Technical Memorandum

Sacramento Valley Groundwater-Surface Water Simulation Model Technical Memorandum 2 (SVSim TM-2)

Subject:	**Model Grid Development**
Prepared For:	Department of Water Resources
Prepared by:	Frank Qian, Mesut Cayar
Reviewed by:	Saquib Najmus
Date:	September 23, 2016
Reference:	0400-027-00

1 Purpose and Introduction

The purpose of this technical memorandum is to summarize the steps taken in the development of the Sacramento Valley Simulation Model (SVSim) grid. This grid will be used in developing an Integrated Water Flow Model (IWFM) application in the Sacramento Valley. IWFM is a finite element integrated hydrologic model developed and supported by the California Department of Water Resources (DWR).

The SVSim model domain, shown in Figure 1 includes all of the Sacramento Valley and Redding Area Groundwater Basins. The model boundary follows Bulletin 118 – Update 2003 groundwater basin boundaries inclusive of the DWR-initiated administrative changes to the Colusa and South Yuba Subbasins as of April 7, 2016 under the Sustainable Groundwater Management Act (SGMA). The model domain extends to the Delta and includes the Suisun Fairfield Valley, Ygnacio Valley, Clayton Valley, Arroyo Del Hambre Valley, and Pittsburg Plain Subbasins in the southeast. The model domain covers portions of the northern San Joaquin Valley Groundwater Basin. While the Cosumnes Subbasin is fully within the model domain, the Tracy and Eastern San Joaquin Subbasins are only partially included. The southern boundary of the model area lies between the Mokelumne and Calaveras Rivers as defined in DWR's review of model southern boundary document[1].

The model grid features are selected through a collaborative process among DWR staff and consultants with due considerations of the modeling goals and objectives and constraints of data and the modeling tool. The model grid features are summarized in Table 1.

Table 1. Summary of Model Grid Features

No.	Feature	Decisions
1	External Boundary	Bulletin 118 - Update 2003 groundwater basin boundaries[2] inclusive of the DWR-initiated administrative changes to the Colusa and South Yuba Subbasins.
2	Southern Boundary	The southern boundary is defined by DWR[1] between Calaveras and Mokelumne Rivers.

[1] Bond, Linda (1/6/2016) - Review of SVSim Southern Boundary Truncation Final.docx

[2] http://www.water.ca.gov/groundwater/bulletin118/gwbasins.cfm

3	Streams	All of the streams, which includes rivers, creeks, canals, aqueducts, bypasses, and channels simulated in C2VSIM-FG (including Honcut Creek) in Sacramento Valley.
4	Mesh refinement (grid refinement around and away from stream)	300-ft horizontal grid spacing near the stream with gradual increase in grid spacing away from the stream. For known transfer projects with production wells less than 300 feet from the stream, the grid is manually adjusted. Current 0.5 mile discretization along the stream and 1.5 mile discretization on the model boundary will be maintained.
5	Faults	Faults represented in C2VSim-FG in the Sacramento Valley are included. Additionally, faults and flow discontinuities represented in the Stony Creek Fan and Yolo County local IGSM models are included. For discrepancies between the local model faults and those in C2VSim-FG, the C2VSim-FG faults are followed.
6	Geologic Outcrops	The Sutter Buttes and Capay Hills geologic outcrops identified by the groundwater basin boundaries in Bulletin 118 – Update 2003 are followed.
7	Surface Geology	The geologic boundaries represented in the grid were developed and smoothed by DWR based on geology maps published by Helley and Harwood (1985)[3] and extended to the Delta, based on the California Geologic Survey Sacramento, Santa Rosa, and San Francisco-San Jose 250,000-scale geologic maps[4].
8	Internal Administrative Boundaries	Preliminary Groundwater Sustainability Agency (GSA) boundaries, based on Bulletin 118 - Update 2003, modified with interim administrative subbasin boundary adjustments along streams and county lines.
9	Local Model Boundaries	The Butte, Stony Creek Fan, Yolo County, and Sacramento County local IGSM model boundaries are included in the grid. In regions where the local models extend beyond the Bulletin 118 – 2003 Update Basin boundaries, the basin boundaries were followed. The IWFM small watershed feature will be utilized to capture recharge and underflow from local model areas extending beyond the SVSim Boundary.

[3] Helley E.J., Harwood, D.S. (1985), Geologic Map of Late Cenozoic Deposits of the Sacramento Valley and Northern Sierran Foothills, California; U.S. Geological Survey Miscellaneous Field Studies Map MF-1790 (https://pubs.usgs.gov/mf/1985/1790/)

[4] Geologic Map of the Santa Rosa Quadrangle, California Geological Survey, Regional Geologic Map No. 2A, 1:250,000 scale, Compilation by: D.L. Wagner and E.J. Bortugno, 1982; Geologic Map of the San Francisco – San Jose Quadrangle, California Geological Survey, Regional Geologic Map No. 5A, 1:250,000 scale, Compilation by D.L. Wagner, E.J. Bortugno, and R.D. McJunkin, 1991; and Geologic Map of the Sacramento Quadrangle, California Geological Survey, Regional Geologic Map No. 1A, 1:250,000 scale, Compilation by: D. L. Wagner, C.W. Jennings, T.L. Bedrossian, and E.J. Bortugno, 1981

