APPENDIX 2-D

SOQUEL-APTOS GROUNDWATERFLOW MODEL: SUBSURFACE MODEL (TASK 3) MEMORANDUM

HydroMetrics WRI
1814 Franklin St, Suite 501
Oakland, CA 94612

TECHNICAL MEMORANDUM

To: Ron Duncan

From: Sean Culkin P.G., C. Hg.
Mike Cloud, P.G.
Cameron Tana, P.E.

Cameron Tana Sean Culkin

Date: November 24, 2015

Subject: Soquel-Aptos Groundwater Flow Model: Subsurface Model Construction (Task 3)

1.0 INTRODUCTION

This technical memorandum documents the completed and ongoing activities to develop the conceptual model, hydrostratigraphy, and subsurface boundary conditions for construction of the groundwater flow model of the Soquel-Aptos groundwater basin (basin). Subsequent technical memoranda on model construction will document the development of the watershed model, land use analysis for water use and return flow, integration of the watershed model with the groundwater model using GSFLOW, and the incorporation of code to simulate seawater intrusion. After the model is constructed and calibrated, the model will be used by the Soquel-Aptos Groundwater Management Committee (SAGMC) to evaluate long-term options for raising groundwater elevations in the basin and eliminating overdraft.

The modeling effort documented in this technical memorandum identifies the model extent and boundaries, as well as translates the Purisima Formation and Aromas Red Sands conceptual model into groundwater model layers. The conceptual model for the basin has been reported in detail in the *Groundwater Assessment of Alternative Conjunctive Use Scenarios, Technical Memorandum 2: Hydrogeologic Conceptual Model* (Johnson *et al*., 2004).

The groundwater component of the groundwater flow model will be built using the U.S. Geological Survey's (USGS) MODFLOW software for groundwater modeling applications. This MODFLOW groundwater flow model will be integrated with a watershed model using the USGS's Precipitation-Runoff Modeling System (PRMS) to create a USGS GSFLOW model.

2.0 DATA COMPILATION

For developing the model stratigraphy, a set of 67 available down-hole electrical resistivity logs (e-logs) were compiled for wells/borings drilled into the Purisima Formation in central Santa Cruz County. These e-logs are from public and private wells, as well as oil and gas wells. Available surface geologic and gravity anomaly maps from USGS, and seafloor maps were also used to update the conceptual basin stratigraphy.

Data for boundary condition development are primarily in the form of monitoring well groundwater elevation data from City of Santa Cruz, Soquel Creek Water District (SqCWD), Central Water District (CWD), and Pajaro Valley Water Management Agency (PVWMA) wells within the basin model domain. Groundwater elevation data from City of Santa Cruz, SqCWD, and CWD are reported by HydroMetrics WRI annually, and updated data from selected PVWMA wells near the southeastern boundary of the model were obtained by request from that agency.

3.0 DOMAIN EXTENT AND MODEL HYDROSTRATIGRAPHY

The lateral extent of the basin model domain is similar to the domain of the previously-constructed PRMS model (HydroMetrics WRI, 2011). The domain covers watersheds that may recharge the aquifers pumped in the area managed by SAGMC. The western boundary of the model is the boundary between the Carbonara Creek and Branciforte Creek watersheds approximately parallel to California State Route 17 from the City of Santa Cruz in the south to Redwood Estates in the north. Outcrops of granite and metamorphic rocks along Carbonara Creek indicate that there is no connectivity of groundwater flow into or out of water-bearing units of the basin along this margin.

The northern watershed boundary of the model approximately follows Summit Road and Loma Prieta Avenue for a distance of about 17 miles along a northwest to southeast alignment. Unlike the previous PRMS model, the oceanic southern boundary of the model has been extended approximately one mile offshore, parallel to the coastline. This allows for adequate contact of outcropping Purisima and Aromas Formation units with the seafloor, in order to simulate saltwater-freshwater interactions such as seawater intrusion.

The eastern boundary of the model follows the eastern boundary of the Corralitos Creek watershed. The extent of the southeastern boundary of the basin model has also been revised from the previous PRMS boundary, in that it extends beyond Buena Vista Drive in Watsonville nearly one-half mile. This boundary is approximately the same as the southeastern boundary of the groundwater model previously developed for CWD covering the Aromas area (HydroMetrics WRI and Kennedy/Jenks, 2014), and it limits the extent of the Pajaro Valley basin included in the groundwater model. It is expected that PVWMA will manage the rest of the Pajaro Valley basin excluded from this model, which will be used for management by SAGMC for the area to the west. As much as is practicable, the selected boundaries are intended to coincide with known hydrologic boundaries. Figure 1 shows the active extent of the groundwater model domain.

Vertically, the groundwater model domain includes surficial alluvium and the more extensive regional hydrostratigraphic units. Earlier reports for the SqCWD had correlated several distinct stratigraphic intervals in this area (Luhdorff & Scalmanini, 1984). Johnson *et al.* (2004) more accurately defined and partitioned these intervals as aquifer or aquitard units. These hydrostratigraphic units were named the Purisima AA aquifer, A aquifer, B aquitard, BC aquifer, D aquitard, DEF aquifer, and F aquifer or, TpAA through TpF for short. The TpAA is the lowermost unit in the Purisima and the TpF is the uppermost unit (Figure 2). Underlying the sedimentary units in this area is a granitic basement complex, except in areas underlain by an undefined Tertiary unit referred to as the Tu unit by Johnson et al. (2004) or the Santa Margarita by others. South of the Zayante Fault (Figure 1), each unit outcrops at the ground surface. The TpAA outcrops primarily in the western portion of the groundwater basin and the TpF outcrops in the east. The units outcrop in this pattern because the Purisima Formation shallowly dips in a southeast direction towards the Pajaro Valley. Outcrop patterns were later projected across the basin and into Monterey Bay (SqCWD and CWD, 2007). In the southeastern portion of the model, the Purisima Formation is overlain by a unit known as the Aromas Red Sands (labeled as Qua and Qa on Figure 2), which is the shallowest water-bearing unit in this area. This unit of poorly consolidated interbedded fluvial, marine, and aeolian material

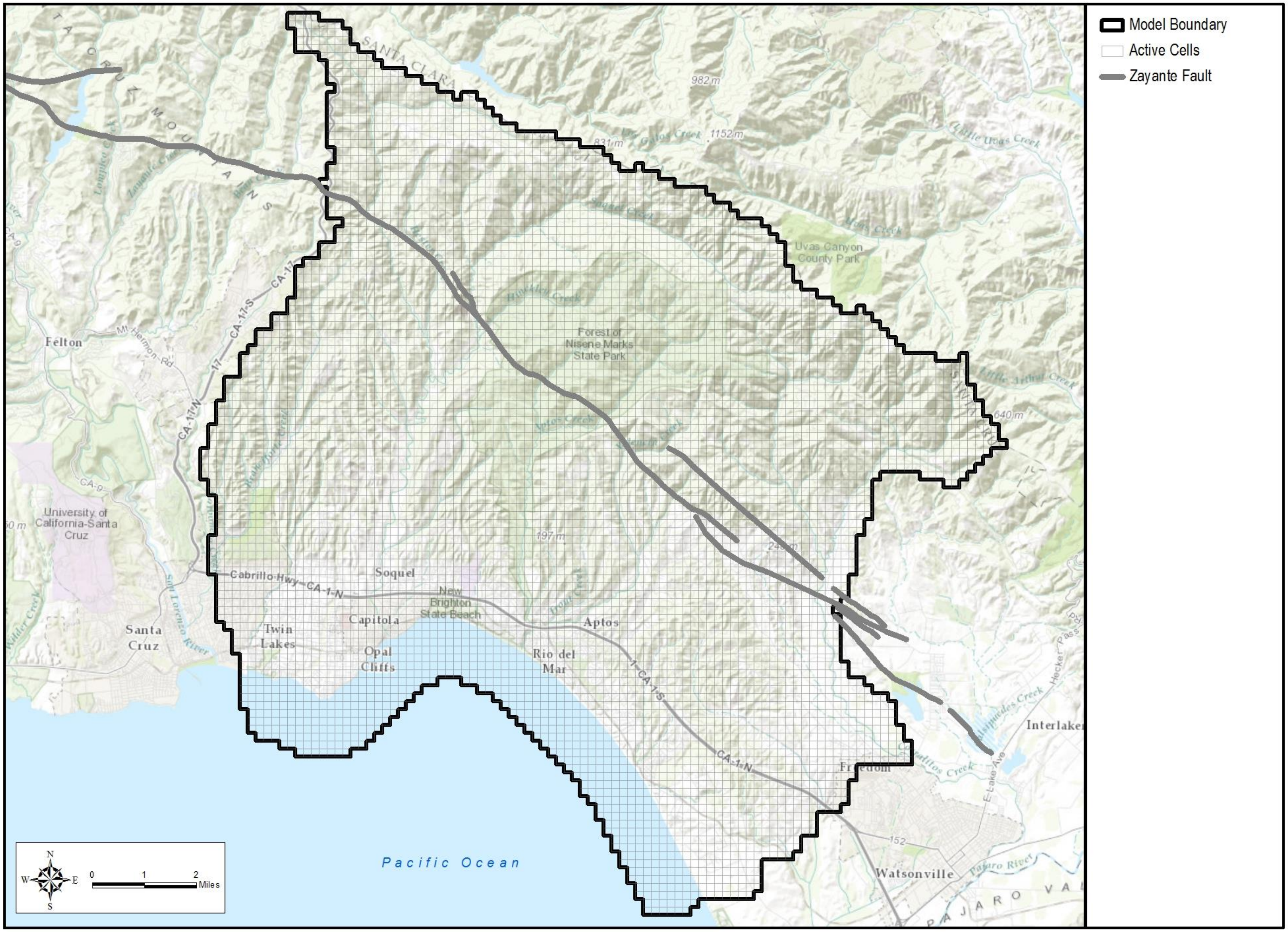
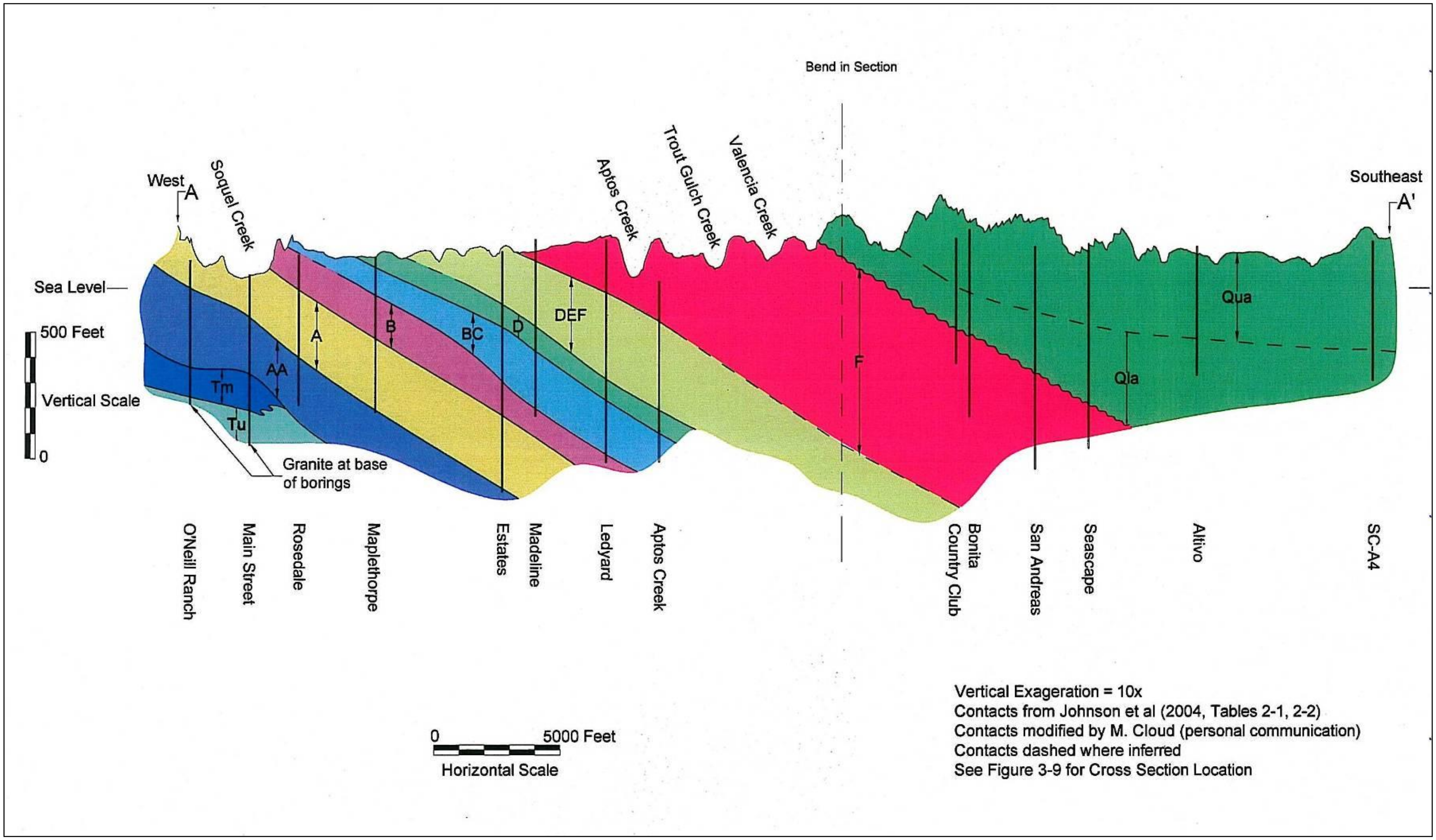


Figure 1: Basin Model Domain Extent



v

Figure 2: Generalized Hydrostratigraphic Cross-Section

overlays the Purisima Formation in the hills and coastal terraces east and southeast of Aptos. A large portion of this unit may be unsaturated, especially where the groundwater table is drawn down to near sea level (Johnson *et. al.*, 2004).

The groundwater model domain encompasses the Aromas Red Sands, the units of the Purisima Formation, and the underlying undifferentiated tertiary deposits. The granitic basement rock of the basin constitutes the base of the groundwater model. To simplify the groundwater model, Purisima Formation units were reduced from the original seven e-log hydrostratigraphic units defined by Johnson et al. (2004) down to six groundwater model layers by combining the DEF and F aquifer units. The laterally-extensive model layers are considered to be either aquifers or aquitards. Aquifer units are those zones dominated with sandstone and aquitards are the zones dominated by mudstone. Table 1 summarizes the hydrostratigraphic units applied in the groundwater model (see also Appendix A). Detailed descriptions of the Aromas Red Sands and Purisima Formation aquifer and aquitard units are available in previous documents (Johnson et. al., 2004; HydroMetrics WRI, 2011).

Table 1: Groundwater Model Hydrostratigraphic Unit Summary

Unit Name (Geologic Unit)	Model Layer	Unit Type
Stream Alluvium	1-9[1]	Stream-associated water-bearing surficial alluvium
Terrace Deposits	1-9[1]	Alluvial terrace deposits near coast
Aromas Red Sands	2	Interbedded sand, silt, and clay deposits
Purisima TpDEF, TpF	3	Aquifer
Purisima TpD	4	Aquitard
Purisima TpBC	5	Aquifer
Purisima TpB	6	Aquitard
Purisima TpA	7	Aquifer
Purisima TpAA	8	Aquifer
Tu[2]	9	Aquifer

[1] Alluvium and terrace deposits assigned to various model layers as described in sections below
[2] Tu unit includes all non-Purisima water-bearing units between base of TpAA Aquifer and top of granitic model base.

