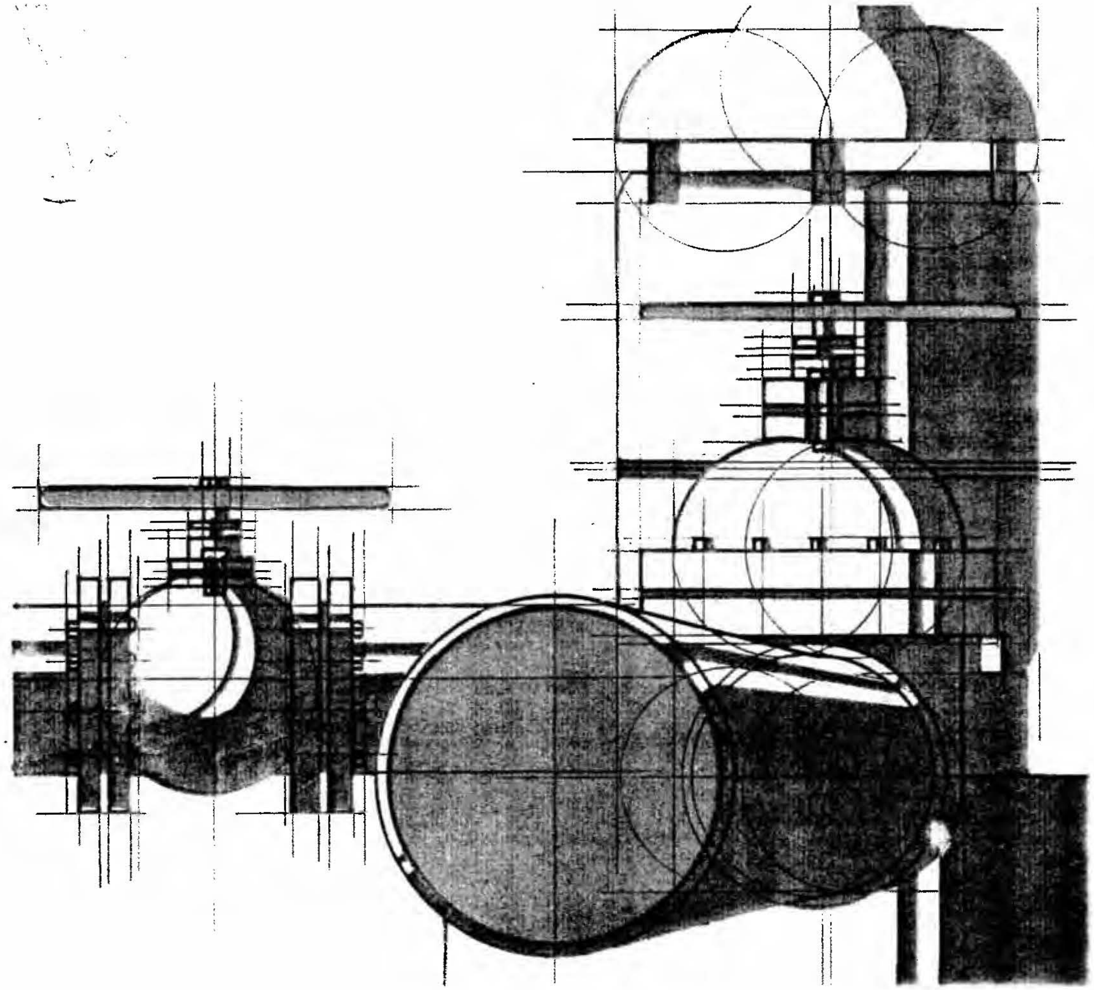

# THE PUMPED WELL

## TECHNICAL BULLETIN 100

# THE PUMPED WELL

by

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# THE PUMPED WELL

## Foreword

Pumping for Irrigation has developed steadily in Colorado since 1930. Many wells have been installed in the Arkansas Valley, the South Platte valley and its tributaries and in the High Plains area in the eastern part of the state. Records indicate that during 1966, 116,383,652 kilowatt-hours of electrical power were being supplied to pumps in the South Platte River Basin. Corresponding figures for the Arkansas River basin and the High Plains area are 15,035,285 and 15,789,065 KWH. The San Luis valley consumed 27,634,980 KWH and Grand Valley an additional 452,394 KWH. The grand total is 175,295,349 KWH.

Although variations in lift and pump efficiency require differing amounts of energy to lift water to the surface, an average of 100 kilowatt-hours per acre foot may be used to get some idea of the amounts of water pumped.[1] On this basis about 1,750,000 acre-feet were lifted by electrically driven pumps during 1966. Additional water was lifted by pumps driven by gasoline engines, diesel engines and engines using natural gas.

The average annual surface water supply to the South Plattey valley is about 1,200,000 acre-feet per year. On the Arkansas River the average flow at Nepesta based upon 47 years of records, is 506,100 acre-feet per year. Infiltration from precipitation is estimated to supply 430,000 acre-feet per year to the ground water in the High Plains area. A comparison of these figures will indicate that the water now lifted by pumps each year is comparable with the natural surface water supplies which, in an earlier era, supplied all of the irrigation water used in the state.

The use of pumps has not only brought benefits but also problems. The natural water supplies of the state are now heavily encumbered. Of the approximately 1,200,000 acre-feet per year of natural surface water supply to the South Platte valley only about 300,000 acre-feet per year pass out of the state unused. The remainder is consumed. The question has been raised as to whether the pumps, drawing water from aquifers where the water table is in contact with a stream, are depleting the streams to the detriment of surface water users dependent on these sources of supply. In the High Plains area the question is asked, "how much water can safely be pumped?" Other questions arise. For example: If this safe limit is exceeded will a "boom and bust" era be initiated? Of the estimated natural recharge in the High Plains area how much can be recovered for use on a permanent basis? Are falling water tables to be expected and if so where should a prospective well owner set his pump so that he may expect it to yield water for at least a long enough period to get the pump paid for? Does a falling water table in the High Plains area mean that the ground water is being exhausted?

Before answers to such questions can be obtained, it will be necessary to assess quantitatively the effect of existing factors or proposed changes. The charts presented herein provide a means for making such estimates. They are presented in generalized form so that their use can be adapted to a specific situation, and their use is illustrated by worked examples. References are given from which more detailed data can be obtained if desired.

## Idealizations

Any attempt to develop useful formulas must be based upon a definite concept of the situation to which the formulas are to apply. Such a concept is called an idealization. The nature of mathematical processes will favor simple, regular boundaries and uniform conditions. The treatment of the pumped well which produced the relations shown on figure (1) is based, for example, on the concept of an infinitely wide aquifer having everywhere a uniform intial saturated depth D and uniform properties as expressed by the constants K and V. An initially level water table is also assumed as well as a completely uniform withdrawal rate as expressed by a constant value of Q.

Real aquifers do not, of course, have such mathematical perfection. They were laid down by erratic processes and variations of texture and saturated depth are the rule rather than the exception. They are always of finite dimensions but until the disturbances produced reach the boundaries they will behave as though they were of infinite extent.

