ANALOG STUDIES OF THE EFFECTS OF PUMPING ON GROUND
WATER LEVELS IN THE HIGH PLAINS AREA OF EASTERN COLORADO

by

R. E. Glover

CER65REG35

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Introduction

The water bearing Ogallala formation underlies an approximately

triangular area in the eastern part of Colorado. The formation has its greatest

thickness near the state line and feather-edges out toward the west. The areal

extent of these formations is shown in figure 1. The area underlain by these

beds in Colorado comprises about 9000 square miles. Dimensions of the area

are about 180 miles north and south by 90 miles east and west. While, in

general, these beds increase in thickness toward the east their conformation

is irregular and a section taken along the state line shows large variations in

thickness. The Ogallala formation also extends eastward into Nebraska and

Kansas.

The formation yields water to wells in amounts suitable for irrigation,

and by 1960, there were about 400 such wells in service.(1) Water is supplied

to these beds by infiltration from precipitation and it is supposed that the sand

hill areas lying these formations contribute effectively to this supply. The U.S.

Geological Survey (1) estimated that the natural recharge to this area is about

430,000 acre feet per year. Of this supply irrigation pumps lifted about

70,000 acre feet in the year 1960. (1)

The rate of replenishment based upon the natural recharge and area

values mentioned previously comes out to be about 0.075 feet or nine tenths

of an inch per year. This is only a small part of the average annual precipitation

which amounts to about 15 inches. The aquifer is not recharged from the South Platte or Arkansas River Systems, nor from the Rocky Mountains.

Purposes

The analog studies described herein were made to explore the possibilities of utilizing the ground waters of the Ogallala formation as a permanent resource rather than a resource to be exploited and exhausted as a mining venture on a short term basis.

The studies described indidcate how an analog can be used to assess the effect of pumping on the behavior of the water table underlying the High Plains area.

Conclusions

The results of the analog studies described herein may be summarized as follows:

(1) It is not possible to recover for use in Colorado, by a long term operation of pumps distributed over the High P ains area, all of the ground water flow which is supplied by the average annual infiltration replenishment.

(2) The limitation on the amount of flow recoverable in Colorado is due to the gradient toward the east and the necessity of having a sufficient saturated depth to supply wells of a capacity suitable for irrigation.

(3) It should be physically possible to recover about 217, 000 acre feet per year for consumptive use from the Ogallala formation in Colorado on a long term basis. This is equivalent to about 900 cubic feet per second flowing for 4 months of each year. This estimate is based on well flows of one cubic foot per second (448. 86 P. M.) or more.

(4) With smaller pumps more closely spaced a greater recovery would be possible.

(5) If 217,000 acre feet per year can be recovered for consumptive use in Colorado about one acre in 26 can be irrigated. This is equivalent to about 25 acres per section.

(6) This study was based upon a pumping development brought about by private enterprise following essentially the present pattern rather than by some overall authority having equipment and technical skills at its disposal to develop ways and means for obtaining a maximum recovery.

Design of the Analog

Front and back views of the analog model are shown in figures 2 and 3. In this device the hydraulic properties of the water bearing formations are represented by analogous electrical quantities as shown in table 1. By making these substitutions the hydraulic conditions can be transferred to the electrical field and the ground water flow problem can then be studied in the laboratory.

Table 1. Correlation between Aquifer and Analog Properties

Aquifer Quantity	Corresponding Analog Quantity
Flow of water	Flow of electrical current
Water table elevation	Voltage
Transmissibility	Electrical conductance
Ground water storage	Capacitance
Time	Time

Before an analog can be constructed it is necessary to assign specific values to these relationships. The values are selected to adapt the analog to available map scales, available instrumentation and readily obtainable electrical components. The relationships incorporated into the present analog are as shown in table 2.

Table 2. Corresponding Aquifer and Analog Quantities

Aquifer Quantity	Corresponding Analog Quantity
1 cubic foot of water per second	0.000001 Ampere
5 feet of water table elevation	1 volt
10 years	1 second
250,000 feet	1 foot

Construction of the Analog

The analog network is mounted upon a sheet of Masonite 1/4 inch thick which has been perforated with 5/16 inch diameter holes on 1 inch centers. The base map used is a U.S. Geological Survey map prepared to a scale of 1/250,000. The network node points are represented, physically, by a small nylon bushing which incorporates a plug for a jack connection. One of these is installed in each hole. The actual land distance corresponding to the distance between node points is then, $\frac{250,000}{12}$ = 20,833 ft., (or about 3.95 miles). Representation of the transmissibility is made in five steps as shown in figure 1. The corresponding transmissibilities and analog conductances are shown in table 3.