Another noteworthy feature of the model domain is the Zayante Fault, which is a northwest-southeast trending fault that runs through the groundwater model domain (Figure 1). North of this fault, the Purisima Formation consists of a number of steeply dipping and folded materials which are offset from Purisima Formation units south of the fault (Johnson et al., 2004). The Purisima Formation materials north of the fault are not well defined as hydrostratigraphic units like they are south of the fault. The material properties of the groundwater model layers north of this fault will likely reflect this lack of differentiation. The area north of the Zayante Fault was retained in the model domain due to the watershed's necessary contribution to the surface water and near-surface flow component of the GSFLOW model. This fault also likely acts as a barrier to deeper groundwater flow between the folded units of the Glenwood Syncline north of the fault and units of the Purisima and Aromas south of the fault (Johnson *et al.*, 2004).

4.0 CONCEPTUAL MODEL METHODOLOGY

In general, the conceptual model as it pertains to the basin groundwater model will follow the conceptual model outlined in the Johnson et. al. report (2004); recent work building upon this model is described in the sections below. As documented in previous studies (Luhdorff & Scalmanini, 1984), the Purisima Formation dips shallowly to the southeast. In the eastern region of the basin, the bedding has a consistent dip of 3 to 4 degrees to the east. West of Soquel Creek, the dip shallows to 2 to 3 degrees to the east. The dip of the Purisima beds appears to mimic the underlying granitic basement structure, suggesting that the Purisima Formation may have been deposited horizontally on the granitic basement, then tilted by the uplift of the basement rock.

HydroMetrics WRI recently updated the Central Water District's (CWD) groundwater model (HydroMetrics WRI and Kennedy/Jenks, 2014). This model covers most of the Aromas area and has layers representing the Aromas Red Sands, TpF unit, and TpDEF unit. Where applicable, the conceptual model of the CWD model will be merged into the larger basin model. For example, the hydrostratigraphic contact between the Aromas Red Sands and Purisima Formation is extracted from the CWD model for use in the larger basin model.

4.1 STRATIGRAPHIC ANALYSIS

HydroMetrics WRI made various assumptions and simplifications during the evaluation of the Purisima Formation stratigraphy and structure for the basin groundwater model. A summary of some of the primary assumptions are as follows:

1) Individual Purisima units tend to maintain relatively constant thicknesses across the groundwater basin.
2) The angle and dip direction of the Purisima Formation units generally reflects the underlying basement structure.
3) The regional gravity anomaly distribution (USGS, 2004) reflects the basement structure.
4) Faults were not used to explain structure unless there was compelling evidence or need for them. No faults other than the Zayante fault are known to significantly offset the hydrostratigraphy such that groundwater flow across the fault zone is impeded. Therefore, we assumed that any other faults are not barriers to groundwater flow.
5) A cemented zone within the lower TpB Aquitard unit is visible in resistivity logs as a spike in resistivity across a large area of the model domain, and is also identifiable in local surface outcrops. As such, the base of the TpB Aquitard is used as a reference elevation surface to aid in defining the hydrostratigraphy of overlying and underlying units within the Purisima Formation.

As in previous analyses (Luhdorff & Scalmanini, 1984), the e-log signatures from different boreholes were compared to identify specific stratigraphic intervals in the Purisima Formation. If individual sedimentary beds are laterally extensive, the same layered sequence of the sedimentary units can be identified at multiple locations. By correlating the elevation of specific intervals from borehole to borehole, the structure of the bedding layers is determined.

Most of the bedding layers can be readily correlated from borehole to borehole. Units TpB through TpF have very distinct e-log signatures, which facilitates correlation between boreholes because they consist of a mixture of sandstone and mudstone beds. The distinctive TpA/TpB contact, which is readily identifiable on every e-log that encounters it, was used as a reference point for stratigraphic analysis. The base of the Purisima Formation is clearly identified on e-logs for sufficiently deep boreholes. The structure of the granitic basement of the model domain was also identifiable in boreholes, gravity anomaly studies, and regional outcrops, which were used to develop inform the basement structure of the model. An example stratigraphic column summarizing the conceptual hydrostratigraphy developed from this investigation is show on Figure 3, and unit thicknesses are summarized in Table 2. Details of the granitic basement structure are shown in Figure 4 through Figure 6, the elevation of the base of individual units, as well as borehole locations used in part to define the base of each unit, are shown on Figure 7 through Figure 14, and the stratigraphic picks made from borehole logs are tabulated in Appendix A.

The TpA and TpAA units have an assumed combined thickness of 600 feet. These units do not have lithologically consistent internal sedimentary layers and therefore it is difficult to identify the contact surface between them in the boring logs and e-logs. As such, both the TpA and TpAA units are assigned a uniform thickness of 300 feet each over most of the model domain. Where the contact between these units is detectable in e-logs, primarily in the southwestern portion of the model domain, they are assigned variable thicknesses, with the thickness of the TpA varying between approximately 200 and 300 feet, and the thickness of the TpAA varying between approximately 300 and 400 feet; generally maintaining the total combined thickness of 600 feet.

The Tu unit is assumed to constitute all the sediments where the granitic basement is lower than the base of the Purisima Formation (i.e. lower than the TpAA). As such, it's thickness is variable between approximately 10 and 3,000 feet. This unit is generally found in the western portion of the basin and pinches out where the base of the Purisima intersects the granitic basement. East of the pinch-out margin of the Tu, the base of the Purisima Formation sits directly on top of the granitic basement. The base of the TpAA generally follows the structure of the granitic basement, but where necessary, the thickness of the TpAA was adjusted to that it met the interpolated granitic basement surface. As such, the thickness of the TpAA and the combined thickness of 600 feet for the TpA and TpAA has some local variation from 300 feet and 600 feet respectively east of the Tu to accommodate the granitic basement structure, but the TpAA generally maintains a thickness of approximately 300 feet.

One significant geologic feature observed in the stratigraphic analysis is a granitic structural high near the western boundary of the model domain, south of the Zayante Fault. West of this structural high, the elevation of the granitic basement dips steeply towards the northwest into a trough.

The location and structure of the granitic high is shown in Figure 4. This figure shows granite elevation contours developed as a part of this analysis, as well as surficial geologic data (USGS, 1997). The western boundary of the model domain is aligned with the watershed boundary shown in the figure, and the strike of the granitic high is shown as the "Granitic Divide" line. The structure of the granitic basement is supported by gravity anomaly surveys of the area (USGS, 2004), from which granite elevation contours can also be inferred (Figure 5).

The structure of the granitic basement in the western area of the model domain has also been documented by Todd Engineers (1997) and ETIC Engineering (2006) in groundwater modeling technical studies of the area. Figure 6 presents a cross-section from a previous modeling study (Kennedy/Jenks, 2015) that crosses the western edge of the model domain. In this figure, the granitic structural trough is evident in the area of the model domain boundary near Carbonera Creek, and the eastward-dipping Purisima Formation is shown to be underlain by geologic units usually associated with the Santa Margarita Basin to the west. As modeling progresses, different material properties may be assigned to the sediments west of the granite high to differentiate them from the Tu unit that dips towards the east beneath the Purisima Formation, since the Tu west of the divide may be more closely associated with westward-dipping stratigraphic units of the adjacent Santa Margarita Basin. Boundary conditions in this area will also be modified to represent groundwater flow conditions out of the Soquel-Aptos Basin.

The highest density of available e-log data is in the coastal terrace area of mid Santa Cruz County, where most urban development has occurred and depth to groundwater is the shallowest. Available e-logs in the inland, hilly areas of the Purisima Formation are sparse, which makes correlation more difficult. Appendix A shows the depth and elevation of each geologic contact in the logs the overlying Aromas Red Sands down to the granitic basement. This Appendix also includes estimated contact depths/elevations where they could be reliably estimated.