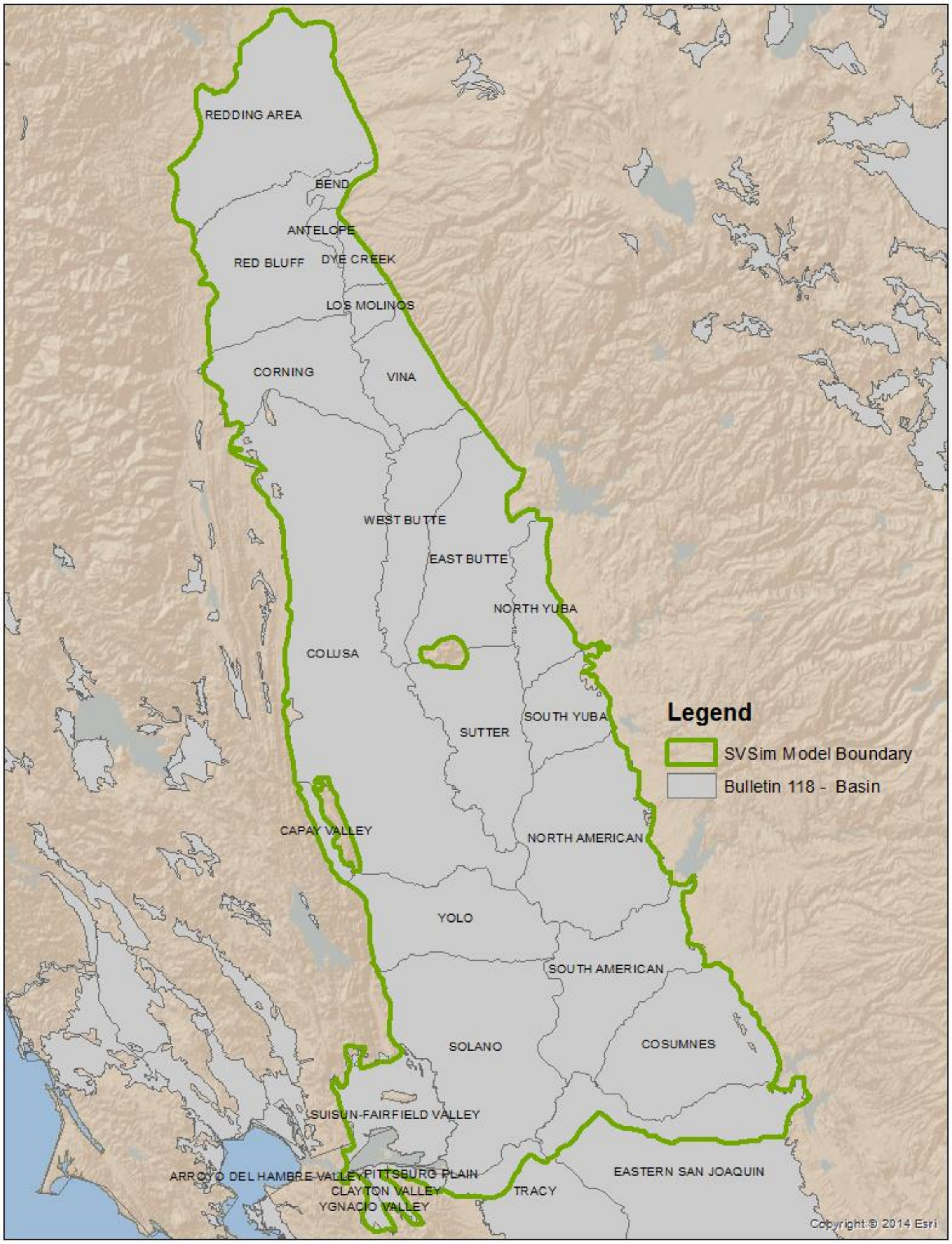

Figure 1. SVSim Model Boundary and Bulletin 118 – Update 2003 Groundwater Basin Boundaries

2 Grid Development Process

The SVSim grid was developed using a two-phased process:

- Phase I: Grid Generation by Automated Tools and
- Phase II: Grid Refinement by Manual Methods

These phases are described below.

2.1 Phase I: Grid Generation by Automated Tools

Phase I of model grid development consisted of the following steps:

1. Development of control
   i. External boundary control points
   ii. Internal control points
2. Development of the SVSim Grid

DWR's Mesh Generator[5] and Aquaveo's Groundwater Modeling System (GMS)[6] finite element grid generation software were used for the automated grid development. DWR's Mesh Generator was used to develop the control points at specified intervals along the model boundaries, streams and faults. GMS was used to generate the finite element grid, while honoring the location of the control points.

2.1.1 Development of Control Points

Automated finite element grid generation requires control points. Both internal and external boundary control points are defined prior to the automated grid generation process to ensure that the features of interest are preserved in the model. A brief discussion on the development of control points is provided below.

