Prepared in cooperation with the California State Water Resources Control Board

Multiple-Well Monitoring Site Within the Poso Creek Oil Field, Kern County, California

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Introduction

The Poso Creek Oil Field is one of the many fields selected for regional groundwater mapping and monitoring by the California State Water Resources Control Board as part of the Oil and Gas Regional Monitoring Program (RMP; California State Water Resources Control Board, 2015, 2022b; U.S. Geological Survey, 2022a). The U.S. Geological Survey (USGS), in cooperation with the California State Water Resources Control Board, is evaluating several questions about oil and gas development and groundwater resources in California, including (1) the location of groundwater resources; (2) the proximity of oil and gas operations to groundwater and the geologic materials between them; (3) evidence (or no evidence) of fluids from oil and gas sources in groundwater; and (4) the pathways or processes responsible when fluids from oil and gas sources are present in groundwater (U.S. Geological Survey, 2022a). As part of this evaluation, the USGS installed a multiple-well monitoring site within the administrative boundary of the Poso Creek Oil Field about 12 miles north of Bakersfield, California (fig. 1). Data collected at the Poso Creek multiple-well monitoring site (PCCT) provide information about the geology, hydrology, geophysical properties, and water quality of the aquifer system overlying the oil-bearing zone, thus enhancing understanding of relations between adjacent groundwater and the Poso Creek Oil Field in an area where groundwater data are limited, particularly at different depths in the aquifer. This report presents construction information for the PCCT and initial geohydrologic data collected from the site. Similar sites installed on the east side of the Lost Hills Oil Field and North and South Belridge Oil Fields were described by Everett and others (2020a, b).

Study Area

The PCCT lies within the northern part of the Premier area of the Poso Creek Oil Field (fig. 1). The Poso Creek Oil Field is in the southern San Joaquin Valley on the eastern edge of the Kern County Groundwater Subbasin (5-022.14; California Department of Water Resources, 2020) of the Tulare Lake Hydrologic Region approximately 12 miles north of Bakersfield, California (California Department of Water Resources, 2020; fig. 1).

The stratigraphy of the Poso Creek Oil Field of interest for this study consists of westward dipping sands, clays, and conglomerates that range from Miocene to Pleistocene (Weddle, 1959; Stephens and others, 2021). Moving deeper from the surface, the stratigraphy includes recent alluvial and river sediments, older alluvium and terrace deposits, the Kern River Formation, the Etchegoin Formation, the Chanac Formation, and the Santa Margarita Sandstone.

The Kern River Formation unconformably underlies the alluvium to the west and crops out throughout the Poso Creek Oil Field (Bartow and Pittman, 1983). The nonmarine Kern River Formation is composed of sands, clays, and conglomerates that grade westward into shallow marine and nonmarine sediments of the Etchegoin, San Joaquin, and Tulare Formations (Bartow and Pittman, 1983; California Department of Conservation, 1998; Scheirer and Magoon, 2008). The Kern River Formation is thought to be deposited in a braided stream environment, and there is little lateral lithologic continuity within the formation (Bartow and Pittman, 1983). Oil is produced from the Kern River Formation within the nearby Kern River Oil Field (approximately 5 miles southeast of the Poso Creek Oil Field; fig. 1) from several oil-bearing zones that are separated by water-bearing zones (Bartow and Pittman, 1983).

