3 HYDROGEOLOGIC CONCEPTUAL MODEL AND GROUNDWATER CONDITIONS

The basin setting of the Plan Area provides the foundation on which to evaluate sustainability indicators, select appropriate sustainability criteria, and develop management actions and projects to achieve and maintain sustainable groundwater management. As provided in the GSP regulations, the basin setting is based collectively on three related analyses:

1. **Hydrogeologic Conceptual Model**, which describes the physical conditions of the groundwater basin including: its regional geologic and structural setting; topography and soils; surface hydrology and related surface features and infrastructure; basin geometry including lateral sides and bottom; and the aquifers and aquitards that control groundwater recharge, storage, and movement.
2. **Groundwater Conditions,** which provides an understanding of groundwater[6] occurrence and flow, groundwater levels, including trends and fluctuations, groundwater quantity and quality, and interconnected surface water, if any.
3. **Water Budgets**, which provides an accounting of inflows and outflows of the groundwater system including an analysis of historical and current conditions. The water budget analysis also provides a baseline on which to project the water budget analysis into the future using projected water supplies and reasonable estimates of land use and water demand. Projected future water budgets are analyzed with various management actions and projects – as described in **Section 6** of this GSP – to determine how best to achieve and maintain sustainability goals for the future.

The first two analyses are provided in **Section 3**; historical, current, and projected water budgets (baseline) are provided in **Section 4**.

Each of these Basin Setting analyses is being coordinated among the various GSPs being prepared in the Subbasin. For example, the KGA is providing a regional analysis of the hydrogeologic conceptual model and groundwater conditions as part of a large coordinated GSP covering about 70 percent of the Subbasin. Individual agencies participating in the KGA GSP are providing more detailed information on these analyses in their local service areas. In addition, water budgets are being developed for the entire Subbasin using a locally-modified surface water/groundwater numerical model based on the DWR regional model C2VSim. The local C2VSim, referred to herein as C2VSimFG-Kern, has been revised with agency-specific water budget data provided by the KRGSA and other GSAs in the Subbasin.

The KRGSA is coordinating with these regional efforts and does not intend for this GSP to duplicate, contradict, or replace detailed regional information being developed by others; however, some of the

[6] Recognizing the extensive conjunctive use and managed aquifer recharge activities in the KRGSA Plan Area, groundwater necessarily includes banked surface water supplies, which are tracked separately by the water managers.

Subbasin regional information is described herein to provide context for the local KRGSA GSP Plan Area analyses.

3.1 Study Periods

Various study periods are being employed in the KRGSA GSP depending on the requirements of specific analyses and available data. GSP regulations indicate a need to identify an average hydrologic Study Period for purposes of the groundwater analyses in a critically over-drafted basin and for the basin-wide water budgets (§354.16(b); §354.18(5)). In order to coordinate on both local and Subbasin-wide analyses, the KRGSA, KGA, and others have selected an average hydrologic Study Period covering a recent 20-year period from WY 1995 through WY 2014.

The coordination is consistent with GSP regulation requirements which generally require all GSAs in a subbasin to use the "same data and methodologies" for development of multiple GSPs (§357.4(a)). In particular, GSP regulations require that the water budgets be coordinated for the entire subbasin (§357.4(b)(3)(B)). It was also acknowledged that the use of this study period does not preclude any of the KRGSA GSP analyses – or analyses done by others – from incorporating data from a different time period when available and necessary for the GSP development.

The historical average hydrologic Study Period of WY 1994 through WY 2014 covers 20 years on a water year basis, from October 1, 1994 through September 30, 2014. The selection of the study period was based on a variety of technical criteria:

- 100 percent of the long-term average streamflow conditions on the Kern River (as indicated by an average annual Kern River Index of 100 percent – see **Figure 2-10**)
- 102 percent of long-term average precipitation (NOAA Bakersfield Meadows Field Airport Station)
- Makes best use of METRIC analysis of monthly evapotranspiration (ET) data, which was available for all but one year of the entire study period
- Sufficiently short time period associated with other widely-available, higher-quality data
- Inclusion of recent time periods to capture ongoing water management practices and more recent land use patterns
- Covers at least 10 years consistent with GSP regulations (§354.18(c)(2)(B))
- Contains 10 years characterized as above normal or wet years based on precipitation; also contains 10 years of below normal or dry years, including 4 critically-dry years (see **Section 3.2.4.1** Climate)
- Begins in a time of relatively stable water levels (October 1994)
- Overlaps time period with consistently-developed basin-wide contour maps by KCWA.

The recent water year (WY 2015 and, as applicable, WY 2016) is used for current conditions throughout this GSP. This Study Period was proposed in 2016 when GSPs were first being initiated in the Subbasin; accordingly, WY 2016 data were not yet widely available. In addition, WY 2016 is not included in the

Beta version of the C2VSim model, which represented the best available data when the model was released by DWR in Spring 2018. Collectively, the entire historical and current study periods are also the most recent 21 years of the C2VSim model; this allows coordination and calibration of the model to the most recent land use and management conditions available so that the model will be more accurate for application to projected future water budgets.

It is recognized that this Study Period ends in the drought of record at a time when then-current water levels were at or near historic lows (and continued to decline as drought conditions persisted in 2015 and 2016). Ending a study period in drought will almost always result in a decline of groundwater in storage on a cumulative basis from the beginning to the end of the Study Period. However, the cumulative decline alone does not necessarily indicate overdraft conditions. Even though the overall period represents average hydrologic conditions, resulting changes in groundwater in storage from the beginning to the end can be either positive or negative depending on the order of the dry and wet years in the period. Although cumulative changes in storage are included in the analysis, the sustainability analysis also focuses on average annual changes in storage.

More recent data were also compiled to ensure that analyses considered the drought conditions of 2015-2016. The analyses were conducted over several years, with much of the work being conducted in 2018 or earlier. Accordingly, most analyses cover either the 20-year Study Period or extend into more recent years through 2017.

3.2 HYDROGEOLOGIC CONCEPTUAL MODEL

The KRGSA is located near the eastern and southern margins of the southern San Joaquin Valley and in the south-southeast portion of the Kern County Subbasin. The groundwater basin beneath the KRGSA Plan Area consists of unconsolidated to consolidated alluvial sediments deposited in the Upper Miocene through Holocene epochs. Most of the groundwater supply in the Plan Area occurs in the unconsolidated alluvium and underlying semi-consolidated Kern River Formation[7], which crops out in the northern and northeastern Plan Area. These aquifers were deposited in fluvial and alluvial fan environments associated with the Kern River and other ancestral drainageways (Robbins, 2014). Lower portions of the Kern River Formation produce oil in the Kern River oilfield north of the Kern River. The regional geologic and structural setting, along with a more complete description of the hydrogeologic conceptual model, is provided in the following sections.

3.2.1 Regional Geologic and Structural Setting

The Kern County Subbasin consists of the upper portion of a deep structural trough between the crystalline rocks of the Sierra Nevada and the basement rocks of the Coast Ranges. The deeper portions

[7] Lower portions of the Kern River Formation produce oil in the Kern River oilfield north of the Kern River and are considered below the bottom of the groundwater basin in this area as discussed in more detail in Section

of the trough contain mostly Miocene and older marine sedimentary units. The upper trough has been infilled over time with mostly Late Miocene and younger continental sediments.

The structural trough and groundwater basin are illustrated on the schematic diagram in **Figure 3-1** with the Kern County Subbasin depicted in the southern San Joaquin Valley portion of the Central Valley. The estimated extent of the Kern County Subbasin and the KRGSA Plan Area are noted on **Figure 3-1**. As shown on the block diagram, deep marine sediments (purple) of pre-Pliocene age transition upward to Pliocene and younger deposits, mostly of continental origin (light yellow). These younger sediments contain most of the groundwater in the Subbasin.

The structural and depositional setting of the KRGSA is controlled in the deep subsurface by the Bakersfield Arch, a homocline[8] of basement rocks below the northern KRGSA Plan Area that plunges to the southwest. This arch and southwesterly dip of basement rocks created a deep trough for infill of sediments (depocenter), mostly during the Neogene period (Miocene and younger) (Bartow, 1991).

3.2.1.1 Regional Surface Geology and Depositional Environments

A regional geologic map shown on **Figure 3-2** illustrates the age and composition of surficial deposits in the Subbasin (Page, 1986). As shown, most of the Subbasin is covered with continental deposits of Quaternary age and is flanked by Miocene and pre-Miocene marine sedimentary units and basement rocks on the eastern and western margins of the valley.

The youngest surficial deposits in the KRGSA Plan Area include Holocene fluvial deposits along the Kern River channel. As shown on **Figure 3-2**, the KRGSA contains most of the Kern River channel, which traverses across the northern Plan Area through the City of Bakersfield. Prior to development, the Kern River continued to flow southwest before turning north near the Elk Hills uplands and flowed about 40 miles to its terminus at the Tulare Lake Bed, near the Kern County line (**Figure 3-2**). Since the regulation of river flows and the construction of Isabella Dam in the early 1950s, the Tulare Lake Bed only rarely receives surface water flood flows and has mostly been converted to agriculture.

In the KRGSA, Quaternary-age and underlying Pliocene-age sediments consist of comingled alluvial fans that were deposited by the ancestral and present-day Kern River (Dale, et al., 1966, Bartow and Pittman, 1983; Page, 1986) and other local drainageways (Robbins, 2014). A portion of the large Kern River Fan covers most of the KRGSA Plan Area. The present-day canals south of the Kern River were developed along the ancestral sloughs and drainageways of the alluvial fan and illustrate the fan-like geometry of the deposits (see canals in the KRGSA on **Figure 3-2**). The southern and eastern margins of the Kern River Fan are defined by fine-grained flood-basin and paleo-lake bed deposits, which were the ancestral terminus of local streams and flood waters (see Buena Vista Lake Bed, Kern Lake Bed, and brown-shaded flood-basin deposits – labeled Qb – on **Figure 3-2**).

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[8] A geologic structure that dips uniformly in a single direction.

The north-south flood-basin deposits in the eastern KRGSA Plan Area (Qb on **Figure 3-2**). represent the inter-fan area between the Kern River Fan and the smaller alluvial fans originating from the east (Dale, et al., 1966). These and other flood-basin deposits beneath the Kern and Buena Vista Lake Beds are associated with thick clay layers that locally impede surface recharge and vertical flow, creating perched conditions in the shallow subsurface and confined groundwater conditions at depth.

3.2.1.2 Surface Geology and Faulting in the KRGSA Plan Area

Surface geologic units have been compiled statewide on the *Geologic Map of California* by the California Geological Survey (CGS, formerly Division of Mines and Geology) (CGS, 2000); a portion of this map[9] is shown on **Figure 3-3** to further examine local contacts and geologic faulting in the vicinity of the KRGSA.

The yellow shading on **Figure 3-3** shows the previously-discussed alluvial deposits of Holocene and Pleistocene age (Quaternary Period, labeled Q), which cover most of KRGSA Plan Area. The Kern River Formation underlies the Quaternary alluvium and consists of a consolidated to semi-consolidated unit of predominantly sandstone (mostly Pleistocene and Pliocene age) that crops out in the northeastern region of the KRGSA Plan Area (labeled QPc on **Figure 3-3**). Similar age formations exist on the western side of the valley, west of the KRGSA Plan Area (labeled QPc on the western portion of **Figure 3-3**). Collectively, the surface alluvium and underlying Kern River Formation compose the principal aquifer system beneath the KRGSA Plan Area.

Older, finer-grained sediments (generally of pre-Pliocene age that represent the transition from continental deposits to marine sedimentary units) are present along the northeast corner of the KRGSA. Both continental and marine deposits (labeled Mc and M, respectively on **Figure 3-3**) lie between the younger deposits and the crystalline basement rocks of the Sierra Nevada (labeled grMz on **Figure 3-3**) on the east.

Geologic faults are also shown on the CGS map on **Figure 3-3**. As indicated on the figure, most of the faulting occurs close to the subbasin margins east and south of the KRGSA Plan Area. Several northwest-trending faults appear to extend into the northeastern KRGSA Plan Area with most faults trending northwest. Displacements along these faults are mapped mostly as normal (tensional) faults associated with deformation along the valley margin by Bartow (1991). However, Bartow notes the occurrence of some northwest-trending surface lineaments in the Kern River area that are unrelated to basement faulting. The ability of these upland faults to impede groundwater flow is unknown, but such impedance would not significantly affect groundwater throughout the KRGSA Plan Area. Although the Edison fault east of the Plan Area (see **Figure 3-2**) has been described as affecting groundwater, no such faults have been documented in the KRGSA.

A geologic map of the Bakersfield area (Jenkins, 1975) on **Figure 3-4** shows similar geologic units and faults as previous **Figures 3-2** and **3-3** but provides more local detail in the KRGSA Plan Area. The map

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[9] Some older units outside of the groundwater subbasin have been combined on Figure 3-3 for simplicity, but most geologic unit labels have been preserved from the source.

shows detailed contacts for units previously discussed including the Quaternary-age stream channel deposits (Qsc) along the Kern River channel, alluvial fan deposits (Qf) throughout the Plan Area, basin deposits (Qb) along the western, eastern and southern regions of the Plan Area and Quaternary lake deposits (Ql) forming the Kern Lake Bed along the southern edge of the KRGSA Plan Area.

The north-south trending flood-basin deposits (Qb) that occur parallel to the eastern boundary of the KRGSA on **Figure 3-4** represent an inter-fan trough of fine-grained sediments between the Kern River Fan and the Caliente Creek Fan, which originated from the eastern valley margin along the Caliente Creek drainageway (**Figure 3-4**). The inferred boundary between the Kern River and the Caliente Creek alluvial fans (Dale et al., 1966) occurs in the eastern KRGSA Plan Area and is shown by the green dashed line on **Figure 3-4**. The low-permeability flood basin deposits at western terminus of the Caliente Creek Fan impede surface recharge and affect local groundwater as discussed in more detail in **Section 3.2.6** of this GSP.

Geologic units cropping out in the northern and northeastern regions of the KRGSA Plan Area are Pleistocene nonmarine (Qc) and Plio-Pleistocene nonmarine (Qp) sedimentary rocks. Quaternary nonmarine terrace deposits (Qt) are present along the upstream reaches of the Kern River.

3.2.1.3 Geologic Framework Geologic Map and Cross Sections

An additional map compiled by Bartow (1983) is provided as **Figure 3-5** to allow an examination of the Subbasin geometry across the eastern margin of the valley. The map shows additional detail of the geologic units at the Subbasin boundary and is accompanied by cross sections that illustrate the geologic framework of the boundary. Two cross sections C-C’ and D-D’, as highlighted on **Figure 3-5**, illustrate the subsurface geometry from the Sierra Nevada crystalline (basement) rocks across the Kern County Subbasin boundaries and into the groundwater basin beneath the KRGSA Plan Area both north and south of the Kern River.

Cross Sections C-C’ and D-D’ by Bartow (1983) are reproduced on **Figure 3-6**. Cross section C-C’ is located north of the Kern River and shows the framework of the basement rocks of the Sierra Nevada (pink) on the east (right side). The eastern boundary of the Kern County Subbasin is coincident with the outcrop of the continental deposits of the Kern River Formation. Although this unit serves as part of the aquifer system further west in the groundwater basin, the Kern River Formation is the oil reservoir for the Kern River oilfield. The top of the oil reservoir would serve as a bottom of the groundwater basin locally as discussed in more detail in **Section 3.2.5**. A small portion of the Kern River oilfield extends into the KRGSA Plan Area along the cross section as shown on C’C. The surface alluvial deposits of the KRGSA are also shown on the section. Collectively, the Alluvium and Kern River Formation reach a thickness of about 3,250 feet beneath the western boundary of the KRGSA at Rosedale Highway.

Cross Section D-D’ on the lower portion of **Figure 3-6** also shows the subsurface geometry across the Kern County Subbasin boundary. The section extends from the Sierra Nevada crystalline rocks (pink) on the east to the KRGSA on the west, although it does not extend very far into the Plan Area. Along this section, the Kern County Subbasin includes an outcrop of Miocene alluvial fan deposits (shown in blue and labeled Tba and Tbp) that aren't present on the C'C'. The section also intersects a series of northwest-trending faults extending up into the Kern River Formation, similar to faults mapped in the northeastern KRGSA Plan Area. At the terminus of the section in the eastern KRGSA Plan Area, the Alluvium and Kern River Formation are approximately 2,800 feet thick. Additional information on the bottom of the subbasin and aquifer thickness and characteristics beneath the Plan Area is provided in **Sections 3.2.5** and **3.2.6** of this GSP, respectively.

3.2.2 Topography

The KRGSA Plan Area extends from the edge of the Sierra Nevada foothills in the northeast to the San Joaquin Valley floor. The Kern River, with headwaters in the Sierra Nevada, cuts across the valley floor through the northern region of the KRGSA. A Digital Elevation Map (DEM) of the topography based on the United States Geological Society (USGS) National Elevation Dataset (NED) is illustrated on **Figure 3-7**.

Ground surface elevations in the Kern River GSA slope to the southwest, ranging from approximately 280 feet mean sea level (msl) to more than 1,000 feet msl. The higher surface elevations are in the northeast within the foothills of the Sierra Nevada. The lowest ground surface elevations (below 300 feet msl) are in the south and southwest coincident with paleo-lakebeds that have been drained and placed into agricultural production.

The Kern River exits the dissected uplands in the northeast at an elevation of about 420 feet, forming the apex of the alluvial fan. The alluvial fan complex covers most of the KRGSA, with ground surface elevations between about 400 and 280 feet msl. From northeast to southwest, the alluvial fan surface has a slope of about 7 to 8 feet per mile.

3.2.3 Soils

The depositional history of the Kern River has influenced the shallow subsurface sediments and soil profile beneath the Kern River GSA. The terminus of the Kern River was historically at large inland lakes. The ancestral Kern River flowed from east to west across the valley and then turned north toward the Tulare Lake Bed approximately 40 miles away. During flood stage in the main east-west channel, flows spilled to the south through the Kern River GSA and flowed into Kern Lake, in the southern region of the GSA, and Buena Vista Lake, west of the GSA. These two now-dry lakebeds received thick deposits of fine-grained sediments as flood flows diminished and dropped their bed load. Since the regulation of river flows with the construction of Isabella Dam in the early 1950s, the lakebeds no longer receive regular surface water inflow and have been converted to agriculture.

These depositional patterns have resulted in thick sequences of coarse-grain sediments (sand) in the central region of the GSA and fine-grained deposits (silt and clay) in the paleo-lakebeds, as shown on the soil texture map on **Figure 3-8**. This soil texture map is from the Soil Survey Geographic (SSURGO) database for Kern County, developed by the U.S. Department of Agriculture, Natural Resources Conservation Service, and covers most of the GSA except for small regions in the northern and northeastern edges of the GSA. Soil textures are color-coded and listed in the legend by decreasing grain size (texture). Loamy sands, sandy loams, and fine sandy loams, shown by shades of yellow and light orange, are the dominant soil textures in the GSA. Alluvium is present along, and primarily to the south of, the present-day Kern River. Loams to clay, shown in dark orange, green, brown, and dark red, are the primary soil textures along the southern boundary of the GSA. An additional north-south band of fine-grain textures also is present in the eastern GSA.

Figure 3-8 also illustrates the canals and recharge ponds within the GSA. The recharge ponds are operated by the City of Bakersfield and Kern Delta Water District, and for the most part, located in areas of coarse-grained soils (loamy sands to fine sandy loams). A recharge pond in the western GSA appears to be primarily on loamy soil.

3.2.4 Hydrologic Setting

The local hydrologic setting is dominated by the Kern River, which provides significant water supply to the KRGSA Plan Area. Deep percolation of precipitation and local stormwater runoff provide additional natural water sources. These surface water supplies are augmented with imported water, supported by associated infrastructure of diversions, conveyance, treatment, and delivery. All of these supplies are actively managed in the KRGSA Plan Area to optimize conjunctive use and groundwater recharge. Details of the local hydrologic setting are provided below.

3.2.4.1 Climate

The climate of the Plan Area is characterized by hot, dry summers and cool, moist winters. The mean annual temperature is 65° F and summer highs frequently exceed 100° F. On average, about 70 percent of the precipitation occurs in December through March. The long-term average precipitation at the Bakersfield Field Meadows Airport station (located in the northern KRGSA Plan Area) is approximately 6 inches per year (NOAA, 2018). Annual precipitation – displayed by Water Year[10] (WY) - is shown on **Figure 3-9**, covering a 52-year period from WY 1966 – WY 2017. As shown on the figure, annual precipitation is highly variable, ranging from 2.26 inches in WY 2008 to 14.99 inches in WY 1998. Average annual precipitation during the period is 6.13 inches.

Each Water Year shown on **Figure 3-9** is color-coded based on the San Joaquin Valley water year hydrologic classification indices (CDEC, 2018): wet (blue), above normal (green), below normal (yellow), dry (orange), and critically dry (dark brown). The San Joaquin Valley water year indices do not always correlate with precipitation measured at the Bakersfield airport station because they are based on runoff in the Stanislaus, Tuolumne, Merced, and San Joaquin Rivers, all north of Kern County. Based on a discussion with DWR, these hydrologic classifications are the best available information for Kern County because DWR does not calculate runoff indices for the Tulare Basin (DWR, personal communication, 2018).

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[10] A Water Year (WY) is defined as October 1 through September 30.

Figure 3-9 shows that the wettest water years in the last 50 years are associated with precipitation totals above 10 inches per year; using this definition, wet years occurred in WYs 1978, 1983, 1995, 1998, and 2011. The driest water years, with precipitation less than 4 inches per year, occurred in WYs 1970, 1972, 1984, 1990, 2002, 2007-2008, and 2013-2014.

The Plan Area is also characterized by relatively high referenced evapotranspiration rates. Over the 20-year Study Period, reference evapotranspiration[11] (ETo) averaged about 60 inches per year. Monthly averages range from an ETo of 1.5 inches in January to 9.1 inches in July (CIMIS, 2018). These rates indicate that much of the local precipitation would be evaporated (or transpired by local vegetation), with relatively small amounts contributing to deep percolation and recharge.

However, most of the precipitation and runoff in the KRGSA Plan Area is actively managed to maximize recharge. The City of Bakersfield maintains almost 400 small stormwater retention facilities (referred to as sumps) that are all open-bottomed and are managed for recharge of urban runoff (City of Bakersfield and Kern County, 2015; CVRWQCB, 2013). Collectively, these small basins cover more than 500 acres, are sited throughout the entire Metropolitan Bakersfield area. Almost all of these facilities reside on relatively permeable soils and underlying sediments and capture about 16,000 AFY of stormwater runoff, on average. Additional recharge of precipitation is accomplished by diversion and management of runoff into unlined canals and larger recharge/banking facilities.

3.2.4.2 Kern River

The Kern River is the primary surface water body in the KRGSA Plan Area and crosses about 16 miles of the northern region of the KRGSA (see **Figures 1-1 and 2-1**). The river enters the Kern County Subbasin at the Kern Gorge fault, runs parallel to the northeastern boundary of KRGSA, and crosses into the KRGSA Plan Area as it reaches the valley floor. The Kern River is about 165 miles long and drains snowmelt and runoff from a watershed of approximately 2,400 square miles. The watershed extends to high elevations near Mt. Whitney in the Sierra Nevada (City of Bakersfield, 2012b). Since 1953, flows in the Kern River have been regulated at Isabella dam, about 25 miles upstream from the KRGSA Plan Area (**Figure 1-1**). Rights to the Kern River and allocations of river flow are summarized in **Section 2.4.2**.

Daily inflows to Lake Isabella are illustrated on the top graph of **Figure 3-10** for wet (1983), dry (2015), and average (1979) years. A Kern River Index is established for runoff between April and July, representing a percentage of the long-term average flow for those months. As indicated on **Figure 3-10**, the wet, dry, and average years selected for illustration of reservoir inflows reflect Kern River flows of 339 percent, 92 percent, and 13 percent, respectively, of the long-term average flow. The large

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[11] Reference evapotranspiration (ETo) refers to ET from a hypothetical reference surface, such as grass, which would potentially occur if unlimited amounts of water were available. It is used to estimate the evaporative demand of the atmosphere independent of crop type.

variability of inflows associated with water year type is illustrated by the differences in the May peak flow rates between a wet year (14,038 cfs), an average year (3,355 cfs), and a dry year (373 cfs).

As described previously in **Section 2.4.2**, two permanent stream gage stations, First Point and Second Point, were established to measure flow in the Kern River (see **Figures 1-1 and 2-1**). The record of daily discharge at First Point is used to allocate water among the various Kern River interests, referred to as First Point diverters, Second Point diverters, and Lower River diverters (as described in **Section 2.4.2**). The Second Point of measurement is approximately 20 miles downstream and is used to check upgradient water use (and entitlements) with diversion rights downgradient of Second Point (Boyle, 1975).

Regulated Kern River flows at First Point are shown in the lower graph on **Figure 3-10**. Data are included for the 20-year Study Period 1995-2014 and extended through 2016 to show more recent conditions. During this period, regulated flows at First Point have ranged from 1,568,932 AFY (1998) to 139,890 AFY (2015). The low flows observed in 2015 represent the historical low flow condition for First Point measurements dating back to 1954.

3.2.4.3 Surface Water Channels, Canals, and Management

The Kern River, along with imported surface water sources, is actively managed for optimized recharge and conjunctive use in the KRGSA Plan Area and other areas. Surface water is managed and regulated using the Kern River channel, weirs, diversion structures, and a web of unlined and lined canals and pipelines that connect regional facilities for operational flexibility. Major lined and unlined canals are shown on **Figure 3-11**. The main Kern River channel is managed with the canal systems for conveyance and intentional recharge; the channel is shown in brown to allow differentiation from the intricate canal system depicted on **Figure 3-11**. The primary river weirs and measurement stations are also included on **Figure 3-11**.

Since 1976, the City of Bakersfield has managed the Kern River channel to improve both flood control and water supply operations, including monitoring and recording of river flows and water use. The City accounts for all diversions and inputs into the Kern River system from First Point to Second Point (**Figure 3-11**). Data are recorded in annual Kern River Hydrographic Reports that also provide information on entitlements and amounts of water diverted or released to others.

Kern River water is diverted primarily for drinking water and agricultural irrigation purposes and is also used in water exchanges to facilitate deliveries of other water sources or supplement local supplies. Between 1970 and 2010, about 80 percent of the water measured at First Point had been diverted above the Calloway Weir (DBS&A, 2012) (**Figure 3-11**).

Canal and pipeline conveyance systems can move Kern River water to any of three regional water purification plants (WPP) for treatment and delivery of drinking water to KRGSA Plan Area customers. Two of these plants, North Garden WPP and North East WPP, are operated by Cal Water and designed to treat Kern River water for distribution in the municipal water system (**Figure 3-11**).

The Henry C. Garnett WPP (HCGWPP), located in the north central Plan Area (**Figure 3-11**), is operated by ID4 for the treatment of imported SWP water. The HCGWPP also receives and treats Kern River water through exchanges, as well as groundwater that has been recovered from local groundwater banking projects both inside and outside of the KRGSA. SWP water is conveyed from the California Aqueduct to the HCGWPP via the Cross Valley Canal[12] for treatment, distribution, and use (**Figure 3-11**). ID4 also banks water in several banking facilities (including the Kern River Channel) via the Cross Valley Canal or other conveyance; recovered water is pumped back into the canal for conveyance to the HCGWPP. Conveyed water is also recharged along the unlined portions of the Cross Valley Canal; this recharge is tabulated and recovered for future use, as needed (ROWC, 2018).

KDWD conveys Kern River water via canals that connect to regional facilities including the Carrier Canal, the Kern River Canal, and the Arvin-Edison Intake Canal (all shared with other users). The facilities allow conveyance of water to the KDWD distribution system consisting of five main canals and laterals covering about 150 miles and associated with the five separate service areas. These canals are shown on **Figure 3-11** and, from west to east, include the Buena Vista Canal, Stine Canal, Farmers Canal, Kern Island Canal (including the main canal and the Central Branch), and Eastside Canal. Canals are mostly unlined; small reaches through some urban areas consist of either concrete-lined canals or pipelines.

KDWD provides intentional and measured groundwater recharge through the unlined canals during conveyance of water deliveries during the irrigation season. KDWD also manages a groundwater replenishment program outside of the irrigation season by diverting water to the unlined canals during winter months when both recharge water and canal capacity are available (Todd, 2013).

In additional to the intentional recharge in canals and basins, recharge also occurs from the use of surface water for agricultural irrigation. Because applied irrigation water may percolate through the root zone too quickly for efficient crop use, a certain percentage of the applied water will percolate to the water table. When groundwater is used to irrigate crops, irrigation inefficiency results in some of the applied groundwater circulating back to the groundwater system, a process referred to as return flows. When the irrigation source water is surface water, the portion of the applied water that percolates to groundwater represents a new source of recharge. KDWD estimates an average irrigation efficiency of about 80 percent in the southern Plan Area – an estimate consistent with recent surface water-groundwater modeling – indicating that about 20 percent of the surface water deliveries to agriculture represent recharge to the groundwater basin. Irrigation inefficiency also results in recharge to the urban areas where outside irrigation occurs, such as lawns, parks, sports fields, and other areas.

Since the late 1980s, large-scale groundwater recharge/banking operations have been constructed along the Kern River. The first major banking project, the City's 2800-acre spreading area (referred to herein as the COB 2800), is located within the GSA on the western edge of Bakersfield with ponds both north and south of the river (**Figure 3-11**). The City's COB 2800 extends about 6 miles, covers approximately 1,470

[12] The Cross Valley Canal is also used to convey CVP exchange water into the Subbasin.

acres of basins within the larger 2800 acre property, and includes old river channels, overflow lands and constructed spreading basins. During the 20-year Study Period WY 1995 – WY 2014, an average of about 13,000 AFY has been recharged at the facility for KRGSA member agencies[13] (ID4 and the City).

An additional banking program, the Berrenda Mesa project, operates east and adjacent to the COB 2800 facility in the KRGSA Plan Area (**Figure 3-11**). The Berrenda Mesa groundwater bank consists of six recharge areas on about 369 acres immediately adjacent to the Kern River channel and downstream of the Bellevue Weir. Stored groundwater is recovered using 14 extraction wells, 9 of which are inside the KRGSA Plan Area. The project is jointly-operated by KCWA and Berrenda Mesa Water District for the benefit of four Kern County water districts (project participants) located outside of the KRGSA Plan Area. During the 20-year Study Period, an approximate average annual of 9,200 AFY was recharged in the groundwater bank.

In the southern KRGSA Plan Area, KDWD has operated a managed aquifer recharge and groundwater banking program since 2003. The program involves approximately 814 acres of spreading basins to allow for groundwater replenishment of surplus district water and for storing water on behalf of its banking partners, which include Metropolitan Water District of Southern California and San Bernardino Valley Municipal Water District. SWP water is received from banking partners using the Cross Valley Canal either directly or via the Arvin-Edison canal; Kern River water can also be banked for partners through an SWP water exchange with BVWSD. The terms of the banking agreement allow KDWD to also use the spreading basins for recharge of its own surface water. Locations and names of in-district recharge basins are shown on **Figure 3-11** (basins in areas south of the Arvin-Edison canal on the figure). Banking for out-of-district partners during six years over the 20-year Study Period (2003, 2005, 2006, 2010, 2011, and 2012) totaled about 245,245 AF.

The Kern River channel is also managed as a recharge and recovery facility by the City, KCWA, and others. The City records river flows and recharge on a daily basis, allocating the amount recharged by each party to track river flow and recharge in accordance with water rights.

In addition to the large number of banking projects in the KRGSA Plan Area, several major banking projects operate adjacent to the east-central KRGSA Plan Area including the Pioneer Project (2,233-acres operated by KCWA) and the Kern Water Bank, (about 20,000 acres operated by the Kern Water Bank Authority) as shown on **Figure 3-11**. As previously mentioned, ID4 uses these facilities for recharge and recovery of SWP water in addition to in-district banking. Also, KDWD is a participant in the Pioneer Project.

Finally, also shown on **Figure 3-11** are numerous recharge basins in adjacent water districts outside of the KRGSA Plan Area that are used locally for groundwater replenishment and banking for outside-District partners. These basins outside of the KRGSA Plan Area are not meant to be comprehensive of

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[13] KCWA also banks water in the COB 2800 facility for parties outside of the KRGSA Plan Area; those totals are not included here.

the large number of additional managed aquifer recharge facilities in the Kern County Subbasin but are provided to illustrate examples of nearby recharge areas.

3.2.4.4 Additional Surface Water Drainageways

In addition to the Kern River, one small drainage – Caliente Creek – flows into the southeastern KRGSA Plan Area during wet years. The Caliente Creek drainageway is shown on **Figure 3-4**. Caliente Creek originates in the Sierra Nevada foothills on the eastern Subbasin margin and flows across Arvin Edison WSD and the community of Lamont. During wet years, the creek floods the valley floor and extends into KDWD, creating problems of erosion and flooding. In 2016, Kern County commissioned a feasibility study to better manage flood waters in the area; options from that study are being evaluated (AECOM, 2017). Although this flood water likely provides some groundwater recharge in KDWD when present, the amount is assumed to be small because most of the flooded area occurs over lower permeability flood basin deposits discussed in **Section 3.2.1.2** and shown on **Figure 3-4**.

3.2.4.5 Recharge Areas in the KRGSA

The primary areas and conditions that promote groundwater recharge as discussed above are shown on the Plan Area map on **Figure 3-12**. Recharge areas include the sandy Kern River channel, unlined canals used for intentional recharge, and other managed aquifer recharge facilities including recharge basins, stormwater basins, and concentrated banking operations. **Figure 3-12** also highlights the occurrence of the more permeable soils discussed in **Section 3.2.3**, where surface water is readily recharged. The occurrence of these higher permeability soils and sediments along the Kern River channel, including unconsolidated alluvial deposits of sand and gravel, illustrate why the channel is used for managed recharge by numerous agencies in the KRGSA. Although soil textures along the southern rim of the Plan Area are finer-grained, local sand lenses allow for some infiltration of surface water (and groundwater return flows) applied for crop irrigation (see areas of agricultural irrigation shown on **Figure 2-9**).

Given the depth to groundwater, there are no known active springs, seeps, or wetlands in the KRGSA Plan Area; some areas of shallow groundwater occur where applied water becomes perched in low permeability soils and drains slowly to the underlying water table; groundwater occurrence and levels are discussed in more detail in **Section 3.3.1 and 3.3.2**. Additional management and recharge of surface water was discussed previously in **Section 3.2.4.3** above. Amounts and locations associated with these and other recharge components are provided in the water budget analysis in **Section 4**.

3.2.5 Basin Geometry and Basin Bottom

The top and lateral sides of the Kern County Subbasin have been defined by DWR (DWR, 2006 and 2016). As described in DWR's Bulletin 118, the Subbasin is "bounded on the west, southwest, and east by the bedrock formations of the Coast Range, San Emigdio Mountains, and Sierra Nevada, respectively. It is separated by the White Wolf Subbasin on the southeast by the White Wolf Fault. The northern boundary is generally coincident with the County line." (DWR, 2016).

As shown on **Figure 3-3** (and other figures), the northeastern boundary of the KRGSA Plan Area is close to or coincides with the eastern Subbasin boundary. In that area, the KRGSA Plan Area boundary abuts the outcrop of Miocene marine sedimentary units (see **Figure 3-3**), which have been excluded from the groundwater Subbasin by DWR. One small segment of the KRGSA Plan Area northeastern boundary abuts these units at the surface and, if projected vertically, would also intersect these units at depth.

The bottom of the Subbasin has not been well-defined and will likely vary significantly across the subbasin based on changes in basin geometry, structural features at depth, and groundwater quality. Previous Central Valley studies have observed saline groundwater in various areas and depths and have used water quality as the effective bottom of groundwater subbasins. Some references define the groundwater basin as consisting of continental deposits as an effective boundary, suggesting that the top of the marine sediments could be used to define the basin bottom. This usage also suggests a change in water quality and assumed saline water in the marine sediments. However, because some of the marine sediments crop out and are capable of producing fresh water, the base of the Subbasin beneath the KRGSA Plan Area is evaluated on available information of water quality changes with depth. Issues affecting deep groundwater quality as related to the bottom of the basin are described in the sections below. Overall groundwater quality within the subbasin is described in **Section 3.3.4**.

3.2.5.1 Oil Fields

The KRGSA Plan Area overlies all or portions of about 23 active or abandoned oil fields[14]. The presence of petroleum hydrocarbon reservoirs indicates that the geologic formation is isolated at depth without the ability to be readily replenished by groundwater recharge (a condition required to trap the hydrocarbons). In addition, the occurrence of petroleum hydrocarbons in the formation would inherently limit the use of formation water. Although water produced from some Kern County oil fields is being separated and treated for beneficial uses in other areas, this formation water would not be connected to the groundwater system and not be considered part of the groundwater basin pursuant to groundwater management. In addition, most of the local oil fields have been exempted from the USEPA definition of protected groundwater (discussed in more detail in **Section 3.2.5.3**). Therefore, the shallow-most top of oil production in an oil field would provide a conservative estimate of the bottom of the Subbasin, where present.

The locations of oil fields are available for download from the California Division of Oil, Gas, and Geothermal Resources (DOGGR) website; administrative boundaries and productive limits of these oil fields are mapped on **Figure 3-13**. As shown on the map, most of the oil fields beneath the KRGSA Plan Area are located along the margins of the boundary with only a small portion of their productive limits in the KRGSA (e.g., see Mountain View and Edison oil fields on the east, and Ten Section and Rosedale on the west, **Figure 3-13**). Nonetheless, oil fields with any productive limits that overlap the KRGSA Plan Area are included in the basin bottom analysis for completeness. Using this criterion, portions of about 24 oil fields extend beneath the KRGSA Plan Area.

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[14] The term "oil fields" is used generically herein to include both oil and gas fields.

The location of a regional geologic cross section line (labeled C-D) that crosses the KRGSA Plan Area and some of these oil fields is shown on **Figure 3-13**. The cross section, with modifications, is provided as **Figure 3-14**. This section was prepared by DOGGR (1998) to show the subsurface geology beneath the oil fields in the southern San Joaquin Valley. It has been modified to include the average depth of the shallowest oil-producing zone in the oil fields (indicated by the red triangles on **Figure 3-14**). The general extent of the KRGSA Plan Area and the Kern County Subbasin are shown for reference. As indicated on the cross section, the shallowest hydrocarbon zone in most of the oil fields occurs within older marine sedimentary units (purple shading) of the Subbasin. Two exceptions include shallow productive hydrocarbon zones at the Kern River and Elk Hills oil fields on the eastern and western sections of the cross section, respectively. In the Kern River and Elk Hills fields, oil production occurs in the continental and continental/marine deposits of the Kern River Formation and the San Joaquin Formation, respectively. Although the shallowest production in the Kern River oil field is at about 400 feet deep, the depth to the production zone at the location of the cross section is the depth depicted on **Figure 3-14** (more than 1,000 feet deep).

Other oil fields illustrated on **Figure 3-14** that are at least partially located beneath the KRGSA, include Fruitvale, Bellevue, McClung, Strand, and Canal fields. Although many of these fields do not appear to be within the KRGSA on the cross section, portions of these fields occur beneath the KRGSA in other areas (see **Figure 3-13**). As illustrated on the cross section, the top of the hydrocarbon zone at the Fruitvale field is within the marine sedimentary units at an approximate depth of 3,200 feet. Depths to the shallowest production zone for fields beneath the KRGSA range from about 1,000 feet to more than 10,000 feet deep (including oil fields not included on the cross section).

3.2.5.2 Base of Fresh Water

An additional consideration in defining the bottom of the groundwater Subbasin is the increasing salinity of groundwater with depth beneath the KRGSA Plan Area. Groundwater quality investigations in the Central Valley have used various methods to delineate the base of fresh water (Berkstresser, 1973; Page, 1973). One such map developed by a USGS investigator (Page, 1973) provides elevation contours on the base of fresh water that covers the KRGSA Plan Area and is reproduced on **Figure 3-15**. Recognizing that there are several definitions for *fresh water* (Todd and Mays, 2005), this map was based on a specific conductance value of 3,000 micromohs per centimeter (umhos/cm), which is equivalent to a concentration of total dissolved solids (TDS) of about 2,000 to 2,880 milligrams per liter (mg/L), varying with temperature and differences in water chemistry.

As shown on **Figure 3-15**, the base of fresh water extends below an elevation of -3,000 feet msl over most of the KRGSA Plan Area. Considering ground surface elevations of about 400 feet msl over this area (**Figure 3-7**), the -3,000 feet msl elevation also represents a depth of about 3,400 feet. The base of fresh water is shallowest in the northeastern KRGSA and along the western boundary, with elevations between about -1,600 feet msl on the west to -2000 feet msl in the northeast (based on limited northeastern data). Between those boundaries, the base of fresh water deepens significantly in the central KRGSA, extending below an elevation of -4,400 feet in the south-central portion of the KRGSA

Plan Area. The map does not extend into the uplands above the valley floor in the northeastern KRGSA Plan Area.

In 1992, the Society of Petroleum Engineers published a study estimating the base of fresh water from resistivity values on more than 70 electric logs in nearby oil and gas field wells (O'Bryan, 1992). This methodology included a definition for the base of fresh water consistent with Page (1973) (i.e., about 2,000 mg/L TDS). The O'Bryan map (not shown) covers an approximately eight square mile area southwest of Bakersfield and overlaps the southwestern region of the Page map, including most of the KRGSA. A comparison of these two maps indicate relatively good agreement for the KRGSA Plan Area although the 1992 map indicates slightly deeper fresh water in the southern KRGSA. Near the southern boundary, the 1992 map shows fresh water below an elevation of -5,000 feet, msl, about 600 feet deeper than the deepest elevation mapped by Page (1973) (O'Bryan, 1992).

3.2.5.3 Base of Underground Source of Drinking Water (USDW) and Exempt Aquifers

As set forth in the Safe Drinking Water Act, the U.S. Environmental Protection Agency (USEPA) has defined groundwater to be protected as part of the Underground Injection Control (UIC) program (CFR, Title 40, Chapter 1, Subchapter D, Part 144.A.). This definition of protected groundwater, referred to as the Underground Source of Drinking Water (USDW), is reproduced below:

> *Underground source of drinking water (USDW) means an aquifer or its portion:*
> *(a) (1) Which supplies any public water system or*
> *(2) Which contains a sufficient quantity of ground water to supply a public water system and*
> *(i) Currently supplies drinking water for human consumption or*
> *(ii) Contains fewer than 10,000 mg/L total dissolved solids; and*
> *(b) Which is not an exempted aquifer. (40 CFR §144.3).*

In general, this definition indicates that any formation containing groundwater with less than 10,000 mg/L outside of an exempted aquifer (including oil-producing zones) would qualify as a USDW if it contains a sufficient quantity of groundwater.

A SWRCB resolution (88-63, as amended by 2006-0008) provides policy on sources of drinking water. According to that guidance, groundwater with a TDS of less than 3,000 mg/L may reasonably be expected to supply a public water system, if aquifer yield is sufficient (more than 200 gallons/day), the supply is not contaminated or beyond reasonable treatment, and the groundwater is not exempted by 40 CFR §146.4 (SRWCB, 2006). This suggests that the use of the base of fresh water represents a usable supply of groundwater; as such, that surface is considered in the definition of the bottom of the basin. Although groundwater quality below the base of fresh water represents a higher salinity, the base of the USDW may also represent additional groundwater supply. Accordingly, both the base of fresh water and the base of the USDW are incorporated into the definition of the bottom of the groundwater basin.

The depth of USDW has recently been defined in the southern San Joaquin Valley by a team of researchers from California State University, Bakersfield (Gillespie, et al., 2017). The group used geophysical log analyses to estimate the depth where water salinity increased above the 10,000 mg/L threshold included in the USDW definition. This map, showing the depth to a water salinity of 10,000 mg/L, was designated as the base of the USDW by the investigators; the map is shown as **Figure 3-16**.

As shown on **Figure 3-16**, the contours defined by water salinity are very deep beneath the KRGSA and extend below 9,000 feet deep in the southwestern portion of the Plan Area. While it seems highly unlikely that groundwater would be extracted from such depths, there is no basis for assuming that USDW could not extend that deep. Further, depths in the western KRGSA Plan Area range from about 3,000 feet to 4,000 feet deep, which are similar to depths associated with the base of fresh water (compare **Figures 3-15** and **3-16**).

It is recognized that the method used to create the USDW map did not consider whether the salinity mapping resulted in depths below an exempt aquifer and/or the top of an oil producing zone (Gillespie, et al., 2017); this suggests that the USDW may be shallower than mapped in some areas. To correct the map for shallow exempt aquifer zones, information on exempt aquifers was downloaded from the EPA and DOGGR websites and considered in the analysis with the oil field data.

