Results of Borehole Geophysical Logging and Aquifer-Isolation Tests Conducted in the John Wagner and Sons, Inc. Former Production Well, Ivyland, Pennsylvania

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CONVERSION FACTORS

MULTIPLY	BY	TO OBTAIN
	LENGTH	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	VOLUME	
gallon (gal)	3.785	liter
	FLOW	
gallon per minute (gal/min)	0.06309	liter per second
	SPECIFIC CAPACITY	
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter
	PRESSURE	
pound per square inch (lb/in^2)	6.895	kilopascal

RESULTS OF BOREHOLE GEOPHYSICAL LOGGING AND AQUIFER-ISOLATION TESTS CONDUCTED IN THE JOHN WAGNER AND SONS, INC. FORMER PRODUCTION WELL, IVYLAND, PENNSYLVANIA

By Ronald A. Sloto

ABSTRACT

A suite of borehole geophysical logs and heat-pulse-flowmeter measurements run in the former production well at the John Wagner and Sons, Inc. plant indicate two zones of borehole flow. In the upper part of the well, water enters the borehole through a fracture at 90 ft (feet) below floor level, moves upward, and exits the borehole through a fracture at 72 ft below floor level. Water also enters the borehole through fractures at 205-213, 235, and 357 ft below floor level; moves downward; and exits the borehole through fractures at 450-459, 468-470, and 483-490 ft below floor level. Five zones were selected for aquifer-isolation (packer) tests on the basis of the borehole geophysical logs. The zones were isolated using a straddle-packer assembly. The lowermost three zones (below 248, 223 to 248, and 198 to 223 ft below floor level) were hydraulically isolated from zones above and below. Specific capacities were 0.12, 0.034, and 0.15 gallons per minute per foot, respectively. The hydrograph from zone 2 (223 to 248 ft below floor level) showed interference from a nearby pumping well. For the upper two zones (81 to 106 and 57 to 81 ft below floor level), similar drawdowns in the isolated zone and the zones above and below the isolated zone indicate that these fractures are hydraulically connected outside the borehole in the unconfined part of the Stockton Formation. The specific capacity of zones 4 and 5 are similar—0.82 and 0.61, respectively.

INTRODUCTION

The John Wagner and Sons, Inc. plant is at 900 Jacksonville Road, Ivyland, Pa., adjacent to and north of the U.S. Naval Air Warfare Center in Warminster, Pa. (fig. 1). The well is in a warehouse area inside the plant. The area is underlain by the Stockton Formation. Sloto and others (1996) provide a description of the Stockton Formation in the area.

This report describes the results of borehole geophysical logging and aquifer-isolation tests, commonly known as packer tests, conducted by the U.S. Geological Survey (USGS) in the John Wagner and Sons, Inc. former production well (USGS well BK-2871). This report provides an interpretation of borehole geophysical logs and heatpulse-flowmeter measurements and describes drawdowns, water-level distributions, and specific capacities of isolated fracture zones. The USGS collected the data presented here and prepared this report as part of the environmental hydrogeological investigations at the Warminster Naval Air Warfare Center in cooperation with the U.S. Navy.

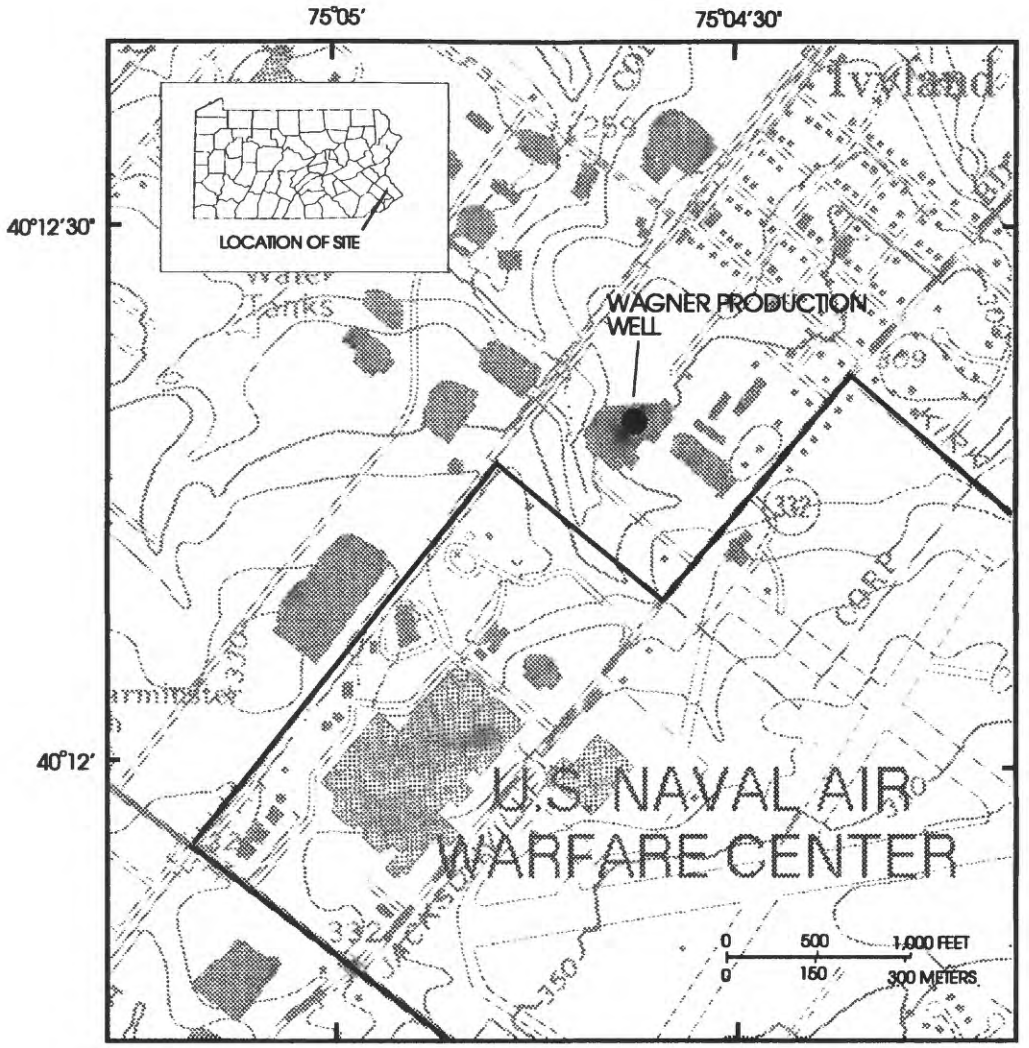


Figure 1. Location of the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania.

