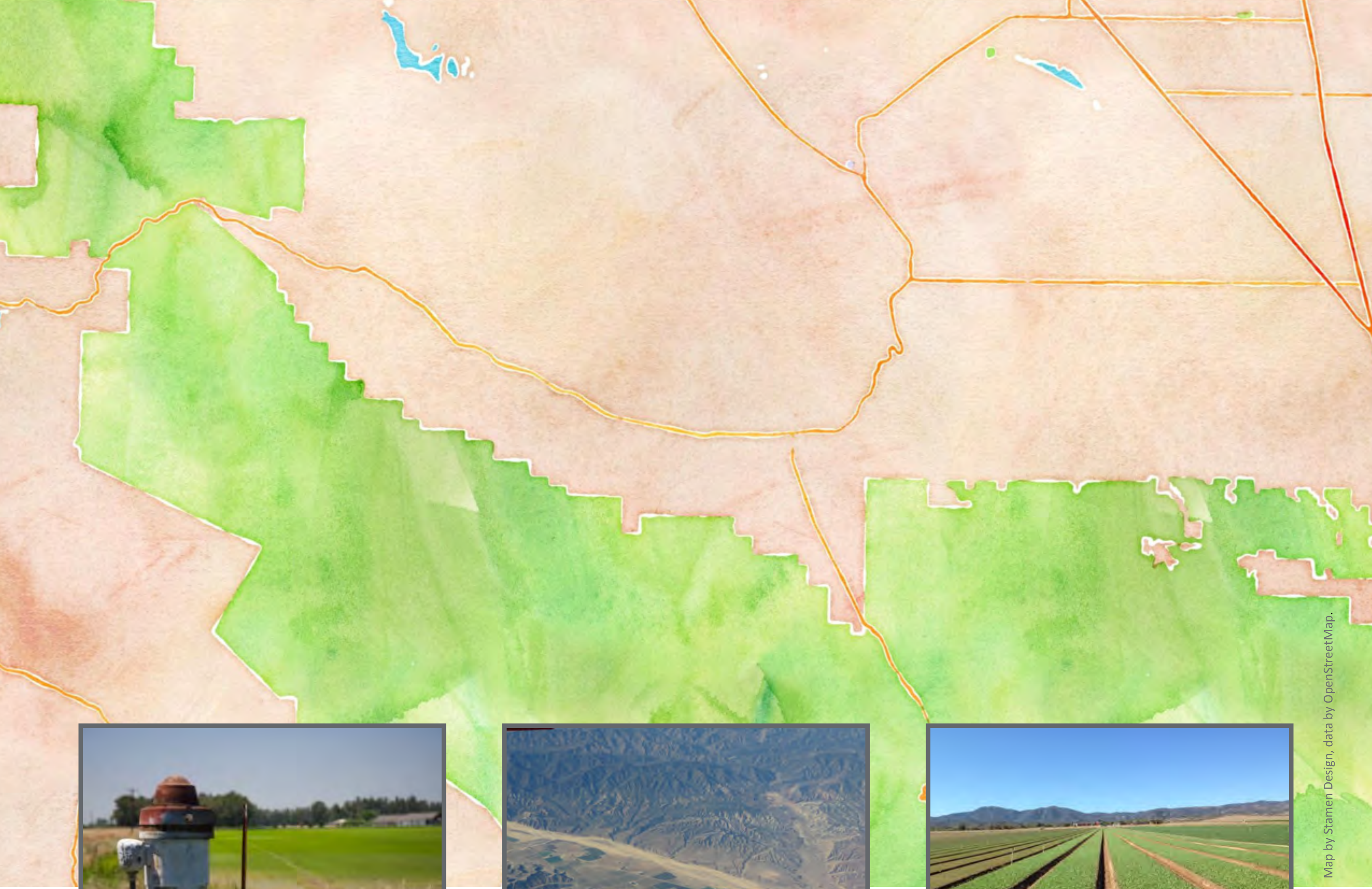

Map by Stamen Design, data by OpenStreetMap.

Preliminary Findings from Review

of the USGS Study of the Cuyama Valley Groundwater Basin

Prepared for:

Cuyama Basin Water District

27 October 2017 | EKI B70069.00

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27 October 2017

MEMORANDUM

To: Cuyama Basin Water District Board of Directors

Cc: Ernest Conant, Esq., Young Wooldridge, LLP

From: Anona Dutton, P.G., C.Hg., EKI Environment & Water, Inc.
Christopher Heppner, Ph.D., P.G., EKI Environment & Water, Inc.
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Subject: Preliminary Findings from Review of the USGS Study of the Cuyama Valley Groundwater Basin
Cuyama Basin Water District
(EKI B70069.00)

EKI Environment & Water, Inc. ("EKI") is pleased to present to Cuyama Basin Water District ("CBWD" or "District") this memorandum describing results from the EKI Team's[1] review of previous studies conducted by the United States Geological Survey ("USGS") regarding hydrogeologic conditions in the Cuyama Valley Groundwater Basin (California Department of Water Resources ["DWR"] basin number 3-013; "Cuyama Basin"). This review was performed pursuant to EKI's scope of work and agreement with Young Woolridge LLP, dated 1 June 2017 ("Agreement").

This memorandum also presents a brief overview of the Cuyama Basin, and then discusses key findings and recommendations for next steps, with particular focus on compliance with the Sustainable Groundwater Management Act ("SGMA"). Much of the information presented herein was verbally presented to the District's Board of Directors during their meetings on 28 June 2017 and 23 August 2017.

OBJECTIVES

As described in the Agreement, the main objectives of this work were to: (1) perform an independent technical review of the five reports published by the USGS about the Cuyama Valley

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[1] The EKI Team consists of EKI and HydroFocus, Inc.

Groundwater Basin between 2008 and 2014 which together comprise the "USGS Study"[2]; and (2) assess whether that body of work can serve as a reasonable foundation for future groundwater management planning efforts in the Cuyama Basin pursuant to SGMA. Specifically, the review conducted by the EKI Team was aimed at assessing the following:

- The validity of the key assumptions and findings of the USGS Study with respect to groundwater conditions, including the conceptualization of the Cuyama Basin hydrogeology and the spatial patterns and temporal trends in groundwater levels and water quality;
- Potential flaws, inconsistencies, or data gaps which have a significant influence on the resultant Cuyama Basin water budget and hydrogeologic conceptual model ("HCM") developed by the USGS; and
- The adequacy of the USGS's numerical Cuyama Valley Hydrologic Model ("CUVHM") to portray conditions in the Cuyama Basin and reasonably estimate the water budget, including identifying sources of sensitivity and uncertainty in model inputs and parameterization.

Upon completion of the technical review and in consultation with the District, the final objective of this work was to: (1) provide recommendations to the District for additional technical work that could be performed to address data gaps, improve data reliability, and/or further vet key assumptions and findings of the USGS Study or work prepared as part of the development of a Basin-wide Groundwater Sustainability Plan ("GSP"); and (2) generally prepare the District for its role as a member of the Cuyama Basin Groundwater Sustainability Agency ("Cuyama GSA").

SUMMARY OF EKI TEAM WORK EFFORT

The EKI Team completed a detailed review of the five USGS reports comprising the USGS Study. Our review focused on verifying the critical assumptions and the supporting technical

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[2] The USGS Study, as defined herein, includes the following reports:

- Everett, R.R., Gibbs, D.R., Hanson, R.T., Sweetkind, D.S., Brandt, J.T., Falk, S.E. and Harich, C.R., 2013, *Geology, water-quality, hydrology, and geomechanics of the Cuyama Valley groundwater basin, California, 2008–12*, U.S. Geological Survey Scientific Investigations Report 2013–5108, 62 p.
- Sweetkind, D.S., Faunt, C.C., and Hanson, R.T., 2013a, *Construction of 3-D geologic framework and textural models for Cuyama Valley groundwater basin, California*, U.S. Geological Survey Scientific Investigations Report 2013–5127, 46 p.
- Sweetkind, D.S., Bova, S.C., Langenheim, V.E., Shumaker, L.E., and Scheirer, D.S., 2013b, *Digital tabulation of stratigraphic data from oil and gas wells in Cuyama Valley and surrounding areas, central California*, U.S. Geological Survey Open-File Report 2013–1084, 44 p.
- Hanson, R.T., Flint, L.E., Faunt, C.C., Gibbs, D., and Schmid, Wolfgang, 2014, *Hydrologic models and analysis of water availability in Cuyama Valley, California*, U.S. Geological Survey Scientific Investigations Report 2014–5150, 150 p.
- Hanson, R.T., and Sweetkind, D.S., 2014, *Cuyama Valley, California hydrologic study—An assessment of water availability*, U.S. Geological Survey Fact Sheet 2014-3075, 4 p.

information via an examination of the reference material used in each study along with supplementary information provided by the District or otherwise readily accessible from public records.

Our efforts included a review of historical geologic reports and hydrogeologic technical studies conducted for the Cuyama Basin and surrounding region, a review of the unsuccessful *2016 Basin Boundary Modification Request*[3] and supporting documents, and compilation and review of historical climate information such as streamflow and precipitation records from the California Data Exchange Center ("CDEC"), land use information from the National Land Cover Dataset ("NLCD"), and water level information from DWR's California Statewide Groundwater Elevation Monitoring ("CASGEM") and Water Data Library online databases. A geodatabase was developed to store geospatial data extracted from the USGS Study and associated references and from other relevant sources used in this analysis, and a preliminary data management system ("DMS") was developed to help organize this information and to facilitate a future technical studies and/or management efforts planned by the District.

In addition, the CUVHM was obtained from the USGS Groundwater Model Archive website[4] and analyzed to assess model reproducibility, transparency, performance and reliability. The EKI team analyzed the model-calculated water levels and water budget components for consistency with the USGS Cuyama Basin HCM. Model-calculated water levels were compared to water level measurements in wells, and water budget components were broken down by USGS model "subregion" and compared to independent historical estimates of water availability in the Cuyama Basin as one means of assessing model performance. A sensitivity analysis was also conducted on select model parameters as a means of testing model response to changes in the HCM and associated model inputs.

The results of our analyses are discussed in detail in the following sections of this document.

CUYAMA BASIN OVERVIEW

The Cuyama Basin is located in the Coast Range Mountains of south-central California at the intersection of the counties of Kern, San Luis Obispo, Santa Barbara, and Ventura (see Figure 1). The basin is bounded on the north and south by the Caliente Range and Sierra Madre Mountains, respectively. The total basin area, as defined by DWR in its Bulletin 118, is approximately 378.3 square miles, and the total area of contributing watersheds is approximately 798 square miles. The Cuyama Basin includes two long, thin areas extending to the northwest which, based on inspection of topographic and geologic information, appear to have limited hydraulic connection to the rest of the basin. The 798-square mile area of contributing watershed does not include watersheds that cross these narrow northwest "fingers" of the basin because surface water runoff in those watersheds does not drain into the main basin floor area. The main surface water

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[3] http://sgma.water.ca.gov/basinmod/basinrequest/preview/31.
[4] https://ca.water.usgs.gov/sustainable-groundwater-management/california-groundwater-modeling.html. Accessed on April 18, 2017.

feature in the basin is the Cuyama River, which flows from the uplands in the southeast through most of the basin and out of the basin near its northwest edge. The Cuyama River is fed by streams emanating from the uplands on the north, east, southeast, and south sides. Numerous faults, some ancient and others more recently active, have been mapped within and along the edges of the basin. As discussed further below, some of these faults have been used by the USGS as a basis upon which to divide the Cuyama Basin into "zones" and further into hydrologic "subregions".

According to the DWR's CASGEM website[5], the total population within the basin in 2010 was 1,236. The main population centers are the towns of Cuyama and New Cuyama, with additional residences scattered throughout the basin. The Cuyama Basin Water District is located in the central portion of the Cuyama Basin (see Figure 2). Irrigated agricultural land use is focused in the central portion of the basin (i.e., largely coincident with the extent of the District; see Figure 3), but additional areas of irrigated agriculture exist or are under development in the western and far southeastern portions of the basin. These developments include the Grapevine Capital Fields (also known as the Harvard Ranch) immediately to the West of the Russell fault line, and the Lockwood Canyon irrigated fields near the southeastern tip of the basin.

Based on the land use statistics reported for 2010 in the Hanson et al., 2014 study, 35 percent ("%") of the portion of the Cuyama Basin included in the USGS Study Area[6] is developed agricultural land, almost 65% is covered by native vegetation, and less than 1% is urban land. The USGS Study reports that "carrots and grains represented over half of all crops grown in the Cuyama Valley in recent decades" (Hanson et al., 2014).

The USGS Study estimates long-term (i.e. 1950-2010) average total groundwater pumpage at approximately 65,400 acre-feet per year ("AFY") within the portion of the Cuyama Basin included in the Study Area. Of this, only 16 AFY and 90 AFY is attributed to domestic and water supply pumpage, respectively, and the remaining 65,300 AFY is attributed to agricultural pumpage. The Study reports an increase in total pumpage in the past decade (i.e., 2000-2010) to approximately 68,300 AFY, where 10 AFY and 190 AFY are attributed to domestic and water supply pumpage, respectively, and the remaining 68,100 AFY is attributed to agricultural pumpage (Hanson et al., 2014).

The Cuyama Community Service District's two production wells are explicitly accounted for in the USGS' estimation of municipal and industrial pumping. According to Hanson et al., 2014, these wells supplied "between 165 and 206 [AFY] for the period 1998 to 2007 (U.S. Wilson, Cuyama Community Service District [CCSD], written commun., 2008)." According to a recent presentation by a CCSD representative, water levels the CCSD's operating supply well have been stable over the last 25 years, with a drop since 2012 of about 30 feet (see Appendix D).

[5] http://www.water.ca.gov/groundwater/casgem/pdfs/PubRel_BasinRank_by_HR_5-18-15.xlsx
[6] The USGS Study Area generally covers the portion of the Cuyama Basin that is east of the Russell Fault; see further discussion below.

The Cuyama Basin has been designated by DWR as a medium-priority basin under the CASGEM Basin Prioritization system (see Appendix A - CASGEM Basin Summary), which means it is subject to all of the requirements of SGMA. The CASGEM ranking score and data indicate that the medium-priority ranking is largely due to the basin's heavy reliance on groundwater (both on a volume per area basis and as a percentage of total supply), and the fact that "Impacts" and "Other Information" have been noted. These impacts and other information include "local salinity and TDS [Total Dissolved Solids] impairments", "declining groundwater levels", and an "annual GW [groundwater] budget deficit of ~28,500 af" (acre-feet) (see Appendix A). The Cuyama Basin is further designated by DWR as being in a condition of critical overdraft[7]. These CASGEM priority and critical overdraft designations mean that, under SGMA, the Basin must be covered by a GSP by 31 January 2020.

OVERVIEW OF THE USGS STUDY AND PRIOR WORK

The Cuyama Valley, known for being one of the most productive agricultural regions in southern California, has been almost completely reliant on groundwater as its sole source of supply since the beginning of its agricultural development in the early 1940s[8]. Increases in population and further agricultural development of the Cuyama Valley, coupled with transitions in some cases to more water-intensive crops, have increased the demand for water within the Cuyama Basin, resulting in documented impacts to groundwater levels and water quality (Hanson et al., 2014). Multiple studies over the years have concluded that the Cuyama Basin has been subject to overdraft since the beginning of agricultural development in the region[9], with water-level declines exceeding 300 feet in some areas of the basin since the early-1940's (Pierotti and Lewy, 1998). Apart from the recent USGS work, several historical studies have estimated groundwater availability in the Cuyama Basin using various approaches at different periods in time (beginning in 1939), and all have arrived at the conclusion that net annual groundwater usage exceeds the

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[7] The Cuyama Basin is one of four California Bulletin-118 groundwater basins that are designated as both medium priority by CASGEM and also as being in a state of critical overdraft by DWR. The three other Bulletin-118 groundwater basins with this designation include the Indian Wells Valley Basin (6-054), the Borrego Springs Subbasin (7-024.01), and the Purisima Formation of the Santa Cruz Mid-County Basin (3-001).

[8] Until as late as 1965 there were spring-fed irrigation pastures and sub-irrigated pastures in the "Main" zone (zones discussed further below), springs on non-irrigated lands that have since gone dry, and there are some areas where springs and sub-irrigated pastures still exist (Cuyama Basin Water District Board member, personal communication, 30 August 2017).

[9] Historical studies of the Cuyama Basin include:

- Singer, J.A. and Swarzenski, W.V., 1970, *Pumpage and Ground-Water Storage Depletion in Cuyama Valley, California, 1947-66*, U.S. Geological Survey Open-File Report 70-304, prepared in cooperation with SBCWA Water Agency, 22 pp.
- Santa Barbara County Water Agency, 1977. *Adequacy of the Groundwater Basins of Santa Barbara County.*
- United States Department of Agriculture, 1988. *Cuyama Valley Irrigation Water Management & Ground Water Study.*
- Pierotti, B., Lewy, R. 1998. *Evaluation of Groundwater Overdraft in the Southern Central Coast Region. CA* DWR TIR SD-98-1.
- Anderson, C., Dobrowski, B., Harris, M., et al., 2009. *Conservation Assessment for the Cuyama Valley: Current Conditions and Planning Scenarios.* U.C. Santa Barbara, Donald Bren School of Environmental Science & Management, in partnership with The Nature Conservancy.

total annual volume of recharge entering the basin (see Table 1). These studies have calculated an annual overdraft on the order of 20,000 to 40,000 AFY for the Cuyama Basin.

Achieving sustainability in a groundwater basin requires a quantitative understanding of the availability and quality of groundwater resources and how the system responses to changes in groundwater supply (i.e., recharge) and demand. In cooperation with the Santa Barbara County Water Agency ("SBCWA"), and building on the previous studies conducted for the region, the USGS recently completed a multi-part study (i.e., the "USGS Study") to evaluate the historical use and current availability of groundwater resources in the Cuyama Basin. This work began in 2008 with the construction of three multi-well monitoring sites located throughout the Cuyama Basin (see Figure 4) and an examination of regional geologic and hydrogeologic conditions and changes in groundwater use, availability, and quality in the basin between 1950 and 2010 (Everett et al., 2013). The USGS then developed a Hydrogeologic Conceptual Model ("HCM") based on the results of these primary analyses, and further stratigraphic information from oil and gas wells was subsequently incorporated into a three-dimensional ("3-D") textural model of the Cuyama Basin developed from the HCM (Sweetkind et al., 2013a and 2013b).

The USGS developed the CUVHM to quantitatively represent the Cuyama Basin HCM. The CUVHM is an integrated surface-groundwater model consisting of two separate but linked models – the "Basin Characterization Model" ("BCM") and the CUVHM. The BCM is a regional scale precipitation-runoff model that calculates runoff from the watersheds[10] that surround the CUVHM, and uses the results to specify water inflows into the CUVHM. The BCM-calculated inflows are allocated between: (1) channel flows into the landscape of the CUVHM, (2) shallow base flow in the subsurface of the CUVHM, and (3) deep recharge to the mountain block or alluvial basin outside the CUVHM boundaries (i.e., excluded from the CUVHM water budget). The CUVHM incorporated subsurface hydrogeologic information from the 3-D textural model along with varying climate, land use, and water use data and employed the USGS's MODFLOW-OWHM (One-Water Hydrologic Flow Model) to calculate monthly water levels and groundwater flow. The CUVHM was calibrated to historical water and land use conditions and then used to assess the use and movement of groundwater throughout the valley and to quantify a water budget for the Cuyama Basin. Several future water use "scenarios" were modeled by the USGS to estimate future groundwater availability and sustainable use in the Cuyama Basin given historical and current conditions (Hanson et al., 2014).

SUMMARY OF FINDINGS

The EKI Team identified several key findings from our review of the USGS Study and associated materials that the District should consider as it begins to examine future applications of the USGS

[10] The USGS disaggregated the contributing watersheds into 144 sub-watersheds that were included in the BCM, including the "major and minor drainages from the surrounding mountains".

model and strategize potential approaches for achieving basin-wide SGMA compliance[11]. In summary, these findings include:

- The USGS Study did not encompass all of the DWR-defined Cuyama Basin and therefore, is insufficient on its own as a basis to fulfill applicable SGMA requirements;
- The USGS-defined subdivisions within the basin (the "Groundwater Basin Zones") will need to be evaluated more closely against available data to assess their validity as a potential basis for basin "management areas" under SGMA; and
- The CUVHM is limited in spatial scope, reported model results were not reproducible, and there is a need to verify model inputs and outputs to improve model transparency and quantify model uncertainty.

A detailed discussion of these findings is presented below.

The USGS Study Does Not Include all of the DWR-Defined Cuyama Basin

Under SGMA, the basin boundaries underpinning all groundwater management activities must be based on the basin boundaries "identified and defined [by DWR] in Bulletin 118" (23-CCR 351(f)). In developing those basin boundaries, the DWR relied primarily on the mapping of the areal extent of unconsolidated alluvial sediments as shown on the 1:250,000-scale Geologic Map of California, prepared/compiled by the California Division of Mines and Geology ("CDMG"). With reference to the Bakersfield and Los Angeles sheets of the CDMG Geologic Map of California, DWR includes within the Cuyama Basin the following geologic units: Qal (Recent Alluvium), Qc (Pleistocene nonmarine), Qp (Plio-Pleistocene nonmarine), Qt (Pleistocene nonmarine terrace deposits), and Pc (Undivided Pliocene nonmarine) (see Figure 5). The Pc unit includes the Morales Formation.

The USGS Study, however, focuses on what the USGS has separately delineated as the "Cuyama Groundwater Basin" which includes a portion, but not all, of the DWR-defined Cuyama Basin (see Figure 6). For the purposes of this memorandum, we refer to the area considered in the USGS Study as the "USGS Study Area". Furthermore, and as discussed further below, the USGS Study includes the BCM and CUVHM whose spatial domains are different from, and a further subset of, the USGS Study Area (see Figure 7). Herein we refer to those spatial domains as the "BCM Area" and the "CUVHM Area", respectively.

The USGS Study Area differs from the DWR-defined Cuyama Basin in the following ways, as illustrated on Figures 5 through 7. On the southeastern end, the USGS Study Area excludes some of the upper watershed areas underlain by Qc and Qp which are included within the DWR-defined Cuyama Basin. The USGS Study Area also excludes the upper portion of the Qal within Quatal Canyon, one of several major tributaries flowing into the Cuyama River from the east. On the northeastern side, the USGS Study Area excludes most of the portion of the DWR-defined

[11] The USGS Study predated the adoption of SGMA and thus was not developed with the intention of meeting requirements for SGMA compliance, but rather to provide a more general assessment of groundwater conditions and availability within the Cuyama Basin.

Cuyama Basin that lies within Kern County. Most significantly, on the northwestern side of the basin, the entire portion of the basin that lies to the west of the approximate surface trace of the Russell fault is excluded (see Figure 5). This area to the west is referred to herein as the "Cottonwood Creek" area[12]. In total, the USGS Study Area only includes approximately 61% of the DWR-defined Cuyama Basin.

As mentioned above, the CUVHM Area covers an even more limited extent of the Cuyama Basin than does the USGS Study Area (i.e., only 44%; see Figure 7). Specifically, the CUVHM Area does not include the southern portion of the "Southern Ventucopa Uplands" subregion as defined by the USGS Study Area (shown on Figure 6), and excludes the (likely) irrigated lands within Lockwood Canyon near the southwestern Cuyama Basin boundary. Additionally, the western boundary of the CUVHM Area does not trace the mapped trace of the Russell fault as it does in the USGS Study Area. Furthermore, the BCM Area used to derive precipitation-runoff relationships and estimate recharge to the Cuyama Basin only accounts for 41 of the 58 watersheds[13] contributing to basin recharge (see Figure 7).

Given its limited spatial extent, the BCM and CUVHM model domain is incapable of representing hydrologic conditions and processes within the entire DWR-defined Cuyama Basin. For example, in its current form, the model cannot be used to estimate or forecast impacts on groundwater conditions and availability stemming from agricultural developments or other projects occurring west of the Russell fault, including the recent Harvard Ranch development.

SGMA Implications

As mentioned above, SGMA regulations require that technical GSP elements, such as the "Basin Setting" and "Sustainable Management Criteria", be developed with respect to the groundwater basin boundaries and extent "identified and defined in Bulletin 118" (23-CCR 351(f)). Here the "Basin Setting refers to the information about the physical setting, characteristics, and current conditions of the basin as described by the [Groundwater Sustainability] Agency in the hydrogeologic conceptual model, the groundwater conditions, and the water budget, pursuant to Subarticle 2 of Article 5" (23-CCR 351(g)).

In total, the USGS Study Area (and associated HCM) only covers 61% of the Cuyama Basin area, and the CUVHM Area (and associated water budget) only covers 44% of the Cuyama Basin area. As such, the USGS Study is alone insufficient to rely on to inform the technical "Basin Setting" and "Sustainable Management Criteria" elements of the Cuyama Basin GSP under SGMA.

[12] In the *2016 Basin Boundary Modification Request*, this area was referred to as the "Chalk Mountain" area.

[13] The 58 watersheds that are depicted on Figure 7 as contributing to Cuyama Basin recharge are based on the National Hydrography Database (a slightly different hydrography data source than the one used in the USGS Study), and exclude several watersheds that cross over the far northwestern "fingers" of the Cuyama Basin, as streamflow in those watersheds is not likely to contribute to recharge of the main basin area.

