Water Availability and Use Science Program

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Characterization of Subsurface Conditions and Recharge at the Irrigated Four-Plex Baseball Field, Fort Irwin National Training Center, California, 2018–20

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Abstract

The U.S. Geological Survey performed subsurface and geophysical site characterization of the irrigated four-plex baseball field in the Langford Valley–Irwin Groundwater Subbasin, as part of a research study in cooperation with the U.S. Environmental Protection Agency, the Agricultural Research Service, and the Fort Irwin National Training Center, California. To help meet future demands, the Fort Irwin National Training Center is evaluating the efficacy of gravity-fed drywells to enhance storm-water recharge into the Langford Valley–Irwin Groundwater Subbasin by bypassing fine-grained, less permeable deposits between land surface and the water table. The amount, rate, and location of recharge beneath an irrigated baseball field in the groundwater basin at the Fort Irwin National Training Center is not well understood, so data were collected using physical and geophysical techniques to characterize subsurface materials, geologic controls, and the vertical movement of water through the unsaturated zone to the water table near the drywell at the Fort Irwin National Training Center. Based on the data collected and interpreted from these techniques, several fine-grained deposits were identified. Although these deposits appear to impede the downward movement of water through the unsaturated zone locally, they are not laterally continuous, and water appears to continue to move downward when it reaches the edges of the deposits. These data will help managers evaluate recharge at the site and determine if the use of gravity-fed drywells enhances recharge from surface runoff.

Introduction

Groundwater historically has been the sole source of water supply for the Fort Irwin National Training Center (NTC). The NTC is concerned with the long-term sustainability of the underlying aquifer. To help meet future demands, the NTC is evaluating the efficacy of gravity-fed drywells to enhance storm-water recharge into the Langford Valley–Irwin Groundwater Subbasin (California Department of Water Resources, 2020), herein referred to as Irwin Basin, by bypassing fine-grained, less permeable deposits between land surface and the water table. In this report, the term “drywell” is used to describe an underground structure that collects excess surface runoff and routes the water into the subsurface to recharge the groundwater aquifer.

In the Irwin Basin, long-term sustainability of groundwater resources is uncertain because of the high demand for water and the low rate of natural recharge to the aquifer (Densmore and Londquist, 1997). Groundwater pumping from the basin resulted in water-level declines of about 30 feet (ft) from 1940 to 1996 (Densmore and Londquist, 1997; Densmore, 2003). Water levels began to recover in the late 1990s as a result of a combination of factors, including but not limited to (1) a reduction in pumping from Irwin Basin, (2) importation of groundwater from the Bicycle Valley Groundwater Basin and Langford Valley-Langford Well Lake Groundwater Subbasin, and (3) artificial recharge of treated wastewater by irrigation-return flow to the aquifer in Irwin Basin (Densmore and Londquist, 1997; Densmore, 2003).

The U.S. Geological Survey (USGS) performed subsurface and geophysical site characterization of the irrigated four-plex baseball field in Irwin Basin (fig. 1) as part of a research study in cooperation with the U.S. Environmental Protection Agency (EPA), the Agricultural Research Service (ARS), and the NTC. This site was chosen because the field has a long history of artificial recharge and an existing drywell. The goal of the research study was to evaluate the efficacy of the local use of drywells to enhance recharge to the water table and how this technique can help the NTC reach Net Zero Water sustainability goals at the NTC (U.S. Environmental Protection Agency, 2016). Net Zero Water strategy water is achieved by reducing water consumption, returning used groundwater to the same hydrological system, and enhancing groundwater recharge with stormwater runoff to prevent resource depletion and degradation over time (U.S. Environmental Protection Agency, 2016). For this project, several techniques were used to collect and analyze data to characterize subsurface conditions and downward movement of water at an irrigated field near a drywell at the NTC. The characterization will help managers evaluate the use of gravity-fed drywells and determine which techniques are most effective for monitoring movement of water through the unsaturated zone to the water table.

