RESULTS OF COMPUTER MODELING OF GROUNDWATER FLOW - THE CALCIUM CARBONATE AQUIFER OF THE CENTRAL ROSWELL BASIN

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INTRODUCTION AND PURPOSE

The flow of groundwater in the Roswell Artesian Basin has been studied since the early 1900s with varied ideas proposed to explain different aspects of the groundwater flow system. The purpose of the present study is to help delineate the distribution and source, or sources, of recharge to the Roswell Basin by using a computer model to simulate groundwater flow in the carbonate aquifer beneath and west of Roswell and in the Glorieta Sandstone and Yeso Formation west of the carbonate aquifer. The use of the computer model offers the unique opportunity to evaluate different theories by simply changing various model parameters such as transmissivity, storage coefficient, interaquifer leakage and recharge.

The results obtained are approximate, but represent the best estimate of the distribution of recharge in the Central Roswell Basin to date. The compatibility of the model results with previously proposed ideas will lend credence to some and refute others. The model results should generate some new ideas, hopefully provoke further research, and serve as a stepping stone to future modeling attempts of the Roswell Basin.

The material in this paper is based on work done by the author for his Master of Science Degree in Hydrology at New Mexico Institute of Mining and Technology in Socorro. Many points that are only mentioned in this paper are explained more fully in the author's thesis.

DESCRIPTION OF THE STUDY AREA

The study area is an east-west strip in the central part of the Roswell Artesian Basin in Chaves and Lincoln Counties, New Mexico, and includes much of the Rio Hondo Drainage Basin (Figures 1, 2). The study area was chosen because of the relative abundance of data in the Hondo valley region as compared to other parts of the Roswell Basin.

HYDROGEOLOGY

This report is concerned mainly with the flow of groundwater in the carbonate aquifer which is composed of the San Andres Limestone and the Grayburg Formation. Groundwater in the carbonate aquifer is affected by groundwater in the underlying formations, the Yeso and Glorieta, and by the overlying formations, the Queen and the Alluvium. A good discussion of the stratigraphy is given by Kelley (1971).

Water is unconfined in the carbonate aquifer west of about Range 24 East and confined in and east of Range 24 East. The western boundary of the carbonate aquifer occurs where the water table intersects the Glorieta-San Andres contact, and the eastern boundary is approximately the Pecos River. The northern and southern boundaries are estimated to be near Arroyo Del Macho and South Seven Rivers, respectively. The boundaries are shown in Figure 3.

Moving from west to east in the Roswell Basin, progressively younger formations are encountered, because the beds dip to the

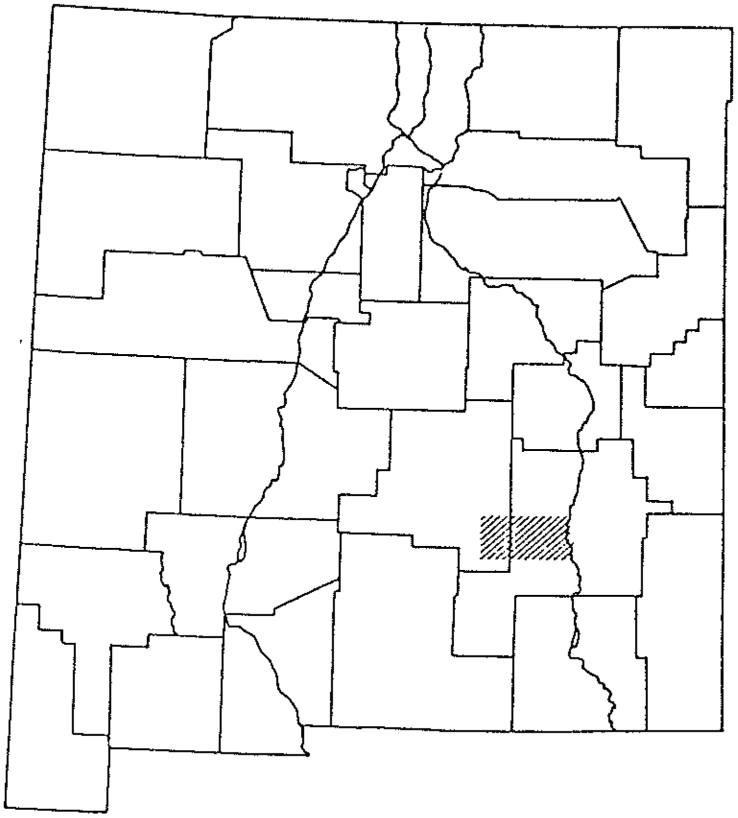


Fig. 1. Location of the study area.

