Hydrographs from the Eastern Principal Aquifer show the greatest depth to water and the most significant water level declines in the Subbasin (hydrographs 5, 6, and 11 through 18). Water level declines increase to the east, with very little recovery evident in the two easternmost hydrographs (17 and 18). Long-term rates of decline from 2000 to 2016 are up to about 6 feet per year within the cone of depression, with some recovery since the recent drought (Hydrograph 14). In the easternmost Subbasin, water level declines between 2006 and 2017 are approximately 8.5 feet per year, with little recovery (Hydrograph 18).

4.3.3. Groundwater Flow

4.3.3.1. Groundwater Elevation Contour Maps

Groundwater elevation contour maps were developed based on measured water level data to examine groundwater flow conditions at the beginning of the GSP Study Period (1991), during the wettest year of the GSP Study Period (1998), at the end of the GSP Study Period during a critically dry year (2015), and the most recent year with a large dataset (2017). These contour maps are illustrated on **Figures 4-28** through **4-31**.[16]

Groundwater elevation contour maps illustrated on **Figures 4-28a** (1991), **4-29** (1998), **4-30a** (2015), and **4-31** (2017) are based on water level measurements from wells screened above the Corcoran Clay (Western Upper Principal Aquifer) and east of the Corcoran Clay (Eastern Principal Aquifer). Water levels from these two principal aquifers are shown and contoured on the same map to represent water table conditions. There are many wells within the Corcoran Clay extent that are screened both above and below the Corcoran Clay or where well construction is unknown; these wells represent average heads or unknown conditions within the Western Upper Principal Aquifer and are not included on these maps.

Groundwater elevations and contours below the Corcoran Clay (Western Lower Principal Aquifer) are presented on **Figure 4-28b** (1991) and **Figure 4-30b (**2015). As indicated on these two maps, wells screened exclusively in this principal aquifer are sparse and the potentiometric surface of this confined aquifer is not well known.

__Groundwater Elevations and Flow in Spring 1991__

Groundwater elevation contours in Spring 1991 above and east of the Corcoran Clay are illustrated on **Figure 4-28a.** Groundwater elevations measured below the Corcoran Clay in Spring 1991 are illustrated on **Figure 4-28b**.

Groundwater elevation contours above and east of the Corcoran Clay (**Figure 4-28a**) represent conditions in the Western Upper Principal Aquifer and the Eastern Principal Aquifer. Contours indicate that groundwater flow within Turlock Subbasin is generally to the west and southwest in the eastern Subbasin with some westerly flow between high and low water levels in the central Subbasin, and then northwesterly toward the Subbasin outflow in

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[16] Supplemental 2015 contour maps simulated with C2VSimTM are provided in **Appendix F;** model documentation, including model calibration and limitations, is provided in **Appendix D**.

the northwest. Groundwater elevations range from above 100 ft msl in the eastern Subbasin, to 33 ft msl within a cone of depression located in the south-central portion of the eastern Subbasin. Groundwater elevations in the western Subbasin range from more than 90 feet msl in an area of high water levels in the southwest to 36 feet msl in the northwest. As indicated on the figure, there are no measured water level data in the eastern one-third of the Subbasin for this time period.

There is a localized pumping depression in the eastern Subbasin defined by a 60-foot elevation contour. The 60-foot elevation contour is closed and illustrates a relatively well-defined area of low water levels and controls groundwater flow locally. Groundwater elevations west of this pumping depression rise to between 85 and 95 feet msl. This area of high water levels creates a mounding effect that controls flow in the west-central portion of the Subbasin. Groundwater from this area flows south to the Merced River, to the west towards the San Joaquin River, and to the north towards the Tuolumne River. The higher water levels in the area adjacent to the pumping depression also creates an area of easterly flow, a flow reversal from typical east-to-west flow in the Subbasin. Groundwater in the central-northwestern portion of the Subbasin flows north-northwest toward the Tuolumne River with groundwater in the western Subbasin generally flowing northwest.

Based on the contours, groundwater in the northern Subbasin flows away from the Tuolumne River into the eastern Subbasin and towards the Tuolumne River in the western Subbasin. With only a few clustered data points near the Merced River, it is difficult to use the data to estimate interaction between the groundwater system and the river at this time period. The integrated surface water-groundwater model is used to evaluate interconnected surface water in a more detailed manner in **Section 5**.

Groundwater elevations measured below the Corcoran Clay in Spring 1991 are shown on **Figure 4-28b**. There are only three wells screened solely below the Corcoran Clay with measured groundwater elevations during this time. Elevations measured at these wells are 48 feet msl near the eastern extent of the Corcoran Clay and 43 feet msl and 47 feet msl in the western Subbasin near the San Joaquin River. These limited data suggest a relatively flat horizontal hydraulic gradient on the potentiometric surface associated with the Western Lower Principal Aquifer, but data are too sparse to make interpretations on groundwater flow directions.

Groundwater Elevations and Flow in March/April 1998

Figure 4-29 illustrate groundwater elevations in March/April 1998 above and east of the Corcoran Clay in the Western Upper Principal Aquifer and the Eastern Principal Aquifer. As shown on **Figure 4-2**, WY 1998 was the wettest year of the historical Study Period (WY 1990 – WY 2015), with almost double the long-term average annual precipitation. Groundwater elevations in March/April 1998 range from almost 140 ft msl south of Turlock Lake to approximately 40 ft msl within the cone of depression in the eastern Subbasin. As shown on **Figure 4-29**, groundwater elevation data in the Western Upper Principal Aquifer are sparse because there are not many water level measurements during this time from wells with known construction that are screened only above the Corcoran Clay.

Based on the available data, groundwater flow patterns are similar to Spring 1991, but the pumping depression in the eastern Subbasin is more pronounced. Similar to 1991, the pumping depression is defined by the 60-foot elevation contour, which has expanded since 1991. Also similar to 1991, the cone of depression has reversed groundwater flow in portions of the western and north central Subbasin. from west-northwesterly flow to east-southeasterly flow.

The groundwater contours on **Figures 4-29** suggest that groundwater flow is to the northwest within the Western Upper Principal Aquifer. Groundwater elevations range from 98 feet msl, west of the GSA boundary in the southwestern Subbasin, to 51 feet msl in the northwest Subbasin. The lowest measured elevation in the Western Upper Principal Aquifer is 33 feet msl, adjacent to the Tuolumne River.

Groundwater Elevations and Flow in October 2015

Groundwater elevation contours in October 2015 above and east of the Corcoran Clay are illustrated on **Figure 4-30a**. Groundwater elevations measured during this time are close to historical lows because of the drought from WY 2013 through WY2016. This map has been chosen to represent the end of the historical Study Period.

Groundwater elevations range from approximately 100 ft msl east of Turlock Lake to approximately 20 feet below sea level within the eastern cone of depression. Groundwater elevations in the western Subbasin range from approximately 80 feet msl in the southwest to approximately 30 feet msl in the northwest.

Groundwater patterns are relatively similar to 1991 (and 1998), but elevations are significantly lower throughout the Subbasin. The elevation differences are most significant in the eastern Subbasin, where groundwater levels have declined more than 50 feet (from 33 ft msl in 1991 to -20 feet msl in 2015). The cone of depression, defined by the 40-foot elevation contour, has also expanded since 1991.

The area of high groundwater levels in the southwestern Subbasin persists during 2015 but covers a smaller area than in 1991. Groundwater from this area flows north toward the City of Turlock, to the east toward the eastern cone of depression, and to the west toward the San Joaquin River. Data are needed on the south side of the Merced River to better understand flows in this area.

Along the Tuolumne River, groundwater flows away from the river toward the eastern pumping depression and toward the river along its western stretch near the confluence with the San Joaquin River.

Groundwater elevation contours based on October 2015 water level measurements in wells screened below the Corcoran Clay in the Western Lower Principal Aquifer are shown on **Figure 4-30b**. As shown, there are a limited number of wells screened below the Corcoran Clay with water level data during this time. These wells are primarily along the Highway 99 corridor, in the eastern section of the Western Lower Principal Aquifer. Groundwater elevations range from 1 to 53 feet msl. There is a pumping depression within the City of Turlock with groundwater elevations between approximately sea level (1-foot msl) and 20 feet msl. Available groundwater elevations outside of this pumping depression generally range from 20 to 30 feet. There are groundwater elevation highs of 53 feet msl along the northern Corcoran Clay boundary and of 43 feet msl along the Tuolumne River.

Simulated groundwater elevation contours from the C2VSimTM model for Fall 2015 in model layers 1 and 2 are presented in **Appendix F**. These simulated contour maps provide a more complete representation of water levels in the Western Lower Principal Aquifer and in the eastern region of the Eastern Principal Aquifer than is possible with the existing well coverage and available measured water level data. **Appendix F-1** illustrates the simulated groundwater elevation contours in model layer 1, which represents the Western Upper Principal Aquifer and the shallow Eastern Principal Aquifer. This figure illustrates the similarity between the model and the measured contour map (**Figure 4-30a**) and provides more information in the eastern region of the Eastern Principal Aquifer. **Appendix F-2** illustrates the simulated groundwater elevation contours in model layer 2, which represents the Western Lower Principal Aquifer and the deeper Eastern Principal Aquifer. The limited measured data, shown on **Figure 4-30b**, generally agrees with the simulated groundwater elevation contours in the Western Lower Principal Aquifer.

Groundwater Elevations and Flow in March 2017

Figure 4-31 illustrates groundwater elevation contours above and east of the Corcoran Clay for March 2017, the most recent month with the most complete set of water level data. Groundwater elevation contours indicate that groundwater flow within Turlock Subbasin is generally to the west and southwest. Groundwater elevations range from approximately 100 ft msl in the eastern Subbasin, adjacent and to the east of Turlock Lake, to approximately sea level (0 ft msl) within a cone of depression located in the east-central Subbasin. Groundwater elevations in the western Subbasin range from approximately 40 feet msl in the northwest to approximately 80 feet msl in the southwest.

There are two localized depressions in groundwater elevations measured in March 2017; a relatively large depression in the eastern Subbasin and a smaller depression in the west-central Subbasin, both of which are generally defined by the 40-foot contours. Both depressions appear to be coincident with local groundwater pumping. In the east, groundwater elevations decline from approximately 60 ft msl immediately west of Turlock Lake to below sea level (0 feet msl) in the center of the pumping depression, located at the boundary between the WTSGSA and ETSGSA. The 40-foot elevation contour is closed and well-defined in the northern cone of depression near the Tuolumne River but is less defined in the southern portion near the Merced River. Groundwater elevations west of the pumping depression rise to between 40 and 60 feet msl and then decline to between 30 and 40 feet msl within a smaller pumping depression beneath the City of Turlock.

Groundwater west of the eastern cone of depression flows generally to the west toward the San Joaquin River and to the northwest toward the Tuolumne River. There is a groundwater mound, with elevations between 80 and almost 100 feet msl, in the southwestern Subbasin near the Merced River. Groundwater from this mound flows to the north toward the central Subbasin and to the northwest toward the San Joaquin River. A second smaller groundwater mound northwest of the City of Turlock has elevations between approximately 60 and 76 feet msl.

Based on the contours, groundwater flows away from the Merced River into the eastern cone of depression and toward the Merced River from the southwestern groundwater mound. In the north, groundwater flows south from the Tuolumne River toward the eastern cone of depression, and northward toward the Tuolumne River from the small groundwater mound north of the City of Turlock.

4.3.3.2. Vertical Groundwater Flow

An analysis of vertical groundwater flow in the western Subbasin, within the footprint of the Corcoran Clay, shows that groundwater movement is downward from the unconfined aquifer through the Corcoran Clay to the confined aquifer. This is consistent with USGS findings (Burow, et al. 2004). The analysis also informs the difference in water levels between the Western Upper Principal Aquifer and the Western Lower Principal Aquifer.

This analysis was based on hydrographs from three groups of nearby shallow and deep wells as shown on **Figure 4-32**. The shallow wells are screened above the Corcoran Clay in the Western Upper Principal Aquifer and shown as red dots, and the deep wells are screened below the Corcoran Clay in the Western Lower Principal Aquifer and shown as brown dots. The extent of the Corcoran Clay, as defined by the USGS (Burow, et al. 2004) and confirmed by the cross sections (and described in **Section 4.1.4.2**), is shown on this figure. Well depths in relation to the Corcoran Clay were verified with the cross sections and the base elevation of the Corcoran Clay in the model. **Figures 4-33** through **4-35** present hydrographs for the wells in each of the three groups.

Group 1 (**Figure 4-33**) includes two wells in approximately the center of the Subbasin, west of the edge of the Corcoran Clay. The shallow well (4S/10E-32N002M) is screened above the Corcoran Clay in the Western Upper Principal Aquifer from 0 to 22 feet bgs and the deep well, a supply well for the City of Turlock (Well 38), is screened below the Corcoran Clay in the Western Lower Principal Aquifer from 285 to 595 feet bgs. Hydrographs for these wells are shown on **Figure 4-33**. Groundwater levels in the deeper well show a declining trend with cyclic seasonal pumping variations since 2004. Water levels in the shallow well show a relatively smooth declining trend during this same period. For the period of overlap, 2004 to 2018, groundwater elevations in the shallow well are 20 of more feet higher than in the deeper well. Therefore, this well pairing shows that groundwater flow is downward, from the Western Upper Principal Aquifer to the Western Lower Principal Aquifer.

Group 2 includes three wells in the northern Subbasin, near the Tuolumne River and the edge of the Corcoran Clay. This group includes two shallow wells screened above the Corcoran Clay in the Western Upper Principal Aquifer between 68 and 85 feet bgs and one deep pumping well screened below the Corcoran Clay (Ceres Well 39). Ceres Well 39 is screened from 219 to 229 feet bgs, and based on the cross sections and the model, is immediately below the Corcoran Clay in the Western Lower Principal Aquifer. The hydrographs on **Figure 4-34** show that the groundwater elevations in the shallow wells are higher than in the deeper well for the period of overlap. The water levels in the deep well has seasonal cyclic pumping fluctuations on the order of 20 to 30 feet from 2014 to 2018. These cycles are evident in the shallower wells, but the fluctuations are much less, on the order of 5 to 10 feet. The difference in groundwater elevation between the two shallow wells likely reflects the groundwater flow direction and gradient. This group of hydrographs shows that there is downward groundwater flow from the Western Upper Principal Aquifer to the Western Lower Principal Aquifer in this area of the Subbasin.

Group 3 includes four wells in the western Subbasin, west of Turlock. Three of the wells in this group are shallow and screened above the Corcoran Clay in the Western Upper Principal Aquifer at depths that extend to 100 feet bgs. One well is deep and screened below the Corcoran Clay from 355 to 380 feet bgs in the Western Lower Principal Aquifer. The hydrographs, presented on **Figure 4-35**, show that groundwater elevations are higher in the shallow wells except in 2008 and 2011 when water levels in one of the shallow wells temporarily drops below the elevation in the deeper well. Otherwise, groundwater elevations in the shallow wells are consistently higher. In 2015, the differences between groundwater elevations in the shallow and deep wells are almost 20 feet, the largest gap since 1990. This was likely a result of increased pumping below the Corcoran Clay during the recent severe drought. For the most part, groundwater elevations in this group of wells shows that vertical flow is downward from the Western Upper Principal Aquifer to the Western Lower Principal Aquifer.

4.3.4. Changes of Groundwater in Storage

As indicated by the groundwater elevation contour maps, data are not sufficient to quantify changes in groundwater in storage over time for the Subbasin. In addition, estimates of subsurface flows and surface water-groundwater interaction that could impact the overall results of the water budget are not able to be considered with the water level contour maps alone.

As mentioned previously, the integrated surface water-groundwater model, C2VSimTM, was revised with local water management data and was used to develop detailed water budgets in support of the GSP. These analyses are presented in **Chapter 5** and represent the best available data for determining change in groundwater in storage over time. As summarized on **Table 5-6**, the annual average change in storage during the historical study period (WY 1991 to WY 2015) is about -63,900 AF. As shown on **Figure 5-16**, the cumulative change in storage during this time period is about -1,600,000 AF.

4.3.5. Groundwater Quality

4.3.5.1. Sources of Groundwater Quality Data

Water quality data were evaluated for vertical and spatial distribution and used to characterize the general water quality and aquifer-specific trends within the Turlock

Subbasin. Water quality data were evaluated against current State of California Division of Drinking Water (DDW) drinking water standards to delineate the spatial distribution and to identify areas of poor-quality groundwater.

All wells with water quality data used in this study (1,081 wells total) are illustrated in **Figure 4-37**. Water quality data used in this assessment were from the Central Valley Salinity Alternative for Long-Term Sustainability (CV-SALTS) dataset as described below and the State Water Resources Control Board (SWRCB) Division of Drinking Water (DDW) drinking water quality database. The CV-SALTS dataset includes concentrations of nitrate and total dissolved solids (TDS) at wells between 1934 and 2014. The DDW dataset used in this assessment includes historical water quality data from public supply wells between 1976 and January 2, 2019. In wells duplicated in the CV-SALTS and DDW datasets, data from the DDW database were used because it is more current and contains additional water quality constituents.

Additional data sources include the Groundwater Ambient Monitoring and Assessment Program (GAMA) wells and private (non-agency) agricultural wells located in the eastern portion of the Subbasin; however, data are limited in this area.

Salinity and nitrate have been ongoing problems in the Central Valley, making management and long-term sustainability of water resources difficult and complex for the Central Valley Regional Water Quality Control Board (CVWQCB or Regional Board), local water jurisdictions and other water purveyors. In 2006, a broad coalition of agricultural, industrial, and municipal entities and regulatory agencies formed the CV-SALTS, with goals of protecting and enhancing the environment and maintaining high-quality water supply while preserving the Central Valley's lifestyle and agricultural economy. Dischargers participating in CV-SALTS formed the Central Valley Salinity Coalition (CVSC) in 2008 to support the development of alternative regulatory approaches to address salinity and nitrate problems in the Central Valley. CV-SALTS was tasked with preparing a Salt and Nitrate Management Plan (SNMP) to achieve these goals for the management of salt and nitrate in the Central Valley, and to meet the requirements of the SWRCB Recycled Water Policy (2009).

To prepare the SNMP, an extensive dataset was compiled to help characterize water quality of groundwater and surface water in the Central Valley and to identify areas where salt and nitrate-loading mitigation strategies would need to be designed and implemented. The CV-SALTS water quality dataset originated from five sources:

- USGS National Water Information System (NWIS) – Types of Wells not Reported
- GeoTracker's Groundwater Ambient Monitoring and Assessment (GAMA) program – Public Supply Wells and Monitoring Wells
- DWR – Domestic; Industrial; Public Supply; Agricultural; and Monitoring Wells
- CDPH – Public Supply Wells
- Dairy CARES program (Dairy) – Monitoring, Domestic and Agricultural Wells

The SNMP was accepted by the Regional Board in March 2017, and in May 2018, the Regional Board approved amendments to the Central Valley's Basin Plans based on the SNMP, which included a Salt and Nitrate Control Program. The Salt and Nitrate Control Program was approved by the State Board in January 2020 and is summarized in more detail in **Section 2.4.4**. The US EPA approved most of the surface water provisions of the Salt and Nitrate Control Program in November 2020.

Where available, well construction data were incorporated to help characterize water quality in the principal aquifer units in the Subbasin. The water quality data sources and number of wells with well construction information are shown in **Table 4-1** below.

Table 4-1: Summary of Wells with Water Quality Data

Data Source	Number of Wells with Water Quality Data	Number of Wells with Construction Information
CV-SALTS	704	106
DDW	364	52
GAMA	11	10
Private (Non-Agency)	2	2
Total Wells	***1,081***	***170***

4.3.5.2. Principal Aquifer Designations for Water Quality Wells

For the purposes of characterizing water quality of the principal aquifers designated in the Turlock Subbasin, wells were classified by their location within each principal aquifer. Using ArcGIS, all water quality data were combined into a geodatabase and related to wells with known construction information (i.e., depth, screen interval). From this data set, wells were queried based on well construction and assigned to a principal aquifer.

Review of WCRs and basic well construction information available in the water quality dataset indicate that within the Turlock Subbasin, there are shallow wells completed in unconfined aquifers above the Corcoran Clay (mostly domestic and stock-watering wells), deep wells completed in confined aquifers below the Corcoran Clay, and numerous wells that are composite (i.e., completed above and below the Corcoran Clay). A composite well has the potential to act as a "conduit" allowing for the migration of groundwater between unconfined and confined aquifers.

The elevation of the base of the Corcoran Clay from C2VSIM (**Figure 4-12**) was used as the defining hydrogeologic barrier that separates the Western Upper and Western Lower Principal Aquifers. Wells that are completed entirely in the unconfined aquifer above the approximate base of the Corcoran Clay were assigned as Western Upper Principal Aquifer wells. Wells where screen and total well depths are completed in the confined aquifer below the base of the Corcoran Clay were assigned as Western Lower Principal Aquifer wells.

Because the Eastern Principal Aquifer is treated as one hydrogeologic unit from ground surface to the approximate base of freshwater, all wells located outside (i.e., east) of the Corcoran Clay extent (Burow et al., 2004) were assigned as Eastern Principal Aquifer wells.

