eki environment & water

Corporate Office
577 Airport Boulevard, Suite 500
Burlingame, CA 94010
(650) 292-9100
ekiconsult.com

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**DRAFT MEMORANDUM**

To: Cosumnes Subbasin Working Group

From: Anona Dutton, P.G., C.Hg., EKI Environment & Water, Inc. (EKI)
John Fio, EKI
Dave Leighton, EKI
Christina Lucero, P.G., EKI

**Subject: Draft Technical Memorandum #2 - Model Evaluation and Recommendation**
Cosumnes Subbasin, Sacramento County, CA
(EKI B80081.00)

EKI reviewed and evaluated groundwater modeling options available to comply with the California Sustainable Groundwater Management Act (SGMA) Groundwater Sustainability Plan (GSP) Regulations.[1] The GSP Regulations require that the "best available science" be used to quantify the water budget for a basin (23-CCR §354.18) and to support the definition of management actions (23-CCR §354.44), among other things. The California Department of Water Resources (DWR) review of GSPs will include consideration of whether the "best available science" supports the assumptions, criteria, findings, and objectives of the GSP. Given the spatial and temporal complexity often observed in groundwater basin conditions and water levels, determination of a basin-scale water budget, the estimate of sustainable yield, and development of other key GSP elements (e.g., sustainable management criteria) will best be accomplished through use of a numerical model.

Based on multiple discussions with the Cosumnes Subbasin Working Group (Working Group), basin stakeholders, and the GSP Leadership Team[2], the modeling options considered to support Cosumnes Subbasin GSP development included:

- California Central Valley Groundwater-Surface Water Simulation Model Fine-Grid (C2VSim-FG);
- Central Valley Hydrologic Model (CVHM);
- Sacramento Valley Groundwater-Surface Water Simulation Model (SVSim);
- Sacramento Area Integrated Water Resources Model (SacIWRM);
- A custom, stand-alone model developed for the Cosumnes Subbasin; and
- A custom, nested model developed for the Cosumnes Subbasin.

[1] California Code of Regulations (CCR) Title 23 – Waters, Division 2 – Department of Water Resources, Chapter 1.5 – Groundwater Management, Subchapter 2 – Groundwater Sustainability Plans and Alternatives.

[2] The Cosumnes Subbasin GSP Leadership Team includes representatives from Water Forum, the Consensus Building Institute, EKI, and Sacramento County (as the grant administrator).

Based on direction provided by the Groundwater Sustainability Agency (GSA) representatives during our call on 19 November 2019, the models were first evaluated against the following pass/fail criteria:

- **Release Date** - The model needs to be available to support Cosumnes Subbasin GSP development;
- **Model Capability** - The model must be able to support water budget development, Sustainable Management Criteria (SMC) development, and evaluation of Project and Management Actions (P&MAs), among other items necessary for GSP development; and
- **Budget** – The model development/update must be able to be achieved within the available budget.

The models were then evaluated against the following criteria in order of importance defined by the by the GSA representatives during our call on 19 November 2019:

1) Represents Hydrogeological Conceptual Model (HCM) accepted by Working Group and employed for Cosumnes Subbasin GSP;
2) Supports coordination with adjacent basins and regional water supply planning (e.g., groundwater banking);
3) Minimum cost for future maintenance, implementation, and adaptive management;
4) Working Group is primary decision maker; and
5) Schedule allows Working Group opportunity to provide input to model development/update.

Our evaluation concluded that a custom, nested model is the preferred approach to support Cosumnes Subbasin GSP development. Using a nested modeling approach, a detailed model is constructed for the area of greatest interest (in this situation, the Cosumnes Subbasin) and the hydrologic conditions at the nest models' boundaries are determined by a larger-scale regional model. In the Cosumnes Subbasin, the nested model can: (1) be based on the most current HCM accepted by the Working Group; (2) more accurately represent the basin; and (3) be nested within a regional model to support coordination with adjacent basins. Because the nested model will be developed by and for the Working Group, the GSAs will be the primary decision makers related to model development and use, and are ensured it will meet their GSP development schedule and budget.

An evaluation of the modeling options considered, the ranking criterion employed, and the evaluation results is included as Attachment 1.

# ATTACHMENT 1:

# Model Evaluation and Recommendation

## 1 INTRODUCTION

To comply with SGMA GSP Regulations, the GSP prepared for the Cosumnes Subbasin must utilize the "best available science" to quantify the water budget for the Basin (23-CCR §354.18) and to support the definition of management actions (23-CCR §354.44), among other things. This Technical Memorandum summarizes the review and evaluation of the modeling options available to the Working Group to support development of the Cosumnes Subbasin GSP.

Existing models were assessed to determine whether one or more would be suitable to support Cosumnes Subbasin GSP development, or whether it would be better for the Working Group to develop a custom model. A comparative analysis of the model histories, construction, and calibration parameters reveals their relative strengths and weaknesses, and supports the recommendations included herein.