USGS Study Area Subdivisions Need Further Evaluation Prior to Being Used as the Basis for Management Areas

In drafting a GSP, SGMA regulations permit GSAs to "define one or more management areas within a basin if the [Groundwater Sustainability] Agency has determined that creation of management areas will facilitate implementation of the [Groundwater Sustainability] Plan. Management areas may define different minimum thresholds and be operated to different measurable objectives than the basin at large, provided that undesirable results are defined consistently throughout the basin" (23-CCR §354.20(a)).

As shown on Figure 6, the USGS divided the USGS Study Area into three groundwater basin "zones" – the "Main zone", the "Sierra Madre Foothills", and the "Ventucopa Uplands" – and then further subdivides those three zones into nine "hydrologic subregions". The USGS states that the reasons for these subdivisions are that they: (a) "are fault bounded"; (b) "represent different proportions of the three alluvial aquifer systems"; (c) "have different water-quality characteristics"; and, (d) are defined "where the response to the use, movement, and consumption of water is similar in specific parts of the aquifers but differ from the response in the other subregions" (Hanson et al., 2014). The USGS further states that the Cuyama Valley can be considered a collection of "partially hydraulically connected" subbasins with "different hydrologic features or hydraulic properties" that "respond differently to natural and anthropogenic stresses."

Given the hydrogeologic complexity within the Basin, the District has expressed an interest in evaluating the use of management areas within the Basin for the purposes of SGMA compliance. The USGS-defined groundwater basin "zones" and/or "subregions" could potentially serve as the basis for creating management areas within the Cuyama Basin; however prior to defaulting to these delineations, it will be important to validate the underlying assumptions and technical evidence that was used as the basis for these subdivisions (and their lateral boundaries) and to assess the value of such an approach in achieving near-and long-term SGMA compliance.

Based on our review of the USGS Study and additional information (i.e., water level data from the Department of Water Resources Water Data Library), we conclude that while there are some notable differences in water level and water quality trends and behavior between different parts of the Cuyama Basin, these differences are not always consistent with the "zone" and "subregion" delineations presented in the USGS Study. This section discusses the lines of evidence that suggest the location of the current USGS subdivisions and/or their basis may need further refinement, especially in the context of SGMA and the consideration of management areas within the Cuyama Basin.

Land Use

Based on the inspection of land use information (see Figure 8a), it appears that the "zone" boundaries put forth by the USGS largely coincide with land use patterns. As shown on Figure 8a, the Main zone is dominated by irrigated crops, the Sierra Madre Foothills zone is dominated by grassland/herbaceous and shrub/scrub land cover, and the Ventucopa Uplands zone is dominated by shrub/scrub except for a strip of cultivated crops and pasture/hay along the Cuyama River. The Cottonwood Creek area, west and outside of the USGS Study Area, is dominated by grassland/herbaceous and shrub/scrub land cover. Given that cultivated crop land use in the Cuyama Basin is supported entirely by pumped groundwater, the predominance of irrigated crop land use in the Main zone likely correlates well with relatively greater groundwater extraction in this area, which may play a role in creating the observed patterns of groundwater movement and level decline, not just the presence or absence of hydrogeologic features or divisions as the USGS Study suggested.

Water Levels

Figure 8b shows water level hydrographs for five representative wells within the USGS Study Area, based on data from 1940 through 2010 as provided in the USGS Study (additional hydrograph data are included in Appendix B). While significant local variability exists within the Basin, the five hydrographs shown are generally representative of wells in their respective areas and exhibit trends that appear to be influenced by water use patterns and their spatial position within the Cuyama Basin, not just by the presence or absence of hydrogeologic features or divisions as the USGS Study suggested.

- In the far southern portion of the Ventucopa Uplands zone, water levels in well CUY-30 are relatively close to the surface (i.e., less than approximately 50 feet below ground surface [“ft bgs”]), relatively stable over the long term, and show fluctuations linked to climate patterns. For example, the hydrograph shows the effects of the late 1980s/early 1990s dry period and subsequent mid 1990s wet period. These patterns suggest the influence of the nearby Cuyama River and the relatively low level of groundwater pumping in the area.
- Further to the north, at well CUY-13, the water level fluctuation pattern is amplified but still relatively stable, indicating that water levels are sensitive to groundwater pumping and recharge, but that the two phenomena are generally in balance.
- In the Main zone, wells CUY-54 and CUY-60 both exhibit long-term downwards trends, indicative of groundwater withdrawal in excess of natural recharge. It should be noted that gaps in the record, filled in on these graphs with dashed lines, could obscure shorter term fluctuations.
- In the Sierra Madre Foothills, well CUY-24 exhibits a steady downward trend from the early 1980s to approximately 2010. As this well is not located directly in an area of irrigated agriculture, this decline may be associated with overdraft occurring in the areas in the Main zone to the north. This would suggest that the two areas are in hydraulic communication to some degree, notwithstanding the USGS subarea boundary and inferred influence of the Rehoboth fault (see Figure 5). Further work may be needed as part of the GSP development process to better understand the hydraulic effects of these and other faults within the basin and the nature of hydraulic connections and variability within and between different areas.

Faults

The USGS Study states that the hydrologic subregions that they defined "are fault bounded". However, inspection of the faults included in the Everett et al. (2013) report indicates that only two of the three groundwater zones and five of the nine hydrologic subregions are delineated by known or mapped faults (see Figure 8c). While the faults bounding the Cuyama Basin on the northern and southern sides of the valley (i.e., the Morales fault and the South Cuyama fault, respectively) are based on surface exposures and distinct rock types juxtaposed against each other across the faults, the internal faults beneath the Cuyama valley floor are generally not exposed at the surface, are concealed by alluvium, and their presence has reportedly been inferred primarily based on groundwater level differences.[14] Acknowledging the hydrogeologic complexity of the basin, the USGS Study states that evidence suggests that some of the inferred faults may not act as hydraulic barriers within the most important aquifer zones (i.e., the Younger and Older Alluvium).

The USGS Study states the following with respect to the Rehoboth (Farms) fault which they used as a basis to separate the Main zone from the Sierra Madre Foothills zone:

- "A qualitative analysis of the InSAR imagery with respect to nearby faulting production showed the Rehoboth Farms fault trend is not a significant barrier to groundwater flow because the majority of interferograms showed symmetrical subsidence or uplift on both sides of this fault. A qualitative analysis with respect to the local Russell Ranch oil field, which runs roughly parallel to the Russell fault, indicated that subsidence did not occur from hydrocarbon extraction and that the fault did not appear to be a contributing barrier to groundwater flow." (Everett et al., 2013)

The USGS Study is also inconsistent in how it discusses the Russell fault and how it incorporates the Russell fault in the CUVHM. The USGS Study makes the statements shown below with respect to how the Russell fault does not appear to act as a barrier to groundwater flow. However, the Russell fault is then used by the USGS as the basis to define the western edge of the USGS Study Area and is represented as a no-flow boundary in the CUVHM:

- "The last fault that is of concern in the study area is the Russell fault, which runs roughly parallel to the Russell Ranch oil field. Similar to the other faults, the Russell fault did not appear to be acting as a barrier to groundwater flow." (Everett et al., 2013)
- "Motion on the Russell fault is documented to have ended during Morales Formation time, and the fault does not affect younger units (Yeats and others, 1989; Ellis and others, 1993)." (Sweetkind et al., 2013)

In 2016, DWR denied the *2016 Basin Boundary Modification Request* that attempted to subdivide the Cuyama Basin along the Russell fault on the basis that "it was not demonstrated that the Russell Fault is a hydrogeologic barrier to groundwater flow adequate to subdivide the basin."[15]

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[14] As reported in the USGS Study, previous investigations (Ellis, 1994) have detected the Turkey Trap Ridge and Graveyard Faults using subsurface geophysical (i.e., seismic) techniques.
[15] http://water.ca.gov/groundwater/sgm/pdfs/Final_Basin_Boundary_Modifications.pdf

Further investigations of the conductivity and vertical extent of the Russell fault zone, as well as mapping of local groundwater gradients on both sides of the fault line will be needed to better quantify the degree to which the Russell Fault acts as hydrogeologic barrier to flow and to determine whether or not it is a suitable feature for delineating a potential management area and/or Subbasin boundary.

The inconsistent treatment of faults by the USGS in its report and in the CUVHM, coupled with the observed low sensitivity of the CUVHM results to specified fault conductance values (further discussed below), suggests that the subdivisions within the USGS Study may be a result of both hydrogeologic complexity and differences in land and water use patterns as mentioned previously. The degree to which the mapped or inferred faults act as hydraulic boundaries likely varies significantly throughout the Basin and is not well documented (given model insensitivity to fault parameterization, the lack of data, and the inconsistent statements about this phenomenon in the USGS Study). Land and water use patterns differ between certain areas, and may also contribute to the observed hydrologic (i.e., water level) differences.

On the other hand, some faults in the Cuyama Basin may have an unrecognized effect on groundwater flow. For example, large differences in well yields observed over a short distance in the narrow valley along the Cuyama River in the Ventucopa Uplands and in portions of the Sierra Madre Foothill zones[16] may be associated with nearby subsurface faulting as mapped in another USGS geologic map (Kellogg et al., 2008)[17].

Given the above, the apparent inconsistencies between how several of these faults are explained in the USGS Study and how they are actually parameterized in CUVHM demonstrates the need for further technical investigations and refinement of fault properties to verify assumptions about inferred hydrogeologic barriers to flow and to better understand the spatial variability in subsurface hydraulic connectivity throughout the Basin.

Groundwater Contours

An examination of historical and recent groundwater contours provided in the Hanson et al. (2014) report further calls into question the groundwater zone and hydrologic subregion boundaries based on water level responses to “the use, movement, and consumption of water.” An apparent groundwater-flow barrier or restriction, indicated by steep groundwater level contours, occurs in the area of the Santa Barbara Canyon Fault (“SCBF”) near the intersection of the three groundwater zones, suggesting that subsurface flows are at least partially restricted across the SCBF and between the Ventucopa Uplands zone and the Main zone (see Figure 8d). However, for some of other faults that were mapped as internal partial barriers to flow within the model domain and between subregions, the USGS Study does not present compelling groundwater level data in support of this fault parameterization.

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[16] Personal communication, members of the Cuyama Basin Water District Board.
[17] Kellogg, K.S., Minor, S.A., and Cossette, P.M., 2008, Geologic Map of the Eastern Three-Quarters of the Cuyama 30’ x 60’ Quadrangle, California: U.S. Geological Survey Scientific Investigations Map 3002, scale 1:100,000, 2 plates, 1 pamphlet, 23 p.

For example, groundwater level contours across the Rehoboth fault (used to delineate the Main zone from the Sierra Madre Foothills zone) indicate generally continuous water levels on either side of the fault with no offset or steep gradient (see Figure 8d). The same can be said for groundwater elevations near the Turkey Trap Ridge and Graveyard Ridge faults, which are used to separate the "Western Main" and "Caliente/Northern Main" subregions from the "Southern Main", though previous water level mapping showing water level offsets and evidence of springs in this area provides some support to this interpretation (Singer and Swarzenski, 1970).[18] Also, the apparent steep groundwater gradient in the northern and northeast Ventucopa Uplands subregions is uncertain due to a lack groundwater elevation data in these largely undeveloped regions (see Figure 4 for locations of wells with water level data). Unfortunately, the lack of water level data in this portion of the Cuyama Basin hinders the ability to characterize local groundwater gradients within these subregions. A similar lack of data is potentially obscuring a more refined understanding of the complex groundwater flow conditions in the Sierra Madre Foothills portion of the Basin[19].

<u>Groundwater Quality</u>

As part of its HCM development, the USGS collected groundwater quality samples from 39 wells throughout the USGS Study Area and analyzed these samples for as many as 53 water quality constituents, including field parameters (water temperature, specific conductance, pH, dissolved oxygen, and alkalinity), major and minor ions, trace metals and contaminants regulated by California State Water Resources Control Board Division of Drinking Water ("Water Board"), stable isotopes of hydrogen and oxygen, as well as tritium and carbon-14 activities (Everett et al.,2013). As summarized below, close examination of these water quality and stable isotope analyses reveals that the "different water quality characteristics" used to support delineation of zones and hydrologic subregions are not clear.

- **Piper Diagrams:** A commonly employed technique for characterizing the chemical quality of a water sample involves plotting the relative proportions of major ions on a Piper diagram. Piper diagrams show the relative abundance of major cations (Sodium, Potassium, Calcium, Magnesium) and anions (Bicarbonate, Carbonate, Sulfate, Chloride, Fluoride) commonly found in water on a charge equivalent basis, as a percentage of the total ion content of the water (Piper, 1944). These diagrams are commonly used to characterize the "water type" or ionic fingerprint of a sample (i.e., if two samples have "distinct" water types from one another they will plot in a different position on the Piper diagram).

  The EKI Team compiled all water quality data contained in the appendices of the Everett et al. (2013) report and plotted the major ions on a Piper diagram, color coding samples by their groundwater zone (see Figure 8e). Results of this exercise indicate that water types are not readily distinct between the different zones. Though significant variability

[18] An approximately 500-acre area to the north of the Turkey Trap Ridge and Graveyard Ridge faults was once irrigated by a spring (Cuyama Basin Water District Board member, personal communication, 30 August 2017).
[19] Personal communication, Cuyama Basin Water District Board member, 30 August 2017.

existed from sample to sample, especially in the Sierra Madre Foothills zone, almost all samples contained high proportions of calcium/magnesium and sulfate, and can thus be characterized as "calcium-magnesium sulfate waters." The USGS Study reaffirms this interpretation, describing how groundwater samples from all three of its dedicated monitoring sites and "the majority of the other groundwater samples" collected throughout the basin can be characterized as calcium-magnesium sulfate waters (Everett et al., 2013).

- **Age Dating:** Another commonly employed approach for characterizing groundwater quality involves analysis of tritium (^{3}He) and carbon-14 (^{14}C) concentrations to approximate the average age of a groundwater sample. Tritium is a short-lived radioactive isotope of hydrogen (half-life of approximately 12.5 years) commonly used to detect "modern" recharge that occurred since the early-1950's (Plummer and others, 1993), while carbon-14 is a slowly decaying radioactive isotope of carbon (half-life of approximately 5,700 years) that can provide estimates of groundwater age on time scales ranging from recent to greater than 40,000 years old (Godwin 1962).

  Analysis of the tritium and carbon-14 in Cuyama Basin groundwater samples indicates there is significant variability in groundwater ages throughout the basin. Carbon-14 analyses indicated that groundwater was generally very "old" throughout the basin, with estimated ages ranging from 600 years old up to 38,500 years old, and that groundwater ages typically increased with increasing well screen depth and distance from the Cuyama River (see Figure 8f). In general, younger waters were found in shallower wells located closer to the Cuyama River, while older waters were found in deeper wells located further away from the Cuyama River. For example, the groundwater samples with the youngest carbon-14 estimated age were collected from wells screened in the younger alluvium (Qya) located in the narrow Cuyama River valley within the Ventucopa Uplands zone (see Figure 8f), where the aquifers are likely shallower and generally more hydraulically connected to the Cuyama River than in the rest of the basin. By comparison, the oldest groundwater was collected from wells screening the Morales Formation (Qtm) within in the Sierra Madre Foothills zone and the southern portion of the Main zone (see Figure 8f). The Morales Formation is the deepest water-bearing unit within the Cuyama Basin and likely receives less direct recharge from the Cuyama River and/or precipitation than the overlying "younger alluvium" (Qya) and "older alluvium" (Qoa) formations, especially with increasing distance from the Cuyama River bed. However, tritium was detected at each of the three USGS monitoring sites and at 14 of the 20 other wells sampled throughout the basin, indicating that some modern groundwater (i.e., less than 70 years old) does exist in each of the three hydrologic zones and within each of the three water-bearing formations of the Cuyama Basin.

- **Stable Isotopes:** Stable isotopes of oxygen (^{18}O) and hydrogen (^{2}H) can be used to estimate the relative contributions of different sources of recharge to an aquifer system, as long as the isotopic compositions of the recharge sources are distinct and well-defined. The dominant natural recharge sources to the Cuyama Basin include: (1) direct precipitation and runoff from contributing watersheds adjacent to and within the basin proper, and (2) surface-water (and baseflow) inflows from the Cuyama River and its contributing watersheds further to the southeast. Recharge from the Cuyama River will generally have a "lighter" isotopic signature (i.e., more depleted in ^{2}H and ^{18}O) than direct precipitation, as the water in the river originates as high-elevation precipitation and snowmelt runoff from the Mount Pinos area, whereas direct precipitation and nearby-runoff will fall at comparably lower elevations and exhibit a "heavier" isotopic signature.

Plotting the stable isotopes of oxygen (^{18}O) and hydrogen (^{2}H) by zone shows very little distinction in stable isotope ratios between zones (see Figure 8g). There does appear to be a tendency for samples collected from the Ventucopa Uplands zone to plot on the "lighter" side of the stable isotope graph (i.e., bottom left), suggesting that this zone receives a greater proportion of recharge from the Cuyama River. This is consistent with the USGS conceptualization of the basin, where the southeastern portion of the basin is shallower and generally exhibits greater hydraulic connectivity to the Cuyama River. However, significant variability exists for samples collected from the Main and the Sierra Madre Foothills zones, indicating that there is no readily discernable trend or distinction in the proportions of recharge sources entering these hydrologic zones. Rather, the variability in stable isotopes within these zones suggests there are significant local complexities in contributing recharge patterns as opposed to general "subregional" or "subzonal" trends.

SGMA Implications

If the Cuyama GSA intends to establish specific management areas within the Cuyama Basin, the GSP Regulations require "an explanation of how the management area can operate under different minimum thresholds and measurable objectives without causing undesirable results outside the management area" (23-CCR §354.20(b)). Based on the evidence above, the USGS Study's definition of hydrologic "zones" and "subregions" is not entirely consistent with the information presented in the study, and the basis for the subdivisions will warrant further investigation and refinement. The data presented above indicates that significant variability exists in groundwater behavior and conditions throughout the Cuyama Basin.[20] However, the apparent distinctions in groundwater conditions between hydrologic zones and/or subregions appear to be not only a result of the hydrogeologic complexity, but also the apparent variability in anthropogenic stresses related to over 75 years of agricultural development and increased groundwater use in certain areas within the Cuyama Basin.

When considering the use of management areas in a future GSP for the Cuyama Basin, it will be important to further distinguish/refine our understandings of the hydrogeologic and anthropogenic drivers causing the apparent variability in groundwater conditions observed throughout the basin. This will further inform the degree of hydraulic connectivity between

[20] Complexity is illustrated by observations of a dry well, a dry spring, and a well in which water depths have been generally stable for decades, all in close proximity (Cuyama Basin Water District Board member, personal communication, 30 August 2017).

"subregions" or "zones" of the Cuyama Basin and will help GSP planners estimate the effects of a particular management action on local conditions, as well as the entire Cuyama Basin as is required by SGMA regulations.

Additionally, as GSPs are intended to deliver Basin-level solutions for sustainable groundwater management, it is important to consider how the use of local management areas will impact Basin-wide coordination and compliance. Though management areas are intended to better reflect local groundwater conditions and to improve local project planning and monitoring efforts, they also necessarily introduce greater complexity into the GSP design and development process. Should the District and Cuyama GSA decide to implement management areas in an upcoming GSP (which, given, the complexity and variability in groundwater and land use conditions, seems a distinct possibility), it will be important to evaluate the tradeoffs associated with actions or assignment of sustainability criteria within each proposed management area to determine the correct balance of local versus Basin-wide management approaches within the Cuyama Basin.

<u>The CUVHM Model and Simulated Water Budget Are Not Reproducible or Necessarily Accurate</u>

As above, the CUVHM was obtained from the USGS Groundwater Model Archive website and analyzed to assess model reproducibility, transparency, performance and reliability. The results of our analyses are discussed in detail below.

<u>The Several Hundred CUVHM Input Parameters Could not be Independently Verified</u>

The CUVHM includes "several hundred" input parameters that vary across the model domain and throughout the 1950-2010 simulation period. The data set potentially provides a digital archive of estimated historical land use, water use and geologic information that includes:

- Monthly rainfall and temperature, from which rainfall-runoff and plant water use is estimated;
- Land and water use information that varies spatially and with time, including a substantial number of parameters that characterize the landscape and surface water processes. For example, land use includes crop types, each of which is characterized by particular root depths, root uptake characteristics, monthly water stress and transpiration factors, etc. Land use types also include associated water application efficiencies, runoff characteristics, etc. Many of the values are from the literature, assumed, or determined by calibration;
- Spatially variable soil types and subsurface lithologic texture maps from which water transmission and storage properties are estimated; and
- Additional processes like subsidence, faulting, springs, channel networks, surface- and groundwater interactions, among others.

However, the model documentation does not describe quality assurance procedures undertaken to verify data set accuracy. The lack of verification, large number and variety of input parameters, and the complexity of land and water processes represented by MODFLOW-OWHM can obscure model dynamics and uncertainty.

Discrepancies Were Identified Between the USGS Study and the Archived Models

The EKI Team ran the CUVHM obtained from USGS Model Archive and compared the results to corresponding output also provided from the archive. The model-calculated and archived water levels agreed, however discrepancies exist between the water budgets. Additionally, neither set of outputs (ours or the archive) agreed with values reported in the model documentation.[21] For example:

- The USGS Study cites a 1,200-foot range in measured water levels, whereas the range in the archived measured water levels was almost 2,300 feet;
- The reported differences between measured and model-calculated water levels ranged from -198 to 371 feet, with a standard deviation of 52 feet, whereas the differences calculated using modeled and the archived water levels range from -288 to 439 feet, with a standard deviation of 65 feet; and
- Hydrographs of model-calculated water levels constructed with our and the archived model results do not agree with all the corresponding hydrographs in the report (see for example wells labeled 10N/26W-9H1, 9N/25W-2N1, and 9N26W-1F2-3 in Figure 26 of the report).

In regard to the water budgets, close inspection indicated that most of the discrepancy between budgets is attributed to "Farm Recharge." Farm Recharge is calculated by MODFLOW-OWHM and represents water that percolates past the plant roots and is intercepted by the underlying water table. The Farm Recharge in the archived version of the model that the EKI Team ran is 20% lower than the corresponding value provided from the archived output. These various discrepancies between water levels and budgets indicate that the CUVHM results reported in the USGS Study were not reproducible. When contacted, the USGS could not readily provide a rationale for the reproducibility issues encountered by the EKI Team and further determination of the exact underlying cause of the model's irreproducibility was determined to be beyond the scope of this current effort.

Modifications to Key Model Parameters Highlighted the Non-Uniqueness of the Model Results

The EKI Team tested the sensitivity of the CUVHM results and the water budget by increasing modeled fault conductivity by six to nine orders of magnitude[22]. Table 2c shows the percentage change in the magnitude of subregional water budget components between the "Base" model run (Figure 9a, Table 2a) and the "Increased Fault Conductance" model run (Figure 9b, Table 2b). As expected, increasing the fault conductance affected the subsurface flux rates between some of the subregions that share an affected fault boundary, notably across the Santa Barbara Canyon fault (i.e., where an 1875%, or 825 AFY increase was observed) and the Turkey Trap Ridge fault

[21] *Ibid.* [2]

[22] The modified fault conductivity values were all set equal to the Rehoboth Farm fault value, which had the largest conductivity value of all the faults represented in the CUVHM.

(i.e., where an 100%, or 597 AFY increase was observed). However, in some cases the flux remained surprisingly unchanged, even with an increased fault conductance. We also noted that certain other subregional water budget components that are driven by simulated groundwater levels (e.g., flux from "storage" and "Farm Recharge") were affected by the change in fault conductance values, suggesting that determination of these sub-regional water budgets through numerical modeling is in some cases non-intuitively driven by the uncertainty in boundary definitions.

Interestingly, increasing the fault conductance resulted in a modest improvement in the comparisons between measured and model-calculated water levels (i.e., the average residual decreased from 65 to 63 feet). This result suggests that the model solution presented in the USGS Study is "non-unique" (i.e., certain model parameters could be adjusted without significantly impacting, or potentially even benefiting, overall model performance). This further indicates that model calibration could be improved to more accurately align simulated and measured groundwater heads. The improved model performance in the "Increased Fault Conductance" run also further calls into question the USGS conceptualization and CUVHM parameterization of internal faults as "hydrogeological barriers to flow."

Significant Additional Issues of Concern

Further data review and model testing identified additional significant issues of concern.

- More than 80% of model-calculated recharge is BCM-calculated rainfall runoff from watersheds that surround and drain into the valley, but there is a fair degree of uncertainty in the modeled values. More than 60% of the total runoff occurs in only 14 drainages, and only seven of those drainages are gauged.
- The CUVHM calculates an average of almost 8,000 AFY of annual groundwater storage accretion in the Ventucopa Uplands Zone, but there is no data to confirm this finding and it may be anomalous. Little to no historical pumping occurred in the upland areas, and measured water levels have been generally stable in the long-term and show cyclical short-term fluctuations (see Figure 8b). As such, it is unclear how or where this additional 8,000 AFY of water has gone or would go.
- The CUVHM calculates approximately 650 AFY and 750 AFY of subsurface inflows to the Northeast Ventucopa Uplands from the Northern and Southern Ventucopa Uplands subregions, respectively (see Figures 9a and 9b), despite the fact that this area is higher in elevation and upgradient of the two adjacent Ventucopa Uplands subregions (see Figure 8d). There is no data to confirm this seemingly anomalous water budget output.
- Pumping is calculated internally by the CUVHM using a large number of land- and water-related parameters, of which many values are estimated, assumed or calibrated. The model calculates more than 65,000 AFY of average annual pumping, which is depleting groundwater storage in most modeled subregions. There is a need to verify estimated pumping and quantify its potential uncertainty.