The relations of figure (2) are similarly based upon the concept of a homogeneous isotropic aquifer of uniform depth extending away from the stream for a very great distance. The stream is also supposed to follow a perfectly straight course. The developments of figures (3), (4) and (5) relate to a valley of uniform width L with the stream following the middle. The developments of figure (6) again are based upon the concept of a uniform, homogeneous, isotropic aquifer that extends to great distances in all directions.

Correct application of a formula must be the responsibility of the user. It is his task to assess the character of the situation he has to deal with and then to select an idealization which is appropriate.

His efforts will often be plagued by lack of data and conditions which are represented only imperfectly by the idealizations for which he possesses formulas. Field tests can be used to determine whether an idealization is effective. If large discrepancies between computed and observed results are found it may well indicate that the idealization being used is not appropriate.



**Definitions, explanations and notations**

Although pertinent notations are shown on most of the graphs a few words of explanation will be helpful. The charts are all prepared for use with consistent units. A consistent unit usage permits only one unit of a kind. In all the examples foot and second units are used, and all quantities must be expressed in these two units. For example: flow quantities must be expressed in cubic feet per second. Data expressed in gallons per minute for example will need to be converted to the foot-second unit system before the charts are entered. Conversion factors are given for units in common use which do not conform to the above choice. The following notation is used:

- D — an initial saturated depth (feet)
- h — a remaining drainable depth (feet)
- i — an infiltration rate (ft/sec)
- K — permeability (ft/sec)
  Permeability is defined as the quantity of water which will flow through a unit area of the aquifer under the action of a unit gradient.
- L — the width of a river valley (See fig. 5) (feet)
- Q — the flow of a well (Cubic feet per second)
- r — radius (feet)
- s — drawdown produced by pumping a well (feet)
- t — time (seconds)
- V — the effective voids ratio of the material in an aquifer.
  It expresses the volume of water which will drain out of an initially saturated volume of the aquifer. It is a dimensionless quantity representing the ratio of the drainable volume to the volume from which it is drained.
- x — distance of a well from a stream (feet)
- $\alpha$ — (alpha) the aquifer constant, ($ft^2/sec$)
  It specifies how rapidly transient changes will take place.
  This constant is defined by the relation $\alpha = \frac{KD.}{V}$
- (KD) — This product of the permeability and saturated depth specifies the ability of an aquifer to transmit water.
  the units are: ($ft^2/sec$) The transmissivity.
- $\pi$ — $= 3.1416$

**Conversion factors and equivalents**

The following factors can be used to convert some commonly used units to the chosen foot-second system.

| *To convert* | *to* | *multiply by* |
|---|---|---|
| gallons per minute | cubic feet per second | .002228 |
| Meinzer's unit (permeability) | feet per second | $1.5472(10)^{-6}$ |
| Meinzer's unit (transmissivity) | feet squared per sec. | $1.5472(10)^{-6}$ |
| Acre feet | Cubic feet | 43560 |
| Cubic feet per second | gallons per minute | 448.8 |

| | | |
|---|---|---|
| One year (365 days) | seconds | 31536000 |
| One month (1/12 year) | seconds | 2628000 |
| One day | seconds | 86400 |

A township has an area of 23,040 acres or 1003.62 x $10^6$ square ft.
A section has an area of 640 acres or $27.8784(10)^6$ square feet.

**Aquifer properties**

South Platte valley[1] (Average of 3 determinations)
D = 67.(ft) KD = 0.270(ft²/sec) V = 0.17 $\alpha$ = 1.58(ft²/sec)

Arkansas valley[7] (Average of 19 determinations)
D = 22. (ft) KD = 0.127(ft²/sec) V = 0.20 $\alpha$ = 0.64(ft²/sec)

High Plains[3]—Kit Carson County (Average of 17 determinations)
D = 120.(ft) KD = 0.120(ft²/sec) V = 0.15 $\alpha$ = 0.80(ft²/sec)

Yuma County (Average of 22 determinations)
D = 128.(ft) KD 0.164(ft²/sec) V = 0.15 $\alpha$ = 1.09(ft²/sec)

## Drawdowns produced by pumping a well

The drawdown s produced by a well pumped at the rate Q can be estimated by use of figure (1). If the drawdown is not small when compared to the original saturated depth the quantity $\sigma$ (sigma) as defined on the chart will be needed. The manner of using the chart will be illustrated by means of examples.

**Example 1**

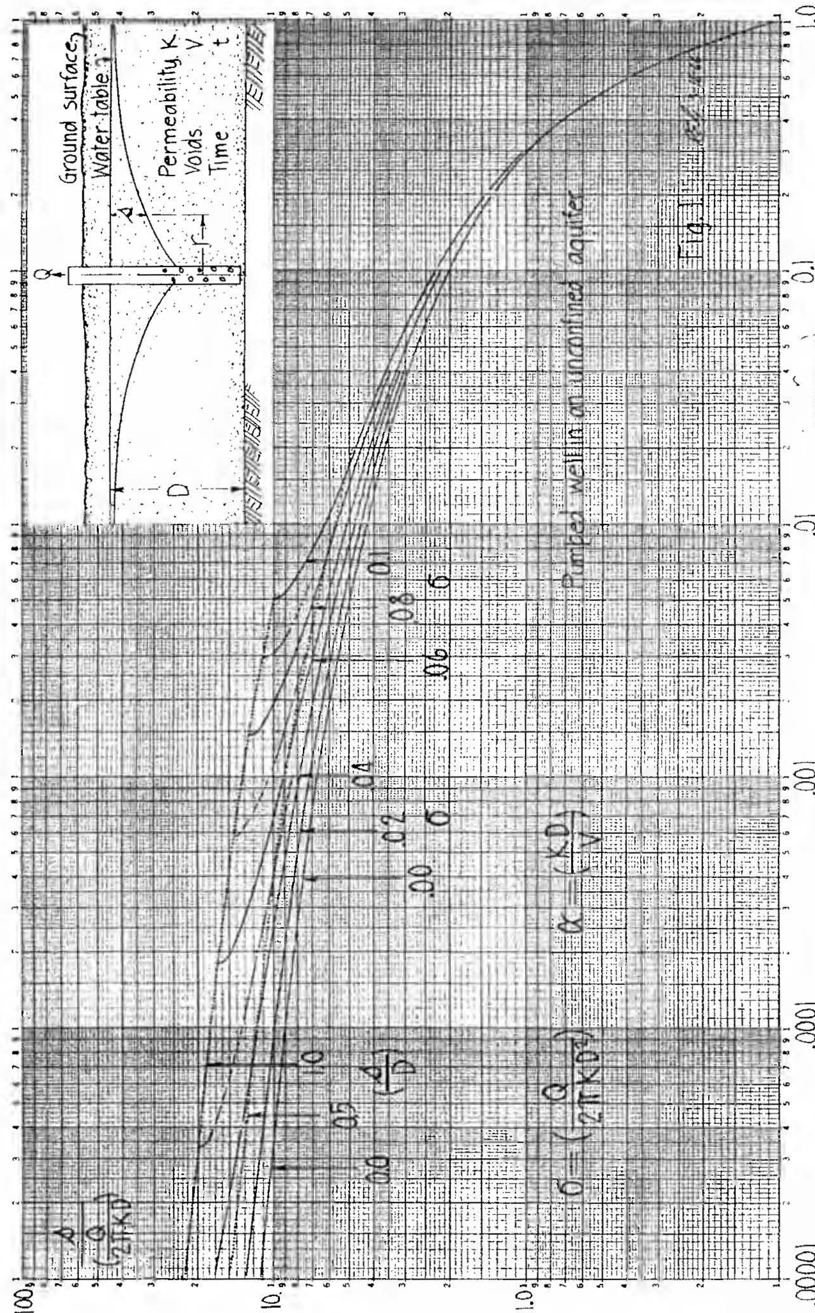
Two farmers A and B own wells a quarter of a mile apart. The well owned by A produces a flow of 975 gallons per minute. It is desired to estimate the drawdown produced by operation of A's well on the elevation of the water table at B's well after A's well has been operated for 120 days. The aquifer transmissivity is given as 142000 Meinzer units. The effective voids ratio also described as the "storage coefficient" or "specific yield" is given as 0.173. The saturated thickness is 60 feet.

