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CONSTRUCTION AND USE OF SPECIAL DRAWDOWN SCALES FOR PREDICTING WATER-LEVEL CHANGES THROUGHOUT HEAVILY PUMPED AREAS

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Problem and Proposed Method of Solution

Frequently the Theis nonequilibrium formula is used in the quantitative analyses that are part of many ground-water investigations. The computations associated therewith may become quite involved and tedious, especially when dealing with predictions of the decline of water levels throughout large areas in which there are many discharging wells. The process of predicting future water-level declines can be greatly simplified and shortened by preparing a special drawdown scale for given conditions. Through use of such a scale much of the computation can be reduced to scaling the values sought from a map, on which the pumped wells have been spotted. The net drawdown effect, which is the sum of the water-level declines caused by the many individual pumped wells, can be determined readily for any desired point in the area. If the net drawdown effect at a number of points is desired, a summation of the effects of all the pumped wells can be repeated for each point. By determining the water-level change at a number of points, for a given period of time, a contour map of predicted water-level changes for the multiple-well system can be drawn.

General Description of Scale

The graduations on the finished special drawdown scale represent conveniently selected values of drawdown, in feet. They are placed, in descending order of magnitude, at the proper distances from the reference point. That this is the correct order may be verified by reflecting that the drawdown

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will be greatest at the pumped well (i.e., the reference point of the scale) and will decrease with increasing distance from the pumped well. The special drawdown scale should be identified by inscribing the values of T, S, Q, and t (see next paragraph) used in its preparation and by giving the map scale for which it is designed.

Preparation of the Drawdown Scale

In preparing the special drawdown scale the following information or conditions must be known, and for convenient reference the units commonly employed by the Geological Survey are also given:

T = coefficient of transmissibility, in gallons per day per foot

S = coefficient of storage, dimensionless

t = period of prediction; years if distance is in miles, or days if distance is in feet

Q = uniform rate of pumping of an individual well, in gallons per minute

In areas where wells are pumped for irrigation the unit "acre-feet per year" is quite convenient. If the prediction is to span a number of years, it is sometimes convenient to pick a value for Q such that a simple value results for the number of acre-feet pumped per year. Thus, a uniform discharge rate of 62 gallons a minute amounts to 100 acre-feet annually. The pumpage at individual wells can therefore be expressed in multiples of hundreds of acre-feet per year and the respective drawdown effects proportionally modified to take into account the many discharge rates that may be encountered in dealing with multiple-well systems.

With the foregoing information given, it is necessary to develop a plot of drawdown, s, in feet, versus distance, r, in miles (if t is in years), or feet (if t is in days). The procedure generally used in the New Mexico district is as follows:

1. Compute, with the aid of the Theis (1951) slide-rule drawdown scales, the drawdown factor, F (see also Theis, 1952), and then the drawdown, s, for various distances, r, arranging the results in form similar to that shown in the accompanying table.

2. Plot on semilogarithmic paper the drawdown, s, on the logarithmic scale, versus distance, r, on the arithmetic scale as shown in figure 1. Distance must be plotted to the same scale as that of the map on which the

Drawdown Factors and Drawdowns for Various Distances Under Conditions as Indicated

$T = 50{,}000$ gpd/ft.

$S = 0.1$

$Q = 62$ gpm (100 ac.-ft./yr.)

$t = 10$ years

$\frac{S}{T} = 2 \times 10^{-6}$

$\frac{Q}{T} = 12.4 \times 10^{-4}$

$s = \frac{Q}{T} F$

Distance, miles r	Drawdown factor F	Drawdown, feet s
0.2	711	0.882
.4	552	.690
.6	460	.570
.8	396	.492
1.0	346	.430
2	196	.244
3	118	.1464
4	71	.088
5	41	.0508
6	24	.0298
7	14	.0174
8	7.25	.0090
9	3.8	.0047
10	1.9	.00236
11	1.0	.00124