RESULTS OF BOREHOLE GEOPHYSICAL LOGGING

A suite of borehole geophysical logs (fig. 2) was run in the well by the USGS. Floor level of the warehouse floor is used as the reference datum in this report. The caliper log shows that the well is 496 ft deep, 6 in. in diameter, and cased to 57 ft below floor level. The fluid-resistivity and fluid-temperature logs show changes in slope at 90, 122, 205, 214, 236, and 355 ft below floor level. A heatpulse flowmeter was used to measure vertical fluid movement in the well under nonpumping conditions. Heatpulse-flowmeter measurements are summarized in table 1. The heatpulse-flowmeter measurements showed upward flow at 80 ft below floor level; no flow at 100, 114, 134, and 198 ft below floor level; and downward flow at 224, 240, 260, 298, 330, 370, 412, 440, 462, and 476 ft below floor level. The suite of borehole geophysical logs and heatpulse-flowmeter measurements indicate that water (0.08 gal/min) enters the borehole through a fracture at 90 ft below floor level, moves upward, and exits the borehole through a fracture at 72 ft below floor level. Water also enters the borehole through fractures at 205-213 (0.14 gal/min), 235 (0.09 gal/min), and 357 (0.09 gal/min) ft below floor level; moves downward; and exits the borehole through fractures at 450-459, 468-470, and 483-490 ft below floor level (fig. 3).

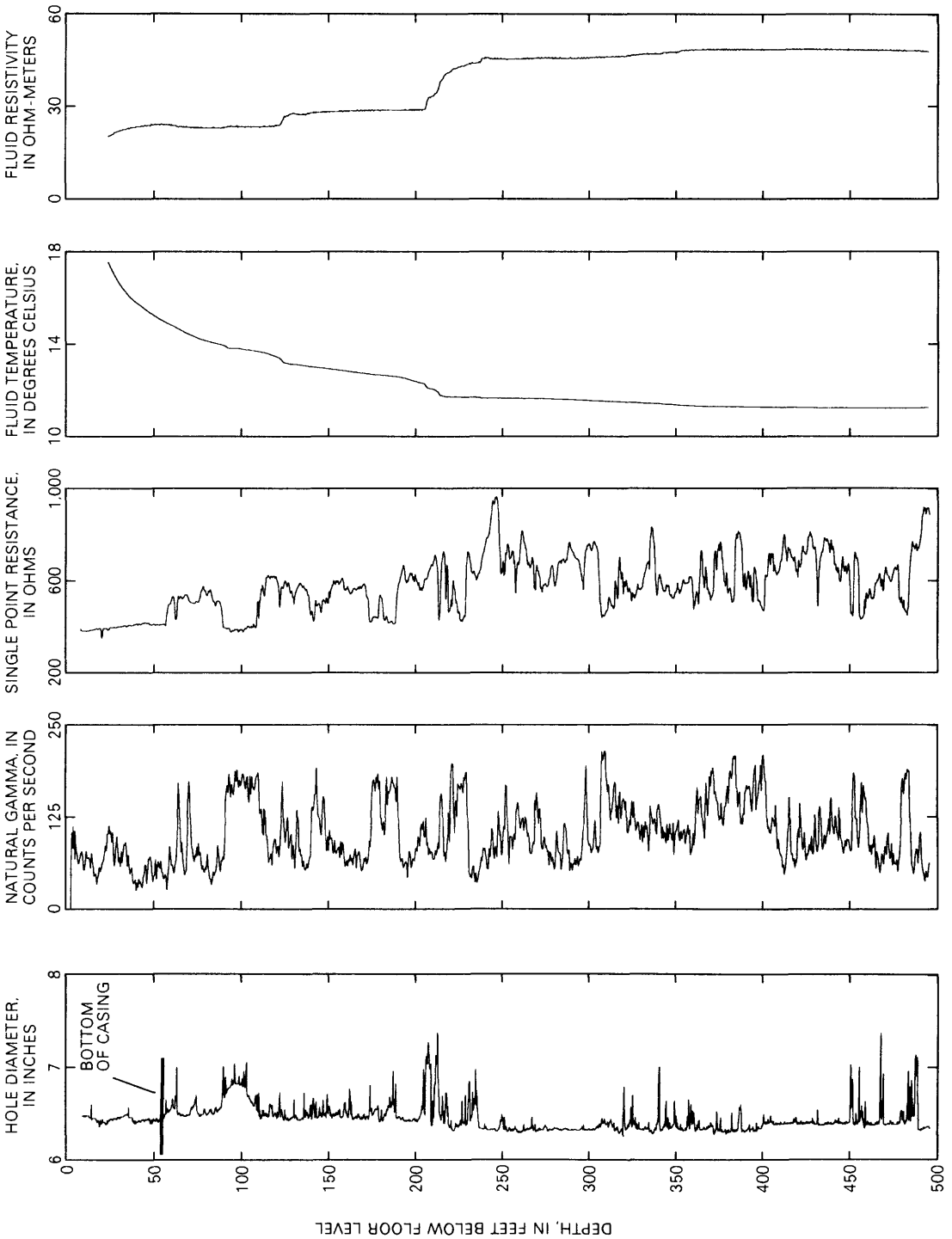


Figure 2. Borehole geophysical logs from the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania.

Table 1. Summary of heatpulse-flowmeter measurements made in the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania

[--, not measured]

Depth (feet below floor level)	Flow (gallons per minute)	Flow direction
80	0.08	Up
100	No flow	--
114	No flow	--
134	No flow	--
198	No flow	--
224	.14	Down
240	.23	Down
260	.26	Down
298	.23	Down
330	.20	Down
370	.32	Down
412	.30	Down
440	.32	Down
462	.28	Down
476	.22	Down

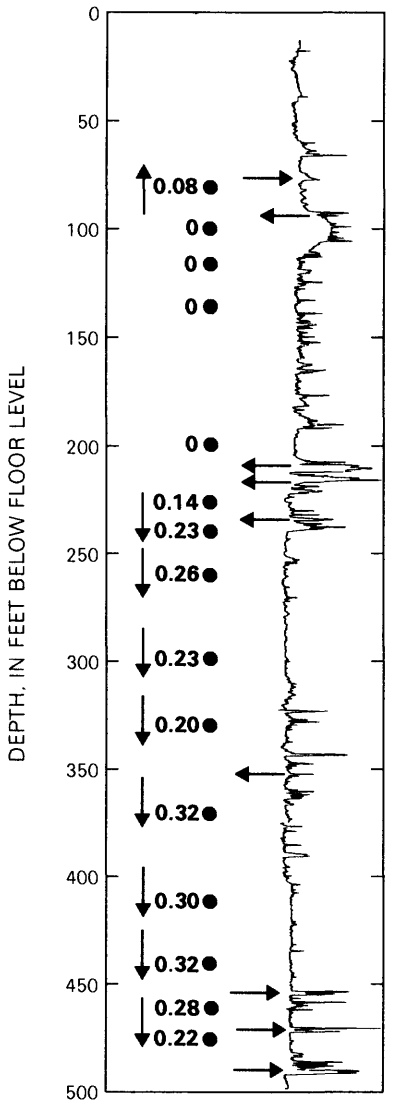
RESULTS OF AQUIFER-ISOLATION TESTS

A straddle-packer assembly was used to isolate discrete fracture zones in the Wagner well to determine depth-discrete specific capacity values and to obtain depth-discrete water samples. The maximum inflation pressure of the packers is 190 lb/in^2, equivalent to the pressure 260 ft below the water surface. The packer assembly consisted of two inflatable packers set on 2-in.-diameter lift pipe with a pump set between the packers. The distance from the center of the upper packer to the center of the lower packer was 25 ft. Packer settings given in this report are from the center of the top packer to the center of the bottom packer. Water samples were collected by Brown and Root Environmental, Inc. for volatile organic compound analysis. Water-quality data are presented by Brown and Root Environmental, Inc. (1997).

