TECHNICAL MEMORANDUM

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SUBJECT: Groundwater Model Assessment and Software Recommendation

This technical memorandum (TM) provides an assessment of integrated hydrologic models that may be used by Glenn County and its collaborators to support development and implementation of one or more Groundwater Sustainability Plan(s) (GSPs) for the groundwater basins underlying Glenn County pursuant to the requirements of the Sustainable Groundwater Management Act of 2014 (SGMA). This TM was prepared as part of the scope of work defined in the County of Glenn's Proposition 1 Stressed Basin Grant administered by the California Department of Water Resources (DWR) under Grant Agreement #4600011470 (Grant Agreement).

This TM is organized in the following sections:

- Existing Integrated Hydrologic Model Applications
- Ranking Criteria (for model codes and applications)
- Ranking Results
- Conclusions
- Recommendations
- References

EXISTING INTEGRATED HYDROLOGIC MODEL APPLICATIONS

This section provides summary descriptions of existing integrated hydrologic model applications that have coverage in or adjacent to subbasins within Glenn County. Regional model applications covering the entire Sacramento Valley or Central Valley are discussed first, followed by discussion of model applications with more localized extent.

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The regional model applications are (Figure 1):

- California Central Valley Groundwater-Surface Water Simulation Model (C2VSim)
- Sacramento Valley Groundwater-Surface Water Simulation Model (SVSim)
- Central Valley Hydrologic Model (CVHM)
- Sacramento Valley Groundwater Model (SacFEM2013)

The applications with more localized extent are:

- Butte Basin Groundwater Model (BBGM)
- Stony Creek Fan Integrated Groundwater Surface Water Model (Stony Creek Fan IGSM)
- Yolo County Integrated Water Flow Model (Yolo County IWFM)

The BBGM primarily covers subbasins adjacent and to the east of Glenn County but has coverage in the Glenn County portion of the West Butte Subbasin (Figure 1). The Stony Creek Fan IGSM covers the Colusa and Corning Subbasins in Glenn County but does not extend into the West Butte Basin portion of Glenn County. The coverage does not extend into the southern portion of the Colusa Subbasin in Colusa County. Also, the Stony Creek Fan IGSM has not been updated since approximately 2003 and the underlying IGSM code has been supplanted by its successor code, Integrated Water Flow Model (IWFM). The Yolo County IWFM provides coverage in the Yolo Subbasin adjacent to the south boundary of the Colusa Subbasin, but its coverage is not adjacent to Glenn County. For these reasons, the applications with more localized extent do not have direct application to Glenn County and are described but not ranked.

Table 1 lists basic information about the model applications. Figure 1 shows the extents of the model applications relative to the subbasins underlying Glenn County. Glenn County overlies portions of the Colusa, Corning, and West Butte Subbasins.

California Central Valley Groundwater-Surface Water Simulation Model

C2VSim is an application of DWR's IWFM (Brush, et.al., 2013a, 2013b; DWR, 2017). IWFM is a quasi-three-dimensional finite element program that simulates stream flow, soil moisture accounting in the root zone, flow in the vadose zone, groundwater flow, and stream-aquifer interaction. Land subsidence is also simulated. IWFM uses a land use-based approach for calculating water demand in the IWFM Demand Calculator (IDC). Agricultural and urban water demands can be pre-specified or calculated internally based on land use. C2VSim provides a complete representation of Central Valley hydrology and hydrogeology using three model layers (DWR, 2016a). The simulation period is from water year 1921 through 2009. The application currently uses a monthly time step.

The IWFM model is available at no cost from DWR and in the public domain, as is the C2VSim application. DWR has developed and supports a graphical user interface and pre- and post-processing tools for the IWFM model and C2VSim applications.