## 2 MODEL OPTIONS

The following modeling options were evaluated herein:

1) **C2VSim-FG**, a numerical model developed by DWR which covers the entire Central Valley. The fine grid version currently available is a "Beta" uncalibrated version and a final calibrated version is expected for release in the first part of 2019;
2) **CVHM**, a numerical model updated by the United States Geological Survey (USGS) in 2009 which covers the entire Central Valley and is currently being updated;
3) **SVSim**, a numerical model developed by DWR which covers the Sacramento Valley;
4) **SacIWRM**, a numerical model developed by RMC Water and Environment/WRIME which covers the North American, South America, Cosumnes, and part of the ESJ subbasins and is currently being updated;
5) **Custom, stand alone**, a numerical model which would be developed for the Cosumnes Subbasin for SGMA purposes. The model extent would be located far enough from the Cosumnes Subbasin geographic boundaries to minimize influence on model-calculations within the basin, but near enough to allow appropriately detailed input, reasonable model run time and manageable processing of model output; and
6) **Custom, nested**, a numerical model which would be developed for the Cosumnes Subbasin for SGMA purposes. The Cosumnes Subbasin and immediately adjacent areas would be "nested" within a larger regional model domain.

Table 1 presents a comparative analysis of the technical model details, including information related to model history, construction, and calibration.

- **Model history** considered who developed the model, who the model was developed for, and its projected availability to support Cosumnes Subbasin GSP development (i.e., would it be available by April 2020).

- **Model construction** considered the modeling platform, the spatial domain represented by the model grid, the spatial resolution of the grid (the size or area of model elements and cells), vertical layering, temporal scheme (steady-state or transient), and temporal resolution (length of time step).
- **Model calibration** considered the type, number, and distribution of calibration points (observations), the calibration period (the historical period the model is calibrated to), hydrologic processes represented by the model, the flexibility of the model relative to changes in the input and processes represented, and effort to run model.

Specific categories compared in Table 1 and their implications are further discussed below.

## Model History

- Model developed (both by and for): Who the model developer is has implications for model reliability as well as potential bias. Model design is also influenced by the question(s) the model was developed to answer.
- Status: If, or when, the model will be available to the Working Group to: (a) support model development for the Cosumnes Subbasin; or, (b) apply directly to support Cosumnes GSP development.

## Model Construction and Calibration

- Model platform: This category defines the numerical engine that is employed to solve the groundwater-flow equation for water levels, fluxes, and volumetric budget terms. All models evaluated are based on SGMA approved platforms (Integrated Water Flow Model [IWFM] and Modular Three-Dimensional Finite Difference Ground-Water Flow Model [MODFLOW]).
- Spatial domain: The geographical area represented by the model grid can be linked to model objectives, refinement and run-times. All models evaluated include at a minimum the geographic extent of the Cosumnes Subbasin.
- Spatial resolution: The size of the element or cell size employed by the model gives perspective on model objectives, refinement and run-times. Where known, this information is specifically provided for the Cosumnes Subbasin.
- Vertical layering: The vertical layering employed by the model gives perspective on model objectives, refinement and the depth distribution of model layers representing one- or more aquifers. All models considered represent the vertical extent of fresh-water bearing zones beneath the Cosumnes Subbasin boundaries and adjacent areas.
- Temporal scheme & resolution:
    - Scheme: Models can be used to represent either steady state (long-term average conditions) or transient (groundwater levels and storage changes over time). Because GSP preparation requires consideration of climatic variability and changes in land and water use, including projected changes that result from climate change and other drivers, a transient model is needed. All models evaluated are transient models.

   - Resolution: Short time steps are typically more stable and can account for similarly short-term events like seasonal changes in groundwater level response to increased pumping during irrigation months. However, short time steps can also increase model run times. Longer time steps can project relatively longer-term trends, but can miss management criteria exceedances. For example, annual time steps can project yearly averages but miss relative minimum or maximum conditions that could be associated with undesirable results. All models evaluated range from daily to monthly time-steps.

- Model calibration: The number of calibration points can help assess model performance and generally increases model reliability within a basin. Where known, the number of calibration points, including both wells and streams, is provided for the Cosumnes Subbasin.

- Calibration period: The period over which model performance to calibration points were compared and calibrated is presented. DWR's Best Management Practices (BMPs)[3] recommend that at least the most recent ten years (from current, defined as 2015) of historical water budget information be quantified and assessed. Therefore, models whose calibration period includes 2005-2015 will more adequately simulate the water budget for SGMA purposes.

- Processes considered: The hydrologic processes represented by the model and modeling platform are inventoried. These include: recharge, pumpage, their relationship to agricultural demand, surface-water groundwater interactions, imported surface water deliveries and conjunctive use operations. All models evaluated have capabilities for the hydrologic processes considered.

- Model input flexibility: This addresses the issue of flexibility of model input, especially changes to model design and construction which can be necessary because of changes to the HCM within the Cosumnes Subbasin. Specific model inputs that may need to vary based on GSP work within the basin include pumping rate specifications, land use, groundwater recharge calculations, aquifer structure and properties, model grid spacing and layering, and solute transport capabilities.