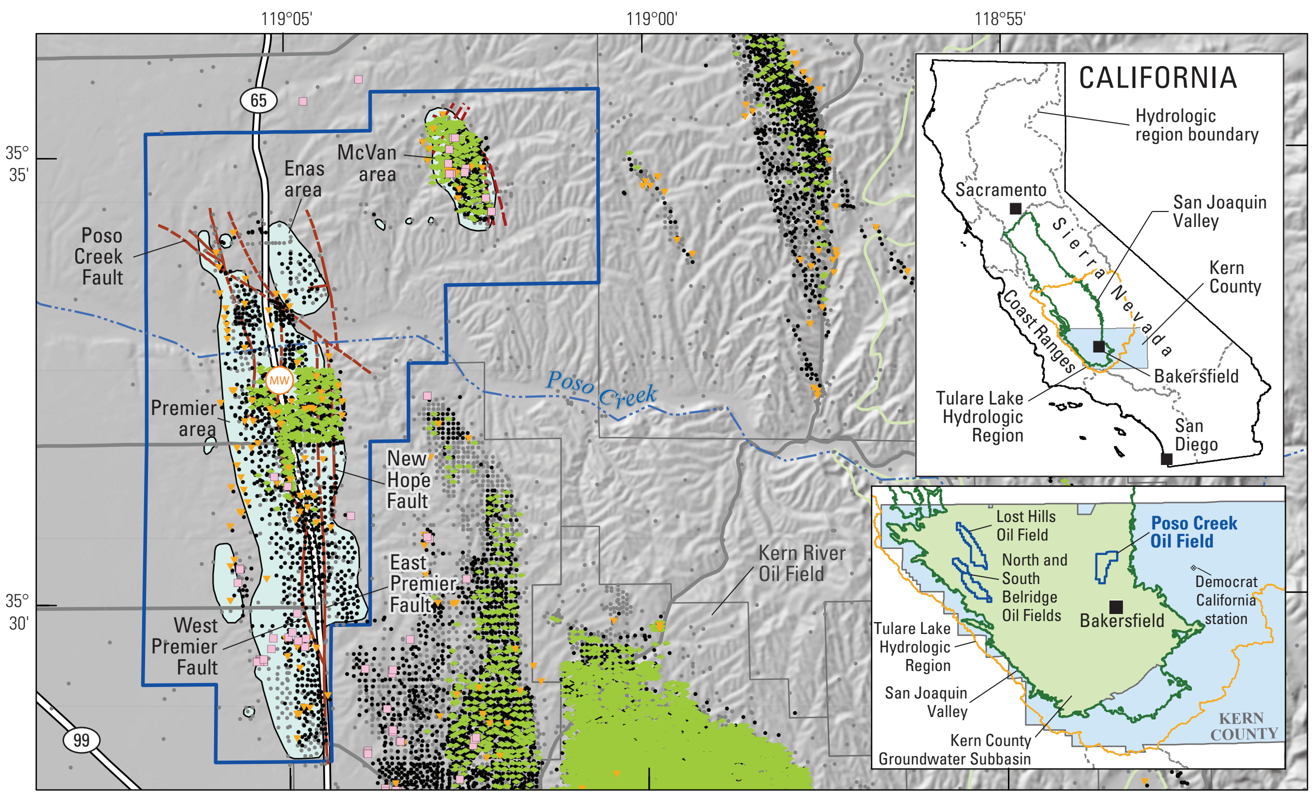
The Kern River Formation grades downward into the marine sands and shales of the Etchegoin Formation, which is divided into the upper Etchegoin sands, Macoma claystone, and the basal Etchegoin sands (California Department of Conservation, 1998). The upper Etchegoin sands consist of marine sands and shales that are from Miocene to Pliocene (Bartow and Pittman, 1983). The upper Etchegoin sands are not economically oil-bearing within the Poso Creek Oil Field. The Macoma claystone dips to the west-southwest and is mapped from approximately 1,580 to 2,600 feet below land surface (ft bls) in the production areas (fig. 1) to approximately 5,000 ft bls in the groundwater basin west of the oil field (Stephens and others, 2021). The Macoma claystone is a significant regional clay layer that restricts vertical groundwater flow and separates the overlying aquifer system from the hydrocarbon-bearing zone below (Stephens and others, 2021). The basal Etchegoin sands are approximately 100 ft thick within the field, thin to the east, and are a significant oil reservoir within the Poso Creek Oil Field (Stephens and others, 2021).

The Chanac Formation unconformably underlies the basal Etchegoin sand (Bartow and Pittman, 1983) and is composed of interbedded non-marine sands that are confined to a narrow band in the subsurface of the southeastern San Joaquin Basin province (Scheirer and Magoon, 2008). The Chanac Formation contains substantial oil for production in the Poso Creek Oil Field and the surrounding fields where it is present.

The Santa Margarita Sandstone unconformably underlies the Chanac Formation (Bartow and Pittman, 1983) and is interpreted as shallow-marine clastic facies that occupies a broad swath of the subsurface of the eastern San Joaquin Basin province (Scheirer and Magoon, 2008). The Santa Margarita Sandstone is not a major oil producing zone in the Poso Creek Oil Field and is typically used for produced water (water extracted with oil) disposal (California Department of Conservation, 2021; Stephens and others, 2021).

Primary water-bearing units that comprise the major aquifers on the east side of the Tulare Lake Hydrologic Region include recent alluvial and river sediments, older alluvium and terrace deposits, and the Pliocene to Pleistocene Kern River Formation (California Department of Water Resources, 2015). Locally important units in the Kern County Groundwater Subbasin include westward dipping sediments lying along the sloping face of the Sierran basement complex, including the Kern River Formation and the Santa Margarita Sandstone and Olcese Sand, which provide fresh water from very deep wells (Rodner, 1950; Hilton and others, 1963; California Department of Water Resources, 2013).

A majority of the recharge to the eastern margin of the San Joaquin Valley is from rainfall and snowmelt originating in the Sierra Nevada bounding the east side of the valley (Faunt, 2009). As a result, groundwater in the eastern San Joaquin Valley is typically much lower in total dissolved solids (TDS) compared to the western San Joaquin Valley, which only receives small amounts of recharge from ephemeral streams draining metamorphic and marine rocks of the Coast Ranges (Laudon and Belitz 1991; Gillespie and others, 2017, 2019).



Base modified from U.S. Geological Survey and other Federal digital data; fault locations from Stephens and others (2021) and Weddle (1959); historic produced water storage area data from California State Water Resources Control Board (2022a); oil and gas well data from the California Department of Conservation (2021); Democrat California station location from Western Regional Climate Center (2022); hydrologic region and groundwater basin boundaries from the California Department of Water Resources (2020); various scales; Albers Equal-Area Conic projection, standard parallels are 29°30′ N. and 45°30′ N.; North American Datum of 1983

0 2 4 MILES

0 2 4 KILOMETERS

EXPLANATION

Oil field administrative boundary

Poso Creek Oil Field administrative boundary

Poso Creek Oil Field production area

Area of historical produced water surface disposal or storage

Fault (dashed where uncertain)

Kern County Groundwater Subbasin boundary

Major road

State highway

Active, new, and idle wells

Water disposal injection well

Injection well (water flood, steam flood, cyclic steam)

Oil and gas production well

Poso Creek multiple-well monitoring site (PCCT)

Plugged or buried well

Figure 1. Location of the Poso Creek multiple-well monitoring site (PCCT), selected other wells, areas of known historical produced water-surface disposal or storage, production areas, and faults in relation to the Poso Creek Oil Field, Kern County, California.

