EDDY CO. Analysis of flow from Carlsbad Springs,
Eddy Co., by L. J. Bjorklund

UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Analysis of flow from Carlsbad Springs

Eddy County, New Mexico

By

L. J. Bjorklund

Prepared in cooperation with the

State Engineer of New Mexico

and the

Pecos River Commission

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EDDY COUNTY, NEW MEXICO

By

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PURPOSE AND SCOPE OF THIS REPORT

The Pecos River Commission requested the U. S. Geological Survey to prepare a brief report on the Carlsbad Springs area, Eddy County, New Mexico with special emphasis on the discharge of the springs during the past several years and an estimate of the part of the spring flow contributed from various sources. The contribution of the spring discharge to the flow of the Pecos River and the part of the spring flow considered to be new water added to the system are information needed in the inflow-outflow computations required by the Pecos River Compact.

Data used in the preparation of this report and much of the text are taken directly from a report now in preparation on the water resources of the Carlsbad area, New Mexico in cooperation with the State Engineer of New Mexico.

LOCATION AND EXTENT OF THE CARLSBAD SPRINGS

The springs comprising the Carlsbad Springs group are situated in the north part of Carlsbad on the bottom and both sides of the bed of the Pecos River mostly along a three-mile stretch of the stream between the Southern Canal flume and Bataan Bridge (fig. 1).

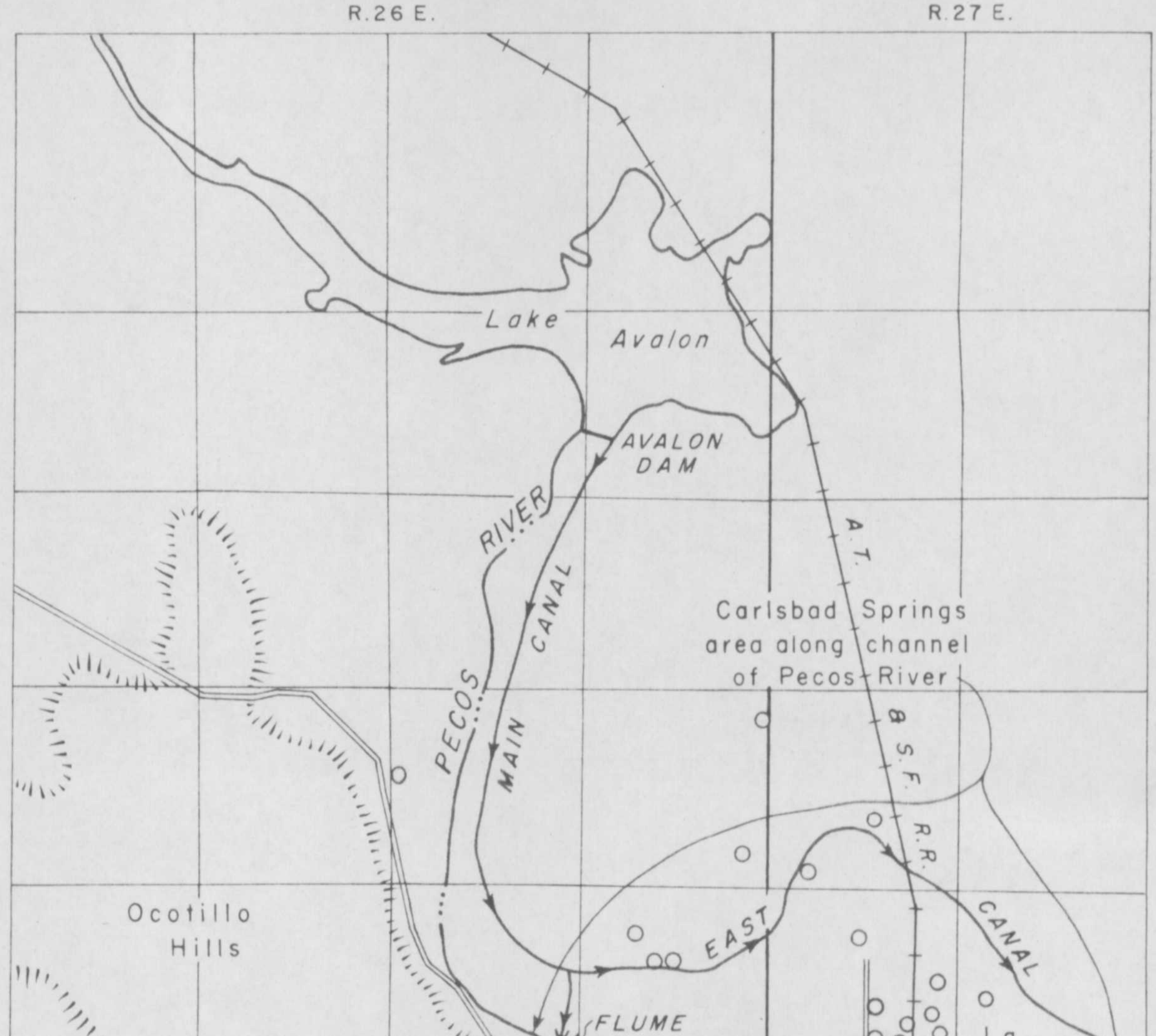

Figure 1.--Map of Carlsbad, New Mexico and vicinity showing Carlsbad Springs and large discharge wells that derive water from the limestone aquifer system.

Most of these springs, and also the largest springs, occur in the first mile below the flume. The lowermost spring found in the group is situated a short distance below Bataan Bridge on the right bank or west side of the streambed.

A single spring, called Carlsbad Spring, is situated in the SW$\frac{1}{4}$, Sec. 25, T. 21 S., R. 26 E. on the right bank or south side of the river a few hundred feet below the canal flume. This spring discharges between 1 and 3 cubic feet per second (cfs) into a concrete tank consturcted on the stream bank about 2 feet above the usual river surface. Other springs in the area, some of which are larger than Carlsbad Spring, are unknown to most local residents because their outlets are below the usual water level in the Tansill reservoir. In this report the name Carlsbad Springs is meant to include all the springs in the Carlsbad Spring area including Carlsbad Spring.