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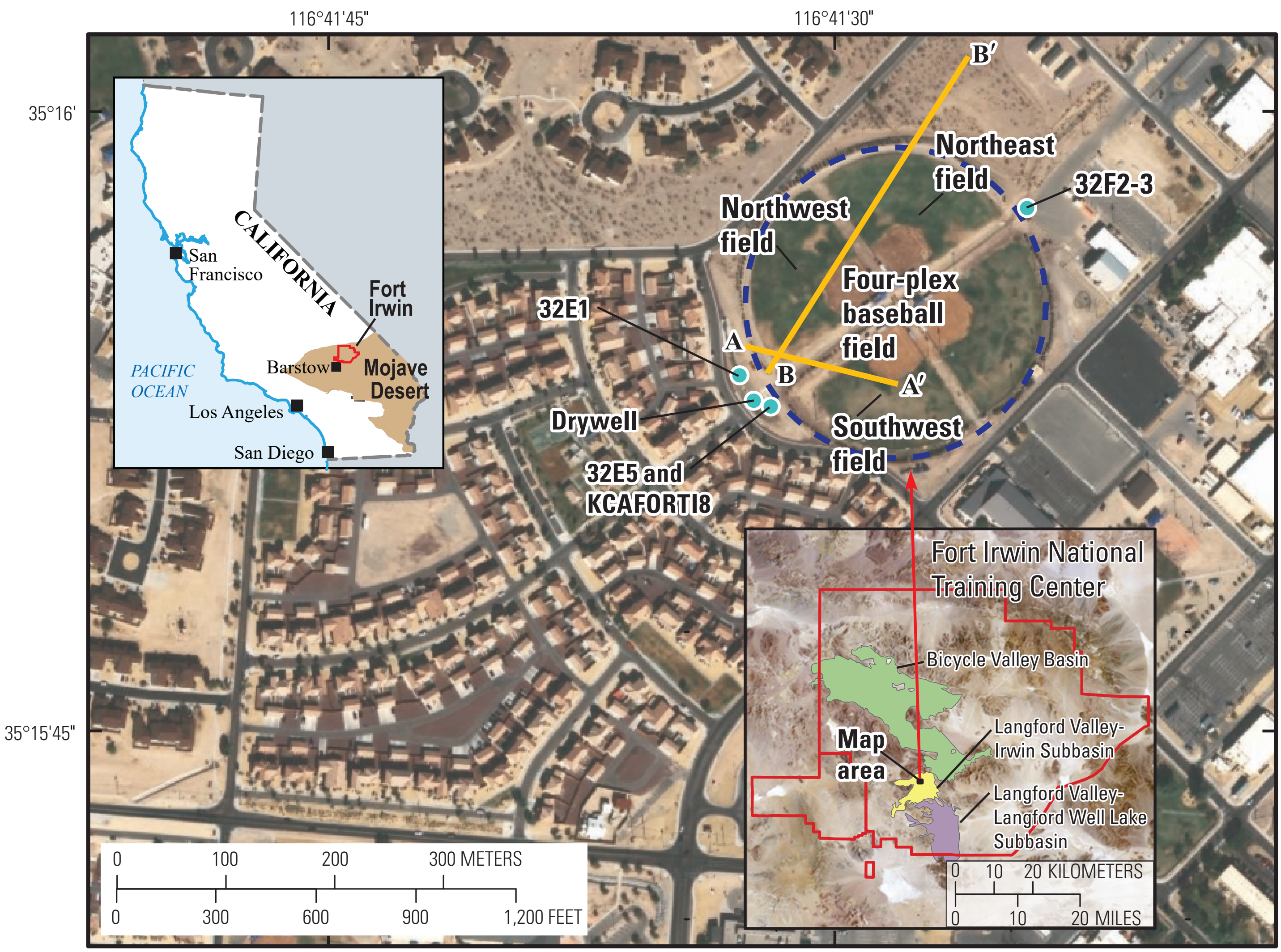
A 90-ft-deep drywell was constructed in a stormwater retention pond as part of residential housing development during 2007 (fig. 1). The lower 8 ft of the well casing was perforated to allow stormwater to recharge the aquifer while bypassing a large portion of the unsaturated zone. The drywell became plugged with sediment over time. In December 2018, the EPA and the NTC rehabilitated the drywell and deepened it to 118 ft below land surface (bls), and perforations were added to the lower 10 ft of the well casing. The EPA also installed two shallow monitoring wells adjacent to the drywell (Milczarek and others, 2020). Monitoring well 014N003E32E001S (32E1) was drilled to 157 ft bls in November 2018 in the unsaturated zone and did not reach the water table. Monitoring well 014N003E32E005S (32E5) was drilled to 240 ft bls in December 2019 and reached the water table. The wells are north and east, respectively, from the drywell (fig. 1). Borehole geophysical logs were collected to assess lithology and water content and evaluate if a fine-grained deposit identified during drilling of 32E1 and 32E5 impeded recharge of stormwater. Surface geophysical surveys were completed to assess the lateral continuity of the fine-grained deposit. These data were supplemented with borehole and water-quality data from a multiple-well monitoring site consisting of monitoring wells 014N003E32F002S (32F2) and 014N003E32F003S (32F3), which were drilled in 1994 (fig. 1; Densmore and Londquist, 1997).

This report summarizes the data collected from physical and chemical measurements on cores, borehole geophysical logs, and surface electrical resistivity tomography (ERT) surveys and characterizes the subsurface environment and movement of water through the unsaturated zone. Water-quality and water-level data presented in this report are available from the USGS National Water Information System (NWIS) database at https://nwis.waterdata.usgs.gov/nwis by searching for the USGS site name (U.S. Geological Survey, 2021b). The data from the measurements on cores, geophysical logs, and ERT surveys are available in Groover and others (2020) and Kohel and others (2020).



Base map from Google, 2015. Groundwater basins from California Department of Water Resources, 2020

Figure 1. Location of study area, the four-plex baseball field, drywell, monitoring wells 014N003E32E001S (32E1), 014N003E32E005S (32E5), 014N003E32F002S (32F2), and 014N003E32F003S (32F3), weather station (KCAFORTI8), electrical resistivity tomography (ERT) survey lines A–A′ and B–B′, and groundwater basins, Fort Irwin National Training Center, California.

Site Background

Irwin Basin is filled with unconsolidated deposits that consist of Quaternary alluvium and older late Tertiary alluvium (Densmore, 2003). The deposits are unconsolidated at land surface and become partly consolidated with increasing depth (Densmore, 2003). The unconsolidated deposits are the only water-bearing materials in the basin from which appreciable amounts of groundwater can be obtained. The Quaternary alluvium is generally more permeable than the older Tertiary alluvium and typically yields more water than the Tertiary alluvium where saturated (Densmore and others, 2017).

The climate in Irwin Basin is typical of the Mojave Desert, with hot summers, cool winters, and little precipitation. Most of the precipitation falls during the winter, with a few isolated monsoonal thunderstorms occurring during the summer. Typical of desert regions, natural recharge is mainly limited to precipitation runoff and recharge along ephemeral washes and near the base of the surrounding hills during winter rains and short summer thunderstorms (Densmore and Londquist, 1997). Historical records from the Goldstone ECHO 2, California, weather station (043498) in Goldstone Valley Groundwater Basin (not shown) from December 1, 1973, to July 31, 2006, indicate an average annual precipitation of 5.80 inches (in.; Western Regional Climate Center, 2009), but this average can vary greatly from year to year (Densmore and others, 2017). Beginning in 2012, Fort Irwin personnel have maintained precipitation records from several weather stations on the NTC (David Housman, U.S. Army, written commun., 2019). As part of the EPA study, weather station KCAFORTI8 was installed near the drywell during November 2017 (fig. 1; Weather Underground, 2019). The KCAFORTI8 station, co-located with monitoring well 32E5 (fig. 1), measured 2.53 in. of precipitation in 2018, 5.21 in. in 2019, and 4.83 in. in 2020, and averaged 4.2 in. per year.

