INSTITUUT VOOR CULTUURTECHNIEK EN WATERHUISHOUDING

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Analysis of the pumping test 'De Vennebulten' near Varsseveld

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Introduction

The pumping test 'De Vennebulten' which will be described in this report forms part of a large-scale groundwater exploration in the 'Achterhoek' region, province of Gelderland. In greater parts of this region, covering some 100 000 ha, groundwater is pumped from Young Pleistocene formations underlain by almost impervious layers of Tertiary clay and clay-bearing fine sands. These water-bearing materials consist chiefly of fluvioglacial deposits and Rhine sediments, varying in thickness from some 10 m to more than 50 m. In the eastern part of the region, however, water-bearing layers are absent or very thin and the impervious Tertiary (Oligocene, Miocene) formations are found at the surface or at shallow depth.

The pumping test site is located between the villages of Varsseveld and Lichtenvoorde (fig. 1). The Water Supply Company 'Oostelijk Gelderland' carried out some exploration wells at this place. Before groundwater resources can be managed they must be quantitatively appraised. For this purpose the Institute for Land and Water Management Research at Wageningen carried out a pumping test which will be described hereafter.

Scheme of the test

Besides a pumping well, four observation wells were made at distances of 10, 30, 90 and 280 m from the pumping well (fig. 2). As can be seen in this figure the aquifer was found at a depth of approximately 10 to 21 m below the surface. It is composed of gravel-bearing coarse and very coarse sands and its thickness is 11 m. The aquifer is underlain by almost impervious marine clays of Middle Miocene age (impervious basis layer) and on its top fine and very fine sands are present with a thickness of about 10 m. A part of this covering layer consists of loamy sand.

A pumping screen of 11 m length and 3" diameter made of polyvinyl chloride (P.V.C.), was installed over the full thickness of the aquifer (so-called fully penetrating well). In the observation wells at 10, 30, 90 and 280 m distance small filters with a length of 1 m and a diameter of 1" were installed somewhere in the middle of the aquifer. Near each well

also a shallow observation well was made in which a filter at a depth of 3 to 4 m was installed. Measuring data from these shallow wells permit to determine whether the groundwater in the underlying aquifer is confined, semi-confined or phreatic.

Prior to the test the water levels in the various wells were measured regularly during 10 days. This was done to determine whether or not a correction of the drawdowns during the test had to be made. As a result of the drainage the water table may fall several millimeters per hour and this has to be accounted for in the analysis of the test data. One day after the test the water levels in all wells were also measured.

Pumping was started at 10^h27 on October 28, 1965 and was continued for a period of about 25,5 hours at a constant rate of 36.37 m^3/hour until 11^h59 on October 29. When pumping stopped the rise of the water levels was measured during about 5 hours (recovery test). The water pumped during the test was discharged through a closed pipe to a ditch in order to prevent any recharge of the tested aquifer.

Analysis of the test data

To analyze the pumping test data drawdowns in the deep observation wells W II 10, W II 30, W II 90 and W II 280 were plotted on semi-logarithmic paper against the time. These so-called time-drawdown curves are shown in figure 3. As can be seen in this figure the curves start to run parallel after 40 to 50 minutes of pumping and at the end of the test drawdowns become very small which indicates that stationary flow conditions (stage of equilibrium) had almost been reached. From this type of curves it can be concluded that the tested aquifer is a leaky aquifer and the groundwater is semi-confined. This means that during pumping not only water was withdrawn from the tested aquifer but also from the overlying fine sand and loamy sand layer. Figure 4, showing the time-drawdown curves of the shallow observation wells (drawn on linear scale) and figure 5 presenting the maximum drawdowns in all wells measured at the end of the pumping period provide evidence for this statement. When the tested aquifer was a confined aquifer no drawdown in the shallow observation wells would have been measured. Under phreatic groundwater conditions drawdowns in the shallow and deep filters of a certain observation well would have been the same.

Since we have to deal with a leaky or semi-confined aquifer the method

of DE GLEE will be applied for calculation of the geohydrologic characteristics. In 1930 DE GLEE derived the following equation

$$\varphi\ (r) = \frac{Q}{2\pi kD}\ K_o\ (\frac{r}{\lambda})$$

where

$\varphi(r)$ is the maximum stabilized drawdown (in m) in an observation well at a distance r(in m) from the pumping well

Q is the discharge of the pumped well (in m^3/day)

kD is the transmissibility of the aquifer (in m^2/day)

K_o is a modified Bessel function of the 2nd kind and of zero order,

$\lambda = \sqrt{kD.c}$ is the leakage factor (in m)

$c = \frac{D'}{k_v}$ is the hydraulic resistance or leakage coefficient of the semi-pervious covering layer (in days)

D' is the thickness of the saturated part of this layer(in m) and

k_v is the vertical hydraulic conductivity of this layer (in m/days).

To calculate the values of kD and c the procedure is as follows: This distance-drawdown curve is constructed on double logarithmic paper by plotting the maximum stabilized drawdown (in m) of each deep observation well against the distance (in m) of this well to the pumped well.