- Effort to run: The level of specialized expertise to run the model and extract the output, the length of time to run the model (lengthy runtimes can be burdensome on the analysis process), and difficulty to process model output for analysis varies between models. For example, some of the modeling platforms do not have existing post-processing tools to examine model-calculated water budgets, groundwater level contour maps, hydrographs, groundwater flow, and solute transport, if needed.

## 3 RANKING CRITERIA

Models were ranked based on the above evaluation relative to key criterion identified by the GSAs as most important to the Cosumnes Subbasin GSP development. The models were ranked using two slightly different approaches – weighted and unweighted criterion. The weighted approach acknowledges that some criterion are more important than others, whereas the unweighted approach assumes all criterion are of equal importance.

[3] California Department of Water Resources, 2016, *Best Management Practices for the Sustainable Management of Groundwater Water Budget BMP*, December 2016

## Pass/Fail Model Selection Criteria

The ranking process considered three criteria as pass/fail, meaning if the model did not meet the criteria it effectively removed it from consideration. The three criteria were:

- Release Date: Is the existing model, or its planned update available on or before April 1, 2020?
- Model supports water budgets, SMC development, and evaluation of P&MAs: Can the model output the necessary information required to support GSP development? Specifically, can the model: (a) tabulate water budget information; (b) assist with SMC development (for example, quantify water levels and streamflow changes under various scenarios); and, (c) provide output for specific areas that will provide reliable information on potential P&MAs within the model domain?
- Budget: Is the model development and update cost within the budgeted amount?

## Ranked Priority Criteria

1) Represents HCM accepted by Working Group and employed for Cosumnes Subbasin GSP: Does the model sufficiently represent the HCM accepted by the Working Group? We note that, as the available data has not yet been compiled and evaluated as part of GSP development, the HCM has not yet been developed or accepted by the Working Group. The HCM is planned for completion September 2019. As such, any models being updated or developed now will necessarily not have the benefit of input by the Working Group and likely will not be able to incorporate such input in late 2019, given the current model update schedules.

2) Supports coordination with adjacent basins and regional water supply planning (e.g., groundwater banking): Does the model support coordination with adjacent basins by capturing cross boundary flows, among other things? Regional models, which potentially represent multiple basins, are generally better able to effectively support regional water supply planning, at a certain scale (i.e., they may be less able to assess the benefit of a local water supply augmentation program).

3) Minimum cost for future maintenance, implementation, and adaptive management: Which model would have the least cost for the Working Group to maintain and use moving forward during GSP implementation?

4) Working Group is primary decision maker: Will the Working Group be the primary decision maker on key model development decisions such as the schedule, cost, grid/mesh extent, cell/element orientation and areas, layering, and boundaries for representing the Cosumnes Subbasin? Furthermore, can the Working Group provide definitive input on the performance criteria employed during model calibration, the determination of acceptable model performance levels, and the reporting and interpretation of results?

5) Schedule allows Working Group opportunity to provide input to model development/update: Does the pre-existing model development schedule allow the Working Group to provide data collected, collated, compiled, and evaluated as part of GSP development for consideration when developing model input data?

## 4 EVALUATION

Tables 2 and 3 present the unweighted and weighted evaluation results, respectively.

**Table 2**. For the unweighted evaluation, all criterion received either a “1” indicating the model meets the criterion or a “0” indicating the model fails the criterion.

**Table 3.** For the weighted evaluation, the pass/fail and ranked priority criteria were evaluated slightly differently. The pass/fail criteria are given the highest score (a value of “5”) when the model passes, and the lowest null (or “0”) score when it fails. In contrast, for the ranked priority criteria the most important criterion received the highest-ranking score of “5” when met, the second most important criterion received a score of “4” when met, and so forth to the lowest criterion which received a score of “1” when met. The null or “0” score is assigned when the model fails to meet the criterion.

All models except for SacIWRM pass the pass/fail categories. SacIWRM is currently being updated by Woodard and Curran for the North American and South American Subbasin Water Purveyors and it’s completion date is not expected until the Summer of 2020, which is after the April 2020 deadline specified in the Cosumnes Subbasin GSP development schedule.

Like the SacIWRM, the Central Valley-wide and regional models all do not meet the HCM criterion (criterion 1) because the HCM has not yet been developed or accepted by the Working Group and therefore cannot be the basis for those models.

The Central Valley, regional, and custom nested models all meet criterion 2, and sufficiently represent the extents of adjacent subbasins to support adjacent basin coordination.

