Geophysical Logging to Determine Construction, Contributing Zones, and Appropriate Use of Water Levels Measured in Confined-Aquifer Network Wells, San Luis Valley, Colorado, 1998–2000

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Abstract

Geophysical logs were recorded in 32 wells in the confined-aquifer monitoring well network maintained by the Rio Grande Water Conservation District. Logging results were used to determine well construction, zones contributing water to the wells, and the purposes for which the ground-water levels measured in the wells can be used. The confined-aquifer well network consists of 42 flowing and nonflowing wells. This network consists of wells used to supply water for irrigation, household use, wildlife refuge supply, and stock use, and wells for water-level monitoring. Geophysical logs recorded in the wells included video, caliper, water specific conductance, water temperature, and water flow. Most wells in the confined-aquifer well network yield a composite water level representing water levels in multiple permeable zones in the confined-aquifer system of the San Luis Valley. A potentiometric-surface map constructed using November 2000 water levels indicates that water levels from most wells in the network are correlated with water levels from nearby network wells. Potentiometric-surface maps that are constructed from water levels measured in most of the wells in the network can be used to understand long-term local and regional changes in water levels in the confined-aquifer system. Water levels measured in 8 of the 42 wells in the confined-aquifer network are not representative of water levels in the confined-aquifer system.

INTRODUCTION

The San Luis Valley in south-central Colorado is a high-elevation valley with an average elevation of about 7,700 feet (ft) above sea level and an area of about 3,000 square miles (Hearne and Dewey, 1988). Much of the central portion of the valley is used for agriculture, which is irrigated with diverted surface water and by ground water that comes from an unconfined aquifer and a confined-aquifer system.

Ground-water levels and the potentiometric head (head) in the confined-aquifer system are measured in 42 wells in the San Luis Valley (fig. 1) by the Rio Grande Water Conservation District in cooperation with the U.S.Geological Survey (USGS). This confined-aquifer well network (CAWN) includes flowing and nonflowing wells and consists of irrigation, household, wildlife refuge supply, stock use, and monitor wells. Water levels are measured in flowing wells by stopping the flow at the surface (shut-in), measuring the pressure in the well with a transducer, and converting the pressure measurements to water level above land surface. Water levels are measured manually in nonflowing wells with an electric or steel tape. Many of the wells are open to multiple permeable intervals of the confined-aquifer system.

Because the construction of many of the wells in the CAWN was not known or the integrity of the well casings may have degraded since construction, the USGS, in cooperation with the Colorado Division of Water Resources and Colorado Water Conservation Board, began geophysical logging of the wells to document well construction, determine the zones contributing water to the wells, and determine the applicability of water levels measured in each well for understanding the hydrology of the confined-aquifer system.

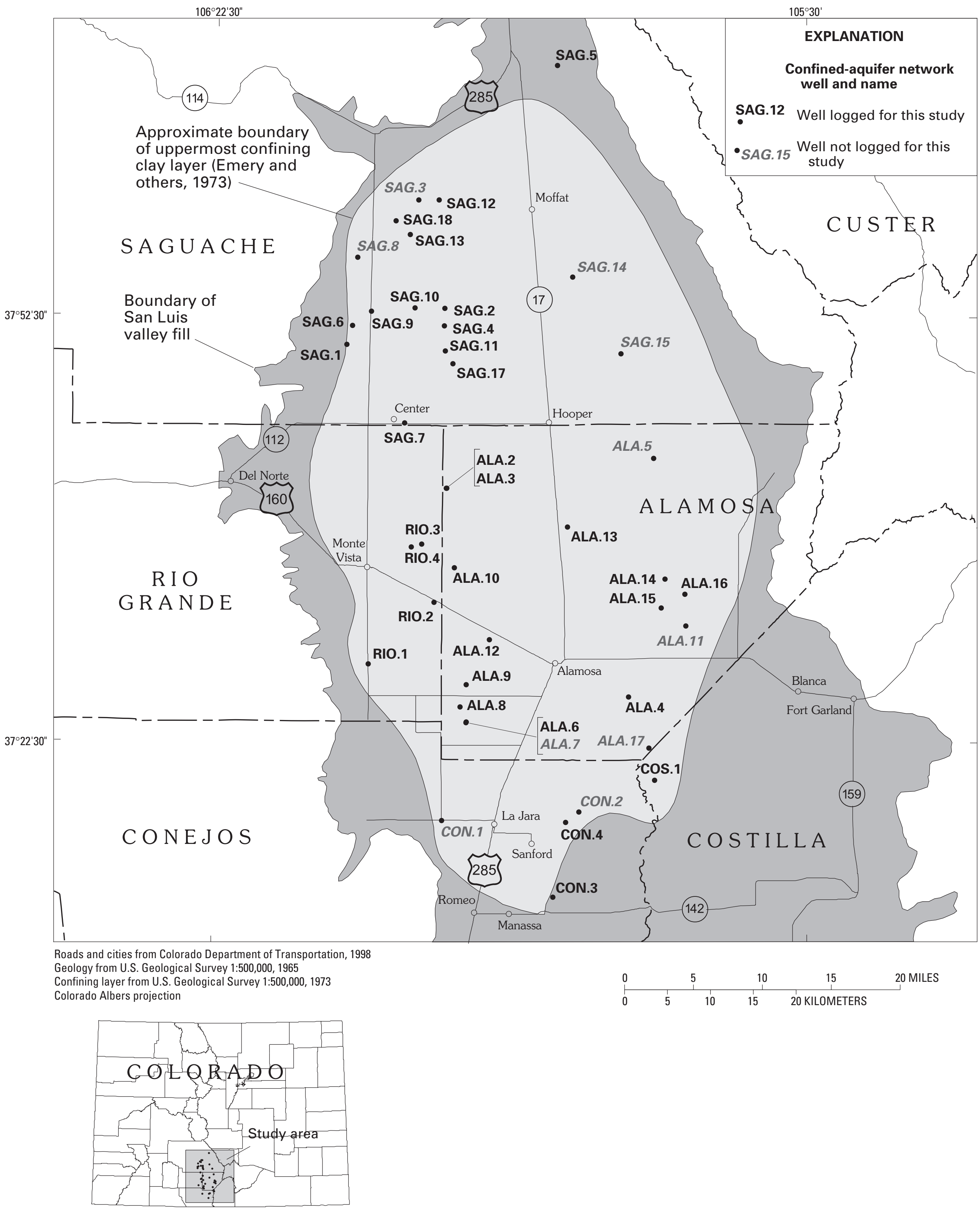


Figure 1. Location of study area and confined-aquifer network wells.

Purpose and Scope

This report describes the results of geophysical logging in 32 wells in the CAWN from September 1998 through May 2000. Logs from one well (SAG.6) yielded inconclusive information that is not described in this report. Logs recorded or attempted to be recorded in wells were video, caliper, water specific conductance, water temperature, and water flow. This report describes well construction and generalized lithology, where available. Logs recorded in each well are discussed and correlations between the logs for a well are made to determine the zones that contribute water to the well. This report also provides an evaluation of the applicability of water levels measured in each well for understanding local and regional changes in the potentiometric surface in the confined-aquifer system of the San Luis Valley in south-central Colorado.

Acknowledgments

The author is grateful to the individual well owners and the Rio Grande Water Conservation District for allowing and facilitating access to the CAWN wells for geophysical well logging and to Michael Haley of the USGS for obtaining logs in the wells. Thanks are also given to Ken Watts and Fred Paillet of the USGS for assistance in data interpretation.

GEOHYDROLOGIC SETTING

The San Luis Valley occupies a structural basin in south-central Colorado bounded by igneous, metamorphic, and sedimentary bedrock. The basin contains valley fill that consists of interbedded deposits of sand, clay, gravel, and some layers of volcanic rocks (Robson and Banta, 1995). The valley fill, which can be as much as about 30,000 ft thick, is thinnest on the margins of the San Luis Valley and thickest in the center of the valley (Gaca and Karig, 1966). Most of the water produced by wells in the San Luis Valley comes from the upper part of the valley fill (Powell, 1958; Hearne and Dewey, 1988).

Two aquifers exist in the valley, the unconfined aquifer and the confined-aquifer system, separated by a fairly extensive confining unit composed of a series of clay layers and unfractured volcanic rocks. The confined-aquifer system consists of several alternating aquifer and confining layers rather than a single aquifer layer and is thus referred to as the "confined-aquifer system" (Hearne and Dewey, 1988).

The clays of the confining layer are referred to as the "blue clay" by local well drillers and as the "clay series" by Emery and others (1973). Many lithologic logs identify the clay series by its bluish color, although the clays are not necessarily a bluish color in all locales. The upper confining layer lies at depths from 20 to greater than 100 ft throughout the central part of the San Luis Valley, with the deepest occurrences of this layer on the eastern side of the valley and in the vicinity of Center (fig. 1) (Emery and others, 1973).

The confined-aquifer system consists of varying combinations of mostly interbedded clay, sand, and gravel. Previous studies have not identified a continuous confining layer that separates an upper confined aquifer from a lower confined aquifer. The interbedded layers of the confined-aquifer system are limited in lateral extent and vary considerably in their hydraulic properties (Hearne and Dewey, 1988).

Generally, recharge to the confined-aquifer system occurs at the perimeter of the valley and discharge occurs in the central portion of the valley (Hearne and Dewey, 1988). Wells completed in the confined-aquifer system have a water level that lies above the bottom of the confining unit between the unconfined aquifer and the confined-aquifer system. Water levels in some wells completed in the confined-aquifer system are above land surface (flowing), and in other wells the water level is below land surface (nonflowing).

The geothermal gradient in the San Luis Valley varies throughout the valley. The average geothermal gradient in the central portion of the valley, where most wells are located, is approximately an increase of 3.17 degrees Fahrenheit (^{o}F) per 100-ft increase in depth (Repplier and Fargo, 1981).

WATER LEVELS AND HEADS IN THE CONFINED-AQUIFER SYSTEM

The water level in a well penetrating a confined aquifer defines the elevation of the potentiometric surface at that point. The potentiometric surface represents the hydrostatic pressure level, or head, in the aquifer (Todd, 1980). The sum of three head components contribute to the total head in an aquifer: pressure head, elevation head, and velocity head. In a static water column within a well, the total head at a depth of 800 ft equals the total head at a depth of 1,500 ft because although the pressure head is greater at 1,500 ft, the elevation head is greater at 800 ft. When the component of velocity head is introduced, as in a flowing well, the total head can be greater at 800 ft when the lithologic layers at that depth are more permeable than layers at 1,500 ft, allowing water to flow at a higher velocity out of the layers at 800 ft (Fetter, 1988). Thus, under flowing conditions, a head difference caused by the addition of the velocity head can occur. When flow from the well is turned off and the water column again becomes static (shut-in), the total head at 1,500 ft is likely to be higher than the total head at 800 ft because of the greater loss of water and, thus, pressure in the layers at 800 ft. Water can then flow within the shut-in well from the layers at 1,500 ft and into the layers at 800 ft (interzonal flow) to equalize pressures among the layers. After a sufficient amount of time, the heads in the permeable layers may equalize and flow will stop or the heads may remain different and interzonal flow from one layer to the others will continue through the well.

The water levels in the confined-aquifer system can vary with depth depending on factors, such as pumpage or wells left open and flowing, that can cause head differences between different zones in the aquifer. The water level in wells open to multiple aquifer layers or a long interval of the confined-aquifer system is a composite head measurement (Domenico and Schwartz, 1990). If the water levels, or heads, differ in each of the aquifer layers open to a well, then the measured water level will represent a composite head and equal some intermediate value between the highest and lowest heads in the aquifer layers. If heads do not differ in aquifer layers open to a well, then the composite head is equal throughout the open intervals.

DESCRIPTION OF WELL LOGS

Several types of well logs were used to determine the construction of wells, the lithologic units penetrated by wells, and the zones contributing water to wells in the CAWN. Driller's logs, from which a generalized description of the lithologic layers penetrated by a well was determined, were obtained from the Colorado Division of Water Resources in Denver. Geophysical logs were recorded by the USGS by lowering various tools attached to the end of a cable into each of the wells. These tools included a well video camera, a caliper (to measure the inside diameter of a well), a water specific-conductance meter, a water temperature meter, and a flowmeter. The logs were recorded as a digital signal at the surface and were later printed on strip charts and plotted on graphs for analysis.

Natural gamma logging typically is used to aid in delineating permeable and nonpermeable lithologic units (Keys, 1990). Gamma logs were recorded in most of the wells in the CAWN, but the traces of these logs did not indicate responses typical of the various lithologies such as clay or sand. This likely is due to several factors: (1) most of the boreholes for these wells are larger than 8 inches in diameter, which might cause attenuation of the natural gamma signal, (2) the lithologies present in the San Luis Valley are not high in natural gamma radiation, or (3) the lithologies that typically emit higher natural gamma (for example, clays) are interspersed within lithologies that do not emit high natural gamma (for example, sand and gravel) thus dampening the gamma response. The large diameters of most wells in the CAWN likely cause the natural gamma signal to be difficult to detect with the logging tools used.

Logging with each of the tools was attempted in most wells. One well was not logged with the flowmeter because there was a possibility of getting the flowmeter stuck in the well. Logs were recorded in some wells but not used in the analysis because the logs did not provide information useful for this study. Thus, the same logs are not shown for all wells in the figures that show all logs for each well (figs. 3, 4, 6–26, 28, 30–36).

Driller's Log (generalized lithology). The driller's log shows the lithologic layers that were penetrated during drilling. The depths to layers and the compositions of the layers are not as exact a representation of lithologies as a continuous core sample would provide. This is because the determination of lithologic character is made (1) by the response of the drilling apparatus to the differing lithologies penetrated during drilling, and (2) by viewing cuttings that reach the surface fairly pulverized and delayed in time from when they were reached by the drilling apparatus. There were many different lithologic descriptions among the logs obtained for the CAWN wells. Each description differed according to the particular driller's method of describing the lithologies. Thus, to simplify use of the driller's logs, the many lithologic descriptions were generalized to four different lithologic types based on the expected permeabilities (fig. 2): (1) permeable—composed of sand, gravel, cobbles, and so forth, or a combination of these types of deposits; (2) nonpermeable—composed of clays; (3) mostly permeable with some nonpermeable character—mostly sand or gravel with a nondominant clay component; and (4) mostly nonpermeable with some permeable character—mostly clay with a nondominant sand or gravel component.

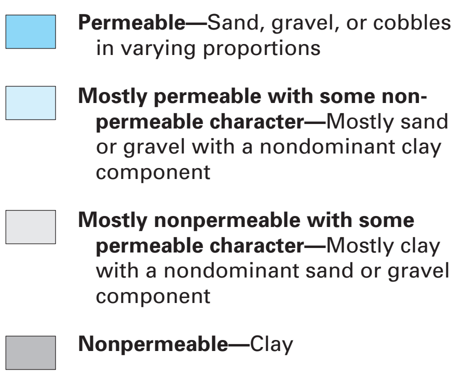


Figure 2. Explanation of colors representing generalized lithologic types (figs. 6, 7, 10, 12, 15, 19, 20, 22–25, 30–32, 34, and 35).

Other layers may exist within each of the generalized layers, such as a description on a driller's log of "sand and clay and gravel." This description would be generalized to being sand or gravel with some clay. Neither the driller's log nor this generalization might delineate layers that are relatively thin but which are hydrogeologically significant in affecting groundwater flow.

Video Log. Videotapes of each well were recorded by using a well video camera designed to be used in wells and submerged in water. The well video camera was useful for determining casing integrity, locating torch-cut slots or well screens, verifying well construction, and detecting the presence of corrosion or colonies of iron bacteria on the casing walls. Only the video observations of torch-cut, saw-cut, or stainless-steel screened intervals are plotted in the figures for each well. In some wells, torch-cut slots or casing perforations may have been obscured due to the extent of corrosion or colonies of iron bacteria.

Caliper Log. The caliper log is a continuous record of the inside diameter of a well casing or borehole (the uncased part of a well). Many wells in the San Luis Valley are constructed with several diameters of casing pipes. The uppermost pipe typically is referred to as the "surface casing," and the lower (normally smaller diameter) pipes are referred to as "liners." The caliper tool is used to measure the inside diameter of well casing, to detect changes in casing diameter such as at the top of a liner, and to locate the bottom of the casing in wells that are not cased the entire length of the borehole. Several wells measured for this study had at least some of the borehole left uncased. The inside diameter of some wells recorded on the caliper logs was affected by thick accumulations of corrosion or iron bacteria. These thick accumulations cause the trace of the caliper log to be irregular rather than smooth, as would be expected for a clean well casing.

A caliper log was not recorded in several wells due to difficulties in getting past the tops of liners. In these cases, the trace of the caliper log shown in the figures was constructed from the reported well diameters and the video observations.

Water Specific-Conductance Log. The specific conductance of water is a measure of the ability of water to conduct an electrical current. Typically, an inflection will be observed in the specific-conductance log where water enters the well. The specific conductance in the water in a well is related to the concentration of dissolved solids in the water. As the dissolved-solids concentration increases in the water, the specific conductance of the water increases. Changes in dissolved solids and, thus, specific conductance can occur as water from different zones with different dissolved-solids concentrations enters the well. Specific-conductance logs were recorded in flowing wells under free-flowing conditions and in nonflowing wells under pumped and static conditions.

Water-Temperature Log. The trace of the water-temperature log is similar to the trace of the water specific-conductance log. An inflection is seen in the temperature logs as water with different temperatures from different zones in the aquifer mixes in the well. Because of the geothermal gradient of the San Luis Valley, water from different depths in the confined-aquifer system can have different temperatures, usually increasing temperature with greater depths in the aquifer. These natural, measurable temperature differences are useful in helping to define zones of inflow to the well and to verify or assist in interpretations of results from other logs. Temperature logs were recorded in flowing wells under free-flowing conditions and in nonflowing wells under pumped and static conditions.

Well-Flow Log. The well-flow log is a measure of the velocity or rate of flow through a flowmeter at each depth for which a measurement is recorded. Flow in the well can be recorded as a continuous profile (trolling log) or as point measurements at specific depths (stationary measurements). Inflections in this log indicate either increasing flow (an inflection to the right) or decreasing flow (an inflection to the left) in the well.

Two types of flowmeters were used to record data: (1) an electromagnetic (EM) flowmeter and (2) a spinner flowmeter. The EM flowmeter measures the velocity of flow by applying a magnetic field to the water and measuring the distortion of the magnetic field caused by water moving through the detector section of the tool. The manufacturer of the EM flowmeter reports its measurement range as 0.3 to 260 feet per minute (ft/min), making it useful for measuring a wide range of flow velocities, including flow at very slow velocities. The spinner flowmeter has a propeller, mounted in a protective housing, that spins in proportion to flow velocity. The manufacturer of this flowmeter reports its measurement range as 9.75 to 200 ft/min. The spinner flowmeter was used in three wells because the EM flowmeter was not available.

The free-flowing trolling EM flowmeter measurements in four wells exceeded the manufacturer's recommended maximum measurable flow of 260 ft/min. The free-flowing trolling flowmeter logs that were recorded in two of those wells appear to reasonably represent the changes in flow in the wells because the shut-in stationary flow logs (within the measurement range of the flowmeter) showed the same profile as the measurements that exceeded the flowmeter's limits.

One of the difficulties in obtaining accurate flowmeter measurements in the CAWN wells is the possibility that many of the wells may have annular spaces (the space between the borehole and the casing pipe) that are not completely sand or gravel packed. Many videos of the CAWN wells show a lack of packing in the annular space through many of the torch-cut slots that were sufficiently open to allow a view of the borehole wall behind the well casing. If the annular spaces are open or not completely packed, vertical flow may occur between the well casing and the borehole wall. An open annular space would cause the effective cross-sectional area of a well to increase, depending on whether annular flow was occurring. The trace of the flowmeter log would indicate outflow from a well as flow entered the annular space and inflow to the well as flow went from the annular space into the well casing. Flow in the annular space of a well would make the smaller inflections in a flowmeter trace difficult to interpret. Therefore, the analysis of the flowmeter data is qualitative rather than quantitative because a quantitative analysis is not possible in poorly constructed wells.

Flowmeter measurements were recorded at two flow rates: free-flowing and shut-in in flowing wells, or pumped and static water column in nonflowing wells. The rate of natural flow in fully open flowing wells or the highest pumping rate that was obtainable for nonflowing wells ranged from less than 10 gallons per minute (gal/min) to more than 1,000 gal/min. Except for one well, the shut-in and static water-column flowmeter logs were always recorded immediately after the free-flowing or pumped flowmeter logs were recorded. The shut-in measurements were recorded a day after the free-flowing measurements were recorded in well SAG.2. Logging the wells under free-flowing or pumped conditions allowed the identification of the predominant flow zones in each well. Shut-in measurements were recorded with flow from each flowing well almost entirely closed off. Shut-in measurements were obtained to detect head differences between flow zones that may exist naturally in the aquifer or because of preferential flow during free-flow conditions resulting in lowered pressures in more permeable zones. Flowmeter measurements recorded under conditions of no pumpage in the static water column of nonflowing wells, did not indicate interzonal flow.

Flowmeter measurements were obtained at different flow rates with the flowmeter being lowered down a well (trolling) or with the flowmeter stationary within the well. Not all the flowmeter logs were recorded successfully because of the variability of conditions in the wells. The objective in attempting to record trolling and stationary flowmeter logs in each well was to obtain as much useful information as possible to be able to decide which logs were most instructive in delineating flow conditions in each well.

Well flow recorded on the logs is the flow that passes through the measurement section of the flowmeter. A flow-diverting skirt can be used to concentrate all flow in a well through the measurement section of the flowmeter when flows are small. Flow-diverting skirts were not used during this study because (1) the diameter of most wells in the CAWN is too large to successfully use a skirt, (2) discharges under free-flowing conditions were too large to allow the use of a skirt, (3) the annular space of many wells appeared to lack gravel or sand packing that potentially could allow flow to bypass the casing and occur in the annular space, (4) the tops of some well liners were bent, or (5) the inside of most wells is rough, reducing the effectiveness of the skirt.

Flowmeter data plotted in the figures showing all well logs for a well are shown in gallons per minute or feet per minute, as measured through the measurement section of the flowmeter. Stationary and trolling flowmeter measurements were selected for presentation in the figures, based on which logs showed clearly definable information about flow zones within the wells. These flow measurements are used to identify zones of inflow rather than to quantify the amount of flow from each of the zones contributing flow to wells. Thus, the flow logs show differences or changes in flow within each well as the flowmeter was advanced upward or downward in each well to record logs or to obtain stationary measurements.

Most of the figures showing trolling flowmeter logs contain a reference line called the “tool-velocity line.” This line shows the response the flowmeter would record if there was no flow in a well and the only velocity was that induced by the downhole movement of the flowmeter. When the trolling logs are recorded in shut-in wells and if there is no flow in the well among flow zones (interzonal flow), the flowmeter log should match the tool-velocity line. Quantitatively, the velocity of water through the flowmeter is equal to the velocity at a point minus the downhole velocity of the flowmeter during logging (usually 20 ft/min). The tool-velocity line is not shown on graphs with a large range in flow rates because the line at 20 ft/min approximately coincides with the left-axis of the graph in those cases and is of little use in the analysis. The tool-velocity line is also not shown for wells in which the trolling rate was less than 20 ft/min due to the shallowness of the well or due to the need to slow the flowmeter down to get past irregularities in the casing or borehole.

ANALYSIS OF GEOPHYSICAL LOGS

Geophysical logging and analysis of the driller’s and geophysical logs were performed to provide better information about wells in the CAWN. The logs provided information on (1) construction of the wells, (2) lithologies or lithologic zones open to the wells through saw- or torch-cut slots or stainless-steel screens or in uncased portions of boreholes, and (3) inflow or outflow zones providing water to the wells. The logs recorded in each of the wells were plotted side-by-side on graphs. This method of plotting the logs allows data at particular depths to be correlated between the logs. The logs plotted in the figures for each well do not start at zero on the charts because it was necessary to lower the logging tools 10–20 ft into the well before the logs could begin to be recorded. The upper, unlogged 10–20 ft of the wells typically does not yield additional information that would change the analyses that are presented in this report.

In the description of the logs for each well, reference is made to features of the well casing or the generalized lithologic layers that occur at depth. All depths given in the well descriptions are depths below land surface.

In most cases, the flowmeter logs are the primary logs used to indicate zones of inflow to the wells. Specific-conductance and temperature logs are useful in indicating inflow to the wells, but these logs are supplementary to the flowmeter logs. Specific-conductance and temperature logs are the primary logs used to define zones of inflow to wells when no flowmeter logs are available for a particular well.

Thirty-two wells in the CAWN were logged; 10 other wells were not logged because (1) known well construction indicated that the zone of inflow to the well was very narrow, (2) well owners denied USGS access to the wells, (3) too much oil was floating on the surface of the water column, (4) wells were obstructed, or (5) well construction prevented access for logging. A complete set of geophysical logs consisted of video, caliper, water specific-conductance, water-temperature, and free-flowing or pumped and shut-in or static water-column well-flow logs. Logging was attempted in several wells but the logs yielded insufficient data for analysis, and several wells were constructed in a way that prevented complete logging. Table 1 lists the availability of logs for each well in the CAWN.

Table 1. Availability of logs for wells in the confined-aquifer well network

[X, driller's log not available; D, driller's log available; C, complete log recorded; P, partial log recorded; O, log not recorded; Y, yes; N, no; ft, feet; USGS, U.S. Geological Survey]

Well name	Site identifier	Driller's log	Geophysical logs: Video	Caliper	Water specific conductance	Water temperature	Flowmeter: Free-flowing or pumped	Flowmeter: Shut-in or static water column	Flowing—Y or N	Well depth (feet)	Logged interval (feet)	Comment
ALA.2	374030106020001	X	P	P	P	P	O	O	Y	415	0–350	Casing reduction to less than 2 inches at 350 ft.
ALA.3	374030106020002	X	P	P	P	P	O	O	Y	970	0–881	Casing reduction to less than 2 inches at 881 ft.
ALA.4	372550105455001	D	C	C	C	C	C	C	Y	1,973	0–1,973	
ALA.5	374239105433902	D	O	O	O	O	O	O	N	118		Not logged because well construction is known.
ALA.6	372403106000901	D	C	C	C	C	C	C	Y	735	0–735	
ALA.7	372403106000902	X	O	O	O	O	O	O	Y	490		Unable to open top of well.
ALA.8	372506106004201	X	C	C	C	C	C	C	Y	1,301	0–1,301	
ALA.9	372641106000901	X	C	C	C	C	C	O	Y	130	0–130	Shut-in flowmeter data are unusable.
ALA.10	373457106003801	D	P	C	C	C	C	C	Y	2,067	0–2,067	Video was recorded only to 2,015 ft because of cable length limitation.
ALA.11	373051105404701	X	O	O	O	O	O	O	Y	321		Not logged because well construction is known
ALA.12	372950105580801	X	C	C	C	C	C	C	Y	908	0–908	
ALA.13	373748105511501	D	C	O	C	C	C	O	Y	1,784	0–1,774	Reported casing diameters shown in figure 12; shut-in flowmeter data are unusable.
ALA.14	373410105423701	X	C	O	C	C	C	P	Y	575	0–569	Reported casing diameter shown in figure 13; shut-in data from 270 to 360 ft are unusable.
ALA.15	373208105425601	X	O	O	O	O	C	O	Y	588	0–570	Reported casing diameter shown in figure 14; shut-in flowmeter data are unusable.
ALA.16	373305105405201	D	C	N	C	C	C	C	Y	600	0–583	Reported casing diameter shown in figure 15.
ALA.17	372215105440101	X	O	O	O	O	O	O	Y	unknown	0–43	Obstructed at 43 ft.
CON.1	371705106021501	D	O	O	O	O	O	O	N	608		Owner denied USGS access to well.
CON.2	371745105501001	D	O	O	O	O	O	O	Y	700		Owner denied USGS access to well.
CON.3	371145105523001	X	C	C	C	C	O	O	N	480	0–480	Flowmeter data not obtained due to long uncased interval.
CON.4	371701105512001	X	C	C	C	C	C	C	Y	716	0–716	

Table 1. Availability of logs for wells in the confined-aquifer well network—Continued

[X, driller's log not available; D, driller's log available; C, complete log recorded; P, partial log recorded; O, log not recorded; Y, yes; N, no; ft, feet; USGS, U.S. Geological Survey]

Well name	Site identifier	Driller's log	Geophysical logs				Flowmeter		Flowing—Y or N	Well depth (feet)	Logged interval (feet)	Comment
			Video	Caliper	Water specific conductance	Water temperature	Free-flowing or pumped	Shut-in or static water column				
COS.1	371959105433001	X	O	C	C	C	O	O	N	182	0–182	Flowmeter data not obtained.
RIO.1	372805106085001	D	C	C	C	O	C	O	N	599	0–599	Temperature and static water-column flowmeter logs unusable.
RIO.2	373227106030301	D	C	O	C	C	C	C	Y	1,446	0–1,446	Reported casing diameters shown in figure 20.
RIO.3	373633106040901	X	C	C	C	C	C	O	Y	199	0–199	Shut-in flowmeter data not obtained.
RIO.4	373620106054001	D	C	C	C	C	C	C	Y	952	0–952	
SAG.1	375035106105501	D	C	C	C	C	C	C	N	801	0–801	
SAG.2	375310106021501	D	C	C	C	C	C	C	Y	1,958	0–1,958	
SAG.3	380045106044501	X	O	O	O	O	O	O	N	580		Oil on the surface of the water column prevented logging.
SAG.4	375155106021501	D	O	C	C	C	C	C	Y	2,298	0–2,298	Too deep to video with available equipment.
SAG.5	381018105521901	X	C	C	C	C	O	O	N	522	0–522	Flowmeter data are unusable.
SAG.6	375154106102501	X	C	C	C	C	O	O	N	120		Logs were inconclusive due to oxidation inside casing.
SAG.7	374505106054501	X	C	C	C	C	O	O	N	386	0–386	Flowmeter data are unusable.
SAG.8	375643106100001	X	O	O	O	O	O	O	N	185		Obstructed at 18 ft.
SAG.9	375255106084401	D	C	C	C	C	C	C	Y	665	0–665	
SAG.10	375310106050001	D	C	C	C	C	P	P	Y	1,974	0–1,974	Flowmeter logs only recorded below the top of the lower liner.
SAG.11	375009106021001	D	C	C	C	C	C	C	Y	1,322	0–1,322	
SAG.12	380047106024801	X	C	C	C	C	C	C	Y	576	0–576	
SAG.13	375820106052001	D	C	C	C	C	C	C	Y	793	0–793	
SAG.14	375523105505302	D	O	O	O	O	O	O	N	118		Not logged because well construction is known.
SAG.15	375001105463403	D	O	O	O	O	O	O	Y	124		Not logged because well construction is known.
SAG.17	374915106013001	D	C	C	C	C	C	C	Y	671	0–671	
SAG.18	375918106063601	X	C	C	C	C	C	O	Y	382	0–382	Shut-in flowmeter data unusable.

