02 April 2021

MEMORANDUM

To: Tom Rooze (Zone 7 Water Agency [Zone 7])
Colleen Winey (Zone 7)

From: Anona Dutton, PG, CHg (EKI Environment & Water, Inc. [EKI])
Aaron Lewis (EKI)
Susan Xie, EIT (EKI)

Subject: **Progress Update on Extending Existing Hydrogeologic Framework**
(EKI C00065.00)

EKI Environment & Water, Inc. (EKI) is pleased to present to Zone 7 Water Agency (Zone 7) a summary of specific technical efforts related to extending the existing Hydrogeologic Conceptual Model (HCM) framework to encompass the entirety of the Livermore Valley Groundwater Basin (Basin). Pursuant to our approved scope of work, EKI's work efforts include application of 3D geologic modeling software to support development of three cross-sections for the Basin. This memorandum is anticipated to be included as an attachment to the 2022 Alternative Groundwater Sustainability Plan (Alt GSP).

GEOLOGIC MODELING SOFTWARE

The 3D geologic modeling software platform RockWorks[1] was selected by Zone 7 to support data integration, HCM representation, and cross-section development.

DATA SOURCES

The primary data sources that have been integrated into the RockWorks platform and are otherwise supporting development of the updated HCM framework include the following:

- Well information, including locations and well construction details as provided by Zone 7;
- Geologic and lithology data and resources as provided by Zone 7, including borehole geophysical (e-log) data, lithology intervals, aquifer layer (stratigraphy) depth intervals, prior hydrogeologic reports and studies, geologic maps, existing cross-sections, faults information, and other supporting resources;
- California Department of Water Resources (DWR) reports and information (e.g., from the SGMA data portal);

[1] RockWorks 2020 Standard Level License from RockWare is downloaded and installed on 15 October 2020: https://www.rockware.com/product/rockworks/

- Lawrence Livermore National Laboratory (LLNL) wells e-logs and lithology data;
- United States Geological Survey (USGS) ground surface elevation data;
- Groundwater elevation data provided by Zone 7; and
- Groundwater dependent ecosystem (GDE) resources, including GDE geospatial data and Sycamore alluvial woodland data.

MAJOR ASSUMPTIONS

Based on EKI's approved scope of work and further direction provided by Zone 7, the following key assumptions have informed the approach presented herein:

- ***On-going refinement of the Basin HCM is anticipated to be an evolving and iterative process that extends beyond the scope of this effort.*** As part of this scope of work, all currently available data have been processed and imported into the RockWorks framework to create a general 3D representation of the Basin. Additionally, detailed analysis and interpretations of the HCM framework are being made along the three proposed cross-section traces. It is anticipated that additional data can be added to RockWorks as available and that refined interpretations can be developed for additional areas of interest and/or to refine the Basin HCM as part of future work efforts by Zone 7 staff or consultants.
- ***For purposes of the 2022 Alt GSP, simplified Basin-scale Interpretations of the hydro-stratigraphic framework are appropriate.*** Multiple cross-sections have been developed by and for Zone 7 over time for different purposes. Previous interpretations of aquifer layer intervals contained as many as 10 stratigraphic units (i.e., overburden, perched aquifer, perched clay, cyan, gray clay, gray, purple clay, purple, red clay, and red) based on previous geological investigations within the Main Basin Management Area (MBMA) (Norfleet Consultant, 2004). However, given the considerable uncertainty involved in extending these stratigraphic units into the Fringe and Uplands management areas of the Basin, simplified stratigraphic units depicting only the overburden, upper aquifer, aquitard, lower aquifer, and the Lower Livermore Formation are used in the 3D modeling performed for the Basin for purposes of the 2022 Alt GSP. The original dataset of contact points between these more detailed stratigraphic units (cyan, gray, etc.) have been imported and are preserved as "I-Data" (interval data) in RockWorks to provide for future use and/or refinement, as applicable.

  Within the MBMA, the "upper aquifer" corresponds to the cyan unit (generally consisting of younger, unconsolidated Holocene to Quaternary alluvial deposits), the "aquitard" represents the gray clay unit, and the "lower aquifer" represents the combined gray-purple-red complex (generally consisting of older, semi-consolidated Quaternary alluvial deposits and the productive upper zone of the Plio-Pleistocene Livermore Formation [defined herein as the "Upper Livermore Formation"]). Where it exists outside the MBMA, the upper aquifer represents younger Quaternary alluvial deposits, while the lower aquifer represents older Quaternary terrace and alluvial deposits and the Upper Livermore Formation. The Basin bottom is defined at the top of the Lower Livermore Formation, i.e. the depth at which deposits become increasingly consolidated (transitioning from gravel beds lain with silts and clay to predominantly blue silts and clays) and well yields diminish considerably. In the Uplands area, it is assumed the Lower Livermore Formation is the dominant outcropping stratigraphic unit and therefore the upper and lower aquifers are not assumed to be present.

- ***Limited structural data can be directly incorporated into RockWorks.*** Given the RockWorks 2020 Standard Level license limitation, only three faults can be mapped and directly incorporated in the model. As such, three major faults[2] within the Basin were selected for modeling purposes, including the Livermore Thrust Fault, Las Positas Fault, and Verona Thrust Fault.

DATA INTEGRATION / APPLICATION OF ROCKWORKS

The following list summarizes the step-wise development process that was used to build the HCM framework in RockWorks. Graphical representations of the work effort to date are also included below:

1) ***Process and import borehole data provided by Zone 7 for 1,053 unique boreholes into the RockWorks Borehole Manager framework.*** As shown in Figure 1, these data included the location, borehole depth, borehole elevation, lithology, stratigraphy, and e-log data (gamma, short normal, long normal, spontaneous potential, single point resistivity, and lateral resistivity)[3].