**Solution**

The transmissivity is KD = $(142000)(1.547)(10)^{-6}$ = 0.220(ft²/sec.)
120 days is (120)(86400) = 10368000 or $10.368(10)^6$ seconds.
975 gallons per minute is (975) (002228) = 2.172 (ft³/sec.)
One quarter of a mile is 1320 feet.
Then

$$Q = 2.172 \text{ cubic feet per second.}$$
$$t = 10.368(10)^6 \text{ seconds.}$$
$$\alpha = \frac{KD}{V} = \frac{0.220}{0.173} = 1.272 \text{ (ft}^2\text{/sec.)}$$
$$\sqrt{4\alpha t} = \sqrt{(4)(1.272)(10.368)(10)^6} = 1000\sqrt{52.752} = 7263.$$
$$\frac{r}{\sqrt{4\alpha t}} = \frac{1320}{7263} = 0.1818$$





From the chart of figure (1) $\dfrac{s}{\left(\dfrac{Q}{2\pi KD}\right)} = 1.44$

$$\left(\frac{Q}{2\pi KD}\right) = \frac{2.172}{(2)(3.1416)(0.220)} = \frac{2.172}{1.3823} = 1.572$$

Then

$$s = \left(\frac{Q}{2\pi KD}\right)(1.44) = (1.572)(1.44) = 2.26 \text{ feet.}$$

It can be estimated, then, that the operation of A's well will lower the water table at B's well by 2.26 feet after it has been operated for 120 days. This result is appropriate if all of the water pumped is consumed. A discussion of water balance in irrigated areas is given later in the paragraph on comments.

**Example 2**

If A's well is gravel packed out to a radius of 1.25 feet from the center of the well how much drawdown can be expected at this radius after the 120 days of pumping?

**Solution**

$$\frac{r}{\sqrt{4\alpha t}} = \frac{1.25}{7263} = .000172$$

A relatively large drawdown can be expected at this radius so a value for $\sigma$ will be needed

$$\sigma = \frac{Q}{2\pi KD^2} = \frac{1.572}{60} = 0.0262$$

From figure (1) $\dfrac{s}{\left(\dfrac{Q}{2\pi KD}\right)} = 9.80$

Then the estimated drawdown at the outside of the gravel pack can be estimated to be

$$s = \left(\frac{Q}{2\pi KD}\right)(9.80) = (1.572)(9.80) = 15.4 \text{ feet.}$$

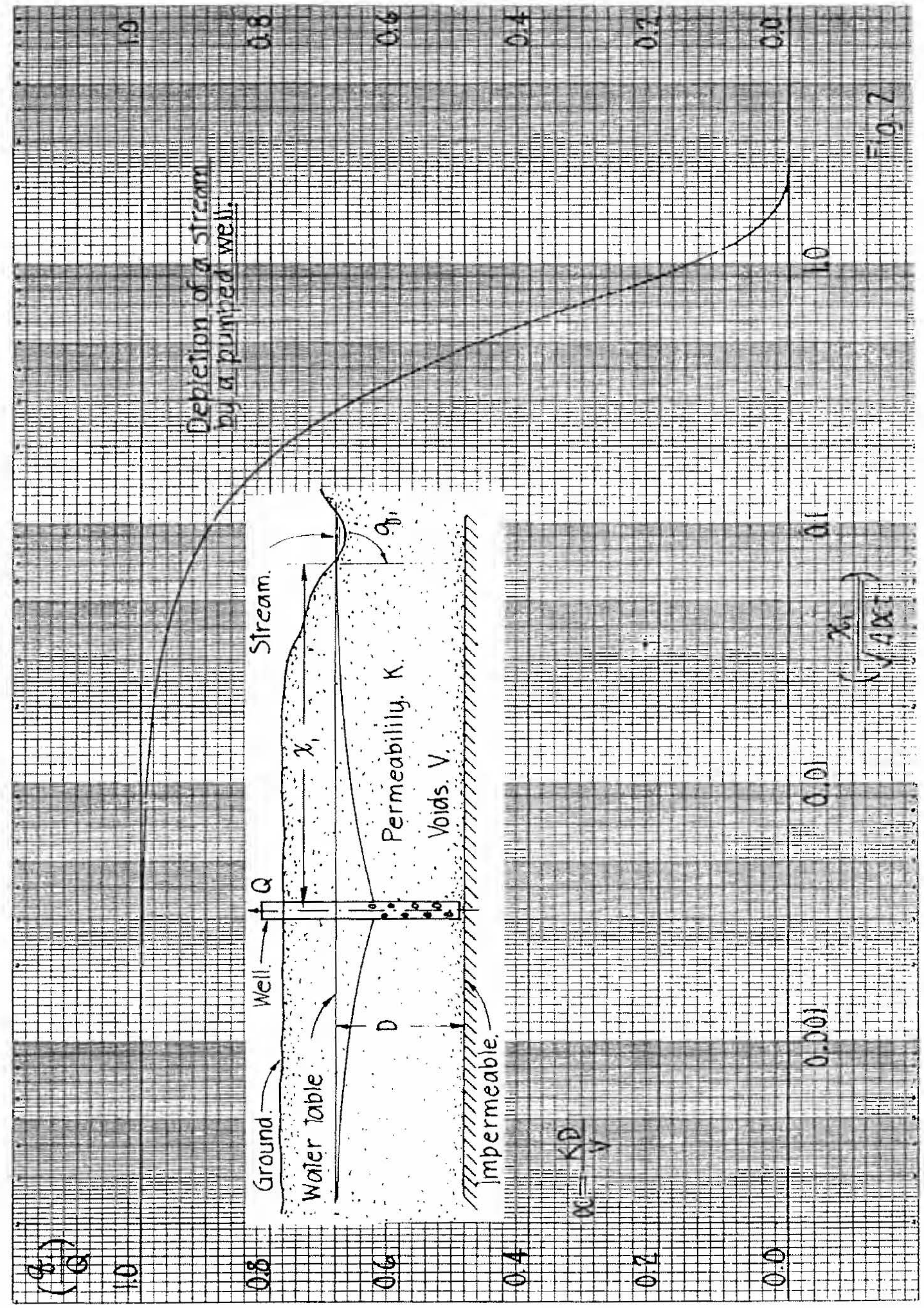
**Stream depletion caused by a well**[9]

The chart of figure (2) can be used for estimating the effect of a well on a nearby stream. If the well is to deplete the stream the stream must run over the top of the aquifer from which the well draws water and be in contact with the ground water in the aquifer.