Aquifer exemptions are approved by USEPA and typically represent formations that will receive oil field wastewater (also referred to as produced water). A typical method of produced water disposal is to inject it back into the oil zone where it originated or into another isolated subsurface zone. Consistent with the methodology of excluding oil fields and Exempt Aquifers from the groundwater basin, the USDW map requires correction if oil fields or exempt aquifers occur at shallower depths than indicated on **Figure 3-16**.

3.2.5.4 Basin Bottom Delineation and Groundwater in Storage Definition

Based on the maps and analysis described above, the bottom of the Subbasin beneath the KRGSA Plan Area is defined as groundwater outside of a hydrocarbon zone that contains no more than 10,000 mg/L TDS unless that water has been determined to be an exempt aquifer pursuant to the Code of Federal Regulations, Title 40 part 146.4. It is further assumed that the Subbasin would be a continuous unit from the surface down to the basin bottom; no formations below the shallowest oil producing zone or shallowest exempt aquifer would be included.

This approach to modifying the base of fresh water and USDW beneath the KRGSA Plan Area and defining the bottom of the groundwater Subbasin is illustrated by the conceptual diagram on **Figure 3-17**. Specifically, the bottom of the groundwater Subbasin beneath the KRGSA Plan Area will follow the base of the USDW as mapped by Gillespie et al. (2017, **Figure 3-16**) but will be modified by the top of oil fields and exempt aquifers where shallower than the base of the USDW. In addition, the Base of Fresh Water will also be modified by the top of oil fields and exempt aquifers where shallower that the elevation of fresh water as mapped by Page (1973, **Figure 3-15**). As indicated on **Figure 3-17**, the adjusted base of fresh water will be used to define the usable fresh water storage of the groundwater basin. The adjusted USDW will be used to define the bottom of the Subbasin and allow for an emergency water supply.

To determine where adjustments to these maps are required, data from the 24 oil fields that wholly or partially overlap the KRGSA Plan Area are provided on **Table 3-1**. For each of the oil fields, the shallowest productive limits within or closest to the KRGSA Plan Area were estimated using oil field data from DOGGR (1998). Both elevations (column C) and depths (column F) of the productive limits are included on the table using ground surface elevations (**Figure 3-7**) at the oil field area of interest.

Several of the oil fields on **Table 3-1** are associated with approved Exempt Aquifers that may be shallower than an oil-producing zone but all Exempt Aquifers except one were either at the same depth or deeper than the oil producing zones. For the Kern River Oilfield, the Kern River Formation is an exempt aquifer and occurs at a shallow depth on the northern boundary of the KRGSA Plan Area. In this area, the exempt aquifer significantly limits the thickness of groundwater supply. Except for the Kern River Oilfield, no adjustments were made to the base of fresh water or USDW maps for Exempt Aquifers.

Table 3-1: Oilfields and Adjustments to Subbasin Bottom in the KRGSA Plan Area

Oil and Gas Field in KRGSA Plan Area	Adjustments to Base of Fresh Water			Adjustments to USDW			Exempt Aquifers
	Elevation Base of Fresh Water in KRGSA (ft, msl)	Shallowest Elevation of Production in KRGSA (ft, msl)	Elevation Base of Fresh Water Adjusted for Oil Production (ft, msl)	Depth to Base of USDW in KRGSA (ft)	Average Depth to Production or Exempt Aquifer in KRGSA	Depth to Bottom of USDW Basin Adjusted for Oil Production	
Ant Hill	-2000	-1200	-1200	6000	2525	2525	
Bellevue	-2000	-5500	-2000	3250	6560	3250	
Canal	-1400	-7500	-1400	2500		2500	
Canfield Ranch	-2600	-5850	-2600	3250	7146.5	3250	
Edison	-2000	0	0	6000	1540	1540	Chanac, Wicker
	-2900	-2400	-2400	6000	3540	3540	Santa Margarita Transition
Fruitvale	-2400	-2300	-2300	4750	3305	3305	Santa Margarita
Greeley	-2200		-2200	3500		3500	
Kern Bluff	-2000	0	0	6000	1065	1065	
Kern Front	-2000	-600	-600	5500	2110	2110	Vedder, Chanac
Kern River	-2000	400	400	5750	100	100	Kern River Formation (100')
Kernsumner (Abd)	-3400	-8600	-3400	6500	9165.5	6500	
Lakeside (Abd)	-2600	-7600	-2600	3000	8328.5	3000	
Lakeside, South (Abd)	-2800	-9400	-2800	3500	10312	3500	
McClung (Abd)	-1800	-6550	-1800	3000	7100	3000	
Mountain View	-3400	-4600	-3400	6000	5392	5392	Kern River, Chanac
	-3200	-7600	-3200	8250	8000	8000	
Paloma	-2400	-11200	-2400	3250	11592	3250	
Rosedale	-2400	-4000	-2400	3500	4361	3500	
Rosedale Ranch	-2200	-3600	-2200	3750	4183.3	3750	Chanac
Round Mountain	-2000		-2000	6000		6000	Walker, Vedder
							Pyramid Hill, Jewett
Seventh Standard	-2400	-6820	-2400	3500	7482.7	3500	
Stockdale	-3200	-5100	-3200	4250	5518.2	4250	
	-3200	-9500	-3200	4250	10218.2	4250	
Strand	-1600	-7450	-1600	2500	7787.8	2500	
Ten Section	-2200	-7150	-2200	2750	7734	2750	
Union Ave.	-3800	-4460	-3800	6000	4960	4960	

Table 3-1 also lists the elevations of the base of fresh water at each of the productive areas in the KRGSA (column D). A comparison of the base of fresh water to the elevation top of the productive limits shows that most of the oil production is significantly below the base of fresh water (compare columns B and D). However, there are 6 of the 24 oil fields on **Table 3-1** that indicate oil production at a shallower

depth than the base of fresh water (see elevations for Ant Hill, Edison, Fruitvale, Kern Bluff, Kern Front, and Kern River on **Table 3-1**). This suggests that water in these oil and gas reservoirs is relatively fresh with possible TDS values less than about 2,000 mg/L. Rather than re-contouring the base of fresh water around these shallower oil fields, the contour map is simply adjusted by assigning one elevation to each applicable oil field and ending the contours at that field boundary; this methodology is shown on **Figure 3-18.**

As shown on **Figure 3-18**, most of the fields with shallower fresh water elevations generally occur in the northeast and east portions of the KRGSA Plan Area; several are located mostly outside of the KRGSA in the uplands of the eastern Subbasin. In the northeast, Subbasin aquifers are thin and shallow and the base of fresh water compared to the local shallow oil production is less certain. The Page analysis of the base of fresh water ends at the edge of the Kern River and Kern Front oil fields. In this area, the basin bottom is likely to be limited by the top of the shallow oil production rather than groundwater salinity.

Table 3-1 also lists the depths to the base of the USDW at each of the productive areas in the KRGSA Plan Area (column E). A comparison of the depth of the USDW with the depth of oil field production indicates that 8 of the 24 oil fields are shallower than the currently mapped depth for the USDW (compare column C to column E). These include the 6 oil fields that were shallower than the base of fresh water and also includes Mountain View and Union Ave. Similar to the methodology applied for the base of fresh water, the depth to the USDW map is modified by assigning one depth to the portion of the oil field in the KRGSA Plan Area and ending the previously-mapped contours at that location. This adjusted map is shown on **Figure 3-19**.

Collectively, these two maps are used in the definition of the Subbasin bottom. **Figure 3-18** defines the elevation on the bottom of usable fresh groundwater in storage. Figure 3-19 represents the bottom of the groundwater Subbasin beneath the Plan Area and serves as the base of an emergency supply. Because the oil bearing zones are defined as beneath the bottom of the Subbasin, there would be no decrease of groundwater in storage associated with water in the oil bearing zones.

3.2.6 Principal Aquifers and Aquitards

Almost all of the groundwater production from the KRGSA Plan Area occurs in the upper 1,200 feet of the aquifer system, consisting of the Quaternary alluvium and the Kern River Formation. Collectively, these two formations are considered the Principal Aquifer for groundwater management purposes. This single designation is appropriate because most production wells are screened in both units, the two units are difficult to differentiate on subsurface logs, and the two formations appear to be hydraulically connected without an intervening, regionally-extensive aquitard.

Groundwater age dating by USGS provides additional support for a single Principal Aquifer. In a groundwater quality study that included 14 wells located throughout the KRGSA Plan Area, USGS found relatively young groundwater (i.e., post-1953 Modern age) in most Plan Area wells screened from about 350 feet to 700 feet (Burton, et al., 2012). This suggests that recently recharged water extends throughout much of the Principal Aquifer including the primary production zones. Several wells along the western Plan Area boundary appeared to have older groundwater with a mix of Pre-Modern- and Modern-age water. This is likely an area where some older subsurface inflow from the Subbasin margin occurs.

The hydraulic connectivity of the Principal Aquifer is supported across the entire Plan Area. The aquifer system is primarily unconfined throughout most of the northern and central Plan Area and transitions to semi-confined and confined in the southern Plan Area and with depth. As discussed previously, the productive sands in the south are confined below silts and clays associated with distal alluvial fan deposits and paleo-lakebeds. As this transition is gradual and complex in areas with heterogeneous deposits, groundwater in the Quaternary Alluvium and Kern River formations functions as one continuous aquifer system throughout the Plan Area.

In brief, the Principal Aquifer reflects a geologic history of Quaternary-Pliocene fluvial deposition on the coalescing Kern River and Caliente Creek alluvial fans, entrenching of those fans by streams and rivers, and subsequent deposition of recent alluvial deposits. With this complex history, identification of single alluvial fan sequences and distinct depositional packages in the subsurface is difficult (Dale, et al., 1966). However, because there is likely no direct relationship between these coalescing alluvial fan packages and overall water-bearing properties of the units, differentiation does not appear necessary for groundwater management.

Nonetheless, it is noted that an abrupt slope change at the convergence of the Caliente Creek fan and the Kern River Fan results in the deposition by Caliente Creek of poorly-sorted heterogeneous material (Dale, et al., 1966). These flood basin deposits are significant to surface recharge and percolation to the underlying groundwater system, as indicated by perched conditions extending along the southern and southwestern KRGSA and beneath the Kern dry lake bed.

Lithology and textures that characterize the two formations composing the Principal Aquifer are described below.

3.2.6.1 Shallow Alluvial Deposits

The surficial distribution of alluvial deposits is shown in **Figures 3-4** and **3-5** and includes younger alluvium presently being deposited along the Kern River and Caliente Creek, flood-basin deposits, and older alluvium. The shallow alluvial deposits, estimated to be up several hundred feet thick in the northern and southern KRGSA, overlie the eroded surface of the Kern River Formation. Deposited by both the Kern River and Caliente Creek, the shallow alluvial deposits are not easily differentiated in the subsurface except for slope angles on the older and younger surfaces and the presence of paleo-soils (Dale, et al., 1966).

3.2.6.2 Kern River Formation

The Kern River Formation crops out on the eastern margin of the valley as shown in **Figure 3-5**. As shown in **Figure 3-6**, the Kern River Formation ranges in thickness from 500 – 2,600 feet thick and overlies the marine Etchegoin and Chanac formations. The Kern River Formation is described (Bartow,

1983) as Pliocene/Upper Miocene nonmarine, semi-consolidated, coarse-grained and pebbly sandstone and conglomerate, containing beds and lenses of siltstone and mudstone; it generally is coarser with decreasing depth and to the east, indicating a source in Sierran granites. Most coarse-grained units are south of the Kern River.

In some areas around the margin of the KRGSA Plan Area, the lower Kern River Formation contains commercial quantities of petroleum hydrocarbons. This occurrence is illustrated on Cross Section C-C' as shown on **Figure 3-6**. Although most of the Kern River Oilfield production occurs outside of the KRGSA Plan Area, the margins of the field, along with the Kern River Bluff and the Kern River Front oilfields overlap a portion of the northeastern KRGSA Plan Area (see production limits of the oilfields on **Figure 3-13**).

3.2.6.3 Aquifer Textures and Cross Sections

Characteristics and textures of the Principal Aquifer system in the KRGSA Plan Area are illustrated on three scaled cross sections shown on **Figures 3-20**, **3-21**, and **3-22**. Cross Section 1-1' (**Figure 3-20**) was constructed along the present-day Kern River to illustrate textures (e.g., sands and clays) associated with the local fluvial deposits. Cross Section 2-2' (**Figure 3-21**) was constructed from northeast to southwest across the approximate direction of alluvial deposition to illustrate the nature of the alluvial fan deposits. Cross Section 3-3' (**Figure 3-22**) was constructed approximately parallel to alluvial fan deposition to illustrate progradation of the alluvial fan deposits over time. These cross sections are described in more detail below. Also included on the cross sections are the groundwater levels representing the historical high levels (WY 1998) and low levels (WY 2015) over the last 50 years (see **Figure 3-9**). Although precipitation was lower in WY 2014 than in WY 2015, most of the historical low water levels occurred during WY 2015 in the KRGSA Plan Area, resulting from the historical low flows on the Kern River (see **Figure 3-10**).

Cross Section 1-1' on **Figure 3-20** illustrates geologic textures and wells on an approximate 18-mile profile along the Kern River in the northern Plan Area. Resistivity logs shown on the section are used to differentiate more permeable textures – such as sand and gravel (in yellow) – from less permeable textures, such as silt and clay (in tan). Approximate resistivity values of 12 to 18 ohm-meters were used as the upper limit for the definition of silt and clay on the logs. As shown on the section, upper units generally contain more sand than deeper units, although the transition is subtle. In addition, clay content generally tends to increase to the southwest. Nonetheless, numerous permeable sand packages occur locally throughout the entire aquifer system as shown.

Water levels for 1998 and 2015 are shown on **Figure 3-20** to illustrate both general groundwater gradients and water level changes from relatively wet conditions to the recent drought of record. Although the section is generally oriented downgradient from northeast to southwest, local water levels are influenced by significant pumping and recharge both along and adjacent to the section. Low water levels in the northeast are affected by pumping to the north of the section (Miles 15 – 17 on **Figure 3-20**). In the southwest, water levels rise due to local banking at the COB 2800 recharge facilities and adjacent banking projects. The difference in banking operations from 1998 to 2015 results in the significant difference in water levels in the southwest (Miles 0 – 3). Specifically, water was being recharged in 1998 and recovered in 2015. Water levels in 2015 are also lower east of the banking areas (near Mile 5) due to local recovery of banked water along the channel (**Figure 3-20**).

Cross Section 2-2' on **Figure 3-21** illustrates the change in textures from the northern Plan Area to the southern Plan Area. The increase in clay content is evident in the south. The cross section also indicates that the southern aquifer system also contains relatively permeable sand packages scattered throughout the vertical section, indicating the heterogeneous nature of the sediments. Water levels for 1998 and 2015 indicate overall lower water levels during the drought, but the changes in water levels from 1998 are generally smaller than seen on Cross Section 1-1.' In the northern Plan Area, water level declines of more than 100 feet are indicated in some northern areas where municipal pumping occurs. In southern agricultural areas, the declines in water levels associated with the drought were generally less than 50 feet.

Cross section 3-3' on **Figure 3-22** provides additional texture data in the southern Plan Area, but in a more conceptual manner. This cross section was modified from the KDWD GWMP, where the section was interpreted more conceptually. The purpose was to identify generalized areas where textures contained more clay or sand, as reflected by representative resistivity logs. As a result, only five resistivity logs are used on the cross section. The increasing clay content in the southeastern Plan Area is illustrated on the section (note the scale changes on the resistivity logs at the bottom of each log). The increased surface and subsurface clays likely result in confined conditions and a larger change in water levels during the drought. The clays also result in perched water as previously discussed and illustrated by an estimated perched water level on **Figure 3-22**.

3.2.6.4 Aquifer Hydraulic Properties

Information on the hydraulic properties for the Principal Aquifer have been compiled from numerous resources including local agencies and publications (Dale, et al, 1966, among others). In particular, pumping test data were compiled and analyzed by Todd Groundwater as part of Kern Fan model development (Todd Groundwater, 2018). These pumping tests were originally conducted by KCWA, City of Bakersfield, Kern Water Bank (KWB) and other local water agencies and provided to KCWA/Todd Groundwater in support of the model project. At the time of compilation, these tests represented the most recent and most reliable data[15] available for determination of aquifer properties. Specifically, most tests consisted of constant-rate pumping tests with observation wells and accurate interpretation of the pumping test data to estimate aquifer transmissivity and hydraulic conductivity. **Table 3-2** presents information from this data set for pumping tests in the KRGSA.

To supplement these data and examine changes in aquifer properties in other portions of the KRGSA, data have been compiled from six additional pumping tests conducted by the USGS in the 1960s (Dale, et al., 1966). Data from the six USGS tests are summarized in **Table 3-3**. The locations of the pumping

[15] Based on documentation of test parameters and results.

tests in **Tables 3-2** and **3-3** and the distribution of transmissivity values from the tests are illustrated on **Figure 3-23**.

As shown on **Figure 3-23**, most of these pumping tests were conducted in the western half of the KRGSA, many near the Kern River and the Kern Water Bank. Pumping tests clustered near the Kern River indicate relatively high transmissivity values. Although data are sparse, the wells farthest from the river have lower transmissivity values.

Table 3-2: Hydraulic Properties from Recent Pumping Tests in the KRGSA Plan Area

Well Identification	Date Drilled	Perforated Interval (feet)	Well Depth (feet)	Total Length of Perforations (feet)	Tested By	Date of Test	Test Type	Data Analysis Method	Pumping Rate (gpm)	Transmissivity (T) (ft^2/day)	Hydraulic Conductivity (K) (ft/day) (T/perf length)
29S/26E-14H		730-1171		441	Kenneth D. Schmidt and Associates	8/1/2005	Unknown	Cooper-Jacob Straight Line[1]	1,230	6,684	15
29S/26E-36K	12/15/2006	200-450, 500-680	720	530	Kenneth D. Schmidt and Associates	4/1/2007	Unknown	Cooper-Jacob Straight Line[1]	4,080	41,975	87
29S/26E-36K01	12/15/2006	200-450, 500-680	720	430	KCWA / KWB	4/18/2007	Constant Rate	Cooper-Jacob Straight Line	4,976	46,000	107
29S/26E-36L01	12/15/2006	200-550, 590-700	740	460	KCWA / KWB	5/10/2007	Constant Rate	Cooper-Jacob Straight Line	5,000	39,000	85
30S/26E-02J03	6/8/1991	224-304, 384-724	740	420	KCWA / KWB	7/27/2001	Constant Rate	Cooper-Jacob Straight Line	2,737	27,000	64
30S/26E-04E03	9/8/2009	280-480, 540-740	820	400	KCWA / KWB	11/12/2009	Constant Rate	Cooper-Jacob Straight Line	1,700	17,800	45
30S/26E-10R01	1/1/1999	160-340, 380-480, 540-730	770	470	KCWA / KWB	2/3/1999	Constant Rate	Cooper-Jacob Straight Line	3,802	16,000	34
30S/26E-11A		210-690		480	Kenneth D. Schmidt and Associates	12/1/2007	Unknown	Cooper-Jacob Straight Line[1]	3,530	24,196	50
30S/26E-11A01				440	KCWA / KWB	12/4/2007	Constant Rate	Cooper-Jacob Straight Line	3,010	22,000	50
30S/26E-11G		200-780		580	Kenneth D. Schmidt and Associates	11/1/2007	Unknown	Cooper-Jacob Straight Line[1]	3,560	29,543	51
30S/26E-11G01					KCWA / KWB	11/16/2007	Constant Rate	Cooper-Jacob Straight Line	3,035	36,000	75
30S/26E-11M		200-780		580	Kenneth D. Schmidt and Associates	12/1/2007	Unknown	Cooper-Jacob Straight Line[1]	3,530	12,165	21
30S/26E-11M01				200	KCWA / KWB	12/5/2007	Constant Rate	Cooper-Jacob Straight Line	3,003	9,400	47
30S/26E-17B01	8/7/1999	170-290, 330-550, 590-690	710	440	KCWA / KWB	9/10/1999	Constant Rate	Cooper-Jacob Straight Line	3,511	19,000	43
30S/26E-17C01	7/20/1999	168-248, 268-308, 328-628, 648-688	708	460	KCWA / KWB	8/23/1999	Constant Rate	Cooper-Jacob Straight Line	3,759	18,000	39
30S/26E-18R01	7/7/1999	160-260, 300-400, 420-620, 640-680	700	440	KCWA / KWB	9/27/1999	Step-Discharge	Step-Drawdown of Single Well	2,008	10,000	23
30S/26E-22P03		280-390		184	Kenneth D. Schmidt and Associates	11/1/2006	Unknown	Cooper-Jacob Straight Line[1]	1,460	10,962	100
30S/26E-23M		270-455		185	Kenneth D. Schmidt and Associates	11/1/2006	Unknown	Cooper-Jacob Straight Line[1]	1,230	31,014	168
30S/27E-19J01	12/7/1948	449-770	712	321	Kenneth D. Schmidt and Associates	4/1/2007	Unknown	Cooper-Jacob Straight Line[1]	1,560	28,607	89
30S/27E-19R		550-710		160	Kenneth D. Schmidt and Associates	3/1/2008	Unknown	Cooper-Jacob Straight Line[1]	1,540	17,512	109
30S/27E-20D		479-669		190	Kenneth D. Schmidt and Associates	4/1/2009	Unknown	Cooper-Jacob Straight Line[1]	1,570	18,448	97
30S/27E-20P	8/15/2006	475-730	750	30	Kenneth D. Schmidt and Associates	9/1/2006	Unknown	Cooper-Jacob Straight Line[1]	1,360	20,854	82
30S/27E-22N		410-620		210	Kenneth D. Schmidt and Associates	1/1/2007	Unknown	Cooper-Jacob Straight Line[1]	1,250	32,217	153
30S/27E-30C		545-670		50	Kenneth D. Schmidt and Associates	3/1/2008	Unknown	Cooper-Jacob Straight Line[1]	1,230	17,378	139
31S/27E-16H		440-505		24	Kenneth D. Schmidt and Associates	5/1/2007	Unknown	Cooper-Jacob Straight Line[1]	485	9,892	152
31S/27E-19A		420-510		190	Kenneth D. Schmidt and Associates	10/1/1991	Unknown	Cooper-Jacob Straight Line[1]	230	6,818	36
									count	26	26
									minimum	6,684	15
									maximum	46,000	168
									average	21,864	75

1 - Test results available in graphical form only; detailed drawdown data not available for review.

Table 3-3: Supplemental Aquifer Test Data in the Plan Area

Well Identification	General Location in KRGSA	Total Length of Perforations (feet)	Transmissivity (ft^2/day)		Hydraulic Conductivity (ft/day)	
			Minimum[1]	Maximum[2]	Minimum[1]	Maximum[2]
29S/26E-4D1	Northwest corner	362	21,388	61,489	59	170
30S/26E-26G1	West-central	700	N/A	48,122	N/A	69
30S/26E-35K01	West-central	699	43,042	65,098	62	93
31S/26E-31A1	Southwest	290	6,684	14,036	23	48
31S/28E-31N1	South-central to Southeast	600	8,555	38,765	14	65
32S/26E-2F1	Southwest corner	573	7,486	26,734	13	47

[1] Most minimum values calculated from recovery data in pumped well
[2] Most maximum values calculated from test data in observation wells
N/A - not available
Modified from Dale, et al., 1966, Table 7

As summarized on **Table 3-2**, 26 wells within the KRGSA provide reliable pumping test data to estimate aquifer parameters. **Table 3-2** summarizes the transmissivity values (at lower right); as shown T values within the KRGSA range from approximately 6,700 to 46,000 ft^2 per day, with an average of approximately 21,900 ft^2 per day. The transmissivity values were divided by the total sand screened in each well to estimate horizontal hydraulic conductivity (K) values for the aquifer. As shown on **Table 3-2**, these horizontal hydraulic conductivity values range from around 15 to 170 feet per day. The average hydraulic conductivity is 75 feet per day, which is representative of clean sand (Todd and Mays, 2005).

Table 3-3 summarizes data from six pumping tests conducted by USGS in the 1960s. The first three tests listed on **Table 3-3** were conducted in the northwest and west-central portions of the KRGSA in areas near the more recent pumping tests described in **Table 3-2**. Average T and K values are higher than more recent pumping tests (47,000 ft/day and 75 feet per day, respectively), which may be affected by test parameters (pumping rates and duration not available for review) and/or the different method of data analyses. Nonetheless, values for the first three tests on **Table 3-3** indicate permeable sands with relatively high transmissivity similar to the more recent test results. The three remaining USGS tests were conducted in the southern and southeast portions of the KRGSA where increasing clay deposits have been mapped. As shown on **Table 3-3**, T and K values for these wells are lower, indicating the presence of less permeable material throughout the Principal Aquifer.

3.3 Groundwater Conditions

Current and historical groundwater conditions are described in this section to provide context and a basis on which to analyze sustainability indicators, develop sustainable criteria, and identify actions and projects to achieve and maintain sustainable groundwater management. The response of the groundwater system to various hydrologic conditions over time is examined using water level hydrographs, groundwater elevation maps, and estimates of changes in groundwater storage. Historical groundwater conditions are analyzed over the 20-year Study Period (WY 1995 – WY 2014) and current conditions are represented by 2015.

3.3.1 Groundwater Occurrence and Flow

Groundwater beneath the KRGSA Plan Area occurs under unconfined to semi-confined conditions in the northern and central KRGSA. Groundwater conditions transition to more confined in the southern KRGSA where shallow clays impede surface recharge. The Principal Aquifer contains a water table that fluctuates seasonally primarily due to managed recharge and groundwater pumping; surface water and groundwater has been managed conjunctively in the Plan Area for more than 120 years.

Groundwater flow in the KRGSA Plan Area is highly influenced by the Kern River. A groundwater mound forms beneath the river during wet periods reflecting surface recharge along the river channel, banking facilities, and unlined canals. Mounding beneath the river results in divergent flow directions to the north and south of the river. When the channel is dry, the mound dissipates, allowing groundwater to flow beneath the river and from one side to the other controlled by hydraulic gradients.

Groundwater levels are generally lower north of the Kern River, controlling subsurface flow to the north. South of the Kern River, groundwater generally flows to the south across the KRGSA. However, local gradients are dynamic and groundwater flow directions are also influenced by local pumping and groundwater banking operations both inside and adjacent to the KRGSA Plan Area. Data and analyses used to further examine groundwater conditions are described below.

3.3.2 Groundwater Elevations

Trends and fluctuations of groundwater elevations in the KRGSA Plan Area are evaluated over the last 50 years using hydrographs constructed from water levels in Plan Area wells. Groundwater elevation contour maps are used to analyze and describe groundwater flow conditions for the historical Study Period (WY 1995 to WY 2014) and recent conditions. A set of Subbasin-wide groundwater elevation contour maps were available to analyze flow directions and horizontal hydraulic gradients. Maps were also used to estimate changes in groundwater in storage over the Study Period.

3.3.2.1 Hydrograph Development

Water levels have been measured within the KRGSA since at least the 1920s, but data availability increases significantly starting in the 1960s, providing a more complete record of water level trends and fluctuations over the last 55 years. Long-term records of water levels in wells within the KRGSA are maintained by several agencies, including KCWA, DWR, and the California Statewide Groundwater Elevation Monitoring (CASGEM) program (also managed by DWR).

Water level data were available at approximately 1,100 wells within the KRGSA. Draft hydrographs were generated electronically for approximately 160 of these wells based on the availability of at least 100 water level measurements. After additional analysis and review, 20 of the hydrographs were selected to illustrate representative long-term trends and fluctuations throughout the KRGSA Plan Area; selected hydrographs are illustrated on **Figure 3-24**. The hydrographs are identified by their unique state well number and also numbered consecutively from 1 to 18 (two graphs show a paired well scenario) for reference. Hydrographs show each well's respective historical water level record between 1965 and 2017. Data are presented as elevation, referenced to mean sea level (msl). The vertical scale of the hydrographs is standardized on **Figure 3-24** from 0 (sea level) to 450 feet msl to facilitate comparisons. The ground surface elevation and depths to the screened intervals are added to the hydrographs when available.

3.3.2.2 Water Level Trends and Fluctuations

Long-term trends in Kern County Subbasin water levels are controlled by both changes in groundwater use and the occurrence of wet and dry hydrologic cycles over time. Although surface water had been used for agricultural irrigation since the late 1800s, an increase in groundwater production occurred in the 1940s associated with increased agricultural production and population growth. Water levels in the KRGSA began a long and sustained decline of about 150 feet from 1945 through the drought of 1977. The portion of this decline from 1965 to 1977 is best illustrated by the long and most complete record on Hydrograph 14 on the lower left of **Figure 3-24**.

The decline through 1977 was arrested, in part, by the wet hydrologic conditions between 1978 and 1983, which allowed water levels to recover across the basin, as illustrated by hydrographs 1, 7, 11 through 14, and 17 (among others). In addition, the widespread availability of imported surface water in the late 1970s contributed to some of the water level recovery across the Subbasin and in the eastern KRGSA. Water levels declined during the drought period of the late 1980s and early 1990s, and then rose in the late 1990s during wet conditions. Water levels declined in the early 2000s and rose slightly during the wet period in 2010 and 2011. After 2011, water levels declined as the result of a severe drought and historic low water levels were reached from 2013 to 2017. Most wells declined about 40 to 50 feet during this recent drought. Wells in the western Plan Area declined more than 50 feet during this period due to increased recovery pumping in many of the groundwater banking areas (see the concentrated areas of recharge basins in and adjacent to the western Plan Area on **Figure 3-24**).

These groundwater banking facilities create larger fluctuations in groundwater elevations than occur elsewhere in the Plan Area (e.g., see hydrographs 16 and 17). As shown on hydrograph 16, wells adjacent to the banking projects can fluctuate more than 200 feet from recharge to recovery operations. The trends and fluctuations near the banking projects typically mirror hydrologic wet and dry cycles because projects generally have more water for recharge during wet periods and need to recover that water for banking partners during droughts. Influences from the banking projects are seen in most wells in the west-central portion of the KRGSA (**Figure 3-24**).

Water levels in wells that are close to the Kern River and away from the groundwater banks (hydrographs 2 through 5) have lower fluctuations and exhibit a distinct seasonal response. The water levels typically peak in the spring and reach their lowest levels in the fall. Groundwater is relatively shallow in wells within close proximity to the river, as illustrated on Hydrograph 3.

Wells on **Figure 3-24** that are farther from the Kern River and groundwater banking facilities are mostly influenced by regional hydrologic cycles and trends and fluctuations are often less pronounced. Some fluctuations appear anomalous and may be due to local pumping. Nonetheless, almost all hydrographs here exhibit a declining trend in water levels with levels at or near historic lows during the recent drought of record (2013-2016). Hydrographs 1, 2, 9 through 15, 17, and 18 show these basin-wide responses.

Hydrographs, 6, 7, and 8 illustrate representative water levels at wells in the eastern KRGSA. Water levels in this area indicate an overall decline from the 1960s to the early 1980s and then generally flatten with small overall fluctuations. SWP water became available for irrigation near this area in the early 1980s and could have some influence on these levels. Hydrograph 6 shows basin-wide water level trends until 1982, then relatively even pumping cycles until the late 1990s. After 1998, these cycles are less evident and water levels become relatively stable. Hydrographs 7 and 8 show water levels that generally follow regional trends until about 1987, but then become relatively steady until they decline around 2015. Hydrograph 8 may be influenced by a local pond. Water levels at these hydrographs may also be influenced by the lower permeability soils and subsurface clay in this area.

As shown on the hydrograph location map on **Figure 3-24**, there is an area where shallow water levels have been observed in the southern and eastern regions of the KRGSA. This area generally coincides with the low permeability flood basin and lake bed deposits as discussed previously in **Section 3.2**. In particular, the geologic maps on **Figures 3-2** and **3-4** show the location of flood basin and lake bed deposits in the Plan Area; these clay-rich units are also reflected on the soil textures map on **Figure 3-8**. In these areas, the shallow clay-rich sediments impede the downward percolation of agricultural irrigation and other surface water applications. Water is trapped temporarily creating perched conditions locally. This water surface is irregular, varies with local irrigation and local conditions, and does not reflect a water table or a separate Principal Aquifer. Rather these clay-rich sediments represent the only mappable aquitard in the local groundwater system. Cross Sections 2-2' (**Figure 3-21**) and 3-3' (**Figure 3-22**) show the occurrence of these clays in the subsurface and Cross Section 3-3' illustrates the area of perched water (**Figure 3-22**). Hydrographs 9 and 10 on **Figure 3-24** show a grouping of two closely-spaced wells, one within the perched zone and one just outside of the zone. Wells screened in the perched water zone have shallow groundwater levels with minimal fluctuations while nearby wells outside of the perched zone (and in some areas below the zone) have deeper groundwater levels that are more representative of basin-wide water levels.

3.3.2.3 Groundwater Elevation Contour Maps

Groundwater elevation contour maps prepared by KCWA have been used to examine groundwater flow patterns in the KRGSA Plan Area. KCWA prepares annual contour maps from water levels measured in the spring, prior to the summer irrigation season when numerous cones of depression complicate local groundwater flow and make consistent mapping difficult. Electronic files of annual Spring groundwater elevation contour maps were obtained from KCWA for 1995 through 2015, except for 1996 and 1997 when no electronic contour maps were available; these maps are reproduced in **Appendix G**. Maps representing wet and dry groundwater conditions are described in more detail below.

3.3.2.4 Groundwater Elevations and Flow

The KCWA Spring contour map for 1998 is provided as **Figure 3-25** to illustrate groundwater flow patterns in the KRGSA Plan Area when water levels were the highest during the 20-year Study Period (WY 1995 – WY 2014). During the wet year of 1998, precipitation and Kern River flows were 223 percent and 236 percent of the long-term averages, respectively (see **Figures 3-9 and 2-10**). As shown on **Figure 3-25**, groundwater elevations range from above 300 feet msl along the Kern River and in groundwater banking areas to below 150 feet msl in the northwest and southeast edges of the Plan Area. The recharge mound near the river creates divergent flow to the north and south, with water levels above 200 feet msl over almost all of the Plan Area. The higher water levels above 200 feet in the southern KRGSA may be influenced by local perching conditions. As groundwater levels rise, it becomes more difficult to differentiate the water table from perched water in low-permeability clays.

As indicated by **Figure 3-25**, subsurface outflows occur along the northern and southeastern KRGSA boundaries. Elevated water levels in the banking areas both inside and adjacent to the west-central KRGSA cause both subsurface inflows and outflows in that area. Subsurface flows along the southern Plan Area boundary are complicated due to subsurface clay deposits and the dynamic and changing groundwater flow conditions in the southern KRGSA resulting from recharge in basins and canals, and local pumping.

The groundwater elevation contour map for spring 2015 data is shown on **Figure 3-26** and illustrates the lowest water levels for any spring map during the Study Period. During spring 2015, groundwater elevations are lower than 200 feet msl over almost all of the KRGSA. Although groundwater elevations on **Figure 3-26** appear higher than 350 feet msl in the northeast, data are sparse, and contours are considered less accurate in this area on most of the maps. A comparison of the two maps on **Figures 3-25** and **3-26** shows that groundwater elevations in 2015 are lower than elevations in 1998 by about 50 feet to 100 feet throughout most of the KRGSA. The highest groundwater elevations along the Kern River are similar to 1998 levels, but cover a smaller area (e.g., areas higher than 300 feet msl).

Although water levels are lower in spring 2015 than in 1998, the levels in 2015 are generally higher than surrounding areas. As such, subsurface outflows are indicated along most of the KRGSA Plan Area boundary (**Figure 3-26**).

Groundwater elevations during these two time periods illustrate that groundwater flow is highly influenced by recharge along the Kern River and by activities at the groundwater banking facilities. Although water levels on the 1998 map are significantly higher throughout most of the KRGSA Plan Area than in 2015, general groundwater flow patterns within the Plan Area are similar. Groundwater mounds beneath the eastern stretch of the river cause divergent flow to the north and south away from the river. During the 1998 wet period, this mound extended along the extent of the Kern River causing divergent flow away from the river throughout the entire stretch within the GSA. But, during the drier periods such as in 2015, the mound covers a smaller area and does not extend to the western reach of the river. Subsurface flows are dynamic and vary over hydrologic conditions and the operations (recharge and recovery) at local banking facilities both inside and adjacent to the KRGSA Plan Area.

3.3.2.5 Current Conditions and Historic Low Groundwater Levels

Although groundwater conditions during spring 2015 represent the lowest water levels for spring conditions during the Study Period, hydrographs on **Figure 3-24** indicate that historic low levels were observed during fall 2015 conditions for many of the representative wells. To further examine water levels during the historic low time period, an additional map was constructed using data from fall 2015 for GSP analysis. This map, shown on **Figure 3-27**, indicates that groundwater elevations are lower than the spring 2015 levels by up to about 50 feet in some areas. For example, groundwater elevations at the northwest boundary of the Plan Area are about 100 feet msl in spring (**Figure 3-26**) and below 50 feet msl in the fall (**Figure 3-27**).

During fall 2015, groundwater elevations were below 150 feet msl over most of the Plan Area and below 100 feet msl in areas along the southern KRGSA border (**Figure 3-27**). In contrast, the area below 150 feet msl during fall 2015 (**Figure 3-27**) was generally below the 250-foot contour in spring 1998 (**Figure 3-25**), indicating water levels about 100 feet lower than high water levels associated with wet years. These historic low water levels in the northern Plan Area impacted municipal wells. During this time period, water levels dropped below the top of screens and, in some cases, below well pump intakes in dozens of municipal wells. Most of the impacted wells were located adjacent to and east of Highway 99 and clustered on both sides of Highway 58. In this area, a groundwater elevation of 150 feet msl is equivalent to a water depth of about 250 (i.e., ground surface elevation of 400 feet msl), lower than the top of screens in almost one-half of the local City and Cal Water municipal wells (with an average top of well screen at about 290 feet below ground surface). Water levels in spring 2015 (**Figure 3-26**) were close to well screens but slightly higher than in fall 2015.

There is significant uncertainty in comparing the two maps from 2015 on **Figures 3-26** (spring) and **3-27** (fall). The spring 2015 map was prepared by KCWA on a specific subset of wells used for consistent spring mapping throughout the Subbasin. The fall 2015 map was prepared using additional data from DWR and KDWD. Although KDWD has maintained a water level monitoring program for many years, many program wells are production wells with incomplete data on ground surface elevation and well construction. KDWD is working on improvements to the in-district monitoring program including identification of dedicated monitoring wells with construction data and measurements of reference point elevation. When completed, those wells will be selected for inclusion in the GSP monitoring networks for minimum thresholds, as appropriate.

3.3.3 Estimate of Change in Groundwater in Storage

Groundwater elevation contour maps prepared for spring conditions over the 20-year Study Period (WY 1995 through WY 2015) have been evaluated to estimate the change in groundwater in storage. The KCWA spring maps were chosen for the analysis because they provide the most complete set of groundwater elevation maps that use methodologies and data sets across the Subbasin. These maps are designed to represent seasonal high groundwater conditions.

The analysis used GIS to electronically subtract groundwater elevations on one map from elevations on the previous map in the time series to provide an average net change in water levels across the contoured area. This net change in water levels was multiplied by an estimated value of aquifer storativity. Because the changes are interpreted to occur primarily in the unconfined zone of the Principal Aquifer, the storativity parameter is represented by a specific yield (generally equivalent to effective porosity, expressed in percent). An average specific yield of 10 percent was applied, given that most of the Plan Area is underlain by relatively permeable soils and sediments.

A graph depicting the estimated annual and cumulative changes in groundwater in storage is included on **Figure 3-28**. The graph covers 19 years of the 20-year period because there wasn't a map available for 1994; as such, the graph begins with the change from spring 1995 to spring 1996. Because the change from spring 1994 to spring 1995 represents a change from a critically dry year to a wet year, the resulting change in groundwater in storage would likely be positive; therefore, the exclusion of the change from 1994 to 1995 is considered conservative. Also, as mentioned previously, individual spring maps for 1996 and 1997 were unavailable. Accordingly, the change that was estimated from 1995 to 1998 (about 580,000 AF) has been partitioned equally among the first three change periods of 1995-1996, 1996-1997, and 1997-1998 (**Figure 3-28**). This methodology was determined to be reasonable based on a consistent annual rise in water levels during each of these years as observed on many representative hydrographs in the Plan Area.

As shown on **Figure 3-28**, annual changes in groundwater in storage range from 435,539 AFY (2011-2012) to -533,901 AFY (2012-2013). Over the 230,818 acres of the Plan Area and using an average specific yield of 10 percent, an annual change in groundwater in storage of about 500,000 AFY represents an average rise (positive number) or decline (negative number) in water levels of about 22 feet. Because these numbers represent annual *changes*, the graph does not always reflect the actual annual hydrologic condition. For example, 2005 was a wet year with a Kern River Index and annual precipitation of 159 percent and 150 percent of the long-term average, respectively. However, groundwater elevations over the KRGSA Plan Area for spring 2005 were very similar to elevations for spring 2004; accordingly, there was only a small change of groundwater in storage from 2004 to 2005 as indicated on **Figure 3-28**, even though overall annual conditions of water availability may have improved.

The cumulative change of groundwater in storage is shown by the red curve on **Figure 3-28**. This curve sums previous change estimates and provides a running total of the overall change in storage. As shown on the graph, the cumulative change in groundwater in storage was -55,325 AF at the end of the Study Period. In general, the pattern illustrated by the cumulative change curve is consistent with the trends and fluctuations observed for the Study Period on representative hydrographs (e.g., see hydrograph 15 on **Figure 3-24**). This check suggest that the analysis results are reasonable.

The negative cumulative change in storage is expected, given that the Study Period begins in a wet year and ends in a critically dry year during the recent severe drought. However, conditions at the beginning and end of a Study Period do not necessarily reflect unsustainable conditions; rather, the average annual change over the Study Period is more relevant to this analysis. As noted on **Figure 3-28**, the average annual change of groundwater in storage is estimated at -2,912 AFY. Although negative, this volume of groundwater in storage is sufficiently small to be well within the uncertainty of the analysis as discussed below.

As requested in the GSP regulations, the water year type for each year in the analysis is also included on the graph. As discussed in **Section 3.2.4.1** and noted on **Figure 3-9**, the water year type is based on the San Joaquin Valley indices that do not exactly align with wet and dry periods in Kern County. Further, water conditions in the KRGSA Plan Area are related more to surface water availability than precipitation.

The analysis contains inherent uncertainties. A review of the contour maps indicates portions of the Plan Area where contours do not extend due to inadequate water level data (for example, see the northeastern portion of the KRGSA Plan Area on **Figures 3-25, 3-26** and **3-27**). To remove bias in these areas, only the contoured area from each map was included in the analysis. Because groundwater elevations range over several hundred feet across the KRGSA Plan Area, the contour interval on the groundwater elevation maps is relatively large (50 feet). This introduces significant uncertainty due to the inability to detect small changes in water levels across large areas. The specific yield is not known with certainty and other reasonable estimates of specific yield would result in different values of change in groundwater in storage. Finally, because of the regional nature of the contour maps, the application of an average specific yield and an average change in elevation across the contoured area, while appropriate, is not precise.

This analysis provides an independent method for estimating changes in groundwater in storage beneath the KRGSA Plan Area over time. However, given the uncertainties, the method cannot be relied on solely for the sustainability analysis. Two additional methods – a “checkbook” accounting of inflows/outflows and groundwater modeling – are also used to estimate changes in groundwater in storage for further analysis and comparisons. Annual groundwater use and other water budget components of inflows and outflows for the Study Period are included in the water budget discussion in **Section 4**.

3.3.4 Groundwater Quality

The water chemistry of KRGSA groundwater is similar to local surface water and contains relatively low TDS levels resulting, in part, from decades of actively managed recharge of both local and imported surface water supplies in the Plan Area. In general, groundwater quality in the Plan Area has been sufficient to meet designated beneficial uses in the Plan Area including municipal, industrial, and agricultural water supply and recreational/environmental uses.

Groundwater quality constituents of concern vary among beneficial uses. Large municipal wellfields in the urbanized northern Plan Area and smaller community water systems throughout the Plan Area rely on groundwater supplies for drinking water. For these systems, state-level drinking water standards apply as provided in Title 22 of the California Code of Regulations. For the large agricultural areas in the southern KRGSA Plan Area, salinity and specific ion toxicity to crops are of more concern. The SWRCB publishes a compilation of Water Quality Goals (SWRCB, 2016), including numeric thresholds such as maximum contaminant levels (MCLs) or Public Health goals. Agricultural Water Quality Thresholds are also included in the Water Quality Goals for various agricultural uses of water including irrigation of various crop types and livestock watering.