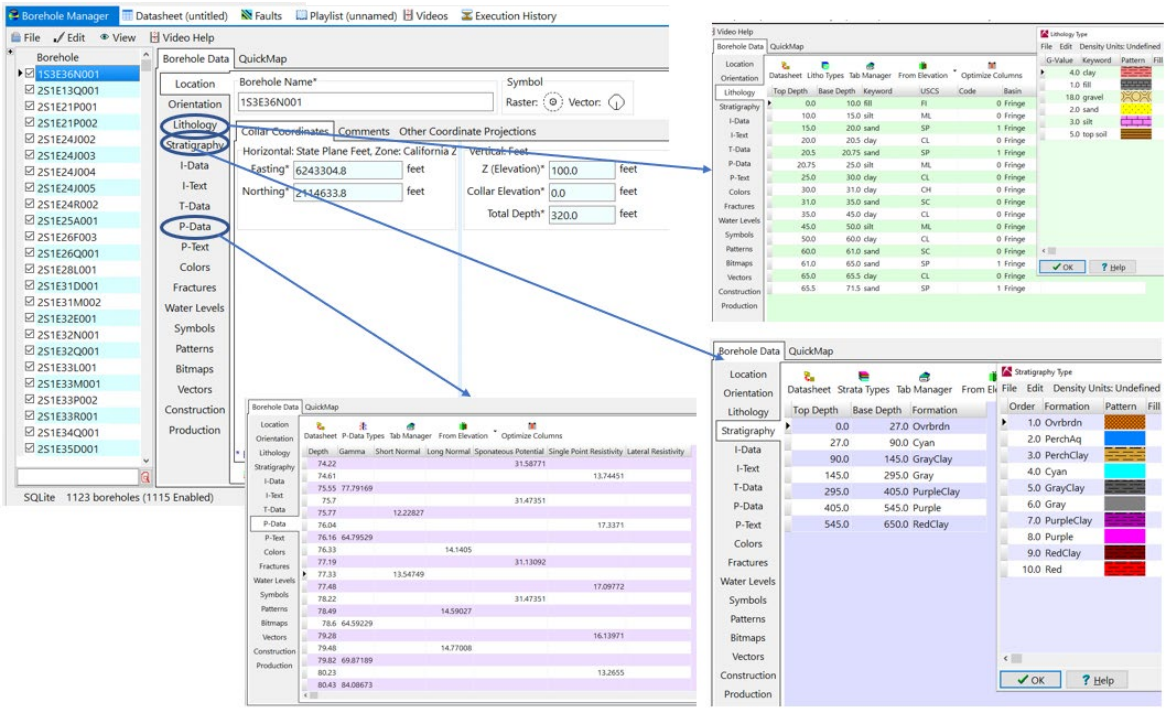
    a. The lithology data were further refined to group the 19 Unified Soil Classification System (USCS) classifications included in the lithology dataset into six simplified types (i.e., clay, silt, gravel, sand, fill, and top soil).

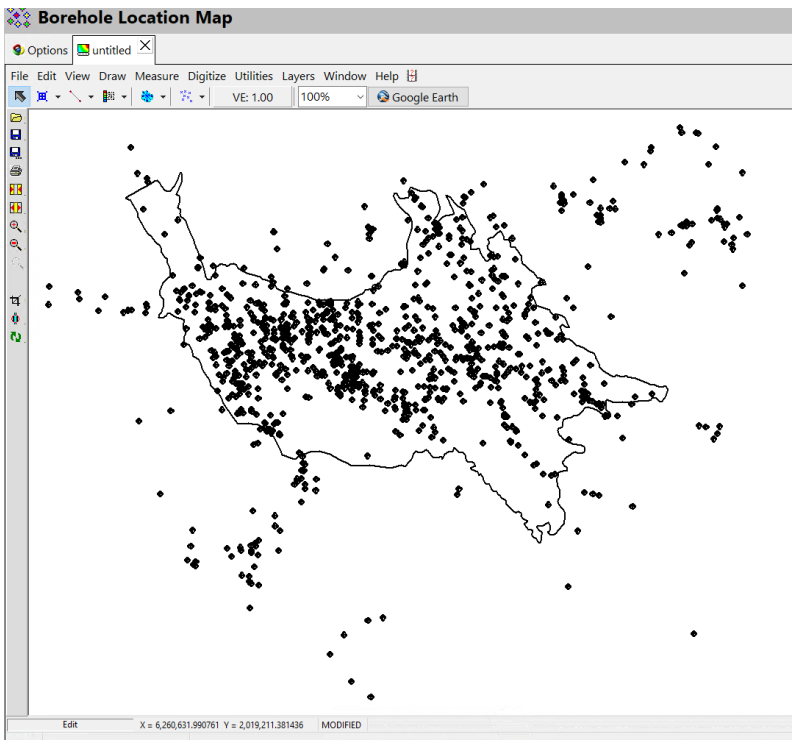
    b. The stratigraphy data were further refined to group the 10 stratigraphic units included in the original Zone 7 stratigraphy dataset into five generalized units (overburden, upper aquifer, aquitard, lower aquifer, and Lower Livermore Foundation), as described below in more detail.

    c. To examine whether there were similar grain-size distribution patterns between wells in each aquifer layer, the lithological data were reclassified as either coarse or fine-grained sediments[4], and their coarse grain percentages within each aquifer layer were summarized by well. This classification was loaded into RockWorks as a separate attribute of the lithology dataset, but was ultimately not used for model development.

[2] Three faults are mapped in Figure 3-3 Preliminary Stratigraphy Evaluation, Main Basin, Norfleet Consultants, dated 15 January 2004.
[3] Data availability varies by borehole.
[4] Coarse/fine classification is based on Standard Practice for Classification of Soils for Engineering Purposes (USCS), American Society for Testing and Materials (ASTM) D2487-06.