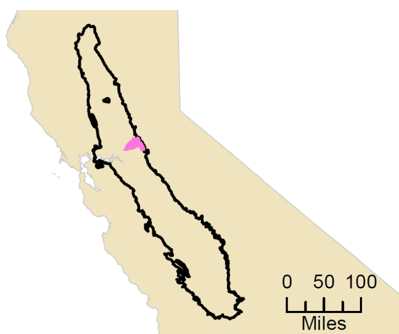
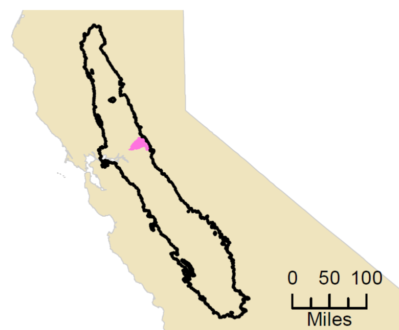
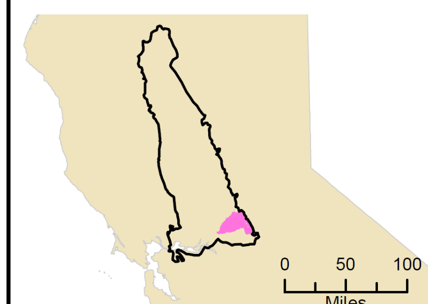
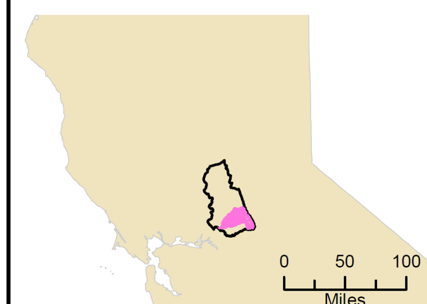
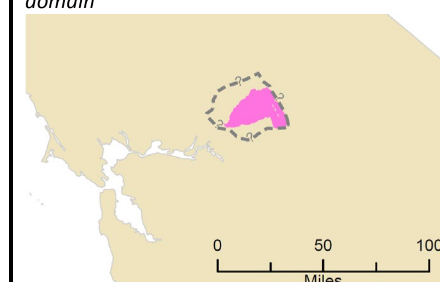
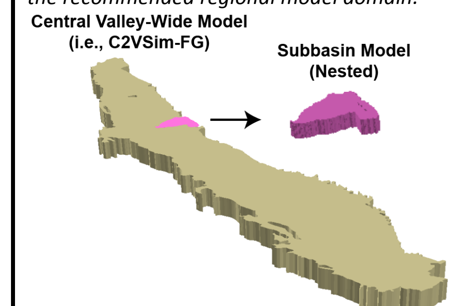
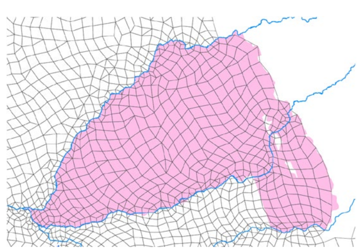
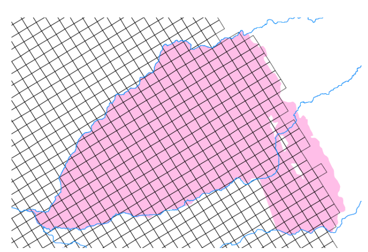
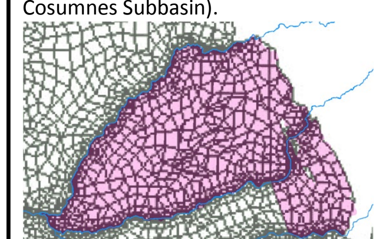
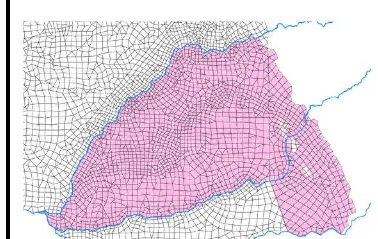
The Central Valley and regional models would require minimum support costs for future maintenance because other agencies are supporting their development and maintenance (criterion 3). However, as a result the Working Group is not the primary decision maker related to modeling development (criterion 4).

Finally, only the schedule for the SacIWRM or either a custom stand alone or custom nested model allows the Working Group to provide input and direction for model development and update (criterion 5). However, as mentioned before the expected release date for the SacIWRM appears to eliminate it as a viable modeling option for the Cosumnes Subbasin.

## 5 RECOMMENDATION

Based on both the unweighted and weighted evaluation results presented in Tables 2 and 3, respectively, our evaluation concludes that a custom, nested model best meets the above criterion and needs of the Working Group for Cosumnes Subbasin GSP development and implementation. The primary strengths for this approach include best representing the HCM accepted by the Working Group and employed in the Cosumnes Subbasin GSP while also supporting coordination with adjacent basins. Because the nested model will be developed by and for the Working Group, the GSAs will be the primary decision makers related to model development and use, and are ensured it will meet their GSP development schedule and budget.

