Downhole video analysis of water supply wells: problem identification and well rehabilitation

MICHAEL L. VAUGHT
EGIS PA Inc. – Water Well and Downhole Investigations, 441 Northside Drive, Chapel Hill, North Carolina 27516, USA
e-mail: gwinvest@aol.com

LYNNE E. BRESLER
SAS Institute, Documentation Development, Technical Support Group, SAS Campus Drive, Cary, North Carolina 27513-2414, USA

Abstract Methods to improve groundwater quality or declining well yield begin with an analysis of the well environment. The dynamic conditions within a borehole and surrounding groundwater reservoirs correlate with functional, geological, biological, and chemical factors within. Water discoloration and turbidity, along with smell and taste, are the first warning signs of well problems. Key indicators of well dysfunction are degradation in water quality and declining well yield. A water well is an active environment and is best interpreted through direct observation during periods of static rest, pumping stress, and recharge. Pumping influences groundwater by creating decreased pressure along preferential pathways away from the well. When these pathways occur too shallow or along high angle fractures, unfiltered near-surface water is pulled down into the well bore. Often, near-surface water is high in nutrients and supports rapid growth of bacteria within the well. Downhole video cameras allow for direct observation and characterization of the inside of the water well.

INTRODUCTION

The most common well types are bored, screened, or open-hole. Bored wells are large diameter, shallow, fully cased infiltration collectors that are accessible for direct maintenance. Screened wells are constructed in unconsolidated, porous, or broken rock zones and are completely cased except for water openings at the reservoirs. Open-hole wells are cased down to the rock and left open-ended to drain water from the rock fractures. Well problems are the result of natural occurrences, pollution events, or functional inefficiencies arising from the construction and completion procedures. Groundwater in wells under the direct influence of near-surface water often is high in dissolved organic carbon (DOC) and oxygen which readily supports slime biofouling and bacterial growth in the well (Cullimore, 1993). A well can be thought of in terms of cells and zones: circulation cells, water production zones, or dead zones (Jones, 1979). Setting a well up for minimal maintenance and maximum long term efficiency simply means to maximize the circulation cell size, eliminate cascading water zones, and minimize the dead or non-circulating zones.

A slim-line downhole colour camera allows for direct inspection of open rock and screened wells with the pump in place (Melikian, 1995, 1997). Through direct observation by the downhole camera, information on the casing type, casing depth, well depth, pump depth, geological structure, water production zones, dead zones, degree of biofouling, and recharge rates can be obtained.

Well rehabilitation and repairs are best accomplished when planned and guided by well characterization and analysis (Katz, 1993). Rehabilitation involves cleaning, which removes organic slime and bacterial growth, and repositioning the pump to the optimum depth (Smith *et al.*, 1993). Repairs involve inserting a sleeve, which is a liner with a packer, to seal out the nutrient rich or contaminated near surface water.

Partial biofouling is the most common symptom observed in crystalline rock wells with water quality or yield problems. When shallow water is allowed to feed into a well, slime growth generally extends from the water surface down to the pump. From the static water level down to a depth of 25 to 30 m (80–100 feet (ft)) is considered shallow for a crystalline fractured rock environment, except for high flow rates (>95 l min^{-1}or >25 gallons per minute (gpm)) in high angle fractures.

After a well problem is investigated and understood, the goal is to make a change in the well to deter re-occurrence (Spon, 1997). It is best to repair the well with a sleeve to seal out the shallow water, especially for biofouling, pathogenic bacteria, or low specific gravity contaminants.

METHOD

To determine a well's real value, it is necessary to identify the well problem, locate the water zones, assign a relative strength to each water zone, and determine the pumping rate and/or the recharge rate. The first step is to examine a well in both the static or non-stressed state and the unrestricted pumping or stressed state. By over pumping to stress a well, the water level may lower to expose shallow water zones. Recharge from the exposed water zones is easily determined from the rate of rise and the borehole size. For example, consider a 15.24 cm (6 inch) diameter well that fills up at a rate of 7 s per 30.48 cm (1 ft) of rise between the depths of 58 to 55 m (190 to 180 ft). Use of the equation for the volume of a cylinder allows determination of the amount of water in a 30.48 cm (1 ft) section:

$$\pi \times r^2 \times h = \text{volume of a cylinder} \quad (1)$$

where π is the constant 3.14, r is the borehole radius and h is the height of the interval. For the example well, the amount of water in a 30.48 cm (1 ft) section is 5.56 l (3.14 × $(7.62\ \text{cm})^2$ × 30.48 cm), ÷ 1000 to give l), (or 1.47 gallons, (3.14 × $(0.25\ \text{ft})^2$ × 1 ft), × 7.48 to convert to gallons). A rate of rise of 30.48 cm per 7 s (1 ft per 7 s) converts to a recharge rate of 47.657 l min^{-1} (12.6 gpm), (30.48 cm/7 s × 60 s × 5.56 l/30.48 cm) or (1 ft/7 s × 60 s × 1.47 gallons/1 ft). In wells that do not pump down, flow is revealed through turbulence of particles in the water and clear or turbid zones in the water column.