Table 1. Model Applications in and Adjacent to Glenn County Subbasins

Application Name	Owner/ Custodian	Model Code	Public Domain Code	Licensing and Support Cost	Code Documentation Available	Application Documentation Available	Code Peer Reviewed	Application Updates	Coverage	Representation of Aquifer System	Layers	Simulation Period (Water Year)	Surface Layer Representation	Simulation of Stream/Aquifer Interactions
C2VSim	DWR	IWFM	Yes	Available at no cost	Yes	Yes, through DWR	Yes	DWR expects to release coarse and fine grid version of the C2Vsim (C2Vsim-CG and C2Vsim-FG) and SVSim applications developed using the latest code version, IWFM 2015, in 2018.	Central Valley: Covers Glenn County subbasins and adjacent subbasins	Layers based on interpreted aquifer units (Layers based on texture model in pending updates)	3 (4 in pending release of C2VSim-FG)	1921-2009 (1922-2015 in pending releases)	Fully integrated with IDC: agricultural and urban water demands can be pre-specified, or calculated internally based on land use	Fully integrated with IWFM Stream Package
SVSim	DWR	IWFM	Yes	Available at no cost	Yes	Under development by DWR	Yes		Sacramento Valley, Redding Area and Delta portions of San Joaquin Basins: Covers Glenn County subbasins and adjacent subbasins	Layers based on texture model	9	1922-2015		
CVHM	USGS	MODFLOW-OWHM	Yes	Available at no cost	Yes	Yes, through USGS	Yes	Updates anticipated from USGS in 2018	Central Valley: Covers Glenn County subbasins and adjacent subbasins	Layers based on texture model	10 (15 in pending release)	1962-2003	Fully integrated with Farm Process (FMP2)	Fully integrated with MODFLOW Stream Flow Routing Package (Stream data from C2VSim in pending release)
SacFEM2013	USBR	MicroFEM IDC	MicroFEM: No IDC: Yes	MicroFEM: Requires licensing fee IDC: Available at no cost	No, proprietary code	Yes, through USBR	MicroFEM: No (Application peer reviewed) IDC: Yes	None planned	Sacramento Valley Groundwater Basin: Covers Glenn County subbasins and adjacent subbasins	Layers based on texture model	7	1970-2010	Calculated externally using IDC	Interactions determined by simulated groundwater elevations, specified transient stream stages and specified stream bed resistances
Butte Basin Groundwater Model	County of Butte	IWFM	Yes	Available at no cost	Yes	Under development by Butte County	Yes	Ongoing by Butte County	Butte County Subbasins: Vina, East and West Butte, Wyandotte Creek South Yuba and portions of Sutter Covers Glenn County subbasin (West Butte) and adjacent subbasins	Layers based on interpreted aquifer units	9	1970-2014	Fully integrated with IDC	Fully integrated with IWFM Stream Package
Stony Creek Fan IGSM	DWR	IGSM	Yes	Available at no cost	Yes	Yes	Yes	None planned	Corning Subbasin and northern Colusa Subbasin: Covers all of Colusa Subbasin in Glenn County and a portion of the Colusa Subbasin in northern Colusa County, and the Glenn County portions of the Corning Subbasin	Layers based on interpreted aquifer units	4	1970-2000	Fully integrated with IGSM Demand Package	Fully integrated with IGSM Stream Package
Yolo County IWFM	UC Davis	IWFM	Yes	Available at no cost	Yes	Yes, but not consolidated in a single document.	Yes	Ongoing by UC Davis	Yolo and portion of Solano Counties Adjacent to Colusa Subbasin	Layers based on interpreted aquifer units	8	1971-2013	Fully integrated with IDC	Fully integrated with IWFM Stream Package

IWFM has been peer reviewed (Harter and Morel-Seytoux, 2013).

There are two versions of C2VSim. Currently, both applications run on IWFM Version 3.02. C2VSim-CG is the coarse grid version with 1,392 elements and a run time of approximately six minutes. The element size ranges from 2.1 to 33 square miles with an average of 14 square miles. C2VSim-CG is available from DWR and is used by DWR for the groundwater component of CalSim3 to assess the impact of Sacramento Valley water transfers on Delta outflows and to assess the effects of extended droughts on groundwater levels (DWR, 2016a).

C2VSim-FG is the fine grid version with over 35,000 elements and a run time of approximately four to six hours (DWR, 2016a). The element size ranges from 0.006 to 2.8 square miles with an average of 0.6 square miles. C2VSim-FG is under development by DWR and currently is not publicly available.

DWR is developing updated versions of C2VSim-CG and C2VSim-FG based on the latest version of the model code, IWFM 2015. IWFM 2015 enables use of more detailed input data and generation of detailed water budgets for user-defined subareas of the model domain. C2VSim will reportedly use DWR's texture model, which is under development. Land use refinements include data from DWR land use surveys, satellite surveys, DWR's 2014 Statewide land use survey, and agricultural commissioner reports. Release of the updated versions is anticipated to be in 2018 (DWR, 2017).