Precipitation records from the Democrat California station operated by the U.S. Forest Service (National Weather Service identified 045002) 26 miles due east of PCCT in the Sierra Nevada indicate an average annual rainfall of 11.2 inches since January 2002 (Western Regional Climate Center, 2022). Nearly 90 percent (10 inches) of the annual precipitation fell during the months of November through April, with more precipitation falling during the month of January, 2.6 inches on average, than any other month.

The PCCT location was selected to provide better information regarding vertical and lateral changes in groundwater gradients and water quality overlying the Poso Creek Oil Field. The site is in the Premier area of the Poso Creek Oil Field where historical data indicate that the Macoma claystone separating underlying oil production zones from overlying groundwater zones may be thin because of an offset along the Premier Fault (Weddle, 1959; referred to as the "west Premier Fault" in Stephens and others, 2021). The monitoring site was designed to permit collection of geochemical, geophysical, and hydrologic data to evaluate if overlying and adjacent groundwater zones may be affected by (1) naturally occurring oil and gas shows in aquifers resulting from geologic processes or (2) a range of historical and current oil- and gas-development activities. These activities can include surface spills, leakage of produced water (water extracted with oil) from disposal ponds, injection of produced water into the subsurface for enhanced recovery and disposal, and potential introduction of preferential pathways such as leaky or improperly abandoned oil and gas wells or test holes (Davis and others, 2018a; Gillespie and others, 2019).

At the PCCT site, the Macoma claystone separates the overlying aquifer in the Kern River Formation and upper Etchegoin sands from the underlying hydrocarbon-bearing basal Etchegoin sands and Chanac Formation. Based on available well logs (03029737, 03057990, 02914895, California Department of Conservation, 2021), the top of the Macoma claystone at the PCCT location is estimated to be approximately 2,240 ft bls on the west side of the Premier Fault, 2,065 ft bls on the east side of the fault, and approximately 115 ft thick. The PCCT was drilled where displacement on the Premier Fault is large, greater than the average thickness of the Macoma claystone, thereby placing the oil-bearing basal Etchegoin sand on the east side of the fault adjacent to the non-oil-bearing Kern River Formation on the west side of the fault (Weddle, 1959; Stephens and others, 2021).

There is a high concentration of oil-production activities near the PCCT (fig. 1). Within 2 miles of the PCCT, 1,436 wells have been drilled, and 315 of these wells have been abandoned. Active, idle, or new wells within 2 miles of the PCCT include 686 oil- or gas-production wells, 345 steam-flood or cyclic-steam wells, 52 water-disposal wells, 20 observation wells, and 18 wells of unknown use. The PCCT is approximately 500 feet from the nearest active oil well, 510 feet from the nearest idle well, 510 feet from the nearest active steam-flood well (injection of steam for enhanced recovery of oil), 1,600 feet from the nearest water-disposal well, and 20,000 ft (3.8 miles) from the nearest water-flood well in the McVan area (California Department of Conservation, 2021). There are four areas within 2 miles of the PCCT that are known historical produced water surface disposal or storage sites (fig. 1; California State Water Resources Control Board, 2022a).

Drilling and Well Installation

The PCCT pilot borehole, with a diameter ranging from 9 $^1/_4$ to 7 $^7/_8$ inches, was drilled to a depth of 1,820 ft bls during February and March 2021 using direct mud-rotary drilling. Drill cuttings were collected throughout the drilling process and analyzed (along with notes from the on-site geologist) to summarize the lithology (fig. 2) following the procedures described by Everett and others (2013). Continuous mud-gas logging of the mud stream was performed during the drilling of the pilot hole, and mud-gas samples were collected at 15 depths and analyzed for the isotopic composition of hydrocarbon gases methane and ethane (fig. 2). Mud logging, also known as hydrocarbon well logging or gas logging, entails gathering qualitative and semi-quantitative data from hydrocarbon gas detectors that record the concentrations of natural gas brought up in the drilling mud (Crain, 2022). Total gas in the mud does not represent the actual quantity of hydrocarbon gas in the reservoir but rather represents the gas detected in the drilling mud with respect to depth and apparent relative concentrations in parts per million by volume. When combined with oil-field gas chromatograph analysis to determine the individual gas components (methane [C1], ethane [C2], propane [C3], butane [C4], and pentane [C5]), mud logging can assist in locating zones of oil or gas as they are penetrated (Crain, 2022).