- Additional comparisons indicate that the CUVHM generally underestimates measured water levels, and that simulated water level declines are greater (steeper) than measured in 23 out of 36 wells, mostly in wells located in the Southern Main subregion[23] (see Figure 10 and Appendix C). These over-estimated rates of decline in simulated versus measured groundwater elevations in the Southern Main subregion are likely caused by inaccuracies in model parameterization resulting in overestimates of pumping, underestimates of recharge, or the coupled effect of both compounded over the 60-year period of simulation.

The Model Results are Highly Variable at Smaller Temporal and Spatial Scales

Finally, it is important to note that considerable mass balance error exists within subregional water budgets of the CUVHM, and within individual simulation years of the Basin-wide model. For example, mass balance errors (i.e., the discrepancy between simulated inflows and outflows) exceeded 20% within the Northern and Northeast Ventucopa Uplands subregions for the "Base Model" over the 1950-2010 simulation period (see Figure 9a and Table 2a), though the Basin-wide long-term water budget had a mass balance error of only approximately 3.4%. Observations of the Basin-wide water budget for the 2008 simulation year (the year used for comparison in Table 1) indicate a mass-balance error of approximately 14.1%, further suggesting the model has limitations in estimating water budget components for individual simulation years.

When discussing model uncertainty and limitations, the USGS Study (Hanson et al., 2014) notes that "the conceptual and numerical models were developed on the basis of assumptions and simplifications that may restrict the use of the model to regional and subregional levels of spatial analysis within seasonal to interannual temporal scales… In particular, the distribution and change in land-use patterns needs to be improved to annual or even monthly scales to significantly increase accuracy of the simulation, [as] many of the stresses that are driven by these land uses varied throughout the simulation period at higher frequencies than the multi-year estimates of most of the historical land use." All of this suggests that the model has been developed and calibrated to perform on a Basin-wide level over extended (i.e., multiannual) periods of observation; thus, employing the model to observe changes in groundwater conditions at enhanced spatiotemporal scales (e.g., to analyze impacts in individual management areas) could prove problematic without further model refinement. The USGS Study (Hanson et al., 2014) provides "a summary of potential components that could improve the accuracy and reduce uncertainty of the simulation," including:

1) Improved temporal estimates of land use from annual to seasonal or monthly.
2) Improved estimation and application of crop and irrigation properties.

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[23] The model-calculated water level trends in the Southern Main subregion reflect declines in response to the almost 15,000 AFY average *simulated* depletion in groundwater storage, which is the net difference between simulated water inflow and outflow. For example, as shown by the model output depicted on Figure 9a and Table 2a, the model estimates that there is more than 24,000 AFY of inflow to the Southern Main subregion from the Sierra Madre Foothills and Ventucopa Uplands zones, with about 6,000 AFY of inflow from Farm Recharge and channel (stream) leakage. The model also calculates almost 46,000 AFY of outflows from the Southern Main subregion, most of which is model-calculated pumping (96%).

3) Improved segregation of natural vegetation into multiple classes in different parts of the valley.
4) Improved estimates of ungauged stream inflows and outflows through additional streamflow gaging (either used directly or to improve the calibration of BCM).
5) Refined location and extents of the trace of the Santa Barbara and Rehoboth Faults.
6) Improved estimates of hydraulic properties through additional field tests.
7) Improved texture estimates at depth and refined zonation of the Morales Formation.
8) Improved simulation of multi-aquifer wells to account for partial penetration and farm well pumping capacities and additional location of potential wells.
9) Improved groundwater, streamflow, land subsidence, and land cover observations for better model evaluation and calibration.

SGMA Implications

The purposes of modeling in the broader context of SGMA implementation include providing knowledge of the past and present behavior of the surface and groundwater system, the likely response to future changes and management actions, and the uncertainty in those responses over the 50-year planning and implementation horizon.[24] The model must at a minimum cover the entire basin, and it must be adaptable for improvement and refinement as more information becomes available and land and water use conditions change. In a basin where there are multiple GSAs (or a single multi-party GSA formed by joint agreement of eligible member agencies), it is critical that the model be transferrable between parties, that the input and output be transparent, that the results are reproducible, and that consensus is developed based on model performance and reliability. Further, in a situation where every acre-foot will make a difference in SGMA implementation, it will be very important to ensure model representativeness and accuracy to the greatest extent possible.

As mentioned previously, the CUVHM is an integrated surface- groundwater model consisting of two separate but linked models – the BCM and the CUVHM. The groundwater-flow portion of the CUVHM is available from the USGS, however the BCM is not. Review and limited testing of the CUVHM identified limitations with the model that in its present form prevent it from being a sufficient and adequate model to use in support of GSP development for the Cuyama Basin. At a minimum:

1. The CUVHM should be expanded to represent the area and hydrology of the entire DWR-defined Cuyama Basin;
2. The CUVHM input and output should be organized to accommodate review, verification, and extension as new information becomes available;
3. It appears that the CUVHM reliability and performance could be increased with improvements to the HCM (for example, by developing a more quantitative understanding of the influence of faults on groundwater flow), verification of model

[24] California Department of Water Resources Sustainability Program, "Best Management Practices for the Sustainable Management of Groundwater – Modeling BMP," December 2016.

results (for example, employing measured water levels, hydraulic gradients, and transmissivity to confirm model-calculated groundwater flow between subregions), and expanded data collection (for example, measuring rainfall runoff for key sub-watersheds to verify simulated inflows, collecting more refined (i.e. seasonal) land-use data, and expanding groundwater level monitoring in upland areas to confirm simulated long-term storage trends); and

4. A critical step will be to compare CUVHM -calculated pumping to measured values or other independent estimates to validate results and quantify uncertainty.

OVERALL SGMA IMPLICATIONS AND NEXT STEPS

Our review of the USGS Study has highlighted certain inconsistencies and deficiencies in the HCM, numerical model, and water budget components, suggesting that the USGS Study alone cannot be used as the sole basis for GSP development for the Cuyama Basin. That being said, the USGS Study and multiple independent studies conducted over several decades have arrived at the same conclusion – that groundwater use is exceeding natural recharge and the Cuyama Basin is operating in deficit (see Table 1).

Under SGMA, in order to address and mitigate any undesirable results related to overdraft conditions occurring in the Cuyama Basin, the Cuyama GSA will need to develop relevant sustainability criteria for the Basin, upon which appropriate management actions and monitoring objectives can be based. To prepare for this effort, the EKI Team has identified several "next steps" focused on resolving existing data/information gaps, as outlined below. These "next steps" include:

- Provide strategic, as-needed technical support to the District for all activities and work efforts involving the Cuyama GSA, including peer review of relevant proposal, work plans, studies, and reports; Proposition 1 grant application; preparation for and attendance at meetings; personal communications, etc.;
- Expand the HCM, water budget and potentially the model to include the portions of the Cuyama Basin that were NOT included in the USGS Study (namely the Cottonwood Creek area west of the Russell fault);
- Conduct/review a detailed land use survey or alternative method (e.g., Irrigation Training and Research Center ["ITRC"] data) within the District to refine estimates of agricultural groundwater usage and crop consumption, both spatially and over time which can be compared to previous CUVHM results and estimates to quantify uncertainty;
- Refine the USGS water budget and model with improved estimates of land use, crop consumption, and contributing recharge (i.e., including input from all watersheds contributing to the Cuyama Basin);
- Further characterize the degree of hydraulic connectivity across fault lines and between basin zones and subregions by:

  - Developing updated groundwater elevation contour maps that clearly reflect data uncertainty, including blank areas where data are not available or where projecting contours is not warranted;
  - Conducting a landowner survey to collect local observations and/or information regarding local hydrologic conditions, spatial trends in well yields, groundwater availability and quality, etc.;
  - Employing available aquifer test results and hydraulic gradients estimated from contour maps to independently estimate groundwater flow between subregions and across inferred hydrogeologic barriers to flow (i.e., faults); and
  - Conducting tracer studies, further isotope analyses, and/or other field methods;
- Developing (or refining the existing) groundwater monitoring network; and
- Considering and identifying a scope for an economic analysis of potential water management actions that may address undesirable results of groundwater overdraft.

Tables

Figures

Appendices

TABLE 1
COMPARISON OF HISTORICAL WATER BUDGET ESTIMATES FOR CUYAMA VALLEY, CA

Cuyama Basin Water District
Cuyama, CA

Study	Method	Time Period	Annual Net Recharge (a)	Annual Net Usage (b)	Deficit / Surplus (c)	Corresponding USGS - CUVHM Deficit / Surplus (d)
Singer & Swarzenski, 1970	Mass Balance	1939-1946	16,000 AFY	18,000 AFY	-2,000 AFY	N/A
Singer & Swarzenski, 1970	Mass Balance	1947-1966	12,000 AFY	33,000 AFY	-21,000 AFY	-32,851 AFY (e)
SBCWA, 1977	Mass Balance	1966-1975	13,000 AFY	51,000 AFY	-38,000 AFY	-24,099 AFY
USDA,1988	Safe Yield	1975-1986	26,500 AFY	56,800 AFY	-30,300 AFY	-39,596 AFY
DWR, 1998	Specific Yield	1982-1993	N/A	N/A	-14,600 AFY	-44,098 AFY
TNC, 2008	Mass Balance	2008	11,500 AFY	42,000 AFY	-30,500 AFY	-9,301 AFY
USGS, 2014 (CUVHM)	Numerical Model	2000-2010	N/A (f)	N/A (f)	-33,912 AFY	
USGS, 2014 (CUVHM)	Numerical Model	1950-2010	N/A (f)	N/A (f)	-34,166 AFY	

Abbreviations
AFY = acre-feet per year
CUVHM = Cuyama Valley Hydrologic Model
DWR = California Department of Water Resources
ET = Evapotranspiration
M&I = Municipal and Industrial
N/A = Not Applicable
SBCWA = Santa Barbara County Water Agency
TNC = The Nature Conservancy
USDA = United States Department of Agriculture
USGS = United States Geological Survey

Notes

(a) Annual Net Recharge = *Inflows* (direct precipitation + surface inflow + subsurface inflow) - *Outflows* (surface outflow + subsurface outflow).

(b) Annual Net Usage = *Net Pumpage* (total agricultural + M&I pumpage - return flows) + *Surface Diversions* + *Phreatophyte Usage* (natural ET).

(c) Deficit/Surplus = *Annual Net Recharge - Annual Net Usage.*

(d) Corresponding USGS-CUVHM deficit/surplus is the model-calculated reduction (or accretion) in storage for the time period included in the comparative historical study (e.g. the SBCWA, 1977 study reports an annual deficit of 38,000 AFY for the time period of 1966-1975, whereas the USGS-CUVHM simulates an average annual reduction of storage of 24,099 AFY through the same time period of 1966-1975).

(e) USGS-CUVHM simulation period begins in Water Year 1950.

(f) Analogous values for net recharge and net usage cannot be readily extracted from USGS-CUVHM output data due to the complex methodology employed by the model in deriving water budget estimates.

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TABLE 2a
SUBREGION WATER BUDGET COMPONENTS FROM THE "BASE" MODEL RUN

Cuyama Basin Water District
Cuyama, CA

	Subregion / Water Budget Component	Northeast Ventucopa Uplands	Southern Ventucopa Uplands	Northern Ventucopa Uplands	Southern Sierra Madre Foothills	Central Sierra Madre Foothills	Northwestern Sierra Madre Foothills	Southern Main	Caliente/ Northern Main	Western Main	All Subregions
Water Budget Components Internal to Subregion	Storage	-4,826	511	-3,450	412	14,494	2,825	14,728	8,269	1,371	34,334
	Drains	0	0	0	0	0	-618	0	-4	-383	-1,005
	GHB	13	2	0	0	0	0	2	0	-3,722	-3,705
	Stream	2,544	7,734	2,858	5,297	1,561	1,218	1,721	153	4,375	27,461
	Wells	0	-5	0	0	-3	-1	-4	-1	-1	-15
	MNW	0	-648	0	0	-17	-64	-15,729	-2,997	0	-19,455
	Farm Wells	0	-4,680	0	-12	-1,034	-1,972	-28,270	-7,755	-2,187	-45,910
	IB Storage	-1	-4	-3	-2	34	11	270	83	10	398
	Farm Rech	79	259	437	95	524	-1,216	4,442	1,249	-314	5,555
Fluxes Between Subregions	From Northeast Ventucopa Uplands	--	-750	-652	0	0	0	0	0	0	
	From Southern Ventucopa Uplands	750	--	1,766	-5,883	126	0	6,682	0	0	
	From Northern Ventucopa Uplands	652	-1,766	--	0	0	0	2,024	0	0	
	From Southern Sierra Madre Foothills	0	5,883	0	--	44	0	0	0	0	
	From Central Sierra Madre Foothills	0	-126	0	-44	--	444	15,331	0	0	
	From Northwestern Sierra Madre Foothills	0	0	0	0	-444	--	633	0	0	
	From Southern Main	0	-6,682	-2,024	0	-15,331	-633	--	1,828	0	
	From Caliente/Northern Main	0	0	0	0	0	0	-1,828	--	840	
	From Western Main	0	0	0	0	0	0	0	-840	--	
	Sum of Inflows (positive terms)	4,038	14,389	5,061	5,804	16,783	4,498	45,833	11,582	6,596	67,748
	Sum of Outflows (negative terms)	4,827	14,661	6,129	5,941	16,829	4,504	45,831	11,597	6,607	70,090
	Mass Balance Error (Inflows - Outflows)	-789	-272	-1,068	-137	-46	-6	2	-15	-11	-2,342

Abbreviations:

GHB = general head boundary
MNW = multi-node well
IB = interbed
Rech = recharge

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TABLE 2b
SUBREGION WATER BUDGET COMPONENTS FROM THE "INCREASED FAULT CONDUCTANCE" MODEL RUN

Cuyama Basin Water District
Cuyama, CA

	Water Budget Component \ Subregion	Northeast Ventucopa Uplands	Southern Ventucopa Uplands	Northern Ventucopa Uplands	Southern Sierra Madre Foothills	Central Sierra Madre Foothills	Northwestern Sierra Madre Foothills	Southern Main	Caliente/ Northern Main	Western Main	All Subregions
Water Budget Components Internal to Subregion	Storage	-4,825	699	-3,520	849	14,350	3,064	14,338	8,161	1,198	34,314
	Drains	0	0	0	0	0	-566	0	-4	-482	-1,052
	GHB	13	2	0	0	0	0	0	0	-3,817	-3,802
	Stream	2,544	7,748	2,858	5,393	1,518	1,307	1,729	151	4,223	27,471
	Wells	0	-5	0	0	-3	-1	-4	-1	-1	-15
	MNW	0	-648	0	0	-17	-64	-15,721	-2,982	0	-19,432
	Farm Wells	0	-4,676	0	-12	-1,034	-1,980	-28,273	-7,758	-2,208	-45,941
	IB Storage	-1	-4	-4	-1	34	13	258	76	7	378
	Farm Rech	79	260	438	103	539	-1,015	4,443	1,241	-386	5,702
Fluxes Between Subregions	From Northeast Ventucopa Uplands	--	-750	-652	0	0	0	0	0	0	
	From Southern Ventucopa Uplands	750	--	1,753	-5,604	68	0	6,682	0	0	
	From Northern Ventucopa Uplands	652	-1,753	--	0	0	0	1,941	0	0	
	From Southern Sierra Madre Foothills	0	5,604	0	--	869	0	0	0	0	
	From Central Sierra Madre Foothills	0	-68	0	-869	--	447	15,921	0	0	
	From Northwestern Sierra Madre Foothills	0	0	0	0	-447	--	615	0	597	
	From Southern Main	0	-6,682	-1,941	0	-15,921	-615	--	1,890	0	
	From Caliente/Northern Main	0	0	0	0	0	0	-1,890	--	791	
	From Western Main	0	0	0	0	0	-597	0	-791	--	
	Sum of Inflows (positive terms)	4,038	14,313	5,049	6,345	17,378	4,831	45,927	11,519	6,816	67,865
	Sum of Outflows (negative terms)	4,826	14,586	6,117	6,486	17,422	4,838	45,888	11,536	6,894	70,242
	Mass Balance Error (Inflows - Outflows)	-788	-273	-1,068	-141	-44	-7	39	-17	-78	-2,377

Abbreviations:

GHB = general head boundary
MNW = multi-node well
IB = interbed
Rech = recharge

TABLE 2c

COMPARISON OF SIMULATED WATER BUDGET COMPONENTS FROM THE "BASE" MODEL RUN TO THE "INCREASED FAULT CONDUCTANCE" MODEL RUN

Cuyama Basin Water District
Cuyama, CA

	Water Budget Component \ Subregion	Northeast Ventucopa Uplands	Southern Ventucopa Uplands	Northern Ventucopa Uplands	Southern Sierra Madre Foothills	Central Sierra Madre Foothills	Northwestern Sierra Madre Foothills	Southern Main	Caliente/ Northern Main	Western Main
Water Budget Components Internal to Subregion	Storage	0%	**37%**	2%	**106%**	-1%	8%	-3%	-1%	**-13%**
	Drains	both zero	both zero	both zero	both zero	both zero	-8%	both zero	no change	**26%**
	GHB	no change	no change	both zero	both zero	both zero	both zero	-100%	both zero	3%
	Stream	no change	0%	no change	2%	-3%	7%	0%	-1%	-3%
	Wells	both zero	no change	both zero	both zero	no change	no change	no change	no change	no change
	MNW	both zero	no change	both zero	both zero	no change	no change	0%	-1%	both zero
	Farm Wells	both zero	0%	both zero	no change	no change	0%	0%	0%	1%
	IB Storage	no change	no change	33%	-50%	-6%	18%	-4%	-8%	-30%
	Farm Rech	no change	0%	0%	8%	3%	**-17%**	0%	-1%	**23%**
Fluxes Between Subregions	From Northeast Ventucopa Uplands	--	no change	no change	both zero	both zero	both zero	both zero	both zero	both zero
	From Southern Ventucopa Uplands	no change	--	-1%	-5%	**-46%**	both zero	no change	both zero	both zero
	From Northern Ventucopa Uplands	no change	-1%	--	both zero	both zero	both zero	-4%	both zero	both zero
	From Southern Sierra Madre Foothills	both zero	-5%	both zero	--	**1875%**	both zero	both zero	both zero	both zero
	From Central Sierra Madre Foothills	both zero	**-46%**	both zero	**1875%**	--	1%	4%	both zero	both zero
	From Northwestern Sierra Madre Foothills	both zero	both zero	both zero	both zero	1%	--	-3%	both zero	**100%**
	From Southern Main	both zero	no change	-4%	both zero	4%	-3%	--	3%	both zero
	From Caliente/Northern Main	both zero	both zero	both zero	both zero	both zero	both zero	3%	--	-6%
	From Western Main	both zero	both zero	both zero	both zero	both zero	**100%**	both zero	-6%	--

Abbreviations:

GHB = general head boundary
MNW = multi-node well
IB = interbed
Rech = recharge

Notes:

(1) Values shown are the percentage change in the water budget component from the Base model run (Run 1) to the Increased Fault Conductance model run (Run 2).
(2) Bold-highlighted values are water budget components with a change between model runs of at least 10% and a magnitude in either Run 1 or Run 2 of at least 100 acre-feet per year.
These are considered the most significant changes between the two model runs.

Path: X:\B70069\Maps\2017\10\Fig1_BasinLocation.mxd

Legend
- Cuyama Valley Groundwater Basin (DWR 3-013)
- County Lines

Abbreviations
DWR = Department of Water Resources

Notes
1. All locations are approximate.

Sources
1. Basemap is ESRI's ArcGIS Online world topographic map, obtained 27 October 2017.

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0 5 10
(Scale in Miles)

Cuyama Valley Groundwater Basin Location

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Cuyama Basin Water District
Cuyama, California
October 2017
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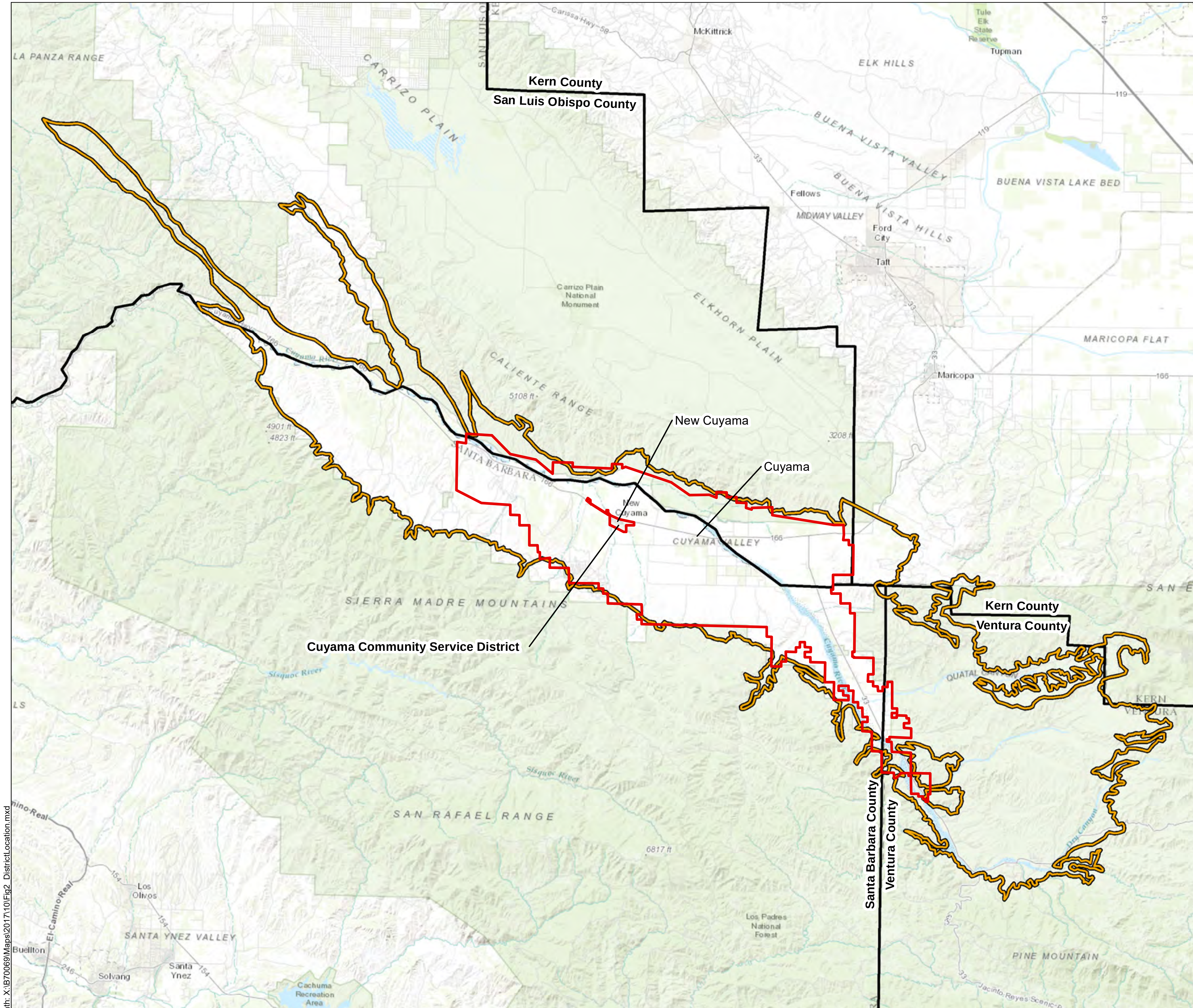
Figure 1



Legend

- Cuyama Basin Water District
- Cuyama Valley Groundwater Basin (DWR 3-013)
- County Lines

Abbreviations

CBWD = Cuyama Basin Water District
DWR = Department of Water Resources
GSA = Groundwater Sustainability Agency

Notes

1. All locations are approximate.
2. The Cuyama Basin GSA includes the following entities:
   - Cuyama Basin Water District (CBWD)
   - Cuyama Community Service District
   - Kern County
   - San Luis Obispo County
   - Santa Barbara County Water Agency
   - Ventura County

Sources

1. Basemap is ESRI's ArcGIS Online world topographic map, obtained 27 October 2017.

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(Scale in Miles)

CBWD Boundary and other Cuyama GSA Entities

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Cuyama, California
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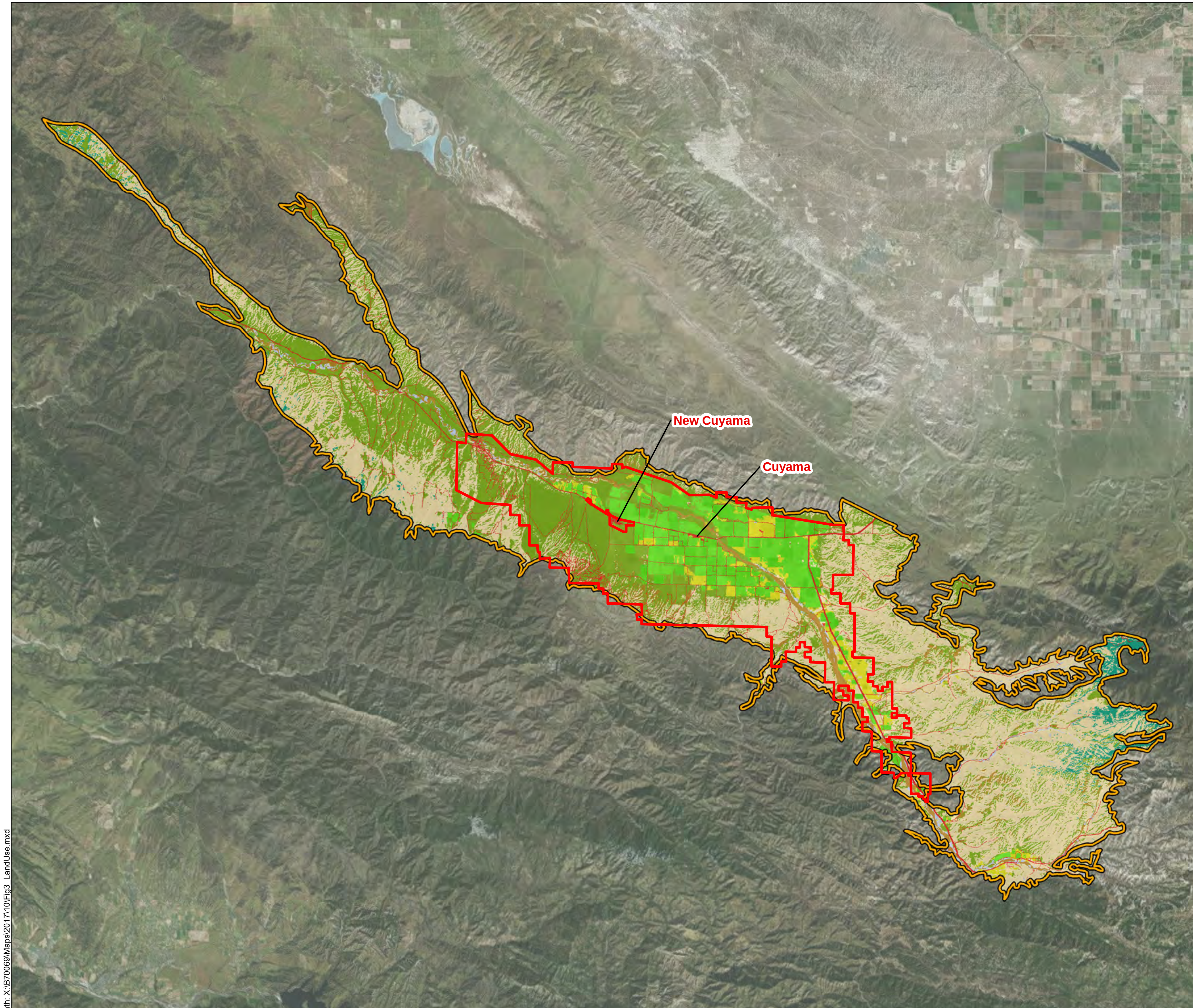
Figure 2

Path: X:\B70069\Maps\2017\10\Fig2_DistrictLocation.mxd



Legend

Cuyama Basin Water District

Cuyama Valley Groundwater Basin (DWR 3-013)

2011 NLCD Land Use Designation

Wetlands

Cultivated Crops

Pasture / Hay

Grassland / Herbaceous

Shrub / Scrub

Mixed Forest

Barren Land

Developed Lands

Abbreviations

DWR = Department of Water Resources
NLCD = National Land Cover Database
USGS = United States Geological Survey

Notes

1. All locations are approximate.

Sources

1. Land cover data obtained from NLCD, published 2014. https://www.mrlc.gov/nlcd2011.php
2. Basemap is ESRI's ArcGIS Online world topographic map, obtained 27 October 2017.