Recently, two water quality constituents of concern for drinking water – 1,2,3-trichlorpropane (TCP) and arsenic – have been detected above the MCL in numerous KRGSA wells. These detections have required increased management of wellfields including taking wells offline, wellhead treatment, and, in some cases, groundwater litigation. Locations and concentrations of these constituents, information on local groundwater chemistry, water quality data sources, and other constituents of concern are described in the following sections as the foundation for establishing sustainable management criteria and developing appropriate management actions relating to groundwater quality.

USGS has conducted numerous regional water quality investigations in the southern San Joaquin Valley and Kern County (e.g., Dale et al., 1966; Shelton, et al., 2008; Burton, et al., 2012) that provide information on groundwater chemistry in the KRGSA Plan Area. In addition, various regulatory programs administered by the Central Valley Water Board and the California Department of Toxic Substances Control (DTSC) have generated local water quality data and information within portions of the Plan Area including the Irrigated Lands Program and various environmental investigation and clean-up programs. Finally, water quality monitoring in municipal wells and the related preparation of Consumer Confidence Reports also provides data and information on local groundwater quality. Although these programs all vary with respect to objectives and regulatory standards, each provides a source of groundwater quality data for the characterization of groundwater quality conditions in the Plan Area.

3.3.4.1 Regional Groundwater Chemistry

USGS has identified regions of similar groundwater chemistry in the southern San Joaquin Valley based on distances from the valley margins; spatial groups of groundwater chemistry are categorized as *east side* (including the KRGSA Plan Area), *west side*, and *axial trough of the valley* (Dale et al., 1966). East side groundwater quality, including the KRGSA Plan Area, is characterized as a bicarbonate type with relatively low TDS, reflecting the geologic units in the groundwater source areas of the granitic Sierra Nevada (Dale et al., 1966). Groundwater quality in the KRGSA Plan Area also reflects the quality of the Kern River, the primary source of recharge to the KRGSA aquifers. Geochemical plots of Kern River and groundwater samples confirm the bicarbonate-carbonate chemistry in the KRGSA Plan Area (DBS&A, 2012).

West side groundwater chemistry (outside and west of the KRGSA) is defined as a sulfate or chloride type with higher TDS concentrations than the east side groundwater. Groundwater chemistry on the west side reflects the quality of the surface waters that drain the Miocene-Pliocene marine sediments of the Temblor Range west of the basin (Dale et al., 1966; Sierra Scientific Services, 2013). Because of the smaller amount of surface water runoff in the west, the sulfate type of groundwater is less prevalent than the bicarbonate type (Sierra Scientific Services, 2013).

Groundwater quality in the axial trough (near the southwestern KRGSA) is a mixture of east side and west side groundwater, as well as surface water that percolates to the aquifer. Groundwater is sodium type but varies in concentration and chemical character. The boundary between the axial trough and west side groundwater is approximated along the West Side Canal, located west of the KRGSA Plan Area (Dale et al., 1966).

3.3.4.2 Local Groundwater Chemistry

Recent USGS groundwater quality analyses involving wells located throughout the KRGSA Plan Area provide additional information on local groundwater chemistry (Shelton, et al., 2008; Burton, et al., 2012). As mentioned previously, USGS dated groundwater beneath the KRGSA Plan Area as primarily of Modern age (post 1953) associated with recharge of the Kern River and other surface waters. Older groundwater (mix of Modern and Pre-Modern) was indicated in deeper wells and in the southern KRGSA Plan Area where shallow clays produce more confined groundwater conditions.

USGS also evaluated redox conditions in local groundwater to identify areas of oxic (oxidized) and anoxic (reduced) geochemical environments (Shelton, et al, 2008; Burton, et al., 2012). The redox state of groundwater can affect the occurrence and concentrations of both naturally-occurring and human-related contaminants. As part of that study, USGS concluded that groundwater in the northern and central Plan Area occurs under oxic conditions (well screens from about 350 to 700 feet) with relatively high dissolved oxygen content, especially below the Kern River and other local groundwater banking projects. Although no wells in the southern Plan Area were included in the sampling, anoxic conditions are indicated just south of the Plan Area, consistent with the presence of the clay soils and sediments at and beneath the paleo-lakebeds. In this area, clay soils limit recharge and exposure of the groundwater to oxygenated (atmospheric) conditions. Anoxic conditions were also observed in deeper wells along the eastern Plan Area boundary. In addition, anoxic conditions, groundwater pH, and elevations of trace metals such as arsenic tended to increase with depth (Burton, et al., 2012).

A 2015 groundwater quality assessment of salts, nutrients and pesticides in Kern County provides additional information to characterize local groundwater quality (P&P, 2015). This study, titled Groundwater Quality Assessment Report (GAR) was conducted by the Kern River Watershed Coalition Authority as part of the Irrigated Lands Program for the Central Valley Water Board. The study included compilation of a database containing more than 100,000 records of TDS, nitrate, and pesticide concentrations from 1909 to July 2014 (P&P, 2015). Data sources for the database include California Department of Public Health (CDPH, now California Division of Drinking Water as part of the SWRCB), DWR, KCWA, USGS, and other sources. Todd Groundwater, as a subconsultant to Provost and Pritchard (P&P), analyzed these data to support a groundwater vulnerability assessment for the GAR. The GAR database, along with additional references and data, was used to characterize these constituents in the KRGSA Plan Area as discussed below.

3.3.4.3 Total Dissolved Solids

Total dissolved solids (TDS) represents the total concentration of anions and cations in groundwater and is used as an indicator of mineralization, salt content, and overall water quality. TDS concentrations up to 1,000 mg/L are typically defined as fresh water, although USGS has defined concentrations up to about 2,000 mg/L as fresh water in other studies (Page, 1973). California has identified 1,000 mg/L as the upper range for a secondary MCL for drinking water, with a recommended secondary MCL[16] of 500 mg/L. TDS concentrations below 450 mg/L are recommended for irrigation of salt sensitive crops.

The TDS content in Plan Area groundwater is influenced by local recharge of both the Kern River and SWP water. From 1995 to 2007, TDS concentrations of the Kern River have ranged from 28 mg/L to 215 mg/L with an average of 97 mg/L (DB&A, 2012; KFMC, 2010). TDS in SWP water imported into Kern County[17] has averaged about 245 mg/L over the 20-year historical Study Period (WY 1995 – WY 2014) with slightly lower averages in wet years and higher averages in dry years. During the drought conditions of WY 2015 – WY 2016, the average monthly TDS in SWP water increased slightly to about 301 mg/L.

TDS concentrations compiled for the GAR study (P&P, 2015) for the 20-year Study Period are illustrated on **Figure 3-29.** Concentrations are illustrated as yellow circles (below the secondary maximum contaminant level (MCL) of 500 mg/L), green circles (between 500 and 1,000 mg/L), blue circles (between 1,000 and 1,500 mg/L), and red circles (above 1,500 mg/L). In order to readily identify any areas of concern, the highest TDS concentration at any given well is represented on **Figure 3-29**.

TDS concentrations in the Kern County Subbasin average between 400 and 450 mg/L but can range up to 5,000 mg/L (DWR, 2006). As shown on **Figure 3-29**, TDS concentrations in groundwater throughout most of the KRGSA are below 1,000 mg/L. Concentrations of TDS are lowest (less than 500 mg/L) in the vicinity of the Kern River and south of the Kern River extending through most of the southern Plan Area. TDS concentrations are higher (above 1,000 and 1,500 mg/L), along the southern rim and extending northward in the southeastern KRGSA. In general, elevated TDS concentrations occur within and near the area where perched water has been observed (**Figure 3-29**) and may indicate concentrations of salts in the clay soils where surface water does not readily infiltrate into the subsurface.

Recent TDS concentrations from municipal wells in Metropolitan Bakersfield are consistent with historical values and average about 208 to 244 mg/L (Cal Water, 2017). During 2017, TDS concentrations in municipal wells ranged from 120 mg/L to 860 mg/L. TDS concentrations are slightly higher in deeper wells and increase with distance from the river, especially north of the river. TDS is also higher in the northeastern Plan Area, consistent with data presented on **Figure 3-29**.

3.3.4.4 Nitrate

Nitrate is a naturally occurring form of nitrogen that can be produced in relatively low concentrations from the atmosphere or from decomposing organic matter (P&P, 2015). Sources of nitrate in

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[16] A secondary MCL is not related to public health and typically refers to the odor, taste, and appearance of drinking water.

[17] California Aqueduct samples near Highway 119 (Check 29), from KFMC, 2018.

groundwater include excess application of nitrogen fertilizer in irrigated areas, feedlot and dairy drainage, leaching from septic systems, wastewater percolation, industrial wastewater, aerospace activities, and food processing wastes. Elevated nitrate in groundwater in the Tulare Lake Basin has been linked primarily to crop and animal agricultural activities with urban wastewater, septic systems, and other sources identified as significant in localized areas (Viers, et al., 2012). Nitrate (as NO_3) has an MCL of 45 mg/L for drinking water.

Concentrations of nitrate (as NO_3) from the GAR database are shown on **Figure 3-30** for the KRGSA Plan Area. Also included on the figure for reference are areas of irrigated agriculture, dairies, and wastewater treatment plants. Nitrate concentrations represent maximum values over the Study Period and are illustrated as yellow circles (below its primary MCL of 45 mg/L), orange circles (between 45 and 90 mg/L) and dark red circles (greater than 90 mg/L). As shown on the figure, most nitrate concentrations are below the MCL throughout the Plan Area. Localized areas have a well that has exceeded the MCL at least once during the Study Period. Most of the elevated detections in the southern Plan Area are in agricultural areas with some detections near a dairy or a wastewater treatment facility. In addition, the detections are in rural areas where domestic septic systems may also be a contributing factor.

There is also an area of nitrate detections exceeding the MCL in the northwestern Plan Area, generally north of the Kern River and west of Highway 99, which is outside of agricultural areas (**Figure 3-30**). In addition, most of the highest concentrations (more than twice the MCL concentration) are located along the eastern margin of the Plan Area; a 2015 study found that areas of elevated nitrate concentrations occurred all along the eastern margin of the Subbasin including areas north of the KRGSA Plan Area (P&P, 2015).

In the east-central KRGSA Plan Area, several small water systems have detected elevated nitrate in drinking water wells (AECOM 2019). The State of California is planning to fund the consolidation of these systems with ENCSD, where nitrate levels in groundwater are relatively low (average of 3.2 mg/L in 2019 samples for all wells) (project described in **Section 7.1.4**).

The source of each elevated nitrate concentration shown on **Figure 3-30** is not known. However, a 1970 study by DWR identified elevated nitrate concentrations in many of these same areas using historical water quality data from 1966 through 1970 (DWR, 1970). The GAR produced an overlay of the elevated nitrate from the DWR study (P&P, 2015). The observation that these areas have been associated with elevated nitrate since the 1960s suggests that some of the concentrations may be legacy issues that occurred from early inefficient agricultural practices or other historical sources. In the eastern and southern KRGSA, clay soils and underlying sediments would be expected to impeded vertical movement of nitrogen in the vadose zone, delaying the transport of nitrate to groundwater by decades (P&P, 2015).

Nitrate in KRGSA groundwater is best handled through Best Management Practices (BMPs) for nitrate application. Ongoing nitrate monitoring and BMPs for nitrate management are being regulated by the Central Valley Water Board through its Irrigated Lands Regulatory Program (ILRP). These efforts are being coordinated on a semi-regional basis by the Kern River Watershed Coalition Authority (KRWCA).

The KRWCA consists of a collection of agricultural water districts in the Kern County Subbasin including KDWD. This GSP intends to cooperate and coordinate with this program to compile and analyze nitrate data and encourage BMPs for nitrate management.

3.3.4.5 Pesticides

Pesticide impacts to groundwater can result from over-application in agricultural areas, landscaping/lawn and garden areas, and along roads and railways for weed control (P&P, 2015). Although pesticides are typically soluble in water, these compounds can be highly sorptive to soils, which may impede migration to underlying groundwater. For the GAR study, investigators focused on any pesticide concentration in groundwater that had exceeded its respective MCL, public health goal, or other numeric standard (P&P 2015). Detections of approximately 60 pesticides were included in the GAR database. For completeness, data also included chemicals commonly associated with pesticides (e.g., naphthalene) even though some of these are also found in industrial/non-pesticide constituents.

Pesticide data in the KRGSA Plan Area are displayed on **Figure 3-31**. Concentrations are shown as yellow circles for samples where no pesticides were detected and orange circles for samples that detected one or more pesticides. As shown on the figure, pesticides were detected at various locations throughout the Plan Area both inside and outside of agricultural areas. As noted on **Figure 3-31**, none of the detections exceeded the respective MCL.

Almost all detections represent two soil fumigants, dibromochloropropane (DBCP) and ethylene dibromide (EDB). These pesticides have previously been detected in groundwater in the northwestern portion of the Plan Area and areas of impacts have been noted in the Kern Fan Monitoring Committee reports (KFMC, 2011). Because these detections occur in areas with current agricultural wells, the concentrations are being managed locally.

A cluster of detections at the east-central boundary of the Plan Area (on East Panama Lane north of Lamont) is associated with industrial operations rather than agriculture. These detections involve concentrations of xylenes and are associated with oil refining activities in this area. While xylenes are found in some pesticide formulations, they are also associated with petroleum hydrocarbons.

An additional contaminant associated with soil fumigants, 1,2,3-tricholorpropane (TCP) has been detected in numerous wells, including municipal wells, and is discussed separately below as a specific constituent of concern in the Plan Area.

3.3.4.6 Constituents of Concern

In addition to the salts, nutrients, and pesticides discussed above, other constituents of concern have been identified as a potential threat to water quality in the KRGSA Plan Area. Some constituents have been identified through groundwater quality monitoring in municipal wells in compliance with California Division of Drinking Water requirements. The City of Bakersfield, California Water Service Company, ENCSD, and Greenfield CWD, among others, have identified and addressed various constituents over time, most recently 1,2,3-trichloropropane (TCP) and arsenic; these two constituents are discussed in more detail below.

Also included below is a discussion of constituents associated with certain commercial and industrial sites as identified by the Central Valley Water Board and the California Department of Toxic Substances Control (DTSC). Information from these regulatory programs was reviewed for the potential for additional constituents of concern in the KRGSA Plan Area.

1,2,3-Trichloropropane (TCP)

1,2,3-Trichloropropane (TCP) is a chlorinated hydrocarbon that occurs as an intermediate in chemical manufacturing. It has also been used directly as a cleaning and degreasing solvent. TCP has also been formulated into a soil fumigant, which was used by the agricultural community through most of the 1980s (Burton, et al., 2012). Although TCP was banned from pesticides in the 1990s, its widespread occurrence in Kern County groundwater has been documented in agricultural areas. As part of the GAMA sampling program, USGS detected TCP at levels in excess of its MCL in all eight of the wells tested in Kern County (Shelton, et al., 2008).

In 2017, the State of California adopted an MCL of 0.005 ug/L, or 5 parts per trillion (ppt) for drinking water. Accordingly, many water supply systems are now beginning to monitor regularly for TCP at sufficiently low detection levels commensurate with the newly-adopted MCL. Data from the publicly-available CDPH database were reviewed for TCP detections in the Plan Area. In addition, Cal Water provided TCP data and information for the City of Bakersfield and Cal Water municipal wells dating back to 2002. Greenfield CWD also provided data for TCP concentrations in its production wells from September 1989 to January 2019. Only limited historical TCP samples are available from these data sources; more than two-thirds of the data were collected after 2009.

TCP data are compiled on **Figure 3-32**. Data are color-coded to reflect the maximum concentration detected at any given well. Green and yellow dots represent wells that have either not detected TCP or have detected it at concentrations below the 0.005 ug/L MCL. Red and purple dots represent wells with maximum detections up to twice the MCL and more than twice the MCL, respectively. TCP treatment facilities have been installed on many impacted municipal wells as shown by the black diamonds on **Figure 3-32**.

As shown on **Figure 3-32**, TCP has been detected above the MCL in municipal wellfields in the northern KRGSA, along the eastern KRGSA boundary, and in other locations in the southern Plan Area. Many of the detections outside Metropolitan Bakersfield are associated with small water systems. Since 1989, Greenfield CWD has detected TCP above the MCL in eight samples from two of its water supply wells (see the two southernmost red dots east of and adjacent to Highway 99 on **Figure 3-32**). These detections occurred in 2012 through 2014; five total samples were greater than the MCL. In the eastern Plan Area, just south of Highway 58, ENCSD and several other local mutual water companies have also reported TCP detections above the MCL in multiple water supply wells (**Figure 3-32**).

The City of Bakersfield and Cal Water have detected TCP at concentrations above the MCL in 65 municipal wells, covering a broad area of the municipal wellfields (**Figure 3-32**). The occurrence of green dots in the central municipal wellfields reflect numerous wells that have not detected TCP even though construction of those wells is similar to impacted wells. The pattern of detections and non-detections in the municipal wellfields appears to correlate roughly to now-urbanized areas that were more recently used for irrigated agriculture (into the 1980s). As such, these detections are considered a legacy issue associated with a broad area of historical "non-point" sources and are not considered to be distinct plumes of contaminants.

In 2017, the City and Cal Water settled a lawsuit against the Dow Chemical Company and Shell Oil Company, the manufacturer of the TCP-contaminated soil fumigant, for damages relating to TCP contamination. The case was brought by the City and Cal Water to recover cleanup and treatment costs for impacted municipal wells. To date, Cal Water and the City have installed granular activated carbon (GAC) treatment on 56 of the 65 wells to treat elevated concentrations of TCP throughout their systems; wells with TCP treatment are highlighted on **Figure 3-32**. Ongoing wellhead treatment, along with blending and redistribution of pumping, is expected to manage this constituent of concern in the urban areas. Greenfield CWD and ENCSD have similar lawsuits pending. In addition, ENCSD has secured a State grant that will address TCP concentrations, if detected, as several small local water systems are being consolidated into the ENCSD system (AECOM, 2019). This project, described in **Section 7.1.4**, includes several of the exceedances of TCP in small water systems along the eastern border of the Northern Plan Area (**Figure 3-32**).

The nature and extent of TCP in the remaining portions of the Plan Area are not yet well understood due to a lack of historical data. As a fumigant applied at the surface, higher concentrations have generally been observed in the shallower wells. TCP has been detected in most of the non-municipal wells with TCP analyses. Concentrations of TCP in agricultural wells are not expected to adversely impact the beneficial use of those wells. Public water supply wells will continue to be tested for TCP concentrations as required by the SWRCB, Division of Drinking Water; these data will be compiled periodically and reviewed by the KRGSA to ensure that management actions do not exacerbate the extent of TCP in groundwater.

Arsenic

Arsenic is a naturally-occurring trace element in the rocks, soils, and groundwater of the Kern County Subbasin and the Plan Area. Arsenic occurs through dissolution of iron or manganese oxyhydroxides under reducing conditions. Dissolved arsenic can also result from pH-dependent desorption under oxic conditions. In general, elevated arsenic concentrations are correlated to deeper groundwater where the dissolved oxygen content is low and pH is high. The occurrence of elevated arsenic concentrations in the KRGSA Plan Area is generally consistent with these conditions, but these conditions are not always associated with elevated arsenic concentrations (Burton, et al., 2012). This suggests that arsenic can also occur in oxic groundwater with elevated pH, conditions that have also been documented in the Plan Area. USGS also suggests that arsenic is more widespread in the distal portions of the Kern County Subbasin (Burton, et al., 2012) referring to the downstream portions of the alluvial fans at the Kern and Buena Vista lakebeds in the southern Plan Area. The California MCL for arsenic is 0.010 mg/L (10 ug/L).

Elevated arsenic concentrations have been detected in municipal wells in the northwest and east-central Plan Area. **Figure 3-33** shows detections of arsenic in Bakersfield municipal wells (including wells owned by the City and Cal Water). Data are represented by the highest concentration detected over the last 25 years; the date associated with the maximum arsenic detection is also provided on the figure. Concentrations are color-coded with green and yellow dots indicative of wells that have either not detected arsenic or detected it at lower levels only (below the MCL). Red dots and purple dots indicate about 27 wells that have detected arsenic at levels up to twice the MCL (20 ug/L) and above, respectively. Arsenic treatment facilities have been installed on eleven wells as shown by the black diamonds on **Figure 3-33** (one treatment facility currently is in design).

Data on **Figure 3-33** indicate primary areas of elevated arsenic concentrations including a cluster of wells southeast of the intersection of Highways 58 and 99 and additional wells in the western Plan Area north of the Kern River and in the groundwater banking areas. For the wells in the southeastern portion of the map, most of the elevated arsenic concentrations occurred in the 1990s. This occurrence may be attributable more to older laboratory methods for analysis of arsenic than actual elevated concentrations. Concentrations after about 2009 are generally below the MCL in almost all of these wells and most data do not support increasing trends. However, water supply wells farther south, owned by Greenfield County Water District GSA, have detected arsenic in past samples and two wells are being equipped with arsenic treatment (see southern-most wells on **Figure 3-33**, east of Highway 99). An additional municipal well in the area west of Highway 99 is also being treated for arsenic. Farther east, several wells owned by ENCSD exhibited increasing arsenic detections during the recent drought (see ENCSD wells on **Figure 3-33**, north of Highway 58 on the eastern portion of the map). In general, arsenic concentrations are lower west of Highway 99 and south of the Kern River.

For arsenic detections in the northwest (**Figure 3-33**), maximum concentrations have generally occurred in recent years when water levels have been declining. Many of these wells suggest an inverse relationship between arsenic concentrations and water levels; that is, arsenic concentrations increase as water levels decrease. These wells are screened across 300 feet of the alluvial aquifer from 400 feet to 700 feet. As water levels decline, deeper zones may be contributing more water to each well's total production, especially in wells where pumps have been lowered to accommodate declining water levels. The occurrence of naturally-occurring arsenic in deeper wells has been documented by others in the groundwater banking areas (Swartz, 1996) and generally confirmed by recent USGS sampling results (Burton, et al., 2012).

This relationship is best illustrated by the co-plotting of a hydrograph and arsenic chemograph from a northwestern well – City of Bakersfield Well 27 – as shown on **Figure 3-34** (see **Figure 3-33** for the well location). As indicated on the graph, arsenic levels tend to rise and fall in response to water level trends and fluctuations. When water levels declined below about 150 feet msl in 2012-2013, arsenic concentrations began to increase; concentrations ultimately rose above the MCL in 2015 when water levels were at historic lows.

Although some data are incomplete, this relationship can be seen from data in several of the arsenic-impacted wells in the northwest Plan Area. One deep well drilled in this area – screened from 970 feet to 1,270 feet – has detected arsenic above the MCL in all samples from 2005 to 2018, with concentrations up to 17 mg/L. Wellhead treatment was installed on six of the northwestern arsenic-impacted wells during the recent drought. If water levels decline below the historic low levels in the future, arsenic concentrations may increase in these and additional wells.

There may be an opportunity to optimize new well construction to lower arsenic concentrations in the future. Two replacement wells recently drilled by Greenfield CWD to a depth of 900 feet found that arsenic was primarily concentrated in zones around 620 feet to 680 feet; arsenic concentrations were lower below a depth of about 700 feet. The wells have been completed with blank casing in these zones to lower overall arsenic concentrations in wells (QK, 2016). Zone sampling would be conducted in either new test wells or existing production wells to determine if modified well construction would assist in achieving arsenic water quality objectives.

Constituents Associated with Environmental Cleanup Sites

Numerous local and state programs provide regulation and oversight of potential impacts to groundwater quality. The State Water Resource Control Board (SWRCB) (and associated Regional Water Boards) and the Department of Toxic Substances Control (DTSC) conduct programs involving groundwater investigation and cleanup relating to environmental or public health impacts. The SWRCB maintains a web-based portal, referred to as Geotracker, where water quality information and data on these programs are stored. DTSC maintains a similar web-based storage site for program information referred to as Enivrostor.

Information and data from Geotracker and Envirostor were downloaded for various regulatory programs to identify potential water quality impacts that may affect the GSP. There are 32 of these regulated sites in the KRGSA Plan Area that are currently active, including 3 sites from the leaking Underground Storage Tank (LUST) program, 8 DTSC-regulated sites, and 21 sites in the SWRCB Site Cleanup Program. Sites are listed on **Table 3-1** and shown on **Figure 3-35**. The map number in the table corresponds to the site number on the figure to facilitate location of the regulated sites. Programs are summarized below.

The SWRCB and regional Water Boards provide regulation and oversight of underground tanks through the Underground Storage Tank (UST) Program. For leaking tanks (LUST), the program requires environmental investigations and remediation, as needed. Leaks involve primarily petroleum hydrocarbons but also include releases of any hazardous substances. The three leaking underground storage tank investigations identified in the Plan Area are listed as sites 1 – 3 on **Table 3-1** and identified by squares (numbers 1 – 3) on **Figure 3-35**.

The DTSC mission is "to protect California's people and environment from harmful effects of toxic substances by restoring contaminated resources, enforcing hazardous waste laws, reducing hazardous waste generation, and encouraging the manufacture of chemically safer products." The agency provides state response actions for sites on the federal National Priorities List (NPL, Superfund sites), oversees activities and corrective actions on sites permitted under the Resource Conservation and Recovery Act (RCRA), and provides assessment and cleanup activities at school sites under the Brownfields Restoration and School Evaluation Branch. There are eight sites associated with the NPL, RCRA Corrective Action, and School programs in the KRGSA Plan Area as listed on **Table 3-4** (sites 4 - 11) and shown by triangles (numbers 4 – 11) on **Figure 3-35**.

The regional Water Boards oversee the investigation and cleanup of unauthorized releases of pollutants to the environment (including groundwater) through the Site Cleanup Program. Regulated sites and activities include industrial and chemical manufacturing, dry cleaners, pesticide facilities, rail yards, ports, refineries, chemical handling and storage, and numerous other activities. The Site Cleanup Program has 21 sites in the KRGSA Plan Area as listed on **Table 3-4** (sites 12 – 32) and shown as diamond symbols (numbers 12 – 32) on **Figure 3-35**.

Table 3-4: Environmental Investigation and Cleanup Sites in the Plan Area

Open/Active Regulated Sites in KRGSA Plan Area				
Map No.	**Site Name**	**Type**	**Address**	**Chemicals of Concern**
1	Francisco Navarro Property	LUST	9270 S Union Ave, Bakersfield	Gasoline
2	Howards Mini Market	LUST	3300 Planz Road, Bakersfield	Benzene, Gasoline
3	Wholesale Fuels, Inc.	LUST	2200 East Brundage Lane, Bakersfield	BTEX, MTBE, Naphthalene
4	Assured Transportation Site	State/NPL	3228 Gibson St, Bakersfield	PCE
5	Benham and Johnson	State/NPL	340 Daniels Ln, Bakersfield	Lead, Pesticides, PCBs
6	K & D Salvage	State/NPL	600 South Union Avenue, Bakersfield	PCBs
7	Kern County SOS-Aurora Program School	School	7900 Niles Street, Bakersfield	Under Investigation
8	KW Plastics of California	Corrective Action	1861 Sunnyside Ct, Bakersfield	Lead
9	Proposed Career and Technical Education Regional Training Center	School	Southwest Of Berkshire Road and Old River Road, Bakersfield	Arsenic, TPH-Diesel
10	Proposed School Site #5	School	NE/S. Fairfax & E. Wilson Rd., Bakersfield	Under Investigation
11	San Joaquin Drum Company	State/NPL	3930 Gilmore Avenue, Bakersfield	Acetone, Metals, Pesticides, PAHS, PCE
12	Bakersfield Airport Business Park (Chevron Land/D)	Cleanup Program	Unicorn Rd. At Hwy 99/65, Bakersfield	Petroleum
13	Bakersfield Refinery - Area 3	Cleanup Program	3663 Gibson Street, Bakersfield	Petroleum
14	Chevron Chem Co - Bakersfield	Cleanup Program	200 E. Minner Ave, Bakersfield	DDD/DDE/DDT
15	Chevron - Kern Pump Station	Cleanup Program	1138 China Grade Loop (Sect 6, T29s/R28e), Bakersfield	Petroleum
16	Garriott Cropdusters	Cleanup Program	2010 S Union Ave, Bakersfield	Pesticides, Fertilizers
17	Golden State Metals, Inc.	Cleanup Program	2000 E Brundage Lane, Bakersfield	Metals, PCBs
18	Independent Detail (Auto Shop)	Cleanup Program	4106 Wible Rd., Bakersfield	Petroleum
19	Western Farm Service Inc	Cleanup Program	1610 Norris Rd, Bakersfield	Chlorinated Hydrocarbons
20	Witco Refinery (Oildale)	Cleanup Program	1134 Manor Street, Bakersfield	Petroleum
21	Bakersfield Refinery	Cleanup Program	6451 Rosedale Highway, Bakersfield	BTEX, MTBE, Petroleum
22	Chevron USA (Aka: Chevron Refinery & Wait Tank Yd)	Cleanup Program	2525 North Manor Street, Bakersfield	Benzene, Crude Oil, Lead, Petroleum
23	J. R. Simplot - Edison	Cleanup Program	430 Pepper Dr., Edison, Bakersfield	DBCP, Fertilizer, Pesticides
24	Kern Oil & Refining	Cleanup Program	7724 E Panama Lane, Bakersfield	Gasoline, BTEX, Diesel, MTBE, Petroleum
25	PG&E Kern Power Plant (former Coffee Rd. Overpass)	Cleanup Program	2401 Coffee Road, Bakersfield	Benzene, Crude Oil, Petroleum
26	San Joaquin Refining Co - Fruitvale Refinery	Cleanup Program	Standard Street, Bakersfield	Diesel
27	Sunland Refining Corporation	Cleanup Program	2152 Coffee Road, Bakersfield	Crude Oil, Gasoline, MTBE/TBA
28	A-1 Battery	Cleanup Program	1230 S. Union Ave, Bakersfield	Metals
29	Kern County Department of Airports	Cleanup Program	1401 Skyway Drive, Bakersfield	Pesticides, Herbicides
30	Sabre Refinery	Cleanup Program	W. Bakersfield-Rosedale Area, Bakersfield	TPH
31	Ten Section Farming Company	Cleanup Program	Township 30 S Range 26 E Section 30 MDB&M, Bakersfield	Petroleum
32	Paloma Station Property	Cleanup Program	17731 Millux Road, Bakersfield	None Specified

LUST – leaking underground storage tanks; NPL – National Priorities List; BTEX – Benzene, toluene, ethylbenzene, and xylene; MTBE – methyl tert-butyl ether; PCE – tetrachloroethylene; PCB – polychlorinated biphenyl; TPH – total petroleum hydrocarbons; PAH – polycyclic aromatic hydrocarbons; DDD - dichlorodiphenyldichloroethane; DDE - dichlorodiphenyldichloroethylene; DDT - dichlorodiphenyltrichloroethane; DBCP – 1,2-Dibromo-3-chloropropane; TBA – tertiary butyl alcohol.

As indicated in **Table 3-4**, constituents of concern at about one-half of the sites involve petroleum hydrocarbons including crude oil, gasoline, and associated products (BTEX, MTBE, TPH, TBA). These sites include refineries, oil companies, transportation sites, schools (with fuel tanks), as well as the three LUST sites. There are five sites located both north and south of the Kern River on the urban fringe that are primarily associated with pesticides and fertilizers (including DBCP and DDT). Remaining sites with constituents of concern are associated with chlorinated hydrocarbons (PCE, PCBs) and metals.

As shown on **Figure 3-35**, almost all of the sites are located in Metropolitan Bakersfield or on the urban fringe. Sites occur both north and south of the river. Most of the Cleanup Program Sites are more tightly clustered in industrial and commercial areas north of the river. Most of these sites are more than a mile from the closest municipal well, but sites south of the river (east of the Highway 99) are more closely interspersed among municipal wells. Although most of the constituents of concern have not been detected at elevated levels in municipal wells to date, the potential impact of these sites will be coordinated with the state agencies for early identification of groundwater contaminant plumes that could impact water supply.

Additional Constituents

Other potential constituents of concern have been identified in KRGSA groundwater over the 20-year Study Period including Radiometric parameters such as uranium and radon, iron, and manganese. These constituents are naturally-occurring, detected at relatively low levels in local areas, and generally managed by water suppliers via pumping distributions and blending, as needed.

3.3.5 Land Subsidence

The decline of water levels in the Plan Area, exacerbated by the recent drought, could contribute to subsidence of the ground surface in susceptible areas, especially in the southern and southwestern KRGSA Plan Area where clay deposits are more prevalent. 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 3-36**. The upper diagram depicts an alluvial groundwater basin with a regional continuous clay layer and numerous smaller discontinuous clay layers. Because clays are most affected by the compaction, the area with the thicker continuous clay layer is associated with the largest land subsidence. Water level declines associated with pumping decrease water pressure within the pore space (pore pressure) of the aquifer system (Galloway, et al., 1999). Because the pore pressure 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 referred to as 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[18], as illustrated on the lower diagram of **Figure 3-36**. 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 3-36**.

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, or 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 of practical significance 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 have been 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
- Land fissures.

Damage to SWP and CVP infrastructure related to historical land subsidence has been documented north of the Kern County Subbasin. In 1976, subsidence along the Tulare-Wasco reach of the Friant-Kern Canal was determined to have interfered with operations (Prokopovich, 1984). A 17-mile segment of the

[18] 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).

canal required rehabilitation and raising of three pumping plants. In 1984, post-construction land subsidence along the damaged reach was reported to be more than about five feet. A more recent study by DWR documented about 6.9 inches of subsidence along a portion of the California Aqueduct that has decreased freeboard and capacity (Pool 20 in the San Luis Field Division, located north of the Kern County Subbasin) (DWR, 2017). Smaller amounts of recent subsidence were also documented along portions of the Aqueduct in the Kern County Subbasin (DWR, 2017).

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. Although the areas with the most documented subsidence are generally north of Kern County Subbasin, both historical and recent subsidence have been documented in portions of the KRGSA Plan Area. According to DWR (2014), the estimated potential for future land subsidence to occur within Kern County is high.

3.3.5.1 Historical Land Subsidence 1900 - 1970

Historical subsidence dating back to the early 1900s was evaluated in a 1983 USGS study of surface deformation, including tectonic uplift and land subsidence, in the area around Oildale (Castle, et al., 1983). Although the study was focused on oilfields located generally north of the KRGSA Plan Area, about a dozen benchmarks in the northern Plan Area were included. Specifically, the report indicated "virtually no subsidence associated with ground-water withdrawals" beneath central Bakersfield (Castle, et al., 1983). The study did, however, indicate that about 2 inches of subsidence may have occurred at a benchmark close to the northern boundary of the KRGSA from 1903 to 1968. In addition, there could have been several inches of historical subsidence associated with the oil and gas withdrawals in the late 1920s in the Fruitvale oilfield (see **Figure 3-13**).

This USGS study was followed by a more foundational study by Ireland (et al., 1984), which evaluated subsidence amounts and locations from 1926 to 1970. The amount of historical land subsidence estimated by this study in the KRGSA is illustrated on **Figure 3-37** (Ireland, et al., 1984). As shown on the map, land subsidence occurred south of the Kern River and was focused along the southeastern and southern boundaries. Subsidence extended northeast to the vicinity of Highway 58 where about one foot of subsidence is estimated to have occurred during the 44-year period (**Figure 3-37**). The largest amount of land subsidence is estimated at about nine feet, occurring at the far southern extent of the KRGSA Plan Boundary (**Figure 3-37**).

Although data represent the accumulated subsidence over a 45-year period, USGS estimates that about 75 percent of the subsidence occurred in the 1950s and 1960s because of extensive groundwater development (Galloway, et al., 1999). Applying the 75 percent factor to the range of subsidence from one foot to nine feet (0.75 feet to 6.75 feet), a rate of subsidence is estimated at 0.04 to 0.34 feet per year (0.48 to 4.1 inches per year) over the 20-year period (1950s and 1960s).

Areas of clay soils and subsurface clay sediments – as indicated by an arcuate area of perched water – coincide with the primary areas of historical subsidence in the KRGSA Plan Area (**Figure 3-37**). Clay soils in this area are related to the fine-grained materials associated with the flood basin deposits and paleo-lake beds discussed previously (see **Sections 3.2.1** and **3.2.3** in this document) and illustrated by the surficial clay soil mapping on **Figure 3-8**.

Pre-1945 water level records are sparse, but available information indicates that water level declines were more significant after the mid-1940s. A period of significant water level decline apparently occurred between 1945 and 1977, with water levels reaching new historical lows during the late 1970s drought. During that 33-year period, water levels may have declined as much as 150 feet along the Kern River (about 4.5 feet per year). Assuming similar declines in the areas of historical land subsidence, the rate of subsidence of 0.04 to 0.34 feet per year roughly correlates to about 0.009 feet (0.11 inches) to 0.076 feet (0.91 inches) per foot of water level decline.

These calculated subsidence rates are general estimates and do not account for the variability of land subsidence and water level declines through time and space across the KRGSA Plan Area. They are provided as a rough approximation to compare to other historical subsidence estimates and future subsidence monitoring measurements.

3.3.5.2 Land Subsidence 1961 - 2016

There are insufficient published subsidence data to fully bridge the time gap between the end of the Ireland study and the more recent subsidence investigations beginning in about 2014. However, the USGS conducted model simulations of land subsidence in the Central Valley for the historical period 1961 through 2009 (Faunt and Phillips, 2014), overlapping a key portion of the Ireland study period (Ireland, et al., 1984) and updating it over an additional 47 years. The modeling suggested maximum subsidence of 2 to 10 feet over the northern and central Plan Area and up to 20 feet in the area of the largest historical subsidence mapped by Ireland. The analysis suggests that significant land subsidence has continued since the Ireland study and that most of the subsidence is coincident with the areas of historical subsidence mapped by Ireland. These estimates indicate that the amount of subsidence over this period is approximately twice the amount that had occurred by 1970, suggesting that subsidence continued throughout the Plan Area at overall similar or lower rates than had occurred prior to 1970.

More recently, DWR commissioned investigators from the U.S. National Aeronautics and Space Administration (NASA), Jet Propulsion Laboratory (JPL) to conduct a detailed investigation of land subsidence in the San Joaquin Valley using radar remote sensing techniques. Investigators compared multiple satellite and airborne Interferometric Synthetic Aperture Radar (InSAR) images dating back to 2006 to document how subsidence had varied over space and time over a recent decade (Farr, et al., 2016). The NASA-JPL study produced a progress report that analyzed InSAR data from March 2015 to September 2016 (Farr, et al., 2017). Maps from that report indicated land subsidence in the range of 1 to 4 inches over most of the KRGSA Plan Area and reached a maximum of 4 to 8 inches in the southern are where historical subsidence had been documented.

These data sets were recently updated and accessed through December 2016 from the JPL website (JPL, 2018). Because most of the water level declines occurred in the Plan Area during 2015 and 2016, data from a 19-month period from May 2015 through December 2016 were used to develop a recent Plan Area subsidence map as shown on **Figure 3-38**. As indicated by the color bar in the legend of **Figure 3-**

38, land subsidence of more than 25 inches was estimated during this period for areas outside of the Plan Area and north of the Kern County Subbasin (not shown). The color ramp on the legend of **Figure 3-38** is difficult to interpret locally because most of the subsidence (or potential tectonic uplift indicated by the +5.9 inches in the legend), are outside of the data range of the KRGSA Plan Area. Rather than modify the valley-wide legend here, data were reviewed and summarized by the labels on **Figure 3-38**.

As indicated by the labels and the range of blues and greens on the color-coded figure, subsidence over this period has ranged from less than one inch in the northern Plan Area up to about eight inches in the southern Plan Area. Although the color scheme on **Figure 3-38** is subtle, a comparison with **Figure 3-37** indicates that most of the recent subsidence is occurring in areas of historical subsidence. The estimate of 4 to 8 inches of subsidence over the 19-month period is equivalent to about 2.5 to 5 inches per year, a rate similar to the previous estimates of up to about 4.1 inches per year estimated from the Ireland (1984) data.

With water levels reaching historic lows in 2015 – 2016, subsidence is expected to continue for some period into the future as recently-impacted sediments continue to compact. If future water levels decline below historic lows, additional inelastic land subsidence could occur. Although subsidence could potentially occur in any area with declining water levels, the areas of historical subsidence are considered most vulnerable because of the thick local clay deposits.

3.3.5.3 Critical Infrastructure

Given the magnitude of historical subsidence within the KRGSA Plan Area, there has been a potential for impacts to land use involving damage to critical infrastructure. A preliminary map identifying critical infrastructure for the KRGSA Plan Area is provided on **Figure 3-39**; it is recognized that this map does not include all infrastructure in the Plan Area, but the widespread nature of the network of canals and conveyance facilities indicate that there could be infrastructure damage throughout the Plan Area if significant inelastic subsidence were to be exacerbated.

For the KRGSA Plan Area, it is recognized that the City of Bakersfield contains a myriad of critical infrastructure including municipal wells, water and other utility pipelines, roads, buildings, associated appurtenances and numerous other facilities that may be at risk if inelastic subsidence occurred in the city. The three water treatment facilities in the Bakersfield area are also specifically recognized as critical infrastructure (**Figure 3-39**). Accordingly, the Bakersfield city limits covering most of the northern Plan Area are identified as containing critical infrastructure for the purposes of protection from subsidence (**Figure 3-39**). Other critical infrastructure exists outside of the City limits and/or away from urban centers including the Bakersfield Meadows Field Airport, industrial pipelines/conduits, and other features (**Figure 3-39**). Major roadways including Highway 99 and Interstate 5 also traverse the Plan Area and are considered critical infrastructure, especially in areas of historical subsidence in the southern Plan Area.

Water conveyance facilities including pipelines and canals are critical for conveyance and provision of surface water supplies and can be damaged from inelastic land subsidence. As shown on **Figure 3-39**, numerous local canals serve the Plan Area. Two important regional canals cross portions of the KRGSA and represent critical infrastructure for the KRGSA, the Subbasin, and the State. The Friant-Kern Canal – a primary component of the Federal CVP – enters the KRGSA and terminates at the Kern River near Coffee Road. The Cross Valley Canal (CVC) in the northwestern and northern KRGSA provides critical infrastructure for importation and conveyance of SWP water and other critical supplies across the KRGSA and the Subbasin. Although not located in the KRGSA, the California Aqueduct is one of the most critical canals for water conveyance in the state and significant damage from subsidence would have state-wide ramifications. As shown on **Figure 3-39**, the aqueduct is more than four miles from the southern KRGSA Plan Area. Nonetheless, KRGSA member agencies all rely on the aqueduct for water supply conveyance.

Damage to well casings could also be considered critical infrastructure, especially if the damage were sufficient to impact the beneficial use of groundwater. If the well could be reasonably modified or its function in not impeded, then the impact to one well could be considered minimal.

Although historical subsidence has been documented in the KRGSA Plan Area, no damage to critical infrastructure relating to land subsidence from groundwater withdrawal has been identified. If land subsidence occurs relatively evenly over a broad area, infrastructure may not be damaged, or the use of the infrastructure may not be affected. Nonetheless, if water levels are managed at or near historic low levels in this area, exacerbation of current land subsidence can be avoided in the future.

3.3.6 Interconnected Surface Water and Groundwater Dependent Ecosystems

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 (California Code of Regulations Title 23). Groundwater Dependent Ecosystems (GDEs) collectively refer to plant, animals, and natural communities that rely on groundwater to sustain all or part of their water needs (TNC, 2018). GDEs occur in areas where groundwater either discharges to the surface (springs, seeps, or wetlands) or the water table is sufficiently shallow to support natural communities. This includes vegetation with rooting depths sufficiently deep to draw a water supply from the underlying water table, referred to as phreatophytes. GDEs can occur along interconnected surface water but can also occur in any area where natural communities are supported by shallow groundwater.

To assist GSAs with the task of identifying GDEs in a groundwater basin, DWR created the Natural Communities Commonly Associated with Groundwater dataset (hereafter referred to as the NCCAG or Natural Communities dataset). This dataset is a compilation of 48 publicly available State and Federal agency datasets that map vegetation, wetlands, springs, and seeps in California. A working group composed of DWR, the California Department of Fish and Wildlife (CDFW), and The Nature Conservancy (TNC) reviewed the compiled dataset and conducted a screening process to exclude vegetation and wetland types less likely to be associated with groundwater and to retain types commonly associated with groundwater. Two habitat classes are included in the Natural Communities dataset: (1) wetland features commonly associated with the surface expression of groundwater under natural, unmodified conditions; and (2) vegetation types commonly associated with the sub-surface presence of groundwater (phreatophytes). DWR notes that the data included in the Natural Communities dataset do not represent DWR's determination of a GDE but are a starting point for identifying GDEs.