To assist in the identification of lithologic and stratigraphic units, geophysical logging of the borehole was completed using techniques described by Keys and MacCary (1971), Shuter and Teasdale (1989), Keys (1990), and Kenyon and others (1995). Logging was completed in the small-diameter pilot hole because higher-quality logs could be collected compared to logs from larger-diameter boreholes. Geophysical logs completed at the site include caliper, natural gamma, normal resistivity (16- and 64-inch, not shown on fig. 2), spontaneous potential (SP), electromagnetic induction (expressed and discussed as resistivity), temperature, full wave sonic (sonic porosity), bulk density, neutron porosity, and nuclear magnetic resonance (fluid volume; fig. 2). Well-screen and filter-pack intervals were selected based on the geophysical and lithologic data. The pilot hole was then reamed to increase the borehole diameter to allow for the construction of the four-well monitoring site. The deepest well (PCCT#1) is constructed with 3-inch-diameter polyvinyl chloride (PVC) casing to allow for future geophysical logging, and the three shallower wells are constructed with 2-inch-diameter PVC casing (U.S. Geological Survey, 2022c). The wells were installed with screened intervals from 1,770 to 1,790 ft bls (PCCT #1); 1,445 to 1,465 ft bls (PCCT #2); 1,050 to 1,070 ft bls (PCCT #3); and 522 to 542 ft bls (PCCT #4; fig. 2; table 1). A filter pack of #3 sand (granules) was installed around each screen, and a low-permeability bentonite grout was placed in the depth intervals between the filter packs to isolate each of the wells.

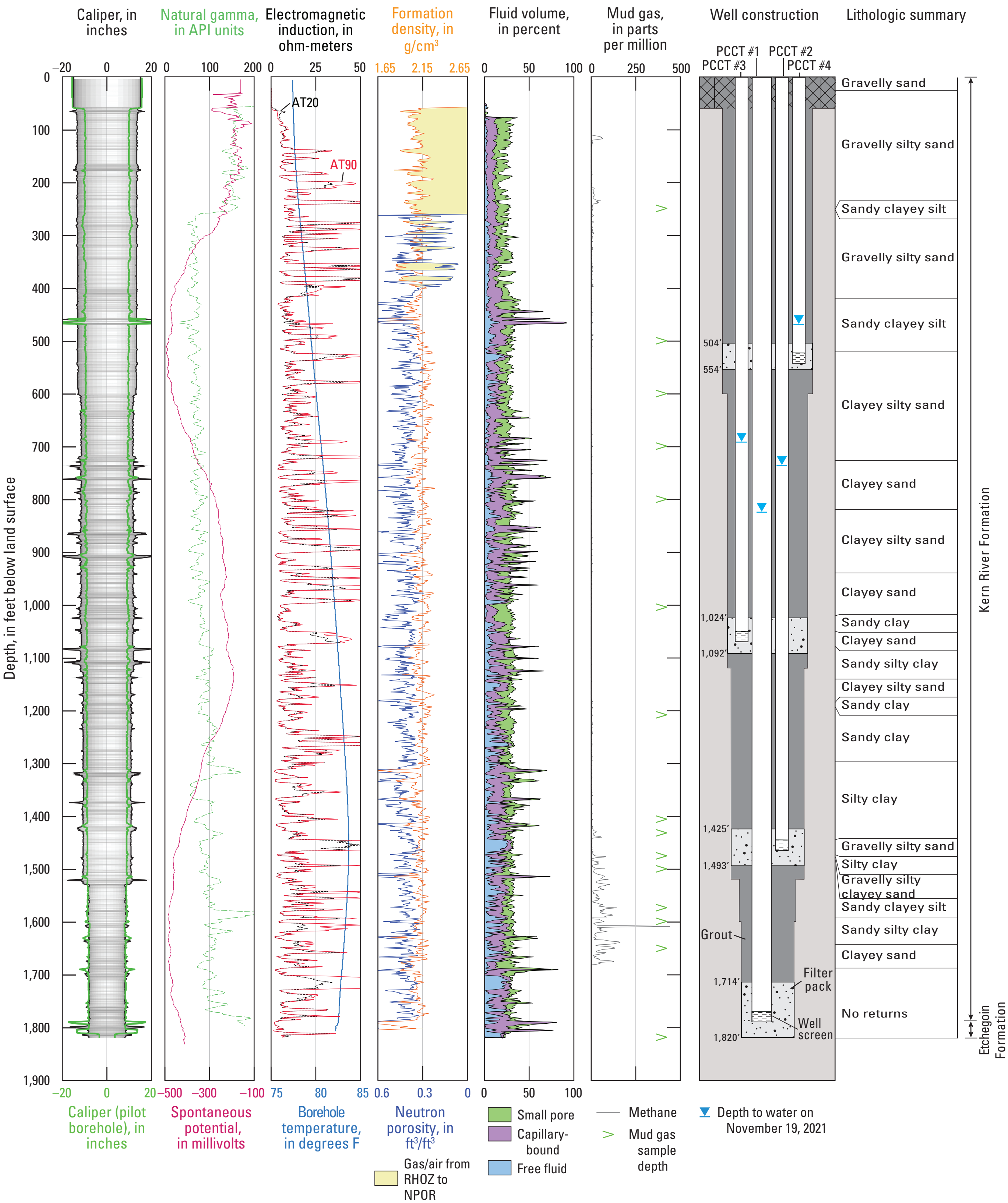


Figure 2. Well construction, summary lithology, and geophysical log data from Poso Creek multiple-well monitoring site (PCCT), Kern County, California. (Abbreviations: API, American Petroleum Institute units; g/cm^3, grams per cubic centimeter; AT20, Array induction resistivity 2-foot resolution 20-inch depth of investigation; AT90, Array induction resistivity 2-foot resolution 90-inch depth of investigation; F, Fahrenheit; ft^3/ft^3, cubic foot per cubic foot; RHOZ, Standard Resolution Formation Density; NPOR, Enhanced Thermal Neutron Porosity in Selected Lithology). Water-level data from U.S. Geological Survey (2022b), geophysical log data from U.S. Geological Survey (2022c), and U.S. Geological Survey site numbers in table 1.