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(Scale in Miles)

Land Use

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Cuyama Basin Water District
Cuyama, California
October 2017
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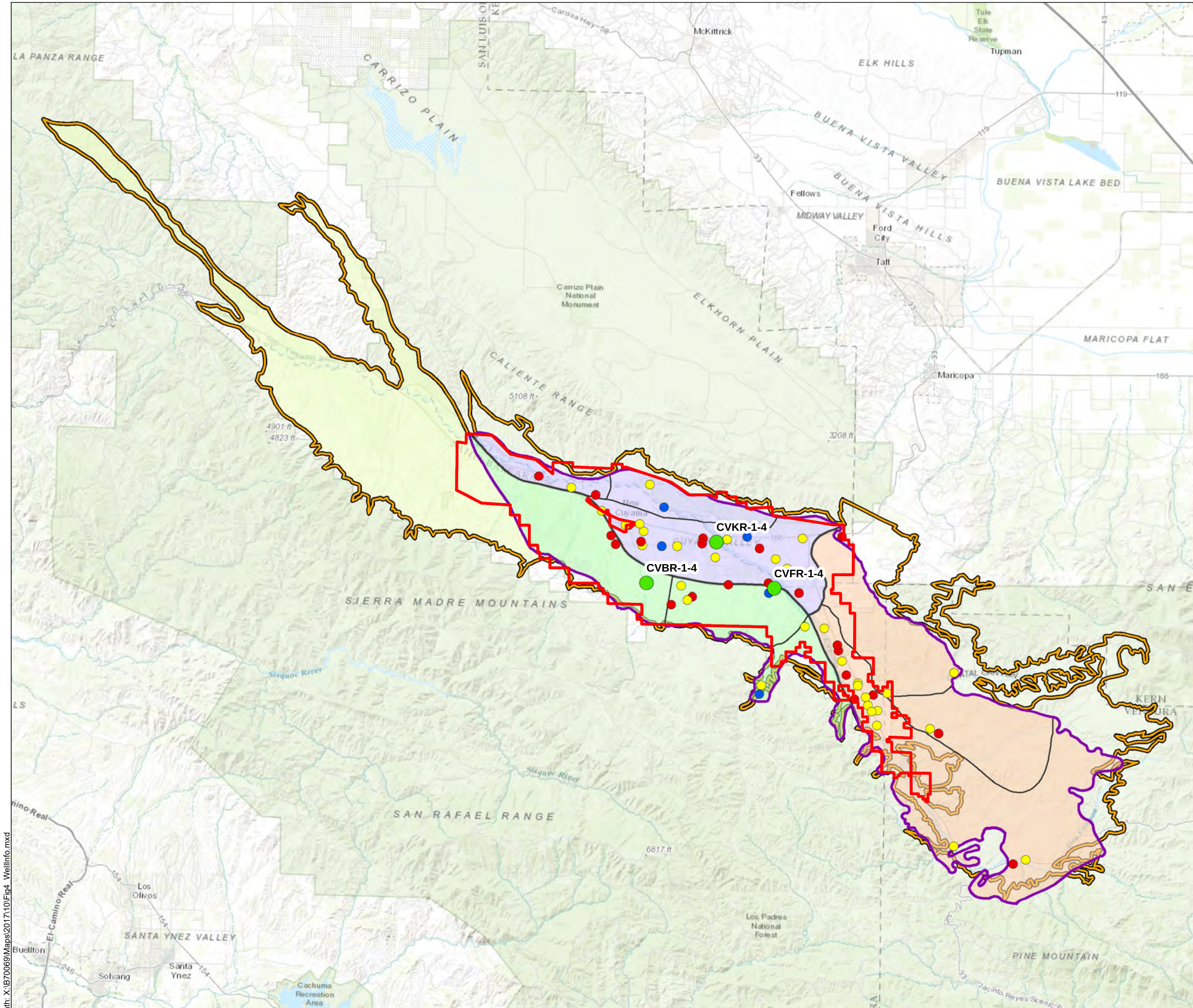
Figure 3



Legend

- Cuyama Basin Water District
- Cuyama Valley Groundwater Basin (DWR 3-013)
- USGS Study Area Boundary
- "Cottonwood Creek" Zone

USGS Study Area Zone

- Main
- Sierra Madre Foothills
- Ventucopa Uplands
- USGS Zone Subregion Boundary

Wells in USGS Study by Data Availability

- Water Quality Only
- Water Level Only
- Water Level & Water Quality
- Water Level, Water Quality, Aquifer Test

Abbreviations

DWR = Department of Water Resources
USGS = United States Geological Survey

Notes

1. All locations are approximate.
2. Well data availability extracted from USGS study tabular data (see Source 1).
3. Large circles mark dedicated monitoring wells developed as part of the USGS Study (see Source 1).

Sources

1. Everett, R.R., Gibbs, D.R., Hanson, R.T., Sweetkind, D.S., Brandt, J.T., Falk, S.E. and Harich, C.R., 2013, Geology, water-quality, hydrology, and geomechanics of the Cuyama Valley groundwater basin, California, 2008–12. USGS SIR 2013–5108.
2. Basemap is ESRI's ArcGIS Online world topographic map, obtained 27 October 2017.

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(Scale in Miles)

Wells in USGS Study

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Cuyama, California
October 2017
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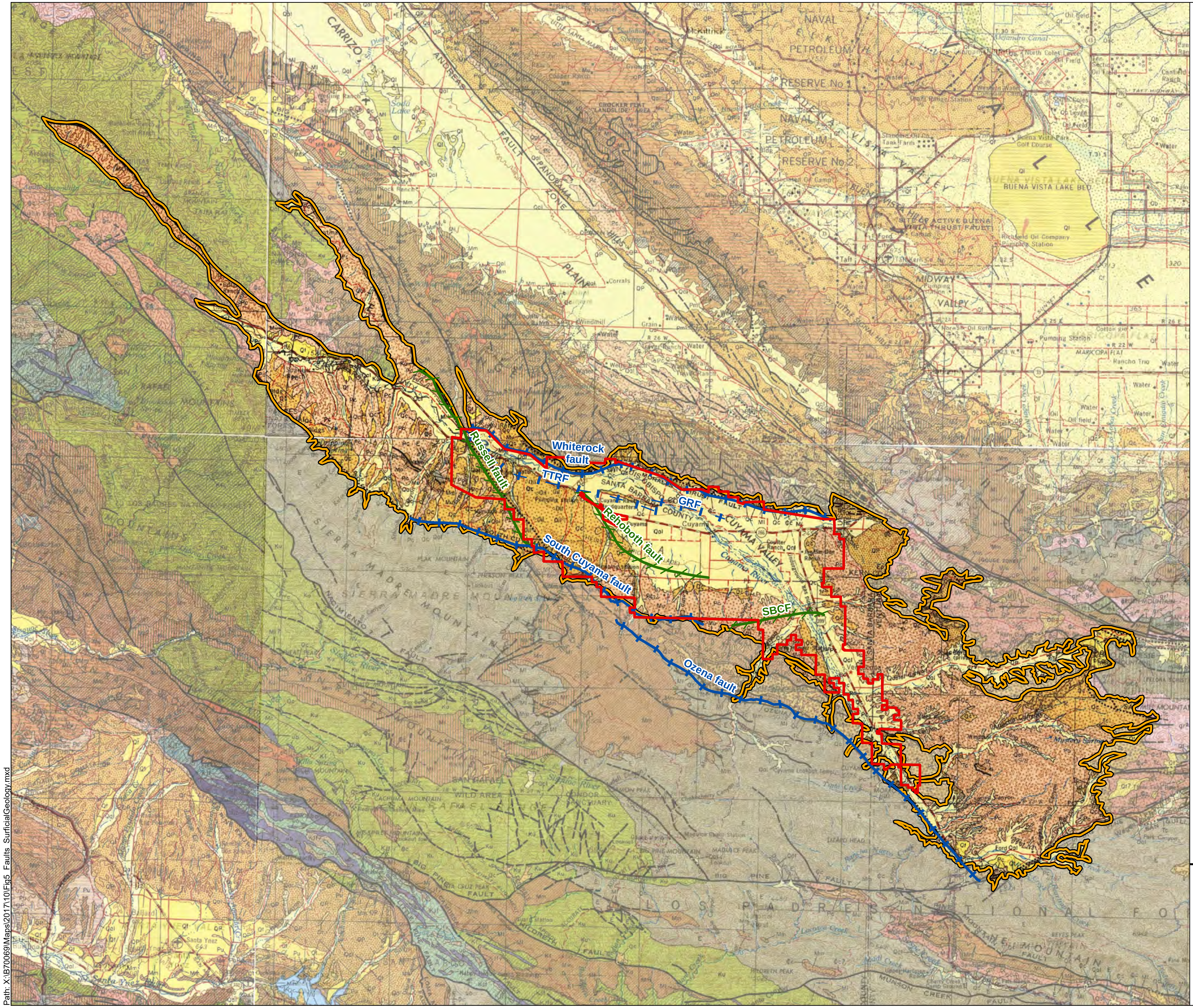
Figure 4



Legend

- Cuyama Basin Water District
- Cuyama Valley Groundwater Basin (DWR 3-013)

Faults in USGS Study

- Normal fault
- Thrust fault
- Thrust fault, concealed

Geologic Units

- Recent alluvium
- Pleistocene nonmarine
- Plio-Pleistocene nonmarine
- Pleistocene nonmarine terrace deposits
- Undivided Pliocene nonmarine
- Upper Miocene marine
- Middle Miocene Marine
- Lower Miocene Marine
- Oligocene nonmarine
- Eocene marine
- Paleocene marine
- Tertiary nonmarine
- Upper Cretaceous marine
- Pre-Cretaceous metamorphic rocks
- Pre-Cretaceous metasedimentary rocks
- Mesozoic granitic rocks

Abbreviations

DWR = Department of Water Resources
GRF = Graveyard Ridge Fault
SBCF = Santa Barbara Canyon Fault
TTRF = Turkey Trap Ridge Fault
USGS = United States Geological Survey

Notes

1. All locations are approximate.

Sources

1. Surface geology from California Division of Mines and Geology, Geologic Map of California, Olaf P. Jenkins Edition, San Luis Obispo, Santa Maria, Bakersfield, Los Angeles Sheets (1969).
2. Basemap is ESRI's ArcGIS Online world topographic map, obtained 27 October 2017.

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(Scale in Miles)

Faults and Surficial Geology

Cuyama Basin Water District
Cuyama, California
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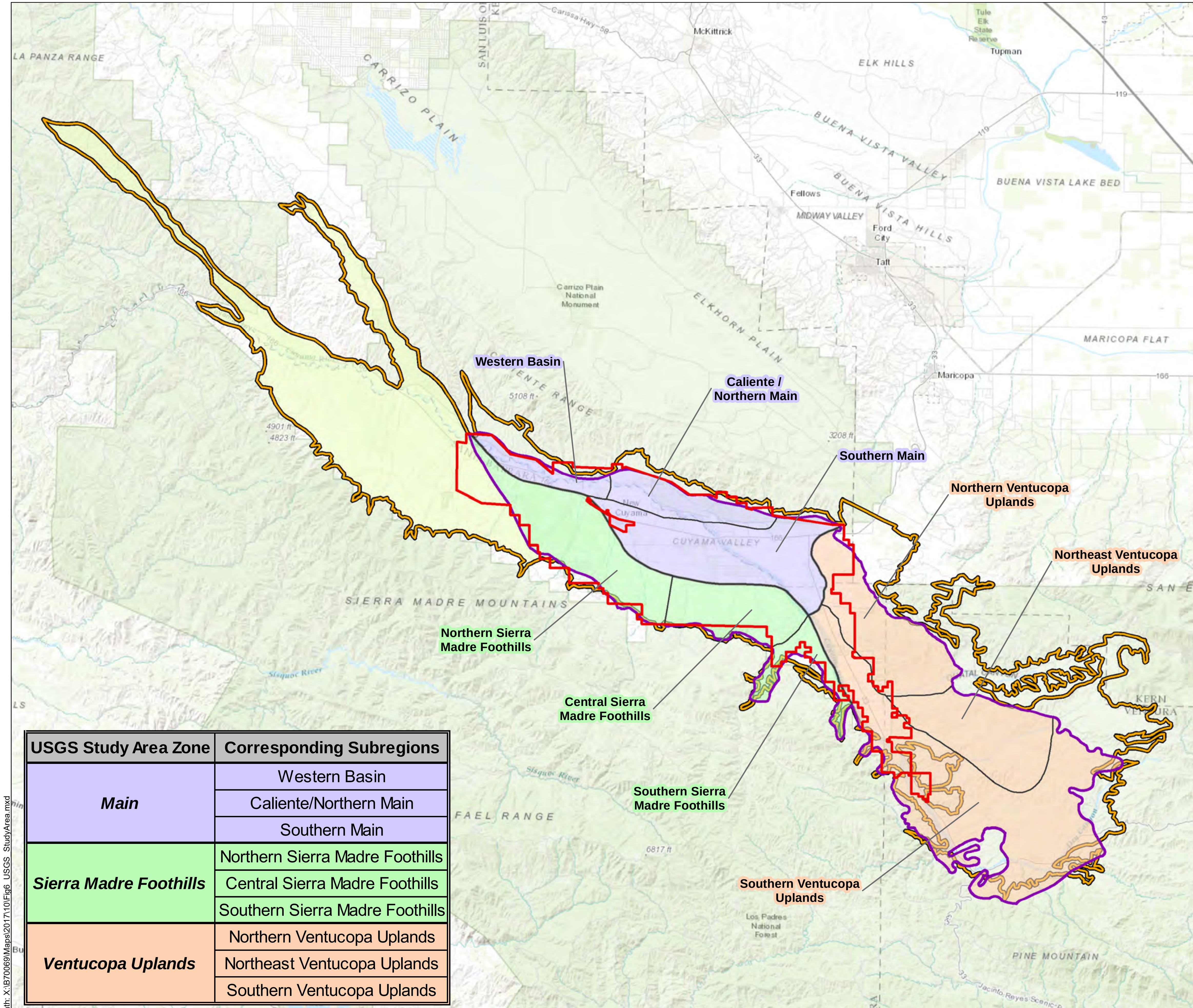
Figure 5

Path: X:\B70069\Maps\2017\10\Fig5_Faults_SurficialGeology.mxd



USGS Study Area Zone	Corresponding Subregions
Main	Western Basin
	Caliente/Northern Main
	Southern Main
Sierra Madre Foothills	Northern Sierra Madre Foothills
	Central Sierra Madre Foothills
	Southern Sierra Madre Foothills
Ventucopa Uplands	Northern Ventucopa Uplands
	Northeast Ventucopa Uplands
	Southern Ventucopa Uplands

Legend

- Cuyama Basin Water District
- Cuyama Valley Groundwater Basin (DWR 3-013)
- USGS Study Area Boundary
- "Cottonwood Creek" Zone

USGS Study Area Zones

- Main
- Sierra Madre Foothills
- Ventucopa Uplands
- USGS Zone Subregion Boundary

Abbreviations

DWR = Department of Water Resources
USGS = United States Geological Survey

Notes

1. All locations are approximate.
2. Colored labels correspond to subregions of a particular USGS Study Area Zone.

Sources

1. Hanson, R.T., Flint, L.E., Faunt, C.C., Gibbs, D., and Schmid, Wolfgang, 2014. Hydrologic models and analysis of water availability in Cuyama Valley, California. USGS SIR 2014-5150.
2. Basemap is ESRI's ArcGIS Online world topographic map, obtained 27 October 2017.

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0 5 10
(Scale in Miles)

USGS Study Area Zones and Subregions

Cuyama Basin Water District
Cuyama, California
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Figure 6

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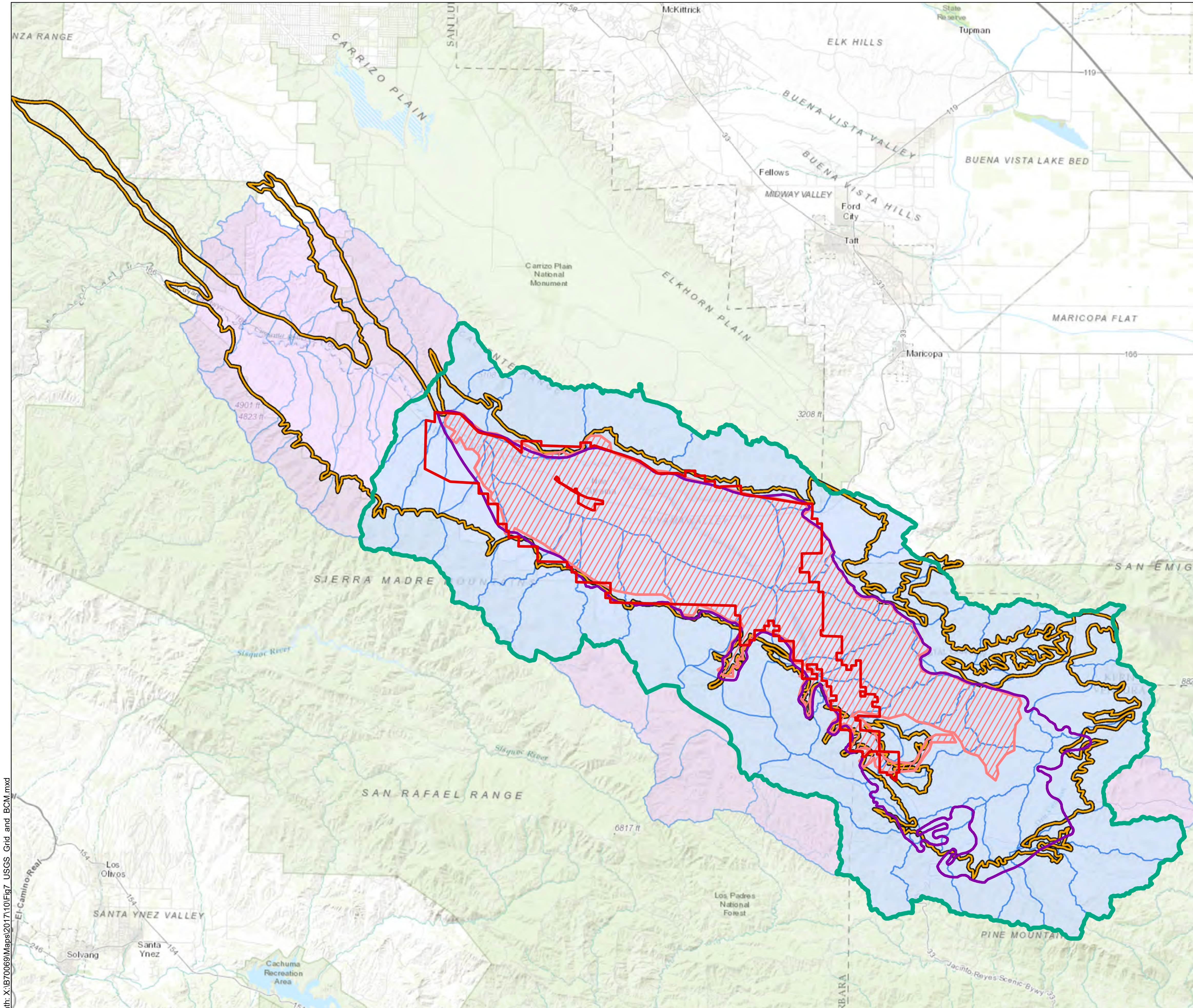

Legend

- Cuyama Basin Water District
- Cuyama Valley Groundwater Basin (DWR 3-013)
- USGS BCM Boundary
- USGS Study Area Boundary
- USGS CUVHM Area Boundary (approx.)
- All Contributing Watersheds to Cuyama Basin
- Watersheds Considered by USGS

Abbreviations

BCM = "Basin Characterization Model"
CUVHM = Cuyama Valley Hydrologic Model
DWR = Department of Water Resources
USGS = United States Geological Survey

Notes

1. All locations are approximate.
2. "Basin Characterization Model" (BCM) boundary delineates the study area included in the USGS regional precipitation-runoff model developed for the Cuyama basin (see Figure 3 of Source 1).

Sources

1. Hanson, R.T., Flint, L.E., Faunt, C.C., Gibbs, D., and Schmid, Wolfgang, 2014. Hydrologic models and analysis of water availability in Cuyama Valley, California. USGS SIR 2014-5150.
2. Watersheds from National Hydrography Dataset (https://viewer.nationalmap.gov/basic/).
3. Basemap is ESRI's ArcGIS Online world topographic map, obtained 27 October 2017.