A second sheet of logarithmic paper with the same scale is used for the construction of the type curve ($K_o(x)$ versus x). The values of $K_o(x)$ for a wide range of x are found in textbooks. The observed field data curve is now superimposed on the type curve, keeping the coordinate axes of the two curves parallel and adjusted until a position is found where the field data curve fall on the type curve (fig.6). The cross mark of the type curve sheet is then indicated on the field data sheet.

The vertical displacement of the axis stands for the quotient $\frac{Q}{2\pi kD}$ from which kD can be derived. The horizontal displacement of the axis stands for the leakage factor $\lambda = \sqrt{kD.c}$, from which the hydraulic resistance c can be calculated.

For the vertical displacement 0.08 m is found

$$\frac{36.37 \times 24}{2\times 3.14\times kD} = 0.08 \qquad kD = 1745\ m^2/day$$

The horizontal displacement is 1000 m

$$\sqrt{kD.c} = 1000 \text{ m} \qquad c = 570 \text{ days}$$

Taking into account the thickness of the aquifer and the covering layer it can be found that the average hydraulic conductivity of the aquifer for horizontal flow $k_h \approx 160$ m/day and that of the semi-pervious covering layer for vertical flow $k_v \approx 0.017$ m/day.

It should be noted that DE GLEE's method of solution is based on the assumption that the leakage through the covering layer is proportional to the drawdown in the aquifer. Above the semi-pervious layer phreatic water with a constant level is assumed to exist. Since some drawdown of the phreatic water level occurred during the test this condition is not satisfied (figures 4 and 5) and an error in the obtained results may be expected.

The condition of a constant phreatic water table would have been satisfied if the drawdowns in all observation wells were some 12 to 18 cm smaller. Subtracting of this amount from the measured drawdowns at the end of the test and applying then DE GLEE's method of solution yield similar results for kD, but a substantial smaller value for c, namely 23 days (see dashed curves in fig. 6). This result seems to be more reasonable than the forementioned relatively high value of 570 days.

Figure 3 shows that 40 to 50 minutes after the pump started the difference in drawdown between the various wells became constant. We can therefore apply the Thiem formula

$$Q = \frac{2\pi kD(h_1 - h_2)}{\ln {}^{r_2}/r_1}$$

Application of this formula for the wells W II/10 and W II/30 gives

$$872.9 = \frac{6.28 \text{ kD} \times 0.075}{\ln {}^{30}/10} \qquad kD = 2041 \text{ m}^2/\text{day}$$

For the wells W II/30 and W II/90

$$872.9 = \frac{6.28 \text{ kD} \times 0.105}{\ln {}^{90}/30} \qquad kD = 1455 \text{ m}^2/\text{day}$$

For the wells W II/90 and W II/280

$$872.9 = \frac{6.28 \text{ kD} \times 0.09}{\ln {}^{280}/_{90}} \qquad \text{kD} = 1753 \text{ m}^2/\text{day}$$

It appears that the transmissibility varies from one place to another. The average of these three values is 1750 m^2/day which is in agreement with the result obtained by applying the method of DE GLEE.

To answer the question whether or not the time-drawdown curves of figure 3 have to be corrected for changes of the water tables not caused by pumping, figure 7 was drawn. This figure shows that during the pumping period a certain drop of the water table must have taken place due to drainage. However, this drop of the water table was so small that it may be neglected.

