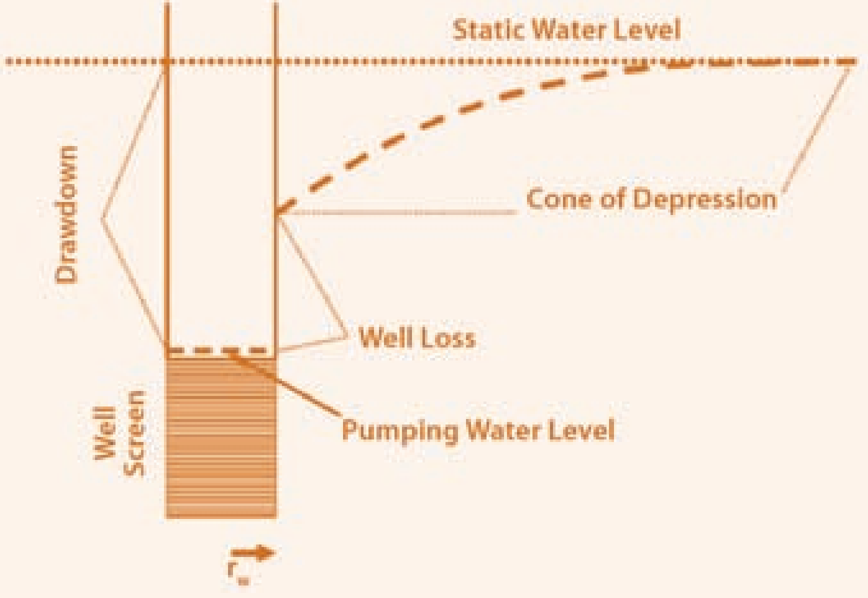
focus on groundwater - part II

By Neil Mansuy

Measuring Well Performance

A closer look at well performance and capacity

Figure 1. The Relationship Between Well Loss, Drawdown, and Static and Pumping Water Levels



There are several quantitative measures of well performance, the most common being discharge (Q), the volume of water produced per unit time. This is often referred to as specific capacity, the vertical distance between the static, non-pumping water level.

The pumping water level is called drawdown (s), and the greater the drawdown, the higher the power costs. If you try to discharge more water than can be supplied by the aquifer, or that will pass the aquifer-well connection, water levels in the well decrease until the pump is exposed and the well runs dry.

Drawdown is reduced by the construction of more efficient wells. Optimization of design results in a well that minimizes drawdown and construction costs while meeting the required discharge rates and intervals.

Wells are often pumped at variable discharge rates, which vary with drawdown, and drawdown increases with the duration of pumping.

Specific capacity is a measure of well performance (Q/s) indicating the amount of water that is available per unit drawdown. A decrease in specific capacity is an indication of well fouling; however, by the time large losses in specific capacity are observed, well plugging has progressed to the point where rehabilitation, rather than maintenance, is required to restore lost capacity.

Losses in specific capacity over time can be nonlinear, and this behavior has negative consequences. First, it makes it difficult to determine when a well requires maintenance in order to avoid rehabilitation. Regional variability in hydrogeology makes the one-size-fits-all approach to scheduling maintenance unreliable.

Second, sudden losses in specific capacity or large increases in drawdown make it impossible to obtain the needed raw water supply. Third, in order to have a reliable production rate of consistent water quality, it may require additional wells at a considerable expense.

These negatives can be offset with reliable preventative maintenance programs. To understand the reasons behind the unpredictability, we need to examine the governing equations and their physical basis in the well-aquifer system.

The well-aquifer system has a natural resistance to flow, and drawdown results from this resistance. The total drawdown (St) under pumping conditions can be expressed by the sum derived from the following equation:

Equation 1:

$$St = Sa + Swl + Spp + Sb - Sr$$

Where:

Sa = the resistance to groundwater flow from within the aquifer;
Swl = the well loss attributable to the transition from laminar to turbulent flow at or outside the well screen;
Spp = the drawdown because of a well screen only partially spanning the thickness of the aquifer due to vertical flow components;
Sb = drawdown caused by the finite extent of an aquifer; and
Sr = the decrease in drawdown (buildup) that is caused by local recharge to the aquifer.