The largest individual springs in the Carlsbad Spring area are situated between 0.1 mile and 0.4 mile below the Southern Canal flume. According to measurements and estimates of spring discharge made in February 1955 when Tansill reservoir was drained, many of the springs in this part of the area discharge more than a cubic foot per second and one spring flow was measured at 8.4 cfs. The flow from a number of large springs that boil up through the streambed silt and mud in this vicinity could not be measured or estimated. The known total discharge of the Carlsbad Springs has ranged from about 30 cfs in 1956 to about 100 cfs in 1942.

GEOLOGIC SETTING OF CARLSBAD SPRINGS

The source of most of the water discharging from Carlsbad Springs is from the aquifer in the Capitan and adjacent limestone formations. The water, however, does not discharge directly into the Pecos River from this aquifer system but moves upward to the land surface through about 100 feet of alluvium or valley fill.

The Capitan Formation

The Capitan formation is a massive reef limestone of Permian age following the approximate location of the mountain front west and southwest of Carlsbad. The formation ranges in width from about 2 to 5 miles and is believed to be more than a thousand feet thick. Near Carlsbad it plunges below the land surface and underlies Happy Valley, West Carlsbad, and La Huerta and continues in subsurface in a northeasterly direction. The formation contains numerous interconnected solution channels and caverns in which water collects in transient storage. Water enters these channels from abutting geologic formations which dip toward the Capitan formation on the westerly side, from infiltration of flood waters in Dark Canyon and other mountain arroyos, from seepage from Lake Avalon or the Pecos River immediately above Lake Avalon, and from the canal below Lake Avalon. Water is prevented from entering or leaving the Capitan formation almost everywhere on the eastward side by the overlying and abutting anhydrite of the Castile formation. Near Carlsbad, where the Castile formation has been eroded away, the alluvium or valley fill has been deposited directly on the Capitan formation and the Carlsbad Springs have developed in the overlying alluvium where this occurred. The Carlsbad Springs are the major natural discharge for the water in the Capitan formation.

The Shelf Formations

The shelf formations that conduct water toward the Capitan formation are of Permian age and consist of the Tansill, Yates, Seven Rivers, Queen, and Grayburg formations (fig. 2). Water derived from precipitation in the Guadalupe Mountains and floods in ephemeral streams percolate into those formations and move along bedding planes, through cracks and joints, and through solution channels in gypsum, dolomite, or limestone toward the Capitan formation. Many of the solution channels in the Capitan aquifer extend into and tap these formations. This is especially true in the Tansill formation which abuts against and immediately overlies parts of the Capitan formation. The Carlsbad Caverns extend from the Capitan formation into the Tansill formation. In like manner solution channels containing ground water extend from one formation to the other in the vicinity of Carlsbad where they have been encountered in wells. In this particular locality the piezometric surface of the water in the Capitan formation is continuous into the Tansill formation. This system of aquifers in the Capitan and shelf formations is referred to as the limestone aquifer system.

