CASITAS
Municipal Water District

July 20, 2021

Via U.S. Mail and E-Mail
InstreamFlows@waterboards.ca.gov

Ann Marie Ore, Program Manager
State Water Resources Control Board
Division of Water Rights
Water Quality Certification and Public Trust Section
P.O. Box 100
Sacramento, CA 95812-0100

Subject: **Comments of Casitas Municipal Water District on the State Water Resources Control Board (SWRCB) Development of Groundwater-Surface Water and Nitrogen Transport Models of the Ventura River Watershed (Ventura River Watershed Modeling Study)**

Dear Ms. Ore:

The Casitas Municipal Water District (Casitas) provides drinking water to approximately 65,000 people and 6,000 acres of agriculture within the District's boundaries. This critical service is provided to residents, farms, businesses, and other retail water providers through the storage of water in Lake Casitas as well as from local groundwater wells. For over 15 years, Casitas has implemented a Fisheries Program completing several projects that improve habitat conditions for endangered steelhead trout, including construction of a state-of-the-art fish ladder at Robles Diversion Facility.

In response to the recent series of SWRCB-hosted webinars on the development of the Ventura River Watershed integrated hydrologic model, Casitas respectfully submits the enclosed technical comments on the effort. These comments have been prepared by an expert groundwater modeling team, who performed a detailed review of the original Study Plan (Geosyntec and DBS&A, December 2019) and also attended the webinars. The comments are intended to provide helpful insights for consideration by your team.

In general, the reviewers raised questions regarding the goals of the Study and concerns that the criteria used for model selection may not have been sufficient. While a more comprehensive evaluation of model selection criteria may have resulted in the use of different modeling codes, Casitas understands the State has already invested in the use of GSFLOW software for the Study, and likely will not re-evaluate the type of modeling software code used at this point in time. As such, several technical comments are provided on the surface-water and groundwater modeling approach underway for consideration going forward. The attached document provides a thorough and detailed technical review of available Study documents. The comments include, but are not limited to, the summary provided herein.

The goal statements in the Study Plan are overly general and imprecise, and it remains unclear as to how the goals would be approached using the model results. Examples include, but are not limited to:

- The goal to *estimate existing instream flows at multiple points of interest (POI) throughout the entire Ventura River Watershed*" is not supported by the current data network. Without seepage runs and a groundwater monitoring network of sufficient spatial and temporal resolution, estimates of groundwater – surface water interactions, and thus model estimates of instream flows, will exhibit large uncertainty.
- The goal of "*Ensure that the model simulation period is long enough to reasonably capture the variability of the full range of water year types from drought to flood years*" will require additional analysis outside of the models proposed. In addition, the Study Plan does not acknowledge available information and relevant studies in other basins which have shown that a historical period of a couple decades may be inadequate to assess the slow rate of nitrate transport.
- The goal of "*Simulate the effects of the December 2017-January 2018 Thomas Fire on hydrology, nitrogen transport, groundwater levels, and instream flows*" will require a change in land use and potentially a different set of parameters for the surface-water network, which are not features available in GSFLOW. In addition, it will necessarily be very high level and general without collection of significant new datasets and integration of that data into the modeling tools.

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Based on the model selection criteria, GSFLOW/MT3DMS-USGS software was selected by the California State Water Resources Control Board and its consultants. However, several model selection criteria were not considered but are relevant to the Study. For instance:

- The model selection evaluation did not include existing Integrated Hydrologic Model (IHM) codes used for regional studies that could be more compatible with the hydrologic , land-use setting, and supply-and-demand issues under analysis.
- The model selection evaluation did not include any of the criteria used by the World Bank evaluation (Borden et al., 2016), in which GSFLOW received low marks for project resources required, longevity and support, and representation of irrigation and septic sources, which may affect its skill for nitrate transport.
- There are several errors in the MODFLOW-NWT portion of GSFLOW that may still not have been corrected relative to SFR (Streamflow Routing Package) and MNW (Multi-aquifer Well Package) features. In addition, one of the biggest challenges of using PRMS with SFR (from within MODFLOW-NWT) is the reconciliation of channel elevations for the surface-water network so that they are accurate and consistent between the separate specifications in PRMS and MODFLOW-NWT.
- The World Bank evaluation of modeling software is consistent with current changes occurring at the USGS headquarters to reduce software support and potentially

curtail development of GSFLOW, and redirect USGS resources to other modeling software. Therefore, longevity of the State's model may be an issue.

- Concerns also relate to meeting the SGMA requirements (23 CCR 352.4) for properly documented public domain code and transparency. Any potential linkages to MOD-SIM with Newton Formulation for Modflow-2005 (MODFLOW-NWT) for additional reservoir operations simulations (within GSFFLOW) would not be compatible with SGMA requirements as this is proprietary software that is not open source or peer reviewed.

The overview of the modeling approach is generally reasonable, but there are several omissions that should be clarified, as described in more detail in the attachment (Executive Summary and Section 3). Specifically:

- For the dry-season only MODFLOW-NWT and wet-season only PRMS calibration, further clarification would be helpful for those definitions and which model parameters (for each model) will be well calibrated under those particular conditions.
- As described in the model webinars, the time periods for calibration and validation have now been adjusted compared to those periods described in the Study Plan. It was the reviewers' opinion that the time periods were potentially ill-posed for the historical period of simulation used for calibration, based on both climate variability in the precipitation and surface-water time series.
- No summary of model packages was provided, and features being simulated by these packages/processes were not provided, including representation of all the components of a conceptual model of the climate, land system, surface-water, and groundwater use and movement of water.
- Overall, the historical periods chosen for calibration may not be consistent with the climate cycles observed in the precipitation and surface-water time series and does not include the period after the Thomas Fire.

For the surface water model development (PRMS only) several points should have been considered, as described in more detail in the attachment (Executive Summary and Section 4). These include, <u>but are not limited to</u>:

- The climate for the Ventura River Basin is dominated by long dry periods punctuated by occasional very wet season. For example, 53 of 85 years (62 percent) are dry years with less than average precipitation (1935–2019). Similarly, on a seasonal basis, during the fish migration season of January to June, 62 percent of the winters and 65 percent of the spring seasons are dry. This suggests that dry-year and dry-season climate will largely influence the fit of any watershed models, and the proposed wet-season only calibration approach for the PRMS-only model will require significant revision during subsequent linking to the groundwater model.
- More specificity is needed in the type of observational data to be used in calibration, especially related to second-order and higher order observations. For instance, there is no discussion of second order observations such as groundwater drawdowns, vertical groundwater head differences, and streamflow gains and losses, as well as higher order observations such as wet- and dry-year streamflow duration distributions at gages and climate cycle percentages. All these types of measures should be looked at as part of the model calibration process and will affect the skill needed to address the modeling objectives.

- The treatment of land surface elevation did not have a clear discussion of potential errors and the need for high-resolution Light Detection and Ranging (LiDAR) datasets for constraining the Cascade Routing Tool (CRT) algorithm used to build the stream network. There is also no comparison between the two LiDAR data sets that have been created nor proposed use of the second survey, which seems vital for proper application of the CRT.
- Separate sampling of elevations for incised stream channels or well-head elevations, and changes in the land surface and stream channels after the Thomas Fire were also not addressed.
- There is no explicit consideration of the storm drain network or its inclusion in the model.

For the groundwater model development (MODFLOW-NWT only), the defined groundwater model domain, stress periods, and timesteps make sense for integration with PRMS, but there are several important data / parameter classes that appear to be overlooked or omitted, as described in more detail in the attachment (Executive Summary and Section 5). Examples include, <u>but are not limited to:</u>

- Fixing the geometric configuration (areal extents, top and bottom surfaces, and thicknesses) of the underlying hydrogeologic units makes sense, but there is no description of how the layering will be constructed, what units are represented, or any additional features that may be derived from the geologic model such as natural faults (considered to act as horizontal flow barriers [HFBs]) or man-made subsurface flow barriers).
- Identifying the agricultural pumpage as a fixed parameter fails to recognize the dynamic feedback between climate and surface-water availability, groundwater recharge patterns, stream-aquifer interactions, and groundwater pumping. For future forecast or alternate adaptation/mitigation-scenario simulations, such dynamic linkages can affect groundwater extraction rates, and an internal supply-demand framework (such as that implemented in MODFLOW-OWHM) provides a better approach for estimating groundwater extraction rates for meeting agricultural irrigation demands.
- The Study Plan also fails to address pumping for common practices, such as crop frost protection, pre-planting soil wetting, and deficit irrigation water management as intentionally employed for some tree-fruit crops and vineyards.
- The list of parameters coming from the PRMS model does not include any surface-water flows, runoff (native, agricultural, or urban), storm drain networks, or spatially varying ET from agriculture, which can be major components of the overall groundwater model.
- The vertical hydraulic conductivity of the streambed, pre- and post-Thomas Fire, is a key parameter for calibration of stream-aquifer interactions, yet it is not listed in the Study Plan.
- Parameters for the Multi-aquifer (MNW2) Well Package are not cited nor is there mention of using this approach to model multi-aquifer wells, but it will likely need to be considered in calibration of the integrated model.
- The treatment of the coastal boundary, and parameters used to define that boundary (for example, the conductance for the General-Head Boundary [GHB] and a time-varying ocean boundary head) are not addressed.

- An important analysis not mentioned in the Study Plan is the uncertainty of the observed groundwater-elevation data used for model calibration. Failing to consider and account for groundwater level observation errors can lead to biases in groundwater model calibration.
- Related to the model domain and discretization, the Study Plan does not describe any model grid orientation that may be needed to align with any structural aspects of the watershed or any related anisotropy of selected geologic units.
- The geologic analysis referred to in the Plan appears to not describe any texture or facies analysis of the recent or older alluvium, as is commonly done in most other modern IHM models.

Related to the development, calibration, and validation of the integrated GSFLOW model, several recommendations are provided in the attachment (Executive Summary and Section 6), which include <u>but are not limited to</u>:

- The overall description indicates that groundwater levels along with surface-water flows will be used to assess the fit of the calibrated model to historic period of 24 years (WY1994–2017). In addition, the constraint of a cumulative mass balance error of 0.5 percent (Reilly and Harbaugh, 2004) (defined as total inflow minus total outflow divided by one half the sum of the inflow and outflow) will be used to assure that the model has reasonable mass balance. In addition to these calibration objectives, it is recommended that mass balance criteria be assessed for the surface-water system as well as other attributes of PRMS, such as Actual ET, as well as use of second- and higher-order calibration targets.
- As noted previously, other higher-order observations could be employed such as wet and dry-year/season daily streamflow duration, residuals of observed and simulated cumulative departure of monthly flows, and climate-cycle frequency analysis to help explore the continuity of transition between wet and dry-climate flows.
- The selected 24-year simulation period for the integrated model is not consistent with the wet and dry-year variations in streamflow cycles with 6 wet years and 18 dry years, and a multi-year recession occurring since 2006 (see Figure 6-1 of the attachment).
- The use of flow observations from streamflow gages, manual streamflow measurements and wet-dry maps is a good subset of observations. Additional observations that should be considered include stage at the streamflow gaging stations, surface-water diversions at the Robles Diversion and any other irrigation diversions, and block flows at the ocean boundary for periods when the river outlet is open.
- Calibration goals for the PRMS surface water model should extend beyond average error metrics for streamflows because the streamflows tend to be lognormally distributed. In addition, RMSE or Nash-Sutcliffe error of log streamflows binned into selected ranges of flow regimes may also be better to address the skill of the model for its ultimate purposes. Recommendations also include the use of weighted residual error, with weights based on the uncertainty of gaging data would also be a good approach to consider (higher uncertainty, lower weight). The evaluation of low-flow periods as well as wet-season periods is also a good idea.
- Related to groundwater model calibration, the Study Plan only discussed fitting to observed groundwater levels. Additional important considerations include evaluating

water level fluctuations (drawdowns) from a defined baseline, obtaining data for outside the stream channel groundwater levels (to avoid confusing hyporheic surface water -groundwater interactions from transfers between the stream and the regional groundwater system), and evaluating vertical gradients from multi-depth monitoring well sites (if data is available).

- There is little to no specificity of using a dynamic approach to streambed conductance with the SFR2 package. Without this approach there could be considerable overestimation of leakage at lower streamflows driven by baseflow conditions.
- It is recommended that groundwater level data be split into different groups that represent different parts of the watershed and different sets of model layers.
- The Study Plan stated groundwater model calibration goals for the goodness-of-fit the statistical measures, with the percent of correlation of > 90 percent between field and simulated observations is considered a good fit (Hill and Tiedeman, 2007). Again, these measures should be assessed with respect to groundwater-level residuals, drawdown residuals, and vertical head-difference residuals.
- The sensitivity analysis approach described in the Plan is rather vague, and it is recommended that the models be set up in the PEST framework to perform trial-and-error analysis in this framework using simple forward runs as well as formal Parameter Estimation sensitivity analysis.

Additional comprehensive technical comments are enclosed for your consideration. Casitas appreciates the Water Board's consideration of these comments which are intended to help with the model development process. If you have any questions or would like additional clarification, please do not hesitate to contact me.

Sincerely,

Michael Flood

Michael Flood
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General Manager
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Attachment:
Review of the California State Water Resources Control Board's December 2019 *Final Study Plan for the Development of Groundwater-Surface Water and Nutrient Transport Models of the Ventura River Watershed*, prepared by GSI Water Solutions, One-Water Hydrologic, and IRP Water Resources Consulting, dated July 2021

Prepared for: Casitas Municipal Water District

Review of the California State Water Resources Control Board's December 2019 *Final Study Plan for the Development of Groundwater-Surface Water and Nutrient Transport Models of the Ventura River Watershed*

July 2021

Prepared by:
One-Water Hydrologic, LLC, San Diego, California and **GSI Water Solutions Inc.**, Santa Barbara, California
With assistance from **IRP Water Resources Consulting LLC**

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Figures

Abbreviations and Acronyms

AET	Actual Evapotranspiration
AG	Agriculture (Package)
ATO	Adaptive Time Output, MODFLOW-SURFACT and MODFLOW-USG Output Control (OC) Package
BAS	Basic (Package)
BCF	Block-Centered Flow
BCM	Basin Characterization Model
CalPIP	California Pesticide Information Portal
CALVEG	California Vegetation Classification & Mapping System
CDFW	California Department of Fish and Wildlife
cfs	cubic feet per second
CIMIS	California Irrigation Management Information System
CMWD	Casitas Municipal Water District
CRT	Cascade Routing Tool
CV-SALTS	Central Valley Salinity Alternatives for Long-Term Sustainability
CWEMF	California Water Environmental Modeling Forum
DBS&A	Daniel B. Stephens and Associates
DEM	Digital Elevation Model
DO	dissolved oxygen
DPWM	Distributed Parameter Watershed Model
DRN	Drain (Package)
DRT	Drain Return (Package)
DWR	California Department of Water Resources
ENSO	El Nino-Southern Oscillation
EPA	U.S. Environmental Protection Agency
ET	Evapotranspiration
EVT	Evapotranspiration (Package)
FEMA	Federal Emergency Management Act
FMP	Farm Process (Modflow-OWHM Process)
FOIA	Freedom of Information Act
FWL4	Fractured-well (Package)
GAMA	Groundwater Ambient Monitoring Program
Geosyntec	Geosyntec Consultants
GHB	General-Head Boundary
GIS	geographic information system
GMG	Geometric Multi-Grid
GSFLOW	Groundwater Surface-water Flow Model
GSI	GSI Water Solutions, Inc.
GSP	Groundwater Sustainability Plan

GWV	Groundwater Vistas
HFB	horizontal flow barrier
HR	High Resolution
HRU	hydrologic response unit
HSPF	Hydrologic Simulation Program-FORTRAN
HUC	hydrologic unit code
IHM	Integrated Hydrologic Model
IWFM	Integrated Water Flow Model
LA	load allocation
LARWRCB	Los Angeles Regional Water Resources Control Board
LiDAR	Light Detection and Ranging
LMT	Modflow Link-MT3DMS Package
MNW2	Multi-aquifer (Well Package)
MODFLOW-NWT	Newton Formulation for Modflow-2005
MODFLOW-OWHM	Modflow-One-Water Hydrologic Flow Model (One-Water)
NAMS	North American Monsoon System
NHD	National Hydrography Dataset
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NWIS	National Water Information System
OBGM	Ojai Valley Basin Groundwater Model
OC	Output Control (Package)
OWTS	On-site Water Treatment System
PNA	Pacific/North American Oscillation
PAEE	Percent of Average Error
PCG	Preconditioned Conjugate Gradient (Solver Package)
PDO	Pacific Decadal Oscillation
PE	parameter estimation
PET	Potential Evapotranspiration
POI	point of interest
POR	Period-of-Record
PPCP	Pharmaceuticals and Personal Care Products
PRISM	Parameter-elevation Relationships on Independent Slopes Model (climate data)
PRMS	Precipitation-Runoff Modeling System
QA/QC	quality assurance/quality control
RGTIHM	Rio Grande Transboundary Integrated Hydrologic Model
RMSE	Root-Mean-Square Error
RSF4	Recharge Seepage Face (Package)
SFR	Streamflow Routing (Package)

SGMA	Sustainable Groundwater Management Act
SSPA	S.S. Papadopulos & Associates, Inc.
SUB	Subsidence (Package)
SWRCB	State Water Resources Control Board
TAC	Technical Advisory Committee
TMDL	total maximum daily load
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey
UZF	Unsaturated-Zone (Package)
VIC	Variable Infiltration Capacity (Model)
VRW	Ventura River Watershed
VSWHM	Ventura Surface Water Hydrology Model
WAP	California Water Action Plan
WEL	Well (Package)
WLA	waste load allocation

Executive Summary

At the request of Casitas Municipal Water District, a team of experts assembled by GSI Water Solutions, Inc. (GSI), has undertaken a detailed technical review of the *Final Study Plan for the Development of Groundwater-Surface Water and Nutrient Transport Models of the Ventura River Watershed* (Study Plan or Plan; Geosyntec and DBS&A, 2019). The technical review was developed by One-Water Hydrologic, LLC, with support from IRP Water Resources Consulting LLC and GSI.

The Study Plan was prepared by Geosyntec Consultants (Geosyntec) and Daniel B. Stephens and Associates (DBS&A) under contract to the State Water Resources Control Board (SWRCB), with additional input from a Technical Advisory Committee (TAC). As a large water provider in the Ventura River Watershed, Casitas Municipal Water District is engaged as a reviewer in the process of development of the Ventura River Watershed model. As described in the following review, the model will be employed by the SWRCB and the Los Angeles Regional Water Quality Control Board and other stakeholder agencies as a planning tool for evaluating water management alternatives in the basin related to management of nitrate loadings and establishing "fish flow" targets, which in turn will identify management constraints on water users in the Ventura River Basin.

For clarity, the comments in the review were structured to follow the major sections of the Study Plan (Geosyntec and DBS&A, 2019). This Executive Summary provides highlights from the detailed findings and review comments provided in this review report. Additional supporting documents and related model codes were also reviewed, and those comments are provided in Appendices A and B.

Section 1. Introduction of the Study Plan provides a high-level background and summary of objectives. It is noted by reviewers that the background summary is provided at such a high level that it fails to mention several important ongoing activities that may share both overlapping and diverging goals and objectives, such as the Sustainable Groundwater Management Act (SGMA) and the Ventura River Basin groundwater adjudication process. Similarly, other relevant completed and ongoing projects in other parts of the state of California that could have provided lessons learned and guidance for the project were not cited. For example, references to the Salt and Nutrient Management Plan from the adjacent Santa Clara River Valley (Geoscience, 2016) and the Central Valley Salinity Alternatives for Long-Term Sustainability (Central Valley Salinity Coalition and CV-SALTS, 2012) are missing from the Study Plan.

The Study Plan states that the model will meet the following seven objectives:

1. *Estimate existing instream flows at multiple points of interest (POI) throughout the entire Ventura River Watershed;*
2. *Predict unimpaired flow at each POI that would occur with no water diversions, pumping, or storage;*
3. *Evaluate how water use affects the water balance and instream flows;*
4. *Simulate groundwater pumping and groundwater-surface water interactions to understand groundwater effects on instream flows;*
5. *Ensure that the model simulation period is long enough to reasonably capture the variability of the full range of water year types from drought to flood years;*
6. *Create a nutrient transport model to inform nitrogen source assessment in the Ventura River Watershed; and*
7. *Simulate the effects of the December 2017-January 2018 Thomas Fire on hydrology, nitrogen transport, groundwater levels, and instream flows.* (Geosyntec and DBS&A, 2019)

Again, this review found the goal statements overly general and imprecise. It remains unclear as to how the goals would be approached in the models, and, in some cases, fails to evaluate the feasibility of meeting the goals as stated. Key questions raised by this review include:

- The current streamflow monitoring and groundwater monitoring data network is insufficient to support Goal #1.
- When discussing Goal #2, the Study Plan does not discuss modeling of Matilija reservoir and Lake Casitas.
- The lack of algorithms that simulate a physically based supply-and-demand framework in Groundwater Surface-water Flow Model (GSFLOW) (in contrast to that capability already embedded in Modflow-One-Water Hydrologic Flow Model [MODFLOW-OWHM]) will make it more difficult to approach Goal #3.
- The lack of well-by-well pumping data, together with GSFLOW's limitation related to internal supply and demand calculations, will make some of the analyses required for Goal #4 difficult to complete.
- There is a general lack of acknowledgment of available information and relevant studies in other basins related to the required climate series discussion for Goal #5.
- For Goal #6, the focus of the nutrient transport model is on nitrogen, which is certainly an important component, but there is no mention of salinity build-up, which has been seen in other basins in California, such as the adjacent Santa Clara River.
- Simulation of the effects of the Thomas Fire (Goal #7) will necessarily be very high level and general without the collection of significant new datasets and integration of that data into the modeling tool.

Section 2. Model Methodology Selection provides a summary of existing models and a detailed discussion of the comparative analysis of different codes considered as the framework codes for development of this model. Related to surface hydrology and recharge estimation, the Plan discusses the Ventura Surface Water Hydrology Model (VSWHM) and the Distributed Parameter Watershed Model (DPWM), and a groundwater model was previously developed covering part of the current study area, specifically the Ojai Valley Basin Groundwater Model (OBGM). Both the DPWM and the OBGM employ proprietary codes, which is contrary to the objective of using public domain, peer-reviewed codes. This review notes that there exists public domain alternatives to these codes (e.g., Basin Characterization Model [BCM] from the U.S. Geological Survey [USGS]) and recommend that their use be considered as a potential benchmark for this study. The OBGM was downloaded and tested, and numerous questions were raised on that model, input file setup, results, and related documentation.

Related to the selection of which modeling tool to use for this project, the Study Plan first defines the model selection criteria:

1. Capability to accurately model essential groundwater-surface water functions
2. Perceived credibility, for instance as demonstrated by citation in peer-reviewed literature
3. Ability to model nitrogen fate and transport in groundwater and track sources back through groundwater to surface-water and landscape sources
4. Meets California Department of Water Resources (DWR) SGMA public domain requirements (DWR, 2016)
5. Ability to model recharge from irrigation and septic systems
6. Ability to meet project requirements within the defined scope and budget
7. Longevity of model, availability of support/updates
8. Transparency

9. Degree of leveraging previous models OBGM and VSWHM
10. Proven use for similar applications

While generally concurring that these are good criteria, this review identifies a variety of potential concerns. Those concerns especially relate to meeting the SGMA requirements for properly documented public domain code, transparency, and longevity of model, and availability of support and updates in relation to the suite of codes finally selected. Technical challenges related to the ability of the model to meet project requirements are raised, as well as the capability of the model to accurately simulate all key hydrologic and hydrogeologic functions.

The reviewers suggest additional criteria that were not considered but are relevant to the success of this study could include:

- Existing Integrated Hydrologic Model (IHM) codes used for regional studies that could be more compatible with the hydrologic and land-use setting and issues under analysis. Potentially including simulation of tightly coupled reservoir operations (which is not afforded by the GSFLOW modeling package).
- Recommendations from other recent related reviews of conjunctive use, such as the code comparisons completed by the USGS with DWR, the California Water Environmental Modeling Forum, and the World Bank (Borden et al., 2016).
- Ongoing projects in other regions that are using a precipitation-runoff model passively or actively linked to an IHM.
- Extensibility of these codes to also perform other related analysis to issues that are related but beyond the scope of this Study Plan, such as climate change, salinity leaching demands, linkage to reservoir operations, and SGMA Groundwater Sustainability Plan (GSP) analysis.
- Other vehicles that could be used for estimating transport, such as particle tracking with MODPATH/MODPATH-OBS (Hanson et al., 2013) as used previously with MODPTH-LGR (Dickinson et al. 2011).
- The completeness of the linkages between the codes chosen to transmit the information needed to passively link the input/output from the sequence of codes chosen.

Had these additional criteria been considered, the final conclusions and selected codes may have been different.

After naming the criteria, the Study Plan lists the various codes and combinations of codes considered. The Study Plan then provides a qualitative evaluation of each against the criteria, to finally arrive at the selection of the GSFLOW – MT3D-USGS code combination. This technical review provides an evaluation and comments on each of the codes evaluate, in all cases supporting the points raised with citations to relevant studies which had employed the model tools under consideration. The review cites several inconsistencies and potential issues in the evaluations. One key issue of code selection relates to reliance on an outdated, incomplete, and erroneous USGS draft report that did not go through the formal USGS Fundamental Science Practices review process that incorrectly led to the conclusion that MODFLOW-OWHM should be withdrawn from further consideration, while simultaneously overlooking recent reports and peer-reviewed publications on the same topic.

Section 3. Overview of GSFLOW and Modeling Approach is a broad overview of the modeling approach to be taken, beginning with a general overview of GSFLOW and the underlying component models (Precipitation-Runoff Modeling System [PRMS] and Newton Formulation for Modflow-2005 [MODFLOW-NWT]), and then summarizing the stepwise model development process:

Step 1: Calibrate PRMS-only surface water model for wet season flows.

Step 2: Develop / construct MODFLOW-only groundwater model (preliminary groundwater model, this step is executed in parallel with Step 1 to compile data and construct required model input files and execute model).

Step 3: Integrate preliminary PRMS and MODFLOW models in GSFLOW and perform comprehensive calibration of the dynamically linked surface water and groundwater models.

Step 4: Based on flow outputs from integrated GSFLOW model, develop stand-alone MODFLOW model to generate flows required for nitrogen transport modeling with MT3D-USGS.

Sections 4 through 7 of the Study Plan subsequently provide a detailed discussion for each of these steps and associated component model development. This technical review found this overall approach generally reasonable, but noted several omissions that should be clarified, specifically:

- For the dry-season only MODFLOW-NWT and wet-season only PRMS calibration, further clarification would be helpful for those definitions and which model parameters (for each model) will be well calibrated under those conditions and which parameter will be difficult to calibrate for those conditions.
- No time period was designated for the historical period of simulation used for calibration.
- No summary of model packages was provided, and features being simulated by these packages/processes were not enumerated that would represent all the components of a conceptual model of the climate, land system, surface-water, and groundwater use and movement of water.
- Overall, the historical periods chosen for calibration may not be consistent with the climate cycles observed in the precipitation and surface-water time series and does not include the period after the Thomas Fire.

Section 4. Surface Water Model Development presents the detailed approach for the development of the PRMS-only surface water model, and how that model development will attempt to leverage knowledge and experience gained for the development and application of the existing VSWHM (previously developed for stormwater management). A summary of model domain and grid cell sizes and set up is followed by a detailed tabulation of input data sources, including land surface hydrologic parameters, precipitation, and evapotranspiration (ET) datasets.

This review identifies several points that should have been considered in the PRMS-only model development, including:

- There is no clear justification for the selected model grid cell size related to physical characteristics of the basin. For example, it would be helpful to know how many 330-foot model cells will occupy the 2,900 acres of active wash deposit in the Ventura River floodplain.
- While the use of some parameters from the VSWHM may make sense for wet-season high flows, the climate for the Ventura River Basin is dominated by long dry periods punctuated by occasional very wet season. For example, 53 of 85 years (62 percent) are dry years with less than average precipitation (1935–2019). Similarly, on a seasonal basis, during the fish migration season of January to June, 62 percent of the winters and 65 percent of the spring seasons are dry. This suggests that dry-year and dry-season climate will largely influence the fit of any watershed models, and the wet-season only

calibration approach for the PRMS-only model will require significant revision during subsequent linking to the groundwater model owing to this potential inherent bias. Figures ES-1. ES-2, and ES-3 below illustrate each of these issues.

Figure ES-1. Cumulative Departure of Annual and Seasonal Precipitation from Kingston Reservoir, Ventura, Station 122, 1935–2019 (PDO: Pacific Decadal Oscillation climate index)

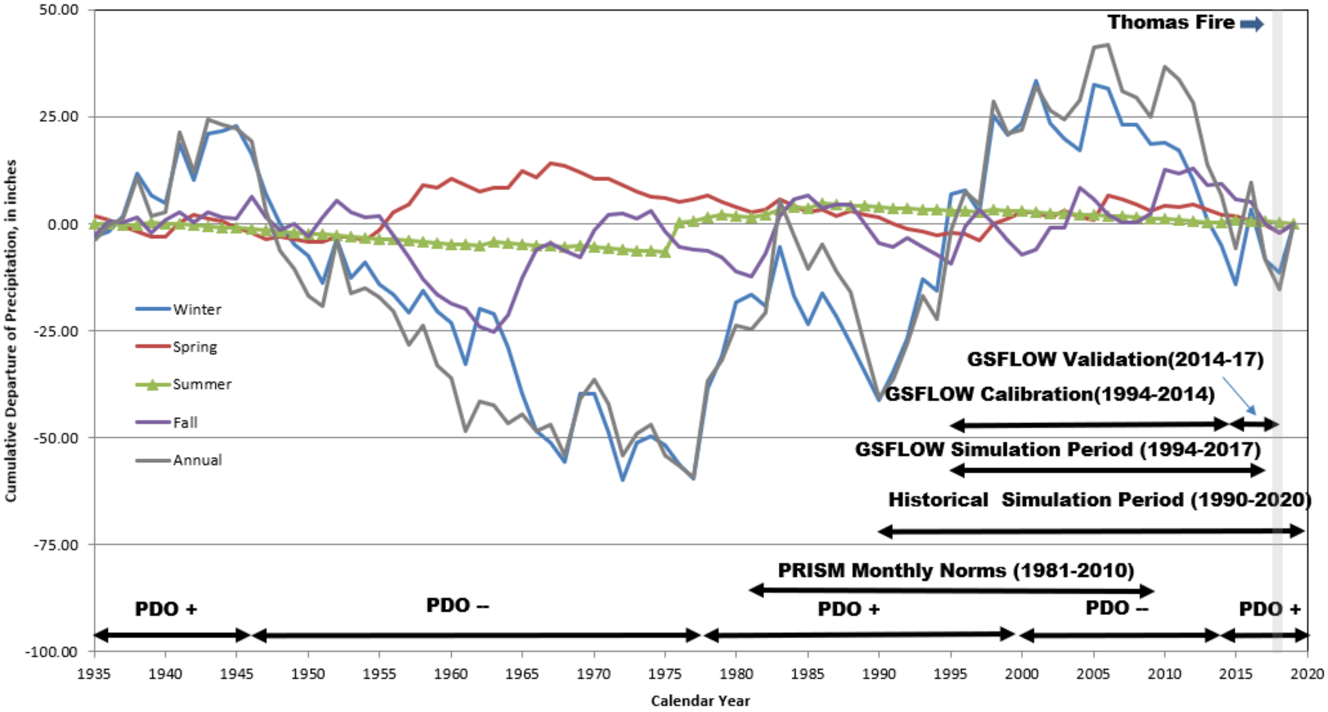


Figure ES-2. Streamflow Duration for Daily and Monthly Flows for Ventura River near Ventura

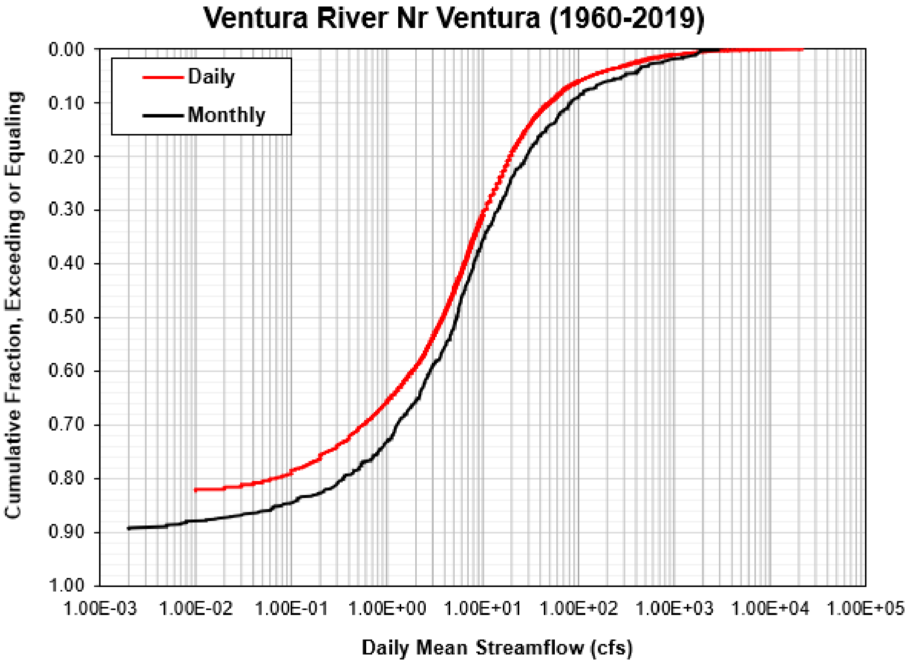
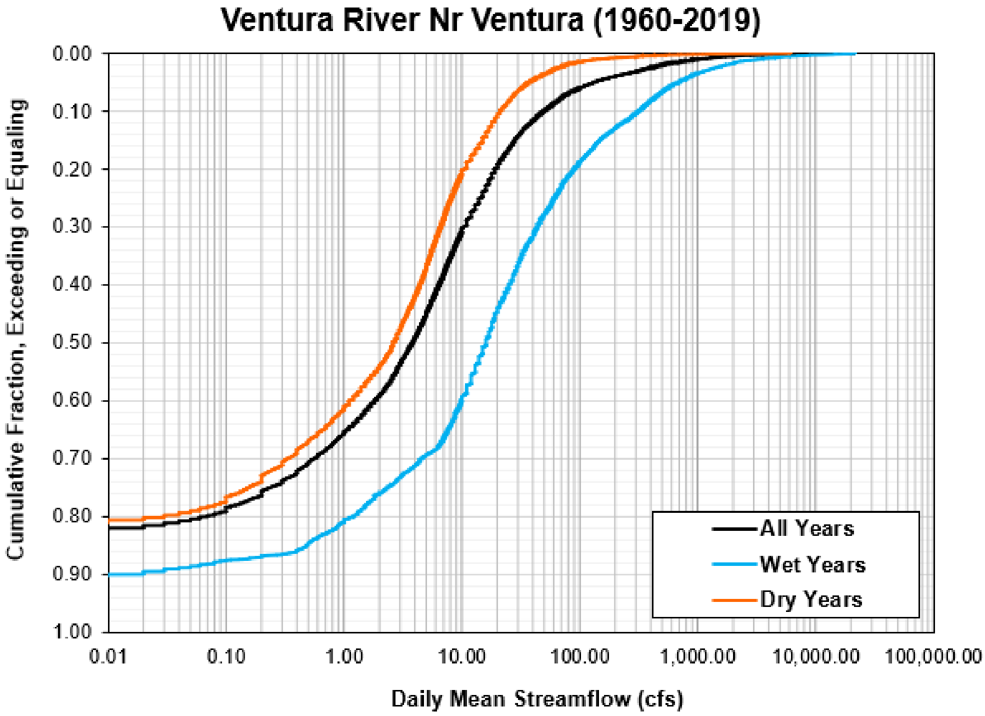


Figure ES-3. Streamflow Duration for Wet and Dry-Year Daily Flows for Ventura River near Ventura



- The lack of specificity in type of observational data to be used in calibration. For instance, there is no discussion of second order observations such as groundwater drawdowns, vertical groundwater head differences, and streamflow gains and losses, as well as higher order observations such as streamflow duration distributions at gages and climate cycles percentages. All these types of measures should be looked at as part of the model calibration process and will affect the skill needed to address the modeling objectives.
- There is little discussion on the development of time- and space-varying ET scaling factors, which will likely be necessary to "dial-in" ET estimates from the simplified temperature methods to observations from California Irrigation Management Information System (CIMIS) stations in the study area.
- The treatment of land surface elevation did not have a clear discussion of potential errors and the need for high-resolution Light Detection and Ranging (LiDAR) datasets for constraining the Cascade Routing Tool (CRT) algorithm used to build the stream network that should also include the storm drain network in this network. Separate sampling of elevations for incised stream channels or well-head elevations, and changes in the land surface and stream channels after the Thomas Fire were also not addressed.
- Actual land use, land use spatial variability, and evolution over time is not well-suited to PRMS's Hydrologic Response Unit approach to treatment of land use, which will require significant preprocessing of land use data.
- The treatment of irrigation as simply an additional "precipitation" component is a poor method for representing irrigation potentially occurring from multiple sources. If the GSFLOW application will use the new Agriculture (AG) Package, then irrigation diversions and irrigation wells will need to be specified for each irrigated parcel.
- The lack of mention and inclusion of storm drains in development of the drainage and surface-water network.