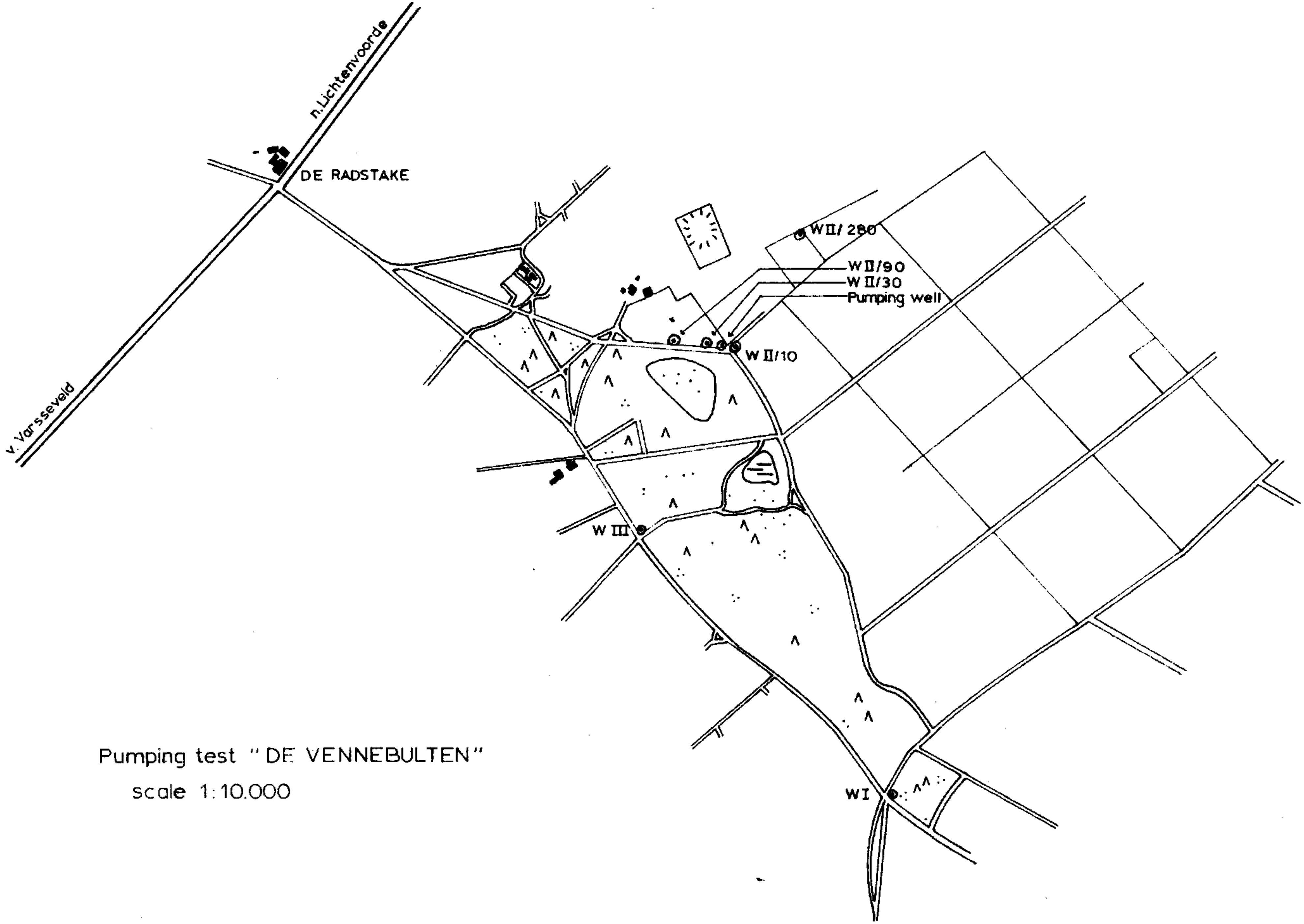
From figure 8 it could be concluded that during the pumping period the drop of the phreatic water level was larger than that of the water level in the aquifer what seems unrealistic. The observation data of the day after the test cannot be used because it is assumed that the phreatic water level was not yet fully re-established at that time.

Finally, it should be noted that application of the Thiem formula for a leaky aquifer is not allowed unless the discharge (Q) of the pumped well is corrected. Strictly taken, the amount of water delivered by the semi-pervious covering layer should be determined. This quantity has to be subtracted from the well discharge (Q), resulting in a somewhat lower value of kD. In the present case this correction is difficult to perform due to insufficient data. On the other hand such a correction seems hardly necessary because the calculated value of kD is on the average in good agreement with that obtained by applying DE GLEE's method of solution.

In summary it can be stated that the transmissibility of the aquifer has the order of magnitude of 1745 m^2/day. The hydraulic resistance of the semi-pervious covering layer is approximately 20 to 25 days, from which can be derived that the vertical hydraulic conductivity of this layer is on the average 0.5 m/day.