Alamosa County

CAWN wells that are in Alamosa County are named with the "ALA" prefix and a sequence number. Geophysical logs were recorded in 12 of the 16 CAWN wells in Alamosa County.

Well ALA.2

Well ALA.2 was constructed by the USGS in 1969 to measure the water level in the confined-aquifer system. A lithologic log is not available for this flowing well. Construction is reported to be 2.0-inch-diameter steel pipe to a depth of 415 ft. Partial logging with the caliper tool showed a reduction in the casing from 2.0-inch diameter to 1.0-inch or 0.75-inch diameter at a depth of 350 ft. Logs could not be obtained below the casing reduction because the diameter of the smallest logging tools is approximately 1.6 inches. Flowmeter logs were not recorded in the 2.0-inch-diameter section of the casing. Inflow is assumed to come from below a depth of 350 ft because both the specific-conductance and temperature logs do not show significant inflections that would indicate inflow between the surface and 350 ft (fig. 3). The location and length of the open interval in ALA.2 are unknown, so it is assumed that flow comes from the entire unlogged section from 350 to 415 ft. The water level measured in ALA.2 represents a composite measurement of the heads in the confined-aquifer system in the 65-ft interval from 350 to 415 ft.

Well ALA.3

Well ALA.3 was constructed by the USGS in 1969 to measure the water level in the confined-aquifer system. A lithologic log was not available for this flowing well. Construction is reported to be 2.0-inch-diameter steel pipe to a depth of 970 ft. Partial logging with the caliper tool showed a reduction in the casing from 2.0-inch-diameter to 1.0-inch- or 0.75-inch diameter at a depth of 881 ft. Logs could not be obtained below the casing reduction because the logging tools are approximately 1.6-inch diameter. Flowmeter logs were not obtained in this well.

A plot of the specific-conductance and temperature logs indicates that flow enters the casing at depths of 110 and 160 ft (fig. 4). The video log shows that a break in the casing may exist at 110 ft and the casing is slightly corroded near 160 ft, but no obvious perforations were seen at either depth.

ALA.2 is about 80 ft from ALA.3, and water levels in both wells fluctuate in a similar manner (fig. 5). The water level in ALA.3 decreased about 20 ft in a short period in 1989. Since mid-1989, the water level measured in ALA.3 typically has been several feet lower than the water level in ALA.2, whereas prior to mid-1989 water levels were higher in ALA.3 than in ALA.2. Possibly nearby pumping or a change in casing integrity caused the water level in ALA.3 to decline while water levels in ALA.2 were not similarly affected. The location and length of the open interval in ALA.3 are unknown, so it is assumed that inflow comes through possible casing imperfections at 110 and 160 ft and from the entire unlogged section from 881 to 970 ft. The water level measured in ALA.3 is a composite of the heads in the aquifer at depths of about 110 and 160 ft and in the open part of the interval between 881 and 970 ft.

Well ALA.4

Well ALA.4 was constructed in 1957 for irrigation use and is a flowing well. The casing is 20.0-inch diameter from land surface to a depth of 38 ft, 12.5-inch diameter from 38 to 1,422 ft, and 8.5-inch diameter from 1,422 to 1,973 ft. The intervals containing torch-cut slots (540 to 690 ft; 885 to 1,973 ft) are open to lithologic layers containing (1) sand, gravel, or cobbles; (2) clay with some sand or gravel; or (3) sand or gravel with some clay (fig. 6). The lithologic layers contributing water to the well are below a thick clay layer that is present from a depth of about 290 to 442 ft.

Specific-conductance and temperature logs and the free-flowing stationary flowmeter measurements indicate two inflow zones in this well from a depth of 1,200 to 1,600 ft and 540 to 640 ft. Specific-conductance and temperature logs also indicate inflow occurs below a depth of 1,600 ft that is not confirmed by the flowmeter data. One possible zone of outflow is indicated from a depth of 970 to 1,000 ft. The small amount of outflow measured is either outflow into a permeable layer or outflow into the annular space around the casing that eventually becomes inflow to the well at a shallower depth. The decrease in flow at a depth of 1,422 ft is caused by the change in casing diameter there.

Under shut-in conditions, one inflow zone exists from a depth of 930 to 1,520 ft, and two outflow zones exist from a depth of 885 to 930 ft and 540 to 690 ft.

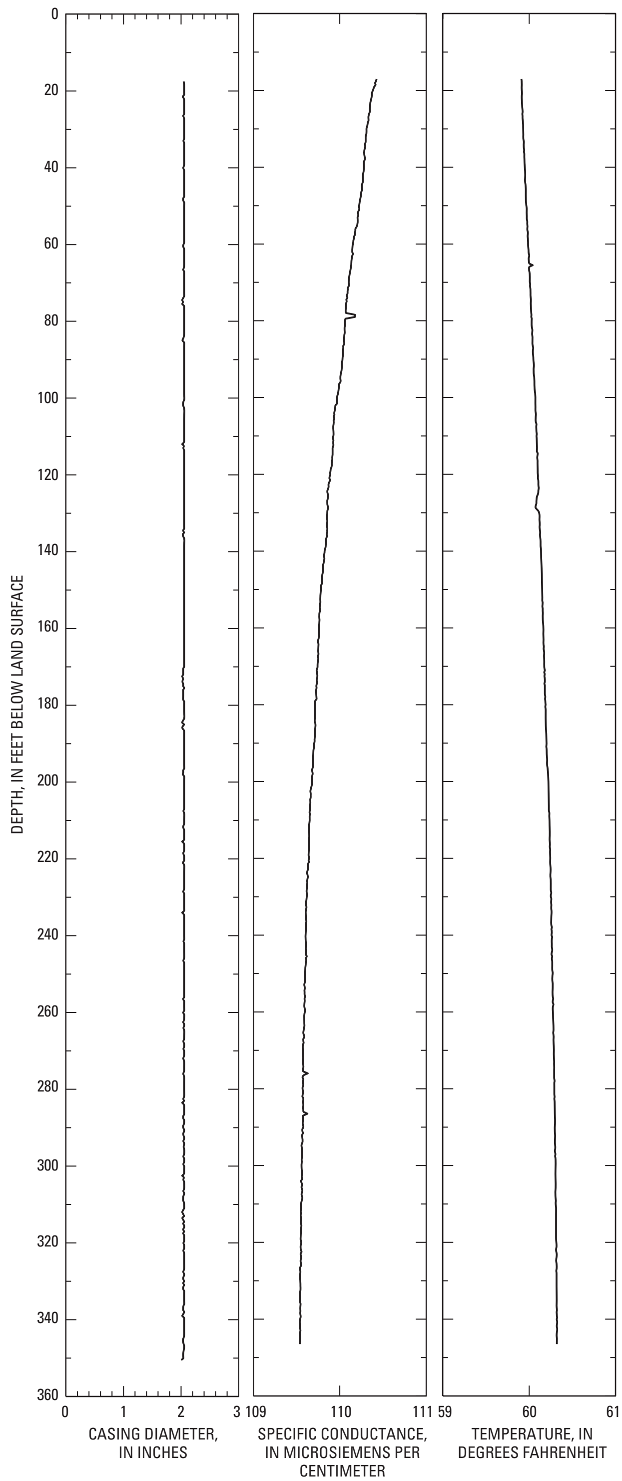


Figure 3. Geophysical well logs for well ALA.2.

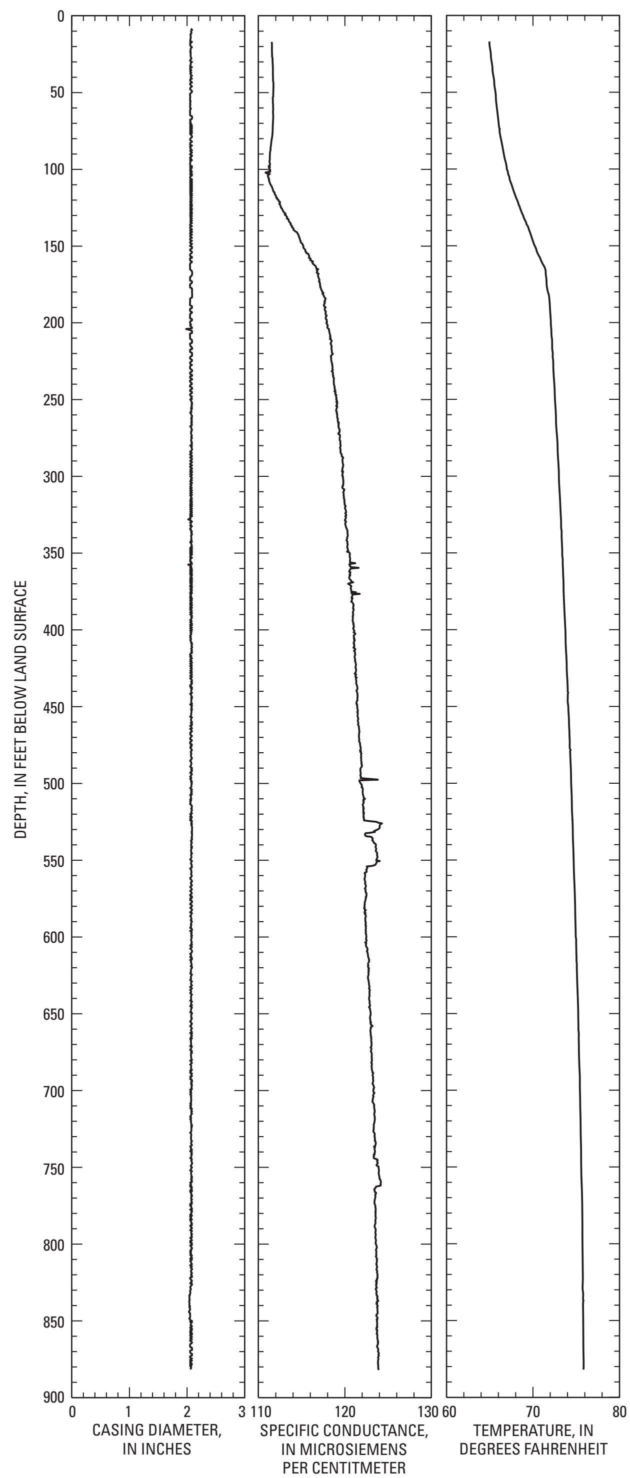


Figure 4. Geophysical well logs for well ALA.3.

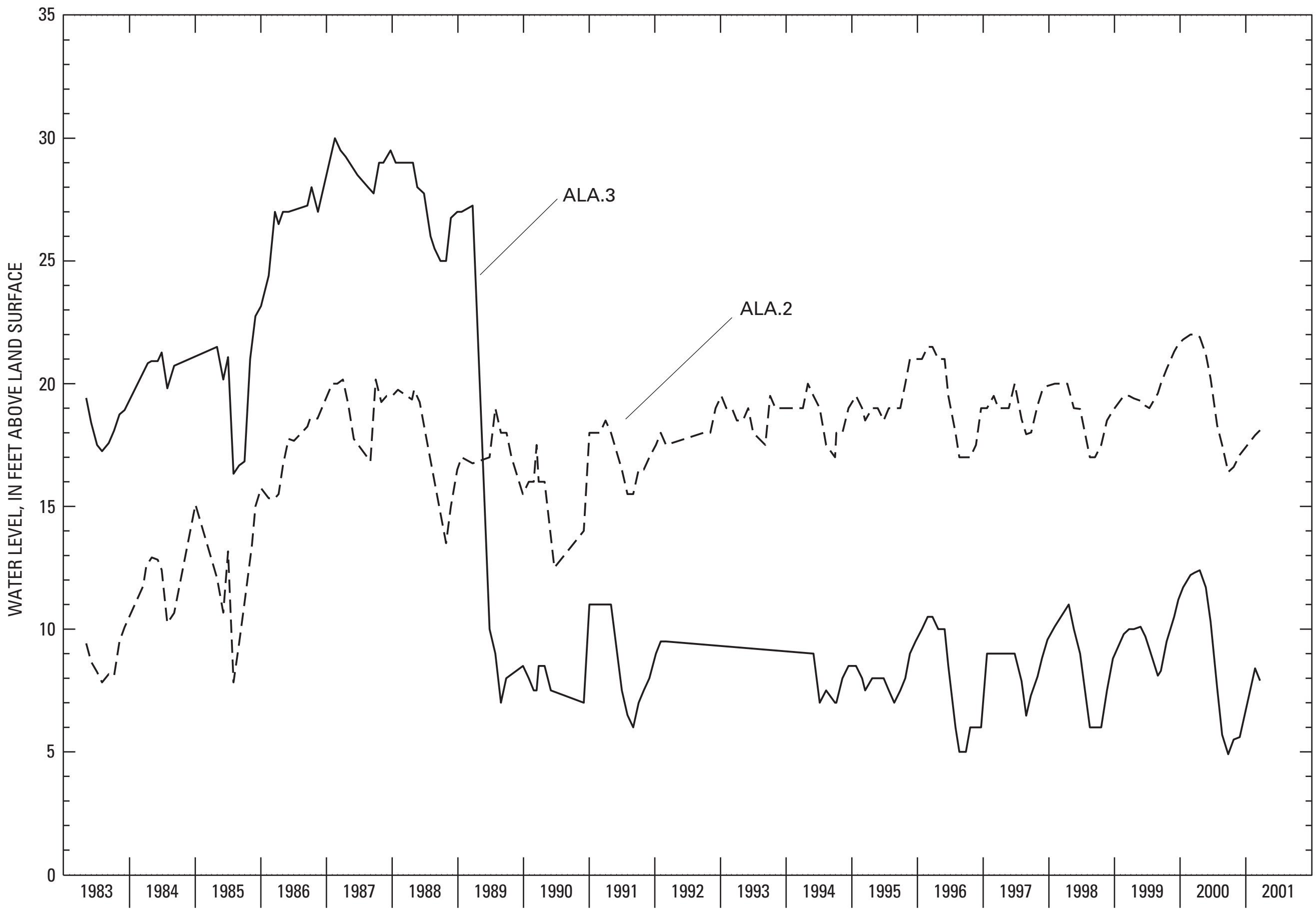


Figure 5. Water levels in wells ALA.2 and ALA.3.

The decrease in flow at a depth of 1,422 ft is due to the change in casing diameter at that depth. The two outflow zones may result because the annular space allows flow into lithologic layers below the clay layer from a depth of 290 to 440 ft that are cased off. Thus, outflow into the zones from 885 to 930 ft and 540 to 690 ft may occur to equalize the head differences among the flow zones below 930 ft and above 930 ft that may have been created during free-flowing conditions, or it may occur due to natural head differences that exist among the different flow zones of the confined-aquifer system.

The water level measured in this well is a composite of heads in the confined-aquifer system because the 1,433-ft interval contributing flow to this well penetrates several different lithologic layers.

Well ALA.6

Well ALA.6 was constructed in 1957 for irrigation use and is a flowing well. The casing is 17.2-inch diameter from land surface to a depth of 51 ft and 12.0-inch diameter from 51 to 735 ft. The intervals containing torch-cut slots (from 446 to 537 ft and from 555 to 735 ft) are open to lithologic layers containing (1) sand, gravel, or cobbles; (2) clay with some sand or gravel; or (3) clay (fig. 7). The lithologic layers open to the well are below a thick clay layer from 34 to 92 ft and a predominantly clay layer from 92 to 401 ft.

The temperature log and free-flowing and shut-in stationary flowmeter measurements indicate inflow occurs in three zones: (1) 446 to 475 ft, (2) 500 to 530 ft, and (3) 670 to 728 ft. The small decreases in flow through the flowmeter of about 0.019 gal/min observed in the shut-in stationary measurements from 280 to 440 ft and 470 to 520 ft are likely measurement errors or diameter effects. Thus, both the free-flowing and the shut-in flowmeter measurements show that flow increases as the depth decreases in the well. The decrease in flow observed in both flowmeter logs at 51 ft is due to the change in casing diameter at that depth.

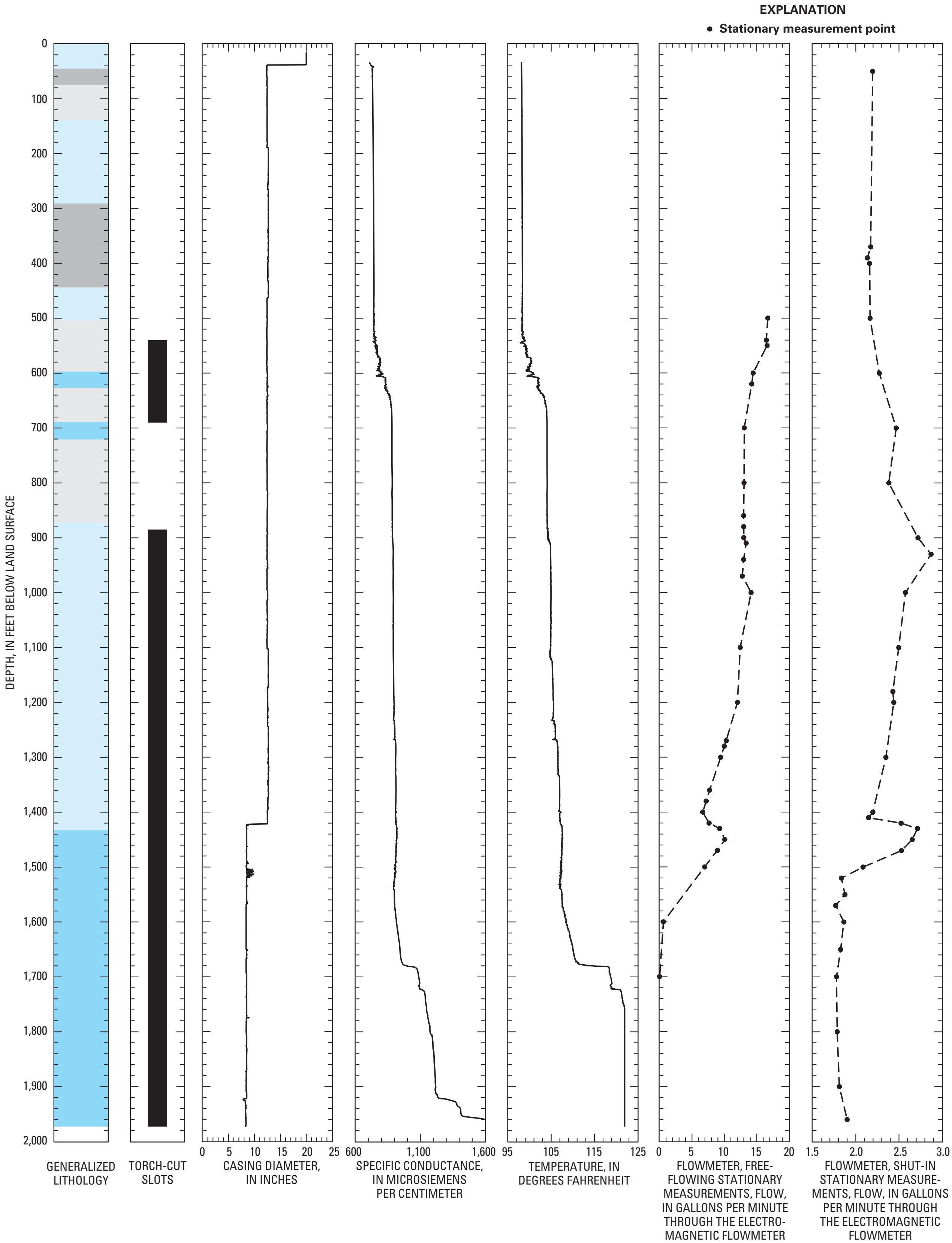


Figure 6. Geophysical well logs for well ALA.4. Refer to figure 2 for generalized lithology.

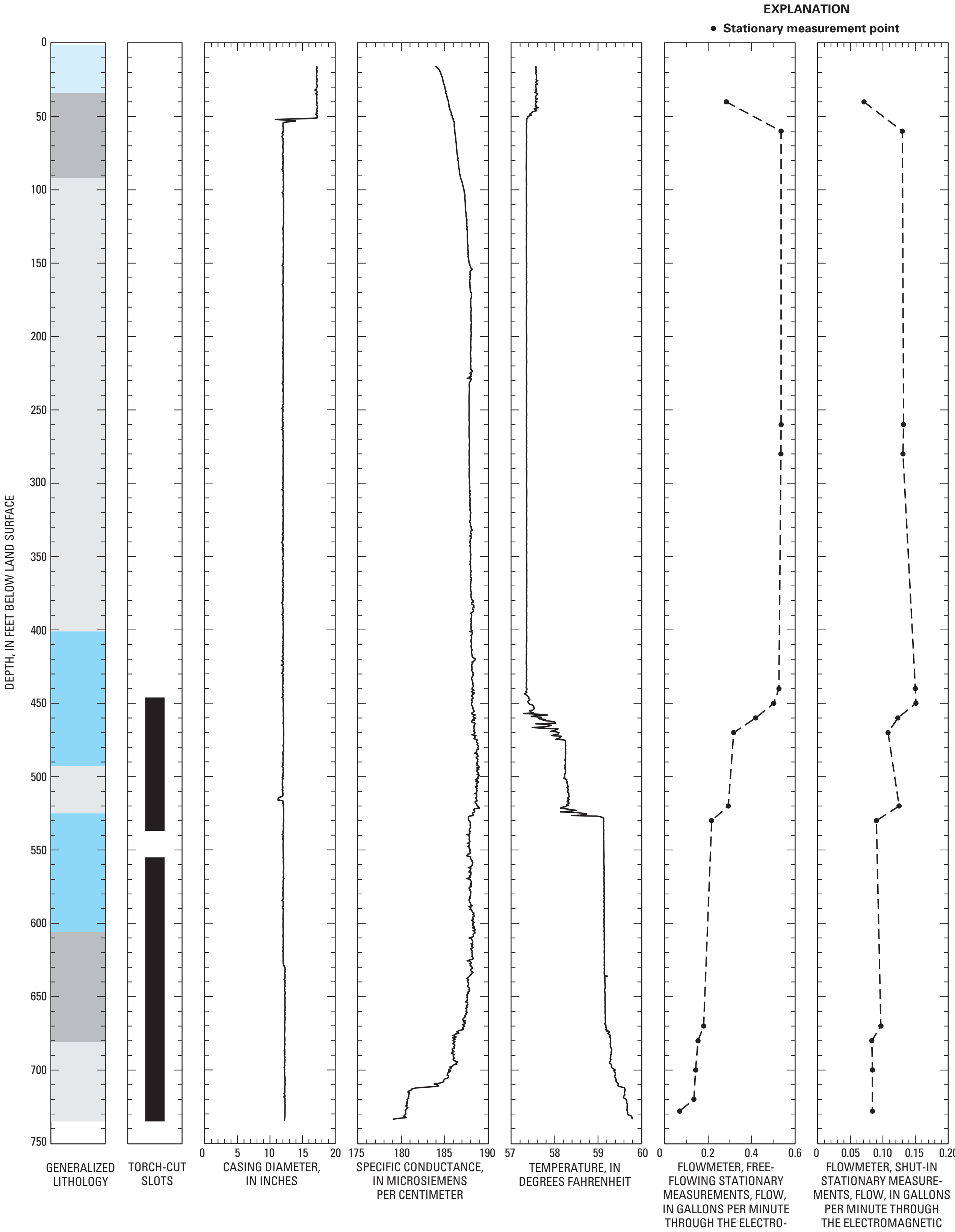


Figure 7. Geophysical well logs for well ALA.6. Refer to figure 2 for generalized lithology.

The inflections in both the free-flowing and shut-in flowmeter measurements occur at similar depths, so under free-flowing and shut-in conditions, significant head differences are not present between the flow zones open to this well. The water level measured in ALA.6 represents a composite of head conditions in several permeable layers over an interval of 271 ft in the confined-aquifer system.

Well ALA.8

Well ALA.8 has 17.0-inch-diameter casing from land surface to a depth of 91 ft, 14.0-inch-diameter casing from 91 to 513 ft, and 10.0-inch-diameter casing from 513 to 1,301 ft. Three intervals contain torch-cut slots: (1) 578 to 663 ft, (2) 683 to 1,080 ft, and (3) 1,100 to 1,301 ft (fig. 8). A lithologic log was not available for this well.

A spinner flowmeter was used to measure flow in this well because the EM flowmeter was not available. The free-flowing trolling flowmeter did not detect flow below 1,280 ft as indicated by the trace of the flow log matching the tool-velocity line below 1,280 ft. The decreases in flow indicated by the free-flowing trolling flowmeter log at 91 ft and 513 ft are caused by changes in casing diameter at those depths.

Specific-conductance, temperature, and free-flowing trolling flowmeter logs show several fairly narrow zones of inflow at depths of about 1,000, 1,070, 1,125, 1,200, and 1,250 ft. The free-flowing trolling flowmeter log also shows inflow zones at a depth of 650 ft and from 720 to 760 ft that are not indicated on the specific-conductance and temperature logs.

Shut-in stationary flowmeter measurements show upflow in the well originating below a depth of 1,100 ft. Much of the inflow measured below a depth of 760 ft exits the well at depths from 650 ft to 760 ft, but there was still measurable flow at a depth of 525 ft. These stationary flow measurements indicate that during the time the measurements were being recorded, the head in the lower zone (below 760 ft) was higher than the head in the upper zone (above 760 ft). This head difference could occur if the flow zone from 650 ft to 760 ft was more transmissive than the flow zone from 1,000 ft to 1,250 ft and the head in the upper zone decreased due to loss of pressure during free-flowing conditions.

