

Aquifer test analysis by inverse modelling of superposed pumping regimes

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Abstract Analysis of an aquifer test in an unconfined shallow aquifer using the production wells of a water supply pumping station suffered from slow response of the aquifer to changes in pumping regimes. A proper aquifer test analysis had to explicitly take prior pumping regimes into account.

Key words aquifer test; inverse modelling; pumping regime; superposition in time

INTRODUCTION

As part of a procedure to assess crop damage related to prolonged operation of the water-supply pumping station "Boxmeer" in the SE-Netherlands (Fig. 1), an aquifer test was carried out using all production wells in 1996. As the 16 m thick unconfined aquifer system responded slowly to changes in the abstraction rates, an analysis of this test using traditional methods was hampered by antecedent effects of prior pumping regimes. In the scope of a reinterpretation it was found that these antecedent pumping periods had to be taken into account explicitly by including them in the inverse modelling process.

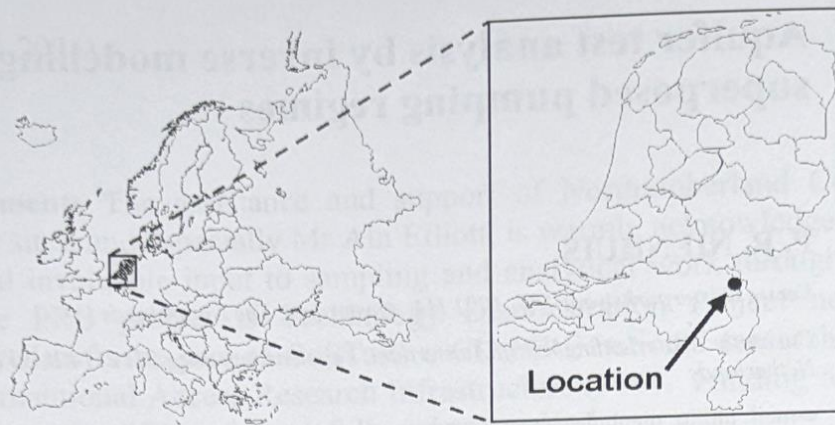


Fig. 3 Location of study area

SETUP OF THE AQUIFER TEST

The aquifer test had to be executed with minimum interruption of the long-term daily water-supply production. First, the total pumping rate in all six production wells was maximised for eight days. Next the abstraction in five wells was stopped for 15 days and finally resumed during 14 days with a fixed rate in all six wells. Among the available data are hydraulic heads recorded with pressure transducers at 10-minutes intervals in 46 observation wells, as well as numerous manual head and surface water level observations at many locations (Fig. 2).

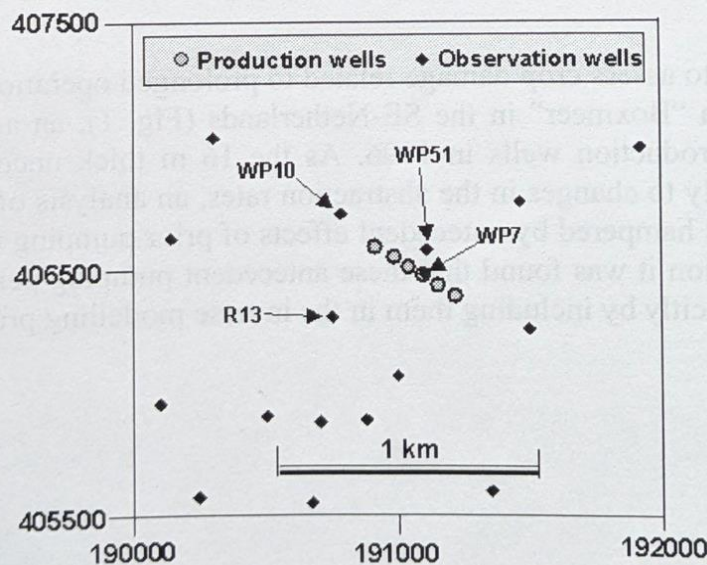


Fig. 4 Location of production wells and some observation wells

INTERPRETATION

During the summer months preceding the test the average abstraction rate of the pumping station was about $240 \text{ m}^3 \text{ hour}^{-1}$. This is considered the base pumping rate to which all following abstraction regimes are compared using superposition in time; a steady-state drawdown condition due to this pumping regime is implicitly assumed. Consequently the analysis involved a series of superposed pumping regimes rather than absolute abstraction rates. Altogether five successive pumping regimes were distinguished (Table 1).

Table 1 Overview of modelled pumping regimes

Period	Pumping regime	Duration (days)	Total discharge ($\text{m}^3 \text{ hour}^{-1}$)	
			Absolute	Relative to period 1
1	Average abstraction during summer, normal operation	-	240	-
2	Normal operation, somewhat increased abstraction rate	21	274	34
3	Fixed abstraction	8	300	60
4	Recovery test	15	50	-190
5	Pumping test	14	300	60

Each well was supposed to have its own fixed abstraction rate during each pumping regime. Individual well abstractions were inferred as much as possible using records of operation hours and individual well capacities.

ANALYSIS AND RESULTS

The analysis of the aquifer test was carried out using the MLPU software (Nienhuis, 1997). This AEM code can be used to compute the cumulative transient effects of multiple wells, each with an independent start and stop time, and allows automated optimisation of hydraulic properties using the Levenberg-Marquardt algorithm (Olsthoorn, 1995). Differences of drawdowns were corrected for background fluctuations due to evaporation, precipitation and barometric effects, using data from relatively distant observation wells that showed no apparent pumping test responses. The occurrence of barometric effects was a surprise, since such effects are not often encountered in phreatic aquifers with a shallow (1.5 m deep) water table. The barometric efficiency of several observation wells was found to be 20%.