**Example 3**

Suppose A's well is located one mile away from a stream. How much will it deplete the stream after it has been operated for 120 days?





**Solution**

The distance from the stream is $x_1 = 5280$ feet

Then

$$\frac{x_1}{\sqrt{4 \alpha t}} = \frac{5280}{7263} = 0.727$$

From figure (2)

$$\frac{q_1}{Q} = 0.30$$

Then the stream depletion after 120 days of operation is

$q_1 = (0.30)(Q) = (0.30)(2.172) = 0.65$ cubic feet per second.

This is equivalent to:

$(0.65)(448.8) = 292$ gallons per minute. This estimate is appropriate if all the water pumped is consumed.

**Intermittent pumping**

Pumps used for irrigation are operated during the growing season and left idle during the winter. The stream depletion due to operation of the well does not, however, cease at the moment the well is shut down. A "cone of depression" has been created by operation of the well, and gradients are still present to influence the movements of the ground water. The mathematically proper way to handle the computations for a situation of this kind is to first assume that the original pumping continues, but that at the time of shut down a recharge sufficient to nullify the flow of the well is put into operation. After the shut down is made the effect of the well is to be computed as the sum of the effects of pumping and recharge.

**Example 4**

To illustrate this procedure suppose that the well is shut down at the end of September and we wish to know what the stream depletion due to it will be six months later at the end of March. Before the well was shut down it had been operated 120 days. From the time of shut down to the end of March is 182 days. Then the pumping time will be $120 + 182 = 302$ days and the assumed recharge will have been in operation 182 days. Then the pumping time is $(302)(86400) = 26092800$ seconds and the recharge time is $(182)(86400) = 15724800$ seconds. The corresponding values of $\frac{x_1}{\sqrt{4 \alpha t}}$ are: $\frac{5280}{11522} = 0.458$

$$\frac{5280}{8944} = 0.590$$

The corresponding q/Q values from fig. (2) are 0.52 and 0.40

The depletion is then $2.172(0.52 - 0.40) = 0.26$ cubic feet per second or 117 gallons per minute. This figure is appropriate if all the pumped water is consumed so that none returns to the water table.



The stream depletion caused by this well will still be occurring during the next growing season. The procedure used here is proper for all cases of intermittent operation.

The computation procedure used here is appropriate if the aquifer extends far beyond the well. The methods for making modifications if the aquifer terminates against an impermeable member, such as the Pierre Shale, will be described later.

**Distributed pumping**

If an area has many wells the effect of each well could be treated by the method just described and the results could be added to evaluate their overall effect. This process could become tedious, however, because of the amount of arithmetic required. It may then be much easier to idealize the situation as being one of uniformly distributed pumping. The pumping distributed over the area will be represented by the symbol $Q_2$. Figure (3) may be used to make an estimate in such cases. The idealized cross section shown on the figure represents a river valley of width L with the river in the middle. The aquifer, in this case, is terminated at the bottom and both sides by an impermeable formation. Along the South Platte the Pierre Shale, the Fox Hills and the Laramie formations provide such relatively impermeable barriers. If the river is not in the middle, each side can be considered separately with appropriate adjustments of L. As an example of the use of this chart the pumping which, in example 3 was one mile from the river, will be distributed over a valley four miles wide with the river in the middle. In this case the average distance of the pumps from the stream will be one mile also. For this reason a substantial agreement might be expected.

**Example 5**

An amount of pumping totaling 2.172 cubic feet per second is distributed over the 4-mile width of a valley having a river in the middle. It is desired to estimate the stream depletion due to the operation of these pumps for a period of 120 days. The aquifer properties are the same as for example 3.

**Solution**

4 miles is 21120 feet.

$$\frac{\alpha t}{L^2} = \frac{(1.272)(10368000)}{21120^2} = \frac{13188100}{446054400} = 0.0296$$

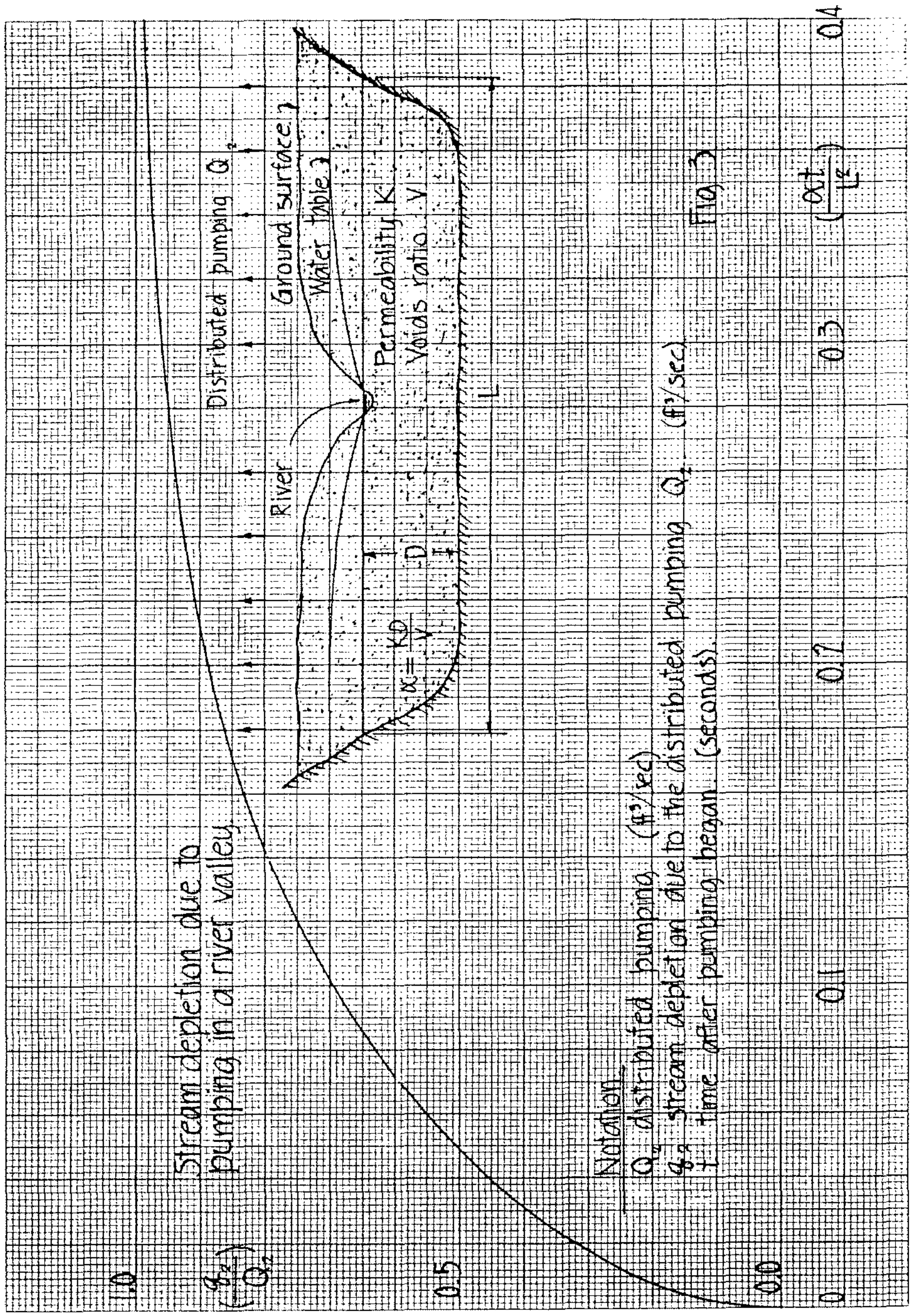
From the chart of figure (3) $q_2/Q_2 = 0.39$