After construction was completed, the wells were developed by airlifting and using a surging technique with compressed air to remove drilling fluid and develop the filter pack surrounding each monitoring well screen. The field parameters that were recorded during the process include specific conductance, pH, water temperature, apparent color, and turbidity. Well development continued until drilling mud was not evident and field parameters were stabilized. The daily average flow rate and development time was used to estimate a daily discharge. The estimated total discharge was calculated by adding the daily estimated discharge during the development period (table 2). The purge per casing volume and purge per sand pack volume are estimates of how many times the casing and sand pack volume were flushed with native groundwater during the development process (table 2). After well development, turbidities of the water in PCCT #1, #2, and #3 were below 10 nephelometric turbidity units (NTU; table 2). The higher turbidity of the water in PCCT #4, 321 NTU, was attributed to sediment (clay and silt) being washed from the formation into the well because of the high hydraulic stresses placed on the formation during development. Turbidity of a sample collected from PCCT #4 during October 2021 under lower stress conditions was below 10 NTU (U.S. Geological Survey, 2022b).

Table 1. Identification and construction information from the Poso Creek multiple-well monitoring site (PCCT), Kern County, California (U.S. Geological Survey, 2022b, 2022c).

[See figure 1 for well locations. Wells ordered from shallowest to deepest. The 15-digit U.S. Geological Survey (USGS) site number is used to uniquely identify the well. The common name is used throughout the report for quick reference. Land-surface datum (LSD) is a datum plane that is approximately at land surface at each well. The elevation of the LSD is described in feet above the North American Vertical Datum of 1988 (NAVD 88). **Abbreviations**: NWIS, National Water Information System; ft bls, feet below land surface]

Common well name	USGS site number (hyperlinked to NWIS)	Elevation of LSD (ft above NAVD 88)	Well diameter (inside, inches)	Depth to bottom of well (ft bls)	Depth to top of perforations (ft bls)	Depth to bottom of perforations (ft bls)
PCCT #4	353229119050604	582.44	1.94	542	522	542
PCCT #3	353229119050603	582.44	1.94	1,070	1,050	1,070
PCCT #2	353229119050602	582.44	1.94	1,465	1,445	1,465
PCCT #1	353229119050601	582.44	2.90	1,790	1,770	1,790

Table 2. Well-development and water-level data from the Poso Creek multiple-well monitoring site (PCCT), Kern County, California (U.S. Geological Survey, 2022b).

[Wells ordered from shallowest to deepest. Pre- and post- development depth-to-water measurements may not represent true static water levels and are not available on U.S. Geological Survey (USGS) National Water Information System (NWIS; U.S. Geological Survey, 2022b). Estimated total discharge was calculated by adding daily estimated discharge during the development period. **Abbreviations**: ft bls, feet below land surface; xx/xx/xxxx, month/day/year; gal/min, gallons per minute; gal, gallon; v/v, volume per volume; NTU, nephelometric turbidity units]

Common well name	Pre-development depth to water (ft bls)	Post-development depth to water (ft bls) (06/17/2021)	Depth to water (ft bls) (11/19/2021)	Final flow rate (gal/min)	Hours of development	Estimated total discharge (gal)	Purge per casing volume `(v/v)	Purge per filter pack volume (v/v)	Post-development turbidity (NTU)
PCCT #4	463.98	467.86	468.39	0.3	255	3,770	315	25	321
PCCT #3	646.29	659.96	690.59	5.9	140	46,400	716	155	7
PCCT #2	718.62	725.55	734.90	7.5	140	53,100	465	175	1
PCCT #1	817.00	817.00	823.29	12.0	140	105,000	316	531	2

Sediment and Drilling Fluid Analysis

The lithology at the site consists of gravel, sand, silt, and clay (fig. 2) from the Pliocene to Pleistocene Kern River Formation and marine deposits of the underlying Etchegoin Formation. The lithology at this location is primarily coarse-grained in the upper 800 ft, interbedded coarse and fine grain layers from 800 to 1,200 ft bls, and primarily fine-grained with occasional coarse zones from 1,200 to 1,680 ft bls. Drill cuttings were not collected from depths below 1,680 ft bls due to a decrease in mud flow related to zones of lost circulation that resulted in uncertainty in the sample quality. No shell fragments were observed in the drill cutting. The contact between the Kern River Formation and the underlying Etchegoin Formation was picked from the geophysical logs to be at a depth of 1,788 ft bls. In comparison to previous log interpretations in the area (Weddle, 1959; Stephens and others, 2021), the contact was picked based on a transition from a generally higher resistivity (electromagnetic induction on fig. 2) of the fluvial sands of the Kern River Formation to comparatively lower resistivity of the marine sediments of the Etchegoin Formation along with a shift in the SP at the corresponding depth. However, because of the gradational nature of the contact and lack of cuttings, the depth of this contact is approximate and may be as shallow as 1,306 ft bls.

