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2 Basin Setting

The Basin setting section is made up of the hydrogeologic conceptual model; the current and historical groundwater conditions; the water budget for the Yolo Subbasin; and the description of the six Subbasin management areas. This section provides the local and regional details as context for defining reasonable sustainable management criteria and projects and management actions for the Yolo Subbasin.

2.1 Hydrogeologic Conceptual Model (HCM)

2.1.1 Basin Regional Setting

The Yolo Subbasin is located in California, USA, in the southwestern side of the Sacramento Valley Groundwater Basin and is roughly 27 miles wide from west to east and up to 45 miles long from north to south (**Figure 2-1**). The western portion of the Yolo Subbasin is bounded on the west by the uplifted, mountainous coast range consisting of marine sedimentary rocks, while the eastern boundary is the Sacramento River. The middle of the basin is mostly alluvium, with relatively flat alluvial fans from the Cache Creek and Putah Creek drainages, with other areas of alluvium in the north from smaller Coast range drainages. The Capay Hills are in the northwestern corner of the Subbasin and are an "inselberg" or island of marine rocks that are excluded from the Yolo Subbasin. Between the Coast Range and the Capay Hills is situated the Capay Valley, a complex mix of alluvium and hardrock aquifers with Cache Creek running through it.

2.1.2 Subbasin Extent and Boundaries

The Yolo Subbasin boundary was updated and subsequently approved by DWR in 2016 and 2018 through jurisdictional basin boundary modifications so that the Subbasin boundary more closely matched the political administrative boundaries of Yolo County. The 2016 modification consisted of consolidation of the Capay Valley (5-21.68) and portions of the Colusa (5-21-52), Yolo (5-21.67), and Solano (5-21.66) subbasins that lie within Yolo County. The 2018 modification consisted of extending the southeastern boundary to the Sacramento River to include several reclamation districts. The 2018 modifications also included boundary adjustments along the Yolo County line.

2.1.2.1 Lateral Subbasin Boundaries

The Yolo Subbasin is adjacent to five other subbasins within the Sacramento Valley Basin, as discussed below and shown in **Figure 2-1**.

2.1.2.1.1 Adjacent Subbasins

- Colusa Subbasin

  The Colusa Subbasin is located north of Yolo Subbasin. These subbasins are separated by the boundary between Yolo and Colusa Counties, except for a small area (2.3 square miles [sq. mi.]) of the Colusa County Water District that extends south of the county line, west of Interstate 5.

- Sutter Subbasin

  The Sutter Subbasin is located along the northeastern portion of the Yolo Subbasin. These subbasins are separated by the boundary between Yolo and Sutter County, which is coincident with the Sacramento River. This boundary extends downriver until the confluence with the Feather River.

- North American Subbasin

  The North American Subbasin is located along the eastern, central portion of the Yolo Subbasin. These subbasins are separated by the Yolo and Sacramento county line, which is also coincident with the Sacramento River.

- South American Subbasin

  The South American Subbasin is located along the southeastern portion of the Yolo Subbasin. These subbasins area separated by the Yolo and Sacramento county line, which is mostly coincident with the Sacramento River but shifts to Sutter Slough for the last two miles.

- Solano Subbasin

  The Solano Subbasin is located along the southern/southwestern boundary of the Yolo Subbasin. These subbasins are mostly separated by the boundary between Yolo and Solano Counties. The Yolo Subbasin extends into small areas of Solano County, including a 3.8-sqmi area bounded by Miner Slough at its southeastern corner and a 2-sqmi area of the University of California, Davis. (The Solano Subbasin extends into Yolo County in three small areas (4.8 sq. mi. total) to the south of Davis and are related to the jurisdiction of two reclamation districts.)

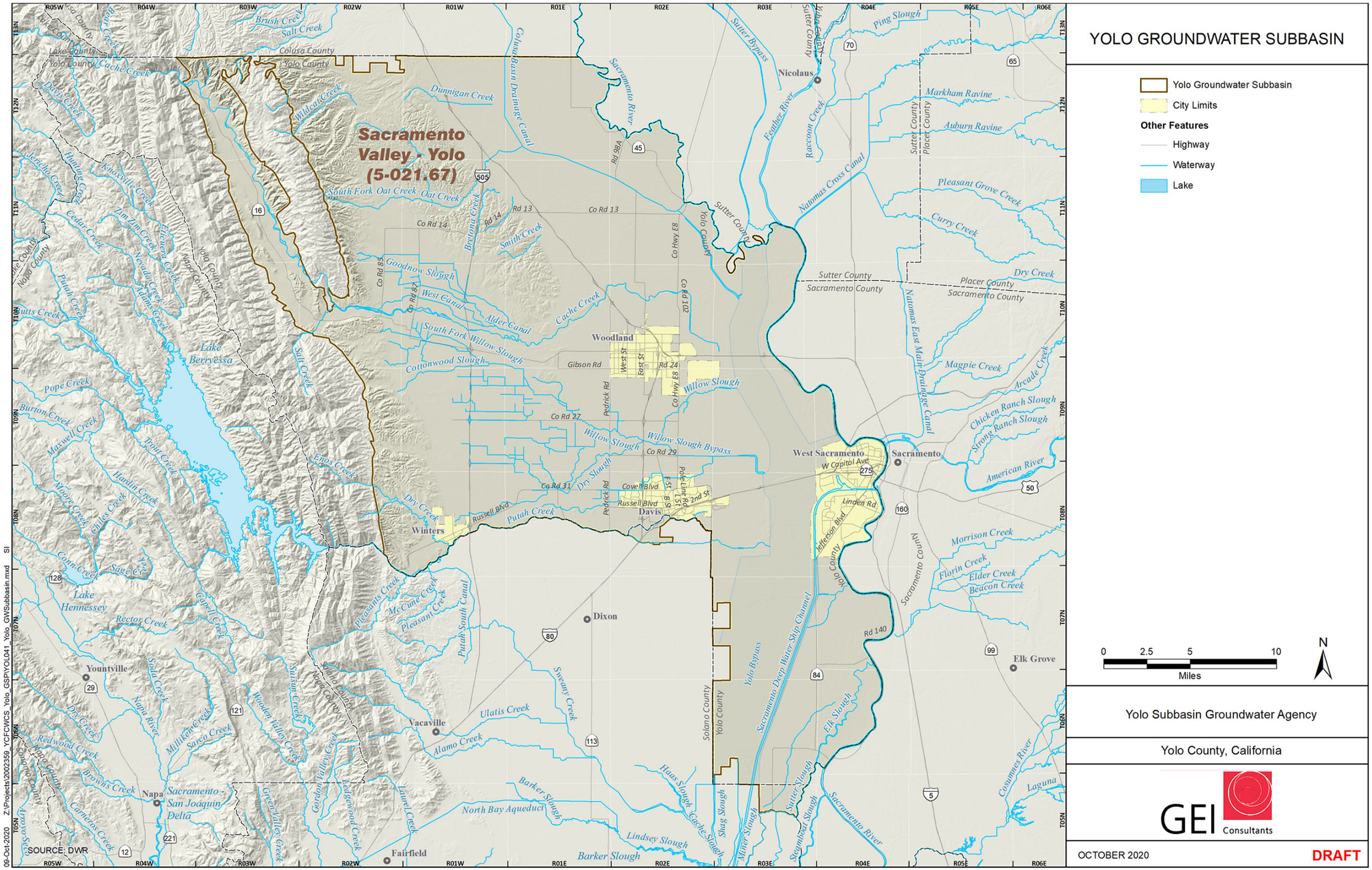


Figure 2-1. Yolo Subbasin Boundaries

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2.1.2.1.2 Physical Subbasin Boundaries

The western boundary of the Yolo Subbasin abuts the Coast Range which is comprised of Upper Cretaceous marine sedimentary and metasedimentary rocks (Ku), including sandstone, shale, and conglomerate (C.W. Jennings, 1977). The consolidated nature of these rock limits infiltration of precipitation, which produces runoff that flows eastward into the Yolo Subbasin. As such, higher groundwater levels are present along the western boundary of the Subbasin, which produces a general easterly direction of groundwater flow. The Capay Hills are a north-south trending ridge of marine rocks (Ku) near the northwestern corner that isolate Capay Valley from the main part of Yolo Subbasin. As such, Capay Valley is a small tributary groundwater body to Yolo Subbasin.

2.1.2.1 Vertical Subbasin Boundaries – Bottom of the Subbasin

The bottom of the Yolo Subbasin has been defined by the base of fresh groundwater as shown by **Figure 2-2** (LSCE, 2004). The base of fresh groundwater was defined as specific conductance measurements less than 3,000 micromhos per centimeter (µmhos/cm) (Olmsted and Davis, 1961). The deepest area of fresh groundwater is located in the southernmost part of the Subbasin at an elevation of below -3,000 feet mean-sea-level (msl). The depths are somewhat less at more than -2,500 feet msl in a broad, north-trending area beneath Davis and Woodland that extend further north toward Zamora. A narrow north-trending trough with a bottom elevation of -2,500 feet msl is present on the east side of Winters and extends northward toward Esparto. These north-trending features area consistent with the structural fabric of the Sacramento Valley. Bottom elevations increase quickly on the west side of the narrow trough to greater than -1,000 feet msl while bottom elevations increase more gradually elsewhere in the Subbasin. Bottom elevations vary between -1,500 and -2,000 feet msl along the eastern boundary of the Subbasin and between -1,000 and -2,000 along the northern boundary.

The base of fresh groundwater is several hundred feet above the base of the post-Eocene continental deposits, which are generally equivalent to the base of the Tehama Formation (Page, 1974).

2.1.3 Principal Aquifers and Aquitards

The hydrogeology of the Yolo Subbasin was described in 2004 by Ludhorff & Scalmanini Consulting Engineers (LSCE) in their report: *Groundwater Monitoring Program, Data Management System, and Update of Groundwater Conditions in the Yolo County Area*, and the following sections are essentially quoting that text.

The report divided the aquifer system, consisting of alluvium and the upper Tehama Formation, into three zones: shallow, intermediate, and deep zones, which are described below. The three zones were delineated by LSCE through "rough correlation of geologic units and on water well completion depths" (LSCE, 2004).

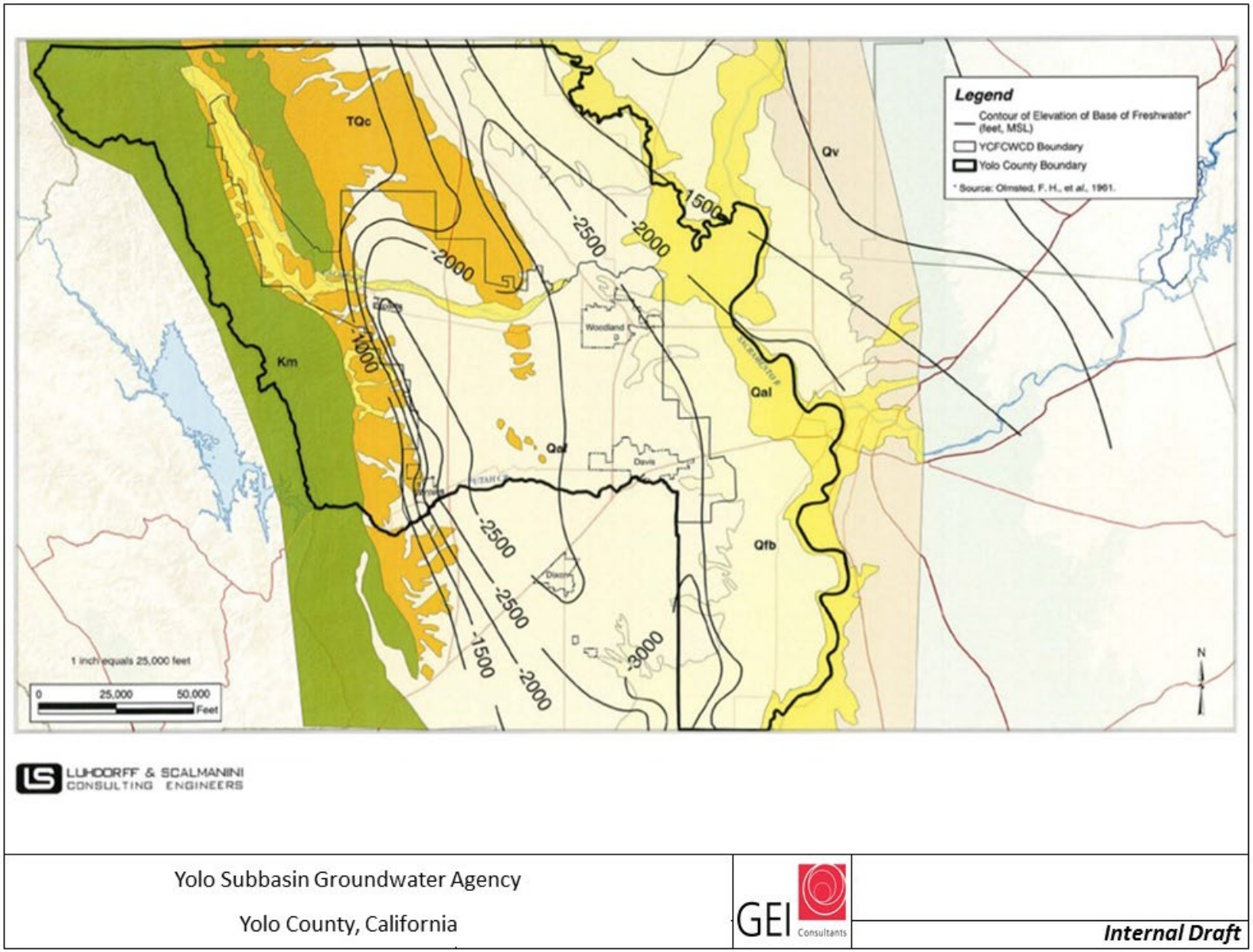


Figure 2-2. Elevation of the Base of Freshwater

2.1.3.1 Shallow Zone

The shallow zone extends from the surface to a depth of about 220 feet below ground surface (bgs) and consists predominantly of alluvium as well as the upper portion of the Tehama Formation. The deposits consist of thick sand and gravel deposits within a mile or two of the major sediment sources of Cache and Putah Creeks. The coarse beds appear to thin laterally from the present stream channels with thinner distributary channel, and sheet flood sand deposits occurring under the more distal alluvial plains.

Well yields can be relatively high where thick channel deposits are encountered with yields of several hundred to 1,500 gallons per minute (gpm). Specific capacities range up to 100 gpm per foot of drawdown or greater in this setting. More modest production (e.g., up to 500 gpm yields) likely results from wells constructed in thin sands that are more distant from stream channels and have lower specific capacities. Wells completed in even just a few thin sand beds produce sufficient quantities for domestic use.

2.1.3.2 Intermediate Zone

The intermediate zone extends from depths of about 220 to 600 feet-bgs and occurs exclusively within the upper Tehama Formation. These deposits are believed to be largely alluvial plains with distributary channel and sheet flood sands interbedded in silts and clays. These deposits are believed to be slightly more consolidated than the shallow zone, although the coarser beds may remain loose.

Well yields appear to be high for eastern areas with ranges of 500 to 1,000 gpm where thick sands are encountered. Wells yields in the western alluvial plain area appear to be lower and range from about 100 to 500 gpm where thick sands are encountered. In this area, a higher percentage of test holes may not encounter sufficient sand to provide desired production well yields. Specific capacities for wells completed in the intermediate zone are comparatively lower than those for the shallow zone. Intermediate zone wells in the western alluvial plain likely have poor to low yields due to the lack of sand beds, in comparison to wells in the eastern alluvial plain. However, thick sand beds are less prevalent in the intermediate zone than the shallow zone.

2.1.3.3 Deep Zone

The deep zone extends from depths of about 600 to 1,500 feet-bgs and encompasses the deeper upper Tehama Formation (Els, Elus, D sands, and F sands). These sands sequences are believed to be of central fluvial origin in eastern Yolo County.

Well yields appear to be high in the eastern area where thick or numerous sand beds or sand sequences are encountered. Well yields of 1,000 to 3,000 gpm are not uncommon. However, if sand sequences with low sand content are encountered, supply wells may not be feasible. Specific capacities for deep zone wells completed in thick sand sequences appear to be about 20 to 30 gpm/foot. The deeper (below –1,500 feet elevation) lower Tehama Formation is not utilized by water wells in Yolo County.

2.1.3.4 Aquifer Properties

A finite element numerical model was established for the Yolo Subbasin in 2006 by Water Resources Information Management Engineering, Inc. (WRIME) using the Integrated Groundwater Surface-Water Model (IGSM). As detailed in **Table 2-1**, the aquifer system was represented by three layers which generally correspond to alluvium in the shallow zone (#1), upper Tehama Formation or intermediate and deep zones (#2) and the lower Tehama Formation or deepest zone (#3).

Table 2-1. Summary of Aquifer Parameters Data in the Yolo Subbasin IGSM (WRIME 2006)

Zone (Layer)	Location/General Area	Transmissivity feet^2/day	Hydraulic Conductivity feet/day	Storage Coefficient unitless
Shallow (1)	Yolo County	3,000 to 46,000		7.3E-02
	RD 108	26,000 to 52,000	13 to 67	8.0E-02 to 9.0E-02
	RD108, RD 787, RD730, Yolo-Zamora WD	26,000 to 65,000	64	6.0E-02 to 1.2E-01
	Yolo-Zamora WD	9,000 to 26,000	48	7.0E-02 to 9.0E-02
	Woodland	10,000 to 105,000		3.1E-02
	Cache Creek above Moore's Siphon	25,000 to 260,000		
	Knights Landing Ridge Drainage District	26,000 to 52,000	21	6.0E-02 to 1.1E-01
Intermediate & Deep (2)	Dunnigan WD	5,600 to 13,000		9.0E-04 to 2.3E-03
	Yolo County			6.5E-02 to 7.2E-02
	RD108, RD 787, RD730, Yolo-Zamora WD	26,000 to 65,000	19 to 119	6.0E-02 to 1.2E-01
	Yolo-Zamora WD	9,000 to 26,000	41 to 118	7.0E-02 to 9.0E-02
	Davis	4,000 to 18,000		
	Capay Valley	9,000 to 10,000		
	Cache Creek below Moore's Siphon	1,000 to 18,000	400	
	Knights Landing Ridge Drainage District	26,000 to 52,000	21 to 139	6.0E-02 to 1.1E-01
Yolo County IGSM				
1	Model-wide		8 to 38	5.0E-02 to 9.0E-02
2	Model-wide		4 to 20	5.0E-02
3	Model-wide		1 to 20	5.0E-02

Similarly, RMC Water and Environment (formerly WRIME) utilized IGSM for a 5-layer simulation of groundwater flow in the Capay Valley (RMC, 2016), see **Table 2-2**. Layers 1 and 2 in Capay Valley represent the shallow zone, while layers 3 and 4 represent the intermediate and deep zone, and layer 5 is the deepest zone.

The following tables summarize the available aquifer properties from these various agencies and/or the two models. As defined by Heath (1983), aquifer properties include

- Hydraulic Conductivity (K): Volume of water that will move through material during a unit amount of time under a unit gradient through a unit area. Units are typically gallons per day per square foot or feet per day.
- Transmissivity (T): Capacity of material to transmit water and is equal to the product of hydraulic conductivity and thickness. Units are typically gallons per day per foot or square feet per day.
- Storage Coefficient (S): Volume of water that is released from or takes into storage per unit surface area per unit change in water level (head). No units.
- Specific Yield (SY): Amount of water that will drain from material under the influence of gravity. Unit is % volume.

Table 2-2. Parameters by Layer for Yolo Subbasin IGSM (WRIME 2006)

Yolo Subbasin Zone (Equivalent IGSM Layer)	Capay Valley Layer	Hydraulic Conductivity feet/day	Storage Coefficient unitless	Specific Yield
Shallow (1)	1	25 to 50	1E-02	15%
	2	10	1E-02	10%
Intermediate & Deep (2)	3	1	8E-03	8%
	4	4	8E-03	8%
(3)	5	2	5E-03	5%

Figure 2-3 indicates that the aquifer system is comprised of mostly sand with some gravel in the intermediate and deep zone. The IGSM values were similar to agency values for the shallow zone but were somewhat less for the intermediate and deep zone, and the Capay Valley model values were less than the Yolo County model.

Finer-grained layers (silt and clay) undoubtedly exist with the Subbasin and the respective hydraulic properties would be notably less than the coarse-grained layers (gravel and sand). However, well are not typically installed (screens) in the fine-grained layers so hydraulic properties have not been measured directly.

Groundwater within the Subbasin occurs under water table or unconfined conditions in the shallow zone and possibly semi-confined conditions and semi-confined confined conditions with increasing depth.

2.1.4 Topography

The topography of the Yolo Subbasin is presented in **Figure 2-4** and is based on the USGS National Elevation Dataset. Detailed topographic information can be obtained from twenty-five 7.5-minute maps, as listed below, plus a tangential portion of the Glascock Mountain map.

Glascock Mtn	Rumsey	Wildwood School	Dunnigan	Kirkville		
	Guinda	Bird Valley	Zamora	Eldorado Bend	Knights Landing	Verona
	Brooks	Esparto	Madison	Woodland	Grays Bend	Taylor Monument
		Monticello Dam	Winter	Merritt	Davis	West Sacramento
					Saxon	Clarksburg
					Liberty Island	Courtland

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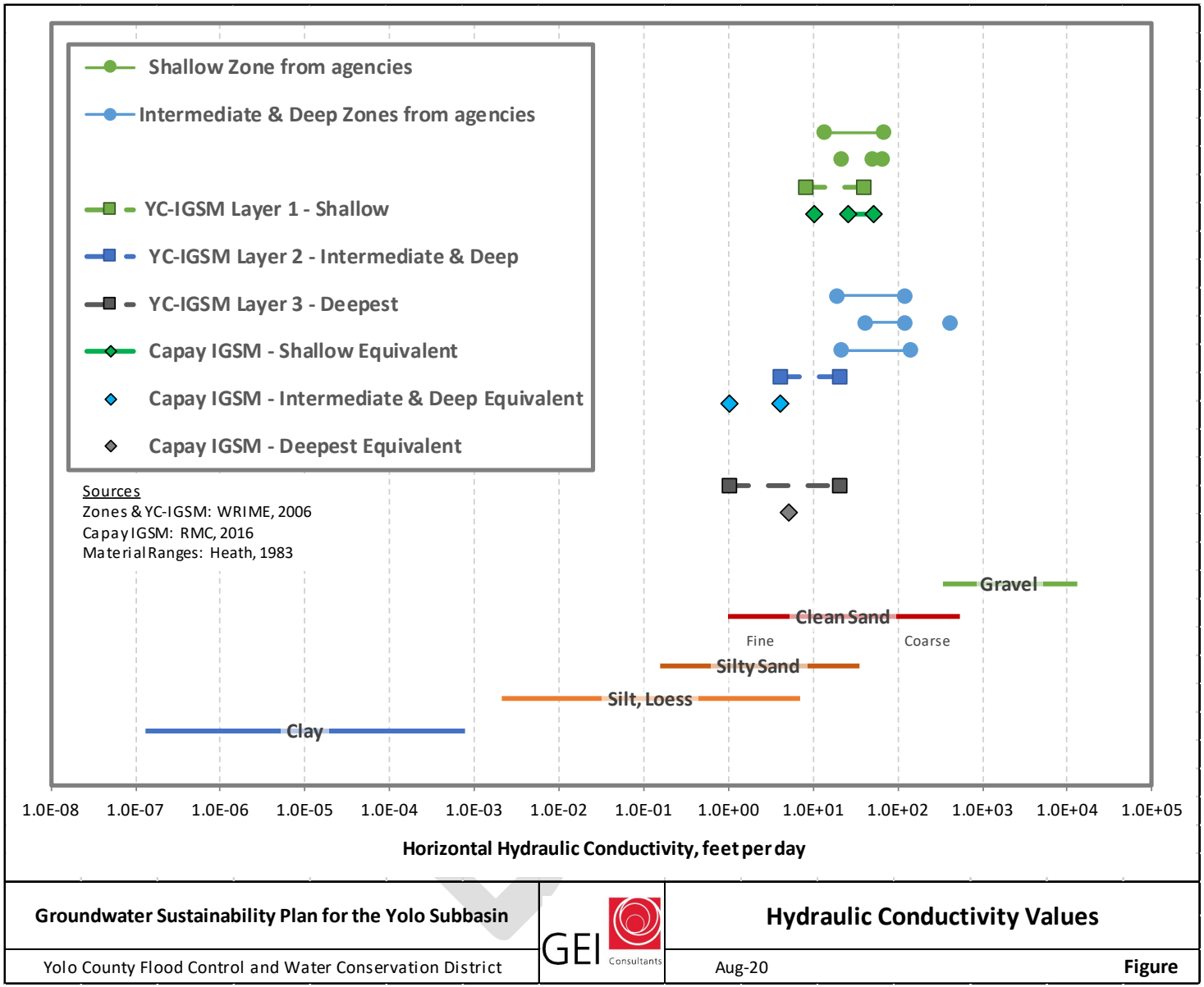


Figure 2-3. Hydraulic Conductivity Values for the Yolo Subbasin

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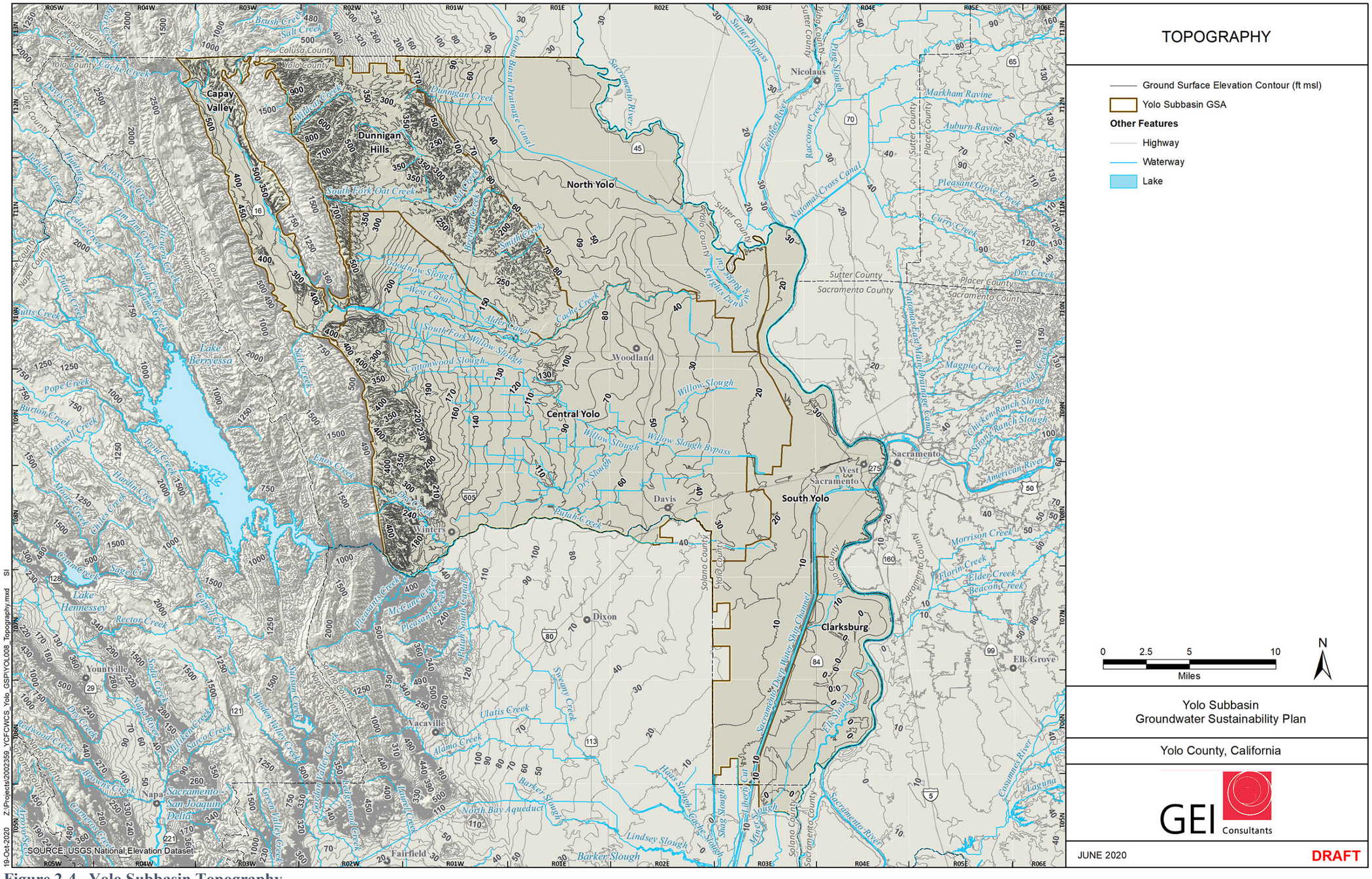


Figure 2-4. Yolo Subbasin Topography

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Ground elevations vary from mean sea level in the Clarksburg and South Yolo management areas (MA) to as over 1,740 feet above mean seal level (amsl) in the Capay Valley MA (Please refer to **Section 2.4** for description of Management Areas). The most rugged terrain occurs in the Dunnigan Hills MA and on the western side of the Central Yolo MA. The highest topographic relief occurs in the Capay Valley MA while the lowest relief occurs in the Clarksburg MA, as listed in **Table 2-3** below.

In general, the topography slopes in an overall easterly direction toward the center of the Sacramento Valley, except for Capay Valley MA where the topography slopes both east and west toward the center of the narrow valley which drains to the south into the Central Yolo MA.

Table 2-3. Summary of Surface Elevations in the Yolo Subbasin

Management Area	Maximum Contour	Minimum Contour	Relief (Difference)
Capay Valley	1,740	210	1,530
Dunnigan Hills	1,250	60	1,190
Central Yolo	880	20	860
North Yolo	220	20	200
South Yolo	40	0	40
Clarksburg	30	0	30

Figure 2-4 also shows the numerous creeks, canals, and sloughs that convey surface water within the Subbasin as well as the Sacramento River, which defines the eastern limit of the Yolo Subbasin. The majority of the surface water bodies are located in the Central Yolo MA, most notably Cache Creek and Putah Creek. The headwaters of these creeks are located in the mountainous terrain to the west of Subbasin and are sustained by Clear Lake and Lake Berryessa, respectively. As noted in a previous section, Putah Creek forms the southern boundary from the southwestern corner of the Subbasin to the City of Davis. Other notable surface water features include the Colusa Basin Drainage Canal in the North Yolo MA and the Sacramento Deep Water Ship Canal in the Clarksburg and South Yolo MAs. The southern Sacramento Valley, including the Yolo Subbasin, has been a tectonically subsiding sedimentary basin with accumulating nonmarine, continental deposits since middle Tertiary time (Miocene, 24 million years before present, [mybp]).

2.1.5 Geology

Considerable effort has been made over many years by numerous investigators to evaluate the geology and groundwater resources of the Yolo Subbasin. Most of this work has focused on the Central Yolo MA. Luhdorff & Scalmanini and Wood Rodgers (2004) provided a comprehensive assessment of this information and is utilized by this GSP. The following regional geologic setting is adapted largely from Harwood and Helley (1987), Page (1986), Hackel (1966), California Department of Water Resources [DWR] (1978), and the California Geological Survey (2010). **Figure 2-5** shows the regional geology of the area around the Yolo Subbasin and the following text provides a description of the groundwater-bearing formations. **Figure 2-6** provides a somewhat larger-scale map and shows the locations of cross sections from previous evaluations of the area.

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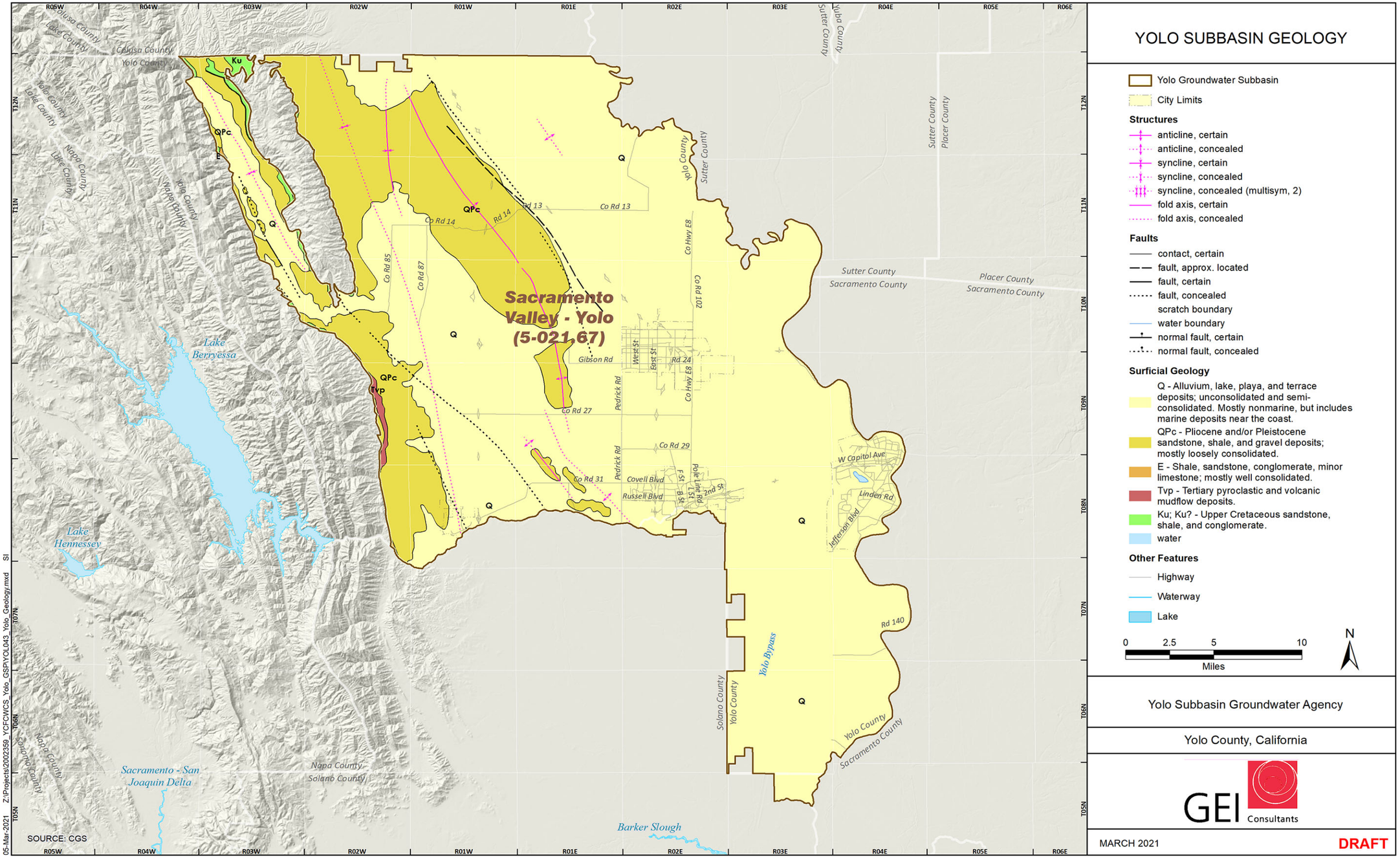


Figure 2-5. Geologic Map for the Yolo Subbasin

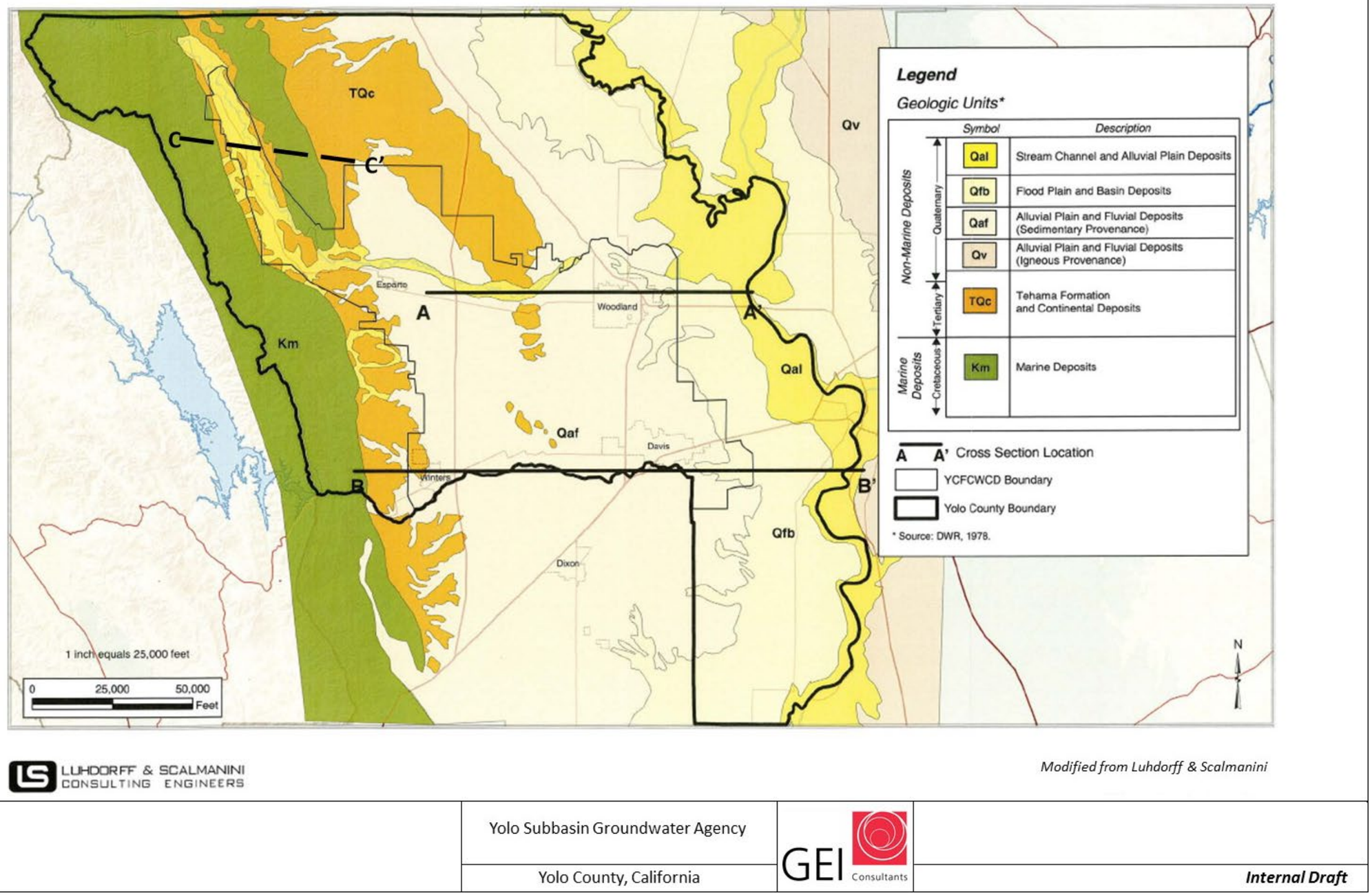


Figure 2-6. Location Map for Geologic Cross Sections

2.1.5.1 Geologic Formations

- Alluvium (Q) - The uppermost nonmarine deposit is the Pleistocene-Holocene alluvium and is 100 to 200 feet thick. The alluvium appears to be a complexly stratified sequence of unconsolidated**,** interbedded sands and gravels with fine-grained silts and clay beds. Coarser-grained deposits of sand and gravel typically occur adjacent to major stream channels like Cache and Putah Creeks. Thinner sand beds occur as alluvium plain and distributary channel deposits s across the areas of the western Subbasin. Separation of the alluvium from the underlying deposits is difficult because of their similar appearance and lack of distinctive marker characteristics. According to Helley and Harwood (1985), the alluvium is considered to be correlative to the Pleistocene Red Bluff, and younger Holocene alluvium deposits.

- Red Bluff Formation (Qrb) - The Red Bluff Formation overlies the Tehama Formation and consists of a thin, wide-spread pediment sand and gravel bed. The age of the Red Bluff is constrained by underlying and overlying aged-dated volcanic beds to between 1.09 mybp and 0.45 mybp (Harwood and Helley, 1987).

- Tehama Formation (TQc) [Upper and Lower] – The Tehama Formation is a non-marine deposit of poorly stratified silts and clay beds interbedded with thin to locally thick sand beds of alluvial plain to fluvial channel sediments. The deposition of the Tehama Formation occurred through the end of the Tertiary Period (Pliocene Epoch) and into the early Pleistocene (5.3 to 1.5 mybp). The formation has been divided into upper and lower units.

    - Upper Tehama Formation - The upper unit occurs from an approximate elevation of -1,500 feet below mean sea level (msl) to depths of 100 to 200 feet below ground surface in the center of the basin. The deposits were previously subdivided into layers called (deep to shallow): the E lower sands, the E lower-upper sands, E upper sands, D sands, and F sands by LSCE (2004). These layers are shown in the cross sections AA' and BB' below, **Figure 2-7** and **Figure 2-8** respectively.

    - Lower Tehama Formation - The lower unit occurs from the base of freshwater (about -3,000 feet msl) to the bottom of the upper unit (about -1,500 feet msl). The Lower Tehama Formation has not been utilized for water supply in Yolo County as the formation occurs below the depths of the deepest production wells. Pre-Pliocene nonmarine deposits are present beneath the lower Tehama Formation, but this contact cannot be identified in the subsurface due to the similar nature of the sediments. The lower unit has been subdivided into fluvial sand sequences: A, B, and C sands. These layers are shown in the cross sections AA' and BB' below (**Figure 2-7** and **Figure 2-8**, respectively). On the west half of the basin, beneath the A sand, a thick (400 feet) to thin, brackish to saline sandy bed (Z sand) has been identified which overlies the distinctly marine deposits and the Markley Gorge Fill. While this unit is below the base of freshwater, it appears to mark the transition to nonmarine deposition in this portion of the valley.

- Marine Deposits (Km) - Mesozoic marine rocks are present in the mountains to the west of the Subbasin and in the ridges that separate the Capay Valley from the main Yolo Subbasin. These rocks occur at depth beneath the Subbasin and extend eastward to pinch out and overlap onto the granitic and metamorphic basement rocks beneath the eastern Sacramento Valley. The marine rocks consist of well-consolidated sandstone and shales that are over 15,000 feet thick. These Mesozoic (and older Tertiary) rocks beneath the Sacramento Valley contain saline water from their original marine deposition.

Figure 2-7 and **Figure 2-8** are east-west cross sections along the northern (A-A') and southern (BB') boundaries of the Central Yolo MA. The cross sections show that the aquifer system extends to a depth of over 2,000 feet throughout much of the area and is over 3,000 feet thick within the center of the basin. The aquifer has been divided into three zones, including a shallow alluvial zone, an intermediate, and a deep zone. These latter two zones are part of the upper Tehama Formation. These three zones are known in the vicinity of the cities of Davis and Woodland and are likely present in much of the Subbasin. A fourth zone could be assigned to the lower Tehama Formation, but this zone has not been developed to much extent for groundwater production.

Figure 2-9 is a nominal east-west cross section (C-C') across the center of Capay Valley and was drawn by Wanger and Saucedo (1984) to illustrate the hard rock structure of the Capay Hills. The cross section shows approximately 1,000 feet of the Tehama Formation (and a veneer of alluvial deposits) within the valley of a syncline in the underlying Cretaceous rocks. The presence of the three groundwater zones has not been defined within the Capay Valley.

The Capay Hills to the east were formed by an anticline with the eastern limb extending beneath the North Yolo MA into a series of synclines and anticlines, as shown in **Figure 2-9**. Normal and reverse faults are present in the folded structures and a normal fault is shown to cut the Tehama Formation.