# TABLE 1
# COMPARATIVE ANALYSIS OF POTENTIALLY APPLICABLE GROUNDWATER MODELS

| Model Characteristics | | *Central Valley-Wide Models* | | *Regional Models* | | *Subbasin Models* | |
|---|---|---|---|---|---|---|---|
| | | C2VSim Fine-Grid | CVHM | SVSim | SacIWRM | Custom (Stand Alone) | Custom (Nested) |
| Model History | Model Developed By: | DWR (2018), as an update to coarse grid model | USGS (2009), as an update to CV-RASA model (Williamson and others, 1989) | DWR | RMC Water and Environment/WRIME (2011) | EKI | EKI |
| Model History | Model Developed For: | DWR, federal/state entities, and public use | USGS Groundwater Availability Program, federal/state entities, and public use | Simulation of basin-wide groundwater conditions with a focus on stream-aquifer interactions | Sacramento Groundwater Authority, Sacramento Central Groundwater Authority, South Area Water Council | Cosumnes Working Group | Cosumnes Working Group |
| Model History | Status: | Development in progress; expected release first part of 2019 | Update in progress; possibly available in late 2019 | Development in progress; expected release 1st Quarter 2019 | Update by Woodard & Curran for North American and South American Subbasin Water Purveyors in progress; expected completion Summer 2020 | Expected completion April 2020 | Expected completion April 2020 |
| Model Construction and Calibration | Model Platform | Integrated Water Flow Model (IWFM) | MODFLOW-2000 with Farm Process (MF2K-FMP) | IWFM | IWFM | MODFLOW or IWFM | MODFLOW or IWFM |
| Model Construction and Calibration | Spatial Domain | Central Valley   | Central Valley   | Sacramento Valley   | North American, South American, Cosumnes, and part of Eastern San Joaquin subbasins   | Physical and hydrologic boundaries are located far enough from the Cosumnes Subbasin geographic boundaries to minimize influence on model-calculations within the Subbasin, but near enough to allow appropriately detailed input, reasonable model run time and manageable processing of model output. *For illustration purposes only – not representative of actual model domain*   | Cosumnes Subbasin and immediately adjacent areas are "nested" within a regional model representing a larger geographical area (for example, SacIWRM, SVSim, CVHM, or C2VSim-FG). Also referred to as "telescopic" modeling approach. *For illustration purposes only – not necessarily the recommended regional model domain.*   |
| Model Construction and Calibration | Spatial Resolution | Finite element model, element size ranges from 24 to 1,064 acres with an average of 351 acres in the Cosumnes Subbasin.  | Finite difference model with 271-317 cells in the Cosumnes Subbasin; Cell area of 1 $mi^2$ (USGS reported accuracy estimated at 5 $mi^2$).  | Finite element model, element size ranges from 0.7 to 2,341 acres with an average of 205 acres over the entire model domain (specific element size not available for Cosumnes Subbasin).  | Finite element model, element size ranges from 19 to 362 acres with an average of 106 acres in the Cosumnes Subbasin. Element sizes could change because of update.  | Element or cell size specifically determined to capture spatial variability in land use, recharge, surface water drainages, and other landscape features and processes as described by the Groundwater Conditions Assessment and Hydrogeological Conceptual Model (HCM) developed for the Cosumnes Subbasin GSP. | Element or cell size specifically determined to capture spatial variability in land use, recharge, surface water drainages, and other landscape features and processes as described by the Groundwater Conditions Assessment and HCM developed for the Cosumnes Subbasin GSP. |
| Model Construction and Calibration | Vertical Layering | Four layers, representing the "unconfined," "pumped-confined," "un-pumped confined," and deep saline aquifers. | Ten layers of increasing thickness with increasing depth: layers 1-3 represent the shallow unconfined to semi-confined aquifers; layers 4-5 represent the Corcoran Clay where present; layers 6-9 represent the deep pumped zone; and layer 10 represents a deep, unpumped zone. | Nine layers: layer 1 designed to include a minimum thickness of 10 feet below streams; layers 1-3 designed to accommodate fluctuations in the water table; layers 4-8 represent deeper production zones; layer 9 extends to base of continental deposits. | Three layers: layers 1-2 represent the freshwater aquifers; layer 3 represents the aquifer material from the base of freshwater to the continental deposits. Layering could change because of update. | Sufficient layering to capture basin structure, vertical heterogeneity, and variability in aquifer parameters as determined by updated Cosumnes Subbasin HCM with scheduled completion date of September 2019. | Sufficient layering to capture basin structure, vertical heterogeneity, and variability in aquifer parameters as determined by updated Cosumnes Subbasin HCM with scheduled completion date of September 2019. |
| Model Construction and Calibration | Temporal Scheme & Resolution | Transient, monthly time step | Transient, monthly time step | Transient, monthly time step | Transient, daily time step | Transient, likely monthly or finer timestep as needed to capture stream-aquifer interactions represented by Groundwater Conditions Assessment, HCM, and Basin-Wide Water Budget developed for Cosumnes Subbasin GSP. | Transient, likely monthly or finer timestep as needed to capture stream-aquifer interactions represented by Groundwater Conditions Assessment, HCM, and Basin-Wide Water Budget developed for Cosumnes Subbasin GSP. |