Hydrocarbon fluorescence under ultraviolet light can indicate the presence of oil in small amounts. The most reliable test for hydrocarbons in drill cuttings is the cut fluorescence, or wet cut test, that utilizes an organic solvent to dissolve the oil and observing the fluorescence of the resulting cut (Swanson, 1981). Samples collected every 10 feet were lightly rinsed in acetone and then inspected under a black light for fluorescence (Wyman and Castano, 1974; Swanson, 1981). Fluorescence was not noted in any of the collected samples, indicating that there were no oil shows in the sediments in the upper 1,680 ft bls.

Hydrocarbon gases monitored in the drilling-mud return flow include methane, ethane, propane, n-butane + isobutane, and n-pentane + isopentane. Methane is the only hydrocarbon gas that was detected. Methane concentrations above the approximate baseline concentration of 10 parts per million (ppm) were most apparent at depth intervals from 110 to 130, 210 to 250, and 1,425 to 1,680 ft bls (fig. 2). The two shallower depth intervals with relatively high methane concentrations were above the depth to water that was measured in PCCT #4 on November 19, 2021 (468 ft bls; fig. 2). The deepest depth interval had the highest methane concentrations and was approximately 1,000 feet below the depth to water that was measured in PCCT #4. The maximum mud gas methane concentration, 440 ppm, occurred at a depth of 1,608 ft bls. The absence of heavier hydrocarbons like propane in the mud logs indicated that the detected methane is likely biogenic in origin (Rosecrans and others, 2021). The source of the methane will be examined more fully once stable hydrogen and carbon isotope data for methane in the mud gas and in water samples from the monitoring wells are analyzed.

Hydrology

Water-level data that were collected included periodic discrete manual measurements and hourly data recorded by downhole pressure transducers. Methods described by Cunningham and Schalk (2011) were used to collect and quality-assure the water-level records. The data were analyzed to identify vertical water-level gradients, which indicate direction and variability of potential groundwater flow between aquifer layers and responses to factors such as recharge and local groundwater withdrawal.

Before installation of the PCCT, data on vertical profiles of groundwater flow through the Kern River Formation within the Poso Creek Oil Field were not available. The vertical water-level gradients at the site, calculated from multiple discrete water-level measurements collected on November 19, 2021 (table 2; fig. 3), indicate that the vertical component of groundwater should flow downward through the Kern River Formation. The groundwater gradient is highest, −0.421 foot per foot (ft/ft), between PCCT #4 and PCCT #3, lowest, −0.112 ft/ft, between PCCT #3 and PCCT #2, and −0.272 ft/ft, between PCCT #2 and PCCT #1. The low gradient between PCCT #3 and PCCT #2 may indicate that the fine-grained layers observed between these two wells do not substantially restrict vertical flow, likely because individual sedimentary layers are not laterally extensive, as noted by Bartow and Pittman (1983). However, Burow and others (2004) and Jurgens and others (2008) have noted that discontinuous clay lenses at depth in the eastern San Joaquin Valley can limit vertical groundwater flow and create semi-confining conditions at depth.

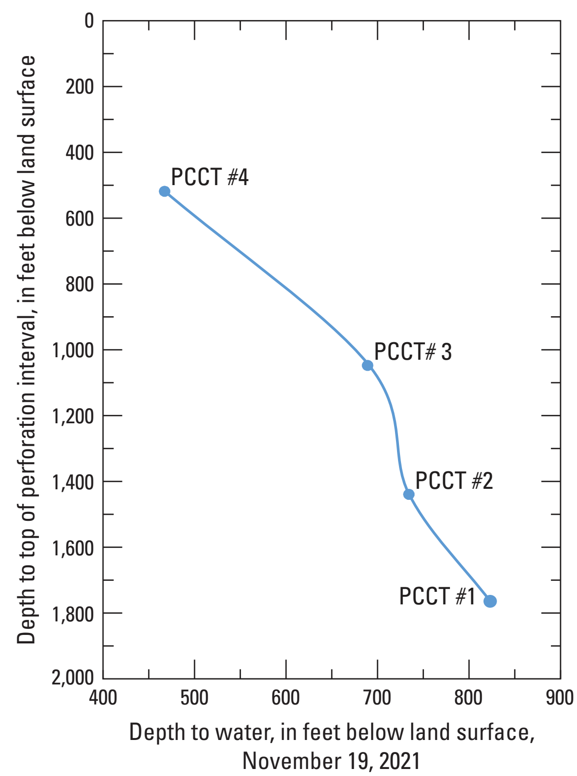


Figure 3. Vertical water-level gradient at the Post Creek multiple-well monitoring well site (PCCT), Kern County, California. Water-level data from U.S. Geological Survey (2022b), and U.S. Geological Survey site numbers in table 1.

Water-level changes through time were used to help determine the degree of hydraulic interaction between aquifer layers to assess restrictions to flow that may be caused by many discontinuous clay layers. The change in water level relative to 9:00 a.m. Pacific Daylight Time (PDT) on November 19, 2021, at the beginning of the period when hourly data were recorded, was calculated for each well (fig. 4). Water levels typically recovered in the winter in correlation with decreased withdrawal and increased recharge from precipitation and declined in the summer due to increased water use and groundwater withdrawal. Water levels were lower in all wells one year after hourly monitoring began, indicating an annual decline from late 2021 to late 2022.

