Causes of Depletion of the Pecos River in New Mexico

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By HAROLD E. THOMAS

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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Effects of recent ground-water development, drought, and phreatophytes

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ABSTRACT

The contribution of water to the Pecos River in the reach between Alamogordo Dam and Red Bluff Reservoir has been trending downward for the past 40 years. This reach, the middle basin of the Pecos River, has been the scene of several significant changes in recent decades, each of them capable of causing a depletion of the Pecos River flow. Although several other factors may be involved in the streamflow depletion measured to date (1958), the principal causes are conceded to be the ground-water developments near Roswell and near Carlsbad, and the natural factors of drought and encroaching phreatophytes.

INTRODUCTION

The Pecos River Compact, entered into by the States of New Mexico and Texas (U.S. Congress, 1949), contains the following key provision: "* * * New Mexico shall not deplete by man's activities the flow of the Pecos River at the New Mexico-Texas State line below an amount which will give to Texas a quantity of water equivalent to that available under the 1947 condition." In any river basin such a provision would pose interesting problems in hydrology, first to establish the fact of depletion below the "1947 condition" and then to determine to what extent that depletion results respectively from man's activities and from natural causes. In the Pecos River basin the determination of the effect of man's activities is complicated by the close interrelation of surface water and ground water and by the great development and use of ground water within the basin.

The Pecos River (fig. 1) rises in the southern Rocky Mountains, flows south across eastern New Mexico and southeast across west Texas, and enters the Rio Grande which forms the international boundary between Texas and Mexico. The Pecos River has a drainage basin of about 35,000 square miles, which is conveniently divided into an upper basin of 4,000 square miles above Alamogordo Reservoir in New Mexico, a middle basin of 16,000 square miles above Red Bluff

FIGURE 1.—Map of Pecos River basin.

Reservoir also in New Mexico, and a lower basin of 15,000 square miles in Texas (Natl. Resources Plan. Board, 1942a). The basin has a semiarid continental climate, and winters that are cold enough but usually too dry for snow, and summers that are hot and dry but punctuated by frequent, local, and intense convectional storms. In four-fifths of the basin the average annual precipitation ranges from 12 to 16 inches, although small headwater areas receive more than 30 inches. About 75 percent of the annual total falls during the 6-month growing season May through October. Irrigation is a prerequisite in all parts of the basin suitable for agriculture because of the low average seasonal rainfall and because of great variations from that average, both from place to place and from time to time.

Soluble rocks are of critical importance in the hydrology of the Pecos River basin, especially in the parts that lie in New Mexico. Strata of limestone, anhydrite and gypsum, halite, and other evaporites (including the valuable mineral sylvite) were deposited about 200 million years ago during the Permian period. Although there has been great reduction of their original thickness in many places by solution and other forms of erosion, the Permian strata in the Pecos River basin presently have an aggregate thickness of 6,000 to 18,000 feet. This includes great thicknesses of soluble rocks in practically all the basin in New Mexico, except for small areas in the mountainous headwaters. Where the soluble salts have been removed, there remain caverns (of which the Carlsbad Caverns are most famed), sinkholes, so-called bottomless pits, ponds, closed depressions, leaks in constructed surface reservoirs, areas of slumping, and changes in the pattern of surface drainage. The soluble salts now being removed contribute mineral matter to ground water, and thence also to the Pecos River and to irrigated soils in many places. Some of the limestone strata, after long exposure to solution by circulating water, are now very productive aquifers.

Obviously ground water has special significance in the Pecos River basin (Natl. Resources Plan. Board, 1942b, p. 27–102), chiefly because of the abundance of soluble rocks. Wells and springs furnish most of the water used for irrigation and for the relatively small municipal and industrial supplies. Much of the rainfall, streamflow, and water collected in surface reservoirs is diverted underground or evaporated in closed basins. Much of this ground water eventually reaches the main stream, and the Pecos River naturally has a substantial dry-weather flow. However, some of the ground water contributed to the river is by brine springs, which increase the salinity of the river substantially and make the entire supply less suitable for irrigation. Some of the ground water maintains water-loving but useless vegetation along the river bottoms so that the water supply for beneficial use downstream is reduced.

