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Water Resources Management

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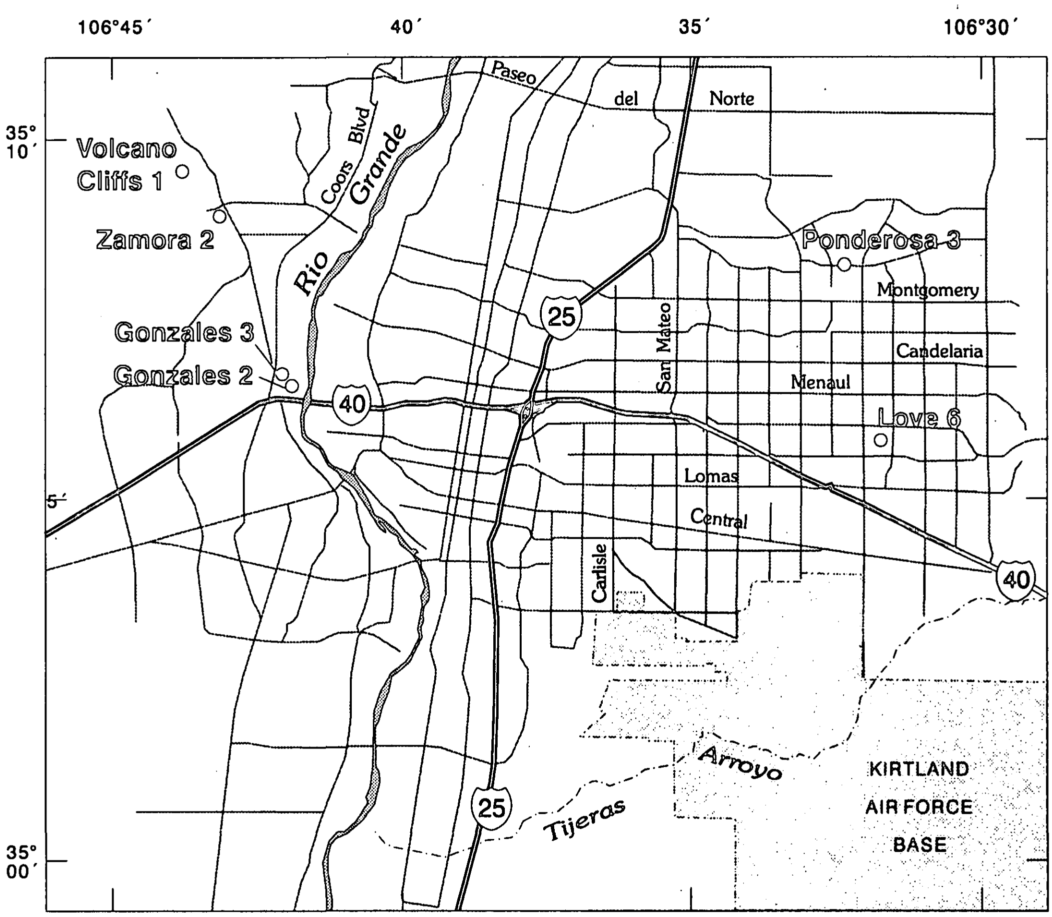
# Results of Well-Bore Flow Logging for Six Water-Production Wells Completed in the Santa Fe Group Aquifer System, Albuquerque, New Mexico, 1996-98

Water-Resources Investigations Report 00-4157

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# Results of Well-Bore Flow Logging for Six Water-Production Wells Completed in the Santa Fe Group Aquifer System, Albuquerque, New Mexico, 1996-98

By Condé R. Thorn

U.S. GEOLOGICAL SURVEY

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Albuquerque, New Mexico
2000

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## CONVERSION FACTORS AND VERTICAL DATUM

| Multiply | By | To obtain |
|---|---|---|
| inch | 25.40 | millimeter |
| foot | 0.3048 | meter |
| mile | 1.609 | kilometer |
| gallon per minute | 0.06309 | liter per second |

**Sea level:** In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

# RESULTS OF WELL-BORE FLOW LOGGING FOR SIX WATER-PRODUCTION WELLS COMPLETED IN THE SANTA FE GROUP AQUIFER SYSTEM, ALBUQUERQUE, NEW MEXICO, 1996-98

By Condé R. Thorn

## ABSTRACT

Over the last several years, an improved conceptual understanding of the aquifer system in the Albuquerque area, New Mexico, has lead to better knowledge about the location and extent of the aquifer system. This information will aid with the refinement of ground-water simulation and with the location of sites for future water-production wells.

With an impeller-type flowmeter, well-bore flow was logged under pumping conditions along the screened interval of the well bore in six City of Albuquerque water-production wells—the Ponderosa 3, Love 6, Volcano Cliffs 1, Gonzales 2, Zamora 2, and Gonzales 3 wells. From each of these six wells, a well-bore flow log was collected that represents the cumulative upward well-bore flow. Evaluation of the well-bore flow log for each well allowed delineation of the more productive zones supplying water to the well along the logged interval.

Yields from the more productive zones in the six wells ranged from about 70 to 880 gallons per minute. The lithology of these zones is predominantly gravel and sand with varying amounts of sandy clay.

## INTRODUCTION

The understanding of the aquifer system within the Albuquerque area, New Mexico, has been refined within the last several years. Hawley and Haase (1992), Hawley and Whitworth (1996), and Connell and others (1998) presented an updated version of the geologic framework of the Albuquerque Basin, with emphasis on the Albuquerque area. Thorn and others (1993) presented information indicating that the aquifer system was not as extensive as previously assumed. Kernodle and others (1995) simulated the surface- and ground-water system and estimated the effect that ground-water withdrawals had on the aquifer system and on flow in the Rio Grande. On the basis of these investigations, officials from the City of Albuquerque decided that a greater understanding of the aquifer system, in particular the location and extent of the primary water-producing zones in the Albuquerque area, was needed. Detailed information concerning the primary water-producing zones would allow for refinement of ground-water simulation that would aid with development of water resources. In July 1995, the U.S. Geological Survey (USGS), in cooperation with the City of Albuquerque, began a project to log well-bore flow in City production wells that were undergoing pump-pulling efforts related to scheduled maintenance and flow in new production wells not yet on-line.

### Purpose and Scope

This report presents down-hole information concerning the position and extent of primary water-producing zones in six production wells (fig. 1). Geophysical logging focused on collecting well-bore flow logs and video logs in wells undergoing scheduled maintenance (pump-pulling efforts) and in newly completed production wells. Information delineating the position and extent of the primary water-producing zones in production wells will be used to refine the regional ground-water-flow model.

