This Technical Memorandum (Tech Memo) contains an inventory of numerical hydrologic models capable of simulating interbasin groundwater flow in the Northern Sacramento Valley Integrated Regional Water Management (NSVIRWM) plan area.

1 Study Area

The NSVIRWM plan area is made up of six counties—Butte, Colusa, Glenn, part of Shasta, Sutter, and Tehama—in the northernmost part of California’s Central Valley (inset in Figure 1). A portion of the NSVIRWM Area constitutes the study area and includes the area bounded to the north, west, and east by the extent of the Sacramento Valley Groundwater Basin and to the south by the Sutter Buttes. Eleven groundwater subbasins (all part of the Sacramento Valley Groundwater Basin) underlie the study area and are the focus of interbasin flows in the study:

1. Red Bluff (5-21.50)
2. Corning (5-21.51)
3. Colusa (5-21.52)
4. Bend (5-21.53)
5. Antelope (5-21.54)
6. Dye Creek (5-21.55)
7. Los Molinos (5-21.56)
8. Vina (5-21.57)
9. West Butte (5-21.58)
10. East Butte (5-21.59)
11. North Yuba (5-21.60)

These groundwater subbasins are shown in Figure 1. All of the subbasins, except for Bend, were categorized as either being medium or high priority under the California Statewide Groundwater Elevation Monitoring (CAGSME) program in June 2014. None of the subbasins were designated as critically overdrafted by the Department of Water Resources (DWR) as of January 2016.

Figure 1 also shows the approximate bounds of the study area. The study area contains all of the subbasin connections for the subbasins listed above (e.g., Corning–Red Bluff, Corning–Los Molinos, Corning–Vina, Corning–West Butte, Corning–Colusa, etc.).
Figure 1: Groundwater Subbasins in Study Area
2 Interbasin Groundwater Flow and the Sustainable Groundwater Management Act

The 2014 Sustainable Groundwater Management Act (SGMA) established new requirements for groundwater management of medium and high priority groundwater basins or subbasins (referred to hereafter collectively as basins). All critically overdrafted basins (i.e., none of the study area subbasins) must have Groundwater Sustainability Plans (GSPs) by January 31, 2020; all other medium and high priority basins must complete GSPs by January 31, 2022.

In the GSP regulations, DWR recognizes that groundwater conditions in one basin may be affected by groundwater management practices in adjacent, hydrologically-connected basins. Each GSP must demonstrate that management activities within a basin will have no adverse impacts on sustainable management of adjacent basins. Therefore, it is important that agencies planning to develop and execute GSPs understand the hydrologic connections between adjacent groundwater basins and how different groundwater models deal with subsurface flows across those boundaries.

Article 8 of the GSP regulations describes interbasin agreements, which are optional interagency agreements for hydrologically connected basins. These interbasin agreements are to include an estimate of groundwater flow across basin boundaries developed using consistent and coordinated data, methods and assumptions; estimates of stream-aquifer interactions at the boundary; and a common understanding of the hydrogeology and hydrology of the basins. Though they are optional, it is likely that DWR will view them favorably when evaluating the interaction of multiple GSPs in adjacent basins.

3 Models Selected to Evaluate Interbasin Groundwater Flow

The first task in the Interbasin Groundwater Flow Evaluation Project is an inventory of numerical hydrologic models capable of simulating interbasin groundwater flow. The models are generally categorized as either regional or local. For this study, regional models are those covering at least an entire Bulletin 118 groundwater basin. Examples include the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), Central Valley Hydrologic Model (CVHM), and Sacramento Valley Finite Element Groundwater Model (SACFEM2013), all of which cover the Sacramento Valley Groundwater Basin at a minimum. Local models are those simulating only a portion of a groundwater basin, for example several subbasins within and adjacent to a given county. Examples of local models include the Butte Basin Groundwater Model (BBGM) developed by Butte County and the Stony Creek Fan Model (SCF Model) developed by DWR. The horizontal extent of the active domain for each of the models in the study area is shown in Figure 2. Cross sections through all models except SACFEM2013 are shown on Figure 3 (see Figure 1 for line of section). Each cross section shown on Figure 3 uses a consistent camera origin and focal point, which results in a consistent perspective and vertical axis for each pane of the figure. This allows for comparison between models (e.g., to show that the BBGM extends to a greater depth than the other models included for comparison).