Often, crystalline rock open-hole water wells are contaminated by direct infiltration of shallow water. Rapid infiltration through shallow rock fractures or leaky surface casing allows unfiltered near-surface water into the well. Understanding the dynamics within a water well is the key to successful rehabilitation or repairs.

Examination of the well from top to bottom in both a relatively static or non-pumping state and also in a stressed or pumping state allows comparisons that serve to identify water zones and rate their relative strength. After the drawdown slows, the well-head column storage is depleted. Once the head storage begins to deplete, water flows more directly from the water producing zones in proportion to their yield as affected by the pump depth.

The use of a downhole camera system reveals how a well produces water. Internal observation of the working well reveals where to position the pump, at what rate to pump the well, and how to repair or rehabilitate the well. The well pump should be placed at a depth and pumped at a rate to maximize circulation cells, minimize dead zones, and eliminate cascading water (over pumping). A problem well can be restored to production by cleaning it and/or repairing it (Smith *et al.*, 1993). It is necessary to use both physical and chemical action to clean accumulated slime and biomass from inside problem wells and install a sleeve to seal out shallow water.

RESULTS

Cost effective solutions for well water problems can be formulated based on the information from standard downhole video investigations (Hayden, 1992). So many variables are involved that "a single maintenance (or repair) programme cannot be devised that will work for every hydrogeological condition and every type of well" (Driscoll, 1986). Problems, such as groundwater under the direct influence of surface water, biofouling, mud and dirt, are easily diagnosed by direct observation with a downhole camera.

The rock type of a typical well investigation in the piedmont region of the United States is a granitic gneiss, tuft basalt, schist, or slate. The problem is often that well water becomes discoloured when it rains and tests positive for faecal coliform bacteria. Usually, the problem is caused by a leaky casing or shallow water zones in the fractured rock below the casing. The results of a typical well investigation follow.

Observation of the example 73 m (240 ft) deep well (with 13 m of 15.24 cm (43 ft of 6 inch) diameter galvanized casing) with a downhole video during both quiet, pumping, and recharge periods, identified water production zones at depths of 68, 55, 24 and 13 m (224, 180, 79 and 43 ft). The pump was located at a depth of 60 m (200 ft). The well pumped down when disconnected from the supply line and pumped continuously.

The borehole walls were relatively smooth except for slight cavernous fractures at the water zones and rougher partially weathered rock down to a depth of 25 m (80 ft). The recharge rate was about 45 l min^{-1} (12 gpm) from depths of 58 to 55 m (190 to 180 ft). Between depths of 55 to 24 m (180 to 79 ft), the recharge rate gradually decreased from 45 to 15 l min^{-1} (12 to 4 gpm); between the depths of 24 to 13 m (79 to 43 ft) the recharge rate decreased from 15 to 4 l min^{-1} (4 to 1 gpm), and above 13 m (43 ft) the water rose very slowly to static water level at 10 m (35 ft). The well was heavily biofouled with an orange slime growth from the water surface down to 23 m (75 ft), with less intense growth down to the pump at 60 m (200 ft). Below the pump, the well was clean because of a deep producing zone supplying water up to the pump. The interface between the deep, cleaner water and the shallow nutrient rich or contaminated water was at the pump.

Depending on the degree and extent of biofouling, the first step to rehabilitate this well may be to use a non-phosphate detergent solution with jetting and/or scrubbing to clean the slime and bacterial growth from the inside. The well could be repaired by installing a deep liner/packer to a depth of at least 36 m (120 ft) to seal out the shallow water.

Because of the deep, cleaner production zones, the liner should go no deeper than 52 m (170 ft). After the sleeve is in place, it should be sealed by completely grouting the liner annulus from the packer to the surface. The entire well should then be disinfected with chlorine. For example, for a 15.24 cm (6 inch) diameter well, 1.134 kg (2.5 lbs) of 65% calcium hypochlorite granules or 11.356 l (3 gallons) of bleach (5% sodium hypochlorite) would be needed per 30.48 m (100 ft) of well to create a 1000 ppm solution. This solution is recirculated in the entire borehole water column by inserting recirculation jets in the well bottom and at the water level (Dideriksen, 1995). Recirculation continues for at least an hour and the chlorine solution remains in the well for at least 12 h. Finally, the pump is set at about 3 m (10 ft) below the pumping water level and no deeper than 55 m (180 ft) (to prevent cascading water). Water should not be tested for bacteria until at least seven days after it is free of chlorine. Note, if the well yield is questionable, grout should not be installed until the sleeved well is pumped and its yield determined. If the yield proves insufficient, it will be necessary to remove the sleeve, deepen the well, and re-install the sleeve. Note also, if a well cannot be repaired and has only contaminated shallow water, it should be abandoned and replaced by a new well with a deep, completely grouted casing.

SUMMARY

Through characterization, analysis, and rehabilitation, problem wells, including those under the influence of surface water, can be restored. Most water quality problems in crystalline rock aquifers can be solved by excluding specific water zones from the well. If sealing water zones removes too much from the total well yield a well is often deepened in order to obtain more water or increased storage.

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