(This compares with the value 0.30 obtained in example 3. In the present case the valley is of limited width whereas in example 3 the valley was assumed to be of unlimited width)

Then the depletion is

$q_2 = (2.172)(0.39) = 0.85$ cubic feet per second or 380 gallons per minute

if all of the pumped water is consumed.






### Example 6

In this example the effect of the pumping for 120 days, ending at the end of September, on the stream depletion at the end of the succeeding March will be estimated. The aquifer properties will be the same as for example 3.

For 302 days of pumping

$$\frac{\alpha t}{L^2} = \frac{(1.272)(26092800)}{446054400} = .0744$$

For 182 days

$$\frac{\alpha t}{L^2} = \frac{(1.272)(15724800)}{446054400} = .0448$$

From the chart of figure (3) the corresponding values of $q_2/Q_2$ are 0.602 and 0.475. Then at the end of March there will still be a depletion of the stream of 2.172(0.602 — 0.475) = 0.28 cubic feet per second or 124 gallons per minute even though the pumps have been shut down for 6 months. The comparable figure for example 4 is 0.26 cubic feet per second or 117 gallons per minute if all of the water pumped is consumed.

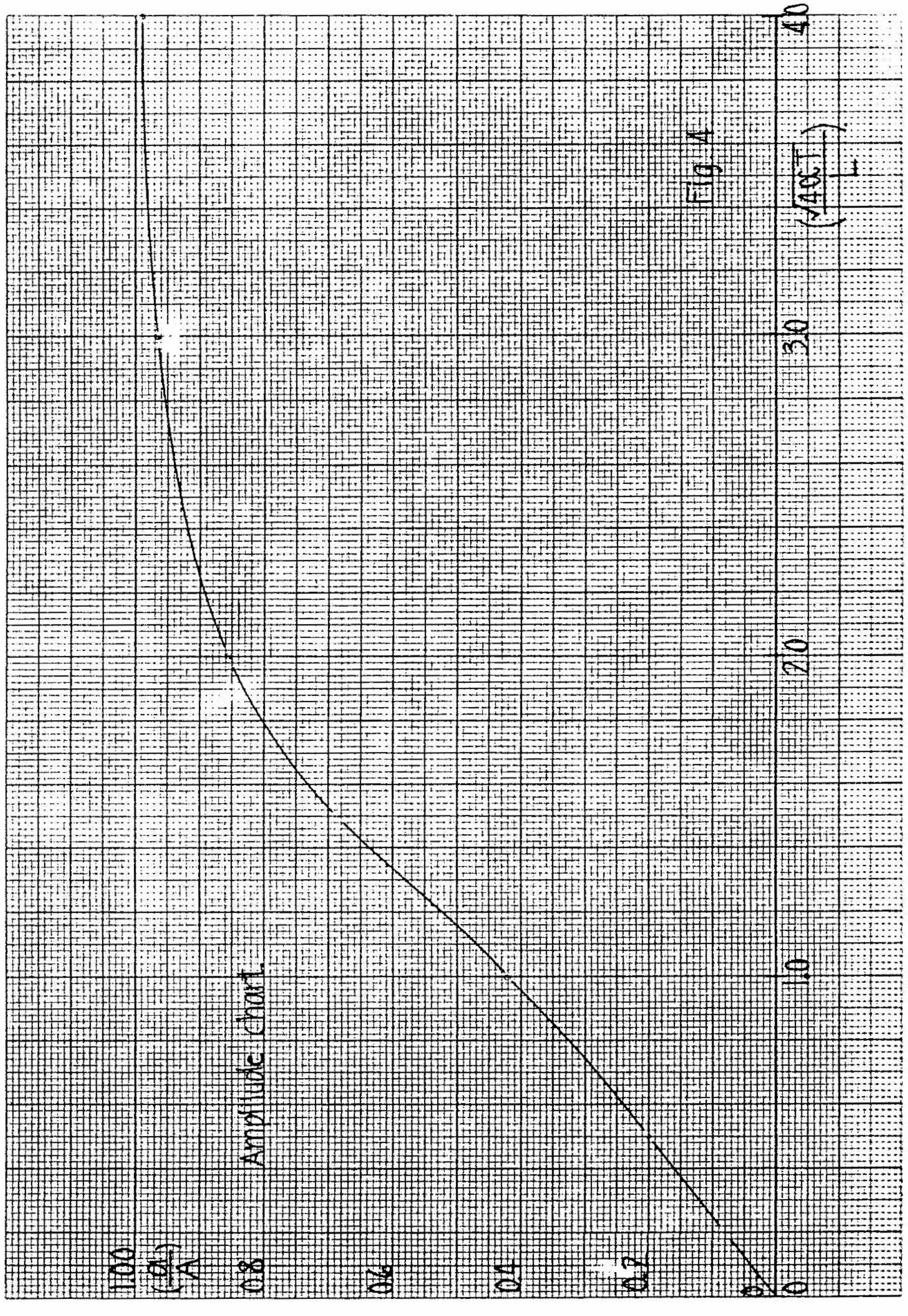
### Seasonal variations of depletion rates due to distributed pumping

If data are available to define the pattern of pumping throughout the year and to fix the amount of water consumed, estimates of the seasonal variations of stream depletion can be made by the methods previously described, but the amount of computation required would make the task a tedious one. The charts of figures (4) and (5) make this approach unnecessary. The consumption of water by pumps can be idealized as an average rate upon which a seasonal variation is superimposed. The seasonal variation reduces the consumption of water to zero about the middle of January and doubles the average rate at about the middle of July at the peak of the irrigation season. This variation has an amplitude equal to the mean as shown on figure (5). The amplitude of the seasonal variation of stream depletion a is expressed in terms of the amplitude of the pumping pattern variation A.

The relationship is shown on figure (4). The symbol T represents the period, which is a year in our case. The chart of figure (5) shows the lag of the seasonal depletion variation in terms of the irrigation pattern seasonal variation. An example will illustrate the method of using this chart which implies a distributed pumping over a valley width L as shown on figure (5).