EVIDENCE OF DEPLETION

The outflow of the Pecos River from the middle basin (as it enters Red Bluff Reservoir), and the outflow from the upper basin (above Alamogordo Reservoir) have been gaged for more than 50 years. For the first 30 years until 1934 the runoff into the lower reservoir averaged about 50 percent greater than that into the upper reservoir. From 1935 to 1958 however, the middle basin has contributed substantially to the river in only 5 of the 23 years. In the decade 1946–55, the outflow from the middle basin was 23 percent less than the quantity entering the middle basin from the upper basin.

In the upper basin the irrigated acreage and irrigation practice have changed little in the past half century, or indeed since the days of Spanish colonization; the annual outflow from the upper basin has been within 20 percent of the median in more than half the years of record, reflecting the stability in pattern of use as well as the natural stability provided by ground-water storage. By contrast, the water production of the middle basin, as computed by the difference in runoff measured at the Alamogordo and Red Bluff gaging stations, has trended generally downward for the past 40 years (fig. 2). This depletion, however, was most marked in the 30 years preceding 1947. Although the Pecos River Compact sets 1947 as the beginning of a new era in the basin, any analysis of possible causes of depletion must include also the records for earlier years, when there was clear evidence of depletion of the flow of the river as it traversed the middle basin (Pecos River Compact Comm., 1948).

POSSIBLE CAUSES OF DEPLETION

The middle basin of the Pecos River has been the scene of several significant changes in recent decades, each of them capable of causing a progressive depletion of the Pecos River flow (Thomas and others, written communication, 1959). Some of these changes are clearly products of man's activity. Use of water from the Roswell ground-water basin for irrigation increased from about 160,000 acre-feet upon 55,000 acres in 1930 to 450,000 acre-feet upon 125,000 acres in 1954. Pumping from wells in the Carlsbad area was negligible prior to 1945, but has exceeded 60,000 acre-feet in some years since then.

Natural phenomena are also partly responsible for the streamflow depletion, and drought is one of these. Precipitation at representative localities has been less than the long-term mean in 18 of the 25 years during 1932–56. In the same quarter century the bottom land area infested by the water-loving saltcedar (*Tamarix pentandra*) increased from about 10,000 to 40,000 acres.

Although several other factors may also be involved in the streamflow depletion measured to date (1958), the principal causes are conceded to be the ground-water developments at Roswell and Carlsbad, and the natural factors of drought and encroaching phreatophytes.