N

0 5 10 (Scale in Miles)

USGS Study Area and Model Area Boundaries

Cuyama Basin Water District
Cuyama, California
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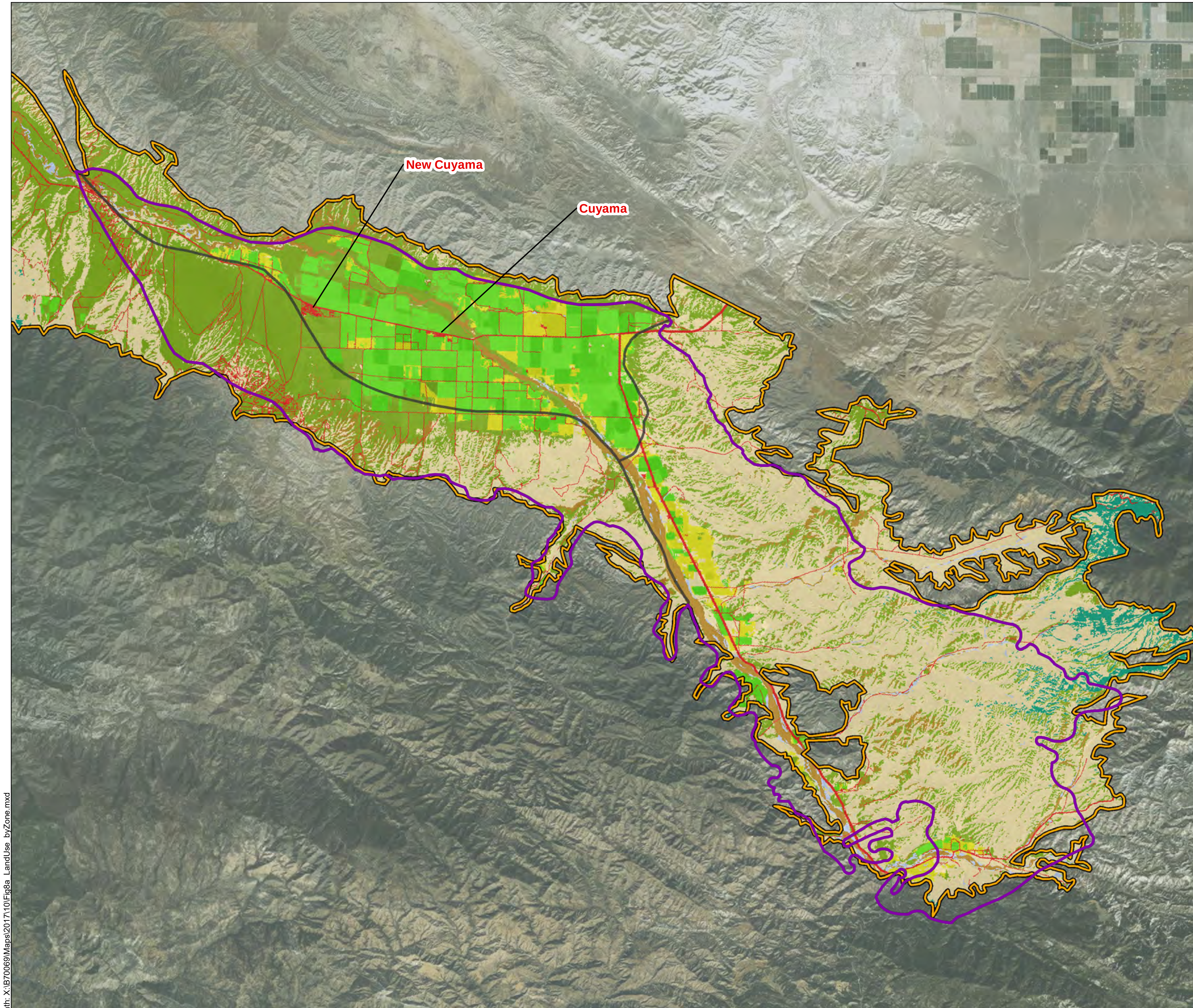
Figure 7



Legend

- Cuyama Valley Groundwater Basin (DWR 3-013)
- USGS Study Area Boundary
- USGS Study Area Zone Boundary

2011 NLCD Land Use Designation

- Wetlands
- Cultivated Crops
- Pasture / Hay
- Grassland / Herbaceous
- Shrub / Scrub
- Mixed Forest
- Barren Land
- Developed Lands

Abbreviations

DWR = Department of Water Resources
NLCD = National Land Cover Database
USGS = United States Geological Survey

Notes

1. All locations are approximate.

Sources

1. Land cover data obtained from NLCD, published 2014. https://www.mrlc.gov/nlcd2011.php
2. USGS Study area boundary obtained from Hanson et al, 2014. Hydrologic models and analysis of water availability in Cuyama Valley, California. USGS SIR 2014-5150.
3. Basemap is ESRI's ArcGIS Online world topographic map, obtained 27 October 2017.

N

0 3 6
(Scale in Miles)

Land Use by USGS Study Area Zone

Cuyama Basin Water District
Cuyama, California
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Figure 8a

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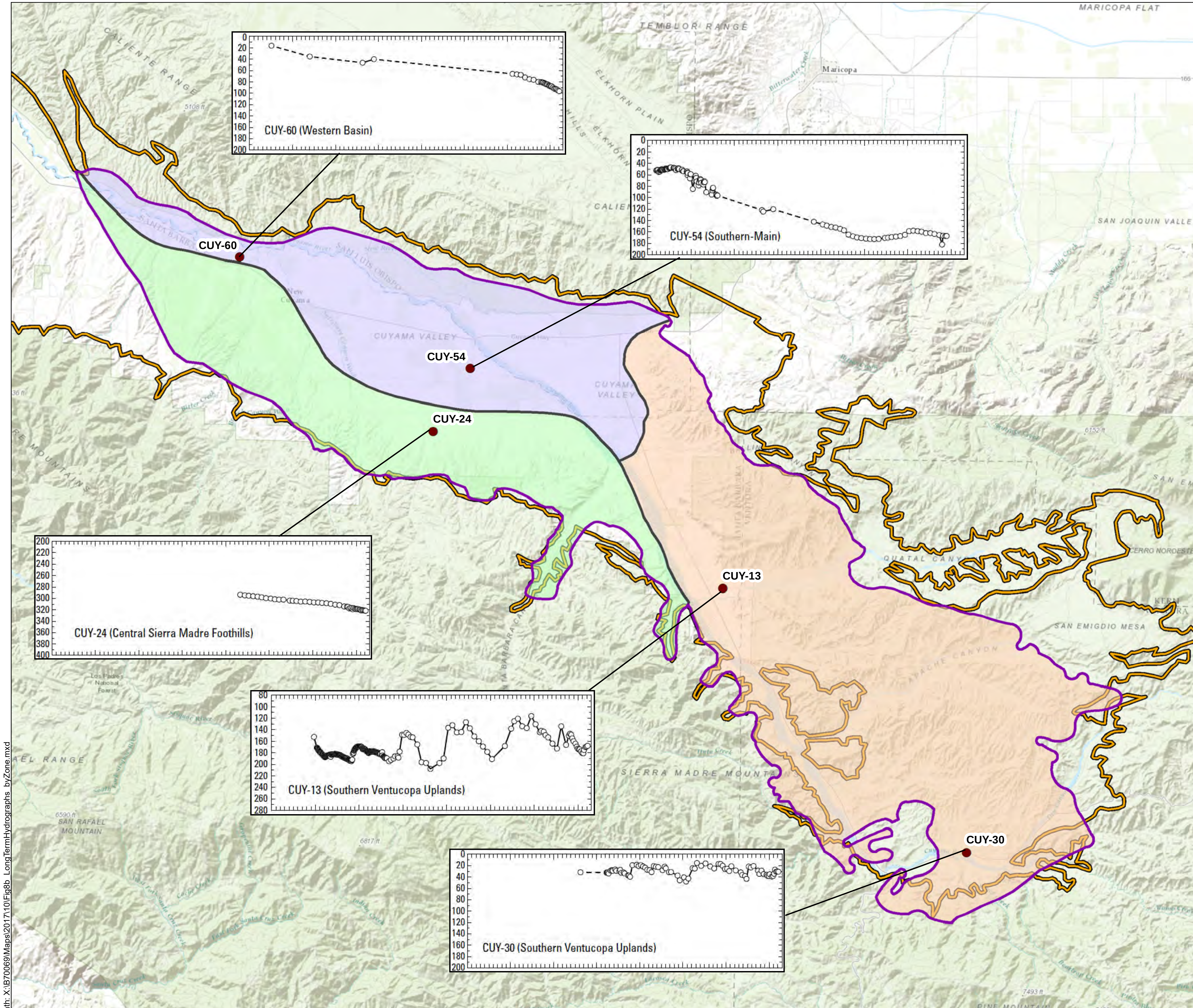
Path: X:\B70069\Maps\2017\10\Fig8a_LandUse_byZone.mxd



Legend

- Cuyama Valley Groundwater Basin (DWR 3-013)
- USGS Study Area Boundary

USGS Study Area Zone

- Main
- Sierra Madre Foothills
- Ventucopa Uplands
- USGS Monitoring Well

Abbreviations

DWR = Department of Water Resources
USGS = United States Geological Survey

Notes

1. All locations are approximate.
2. The five hydrographs included in this figure are a representative subset of 16 historical hydrographs included in the USGS Study (see Figure 24 of Source 1).
3. Hydrographs display water levels from 1940 - 2010, measured in feet below ground surface.

Sources

1. Everett, R.R., Gibbs, D.R., Hanson, R.T., Sweetkind, D.S., Brandt, J.T., Falk, S.E. and Harich, C.R., 2013, Geology, water-quality, hydrology, and geomechanics of the Cuyama Valley groundwater basin, California, 2008–12. USGS SIR 2013–5108.
2. Basemap is ESRI's ArcGIS Online world topographic map, obtained 27 October 2017.

N
0 3 6
(Scale in Miles)

Representative Long-Term Hydrographs by USGS Study Area Zone

Cuyama Basin Water District
Cuyama, California
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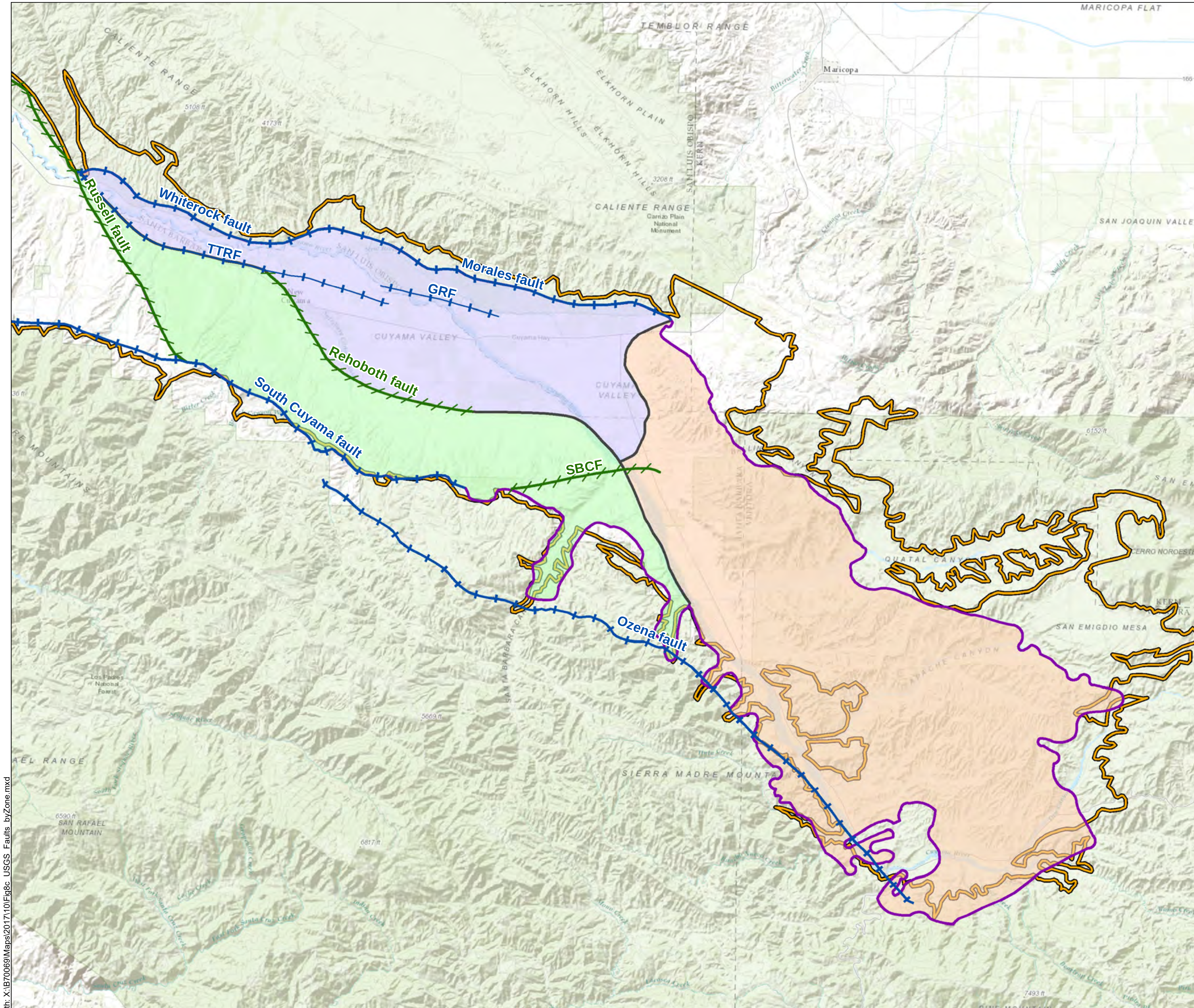
Figure 8b

Path: X:\B70069\Maps\2017\10\Fig8b_LongTermHydrographs_byZone.mxd



Legend

- Cuyama Valley Groundwater Basin (DWR 3-013)
- USGS Study Area Boundary

USGS Study Area Zones

- Main
- Sierra Madre Foothills
- Ventucopa Uplands

Faults in USGS Study

- Normal fault
- Thrust fault
- Thrust fault, concealed

Abbreviations

DWR = Department of Water Resources
GRF = Graveyard Ridge Fault
SBCF = Santa Barbara Canyon Fault
TTRF = Turkey Trap Ridge Fault
USGS = United States Geological Survey

Notes

1. All locations are approximate.

Sources

1. Hanson, R.T., Flint, L.E., Faunt, C.C., Gibbs, D., and Schmid, Wolfgang, 2014. Hydrologic models and analysis of water availability in Cuyama Valley, California. USGS SIR 2014-5150.
2. Basemap is ESRI's ArcGIS Online world topographic map, obtained 27 October 2017.

N

0 3 6

(Scale in Miles)

Mapped Faults by USGS Study Area Zone

Cuyama Basin Water District
Cuyama, California
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Figure 8c

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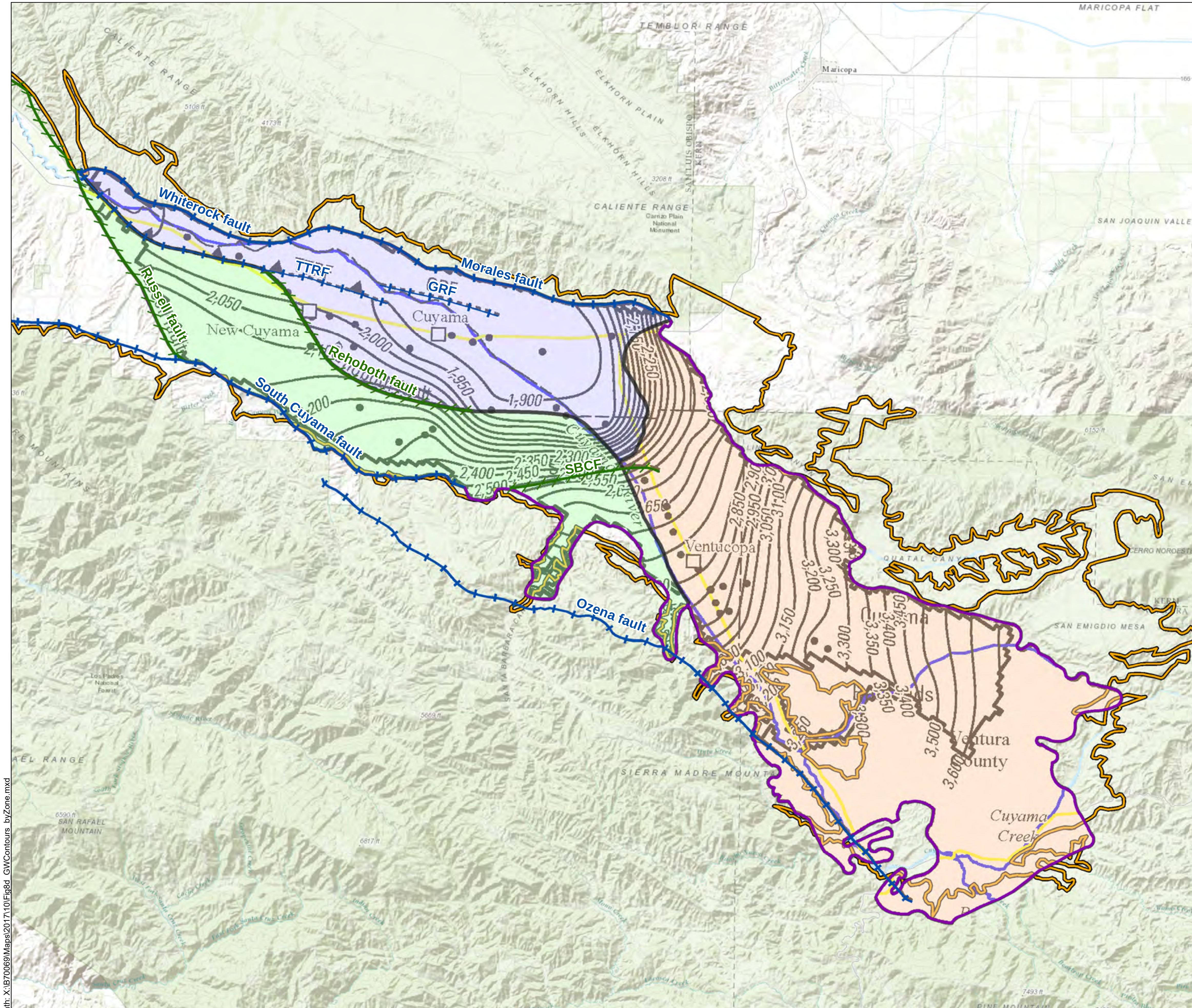
Path: X:\B70069\Maps\2017\10\Fig8c_USGS_Faults_byZone.mxd



Legend

- Cuyama Valley Groundwater Basin (DWR 3-013)
- USGS Study Area Boundary

USGS Study Area Zones

- Main
- Sierra Madre Foothills
- Ventucopa Uplands

Faults in USGS Study

- Normal fault
- Thrust fault
- Thrust fault, concealed

Abbreviations

DWR = Department of Water Resources
GRF = Graveyard Ridge Fault
SBCF = Santa Barbara Canyon Fault
TTRF = Turkey Trap Ridge Fault
USGS = United States Geological Survey

Notes

1. All locations are approximate.
2. 2010 groundwater elevation contours extracted from USGS Study (see Figure 15d of Source 1).
3. Groundwater elevation contour interval is 50 feet.

Sources

1. Hanson, R.T., Flint, L.E., Faunt, C.C., Gibbs, D., and Schmid, Wolfgang, 2014. Hydrologic models and analysis of water availability in Cuyama Valley, California. USGS SIR 2014-5150.
2. Basemap is ESRI's ArcGIS Online world topographic map, obtained 27 October 2017.

N 0 3 6 (Scale in Miles)

2010 Groundwater Elevation Contours by USGS Study Area Zone

Cuyama Basin Water District
Cuyama, California
October 2017
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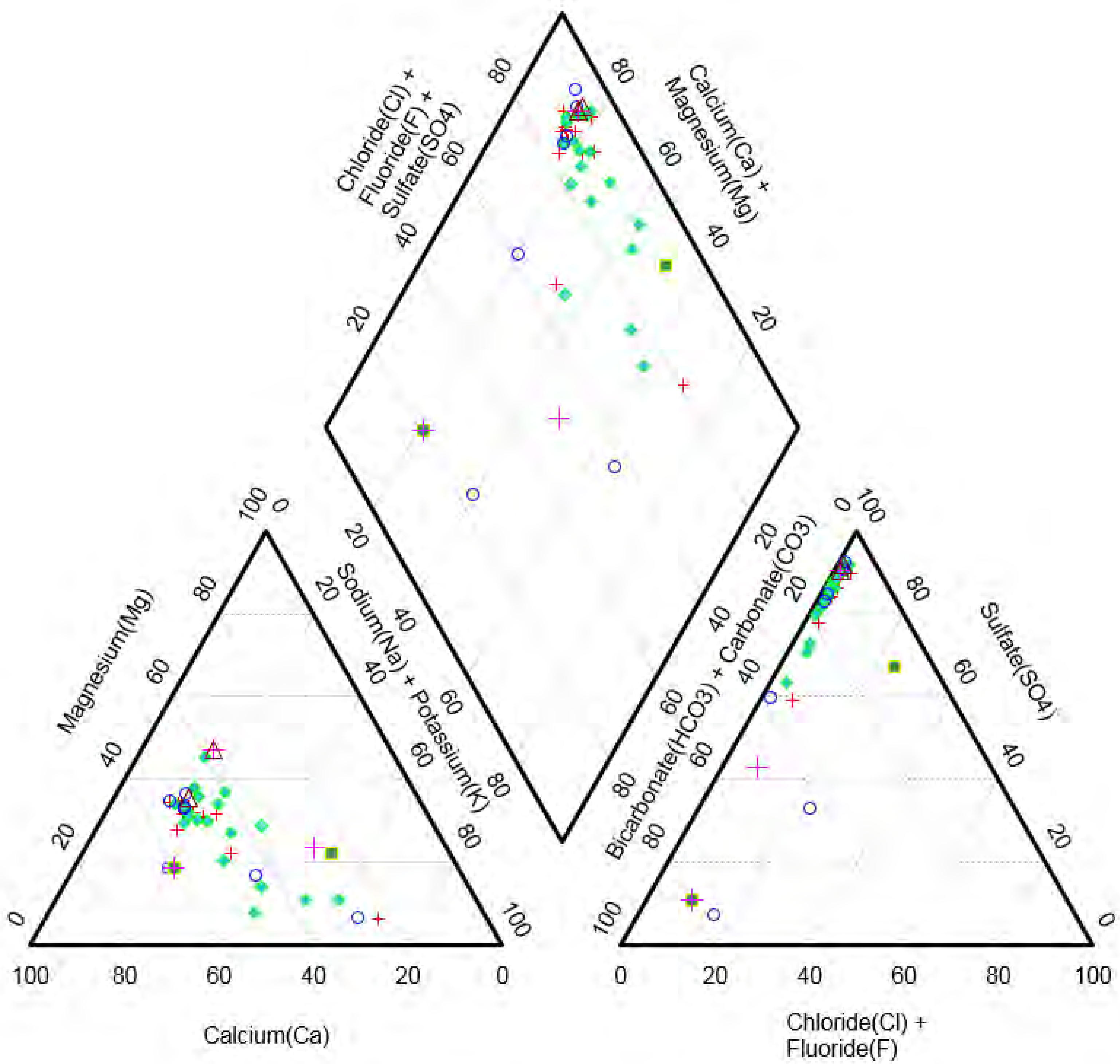
Figure 8d

Path: X:\B70069\Maps\2017\10\Fig8d_GWContours_byZone.mxd



Legend

- + = Main Zone
- ◆ = Sierra Madre Foothills Zone
- ○ = Ventucopa Uplands Zone
- = Spring
- △ = Cuyama River
- ■ = Outside Basin

Abbreviations

USGS = United States Geological Survey

Notes

1. Water quality data extracted from USGS study tabular data (see Source 1).
2. Water quality measurements collected from September 2008 – August 2011

Sources

1. Everett, R.R., Gibbs, D.R., Hanson, R.T., Sweetkind, D.S., Brandt, J.T., Falk, S.E. and Harich, C.R., 2013, Geology, water-quality, hydrology, and geomechanics of the Cuyama Valley groundwater basin, California, 2008– 12. USGS SIR 2013– 5108.

