Prepared in cooperation with the City of Sioux Falls

Hydraulic Conductivity Estimates from Slug Tests in the Big Sioux Aquifer Near Sioux Falls, South Dakota

Scientific Investigations Report 2019–5013

U.S. Department of the Interior
U.S. Geological Survey

Cover photographs:

Front cover: The Big Sioux River near the Sioux Falls diversion dam, Sioux Falls, South Dakota, October 11, 2017. Photograph by Joshua Valder, U.S. Geological Survey.

Rear cover:

The Big Sioux River, west of the Sioux Falls Regional Airport, Sioux Falls, South Dakota, June 2017. Photograph by Joshua Valder, U.S. Geological Survey.

The Big Sioux River, west of the Sioux Falls Regional Airport, Sioux Falls, South Dakota, June 2017. Photograph by Joshua Valder, U.S. Geological Survey.

U.S. Geological Survey hydrologist Bill Eldridge preparing to complete a slug test at a South Dakota State observation well near Sioux Falls, South Dakota, June 11, 2017. Photograph by Joshua Valder, U.S. Geological Survey.

A South Dakota State observation well used for water-level observations and slug tests on the grounds of the Sioux Falls Regional Airport, Sioux Falls, South Dakota, October 11, 2017. Photograph by Joshua Valder, U.S. Geological Survey.

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A South Dakota State observation well used for water-level observations and slug tests on the grounds of the Sioux Falls Regional Airport, Sioux Falls, South Dakota, October 11, 2017. A National Weather Service Next Generation Weather Radar (NEXRAD) is in the background. Photograph by Joshua Valder, U.S. Geological Survey.

U.S. Geological Survey hydrologist Bill Eldridge collecting water-level data at a South Dakota State observation well near Sioux Falls, South Dakota, October 11, 2017. Photograph by Joshua Valder, U.S. Geological Survey.

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

PVC polyvinyl chloride

SDDENR–WR South Dakota Department of Environment and Natural Resources-Water Rights Division

SDGS South Dakota Geological Survey

USGS U.S. Geological Survey

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Abstract

Hydraulic conductivity estimates were made for 15 observation wells using slug-out (rising-head) tests in the Big Sioux aquifer near Sioux Falls, South Dakota, as part of a cooperative study with the City of Sioux Falls to characterize the hydrogeology and the extent of the Big Sioux aquifer north of the city. Well and aquifer data were collected from field measurements and drillers' logs. Multiple slug tests were completed at each observation well with a transducer to record the change in water level and a U.S. Geological Survey standard mechanical slug to displace the well's water column. In total, 110 slug-out test trials were completed among the 15 observation wells. Hydraulic conductivity was estimated by curve fitting with AQTESOLV Pro version 4.50.002. Hydraulic conductivity estimates ranged from 64 to 379 feet per day (ft/d). The mean, standard deviation, and median hydraulic conductivity for the 110 slug-out test trials were 171 ft/d, 73 ft/d, and 157 ft/d, respectively. The mean hydraulic conductivity calculated for each well ranged from 88 to 270 ft/d, the standard deviation ranged from 7 to 66 ft/d, and the median hydraulic conductivity ranged from 86 to 256 ft/d.

Introduction

The section of the Big Sioux aquifer that extends from Dell Rapids, South Dakota, to Sioux Falls (city), S. Dak., is about 18 miles (mi) long, 2 mi wide, and 80 to 100 feet (ft) deep (Rothrock and Otton, 1947; fig. 1). The Big Sioux aquifer is an unconfined aquifer and was formed in a valley incised into Early Proterozoic-age Sioux Quartzite bedrock by episodes of glacial transgression and regression (Rothrock and Otton, 1947). Quaternary-age deposits from ice sheets and glacial outwash, coupled with modern alluvial deposits, line the valley with boulders, gravels, sands, and clays. In some locations, a till layer of variable thickness exists between the Big Sioux aquifer materials and the Sioux Quartzite (Valseth and others, 2018). Groundwater from gravel and sand deposits that form the Big Sioux aquifer provides for various water uses including public and domestic supply. Hydraulic conductivity estimates from previous aquifer tests in the Big Sioux aquifer ranged from 160 to 1,470 feet per day (ft/d; Ellis and others, 1969).

In 2015, the U.S. Geological Survey (USGS) began a cooperative study with the city to characterize the hydrogeology and the extent of the Big Sioux aquifer north of the city to support construction of a groundwater-flow model of the Big Sioux aquifer (Valder and others, 2016). Aquifer characterization included an airborne electromagnetic survey to collect electrical resistivity data of aquifer materials (Valseth and others, 2018); however, airborne electromagnetic data collected within and near the city regional airport were unusable because of electrical interference from utilities infrastructure, such as power lines and water pipelines. Therefore, aquifer testing was completed at seven observation wells in the airport area and eight observation wells outside the airport area (fig. 1) to better estimate the hydraulic properties of the Big Sioux aquifer in the study area.

The purpose and scope of this report is to document the field methods, analytical methods, and hydraulic conductivity estimates from slug tests at 15 observation wells in the Big Sioux aquifer near Sioux Falls, S. Dak. (fig. 1). A slug test is a type of aquifer test that estimates hydraulic conductivity of aquifer materials close to a well by measuring the subsequent rise (slug-out test) or fall (slug-in test) of the water level in a well in response to a nearly instantaneous change in hydraulic head. Slug tests typically are accomplished by adding or removing an impermeable solid object of known volume (mechanical slug) that is heavy enough to displace water and can be easily raised and lowered quickly in the water column of a well (Cunningham and Schalk, 2011).

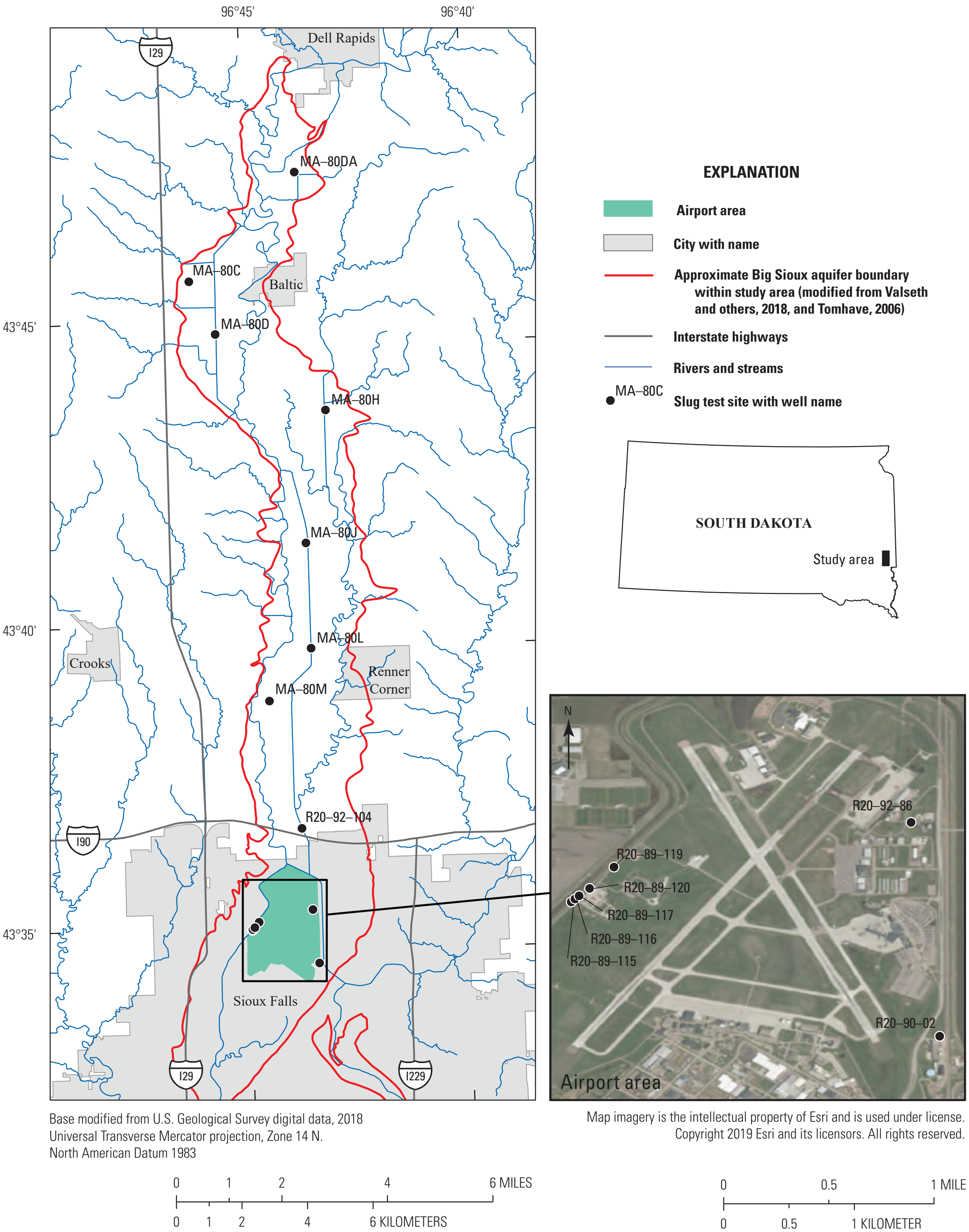

Figure 1. Approximate boundary of the Big Sioux aquifer within the study area and slug test sites annotated by well name.

Field Methods

Slug tests were accomplished June 11–13, 2017, at 15 observation wells completed in the Big Sioux aquifer near Sioux Falls. Seven of the observation wells were in the regional airport area (fig. 1). The remaining eight observation wells were outside the regional airport area and were tested to improve understanding of hydraulic properties throughout the aquifer. The wells were constructed in the 1980s and 1990s by the South Dakota Department of Environmental and Natural Resources-Water Rights Division (SDDENR–WR) and the South Dakota Geological Survey (SDGS). Wells used in this study constructed by the SDDENR–WR have names with “MA” prefixes (South Dakota Department of Environment and Natural Resources, 2018), and wells constructed by the SDGS have names with “R” prefixes (South Dakota Geological Survey, 2018; fig. 1). The latitude and longitude of each well were determined using a hand-held global positioning system unit with an inferred accuracy of about 10 ft (U.S. Geological Survey, 2018a). Each well name, well owner, USGS site number, latitude, and longitude are listed in table 1, and selected information for each well is available in the USGS National Water Information System database (U.S. Geological Survey, 2018b).