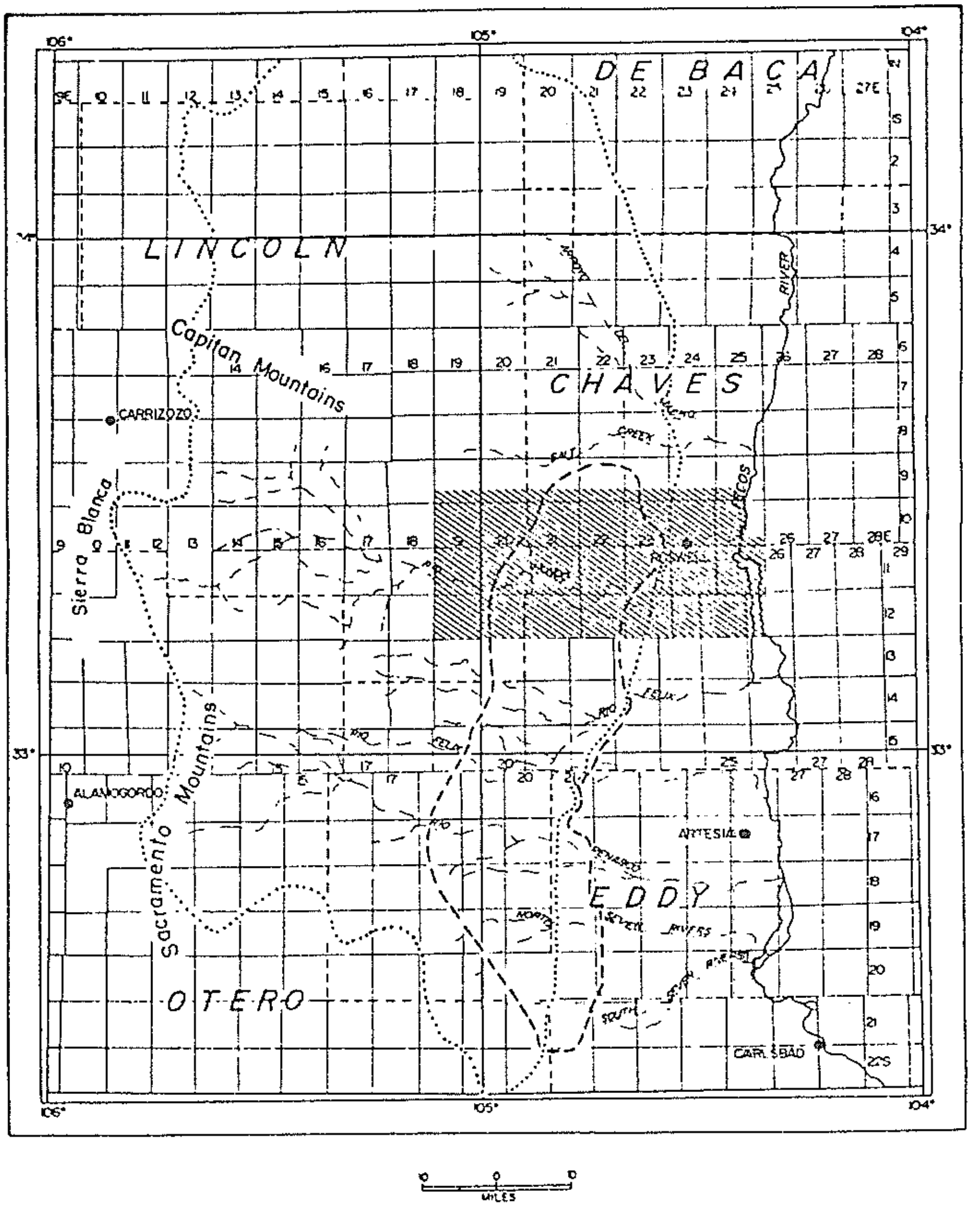


Fig. 2. Location of the study area in relation to hydrologic boundaries.