Sacramento Valley Groundwater-Surface Water Simulation Model

DWR is developing a new model, SVSim, based on the C2VSim-FG datasets and using the IWFM 2015 model code. General characteristics of the model code are described above for C2VSim. The model domain includes all the Sacramento Valley Basin, the Redding Area Groundwater Basin, and the Delta. The southern boundary of the model lies between the Mokelumne and Calaveras Rivers. SVSim includes nine layers of variable thickness. The simulation period is from water years 1922 through 2015. The application is anticipated to use a monthly time step.

The IWFM model code is available at no cost from DWR and in the public domain. The SVSim application will be available at no cost and in the public domain when released. DWR has developed and supports a graphical user interface and pre- and post-processing tools for the IWFM model and SVSim applications.

SVSim is being developed to support detailed analysis of stream depletion due to groundwater substitution transfers in the Sacramento Valley and to provide a modeling tool for SGMA implementation, including the capability to evaluate water budgets, stream-aquifer interactions, land subsidence, potential projects, and management scenarios.

SVSim has a more refined mesh and layering than C2VSim-FG near major rivers. The element size ranges from ranges from 0.001 to 3.7 square miles with an average of 0.3 square miles. The run time is anticipated to be approximately six hours. SVSim also has an updated representation of aquifer properties based on an extensive lithologic texture analysis developed using data from USGS, DWR, and other sources. SVSim is anticipated to be released to the public in 2018.

Central Valley Hydrologic Model

The CVHM is an application of MODFLOW developed by the United States Geological Survey (USGS) (Faunt, 2009). MODFLOW is a widely used, thoroughly tested, and well-documented program developed by the USGS (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996; and Harbaugh, et. al., 2000; Schmid, et. al., 2009). MODFLOW implements an approximate quasi-three-dimensional finite difference solution to the groundwater flow equation. CVHM incorporates the Farm Process, Stream Flow Routing, Basin Characteristics Model, Subsidence, and Flow Barriers modules to simulate land use and unsaturated zone processes, streamflow, and land subsidence (Faunt, 2009). CVHM provides a complete representation of Central Valley hydrology and hydrogeology using ten model layers (Faunt, 2009). The simulation period is from water year 1922 through 2009. The application currently uses a monthly time step.

The MODFLOW code and CVHM application are available at no cost from USGS and in the public domain. Graphical user interfaces are available through USGS and commercially. MODFLOW has been widely used for over 30 years and has undergone extensive peer review.

CVHM has approximately 20,000 grid cells with a uniform, one-square mile area. The USGS used CVHM to help complete its study entitled "Groundwater Availability of the Central Valley Aquifer: U.S. Geological Survey Professional Paper 1766" (Faunt, 2009). CVHM has subsequently been used to evaluate water availability and land subsidence in the Central Valley.

The USGS is updating CVHM to run on the new model code MODFLOW-One Water Hydrologic Model (OWHM). The updates reportedly also include refinement of the vertical discretization to include 15 layers, updated stream data from DWR's C2VSim datasets, and updated land use information, including data from DWR land use surveys, historical land use maps, and agricultural commissioner reports. The time step is anticipated to be 0.5 day. The updated version of CVHM is anticipated to be released in 2018.

Sacramento Valley Groundwater Model

SacFEM2013 is an application of the MicroFEM model and was developed by United States Bureau of Reclamation (USBR). MicroFEM is a proprietary, three-dimensional, finite element modeling platform (Hemker, 1997). SacFEM2013 is a transient groundwater/surface water flow application that operates on a monthly time step over a simulation period extending from 1970 through 2010 (USBR, 2015). The finite element mesh has 120,761 nodes; 241,001 elements; and seven layers. The mesh covers the entire Sacramento Valley. DWR's IDC was used to externally calculate agricultural water demand, agricultural groundwater pumping, and deep percolation rates (WRIME, 2011).

The proprietary MicroFEM model is available as part of commercially available graphical user interface software packages. The SacFEM application has been peer reviewed, and recommended updates were included in SacFEM2013 (WRIME, 2011; USBR 2015). Documentation is publicly available for the SacFEM2013 application (USBR, 2015).

USBR used the application to evaluate conjunctive water management in support of the Sacramento Valley Water Management Program and to support the Long-Term Water Transfers Environmental Impact Statement/Environmental Impact Report (USBR, 2015).