Composite wells (i.e., completed in multiple principal aquifers) and wells with unknown construction within the Corcoran Clay extent were not assigned a principal aquifer. Water quality data for wells completed in these three principal aquifers and wells with undesignated principal aquifers are shown in **Figures 4-37** through **4-56**.

4.3.5.3. Groundwater Quality in the Turlock Subbasin

Potential constituents of concern were identified from a preliminary review of the database in combination with recent investigations for public water suppliers and local professional knowledge of Subbasin water quality concerns. Potential constituents of concern identified in groundwater within the Turlock Subbasin include naturally-occurring arsenic, uranium, manganese, sulfur, and total dissolved solids (TDS). Anthropogenic-sourced contamination include nitrate (as N), salinity (TDS), 1,2,3-trichloropropane (1,2,3-TCP), tetrachlorethylene (PCE), and dibromochloropropane (DBCP), all from various agricultural or industrial-related land use.

Water quality data for the constituents of concern were queried from the CV-SALTS, DDW dataset, and specific hydrogeologic assessments conducted by the cities of Ceres and Turlock. The most recent available data were included in this assessment from the CV Salts and DDW datasets. Where site- and depth-specific data were obtained through hydrogeologic exploration efforts, these data were projected in the respected aquifers. Descriptions of each constituent, occurrence and distribution within the Subbasin are provided below. This water quality analysis used the current State of California DDW Drinking Water Standards as a metric for comparing the spatial and aquifer-specific water quality trends.

4.3.5.3.1. Nitrate (as N)

Concentrations of nitrate in the groundwater system are most commonly anthropogenic-sourced and are introduced through septic systems, fertilizers, or confined animal operations.

For California public drinking water systems, the primary (health-based) maximum contaminant level (MCL) for nitrate (as N) is 10 milligrams per liter (mg/L). At concentrations exceeding the MCL, nitrate can interfere with the blood's ability to carry oxygen. This effect can be especially pronounced in infants, where it is known as "blue baby syndrome."

Concentrations of nitrate in the DDW dataset were historically reported as NO3; however, recent changes in reporting standards require public health data for nitrate to be reported as nitrogen (N). Concentrations of nitrate (as NO3) in the dataset were converted to nitrate (as N) where applicable. **Figure 4-37** shows the most recent concentrations of nitrate (as N) available for wells located in the principal aquifers. High nitrate concentrations are found in the Western Upper Principal Aquifer near Ceres and west of the Highway 99 corridor, with several shallow wells near or exceeding the MCL of 10 mg/L. Additionally, nitrate (as N) concentrations are near or exceed the primary MCL of 10 mg/L in several Western Lower Principal Aquifer wells in the vicinity of Turlock. Insufficient annular seals and wells in this area that connect multiple aquifers can contribute to groundwater contamination of the deeper aquifers. In general, the deeper aquifers exhibit lower concentrations of nitrate than in the shallow wells. Recent depth-specific hydrogeologic investigations by the City of Turlock indicate elevated concentrations of nitrate are present in the Western Lower Principal Aquifer that have migrated vertically into the deeper zones within this aquifer.

Within the eastern portion of the Eastern Principal Aquifer, concentrations of nitrate are generally low concentrations (below 50-percent of the MCL). Nitrate concentrations appear to increase moving west toward the eastern extent of the Corcoran Clay and the Highway 99 corridor; nitrate concentrations are very high and exceed the MCL in the Denair and Hughson areas of the Eastern Principal Aquifer and near the Tuolumne River.

As shown in **Figure 4-38**, numerous wells within the extent of the Corcoran Clay (either within both principal aquifers or lacking construction data) have concentrations that are near or exceed the MCL of 10 mg/L.

The vertical and geographic distribution of data suggests that nitrate concentrations generally decrease with depth, and nitrate concentrations are elevated near the Highway 99 corridor and generally increase to the west, toward the San Joaquin River.

4.3.5.3.2. Total Dissolved Solids (TDS)

TDS is related to the concentration of dissolved salts (salinity) of water. Salts can enter groundwater naturally or from human activities. Evaporative enrichment from irrigation of crops and application of synthetic fertilizers, manures, and wastewater treatment facilities can all contribute salts to surface and groundwater.

For California public drinking water systems, the secondary (aesthetic) MCLs for TDS are 500 mg/L (recommended), 1,000 mg/L (upper), and 1,500 mg/L (short-term).

For irrigation, crop yields decrease above a threshold TDS value, which is crop-dependent.

Figure 4-39 shows the most recent concentrations of TDS available for wells located in the principal aquifers. TDS concentrations are typically below the secondary MCL of 500 mg/L in the Western Upper and Western Lower Principal Aquifer wells. However, TDS concentrations are higher in shallow wells near the San Joaquin River. Salt loading or evaporative enrichment from irrigation of crops may be contributing to these elevated TDS concentrations in the Western Upper Principal Aquifer. TDS data are limited in the Western Lower Principal Aquifer west of the Highway 99 corridor.

In the Eastern Principal Aquifer wells, there appear to be areas of slightly elevated TDS in the vicinity of Denair and Hughson; however, with one exception, concentrations are below the upper MCL of 1,000 mg/L. One well (WCR No. e0134312) located east of Turlock Lake in the eastern portion of the Subbasin produced brackish water; however, this agricultural well was drilled very deep (up to 1,680 feet) and penetrated sediments below the Ione Formation. Therefore, this well is below the Eastern Principal Aquifer and is not shown on **Figure 4-39**. The lower portion of this well was filled with cement to a depth of approximately 800 feet to seal off water produced from the marine sediments and to help improve overall water quality.

The geographic distribution of data suggest that salinity generally is higher along the Tuolumne River and the San Joaquin River.

As shown in **Figure 4-40,** numerous wells without construction data located within the extent of the Corcoran Clay have concentrations that are near or exceed the recommended secondary MCL of 500 mg/L, especially in the vicinity of Ceres and in wells located west of the Highway 99 corridor.

The City of Ceres constructed a 460-foot well with screen intervals below the Corcoran Clay in the norther region of its service area. The well encountered groundwater with elevated concentrations of specific conductance (EC), above 1,700 µmhos/cm (approximately 1,200 mg/L TDS), as shown on **Figure 4-39**. At this location, the deeper aquifer has a higher head than the shallower aquifers normally used by the City of Ceres for municipal water supply. Surveys within the well structure indicated upward movement of groundwater leading to high TDS groundwater migrating upwards into the shallower aquifer zones. Attempts by the City to mitigate the movement of groundwater included destroying the lower portion of the well structure using blast perforations and cement. The source of this shallow (460 foot) brackish groundwater and its distribution are not known. Nested monitoring wells in this area are needed to characterize this brackish unit to help prevent further water quality degradation.

4.3.5.3.3. Arsenic

Arsenic is naturally-occurring and leaches from aquifer materials into groundwater. For California public drinking water systems, the primary MCL for arsenic is 10 µg/L.

Exposure to arsenic can cause both short- and long-term health effects. Long-term exposure to arsenic has been linked to cancer of the bladder, lungs, skin, kidneys, liver, prostate, and nasal passages. Short-term exposure to high doses of arsenic can cause other adverse health effects.

Figure 4-41 shows the most recent concentrations of arsenic available for wells located in the principal aquifers. Several wells completed in the Western Upper and Western Lower Principal Aquifers near Turlock and Ceres have arsenic concentrations that exceed 50 percent of the MCL. Data near Ceres suggest that arsenic concentrations increase with depth in most of the wells constructed within the principal aquifers. One deeper well within the City of Turlock exceeds the MCL for arsenic.

An exploratory drilling program conducted by the City of Turlock in 2018 indicated highly variable levels of arsenic within the principal aquifers. Additional work is being conducted to refine the understanding and distribution of elevated concentrations of arsenic; however, at this time it does not appear a single aquifer zone is the main source.

Wells in the Eastern Principal Aquifer also contain elevated concentrations of arsenic near Hughson and Denair, with some wells exceeding the MCL. Wells located in the eastern and southern portion of the Eastern Principal Aquifer are below 50-percent of the MCL.

Figure 4-42 shows wells within the extent of the Corcoran Clay that are completed in the Western Upper and Western Lower Principal Aquifers or lack construction details. As shown, many wells are characterized by concentrations that are near or exceed the MCL.

The geographic distribution of the available data indicate that arsenic is elevated within the extent of the Corcoran Clay in wells where there is no construction information. There does not appear to be any specific trends in the distribution of arsenic; however, concentrations are lower in the Eastern Principal Aquifer wells when compared to the aquifers within the extent of the Corcoran Clay. Elevated concentrations of arsenic in groundwater can occur through dissolution of iron or manganese oxyhydroxides under reducing conditions. Recognizing that reducing conditions can be associated with depth, arsenic concentrations are observed in other portions of the Central Valley to increase with declining water levels. Additional data are needed to better understand the occurrence of arsenic concentrations in the Turlock Subbasin.

4.3.5.3.4. Manganese

Manganese is naturally-occurring and leaches from aquifer materials into groundwater. Manganese can cause staining of plumbing and fixtures and can contribute a metallic odor to water. At very high concentrations (above the notification level) manganese can cause neurologic problems.

For California public drinking water systems, the secondary (aesthetic) MCL for manganese is 50 µg/L. There is also a notification level for manganese of 500 µg/L. Notification levels are health-based advisory levels for chemicals that do not have MCLs. It is important to note that analysis for manganese is very sensitive to turbidity of collected water samples. Turbid samples will often have artificially high results for manganese.

Figure 4-43 shows the most recent concentrations of manganese available for wells located in the principal aquifers. Wells completed in the Western Upper and Western Lower Principal Aquifers near Turlock and Ceres have manganese concentrations that are below 50 percent of the secondary MCL. Wells located in the Eastern Principal Aquifer typically have manganese concentrations below 50 percent of the secondary MCL; however, elevated concentrations near or exceeding the secondary MCL were detected in some wells near Hughson and the Tuolumne River. Historical water quality data from the 460-foot well within the City of Ceres exceeded the MCL for manganese, prior to efforts to modify the well structure. This well was not put into service. This same well encountered elevated TDS, as discussed above.

Figure 4-44 shows numerous wells within the Corcoran Clay extent that are within the Western Upper and Western Lower Principal Aquifers or that do not have any construction details. The wells with concentrations near or above the MCL are generally west of the Highway 99 corridor.

The geographic distribution of data suggests that manganese concentrations are generally higher in the western Subbasin.

4.3.5.3.5. Uranium

Uranium is a naturally-occurring metal that leaches into groundwater from certain types of soils and rocks, such as granite and some sedimentary rocks. For California public drinking water systems, the primary MCL for uranium is 20 picoCuries/liter (pCi/L).

Adverse health effects from natural uranium can be from its radioactive properties or its chemical properties. Radioactive effects are very small from natural uranium; chemically, uranium can be harmful to the kidneys from large exposures.

Figure 4-45 shows the most recent concentrations of uranium available for wells located in the principal aquifers. Uranium in wells completed in the Western Upper Principal Aquifer near the City of Ceres indicate that concentrations of uranium in the shallow aquifers are near or above the MCL.

Wells in the Western Lower Principal Aquifer, near Turlock, have uranium concentrations that are below 50-percent of the MCL, however, an exploratory drilling program conducted by the City of Turlock in 2018 identified uranium above the MCL in the aquifer zone immediately below the Corcoran Clay. Wells located in the Eastern Principal Aquifer underlying Hughson and Denair had concentrations more than 50 percent of the MCL; whereas wells near the Tuolumne River had concentrations which exceed the MCL. Hydrogeologic investigations by the cities of Turlock and Ceres indicated that high concentrations of uranium are encountered in aquifers adjacent to the Corcoran Clay, with the highest concentrations identified at the base of the Corcoran Clay. The City of Turlock investigation is ongoing, with a report expected to be released in 2019. The distribution and occurrence of elevated uranium in the zones below the Corcoran Clay is currently unknown.

Figure 4-46 indicates wells completed in multiple principal aquifers and wells without available construction. Wells with concentrations of uranium that are near to, or exceed the MCL, are in the vicinity of Ceres and Turlock, and in some areas west of the Highway 99 corridor.

The geographic distribution of data suggest that uranium concentrations are sporadic, with a random population of elevated concentrations. However, elevated uranium concentrations are present throughout the western Subbasin within the extent of the Corcoran Clay, with higher density of MCL exceedances in Ceres, Hughson and Turlock.

4.3.5.3.6. Sulfate

Sulfates are a combination of sulfur and oxygen and are a part of naturally-occurring minerals in some soil and rock formations that can leach into groundwater. For California public drinking water systems, the secondary (aesthetic) MCLs for sulfate are 250 milligrams per liter (mg/L) (recommended), 500 mg/L (upper), and 600 mg/L (short-term).

Sulfate minerals can cause scale buildup in water pipes. Sulfate in water can cause a “bitter taste” and can have a laxative effect on infants and young livestock. Sulfur-reducing bacteria (which use sulfur as an energy source) can produce hydrogen sulfide gas, making an unpleasant “rotten egg” odor.

Figure 4-47 shows the most recent concentrations of sulfate available for wells located in the principal aquifers. Wells completed in the principal aquifers have sulfate concentrations that are generally below 50 mg/L.

Figure 4-48 shows wells completed in multiple principal aquifers or lacking construction data; as shown these have sulfate concentrations that are typically below 50 mg/L. There are two locations with reported sulfate concentrations between 100 and 120 mg/L, which are below the MCLs.

Sulfate does not appear to be a constituent of concern in the Subbasin based on available data.

4.3.5.3.7. Boron

Boron can occur in groundwater from leaching of rocks and soils, or can be introduced by anthropogenic sources, such as wastewater and fertilizers/pesticides. For California public drinking water systems, there is a notification level for boron of 1,000 µg/L. Notification levels are health-based advisory levels for chemicals that do not have MCLs.

For irrigation, boron is necessary for crop growth, but can become toxic to the point that crop yields may begin to decrease above certain threshold levels. These thresholds are crop-specific.

Figure 4-49 shows the most recent concentrations of boron available for wells located in the principal aquifers. With one exception, wells in the principal aquifers have boron concentrations that are below 250 µg/L.

Figure 4-50 shows wells that are completed in multiple principal aquifers or that do not have any construction data available; as shown, these have boron concentrations that are typically below 250 µg/L, except for seven locations with reported boron concentrations above 250 µg/L.

Boron does not appear to be a constituent of concern in the Subbasin based upon the available data.

4.3.5.3.8. 1,2,3-Trichloropropane (TCP)

1,2,3-Trichloropropane (TCP) is a manufactured chemical (chlorinated hydrocarbon) used as a cleaning and degreasing solvent and is typically found at industrial or hazardous waste sites. TCP has also been formulated into a soil fumigant, which was widely used in agriculture through most of the 1980s. Its widespread use in agricultural products is likely the cause of its wide distribution within the Subbasin groundwater. Occurrence of TCP in groundwater is caused by leaching from the soil. TCP occurs as a dense non-aqueous phase liquid (DNAPL)that it is denser than water, allowing its downward migration in the groundwater column until impeded by a low-permeability layer.

For California public drinking water systems, the MCL for TCP is 0.005 µg/L (5 parts per trillion, ppt). TCP is a known carcinogenic to animals and humans. Short-term exposure can cause irritation of eyes, skin, and the respiratory system. Long-term exposure may cause liver and kidney damage, reduced body weight, and tumors.

Figure 4-51 shows the most recent concentrations of TCP available for wells located in the principal aquifers. Wells completed in the Western Upper and Western Lower Principal Aquifers in Turlock and Ceres have reported concentrations of TCP that are more than 50-percent of or exceed the MCL, with concentrations above 0.5 µg/L within Ceres. Wells located in the Eastern Principal Aquifer have reported concentrations of TCP that are more than 50-percent of or exceed the MCL in the vicinity of Denair, Hughson, Delhi and southeast of Turlock Lake.

Figure 4-52 shows that wells completed in multiple principal aquifers or lacking construction data have reported TCP concentrations that range from below 0.0025 µg/L to greater than 0.0075 µg/L (above the MCL) in the western Subbasin.

The vertical and geographic distribution of the data indicate that elevated concentrations of TCP occur in all three principal aquifers in or near urban areas, with less occurrences in rural areas in the eastern portion of the Subbasin. Concentrations are highest in the Western Upper Principal Aquifer in Ceres and in the Eastern Principal Aquifer near Hughson. TCP has also impacted the Lower Principal Aquifer in the City of Turlock. The data indicate that TCP is a widespread contaminant in the Subbasin. The distribution appears to indicate numerous non-point sources and is not consistent with a distinct contaminant plume in the Subbasin.

4.3.5.3.9. Tetrachloroethylene (PCE)

Tetrachloroethylene (PCE) is a manufactured chemical associated with dry cleaning, textile operations, and metal degreasing activities, and used in printing inks, glues/sealants, lubricants and pesticides. Occurrence of PCE in groundwater is a result of releases into the environment. PCE occurs as a DNAPL that can settle to the bottom of an aquifer.

For California public drinking water systems, the MCL for PCE is 5 µg/L. Long-term exposures in drinking water above the MCL can cause adverse effects to the liver, kidneys, and central nervous system. Prolonged exposure to PCE, even at levels below the MCL, may be carcinogenic.

Figure 4-53 shows the most recent concentrations of PCE available for wells located in the principal aquifers. Concentrations in the principal aquifers are less than the laboratory detection limit of 0.5 µg/L, with the exception of two wells in Turlock and two wells near Hughson that were more than 50-percent of or exceeded the MCL.

Figure 4-54 shows that wells completed in multiple principal aquifers or lacking construction data generally have PCE concentrations that are below 0.5 µg/L, with the exception of a few wells along the Highway 99 corridor near Turlock, Keyes, and Ceres that have had recent concentrations near or exceeding the MCL.

The vertical and geographic distribution of the data indicate that elevated concentrations of PCE have occurred in all three principal aquifers in the Subbasin but appear to be isolated to potential point sources within urban areas primarily along the Highway 99 corridor.

Since the early 1990s, the City of Turlock has been working cooperatively with the CVRWQCB to evaluate the nature and extent of tetrachloroethene (PCE) in groundwater beneath Turlock and other local communities. Discharges from a number of dry cleaners in the City were determined to be the source of the PCE. Although PCE has not been detected in active wells, three City wells detected PCE in the past and were removed from service. As part of a 1994 cooperative agreement between the City of Turlock, the CVRWQC, and the DTSC, the City began working on potential remedial actions to protect the groundwater supply. Since that time, the City has completed the construction of a groundwater extraction system, funded in part by a grant from the SWRCB. The City also conducts monitoring and reporting associated with the PCE plume. As part of a 2020 work plan, the City is currently installing additional monitoring wells and planning for treatment of extracted contaminated groundwater to manage and contain the PCE plume.

4.3.5.3.10. Dibromochloropropane (DBCP)

Dibromochloropropane (DBCP) is a manufactured chemical that was used as a soil fumigant in agricultural practices until it was banned in California in 1979. DBCP readily dissolves in water and may occur as a DNAPL, where it may sink to the bottom of an aquifer and persist for long periods of time.

For California public drinking water systems, the MCL for DBCP is 0.2 µg/L. Human exposure to DBCP may cause sterility in males, or other reproductive effects. DBCP may also be carcinogenic with long-term exposure at levels above the MCL.

Figure 4-55 shows the most recent concentrations of DBCP available for wells located in the principal aquifers. Wells completed in the Western Upper and Western Lower Principal Aquifers typically have DBCP concentrations below the laboratory detection limit of 0.01 µg/L. In the southern and eastern portion of the Eastern Principal Aquifer, concentrations of DBCP are below 0.01 µg/L; however, elevated concentrations of DBCP (more than 50-percent of or exceeding the MCL) are prevalent in the vicinity of Denair and Hughson.

Figure 4-56 shows that wells completed in multiple principal aquifers or having no available construction data generally have DBCP concentrations that are generally below 0.075 µg/L; however, several wells near and west of Ceres have had recent concentrations of DBCP that are greater than 50-percent of or exceed the MCL.

The vertical and geographic distribution of the data indicate that DBCP does not appear to be a widespread problem throughout the Subbasin; however, localized areas of DBCP MCL exceedances occur in urban areas near Hughson and west of Ceres.

4.3.5.4. Other Contamination Sites Assessed from GeoTracker

The State Water Resources Control Board (SWRCB) GeoTracker online database was accessed to identify active and former anthropogenic contamination sites and other

Potentially Contaminating Activities (PCAs) within the Subbasin. Currently 262 documented contamination sites are known in the Turlock Subbasin. Of these, 209 are closed and 53 are open, meaning active remediation or monitoring is still occurring. The open cases include Leaking Underground Storage (LUST) sites, Cleanup Program sites, and Military sites. Included in the open cases, there are seven sites designated as land disposal sites, which have the potential to impact an aquifer used for drinking water supply. These sites are considered PCAs due to the possibility of contaminants leaching into the subsurface.

The number of contamination sites of each type are presented in **Table 4-2** below. Most of the open and closed sites are in urban areas along the Highway 99 corridor and near the cities of Ceres and Turlock, as shown in **Figure 4-57**.