External Boundary Control Points

The selection of model external boundary control points was performed as specified below:

- The SVSim external boundary was digitized following the Bulletin 118 - Update 2003 groundwater basin boundaries with the assumption that external boundaries of the Sacramento Valley Groundwater Basin or the boundary around the Sutter Buttes would not change within the time frame of SVSim development.
- DWR initiated significant changes to Bulletin 118 – 2003 Update Basin boundary in the Colusa and South Yuba Subbasins for the 2015 administrative edits. The updated basin boundaries were used to develop the external model boundary of SVSim. The Northeast corner of the revised South Yuba Subbasin extends east following the Yuba River. The southeast corner of the North Yuba Subbasin was extended to follow the Laguna Formation (alluvial gravel, sand, and silt). It was preferable for the Yuba River to flow through the basin rather than flowing on the model boundary.
- The external model boundary follows the streams for areas where the streams and the Bulletin 118 - Update 2003 groundwater basin boundaries run very close (less than 300 feet) and parallel to each other. Sections of the model boundary follow Clear

[5] http://baydeltaoffice.water.ca.gov/modeling/hydrology/IWFM/SupportTools/index_SupportTools.cfm

[6] Version 10.1 (http://www.aquaveo.com/software/gms-groundwater-modeling-system-introduction)

Creek, Cottonwood Creek, the Tehama-Colusa Canal, and Putah South Canal. A significant portion of the western boundary of the Colusa Subbasin follows the Tehama-Colusa Canal. The Tehama-Colusa Canal was followed where the basin boundary and canal were not in agreement.

- The southern boundary of SVSim follows the "between streams" (between Calaveras and Mokelumne Rivers) southern boundary defined in DWR's review of model southern boundary document[2].
- An average of 1.5 mile spacing was used between the boundary control points. Sections of the model boundary falling between two streams within 4 miles of each other used finer spacing to maintain consistency with the node spacing of internal control points (See Figure 2).

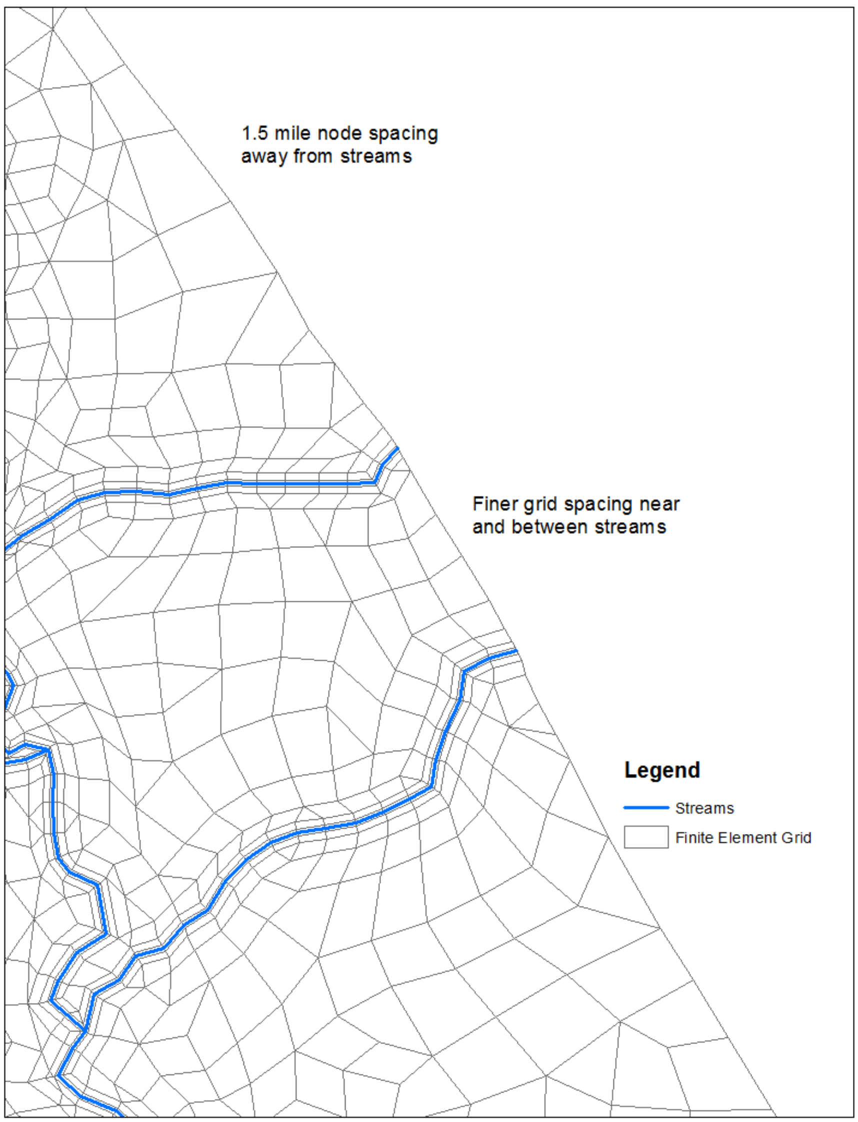

Figure 2. Node Spacing at Model Boundary between Streams

Internal Control Points

The selection of the internal control points on the streams, buffer zones, faults, outcrops, surface geology, and administrative boundaries were performed as specified below:

- **Streams:**
  - All of the streams simulated in C2VSIM-FG (including Honcut Creek) in Sacramento Valley were digitized. See Figure 5 and Table 2 for a map and a complete list of simulated streams, respectively.
  - Existing C2VSim stream nodes were adjusted slightly to match USGS National Hydrography Dataset (NHD) flowlines, if necessary.
  - IWFM represents the streams as lines that follow the centerline of the stream. Rating table, stream conductance, and stream invert elevation are defined at each stream node to represent the full cross section of the stream.
  - An average of 0.5 mile node spacing (longitudinal) was used for control points along the streams.
  - An average of 1.5 mile node spacing (longitudinal) was used for control points along canals.
  - Streams were prioritized over other internal features. For basins, counties, and other administrative boundaries that follow streams, NHD flowlines were followed.
- **Bypasses:**
  - Unlike streams, the surface water and groundwater interaction for the Sutter and Yolo bypasses in SVSim will be simulated dynamically across the entire width of the channel (Figure 3). Simulating the bypasses and wide streams as a one dimensional flow system with a single groundwater node per stream node does not adequately capture the physical representation and accuracy of the stream aquifer interaction.
  - The variability in streambed hydraulic conductivity, stream aquifer head gradient, and stream aquifer interaction across the width of the bypass will be addressed by associating multiple groundwater nodes rather than lumping all on the center groundwater node as explained in the Technical Note developed by Saquib Najmus[7]. Doing this better captures variations in groundwater head across the stream width and simulates results using a more physically accurate approach.

[7] Najmus, S. (2016), Alternative Approach for Simulation of Wide Streams in DWR's Integrated Water Flow Model (IWFM): Technical Note prepared for Department of Water Resources