Perennial streams are not present at the NTC. Recharge of precipitation runoff in ephemeral washes during and shortly after high-intensity or long-duration storms is the sole source of natural recharge in the Irwin Basin and is considered to be minimal (Densmore, 2003). More than 96 percent of the recharge in the basin (Densmore, 2003, table 7) is artificial and results from (1) the infiltration of irrigation water applied to lawns and playing fields that is not consumed by the plants or lost through evaporation and (2) seepage of treated wastewater disposed of in percolation ponds at the Wastewater-Treatment Facility (WWTF) in the southeastern part of the basin (not shown). Irrigation of the four-plex baseball field (fig. 1) began during 1984–85: untreated, native groundwater was pumped from the Irwin Basin, Bicycle Valley Groundwater Basin, and Langford Valley-Langford Well Lake Groundwater Subbasin (fig. 1; California Department of Water Resources, 2020). During 2010, irrigation of the baseball field switched from native groundwater to tertiary-treated recycled wastewater after an upgrade of the WWTF from secondary to tertiary treatment of wastewater during 2004–07 (Chris Woodruff, U.S. Army, oral commun., 2019). Since 2010, about 1,540 acre-feet (53 percent) of the total water used for irrigation was recycled water. Wastewater is sent to the WWTF, where some is treated and recycled for irrigation uses. In 2016, the native groundwater began being processed to drinking water standards at the Water Works drinking water treatment plant, for use as drinking water and irrigation in the residential housing areas.

Data Collection and Evaluation

To aid in the understanding of the subsurface near the drywell and four-plex baseball field, the USGS evaluated physical and chemical measurements on cores (physical-property data), borehole geophysical logs, and surface ERT surveys (surface geophysical data) during 2018–20 (fig. 1). Physical properties were measured on cores collected from boreholes during drilling and included lithology, grain size, water content, hydraulic potential, estimated porosity, and specific conductance of leachate. Geophysical logs were collected in the boreholes before the monitoring wells were constructed. Repeat logs were completed in monitoring wells, when possible. Not all monitoring wells could be logged a second time as described in the “Borehole Data” section. During drilling of monitoring well 32E5 in November 2018, consultants to the EPA observed fine-grained deposits between 105 and 120 ft bls, 15 ft below the perforations of the drywell. There was concern these deposits could potentially impede the flow of water from the drywell to the water table below, thereby reducing the efficiency of the drywell (Milczarek and others, 2020). Subsequently, surface geophysical surveys were completed to evaluate the lateral continuity of the fine-grained deposits observed during drilling.

Physical-Property Data

Continuous cores, collected from the monitoring-well boreholes drilled in 2018–19, were described visually in the field by grain size, sorting, color, and mineralogy (Milczarek and others, 2020). The cores were subsampled on site by USGS personnel for further processing using methods briefly described as follows (Kohel and others, 2020). Grain-size distributions were measured using an optical automated grain-size analyzer (Analysette 28; Fritsch Milling and Sizing Inc., 2021) with a dry dispersion unit according to manufacturer recommendations for instrument settings and operation.

Oven-dried and disaggregated samples were homogenized and split using a stainless-steel sample splitter. A subsample from each depth was measured in triplicate; 10 percent of samples were measured in triplicate on different sample splits and 10 percent were also processed using the American Society for Testing and Materials (ASTM) International method D6913 for sieve analysis (ASTM International, 2017) as a quality-assurance check. Sample controls with known grain sizes and distributions (NIST-RM 8010; National Institute of Standards and Technology, 2004) were measured daily before core sample analysis. Bulk water content was measured gravimetrically on unaltered core samples following ASTM method D2216 (ASTM International, 2019). These measurements likely underestimated site saturation because the cores were not sleeved. Additionally, the sonic drilling method is fluidless but generates heat at depth. Therefore, matric potential and bulk water content measurements were useful as relative minimum values, not absolute numbers.

Hydraulic potential in meters of head above the water table was calculated by summing the matric potential (converted from bars into meters) and the gravitational head (in meters).

Soil samples also were processed using a filter-paper technique to determine minimum matric potential following techniques described by Campbell and Gee (1986) and Deka and others (1995). Core densities adjusted for bulk water content were used to estimate porosity by dividing the dry bulk density by the average density of quartz (2.66 grams per cubic centimeter [g/cm^3]) and subtracting the resulting value from 1 (McMahon and others, 2003). Additional subsamples of the cores also were sieved and leached with distilled water. The leachate was analyzed for specific conductance and used as a surrogate for total dissolved solids to evaluate long-term downward movement of water through the unsaturated zone. These data were published in Kohel and others (2020).

Physical-property data, including lithology, indicated that beneath approximately 15 ft of fill, about 5 ft of silty sand and clay overlie coarser-grained alluvium consisting of gravelly sand with volcanic clasts from about 20 to 60 ft bls (fig. 2). Beneath 60 ft bls, fine-grained deposits interfingered with coarser-grained deposits. From about 60 to 102 ft bls, these deposits consisted primarily of silty sand with minor amounts of sand, gravel, and sandy silt and were underlain by a coarser-grained gravelly sand from about 102 to 110 ft bls. Silt, sand, clay and sandy clay to clay deposits (hereafter referred to as sandy clay deposits) were predominant from 110 to 135 ft bls. The clay content of this layer could impede downward movement of water. These sandy clay deposits were underlain by sandy gravel deposits from 135 to 160 ft bls. Fine-grained deposits consisting of silty sand and clay were predominant from 160 ft bls to the water table at about 220 ft bls.

Bulk water content (fig. 2*A*), hydraulic potential (fig. 2*B*), estimated porosity (fig. 2*C*), and specific conductance (fig. 2*D*) were used to assess the vertical movement of water in the unsaturated zone (Izbicki and others, 2000) near the drywell. In this report, bulk water content (hereafter referred to as water content) is reported as gravimetric water content (mass of water per mass of material, or grams per gram). Hydraulic potential is a summation of gravitational potential and matric potential (Hillel, 1982). The movement of the water through the unsaturated zone at well 32E5 was estimated by evaluating the water-content data measured from core material collected from the borehole during drilling. The water-content and hydraulic potential data indicate that the unsaturated zone was wet, with gravimetric water contents ranging from 0.04 to 0.19 grams per gram (g/g; fig. 2*A*), compared to other native unsaturated deposits (ranging from 0.01 to 0.13 g/g) underlying the Mojave Desert (Izbicki and others, 2000, 2002).