The water level measured in well ALA.8 is a composite measurement of the heads in the lower (760–1,250 ft) and the upper (650–760 ft) flow zones.

Well ALA.9

Well ALA.9 is an intermittently flowing well. The 6.2-inch-diameter casing extends from land surface to a depth of 26 ft and the well is uncased from 26 to 130 ft. A lithologic log was not available for this well (fig. 9).

The free-flowing trolling flowmeter log indicates that most inflow to this well occurs at depths from about 114 to 130 ft. Discharge from the well during the time the flowmeter log was being recorded was about 5 gal/min. A decrease in specific conductance indicates that inflow may occur at a depth of about 74 ft, although the flowmeter did not detect inflow at that depth.

Inflow to well ALA.9 occurs in a fairly narrow depth interval from 114 to 130 ft, even though the well is uncased over the entire interval from 26 to 130 ft. The water level measured in ALA.9 is a composite head measurement derived from the relatively long uncased interval in this well.

Well ALA.10

Well ALA.10 was constructed in 1964 for irrigation use and is a flowing well. The casing is 12.0-inch diameter from land surface to a depth of 824 ft and 9.0-inch diameter from 824 to 2,067 ft. The intervals containing torch-cut slots (907 to 1,189 ft; 1,228 to 2,015 ft) are open to lithologic layers containing (1) sand or gravel with some clay or (2) sand, gravel, or cobbles (fig. 10). These lithologic layers contributing water to the well occur below a 603-ft-thick layer of clay with some sand or gravel that is present from 93 to 696 ft.

The temperature and free-flowing trolling flowmeter logs indicate four inflow zones in this well at depths from 900 to 940 ft, 1,440 to 1,600 ft, 1,700 to 1,860 ft, and 1,880 to 1,980 ft. Under shut-in conditions, the stationary flowmeter measurements indicate inflow from 1,400 to 2,067 ft and outflow from 907 to 1,200 ft. The decrease in flow recorded in both flowmeter logs at a depth of 824 ft is caused by the change in casing diameter at that depth. Outflow into the zone from 907 to 1,200 ft may occur to equalize the difference in heads among the flow zones below 1,400 ft

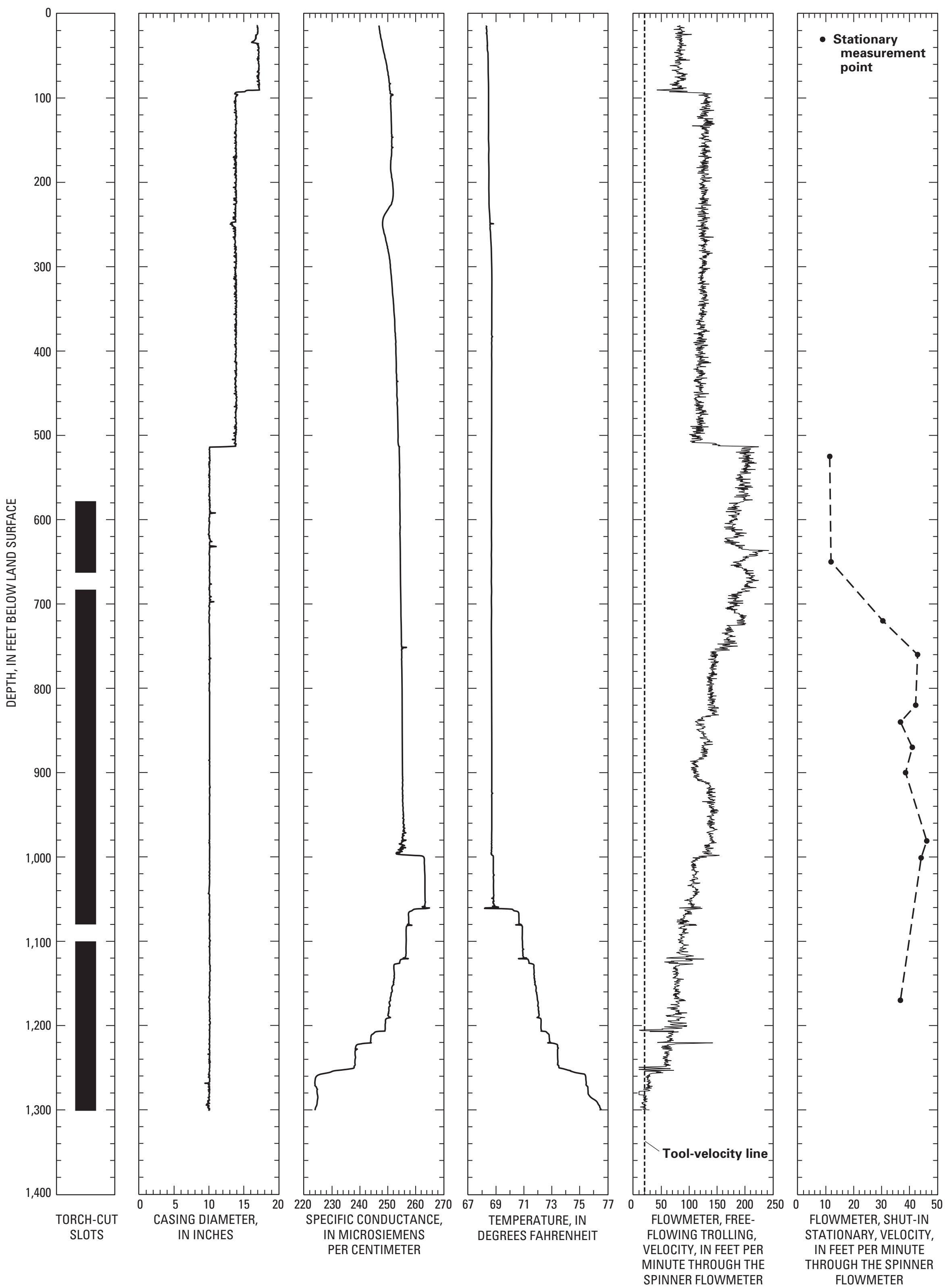


Figure 8. Geophysical well logs for well ALA.8.

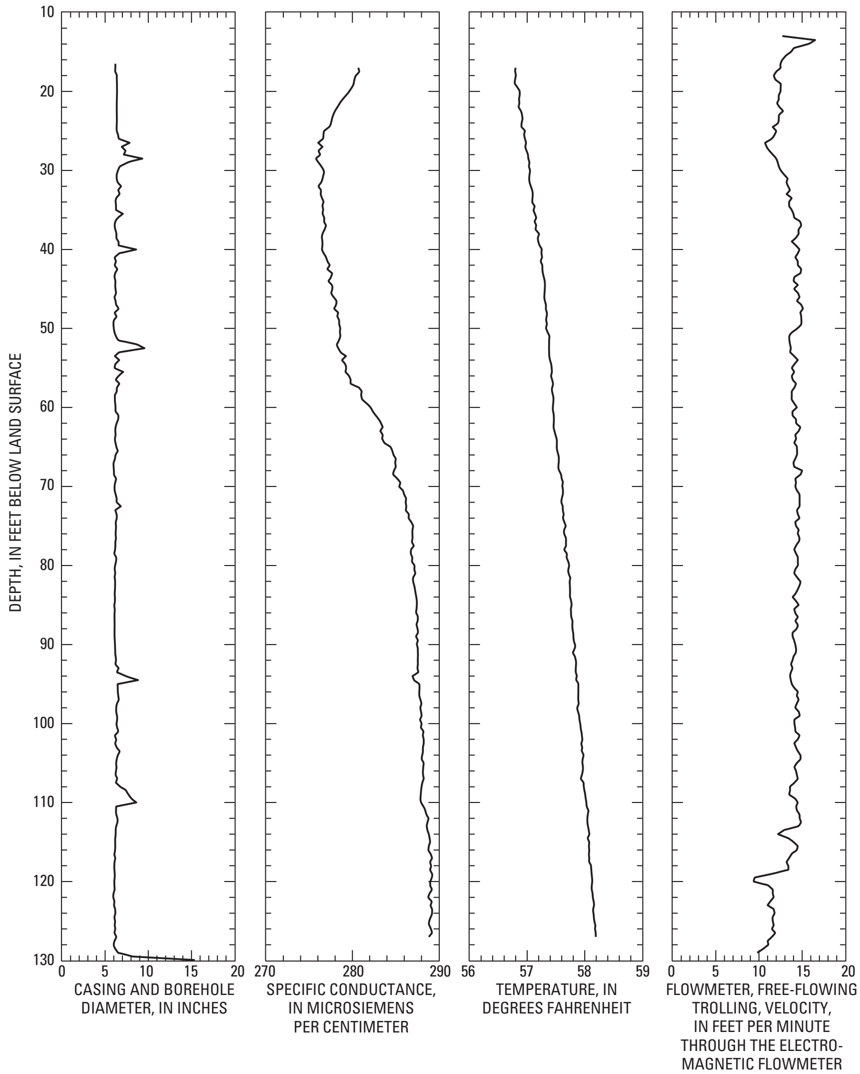


Figure 9. Geophysical well logs for well ALA.9.

and above 1,200 ft that may have been created during free-flowing conditions, or it may occur due to natural head differences that exist among the different flow zones of the confined-aquifer system.

The water level measured in well ALA.10 represents a composite head because the well is open to several permeable zones over an interval of about 1,100 ft.

Well ALA.12

Well ALA.12 is a flowing well that has 6.4-inch-diameter casing from land surface to a depth of 899 ft. The casing has torch-cut slots from a depth of 797 to 899 ft (fig. 11). The well is uncased from a depth from 899 to 908 ft. A lithologic log was not available for this well.

The specific-conductance, temperature, and free-flowing trolling flowmeter logs indicate two inflow zones at depths of 810 to 830 ft, and 860 to 908 ft. The reduction in flow detected by the free-flowing trolling flowmeter at a depth of 862 ft may be due to water flowing out of the casing, flowing in the annular space, and then reentering the casing above 862 ft. Apparent inflow in three depth intervals (120 to 200 ft, 360 to 390 ft, and 650 to 735 ft) is probably due to small changes in the casing diameter as observed in those intervals on the caliper log.

The shut-in trolling flowmeter log contains some spikes that do not represent valid flow measurements near depths of 270 ft, 730 ft, and 740 ft. Under shut-in conditions, inflow occurs in two zones at depths from 720 to 790 ft and 885 to 908 ft. The

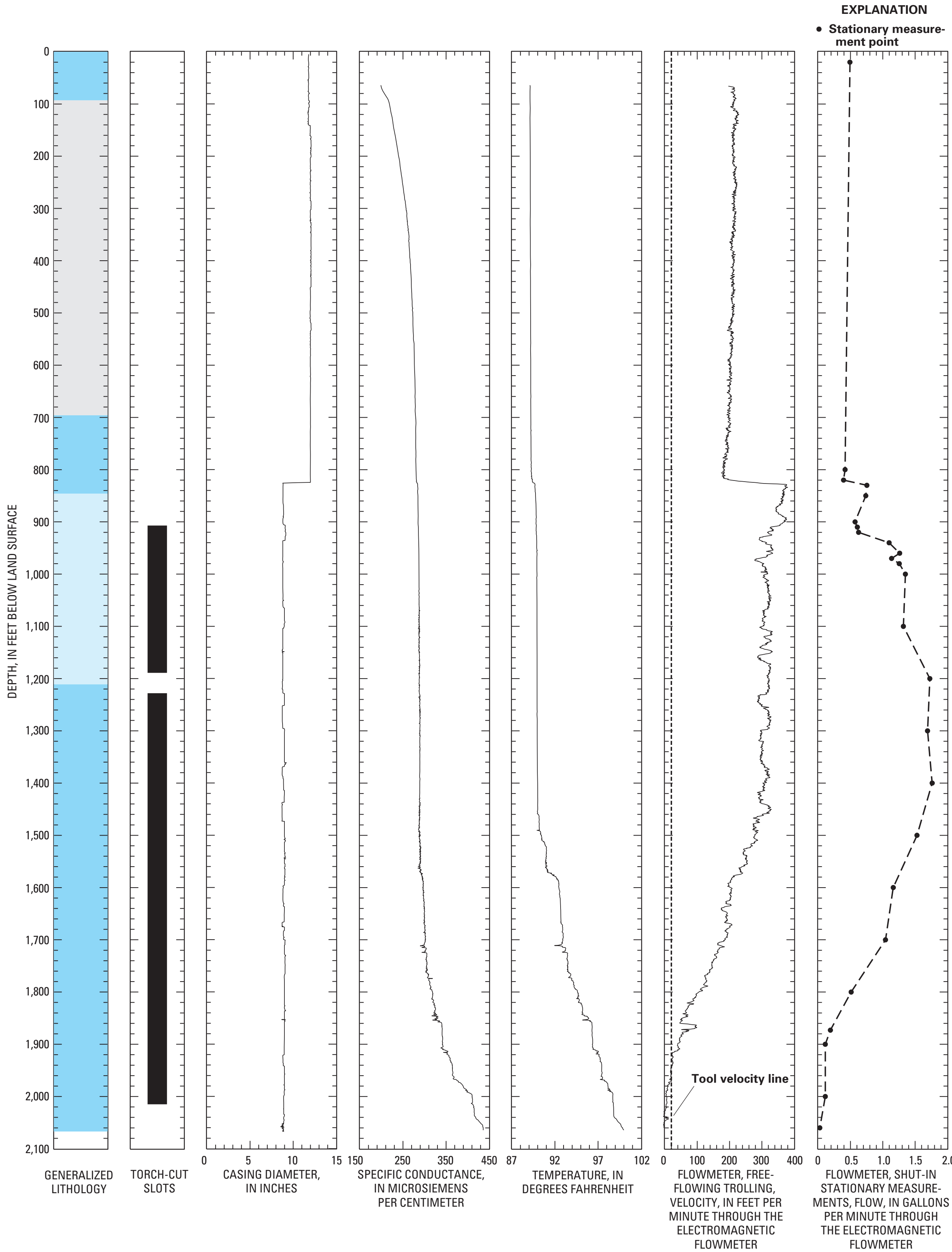


Figure 10. Geophysical well logs for well ALA.10. Refer to figure 2 for generalized lithology.

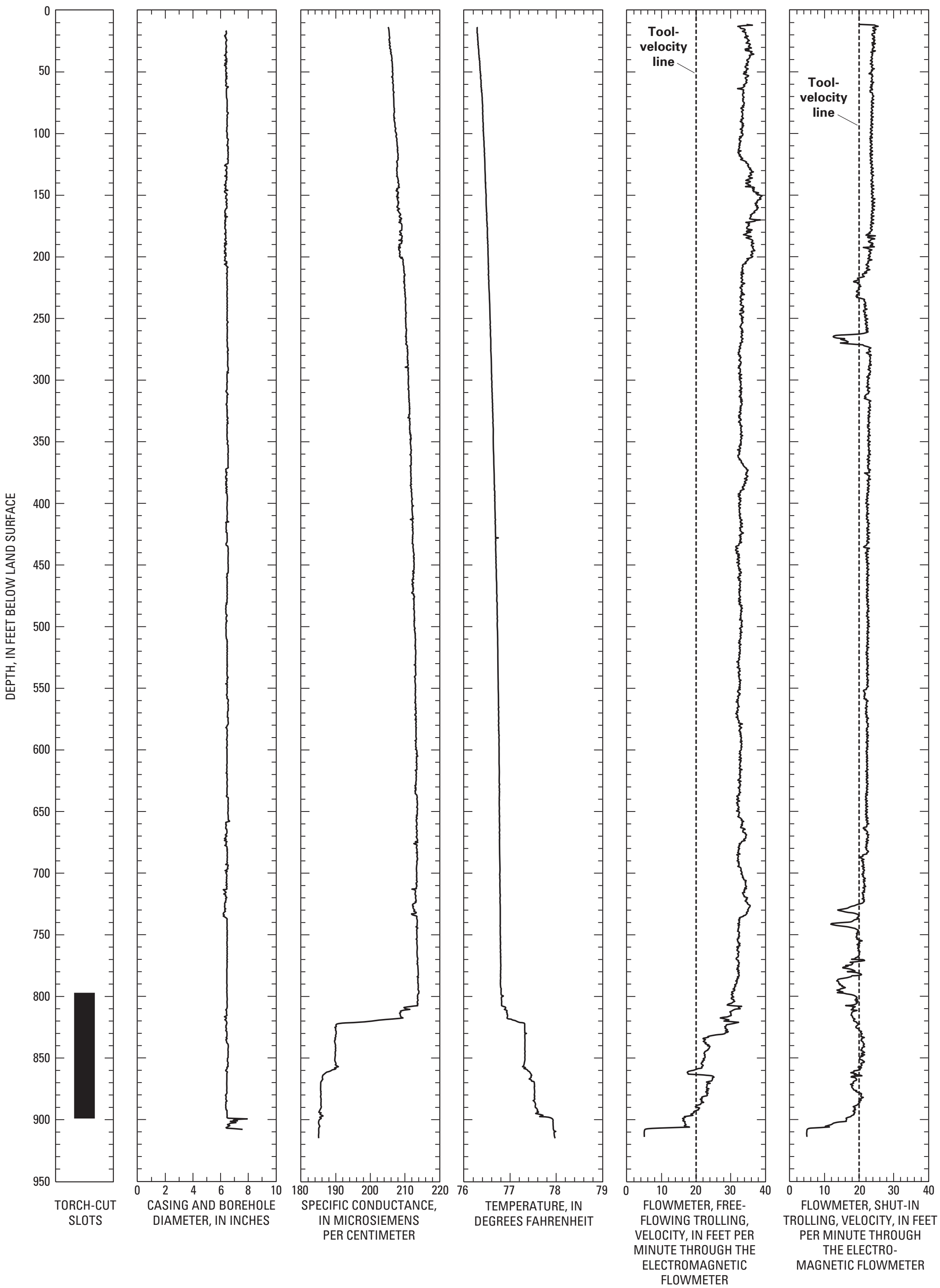


Figure 11. Geophysical well logs for well ALA.12.

section of the shut-in trolling flowmeter log from 720 to 790 may erroneously indicate inflow to the well because this apparent flow zone is present in a casing interval without torch-cut slots.

Head differences in the flow zones open to this well are small to none because both the free-flowing and shut-in flowmeter traces show similar profiles. The water level measured in ALA.12 is a composite head measurement because the well is open to the confined-aquifer system in an 111-ft interval from 797 to 908 ft.

Well ALA.13

Well ALA.13 was constructed in 1964 for irrigation use and is a flowing well. The casing is 12.0-inch diameter from land surface to a depth of 945 ft and 8.0-inch diameter from 945 to 1,784 ft. The casing diameter shown in figure 12 was constructed from the reported casing diameters. Eight depth intervals containing torch-cut slots (968 to 1,115 ft; 1,150 to 1,345 ft; 1,381 to 1,457 ft; 1,493 to 1,551 ft; 1,588 to 1,612 ft; 1,651 to 1,678 ft; 1,715 to 1,741 ft; 1,778 to 1,784 ft) are open to lithologic layers containing (1) clay with some sand or gravel or (2) sand or gravel with some clay (fig. 12). The lithologic layers contributing water to the well are below a 940-ft-thick layer that contains clay with some sand or gravel and three clay layers at depths from 151 to 253 ft, 325 to 455 ft, and 738 to 798 ft.

The specific-conductance and free-flowing trolling flowmeter logs indicate four inflow zones in this well at depths from 1,050 to 1,090 ft, 1,220 to 1,260 ft, 1,340 to 1,550 ft, and 1,650 to 1,784 ft. The fairly large reduction in flow between 960 and 1,000 ft may result from flow being diverted into the annular space or into a permeable layer between 968 and 1,000 ft. The flow increase detected by the free-flowing trolling flowmeter at 945 ft indicates inflow to the well just below 945 ft or through the annular space at the top of the liner. The decrease in flow at 945 ft is caused by the change in casing diameter at that depth. Shut-in flowmeter logs were not available for this well.

The water level measured in well ALA.13 is a composite head measurement in the confined-aquifer system because the 816-ft interval contributing flow to this well penetrates several different lithologic layers.

Well ALA.14

Well ALA.14 is a flowing well that has 6.6-inch-diameter casing from land surface to a depth of 575 ft with stainless-steel screens in five depth intervals from 268 to 278 ft, 426 to 446 ft, 461 to 481 ft, 532 to 542 ft, and 548 to 575 ft (fig. 13). The casing diameter shown in figure 13 was constructed from the reported casing diameters. A lithologic log was not available for this well.

The specific-conductance, temperature, and free-flowing trolling flowmeter measurements indicate inflow zones that correspond to the screened intervals. The shut-in trolling flowmeter did not record data in the depth interval from 270 to 360 ft. A screened interval is not present where data are missing and the average flow through the EM flowmeter sensor of 51 ft/min at a depth of 360 ft is nearly equal to the average flow of 49 ft/min at a depth of 260 ft. A significant change in flow probably did not occur where data are missing. Under shut-in conditions, most of the inflow occurs in the lower screened intervals (532 to 542 ft and 548 to 575 ft) and outflow to the upper screened intervals was not detected.

Head differences in the flow zones open to this well are small to none because the traces of both the free-flowing and shut-in flowmeter logs show similar profiles. The water level measured in ALA.14 is a composite head measurement in the confined-aquifer system because the 307-ft interval from 268 to 575 ft that contains the screened intervals in this well is open to several lithologic layers.

Well ALA.15

Well ALA.15 is a flowing well that has 6.6-inch-diameter casing from land surface to a depth of 588 ft with stainless-steel screens in six depth intervals from 141 to 151 ft, 235 to 245 ft, 295 to 325 ft, 400 to 420 ft, 534 to 544 ft, and 565 to 575 ft (fig. 14). The casing diameter shown in figure 14 was constructed from the reported casing diameters. A lithologic log was not available for this well.

The free-flowing stationary flowmeter measurements indicate inflow at each of the depths where screens are installed. Shut-in flowmeter data were not available for this analysis. The water level measured in ALA.15 is a composite head measurement in the confined-aquifer system because the 434-ft interval from 141 to 575 ft that contains the screened intervals in this well is open to several lithologic layers.

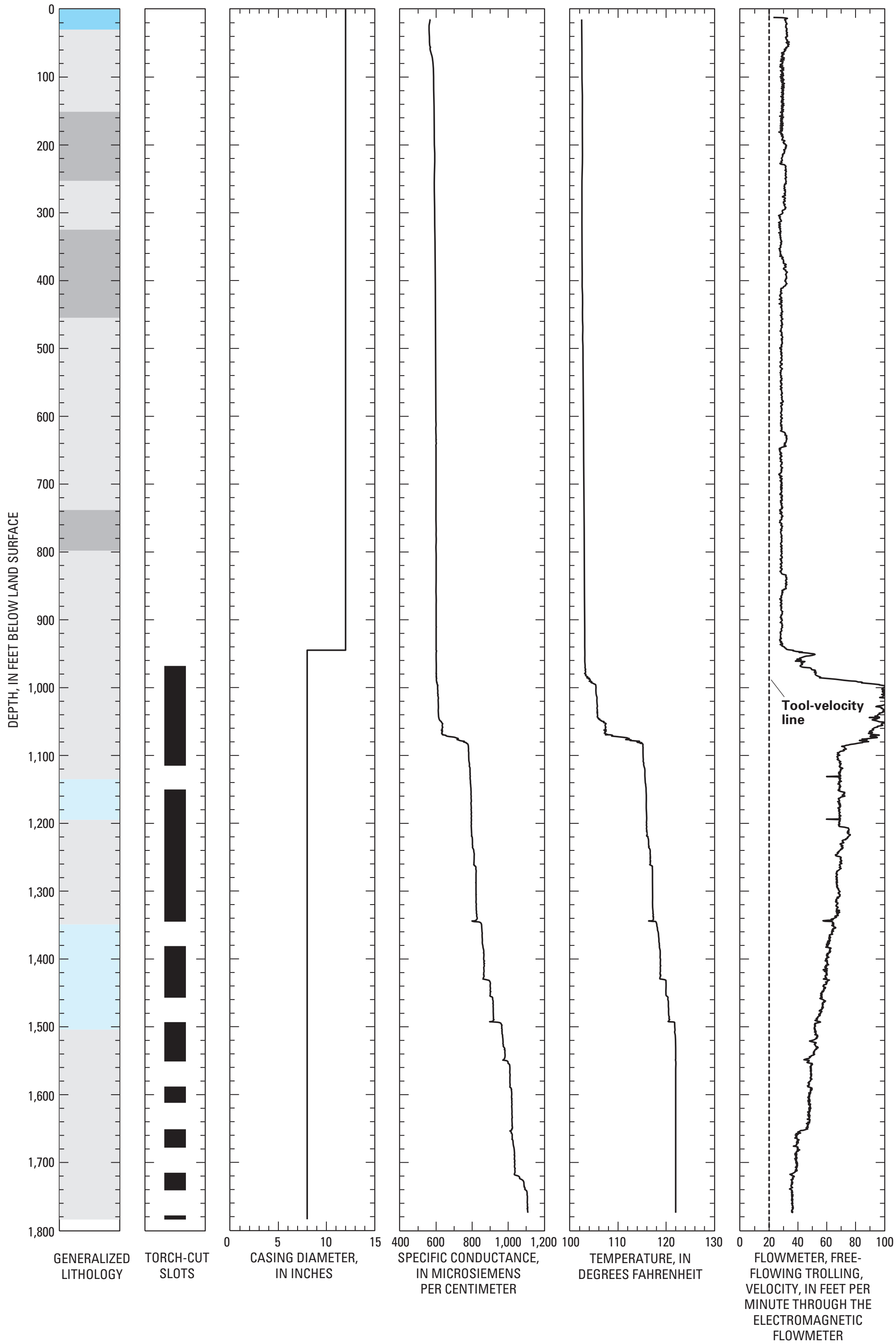


Figure 12. Geophysical well logs for well ALA.13. Refer to figure 2 for generalized lithology.

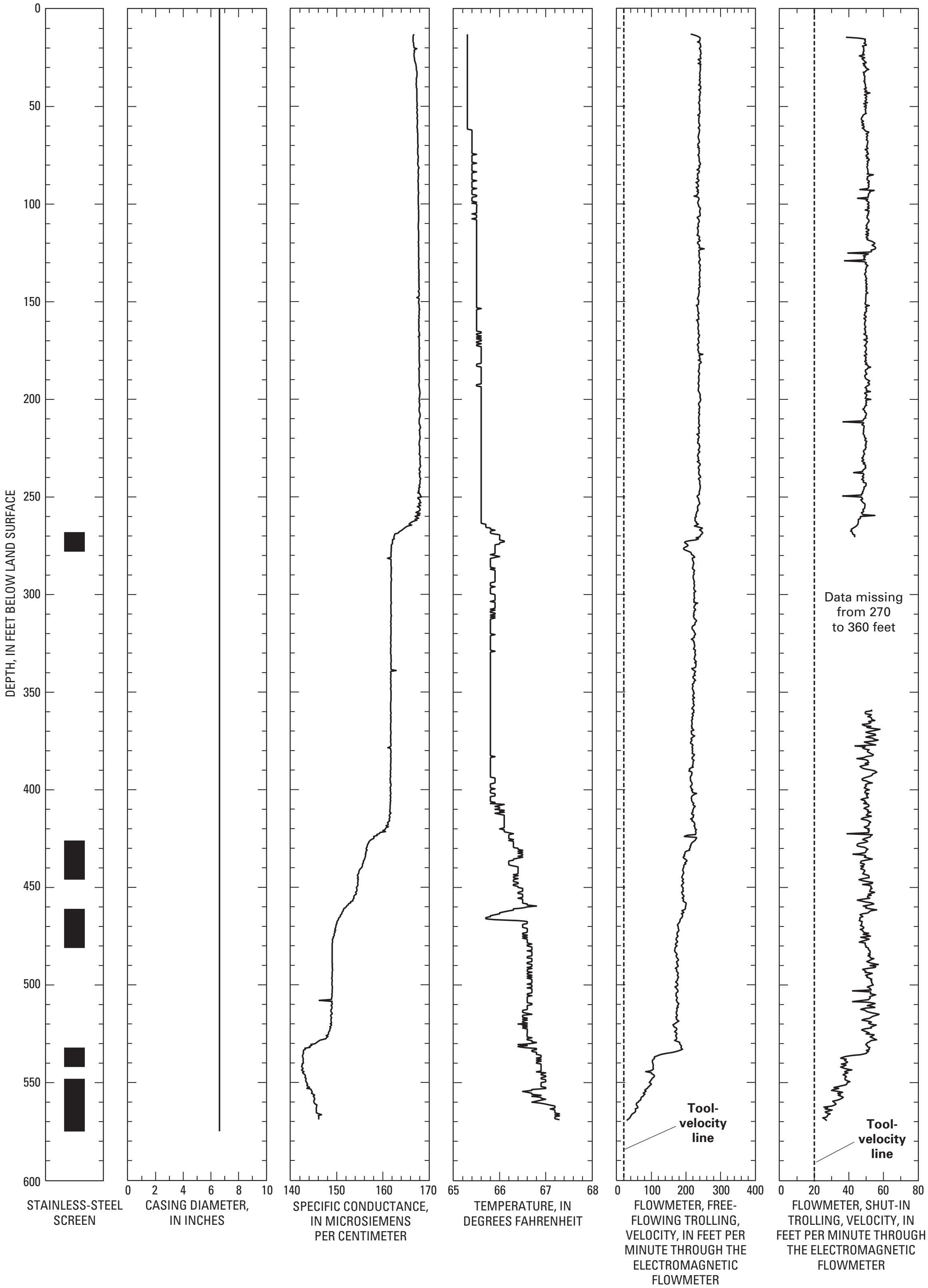


Figure 13. Geophysical well logs for well ALA.14.