The packer assembly was lowered to the selected depth in the borehole, and the packers were inflated against the borehole wall, isolating the selected interval. Depths to set packers were based in part on the location of smooth sections of borehole wall determined from the caliper log. Inflation of both packers created three zones—an upper zone above the upper packer, the isolated zone between the packers, and a lower zone below the lower packer (fig. 4B). Pressure in the packers was continuously monitored so that the packers always remained at maximum inflation. Water levels in each zone were measured throughout the tests. Three pressure transducers were used to measure depth to water in the upper, lower, and isolated zones. Data from the transducers were recorded by a data logger at the surface. Measurements also were made during the tests with electric water-level-measurement tapes to verify transducer performance.

On the basis of the borehole geophysical logs and heat-pulse flowmeter measurements, five intervals were selected for aquifer-isolation tests (fig. 5). These intervals are listed in table 2. For the test of the lowermost isolated interval (zone 1), only the upper packer was inflated (fig. 4A). For the test of the uppermost isolated interval (zone 5), only the lower packer was inflated (fig. 4C). For the test of the other intervals (zones 2, 3, and 4), both packers were inflated (fig. 4B).

After the packers were inflated, water levels in each zone were allowed to reach static levels. Water levels were measured with electric tapes for approximately 1 hour unless static levels were reached in a shorter amount of time. After water levels stabilized, a step-drawdown test was run. Each isolated interval was pumped at 2 or 3 pumping rates for 29 to 49 minutes at each rate (table 3). All pumped water was routed through the existing treatment system (activated granular carbon) before being discharged. During the step-drawdown tests, water levels were recorded above, below, and in the isolated interval. After the pump was shut off, water levels were allowed to recover for approximately 15 minutes before packer deflation.



EXPLANATION

● **0.20** BOREHOLE-FLOW MEASUREMENT—Circle at depth of flow measurement. Number is measured flow in gallons per minute

↑ DIRECTION OF VERTICAL BOREHOLE FLOW—Arrow indicates direction of flow

← FLOW INTO OR OUT OF BOREHOLE—Arrow pointing toward caliper log indicates flow out of borehole. Arrow pointing away from caliper log indicates flow into borehole

Figure 3. Caliper log and borehole-flow measurements, John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania.

The specific capacity of each isolated interval was determined by the following method. The specific capacity for each step was calculated by dividing the average pumping rate during the step by the total drawdown at the end of the step. The specific capacity of the isolated interval is the mean of the specific capacities of each step in the test of the isolated interval.

Aquifer-Isolation Test of Zone 1 (248 to 496 Feet Below Floor Level)

For the aquifer-isolation test of zone 1, the center of the upper packer was set at 248 ft below floor level. Only the upper packer was inflated. Before packer inflation, the depth to water in the open borehole was 6.48 ft below floor level. Fifty-five minutes after packer inflation, the depth to water in the zone above the packer was 5.85 ft below floor level, an increase in water level of 0.63 ft, and the depth to water in the zone below the packer was 16.69 ft below floor level, a decrease in water level of 10.21 ft. This is consistent with the downward borehole-flow measurements, which indicate a higher head in the water-producing fractures in the upper part of the well and a lower head in the water-receiving fractures in the lower part of the well.

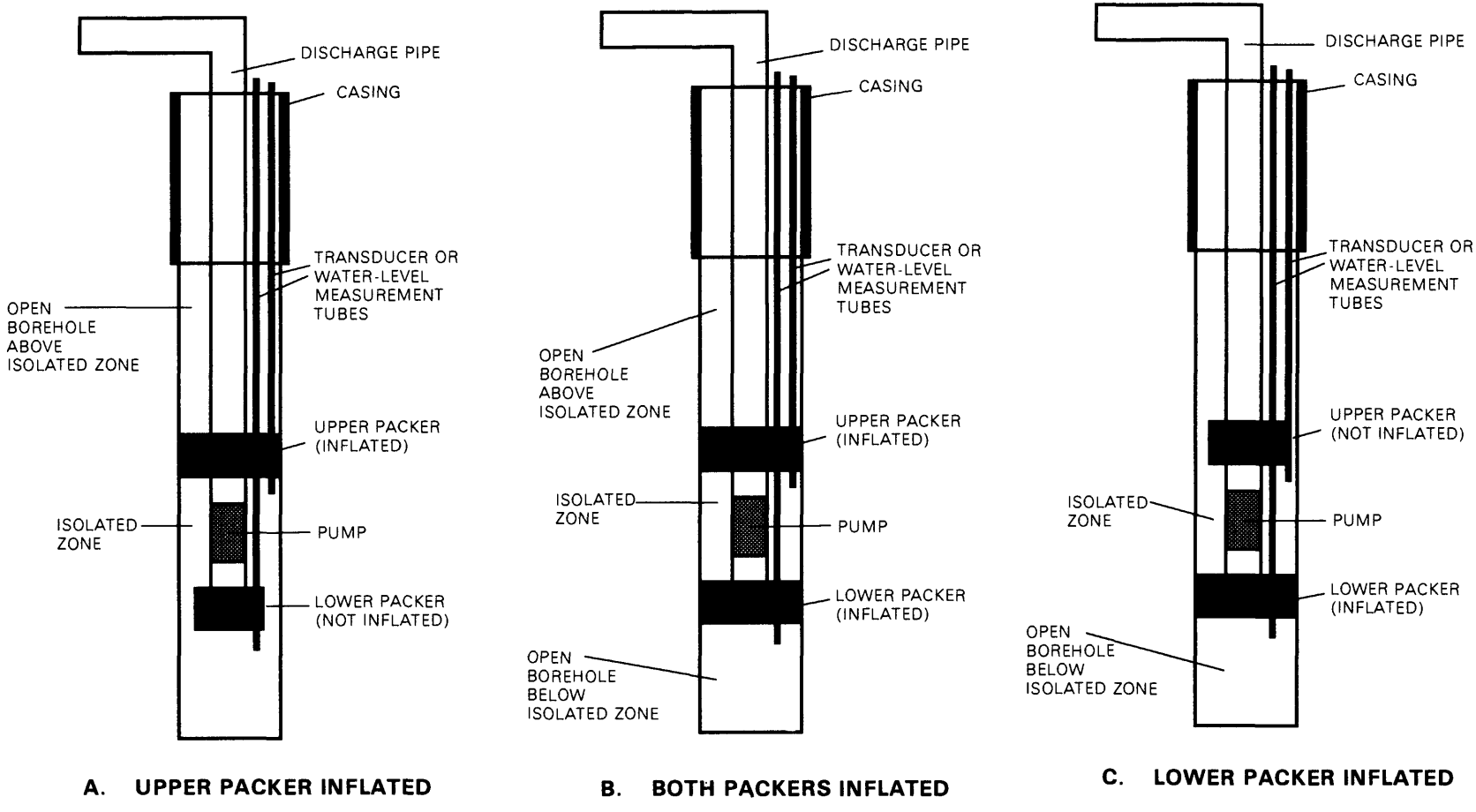


Figure 4. Generalized sketch of straddle-packer assembly and pump in borehole.