Table 3. Corresponding Transmissibilities and Conductances

Actual Aquifer Thickness (feet)	Assumed Aquifer Thickness (feet)	Aquifer Transmissibility (ft^2/sec)	Analog Conductances (ohms)*
0-50	25	.025	8200000
50-100	75	.075	2700000
100-200	150	.150	1300000
200-300	250	.250	820000
Over 300	350	.350	560000

* These are the ratings of the resistors used.

The resistors provide a conductance representing the capacity of the aquifer to transmit ground water over a width of 20,833 feet. Each node point represents an area 20,833 feet on a side. The capacity of the Ogallala formation to store water with a rise of the water-table levels is represented in the analog by a capacitor. One of these is connected between each node point and the ground. Their capacitance is 1 Microfarad. They are mounted directly on the bakc of the panel as shown in figure 3.

The pumping of a well is represented by a constant current flow. provided by a Constant Current Power Supply. This is an electronic device which will maintain a specific rate of current supply regardless of voltage changes in the analog network. The input rate is adjustable from 1 microampere to 10 milliamperes.

The recorder is a direct writing oscillograph. It provides paper speeds of 5, 10, 20, 50, 100 and 200 millimeters per second and sensitivities of 0.5, 1, 2.5, 10, 50, 100, 200, 500, 1000, 2000, 5000 and 10,000 volts per line. The chart width is 50 lines. The response of the water table to factors being studied on the analog is drawn out by the recorder in the form of a graph on which the ordinate pepresents rise or fall of the water table and the abscissa represents time. A change of voltage on the analog simulates a change in the level of the water table.

This oscillograph recorder has an input impedence of 1,000,000 ohms. Measurements of the analog network resistance show that it ranges from about 600,000 to 11,000,000 ohms depending upon the node point chosen. It will be apparent that the analog would be substantially short-circuited by connecting the oscillograph between a node point and the ground. To overcome this difficulty a servo-unit is interposed between the network and the oscillograph. This is an electronic device which senses the voltage in the network and acts to maintain this voltage upon the oscillograph input without drawing current from the analog network. A circuit diagram for the analog and the input and readout equipment is shown on figure 4. A sample recorder chart is shown in figure 5.

Use of the Analog

The analog was used to evaluate the effect of pumping in the High Plains area as outlined in table 5. To facilitate the study this area was divided into twelve sub-areas identified by the name of a town located in the sub-area. Interferences between sub-areas were first investigated. In general, only small interferences were found between areas at the end of the first 100 years of pumping as shown in table 4. A blank in the table with no entry indicates that the effect is too small to be found by the analog. The heavy pumping rate allotted to the Yuma area does, however, produce a significant drawdown at Wray and an excessively heavy drawdown at Otis.

The effects of distributed and local pumping in the sub-areas was next studied with the results shown in table 5. The total amount of pumping permitted by aquifer limitations and the distribution of pumping permitted by aquifer conditions had to be determined essentially by trial. In computing the local drawdown a well discharge of 1 cubic foot per second was used with an assumed effective well radius of 1 foot. An initial saturated thickness of about 50 feet was assumed to be needed to sustain this flow. Where the aquifer thickness was 25 feet, however, it was found that a yield of 1 cubic foot per second would produce excessive drawdowns and a rate of 0.25 ft^3/sec was then used instead. The effect of the distributed pumping in the area was determined by use of the analog. The local drawdown at a pumped well was then computed for point just outside the casing. The sum of the area drawdown and the local drawdown gives

the total drawdown at the well. The computation of the local drawdown was based upon the aquifer properties in the immediate neighborhood of the well. The reason for computing the local drawdown is that the mesh of the analog network is too coarse to determine it. The local aquifer properties were obtained from reference 1.

Because the pumping season does not generally extend through the entire year and because a part of the water pumped will return to the aquifer, an installed pump capacity greater than the assumed steady draft on the aquifer is allowable. The installed pump capacity was based upon an assumed 4 month pumping period and a consumptive use of one third of the amount pumped. This basis gives a factor of 9 to apply to the "equivalent continuous flow" of table 5 to obtain the installed capacity figure.

Although the values given are based upon 100 years of pumping they should represent fairly well the amount that could be drawn from the aquifer on a permanent basis. Some mutual interferences should begin to be felt between the sub-areas after about 100 years but these should not be important enough to modify the total aquifer yield materially although they would modify it locally.