Well and aquifer characterization data were determined from field measurements and obtained from drillers’ logs filed with the SDGS (South Dakota Geological Survey, 2018). Although similar in construction, wells varied by completion depth and measuring-point height. The total depth and measuring-point height for each well were field measured using an electric water-level tape and a surveyor’s tape measure, respectively, using methods described by Cunningham and Schalk (2011). Drillers’ logs provided geologic and well construction information, such as the depth to the bottom of the aquifer and well screen length (South Dakota Department of Environment and Natural Resources, 2018; South Dakota Geological Survey, 2018). If specified, the bottom of the aquifer was determined from the drillers’ log; however, if not specified, the bottom of the aquifer was assumed to be at the bottom of the well. Although all wells selected for this study were completed in the Big Sioux aquifer, drillers’ logs indicated that wells MA–80C and MA–80D slightly penetrated the till layer underlying the Big Sioux aquifer. However, the till layer at the bottom of wells MA–80C and MA–80D was not expected to affect the estimated hydraulic conductivity at those wells because the mean till thickness was about 13 percent of the aquifer’s mean thickness of 44 ft. Screen lengths were assumed to start from the bottom of the well except for wells R20–92–104 and R20–92–86, which were screened starting above the bottom of the well. Wells were constructed with 2-inch (in.) diameter polyvinyl chloride (PVC) casing. Drillers’ logs for SDGS wells indicated that schedule 40 PVC casing was used. Although not specified in the SDDENR–WR drillers’ logs, it was assumed that schedule 40 PVC casing also was used. The depth to the top of the well screen, the length of the well screen, and total well penetration depth for each well were provided by drillers’ logs (table 2).

Table 1. Observation wells used for slug tests in the Big Sioux aquifer near Sioux Falls, South Dakota.

[USGS, U.S. Geological Survey; NWIS, National Water Information System; SDDENR–WR, South Dakota Department of Environment and Natural Resources-Water Rights Division; SDGS, South Dakota Geological Survey]

Well name	Well owner	USGS site number (NWIS)	Latitude	Longitude
MA–80DA	SDDENR–WR	434729096434801	43.790555	−96.730040
MA–80C	SDDENR–WR	434540096461502	43.761220	−96.771100
MA–80D	SDDENR–WR	434446096454101	43.746555	−96.761663
MA–80H	SDDENR–WR	434330096431201	43.725008	−96.720677
MA–80J	SDDENR–WR	434117096434401	43.688655	−96.729463
MA–80L	SDDENR–WR	433934096434101	43.659722	−96.728590
MA–80M	SDDENR–WR	433843096444301	43.645513	−96.744862
R20–92–104	SDGS	433637096440202	43.610323	−96.733892
R20–92–86	SDGS	433517096435001	43.587952	−96.730587
R20–89–119	SDGS	433506096450401	43.584877	−96.751033
R20–89–120	SDGS	433500096451001	43.583408	−96.752710
R20–89–117	SDGS	433458096451201	43.582898	−96.753433
R20–89–116	SDGS	433458096451302	43.582810	−96.753538
R20–89–115	SDGS	433458096451301	43.582697	−96.753603
R20–90–02	SDGS	433424096434301	43.573235	−96.728615

Additional well and equipment dimensions required for hydraulic conductivity estimation included the inside radius of the well casing, the radius of downhole equipment, the radius of the packer, the well screen radius, the outer radius of the well skin, and the annular space diameter. The inside radius well casing, $r(c)$, for a schedule 40, 2-in. diameter PVC well is about 0.085 ft. The radius of the downhole equipment (an unvented Solinst Levelogger LT F30/M10 electronic transducer), $r(eq)$, was 0.036 ft. None of the wells contained a packer, so the packer radius was zero. The well radius, $r(w)$, was 0.085 ft, and the outer radius of the well skin, $r(sk)$, was assumed to be about 0.188 ft. The annular space diameter was not specified in the drillers' logs, but it was assumed to be 0.375 ft (4.5 in.), based on typical monitor well designs reported by Striggow (2013).

Before each slug test, the static water-level at each well was measured with an electric water-level tape from the top of the casing using procedures specified by Cunningham and Schalk (2011). All static water-level measurements are available in the USGS National Water Information System database (U.S. Geological Survey, 2018b). The static water-level measurement at each well was used to determine the aquifer's saturated thickness. Additionally, the static water-level measurement was used to determine the depth to suspend the transducer below the water surface before completing the slug test and the depth to lower the slug to ensure it was fully submerged during the slug test. Well diagrams summarizing the well and aquifer data that were required for analysis (table 2) are in appendix 1.

Table 2. Well and aquifer characteristics used in the analysis to estimate hydraulic conductivity.

[*H*, static water-column height; *b*, saturated thickness; *d*, depth to the top of the well screen; *L*, length of the well screen; *Td*, transducer depth]

Well name	*H*[a], in feet	*b*[b], in feet	*d*[c] (open or perforated interval), in feet	*L* (open or perforated level), in feet	*Td*[d], in feet	Total well penetration depth[e], in feet
MA–80DA	19.19	19.19[f]	21.44	5[g]	22	26.44
MA–80C	29.29	27.60[h]	32.69	5[i]	20	37.69
MA–80D	45.48	41.87[h]	50.61	5[i]	20	55.61
MA–80H	25.33	25.33[f]	27.58	5[g]	20	32.58
MA–80J	20.75	20.75[f]	22.41	5[i]	20	27.41
MA–80L	26.64	26.64[f]	31.61	5[i]	20	36.61
MA–80M	25.61	25.61[f]	28.61	5[g]	20	33.61
R20–92–104	31.41	29.33[h]	28	10[i]	18	40.08
R20–92–86	22.85	20.49[h]	23	10[i]	20	35.36
R20–89–119	4.57	4.57[f]	9.8	10[i]	19	19.8
R20–89–120	5.61	5.61[f]	9.89	10[i]	19	19.89
R20–89–117	16.03	16.03[f]	9.63	20[i]	20	29.63
R20–89–116	15.87	15.87[f]	9.75	20[i]	20	29.75
R20–89–115	16.88	16.88[f]	9.75	20[i]	25	29.75
R20–90–02	5.25	5.25[f]	9.81	10[i]	19	19.81

[a]Field-measured total well depth from the measuring point (MP) minus the field-measured static water-level depth from the MP.

[b]The depth to the bottom of the aquifer minus the depth to the static water level.

[c]Numeric precision varied based on data sources. Values are from drillers' logs, but if not specified, are calculated by the total depth of the well from the top of the MP minus screen length.

[d]Measured from the MP.

[e]Depth to the top of the well screen plus the length of the well screen.

[f]Depth to the bottom of the aquifer was not specified in the drillers' log and was assumed to equal the total well depth.

[g]Well did not have a specified screen length listed on the drillers' log. Screen lengths were assumed based on nearby wells similarly named ("MA" for South Dakota Department of Environment and Natural Resources-Water Rights Division and "R" for South Dakota Geological Survey).

[h]Depth to the bottom of the aquifer reported from a drillers' log (depth to Sioux Quartzite or till contact).

[i]Data are from drillers' logs.

Slug tests were accomplished using techniques described by Cunningham and Schalk (2011) with a mechanical slug and a submersed pressure transducer. Several slug-out and slug-in test trials were accomplished at each well. The number of trials that yielded a measurable water-level change ranged from 4 to 11 depending on the well. Capturing data during slug-in tests was difficult and often did not provide enough data points for analysis because of the short recovery time of the water levels during testing. Additionally, slugs were inserted slowly into the well to avoid bumping the transducer suspension cable. The slow slug insertion likely reduced the initial water-level displacement because the water level returned to its static level during the slug emplacement. With an imperceptible initial water-level displacement and few water-level data points, nearly all the slug-in data could not be analyzed to estimate hydraulic conductivity; therefore, only slug-out tests were analyzed.

A Solinst Levelogger LT F30/M10 electronic transducer (unvented) was used to record water-level changes during each slug test. For the first trials at well MA–80DA, the transducer was set to record the water levels at 1-second intervals. At subsequent wells, water levels were measured at 0.5-second intervals (the minimum time interval for the transducer) to provide additional water-level data points. To allow for adequate spacing in the well for the slug, transducer depth varied based on the static water level at the time of the test and the total well depth. Each test used a 3-ft long, 1-in. diameter mechanical slug that was constructed to the standards described by Cunningham and Schalk (2011). The slug was lowered slowly into the well about 1 ft below the static water level to avoid large fluctuations in the static water level and to ensure that the transducer suspension cable was not displaced. The water level was measured with an electric tape to ensure it stabilized, and then the slug was quickly removed.

Water-level response during slug removal at each well usually was oscillatory, and the water level returned to equilibrium in less than 1 minute. Water-level displacement was calculated by subtracting the raw transducer reading during each slug test from a datum water level. The datum water level for each trial was selected at a time shortly before the removal of the slug, when the water level was stable. Transducer readings were raw, meaning that they were not corrected for barometric pressure because only changes in water level, and not absolute values, were needed for analyses. Data generated during this study are available as a USGS data release (Eldridge, 2019). This data release provides the slug test trial number, time of water-level measurement, raw transducer reading, and water-level displacement from a datum. The peak water-level displacement recorded by the transducer for each trial varied from a high of 2.75 ft at well R20–92–104 to a low of 0.63 ft at well R20–89–115. The mean and median peak water-level displacements for all wells were 1.35 ft and 1.10 ft, respectively. The expected increase in water level was about 0.7 ft (Cunningham and Schalk, 2011). The displacements exceeding 0.7 ft likely were caused by water movement during slug removal.

Analytical Methods

Water-level changes for each trial were analyzed with AQTESOLV Pro version 4.50.002 (Hydrosolve, Inc., 2007) using the Springer and Gelhar method of curve fitting (Springer and Gelhar, 1991). The Springer and Gelhar method was used because of the oscillatory water-level response observed in most slug-out tests. Oscillatory water recovery during slug testing is a known phenomenon that Springer and Gelhar (1991) attributed to inertial effects in highly permeable, unconfined aquifers, such as the Big Sioux aquifer. The Springer and Gelhar method also was used on trials with nonoscillatory water-level responses to maintain analytical consistency.

AQTESOLV uses curve fitting to provide an estimate of hydraulic conductivity. The curve-fitting algorithm creates a best-fit curve by varying the effective well length (*Le* in AQTESOLV; the height of the water column above the top of the screen plus one-half the screen length) and the hydraulic conductivity parameters until the curve best fits the water-level observations (Hydrosolve, Inc., 2007; Springer and Gelhar, 1991). Optimized *Le* values ranged from 0.1 to 71.6 ft for all trials (Eldridge, 2019). Values close to 0.1 indicated a less oscillatory water-level response. Conversely, *Le* values close to the actual measured static water-column height indicated a more oscillatory response. Even though some trials at the same well were less oscillatory (low *Le*) and others were oscillatory, the hydraulic conductivity estimates were similar. The automatic curve-fitting feature in AQTESOLV usually was used, but for some trials, the curve was manually adjusted to improve the fit. Manual adjustments were necessary when spurious water-level measurements, likely from splashing and sloshing water, were recorded by the transducer. For each trial, the aquifer anisotropy ratio (*Kz/Kr* ratio in AQTESOLV, where *Kz* is the vertical hydraulic conductivity and *Kr* is the horizontal hydraulic conductivity) was assumed to be one for all trials because the aquifer material was mostly unconsolidated sands and gravels and the aquifer depth was shallow without much compaction. Therefore, a negligible variation between the horizontal and vertical properties of the aquifer materials measured in the study area was assumed. The AQTESOLV plots for each well and subsequent trial are provided in the data release (Eldridge, 2019).