Butte Basin Groundwater Model

The area simulated by the BBGM is adjacent to the east side of the Colusa and Corning Subbasins (Figure 1). The BBGM is being maintained and updated by Butte County as an application of DWR's IWFM (Brush, et.al., 2013a, 2013b; DWR, 2017). General characteristics of the model code are described above for C2VSim. The extent of the application encompasses groundwater subbasins in Butte County, including the entire Vina, East and West Butte (including the Glenn County portion of the West Butte Subbasin), Wyandotte Creek (formerly part of the North Yuba Subbasin), and North Yuba Subbasins, and portions of the Sutter Subbasin. The finite element mesh contains approximately 7,200 variably-sized elements with an average area of approximately 0.18 square miles. The BBGM has nine layers. The simulation period is from water year 1970 through 2014. The application currently uses a monthly time step. The run time is estimated to range from three to six hours.

The IWFM model code is available at no cost from DWR and in the public domain. The BBGM application is anticipated to be available at no cost and in the public domain when released by Butte County. DWR has developed and supports a graphical user interface and pre- and post-processing tools for the IWFM model and BBGM applications.

The BBGM has been used for evaluating project feasibility, determining water budgets by model subregion, estimating changes to surface water availability, modeling climate change effects and system vulnerabilities, and assessing the effects of changing future demands (RMC-Woodard & Curran, 2017).

Butte County is in the process of updating the BBGM to run on IWFM 2015.

Stony Creek Fan Integrated Groundwater Surface Water Model

The Stony Creek Fan IGSM is a local application of the Integrated Groundwater Surface Water Model (IGSM), which is a quasi-three-dimensional finite element program that simulates the same hydrologic processes as IWFM but through different numerical processes (WRIME, 2003). IGSM is a predecessor of IWFM. The Stony Creek Fan IGSM encompasses all the Corning Subbasin and parts of the Colusa Subbasin, including the entire Glenn County portion of the Colusa Subbasin and the northern Colusa County portion of the Colusa Subbasin (Figure 1). The finite element mesh contains approximately 2,105 variably-sized elements with an average area of approximately 0.5 square miles. The Stony Creek Fan IGSM application has four layers. The simulation period is from water year 1970 through 2000. The application uses a monthly time step. The run time is estimated to range from four to six hours.

The model code and the application are available at no cost through DWR and are in the public domain. Graphical user interfaces and pre- and post-processing tools for the IGSM and the Stony Creek Fan IGSM application are commercially available.

The application has been used to evaluate conjunctive use scenarios associated with the Stony Creek Fan in Glenn, Colusa, and Tehama Counties. The Stony Creek Fan IGSM has not been updated since 2003 (WRIME, 2003).

Yolo County Integrated Water Flow Model

The Yolo County area simulated by the Yolo County IWFM application is adjacent to the south side of the Colusa Subbasin and is not adjacent to Glenn County (Figure 1). The Yolo County IWFM is an application of DWR's IWFM (WRIME, 2006; Brush et. al., 2010; West Yost Associates, 2015). General characteristics of the model code are described above for C2VSim. The Yolo County IWFM application encompasses all of Yolo County and the parts of Solano County adjacent to Putah Creek. The finite element mesh contains approximately 3,068 variably-sized elements with an average area of approximately 0.29 square miles. The Yolo County IWFM application has eight layers. The simulation period is from water year 1971 through 2013. The application uses either a monthly or daily time step. The run time for the monthly time step version ranges from four to six hours. The run time for the daily time step version ranges from 16 to 30 hours. The Yolo County IWFM application is currently running on IWFM version 4.0.

The IWFM model code is available at no cost from DWR and in the public domain. The Yolo County IWFM application is in the public domain and available at no cost from the University of California at Davis (UC Davis). DWR has developed and supports a graphical user interface and pre- and post-processing tools for the IWFM model and Yolo County application.

The most recent development of the Yolo County IWFM application was conducted as part of the Woodland-Davis Clean Water Agency's Aquifer Storage and Recovery evaluation and concurrent efforts undertaken by Carlos Arenas Flores, a Ph.D. candidate in the Department of Land, Air and Water Resources at UC Davis, and his advisor, Dr. Graham Fogg, with technical support from the DWR Modeling Support Branch (West Yost Associates, 2015). UC Davis updates the application to support research.

RANKING CRITERIA

Table 2 provides ranking criteria developed from DWR's Modeling Best Management Practices (BMP) (DWR, 2016b). In the BMP, DWR provides modeling criteria in three categories:

- Guiding Principles
- General Modeling Requirements
- Modeling Considerations

The guiding principles are intended to "…foster SGMA's intent to promote transparency, coordination, and data sharing…help guide GSAs in their selection and use of models for sustainable groundwater management, and expedite Department review of GSP-related modeling analysis and findings" (DWR, 2016b). Three guiding principles are:

1. The model code is publicly available at no cost.
2. The model code has been peer reviewed for the intended use.
3. The complete modeling platform can be provided to DWR at no cost.