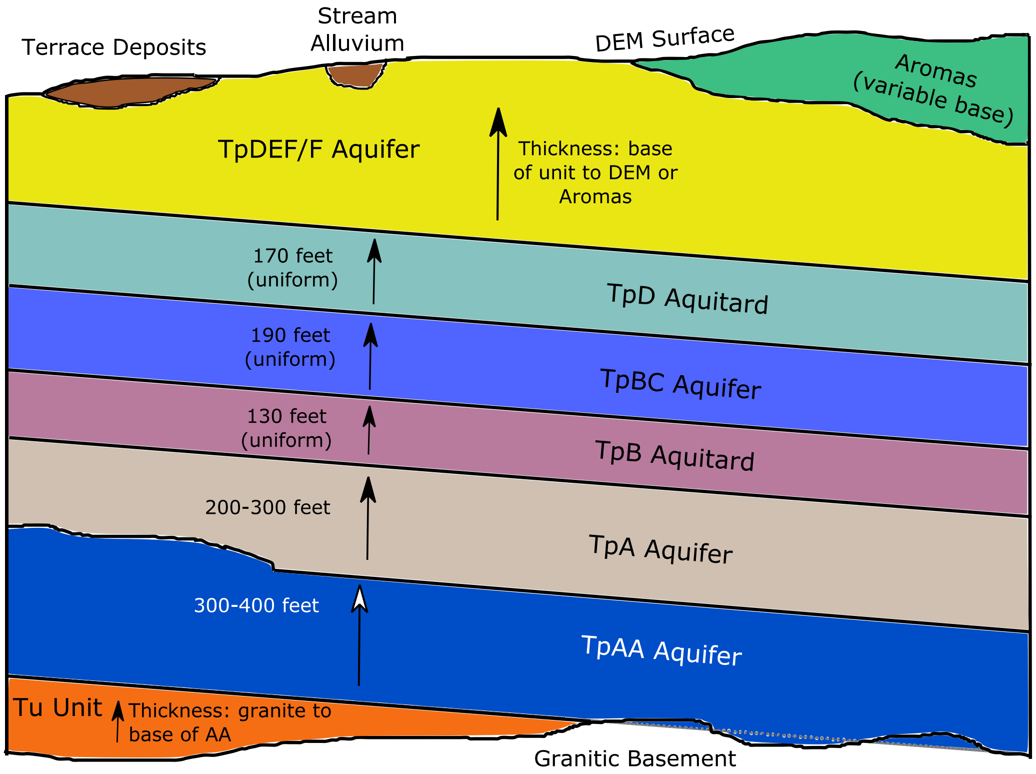


Figure 3: Example Stratigraphic Column of Model Hydrostratigraphy

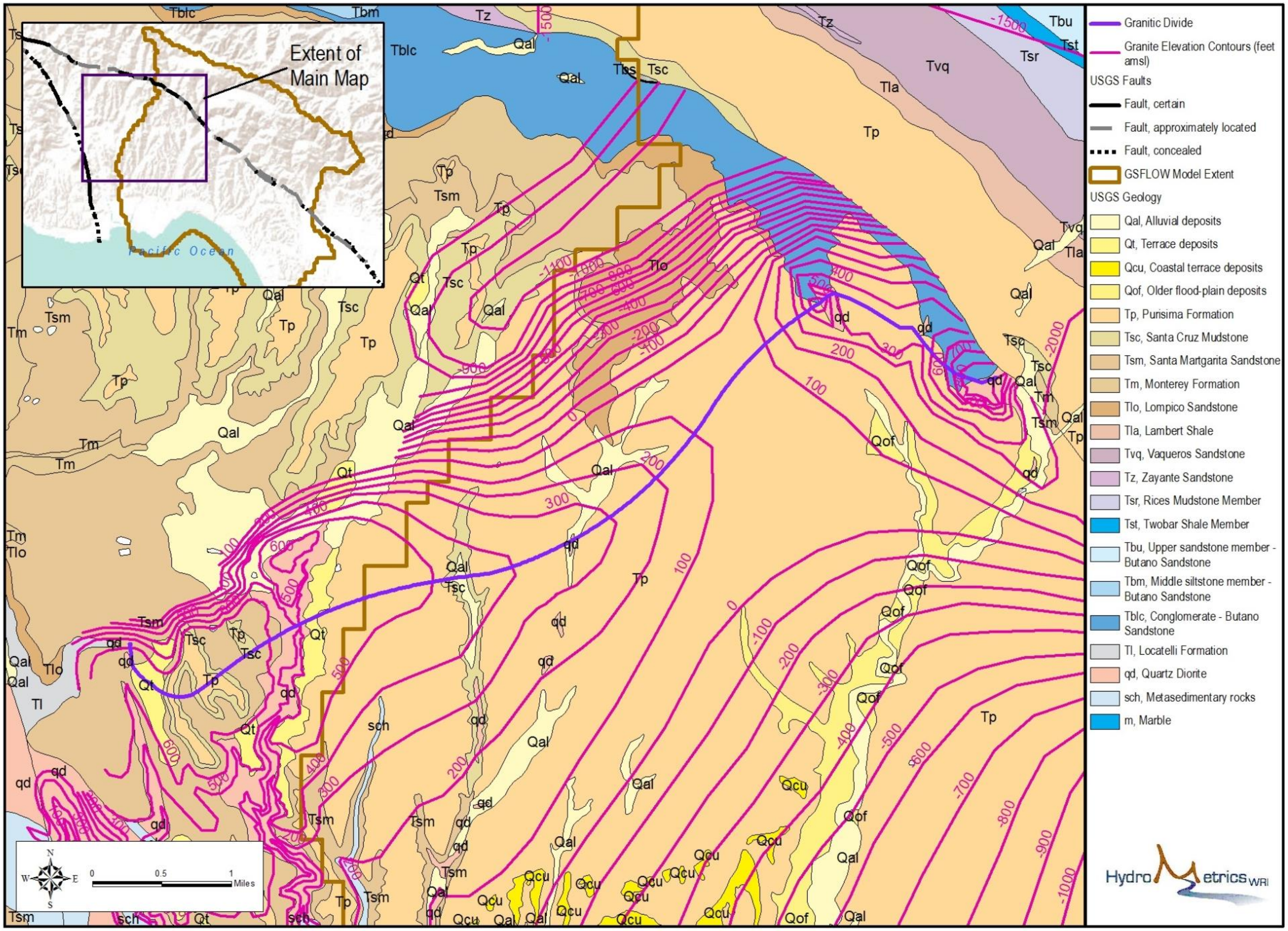


Figure 4: Structure of Granitic Basement Elevation, Western Area of Model Domain

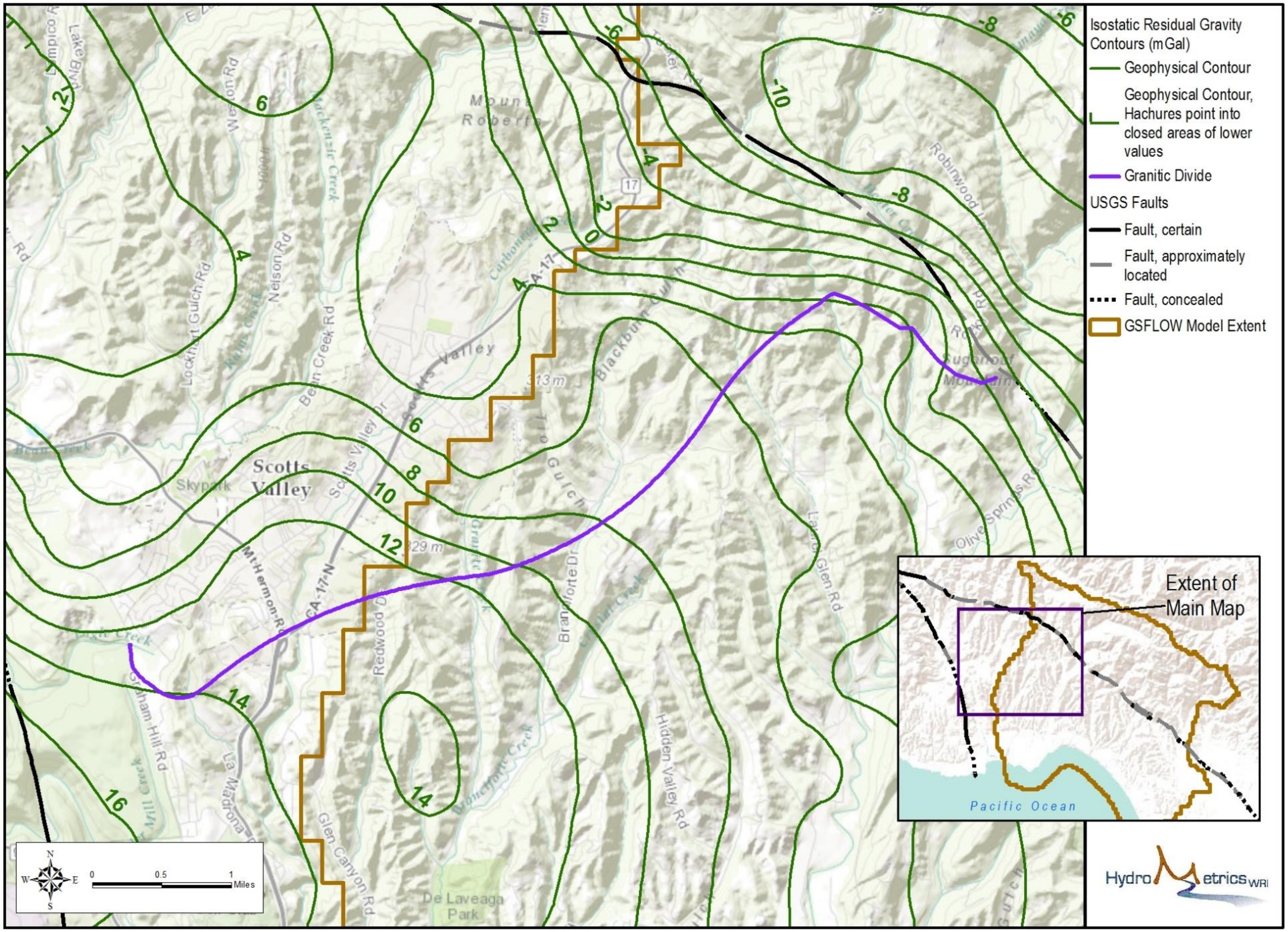


Figure 5: Gravity Anomaly Contours, Western Area of Model Domain

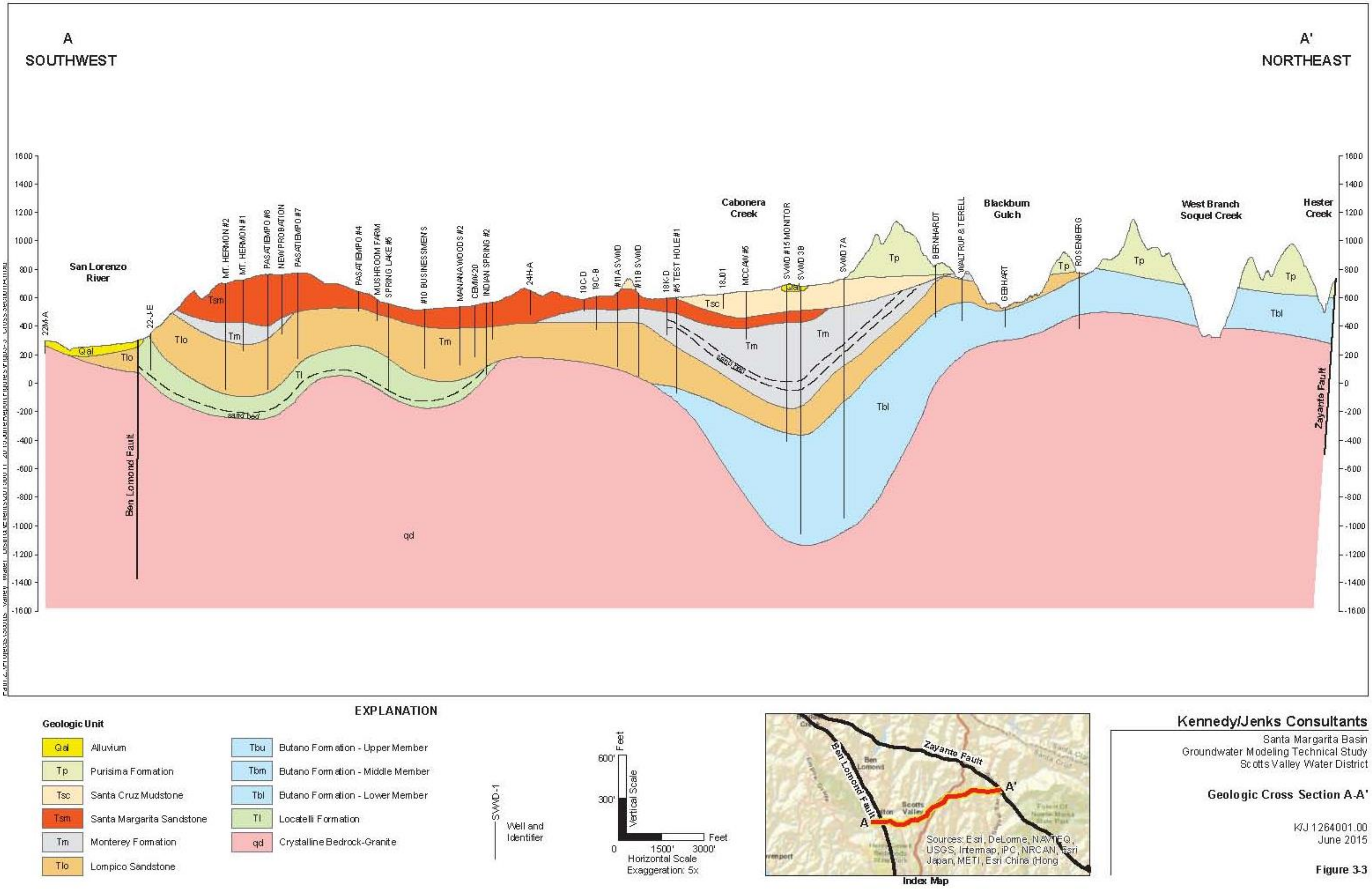


Figure 6: Cross-Section Near Western Boundary of Model Domain (from Kennedy/Jenks Consultants, 2015)

Table 2: Model Hydrostratigraphic Unit Thicknesses

Unit Name	Thickness
Stream Alluvium	Uniform (20 feet)
Terrace Deposits	Uniform (50 feet)
Aromas Red Sands	Variable (approximately 10 to 1,000 feet - consistent with CWD model)
Purisima TpDEF, TpF	Variable (base of Aromas to top of D Aquitard)
Purisima TpD	Uniform (170 feet)
Purisima TpBC	Uniform (190 Feet)
Purisima TpB	Uniform (130 feet)
Purisima TpA	Variable (approximately 200 to 300 feet)
Purisima TpAA	Variable (approximately 300 to 400 feet)
Tu	Variable (approximately 10 to 3,000 feet - distance from base of Purisima to top of granitic basement)

4.2 MODEL GEOMETRY AND GRID

The groundwater model domain consists of 135 rows and 105 columns of uniformly-sized grid cells. Only the grid cells contained within the area shown on Figure 1 will actively simulate groundwater flow. The size of each grid cell is 800 feet by 800 feet. The selection of an 800-foot uniform grid cell size followed an analysis that showed this resolution would sufficiently capture surface elevation features for the hydrologic response units (HRU) of the PRMS watershed model. For GSFLOW models, the USGS recommends using HRUs in PRMS that match the size and dimensions of the MODFLOW grid cells.

4.3 GROUNDWATER MODEL LAYERS

The hydrostratigraphy of much of the groundwater model domain was developed using three reference elevations: the land surface, the base of the Purisima TpB aquitard (i.e. the identifiable basal TpB marker unit), and the top of the granitic basement. The land surface was defined using a digital elevation model (DEM) interpolated to the 800-foot uniform groundwater grid spacing. The bottom of the Purisima TpB aquitard and the top of the granitic basement were developed by manually picking the depths of these surfaces from borehole logs, as described in the sections above. The structure of the granitic basement was also informed by regional gravity anomaly maps. Top of the granitic basement and base of the Purisima TpB aquitard elevations as intersected by boreholes were hand-contoured over the groundwater model domain south of the Zayante Fault, and revised using GIS software to ensure the outcrop patterns of each surface were consistent with the previously mapped and reported outcrop patterns of the region (Johnson et al., 2004 and SqCWD and CWD, 2007). North of the Zayante Fault, the granite and bottom of the Purisima TpB aquitard surfaces were extended uniformly and perpendicular to the general trend and dip of the fault because Purisima Formation layers are not well defined north of the fault and differentiation of the layers likely will not be simulated.

The contact elevations between each hydrogeologic unit in the model are mapped on Figure 7 through Figure 14, along with applicable borehole control points estimated from available e-logs. The bottom of the Purisima TpB aquitard was interpolated to the uniform grid spacing of the groundwater model via kriging within the Surfer® software program. The Purisima TpB aquitard elevations are used as a reference surface for defining the depths of the other Purisima Formation units. Thicknesses were assigned to aquifer and aquitard units based on the e-log analysis described in the previous section (see Table 2). The bottom elevations of the DEF/F aquifer, D aquitard, and BC aquifer layers are determined by adding the uniform thicknesses to the B aquitard bottom elevations, while the bottom elevations of the AA aquifer layer are determined by subtracting the total A/AA thickness of 600 feet from the B aquitard bottom elevations. This combined A/AA unit is subdivided into two units of generally uniform, but locally variable thickness as described in the section above.

The Tu unit model layer, which combines any units below the Purisima Formation and above the granitic basement into one model layer, extends from the base of the TpAA aquifer model layer to the top of the granitic basement. Where granitic basement meets the base of the Purisima Formation in the eastern part of the domain, the Tu unit is inactive. Additionally, the Tu unit was made inactive within the model domain east of the limit shown in Figure 7, based on the assumed pinch-out margin of the Tu. As such, the bottom of the model is represented by the base of the Tu with elevations of the granitic basement west of the pinchout margin as shown in Figure 7. The bottom of the model is represented by the base of the AA aquifer with elevations of the granitic basement east of this margin as shown in Figure 9.

The depth of the bottom of the Aromas model layer is also variable over parts of the model domain. This surface contact was interpolated from the base of the deepest Aromas layer in the CWD model to the 800-foot uniform model grid. Model elevations in the CWD model (HydroMetrics WRI and Kennedy/Jenks, 2014) were based on Johnson (2006). This surface was contoured, and the contours were extended beyond the CWD model domain to areas of the Aromas Red Sands that are outside of that domain, but within the basin wide model domain. The CWD model domain shown on Figure 14. The distance between the top of the D aquitard layer to either the land surface or the bottom of the Aromas layer was assigned as the same thickness of the DEF/F aquifer layer.

Model layer contact surfaces were assigned to the model grid using the Groundwater Modeling System (GMS) software package, where layer thicknesses were determined according to the variable or uniform thickness between the reference surfaces of the base of the B aquitard and the granitic basement. The top of all model layers were cropped to the DEM land surface, and inactivated where those layers artificially extended above the land surface according to the imposed dip and interpolation method. Therefore, thicknesses of layers as they outcrop are less than the uniform thicknesses shown in Table 2. The result is an outcrop map that reasonably approximates available maps of surface units. Some simplification was applied to the model grid so that disconnected islands of active cells, usually in upland areas within a given hydrostratigraphic unit, were minimized. Where the granitic basement surface was interpolated to extend close to DEM surface (within approximately 10 feet), all model layers were inactivated to represent the no-flow areas where granite outcrops to the surface.

Figure 15 shows the extent of the outcropping model layers representing the Aromas and Purisima units and location of cross-sections A-A′, B-B′, and C-C′. Figure 16 through Figure 18 show the simulated model layers along these cross-section lines. Cross-section A-A′ runs roughly parallel to California State Route 1, and shows that the southeasterly-dipping Purisima units are well-represented in the groundwater model domain. The variable thickness of the Aromas layer is also evident, as is the pinch-out of the Tu layer where the Purisima Formation extends to the granitic basement in the western portion of the model domain. Cross-section B-B′ runs roughly parallel to Soquel Creek, and shows an area where the model grid is inactive due a surface outcrop of granite, Cross-section C-C′ runs parallel to the model domain's southern offshore boundary, showing a similar dip direction as in cross-section A-A′, and the geologic units that outcrop to the ocean floor along that line.