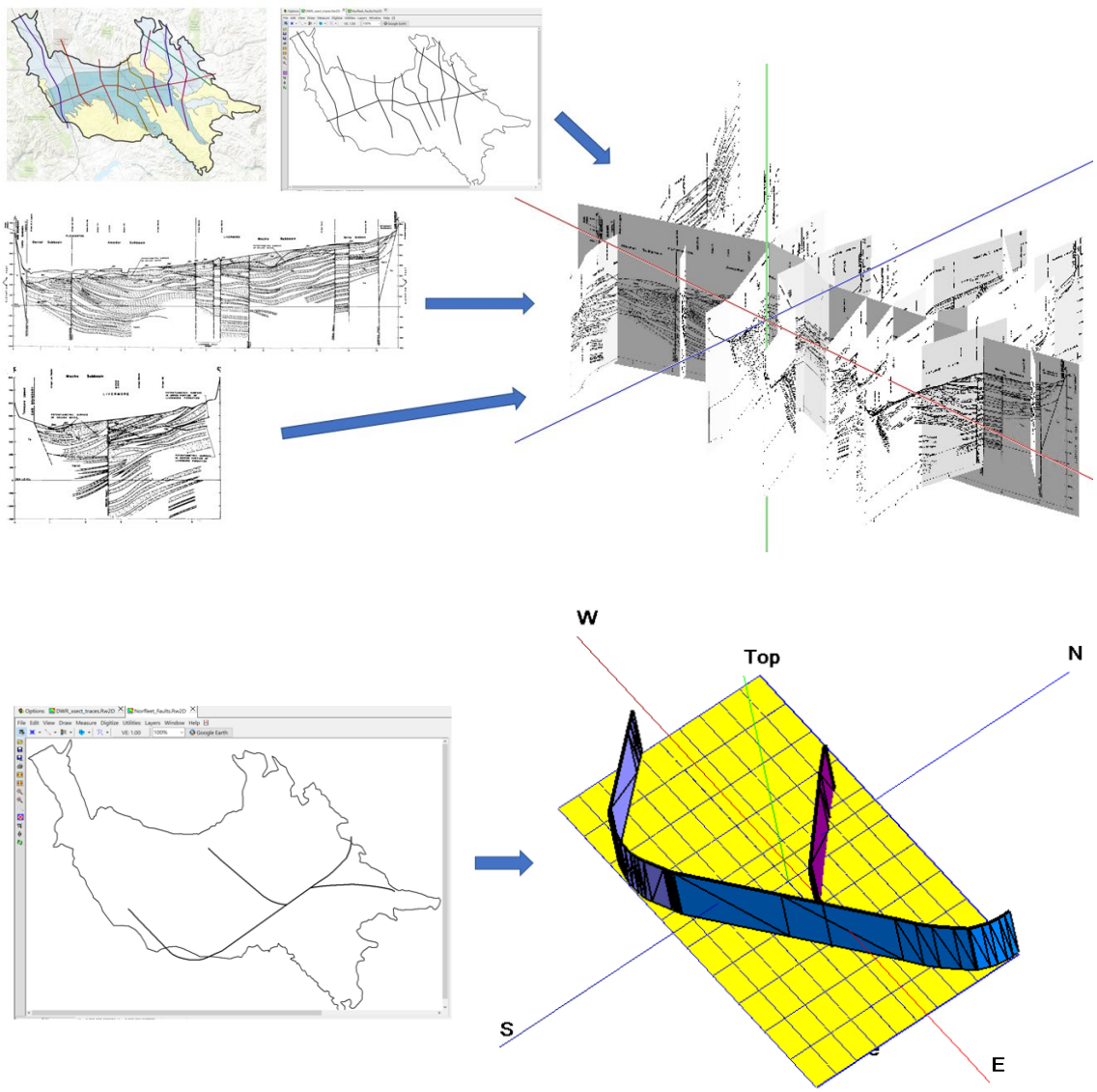
Figure 1 - Processing of Well and Borehole Data





2) ***Process and import selected 2D shapefiles and imagery into the RockWorks framework.*** As shown in Figure 2, these files included the Basin boundary, the DWR (1974) cross-section traces[5] that were digitized by EKI, and three major faults within the Basin (Livermore Thrust, Las Positas Fault, and Verona Thrust) that were also digitized by EKI. EKI created georeferenced 3D RockWorks files for the 1974 DWR cross-section traces and three major faults.

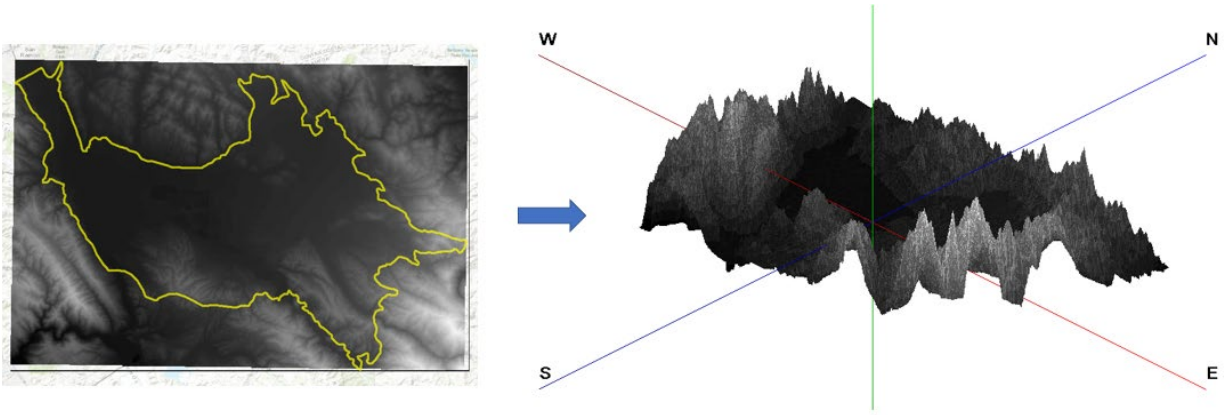
Figure 2 - Processing of Additional Basin Data and Structural Features



[5] California Department of Water Resources Bulletin 118-2, Evaluation of Ground Water Resources: Livermore and Sunol Valleys, dated June 1974.