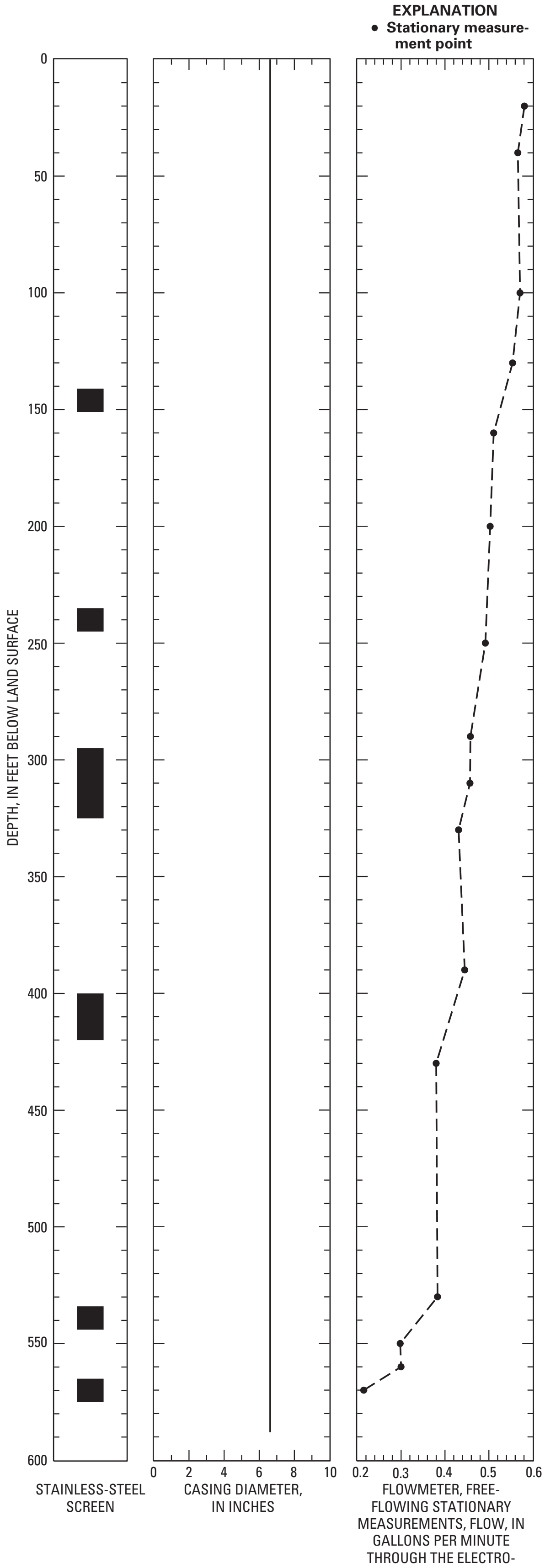


Figure 14. Geophysical well logs for well ALA.15.

Well ALA.16

Well ALA.16 is a flowing well that has 6.6-inch-diameter casing from land surface to a depth of 600 ft. The casing diameter shown in figure 15 was constructed from the reported casing diameters. Four stainless-steel screened intervals (153 to 173 ft; 362 to 404 ft; 530 to 550 ft; and 576 to 586 ft) are open to lithologic layers containing (1) sand or gravel with some clay or (2) clay with some sand or gravel (fig. 15). A video log was not recorded in this well.

The specific-conductance, temperature, and free-flowing trolling flowmeter measurements indicate inflow zones that correspond to the screened intervals. The free-flowing trolling flowmeter log detected variable flow in the zones of inflow due to turbulence in the casing. A decrease in flow at a depth of about 135 ft and an increase in flow, that is about the same magnitude as the decrease, at a depth of about 75 ft may have resulted from a change in casing diameter. This 60-ft-long interval (75 ft to 135 ft) equals three pipe lengths, and there are no reported screened intervals between 75 and 135 ft.

The shut-in trolling flowmeter detected widely variable flow in the screened intervals that likely is due to turbulence. Inflow or outflow are indicated where screened intervals are not present (200 to 220 ft; 440 ft) and are assumed to be changes in flow velocities due to turbulence or other effects rather than due to changes in flow. Inflow to the well occurs through the lower three screened intervals, and outflow from the well occurs through the upper screened interval.

The free-flowing and shut-in flowmeter logs indicate head differences between the open intervals of well ALA.16. Outflow into the interval from 153 to 173 ft may occur to equalize the head differences between the three lower screened intervals and the upper screened interval that may have been created during free-flowing conditions, or it may occur due to natural head differences that exist between the different flow zones of the confined-aquifer system. The water level measured in well ALA.16 is a composite head measurement in the confined-aquifer system because the 433-ft interval from 153 to 586 ft that contains the screened intervals contributing flow to this well penetrates several different lithologic layers.

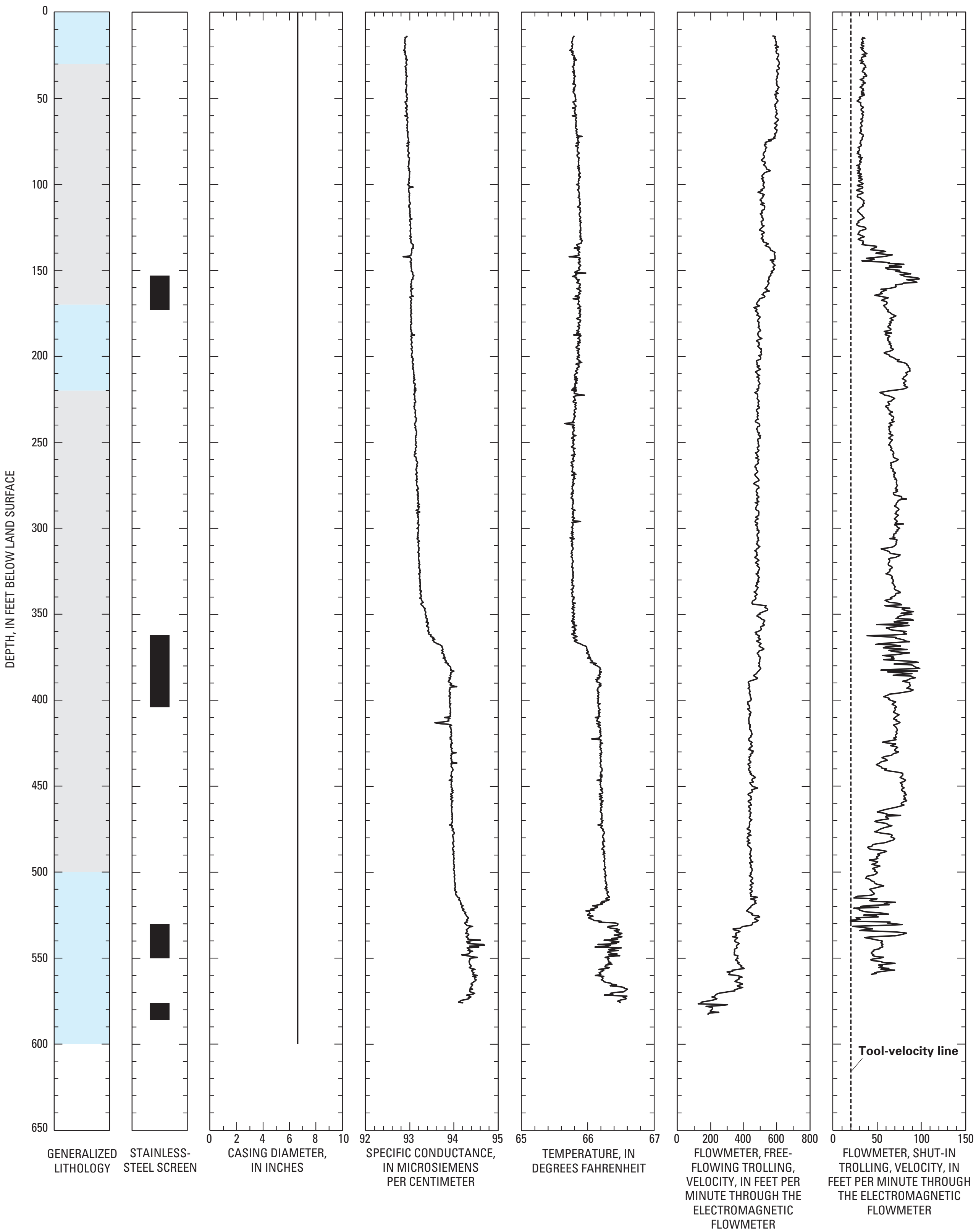


Figure 15. Geophysical well logs for well ALA.16. Refer to figure 2 for generalized lithology.

Conejos County

CAWN wells in Conejos County are named with the "CON" prefix and a sequence number. There are four CAWN wells in Conejos County, but only two were logged.

Well CON.3

Well CON.3 is a 480-ft-deep nonflowing well that has 8.6-inch-diameter casing from land surface to a depth of 65 ft (fig. 16). The borehole is uncased from a depth of 65 to 480 ft. A lithologic log was not available for this well. Flowmeter logs were not recorded in this well because of the potential risk of the flowmeter getting stuck in the uncased section and then becoming unretrievable.

Below 190 ft, the temperature log approximates the assumed average geothermal gradient (Repplier and Fargo, 1981). Water may be flowing fairly slowly up the well from a depth of 190 to 80 ft, as indicated by little change in the trace of the temperature log above 190 ft. The large increase in specific conductance at a depth of about 470 ft most likely results from the tool bumping the top of the smaller-diameter hole indicated on the caliper log at that depth.

The water level measured in CON.3 is a composite head measurement in the confined-aquifer system because the 415-ft uncased interval contributing flow to this well probably penetrates several different lithologic layers.

Well CON.4

Well CON.4 is a flowing well that has 11.6-inch-diameter casing from land surface to a depth of 57 ft and 9.0-inch-diameter casing from 57 to 693 ft. The borehole is uncased from 693 to 716 ft. One interval contains torch-cut slots from 370 to 683 ft (fig. 17). A casing joint at a depth of about 359 ft is offset by about 2 inches. Water can likely flow into or out of the well at this point. A lithologic log was not available for this well.

The temperature log and free-flowing stationary flowmeter measurements indicate inflow zones at depths of about 130 ft, 350 ft, 390 ft, and from 510 to 540 ft, and 640 to 695 ft. Specific-conductance and temperature logs indicate inflow at the top of the 9.0-inch-diameter casing at a depth of 57 ft. The decrease in flow indicated by the free-flowing stationary flowmeter at 57 ft is caused by the change in casing diameter at that depth. The shut-in stationary flowmeter measurements indicate inflow at depths of about 440 ft, from 490 to 570 ft, and below 650 ft. This log does not indicate either inflow or outflow at the top of the 9.0-inch-diameter casing.

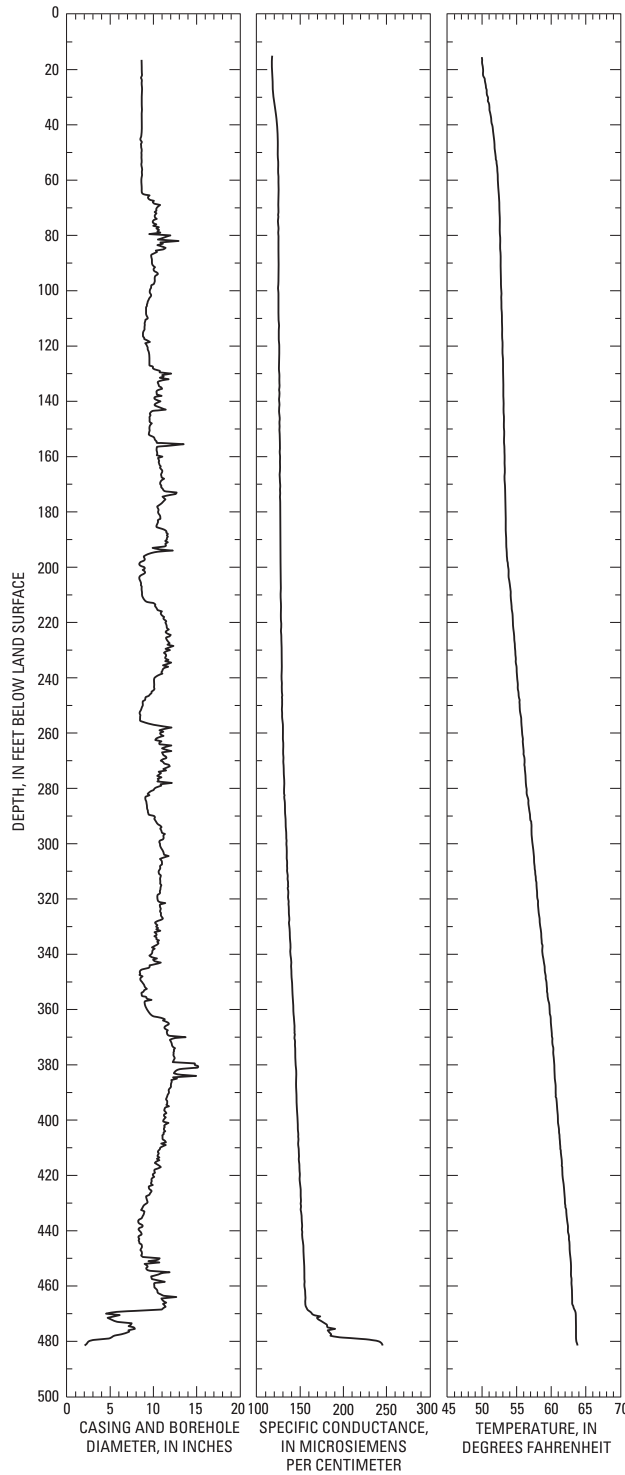


Figure 16. Geophysical well logs for well CON.3.

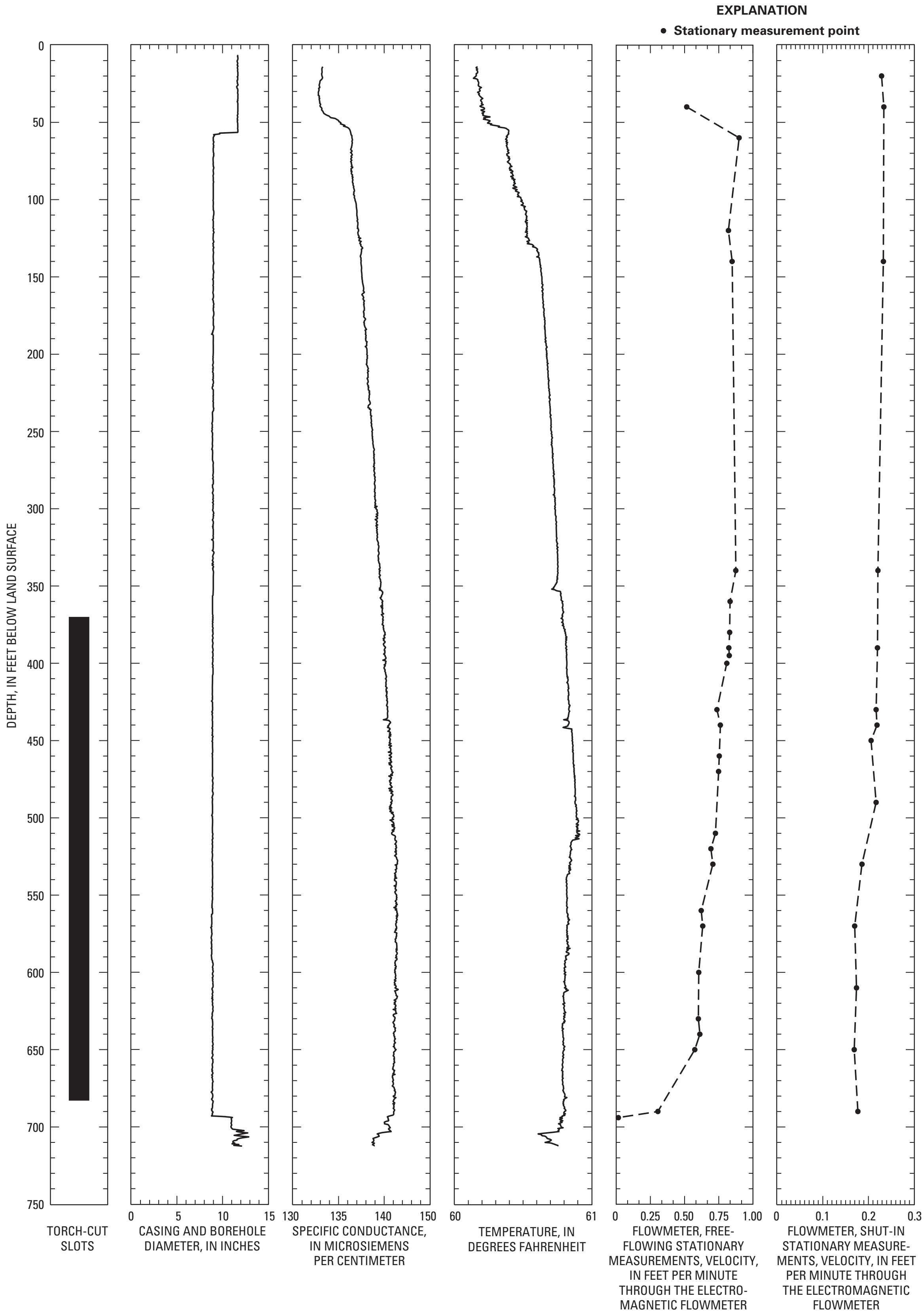


Figure 17. Geophysical well logs for well CON.4.

The video of well CON.4 did not show a break in the casing at a depth of 130 ft. The seal between the surface casing and the 9.0-inch-diameter casing may be leaking. The flowmeter did not detect outflow at the top of the 9.0-inch-diameter casing under shut-in conditions. Water-level measurements in CON.4 are representative of the 346-ft interval with torch-cut slots and any open intervals that result from poor casing integrity that contribute water. The torch-cut slots and open intervals probably intersect several different layers of varying lithologic composition. Thus, because several permeable layers over an interval of at least 346 ft contribute water to CON.4, the water level measured in this well is a composite head measurement.

Costilla County

There is one CAWN well in Costilla County. Wells in Costilla County are named with the "COS" prefix and a sequence number. This well was only partially logged because of difficulties obtaining logs.

Well COS.1

Well COS.1 is an intermittently flowing well that has 5.0-inch casing from land surface to a depth of 182 ft (fig. 18). The locations of casing slots are not known. A lithologic log was not available for this well. A video of well COS.1 was not recorded because of water turbidity and problems with the camera leaking. Flowmeter logs were not recorded in this well.

Specific-conductance and temperature logs recorded under free-flowing conditions indicate that water enters the casing near the bottom of the well. No other inflow zones were apparent from these data. The only conclusion that can be made from the limited amount of data obtained is that well COS.1 is at least partially open to the confined-aquifer system because the water level is above land surface.

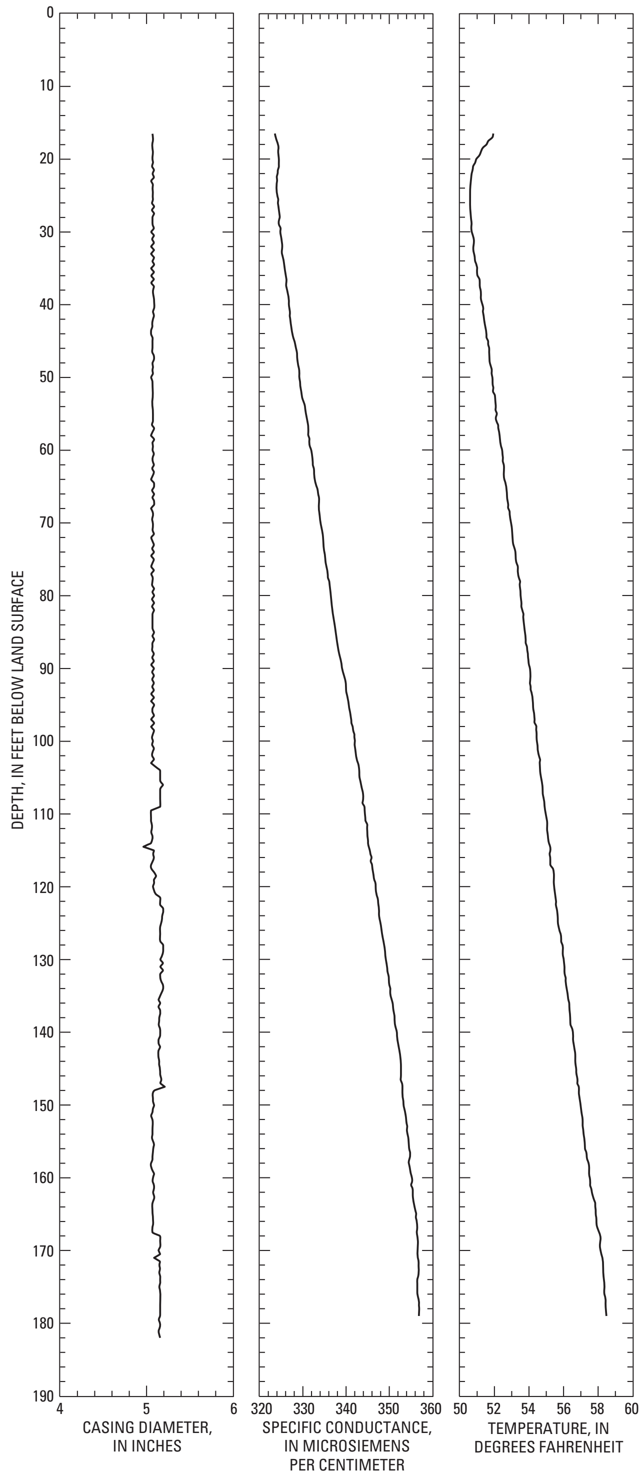


Figure 18. Geophysical well logs for well COS.1.

Rio Grande County

CAWN wells that are in Rio Grande County are named with the "RIO" prefix and a sequence number. All of the four CAWN wells in Rio Grande County were logged.

Well RIO.1

Well Rio.1 was constructed in 1955 and is a nonflowing well used for irrigation and to supply water for wildlife habitat. The casing is 15.3-inch diameter from land surface to a depth of 143 ft, 9.5-inch diameter from 143 to 497 ft, and 9.0-inch diameter from 497 to 599 ft (fig. 19). The video of this well shows that the inside of the casing is thickly encrusted as a result of corrosion of the casing or due to the presence of iron bacteria. The irregular-looking trace of the caliper log results from the encrustations inside the casing. The interval containing torch-cut slots (320 to 599 ft) is open to lithologic layers containing sand, gravel, or cobbles. The lithologic layers contributing water to the well underlie a thin clay layer at a depth from 300 to 305 ft.

Specific-conductance and trolling flowmeter logs recorded during pumping indicate several inflow zones. The flowmeter log indicates a gradual increase in flow in the well from a depth of about 380 to 599 ft, a fairly large increase in flow at a depth of about 380 ft, a gradual increase in flow from a depth of about 280 to 380 ft, and possible flow entering the well just above the top of the 9.5-inch-diameter casing from a depth of about 120 to 143 ft. The temperature log during pumping and flowmeter log in the static water column are not available for this analysis.

The water level measured in well RIO.1 represents a composite head measurement because the well is open to several permeable zones over a 279-ft interval. The zones open to the well through the torch-cut slots (320 to 599 ft) and the zones that may be open to the well due to degraded casing (120 to 143 ft and 280 to 320 ft) or degraded seals (at a depth of 143 ft) contribute to the head measured in well RIO.1.

Well RIO.2

Well RIO.2 was constructed in 1970 for irrigation and domestic uses and is a flowing well. The casing diameter shown in figure 20 was constructed from the reported casing diameters. The casing is 15.5-inch diameter from land surface to a depth of 633 ft and 12.0-inch diameter from 633 to 1,396 ft (fig. 20). The borehole is uncased from 1,396 to 1,446 ft. The intervals containing saw-cut slots (790 to 842 ft; 862 to 901 ft; 993 to 1,027 ft; 1,106 to 1,141 ft; and 1,177 to 1,396 ft) are open to lithologic layers containing (1) sand, gravel, or cobbles and (2) sand or gravel with some clay. The lithologic layers contributing water to the well underlie a thick clay layer at a depth from 103 to 189 ft that lies within a thicker clay layer containing sand or gravel from 65 to 434 ft.

Specific-conductance and temperature logs indicate inflow zones that correspond with intervals having saw-cut slots at depths from 993 to 1,027 ft, 1,106 to 1,141 ft, and 1,177 to 1,380 ft. Inflow also is indicated in two locations that are not identified as open from 920 to 970 ft, and at a depth of about 1,065 ft.

The free-flowing trolling flowmeter log indicates three inflow zones in well RIO.2 at depths from 740 to 990 ft, 1,060 to 1,140 ft, and 1,180 to greater than 1,290 ft. The flowmeter data were not recorded at depths greater than 1,290 ft, but flow probably enters the well at depths greater than 1,290 ft because recorded flow is greater than the tool velocity. Three inflow zones identified in the flowmeter log (740 to 790 ft; 901 to 990 ft; and 1,060 to 1,106 ft) do not correspond to identified saw-cut slots in the casing. Corrosion of the casing or colonies of iron bacteria were found covering much of the casing and potentially obscuring slotted intervals. The decrease in flow observed in the free-flowing trolling flowmeter log at a depth of 633 ft is due to the change in casing diameter at that depth.

Shut-in stationary flowmeter measurements indicate inflow to the well at depths greater than 1,050 ft and outflow from the well at depths less than 1,000 ft. Outflow in the depth interval from 650 to 850 ft may be caused by flow in the annular space behind the casing.

Outflow into the flow zones above 1,000 ft may occur to equalize the difference in heads among the flow zones below 1,050 ft and above 1,000 ft that may have been created during free-flowing conditions, or it may occur due to natural head differences that exist among the different flow zones of the confined-aquifer system. The water level measured in well RIO.2 represents a composite head measurement in the confined-aquifer system because the 606-ft interval contributing flow to this well intersects several different lithologic layers.