Table 4-2: GeoTracker Contamination Sites within the Turlock Subbasin

Contamination Site or PCA Site	Case Status		Total Sites
	Open	Closed	
LUST Site	13	176	189
Cleanup Program Site	30	29	59
Military Site	3	4	7
Land Disposal Site	7	N/A	7
Total Sites	***53***	***209***	**262**

4.3.6. Land Subsidence

No impacts from land subsidence have been documented in the Turlock Subbasin. The overdraft conditions exacerbated by the recent drought have resulted in lowered groundwater levels – a condition that can contribute to subsidence of the ground surface. As water levels decline in the subsurface, dewatering and compaction of predominantly fine-grained deposits (such as clay and silt) can cause the overlying ground surface to subside.

This process is illustrated by two conceptual diagrams shown on **Figure 4-58**. The upper diagram depicts an alluvial groundwater basin with a regional clay layer and numerous smaller discontinuous clay layers. Water level declines associated with pumping cause a decrease in water pressure in the pore space (pore pressure) of the aquifer system (Galloway, et al., 1999). Because the water pressure in the pores helps support the weight of the overlying aquifer, the pore pressure decrease causes more weight of the overlying aquifer to be transferred to the grains within the structure of the sediment layer. The difference between the water pressure in the pores and the weight of the overlying aquifer is termed the effective stress. If the effective stress borne by the sediment grains exceeds the structural strength of the sediment layer, then the aquifer system begins to deform. This deformation consists of re-arrangement and compaction of fine-grained units[17], as illustrated on the lower diagram of **Figure 4-58**. The tabular nature of the fine-grained sediments allows for preferred alignment and compaction. As the sediments compact, the ground surface can sink, as illustrated by the 2nd column on the lower diagram of **Figure 4-58**.

Land subsidence due to groundwater withdrawals can be temporary (elastic) or permanent (inelastic).

Elastic deformation occurs when sediments compress as pore pressures decrease but expand by an equal amount as pore pressures increase. A decrease in water levels from groundwater pumping causes a small elastic compaction in both coarse- and fine-grained sediments; however, this compaction recovers as the effective stress returns to its initial value. Because elastic deformation is relatively minor and fully recoverable, it is not considered an impact.

Inelastic deformation occurs when the magnitude of the greatest pressure that has acted on the clay layer since its deposition (pre-consolidation stress) is exceeded. This occurs when groundwater levels in the aquifer reach a historically low water level. During inelastic deformation, or compaction, the sediment grains rearrange into a tighter configuration as pore pressures are reduced. This causes the volume of the sediment layer to reduce, which causes the land surface to subside. Inelastic deformation is permanent because it does not recover as pore pressures increase. Clay particles are often planar in form and more subject to permanent realignment (and inelastic subsidence). In general, coarse-grained deposits (e.g., sand and gravels) have sufficient intergranular strength and do not undergo inelastic deformation within the range of pore pressure changes encountered from groundwater pumping.

The volume of compaction is equal to the volume of groundwater that is expelled from the pore space, resulting in a loss of storage capacity. This loss of storage capacity is permanent but may not be substantial because clay layers do not typically store significant amounts of usable groundwater (LSCE, et al., 2014). Inelastic compaction, however, may decrease the vertical permeability of the clay resulting in minor changes in vertical flow.

The following potential impacts can be associated with land subsidence due to groundwater withdrawals (modified from LSCE, et al., 2014):

- Damage to infrastructure including foundations, roads, bridges, or pipelines;
- Loss of conveyance in canals, streams, or channels;
- Diminished effectiveness of levees;
- Collapsed or damaged well casings; and

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[17] Although extraction of groundwater by pumping wells causes a more complex deformation of the aquifer system than discussed herein, the simplistic concept of vertical compaction is often used to illustrate the land subsidence process (Galloway, et al., 1999; LSCE et al., 2014).

- Land fissures.

Land subsidence in the San Joaquin Valley has been documented for more than 90 years and recent investigations using satellite imagery indicate continuing problems in some areas. However, subsidence is not a significant issue in Turlock Subbasin. **Figure 4-59** illustrates the results of a subsidence study conducted by the USGS (Faunt et al., 2015) from 2008 to 2010. This study shows that subsidence has occurred south of the Turlock Subbasin, but not within Turlock Subbasin.

The Bureau of Reclamation monitors subsidence over a network of more than 70 control points across the San Joaquin Valley, extending from Turlock to Fresno, as part of the San Joaquin River Restoration Program. There is one monitoring point in the Turlock Subbasin near the City of Turlock. As shown on **Figure 4-60,** measured subsidence in Turlock over a six year period, from July 2012 to July 2018, was 0.22 feet, which is equivalent to 0.04 feet per year (US Bureau of Reclamation, 2018). In the last year of this period, from July 2017 to July 2018, measured subsidence was 0.16 feet per year (US Bureau of Reclamation, 2018). This indicates that the rate of subsidence in Turlock has accelerated about four-fold between July 2017 and July 2018. This measured subsidence is minimal compared to subsidence rates that were measured south of the Turlock Subbasin (up to 0.6 feet per year from July 2017 to July 2018). However, there is the potential for subsidence in the Turlock Subbasin to continue or to accelerate if groundwater levels are lowered below the Corcoran Clay. These monitoring points remain active and are measured once or twice per year.

Beginning in June 2015, vertical displacement was estimated throughout many California groundwater basins using Interferometric Synthetic Aperture Radar (InSAR) data. The InSAR data are collected by the European Space Agency (ESA) Sentinel-1A satellite and processed by TRE ALTAMIRA Inc. (TRE), under contract with DWR as part of DWR's SGMA technical assistance. **Figure 4-61** illustrates vertical displacement (in feet) for the Turlock Subbasin from June 2015 to September 2019. Some of the Subbasin is shaded grey on this figure, meaning that ground surface elevations actually rose between 0 and 0.05 feet (0.6 inches). Negative vertical displacement (subsidence), shown by yellow, light brown, and pink/red colors, occurred throughout remaining portions of the Subbasin. Most of the Subbasin appears to have subsided between 0 and 0.05 feet (0.6 inches), as shown by the yellow shading. Subsidence ranging from 0.05 to 0.3 feet (0.6 to 3.6 inches) has been indicated in southern areas of the western Subbasin and in the central region of the eastern Subbasin. The amount of subsidence indicated on **Figure 4-61** is not likely to impact critical infrastructure.

A recent study conducted by Towill, Inc. and TRE Altamira, Inc., under contract with DWR, showed that InSAR vertical displacement data is highly accurate in most areas. The study compared vertical displacement ground surface elevation data from InSAR to continuously operating global positioning system (CGPS) base stations (Towill, 2021). The study found that the two data sets had a high degree of correlation and concludes that InSAR data accurately measured vertical displacement in California’s ground surface to within 18 mm (0.7 inches) between January 1, 2015, and October 1, 2020.

The InSAR data cover the full extent of the Subbasin and provide a reasonable dataset to use as a screening tool for ongoing evaluations of subsidence in the Turlock Subbasin. The InSAR data will be updated annually and discussed in the GSP annual reports. Given the linkage between significant land subsidence in other portions of the Central Valley and the Corcoran Clay, it is reasonable to conclude that there is a higher potential for subsidence in the western Turlock Subbasin where the clay is present. Water levels will need to be managed so as not to depressurize / dewater the Corcoran Clay.

4.3.7. Interconnected Surface Water

The analysis of interconnected surface water for the Turlock Subbasin considers conditions along the three river boundaries of the Subbasin – the Tuolumne River on the north, the Merced River on the south, and the San Joaquin River on the west. The Tuolumne and Merced rivers drain watersheds extending into the Sierra Nevada and are tributaries to the larger San Joaquin River.

GSP regulations define interconnected surface water as “surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted.” (§351(o)). Under these conditions, groundwater and surface water are in hydraulic communication, and interaction can be characterized in two primary ways. If the groundwater surface is higher than the stage[18] of the river, then the groundwater flows into the river channel as baseflow. This condition is referred to as a *gaining stream*. Alternatively, if the groundwater surface is lower than the stage of the river, the river will recharge the groundwater system, a condition referred to as a *losing stream*. Although this recharge is beneficial to the groundwater system, it reduces water in the river (i.e., streamflow depletion) and can impact beneficial uses of surface water. If groundwater levels decline significantly below the river channel, the two systems can become disconnected resulting in loss of baseflow and ongoing groundwater recharge controlled by the seepage characteristics of the streambed.

In the Turlock Subbasin, each of the three Subbasin river boundaries have been characterized as interconnected surface water (Phillips, et al., 2015; Durbin, 2003). Given the varying conditions of the river stage and groundwater levels – both seasonally and over time – groundwater-surface water interaction is dynamic and can alternate between losing and gaining conditions along various river reaches.

In 2016, the Nature Conservancy documented a multi-year evaluation of the interaction between groundwater and surface water resources along rivers throughout the Central Valley, including the river boundaries of the Turlock Subbasin (The Nature Conservancy, 2016). The evaluations employed the regional DWR C2VSim-FG model to simulate historical hydrology, land and water use, and groundwater flow conditions on a valley-wide basis. Model revisions were made in support of the study to improve streambed conductance values (among other improvements) and better match local streamflow studies. Simulations

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[18] Stage refers to the height of the water surface in the river.

indicated that all three river boundaries of the Turlock Subbasin were net gaining streams through the 1960s. By the 2000s, simulations indicated that the Merced River had become a net losing river due to declines in groundwater levels. At that time, the Stanislaus River, the Tuolumne River, and certain reaches of the San Joaquin River were the only rivers remaining in the San Joaquin Valley with consistent net gaining conditions (The Nature Conservancy, 2016).

As described in the water budget analyses (**Chapter 5**), the local revised C2VSimTM model applied to this GSP indicated that the Merced River was interconnected at least some of the time even during the drought conditions in WY 2014. In addition, Merced ID, who holds water rights on the river, provided operational information regarding response to pumping along the river in 2015 that indicated connectivity between the surface water and groundwater systems. Those observations, along with additional information from C2VSimTM, suggested interconnection between the groundwater and surface water at least downstream of Highway 59. The C2VSimTM model also indicates dynamic conditions that switch between losing and gaining annually and over time. While the Merced River may be mostly a losing river along upstream reaches, water levels appear to have been close enough to the invert of the channel to establish connection during the historical study period.

These conditions are similar to the results of a field investigation conducted by USGS in 2004-2005 on the lower reaches of the Merced River (Zamora, 2008). As part of that study, temperature loggers and pressure transducers were placed in monitoring wells along two transects installed about 100 meters apart and about 3 miles downstream of Highway 99. Wells were installed both on the banks and in the river; temperature and water levels were continuously monitored from March 2004 to October 2005 (recorded at 15-minute intervals). USGS analysis of the data indicated that the Merced River was a slightly gaining stream over the 100-meter reach with groundwater contributing to flow in the river on a net basis over the study period. However, groundwater levels were very close to surface water levels and flow reversals (groundwater recharge) were indicated during high streamflow events.

Surface water-groundwater interaction along the three river boundaries of the Turlock Subbasin was evaluated for the GSP using the integrated surface water-groundwater C2VSimTM model. Results of that evaluation are included in the water budget analyses for historical, current, and future projected conditions as presented in **Chapter 5.** Based on the model, and summarized in **Table 5-2**, total stream inflows[19] into the Subbasin during the historical period averaged approximately 2.3 MAF, split relatively evenly among the three river systems. Average inflows on the Merced River below Merced Falls were about 0.9 MAF; inflows from the Tuolumne River below La Grange and the San Joaquin River upstream of the confluence with the Merced River averaged about 0.7 MAF for each river (**Table 5-2**). San Joaquin River flows at the confluence with the Tuolumne River represent total surface

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[19] These inflows are measured downstream of surface water diversions by TID, Modesto ID, and Merced ID.

water flows leaving the Subbasin; those flows averaged approximately 2.1 MAF during the historical study period. These outflows represent net flows resulting from tributary inflows, native and riparian use, diversions on the San Joaquin River by the adjacent Delta-Mendota Subbasin, baseflow (from groundwater) and streamflow depletions (recharge to groundwater) in the Subbasin.

As shown on **Table 5-7**, during the historical period (WY 1991 – WY 2015), the Tuolumne River and the San Joaquin River were net gaining rivers (negative numbers) in the Turlock Subbasin, while the Merced River was a net losing river (positive number) in the Turlock Subbasin. The projected condition baseline predicts that the San Joaquin River will remain a net gaining river into the future (**Table 5-7**). The Tuolumne River is predicted to transition to an overall net losing river; the Merced River is predicted to remain a net losing river, with an increase in streamflow depletions predicted for both rivers if current land and water use remain the same without additional water supplies.

Streamflow depletions for the projected future water budgets are predicted to increase along each river from the historical water budgets: by 43,000 AFY on the Merced River (from 17,300 to 60,300 AFY), 41,600 AFY on the Tuolumne River (from -35,400 to 6,200 AFY), and 10,400 AFY on the San Joaquin River (from -38,500 to -28,100 AFY) (**Table 5-7**). As explained further in **Chapter 8**, GSP projects and management actions have been developed to reduce the potential for significant increases in future streamflow depletions.

The gaining and losing reaches along each river are dynamic in space and time. The C2VSimTM model was used to evaluate the location and timing of these conditions throughout the historical and projected future study periods. Specifically, each river was analyzed for net gains and losses at each model node along the river. Results of these analyses are summarized in two figures, **Figure 4-62** and **Figure 4-63**, for historical and future conditions, respectively.

For illustration purposes, circles representing model nodes along the rivers are color coded with respect to net gaining or losing conditions for various time intervals. Although conditions are highly dynamic at each node, the predominant condition (occurring in 85 percent of the model months represented) is highlighted. If conditions at the node are predominantly gaining, the node is blue; predominantly losing nodes are orange, and nodes that are not predominantly losing or gaining are “mixed” and green. The node color does not represent quantity and does not account for seasonal or annualized volumes of water.

Figure 4-62 presents the node analysis for two periods during the 25-year historical study period (WY 1991 through WY 2015). The node maps on the left and right sides of the figure summarize conditions from the first decade (WY 1991 through WY 2000) and the last decade (WY 2006-2015) of the study period, respectively.

The map on the left of **Figure 4-62** (WY 1991 – 2000) suggests mostly gaining conditions in the upper Tuolumne River reaches with more mixed conditions in the lower reaches. A comparison with the map on the right indicates that many of the upstream nodes on the Tuolumne River transition to more variable conditions by the end of the historical simulation (e.g., see area adjacent to and downstream of Turlock Lake). Conditions along the lower reaches of the Tuolumne (downstream of Hughson) appear to transition from predominantly mixed conditions in WY 1991 – 2000 period to more losing conditions in WY 2006-2015, especially between Hughson and Highway 99.

These observations indicate that streamflow depletions increase over time along certain reaches of the Tuolumne River during the historical study period. These conditions are directly correlated to areas of declining water levels, which are both observed and simulated in these areas.

Conditions along the Merced River indicate predominantly losing conditions upstream and predominantly gaining conditions downstream during the historical simulation WY 1991-2000. For the simulation period WY 2006-2015, areas downstream transition to more mixed conditions (**Figure 4-62**). In general, the losing conditions during WY 1991-2000 extend further downstream during WY 2006-2015.

Similar to conditions on the Tuolumne River, gaining/losing reaches on the Merced River are consistent with changes in water levels over time. Lowering of water levels in the eastern Subbasin near the Merced River correlate to the movement of predominantly losing conditions further downstream in the last decade of the historical study period.

On the San Joaquin River, conditions appear to be relatively consistent over time with most nodes indicating gaining or mixed conditions (**Figure 4-62**). These conditions are also consistent with the observed water levels, which are relatively shallow and stable along the river boundary during the historical study period.

Figure 4-63 presents a similar model river node analysis as on **Figure 4-62** but represents the first and last decades within a 50-year projection of future conditions (baseline).[20] Compared to the historical study period, the model simulations represented on **Figure 4-63** predict more mixed and losing conditions along both the Tuolumne and Merced rivers in the future. These conditions correlate to future water level declines simulated by the model, associated with groundwater extractions.

Model simulations indicate that future water level declines would correlate with increases in streamflow depletion. Such depletions would be potentially significant for beneficial uses of surface water on the Tuolumne and Merced rivers (see **Chapter 6**). Although some increased streamflow depletion was also predicted for the projected future conditions along the San Joaquin River, amounts were relatively small (see **Table 5-7**).

The gaining/losing conditions presented in **Figures 4-62** and **4-63** do not address the connectivity between the surface water and groundwater systems. Even predominantly losing conditions along a river do not necessarily indicate disconnection. The C2VSimTM model was used to compare the average simulated water level in WY 2014 to the invert

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[20] See **Chapter 5** for a more detailed description of the setup for the Projected conditions baseline.

channel elevation at each node. That analysis indicated that the groundwater and river systems were likely interconnected along each river in the Subbasin for at least some part of WY 2014. However, the Merced River may be subject to disconnection with future projected declines in water levels, a condition determined to be an undesirable result as described in more detail in **Chapter 6** (see **Section 6.8**).

As with any of the GSP modeling analyses, the interconnected surface water analysis described above has some uncertainty (see model documentation in **Appendix D**). These uncertainties will be reduced, in part, over time with additional monitoring and analysis as summarized in Annual Reports and with future model refinements (see planned implementation support activity described in **Chapter 9** and included in **Table 9-1**).

4.3.8. Groundwater Dependent Ecosystems

Groundwater levels near the land surface are commonly associated with phreatophytic vegetation – i.e., vegetation that obtains water from the underlying groundwater. Because California's Mediterranean climate is dry in summer, access to the water table supports vegetative health throughout the dry season, resulting in lush vegetation with high ecological value. The riparian and aquatic habitats associated with shallow groundwater and perennial base flow are referred to as groundwater dependent ecosystems (GDEs).

SGMA defines GDEs as "ecological communities and species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface" (23 CCR §351(m)). SGMA and GSP regulations require a GSP to identify GDEs within a Subbasin using data provided by DWR or the best available information (§354.16 (g)) and to consider environmental beneficial uses of groundwater (§10723.2(e)). To support identification of GDEs, DWR created the Natural Communities Commonly Associated with Groundwater (NCCAG) dataset (DWR, 2018). The NCCAG dataset is a compilation of 48 publicly available State and federal agency datasets that map vegetation, wetlands, springs, and seeps in California. The NCCAG dataset was reviewed and screened by a working group consisting of DWR, California Department of Fish and Wildlife (CDFW), and The Nature Conservancy (TNC) and provided online by DWR (https://gis.water.ca.gov/app/NCDatasetViewer/).

The NCCAG dataset includes two sets of polygons that represent different habitat classes. The first class is wetland features commonly associated with the surface expression of groundwater under natural, unmodified conditions. The second class is vegetation types that are commonly associated with the sub-surface presence of groundwater (phreatophytes) (DWR, 2018d). The presence of wetland or vegetation polygons in the NCCAG dataset, however, does not necessarily indicate the presence of a GDE. Rather, the NCCAG dataset provides a starting point for identifying potential GDEs within the Turlock Subbasin.

The vegetation and wetland polygons from the NCCAG dataset within the Turlock Subbasin are illustrated on **Figure 4-62**. Most of the vegetation and wetland polygons are present along the Tuolumne, Merced, and San Joaquin rivers. There are also polygons identified within the interior of the Subbasin, primarily along Dry Creek, between Dry Creek and the

Merced River, near Turlock Lake, and scattered along the eastern Subbasin boundary and within the western Subbasin. The NCCAG dataset includes approximately 2,500 polygons (1,873 vegetation and 618 wetlands) in the Turlock Subbasin.

Given this large number of polygons, it was not feasible to investigate the details of each polygon on an individual basis. Accordingly, a reasonable approach was developed to eliminate polygons that were unlikely to be GDEs based on groundwater levels, local hydrology, and land use. Through a series of three steps, vegetation and wetland polygons unlikely to be GDEs were identified and eliminated from consideration as potential GDEs.

The first step identified vegetation and wetland polygons in areas where depth to water exceeds rooting depths, in accordance with The Nature Conservancy's guidance (The Nature Conservancy, 2018). The second step used the GDE Pulse tool, developed by The Nature Conservancy and available online (https://gde.codefornature.org/#/home), to evaluate the relationship between vegetation health and precipitation. The third and final step involved a visual land use assessment using Google Earth and local knowledge of manmade structures to eliminate polygons that most likely depend on water sources other than groundwater. Details and results of this 3-step analysis are summarized below.

4.3.8.1. Depth to Water

The depth to water analysis was developed to compare the groundwater levels and fluctuations beneath the NCCAG polygons throughout the Subbasin. Specifically, groundwater elevations were used to estimate depth to water during the wettest year of the GSP Study Period (1998) and during a critically dry year at the end of the recent drought (2015). These two years generally represent periods of high (1998) and low (2015) water levels over average hydrologic conditions. Using ArcGIS, a groundwater elevation surface was developed from simulated groundwater elevations from the C2VSimTM model for each of the two years. This methodology represented the best available way to estimate groundwater elevations along the river boundaries, where most NCCAG polygons are present. That surface was then subtracted from a digital elevation map (DEM) of ground surface elevations to develop depth to water maps.