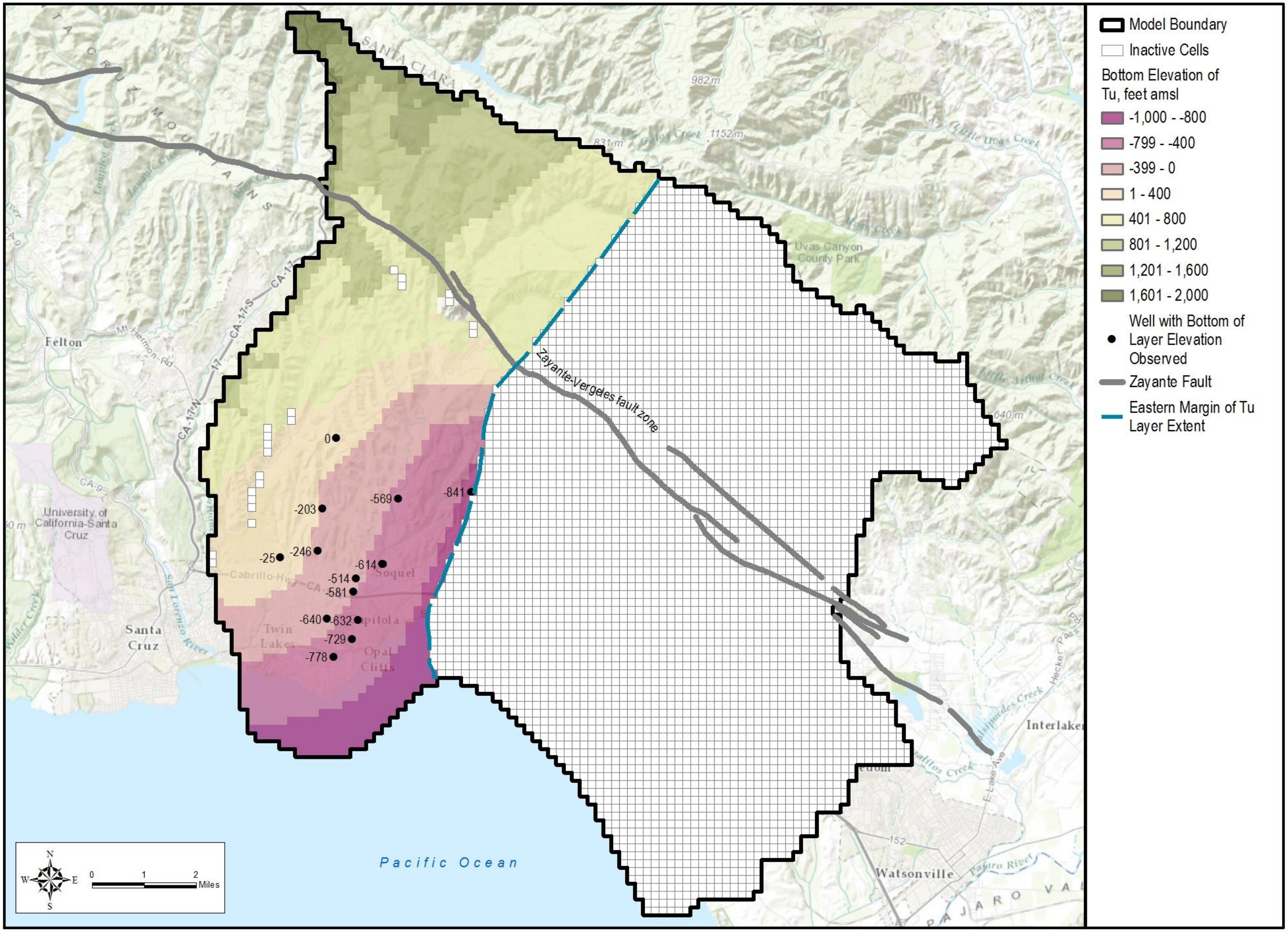


Figure 7: Base of Tu Unit Elevations in Model

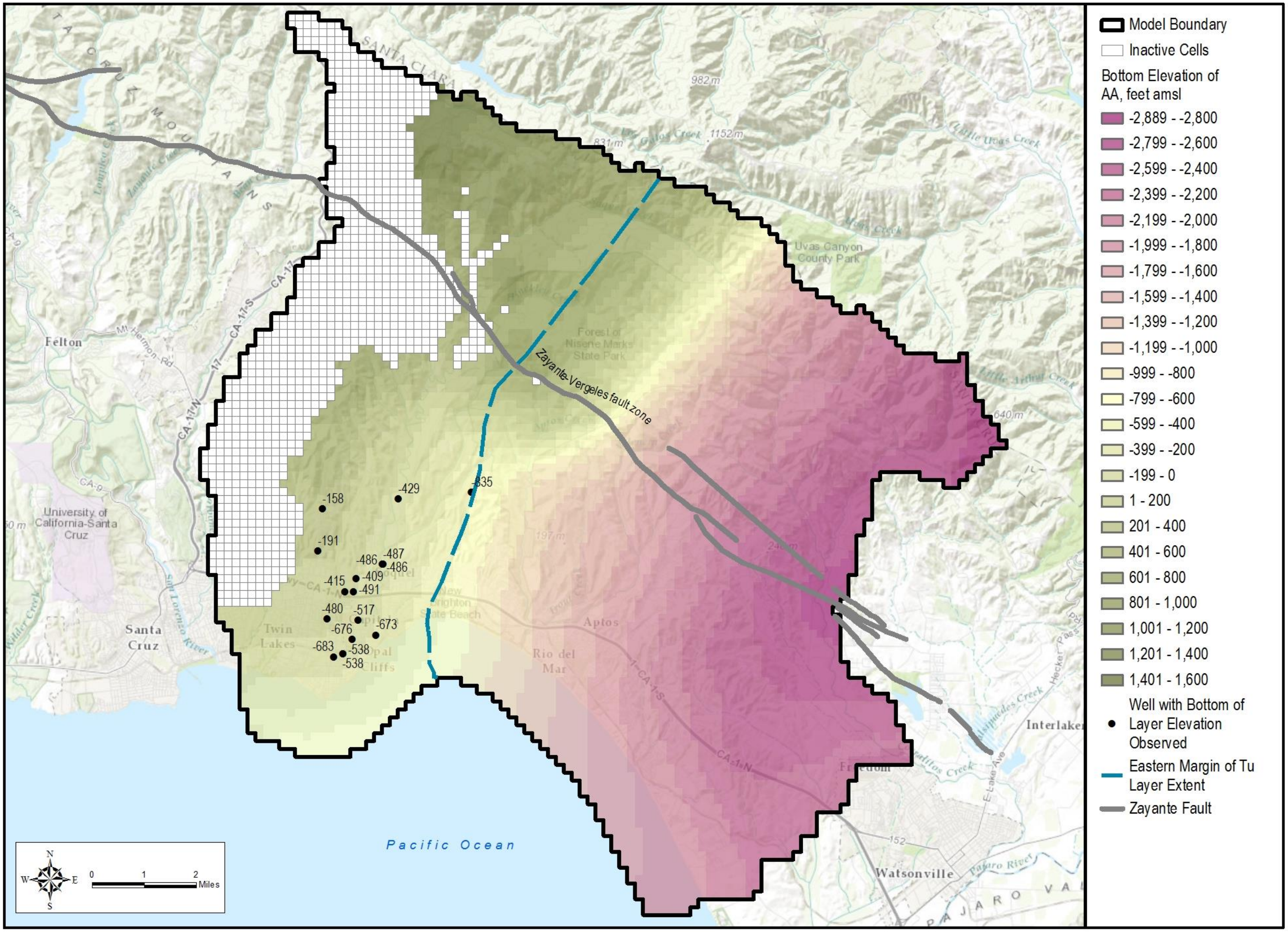


Figure 8: Base of TpAA Unit Elevations in Model

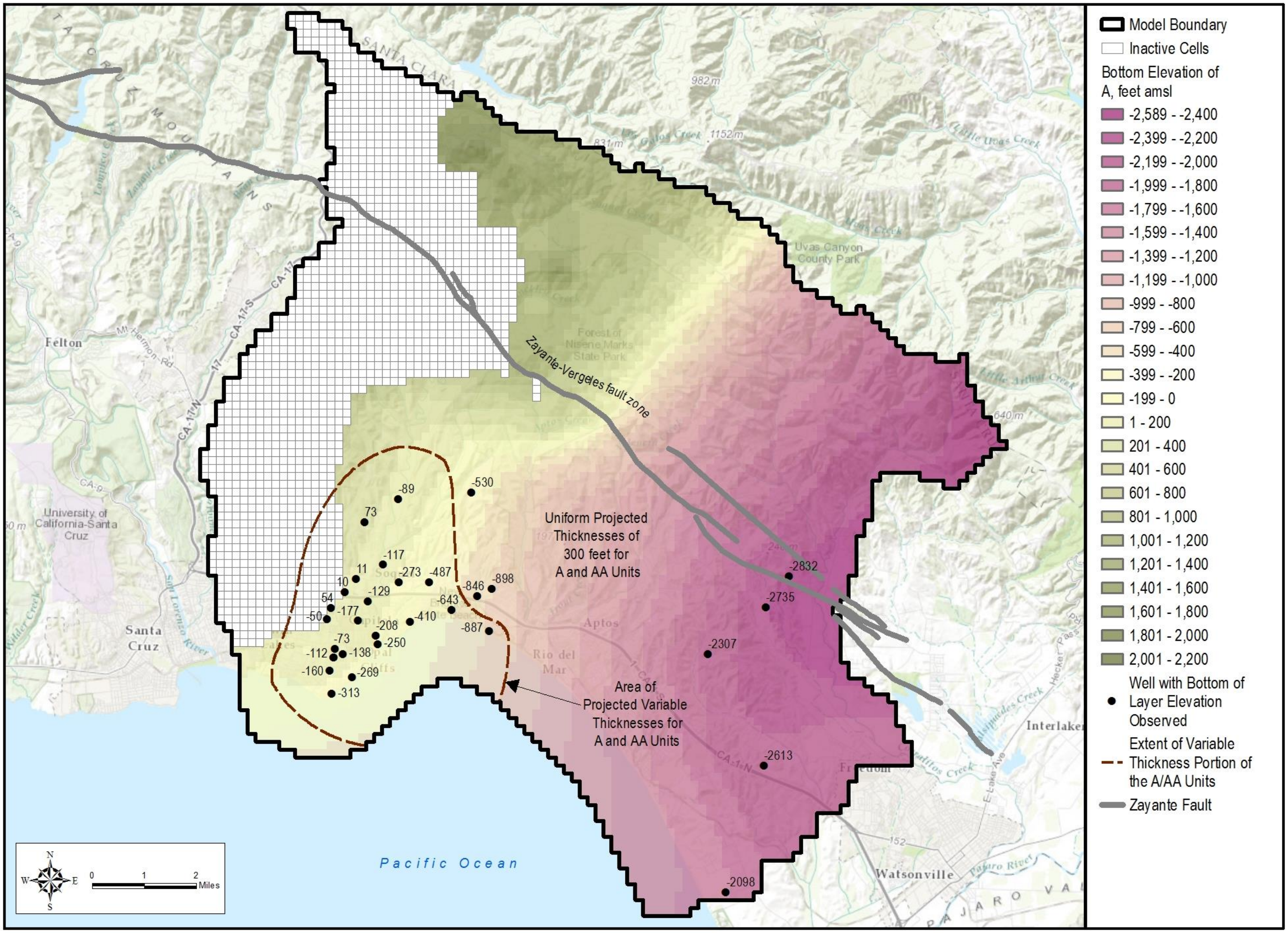


Figure 9: Base of TpA Unit Elevations in Model

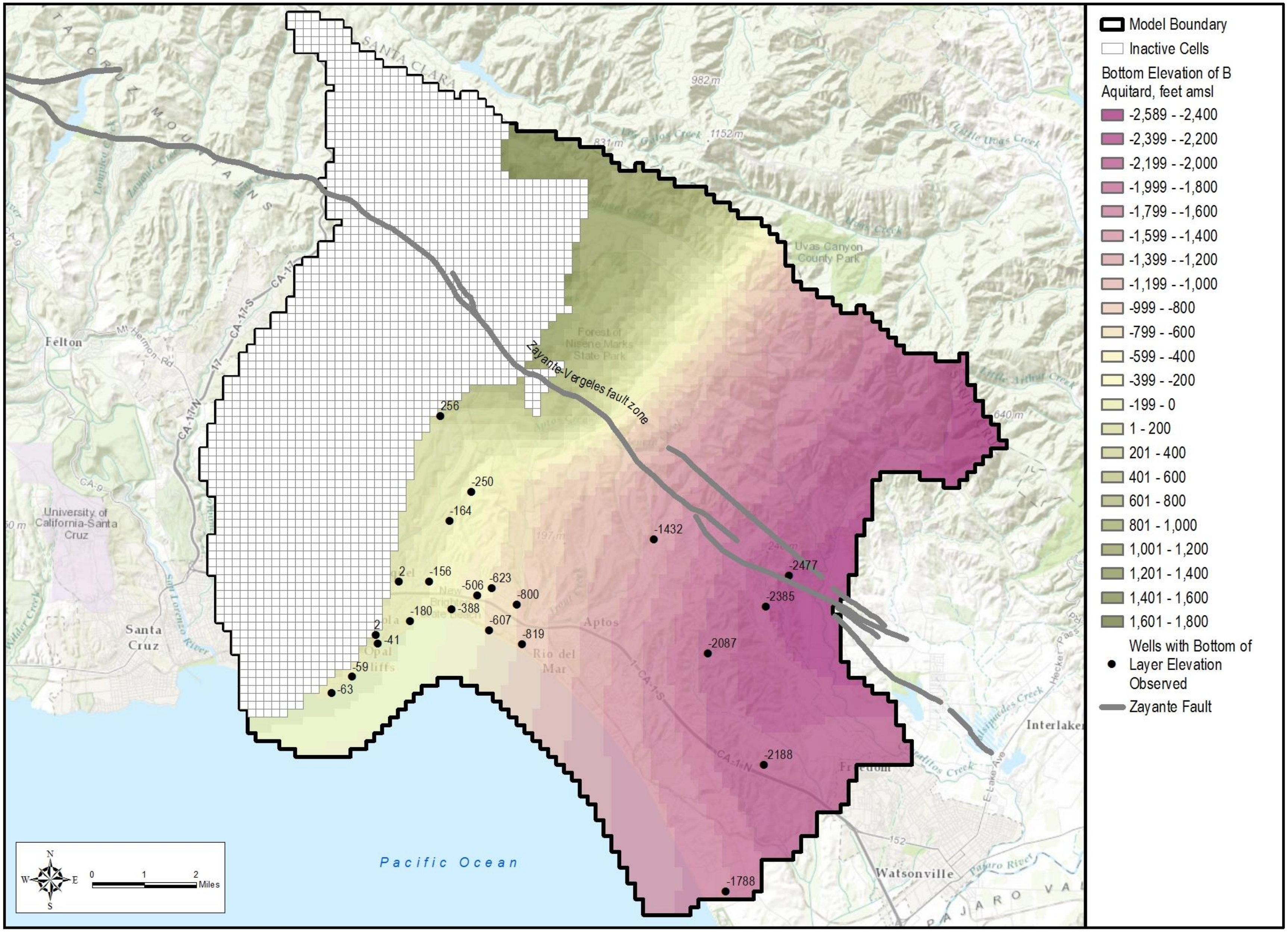


Figure 10: Base of TpB Aquitard Elevations in Model

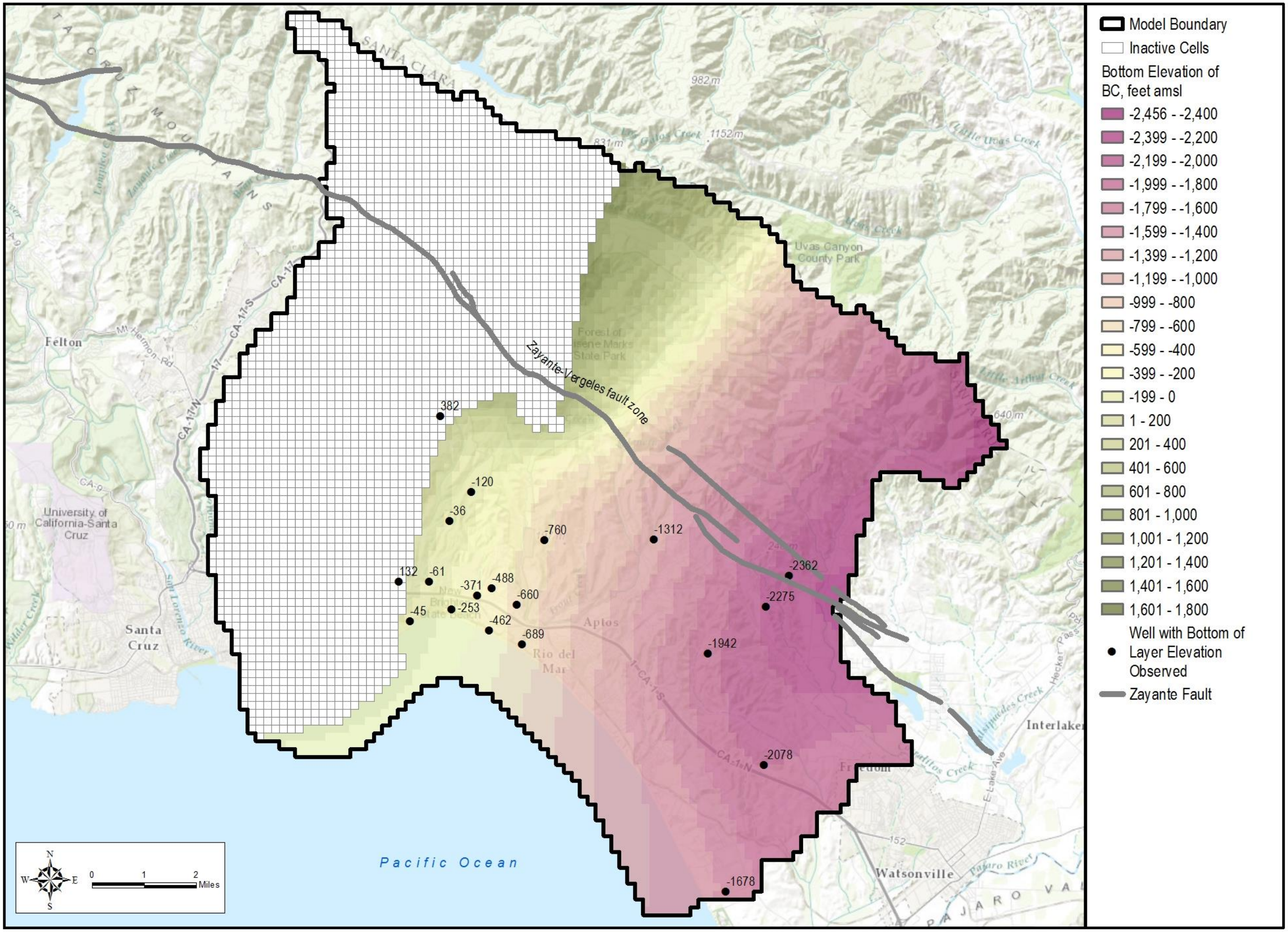


Figure 11: Base of TpBC Unit Elevations in Model

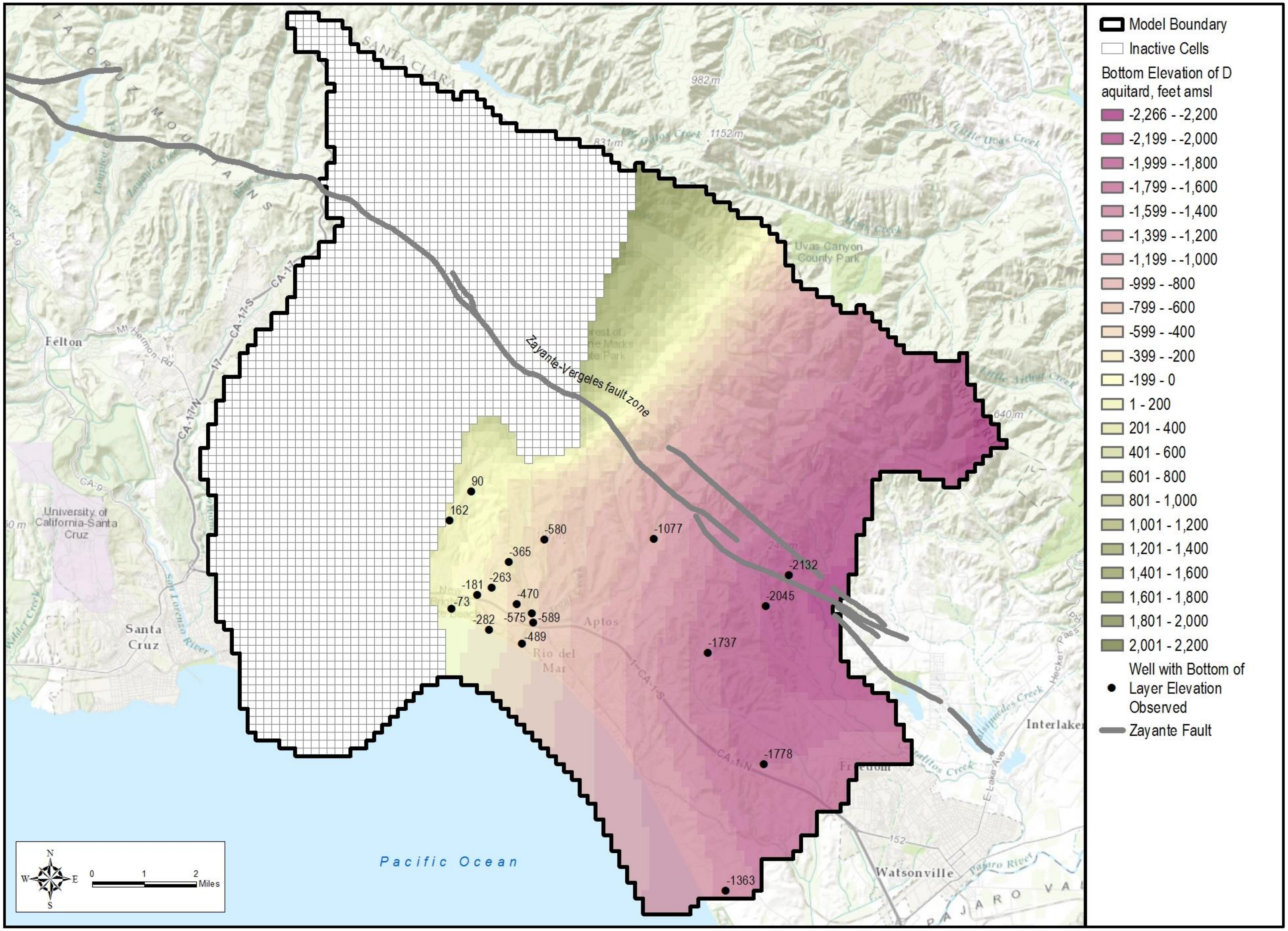


Figure 12: Base of TpD Aquitard Elevations in Model

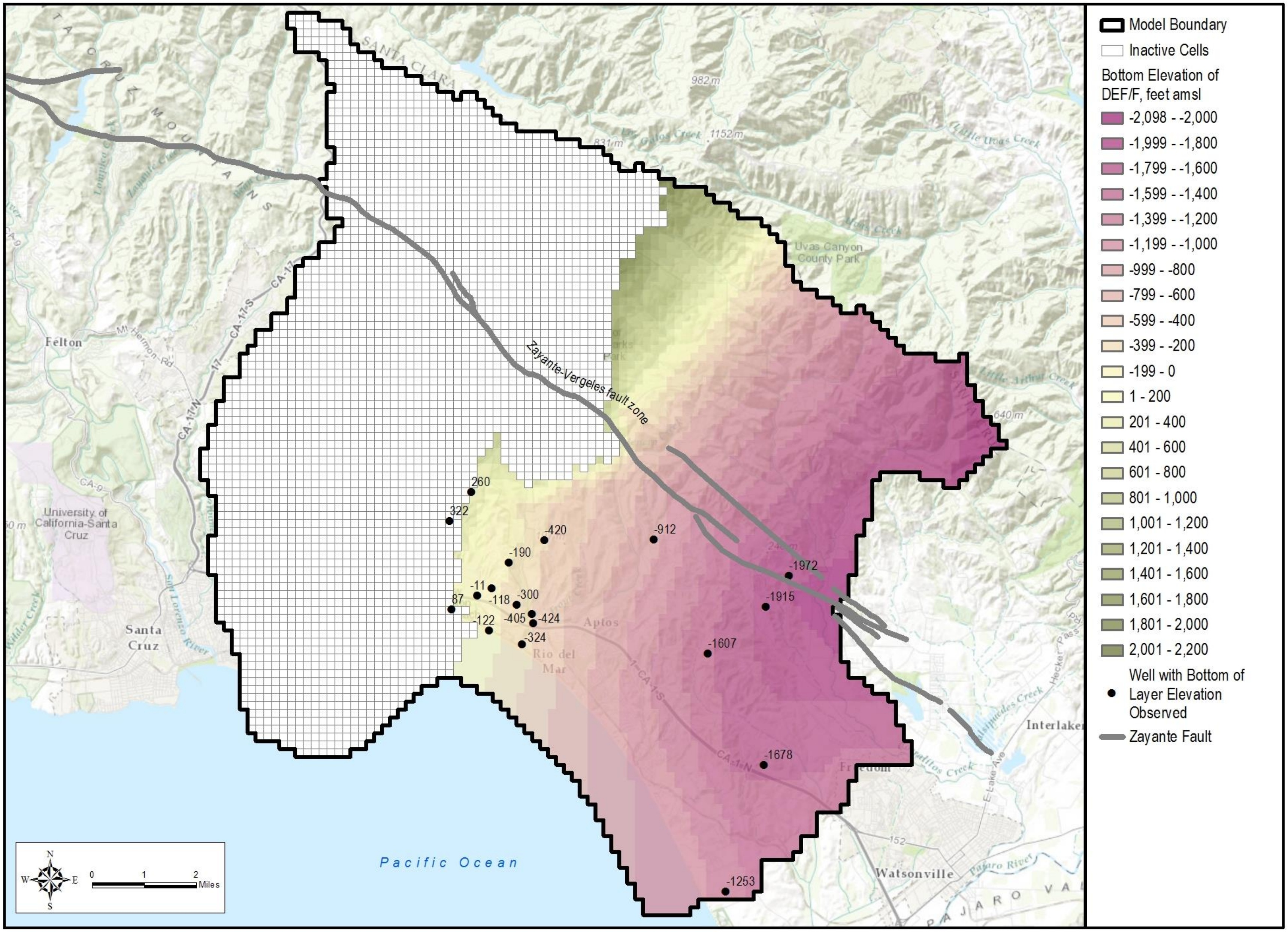


Figure 13: Base of TpDEF/F Unit Elevations in Model

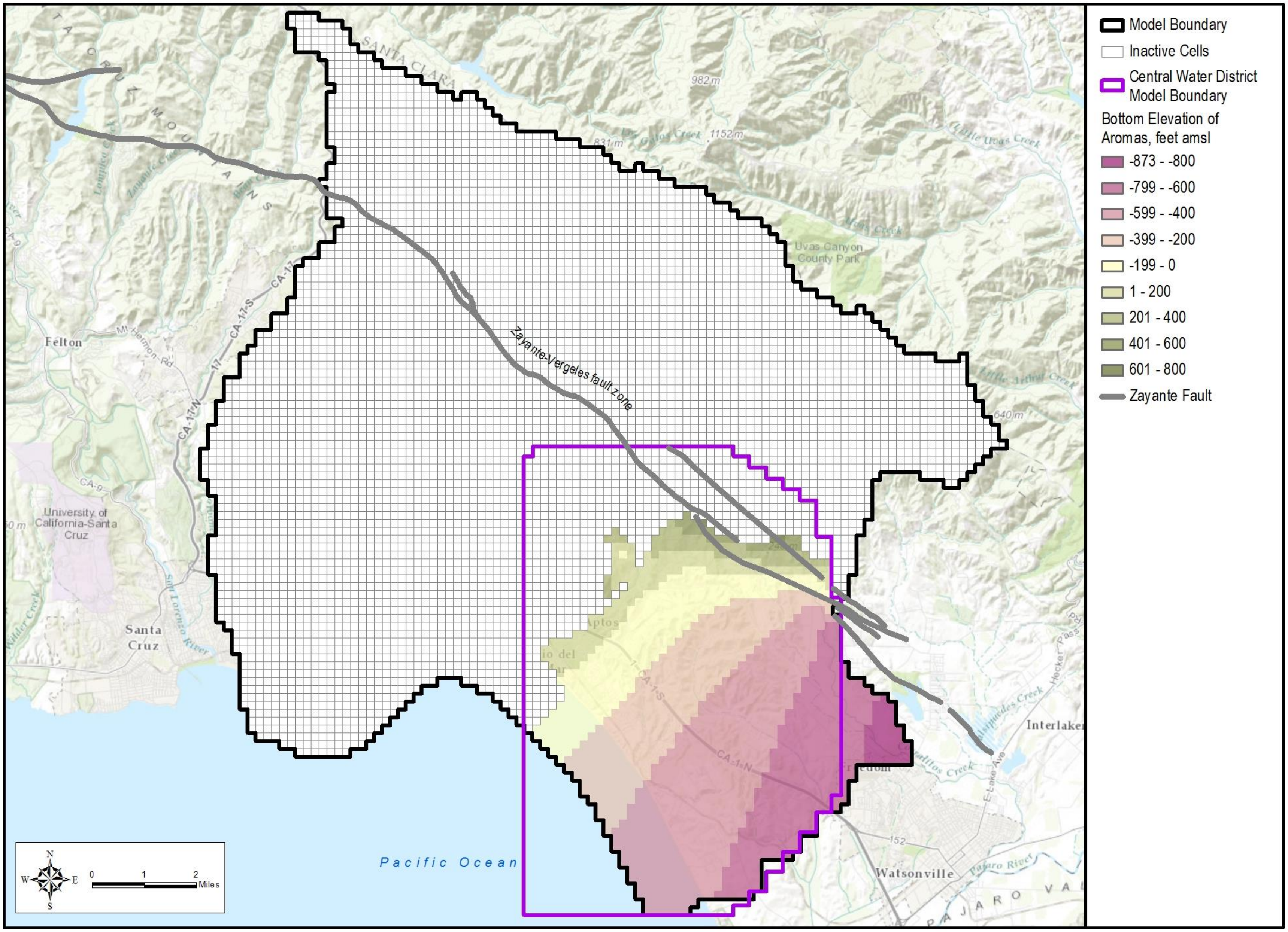


Figure 14: Base of Aromas Red Sands Elevations in Model

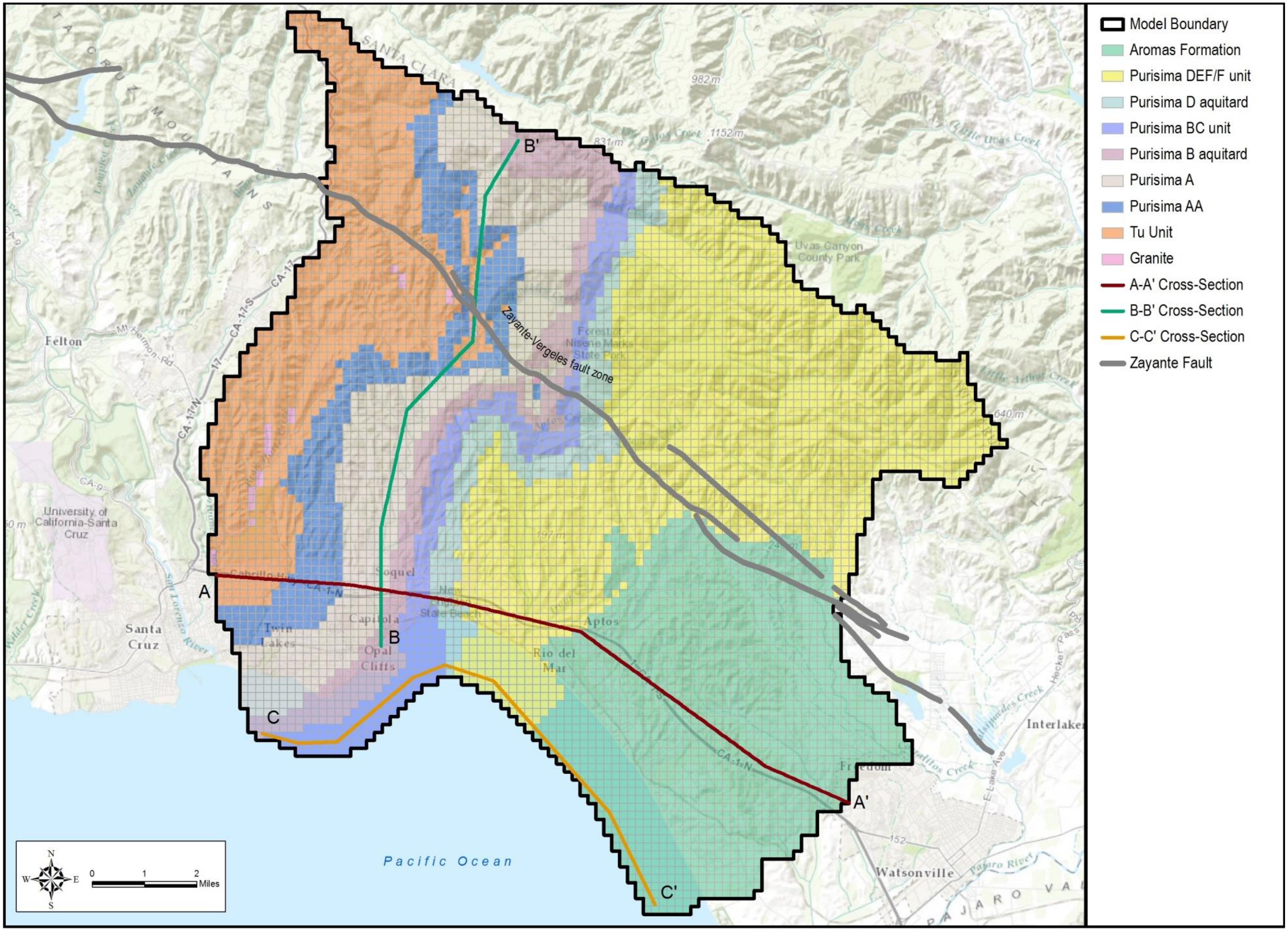


Figure 15: Simulated Aromas and Purisima Outcrop Extents

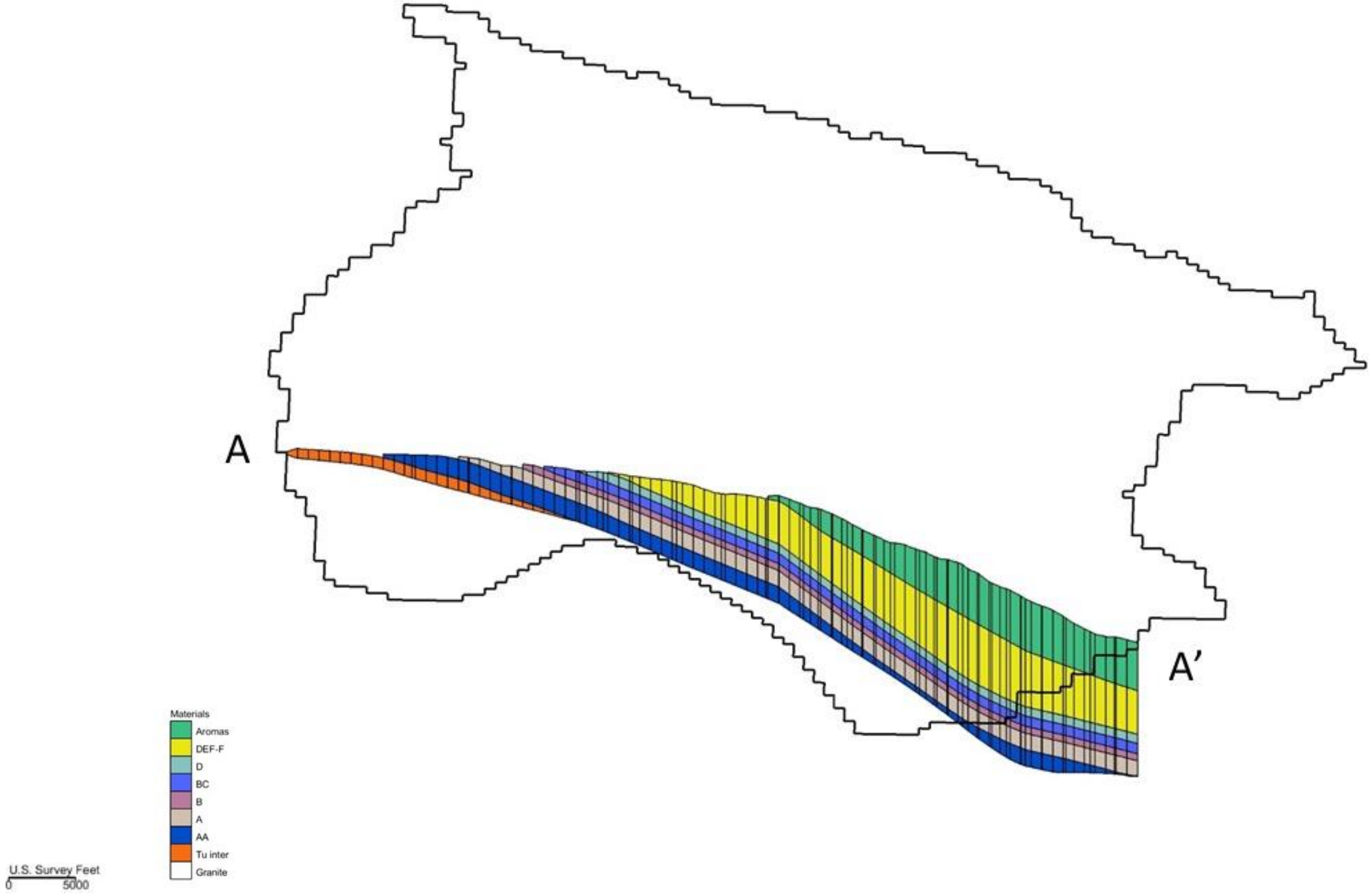


Figure 16: Simulated Cross-Section A-A’

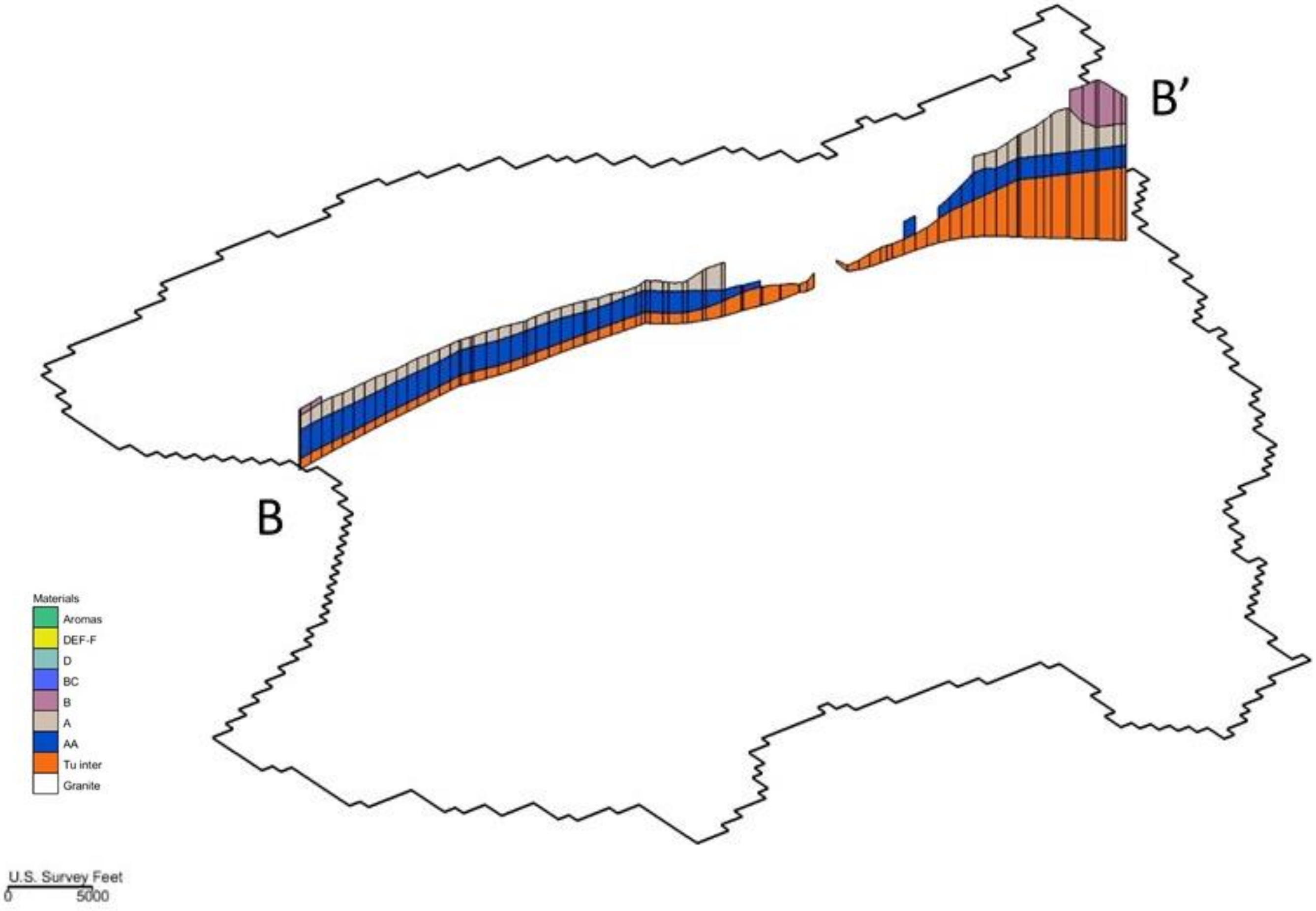


Figure 17: Simulated Cross-Section B-B'