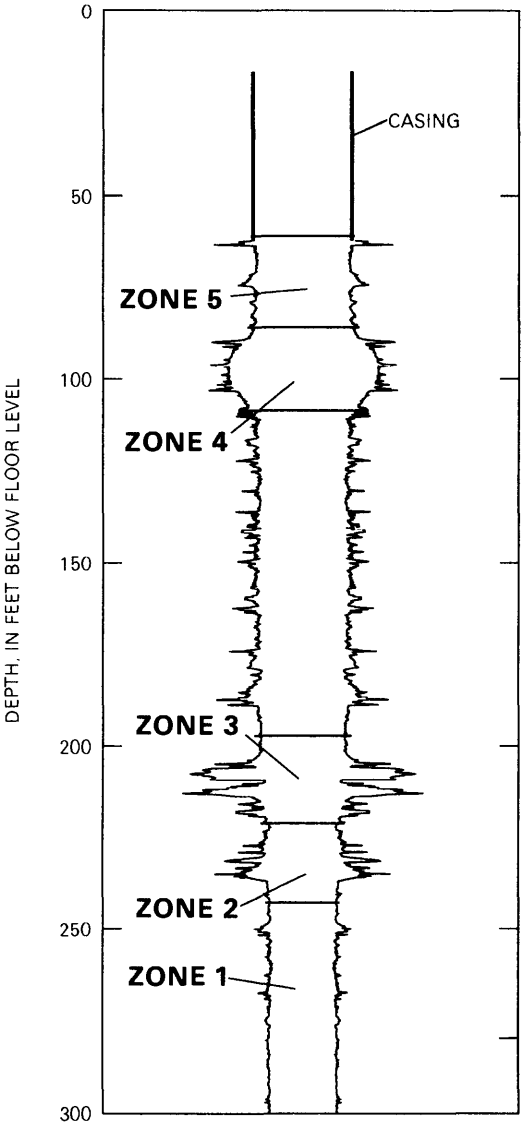


Figure 5. Caliper log showing zones isolated in the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania.

Table 2. Intervals isolated in the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania

Zone	Depth (feet below floor level)	Reason for selection
1	248-496	Water-producing fracture at 357 feet and water-receiving fractures at 450-490 feet
2	223-248	Water-producing fracture at 235 feet, which produces downward flow at 0.09 gallons per minute
3	198-223	Water-producing fractures at 205-213 feet, which produce downward flow at 0.14 gallons per minute
4	81-106	Water-producing fracture at 90 feet, which produces upward flow at 0.08 gallons per minute
5	57-81	Water-receiving fracture at 72 feet

Table 3. Pumpage from and specific capacity of isolated zones in the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania.

Zone	Depth (feet below floor level)	Number of steps	Total water pumped (gallons)	Specific capacity (gallons per minute per foot)
1	248-496	2	476.5	0.12
2	223-248	3	239.2	.034
3	198-223	2	274.6	.15
4	81-106	3	476.7	.82
5	57-81	2	243.6	.61

The average pumping rate for the first step (table 4) was 5.2 gal/min. The first step was 30 minutes long. The water level in the zone above the packer increased 0.07 ft, and drawdown in the pumped zone below the packer was 38.90 ft. For the second step, the pumping rate was increased to 7.0 gal/min. The second step was 46 minutes long. At the end of the second step, the total increase in water level in the zone above the packer was 0.08 ft, and the total drawdown in the pumped zone below the packer was 61.79 ft. The specific capacity of zone 1 is 0.12 (gal/min)/ft. The hydrographs for the zones above and below the packer are shown in figure 6. The hydrographs indicate no hydraulic connection between the zones.

Table 4. Schedule and pumping rates for the aquifer-isolation test of zone 1 (248 to 496 feet below floor level) in the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania, December 12, 1996

Time	Activity
1245	Begin packer inflation
1340	Start datalogger (test00)
1345	Start pump - step 1, average rate = 5.2 gallons per minute
1415	Increase pumping rate - step 2, average rate = 7.0 gallons per minute
1501	Pump off
1516	Begin packer deflation