Other studies such as Yolo County Integrated Groundwater and Surface water Model developed in 2006 have reviewed driller's logs and created cross sections in many areas of the basin. They are shown in **Figure 2-10** for reference purposes and are not evaluated here.

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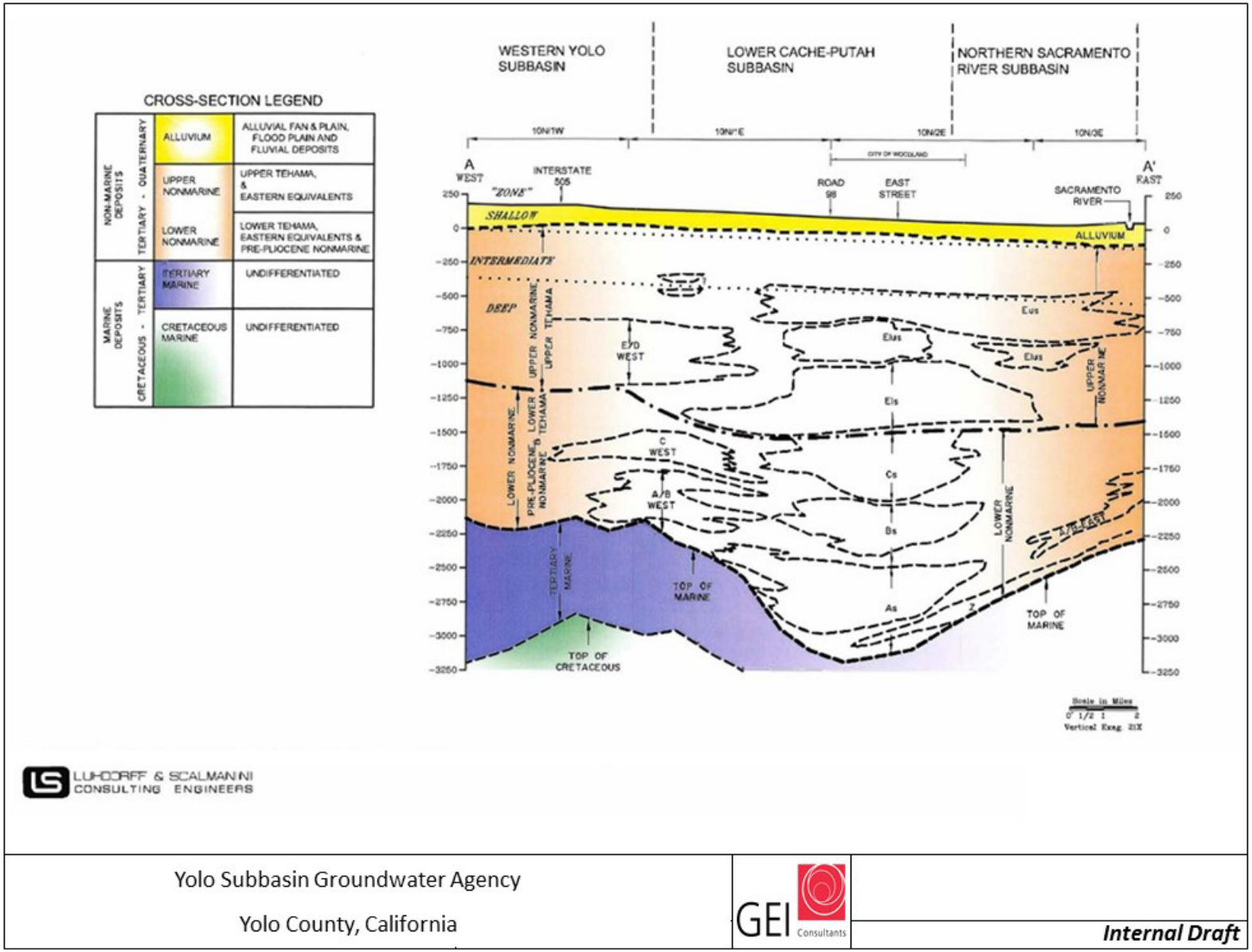


Figure 2-7. Geologic Cross Section A-A'

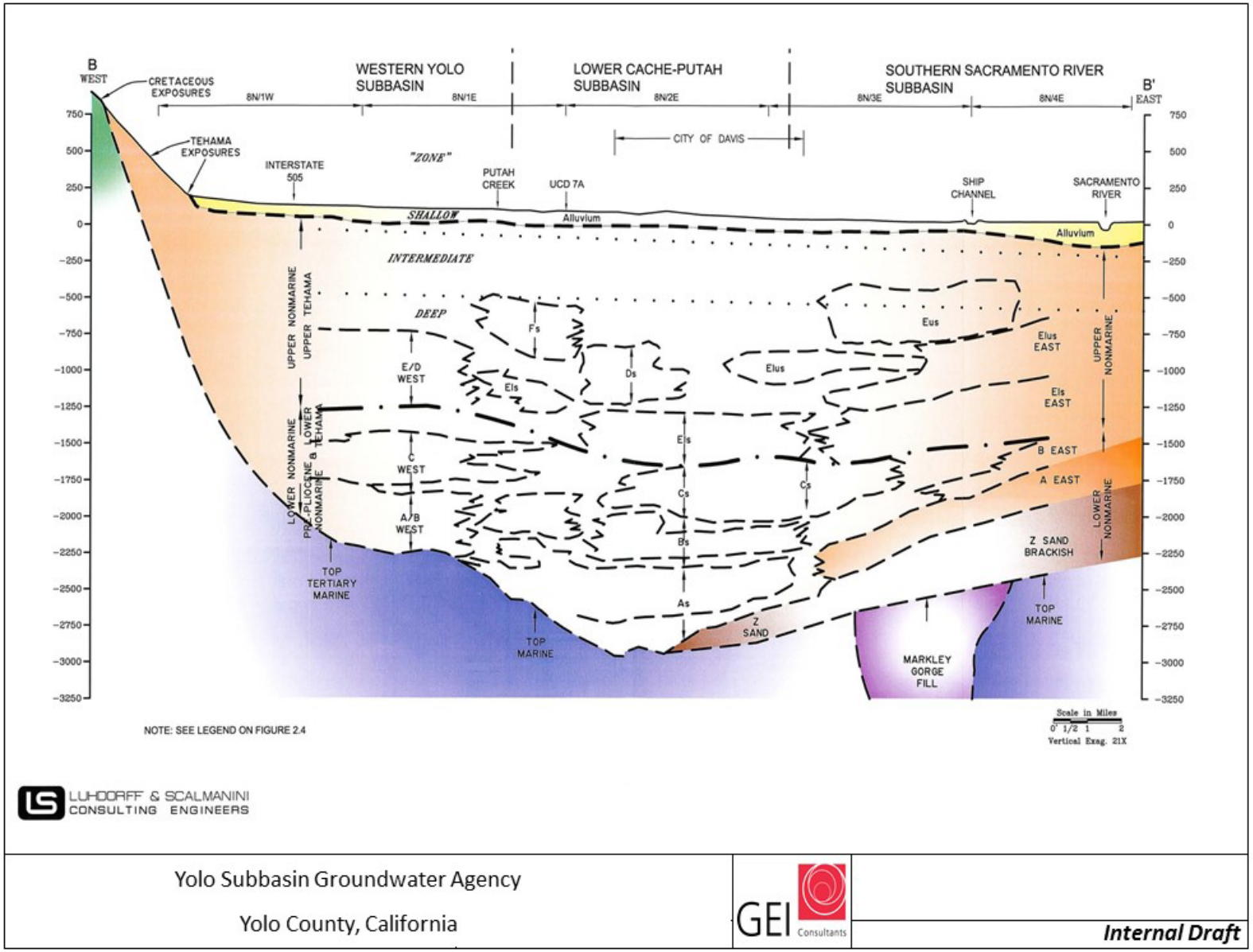


Figure 2-8. Geologic Cross section B-B'

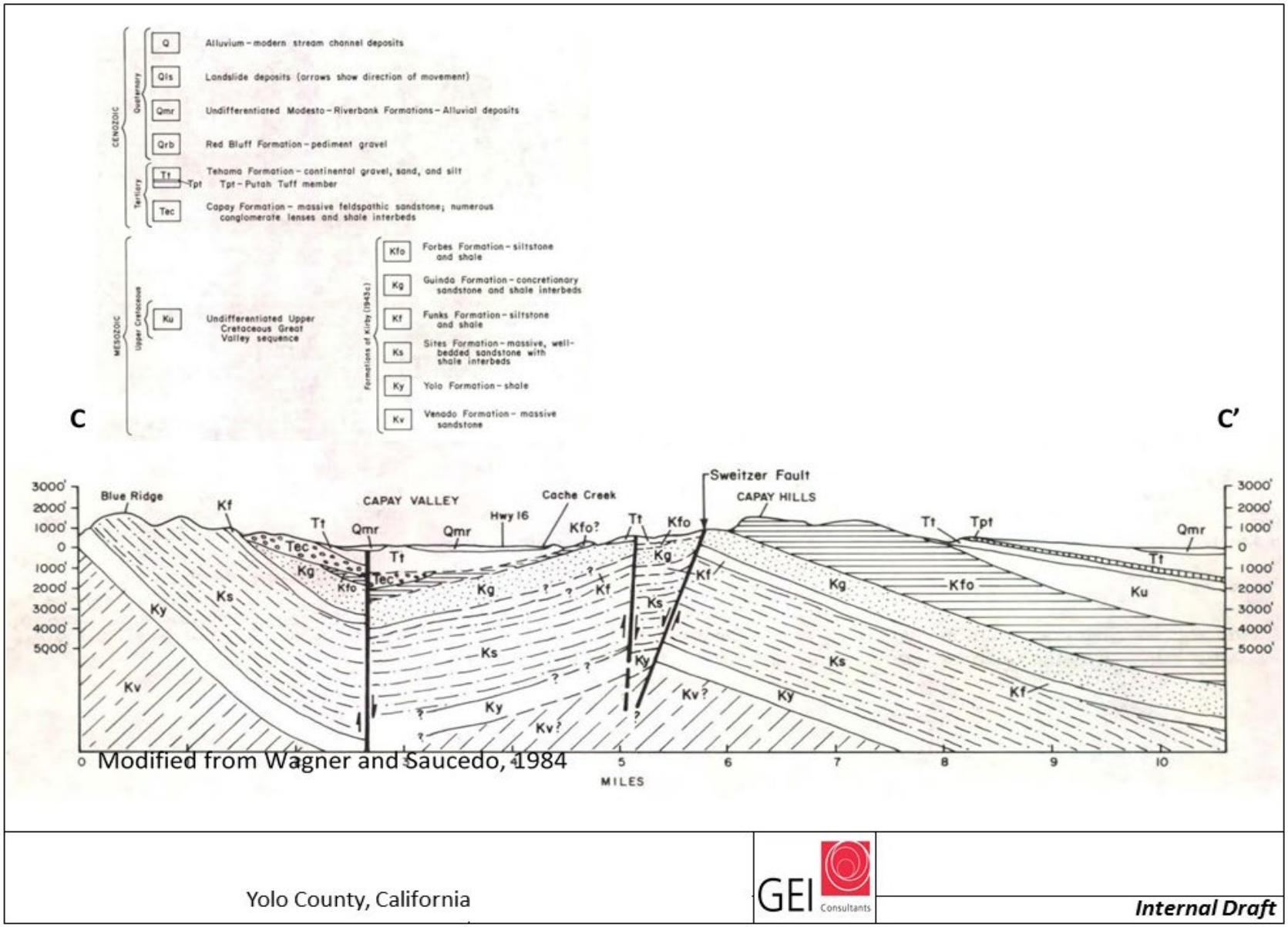


Figure 2-9. Geologic Cross Section C-C'

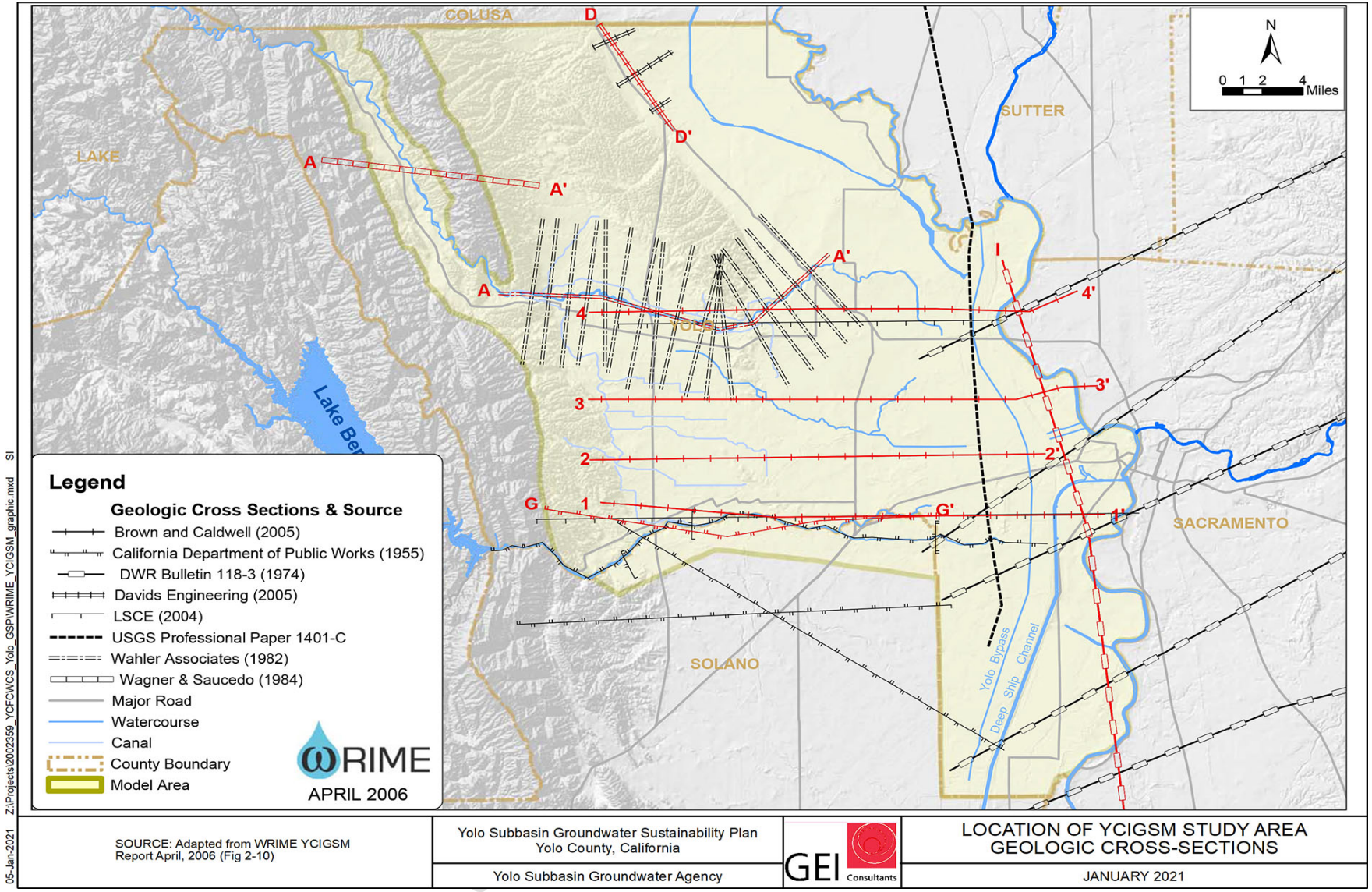


Figure 2-10. Geologic Cross Sections evaluated in Yolo County Integrated Groundwater and Surface Water Model

2.1.5.2 Structural Restrictions to Groundwater Flow

The Yolo Subbasin portion of the Sacramento Valley Basin has structural deformation that may restrict the flow of groundwater, as previously described by the YCIGSM model report (WRIME, 2006) and the Groundwater Monitoring Program (LSCE, 2004). The main features are the Madison syncline and the Dunnigan Hills/Plainfield Ridge anticline that trend north-south (WRIME, 2006).). As discussed in SCWA (2005),

The Plainfield Ridge (Ridge) consists of an upward bulging of the denser, less pervious Tehama geologic formation. The Ridge, which is barely visible at the surface of the ground, is oriented in a north - south direction and acts as a "cutoff wall", intercepting groundwater moving southeasterly… and directs the groundwater flow more southerly, toward the deeply incised Lower Putah Creek [and Cache Creek] stream channel[s], where it "daylights" and becomes part of the surface stream flow. The stream segment where these isolated pools historically occurred is commonly referred to as the "gaining reach" of Lower Putah [and Cache] Creek[s]."

Exposures of the Red Bluff Formation around and on top of Tehama Formation on the Dunnigan Hills and Plainfield Ridge, has been used to define the Pleistocene to present structural Dunnigan Hills domain. The domain consists of the reverse Zamora fault on the northeast edge of the Hills which offsets Tehama, Red Bluff, and alluvium; the doubly plunging Dunnigan Hills anticline; and the southeast plunging Madison syncline. South of the Dunnigan Hills, subsurface expression of the syncline and anticline in the Tehama Formation is difficult to discern due to lack of correlative stratigraphic units and a lower density of well control information (LSCE, 2004).

2.1.5.3 Soils

Information on soils within the Yolo Subbasin were obtained from the Soil Survey Geographic Database (SSURGO) of the Natural Resources Conservation Service (NRCS). The SSURGO data included two categories of information relevant to the GSP: taxonomic soil orders and hydrologic soil groups. Taxonomic data include general characteristics of a soil and the processes of formation while hydrologic data relate to the soil's ability to transmit water under saturated conditions and is an important consideration for hydrology and groundwater recharge. In addition, the Soil Agricultural Groundwater Banking Index (SAGBI) was developed by the University of California at Davis and provides a rating of suitability of the soils for groundwater recharge. SAGBI is based on the hydrologic soil groups but includes considerations for topography, soil surface conditions, and chemical limitations. The following section describes the soils of Yolo Subbasin.

2.1.5.3.1 Taxonomic Soil Orders

Of the 12 established taxonomic soil orders, five are present within the Yolo Subbasin, as listed below, and their distributions are presented in **Figure 2-11** and in **Table 2-4**. Descriptions below were taken from the *Illustrated Guide to Soil Taxonomy* (NRCS, 2015):

- Alfisols – Naturally fertile soils with high base saturation and a clay-enriched subsoil horizon. Alfisols develop from a wide range of parent materials and occur under broad environmental conditions, ranging from tropical to boreal. The movement of clay and other weathering products from the upper layers of the soil and their subsequent accumulation in the subsoil are important processes. The soil-forming processes are in relative balance. As a result, nutrient bases (such as calcium, magnesium, and potassium) are supplied to the soil through weathering and the leaching process is not sufficiently intense to remove them from the soil before plants can use and recycle them.

- Entisols – Young soils with little or no soil profile development. Entisols occur in settings where processes of erosion or deposition are happening at rates faster than those needed for the formation of soil horizons. Typical settings include steep, actively eroding slopes, flood plains that receive new deposits at frequent intervals, and shifting sand dunes. Entisols have not been in place long enough for soil-forming processes to create distinctive horizons.

- Inceptisols – Youthful soils with a weak, but noticeable, degree of profile development although the soil profile is no adequate for other soil orders. Inceptisols occur on relatively young geomorphic surfaces that are stable enough to allow some development of a soil profile. Typical settings include upland slopes, flood plains, and stream terraces, and are found in diverse settings but not in desert or very cold regions. Drainage for Inceptisols can vary from very poorly to excessive.

- Mollisols – Very dark-colored, naturally very fertile soils of grasslands. Mollisols develop from predominantly grasslands in temperate regions at midlatitudes and result from deep inputs of organic matter and nutrients from decaying roots, especially the short, mid, and tall grasses common to prairie and steppe areas. Mollisols have high contents of base nutrients throughout their profile due to mostly non-acid parent materials in environments (subhumid to semiarid) where the soil was not subject to intense leaching of nutrients.

- Vertisols – Very clayey soils that shrink and crack when dry and expand when wet. They are dominated by clay minerals (smectites) and tend to be very sticky and plastic when wet and very firm and hard when dry. Vertisols are commonly very dark in color and distinct soil horizons are often difficult to discern due to the deep mixing (churning) that results from the shrink-swell cycles. Vertisols form over a variety of parent materials, most of which are neutral or calcareous, over a wide range of climatic environments, but all Vertisols require seasonal drying.

- Alifols and Vertisols account for nearly half the soils in the Yolo Subbasin, followed by Inceptisols and Entisols, and then Mollisols as shown below. However, each management area exhibits a unique composition of soils

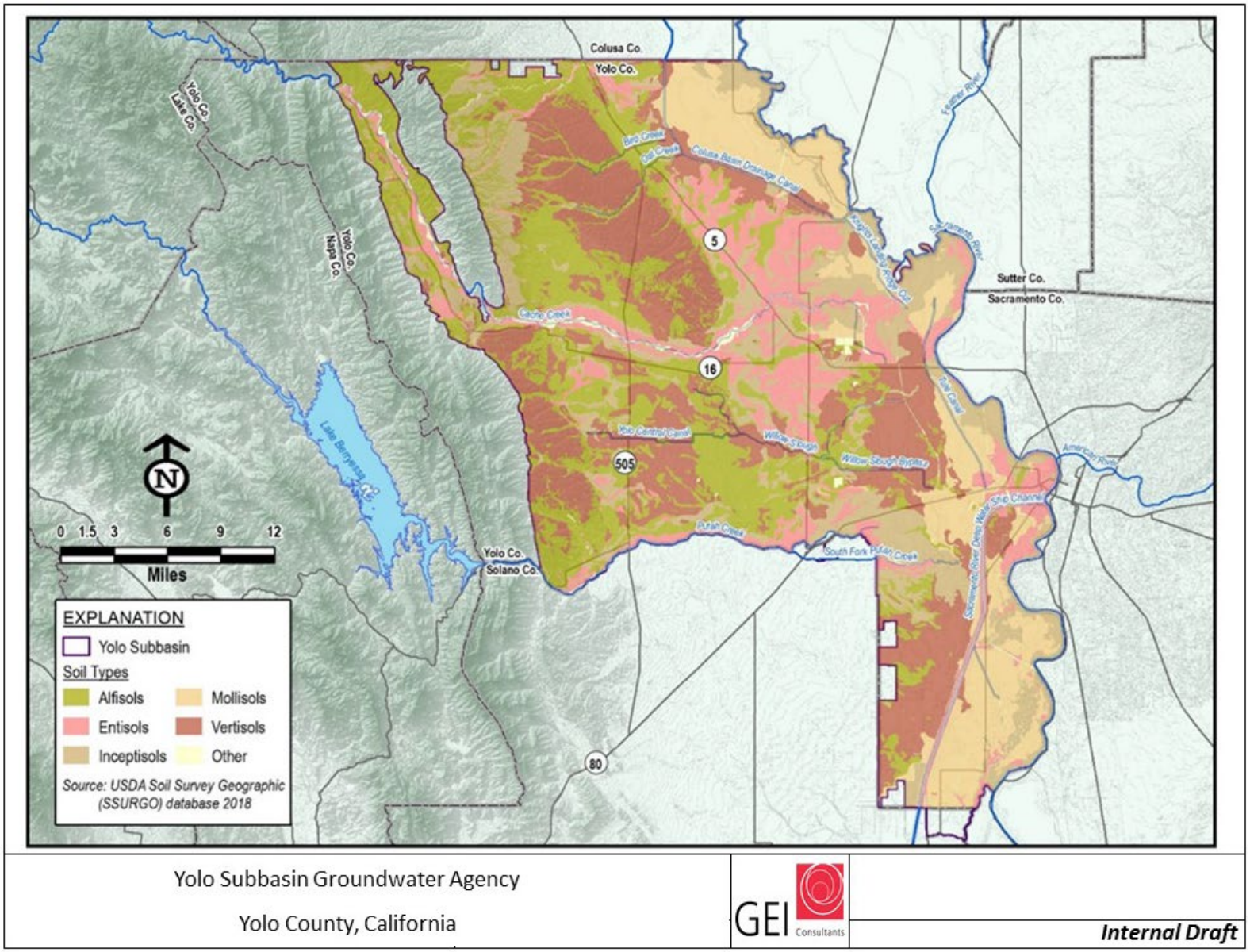


Figure 2-11. Soils in the Yolo Subbasin

Table 2-4. Distribution of Soils by Management Area in the Yolo Subbasin

		Management Areas					
Soil Order	Yolo Subbasin	Capay Valley	Dunnigan Hills	North Yolo	Central Yolo	South Yolo	Clarksburg
Alfisols	25%	48%	32%	16%	33%	8%	0%
Entisols	14%	17%	3%	20%	14%	17%	6%
Inceptisols	20%	30%	16%	23%	18%	22%	22%
Mollisols	14%	0%	0%	27%	2%	21%	71%
Vertisols	27%	4%	49%	13%	33%	32%	1%

2.1.5.3.2 Hydrologic Soil Groups

The NRCS Hydrologic Soils Group (HSG) classifications provide an indication of soil infiltration potential and ability to transmit water under saturated conditions, based on hydraulic conductivities of shallow, surficial soils. **Table 2-5** shows the distribution of the hydrologic soil groups, where higher conductivities (greater infiltration) are labeled as Group A and lowest conductivities (lower infiltration) as Group D. As defined by the NRCS (2012), the four HSGs are:

- Hydrologic Soil Group A – "Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures." Group A soils have the highest conductivity values (greater than 5.67 inches per hour [in/hr]) and therefore a high infiltration rate[1], and the greatest recharge potential.

- Hydrologic Soil Group B – "Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures. Group B soils have a wide range of conductivity values (1.42 in/hr to 5.67 in/hr), a moderate infiltration rate, and a moderate potential for recharge.

- Hydrologic Soil Group C – "Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures." Group C soils have a relatively low range of conductivity values (0.14 to 1.42 in/hr), a slow infiltration rate[2], and limited potential for groundwater recharge due to their fine textures.

[1] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey

- Hydrologic Soil Group D – "Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures. In some areas, they also have high shrink-swell potential." Group D soils have conductivity values less than 0.14 in/hr, a very slow infiltration rate, and a very limited capacity to contribute to groundwater recharge.

Table 2-5. Distribution of Hydrologic Soils Groups in the Yolo Subbasin.

		Management Areas					
HSG (Infiltration)	**Yolo Subbasin**	**Capay Valley**	**Dunnigan Hills**	**North Yolo**	**Central Yolo**	**South Yolo**	**Clarksburg**
A (high)	3%	3%	1%	4%	4%	0%	1%
B (moderate)	14%	14%	3%	27%	15%	12%	7%
C (slow)	**49%**	**60%**	**60%**	**34%**	**57%**	**49%**	19%
C / D	14%	1%	0%	26%	5%	15%	**70%**
D (very slow)	20%	22%	35%	10%	19%	24%	3%
High to Moderate	17%	17%	4%	31%	19%	12%	8%
Slow to Very Slow	83%	83%	96%	69%	81%	88%	92%

A dual hydrologic group (C/D) is assigned to an area to characterize runoff potential under drained and undrained conditions, where the first letter represents drained conditions and the second letter applies to undrained conditions. For the purposes of this GSP, these dual soils are considered to have a very slow infiltration rate.

Note that the NRCS develops these data using a variety of information, including remote sensing and some limited field data collection, and does not always capture variations that may occur on a small scale. Additionally, Group C and D soils may have slow infiltration rates due to shallow hardpan, and groundwater recharge could potentially be enhanced if this hardpan can be disrupted.

As shown in the following summary, most of the Yolo Subbasin (83%) has slow to very slow infiltration rates although each management area exhibits a unique proportion of classifications. The Dunnigan Hills MA has the largest proportion (96%) of soils with slow to very slow infiltration while the North Yolo MA has the smallest proportion (69%).

2.1.5.3.3 Soil Agricultural Groundwater Banking Index

The University of California at Davis (UCD) has established the Soil Agricultural Groundwater Banking Index (SAGBI), using data from the SSURGO database, and produces a rating of suitability of the soils for groundwater recharge. This index expands on the HSG to include topography,

chemical limitations, and soil surface condition. This effort has resulted in a mapping tool that illustrates six SAGBI classes (excellent to very poor) and has been completed for much of the state, although over 25% of the Yolo Subbasin was not assigned a SAGBI value. SAGBI values are not available for over half of the areas within the Capay Valley MA and Dunnigan Hills MA. Note that the SAGBI is a large-scale planning tool and does not preclude local site conditions that are good for groundwater recharge.

Table 2-6 shows the SAGBI distribution across the Yolo Subbasin. Overall, the Subbasin indices are mostly poor (moderately to very) as summarized below, while the management areas exhibit unique proportion of indices. Three MAs have very large proportions (+90%) of poor SAGBI values, including Dunnigan Hills Clarksburg and South Yolo, although the conditions in Dunnigan Hills MA are considerably different than the conditions in Clarksburg and South Yolo MAs. The Capay Valley MA appears to have the smallest proportion (54%) of poor SAGBI values but this condition might be related to the reduced acreage of values.

Table 2-6. SAGBI Distribution in the Yolo Subbasin.

		Management Areas					
SAGBI	Yolo Subbasin	Capay Valley	Dunnigan Hills	North Yolo	Central Yolo	South Yolo	Clarksburg
Excellent	4%	4%	2%	5%	4%	5%	6%
Good	11%	25%	3%	19%	12%	1%	3%
Mod Good	6%	17%	3%	5%	8%	4%	1%
Mod Poor	15%	27%	10%	11%	21%	10%	1%
Poor	**44%**	5%	3%	**51%**	**37%**	**66%**	**87%**
Very Poor	20%	22%	**79%**	10%	17%	15%	2%
Excellent to Mod Good	21%	46%	8%	29%	24%	9%	9%
Mod Poor to Very Poor	79%	54%	92%	71%	76%	91%	91%

2.1.6 Natural Recharge, Direct Recharge Areas, and Potential Recharge Areas

According to LSCE (2004), recharge to the shallow zone occurs from infiltration along Cache and Putah Creeks and the associated YCFCWQCD distribution system of unlined canals and laterals. Aquifer sand bodies are probably weakly connected to sand bodies surrounding the major streams. Recharge from the Sacramento River may occur along the northeastern boundary of the Subbasin (but the river could be a discharge area along the southeaster boundary). Additional recharge likely occurs by deep percolation of precipitation and irrigation waters. The shallow zone is probably unconfined, although local confinement in thin sands may occur where overlain by a thick flood clay sequence.

Recharge to the intermediate zone occurs generally through precipitation recharge at outcrop areas and by interconnection and leakage from the overlying shallow zone, including possibly from the Sacramento River, Cache Creek, and Putah Creek via the shallow alluvium. The Coast Range may transmit a limited amount of recharge to the intermediate aquifer along the interface between the fractured rock and the sedimentary basin. The intermediate zone may be unconfined in the upper portions of the zone, although local confinement occurs due to thick overlying clay, but probably becomes progressively confined with depth due to the additive effects of the variable fine/coarse stratigraphy.

Recharge to the deep zone beneath the eastern alluvial plain is believed to be from leakage from overlying aquifers, probably sourced from Sacramento River and Cache Creek to the north. The western alluvial plain deep zone is probably recharged from the overlying units and Tehama Formation outcrops to the west, especially those units associated with Cache and Putah Creeks. The deep zone is an increasingly confined system due to the presence of extensive overlying clay units and its overall depth.

2.1.7 Natural Discharge Areas

Natural discharge areas are limited within the Yolo Subbasin and the primary area is probably located along the Sacramento River in the southeastern portion of the Subbasin in the vicinity of the Delta. Several springs are present along the central east side of Capay Valley and at the mountain front east of Winters, and single springs are located at other locations along the mountain front and beyond the southeastern base of Dunnigan Hills. **Figure 2-11** shows the location of these springs based on the National Hydrography Dataset.

2.1.8 Surface Water Bodies

Surface water supplies in Yolo Subbasin include numerous creeks emanating from the Coast Range and foothills. These creeks flow eastward toward the Sacramento River, which is the eastern boundary of the Subbasin. Significant surface water courses include Cache Creek, Putah Creek, the Sacramento River, and the Colusa Basin Drainage Canal. **Figure 2-12** shows the location of these surface water bodies.

Precipitation and runoff strongly influence local hydrology. According to Scott and Scalmanini (1975) precipitation occurs in cyclonic storm fronts where most of the rainfall occurs during 6 to 12-hour periods. Topographic characteristics result in high percentages of runoff from the mountains and foothills and the potential for flooding.

The Yolo County Flood Control and Water Conservation District's (YCFCWCD) water supply system consists of Clear Lake and Indian Valley Reservoir, which are located west of the Subbasin in the Coast Range, and Cache Creek which conveys surface water to the Subbasin, plus groundwater within the Subbasin. The District manages two small hydroelectric plants, two reservoirs, more than

150 miles of canals and laterals, and three dams including the world's longest inflatable rubber dam (LSCE, 2006).

2.1.9 Source and Point of Delivery for Imported Surface Water

Importation of surface water occurs to a limited extent in the northeastern corner of the Yolo Subbasin via flows from the Colusa Basin Drain and from the Tehama-Colusa Canal. The Colusa Basin Drain enters the Yolo Subbasin from the north, east of I-5, and arches eastward to Knights Landing where it terminates with the Sacramento River. Similarly, the Tehama-Colusa Canal enters the Subbasin from the north, west of I-5 and skirts the base of the Dunnigan Hills to its abrupt termination three miles south of Dunnigan, near the intersection of I-5 and I-505. **Figure 2-13** shows the location of these conveyance structures.

Diversions from Sacramento River water are not considered importation because the Sacramento River flow along the eastern boundary of the Subbasin. Similarly, diversions from Cache Creek and Putah Creek are not considered importation of water because these creeks flow through the Subbasin and along the southwester boundary, respectively, even the headwaters are located in the mountains on the west side of the Subbasin. These surface water bodies are part of the natural hydrology of the Yolo Subbasin and should not be considered foreign to the Subbasin. While the use of reservoirs in the mountains changes the natural flow of the creeks and facilitates the management of this resource, the locations of the reservoirs in the mountains do not justify any designation as imported water.

2.1.10 Water Rights

A water right is a legal entitlement authorizing water to be diverted from a specified source and put to beneficial use. Based on the State Water Resources Control Board (SWRCB) water rights database, there are approximately 243 water right holders in the Yolo Subbasin. **Figure 2-14** shows the active points of diversion in the Yolo Subbasin.

2.1.11 Data Gaps in the Hydrogeologic Conceptual Model

Due to the Yolo Subbasin being redefined in 2016 and 2018 by combining portions of four different subbasins, additional research needs to be conducted to assess the connectivity of these different regions and the continuity of the three aquifer zones as described in this HCM.

The delineation of the different aquifer zones and their corresponding aquifer characteristics is the primary data gap of this HCM. More research is required to study the lithology in the uppermost 1,500 feet of the upper nonmarine deposits and to assess if any regional aquitards are present and create district separation between the different zones for groundwater management purposes.

The hydrogeology of the Dunnigan Hills area is not well defined due to the limited number of wells in the area and availability of data.

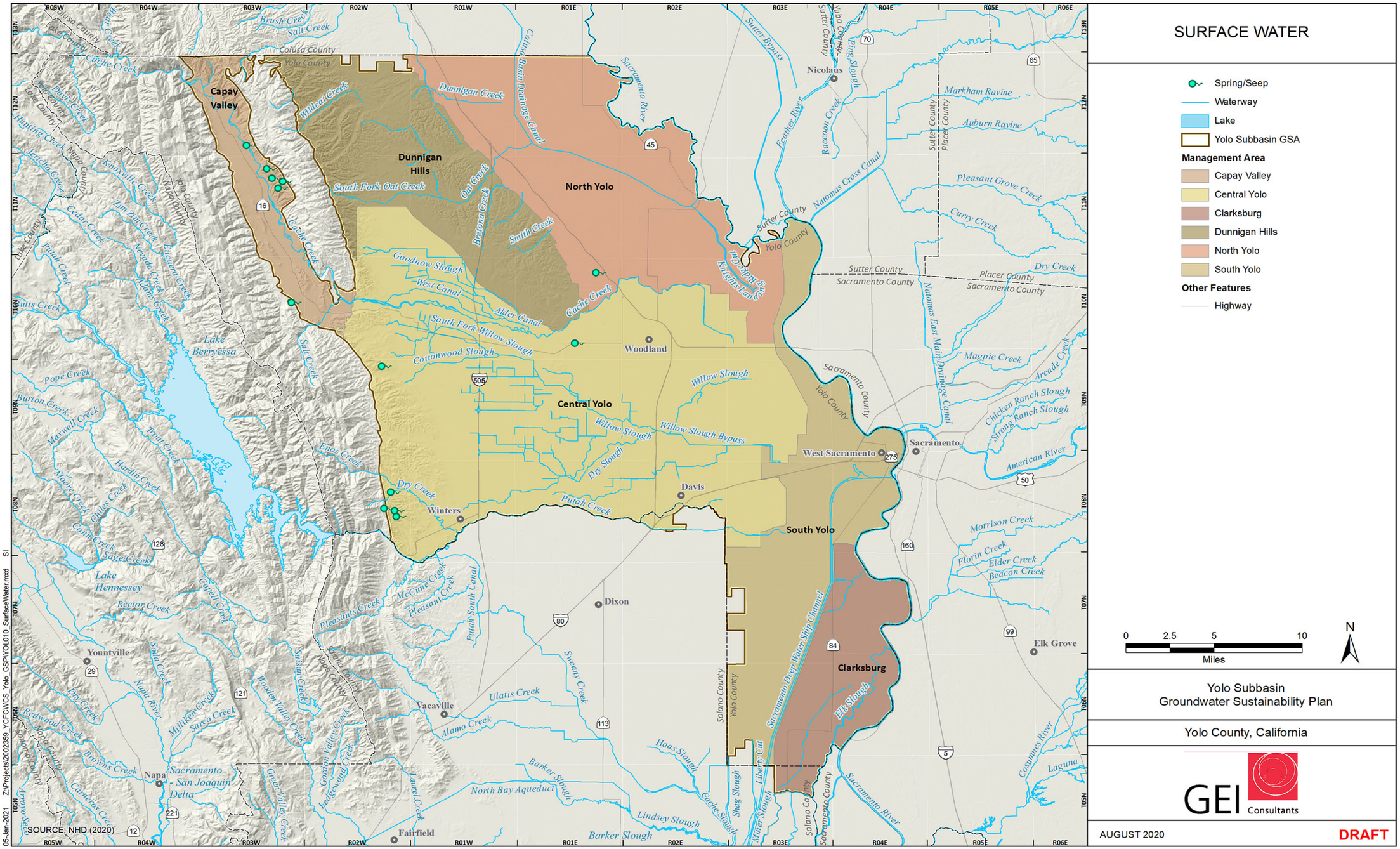


Figure 2-12. Surface Water Features and Springs in the Yolo Subbasin

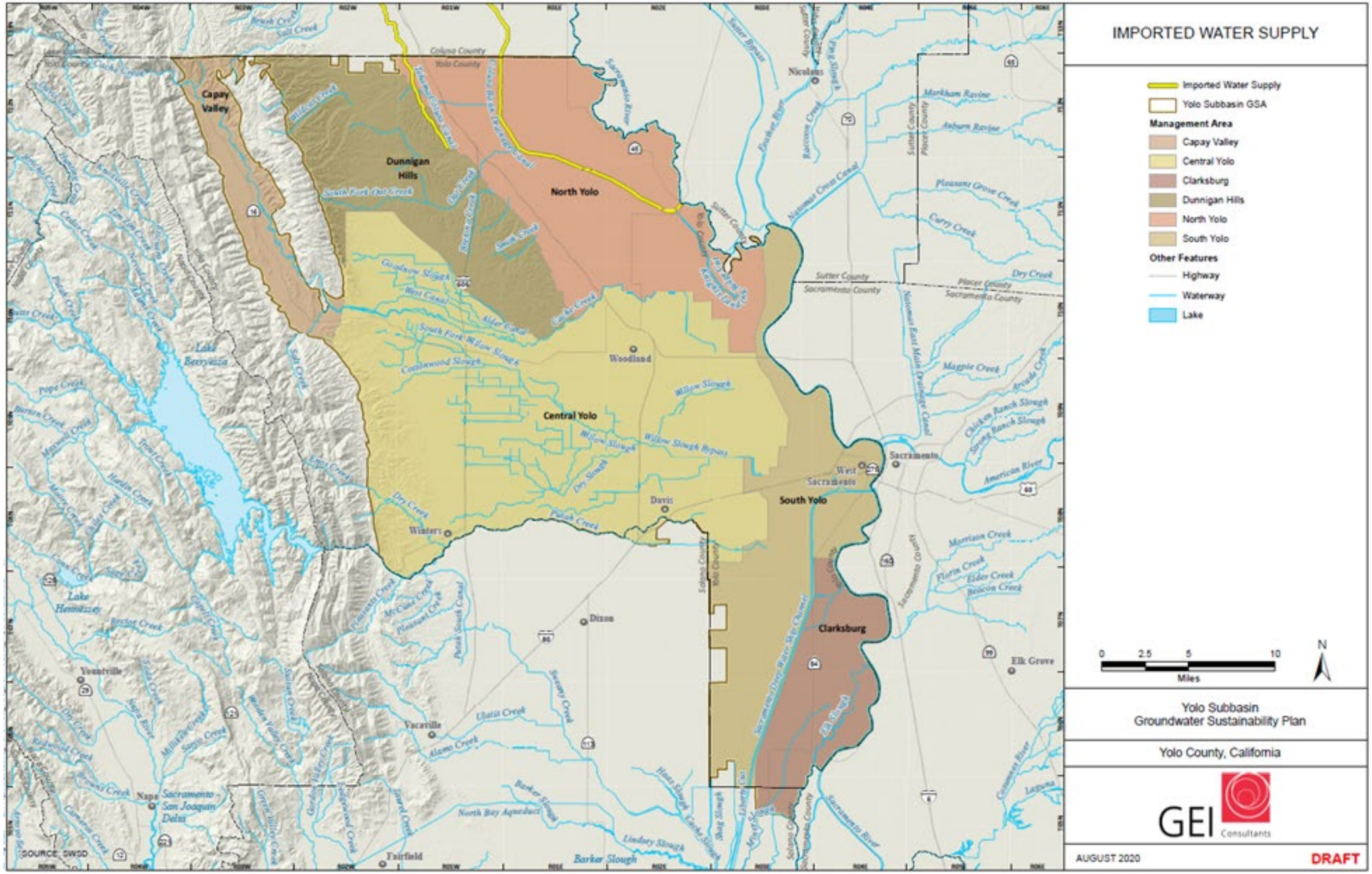


Figure 2-13. Location of Facilities for importation of Surface Water into the Yolo Subbasin

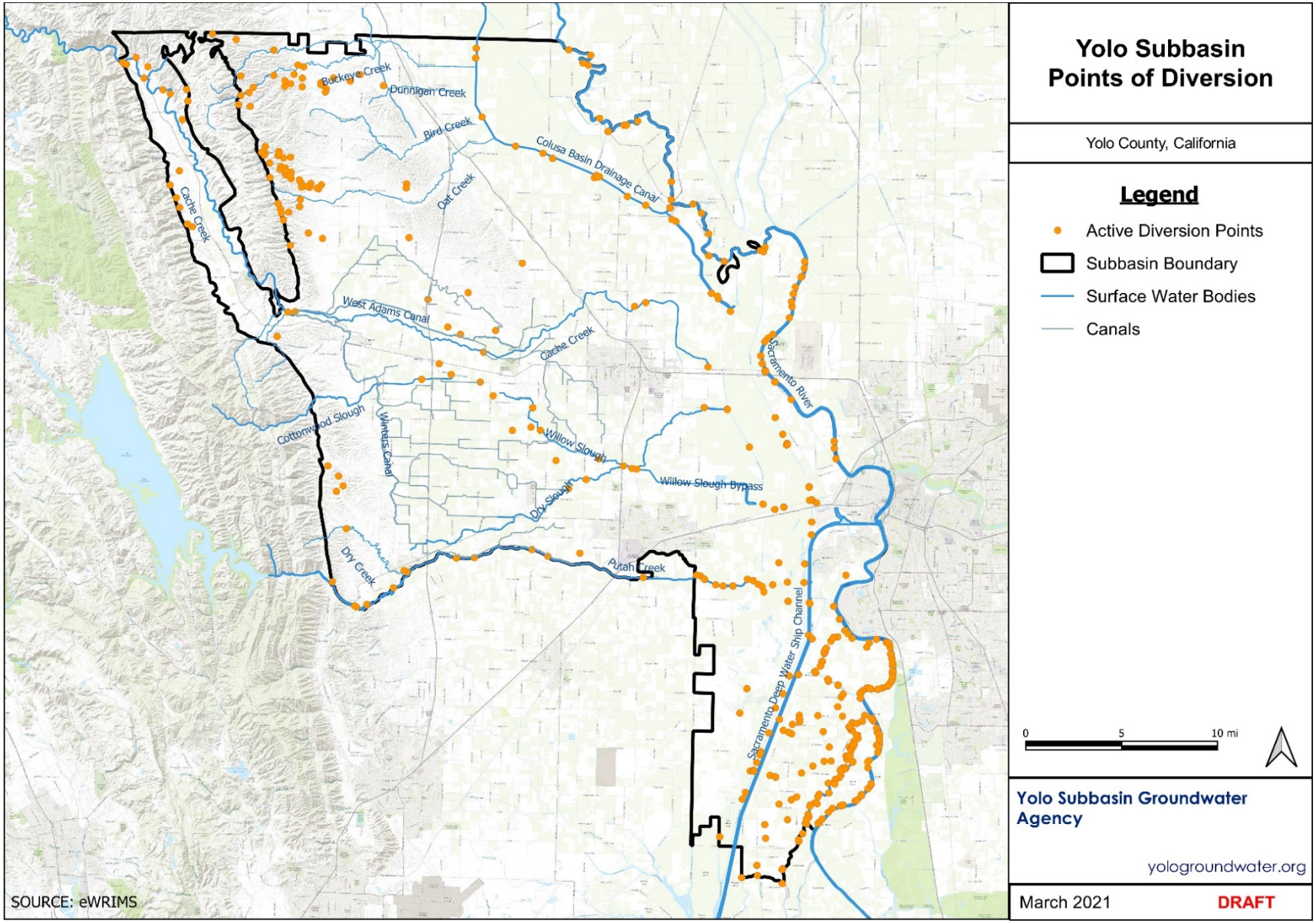


Figure 2-14. Yolo Subbasin Points of Diversion

2.1.12 Previous Studies

Groundwater resources in Yolo County have been investigated by numerous studies over the last century; the most significant or relevant reports are identified below.

