those assigned in the lumped parameter approach.

Other model inputs are not considered important once the PRMS and MODFLOW models are coupled within GSFLOW. For example, the PRMS gravity drainage parameter, ssr2gw_rate, governs the rate of drainage from the soil to the groundwater in PRMS. Once the models are coupled, the vertical hydraulic conductivity in MODFLOW will control ssr2gw rate. Therefore, ssr2gw_rate is not included in the sensitivity analysis.

3.2.3 Groundwater and Unsaturated-Zone Input Parameters

Sustainable Groundwater Management Act guidance (DWR, 2016) suggests sensitivity analyses be conducted for input parameters that are both highly sensitive and poorly constrained. Groundwater and unsaturated-zone input parameters that will be varied are listed in Table 3-1. Horizontal hydraulic conductivity, vertical anisotropy (i.e., the ratio of vertical to horizontal hydraulic conductivity), and storage coefficient will be varied sequentially for each model layer within each basin and the bedrock areas. Unsaturated-zone vertical hydraulic conductivity will also be varied for each basin and the bedrock areas. Horizontal-flow barrier conductance representative of faults that transect the alluvial basins, and general-head boundary conductance (assigned at the Pacific Ocean and at the watershed boundary within the Upper Ojai Basin) will also be included in the sensitivity analysis.

The amount each input parameter will be varied during sensitivity analysis is specified in Table 3-1. Hydraulic-conductivity related parameters and specific storage will be varied one-order-of-magnitude, consistent with other studies summarized in Section 2. Specific yield will be varied from a factor 0.3x to 2x with the constraint that the values used in the sensitivity analyses will be within the typical range of 0.02 to 0.3 (i.e., will not be less than 0.02 or greater than 0.3; see Fetter, 2001).

3.2.4 Water Supply and Use Assumptions

There are limited data related to groundwater pumping and surface water supplies in many parts of the watershed. Analysis of available water use data, consumption reports, groundwater pumping data from the water agencies that serve the region, as well as information on surface water diversions will estimate these unavailable volumes. Assumptions on the supplies and demands (e.g., assumed irrigation rates) will be made to complete these estimates. There are inherent uncertainties within these assumptions.

These assumptions, including the distribution of water supply from groundwater pumping versus surface water diversions, will be evaluated and varied as part of the sensitivity analysis. It is known that groundwater levels within certain areas of the groundwater basins are highly dependent on the quantity of groundwater pumping, and as such, the assumptions will be varied in order to obtain an anticipated reasonable range in groundwater pumping rates, which may be as high as +/- 20% in some regions, but could be lower in other regions (e.g., in the Ojai Valley Groundwater Basin, where data reporting is mandated).

4. SUMMARY

A methodology has been presented to perform a sensitivity analysis on the calibrated Ventura River Watershed GSFLOW model. The approach systematically varies model inputs (including parameters, data, or assumptions) and qualitatively (i.e., timeseries plots) and quantitatively (i.e., statistical error metrics) evaluates changes in model output. A total of 15 different model inputs will be evaluated, each for two different scaling factors, for a total of 30 model simulations.

The model inputs were selected based upon review of previous studies, specific insight gained during model development and preliminary calibrations, and consideration of the importance of the low-flow periods to the current study.

The results of the sensitivity analysis will aid in the understanding of the model and the relative importance of different model inputs. The results will partly document the model calibration process. In addition, the results of this sensitivity analysis will be useful as a basis for focusing future monitoring and characterization efforts on critical parameters controlling the hydrologic dynamics of the watershed.

5. REFERENCES

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