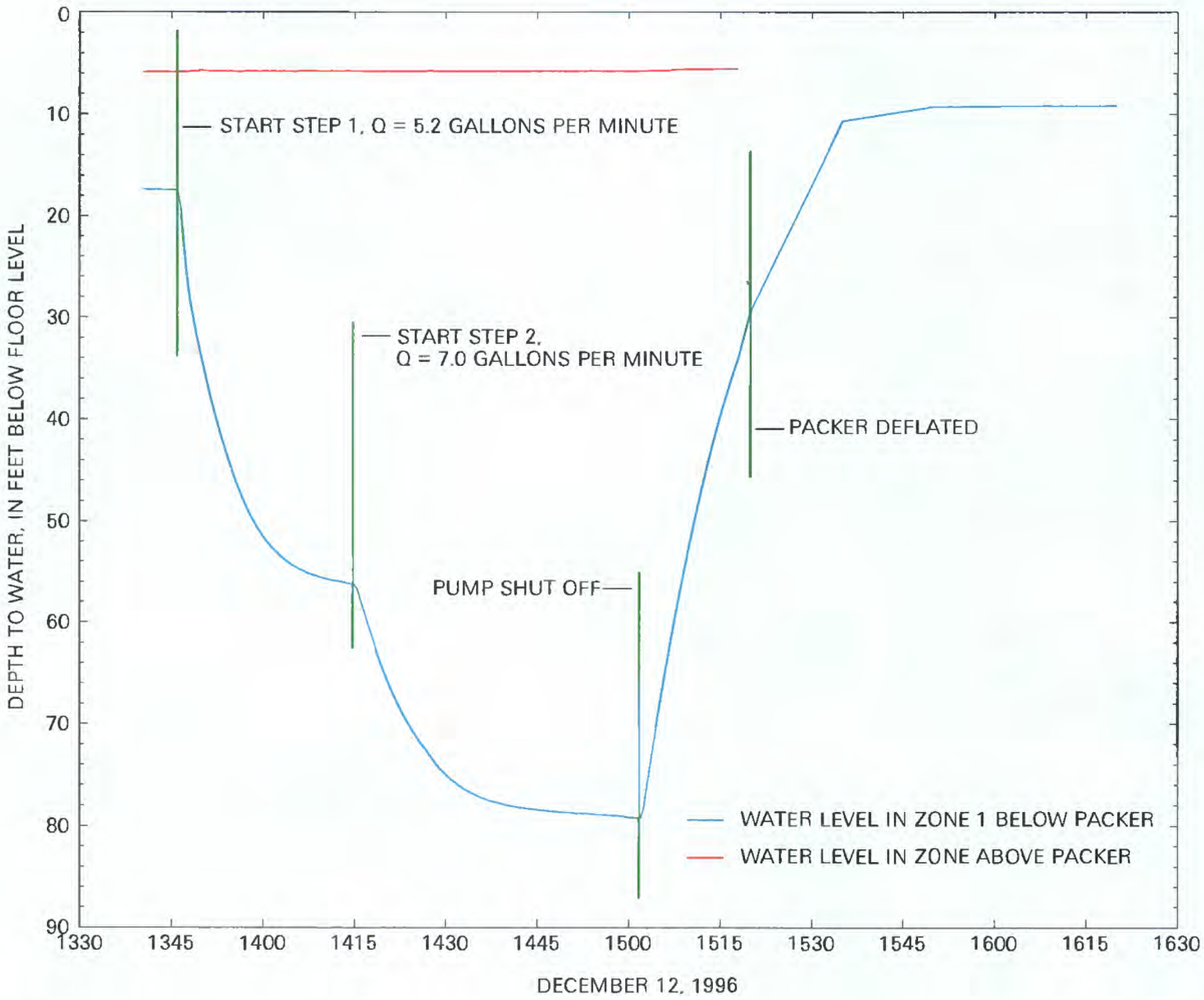


Figure 6. Hydrographs from aquifer-isolation test of zone 1 (248 to 496 feet below floor level) in the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania.

Aquifer-Isolation Test of Zone 2 (223 to 248 Feet Below Floor Level)

For the aquifer-isolation test of zone 2, the center of the upper packer was set at 223 ft below floor level; the center of the lower packer was 248 ft below floor level. Before packer inflation, the depth to water in the open borehole was 7.52 ft below floor level. Fifty minutes after packer inflation, the depth to water in the upper zone (zone above the upper packer) was 5.86 ft below floor level, an increase in water level of 1.66 ft; the depth to water in the isolated zone was 5.74 ft below floor level, an increase in water level of 1.78 ft; and the depth to water in the lower zone (zone below the lower packer) was 17.75 ft below floor level, a decrease in water level of 10.23 ft. This is consistent with the downward borehole-flow measurements, which indicated a higher head in the water-producing fractures in the upper part of the well and a lower head in the water-receiving fractures in the lower part of the well.

The average pumping rate for the first step (table 5) was 2.2 gal/min. The first step was 30 minutes long. At the end of the first step, drawdown in the upper zone was 1.57 ft, drawdown in the isolated zone was 62.05 ft, and drawdown in the lower zone was 0.71 ft. For the second step, the pumping rate was increased to 4.3 gal/min. The second step was only 10 minutes long because the water level in the isolated zone quickly dropped to near the depth of the transducer. At the end of the second step, the total drawdown in upper zone was 3.03 ft, the total drawdown in the isolated zone was 102.57 ft, and the total drawdown in the lower zone was 0.85 ft. For the third step, the pumping rate was decreased to 2.6 gal/min. The third step was 49 minutes long. At the end of the third step, the total drawdown in upper zone was 1.35 ft, the total drawdown in the isolated zone was 107.19 ft, and the total drawdown in the lower zone was 0.88 ft. The specific capacity of zone 2 is 0.034 (gal/min)/ft. The hydrographs for the upper zone, isolated zone, and lower zone are shown in figure 7. The hydrographs indicate no hydraulic connection among the three zones. The hydrograph of the isolated zone shows changes in water level not related to the pumping of the Wagner well. These changes in water level probably are caused by the pumping of a nearby industrial well that is hydraulically connected to the isolated zone.

Table 5. Schedule and pumping rates for the aquifer-isolation test of zone 2 (223 to 248 feet below floor level) in the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania, December 13, 1996

Time	Activity
0853	Start datalogger (test02)
0900	Begin packer inflation
0908	Packer inflation completed
0946	Start pump - step 1, average rate = 2.2 gallons per minute
1016	Increase pumping rate - step 2, average rate = 4.3 gallons per minute
1026	Decrease pumping rate - step 3, average rate = 2.6 gallons per minute
1115	Pump off
1132	Begin packer deflation
1136	Datalogger off

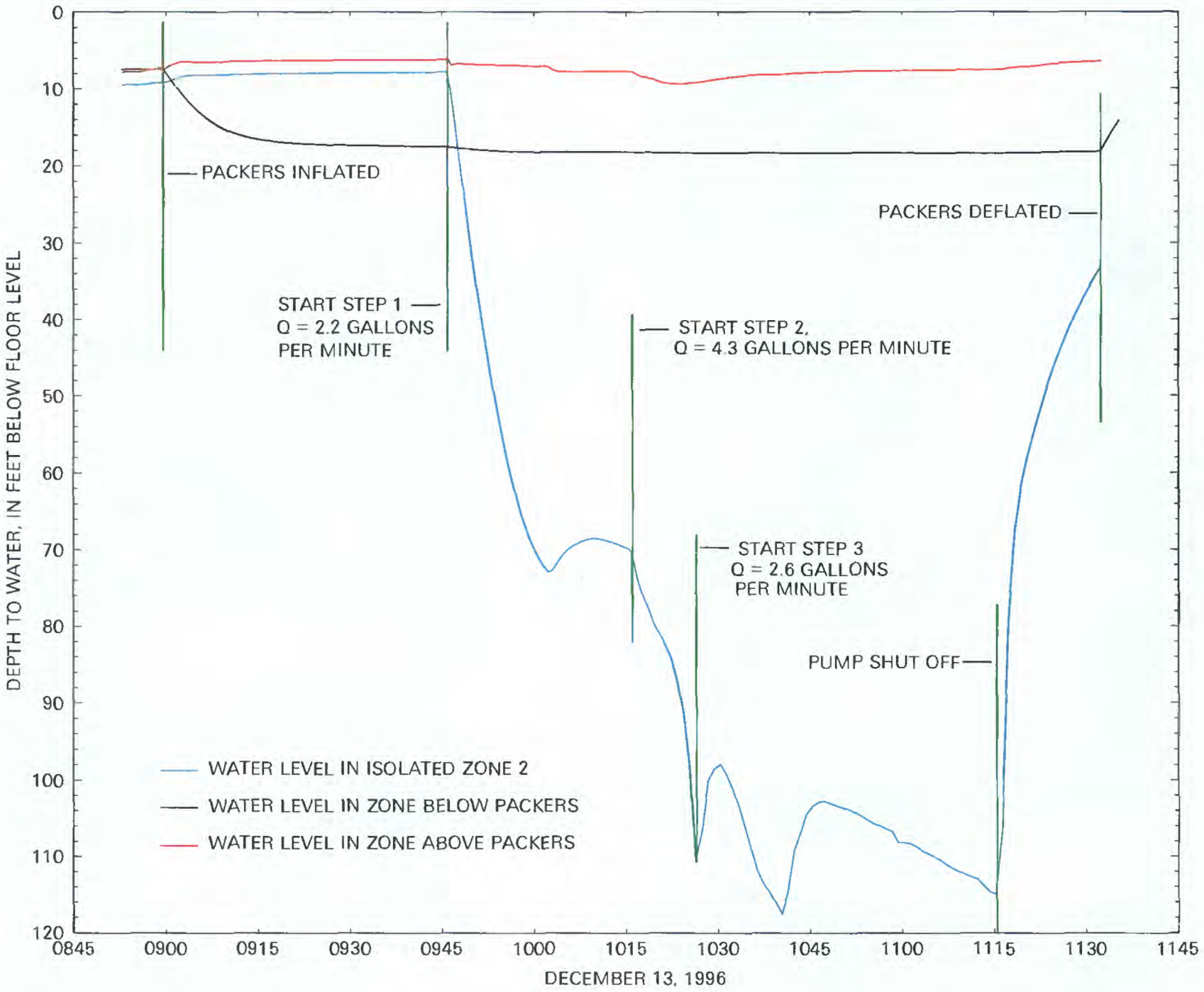


Figure 7. Hydrographs from aquifer-isolation test of zone 2 (223 to 248 feet below floor level) in the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania.