- An early reconnaissance report of the Sacramento Valley groundwater resources was presented by Bryan (1923).
- The California Division of Water Resources (1955) encompassed most of the groundwater areas of Yolo County, curiously titled "The Putah Creek Cone Investigation." This report presented shallow cross-sections along and across Putah Creek and preliminary deep cross-sections from a concurrent U.S. Geological Survey (USGS) investigation.
- The USGS published their detailed study of southern Yolo and parts of Solano County with the finalized deep cross-sections as Thomasson Jr., Olmsted, and LeRoux (1960). A regional study of the entire Sacramento Valley soon followed (Olmsted and Davis, 1961).
- Scott and Scalmanini (1975) presented a study of Yolo County groundwater resources. A DWR report (1978) covered the evaluation of the groundwater resources of the Sacramento Valley.
- The USGS published a series of reports on the entire Central Valley in their regional-aquifer system investigations (Bertoldi et al., 1991).
- Hull (1984) and Bertoldi et al. (1991) covered the geochemistry of groundwater in the Sacramento Valley.
- Page (1986) summarized the geology of the entire Central Valley with an extensive list of references.
- The most widely available geologic maps covering the Yolo County area is from California Division of Mines and Geology (Wagner et al., 1981; Wagner et al., 1982).
- The most detailed surficial geologic mapping of groundwater basins was summarized in Helley and Harwood (1985) from previous mapping by themselves and others.
- Detailed soil mapping of Yolo County by the U.S. Soil Conservation Service was published in 1972.
- A report by the State of California (1987) as a proposal for siting the Super Conductor Super Collider provides a 360-degree cross-section extending to about 200 feet deep at about a ten-mile radius centered on the City of Davis.

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- Hubbard (1989) presented an evaluation of the youngest alluvial deposits across the Yolo County area with an interpretive map of the top of the underlying Tehama Formation.
- Graham (1997) presented a hydrological and geological study of the alluvial aquifer in the Davis area.
- West Yost and Associates (1991 and 1992) presented the results of a groundwater investigation of eastern Yolo County.
- LSCE (2003) presented a conceptualization of the deep freshwater stratigraphy around Davis.

Additional references on Yolo County containing shallow hydrogeologic information are a result of aggregate resources evaluations along Cache Creek. Some of these reports include Wahler et al. (1982); Woodward-Clyde Consultants (1976); and Dames and Moore (1990). Numerous additional references for individual aggregate resources sites exist.

2.2 Groundwater Conditions

The sections that follow summarize current and historical groundwater conditions in the Yolo Subbasin. SGMA Regulations §354.16 define current conditions as those existing after January 1, 2015, and therefore implicitly define historical conditions as those existing prior to January 1, 2015. The provided summaries emphasize information required by the GSP regulations. Current and historical groundwater conditions summarized herein are presented at a scale and level of detail appropriate for meeting the GSP sustainability requirements under SGMA.

This section is organized to align with the six indicators of groundwater sustainability, including:

- Chronic lowering of groundwater elevations (Section 2.2.1)
- Changes in groundwater storage (Section 2.2.2)
- Seawater intrusion (Section 2.2.3)
- Groundwater quality (Section 2.2.4)
- Subsidence (Section 2.2.5)
- Depletion of interconnected surface waters (Section 2.2.6)
- Groundwater Dependent Ecosystems (Section 2.2.7)

The freshwater aquifer system in the Yolo Subbasin includes the shallow alluvium and upper Tehama Formation, which together have been divided into the shallow, intermediate and deep zones. All three zones occur within the non-marine deposits. The shallow zone consists of

groundwater encountered from the water table to approximately 220 feet bgs and is considered unconfined. The intermediate zone occurs from the base of the shallow zone to a depth of approximately 600 feet bgs and is considered unconfined, and the deep zone extends from approximately 600 feet bgs to approximately 1,500 feet bgs.

2.2.1 Groundwater Levels

Groundwater levels have been measured at numerous wells in the Yolo Subbasin for the last 90 years, starting the early 1930s. These data are available from the California Statewide Groundwater Elevation Monitoring (CASGEM) program and the Yolo County Water Resources Information Database (WRID), as well as the DWR SGMA Data Viewer[2], and various historical reports, including groundwater management plans.

The CASGEM network includes 145 wells, including 144 active wells and one well with data through October 2013. Total depth is known for 126 CASGEM wells (87%), including 56 wells in the Shallow Zone, 63 wells in the Intermediate Zone, and seven wells in the Deep Zone. The average depths of these three groups of wells is 118 feet, 359 feet, and 739 feet, respectively. The duration of monitoring for groundwater levels is variable as shown in **Table 2-7**.

Table 2-7. Groundwater Monitoring via CASGEM Network over Time and by Aquifer Zone

	Aquifer Zone				
Decade	**Shallow**	**Intermediate**	**Deep**	**Unknown**	**Total**
1950s	3	2	0	0	5
1960s	3	1	0	1	5
1970s	0	2	0	0	2
1980s	0	0	0	1	1
1990s	0	12	5	0	17
2000s	4	9	2	0	15
2010s	46	37	0	17	100
Total	**54**	**65**	**7**	**19**	**145**

The CASGEM program also includes numerous "voluntary" wells (311) with groundwater level data. Active groundwater monitoring is occurring in a minority of these wells (58), and many of these wells have several decades of data, as listed in **Table 2-8**.

[2] https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer#gwlevels

Table 2-8. Groundwater Monitoring over Time via CASGEM Voluntary Wells

Decade	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Total
# of wells	1	4	10	10	3	6	3	21	58

The WRID database contains groundwater levels for numerous wells, including 174 "representative" wells, and most of these wells (147) are either in the CASGEM network (33) or a voluntary well (114), while some wells (27) are WRID-only wells. A total of 51 wells appear to be active, based on recent data, including 17 CASGEM wells, 30 voluntary wells, and four WRID wells. Many of these wells have many decades of data, as would be expected from the overlap with the CASGEM database and shown in **Table 2-9**.

Table 2-9. Groundwater Monitoring via WRID Network over Time and by Aquifer Zone

	Aquifer Zone				
Decade	Shallow	Intermediate	Deep	Unknown	Total
1930s	0	1	0	1	2
1940s	4	4	0	1	9
1950s	15	9	0	3	27
1960s	3	0	0	1	4
1970s	1	1	0	0	2
1980s	0	2	0	1	3
1990s	0	1	0	0	1
2000s	1	0	0	1	2
2010s	1	0	0	0	1
Total	**25**	**18**	**0**	**8**	**51**

2.2.1.1 Elevation and Flow Direction

Figure 2-15 and **Figure 2-16** display 2018 groundwater elevation contours in the spring and fall respectively. These contours represent below-normal water conditions, following an extraordinary wet year (2017), following a historic 5-year drought (2012-2016).

Groundwater in the Yolo Subbasin generally moves from west to east because groundwater levels occur at a higher elevation along the western mountain front, where recharge occurs, to lower elevations on the valley floor. In spring, this eastward gradient is the predominant hydrologic feature across much of the Subbasin (**Figure 2-15**) due to recent recharge during the previous winter wet season and minimal pumping. Localized gradients are more prominent in the fall, the result of pumping occurring over the summer months (**Figure 2-16**). As discussed in Section 2.2.1.4 vertical gradients exist between the shallow, deep, and intermediate zones, driving groundwater flow downward in the Subbasin. Vertical groundwater flow occurs relatively slowly due to the

intermingling of fine-grained sediments with coarser sands and gravels being common across the Subbasin (WRIME, 2006).

Groundwater elevations are highest in the western portion of the Subbasin between Winters, Capay, and Guinda. These areas border the foothills of Northern California Coast Ranges, and therefore benefit from increased rainfall and higher surface elevations. Groundwater elevations are generally 60-100 feet lower in the eastern portion of the Subbasin near Davis, Woodland, and West Sacramento. Here conditions reflect the relatively low gradients seen across the Central Valley floor. Cones of depression exist near Davis and Woodland due to groundwater extraction for municipal supply and in rural areas, particularly the Zamora area, due to extraction for agricultural irrigation. These cones of depression are more prominent during the fall, a result of minimal precipitation during the dry season and increased extraction during the growing (dry) season. Seasonal variation in recharge and groundwater extraction results in a difference in groundwater elevations of around 20 to 40 feet between spring and fall (**Figure 2-15** and **Figure 2-16**). Groundwater elevations in spring reflect recharge received during the rainy season, while groundwater elevations in fall reflect the antecedent dry season and the cumulative effects of groundwater extraction throughout of the growing season.

Figure 2-17 and **Figure 2-18** are respective contour maps for groundwater conditions during spring and fall 2015 which are similar to 2018 conditions. Groundwater flows from uplands along the mountain front on the west side of the valley toward the center of the valley on the east. Groundwater levels were nearly 20 feet lower during Fall 2015 beneath the City of Davis, 10 feet lower beneath the City of Woodland, and 35 feet lower beneath Zamora. The seasonal decline was less along the mountain front with up to 10 feet of decline in the vicinity of Capay-Esparto-Madison and beneath Winters. The 2015 contours represent the gravest, critically dry conditions in the fourth year of the 5-year drought.

A comparison of 2015 and 2018 conditions shows that groundwater levels rose 10 to 20 feet across much of the Subbasin during the Spring seasons with a few isolated areas with a 30-foot rise. For Davis and Zamora, the rise was approximately 15 feet, 20 feet for Woodland, and 30 feet for Yolo. For mountain-front communities (Winters, Capay, Esparto, and Madison), groundwater levels rose 10 feet. For the Fall seasons, the change in groundwater levels is more complicated due to the residual effects of variable pumping during the irrigation season. In general, groundwater levels were higher in much of the Subbasin in 2018, compared to 2015.

A comparison of Spring 2006 (wet year at the end of a mostly wet 10-year period) to Spring 2016 (below-normal year at the end of a mostly dry 10-year period) shows on overall decline throughout the Subbasin as might be expected from the mostly dry conditions (**Figure 2-19**). The decline was 10 feet in the vicinity of Esparto and Madison, over 30 feet in the broad area west of Davis and Woodland and the Winters area, over 30 feet northwest of Zamora, and over 40 feet near the northern boundary of the Subbasin west of Interstate 5.

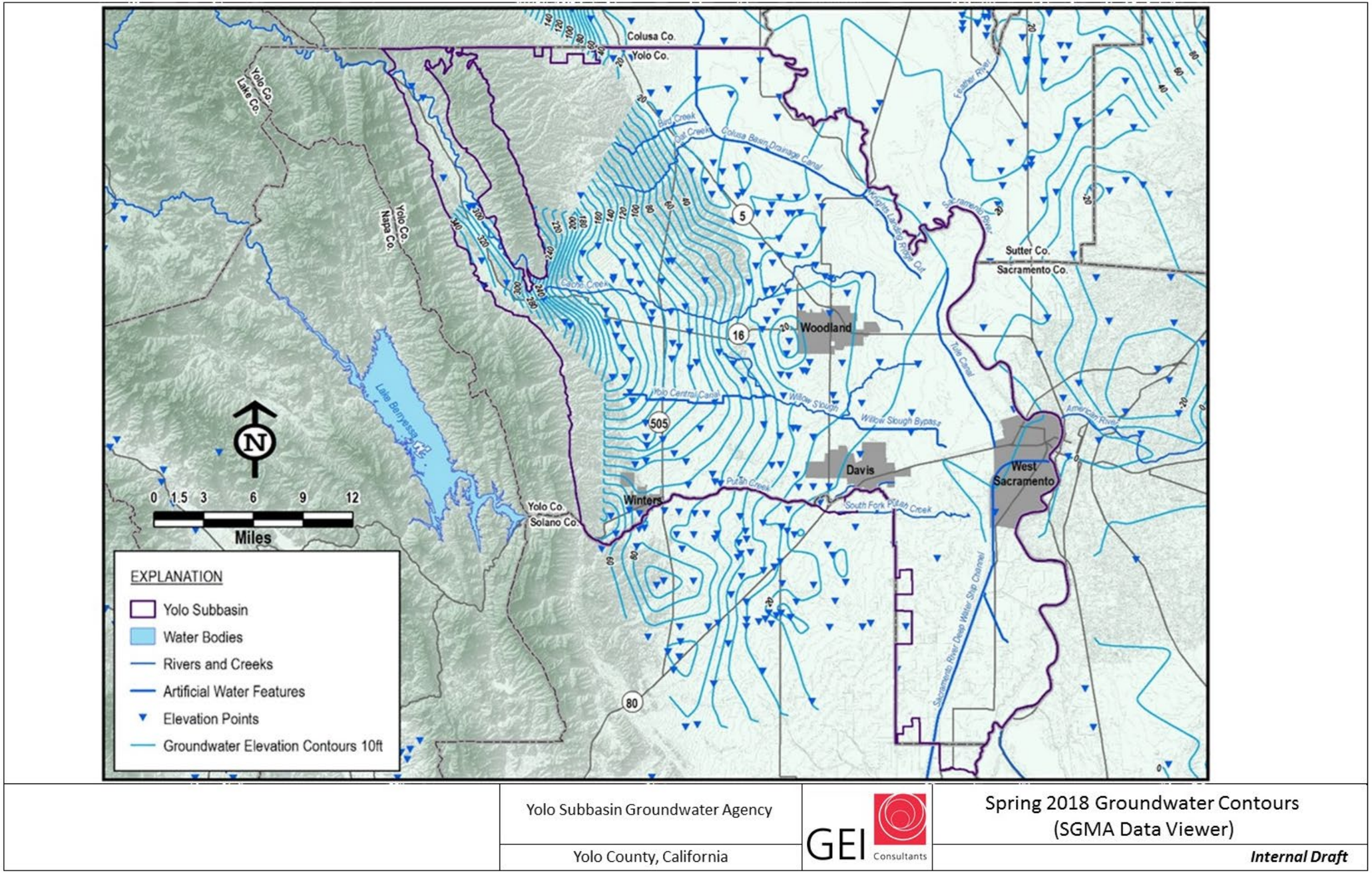
2.2.1.2 Subbasin-Wide Groundwater Elevations

Groundwater is an important resource in Yolo Subbasin, supporting multiple beneficial uses including urban and domestic supplies; and agriculture. Historically, groundwater pumping and associated depth to water measurements have occurred in the shallow and intermediate zones, resulting in a groundwater elevation dataset from approximately 1955 to the present. Data are more robust from the late 1970s onward, due to an increasing focus on groundwater management. Development of deep zone groundwater has occurred more recently and available groundwater elevation data from this zone are available after approximately 1980. **Figure 2-20** shows average depth to groundwater in the YCFCWCD's groundwater monitoring network portion of the Yolo Subbasin for 1975 through Spring 2020. The YCFCWCD's monitoring wells, along with other Yolo Subbasin monitoring wells, are updated in the WRID twice a year with the spring and fall water level measurements. The subset of 113 wells shown in **Figure 2-20** capture YCFCWCD's wells with a current water level measurement and a long data record. The YCFCWCD provides this bi-annual summary of this hydrograph to illustrate the state of the central-western portion of the Yolo Subbasin.

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	Yolo Subbasin Groundwater Agency	GEI Consultants	Spring 2018 Groundwater Contours (SGMA Data Viewer)
	Yolo County, California		*Internal Draft*

Figure 2-15. Spring 2018 Groundwater Contours (Source: SGMA Data Viewer)

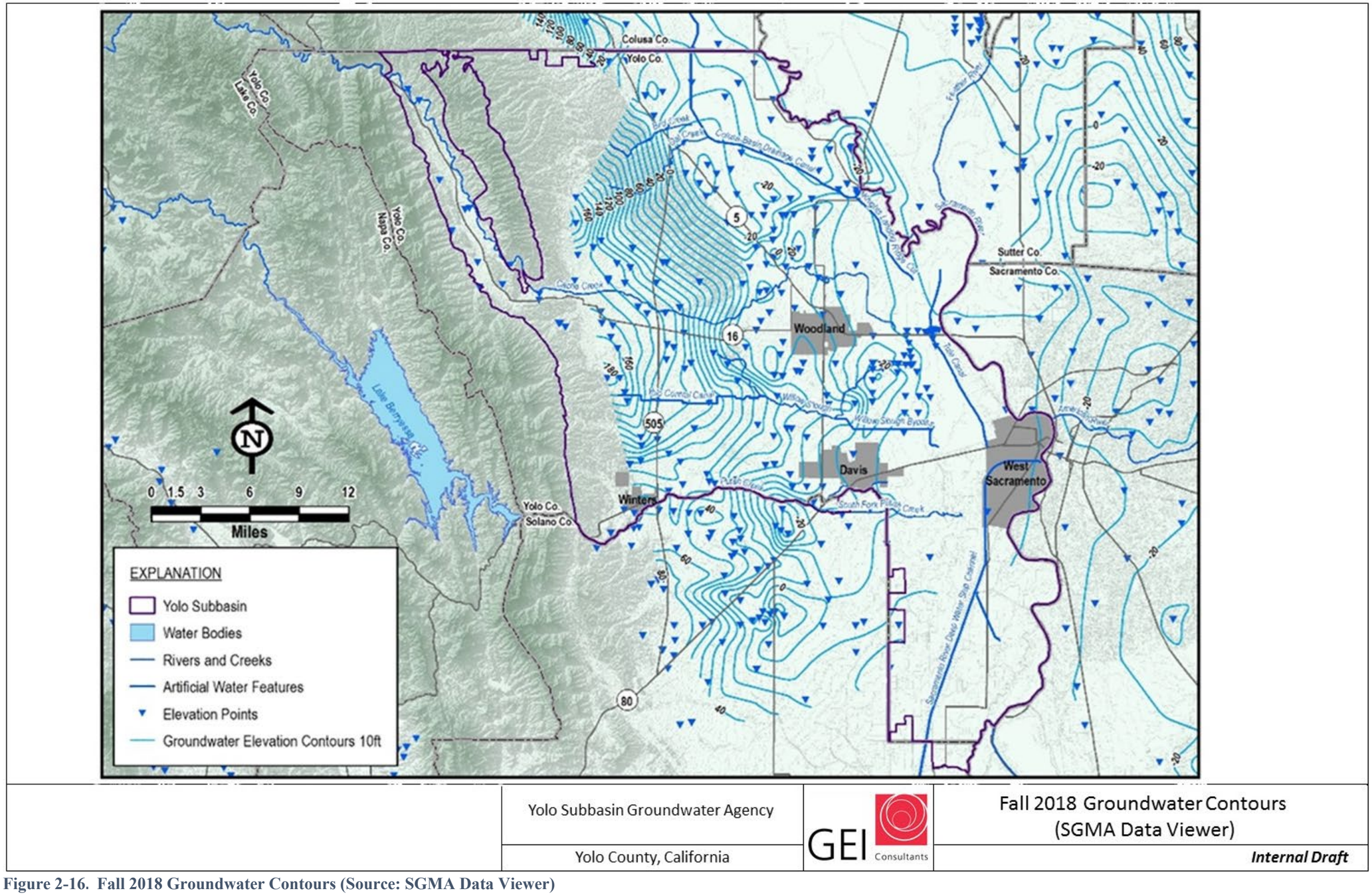


Figure 2-16. Fall 2018 Groundwater Contours (Source: SGMA Data Viewer)

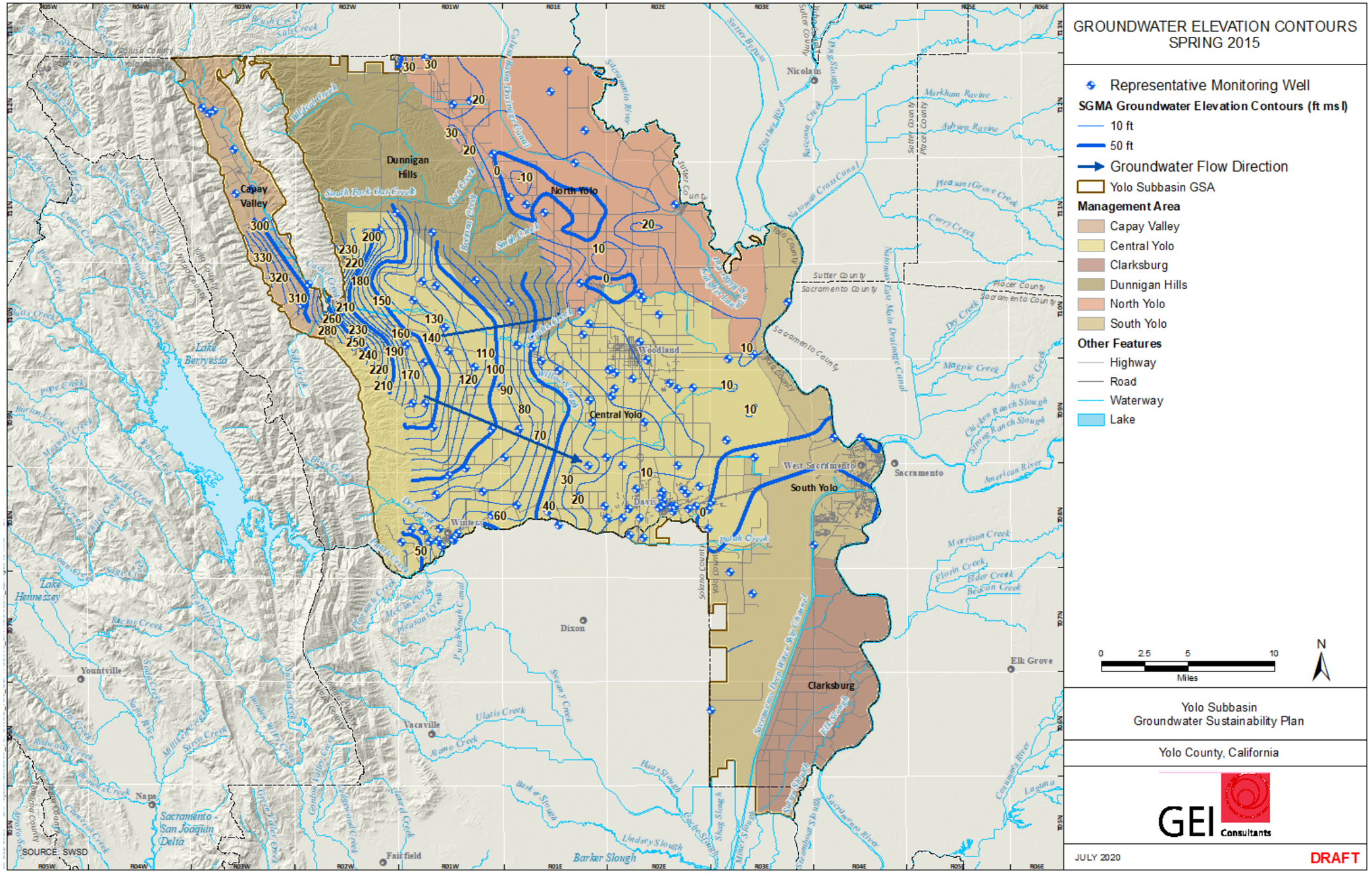


Figure 2-17. Spring 2015 Groundwater Contours.

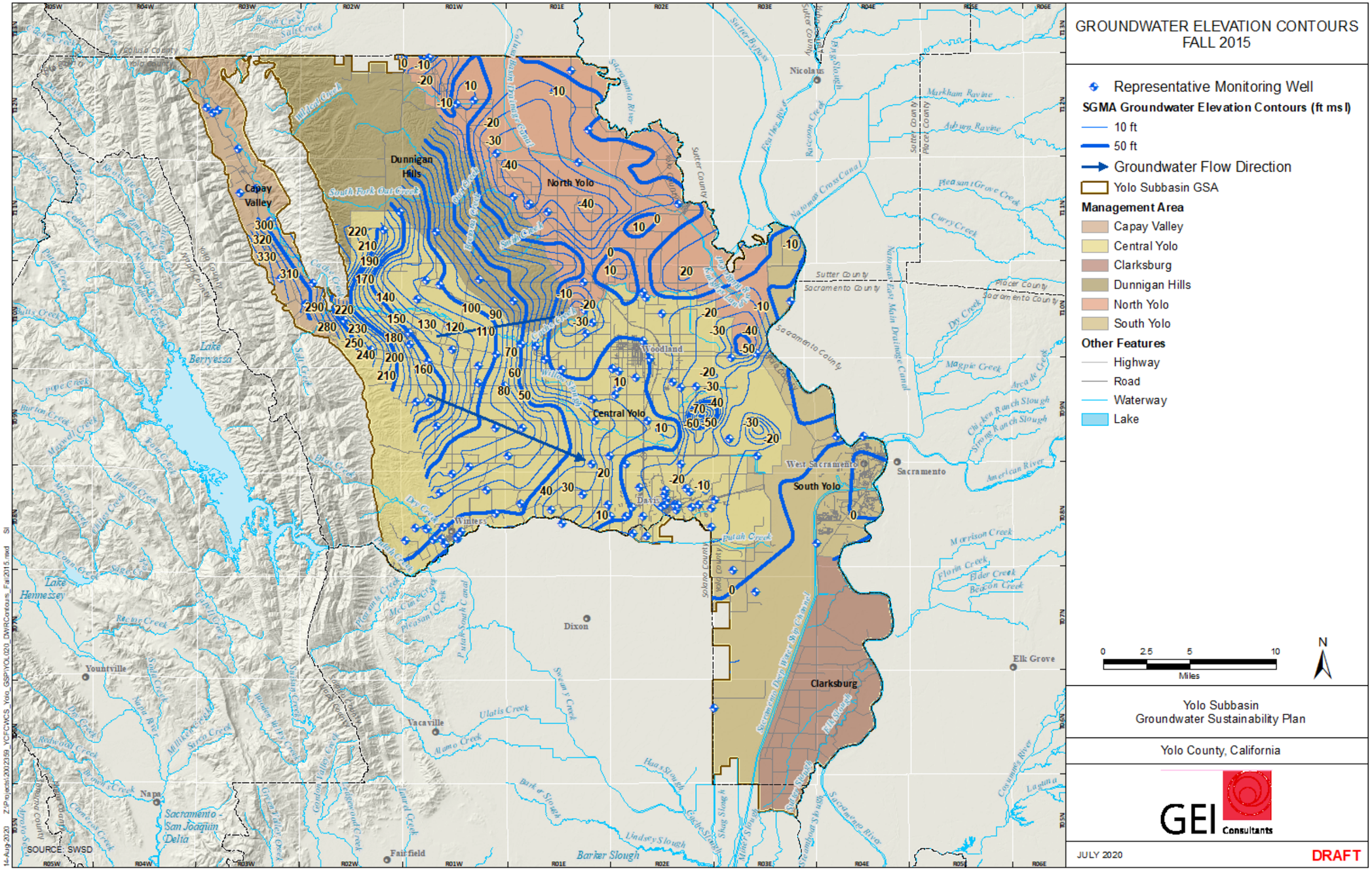


Figure 2-18. Fall 2015 Groundwater Contours (Source: SGMA Data Viewer)

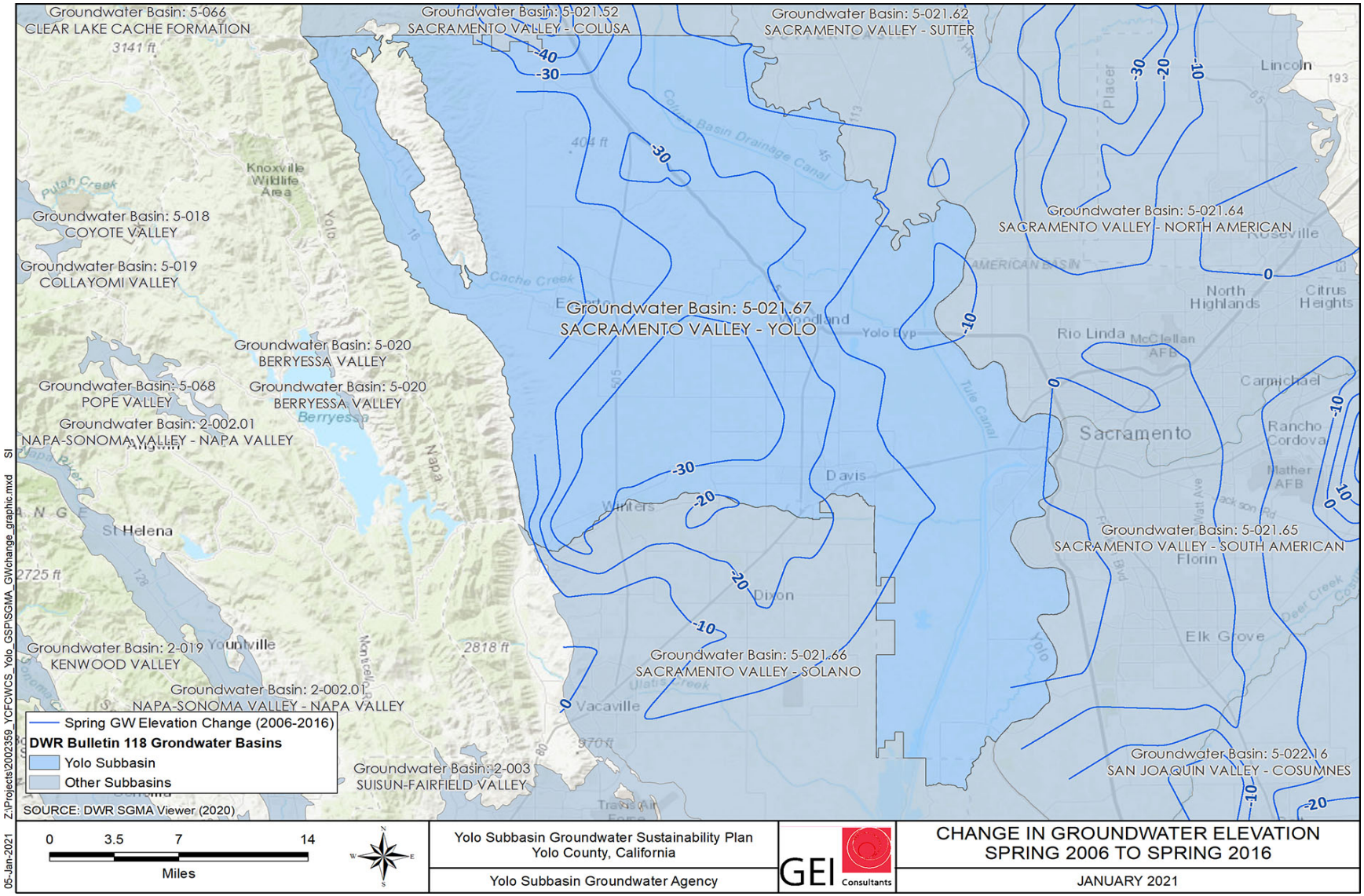


Figure 2-19. Change in Groundwater Elevations from Spring 2006 to Spring 2016. (Source: SGMA Data Viewer)

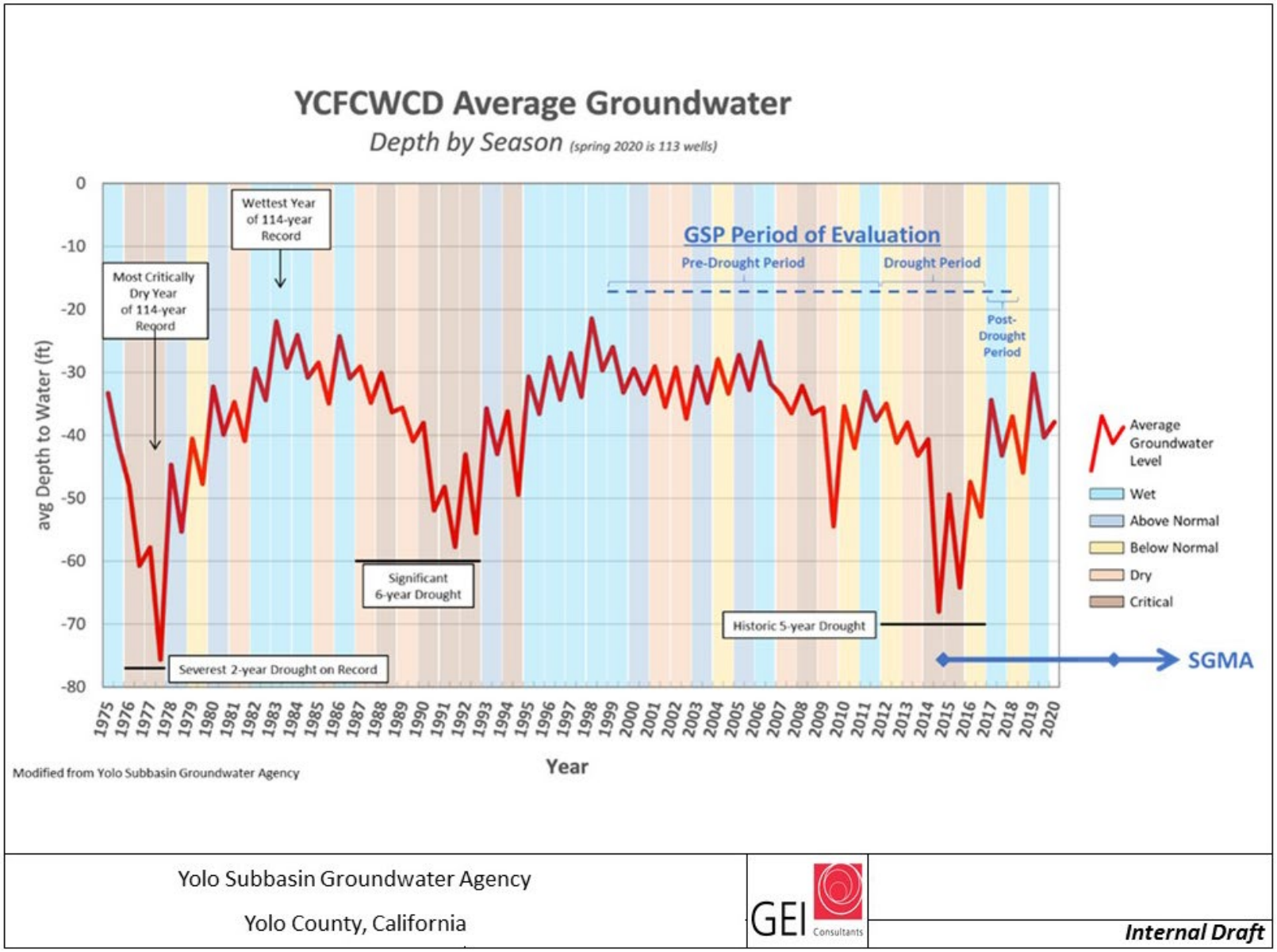


Figure 2-20. Historical Average Depth to Groundwater in YCFCWCD Service Area.

Figure 2-20 shows that:

- Depths to groundwater fluctuate seasonally due to recharge by precipitation (higher levels) during the late fall, winter, and early spring (wet months) and become deeper during the late spring, summer, and early fall (dry months) due to the paucity of recharge and the use of groundwater during the irrigation season.

- Depths to groundwater also fluctuate due to variations between water year (WY) type which have been classified as wet, above normal, below normal, dry, and critical.

- Depths to groundwater increased significantly during 1976 and 1977, which was the severest 2-year drought period for the 114-year period of water year records, resulting in limited groundwater recharge and greater reliance on groundwater extraction to meet local demands. The preceding 10-year period, ending in 1975, was an overall wet period which produced relatively shallow depths.

- Depths to groundwater recovered between 1978 and 1984. Conjunctive use, specifically the completion of the Indian Valley Project in 1975, likely contributed to this recovery along with three consecutive wet years, including the wettest year (1983) in the 114-year period of records. During this period, the average groundwater depth rose to one of the highest levels during this 45-year period.

- Depths to groundwater fluctuated notably due to a dry 1985 and a wet 1986, and this rapid response was also evident between a critical 1992, above-normal 1993, and a critical 1994. These fluctuations are indicative of a robust groundwater system.

- Depths to groundwater increased between 1987 and 1992 due to a significant 6-year drought period of mostly critical WYs.

- Depths to groundwater generally decreased from 1993 to 1999 during a mostly wet period, including five consecutive wet years Groundwater depths rose again to one of the highest levels in 1998, which is the fourth wettest WY on record (1995 is the seventh wettest WY).

- Depths to groundwater were relatively stable between 2000 and 2006, fluctuating as might be expected from a mixture of WYs (overall above-normal conditions).

- Depths to groundwater increased again between 2007 and 2011, including a notably dip in 2009, due an overall dry period of WYs. Groundwater depths recovered briefly thereafter through 2011 due to overall above-normal conditions.

- Depths to groundwater increased after 2011 during most of the historic 5-year drought period, including a significant drop between 2014 and 2015, which are the sixth and fourth lowest WYs respectively. This decline occurred during the transition from the pre-SGMA

Historical Period (prior to January 1, 2015) and the SGMA GSP development or Current Period.

- Depths to groundwater decreased after the drought due to an overall wet period, including the second wettest WY (2017) on record. New water management actions likely contributed to the decrease in depths to groundwater, including the Woodland-Davis Clean Water Project which reduced groundwater pumping with the development of potable water from the Sacramento River sources.

The Yolo Subbasin appears to have a robust groundwater system that has recovered quickly after various periods of dry and critical WYs, including single- and multi-years. Overall, the last 21 years of the 45-year hydrograph could be considered a below normal period. Future years are expected to be variable and possibly more extreme which will require vigilant attention to hydrologic conditions and a flexible management plan for surface water and groundwater.

2.2.1.3 Vertical Groundwater Gradients

Natural groundwater flow is typically downward in recharge areas, such as the upland areas on the west side of the Subbasin, and upward in discharge areas, which should be along floodplain of the Sacramento River. Groundwater pumping can alter these natural gradients seasonally and over time as groundwater is withdrawn from the Subbasin. **Figure 2-21** and **Figure 2-22** are hydrographs for two multi-depth well configurations with four well completions at each location. The hydrographs illustrate 14 years of data, WY 2005 through 2019.

These wells were installed in association with an extensimeter for subsidence monitoring. Nested wells 11N01E-24Q-04 / -05 / -06 / -07 were installed in single boring and are located in the North Yolo MA to the southeast of Zamora. Well cluster 09N03E-08C-01 / -02 / -03/ -04 is a configuration of four separate wells, which are located in the Central Yolo MA, east of Woodland (Conway). Construction details and groundwater gradients are summarized below.

The nested North Yolo MA wells provide groundwater data for the shallow (1), intermediate (2), and the deep (1) zones. **Table 2-10** summarizes vertical gradient observations for these wells. The seasonal fluctuations in groundwater levels are substantial, especially in the shallow and intermediate zones. Groundwater levels start out relatively high and in unison during the wet WY 2005 but were generally on the decline thereafter, with increasing divergence after WY 2008. The shallow and intermediate zones rise somewhat in response to wet WY 2010, while declining to lows at the end of the historic 5-year drought, in WY 2016. Groundwater levels increased after the wet WY 2017 held relatively steady due wet WY 2019. The vertical gradient is downward from the shallow zone to the upper intermediate zone, somewhat upward between the lower and upper intermediate zones, and upward from the deep zone to the intermediate zone.