Hydraulic Conductivity Estimates

Hydraulic conductivity estimated from AQTESOLV curve-fitting analysis for all 110 trials from the 15 observation wells in the study ranged from 64 to 379 ft/d (table 3). The mean, standard deviation, and median hydraulic conductivity of all trials were 171 ft/d, 73 ft/d, and 157 ft/d, respectively. The mean hydraulic conductivity for an individual well ranged from 88 ft/d at MA–80J to 270 ft/d at R20–92–86. The median hydraulic conductivity for an individual well ranged from 86 ft/d at MA–80J to 256 ft/d at R20–92–86, with the absolute difference between the mean and median ranging from less than 10 ft/d at most wells to 27 ft/d at well R20–90–02. The standard deviation of measurements for an individual well ranged from 7 ft/d at MA–80J to 66 ft/d at R20–90–02. The mean, median, and standard deviation for all 110 trials and for each of the 15 individual wells are listed in table 3. The range of hydraulic conductivity estimates compared favorably with those reported by Ellis and others (1969). Additionally, the water-level responses were consistent with tests completed in similar unconfined aquifers consisting of glacial deposits (Springer and Gelhar, 1991).

Table 3. Summary of slug-out test analyses with estimated hydraulic conductivities.

[All values are in feet per day; —, trial not completed or no data observed]

Well name (fig. 1)	Hydraulic conductivities for slug-out test trials[1]											Hydraulic conductivity statistics for individual wells[2,3]			
	1	2	3	4	5	6	7	8	9	10	11	Mean	Median	Standard deviation	Absolute difference between mean and median values
MA–80DA	200	64	203	156	—	—	—	—	—	—	—	156	178	56	22
MA–80C	175	119	171	151	193	147	168	201	210	176	—	171	173	26	2
MA–80D	109	139	123	172	169	123	126	119	126	—	—	134	126	21	8
MA–80H	157	217	289	311	162	267	216	267	—	—	—	236	242	53	6
MA–80J	79	97	83	83	99	88	86	—	—	—	—	88	86	7	2
MA–80L	257	230	226	196	198	290	—	—	—	—	—	233	228	33	5
MA–80M	136	139	188	130	147	140	193	—	—	—	—	153	140	24	13
R20–92–104	379	224	244	249	251	253	255	257	284	—	—	266	253	42	13
R20–92–86	226	237	292	338	261	256	234	315	357	224	227	270	256	46	14
R20–89–119	160	207	156	184	—	—	—	—	—	—	—	177	172	21	5
R20–89–120	88	68	91	86	132	—	—	—	—	—	—	93	88	21	5
R20–89–117	93	116	133	96	98	151	225	157	—	—	—	134	125	41	9
R20–89–116	73	94	125	91	87	79	90	—	—	—	—	91	90	15	1
R20–89–115	80	85	71	92	102	96	94	—	—	—	—	89	92	10	3
R20–90–02	168	133	116	274	284	112	123	204	—	—	—	177	150	66	27

[1]Minimum 64, maximum 379, mean 171, standard deviation 73, and median 157.

[2]Minimum mean 88, minimum median 86, minimum standard deviation 7, and minimum absolute difference between mean and median values 1.

[3]Maximum mean 270, maximum median 256, maximum standard deviation 66, and maximum absolute difference between mean and median values 27.

Summary

The Big Sioux aquifer between Dell Rapids and Sioux Falls, South Dakota, is about 18 miles long, 2 miles wide, and 80 to 100 feet deep. Groundwater from gravel and sand deposits that form the Big Sioux aquifer is used for various water uses including public and domestic supply in the study area. In 2015, the U.S. Geological Survey began a cooperative study with the city of Sioux Falls to characterize the hydrogeology and the extent of the Big Sioux aquifer north of the city for use in a groundwater-flow model. Aquifer characterization included an airborne electromagnetic survey to collect electrical resistivity data of aquifer materials, but electrical interference from infrastructure within and near the regional airport caused some of the airborne electromagnetic data to be unusable. Therefore, aquifer testing at 15 observation wells was completed to better characterize aquifer conditions of the Big Sioux aquifer in the study area between Dell Rapids and Sioux Falls. Field methods included collecting well and aquifer data in the field and from drillers' logs. Multiple slug-out tests were completed at each well using a mechanical slug constructed to U.S. Geological Survey standards. Rising water-level changes were recorded with a transducer. In total, 110 slug-out tests were completed among 15 observation wells. Water-level data from the transducer were analyzed with AQTESOLV Pro version 4.50.002 using curve fitting. Hydraulic conductivity estimates ranged from 64 to 379 ft/d. The mean, standard deviation, and median hydraulic conductivity for the 110 slug-out trials were 171 ft/d, 73 ft/d, and 157 ft/d, respectively. The mean hydraulic conductivity for each well ranged from 88 to 270 ft/d, the standard deviation ranged from 7 to 66 ft/d, and the median hydraulic conductivity ranged from 86 to 256 ft/d. Hydraulic conductivity estimates in this report compared favorably with those from previous aquifer tests.

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Appendix 1. Well Diagrams

Well diagrams annotated with well and aquifer information needed to estimate hydraulic conductivity using AQTESOLV Pro version 4.50.002 (Hydrosolve, Inc., 2007) are presented in figures 1.1 through 1.15. Data were obtained from either field measurements or online databases (South Dakota Department of Environment and Natural Resources, 2018; South Dakota Geological Survey, 2018; U.S. Geological Survey, 2018). Static water levels were measured in the field from June 11 to 13, 2017, and recorded in the U.S. Geological Survey National Water Information System database (U.S. Geological Survey, 2018).

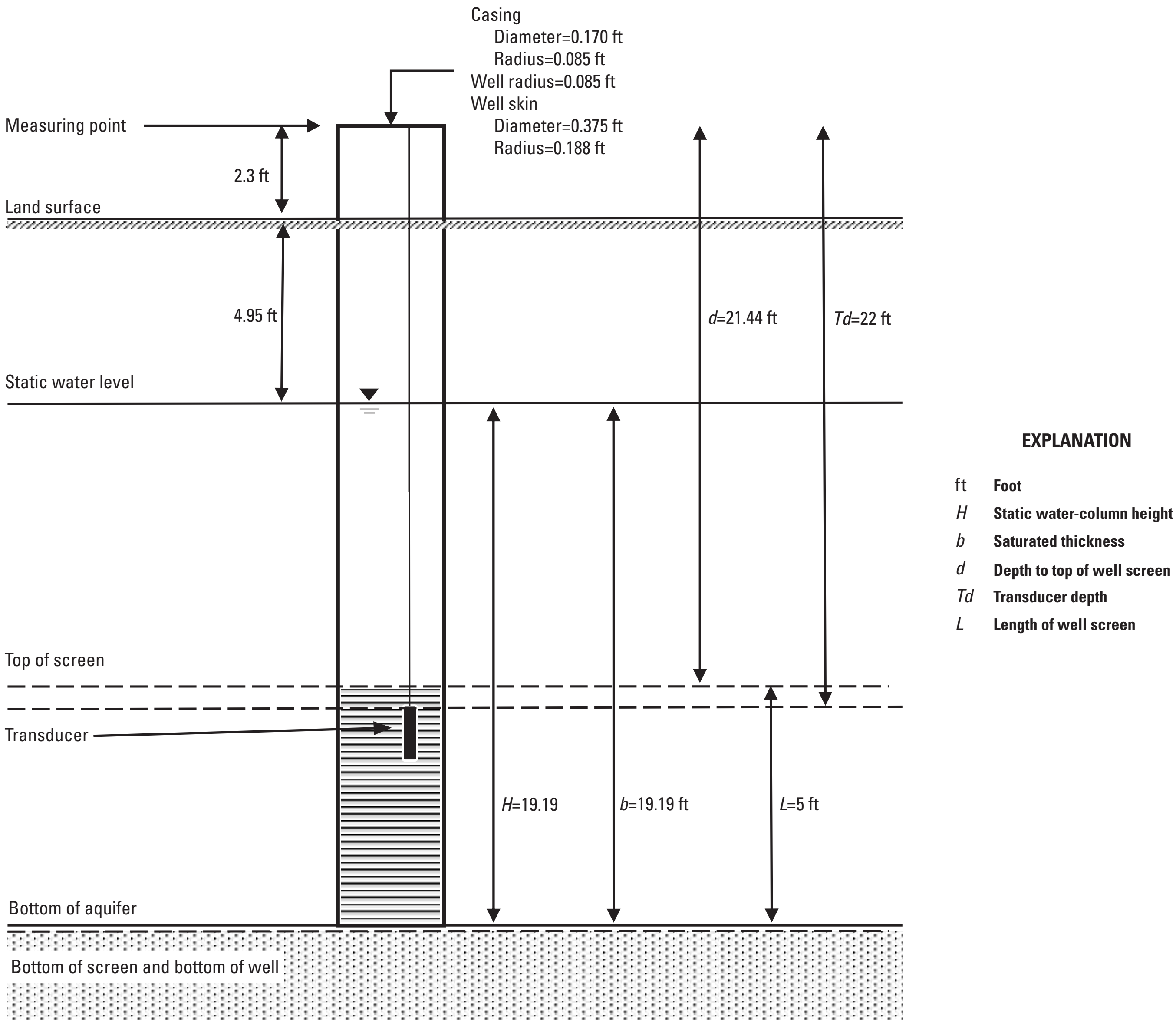


Figure 1.1. Well diagram for well MA–80DA.