Hydraulic potential was plotted against a line indicating a hydraulic potential gradient equal to 1 (fig. 2*B*). Hydraulic potential measurements that plot left of the trend line are considered unsaturated and measurements that plot right of the trend line are assumed to be near saturation and will likely drain with gravity. The range in hydraulic potential data indicate gravity drainage near the well through the unsaturated zone to the water table (fig. 2*B*). Saturated conditions, where the hydraulic potential measurement was to the right of the potential line, were present intermittently at 15–40, 85, 95, 130, 140, 155, 165, 180, 185, 190, 195, and 215 ft bls. The saturated conditions may be related to irrigation patterns and percolation of daily irrigation runoff from the residential housing area into the storm drain that discharges to the drywell (Salini Sasidharan, ARS Riverside, oral commun., 2020). Sasidharan and others (2020) found that percolation from the drywell to the water table could be as short as a few months to a year if the unsaturated zone contained moisture from previous recharge and recharge remained constant. The saturated conditions observed at 140 and 190 ft bls are questionable because field notes indicate water was added during drilling to free the casing at about 145 and 190 ft bls (fig. 2*B*; Bob Rice, GeoSystems Analysis, Inc., written commun., 2019). We do not know if other depths also were wetted during drilling; however, for this study, it was assumed that water was not added at other depths.

Gravity drainage also occurred through the sandy clay deposits encountered between 115 and 135 ft bls (fig. 2*A*, *B, F*). Increases in water content below higher potential values generally coincided with finer-grained deposits. The highest water content (0.19 g/g) was at 135 ft bls, coinciding with the base of the sandy clay deposits and top of sandy gravel deposits (fig. 2*A*, *B, F*). Comparison of the higher water content above 135 ft bls with the sharp decrease in water content below 135 ft bls indicates that the entry pressure needed for downward flow through the perching layer (110–135 ft bls) likely was reached. Based on high hydraulic potential in the sandy clay, that layer is under pressure and saturated. The hydraulic potential of the sandy clay suggests the water is being held in the sandy clay due to matric potential outweighing gravitational potential, reducing gravity drainage. In contrast, the sandy gravel deposits below have a low hydraulic potential and are relatively empty, which would allow water to freely drain. Movement of water in the unsaturated zone can be inhibited when it forms films that are related to capillary (and other) pressures. When enough pressure forms in the sandy clay deposits to overcome the capillary pressure that is at the bottom of the sandy clay deposits (caused by the contrast in matric potentials), water enters the gravel layer. The highest estimated porosity of 0.51 percent was in the sandy clay deposit at 115 ft bls (fig. 2*C*). The lowest estimated porosities of 0.19 percent and 0.14 percent were in coarser deposits at 40 ft bls in the unsaturated zone and at 235 ft bls, which was below the water table.

Specific conductance of leachate (used as a proxy for dissolved solids) in the unsaturated zone can be used to estimate the long-term downward movement of water in desert regions (Izbicki and others, 2000; fig. 2*D*). Specific conductance in leachate from core samples varied with depth, ranging from 23 to 261 microsiemens per centimeter at 25 degrees Celsius (µS/cm; Kohel and others, 2020). Specific conductance in leachate generally was higher at depths with high water content (fig. 2*A*, *D*. The specific conductance and water content was high from 115–135 ft bls (261 µS/cm) where the fine-grained deposits may impede the downward movement of water. High specific conductance in leachate present in the shallow subsurface above 40 ft bls may be attributable to evaporative deposits from irrigation and a suspected caliche layer (a sedimentary rock made of hardened natural cement of calcium carbonate).

Differences in groundwater-quality data collected in 2020 from wells 32E5 and 32F3 provide further support that recharge has reached the water table beneath the baseball field. The specific conductance of groundwater collected in October 2020 from well 32E5 was 459 µS/cm. The specific conductance of potable water from the Water Works plant (used for irrigation