The accuracy of the hourly water-level data recorded in all wells generally is ±0.03 ft. The accuracy of the water-level data recorded from PCCT #1 between November 19, 2021, and March 30, 2022, was ±0.57 ft because of limitations of the instrumentation measuring the levels. The change in water level in PCCT #1 during this period was greater than the error in accuracy. Therefore, the water-level data are presented to show the change in water level in comparison with the water levels in the shallower wells. Discrete measurements collected on November 19, 2021, March 10, 2022, and March 30, 2022, were used to verify the time-series data during this period. The accuracy of the hourly water-level data from PCCT #1 increased to ±0.03 ft after March 30, 2022, with the use of different instrumentation.

A rise in water level was observed in PCCT #2, #3, and #4 from mid-November 2021 to early February 2022, when the highest water levels were observed in these wells (fig. 4). The water level in PCCT #3 rose 47.9 ft to its highest observed level on February 9, 2022, then declined more than 74 ft by early July 2022, when the water level dropped below the recording device. On September 20, 2022, the water level was more than 93 ft lower than the February high, based on a discrete measurement. The water level in PCCT #2 rose 14.2 ft to its highest observed level on February 11, 2022, and then declined 42.4 ft to the lowest level on August 14, 2022. The similar pattern of the changes in water level in PCCT #3 and PCCT #2 indicates these two parts of the Kern River Formation are responding to the same hydrologic stresses, such as groundwater pumping and recharge. The greater changes in water level observed in PCCT #3 indicate this zone is more affected by local pumping. The water level in PCCT #4 rose 1.1 ft to its maximum observed level on March 31, 2022, and then declined 4.9 ft to the lowest level on October 29, 2022. The smaller change in water level observed in PCCT #4 compared to the larger water-level changes in the deeper wells (PCCT #2 and #3) indicates that the upper part of the Kern River Formation is hydrologically isolated from the lower part and is likely to be unconfined (in contact with atmospheric pressure), while deeper wells are in parts of the aquifer with confined hydraulic conditions isolated from atmospheric pressure.

The water level in PCCT #1 declined over 10 ft during the period between November 2021 and March 2023 (fig. 4). The time-series water-level data indicated a slight decline in December 2021 followed by a recovery in January 2022 that ended in mid-February when the water levels returned to their mid-November levels. A steady decline was observed from mid-February to mid-October 2022 when the rate of decline decreased. The difference in the trend and magnitude of the changes in water level observed in well PCCT #1 compared to the larger changes observed in the shallower wells (PCCT #2–#3) indicates that water levels at the bottom of the Kern River Formation and top of the Etchegoin Formation are responding to different hydrologic stresses than the overlying layers.

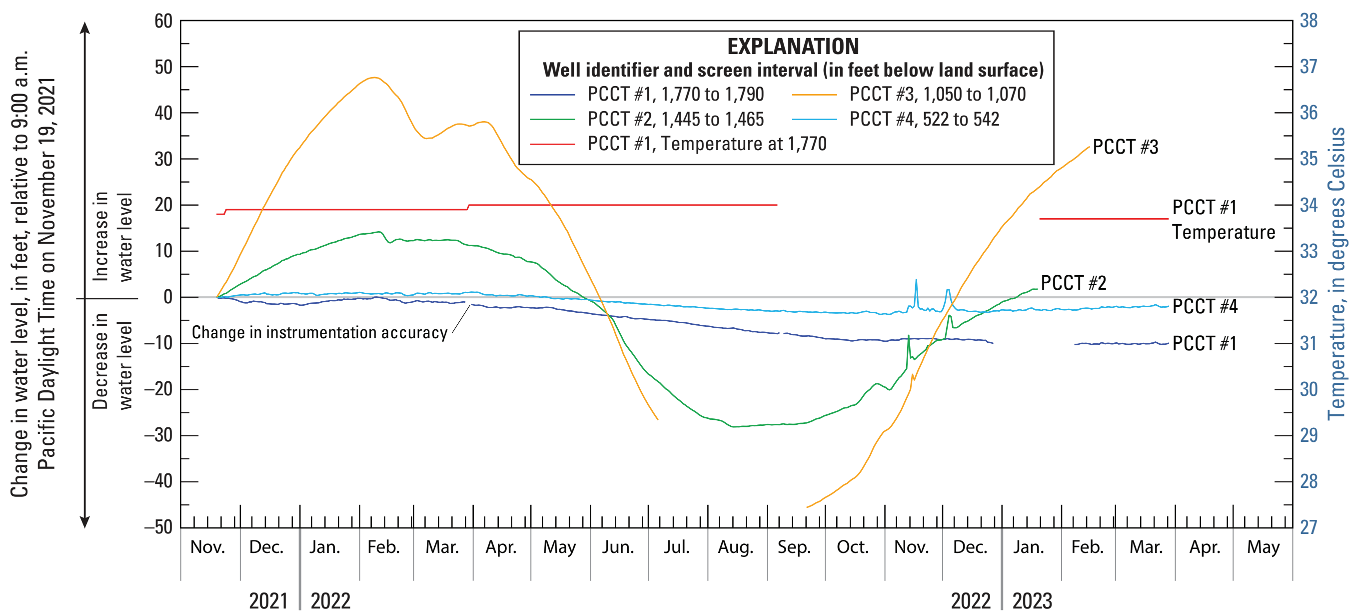


Figure 4. Change in water level relative to 9:00 a.m. Pacific Daylight Time on November 19, 2021, and temperature observed in wells at the Poso Creek multiple-well monitoring well site (PCCT), Kern County, California. Water-level data from U.S. Geological Survey (2022b), and U.S. Geological Survey site numbers in table 1.