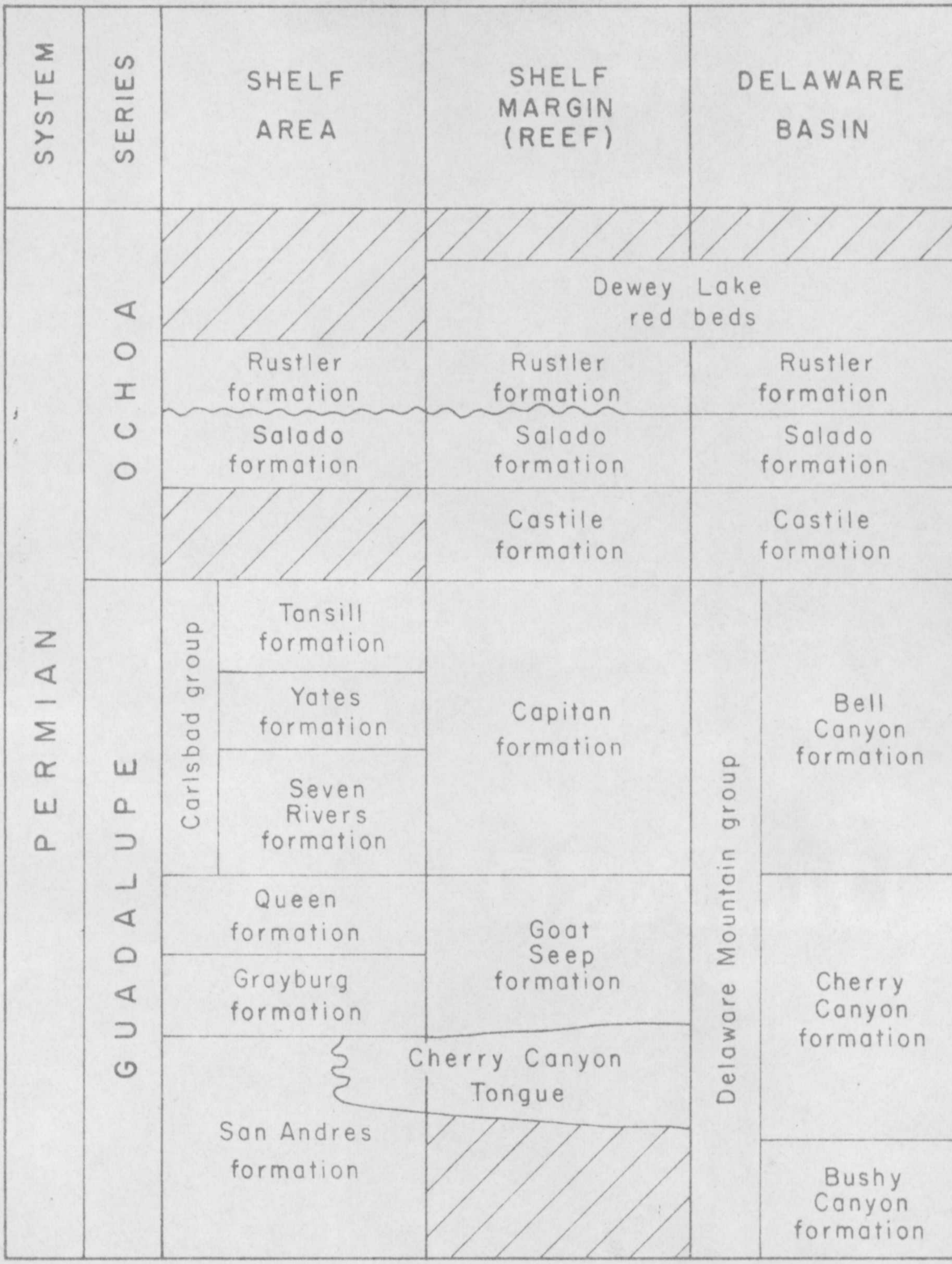

Figure 2.--Correlation of formations of Permian age in the vicinity of Carlsbad, N. Mex. (Modified from Motts, in Bjorklund and Motts, Geology and Water Resources of the Carlsbad area, Eddy Co., N. Mex., in preparation)

Alluvium or Valley Fill

The alluvium of Quaternary and Recent age consists of unconsolidated to consolidated boulders, cobbles, gravel, sand, and silt. Water is contained and transmitted between particles of unconsolidated rocks and, locally, in solution channels developed in consolidated limestone gravels. Both consolidated deposits, called limestone conglomerate, and unconsolidated deposits of alluvium occur in the vicinity of the Carlsbad Springs. Water is forced from the Capitan limestone and through the alluvium to the surface by a hydraulic head of a few feet. The discharge of water from the Capitan aquifer is retarded by resistance to the upward movement of water within the overlying alluvium; otherwise water in the Capitan aquifer above the altitude of the springs would drain away rapidly and the water involved would be lost from storage.

Limestone Conglomerate

The limestone conglomerate probably underlies all of the Carlsbad Spring area and adjacent areas and is exposed along the river bed in many places along the stretch where the springs occur. Although the bulk of the conglomerate is dense, extensive solution channels have developed along fractures in the rocks and many of the springs discharge directly from these solution channels in the conglomerate. Mud boils and sand boils occur along the streambed in places where the limestone conglomerate is covered with sand, silt, or mud. In the area surrounding the Carlsbad Springs ground water enters the solution channels in the limestone conglomerate from both saturated unconsolidated alluvium above and indirectly from the Capitan formation below. The limestone conglomerate probably is separated from the underlying Capitan formation by beds of unconsolidated gravels, sands, or silts, otherwise water in the solution channels of the limestone would escape rapidly through the conduits in the conglomerate.

ORIGIN OF WATER DISCHARGING FROM CARLSBAD SPRINGS

The Carlsbad Spring area is the discharge point for water moving through the limestone aquifer system toward the springs from the north, the south, the west, and probably to a small extent from the east. The water is derived from many sources and hence it is not surprising that the water discharged is a mixture of waters of different quality. North of the Carlsbad Springs, water enters the aquifer by seepage from Lake Avalon and the Pecos River above Lake Avalon, from seepage from canals and irrigated lands, and to a small extent from precipitation. South and west of the springs, water enters the aquifer from percolation from floods in mountain arroyos that are eroded into the Capitan formation, and from eastward movement of water into the aquifer from the various shelf formations. Some water may move from the east through the Capitan aquifer to be discharged at the springs but the amount would be small as the Capitan formation east of Carlsbad is covered in part by anhydrites and silts and other relatively impermeable materials that retard recharge to the aquifer in that area.

Seepage from Lake Avalon

An important source of the water discharged from Carlsbad Springs is seepage from Lake Avalon. This water percolates downward from the bed of the reservoir and probably enters solution channels in the Tansill formation directly beneath or adjacent to the reservoir. At a gage height of 12 feet, the water surface in the reservoir is about 60 feet above the water table in the Tansill formation immediately south and west of Lake Avalon. During most years between 10,000 and 20,000 acre-feet of water leaks from Lake Avalon through the underlying sediments into the ground-water reservoir.

The rate of leakage from Lake Avalon varies with the water stage and ranges from a very small amount when the reservoir is almost empty at gage-height 12 to more than 40 cfs when the reservoir is almost full at gage-height 20. This relation, shown in figure 3, was developed by determining the difference between inflow to Lake Avalon, measured at Damsite 3 gaging station, and outflow, measured at the main canal gaging station, during periods between May 1951 and December 1954 when the gage height of the reservoir was constant and correcting this difference for evaporation from the lake surface. There is, however, some loss in the flow of the Pecos River between the Damsite 3 gage and Lake Avalon and this loss is included as part of the leakage from Lake Avalon. In this reach the river is perched about 70 feet above the water table. Losses amounting to a few cubic feet per second have been measured in this reach and probably normally range between 1 and 5 cfs. Thus, most of the water lost between Damsite 3 and the outflow at the main canal is leakage from the reservoir. In figure 3, the leakage in cubic feet per second is plotted against the gage height of Lake Avalon in feet. The position of the plotted points suggests a linear relation between gage height and leakage and a straight line fit by method of least squares was drawn to express approximately this relation. Leakage quantities, discussed and illustrated in following sections, were determined from this relation of gage height to leakage.