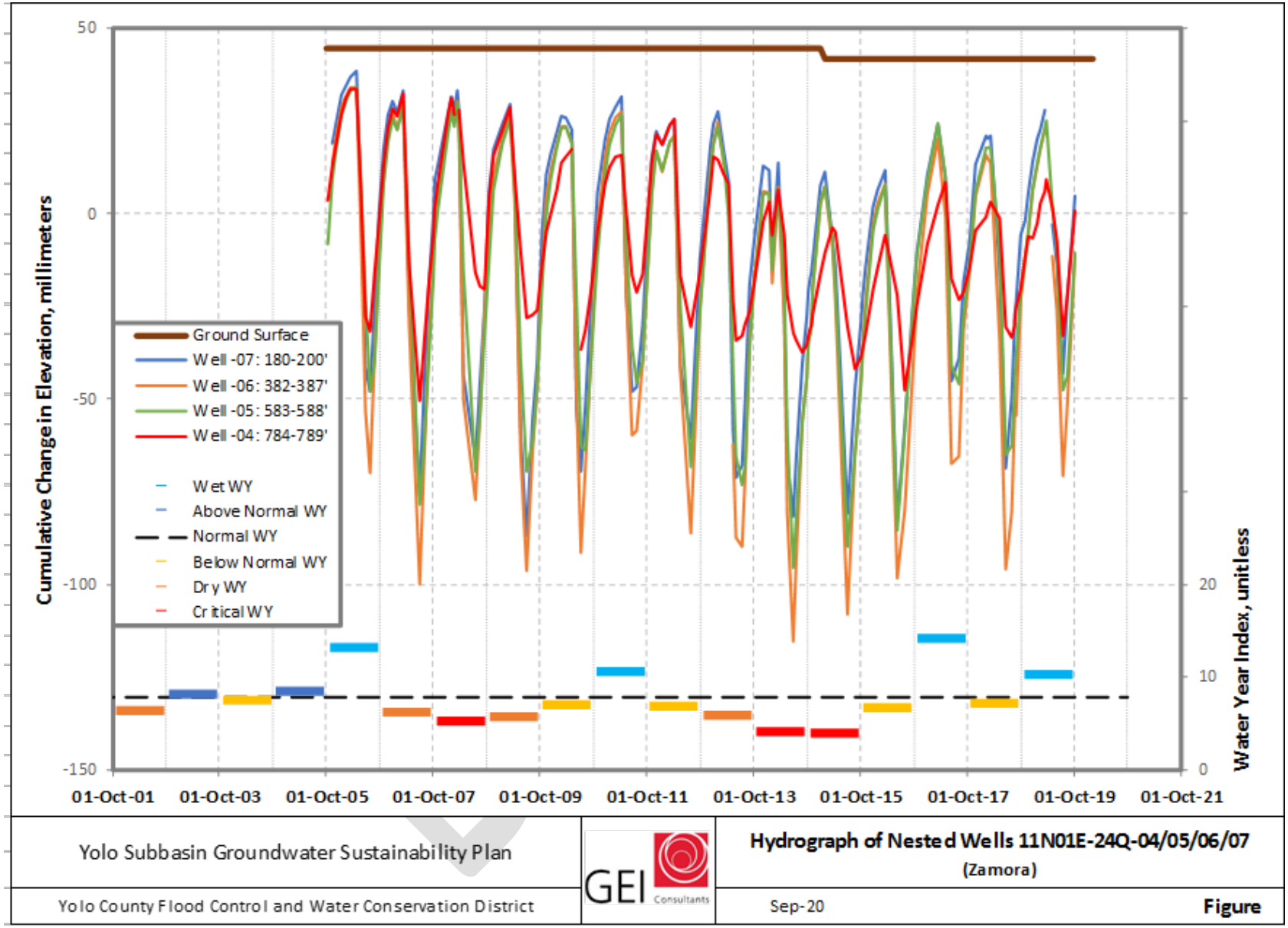


Figure 2-21. Hydrograph of Nested Well 11N01E-24Q-04 / 05 / 06 / 07

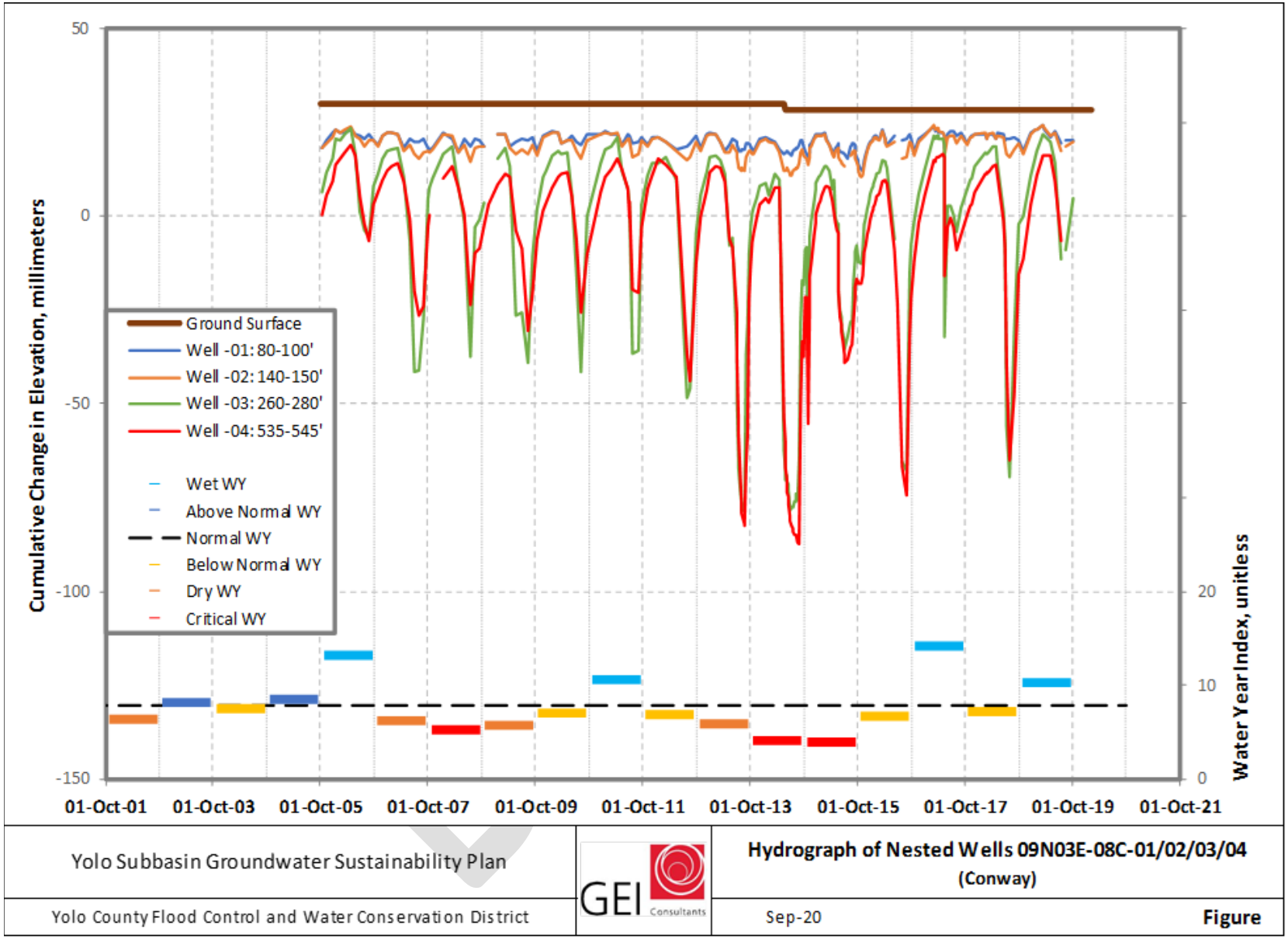


Figure 2-22. Hydrograph of Nested Well 11N01E-24Q-04 / 05 / 06 / 07

Table 2-10. Vertical Gradient Summary for the North Yolo MA Wells.

Aquifer Zone	Well Depths	Mean WL	Mean Gradient	
Shallow well	180-200'	-9.4'	Downward	0.058
Intermediate well	382-387'	-19.9'		
Intermediate well	583-588'	-14.4	Upward	-0.025
Deep well	784-789'	-6.9'	Upward	-0.040

The nested Central Yolo MA well provide groundwater data for the shallow (2) and the intermediate (2) zones. **Table 2-11** summarizes vertical gradient observations for these wells. Seasonal fluctuations occur in all four wells, but the fluctuations are considerably less in the shallow zone. Fluctuations in the intermediate zone are substantially greater due the groundwater pumping during the irrigation season, with the upper intermediate zone exceeding the lower intermediate zone until the 5-year drought period, when the relationship reverses. During the wet, non-pumping period, the shallow zone groundwater levels are quite similar and somewhat higher than the levels in the intermediate zone to produce a vertical downward gradient between the Shallow and Intermediate Zones. During the irrigation season, the lower Shallow Zone levels are deeper than the upper Shallow Zone due to groundwater pumping and the downward vertical gradient increases. For the two intervals in the Intermediate Zone, the vertical gradient was downward during the non-pumping period but was reversed during the pumping season (upward gradient) in the early period of record. During the drought, groundwater levels in the lower Intermediate Zone decreased to better match the levels in the upper Intermediate Zone to minimize the vertical gradient within the Intermediate Zone. However, the downward vertical gradient between the Shallow and Intermediate Zone increased substantially.

Table 2-11. Vertical Gradient Summary for the Central Yolo MA Wells.

Aquifer Zone	Well Depths	Mean WL	Mean Gradient	
Shallow well	80-100'	19.8'	Downward	0.031
Shallow well	140-150'	18.3'	Downward	0.206
Intermediate well	260-280'	-8.6	Downward	0.016
Intermediate well	535-545'	-12.7'		

2.2.2 Change in Groundwater Storage

2.2.2.1 Change in Storage Calculations

Change in storage over time across the Yolo Subbasin can be estimated from hydrologic modeling results. Previous modeling reports have estimated change in groundwater storage, presented as an average over the model calibration period. For example, the previously developed Yolo County Integrated Groundwater Simulation Model (YCIGSM) provided simulation results for inflows,

outflows, and changes in storage for each year from 1971 to 2000 (WRIME, 2006). Over this 30-year period, groundwater storage increased slightly by roughly 7,200 acre-feet. However, the Subbasin experienced a wide range of variation in climate and groundwater use during the time period. In addition, this model encompassed the old subbasin boundary, which included an area almost half of the current subbasin boundary.

The more recent Water Evaluation and Planning System (WEAP) model, which is used for the development of this GSP and encompasses the new Subbasin boundary, provides annual cumulative change in groundwater storage estimates between 1975 and 2018, as shown on **Figure 2-23**. Values above the x-axis (positive values) indicate an increase in groundwater storage, and values below the x-axis (negative values) indicate a decrease in groundwater storage (or loss of groundwater in storage). While the change in groundwater storage in the Yolo Subbasin is generally positive and a substantial loss of storage cannot be seen over this period, the 2012 to 2016 drought showed a large decline in storage of nearly 400,000 acre-feet, similar to the drought of the late 1970's. Change in storage increased to a positive value during 2017 due to a wet year, but then started decreasing again due to a below normal 2018. This illustration shows that the Subbasin responds quickly to variable recharge and pumping conditions.

2.2.3 Seawater Intrusion

Seawater intrusion, as observed in California's coastal aquifers, will not likely occur within the Yolo Subbasin because the ocean is over 50 miles away, farther if measured along the waterways. The southern portion of the Yolo Subbasin is located within the Sacramento-San Joaquin Delta and has been subject to salinity intrusions[3] during the early part of the last century but not since 1944 and 1990 (DWR, 1995) and probably not thereafter due to the state management of flows through the Delta to prohibit salinity intrusion. The maximum annual salinity intrusion occurred in 1931 and flowed upstream midway between Courtland and Hood during the period 1921 to 1990. A maximum salinity intrusion reached the southern boundary of the Yolo Subbasin at Miner Slough in 1934 and was within a mile of the slough during 1939. Undoubtedly, salinity intrusion occurred during 19th-century drought periods and throughout early history. As such, elevated levels of sodium and chloride are likely to occur along the southern and southeastern boundaries of the Subbasin, and at depth due to the deposition of sediments in a marine environment during the Miocene epoch.

[3] Maximum salinity is defined as 1000 parts per million of chloride measured 1 ½ hours after high tide.

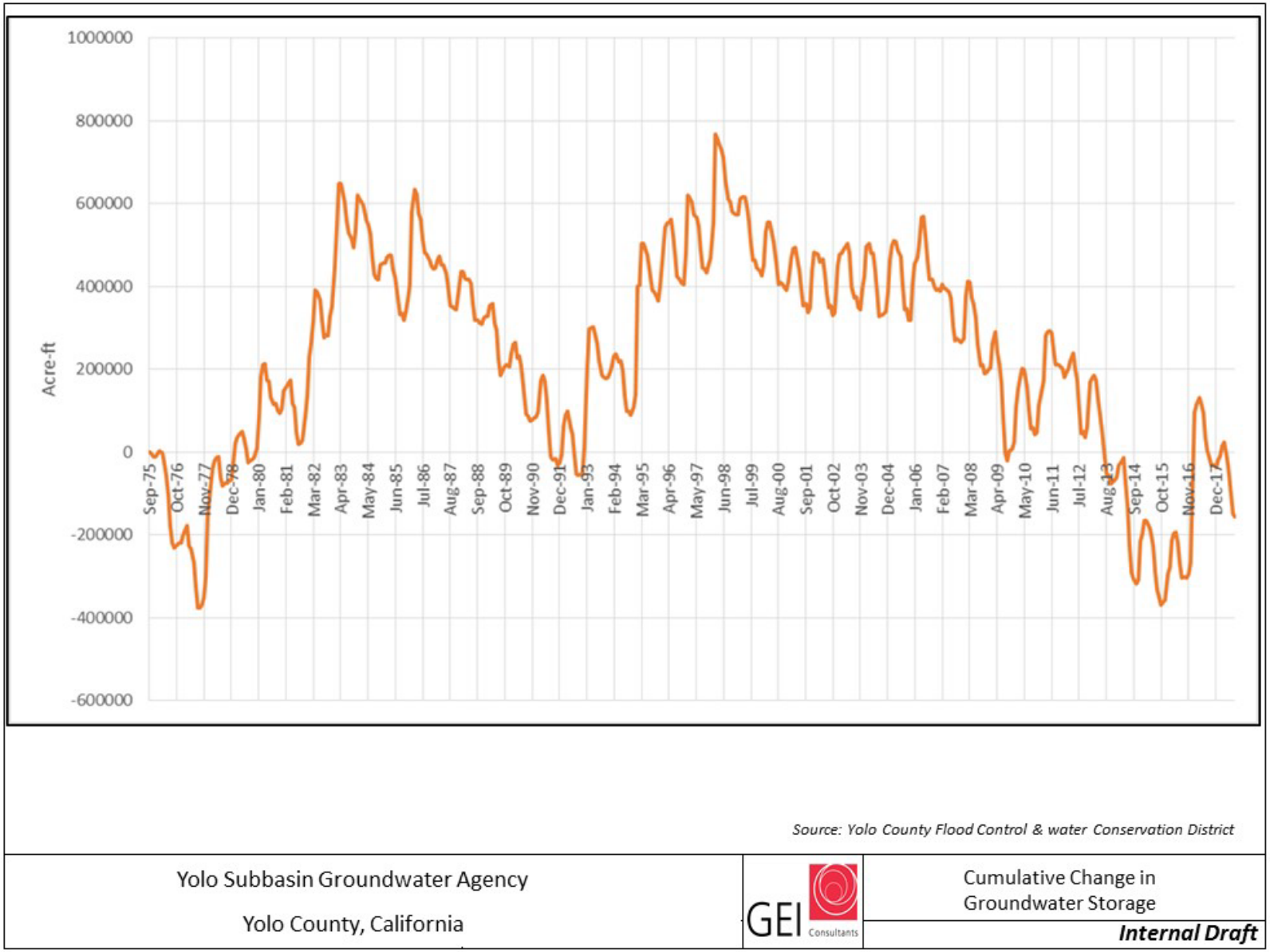


Figure 2-23. Cumulative Groundwater Storage Change

2.2.4 Groundwater Quality

The purpose of this groundwater quality section is to review groundwater quality issues that may affect the supply and beneficial uses of groundwater as stated under CCR §354.16. This section includes a discussion of water quality standards used and information relevant to capturing groundwater quality conditions in Yolo Subbasin.

2.2.4.1 Existing Water Quality Monitoring Programs

Groundwater quality monitoring and reporting is conducted through numerous public agencies. The following sections provide a summary of databases, programs and agencies that actively collect groundwater data, information on where the data is stored, and how it was used in the Basin Setting.

2.2.4.1.1 Irrigated Lands Regulatory Program (ILRP)

The ILRP was initiated in 2003 with focus on protecting surface waters; groundwater regulations were added in 2012. ILRP was implemented to protect receiving water bodies from impairment associated with agricultural runoff, tile drain flows, and storm water runoff from irrigated fields. Elements of this program that overlap with SGMA requirements are the monitoring programs focused on identifying groundwater impairment associated with irrigated agriculture. As of March 12, 2014, a new set of water quality regulations were imposed on Sacramento River Watershed irrigated agriculture and managed wetland landowners and operators.

The Sacramento Valley Water Quality Coalition (Coalition) was formed in 2003 as a logical extension of the Northern California Water Association (NCWA) mission to partner with over 200 agricultural representatives, natural resource professionals, wetlands managers and local governments throughout the region. The Coalition is composed of more than 8,600 farmers and wetlands managers encompassing more than 1.3 million irrigated acres. They are supported by local farm bureaus, resource conservation districts, County Agricultural Commissioners, and crop specialists with the University of California Cooperative Extension. The Coalition is comprised of 13 sub-watershed groups. In Yolo County, the Yolo County Farm Bureau formed as a sub-watershed group.

To date, the program has focused on sampling surface waters. Since groundwater regulations were implemented in 2012, planning has been underway, with data collection that began in Fall 2018. NCWA and the Coalition's *Comprehensive Groundwater Quality Management Plan* (ch2m, 2016) identified areas where groundwater is vulnerable to degradation that is contributed by irrigated agriculture, which were classified as high vulnerabilities. This addressed the requirements of the Waste Discharge Requirements General Order for Growers within the Sacramento River Watershed that are Members of the Third-Party Group (Sacramento River WDR) (R5-2014-0030-R1). The *Groundwater Trend Monitoring Work Plan,* (LSCE, 2018b) outlines the Coalitions compliance strategies, which includes continuing to educate their members on management practices that are protective of water quality; reporting on management practices that are actively used; and an annual sampling program to trend nitrate levels in groundwater.

The focus of ILRP's groundwater regulation is to trend nitrate and demonstrate that current management practices are protecting groundwater from further degradation. The State Water Board's objective is to eventually restore nitrate concentrations to levels below the drinking water standard of 10 parts per million (mg/L) as nitrogen. Data collected and reported as a part of ILRP are provided to the SWRCB and will be available in the State Water Resources Control Board GeoTracker (GeoTracker) database for download and use.

The Fall 2018 sampling event was successfully completed for 21 Groundwater Trend Monitoring wells (LSCE, 2019). Annual monitoring will include static water level; temperature; pH; electrical conductivity; dissolved oxygen; oxidation-reduction potential; turbidity; and nitrate as nitrogen. Once every five years, a limited group of general minerals will be collected.

2.2.4.1.2 Central Valley-Salinity Alternatives for Long-Term Sustainability (CV-SALTS)

CV-SALTS is a collaborative stakeholder driven and managed program to develop sustainable salinity and nitrate management planning for the Central Valley. The program objective is intended to facilitate the salt and nitrate implementation strategies recommended in the Salt and Nitrate Management Plan (SNMP) developed in 2017. They are designed to address both legacy and ongoing salt and nitrate accumulation issues in surface and groundwater. The overarching management goals, and priorities of the control are: 1) ensure safe drinking water supply; 2) achieve balanced salt and nitrate loading; and 3) implement long-term, managed restoration of impaired water bodies. The program is phased with the primary focus of early actions on nitrate impacts to groundwater drinking water supplies and established specific implementation activities. The Yolo Subbasin is a Priority 2 basin for nitrate management. Consequently, the nitrate control program schedule is set to begin in 2022.

CV-SALTS will enact a nitrate control program as part of the SNMP which requires forming a management zone as a regulatory option to comply with the requirements of the nitrate program. The management zones will consist of a defined management area to manage nitrates, ensure safe drinking water, and meet applicable water quality objectives. Local management plans will be created to implement the long-term goals of the nitrate control program. As programs are implemented, there will be versions of management areas to meet the objectives of their individual programs. While ILRP allows for compliance of their regulatory program through coalitions that cover a broad, non-contiguous area based on similar land use, SGMA and CV-SALTS will both require contiguous management areas/zones to be contiguous area's regardless of land use.

Both the ILRP and CV-SALTS programs involve permittees and local stakeholders working towards water management objectives set forth by the State. In this regard, collaborative efforts should be made to maximize the resources of each program and provide a more integrated approach to developing local solutions for groundwater management.

2.2.4.1.3 Groundwater Ambient Monitoring and Assessment Program (GAMA)

The GAMA Program was created by the SWRCB, in 2000. It was later expanded by the Groundwater Quality Monitoring Act of 2001 (AB 599). AB 599 required the State Water Board, to

integrate existing monitoring programs and design new program elements as necessary, to monitor and assess groundwater quality. The GAMA Program is based on collaboration among agencies including the State and Regional Water Boards, DWR, Department of Pesticide Regulations (DPR), USGS and USGS National Water Information System (NWIS), and Lawrence Livermore National Laboratory (LLNL). In addition to these state and federal agencies, local water agencies and well owners also participate in this program.

The main goals of GAMA are to:

1) improve statewide comprehensive groundwater monitoring; and
2) increase the availability to the general public of groundwater quality and contamination information.

2.2.4.1.4 GeoTracker and EnviroStor Databases

The SWRCB oversees the GeoTracker database. This database systems allows the State Water Board and Regional Water Quality Control Board (RWQCB) to house data related to sites that impact or have the potential to impact the groundwater. Records available on GeoTracker include cleanup sites for Leaking Underground Storage Tank (LUST) Sites, Department of Defense Sites, and Cleanup Program Sites. Other records for various unregulated projects and permitted facilities include Irrigated Lands, Oil and Gas production, operating Permitted Underground Storage Tanks (USTs), and Land Disposal Sites.

GeoTracker is a public and secure portal that can retrieve records and view data sets from multiple State Water Board programs and other agencies through Google maps GIS interface. This database is not only useful for the public, but also to help other regulatory agencies to monitor the progress of cases. It also provides a web application tool for secure reporting of lab data, field measurement data, documents, and reports.

The California Department of Toxic Substances Control (DTSC) oversees the EnviroStor database. This data management system tracks cleanup, permitting, enforcement, and investigation efforts at hazardous waste facilities and sites with known contamination or sites where further investigation is warranted by the DTSC. This database only provides reports, inspection activities and enforcement actions completed on or after 2009. Like the GeoTracker database, this is not only useful for the public, but other regulatory agencies that may use it to monitor progress of ongoing cases. The primary difference between the two databases is that EnviroStor only houses records of cases for which the DTSC is the lead regulatory agency, whereas the GeoTracker database houses records of cases from many regulatory programs, including the DTSC, Department of Defense, EPA Cleanup sites, and many others. For the Basin Setting, both databases were searched to identify and report on any contaminated sites that may have had impacts to groundwater water quality.

2.2.4.1.5 State of California Drinking Water Information System (SDWIS)

All public drinking water systems (a system that has 15 or more service connections or regularly serves 25 individuals daily at least 60 days out of the year) are regulated by the SWRCB – Division of

Drinking Water (DDW) to demonstrate compliance with State and Federal drinking water standards through a rigorous monitoring and reporting program. Required monitoring for each well within each water system is uploaded to the DDW's database and subsequently available for the public through the State Drinking Water Information System (SDWIS). In addition to providing compliance monitoring data for each regulated water system, other information such as monitoring frequency, basic facility descriptions, lead and copper sampling, violations and enforcement actions, and consumer confidence reports are also available.

All drinking water systems are required to collect samples, known as Title 22 constituents on a given frequency depending on the constituent and regional groundwater vulnerability. The following is a summary of the minimum sampling frequency for a public water supply well:

- General minerals, metals and organics (Synthetic Organic Chemicals and Volatile Organic Compounds) sampling is required every 3 years. If any organics are detected, sampling frequency must be increased to quarterly.
- Nitrate is required annually. If nitrate is ≥5 ppm, then sampling is required quarterly.
- If arsenic is ≥5 ppb, sampling should be increased to quarterly but is not always done.
- Radiologicals (gross alpha and uranium) are sampled one every 3 (when initial monitoring is ≥ ½ the MCL), 6 (when initial monitoring is ≤ ½ the MCL) or 9 (when initial monitoring is non-detect) years depending on historical results.

Public water systems provide the most abundant source of data since the testing requirements are fairly frequent intervals, and data collection began in 1974. All sample results are easily available from the SDWIS database. When using this data to characterize groundwater quality for the Basin Setting, only raw water quality data is considered. It is important to understand that this characterization is not intended to represent water supplied by purveyors because they may provide wellhead treatment to remove or reduce contamination.

2.2.4.1.6 United States Geological Survey (USGS)

The USGS California Water Science Center (CWSC), provides California water data through data collection, processing, analysis, reporting, and archiving. Data include surface water, groundwater, spring sites, and atmospheric sites, with data often available in real-time via satellite telemetry. The NWIS groundwater database consists of records of wells, springs, test holes, tunnels, drains, and excavations. Available information includes groundwater level data, well depth, aquifer parameters, and more.

2.2.4.1.7 Department of Pesticide Regulation

The DPR Ground Water Protection Program evaluates and samples for pesticides to determine if they may contaminate ground water, identifies areas sensitive to pesticide contamination and develops mitigation measures to prevent that movement. DPR obtains ground water sampling data from other public agencies, such as SDWIS, USGS and GAMA, and through its own sampling

program. Sampling locations and constituents are determined by pesticides used in a region, and from review of pesticide detections reported by other agencies. Because of their sample selection methodology, DPR typically only collects one sample per well, they do not confirm positive detections with repeat sampling. Rather, their focus is on validating contamination through their research and sampling program. These data are reported annually along with the actions taken by DPR and the State Water Resources Control Board to protect ground water from contamination by agricultural pesticides.

2.2.4.1.8 California Integrated Water Quality System (CIWQS)

CIWQS is a database used by the State and Regional Water Quality Control Boards for tracking information about places of environmental interest, manage permits and other orders, track inspections, and manage violations and enforcement activities. Programs within this database that is used for SGMA water quality evaluation are the Waste Discharge Requirements (WDRs) through Non-Subchapter 15 and Confined Animal Sites. Non-Subchapter 15 program are discharges of wastewater to land or non-federal waters which are exempt from Title 27 regulations and National Pollutant Discharge Elimination System (NPDES) regulations. This program regulates both point and non-point source discharges to land or to groundwater that could affect the quality of the groundwater. WDRs and WDR waivers are important since they are in place to protect groundwater quality and compliance with Basin Plans. Some regulated discharges that have the potential to affect groundwater quality include: agricultural runoff, domestic septic systems, injection wells, wastewater recycled for reuse or discharge to land, dairy operations, and timber harvesting.

2.2.4.1.9 Water Resources Association of Yolo County Water Resources Information Database

YCFCWCD has developed a robust groundwater monitoring program and data management system and was a key player in building out the Water Resources Association of Yolo County's Water Resources Information Database (WRID). Through Assembly Bill 303 Project (AB 303 Project), California Department of Water Resources (DWR) awarded AB 303 grant funds to implement a formal Yolo County region-wide comprehensive groundwater quality monitoring program in 2002. The YCFCWCD was established as the lead agency for implementing an ongoing groundwater monitoring program for the Yolo County area and to promote coordinated and effective water resources management and dissemination of information on water resources management of groundwater conditions. As a result of AB 303, the Yolo County Water Resources Information Database (WRID) was created. Data obtained for this monitoring program includes the south to southwest portions of the Sacramento Valley Groundwater Basin that underlie the Cache and Putah Creeks Alluvial Plain and all of Yolo County.

The YCFCWCD's WRID includes data from various regulatory agencies such as DDW, DPR, DWR, and Yolo County Environmental Health Department. Information obtained from the regulatory agencies included: well construction, well location, groundwater levels, groundwater quality data. In addition, groundwater quality data from potentially contaminated sites were also collected for the database. To better understand and fill in potential gaps in groundwater level and

groundwater quality data, domestic/private well owners were included in the baseline monitoring network.

2.2.4.2 Water Quality Standards

Federal and State Drinking Water Standards are predominantly referenced when discussing water quality standards. However, land use in the Yolo Subbasin is about half for agricultural purposes and drinking water salinity limits are not protective enough for agriculture. For this reason, the SWRCB's *Agricultural Water Quality Goals* (Ag goals) is also be referenced for evaluation of groundwater quality in this area. The most applicable standard, Drinking Water Standard or Ag goals will be used as a reference point when discussing each constituent.

Water quality constituents that have the potential to impact the groundwater quality of the Yolo Subbasin are arsenic, hexavalent chromium, nitrate, chloride, sodium, boron, selenium, conductivity, and total dissolved solids (TDS). The list of these constituents along with their corresponding standards are listed in **Table 2-12**. In the Subbasin, arsenic, hexavalent chromium, boron, and selenium are predominately naturally occurring. Constituents related to salinity – chloride, conductivity, sodium, and TDS - also naturally occurring but concentrated by surface activities. Nitrate is predominately anthropogenic.

Table 2-12. List of Constituents and Standards

Constituent	Units*	Drinking Water Standard	Agricultural Water Quality Goal
Arsenic	ppb	10	100
Boron	ppb	1,000	700
Chloride	ppm	250	106
Hexavalent Chromium	ppb	n/a	n/a
Nitrate	ppm	10	n/a
Selenium	ppb	50	20
Sodium	ppm	n/a	69

ppb = parts per billion
ppm = parts per million

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2.2.4.3 Public Water Systems

While land use within Yolo Subbasin is roughly 60-percent agricultural, there are 83 public water systems that are identified through the Groundwater Ambient Monitoring and Assessment Program (GAMA) and State Drinking Water Information System (SDWIS). 17 of these water systems are classified as community water systems, meaning that there are at least 15 service connections, or 25 year-round residents are served. The remaining public water systems are either Non-Transient Non-Community (NTNC) or Transient Non-Community water systems (TNC). These classifications are generally designated for businesses who supply water to their employees, or a transient (pass through) population. **Table 2-13** lists the community public water systems with a brief description and estimated population served. **Figure 2-24** shows where the community public water systems are located within the Yolo Subbasin.

Water quality data from regulated drinking water systems is available through SDWIS. NTNC water systems are required to test for most regulated constituents at least once every 3 years. TNC have reduced monitoring requirements and typically only test for nitrate and bacteria on a regular basis.

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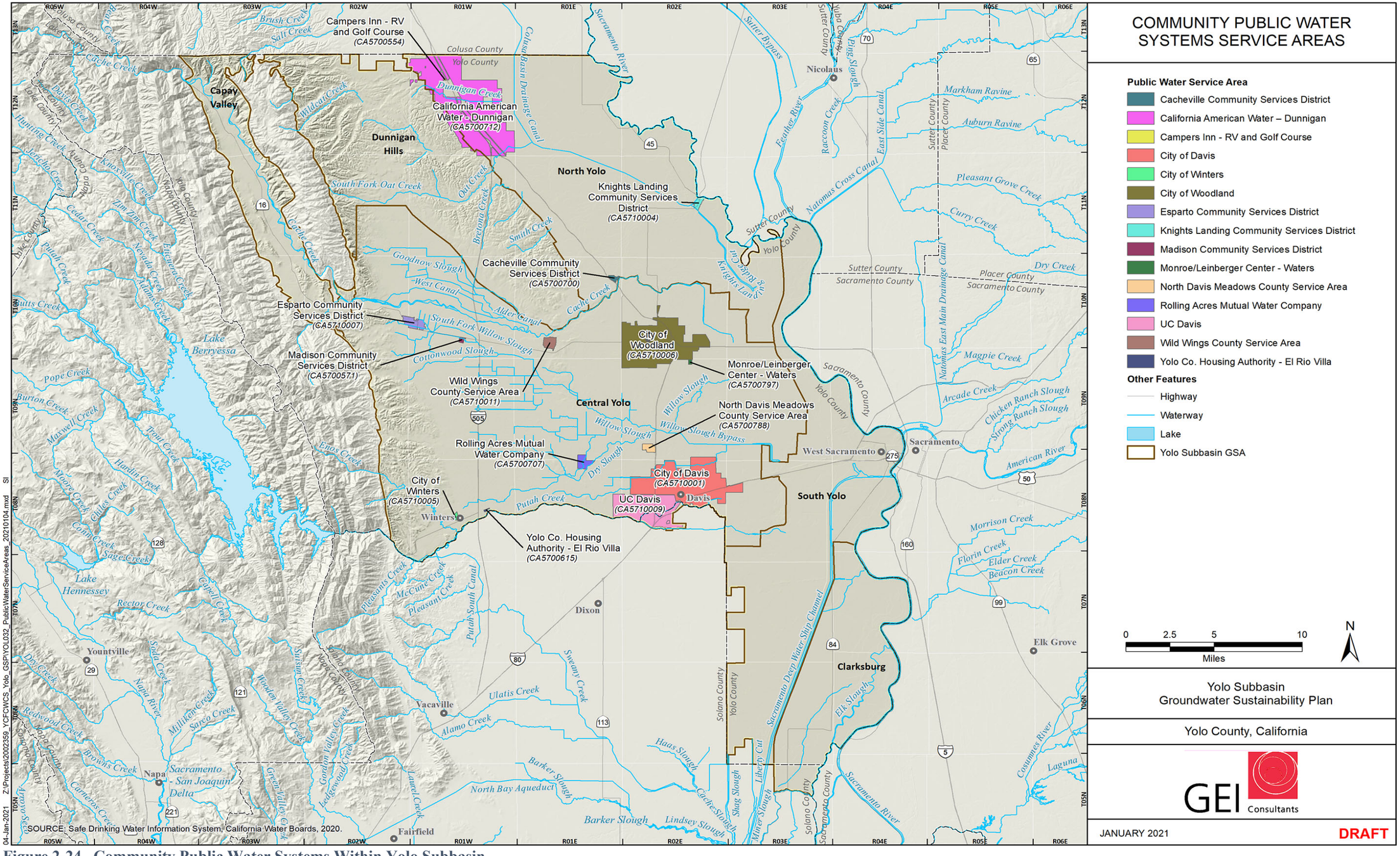


Figure 2-24. Community Public Water Systems Within Yolo Subbasin

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Table 2-13. Community Public Water Systems within Yolo Subbasin

Water System #	Water System Name	Population Served	Service Area	Number of Wells
CA5700700	Cacheville Community Services District	400	Residential	2
CA5700712	Cal-American Water Company - Dunnigan	400	Mobile Home Park	2
CA5700554	Campers Inn - RV & Golf Course	120	Mobile Home Park	1
CA5710001	City of Davis	71,311	Residential	9
CA5710003	City of West Sacramento	55,000	Residential	0
CA5710005	City of Winters	7,417	Residential	5
CA5710006	City of Woodland	60,292	Residential	8
CA5710007	Esparto Community Services District	3,108	Residential	4
CA5710004	Knights Landing Community Services District	1,300	Residential	3
CA5700571	Madison Community Services District	876	Residential	2
CA5700797	Monroe/Leinberger Center/Waters	800	Institution	1
CA5700788	North Davis Meadows County Service Area	314	Residential	3
CA5700707	Rolling Acres Mutual Water Company	40	Residential	1
CA5710009	University of California, Davis	48,828	School	6
CA5710011	Wild Wings County Service Area	1,115	Residential	2
CA5710012	Woodland-Davis Clean Water Agency	129,820	Wholesaler	0
CA5700615	Yolo Co. Housing Authority - El Rio Villa	432	Residential	2

2.2.4.4 Water Quality Evaluation

Several groundwater quality constituents are of particular concerns within the Subbasin and are summarized in the following sections, including salinity, nitrate, boron, arsenic, total and hexavalent chromium, manganese, and selenium.

Public water systems were identified through GAMA and water quality data was extracted from SDWIS. Since most of the water systems identified are businesses, monitoring requirements are sometimes less extensive than municipalities serving residential communities. Therefore, this section is a summary of the water quality from the public community water systems in the Yolo Subbasin.

All available water quality data was evaluated to identify constituents of concern. City of West Sacramento community water system do not have groundwater wells, therefore were not included in the evaluation. Not all constituents that are commonly found in the Subbasin, as identified in **Table 2-12**, are found at concerning concentrations in community water systems. Therefore, only boron, hexavalent chromium, chloride, and sodium, are addressed as constituents of concern. Based on the 'Nitrate Fingerprinting and Groundwater Age Determination Study' in December 2012, Nitrate was identified as a concern and will be discussed to align with other regulatory programs in the Subbasin such as ILRP and CV-SALTS.

It is important to note that this water quality evaluation of public water systems does not include Non-Transient Non-Community (NTNC) or Transient Non-Community water systems (TNC). NTNC and TNC water systems typically serve a smaller population and groundwater wells may tend to be shallower. To better represent the groundwater quality of the principal aquifers, community water system water quality was evaluated.

2.2.4.4.1 Salinity – Basinwide Conditions

Electrical conductivity (EC) can be used to characterize salinity in Yolo Subbasin. **Figure 2-25** shows the maximum recorded EC in groundwater quality monitoring wells from 2000 to 2004, collected as part of the AB 303 Groundwater Management Assistance Act Program. In the shallow groundwater zone, average EC ranges from around 480 µmhos/cm near Buckeye and Zamora, to over 1,450 µmhos/cm in the Lower Cache-Putah and Southern Sacramento River areas (YCFCWCD, 2004). High EC in the shallow zone is also observed in southern portions of the Capay Valley. Intermediate groundwater EC values are similar to the shallow zone, in the vicinity of Davis and Woodland. The deep groundwater zone, though limited to the Davis and Lower Cache-Putah areas, display lower EC values than the intermediate and shallow groundwater zones.

TDS data were obtained from 603 wells, which were described in the Groundwater Quality Assessment Report ([GAR] NCWA, 2016), and are presented in **Figure 2-26**. The GAR provides available data as of 2014. The GAR distributions generally agree with results mentioned above, as TDS is elevated in the agricultural areas surrounding Woodland and Davis and the Capay Valley. However, these data show additional pockets of elevated TDS, including areas near Clarksburg and Knight's Landing.

Recent data (2000 to 2016) have been collected for the Central Valley Salinity Alternatives for Long-Term Sustainability database (NCWA, 2019) and display similar concentration trends to the AB 303 and GAR data discussed above. In the shallow groundwater zone, TDS is high (>1000 milligrams per liter [mg/l] or parts per million [ppm]) across a large portion of the eastern Subbasin, overlying West Sacramento, Davis, and Woodland. TDS values are also elevated in the Capay Valley. TDS is generally lower in the deeper groundwater zone, though patches of elevated TDS are present near Madison and north of Woodland, and concentrations in Capay Valley are uniformly above 500 mg/l.

Salinity tends to decrease with depth in Yolo Subbasin. For example, EC measurements taken from 2000 to 2004 in the Lower Cache-Putah area decrease from 1,470 to 1,040 to 600 umhos/cm for the shallow, intermediate, and deep groundwater zones respectively. Notable decreases in salinity with depth were also present in the Capay Valley and Southern Sacramento River areas (**Figure 2-27**). Intermediate zone EC is slightly higher than shallow zone EC near Davis, though this condition is likely a byproduct of data availability (YCFCWCD, 2004).

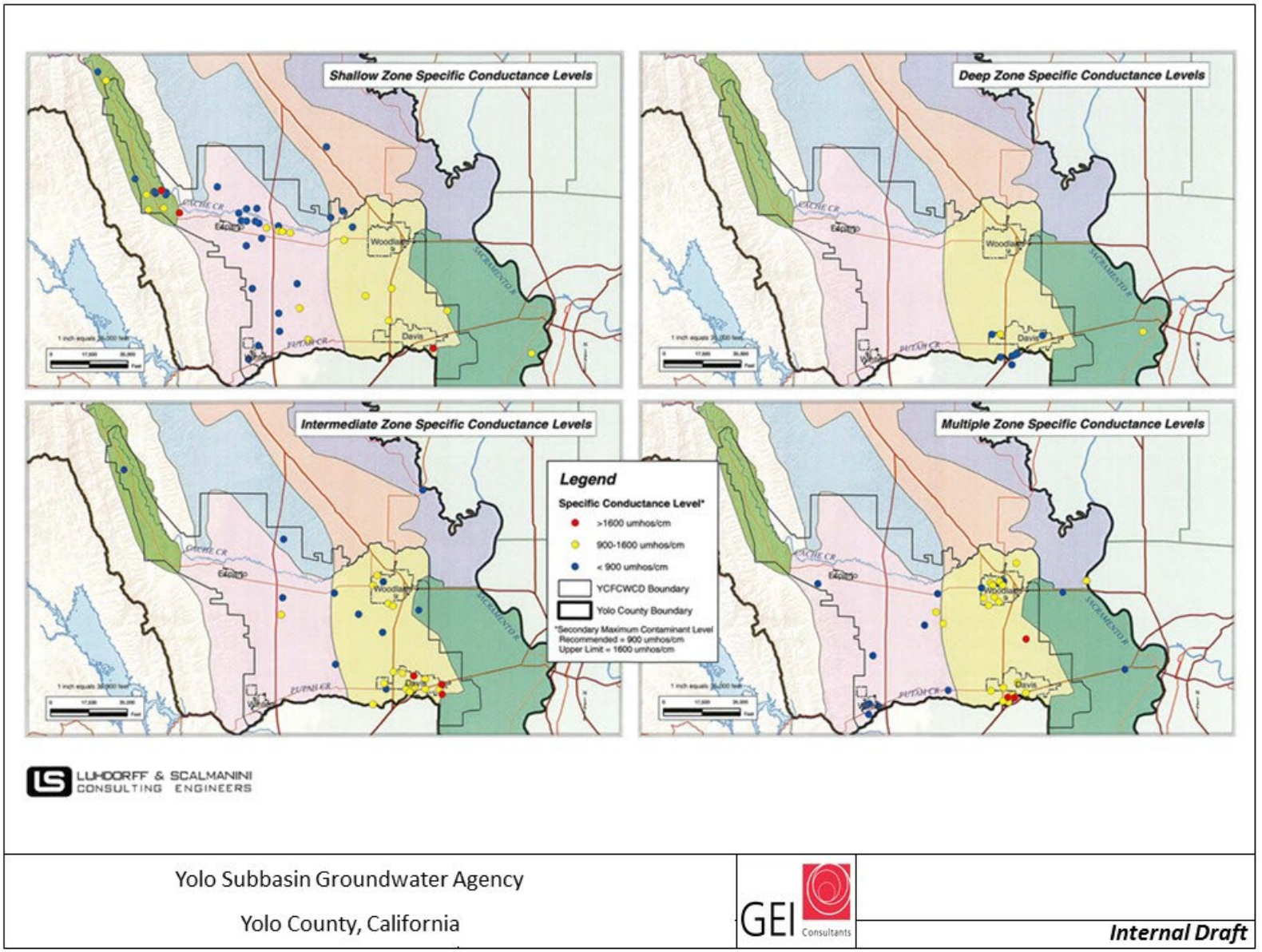


Figure 2-25. Maximum Observed Specific Conductance by Groundwater Zone, 2000-2004

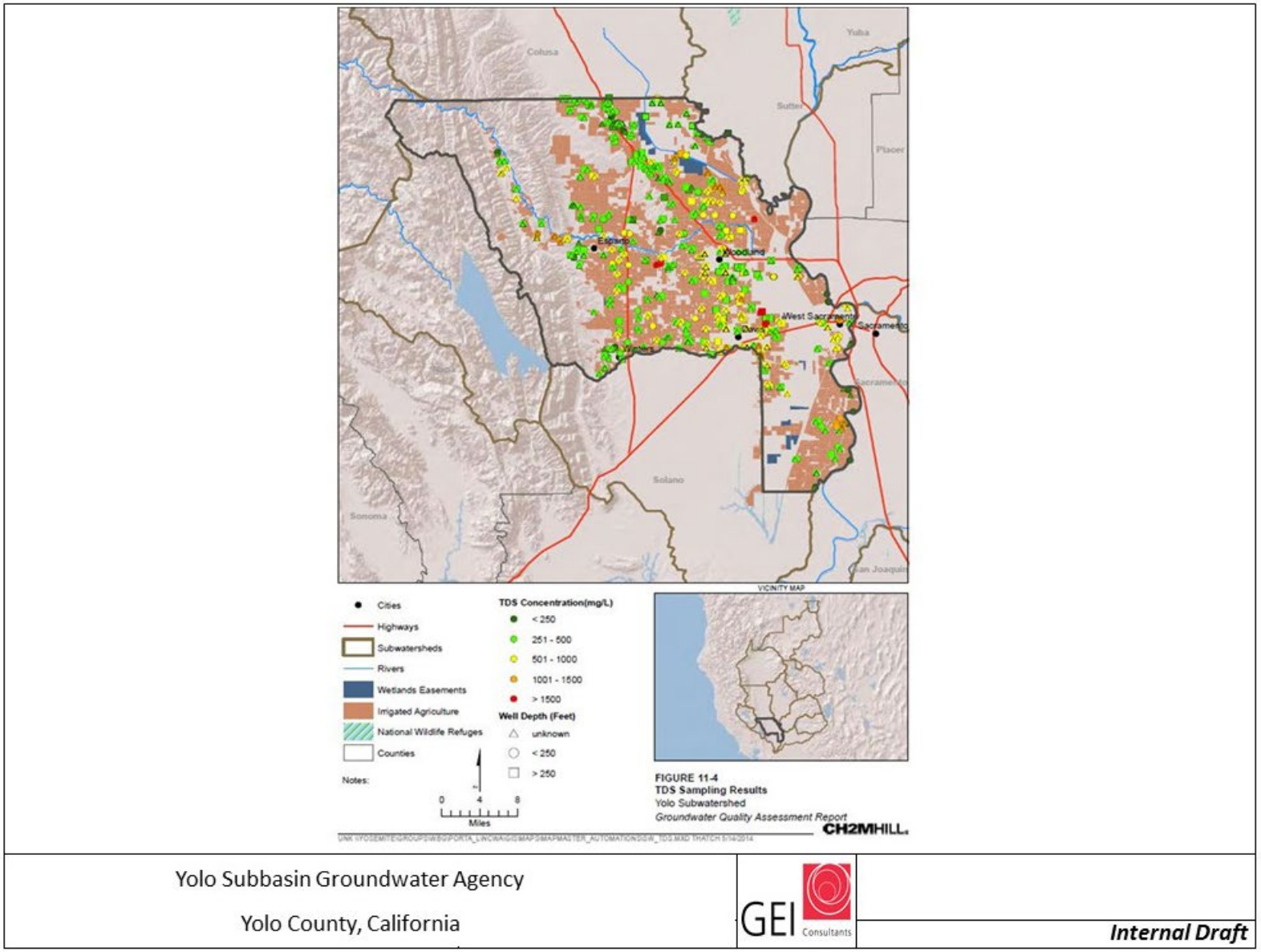


Figure 2-26. TDS Concentrations, 2014

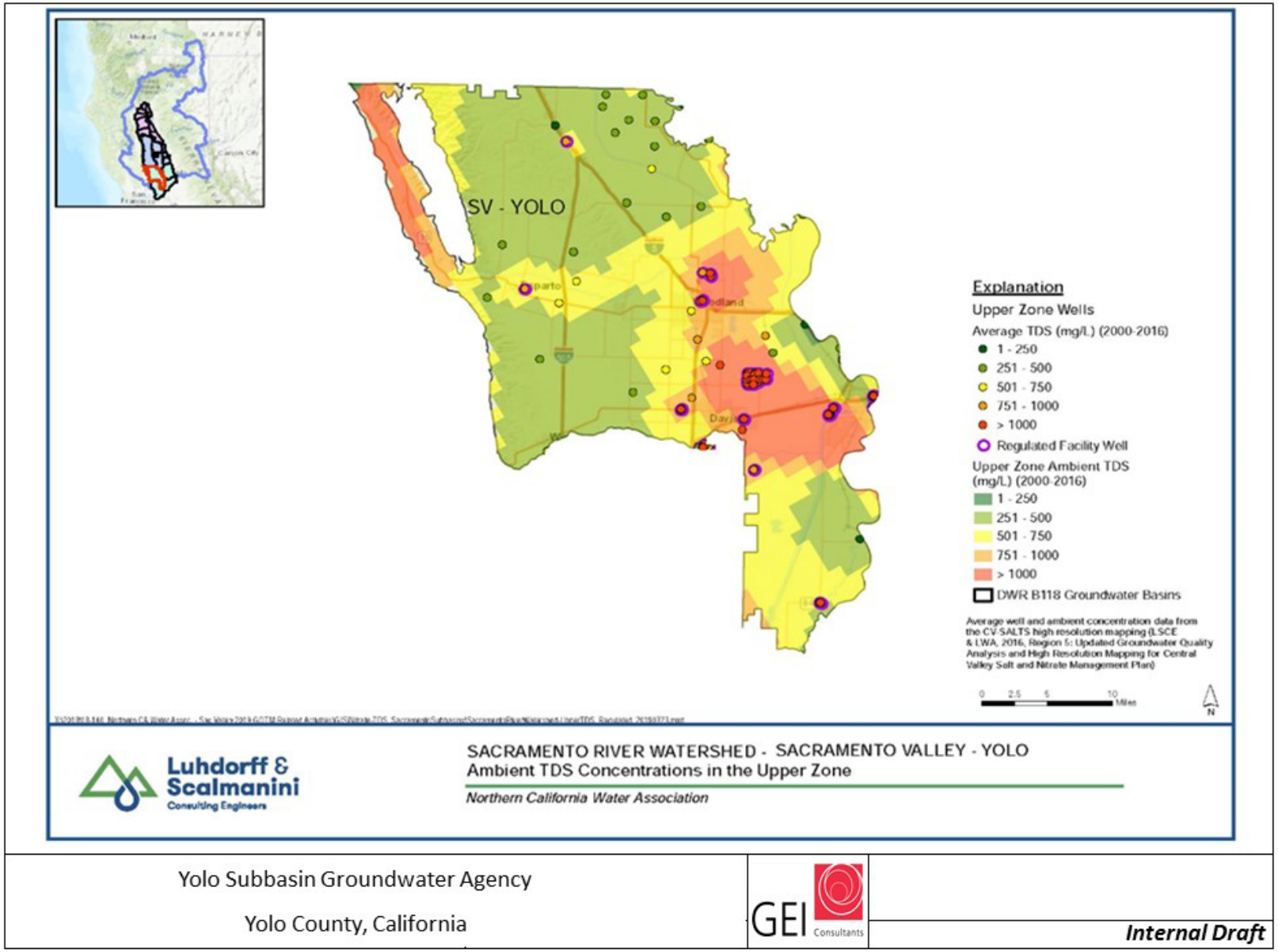


Figure 2-27. TDS Concentrations, 2014

Salinity in the shallow and intermediate zones of the Yolo Subbasin is generally increasing. An early groundwater quality investigation (Scott and Scalmanini, 1975) found that TDS in the shallow zone near Davis increased from 500 mg/l in 1931 to 684 mg/l in 1970. Current levels in that area exceed 1,000 mg/l (**Figure 2-25**). Similarly, shallow zone TDS near Woodland was around 480 mg/l in 1950 to 1959, around 455 mg/l in 1970, which was around half the current concentrations (**Figure 2-26**).