- The lack of discussion of the Robles Diversion and Lake Casitas in development of the surface water network.
- Missing discussion on potential errors in the National Hydrography Dataset (NHD), if NHDPlus-High Resolution (HR) will be used, and quality assurance/quality control data clean-up steps that will be required when applying these datasets.
- Lack of discussion of flow-stage rating curves and how they must be considered when reviewing stream flow gage data and using it for model calibration.
- The discussion on post-Thomas Fire simulations lacks specificity and words of caution on the broad scope of model parameters that will need to be updated / significantly modified. The long list of parameters requiring modification includes land surface elevations, land surface hydrologic properties, and significant changes and continuing evolution of stream channel morphologies.

Section 5. Groundwater Model Development summarizes the development of the groundwater model, including the goals of the model development and a summary of comments for selected the elements of development in the following sections. The reviewers support the modest goals of ensuring that the model runs without error and is consistent with the conceptual model of the features within the Ventura River Watershed, although they suggest additional important goals for the groundwater-only MODFLOW-NWT model. Specifically, the groundwater model should also:

- Replicate the important parts of the geologic framework,
- Include all the uses and sources of water (supply and demand components),
- Cover a reasonable period of historical calibration that captures climate variability,
- Use a complete set of observations that constrain as many of the features of an integrated model as possible, and
- Yield a reasonable mass balance for the groundwater and surface-water systems.

This review also supports the notion of extending the model domain to the limits of the surface water hydrographic basins the contribution of surface flows into the surface water network. The selection of monthly stress periods and daily timesteps makes sense and doing so will deliver easy linkage to the daily stress period structure of the PRMS model.

The Study Plan's outline of the segregation of groundwater-only model data into three broad categories of input (input parameters that will remain the same pre- and post-integration with PRMS model, input parameters for MODFLOW groundwater model that will come from PRSM as "initial placeholder" values, and those which may be adjusted during calibration of the integrated model). These definitions suggest that the model development will occur in a phased approach with surrogate inflows/outflows used to initially develop a stand-alone MODFLOW model. While this approach makes sense, the Study Plan discussion of these data/parameter classes appears to overlook some key factors, for example:

- Fixing the geometric configuration (areal extents, top and bottom surfaces, and thicknesses) of the underlying hydrogeologic units makes sense, but there is no description of how the layering will be constructed, what units are represented, or any additional features that may be derived from the geologic model such as natural faults (considered to act as horizontal flow barriers [HFBs]) or man-made subsurface flow barriers (e.g., Ventura River subsurface barrier at Foster Park).
- Identifying the agricultural pumpage as a fixed parameter fails to recognize the dynamic feedback between surface-water availability, groundwater recharge patterns, stream-aquifer interactions, and groundwater pumping.

- The list of parameters coming from the PRMS model does not include any surface-water flows, runoff (native, agricultural, or urban), storm drain networks, or spatially varying ET from agriculture, which can be major components of the overall groundwater model.
- Of the third category of parameters (those that may be adjusted during model calibration), the vertical hydraulic conductivity of the streambed, pre- and post-Thomas Fire, is a key parameter for calibration of stream-aquifer interactions, yet it is not listed in the Study Plan.
- Parameters for the Multi-aquifer (MNW2) Well Package are not cited, but likely will need to be considered in calibration of the integrated model.
- The treatment of the coastal boundary, and parameters used to define that boundary (for example, the conductance for the General-Head Boundary [GHB]) and a time-varying ocean boundary head.
- The treatment of fractured bedrock using discrete features versus equivalent porous media may be important if there are points of discrete inflows associated with discrete features.
- Additional transient features, such as the buried timber-pile dam installed at the Robles Diversion, within the Horizontal Flow Barrier Package.

The Study Plan identifies and discusses data gaps for development of the groundwater-only model, specifically: media properties/hydraulic parameters (e.g., hydraulic conductivity and storativity), the subsurface geology, and the groundwater extraction rates. The reviewers found this list generally correct but lacking. Related to subsurface geology, it should have also included faults and any man-made features that could represent groundwater flow barriers for selected layers. Other gaps could be the estimation of gains and losses along specific parts of the surface-water network under different wet and dry conditions, identification, and measurement of surface-water diversions.

Related to estimating agricultural pumpage, the Study Plan lays out a three-step approach. While that approach makes sense and is commonly applied, it is a "one-way" calculation that leads to a fixed specified pumping which fails to account for potential feedbacks between the particular hydrologic condition (surface and groundwater) in the basin at that time. For future forecast or alternate adaptation/mitigation-scenario simulations, such dynamic linkages can affect groundwater extraction rates, and an internal supply-demand framework (such as that implemented in MODFLOW-OWHM) provides a better approach for estimating groundwater extraction rates for meeting agricultural irrigation demands. The three-step approach outline in the Study Plan also fails to address pumping for common practices, such as crop frost protection, pre-planting soil wetting, and deficit irrigation water management as intentionally employed for some tree-fruit crops and vineyards.

Another important analysis not mentioned in the Study Plan is the uncertainty of the groundwater-level elevations used as observations for model calibration. Failing to consider and account for this can lead to biases in groundwater model calibration. For example, in the Rio Grande Transboundary Integrated Hydrologic Model (RGTIHM) for the Lower Rio Grande, the average wellhead elevation error was 5 feet (Hanson et al., 2020)—that was about half the RMSE of the groundwater-level observation errors, and in contrast with the average wellhead elevation for wells in the Avra Valley Model, Arizona (Hanson, 1996) where all wells were surveyed to an accuracy of 0.1 feet and was not an issue. These estimation errors need to be accounted for in the observations and RMSE of the model fit as well as uncertainty in model predictions. For the integrated model being developed for this Study, these elevations could also be adjusted to the LiDAR equivalent elevation or at least checked against these elevations to enhance the accuracy of these elevations. Additional forms of uncertainty are cited and, in summary, an estimation of groundwater level observation errors should be included in the model calibration assessment.

Additional comments on development of the groundwater-only model raised by the technical reviewers include:

- Related to the model domain and discretization, the Study Plan does not describe any model grid orientation that may be needed to align with any structural aspects of the watershed, nor does it describe the model extent and boundary condition treatment at the coast but based on the figures presented appears to stop at the coast and does not include any offshore regions.
- The specific layering in the alluvium is not described in any detail outside of probably including 10 layers that include aquifer and aquiclude layers and enough bedrock to cover the partial penetration of the wells and does not address any potential perched groundwater zones.
- The geologic analysis referred to in the Plan appears to not describe any texture or facies analysis of the recent or older alluvium, as is commonly done in most other modern models.
- Based on the Study Plan's geologic structural map (see Figure 5-2 in the Plan), there appear to be several faults that may serve as potential barriers to groundwater flow. Some of the more extreme deformation in the bedrock units that have caused the formation of anticlines also may serve as potential flow barriers or enhanced vertical anisotropy and may need to be evaluated during model development.
- Related to model boundary conditions, the Study Plan provides a good list of potential boundary conditions and packages used to represent each of these features, but a table would facilitate what packages/processes are used for which boundary conditions, and what data sources and data types will be used to implement them.
- The technical reviewers raise concern on the lack of specificity of the initial conditions and offer suggestions on an objective approach to develop the initial head conditions.
- The section on preliminary groundwater model simulation summarizes the estimated strategy to model build, debugging and analysis. The use of specific years to test the model will preclude the effects of antecedent conditions. The overall simulation of the period WY1994–2017 is different than what was described before for the PRMS model (i.e., WY1990–2020).
- The major thing that is missing from this section is a summary of observation types and locations. While the potential groundwater observation wells are shown in Figure 5-3 of the Plan, there is no description of how these could be used with the Head Observation Package. As noted previously, types of observations needed for IHM calibration should include first-order observations of groundwater levels, streamflow, and diversions, as well as second-order observations of vertical groundwater head differences, streamflow gains and losses, and streamflow seepage. These are not discussed in the Study Plan.

Section 6. GSFLOW Model Development, Calibration, and Validation describes how the GSFLOW model is developed by integrating the PRMS surface water model with the MODFLOW groundwater model. The overall description indicates that groundwater levels along with surface-water flows will be used to assess the fit of the calibrated model to historic period of 24 years (WY1994–2017). In addition, the constraint of a cumulative mass balance error of 0.5 percent (Reilly and Harbaugh, 2004) (defined as total inflow minus total outflow divided by one half the sum of the inflow and outflow) will be used to assure that the model has reasonable mass balance. In addition to these calibration objectives, this review also recommends that mass balance criteria be assessed for the surface-water system as well as other attributes of PRMS, such as Actual ET.

Related to the simulation period for the integrated model, the review notes that the selected period is not consistent with the wet and dry-year variations in streamflow cycles (see Figure 6-1 in this report) that comprise 6 wet years and 18 dry years with multi-year recession occurring since 2006.

The Study Plan describes in more detail the model calibration approach and related data sources for each component model, with more detail than summarized previously in Section 3 of the Plan. The major modeling issues include:

- For the PRMS surface-water model, the calibration strategy is to focus on "wet-weather flows." However, the meaning or criteria for delineating wet-weather periods is not clear. Could such "wet-weather flows" occur only in overall wet years, or could it be a wet season in an average or dry year, or simply be synoptic storm events that could occur in any climate setting?
- The use of flow observations from streamflow gages, manual streamflow measurements and wet-dry maps is a good subset of observations. Additional observations that should be considered include stage at the streamflow gaging stations, surface-water diversions at the Robles Diversion and any other irrigation diversions, and block flows at the ocean boundary for periods when the river outlet is open.
- The use of stream stage observations will be especially relevant because California Department of Fish and Wildlife (CDFW) flow targets for fish migration include a flow and a stage requirement for wet and dry periods.
- As noted previously, other higher-order observations could be employed such as wet and dry-year/season daily streamflow duration, residuals of observed and simulated cumulative departure of monthly flows, and climate-cycle frequency analysis to help explore the continuity of transition between wet and dry-climate flows.
- Calibration goals for the PRMS surface water model should extend beyond average error metrics for streamflows because the streamflows tend to be lognormally distributed. In addition, RMSE or Nash-Sutcliffe error of log streamflows binned into selected ranges of flow regimes may also be better to address the skill of the model for its ultimate purposes. The review team also recommend use of weighted residual error, with weights based on the uncertainty of gaging data would also be a good approach to consider (higher uncertainty, lower weight). The evaluation of low-flow periods as well as wet-season periods is a good idea.
- Related to groundwater model calibration, the Study Plan only discussed fitting to observed groundwater levels. Additional important considerations include evaluating water level fluctuations (drawdowns) from a defined baseline, obtaining data for outside the stream channel groundwater levels (to avoid confusing hyporheic surface water -groundwater interactions from transfers between the stream and the regional groundwater system), and evaluating vertical gradients from multi-depth monitoring well sites (if data is available).
- The review team recommends splitting groundwater level data into different groups that represent different parts of the watershed and different sets of model layers.
- The Study Plan stated groundwater model calibration goals for the goodness-of-fit the statistical measures, with the percent of correlation of > 90 percent between field and simulated observations is considered a good fit (Hill and Tiedeman, 2007). Again, these measures should be assessed with respect to groundwater-level residuals, drawdown residuals, and vertical head difference residuals.
- The sensitivity analysis approach described in the Study Plan is rather vague, and it is recommended that the models be set up in the PEST or UCODE framework and then perform trial-and-error analysis in this framework using simple forward runs.

Finally, the Study Plan notes that there will be eight scenarios simulated with the integrated GSFLOW model, with four generally defined, but with the remaining four to be defined in detail at a later date. The technical reviewers recommend that all the climate-change scenarios should also include sea-level rise. In addition, climate variability scenarios should be considered to assess the common Pacific Decadal Oscillation (PDO) cycles estimated in local climate and streamflow data (see Figures 4-1 and 6-3 in this report). For example, some climate studies are suggesting that we are in the worst mega-drought since the late 1500s (Williams et al., 2020), so prolonged decadal drought may need to be assessed and available for other analyses, such as flow thresholds for fish migration by CDFW and National Marine Fisheries Service (NMFS) and nitrate transport.

Section 7. Nitrogen Transport Model Development describes how the nitrate transport model will be developed in MT3D-USGS from the flow quantities simulated by the GSFLOW model, including identifying datasets and sources for model inputs and calibration, and the calibration process and goals. The modeling calibration and validation periods will be the same as used for the GSFLOW model described above, and the review concerns raised previously related to the selected time Period-of-Record (POR) remain.

The Study Plan states they will be explicitly accounting for (1) On-site Water Treatment System (OWTS; in the past commonly known as septic tank disposal systems), (2) livestock ranching, and (3) leaching of agricultural fertilizers to groundwater under irrigated lands. They will employ a nitrogen mass balance approach as developed and described by Viers et al. (2012), accounting for the three sources described above plus atmospheric deposition, atmospheric nitrogen-fixing legume crops (e.g., alfalfa, clover), and losses due to crop uptake and release to the atmosphere.

The Study Plan notes that MT3D is designed to run with output from MODFLOW-only, but MT3D is not directly compatible with GSFLOW (Morway, 2017). This requires that custom codes be written to assign MODFLOW boundary conditions from the GSFLOW model output, to provide the flow input structure needed for MT3D. This restriction is probably not accurate and some features that would be relevant to transport are not included in the transition of simulated data from MODFLOW-NWT and MT3D-USGS.

The Study Plan covers two types of input data needed for the nitrogen transport model: (a) data on the soil zone model nitrogen mass balance model inflows and outflows, and (b) water quality data for the surface water that recharges the groundwater along losing stream reaches. There are seven distinct components / input data needs for the nitrogen mass balance model (a), and the review notes that five out of these seven will be obtained from "literature values" and "published values," without clarification as to the relation to the study area. Similarly, for (b) nitrogen loading to groundwater from surface water sources, three components are identified and only one can use actual water quality monitoring data (the concentration of nitrate in surface water for losing reaches of stream). The other two either rely on "published" and "literature" values (the flow rates into the soil zone from the ground surface) or are nitrate concentration out the base of the soil zone calculated from the nitrogen mass balance equation. The review team recommends that the California Pesticide Information Portal (CalPIP) database be reviewed as a potential data source. This database gives monthly applications of pesticides and herbicides and type of crops being grown and can potentially help inform estimates for nitrate application rates.

This review notes that the calibration target dataset is expected to be limited and less than ideal, due to the lack of long-term regular synoptic water-quality sampling. However, the recent nitrogen loading / algae study by Geosyntec provides excellent recent data from surface water and groundwater samples collected in three events over an 8-month period in 2017–2018. The related calibration goals for the targets are similarly undefined in the Study Plan, other than noting that calibration goals for the goodness-of-fit parameters will be defined in subsequent model development steps. One exception is the definition of a preliminary threshold for the normalized RMSE of nitrate concentration is less than 20 percent; the calibration will be considered adequate. However, this goal does not appear to be tied to any specific total maximum daily load (TMDL) regulatory criteria or uncertainty of physical samples or physical processes.

For sensitivity analysis for the integrated GSFLOW model, runtimes may dictate that manual sensitivity analyses may be the only viable approach. Because of the wide range in actual magnitude of the various observations, the use of weighted residuals is essential, although this is not mentioned in the Study Plan.

Finally, potential nitrogen transport model scenarios are covered in Section 7.7 of the Study Plan. The section notes that four mass loading scenarios will be investigated with the MT3D-USGS model, but no details are provided and instead it is stated that those scenarios will be defined later in the project. The Plan does not discuss how scenarios may, or may not, be shuffled with the integrated PRMS–GSFLOW model scenarios. The transport or limitations of salinity loading are also not addressed even though they were the focus of TMDL analysis for the adjacent Santa Clara River.

Introduction and Scope of Review

At the request of Casitas Municipal Water District, GSI Water Solutions, Inc. (GSI), with assistance from One-Water Hydrologic, LLC, and IRP Water Resources Consulting LLC, have undertaken a detailed technical review of the *Final Study Plan for the Development of Groundwater-Surface Water and Nutrient Transport Models of the Ventura River Watershed* (Study Plan or Plan; Geosyntec and DBS&A, 2019). The Study Plan was developed by Geosyntec Consultants (Geosyntec) and Daniel B. Stephens and Associates (DBS&A) under contract to the State Water Resources Control Board (SWRCB). Casitas Municipal Water District (CMWD) is the single largest water provider in the Ventura River Watershed, and as such it is critical that CMWD be engaged at a reviewer level in the process of development of the Ventura River Watershed model. As described in the following review, the model will be employed by the SWRCB and other agencies as a planning tool for evaluating water management alternatives in the basin related to the transport of nitrates and guidance in establishing "fish flow" targets, which in turn will present management constraints on water users in the Ventura River Basin. Overall, this review could be constructive guidance for the development of the models and related assessment of management issues.

The following review comments are structured to match the major sections of the Study Plan (Geosyntec and DBS&A, 2019). This review also includes two appendices with additional cursory comments about selected supplementary documents as they were used to support the major tasks of this Study Plan and of the codes that were proposed for use in this study. A few additional comments about the proposed eight groups of deliverables area are also included. This review does not include any comments about the timeline of project development or outreach efforts such as Technical Advisory Committee (TAC) evaluations, data or code requests, or public webinars. While these comments did not get offered during the comment periods of the draft Study Plan review period, they still can be used to address questions by CMWD and other interested parties and stakeholders as well as the technical staff of the SWRCB that are guiding the completion of this project with their consultants Geosyntec and DBS&A. The review also includes the review of the "supporting documents" that were used to develop the Study Plan and related models. Some of these documents are reviewed as part of their use in the Study Plan and others are reviewed separately in Appendix A of this document. Finally, there is also a summary of the model codes and related issues between different codes in Appendix B.

SECTION 1: **Review of 1. Introduction**

Key Takeaways:

The goal statements in the Study Plan are overly general and imprecise. It remains unclear as to how the goals would be approached using the model results. The reviewers raised key questions related to each of the stated goals.

The following review comments are responses to the brief description given in this section of the Study Plan regarding the background, goals and objectives of the model, overview of report, and Thomas Fire summaries.

1.1 Background

The background section of the Plan describes the SWRCB's ongoing programs to implement the Study Plan in response to:

1. The Ventura River, predominantly in Ventura County, which was identified as one of five priority stream systems in the California Water Action Plan (WAP) enacted in January 2014 by Governor Edmund G. Brown Jr. Action four (4) of the WAP, to "Protect and Restore Important Ecosystems," and
2. The Los Angeles Regional Water Quality Control Board's adoption of a total maximum daily load (TMDL) for algae, eutrophic conditions, and nutrients in the Ventura River Watershed (LARWQCB 2012a and 2012b).

The Plan does state that there are other ongoing initiatives in the basin that are independently collecting data, developing management actions and potentially water resources management tools, but does not cite by name ongoing parallel efforts with different objectives. Such parallel efforts would include at a minimum:

1. The ongoing Ventura River Basin groundwater adjudication (City of Buena Ventura, 2019)
2. Sustainable Groundwater Management Act (SGMA) Groundwater Sustainability Agency/ Groundwater Sustainability Plan (GSP) requirements
3. Ongoing projects for dismantling of Matilija Dam

Thus, other current litigation and governance issues may not be covered or accommodated in the design and related analysis of this study. In addition, other state activities such as the California Environmental Protection Agency/U.S. Geological Survey (USGS) Groundwater Ambient Monitoring Program (GAMA) (Montrella and Belitz, 2009; Burton et al., 2011; USGS, 2018) that identified additional characterizations were not included in the design, build, observations, or analysis framework of this study. This project straddles two counties and multiple water purveyors, that include CMWD that may have ongoing projects or operational restrictions and goals that are not considered as part of the impetus for this study. Finally, other salt-nutrient studies have been completed, such as Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS) in the Central Valley (Central Valley Salinity Coalition and CV-SALTS, 2012), the Salt and Nutrient Management Plan from the adjacent Santa Clara River Valley (Geoscience, 2016), and for the Ventura River (VCWPD, 2015 and Cardno ENTRIX 2012) also were not considered in the design of this study. Overall, no other studies were referred to as examples of good practices or as a starting point to potentially develop an even better approach to this type of study.

While the Plan states that the SWRCB and the Los Angeles Regional Water Quality Control Board (LARWQCB) are open to "coordinating with interested parties," it is not stated how, or if, they will proactively engage with those parallel activities where a clear nexus exists.

1.2 Goals and Objectives of the Model

The goals and objectives stated in Section 2.1 of the Plan are not consistent with the deliverables indicated later in Table 8-1 of the Plan. The following goals were enumerated as:

- *Estimate existing instream flows at multiple points of interest (POI) throughout the entire Ventura River Watershed;*
- *Predict unimpaired flow at each POI that would occur with no water diversions, pumping, or storage;*
- *Evaluate how water use affects the water balance and instream flows;*
- *Simulate groundwater pumping and groundwater-surface water interactions to understand groundwater effects on instream flows;*
- *Ensure that the model simulation period is long enough to reasonably capture the variability of the full range of water year types from drought to flood years;*
- *Create a nutrient transport model to inform nitrogen source assessment in the Ventura River Watershed; and*
- *Simulate the effects of the December 2017-January 2018 Thomas Fire on hydrology, nitrogen transport, groundwater levels, and instream flows.*

The goal of "*Estimate existing instream flows at multiple points of interest (POI) throughout the entire Ventura River Watershed*" is not supported by the current data network. Without seepage runs and a groundwater monitoring network of sufficient spatial and temporal resolution, estimates of groundwater – surface water interactions, and thus model estimates of instream flows, will exhibit large uncertainty.

The goal to "*Predict unimpaired flows*" does not explicitly list the diversions and storage related to Lake Casitas and Matilija reservoirs. While diversions and streamflow gains and losses to and from the groundwater are relatively important, the inflows from reservoir releases and from any additional effluent discharge sites should also be considered. In addition, unimpaired flows would only be comparable to historical flows without development that has altered both inflows or outflows, and this is unlikely to be restored in this watershed setting.

The goal of "*Evaluate how water use affects the water balance and instream flows*" can be assessed with the development of an integrated hydrologic model such as Groundwater Surface-water Flow Model (GSFLOW) or Modflow-One-Water Hydrologic Flow Model (One-Water or MODFLOW-OWHM). Since GSFLOW does not include a physically based supply-and-demand framework like One-Water (MODFLOW-OWHM), this will be more difficult to achieve with the chosen model code.

The goal of "*Simulate groundwater pumping and groundwater-surface water interactions to understand groundwater effects on instream flows*" will be difficult to accomplish without measured or reported pumpage on a well-by-well basis. In addition, the GSFLOW code only allows for specified pumpage and does not estimate pumpage internally, so all pumpage from municipal, industrial, agricultural, and domestic uses will have to be pre-estimated if not available as reported pumpage for most times and uses. While GSFLOW is capable of simulating this, GSFLOW cannot change land use or simulate any potential return flows from agriculture, within a simulation like One-Water, so some of this analysis may be difficult to complete.

The goal of "*Ensure that the model simulation period is long enough to reasonably capture the variability of the full range of water year types from drought to flood years*" is fundamental to all models and will require additional analysis outside of the models proposed. Some of this type of analysis was already completed by the USGS studies of the adjacent Santa Clara-Calleguas Basin study (Hanson et al., 2003; Figure 6-2 in this report) and by the more recent climate variability studies (Hanson et al., 2006). An analysis of climate variability from precipitation streamflow, and possibly tree-ring indices may be required to give a more complete and quantitative analysis to the period long enough for capturing the drought and flood years. This could easily be facilitated using the USGS HydroClimate Toolkit (Dickinson et al., 2014) for selected hydrologic time series to assess the proper periods of simulation and the climate cycles that are embedded within that period. Additionally, the other major issue for having an adequate period of simulation is the slow rate of transport of nitrates. This was a major issue for CV-SALTS in the Central Valley assessments that used the Central Valley Hydrologic Model but only had a historical period of a couple decades and that was inadequate to assess the slow transport from potential nitrate sources to points of observations, such as rivers and wells. This consideration was not identified in the Study Plan but needs to be an additional consideration for having any verification of actual transport relative to measured nitrate samples from wells or surface water sources.

The goal of "*Create a nutrient transport model to inform nitrogen source assessment in the Ventura River Watershed*" is a fundamental component to this Study Plan but overlooks the equally important issues of salt build-up and transport or any other emerging natural or anthropogenic contaminants. Use of saline waters may have a larger affect if agriculture expands and salt leaching is required with the application of additional water during irrigation. While the One-Water code can simulate these additional demands, GSFLOW cannot. There is also a mismatch between GSFLOW and the use of MT3DMS-USGS that will be addressed in review comments below. Related to the water quality modeling, the lack of regular synoptic water-quality sampling, including isotope sampling, the occurrence and movement of nitrates and their relation to nitrate sources will remain highly uncertain as well. This is discussed in more detail below in Section 7, Review of 7. Nitrogen Transport Model Development.

The goal of "*Simulate the effects of the December 2017-January 2018 Thomas Fire on hydrology, nitrogen transport, groundwater levels, and instream flows*" will require a change in land use, which is not a feature in GSFLOW. While other codes such as One-Water can accommodate these types of changes in land use, the GSFLOW model will have to be stopped and restarted similar to what was done with the GSFLOW model of the Santa Rosa Plain, California. The effects of the fire also may not be complete without field data from the burn areas that can provide real (and not literature values) for dissolved organic carbon, nitrate, heavy metals, or other anthropogenic attributes that would potentially have been released during a Thomas Fire. Background data like these have been collected for other fire areas such as the Paradise Fire near Chico, California. Any Federal Emergency Management Agency (FEMA), California Department of Forestry and Fire Protection, USGS Data collections, geographic information system (GIS) shape files. or reports that may address the effects of the fire were not referenced in this Study Plan.

In addition, public transparency through public outreach meetings is necessary but not sufficient. Additional transparency can only be achieved through full disclosure of the model, data used to build the model, and full disclosure of the tools and methods used in support of the build, simulation, and analysis of the models developed. This should also include the use of open-source, documented software for all models and analysis.

The additional analysis goals to assess additional capabilities of interest include:

- *Support assessments of habitat for important species.*
- *Represent the water rights priority system to evaluate water management scenarios.*
- *Simulate climate change and future water demands scenarios; and*
- *Model water temperature, other water quality characteristics, or have the ability to link the integrated groundwater-surface water model to separate water temperature or water quality models.*

These attributes will be reviewed in section 2 entitled "modeling methodology selection" of this review.

1.3 Overview of Report

This section of the Study Plan briefly describes the contents of four of the sections in the Plan (i.e., Sections 2, 4, 7, and 8). There are no comments on this section by the reviewers.

1.4 Thomas Fire

The Thomas Fire section includes a summary of the fire and claims that physical and hydrological properties of the watershed were affected by the extensive fire. The Thomas Fire also affected the chemical attributes and these attributes as well as changes in vegetation and related landscape attributes were not mentioned or reviewed in this summary or this document. An extensive list of properties was listed as attributes that were identified as potentially subject to change from the fire. However, these attributes do not include any geochemical attributes that could affect the sources of nitrate or other potential contaminants from fire-related sources. No data sets or references were provided relative to fire assessment or any analysis of changed properties as part of this summary.

SECTION 2: **Review of 2. Model Methodology Selection**

Key Takeaways:

While generally concurring with the selection approach and evaluation criteria, a variety of potential concerns are identified. Those concerns include not meeting relevant (e.g., SGMA) requirements for properly documented public domain code, transparency in model development, and longevity of model (i.e., availability of support and updates in relation to the suite of codes finally selected). Technical challenges related to the ability of the model to meet project requirements are raised, as well as the capability of the model to accurately simulate all key hydrologic and hydrogeologic functions.

The introductory subsection in the Study Plan that lays out the possible types of Integrated Hydrologic Models (IHMs) acknowledges that some require a license while others are free. However, this summary does not acknowledge whether each of these model codes has been through a robust technical review process and whether the code(s) are open source. While these factors may not be an immediate concern for this proposed study, they would be a criterion if the models developed under this study using GSFLOW (PRMS + MODFLOW-NWT) and MT3D-USGS were to be used for other requirements such as SGMA.