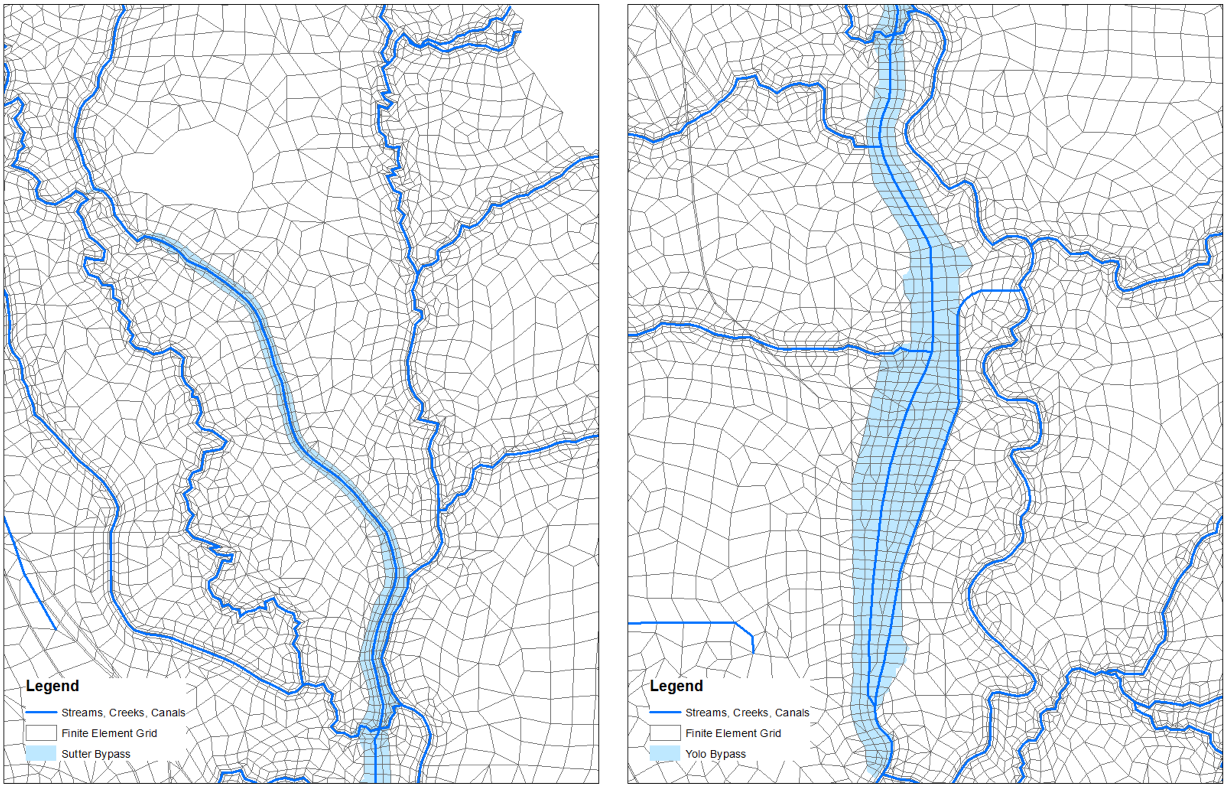

Figure 3. Sutter and Yolo Bypasses

- **Buffer Zones:** Since the streams are digitized with 0.5-mile node spacing, buffer zones were incorporated on each side of the streams to allow for proper transition from fine grid to coarse grid spacing. Additionally, the use of buffer zones helps better simulate stream aquifer interactions close to the streams. The buffer zones were set on both sides of the stream centerlines and follow the recommendations developed during Phase 1 of this project and guidelines followed during C2VSim-FG grid development:
  - A horizontal grid spacing (ΔL) 300 feet near the stream centerlines was used assuming it is smaller than the minimum distance between transfer wells and streams.
  - Because streams are simulated along the centerlines, most transfer wells are farther than 300 feet away from the simulated stream. One of the transfer projects, Pelger Road 1700, LLC, included production wells less than 300 feet from the centerline of the stream; for this project, the buffer zone was manually adjusted to ensure a minimum of 1 element between the simulated stream centerline and the production wells (Figure 4).
  - ΔL gradually increases away from the streams as follow:

Distance from the stream (mile)	0.06	0.18	0.43	0.95	2.00
Horizontal Grid Spacing (ΔL) (feet)	300	620	1,300	2,750	5,280

  - A final buffer zone was set at 5 miles on each side of the streams to allow for a proper transition from 1 mile to 1.5 mile grid spacing.
  - No changes were made to the longitudinal spacing of stream nodes (0.5 miles). The longitudinal grid spacing gradually increases to 1.5 miles

within the 5 mile buffer zone.

- A final buffer zone was set at 5 miles on each side of the streams to allow for a proper transition from 1 mile to 1.5 mile grid spacing.
- Buffer zones have the lowest priority among internal boundaries and are adjusted accordingly to conform to other features.
- Canals and aqueducts were not assigned buffer zones since fine spacing for stream aquifer interactions is not required.

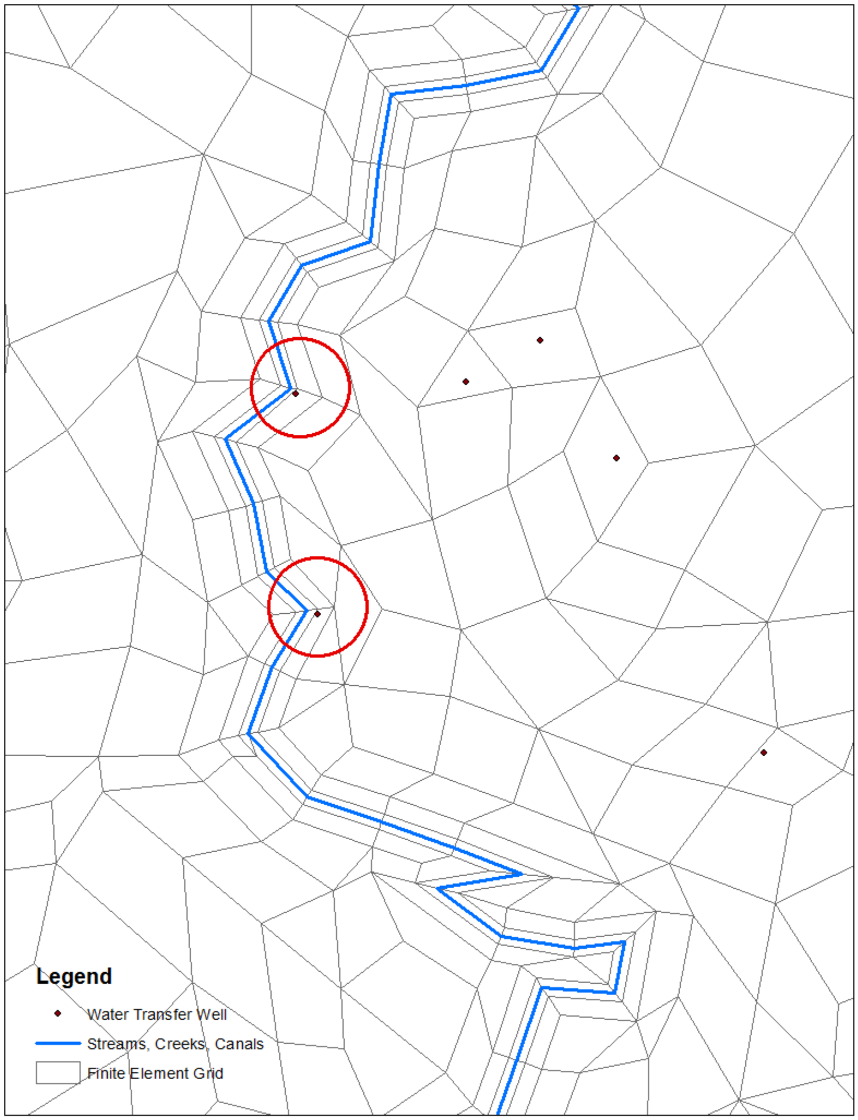

Figure 4. Pelger Road 1700, LLC Water Transfer Wells near Sacramento River

- **Faults:** Groundwater levels are not delineated in the grid. In addition, discontinuities in groundwater levels, associated with faults have only been identified in a few locations. The grid is configured to represent the location of faults, which will allow for the representation of discontinuities in hydraulic conductivities and the resulting groundwater discontinuities. Faults were delineated by a thin 0.1 miles wide strip of elements, which allow for the representation of discontinuities in the groundwater levels, as observed. Model mesh includes the same fault boundaries represented in C2VSim-FG in the Sacramento Valley as well as the faults and flow discontinuities simulated in the local Stony Creek and Yolo County IWFM models. In cases when there were discrepancies between the faults in C2VSim-FG and the local models, C2VSim-FG represented faults were honored. See Figure 5 and Table 3 for a map and a list of faults simulated in the SVSim model, respectively.