Salinity in Yolo Subbasin can be attributed to a variety of land use factors (YCFCWCD, 2004). Elevated salinity in the south of the Subbasin may be attributable to the prehistoric/historic influence of the nearby Sacramento-San Joaquin Delta, which allowed brackish water to encroach into Subbasin prior to implementation of water quality programs that began during the 1950s. Extreme climatic conditions have the potential to introduce brackish waters into the Subbasin again and possibly saline waters, depending on future sea level rise and mitigation. However, further chemical analysis must be performed to robustly identify potential seawater intrusion, especially analysis of chloride concentrations and sodium/chloride ratios.

2.2.4.4.2 Salinity – Public Water Systems

Based on drinking water standards, the recommended secondary maximum contaminant level (SMCL) of total dissolved solids is 500 ppm with an upper limit of 1,000 ppm and chloride is 250 ppm with an upper limit of 500 ppm. There is no drinking water standard for sodium; however, Water Quality Goals for Agriculture, published by the Food and Agriculture Organization of the United Nations in 1985, has set agricultural goals for TDS, sodium, and chloride at 450 ppm, 69 ppm, and 106 ppm, respectively. The criteria identified are protective of various agricultural uses of water, including irrigation of various types of crops and stock watering. These levels are used as a baseline to compare against and are not intended to represent an acceptable maximum value for the Subbasin. Since land use in the Yolo Subbasin is roughly half irrigated lands, the agricultural goals for TDS, sodium, and chloride are referenced as the appropriate value rather than drinking water standards.

TDS is comprised of several dissolved minerals (calcium, phosphates, nitrates, sodium, potassium, and chloride), most of which have minimal impact on beneficial uses of the groundwater. Throughout the Subbasin, sources of salinity identified include a combination of naturally occurring marine deposits; infiltration from produced water disposal ponds; perched water subject to evaporative pumping; or agricultural drainage ponds.

Sodium and chloride ions contribute to TDS and in this region are more important to evaluate due to its impact to the agricultural industry. Both sodium and chloride show similar trends in the wells evaluated; therefore, some sections of the water quality evaluation collectively refer to these ions as salinity. Since sodium concentrations is an important measurement to crop yield, the focus of salinity level discussion will be on sodium.

Table 2-14 summarizes sodium concentrations among the community water systems within the Yolo Subbasin. Sodium data was not available for any wells within North Davis Meadows water

system. About 75-percent of the wells either have sodium concentration greater than half or over the agricultural goal of 69 ppm. Since managing sodium concentrations to meet agricultural goals is important to the land uses within Yolo Subbasin, management actions that will slow or reverse the increasing sodium trend should be considered. Studies conducted through CV-SALTS, and the projects that are planned, will aid in salinity management.

Table 2-14. Summary of Sodium Prevalence Among Community Water Systems

	Sodium Concentrations		
Water System	0-34 ppm	35-69 ppm	>70 ppm
Cacheville Community Services District		2	
Cal-American Water Company - Dunnigan	2		
Campers Inn - RV & Golf Course	1		
City of Davis			9
City of Winters	5		
City of Woodland	2	6	
Esparto Community Services District		4	
Knights Landing Community Services District		1	2
Madison Community Services District		2	
Monroe/Leinberger Center/Waters		1	
North Davis Meadows County Service Area	n/a		
Rolling Acres Mutual Water Company		1	
University of California, Davis			6
Wild Wings County Service Area			2
Yolo Co. Housing Authority - El Rio Villa		2	
Total Wells	**10**	**19**	**19**

2.2.4.4.3 Nitrate – Basinwide Conditions

Figure 2-28 shows the maximum observed nitrate concentrations in groundwater quality monitoring wells, collected from 2000 to 2004 as part of the AB 303 Groundwater Management Assistance Act Program. Nitrate (NO_3) averages in the shallow groundwater zone range from about 16 mg/L near Buckeye and Zamora to 64 mg/L in the Southern Sacramento River area (YCFCWCD, 2004). Nitrate poses a significant threat to human health and therefore is subject to a primary drinking water standard. The maximum contaminant level (MCL) is 45 mg/l as nitrate (NO_3) or 10 mg/l as nitrogen (N).

Notably, wells along Cache Creek also show elevated nitrate concentrations, which may reflect the shallow completion depths of these wells. Elevated shallow zone nitrate (N) concentrations (≈44 mg/l) in the Lower Cache-Putah area are very near or exceed the primary MCL, indicating a significant water quality concern for shallow zone wells.

Figure 2-29 presents the nitrate concentrations for 384 wells as a part of the GAR (NCWA, 2016). The GAR provides available data as of 2014. The nitrate distributions are consistent with the results

of the previous studies discussed above – nitrate concentrations are elevated in the agricultural areas surrounding Woodland and Davis.

Recent nitrate concentrations (2000 to 2016) have been collected for the Central Valley Salinity Alternatives for Long-Term Sustainability database (NCWA, 2019) and display similar concentration trends to the AB 303 and GAR data discussed above. In the unsaturated zone, nitrate concentrations are high (>10 mg/l) across a broad swath of the central Subbasin (**Figure 2-30**). A particularly large strip of nitrate concentration exists between West Sacramento and Davis, with other pockets of high nitrate present near Woodland, Knight's Landing, and Madison. Nitrate contamination in the lower groundwater zone is less extensive than in the upper zone, however pockets of high concentrations are present north of Woodland and near Madison (**Figure 2-31**).

As mentioned previously, nitrate concentration typically decreases with depth in Yolo Subbasin. Notable differences between zones are especially present in the Western Yolo, Southern Sacramento River, and Lower Cache-Putah areas. For example, average nitrate concentrations in the Lower Cache-Putah area decline with depth from 44 to 19 to 3 mg/L in the shallow, intermediate and deep zones, respectively. **Figure 2-28** through **Figure 2-31** further illustrate differences in nitrate concentrations at depth.

Historical groundwater quality investigations in Yolo County have shown increasing shallow and intermediate zone nitrate concentrations in much of the central-eastern portion of the Subbasin, particularly near Davis and Woodland (Scott and Scalmanini, 1975). For example, shallow zone nitrate concentrations near Davis increased from 4 mg/L in 1931 to 11 mg/L in 1970. Similarly, shallow zone nitrate concentrations near Woodland increased from 2.7 mg/L in the 1950s to 4.5 mg/L in 1970. More current data suggest nitrate accumulation in the shallow and intermediate groundwater zones is ongoing in some areas and may be extending into the deep zone (YCFCWCD, 2004; NCWA, 2016; NCWA, 2019).

Nitrate in Yolo Subbasin is mostly of agricultural origin. A recent fingerprinting study (YCFCWCD, 2012) identified 24 wells with nitrate, and 83% of the nitrate originated from artificial fertilizer. For the remaining 17% of wells, the nitrate was an organic source, either septic which is commonly rural or manure. Previous studies have obtained similar results, indicating that the elevated nitrate in Yolo Subbasin is mostly a byproduct of agricultural discharges in the Subbasin (LW&A, 2010; YCFCWCD, 2006).

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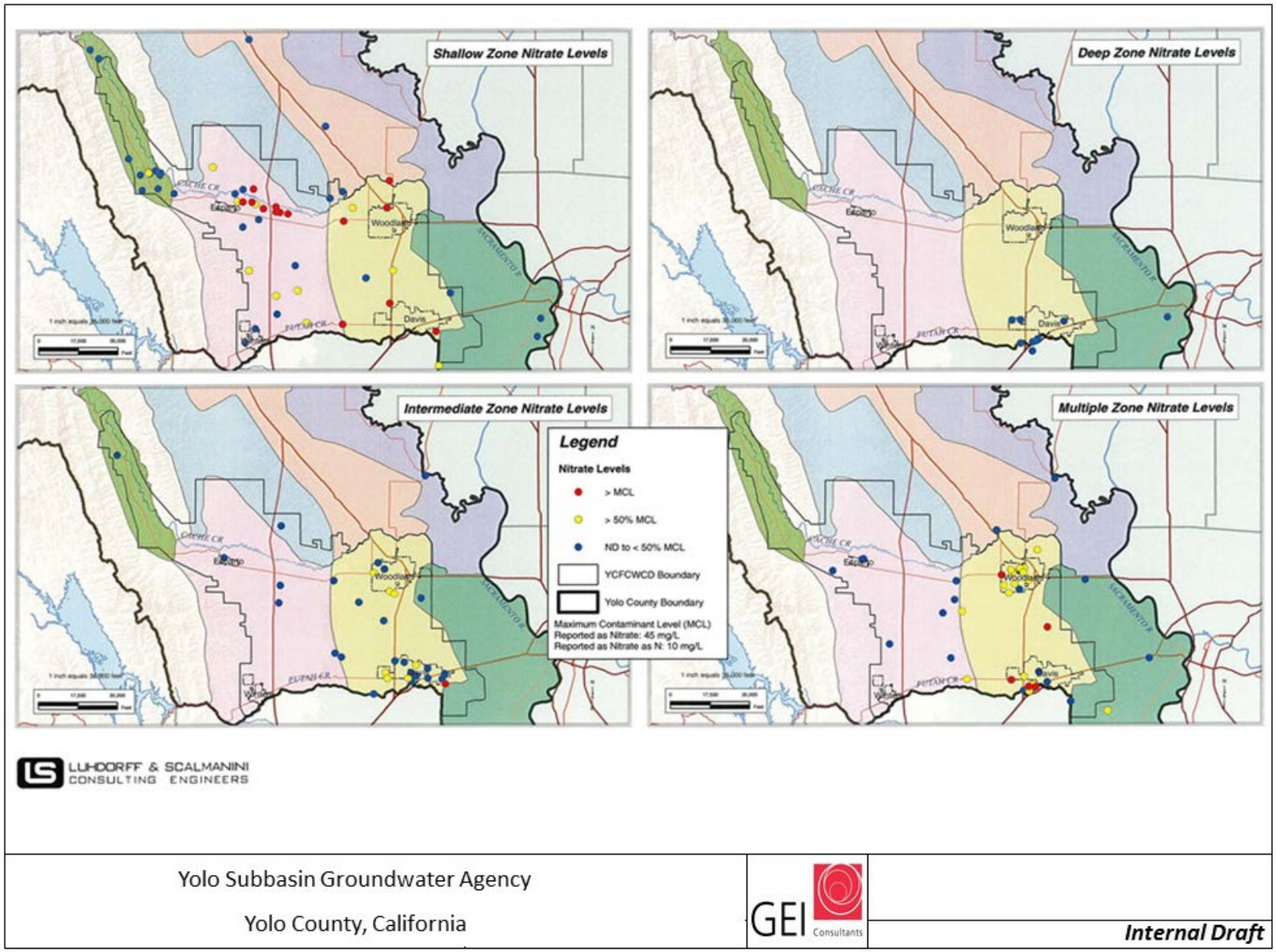


Figure 2-28. Maximum Observe Nitrate Concentrations by Groundwater Zone, 2000-2004

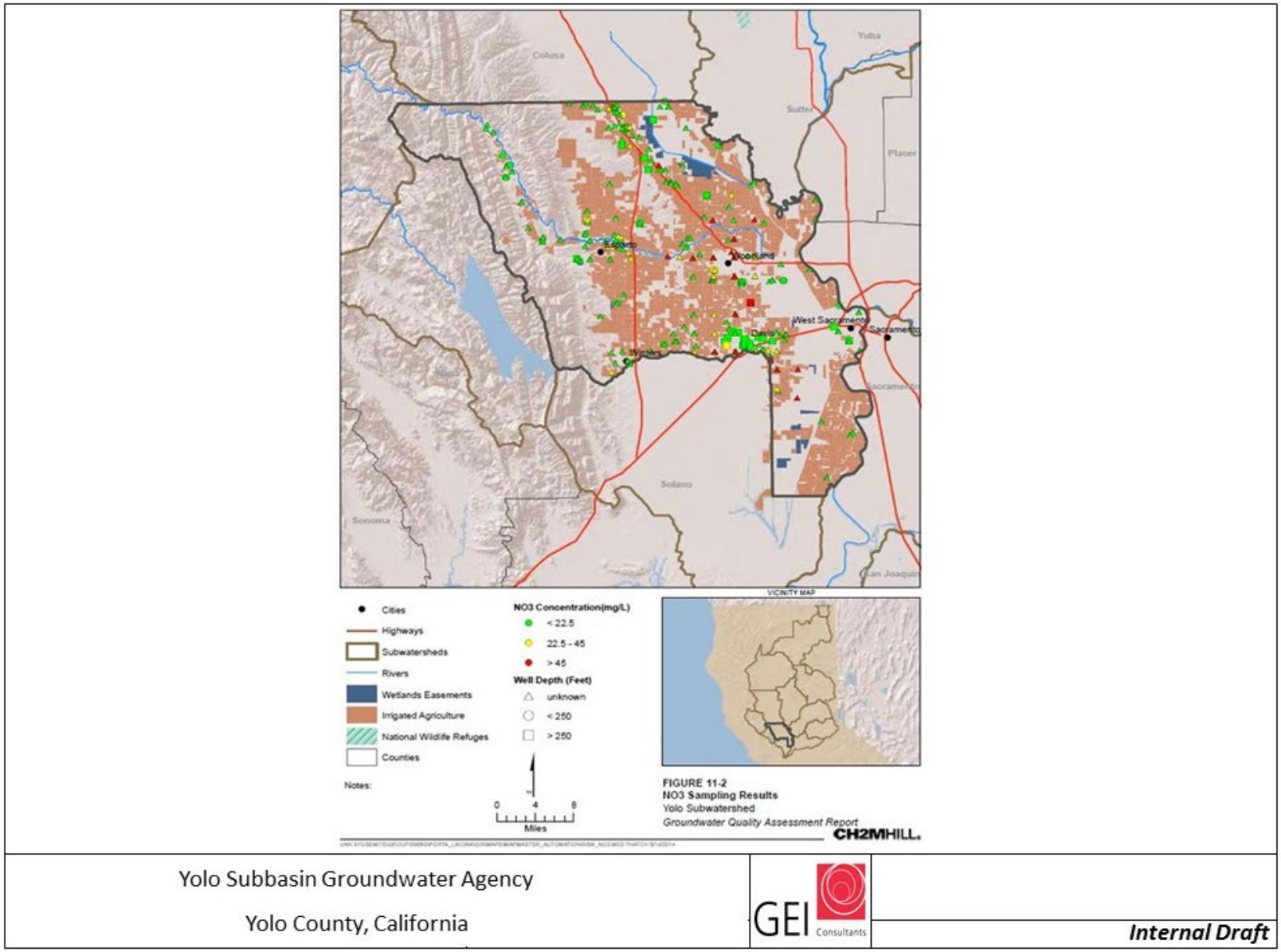


Figure 2-29. Nitrate Concentrations, 2014

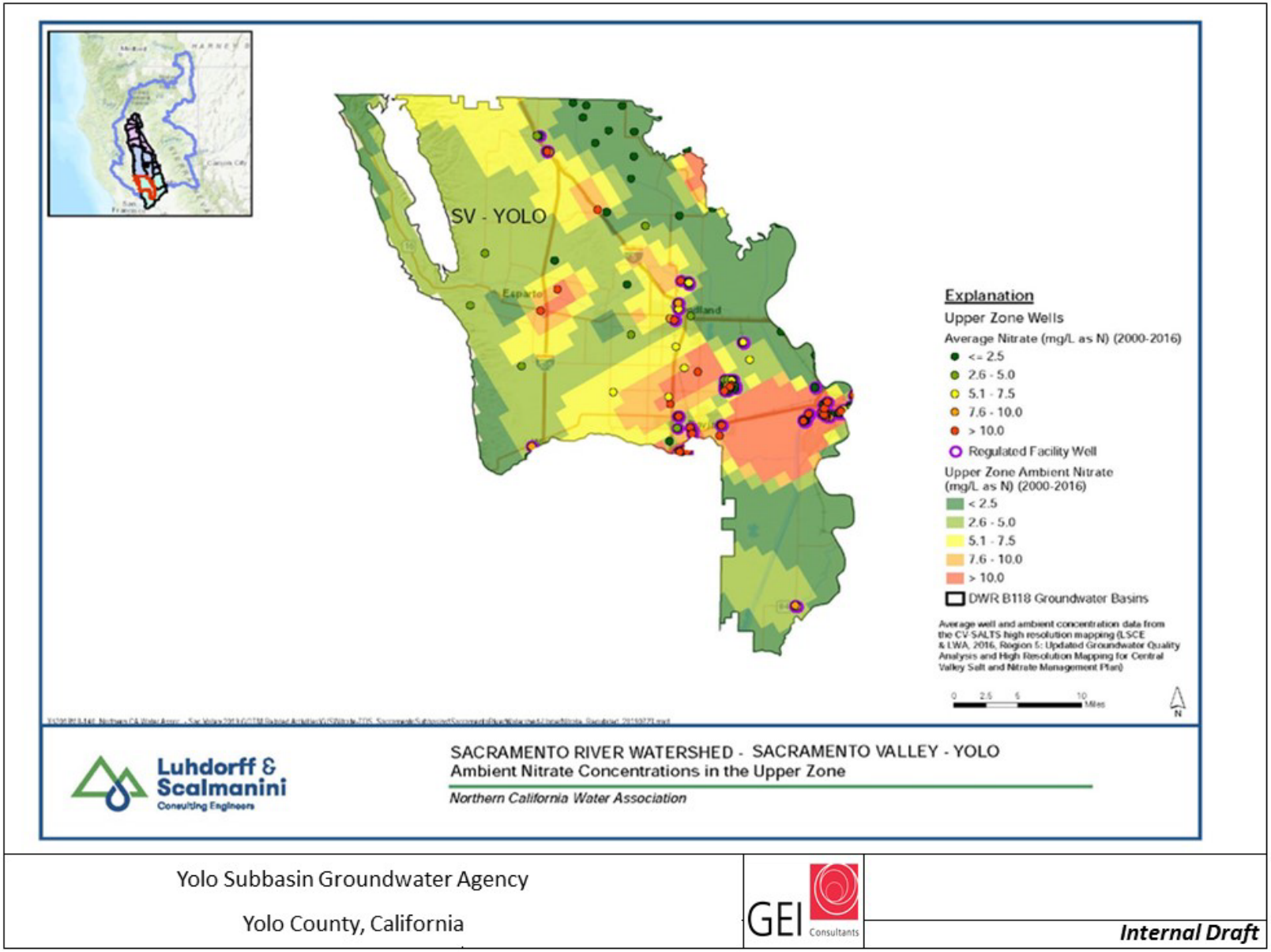


Figure 2-30. Upper Groundwater Zone Nitrate Concentration in Yolo Subbasin, 2000-2016

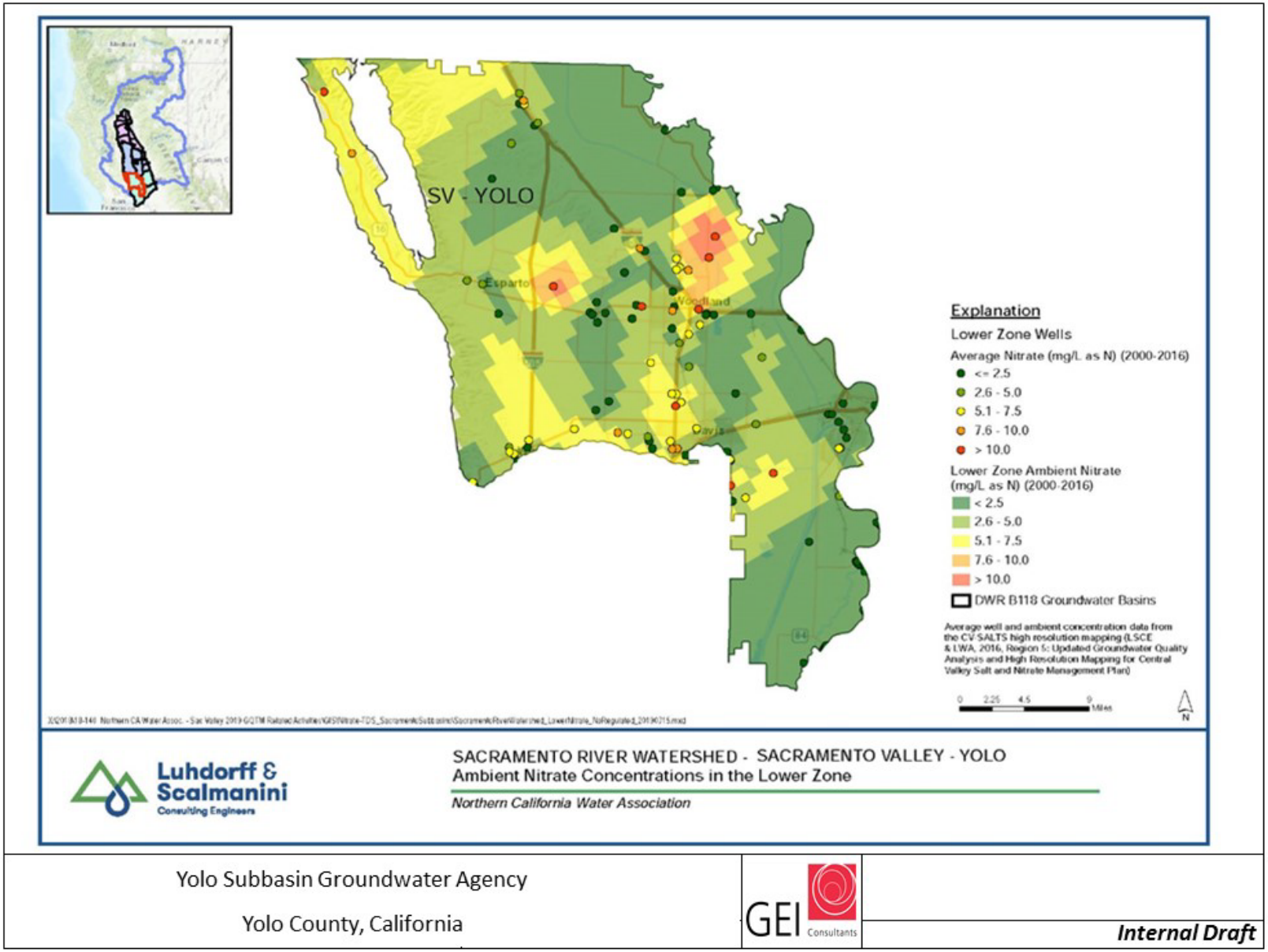


Figure 2-31. Lower Zone Nitrate Concentration in Yolo Subbasin, 2000-2016

2.2.4.4.4 Nitrate – Public Water Systems

Even though nitrate is not considered a concern for community water systems, which most likely have deeper wells and annular seals, it is mentioned in this evaluation for potential future references from the ILRP or CV-SALTS programs. There is a primary drinking water standard of 10 ppm for nitrate (N). An agricultural goal is not available. Nitrate contamination is a significant concern in rural communities, particularly where agriculture is the predominant land use. However, a significant source of nitrate also comes from septic systems used in these rural communities. Since municipal services (drinking water or wastewater collection systems) may not be available in rural areas of the Yolo Subbasin, all domestic and public wastewater disposal is through onsite septic systems.

Nitrate can be naturally present at low concentrations in groundwater, typically less than 2 ppm. Moderate and high concentrations generally occur because of human activities. Septic systems typically contribute moderate concentrations between 5 and 15 ppm of nitrate as nitrogen. Typically, higher concentrations (greater than 20 ppm) are associated with applying fertilizers to crops. Nitrate contamination is a significant public health concern because it has acute health effects. High concentrations of nitrate are typically found in shallow groundwater, such as those in the unconfined aquifer. Among the community water systems, one well has nitrate over the drinking water MCL for nitrate. **Table 2-15** shows the summary of number of wells of nitrate prevalence (source water) in community water systems.

Table 2-15. Summary of Nitrate Prevalence Among Community Water Systems

	Nitrate Concentrations		
Water System	0-5 ppm	6-10 ppm	>11 ppm
Cacheville Community Services District	2		
Cal-American Water Company - Dunnigan	1	1	
Campers Inn - RV & Golf Course		1	
City of Davis	5	4	
City of Winters	5		
City of Woodland	3	5	
Esparto Community Services District	4		
Knights Landing Community Services District	3		
Madison Community Services District		2	
Monroe/Leinberger Center/Waters	1		
North Davis Meadows County Service Area		2	1
Rolling Acres Mutual Water Company	1		
University of California, Davis	6		
Wild Wings County Service Area	2		
Yolo Co. Housing Authority - El Rio Villa		2	
Total Wells	**33**	**17**	**1**

2.2.4.4.5 Boron – Basinwide Conditions

Figure 2-32 and **Figure 2-33** display maximum observed boron measurements in groundwater quality monitoring wells for 1951 to 2004. This compilation was part of the AB 303 Groundwater Management Assistance Act Program. Average boron concentrations for the shallow groundwater zone ranged from about 660 micrograms per liter (ug/L) in the Western Yolo area to 2,300 ug/L in the Capay Valley area. The Capay Valley has been identified as particularly high in boron, and hosts a disparate range of boron concentrations, ranging from 392 to 9,490 ug/L. The second highest average shallow boron concentration (1,600 ug/L) was present in the Lower Cache-Putah area (YCFCWCD, 2004).

In general, boron concentrations decrease with depth in Yolo Subbasin. For example, average concentrations in the Lower Cache Creek-Putah area decrease from 1,600 ug/L to 1,100 ug/L to 730 ug/L for the shallow, intermediate, and deep groundwater zones respectively. Boron concentrations also decline notably with depth in the Capay Valley and Southern Sacramento River areas.

In general, boron concentrations in Yolo Subbasin have been historically stable. While some wells across the Subbasin have been identified as increasing in boron concentration, these fluctuations are small relative to the historical range and are not spatially correlated (YCFCWCD, 2004). Previous studies of the boron distribution in Yolo Subbasin correlate well with more current data, suggesting large changes in boron concentration have not occurred historically (Scott and Scalmanini, 1975; Evenson, 1985)

While boron is an essential plant nutrient, concentrations greater than 4 mg/L are generally toxic to non-tolerant plants. Further, concentrations between 0.5 and 4 mg/L can be harmful to sensitive plant species (Ayers and Westcot, 1985). Boron in groundwater systems is often occurs naturally, a result of interaction between water and borate/borosilicate minerals in rocks and soils. In some instances, boron may be present in groundwater as a result of wastewater discharges, typically associated with domestic washing products (WHO, 1998). The distribution of boron in Yolo Subbasin suggest a naturally occurring source, associated with the hydrogeologic setting of the Subbasin (YCFCWCD, 2004).

2.2.4.4.6 Boron – Public Water Systems

There is no federal or state MCL for boron. However, California does have a Notification Level of 1,000 parts per billion (ppb), and there is an agricultural goal of 700 ppb. The agricultural goal is set to protect various agricultural uses of water, including irrigation of various types of crops and stock watering. These levels are used as a baseline to compare against and are not intended to represent an acceptable maximum value for the Subbasin. Since land use in the Subbasin is about half irrigated lands, the agricultural goal for boron is used as a reference point, rather than the drinking water Notification Level. The most prevalent sources of boron in drinking water are from leaching of rocks and soils, wastewater, and fertilizer/pesticides applications.

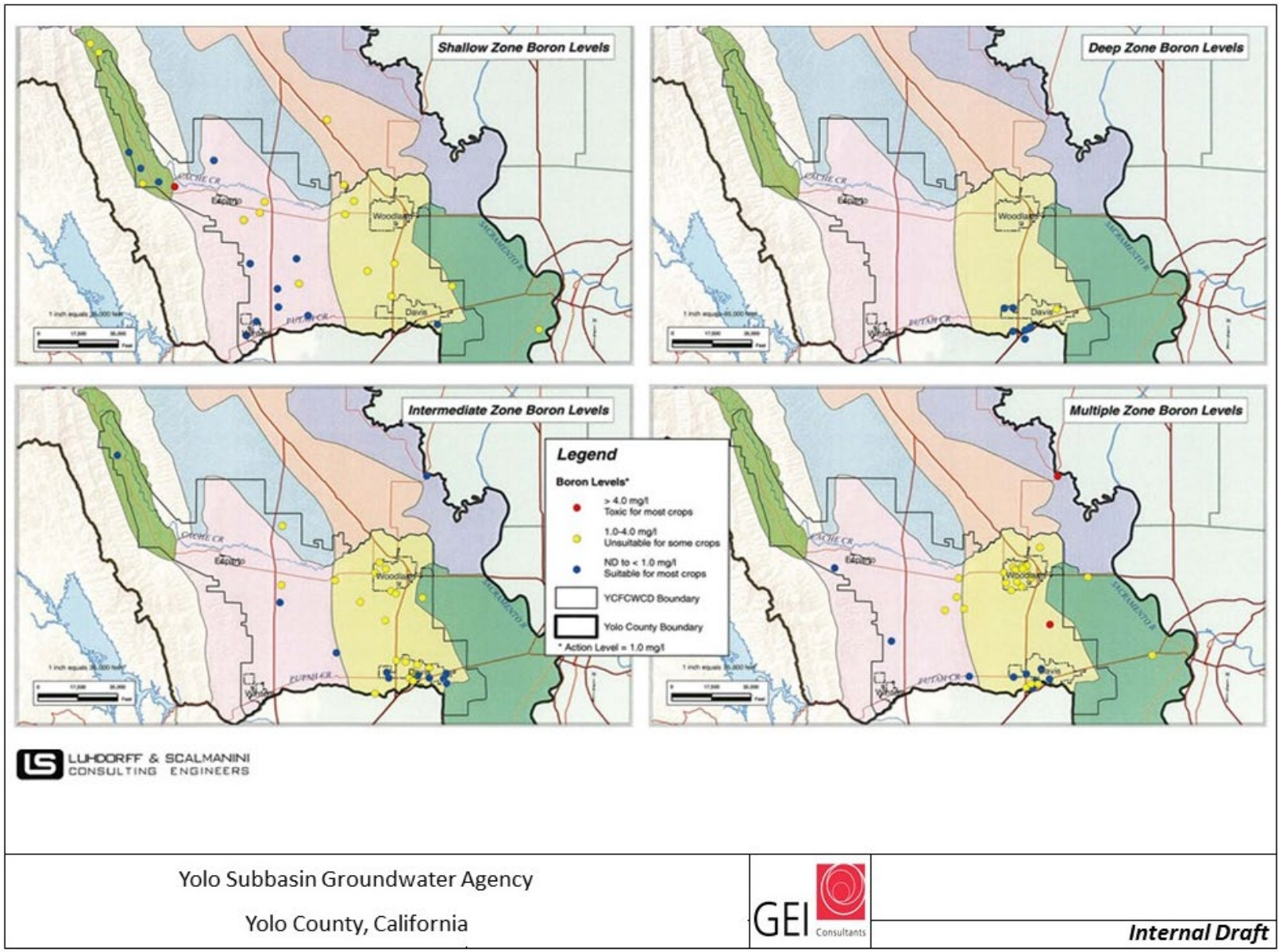


Figure 2-32. Maximum Observed Boron Concentrations by Zone, 2000-2004

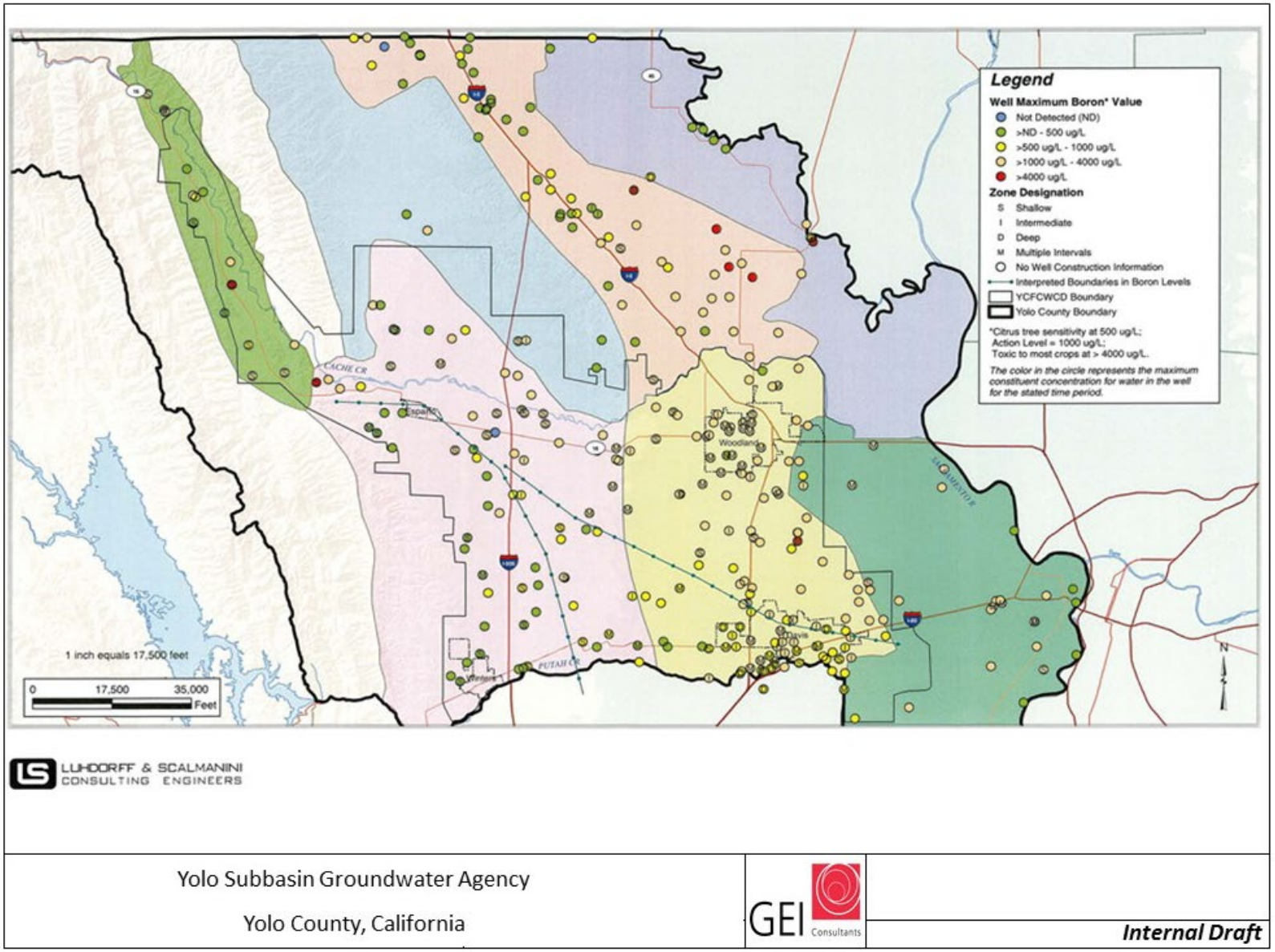


Figure 2-33. Maximum Observed Boron Concentrations, 1951-2004

According to the USGS Scientific Investigations Report 2011-5002 (Bennett et al, 2011) boron is a trace element that occurs naturally in many minerals, primarily borax. Most elevated boron detections above the Notification Level were found in the Southern Sacramento Valley Study Unit, which includes Yolo Subbasin. High concentrations in wells along Cache and Putah Creeks are likely associated with old marine sediments from the Coast Ranges (YCFCWCD, 2007).

Table 2-16 summarizes boron concentrations among the community water systems within the Yolo Subbasin. Boron data was not available for 12 of 51 wells. About 33-percent of the wells have boron concentrations over the Notification Level.

Table 2-16. Summary of Boron Prevalence Among Community Water Systems

	Boron Concentrations		
Water System	**0-500 ppb**	**501-1,000 ppb**	**>1,001 ppb**
Cacheville Community Services District	n/a		
Cal-American Water Company - Dunnigan	2		
Campers Inn - RV & Golf Course	1		
City of Davis		9	
City of Winters	4		
City of Woodland			6
Esparto Community Services District	2		
Knights Landing Community Services District			3
Madison Community Services District			2
Monroe/Leinberger Center/Waters	n/a		
North Davis Meadows County Service Area	n/a		
Rolling Acres Mutual Water Company		1	
University of California, Davis		5	
Wild Wings County Service Area			2
Yolo Co. Housing Authority - El Rio Villa		2	
Total Wells	**9**	**17**	**13**

Arsenic – Basinwide Conditions

Figure 2-34 shows arsenic data compiled for samples collected from 1951 to 2004 as part of the AB 303 Project. Although the data are limited due to high detection limits and sampling quantity, results are useful in the identification of potential arsenic trends in the Subbasin. The limitations were discussed in the full report (YCFCWCD, 2004). Maximum arsenic detection values from 1951 to 2004 are displayed on **Figure 2-34**. Arsenic was not typically detected in the shallow groundwater zone, while concentrations range up to 6.4 ug/L in the intermediate zone. Arsenic detections in the deep groundwater zone are slightly higher, ranging up to 10 ug/L.

The distribution of arsenic across the Subbasin illustrate some possible patterns of distribution. However, the high detection limit(s) of the older analyses may have actually omitted an area(s) of naturally-occurring arsenic at very low concentrations. In general, concentrations increase from the west to the east of the Subbasin, possibly correlated with increased thickness of the Tehama formation. Historical arsenic results in the Capay Valley and Western Yolo area show mostly non-detects and low concentrations up to 2.5 ug/L. Arsenic trends relatively higher in the area between Woodland south to Davis, exhibiting a greater prevalence of values between 2.5 and 5 ug/L. Near Davis, arsenic concentrations can range from 5 to 10 ug/L.

Arsenic is a trace element naturally present in the basin-fill aquifers in the Western U.S that can negatively impact human health when consumed in drinking water (Smith et al., 2002; Henke, 2009; Anning et al, 2012). The source of arsenic has not been documented thoroughly for the Yolo Subbasin.

2.2.4.4.7 Chromium / Hexavalent Chromium – Basinwide Conditions

Total chromium (chromium III and chromium VI) data were compiled for samples collected from 1951 to 2004 as part of the AB 303 Project and are displayed on **Figure 2-35**. While the following discussion focuses on total chromium, it should be noted that hexavalent chromium, when detected, generally occurred at lower concentrations than chromium (YCFCWCD, 2004).