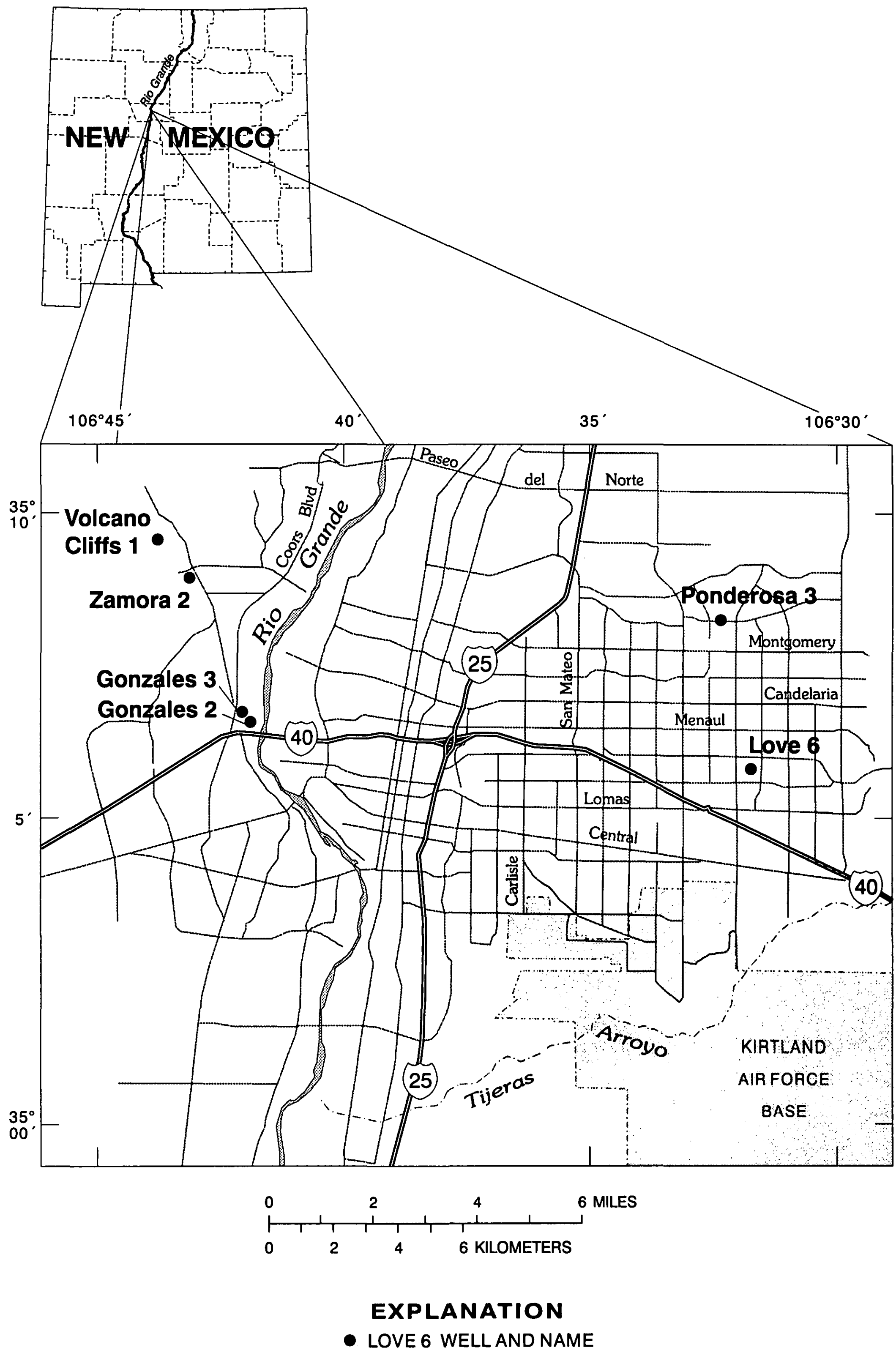


**Figure 1.** Location of production wells where well-bore flow logs were collected, 1996-98.

## Acknowledgments

The author thanks the City of Albuquerque Public Works Department Water Utility Division personnel who allowed the disruption of their normal maintenance routine so that well-bore flow logging could be conducted. A special thanks is extended to the personnel at Alpha Southwest who were responsible for implementing the design procedures for the production wells and who supplied the submersible pumps that allowed the well-bore flow logging to take place.

## DESCRIPTION OF WELL-BORE FLOW LOGGING

A flowmeter is a device that measures the vertical flow of water in a well bore (Molz and others, 1989; Rehfeldt and others, 1989; and Hanson and Nishikawa, 1996). For this project, well-bore flow was logged with a Well Reconnaissance four-bladed impeller flowmeter that transmitted electric pulses indicating the number of revolutions of the impellers per second. Vertical movement of water past the flowmeter impellers causes them to rotate about their axis at a speed proportional to the water velocity—that is, the higher the water velocity, the faster the impeller rotation. Impeller rotations are registered as counts per second at 0.1-foot intervals by the geophysical logging equipment located at the surface near the well head. Data on well-bore flow are related to well construction and well condition, differences in head, and the relative magnitude of permeability of the water-yielding units open to the well (Keys and MacCary, 1971, p. 109). Records of well construction were examined, and a qualitative assessment of well conditions was obtained in the three older wells (Ponderosa 3, drilled in 1977; Love 6, drilled in 1973; and Volcano Cliffs 1, drilled in 1968) from video surveys collected just before the well-bore flow log was obtained.

The video surveys were collected with a Wellcam model 9941 color video camera in the down-hole trolling direction and under nonpumping conditions. These surveys provided information about the physical condition of the screened interval, in particular the display of any zones where the screen may have become encrusted with mineralization over time. Zones where the screen showed extensive mineral encrustation were assumed to be zones in the well that had minimal or no contribution of water from the adjacent aquifer. The video surveys verified that the older wells contained no mineral encrustation along their screened intervals. Such surveys were not run in the three newer wells (Gonzales 2, drilled in 1990; Zamora 2, drilled in 1997; and Gonzales 3, drilled in 1997). The screens were assumed to not have been exposed to the aquifer system long enough for substantial encrustation of minerals to have developed.

The flowmetering tool used for the well-bore flow logging consisted of three components (fig. 2). Connected above and in-line with the flowmeter was a three-armed caliper tool that was used to centralize the flowmeter in the well bore. In-line and below the flowmeter was a 5-foot-long, solid steel cylinder designed to provide additional mass (sinker bar). The total length of this in-line combination of the caliper tool, flowmeter, and sinker bar (collectively referred to as the flowmetering tool) was about 15 feet. The diameter of the widest section of the flowmetering tool, the protective cage surrounding the flowmeter impellers, was 3.75 inches.

To successfully collect well-bore flow logs in the screened intervals of the production wells, the following modifications to the wells were necessary. The production wells are equipped with turbine pumps, whose water-intake "bowls" are typically situated in the well bore above the top of the screen. The diameter of the bowls is close to the inside diameter of the well casing, which leaves no room for the well-bore logging tool(s) to pass and operate beneath the pump bowls. Thus, the turbine pump and bowls have to be removed from the well before logging can commence, and this removal process is costly. Therefore, well-bore logging was somewhat opportunistic in that logging was conducted only on those production wells subject to pump-pulling maintenance or on new wells whose pumps had not yet been installed.

After the removal of the turbine pump and associated pump bowls, a submersible pump and entry pipe were installed in the production well (fig. 2). The submersible pump and entry pipe were installed in tandem, with the bottom of the entry pipe extending below the submersible pump. The entry pipe was a 4-inch (inside diameter) steel pipe that protected the down-hole camera and flowmeter tool and their associated cables from getting entangled with the submersible pump and its cables and discharge pipe (fig. 2).