Water Quality – Piper Diagrams by USGS Study Area Zone

Cuyama Basin Water District
Cuyama, California
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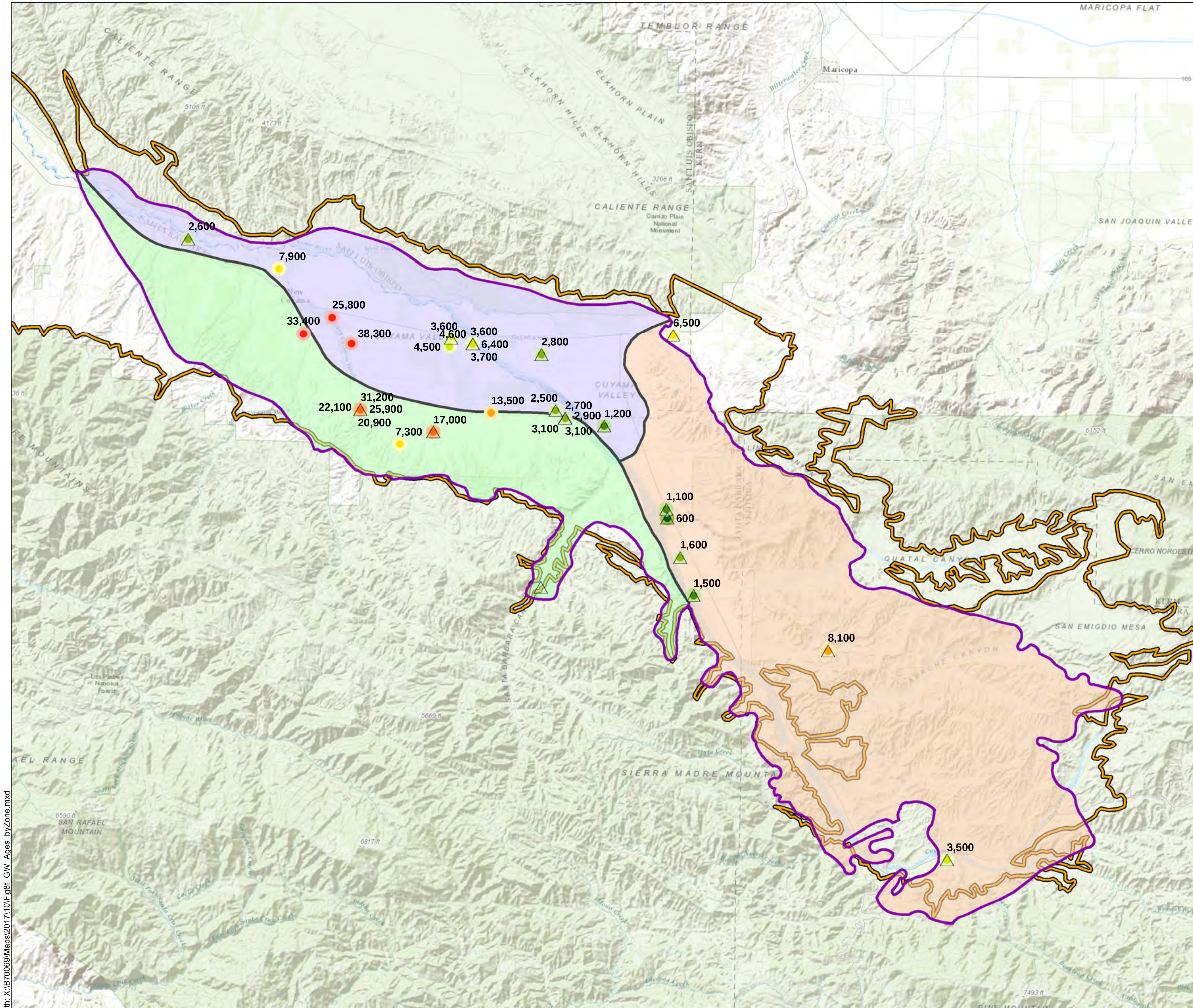
Figure 8e



Legend

- Cuyama Valley Groundwater Basin (DWR 3-013)
- USGS Study Area Boundary

USGS Study Area Zone

- Main
- Sierra Madre Foothills
- Ventucopa Uplands

Average Groundwater Age (years)

- < 1,000
- 1,000 - 1,500
- 1,500 - 3,000
- 3,000 - 5,000
- 5,000 - 8,000
- 8,000 - 15,000
- 15,000 - 25,000
- > 25,000
- Tritium Detected (see Note 5)

Abbreviations

DWR = Department of Water Resources
USGS = United States Geological Survey

Notes

1. All locations are approximate.
2. Water quality data extracted from USGS study tabular data (see Source 1).
3. Water quality measurements collected from September 2008 - August 2011.
4. Average groundwater ages are approximated via Carbon-14 dating of water quality samples.
5. Tritium detected in a sample indicates presence of recent (post-1950) recharge.

Sources

1. Everett, R.R., Gibbs, D.R., Hanson, R.T., Sweetkind, D.S., Brandt, J.T., Falk, S.E. and Harich, C.R., 2013, Geology, water-quality, hydrology, and geomechanics of the Cuyama Valley groundwater basin, California, 2008–12. USGS SIR 2013–5108.
2. Basemap is ESRI's ArcGIS Online world topographic map, obtained 27 October 2017.

N

0 3 6
(Scale in Miles)

Water Quality - Groundwater Age by USGS Study Area Zone

Cuyama Basin Water District
Cuyama, California
October 2017
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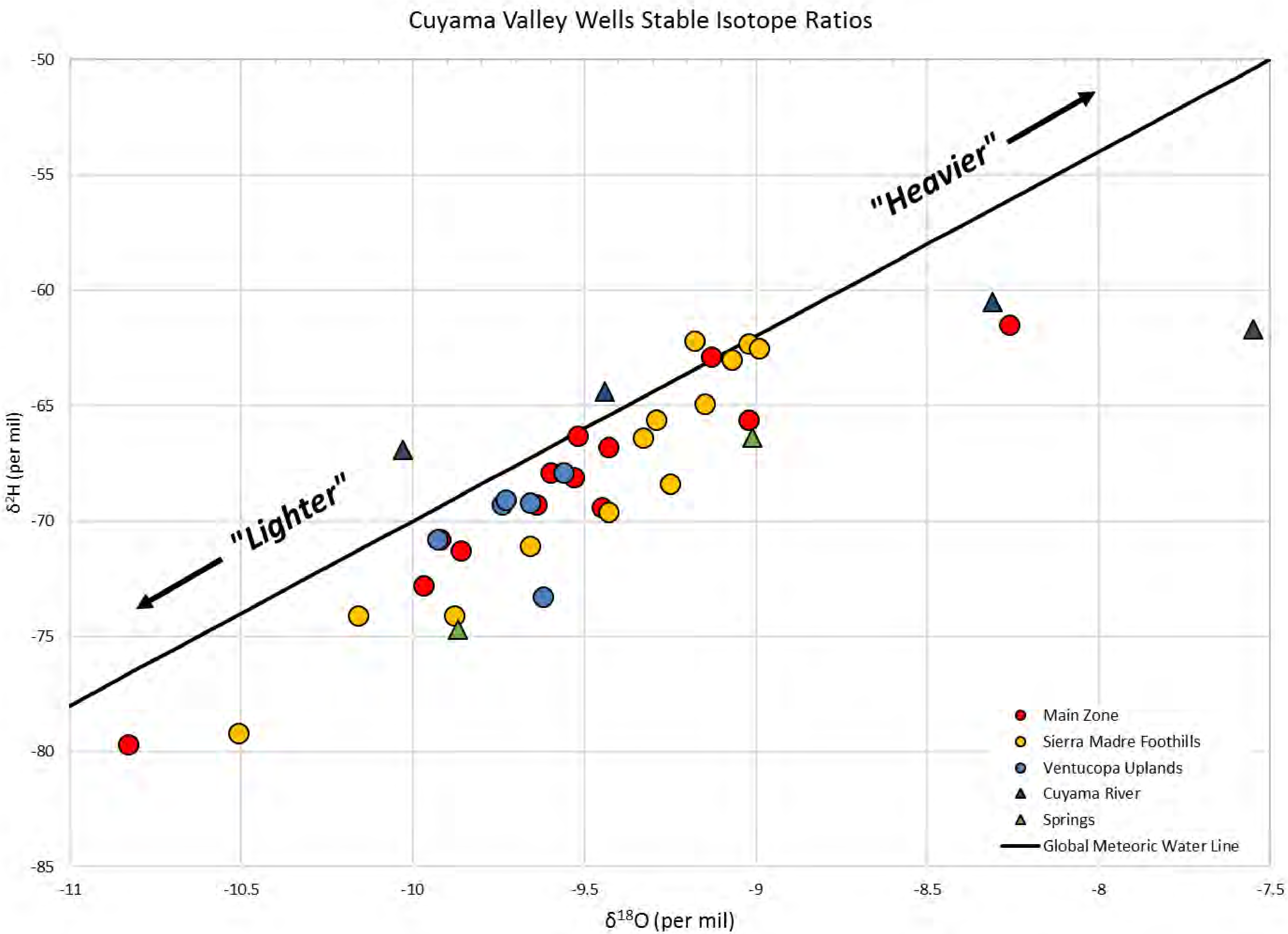
Figure 8f

Path: X:\B70069\Maps\2017\10\Fig8f_GW_Ages_byZone.mxd



Abbreviations

per mil = parts per thousand

USGS = United States Geological Survey

Notes

1. $\delta^{18}O$ is the ratio of Oxygen-18 to Oxygen-16 in a sample versus the same ratio in a standard.
2. $\delta^{2}H$ is the ratio of Deuterium to Hydrogen in a sample versus the same ratio in a standard.
3. Water quality data extracted from USGS study tabular data (see Source 1).
4. Water quality measurements collected from September 2008 – August 2011.

Sources

1. Everett, R.R., Gibbs, D.R., Hanson, R.T., Sweetkind, D.S., Brandt, J.T., Falk, S.E. and Harich, C.R., 2013, Geology, water-quality, hydrology, and geomechanics of the Cuyama Valley groundwater basin, California, 2008– 12. USGS SIR 2013– 5108.

Water Quality – Stable Isotopes by USGS Study Area Zone

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Cuyama, California
October 2017
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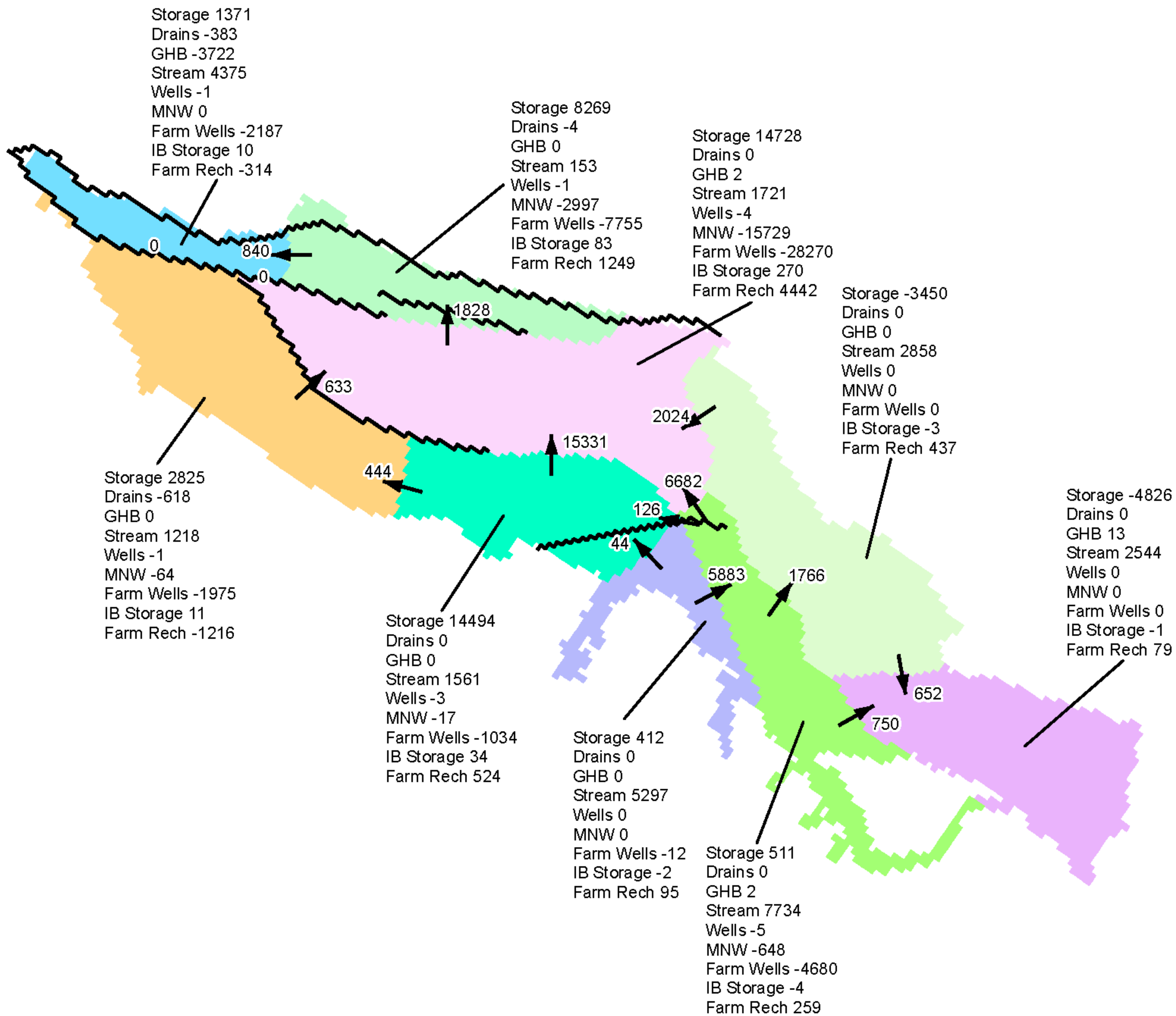
Figure 8g

WY 1950-2010 Budget (AF/yr)
Run 1 - Base Model



Legend

- HFB Faults

USGS Study Area Subregion

- Southern-Main
- Western-Main
- Caliente/Northern-Main
- Northwestern Sierra Madre Foothills
- Central Sierra Mader Foothills
- Southern Sierra Madre Foothills
- Northeast Ventucopa Uplands
- Northern Ventucopa Uplands
- Southern Ventucopa Uplands

Abbreviations

AF/yr	=	acre-foot per year
GHB	=	General Head Boundary
HFB	=	Horizontal Flow Barrier
IB	=	Interbed Storage
MNW	=	Multi-Node Well
Rech	=	Recharge
USGS	=	United States Geological Survey
WY	=	Water Year

Notes

1. “Base run” indicates model inputs were unchanged before extracting water budget output components.
2. Water budget components extracted from USGS model Z-Budget output files (see Source 1).
3. Arrows indicate direction of horizontal subsurface exchange between subareas.

Sources

1. Hanson, R.T., Flint, L.E., Faunt, C.C., Gibbs, D., & Schmid, W., 2014. Hydrologic models and analysis of water availability in Cuyama Valley, California USGS SIR 2014-5150.

USGS Model Water Budget by Study Area Subregion – Base Case

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Cuyama, California
October 2017
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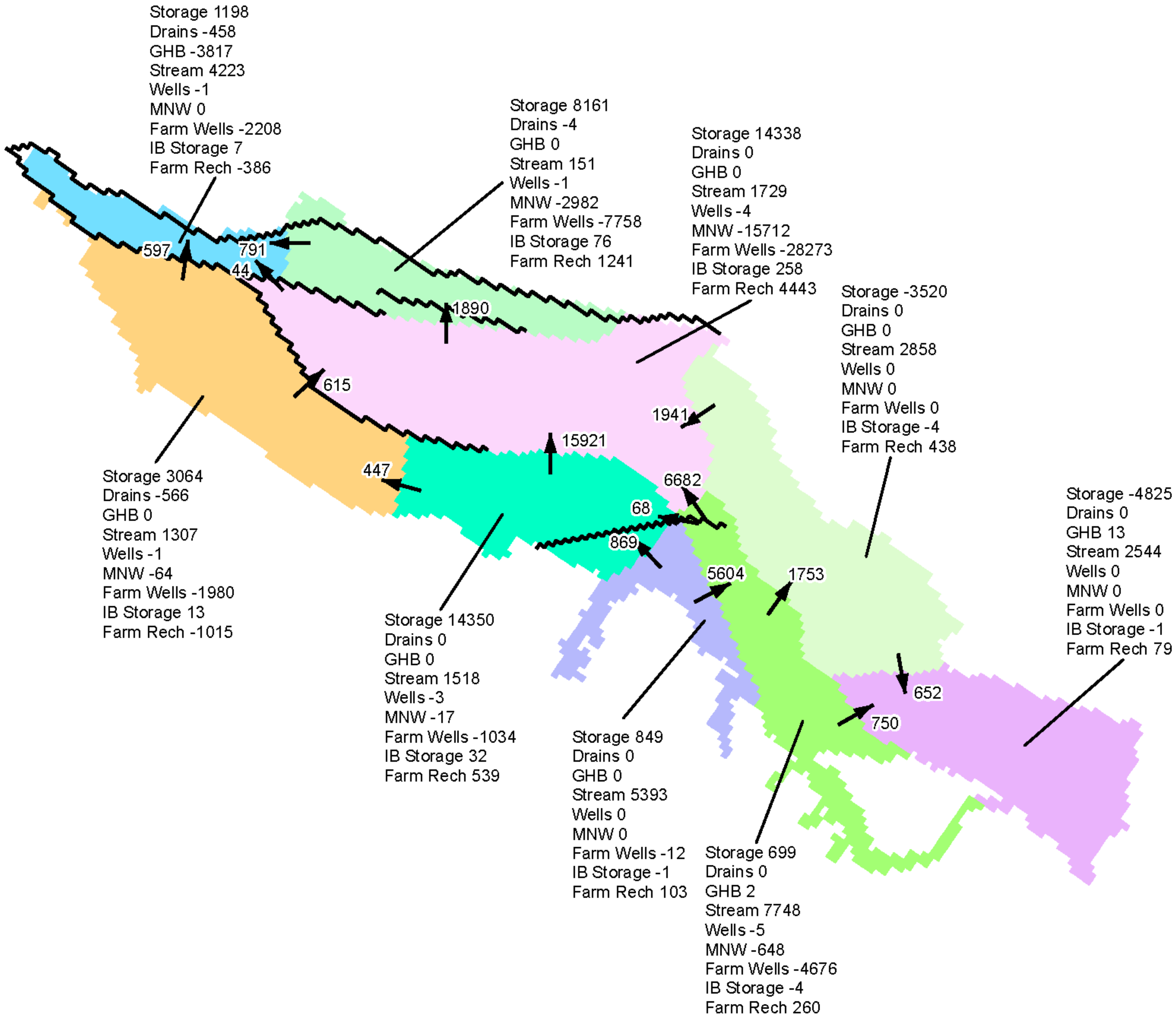
Figure 9a

WY 1950-2010 Budget (AF/yr)
Run 2 - Increased Fault Conductance



Legend

HFB Faults

USGS Study Area Subregion

- Southern-Main
- Western-Main
- Caliente/Northern-Main
- Northwestern Sierra Madre Foothills
- Central Sierra Mader Foothills
- Southern Sierra Madre Foothills
- Northeast Ventucopa Uplands
- Northern Ventucopa Uplands
- Southern Ventucopa Uplands

Abbreviations

AF/yr = acre-foot per year
GHB = General Head Boundary
HFB = Horizontal Flow Barrier
IB = Interbed Storage
MNW = Multi-Node Well
Rech = Recharge
USGS = United States Geological Survey
WY = Water Year

Notes

1. "HFB Fault" conductances were increased to match that of Rehoboth Fault (3.5e-5) as a means of testing model sensitivity to HFB package.
2. Water budget components extracted from USGS model Z-Budget output files (see Source 1).
3. Arrows indicate direction of horizontal subsurface exchange between subareas.

Sources

1. Hanson, R.T., Flint, L.E., Faunt, C.C., Gibbs, D., & Schmid, W., 2014. Hydrologic models and analysis of water availability in Cuyama Valley, California USGS SIR 2014-5150.

USGS Model Water Budget by Study Area Subregion – Increased Fault Conductance

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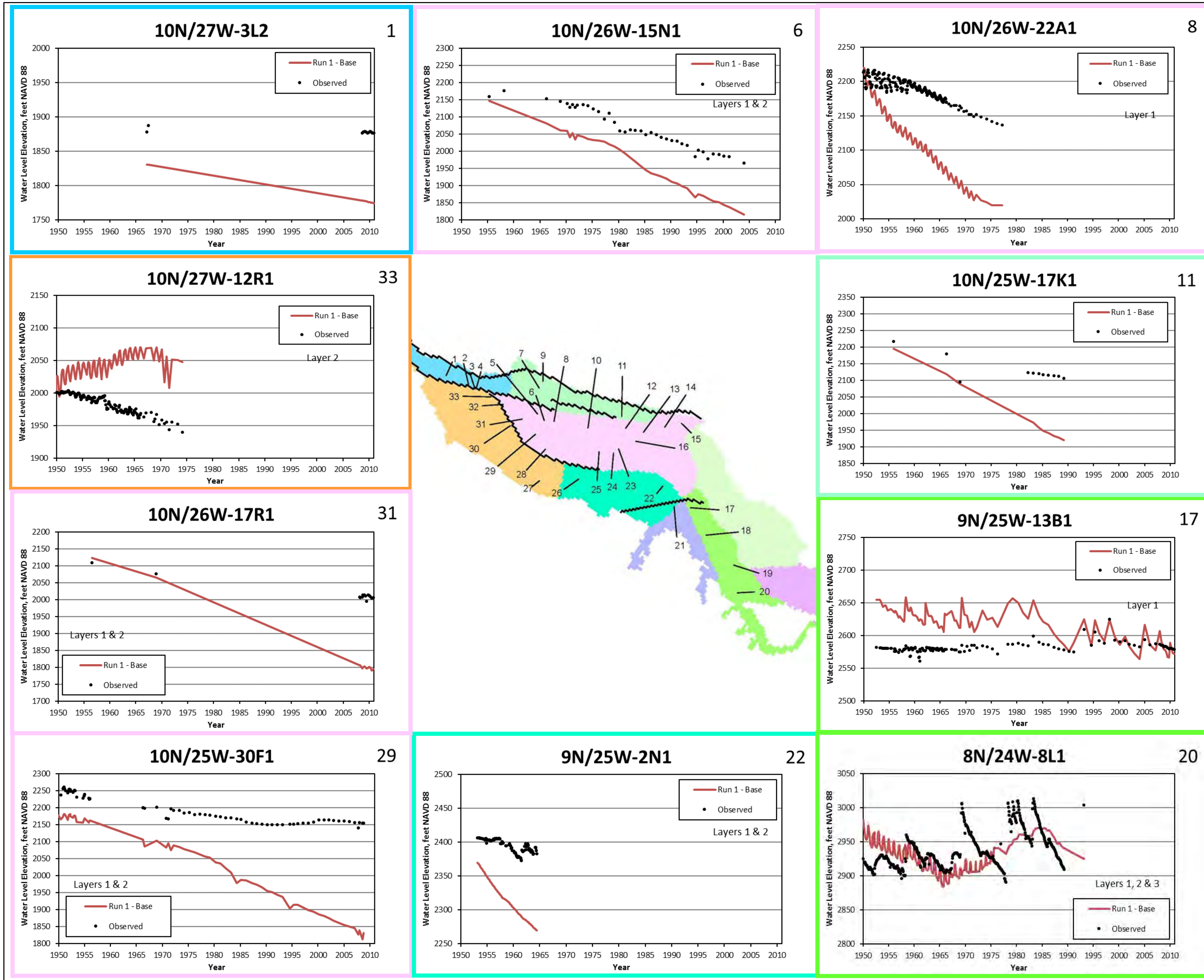
Figure 9b



Legend

HFB Faults

USGS Study Area Subregion

- Southern-Main
- Western-Main
- Caliente/Northern-Main
- Northwestern Sierra Madre Foothills
- Central Sierra Mader Foothills
- Southern Sierra Madre Foothills
- Northeast Ventucopa Uplands
- Northern Ventucopa Uplands
- Southern Ventucopa Uplands

Abbreviations

HFB = Horizontal Flow Barrier
USGS = United States Geological Survey

Notes

1. Simulated and observed water level data extracted from USGS model input and calibration files (see Source 1).
2. Hydrograph border color represents corresponding subregion.
3. See Appendix A of EKI memorandum for full collection of observed vs. simulated hydrographs (36 wells in total).

Sources

1. Hanson, R.T., Flint, L.E., Faunt, C.C., Gibbs, D., & Schmid, W., 2014. Hydrologic models and analysis of water availability in Cuyama Valley, California USGS SIR 2014-5150.