Aquifer-Isolation Test of Zone 3 (198 to 223 Feet Below Floor Level)

For the aquifer-isolation test of zone 3, the center of the upper packer was set at 198 ft below floor level; the center of the lower packer was 223 ft below floor level. Before packer inflation, the depth to water in the open borehole was 7.43 ft below floor level. Fifty-eight minutes after packer inflation, the depth to water in the upper zone (zone above the upper packer) was 6.30 ft below floor level, an increase in water level of 1.13 ft; the depth to water in the isolated zone was 4.60 ft below floor level, an increase in water level of 2.83 ft; and the depth to water in the lower zone (zone below the lower packer) was 16.50 ft below floor level, a decrease in water level of 9.07 ft. This is consistent with the downward borehole-flow measurements, which indicated a higher head in the water-producing fractures in the upper part of the well and a lower head in the water-receiving fractures in the lower part of the well.

The average pumping rate for the first step (table 6) was 2.1 gal/min. The first step was 40 minutes long. At the end of the first step, drawdown in the upper zone was 0.17 ft, drawdown in the isolated zone was 11.90 ft, and drawdown in the lower zone was 0.27 ft. For the second step, the pumping rate was increased to 4.8 gal/min. The second step was 40 minutes long. At the end of the second step, the total drawdown in upper zone was 0.18 ft, the total drawdown in the isolated zone was 42.22 ft, and the total drawdown in the lower zone was 0.43 ft. The specific capacity of zone 3 is 0.15 (gal/min)/ft. The hydrographs for the upper zone, isolated zone, and lower zone are shown in figure 8. The hydrographs indicate no hydraulic connection among the three zones.

Aquifer-Isolation Test of Zone 4 (81 to 106 Feet Below Floor Level)

For the aquifer-isolation test of zone 4, the center of the upper packer was set at 81 ft below floor level; the center of the lower packer was 106 ft below floor level. Before packer inflation, the depth to water in the open borehole was 6.23 ft below floor level. Water levels stabilized quickly after packer inflation. At 32 minutes after packer inflation, the depth to water in the upper zone (zone above the upper packer) was 6.24 ft below floor level, an increase in water level of

Table 6. Schedule and pumping rates for the aquifer-isolation test of zone 3 (198 to 223 feet below floor level) in the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania, December 13, 1996

Time	Activity
1219	Begin packer inflation
1316	Start datalogger (test04)
1320	Start pump - step 1, average rate = 2.1 gallons per minute
1400	Increase pumping rate - step 2, average rate = 4.8 gallons per minute
1440	Pump off
1456	Begin packer deflation
1500	Datalogger off

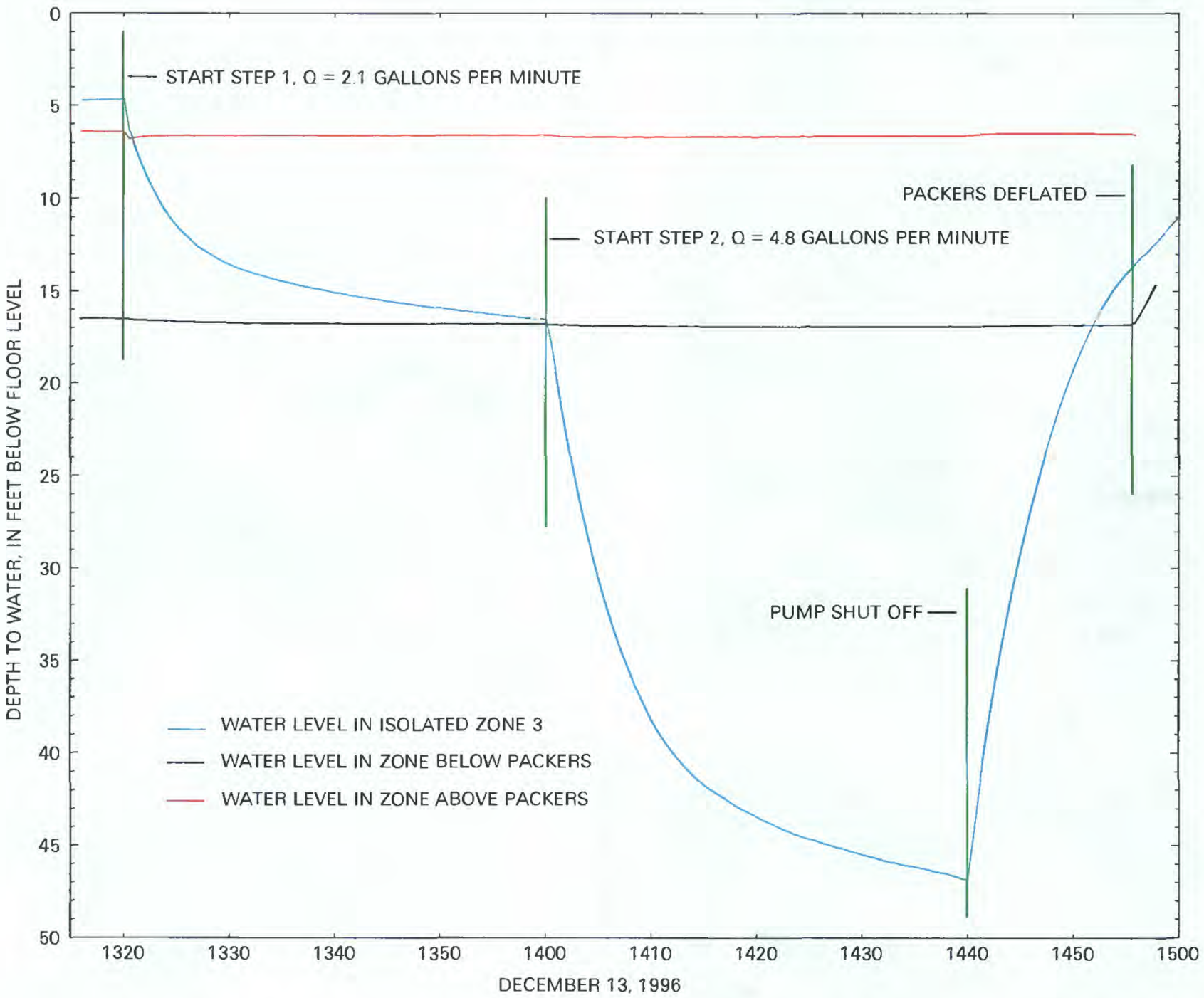


Figure 8. Hydrographs from aquifer-isolation test of zone 3 (198 to 223 feet below floor level) in the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania.