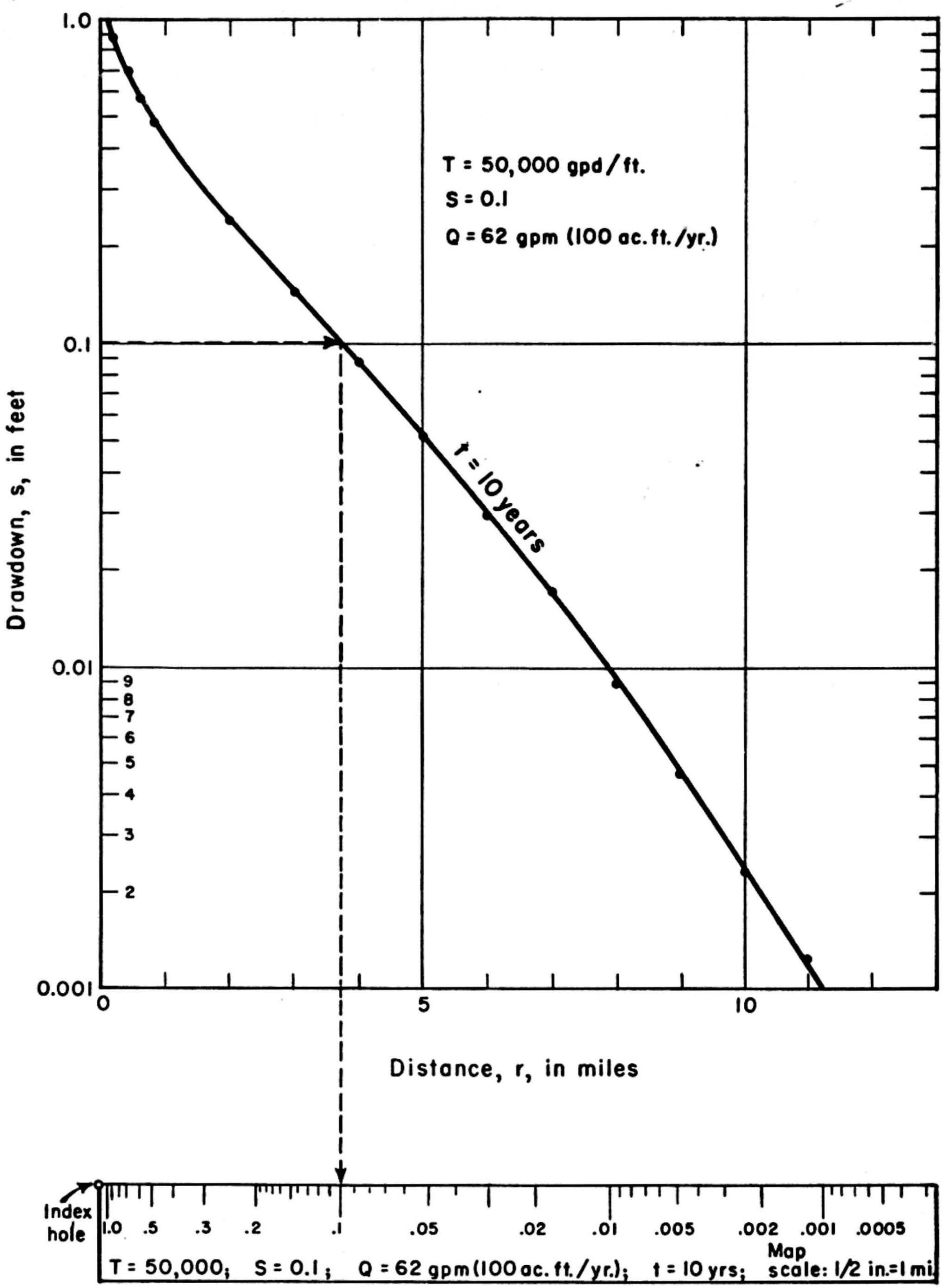

Figure 1-- Diagram of special drawdown scale constructed from graph of drawdown with conditions as given.

special drawdown scale is to be used. Note that this semilogarithmic distance-drawdown plot differs from the conventional type used in analyzing aquifer tests for the rather obvious reason that the end result sought here is an arithmetic scale of distance on which selected values of drawdown will be correctly positioned. Thus distance is plotted on the arithmetic rather than the logarithmic scale, and drawdown is plotted on the logarithmic scale to hold the plot to a reasonable size.

3. Draw a smooth curve through the points plotted on the graph. (See fig. 1).

4. Calibrate the special scale by marking off selected values for drawdown at the proper distances on the scale. This is accomplished by holding the special drawdown scale parallel to and exactly opposite the distance scale of the graph. To place a drawdown value of, say, 0.1 foot on the special scale, start at this value on the log scale of the graph (see fig. 1), and move horizontally to the plotted curve and vertically downward to the special map scale, marking the point thus found with the number 0.1. This is the drawdown expected, at the distance indicated on the graph, in response to the pumping of one well under the known conditions. The distance in miles (or feet) from the well being pumped to the point at which drawdown occurs need not be shown on the special drawdown scale.