3) ***Process and import USGS topography raster data and create 3D RockWorks file*.** As shown in Figure 3, the USGS dataset serves as an upper boundary (i.e., ground surface) to clip other RockWorks 3D models to. This dataset was resized and clipped to match the Basin dimensions as specified in RockWorks.

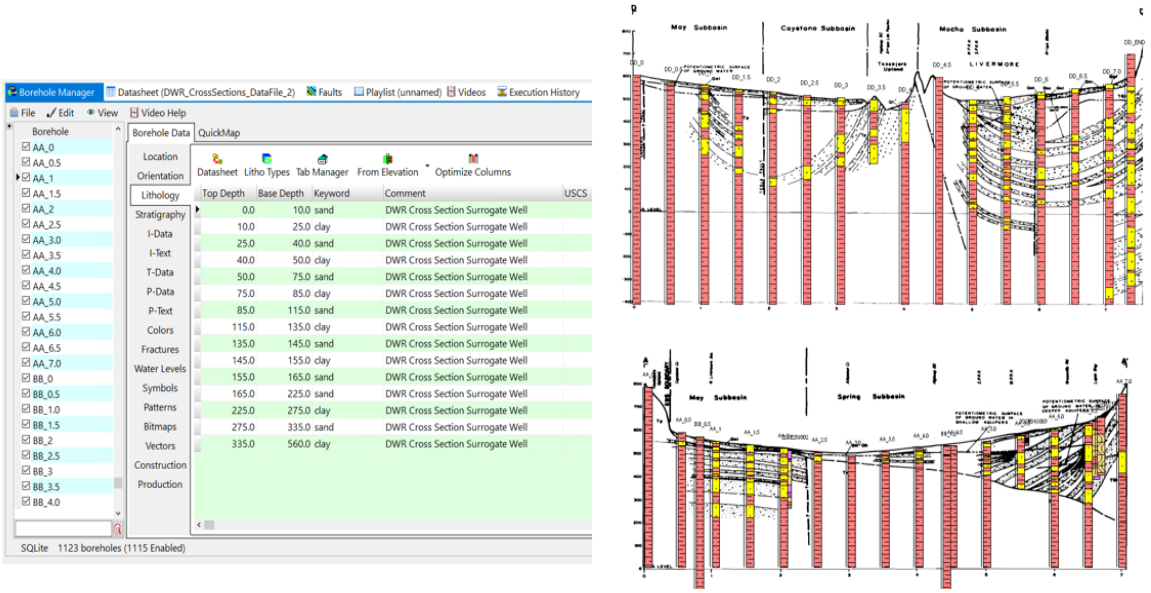
Figure 3 - Processing of Digital Elevation Model



4) ***Digitize and import lithology from select DWR (1974) cross-sections to fill data gaps***. Limited borehole data exist in certain portions of the Basin. To fill in data gaps, a total of 83 "surrogate" boreholes were developed and their generalized lithology profiles were characterized along the DWR (1974) cross-section traces A-A', B-B', C-C', D-D', E-E', and I-I'[6] to densify lithology information in the Fringe and Uplands management areas of the Basin. The DWR (1974) cross-sections approximate water bearing and non-water bearing units by elevation, which were then classified by EKI as either sand or clay in the surrogate boreholes. As shown in Figure 4, these surrogate boreholes were imported into RockWorks for subsequent use in developing the 3D lithology and stratigraphy models.

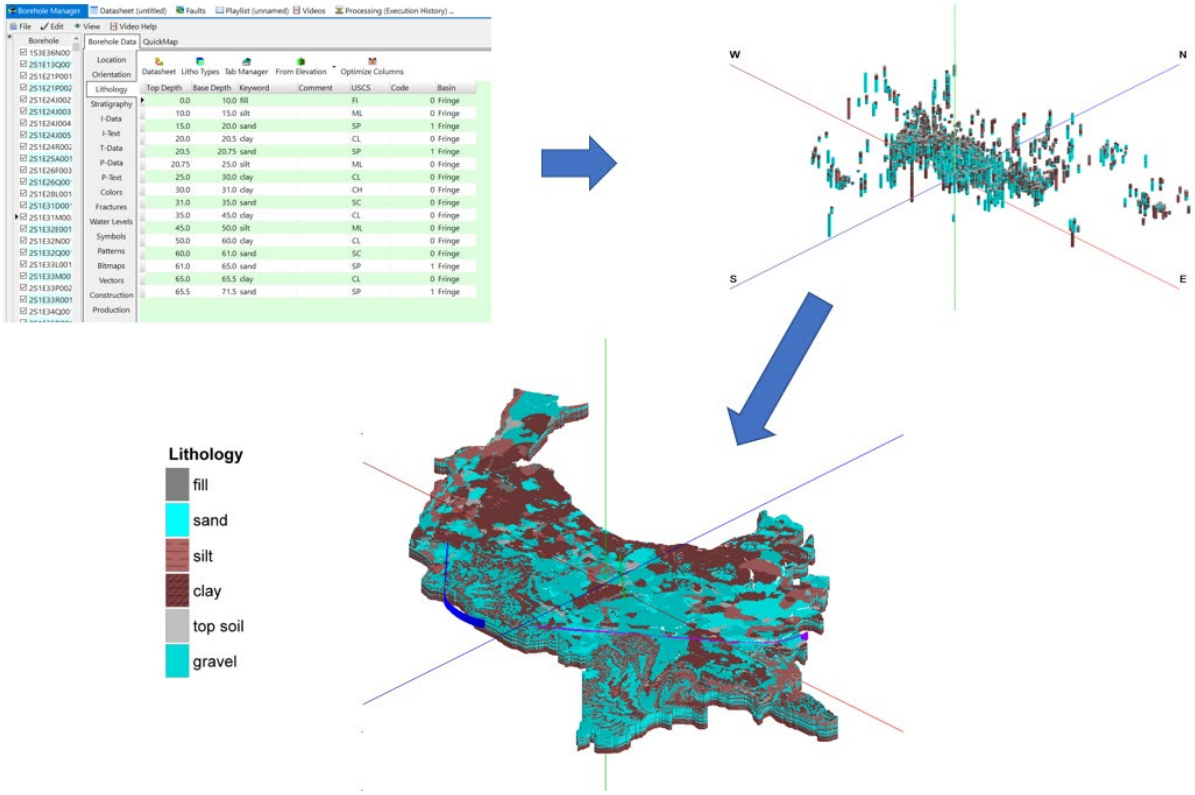
[6] *Ibid* [5].