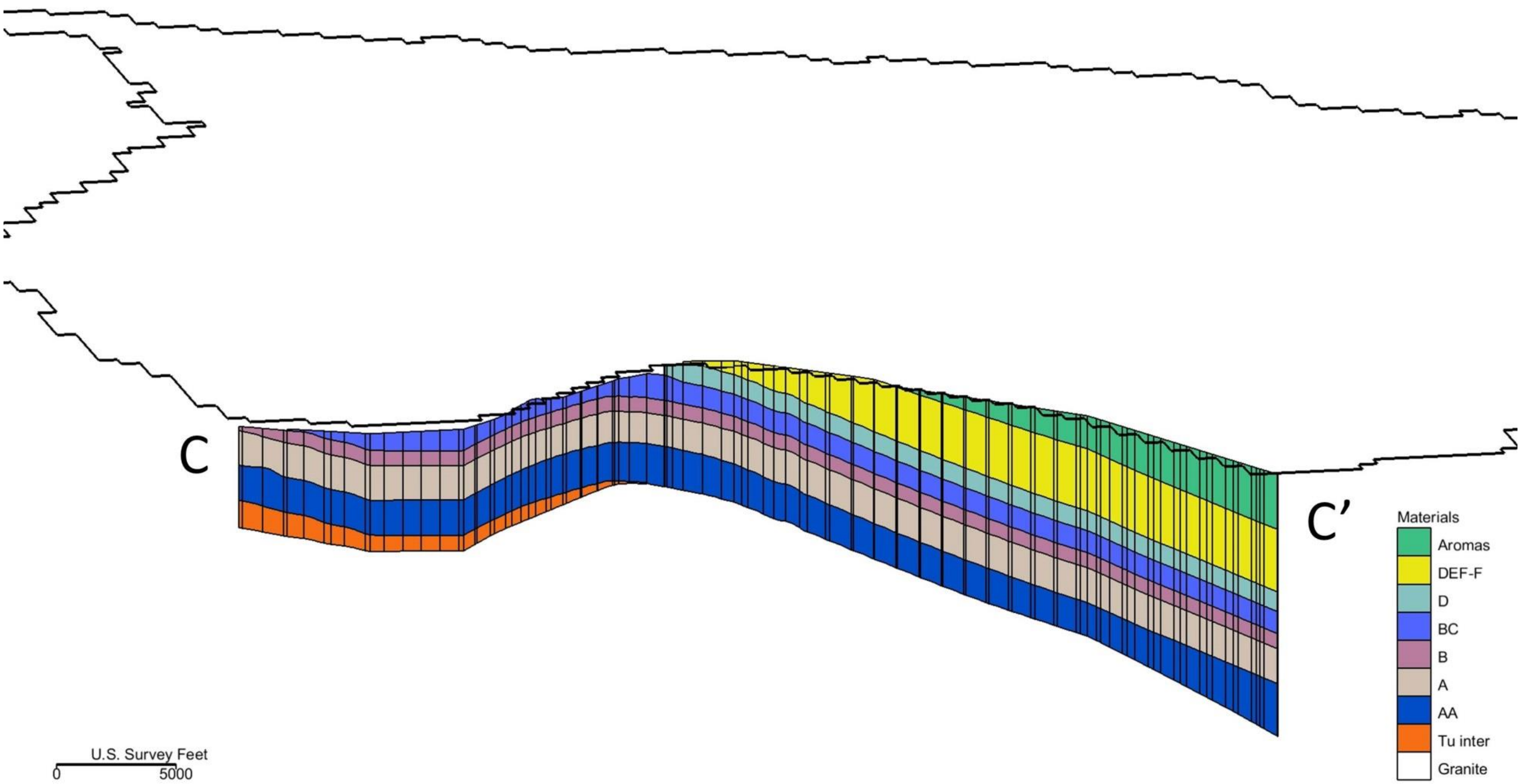


Figure 18: Simulated Cross-Section C-C′

4.4 EXTENT AND DEFINITION OF SIMULATED ALLUVIAL MATERIAL

In addition to the Aromas Red Sands and Purisima Formation, alluvial material associated with streambed deposits and coastal terrace deposits are defined within the model domain. Streambed sand and gravel deposits may be of relatively higher-permeability material than the surrounding surficial geology, so they are considered necessary to represent the groundwater-surface water interactions that occur in the integrated GSFLOW model. Terrace deposits consist of unconsolidated sediments formed by surf erosion in periods of high sea levels during the Pleistocene epoch. While they may yield only relatively minor quantities of groundwater to wells, they were added to the model to accommodate their potential for affecting recharge to the underlying aquifer units. The simulated thicknesses of these alluvial materials is simplified to be uniform wherever they exist within the model domain.

Because the Aromas and Purisima Formation outcrop over the extent of the model domain, the ground surface is defined by various model layers. The alluvium may be found overlying any of these outcropping model layers; therefore the alluvium cannot be defined as a single layer within the model. Rather, alluvium will be assigned to whatever model layer overlies the regional aquifers where that alluvium is identified to exist. The exact material properties of the alluvium will be documented in a future technical memorandum. To accommodate the alluvium thickness, the top-of-layer elevations of the underlying units are revised by subtracting the alluvium thickness from the interpolated DEM surface. Figure 19 and Figure 20 show the simulated extents of active streambed alluvium and terrace deposit materials within the model domain, respectively. The streambed alluvial areas are congruent with the anticipated extent of stream cells developed for the PRMS component of the model. The extent of terrace deposits was inferred from existing USGS surficial geology maps.