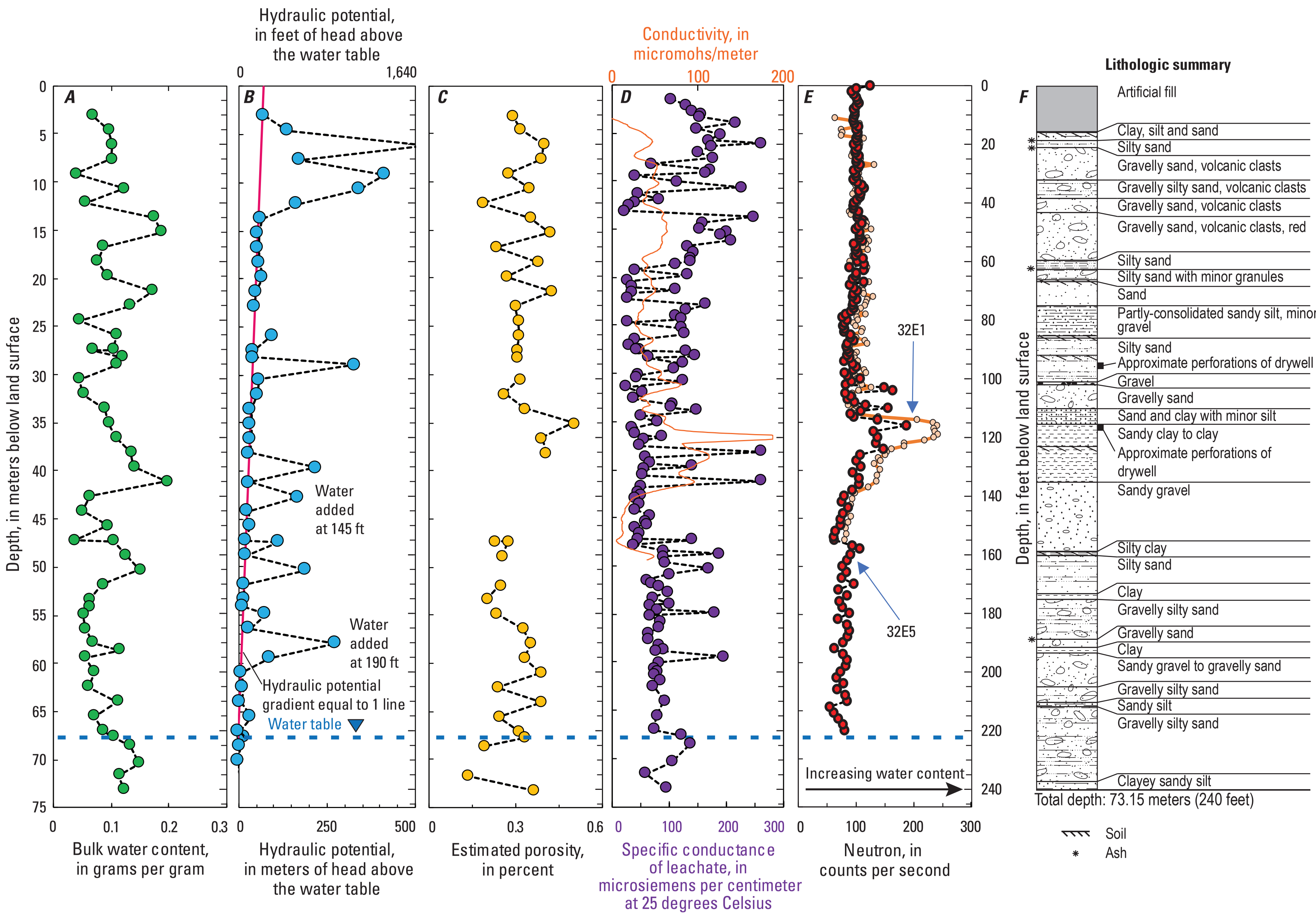


Figure 2. Physical properties and lithology determined from core samples and borehole geophysics collected during drilling of well 014N003E32E005S (32E5), Fort Irwin National Training Center, California. A, bulk water content; B, hydraulic potential; C, estimated porosity; D, specific conductance and conductivity; E, neutron logs; and F, lithology. Neutron logs collected from well 014N003E32E001S (32E1) are overlain in E.

in the housing area and baseball fields) ranged from 102 to 220 µS/cm (Edgar Ortusiastigue, Jacobs, written commun., 2019). High concentrations of tribromomethane, a byproduct of chlorination (Agency for Toxic Substances and Disease Registry, 2005), were present in groundwater from this well. The low specific conductance and the presence of tribromomethane in groundwater collected from well 32E5 (U.S. Geological Survey, 2021b) indicates that recharge likely from the drywell has reached the water table. The specific conductance in well 32E5 was much lower in comparison to specific conductance of 2,060 µS/cm in the nearest shallow USGS monitoring well (32F3). The specific conductance of recycled water (used for irrigation on the baseball fields) decreased from 1,300 µS/cm during 2015 in tertiary-treated wastewater to less than 700 µS/cm during 2017 in wastewater after the Water Works plant went online (Edgar Ortusiastigue, Jacobs, written commun., 2019). The deposits underlying the fields, having been irrigated since the 1980s (Densmore, 2003), were prewetted and receive constant recharge. Constant recharge due to prewetting allows water to move downward more quickly than in areas of intermittent recharge, thereby reducing the time for water moving through a thick unsaturated zone to reach the water table.

Geophysical Data

Geophysical data collected to assess subsurface lithology and water content included borehole geophysical logs and ERT surveys at land surface. Ideally, standard electric borehole geophysical logs (including short- and long-normal resistivity, lateral resistivity, electromagnetic resistivity, natural gamma, and spontaneous potential) are collected in the open borehole before well casing is added during construction of the monitoring well. However, the sonic drilling method used for boreholes 32E1 and 32E5 involved installation of steel casing to keep the borehole open during the drilling and construction of monitoring well 32E5, so the resistivity logs could not be collected. Therefore, only natural gamma and neutron log data were collected in boreholes 32E1 and 32E5. Natural gamma-logging tools measure background gamma radiation emitted by alluvium and rocks, whereas neutron-logging tools actively emit high-energy neutrons that are sensitive to water content (Keys and McCary, 1971). Natural gamma logs were used for the identification of lithology and stratigraphic correlation. Neutron logs were used primarily to estimate the moisture content of the deposits above the water table. In general, an increase in counts per second indicates an increase in water content. More details on these borehole geophysical methods are provided in Keys and McCary (1971). ERT tools inject an electrical current at land surface and measure the corresponding voltages. The resulting data are converted to subsurface resistivity, which is correlated with water content, lithology, and conductivity of pore fluids (Archie, 1942; Biella and others, 1983).

Borehole Data

Borehole geophysical data (gamma and neutron logs) were collected immediately after the boreholes were drilled whenever possible. Natural gamma and neutron logs were run in borehole 32E1. A natural gamma log was attempted in borehole 32E5 during December 2019 before the well was constructed, but equipment problems prevented collection. A repeat visit was done in February 2020 to collect follow-up geophysical logs, but a bend in the well casing of well 32E5 at about 10 ft bls obstructed the geophysical tools and repeat geophysical logs could not be collected from well 32E5. During the site visit on February 5, 2020, an electromagnetic (EM) induction log was collected in well 32E1, and an electric log (including EM induction, fluid resistivity, and natural gamma logs) was collected in the nearest USGS monitoring well (32F2). The logs collected from wells 32E1, 32E5, and 32F3 in 2019 and 2020 are published in a Groover and others (2020). The logs collected from wells 32F2 and 32F3 in 1994 are available from the USGS GeoLog Locator (U.S. Geological Survey, 2021a).

As previously stated, neutron logs are sensitive to soil water content. Neutron logs collected at wells 32E1 and 32E5 indicated increased moisture in the sandy clay deposits consistent with a perched layer at about 110 ft bls (fig. 2*E*). The natural gamma log of borehole 32E1 indicated a decrease in counts per second and shift to the left between 105 and 110 ft bls, and the EM induction log of borehole 32E1 indicated a high conductivity layer at 110 ft. The EM induction log of well 32F2, collected in February 2020 (fig. 3), indicated a high conductivity (low resistivity) layer at about 100 ft bls that may indicate fine-grained deposits saturated with relatively high conductivity water. However, water-quality data or core data from the unsaturated zone at this well are not available to test this hypothesis. Geophysical logs (short- and long-normal resistivity) collected from well 32F2 in 1994 (Densmore and Londquist, 1997) indicated lower resistivity at a depth of about 100 ft bls, but analyses of drill cuttings compiled over 20-ft depth intervals did not identify this relatively thin fine-grained deposit (fig. 3).