A brief description of each model described above is provided below, including the historical calibration period, horizontal and vertical extent and discretization, and modeling code and packages used. Each description includes details on model features relevant to the simulation of interbasin groundwater flow and a summary of those features are shown on Table 1 for all the models. Note that this inventory report is not an exhaustive review and comparison of each model. However, we have included references to the most recent development information and reports for each model. Also note that this analysis focuses on models

1 http://www.water.ca.gov/groundwater/sgm/pdfs/Proposed_GSP_Regs_2016_05_10.pdf
that are complete as of the time this memo was developed. DWR is developing a new model of the Sacramento Valley, named the Sacramento Valley Simulation Model (SVSim), but it is not complete. SVSim is being developed to evaluate water transfer projects in the Sacramento Valley, and will be more refined than the fine grid version of C2VSim, both in terms of horizontal and vertical discretization and input datasets.
Figure 2. Groundwater Model Grids

- SACFEM2013
- C2VSM - Fine Grid
- CVHM
- SCF Model
- BBGM
Note: See Figure 1 for line of section. Viewing direction is to the north. Camera origin and focal point are the same for each figure, resulting in a consistent vertical scale for each pane of the figure.
<table>
<thead>
<tr>
<th>Key Feature</th>
<th>C2VSim</th>
<th>CVHM</th>
<th>SACFEM2013</th>
<th>BBGM</th>
<th>SCF Model</th>
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</thead>
<tbody>
<tr>
<td>Code Platform</td>
<td>IWFM</td>
<td>MODFLOW-FMP</td>
<td>IDC coupled with MicroFEM</td>
<td>IWFM</td>
<td>IGSM</td>
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<tr>
<td>Public Domain Code</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes for IDC; MicroFEM is proprietary</td>
<td>Yes</td>
<td>Yes</td>
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<td>Model Ownership</td>
<td>DWR</td>
<td>USGS</td>
<td>Reclamation</td>
<td>Butte County</td>
<td>DWR</td>
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<tr>
<td>Availability</td>
<td>Course grid available on DWR website and fine grid available upon request to DWR</td>
<td>Available on USGS website</td>
<td>Uncertain</td>
<td>Available upon request to Butte County</td>
<td>Available upon request to DWR</td>
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<tr>
<td>Documentation</td>
<td>Available on DWR website</td>
<td>Available on USGS website</td>
<td>Available online</td>
<td>Available on Butte County website</td>
<td>Available upon request to DWR</td>
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<tr>
<td>Integrated Model</td>
<td>Yes</td>
<td>Yes</td>
<td>Partially: two separate codes used to simulate hydrologic processes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Geographic Area</td>
<td>Central Valley</td>
<td>Central Valley</td>
<td>Sacramento Valley Groundwater Basin</td>
<td>Groundwater Subbasins in Butte County (including East Butte, West Butte, Vina, North Yuba, and portions of Sutter)</td>
<td>Corning Subbasin and northern Colusa Subbasin</td>
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<tr>
<td>Number of Layers</td>
<td>3</td>
<td>10</td>
<td>7</td>
<td>9</td>
<td>4</td>
</tr>
</tbody>
</table>
### Key Feature

<table>
<thead>
<tr>
<th>C2VSim</th>
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<th>BBGM</th>
<th>SCF Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geologic Formations Represented in the Model</strong></td>
<td>Generalized upper unconfined aquifer, confined production zone, deep confined zone</td>
<td>Layers not explicitly tied to hydrogeologic units except for Corcoran Clay in the San Joaquin Valley, remainder based on sediment texture model</td>
<td>Layers not explicitly tied to hydrogeologic units except for portions of the Tuscan Formation</td>
<td>Holocene basin deposits, Alluvium, Sutter/Laguna Formation, Tehama Formation, Tuscan C/B/A Formations, older marine (Neroly, Upper Princeton Gorge, Ione)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Agricultural Demand Estimation Method</th>
<th>Integrated methodology using IDC</th>
<th>Integrated methodology using the Farm Process</th>
<th>Calculated externally by IDC</th>
<th>Integrated methodology using IDC</th>
<th>Integrated methodology using IGSM Ag Demand Package</th>
</tr>
</thead>
</table>

Note: Descriptions in this table may not reflect ongoing, unpublished updates to these models.