A fourth guiding principle pertains to the completeness of the model documentation in the GSP. This principle was not used directly in developing ranking criteria because it applies to preparation of the GSP documentation. It was assumed for the purposes of this evaluation that any model selected to support GSP development for the subbasins within Glenn County will be sufficiently documented and adhere to this principle.

The general modeling requirements are taken from the Emergency Regulations (23 CCR §352.4(f)) (DWR, 2016b), which state:

1. The model shall include publicly available supporting documentation.
2. The model shall be based on field or laboratory measurements, or equivalent methods that justify the selected values, and calibrated against site-specific field data.
3. Groundwater and surface water models developed in support of a Plan after the effective date of these regulations shall consist of public domain open-source software.

The Emergency Regulations also state that "models developed and actively used in groundwater basins prior to the GSP Regulations effective date can be used for GSP development and implementation, even if they do not use public domain and open-source software…" (DWR, 2016). This was interpreted to mean that SacFEM2013 may potentially be used for GSP development because it has been actively used in recent years.

In Table 2, the guiding principles and general modeling requirements are combined and represented by binary scores, depending on whether or not the model meets the requirement. These criteria apply to the model code and modeling platform. The same binary scoring was also applied to one of the BMP modeling considerations discussed below. This modeling consideration states that the extent of the model application must cover the entire subbasin at a minimum. Models and applications not meeting these requirements were judged unsuitable for SGMA purposes. Models and applications not meeting these requirements received a score of zero, and models and applications meeting the requirements received a score of ten for each guiding principle.

Table 2. Ranking Criteria

	Binary Scoring		Gradational Scoring		
	No	Yes	Limited Capability	Moderate Capability	Full Capability
Criteria Based on BMP Guiding Principles and General Modeling Requirements[a]					
Model code is publicly available at no cost and complete modeling platform (input and output files and executables) can be provided to DWR at no cost	0	10	Category not used in ranking	Category not used in ranking	Category not used in ranking
Model code has been peer reviewed for the intended use	0	10	Category not used in ranking	Category not used in ranking	Category not used in ranking
Model has publicly available supporting documentation, including explanation of the model code (physical processes simulated, mathematical equations, and assumptions) and model application (conceptual model, application development, assumptions, inputs, etc.)	0	10	Category not used in ranking	Category not used in ranking	Category not used in ranking
Models developed after effective date of GSP regulations (August 15, 2016) must use public domain open-source software, per 23 CCR Section 352.4(f)[b].	0	10	Category not used in ranking	Category not used in ranking	Category not used in ranking
Spatial extent of model application covers entire subbasin at a minimum[c]	0	10	Category not used in ranking	Category not used in ranking	Category not used in ranking
Maximum Possible Score Based on Binary Criteria		**50**			
Criteria Based on BMP Modeling Considerations[d]					
Model capable of evaluating each sustainability indicator and the potential presence of and magnitude of undesirable results in the basin, including:					
Lowering of Groundwater Levels	Category not used in ranking	Category not used in ranking	1	2	3
Reduction of Groundwater Storage	Category not used in ranking	Category not used in ranking	1	2	3
Seawater Intrusion	Category not used in ranking	Category not used in ranking	Likely not applicable to Glenn County Subbasins		
Degraded Water Quality	Category not used in ranking	Category not used in ranking	1	2	3
Land Subsidence	Category not used in ranking	Category not used in ranking	1	2	3
Depletion of Interconnected Surface Water	Category not used in ranking	Category not used in ranking	1	2	3
Model supports development of water budgets	Category not used in ranking	Category not used in ranking	1	2	3
Model capable of forecasting future conditions, such as reduction of surface water supplies, changes in land use and associated water demands, the effects of climate change, and quantifying the uncertainty in these predictions	Category not used in ranking	Category not used in ranking	1	2	3
Model capable of demonstrating how selected projects and management actions will achieve the sustainability goal within 20 years of GSP implementation	Category not used in ranking	Category not used in ranking	1	2	3
Model capable of identifying data gaps and monitoring needs	Category not used in ranking	Category not used in ranking	1	2	3
Model capable of assessing impacts on adjacent basins	Category not used in ranking	Category not used in ranking	1	2	3
Model adaptable to refined hydrogeologic interpretations and incorporation of additional data.	Category not used in ranking	Category not used in ranking	1	2	3
Model capable of simulating forecast changes in agricultural practices, including changes in crop types, irrigation practices, irrigation water source, etc.	Category not used in ranking	Category not used in ranking	1	2	3
Model capable of efficiently and effectively conveying simulation outputs, either directly or with post-processing tools	Category not used in ranking	Category not used in ranking	1	2	3
Maximum Possible Score Based on Gradational Criteria					**39**
Maximum Total Possible Score					**89**