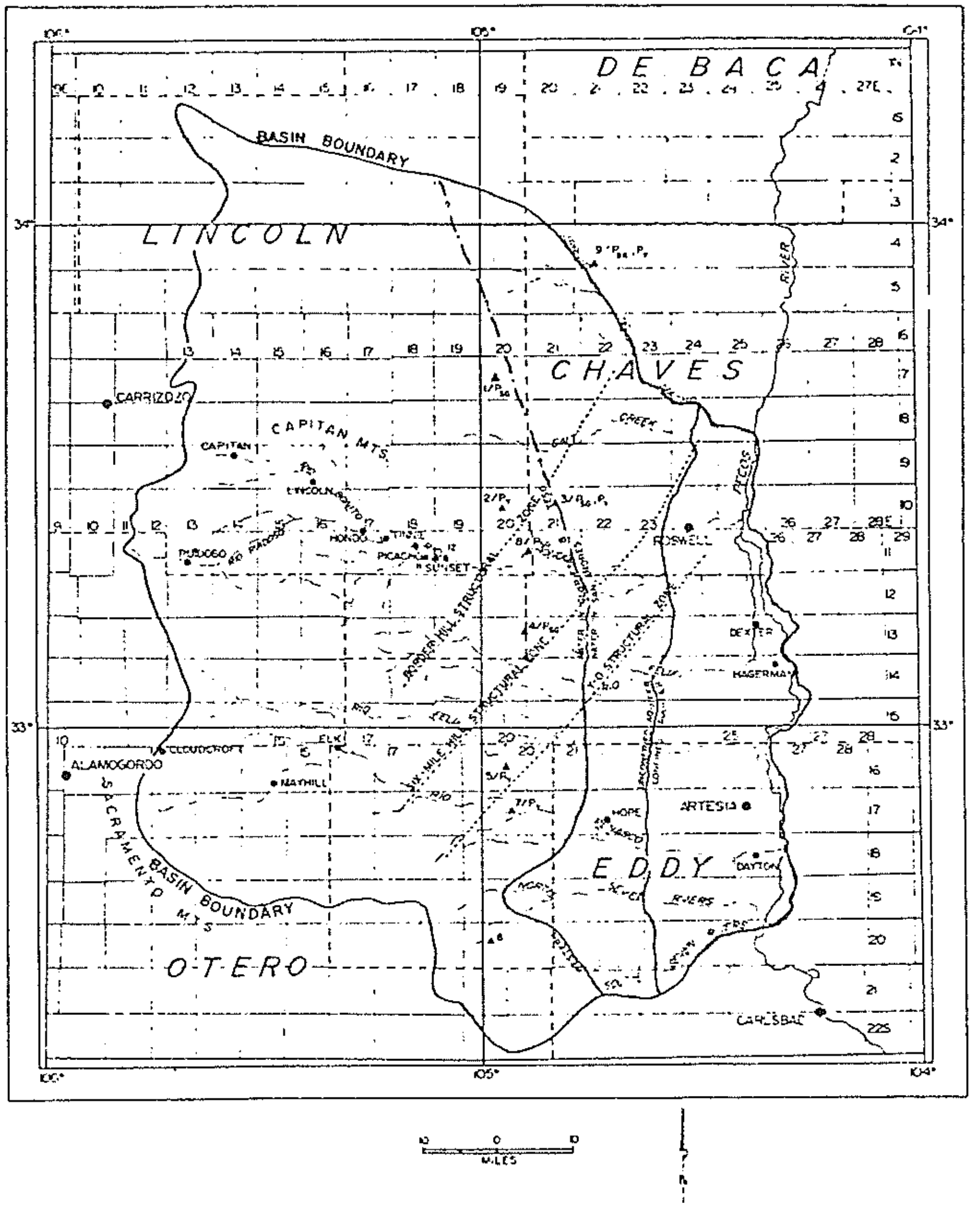


Fig. 3. Outline of the Roswell Basin with the hydrologic boundaries.

east-southeast at a greater angle than the topography. The slope of the water table in the western (unconfined) part of the main aquifer is less than the dip of the strata, and consequently the water table intersects progressively younger formations from west to east.

Interaquifer leakage occurs between the carbonate aquifer and the alluvial aquifer through the Queen aquitard in a band about 20 miles wide adjacent to the Pecos River. Leakage is generally greatest in the vicinity of Roswell and decreases to the south and southwest. Prior to the development of irrigation wells, water leaked vertically upward from the carbonate aquifer to the alluvial aquifer. Recently, the large drawdown of the potentiometric surface of the carbonate aquifer during the summer irrigation season reverses the direction of vertical leakage, and the net yearly leakage may be nearly zero. A good summary of the hydrogeology is given by Gross, Hoy and Duffy (1976).

COMPUTER MODEL

The computer model chosen is a two-dimensional finite-difference model written by Trescott, Pinder and Larson (1976), herein called the Trescott model, or the model. The model was chosen because it is easy to obtain, extremely well documented, and easy to use. The application of a computer model to an aquifer is a three-step process of calibration, verification, and prediction.

Calibration is the trial and error process of adjusting the aquifer parameters in a model in order to match the computed head distribution to the observed head distribution for some historic period of time. If the computed head map does not match the observed head map, the parameters are adjusted and another computed head map is generated. For this study, the parameters of interest are transmissivity, storage coefficient, hydraulic conductivity of the aquitard, and recharge.

