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A SMALL-DIAMETER SAMPLE PUMP FOR COLLECTION OF DEPTH-DEPENDENT SAMPLES FROM PRODUCTION WELLS UNDER PUMPING CONDITIONS

By John A. Izbicki

The U.S. Geological Survey, in cooperation with the manufacturer ([1]Besst In$_2$c. http://www.besstinc.com), has modified a commercially available gas-displacement sample pump to collect water at selected depths within production wells under pumping conditions. The modified pump is about 6 inches long, less than 1 inch in diameter, and is operated through repeated application and release of compressed gas. The pump is intended for use in production wells having limited access that prevents the use of traditional geophysical tools, such as wire-line bailers, used to collect depth-dependent water samples. In most cases, the production pump does not have to be removed or the well modified for insertion of the sample pump. Data collected at different depths within the production well reflect water quality at those depths under actual pumping conditions. If well-bore flow velocities are known, the quality of water in the aquifer between sample depths can be estimated.

DESIGN AND BASIC OPERATING PRINCIPLES OF THE SAMPLE PUMP

The modified sample pump consists of a series of one-way flow valves connected to the surface by two 1/8-inch-diameter Teflon tubes bonded together into a single hose. One tube serves as a pressure line, and the other serves as the sample line (fig. 1). After the pump is lowered into the well to the sample depth, water enters the pump, filling both Teflon tubes to the water level in the well (Initial conditions, fig. 1). The pressure line is pressurized using compressed gas, and water is displaced from this tube into the sample line (Pressure cycle, fig. 1). A one-way flow valve at the pump intake prevents the displaced water from flowing back into the well. Once the water is in the sample line, another one-way valve prevents the water from flowing back toward the sample pump after pressure is released (Release cycle, fig. 1).

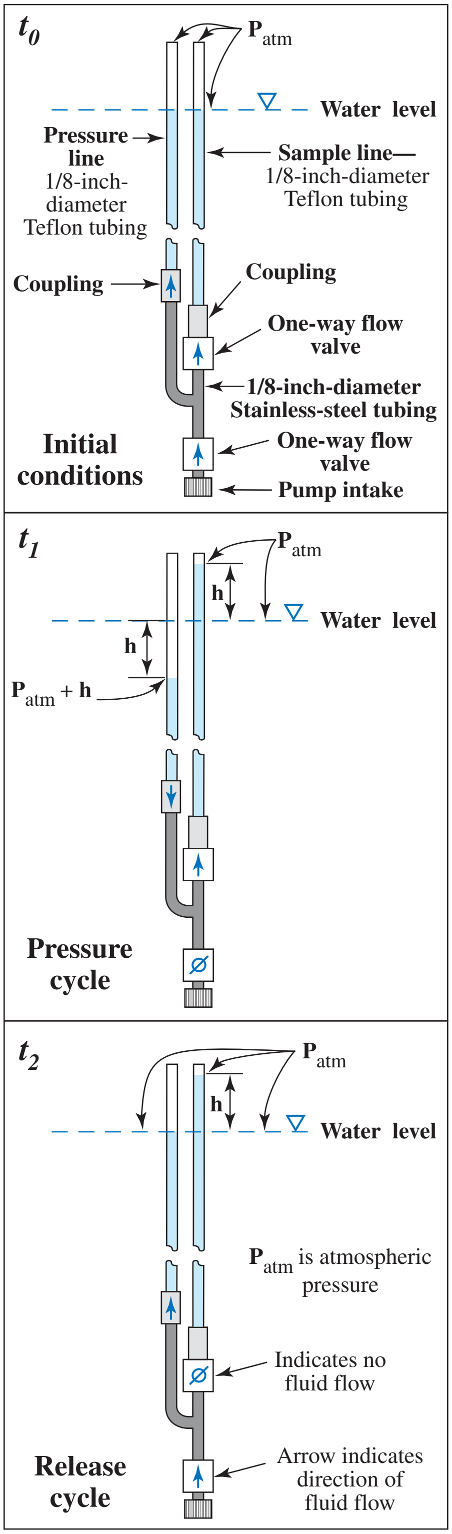

Figure 1. Diagram showing schematic of small-diameter pump and basic operating principles.