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|---|---|---|---|---|---|---|---|
| | | **C2VSim Fine-Grid** | **CVHM** | **SVSim** | **SacIWRM** | **Custom (Stand Alone)** | **Custom (Nested)** |
| **Model Construction and Calibration (Continued)** | Model Calibration | • Number of calibration wells in the Cosumnes Subbasin unknown. No wells in the Subbasin specified to produce output of simulated groundwater levels. The C2VSim-CG model employed 15 calibration wells in the Cosumnes Subbasin.<br>• Streamflow calibration unknown. The C2VSim-CG used one streamflow calibration gauge on Cosumnes River. | • Four calibration wells in the Cosumnes Subbasin. The number of wells may change as part of the on-going update.<br>• Stream gains/losses for 1961-77 calibrated along a short segment of the Cosumnes River but may change as part of on-going update.<br>• Model calibrated for entire Central Valley, performance reported only for five aggregated multi-basin areas. | • Calibration details unknown | • Current version utilizes 52 calibration wells within the Cosumnes Subbasin, 7 of the 52 wells considered "representative" with the most complete long-term records. The number of wells may change as part of the on-going update.<br>• Cosumnes River streamflow calibrated at one gauge having measured data from October 1941 through October 1982, but this may change as part of the on-going update. | Determined from publicly available data, local data, and collected specific data incorporated into the Cosumnes Subbasin GSAs Data Management Systems and evaluated to prepare the Basin Conditions, HCM, and Water Budget Analysis (scheduled completion date of September 2019). Data from areas beyond the Subbasin boundaries, for example information available from GSAs in adjacent basins will be employed in the area between the Subbasin boundaries and the model limits/boundaries. | Determined from publicly available data, local data, and collected specific data incorporated into the Cosumnes Subbasin GSAs Data Management Systems and evaluated to prepare the Basin Conditions, HCM, and Water Budget Analysis (scheduled completion date of September 2019). |
| | Calibration Period | 1974-2015 | April 1961- September 2003 (update will include data through September 2013) | 1973-2015 | 1970-2004, but likely will be extended as part of the current update. | Determined by data in the Cosumnes Subbasin GSAs Data Management Systems. At the very least, the calibration period will represent the most recent ten years relative to SGMA regulations and DWR's BMP's (e.g., 2005-2015); calibration period will most likely be greater than most recent ten years. | Determined by data in the Cosumnes Subbasin GSAs Data Management Systems. At the very least, the calibration period will represent the most recent ten years relative to SGMA regulations and DWR's BMP's (e.g., 2005-2015); calibration period will most likely be greater than most recent ten years. |
| | Processes Considered | Percolation Recharge: Yes<br>Agricultural/Plant Water Demands: Yes<br>GW/SW interactions: Yes<br>GW Pumping: Yes<br>Surface Water Imports: Yes<br>GW banking: Yes | Percolation Recharge: Yes<br>Agricultural/Plant Water Demands: Yes<br>GW/SW interactions: Yes<br>GW Pumping: Yes<br>Surface Water Imports: Yes<br>GW banking: Yes | Percolation Recharge: Yes<br>Agricultural/Plant Water Demands: Yes<br>GW/SW interactions: Yes<br>GW Pumping: Yes<br>Surface Water Imports: Yes<br>GW banking: Yes | Percolation Recharge: Yes<br>Agricultural/Plant Water Demands: Yes<br>GW/SW interactions: Yes<br>GW Pumping: Yes<br>Surface Water Imports: Yes<br>GW banking: Yes | Percolation Recharge: Yes<br>Agricultural/Plant Water Demands: Yes<br>GW/SW interactions: Yes<br>GW Pumping: Yes<br>Surface Water Imports: Yes<br>GW banking: Yes | Percolation Recharge: Yes<br>Agricultural/Plant Water Demands: Yes<br>GW/SW interactions: Yes<br>GW Pumping: Yes<br>Surface Water Imports: Yes<br>GW banking: Yes |
| | Model Input Flexibility | • Pumping rates specified either by sub-region or individual well.<br>• Land use (four categories: urban, riparian, native, agricultural) and hydrologic soil type by element; crop acreages by sub-region (14 total crop types).<br>• GW recharge calculated internally and dependent on multiple specified inputs.<br>• Aquifer properties specified by node and layer. Based on texture analysis interpolated to nodes.<br>• Model mesh not easily modified. Layer modifications are feasible.<br>• No solute transport capability. | • Pumping rates specified by sub-region, allocated to model cells based on land use and simulated by layer based on well screen interval depths for known wells.<br>• Land use (urban, agricultural, natural), hydrologic soil type, and crop type (22 categories) all input by model cell.<br>• GW recharge calculated internally and dependent on multiple specified inputs.<br>• Aquifer properties specified by cell and characterized by 50-feet texture intervals.<br>• Adjustments to model grid and layering are feasible.<br>• Solute transport capability available. | • Specification of pumping unknown. Pumping rates can be specified by well, element, and/or subregion in IWFM models.<br>• Specification of land use unknown. Land use can be specified by element or subregion in IWFM models.<br>• GW recharge calculated internally and dependent on multiple specified inputs.<br>• Aquifer properties specified by node and layer. Based on detailed texture analysis at wells and interpolated to nodes.<br>• Model mesh and layering not easily modified. Layer adjustments are feasible.<br>• No solute transport capability. | • Pumping rates specified by well for all water purveyors, and by element for private pumpers.<br>• Land use (urban, agricultural, native vegetation, and riparian vegetation), hydrologic soil type (four soil groups), and crop acreages (11 crop types) by element.<br>• GW recharge calculated internally and dependent on multiple specified inputs.<br>• Specification of aquifer properties unknown. Aquifer properties may be specified using a course parametric grid and interpolated to the model nodes or may be specified at individual nodes.<br>• Model mesh not easily modified. Layer adjustments are feasible.<br>• No solute transport capability. | • Pumping rates specified by well location and depth where data is available, by cell/element when estimated.<br>• Land use (urban, agricultural, native vegetation, and riparian vegetation), hydrologic soil type, and crop acreages by cell/element.<br>• GW recharge calculated either internally or externally dependent on method selected.<br>• Aquifer properties by node or cell, depending on model platform used, and by layer. Based on texture analysis and available aquifer test data.<br>• Model mesh/grid will be optimized during development.<br>• Solute transport capability using MODFLOW. | • Pumping rates specified by well location and depth where data is available, by cell/element when estimated.<br>• Land use (urban, agricultural, native vegetation, and riparian vegetation), hydrologic soil type, and crop acreages by cell/element.<br>• GW recharge calculated either internally or externally dependent on method selected.<br>• Aquifer properties by node or cell, depending on model platform used, and by layer. Based on texture analysis and available aquifer test data.<br>• Model mesh/grid will be optimized during development.<br>• Solute transport capability using MODFLOW. |
| | Ease of Use | • Straightforward. DWR support available.<br>• Run time approximately 6 hours.<br>• Post-processing capabilities include water budgets by user defined zones, output for plotting hydrographs, output for preparing contour maps. No particle tracking. | • Straightforward. USGS support available.<br>• Run time approximately 6 hours (likely longer after update).<br>• Post-processing capabilities include water budgets by user defined zones, output for plotting hydrographs, output for preparing contour maps, and particle tracking. | • Straightforward. DWR support available.<br>• Run time unknown.<br>• Post-processing capabilities include water budgets by user defined zones, output for plotting hydrographs, output for preparing contour maps. No particle tracking. | • Straightforward.<br>• Run time unknown.<br>• Post-processing capabilities include water budgets by user defined zones, output for plotting hydrographs, output for preparing contour maps. No particle tracking. | • Straightforward.<br>• Run time unknown.<br>• Post-processing capabilities include water budgets by user defined zones, output for plotting hydrographs, output for preparing contour maps. Particle tracking available using MODFLOW only. | • Straightforward.<br>• Run time unknown.<br>• Post-processing capabilities include water budgets by user defined zones, output for plotting hydrographs, output for preparing contour maps. Particle tracking available using MODFLOW only. |