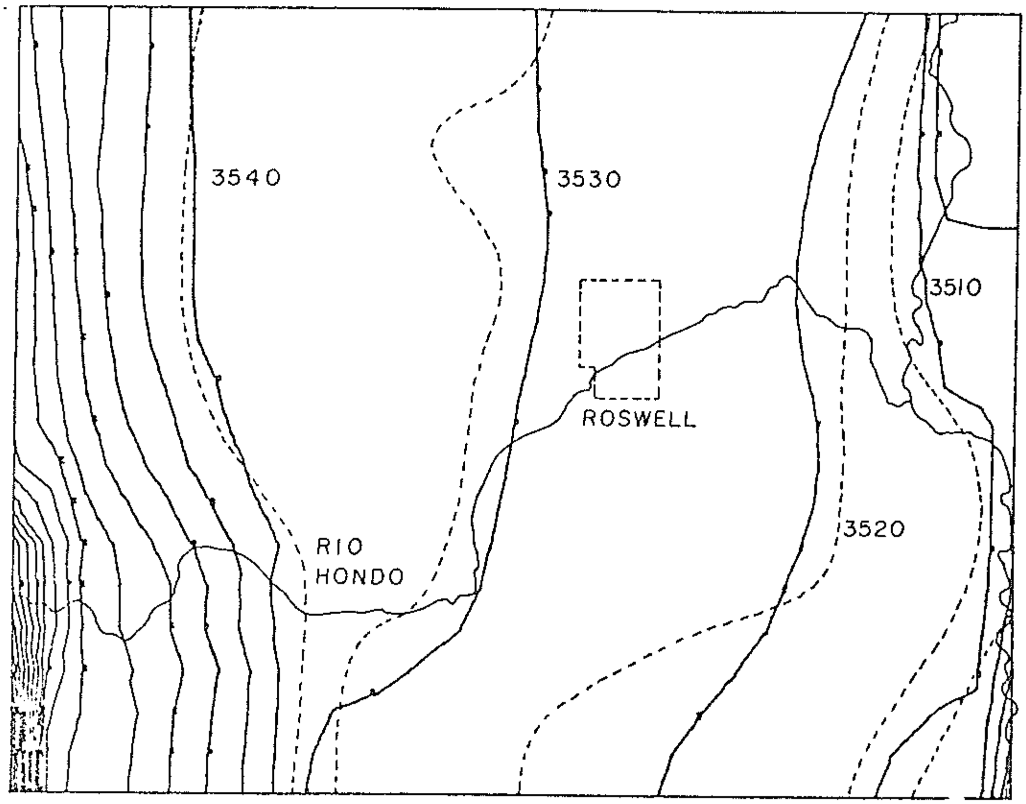
Following the calibration, the calibrated parameters are verified against another historic period of time. The purpose of the verification is to provide a check on the calibration. For example, if the observed water levels used for the calibration were the result of some anomalous condition, the verification would produce a poor match between the computed and observed heads at the end of the verification period. On the other hand, if the verification produces a good match, we can be reasonably sure the calibrated parameters are correct.

The final step in the modeling process is prediction. The model is used to predict future water levels given expected pumpage and recharge.

For the present study, the calibration period is January 1967 to January 1968, and the verificaton period is January 1967 to January 1975. Predictions using the model have not yet been performed.

RESULTS

Figure 4 contains both the computed and observed hydraulic head map for January 1968 for the eastern two-thirds of the study area. For the most part, the computed and observed heads differ by less than 3 feet. An exact match would be unwarranted because of inaccuracies in the water level data used to draw the observed water level contours.

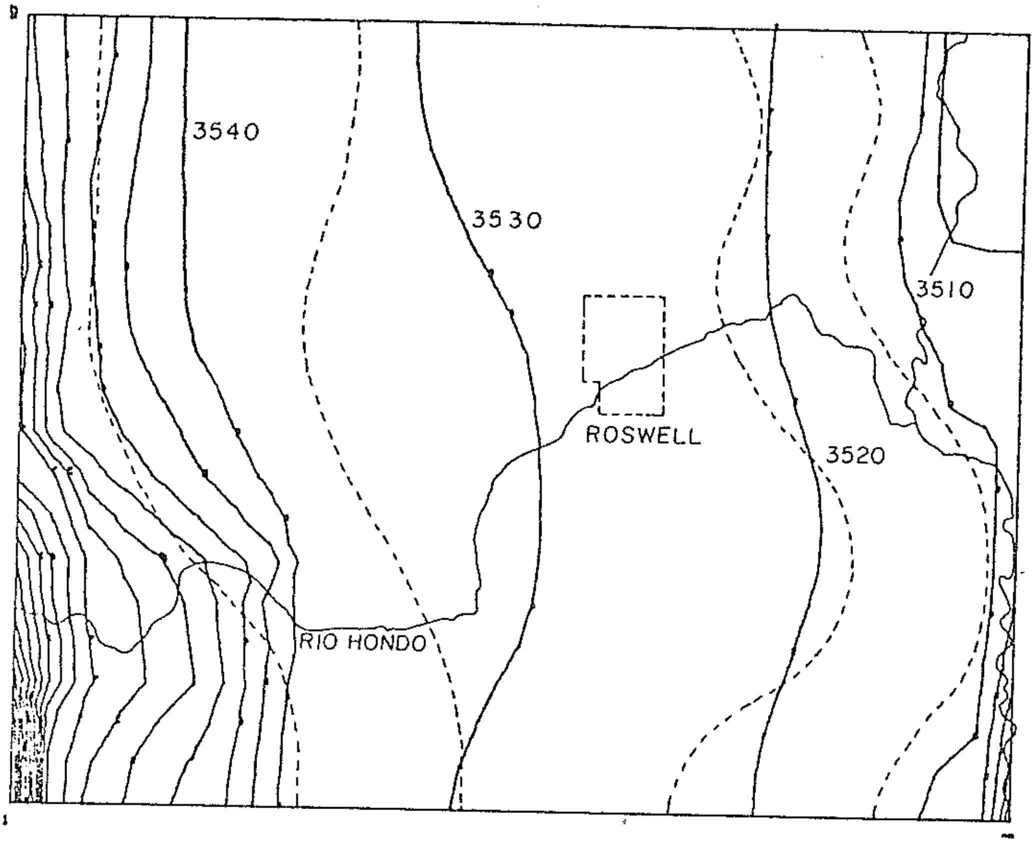


HYDRAULIC HEAD 1968

Fig. 4. Computed (solid lines) and observed (dashed lines).

