Results of calculations on pump test - Saturday Morning

I want to report to you the results of my calculations on the step-drawdown test that Andrew completed before they pulled the pump out. The pump you saw yesterday failed early this week. I believe it was an electrical fault. There was no problem with the hole. They put a new pump in the hole. The question is whether or not we can sense the presence of bacteria. I have done a number of standard tests on wells, through students’ activities over the past 20 years or so, and some specially for this workshop. In addition, Murdoch has commissioned step-drawdown tests or simplest specific capacity tests including outlet pressure and current to the well equipment on irregular occasions through many years with several different consultants. Andrew Ogden of Western Irrigation has completed a number of them, including a recent test on this particular bore hole, in November of last year, and now a step drawdown test with a new pump.

In doing pumping tests, one must recognise that there is a substantial investment in time and money. Usually, nothing is done unless something untoward is suspected. It is usual for everything to be OK, with perhaps a 10 to 20% reduction in specific capacity - then - failure. That is, plugging is dramatic and abrupt. One soon recognises that there is going to be a failure, and this failure point, whatever happens, happens very abruptly. We have had no real systematic recognition of partial failure in all the pumping tests I have done. In the most recent tests, I haven’t seen a lot of effect that I could say was due to bacteria. Still, a number of wells have failed. The point is they run along on an even keel with relatively little wrong hydrologically. The chance of doing pumping tests at the right time and catching the failure is relatively small. People generally do not flog dead horses; they are not interested in investing money when they know the well is dead. Dead doesn’t tell you anything. The advice is that we need another approach to looking at bacterial effects.

Consider a pumping well and a step-drawdown test. The idea is to partition the activities at the well from the activities in the formation. During the pumping the drawdown is measured, the drop in water level relative to the static level. With each step in the flow rate, the drawdown settles into a new value which, perhaps, becomes steady. The test is run at several flow rates and the drawdown at the well is recorded.

Here is the pumping well and the ground level at the well (bottom left). If you read Bouwer (1978) or other text books, the step-drawdown test allows for effects at the well and effects in the formation. At the well there is the developed zone where there is head loss. There will be loss of head at the screen and loss at the pump. There are two different types of drawdown.

The formation part is fairly simple because even with the very simplest formation you find out that everything is proportional to the pumping rate. You write down the ‘formation coefficient,’ $C_f$, as the proportionality factor. If the pumping rate doubles,
you expect that the drawdown doubles. If the pumping rate halves, you expect the drawdown to halve.

At the pumping equipment, there are other things going on, probably a lot of turbulence. In the simplest case, the Cooper-Jacob¹, Sheahan² calculation, the drawdown goes perhaps as the square of the pumping rate. So we are looking at another coefficient - again, just an arbitrary coefficient - we call it $C_w$ - the well coefficient. There are two terms: one goes as $Q$, the other as $Q^2$. You add the two together to get the total drawdown. The total drawdown is the sum of the drawdown from the formation and the drawdown from the pump equipment, total drawdown = $s_f + s_w = C_f Q + C_w Q^2$. The step-drawdown test runs the pump at several flow rates by adjusting the downstream resistance to flow. Different drawdowns are observed as the drawdown ‘settles into’ a steady value. There are various ways to fit an equation to these data. A proper regression equation can be obtained by going to Excel and fitting the data, to find $C_f$ and $C_w$. The simplest is to divide $s = s_f + s_w$ by $Q$.

In this particular case, just a few days back, I could not fit the test with this kind of a form. Other step-drawdown tests at Murdoch have shown similar effects, but some do show the above, classic, $Q/Q^2$ effect. Bouwer (1978, pp 83-85) and others say the turbulence effect can be any power to about 4.5. There is a good argument for a simple linear relationship at the well; everything is performing perfectly; it is not turbulent, there are no problems. Statistically, it is quite possible.

Surprisingly, the data statistics do not allow one to say that there is a power much different to 1! There is close to a simple linear relationship or the power of $Q$ in $s_w$ is around 1.3, not 2.