2.1 Overview of Existing Models

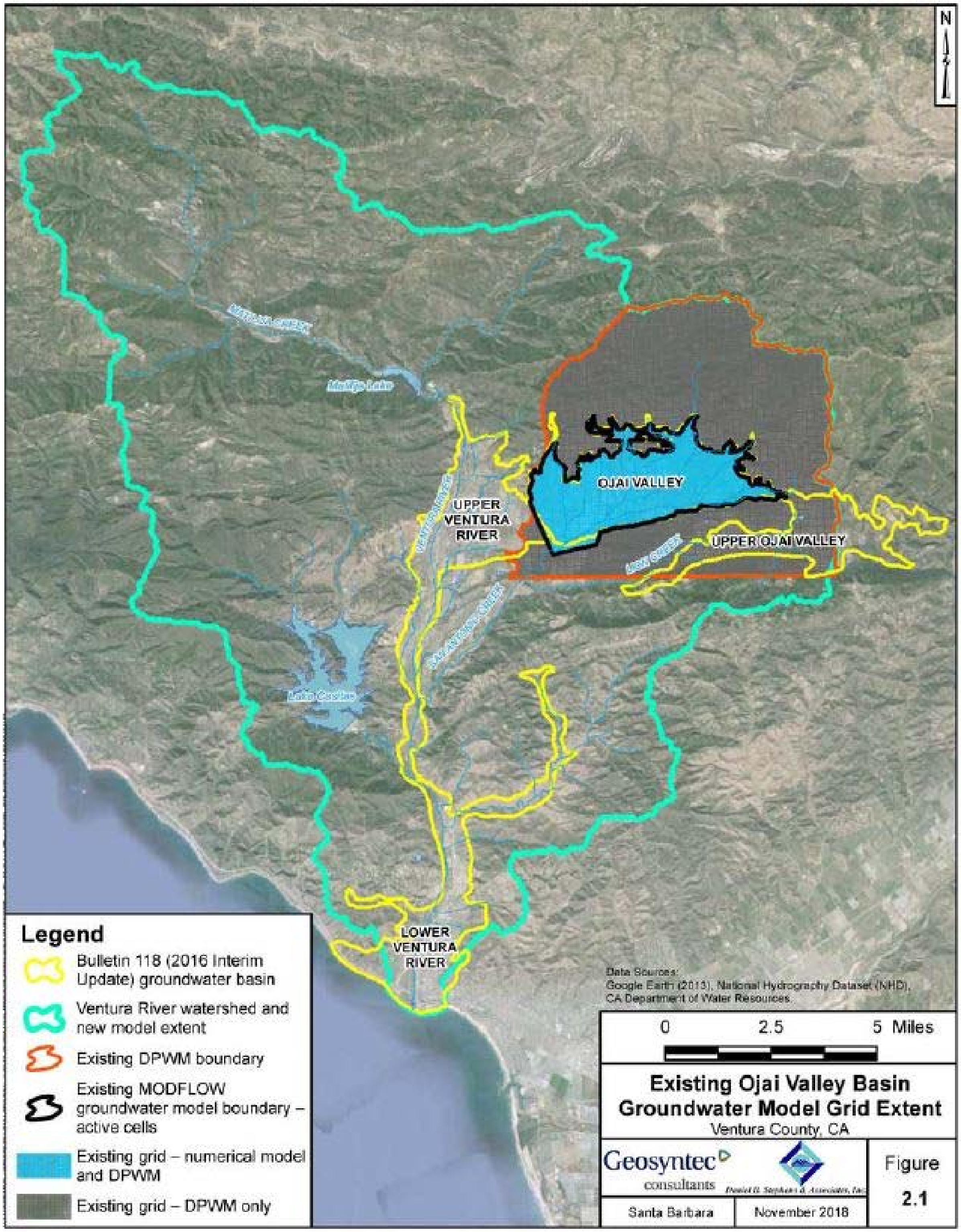
Two flow models of parts of the Ventura River Watershed were summarized in this section of the Plan as the Ojai Valley Basin Groundwater Model (OBGM) and Ventura Surface Water Hydrology Model (VSWHM) (see Figure 2-1 below) (Geosyntec and DBS&A, 2019, Figure 2-1). This applied model uses the proprietary version of MODFLOW called MODFLOW-SURFACT (developed by HydroGeoLogic Inc. https://www.hgl.com/softwareproducts-new/modflow-surfact/) for flow and transport simulation and the proprietary water-balance model code developed by DBS&A called Distributed Parameter Watershed Model (DPWM, http://dbsa.sks.com/distributed_parameter_watershed_model.aspx). DPWM is a grid-based water-balance model similar to the Basin Characterization Model (BCM) developed by the USGS (Flint et al., 2021) and the Variable Infiltration Capacity (VIC) Model developed at the University of Washington. While both of these other models have been used extensively for applied water-resource evaluation projects, there is no open-source code or published documentation or references to a peer-reviewed document for DPWM. The use of proprietary and undocumented software, or software lacking peer-reviewed published open-source code, may be difficult for this project given SGMA requirements (23 CCR 352.4) that prevent use of these types of codes for any projects after 2014. Comparisons of the DPWM and BCM results would be warranted along with comparisons with the distribution of precipitation from DPWM and Parameter-elevation Relationships on Independent Slopes Model (PRISM) Climate Data for estimates of precipitation. Statewide estimates of BCM are available, so this would be a feasible and warranted comparison for this study at the monthly time intervals.

2.1.1 Ojai Valley Basin Groundwater Model (OBGM)

The OBGM spans the historical period from April 1, 1970 to December 31, 2013 with projections for water years 1/1/2014–9/30/2020. These projections used 25th percentile (representing dry conditions), median (1980-85 conditions), and 75th percentile (representing wet conditions) of precipitation from the record of precipitation at the Ojai Fire Station overlaid onto the distribution of precipitation for the median period. However, this approach can potentially create a "tear" in groundwater storage, recharge, and streamflow between the end of historical period and the projections. Historical groundwater level declines at the four monitoring wells shown (DBS&A, 2014) suggest that inspection for potential land subsidence is warranted in the central parts of the basin based on observation wells 1 and 2. The OBGM is largely coincident with the extent of the alluvial valley of the Ojai Valley as delineated in Bulletin 118 but does not include the Upper Ojai Valley or the Upper and Lower Ventura River basins.

The OBGM model includes 10 layers of variable thickness with 109 rows and 190 columns of square (equal-dimensioned cells) of 200 feet by 200 feet simulating 175 seasonal (3-month) stress periods. Time stepping through these seasonal stress periods is amplified by a factor of 1.2 resulting in time steps ranging from less than a day up to 10 days in length. The model was run in MODFLOW-SURFACT (MS, version 3) and in Groundwater Vistas (GWV) using the Basic (BAS) Package to define the active extent and initial groundwater levels for all cells within each model layer, Block-Centered Flow (BCF) Aquifer Package, the Drain (DRN) Package, the Evapotranspiration (EVT) Package, the General-Head Boundary (GHB) Package, the Recharge Seepage Face (RSF4) Package, the Single-Aquifer Well (WEL) Package and the Fractured-Well Package (in MODFLOW-SURFACT only), the Output Control (OC) Package renamed as the ATO (Adaptive Time Output) Package in MODFLOW-SURFACT, and the Preconditioned Conjugate Gradient (PCG) Solver Package. The upper most parts of all 10 layers are potentially convertible from confined to unconfined storage properties from within the UGSS BCF flow package that was also used to delineate the primary and secondary storage, horizontal hydraulic conductivity, vertical leakance, and top of each of the 10 model layers. The output included the MODFLOW-style list file, and an error file, as well as cell-by-cell flows and cell-by-cell recharge, heads, and drawdowns.

Figure 2-1. Existing Ojai Valley Basin Groundwater Model Grid Extent of Active Model Cells (OBGM), Bulletin 118 Groundwater Basin, and Watershed Extent (Geosyntec and DBS&A, 2019, Figure 2-1)

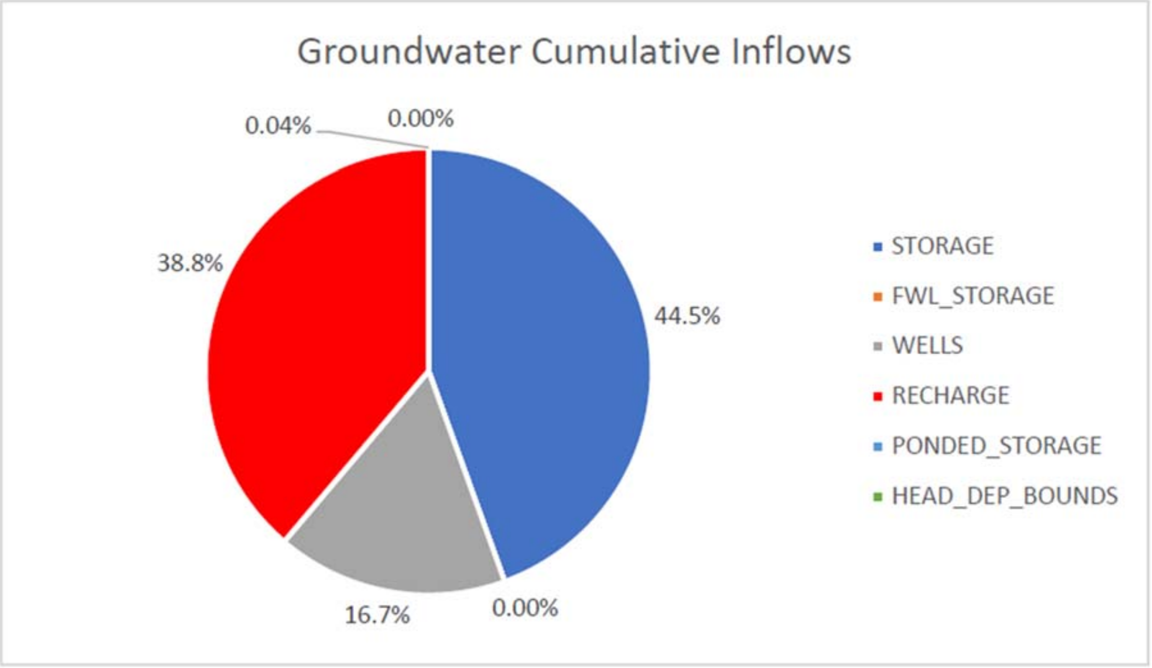


Data Sources:
Google Earth (2013), National Hydrography Dataset (NHD),
CA Department of Water Resources

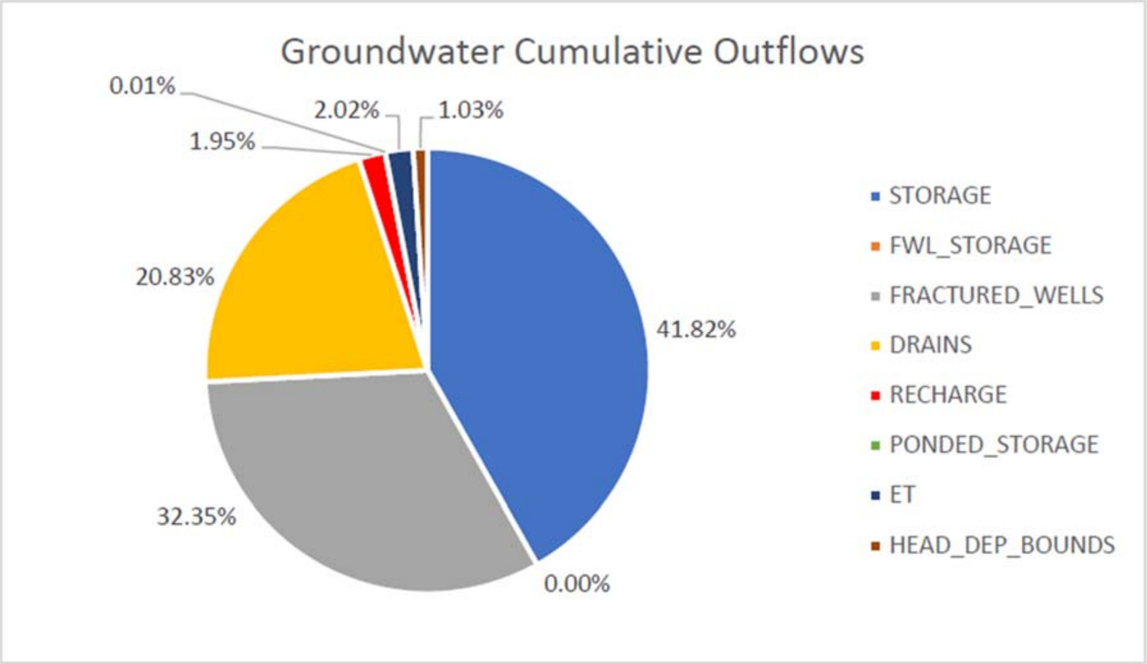
Thus, no flow-dependent packages such as Streamflow Routing (SFR), Farm Process (FMP), or Drain Return (DRT) were used to simulate any landscape or surface-water processes, including the surface-water network and any potential related diversions or effluent inflows. In addition, no hydrologic flow barriers representing faults or buried dams were implemented with the HFB Package. In addition, some of the features used from MS and GWV are proprietary and not part of the MODFLOW family of public and peer-reviewed model codes that are all publicly available open-source freeware. In addition, the MODFLOW error file indicated 16 cells with half-layer thicknesses less than or equal to 0.0 feet thick, 3,328 cells in model layer 1 where the drain elevation is below the specified model-layer bottom, 239 cells with GHB elevation below the model layer bottom for cells in model layer 5, 689 cells with GHB elevation below the model layer bottom for cells in model layer 6, and 1,202 cells in layer 10. In addition, the model run indicated 9 warnings with numerous starting heads below cell bottoms, with 3,997 in layer 1, 1,135 cells in layer 2, 740 cells in layer 3,134 cells in layer 5, 9 cells in layer 6, 5 cells in layer 7, 2 in layer 9 and 1 in the bottom layer 10. Finally, numerous well-bottom elevations were lower than the bottom of the model and were reset to the bottom of layer 10 (bottom layer) with the Fractured-well (FWL4) Package.

The cumulative mass-balance error was still within -0.04 percent for the entire simulation period. Most of the inflow to groundwater flow was from groundwater storage, recharge, and wells (see Figure 2-2A below), with the wells used to simulate injection of water into groundwater. Most of the outflow from groundwater was from groundwater storage, fractured-rock wells, and drains (see Figure 2-2B below). Minor outflow from recharge, evapotranspiration (ET), and Head-Dependent Bounds, and no outflow from standard wells. The outflow and inflow from ponded storage is not well defined. The inflow items of "fractured-Well Storage" and "Ponded Storage" are not well defined and are minor inflows to groundwater flow along with underflow from GHBs. Similarly, the outflow terms "Fractured-Well Storage", "Ponded Storage" and neither the conceptual model nor the physics of these features is not well defined nor documented.

Figure 2-2. Groundwater Flow Budget Pie Charts for Percentages of Flow for (A) Inflows to Groundwater Flow, and (B) Outflows to Cumulative Groundwater Flow in the OBGM Historical Model Simulation



A.



B.

Based on the selected hydrographs shown in the presentation of November 11, 2011, the model generally tracks the measured groundwater levels but does not replicate the amplitude of the interannual changes which will have an effect on groundwater-surface-water relations and potential capture of surface water from groundwater depletions or reduced discharge to surface water from groundwater. The hydrographs also indicate from both measured and simulated groundwater levels that water-levels declines are relatively large in the central parts of the basin, have declined to near historic lows, and represent large enough declines to warrant inspection for potential land subsidence.

2.1.2 Ventura Surface Water Hydrology Model (VSWHM)

The VSWHM simulates the watershed water balance for the period October 1996–September 2005 and overlaps the OBGM (Tetra Tech, 2009). The VSWHM is a lumped-parameter Hydrologic Simulation Program-FORTRAN (HSPF) model comprised of Hydrologic Response Units composed of subbasins ranging in size from 100 acres to more than 6,000 acres. While the model was originally intended for predicting peak flow events for hydraulic design of flood control structures, it also was used to provide selected groundwater and surface-water inflows for the OBGM, as well as the original period of historical simulation to estimate the historical groundwater budget. The VSWHM model extent overlaps OBGM model extent but truncates some of the watersheds along its southern boundary. All the inflows and outflow to the groundwater model were pre-estimated and treated as specified time-varying inflows and outflows to develop a groundwater budget (Equation 1, DBS&A, 2010):

Change in Groundwater Storage = Inflows – Outflows

$$= [I_p + I_i + GW_i + SW_i + S + B_i] - [E_m + E_d + E_a + E_p + GW_o + R + B_o + SW_o] \quad \text{(Equation 1)}$$

Where:

Inflows are,

I_p = groundwater infiltration from precipitation

I_i = groundwater infiltration from irrigation

GW_i = upgradient groundwater underflow from adjacent subbasins

SW_i = recharge of surface water to groundwater

S = recharge of water from domestic septic systems

B_i = groundwater flux from bedrock into the alluvium aquifer

Outflows are,

E_m = groundwater extractions from municipal uses

E_d = groundwater extractions from domestic uses

E_a = groundwater extractions from agricultural uses

E_p = groundwater extractions from industrial uses

GW_o = groundwater underflow to downgradient basins or to the ocean

R = evapotranspiration by riparian vegetation

B_o = groundwater underflow from the alluvium to bedrock

SW_o = groundwater discharge to surface water

The land uses, irrigation application rates, and irrigation efficiencies for the major agricultural land uses included orchards and vineyards (citrus and avocados) and truck produce crops (various row crops, bush berries, and strawberries) from California Department of Water Resources (DWR) (2010). All specified flows were implemented with constant flux packages of MODFLOW within the version MODFLOW-SURFACT. This includes leakage from Lake Casitas to the groundwater system below the reservoir. A separate mass balance was used for the net groundwater-surface-water balance (Equation 2; DBS&A, 2010) as:

Net Change in surface-water/groundwater balance =

$(Q_o + E + D_o) - (R + D_i + P + Q_i)$ (Equation 2)

Where:

Q_o = the surface water flow at the downstream boundary

E = Evaporation from the river

D_o = diversions out of the river

R = surface runoff into the river along the reach of the Subbasin

P = Direct precipitation into the river

D_i = point sources of water into the river

Q_i = the surface water flow at the upstream boundary of the Subbasin

This was simplified to:
Change in interaction = $(Q_o + D_o) - (R + D_i + Q_i)$ (Equation 3)

2.2 Model Selection Criteria

Review of the Model Selection Criteria includes a summary with individual review comments on the criteria listed in the Study Plan and additional potential criteria with comments that were not used or overlooked by the Plan developers. The model selection criteria developed for this Study Plan (Geosyntec and DBS&A, 2019) are included with associated comments as:

- *Capability to accurately model essential groundwater-surface water functions, including rainfall-runoff relationships, streamflow accumulation, surface water hydrology, variable groundwater elevations, groundwater discharge to surface water, and precipitation and irrigation-related recharge to groundwater.*

  While these are good criteria, it may need to include a broader suite of codes and combination of codes than was considered in this Study Plan. The most recent modifications to GSFLOW now includes an Agriculture (AG) Package (Niswonger, 2020) that is a simpler version of what is represented in MF-OWHM (Boyce et al., 2020, version 2; Hanson et al., 2014, version 1), but this approach has some limitations that may preclude defining hydrologic response units (HRUs) that represent accounting units (Water-Balance Subregions) and related supply-and-demand components needed for SGMA budgets.

- *Perceived credibility, for instance as demonstrated by citation in peer-reviewed literature.*

  GSFLOW has a lot of applications but the newer features, such as the AG Package, are not well documented or demonstrated by applied published studies. GSFLOW runtimes were also excessively long and problematic over large areas such as the Santa Rosa Plain (Woolfenden and Nishikawa, 2014) that precluded parameter estimation calibration with excessively long simulation run times.

- *Ability to model nitrogen fate and transport in groundwater and track sources through groundwater to surface water.*

  This can be done to some degree but sources from the AG Package or from the Farm Process in MF-OWHM are not accommodated and are not available for simulation with MT3DMS-USGS or Modpath/Modpath-OBS.

- *Meets DWR SGMA public domain requirements (CA-DWR, 2016).*

  The recent AG Package and other modifications to GSFLOW may not be adequately documented and presented in peer reviewed USGS Techniques and Methods publication series. In addition, any linkages to MOD-SIM with Newton Formulation for Modflow-2005 (MODFLOW-NWT) (within GSFFLOW) would not be compatible with SGMA requirements as this is proprietary software that is not open source or peer reviewed.

- *Ability to model recharge from irrigation and septic systems.*

  While there are a variety of ways to simulate these features as specified fluxes, it is not possible to provide analysis of recharge from irrigation with the new AG Package except within Precipitation-Runoff Modeling System (PRMS) HRUs. Unlike One-Water or Integrated Water Flow Model (IWFM), there is no supply-and-demand framework nor accounting units within GSFLOW.

- *Ability to meet project requirements within the defined scope and budget.*

  This is project dependent and may depend on the level of detail, features included, and observations used to evaluate the skill of the model to adequately simulate key components of the conceptual model and underlying mathematical model(s) that represent the underlying flow physics. The model should have the capability to simulate the broad range of particular hydrologic and hydrogeologic settings found across study area, including key attributes related to fish migration, climate change, nitrate transport, and the uses and movement of all the sources of water that will control fish migration and nitrate distributions. A special concern is the ability to confidently predict variable streamflows and stream stages driven by climate variability or distribution of nitrates from multiple sources.

- *Longevity of model, availability of support/updates.*

  While GSFLOW and the internal linkage with MODFLOW-NWT have been in development for many years, the support for technical issues may be an issue, as the support for this part of USGS model development has been reduced and redirected. In contrast, the USGS development and support for One-Water applications continues with the partnership of the U.S. Bureau of Reclamation (USBR). Several recent studies have switched over to One-Water because of the lack of support from the other USGS codes.

- *Transparency.*

  Transparency and related technical and public outreach are critical to any successful modeling project. This is especially true if the model will be used as a neutral vehicle for water-related conflicts that may include analyzing mitigation and adaptation scenarios as part of the resolution process.

- *Degree of leveraging previous models OBGM and VSWHM.*

The previous OBGM model could provide some preliminary input but will not have the detail needed to generate a new integrated hydrologic model. Similarly, VSWHM, along with BCM, may have some limited utility as comparisons but is not compatible with many of the inputs needed for PRMS. In addition, VSWHM is not public-domain and open-source code so this may not be acceptable in the context of SGMA applications.

- *Proven use for similar applications.*

  While GSFLOW has been used for some applications related to fish migration, its applications that are combined with agricultural settings are more limited and some of these were developed with longer than daily stress periods. Other GSFLOW models, such as the USGS Santa Rosa Plains model, had exceptional runtimes of 4 days that caused calibration problems and precluded systematic calibration methods.

While these criteria are necessary and potentially relevant, they may not be sufficient criteria. Additional criteria that were not considered but are relevant to this study could include:

(1) Existing IHM codes used for regional studies that could be more compatible with the hydrologic and land use setting and issues under analysis.

(2) Recommendations from other recent related reviews of conjunctive use such as the code comparisons completed by the USGS with DWR, by the California Water Environmental Modeling Forum (CWEMF), and by the World Bank (Borden et al., 2016).

(3) Ongoing projects in other regions that are using a Precipitation-runoff model passively or actively linked to an IHM.

(4) Extensibility of these codes to also perform other related analysis to issues that are related but beyond the scope of this Study Plan, such as climate change, linkage to reservoir operations, and SGMA GSP analysis.

(5) Other vehicles that could be used for estimating transport, such as particle tracking with MODPATH/MODPATH-OBS.

(6) The completeness of the linkages between the codes chosen to transmit the information needed to passively link the input/output from the sequence of codes chosen.

2.3 Available Integrated Groundwater-Surface Water Models

The list of models provided by the Study is incomplete. There are several other models that could have been mentioned but would probably not be suitable for a variety of reasons. These other models include HydroGeoSphere, ParFlo, IWFM, MODFLOW-SURFACT, MODFLOW-USG, SWAT-MOD, and FEFlow-MikeShe. Many of these are proprietary codes, do not contain links to MT3DMS, nor contain a supply-and-demand framework that allow for the full set of analysis needed for this project. Additional code comparisons, options, and reviews are provided by USGS/DWR (Dogrul et al., 2011; Schmid et al., 2011) by CWEMF (Harter and Morel-Seytoux, 2013), and more recently by Stanford University (Moran, 2016) and the World Bank (Borden et al., 2016).

Additional Precipitation-Runoff or Water-Balance models that could be eligible for linkage include the BCM (Flint, et al., 2021) and the VIC (Liang et al., 1994; VIC-5, Hamman et al., 2018) that are both used for a wide variety of SGMA models. In addition, other combinations of models can also be used. For example, for modeling the Osage Nation in Oklahoma, a PRMS model (Hevesi et al., 2019) was used with MF-OWHM (Traylor et al., 2021), and BCM is used with MF-OWHM for the Central Valley (Hanson et al., 2012), and HSPF is used with MF-OWHM for the Salinas Valley (Hevesi et al., 2020).

There are two fundamental approaches to modeling that were not considered in this selection process. Some modeling projects use a precipitation-runoff or water-balance model that are passively linked and provide input values and observations to an integrated hydrologic model such as MF-OWHM (Boyce et al., 2020; Hanson et al., 2014) and are exemplified by the selected examples referred to above, while others try to use models that integrate these processes together into one simulation such as GSFLOW. Among the significant differences in these two approaches are time stepping, supply-and-demand frameworks for evaluating conjunctive use, and data available for all input, as well as run times and their impact on calibration approaches. Finally, the GSFLOW can be run with just PRMS active, just MODFLOW-NWT, or both. The groundwater model (MF-NWT) engine within GSFLOW, is incomplete in offering features and upgrades that are available in other modern versions of MODFLOW, such as MF-OWHM. In addition, there are critical features within MF-NWT (see Appendix B, Section B.2 of this review), that are not available from MF-NWT when using GSFLOW in the combined mode. The missing features include solvers, specific package features, additional budgets, and enhanced error handling. Finally, selected errors have been discovered and corrected in the MF-NWT algorithms that are included in MF-OWHM, but not all have been corrected, with some significant errors remaining.

2.3.1 MODFLOW/MT3D-USGS + HSPF

The combination of MF-OWHM with HSPF is actively being used by the USGS Salinas Valley model as well as the combination of the Salinas Valley models being used for the Water Smart project (USBR Basins Study for the Salinas Valley and Carmel River Valley) for the lower and upper (Paso Robles) Salinas Valley models. The version of HSPF being used is modified from the original U.S. Environmental Protection Agency (EPA) release version that is embedded within the EPA BASINS software. A more recent version is now available from EPA as a plug in within BASINS but may not represent the version being used for the Salinas Valley which was stand alone and had unlimited HRUs and no size restrictions on the Watershed Data Management file. The Study Plan document does not specify which version or source of HSPF they had considered using. The Study Plan also indicates that this would need to be a two-way coupling, which may not be necessary if MF-OWHM was used with the NWT options and HSPF only used to supply boundary inflows of runoff and recharge, similar to the USGS approach for Salinas Valley. Use of HSPF would also facilitate the option to analyze streamflow temperatures if data was available and this was considered another potential issue for steelhead migration in the Ventura River Watershed.

2.3.2 MODFLOW/MT3D-USGS + DPWM + HSPF

This is similar to the first option considered but also includes the DPWM model. The DPWM model is based on proprietary code and potentially could be an issue if any SGMA applications were planned for this model. Similarly, BCM could replace DPWM for the proposed matching indicated in the Study Plan summary of this option. While the Study Plan indicates that DPWM executable and documentation are available, this was not located on the DBS&A website, and source code plus peer reviewed documentation would be needed for any potential SGMA applications. While they state that it is being used for another SGMA GSP, this may require clarification to see if proprietary codes are eligible for SGMA applications. The claim that the use of HSPF and DPWM together is complicated is unlikely as a similar association between BCM and HSPF is being used for the Salinas Valley modeling.

2.3.3 GSFLOW + MT3D-USGS

The combination of GSFLOW and MT3D-USGS is assuming that the new version of GSFLOW is used that has additional features recently released with version 2.0.1. There are several errors in the MODFLOW-NWT portion of GSFLOW that may still not have been corrected relative to SFR and MNW features. In addition, one of the biggest challenges of using PRMS with SFR (from within MF-NWT) is the reconciliation of channel elevations for the surface-water network so that they are accurate and consistent between the separate specifications in PRMS and MF-NWT. For example, this was an issue for the Santa Rosa Plain GSFLOW model and without Light Detection and Ranging (LiDAR) data could be an issue in the flatter areas of the Ventura River Watershed where 10-meter Digital Elevation Model (DEM) data used to estimate the land surface and river-channel elevations may be more uncertain.

The Study Plan indicates that GSFLOW will be linked with MF-NWT "*which is necessary for representation of the variable groundwater levels in the Ojai Basin*." The representation of streamflow and the conjunctive use and movement of water will be more essential if this study will successfully address the context, parameters, and limits of flows needed for steelhead migration. Therefore, the representation of groundwater levels is necessary but not sufficient for a successful analysis of the environmental flow and conjunctive use issues within the Ventura River Watershed. While PRMS has a better suite of flow processes, it also relies on interpolation of historical station data and good distribution of stations.

Finally, and contrary to the Study Plan description, the USGS will no longer support development of GSFLOW and has limited support for any software bugs or other code-related issues. Contrary to the description, some additional coding would be required to accommodate linkage with MT3DMS-USGS to the additional features related to MT3D Linker (LMT) Package, such as the addition of the AG Package to LMT8 Package in MODFLOW-NWT (MF-NWT). Because this subroutine is a part of MF-NWT embedded within GSFLOW, I would have to disagree with the claim cited from Eric Morway (Nevada Water Science Center, USGS) that this capability is, in fact, partially available within GSFLOW. Unfortunately, the list provided in the LMT8 PDF document that is released with GSFLOW (shown below) is not consistent with the LMT8 source code that provides output from MF-NWT as input to MT3D-USGS. Here is the list of packages that are claimed to be supported with this interface through the LMT8 subroutine of MF-NWT from the LMT8 PDF document in the GSFLOW release package:

PCKGTXT—(character*20)—a character string used by MT3D-USGS to signify the type of information that is contained in the flow-transport link file. Values for PCKGTXT include:

o "STR"

o "RES"

o "FHB"

o "DRT"

o "ETS"

o "MNW"

o "MNW FLOWS" (not supported yet)

o "UZF"

o "UZF FLOWS"

o "LAK"

o "LAK FLOWS"

o "SFR"

o "SFR FLOWS"

o "SWR" (not supported yet)

o "SWR FLOWS" (not supported yet)

o "CONNECT SFR LAK"

o "CONNECT SFR UZF"

o "CONNECT LAK UZF"

o and others that may be added in the future (no plan or funding for this development was confirmed at the time of writing of this review).

Thus, the claim in the Study Plan that there is a need for a separate model just for transport is unlikely and potentially unnecessary. However, the LMT Package cannot be activated when running GSFLOW with both PRMS and MF-NWT active. In addition, the option to add additional packages or linkages is also problematic based on the array structures used in the MT3D_USGS source code. The linkage to MNW is also potentially problematic as there are inflows and outflows that occur between model layers that may not be represented from any net flows that are output from LMT8. This problem was originally identified by the USGS when they studied nitrate contamination in the USGS TANC study in Nebraska using MODFLOW with Modpath (Clark et al., 2007). While the list of connections is incomplete and also not consistent with the MF-NWT LMT8 subroutine source code that was released with this version of GSFLOW, the additional features that may be needed may require additional updates to MT3D-USGS, which is not currently planned or funded. Some questions may remain that there could be a complete linkage to any GSFLOW application developed for the Ventura River Watershed that could be used with MT3DMS-USGS based on the potential sources that would need to be simulated.

2.3.4 MODFLOW-OWHM/MT3D-USGS

MF-OWHM combined with MT3D-USGS was also considered as an option, but was discounted based on the false, incomplete, and out-of-date document published by Paul Barlow (USGS, 2017 on the USGS MODFLOW Website). While these SWRCB consultants would not have known of the issues with this misleading document, they also did not directly contact anyone else in the USGS, such as Randall Hanson or Scott Boyce (leaders of the USGS MF-OWHM development team), and Wolfgang Schmid (Commonwealth Scientific and Industrial Research Organization), or attend any of the One-Water classes (sponsored by the CWEMF in the USA) to become more fully informed about issues, capabilities or ongoing model-code developments. The USGS MF-OWHM development team was not provided an opportunity to review or provide updates or modifications to the final version of this "guidance document" and it was posted on the USGS MODFLOW website without going through the required Fundamental Science practices of the USGS for formal Peer Review and Department of Interior Bureau approval of the publication prior to publication by the authors. There was also no additional approval of this document by the model-code developers of both codes. The MF-OWHM developers consider this document misleading, and it needs to be removed from the website or updated and corrected. Because of USGS's long-term association with USBR, development for MF-OWHM (also known as One-Water) continues while development and support for GSFLOW may be questionable at best, as the USGS is discontinuing almost all model code development and limiting support.

The newest version of MF-OWHM version 2 (Boyce et al., 2020), combined with BCM (Flint et al., 2021), is still a viable candidate for a code that could be used with this study. It is the most complete, fastest, and most recent version of MODFLOW that could be used for this application, has remedied the known errors recently discovered in MF-NWT, and can be used with MT3D-USGS or with MODPATH/MODPATH-OBS to help simulate and assess nitrate transport. Contrary to the Study Plan description, the World Bank Survey from 2016 (Borden et al., 2016) indicated that MF-OWHM is one of the three best codes for simulating and analyzing conjunctive use and did not include GSFLOW in that group of codes.