LOCATION OF TEST SITE

Fig.1

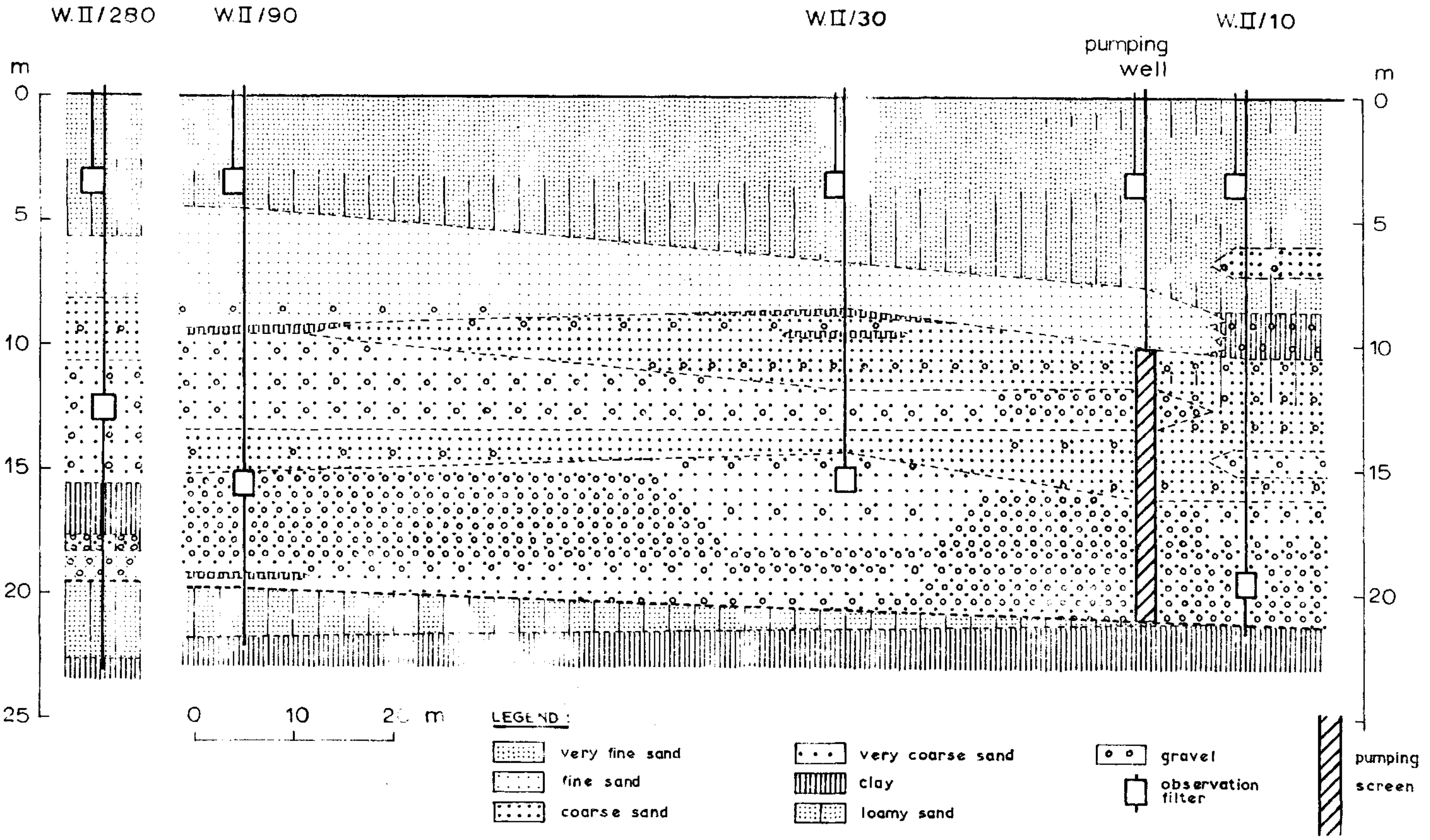


Pumping test "DE VENNEBULTEN"
scale 1:10.000

Fig. 2

Lithological profile

Pumping test "DE VENNEBULTEN"



Time-drawdown curves of the deep observation wells W II /10, /30, /90 and /280
Pumping test "De Vennebulten"