The NCCAG polygons were overlaid onto the two depth-to-water maps. NCCAG polygons in areas where depth to water exceeded 30 feet in both 1998 and 2015 were eliminated from consideration. This initial step was developed because maximum rooting depths are not likely to exceed 30 feet; this 30-feet criterion is also used in the initial steps for identification of GDEs by TNC (TNC, 2019). In addition, TNC recommends the consideration of groundwater fluctuations as a BMP for GDE analysis (TNC, 2019). By evaluating the depth to water in both 1998 and 2015, the fluctuation between the high and low groundwater level for historical average hydrologic conditions is considered. The use of the depth to water during the recent drought (2015) is also consistent with the GDE analysis conducted for the neighboring Merced Subbasin GSP. For the purposes of this analysis, it is assumed that the vegetation does not have access to groundwater when groundwater is deeper than 30 feet under both wet and dry groundwater conditions. Accordingly, the vegetation in these areas is not likely reliant on groundwater for water supply.

Approximately 700 NCCAG polygons were identified in areas where depth to water exceeded 30 feet in both 1998 and 2015. These polygons were eliminated from further consideration as potential GDEs.

Approximately 1,785 NCCAG polygons (1,386 vegetation and 399 wetlands) remain after this analysis in areas where depth to water is within 30 feet. The areas where depth to water was within 30 feet in 1998 are illustrated on **Figure 4-63**. Most of the NCCAG polygons within the interior of the Subbasin, especially in the central and eastern Subbasin, were eliminated during this step. The remaining polygons are located primarily along the river boundaries.

4.3.8.2. GDE Pulse Tool

The GDE Pulse Tool (https://gde.codefornature.org/#/methodology) was developed by TNC to assist water managers in monitoring changes in vegetation health over time. The online mapping tool allows visualization of qualitative changes in vegetative health over several time periods for the Turlock Subbasin polygons. In general, significant areas of large decreases in vegetative health were not indicated in the remaining polygons over a long-term period of 1985-2018. In general, groundwater levels have declined over this period.

The GDE Pulse Tool also contains charts of Normalized Derived Vegetation Index (NDVI), Normalized Derived Moisture Index (NDMI) and precipitation from 1985 to 2018 for each NCCAG vegetation polygon. NDVI and NDMI are ratios of wavelengths that estimate vegetative greenness and moisture as processed from satellite imagery in the Landsat program. These indices are used to indicate chlorophyll concentration and moisture status in the vegetation during the dry season and are commonly used to indicate vegetative health. During California's dry summer season, natural vegetation that can access groundwater grows more vigorously than vegetation that does not.

For the Turlock Subbasin, the GDE Pulse Tool was used to analyze each vegetation polygon that remained after the depth to water analysis, described above. A qualitative assessment was made by comparing NDVI and NDMI trendlines with precipitation trendlines for each polygon. If the NDVI and NDMI charts correlated less than about 50 percent of the time with precipitation, then it was assumed that the vegetative health did not rely on precipitation for its primary water source; rather another water source (potentially groundwater) was suggested, and the polygon was retained as a potential GDE.

If the NDVI and NDMI charts correlated with the precipitation trendlines more than about 50 percent of the time, then precipitation was suggested as the predominant water source, and the polygon was removed from the likely GDE category. For polygons where correlations were ambiguous, polygons were retained in the dataset as potential GDEs, consistent with a conservative approach.

Based on these comparisons, 521 vegetation polygons were eliminated from the Turlock Subbasin dataset as potential GDEs.

4.3.8.3. Visual Land Use Assessment

As a final step, a visual assessment of land use was conducted to identify polygons that are connected to human-related features, such as a recharge basin, a wastewater treatment plant, or local irrigated agricultural lands, and are more likely reliant on a primary water source other than groundwater. These vegetative/wetland areas were removed from the potential GDE dataset as unlikely to be reliant on groundwater. As examples, some NCCAG polygons were found to be dairy/stock ponds or wastewater ponds rather than natural wetlands. Many of these polygons had already been eliminated during the previous two steps, but some remained. This assessment resulted in removal of 31 additional polygons consisting of 16 vegetation and 15 wetland polygons.

4.3.8.4. Results

After this three-tiered elimination process, approximately 1,233 NCCAG polygons (849 vegetation and 384 wetlands) remain as potential GDEs in the Turlock Subbasin. These potential GDEs, illustrated on **Figure 4-64**, occur primarily along the river boundaries. Most occur along the San Joaquin River where groundwater elevations have been historically high and consistently contribute to baseflow in the river.

Model simulations have been used to evaluate surface water-groundwater interaction along the Tuolumne and Merced river boundaries of the Subbasin. Those results are presented in **Section 5**. As a conservative assumption, none of the polygons were removed from the dataset based on the possibility of disconnection.

Recognizing the uncertainty associated with this analysis, groundwater conditions along the river boundaries will continue to be evaluated with improved future monitoring and local groundwater management.

4.4. DATA GAPS AND UNCERTAINTIES

GSP regulations define “data gap” as “a lack of information that significantly affects the understanding of the basin setting or evaluation of the efficacy of Plan implementation and could limit the ability to assess whether a basin is being sustainably managed.” This definition recognizes the importance of identifying the data gaps that specifically relate to sustainable groundwater management and does not necessarily include all missing or incomplete data.

The following data gaps have been identified for the GSP requirements regarding the hydrogeologic conceptual model and groundwater conditions. Management Actions will be considered for filling these data gaps as part of GSP implementation, as needed.

Table 4-3: Data Gaps

Issue	Area	Groundwater Management	Actions to Address
Groundwater Elevations in the Western Lower Principal Aquifer	Western Subbasin beneath the Corcoran Clay	Mitigate future subsidence related to Corcoran Clay; understand groundwater occurrence and flow in the confined aquifer	Installation of additional deep monitoring wells; incorporation of existing municipal multi-depth wells into monitoring program.
Water Quality / Conditions in Deeper Aquifers	Subbasin	Improve delineation of base of fresh water and characterize water quality with depth.	As deep wells are drilled in the Subbasin, collect data and information regarding deeper aquifers and water quality; track water quality changes with depth.
Groundwater Conditions in Eastern-most Subbasin Areas	South and southeast of Turlock Lake	Document and monitor groundwater conditions in areas not previously monitored.	Coordinate with ETSGSA on recently monitored wells and new well locations planned for installation. Incorporate into GSP monitoring program.
Groundwater Conditions along River Boundaries	All river boundaries	Better understand and monitor groundwater-surface water interaction.	Install shallow wells along rivers; coordinate monitoring with adjacent subbasins.

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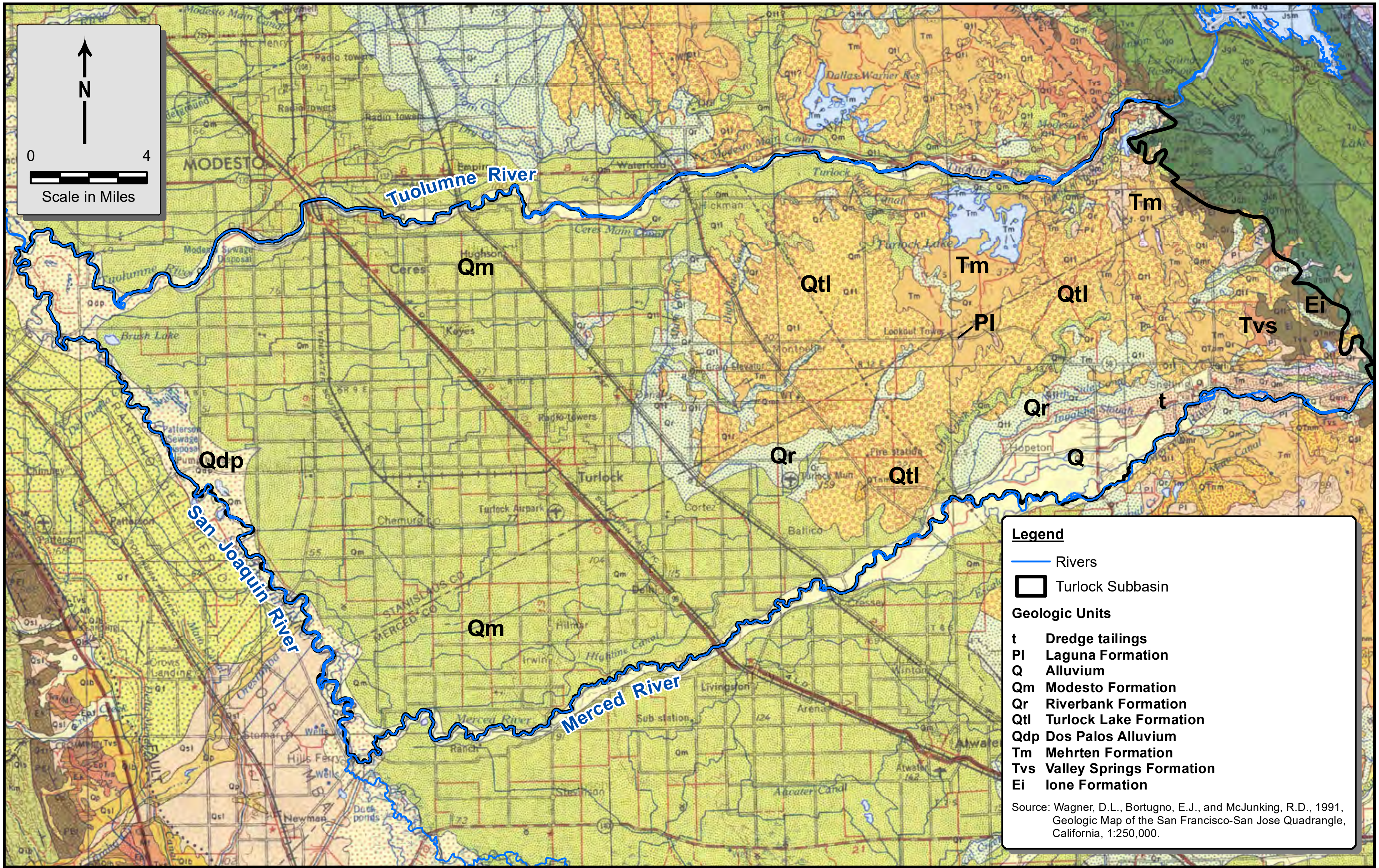

Source: Wagner, D.L., Bortugno, E.J., and McJunking, R.D., 1991, Geologic Map of the San Francisco-San Jose Quadrangle, California, 1:250,000.

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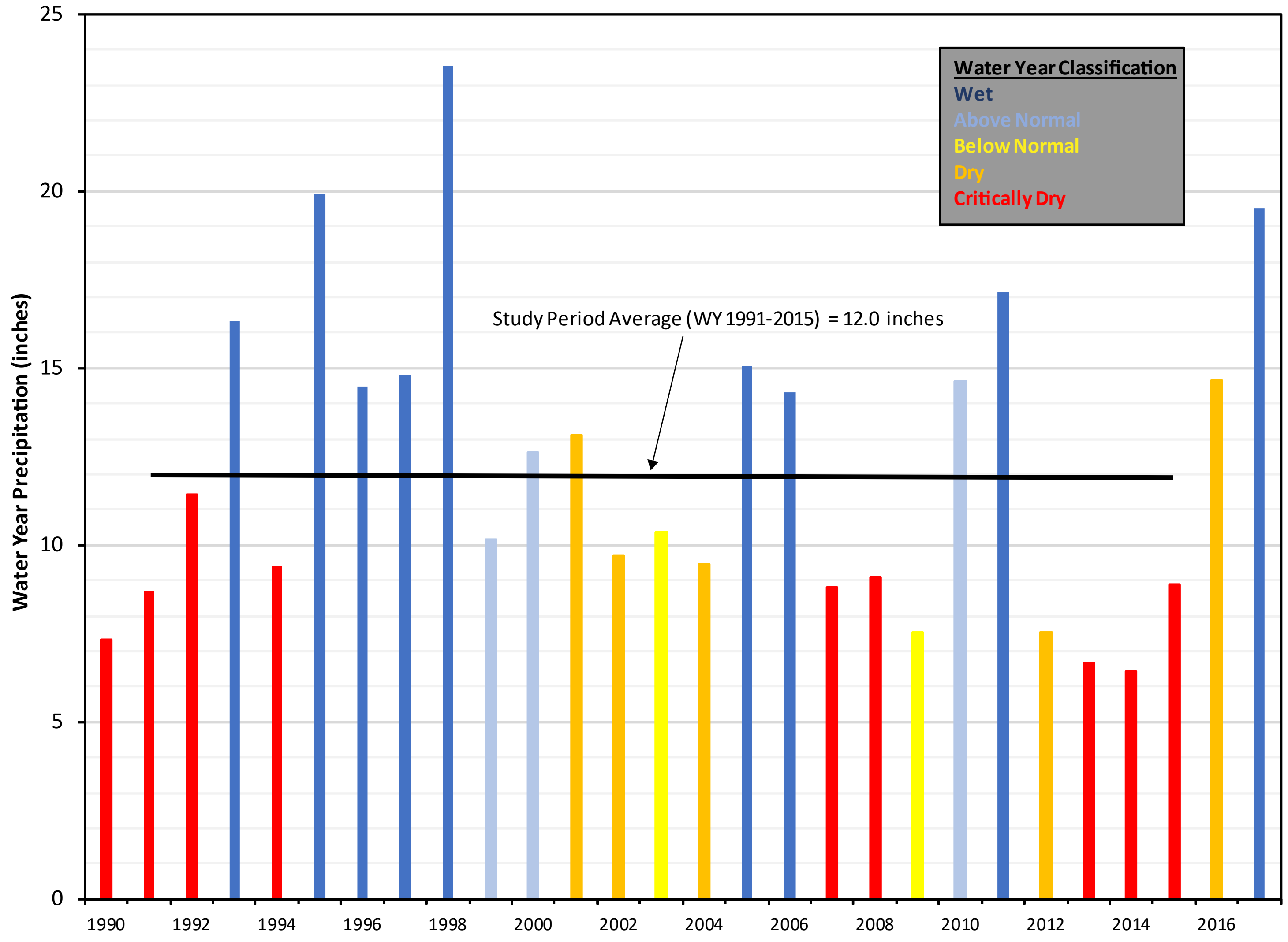
Figure 4-1
Regional
Geology



Water Year = October 1 through September 30

Sources: NOAA Turlock #2 Site 049073
CIMIS, Denair Station 168 and Denair II Station 206

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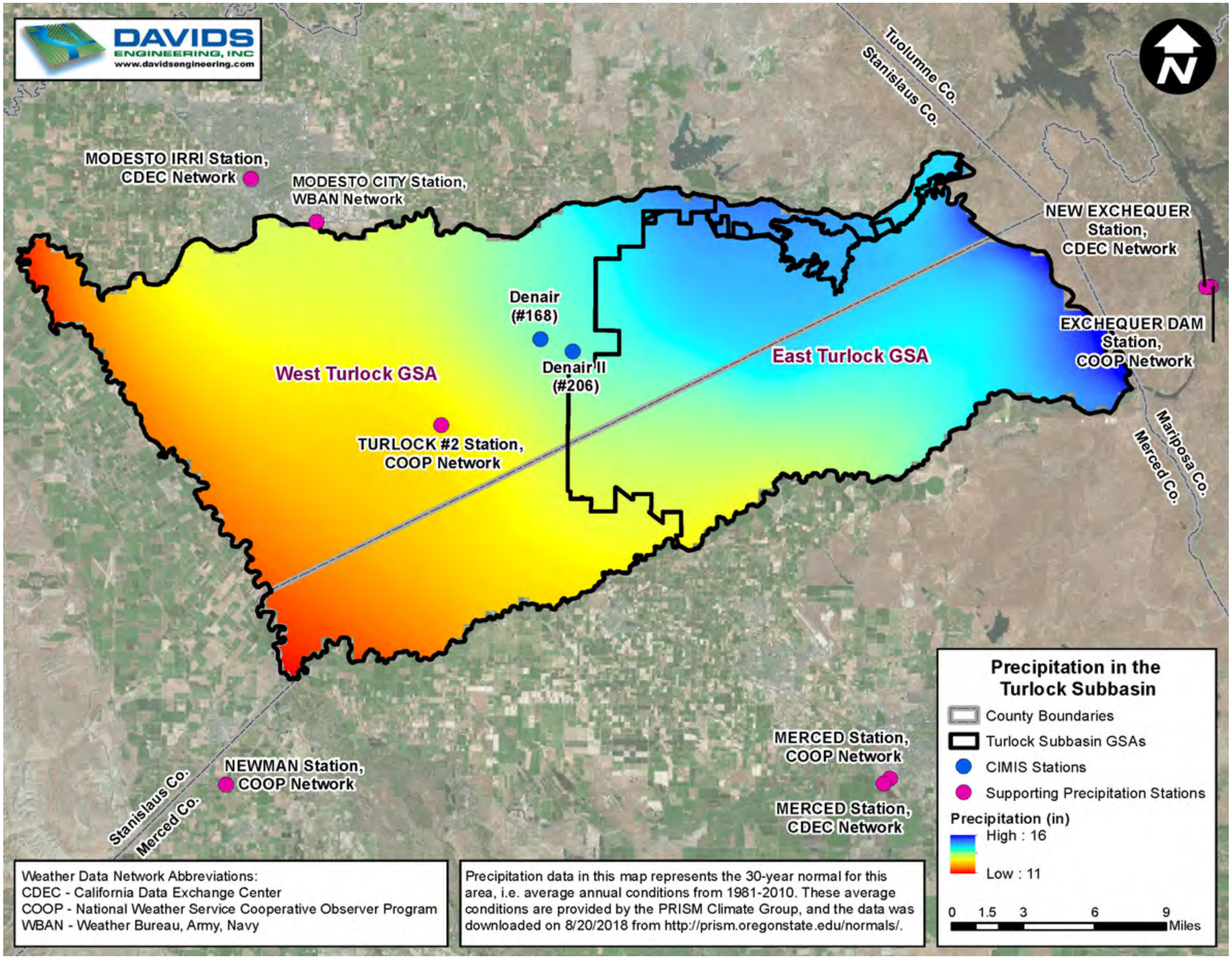
Figure 4-2
Annual Precipitation
Water Year



Weather Data Network Abbreviations:
CDEC - California Data Exchange Center
COOP - National Weather Service Cooperative Observer Program
WBAN - Weather Bureau, Army, Navy

Precipitation data in this map represents the 30-year normal for this area, i.e. average annual conditions from 1981-2010. These average conditions are provided by the PRISM Climate Group, and the data was downloaded on 8/20/2018 from http://prism.oregonstate.edu/normals/.