The Study Plan incorrectly indicates that MF-OWHM was never intended to link to a watershed model, yet every application of MF-OWHM has linked to watershed models for boundary inflows from surrounding sub watersheds. The MF-OWHM linkage approach is different and more flexible in the context that MF-OWHM has been linked to a wider variety of watershed models including PRMS, BCM, VIC, and HSPF. Since agricultural pumpage is not known, the application of a model that could evaluate this stress and potential source of nitrate could be very useful. Conjunctive-use analysis includes water quality from all the sources, use and movement of all sources of water and could also include salinity leaching for agricultural applications, which is only available in MF-OWHM. In that context, MF-OWHM is a better platform for this type of project, whereas codes such as GSFLOW are better suited for simulation of native vegetation or synoptic events where daily time steps may be more important. While MF-OWHM does not solve any rainfall-runoff equations, it does provide and use climate data to simulate deep percolation and runoff as well as linkages along the boundaries of the active model with any of the other watershed models. Simulation run times are also much less than many GSFLOW models, thus allowing better calibration and even parameter estimation. This is clearly documented, and a wide variety of examples have been developed in hydrologic settings similar to the Ventura River Watershed.

2.3.5 Integrated Hydrologic Model MT3D-USGS

This private version of MODFLOW links MODFLOW and HSPF. The recentness of the MODFLOW code and connectivity with MT3D-USGS is also questionable. As indicated in the Study Plan, because it is not in the public domain and may not be current code, this modeling platform was not considered further for this application.

2.4 Model Selection

After the initial largely qualitative screening process of the models described above, the final Model Selection Process was limited to MODFLOW/MT3DMS-USGS+HSPF and GSFLOW/MT3DMS-USGS. Based on the selection matrix, GSFLOW/MT3DMS-USGS was selected by the California State Water Resources Control Board and its consultants. The criteria were not complete in the evaluation of the code selection, as described in the sections above. In particular, the evaluation table did not include any of the criteria used by the World Bank evaluation, an evaluation of representation of land use or land-use processes, or skill in representing regionalized climate estimates. For example, in the World Bank evaluation GSFLOW got a low score for representing irrigation and septic sources, which may affect its skill for nitrate transport. The ability to simulate sub-daily temperature seems to be a curious requirement. GSFLOW does include the one-dimensional Stream-Network Temperature (SNTEMP) model so it can at least simulate daily temperatures. GSFLOW also got low marks for project resources required, longevity, and support, which is consistent with the current changes occurring at the USGS headquarters as support is reduced and additional development is potentially curtailed.

SECTION 3: **Review of 3. Overview of GSFLOW and Modeling Approach**

Key Takeaways:

Overall approach to development and calibration of the component models and integrated model is generally reasonable, but there are several omissions that should be clarified. Those include: (a) for the dry-season only MODFLOW-NWT and wet-season only PRMS calibration, further clarification would be helpful for those definitions and which model parameters (for each model) will be well calibrated under those particular conditions; and (b) no time period was designated for the historical period of simulation used for calibration.

This broad overview in the Study Plan does not include a discussion of possible additional types of observations needed to calibrate an IHM; how the observations will be used and related measures of fit; and calibration strategies needed to calibrate both the PRMS model, the MF-NWT model, and the two combined.

3.1 Overview of GSFLOW

This overview does not indicate what version of GSFLOW the SWRCB consultants intend to use and what features within both PRMS and MF-NWT will be employed for this application. Similarly, Figure 3-1 in the Plan does not include detailed and time-varying simulation of the land system as is done in MF-OWHM and is expected for this type of analysis by DWR SGMA. Figure 3-1 refers to MODFLOW-2005 when MF-NWT will be used for this application, and also neglects flow-dependent flows that occur in an IHM. While MF-NWT packages are mentioned, there is no initial list of features and related packages that would be used within MF-NWT to simulate groundwater flow and connections to the surface-water, climate, and land system. Figure 3-1 does not describe how agriculture or municipal/suburban regions and related supply-and-demand occur in Region 1. It is also not clear how HRUs will be defined as this could limit their ability to use the new AG Package or identify agricultural regions within larger HRUs that could be as large as hydrologic unit code (HUC)-12 sub watersheds. There is also no mention if a gridded or polygon of HRUs will be used. In addition, gravity drainage is not the only one process that represents the vertical flow of water between aquifers and geologic units, with wellbore flow being the other major pathway.

3.2 Development Approach

This overview section of the Plan is incomplete, as it does not identify the full suite of calibration targets or calibration strategy for PRMS or MF-NWT. Using the "wet-weather flow" may yield a biased approach as runoff and infiltration are significantly different after dry periods. There is also no mention of how the models will be discretized, time period of simulation, or options used to represent the climate input.

Step 1: Calibration of GSFLOW (PRMS with MF-NWT) for "dry-weather flows" is questionable as this may assume that the entire region is potentially a discharge area, the groundwater system is full and rejecting groundwater to the land system and surface-water network throughout the watershed. The recent studies of transient nature of soil moisture performed by the DWR FloodMAR indicate that soil moisture is not the controlling factor and is typically transient within days to a couple weeks duration. Therefore, land use and other aspects of anthropogenic modifications to the watershed may be more relevant and a bigger driving force than the amount or changes in soil moisture. In addition, multi-year recession of baseflow in dry-year periods following wet-year periods was documented for the tributaries of the nearby Santa Clara River (Hanson et al., 2003, Figure 5) and the envelope of minimum flows is also occurring on the Ventura River. So "dry-weather" periods may not be adequate to address this multi-year recession behavior that will affect both nitrate transport and fish migration considerations.

Step 2: While this cursory description looks like a reasonable step, there are several important missing components to getting the MF-NWT model designed, built, and running. These include designing the capabilities needed for the transport mode, that may include identifying and simulating all sources of nitrate from septic, municipal effluent, and agriculture. The MF-NWT model also requires some specific inputs from the watershed model that would need to be passively coupled to this groundwater model to have a complete and successful model. These include mountain-block recharge (i.e., groundwater underflow), runoff, and mountain-front recharge, as well as artificial recharge from inefficient irrigation and from septic systems. This step also does not address the need for a new and updated geologic framework model that would provide the layering needed for this model. Finally, there is no discussion of types of observations, data sets needed to construct the model, nor methods of calibration with and without coupling to PRMS.

Step 3: The brief description of this step is potentially in error. The use of dry-weather surface flows is necessary but not a sufficient approach to the combined calibration. To successfully simulate the climate variability and the transition from wet seasons to dry seasons, the integrated model should have the skill to address the water supply and nitrate issues. In addition, it should represent the potential low-flow streamflow that could affect fish habitat. For example, while the median daily streamflow for the period 1960–2019 is about 4 cubic feet per second (cfs), the contrast in median daily streamflow duration between wet years (17 cfs) and dry years (2.8 cfs) would indicate that the ability to simulate these two regimes and transition between them will be essential for analysis of nitrate transport, SGMA issues, and fish migration flow/stage targets. Finally, no time period was designated for the historical period of simulation used for calibration, or a summary of packages and features being simulated by these packages/processes that would represent a conceptual model of the climate, land system, surface-water, and groundwater use and movement of water. This will be a critical part of having a successful and reliable calibration that can be used to address all the different issues of water supply and quality in the Ventura River Watershed.

Step 4: This step indicates a separate groundwater model, which is unnecessary. Besides potential groundwater sources, the other sources of nitrate may be related to direct contributions to surface-water flow such as urban runoff or wastewater effluent discharge, as well as from other surface sources such as agricultural runoff.

SECTION 4: **Review of 4. Surface Water Model Development**

Key Takeaways:

This review identifies several points that should have been considered in the PRMS-only model development, including: (a) there is no clear justification for the selected model grid cell size related to physical characteristics of the basin.(e.g., knowing how many 330-foot model cells will occupy the deposits in the Ventura River floodplain); (b) the wet-season only calibration will be insensitive to antecedent moisture conditions, while 62 percent of the years experience less than average precipitation; (c) more specificity is needed in the type of observational data to be used in calibration, especially related to second-order and higher order observations; (d) treatment of land surface elevation without clear discussion of potential errors and need for high-resolution LiDAR datasets for constraining the stream network; and (e) there is no explicit consideration of the storm drain network.

The strategy to develop and calibrate the PRMS model for "wet weather flows" presented in the Study Plan will help to reduce the possibility of groundwater contributions to streamflow as baseflow but may not include other contributions to surface water from rejected groundwater recharge, springs and seeps, or other contributions from urban runoff or waste-water effluent discharge.

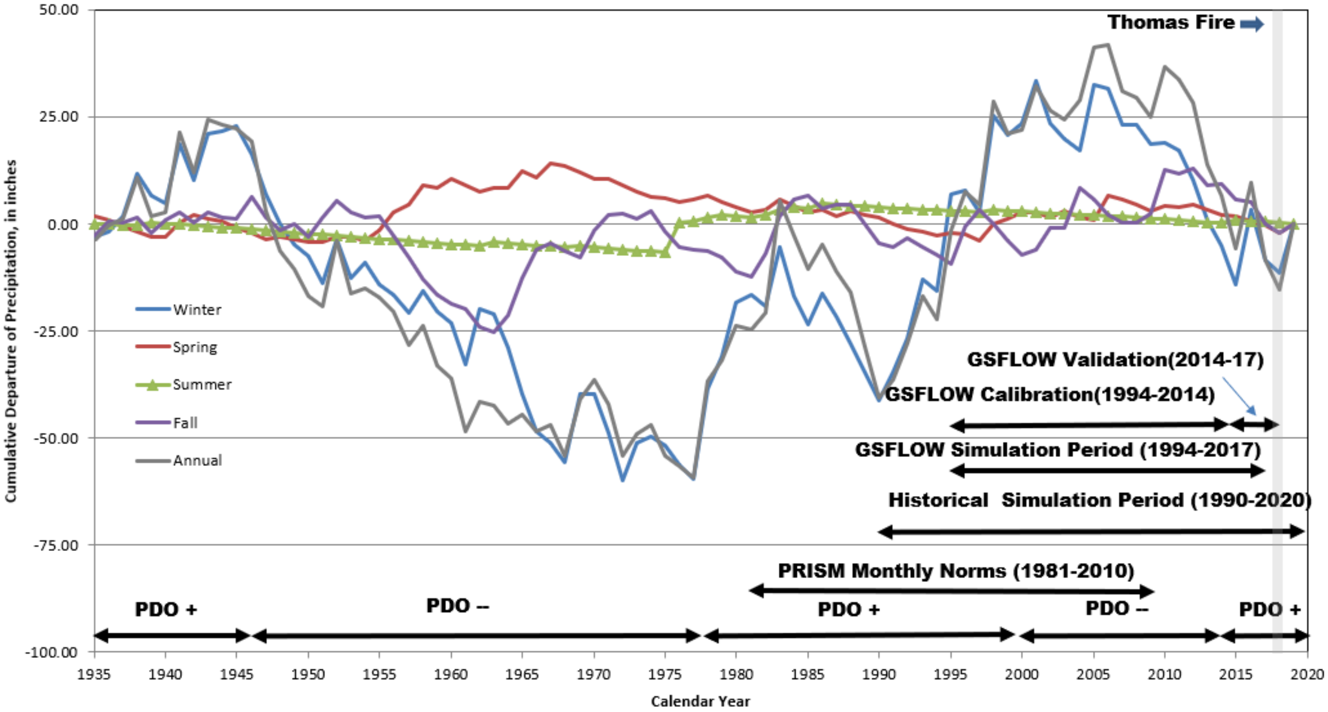
4.1 Model Grid

The discretization of the surface-water model grid for PRMS does not consider the distribution of parcel sizes or sources of data such as PRISM for precipitation and temperature data (800 meters), BCM data (270 meters), or Land-IQ land use that may be used for developing HRUs that are equivalent to the Water-Balance Subregions used in MF-OWHM. The example of the Santa Rosa Plain model (Woolfenden and Nishikawa, 2014) is a poor example considering their 4-day run times and inability to calibrate using parameter estimation techniques because of these long run times. The criteria for 330-foot model grid cells (2.5 acres) are not described in the Study Plan outside of suggesting this is a simple division of a square mile by 16. The discussion of the active wash deposits representing 2,900 acres does not include any assessment of the range of widths that would be needed to capture this feature. As noted, this may need to be revisited and may also be dependent on any rotation of the model grid from north-south that would also affect spanning the river-wash deposits. Since neither GSFLOW nor MODFLOW-NWT can use fractional land use within a model cell, this may also bear on the consideration of model-cell size and the related accuracy of ET estimates within model cells.

4.2 Leveraging the Existing Ventura Surface Water Hydrology Model

The HSPF applied model, VSWHM, is proposed to be used for selected input. Specifically, if the "special actions" module was used within HSPF to include additional features, such as irrigation, diversions, dam operations, and discharges, these time series data could be leveraged into a new modeling input but may not be compatible with the features available in gridded PRMS versus an HSPF model developed for HRUs. While VSHWM was mainly used to analyze "high-flow events" that typically occur in wet years, most of the climate in the Ventura River Watershed is dry (see Figure 4-1 below); 53 out of 85 years (62 percent) were dry years with less than average precipitation (1935–2019). Similarly, on a seasonal basis, during the fish migration season of January–June, 62 percent of the winters and 65 percent of the spring seasons are dry. This suggests that dry-year and dry-season climate will largely influence the fit of any watershed models.

Figure 4-1. Cumulative Departure of Annual and Seasonal Precipitation from Kingston Reservoir, Ventura, Station 122, 1935–2019 (PDO: Pacific Decadal Oscillation climate index)



4.3 Datasets and Sources

The Plan's data sources summary needs to include not only data used for input and observations but also the types of structures used for the observations. This should include first-order state observations, such as groundwater levels, streamflows, and stage at gages. This should also include second-order observations, such as groundwater drawdowns, vertical groundwater head differences, differences between groundwater levels and streamflow stages, and streamflow gains and losses. Additional higher-order observations such as streamflow duration distributions at gages and climate cycles percentages are also required based on the model skill needed for the proposed analysis goals.

4.3.1 Precipitation Data

The regional estimates developed within PRMS from the climate stations (Figure 4-1 in the Study Plan) that are proposed as used for the PRMS model for the period 1990–2020 should be checked against PRISM estimates of precipitation and BCM estimates of Potential Evapotranspiration (PET) and Actual ET. The cumulative departure curve (Figure 4-1) for the period 1990–2019 represents 14 wet years and 16 dry years. However, this interval is a predominantly wet period (1990–2005) followed by a predominantly dry period (2006–2019). In addition, the period from 1981–2010 shows parts of two other composite climate cycles with 13 wet years and 17 dry years (Figure 4-1) are part of two other composite climate cycles.

4.3.2 Potential Evapotranspiration Data

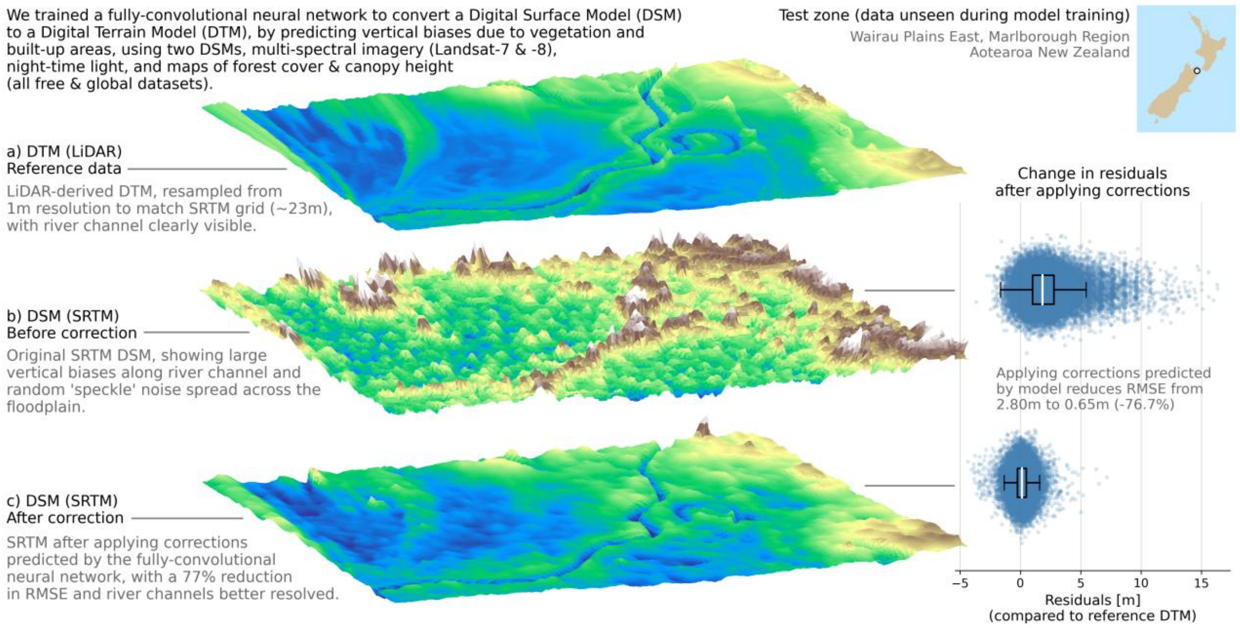
As has been shown in other studies, such as the Pajaro Valley Hydrologic Model (Hanson et al., 2014, Figure 20), comparison with PET estimates made from local California Irrigation Management Information System (CIMIS) station data using the Penman-Monteith method is essential as these simpler methods such as Hargrave-Semani, Prestley-Taylor, and Hamon have a tendency to under- and over-estimate PET for selected months by as much as 3-50 percent. This typically requires adding scaling factors to the estimated PET to rectify these estimation errors from using these simpler PET models with the IHM model input. PET can also be checked against other estimates, such as BCM and Metric, and this may provide some arrays of scaling across the entire active model region. In addition, PRMS only allows one scaling factor per month, so additional scaling for any exceptional climate regimes could be limited. Having a model like BCM, which interpolates uniquely for each day or month (based on monthly parameters, not 30-year mean monthly parameters), is far superior to this approach.

4.3.3 Topography

Topography data may be one of the most important data types needed for not only modeling integrated hydrologic flow but also ensuring skill for analysis of flow and stage targets for steelhead migration. The Study Plan indicates that the 2005 LiDAR data will be used to supplement the USGS 10-meter DEM data set. The Ventura County Watershed Protection District Database also includes 2018 LiDAR data (http://vcwatershed.net/publicMaps/data/) as QL1 and QL2 data layers that should also be considered for use along with additional LiDAR data that was collected for the Thomas Fire Region by the Ventura Watershed Protection District and National Oceanic and Atmospheric Administration (NOAA) coastal LiDAR surveys.

Based on the quality assurance/quality control (QA/QC) report, the 2005 LiDAR survey has a range of accuracy as required by FEMA of between 0.965 and 0.798 feet, based on 20- and 60-point comparisons, respectively (RBF Consulting, 2009). Similarly, the total accuracy (RMSE) from low, medium, and high vegetations heights was summarized at 0.731 feet. As has been shown in other recent studies (e.g., Hanson et al., 2020), digital terrain data as DEM or LiDAR can include some errors that may need resolution, especially in the flat areas of a watershed. The most common approach is to use surveyed land-surface elevations from benchmarks, stream gages, highways, and wells to check and potentially adjust for errors in land-surface elevation model data. More recently, Meadows and Wilson (2021) developed a public domain correction software to help mitigate this issue for regions where only DEM data is available and LiDAR data may not be available, as shown below in Figure 4-2. Even the LiDAR data should be checked against other 1st-order and 2nd-order surveyed points, where possible, along the flatter regions of the watershed and floodplain.

Figure 4-2. Example of Digital Elevation Model Correction Issues (Meadows and Wilson, 2021)



We trained a fully-convolutional neural network to convert a Digital Surface Model (DSM) to a Digital Terrain Model (DTM), by predicting vertical biases due to vegetation and built-up areas, using two DSMs, multi-spectral imagery (Landsat-7 & -8), night-time light, and maps of forest cover & canopy height (all free & global datasets).

Test zone (data unseen during model training)
Wairau Plains East, Marlborough Region
Aotearoa New Zealand

a) DTM (LiDAR)
Reference data
LiDAR-derived DTM, resampled from 1m resolution to match SRTM grid (~23m), with river channel clearly visible.

b) DSM (SRTM)
Before correction
Original SRTM DSM, showing large vertical biases along river channel and random 'speckle' noise spread across the floodplain.

c) DSM (SRTM)
After correction
SRTM after applying corrections predicted by the fully-convolutional neural network, with a 77% reduction in RMSE and river channels better resolved.

Change in residuals after applying corrections

Applying corrections predicted by model reduces RMSE from 2.80m to 0.65m (-76.7%)

In 2018, FEMA and the USGS developed a new LiDAR data set that included Ventura County. This data set was post-Thomas Fire and appears to have higher resolution. The evaluation of error for 205 points for this survey was an RMSE of 0.19 feet (0.057 meters) with a 95 percent Confidence interval of 0.37 feet (0.112 meters) (USGS, 2019). These elevation data should be considered for use for the post-Thomas Fire regions as well as to check the 2005 data in the areas not affected by the fire. These data could especially be useful in building a new streambed elevation for a post-Thomas Fire surface-water network for use with PRMS and SFR within MF-NWT.

The use of the Cascade Routing tool (CRT, Henson et al., 2013) is a standard approach but use of DEM data may provide some issues in the flatter areas where DEM data is typically more uncertain and less accurate and can result in questionable routing. Therefore, the incorporation of LiDAR data may be very useful. In addition, the Study Group hydrologists that are applying the Cascade Routing tool may also want to consider the potential impact of the extensive Storm Drain network (see Figure 4-4 below) that may "short circuit" with engineered drainage pathways that are different from some of the natural drainage networks.

Figure 4-3. Extent of 2018 USGS/FEMA LiDAR Elevation Mapping (USGS, 2019)

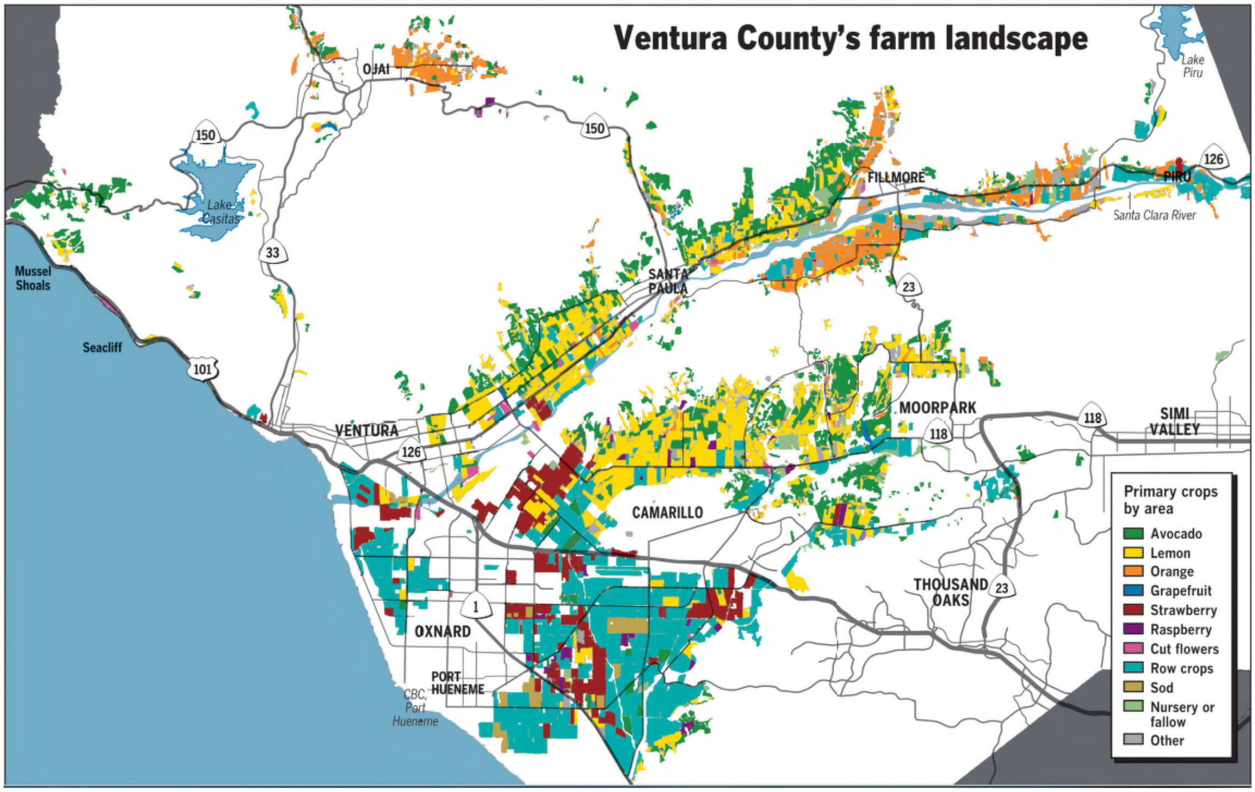
Figure 4-4. Map of 2015 Storm Drains for the Ventura River Watershed from the Ventura County Watershed Protection District

4.3.4 Land Use

While PRMS does use soil data, it does not directly use land use data. Instead, land use data would have to be preprocessed to create percent impervious area and cover type is assigned from a limited choice and typically only one per HRU, but this can now change through time for each model stress period (typically monthly). Fractional land use, as is allowed in MF-OWHM, can only be done as pre-processing step in GIS for GSFLOW. Additional sources for land use could include the DWR Land-IQ land use maps as well as the California Vegetation Classification & Mapping System (CALVEG) maps. While the National Land Cover Database (NLCD, 2011) can provide some distribution of impervious areas, additional input from recent urbanization may also need to be added to update any additional changes in the last 20 years. The current agricultural landscape is provided in the Ventura County Farm Bureau map (see Figure 4-5 below) (http://www.farmbureauvc.com/county-crop-data).

The other data that should be included and will be relevant to irrigation, cultivation, and potentially to nitrate applications relative to agriculture could include the California Pesticide Information Portal (CalPIP) database, which gives monthly applications of pesticides and herbicides and type of crops being grown. Finally, the distribution of Arundo as well as some fennel and castor bean crops needs to be included in the riparian corridor as two of the major invasive species that could affect streamflow, fish migration, groundwater dependent ecosystems (as needed also for SGMA), and modeling of stream flows.

Figure 4-5. Ventura County's Farm Landscape (http://www.farmbureauvc.com/county-crop-data)



4.3.5 Irrigation Data

The Study Plan indicates that the irrigation data will be preprocessed from previous modeling (the VWSHM–HSPF model) and from DWR annual irrigation rates. The Study Plan indicates that irrigation will simply be preprocessed as additional "precipitation," which is a poor method for representing irrigation potentially occurring from multiple sources. If the GSFLOW application will use the new AG Package, then irrigation diversions and irrigation wells will need to be specified for each irrigated parcel. Some of the attributes required for the AG Package are commonly unknown, such as the length of time water is diverted for a single irrigation event. In addition, based on previous MF-OWHM studies, the calculation of Actual ET from Potential ET requires Crop Coefficients, Kc's, and these vary greatly from generalized published values. Published Kc's also typically represent unstressed conditions and do not reflect stressed conditions (Allen et al., 1998) from wet or dry conditions or from deficit irrigation used to increase sugar content of fruit orchards, berries, or vineyards. Remotely sensed data from the Land IQ estimates of land use and metric estimates of potential and actual ET could also be helpful in delineating newer distributions of irrigation and related surrogates for

Kc's for native vegetation and agriculture. Kc's for native vegetation are also available as part of the BCM model from the USGS (Flint et al., 2020). In addition, irrigation demand and irrigation efficiencies may vary widely between coastal and inland regions, so the use of global consumptive-use values would not account for elevated demand from higher temperatures, solar radiation, and wind for inland regions. This could then result in mis-estimation of actual irrigation requirements and related use of groundwater and surface water for irrigation.

Irrigation data sources may also include agricultural pumpage on a monthly basis. These data could be used for observations for training the AG Package if used to stimulate agricultural consumption from groundwater and surface water irrigation.

4.3.6 Stream Network

The stream network needs to include the major and minor streams that drain each of the HUC-12 sub watersheds as well as springs and Lake Casitas. Were any of the storm-drain networks from the VCWPD GIS database added to the modeled surface-water network (see Figure 4-4 in this report)? These would also be related to Ventura County National Pollutant Discharge Elimination System (NPDES) sampling sites and could provide additional information needed for transport modeling[1]. However, storm drains would need to be added to the surface-water network to facilitate this part of the surface-water network.

The storm-drain network also needs to be added to the Cascade Routing Tool network used to route the runoff from the PRMS model. First flush from urban areas and "short-circuited" and focused runoff via storm drain networks could be a significant issue in representing transport of nitrate and other pollutants, as was the case in the Santa Ana River watershed.

The other potential component of the surface-water network that is not mentioned in the Study Plan is the Robles Diversion and Lake Casitas. These also need to be part of the surface-water network and could include reservoir and diversion operations. One of the features that may not be available for construction of the stream network with the Python tools is the establishment of incised elevations and stream-channel geometries that will be critical for simulating stage-width-flow relations for analyzing the stream dynamics that could affect fish migration and relation to flow and stage targets from the California Department of Fish and Wildlife (CDFW) under different climate conditions. Rejected subsurface flow from the buried timber piles (which extend to approximately 25-foot depth and are aligned with the crest of the diversion dam in the river channel) at the Robles Diversion structure. This also could contribute to additional baseflow below the diversion that would need to be potentially accounted for in the model.

The simulation of other features, such as dams, debris basins, and subterranean dams, may need additional modeling features that are not available in GSFLOW. If the USGS National Hydrography Dataset (NHD) Plus is used to construct the surface-water network, this data will need to be carefully inspected for segments that may go across structures where flow cannot physically occur. In addition, while NHDPlus HR[2] provides some new data for flow lines, it still does not include incised stream-channel elevations or Manning Roughness coefficients for each segment, which will need to be sampled and specified as an incised lower elevation that is different from the model cell land-surface elevations to more accurately capture baseflow contributions to streamflow. NHDPlus HR also has considerable segmentation that in many applications requires review and merging of selected segments into a simpler framework that is also consistent with other aspects such as inflows/outflows, and streambed sediment properties and geomorphology. Finally, to achieve better detail for stage-discharge relations, the SFR2 package will need to employ the REACHINPUT

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[1] https://www.vcstormwater.org/programs/monitoring/core-monitoring
[2] https://www.usgs.gov/core-science-systems/ngp/national-hydrography/nhdplus-high-resolution

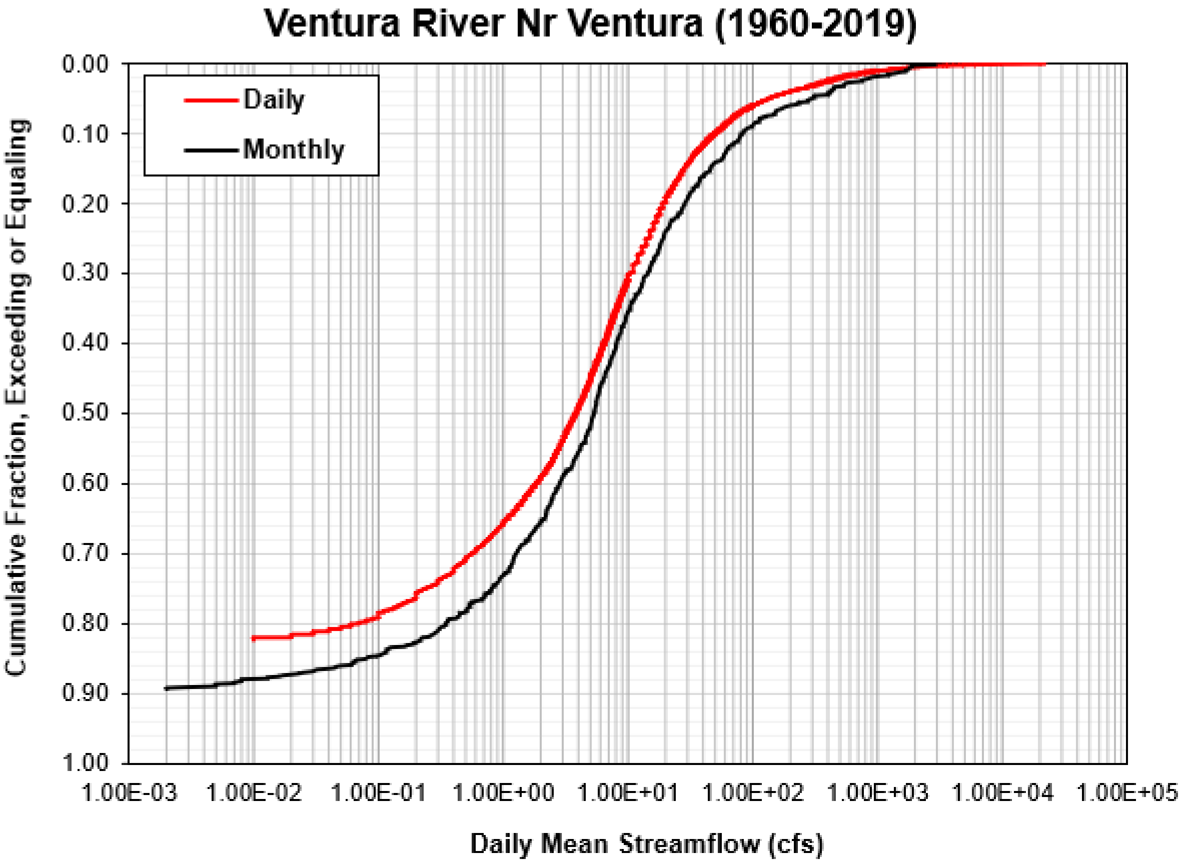
option for reach-specific properties and stage-width-flow-dependent streambed conductances (ICALC = 2, 3, or 4) and may also require this approach to the stream-network properties available in SFR2.