Figure 4 – Development of Surrogate Boreholes to Fill Data Gaps



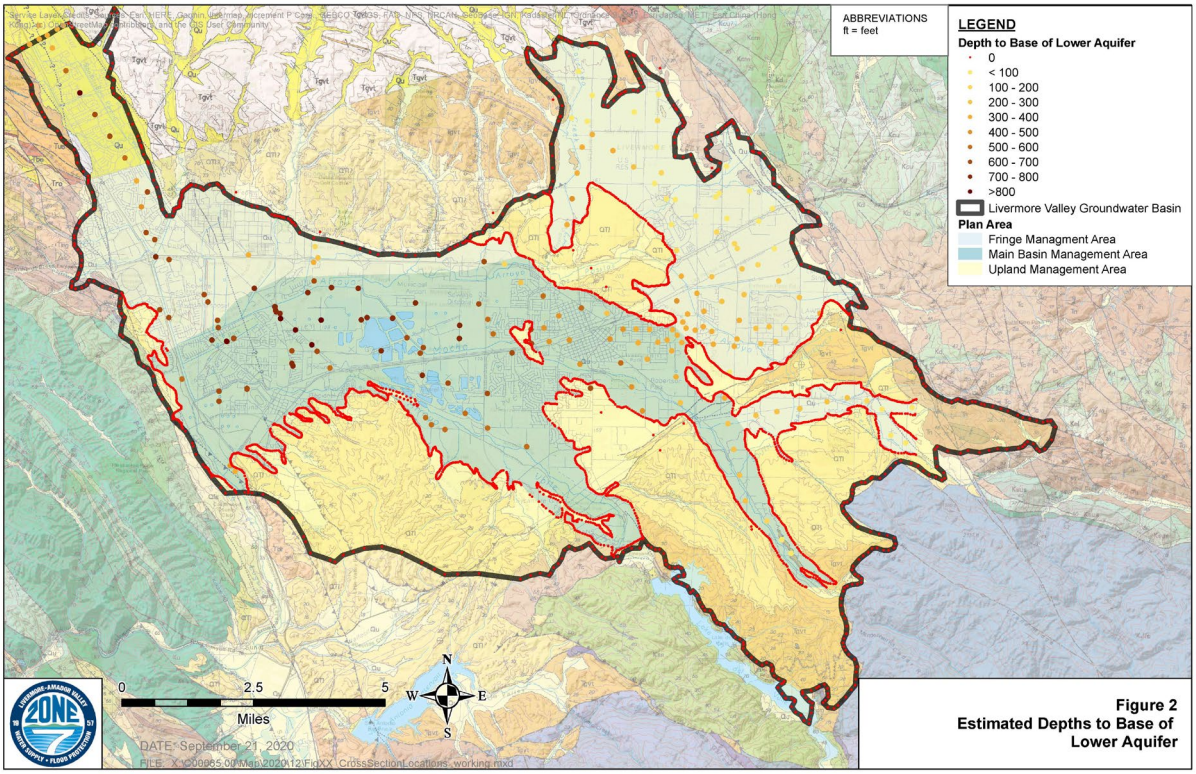
5) Create 3D RockWorks lithology model using the six simplified lithological classifications. As shown in Figure 5, a 3D gridded lithology model (200 x 200 x 20 ft resolution) was developed in RockWorks using the five simplified lithological classifications described in Step 1 to visualize the spatial distribution of lithology throughout the Basin. Discrete borehole lithology data from 991 wells were interpolated across the Basin to create a 3D gridded lithology model that extends from the ground surface down to the bottom of the Basin (i.e., the top of the Lower Livermore Formation).