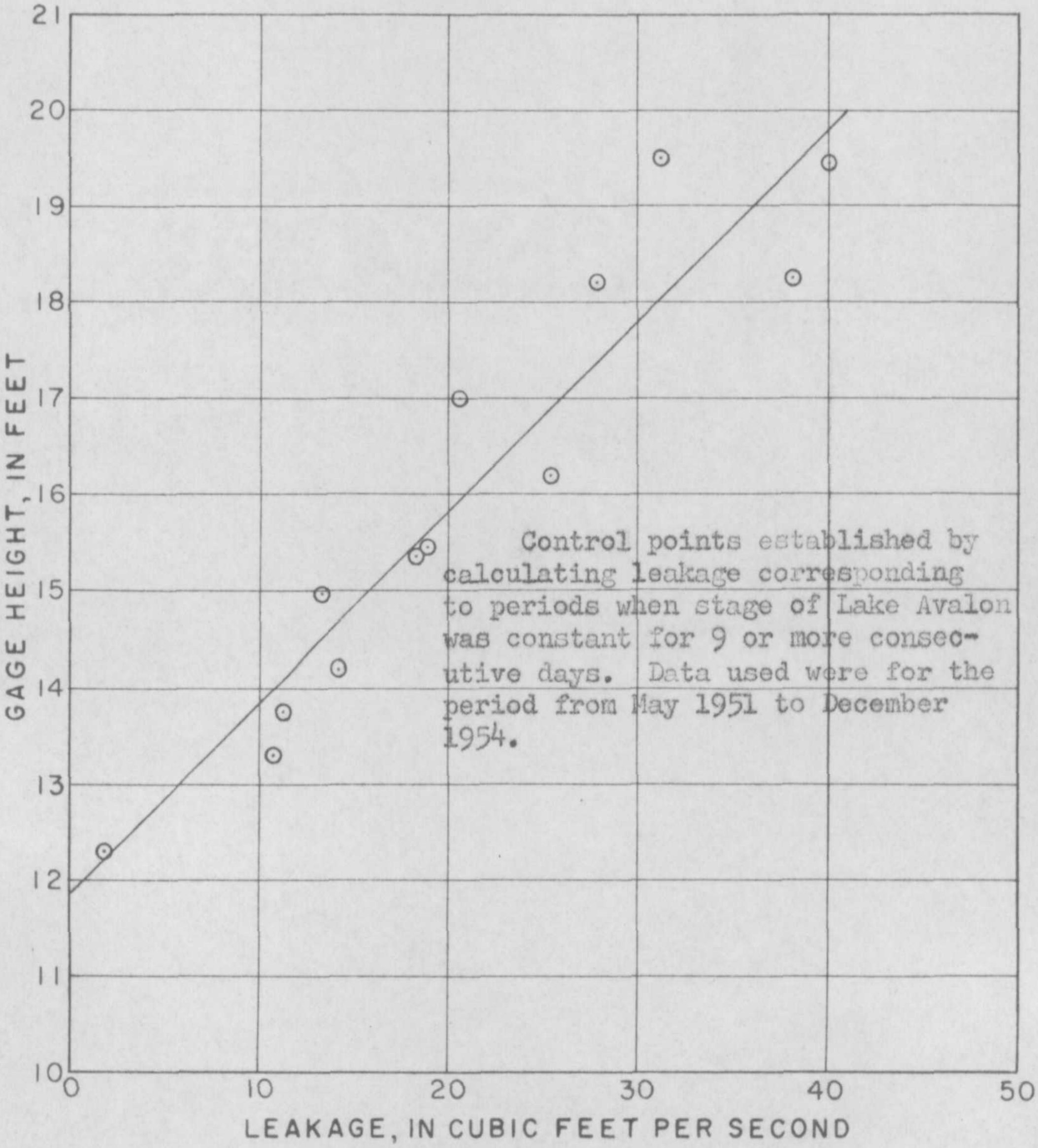

Fig. 3.--Relation of stage to leakage from Lake Avalon, Eddy County, N. Mex.

Average monthly leakage from Lake Avalon, based upon daily gage height readings since 1939 are shown in figure 3. A seasonal fluctuation is indicated; the greatest leakage occurs during the winter and early spring when water is being stored for use during the approaching irrigation season. Further, more leakage is indicated for the years 1940-1945 when more water was available for storage in Lake Avalon and less leakage is indicated for the years 1951-1954 when only a comparatively small quantity was available for storage in the reservoir due to general drouth conditions.

The water percolating from Lake Avalon to the limestone aquifer usually is quite highly mineralized, especially after a period of drouth. This water has leached minerals from the earth in upstream areas, including Roswell basin, where some of it is return flow from irrigation. Furthermore, the mineral constituents in the water have been concentrated by evaporation while being stored in Lake McMillan and Lake Avalon. Part of the water seeping from Lake McMillan into the evaporite facies of the Seven Rivers formation dissolves additional minerals while moving through solution channels in gypseous members of the Seven Rivers formation toward the discharge area at Major Johnson Springs at the south end of Roswell basin. Only during and following flood conditions in the Pecos River is the water in Lake Avalon relatively fresh.

Seepage from Canals

Seepage from three canals belonging to a common system contributes between 2,000 and 6,000 acre-feet each year to the flow from Carlsbad Springs. Seepage occurs in the Main Canal, which comprises a length of about 3 miles, from the diversion point at Lake Avalon southward to where it is divided into two canals, the Southern Canal and the East Canal. Seepage that contributes to the flow of Carlsbad Springs occurs also in both the Southern and East Canals for a distance of about 3 miles below the point of division (fig. 1).

It is estimated that about 5 percent of the annual flow in the canal system is lost by seepage in the stretches mentioned above and eventually is discharged as part of the flow from Carlsbad Springs. It is estimated also that, usually about 10 percent of the seepage occurs during the first quarter of each year, about 30 percent during the second quarter, about 60 percent during the third quarter, and a negligible amount during the fourth quarter of the year. These estimates are based on flow measurements made near both ends of the Main Canal and other considerations. The leakage from canals and also the leakage from Lake Avalon was related by quarter years to the flow of Carlsbad Springs, shown in figure 4, on the basis that one half of the leakage during a particular quarter appeared as spring flow during the quarter, one third during the following quarter and one sixth during the next quarter.

Recharge from Precipitation

Most of the potable water in the Capitan formation percolates to the aquifer during and following periods of heavy precipitation, either directly from floods in arroyos or canyons cutting into the formations or indirectly form water percolating into the shelf formations and thence into the Capitan formation. During periods of flow in ephemeral streams the gravels generally filling the streambeds become saturated with water which remains in the bed after the flood has past. Much of this water moving downstream through the gravels finds its way into rocks and solution channels in underlying bedrock and eventually reaches the ground-water reservoir in the Capitan formation. Water percolating directly into the Capitan formation from floods due to precipitation would be relatively pure as the Capitan formation is composed almost entirely of limestone and dolomites and the only minerals available in quantity for solution would be carbonates of calcium and magnesium. The water, therefore, is potable but rather hard.