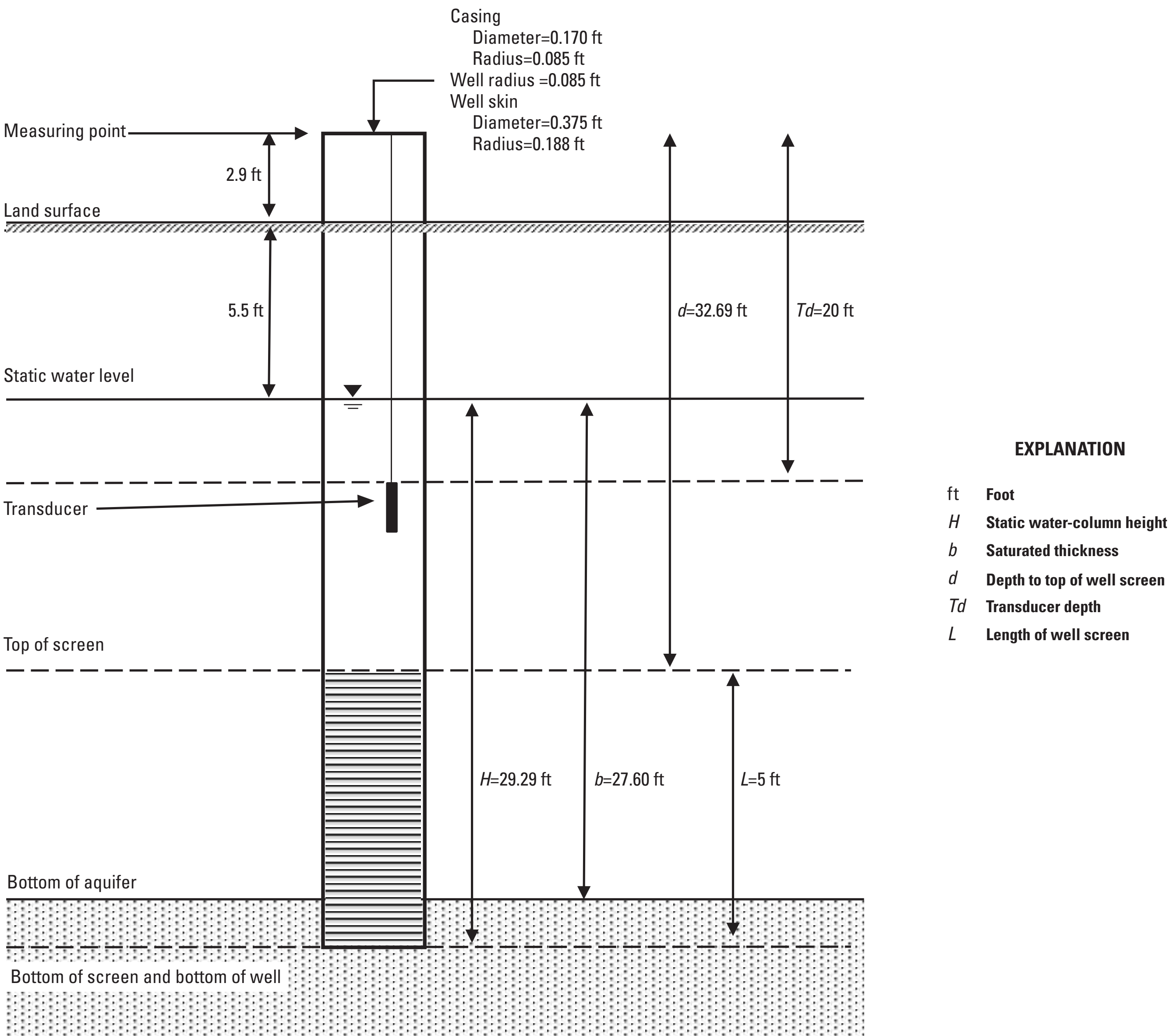


Figure 1.2. Well diagram for well MA–80C.

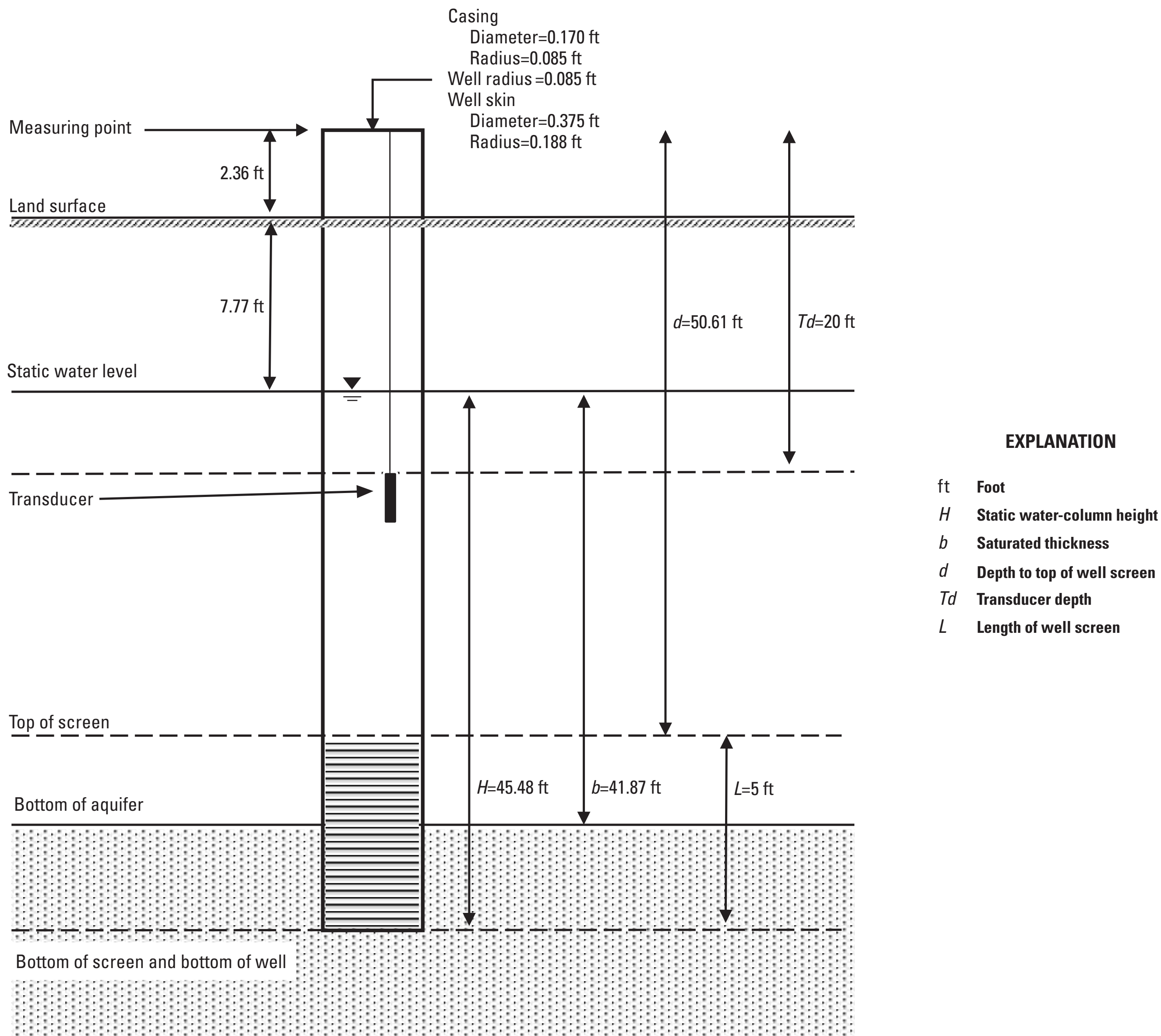


Figure 1.3. Well diagram for well MA–80D.

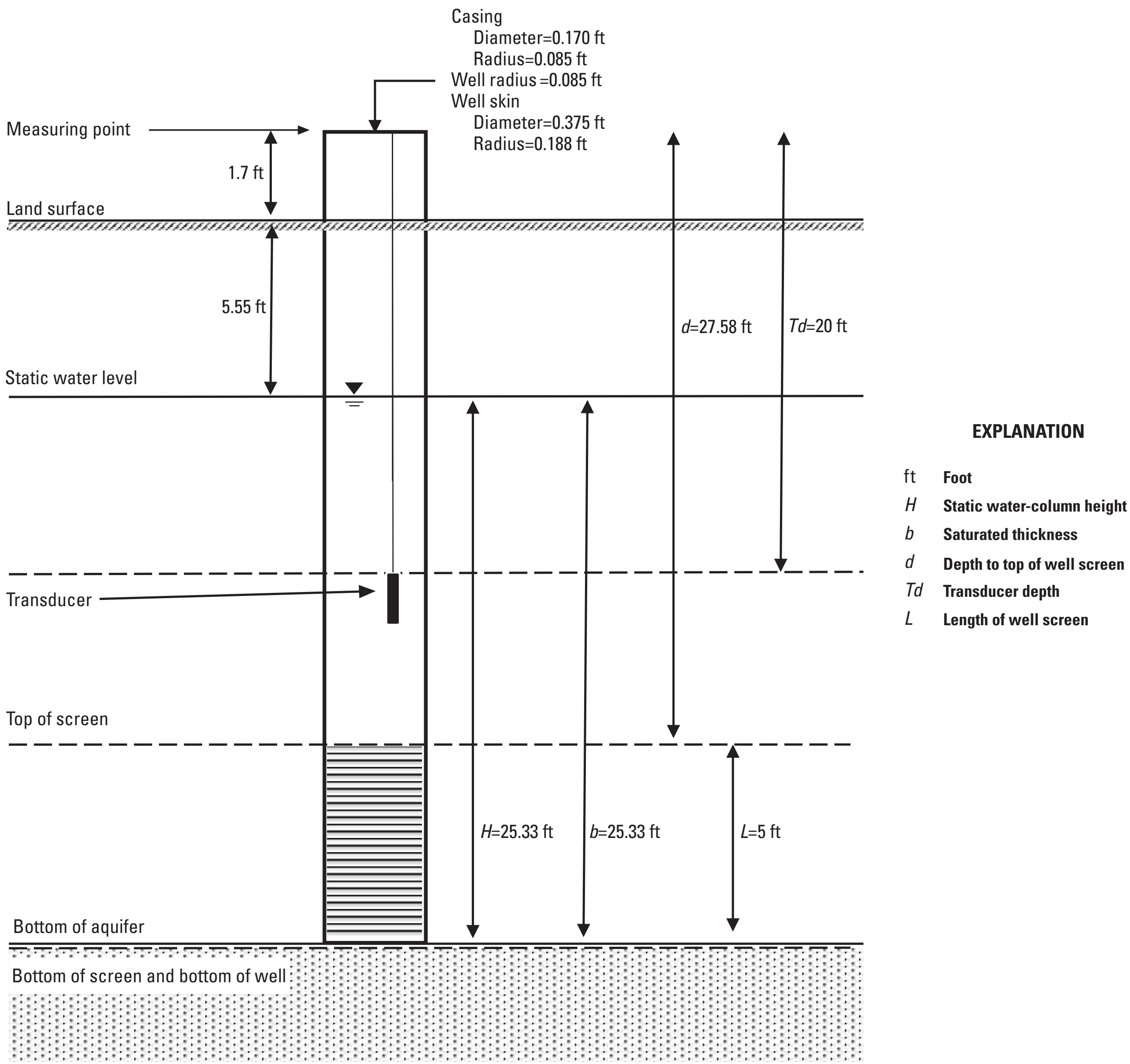


Figure 1.4. Well diagram for well MA–80H.