5. Make a small hole in the special drawdown scale, at the index or reference point, through which a tack or other pointer can be inserted and held at the point on the map where the net drawdown effect of all pumping in the area is desired.

The drawdown scale can also be constructed directly by using the Theis slide-rule scales. The procedure involves computing the drawdown factor for each value of drawdown desired to be inscribed on the special drawdown scale, and then solving for the particular distance at which the drawdown occurs. This procedure is convenient if the Theis slide-rule scales are available but evidently requires a separate determination for each desired drawdown value. Furthermore, because of the wide spacing of graduations on the Theis slide-rule scales, the computed distances may differ slightly from those determined by the graphical method, which tends to smooth out irregularities inherent in the calculations.

Use of the Scale

With a tack or pin, place and hold the reference point of the scale over the first point on the areal map at which a net drawdown prediction is desired. Move the scale in a circle around the point, reading off and tabulating the drawdown value for each pumped well at its intersection with the scale. Multiply each of these values by the rate, in hundreds of acre-feet per year, at which each well is pumped or is expected to be pumped. The sum of all these adjusted values is the net drawdown prediction desired, based on the given or assumed conditions. The foregoing process can be repeated for each point on the map at which a drawdown prediction is desired.

By using an adequate number of points the drawdown predictions may be conveniently exhibited in the form of a contour map showing the expected lowering of water levels, throughout the area, over a designated period of time and for certain given or assumed conditions. In practice, the points selected for the drawdown predictions are at some distance from any pumped well to insure that the results are as realistic as possible.

If a boundary or boundaries are present the appropriate system of image wells can be plotted on the areal map and the foregoing procedures followed. The effect of each image well will be added or subtracted, depending upon the type of boundary, in determining the net drawdown effect.

A Practical Application of the Scale

Figure 2 is a map of the Animas Valley, New Mexico, where practical application has been made of the special drawdown scale. All the irrigation wells for which permits have been granted are shown on the map. It was desired to know the future decline of the water level throughout the area as a result of pumping these wells. The points shown as triangles in fig. 2 were arbitrarily established on what is primarily a 3-mile grid, and the drawdown was determined at each of these points for the end of a 10-year period in which normal water consumption or crop requirements was assumed. The index point of the scale was held at one of the selected points on the map. As the scale was revolved around the point to each pumped well, the respective drawdown effects were read off and tabulated. As a steady discharge of 62 gallons a minute (100 acre-feet a year) was used in the construction of the special scale, the individual drawdown effects were adjusted through multiplication by the number of hundreds of acre-feet each pumped well is expected to deliver annually. In this example the forecasts on pumping rates were based on water permits. For each selected point on the map the individual drawdown effects were totaled and plotted. The plotted values are the declines, assuming an areally extensive aquifer. However, as shown on figure 2, there are two boundaries across which no recharge occurs.