The NCCAG mapped areas of vegetation and wetlands are provided as polygons in GIS shapefiles, which also contain information on vegetation types and species; rooting depths and local habitat are available in separate databases developed by TNC (TNC, 2018).

The NCCAG mapping of the KRGSA Plan Area indicates 177 polygons of vegetation and 65 additional polygons for wetlands; areas are shown on **Figure 3-40**. Most of these wetlands and vegetation areas occur along a 12-mile reach of the Kern River, beginning about one-half mile upstream of the Beardsley River Weir (where the river enters the Plan Area) and extending just downstream of the Bellevue Weir. Additional polygons are mapped away from the river, consisting primarily of small local drainageways in the northeast and undeveloped areas in the south (**Figure 3-40**). The number of polygons by community type (vegetation and wetlands) are summarized in **Table 3-5** for the northern and southern Plan Area.

Table 3-5: NCCAG-Mapped Natural Communities Polygons in KRGSA Plan Area

Natural Communities	Vegetation (number of polygons)	Wetlands (number of polygons)	Total Natural Communities Areas
Northern Plan Area	110	52	162
Southern Plan Area	67	13	80
Total in KRGSA	177	65	242

For the KRGSA Plan Area, the evaluation of interconnected surface water is focused on the Kern River and other smaller drainageways identified for additional study. The analysis of potential GDEs extends into the southern Plan Area, focusing on depth to water, groundwater conditions, and local land use. Although potential impacts to interconnected surface water and GDEs represent new analyses required under SGMA, published data along the Kern River are available to support these initial analyses. Surface water flows and losses in the river channel – and along an interconnected web of adjacent unlined canals – are monitored to allocate river water diversions by surface water rights holders in the KRGSA. Data are published in annual hydrographic reports prepared by the City of Bakersfield on behalf of the Kern River Watermaster. The City also actively manages and maintains the river channel throughout the entire Plan Area to prevent flooding and to enhance groundwater recharge as described in previous sections (**Sections 3.2.4.2** and **3.2.4.3**).

Operations and management of the Kern River by the City of Bakersfield, including measurements along the channel from First Point to Second Point, have demonstrated that the Kern River is a losing stream across the KRGSA Plan Area. In a separate Kern County Subbasin GSP, the KGA GSA has conducted a basin-wide evaluation for the potential of interconnected surface water and concluded that the Kern River was not interconnected with the underlying groundwater downstream of First Point (**Figure 3-40**).

A comparison of stream gage data upstream between First Point and Isabella Dam (40 miles upstream of First Point) indicated that groundwater is likely contributing to baseflow somewhere along this reach, indicating some interconnected surface water. Although the location of this contribution could not be determined, the analysis suggested that baseflow is more likely to occur outside of the Subbasin boundary in the Kern River canyon as evidenced by the presence of local springs.

In addition to the KGA GSP upstream study, the Kern Water Bank has also documented losing stream conditions downstream of the KRGSA Plan Area, concluding that the river is not interconnected with local groundwater (reference KGA GSP, 2019 when available). For GSP coordination, the results of those two studies are incorporated into this GSP and not repeated here. Additional information and analyses relating to the potential for interconnected surface water and GDEs in the KRGSA Plan Area are discussed in the sections below.

3.3.6.1 Kern River Monitoring and Management

The Kern River is a highly-managed system throughout the KRGSA Plan Area. The City implements a channel maintenance program, which includes the removal of sand, soil, and vegetation within the designated floodway; channel alignment within the designated and secondary floodway; and maintenance and operations of designated river weirs and diversion structures (QUAD, 1985). These activities preserve the carrying capacity of the river and permit passage of an intermediate regional flood. Throughout the urban area of Bakersfield, the channel is contained by continuous levees constructed and maintained for flood management. Downstream of the urban area, the river is contained by natural banks and/or low discontinuous levees. The channel has a sandy, shifting bottom; channel clearing, sand removal, and levee repair is a part of the continuous channel maintenance program (QUAD, 1985). Most of the maintenance occurs from the Bellevue Weir to upstream of the Calloway Weir, covering most of the river in the Plan Area (**Figure 3-40**).

Riparian vegetation along the Kern River is supported by regulated releases from Isabella Reservoir, as well as surface water and imported water that is intentionally released into the channel for groundwater banking and/or replenishment of groundwater to support local wellfields. The river channel is used extensively for managed aquifer recharge, along with adjacent recharge basins and unlined canals. Quantities of released and recharged water into the channel are managed by the City. A series of stream gage and weir data are maintained by City staff and documented in annual Kern River Hydrographic Reports. These reports also record entitlements and diversions in accordance with pre-1914 surface water rights as modified by court decisions over the years. The primary gages and weirs along the river channel are shown on **Figure 3-40**.

For more than 100 years, the river has been diverted for agricultural, drinking water, and other beneficial uses. Early diversions occurred along natural sloughs and ditches associated with depositional drainageways related to alluvial fan development. Over the last 50 years, river water has been conveyed with constructed lined and unlined canals. Numerous diversion canals connect to the channel throughout the KRGSA Plan Area for conveyance of river water throughout the Plan Area – and beyond – for beneficial use. Canals are also used to release water into the river channel along dry reaches for managed aquifer recharge. Surface water rights holders coordinate with holders of other water sources to optimize supplies through numerous and complex water exchanges. Volumes of water diverted to and from the channel are measured at weirs and other devices at canal and pipeline turnouts and recorded by the City between First Point and Second Point.

3.3.6.2 Kern River Flow Conditions Downstream of the Calloway Weir

Diversions on the Kern River typically create low flow conditions or dry reaches in the river channel. Between 1970 and 2010, about 80 percent of the river flow at First Point was diverted above the Calloway Weir (DBS&A, 2012) (see the location of First Point and the Calloway Weir on **Figure 3-40**). A graph of recorded annual flows at First Point and the Calloway Weir is shown on **Figure 3-41**. As indicated by the graph, the river was dry at the Calloway Weir during an entire year for more than 25 percent of the years in the period, including recent years of 2007 and 2009. In addition, if periods of very low flow are also considered, then little to no flow occurs downstream of the Calloway Weir for almost one-half of the time. During years with relatively low total flows, the river would have produced very few discharge events to sustain a wet channel very far downstream. This condition was intensified during the recent drought of 2013 – 2016, when river flows and groundwater levels both reached historic lows. In 2015, regulated flows at First Point were only about 13 percent of the long term average (see also **Figures 2-10 and 3-10** and **Section 3.2.4.2**). Given that natural surface water is often depleted in the Kern River channel downstream of the Calloway Weir for long stretches of time (months to years), the river below the weir is not interconnected surface water.

3.3.6.3 Groundwater Elevations at the Calloway Pool

Upstream of the Calloway weir is a relatively flat area of the river channel, referred to as the Calloway Pool, where water is allowed to back up behind the weir for storage and diversion. The reach of the river upstream of the Calloway Weir to Rocky Point Weir (**Figure 3-40**) is typically the most consistently wetted part of the channel in the Plan Area. According to an evaluation of the river's biological resources, this relatively short reach of the river supports the most extensive, vigorous, and biodiverse riparian habitat of the river within the KRGSA Plan Area (City of Bakersfield, 2012). The reach includes portions of the Kern River Parkway and the Panorama Vista Preserve. Habitat includes stands of mature cottonwood-sycamore riparian forest, the most continuous riparian corridor in the Plan Area, and the greatest diversity of riparian trees and shrubs (City of Bakersfield, 2012).

At Rocky Point Weir (**Figure 3-40**), the unlined Carrier Canal is used to divert river water for agricultural use in the southern Plan Area. The Carrier Canal runs parallel to the river before turning south at the Calloway Pool. Flow measurements on the river and the canal indicate that this entire reach from Rocky Point Weir to the Calloway Weir is a losing stream. Recharge at the Calloway Pool and along the Carrier Canal is recorded in annual hydrographic reports.

Despite the relatively large quantities of recharge, the depth to groundwater adjacent to the river is typically more than 50 feet deep in this area. Water levels at the Calloway Pool are measured by ID4 in a dedicated monitoring well (ID4 No. 13) located in the Kern River Parkway on the south side of the

Calloway Pool and the Kern River channel; the location of the well is shown on **Figure 3-40** (and also on **Figure 3-24**, see Hydrograph 3). Groundwater elevations in the well are shown in the hydrograph on **Figure 3-42**. The top of the well screen is relatively shallow and capable of measuring the local water table (i.e., when water levels are low, the water table is below the top of the screen). As shown by the hydrograph, water levels from 2000 through 2017 have been relatively stable, ranging from elevations of about 320 to 360 feet msl. The highest elevations were recorded during the summer and fall of 2017 (**Figure 3-42**). Since monitoring began in 2000, the average depth to the water table has been more than 80 feet. The depth to water was about 60 feet during 2017. This separation between the water table and the river demonstrates that there is no interconnected surface water at the Calloway Pool. With ground surface elevations rising upstream, groundwater is expected to be even deeper above Rocky Point Weir to the edge of the Plan Area. Given these conditions, the Kern River does not appear to be interconnected surface water in the KRGSA Plan Area.

3.3.6.4 Hydrologic Profiles Along the Kern River

To further evaluate potential surface water/groundwater interactions beneath the Kern River, groundwater elevations over time along the entire reach of the river in the Plan Area are incorporated into the analysis. Profiles of groundwater elevations were developed along an approximate 23-mile transect between First Point and Second Point. The transect location is shown on **Figure 3-40** and labeled A to A’ from First Point to just past Second Point, respectively. Because the transect is a straight line, it deviates from the river channel in numerous locations. For those deviations, the actual elevations in the river channel were checked against the profile and incorporated into the discussion below. The largest differences in ground surface elevation between the transect and the channel occur primarily outside of the KRGSA Plan Area in the northern portion of the transect. These deviations also affect the groundwater elevations, creating uncertainty in several areas of the transect including those areas outside of the KRGSA Plan Area.

Profiles were created in GIS based from annual groundwater elevation contour maps developed by KCWA for the Principal Aquifer, as discussed in **Section 3.3.2.3 and 3.3.2.4**. Maps are prepared using spring data and represent the high groundwater elevation for that year. There are numerous limitations recognized for this analysis that could cause water levels to be higher or lower than represented by the profiles. It is recognized that the contour maps are not sufficiently precise to determine the exact height of the groundwater mound beneath the river in spring in every small segment of the river, given the relatively large contour intervals. In addition, the northeastern portion of the transect contains limited data and water levels in that area are less certain. Finally, many of the wells used for contouring are water supply wells with long screens that may represent a lower water level than at the water table.

These limitations suggest that spring groundwater elevations could be higher beneath the river than shown by the maps and the associated profiles. However, elevations could also be lower than mapped as evidenced by the number of municipal wells close to the river, most of which are not included in the contouring (see **Figure 2-14**). In addition, groundwater elevations decline significantly following the spring highs as groundwater and available surface water use increases with summer demands.

Notwithstanding these limitations, the KCWA contour maps represent the best available understanding of groundwater elevations in the Plan Area over a 20 year period for the purposes of this analysis.

A groundwater elevation profile developed for each annual spring map is plotted on **Figure 3-43** in relation to the ground surface elevation. (The ground surface elevation is based the USGS DEM shown on **Figure 3-7** and checked against channel surveys). The profiles are color-coded according to DWR Indices for the San Joaquin Valley water year type, which are not always coincident with water year type in Kern County (discussed in **Section 3.2.4.1**). Although the large number and crisscrossing nature of the profiles make it difficult to follow any single profile, the clustered nature of the data provide a method of viewing a wide range of spring water levels over 20 years beneath the river. The range of groundwater elevations and the amount of groundwater separation from the ground surface can be readily seen on **Figure 3-43**, regardless of the year type or the actual year.

The profiles on **Figure 3-43** suggest that groundwater elevations occur well below the entire reach of the Kern River within the Plan Area throughout the 20-year Study Period and indicate an absence of interconnected surface water. Although it is difficult to discern the pattern of a profile in any specific year, **Figure 3-43** illustrates that there is always a separation between the bottom of the Kern River channel and groundwater in the Principal Aquifer even at the highest elevation of each year, which the profiles represent.

Collectively, the crossing profiles on **Figure 3-43**, indicate a relatively consistent pattern of areas along the river reach with high and low groundwater elevations. In the northeast from Mile 0 to Mile 3, groundwater elevations are relatively high for most profiles although the depth to groundwater is typically deeper than 50 feet below the channel as ground surface elevations rise into the western uplands (note the river channel elevation extrapolated onto the northeastern portion of the transect on **Figure 3-43**). The low groundwater elevations from Mile 3 to Mile 5 are in an area north of the river where contours are being controlled by much lower groundwater elevations to the northwest.

From Mile 5 to Mile 11, groundwater rises relatively close to the channel, especially in wet years (**Figure 3-43**). This area includes recharge at the Calloway Pool but extends downstream of the Calloway Weir, where the channel is often dry. Accordingly, these high water levels are not the result of natural recharge. As discussed above, water is held above the weir in the Calloway Pool for groundwater recharge and diversion. Downstream of the weir, recharge continues in numerous unlined canals over a broad area moving away from the channel. In addition to managed recharge in the channel and canals, imported water is also being banked in this area through an unlined portion of the Cross Valley Canal. Recovery wells along the river channel downstream are used to extract this banked water when imported water is less available, creating lower groundwater elevations to the southwest. At Mile 10.8 of the transect, the sandy river channel is crossed by a complex system of lined and unlined canals including the Friant Kern Canal, which brings CVP water into the Subbasin. Referred to as the “Spaghetti Bowl” the channel is actively managed to optimize flexibility in conveying various water sources in many directions.

Groundwater elevations between Mile 5 and Mile 11 appear to rise within about 20 feet of the bottom of the channel during the spring of wet years (**Figure 3-43**). However, in dry years, water levels fall to 50 feet or more below the channel elevation. Fluctuations in groundwater elevations of more than 150 feet are indicated between wet and critically dry years (**Figure 3-43**). This wide fluctuation is attributable to the difference in the amount of surface water (imported and river water) available for managed recharge along the channel.

Groundwater elevations generally decline over the next few miles until the transect reaches the eastern extent of numerous groundwater banking projects near Mile 14.5, including Berrenda Mesa and the COB 2800 recharge facilities in the Plan Area (**Figure 3-43**), as well as the adjacent Pioneer Project and the Kern Water Bank. Profiles indicate groundwater mounding during recharge operations and groundwater declines when banked water is being recovered. This area contains the largest water level fluctuations (more than 250 feet) observed in the Plan Area (**Figure 3-43**).

Collectively, the hydrologic profiles across the KRGSA Plan Area do not indicate interconnected surface water or sufficiently high water levels to support GDEs along the Kern River. Although groundwater levels may rise within 20 feet of the base of the channel in some areas, this appears to occur only in wet years and/or as a result of intentional recharge along the channel. The profiles corroborate the information in the annual Kern River hydrographic reports, which show the Kern River channel to be a losing stream from First Point to Second Point (approximate area from Mile 2.5 to Mile 21 on **Figure 3-43**). This includes the area along the river where TNC has mapped vegetation and wetlands (Mile 2.5 to Mile 13.4 on **Figure 3-43**). This riparian vegetation appears to be supported by surface water in the river channel (when and where it occurs), local irrigation and runoff, and local infiltration of water on sides and bottoms of nearby unlined canals and recharge basins; the vegetation does not appear to be supported by groundwater.

3.3.6.5 Depth to Water for Spring 1998

To assess NCCAG-mapped vegetation away from the Kern River channel, a regional depth to water map was constructed from the Spring 1998 groundwater elevation contour map developed by KCWA. That map was evaluated electronically in GIS with the USGS DEM of ground surface elevations to create a depth to water raster as shown on **Figures 3-44** and **3-45** for the northern and southern Plan area, respectively. Spring 1998 conditions were chosen because it was a wet year with relatively high water levels. Water levels for 1998 are not the highest water levels observed everywhere beneath the river channel; water levels continued to rise in 1999 and 2000. In addition, the regional raster is not sufficiently detailed beneath the river for precise analysis. However, 1998 groundwater elevations are higher overall across the Plan Area and represent the best period for analysis of potential GDEs away from the river. The 1998 map was also chosen because it was based on a large data set with more complete contouring over the area than some of the other wet-year maps.

The 1998 depth to water beneath the northern Plan Area is shown on **Figure 3-44**. The regional map indicates deeper groundwater beneath the uplands in the northeast where ground surface elevations rise above 900 feet msl (more than 500 feet above the valley floor). Although there are few wells to confirm groundwater elevations over the entire upland area, wells with water levels deeper than 250 feet were used to confirm the conceptualization of deeper groundwater in the upland areas. For the remaining area shown on **Figure 3-44**, spring 1998 data indicate groundwater depths from about 50 to 200 feet deep, with the shallower depths indicated along the river (**Figure 3-44**).

The depth to groundwater for spring 1998 conditions in the southern Plan Area is shown on **Figure 3-45**. In general, groundwater is shallower in the southern Plan Area with most of the groundwater ranging from 150 feet to 50 feet deep. This condition is mostly related to lower ground surface elevations toward the south with the lowest ground surface elevations at the paleo-lakebed of Kern Lake on the southern boundary; most of this area is now cultivated for agriculture. Groundwater is estimated to be within about 50 feet of the ground surface beneath the Kern Lake. This area contains clay soils and underlying clay sediments that impede surface water infiltration and create perched water. As discussed previously, a broad area of perched water has been mapped in the southern Plan Area over time as shown on **Figure 3-45**. This area of perched water was discussed previously and correlated the distal portions of alluvial fans and paleo lakes in the area (see previous discussions in **Sections 3.2.3** and **3.3.2.2**).

Two hydrographs provided on **Figure 3-46** allow a comparison of perched water elevations (31S/28E-28D01) and groundwater elevations in the Principal Aquifer (31S/27E-25D01). Well locations are shown on **Figure 3-45**. As shown on the graph, the perched water averages about 18 feet below ground surface. During the recent drought, perched water declined to about 30 feet below ground surface. Although wells with long-term records in the perched zone are sparse, the zone has been observed at depths of about 20 feet to 50 feet. The perched zone appears to be hydraulically separated from the Principal Aquifer and does not typically respond with variations seen in deeper wells, as evidenced by the pair of wells on **Figure 3-46** and other wells (e.g., see Hydrograph 10 on **Figure 3-24**). As shown by the hydrograph from the Principal Aquifer on **Figure 3-46**, depth to water in the Principal Aquifer ranges from about 75 feet below ground surface to more than 150 feet below ground surface.

3.3.6.6 Local NCCAG-Mapped Areas

To further examine the large number of NCCAG-mapped vegetation and wetlands polygons, four local areas have been selected for both the northern and southern Plan Area to allow detailed viewing on a 2016 aerial photograph. The extents of the four local-scale maps for the northern and southern Plan Area areas are shown on **Figures 3-44** and **3-45**, respectively. The local-scale maps are shown on **Figures 3-47** and **3-48**, as panels a though d.

Northern Plan Area

There are about 110 areas with vegetation commonly associated with groundwater and 52 wetland areas mapped in the northern Plan Area (**Figure 3-44**), most of which can be characterized as occurring along the Kern River corridor or in upland drainageways. The four local-scale areas for the northern Plan Area cover 82 vegetation and 34 wetland polygons to allow examination of about 70 percent of the total mapped areas in more detail; these are shown on **Figure 3-47** as **Figure 3-47a** through **3-47d**.

Figure 3-47a covers an approximate one-half-mile segment of the Kern River upstream of the Bellevue Weir. Mapped vegetation in this area includes Red Willow, Mule Fat, Fremont Cottonwood, and Narrowleaf Willow shown by the shaded polygons in the Kern River channel. A riverine wetland (semi-permanently flooded) has also been mapped within the channel. The river is rimmed by the Cross Valley Canal to the north and the Kern River Canal to the south. The City maintains recharge basins that are shown on the western portion of the map and include Aera Park north of the river and two small basins in the Park at River Walk south of the river[19]. In addition to maintaining the recharge basins, the City also provides river channel maintenance in this area involving sand and vegetation removal for flood control. As discussed above, the channel in this area is typically dry as shown on this 2016 aerial photograph. KCWA monitors water levels in a nearby well (30S/27E-05D01), located about 800 feet south of the channel (**Figure 3-47a**). With the top of the well screen at 58 feet below ground surface, the well is a reliable monitoring point for the local water table. Since 1995, the water table has always been deeper than 70 feet below ground surface. During 2015, the water table was measured at a depth of 198 feet below ground surface.

Figure 3-47b shows the Calloway Weir and the Calloway Pool as discussed above. During this period in 2016, the river channel is partially wetted with several braided channels shown on the map. As shown, vegetation and wetlands have been mapped within and adjacent to the channel. Vegetation includes Goodding's Willow, Fremont Cottonwood, Mule Fat, Red Willow, Common Elderberry, Arrow-weed, and riparian evergreen and deciduous woodland. As discussed above, this area of the river is the most wetted and supports the most diverse habitat with riparian vegetation in the KRGSA Plan Area. This is also an area of significant recharge both in the pooled area of the river as well as in the adjacent unlined canals such as the Carrier Canal (**Figure 3-47b**). As discussed above, water levels in monitoring well ID4 No. 13, adjacent to the pool, have been about 80 feet deep on average since monitoring began in 2000 (see **Figure 3-42**).

Figure 3-47c includes a reach of the Kern River downstream of the Beardsley Weir. The lined Beardsley Canal lies north of the river and the unlined Carrier Canal diverts from the channel at the Rocky Point Weir. The ground surface elevation is higher in this upstream area; the approximate channel elevation at the eastern edge of the map is about 443 feet msl. The ground surface profile on **Figure 3-43** shows that this elevation is transitioning into the western uplands of the river. The soils associated with this reach of river include silty loam, which is less permeable than the downstream sandy loams and sand and holds more water in the river. Mapped vegetation along this reach consists primarily of Fremont Cottonwood, California Sycamore, Goodding's Willow, and Common Elderberry. **Figure 3-47c** also illustrates the land uses surrounding the vegetation areas, including the Kern River Oil Field. Although water level data are limited in this area, nearby water supply wells at the oil fields indicate water depths of more than 100 feet in the area. Shallow wells drilled in the 1960s along the channel indicate shallow water levels of about 10 to 20 feet.

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[19] An additional City recharge facility, referred to as Truxtun Lakes, is located about 1.5 miles upstream and not shown on Figure 3-47a.

Figure 3-47d shows an area about 7 miles upstream of First Point on the Kern River. An isolated "island" of the Plan Area is shown north of the river and the larger portion of the Plan. The "island" contains development along Rancheria Road north of the river and includes an area of mapped vegetation including Fremont Cottonwood and Scalebroom. The map also includes two examples of NCCAG-mapped vegetation and wetlands along drainageways in the northwestern uplands of the Plan Area. The eastern most drainage, Cottonwood Creek, contains mapped wetlands, Fremont Cottonwood, and Mule Fat. These upland drainages extend from high elevations in the south (800 to 900 feet, msl) down to the river channel in the north at ground surface elevations of about 550 to 600 feet, msl. Although no water level data are available for these drainageways in the Plan Area, it seems unlikely that the water table could be sufficiently high to support vegetation. These drainageways are more likely located along relatively less permeable consolidated sediments and hold enough local runoff to support vegetation and wetted areas.

Southern Plan Area

For the southern Plan Area, four local areas shown by the map extents on **Figure 3-45** were selected for closer examination on **Figure 3-48**. These local areas include more than 70 percent of the total number of vegetation and wetlands polygons in the southern Plan Area.

Figure 3-48a includes four areas of vegetation with dominant species of Narrowleaf Willow and Goodding's Willow. As shown on the photo, this vegetation grows along and within a recharge basin developed by KDWD for replenishment of groundwater and groundwater banking in the far southwestern Plan Area. Vegetation within the area is controlled to maximize recharge capacity.

Figure 3-48b in an area in the south central Plan Area north and south of Di Giorgi Road. The area is surrounded by cultivated agriculture and two small communities served by El Adobe POA and Panama Road Homeowners Association water systems. Part of the undeveloped land in the north contains the Greenfield Flyers, a radio control aircraft club. Vegetation in this area includes primarily Iodine Bush, Alkali Goldenbush, and Tamarisk (a non-native invasive species). The unlined Central Branch Canal is located just off the map to the west and runs parallel to the mapped vegetation. Although the entire area is likely within the area of perched water, groundwater in the Principal Aquifer is about 150 feet deep. As indicated on Figure 3-48b, much of the NCCAG-mapped areas do not appear to contain a dense natural community of vegetation in 2016.

Figure 3-48c contains areas of mapped vegetation with dominant species of Tamarisk (an invasive non-native), Alkali Goldenbush, Shrubby Seepweek and Iodine Bush. As shown on **Figure 3-45**, this area is located in the far southeastern Plan Area where underlying clay soils allow retention of ponded water used for recreation as water ski lakes. The land, owned by Ski West Village, has developed the land for housing and recreation. A mapped wetland on the southern portion of the property appears to be an additional developed lake.

Figure 3-48d includes private property surrounding the New Rim Ditch Canal bordering the southern Plan Area boundary. Wetlands, invasive tamarisk, and other vegetation are mapped along a constructed and maintained canal are not natural communities. The canal is used to convey agricultural water around the southern Plan Area. NCCAG-mapped area is referred to as the Kern Lake Preserve. The area apparently contains Quailbush, Iodine Bush, and willows, which receive agricultural tailwater. Perched water west of I-5 has been observed to contain elevated salt content and high concentrations of TDS. Although perched water has been mapped in the area, groundwater in the Principal Aquifer is more than 50 feet deep in this area. None of the local vegetation is supported by groundwater.

3.3.6.7 Summary

Information regarding Kern River operations and flow, channel elevation, and groundwater elevation data over a 20-year period indicate that the Kern River is not interconnected surface water in the KRGSA Plan Area. Riparian vegetation along the river is supported primarily by regulated flows from Lake Isabella, pooled water to support river operations (above the Calloway Weir), and managed aquifer recharge in the river channel and adjacent unlined canals. The Plan Area also contains a small segment of riparian vegetation along the river above First Point (**Figure 3-47d**), which is limited to a small area in the northeastern Plan Area where data are insufficient to determine surface water-groundwater interactions. However, this area also is characterized by regulated flows in the river.

Data on groundwater depth and other local conditions do not indicate the presence of GDEs in the Plan Area. Irrigation water infiltration and agricultural return flows could be contributing to local vegetation water use in the southern Plan Area. In this area, infiltration of irrigation water and agricultural return flows are impeded by clay soils and subsurface clay sediments; this creates shallow perched water conditions that appear disconnected from regional groundwater. If GDEs are being supported by locally perched water, this condition will likely continue under the GSP as surface water continues to be an important source for irrigation in the southern Plan Area.

3.4 DATA AND KNOWLEDGE GAPS

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.

In general, well construction information is unknown for many wells currently monitored, especially for private wells being monitored in the southern Plan Area. Efforts to match known active wells to construction data have been difficult. In particular, the area of perched water in the southern Plan Area indicates complications with respect to intervals of well screens. Although well completion reports indicate that most wells are similarly-constructed, water levels in some areas appear to be associated with locally high water levels even if well completion reports in the area are associated with deep screens. A systematic approach to better link water level response to well construction throughout the Plan Area would provide useful information.

Although the northern Plan Area is associated with a large amount of water quality data, results of local environmental investigations are not well known. Multiple cleanup sites in the KRGSA are listed in **Table 3-4**. Sites within municipal wellfields are prioritized for review of more detailed information. Coordination and communication with the Central Valley Water Board may be the most efficient method for identifying and prioritizing sites to watch. These sites often have monitoring wells installed and a regulatory order to conduct monitoring. It would be helpful to the KRGSA to compile a list of these wells and download data from the more relevant monitoring wells as available.

In addition, the widespread detection of TCP across the KRGSA should be better understood. Tens of wells have installed wellhead treatment facilities to manage the problem. However, because the MCL was only recently adopted, many smaller water systems are analyzing TCP at sufficiently low detection levels for the first time. Coordination with DDW and data from the SWRCB/Geotracker would be helpful in making sure that TCP concentrations are well-managed.

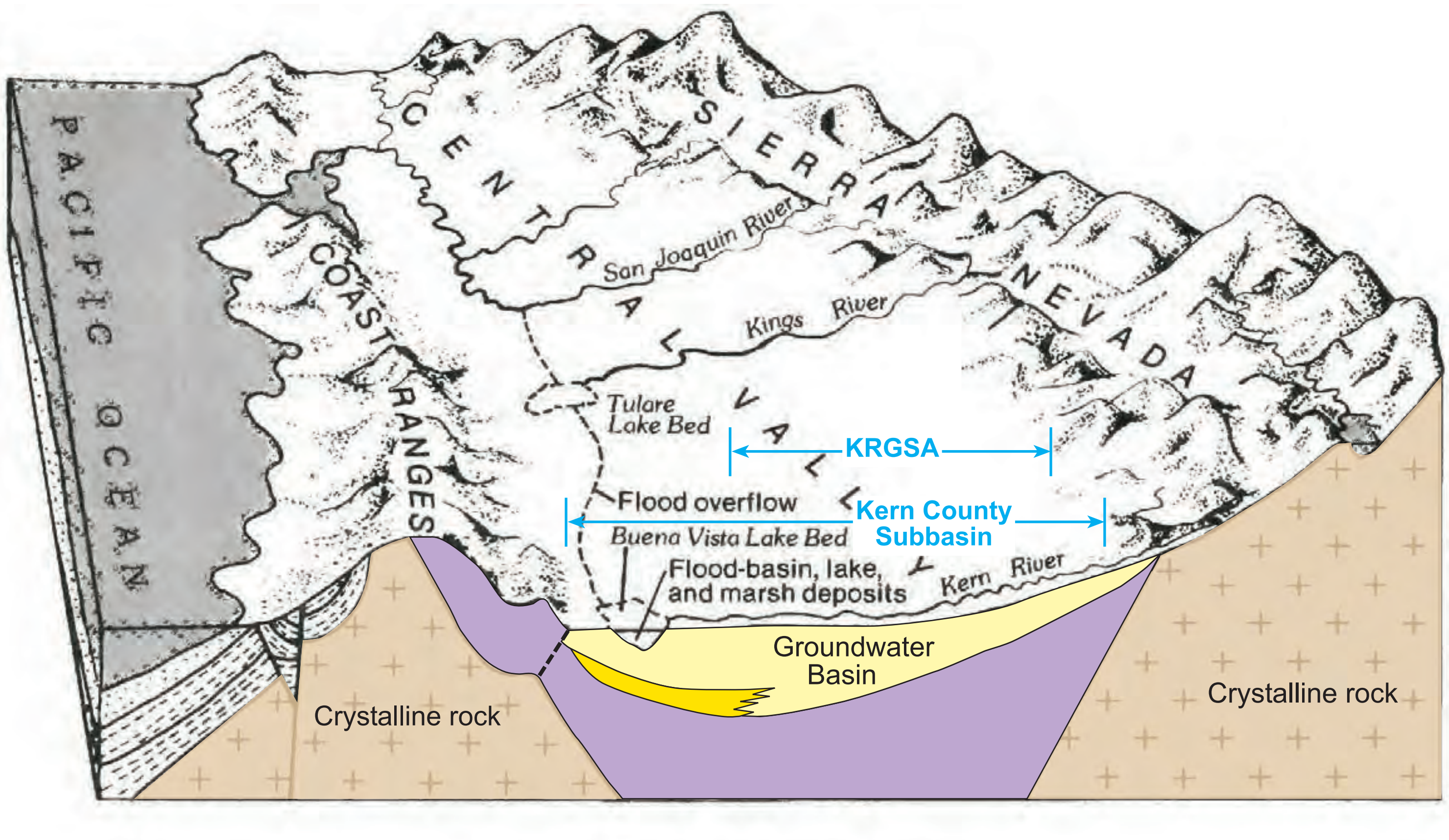
Finally, the northeastern Plan Area contains few wells and sparse water level data. This portion of the KRGSA consists of a large upland area covering about 15,000 acres (northeastern area above about 700 feet msl on **Figure 3-7**). The area contains large areas of undeveloped lands including more than 4,000 acres of oilfield lands. Some portions contain low density residential development, relying primarily on domestic wells.

Although this northeastern upland area is within Metropolitan Bakersfield (**Figure 1-2**), only a few active municipal wells are nearby (**Figure 2-14**). KCWA has added private wells to its water level monitoring program when candidate wells could be found. For the GSP, a few of these currently-monitored wells are being incorporated into the monitoring program, but long-term access is uncertain. There may be a need to locate additional existing wells or install new wells in this area. At this time, local groundwater production can likely be considered de minimis. However, this uncertainty would be prioritized if urban development and associated well drilling increases in this area.

Data and knowledge gaps for the hydrogeologic conceptual model and groundwater conditions are summarized in **Table 3-6**.

Table 3-6 Data Gaps for the Hydrogeologic Conceptual Model and Groundwater Conditions

Issue	Area	Groundwater Management	Actions to Address
Well Construction	Southern and southeastern Plan Area	Vertical gradients, water levels, and primary production zones in Principal Aquifer	Improvements to monitoring network; match construction data to monitoring wells, where possible
Water Quality	Primarily northern Plan Area	Impacts from Environmental Sites	Coordinate with Water Board; ongoing document/data review
Water Quality	Entire KRGSA Plan Area	Water level impacts on 1,2,3-TCP, arsenic and other constituents of concern	Coordinate with SWRCB and Community Water Systems; ongoing evaluation of water supply well data
Northeastern KRGSA Plan Area	12,000 acres with limited aquifer and groundwater data	NE corner of ID4 and areas to northeast of ID4 service area	Research existing wells in the area and identify priority areas for monitoring; work with City planning to identify growth in the area and plan for new wells



Continental Deposits

San Joaquin Formation (transition from marine to continental deposits)

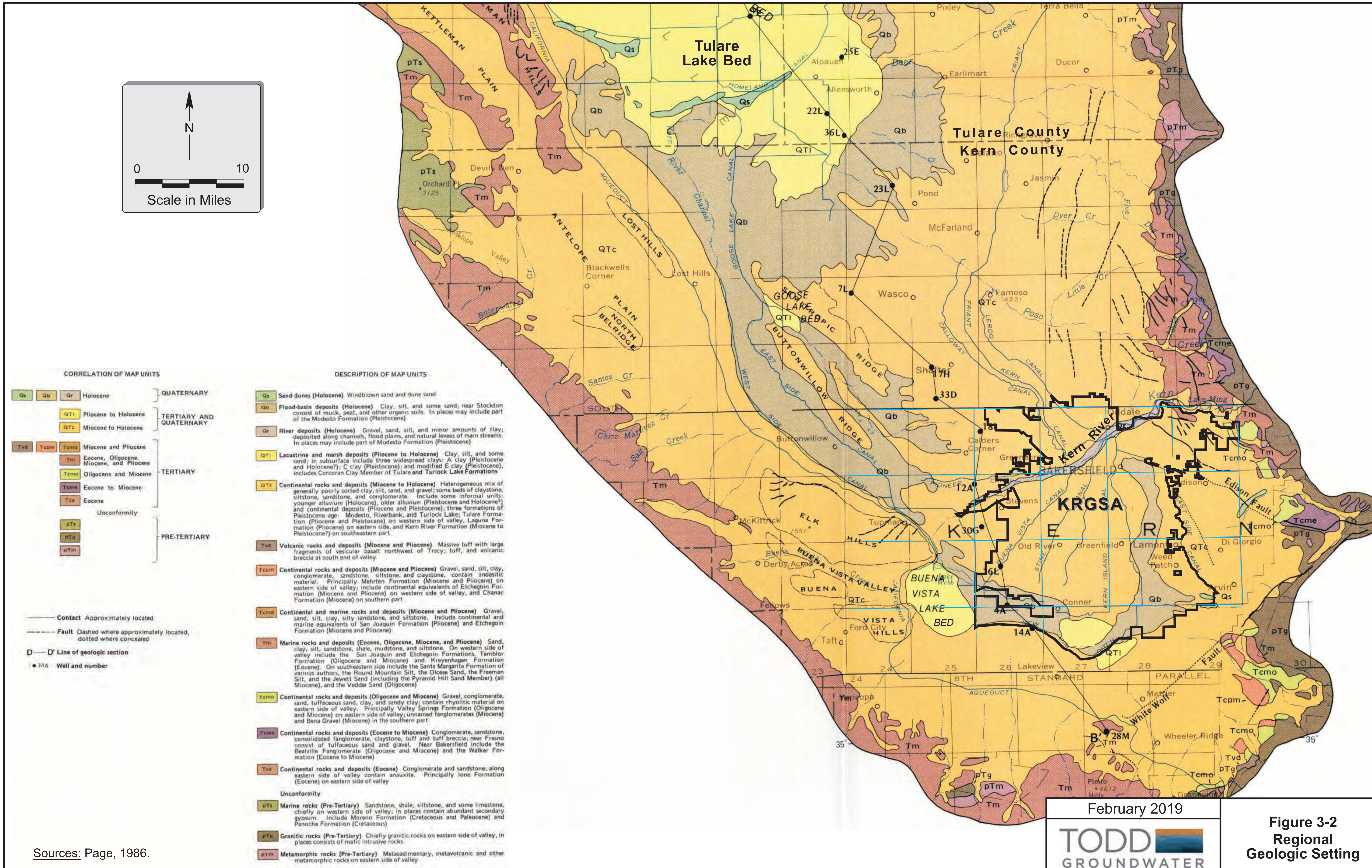
Marine Sedimentary Units

Source: Modified from Page, 1986 and DOGGR, 1998.

February 2019

TODD GROUNDWATER

Figure 3-1
Schematic Diagram Regional Setting Kern County Subbasin



Sources: Page, 1986.