The next step in the modeling process is the verification of the calibrated parameters. Figure 5 contains the computed and observed head map for January 1975. East of Roswell the match is as good as for January 1968. However, northwest of Roswell, the computed and observed heads deviate. The reasons for the lack of fit are not clear. Obviously, the calibrated parameters are in error. The question is which ones. Sensitivity studies have shown that the most sensitive parameter is the observed water level. In the area where the fit is poor, water level data are sparse to nonexistent. Therefore, the contours drawn from observed data may be significantly in error in the area northwest of Roswell. Until such time as water level data are improved in that area, the calibrated parameters cannot be improved. All in all, the match of heads for January, 1975, is acceptable.

Figure 6 contains the yearly average sources and discharges to the flow system calculated from the verificaton simulation. Some of the terms in Figure 6 require an explanation. The recharge includes the amount distributed over the area and the amount contributed by the Rio Hondo. The western flow source is largely flow across the western boundary and represents the amount of water entering the carbonate aquifer by flow along the regional water table. However, this is not to say that the total contribution to the carbonate aquifer from the Glorieta and Yeso is only 1,100 acre-feet per year. In fact, a significant amount of water in the carbonate aquifer is derived from upward leakage of water from the underlying



HYDRAULIC HEAD 1975

Fig. 5. Computed (solid lines) and observed (dashed lines).

MASS FLUX

SOURCES	ACRE-FEET/YEAR
Recharge	124,403
Western Flow	1,117
Leakage	36,032
DISCHARGES	
Eastern Flow	2,012
Pumpage	105,866
Leakage	48,225
NET LEAKAGE (UPWARD)	12,194

Fig. 6. Yearly average sources and discharges.

Glorieta and Yeso, as will be shown later. The eastern flow is the amount of water flowing out of the model area to the east beneath the Pecos River. The leakage is the amount of water entering and leaving the confined portion of the carbonate aquifer through the overlying aquitard. The fluxes obtained appear to be reasonable when compared to similar estimates by Fiedler and Nye (1933), Hantush (1957), and Saleem and Jacob (1971).

RECHARGE

The calibrated distribution of recharge is presented in Figure 7. The other calibrated parameters, transmissivity, storage coefficient, and aquitard hydraulic conductivity will not be presented here. The other parameters are entirely consistent with published data from the basin. The calibrated recharge is therefore determined using the model with parameters that are consistent with the published values. One can then assume that the calibrated recharge is a reasonable approximation to the true recharge distribution.

The amount of recharge, as calculated by the model, varies over the basin. In the western region where the flow occurs largely in the Yeso, the calculated recharge was about 0.1 inches per year. This is the amount that actually recharges the deep, or regional, water table as opposed to perched systems. Undoubtedly, more water actually infiltrates into the overlying carbonate because of the presence of many springs which issue from perched systems along the Yeso-Glorieta (San Andres) contact (Davis, Wilcox and Gross 1979).