Subsurface Movement of Water from Shelf Aquifers to the Capitan Aquifer

Water moves through the Tansill, Yates, Seven Rivers, Queen and Grayburg formations in the Guadalupe Mountain area toward the Capitan formation. Most of this water is potable as it is derived from rainfall and percolation in limestone terrain. Some of the water, however, percolates into the gypseous or evaporite facies of the shelf formations and is impotable due to a heavy concentration of sulfates. Nevertheless the average water contributed to the Capitan formation by subsurface movement of water from the shelf aquifers, which abut against and dip toward it, is potable.

Seepage from Irrigation

Water is applied to land adjacent to the Carlsbad Springs area for the irrigation of crops or watering of lawns, trees, shrubs or flowers. Some of this water percolates to the ground-water reservoir and is discharged at Carlsbad Springs. Very little of this water is believed to actually reach the limestone aquifer system, but is thought to move through the alluvium to the Carlsbad Springs. The quality of the water derived from seepage from irrigation generally is poor.

Other Sources of Recharge

A small quantity of water may move through solution channels in the limestone toward the springs from the northeast. This quantity would be small due to the lack of opportunity for recharge to the east where the limestone is covered with relatively impermeable anhydrites, silts, and clays, of, or derived from, the Castile, Rustler, or Salado formations. The water derived from this source would be heavily mineralized, especially in sulfates and chlorides but the small quantities involved would not significantly affect the quality of water discharged from the springs.

A small quantity of water probably moves toward the springs from the east and northeast through solution channels in the gypsum of the Rustler or Castile formations. Here again the quantity probably would be small because of the lack of opportunity for recharge due to overlying silts and anhydrites.

A small quantity of water may move southward from the Roswell basin through rocks of Permian age and finally reach solution channels in the Capitan formation and be discharged at Carlsbad Springs but there is no evidence that such movement of water occurs. The quantity of the water involved probably would not be significant due to the low permeability of the Permian rocks south of Major Johnson Springs.

DISCHARGE OF GROUND WATER AT CARLSBAD SPRINGS

The flow of the Pecos River below the Carlsbad Spring area is measured at the gage near Bataan Bridge in Carlsbad. Except during flood conditions and times when water is being released into the river from Lake Avalon or spills from the Southern Canal the river flow measured at Carlsbad is the spring discharge because all the flow at Avalon usually is diverted for irrigation and the river normally is dry between Avalon Dam and Carlsbad Springs. Therefore the Pecos River flow record at Carlsbad, corrected for floods and releases of water, is the discharge from Carlsbad Springs. A plot of the spring area discharge by months for 1939-56 is shown in figure 4.

The water discharged from the Carlsbad Springs represents mostly the natural discharge from the Capitan limestone aquifer. Under natural conditions a state of equilibrium existed whereby the natural discharge from the springs was equal to recharge over an extensive period of time; the flow from the springs was thus about equal to the recharge to the aquifer from the various sources. During recent years, however, a new factor of discharge, pumping from wells, has been introduced. Today, natural discharge plus artificial discharge is more nearly a measure of recharge over an extensive period of time. In other words flow from the Carlsbad Springs plus the net amount of water diverted by pumping from wells penetrating the Capitan limestone and the alluvium near the spring area is equal to recharge to the Capitan aquifer over an extensive period of time, provided there is no long term change in storage. Thus, in general, the flow of the springs is diminished by the net amount diverted by pumping from the limestone aquifer system and the alluvium in the vicinity of Carlsbad.

Rate and Fluctuation of Discharge

From 1939 through 1957 the flow from Carlsbad Springs has ranged from less than 30 cfs in the summer of 1954 to more than 100 cfs in the fall of 1941. There was a general decrease in flow from 1941 through 1947, a general increase through 1948 and 1949 and then a general decrease during the years 1950-1954. A slight increase is indicated in 1955 and a decrease during 1956. Many intermediate fluctuations of short duration have occurred during the period of record but no particular season is noted for either high or low flow. The monthly mean flow of the springs along with various factors that affect flow are shown plotted in figure 4.

The rate of flow from Carlsbad Springs depends on many factors including water levels in wells, rainfall, storage in Lake Avalon, pumping from wells, irrigation, atmospheric pressure and water stage in Tansill Reservoir. These factors are interrelated and some have positive and some negative effects on the flow of the springs; furthermore, some of the effects are drawn out; consequently the relation of discharge to the various factors is complex. For example a lack of water in Lake Avalon results in need for additional pumping from the ground-water reservoir; both conditions cause a decrease in spring flow. On the other hand, water available for irrigation and stored in Lake Avalon, and also local rainstorms, not only result in increased recharge to the water-bearing materials but also results in a reduction or cessation of pumping from wells for irrigation which in turn causes a greater discharge from the springs.

Relation of Discharge to Water Levels

A close relation exists between the altitude of static water levels in wells deriving water from the Capitan limestone and the rate of flow from the Carlsbad Springs. The difference in altitude between the water surface in Tansill Reservoir, into which the springs discharge, and the static water surface in wells penetrating the Capitan limestone in the area is an index of the quantity of water in the Capitan aquifer that is available for discharge at Carlsbad Springs although the precise quantities of water involved are not known. This difference in altitude also is the hydraulic head that determines the rate of ground-water movement toward the Carlsbad Springs through the alluvium overlying the Capitan aquifer. The relation between the altitudes of water in Capitan aquifer wells and the rates of discharge from the Carlsbad Springs is clearly indicated in figures 4 and 5. The water surface in Tansill Reservoir usually is maintained at an altitude of about 3,095 feet above sea level or slightly below the crest of Tansill Dam. Some of the springs discharge from the banks of the river several feet above the water surface of the reservoir, at altitudes of 3,097 or 3,098 feet above sea level but most of the springs discharge below the water surface of the reservoir. In January 1950 the water levels in limestone wells were almost at 3,108 feet; consequently the maximum head on any of the springs was 3,108 feet less 3,095 feet or 13 feet. In January 1957, however, the water levels were at 3,100 feet and the maximum head was 5 feet. If and when the altitude of water levels in the limestone aquifer system declines to about 3,095 feet above sea level the flow from Carlsbad Springs should stop. At this point some flow from the lowermost springs along the bottom of the