Historical total chromium data in the Capay Valley and Western Yolo areas were generally non-detects or up to 10 ug/L. Chromium levels were relatively high in the area between Woodland and Davis, which exhibited a greater prevalence of values between 10 and 50 ug/L. Total chromium was particularly elevated near the City of Davis, where results ranged between 25 and 50 ug/L. It is possible that chromium concentrations decrease with depth, as maximum detected chromium decreases from 71 ug/L to 31 ug/L between the intermediate and deep groundwater zones respectively. Existing data are not sufficient to pinpoint trends in chromium concentration over time.

Chromium (III) in Yolo Subbasin probably occurs naturally due to its presence in the serpentine geology of the Coast Range (Chung, Buran, and Zasoski, 2001). Chromium, especially hexavalent chromium, is commonly present in geologic environments associated with convergent plate boundaries (Oze et al., 2007) which were present in the geologic history of the Subbasin. Chromium can also be anthropogenic in origin, typically a byproduct of the engineering metal industry (Johnson et al., 2006).

2.2.4.4.8 Hexavalent Chromium – Public Water Systems

There is no federal MCL for hexavalent chromium. In July 2014, California adopted a primary MCL of 10 ppb, which was invalidated as of September 2017. While DDW is repeating the regulatory process for adopting a new MCL, the federal MCL of 50 ppb for total chromium applies. There is no agricultural goal for hexavalent chromium.

Hexavalent chromium can come from anthropogenic and natural sources. Anthropogenic sources include discharges of dye and paint pigments, wood preservatives, chrome-plating liquid wastes, and leaching from hazardous waste sites into the environment. Naturally occurring chromium is a metal found in ore deposits containing other elements, mostly as chrome-iron ore. Chromium is also prevalent in soil and plants: the phenomenon of releasing chromium into groundwater is believed to be similar geochemical processes to arsenic. Generally, natural chromium in the environment occurs as trivalent chromium (Cr3) then is oxidized to a hexavalent state (Cr6+). This typically occurs in oxidizing conditions such as alkaline pH range (between 8 and 14 units) or in the presence of manganese dioxide; in these conditions, naturally occurring hexavalent chromium is likely to exist.

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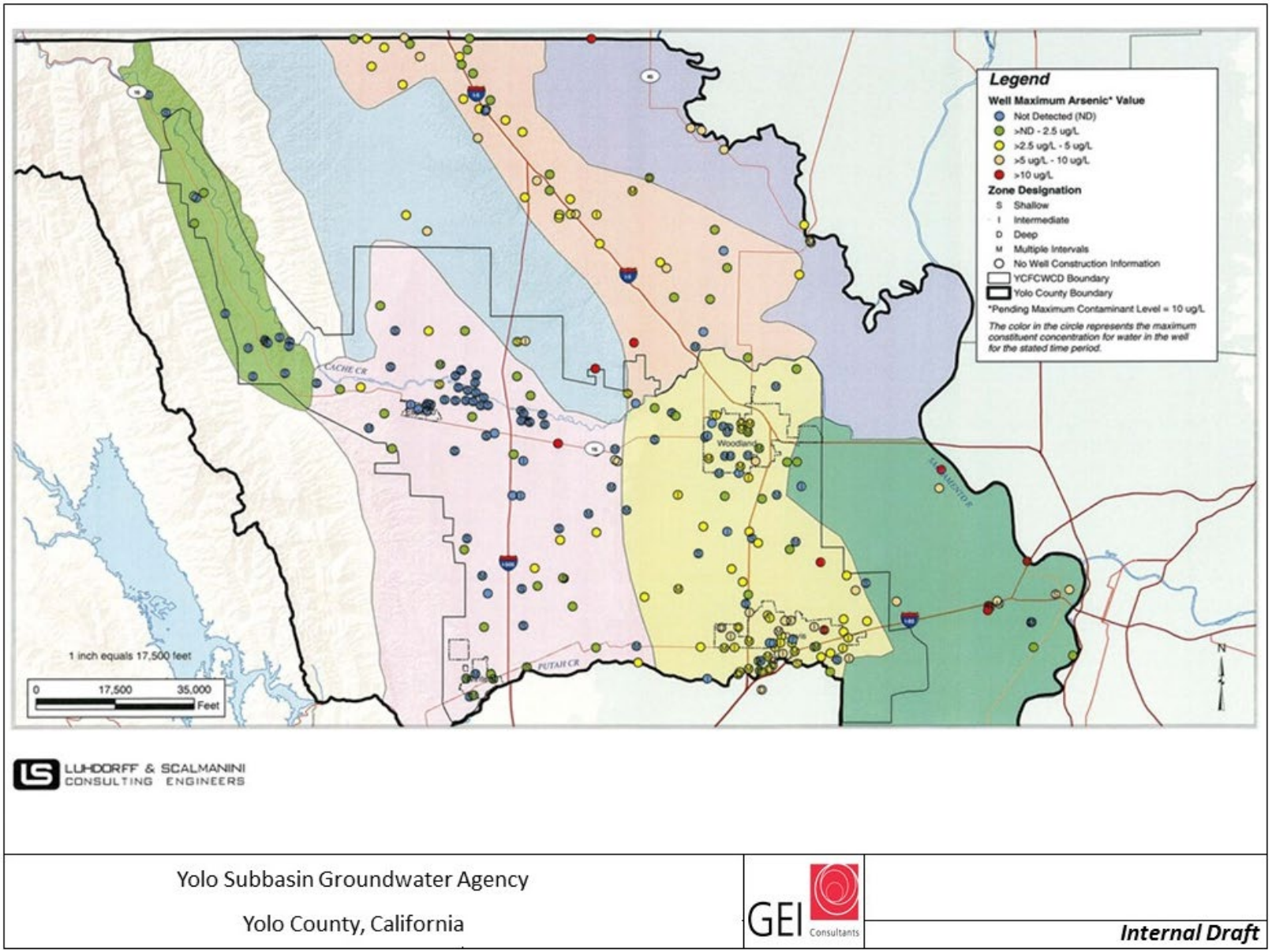


Figure 2-34. Maximum Observed Arsenic Concentrations, 1951-2004

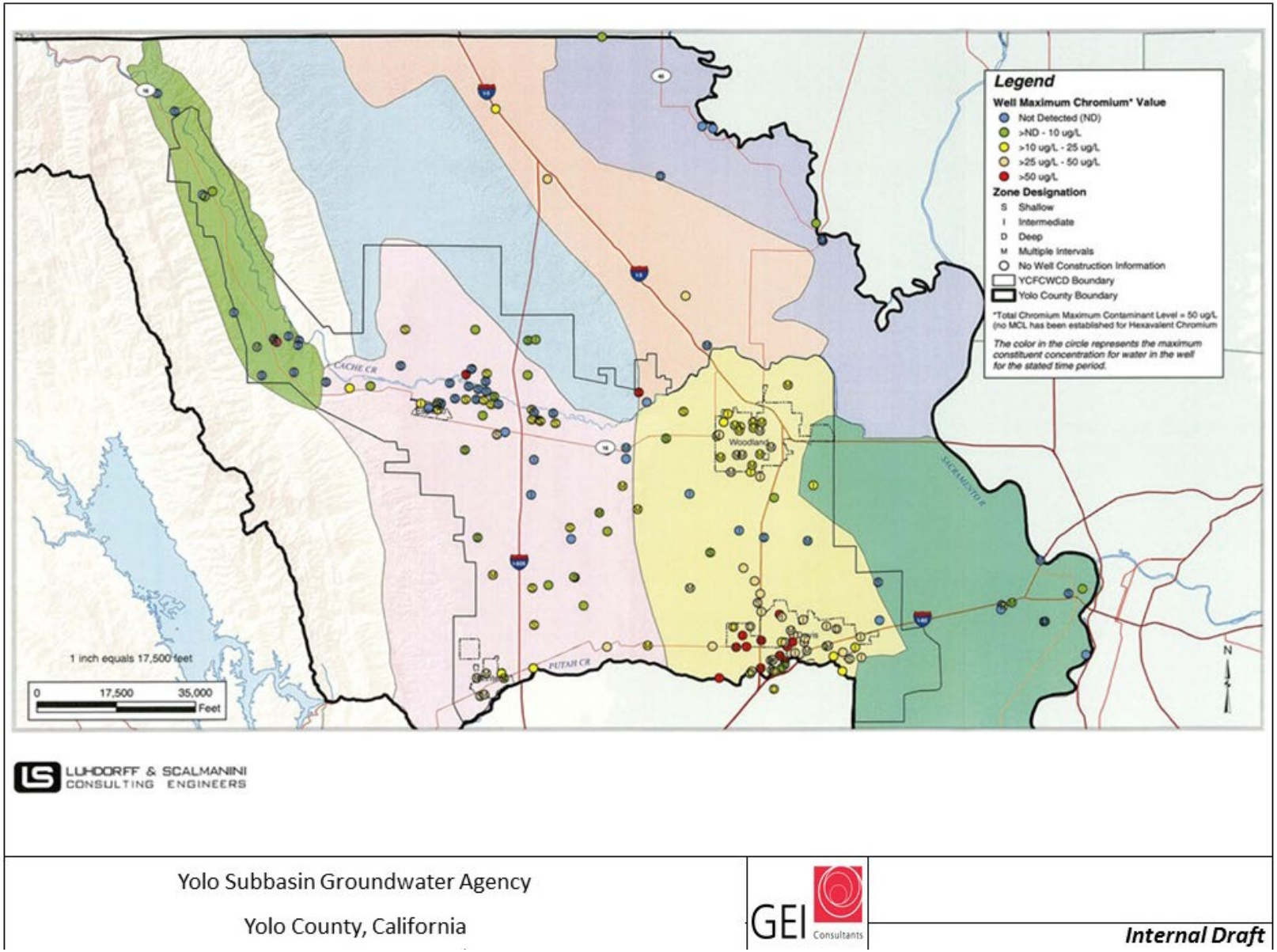


Figure 2-35. Maximum Observed Chromium Concentrations, 1951-2004

The presence of manganese oxide minerals within ultramafic and serpentinite derived soils and/or sediments can trigger the oxidation of chromium, leading to the presence of naturally occurring hexavalent chromium in the aquifers (SWRCB, 2017; Groundwater Information Sheet 2017). While studies have not been conducted on the types of soils and sediments in the Subbasin where hexavalent chromium is present, the relatively low concentrations (typically in the range of 5 – 13 ppb) indicate the source is naturally occurring (GAMA).

Table 2-17 summarizes hexavalent concentrations among the community water systems within the Yolo Subbasin. Hexavalent chromium data was not available for 4 of 51 wells. About 68-percent of the wells have hexavalent chromium concentrations over 10 ppb.

Table 2-17. Summary of Hexavalent Chromium Prevalence Among Community Water Systems

	Hexavalent Chromium Concentrations		
Water System	**0-5 ppb**	**6-10 ppb**	**>11 ppb**
Cacheville Community Services District	n/a		
Cal-American Water Company - Dunnigan			2
Campers Inn - RV & Golf Course			1
City of Davis	3	2	4
City of Winters		1	4
City of Woodland			8
Esparto Community Services District			4
Knights Landing Community Services District	3		
Madison Community Services District			1
Monroe/Leinberger Center/Waters			1
North Davis Meadows County Service Area			2
Rolling Acres Mutual Water Company			1
University of California, Davis		4	2
Wild Wings County Service Area	2		
Yolo Co. Housing Authority - El Rio Villa			2
Total Wells	**8**	**7**	**32**

2.2.4.4.9 Manganese – Basinwide Conditions

Maximum manganese detections were compiled for samples collected from 1951 to 2004 as part of the AB 303 Project and are displayed on **Figure 2-36**. The distribution of high manganese is quite scattered, with few obvious patterns present in the data (YCFCWCD, 2004). Pockets of high concentration (>0.05 mg/L) exist between West Sacramento and Davis and in the vicinity of Davis. The Western Yolo area displays elevated concentrations along Cache Creek and east of I-505 between Madison and Winters.

Near the City of Davis, manganese concentration appears to increase with depth, and is especially high to the north and east of the Davis area. (YCFCWCD, 2004). Historical data are not sufficient to establish significant increasing or decreasing trends.

Though manganese is a required nutrient in the human diet, concentrations greater than 0.05 mg/L (secondary MCL) can create aesthetic problems for drinking water, including metallic taste, staining of plumbing fixtures and laundry, and accumulation of manganese oxides in pipes.

Concentrations above 0.3 mg/L may pose a significant risk for human health (Agency for Toxic Substances and Disease Registry, 2000; U.S. EPA, 2004). The State Water Resources Control Board established a notification level of 0.5 mg/L, which requires purveyors to notify local government of the condition and recommends consumer notification.

Manganese occurs naturally in much of the world's groundwater and surface water. However, elevated manganese concentrations can also originate from anthropogenic sources including automobile exhaust and manufacturing (WHO, 2011). Historically, manganese has been a constituent of concern in community water supplies in the eastern Subbasin including Broderick, Bryte, and West Sacramento (YCFCWCD, 2004).

2.2.4.4.10 Selenium – Basinwide Conditions

Maximum detected selenium data were compiled for samples collected from 1969 to 2004 as part of the AB 303 Project and are displayed on **Figure 2-37**. Relatively high detection limits were common for the older analyses so non-detects may have omitted an area(s) of low concentration selenium (YCFCWCD). Nevertheless, some general selenium trends can be gleaned from the data. Elevated concentrations of selenium were historically present in the lower Cache-Putah area, particularly near Davis and generally range from 10-50 ug/L. Conversely, selenium is quite low in the Capay Valley and Western Yolo areas, where concentrations range up to 10 ug/L.

While selenium is an essential nutrient, concentrations greater than 50 ug/L can be harmful to human health. Selenium is naturally occurring in many areas, though it may also be generated by industrial and manufacturing processes such as copper refining (ATSDR, 2003).

2.2.4.5 Groundwater Quality Findings for Community Water Systems

Based on data evaluated in this groundwater quality characterization; boron, hexavalent chromium, nitrate, and salinity are the primary constituents of concern for the Yolo Subbasin. This is based upon the data available for the area, consisting of supply wells for the public community water systems. At the time of this evaluation, data in the WRID after 2004 were not easily accessible. Consequently, future evaluation of water quality in the Yolo Subbasin should include any updated data from the WRID to be more comprehensive.

Nitrate is a primary drinking water standard with acute health effects. Although a review of public community water systems did not show nitrate being a constituent of concern, brief discussion is included. One well has nitrate levels over the drinking water MCL. About 33-percent have nitrate

levels between 5 to 10 ppm. Since nitrate is a surface contaminant, wells with shallow screened intervals or annular seals typically show the highest levels of contamination. Community water system wells tend to have deeper screens and annular seals; which most likely explains nitrate levels

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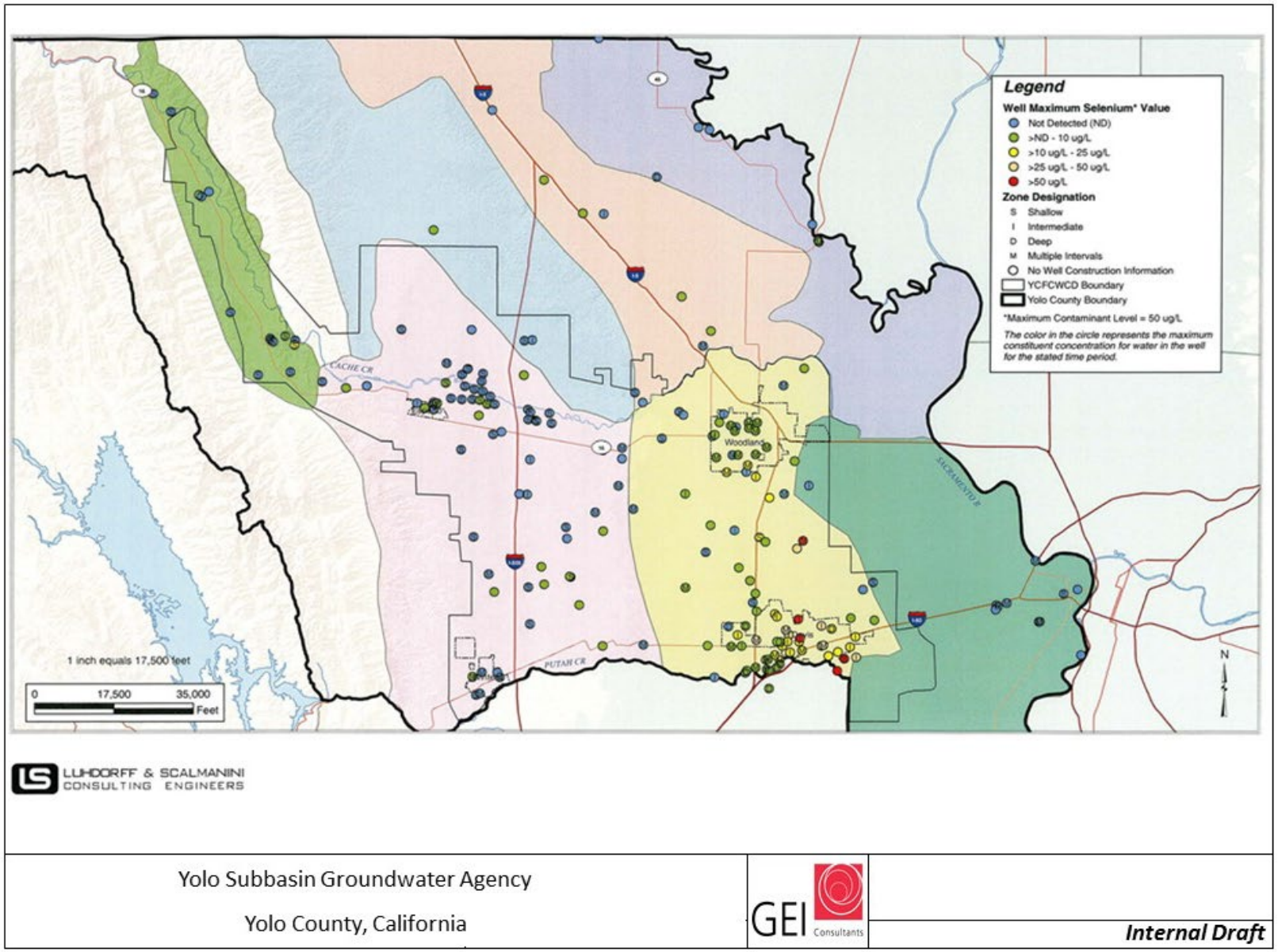


Figure 2-36. Maximum Observed Manganese Concentrations, 1951-2004

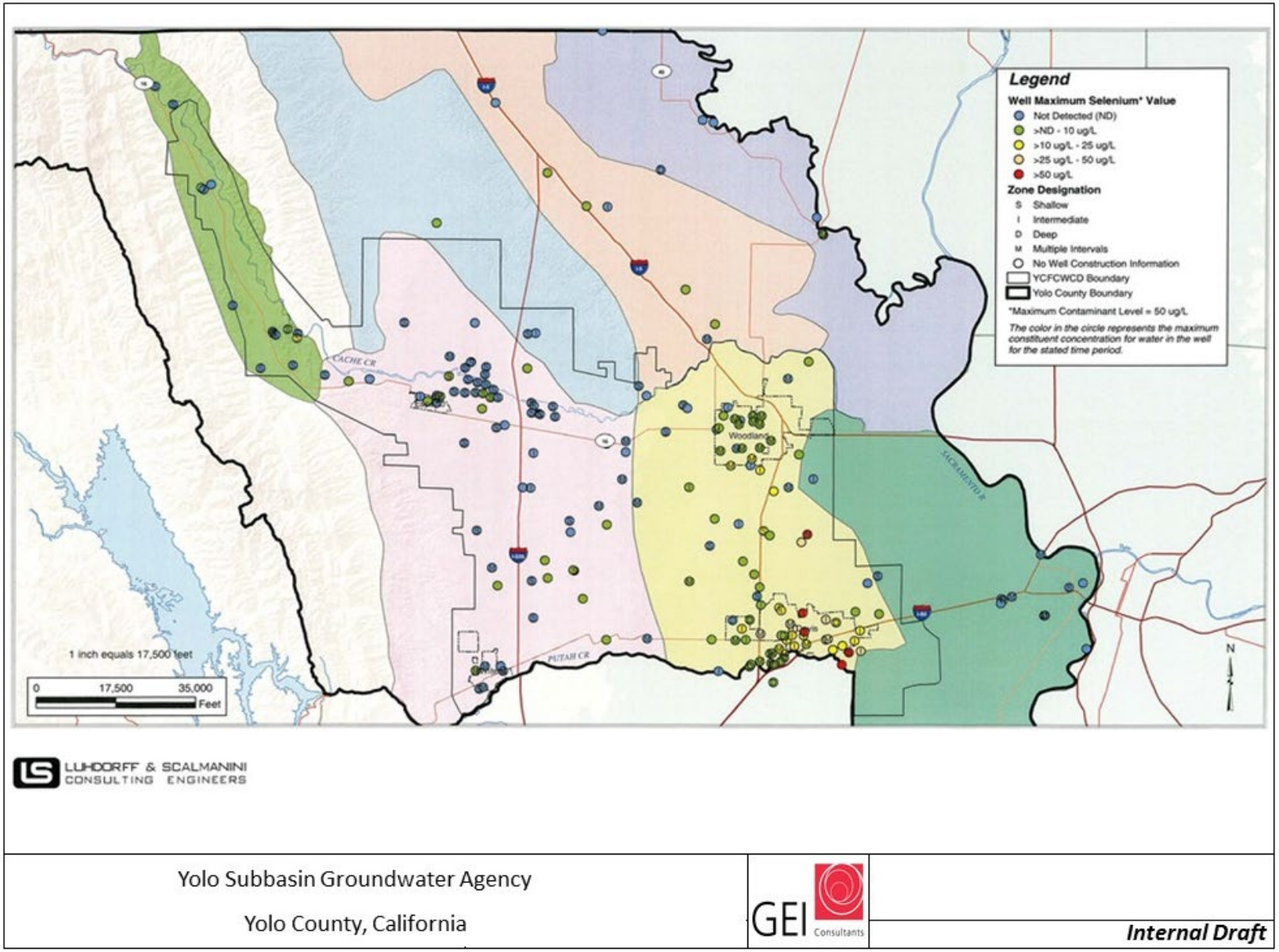


Figure 2-37. Maximum Observed Selenium Concentrations, 1969-2004

below the drinking water standard in most of the water systems in this evaluation. However, this is most likely not the case for private domestic wells, which tend to have shallower wells and annular seals. Sacramento Valley Water Quality Coalition's 2018 Annual Groundwater Monitoring Results from Fall 2018 sampling event for compliance with ILRP indicated 3 of 21 wells had nitrate concentrations over the MCL. To comply with the Human Right to Water, nitrate levels will need to be closely monitored and management actions will need to be in place to comply with the nitrate drinking water standard.

Salinity levels over the agricultural goal of were found in most community water systems. About 75-percent of the wells either have sodium concentration greater than half or over the agricultural goal of 69 ppm. Constituents related to salinity have a greater impact to agriculture, which explains the lower limits established for agricultural industry than the secondary drinking water standards. Since land use in the Yolo Subbasin is about half agricultural land, management actions that will slow or reverse the increasing sodium trend should be considered. CV-SALTS program and goals will address salinity concerns in the Yolo Subbasin.

Boron and hexavalent chromium are considered elevated in the water quality evaluation of public community water systems. About 33-percent of the municipal wells that were sampled have boron levels over the Notification Level. USGS studies indicate boron to be naturally occurring and elevated levels tend to be in wells near the Cache and Putah Creeks. Hexavalent chromium is also considered to be naturally occurring in the Yolo Subbasin. About 68-percent of the municipal wells sampled have hexavalent chromium levels above 10 ppb.

While other groundwater contaminants commonly found throughout the Yolo Subbasin were evaluated, there was limited presence of most constituents. Water quality data used was collected between 2010 and 2020. Most wells showed stable trends of evaluated constituents. Overall, there is high-quality water in the portion of the aquifer that public community water systems draw from.

2.2.4.6 Point Sources of Groundwater Pollutants

Groundwater pollutants are the responsibility of two overlapping state agencies' responsibilities, including the Central Valley Regional Water Quality Control Board (Regional Board) which typically focuses on water quality impacts to groundwater and surface water and the California State Department of Toxic Substances Control (DTSC) hazardous waste sites and contaminated soils. Both agencies require clean-up and monitoring of point source pollutants. The Regional Board and DTSC provide information about their project sites to the public through their respective public portals: GeoTracker (https://geotracker.waterboards.ca.gov/) and Envirostor (https://www.envirostor.dtsc.ca.gov/public/).

Figure 2-38 displays all historical and current cleanup sites, including permitted sites, utilizing information from the GeoTracker database. Cleanup sites exist across the county, with large clusters near Davis, West Sacramento, and Woodland. Open-case cleanup sites, classified by site type, are displayed on **Figure 2-39**. An open-case site designation indicates that some sort of contamination

has occurred at the site, and that investigation or remediation are ongoing. Ten land disposal sites are present in the Subbasin, of which nine are located in the roughly triangular areas between Winters, Woodland, and West Sacramento. These sites include the Old Davis landfill, the West Sacramento landfill, and the Old Woodland landfill. One military cleanup site is located between Winters and Davis, originally a radio transmitter station. Compounds associated with this site include chlorinated solvents, diesel, TCE, and PCE. Leaking underground storage tank (UST) sites are present near West Sacramento, Davis, Woodland, and in the Western Yolo area. UST sites are associated with release of petroleum and related compounds like MTBE. Cleanup program sites on **Figure 2-38** represent a wide range of potential water quality contaminants.

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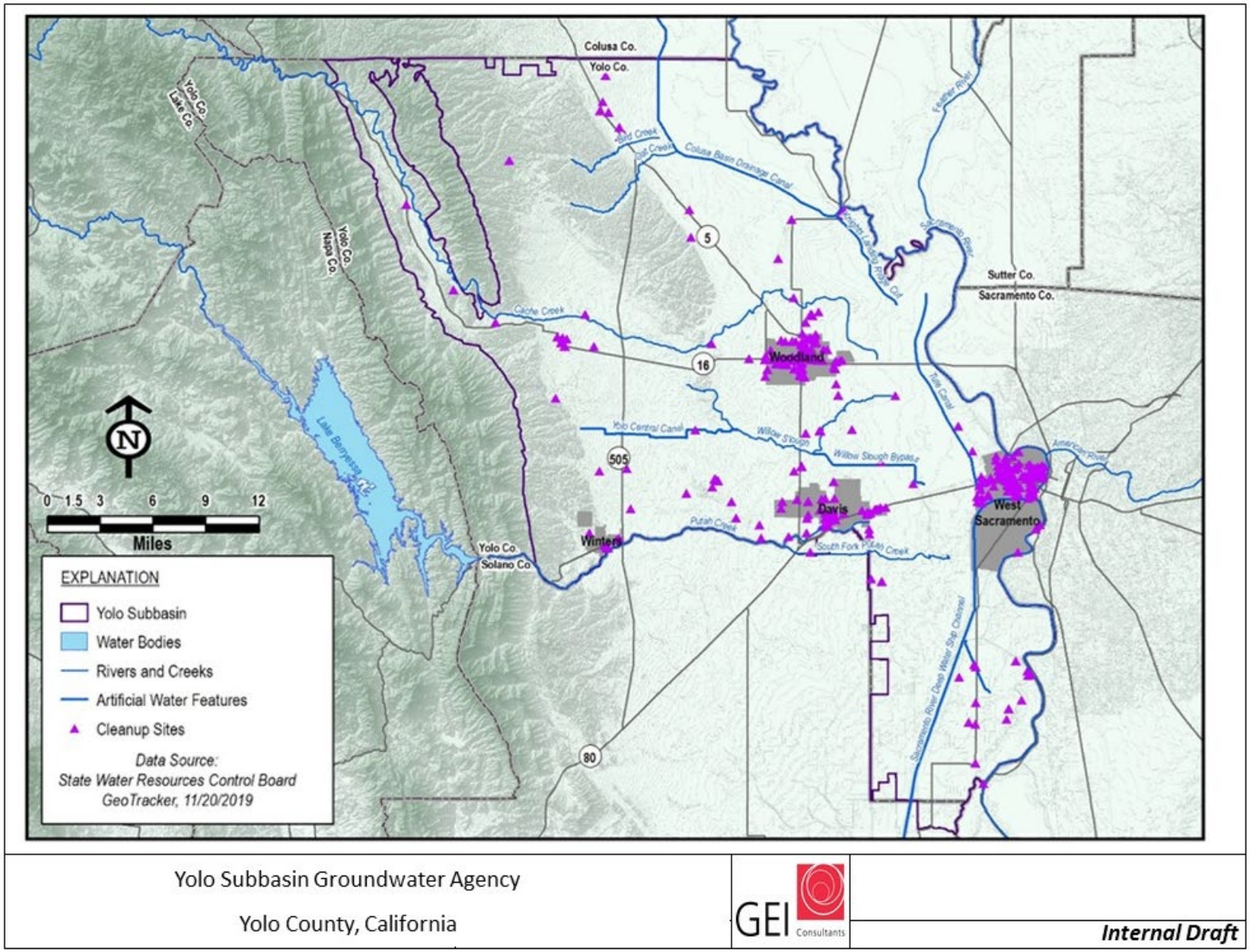


Figure 2-38. All Historic and Current Cleanup Sites

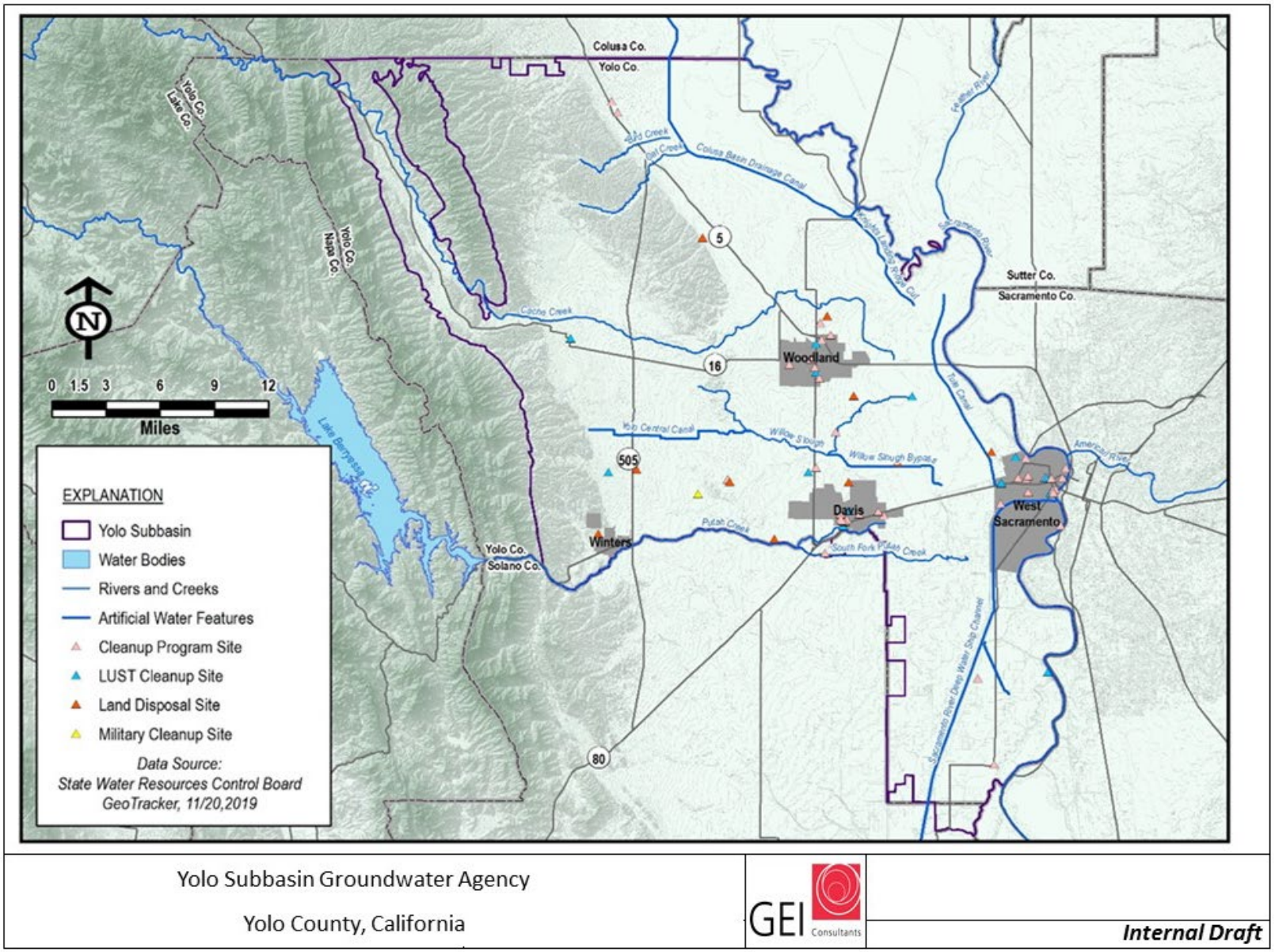


Figure 2-39. Open-Case Cleanup Sites

2.2.5 Land Subsidence

Land subsidence has been measured in the Yolo Subbasin since at least the late 1960s and has been subject to various technologies, including terrestrial (optical, laser) surveys, periodic surveys of numerous stations via the global position [satellite] system (GPS) since 1999, two continuous GPS stations since 2004, two extensometers, and by Interferometric Synthetic-Aperture Radar (InSAR). Subsidence includes an elastic component that fluctuates in response to changes in hydrostatic pressure among other factors and an inelastic component that manifests when the hydrostatic pressure decreases enough to allow the aquifer structure to collapse, primarily in the fine-grained layers within the aquifer and the aquitards.

2.2.5.1 Yolo Subbasin Network Monitoring Events

Since 1999, several GPS surveys have been conducted for the Subbasin on behalf of the Water Resources Association of Yolo County (WRA), including 1999, 2002, 2005, 2008, and 2016. These surveys utilized over 50 stations throughout the Subbasin, including several continuous GPS stations, to define the magnitude and extent of subsidence. The results (reports) of these surveys area available at the WRA's website. The accuracy of a GPS survey is dependent on the equipment and survey duration at each station, and these surveys used criteria that varied between two and five centimeters for the various attributes of each survey.

The latter surveys define a roughly diamond-shaped area of subsidence encompassing Davis, Dunnigan, Zamora, Woodland, and Madison (**Figure 2-40**). The greatest amount of subsidence occurred in pockets near Zamora and Woodland, where subsidence varied from 0.20 to 0.27 meters at three locations. According to Frame (2016), subsidence rates "have averaged as much as 3 cm per year in the most heavily affected locations during the 2008 to 2016 period" or up to 1.18 inches per year. The tabulated data for the stations (Appendix H of the Frame report) confirm the maximum subsidence value of 0.27 meters (0.9 feet) for the 8-year period, which is similar to the DWR value of 1.1 feet for a similar, overlapping 9-year period, as discussed below. Total subsidence in these two pocket areas was found to range between 6 and 11 inches between 2008 and 2016.

The earlier surveys utilized a mix of other stations and the 1999 survey used an alternate survey approach so comparable data are limited to 41 stations with complete sets of triennial data. Between 1999 and 2008, a total of 25 stations showed an overall increase in ground surface elevation, over two inches higher, while 16 stations showed an overall decrease in ground elevation, as much as 6 inches lower. Of this latter group, Frame (2009) identified six stations in the vicinity of Woodland and Zamora where the decreasing trends were indicative of subsidence and probably could have included a seventh station. Ground elevations at the other nine stations did not decrease as much and/or showed a variable trend. The maximum amount of subsidence was nearly 0.5 feet between 1999 and 2008 and the average annual maximum rate of subsidence is calculated to have been 0.6 inches. Subsidence appears to be a relatively new impact on the Yolo Subbasin, since the 1990s, based on the variable GPS survey results (increasing and decreasing elevations) in the early data (1999 to 2008) and the lower average annual maximum rate versus more consistent data thereafter

(2008 to 2016) and the doubling of the average annual subsidence rate (1.3 versus 0.6 inches per year). The 1999 survey occurred during the last year of 5-year period of wet conditions, which would have "inflated" the elastic character of the aquifer.

2.2.5.2 Stanford InSAR Study

Interferometric Synthetic-Aperture Radar (InSAR) is an aerial- and space-based technology that has been used to evaluate ground surface elevation and deformation since the early 1990s. More recently, InSAR has been used to evaluate subsidence, including much of Yolo County between 2007 and 2011. InSAR measures ground elevation using microwave satellite imagery data. This effort, headed by scientists from Stanford University, observed subsidence across much of the central-eastern portion of the Subbasin, stretching from Davis in the south to Dunnigan in the north (**Figure 2-41**). Within this area, maximum deformation was measured in the area between Zamora and Woodland, at a rate of up to 3 cm per year (Crews et al., 2017). Many areas in the south and east of the Subbasin display positive gains in surface elevation, which may be indicative of elastic rebound from subsidence due to a "wet" water year in 2011 after four preceding drought water years (dry, critical, dry, below normal). Crews (2017) recommended the use of InSAR to define subsidence at a recurring interval of three to four years coupled with a reduced cycle of GPS surveys, from a 3-year cycle to a 9- or 10-year cycle

2.2.5.3 Sacramento Valley Subsidence Survey

The 2017 GPS Survey of the Sacramento Valley Subsidence Network (DWR, 2018) presented the change in surface elevation between 2008 and 2017 using measurements from more than 50 surface elevation monuments across the Subbasin. Subsidence values ranged from 0.1 to 1.1 feet (median: 0.3 feet, mean: 0.4 feet). Twelve stations showed subsidence values of 0.19 feet or less, and one station (COTT) showed a slight increase in elevation (< 0.1 feet). These low value stations are mostly located on the southeastern side of the Subbasin and, to a lesser extent, along the western side. Subsidence was evident in the northeastern portion of the Subbasin near Zamora and Woodland (**Figure 2-42**), where five stations showed more than 12 inches of subsidence and five stations showed at least nine inches. Of all the areas surveyed in the report, Yolo County showed "the largest spatial extent" of subsidence within the Sacramento Valley (DWR, 2018). For the 9-year period between the GPS surveys (2008 – 2017), the rate of subsidence varied up to 1.5 inches per year (in/yr) with a median value of 0.4 in/yr and a mean value of 0.6 in/yr.

2.2.5.4 Continuous GPS Stations

Three continuous GPS stations are located in the Yolo Subbasin and provide "real-time" data on subsidence in the Subbasin, as discussed below. Two stations are part of the broad GPS network within California. GPS data have been acquired daily since 2004 and 2005; and these data are readily available from the University NAVSTAR Consortium (UNAVCO) website. One UNAVCO station (P265) is located near the southwestern corner of the Subbasin, east of Winters, on the western flank of the Sacramento Valley and the second station (P271) is located on the southeast side of Woodland, near the axis of the Sacramento Valley.