0.01 ft; the depth to water in the isolated zone was 6.25 ft below floor level, a decrease in water level of 0.02 ft; and the depth to water in the lower zone (zone below the lower packer) was 6.21 ft below floor level, an increase in water level of 0.02 ft. This indicates little or no difference in head among the three zones and indicates that the zones probably are interconnected. The difference of 0.01 to 0.02 ft may be measurement error.

The average pumping rate for the first step (table 7) was 2.1 gal/min. The first step was 29 minutes long. At the end of the first step, the drawdown in the upper zone was 2.15 ft, the drawdown in the isolated zone was 2.32 ft, and the drawdown in the lower zone was 2.53 ft. For the second step, the pumping rate was increased to 4.6 gal/min. The second step was 30 minutes long. At the end of the second step, the total drawdown in the upper zone was 5.74 ft, the total drawdown in the isolated zone was 5.74 ft, and the total drawdown in the lower zone was 5.66 ft. For the third step, the pumping rate was increased to 8.4 gal/min. The third step was 33 minutes long. At the end of the third step, the total drawdown in the upper zone was 10.36 ft, the total drawdown in the isolated zone was 11.05 ft, and the total drawdown in the lower zone was 11.01 ft. The specific capacity of zone 4 is 0.82 (gal/min)/ft.

The hydrographs for the upper zone, isolated zone, and lower zone are shown in figure 9. The hydrographs for the three zones are similar, indicating that they are hydraulically connected outside the borehole. The upper part of the Stockton Formation is under unconfined conditions (water table) and is characterized by an interconnected system of fractures (Sloto and others, 1996). Therefore, the specific capacity of zone 4 is greater than that of the isolated fractures.

Aquifer-Isolation Test of Zone 5 (57 to 81 Feet Below Floor Level)

For the aquifer-isolation test of zone 5, the center of the lower packer was set at 81 ft below floor level. The well is cased to 57 ft below floor level. Only the lower packer was inflated, creating two zones, the pumped zone above the lower packer and zone below the lower packer. Before packer inflation, the depth

Table 7. Schedule and pumping rates for the aquifer-isolation test of zone 4 (81 to 106 feet below floor level) in the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania, December 16, 1996

Time	Activity
0913	Begin packer inflation
0947	Start datalogger (test06)
1031	Start pump - step 1, average rate = 2.1 gallons per minute
1100	Increase pumping rate - step 2, average rate = 4.6 gallons per minute
1130	Increase pumping rate - step 3, average rate = 8.4 gallons per minute
1203	Pump off
1221	Begin packer deflation
1225	Datalogger off

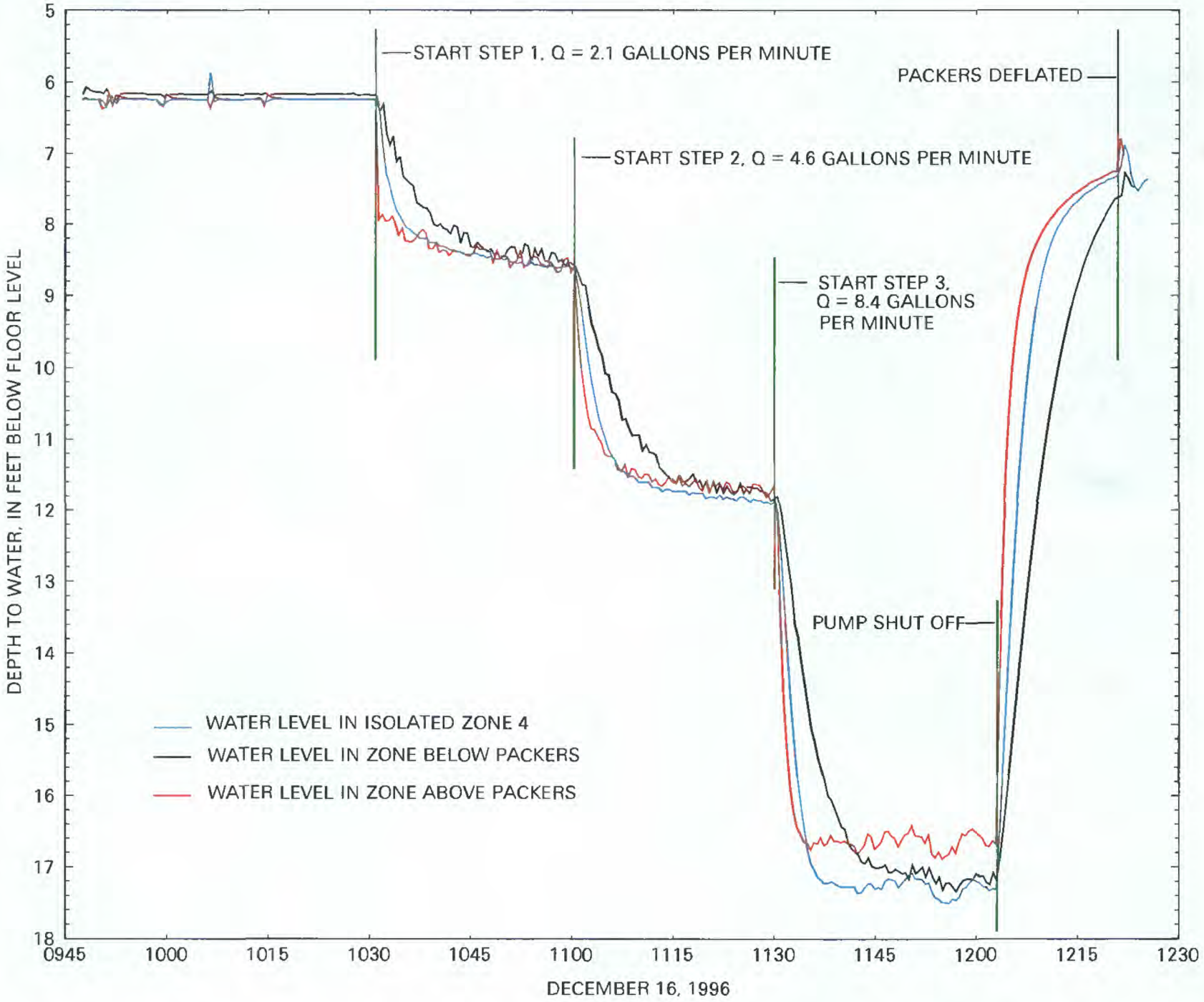


Figure 9. Hydrographs from aquifer-isolation test of zone 4 (81 to 106 feet below floor level) in the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania.

to water in the open borehole was 6.61 ft below floor level. Water levels stabilized quickly after packer inflation. At 12 minutes after packer inflation, the depth to water above the packer was 6.51 ft below floor level, an increase in water level of 0.08 ft, and the depth to water below the packer was 6.54 ft below floor level, an increase in water level of 0.11 ft. This indicates little or no difference in head between the two zones.