fig. 3

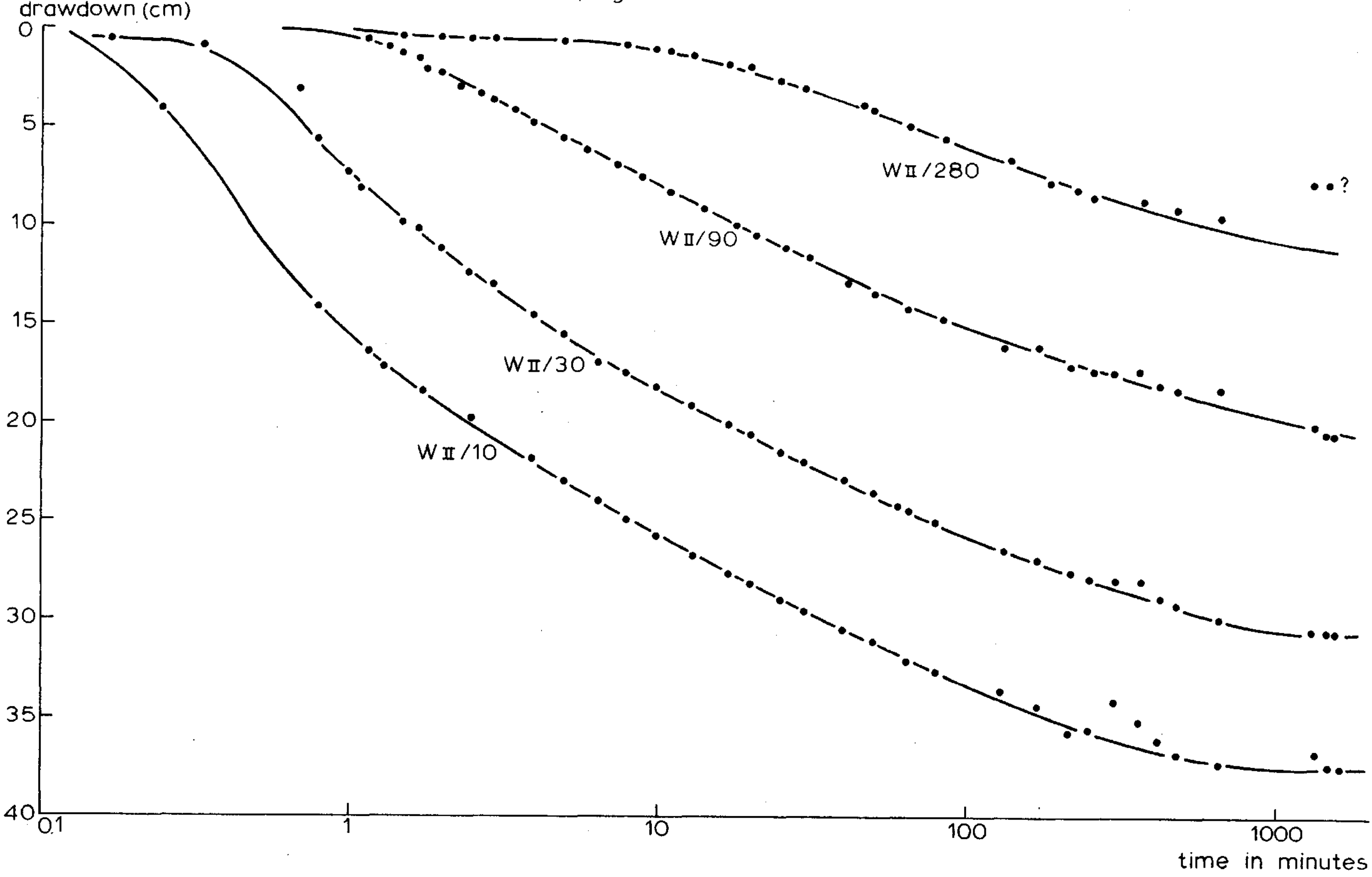


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fig. 4

Time - drawdown curves of the shallow observation wells
Pumping test "De Vennebulten"

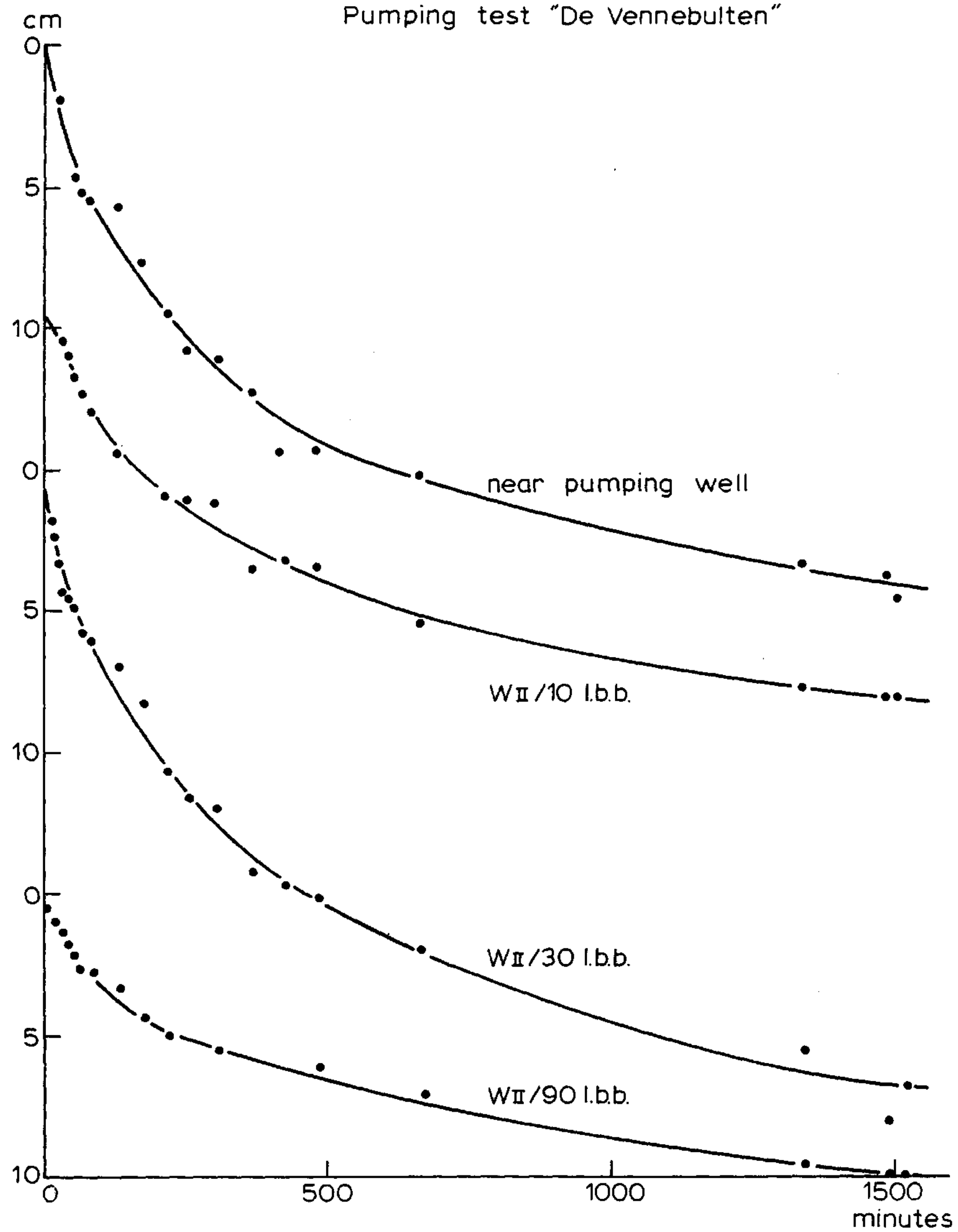

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Fig. 5

Drawdowns at the end of the pumping period

Pumping test " DE VENNEBULTEN"