Figure 5 – Development of a Basin Lithology Model



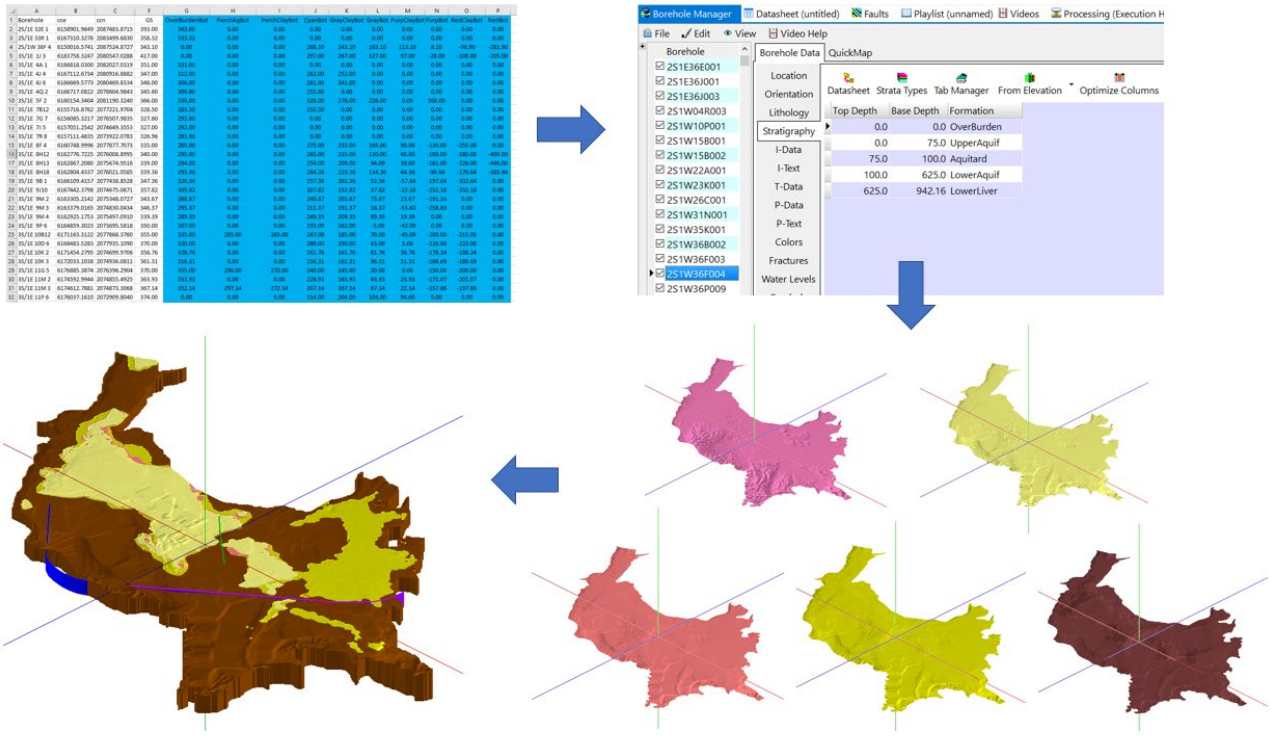
6) ***Refine stratigraphic contacts to inform 3D RockWorks stratigraphy model.*** The original "aquifer layers" dataset provided by Zone 7 only contained stratigraphy interval data for 72 boreholes, all of which were located in the MBMA and many of which only contained information for a few of the (10) stratigraphic units. To provide for a reasonable representation of Basin-wide geometry, these data were augmented with the "surrogate" boreholes used to densify the dataset of stratigraphic contact points within the Fringe and Upland areas and along the Basin boundaries (see Step 4). These "surrogate" boreholes included the 83 digitized DWR records mentioned above, the >6,000 vertices of Zone 7's Basin subareas shapefile used to delineate the Uplands and Fringe areas and the Basin boundaries, and several other locations within the MBMA, Fringe, and Upland management areas where aquifer depths were estimated based on nearby borehole (lithology, elog) information and other available geologic information (see Figure 6).

Figure 6 – Refine Stratigraphic Contacts Based on Additional Data



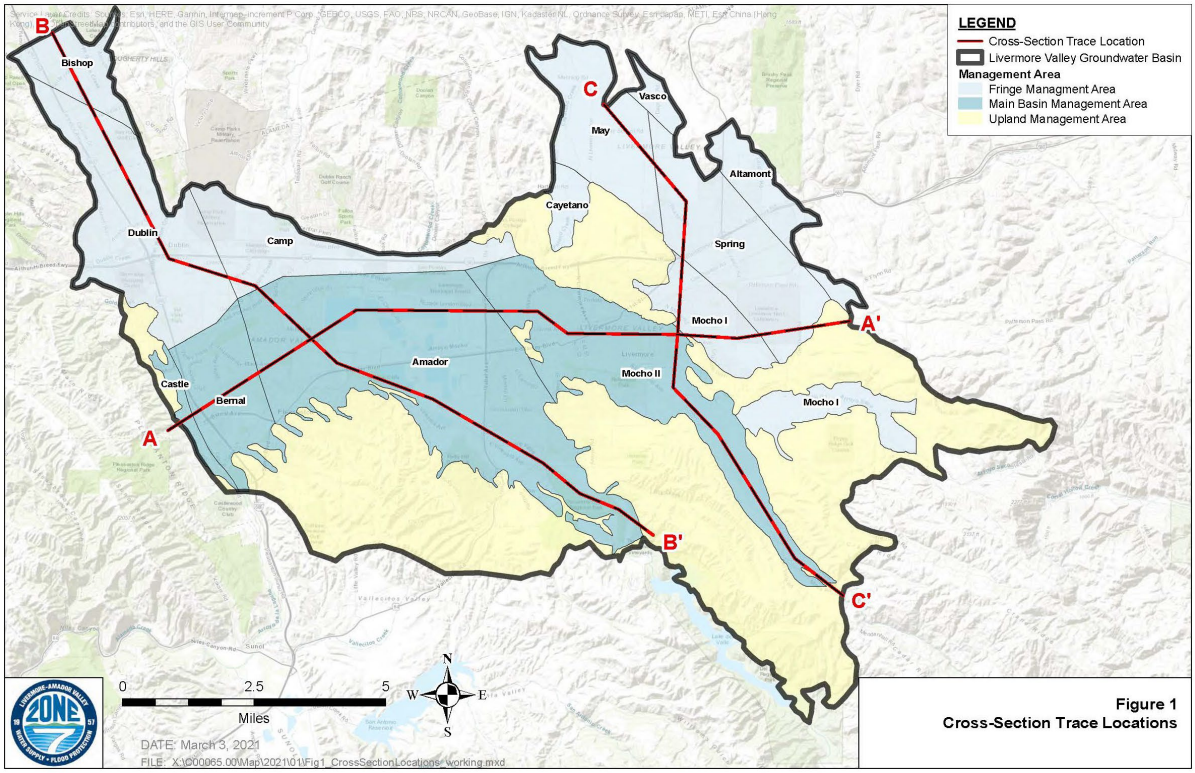
7) ***Create 3D RockWorks stratigraphy model.*** A 3D model of Basin stratigraphy was subsequently developed in RockWorks using the refined dataset of stratigraphic contacts described above (Step 6) along with other available lithology and e-log information (Step 1). As shown in Figure 7, the 3D stratigraphy model is a system of interpolated surfaces representing the top and base of the major aquifer units that have been "filled in" to produce a volumetric representations of each major aquifer unit across the Basin, and includes modeled hydrogeologic discontinuities resulting from the three major faults imported into RockWorks (Step 2).