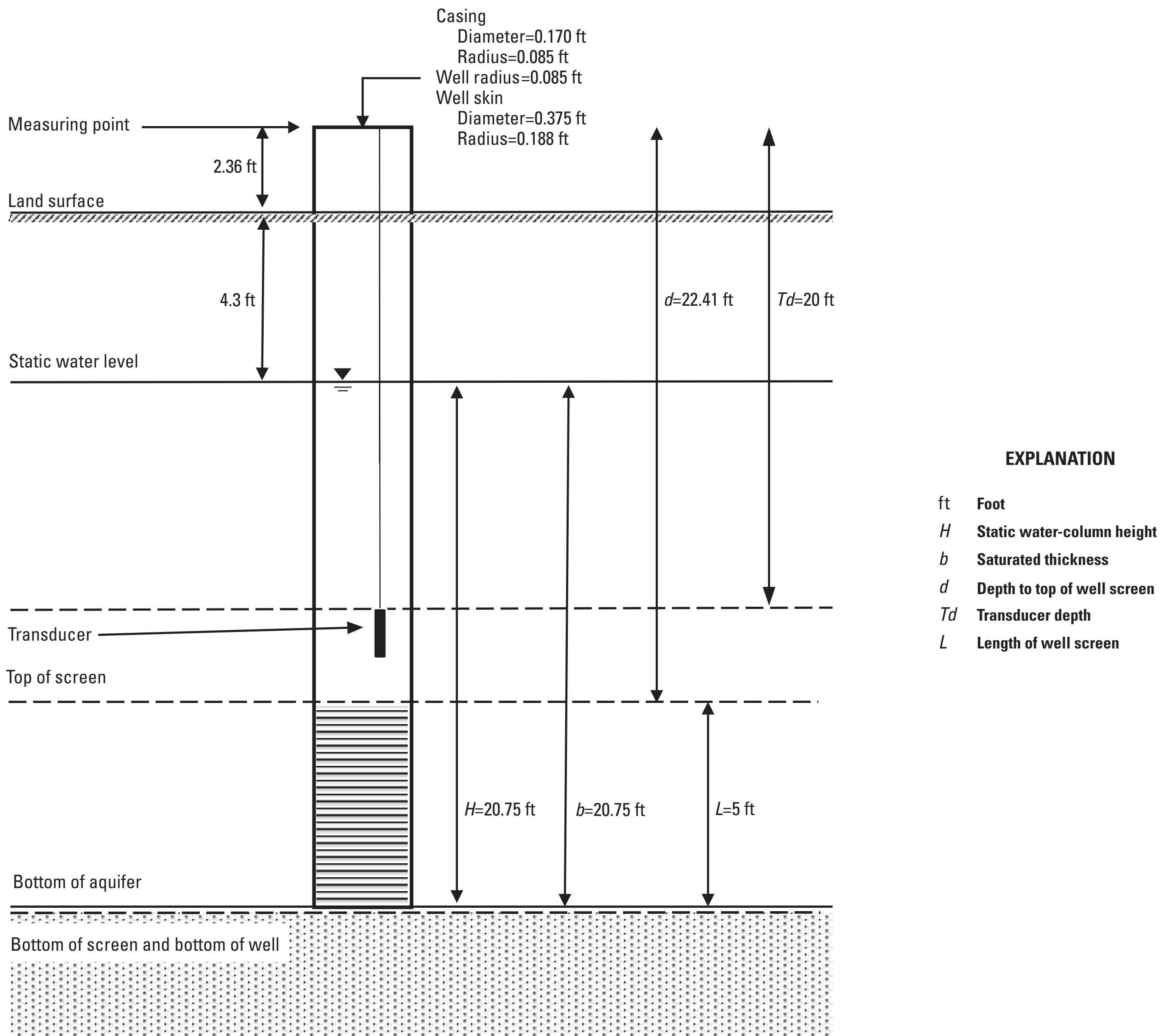


Figure 1.5. Well diagram for well MA–80J.

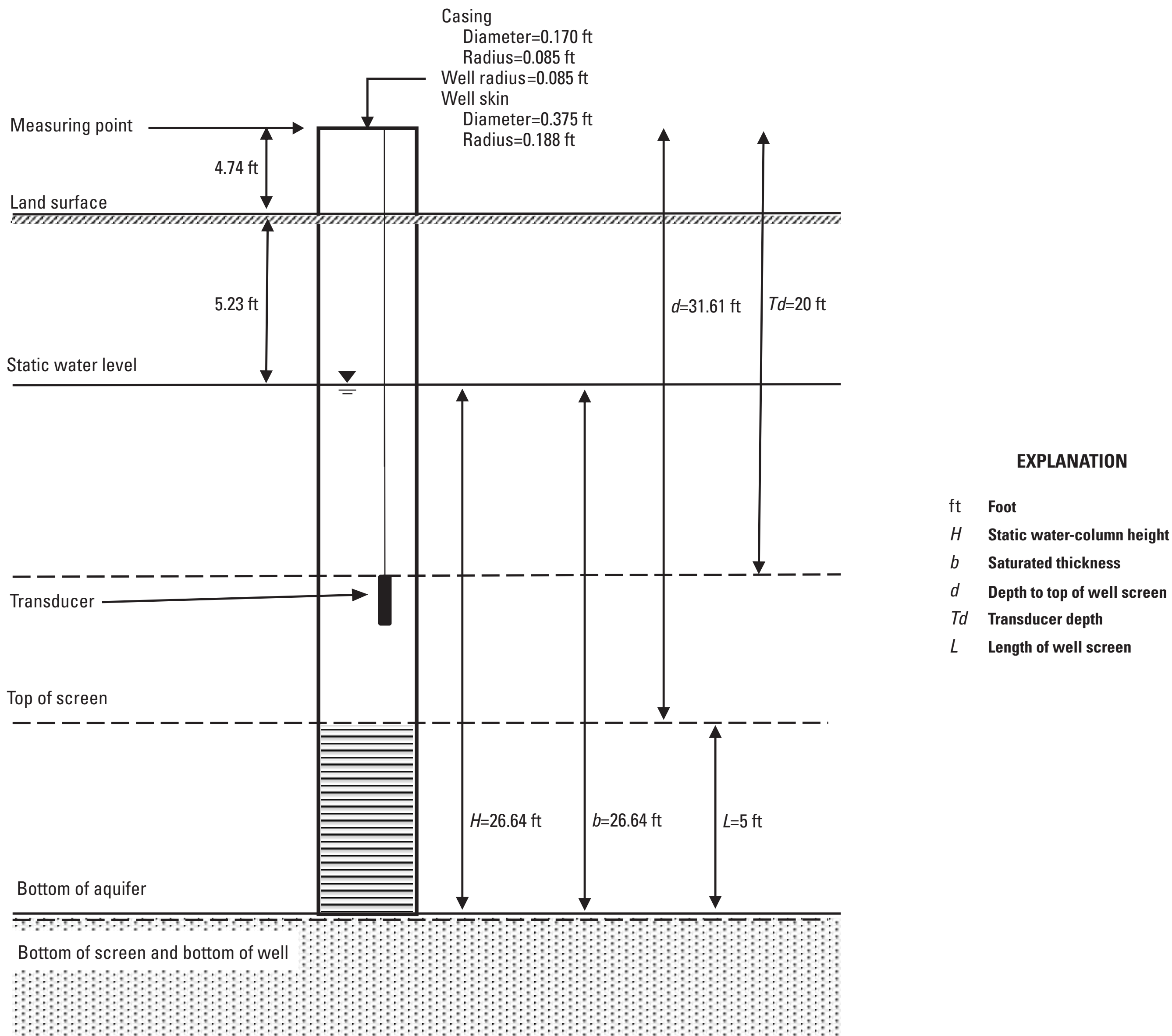


Figure 1.6. Well diagram for well MA–80L.

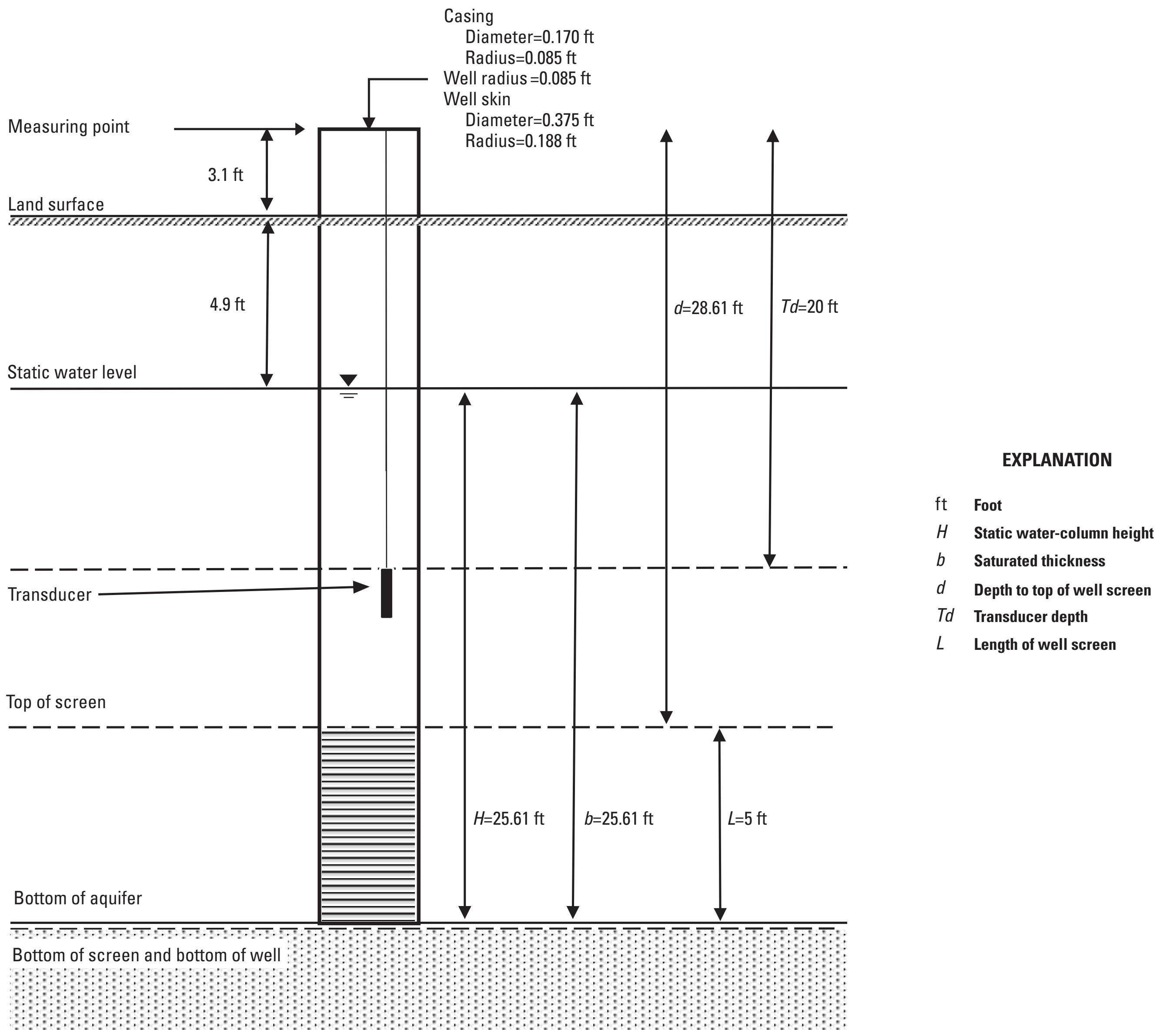


Figure 1.7. Well diagram for well MA–80M.