4.3.7 Streamflow Gages

Using measured versus "observed" streamflows is one form of "first-order" observations that will be needed to identify the skill of the GSFLOW to simulate the flows and stage of the major river and tributaries in the Ventura River Watershed. Since both flow and stage are part of the flow targets stipulated by the CDFW, both will need to be assessed within the model as separate observation groups. Since most "observed flows" at gaging stations are an estimate based on measured stage and a rating table of stage-width and flow from field estimates, other uncertainty and stage observations will be needed to further constrain the model fit to these features.

In addition, higher-order observations, such as wet-year and dry-year daily, monthly. or seasonal streamflow duration, should also be used to further estimate the skill of the calibrated model to replicate the flows at several exceedance values (see Figure 4-6 below). For example, streamflow duration for wet and dry years has a considerable difference and would need to be explicitly analyzed since the CDFW flow and stage targets for various streams are commonly segregated into wet and dry-year conditions (see Figure 4-6 below). The difference here indicates that for the median streamflow, the wet-year streamflow (17 cfs) is 6.5 times greater flow than the dry-year median streamflow (2.6 cfs), and there are only 5 years in the proposed simulation period (1990–2020) that include both a wet winter and spring. This is similar to the tributary wet and dry-year flows estimated for tributaries of the Santa Clara River draining the nearby Topatopa Mountains that ranged from five to seven times greater daily median flows for wet years (Hanson et al., 2003). As mentioned previously, the multi-year recession of minimum flows will also need to be a separate group of observations to assess skill of the model for surface-water flows for assessing nitrate transport and fish passage.

Figure 4-6. Streamflow Duration for Daily and Monthly Flows for Ventura River near Ventura



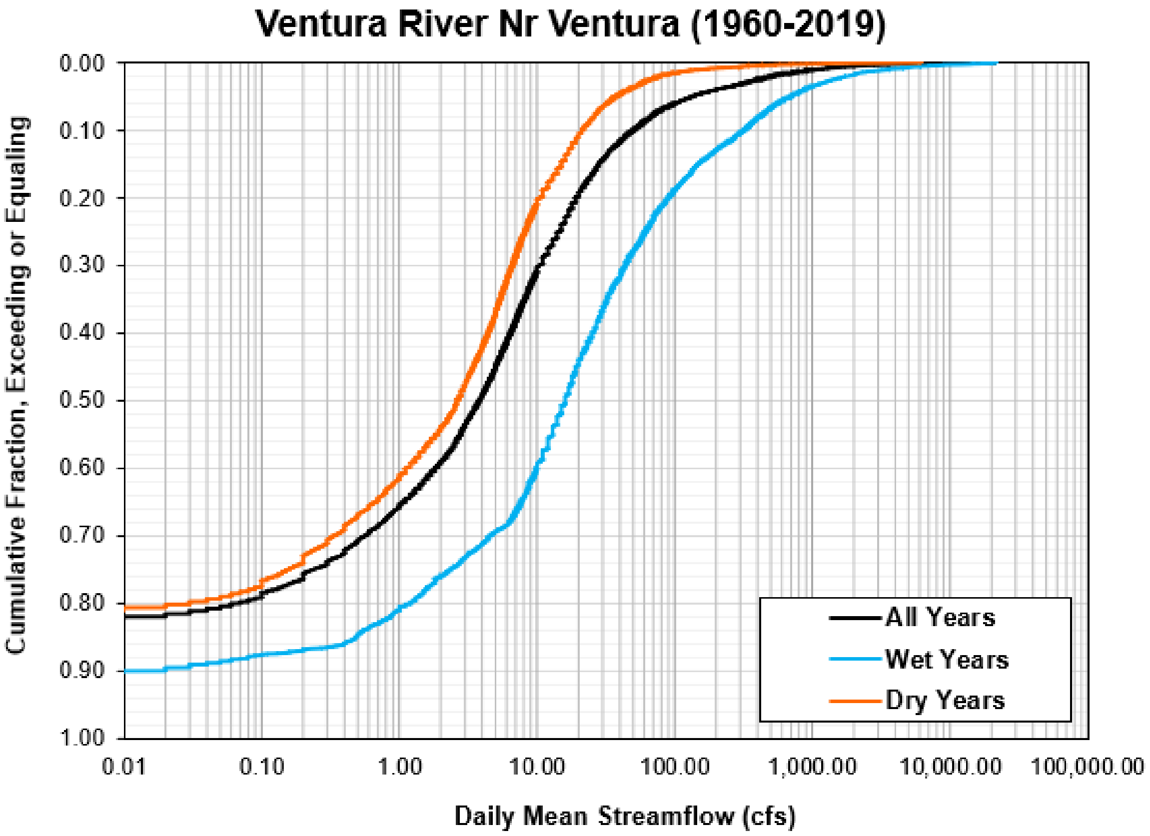
Another form of gaged observations is from any and all diversions where the diversion is measured or estimated such as the Robles Diversion by CMWD. The use of diversions as additional checks on streamflow conveyance is not mentioned in the Study Plan but should be considered as an additional check on streambed conductivities that contribute to simulated conveyance. Overflow from Matilija Dam or Lake Casitas may also be needed to further constrain the simulated surface-water network. The uncertainty of the gaged values based on the gage rating and history of "Field Measurements" should also be used to determine the range of skill of the estimated "observed' values. For example, the field measurements from the USGS gage at Ventura River near Ventura range from 0.00/0.03 – 21,500 cfs that ranged from "Poor" (>15 percent error) to "Good" (10 percent error) with most in the "Fair" (10-15 percent error) category. Many of highest and lowest flows were either unspecified in their rating quality or were rated "Poor," and many measurements affected by debris and moderate vegetation or "fill control changed." Thus, the uncertainty of these measurements may provide limits on flow/stage targets for fish migration or the skill of model to replicate low flows that can affect fish habitat.

Review of past rating curves is definitely a good idea, but access to physical field measurements and related rating curve estimates in the technical files at the USGS offices in Santa Maria, California, may require a Freedom of Information Act (FOIA) if all USGS Field offices are closed to the public due to the pandemic.

The implementation of new gages such as VCWPD #616 is good, but it is unclear if VCWPD is using the USGS protocol for stream gage operations, QA/QC, and rating curve analysis. The reviewers recommend that electric conductivity and temperature also be measured at selected gages to give additional indication of potential contributions to surface-water derived from groundwater or from runoff from areas of the Thomas

Fire. Reworking of the rating curve for Ventura River near Ventura (11118500) is also good. These weekly measurements for the period December 2017 to October 31, 2018 are posted in National Water Information System (NWIS) and most are in the Fair to Poor category. Post-Thomas Fire simulation periods may require a change in streambed morphology and streambed vertical hydraulic conductivities for this part of the historical simulation period. There are also selected abandoned wells near the stream channel and near the gage at Foster Park that could be used to assess the vertical head difference between groundwater levels and stream stage that should be included in the model calibration observations.

Figure 4-7. Streamflow Duration for Wet and Dry-Year Daily Flows for Ventura River near Ventura



4.3.8 Wet-Dry Maps

Wet-Dry maps have been used in other studies as a qualitative measure of model skill. These maps can be useful but need to be segregated based on wet and dry-year periods so that the flow regimes are compared separately under these different climate conditions. The only wet-dry maps presented in the Study Plan represent the dry periods of March 2016 and November-December 2016 (Figure 4-13 from Geosyntec and DBS&A, 2019). No known maps for wet periods have been developed for this study.

4.3.9 Data for Post-Thomas Fire Scenario

Changes in land use and related properties, such as percent impervious and other attributes used by PRMS for the post-Thomas Fire period of simulation, will improve the skill of the historical simulation. Fires typically mobilize some additional transport of dissolved and total organic carbon, and this may also entrain other constituents that may affect hydraulic properties such as streambed vertical hydraulic conductivities that may also need to be changed for the post-Thomas Fire period for selected parts of the surface-water network. Since more recent LiDAR data (USGS, 2019) is also available, a rebuild of the surface-water network may be required that would include new elevations, regions of invasive species or debris that could affect manning roughness coefficients, and potentially reduced streambed vertical hydraulic conductivity values for selected reaches affected by fire debris runoff.

SECTION 5: **Review of 5. Groundwater Model Development**

Key Takeaways:

The Study Plan's stated modest goals of ensuring that the model runs without error and is consistent with the conceptual model of the features within the Ventura River Watershed are reasonable, although the reviewers suggest several additional, important goals for the groundwater-only MODFLOW-NWT model. The defined model domain, stress periods, and timesteps make sense for integration with PRMS, but there are several important data / parameter classes that appear to be overlooked or omitted, which are discussed by the reviewers in this section.

This section of the Study Plan summarizes the development of the groundwater model, including the goals of the model development. The goals stated in the Study Plan include ensuring that the model runs without error and is consistent with the conceptual model of the features within the Ventura River Watershed. These are excellent goals as briefly stated. In addition to these fundamental goals the groundwater model should also replicate the important parts of the geologic framework, all the uses and sources of water (supply and demand components), a reasonable period of historical calibration that captures climate variability, a complete set of observations that constrain as many of the features of an integrated model as possible, and a reasonable mass balance for the groundwater and surface-water systems.

The extension of the model domain beyond the groundwater basin to the limits of the entire watershed is a good choice too, as these areas need to connect to the entire domain of the PRMS model and provide additional flexibility for addressing any potential development of environmental concerns that are outside of the Bulletin-118 groundwater basin. The temporal discretization of monthly stress periods and, daily time steps are also reasonable and will be required to link to the PRMS component of GSFLOW. For additional clarification, stress periods define any and all stresses which are all specified boundary conditions (specified inflows/outflows or specified heads), so are not just constrained to pumping rates, as mentioned in the Study Plan. While the MODFLOW model can be built independent of the PRMS model, it will significantly rely on inflows from the PRMS model and will potentially be difficult to run autonomously without these additional inputs. In addition, like the Osage Nation, OK IHM model that superimposed PRMS over a MF-OWHM model, the PRMS model can also provide estimated/simulated observations for parts of the surface-water network flows where no measurements from gages are available.

Based on the choice of GSFLOW, the final calibration may only occur in the context of the combined PRMS/MODFLOW model. The term validation is a potential misnomer as models are typically not validated but only calibrated to historical conditions over some specified reasonable historical period where observations are available to estimate the skill of the model and all the needed boundary conditions (inflows/outflows) are represented. Based on the figures presented in the Study Plan, the model domain appears to include the entire Ventura River Watershed and stops at the coast. There is no discussion in the Study Plan for the coastal boundary nor the lack of extension of the model beyond the coastline to the offshore regions.

5.1 Model Input Data

The segregation of Model Input data in the Study Plan represents three broad categories of input. This suggests that the model development will occur in a phased approach with surrogate inflows/outflows used to initially develop a stand-alone MODFLOW model. Model input also included observations which are not explicitly mentioned in the Study Plan.

The Input parameters are categorized here into three main groups as:

1. Parameters that will remain the same in integrated model

The input for extent and thickness of alluvial and bedrock layers do not indicate any cursory description of how the layering will be constructed, what units are represented, or any additional features that may be derived from the geologic model such as natural faults (considered to act as horizontal flow barriers, HFBs) or man-made subsurface flow barriers (for example, Ventura River barrier at Foster Park or Matilija Dam). In addition, the specification of agricultural pumpage indirectly suggests that all agricultural pumpage will be pre-calculated instead of using the new AG Package in GSFLOW. Recharge from On-site Water Treatment System (OWTS) will be essential for the nitrate assessment and modeling but estimates of artificial recharge from inefficient irrigation is not mentioned in this cursory list but is included as PRMS input.

2. Parameters that will come from PRMS

The list of items does not include any surface-water flows, runoff (native, agricultural, or urban, storm drain networks, or ET from agriculture. These are major components that were overlooked in this cursory list.

3. Parameters that will be adjusted during calibration

This list of adjustable parameters also needed to include the vertical hydraulic conductivity of the various streambed networks before and after the Thomas Fire. The vertical hydraulic conductivity between layers and the SKIN factor for any multi-aquifer wells (MNW2) also may need adjustments to control the source of water from pumpage and constrain vertical flow between layers. If the distribution of alluvial properties uses the Multiplier (MULT) Package, then porosity can also be specified as part of the storage properties, and this will be useful for the transport model as well. Unfortunately, many useful packages such as the MULT and Parameter Value (PVAL) Packages are not available as they have been removed from MF-NWT. If Unsaturated-Zone Flow (UZF) Package is also used to simulate the delayed infiltration and perching of any natural or artificial recharge, these properties may also require some adjustment during calibration. If the coastal boundary will be treated like a general-head boundary then this conductance may also require adjustment.

In addition, any HFB may need adjustment during calibration. This could include temporally variable HFBs (only available in MF-OWHM) such as the subsurface flow barrier that was installed in the river channel adjacent to the Robles Diversion. Other attributes that may also need adjustment during calibration could include the elevations of the model and surface-water network, based on the uncertainty in the LiDAR and DEM data. Finally, the outflow to the Pacific Ocean needs to be represented in the context of addressing outflow (and fish migration) to properly represent block flows and related seasonal barriers to surface-water discharge to the ocean.

> The simulation of fractured bedrock aquifers could be better simulated with the Conduit Flow Package CFP Process within MF-OWHM as opposed to implementing an equivalent porous medium approach referenced in this section. The anisotropy of the fractured bedrock units that are also steeply dipping could also be an issue that was not addressed here.

5.2 Data Gaps

The Key Data Gaps listed in the Study Plan include hydraulic parameters, subsurface geology, and groundwater extraction rates. While the use of aquifer-test data can provide some initial estimates for model construction and calibration, they may also be problematic as these can typically overestimate hydraulic properties (Hanson, 1996; Hanson and Nishikawa, 1996; Halford and Hanson, 2003). The other data gaps in the subsurface geology could include faults or any man-made features that could represent groundwater flow barriers. Another data gap could be the estimation of gains and losses along specific parts of the surface-water network under different wet and dry conditions, identification and measurement of surface-water diversions, better well construction data and monthly pumpage reporting for all agricultural and supply wells as is done by United Water Conservation District and Fox Canyon Groundwater Management Agency in the adjacent Santa Clara-Calleguas Basin. The pre-calculation of agricultural demand as outlined in the three bullet points is unnecessary if MF-OWHM was used to embed these steps into the simulation framework. This would also open up the model to be used for other purposes such as mitigation, adaptation, sustainability and climate change scenarios, which will be more difficult to do with the approach outlined in the Study Plan. Working with Upper Ventura River Groundwater Agency (UVRGA) to identify local growing practices and water use is a good idea and is always done to the extent possible for the application of IHMs. This approach will be more problematic as a pre-calculation because conditions can change along with climate and sources of water. Based on the plot of known well depths (Figure 5-1 in the Plan) in the Study Plan, it is clear that many of these wells are multi-aquifer wells and will need to be simulated with the MNW2 Package within MODFLOW. While not mentioned, the Study may need to investigate whether some agricultural regions may also employ surface ponds for delayed irrigation. Extrapolation of monthly agricultural pumpage will be dependent on the crops being irrigated and their growing cycle and different rates of demand in coastal versus inland regions for the same crops. Extraction rates are not strictly a function of reference ET (potential ET of grass, Reference ET, RET) as other uses for water may also occur for agricultural areas such as frost or heat protection, pre-wetting of the root zone, and even dust control in some settings. In addition, some crops, such as fruit orchards, berries, and vineyards are subject to deficit irrigation that is independent of RET, and some berry crops are multi-year crops. Finally, salinity and additional irrigation to flush saline irrigation waters from the root zone may be necessary for citrus and avocado crops and can be simulated with MF-OWHM but the data are missing to assess this additional demand and there is no ability to add this additional demand factor in MF-NWT. Control of salinity along with nitrates may be equally important as it was in the adjacent Santa Clara River areas of the Santa Clara-Calleguas Basin.

Use of CIMIS data is essential and will be needed to rescale the estimates of PET made within PRMS, so replacement of these estimates would need to use the scale adjusted PRMS RET values. While collection of soil moisture data from agricultural areas is not proposed, these data could represent another potential set of observations and constraints on the PRMS and MF-NWT UZF simulation of the soil zone. Since UZF can be sensitive to the number of leading and trailing waves specified, this also could help constrain the specification of leading and trailing wetting waves used to simulate unsaturated flow pulses of infiltration.

Another important analysis not mentioned in the Study Plan is the uncertainty of the groundwater-level elevations used as observations for model calibration. Any groundwater model calibration should include this potential uncertainty in the groundwater levels used as observations for calibration. Like streamflow, groundwater elevations are not what is measured in the field. Groundwater levels are typically measured as depth-to-water (typically ranging in accuracy from a foot to a hundredth of a foot), and then converted to groundwater elevations based on a wellhead land-surface elevation minus any measuring point (i.e., reference point) offset. Unless the wellhead elevations have been surveyed at all wells used for observations, there can be a wide range of uncertainty in the wellhead elevations. For example, in the Rio Grande Transboundary Integrated Hydrologic Model (RGTIHM) for the Lower Rio Grande the average wellhead elevation error was 5 feet (Hanson et al., 2020) that was about half the RMSE of the groundwater-level observation errors. In the Avra Valley Model, Arizona (Hanson, 1996), all wells were surveyed to an accuracy of 0.1 feet and average wellhead elevation error was not an issue. Wellhead elevations typically have a land-surface elevation accuracy and method of estimation from the USGS NWIS database. These estimation errors need to be accounted for in the observations and RMSE of the model fit. Elevations could also be adjusted to the LiDAR equivalent elevation or at least checked against these elevations to enhance the accuracy of these elevations.

Other forms of uncertainty may also exist that include land subsidence and wells with deep turbine pumps (if oil is leaking from the pump and building up on the top of the water surface in the well), as well as from cascading water or composite heads from multi-aquifer wells (unless the simulated heads are also representing a multi-aquifer well). In summary an estimation of groundwater level observation errors should be included in the model calibration assessment. While there is no direct evidence that was presented that could indicate land subsidence, water level declines of more than 100 feet in the Ojai Basin could represent regions where the initiation of land subsidence could occur. The review of time series from Caltrans highway surveys and benchmarks, as well as multi-year InSAR maps could address this potential issue that may also need to be addressed under the SGMA requirements for this subregion.

5.3 Model Domain and Spatial Discretization

This section of the Study Plan simply states that the watershed is the model extent. It does not describe any model grid orientation that may be needed to align with any structural aspects of the watershed. This section also does not describe the model extent at the coast but based on the figures presented appears to stop at the coast and does not include any offshore regions. The specific layering in the alluvium is not described in any detail outside of probably including 10 layers that include aquifer and aquiclude layers and enough bedrock to cover the partial penetration of the wells.

5.4 Geologic Analysis

The geologic analysis referred to in this Plan appears to not describe any texture or facies analysis of the recent or older alluvium, as is commonly done in most other modern models and uses the MULT Package to build hydraulic properties as spin-up in MF-OWHM but not available in MF-NWT. While a TAC was convened, the members of this review team were not part of that review. Based on the Study Plan structural map (Figure 5-2 in the Plan), there are several faults that may serve as potential flow barriers to groundwater flow that are identified to be included into the groundwater model. Some of the more extreme deformation in the bedrock units which has created anticlinal folds may also serve as potential flow barriers and may need to be evaluated during model development.

5.5 Model Boundary Conditions

Overall, this is a good list of potential boundary conditions and packages used to represent each of these features, but a table would facilitate what packages/processes are used for which boundary conditions. It is missing ET as an additional boundary conditions as well as the potential linkage from the root/soil zone to the aquifer with the UZF Package. The use of a constant mean sea level at the coastal boundary, precludes the analysis of climate change rise in sea level and climate driven sea level changes that can exceed several meters during El Nino Southern Oscillation (ENSO) events as shown for the Pajaro Valley Hydrologic model (Hanson et al., 2014). In addition, the treatment of the Matilija Dam is not included in this list. The use of time-varying GHB heads in MF-NWT for the underflow between the Ventura and Santa Clara River watersheds will be problematic as it will require the use of instances as opposed to tabfiles of time-varying heads as is available for boundary heads in GHB within MF-OWHM (Boyce et al., 2020).

Another missing component of the boundary conditions includes the Initial Conditions of Head for each model layer, initial boundary heads for GHB, and initial flows. The use of scale factors that could also induce initial vertical head gradients are also not discussed or proposed in the Study Plan. The potential effects and criteria for developing initial conditions are summarized by Reilly and Harbaugh (2004) as:

> 1. Does the transient model simulation start from a steady-state condition?
>
> If yes –
>
> A. Were the initial conditions generated from a steady-state simulation of the period of equilibrium, which is the preferred method?
>
> B. If the initial conditions were not generated from a steady-state simulation of the period of equilibrium, then is there a compelling reason why they were not generated, or are the initial conditions invalid?
>
> If no –
>
> A. Was it possible to select a period of equilibrium to start the simulation and make the determination of initial conditions more straightforward? If it is possible, then the model should have simulated the transient period from the period of equilibrium.
>
> B. If it was not possible to select a period of equilibrium to start the simulation, then what was the justification for selecting the starting time and the initial conditions for the simulation? How was it shown that the initial conditions used did not bias the result of the simulation?

Fundamentally, the dissipation of initial condition errors is a function of a combination of the hydraulic diffusivity and the magnitude and fluctuations of boundary conditions that represent sources and sinks to the flow system. The simpler time constant based on aquifer properties and distance from a boundary condition is given as an example by Reilly and Harbaugh (2004). Most systems, especially in settings such as California, are rarely in equilibrium or even a "steady-state nonequilibrium" with transient changes associated with human activities and climate variability. There are several alternatives to estimating a "steady-state" initial condition, including reapplying solved transient head solutions back into the model and/or apply scale factors to initial conditions and even use these scale factors as an adjustment parameter for calibration with trial-and-error and parameter estimation. Another feature that can reduce the effects of poor initial conditions during calibration, is the use of groundwater-drawdown observations that are relative changes and are not strictly dependent on initial conditions. This approach of scale factors for initial conditions combined with drawdown observations was used, for example for the model of the Lower Rio Grande (Hanson et al., 2020) where initial heads were relatively uncertain both overall and on a layer-specific basis.

5.6 Preliminary Groundwater Model Simulations

This section of the Study Plan briefly summarizes the proposed strategy for model build, debugging and analysis. The use of specific years to test the model will preclude the effects of antecedent conditions and related effects from multi-year wet and dry periods. The overall simulation of the period WY1994–2017 is different than what was described before for the PRMS model (WY1990–2020).

Debugging of input errors and accelerated simulation features available in MF-OWHM that are not available in MF-NWT include the features:

- INPUT_CHECK
- FASTFORWARD STR STP
- NOCBC

As well as numerous flux and solver output features and additional NWT solver features that help with debugging, build, and calibration available in the MF-OWHM and not available in MF-NWT.

The major description that is missing from this section is a summary of observation types and locations. While the potential groundwater observation wells are shown in the Plan's Figure 5-3, there is no description of how these could be used with the Hydrograph Observation (HOB) Package (appears to be missing from MF-NWT in the GSFLOW release). Types of observations needed for IHM calibration include first-order observations of groundwater levels, streamflow, and diversions, as well as second-order observations of vertical groundwater head differences, streamflow gains and losses, and streamflow seepage. These types of observations can be estimated from MF-NWT, but the composite head observations may be more difficult as GSFLOW only offers the old 2006 BAS-OBS Package instead of HOB in MF-NWT, so some of the attributes such as fractions of layers have to be precomputed as input. Additional types of point observations such as hydraulic conductivity values, CIMIS ET, spring flows, etc. may also be needed for parameter estimation. Additional subregional observations may include runoff, Actual ET (AET), and agricultural pumpage that may also be needed for parameter estimation.

SECTION 6: **Review of 6. GSFLOW Model Development, Calibration, and Validation**

Key Takeaways:

The overall description indicates that groundwater levels along with surface-water flows will be used to assess the fit of the calibrated model to historic period of 24 years (WY1994-2017). The constraint of a cumulative mass balance error of 0.5 percent to assure that the model has decent mass balance is reasonable. In addition to those calibration objectives, the GSI review team recommends that mass balance criteria be assessed for the surface-water system and other attributes of PRMS, such as Actual ET, as well as use of second- and higher-order calibration targets. The selected simulation period for the integrated model is not consistent with the wet and dry-year variations in streamflow cycles that comprise 6 wet years and 18 dry years with multi-year recession occurring since 2006. Flow observations from streamflow gages, manual streamflow measurements, and wet-dry maps are a good subset of observations. The sensitivity analysis approach described in the Plan is rather vague, and it is recommended that the models be set up in the PEST framework to perform trial-and-error analysis in this framework using simple forward runs.

The use of GSFLOW is summarized with respect to the subsections presented in the Study Plan document. The overall description indicates that groundwater levels along with surface-water flows will be used to assess the fit of the calibrated model to historic period of 24 years (WY1994–2017). In addition, the constraint of a cumulative mass balance error of 0.5 percent (Reilly and Harbaugh, 2004) (defined as total inflow minus total outflow divided by one half the sum of the inflow and outflow) will be used to assure that the model has reasonable mass balance. Additional mass balance criteria should also be assessed for the surface-water system as well as other attributes of PRMS such as Actual ET.

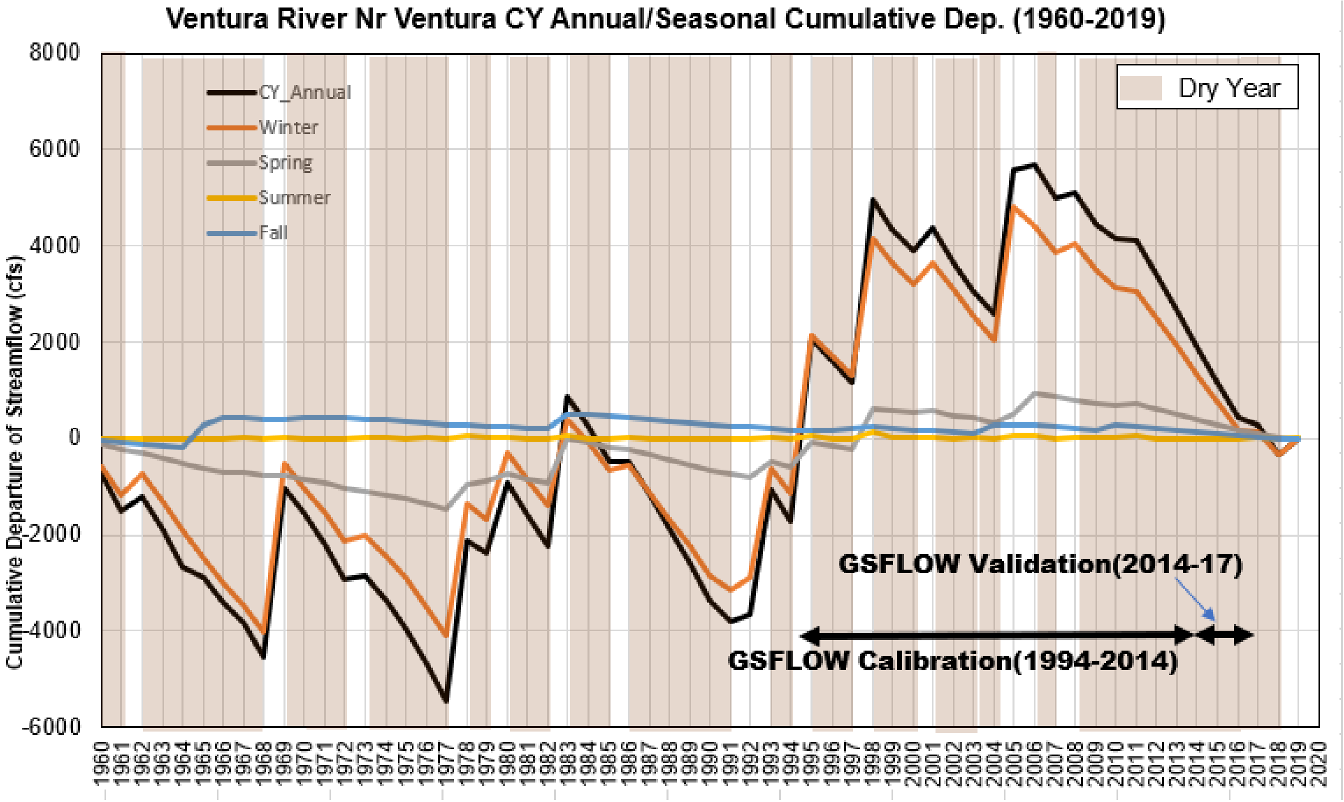
6.1 Modeling Period

The modeling periods delineated for the calibration (21 years) and "validation" (2 years) of the GSFLOW model occur under different climate regimes of the PDO climate cycles (see Figure 4-1 in this report). However, these periods are not consistent with the wet and dry-year variations in streamflow cycles (see Figure 6-1 below) that comprise 6 wet years and 18 dry years. Multi-year recession periods have occurred since 2006 and is likely in concert with inflows and related changes in reservoir storage and stage level at Lake Casitas. This figure is comparable to the historical time series of stage presented for Lake Casitas, suggesting that they are both responding to similar flows.

In addition, the model calibration does not include the post-Thomas Fire period 2018–2020.

The assertion that GSFLOW uses fixed land use is no longer true for the latest release but was a major limitation of GSFLOW for the Santa Rosa Plains model (Woolfenden and Nishikawa, 2014).

Figure 6-1. Cumulative Departure of Annual and Seasonal Streamflow of the Ventura River near Ventura (USGS 11118500) 1960–2019



6.2 Calibration Approach and Parameters

This introductory section on model calibration should also briefly summarize the methods and potential strategy used for both the surface-water and groundwater models. For example, will a combination of trial-and-error and parameter estimation (PE) methods be used? Will the PE include sensitivity analysis? What measures of fit will be used to assess error and uncertainty and sensitivity to observations and parameters?

Since PE was problematic for the Santa Rosa Plains model owing to the excessive run times, will any PE for calibration, sensitivity, and uncertainty analysis be feasible? In addition, classic PE methods are typically global in assessment of error and do not perform well with IHMs that have additional couplings that may induce "feedback effects" that may counteract parameter perturbation. Calibration of the surface-water model first makes sense and calibration of the groundwater model without the dynamic connections of the surface-water model may be problematic as the feedback from parameter perturbation will not include feedbacks from the other model.

6.2.1 Surface Water

As stated in the Study Plan, calibration to dry-weather flows that potentially represent periods of baseflow contribution to streamflow will be essential, since these are a part of the Ventura River flow regime for selected reaches.