The systematic model errors caused by the slow aquifer response were effectively eliminated by superposition in time of all aforementioned pumping regimes. In Fig. 3 computed drawdown curves (Thick lines) are plotted for periods 2 - 5, together with the corrected observed drawdowns for the periods 4 and 5 (the recovery and the pumping tests, respectively). The thin lines are the computed drawdown curves if pumping had not stopped in period 4 (recovery); these lines show the corrections resulting from the antecedent pumping periods 2 and 3.

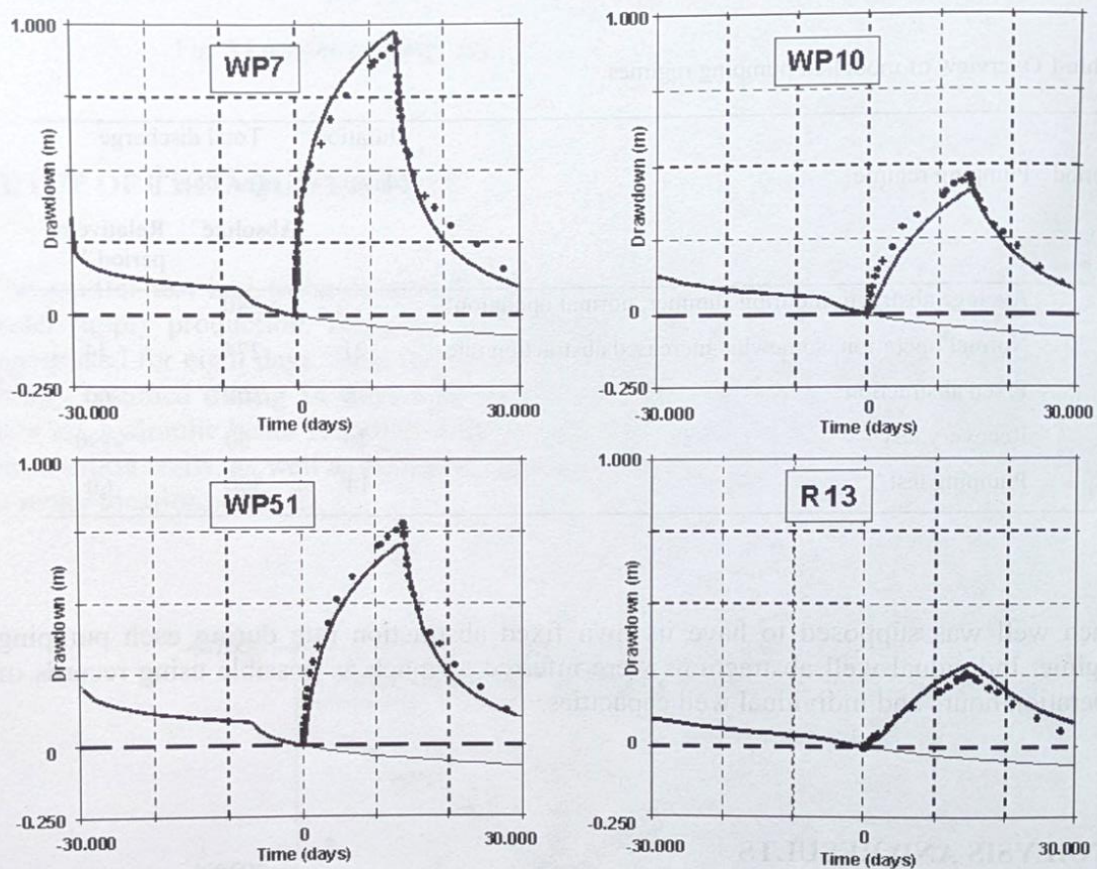


Fig. 5 Computed (thick and thin lines) and corrected observed drawdowns (dots) in four wells: WP7, WP10, WP51 and R13.

DISCUSSION

The corrections for antecedent pumping regime effects are smaller for observation wells close to the abstraction wells (e.g. WP7) than for observation wells at a greater distance (e.g. R13). This implies that just using data from observation wells close to the pumping station would yield more reliable results. However, because effects of erroneously inferred individual well pumping rates are smoothed out with increasing distance from the pumping station, data from observation wells at greater distances are considered more reliable.

Only after elimination of antecedent pumping regime effects it became clear that a proper fit could still not be obtained because of several other complicating factors that may hamper pumping-recovery tests:

1. A different specific yield for a declining and for a rising water table (Youngs and Smiles, 1963; Dos Santos and Youngs, 1969);
2. A storage coefficient that increases with pumping (or recovery) time (Nwankor et al., 1984; 1992);
3. Effects of a heterogeneous transmissivity of the phreatic aquifer;
4. Possibly decreasing pump yields associated with steady lowering of the groundwater table in the phreatic aquifer.

After many experiments with fitting just the recovery or pumping period, or a combination of both using several selected sets of observation wells, transmissivity and specific yield values were inferred based on the last four days of the recovery test period. These results are believed to be more reliable than when the analysis was carried out using traditional pumping test techniques.

CONCLUSIONS

Because the individual abstraction rates of the production wells could not be reliably inferred, emphasis was laid on drawdowns in wells at greater distances from the well field. In this way the effects of possible errors in the individual production well rates is smoothed out. However, at these greater distances antecedent effects of prior pumping regimes were much more pronounced. To obtain the most reliable results, these prior pumping regimes had to be taken into account explicitly in the course of the aquifer test analysis. This was accomplished using appropriate analytical modelling software.

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