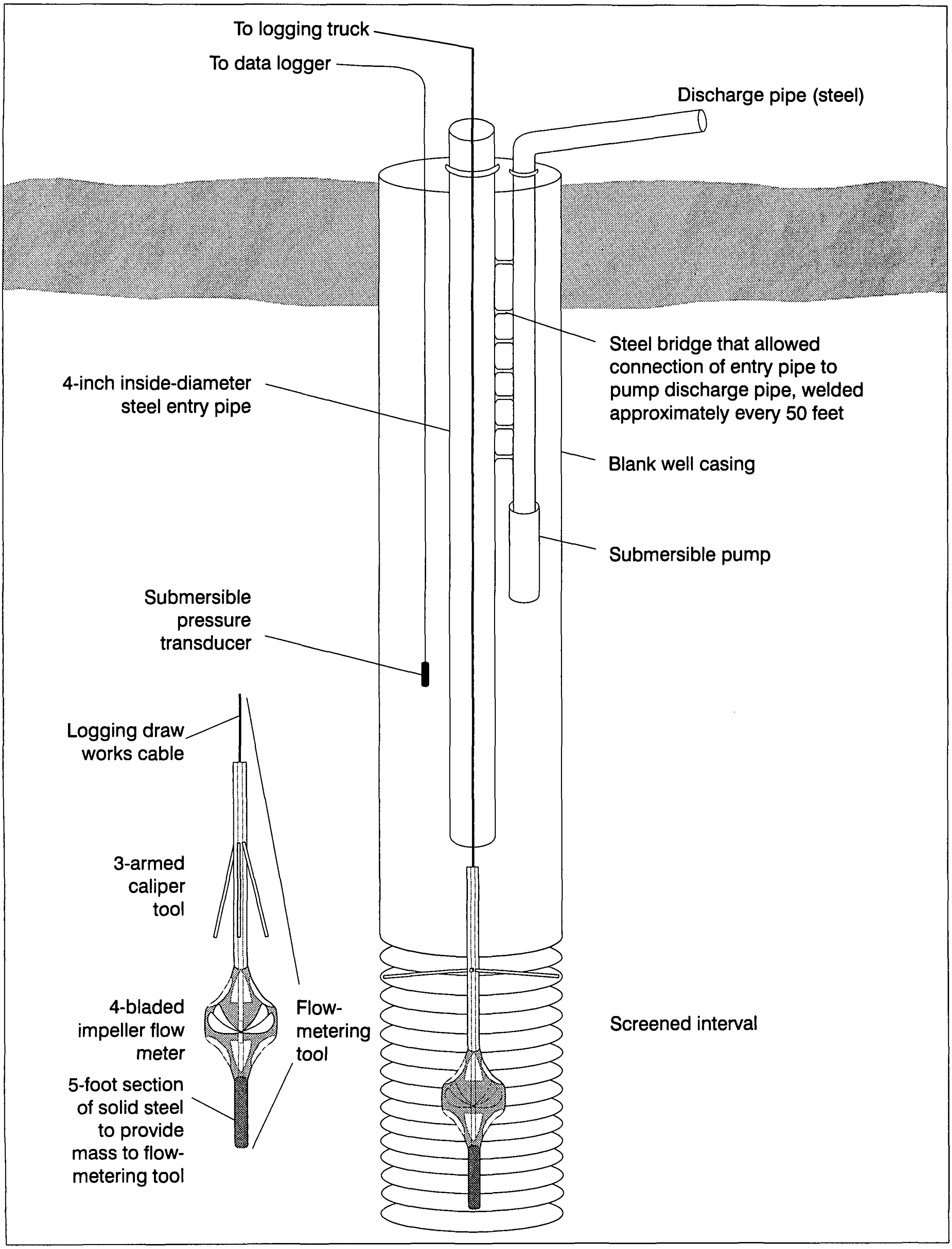


**Figure 2.** Schematic of production-well setup used for well-bore flow logging.

The well-bore flowmeter was calibrated at the start of logging operations for each well. This calibration process involved the collection of stationary flowmeter measurements (the flowmetering tool remained at a constant depth within the well bore) within the blank section of the well casing, somewhere below the bottom of the entry pipe and the top of the screened interval. When the flowmetering tool reached the desired location within the blank casing, the caliper arms were opened and the submersible pump was started. After drawdown in the well stabilized, as monitored by a pressure transducer installed in the production well, the calibration process began. Flowmeter measurements were recorded at the same depth, within the blank casing portion of the well, for different pump discharges. The rate of pumped discharge was typically monitored at the surface by an in-line magnetic flowmeter located in the pump house of each production well. These magnetic flowmeters were rated to measure discharge with an accuracy of 0.5 to 2 percent (City of Albuquerque Water Utility Division, oral commun., 1999). Flowmeter readings corresponding to different pump discharges allowed for a relation to be developed, whereby the counts per second recorded by the down-hole flowmeter could be converted to approximate gallons per minute for a given casing diameter. Once the calibration process was completed, the flowmetering tool was lowered into the screened interval of the well bore to the starting point of the continuous logging (trolling) measurements.

To protect the wellbore flowmeter and ensure the integrity of the logging results, the flowmetering tool was not emplaced in sections of the well where poor visibility was noted in the video survey, generally the lowermost 10-90 feet of the screened interval. When the intended depth in each well was reached, the caliper arms were opened. Once the caliper arms were fully opened, the well-bore flowmeter was activated and the tool was raised at a speed of either 10 or 20 feet per minute to the top of the screened interval, thus producing a vertically continuous measurement of the cumulative upward well-bore flow. A constant pumping rate was maintained that approximated the "normal" operational pumping rate for that particular production well; thus, the well-bore flow rates during logging were representative of typical conditions encountered during normal operations.

The resulting well-bore flow log graphically shows the quantitative flow contribution of the aquifer adjacent to the well screen. The horizontal axis of the flow log represents the approximate flow contribution from the aquifer. Thus, a somewhat vertical trend displayed on the flow log indicates an aquifer interval that contributes little flow to the well; conversely, a substantial horizontal shift in the log indicates an aquifer interval that contributes significant flow to the well. For this study, sections of the well-bore flow log that exhibit a large horizontal shift were identified as more productive aquifer zones, and the approximate flow contributions of these zones were determined. For example, an expanded trace of the flow log from the Love 6 well is shown in figure 3. The log trending a more horizontal slope delineates a more productive aquifer zone in the well from a depth 900 to 930 feet below land surface. The continuous flow logging was conducted in an upward direction, so this zone was first penetrated by the flowmeter at about 930 feet where the cumulative flow was about 400 gallons per minute. At the top of the zone, the flow had increased to about 520 gallons per minute and, consequently, the flow contribution from that zone was estimated to be about 120 gallons per minute (the difference between the cumulative flow at the bottom and top of the interval). Because these flow rates are approximations, ranges of flow contributions are noted in table 1 and in figures 5-10. In contrast, an example of a well-bore flow log recorded when the tool passed through a section of blank casing in the screened interval of the Gonzales 3 well is shown in figure 4. The log smoothes markedly and trends in a more vertical direction, indicating minimal flow contribution from this interval.