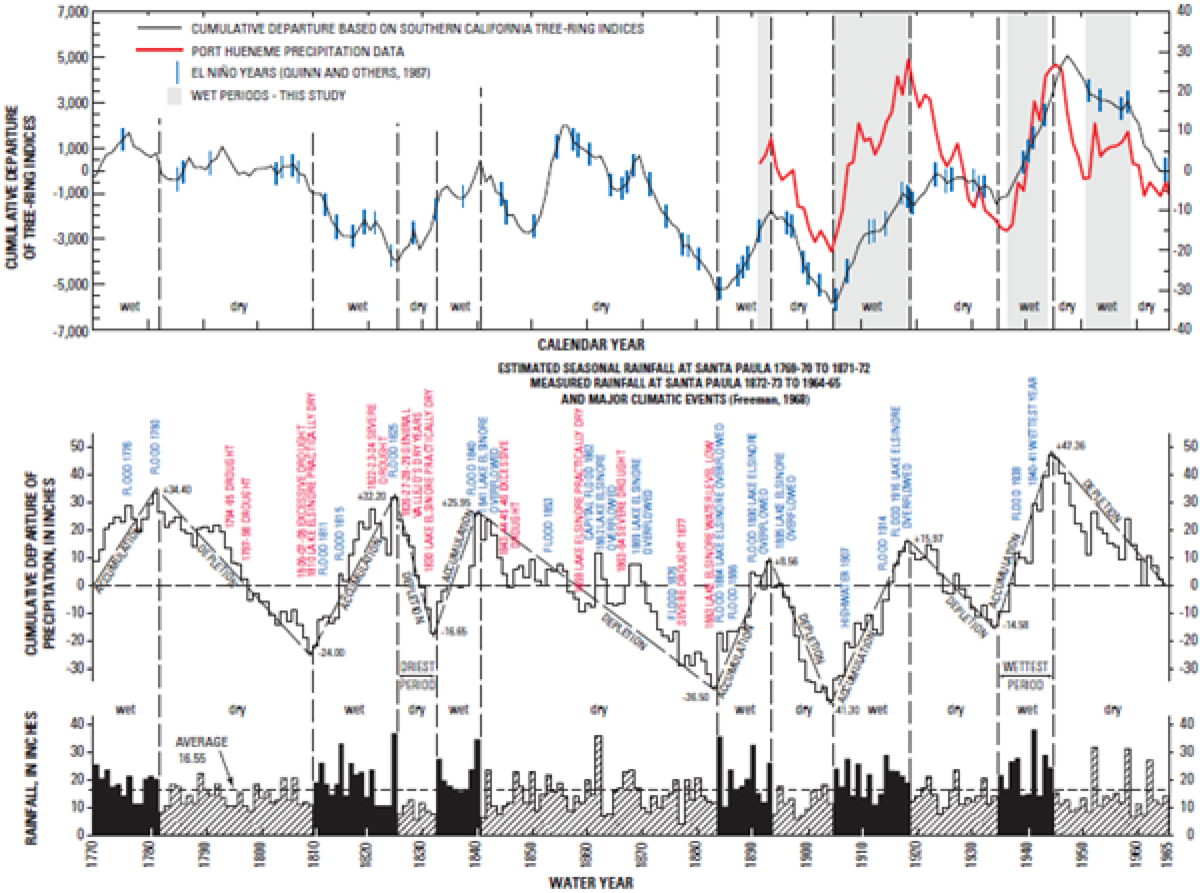
However, the PRMS model calibration strategy is focused on wet-weather flows. The meaning or criteria for delineating wet-weather periods is not clear and could be wet years, seasons or synoptic storm events that could occur in any climate setting as shown for the adjacent Santa Clara River (Hanson et al., 2003), as shown below in Figure 6-2. While the PRMS model will use daily time steps, the example from the Lower Walker River model required running the groundwater model of GSFLOW in monthly time steps. When it was connected to the proprietary software (MODSIM) to include reservoir operations, the PRMS model had to be run in weekly time steps because of the 7-day transit-time delay between reservoir releases and downstream diversions. Therefore, the transit time for surface water flows may need to include consideration in this context if reservoir operations will be added during or after calibration.

The use of flow observations from streamflow gages, manual streamflow measurements and wet-dry maps is a good subset of observations. Additional observations that should be considered include stage at the streamflow gaging stations, surface-water diversions at the Robles Diversion and any other irrigation diversions, and block flows at the ocean boundary for periods when the river outlet is open. The use of stage observations will be especially relevant because CDFW flow targets for fish migration include both flow and stage requirements for wet and dry periods. It is the reviewers' understanding that CDFW flow targets are based in part on surface water flow depths projected across high resolution descriptions and images of the channel bed, suggesting stage is just as important as observations of flows. These observations should be segregated into wet and dry season observation groups which is easy to do with PE codes such as PEST or UCODE.

Finally, other higher-order observations could be employed such as wet and dry-year/season daily streamflow duration, residuals of observed and simulated cumulative departure of monthly flows, and climate-cycle frequency analysis to help explore the continuity of transition between wet and dry-weather flows. The use of soil-moisture observations from agricultural areas also may be another state observation that should be considered.

This section also could briefly review the measures of error to estimate the ability to predict groundwater and surface-water attributes and related correlations that will be used to assess the skill and fit of the model calibration. There is also no mention of probable parameters that could be considered or are typically altered in other PRMS model examples, calibration methods, or sensitivity and uncertainty analysis.

Figure 6-2. Santa Clara Historical Climate and Surface-Water Events (Hanson et al., 2003, Figure 2B)



6.2.2 Groundwater

Similar to the surface-water model calibration, the same issues need to be addressed for the groundwater model calibration summary. In addition to the other observation types and methods of calibration mentioned previously, groundwater levels at streamflow gages should also be determined to verify that periods of baseflow are contributing groundwater, and not just within stream segments that have potentially perennial flow, since some of the perennial flow can also be contributions of hyporheic flow and bank-storage discharge as well as groundwater seepage from rejected recharge. In addition, groundwater levels should be split into different groups that represent different parts of the watershed and different sets of model layers. Other estimated observations could include slug test or other short-term aquifer test estimates of transmissivity, vertical groundwater head differences, and groundwater-surface-water head differences at gages. In addition, groundwater heads at the coast may also need to be evaluated if rejected groundwater contributes to the coastal lagoons and related block flows.

While the ASTM standards (ASTM, 2008) are important, they are out of date and incomplete, as calibration methods and observations have advanced considerably, especially for IHMs. Calibration summary does not include any brief summary of calibration methods, especially for more modern IHM models.

6.3 Calibration Goals

The discussion of calibration goals may also want to include calibration methods and estimates of weighting of observations, as well as major features that are most important to the skill and usefulness of the model.

6.3.1 Surface Water

The "weight of evidence" criteria is somewhat vague and arbitrary. In contrast, a level of observation correlation with simulated values is used for groundwater models along with higher-order criteria such as no systematic trend in errors, and other statistical measures. These should be considered for this model based on the types of flows that need to be achieved for transport and flows for fish migration. Uncertainty of observations used can be quantified based on streamflow gaging rating evaluations for different ranges of flow regimes. Using average error metrics for streamflows is not advised because the streamflows are lognormally distributed which will result in a bias to larger flows generating the largest average errors. The RMSE or Nash-Sutcliffe error of log streamflows binned into selected ranges of flow regimes may also be better to address the skill of the model for its ultimate purposes along with the other measures mentioned above. If daily surface-water flows are all used, the sheer number of values will also potentially bias the fit. In other model applications, these data are filtered to reduce the number of observations to values that represent specific quartiles of the distribution of flows, such as the 25th, 50th, and 75th percentile of flows. This also allows for segregation of low flows from median and higher flows.

The consideration of weighted residual error, with weights based on the uncertainty of gaging data, would also be a good approach to consider. The evaluation of low-flow periods as well as wet-season periods is a good idea. The source of the "Goodness of fit Categories" shown in Table 6-1 are not identified in the Study Plan but the Percent of Average Error (PAEE) percentage ranges should be better aligned to the categories used by the USGS for the accuracy of the rating tables for streamflow gages, including "Poor" ratings which are the most uncertain. This is briefly mentioned as a consideration and will give some additional qualification of the skill relative to the uncertainty inherent to the estimated "Observed flows." Including measures of gage stage could be a more certain observation for additional analysis of calibration and goodness-of-fit. Finally, the comparison of wet and dry reaches will be important and could be also supplemented with the percentage of days of flow for those reaches to better quantify this observation. These uncertainties could then be used to weight the quartiles of flows with the lowest flows being the most uncertain at the gaging stations.

6.3.2 Groundwater

The statistical measures indicated in the Study Plan are necessary. For example, the percent of correlation of > 90 percent between field and simulated observations is considered a good fit (Hill and Tiedeman, 2007). Again, these measures should be assessed with respect to groundwater-level residuals, drawdown residuals, and vertical head difference residuals.

Part of initial trial-and-error calibration is also assessing the mass balance, locations driving iteration problems, and the initial hydrologic budget. The hydrologic budgets also help to verify that the proportions of inflows and outflows are reasonable. This section also mentions using PEST for PE but based on the issues with the Santa Rosa Plain model this may only be feasible for limited sensitivity analysis. We highly recommend setting the models up in the Pest or UCODE framework and then perform trial-and-error analysis in this framework using simple forward runs. This will yield much more calibration information and make modification of parameters much easier and faster.

6.4 Sensitivity Analysis

Manual sensitivity may be all that can occur if there are excessive runtimes with the PRMS or combined GSFLOW model. Using PE for sensitivity analysis will give weighted residual sensitivities which will be more difficult to do with manual sensitivity analysis. Because of the wide range in actual magnitude of the various observations, the use of weighted residuals is essential. In addition, some parameters may dominate the estimation of sensitivity within a PE approach, and may need to be excluded from this analysis. The PE process also allows estimation of the percent of total observation variance that is contributed by each observation group, allowing for assessment of the relative importance of different types and groups of observations. Segregation of low-flow and high-flow periods is also easy to construct in the PE framework as different observation groups as discussed in the previous section.

6.5 GSFLOW Scenarios

The eight potential GSFLOW scenarios will be provided in detail at a later date, with some possible scenarios briefly listed in the Study Plan (italicized/underlined text below is from the Study Plan, with reviewer comments in regular font).

(1) *<u>One scenario shall simulate surface water flows and groundwater levels in the watershed under unimpaired conditions</u>*: The scenario of "unimpaired conditions" suggests turning off all pumpage and diversions, removing the subsurface dam and Matilija Dam. This may require rebuilding the model.

(2) *<u>One scenario shall evaluate the effects of climate change and population change on surface water flows and groundwater levels in the watershed</u>*: One scenario with climate change alone may not be adequate. For example SGMA typically suggests three different scenarios that include:

  (a) A "normal" projection to 2085 or longer with little change but similar variability, CCSM4 for Representative Concentration Pathway (RCP) 4.5, which is near the ensemble mean of 10 typical California GCM futures.

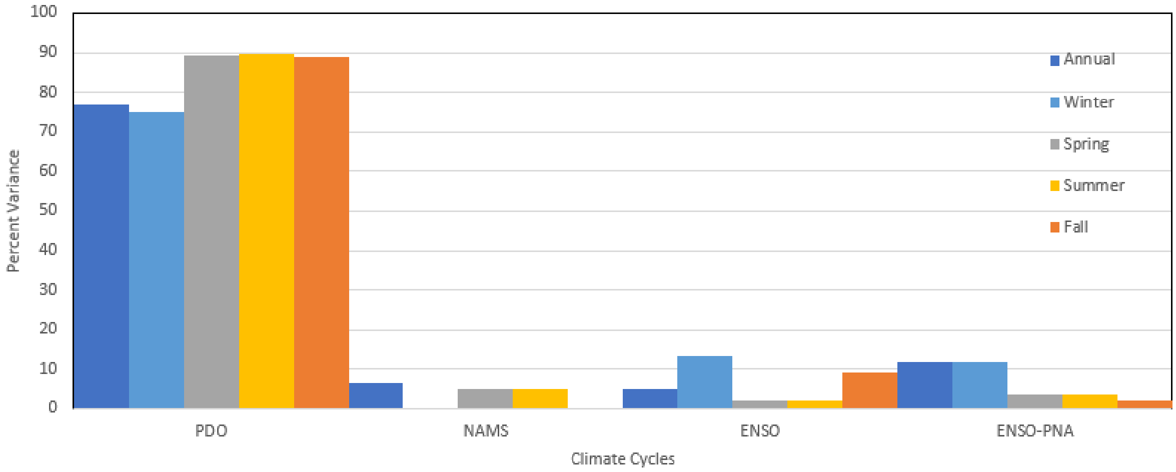
  (b) The DWR-SGMA Wetter/Moderate-Warming (WMW Scenario) "Cool and Wet" using the General Circulation Model (GCM) called CNRM_cm5 for the RCP4.5 greenhouse gas emission scenario.

  (c) The DWR-SGMA Drier/Extreme-Warming (DEW Scenario) "Hot and Dry" using the GCM called HadGEM2-ES for the RCP8.5 greenhouse gas emission scenario.

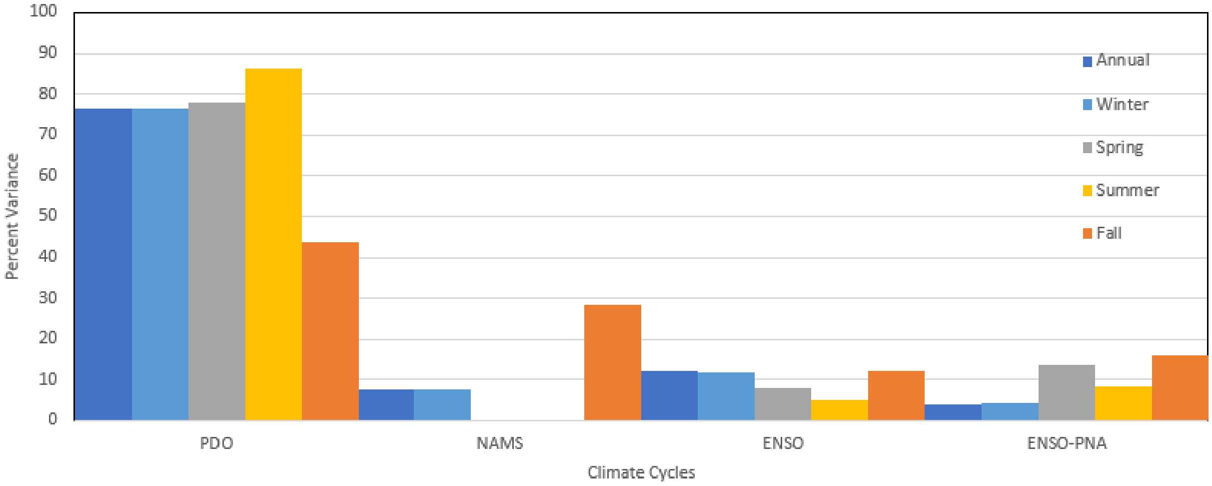
These climate-change scenarios should also include sea-level rise. In addition, climate variability scenarios should be considered to assess the common PDO cycles estimated in local climate and streamflow data (see Figures 4-1 and 6-3 in this report). For example, some climate studies are suggesting that we are in the worst mega-drought since the late 1500s (Williams et al., 2020), so prolonged decadal drought may need to be assessed and available for other analysis such as flow thresholds for fish migration by CDFW and National Marine Fisheries Service (NMFS) as well as nitrate transport. The estimated climate frequencies also are comparable to recurrence intervals estimated for the Log Pearson III peak flow events of selected streamflow gages (Tetra Tech, 2009, Table 5-1).

Figure 6-3. Estimation of percentages of historical climate-cycle Histograms for (A) Precipitation, and (B) Ventura River (USGS Station No. 11118500) grouped by climate cycles of Pacific Decadal Oscillation (PDO), North American Monsoon System (NAMS), El Nino-Southern Oscillation (ENSO) and ENSO-Pacific/North American Oscillation (ENSO-PNA).

(A) Summary of Kingston Reservoir Annual and Seasonal Percent Precipitation Variance



(B) Summary of Ventura River Annual and Seasonal Percent Streamflow Variance



One scenario shall evaluate the effects of Matilija Dam removal on surface water flows and groundwater levels in the watershed: This is an important scenario and will need to span wet and dry conditions as well as removal of invasive species vegetation that is clogging sections of the rivers and tributaries.

(3) *One scenario shall evaluate the impacts of the Thomas Fire on surface flows and groundwater levels from January 2018 through Spring 2020*: This is another important scenario but may require different input such as land use, percent impervious areas, streambed conductivities, and other attributes altered by the fire.

(4) *Four (4) additional scenarios to be determined by the Water Boards* [i.e., the SWRCB and the LARWRCB] *after consideration of TAC and stakeholder input*: These will be equally important and may also include combinations of scenarios 1-4 along with other suggested sustainability, mitigation, or adaptation components suggested by the TAC or stakeholders. These scenarios also need to capture all of the original 7 goals of the model study.

SECTION 7: **Review of 7. Nitrogen Transport Model Development**

Key Takeaways:

The nitrate transport model will be developed in MT3D-USGS from the flow quantities simulated by the GSFLOW model. The section identifies all nitrogen sources considered, datasets and sources for model inputs and calibration, and the calibration process and goals. The model will explicitly account for (a) OWTS (in the past commonly known as septic tank disposal systems), (b) livestock ranching, and (c) leaching of agricultural fertilizers to groundwater under irrigated lands. They will employ a nitrogen mass balance approach as developed and described by Viers et al. (2012), accounting for the three sources described above plus atmospheric deposition, atmospheric nitrogen-fixing legume crops (e.g., alfalfa), and losses due to crop uptake and release to the atmosphere. It is noted that most of the input data appears to sources from "literature" with limited site-specific data. The calibration target dataset appears to be limited and less than ideal, due to the lack of regular long-term synoptic water-quality sampling. However, the recent nitrogen loading / algae study by Geosyntec provides excellent recent data from surface water and groundwater samples collected in three events over an 8-month period in 2017–2018.

This section of the Study Plan describes how the groundwater nitrogen transport model will be developed, including identifying datasets and sources for model inputs and calibration, and the calibration process and goals.

They note that the modeling calibration and validation periods will be the same as used for the GSFLOW model described above, and the concerns we raised previously related to the selected time Period-of-Record (POR) remain.

7.1 Mass Balance Approach

The Study Plan states they will be explicitly accounting for (a) OWTS (in the past commonly known as septic tank disposal systems), (b) livestock ranching, and (c) leaching of agricultural fertilizers to groundwater under irrigated lands. They will employ a nitrogen mass balance approach as developed and described by Viers et al. (2012), accounting for the three sources described above plus atmospheric deposition, atmospheric nitrogen-fixing legume crops (e.g., alfalfa, clover), and losses due to crop uptake and release to the atmosphere. The portion of the nitrogen balance that eventually leaches to groundwater is assumed to arrive as Nitrate.

According to the Study Plan, "*This relatively simple mass balance approach has been shown to be comparable to more complex two- and three-dimensional modeling approaches in terms of yielding estimates for nitrogen loading to groundwater (Botros et al., 2012).*" This review of that paper (Botros et al., 2012), as well as a similar more recent paper focused on this topic (Akbariyeh et al., 2018), demonstrate that at a field scale soil heterogeneity leads to spatially variable N and nitrate distributions, but that at a larger scale (such as model cell scale for this model), this variability has minimal impact on the total mass of nitrate-N in the domain. This suggests that care must be taken when comparing model results to the 20 localized discrete Nitrate monitoring locations that will be sampled as part of the Ventura County Environmental Health Department (VCEHD) OWTS study.

7.2 Implementing Flows from GSFLOW into MT3D-USGS

This section of the Study Plan discusses MT3D-USGS as the modeling platform for groundwater nitrate transport simulations (Bedekar et al., 2016) and how it will be linked with the GSFLOW simulated flows. It is noted that MT3D is designed to run with output from MODFLOW-only, but MT3D is not directly compatible with GSFLOW (Morway, 2017). This requires that custom codes be written to assign MODFLOW boundary conditions from the GSFLOW model output, to provide the flow input structure needed for MT3D. This may not be completely true as the output from MF-NWT within GSFLOW is designed to be compatible with MT3D-USGS, but some features are not supported that could be relevant to output from MF-NWT.

7.3 Datasets and Sources

This section describes data sources that will be utilized for two specific components of the integrated model: (a) the soil zone mass balance nitrogen model, and (b) the surface water that recharges the groundwater along losing stream reaches.

7.3.1 Nitrate Concentrations from the Soil Zone to Groundwater

Noting that direct measurement of nitrogen concentrations in soil zone pore water are not generally available, the Study Plan describes how data for the various nitrogen sources that are discharged at or near the surface will be compiled and integrated via a nitrogen mass balance model. The Study Plan's Table 7-1 identifies the source data to be used for seven nitrogen inflow types:

1. Urban areas,
2. Agriculture fertilization,
3. Agriculture and horse facilities manure loading,
4. OWTS (domestic septic tanks) loading,
5. Sanitary sewer leaks loading,
6. Background loading from upgradient undeveloped areas and
7. Uptake by plants and crops (which applies to only one of the nitrogen balance outflow components).

For components (1), (2) and (7), "literature values" are listed as the primary data sources. For components (3), (5), and (6), "published" values are listed as the sources, and in these cases, it is unclear if they are project-area specific published values or perhaps generic literature values as well. Only for OWTS loading does there appear to be a study-area specific data source.

7.3.2 Nitrate Concentrations from Surface Water to Groundwater

Table 7-2 in the Study Plan identifies the data to be used for three direct nitrogen inflows:

1. Flow rates from the land surface (and soil zone),
2. Nitrate concentrations leaving the soil zone,
3. Surface water concentration in losing reaches,

In this case, it appears that actual site-specific data will be used for input 3.

Another dataset that should be reviewed (and which is relevant to irrigation, cultivation and potentially to nitrate applications relative to agriculture) is CalPIP database. This database provides monthly applications of pesticides and herbicides and type of crops being grown.

7.3.3 Data to be Used for Calibration

The Study Plan notes that surface water concentrations in gaining reaches and groundwater concentrations in monitoring wells will be the calibration targets. Other key information that "will inform" the calibration will come from a recent study by Ventura County Environmental Health Department and the LACWRCB. It is not clear what is meant by "inform the calibration." This document and the supporting technical report by Geosyntec (2018, included as Appendix 3 to VCEHD report), prepared to address TMDL standards, provides valuable data on nitrogen sources, including using oxygen and nitrogen isotopes of nitrate to determine if animal manure and/or discharges from human OWTS are much greater than from ammonium agricultural fertilizers. The study yielded data on a broad range of water quality and nutrient parameters collected from both surface water and groundwater in three events over an eight-month period, August 2017, April 2018 and May 2018.

Due to the lack of long-term regular synoptic water-quality sampling, the occurrence and movement of nitrates and their relation to nitrate sources will remain highly uncertain. For those components based on "published" and "literature values," the lack of sampling data from nitrate sources, any inference of source, use, and movement from model or statistical analysis will be an incomplete inference at best. The proposed study lacks any new data collection that would include the sources as well as additional synoptic samples at key locations and including source samples needed to assess mixing of sources. The lack of complete water-quality analysis and sampling and analysis for isotopes will continue to be a significant shortcoming of this analysis and result in significant uncertainty in relations between potential multiple sources and their mixing, movement, and occurrence in stream flows along the Ventura River and its major tributaries or in groundwater from wells.

7.4 Calibration Approach and Parameters

The Study Plan describes the calibration approach and identifies four model parameters that will be adjustable during model calibration. Not stated in the Plan, one of these four parameters, the effective porosity, should be constrained based on the final specific yield values determined for the calibrated groundwater flow equation. In fact, this may be one of the parameters subject to the potential need to re-visit calibration of the flow equation and mentioned in this section of the Study Plan. Another cited parameter, dispersivity (the model parameter which accounts large-scale spreading of nitrate plumes in groundwater), is a scale-dependent parameter and how the scale dependence will be treated is not mentioned.

7.5 Calibration Goals

This section summarizes the calibration goals for the goodness-of-fit parameters for calibration of the transport model to be defined in subsequent model development steps and cites a specific preliminary threshold for the normalized RMSE of nitrate concentration to be less than 20 percent. This goal does not appear to be tied to any specific TMDL regulatory criteria.

7.6 Sensitivity Analysis

As discussed in Section 6.4 of the Study Plan, for sensitivity analysis for the PRMS or combined GSFLOW model, model runtimes may dictate that manual sensitivity analyses may be the only viable approach.

Because of the wide range in actual magnitude of the various observations, the use of weighted residuals is essential, and this is not mentioned.

7.7 Nutrient Transport Model Scenarios

This section of the Study Plan notes that four mass loading scenarios will be investigated with the MT3D-USGS model, to be defined later in the project. The Plan does not discuss how scenarios may, or may not, be shuffled with the integrated PRMS–GSFLOW model scenarios. For example, will these four selected mass loading scenarios be run for only one "baseline" GSFLOW scenario, or will the four mass loading scenarios be run with more than one GSFLOW scenario?

SECTION 8: **Review of 8. Outreach Anticipated Approach and Timeframe**

The final section of the Study Plan covers the outreach approach and schedule, which is outside the scope of the technical review.

SECTION 9: **Selected References**

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APPENDIX A: **Review of Additional Supporting Documents**

A.1 Methods

(1) American Society for Testing and Materials (ASTM). 2008. Standard Guide for Calibrating a Groundwater Flow Model Application. D5981 – 96.

The ASTM standard is a good reference from 2008, but only references other ASTM documents and not any other previous guidelines for model calibration, such as from the USGS (Reilly and Harbaugh, 2004). It is out of date and does not cover the more modern types of models, such as IHM models that include GSFLOW, One-Water, IWFM, HydroGeosphere, ParFlo, etc. While it discusses calibration, it also makes reference to another ASTM guide (D5447) for application of groundwater models. The Study Plan does not reference guidelines or examples for application of groundwater models, or more importantly, integrated hydrologic models, are not referenced in the Study Plan. Other guidelines that could be relevant to this type of study include the guidelines from DWR's *Best Management Practices for the Sustainable Management of Groundwater* (DWR, 2016) and *Hydrologic Budget Handbook* (DWR, 2020), as well as other recent studies that have used IHMs in a similar setting or with similar hydrologic issues.

(2) Bedekar, V., E.D. Morway, C.D. Langevin, and M. Tonkin. 2016. MT3D-USGS Version 1: A U.S. Geological Survey Release of MT3DMS Updated with New and Expanded Transport Capabilities for Use with MODFLOW. U.S. Geological Survey Techniques and Methods 6-A53, 69 p. https://water.usgs.gov/ogw/mt3d-usgs/.

This newest version of MT3DMS is a collaboration between selected USGS personnel and S.S. Papadopulos and Associates, Inc. (SSPA). There are no current contracts with USGS and SSPA to further support development, nor USGS funding for additional development such as the addition of the AG Package or generalizing input to allow input from more packages/processes from any MODFLOW versions. Only bug fixes are being completed with the new releases. The current version of MT3D_USGS may not have linkages for selected packages that may be useful for this study, including the DRT Package and the new AG Package. In addition, the net flows transferred from MF-NWT to MNW may not reflect the actual inflows and outflows related to wellbore flow and, as such, may result in a different result relative to transport as was identified by other studies (Clark et al., 2007; Konikow and Hornberger, 2006).

(3) Joshua H. Viers, Daniel Liptzin, Todd S. Rosenstock, Vivian B. Jensen, Allan D. Hollander, Alison McNally, Aaron M. King, Giorgos Kourakos, Elena M. Lopez, Nicole De La Mora, Anna Fryjoff-Hung, Kristin N. Dzurella, Holly Canada, Sarah Laybourne, Chiara McKenney, Jeannie Darby, James F. Quinn, Thomas Harter, 2012. Nitrogen Sources and Loading to Groundwater with a Focus on Tulare Lake Groundwater Basin and Salinas Valley Groundwater, Technical Report 2, UC Davis Center for Watershed Sciences.

As the second in a series of technical reports prepared as part of the SB x2-1 California Nitrate Project, the report was referenced in the Study Plan as the source for the methodology to be employed for developing the nitrate sources for Ventura Basin water quality. The report provides a comprehensive evaluation of anthropogenic sources of nitrate, focused especially on agricultural sources and their impacts on groundwater in the Tulare Lake Basin and Salinas Valley. As part of this data compilation, analysis, and interpretation, a nitrogen mass balance modeling approach was developed and tested. The mass balance approach estimates nitrate loading from all croplands, by crop type (crop category), except for alfalfa cropland. Alfalfa obtains its nitrogen from the atmosphere via nitrogen fixing bacteria in the alfalfa roots, which prevents it from part of the Viers et al. mass balance model. The method provides an accounting for the amount of material entering and leaving a system of interest and relies on the concept of the conservation of mass (i.e., mass can neither be created nor destroyed). This approach allows one to approximate flows of material, such as nitrate, that might otherwise have been unknown or difficult to measure (e.g., leaching to groundwater). This approach is often employed in water quality studies involving nitrates, including for nitrogen mass balance in surface waters of the Central Valley (Sobota et al., 2009). Water quality data from monitoring wells installed downgradient of fields receiving manure applications indicate that the nitrate concentration in recharge from these fields is closely related to the nitrogen losses estimated from a field-scale nitrogen mass balance.

The nitrogen mass balance is performed on the root zone of each field and considers only annualized fluxes into and out of the root zone. On the input side, each field root zone receives nitrogen from the following sources:

- N from atmospheric deposition, $N_{deposit}$
- N contained in the source irrigation water (well, stream), N_{irrig}
- N from synthetic fertilizer, N_{fertil}
- N from manure, where applied, N_{manure}
- N from WWTP (wastewater treatment plant) effluent or biosolids, where applied, N_{WWTP}

On the output side, the following pathways are considered:

- N in the harvest, $N_{harvest}$
- N losses to the atmosphere via volatilization or denitrification, N_{loss}
- N loading to groundwater, N_{GW}
- N in surface runoff, N_{runoff}

The report goes on to describe how the inflows and outflows are combined into a mass balance equation and provides a detailed analysis of data sources and supporting parameters and calculations for each of the terms. Via this detailed analysis, the final result is a Groundwater Nitrate Loading Model, which is the approach to be employed for estimating nitrate loading to groundwater in the Ventura River water quality model. Thus, the report provides valuable background, including some data and model parameters, for reviewing and understanding loading of nitrate to the groundwater system in the MT3D water quality model.

(4) Geosyntec and DBS&A, 2020a. Draft Data Compilation Report for the Development of Groundwater-Surface Water and Nitrogen Transport Models of the Ventura River Watershed, prepared for State Water Resources Control Board (Division of Water Rights) and Los Angeles Regional Water Quality Control Board (TMDL and Nonpoint Source Unit)

In summary, the Casitas reviewers found the technical memo clear in its description of approach to be employed in their sensitivity analyses, but found it lacking in that it does not include additional well attributes needed to simulate the larger multi-aquifer wells with MNW2, any multi-level monitoring well vertical head differences, alternate analysis of aquifer tests, additional land use and diversion data, irrigation data and methods, wet dry maps for wet periods, and additional chemical data to not only characterize nitrate but also salinity and any other emerging contaminants.

(5) Geosyntec and DBS&A, 2020b. Draft Sensitivity Analysis Approach Memo for the Development of The Groundwater-Surface Water Model of the Ventura River Watershed, prepared for State Water Resources Control Board (Division of Water Rights) and Los Angeles Regional Water Quality Control Board (TMDL and Nonpoint Source Unit)

In summary, the Casitas reviewers found the technical memo clear in its description of approach to be employed in their sensitivity analyses, but found it lacking in that it does not include sensitivity to observations or to predictive uncertainty that could be obtained with more formal parameter estimation methods such as PEST or UCODE.

A.2 Previous Models

The following additional selected review comments are relative to the ongoing model development and not meant to be an exhaustive or complete review of these supporting documents.

(1) DBS&A. 2010. Groundwater Budget and Approach to a Groundwater Management Plan, Upper and Lower Ventura River Basin. Prepared by Daniel B. Stephens & Associates, Inc. (DBS&A). December 30, 2010.

This budget analysis was completed without numerical modeling of groundwater or surface-water frameworks. Many of the estimates from this study will likely be used to implement specified flux inputs and outputs for the new GSFLOW model. All inflow and outflow components of a groundwater-flow budget were estimated based on a mix of local information and assumed literature-based values. This report also notably summarizes the inherent water-quality issues throughout most of the watershed. However, the sources of the salinity and nitrate are not well explained, yet the values are significantly high and may affect drinking water and agricultural supplies as well as demand and use of water. As noted in the comprehensive set of limitations and associated recommendations, the groundwater budget is highly dependent on the historical time period (here 1997–2007), and this may be an issue with the proposed time periods selected for the new model under development, as shown in the previous cumulative departure of precipitation and streamflow figures. In addition, the age and isotopic nature of the various groundwater sources was not identified as they were in the adjacent Santa Clara-Calleguas basin with the USGS studies. Other flow components between aquifers, such as wellbore flow in multi-aquifer wells, were not accounted for in these budgets but were a significant issue for water quality and flow in the adjacent Santa Clara-Calleguas basin studies.

(2) DBS&A. 2011. Groundwater Model Development, Ojai Valley Basin, Ventura County, California. November 15, 2011, 203p. Prepared for Ojai Basin Groundwater Management Agency. Prepared by Daniel B. Stephens & Associates, Inc. (DBS&A). https://www.dropbox.com/s/fy0h14po11yvwe6/Ojai%20Basin%20Groundwater%20Model%20Development_11-15-11.pdf?dl=0.

This PowerPoint presentation provides some of the highlights from the model development. Slide 15 shows groundwater level changes of more than 150 feet, which could indicate a potential for land subsidence. The groundwater flow budget indicates a small deficit of about 30 ac-ft/yr. The 1-day aquifer test presented with two observation wells, was used as an example of local tests. While it is good to use Hantush Leaky Aquifer model, this test could have also been analyzed with the Neuman Delayed Yield model if this was a partially unconfined set of wells. Based on the assumed saturated thickness of 100 feet, the transmissivity (T) of 6,263 ft/d yields a hydraulic conductivity (K) of about 623 ft/d, which seems large. Based on the specified saturated thickness, the estimated storage coefficient of 0.0003919 yields a Specific Storage, Ss, of about 3.9×10^{-6}/feet, and did not require any vertical anisotropy. The early-time data (<10 minutes) may indicate delayed yield or wellbore storage effects delaying early-time drawdown. Some wellbore flow profiles under pumped and unpumped conditions could have been useful from selected wells for this analysis and for constraining model properties such as distributing the proportions of K within T and constraints on vertical K's too (Hanson and Nishikawa, 1996).