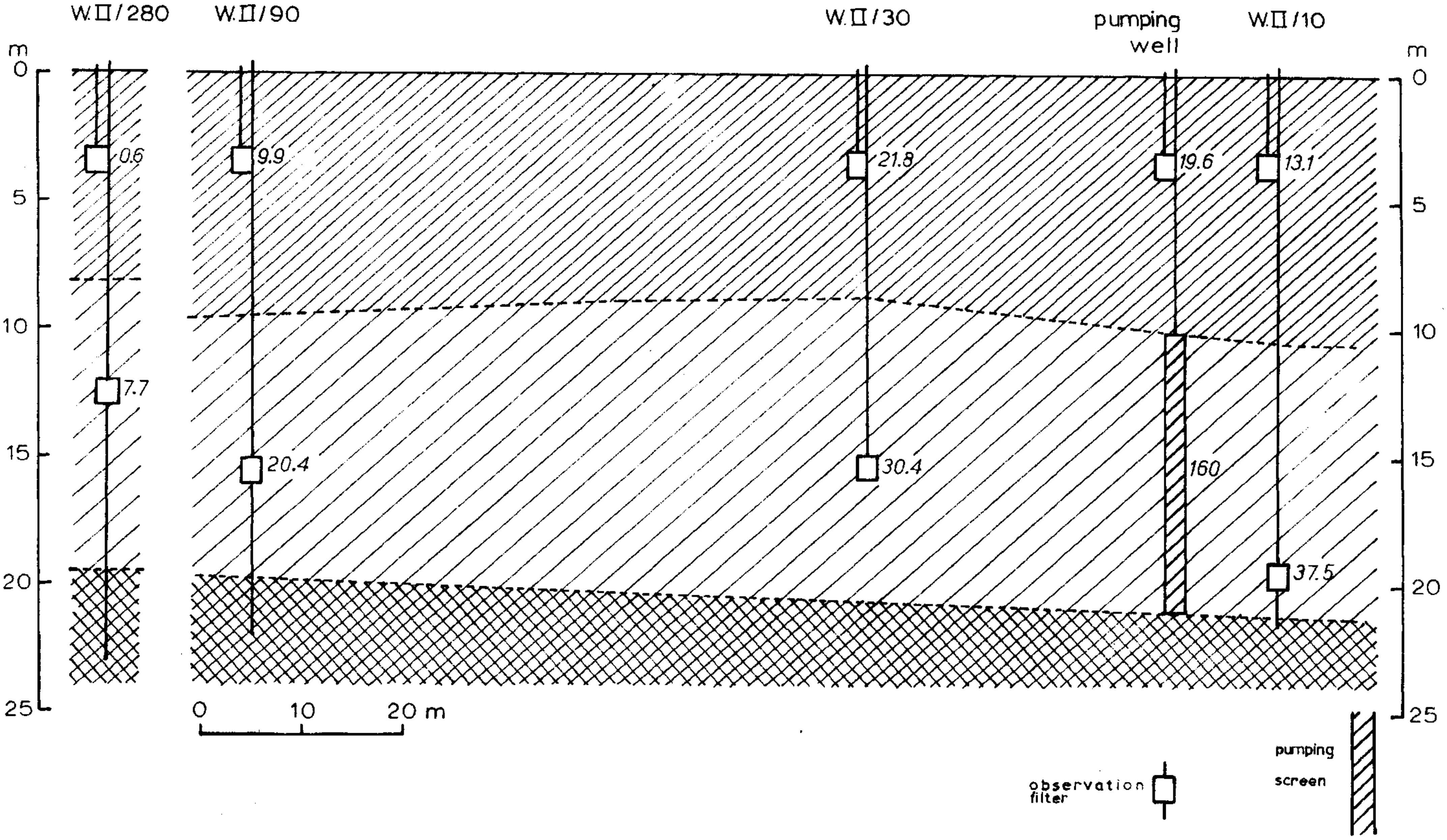
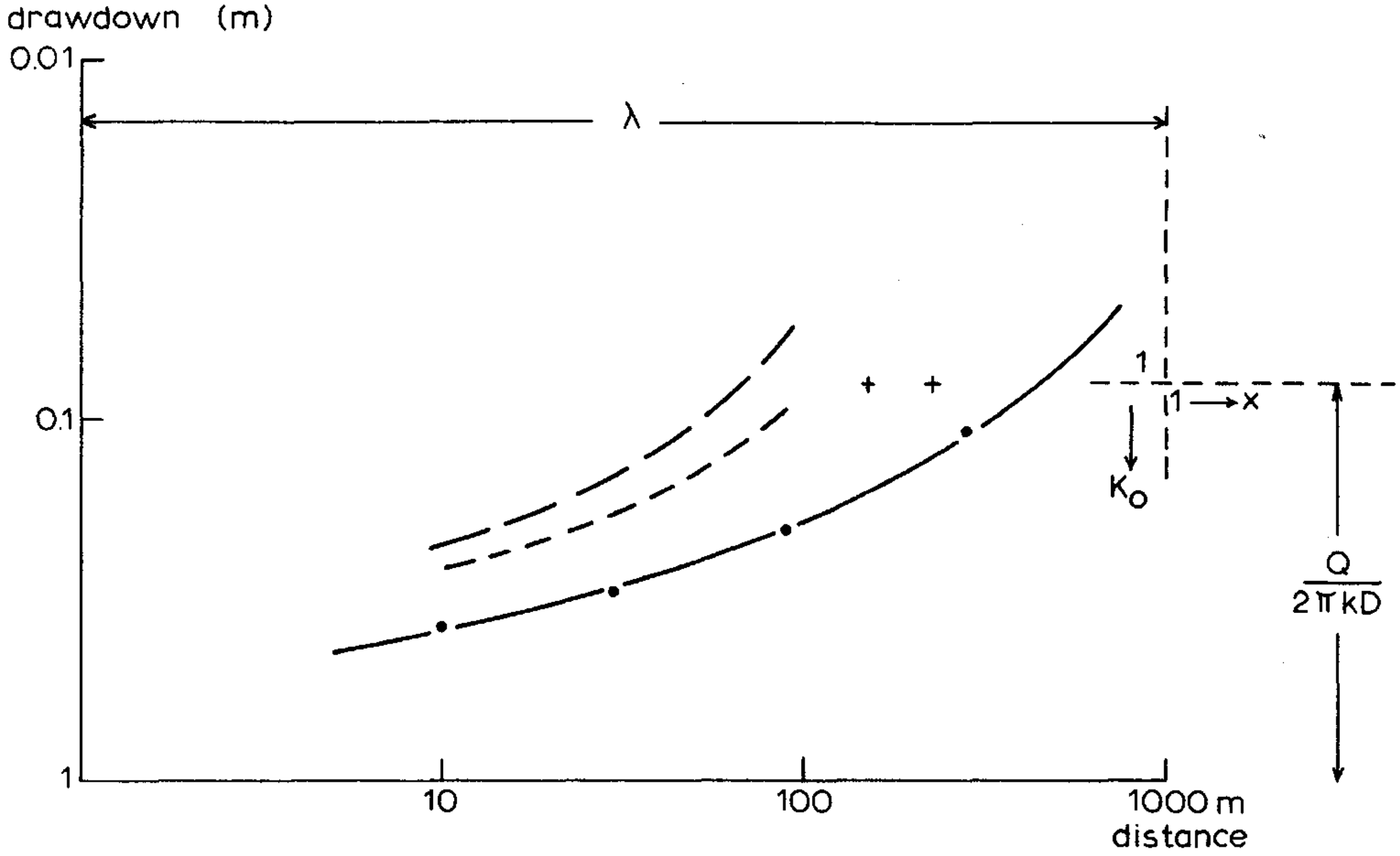