The continuous well-bore flow logs from the first three wells were examined, and intervals in the logs that delineated more productive zones in the aquifer were identified. Stationary flowmeter measurements were then collected at the bottom and top of these intervals while the pumping rate remained the same as during the trolling flow logging. The objective of the stationary measurements was to compare these measurements to the trolling measurements to confirm the accuracy of the latter data. The flow measurements obtained during the trolling were known to be slightly greater than the stationary measurements because of the additional impeller rotation caused by the upward trolling speed (10 or 20 feet per minute for these logs). The stationary flow measurements were comparable to and supported the continuous estimates of flow (table 1); therefore, stationary measurements were not collected during the bore-hole flow logging of the last three wells.

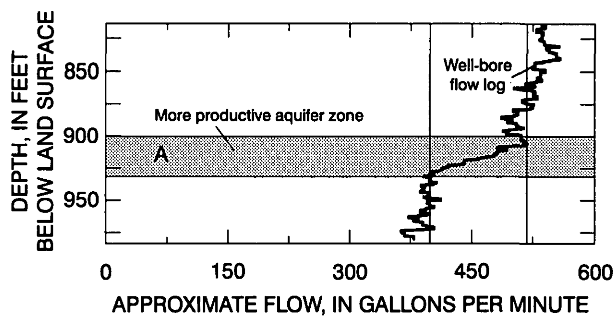


**Figure 3.** Method to determine approximate well-bore flow in Love 6 well (see figure 1 for well location).

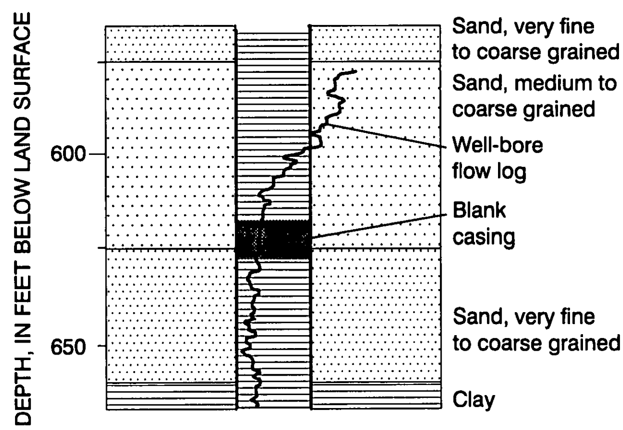


**Figure 4.** Effect of a section of blank casing on well-bore flow log for the screened interval of Gonzales 3 well (see figure 1 for well location).

Table 1. Well and flowmeter information

[bls, below land surface; gal/min, gallons per minute;
--, stationary flowmeter measurements not obtained]

| Well name and zone | Date drilled | Screened interval of well, in feet bls | Continuous flow log interval, in feet bls | Flow from zone measured by stationary flowmeter, in gal/min[1] | Range of flow from zone estimated from trolling flowmeter, in gal/min |
|---|---|---|---|---|---|
| Ponderosa 3 | 1977 | 870-1,590 | 866-1,500 | | |
| A | | | | 69 | 100-150 |
| B | | | | 161 | 200-250 |
| C | | | | 161 | 150-200 |
| D | | | | 69 | 125-175 |
| Love 6 | 1973 | 750-1,509 | 800-1,480 | | |
| A | | | | 97 | 100-150 |
| B | | | | 135 | 125-175 |
| Volcano Cliffs 1 | 1968 | 552-1,080 | 580-1,042 | | |
| A | | | | 270 | 250-300 |
| B | | | | 240 | 225-275 |
| C | | | | 180 | 225-275 |
| Gonzales 2 | 1990 | 400-1,100 | 400-1,090 | | |
| A | | | | --- | 625-675 |
| Zamora 2 | 1997 | 440-977 | 450-900 | | |
| A | | | | --- | 850-900 |
| B | | | | --- | 525-575 |
| C | | | | --- | 300-350 |
| Gonzales 3 | 1997 | 420-940 | 426-950 | | |
| A | | | | --- | 300-350 |
| B | | | | --- | 450-500 |
| C | | | | --- | 300-350 |

[1]Flow estimates obtained by stationary flowmeter were not influenced by the additional impeller rotation associated with trolling during the continuous flowmetering.

## RESULTS OF WELL-BORE FLOW LOGGING

Results of the well-bore flow logging obtained for the six wells are presented in this section. The well-bore flow logs, lithologic logs, and well-completion information for the six wells are displayed in figures 5-10. The lithologic logs (figs. 5-7) for the older wells (Ponderosa 3, Love 6, and Volcano Cliffs 1) were constructed using data from driller's logs, whereas the logs for Gonzales 2, Zamora 2, and Gonzales 3 (figs. 8-10) were constructed using data from consultant reports (Shomaker, 1991; 1997; 1998) and contain much greater lithologic detail.

The well-bore flow log for the Ponderosa 3 well (fig. 5) was collected while pumping the well at about 1,500 gallons per minute and raising the flowmeter at a rate of 10 feet per minute. Four zones were delineated where the aquifer is more productive (shaded zones A-D). The flow contribution from these zones to the well bore ranged from about 70 to 160 gallons per minute from stationary flowmeter measurements and from about 100 to 250 gallons per minute from trolling flowmeter measurements (table 1). Aquifer lithology adjacent to all four zones coincides with sand and gravel with some clay, as documented by the driller's log. The lowermost section of the flow log, from a depth of 1,455 to 1,500 feet, shows minimal to no flow contribution.

The well-bore flow log for the Love 6 well (fig. 6) was collected while pumping the well at about 900 gallons per minute and raising the flow meter at a rate of 10 feet per minute. Two zones were delineated where the aquifer is more productive (shaded zones A and B). The flow contribution from these zones to the well bore ranged from about 97 to 135 gallons per minute from stationary flowmeter measurements and from about 100 to 175 gallons per minute from the trolling flowmeter measurements (table 1). Aquifer lithology adjacent to zone A corresponds to sand and gravel and adjacent to zone B corresponds to sand and small gravel mixed with clay. The basal section of the flow log, from a depth of 1,083 to 1,480 feet, shows minimal to no flow contribution; much of this interval consists primarily of clay.

The well-bore flow log for the Volcano Cliffs 1 well (fig. 7) was collected while pumping the well at about 1,800 gallons per minute and raising the flowmeter at a rate of 10 feet per minute. Three zones were delineated where the aquifer is more productive (shaded zones A-C). The flow contribution from these zones to the well bore ranged from about 180 to 270 gallons per minute from stationary flowmeter measurements and from about 225 to 300 gallons per minute from trolling flowmeter measurements (table 1). Aquifer lithology adjacent to zone A corresponds to sand and gravel and adjacent to zones B and C corresponds to sand and gravel with clay streaks (fig. 7). The basal section of the flow log, from a depth of 900 to 1,042 feet, shows minimal to no flow contribution; much of this interval consists primarily of clay.

All three log traces for the older wells—Ponderosa 3, Love 6, and Volcano Cliffs 1—indicate minimal to no flow to the well bore across the lowermost section of the screened interval. These log responses across basal sections likely are the result of a combination of two conditions. First, for the flowmeter to record the movement of water past the rotating impellers, water entering the screened section of the well bore must exceed the trolling—10 feet per minute upward for the three wells. Second, the rate of water coming into the well bore is dependent on the transmissivity of the aquifer material adjacent to the screened interval.