Total drawdown increases with pumping duration because the aquifer is dewatered, decreasing the saturated thickness and increasing the value of Sa. With respect to well rehabilitation and maintenance, the primary term of interest is the well loss (Swl). We expect the other three variables in Equation 1 to remain relatively constant over time.

Figure 1 illustrates the relationships between well loss, drawdown and static and pumping water levels. If the well-loss term is insignificant, the well is near 100% efficient and the pumping water level is equal to the lowest level of the cone of depression. High-capacity wells are rarely 100% efficient, even when they are new, due to a combination of factors, the most common being a transition from laminar to turbulent flow.

Our current ability to quantify the physical controls on well losses is poor, although the combined value of Sa and Swl can be measured accurately. Part of the problem is that the well losses are assumed equal radially and vertically from the well screen, when in reality those conditions are rare. Additionally, the well-loss analysis requires that we identify the radial distance of the transition from laminar to turbulent flow (rw). This distance is poorly known and often arbitrarily set as the well screen radius.

The relationship between the rw turbulent flow transition and specific capacity may be counterintuitive. Turbulent flow contributes to drawdown because of energy losses. The vertical zones of an aquifer with the longest rw are transitioning to turbulent flow farther from the well screen because these are preferential flow paths.

One might expect the energy losses over longer distances to cause turbulent flow zones to be less transmissive and provide less water overall; however, high velocities are a result of the large flow volume. Plugging reduces flow and velocity, causing rw to be shortened. When highly transmissive, vertically discrete production zones reach an abrupt breakpoint, accelerated loss of production occurs generally without warning.

Zone Performance

In all wells, highly transmissive zones gradually plug, and discharge is derived more from pathways of lower flow resistance than from the plugged zone. Drawdown data provides no early indication of this

Table A. Redistribution of Production Due to Flow Resistance

Production Zone (ft)	Pre-Rehabilitation Production 3,000 gpm total	Post-Rehabilitation Production 3,000 gpm total
Zone 1 0-400	600 gpm	1,074 gpm
Zone 2 400-570	568	1,002
Zone 3 570-700	793	267
Zone 4 700-800	481	150
Zone 5 800-1,000	314	194
Zone 6 1,000-1,030	244	313

plugging to trigger maintenance. As plugging continues, all flow paths develop shortened rw, and large changes in drawdown and specific capacity are noted.

Table A presents the pre- and post-rehabilitation data obtained from a spinner log. The subject well is screened across multiple water production zones, and a spinner log measures the contribution of each zone to the total production under pumping conditions.

Based on Table A, zones 1 and 2 experienced significant loss of capacity; however, the well was still supplying its needed capacity (3,000 gpm) at higher drawdown. Keep in mind, this is a high-capacity well but variability in flow with depth occurs over short intervals.

The spinner log reveals that zones 3 and 4 were supplying the flow lost from zones 1 and 2. When rw in zones 1 and 2 decreases to below that available in other zones, the zones with the highest rw will supply the water at increased drawdown. If these zones differ in water quality, as most zoned aquifers do, the water quality produced by the well will be variable as plugging progresses.

If spinner logs were conducted frequently and a model for the progression of incipient plugging to unacceptable lost capacity was developed for this particular well, it may be possible to detect and trigger preventative maintenance. Spinner logs, however, can be expensive compared to maintenance treatments.

Effective Practices

In the past, a 15% to 20% loss in specific capacity was the recommended guideline to commence a rehabilitation effort. In many cases, it may be too late to create enough disruptive action with the pump in place because significant deposition can occur prior to recognizing a loss of capacity. It would be better to use a timeframe approach (i.e., every three months, six months or once a year) than to rely on the loss in a specific capacity.

Using the scheduled approach, the timeframe between maintenance would be determined geographically from experience in the area.

Critical lost-capacity conditions are generally met by crisis-management strategies or emergency rehabilitation. Historically, maintenance operations were often ineffective because the volume, extent and durability of the encrustations and plugging prevent effective cleaning without pulling the pump. A well rehabilitation is undertaken, and downtime often stretches into weeks of lost water production.

The well is restored to operation, or replaced with a new asset, and the historic paradigm of ruin, rehabilitate and replace continues. Effective preventative maintenance strategies clean the well during the plugging phase when the deposits are softer and easier to remove—the only time that maintenance results in effective restoration of lost capacity.

The final article in this three-part series will discuss preventative maintenance systems that were effective against bacterial growth in a pilot installation. *wqp*

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