Electrical Resistivity Tomography Data

After lithologic data and borehole geophysical logs indicated the presence of a fine-grained perching deposit in well 32E1, ERT data were collected on the four-plex baseball field during 2019–20 to evaluate the spatial extent of this fine-grained deposit and guide placement of well 32E5. A SuperSting R8 resistivity/induced polarization meter (Advanced Geosciences, Inc., 2011) was used to collect the ERT data by injecting a known current into the subsurface through electrodes and then measuring the voltage difference between the electrodes (fig. 4). Data about lateral variability in the subsurface were obtained through different electrode configurations across the transect. Likewise, data about greater depths were obtained by increasing the spacing between transmitter and receiver electrodes. More details on these ERT methods are provided in Zohdy and others (1974). The resistance data were converted to apparent resistivity by using geometric factors specific to the electrode configuration. Resistivity structure was determined through numerical inversion of the measured data using EarthImager 2D 2.4.4 build 649 (Advanced Geosciences, Inc., 2011). The electrical resistivity is a function of the lithology, water content, and the concentration of dissolved solids in the pore fluid of the unsaturated materials. Thus, repeat resistivity measurements may provide information about the downward and lateral movement of water through the unsaturated zone with time.

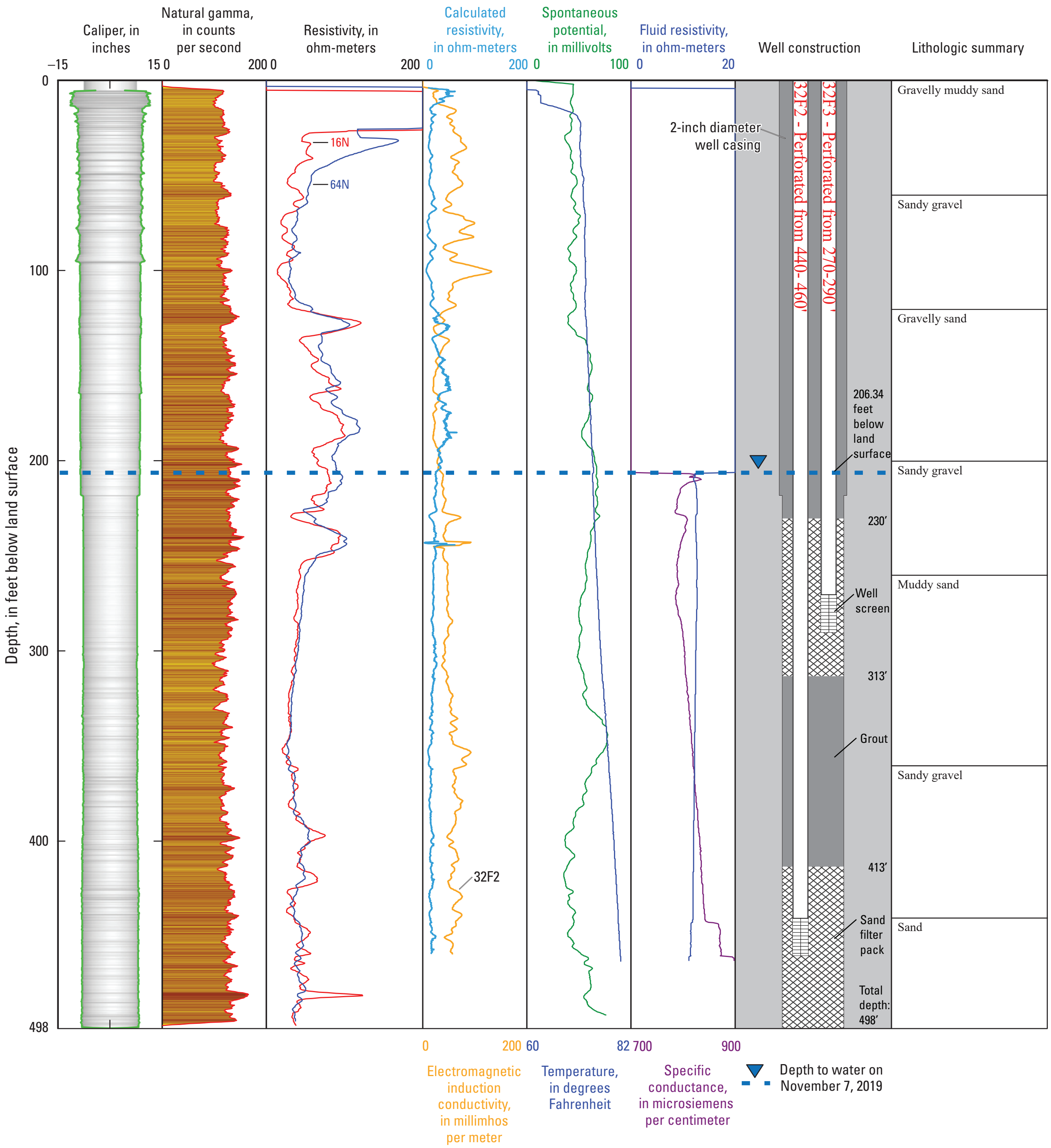


Figure 3. Well construction, lithologic summary, and geophysical log data from multiple-well monitoring site 32F2-3 before well construction, 1994, and electromagnetic induction log from monitoring well 32F2 collected February 5, 2020, Fort Irwin National Training Center, California. (Abbreviations: 16N, 16-inch normal; 64N, 64-inch normal).

The ERT data were collected during July 2019 and February 2020 to assess moisture changes from summer to winter months (figs. 1, 5*A*, *B*). Because of the grading of both northern fields, a repeat ERT survey could not be completed along the northeast trending line in February. The data and inverted resistivity models are published in Groover and others (2020). For simplicity, in this report the two ERT survey lines are referred to as lines A–A' and B–B' (figs. 1, 5*A*, *B*, 6). Line A–A' transects from near the drywell across the baseball fields toward the southeast, and line B–B' transects from near the drywell across the northern baseball fields toward the northeast. Where possible, the final inverted resistivity cross sections were annotated with preliminary geologic interpretations based on field observations made during this study.

The ERT data indicated that subsurface deposits were highly variable and that fine-grained layers are not laterally continuous. Comparison of line A–A' (figs. 1, 5*A*, *B*) from July 2019 (fig. 5*A*; Groover and others, 2020) with the repeat line from February 2020 (fig. 5*B*; Groover and others, 2020) indicated that the near surface of the fields and the berms between the fields became drier (more resistive, warm colors) in February, whereas a caliche layer, resulting from evaporation of irrigation water on the fields, at about 5–15 and 30–40 ft bls (between line distance 118 and 157 ft) became moister (conductive, cooler colors; figs. 5*A*, *B*). The northwest field and berms between the fields became more resistive than the southeast field in February 2020. The fields are irrigated year-round; however, the increase in resistivity may reflect a decrease in irrigation of the northern fields during the winter. Irrigation of the southern fields continued during the winter. During July 2019, 11 acre-feet of irrigation was applied on the fields, whereas during February 2020, only 1 acre-foot of irrigation was applied on the fields (Edgar Ortusiastigue, Jacobs, written commun., 2020). During data collection in February 2020, the grass of the northwest and northeast fields was being removed, and only the southern fields were being irrigated.