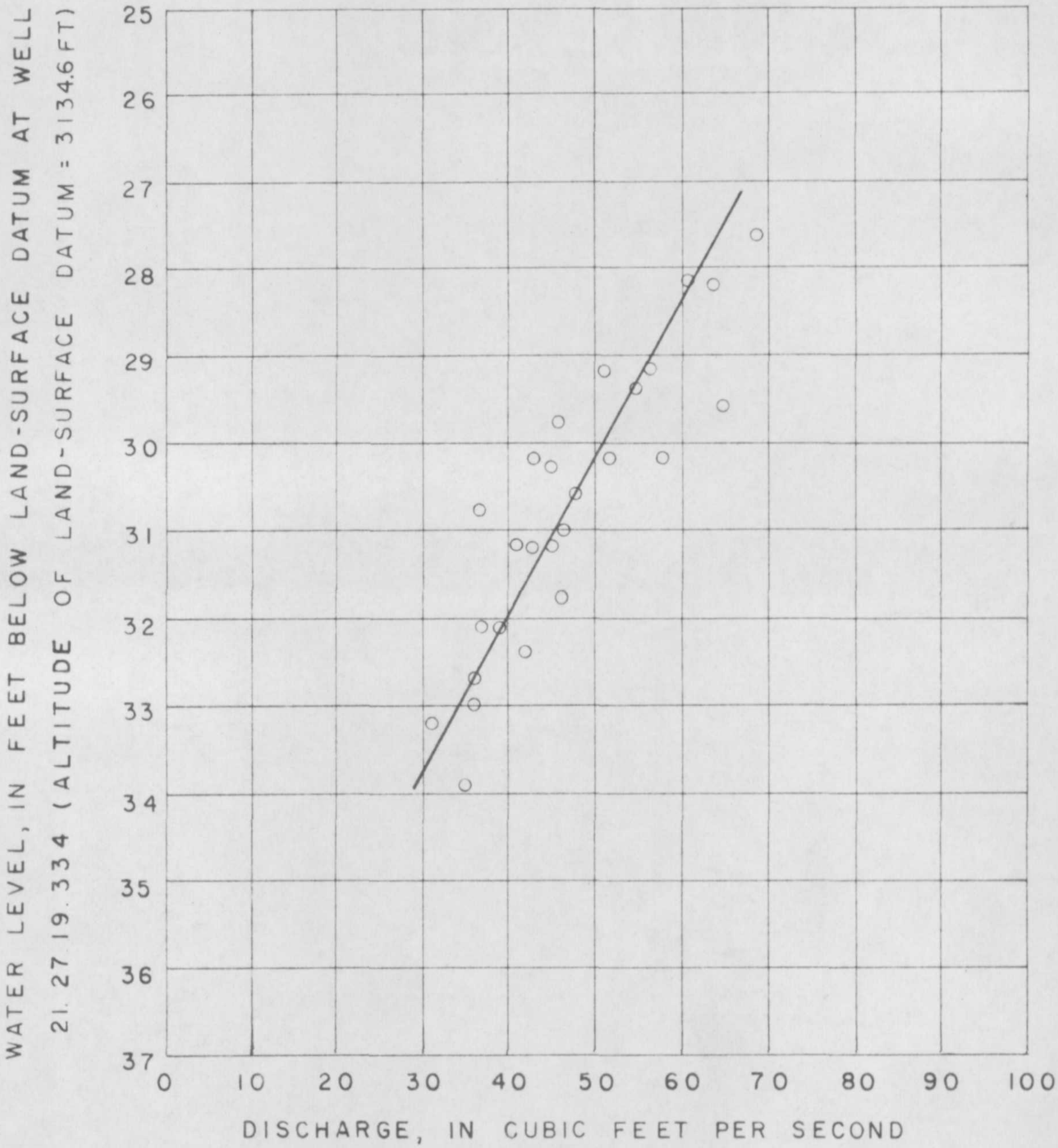

Figure 5.--Relation of water level in the limestone aquifer system to the rate of discharge from Carlsbad Springs, Eddy County, N. Mex.

reservoir could be induced by lowering the water level in the reservoir. As the water levels in the limestone continue to decline the water level in the reservoir will have to be lowered more and more to maintain a flow from the springs. If and when water levels in the limestone reach a point below the bed of Tansill Reservoir the hydraulic head will reverse and water in the Pecos River derived from other sources such as flood waters will drain from the reservoir through the alluvium into the limestone aquifer.

The Effects of Precipitation on Carlsbad Spring Discharge

The flow from Carlsbad Springs, extracted from streamflow records since 1939, has been greatest following heavy general rains. During 1941, when almost three times the normal precipitation occurred in the area, the rate of springs discharge increased from about 60 to more than 100 cfs. The effects of this heavy precipitation lasted for several years and the flow remained above 60 cfs until the summer of 1946. Another increase in discharge occurred in 1949 and 1950 and this was due to near or slightly above normal precipitation during 1948, 1949, and 1950. The highest discharge during this period was about 80 cfs. Drouth or near-drouth conditions followed these relatively wet years with the result that the spring discharge declined steadily and became less that 30 cfs in 1954. Late in 1954 two heavy rainstorms caused a rise in water levels with a consequent increase in spring discharge. Relatively dry conditions followed with the result that the spring discharge became less than 30 cfs late in 1956.

Precipitation affects spring flow in that it replenishes the ground-water reservoir and causes a rise in water levels which in turn would increase the rate of spring flow. Heavy flood-producing storms seem to have a greater effect than slow soaking storms. This probably is because much of the recharge comes from percolation from flooded arroyos. The greatest effect probably would be from slow soaking rains followed by heavy rains.