Figure 7 – Development of a Basin Stratigraphic Model



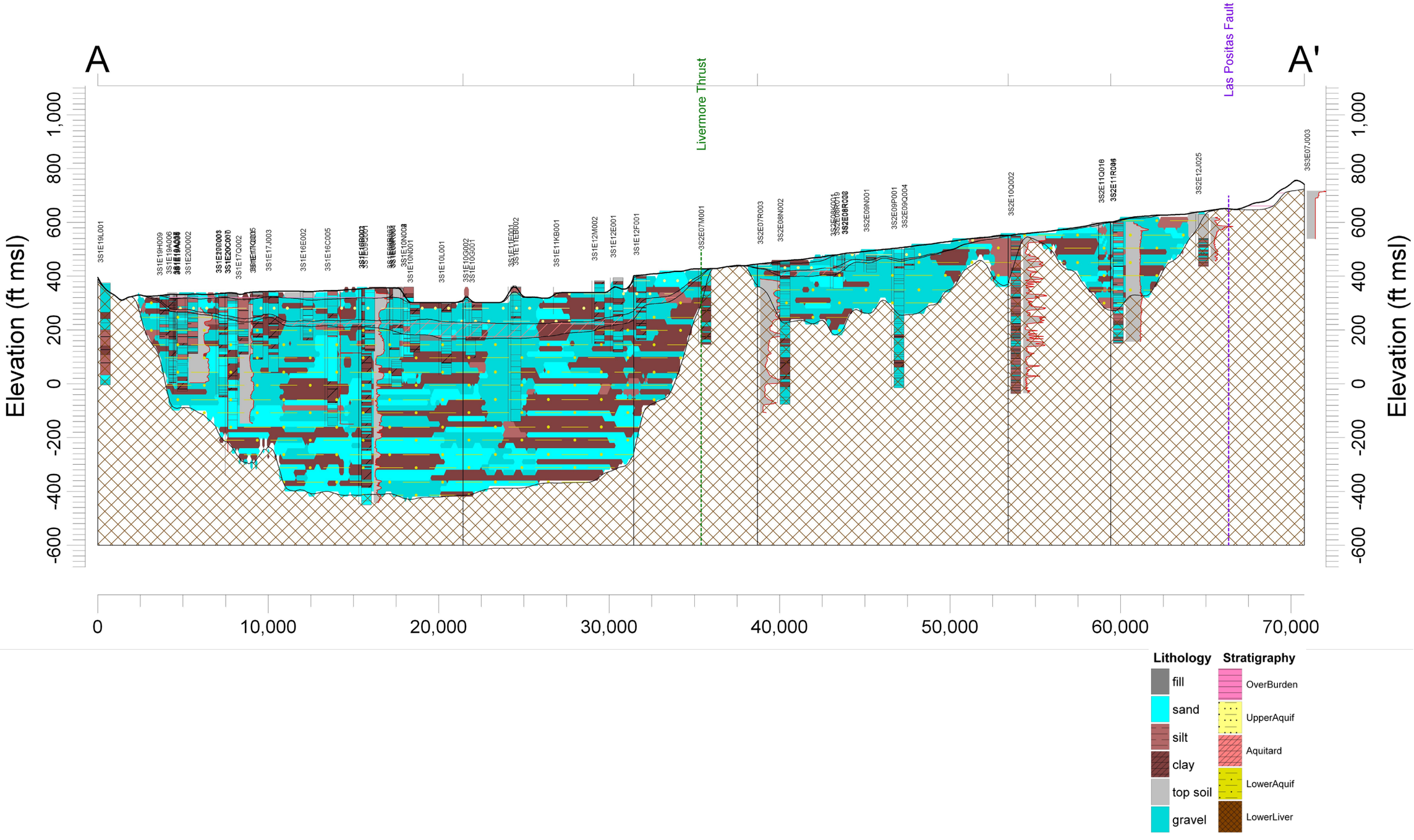
8) ***Develop cross-section traces*.** Various sources of available information, including well, lithology, and e-log dataset locations, surficial geology and fault maps, critical infrastructure facilities (e.g., Chain of Lakes recharge basins), potential GDE areas, and previous cross-section locations were assessed to develop proposed locations of three cross-section traces, A-A', B-B', and C-C', to be built in RockWorks for inclusion in the 2022 Alt GSP. These draft cross-section trace locations were reviewed and edited by Zone 7 technical staff to produce the final cross-section traces shown in Figure 8.