The average pumping rate for the first step (table 8) was 2.3 gal/min. The first step was 33 minutes long. At the end of the first step, drawdown in the pumped zone above the packer was 3.41 ft, and drawdown in the zone below the packer was 2.36 ft. For the second step, the pumping rate was increased to 4.9 gal/min. The second step was 32 minutes long. At the end of the second step, the total drawdown in the pumped zone above the packer was 8.93 ft, and the total drawdown in the zone below the packer was 5.30 ft. The specific capacity of zone 5 is 0.61 (gal/min)/ft. The hydrographs for the zones above and below the packer are shown in figure 10. The hydrographs indicate a hydraulic connection between the two zones outside the borehole. Therefore, the specific capacity of zone 5 is greater than that of the isolated fractures.

SUMMARY AND CONCLUSIONS

A suite of borehole geophysical logs and heat-pulse-flowmeter measurements run in the former production well at the John Wagner and Sons, Inc. plant indicate two zones of borehole flow. In the upper part of the well, water enters the borehole through a fracture at 90 ft below floor level, moves upward, and exits the borehole through a fracture at 72 ft below floor level. Water also enters the borehole through fractures at 205-213, 235, and 357 ft below floor level; moves downward; and exits the borehole through fractures at 450-459, 468-470, and 483-490 ft below floor level.

Five zones were selected for aquifer-isolation tests on the basis of interpretation of the borehole geophysical logs run in the well. The zones were isolated using a straddle-packer assembly. The lowermost three zones (below 248, 223 to 248, and 198 to 223 ft

Table 8. Schedule and pumping rates for the aquifer-isolation test of zone 5 (57 to 81 feet below floor level) in the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania, December 16, 1996

Time	Activity
1311	Start datalogger (test07)
1312	Begin packer inflation
1327	Start pump - step 1, average rate = 2.3 gallons per minute
1400	Increase pumping rate - step 2, average rate = 4.9 gallons per minute
1432	Pump off
1448	Begin packer deflation; datalogger off

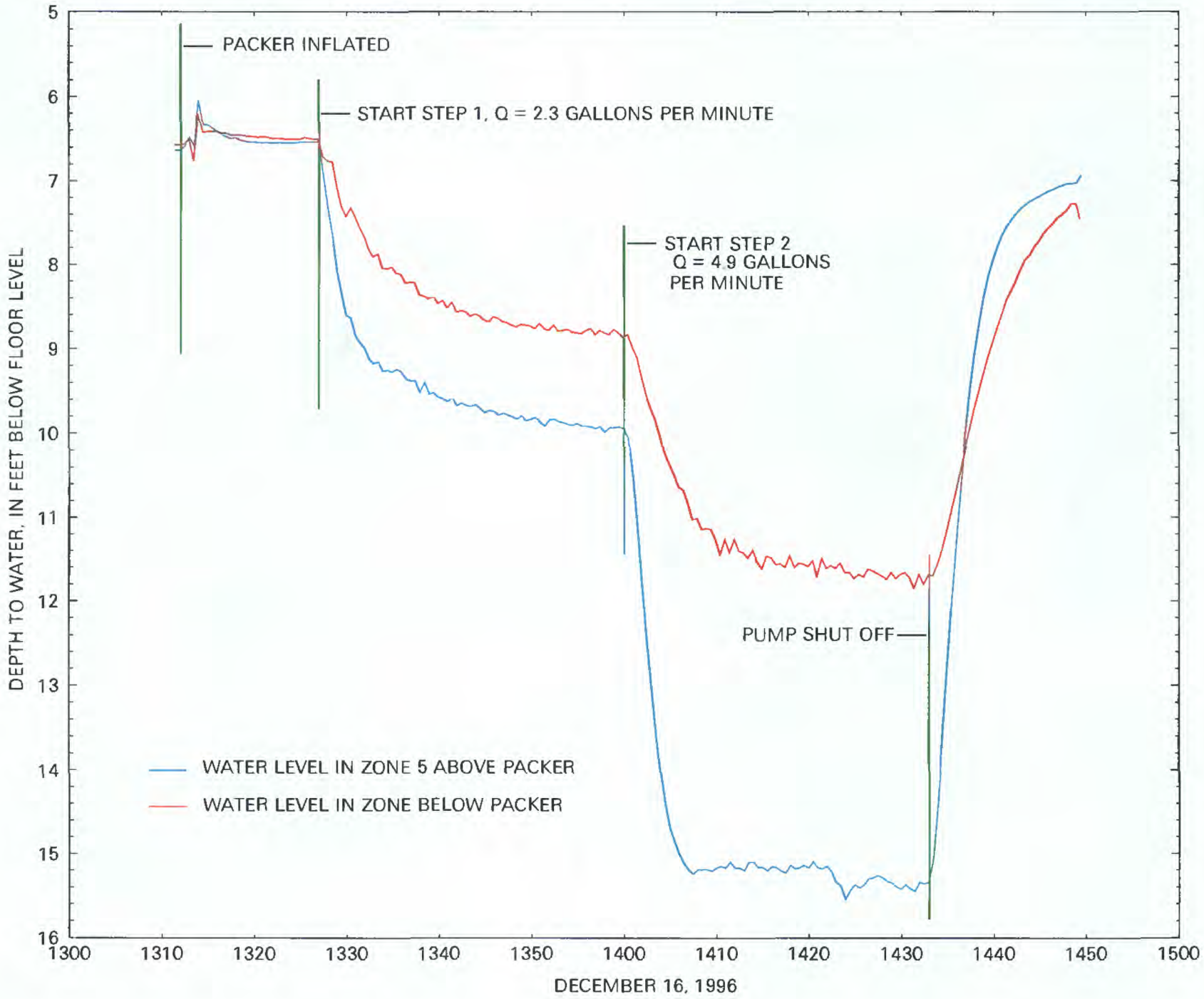


Figure 10. Hydrographs from aquifer-isolation test of zone 5 (57 to 81 feet below floor level) in the John Wagner and Sons, Inc. former production well, Ivyland, Pennsylvania.

below floor level) were hydraulically isolated from zones above and below. Specific capacities were 0.12, 0.034, and 0.15 (gal/min)/ft, respectively. The hydrograph from zone 2 (223 to 248 ft below floor level) showed interference from a nearby pumping well. The isolated zone 81 to 106 ft below floor level (zone 4) isolated a water-producing fracture at a contact between a sandstone and an underlying siltstone. Similar drawdowns in the isolated zone and the zones above and below the isolated zone indicate that this fracture is hydraulically connected with the sandstone above it and the siltstone below it outside the borehole in the unconfined part of the Stockton Formation. Pumping the isolated zone 57 to 81 ft below floor level (zone 5) produced some drawdown in the zone below, indicating a hydraulic connection in the sandstone unit outside the borehole. Zones 4 and 5 are in the unconfined part of the Stockton Formation and have similar specific capacities—0.82 and 0.61, respectively. The specific capacity of zones 4 and 5 is greater than that of the isolated fractures.

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