Figure 4. Example of a deployed electrical resistivity tomography (ERT) computer and electrode array. Photograph by the U.S. Geological Survey.

Line B–B' indicated that sediments at depth under the northeast field had higher conductivity (lower resistivity, cooler colors) than the sediments at depth under the northwest field during July 2019, which indicates there was more moisture under the northeast field (fig. 6). Two wet zones observed under the northeast field, as indicated by the less resistive, blue-colored sediment beneath the edges of the grass of the northeast field (near 394 ft and between 591 and 689 ft line distance), indicated the downward movement of water. This observation indicated that fine-grained deposits are not laterally continuous and allow water to move downward to the water table. Downward movement of water appeared to be hampered beneath the northwest field by a fine-grained deposit (perching layer) observed in wells 32E1 and 32E5 (Groover and others, 2020). Additionally, the perching layer in line B–B' appeared to pinch out, which indicates the presence of a possible fault between the northeast and northwest fields. This interpretation is supported by a difference in water levels between wells 32E5 and 32F2-3. The wet zone apparent beneath a dry channel north of the fields indicated that recharge occurred along the wash as a result of intermittent runoff. However, a horizontally oriented continuous zone of increased moisture (cooler colors) was not observed in line B–B'. Therefore, the perching layer observed at borehole 32E5 (sandy clay deposits between line distance 110 to 135 bls) does not appear to be present or to restrict downward flow beneath this part of the baseball fields (fig. 6).

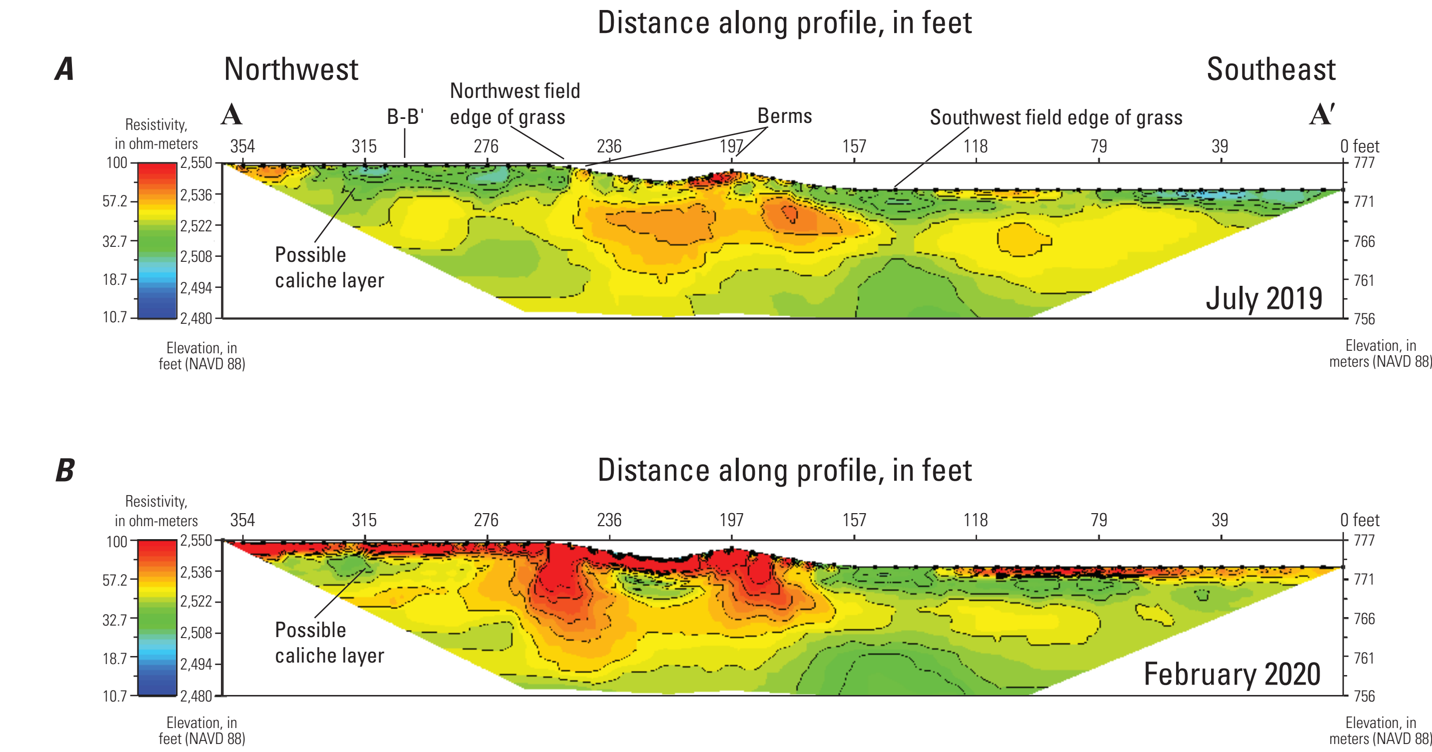


Figure 5. Inverted electrical resistivity data, in ohm-meters, collected along electrical resistivity tomography line A–A′ across the four-plex baseball field, Fort Irwin National Training Center, California. *A*, summer (July 2019; L3IS0718, Groover and others, 2020); and *B*, winter (February 2020; F1IS0204, Groover and others, 2020). Line of transect shown in figure 1. Warmer colors indicate more resistive (or drier) materials; cooler colors indicate more conductive (or wetter) materials. [Abbreviation: NAVD 88; North American Vertical Datum of 1988]