**Abbreviations:**

BMP = Best management practices
C2VSim = California Central Valley Groundwater-Surface Water Simulation Model
CG = Coarse Grid
CVHM = Central Valley Hydrologic Model
CV-RASA = Central Valley Regional Aquifer System Analysis
DWR = California Department of Water Resources
EKI = EKI Environment & Water, Inc.
FG = Fine Grid
GSA = Groundwater Sustainability Agency
GSP = Groundwater Sustainability Plan
GW = Groundwater
IWFM = Integrated Water Flow Model
MF2K-FMP = MODFLOW-2000 with Farm Process
$mi^2$ = square miles
MODFLOW = Modular Three-Dimensional Finite Difference Ground-Water Flow Model
SacIWRM = Sacramento Area Integrated Water Resources Model
SGMA = Sustainable Groundwater Management Act
SVSim = Sacramento Valley Groundwater-Surface Water Simulation Model
SW = Surface water
USGS = United States Geological Survey

**Sources:**

1. Brush, C. F., Dogrul, E.C., 2013. User's Manual for the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), Version 3.02-CG, CA Dept. Water Resources, dated June 2013.
2. Faunt, C., 2009. Groundwater Availability of the Central Valley Aquifer, California. U.S.G.S. Professional Paper 1766, dated 2009.
3. RMC, 2011. Sacramento Area Integrated Water Resources Model (SacIWRM), Model Development and Baseline Scenarios, October 2011.
4. Personal communication with representatives of entities responsible for model development and updates.