The well-bore flow log for the Gonzales 2 well (fig. 8) was collected while pumping the well at about 2,700 gallons per minute and raising the flowmeter at a rate of 20 feet per minute. One zone, at the uppermost part of the screened interval, was delineated where the aquifer is more productive (shaded zone A). This zone had an estimated flow contribution to the well bore of about 625-675 gallons per minute (table 1). Aquifer lithology adjacent to this zone corresponds to gravel and sandy clay fragments. The two spikes displayed on the well-bore flow log between 800 and 825 feet probably represent temporary flowmeter malfunction.

The well-bore flow log for the Zamora 2 well (fig. 9) was collected while pumping the well at about 2,800 gallons per minute and raising the flowmeter at a rate of 10 feet per minute. Three zones were delineated where the aquifer is more productive (shaded zones A-C). The flow contribution from these zones to the well bore ranged from about 300 to 900 gallons per minute (table 1). Aquifer lithology adjacent to zone A coincides with fine- to coarse-grained, well-sorted sand; zones B and C, respectively, correspond to sand with some clayey silt beds and to sand interbedded with sandy clay. A small interval having a section of blank casing within the screened interval is represented as a near vertical trace on the well-bore flow log from 640 to 646 feet.

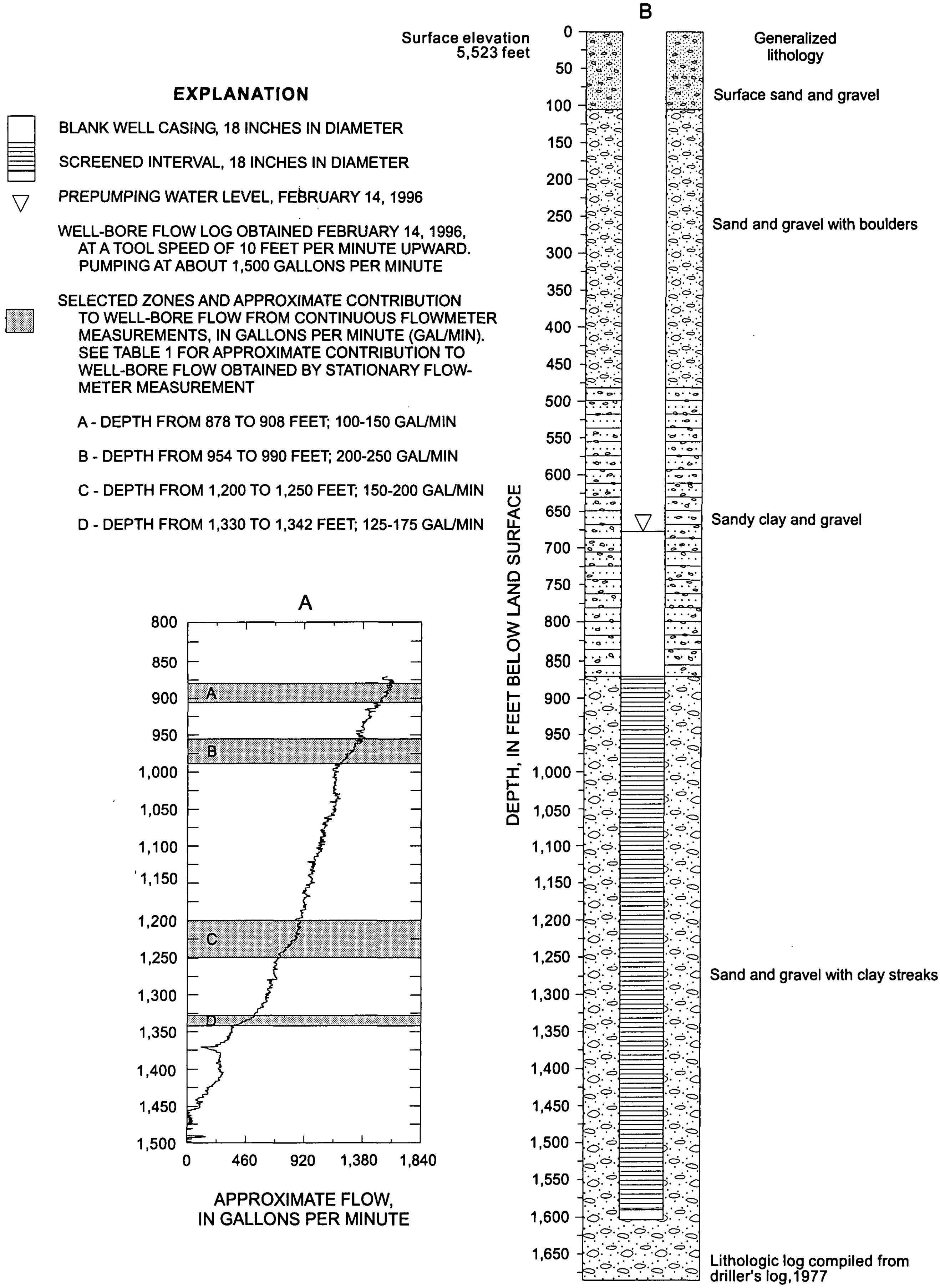


**Figure 5.** Well-bore flow log (A) and lithologic log and well completion (B) for Ponderosa 3 well (see figure 1 for well location).