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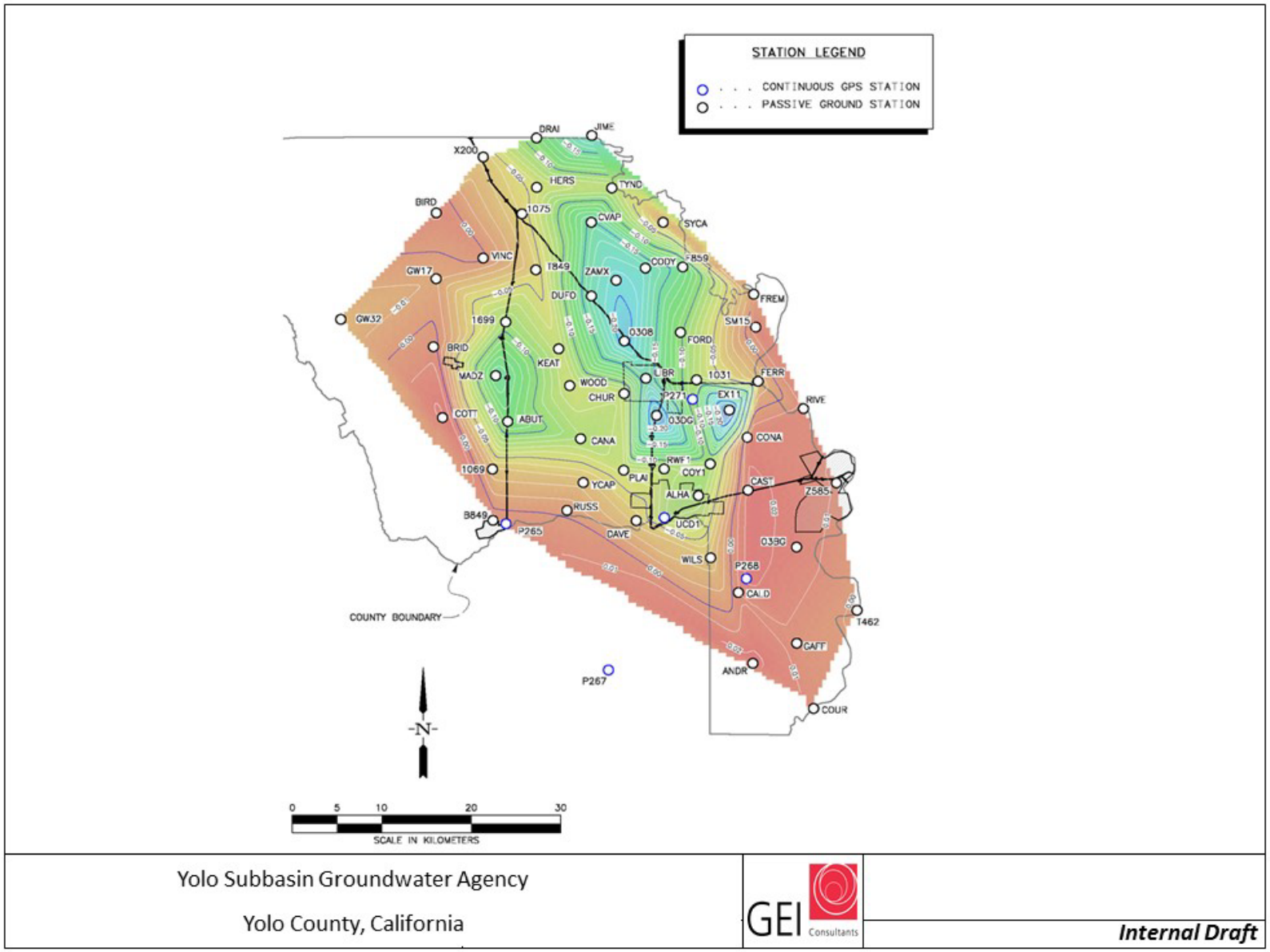


Figure 2-40. Yolo Subsidence Network Recorded Subsidence, 2008-2016 (Frame, 2017)

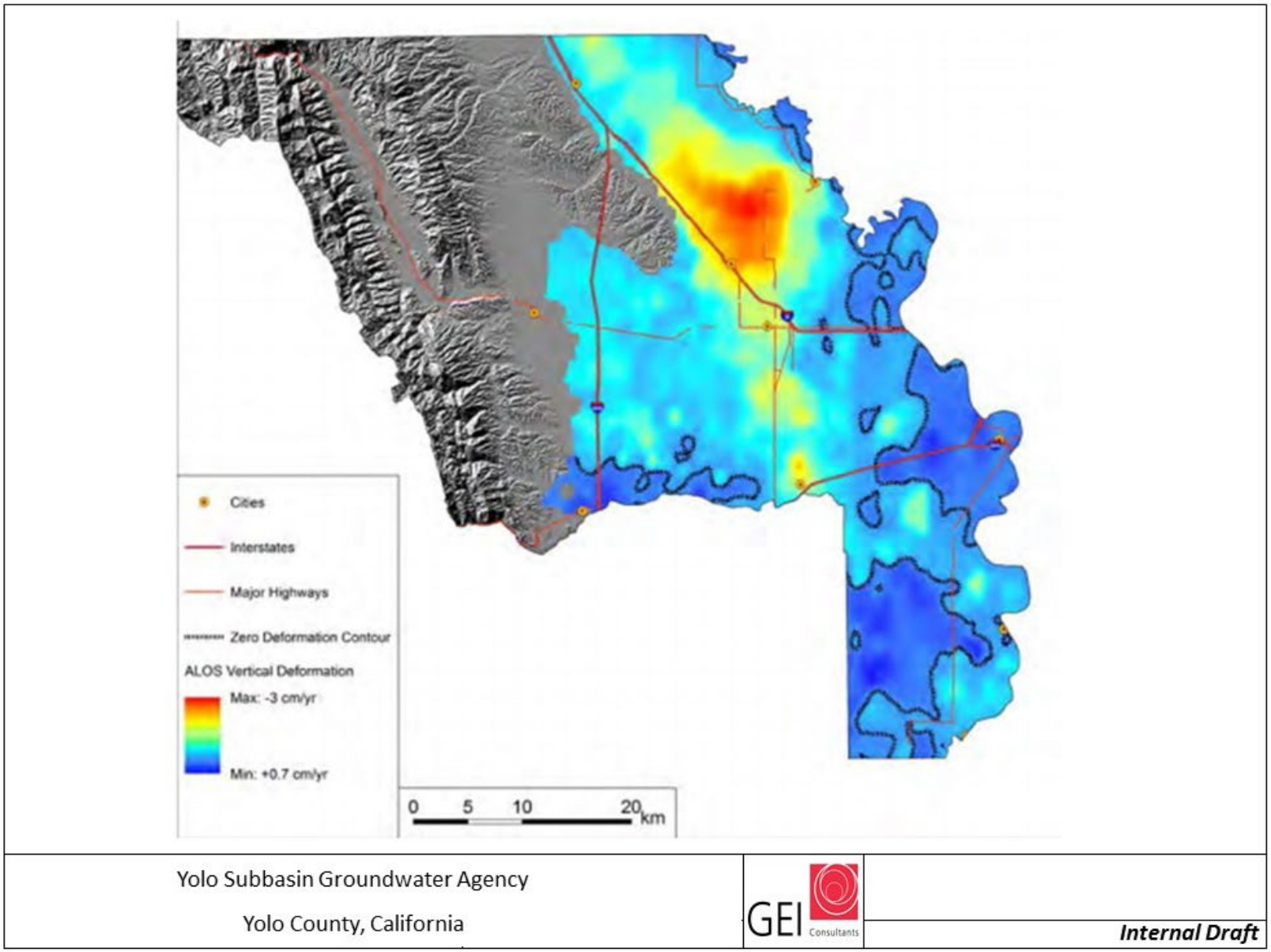


Figure 2-41. Stanford InSAR Subsidence in Yolo Subbasin, 2007-2011 (Crews, 2017)

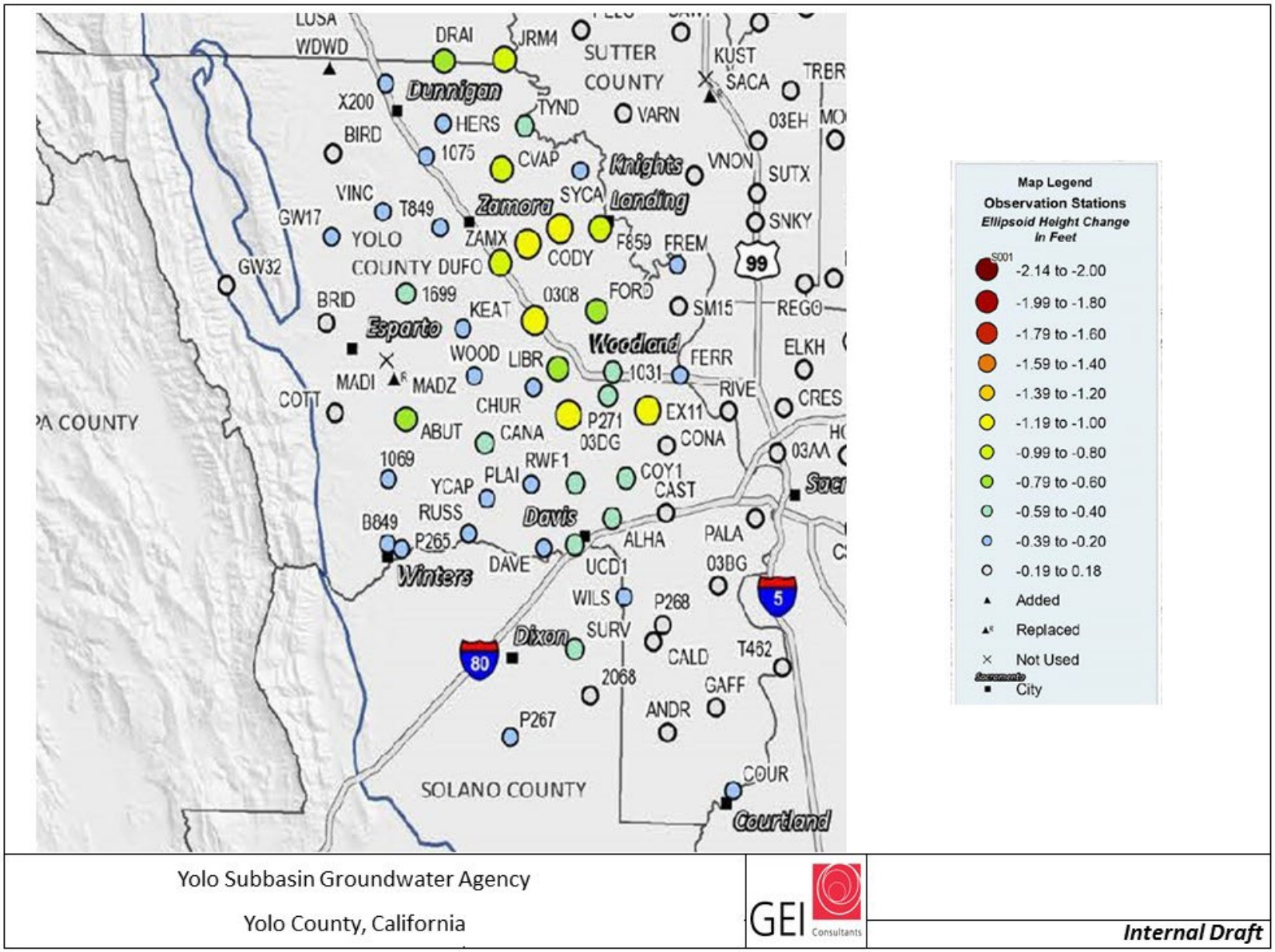


Figure 2-42. DWR's 2017 GPS Survey of Sacramento Valley Subsidence Network, 2008-2017

A third continuous GPS station (UCD1) is located at the University of California in Davis, along the southern boundary of the Subbasin, midway toward the center of the Sacramento Valley. UCD1 is part of the Bay Area Regional Deformation Network, which provides daily values since 1996 as a text file. Note that the antenna has been changed twice, most recently in November 2019, which created a base-line shift of the vertical data.

Figure 2-43 illustrates the change in ground elevation at these three stations, including daily values and annual mean values, and compares these data to water year (WY) indices. The figure shows that daily values are variable at the three stations, increasing during the wet winter months and decreasing during the dry summer months. During the 2006 to 2011 WYs, both P265 (blue/black symbols) and P271 (orange/rust symbols) showed similar rates of decline (-0.16 and -0.19 in/yr, respectively), while UCD1 (green symbols) showed a higher rate of decline (~3X). The amplitude of annual change, which is related to the elasticity of the aquifer, was least at P265 and greatest at UCD1. This 6-year period included two wet years at the beginning and end and an overall dry period in the middle.

Beginning in 2012, the P271 rate of decline increased 5-fold during the historic 5-year drought period and diverged from P265, which continued to decline at roughly the same rate. Similarly, UCD1 continued its decline. In addition, the annual amplitude of P271 increased substantially due to the rapid decline in elevation during the latter part of each WY. These steep declines resulted in a 2-inch decrease in elevation during 2014 due to inelastic subsidence, and a 1-inch decrease during 2016. Conversely, the amplitudes of P265 and UCD1 remained relatively consistent with their respective previous values, although both stations showed an overall decrease in their elevation.

The 2012-16 drought was followed by a historic wet WY during 2017, the second highest of the 114-year record, a below-normal WY during 2018, and another wet WY during 2019. This improved WY period flattened the decline considerably at P265 and UCD1 and lessen the decline at P271. However, subsidence was still occurring to some degrees at these locations during WY 2019.

2.2.5.5 Extensometers

Two extensometers were installed in the Subbasin during 1992 in association with the installation of two nested monitor wells. Details of the construction are not available but, in general, an extensometer pipe (2-inch) is anchored in a cement grout at a particular depth below a protective casing relative to a reference table over the pipe at the ground surface. Changes in the distance between the extensometer and table occur due to subsidence, earthquakes, and other tectonic factors.

The first installation is located east of Woodland and included an extensometer (CON Ext, 09N03E08C004M) to a depth of 716 feet and a 3-completion monitor well. The second installation is located east of Zamora and included an extensometer (ZAM Ext, 11N01E24Q008M) to a depth of 1,000 feet and a 4-completion nested monitor well.

Figure 2-44 illustrates the change in ground elevation at these two extensometers, including mean daily values and annual mean values, and compares these data to water year (WY) indices. The figure shows that daily values are variable at the two installations, increasing during the early part of each WY, concurrent with wet winter months, and decreasing during the latter part of the WY after the dry summer months. However, the two extensometers exhibit very different data due to their different locations and depth settings but do react to variations in the WY indices (type).

CON Ext data show a relatively low-amplitude annual cycle of ground movement (elastic), starting in WY 1993 through WY 2012. The amplitudes were minimal during the wet WYs of the middle to late 1990s, and gradually increased with time along with the relatively small, overall decline (inelastic) in the ground surface, as shown by the annual mean values. During the middle three years of the historic 5-year drought, ground surfaces dropped rapidly (0.3 ft/yr or ¾ -foot of inelastic subsidence) and the annual amplitude increased substantially, especially during WY 2014. This rapid decline is likely related to groundwater pumping in the area. After the drought, the rate of subsidence at CON Ext decreased 10-fold, but at a higher rate than before the drought, and continued to fluctuate according to WY type.

ZAM Ext data show a higher-amplitude and a more uniform annual cycle of ground movement (elastic) throughout much of its history. During the first three years of operations, the ground surface rose about one inch and was then followed by an overall long-term decline that is probably related to groundwater pumping. Some variability in the decline appears to be related to WY type, and the rate of decline doubled during the middle years of the drought. After the drought, the rate of subsidence at ZAM Ext decreased 10-fold but continue to decline at a lesser rate than before the drought.

2.2.5.6 DWR InSAR Subsidence Mapping

Subsidence can be estimated for the Subbasin using InSAR data provided by DWR for medium- and high-priority basins across California. The DWR website includes an interactive mapping application that covers the Subbasin and depicts land subsidence as 1) cumulative totals for various time periods beginning with June 2015 and extending monthly through September 2019 and 2) annual rates of subsidence beginning with July 2015-16 and proceeding monthly through September 2018-19. These InSAR data were obtained from European Space Agency (ESA) Sentinel-1A satellite and were processed by TRE ALTAMIRA Inc.

These DWR InSAR data were calibrated with continuous GPS data from 232 stations and then checked against 160 continuous GPS stations not associated with the calibration as well as 21 calibration stations in northern California. Nevertheless, the InSAR data are subject to measurement error, and DWR has stated that the total vertical displacement measurements are subject to two error sources (Brezing, personal communication, June 2019):

1) The error between InSAR data and continuous GPS data is 16 mm (0.052 feet or 0.63 inches) with a 95% confidence level for January 1, 2015 through September 19, 2019.

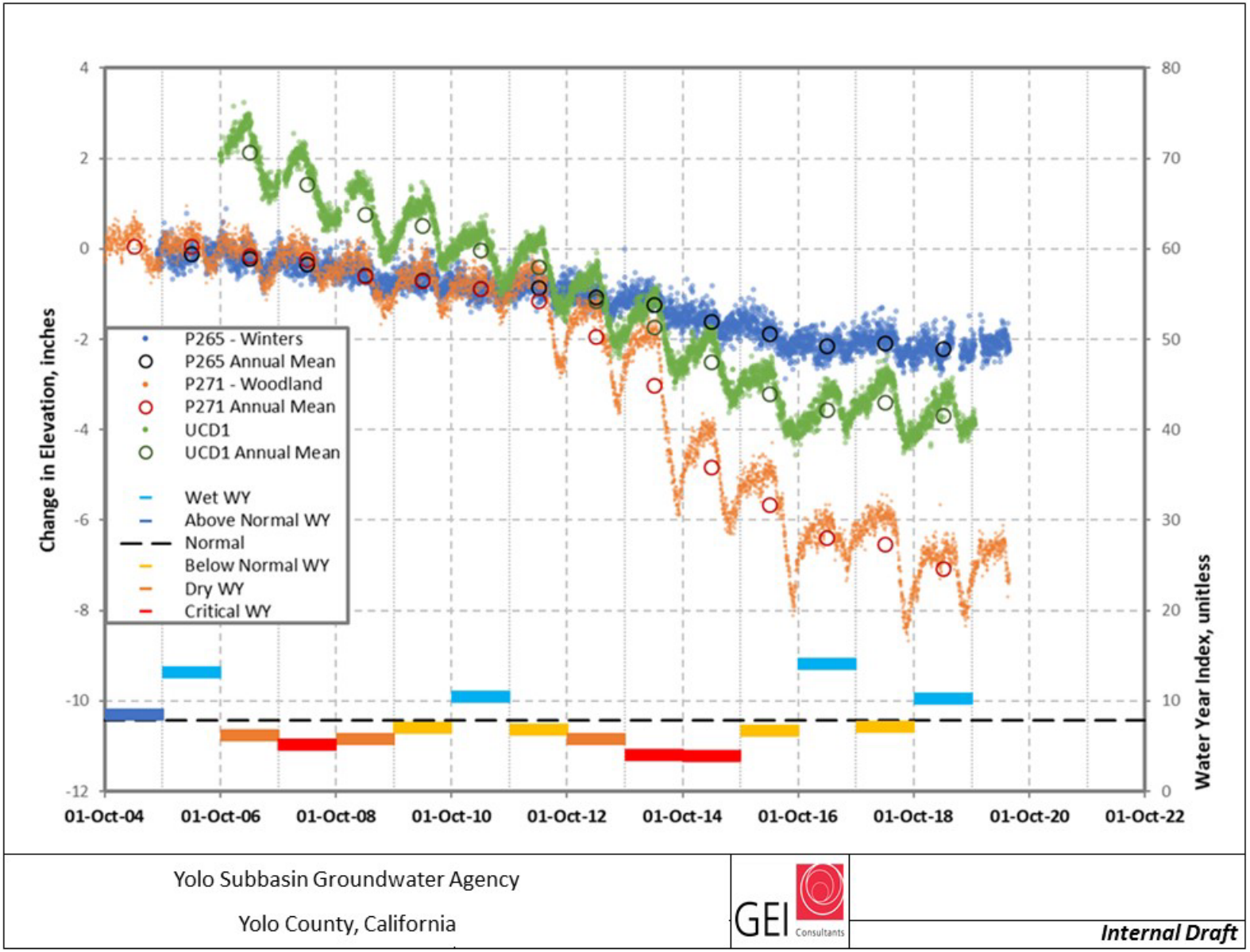


Figure 2-43. Ground Elevation Variation at Continuous GPS Stations

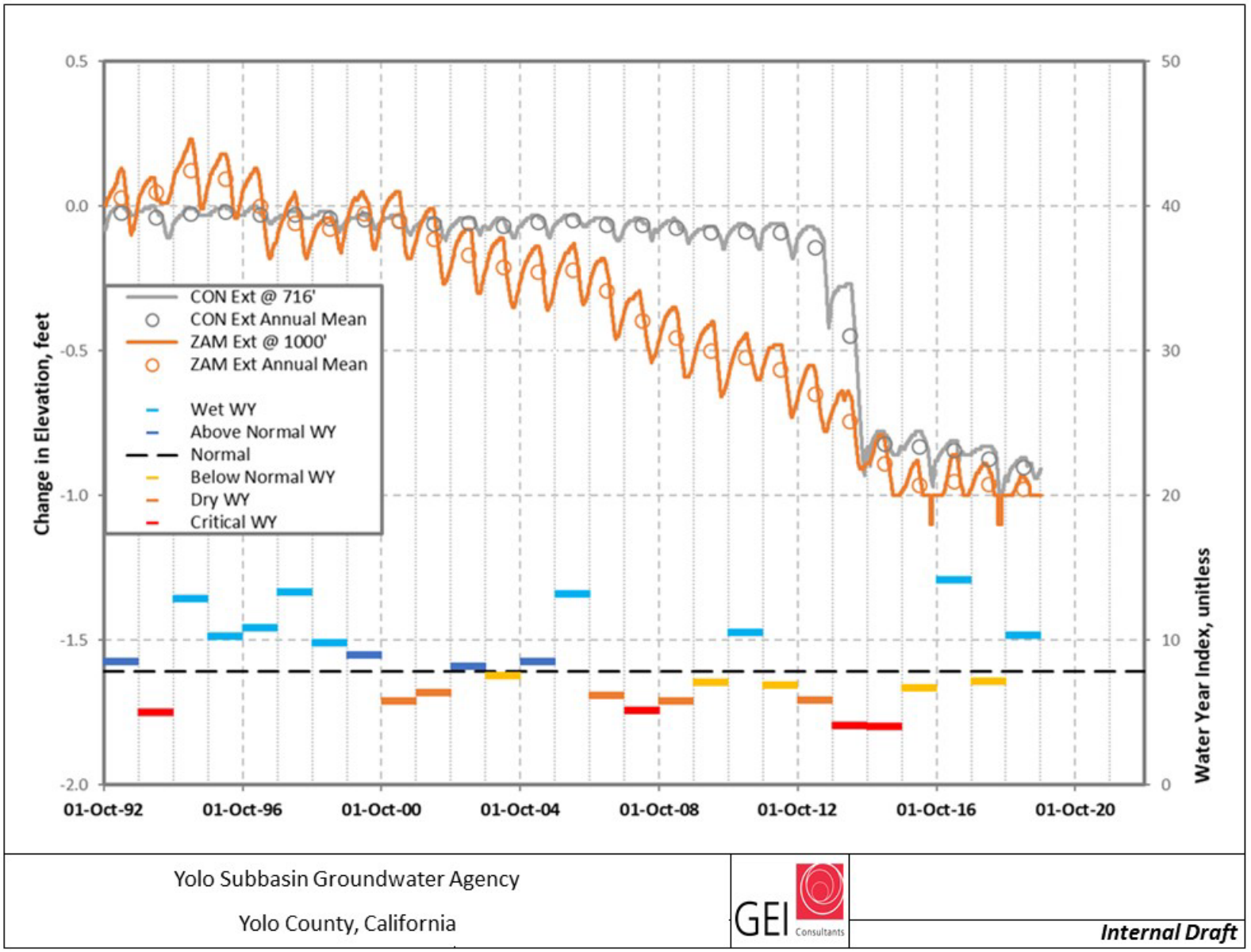


Figure 2-44. Ground Elevation Variation at Extensometers

2) The measurement accuracy when converting from the raw InSAR data to the maps provided by DWR is 0.048 feet (0.58 inches) with 95% confidence level.

Simply adding the two sources of errors produces a combined potential error of 0.1 foot (or 1.2 inches). As such, land surface changes of less than 0.1 feet are therefore within the noise of the data and are equivalent to no subsidence in this GSP.

The DWR interactive mapping tool also includes numerous 'data points' for vertical displacement that link to a detailed map with an interactive time-series plot and a tabulation of monthly displacement values (feet). The data points are distributed throughout the Subbasin in various configurations – single 2.5-acres squares (330 by 330 feet) to linear and blocky arrangements of the squares. Interpolated displacement values are available in areas without squares.

Figure 2-45 shows the InSAR-measured subsidence in the Subbasin for the period June 2015 to June 2018. The green area denotes a ground surface rise or drop of less than 0.1 feet, which is within the measurement error and therefore is an area of no subsidence. The blue areas signify an increase in surface elevation from 0.1 to 0.3 feet. These measurements likely reflect areas subject to elastic subsidence, where relatively wetter conditions in recent years have facilitated groundwater recharge, expanding the aquifer structure and leading to an increase in surface elevation. The red areas reflect a drop in ground surface between 0.1 feet and 0.3 feet. These locations correspond spatially to areas that exhibited high levels of subsidence in previous surveys.

In contrast to previous surveys discussed above, recent InSAR results display a relatively low level of subsidence across much of the Subbasin, and even some recovery in the area between Davis and Winters. However, the northeastern portion of the Subbasin, including the area of high subsidence between Zamora and Woodland noted in previous studies, continues to experience subsidence. Ongoing subsidence over many years could add up to a more significant ground surface drop. It should also be noted that the climate during 2015-2018 was relatively wetter than some other previous time periods during which survey measurements were taken, and the associated increase in recharge may have slowed or reversed elastic subsidence in some areas.

2.2.6 Interconnected Surface Water Systems

Surface water forms some of the boundaries of Yolo Subbasin, including the Sacramento River as the east boundary and Putah Creek for part of the southern boundary. Numerous other creeks and sloughs (streams) emanate from the mountains and hills along the western boundary and flow eastward toward the Sacramento River, most notably Cache Creek from the Capay Valley. The Yolo Bypass is located to the west of the Sacramento River and is used for flood mitigation during the winter. The bypass drains into the Sacramento River at the Delta. Several man-made water features cross or traverse the Subbasin, including Colusa Basin Drainage Canal, Tule Canal, and the Sacramento River Deep Water Ship Channel

In general, rivers, streams, canals, and sloughs in the Yolo Subbasin can be considered to have 'gaining' or 'losing' reaches. A gaining reach receives upwelling groundwater and thereby has an

increase in water flow. A losing reach leaks water out of the bottom of the channel and loses water to groundwater.

Streams are categorized by flow regime as perennial, intermittent, and ephemeral. Perennial streams have year-round water, either from natural base flow, or from releases from storage reservoirs. The Sacramento River, the Sacramento Deep Water Ship Channel, Putah Creek, and Cache Creek – upstream of Capay Diversion Dam – are all perennial. If groundwater levels decline significantly below the historic range, these waterways would still be flowing, although losses to groundwater may increase.

Below Capay, Cache Creek is considered intermittent, as losing and gaining stretches create dry and wet sections during the summer (and during drier winters). If groundwater levels decline significantly beyond their historic range, these historically wet areas (or gaining reaches) could become dry. All other waterways in the Subbasin would be considered ephemeral, only running after rainstorms.

This Surface Water/Groundwater Interaction section of the GSP is organized into four areas -

- Sacramento River area
- Putah Creek area
- Cache Creek area
- Canals and Sloughs in YCFC&WCD

Sacramento River Area

In Yolo Subbasin, areas along the Sacramento River are generally irrigated with surface water from the River. However, when surface water is transferred to other areas, sometimes the transferred water is replaced with pumped groundwater, referred to as 'Groundwater Substitution Transfer'. This pumping of groundwater could draw water from the Sacramento River itself, reducing surface water flows. Therefore, pumping near the Sacramento River is well regulated during groundwater substitution transfers. Effects on streamflow, groundwater levels, subsidence, and groundwater quality are monitored and potentially mitigated (by State regulation). Adherence to local ordinance and YGSA review is required.

Putah Creek Area

Putah Creek channel lies on a perched alluvial fan, with no tributaries to the Creek as it flows westward from the Winters, CA to the east of Highway 80. The historical hydrology of Putah Creek has been altered, beginning with a new south channel alignment and abandonment of the original channel near Davis, CA in 1871. In 1955, Putah Creek was dammed upstream of Winters, CA, further altering its hydrology.

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While Putah Creek historically was an ephemeral stream, a lawsuit in 2000 made releases of water required for permanent flows. The "Lower Putah Creek Riparian Water Availability Forecasting Model" was developed to determine where riparian water would occur in the absence of dam releases, and where Putah Creek would normally have been dry. The most up-to-date results of the model for 2020 can be accessed at https://www.scwa2.com/putak-creek-riparian-forecast/

Sanford (2005) (https://www.scwa2.com/documents/lpccc/reports/PC-35.pdf) provides an excellent historical review of the gaining and losing reaches, and additionally the related hydraulic continuity of the surface water along Putah Creek.

In 2010, Luhdorff & Scalmanini Consulting Engineers (LSCE, ftp://ftp.scwa2.com/Prop%201/PC-61.pdf) conducted a review of over 50 documents regarding streamflow, seepage gains and losses, and stream-aquifer interactions in Putah Creek to evaluate the ability to predict streamflow's in Lower Putah Creek from groundwater levels.

Putah Creek Council also maintains a bibliography of technical documents related to Putah Creek, that can be accessed at - https://docs.google.com/spreadsheets/d/11ZPRLudIi4ebLbXRxnzlJ2LpSZtsE38YJ5rAALKzu4M/edit#gid=0

Putah Creek defines the border between the Yolo and Solano groundwater subbasins. The Solano GSA is taking the lead role in managing Putah Creek groundwater, with a supporting role from the YSGA. Additional information about Solano GSA can be found at - https://www.solanogsp.com/

Cache Creek Area

Cache Creek flows generally southeast through the Capay Valley and exits into the Sacramento Valley near the town of Esparto, where it then heads due east towards Woodland, CA and eventually to the Cache Creek Settling Basin. Downstream of Capay, Cache Creek is an intermittent stream and is dry in some reaches during the summer, like the historic behavior of Putah Creek. The Cache Creek channel is located on a perched alluvial fan, also like Putah Creek, so there are no tributaries to the Creek east of Esparto, CA, except for the Salisbury Spill at Gordon Slough.

Two reservoirs are located upstream in the Cache Creek watershed - Clear Lake and Indian Valley Reservoir. These reservoirs are managed for summertime irrigation and limited flood control purposes. Releases into Cache Creek travel approximately 70 miles downstream to the Capay Diversion Dam. The Capay Diversion Dam has no storage and is used to direct water into the 165 miles of canals operated by the Yolo County Flood Control and Water Conservation District. Upstream of the Capay Diversion Dam is generally perennial, almost always flowing, due to releases from storage. In the summer, downstream of the Capay Dam, Cache Creek is only flowing in gaining reaches (and just downstream of gaining reaches).

Gravel mining has occurred in Cache Creek since the late 1800's, as described in the Cache Creek Resources Management Plan. Over time, as mining increased, degradation (lowering) of the Creek

bottom occurred. Multiple bridges were also constructed spanning Cache Creek. This constricted the channel, increasing water velocity during floods, further scouring the Creek bed and causing more degradation of the Creek bed. By the early 1990's environmental concerns about in-channel gravel mining resulted in the "Gravel Wars". An agreement between Yolo County and the aggregate mining companies resulted in the end of in-channel mining and the creation of the "Cache Creek Resources Management Plan". Part of the plan was the installation of a network of dedicated groundwater monitoring wells. This well network exists today, but according to approved and permitted mining reclamation plans, these wells will be destroyed when mining is completed. With 30 years of groundwater level and water quality data from these wells, the YSGA would like to work with the mining companies and Yolo County to amend the reclamation plans to allow the monitoring well network to be preserved for future management of water resources along Cache Creek.

Upwelling groundwater can be a problem in urban areas during hydrologically wet periods. In Woodland, the East Beaman Street undercrossing of Hwy 5 is below grade and has a dedicated electric pump to remove upwelling groundwater. In the mid-2000s, City of Woodland was spending more than $1,000,000 per year on electricity expenses to pump out groundwater, flooding a baseball facility called Dubach Park. Dubach Park was an old gravel mine pit below grade. It has since been converted to a wakeboarding water park with a permanent lake.

The Cities of Davis, Woodland, and the campus of UC Davis historically relied on groundwater pumping for all municipal and industrial needs. In 2016, a new water treatment plant and new pipeline from the Sacramento River was constructed to bring up to 45,000 acre feet of river water per year to the Cities and Campus. Groundwater simulation models from 2011 show that, due to imported river water, groundwater levels will rise underneath the Cities. This will also cause increased surface water flows in Cache Creek. Other scenarios in the model showed that theoretical increases in groundwater pumping could decrease the flows in Cache Creek and impact or deplete interconnected surface water; however, recharge would also increase, and extended overdraft conditions would be avoided.

Canals and Sloughs in the YCFC&WCD Area

Canals and sloughs in the YCFC&WCD area are flowing all summer due to surface water deliveries and runoff from irrigated agriculture and are considered intermittent waterways as they go dry otherwise, except during times of rain. Most of the 165 miles of canal in the YCFC&WCD service area are unlined by District policy and lose about 25% of summertime water deliveries to groundwater. This keeps groundwater levels high during times of water shortages. These shortages historically happen 3 out of every 10 years. So, although some reaches of the canal system could be considered gaining from groundwater, overall, more water is lost than is gained.

A 2012 study compared three different methods to measure and calculate losses in the canal system. It was estimated that approximately 15,000 and 65,000 acre-feet per year was 'lost' to groundwater. However, it is important to note that this water is not actually lost. It can and is recovered through

groundwater pumping and elevated groundwater levels benefit streamflow and groundwater dependent ecosystems (GDEs).

New wells are continued to be drilled adjacent to the YCFC&WCD canal system. Water pumped from these wells is coming from the canal. The distribution and pumping volumes of these wells needs further study, as YCFC&WCD customers pay for canal operations while pumpers do not share in the costs.

2.2.7 Groundwater Dependent Ecosystems

Groundwater dependent ecosystems (GDEs) within the Yolo Subbasin are identified in accordance with §354.16(g) of the Groundwater Sustainability Plan regulations. The procedure for identifying GDEs follows guidance from The Nature Conservancy (TNC) and detailed in the *Groundwater Dependent Ecosystems under the Sustainable Groundwater Management Act: Guidance for Preparing Groundwater Sustainability Plans* report (Rohde et al., 2018). This process differentiates between indicators of Groundwater Dependent Ecosystems (iGDEs), potential Groundwater Dependent Ecosystems, and true Groundwater Dependent Ecosystems.

- iGDEs were developed by The Nature Conservancy in partnership with the California Department of Fish and Wildlife (DFW) and DWR using the best available statewide data. The iGDEs are identified using locations of springs and seeps, wetlands, and vegetation known to rely on groundwater. The Nature Conservancy also uses the term "Natural Communities Commonly Associated with Groundwater" to refer to these iGDEs, which are presented on **Figure 2-46**.
- Potential GDEs are iGDEs that, through mapping analyses, may be connected to and therefore supported by shallow groundwater. iGDEs are presented, along with fall shallow groundwater elevation contours and areas of groundwater-surface water connection, on **Figure 2-46**.
- True GDEs are potential GDEs that have been field-verified to establish that they are supported by groundwater. The methodology described herein does not identify true GDEs.

This section identifies potential GDEs using the following three criteria:

1) iGDEs exist as defined by The Nature Conservancy and DWR (see **Figure 2-46**).
2) If the area is near a riverine environment, existing data demonstrate surface water and groundwater are interconnected.
3) Water levels in this area are consistently less than 30 feet below ground surface.

An area must comply with all three criteria to be considered a potential GDE. **Figure 2-46** displays iGDEs in the Subbasin, including both wetlands and vegetation areas. Cache Creek, Putah Creek, and the Sacramento River are associated with a high density of wetlands and vegetation iGDEs.

Vegetation iGDEs are more prominent in the northern part of the Subbasin, particularly along Cache Creek and the Sacramento River. Vegetation iGDEs also exists in the area between Davis and West Sacramento, and along the south fork of Putah Creek. Wetlands in the Subbasin are concentrated along the Sacramento River and in the southeastern portions of the Subbasin, where groundwater depths are near the ground surface, creating high-water table conditions year-round.

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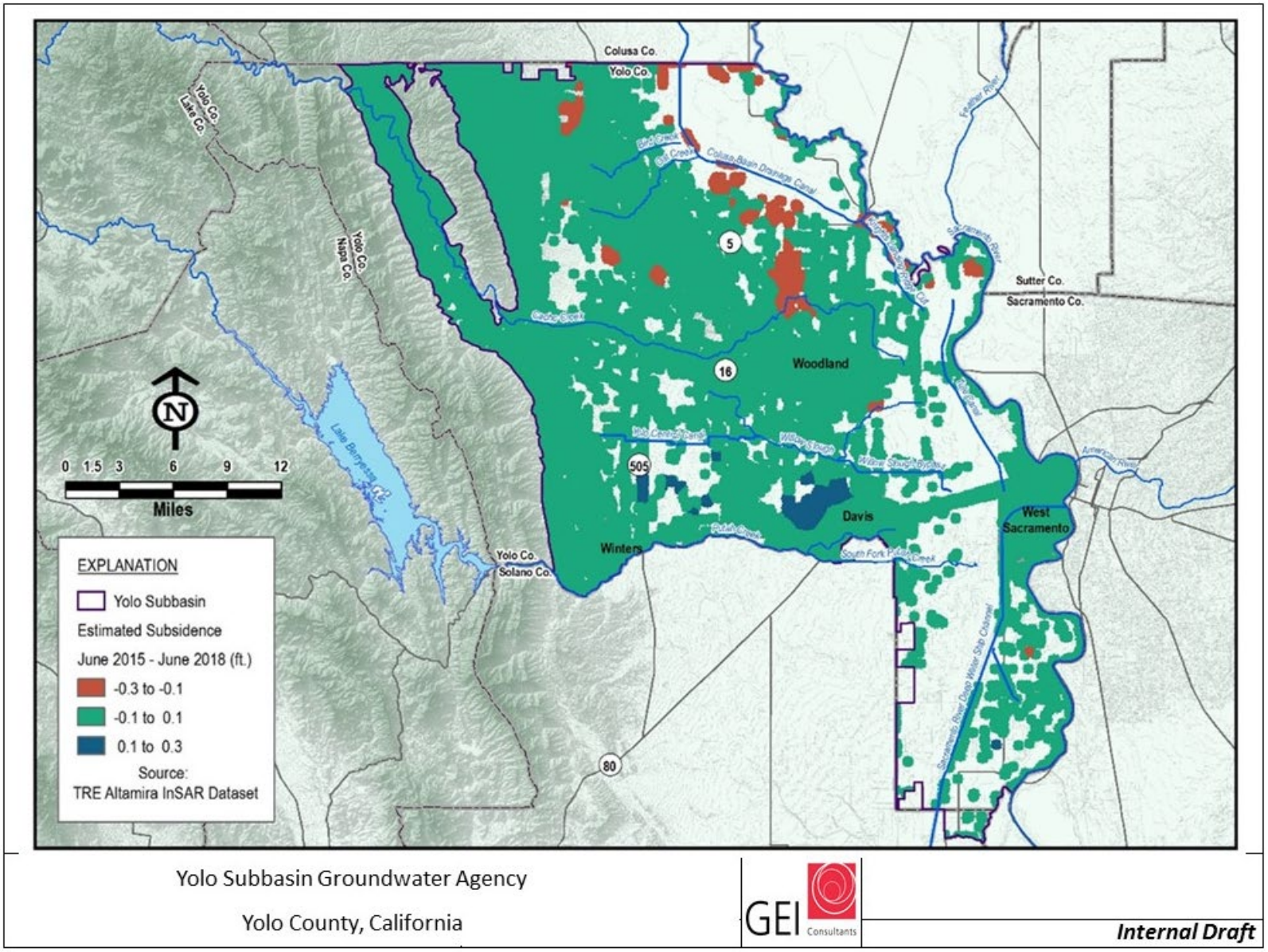


Figure 2-45. DWR InSAR Subsidence in Yolo Subbasin, 2015-2018

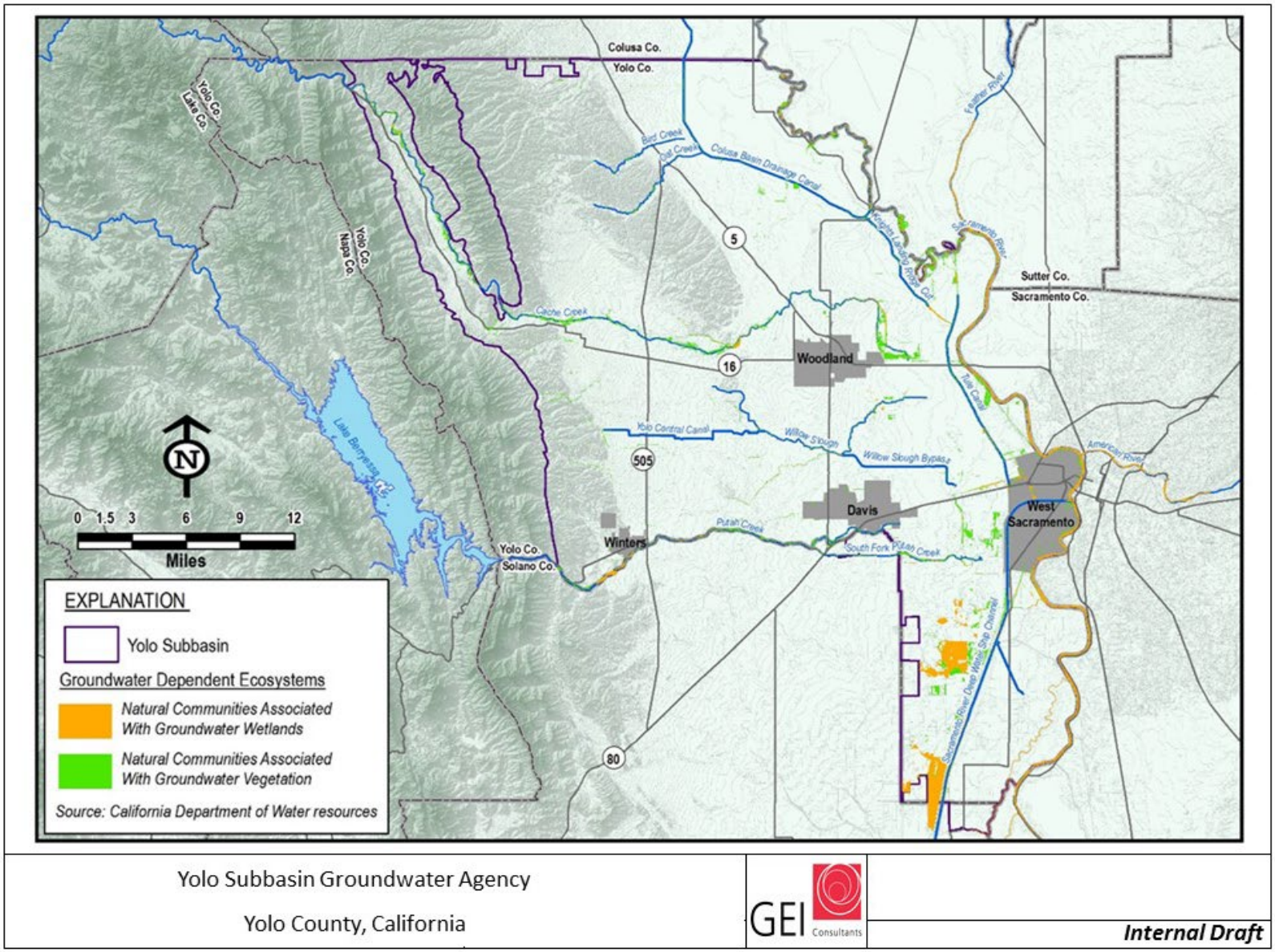


Figure 2-46. iGDEs in Yolo Subbasin

2.3 Water Budget Information

This section describes the water budget information of the Yolo Subbasin. Water budgets quantify all inflows and outflows of the area of interest with surrounding boundaries, and within the area of interest boundary at a spatial and temporal resolution that balances data and resource (human, financial, and time) availability with the overall goals of the water budget.

Historical, present, and future land surface and groundwater budgets were estimated at catchment, management area, and Subbasin scale. This Executive Summary is primarily a summary of the water budgets at the Subbasin-scale; please refer to the Water Budget and Model Documentation chapters for explanations of the Management Area-scale budgets. Please refer to Appendix A for additional information on Water Budget and Appendix B for additional information of model documentation.

Land surface water budgets quantify all the inflows and outflows to a specified area, from the bottom of the root zone, up to the land surface. Land surface inflows in the Yolo Subbasin are dominated by precipitation, surface water supply, and groundwater supply to meet multiple water demands (primarily agricultural and municipal water needs). Applied water re-use and recycled water are relatively minor inflows, quantitatively. Land surface outflows in the Yolo Subbasin are dominated by evapotranspiration (of precipitation and applied water), deep percolation (i.e., groundwater recharge), and surface runoff. Managed aquifer recharge is a quantitatively small land surface outflow for the Yolo Subbasin as a whole. The difference between these inflows and outflows represents the net change in land surface storage.

Groundwater budgets show all the inflows and outflows to the aquifer from the bottom of the root zone, down through all aquifer layers. Much of the Yolo Subbasin is underlain by an aquifer with three layers, as described in the Basin Setting chapter. Groundwater inflows in the Yolo Subbasin are dominated by deep percolation from the overlying land surface, followed by smaller contributions as recharge from the Yolo County Flood Control and Water Conservation District's unlined, earthen canal system. Groundwater outflows are largely comprised of pumping (for irrigation and municipal uses). Lateral flows (exchanges with neighboring subbasins) include groundwater exchanges with surface water bodies like rivers and creeks, and other smaller groundwater outflows from the Subbasin. The difference between groundwater inflows and outflows represents the net change in groundwater storage.

In the Yolo Subbasin, groundwater storage changes are positive in wet years and negative in dry years, with no significant trend (decline or increase) over the past 50 years.

Please see Appendix A - Section 1.3.7 Evaluating Water Budget Estimates to learn more about the uncertainty in the water budgets and YSGA model overall.

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2.3.1 Model Overview

The Yolo Subbasin Groundwater Agency model (YSGA model) is a linked surface water-groundwater model developed using Water Evaluation and Planning (WEAP)[4] and MODFLOW[5]. The YSGA model includes not only the Yolo Subbasin but also portions of the Cache Creek watershed upstream of the Capay Valley (including Clear Lake and Indian Valley Reservoir). **Figure 2-48** shows the spatial domain of the YSGA model.

The YSGA model relies on a 48-year historical period, which covers a large spread of water year types: significant and contiguous drought and wet periods. The YSGA model runs at a monthly time step from Water Year 1971 to Water Year 2018. Water Year 2018 is treated as the current period within the model and documentation – climate and water rights data is updated to 2018; however, land use data was only available for 2016 (land use data from 2016 was kept constant until 2018).

Future projections in the YSGA model only capture climate change projections based on climate change model simulations centered around the mid-2030's and mid-2070's. Five future scenarios were incorporated where the demand is the same: urban demand is increased based on Urban Water Management Plan (UWMP) projections; the 2016/2018 irrigated crops are kept constant at 2016/2018 levels; and any change in irrigation demand is driven by the climate signal.

The five scenarios are as follows and the cumulative and average precipitation for the Yolo Subbasin is higher in all climate projections, compared to that in the 'Historical' scenario.

1. 'Future_baseline' – urban demand increasing; irrigated crops constant; climate same as historical
2. 'Future_2030' – central tendency centered around 2030
3. 'Future_2070' – central tendency centered around 2070
4. 'Future_2070_DEW' – Dry-Extreme Weather
5. 'Future_2070_WMW' – Wetter-Moderate Warming

[4] WEAP is an integrated surface water-groundwater modeling tool, which integrates rainfall-runoff hydrology, reservoir operation, water demands from cities and crops, and allocations of water to those demands from surface water and groundwater supplies.