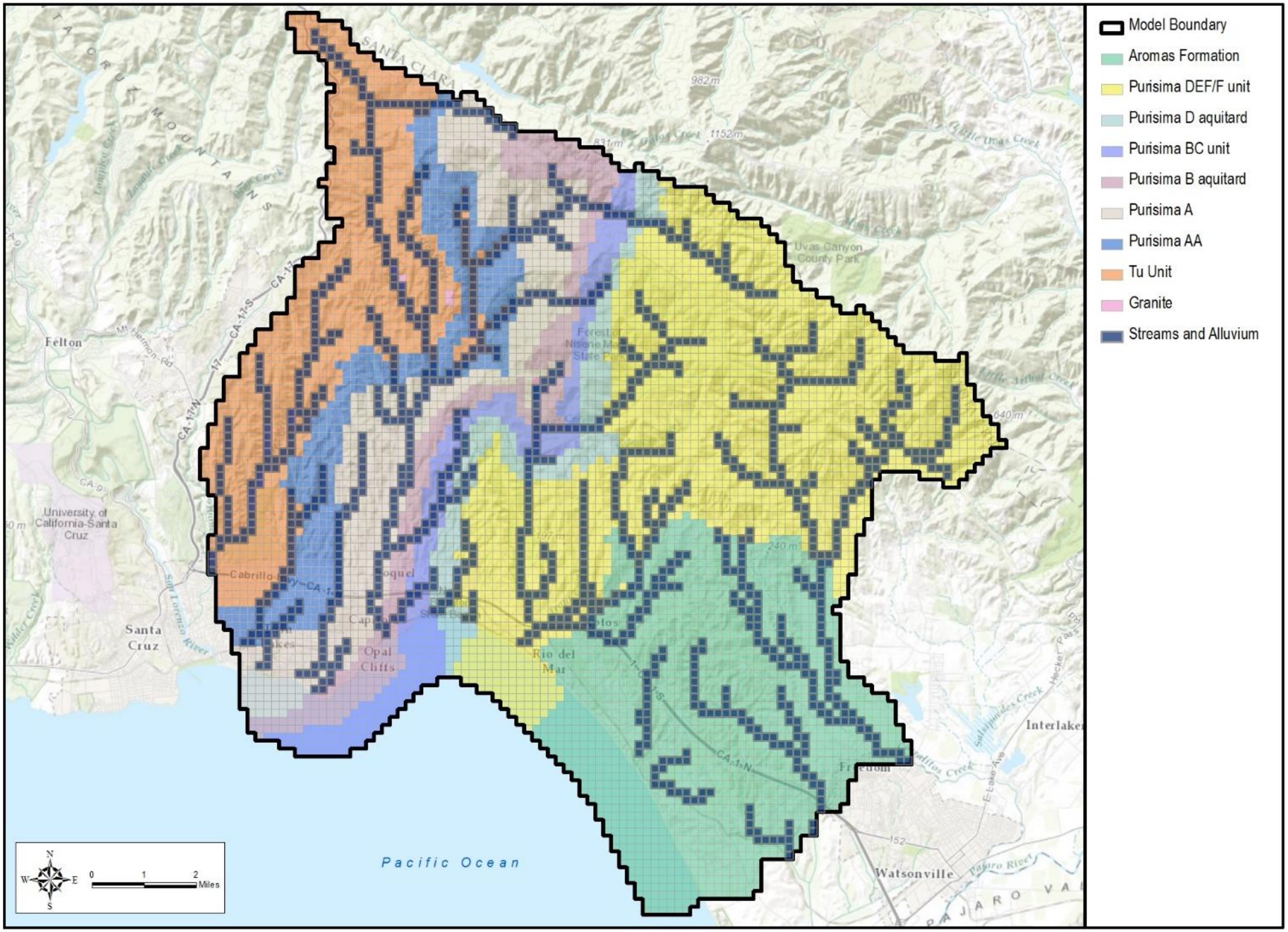


Figure 19: Simulated Extent of Streambed Alluvium

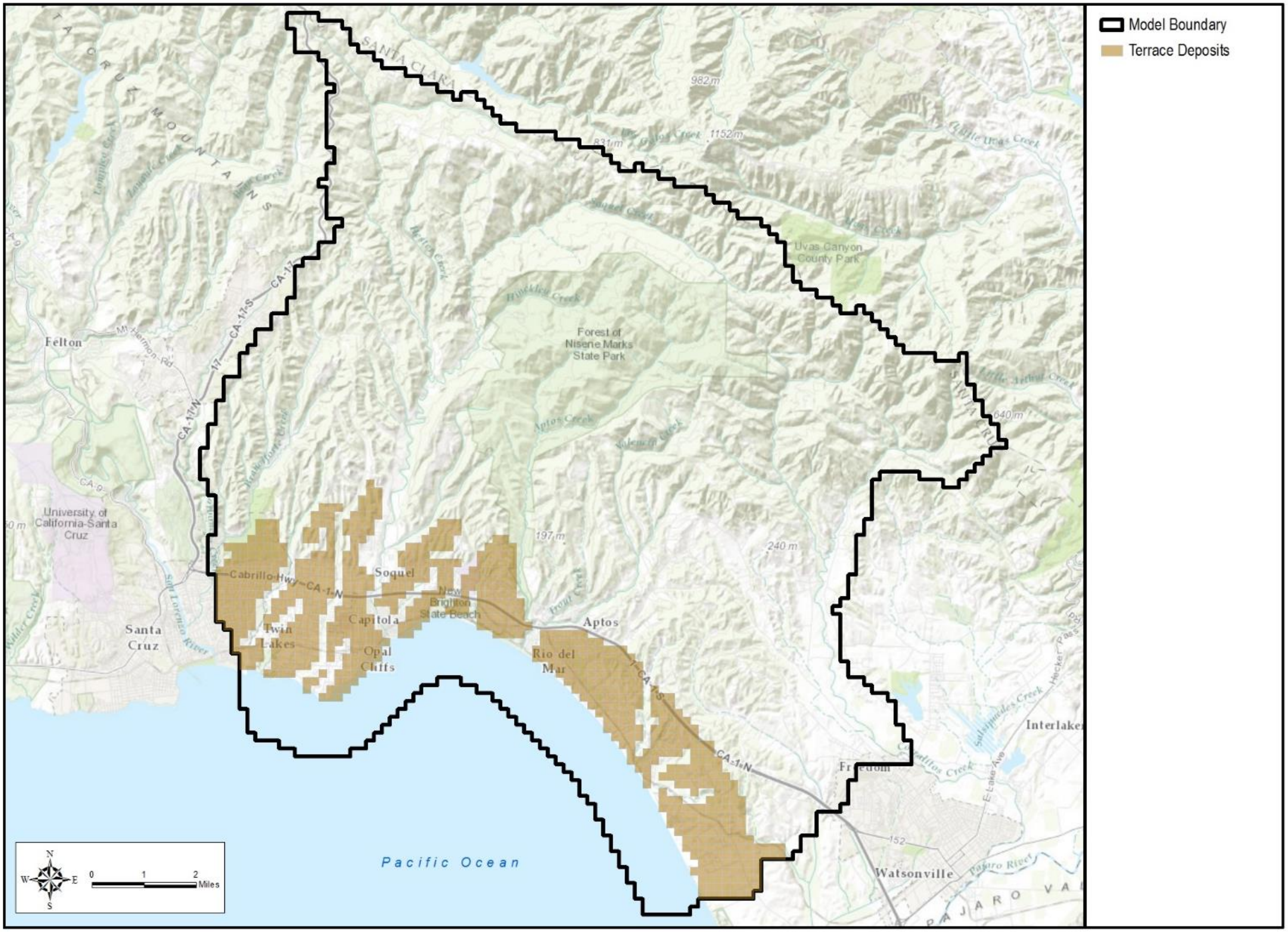


Figure 20: Simulated Extent of Terrace Deposits

Assigning streambed alluvium to various model layers was complicated by areas where streams cross simulated outcrop boundaries. In order to allow for hydraulic connectivity in these streambed units, additional layering was necessary to ensure that flow within the streambed units is not impeded by an effective boundary created where adjacent stream cells are assigned to different model layers. Figure 21 shows a diagram outlining the stream alluvial layering approach within the groundwater model where streams cross outcrop boundaries. In these instances, an additional vertical layer of alluvium is added to create a stack of cells connecting the alluvium overlapping the different outcropping aquifers. Minimal vertical anisotropy applied to the alluvial cells will facilitate a continuous flow path laterally out of the upstream alluvial cell, downward or upward through the stacked alluvial cells, and then laterally in the downstream direction through the alluvium. Without this additional layering, no lateral flow would occur in the alluvial cells of streams that cross outcrop boundaries.

As developed for PRMS, simulated streamflow may occur between adjacent stream cells, but also between cells that overlay diagonally-aligned model cells. However, groundwater flow is not simulated between diagonally-aligned model cells. As such, “bridge” streambed alluvium cells were defined to maintain lateral hydraulic connectivity between model cells representing the alluvium of a diagonally-flowing stream, with a continuous flow path maintained using stacking of two or more layers at the bridge cell as described above. Figure 22 demonstrates the process by which these additional bridge cells were defined, including cases where the stream crosses an outcrop boundary, as described above.

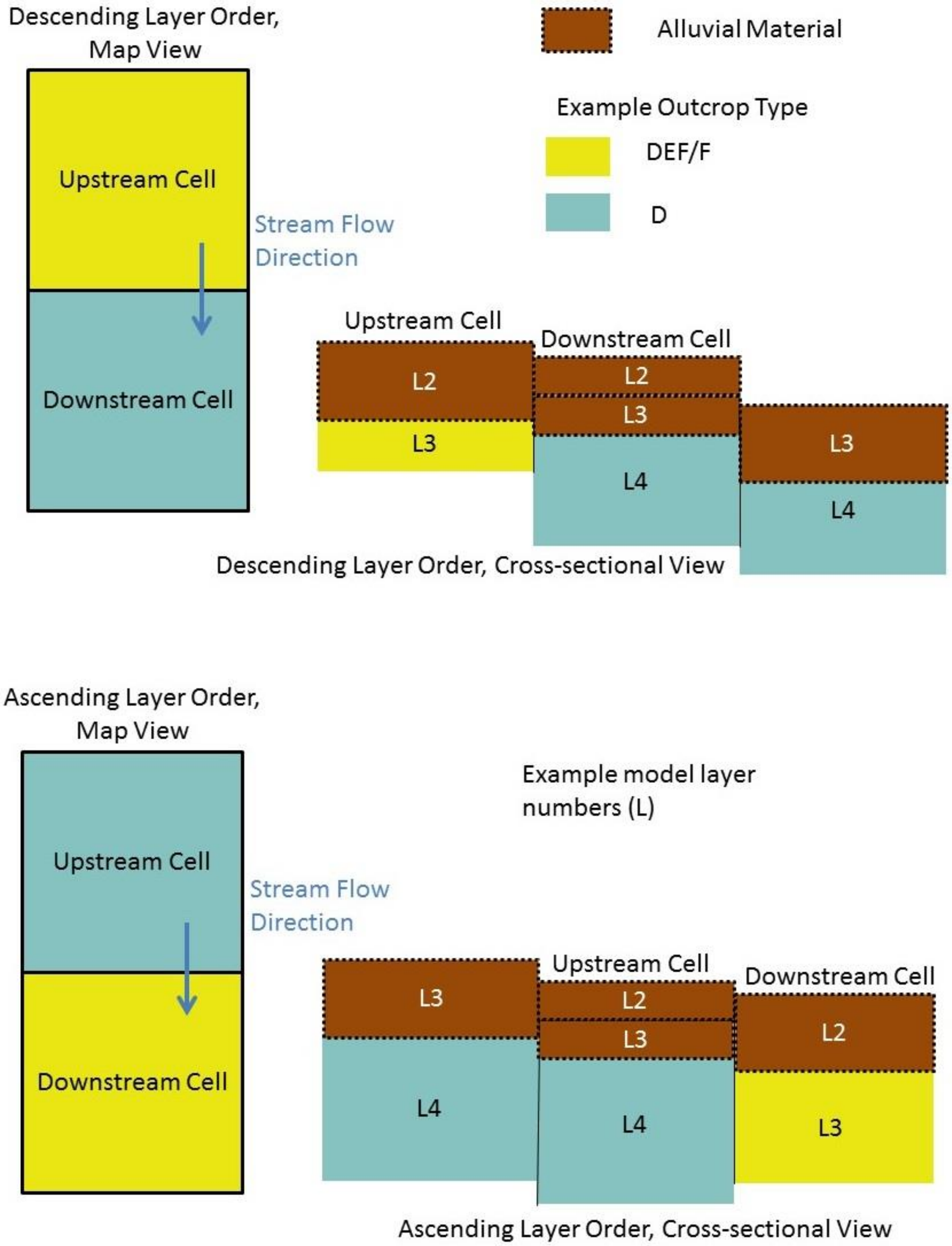


Figure 21: Example Stream Alluvium Layer Assignment

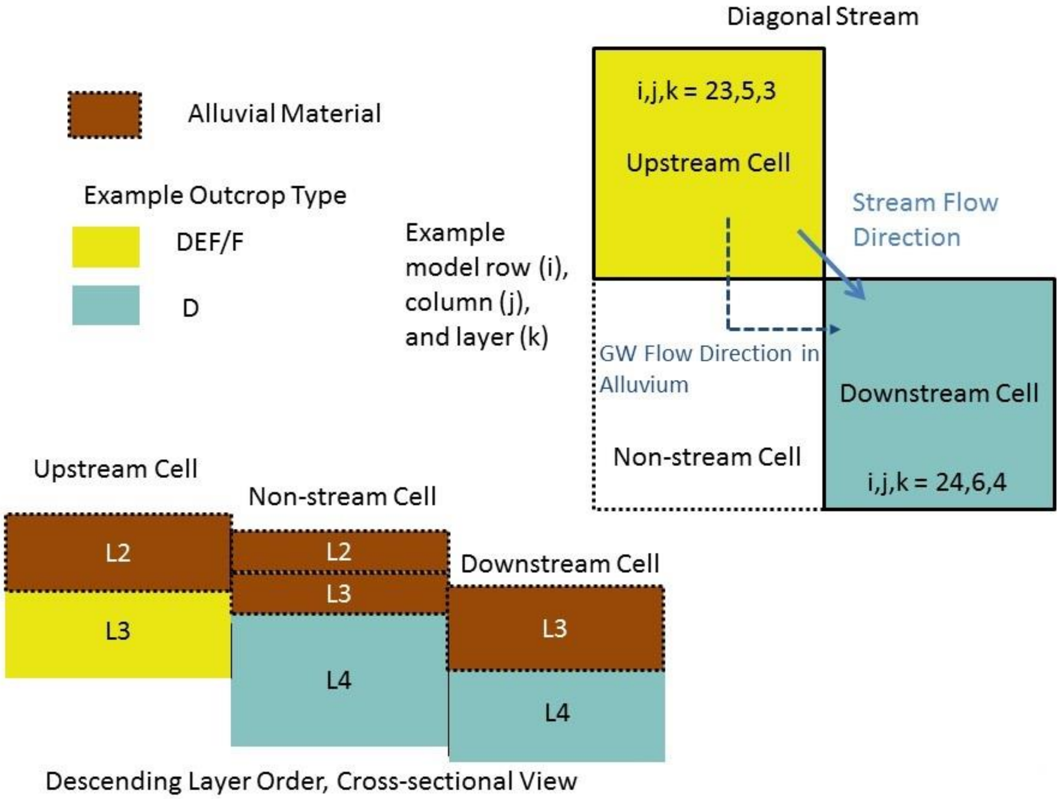


Figure 22: Example Stream Alluvium Layer Assignment for Diagonally-aligned Streams

5.0 BOUNDARY CONDITIONS

Model boundaries have been selected so that they generally follow existing watershed boundaries or other hydraulic boundaries within the model domain. As such, the northern, western, and eastern edges of the model will be assigned no-flow boundary conditions. The extent and type of anticipated boundary conditions is shown on Figure 23.

Active Aromas or Purisima model cells that outcrop beyond the coastline will be assigned as general head boundary (GHB) cells where the simulated head value is equivalent to mean sea level similar to the CWD model (HydroMetrics WRI and Kennedy/Jenks, 2014). Conductance will be estimated as model construction and calibration proceeds. Conductance values will also be varied spatially to account for changes in seafloor sediment type and thickness.

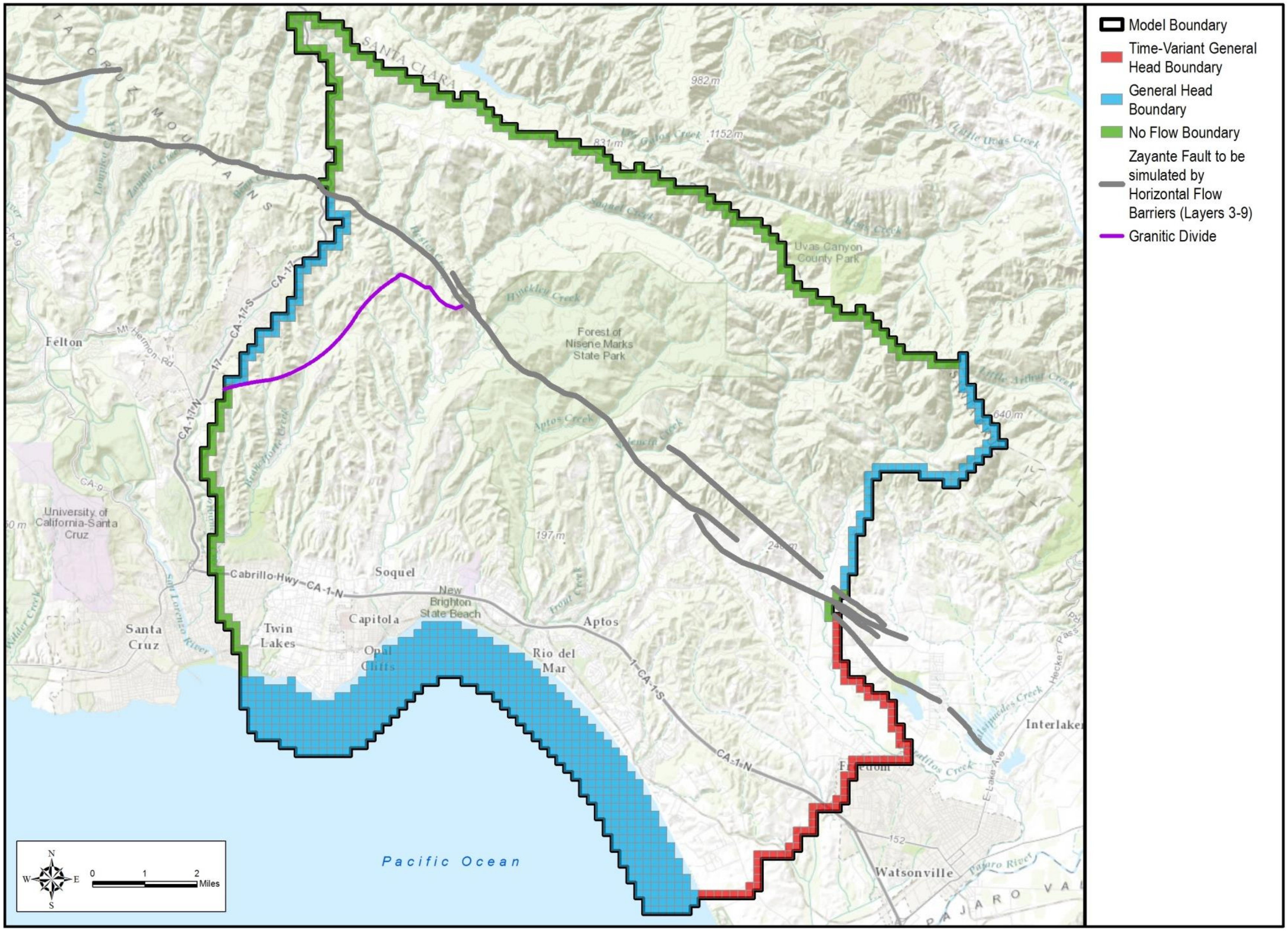


Figure 23: Generalized groundwater model boundary conditions.