fig.6

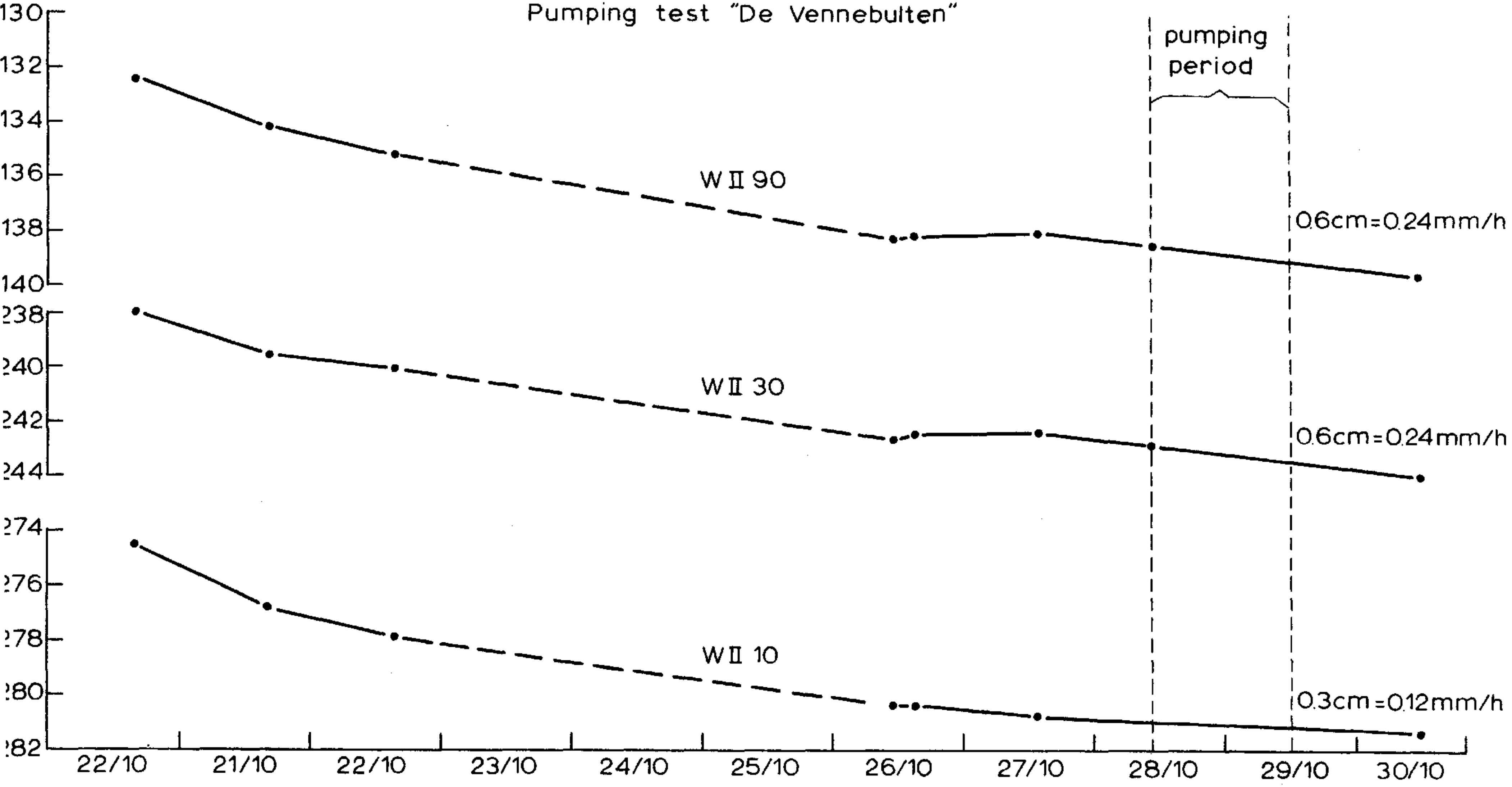
Distance – drawdown curve superimposed on the type curve
Pumping · test "De Vennebulten"