[a] Criteria apply to model codes and platforms except as described in footnote c.
[b] The GSP Regulations (23 CCR Section 352.4(f)) "require that all new models developed in support of a GSP after the effective date of the GSP Regulations (August 15, 2016) use public domain open-source software to promote
[c] Spatial extent of model application is listed in the Modeling BMP as a BMP Modeling Consideration.
[d] Criteria apply to model applications.

The BMP modeling considerations address the capability of the model code and application in addressing the technical requirements of SGMA. They include the following capabilities:

- Evaluating the six sustainability indicators and the potential presence of and magnitude of undesirable results in the basin.
- Developing water budgets.
- Forecasting future conditions.
- Demonstrating how selected projects and management actions will achieve the sustainability goal within 20 years of GSP implementation.
- Identifying data gaps and monitoring needs.
- Assessing impacts on adjacent basins.
- Adapting to refined hydrogeologic interpretations and incorporation of additional data.
- Simulating forecast changes in agricultural practices.
- Conveying simulation outputs, either directly or with post-processing tools.

In Table 2, these modeling considerations were evaluated using gradational scoring. The following scores were assigned to the model applications evaluated:

- Limited capability: 1
- Moderate capability: 2
- Full capability: 3

RANKING RESULTS

Table 3 provides documentation of the ranking for each model and application based on the ranking criteria and scoring system described in the preceding section. Major assumptions used in developing the ranking were:

- Updated versions of DWR's C2VSim-FG and the USGS's CVHM applications will be available in 2018.
- DWR's SVSim application will be available in 2018.
- Current and to-be-released versions of DWR's C2VSim-CG do not have sufficient spatial resolution for the purpose of developing GSPs for subbasins within Glenn County.

With consideration of these assumptions, C2VSim-FG, SVSim, and CVHM were evaluated based on the anticipated capabilities of the applications when released in 2018, and C2VSim-CG was excluded from the scoring.

Table 3. Ranking Results

	Model/Application			
	C2VSim-FG	SVSim	CVHM	SacFEM2013
Criteria Based on BMP Guiding Principles and General Modeling Requirements[a]				
Model code is publicly available at no cost and complete modeling platform (input and output files and executables) can be provided to DWR at no cost	10	10	10	0
Model code has been peer reviewed for the intended use	10	10	10	0
Model has publicly available supporting documentation, including explanation of the model code (physical processes simulated, mathematical equations, and assumptions) and model application (conceptual model, application development, assumptions, inputs, etc.)	10	10	10	0
Models developed after effective date of GSP regulations (August 15, 2016) must use public domain open-source software, per 23 CCR Section 352.4(f)[b].	10	10	10	0
Spatial extent of the model application covers entire subbasin at a minimum[c]	10	10	10	10
Score Based on Binary Criteria	**50**	**50**	**50**	**10**
Criteria Based on BMP Modeling Considerations[d]				
Application capable of evaluating each sustainability indicator and the potential presence of and magnitude of undesirable results in the basin, including:				
Lowering of Groundwater Levels	3	3	3	3
Reduction of Groundwater Storage	3	3	3	3
Seawater Intrusion	Likely not applicable in the Glenn County Subbasins			
Degraded Water Quality	1	1	1	1
Land Subsidence	3	3	3	1
Depletion of Interconnected Surface Water	2	3	1	1
Model application supports development of water budgets	2	3	1	2
Model application capable of forecasting future conditions, such as reduction of surface water supplies, changes in land use and associated water demands, the effects of climate change, and quantifying the uncertainty in these predictions	3	3	3	2
Model application capable of demonstrating how selected projects and management actions will achieve the sustainability goal within 20 years of GSP implementation	3	3	3	2
Model application capable of identifying data gaps and monitoring needs	2	3	1	2
Model application capable of assessing impacts on adjacent basins	2	3	1	2
Model application adaptable to refined hydrogeologic interpretations and incorporation of additional data.	3	3	3	3
Model application capable of simulating forecast changes in agricultural practices, including changes in crop types, irrigation practices, irrigation water source, etc.	3	3	2	3
Model application capable of efficiently and effectively conveying simulation outputs, either directly or with post-processing tools	3	3	3	2
Score Based on Gradational Criteria	**33**	**37**	**28**	**27**
Total Score	**83**	**87**	**78**	**37**

[a] Criteria apply to model codes and platforms except as described in footnote c.