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Figure 3-2
Regional Geologic Setting

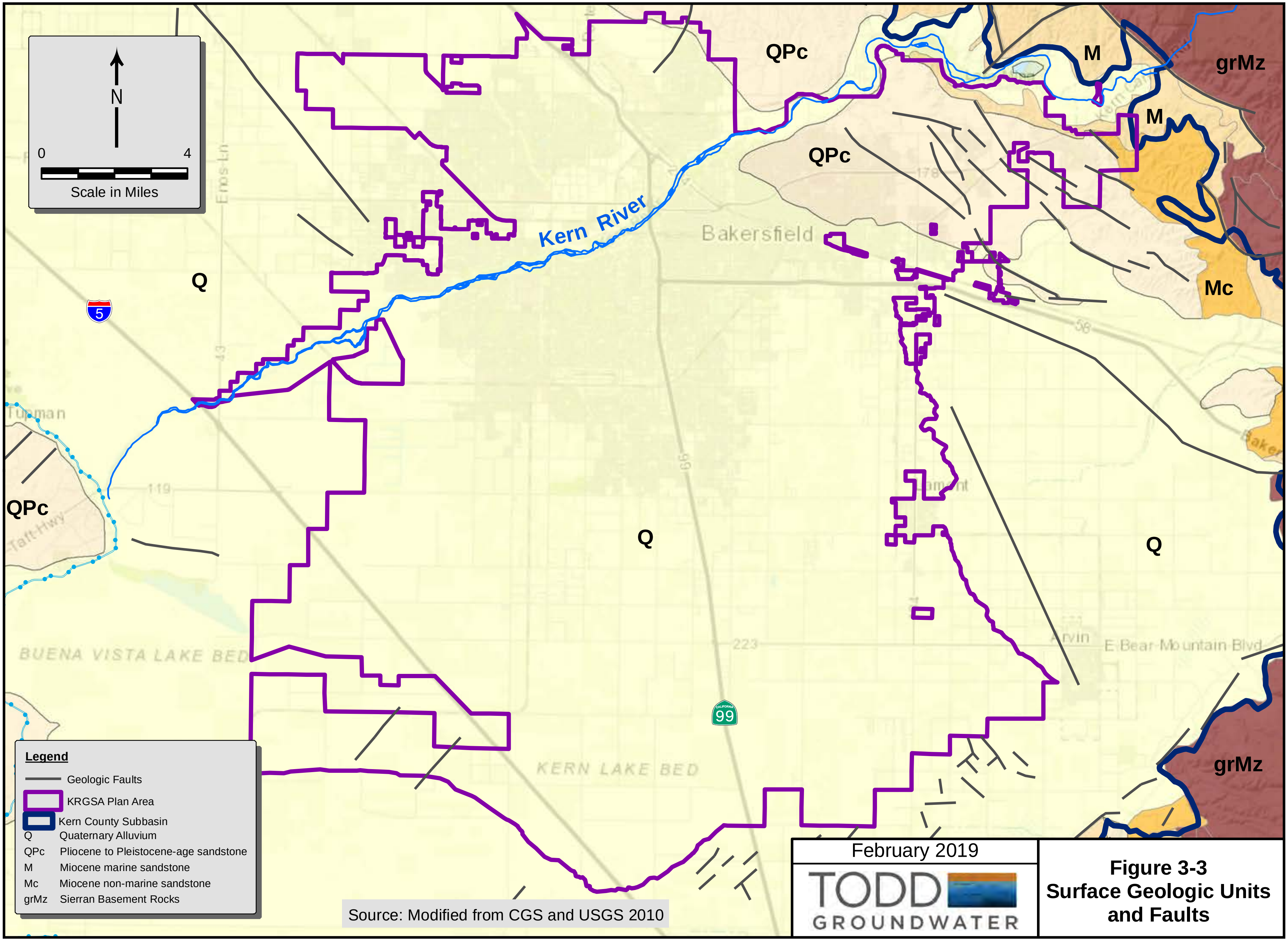
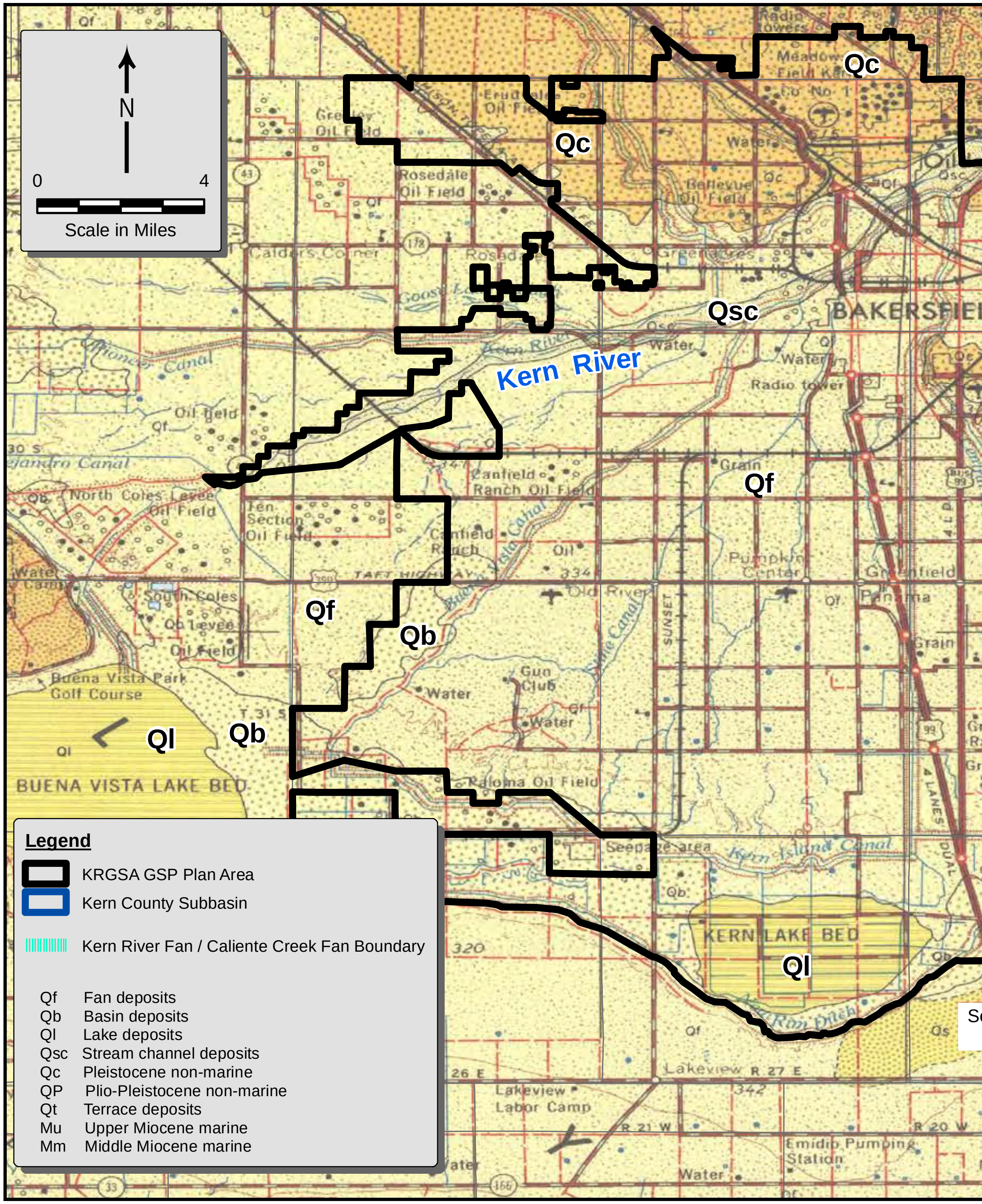


Figure 3-3
Surface Geologic Units and Faults



March 2019

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Figure 3-4
Local Geologic Map
KRGSA GSP Plan Area

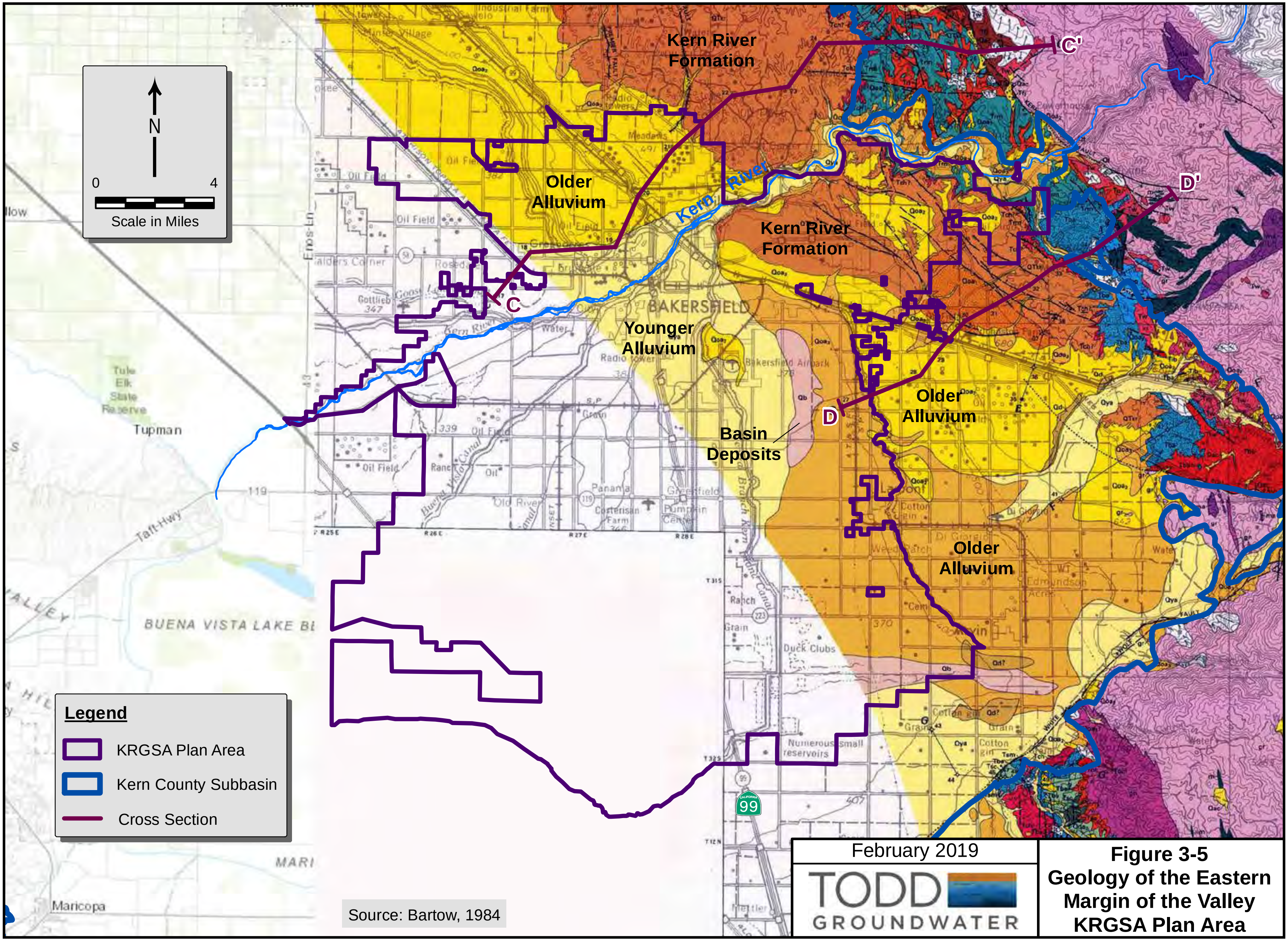

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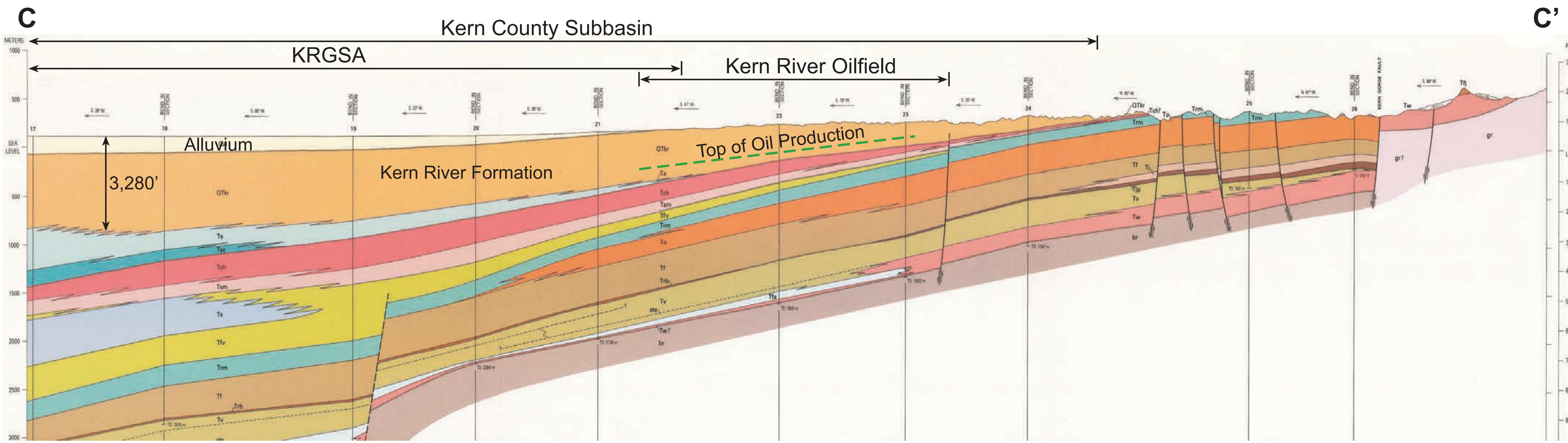
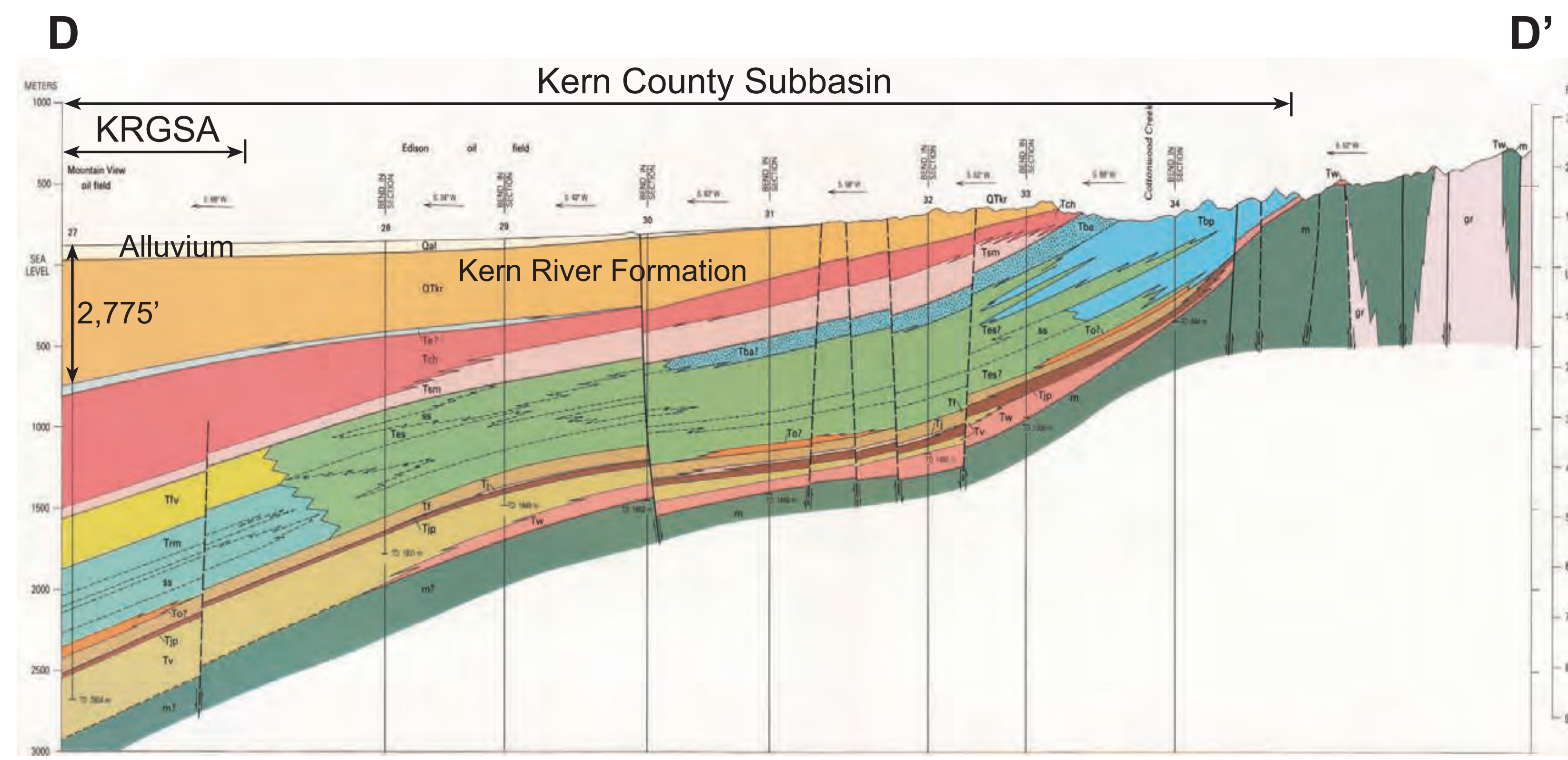
Figure 3-5
Geology of the Eastern Margin of the Valley
KRGSA Plan Area



North of the Kern River



South of the Kern River

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Figure 3-6
Subbasin Geometry Eastern Margin Cross Sections

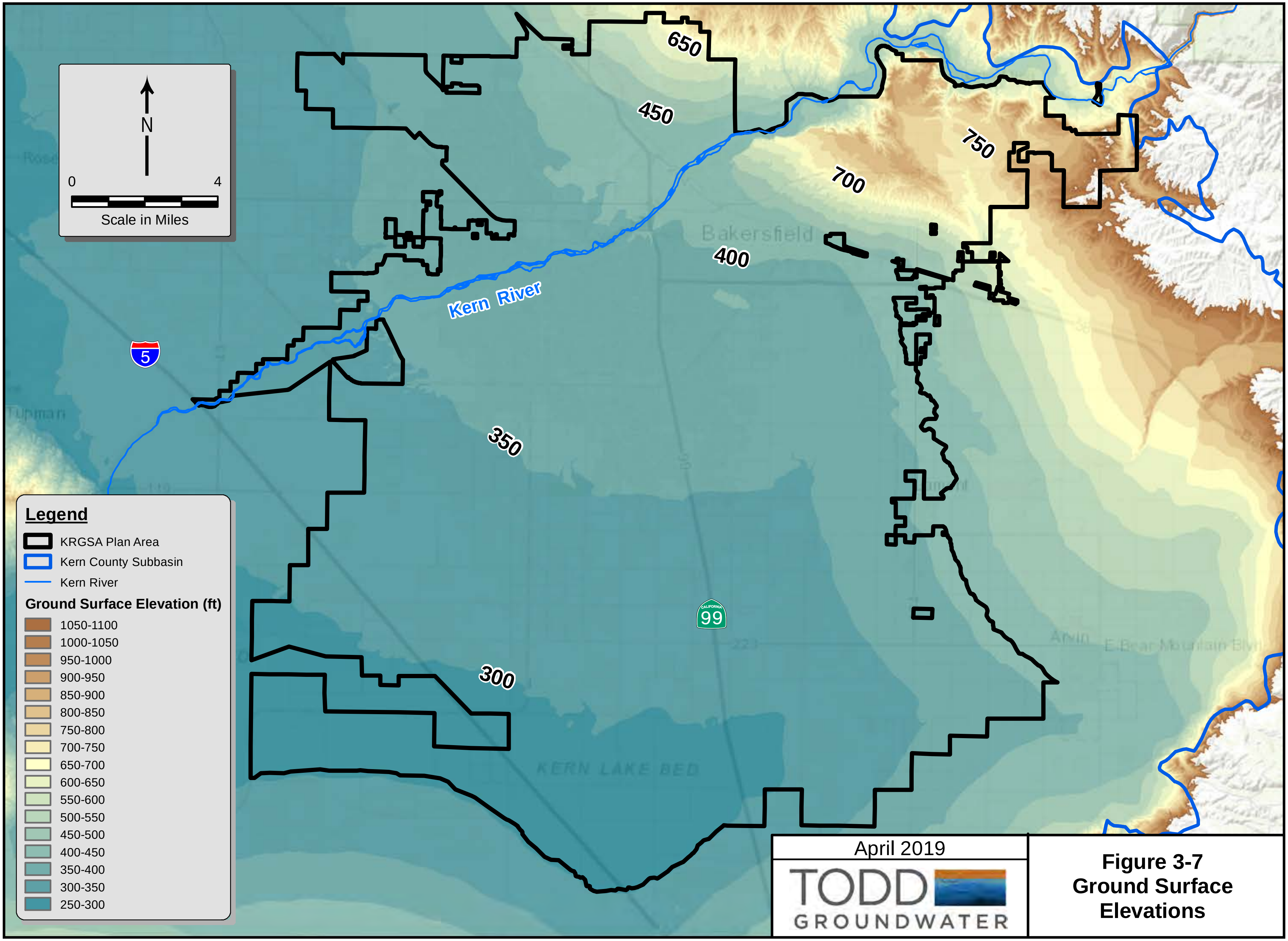


Figure 3-7
Ground Surface Elevations

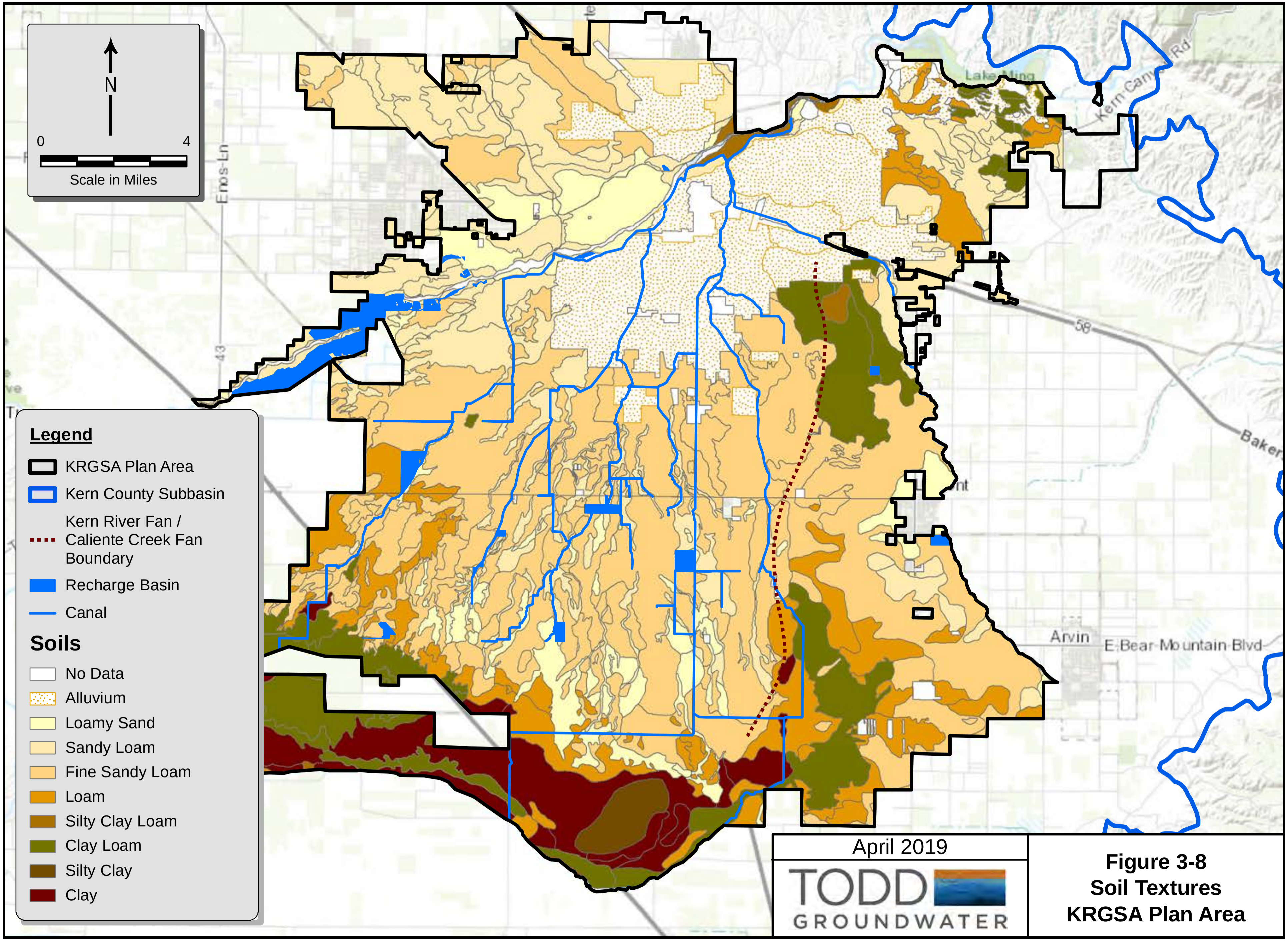
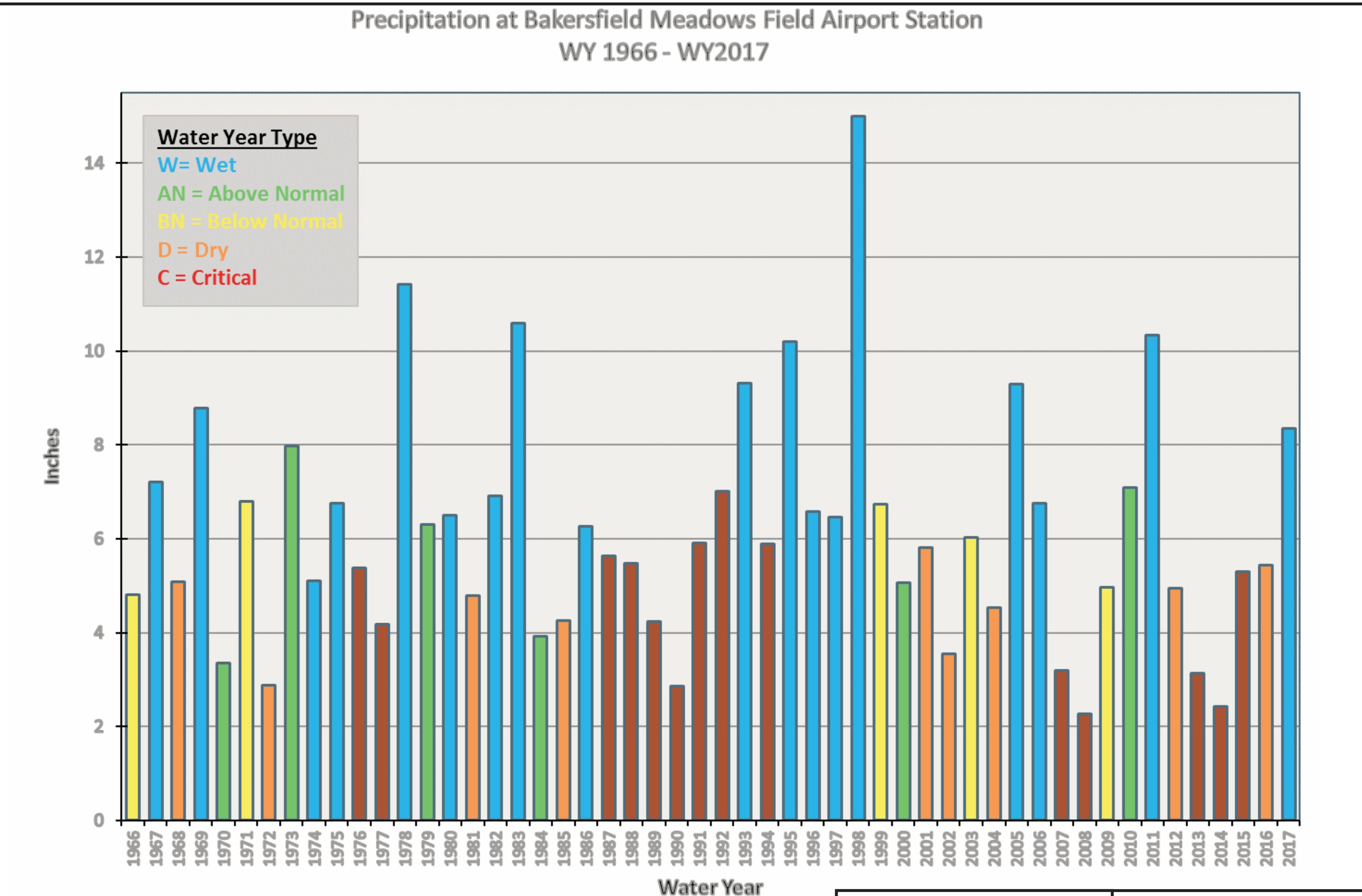


Figure 3-8
Soil Textures
KRGSA Plan Area



Sources: Precipitation - NOAA, 2018
Water Year Type - DWR, San Joaquin Valley Indices

February 2019

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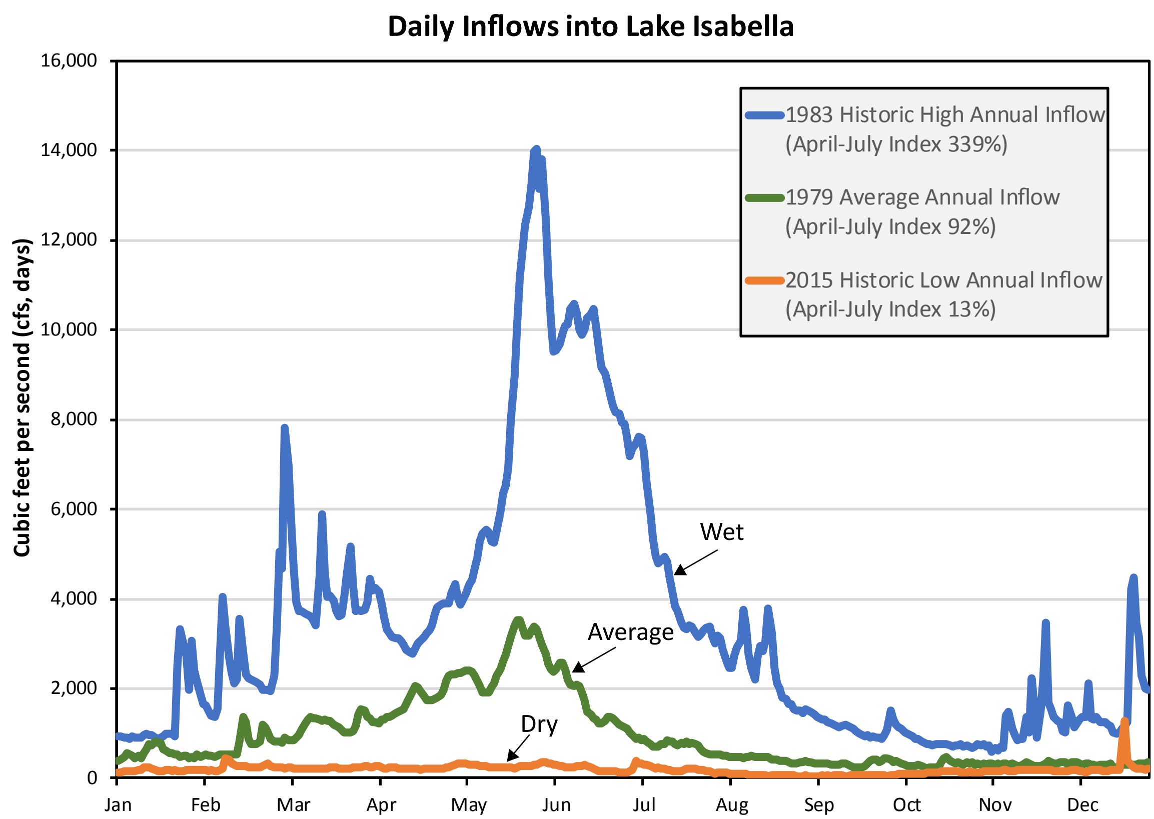
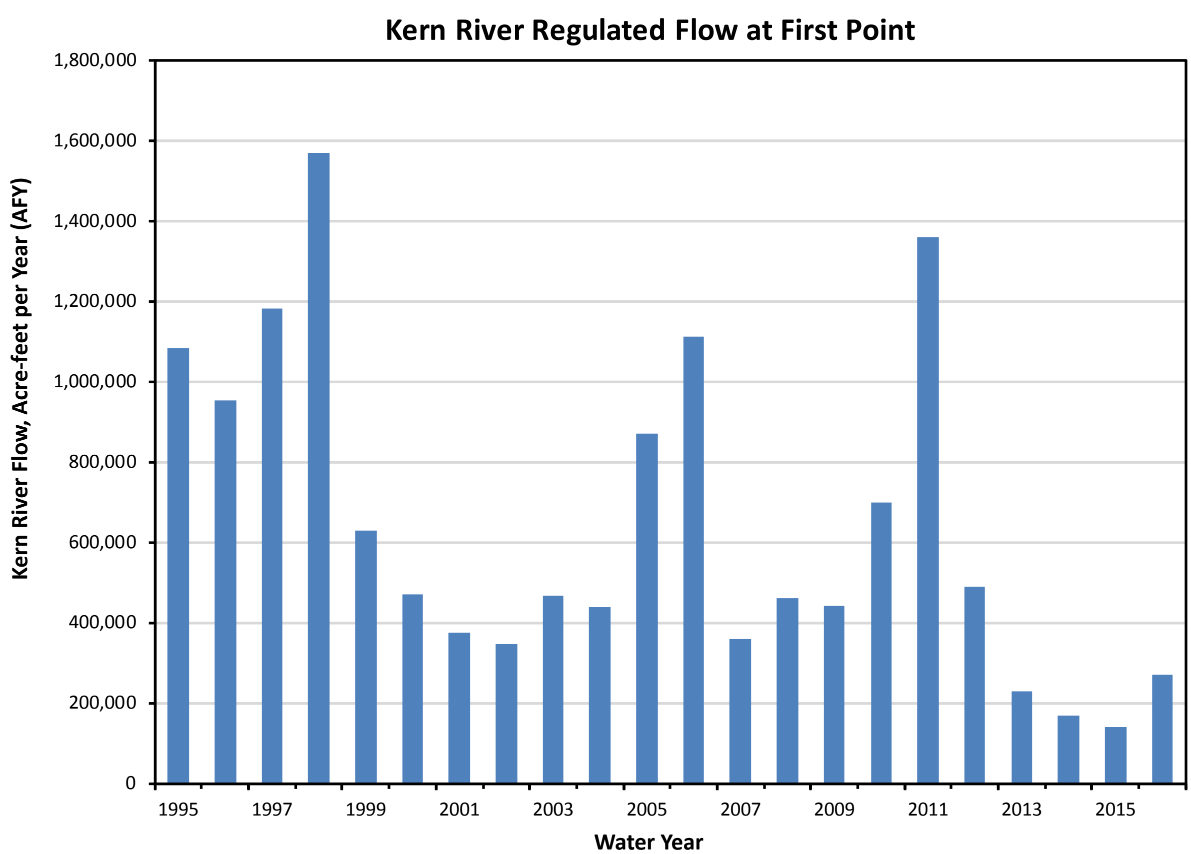
Figure 3-9
Precipitation and Water Year Type





March 2019	**Figure 3-10**
TODD GROUNDWATER	**Kern River Flows**

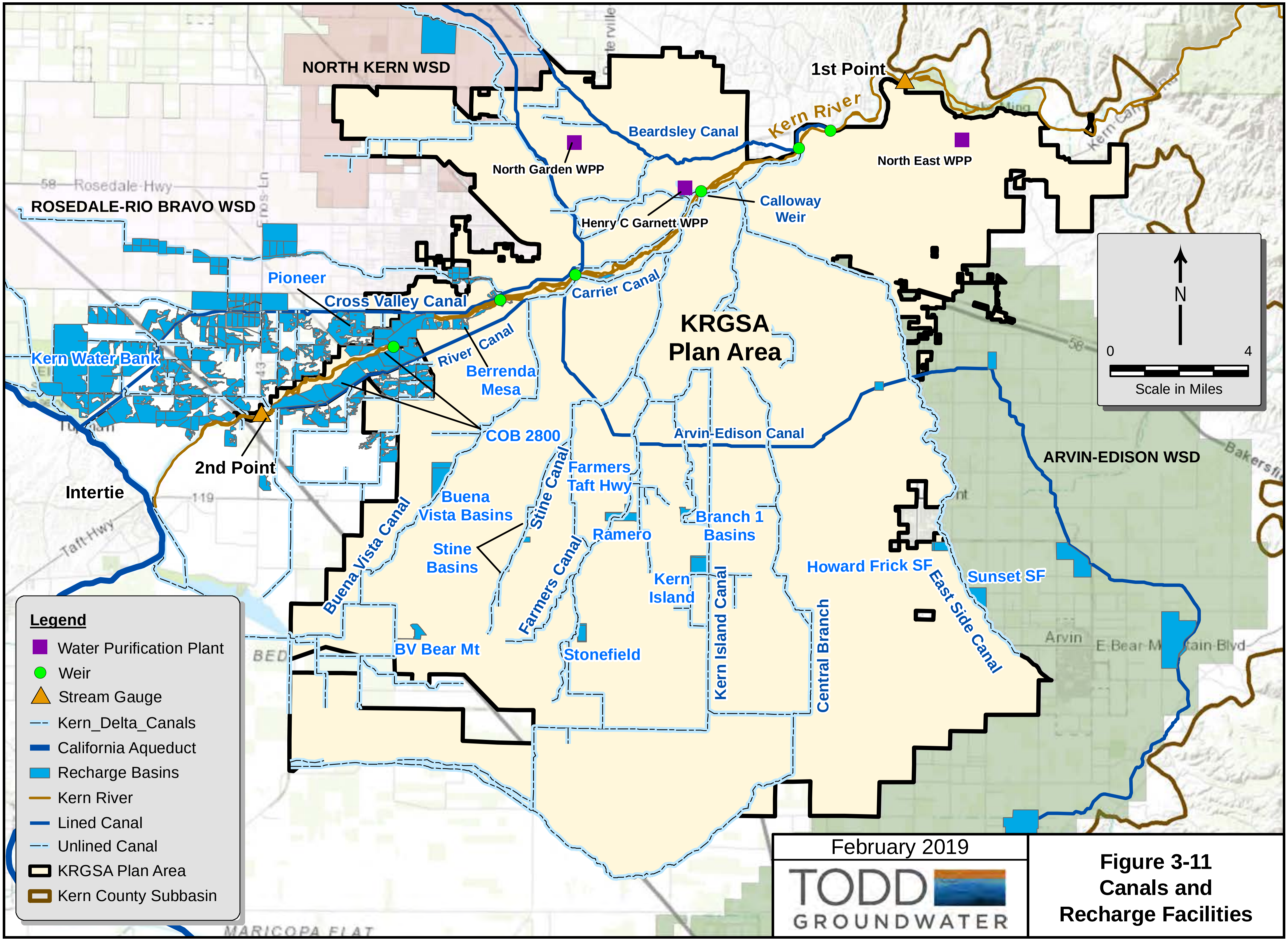
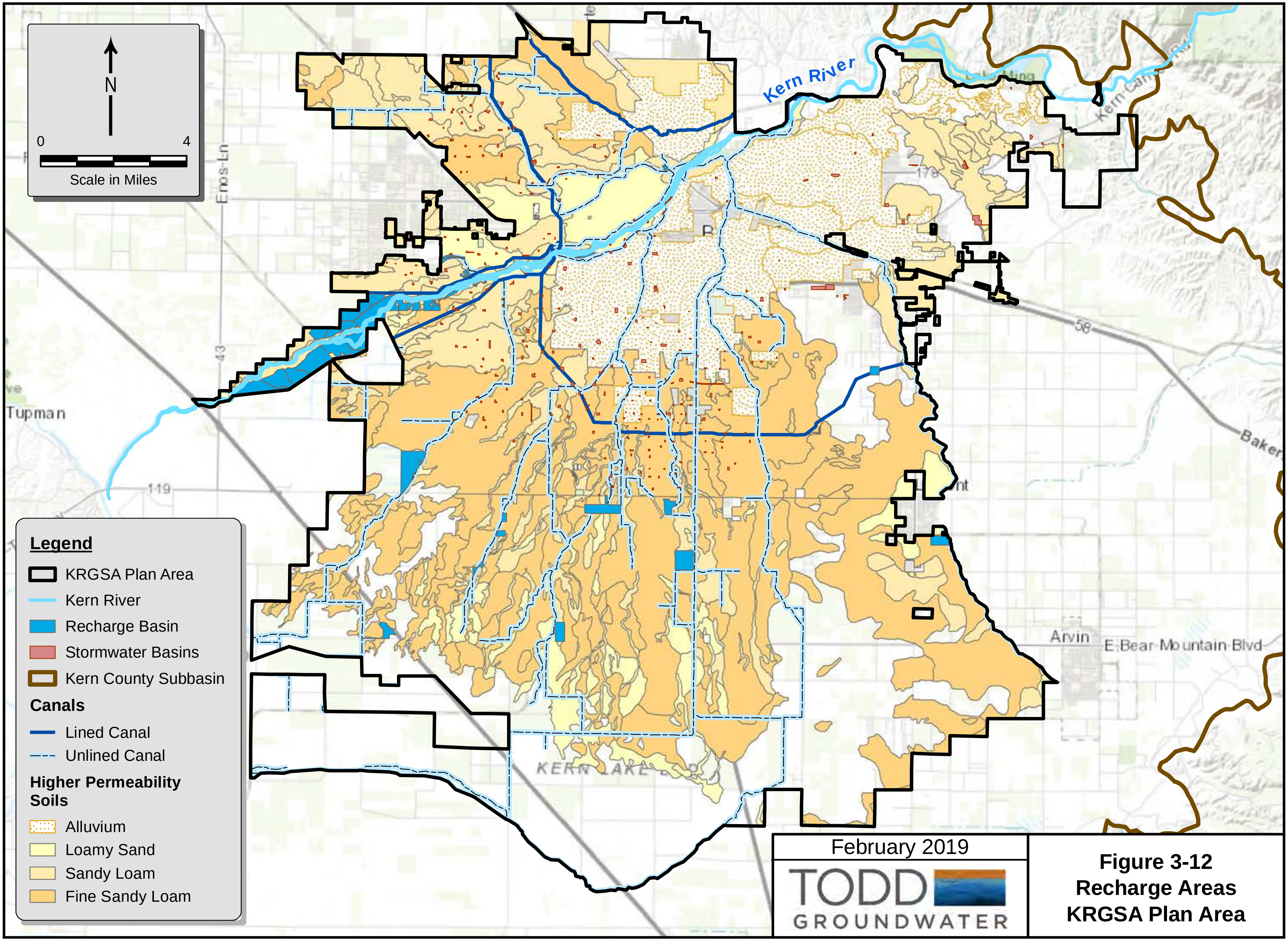


Figure 3-11
Canals and Recharge Facilities



February 2019

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Figure 3-12
Recharge Areas
KRGSA Plan Area

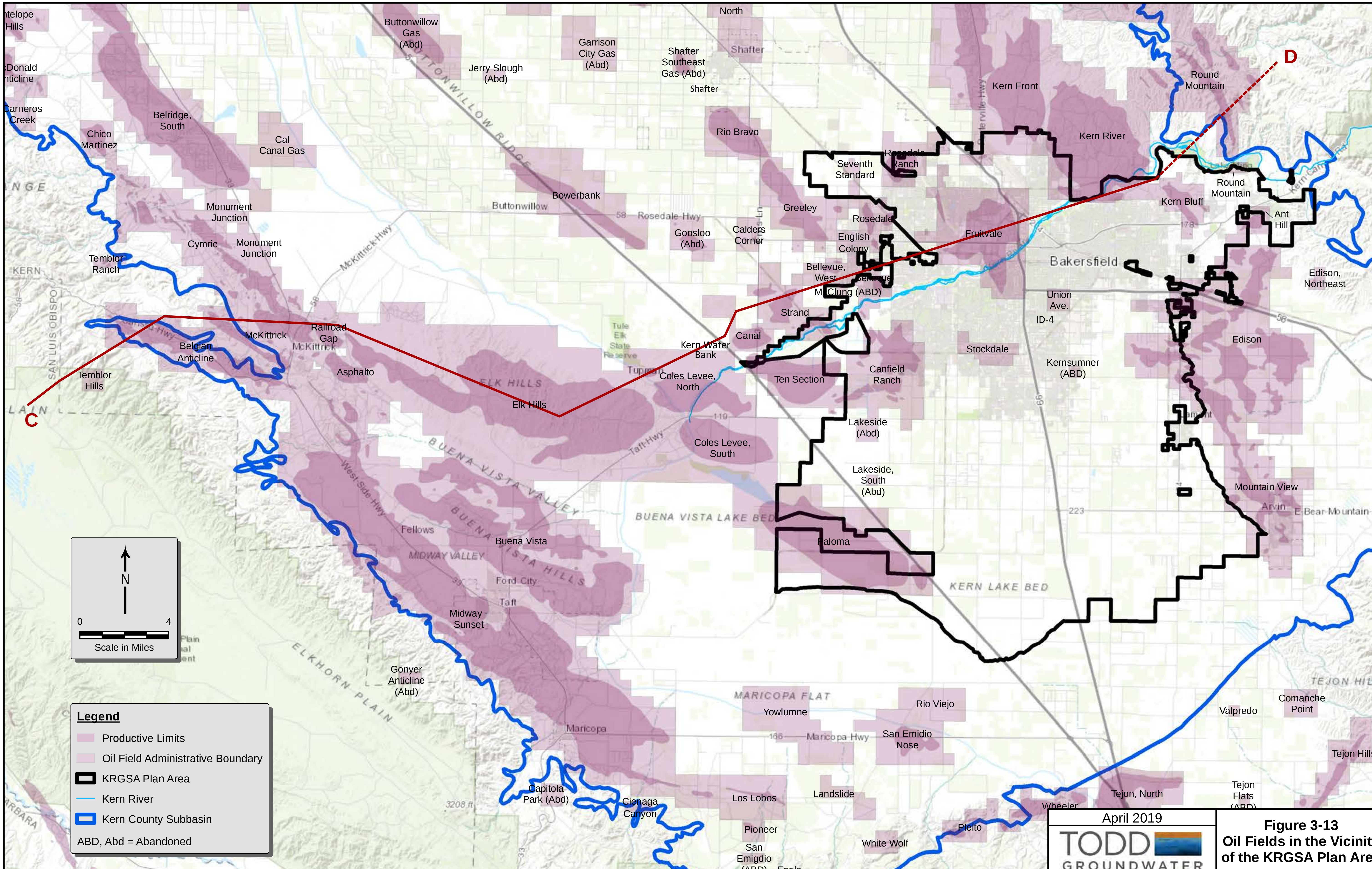
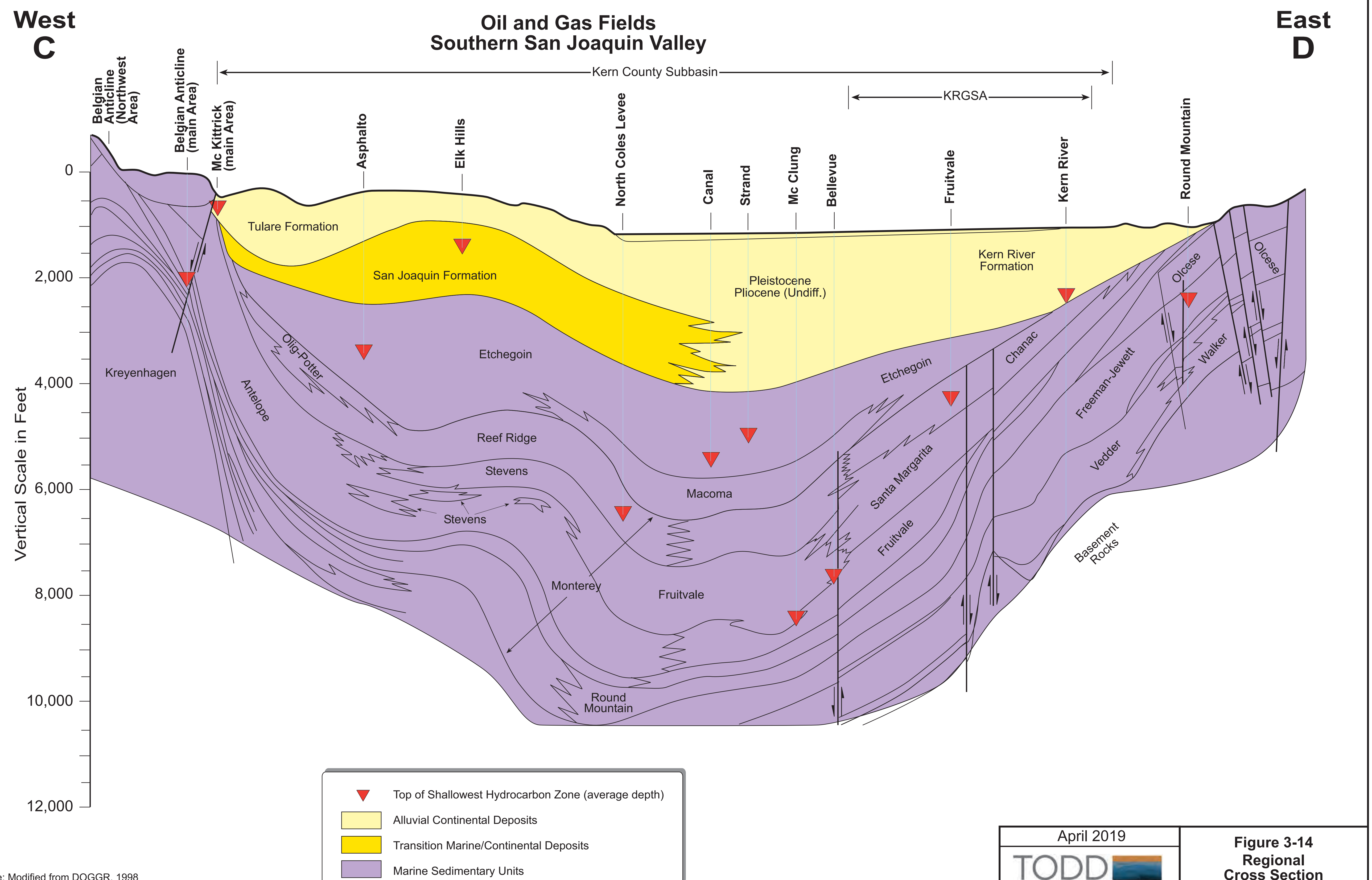