Figure 8 – Cross-Section Traces for the 2022 Alt GSP



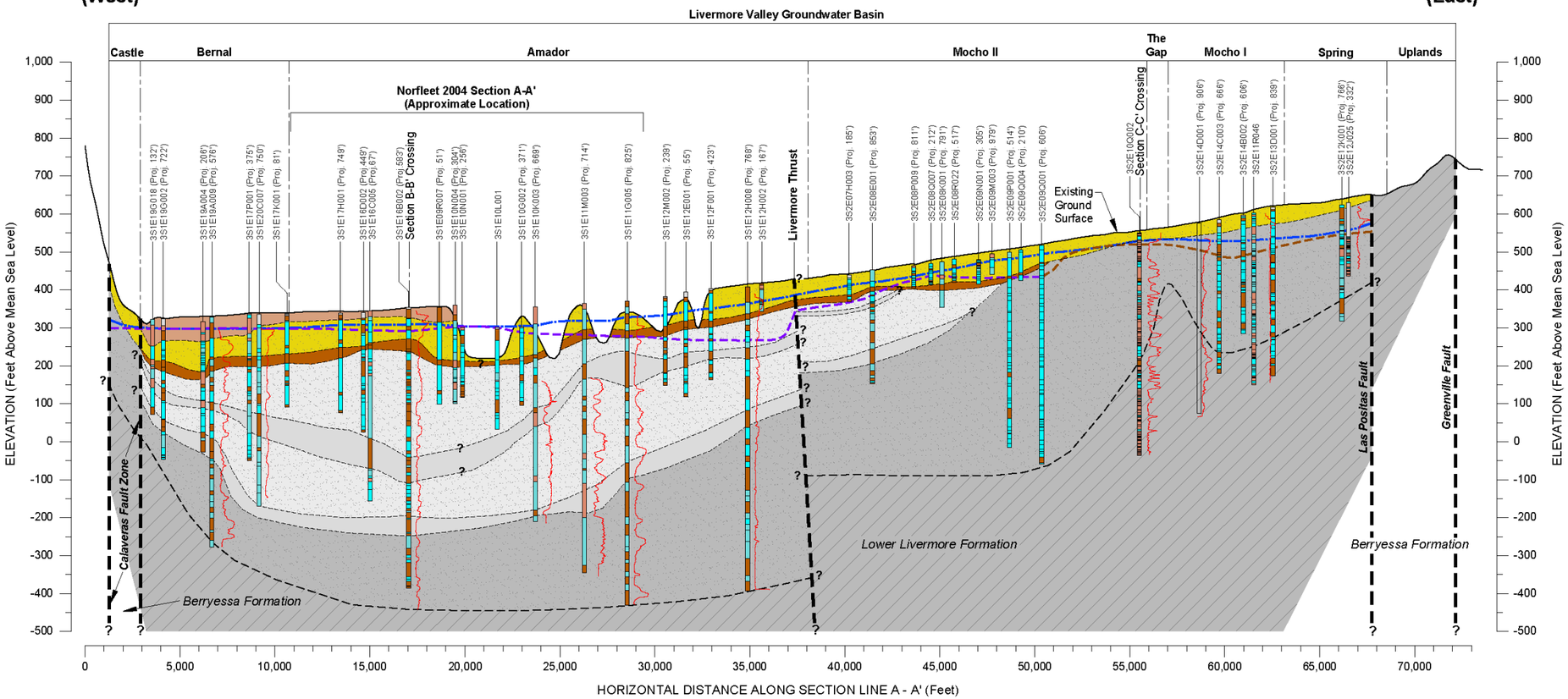
9) Develop preliminary cross-sections. The 3D stratigraphy model (Step 7) was subsequently "sliced" by the cross-section traces (Step 8) to produce cross-section profiles of the Basin. These cross-sections depict the major aquifer units represented in the stratigraphy model and also show projected lithology and e-log information from nearby wells along the traces. Depending on preference, the cross-sections can also be underlain by the interpolated lithology model produced from the bulk lithology dataset (Step 5). Figure 9 shows a "first-cut" example of cross-section A-A' as output from RockWorks.

Figure 9 – Draft Cross-Section A-A'



10) ***Export to AutoCAD and refine cross-sections.*** After receiving feedback from Zone 7 on the preliminary cross-section outputs from RockWorks, each cross-section was exported from Rockworks in .DXF format and imported into AutoCAD software. AutoCAD was ultimately employed for subsequent cross-section refinement as it allowed EKI to more efficiently modify stratigraphic contacts at individual borehole locations based on available lithology and e-log data, and to more accurately portray complex geological features such as the Livermore Thrust plate and Calaveras Fault deformation zone along the section traces. AutoCAD also provides for greater control of symbology, annotations, and formatting edits compared to RockWorks' Plot2D tool. Figure 10 presents the refined Cross-Section A-A' after subsequent editing in AutoCAD.

Figure 10 – Revised Cross-Section A-A'



Cross-Section A - A'

Legend:

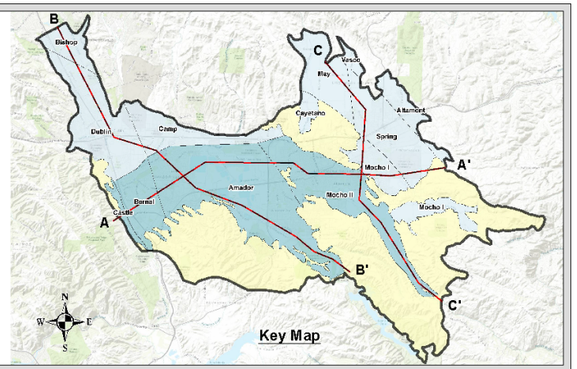
Stratigraphy
- Overburden
- Upper Aquifer
- Aquitard
- Lower Aquifer (Quaternary Gravels/Sands)
- Lower Aquifer (Quaternary Clays/Silts)
- Upper Livermore Formation
- Lower Livermore Formation
- Bottom of Groundwater Basin
- Static Water Level in Upper Aquifer (Fall 2019)
- Static Water Level in Lower Aquifer (Fall 2019)
- Static Water Level in Upper Livermore (Fall 2019)

Lithology
- Topsoil/Fill
- Gravel
- Sand
- Silt
- Clay

Geophysical
- Long-Normal Resistivity

Map Elements
- A — A' Cross-Section Trace Location
- Livermore Valley Groundwater Basin

Management Area
- Fringe Management Area
- Main Basin Management Area
- Upland Management Area



(20X Vertical Exaggeration)
(Vertical Scale in Feet)
(Horizontal Scale in Feet)

Geologic Cross-Section A - A'

Zone 7 2022 Alternative GSP
Livermore, CA
April 2021
EKI C00065.00

Figure 2a

NEXT STEPS

As discussed previously, refining the Basin-wide stratigraphy model in RockWorks is an evolving and iterative process and can be routinely revisited as new information and/or borehole data becomes available. Under the current scope, EKI will reimport revisions to stratigraphic contacts made in AutoCAD into RockWorks in order to update the Basin-wide stratigraphy model. This updated stratigraphy model will subsequently be used to develop estimates of total available groundwater storage in each principal aquifer unit of the Basin for use in designing groundwater storage sustainability criteria for the 2022 Alt GSP. If desired, this updated Basin-wide stratigraphy model can also be used to inform future refinements to the layering and structure of Zone 7's MODFLOW groundwater flow model.