[b] The GSP Regulations (23 CCR Section 352.4(f)) "require that all new models developed in support of a GSP after the effective date of the GSP Regulations (August 15, 2016) use public domain open-source software to promote transparency and expedite review of models by DWR. Models developed and actively used in groundwater basins prior to the GSP Regulations effective date can be used for GSP development and implementation, even if they do not use public domain and open-source software" (DWR, 2016).

[c] Spatial extent of model is listed in the Modeling BMP as a BMP Modeling Consideration.

[d] Criteria apply to model applications.

C2VSim-FG, SVSim and CVHM meet all the criteria based on the BMP guiding principles and general modeling requirements, and therefore each received the maximum score of 50 points (Table 3).

MicroFEM is proprietary, not publicly available, not available at no cost, and therefore does not meet the criteria based on the BMP guiding principles and general modeling requirements. Based on this initial screening, SacFEM2013 is excluded from further discussion of the ranking results, even though SacFEM2013 does have the capability to address the technical requirements listed in the BMP modeling considerations (see SacFEM2013 scoring in Table 3).

SVSim, C2VSim-FG, and CVHM can meet the technical requirements listed in the BMP modeling considerations, with the following qualifications:

1. SVSim is anticipated to have the best capability to simulate stream-aquifer interactions and interbasin flows that are coincident with major streams, and to identify data gaps and monitoring needs in these critical areas, because it has the most refined grid and the finest vertical discretization near major streams. These refinements are based on an updated database of borehole data and an updated textural model.

   C2VSim-FG also has grid refinements and increased vertical discretization, based on the updated textural model used for SVSim, but not to the extent anticipated in SVSim. The CVHM has the least refinement near major streams, with a one-square mile grid spacing, and is based on a less detailed textural database and textural model. Based on these considerations, SVSim, C2VSim-FG and the CVHM were ranked from most capable to least capable in the following categories (Table 3):

   - Evaluating depletion of interconnected surface water
   - Developing water budgets
   - Identifying data gaps and monitoring needs
   - Assessing impacts on adjacent basins

2. Each of the three applications have limited ability to address degraded water quality, without the use of a companion particle tracking or transport program. Also, the regional scale of all the applications is a limitation in simulating local water quality conditions, which may be a consideration for Groundwater Sustainability Agencies during GSP development.

3. The CVHM received a lower ranking for its capability of simulating forecast changes in agriculture because, as shown in Table 1, it will reportedly use a more limited land use data set. Also, local experience in the Sacramento Valley has shown that IDC (used in the C2VSim-FG and SVSim applications) provides a more realistic representation of irrigated lands and root zone processes than the Farm Process used in the CVHM.

Based on the BMP modeling considerations, SVSim received a score of 37 points, C2VSim-FG received a score of 33 points, and CVHM received a score of 28 points out of a possible score of 39 points (Tables 2 and 3).

The three model applications had the following overall scores out of a maximum possible total score of 89:

- SVSim: 87 points
- C2VSim-FG: 83 points
- CVHM: 78 points

CONCLUSIONS

The new or updated versions of SVSim, C2VSim-FG, and the CVHM anticipated to be released in 2018 appear to be capable of meeting the Modeling BMP requirements; however, SVSim appears to be the most capable of the applications followed by C2VSim-FG and the CVHM, based on the scoring discussed above.

The underlying models, IWFM and MODFLOW, meet the Modeling BMP requirements and are acceptable modeling platforms.

RECOMMENDATIONS

There is some uncertainty over when the updated or new applications will be publicly available for evaluation and use. However, it is recommended that Groundwater Sustainability Agencies in Glenn County evaluate each of the three applications when they become available. This evaluation should focus on the applications' capabilities in the meeting the technical requirements listed in the BMP modeling considerations summarized in Tables 2 and 3. This should include evaluating the following for appropriateness to the modeling needs of Glenn County, its collaborators, and stakeholders:

- Underlying conceptualization in comparison to the Hydrogeologic Conceptual Models of the Subbasins.
- Simulated surface layer and groundwater budgets in comparison to the current understanding of the corresponding Subbasins' budgets and budget inputs.
- Approach used for simulating crops grown and irrigation practices used in the Subbasins.
- Approach used for simulating surface water supplies, including water transfers.
- Approach used for simulating stream-aquifer interactions and interconnected surface water.