To force additional water into the sample line, pressure is alternately applied and released on the pressure line at the surface using compressed gas regulated through a control panel built by the U.S. Geological Survey. The column of water in the sample line can be forced upward to the surface through the sequential application and release of pressure. Alternately, when sufficient volume is accumulated, water in the sample line can be forced to the surface using compressed gas. With proper use, water from the pump is suitable for analysis for a wide variety of constituents, including volatile organic carbon and dissolved gasses. The pump is capable of lifting water from depths as great as 1,200 feet. The pump and hose are mounted on a motorized reel (fig. 2).

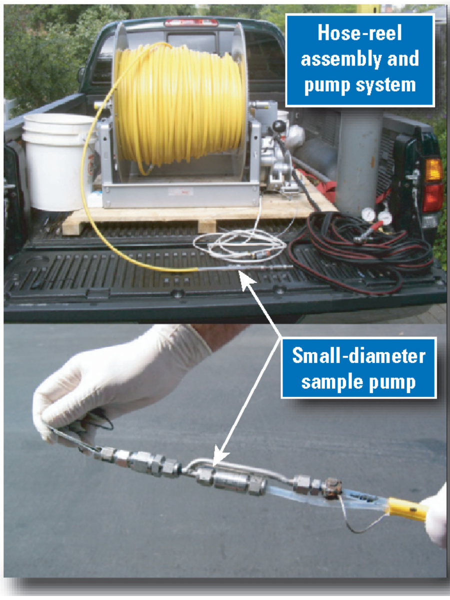

Figure 2. Photograph showing a) hose-reel assembly and b) small-diameter sample pump.

Samples from different depths within production wells can be collected by sequentially moving the pump to a different sample-collection depth without retrieving the pump from the well after each sample is collected. The pump pro-

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vides an alternative to traditional sample-collection methods using wire-line bailers or sample-collection methods developed by Izbicki and others (1999), both of which require sample equipment to be pulled from the well to bring each depth-dependent sample to land surface.

DATA INTERPRETATION

Depth-dependent water-quality data collected within production wells under pumping conditions can be used to estimate the quality of water yielded to a well from a selected depth interval using the following equation:

$$C_a = (C_i Q_i - C_{i+1} Q_{i+1})/Q_a, \quad \text{(eq. 1)}$$

where:

C is the concentration of a given constituent,

Q is the flow of water within the well (either as volume per unit time, as velocity, or as percent of total discharge),

i is the first sample collection and flow measurement depth,

$i+1$ is the second sample collection and flow measurement depth, and

a is the interval between i and $i+1$.

(In this example, flow in the well is presumed to be upward toward the pump intake and the first sample-collection depth is shallower than the second sample-collection depth.)

Depth-dependent water-quality data collected from production well 4N/5W-2H1 near Victorville, California, using this small-diameter sample pump are shown in figure 3. The well is screened between 600 and 836 feet below land surface, and the pump intake is at 685 feet. The well was pumped at 1,000 gallons per minute. Flow was upward from the bottom of the well screen toward the pump intake. The deepest sample collected from the well is presumed to be representative of water in the aquifer at that depth. The next deepest sample is a mixture of water already in the well and water that entered the well between the two sample depths. The combination of velocity-log and depth-dependent water-quality data can be used to resolve the mixture within the well and estimate the concentration of a constituent in water contributed from the aquifer to the well at selected sample depths below the pump intake during pumping (fig. 3). Results of calculations show that, in general, arsenic concentrations increased with depth below the pump intake but remained below the U.S. Environmental Protection Agency proposed Maximum Contaminant Level for arsenic of 10 micrograms per liter (µg/L).

Flow was downward in the well from the top of the screened interval to the pump intake (fig. 3). No samples were collected above the pump intake and the arsenic concentration of water yielded from the aquifer to the well above the pump intake was not calculated.