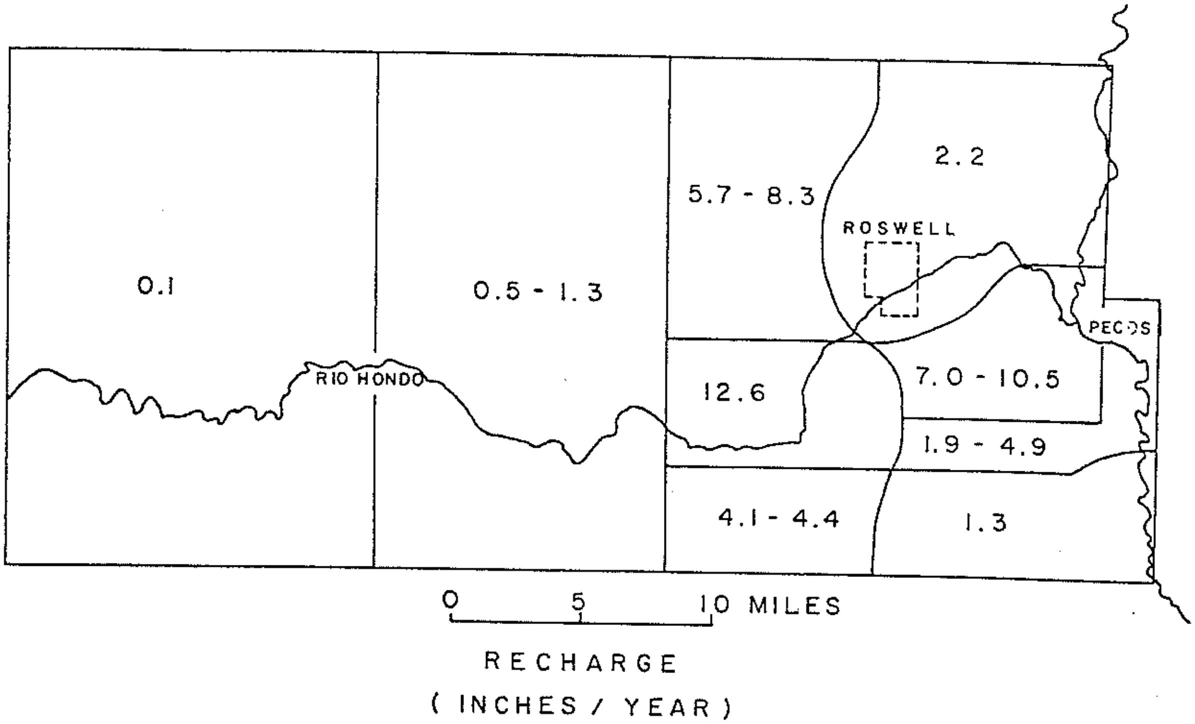


Fig. 7. Calibrated recharge.

Progressing eastward, a zone of about 0.5 inches per year occurs at about the location where the water table lies in the Glorieta Sandstone. The Glorieta, being more permeable than the Yeso allows more water to infiltrate and may, in fact, absorb water that is flowing eastward along the Glorieta-Yeso contact.

East of the line where the water table intersects the San Andres (Fig. 3), the amount of recharge again increases to the range of 0.8 to 1.3 inches per year. The increase may be due to a lessening of the land surface gradient which allows more water to infiltrate. East of the above region and west of the line where the San Andres becomes confined, something unusual occurs. The amount of recharge jumps from the range 5.7 to 8.3 inches per year above Township 11 to almost 13 inches per year in the region east of the Hondo Reservoir.

In the confined zone "recharge" was needed over and above leakage. Large amounts of this "recharge" were added to Township 11, Ranges 24 and 25, which is an area of heavy pumping. Possibly the value of transmissivity could have been increased to a point where recharge in the PIA would reach the pumping centers. That would have been inconsistent with pumping test values obtained by Hantush (1957, 1961), which are at worst an overestimate of the actual transmissivity (Neuman and Witherspoon 1969). Therefore, the "recharge" is probably a real phenomenon, and not a failure to calibrate the model properly. The source of the "recharge" in the confined zone is obviously not precipitation, and is probably not leakage from the overlying aquitard, because leakage is calculated separately in the model.

The amount of yearly recharge in the Principal Intake Area jumps from a maximum of 1.3 inches west of Range 23 East to a minimum of 4 inches in Range 23 East. Much of Range 23 East has a recharge of greater than 6 inches and a maximum of 12.6 inches occurs in the lower two-thirds of Township 11 South. The question arises as to how 6 to 12 inches of recharge can occur in an area where the average annual precipitation is about 13 inches (Mourant, 1963, the average of Roswell and Picacho).

Two possible explanations can be proposed: (1) precipitation infiltrates rapidly through solution features, cracks, and along stream channels, and (2) water in the Glorieta and Yeso is leaking vertically upward into the carbonate aquifer. Evidence for either explanation is available, as it appears that the answer is probably a combination of both.

In support of the first explanation, Motts and Cushman's (1964) Northern Evaporite Area corresponds closely to the area of high recharge in the model. They describe the Northern Evaporite Area as having good to excellent recharge capacity, numerous sinkholes, and that the seepage loss per mile of stream channel is probably greater than in other parts of the intake area. Precipitation will infiltrate rapidly and reach the water table sooner than in other parts of the intake area, because the water table is closer to the land surface (Fiedler and Nye 1933). Also, water from the west will enter the area in the stream channels and will be lost through leakage. Therefore, the potential for large amounts of infiltration exists along the eastern edge of the Principal Intake Area.

Rabinowitz and Gross (1972) also described the above area as one of rapid recharge as opposed to slower recharge to the west. However, Gross, Hoy and Duffy (1976), have shown that Rabinowitz and Gross's interpretation of the data may be questionable, and are the most recent proponents of the idea of upward leakage from the Glorieta and Yeso.

Fiedler and Nye (1933) were the first to propose a possible deep flow component from the Yeso and Glorieta. They said water in the Yeso and Glorieta had a greater artesian head than the main aquifer, and that water may be forced upward along joints and fractures, but the amount was assumed small, although never measured. Hantush (1957) and Saleem and Jacob (1971) also said that some recharge may be leakage from the Yeso and Glorieta. Bunte (1960) showed that the Glorieta is a major conduit of recharge north of the study area. Havenor (1968) presents some data which indicate the presence of upward vertical flow. The combined water level in the City of Roswell Test Well No. 2 (11.22.04) was 5 feet higher with both the San Andres and Glorieta producing than the water level of the San Andres alone. Many authors have said that the Glorieta and Yeso are not permeable enough to produce much water. Over an area as large as the Roswell Basin significant amounts of water can be produced from leakage through very tight formations. The overlying aquitard for example, allows about 40,000 acre-feet per year to leak through in either direction. The strongest evidence for a deep flow comes from tritium data (Gross, Hoy and Duffy 1976; Gross and Hoy 1979).