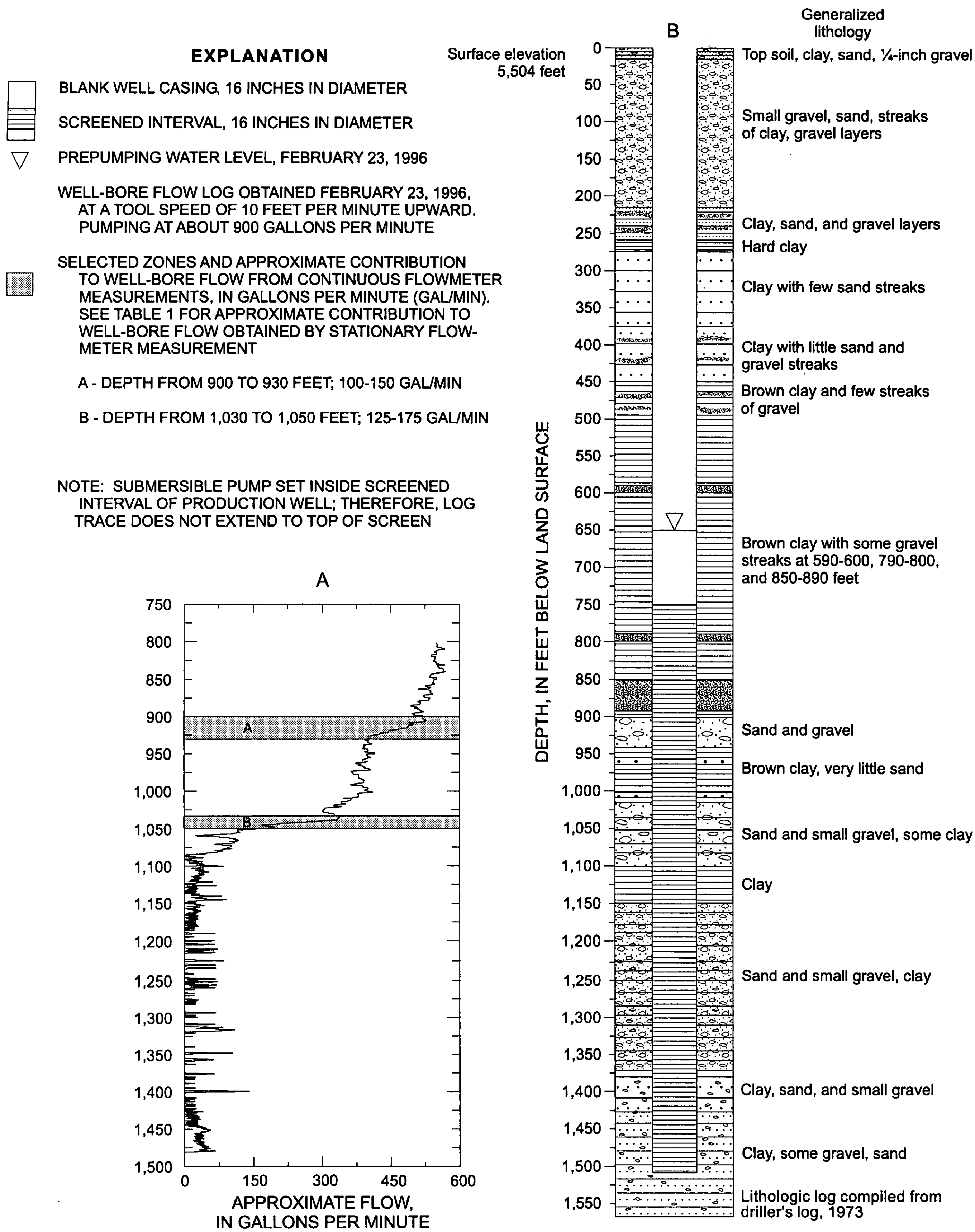


**Figure 6.** Well-bore flow log (A) and lithologic log and well completion (B) for Love 6 well (see figure 1 for well location).

**EXPLANATION**

BLANK WELL CASING, 16 INCHES IN DIAMETER

SCREENED INTERVAL, 16 INCHES IN DIAMETER

PREPUMPING WATER LEVEL, MARCH 4, 1996

WELL-BORE FLOW LOG OBTAINED MARCH 4, 1996, AT A TOOL SPEED OF 10 FEET PER MINUTE UPWARD. PUMPING AT ABOUT 1,800 GALLONS PER MINUTE

SELECTED ZONES AND APPROXIMATE CONTRIBUTION TO WELL-BORE FLOW FROM CONTINUOUS FLOWMETER MEASUREMENTS, IN GALLONS PER MINUTE (GAL/MIN). SEE TABLE 1 FOR APPROXIMATE CONTRIBUTION TO WELL-BORE FLOW OBTAINED BY STATIONARY FLOW-METER MEASUREMENT

A - DEPTH FROM 624 TO 650 FEET; 250-300 GAL/MIN

B - DEPTH FROM 680 TO 720 FEET; 225-275 GAL/MIN

C - DEPTH FROM 870 TO 900 FEET; 225-275 GAL/MIN

NOTE: 4-INCH-DIAMETER ENTRY PIPE EXTENDED BELOW TOP OF SCREEN; THEREFORE, LOG TRACE DOES NOT EXTEND TO TOP OF SCREEN

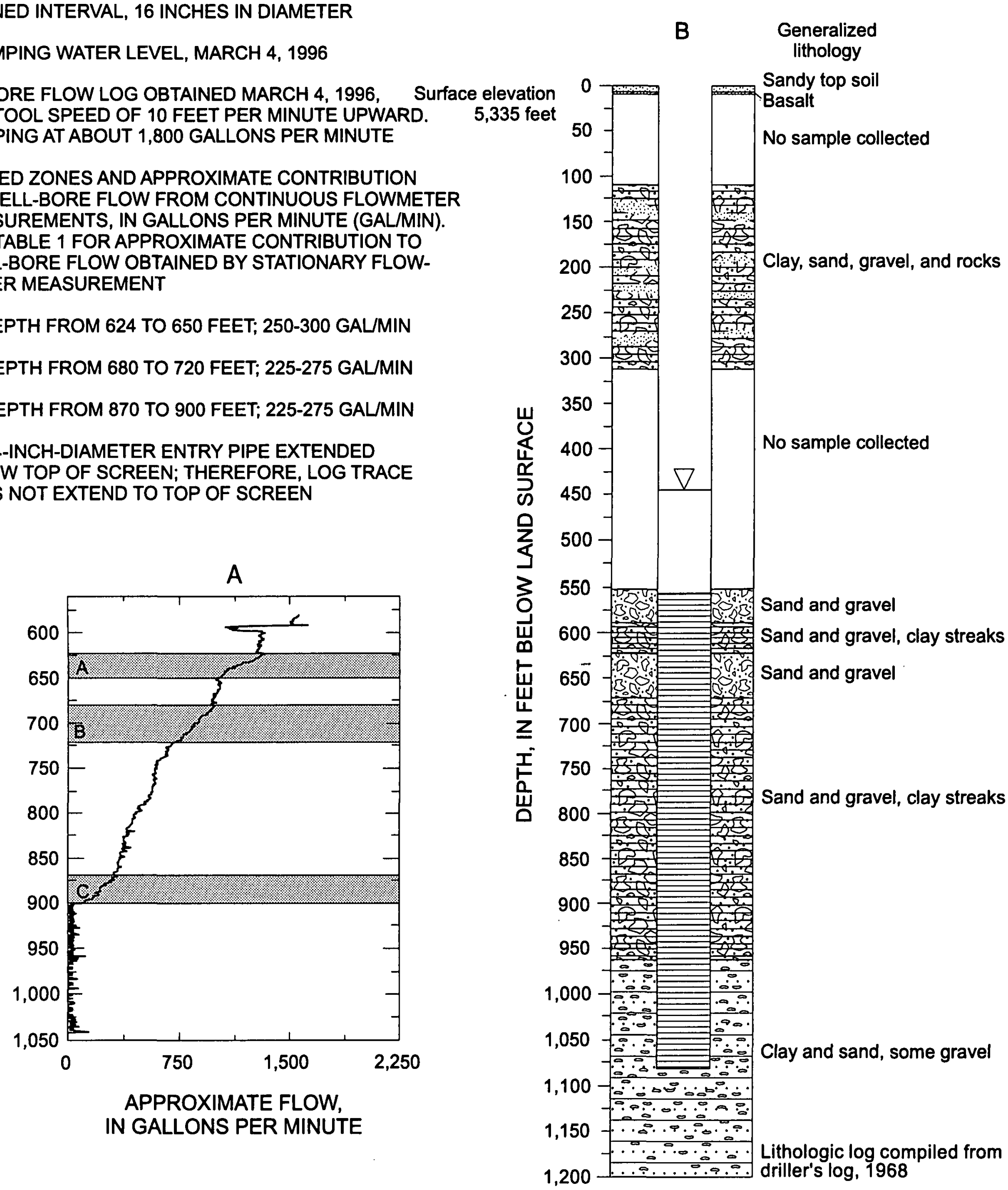


**Figure 7.** Well-bore flow log (A) and lithologic log and well completion (B) for Volcano Cliffs 1 well (see figure 1 for well location).