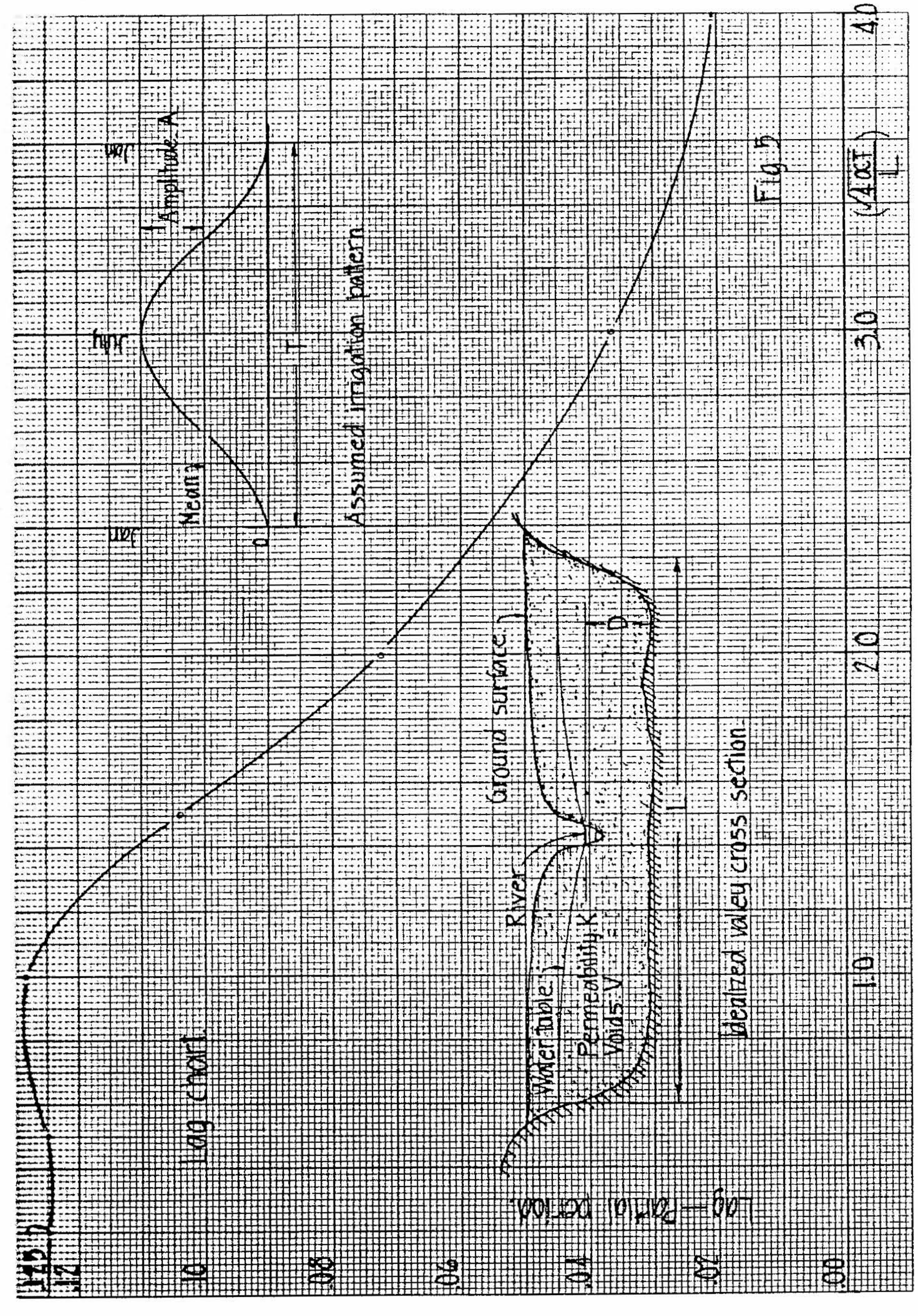
### Example 7

Pumping of water from many wells is practiced in a valley four miles wide. The aquifer properties are as in example 1. The number of wells being pumped is large enough to justify the idealization that the pumping is distributed uniformly over the valley area. It is desired to estimate the



Amplitude chart.
Fig. 4
1.00
(a/A)
0.8
0.6
0.4
0.2
0
1.0
2.0
3.0
4.0
(√4αT / L)



Lag chart
Fig. 5
Assumed irrigation pattern
Mean
Amplitude A
T
Idealized valley cross section.
Ground surface
River
Water table
Permeability K
Voids V
D
L
Lag—Partial period
.12
.10
.08
.06
.04
.02
.00
1.0
2.0
3.0
4.0
(√4αT / L)

amplitude a of the seasonal depletion variation and its lag with respect to the pumping variation if the amount of water lifted by the pump is 120,000 acre-feet per year.

**Solution**

$$\frac{\sqrt{4\,\alpha\,T}}{L} = \frac{\sqrt{(4)(1.272)(31536000)}}{21120} = \frac{12667}{21120} = 0.600$$

From figure (4) the ratio $\frac{a}{A} = 0.24$

From the figure (5) the lag is 0.125 period

120,000 acre-feet per year is equivalent to 165.8 cubic feet per sec.

This is the average annual rate. The amplitude of the pumping pattern variation must be equal to this so that $A = 165.8(\text{ft}^3/\text{sec})$.

The amplitude of the stream depletion variation is:

$$a = 0.24A = (0.24)(165.8) = 39.8\ (\text{ft}^3/\text{sec})$$

The lag is $(12)(0.125) = 1.5$ months.

Then if all of the pumped water is consumed the average stream depletion would be 165.8 cubic feet per second and the amplitude of the seasonal variation would be 39.8 cubic feet per second. The lag is 1.5 months. Then if the pumping reaches its peak at the middle of July the stream depletion would reach its peak about the first of September when it would be $165.8 + 39.8 = 205.6(\text{ft}^3/\text{sec})$. The minimum depletion would come 6 months later at about the first of March when it would be $165.8 - 39.8 = 126.0$ cubic feet per second. In comparison, the pumping pattern would reach a peak of $(2)(165.8) = 331.6$ cubic feet per second at the middle of July and fall to zero by the middle of January.

These computations have been made on the basis that all of the pumped water is consumed. Actually only a part of the pumped water is consumed and the remainder returns to the water table. Only the consumed part contributes to the stream depletion. Some further studies are needed to fix the ratio of the consumed to the applied water. This ratio depends upon the soil type being irrigated, the crop and the method of irrigation. Precipitation also is a factor. In the South Platte Valley with its light soils and with furrow irrigation this ratio may be as low as one-fourth. The above factor is to be applied to the irrigation water. On this basis the actual maximum and minimum depletions would be reduced to

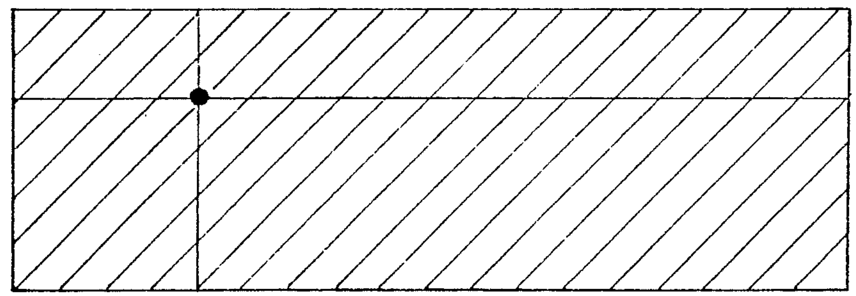
$$205.6(0.25) = 51.4\ (\text{ft}^3/\text{sec}) \text{ and } (126.0)(0.25) = 31.5(\text{ft}^3/\text{sec}).$$