DISCUSSION

The small-diameter pump provides a means to collect depth-dependent water-quality data from specific intervals in long-screened production wells under pumped conditions. Coupled depth-dependent water-quality and velocity-log data have application to a wide range of hydrologic problems including seawater intrusion, brine invasion, naturally occurring trace-elements, and anthropogenic contamination. The small-diameter sample pump described in this fact sheet enables more efficient collection of depth-dependent samples from production wells having limited access by increasing the ease with which water samples are collected (thereby reducing the time and cost) through eliminating the need to retrieve the sample pump from the well after each sample is collected.

REFERENCES CITED Izbicki, J.A., Christensen, A.H., and Hanson, R.T., 1999, U.S. Geological Survey combined well-bore flow and depth-dependent water sampler; U.S. Geological Survey Fact Sheet FS 196-99.

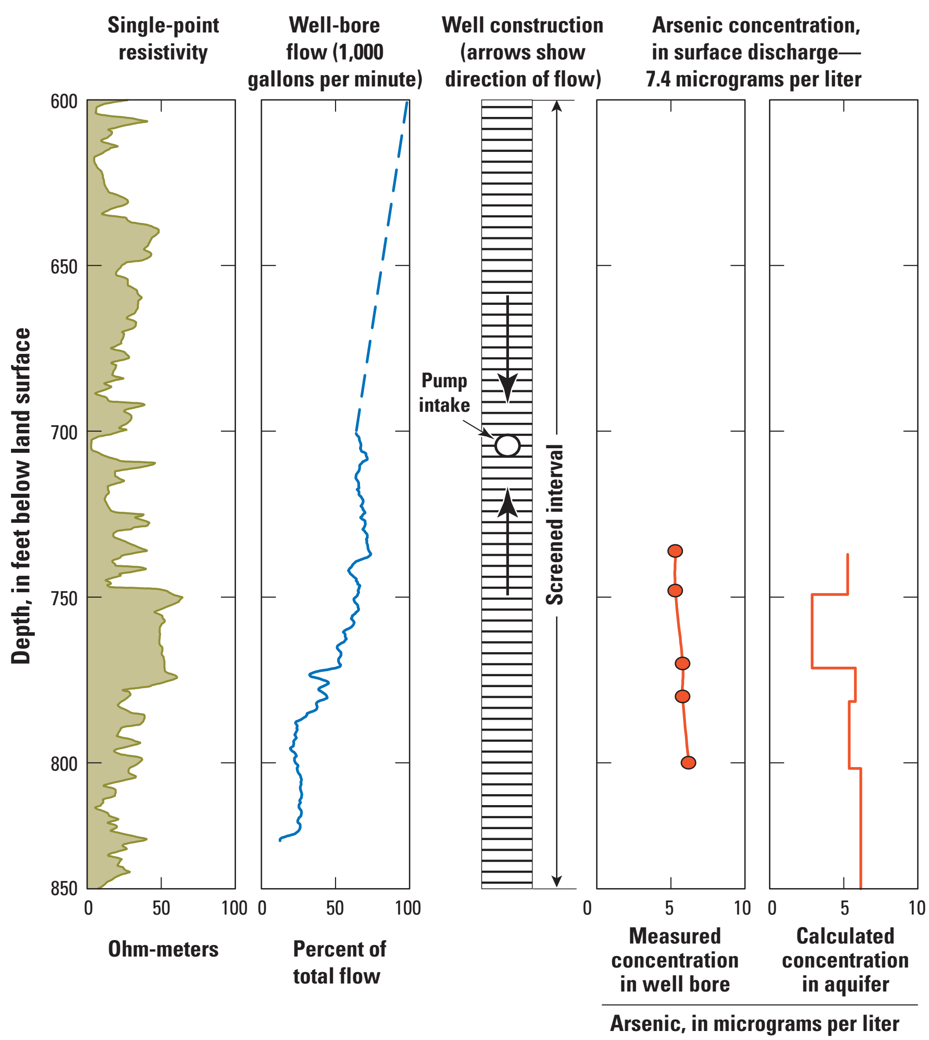

Figure 3. Depth-dependent water-quality data collected from production well 4N/5W-2H1 near Victorville, California.