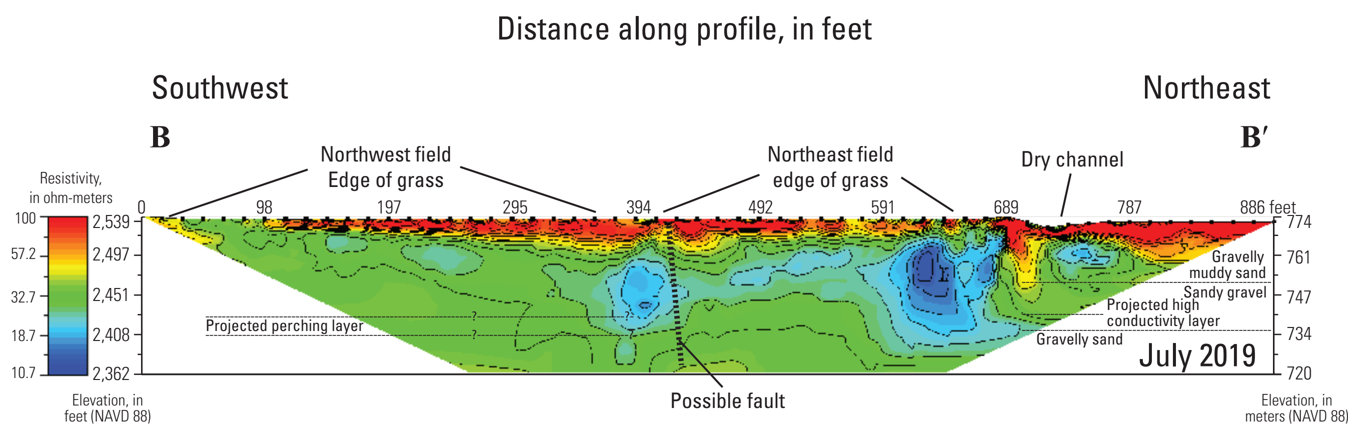


Figure 6. Inverted electrical resistivity data, in ohm-meters, collected along electrical resistivity tomography (ERT) line B–B′ (July 2019; L1IS0717; Groover and others, 2020) across the four-plex baseball field, Fort Irwin National Training Center, California. Location of transect shown in figure 1. Warmer colors indicate more resistive (or drier) materials; cooler colors indicate more conductive (or wetter) materials. [Abbreviation: NAVD 88; North American Vertical Datum of 1988]

Summary

The U.S. Geological Survey performed subsurface and geophysical site characterization of the irrigated four-plex baseball field in Langford Valley–Irwin Groundwater Subbasin, as part of a research study in cooperation with the U.S. Environmental Protection Agency, the Agricultural Research Service, and the Fort Irwin National Training Center, California. Data were collected using physical and geophysical techniques to characterize subsurface materials and the vertical movement of water through the unsaturated zone to the water table at the irrigated four-plex baseball field near the drywell at Fort Irwin. Physical-property data and lithologic logs from drilling indicated that beneath about 15 feet (ft) of fill, about 5 ft of silty sand and clay overlie coarser-grained alluvium consisting of gravelly sand with volcanic clasts from about 20 to 60 ft below land surface (bls). Beneath 60 ft bls, fine-grained deposits interfinger with coarser-grained deposits but generally become finer with depth. Fine-grained deposits from 110 to 135 ft bls consisting predominantly of sandy clay impede downward movement of water. In this depth interval, the water-content and hydraulic potential data indicated that the unsaturated zone was wet compared to other native unsaturated deposits underlying the Mojave Desert. Saturated conditions may be related to irrigation patterns and daily irrigation runoff from the housing area into the storm drain that discharges to the drywell.

The range in water content and hydraulic potential data measured in core samples collected from nearby wells indicated that gravity drainage occurs near the drywell through the unsaturated zone to the water table. The highest water content and specific conductance were at 135 ft bls and coincided with the base of the sandy clay deposits and the top of underlying sandy gravel deposits. The highest estimated porosity was at 115 ft bls in the sandy clay deposits. The lowest estimated porosities were in coarser deposits at 40 ft bls in the unsaturated zone and at 235 ft bls, which was below the water table Specific conductance in leachate from core samples varied with depth, ranging from 23 to 261 microsiemens per centimeter at 25 degrees Celsius. Specific conductance in leachate generally was higher at depths with high water content and may be related to prior irrigation practices that may concentrate salts at depth or recharge from the drywell.

Geophysical data indicated that subsurface deposits are highly variable and fine-grained layers are not laterally continuous. The neutron logs of wells 32E1 and 32E5 indicated increased moisture in the sandy clay deposits consistent with a perched layer at about 110 ft bls. The electromagnetic induction log of well 32F2 indicated a high conductivity (low resistivity) layer at about 100 ft bls that could be caused by the presence of fine-grained deposits saturated with relatively high conductivity water. Electrical resistivity tomography (ERT) line A–A' that started near the drywell and trends southeast across the baseball fields indicated the near surface of the fields became more resistive and drier in February 2020, whereas a caliche layer became more conductive and moister. The northwest field became more resistive and drier than the southeast field in February. ERT line B–B' that started near the drywell and trends northeast across the northern baseball fields indicated that the northeast field had higher conductivity (lower resistivity) and was moister than the northwest field during July 2019.

Downward movement of water appears to be hampered beneath the northwest field by fine-grained deposits. A wet zone also was apparent beneath a dry channel north of the fields, indicating that recharge occurred along the wash. Although neither of the ERT lines reached the water table, the water content and hydraulic potential data are consistent with water movement in the unsaturated zone toward the water table beneath the field. The water-content and hydraulic potential data indicated that the unsaturated zone was wet. The hydraulic potential data indicated gravity drainage near monitoring well 32E5 through the unsaturated zone to the water table, with saturated conditions present intermittently at 15–40, 85, 95–100, 130, 140, 155, 165, 180, 185, 190, 195, and 215 ft bls. Differences in water-quality data collected in 2020 from wells 32E5 and 32F3 provide further support that recharge has reached the water table beneath the baseball field.

Study results indicated that the subsurface deposits near the drywell are variable with interlayered fine- and coarse-grained deposits. Based on the physical-property and geophysical data, the downward movement of water at the drywell and monitoring wells 32E1 and 32E5 appears to be impeded by fine-grained deposits. However, the ERT data indicate these fine-grained deposits have limited lateral extent. Water in the subsurface above the water table likely moves laterally to the edge of the fine-grained deposits, allowing downward movement of water, and is consistent with the water content, hydraulic potential, and water-quality data.

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Banner: An out of service armored personnel carrier on a hill overlooking Fort Irwin. Photograph by Meghan Dick, U.S. Geological Survey, November 3, 2021.

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