The effect of the heavy rains in August and October 1954 on water levels and also spring discharge is shown in figure 4. The evidence for abrupt rises in water level was obtained from a recording gage on well 22.26.2.242 which penetrates the Capitan limestone several miles from any likely source of recharge. Water levels in the aquifer rose almost two feet within a few hours and then continued to rise at a slow rate throughout 1955 amounting to a total rise of almost 4 feet. During this time the spring discharge increased from less than 30 cfs to more than 50 cfs.

Effects of Water Stage at Lake Avalon on Discharge from Carlsbad Springs

The rate of leakage from Lake Avalon to underlying geologic formations, affects the rate of discharge from Carlsbad Springs. Percolation of water to the ground-water reservoir in the Capitan limestone rises water levels and increases the hydraulic head which forces water to the surface at Carlsbad Springs. The net effect of seepage from Lake Avalon on the discharge at Carlsbad Springs probably lags from one to three months as is indicated in figure 4 for the years 1943-1947. These years probably are the best indices of the effects of water stage at Lake Avalon on the discharge from Carlsbad Springs because the water stage was high during winter months and low during summer months and also because effects due to pumping from the limestone aquifer for irrigation were not appreciable because of the small amount of water pumped.

The correlation of leakage from Lake Avalon with the flow of Carlsbad Springs shown in figure 4, was applied by quarter years on the basis that one half the leakage would be reflected in the spring flow during the first quarter, one third the leakage would appear in the spring flow during the second quarter, and one sixth during the third quarter.

Effects of Pumping from Wells on the Discharge from Carlsbad Springs

It is estimated that water pumped from the Capitan formation for irrigation, public supply, industrial use, and other uses amounted to about 16,950 acre-feet in 1956, 15,200 acre-feet in 1955, and 15,070 acre-feet in 1954. The quantities estimated for 1945 and 1939 were 7,200 and 2,488 acre-feet respectively (Hendrickson and Jones, 1952, p. 59).

The increasing withdrawal of water from the aquifers during recent years is a factor in causing declining ground-water levels and consequently a reduction in spring flow over that of the spring flow had no pumping occurred. It is significant that a decline in water levels and spring discharge has been concomitant with increasing pumpage from wells although drouth conditions have also caused a decline and decrease in spring flow because of decreased recharge. A decrease in spring flow during the summer months, which is the season of heaviest pumping, is indicated for

1953, 1954, 1955, and 1956 in figure 4. It is significant also that the total water leaving the aquifer, spring flow plus pumpage, has increased each year since 1953.

Effects of Canal Loss and Irrigation Return on Discharge from Carlsbad Springs

Some of the water diverted from Lake Avalon for irrigation seeps from canals, ditches, and irrigated fields to return to the ground-water reservoir. In like manner some of the water pumped from wells for irrigation, including sprinkling of lawns, percolates back to the ground-water reservoir. Probably about 25 percent of the water applied to the land in the vicinity of Carlsbad seeps into the alluvium and is discharged into the Pecos River in the Carlsbad Springs area. Very little of this water actually reaches the Capitan formation; this is especially true in the vicinity of La Huerta where water in the alluvium stands at a lower hydraulic head than water in the underlying limestone.

Relation of Water in Storage in the Capitan formation to the Discharge from Carlsbad Springs

The Piezometric surface of the water in the Capitan aquifer is virtually level, due to the relatively free and unimpeded movement of water within the interconnected solution channels, consequently a rise or decline of water levels is consistant over a large area and is an index to a gain to or loss from storage in the aquifer of approximately the same quantity of water per unit area of aquifer. The change in the quantity of water in storage over the entire aquifer represented by a change in water levels is not known although the general magnitude of the volume may be inferred from considerations based on data collected and shown in part in table 1 and figures 4 and 5.

It is believed that between 500 and 1,000 acre-feet of water would be required to raise the water level in the Capitan aquifer one foot. This conclusion is based on the following observations and calculations: There have been several extended periods when little or no net changes in water level in the aquifer have occurred. During such a period net inflow was assumed to be equal to net outflow. Thus spring discharge plus pumpage during the period should be equal to the total of the effects of seepage from Lake Avalon, seepage from canals, irrigation return, and inflow to the aquifer from the shelf aquifers in the Guadalupe Mountain area. All of these items except inflow from the shelf aquifers can be estimated directly and are contained in table 1 and figure 4. The inflow from the shelf aquifers was solved for each period of no-water-level-change by using the simple equation indicated above. These values ranged from 16 cfs when water levels were low during the summer of 1954 to 64 cfs when water levels were highest during 1941 although the bulk of the results ranged between 16 and 41 cfs. Periods of water-level decline, during which outflow from the aquifer was greater than inflow, were then selected and values for spring flow, pumpage, leakage from Lake Avalon, leakage from canals, irrigation return, and inflow from the shelf aquifers were then applied for each period selected. The difference between inflow and outflow derived from the above relationship was the amount of discharge causing the change in water level and the change in storage. Estimates of the change in storage based on the various periods of decline ranged from about 300 to about 1,100 acre-feet for each foot of water level. If the highly permeable part of the Capitan aquifer includes an area of 100 aquare miles (25 miles long and 4 miles wide) these figures would indicate storage coefficients ranging from about .005 to about .015.