**Pumping distributed over a rectangular area**

In the High Plains area,[3,4] pumps draw water from an aquifer recharged from precipitation and the aquifer may not be in effective contact with a stream. In such an area the level of the water table at some individual well can be influenced by the other wells in the area and these may be so numerous that computation of their individual effects would be burdensome even though data could be obtained to provide a basis for the

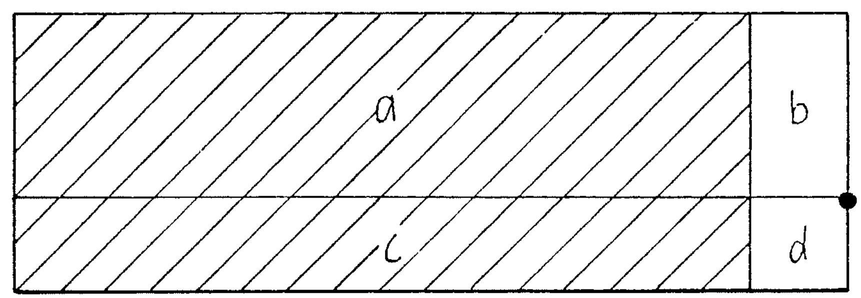


computations. It can be expected, however, that data on the numbers of wells, their distribution and total amounts pumped will be obtainable. The idealization of pumping distributed over the area can be used to advantage here to shorten the computation work and to use the type of data which will generally be available. The chart of figure (6) has been prepared for this purpose. The drawdown is computed at the corner of a rectangle. An area, either rectangular or irregular can generally be approximated closely enough by a series of rectangles to permit the computation to be easily made. Drawdown at points either inside or outside of a rectangular area can be estimated by the arrangements shown on the three following sketches. The shaded part represents the pumped area. Drawdowns are to be computed at the point marked by the black circle.



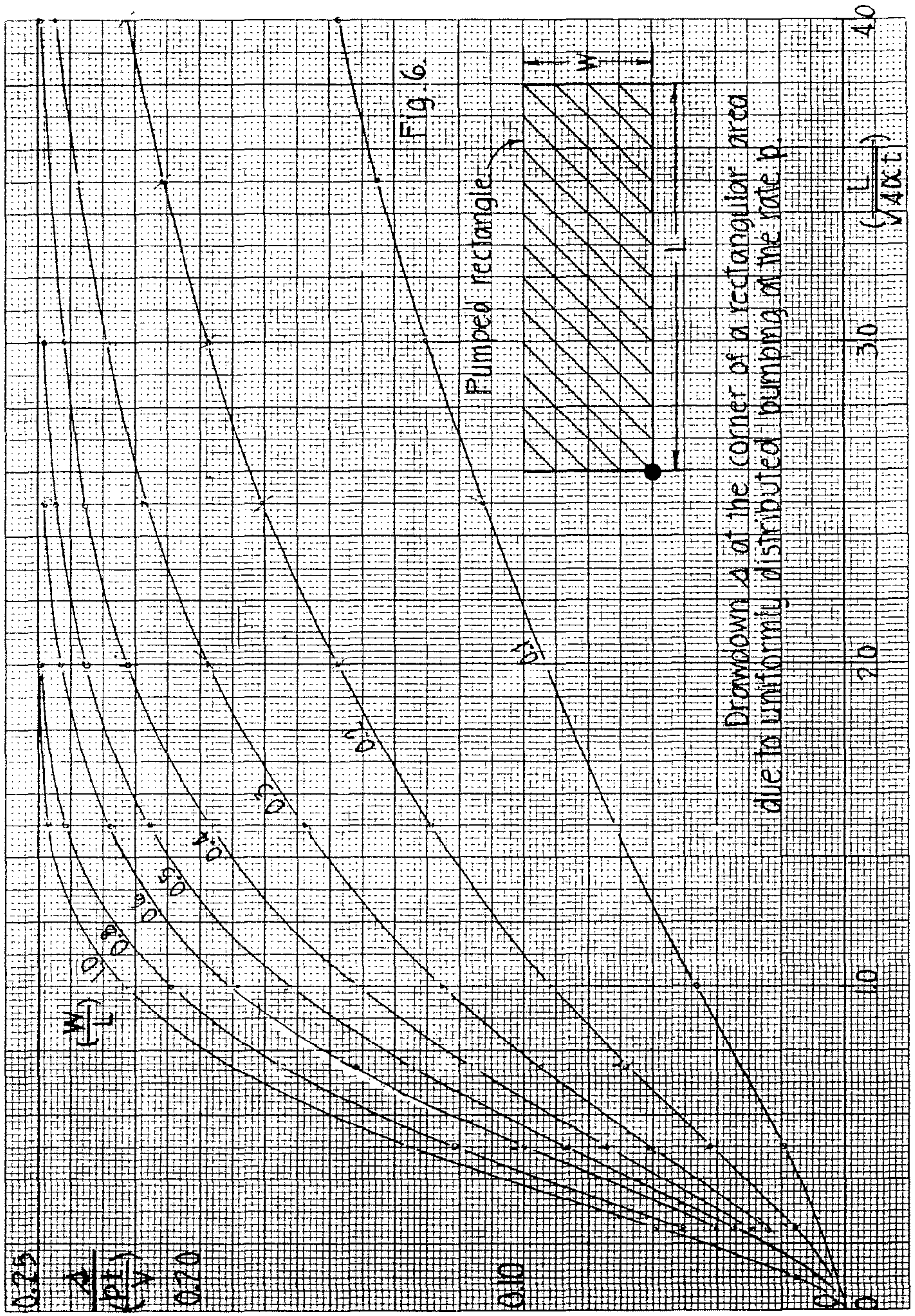
Point inside the area.

Procedure: Divide the area into four rectangles. Compute the drawdowns due to each and add.

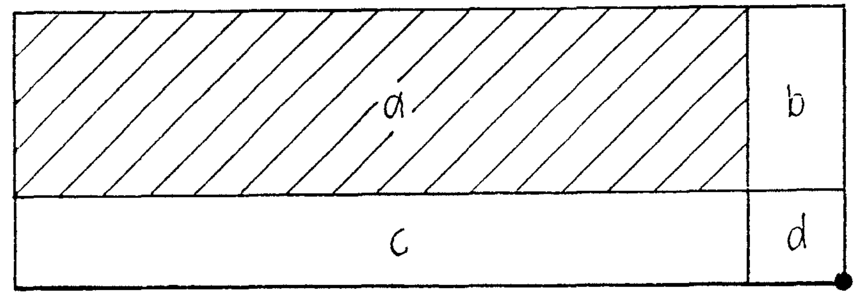



Point outside the area but between the sides extended.

Procedure: Compute drawdown at the point due to pumping over the areas (a + b) and (c + d). Deduct the effect of pumping on the areas b and d.






Point outside the pumped area a and not between the sides extended.