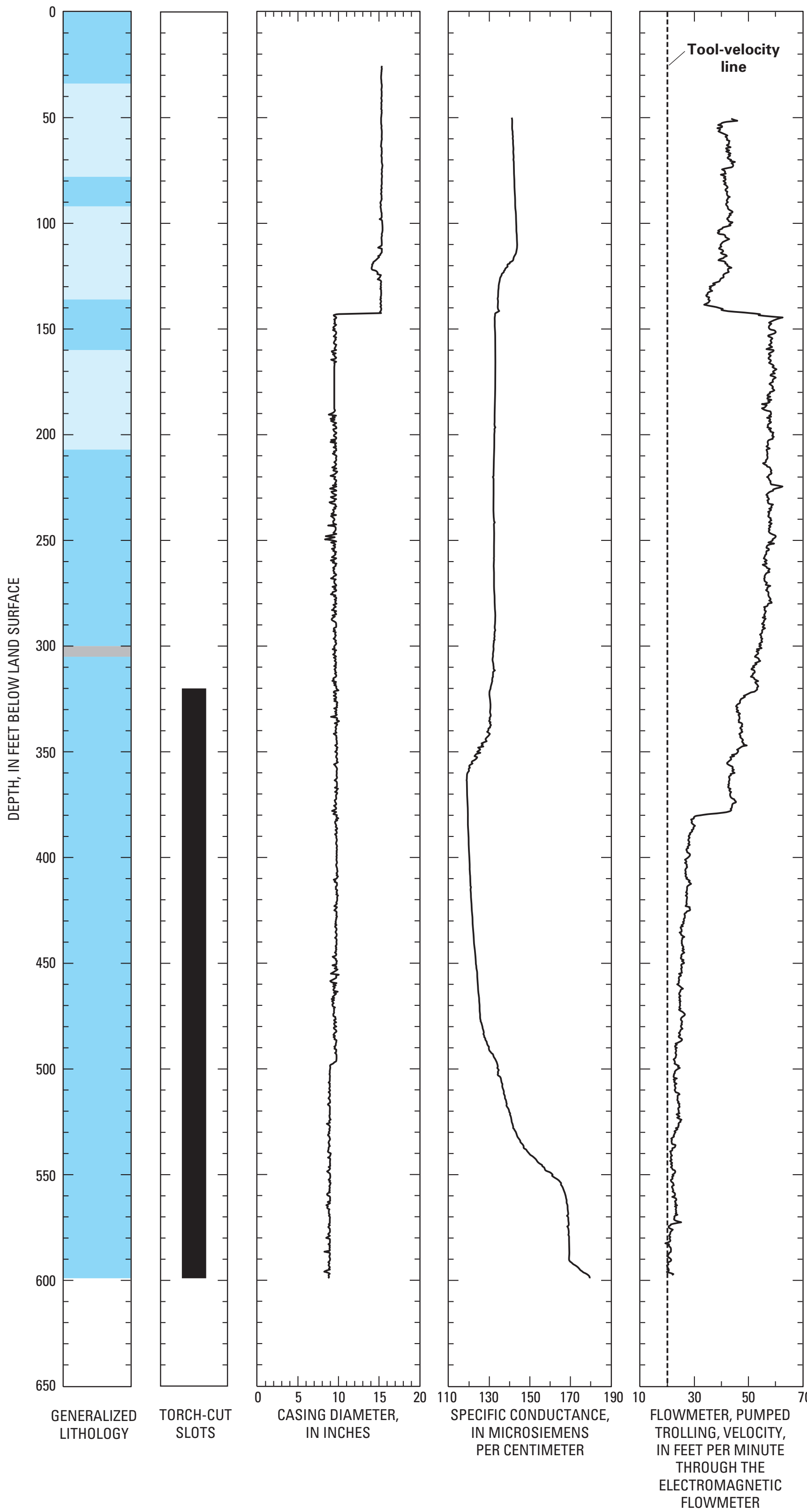


Figure 19. Geophysical well logs for well RIO.1. Refer to figure 2 for generalized lithology.

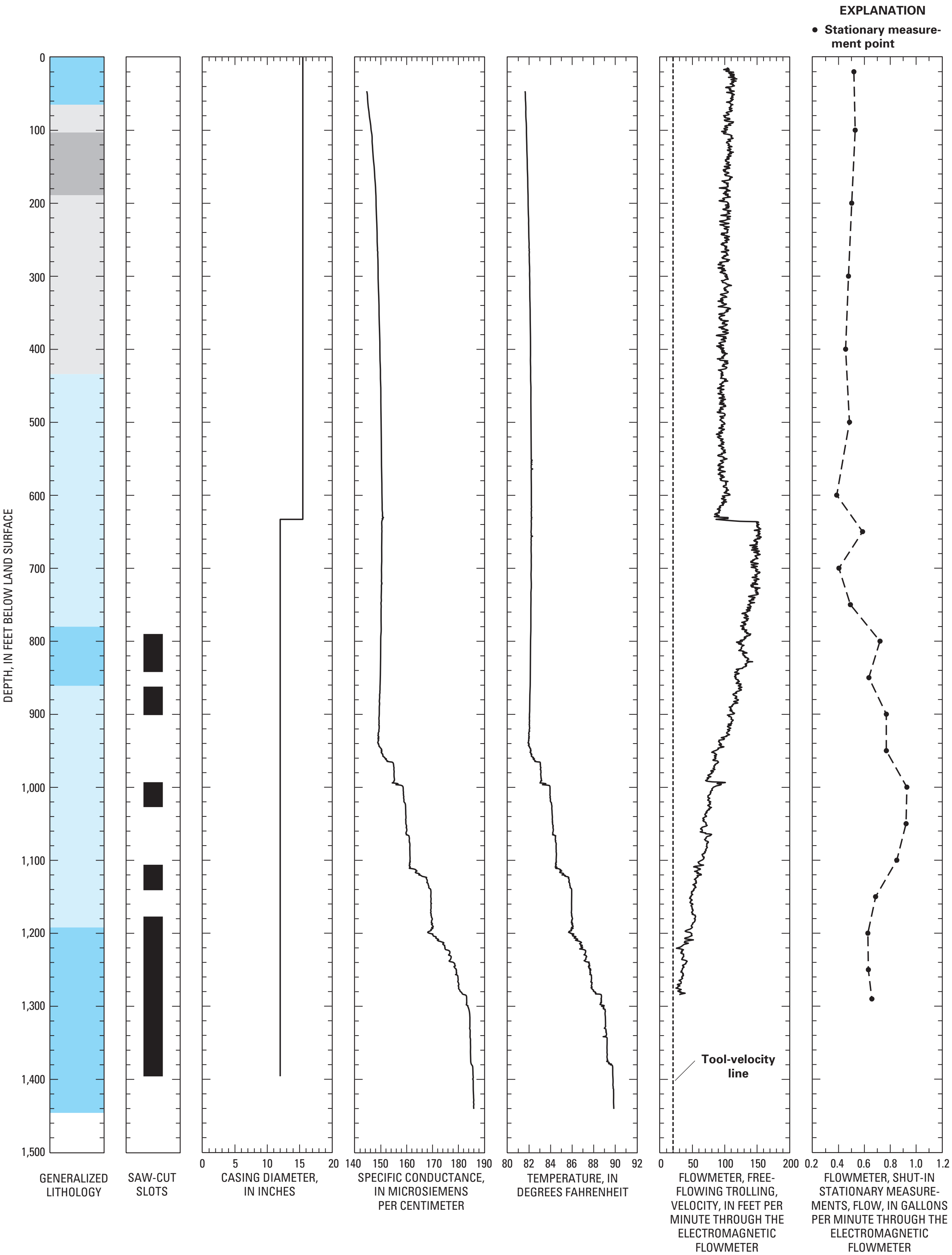


Figure 20. Geophysical well logs for well RIO.2. Refer to figure 2 for generalized lithology.

Well RIO.3

Well RIO.3 is a flowing well that has 3.1-inch casing from land surface to a depth of 199 ft (fig. 21). A lithologic log was not available for this well. Casing perforations were not observed in the video log, but this log showed inflow at a depth of 148 ft as indicated by turbulence in the suspended particles in the water at this depth. The video also showed turbulence at the bottom of the well at a depth of 199 ft.

The free-flowing trolling flowmeter log indicates that most flow in this well comes from the bottom of the well and inflow at a depth of 148 ft is not apparent. Specific-conductance and temperature logs indicate no inflow between the bottom of the well and 148 ft. Inflections in these two logs indicate flow entering the well at 148 ft. None of the logs indicate other inflow zones to this well.

The water level measured in this well is a composite head measurement from two inflow zones at depths of 148 ft and 199 ft.

Well RIO.4

Well Rio.4 was constructed in 1956 for irrigation use and is a flowing well. The casing is 17.3-inch diameter from land surface to a depth of 59 ft and 13.9-inch diameter from 59 to 952 ft. The one interval containing torch-cut slots from 350 to 952 ft is open to

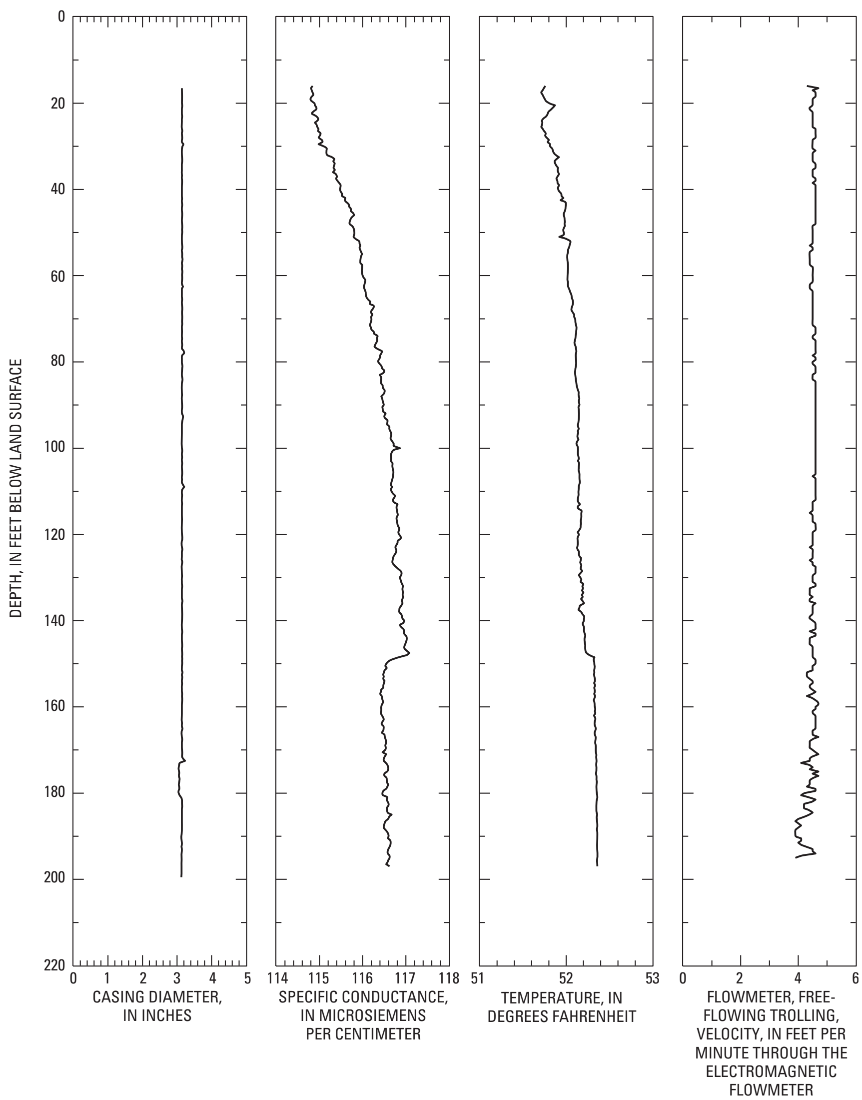


Figure 21. Geophysical well logs for well RIO.3.

lithologic layers containing (1) sand, gravel, or cobbles and (2) clay with some sand or gravel (fig. 22). The lithologic layers contributing water to the well underlie a clay layer at a depth from 64 to 90 ft.

Both the free-flowing and shut-in trolling flowmeter logs indicate that most of the flow in this well comes from an upper inflow zone at depths from 400 to 570 ft. The free-flowing trolling flowmeter log indicates that the two lower inflow zones indicated on the temperature log from 770 to 800 ft and 850 to 880 ft contribute little to the total amount of free-flowing discharge. The predominance of inflow from the upper zone (400 to 570 ft) rather than the lower zones (770 to 800 ft and 850 to 880 ft) may be due to greater permeabilities in this upper zone. The traces of both the free-flowing and shut-in trolling flowmeter logs show similar profiles, so there are no significant head differences between the upper (400 to 570 ft) and lower (770 to 880 ft) flow zones.

The water level measured in well RIO.4 is a composite head measurement representative of the 602-ft open interval at depths from 350 to 952 ft.

Saguache County

CAWN wells that are in Saguache County are named with the “SAG” prefix and a sequence number. Geophysical logs were recorded in 13 of the 17 CAWN wells in Saguache County. One well, SAG.6, is not discussed in detail because the inside of the casing was too encrusted to allow flowmeter logging and the other logs did not provide useful information for analysis.

Well SAG.1

Well SAG.1 was constructed in 1963 for irrigation use and is a nonflowing well. The casing is 15.0-inch diameter from land surface to a depth of 183 ft and 12.0-inch diameter from 183 to 801 ft. One interval containing torch-cut slots (276 to 800 ft) is open to lithologic layers containing (1) sand, gravel, or cobbles; (2) clay with some sand or gravel; and (3) sand or gravel with some clay (fig. 23).

Inflections in the temperature log indicate inflow may occur near the bottom of the well and above the top of the 12.0-inch-diameter casing at a depth of 183 ft. The trolling flowmeter log recorded during pumping does not indicate an increase in flow above the bottom of the well. The flowmeter calibration is probably shifted by about 8–10 ft/min, as indicated by the poor match between the log and the tool-velocity line. The trace of the flowmeter log indicates most of the inflow occurs near the top of the 12-inch casing at a depth of 183 ft and a smaller amount of inflow occurs at depths from 80 to 175 ft. Flooding that occurs in a neighbor’s basement is reported to subside when this well is being pumped (Fred Huss, Rio Grande Water Conservation District, oral commun., February 2000), which indicates a deteriorated surface casing or seal between the two casings that provides connection with the shallow aquifer.

The water level measured in this well is a composite of head conditions at depths of 183 and 801 ft. No increase in flow was measured in the depth interval from 183 to 801 ft, but this well is open to lithologic layers of the confined-aquifer system through the 524-ft-long interval containing torch-cut slots.

Well SAG.2

Well SAG.2 was constructed in 1967 for irrigation and stock-water use and is a flowing well. The casing is 15.8-inch diameter from land surface to a depth of 86 ft, 12.5-inch diameter from 86 to 884 ft, and 9.1-inch diameter from 884 to 1,958 ft. The intervals containing torch-cut slots (901 to 1,203 ft; 1,249 to 1,380 ft; 1,425 to 1,510 ft; 1,556 to 1,683 ft; 1,728 to 1,812 ft; and 1,838 to 1,953 ft) are open to lithologic layers containing (1) clay; (2) sand, gravel, or cobbles; (3) clay with some sand or gravel; and (4) sand or gravel with some clay (fig. 24). The lithologic layers contributing water to the well underlie a thick clay layer that occurs from a depth of 290 to 380 ft.

Specific-conductance, temperature, and free-flowing trolling flowmeter logs indicate inflow occurs from a depth of 1,020 to 1,958 ft. At depths greater than 1,200 ft, inflow does not occur uniformly. Narrow inflow zones are interspersed with zones of no inflow to the well and yield a rate of inflow to the well that is fairly uniform from a depth of 1,200 to 1,958 ft. Most of the inflow occurs in two zones from 1,020 to 1,060 ft and 1,150 to 1,200 ft and lesser amounts of inflow occur from a depth of 1,060 to 1,150 ft.

In addition to the inflow zones identified on the free-flowing trolling flowmeter log, the free-flowing

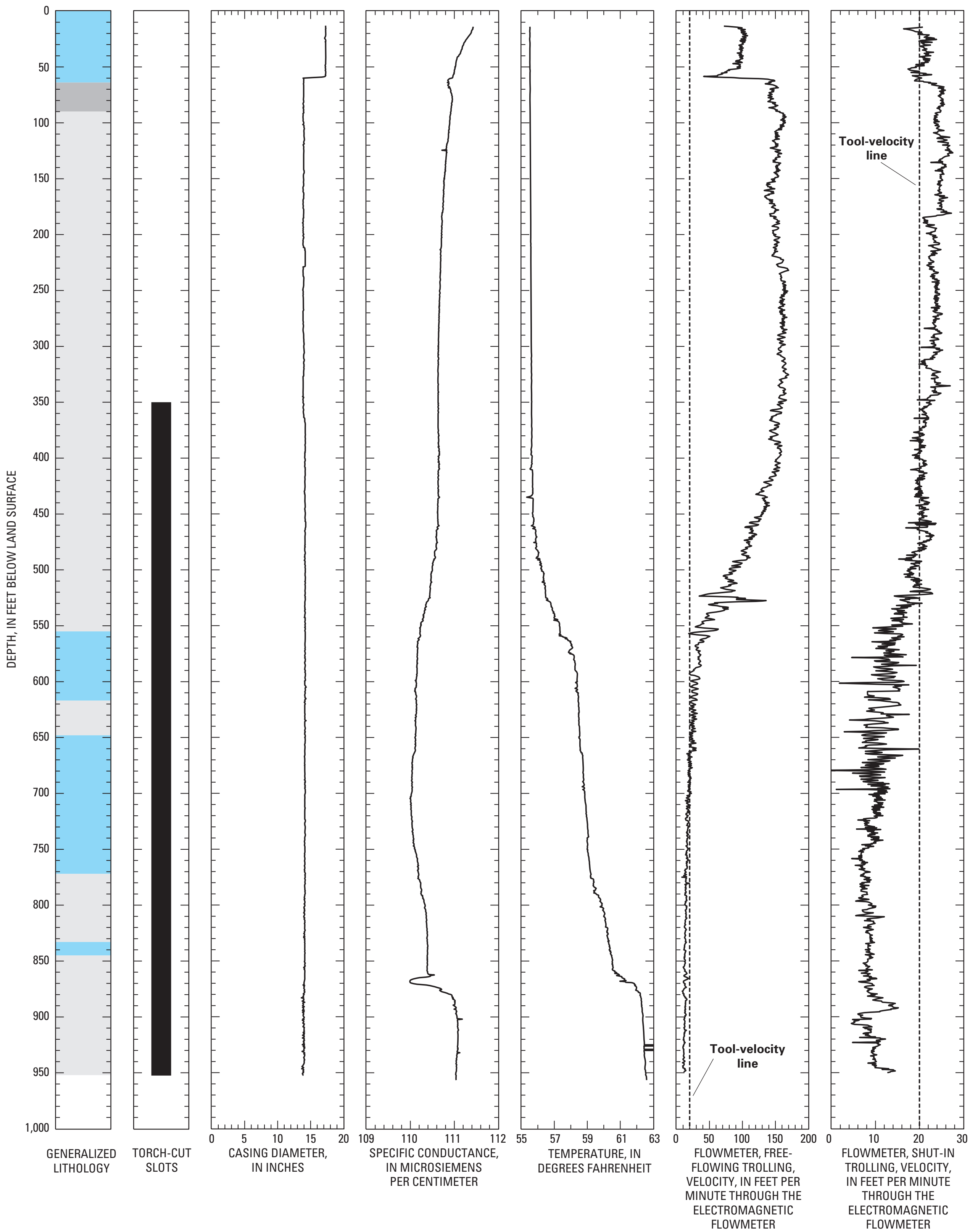


Figure 22. Geophysical well logs for well RIO.4. Refer to figure 2 for generalized lithology.

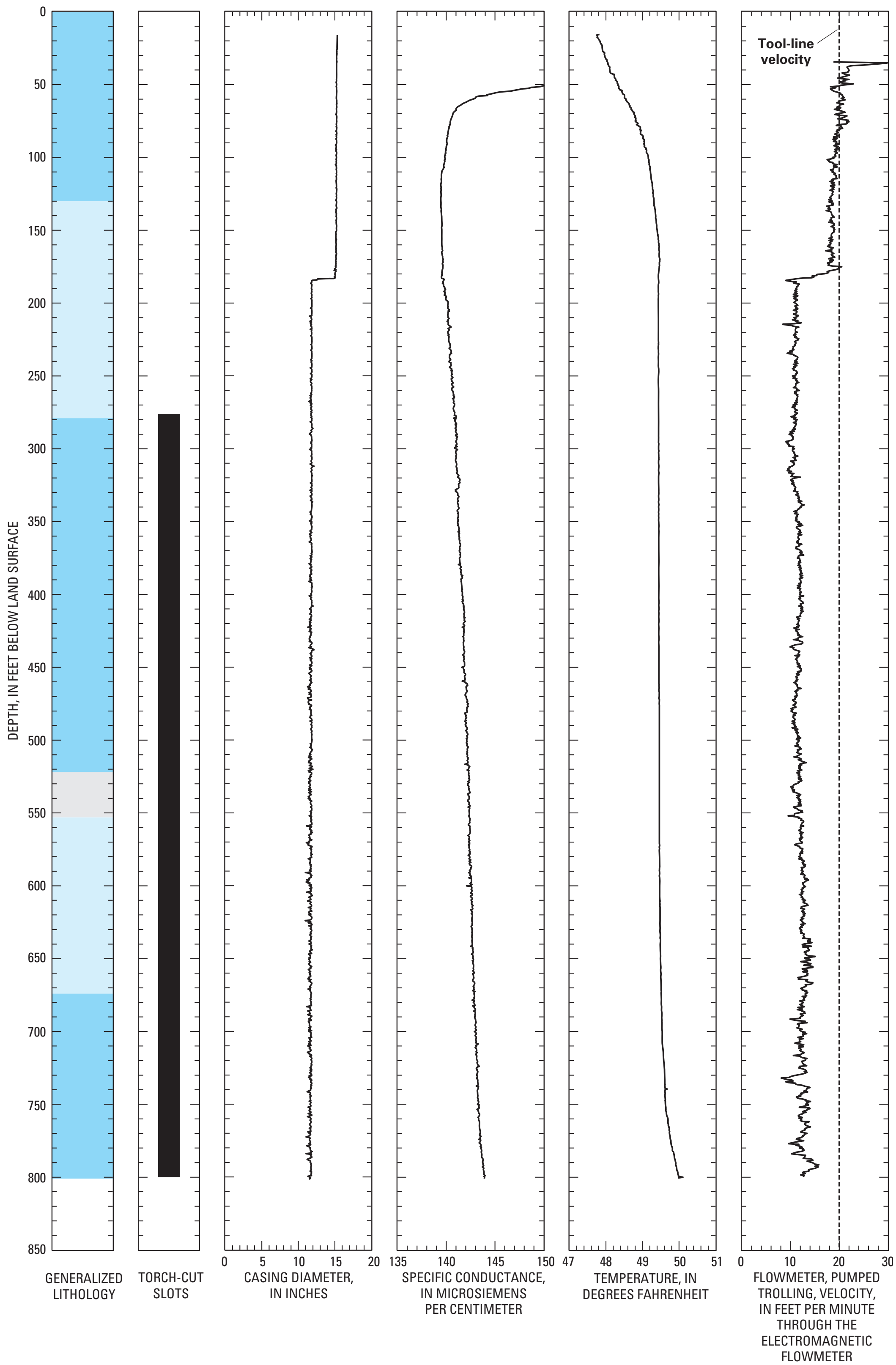


Figure 23. Geophysical well logs for well SAG.1. Refer to figure 2 for generalized lithology.

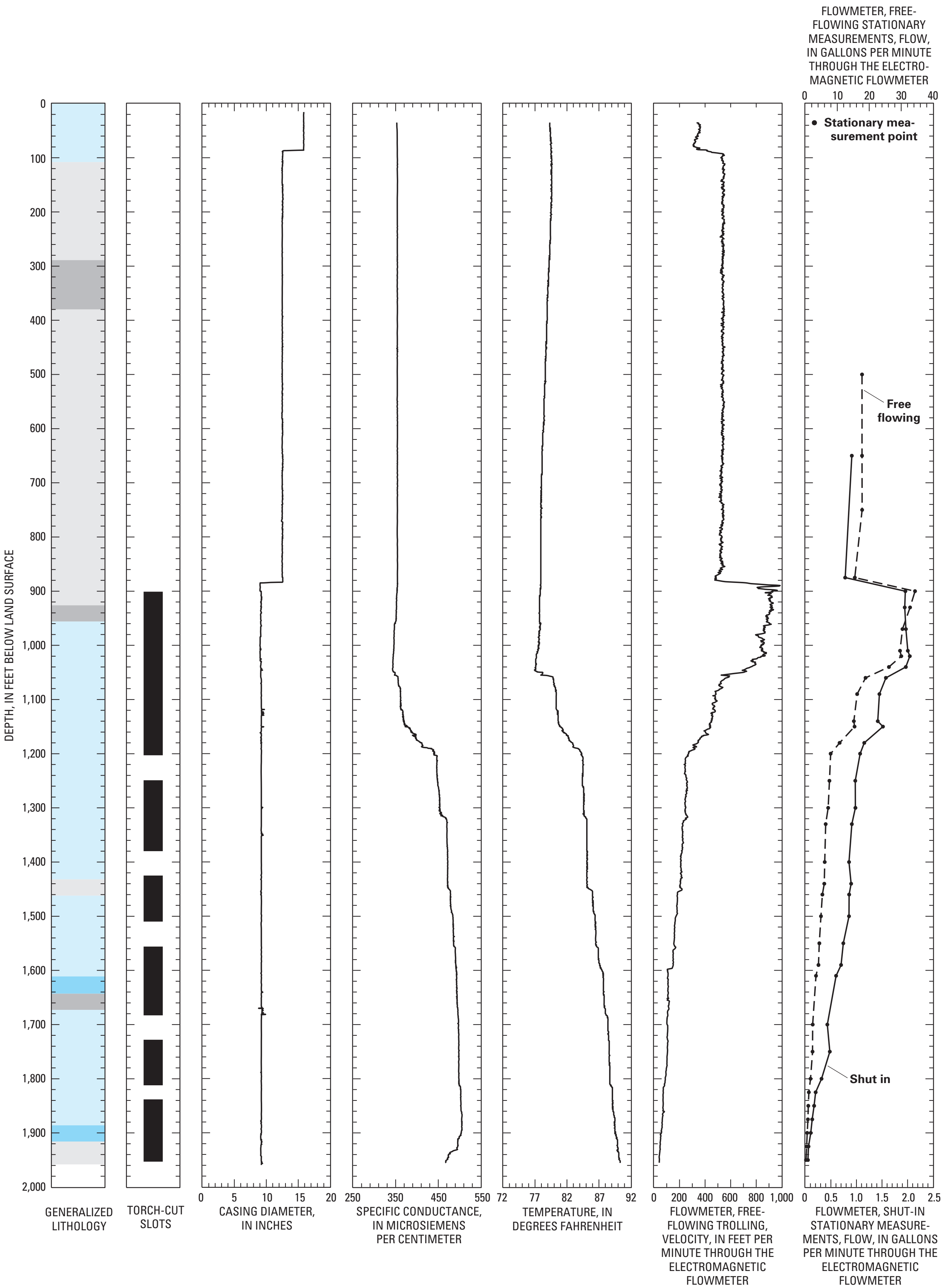


Figure 24. Geophysical well logs for well SAG.2. Refer to figure 2 for generalized lithology.

stationary flowmeter measurements indicate a small amount of inflow from a depth of 901 to 1,000 ft. The shut-in stationary flowmeter measurements indicate outflow either to lithologic layers or into the annular space between depths of 901 and 1,000 ft. The decrease in flow observed in all flowmeter logs at a depth of 884 ft results from the change in casing diameter at that depth.

A small reduction of flow is indicated by the shut-in stationary flowmeter measurements from a depth of 1,080 to 1,140 ft. This reduction in flow may be due to imperfections in the casing diameter, to annular flow, or to outflow into a flow zone above a depth of 1,200 ft. It is not known whether a difference in heads between the lower (below 1,200 ft) and upper (above 1,200 ft) flow zones exists under stable conditions.

The water level measured in SAG.2 represents a composite measurement of the heads in the permeable intervals open to the well from a depth of 901 to 1,958 ft and which extend over a distance of 1,057 ft.

Well SAG.4

Well SAG.4 was constructed in 1964 for irrigation use and is a flowing well. The casing is 12.6-inch diameter from land surface to a depth of 916 ft and 9.4-inch diameter from 916 to 2,298 ft. The interval containing torch-cut slots (1,039 to 2,298 ft) is open to lithologic layers containing (1) sand, gravel, or cobbles; (2) sand or gravel with some clay; and (3) clay with some sand or gravel (fig. 25). Four layers containing mostly clay with some sand or gravel are at depths from 184 to 549 ft, 701 to 822 ft, 944 to 1,451 ft, and 1,916 to 2,035 ft. A video of the well was not available to confirm the integrity of the casing or to confirm the location of the torch-cut slots. Construction details listed here are taken from the construction information reported on the well permit.