[5] MODFLOW is a finite-difference groundwater modeling tool develop by the USGS, which simulates the groundwater budget of the Yolo Subbasin's three-later aquifer and was built using the inputs, aquifer parameters, boundary conditions, and aquifer representation from a Yolo County Integrated Water Flow Model (IWFM).

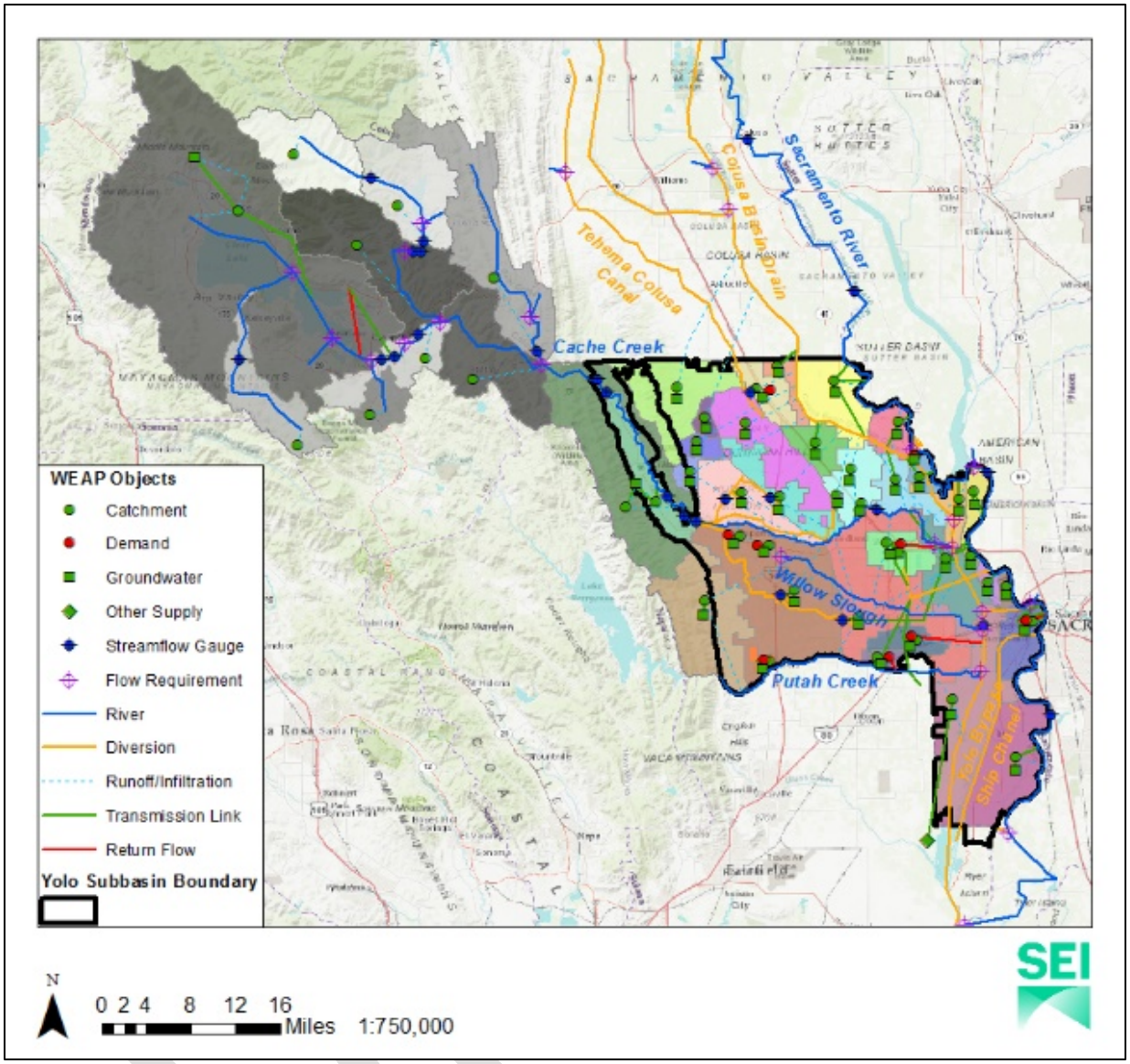


Figure 2-47. YSGA Model Spatial Domain

2.3.2 Land Use

Landcover in the Yolo Subbasin is dominated by agriculture and native vegetation. **Table 2-18** below shows the acreage and proportion of the main categories of Subbasin-wide land use for specific years where GIS data were available (1989, 1997, 2008, and 2016). An important feature of land use changes in the Yolo Subbasin is an increasing acreage of perennials, which have partly replaced field crops, and brought previously uncultivated area into production in some regions.

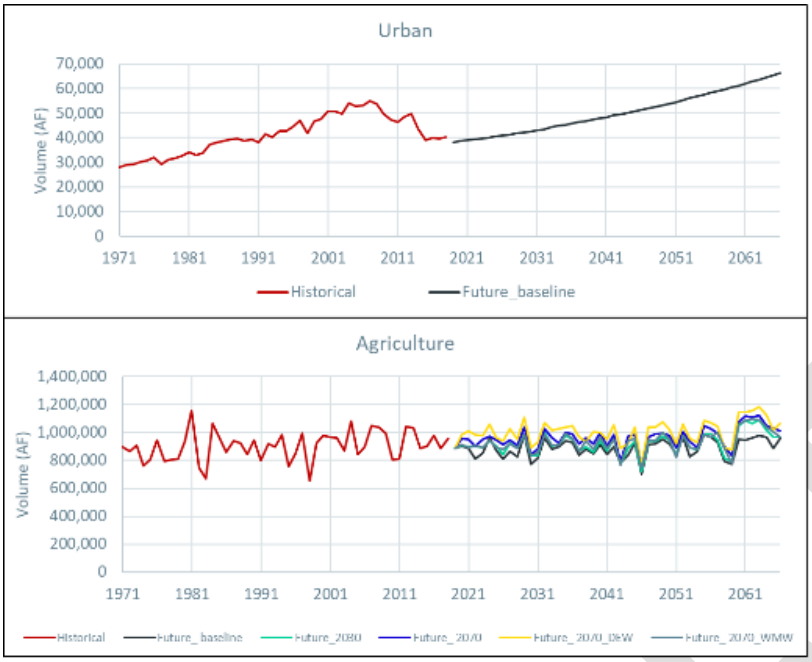
Table 2-18. Land Use in the Yolo Subbasin

	Land Use (ac)				Land Use (Percent)			
	1989	1997	2008	2016	1989	1997	2008	2016
Entire Basin	**639,089**	**639,089**	**639,089**	**639,089**				
Deciduous	17,550	18,406	30,717	59,434	3	3	5	9
Field Crops	96,679	108,427	36,475	41,446	15	17	6	6
Grain	80,354	57,993	52,369	27,200	13	9	8	4
Managed Wetlands	0	483	459	0	0	0	0	0
Native Vegetation	288,058	284,997	319,938	330,463	45	45	50	52
Pasture	42,612	44,822	63,801	33,129	7	7	10	5
Rice	22,652	24,754	35,056	38,847	4	4	5	6
Subtropical	118	135	1,331	3,670	0	0	0	1
Truck Crops	56,953	55,160	46,968	46,930	9	9	7	7
Urban	26,347	29,153	33,220	33,270	4	5	5	5
Vine	2,543	9,536	13,384	19,329	0	1	2	3
Water	5,222	5,222	5,372	5,372	1	1	1	1

2.3.3 Water Demand and Supply

Total water demands for each of the five scenarios are presented in the **Figure 2-49**. Urban water demands (based on UWMPs) rise steadily but remain small relative to irrigation demand. Irrigation demand in the future scenarios stay within the range of historical simulations, but averages are successfully higher than the historical scenario.

Since 'Future_baseline' and 'Historical' scenarios have the same climate, the impact of current, increased perennial crop acreage within the Yolo Subbasin is apparent (less inefficient, or more efficient, irrigation practices are altering evapotranspiration and deep percolation quantities). The supply sources for the 'Historical' and 'Future_baseline' scenarios shown in the pie chart illustrate the supply sources are expected to be about the same: the WDCWA's water supply accounts for the increase in urban surface water supply in the 'Future_baseline' scenario. Overall, the average annual water demand increases from 945 TAF to a maximum of 1,055 TAF from the 'Historical' to the 'Future_2070_DEW" (dry-extreme warming) scenario.



Average Annual Demand (Acre Feet)	
Urban	
Historical	41,102
Future(all scenarios are equal)	50,270
Agriculture	
Historical	904,090
Future_baseline	888,139
Future_2030	922,000
Future_2070	961,712
Future_2070_DEW	1,005,341
Future_2070_WMW	931,403

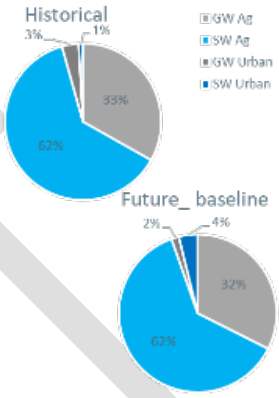


Figure 2-48. Water Demand for Historical and Future Scenarios

2.3.4 Land Surface Water Budget

For the land surface water budget, outflows are dominated by evapotranspiration, surface runoff, and deep percolation. **Figure 2-50** below provides a breakdown of the historical land surface water budget. The key results for the *historical* average land surface water budget are discussed below:

- Precipitation accounts for 1.15 MAF, with total water supply accounting for the remaining 0.955 MAF of inflows
- Surface waters supply (0.6 MAF) makes up about 60% of the total water supply, with groundwater pumping making up the remaining 40%
- Agricultural irrigation demand accounts for more than 90% of the total water demand of 1 MAF
- Water supply sources to meet agricultural and urban demands are shown – note the urban demand was historically mt primarily by groundwater pumping
- Total outflows are very close to total inflows, indicating an overall mass balance of inflows and outflows
- Evapotranspiration is the largest of the outflows (at 1.2 MAF), approximately 8% higher than precipitation

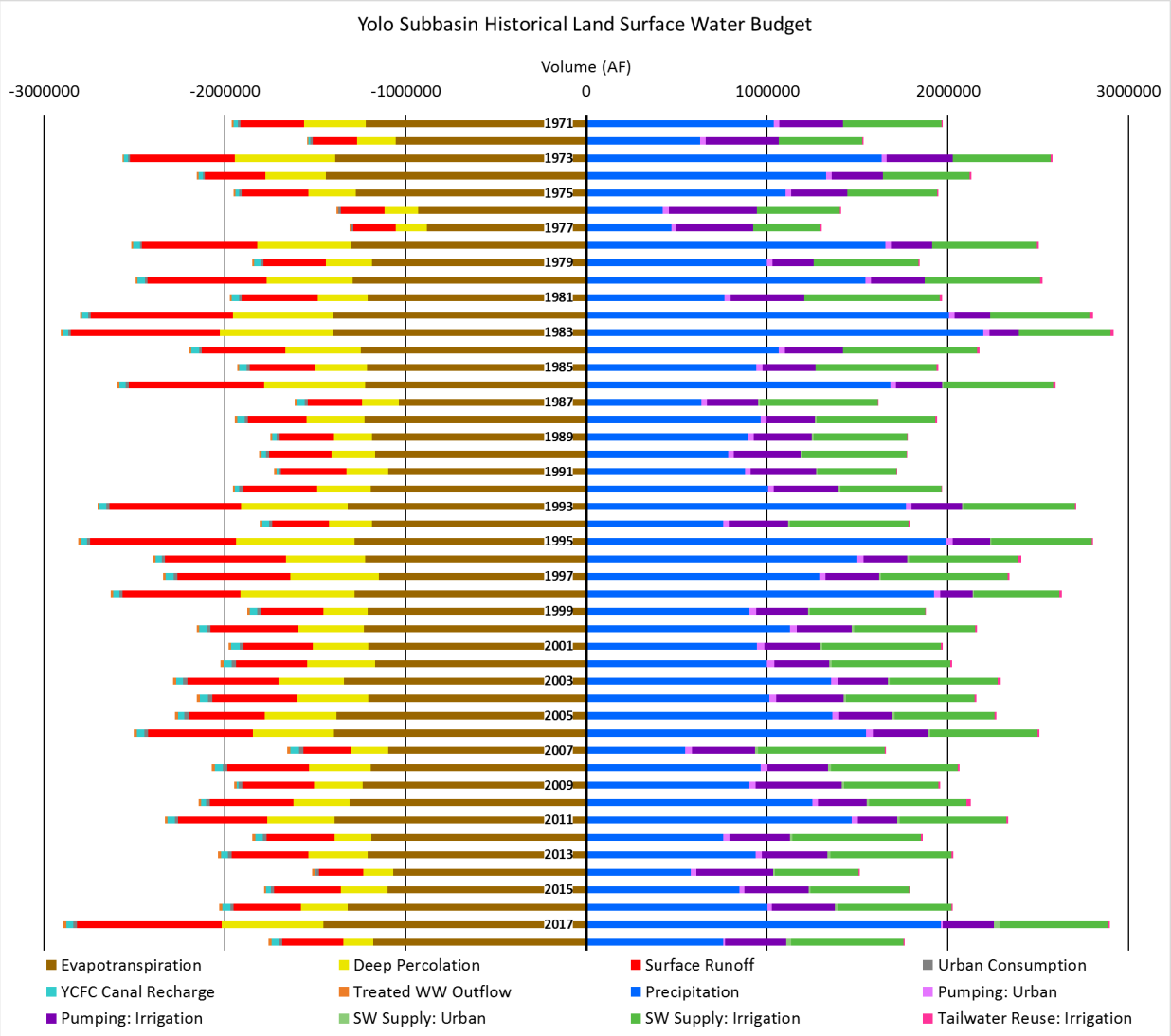


Figure 2-49. Yolo Subbasin Historical Land Surface Water Budget

The modeled time period of WY 1971 to WY 2018 cover a large spread of water year types, significant and contiguous drought periods (WY 1976-WY 1977, WY 1987-WY 1992, WY 2007-WY 2009, and WY 2012-WY 2016), and significant and contiguous wet periods of note (WY 1971-WY 1975, WY 1982-WY 1984, WY 1995-WY 2000, and WY 2005-WY 2006). Water Year 2018 – the last year of the model simulation in the historical period – is treated as the current period. This is the most recent year for which almost all datasets are available. Climate and water rights data are updated to WY 2018 in the YSGA model. Land use data, however, is only available to 2016 (the LandIQ dataset provided by DWR in the SGMA Data Viewer[6]). Hence 2016 Land use data is used and kept constant through WY 2018.

[6] See https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer#waterbudget; Accessed 8.31.2018

Table 2-19 shows the Water Year Index (Sacramento Valley) and the Water Year Types for the historical to current water year type and **Table 2-20** shows the historical and projected future annual average inflows and outflows in the land surface water budget.

Table 2-19. Historical Sacramento Valley Water Year Index and Water Year Type

Water Year	Water Year Index	Water Year Type	Water Year	Water Year Index	Water Year Type
1971	10.37	W	1995	12.89	W
1972	7.29	BN	1996	10.26	W
1973	8.58	AN	1997	10.82	W
1974	12.99	W	1998	13.31	W
1975	9.35	W	1999	9.80	W
1976	5.29	C	2000	8.94	AN
1977	3.11	C	2001	5.76	D
1978	8.65	AN	2002	6.35	D
1979	6.67	BN	2003	8.21	AN
1980	9.04	AN	2004	7.51	BN
1981	6.21	D	2005	8.49	AN
1982	12.76	W	2006	13.2	W
1983	15.29	W	2007	6.19	D
1984	10.00	W	2008	5.16	C
1985	6.47	D	2009	5.78	D
1986	9.96	W	2010	7.08	BN
1987	5.86	D	2011	10.54	W
1988	4.65	C	2012	6.89	BN
1989	6.13	D	2013	5.83	D
1990	4.81	C	2014	4.07	C
1991	4.21	C	2015	4.00	C
1992	4.06	C	2016	6.71	BN
1993	8.54	AN	2017	14.14	W
1994	5.02	C	2018	7.14	BN

Table 2-20. Historical Average Annual Land Surface Water Budget

Historical Average Annual Land Surface Water Budget (TAF)														
	Outflows							Inflows						
	Evapotranspiration	Deep Percolation	Surface Runoff	Urban Consumption	YCFC Canal Recharge	Treated WW Outflow	Total Outflows	Precipitation	Pumping: Urban	Pumping: Irrigation	SW Supply: Urban	SW Supply: Irrigation	Tailwater Reuse: Irrigation	Total Inflows
Entire Basin														
Historical	-1,227	-353	-459	-18	-33	-13	-2,102	1,147	33	313	9	591	10	2,102
Future_Baseline	-1,274	-308	-437	-23	-37	-16	-2,095	1,147	16	304	34	584	10	2,095
Future_2030	-1,314	-321	-471	-23	-39	-16	-2,184	1,201	15	322	35	600	11	2,184
Future_2070	-1,345	-340	-519	-23	-40	-16	-2,282	1,259	15	343	36	619	11	2,282
Future_2070_DEW	-1,346	-323	-549	-23	-37	-16	-2,293	1,229	15	385	35	620	9	2,293
Future_2070_WMW	-1,326	-424	-692	-23	-43	-16	-2,523	1,530	14	311	37	620	11	2,524

The key results for the *future* average land surface water budget are discussed below:

- Overall land surface mass balance is maintained (total inflows = outflows)
- The effect of increased perennial acreage results in more evapotranspiration and less deep percolation
- The effect of climate change results in more evapotranspiration and more deep percolation

2.3.5 Groundwater Budget

Figure 2-51 shows the historical groundwater budget and the key findings are as follows:

- Inflows to the Yolo Subbasin are dominated by deep percolation
- Pumping (urban and irrigation) is the largest groundwater outflow
- Groundwater-surface exchange is on average positive
- The net lateral exchange with neighboring basins is negative; on average, lateral flow is leaving
- Some fluxes are 0 in some years (1976/77 and 2014 droughts led to no surface water deliveries)

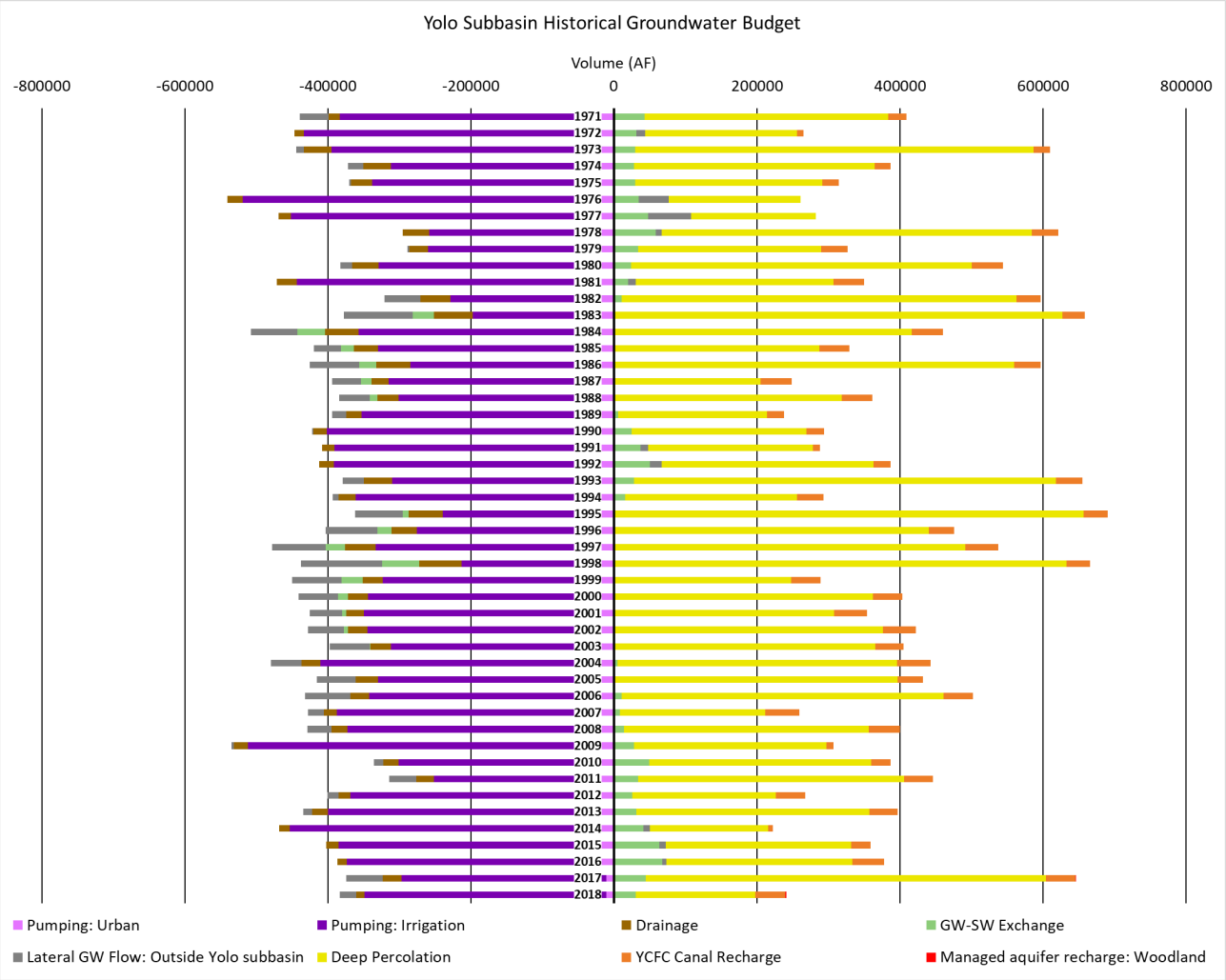


Figure 2-50. Yolo Subbasin Historical Ground Water Budget

The key findings for the *future* average groundwater budgets are as follows:

- Less deep percolation and more outflow than inflow is the result of increased perennial acreage and change in irrigation management
- The effect of climate change can be seen in the increase in deep percolation, falling storage in extreme dry scenario, balanced budgets in the central tendency scenarios, and increasing storage in the extreme wet scenario

Table 2-21 below include the average annual groundwater budget for the historical and five scenarios evaluated.

Table 2-21. Average Annual Groundwater Budget

Average Annual Groundwater Budget (TAF)												
	Outflows				Varying Flows				Inflows			
	Pumping: Urban	Pumping: Irrigation	Drainage	Total Outflows	GW-SW Exchange	Lateral GW Flow: Outside Yolo [illegible]	Lateral GW Flow	Total Varying Flows	Deep Percolation	YCFC Canal Recharge	Managed aquifer recharge: [illegible]	Total Inflows
Entire Basin												
Historical	-33	-313	-28	-374	15	-28	0.0	-13	353	33	0.04	386
Future_Baseline	-16	-304	-16	-336	25	-40	0.0	-15	308	37	1.37	346
Future_2030	-15	-322	-15	-352	23	-37	0.0	-15	321	39	1.43	361
Future_2070	-15	-343	-15	-373	22	-35	0.0	-13	340	40	1.31	381
Future_2070_DEW	-15	-385	-13	-413	46	-6	0.0	39	323	37	1.30	360
Future_2070_WMW	-14	-311	-24	-348	-29	-79	0.0	-108	424	43	1.40	468

Notes: In the historical scenario: GW-SW exchange is positive with Cache Creek (29 TAF), Putah Creek (13.9 TAF), Sacramento River (0.9 TAF) and negative with Yolo bypass (25.7 TAF), Knights Landing Ridge Cut (1.5 TAF) and Colusa Basin Drain (2 TAF). Other GW-SW exchanges are minor.

Table 2-22 below provides another way to view the average annual groundwater fluxes by observing the delta, or difference, from the 'Historical' scenario.

Table 2-22. Average Annual Groundwater Budget relative to Historical Scenario

Historical Average Annual Groundwater Budget (TAF)												
	Outflows				Varying Flows				Inflows			
	Pumping: Urban	Pumping: Irrigation	Drainage	Total Outflows	GW-SW Exchange	Lateral GW Flow: Outside Yolo subbasin	Lateral GW Flow	Total Varying Flows	Deep Percolation	YCFC Canal Recharge	Managed aquifer recharge: Woodland	Total Inflows
Entire Basin												
Historical	-33	-313	-28	-374	15	-28	0	-13	353	33	0.04	386
	Delta from Historical				Delta from Historical				Delta from Historical			
Future_Baseline	17	9	12	38	10	-12	0	-2	-45	4	1.33	-40
Future_2030	18	-9	13	22	8	-9	0	-2	-32	6	1.39	-25
Future_2070	18	-30	13	1	7	-7	0	0	-13	7	1.27	-5
Future_2070_DEW	18	-72	15	-39	31	22	0	52	-30	4	1.26	-26
Future_2070_WMW	19	2	4	26	-44	-51	0	-95	71	10	1.36	82

2.3.6 Groundwater Storage

Changes in groundwater storage over time are the aggregate (net) outcome of the individual inflows and outflows from the aquifer. Available groundwater storage in Yolo County (20 to 420 feet below ground surface), has been estimated at 14 million acre-ft (MAF) (Clendenen & Associates, 1976).

The MODFLOW portion of the YSGA model estimates Basin-wide groundwater storage capacity at 13.7 MAF.

Modeled basin groundwater storage is presented as cumulative change from initial storage in September 1970, as shown in the **Figure 2-52**. As you can see, groundwater is lost from storage in dry years and recharge occurs in wet years to allow Basin-wide recovery. Deep groundwater storage declines follow the deep droughts and storage recovery follows in the intervening wet periods. Over the past 50 years, there is no evidence of Basin-wide overdraft. Additionally, as previously mentioned, the dominant shift in land use in the Yolo Subbasin over this historical period has been from annual to perennial crops. **The groundwater storage trace implies that the climate signal has dominated over this historical period at the Basin-wide level.**

Groundwater extraction increases over the past decade were driven by the extended drought and acceleration of perennial acreage. Despite these factors, a wetter 2017 appears to have helped the Basin storage to almost recover to initial levels (at the end of the simulation in the historical period, modeled Basin groundwater storage is lower than the initial level by 86 TAF).

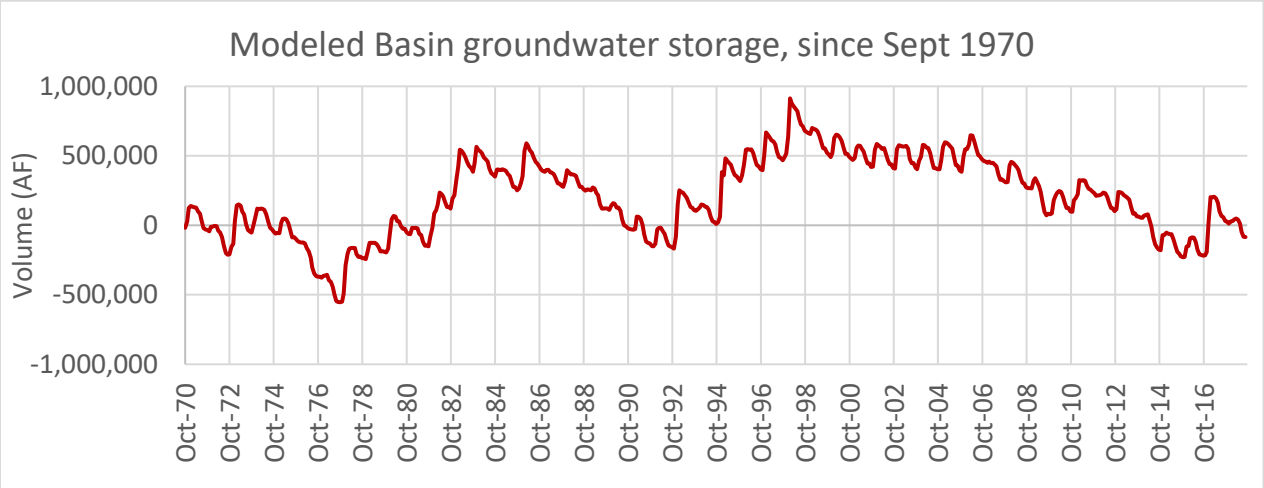


Figure 2-51. Modeled Basin Groundwater Storage

Decadal changes in storage are summarized below in **Table 2-23** to further illustrate the fluctuation of groundwater storage in different wet and dry decades.

Table 2-23. Change in Groundwater Storage by Decade

Decade	Change in Storage (AF)
WY 1971-1980	-24,806
WY 1981-1990	17,992
WY 1991-2000	521,671
WY 2001-2010	-390,769
WY 2011-2018	-208,710

Figure 2-53 illustrates the change in groundwater storage for each of the future scenarios relative to the 'Historical' scenario (red line). Groundwater storage patterns among scenarios follow the precipitation and temperature trends among scenarios, such as the following:

- The most groundwater declines occur in the driest, warmest scenario ('Future_70_DEW')
- Groundwater storage shows an overall increase in 'Future_70_WMW' scenario
- There is not much difference in groundwater storage between the central tendency scenarios ('Future_30' and 'Future_70') and the 'Future_baseline'.
- The 'Historical' and 'Future_baseline' have the same climate input and comparing them shows the sensitivity to current cropping patterns and irrigation management.

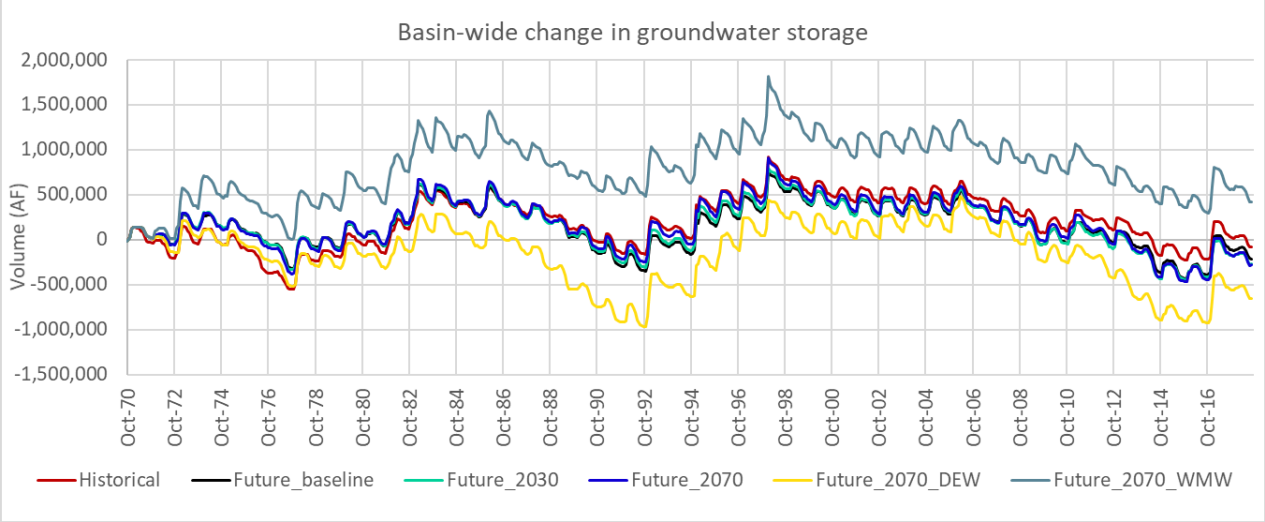


Figure 2-52. Basinwide Change in Groundwater Storage

2.3.7 Sustainable Yield

Based on the information presented above, a Sustainable Yield of 346 TAF per year is being proposed for the Yolo Subbasin. (This number will be discussed by the TAC, Working Group, and Board of Directors before included in the final Yolo Subbasin GSP.)

Figure 2-54 below shows the modeled pumping time series for the historical period with the future scenarios included along with the proposed sustainable yield (the horizonal reference line).

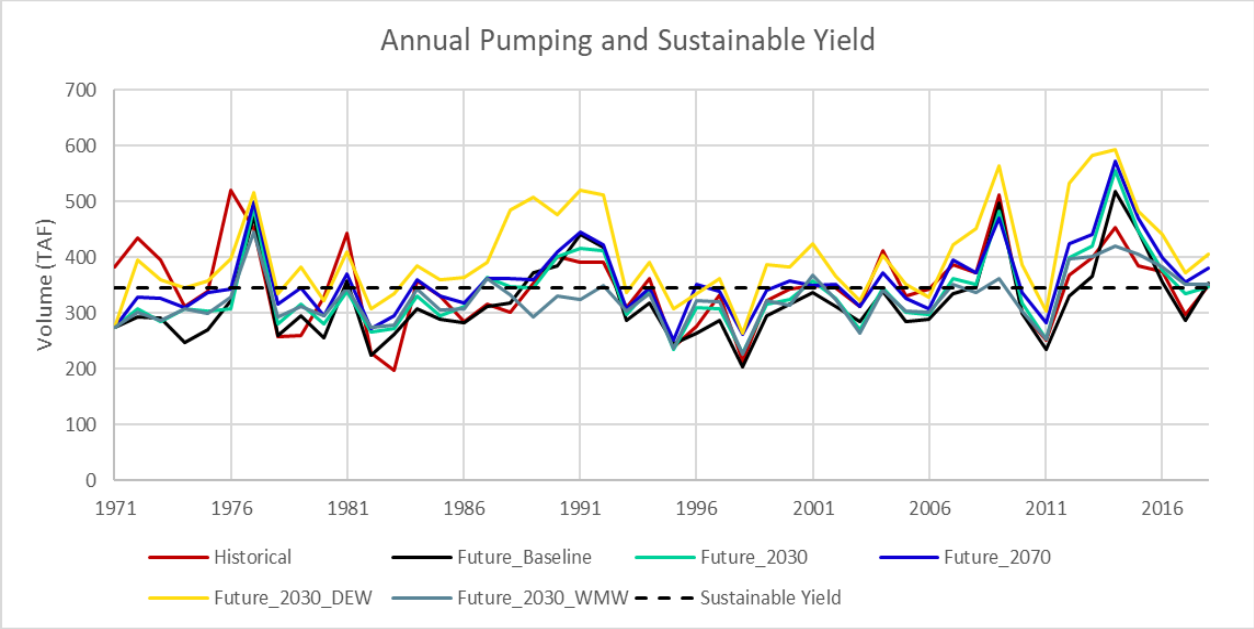


Figure 2-53. Sustainable Yield and Annual Pumping for Historical and Future Scenarios

2.4 Management Areas

Six management areas have been established within the Subbasin for implementation of project and management actions to achieve groundwater sustainability. In developing these management areas, YSGA considered geologic, aquifer, and topographic characteristics. The groundwater bearing deposits in Yolo County are contained in the Sacramento Valley Basin (DWR, 1978). This report utilizes a subdivision of the Yolo County groundwater-bearing area into six informal hydrologic units, or management areas. Management areas were developed based on prior investigations, which delineated somewhat different subbasin areas, and have been adapted for the purpose of this GSP. To prevent undesirable results in adjacent management areas, consistent minimum thresholds and measurable objectives have been developed as discussed in Section 3. For purposes of this report, the six management areas are described below and shown on **Figure 2-55**, including:

- Capay Valley
- Dunnigan Hills
- North Yolo
- Central Yolo
- South Yolo
- Clarksburg

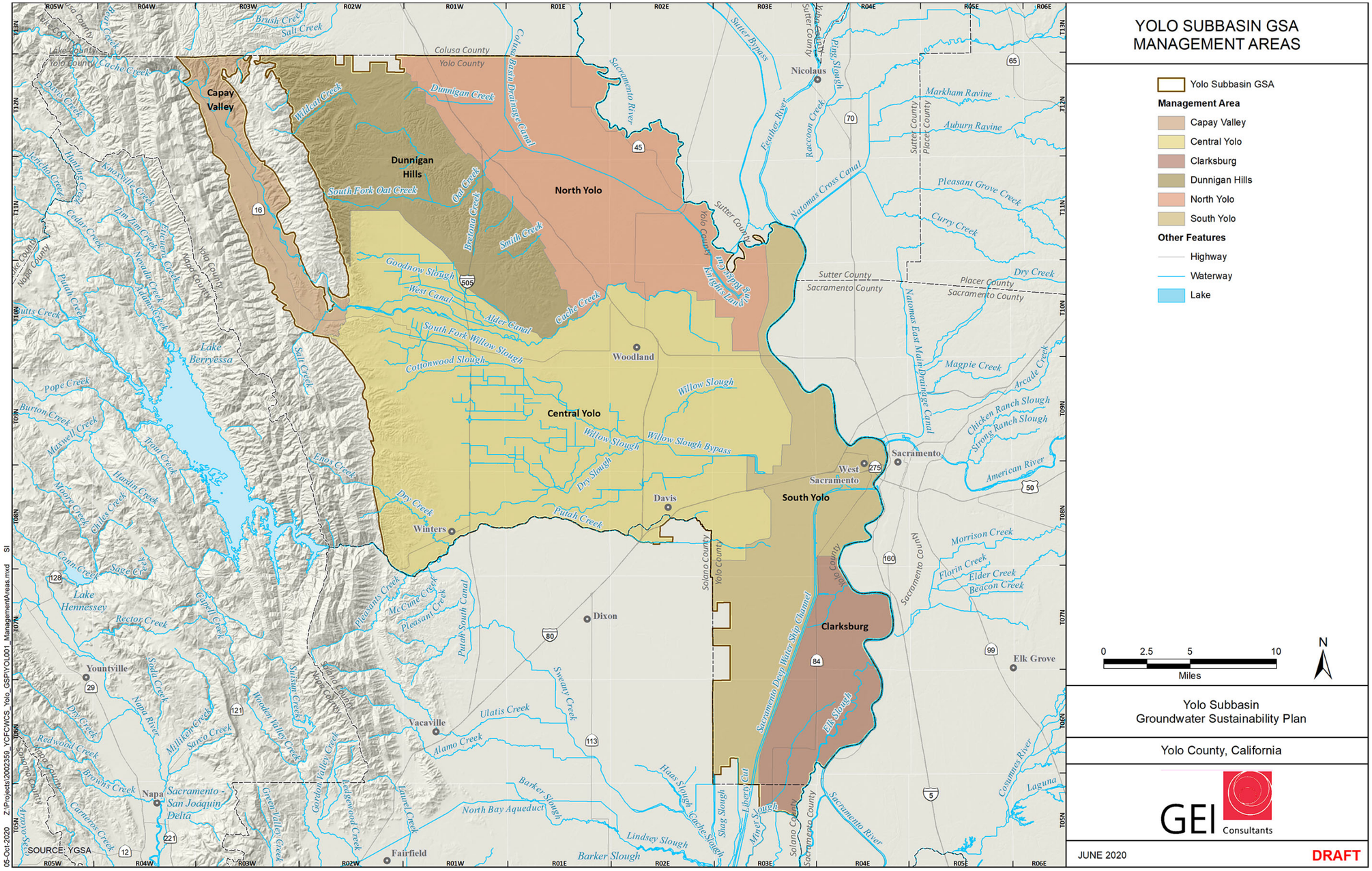


Figure 2-54. Yolo Subbasin Management Areas

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During the formation of the GSA, the delineations for these subunits were modified. Specifically, the Northern Sacramento River and Buckeye/Zamora subunits where combined to form the North Yolo Management Area. The Western Yolo and Lower Cache-Putah subunits where combined to form the Central Yolo Management Area, and the Southern Sacramento River subunit was divided into the South Yolo and Clarksburg Management Areas. Furthermore, certain YSGA entities were transferred to a neighboring management area, namely RD1600 which moved from the North Yolo Management Area to the South Yolo Management Area. Beyond this, geologic units in the area, features such as the Capay Dam, and YSGA entities were used to adjust the management area boundaries.

In coordination with DWR several steps occurred to develop consistent management area nomenclature. The Western Yolo subunit, part of the Central Yolo Management Area, referenced in this report is described as including two subunits in the IRWMP. These subunits include the Hungry Hollow unit located north of Cache Creek and the Upper Cache-Putah unit located south of Cache Creek. Similarly, this report refers to the Buckeye/Zamora subunit located north of Cache Creek and east of the Dunnigan Hills. This subunit was originally planned to be further divided into two management areas. This plan has since been altered and the Buckeye/Zamora subunit has merged with the Northern Sacramento River subunit to form the North Yolo Management Area.

2.4.1 Dunnigan Hills Management Area

To the northwest, the Dunnigan Hills represent a low hilly area of uplifted Tehama Formation or nonmarine deposits with a thickness of up to 2,000 feet. These deposits appear to contain fresh groundwater, but previous reports indicate that aquifer material may be largely lacking. Little groundwater development appears to have occurred in the hills, and the area may be important only as a recharge area to the rest of the basin. In the past 15 years, many thousands of acres olives, grapes, and almonds have been planted. Many new wells have been drilled to service these new plantings. Details of this new development are covered in the water budget and modeling Section 2.3.

2.4.2 North Yolo Management Area - Buckeye/Zamora & Northern Sacramento River

The North Yolo Management area consists of the Buckeye/Zamora and Northern Sacramento River subunits. To the northeast, the Buckeye/Zamora subunit underlies the Valley floor east of the Dunnigan Hills. The area is considered to be underlain by alluvium and nonmarine deposits similar to those seen further south. Future detailed hydrogeologic study may be considered as a potential objective to better define the aquifer system in the Yolo County area. The Northern Sacramento River subunit encompasses the northernmost portion of the eastern part of Yolo County and contains the flood plain/basin and Sacramento River area. The area is underlain by alluvium and nonmarine deposits. While at least some of the sand sequences occur in the management area, there is also a component of eastern sourced alluvial plain and/or tributary fluvial deposits in the

nonmarine section. In addition, northeast of Woodland, a lower concentration of sand units occurs in the Tehama Formation.

2.4.3 Capay Valley Management Area

The Capay Valley Management area is a small, structurally controlled valley of Cache Creek bound by faulted marine deposits to the east in the Capay Hills and the Coast Range to the west. Alluvium and the Tehama Formation are present in the valley floor with a thickness up to 1,000 feet. The valley appears to be connected to the larger groundwater basin through downstream alluvium and the underlying Tehama Formation along Cache Creek. The northern end of the valley is separated by a topographic divide of the Tehama Formation, although some groundwater connection may be possible north to Colusa County.

2.4.4 Central Yolo Management Area - Western Yolo & Lower Cache-Putah

The Central Yolo Management Area consists of the Western Yolo and Lower Cache-Putah subunits. The Western Yolo subunit is defined on the north and east by the alluvial plains lying west of the roughly north-south line extending from the western edge of the Dunnigan Hills north of Cache Creek, just east of the mapped Tehama Formation exposures near the Woodland-Watts Airport area and Plainfield Ridge and south to Putah Creek. This management area is bound on the south by Putah Creek and extends to the western edge of the mapped Tehama Formation in the low hills marginal to the Coast Range. The exposures of the Tehama Formation may be an important source of recharge for the Tehama Formation further east. The gentle alluvial plain area is underlain by thin alluvium overlying the Tehama Formation. These nonmarine deposits appear to be sand poor except in the vicinity of Putah Creek. Deep test hole control is relatively poor in this management area, and additional geologic study using water well data may be warranted to examine shallow and intermediate zone stratigraphic relationships.

2.4.5 South Yolo Management Area

The South Yolo Management Area encompasses a portion of the south eastern section of the county. It contains the middle swath of the flood plain/basin, Yolo Bypass and the Sacramento River area within Yolo County. The area is underlain by alluvium and nonmarine deposits. While at least some of the sand sequences occur in the management area, there is also a component of eastern sourced alluvial plain and/or tributary fluvial deposits in the nonmarine section.

2.4.6 Clarksburg Management Area

The Clarksburg Management Area encompasses the southernmost portion of the eastern part of Yolo County and contains the flood plain/basin and Sacramento River area. The area is underlain by alluvium and nonmarine deposits. While at least some of the sand sequences occur in the management area, there is also a component of eastern sourced alluvial plain and/or tributary fluvial deposits in the nonmarine section.

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