Figure 3-13
Oil Fields in the Vicinity of the KRGSA Plan Area



Source: Modified from DOGGR, 1998

April 2019

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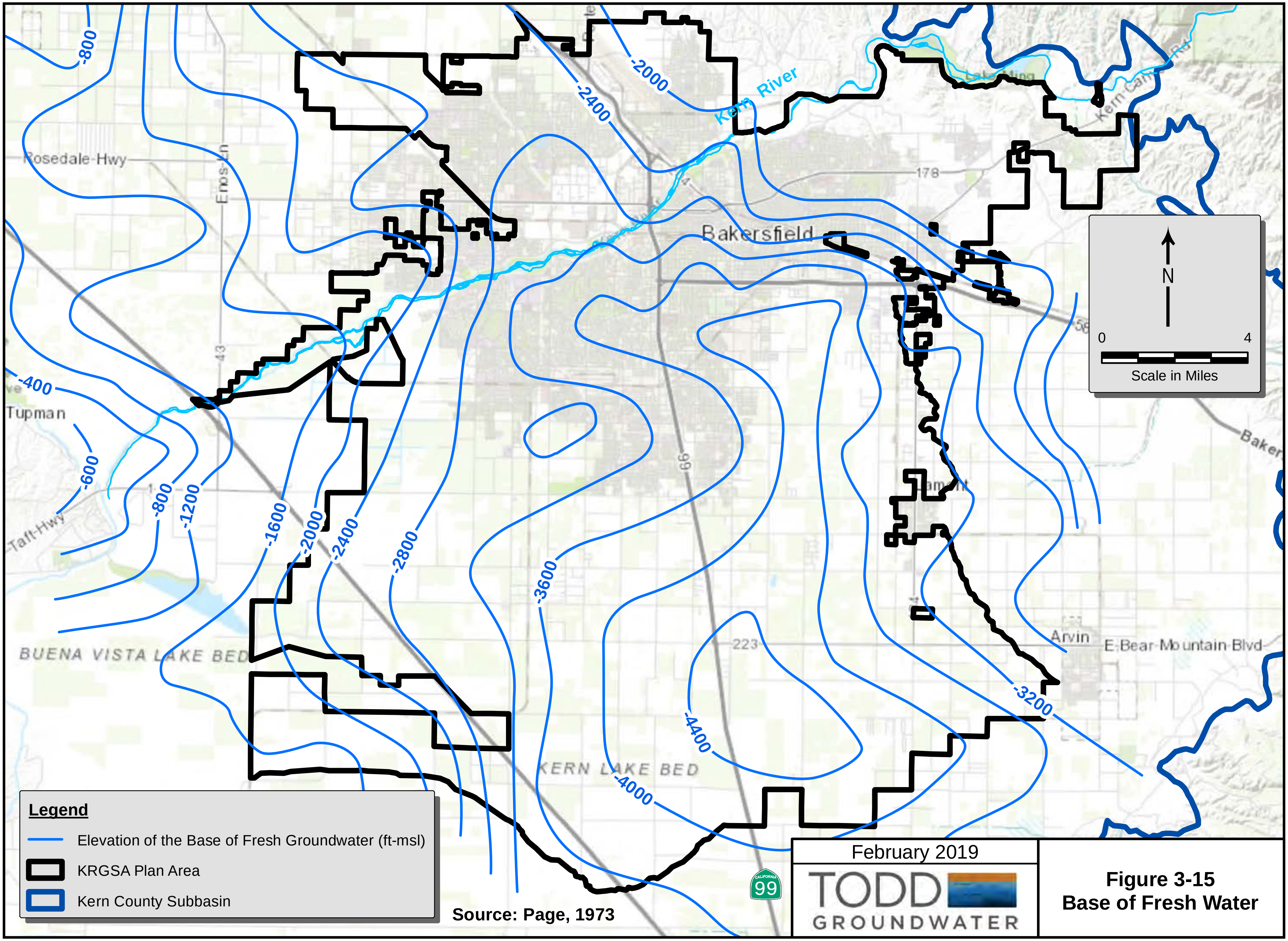
Figure 3-14
Regional Cross Section with Oil Fields

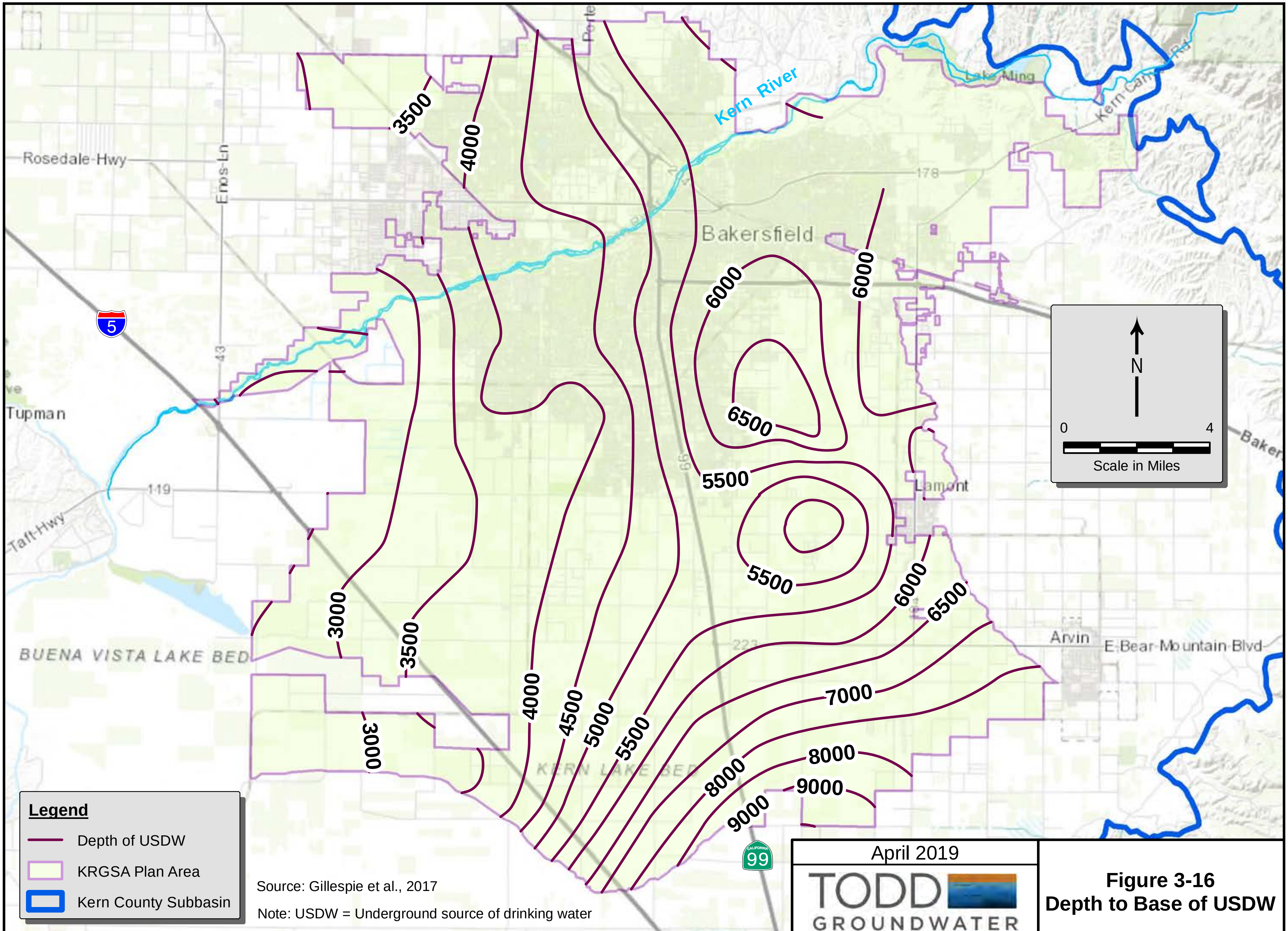


Source: Page, 1973

February 2019

TODD GROUNDWATER

Figure 3-15
Base of Fresh Water



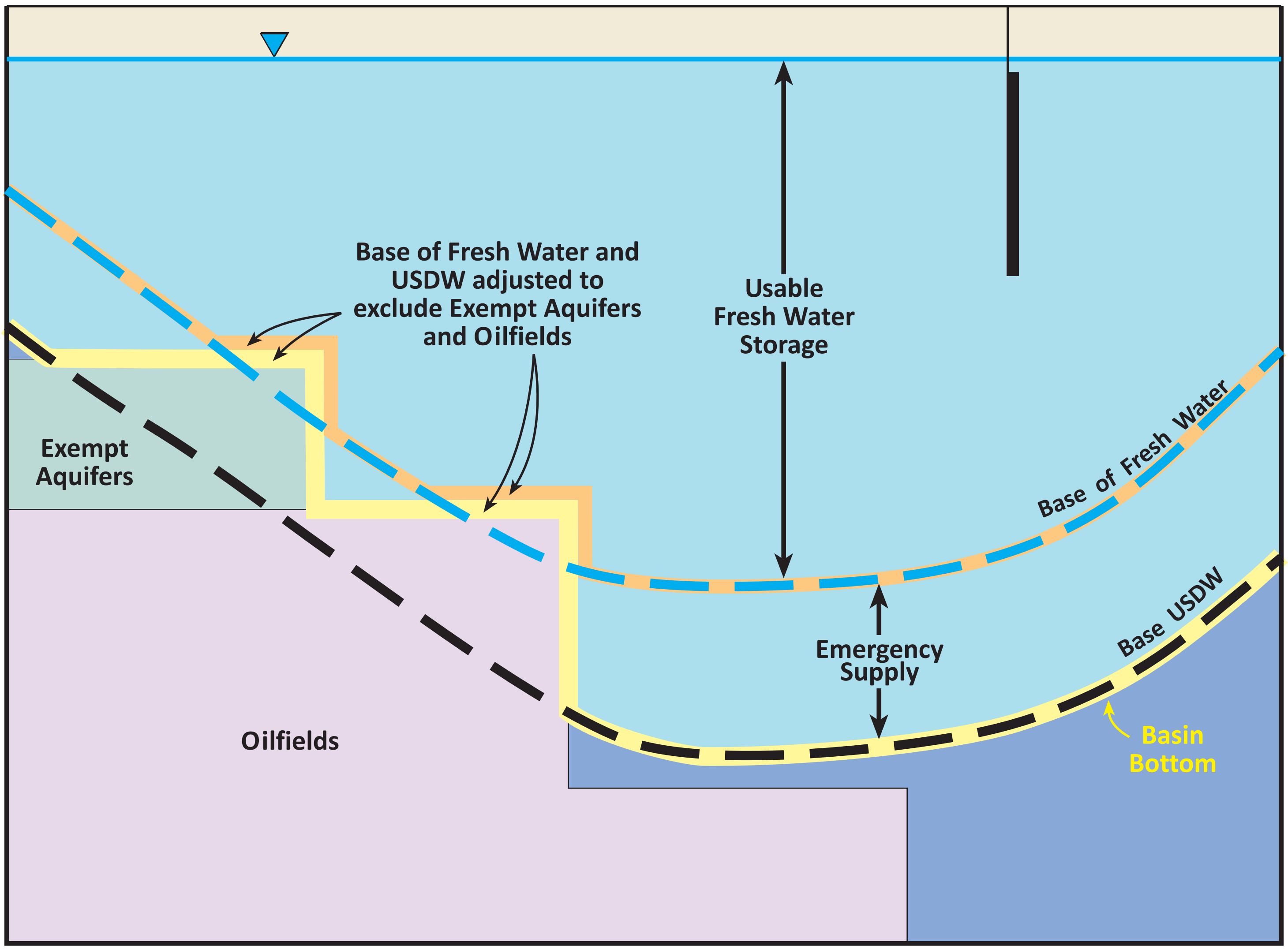
Source: Gillespie et al., 2017

Note: USDW = Underground source of drinking water

April 2019

TODD GROUNDWATER

Figure 3-16
Depth to Base of USDW



Base of Fresh Water adjusted to exclude Exempt Aquifers and Oilfields (see Figure 3-18)

Base of USDW adjusted to exclude Exempt Aquifers and Oilfields (see Figure 3-19)

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TODD GROUNDWATER

Figure 3-17
Conceptual Approach Bottom of the Subbasin in the Plan Area

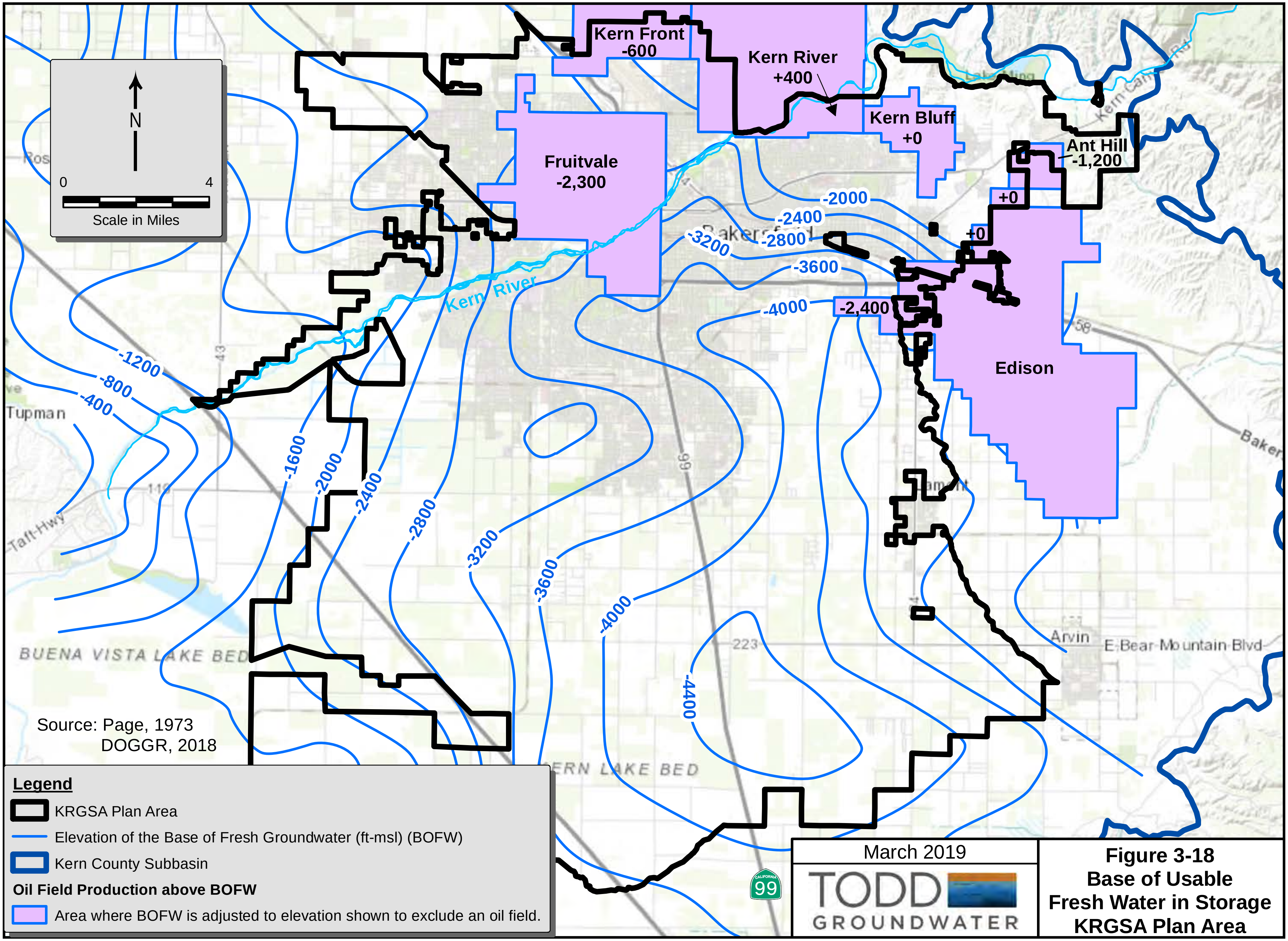
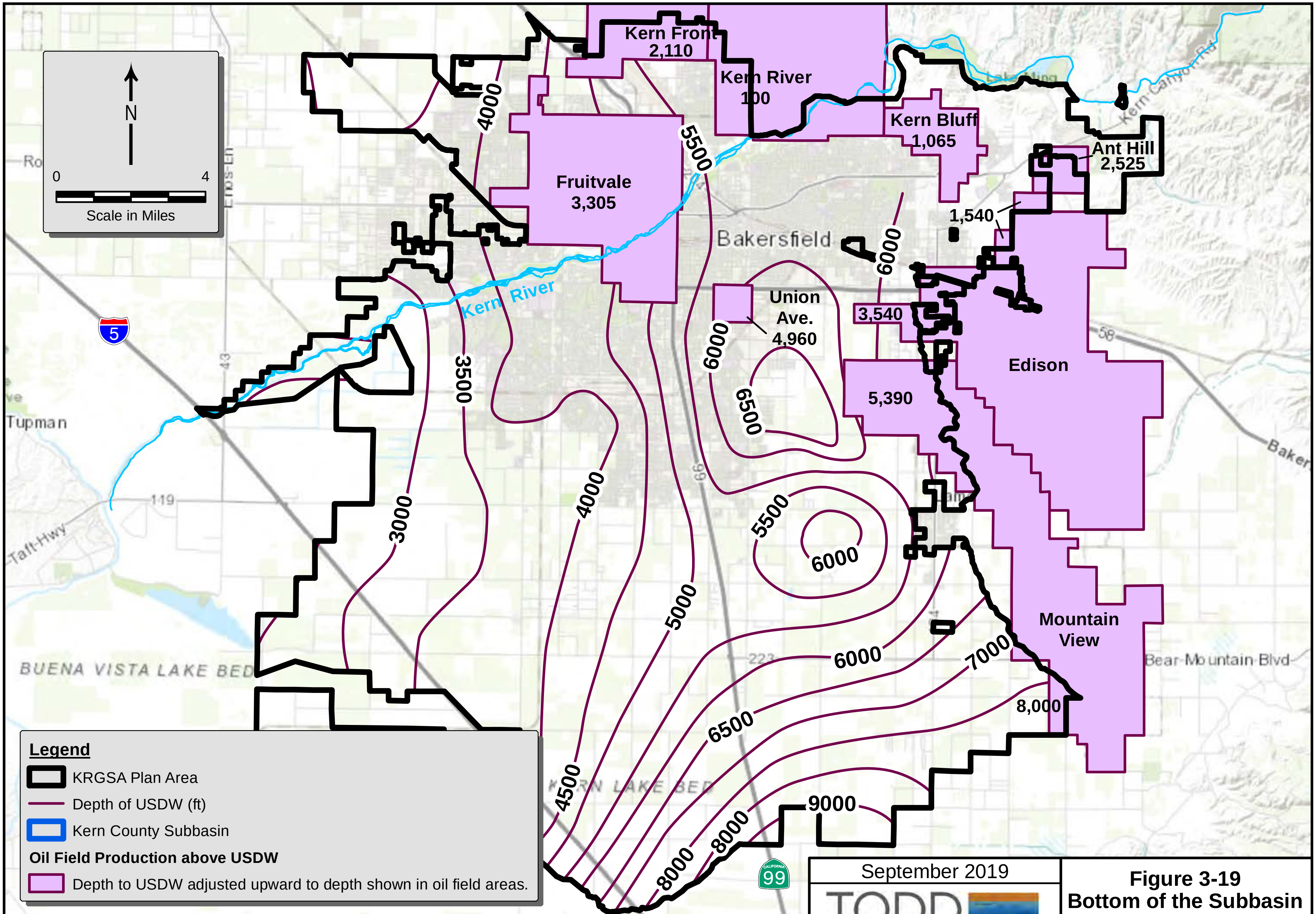


Figure 3-18
Base of Usable Fresh Water in Storage
KRGSA Plan Area



Source: Gillespie et al., 2017
DOGGR, 2018

September 2019

TODD GROUNDWATER

Figure 3-19
Bottom of the Subbasin Adjusted in Oil Field Areas

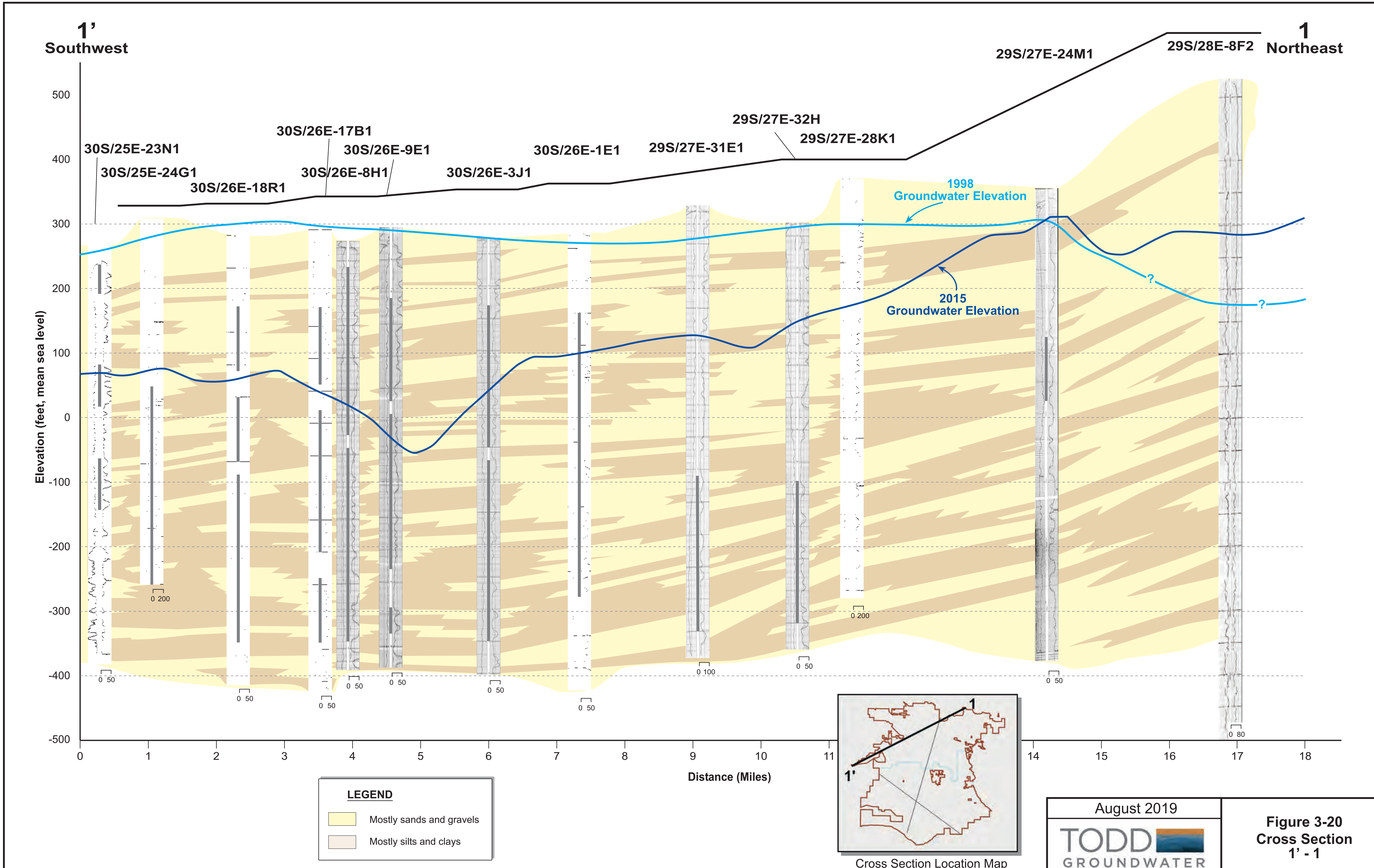
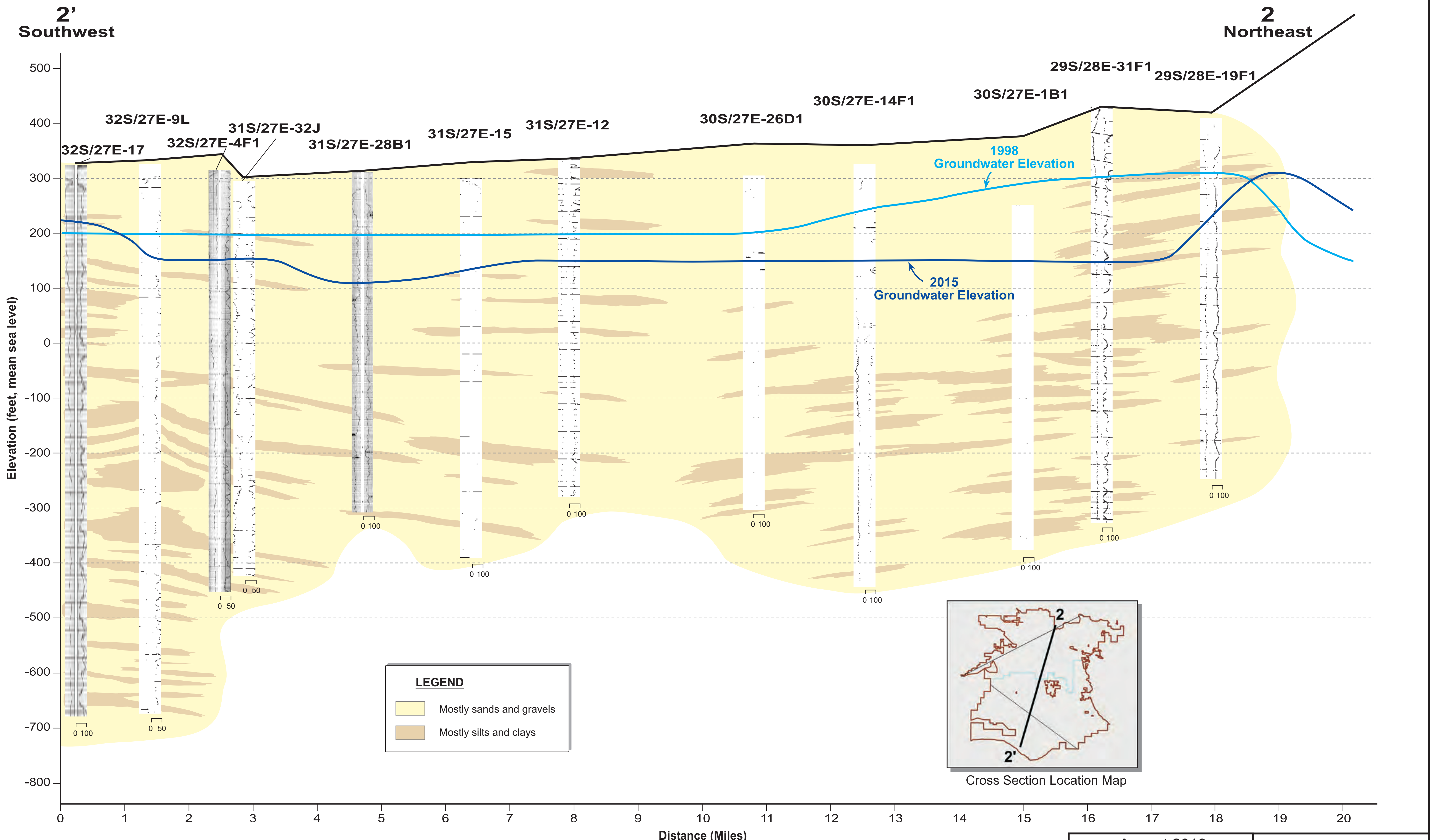


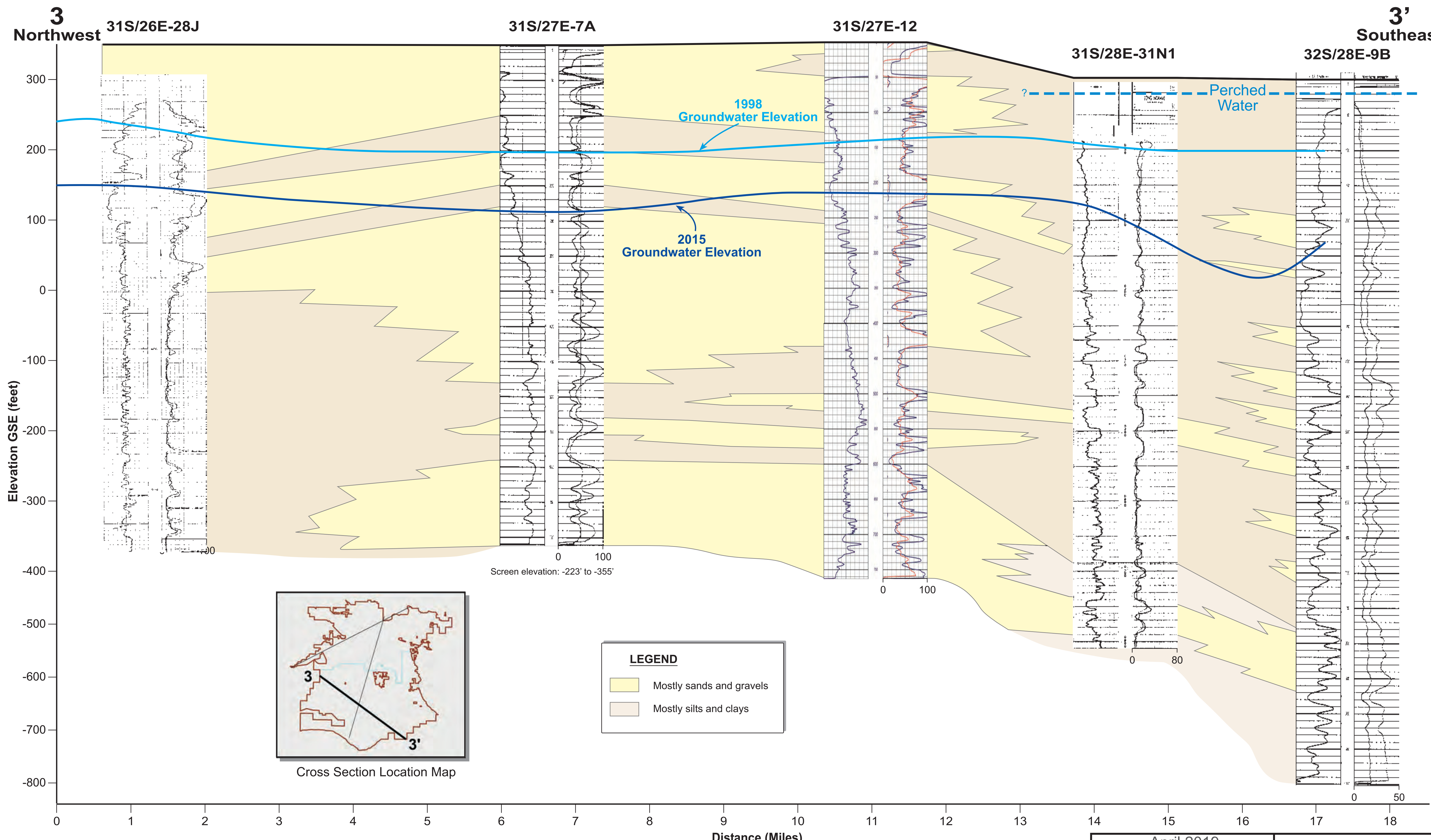
Figure 3-20
Cross Section
1' - 1



August 2019

TODD GROUNDWATER

Figure 3-21
Cross Section
2' - 2



April 2019

TODD GROUNDWATER

Figure 3-22
Cross Section
3 - 3'

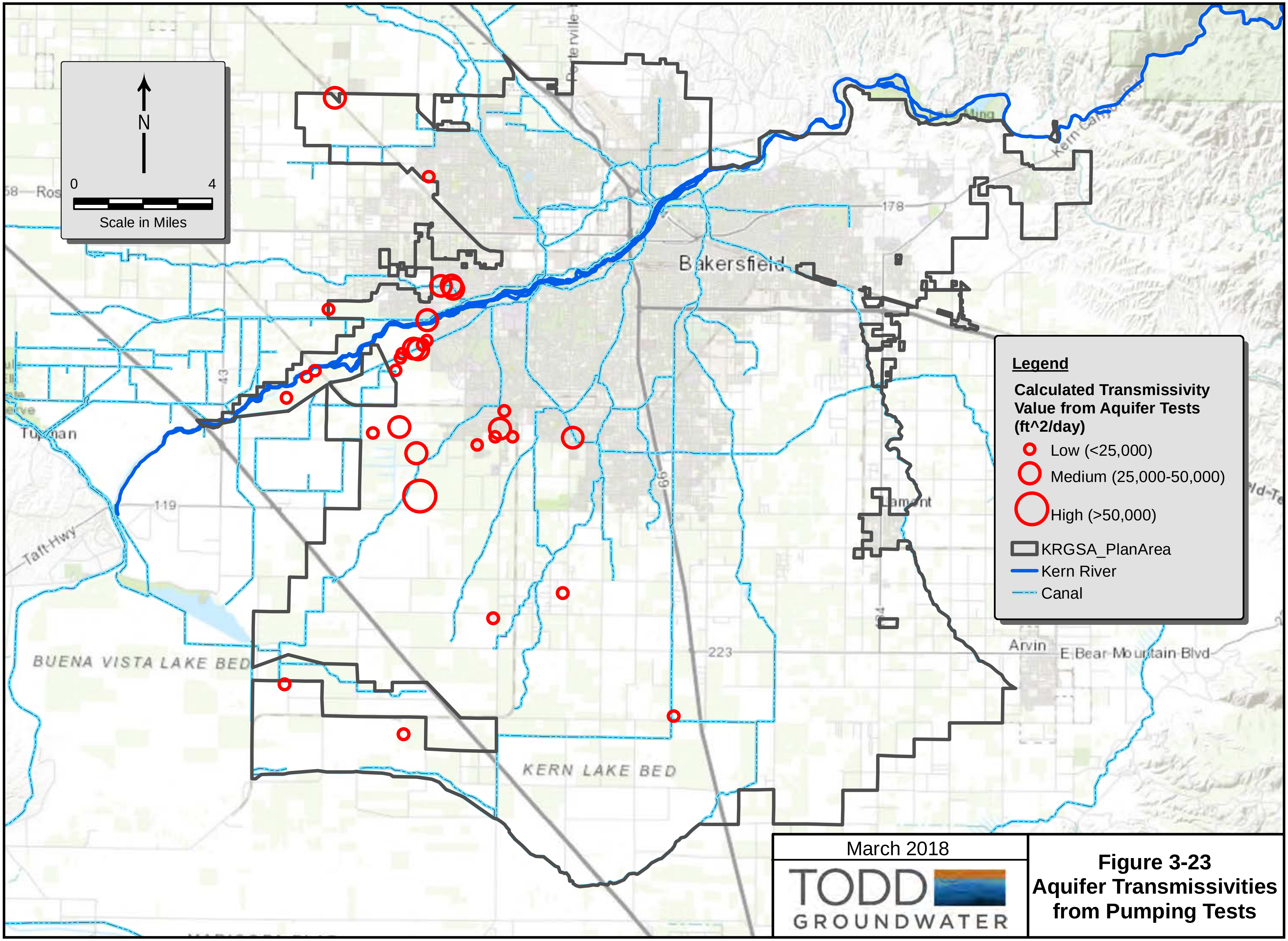
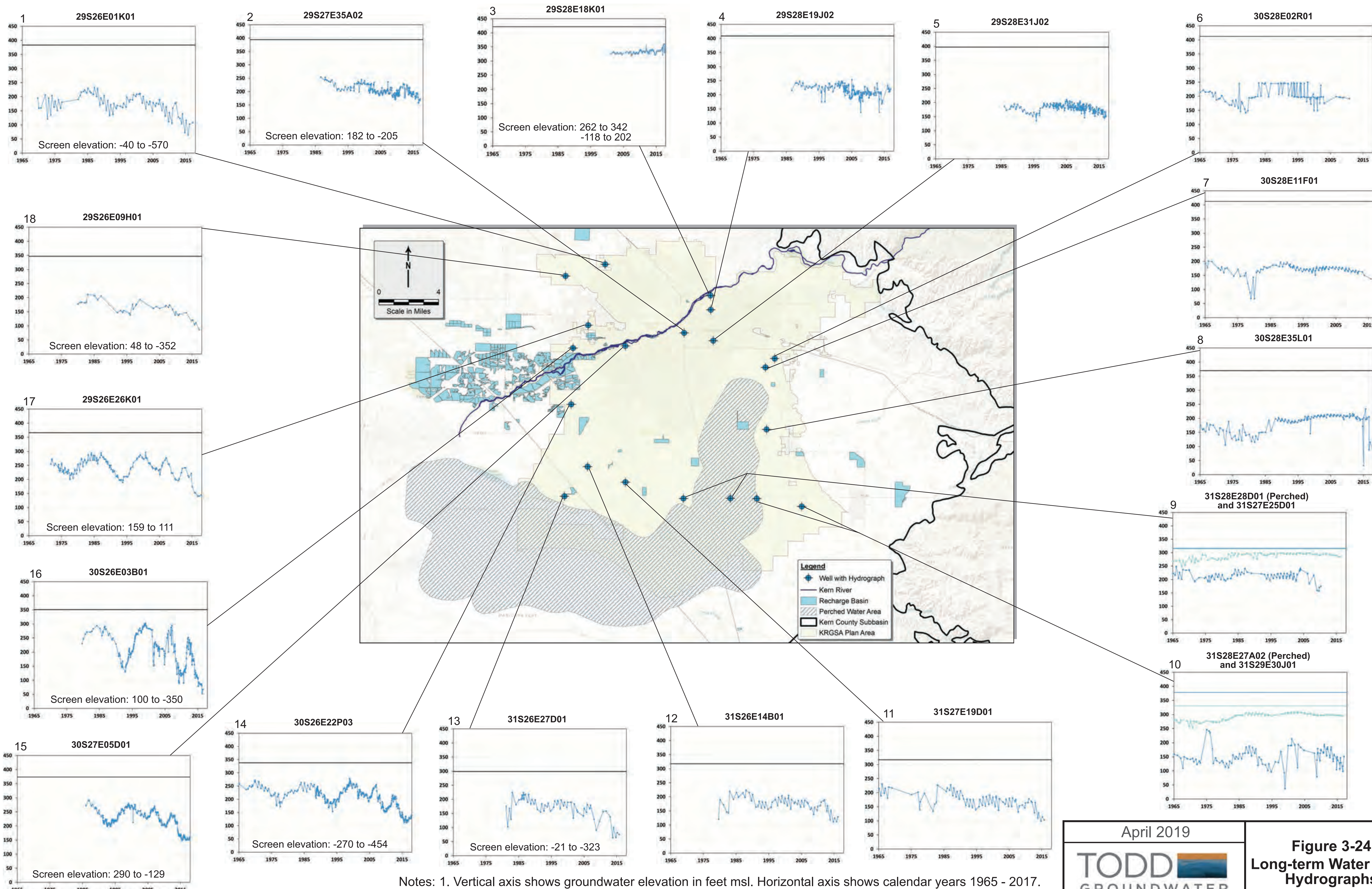


Figure 3-23
Aquifer Transmissivities from Pumping Tests

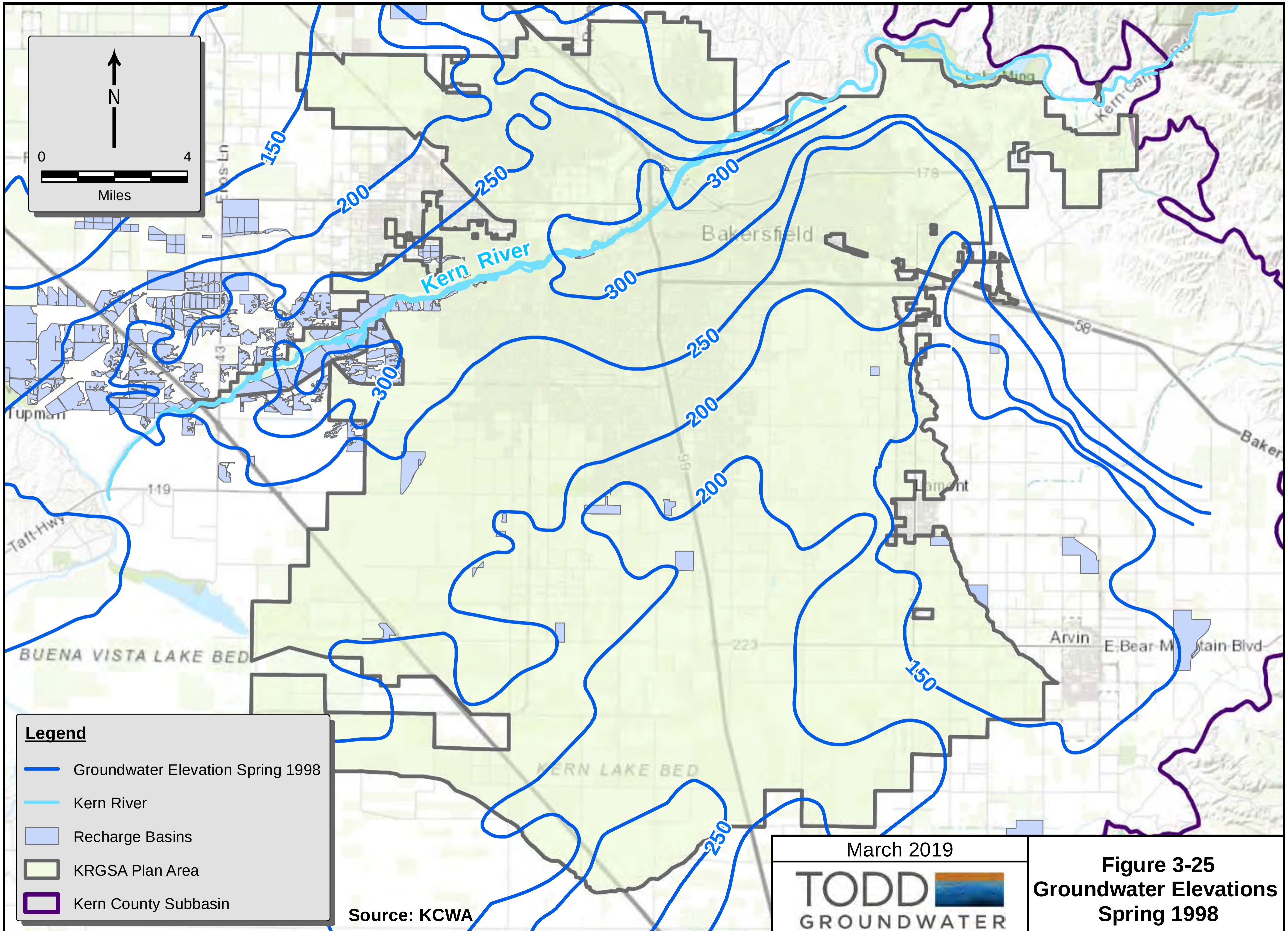


Notes: 1. Vertical axis shows groundwater elevation in feet msl. Horizontal axis shows calendar years 1965 - 2017.
2. Bold horizontal lines represent ground surface elevation.