Specific-conductance, temperature, free-flowing trolling flowmeter, and free-flowing stationary flowmeter logs indicate inflow occurs throughout the zone from a depth of 1,000 to 2,298 ft. Inflow occurs at three different rates in three zones at depths from 1,000 to 1,440 ft, 1,440 to 1,640 ft, and 1,640 to 2,298 ft. Most of the inflow occurs within the zone from a depth of 1,440 to 1,640 ft. Alternating zones of inflow to and outflow from the well from a depth of 1,020 to 1,160 ft may indicate flow into the annular space behind the casing where outflow is indicated and flow reentering the well from behind the casing where inflow is indicated. The decrease in flow observed in all the flowmeter logs at a depth of 916 ft is due to the change in casing diameter at that depth.

Under shut-in conditions, inflow to SAG.4 occurs at depths from 1,400 to 2,298 ft and outflow was observed at depths from 1,020 to 1,340 ft, with possible annular flow at depths from 1,020 to 1,160 ft.

Depths of the open interval of this well might differ from the reported construction because changes in flow were detected at depths from 1,020 to 1,039, where no slots are reported. Outflow into the flow zones above 1,420 ft under shut-in conditions may occur to equalize the difference in heads among the flow zones below 1,420 ft and above 1,420 ft that may have been created during free-flowing conditions, or it may occur due to natural head differences that exist among the different flow zones of the confined-aquifer system. The water level measured in SAG.4 represents a composite measurement of the heads in the permeable intervals open to the well from a depth of 1,020 to 2,298 ft, which extend over a distance of 1,278 ft.

Well SAG.5

Well SAG.5 is a nonflowing well with 6.3-inch casing from land surface to a depth of 522 ft (fig. 26). Video observations indicate two intervals containing stainless-steel screens at depths from 458 to 463 ft, and 477 to 497 ft. A lithologic log was not available for this well. Flowmeter logs were recorded in SAG.5 under static and pumped conditions. Neither of these logs provided information that was useful for this analysis.

The specific-conductance log recorded in the static water column indicates some variation with depth; but after each departure, the log returns to a steady trend so flow is not indicated on this log. The specific-conductance log recorded during pumping shows a sharp inflection at a depth of 340 ft and a smaller inflection that indicates inflow probably enters the well between 458 and 497 ft. The sharp inflection at a depth of 340 ft likely is a front of higher specific-conductance water that entered the well in the open interval and then slowly moved up the well as pumping continued. The temperature log recorded during pumping approximately reflects the geothermal gradient above a depth of 350 ft and indicates possible inflow to the well from a depth of 460 to 520 ft.

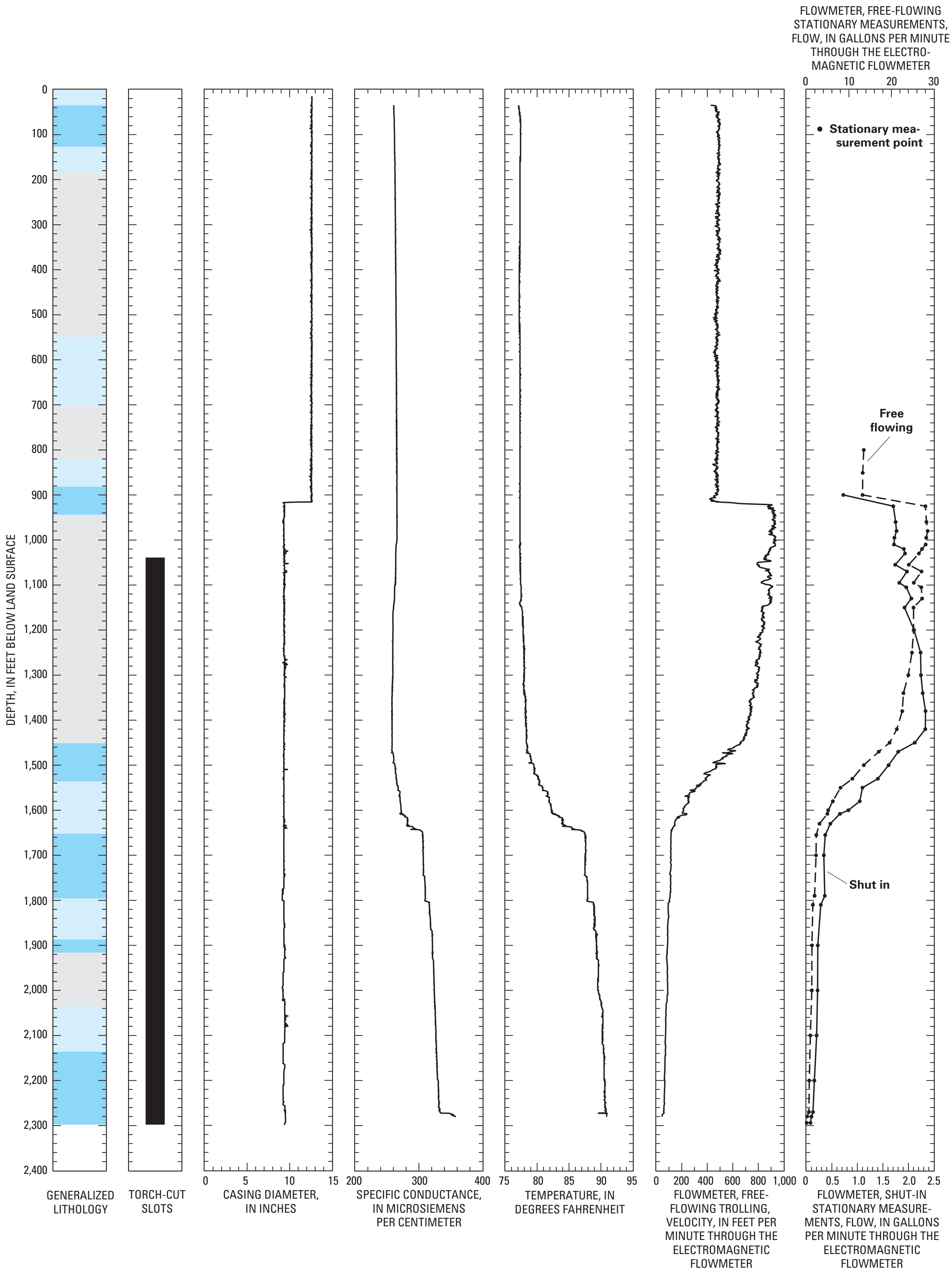


Figure 25. Geophysical well logs for well SAG.4. Refer to figure 2 for generalized lithology.

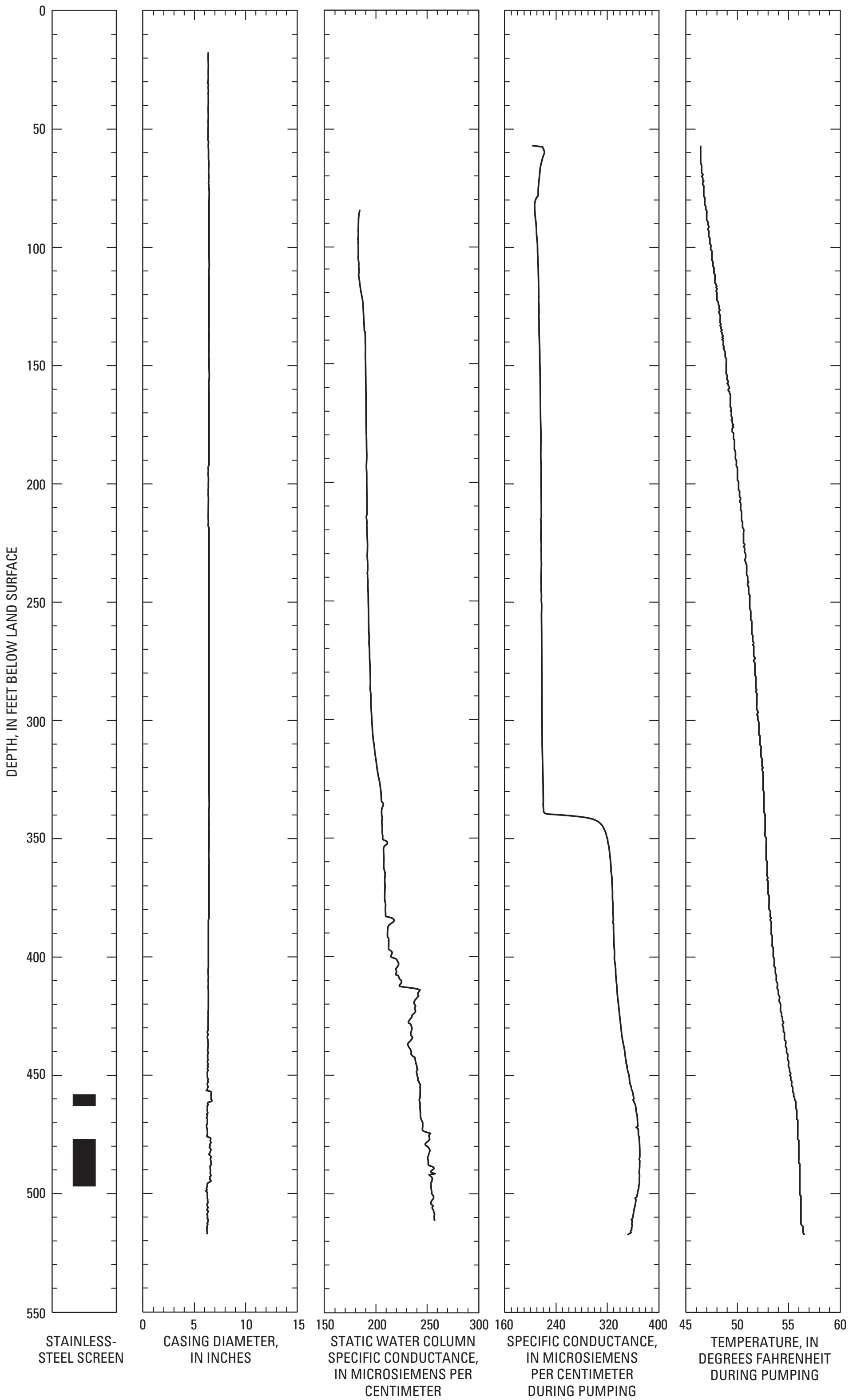


Figure 26. Geophysical well logs for well SAG.5.

The specific-conductance log recorded during pumping indicates that inflow enters well SAG.5 in the screened intervals. Water levels in this well from July 1995 through February 2001 are shown in figure 27. The water level in SAG.5 dropped approximately 6 ft during the time the well was pumped during well logging in August 1999. After almost 2 years, the water level was still not recovered to the level it had before the well was pumped for logging. Although well SAG.5 is open to a narrow interval, the water level measured in this well is probably not representative of head conditions in the confined-aquifer system.

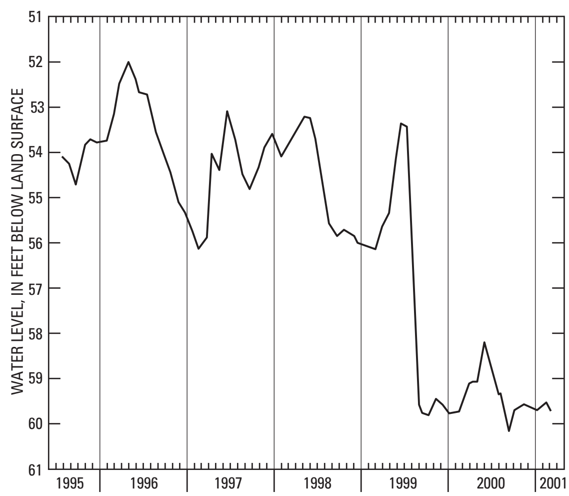


Figure 27. Water level in well SAG.5.

Well SAG.7

Well SAG.7 is a nonflowing well used only for monitoring water levels in the confined-aquifer system. The atypically constructed casing is 6.2-inch diameter from land surface to a depth of 24 ft and 10.3-inch diameter from 24 to 386 ft (fig. 28). A lithologic log was not available for this well. The video of this well did not show slots in the casing above the bottom of the well. Well SAG.7 was previously reported to be 500 ft deep with the first torch-cut slots at 437 ft. Flowmeter logs recorded in this well did not provide useful information for this analysis.

The specific-conductance and temperature logs recorded in the static water column do not show movement of water in the casing. Below a depth of 30 ft, the temperature log approximates the geothermal gradient of 3.17 degrees Fahrenheit per 100 ft. The specific-conductance log recorded during pumping shows an inflection from a depth of 230 to 280 ft and uniform specific-conductance water below a depth of 280 ft. The temperature log recorded during pumping also shows an inflection from a depth of about 230 to 280 ft.

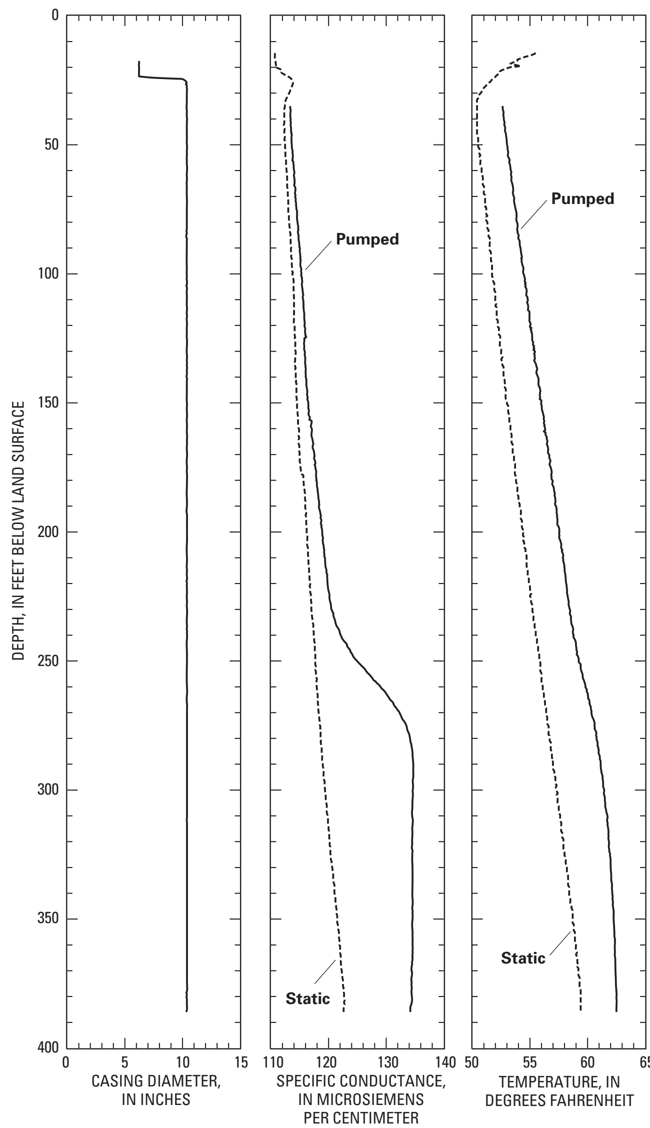


Figure 28. Geophysical well logs for well SAG. 7.

Because SAG.7 was previously reported to be 500 ft deep and data collected for this study indicate a depth of 386 ft, the depth where the casing slots occur is unknown. Specific-conductance and temperature data indicate that water is rising from the bottom of the well at a depth of 386 ft. Water levels in SAG.7 are responsive to water-level changes in the confined-aquifer system (fig. 29). Therefore, the water level measured in this well probably is a composite measurement of the head in the confined-aquifer system within some unknown depth interval.

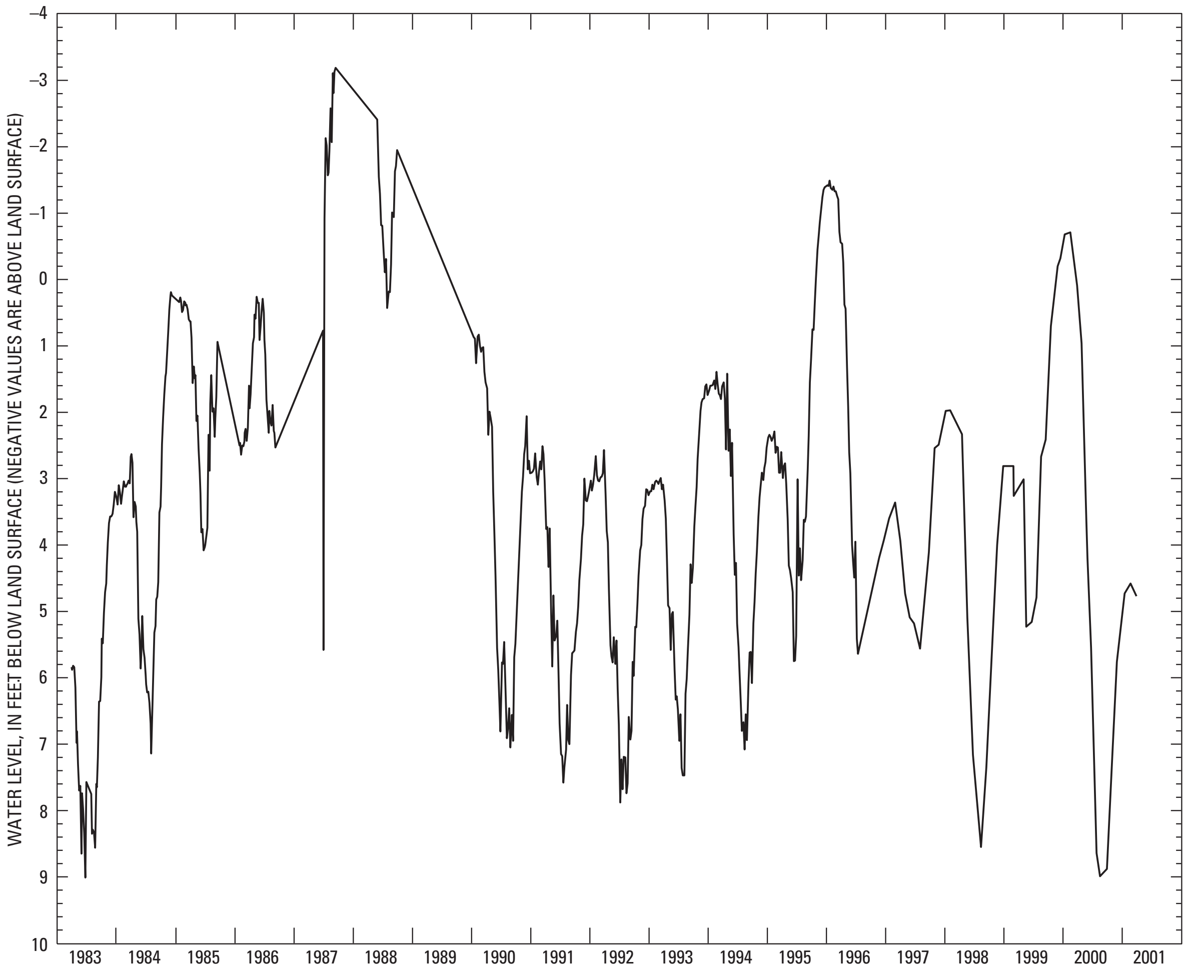


Figure 29. Water level in well SAG.7.

Well SAG.9

Well SAG.9 was constructed in 1998 for irrigation and stock-water use and is a flowing well. The casing is 17.6-inch diameter from land surface to a depth of 147 ft and 11.9-inch diameter from 147 to 649 ft (fig. 30). The borehole is uncased from 649 to 665 ft. SAG.9 is a replacement for a similarly constructed well that existed about one-quarter mile north. A lithologic log was not available for well SAG.9, but the lithologic log for the previous well was used for generalized lithology at this well. The interval containing torch-cut slots from 285 to 647 ft likely is open to lithologic layers containing (1) sand, gravel, or cobbles; (2) clay; and (3) clay with some sand or gravel. The replaced well had a clay layer at depths from about 105 to 280 ft, so a fairly thick clay layer probably exists above the permeable interval of this well.

The specific-conductance and temperature logs indicate that under free-flowing conditions inflow to this well occurs in two zones from a depth of 290 to 500 ft and at depths greater than 625 ft. The spinner flowmeter was used in this well because the EM flowmeter was unavailable. The free-flowing trolling flowmeter log indicates that water enters the well in the uncased portion of the well and at depths from 300 to 590 ft. The shut-in trolling flowmeter log indicates a small amount of inflow to the well at depths from 380 to 430 ft. Only a small amount of outflow from well SAG.9 is indicated because the trace of the shut-in trolling flowmeter log lies near the tool-velocity line.

The two inflow zones likely are separated by a clay layer at a depth of about 475 to 550 ft that was identified in the lithologic log for the replaced well north of well SAG.9. Only a small amount of flow was measured under shut-in conditions, which indicates

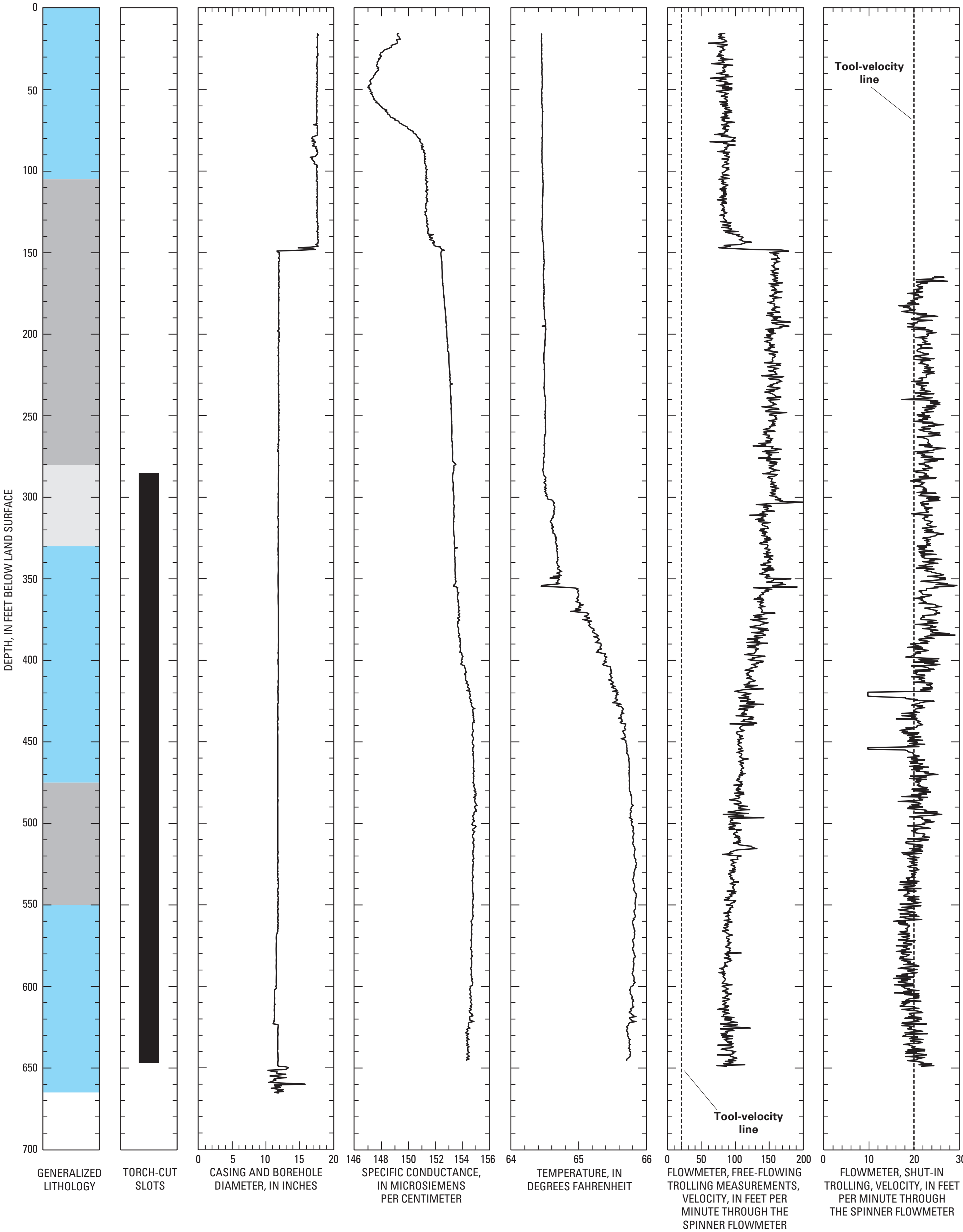


Figure 30. Geophysical well logs for well SAG.9. Refer to figure 2 for generalized lithology.

little or no head difference between the two inflow zones at the time the measurements were recorded. Water levels in this well represent a composite measurement of the head in the two inflow zones within the 380-ft interval from a depth of 285 to 665 ft.

Well SAG.10

Well SAG.10 was constructed in 1963 for irrigation and stock-water use and is a flowing well. The casing is 11.7-inch diameter from land surface to a depth of 848 ft and 8.9-inch diameter from 848 to 1,974 ft (fig. 31). Three intervals containing torch-cut slots (886 to 1,245 ft; 1,290 to 1,376 ft; and 1,424 to 1,974 ft) are open to lithologic layers containing (1) sand, gravel, or cobbles; (2) sand or gravel with some clay; and (3) clay with some sand or gravel. The lithologic layers contributing water to the well are below a thin clay layer from a depth of 102 to 128 ft and a thick, predominantly clay layer from a depth of 128 to 670 ft.

The specific-conductance and temperature logs indicate several inflow zones to well SAG.10. The free-flowing trolling flowmeter log indicates three different rates of inflow in three adjacent zones at depths from 886 to 1,140 ft, 1,140 to 1,500 ft, and 1,500 to 1,800 ft. The rate of inflow to the well increases between these three zones as depth decreases. Shut-in stationary flowmeter measurements indicate a zone of inflow from 1,140 to 1,500 ft and a zone of outflow from 860 to 1,140 ft. Flowmeter measurements were not made above the top of the 8.9-inch-diameter casing.

Outflow into the flow zones from 860 to 1,140 ft may occur to equalize the difference in heads among the flow zones below 1,140 ft and above 1,140 ft that may have been created during free-flowing conditions, or it may occur due to natural head differences that exist among the different flow zones of the confined-aquifer system. The water level measured in well SAG.10 represents a composite head measurement in the confined-aquifer system, because the 1,088-ft interval contributing flow to this well intersects several different lithologic layers.

Well SAG.11

Well SAG.11 was constructed in 1955 for irrigation use and is a flowing well. The casing is 15.6-inch diameter from land surface to a depth of 34 ft and 10.6-inch diameter from 34 to 1,322 ft (fig. 32). Two intervals containing torch-cut slots (540 to 670 ft and 834 to 1,320 ft) are open to lithologic layers containing (1) sand or gravel with some clay and (2) clay with some sand or gravel. The lithologic layers contributing water to the well lie below a thick clay layer that is present from a depth of 231 to 299 ft.

The temperature log indicates that water enters well SAG.11 throughout both of the intervals that contain torch-cut slots. The free-flowing stationary flowmeter measurements indicate four zones of inflow at depths from 850 to 900 ft, 1,065 to 1,090 ft, 1,170 to 1,250 ft, and greater than 1,274 ft. Outflow from the well from a depth of 600 to 640 ft may be caused by flow into the annular space or to flow into a lithologic layer.

The shut-in stationary flowmeter measurements indicate that water enters the casing from depths of about 1,100 to 1,300 ft, and water flows out of the casing from depths of about 550 and 700 ft. Shut-in measurements were recorded before the heads in each of the open zones had stabilized. Thus, outflow into the zone from 550 to 700 ft may occur to equalize the heads among the upper and lower slotted intervals, or the outflow may occur due to head differences that exist under both stable and nonstable head conditions.

The water level measured in well SAG.11 represents a composite head measurement in the confined-aquifer system, because the 780-ft interval contributing flow to this well intersects several different lithologic layers.