- **Geologic Outcrops:** Boundaries of the major geologic outcrops in the Sutter Buttes and Capay Valley Hills were digitized based on Bulletin 118 - Update 2003 groundwater basin boundaries. An average control point spacing of 1.5 miles was used for digitizing the outcrop boundaries. The model area falling within these outcrop areas was removed from the grid and is not used in spatial discretization of the model.
- **Surface Geology:** Boundaries of the coarse fluvial deposits and fine basin deposits were digitized using a shapefile developed and smoothed by DWR that was based on geology maps published by Helley and Harwood (1985) [3] and extended to the Delta, based on the California Geological Survey Sacramento, Santa Rosa, and San Francisco-San Jose 250,000-scale geologic maps (1981) [4]. Control point spacing varies from 300 feet to 1.5 miles depending on the position of the boundary with respect to streams. Geologic features away from the streams were added as control points while those within 920 feet of simulated streams were manually incorporated through node adjustments.
- **Bulletin 118 Interim Administrative Subbasin Boundaries:** The subbasin boundaries represented in the model grid follow the Bulletin 118 - 2003 Update interim administrative subbasin boundaries. The original Bulletin 118 - 2003 Update boundary file contains some line work inaccuracies due to digitizing and resolution issues at the time the file was developed. DWR is in the process of resolving these issues with minor administrative adjustments. These changes will not be available during the time frame of the SVSim development. However, some of these changes were captured in the grid as follows:
    - NHD flowlines were used for subbasin boundaries that follow streams.
    - County lines were used for subbasins boundaries that follow county lines.
    - Some additional changes may be made to Bulletin 118 - 2003 Update interim administrative subbasin boundaries in the future, based on local agency requests (approved by DWR) and review of geology maps, but those will not be available in the time frame needed for SVSim development and will not be incorporated in the grid.
- **County Boundaries**: The model grid follows county boundaries to facilitate input data collected based on these subdivisions. Boundaries away from streams were digitized and discretized while those along streams followed NHD flowlines.
- **Other Administrative Boundarie**s: The model grid conforms to the C2VSim-FG subregions, Detailed Analysis Units (DAU), and Depletion Study Area (DSA) boundaries to facilitate input data collected based on these subdivisions. Model subregions are consistent with those in C2VSim- FG and follow DAU boundaries. Boundaries away from streams were digitized and discretized while those along streams followed NHD flowlines.
- **Local Model Boundaries**: As a part of the Sustainable Groundwater Management Act (SGMA), local Groundwater Sustainability Plans (GSPs) are required to develop water budgets. To facilitate water budget comparisons between SVSim and local models, control points were added so that the SVSim grid conforms to the boundaries of local models. Internal boundaries away from streams were digitized and discretized while those along streams followed NHD flowlines. In areas where local models extended beyond existing

Bulletin 118 – 2003 Update boundaries, basin boundaries are followed. Small watershed features will be used to capture recharge and underflow from external regions.

- **Mesh generation interval of internal control points**: Internal control points were used to generate the finite element grid. The longitudinal spacing of finite element nodes range between 0.5 miles and 1.5 miles (depending on distance from streams). Spacing was adjusted to be consistent with the spacing of stream buffer zones. Spacing of control points is as follows:

Distance from the stream (mile)	0-0.43	0.43-0.95	0.95-2.00	Greater than 2.00
Longitudinal Grid Spacing (ΔL) (feet)	2,824	3,396	4,532	7,920

2.1.2 Development of SVSim Grid

The SVSim grid was developed using GMS. GMS is capable of generating finite element grids with triangular and quadrilateral elements. The generated grid was refined in the next phase of the grid development using manual methods described below.

2.2 Phase II: Grid Refinement by Manual Methods

Phase II of the model grid development consists of the following steps:

1. Adjustment of grid elements to conform to internal features not set as control points in Phase I
2. Optimization of the number of elements

2.2.1 Adjusting Grid Elements to Conform to Other Internal Features

Certain features could not be easily set as control points and were instead incorporated into the model grid through manual adjustment of nodes. As a result, the automatically generated model grid was manually refined through a process of visual inspection. For example, surface geology often crosses back and forth across streams, making it difficult to set as control points. Therefore, the nodes near the streams are manually adjusted to better match the surface geology.

2.2.2 Optimization of Number of Elements

The IWFM code is capable of using both triangular and quadrilateral grid cells. In order to optimize the model run time, the grid mesh is optimized by minimizing the number of triangular elements. In addition, any concave elements that are generated by the automatic grid generation tool are adjusted to remove the concavity. Boundaries defined by internal control points are preserved to avoid crossing elements.