April 2019

TODD GROUNDWATER

Figure 3-24
Long-term Water Level Hydrographs



March 2019

TODD GROUNDWATER

Figure 3-25
Groundwater Elevations
Spring 1998

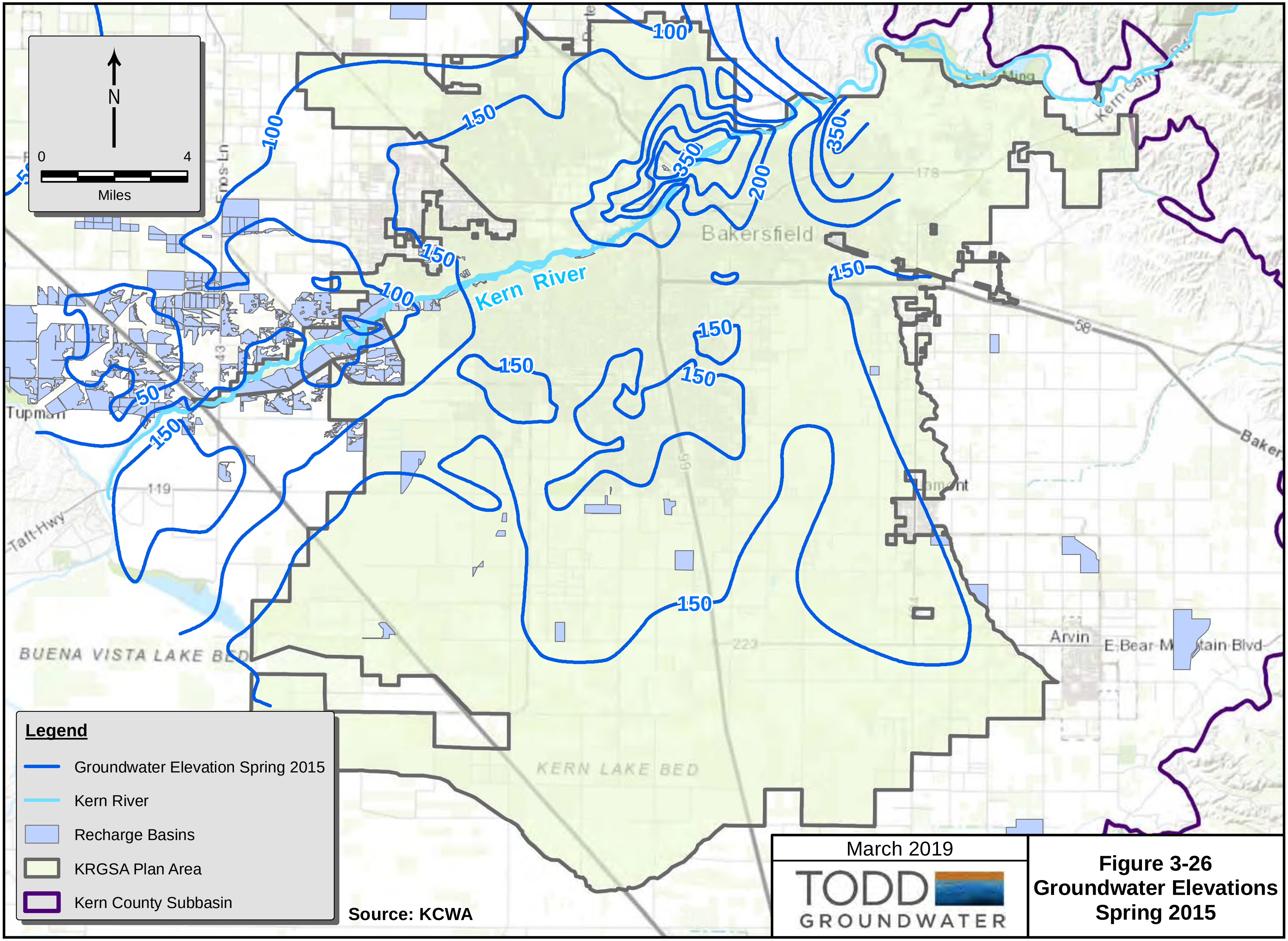


Figure 3-26
Groundwater Elevations
Spring 2015

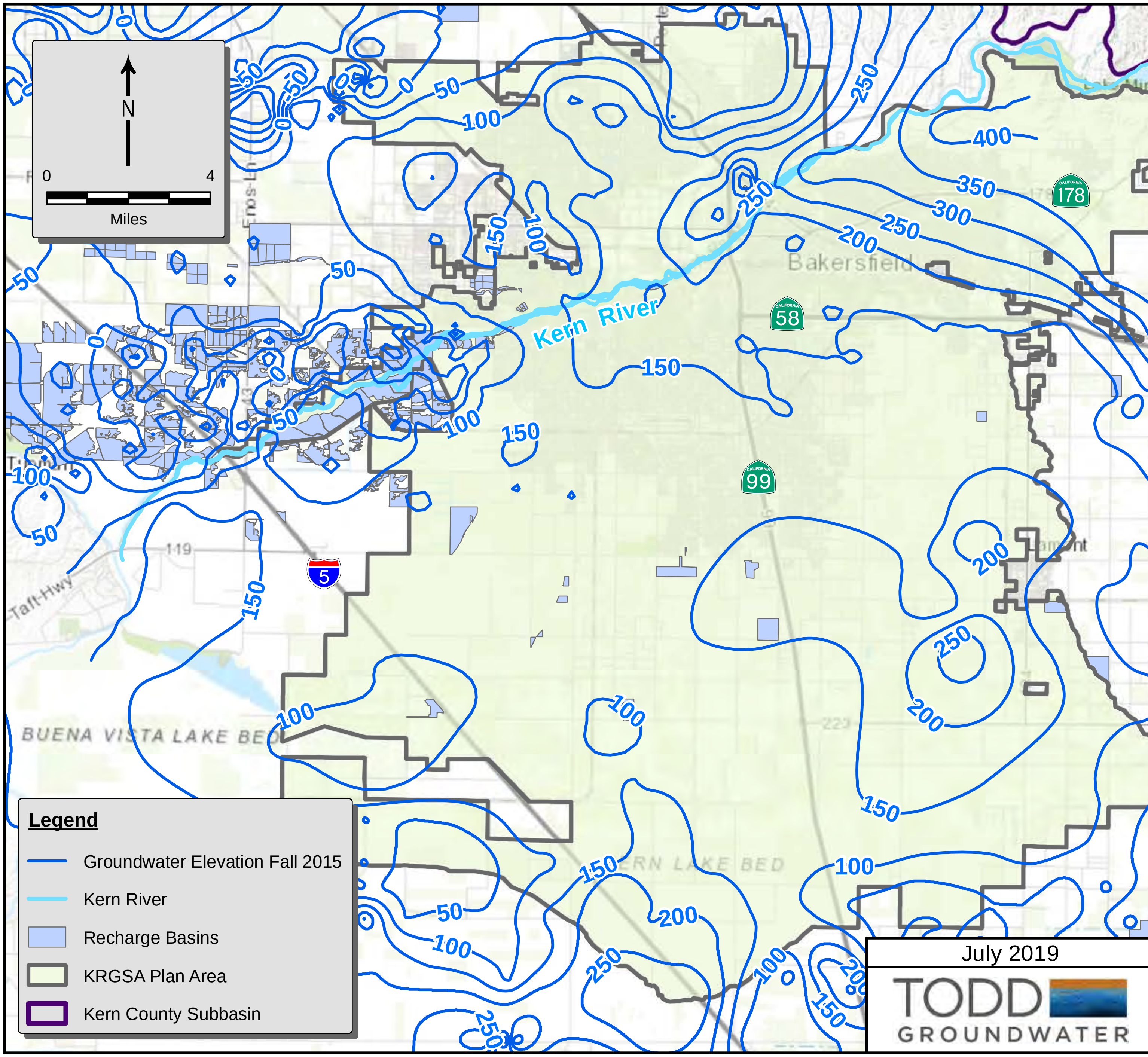
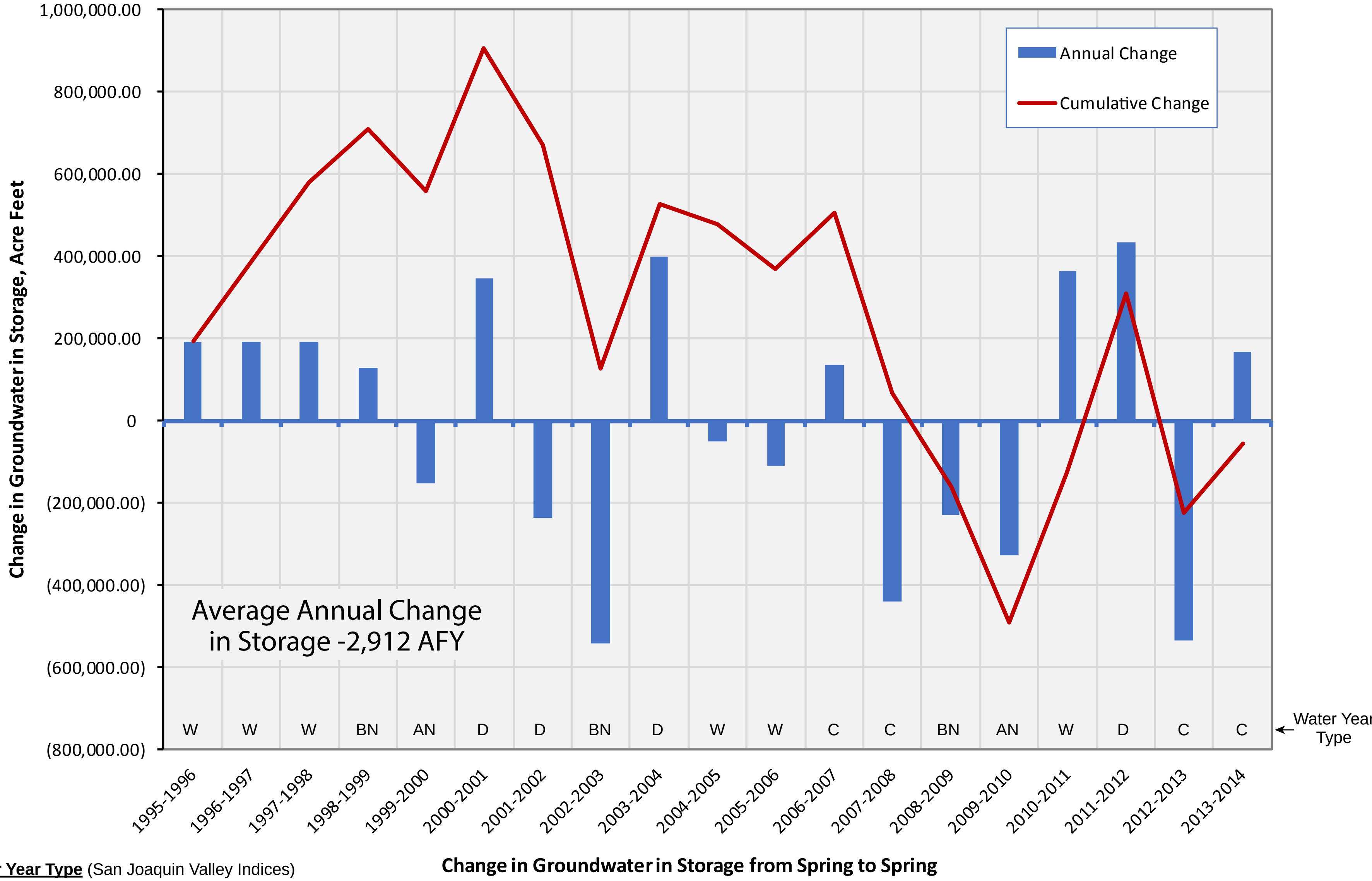


Figure 3-27
Groundwater Elevations
Fall 2015



Water Year Type (San Joaquin Valley Indices)

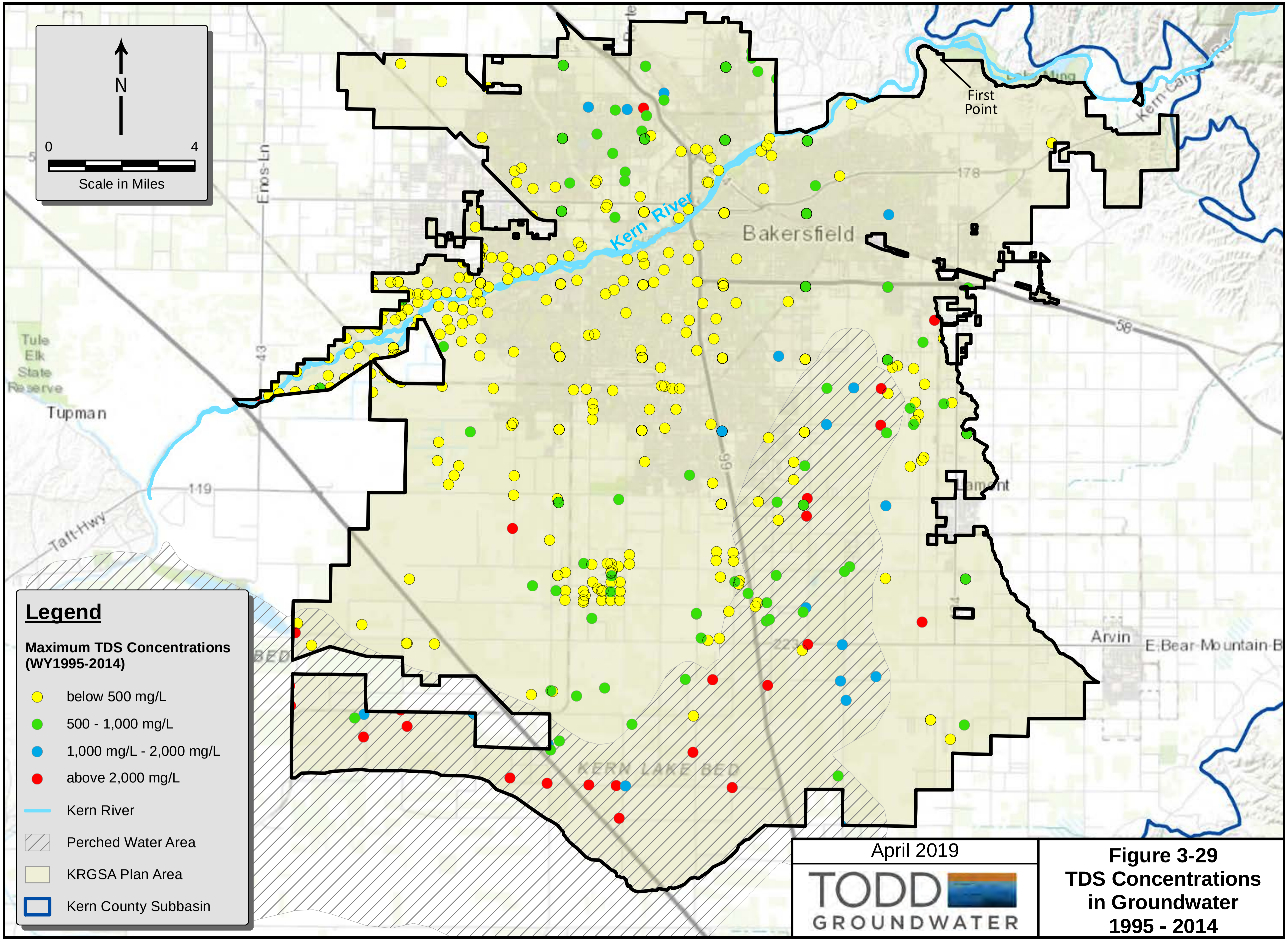
W - Wet
AN - Above Normal
BN - Below Normal
D - Dry
C - Critical

Analysis is based on annual Spring groundwater elevation contour maps by KCWA, 1995-2014 (missing 1996 and 1997).

March 2019

TODD GROUNDWATER

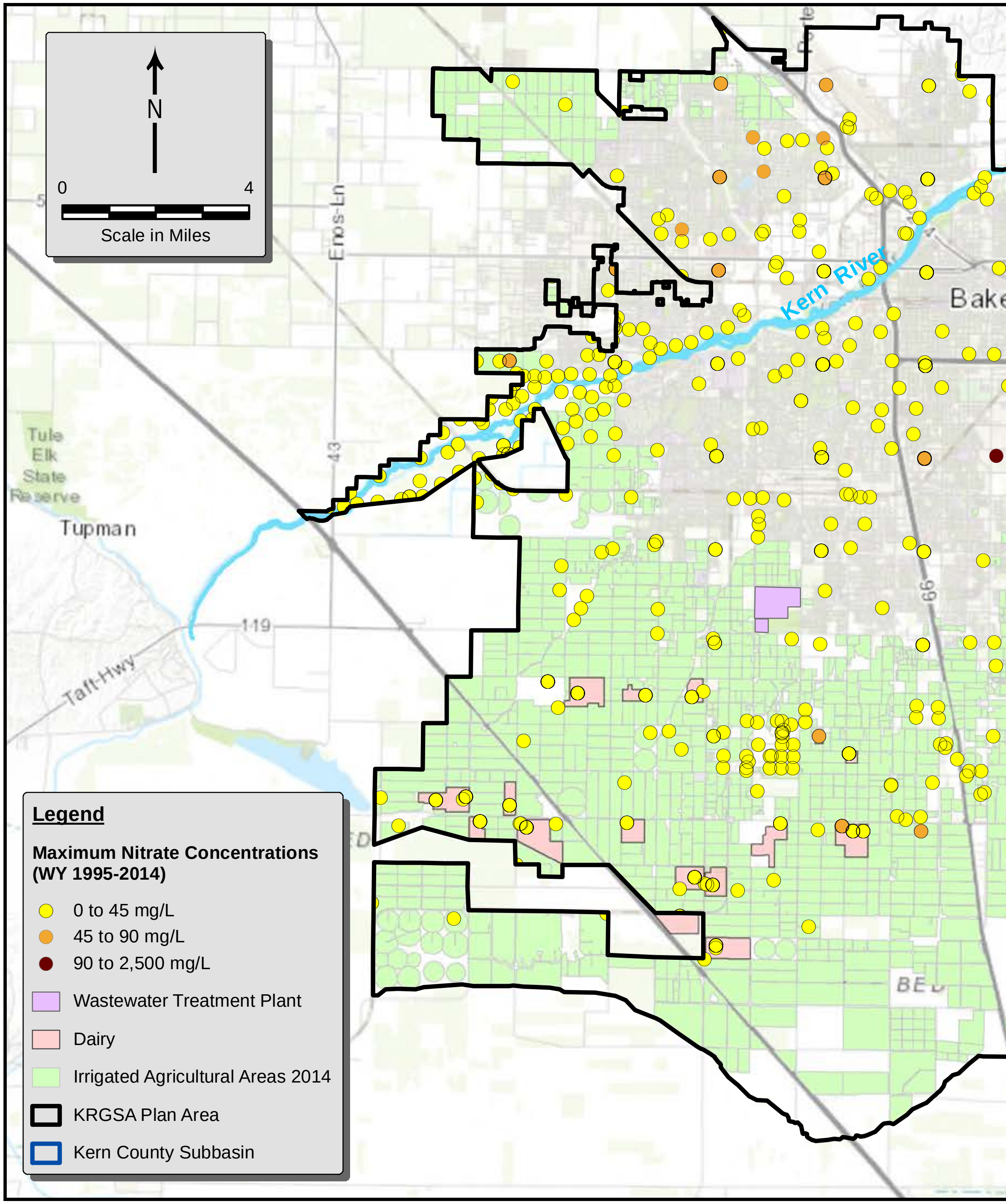
Figure 3-28
Change in Groundwater in Storage
KRGSA Plan Area



April 2019

TODD GROUNDWATER

Figure 3-29
TDS Concentrations in Groundwater
1995 - 2014



April 2019

TODD GROUNDWATER

Figure 3-30
Maximum Nitrate (NO3) Concentrations in Groundwater

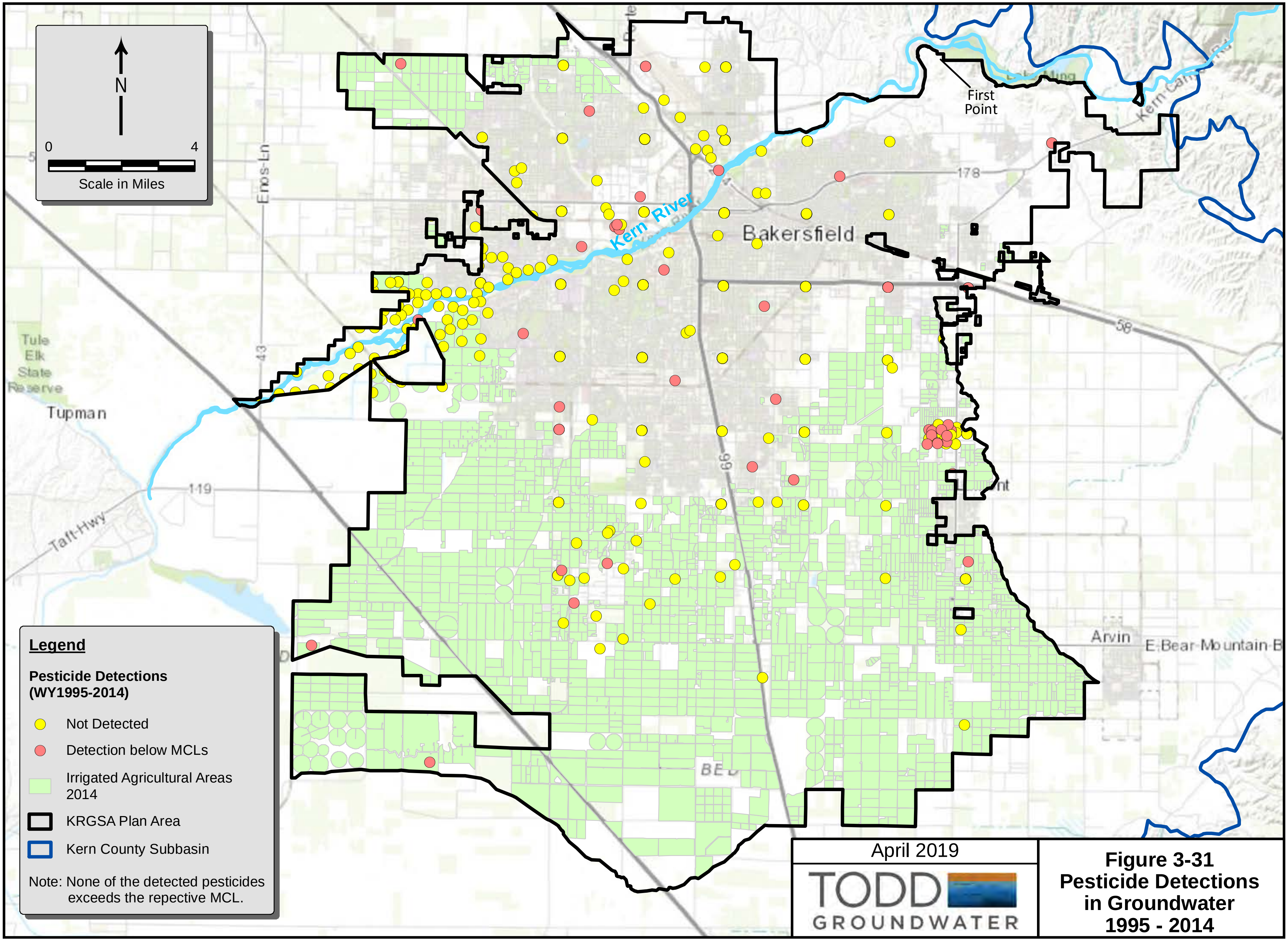


Figure 3-31
Pesticide Detections in Groundwater 1995 - 2014

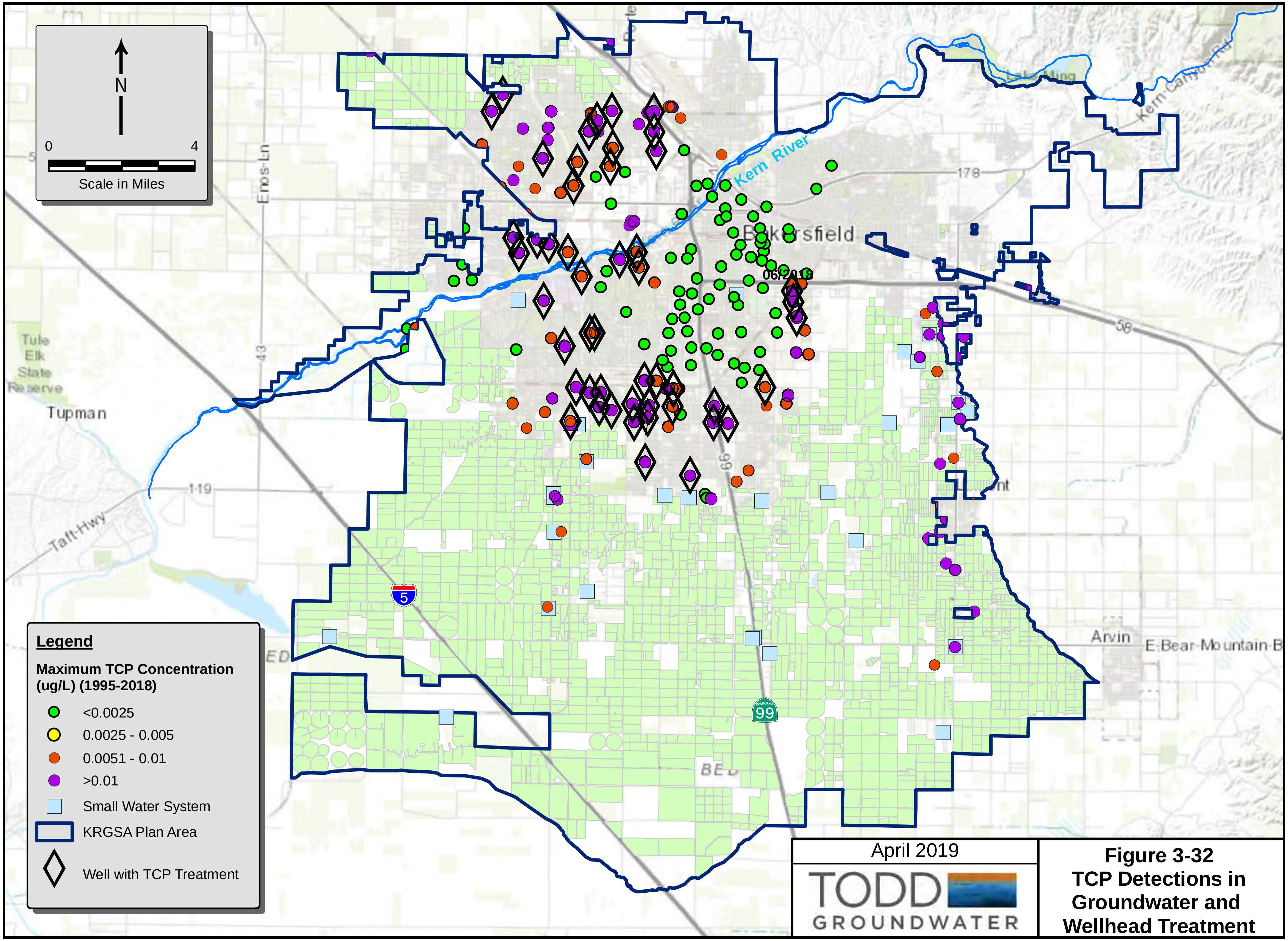


Figure 3-32
TCP Detections in Groundwater and Wellhead Treatment

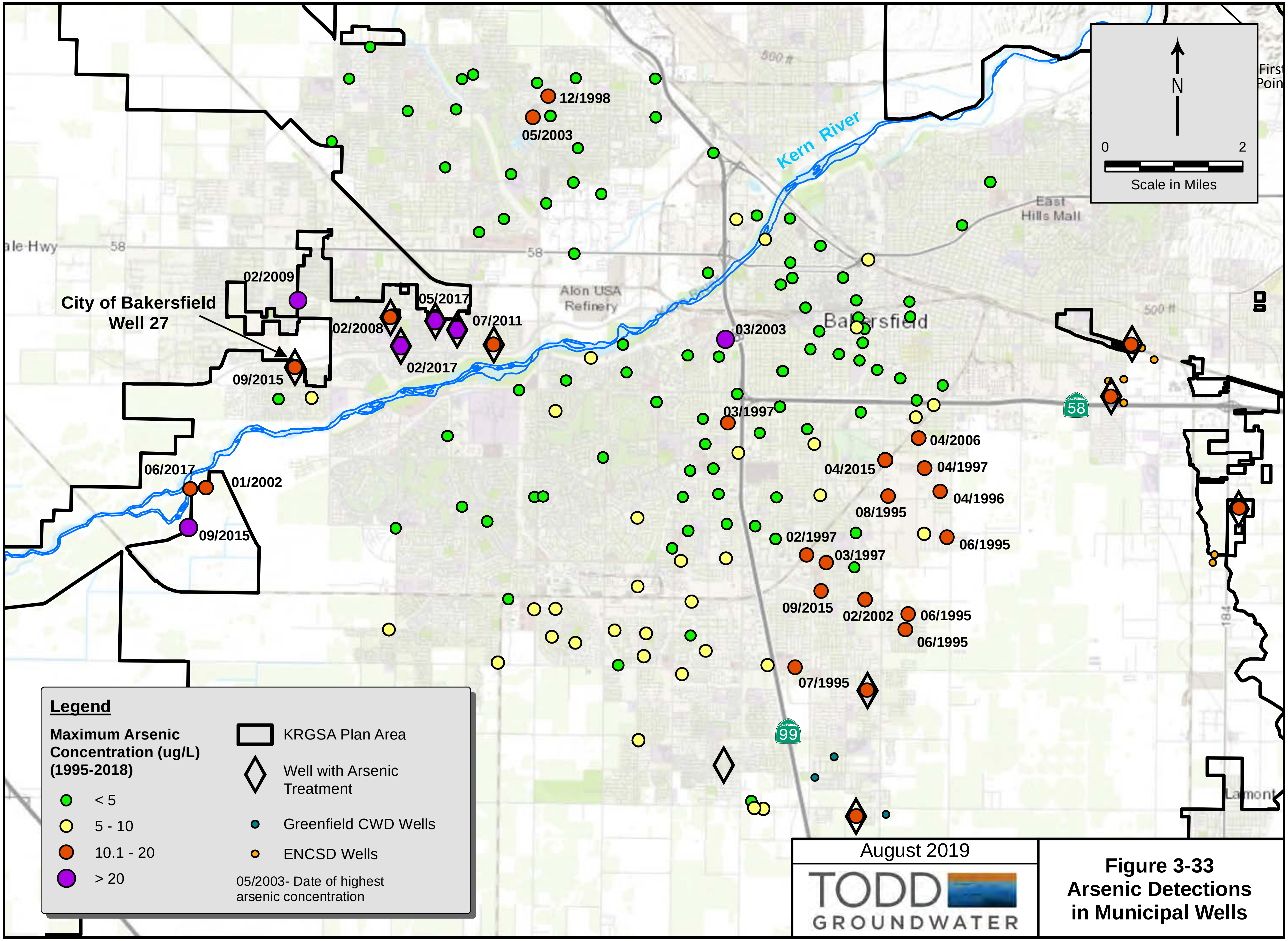
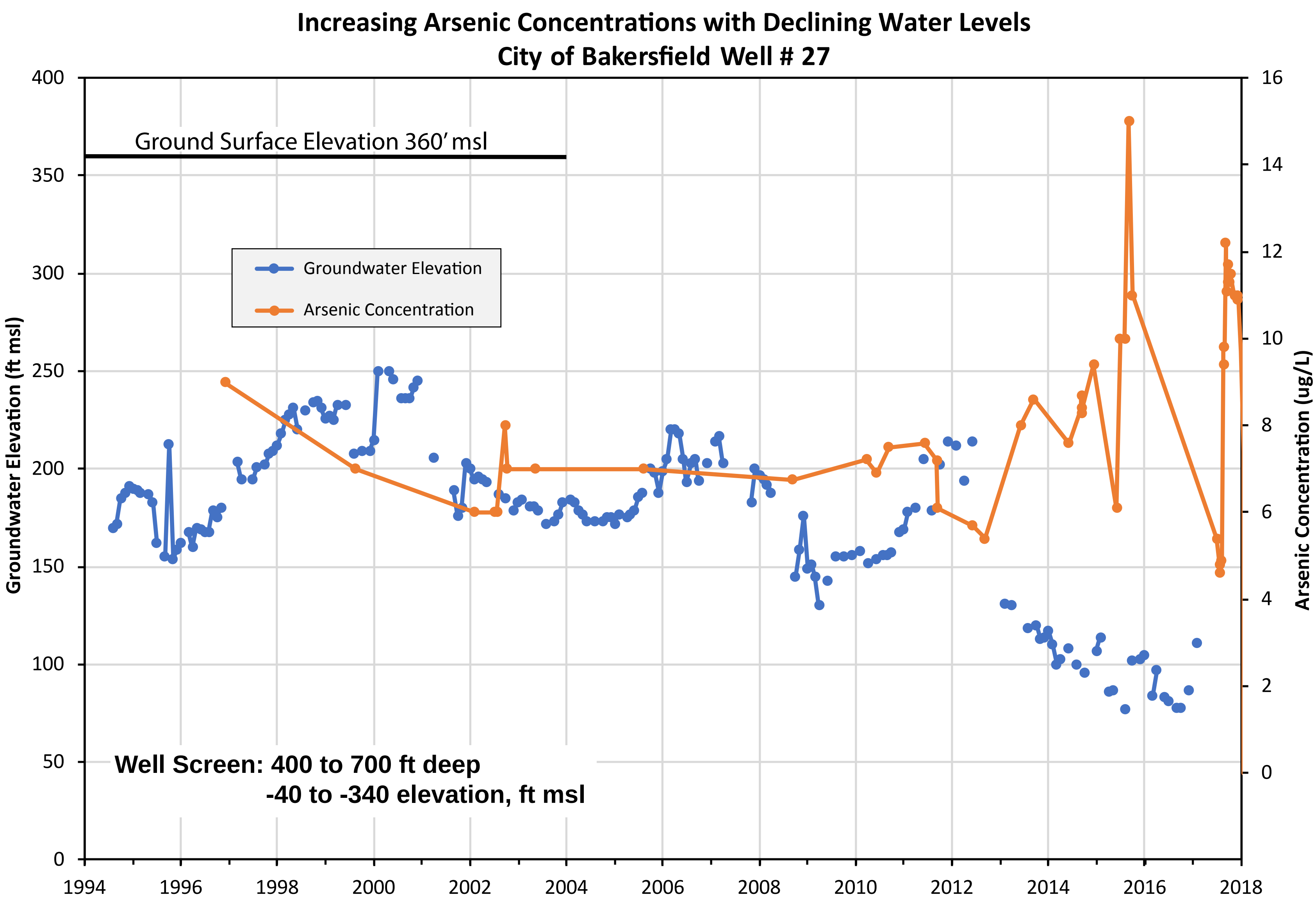


Figure 3-33
Arsenic Detections in Municipal Wells



April 2019	Figure 3-34
TODD GROUNDWATER	Arsenic Concentrations and Groundwater Elevations

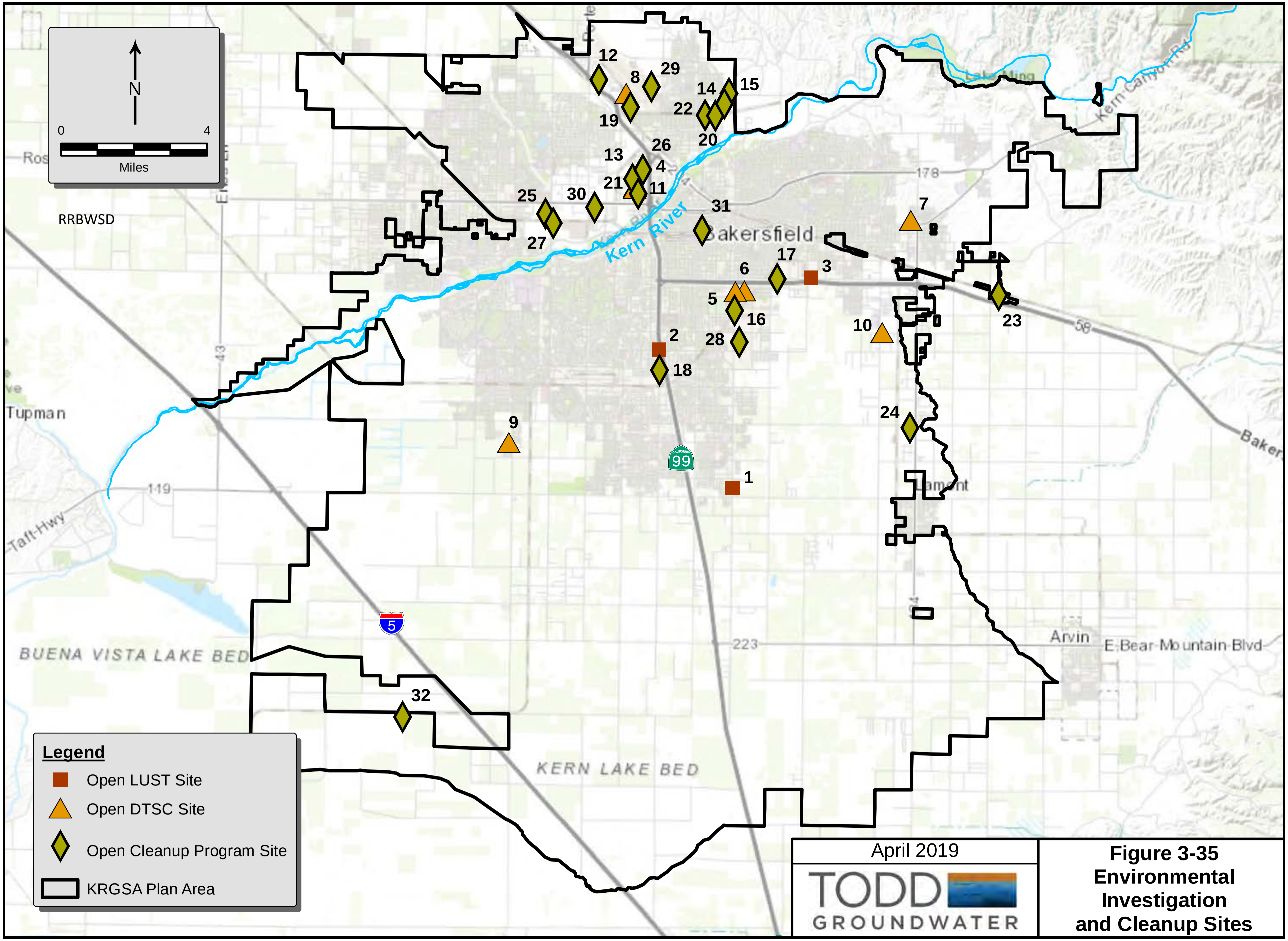
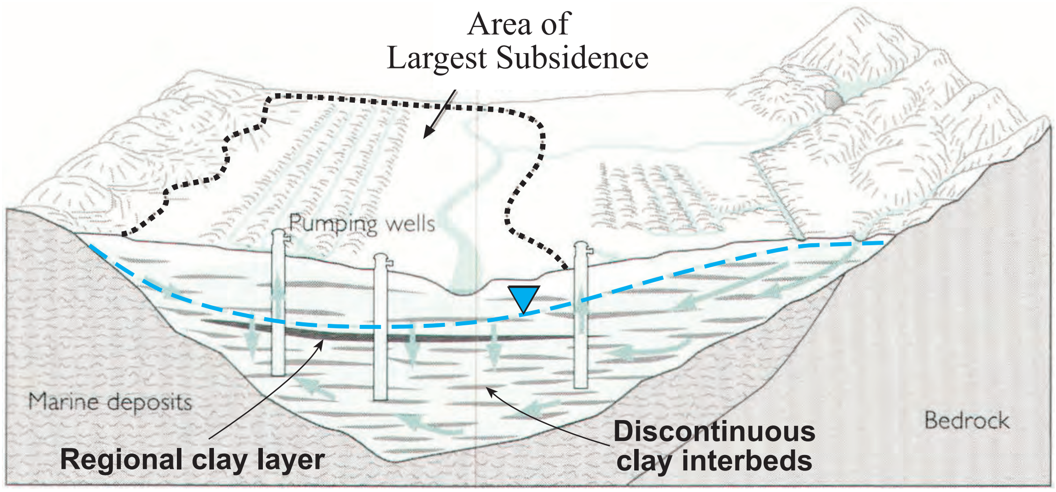
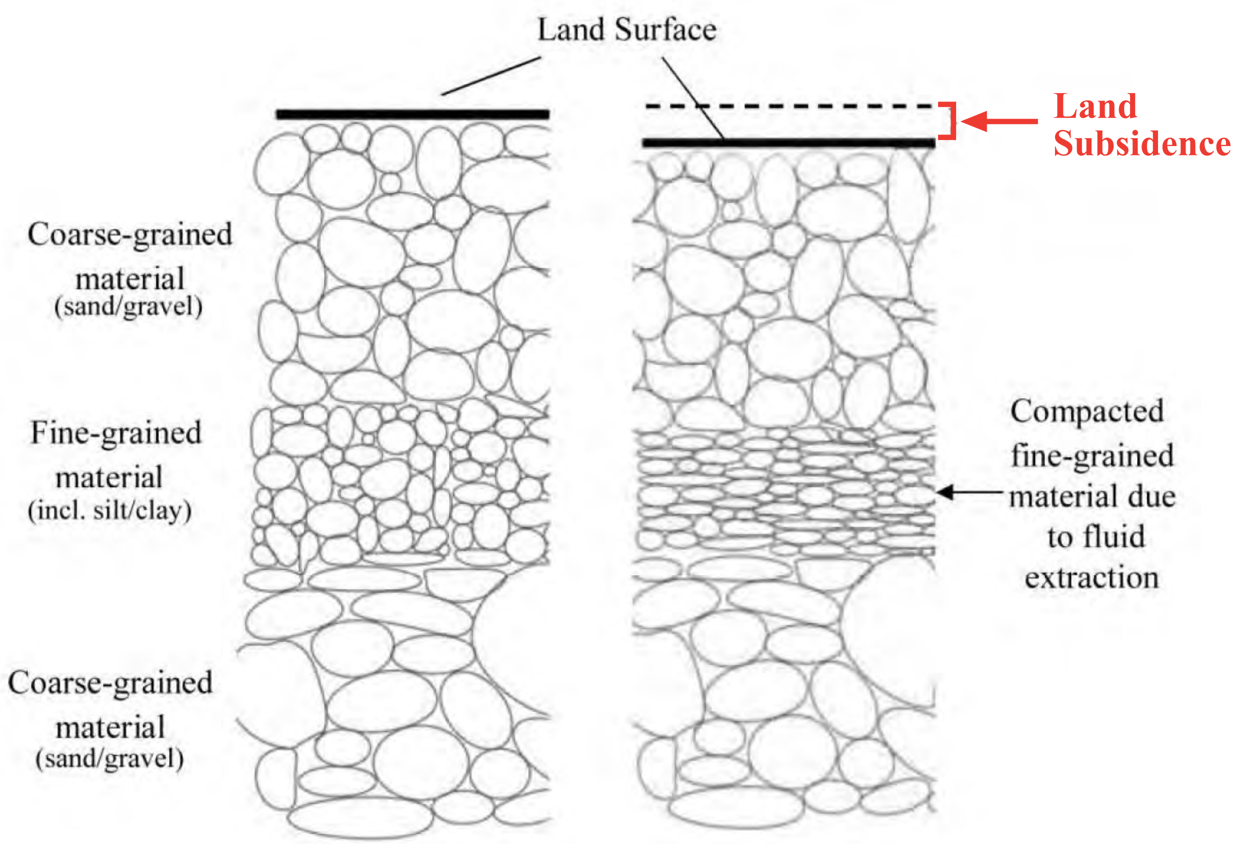


Figure 3-35 Environmental Investigation and Cleanup Sites



Source: Galloway et al., 1999.

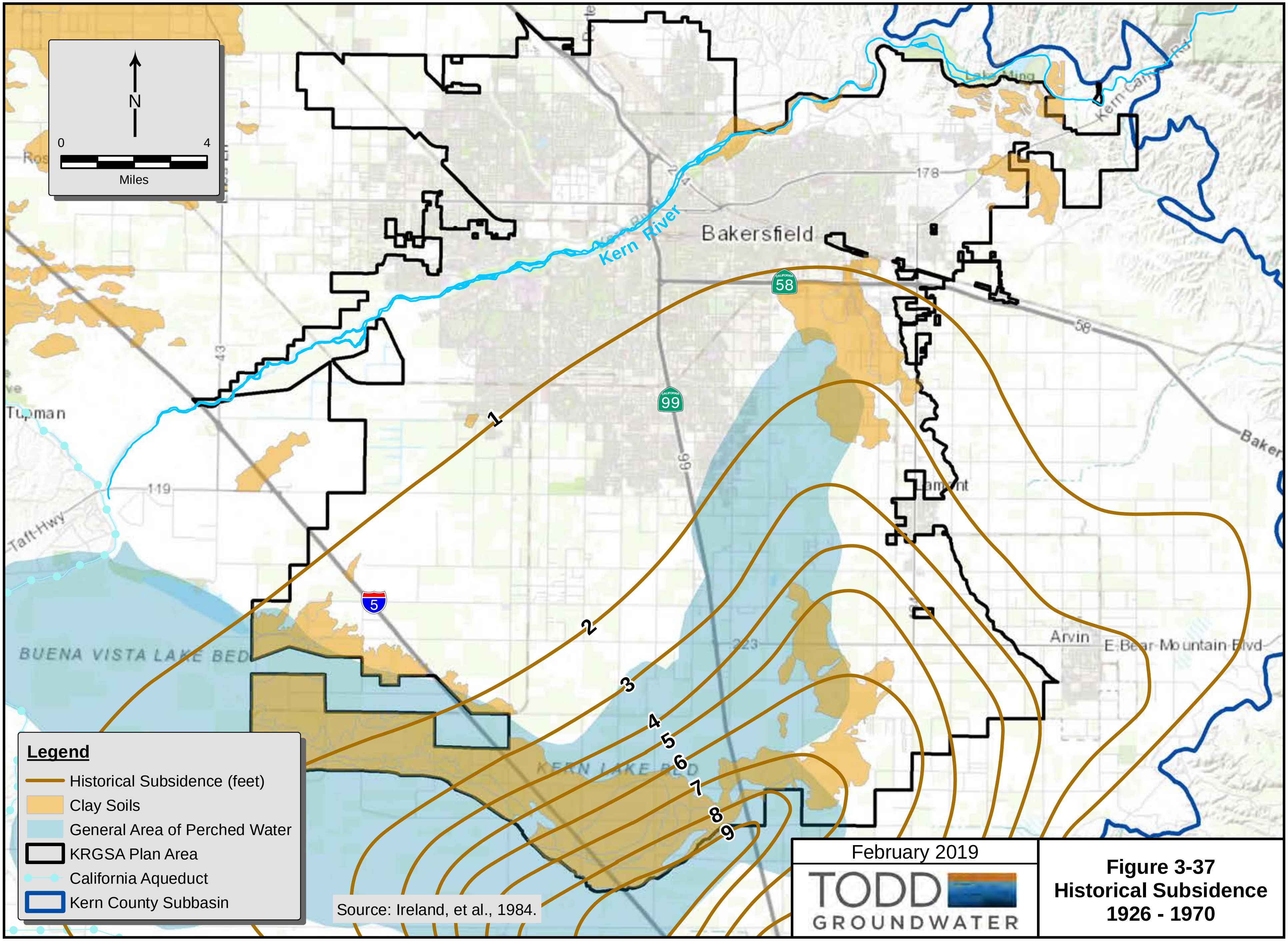


After LSCE et al., 2014.