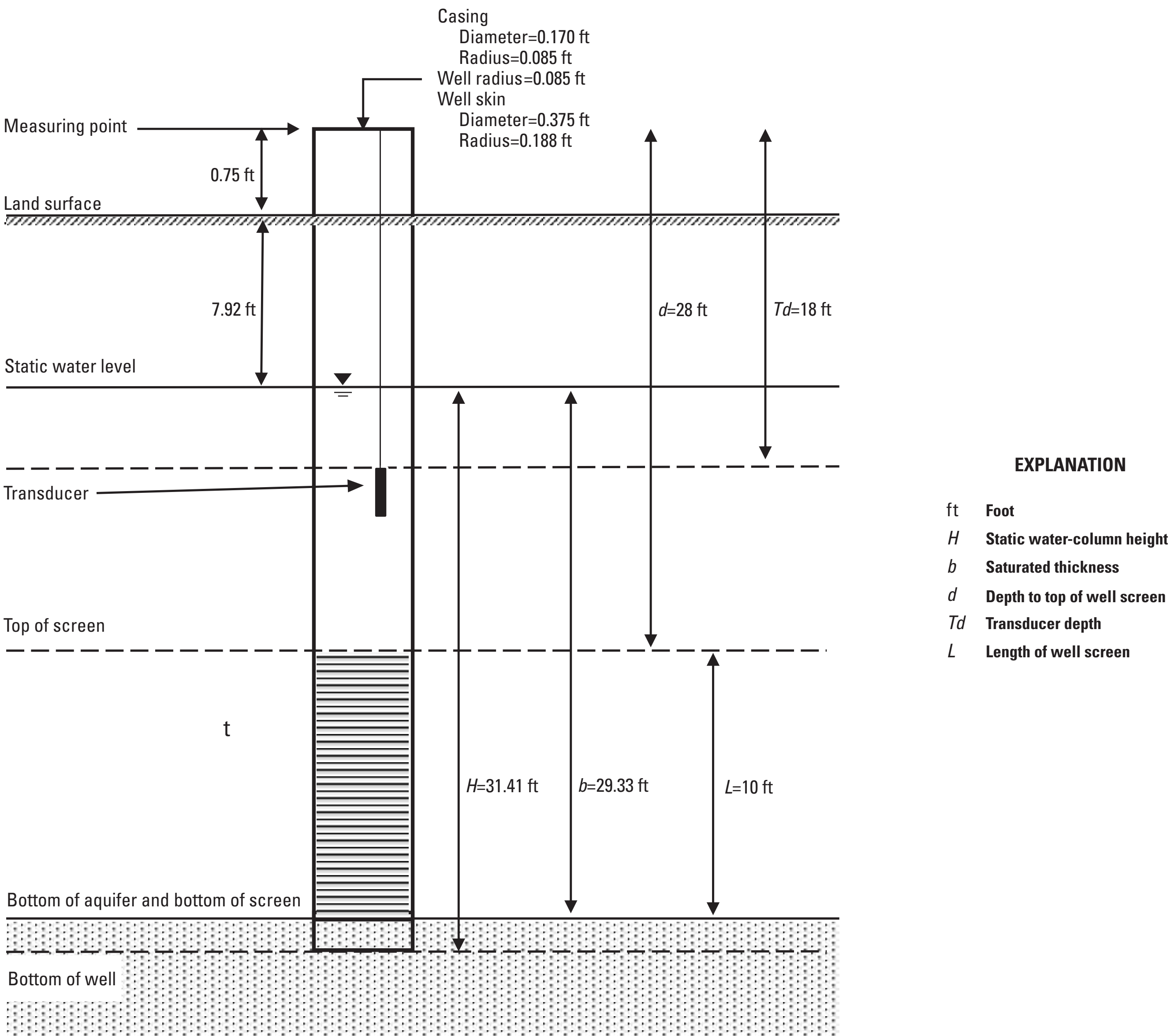


Figure 1.8. Well diagram for well R20–92–104.

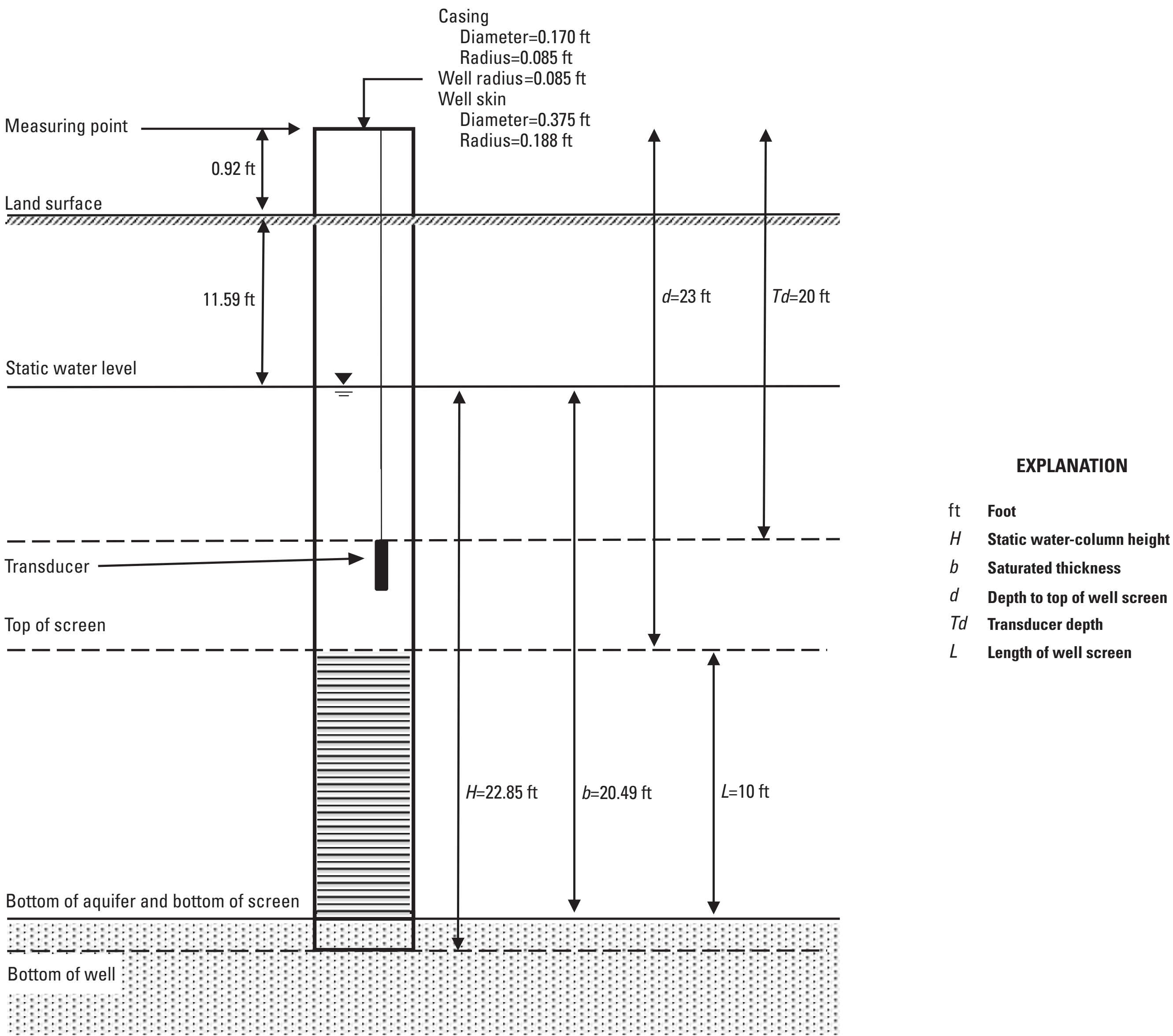


Figure 1.9. Well diagram for well R20–92–86.