Procedure: Compute the drawdown due to the area (a + b + c + d). Deduct the effect of pumping on the areas (b + d) and (c + d). Add the effect of pumping on the area d.

**Example 8**

A farmer plans to install a well to supply water for irrigation. Other wells have been operating in the area for a period of five years. The area is two townships wide by three townships long. His proposed well is near the center of one of the corner townships. The pumps in the area lift 45,000 acre-feet per year of which 15,000 acre-feet per year is consumed. It is expected that this pumping rate will continue. Aquifer properties are $\alpha = 1.00 \text{ft}^2/\text{sec}$.

$K = 0.001$ ft/sec $\quad V = 0.15 \quad KD = 0.150\ \text{ft}^2/\text{sec}$

How much sinking of the water table must be allowed for if the proposed well is to have a life of at least 20 years?

**Solution**

The point is inside the area and the four rectangles have the dimensions 9 by 15 miles, 3 by 15 miles, 3 by 9 miles and 3 by 3 miles on a side. The total area of the six townships is

$(6)(1003.62)(10)^6 = 6021.72(10)^6$ square feet

The rate of the distributed pumping is

$$p = \frac{(15000)(43560)}{6021.72(10)^6\ 31.536(10)^6} = \frac{653.4(10)^6}{189900(10)^{12}} = 3.441(10)^{-9} \text{ ft/sec}$$

The sinking of the water table due to well operation over the past 5 years must first be estimated. The computation can be arranged as follows:

| Area | $\frac{W}{L}$ | L (feet) | $\frac{L}{\sqrt{4\alpha t}}$ | $\frac{s^*}{\left(\frac{pt}{V}\right)}$ | s (feet) |
|---|---|---|---|---|---|
| 9 by 15 | 0.600 | 79200 | 3.154 | 0.250 | 0.904 |
| 3 by 15 | 0.200 | 79200 | 3.154 | 0.202 | 0.731 |
| 3 by 9 | 0.333 | 47520 | 1.892 | 0.203 | 0.734 |
| 3 by 3 | 1.000 | 15840 | 0.631 | 0.167 | 0.604 |
| | | | | Total sinking | 2.973 |

*From the chart.

5 years is 157,680,000 seconds or $0.157680(10)^9$ seconds

$$\sqrt{4\alpha t} = \sqrt{(4)(1)(157680000)} = \sqrt{630720000} = 25114$$

$$\frac{pt}{V} = \frac{(3.441)(10)^{-9}\,(0.15768)(10)^9}{0.15} = 3.617 \text{ feet}$$

This is the amount the water table would sink if no water could flow into the area from outside. The estimate for the 25 year period is made similarly.

| Area | $\frac{W}{L}$ | L (feet) | $\frac{L}{\sqrt{4\alpha t}}$ | $\frac{s}{\left(\frac{pt}{V}\right)}$ | s (feet) |
|---|---|---|---|---|---|
| 9 by 15 | 0.600 | 79200 | 1.410 | 0.222 | 4.014 |
| 3 by 15 | 0.200 | 79200 | 1.410 | 0.122 | 2.206 |
| 3 by 9 | 0.333 | 47520 | 0.846 | 0.113 | 2.043 |
| 3 by 3 | 1.000 | 15840 | 0.282 | 0.069 | 1.248 |
| | | | | Total sinking | 9.510 |

25 years is 788,400,000 seconds or $0.7884(10)^9$ seconds

$$\sqrt{(4)(1)(0.7884)(10)^9} = 56156$$

$$\frac{pt}{V} = \frac{(3.441)(10)^{-9}\,(0.7884)(10)^9}{0.15} = 18.08 \text{ feet}$$

Then the sinking of the water table to be expected in the next twenty years is:

$9.51 - 2.97 = 6.54$ feet.

This figure can be added to the estimated local drawdown to determine the elevation at which the pump should be set.

## Comments

Where water is pumped for irrigation, a considerable part may find its way to the water table with the result that the influence of the well at a distance may be due only to that part of the pumped water which was consumed by evaporation and transpiration. Although the computations are often most easily made on the basis of the water pumped, the possibility of the return of a part of it to the water table should be considered. The computation is then easily corrected by applying an appropriate factor to the final result.

The amounts of water that go to supplying evaporation and plant transpiration, and to deep percolation depend upon several factors.[10] The type of soil, the crops grown, and the method of applying irrigation water all exert an influence. With the light soils of the South Plate Valley the water budget may be about as follows in terms of depths of water applied to the land in one irrigation season.



| | |
|---|---|
| Irrigation supply | 2.50 feet |
| Precipitation | 1.10 feet |
| Total water supply | 3.60 feet |
| Consumptive use (evapotranspiration) | 1.70 feet |
| Deep percolation losses | 1.90 feet |
| Total losses | 3.60 feet |

In terms of the irrigation water applied these figures can be interpreted in the following way:

| | | |
|---|---|---|
| Water reaching the water table | $\frac{1.90}{2.50} =$ | 0.76 |
| Irrigation water consumed | $\frac{2.50 - 1.90}{2.50} =$ | 0.24 |
| Total irrigation water | | 1.00 |

This interpretation implies that the precipitation is all consumed so that the evapotranspiration requirement is supplied by:

| | |
|---|---|
| Precipitation | 1.10 ft |
| Irrigation water consumed | 0.60 ft |
| Total | 1.70 ft |

Studies of the performance of the stream carried out in terms of irrigation supplies and river flows, only, lead to an interpretation of this sort. Actually the part of the water supply consumed is

$$\frac{1.70}{3.60} = 0.47$$

or nearly half.

Interpreted in terms of the irrigation water supply only, it appears that about one-fourth of the applied irrigation is consumed and about three-fourths returns to the water table and subsequently to the river.

Comparative studies made on the basis of field tests indicate that sprinkler irrigation will use about 0.6 foot less water per season than will furrow irrigation. The water balance in this case might be about as follows:

| | |
|---|---|
| Irrigation supply | 1.90 feet |
| Precipitation | 1.10 feet |
| Total water supply | 3.00 feet |
| Consumptive use | 1.70 feet |
| Deep percolation losses | 1.30 feet |
| Total losses | 3.00 feet |

Based upon the irrigation water supply, the water reaching the water table would be:

Water reaching the water table $\frac{1.30}{1.90} = 0.68$

Irrigation water consumed $\frac{1.90 - 1.30}{1.90} = 0.32$

Total irrigation water $1.00$

In this case the actual consumption is: $\frac{1.70}{3.00} = 0.57$

Based upon the irrigation supply only, however, the interpretation would now be that about one-third is consumed and two-thirds returns to the water table.

There is an element of convenience in using factors based upon the irrigation water supplied since these are the measured quantities. The tacit assumption that precipitation is all consumed in supplying evaporation and transpiration may not be greatly in error since a study of the water supply to the High Plains area[4] indicates that only about 0.075 foot per year reaches the water table. This is supplied by precipitation alone. It is also true that, in eastern Colorado, the bulk of the natural precipitation is received during the growing season.

It is always important to review the water balance when any specific area is to be considered because local conditions can strongly affect the water balance. Fine grained soils with high water retention abilities can, for example, reduce the amounts of irrigation water needed to grow crops. The amount of water reaching the water table will be correspondingly reduced.



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