Comparison of Simulated vs. Observed Hydrographs for Wells Included in USGS Study

Cuyama Basin Water District
Cuyama, California
October 2017
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Figure 10

APPENDIX A

CASGEM Basin Summary

CASGEM BASIN SUMMARY

Basin: CUYAMA VALLEY
Sub_Basin: N/A
Basin Number: 3-13
Date: 5/30/2014

Hydrologic Region: Central Coast
South Region Office (SRO)
Basin Area: 242114 acres (378.3 miles)
2010 Population: 1236

DATA COMPONENT RANKING VALUE TABLE

Data Component		Ranking Range (R)	Units	Ranking Value	Confidence Adjustment	Average of Components	Adjusted Ranking Values
1. Population		R < 7	persons/sq-mi	0			0
2. Population Growth		R < 0	percent	0			0
3. Public Supply Wells		0 < R < 0.1	wells/sq-mi	1			1
4. Total Wells		0 < R < 2	wells/sq-mi	1	0.75		0.75
5. Irrigated Acreage		25 ≤ R < 100	acres/sq-mi	2			2
6. GW Reliance	GW Use	0.25 ≤ R < 0.5	acre-foot/acre	3		4	4
	% of Total Supply	R ≥ 80%	percent	5			
7. Impacts*		--	--	3			3
8. Other Information**		--	--	3			3
Overall Basin Ranking Score		**13.42 ≤ R <**	**--**				**13.8**

Overall Basin Priority: Medium

Very Low Ranking Range	Low Ranking Range	Medium Ranking Range	High Ranking Range
Range < 5.75	5.75 ≥ Range < 13.42	13.43 ≥ Range < 21.08	Range ≥ 21.08

Data Sources and Calculation Notes:

1. Population: Department of Finance 2010 census data.
2. Population Growth: Department of Finance 2010 census data projected to 2030.
3. Public Supply Wells: Department of Public Health, 2012 Drinking Water Supply Database.
4. Total Wells: DWR 2012 Well Master database.
5. Irrigated Acreage: DWR, most recent land use projection and public comment feedback.
6. Groundwater Reliance: DWR, most recent land use projection and public comment feedback.
7. Documented Impacts: DWR Region staff review of DWR Bulletin 118-2003, Groundwater Management Plans, public comment feedback, or other readily available published information.
8. Other Information: DWR Region staff review of DWR Bulletin 118-2003, Groundwater Management Plans, public comment feedback, or other readily available published information.
9. Data component values were reduced by 25% due to data confidence, prior to calculating total groundwater basin ranking value.
10. Overall Basin Ranking = Population + Population Growth + Public Supply Wells + (Total Wells x .75) + Irrigated Acreage + (Groundwater Use + % of Total Supply)/2 + Impacts + Other information

Notes on CUYAMA VALLEY Basin

* Impacts: Local salinity and TDS impairments in basin (B-118)
**Other Information: Declining Groundwater levels of 150-300' over the last 40-50 years (DWR, 1998).
Conservation Assessment by TNC (2009) indicates annual gw budget deficit of ~ 28,500 af

APPENDIX B

Selected Figures from Sweetkind et al., 2013

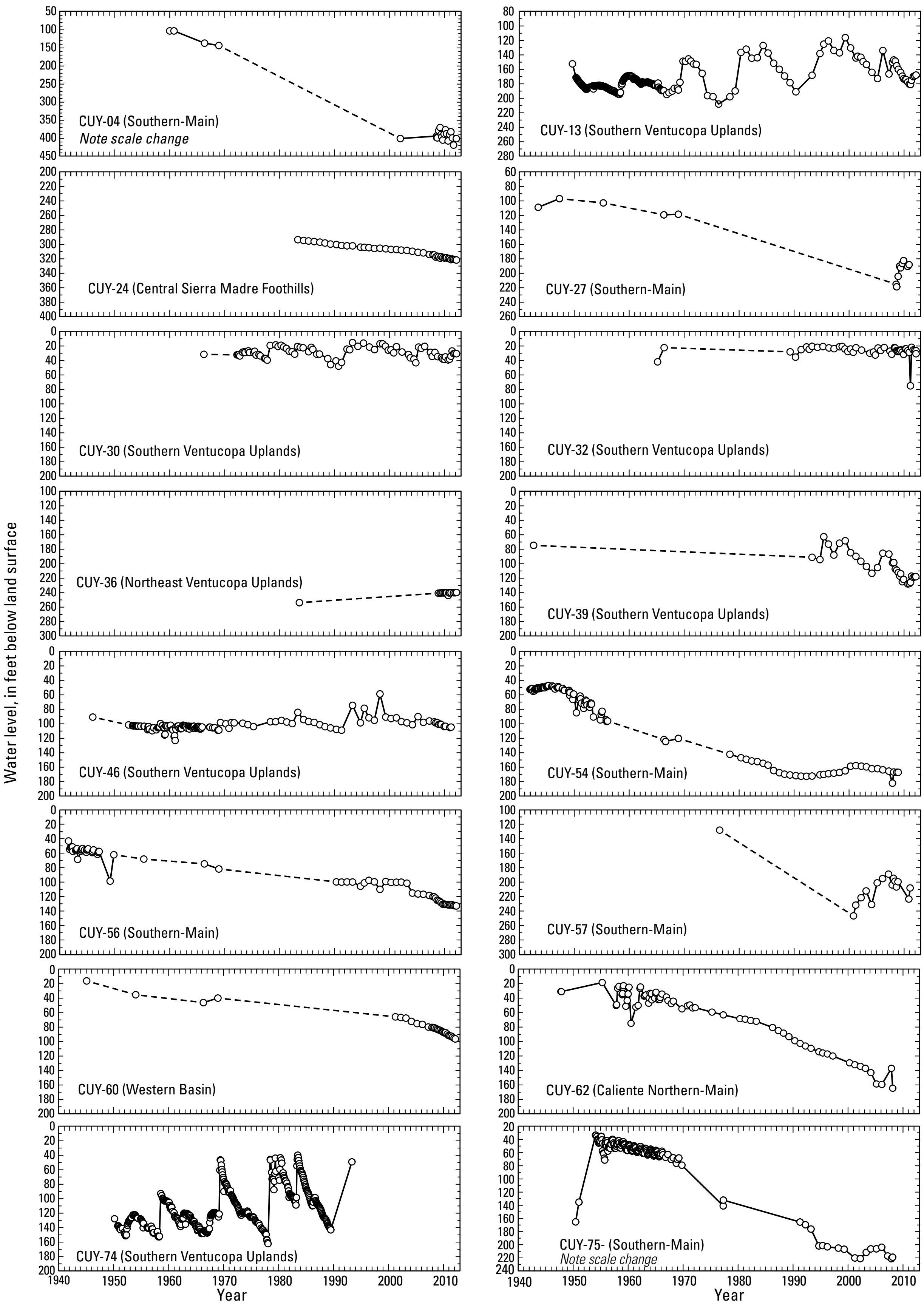
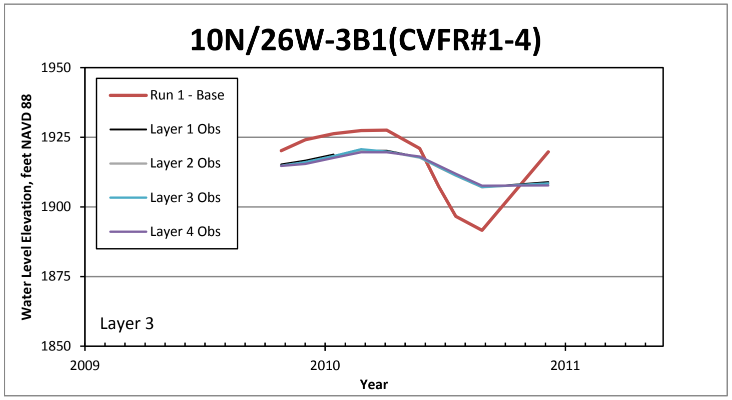


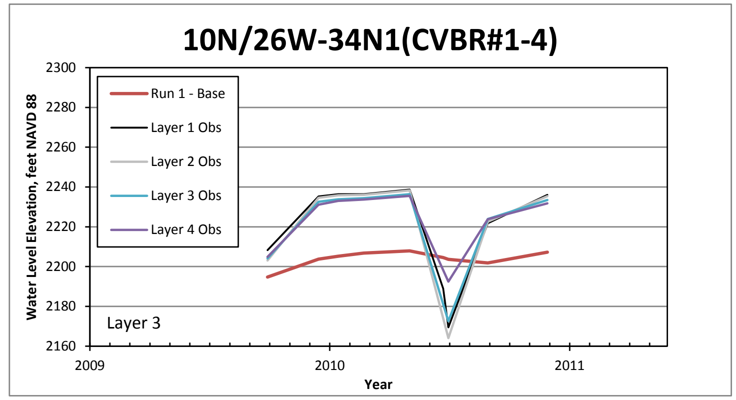
Figure 24. Historic water-level hydrographs from 16 selected domestic and supply wells, Cuyama Valley, Santa Barbara County, California.

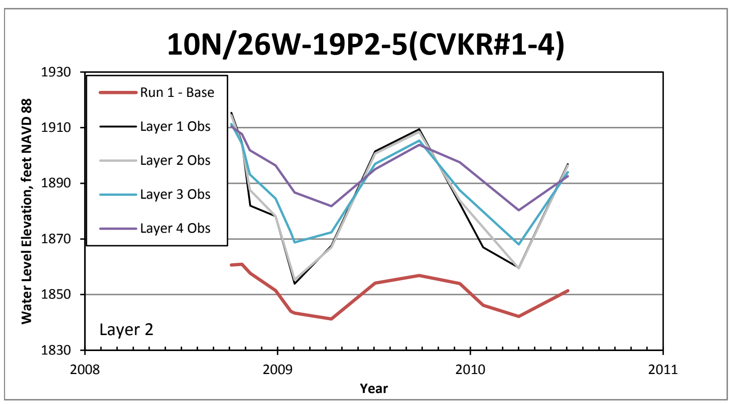
APPENDIX C

Complete Set of Simulated vs. Observed Hydrographs for Wells Included in USGS Study

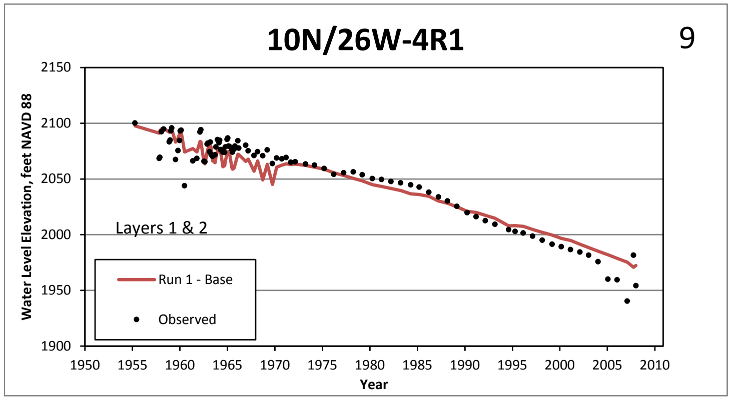
USGS OBSERVATION WELLS

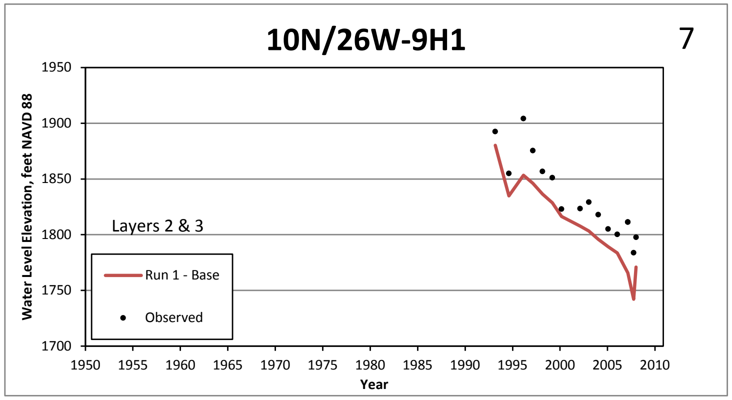


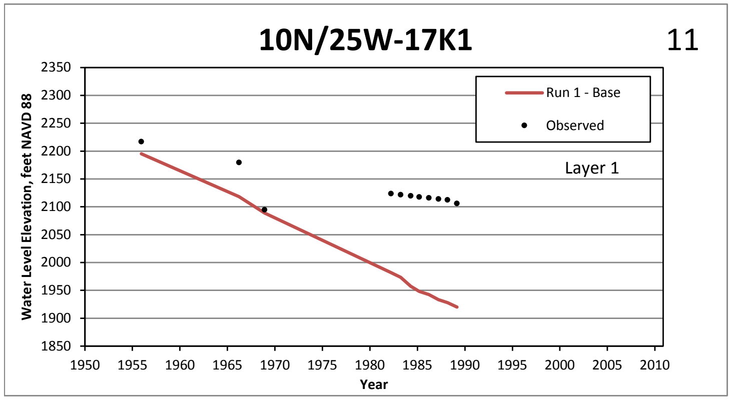




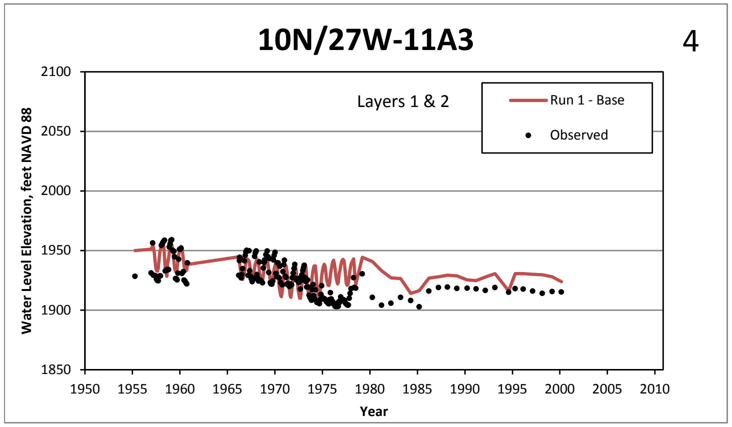
NORTHERN MAIN ZONE

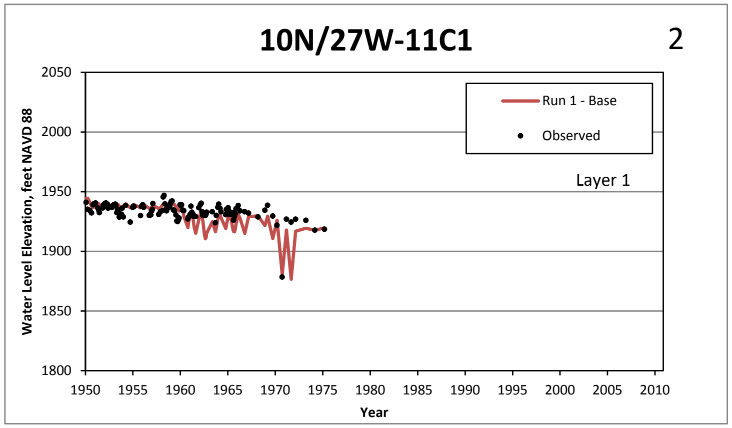


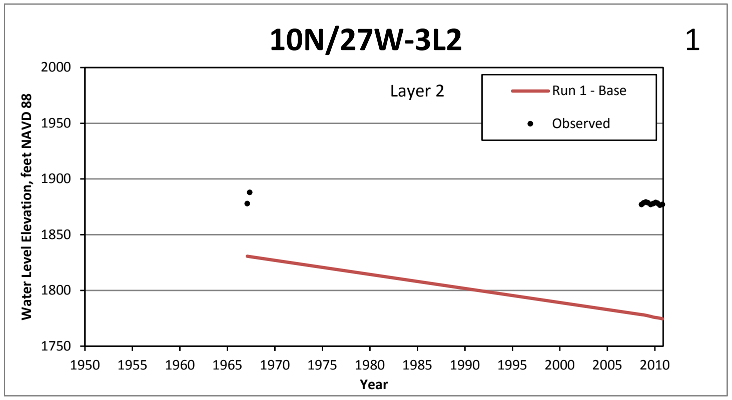




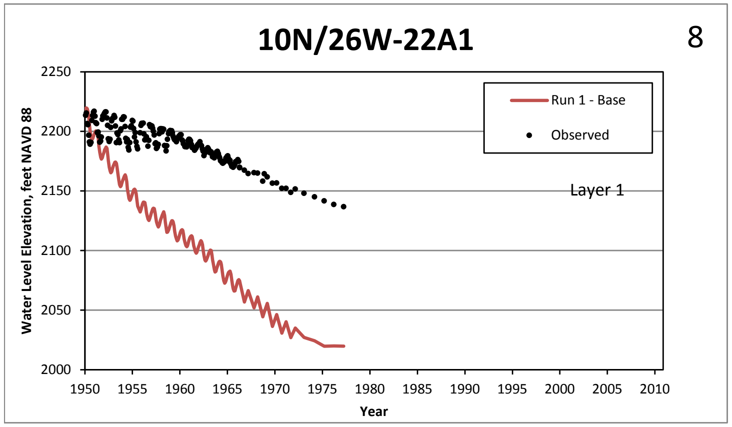
WESTERN BASIN ZONE

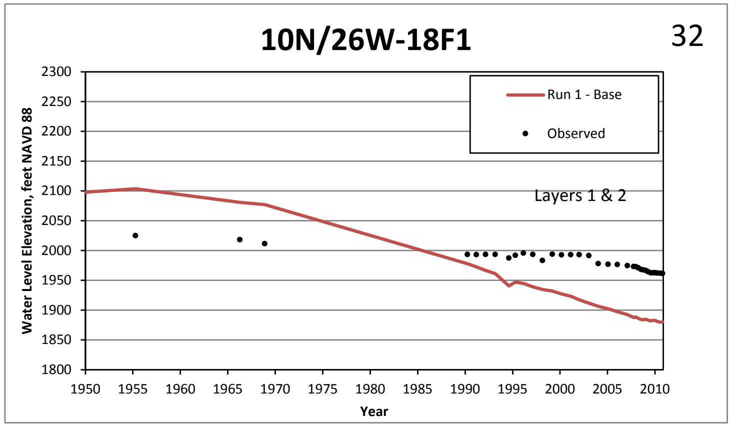


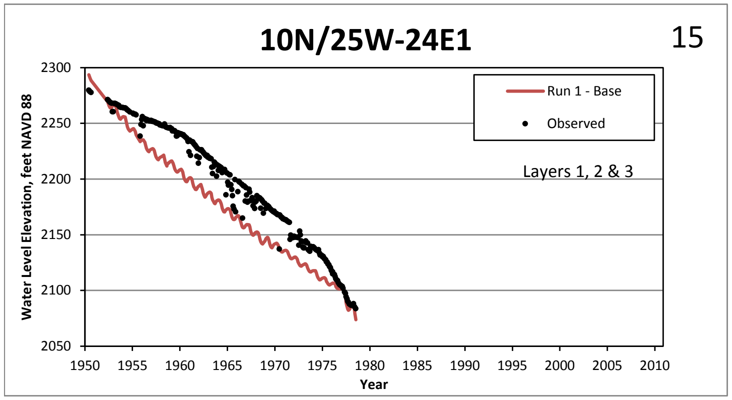


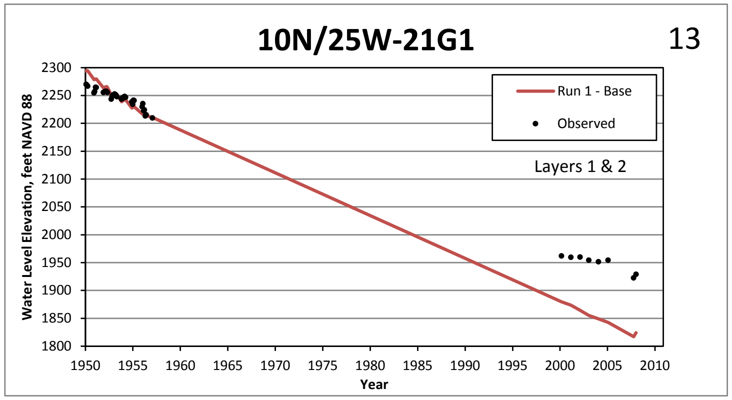


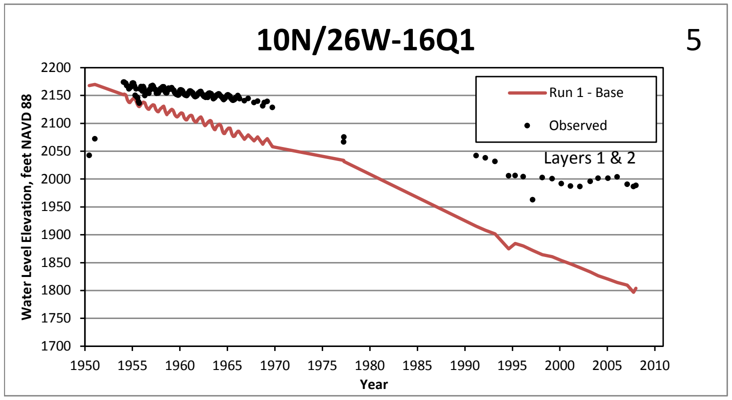
SOUTHERN MAIN ZONE

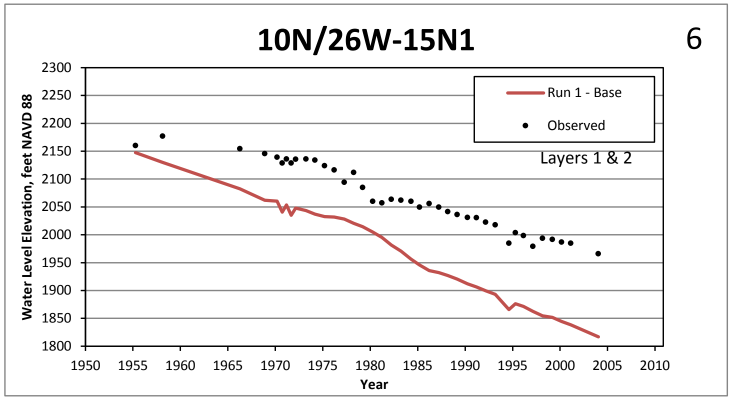












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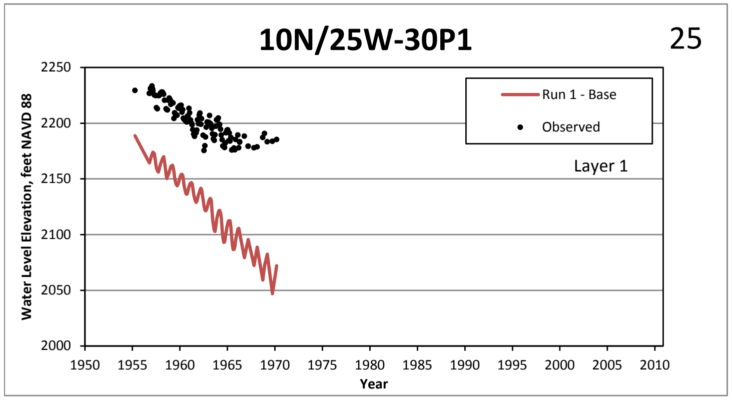
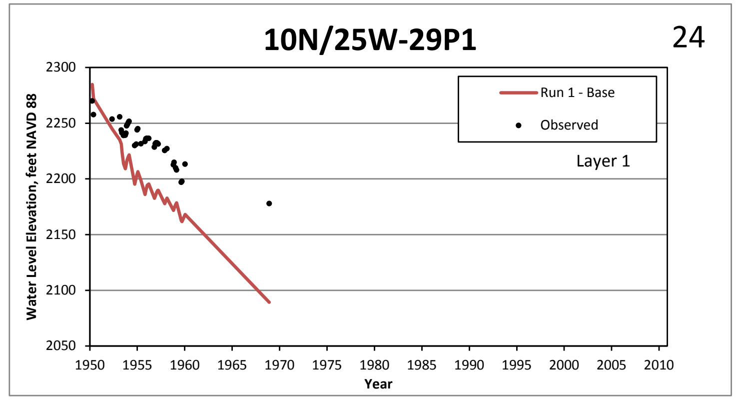
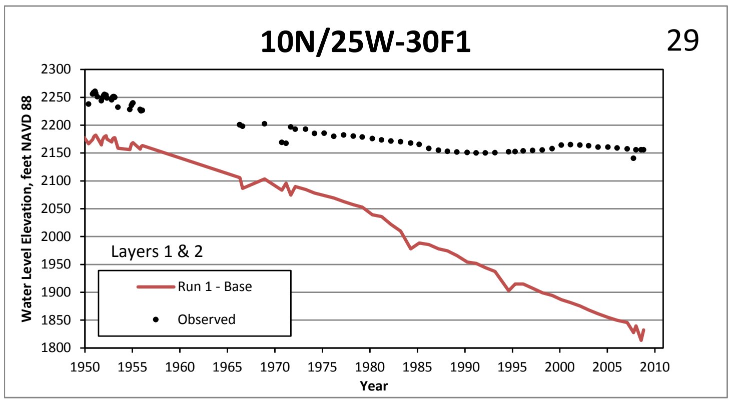
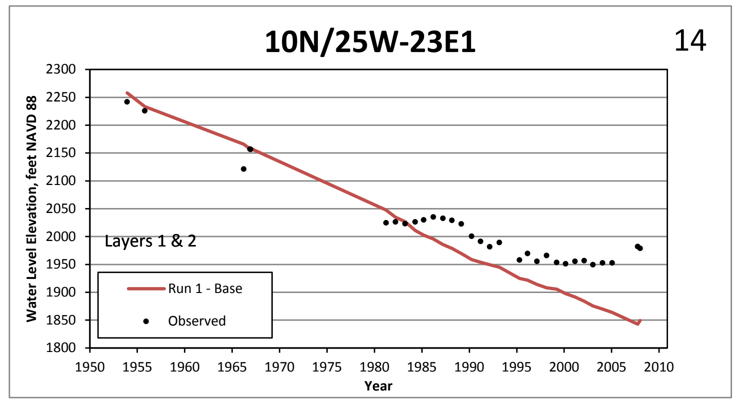
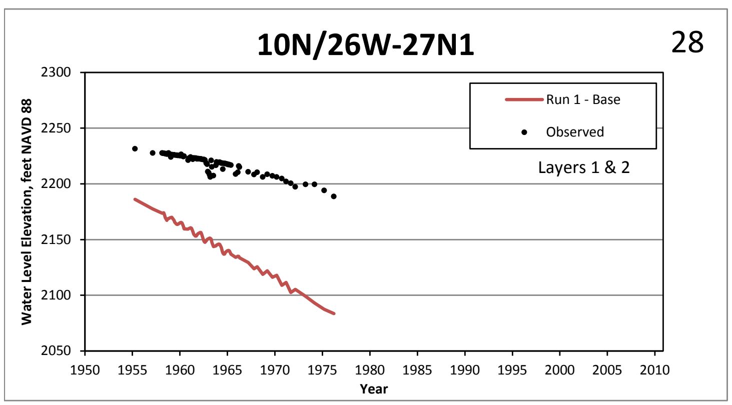
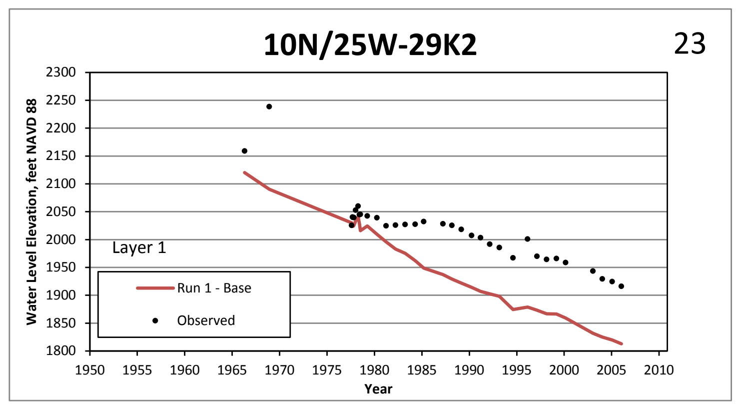