Groundwater tables in the deep observation wells before and after pumping

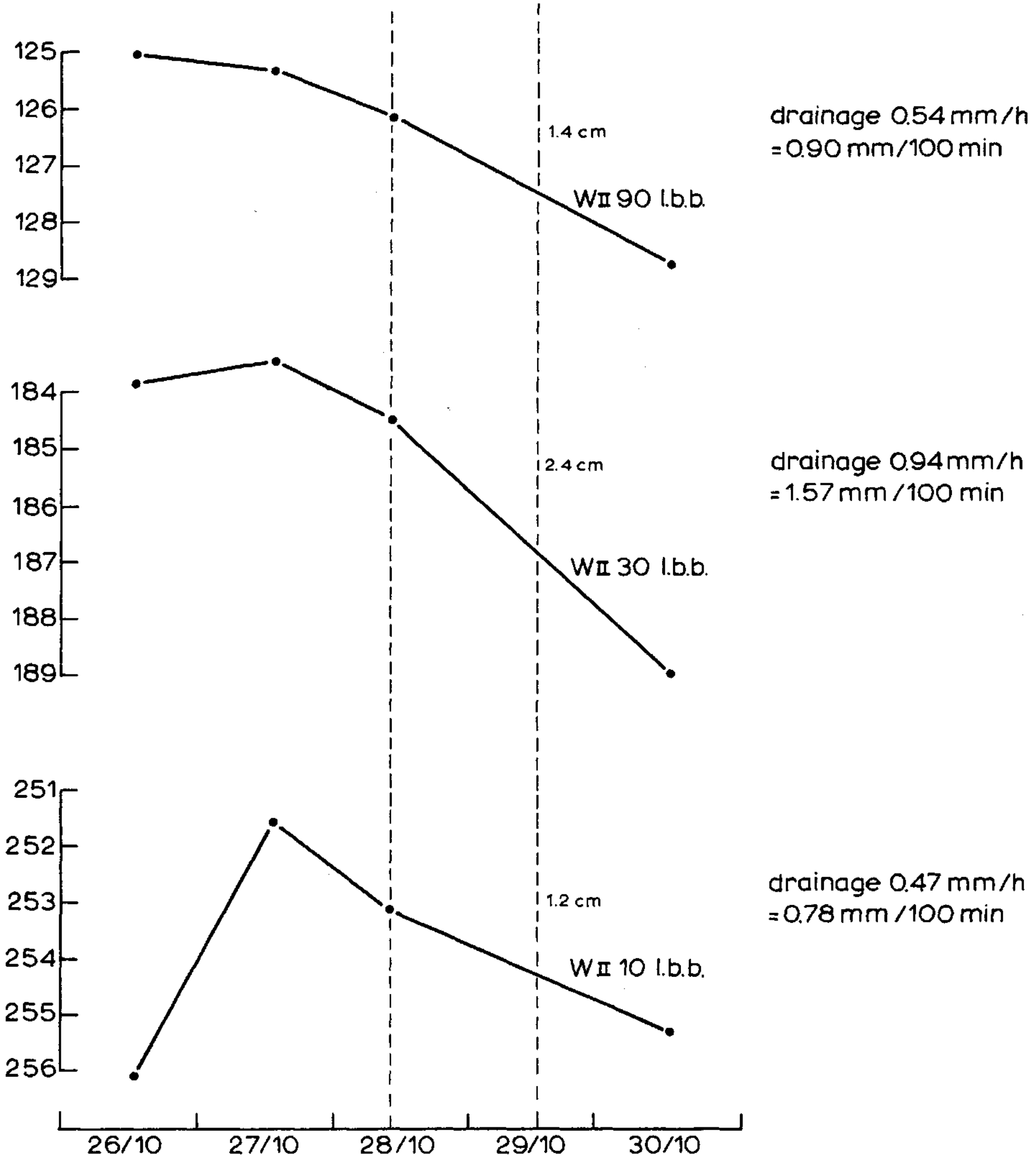
fig. 7

Pumping test "De Vennebulten"



Groundwater tables in the shallow observation wells before and after pumping
Pumping test "De Vennebulten"

fig. 8



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