Effect of Pumping for Irrigation on the Yield of Domestic Wells

Extensive pumping for irrigation will produce a lowering of the water table. This lowering may well put some present wells out of operation but a deeper well may be able to obtain water. An important question is whether the water table will be lowered, in the areas where shale ridges exist under the aquifer, to such an extent that domestic water could not be obtained even though the casing were sunk to the shale. The Ogallala formation appears to have been

laid down upon an eroded surface of the shale which had well developed valleys

and ridges in it. After the water table is lowered by pumping it may be

physically possible for recharge coming from a local area to flow down the

shale valleys leaving the ridges dry. If replenishment comes principally from

the sand hill areas this may be a possibility but if replenishment comes from

infiltration distributed over the area, this outcome seems unlikely because

some saturated depth is necessary to transmit the ground water flow. The

performance of domestic wells in the shale ridge areas should be watched

for information on trends as pumping develops.

Status of the Present Analog

The present analog has been constructed to represent the aquifer

conditions as they are defined by presently available information. As more

wells are put down and more information on aquifer properties is obtained

it will be possible to build an analog which provides an improved representation

of aquifer conditions as they actually exist. The present analog should be

sufficiently accurate however, to yield good information on the effect of

pumping over an area. Mutual interference and local effects may not be so

well shown because locally significant features of the aquifer may not be

revealed by the presently available data.

Comments

A study such as this one, which attempts to evaluate the effects of pumping

continued into the future must, of necessity, be based upon some appraisal of

possible future conditions. As pumping increases it must be expected that the

water table will drop and with its lowering there must be an expected decrease

in the yield of wells. Economic and operational considerations may well set

a lower limit of well yield beyond which irrigation may be unprofitable. For the purpose of this study it has been assumed that well flows of 1 ft³/sec (443.8 gallons per minute) would be needed for profitable irrigation operations. In some thinner parts of the aquifer, wells of this capacity will not, on the basis of present estimates, be obtainable. The amount of water recoverable from these parts of the aquifer is estimated to be small and it is supposed that uses of higher value than crop irrigation will absorb these. Such uses could include domestic and stock water supplies and municipal supplies. A consumptive use of one acre foot per acre per year was assumed to be sufficient for irrigated crops. A pumping period of 4 months was used as a basis for estimating drawdowns. The gross pumpage may be 3 feet per year or 3 acre feet per acre per year. It was assumed that the water not consumptively used returned to the water table.

The part of the precipitation which now reaches the water table is very small. If effective methods for increasing the infiltration from precipitation can be found, the available water supply can be correspondingly increased. The amount of well concentration to be expected is not now known but it will be somewhat on the safe side to assume a certain amount of concentration since this will produce deeper drawdowns than would be observed if the pumping were more uniformly distributed over the area. A reference to table 5 will show that an allowance for well concentration was incorporated into the study.

The amounts of concentration considered may be expressed in terms of the parts of the area irrigated within the gross areas assumed to be supplied from wells. Of the assumed 20 mile square or 256,000 gross acres around Holyoke, Yuma and Burlington about 1 acre in 2 would be irrigated in the Yuma area and

and about 1 acre in 10 in the Holyoke and Burlington areas. Of the 92, 160 gross acres in the 12 mile square gross area assumed to encompass the irrigated portion of the remaining sub-areas, 1 acre in 6 would be irrigated around Haxton and Wray, 1 acre in 14 around Otis, Cope, Stratton and Cheyenne Wells. In the remaining sub-areas the available water supplies were presumed to be used for domestic supplies and other high priority uses.

Pumping developments made by private enterprise may impose a lesser limitation on the attainable recovery than would be the case if the whole area were placed under some sort of authority having facilities, equipment and technical skills at its disposal to be applied to the task of getting the greatest recovery possible. This study is based upon the assumption that development will be by private enterprise.

The present study should be looked upon more as an example of what the analog is capable of doing rather than as a final assessment of what can or will happen in the Ogallala area. If it is desired to make studies based upon other assumptions, the analog is available and could be put to use.

An attempt to irrigate large solid blocks of land with high capacity wells of 2 ft^3/sec (900 G. P. M.) capacity each serving 120 acres could be expected to increase the local drawdowns and reduce the amount of the average annual supply of water which could be extracted from the aquifer on a permanent yield basis, below that estimated on the basis of the present study.

The drawdowns at 100 years were used as a basis of the present analog study as this was considered to be as far in the future as could be of concern at the present time.

Checks

Before the parts for the analog were purchased a small panel representing a sector of a circular area with a pump at the center was made up and recordings were obtained. These were read and the readings compared with the results obtained from an analytical treatment of the same case. A close check was obtained.

Recordings from the analog have been compared with other computed values based upon an aquifer of uniform average properties. The results compared well when the non-uniformities of the aquifer represented by the analog were taken into consideration.

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