Well SAG.12

Well SAG.12 is a flowing well with casing that is 16.0-inch diameter from land surface to a depth of 149 ft, 12.0-inch diameter from 149 to 349 ft, and 7.3-inch diameter from 349 to 576 ft (fig. 33). Torch- and saw-cut slots occur from a depth of 150 to 570 ft. A lithologic log was not available for this flowing well. The spinner flowmeter was used in this well because the EM flowmeter was unavailable.

The specific-conductance, temperature, and free-flowing trolling spinner flowmeter logs indicate two inflow zones in this well at depths from 458 to 465 ft, and 490 to 576 ft. The flowmeter log indicates outflow from a depth of 410 to 430 ft. The decrease in flow observed in both flowmeter logs around depths of 149 and 349 ft result from the changes in casing diameters at those depths. Under shut-in conditions, flow is

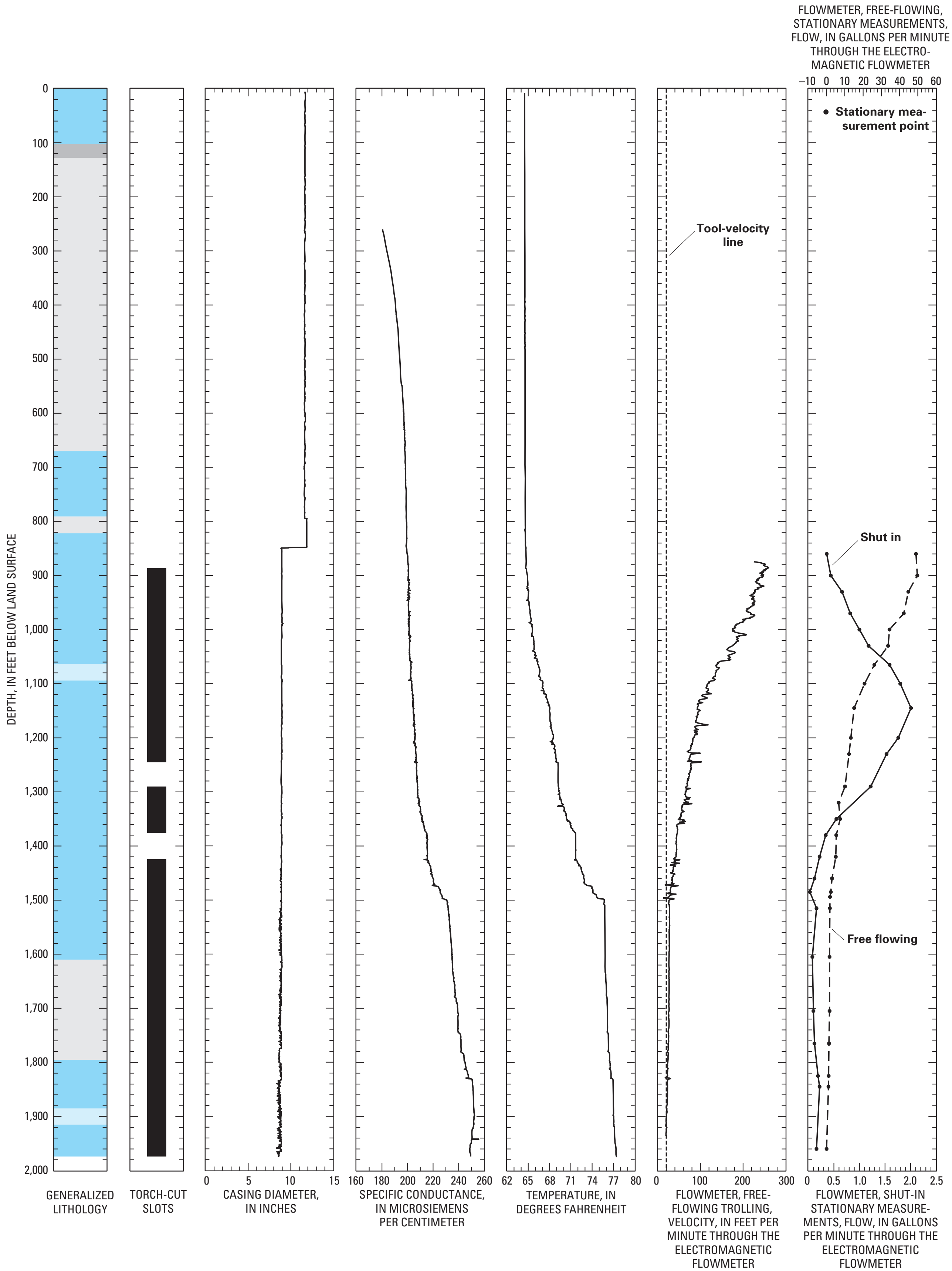


Figure 31. Geophysical well logs for well SAG.10. Refer to figure 2 for generalized lithology.

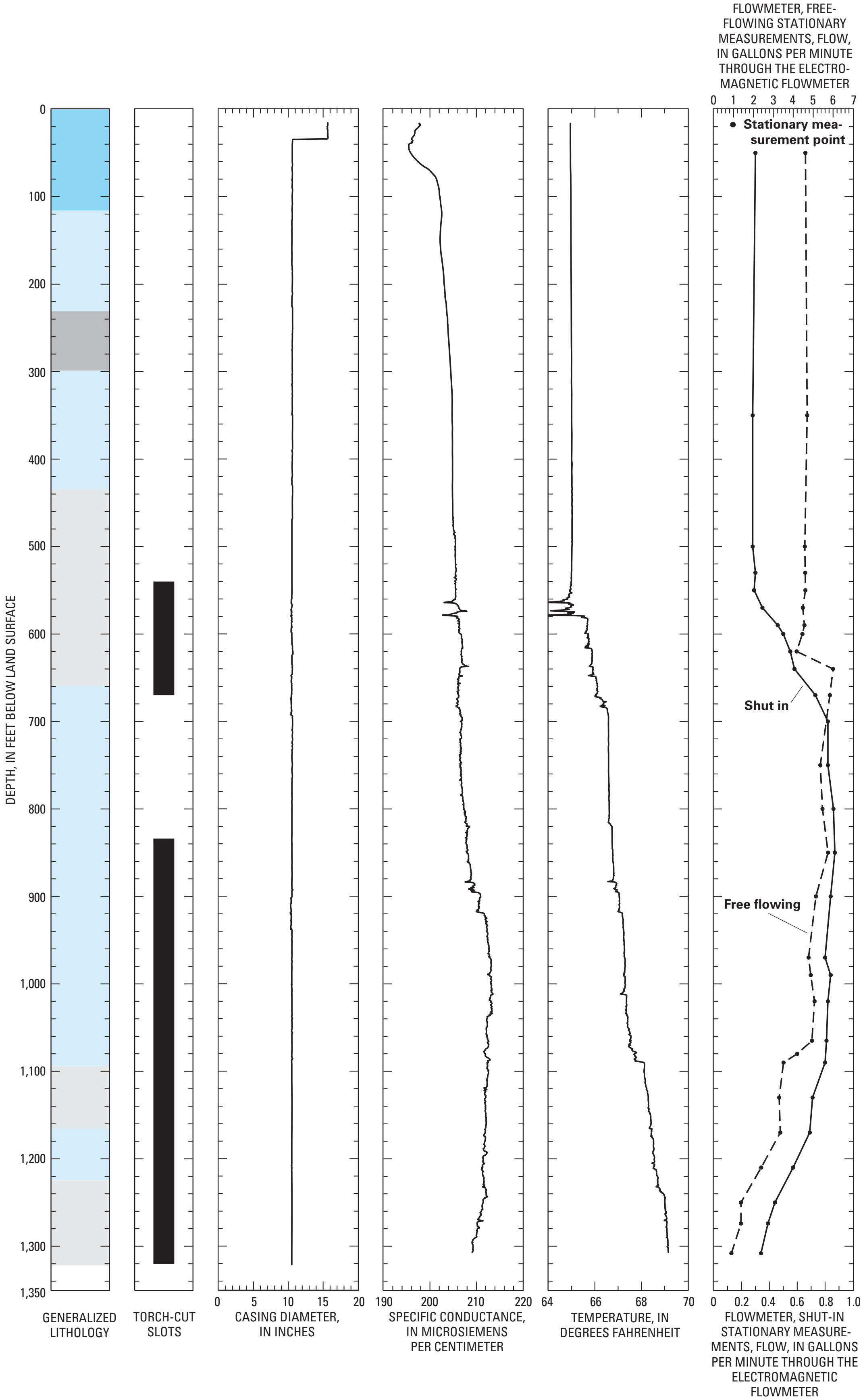


Figure 32. Geophysical well logs for well SAG.11. Refer to figure 2 for generalized lithology.

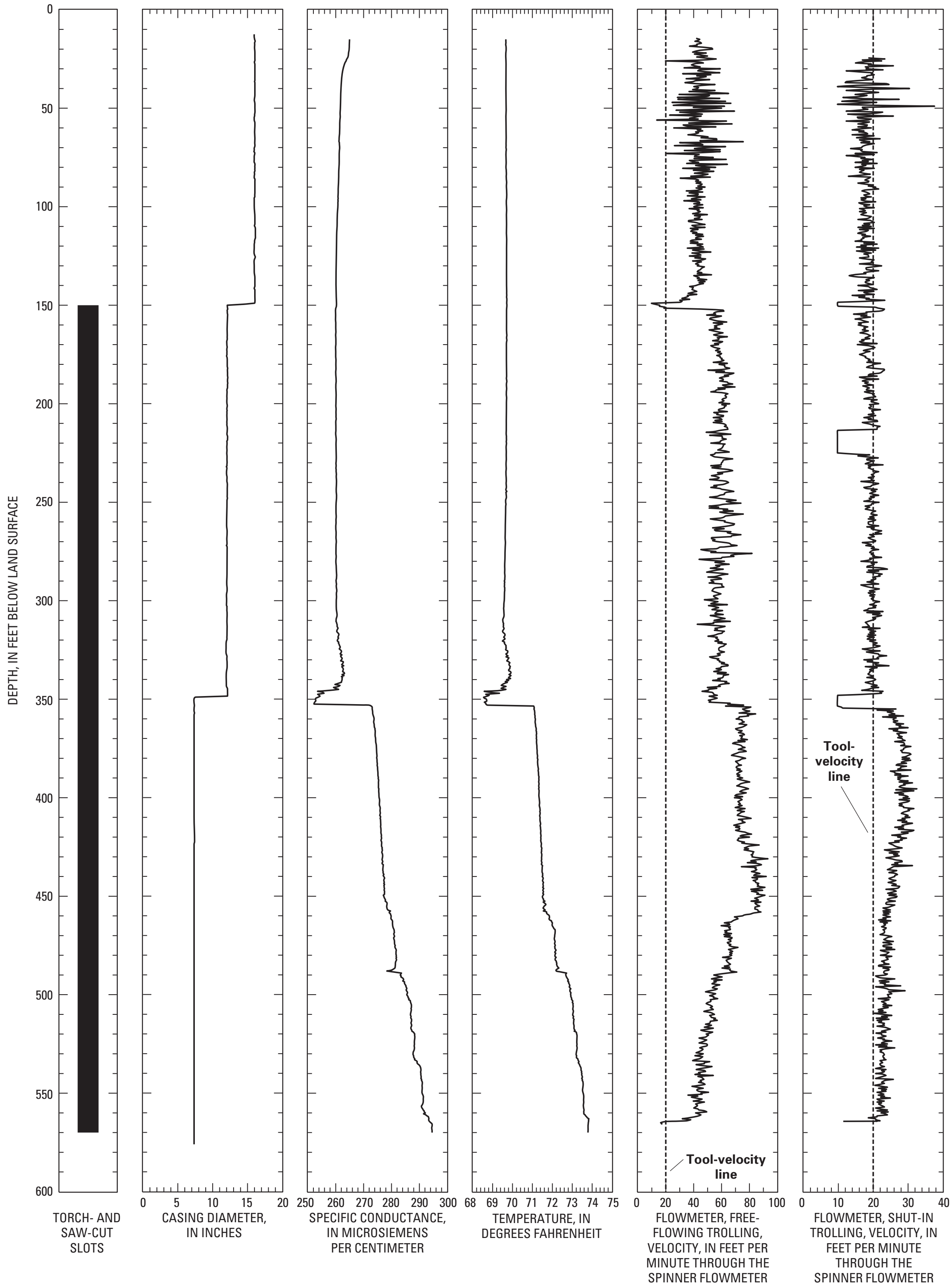


Figure 33. Geophysical well logs for well SAG.12.

not indicated in most of the well because the shut-in trolling flowmeter log lies on the tool-velocity line at depths less than 350 ft; however, inflow does occur at depths from 420 to 460 ft and just above 576 ft. Outflow from the casing occurs from a depth of 355 to 380 ft. The outflow measured under shut-in conditions likely was flow into lithologic layers rather than into the annular space because flow was not detected in the casing above the 7.3-inch casing. Outflow into the flow zones from 355 to 380 ft may occur to equalize the difference in heads among the flow zones below 400 ft and above 400 ft that may have been created during free-flowing conditions, or it may occur due to natural head differences that exist among the different flow zones of the confined-aquifer system.

The water level measured in SAG.12 represents a composite head measurement in the confined-aquifer system, because the 420-ft interval contributing flow to the well likely is open to several permeable layers.

Well SAG.13

Well SAG.13 was constructed in 1965 for irrigation and stock-water use and is a flowing well. The casing is 12.4-inch diameter from land surface to a depth of 452 ft and 9.2-inch diameter from 452 to 793 ft (fig. 34). The interval containing torch-cut slots from 458 to 790 ft is open to lithologic layers containing (1) clay, (2) clay with some sand and gravel, and (3) sand or gravel with some clay. The lithologic layers contributing water to well SAG.13 are below a thick clay layer from 75 to 185 ft. Another clay layer identified on the drillers log from 444 to 489 ft appears to contribute inflow to the well.

The specific-conductance, temperature, and free-flowing trolling flowmeter logs indicate a somewhat continuous zone of inflow from a depth of 630 to 790 ft, with small amounts of inflow in narrow zones from a depth of 460 to 600 ft. The shut-in trolling flowmeter log does not indicate flow in the casing at depths shallower than 490 ft. The shut-in flowmeter log indicates inflow occurs from a depth of 670 to about 790 ft, and outflow occurs from a depth of about 550 to 650 ft.

Outflow into the flow zone from 550 to 650 ft may occur to equalize the difference in heads among the flow zones below 670 ft and above 650 ft that may have been created during free-flowing conditions, or it may occur due to natural head differences that exist among the different flow zones of the confined-aquifer system. The water level measured in well SAG.13 represents a composite head measurement in the confined-aquifer system because the 332-ft interval contributing flow to this well intersects several lithologic layers.

Well SAG.17

Well SAG.17 was constructed in 1961 for irrigation use and is a flowing well. The casing is 5.9-inch diameter from land surface to a depth of 519 ft and 4.2-inch diameter from 519 to 671 ft. The interval containing torch-cut slots from 540 to 670 ft is open to lithologic layers containing (1) clay; (2) sand, gravel, or cobbles; and (3) sand or gravel with some clay (fig. 35). The lithologic intervals open to the well underlie a clay layer from a depth of 520 to 560 ft.

The specific-conductance, temperature, and free-flowing trolling flowmeter logs all indicate inflow to the well occurs from a depth of 540 to 670 ft. The flowmeter log indicates two inflow zones that can be differentiated by two rates of inflow: (1) a higher rate of inflow in the interval from 540 to 580 ft (upper zone) and (2) a lower rate of inflow from 580 to 670 ft (lower zone).

Little outflow from well SAG.17 occurred at the surface during the time the shut-in trolling flowmeter log was being recorded; thus, the log trace matches the tool-velocity line fairly well. Inflow to well SAG.17 indicated on the shut-in trolling flowmeter log trace from a depth of 400 to 520 ft is likely measurement error caused by either the tool speed not being exactly 20 ft/min or slight roughness on the inside of the 5.9-inch-diameter casing. The video log did not show casing openings in this interval, so inflow was not expected. Inflow occurs at depths from around 540 to 560 ft and 620 to 650 ft, and outflow occurs from a depth of 575 to 585 ft.

Outflow into the flow zone from 575 to 585 ft may occur to equalize the difference in heads among the flow zones below 585 ft and above 585 ft that may have been created during free-flowing conditions, or it may occur due to natural head differences that exist among the different flow zones of the confined-aquifer system. The outflow observed in the shut-in flowmeter log might also be due to flow entering the annular space between 575 and 585 ft. The water level measured in well SAG.17 under shut-in conditions represents a composite measurement of the head in the confined-aquifer system in the zone from a depth of 540 to 670 ft.

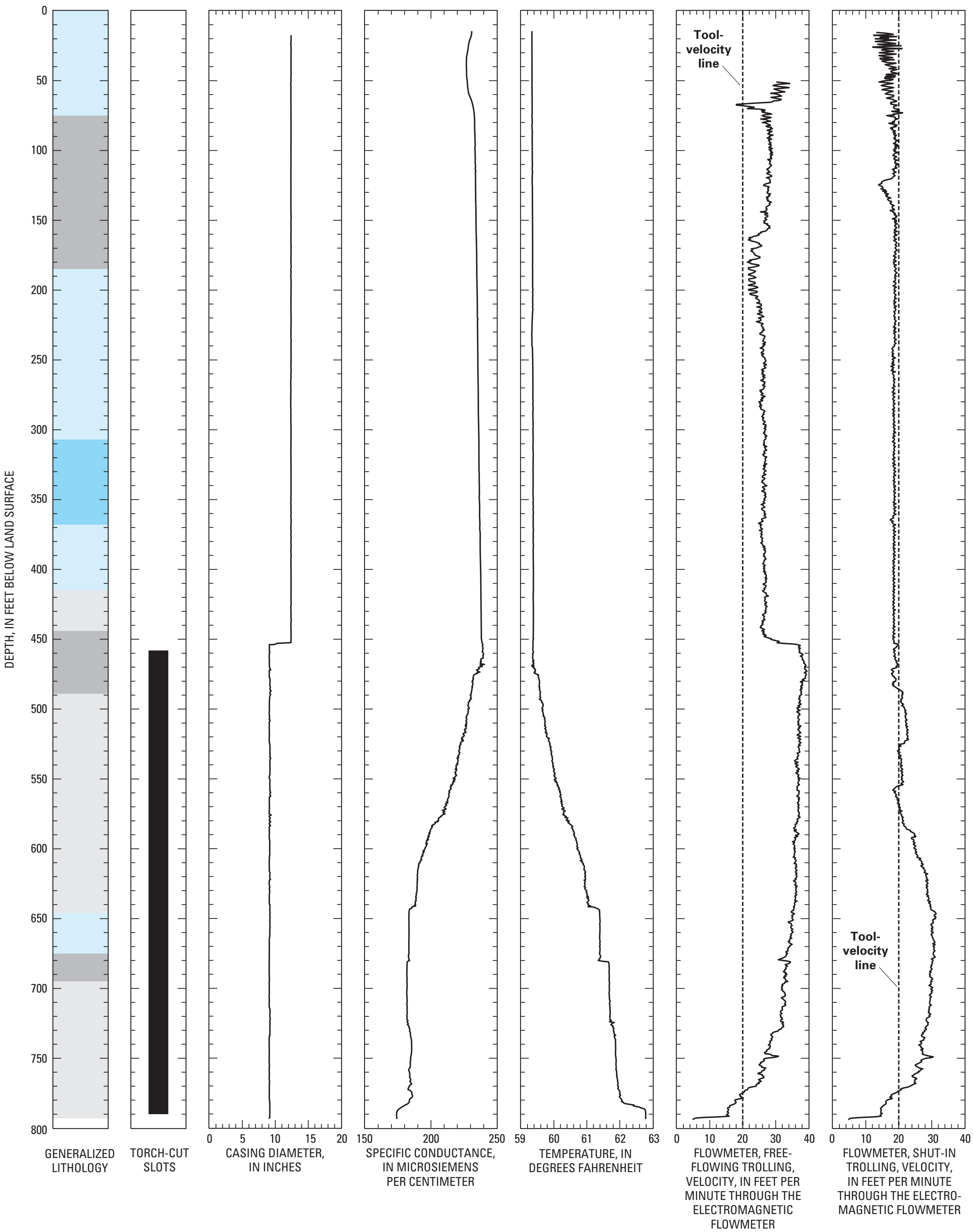


Figure 34. Geophysical well logs for well SAG.13. Refer to figure 2 for generalized lithology.

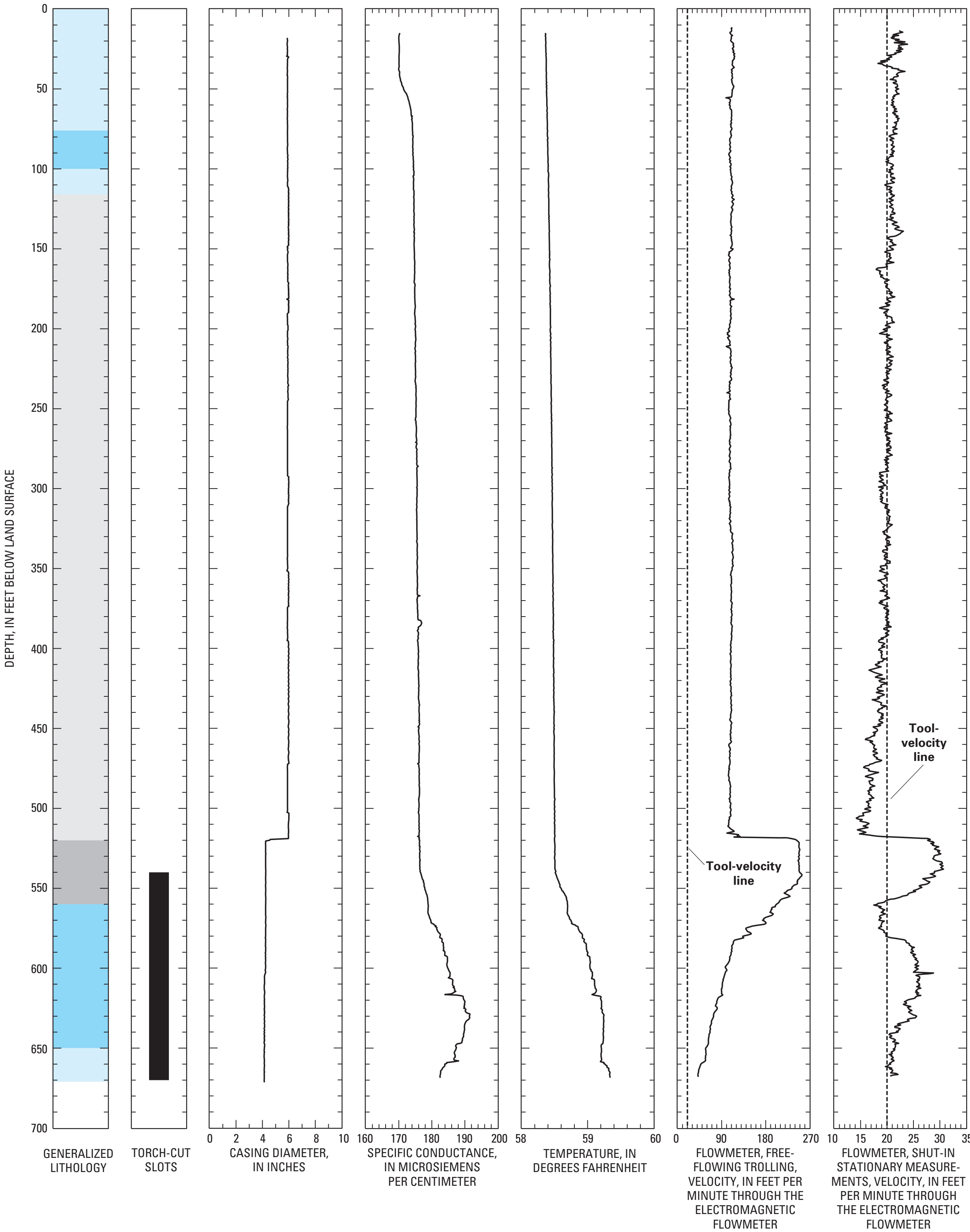


Figure 35. Geophysical well logs for well SAG.17. Refer to figure 2 for generalized lithology.

Well SAG.18

Well SAG.18 has 3.2-inch diameter casing from land surface to a depth of 372 ft. The well is open to the confined-aquifer system only within the uncased portion of the borehole from 372 to 382 ft (fig. 36). A lithologic log was not available for this flowing well.

All logs indicate inflow to this well occurs within the uncased portion of the borehole. The video log indicates a significant amount of the inflow enters the well at a depth of 382 ft, as seen in resuspension of debris particles in the well. The inflection in the free-flowing trolling flowmeter log from 180 to 190 ft is due to a slight casing diameter change. The inflections in the flow log from a depth of 130 to 140 ft and near 160 ft likely are interference in the log rather than valid measurements of flow.

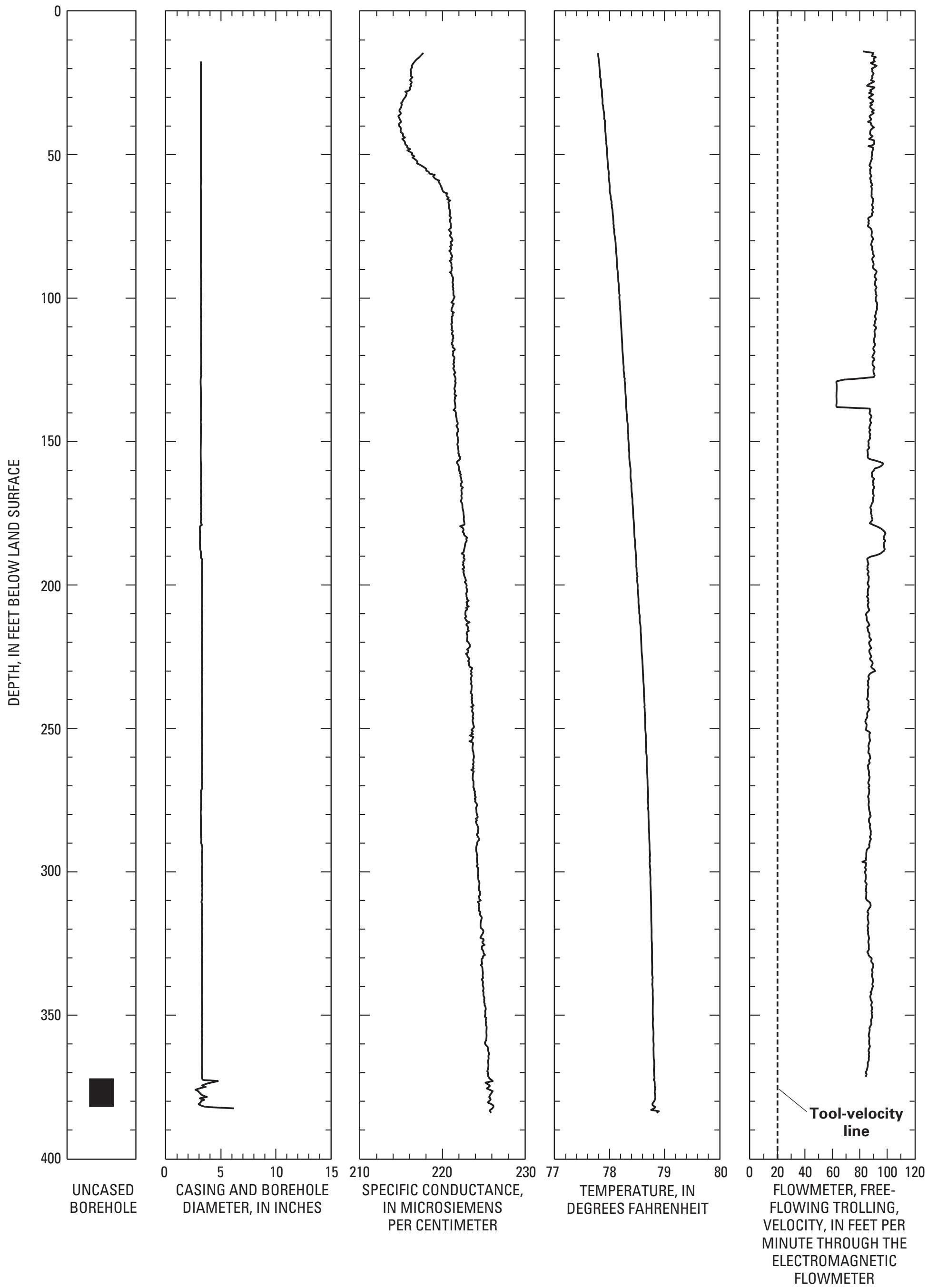


Figure 36. Geophysical well logs for well SAG.18.