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Figure 4-3
Average Annual Precipitation in the Turlock Subbasin

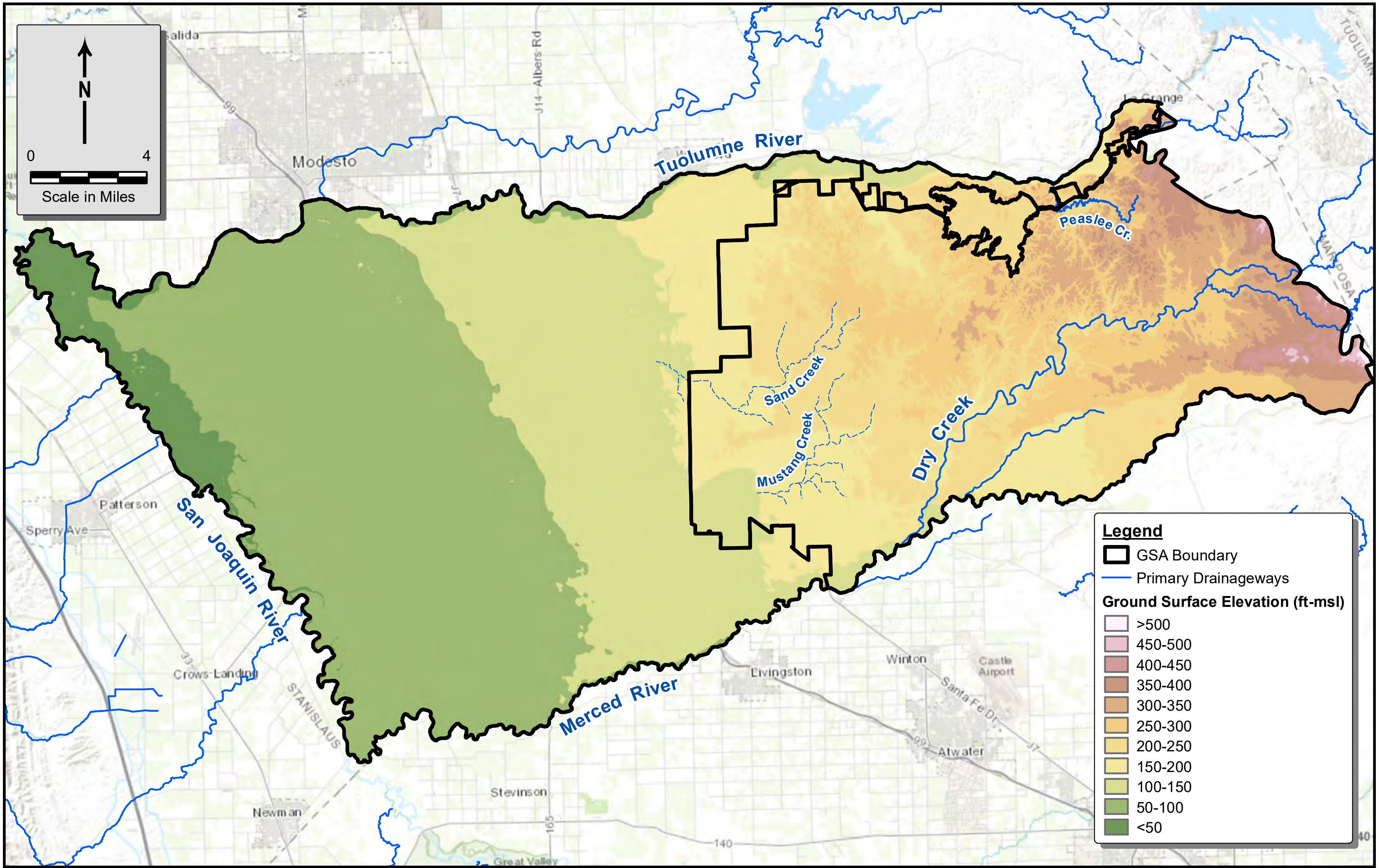

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Figure 4-4
Ground Surface
Elevations

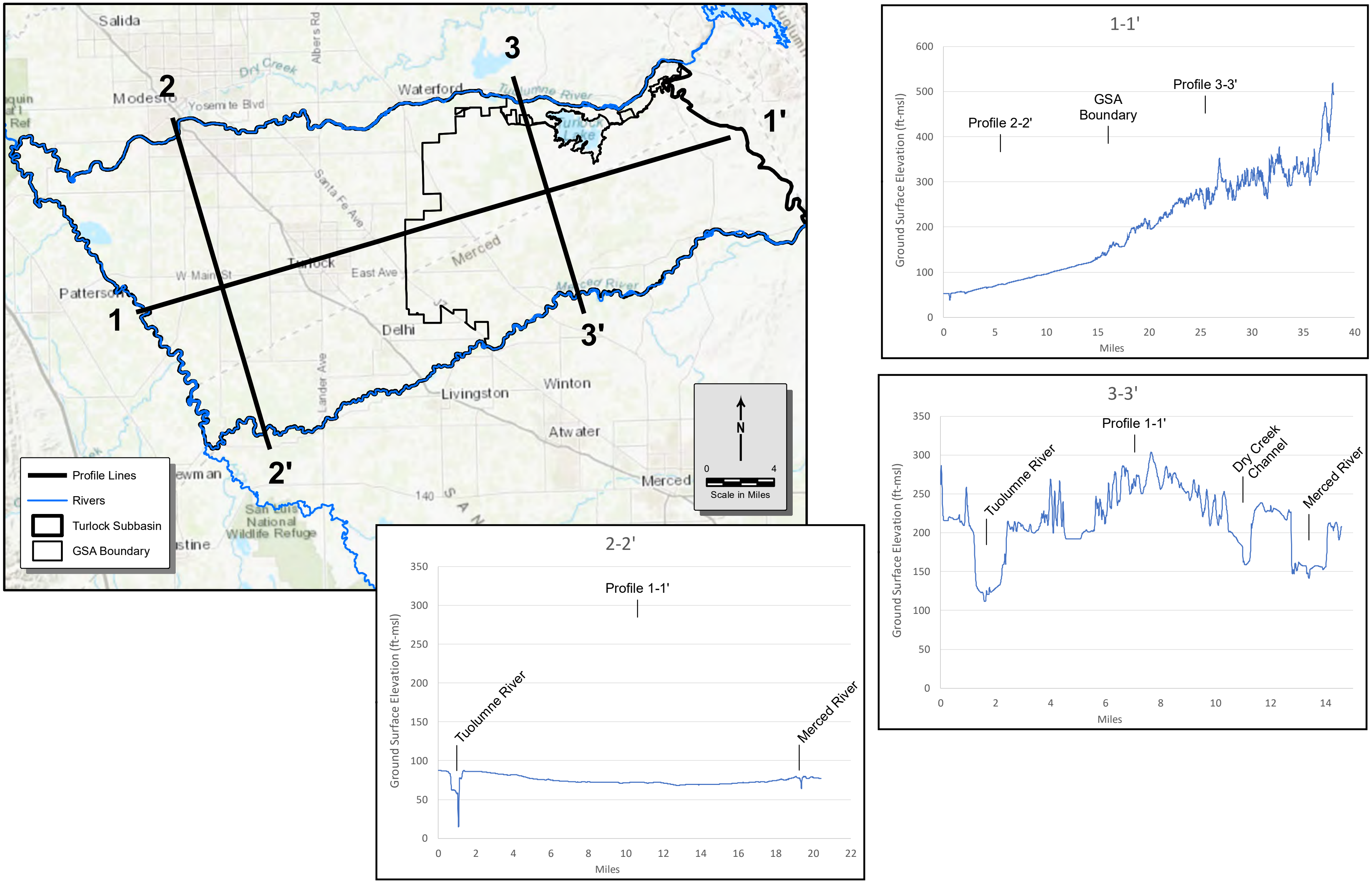

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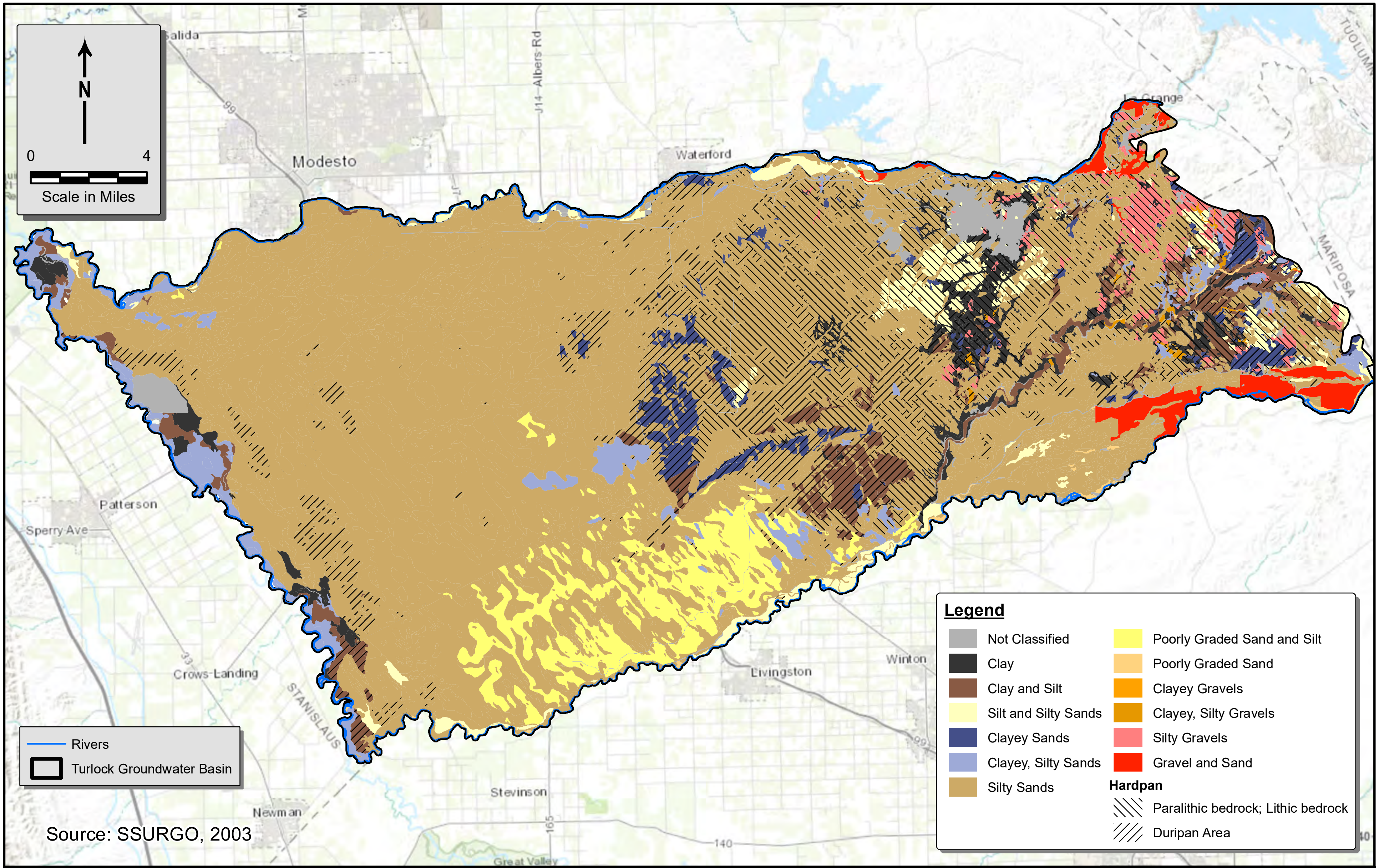
Figure 4-5
Topographic Profiles



Source: SSURGO, 2003

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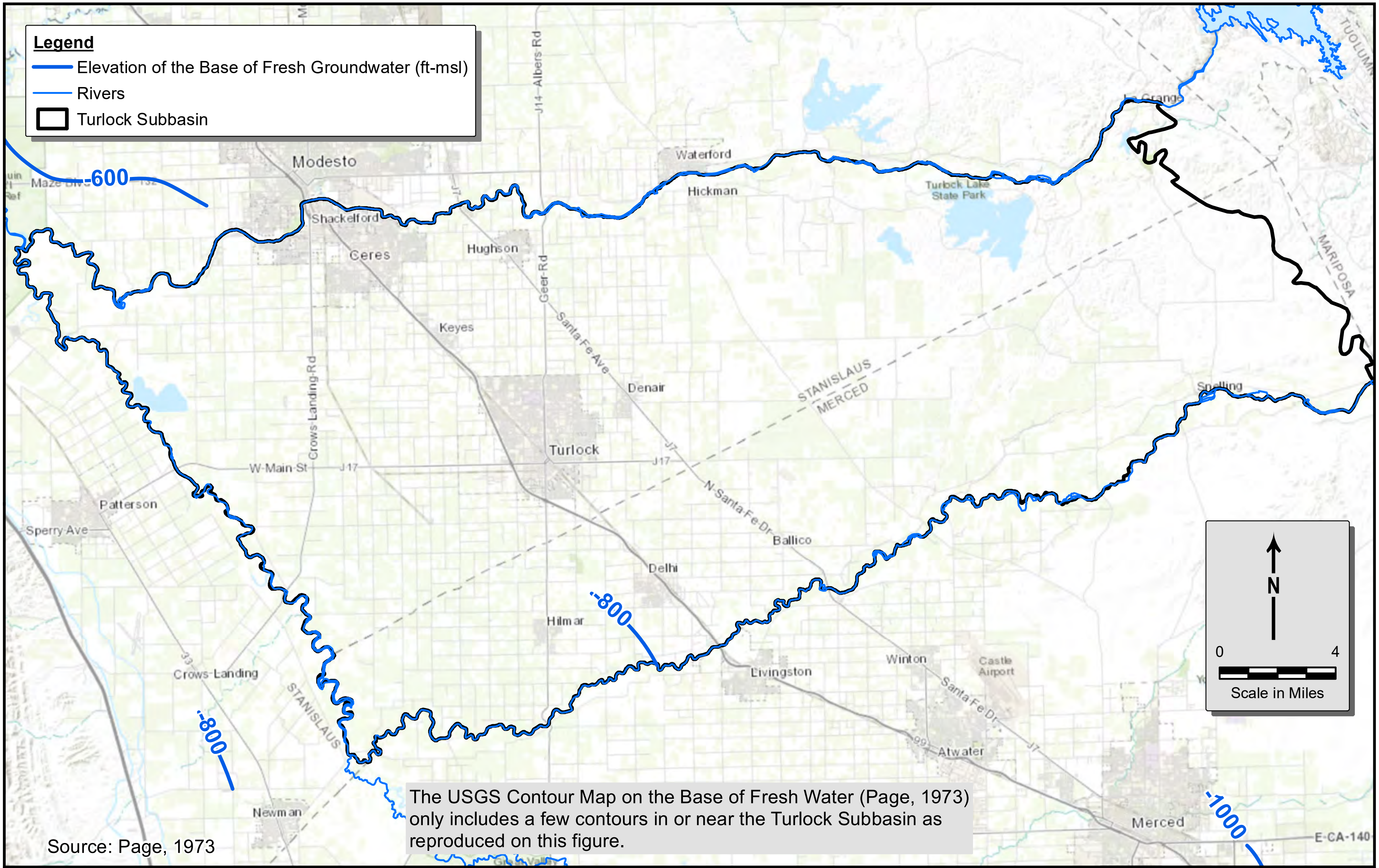
Figure 4-6
Soils and Surficial Restrictive Layers



The USGS Contour Map on the Base of Fresh Water (Page, 1973) only includes a few contours in or near the Turlock Subbasin as reproduced on this figure.

Source: Page, 1973

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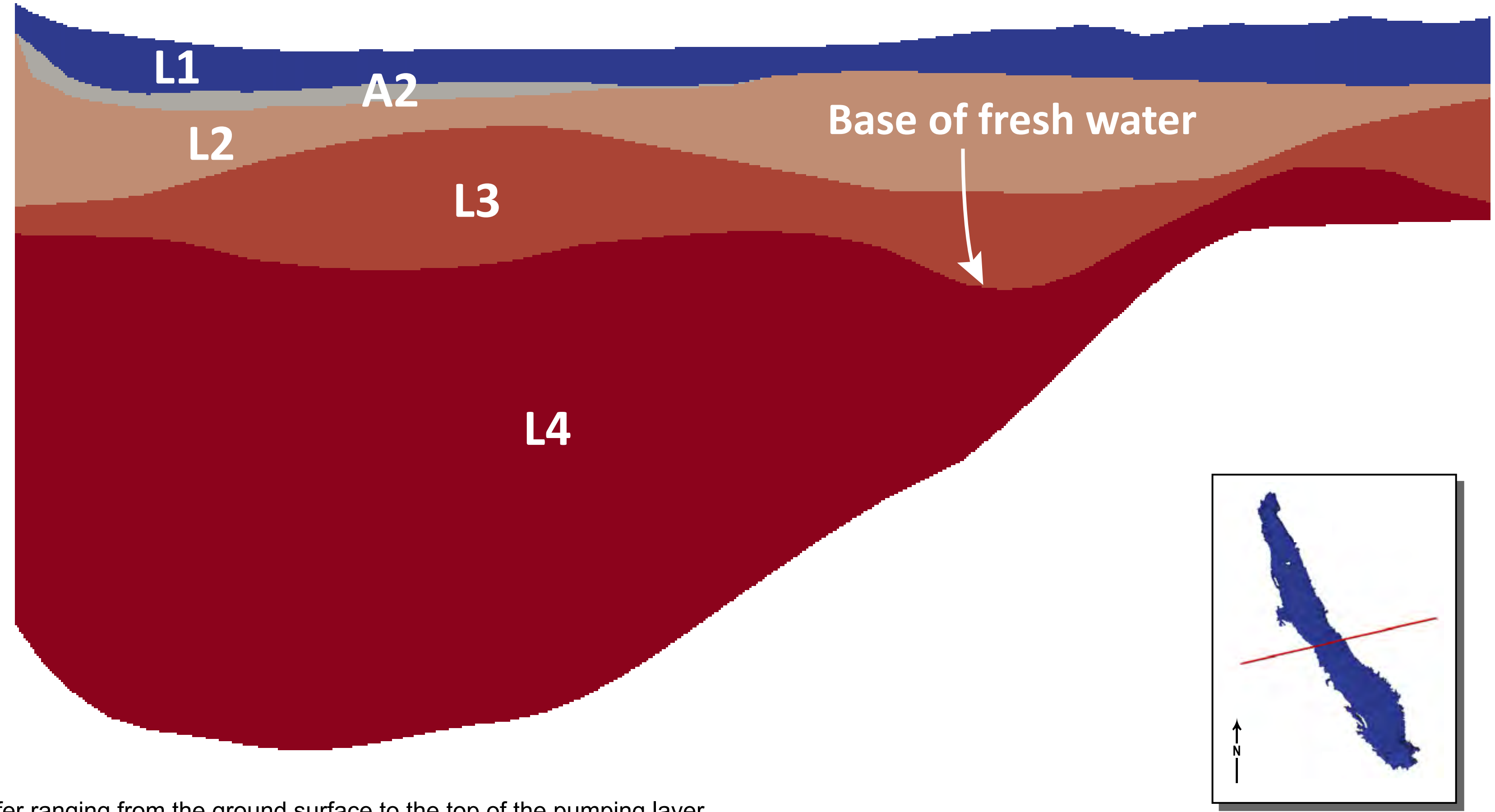
Figure 4-7
Base of
Fresh Water
as Mapped by USGS



Cross Section Location

L1: Aquifer ranging from the ground surface to the top of the pumping layer
A2: Corcoran Clay
L2: Primary shallow pumping layer
L3: Deeper pumping layer (bottom of layer is the base of fresh water)
L4: Saline aquifer (bottom of layer is the base of continental deposits)

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Figure 4-8
C2VSim
Model Layers

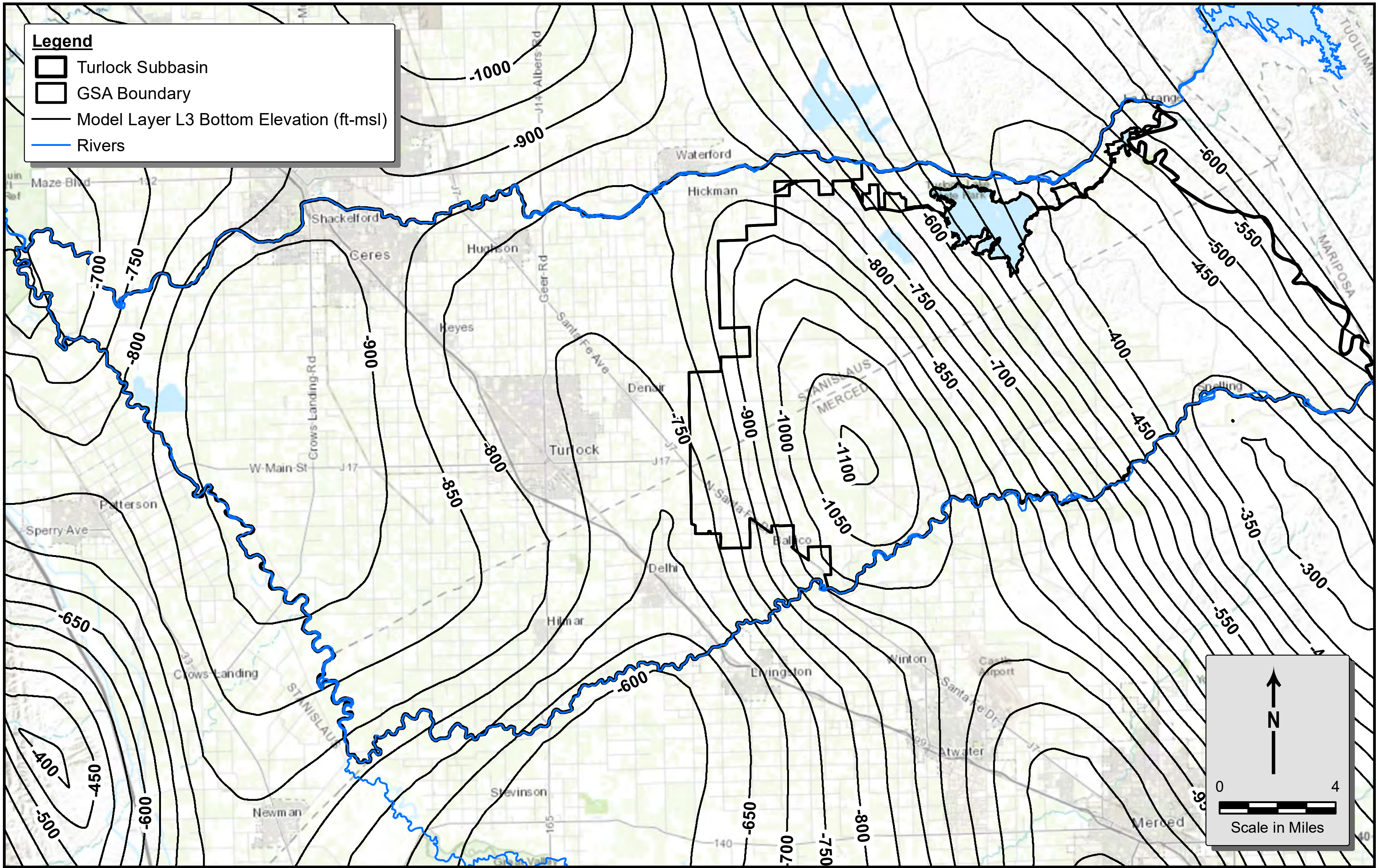

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Figure 4-9
C2VSim Base of Fresh Water