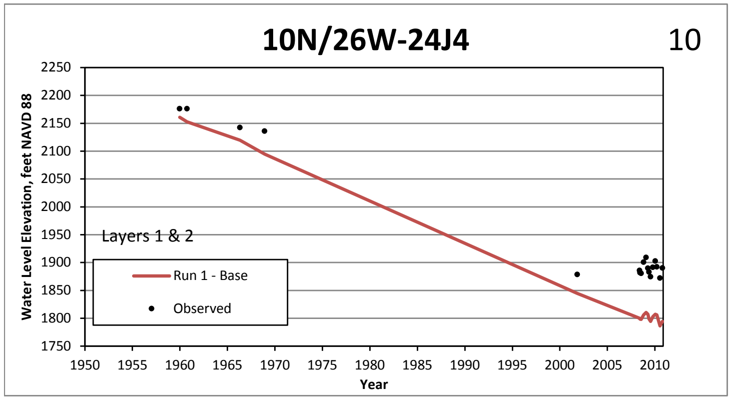


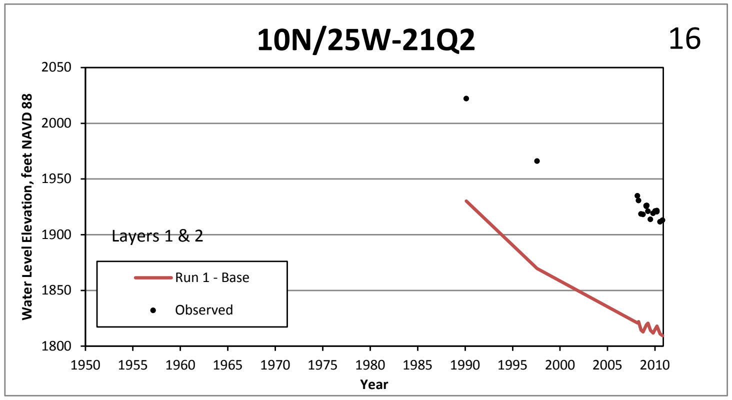


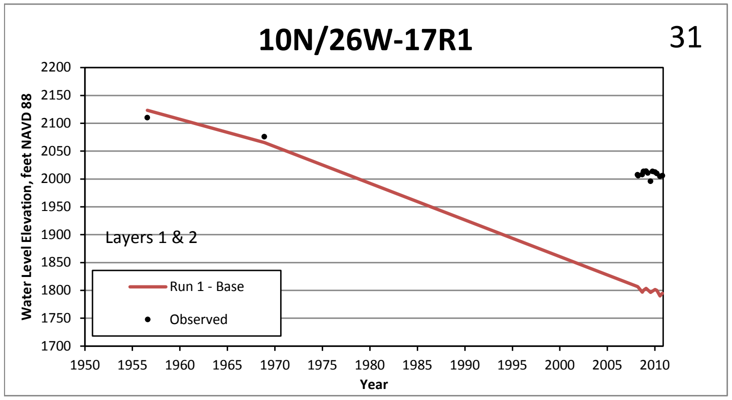


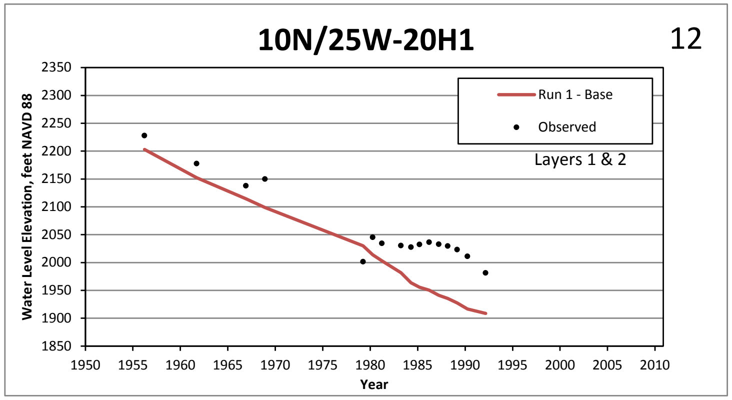


SOUTHERN MAIN ZONE (cont...)

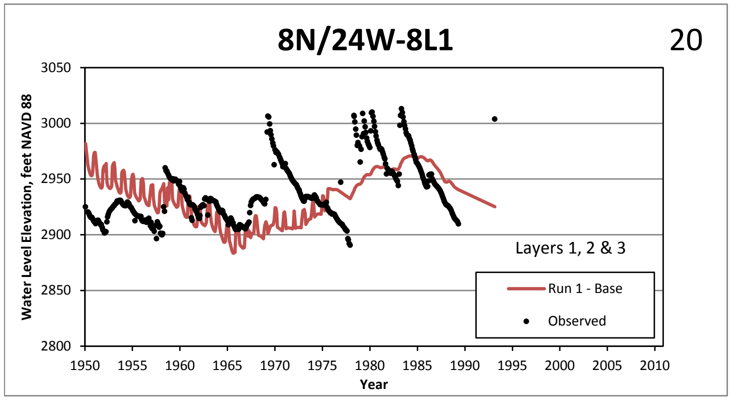


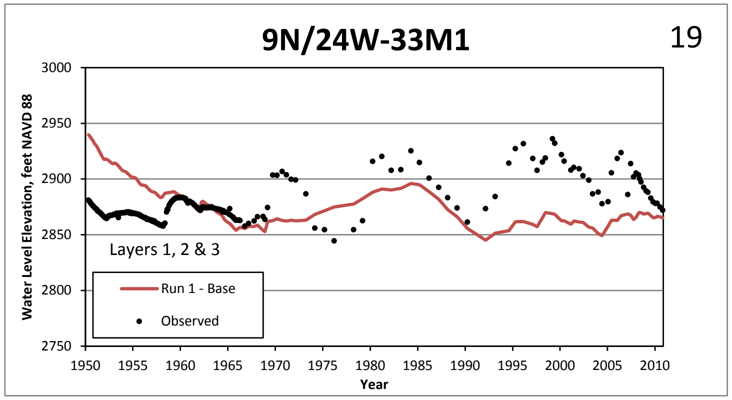


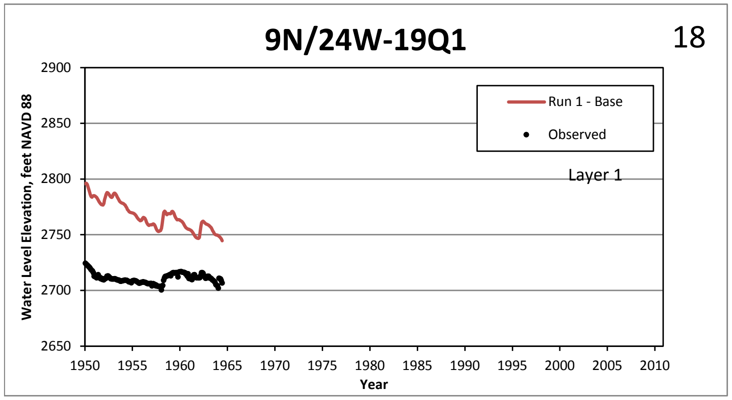


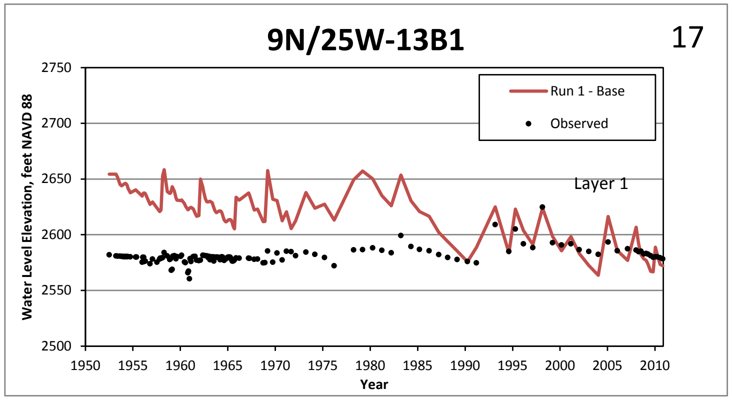


SOUTHERN VENTUCOPA UPLANDS

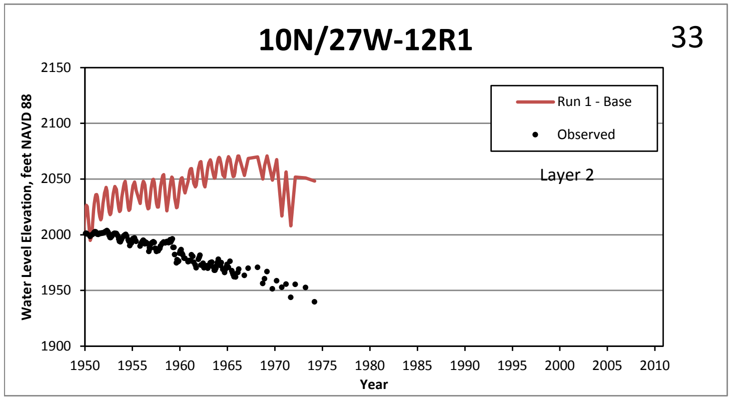


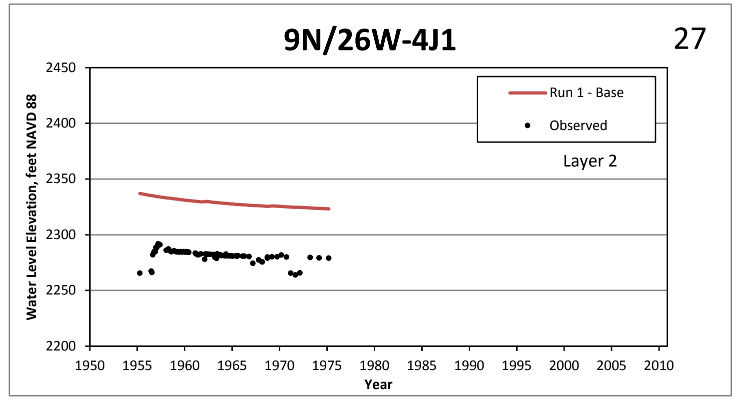


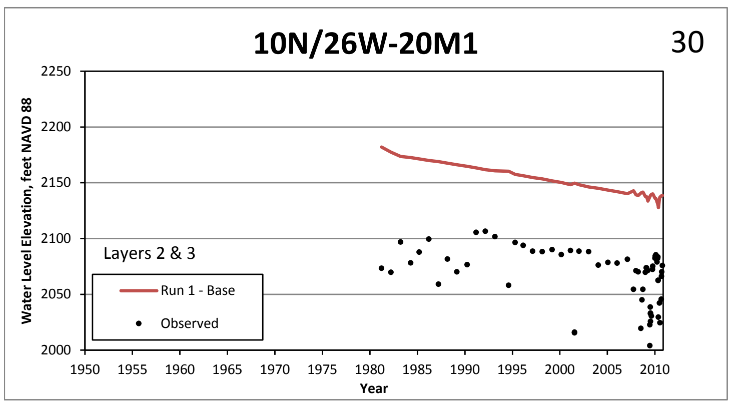


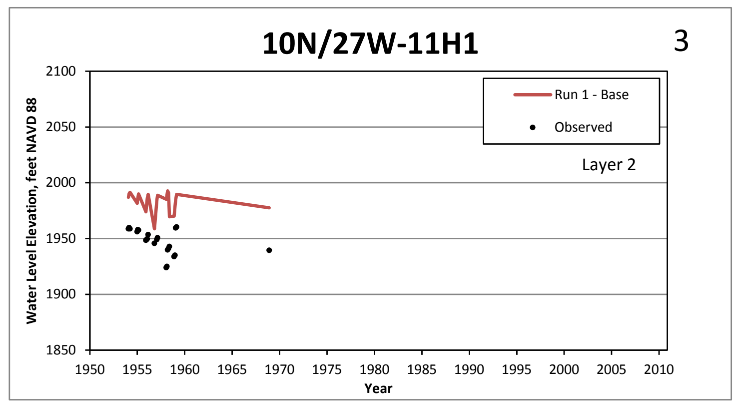


NORTHERN SIERRA MADRE FOOTHILLS

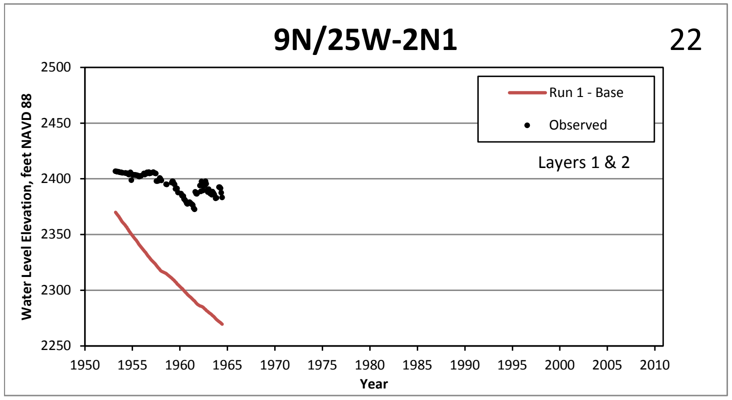


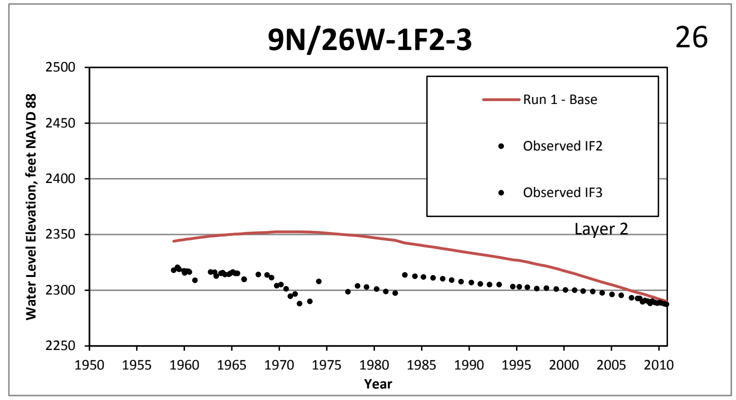




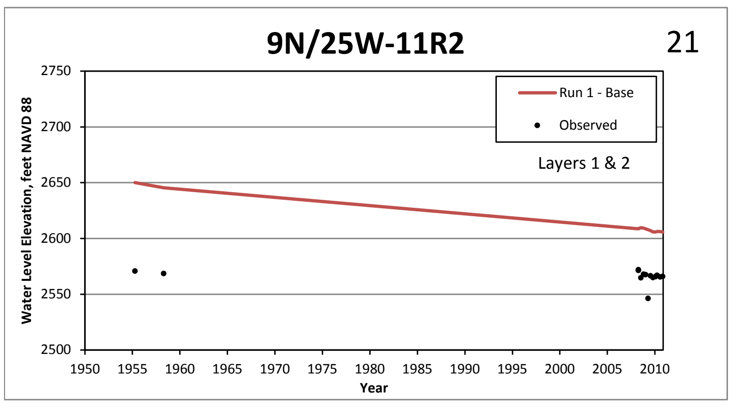


CENTRAL SIERRA MADRE FOOTHILLS



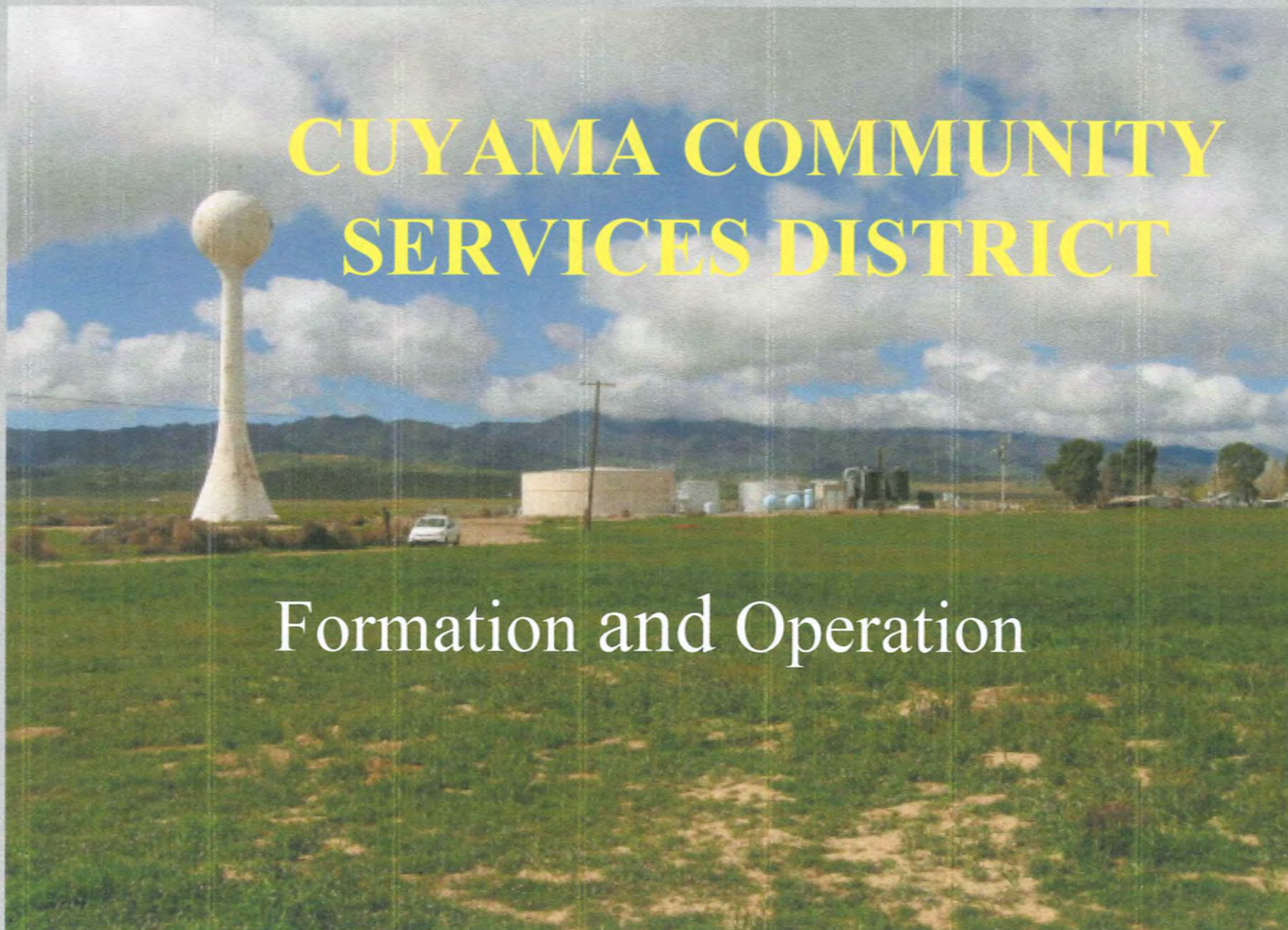


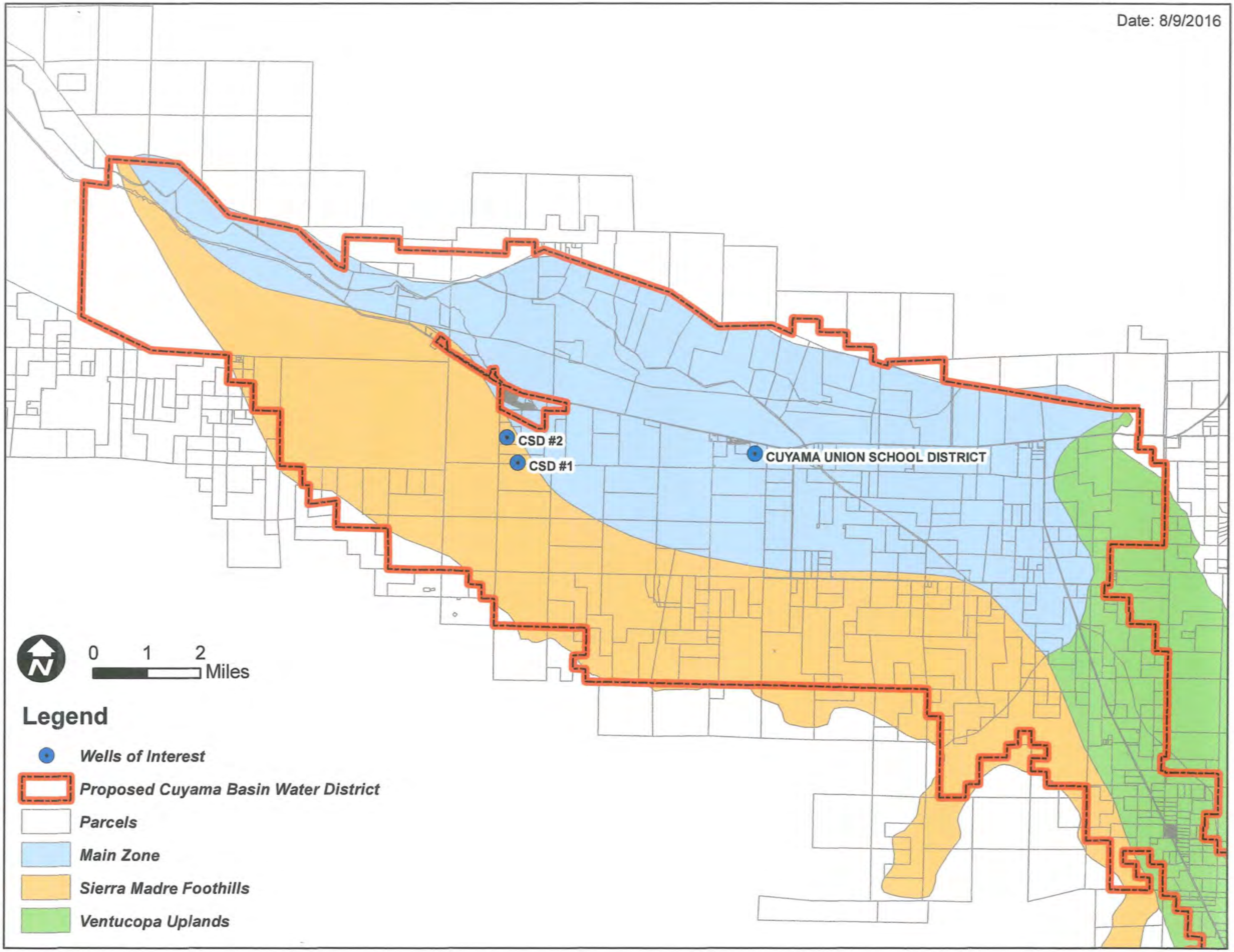
SOUTHERN SIERRA MADRE FOOTHILLS



APPENDIX D

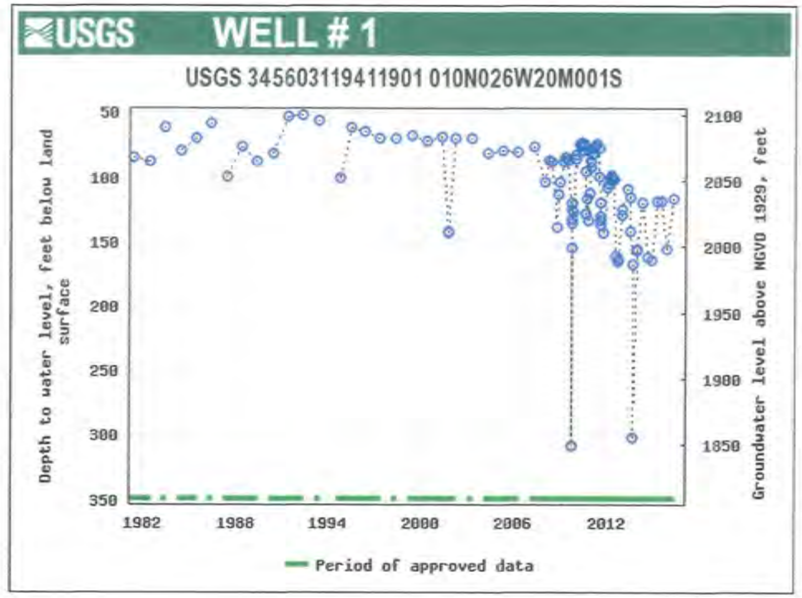
Selected Figures from Cuyama Community Services District Presentation


CUYAMA COMMUNITY
SERVICES DISTRICT
Formation and Operation



Date: 8/9/2016
CSD #2
CSD #1
CUYAMA UNION SCHOOL DISTRICT
0
1
2
Miles
N
Legend
Wells of Interest
Proposed Cuyama Basin Water District
Parcels
Main Zone
Sierra Madre Foothills
Ventucopa Uplands

Wells have been stable over last 25 years but have shown recent drop of about 30 feet in water level since 2012. DAC grant funded hydrological study will help to identify the aquifer characteristics



Well #2 suffered significant damage while pump and motor were being removed. Plan to drill new larger diameter well over damaged casing and to either retrieve motor or force it to the bottom of the well.