1. The use of trade names in this fact sheet is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

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U.S. Geological Survey Combined Well-Bore Flow and Depth-Dependent Water Sampler

The U.S. Geological Survey has developed a combined well-bore flow and depth-dependent sample collection tool. It is suitable for use in existing production wells having limited access and clearances as small as 1 inch. The combination of well-bore flow and depth-dependent water-quality data is especially effective in assessing changes in aquifer properties and water quality with depth. These are direct measures of changes in well yield and ground-water quality with depth under actual operating conditions. Combinations of other geophysical tools capable of making these measurements, such as vertical-axis current meters used with wire-line samplers, are commercially available but these tools are large and can not easily enter existing production wells.

BASIC OPERATING PRINCIPLES

The U.S. Geological Survey device is a high-pressure hose equipped with valves for dye injection and sample collection. The hose is mounted on a reel for deployment, retrieval, and storage (fig. 1). The hose can be used to collect velocity-log data and, after cleaning and decontamination, the same hose can be used to collect depth-dependent water-quality data. Accessories, such as a Teflon® hose extension, are available for collection of organic compounds.

Velocity-Log Data

The equipment is used to obtain flow data within the well bore under pumping conditions using a technique we named the 'tracer-pulse method.' When operated in this mode, the hose is filled with fluid containing an easily measured tracer, such as water colored with Rhodamine dye. The hose is lowered to a known depth in the well (d_1) and a pulse of the tracer is injected into the water column. The travel-time of the tracer to a detector on the surface is measured (t_1). If Rhodamine dye is used, a commercially available fluorimeter is used to measure the arrival of the dye at the surface. The hose is then lowered to the next depth (d_2), another pulse of dye is released, and the travel-time is measured (t_2). The velocity is calculated as the difference in the travel-times. Assuming piston flow, the flow rate (Q), given a known well radius (r), is calculated using the following equation:

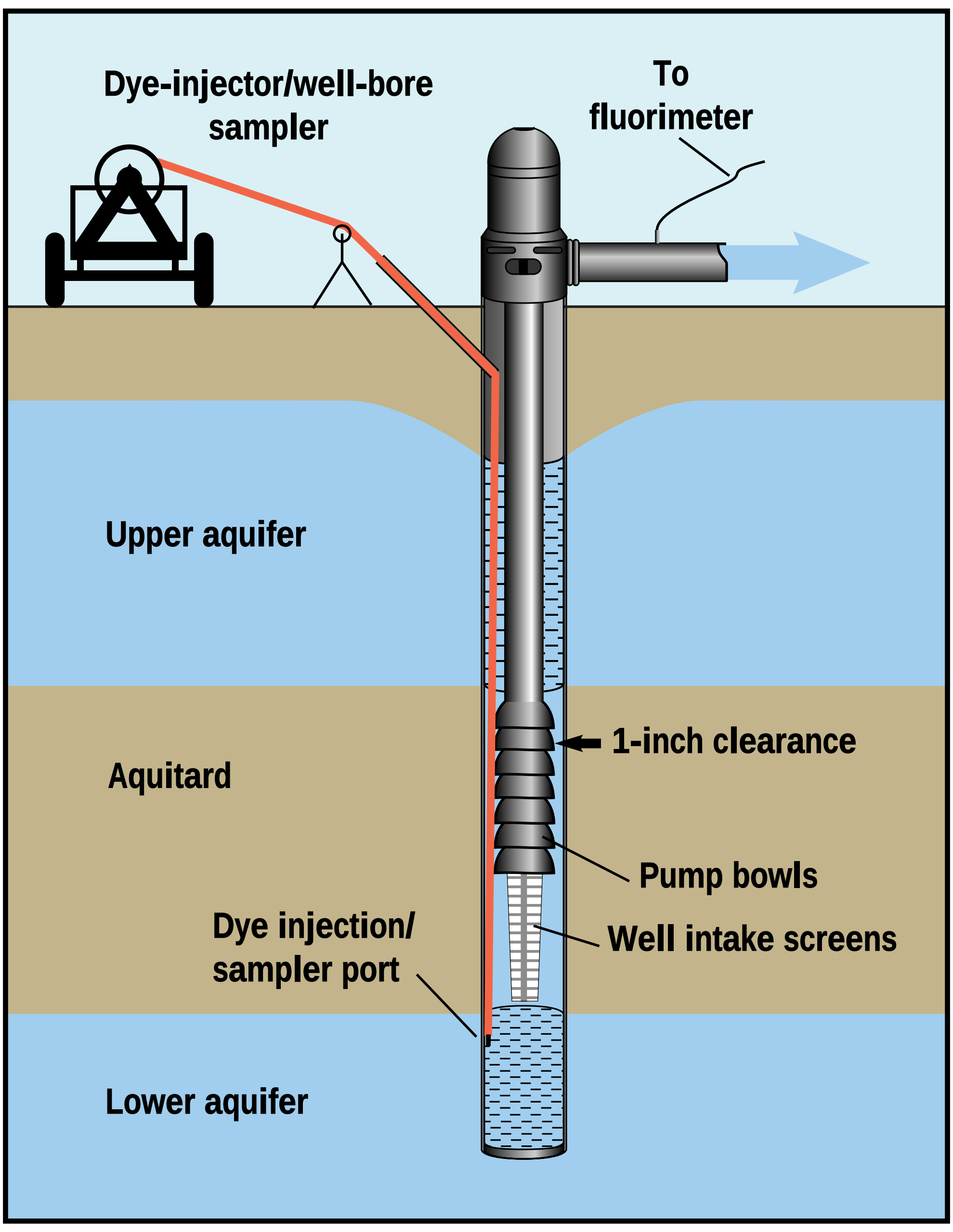


Figure 1. Example of typical deployment in a deep-turbine production well.

$$Q = (V\pi r^2) \quad \text{where: } V = (d_2 - d_1)/(t_2 - t_1)$$

A series of injections at different depths is done to construct a velocity profile for the well. The velocity profile can then be used to guide the collection and interpretation of depth-dependent water-quality data.

Depth-Dependent Water-Quality Data

To collect a water-quality sample from a given depth in the well, the hose is pressurized to greater than the hydrostatic pressure at that depth and lowered into the well. When the sample depth is reached, the hose is vented at the surface and water from the well at the sample depth enters the hose. The hose is retrieved and the sample expelled from the hose under pressure. The process is repeated at several depths to complete a water-quality profile within the well. If the concentrations of a constituent at the first sample depth (C_1) and the second sample depth (C_2) are known, the concentration in water entering the well from the intervening water-bearing zone (C_a) can be calculated from the water-quality profile and the velocity-log data:

$$[(C_1Q_1 - C_2Q_2)/Q_a] = C_a$$
$$\text{where } Q_a = (Q_1 - Q_2)$$

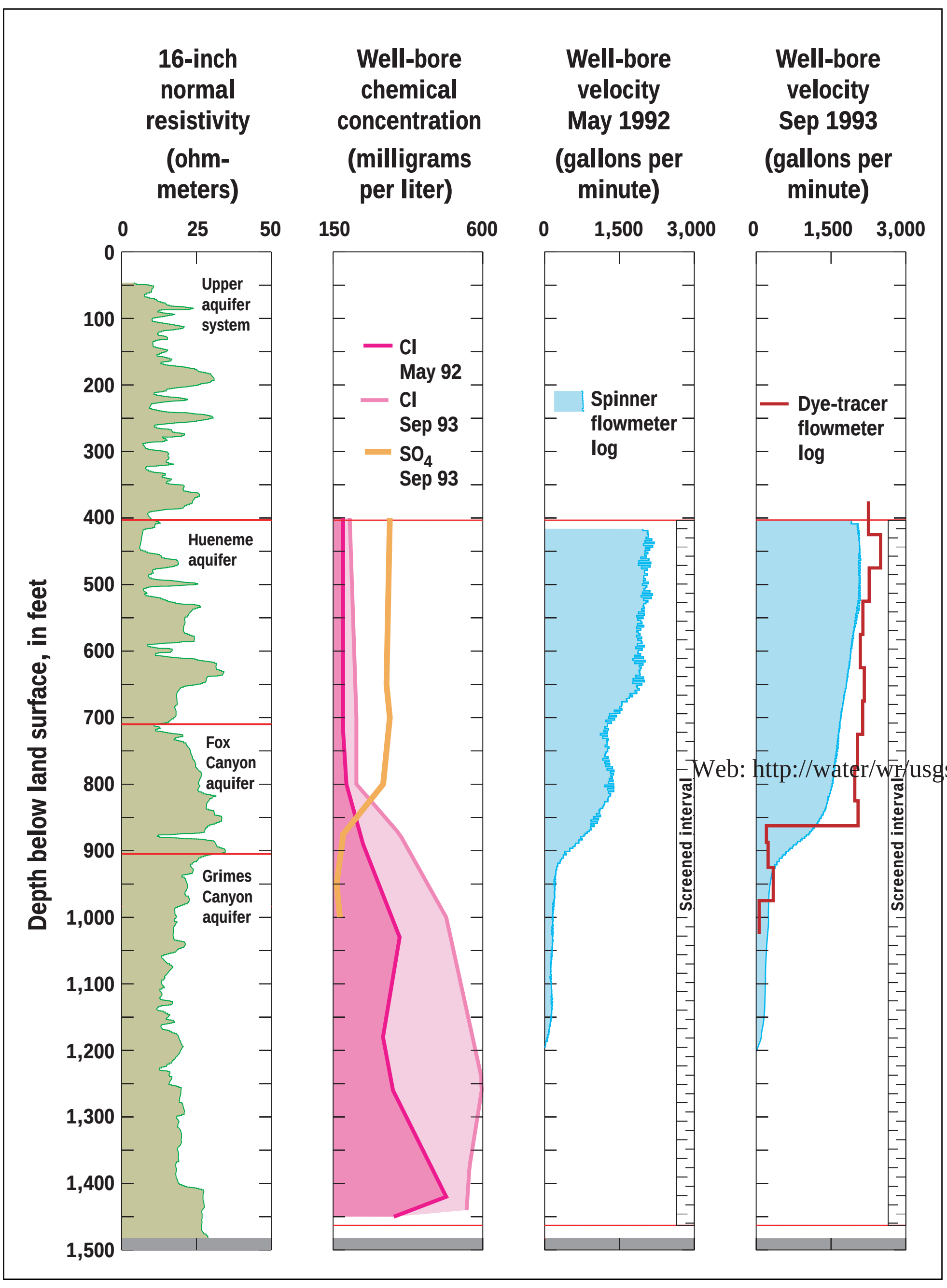
This calculation assumes conservative mixing and conservation of mass.

APPLICATIONS

The data shown in figure 2 are from a deep production well in a complex multiple-aquifer system. These data illustrate changes with time in the chloride concentration of water entering the well at depth and changes with time in the distribution of flow into the well. Because changes in well yield and water quality measured at the surface were small, these changes would not have been detected using conventional sample collection methods which are a composite of all the water flowing into the well. A comparison of data from a velocity log using a conventional spinner tool and a velocity log using the tracer-pulse method is also shown in figure 2. The tracer-pulse method correctly identified the most important water-yielding zone and the depth below which almost no water enters the well. Neither of these important hydrologic features could have been identified on the basis of indirect data, such as a resistivity log (fig. 2).

The combination of velocity-log data and depth-dependent water-quality data is an especially effective data set for hydrologic interpretations. Specific applications for data collected using this approach include:

(1) Identification of changes in ground-water quality and well yield with time.
(2) Identification of different water-bearing units with depth.



Web: http://water/wr/usgs.g

Figure 2. Example of depth-dependent flow and chemical data sampled from a deep production well.

(3) Identification of changes in natural ground-water chemistry with depth.
(4) Identification of man-made or natural contaminants with depth.

Although the applications described here are primarily for production wells, the approach also can be used in observation wells. This approach may be especially useful to assess the performance of wells used for remediation if contaminants are stratified within the aquifer.