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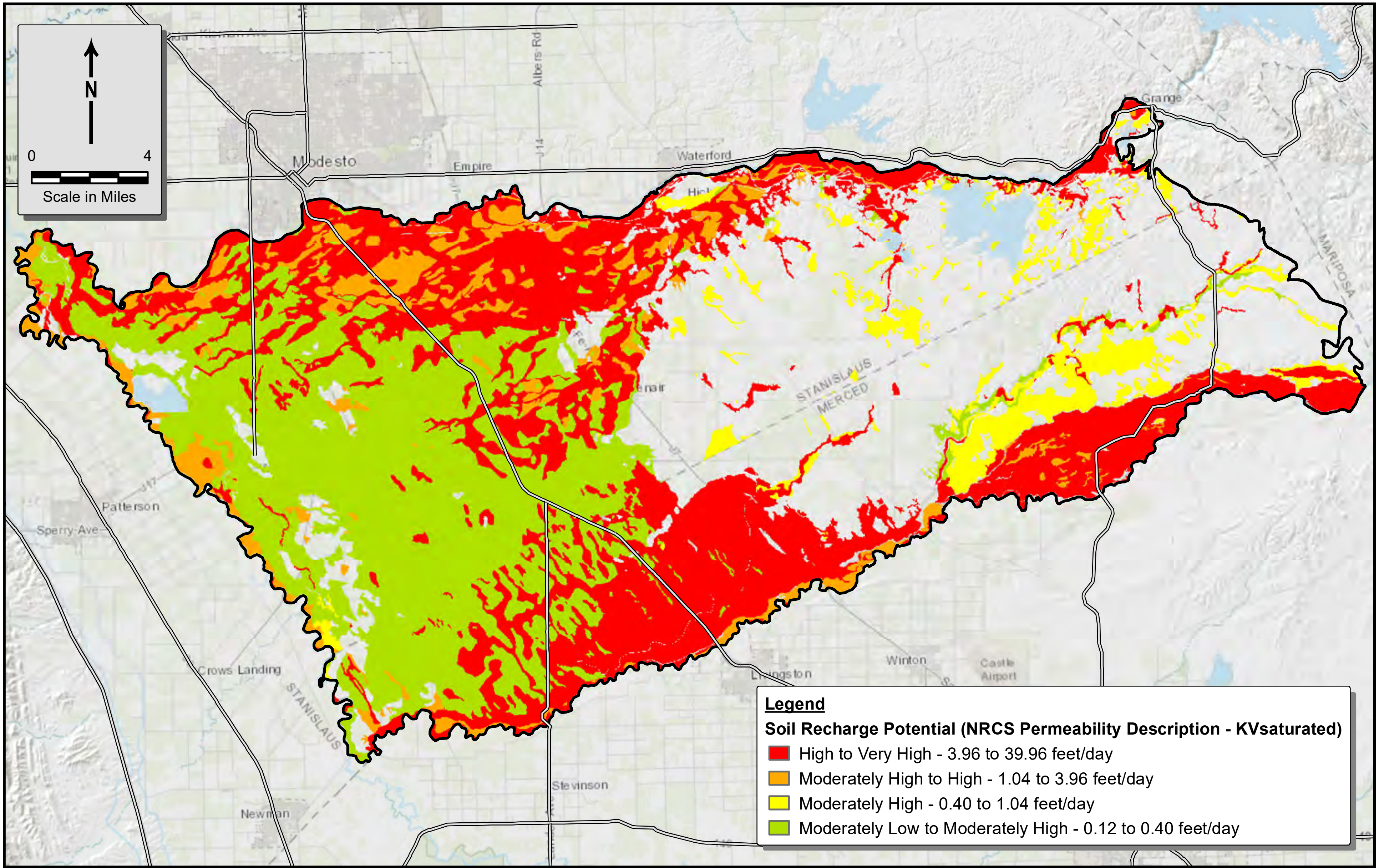

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Figure 4-10
Soil
Recharge Potential

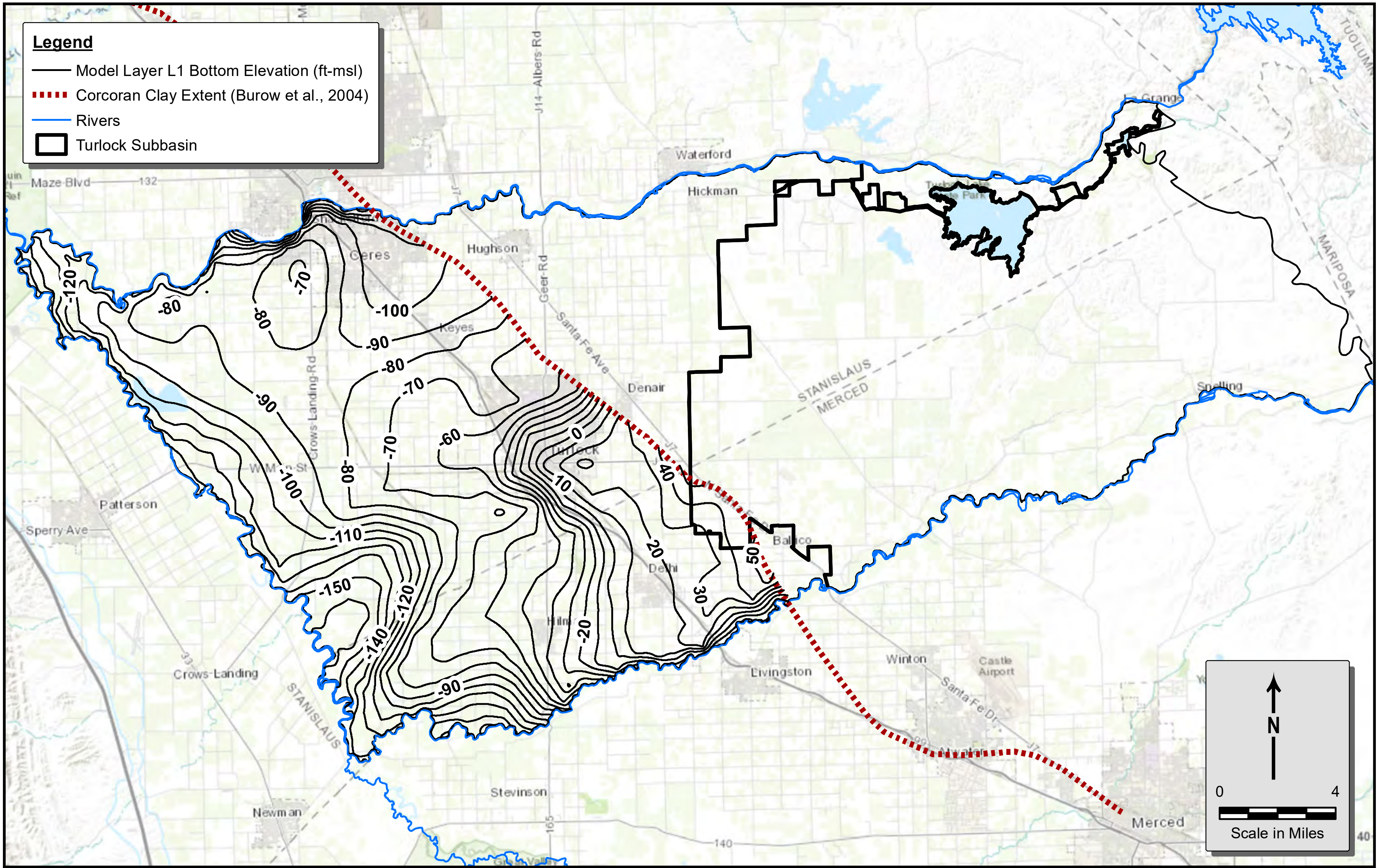

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Figure 4-11
C2VSim Top of Corcoran Clay

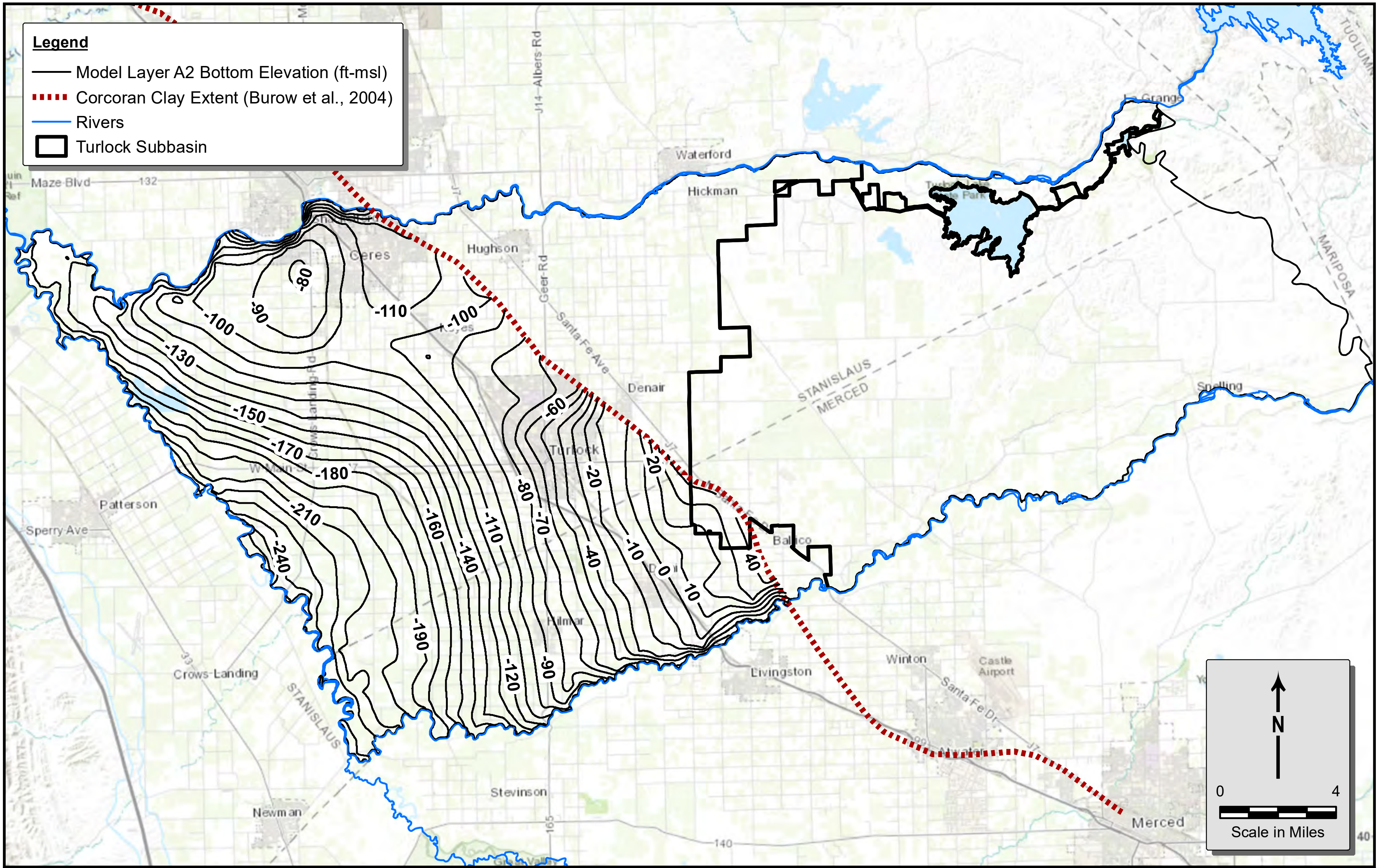

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Figure 4-12
C2VSim Bottom of Corcoran Clay

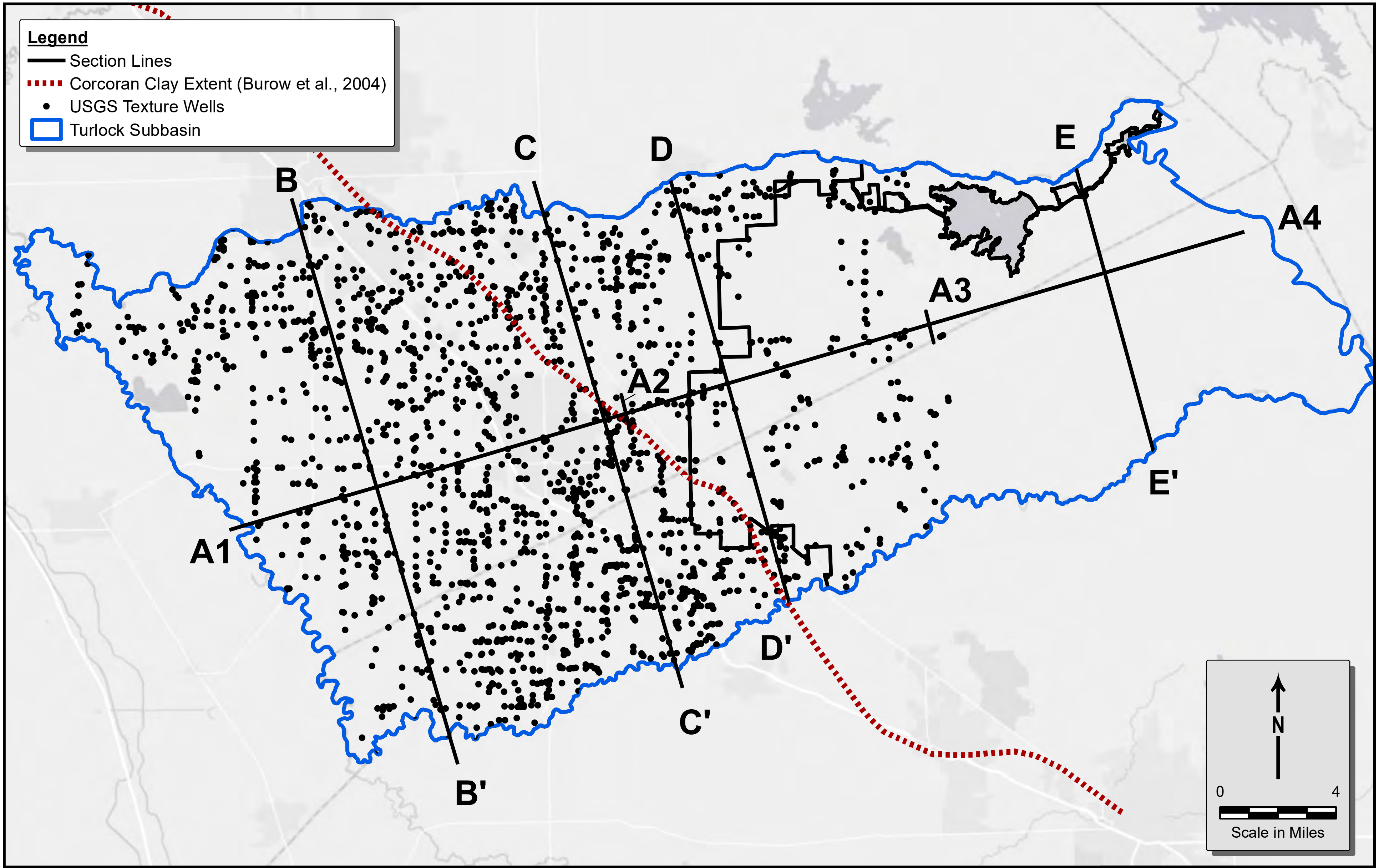

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Figure 4-13
Cross Section Locations

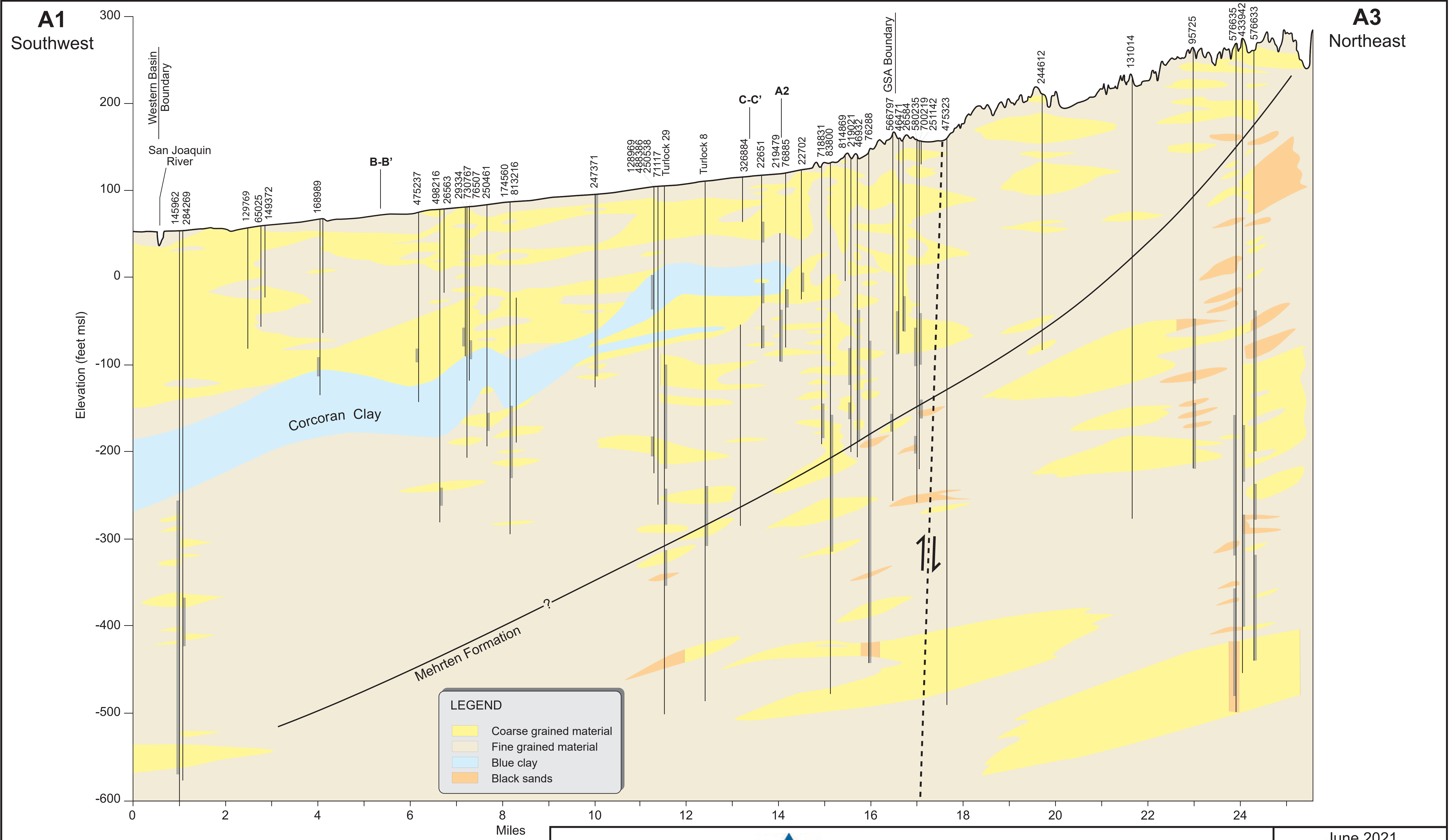

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Figure 4-14
Cross Section
A1 - A3
Western Subbasin

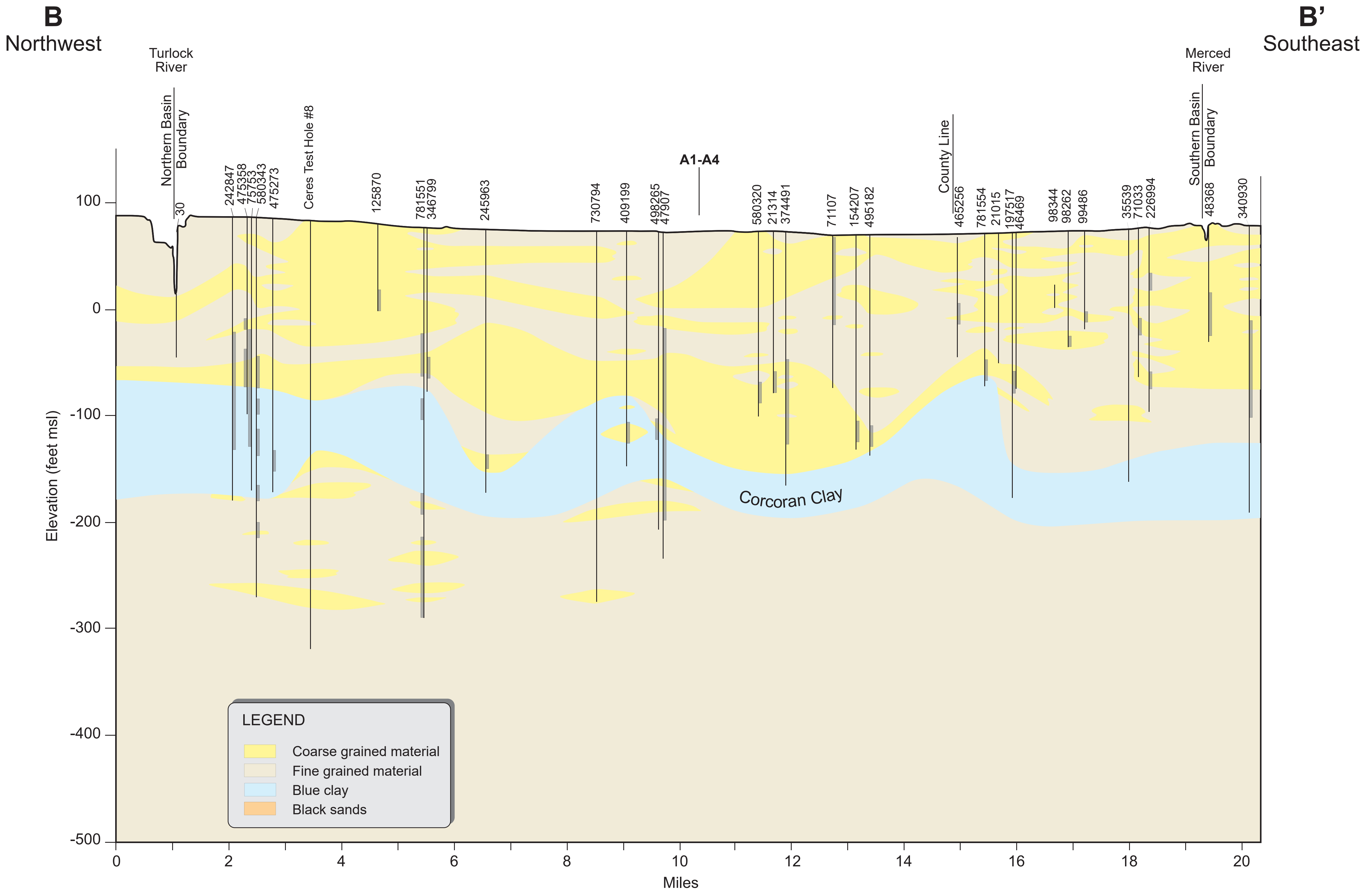

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Figure 4-15
Cross Section
B - B’