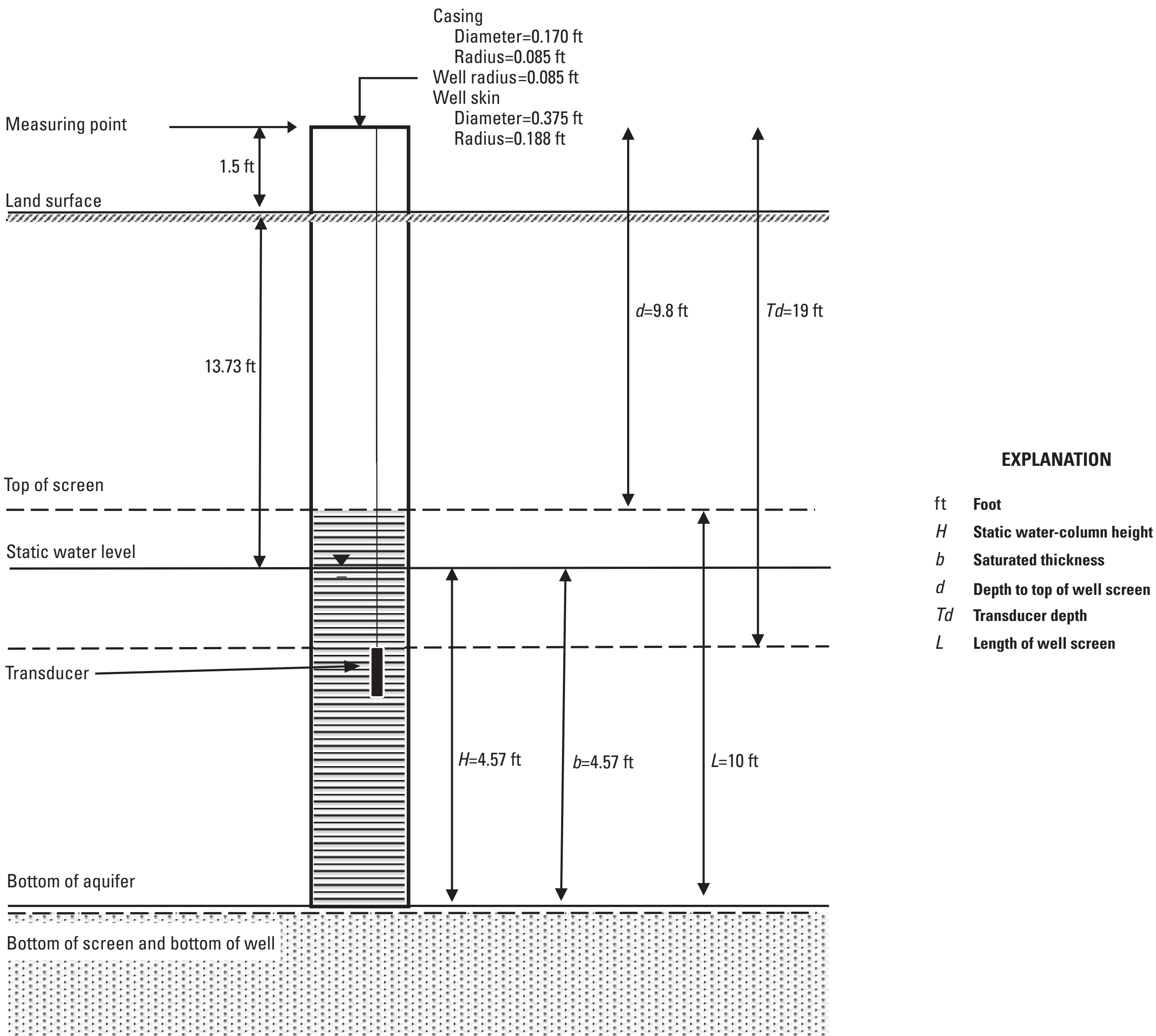
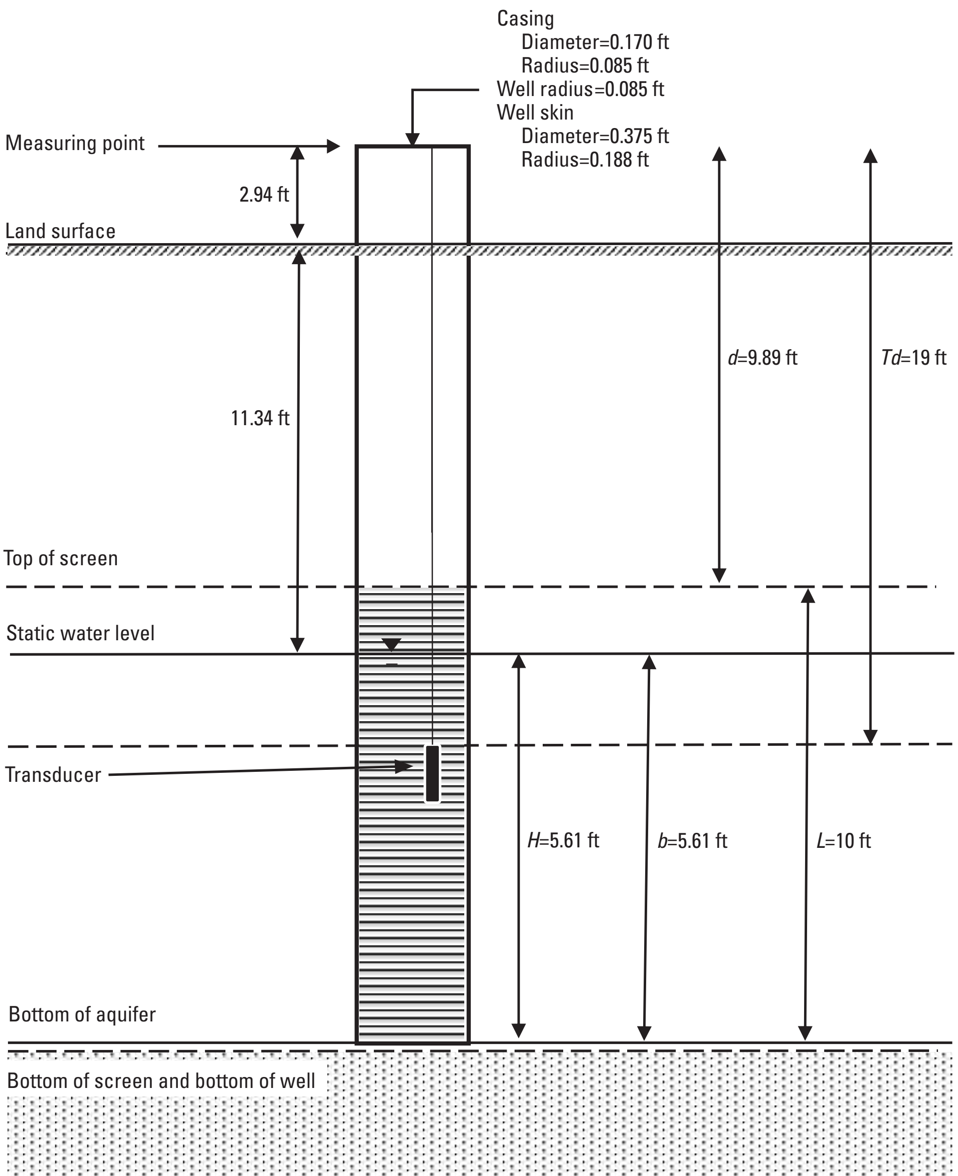


Figure 1.10. Well diagram for well R20–89–119.



EXPLANATION

ft	**Foot**
H	**Static water-column height**
b	**Saturated thickness**
d	**Depth to top of well screen**
Td	**Transducer depth**
L	**Length of well screen**

Figure 1.11. Well diagram for well R20–89–120.

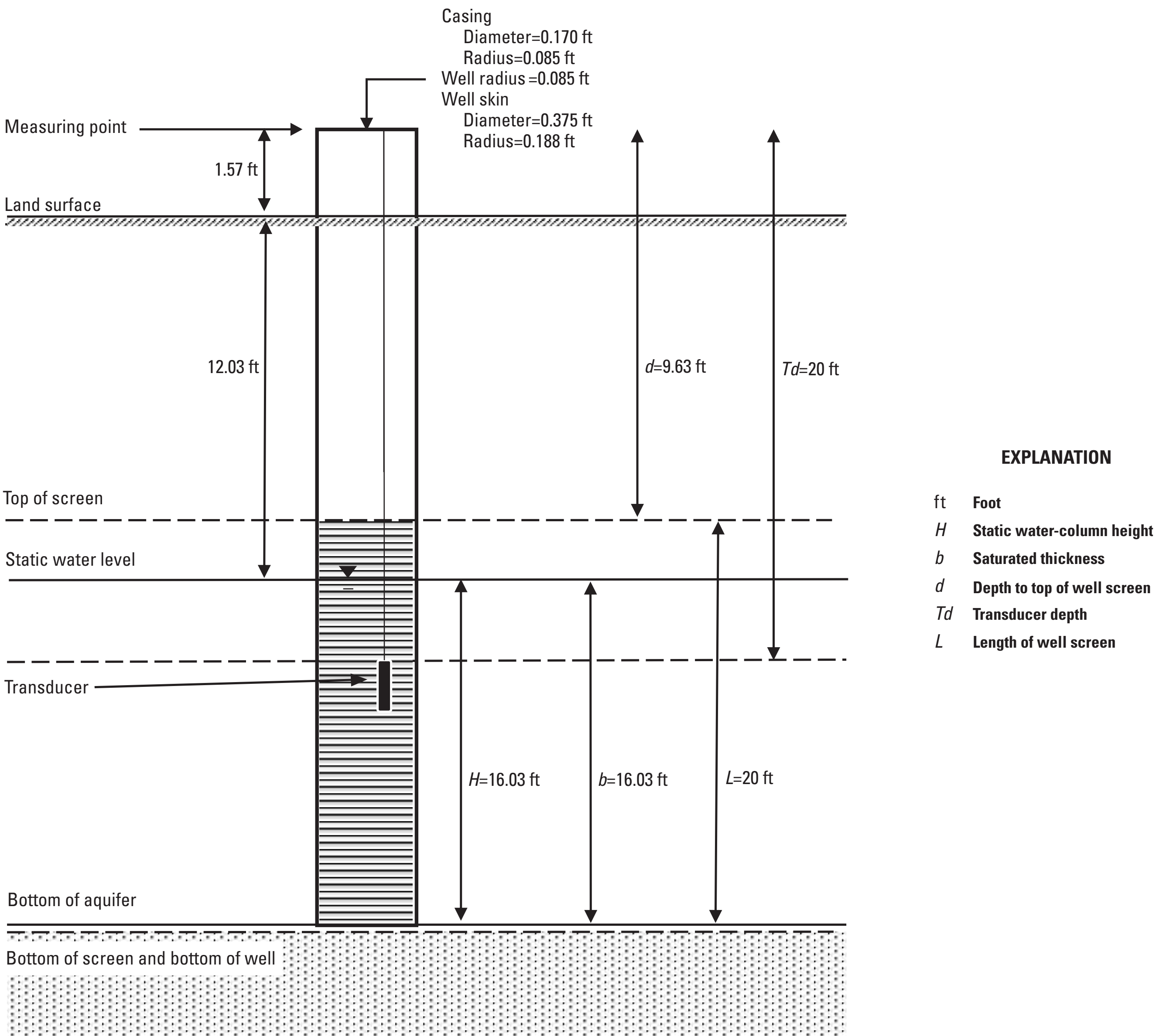


Figure 1.12. Well diagram for well R20–89–117.