The Zayante Fault will be represented by the horizontal flow barrier (HFB) package. Implementing these flow barriers between cells north and south of the fault will provide resistance to flow between the well-defined Purisima unit layers south of the fault and the undefined Purisima Formation north of the fault as described in section 4.3. HFB conductance will be estimated during model calibration.

The area of the model north of the Zayante Fault is within the watershed area of the Soquel-Aptos Basin, and will receive surface water in the form of precipitation and streamflow. However, groundwater flow from infiltration into the simulated undifferentiated Purisima units north of the fault will be impeded by the fault HFB. In order to avoid mounding and unreasonably high groundwater levels in this area, an additional GHB will be applied to the eastern boundary of the model north of the fault. The head and conductance along this boundary will be varied as model work progresses to maintain reasonable groundwater head elevations north of the Zayante Fault. It is unlikely that model calibration will be sensitive to this boundary condition, as the majority of pumping wells and groundwater calibration targets will be south of the fault.

Groundwater modeling studies of the Santa Margarita Basin and Scotts Valley area (Todd Engineers, 1997; ETIC Engineering, 2006; Kennedy/Jenks Consultants, 2015) indicate that groundwater flow west of the granitic structural divide shown on Figure 4, Figure 5, and Figure 23 within the aquifer units below the Purisima Formation is directed roughly westward, away from the Soquel-Aptos Basin. As such, assigning a no flow boundary west of this structural divide may result in unreasonable mounding and flow directions to occur in the thick portion of the simulated Tu unit west of the divide. It may also be problematic to inactivate model cells west of the structural divide as at the surface, this area is still within the Soquel-Aptos watershed and contains steams that necessarily contribute flow to model domain. To accommodate this feature of the hydrostratigraphy, a GHB will be applied to the western boundary of the model between the intersection of the granitic structural divide with the western model boundary and the Zayante Fault, which is also the northern boundary of the Santa Margarita Basin. This will induce westward groundwater flow out of the model domain west of the structural divide and maintain reasonable groundwater elevations within the Tu unit in this area.

The southeastern boundary is the only boundary that does not intersect a watershed or naturally-occurring hydraulic barrier. Rather, it is similar to the southeastern boundary of the CWD model in the coastal plain area of the City of Watsonville. Model cells representing this boundary will be defined as GHB cells via similar method as was applied to the CWD model (Hydrometrics WRI and Kennedy/Jenks, 2014). In the CWD model, a GHB boundary with transient heads estimated for the entire boundary length was developed based on groundwater elevation data provided by PVWMA. As groundwater data in this area are relatively limited, the transient heads were assigned to three separate segments of the boundary according to a function for seasonally-fluctuating groundwater elevations that was fit to historical water level data at the PVWMA wells. Historical lateral groundwater gradients were used to apply a generalized spatial trend to each segment of the boundary (Hydrometrics WRI and Kennedy/Jenks, 2014). These interpolated time series extend through 2012 for the CWD model, and will be updated to extend through 2015 to be applied to the basin wide model. The CWD model did not extend vertically into the Purisima along this southeastern boundary, and groundwater level data from PVMWA wells in this area are limited to the Aromas Formation. To account for this, a consistent vertical gradient will be estimated, and transient and spatial head data will be interpolated according to the gradient at GHB cells in the underlying Purisima layers along the boundary in the basin wide groundwater model. Where necessary, the extent of each boundary segment, the function applied to develop transient head conditions, or the vertical gradient will be adjusted as model construction and calibration proceeds. Figure 24 shows the area of the southeastern model boundary, the wells used to define the spatial variability of the boundary in the CWD model, as well as other PVMWA wells in the vicinity that may be used as sources of groundwater elevation data to define the boundary heads. Pumping from the City of Watsonville also occurs in this area, and will be explicitly defined by pumping wells in the model. City of Watsonville wells that fall within the model domain are also shown in Figure 24. Future changes to pumping at other City of Watsonville wells will need to be simulated by adjusting the boundary condition.

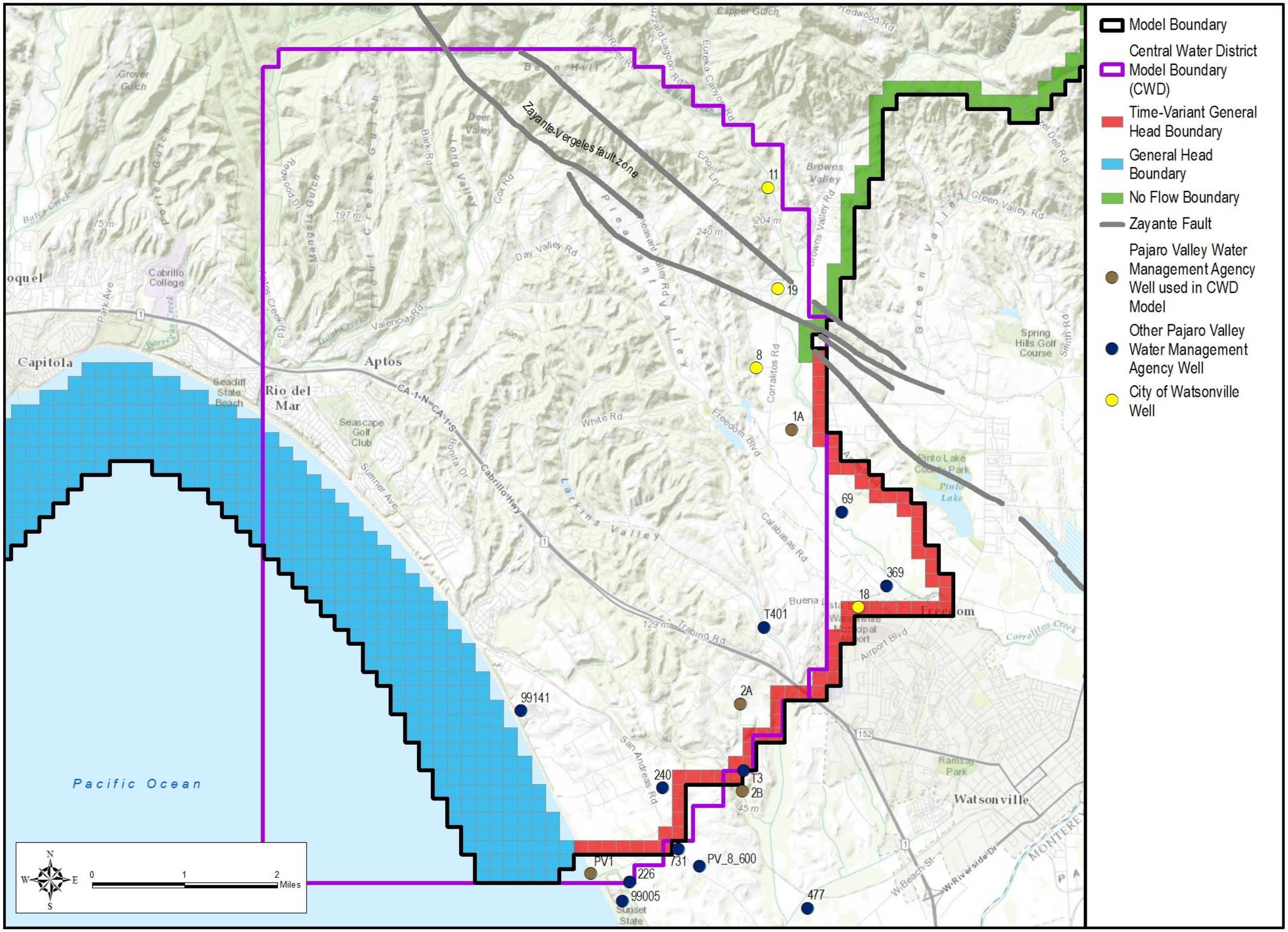


Figure 24: Southeastern Model Boundary

There may also be the need for boundary conditions in layer 9, the deepest active layer, to the west. As discussed in section 4.1, sediments in this layer west of the granitic high shown in Figure 4 may be more closely associated with the Santa Margarita basin and a boundary condition representing this association may need to be added. This will be evaluated as modeling proceeds.

6.0 NEXT STEPS

This memorandum will be reviewed by the model Technical Advisory Committee (TAC) and a meeting with the TAC and SAGMC member staff will be held by November 17, 2015 to discuss the memorandum and subsurface model construction. The next draft memorandums that will be produced are:

- A memorandum on estimates for non-agency water use and basinwide return flow (Task 2). This memorandum will be first reviewed by the SAGMC subcommittee on estimating private water use.
- A memorandum on construction of the PRMS watershed model (Task 2)

The above two memorandums will be provided to the TAC for review in advance of a meeting by early December 2015. Any necessary changes to the model setup based on TAC comments will be made and the model components discussed in the three memorandums will be integrated into a GSFLOW model. After integration, the following memorandums will mark project milestones.

- GSFLOW Integration (February 2016)
- Model Calibration (May 2016)
- Model Simulations of Groundwater Management Alternatives (July 2016)
- Integration of Seawater Interface Package and Seawater Intrusion Simulation (October 2016)

7.0 REFERENCES

ETIC Engineering, 2006, *Groundwater Modeling Study of the Santa Margarita Groundwater Basin, Scotts Valley Water District*. Prepared for Scotts Valley Water District. May.

HydroMetrics WRI, 2011, *Estimation of Deep Groundwater Recharge Using as Precipitation-Runoff Watershed Model, Soquel-Aptos, California*, prepared for Soquel Creek Water District, Central Water District, City of Santa Cruz, August.

HydroMetrics WRI, 2014, *Proposal for developing groundwater model,* Letter to Kim Adamson. July 10.

HydroMetrics WRI and Kennedy/Jenks, 2014, *Aromas and Purisima Basin Management Technical Study, Santa Cruz Integrated Regional Water Management Planning Grant Task 4*, prepared for Central Water District, March.

Johnson, N.M., D. Williams, E.B. Yates, and G.T. Thrupp, 2004, *Technical Memorandum 2: Hydrogeological Conceptual Model,* Prepared for Soquel Creek Water District, September.

Johnson, N.M. 2006. *Supplement to Hydrogeologic Conceptual Model,* technical memorandum to Clarke Wales, Central Water District, December.

Kennedy/Jenks Consultants, 2015, *Santa Margarita Groundwater Modeling Technical Study*. Prepared for Scotts Valley Water District. June.

Luhdorff and Scalmanini, Consulting Engineers, 1984, *Groundwater Resources and Management Report, 1983*, Soquel Creek Water District, January.

Soquel Creek Water District and Central Water District, 2007, *Groundwater management plan -2007 Soquel-Aptos area,* Santa Cruz County, California, April.

Todd Engineers, 1997, *Computer Modeling for Groundwater Management, Scotts Valley Groundwater Basin*. Prepared for Scotts Valley Water District. June.

U.S. Geological Survey (USGS), 1997, Geologic Map of Santa Cruz County, California, Open File Report 97-489.

USGS, 2004, Isostatic residual gravity map of The Santa Clara Valley and vicinity, California. Open-File Report 2004-1297.

Appendix A: List of Stratigraphic Unit Elevation Data

Well or Borehole	**Elevation Interpolated from E-Log (feet above mean sea level)**						
	Bottom Tu / top of Granite	**Bottom TpAA**	**Bottom TpA**	**Bottom TpB**	**Bottom TpBC**	**Bottom TpD**	**Bottom TpDEF/F**
Aptos Creek	--	--	--	--	--	-588.78	-423.78
Aptos School	--	--	--	--	--	--	--
Austrian Way	--	--	--	--	--	-365	-190
Cornwell	--	--	73	328	--	--	--
Estates	--	--	-845.7	-505.7	-370.7	-180.7	-10.7
Ledyard	--	--	--	-799.59	-659.59	-469.59	-299.59
Madeline	--	--	-897.92	-622.92	-487.92	-262.92	-117.92
Main St.	-614.5	-486.5	-116.5	--	--	--	--
Monte Toyon Test	--	--	--	--	-760	-580	-420
Opal #5 (Garnet)	--	-673	-208	2	--	--	--
Rosedale	--	--	--	2	132	--	--
T. Hopkins	--	--	--	--	--	-574.51	-404.51
Tannery	--	--	-486.48	-156.48	-61.48	--	--
O'Neill Test	-514	-409	11	256	--	--	--
SC-1A,B (Prospect)	--	--	-249.67	-40.67	--	--	--
SC-3A,B,C (Escalona)	--	--	-410	-180	-45	--	--
SC-5A,B,C,D,E (New Brighton)	--	--	-643	-388	-253	-73	87
SC-8A,B,C,D,E,F	--	--	--	-819.36	-689.36	-489.36	-324.36

Well or Borehole	Elevation Interpolated from E-Log (feet above mean sea level) Bottom Tu / top of Granite	Bottom TpAA	Bottom TpA	Bottom TpB	Bottom TpBC	Bottom TpD	Bottom TpDEF/F
(Aptos Crk)							
SC-9A,B,C,D,E (Seacliff)	--	--	-887	-607	-462	-282	-122
SC-10AA,A (Cherryvale)	-568.75	-428.75	-88.75	--	--	--	--
SC-11A,B,C,D	-841	-835	-530	-250	-120	90	260
SC-12	--	--	--	-1432	-1312	-1077	-912
SC-18A	-614	-486	--	--	--	--	--
SC-18AA	-614	-486	--	--	--	--	--
SC-22 Tu	-632	-517	-177	--	--	--	--
Rosedale	--	--	-273	--	--	--	--
Foster-Gamble	--	--	--	-164	-36	162	322
Anderson	0	--	-50	--	--	--	--
65GHR	--	--	--	256	382	--	--
Auto Plaza Drive	--	--	-129	--	--	--	--
Axford Rd	-640	-480	-50	--	--	--	--
Beltz #4	--	--	-73	--	--	--	--
Beltz #6 (TH-3)	--	-538	-138	--	--	--	--
Beltz #7 (TH-2)	--	--	-112	--	--	--	--
Beltz #8 (TH-3)	--	-538	--	--	--	--	--
Beltz #9 (TH-1)	--	--	-160	--	--	--	--

Well or Borehole	Elevation Interpolated from E-Log (feet above mean sea level)						
	Bottom Tu / top of Granite	Bottom TpAA	Bottom TpA	Bottom TpB	Bottom TpBC	Bottom TpD	Bottom TpDEF/F
Coffey Lane	--	--	54	--	--	--	--
Beltz #12 Cory St	--	-415	10	--	--	--	--
Delaveaga Test	-25	15	--	--	--	--	--
Pleasure Pt A,B,C	--	--	-268.72	-58.72	--	--	--
SC TH-1 (57)	-581	-491	--	--	--	--	--
SC TH-2 (57)	-729	-676	--	--	--	--	--
SC TH-3 (57)	-119	-64	--	--	--	--	--
Thurber Lane Pump Sta	-246	-191	--	--	--	--	--
Thurber Lane (North)	-203	-158	--	--	--	--	--
Santa Margarita Test (TH-2)	-778	-683	-112	--	--	--	--
Soquel Point	--	--	-313	-63	--	--	--
Blake (O&G)	-2153	--	-2098	-1788	-1678	-1363	-1253
Carpenter (O&G)	-2748	--	-2613	-2188	-2078	-1778	-1678
J.H. Blake (O&G)	--	--	-2832	-2477	-2362	-2132	-1972
Light (O&G)	--	--	-2735	-2385	-2275	-2045	-1915
Pierce (O&G)	--	--	-2307	-2087	-1942	-1737	-1607
Leonardich (O&G)	--	--	--	-2645	-2530	-2300	-2165
Dicicco	--	--	--	-2470	-2340	-1950	-1820

Note: “-- “ indicates data for given stratigraphic interval is unavailable at that well or borehole