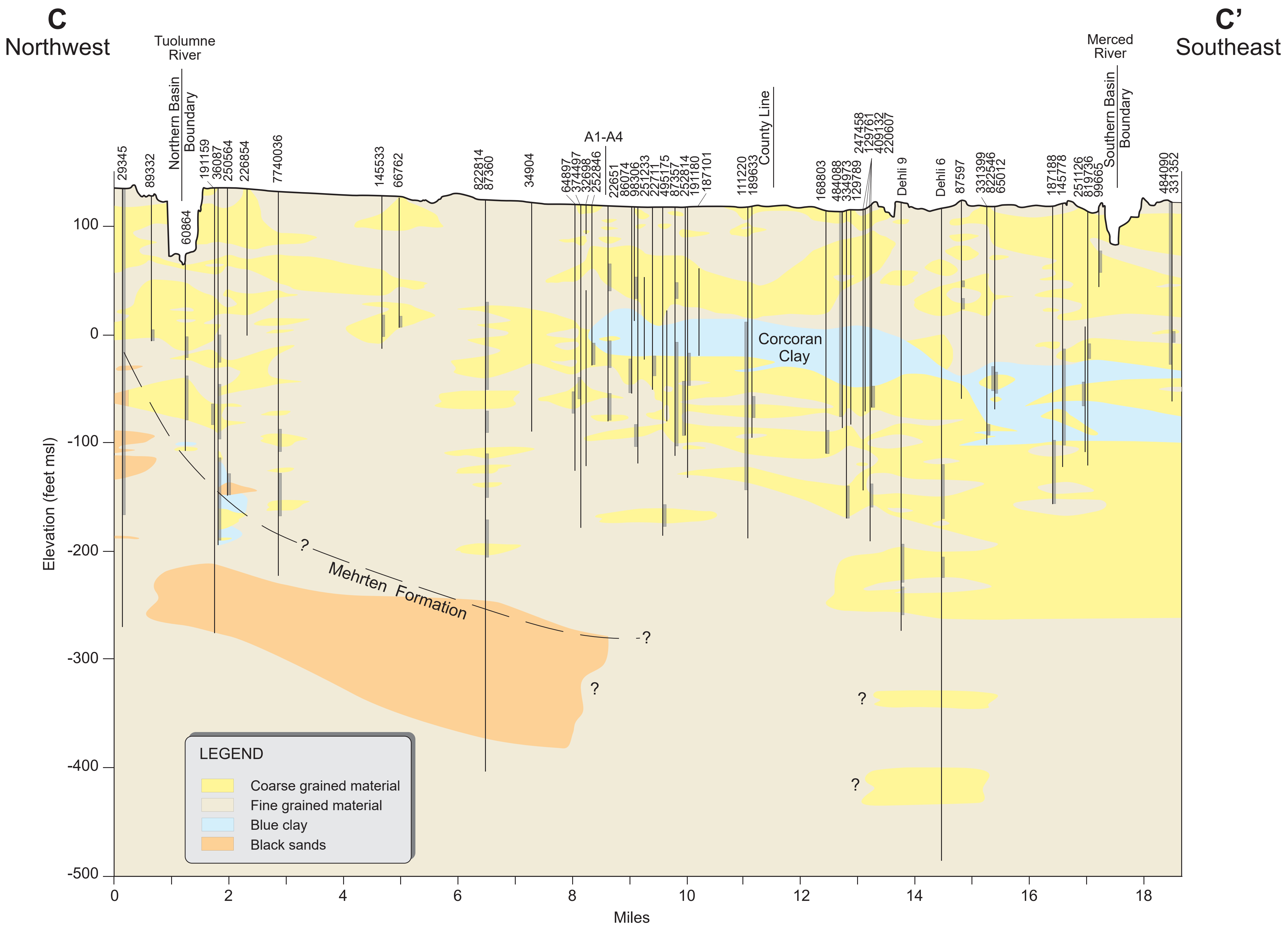

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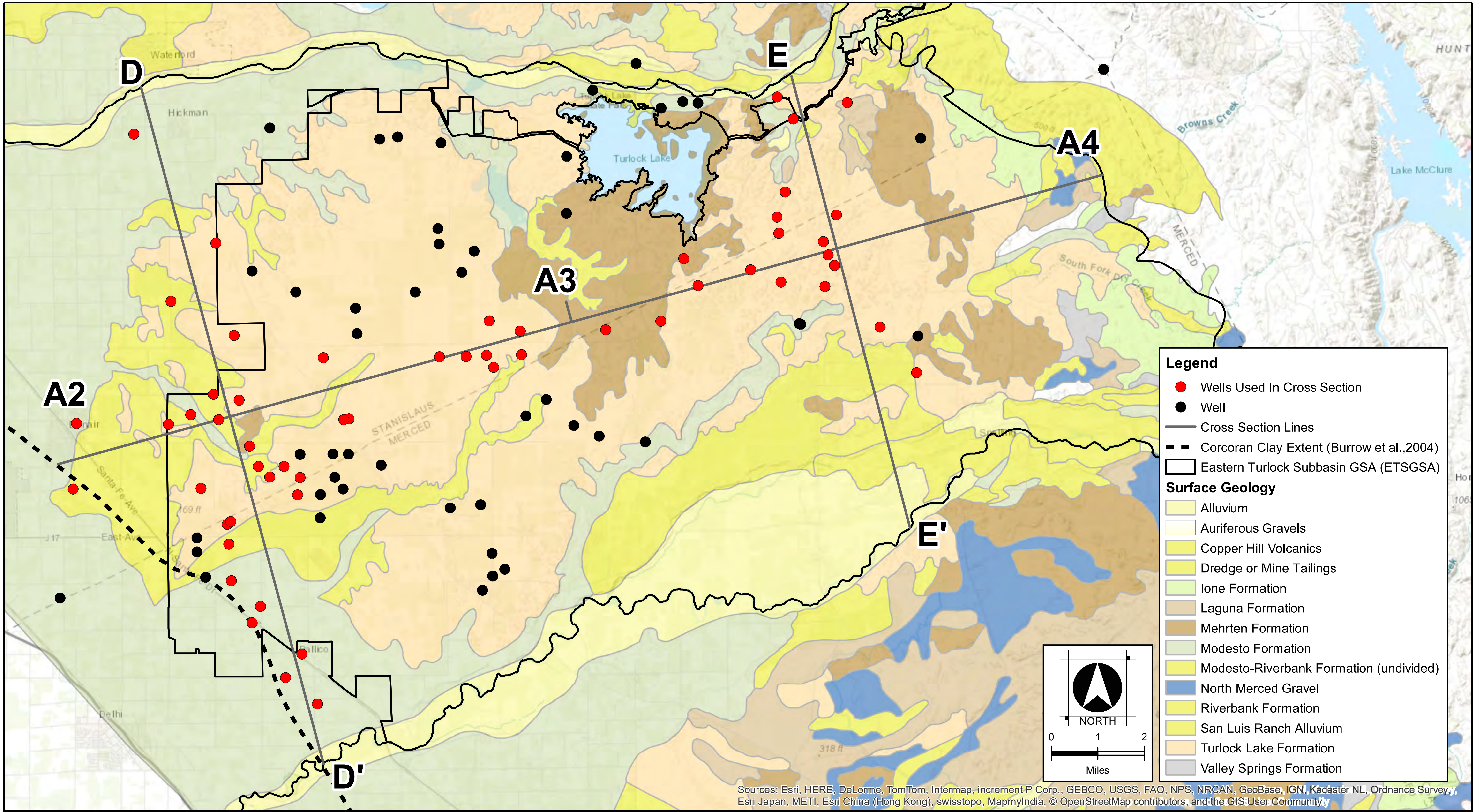
Figure 4-16
Cross Section
C - C'



Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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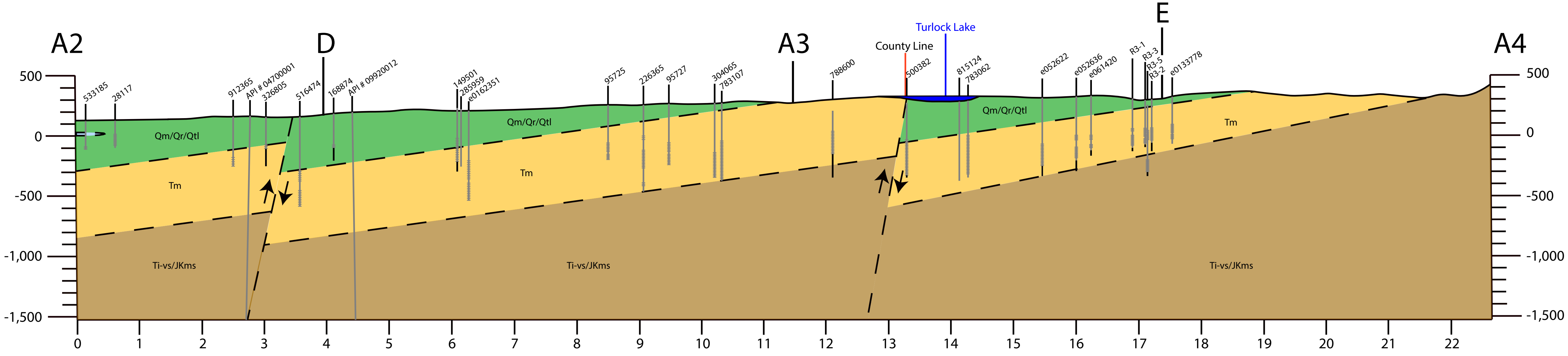
Figure 4-17
Surface Geology
& Geologic Cross
Section Locations
Eastern Subbasin



Geologic Legend

Qm/Qr/Qtl	Undifferentiated Modesto, Riverbank, and Turlock Lake Formations
Qtc	Corcoran Clay
Tm	Mehrten Formation
Ti-vs/JKms	Undifferentiated Continental and Marine Sediments

Map Symbols

– – –	Geologic Contact - Dashed Where Inferred
⇅	Approximate Location of Fault
|	Well Used for Geologic Correlation

Vertical Scale
In Feet (msl)
500′
250′
0′

Horizontal Scale
In Miles
0 0.5 1

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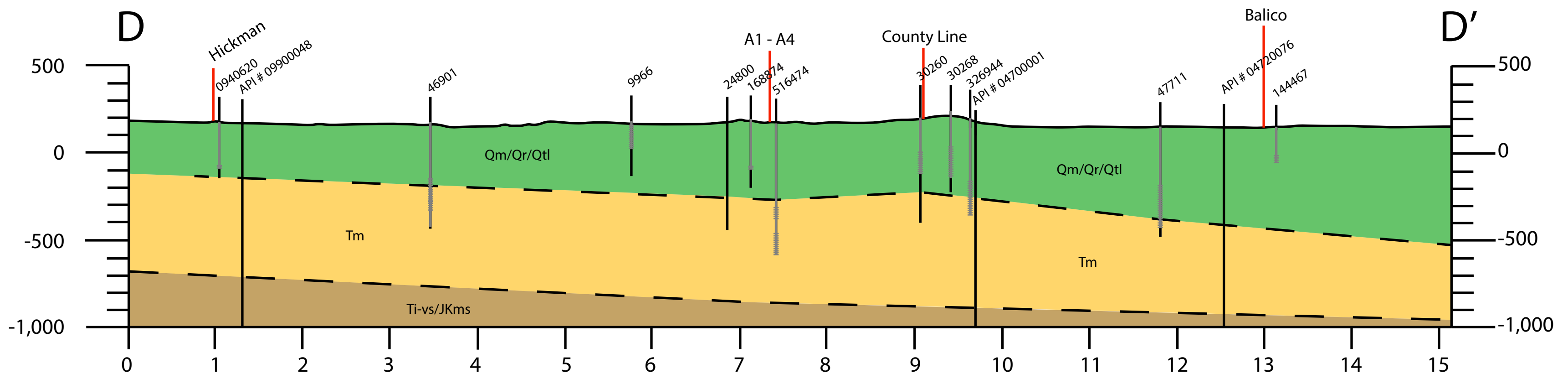
Figure 4-18
Cross Section
A2 - A4’



Geologic Legend

Qm/Qr/Qtl	Undifferentiated Modesto, Riverbank, and Turlock Lake Formations
Tm	Mehrten Formation
Ti-vs/JKms	Undifferentiated Continental and Marine Sediments

Map Symbols

– – –	Geologic Contact - Dashed Where Inferred
┃	Well Used for Geologic Correlation
│	Borehole Data Used for Geologic Correlation

Vertical Scale
In Feet (msl)
500’
250’
0’

Horizontal Scale
In Miles
0 0.5 1

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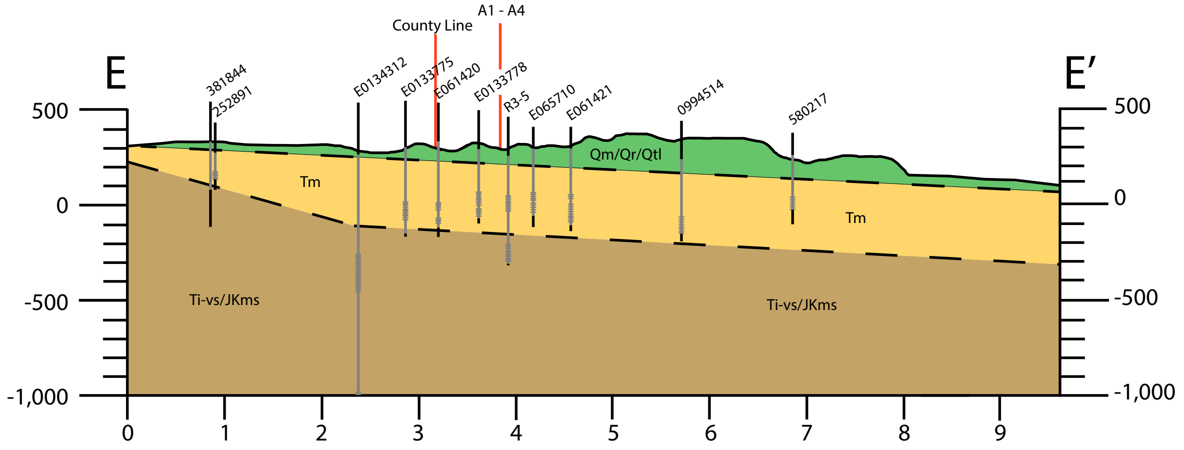
Figure 4-19
Cross Section
D - D’



Geologic Legend

🟩 Qm/Qr/Qtl Undifferentiated Modesto, Riverbank, and Turlock Lake Formations

🟨 Tm Mehrten Formation

🟫 Ti-vs/JKms Undifferentiated Continental and Marine Sediments

Map Symbols

– – – Geologic Contact - Dashed Where Inferred

| Well Used for Geologic Correlation

| Borehole Data Used for Geologic Correlation

Vertical Scale
In Feet (msl)
500’
250’
0’

Horizontal Scale
In Miles
0 0.5 1

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Figure 4-20
Cross Section
E - E’

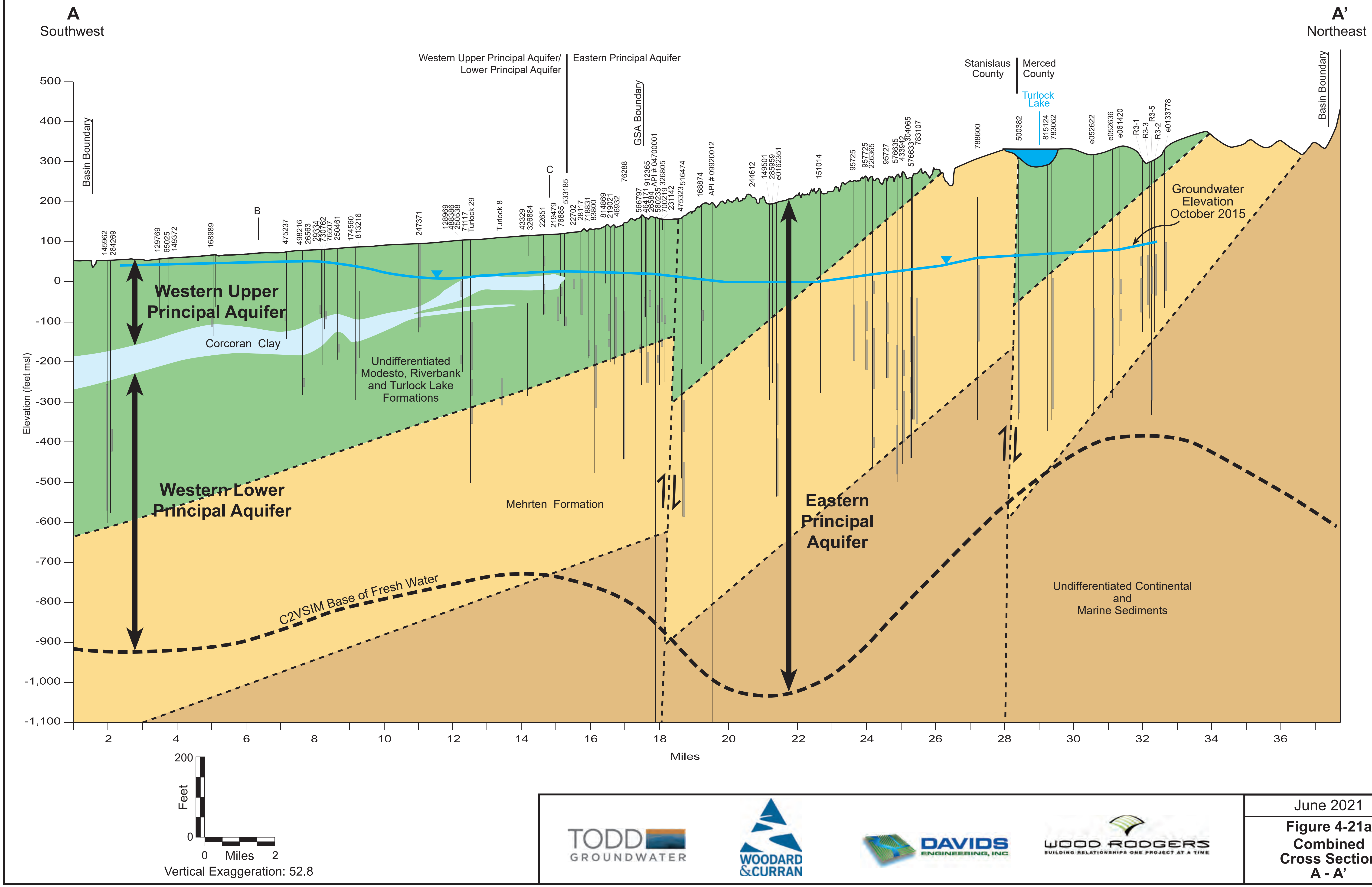

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Figure 4-21a
Combined
Cross Section
A - A'