The water level measured in well SAG.18 represents a good measurement of the head in the confined-aquifer system because the well is only open to the aquifer within a 10-ft interval. All inflow to this well, and thus the only zone contributing to the head in this well, occurs from 372 to 382 ft.

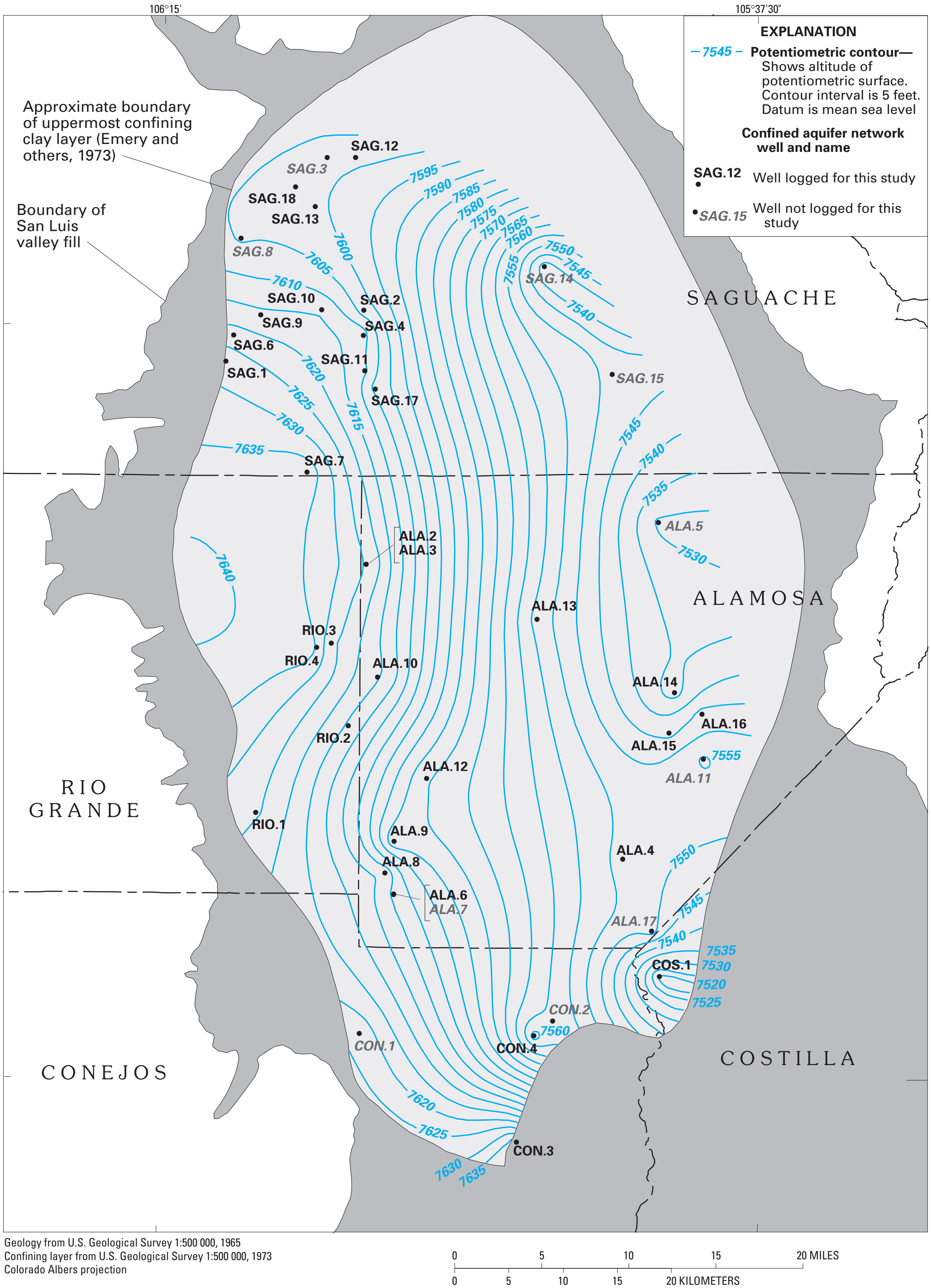
APPROPRIATE USE OF WATER LEVELS MEASURED IN CONFINED-AQUIFER NETWORK WELLS

Water levels from the CAWN can be used to understand local and regional changes in the potentiometric surface of the confined-aquifer system of the San Luis Valley. Contour maps of the potentiometric surface constructed from water-level data from the CAWN can be generated periodically to monitor regional changes in storage in the confined-aquifer system.

To help identify which wells in the CAWN yield useful water-level measurements for development of regional potentiometric-surface-contour maps, a contour map of the water levels measured during November 2000 was constructed (fig. 37). Most of the measured water levels are spatially correlated with water levels in neighboring wells. Even though the construction of wells is not always consistent among neighboring wells, the measured water levels depict reasonable hydraulic gradients in the confined-aquifer system. Several wells yielded water-level information that did not correlate well with neighboring CAWN wells because the water level in the wells was too low or too high relative to the water levels in neighboring wells. This occurrence is shown on the map where contour lines near a well do not fit the regional potentiometric surface (for example, well ALA.9) or where a well point lies within closed contours of declining or increasing altitude (for example, wells CON.3 and COS.1). The water level in some wells may be low relative to the water level in neighboring wells because (1) well construction may allow water to flow from a lower zone to an upper zone (interzonal flow), thus decreasing head and causing the water level measured in that well to be low (as is likely the case for well ALA.3 after mid-1989); (2) nearby pumpage or continuous flow from a well may cause the water level measured in that well to be low; (3) the open interval is plugged by corrosion or bacterial accumulation and the well is not in good hydraulic connection with the confined-aquifer system; or (4) the open interval is adjacent to a laterally discontinuous, permeable layer that is not in good hydraulic connection with other permeable layers of the confined-aquifer system. Table 2 lists all the wells in the CAWN, comments regarding the appropriate use of water-level data measured in each well based on information from the well logs and from the potentiometric-surface contour map, and the predominant flow zones identified from the well logs. The determination of the intervals containing the predominant flow zones applies to the time when the logs were recorded. The importance of the flow zones in contributing water to the wells could change if seasonal pumpage or other effects cause head differences between the flow zones to change.

Adjacent wells that are open to the confined-aquifer system at different depths indicate water levels can vary with depth or be nearly the same for different depths. Two pairs of wells in the CAWN are adjacent: ALA.2 is about 80 ft from ALA.3, and ALA.6 is about 30 ft from ALA.7. Water levels measured in wells ALA.2 and ALA.3 (fig. 5) indicate that before 1989, the water level measured in both wells showed similar changes. But the water level in well ALA.3, which is reported to be open to the confined-aquifer system in the depth interval from 881 to 970 ft, was consistently about 6 to 12 ft higher than the water level in well ALA.2, which is open to the confined-aquifer system in the depth interval from 350 to 415 ft. The water levels measured in neighboring wells ALA.6 and ALA.7 have the same trend and magnitude (fig. 38). Well ALA.6 is open to the confined-aquifer system in the depth interval from 446 to 735 ft, and well ALA.7, which could not be opened for logging, is reported to be open in the depth interval from 290 to 490 ft. Thus, water levels in the confined-aquifer system may or may not vary with depth, and the amount that water levels vary with depth depends on the locations of the wells in the San Luis Valley.

Most of the wells in the CAWN, and probably most of the wells in the San Luis Valley, were constructed with long open intervals to maximize the amount of water yielded by the well. The long open intervals in these wells allow water to flow from zones in the confined-aquifer system having higher heads to zones having lower heads when head differences exist. This interzonal flow can cause heads to equalize over time as long as the interzonal flow is greater than the



Geology from U.S. Geological Survey 1:500 000, 1965
Confining layer from U.S. Geological Survey 1:500 000, 1973
Colorado Albers projection

Figure 37. Potentiometric surface of the confined aquifer, November 2000.

Table 2. Well name, local identification number, comments, and appropriate use of water-level data

[ft, foot]

Well name	Local identification number	Comments	Appropriate use: Useful for confined-aquifer well network?	Appropriate use: Useful for regional potentiometric-surface map?	Depth interval containing casing openings (feet)	Depth interval containing predominant flow zones (feet)
ALA.2	NA40–09–31–BAB	ALA.2 yields a good water-level measurement in the confined-aquifer system (the length of the open interval was not determined).	YES	YES	350–415	unknown
ALA.3	NA–40–09–31-BAB1	ALA.3 does not yield a good water-level measurement in the confined-aquifer system because ALA.3 is open to shallow zones in the ground-water system at 110 and 160 ft and to a deeper interval in the confined-aquifer system from a depth of 881 to 970 ft. The water level from this well was not plotted on the potentiometric-surface-contour map.	NO	NO	110, 160 and 881–970	unknown
ALA.4	NA–37–11–22–CCC1	ALA.4 yields a good water-level measurement in the confined-aquifer system.	YES	YES	540–1,973	1,200–1,600
ALA.5	NA–40–11–14–DAD2	ALA.5 yields a good water level measurement in the confined-aquifer system. The water levels measured in ALA.5 lie in a low in the contour map, but the water-level data are consistent with water levels measured in neighboring wells.	YES	YES	108.4–118.4	108.4–118.4
ALA.6	NA–37–09–33–CCC1	ALA.6 yields a good water-level measurement in the confined-aquifer system.	YES	YES	446–735	446–475; 500–530; 670–728
ALA.7	NA–37–09–33–CCC2	ALA.7 yields a good water level measurement in the confined-aquifer system. Well construction could not be confirmed due to the top of the well being welded shut.	YES	YES	290–490	unknown
ALA.8	NA37–09–29–DCB	ALA.8 yields a good water level measurement in the confined-aquifer system.	YES	YES	578–1,301	640–663; 683–760; 1,000–1080; 1,100–1,260
ALA.9	NA–37–09–16–CCC	ALA.9 does not yield a good water-level measurement in the confined-aquifer system. The water level measured in ALA.9 is a combined water-level measurement in the unconfined aquifer and the confined-aquifer system because this well is uncased from 26 to 130 ft.	NO	NO	26–130	114–130
ALA.10	NA–39–09–32–BCC	ALA.10 yields a good water-level measurement in the confined-aquifer system.	YES	YES	907–2,015	900–940; 1,440–1,600; 1,700–1,980
ALA.11	NA–38–12–29–ADB	ALA.11 yields a good water-level measurement in the confined-aquifer system.	YES	YES	302–321	302–321

Table 2. Well name, local identification number, comments, and appropriate use of water-level data—Continued

[ft, foot]

Well name	Local identification number	Comments	Appropriate use: Useful for confined-aquifer well network?	Appropriate use: Useful for regional potentiometric-surface map?	Depth interval containing casing openings (feet)	Depth interval containing predominant flow zones (feet)
ALA.12	NA–38–09–34–ADB	ALA.12 may yield a good water-level measurement in the confined-aquifer system but it appears the water-level measured in ALA.12 is slightly low in relation to water levels in neighboring wells.	YES	YES	797–908	810–830; 860–908
ALA.13	NA–39–10–14–BBC1	ALA.13 yields a good water-level measurement in the confined-aquifer system.	YES	YES	968–1,784	1,050–1,090; 1,340–1,550; 1,650–1,784
ALA.14	NA–38–12–06–BCC	ALA.14 yields a good water-level measurement in the confined-aquifer system.	YES	YES	268–575	532–542; 548–575
ALA.15	NA–38–11–13–DDB	ALA.15 yields a good water-level measurement in the confined-aquifer system.	YES	YES	141–575	534–544; 565–575
ALA.16	NA–38–12–08–DBD	ALA.16 yields a good water-level measurement in the confined-aquifer system.	YES	YES	153–586	153–173; 530–550; 576–586
ALA.17	NA–36–11–11–DDC	ALA.17 could not be logged because it is obstructed at 43 ft. The open interval of this well is not known. When compared to data from neighboring wells, ALA.17 yields a good water-level measurement in the confined-aquifer system.	YES	YES	unknown	unknown
CON.1	NA–35–09–07–CCC	CON.1 was not logged, but construction details listed on the well permit indicate that this well should yield a good water-level measurement in the confined-aquifer system.	YES	YES	165–608	unknown
CON.2	NA–35–10–12–BBC	CON.2 was not logged, but construction details listed on the well permit indicate that this well should yield a good water-level measurement in the confined-aquifer system.	YES	YES	98–700	unknown
CON.3	NA–34–10–16–AAA	The upper limit of the uncased interval in CON.3 (65 ft) might be open to the unconfined-aquifer system. No lithologic log was available to determine the depth to the upper confining bed at this well. Based on the fit of the water-level data from CON.3 with data from nearby wells in November 2000, this well does not yield a good water level measurement in the confined-aquifer system.	NO	NO	65–480	unknown
CON.4	NA–35–10–11–CCC	CON.4 does not yield a good water-level measurement in the confined-aquifer system. CON.4 may be open to the unconfined aquifer through a potentially bad seal between the surface casing and the top of the well liner at 57 ft.	NO	NO	370–716	640–695

Table 2. Well name, local identification number, comments, and appropriate use of water-level data—Continued

[ft, foot]

Well name	Local identification number	Comments	Appropriate use: Useful for confined-aquifer well network?	Appropriate use: Useful for regional potentiometric-surface map?	Depth interval containing casing openings (feet)	Depth interval containing predominant flow zones (feet)
COS.1	NA–31–75–25–DDA	COS.1 does not yield a good water-level measurement in the confined-aquifer system. The water level measured in COS.1 is too low when compared to water levels in neighboring wells on the potentiometric-surface-contour map for November 2000 data.	NO	NO	unknown	unknown
RIO.1	NA–37–08–07–BCC	RIO.1 yields a good water-level measurement in the confined-aquifer system.	YES	YES	320–599	320–385
RIO.2	NA–38–08–13–BDB	RIO.2 yields a good water-level measurement in the confined-aquifer system.	YES	YES	790–1,446	790–1,280
RIO.3	NA–39–08–23–CAB	RIO.3 may yield a good water-level measurement in the confined-aquifer system. Water levels measured in this well appear to correspond well with water levels from neighboring wells.	YES	YES	148 and 199	148 and 199
RIO.4	NA–39–08–21–DDA	RIO.4 yields a good water-level measurement in the confined-aquifer system.	YES	YES	350–952	400–570
SAG.1	NA–42–07–35–BCC	SAG.1 yields a good water-level measurement in the confined-aquifer system even though the well appears to be open to the shallow ground-water system due to the reported response in a neighboring basement during pumping of this well.	YES	YES	276–800	183
SAG.2	NA–42–09–07–CCC	SAG.2 yields a good water-level measurement in the confined-aquifer system.	YES	YES	901–1,953	1,020–1,200
SAG.3	NA–43–08–03–ABB	SAG.3 yields a good water-level measurement in the confined-aquifer system. This well was not logged because it is a nonflowing well that has a layer of floating oil on its water surface. It is not known how thick the layer of oil is or how much the lower density of this oil layer might affect the water level measured in this well.	YES	YES	340–580	unknown
SAG.4	NA–42–09–19–CCC1	SAG.4 yields a good water-level measurement in the confined-aquifer system.	YES	YES	1,039–2,298	1,440–1,640
SAG.5	NA–45–10–09–ABB1	SAG.5 does not yield a good water-level measurement in the confined-aquifer system Data from this well were not plotted on the potentiometric-surface-contour map of water levels.	NO	NO	458–497	458–463; 477–497
SAG.6	NA–42–07–23–CDD	SAG.6 is only 120 ft deep, but it may yield a good water-level measurement in the confined-aquifer system. The data from this well are consistent with the water level data in neighboring wells.	YES	YES	unknown	unknown

Table 2. Well name, local identification number, comments, and appropriate use of water-level data—Continued

[ft, foot]

Well name	Local identification number	Comments	Appropriate use: Useful for confined-aquifer well network?	Appropriate use: Useful for regional potentiometric-surface map?	Depth interval containing casing openings (feet)	Depth interval containing predominant flow zones (feet)
SAG.7	NA–41–08–32–DDA	The water level in SAG.7 is reflective of ground-water conditions in unknown openings below the bottom of the well at a depth of 386 ft. SAG.7 yields a good water-level measurement in the confined-aquifer system, although the depth and length of the interval open to the aquifer are unknown.	YES	YES	unknown	unknown
SAG.8	NA–43–07–26–ADC	SAG.8 could not be logged because of an obstruction at 18 ft. The water-level-contour map indicates the data from this well are not consistent with the water-level data in neighboring wells. SAG.8 does not yield a good water-level measurement in the confined-aquifer system.	NO	NO	120–185	unknown
SAG.9	NA–42–08–18–CCB	SAG.9 yields a good water-level measurement in the confined-aquifer system.	YES	YES	285–665	350–440
SAG.10	NA–42–08–15–ACC	SAG.10 yields a good water-level measurement in the confined-aquifer system.	YES	YES	886–1,974	886–1,140
SAG.11	NA–42–09–31–CCC	SAG.11 yields a good water-level measurement in the confined-aquifer system.	YES	YES	540–1,320	1,065–1,090; 1,170–1,250
SAG.12	NA–43–08–01–BBA	SAG.12 yields a good water-level measurement in the confined-aquifer system.	YES	YES	150–570	458–465; 490–576
SAG.13	NA–43–08–15–CBB	SAG.13 yields a good water-level measurement in the confined-aquifer system.	YES	YES	458–790	730–790
SAG.14	NA–43–10–35–CAC2	SAG.14 does not yield a good water-level measurement in the confined-aquifer system because the data from this well are not consistent with the water-level data in neighboring wells.	NO	NO	unknown	unknown
SAG.15	NA–41–11–04–BDB3	SAG.15 yields a good water-level measurement in the confined-aquifer system.	YES	YES	114.3–124.3	114.3–124.3
SAG.17	NA–41–09–06–DCD	SAG.17 yields a good water-level measurement in the confined-aquifer system. Data from this well appear to be slightly low in relation to data from neighboring wells.	YES	YES	540–670	540–580
SAG.18	NA–43–08–08–ADC	SAG.18 yields a good water-level measurement in the confined-aquifer system.	YES	YES	372–382	372–382

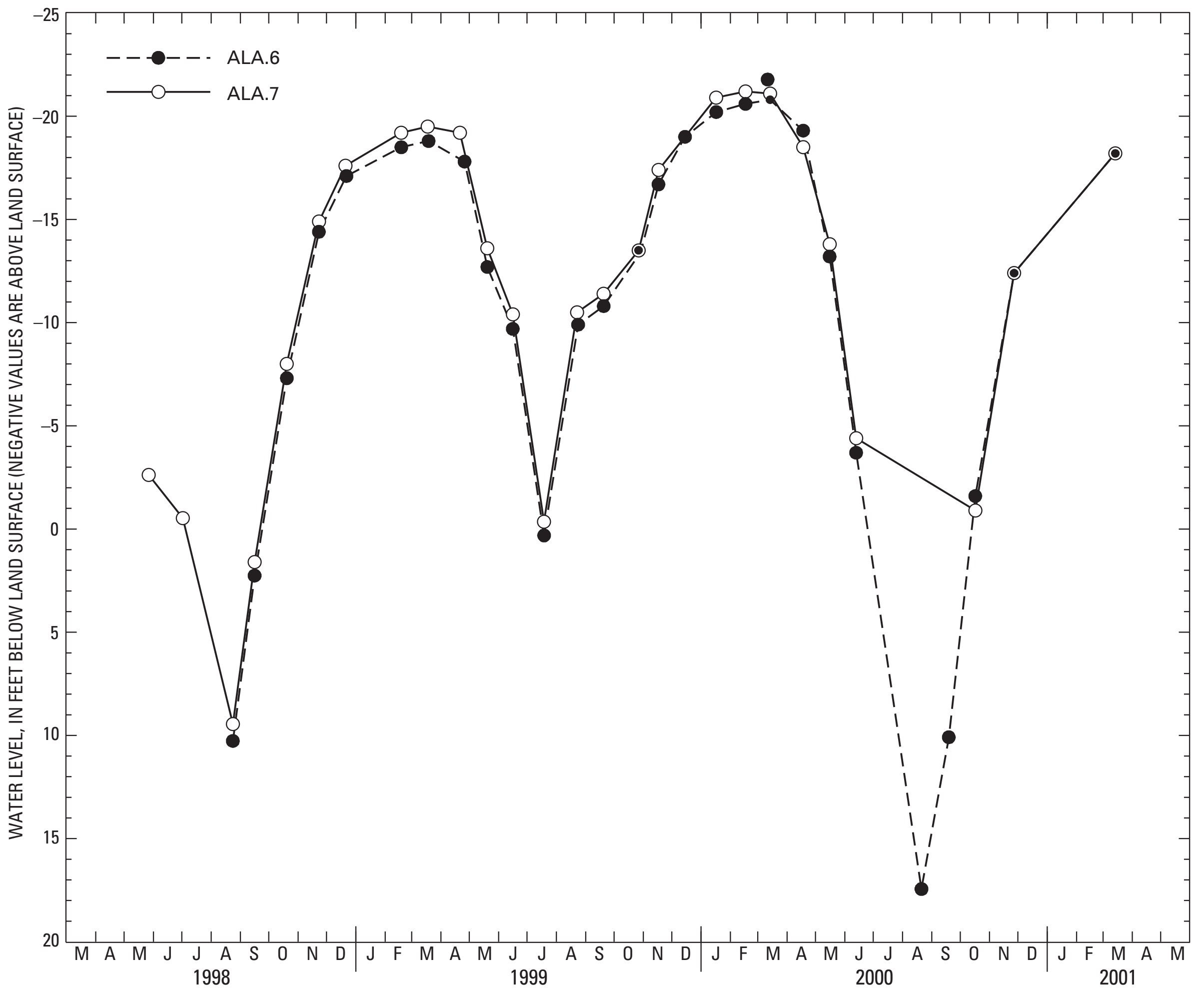


Figure 38. Water levels in wells ALA.6 and ALA.7.

combined withdrawals and outflows from the aquifer (Metz and Brendle, 1996). In wells open to multiple flow zones with head differences among the flow zones, interzonal flow can occur freely, so equalization of heads in different flow zones of the aquifer can occur freely. The rate of interzonal flow varies by the head difference and the transmissivity in the flow zones open to a well. Several wells logged for this study showed significant interzonal flow that may have decreased if the wells were shut in for a long enough period to allow heads in different zones to equalize before geophysical logs were recorded. Wells in which interzonal flow occurs will yield a composite head measurement that is intermediate between the highest and lowest heads in the permeable zones open to a well.

SUMMARY

Ground-water levels and the potentiometric head in the confined-aquifer system of the San Luis Valley are measured in 42 wells by the Rio Grande Water Conservation District, in cooperation with the USGS. This confined-aquifer well network (CAWN) includes flowing and nonflowing wells and consists of irrigation, household, wildlife refuge supply, stock-use, and monitor wells. Many of the wells are open to multiple permeable intervals of the confined-aquifer system. Because the construction of many of the wells in the CAWN was not known or the integrity of the well casings may have degraded since construction, the USGS, in cooperation with the Colorado Division of Water Resources and Colorado Water Conservation

Board, began geophysical logging of the wells to document well construction, determine the zones contributing water to the wells, and determine the applicability of water levels measured in each well for understanding the hydrology of the confined-aquifer system.

The San Luis Valley in south-central Colorado is a high-elevation valley with an average elevation of about 7,700 ft above sea level and an area of about 3,000 square miles. The San Luis Valley occupies a structural basin in south-central Colorado bounded by igneous, metamorphic, and sedimentary bedrock. The basin contains valley fill consisting of interbedded deposits of sand, clay, gravel, and some layers of volcanic rocks. The valley fill, which can be up to about 30,000 ft thick, is thinnest on the margins of the San Luis Valley and thickest in the center of the valley. Two aquifers exist in the valley—the unconfined aquifer and the confined-aquifer system—separated by a fairly extensive confining unit composed of a series of clay layers and unfractured volcanic rocks. The upper confining layer of the confined-aquifer system lies at depths from 20 to greater than 100 ft throughout the central part of the San Luis Valley, with the deepest occurrences of this layer on the eastern side of the valley and in the vicinity of Center.

Generally, recharge to the confined-aquifer system occurs at the perimeter of the valley and discharge occurs in the central portion of the valley. Water levels in some wells completed in the confined-aquifer system are above land surface (flowing), and in other wells the water level is below land surface (nonflowing).

Several types of well logs were used to determine the construction of wells, the lithologic units penetrated by wells, and the zones contributing water to wells in the CAWN. Driller's logs were used to identify the lithologic layers penetrated by wells. Geophysical logs were recorded by the USGS by lowering various tools attached to the end of a cable into each of the wells. These tools included a well video camera, a caliper, a water specific-conductance meter, a water temperature meter, and a flowmeter.

In most cases, the flowmeter logs are the primary logs used to indicate zones of inflow to the wells. Specific-conductance and temperature logs were the primary logs used to define zones of inflow to wells when no flowmeter logs were available for a particular well.

Flowmeter measurements were recorded at two flow rates: free-flowing and shut-in in flowing wells, or pumped and static water column in nonflowing wells. The rate of natural flow in fully open flowing wells or the highest pumping rate that was obtainable for nonflowing wells ranged from less than 10 gal/min to more than 1,000 gal/min. Shut-in measurements were recorded with flow from each flowing well almost entirely closed off.

Thirty-two wells in the CAWN were logged. A complete set of geophysical logs consisted of video, caliper, water specific-conductance, water-temperature, and free-flowing or pumped and shut-in or static water-column well-flow logs.

Water levels from the CAWN can be used to understand local and regional changes in the potentiometric surface of the confined-aquifer system of the San Luis Valley. Contour maps of the potentiometric surface constructed from water-level data from the CAWN can be generated periodically to monitor regional changes in storage in the confined-aquifer system.

Most of the water levels measured in the CAWN are spatially correlated with water levels in neighboring wells. Even though the construction of wells is not always consistent among neighboring wells, the measured water levels depict reasonable hydraulic gradients in the confined-aquifer system when the data are plotted on a map and potentiometric-surface contours are drawn. Several wells yielded water-level information that did not correlate well with neighboring CAWN wells because the water level in the wells was too low or too high relative to the water levels in neighboring wells.

Adjacent wells that are open to the confined-aquifer system at different depths indicate water levels can vary with depth or be nearly the same for different depths. There are two pairs of adjacent wells in the CAWN: ALA.2 is about 80 ft from ALA.3, and ALA.6 is about 30 ft from ALA.7. Water levels measured in wells ALA.2 and ALA.3 show that before 1989, the water level measured in both wells showed similar changes. But the water level in well ALA.3, which is reported to be open to the confined-aquifer system in the depth interval 881 to 970 ft, was consistently about 6 to 12 ft higher than the water level in well ALA.2, which is open to the confined-aquifer system in the depth interval 350 to 415 ft. The water levels measured in neighboring wells ALA.6 and ALA.7 have the same trend and magnitude. Well ALA.6 is open to the confined-aquifer system in the depth interval 446 to 735 ft, and well ALA.7 is reported to be open in the depth interval from 290 to 490 ft. Thus, water levels in the confined-aquifer system may or may not vary with depth, and the amount that water levels vary with depth depends on the locations of the wells in the San Luis Valley.

Most of the wells in the CAWN, and probably most of the wells in the San Luis Valley, were constructed with long open intervals to maximize the amount of water yielded by the well. The long open intervals in these wells allow water to flow from zones in the confined-aquifer system having higher heads to zones having lower heads when head differences exist. Several wells logged for this study showed significant interzonal flow that may have decreased if the wells were shut in for a long enough period to allow heads in different zones to equalize before geophysical logs were recorded. Wells in which interzonal flow occurs will yield a composite head measurement that is intermediate between the highest and lowest heads in the permeable zones open to a well.

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