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# TABLE 2
## SELECTION CRITERIA FOR POTENTIALLY APPLICABLE GROUNDWATER MODELS, UNWEIGHTED[1]

| Model Selection Criteria | | *Central Valley-Wide Models* | | *Regional Models* | | *Subbasin Models* | |
|---|---|---|---|---|---|---|---|
| | | **C2VSim Fine-Grid** | **CVHM** | **SVSim** | **SacIWRM** | **Custom (Stand Alone)** | **Custom (Nested)** |
| Pass/Fail | Release Date (available on or before April 1, 2020) | **1** | **1** | **1** | **0** | **1** | **1** |
| | Supports water budgets, SMC development, & evaluation of P&MAs | **1** | **1** | **1** | **1** | **1** | **1** |
| | Development / Update cost within available budget | **1** | **1** | **1** | **1** | **1** | **1** |
| Ranked Priority | 1) Represents HCM accepted by Working Group and employed for Cosumnes Subbasin GSP | **0** | **0** | **0** | **0** | **1** | **1** |
| | 2) Supports coordination with adjacent basins and regional water supply planning (e.g., GW banking) | **1** | **1** | **1** | **1** | **0** | **1** |
| | 3) Minimum cost for future maintenance, implementation, and adaptive management | **1** | **1** | **1** | **1** | **0** | **0** |
| | 4) Working Group is primary decision maker | **0** | **0** | **0** | **0** | **1** | **1** |
| | 5) Schedule allows Working Group opportunity to provide input to model development/update | **0** | **0** | **0** | **1** | **1** | **1** |
| ***SUM*** | | ***5*** | ***5*** | ***5*** | ***5*** | ***6*** | ***7*** |

**Abbreviations:**

C2VSim = California Central Valley Groundwater-Surface Water Simulation Model
CVHM = Central Valley Hydrologic Model
GSP = Groundwater Sustainability Plan
GW = Groundwater
HCM = Hydrogeological Conceptual Model
P&MAs = Project and Management Areas
SacIWRM = Sacramento Area Integrated Water Resources Model
SMC = Sustainable Management Criteria
SVSim = Sacramento Valley Groundwater-Surface Water Simulation Model

**Notes:**

1. All criterion ranked as pass/fail, whereby a "1" indicates the model meets the criterion and a "0" indicates the model fails the criterion.

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# TABLE 3
# SELECTION CRITERIA FOR POTENTIALLY APPLICABLE GROUNDWATER MODELS, WEIGHTED

| Model Selection Criteria | | *Central Valley-Wide Models* | | *Regional Models* | | *Subbasin Models* | |
|---|---|---|---|---|---|---|---|
| | | C2VSim Fine-Grid | CVHM | SVSim | SacIWRM | Custom (Stand Alone) | Custom (Nested) |
| Pass/Fail | Release Date (available on or before April 1, 2020)[1] | 5 | 5 | 5 | 0 | 5 | 5 |
| | Supports water budgets, SMC development, & evaluation of P&MAs[1] | 5 | 5 | 5 | 5 | 5 | 5 |
| | Development / Update cost within available budget[1] | 5 | 5 | 5 | 5 | 5 | 5 |
| Ranked Priority | 1) Represents HCM accepted by Working Group and employed for Cosumnes Subbasin GSP[2] | 0 | 0 | 0 | 0 | 5 | 5 |
| | 2) Supports coordination with adjacent basins and regional water supply planning (e.g., GW banking)[2] | 4 | 4 | 4 | 4 | 0 | 4 |
| | 3) Minimum cost for future maintenance, implementation, and adaptive management[2] | 3 | 3 | 3 | 3 | 0 | 0 |
| | 4) Working Group is primary decision maker[2] | 0 | 0 | 0 | 0 | 2 | 2 |
| | 5) Schedule allows Working Group opportunity to provide input to model development/update[2] | 0 | 0 | 0 | 1 | 1 | 1 |
| ***SUM*** | | ***22*** | ***22*** | ***22*** | ***18*** | ***23*** | ***27*** |

**Abbreviations**:

C2VSim = California Central Valley Groundwater-Surface Water Simulation Model
CVHM = Central Valley Hydrologic Model
GSP = Groundwater Sustainability Plan
GW = Groundwater
HCM = Hydrogeological Conceptual Model
P&MAs = Project and Management Areas
SacIWRM = Sacramento Area Integrated Water Resources Model
SMC = Sustainable Management Criteria
SVSim = Sacramento Valley Groundwater-Surface Water Simulation Model

**Ranking and Weighting Notes:**

1. The first three criteria are considered pass/fail, and therefore those that pass receive the highest numerical ranking score available (5), and those that fail receive a zero.
2. The following five criteria are listed in order of importance based on feed-back from the Working Group. For example, the first ranked criterion (represents the Basin HCM) was identified by the Working Group as the most important criterion for the model to meet, whereas the last ranked criterion (having the opportunity to provide input to development) was the least important. The most important criterion received the highest-ranking score of 5, the second most important received a score of 4, and so forth down to the lowest criterion which received a score of 1. A score of zero (0) indicates the model does not meet the criterion.