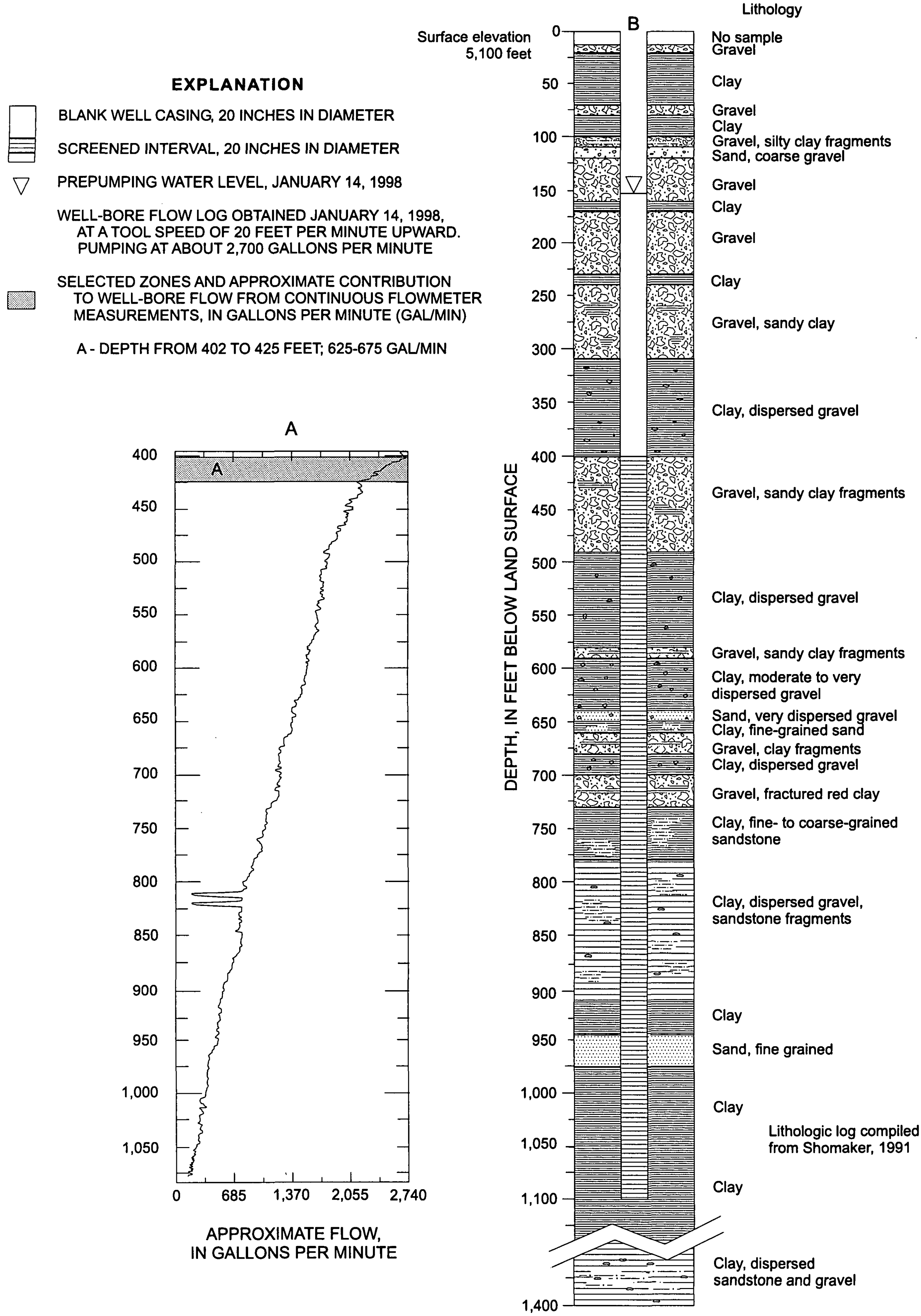


**Figure 8.** Well-bore flow log (A) and lithologic log and well completion (B) for Gonzales 2 well (see figure 1 for well location).

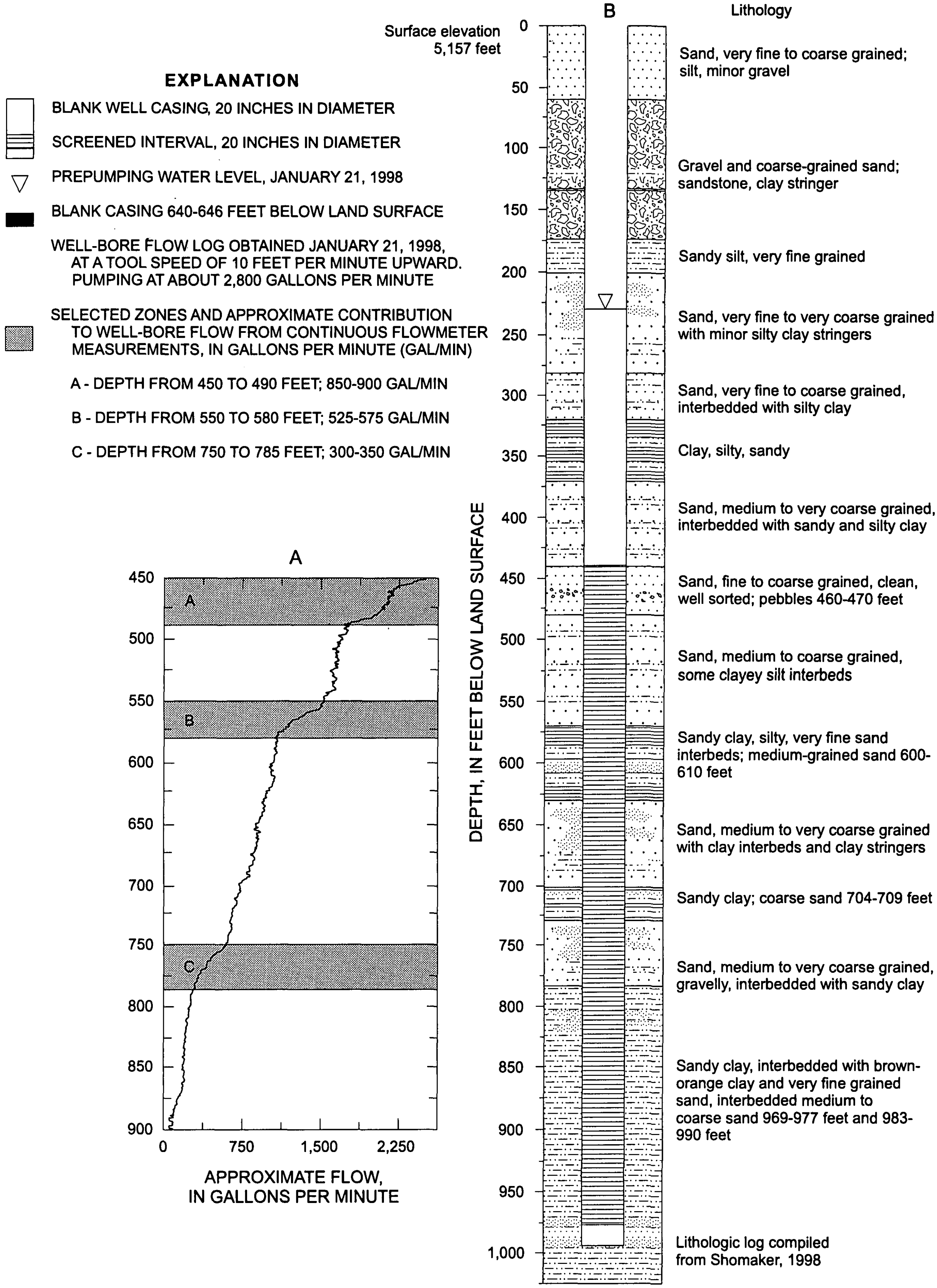


**Figure 9.** Well bore flow log (A) and lithologic log and well completion (B) for Zamora 2 well (see figure 1 for well location).