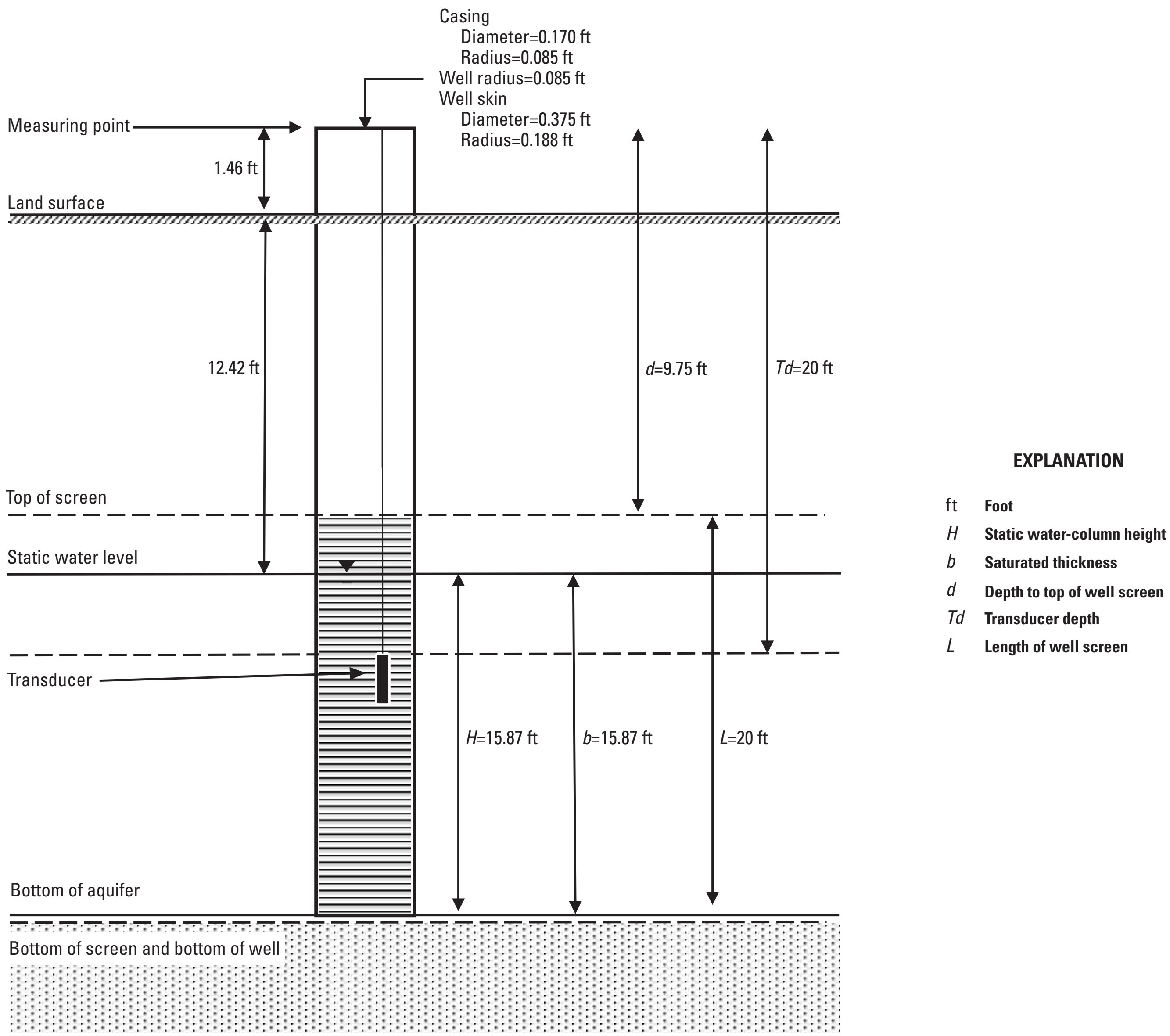


Figure 1.13. Well diagram for well R20–89–116.

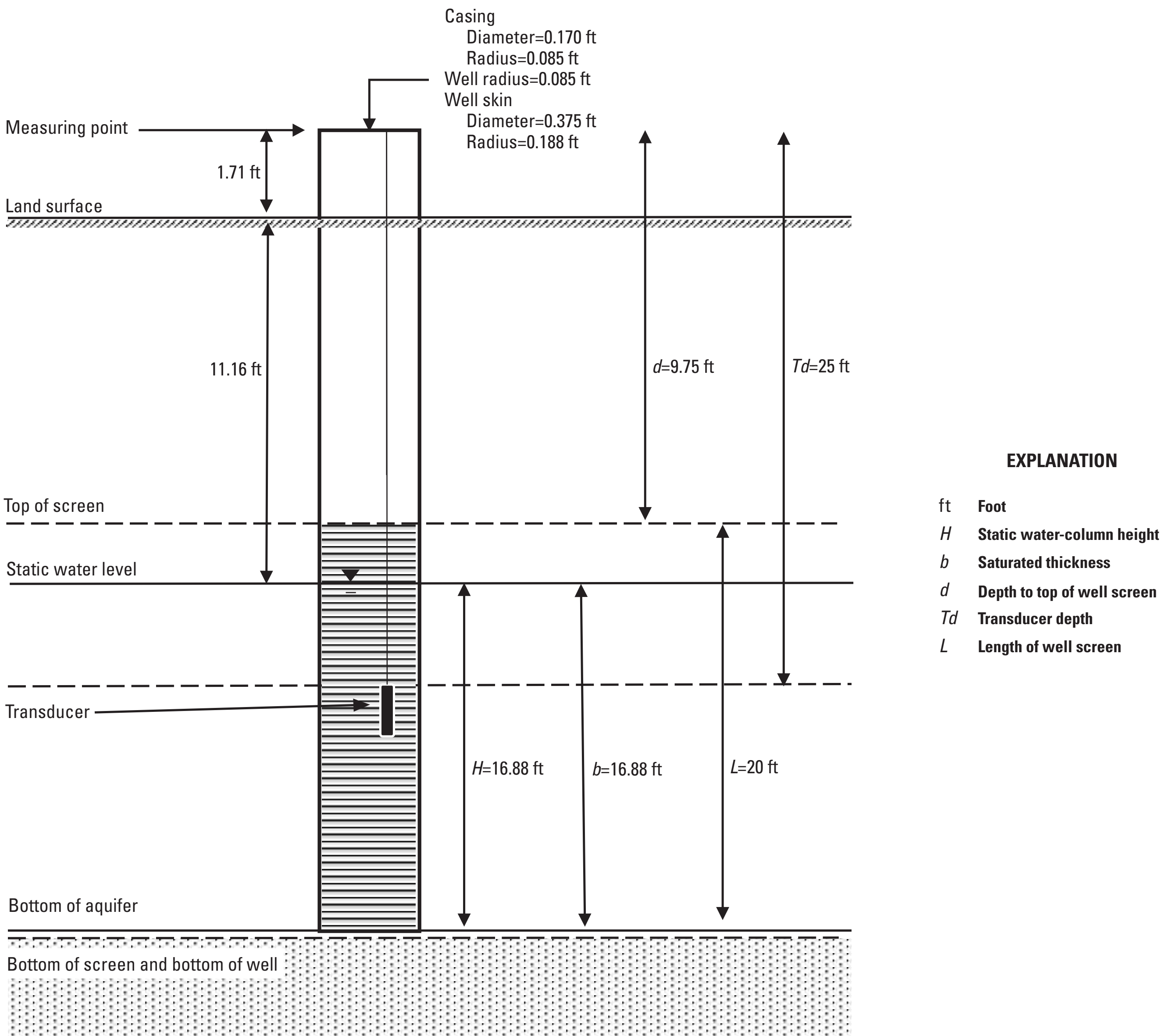


Figure 1.14. Well diagram for well R20–89–115.

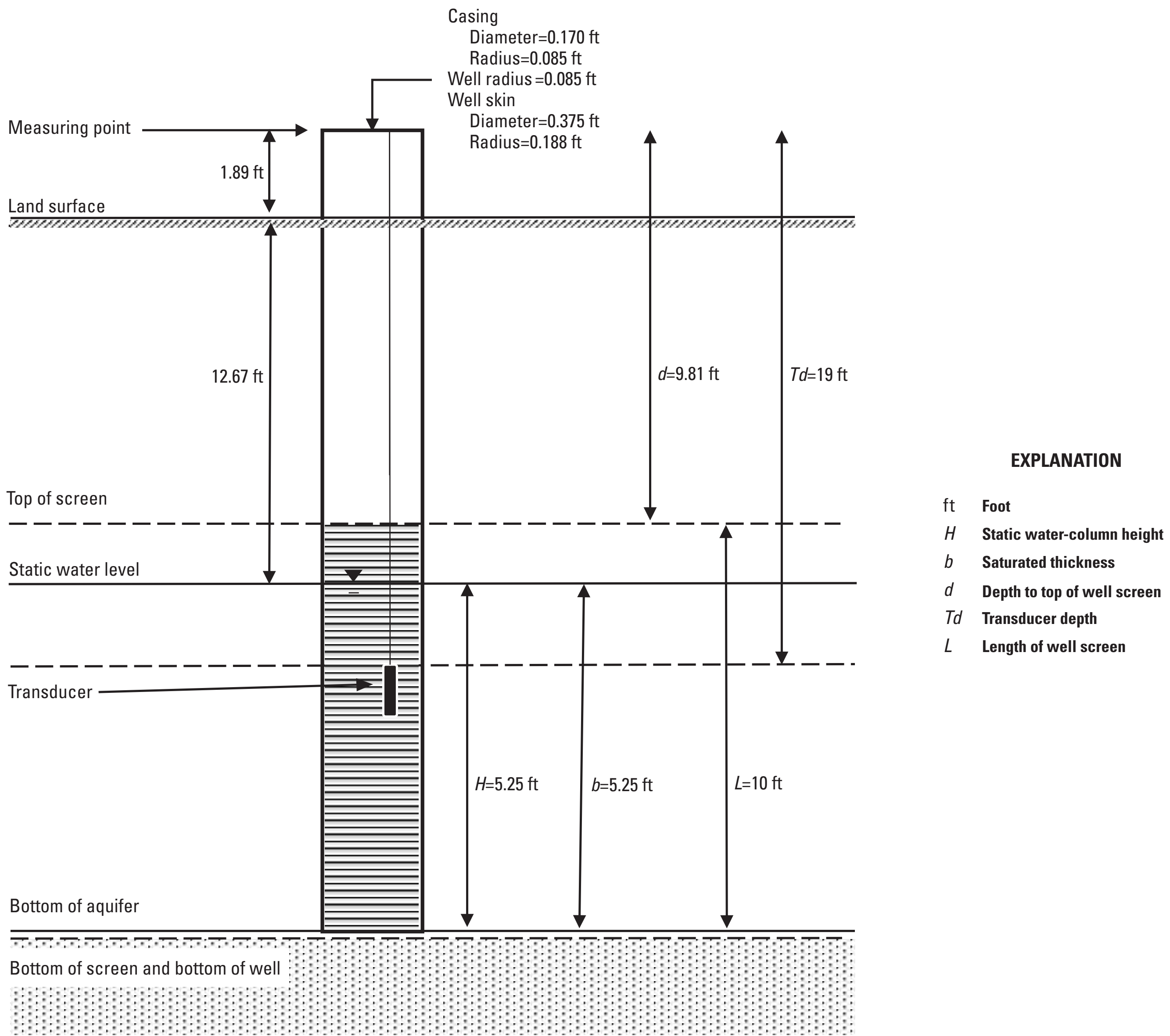


Figure 1.15. Well diagram for well R20–90–02.

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