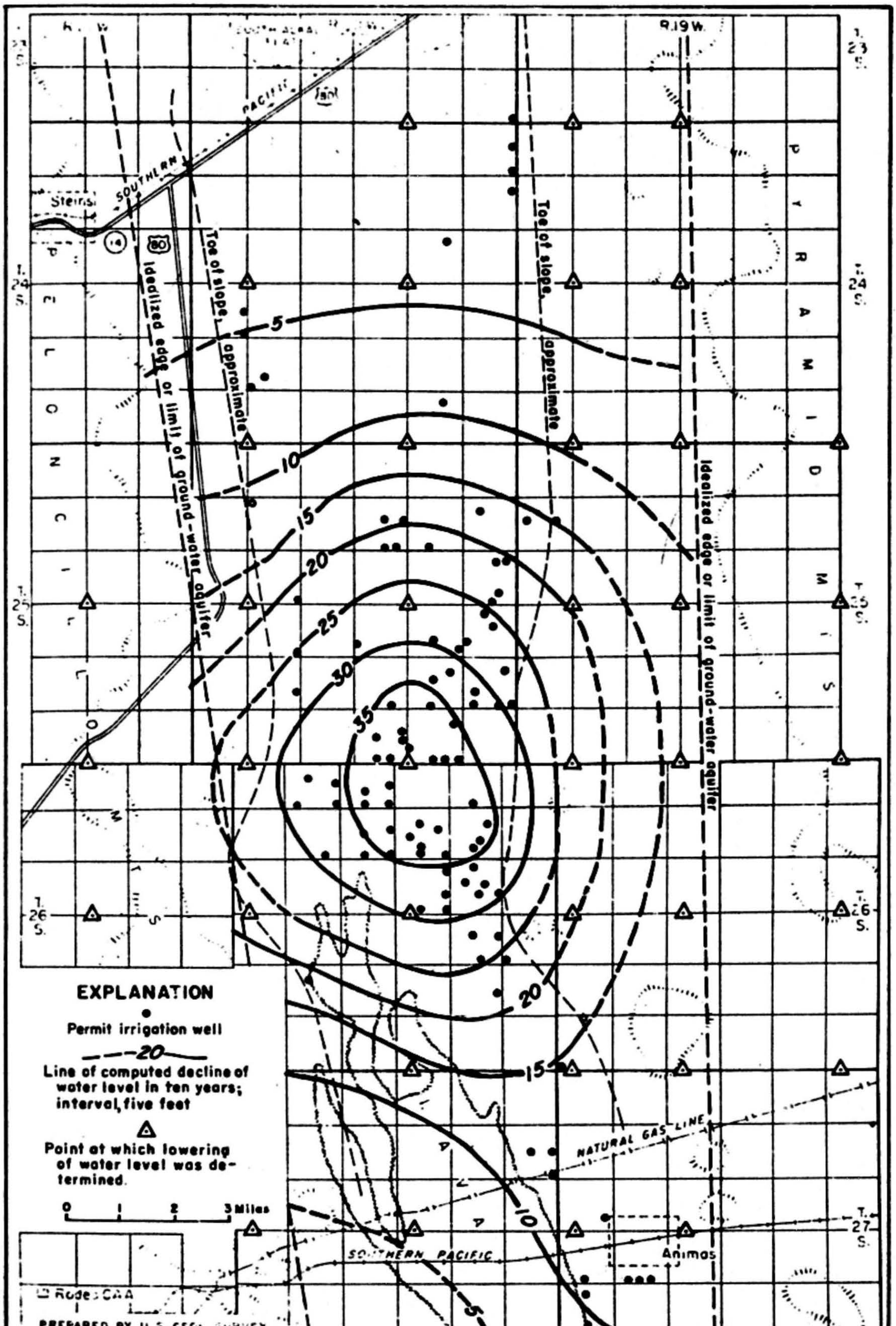

Figure 2.-- Computed lowering of the water table in 10 years (1948-58) in the Lower Animas Valley, Hidalgo County, N. Mex.

The real pumped wells were reflected across each boundary to establish two systems of image wells. This can be done simply by folding over at each boundary a transparency print of figure 2, thus eliminating the need for replotting all the real wells. The drawdown effects from the image wells were determined for each of the selected points on the map, using the method previously described, and added to the previously plotted value. Drawdown contours were then sketched in to show graphically the predicted water-level changes throughout the area. Successive reflection of the image wells, beyond the first set of images, was not necessary in this example although in other problems it might be mandatory. If one of the boundaries had been a recharge boundary, the water-level changes caused by the image wells opposite that boundary would have been subtracted from those of the real wells.

Possibly a simpler method of dealing with boundaries, especially if the position of the boundary is uncertain, is to consider the aquifer as areally extensive. The drawdown effects can be determined beyond the boundary as if no boundary were present. After the drawdowns due to the real wells are plotted on the map, and contours drawn, the map can be folded at the best estimated position of the boundary or boundaries. The drawdown contours on the folded portion or portions of the map will then be superposed on the contours on the remaining part of the map. By algebraically adding the several sets of contours, in accord with the recognized nature of the boundary or boundaries, a new set of contours may be drawn to show the resultant water-level changes. The primary advantage of this method is that the position of the boundary can be shifted, if necessary, after the computations are made and the water-level changes caused by the new positions of the image wells need not be recomputed. The sets of drawdown contours, properly superposed by refolding the map, need only to be added (or subtracted) again and a new resultant set of contours drawn.

Conclusion

Although only one practical application of the special drawdown scale has been described, it should be obvious that there will be numerous other kinds of field problems where its use would prove helpful. Thus, in many problems involving aquifer boundaries that are to be analyzed by systems of multiple image wells the special scale should offer a short-cut method for summing the various drawdown or buildup effects.

Correct use of this method is, of course, contingent upon most of the same assumptions inherent in the Theis non-equilibrium formula (see Theis, 1935).

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