3 Summary

Features and selected statistical properties of the final refined finite element grid for the Sacramento Valley are summarized in Table 4. A map of the final grid is attached as Figure 6.

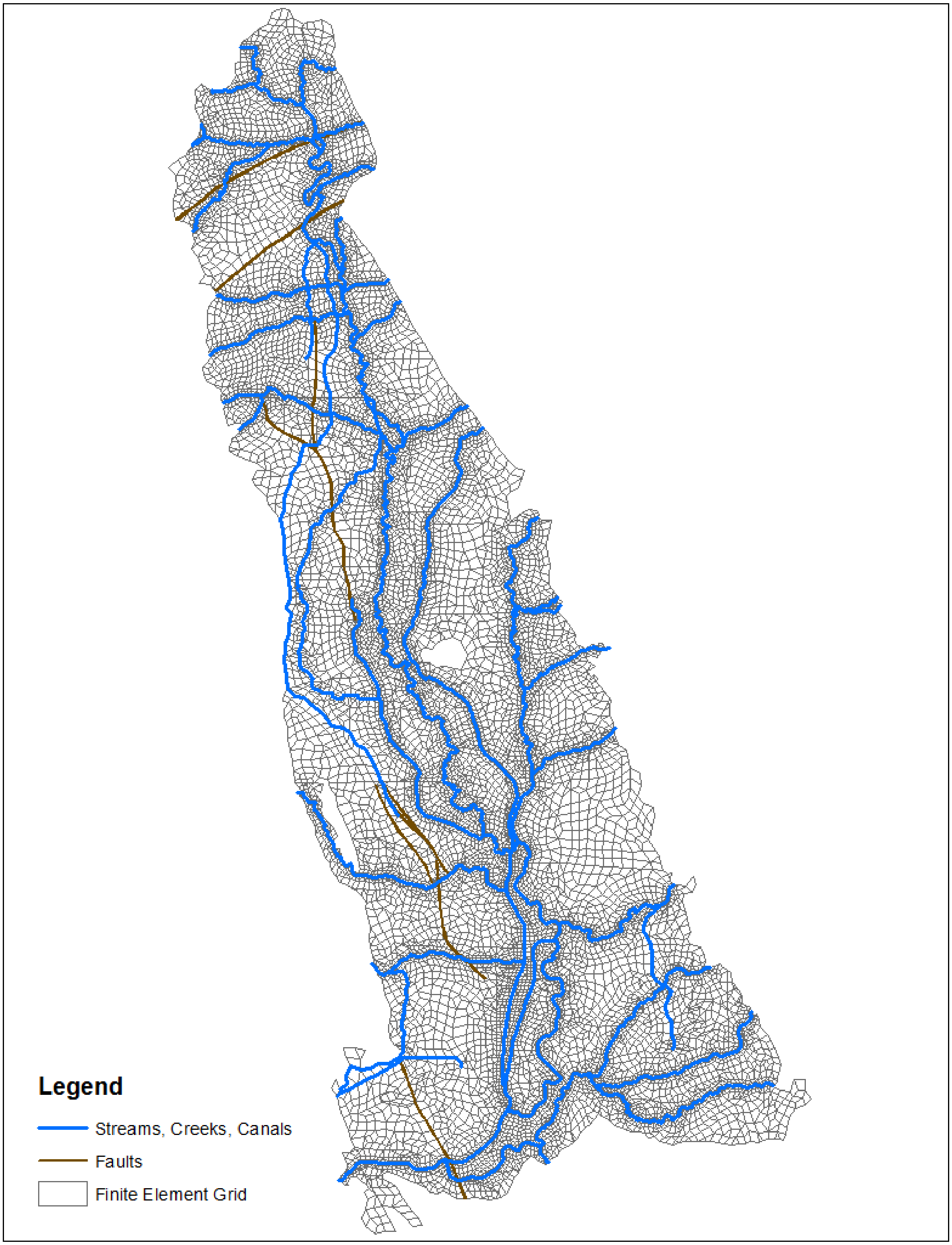

Figure 5. Model Grid with Streams and Faults

Table 2. Streams in SVSim

Stream	Resolution (Miles)	Buffer
American River	0.5	
Antelope Creek Group	0.5	
Auburn Folsom South Canal	1.5	None
Battle Creek	0.5	
Bear River	0.5	
Big Chico Creek	0.5	
Cache Creek	0.5	
Clear Creek	0.5	
Colusa Drain	0.5	
Corning Canal	1.5	
Cosumnes River	0.5	
Cottonwood Creek	0.5	
Cow Creek	0.5	
Deer Creek Group	0.5	
Dry Creek	0.5	
Elder Creek	0.5	
Feather River	0.5	
Glenn-Colusa Canal	0.5	None
Honcut Creek	0.5	
Mill Creek	0.5	
Mokelumne River	0.5	
North Bay Aqueduct	1.5	None
North Honcut Creek	0.5	
Paynes Creek	0.5	
Putah Creek	0.5	
Putah South Canal	1.5	None
Sacramento River	0.5	
Sacramento River Deep Water Ship Channel	0.5	None
San Joaquin River	0.5	
South Honcut Creek	0.5	
Stony Creek	0.5	
Suisun Bay	0.5	
Sutter Bypass/Butte Creek	0.5	
Tehama-Colusa Canal	1.5	None
Thomes Creek	0.5	
Yolo Bypass	0.5	None
Yuba River	0.5	