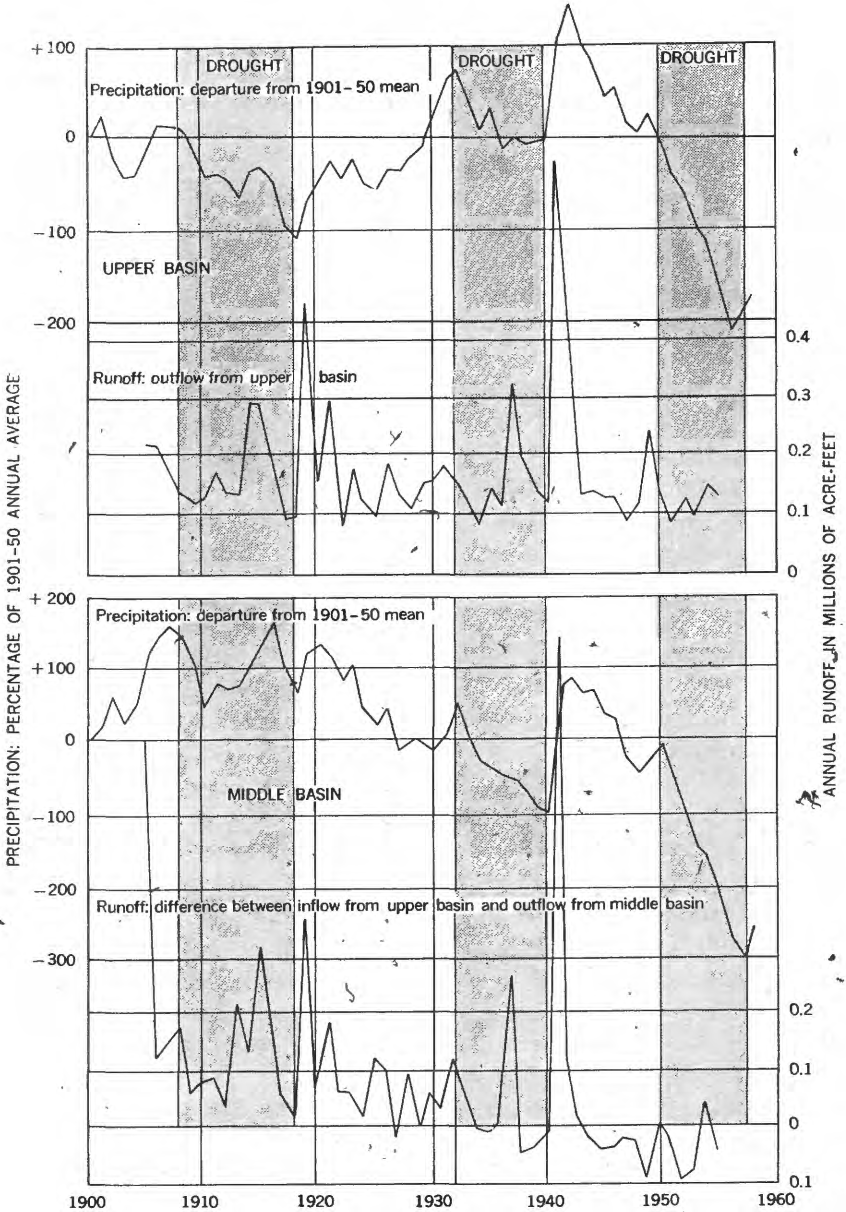

FIGURE 2.—Trends in precipitation and runoff, 1900–58.

DROUGHT

In the Pecos River basin, as in most of the arid southwestern United States, the term "drought" is not applied to a few rainless weeks or even to a year of deficient precipitation, because such events are commonplace and expected, and are ameliorated by water that had previously been accumulated in surface- or ground-water reservoirs. Instead, drought is commonly reserved for a succession of dry years, when the cumulative deficiency in precipitation is sufficient to be reflected in depleted storage in those reservoirs.

In the Great Plains, which lie east and north of the Pecos River basin, extended droughts occurred in 1909–18, 1933–40, and 1951–57 inclusive. Graphs of cumulative departure from average precipitation of representative localities (fig. 2) show that the precipitation within the Pecos River basin was deficient during each of these periods (shaded on fig. 2), and especially so during the most recent one (1951–57). The uppermost graph shows the cumulative departure from average precipitation at two localities (Las Vegas and Santa Rosa, fig. 1) in the upper basin. The second graph shows the annual outflow from the upper basin—less during droughts than during the intervening wetter years—but no indication of progressive diminution.

The third graph shows the cumulative departure from average precipitation at three places (Roswell, Artesia, and Carlsbad, fig. 1) in the middle basin. In the 40 years from 1917 to 1957, there was a net deficiency of precipitation equivalent to four times the annual average, reflected in the record of streamflow generated by the middle basin, which is computed as the difference between the measured inflow and outflow, as shown in the lowest graph.

A cumulative-mass diagram of precipitation and runoff in the middle basin (fig. 3) shows that the contributions from the middle basin to the Pecos River per unit of precipitation have decreased progressively since 1919, and have been negative (that is, the Pecos has lost water within the middle basin) since 1943. This decrease may be ascribed in part to drought, for abundant precipitation causes not only higher runoff but a higher proportion of runoff. But since there were droughts also in the early part of the record, it is not possible to attribute the progressive change in precipitation-runoff relation entirely to drought.