### 3.1 C2VSim

C2VSim\(^2\) is a regional numerical hydrologic model covering the approximately 20,000 square miles (i.e. 12.8 million acres) of California’s Central Valley. C2VSim was originally developed in 1990 for DWR, U. S. Bureau of Reclamation, and the State Water Resources Control Board as the Central Valley Groundwater and Surface water Model (CVGSM). The model was upgraded in 2005 to the public domain IWFM platform and was renamed C2VSim. IWFM, also developed by DWR, is an open source finite element simulation code that supports triangular and quadrilateral elements. C2VSim has been used in numerous applications, including planning studies, climate change assessments, improved understanding of stream–groundwater flows, groundwater storage investigations, ecosystem enhancement scenarios, infrastructure improvements, and Delta flows specific studies. IWFM and C2VSim are both specifically designated as useful in developing water budgets for SGMA compliance, though other models or codes may be used.

There are two versions of C2VSim maintained by DWR, a coarse-grid version (C2VSim-CG) and a fine-grid version (C2VSim-FG). C2VSim-CG is publicly available for download from DWR, while C2VSim-FG is under refinement and calibration. Both versions are currently being updated through 2015.

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\(^2\) [http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/index_C2VSIM.cfm](http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/index_C2VSIM.cfm)
This Tech Memo will focus on the fine-grid version of C2VSim; all references to C2VSim hereafter refer to C2VSim-FG.

C2VSim currently contains monthly historical stream inflows, surface water diversions, precipitation, land use, and crop acreages from October 1921 through September 2009. C2VSim dynamically calculates crop water demands; allocates contributions from precipitation, soil moisture, and surface water diversions; and calculates groundwater pumping required to meet the remaining demand. The model simulates the historical response of the Central Valley’s groundwater and surface water flow system to historical stresses.

The C2VSim grid has more than 32,000 elements and 30,000 nodes, with an average element area of approximately 400 acres. The C2VSim model grid, which covers the entire Central Valley, is shown for the study area in Figure 2. C2VSim is vertically discretized into 3 aquifer layers and 1 aquiclude with a generalized upper unconfined aquifer, a confined production zone, and a deep confined zone. Additional details of C2VSim are provided in Table 1.

### 3.2 CVHM

CVHM³ is a regional model developed by the U.S. Geological Survey (USGS) to simulate historical hydrology and groundwater conditions of California’s Central Valley. Some applications have included simulating land subsidence, determining groundwater availability in the Central Valley, and evaluating the effect of climate change on streamflow, demands, and other hydrology. CVHM utilizes USGS’ open source MODFLOW code plus the Farm Process Package, Stream Flow Routing, Basin Characteristics Model, Subsidence, and Flow Barriers modules and simulates conditions from October 1961 through September 2003. CVHM, like C2VSim, accounts for historical stream inflows, surface water diversions, precipitation, land use, and crop acreages. USGS developed a Central Valley sediment texture model to account for the heterogeneous distributions of fine and coarse grained materials that control groundwater flow. Although not yet released, USGS is reportedly updating CVHM to simulate recent conditions and to use a new simulation code, MODFLOW-One Water Hydrologic Model (OWHM).

CVHM contains about 20,000 elements with a uniform cell size of 640 acres (i.e., 1 square mile) and covers approximately 20,000 square miles (12.8 million acres) of the Central Valley. The subsurface is simulated using 10 layers. Additional details of CVHM are provided in Table 1.