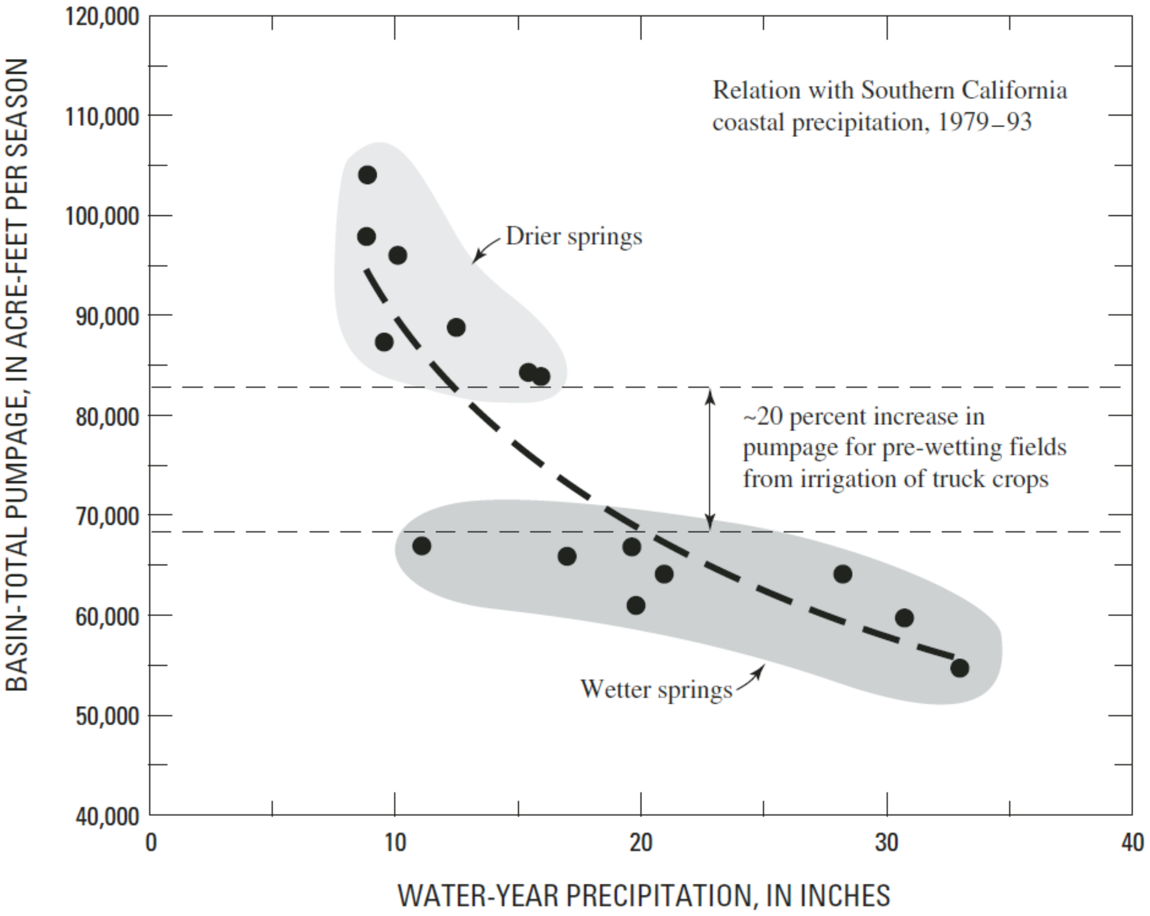
Safe yield analysis is potentially flawed as it may not account for captured recharge or discharge in excess of the storage depletion (Bredehoeft, 1997, 2002; Bredehoeft et al., 1982; Alley and Leake, 2004). This is further exemplified by the omission of net streamflow infiltration in the estimation of average and median recharge (slide 18). The "Safe Yield" analysis figure (slide 19) with cumulative distribution of recharge could also be presented in the context of storage change as a double-mass curve against cumulative extractions/outflows, but this would still not reflect any potential captured recharge and discharge or wellbore flow. Long-term drought is an issue as shown in slide 20 both in the alluvial and bedrock aquifers, and relevant to the mega-drought (2000–2020) that is currently occurring. The rapid desaturation shown in slide 21 also indicates a relatively high sensitivity to climate variability. Artificial recharge benefits demonstrated in slide 23, but changes in saturated thickness may be small as indicated in slide 24 and with limited extent of benefit as shown in slide 25. The statement of multi-year drought driving declines in groundwater levels (slide 28) does not also include the potential capture of recharge and discharge during droughts and more widespread decline in sustainability.

(3) DBS&A. 2014. Memorandum from Gregory Schnaar and Stephen J. Cullen to Jerry Conrow (Ojai Basin Groundwater Management Agency) Re: Update to Ojai Valley Basin Groundwater Model. May 28, 2014.

This memo summarizes the 4-year update (2010–2013) of the OBGM model. It initially recognizes the current effects of the ongoing mega-drought but does not supplement this with any kind of climate analysis. The model provides updates and refinements of recharge using the proprietary watershed model (latest version of DBS&A's DPWM) and projects drought-driven groundwater-level declines. The use of proprietary codes that are not peer reviewed, public domain and open-source code may not be acceptable for SGMA requirements. The impervious areas that affect recharge in urban areas noted in use of the DPWM may not also include the impervious areas of buildings. The new DPWM is also used to estimate irrigation rates and amounts of potential deep percolation. A constant rate is used for irrigation rates, indicating that there is no climate influence based on the Staal, Gardner & Dunne, Inc. (SGD, 1992) study. In contrast, the analysis of reported agricultural pumpage in the adjacent Santa Clara–Calleguas basin indicated some climatic variation with differences of about 20 percent between wetter and drier springs (Hanson et al., 2009, Figure 4B) (see Figure A-1 below). This approach also does not account for any other potential factors such as deficit irrigation. The summary does not mention the range of irrigation efficiencies for different crops, other demands for water such as frost protection, or potential salinity leaching of these poor-quality waters. As noted in the TMDL study of the Santa Clara Valley with a Water Quality Objective of 100mg/l Chloride (RWQCB-LA, 2008), citrus root systems can be sensitive to elevated chloride concentrations above 2,200 - 2,300 ppm (https://www.gardeningknowhow.com/edible/fruits/citrus/are-citrus-trees-salt-tolerant.htm#:~:text=As%20previously%20mentioned%2C%20citrus%20trees,their%20leaves%20can%20kill%20them) and results in reduced productivity with increased salinity (Maas, 1993). Many varieties of avocados are also salt sensitive (Celis et al., 2018). The related assumptions about irrigation for the DPWM model being less may also need to be revised with the newer GSFLOW model and the proportion of runoff during winter months was not mentioned.

The updated model parameters focused on increases in specific yield from a factor of 1.6 to 2, which will reduce declines and dampen seasonal oscillations. Overestimation of groundwater levels was noted as in the original model. While some budget components are summarized, the model does not simulate some features such as streamflow routing.

Figure A-1. Effects of Wet and Dry Springs on Groundwater Pumpage in the Santa Clara–Calleguas Basin (Hanson et al., 2009, Figure 4B)



The groundwater budget components are summarized but many are specified inflows and outflows. The projected simulations predict relatively large groundwater-level declines that may prompt the possibility of land subsidence and substantial discharge capture as declines in groundwater baseflow to streams if these were simulated.

(4) DBS&A, 2018. Geologic Analysis, Ventura River Watershed (Preliminary/Draft). Submitted to Geosyntec and the State Water Board, FINAL March 2020.

This memorandum summarizes geologic analysis performed for the Ventura River Watershed (VRW) by Daniel B. Stephens & Associates, Inc. (DBS&A) in support of numerical model development. This geologic analysis is based on data available to DBS&A at the time the analysis was conducted. An initial version of the memo was submitted in August 2018, and the final version was submitted in March 2020. The memo provides a clear description of the data sources, and methodology employed in developing the cross sections. The geologic analysis was performed by mapping the three-dimensional extent of surficial geologic units within the VRW, and results were plotted on a series of geologic cross-sections. Heavy emphasis was placed on defining the lateral extent and thickness of the unconsolidated sediments in the basin, which makes good sense. The cross sections provide good coverage across the study area, to the depths of wells along the section. The well depths along the river generally appear to not extend below 300 feet (based on the cross-sectional data). Following mapping of undifferentiated alluvium, additional geologic analysis was conducted to map the three-dimensional extent of bedrock geologic units that are used for water supply in the VRW and to map the presence of structural features (i.e., faults). While one of the stated purposes of the memo was to develop the three-dimensional (3D) geologic grid for the numerical model, there is no description in the memo as to how these individual hydrogeologic cross-sections would be integrated into the 3D model.

(5) Geosyntec Consultants (Geosyntec) and Daniel B. Stephens & Associates (DBS&A), Inc. 2017. Draft Study Plan for the Development of an Integrated Groundwater-Surface Water Model of the Ventura River Watershed. Prepared for State Water Resources Control Board, November 2017. https://www.waterboards.ca.gov/waterrights/water_issues/programs/instream_flows/cwap_enhancing/docs/ventura_river/

This is a preliminary draft of the final study report that is reviewed above.

(6) Tetra Tech, 2009. Baseline Model Calibration and Validation Report, Ventura River Watershed Hydrology Model, 21 July 2009.

This report summarizes the Ventura River Watershed Hydrology Model developed with HSPF for the period October 1996 to September 2006 for historical conditions and projected potential extreme high-flow events using the longer period starting in October 1967 (a Natural Condition scenario). The primary objective of this work is to support VCWPD's analysis of hydrologic conditions in the Ventura River Watershed, including both water availability and storm flow analyses. The approach used was similar to their HSPF model of the adjacent Santa Clara-Calleguas basin watersheds. The analysis of land use also includes the inclusion of effects from several previous fires and 35 fires within the period 1965–2007, of which the Creek Road (9/18/1079, 15 percent of Watershed) and the Wheeler (7/1/1985, 54 percent of watershed) were two of the largest prior to the more recent Thomas Fire. The surface-water watersheds were subdivided into 88 sub watersheds that were combined with four soil groups and three impervious categories. The watershed was also subdivided into 20 meteorological subregions for Theisen polygon approximation of climate attributes. The stream network was segmented into 96 segments with the smallest about 1 mile in length. Many other features, such as diversions, point source inputs, and an approximation of groundwater flow, were also included in the HSPF model. The recurrence intervals of peak flow events (1934–2007), estimated from Log Pearson III annual maxima (Table 5-1 from Tetra Tech, 2009)) for gage 605 (San Antonio Creek at Highway 33) and gage 604 (North Fork Matilija Creek) generally ranged from 5.5 to 41.8 years and 2.5 to 44.4 years, respectively, and are consistent with the largely PDO estimates of cycles for precipitation estimated in the Study Plan Review. Calibration included 12 streamflow gaging stations based on annual and seasonal estimates of streamflow. The RMSE of the calibrated HSPF model for 8 streamflow gages ranged from 25.3 to 280.94 cfs and an overall R^2 of daily flows > 84 percent and Nash-Sutcliffe E coefficients (NSE_C) > 0.8. Similarly, for the validation period the RMSE ranged from 15.47 to 143.81 cfs, R^2 daily and monthly ranging from 84.4-91.8 percent and 96.5-98.8 percent, respectively, and an NSE_C ranging from 0.83-0.92. The water balance for the period 1997–2007 representing downstream flow to the Pacific Ocean constitutes 69 percent of the water entering stream reaches or about 25 percent of precipitation on the watershed. About 16 percent of the surface water flow is diverted for consumption, while the remainder is lost to ground water or evaporation.

A.3 Support-Data Analysis

(7) Geosyntec Consultants (Geosyntec). 2018. Technical Report for the Study of Water Quality Impairments Attributable to Onsite Wastewater Treatment Systems (OWTS) in the Ventura River Watershed. Prepared for the Ventura County Environmental Health Division, November 2018.

Prepared in support of technical report compliance report to LARWRCB over TMDL compliance and designation as impaired water along certain reaches of the Ventura River. The study provides valuable data on nitrogen sources, including oxygen and nitrogen isotopes of nitrate, to determine the likely source of the nitrogen loading. Analyses were undertaken to tie the sampling network and source identification to land use.

Data on a broad range of water quality and nutrient parameters were collected from both surface water and groundwater in three events over an eight-month period, August 2017, April 2018, and May 2018. Thus, the first event was pre-Thomas Fire, whereas the second and third were post-Thomas Fire. Groundwater and surface water samples were analyzed for ammonia, nitrite, nitrate, and total nitrogen, as well as for a suite of PPCPs (Pharmaceuticals and Personal Care Products) commonly associated with sewage and septic effluent. The stable isotope results indicate that OWTSs and animal manure contribute a far higher nitrogen load to the system than does application of agricultural ammonium nitrate fertilizers. The results were interpreted to identify zones of likely heavy nitrogen loading to the river, most of it coming from high nitrate groundwater discharging to surface water bodies, including both San Antonio Creek and into the Ventura River itself. Several maps were prepared illustrating key data results, and a risk zone map (shown below) identifying areas where controls to OWTS discharges should be considered. While these are valuable data, the value increases immensely if the same sampling points (or a subset of those points) and analyses are regularly sampled long into the future.

Figure A-2. Nitrate Isotopes Summary in Groundwater and Surface Water (by Group) (Geosyntec, 2018, Figure 18)

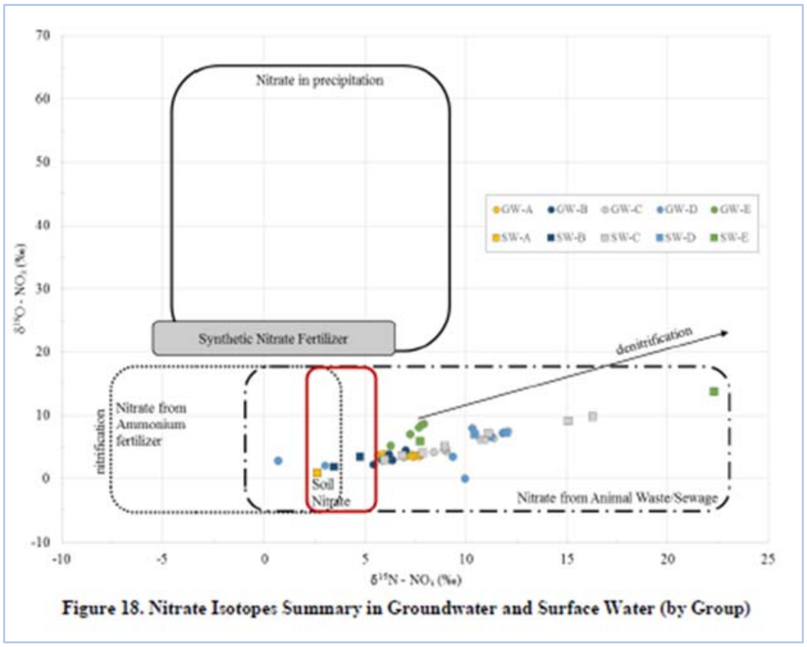
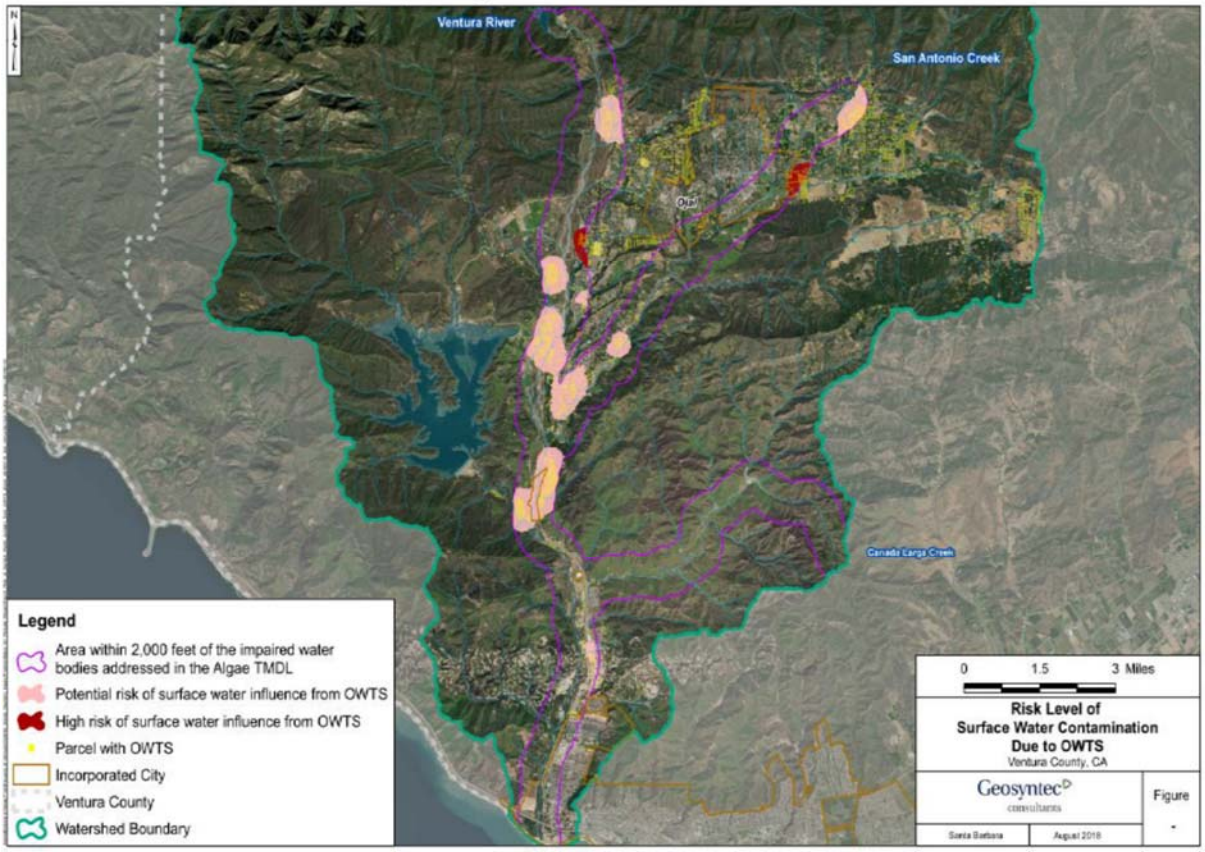


Figure 18. Nitrate Isotopes Summary in Groundwater and Surface Water (by Group)

Figure A-3. GIS Map of High-Risk OWTS Areas in the Ventura River Watershed (Geosyntec, 2018, Figure 1)

FIGURE 1: GIS Map of High-Risk OWTS Areas In the Ventura River Watershed



(8) Tetra Tech. 2012. Ventura River Flows and Estuary Conditions. Prepared for EPA Region IX. June 30, 2012. Prepared by Tetra Tech, Inc.

This memorandum from the Ojai Valley Sanitary District covers the "RWQCB- Proposed TMDL for Pumping & Water Diversion in the Ventura River Watershed" and a comparative overview by Larry Walker & Associates of the RWQCB's Algae & Flow TMDLs for Ventura River Reaches 3 and 4. As summarized in this document:

> As documented in this TMDL, the pumping and water diversion impairments of Reach 3 and Reach 4 affect the same beneficial uses addressed in the Ventura River Watershed Algae TMDL (LARWQCB, 2012). This TMDL presents data evaluation and documentation of the impairments observed at Reaches 3 and 4. Our assessment confirms that impairments due to nutrient loading, including low DO conditions, are strongly related to the effects of pumping and water diversions. We find that addressing the nutrient-related water quality impairments will simultaneously benefit the waterbodies impacted from pumping and water diversions. This will result in significant improvement towards protection of the identified beneficial uses for Reaches 3 and 4 of Ventura River. Because the identified impairments are linked to complex sources, a full restoration of Reaches 3 and 4 would require addressing the nutrient-related water quality impairments, as proposed in this TMDL.

Overall, the document summarizes problem identification, numeric targets, source assessment, linkage analysis, TMDL and pollutant allocations, and implementation and monitoring. The summary of the steelhead trout life history in the watershed is as follows:

> Southern steelhead trout are acclimated to the highly variable conditions described above. During average to wet water-years, winter storms breach the lagoons often formed at the mouths of rivers. This provides both access and a signal for the anadromous fish to leave the ocean and start the journey upstream to spawn. In a watershed unrestricted by physical barriers to passage such as dams, the fish would normally transit through the mainstem of the river over several days and eventually spawn where habitat is generally most suitable, in tributaries such as Matilija Creek. Even in barrier-free watersheds, however, smaller than normal winter storms might fail to breach the lagoon leaving the fish to stay in the ocean for another year. Or a large initial storm might breach the lagoon, but not be followed by enough subsequent rainfall to maintain streamflows in order for the fish to transit through the whole system. The steelhead runs for years such as those might be very small to nonexistent. In the Ventura River Watershed, during normal to wet years before dams were constructed that created physical barriers (i.e., prior to 1948), the steelhead run was estimated at 4,000-5,000 individuals. However, following the construction of Matilija Dam (located upstream of Reach 3), which cut off access to about half of the prime spawning habitat, and coincident with a drought in the late 1940s, steelhead runs dropped to about 2,000-2,500 individuals. Once the Robles Diversion was constructed around 1959, access to good spawning habitat in the North Fork of Matilija Creek was also cut off and fewer fish were produced that would eventually return to spawn as adults. The steelhead run dropped to around 100 individuals; these individuals had to utilize remaining favorable areas within the mainstem for spawning and rearing. Considering the high flows that can occur in the mainstem with larger storms (relative to flows in the tributaries), access might be attained but spawning and rearing might prove to be impossible at times. Conversely, during dry years, fish unable to transit back downstream to the ocean due to low flows must survive in pools in the mainstem and be subjected to elevated temperatures at times, endure competition with other fish for a decreasing food supply, and survive exposure to predators. Spawning might not occur or be extremely limited due to lack of water at sites appropriate for spawning during wetter years.

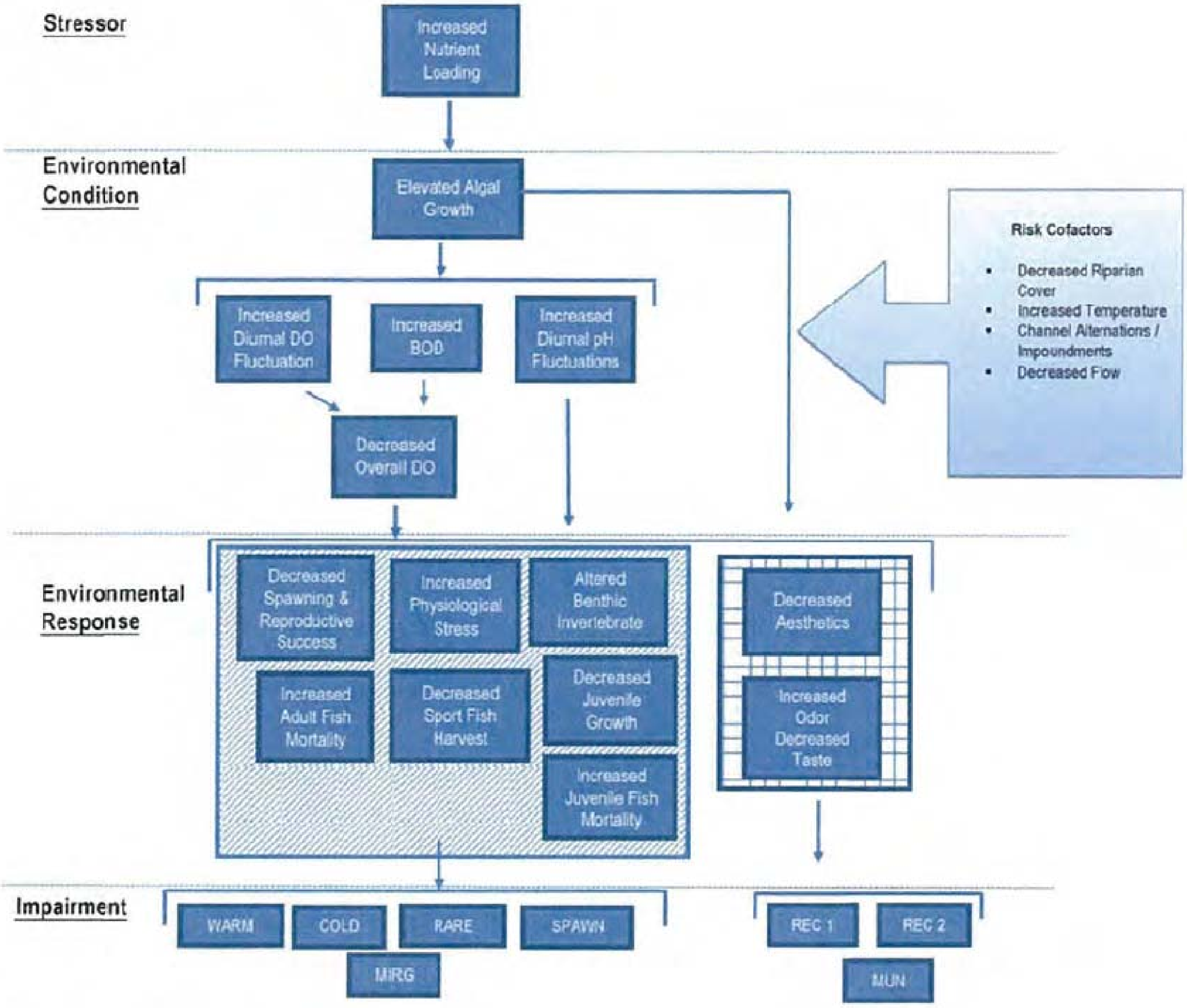
Problem Statement:

The report identified the following:

> To protect beneficial uses, limiting nutrient input and maintaining river flow would increase minimum DO concentrations, restore a natural nutrient balance in the system, and overall improve aquatic life habitat; therefore, the pumping and water diversion impairments addressed in this TMDL should be considered concurrently with the impairments documented in the Ventura River Watershed Algae TMDL (LARWQCB, 2012).

Figure A-4 below identifies the proposed hierarchy of the stressor, environmental condition, environmental response, and impairment (Tetra Tech, 2012, Figure 2-1).

Figure A-4. Conceptual Model for Rivers (Tetra Tech, 2012, Figure 2-1)



Numeric Targets:

In Figure A-5 below, the numeric targets are expressed as algal biomass, macro algal percent cover, phytoplankton biomass, dissolved oxygen, and pH (Tetra Tech, 2012, Table 3-1) and are consistent with those in Ventura River Watershed Algae TMDL (2012).

Figure A-5. TMDL Numeric Targets (Tetra Tech, 2012, Table 3-1)

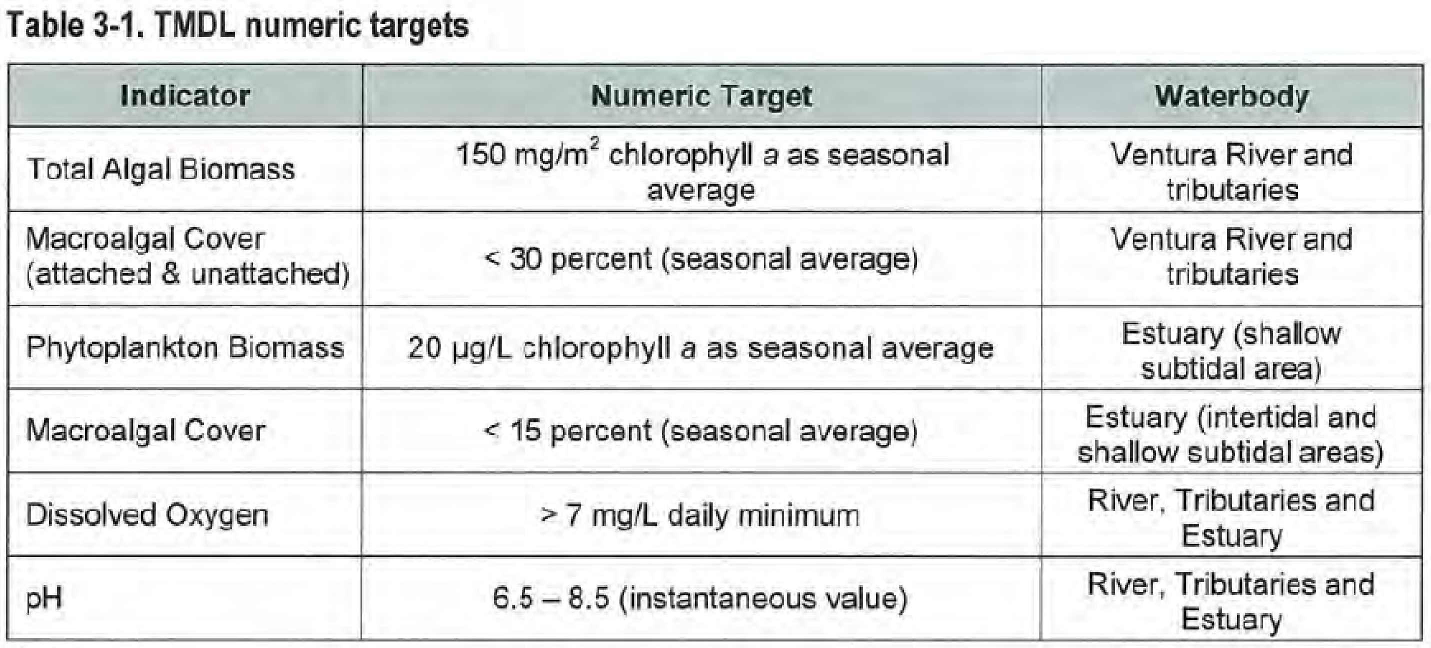


Table 3-1. TMDL numeric targets

Indicator	Numeric Target	Waterbody
Total Algal Biomass	150 mg/m^2 chlorophyll *a* as seasonal average	Ventura River and tributaries
Macroalgal Cover (attached & unattached)	< 30 percent (seasonal average)	Ventura River and tributaries
Phytoplankton Biomass	20 µg/L chlorophyll *a* as seasonal average	Estuary (shallow subtidal area)
Macroalgal Cover	< 15 percent (seasonal average)	Estuary (intertidal and shallow subtidal areas)
Dissolved Oxygen	> 7 mg/L daily minimum	River, Tributaries and Estuary
pH	6.5 – 8.5 (instantaneous value)	River, Tributaries and Estuary

Source Assessment:

The report summarizes the sources as:

> This section identifies the potential sources of pumping and water diversion and nutrients in the Ventura River Watershed, in particular those associated with Reaches 3 and 4. In the context of TMDLs, pollutant sources are classified as either point sources or nonpoint sources. Nonpoint sources originate from land runoff, precipitation, atmospheric deposition, drainage, seepage, or hydrologic modification. The term "nonpoint source" is defined to mean any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act. A point source, as defined in the Clean Water Act, means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. Point sources include discharges from wastewater treatment plants and industrial and municipal storm drain outfalls, but do not include agricultural storm water discharges and return flows from irrigated agriculture.
>
> The major categories of pumping and water diversion and nutrient sources in the Ventura River Watershed are (note: these sources are present throughout the watershed; however, those directly connected to Reach 3 and/or Reach 4 are identified in parentheses below):

> Point Sources
>
> - Stormwater and dry weather runoff from storm drains (Reaches 3 and 4)
> - Ojai Valley WWTP discharge (Reach 3)
> - Other NPDES permits (Reach 4)
>
> Nonpoint sources
>
> - Runoff from horse and cattle facilities (Reaches 3 and 4)
> - Runoff from agricultural areas (Reaches 3 and 4)
> - Runoff from undeveloped natural areas (Reaches 3 and 4)
> - Onsite wastewater treatment systems (i.e., septic tanks) (Reaches 3 and 4)
> - Groundwater discharge (Reaches 3 and 4)
> - Atmospheric deposition (Reaches 3 and 4)
>
> Additional Entities to Assimilative Capacity
>
> - Robles-Casitas Canal (Reach 4) - operated by CMWD
> - City of Ventura municipal wells (Reach 4)
> - Foster Park Subsurface Diversion - operated by the City of San Buenaventura (Reach 4)

The sources were identified in the context of subdividing the Ventura River Watershed into seven sub watersheds: Upper Watershed, Ventura River Reach 4, Ventura River Reach 3, the Lower Watershed, San Antonio Creek, Canada Larga, and Other (Coyote Creek above Casitas Dam) (Tetra Tech, 2012, Figure 4-1) (Figure A-6 in this review report appendix).