Table 3. Faults included in SVSim model grid

Faults
Battle Creek Faults
Black Butte Fault
Dunnigan Hills
Plainfield Ridge Anticline
Pittsburg Kirby Hills Vaca Fault
Red Bluff Arch
Willows Corning Fault
Zamora Fault
Zamora Syncline

Table 4. Features and selected statistical properties of the final model grid

Projection:	NAD_1983_UTM_Zone_10N
Number of Nodes:	22,647
Number of Elements:	23,767
Number of Triangular Elements:	3,074
Number of Quadrilateral Elements:	20,693
Min Element Area (Acres):	0.72
Max Element Area (Acres):	2,341
Average Element Area (Acres):	205
Total Model Area (Sq. Mile):	7,622
Number of Stream Nodes:	2,390
Number of Stream Reaches:	67

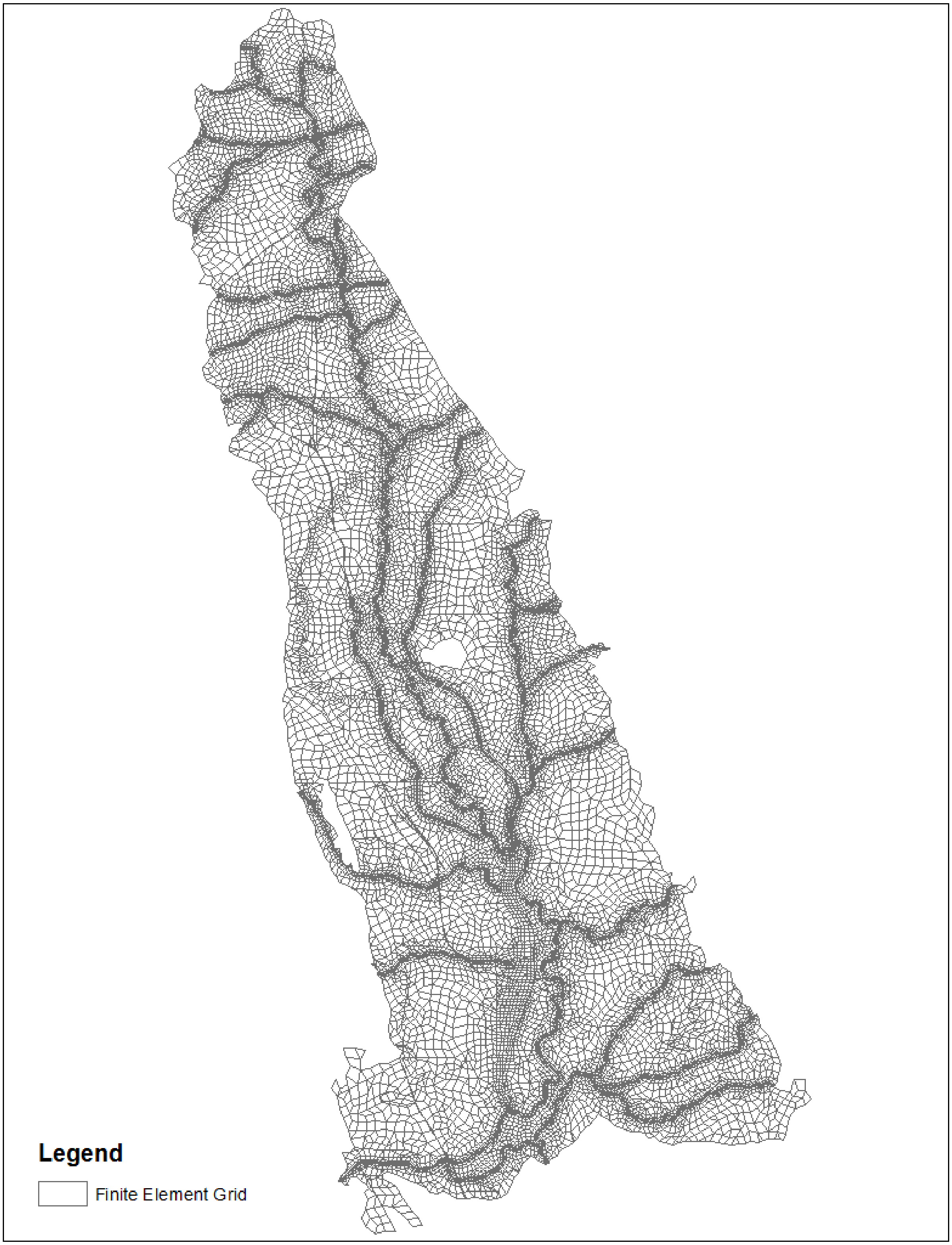

Figure 6. Final SVSim Model Grid