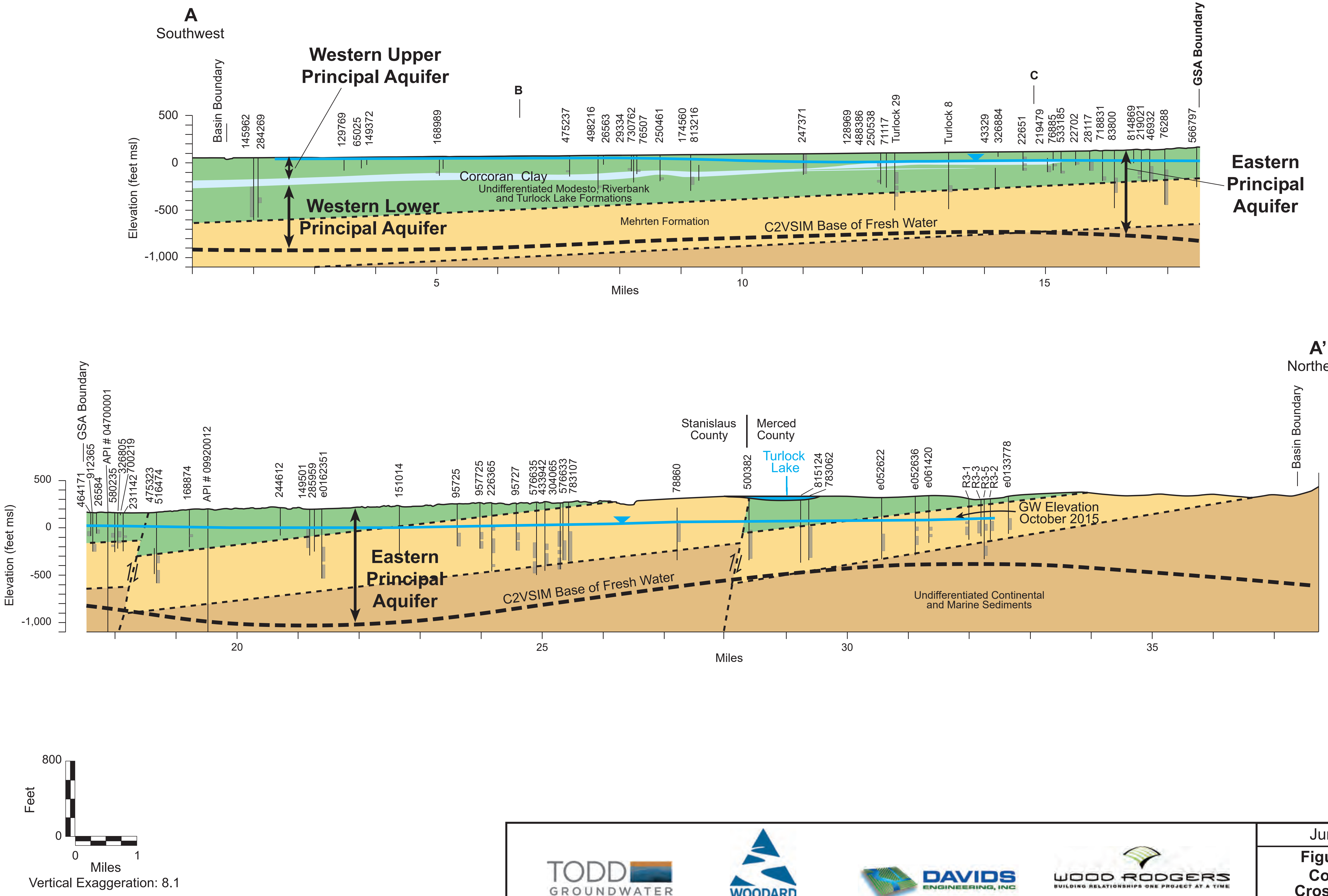

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**Figure 4-21b
Combined
Cross Section
A - A'**

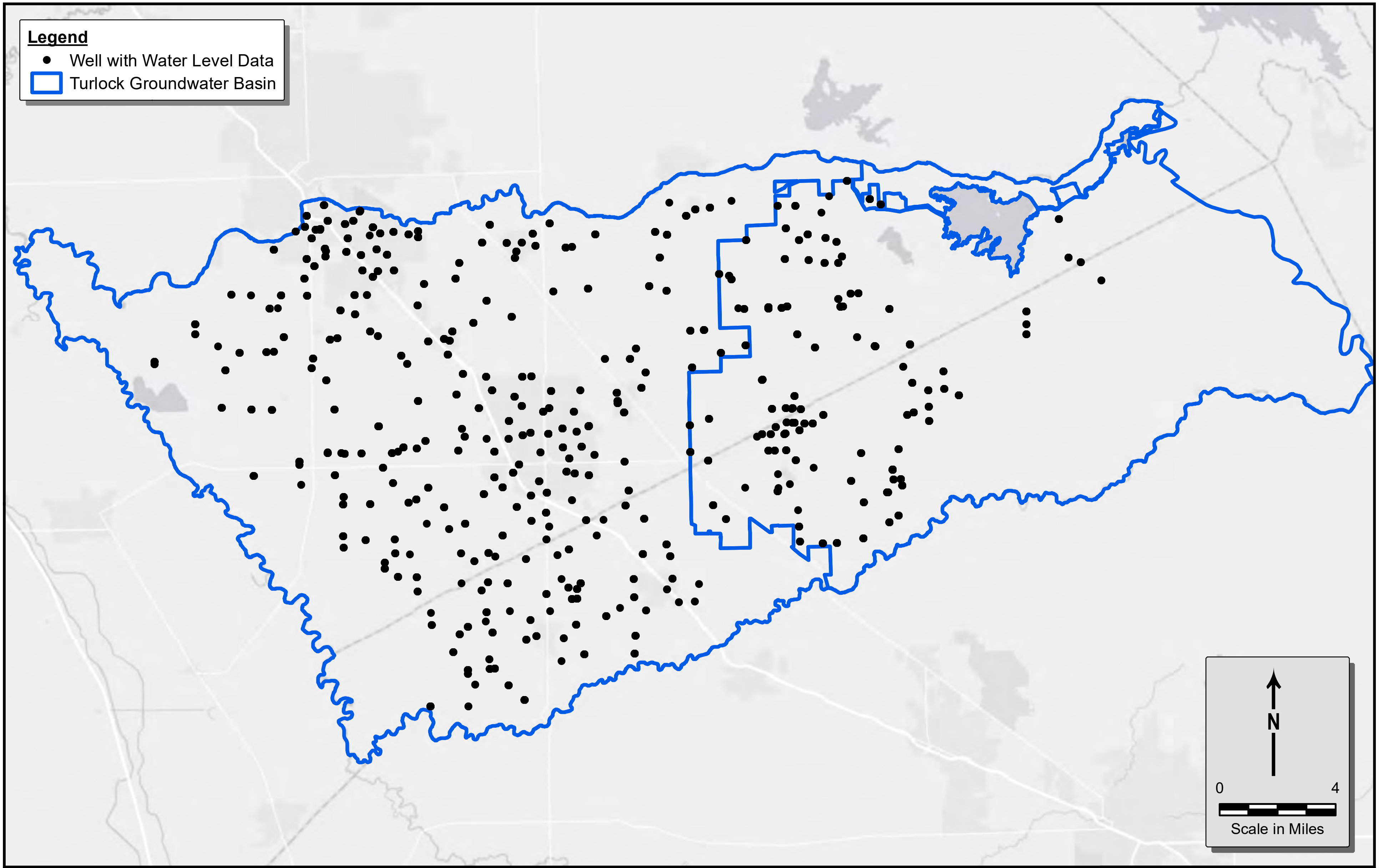

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Figure 4-22
Available Water Level Data

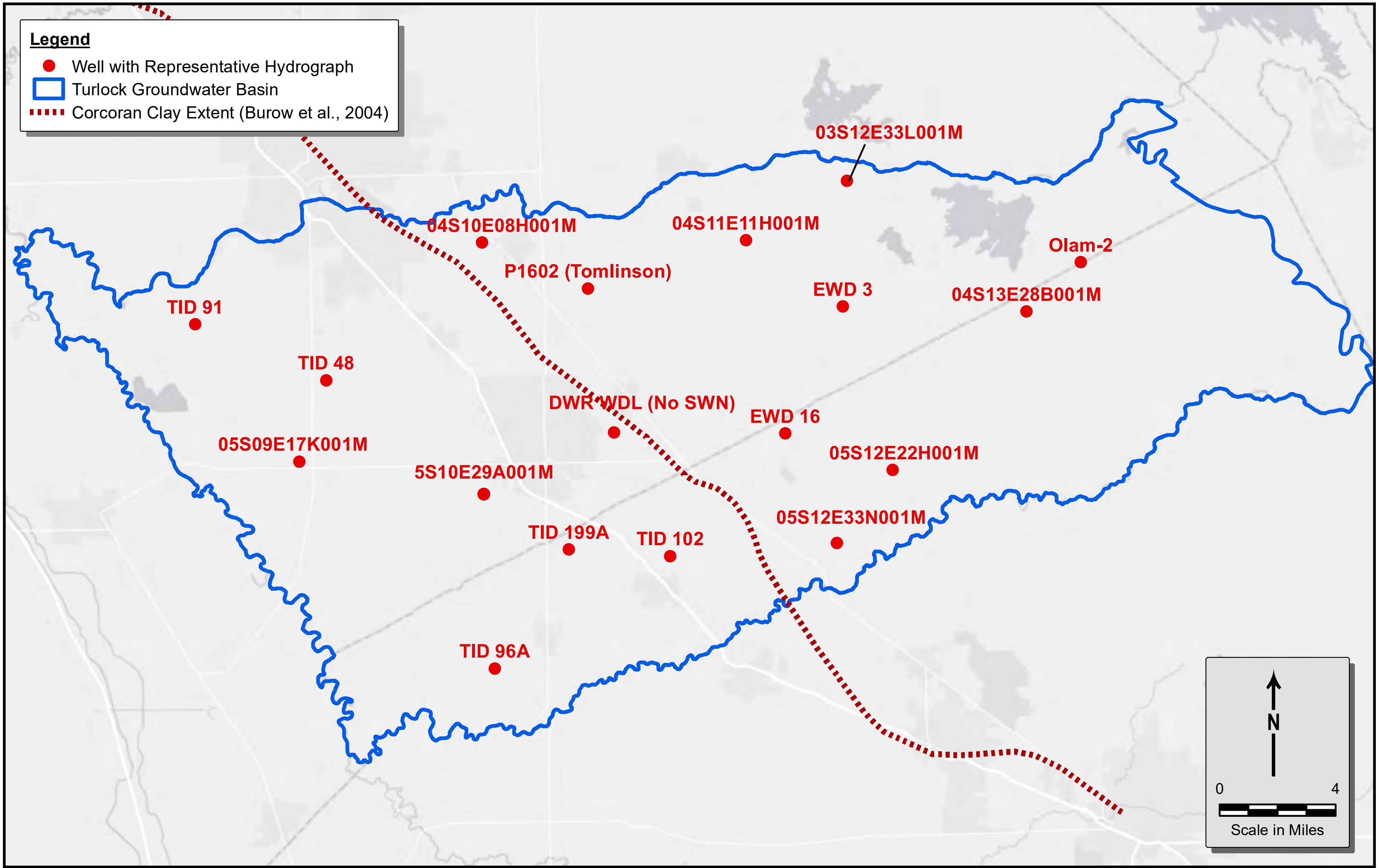

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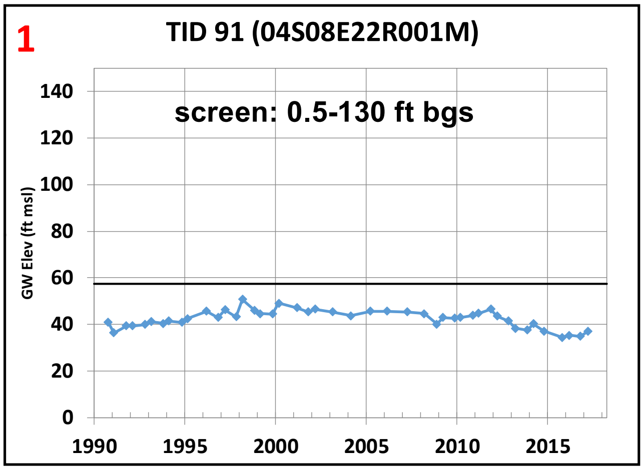
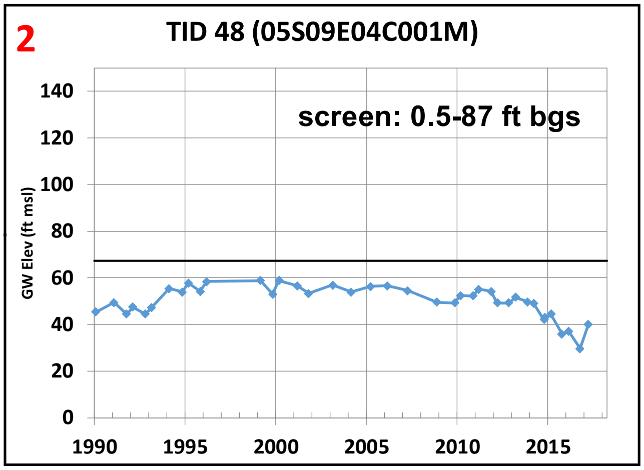
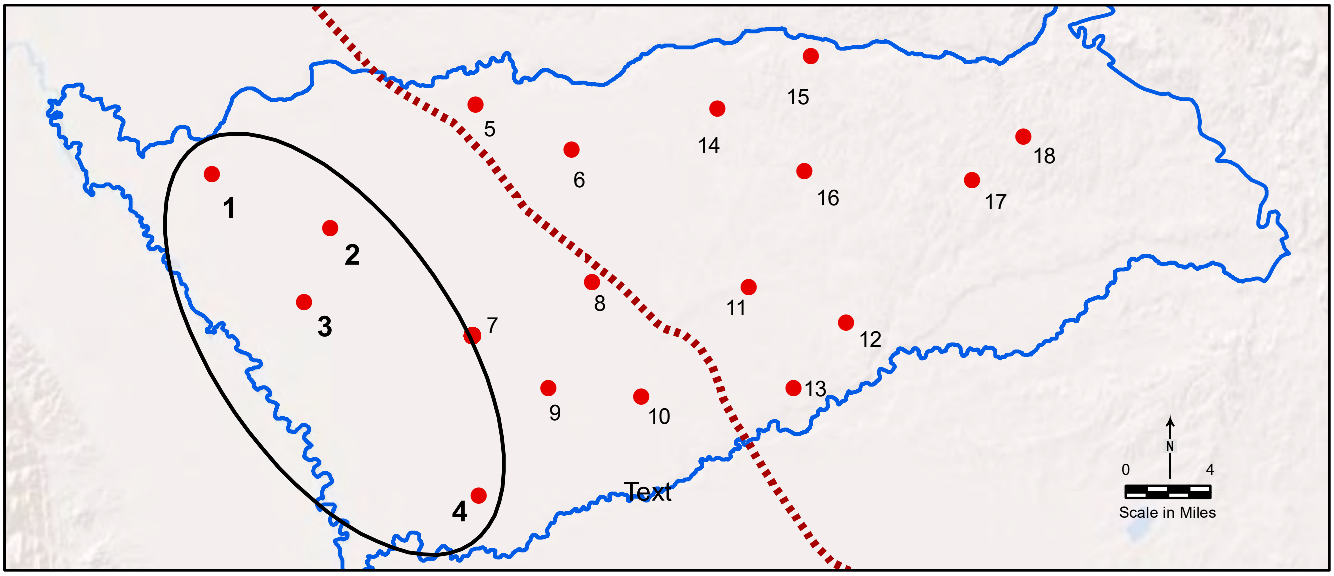
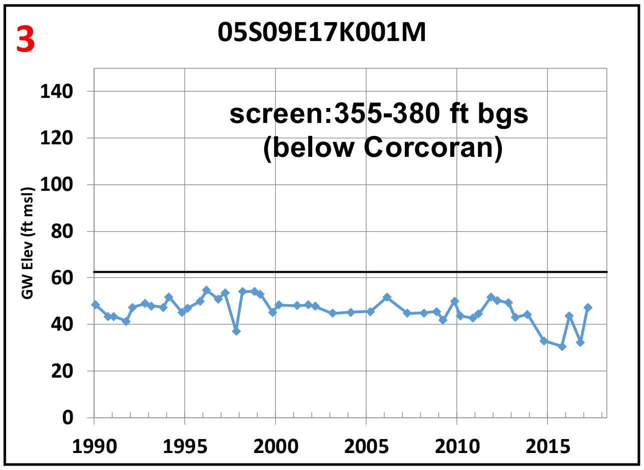
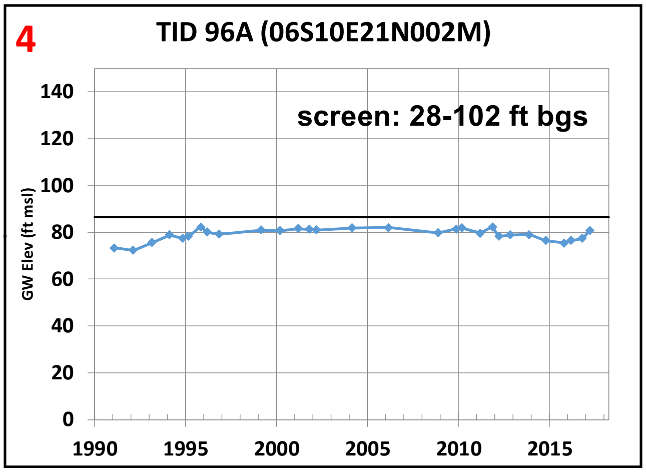
Figure 4-23 Location of Representative Hydrographs











Note: Ground surface elevation shown as black line on hydrographs.

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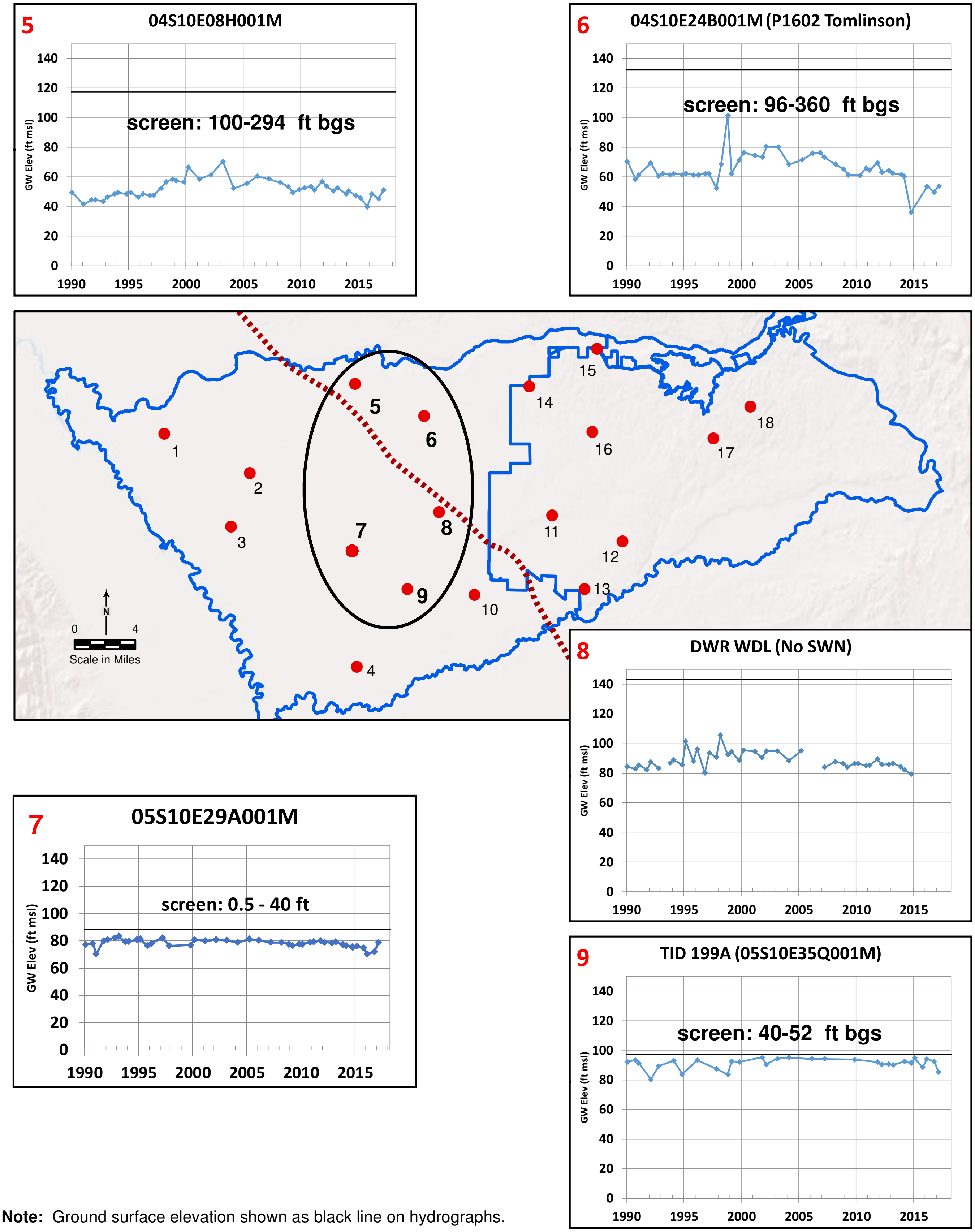
Figure 4-24
Representative
Hydrographs
Western Subbasin



Note: Ground surface elevation shown as black line on hydrographs.

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Figure 4-25
Representative
Hydrographs
Central-North Subbasin