### 3.3 SACFEM2013

SACFEM2013⁴ is a regional model that uses the proprietary MicroFEM model for simulation of groundwater flow and the IWFM Demand Calculator model (IDC) for simulation of land surface processes. SACFEM2013, originally developed in 2008, links the groundwater model with the surface water budget and root zone model (i.e., IDC model) to estimate deep percolation and agricultural pumping on a node by node basis from October 1969 through September 2010. SACFEM2013 was primarily developed as a tool to estimate the impact of conjunctive water management projects on surface water and groundwater resources within the Sacramento Valley. RMC performed a peer review of SACFEM in 2011⁵. SACFEM2013 was used to evaluate water transfers to mitigate Central Valley Project supply shortages for

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the Long-Term Water Transfers Environmental Impact Statement/Environmental Impact Report (EIS/EIR) in 2014. It was also reviewed as a part of the Review and Comments for the EIS/EIR.

SACFEM2013 covers the entirety of the Sacramento Valley Groundwater Basin (i.e., almost 6,000 square miles) and contains about 150,000 nodes and over 300,000 elements. Spacing between the nodes is as large as 3,300 feet and as small as 410 feet. The subsurface is simulated using 7 layers. Additional details of SACFEM2013 are provided in Table 1.

3.4 BBGM

BBGM7 is a local model that uses the public domain IWFM code to simulate surface water and groundwater conditions in Butte County and selected surrounding areas from October 1970 through September 2014. Applications have included 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. The model is a successor to the earlier Butte Basin Water Users Association Groundwater Model developed using the FEMFLOW3D code. Butte County staff and their consultants are currently updating the BBGM to utilize a newer version of IWFM. The update will allow for representation of additional complexity, including elemental land use distributions and details of water use for ponded crops (e.g., water use changes associated with laser levelling of rice fields).

The boundaries of the model are Deer Creek to the north, Sacramento River to the west, the Sutter Buttes and Yuba River to the south, and foothills to the east. The model covers about 1,200 square miles with nodes spaced between 2,500 and 5,000 feet that form over 7200 elements. The average element size is 112 acres and the model has 9 layers. BBGM contains portions of the Sacramento Valley Groundwater Basin—the Vina, West Butte, East Butte, Sutter, and North Yuba subbasins. Additional details of BBGM are provided in Table 1.

3.5 SCF Model

The SCF Model8 is a local model developed for DWR and local program sponsors in 2003 to study Stony Creek Fan, a geologic feature in Glenn and Tehama Counties. The model has been used to evaluate changes in land and water use and make assumptions about the availability of water supply. The SCF Model is a comprehensive hydrologic model that simulates the surface water and groundwater flow systems using the public domain Integrated Groundwater-Surface Water (IGSM) code, which is a predecessor code to DWR’s IWFM. The historical simulation period of the SCF Model is from 1970 through 2000. An extensive geologic analysis was conducted to develop model layering and parameters. The model simulates conditions in the Corning and northern Colusa groundwater subbasins, and includes the Tehama, Upper, and Lower Tuscan Formations. The calibration period of the model has not been updated since 2003 and we are not aware of any ongoing efforts to update this model.

At its largest points, the model extends about 30 miles from west to east and about 70 miles from north to south to cover an area of about 1,000 square miles covering the Corning groundwater subbasin and a portion

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6 http://www.usbr.gov/mp/nepa/nepa_projdetails.cfm?Project_ID=18361
7 https://www.buttecounty.net/waterresourceconservation/Groundwater.aspx
8 Stony Creek Fan Integrated Groundwater and Surface Water Model (SCFIGSM): Model Development and Calibration Baseline Analysis, Volume 3 of 4, May 2003. Prepared for Glenn-Colusa Irrigation District, Orland-Artois Water District, and Orland Unit Water Users’ Association by WRIME, Inc. (now RMC) in coordination with DWR.
of the Colusa subbasin (i.e., approximately the same portion within the study area). The SCF Model grid is made up of over 2,000 elements and approximately 1,800 nodes. The subsurface is modeled using 4 layers. Additional details of the SCF Model are provided in Table 1.