The report summarizes special groupings and classifications as:

> Most water in Lake Casitas goes to consumptive uses or evaporation and is rarely released below the dam (Tetra Tech, 2012). According to CMWD staff, water is only released from the dam when it overflows. The last time water spilled over the Dam was in 1998 (an El Nino year). Thus, water is only released from the dam during very high flows and is released from the top of the reservoir. Therefore, the sub watershed draining to Lake Casitas (named "Other" in the figure below) is not considered a potential source of nutrients to the Ventura River for the purposes of this source assessment. Land that drains to Coyote Creek downstream of the dam is considered a source and is included as part of the Reach 3 sub watershed.
>
> The Upper Watershed, reach 4, and San Antonio Creek sub watersheds all contribute loadings to Reach 4. Loads to Reach 3 are comprised of the total loadings to Reach 4 as well as those from the Reach 3 sub watershed. The drainage to Ventura River Reaches 3 and 4 (Upper Watershed, reach 4, San Antonio Creek, and Reach 3 sub watersheds) makes up two thirds of the Ventura River Watershed. Overall, the Reach 3 and 4 drainage area is 85 percent open. Residential (combination of high and low density) and agricultural (sum of cropland, orchards, nurseries, and other agriculture) areas each contribute about 6 percent of the total area.

Linkage Analysis:

This section summarizes the potential linkages with respect to geographic and temporal analysis of flow and water-quality trends for attributes of nutrients and dissolved oxygen (DO):

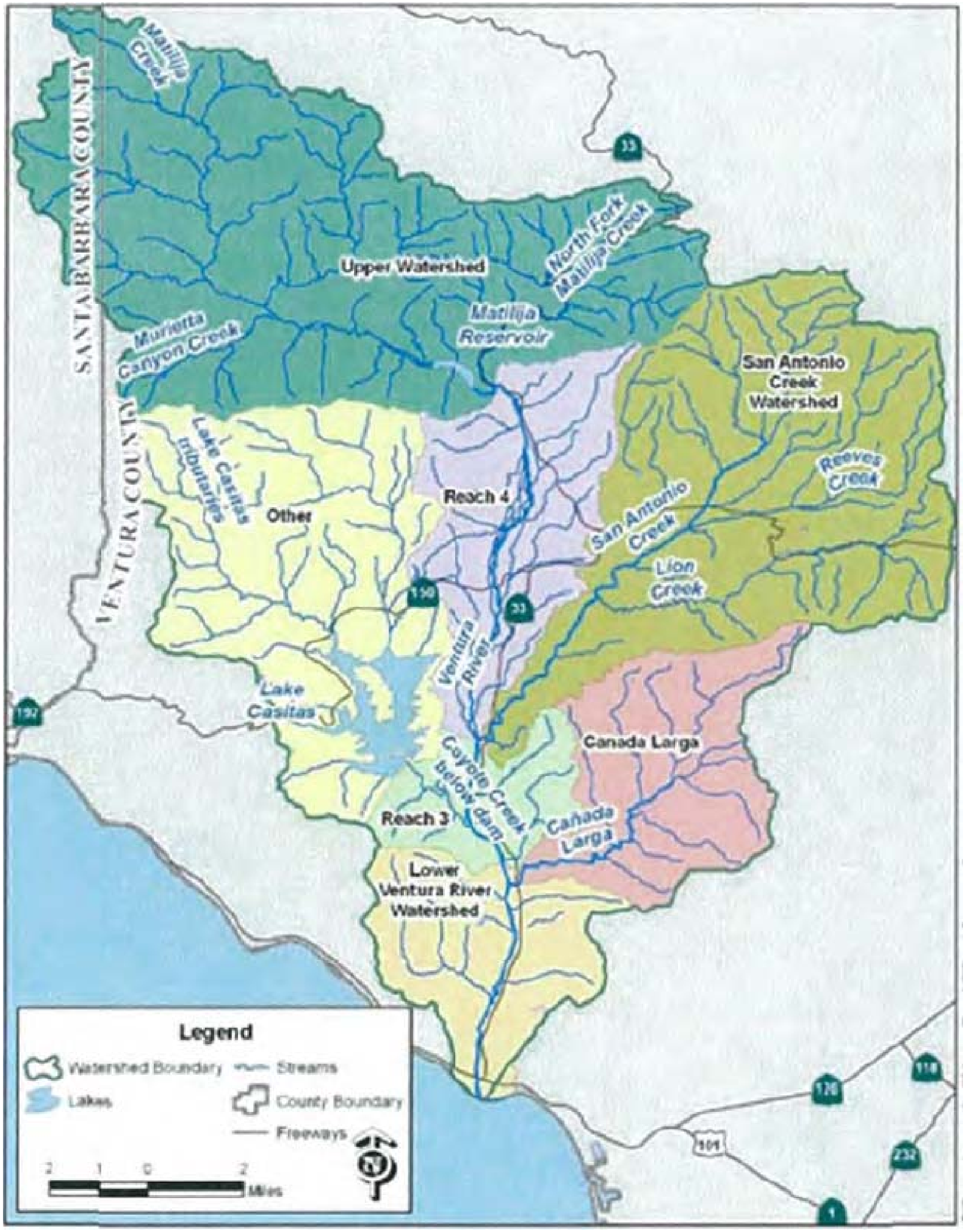
> In general, we observe between a 25% to over 75% exceedance of the DO objective at Reaches 3 and 4 based on pre-dawn data and a 0 to 20% exceedance rate later in the day along the main stem (including stations immediately upstream and downstream of the

impaired reaches). Furthermore, upon review of the pre-dawn and other DO data, it is evident that the critical location during the summer dry season for low dissolved oxygen is near and along Reach 4, immediately around the San Antonio Creek confluence. This area has the potential to significantly impair the aquatic life beneficial uses as survival is threatened in such degraded water quality. When comparing this area with the flow analyses, this stretch of Reach 4 appears to be gaining flow, despite the presence of diversions and well withdrawals; therefore, flow conditions are only a contributing factor to the overall impairments of the aquatic life beneficial uses. As discussed earlier, there are multiple factors that cause the observed impaired conditions of Reach 4, and these results support the conclusion that this TMDL examine all the relevant and applicable parameters responsible for the impaired condition.

The Ventura River Watershed Algae TMDL presents a detailed linkage between nutrient sources and their resulting in-stream concentrations for the Ventura River. This approach utilizes a one-dimensional QUAL2K steady state model that simulates stream transport and mixing processes.

Conditions in the estuary were assessed using the NNE BATHTUB spreadsheet modeling tool as well as empirical relationships between nutrient loading and algal biomass (see LARWQCB, 2012 for additional detail). Given that the Ventura River Watershed Algae TMDL focuses on the same beneficial use impairments and the pollutants causing these impairments are related, the results of the Ventura River Watershed Algae TMDL inform this TMDL's calculations.

Figure A-6. Ventura River Sub Watersheds Reach Segments (from LARWQCB, 2012) (Tetra Tech, 2012, Figure 4-1)



Pollutant Allocations and TMDLs:

This section of the report summarizes pollutant allocations and TMDLs. Summarized in the report (Tetra Tech, 2012) as:

> This section explains the development of the loading capacity and allocations for Ventura River Reaches 3 and 4. USEPA regulations require that a TMDL include waste load allocations (WLAs), which identify the portion of the loading capacity allocated to existing and future point sources (40 CFR §130.2(h)), and load allocations (LAs), which identify the portion of the loading capacity allocated to nonpoint sources (40 CFR § 130.2 (g)). TMDLs also include a margin of safety to account for any uncertainty in the analyses.

This included dry-weather allocations that include "additional entities related to assimilative capacity," wet-weather allocations, critical conditions, and margin of safety.

Implementation:

This section of the report summarizes implementation (Tetra Tech, 2012) as:

> This section describes the regulatory mechanisms that may be used to implement the TMDL and monitoring recommendations. The Ventura River Watershed Algae TMDL provided a detailed implementation plan, including specific regulatory mechanisms, how compliance with WLAs and LAs will be determined, implementation measures that could be used to attain WLAs and LAs and their associated costs, and an implementation schedule (LARWQCB, 2012).
>
> Implementation of this plan will attain both the Ventura River Watershed Algae TMDL as well as this TMDL for pumping and water diversions by restoring all applicable beneficial uses.

This action item includes WLAs and LAs. The potential implementation strategies and components considered included compliance and enforcement of state water rights, maintenance of bypass flow at Robles Diversions, continued implementation of the 2004 Ecosystem Restoration Feasibility Study, development of a Groundwater Management Plan, identification and completion of studies to evaluate the effects of pumping on habitat, and implementation of actions from NMFS's 2012 *Southern California Steelhead Recovery Plan*.

Finally, the structure of a proposed monitoring program is outlined with the following goals:

- Determine attainment of numeric targets;
- Determine compliance with the waste load and load allocations; and
- Monitor the effect of implementation actions on river and estuary water quality.

This monitoring program needs to be consistent with other ongoing programs and consist of three components: (1) receiving water monitoring, (2) discharger monitoring, and (3) optional special studies. Any special studies to be conducted by local responsible parties are designed to refine waste load and load allocations and numeric targets for potential refinements or changes in the TMDLs were listed in the report (Tetra Tech, 2012) as:

- Build upon the algal biomass and total nitrogen relationship established in the 2008 University of California at Santa Barbara Study (Klose et al., 2009) and collect data to support the establishment of reach-specific relationships.
- Confirm the conclusion that an algal biomass target of 150 mg/m^2 is fully protective of aquatic life and minimizes the risk of low DO events.
- Collect additional source assessment information and model input data to refine model predicted relationships between watershed loading and in-stream nutrient concentrations.
- Investigate the influence of OWTS on surface water quality.

- Collect data to support development of an estuary model, which takes into account tidal influence, the dynamics of macroalgae and phytoplankton growth, residence time, and breaching conditions.
- Collect continuous flow and DO data in Reach 4 to characterize these parameters within stream inputs and outputs, especially near and downstream of San Antonio Creek.
- Investigate potential sources of low DO exceedances with Reach 4, especially near and downstream of San Antonio Creek.

(9) Selected Additional Documents: (http://friendsofventurariver.org/document/)

Most of the documents in this archive are related to biological-related activities. This included reports from CMWD from Scott Lewis and Michael Gibson on the 2010 monitoring program presentation as well as mapping of invasive species such as Arundo from 2011, that may not have been considered in the current study plan for model development. Also posted are other historical documents such as the *Avenue Water Treatment Plant/Foster Park Facility Improvements Project Draft EIR* from URS Corp published by the City of San Buenaventura in 2003. However, the Friends of Ventura River did post one report from June 2013 entitled the *Comprehensive Water Resources Report* and its related appendices that was completed by Kevin Custorf of RBF Consulting that was funded and published by the City of San Buenaventura. Other older groundwater-related reports also were posted in this repository.

Based on the Executive Summary of the *Comprehensive Water Resources Report* the major summary issues identified by this study were:

- The City’s historical water rights to the Ventura River may be significantly limited as concern for the health of the endangered Southern California steelhead and its habitat ecosystem restrict how much and at what time of the year this water source is available. Storm events over the past 15 years have restricted our ability to withdraw historical amounts from this source.
- City allocation from two groundwater basins, Oxnard Plain Basin and Santa Paula Basin, are increasingly regulated and monitored. Studies being conducted by the oversight agencies have indicated that potential overdraft and water quality issues may occur in the near future.
- The Mound Groundwater Basin has experienced water quality degradation and projections for reliable supply may be lower than originally anticipated.

As stated in the summary, “This Comprehensive Water Resources Report (’Report’) is intended to be a tool in the development review process as it pertains to water supply and demand.” While the first summary item is relevant to the Ventura River Watershed resources, the other two items may also indirectly affect sources of water needed by the City of San Buenaventura. The first item acknowledged the constraints of water supply related to preserving steelhead habitat and climate variability representing the dry conditions of the recent and ongoing Mega-Drought.

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APPENDIX B: **Review of Codes and Code Issues**

As part of this Study Plan review, these code comparisons are required because the differences between them may result in different and potentially erroneous results from MF-NWT applications.

As part of the recent release of the newest USGS version 2 of MF-OWHM (also known as One-Water) the USGS MF-OWHM development team always scans all other new releases of other versions of MODFLOW and looks to incorporate any and all changes that are consistent with MF-OWHM. Since MF-OWHM is the most complete version of MODFLOW, it always contains all the original packages and supports the ability to run models built for any of the other versions of MODFLOW from MF-2005 to MF-NWT. In addition, prior to any release of MF-OWHM, the MF-OWHM team runs all example models that are released with any other packages and processes to verify that all features are still working properly and as originally demonstrated for that model feature. Only MF-OWHM provides all example models from all other releases of packages/processes as part of their release package. In this latest release, it was discovered that several features had potential coding errors that are relevant to any MF-NWT types of applications of MF-OWHM. These coding errors are similar to the 2014 MF-OWHM release (Hanson et al., 2014), where USGS discovered and fixed the coding error in MF-NWT relative to the Subsidence (SUB) Package, which was not tested prior to the release of MF-NWT (version 1.0.7, 1/12/2013) but was acknowledged and fixed in the release of version 1.0.8 (9/24/2013). The following errors are summarized in the release notes of MF-OWHM version 2, and some remain an issue for MF-NWT or any other codes that use MF-NWT, such as GSFLOW.

B.1 MF-OWHM Bug Fixes – Version 2.0.1 (6/25/2020) and 2.01a (4/14/2021)

The following summary of bug fixes exemplifies the ongoing support and development of MF-OWHM and some errors that may also exist in MF-NWT that may be outstanding.

(a) SFR issue that causes it to use one layer deeper than the water table layer when all layers are defined as convertible. Scott Boyce fixed this bug where One-Water was pointing to the Water Table at one layer lower than it should be. This only affected SFR and FMP when all the layers are convertible and using the NWT solver and was an issue in MF-OWHM only. \`SFR\` issue for segments with \`ICALC >= 2\` that would solve for stream depth with Newton-Raphson with an initial stream flow guess of zero instead of the stream reach's inflow. For most cases this fix only affected simulation runtime and only altered the solution after the sixth significant digit (single precision tolerance).

(b) \`MNW2\` using \`NWT\` resulted in the specific storage was not calculated correctly for use in the partial penetration correction.

(c) MNW2 using QLIMIT with NWT resulted in the models that failed to converge do to a bad index reference for well head.

(d) RCH and NWT packages with NRCHOP=3 did not pass recharge to the time step's upper most active layer. Previously, it only passed water to the upper most non-zero IBOUND cell rather than the upper most non-dry cell.

- To mimic the original behavior of RCH with NWT set NRCHOP = -1 , which applies recharge to the initial upper most non-zero IBOUND cell.

(e) UPW / NWT packages with convertible layers kept releasing water from storage after a model cell was dry.

(f) HydMod issue with HD (head) interpolation used the same four points for all observation points, which resulted in an extrapolation. Fixed such that head observations are interpolated by creating a four point finite element from the four closest surrounding cells

(g) \`FMP\` - \`LAND_USE (Crop) Block\` output files did not correctly write \`TOT_SURF_RUNOFF\` for crops that set \`SURFACEWATER_LOSS_FRACTION_PRECIPITATION\` to one. The affected options were \`BYWBS\`, \`BYWBS_BYCROP\`, \`BYCROP\`, \`ALL\`, and \`ALL_VERBOSE\`. This error had no affect on the actual simulation results nor other output files.

(h) \`MNW2\` using the \`THIEM\` losstype resulted in a warnings being triggered for a near zero skin radius, which is an input option used by he \`SKIN\` losstype. Error trapping in MNW2 added when user specifies top and bottom of well as same elevation that deactivates these wells and notifies user in the List and Warning Files (only available in MF-OWHM).

(i) Improvement on warning and error messages in \`MNW2\`, \`UPW\`, and \`NWT\` packages.

B.2 MF-NWT Functionality and Bug Fixes – Version 2.0.1 (6/25/2020)

Below is a summary of MF-NWT functionality and packages supported, along with published recent bug fixes for MF-NWT within the most recent release notes. Note that some of the bug fixes described for MF-OWHM that also overlap the MF-NWT are not included in this summary.

MF-NWT is on release 1.2.0 from 3/3/2020. The release notes specifically detail that the following packages are included but have not been tested with any of changed or new features of MF-NWT described in the MF-NWT release notes at one of the USGS software download sites (https://www.usgs.gov/software/modflow-nwt-a-newton-formulation-modflow-2005):

```
MF-NWT FUNTIONALITY

     MODFLOW-NWT can be run using the Newton linearization (NWT Package) and the
     Upstream-Weighting (UPW) Package or it can be run using the standard
     MODFLOW-2005 Picard linearization method (Harbaugh, 2005). Thus, some
     MODFLOW-2005 Packages are supported by MODFLOW-NWT only when using the Picard
     linearization method of MODFLOW-2005. This version of MODFLOW-NWT includes
     the following MODFLOW-2005 packages:

     MODFLOW-2005 packages:
         BAS -- Basic Package
         BCF -- Block-Centered Flow Package (Picard only)
         CHD -- Time-Variant Specified-Head Option
         DE4 -- Direct solver (Picard only)
         DRN -- Drain Package
         EVT –– Evapotranspiration Package
         GAG -- Gage Package
         GHB -- General Head Boundary Package
         HFB -- Horizontal Flow Barrier Package
         HUF -- Hydrogeologic-Unit Flow Package (Picard only)
         LAK -- Lake Package
         LPF -- Layer-Property Flow Package (Picard only)
         MNW1 -- Multi-Node Well Package, version 1
         MNW2 -- Multi-Node Well Package, version 2
         OBS –– Observation Process
         PCG -- Preconditioned Conjugate Gradient Package (Picard only)
         RCH –– Recharge Package
         RIV –– River Package
         SFR -- Streamflow-Routing Package
         SIP -- Strongly Implicit Procedure Package (Picard only)
         SWR -- Surface-Water Routing Package
         UZF -- Unsaturated-Zone Package
         WEL -- Well Package
         SWT -- Subsidence-Water Table Package
         SWI -- Sea Water Intrusion Package
         LMT -- Link-MT3DMS Package
```

```
     Other packages that are included with the MODFLOW-NWT release but have not
been
     tested include:

     MODFLOW-2005 packages:

         DRT -- Drain Return Package
         ETS -- Evapotranspiration Segments Package
         FHB -- Specified Flow Package
         Hydmod -- Hydrograph data for BAS Package
         IBS -- Interbed Storage Package
         RES -- Reservoir Package
         STR -- Stream Package
         SUB -- Subsidence Package

     Packages originally developed for MODFLOW-NWT

         AG -- Agricultural Water Use Package
```

The most recent bug fixes and upgrades reported in the MF-NWT Release notes are summarized below for version 1.2.0. These changes do not reflect the additional bug fixes identified for NWT-related packages with the release of MF-OWHM (4/7/2020) summarized above.

```
MF-NWT Version 1.2.0 03/01/2020:

Agricultural (AG) Water Use Package
• This is the first version of MODFLOW-NWT that includes this package.
Refer to Niswonger (2020) for details. Documentation for the AG Package
in included in the pdf document called AG_Package_EM&S.pdf located in
the "doc" folder. Additionally, input instructions for the AG Package are
included in the document called Input_instructions_AG.pdf located in
the "doc" folder.

Streamflow Routing (SFR2) Package
• A check was added to allow stream reaches to have altitudes below the
cell bottom if streambed K (UHC) is zero.
```

- Capability was added to allow a single tabfile to specify flows into multiple stream reaches.

Well (WEL) package

- Character variable text was initialized in PARSEWELLOPTIONS
- A bug was fixed that was setting IUNITRAMP to default value; an incorrect write statement was stating that PSIRAMP was also changed; however, it was not changing from user-specified value. The default value for PSIRAMP was changed to 0.10.

Unsaturated-Zone Flow (UZF1) Package

- A new option was included for specifying the layer to which UZF recharge is added (NUZTOP=4). If NUZTOP is specified as 4, then the values of IUZFBND are used to define the top of the unsaturated zone, and recharge is added to the uppermost layer in a column that contains a water table. The layer to which recharge is added is updated at the beginning of each new time step and is held constant during a time step.
- A small bug was fixed that was causing the counter on trailing waves to be off by one. This bug only affected model in very rare cases; but, this bug could cause the model to stop suddenly.
- The calculation for total applied runoff that is output to the UZF gage file option 4 was incorrect. This variable only is used for gage file output and does not affect any other calculated values.
- A new option was added to simulate root uptake from the unsaturated zone. This option simulates root water uptake using a capillary gradient between a user specified root pressure and the simulated capillary pressure in the root zone. This formulation is documented in Lappala and others (1987).

Lappala, E. G., Healy, R. W., & Weeks, E. P. (1987). Documentation of computer program VS2D to solve the equations of fluid flow in variably saturated porous media. Water-Resour. Invest. Rep, 83, 4099.

Lake (LAK) Package

- The interval for which derivatives are smoothed to zero in the calculation of specified outflows from lakes was changed from a constant to a variable.
- The dead pool storage for a lake (volume of water below lowest outflow reach) is calculated and printed to the main listing file.

Basic (BAS) Package

- The size of character variables was increased to print larger words to the LIST file budget table.

Link-MT3DMS (LMT) Package

- A change was made to make diversions from the last reach of a segment, rather than the first reach as was incorrectly assumed.
- Bug fix to prevent specification of linker file in both the name file and the LMT input file. This was creating a potential for conflicting unit numbers
- Bug fix in LMT that was wrongly listing the first reach of IUPSEG as the 'from' node when it should have been using the last reach of the IUPSEG as the node from which flow is diverted to the diversion segment.
- Bug fix for writing cross-sectional area to linker file for MT3D-USGS. Previously, when a diversion diverts all flow, the code was using the wrong variable for flow for calculating stream cross-sectional area.

Gage Package

- A minor output problem occurred when writing output for lakes when the Lake Package input specified RNF as a negative value, which is used as a flag, and OUTTYPE = 1, 3, or 4. The Gage output file incorrectly included the negative value rather than the actual computed value of runoff to the lake. This problem was corrected. The model user does not need to do anything differently. Note, all model calculations were correct (and not affected by the fix) and that correct values for runoff to a lake were always printed in the main output (listing) file.

Upstream Weighting (UPW) Package

- A warning was added indicating that IPHDRY is set to 1 (print HDRY) and observation packages are active. IPHDRY should be set to zero because if IPHDY is set to 1 then observation values could erroneously be calculated using HDRY.

MF-NWT Case Studies: Some are listed on the USGS-MF-NWT website, but none are more recent than 2016.

Selected differences between MF-OWHM and MF-NWT:

(1) The new MF-NWT AG Package has limited functionality and does not perform some of the tasks included in previous or the current version of the Farm Process (FMP4) within MF-OWHM.

(2) The new AG Package also uses PRMS HRUs, so its ability to delineate specific regions that demand water from specific sources may be problematic and may not be compatible with a gridded PRMS model structure.

(3) The UZF Package now has a root uptake feature like FMP but does not account for anoxia or wilting.

(4) PRMS now allows for transient land use but not fractional land use within each model cell as is done by FMP4 and RIP-ET within MF-OWHM.

(5) MF-OWHM has additional NWT features, such as interlayer flow across HFBs and additional NWT solver options, that are not available in MF-NWT.

(6) HFB in MF-OWHM allows for transient HFB features and redirected flow (with NWT solver only) not available in MF-NWT.

(7) Additional solvers are available in MF-OWHM (Geometric Multi-Grid [GMG] & Preconditioned Conjugate Gradient Solver with Improved Nonlinear Control (PCGN) Package.

(8) Many bug fixes and programming issues were resolved in MF-WOHM that may persist in MF-NWT.

B.3 MT3D-USGS Code Summary

Version 1.1.0 was released on 6/28/2019 (https://www.usgs.gov/software/mt3d-usgs-groundwater-solute-transport-simulator-modflow) with the collaboration of Vivek Bedekar (SSPA). Based on recent written communication with Mr. Bedekar (Bedekar, 2021), only bug fixes are being completed now with no new or additional ongoing development.

The release notes indicate minor bug fixes, but do not include any additional linkages to the new MF-NWT AG Package:

> Bug Fixes:
>
> - Fixed floating-invalid error in SSM1OT (ssm1.f)
> - Fixed wrongful reporting of mass lost to ET when the DRYCELL keyword is used in BTN. Occurred when user specified non-zero value of CINACT
>
> Other:
>
> - Added a comment to reflect that the ICBCSF flag is currently inactive in sft1.f
> - Time interpolation added for TVD in adv1.f
> - Changes to the github auto-testing framework suggested by Mike Toews were adopted.

Based on the Flow-Transport Link Subroutine (fmi1.f) the following features are currently supported for flow linkages for 28 features. Because of this coding design/structure, with "hard-wired" variables for individual features, the code would have to be rewritten to add any other features from LMT8 or an updated version of LMt8 from MF-NWT:

(1) WEL,
(2) DRN,
(3) RCH,
(4) EVT,
(5) RIV,
(6) GHB,
(7) STR,
(8) RES,
(9) FHB,
(10) IBS,
(11) TLK, (If this is the Transient Leakage Package this is not present in MF-NWT or MF-OWHM)
(12) LAK,
(13) MNW,
(14) DRT,
(15) ETS,
(16) SWT,
(17) SFR,
(18) UZF,
(19) LAKFLOWS,
(20) MNWFLOWS,
(21) SFRFLOWS,
(22) UZFFLOWS,
(23) SWR,
(24) SWRFLOWS,
(25) SFRLAK,
(26) SFRUZF,
(27) LAKUZF, and
(28) SNKUZF

Packages and Processes not supported by MF-NWT or MF-OWHM LMT8 flow interface package include FMP, RIP-ET, DRT, SWI, SUB, and MF-NWT's AG Package.

B.4 GSFLOW Code Summary (Version 2.1.0, 4/4/2020) (Markstrom et al., 2008)

The following code summary itemizes the components of the GS-FLOW code for this version and release.

FUNCTIONALITY, Version 2.1.0 Additional Bug Fixes and modifications and release summary are summarized in the release document GSFLOW_Release_Notes_2.1.0.pdf.

PRMS Modules and Utility Routines (listed in computation order; all are modules, unless noted; yellow highlight designates new modules for this version]

basin Module
climateflow Climate and Flow Parameters and Variables Input (Utility Routine)
cascade Cascading-Flow Module
obs Observed-Data Module
dynamic_param_read Dynamic Parameter Input Module
water_use_read Water-Use Input Module
prms_time Time Variable Computation (Utility Routine)
soltab Potential Solar-Radiation Module
temp_1sta One-Station Air-Temperature-Distribution Module
temp_laps Lapse-Station Air-Temperature-Distribution Module
temp_dist2 Inverse-Distance Air-Temperature-Distribution Module
temp_sta Station Air-Temperature-Distribution Module
precip_1sta One-Station Precipitation-Distribution Module
precip_laps Lapse-Station Precipitation-Distribution Module
precip_dist2 Inverse-Distance Precipitation-Distribution Module
xyz_dist Multiple Linear Regression Precipitation and Temperature-Distribution Module
ide_dist Inverse Distance and Elevation Precipitation and Temperature-Distribution Module
climate_hru Pre-computed and Distributed Climate Module
ddsolrad Degree-Day Solar-Radiation Distribution Module
ccsolrad Cloud-Cover Solar-Radiation Distribution Module
potet_jh Jensen-Haise Potential-Evapotranspiration Module
potet_hamon Hamon Potential-Evapotranspiration Module
potet_pan Pan-Evaporation Potential-Evapotranspiration Module
potet_hs Hargreaves and Samani Potential-Evapotranspiration Module
potet_pt Priestly–Taylor Potential-Evapotranspiration Module
potet_pm Penman–Monteith Potential-Evapotranspiration Module that uses wind-speed and humidity data specified in CBH Files
potet_pm_sta Penman–Monteith Potential-Evapotranspiration Module that uses wind-speed and humidity data specified in the PRMS Data File
transp_frost Frost Based Active Transpiration Period Module
frost_date1 Preprocess Spring and Fall Frost Module
transp_tindex Temperature Index Based Active Transpiration Period Module
intcp Precipitation-Interception Module
snowcomp Snow Module
srunoff_smidx Nonlinear source Area Surface-Runoff and Infiltration Module
srunoff_carea Linear Source Area Surface-Runoff and Infiltration Module
soilzone Soil-Zone Module
gwflow[1] Ground-Water Reservoir Module

subbasin Subbasin Module
routing[1] Stream Network Computations Routing (Utility Routine)
strmflow[1] Streamflow Module
muskingum[1] Muskingum Streamflow Routing Module muskingum_mann1 Muskingum Streamflow Routing using
Manning's N Module
strmflow_in_out1 Streamflow routing with inflow equals outflow for each segment
muskingum_lake1 Muskingum Streamflow and Lake Routing Module stream_temp1 Stream Network
Temperature Module
water_balance Water Balance Debug (Utility Routine)
nhru_summary Write User-Selected HRU-based Variables to CSV File Module
nsegment_summary Write User-Selected Stream Segment Variables to CSV File Module
nsub_summary Write User-Selected Subbasin Variables and HRU-based Variables Summarized by Subbasins to CSV File Module
basin_summary Write User-Selected Basin Variables to CSV File Module
prms_summary1 PRMS Summary Module
basin_sum1 Watershed Flow-Summary Module
map_results Map Based Output Module
write_climate_hru1 Generate Climate-by-HRU Files Preprocess Module
convert_params Generate PRMS-IV or PRMS-V Parameters Preprocess Module

[1]This module is used for PRMS-only simulations.

[2]Note that the names of PRMS modules are different than those shown in the GSFLOW manual (TM 6-D1) and in previous release notes. A warning message is printed if an old name is used, but the code is downward compatible, so users do not need to change the old module names.

GSFLOW Modules

gsflow_prms Computational-Sequence Control for PRMS and GSFLOW
gsflow_modflow Computational-Sequence Control for MODFLOW Module
gsflow_prms2mf PRMS to MODFLOW Integration Module
gsflow_mf2prms MODFLOW to PRMS Integration Module
gsflow_budget Watershed-Budget Summary Module
gsflow_sum Flow-Components Summary Module

MODFLOW Packages In GSFLOW: The Geometric Multi-Grid (GMG) and PCGN Solver Packages are not included in this version of GSFLOW; it is available in version 1.2.1. [yellow highlight designates existing MODFLOW packages that were added to GSFLOW for this version] Packages that cannot be used with GSFLOW are also (green highlight) and include Subsidence, Seawater Intrusion, Surface-Water Routing Process, Drains, Recharge, ET (outside of UZF), reservoir leakage, and output to MT3D-USGS.

BAS Basic Package
BCF Block-Centered Flow Package
UPW Upstream-Weighting Flow Package
LPF Layer-Property Flow Package
HUF Hydrogeologic-Unit Flow Package
HFB Horizontal Flow Barrier Package
DRN[1] Drain Package
DRT[1] Drain and Return Flow Package
ETS[1] Evapotranspiration Segments Package

EVT[1] Evapotranspiration Package
IBS[1] Interbed Storage Package
RCH[1] Recharge Package
WEL Well Package
GHB General Head Boundary Package
FHB Flow and Head Boundary Package
CHD Time-Variant Specified-Head Option
RES[1] Reservoir Package
RIV[1] River Package
STR[1] Stream Package
SWR[1] Surface-Water Routing Package
SUB[1] Subsidence Package
UZF Unsaturated-Zone Flow Package
SFR Streamflow-Routing Package
LAK Lake Package AG Agriculture Package
AG Agriculture Package
GAG Gage Package
MNW1 Version 1 of the Multi-Node Well Package
MNW2 Version 2 of the Multi-Node Well Package
SWI[1] Sea Water Intrusion Package
SWT[1] Subsidence for Water-Table Package
SIP Strongly Implicit Procedure Package
DE4 Direct Solver Package
PCG Preconditioned-Conjugate Gradient Package
NWT Newton Solver Package
LMT[1] Link MT3DMS Package
OBS Observation Process (BAS, CHD, GHB, DRN1, RIV1, STR1)
[1] This package is used for MODFLOW-only simulations.

B.5 Cascade Routing Tool (CRT) (Version 1.3.1, 3/30/2017, Henson et al., 2013)

The Cascade Routing Tool (CRT) is used to define and visualize flow paths for grid-based watershed models. CRT is available through the USGS California Water Science Center at: https://www.usgs.gov/software/crt-cascade-routing-tool-define-and-visualize-flow-paths-grid-based-watershed-models.

The USGS Cascade Routing Tool (CRT) is a computer application for watershed models that include the coupled groundwater and surface-water FLOW model GSFLOW and the PRMS. CRT generates output to define cascading surface and shallow subsurface flow paths for grid-based model domains. CRT also includes an option to condition the grid-scale DEM to fill unintended swales and to provide continuous down-sloping HRUs that follow streams. CRT requires a land-surface elevation for each HRU of the model grid; these elevations can be derived from a DEM raster data set of the area that contains the model domain. Additionally, a list is required of the HRUs that contain streams, swales, lakes, and other cascade termination features along with indices that uniquely define these features. Cascade flow paths are determined from the altitudes of each HRU. Cascade paths can occur across any of the four faces of an HRU, to a stream, or to a lake within or adjacent to an HRU. Cascades can terminate at a stream, lake, or HRU that has been designated as a watershed outflow location. The CRT tool can be used for a combination of SFR segments from natural channels combined with segments that can represent storm-drain networks, as is the case in the lower part of the Ventura River Watershed and the Ojai Basin.

B.6 Appendix B References

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