The evaluation should also consider the type and quality of the data used in the applications, data gaps potentially affecting the simulation results, and the adequacy of the calibration.

Glenn County and partner Groundwater Sustainability Agencies should also coordinate with neighboring basins to select the most appropriate model application.

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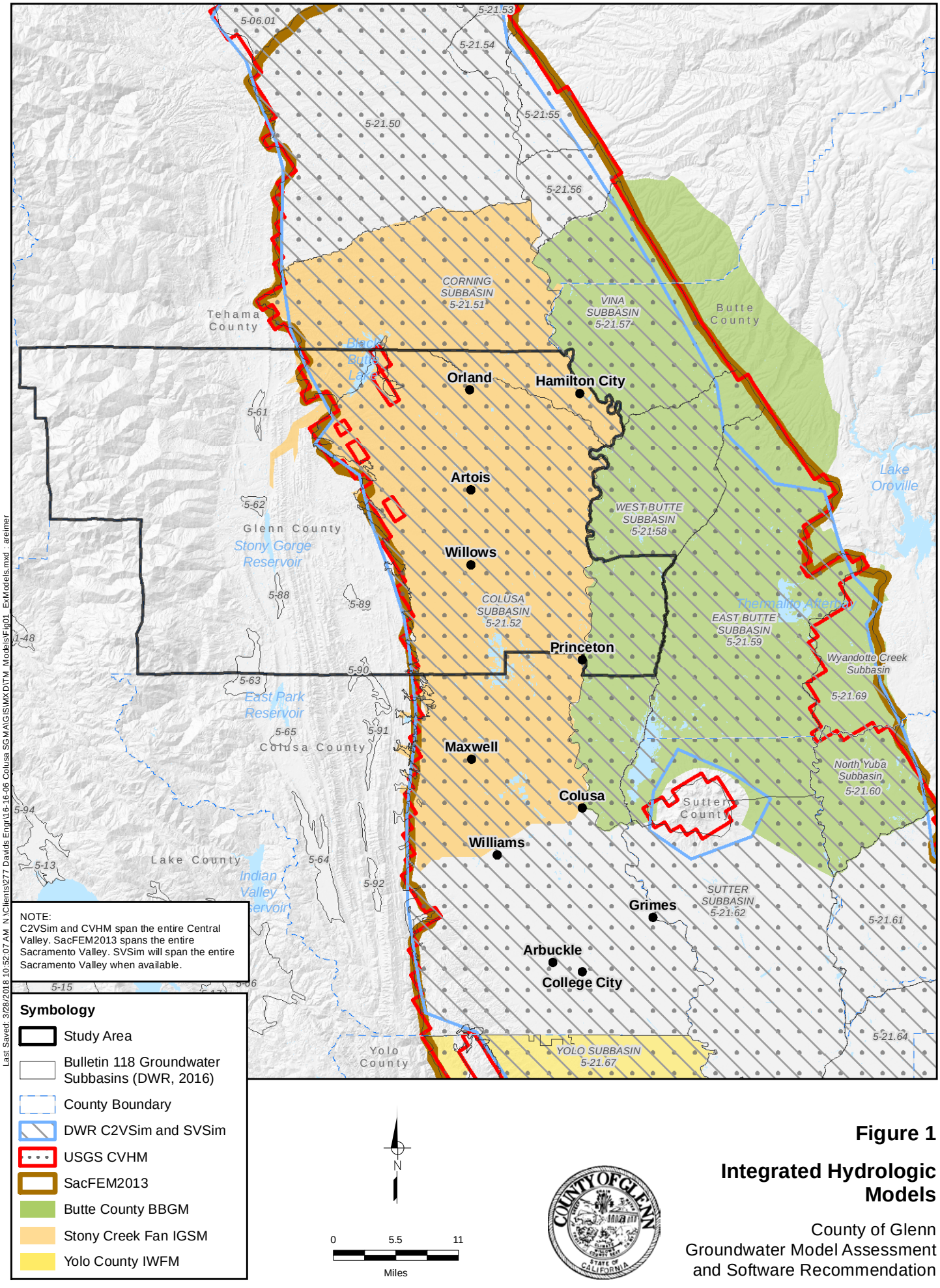

Figure 1

Integrated Hydrologic Models

County of Glenn
Groundwater Model Assessment
and Software Recommendation