Table 1.--Average annual flow from Carlsbad Springs, Eddy County, N. Mex., and the flow accredited to various sources of recharge, in cubic feet per second

Year	Total Spring Flow	Contribution to Spring Flow			
		Canal loss	Irrigation return	Seepage from Lake Avalon	Previously unmeasured water
1940	65	8	3	27	27
1941	94	5	3	35	51
1942	102	7	3	33	59
1943	94	8	3	28	55
1944	82	6	3	25	48
1945	78	5	3	23	47
1946	71	5	3	24	39
1947	62	4	3	21	34
1948	54	5	3	21	25
1949	70	6	3	30	31
1950	66	6	3	27	30
1951	54	6	4	20	24
1952	41	5	4	20	12
1953	35	4	4	23	4
1954	38	4	4	27	3
1955	42	7	4	27	4
1956	36	6	4	21	5

The Capitan formation functions as a regulating reservoir for probably a relatively large quantity of water stored in the shelf aquifers, which cover a much larger area than the Capitan formation, and also for water entering the aquifer from the other sources. When the inflow rate to the Capitan aquifer from the various sources is greater than the outflow rate there is an increase in storage resulting in an increase in the hydraulic head on Carlsbad Springs and, consequently, an increase in the rate of discharge from the springs. The heavy rainstorms of August 22-24 and October 4-6 in 1954 caused a rather sharp rise in water levels of about 2 feet followed by a slow steady rise that lasted throughout 1955 and amounted to almost two feet (fig. 4). Both rises were due to the heavy general rains, the sharp initial rise probably caused by water entering the aquifer directly from floods in arroyos that are cut into the Capitan formation and the slow steady rise probably from an increase in inflow from the shelf aquifers. The sharp rise probably was augmented by a temporary retardation or cessation of the flow from Carlsbad Springs caused by flood conditions which lasted for several days in the Pecos River. During this flood all of the springs were innundated by several feet of water. The quantity of the water entering the aquifer from the shelf aquifers during the 14 months of slow steady rise was much greater than the quantity that caused the sharp rise in November, 1954 although the net change in storage was about the same. This is because most of the water that entered the aquifer during the slow steady rise was discharged from springs and wells during the same period.

INTERRELATION OF THE COMPONENTS OF DISCHARGE FROM CARLSBAD SPRINGS

The total discharge from Carlsbad Springs, shown graphically in figure 4 and in tabular form in table 1, is derived from several components. These components may be listed as follows: (1) Discharge due to underground leakage from Lake Avalon, including the Pecos River immediately above Lake Avalon, (2) Discharge due to leakage from canals, (3) Discharge due to irrigation return, including the watering of lawns etc. in the north part of Carlsbad and (4) Discharge due to natural recharge resulting mostly from precipitation in the Guadalupe Mountain area west of Carlsbad.

Previously unmeasured water contributing to the flow of Pecos River at Carlsbad Springs

Discharge due to natural recharge, listed as item (4) in the paragraph above, may be divided into two separate components, (1) discharge due to direct recharge to the Capitan formation from floods in arroyos eroded into the formation and (2) discharge due to indirect recharge to the Capitan formation from precipitation, or inflow into the Capitan formation from the shelf aquifers. In either case this water is not previously measured in the flow of the Pecos River and may be regarded as side inflow to the Pecos River or "new" water. All other water emerging from Carlsbad Springs presumably has been previously measured, estimated, and accounted for along the course of the Pecos River upstream.

The flow of previously unmeasured water derived from the Capitan aquifer, shown in table 1 and figure 4, was determined by extracting the effects of underground leakage from Lake Avalon, canals, and irrigation from the total flow of Carlsbad Springs. This was done by quarter-year increments with the assumption that one half the water lost by seepage was discharged from the springs during the current quarter year, one third of the water was discharged during the second or following quarter, and one sixth of the water was discharged during the third quarter. Other lag-effect combinations were tried but the method based on the above assumptions resulted in the best correlation. While it is recognized that the methods used in evaluating the flow from Carlsbad Springs are not perfect it is believed that the end results are logical and, in general, true.

The average annual amount of previously unmeasured water flowing from Carlsbad Springs ranged from about 60 cfs in 1942 to about 5 cfs in 1954. Except for 1949 and 1950 and part of 1954 and 1955 the amount of this water emerging at the springs since 1942 has diminished steadily. During the excepted periods a slight increase in previously unmeasured water occurred due to heavy precipitation in 1949 and 1950 and also late in 1954. It is noteworthy that the discharge of previously unmeasured water increased from about 25 cfs in 1940 to about 60 cfs in 1942, due mostly to heavy precipitation during 1941 when more than 30 inches of water fell in most of the general area. Near average and greater-than average rainfall continued through 1946 with the result that the discharged new water derived from natural recharge remained above 40 cfs through 1945. During 1946 pumping from the Capitan formation for irrigation and other uses was a potent factor in decreasing the natural discharge of previously unaccounted water to about 29 cfs during late summer and early fall.

During 1946 through 1956 the amount of previously unmeasured water discharged from Carlsbad Springs decreased significantly due to the combination of general drouth conditions and diversion from natural discharge by pumping from wells. Although the average annual discharge of new water remained above zero during these years the average quaterly discharge went below zero during or following the heavy pumping seasons of 1953 and 1954. During these relatively brief periods the pumpage in excess of available "new" water was supplied by water that had seeped from Lake Avalon, canals, and irrigation.

Total Previously Unmeasured Water discharged from the Capitan Formation

The total previously unmeasured water discharged from the Capitan aquifer was determined by adding the pumpage to the previously unmeasured water discharged at the Carlsbad Springs. These quantities are shown on an average annual basis in figure 4. These figures range from about 70 cfs in 1942 to about 25 cfs in 1954. It should be noted here that the average annual pumpage from the Capitan aquifer has increased from about 3 cfs in 1940 to about 22 cfs in 1954 and 1956. As these pumpage figures approach the figures representing the total discharge of previously unmeasured water, more and more of the water is diverted from natural discharge. Thus, in 1954, all but 5 cfs of this water was diverted from natural discharge. If and when the two curves coincide all the previously unmeasured water will be diverted from natural discharge and used before it reaches the Pecos River. If and when the curves cross, indicating that pumpage is greater than the total supply of previously unmeasured water, the difference must be supplied from water that has seeped from Lake Avalon, canals, or irrigation. This will result in a general lowering of the average quality of the water in the Capitan aquifer. As more and more previously unmeasured water is diverted from natural discharge the average chemical constituents in the water being discharged at the springs should increase and approach the average chemical content of the water in Lake Avalon. If and when the pumpage becomes large enough to divert all the water being discharged at Carlsbad Springs, including all the water seeping from Lake Avalon, canals, and irrigation in addition to previously unmeasured water from the Capitan aquifer, the springs will cease to flow.