Changes in groundwater temperature may indicate changes in groundwater flow. Instrumentation to measure the temperature of the water within the screened interval of PCCT #1 was installed for long-term monitoring of the temperature (Wagner and others, 2006). The temperature ranged from 33.7 to 34.0 degrees Celsius (°C; 92.7–93.2 degrees Fahrenheit) during the period, which is consistent with the pre-injection temperature versus depth model of the Poso Creek Oil Field developed by Stephens and others (2021; fig. 4). The borehole temperature measured during geophysical logging (fig. 2) and temperature of the water-quality samples collected from PCCT #1 (table 3) were lower compared to the in situ measurement because of heat loss caused by the drilling and sampling processes.

Water Quality

To delineate the chemical characteristics and source of the groundwater, samples were collected from each well in accordance with the protocols established by the USGS National Field Manual (U.S. Geological Survey, variously dated) and analyzed for major-ion chemistry, minor and trace elements, nutrients, radium isotopes, dissolved organic carbon and organic carbon characteristics, volatile organic compounds, concentrations and isotopic values of light hydrocarbon gases, the stable isotopes of hydrogen (deuterium) and oxygen (oxygen-18) in water, boron and strontium isotopes, carbon (carbon-13) stable isotopes and carbon-14 activities in dissolved inorganic carbon, noble gases, atmospheric gases, and groundwater-age tracers tritium and sulfur hexafluoride. The collection and analysis procedures are further described by Dillon and others (2016), Davis and others (2018b), and Wright and others (2019). Sampling of the four monitoring wells occurred during late October 2021. Other than the distribution of TDS, results of water-quality samples are not discussed in this report.

Concentrations of TDS in water samples collected from the PCCT wells ranged from 127 (PCCT #4) to 211 (PCCT #1) milligrams per liter residue on evaporation at 180 °C (table 3) and increased with depth. Values of TDS were not calculated at multiple depths using the geophysical log data because the groundwater samples indicated that TDS was too low to be accurately estimated by Archie's equation methods like those used in the TDS model of deeper portions of the Poso Creek Oil Field by Stephens and others (2021).

Accessing Data

Site information and water-level and water-quality data presented in this report can be accessed using the USGS National Water Information System (NWIS) at https://waterdata.usgs.gov/nwis/ (U.S. Geological Survey, 2022b). All discrete water-level measurements, daily minimum depths to water, and daily maximum water-surface elevations for all continuously monitored wells presented in this report are available on NWIS. In digital copies of this report, the USGS site numbers (table 1) presented in the tables are hyperlinked directly to the data on NWIS. Any updates applied to data presented in this report after publication will be available on NWIS.

Geophysical logs can be accessed through the USGS GeoLog Locator portal (https://webapps.usgs.gov/GeoLogLocator; U.S. Geological Survey, 2022c), using the USGS site number for the deepest monitoring well PCCT #1 (353229119050601). Sites with available geophysical logs can be searched by the USGS site number (table 1) or can be located using the interactive map. Lithologic samples (shaker and sieve) collected during the drilling of the multiple-well monitoring site are archived at the USGS office in San Diego, California. Photographs of the shaker and sieve samples, along with the full descriptions and notes recorded by the site hydrologist, can be accessed through the USGS GeoLog Locator. Formal requests for access to samples, field notes, or bench notes can be directed to the U.S. Geological Survey California Water Science Center.

Table 3. Water-quality indicators (field parameters) and total dissolved solids in samples collected from the Poso Creek multiple-well monitoring site (PCCT), Kern County, California (U.S. Geological Survey, 2022b).

[Wells ordered from shallowest to deepest. The five-digit U.S. Geological Survey (USGS) parameter code below the constituent's name is used to uniquely identify a specific constituent or property. Threshold type: SMCL-CA, California Department of Public Health secondary maximum contaminant level; SMCL-US, U.S. Environmental Protection Agency secondary maximum contaminant level. **Abbreviations**: mg/L, milligrams per liter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; $CaCO_3$, calcium carbonate; na, not available; *, value above threshold level; <, less than]

Common well name	Sample date	Dissolved oxygen, field (mg/L) (00300)	pH, field (standard units) (00400)	Water temperature, field (°C) (00010)	Specific conductance, field (µS/cm at 25°C) (00095)	Alkalinity, lab (mg/L as $CaCO_3$) (29801)	Total dissolved solids (mg/L) (70300)
Threshold type	na	na	SMCL-US	na	SMCL-CA	na	SMCL-US
Threshold level	na	na	6.5–8.5	na	[1]900 (1,600)	na	500
PCCT #4	10/27/2021	2.0	9.7*	24.7	208	56.4	127
PCCT #3	10/26/2021	0.110	9.5*	24.3	254	83.2	151
PCCT #2	10/27/2021	0.065	10.0*	24.0	274	111	176
PCCT #1	10/26/2021	<1.0	9.4*	25.8	325	120	211

[1]The SMCL-CA for specific conductance has recommended lower and upper threshold values. The upper value is shown in parentheses. SMCL-US from U.S. Environmental Protection Agency, 2022. SMCL-CA from California State Water Resources Control Board, 2022c.

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