Briefly, tritium is a naturally-produced radioactive isotope of hydrogen that decays with a half-life of 12.3 years. Prior to 1953, only small amounts of tritium were present in precipitation and groundwater. With the onset of atmospheric testing of thermonuclear devices in 1953, the amount of tritium in precipitation increased nearly 3 orders of magnitude to a peak in 1963 (Rabinowitz and Gross 1972). Since the Test Ban Treaty in 1963, atmospheric tritium levels have dropped, but are still above the pre-testing level. Consequently, the tritium activity in groundwater has increased as the high tritium precipitation recharges the groundwater.

In the area of rapid, high recharge, one would expect the tritium activity of the groundwater to be very near that of the precipitation. This, unfortunately, is not the case. Gross, Hoy and Duffy (1976) found the tritium activity of water from the Principal Intake Area to be well below expected values.

Based on the published tritium measurements of Gross and Hoy (1979), the average tritium activity in precipitation at Roswell for the period of 1972 to 1978 was 56.8 TU (1 TU = tritium unit = 1 tritium atom per 10^{18} hydrogen atoms), while the average tritium activity for 14 wells in the intake area for 1968 to 1978 was 13.2 TU. The average tritium activity in six wells in the area of high recharge (Range 23) for 1972 to 1978 was 15.2 TU. The tritium activity of wells just east of the intake area was only 9.3 TU. The difference between the tritium activity of groundwater and precipitation is significant when viewed in terms of the 12.3 year half-life of tritium, because it would take about 24 years for a set volume of water of tritium activity 56 TU to reach 14 TU by the natural decay of tritium. One might argue that the groundwater tritium activity is lower because of mixing of recharge with the ambient groundwater.

This is not the case in the carbonate aquifer. If we assume the aquifer is 200 feet thick with a porosity of 0.03 we have 6 feet of water per unit area in storage. With half a foot of recharge per year, the water in the aquifer should be replaced every 12 years. In the 12 years or so prior to the 1968 to 1978 period used above, the tritium activity of precipitation was much greater (Gross, Hoy and Duffy 1976, p. 54). Therefore, the ambient groundwater activity in 1968 should have been quite high, perhaps even higher than the precipitation in 1968. The low tritium activity of water in the Principal Intake Area cannot be explained simply as the mixing of recharge and ambient groundwater.

A deep recharge component appears to be the best way to explain the low tritium levels in the Principal Intake Area and the needed "recharge" in the confined zone. A rough calculation to determine the percentage of recharge from precipitation and from the deep flow can be done with the tritium data. If the measured average tritium of the groundwater in the PIA is assumed to be a mixture of deep water and precipitation, we can use a simple mixing model.

The model (Fig. 8) simply says that part of the groundwater is derived from precipitation of average tritium activity of 56.8 TU and the remaining groundwater is derived from a deep flow. The tritium activity of the deep flow can be estimated from the tritium activity of the PVACD observation wells located at the western edge of the PIA. Four of the wells, numbers 1, 2, 3, and 4, are located in the study area and monitor water levels in the Glorieta and Yeso. For the period of 1974 to 1976, the average tritium activity of the four wells was 5.08 TU. The percentage of each recharge component is calculated by

$$T_{aq} = xT_p + (1-x)\ T_d$$

where

T_{aq} = average tritium activity of the PIA

T_p = average tritium activity of precipitation

T_d = average tritium activity of deep flow

x = percentage of recharge from precipitation

$1-x$ = percentage of recharge from deep flow

T_{aq} = 13.2 TU, T_p = 56.8 TU, T_d = 5.1 TU.

The percentage of recharge from precipitation is only 16%. Deep flow accounts for over 80% of the recharge. If the calculation is done using the aquifer tritium activity of 15.2 TU from only the wells in the high recharge zone, the percentage of recharge from precipitation increases to only 20%.

Assuming that 20% is approximately correct, one would not expect normal fluctuations in precipitation to cause a significant fluctuation in water levels. Although a strong correlation appears

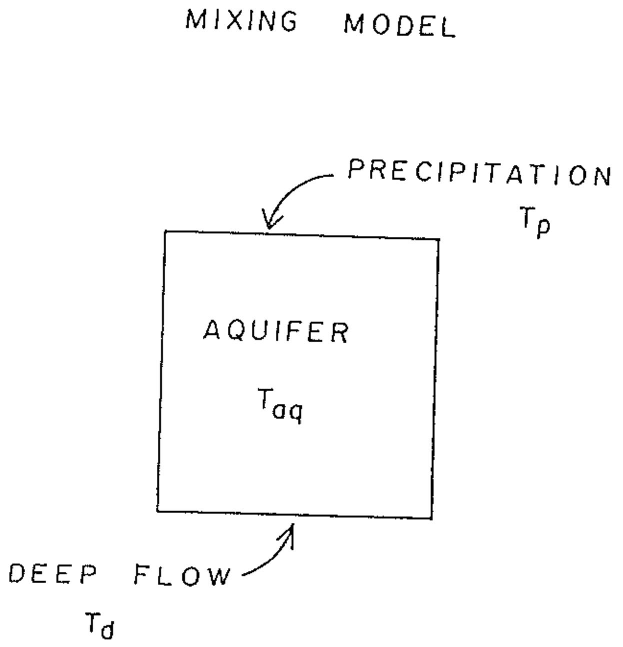


Fig. 8. T_{aq} = tritium activity of the aquifer
T_p = tritium activity of the precipitation
T_d = tritium activity of the deep flow