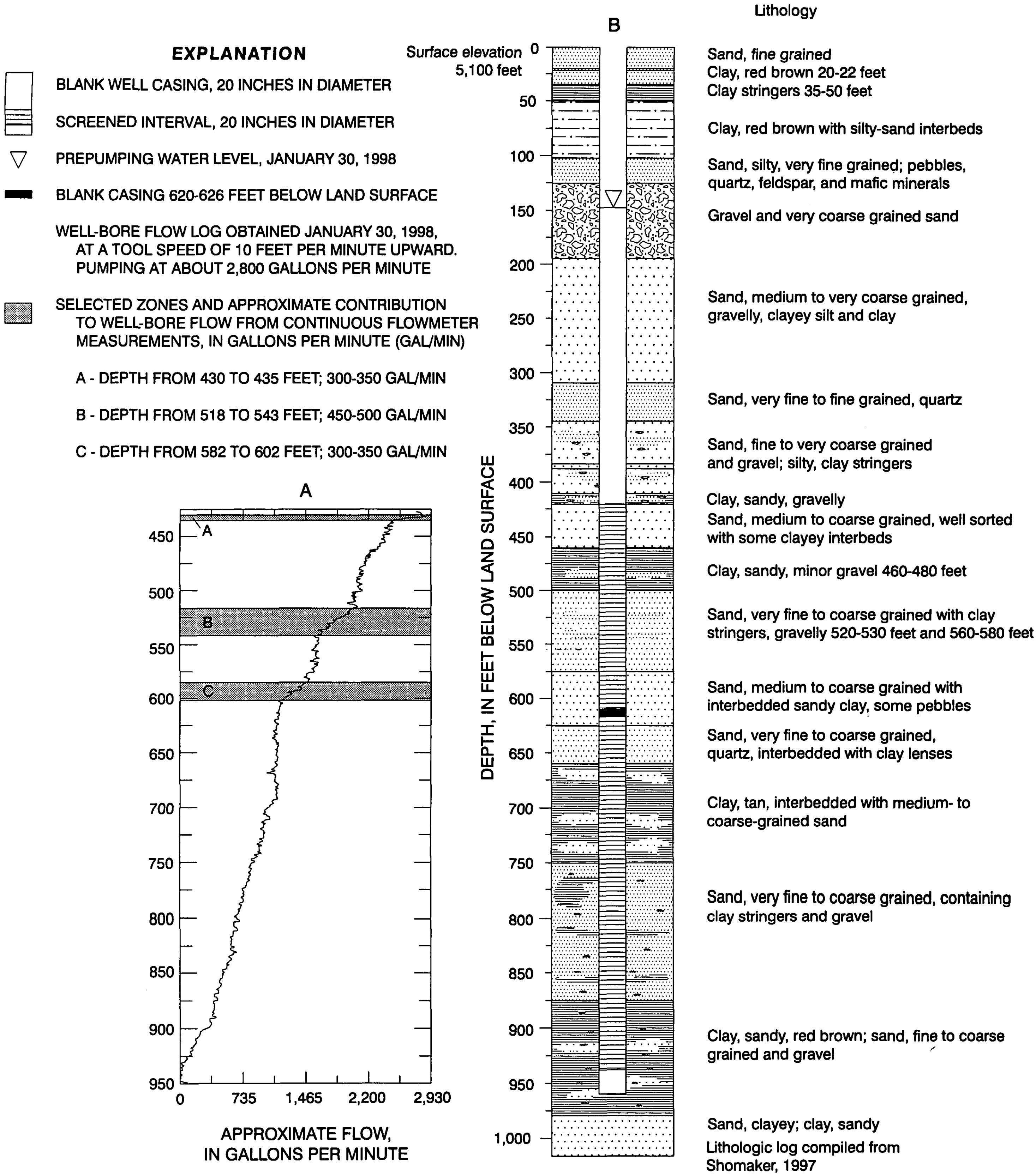


**Figure 10.** Well-bore flow log (A) and lithologic log and well completion (B) for Gonzales 3 well (see figure 1 for well location).

The well-bore flow log for the Gonzales 3 well (fig. 10) was collected while pumping the well at about 2,800 gallons per minute and raising the flowmeter at a rate of 10 feet per minute. Three zones were delineated where the aquifer is more productive (shaded zones A-C). The flow contribution from these zones to the well bore ranged from about 300 to 500 gallons per minute (table 1). Aquifer lithology adjacent to all three zones corresponds to very fine to coarse-grained sand interbedded with gravel and pebbles, sandy clay, and clayey interbeds. Again, the straightest section on the trace (with the least amount of scatter, located at 620-626 feet) corresponds to a section of blank casing within the screened interval.

## SUMMARY

Over the last several years, an improved conceptual understanding of the aquifer system in the Albuquerque area, New Mexico, has lead to better knowledge about the location and extent of the primary water-producing zones. This information will aid in the refinement of ground-water simulations and in locating sites for future water-production wells. This report presents down-hole information concerning the position and extent of primary water-producing zones in six production wells.

The down-hole data were obtained by conducting video surveys and well-bore flow logging. The video surveys provided information from which to assess the degree of mineral encrustation present on any part of the well screen. Well-bore flow logging was performed with a four-bladed impeller flowmeter used in conjunction with a caliper tool and a sinker bar, collectively referred to as the flowmetering tool. The flowmetering tool, when used in a continuous logging mode (trolling), produced a log representative of the cumulative upward well-bore flow along the screened interval of that particular well. The flowmetering tool was also used in a stationary mode to record flow in both the blank and screened sections of the well bore for calibration purposes. The trolling and stationary measurements were made during pumping. Each well was pumped at a constant rate during logging; the rates ranged from about 900 to 2,800 gallons per minute.

The estimated flow contributions from the more productive zones represented by the well-bore flow log from the Ponderosa 3 well ranged from about 70 to 160 gallons per minute from stationary flowmeter measurements and from 100 to 250 gallons per minute from trolling flowmeter measurements; from the Love 6 well ranged from about 97 to 135 gallons per minute from stationary flowmeter measurements and from about 100 to 175 gallons per minute from trolling flowmeter measurements; and from the Volcano Cliffs 1 well ranged from 180 to 270 gallons per minute from stationary flowmeter measurements and from 225 to 300 gallons per minute from trolling flowmeter measurements. The lithology of these more highly productive zones generally is sand and gravel with some associated clay component.

Yields from some of the more productive zones from the Gonzales 2, Zamora 2, and Gonzales 3 wells ranged from 300 to 900 gallons per minute. The lithology of these zones generally is gravel and fine- to coarse-grained sand interbedded with sandy clay.

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