March 2019

TODD GROUNDWATER

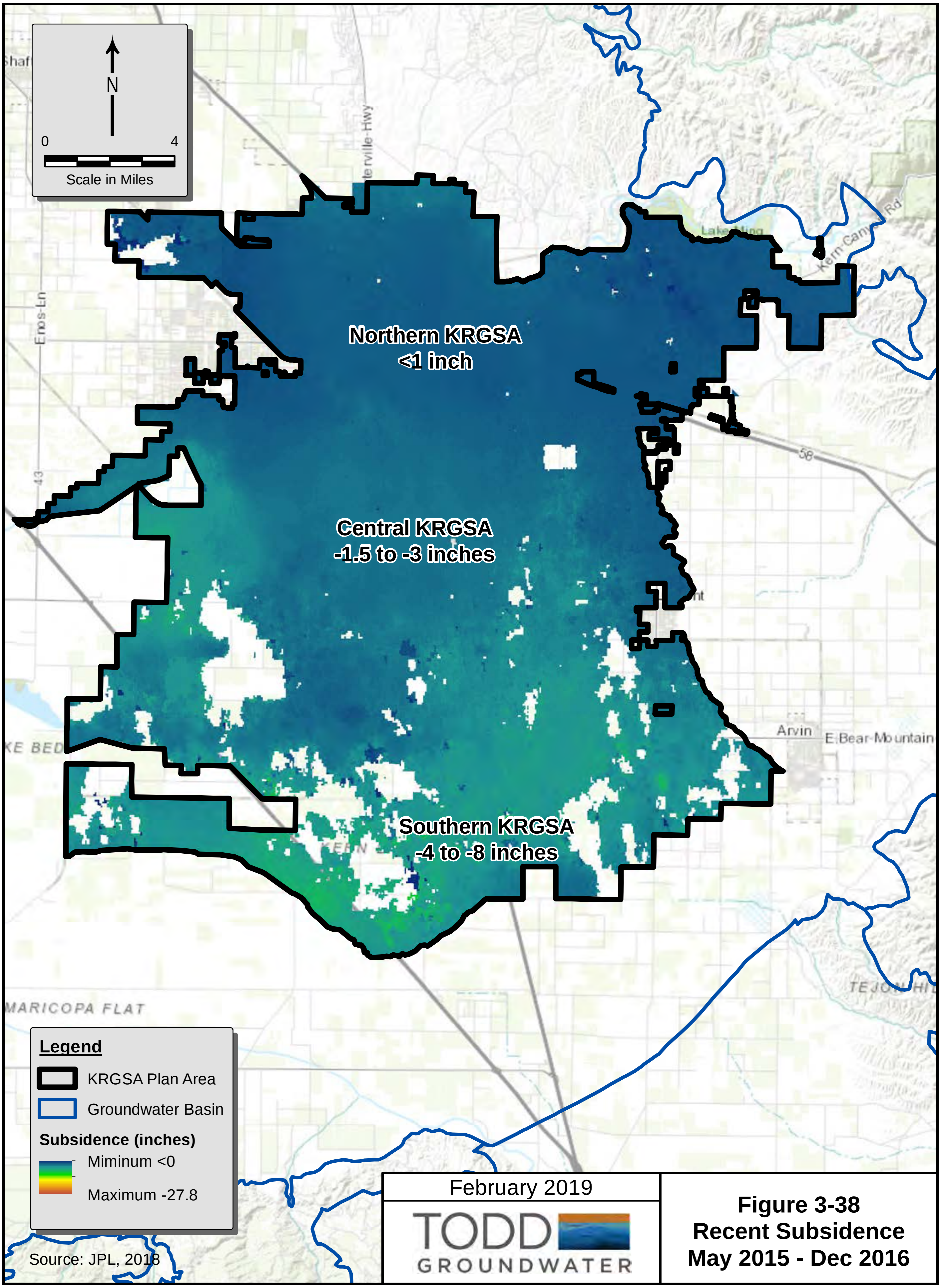
Figure 3-36
Concepts of Land Subsidence



February 2019

TODD GROUNDWATER

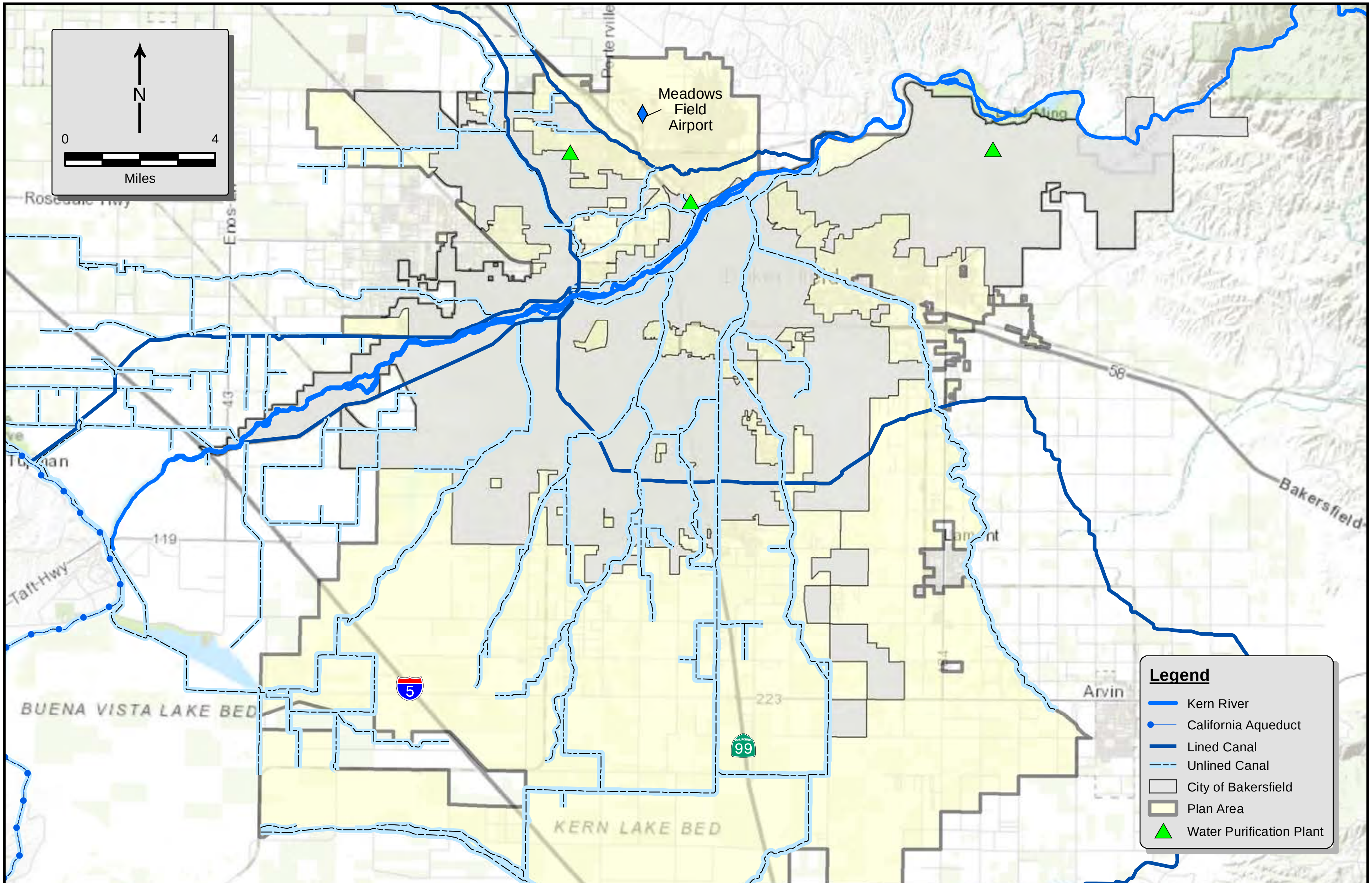
Figure 3-37
Historical Subsidence
1926 - 1970



February 2019

TODD GROUNDWATER

Figure 3-38
Recent Subsidence
May 2015 - Dec 2016



July 2019

TODD GROUNDWATER

Figure 3-39
Critical
Infrastructure

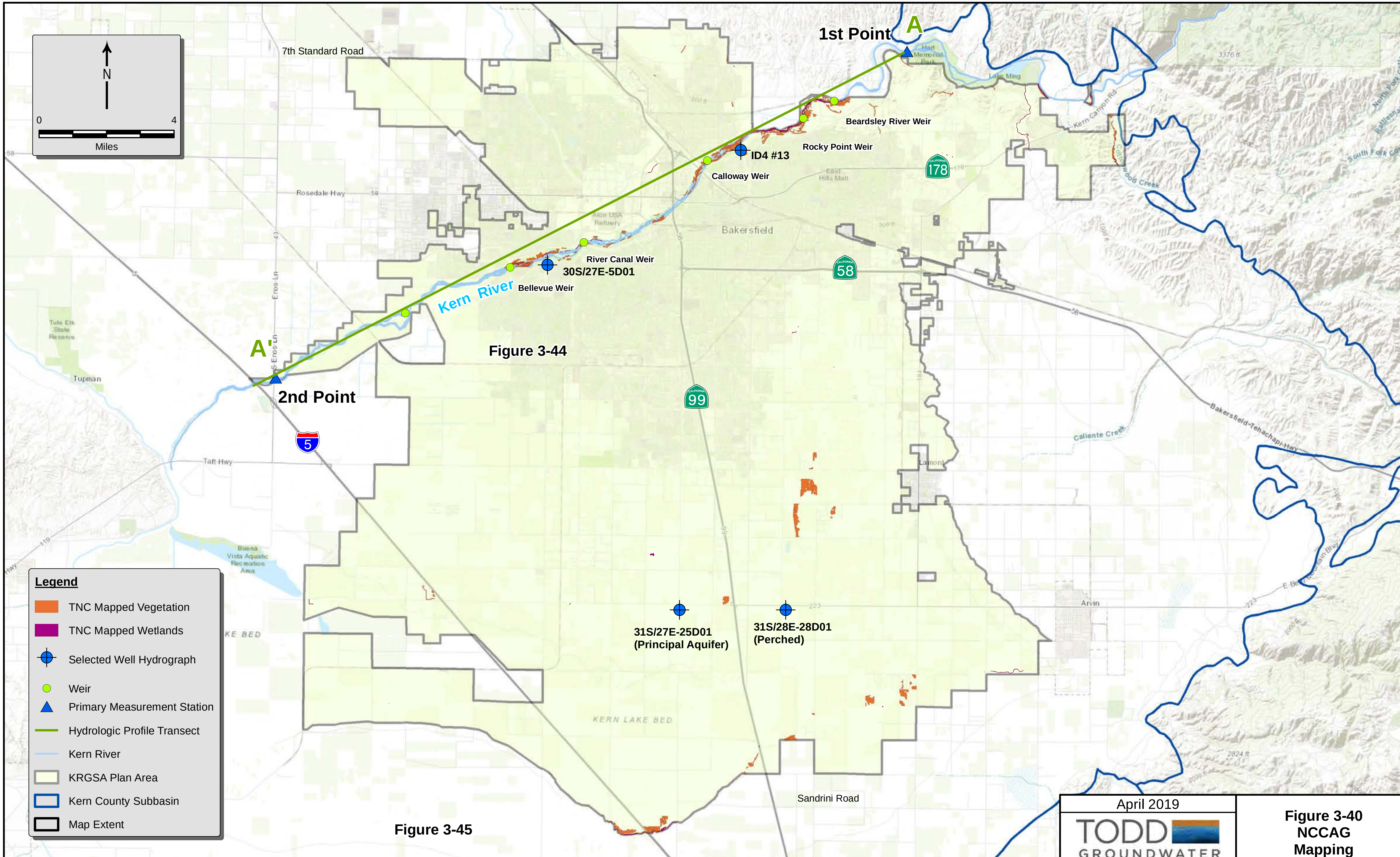
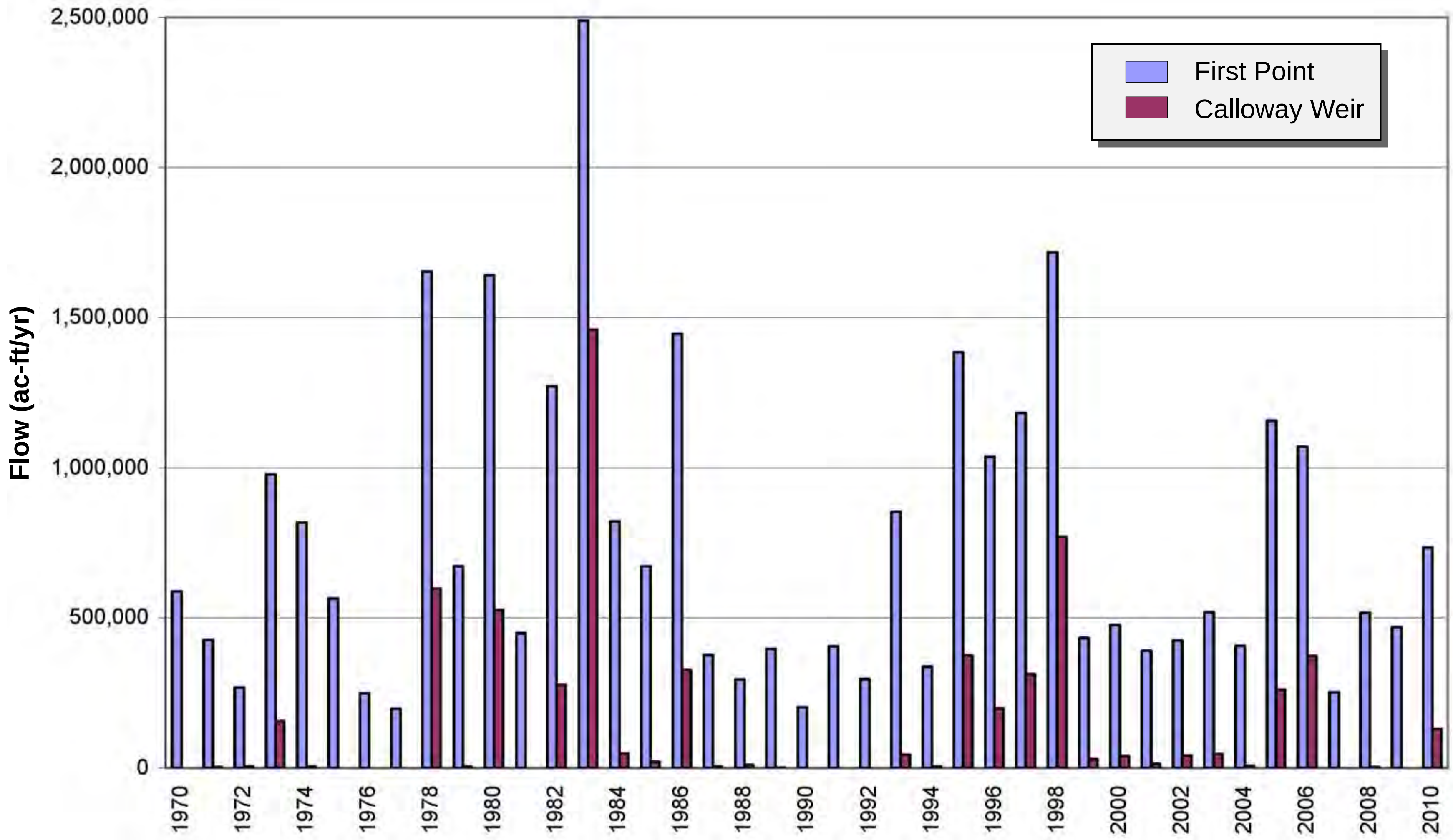


Figure 3-40
NCCAG
Mapping

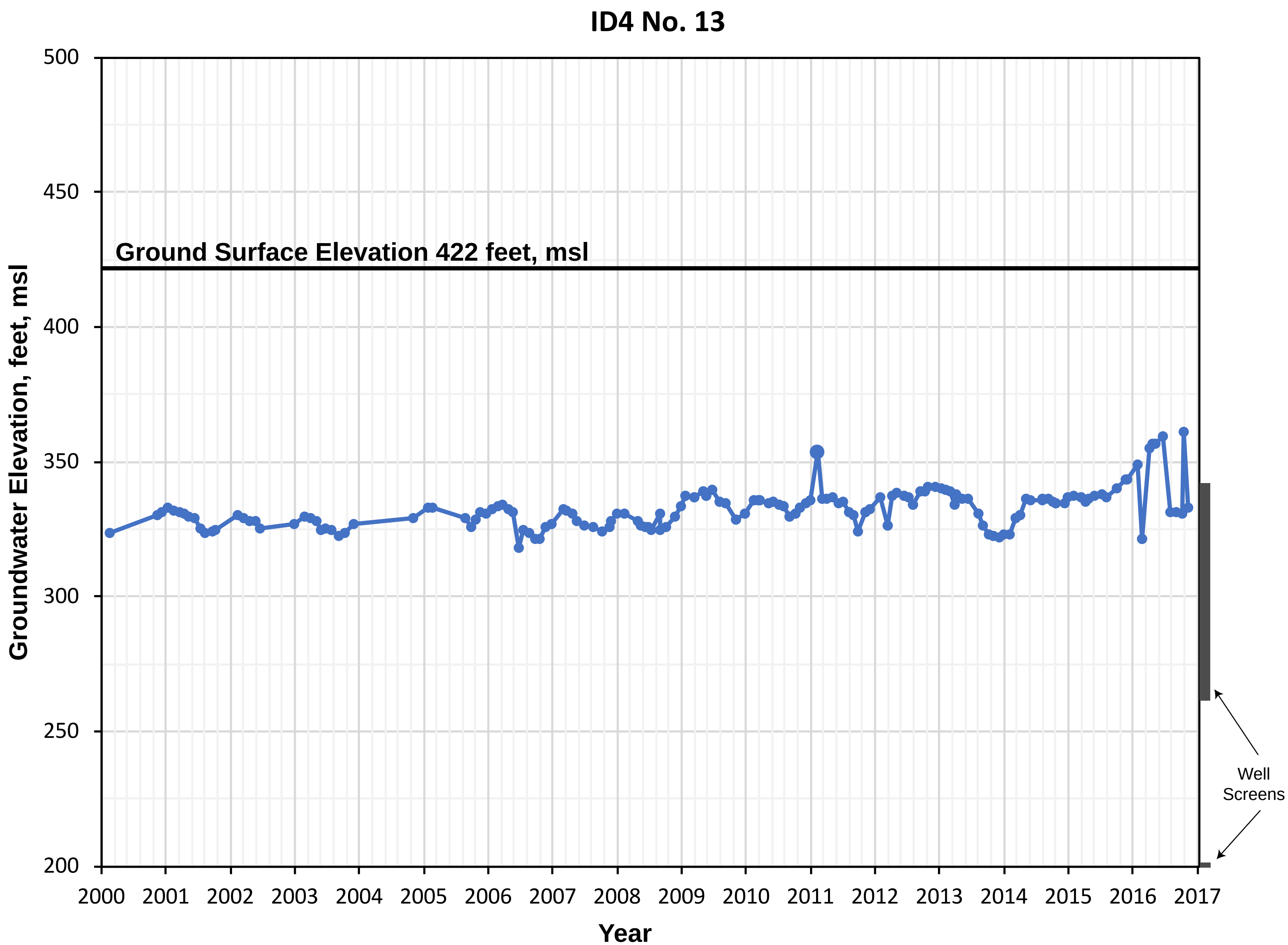


Source: DBS&A, 2012.

April 2019

TODD GROUNDWATER

Figure 3-41
Annual Flow at
First Point and Callloway Weir
1970 - 2010

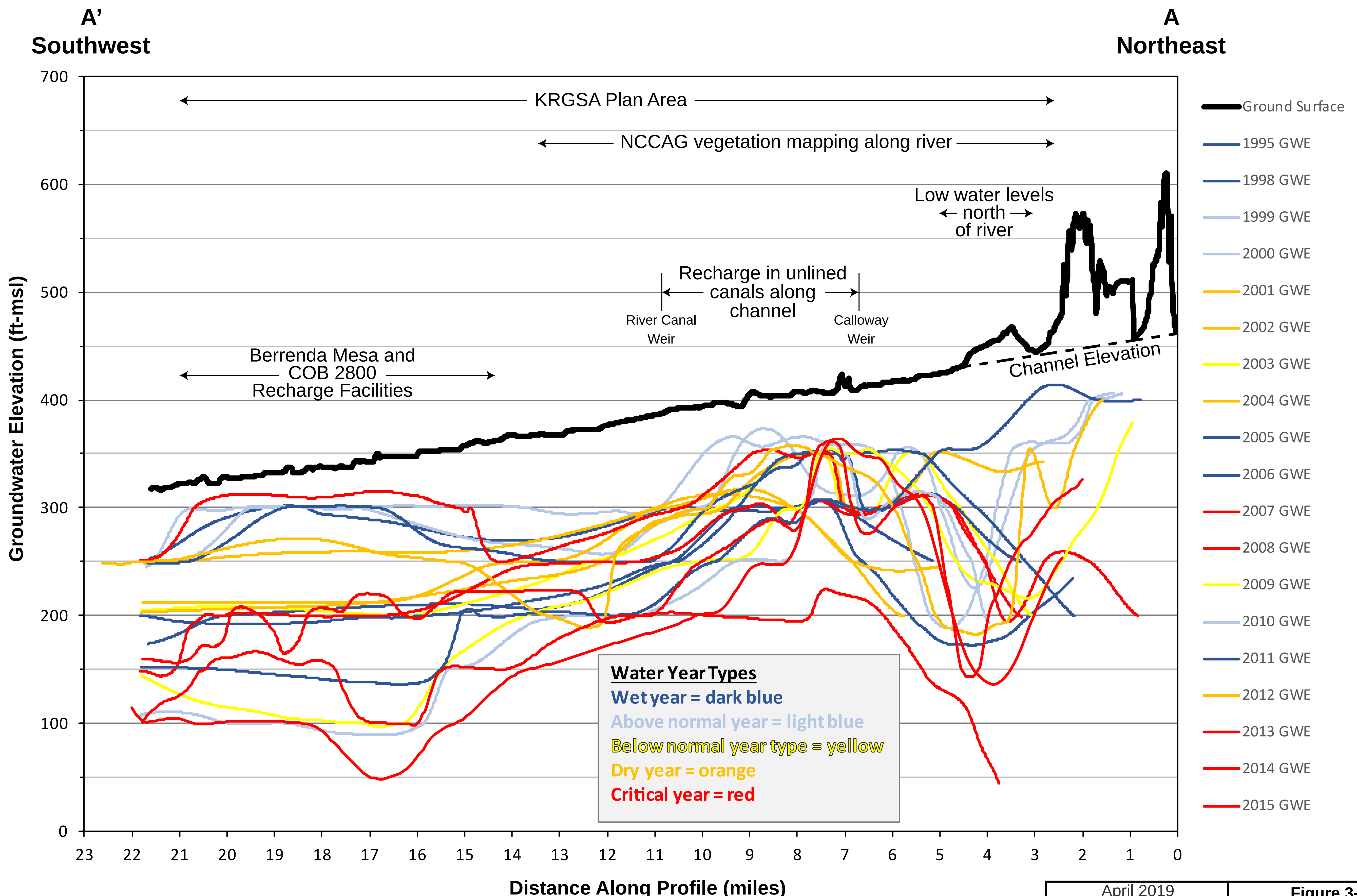


Screen Elevation: 262 to 342
-118 to 202

April 2019

TODD GROUNDWATER

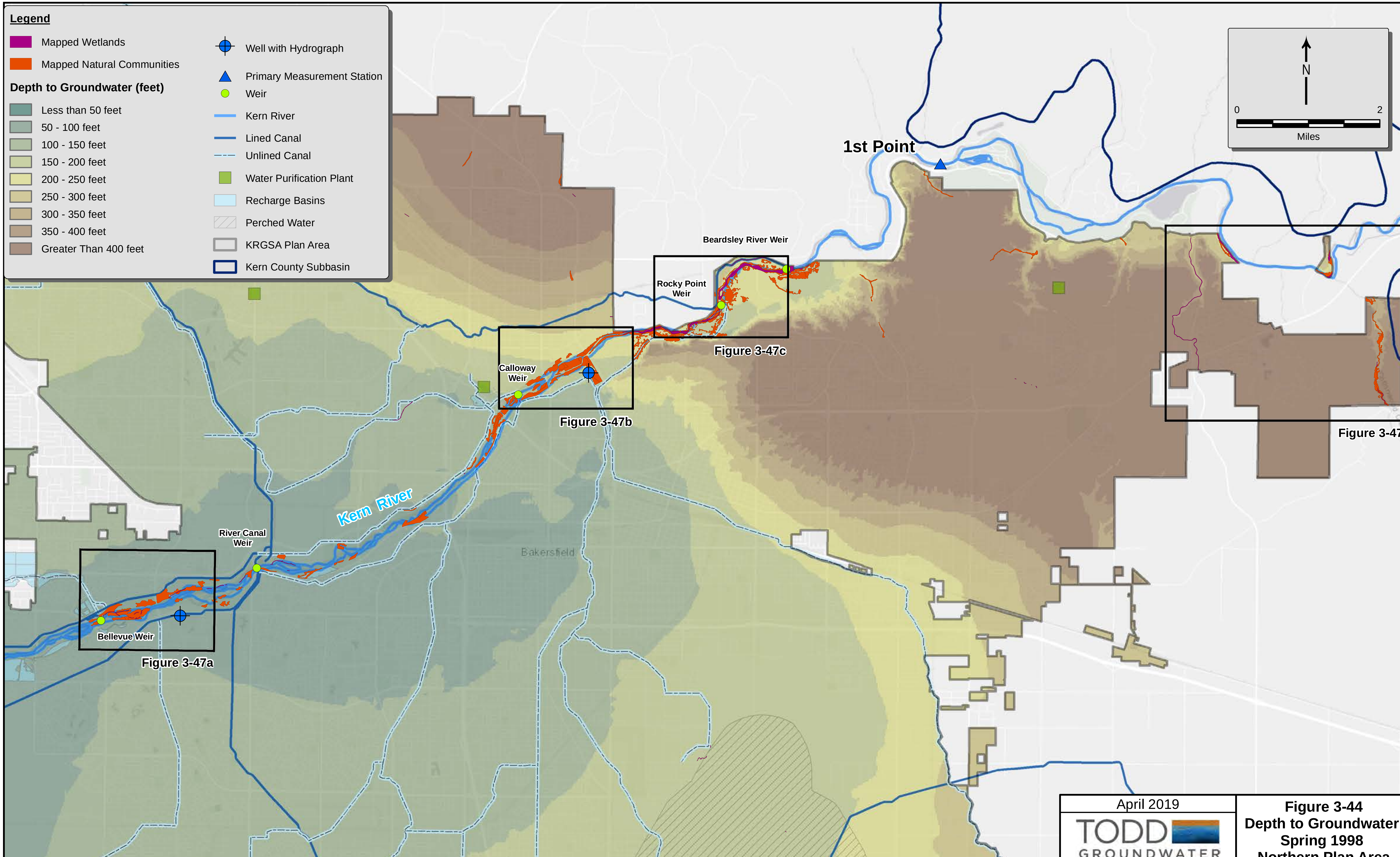
Figure 3-42
Water Levels
at the Calloway Pool



April 2019

TODD GROUNDWATER

Figure 3-43
Hydrologic Profiles
Along Kern River
1995 - 2015



April 2019

TODD GROUNDWATER

Figure 3-44
Depth to Groundwater
Spring 1998
Northern Plan Area

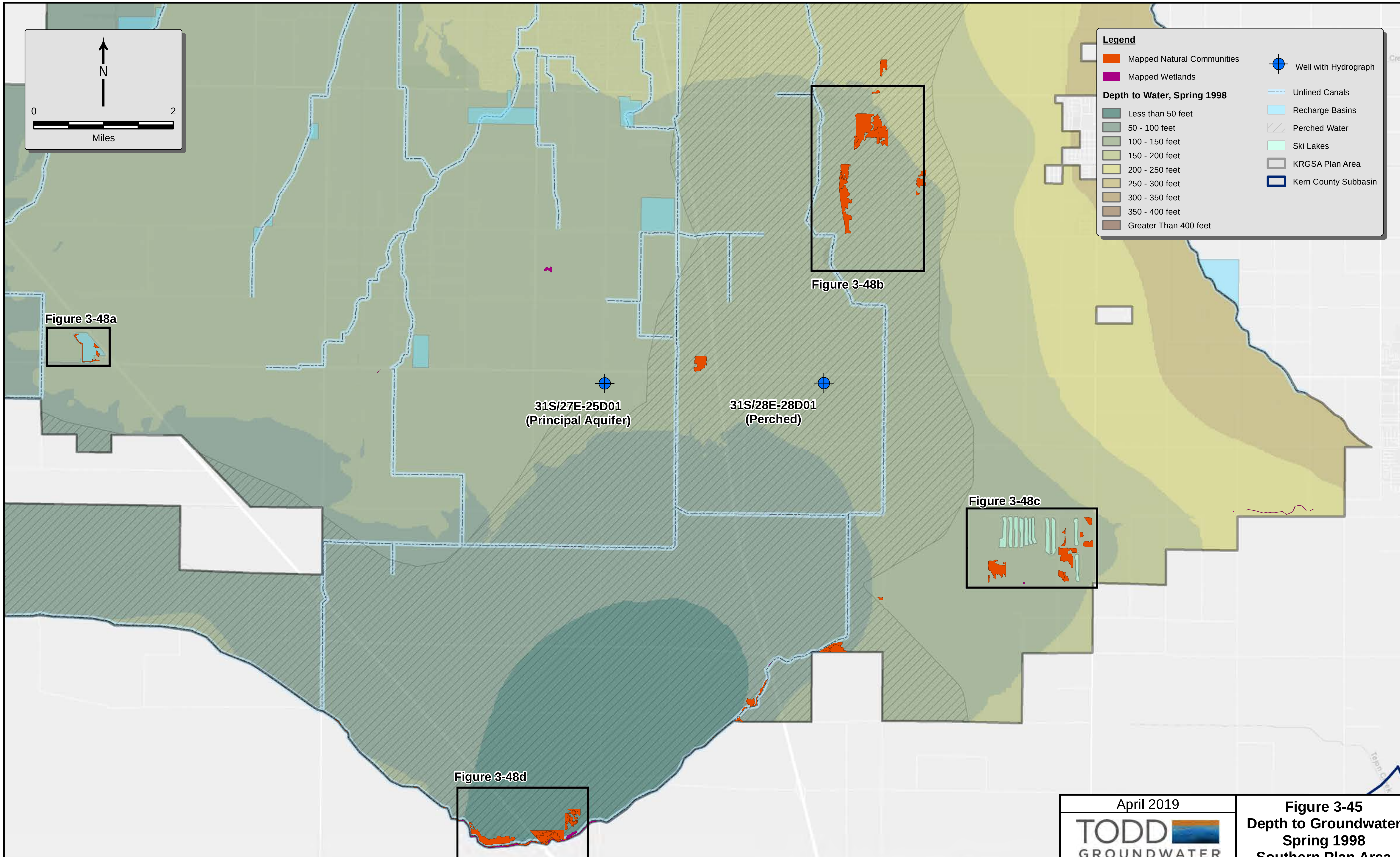
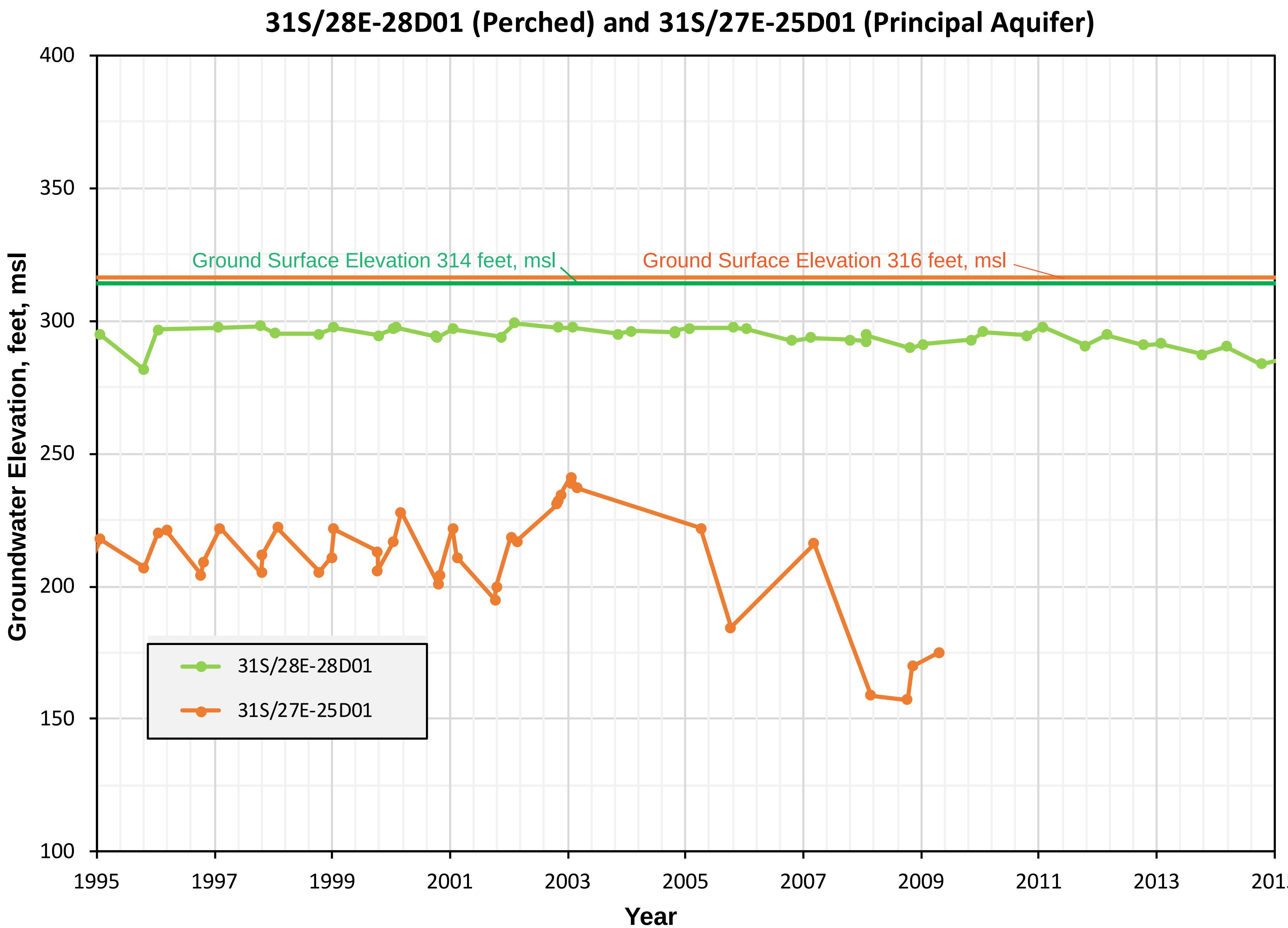


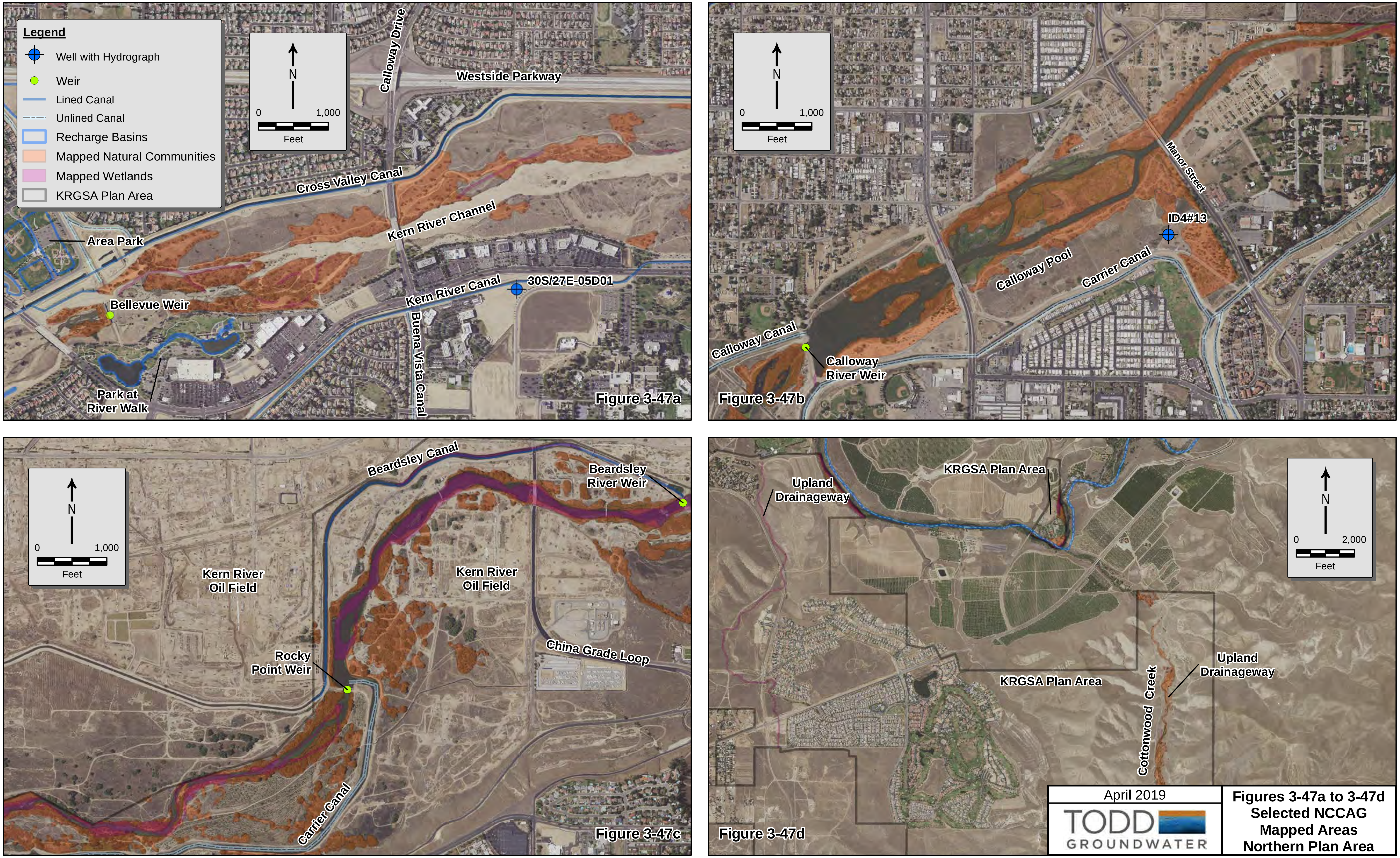
Figure 3-45
Depth to Groundwater
Spring 1998
Southern Plan Area



April 2019

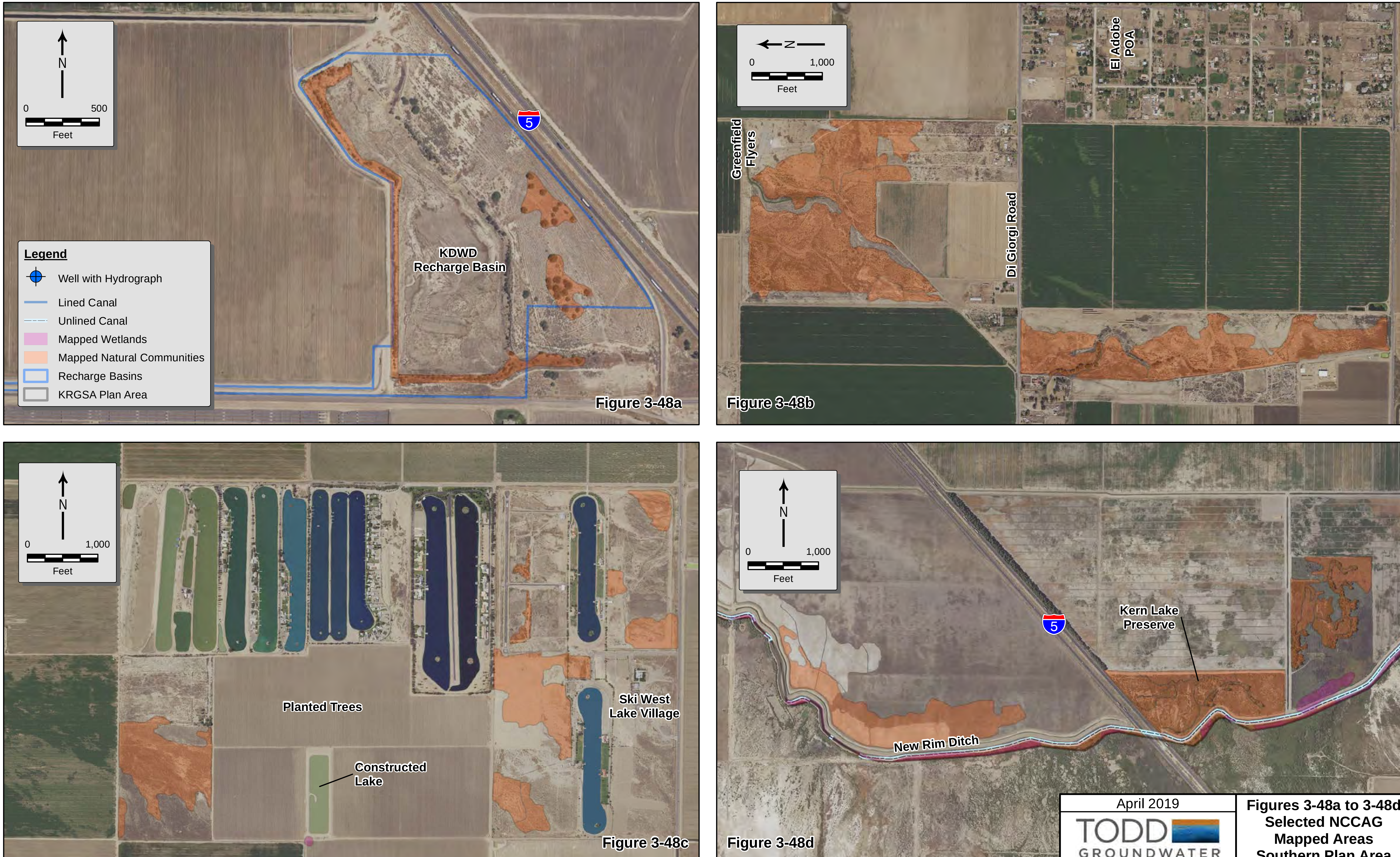
TODD GROUNDWATER

Figure 3-46
Perched Water
Southern Plan Area



April 2019

Figures 3-47a to 3-47d
Selected NCCAG
Mapped Areas
Northern Plan Area



Figures 3-48a to 3-48d
Selected NCCAG
Mapped Areas
Southern Plan Area