Phil Mulvey: The usual way to test performance is to run a series of multirate stepdown tests at different time intervals. It would be usual for the test to be run at 30% of the maximum pumping rate and step downward. In one test we would obtain a plot with an increasing slope at higher flow rates. At the lower flow rates, as you suggest, the slope would be indicative of the formation coefficient. In principle, changes in the formation coefficient in separate stepdown tests over months or years might show the effect of bacteria on the formation, perhaps a metre or more out from the developed zone. Effectively, the multistep test splits the drawdown between the formation and the well, the formation function compared to the well function. Extrapolation to low flow rates gives the effect on the function (see graph, next page). In a usual stepdown test, each pumping rate might be held for 20 minutes. My question - did you find that the slope changes?

Bill: Full step-drawdown tests have only been performed irregularly, when the well is suspect and usually the pump equipment are in need of maintenance. That shows little about the formation. The tests are expensive and, usually, have been completed in steps of about an hour. The use of smaller time intervals uses less than a ‘steady state’ and the standard Theim equation incorrectly; the proportionality is not so easy to interpret. Answer - no. I have not had sufficient data from step-drawdown tests on a single well in a known stable condition that would allow one to see a change in the slope with time; the formation constant should increase as the bacterial infection ensues.

Phil: If you increase your pumping speed, particularly if there is clogging, doesn’t the slope change? That is, the formation is affected by bacteria and sloughing, so there is more resistance and turbulence?

Bill: It is only very close to the well that there is sufficient velocity for there to be a high Reynold’s number and turbulence so that one gets a response which is a power function, say, 2 - 4.5, the classical, quite different, function that allows a separation of the effects of the well equipment from those of the formation. A classical case is given in Bouwer (1978, page 85). This has little or no effect at low flows but becomes important at high flow rates when friction in the equipment contributes substantially to the drawdown at the well. See graph on next page. The four ‘Xs’ are the above 4 steps shown in the test; note the slope near-to-zero flow shows the effect of the formation. The bacterial
Step Drawdown Test Results

Colin: Isn’t there an issue with the pumping? If you don’t take uniform steps, then the asymptotic approach to the next step is not going to be in the same time frame.

Bill: We are plotting the drawdown as a function of flow rate or plotting the drawdown as a function of time. For plotting drawdown as a function of time, we start out at a given pumping rate which is fairly small and you get a response, a small drawdown (see figure two pages back). I suggest you need at least four different flow rates. Monitoring the drawdown, you wait until it settles down, and doesn’t change with time. The steady condition probably never happens. The first flowrate, Q, might be 1 cubic metre per minute; then 2 metres per minute, then three and so forth. There are issues about uniform changes to pumping because the regression plot doesn’t place emphasis on the higher pumping rates. There is an issue as to whether you use increased or decreased flow rates, especially with bacterial sloughing. It is probably better to be moderate and only operate at or below your normal flow rates. Provided the flow is well below the maximum pumping rate, the curve should be mostly linear and equal pumping steps, equal changes in Q and time, would be appropriate.

In the present data - with little statistical validity - the well frictional effect goes as a power something like 1.3. With the poor statistics we shouldn’t go further; it simply doesn’t fit a standard mould. It may suggest that the efficiency is around 70%, but that could well mean that there is little-or-no loss in the well equipment, but a bacterial infection in the well surrounds. There is relatively little turbulence. It may be we are doing a good job of management by putting in copper electrodes.

Q: You have a gravel pack. Can’t you add terms for the friction/loss for that? Perhaps another term for the gravel pack and a further one for the surroundings? The gravel pack probably lines up beautifully with the pristine, nearly pure white Bassendean sand in the formation.

Bill: I agree. However, the country, the formation and the gravel pack are mostly in regions of small laminar flows and are expected to show proportional frictional effects.

Colin: I can see that there is a bit of work-in-progress on the mathematics of well drawdown. We posed a question for ourselves in the workshop as to whether we can diagnose clogged wells by routine pump testing. It does seem we can not say that hydrological testing alone (pump testing) can give a straightforward indication of the presence of bacteria.

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