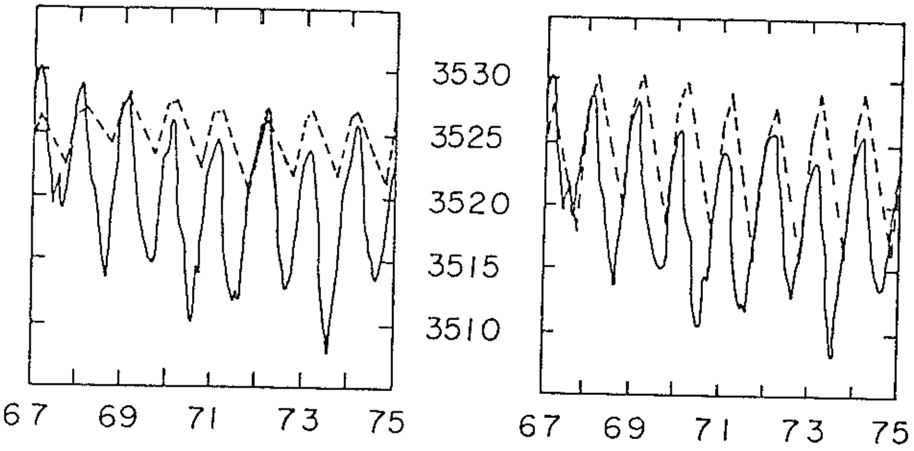
to exist between precipitation events and water level rises, Hantush (1957) and Mourant (1963) have stated that the water level rise is caused mainly by the reduction in pumping associated with the precipitation. Mourant (1963, p. 22) presents the hydrograph of a well located in the region of high recharge (11.23.03.342). The water level in the well rose in June and July because the local rainfall caused a decrease in pumpage. In October, when pumping was small, a heavy rainfall produced no noticeable response in water level. Therefore, it appears that local fluctuations in precipitation have little effect on the water level in the main aquifer. Duffy, Gelhar and Gross (1978, p. 20) present some evidence to suggest that long-term trends in precipitation affect the water level in the PVACD observation wells located just west of the Principal Intake Area. That being the case, long-term trends in precipitation will affect the deep recharge component, and will have a considerable effect on water levels in the carbonate aquifer. More work needs to be done, however, before any definite conclusions can be made.

HYDROGRAPH

As stated in the introduction, the computer model can be easily changed to incorporate new theories. In the calibration, the recharge was unevenly distributed throughout the year in the same manner as precipitation. As the model results were analyzed, the effect of precipitation was shown to be small and deep flow appears to be the major component of recharge. The deep flow is relatively unaffected by yearly variation in precipitation and should be essentially constant. Therefore, two more computer simulations were performed; one of one year and one of eight years corresponding to the calibration and verification simulations, respectively. In each, the recharge was held constant throughout the year. In addition, during the eight-year simulations, only the stream recharge and pumpage were changed from year to year, while the areal recharge remained constant. The resulting hydraulic head maps are very similar to the results obtained with recharge variable throughout the year. In general, the water levels in the high recharge area increased slightly, and the net upward leakage through the aquitard was decreased by almost 4,000 acre-feet per year. The decrease in net upward leakage is the result of increased drawdown in the confined zone during the pumping season caused by the redistribution of recharge.

The hydrograph of the Berrendo-Smith recorder well (10.24.21.212, Hudson, 1978) is compared to the hydrograph of the corresponding node in the model in Figure 9. The predicted hydrograph using constant recharge is a much closer approximation to the observed hydrograph than the predicted one with variable recharge. This also supports the theory that a substantial portion of the recharge to the carbonate aquifer is derived from the underlying formations.

The biggest argument against a deep flow hypothesis is that the deep water is of poor quality. Mourant (1963) has shown that the



DISTRIBUTED RECHARGE

CONSTANT RECHARGE

Fig. 9. Hydrographs of the Berrendo-Smith recorder well (solid lines) and the corresponding node in the model (dashed lines) for distributed and constant recharge.

Yeso contains potable water in the area west of the PIA. However, the water is of poorer quality than the carbonate aquifer in the PIA. It would appear then, that the Yeso probably does not contribute significantly to the deep flow. On the other hand, the Glorieta water is of better quality than that of the carbonate aquifer. Therefore, the Glorieta is the likely source of the deep flow.

CONCLUSIONS

1) Most of the recharge to the carbonate aquifer occurs in and east of Fiedler and Nye's Principal Intake Area.
2) Only 20% of the recharge to the PIA is from precipitation.
3) About 80% is deep flow, most of which is probably from the Glorieta Sandstone.

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