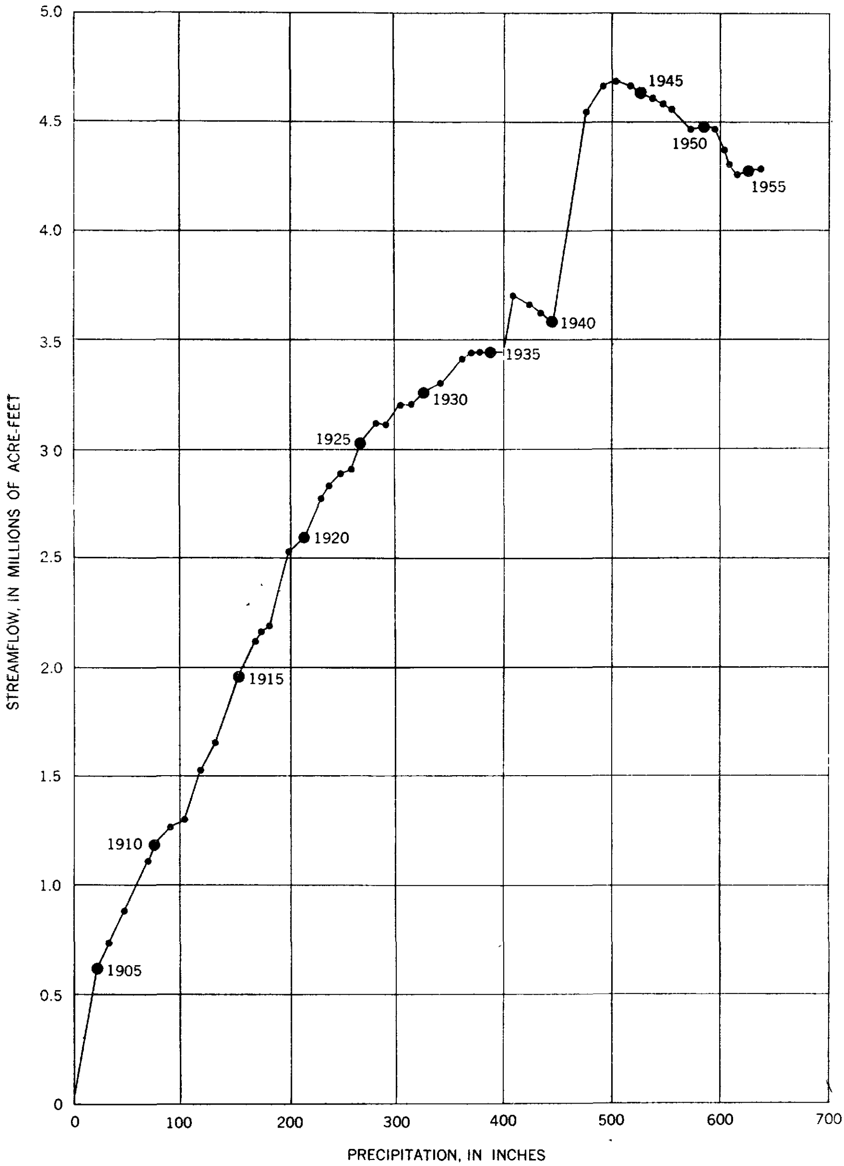

Figure 3.—Cumulative-mass diagram of precipitation-runoff relation in the Pecos River middle basin, 1905–57.

PHREATOPHYTES

The Pecos River flood plains apparently provide an ideal environment for the saltcedar, for it has spread rapidly and displaced most of the native phreatophytes since it was first observed near Lake McMillan in 1914. Starting with about 500 acres within the middle basin of the Pecos River in 1915, the area covered by saltcedar increased to 15,000 acres by 1939, 25,000 by 1946, and 40,000 acres by 1957 (Thompson, 1959). The water consumed by saltcedar in the middle basin during 1957 is estimated at 100,000 acre-feet.

The water consumed by saltcedar and other phreatophytes along the Pecos River is a direct draft upon ground water that might otherwise have contributed to riverflow (or in some areas, ground water that must be replaced by seepage from the river). Thus the progressive depletion of riverflow since 1920 may result in part from the concurrent increase in saltcedar infestation. In particular, the net reduction in recent years of riverflow between the gaging stations at the upper and lower ends of the middle basin is caused by consumption of water within the flood plain, and this is chiefly by phreatophytes.

WELLS IN ROSWELL AREA

The Roswell ground-water basin is an eastward-sloping area bounded by a mountain crest on the west and the Pecos River on the east; the basin extends nearly 150 miles from north to south (fig. 1). The broad pattern of the hydrologic cycle in the Roswell basin includes inflow (by precipitation) which is greatest at the west boundary, eastward movement of this water both underground and in ephemeral streams with some losses by evapotranspiration, and eventual disposal to the Pecos. The streams flowing eastward have formed an alluvial basin that extends along the Pecos River for about 70 miles and ranges in width from 10 to 25 miles. Alluvial plains and terraces built by these streams are now the areas most desirable for agricultural use, and include practically all the area presently under irrigation. The alluvial sediments are less than 200 feet thick in most places, but they constitute an important aquifer in the Roswell area.

The major source of water in the Roswell area, however, is the San Andres limestone of Permian age, which is more than 1,000 feet thick and yields water for irrigation of 75,000 acres. In the irrigated area the top of the San Andres ranges from 250 to 1,200 feet below the surface; it is covered by red beds, sandstone, shale, and gypsum of the Permian Chalk Bluff formation, and by the shallow alluvial aquifer. The San Andres also occurs east of the Pecos, where it has an eastward dip and therefore occurs at increasing depth, but wells east of the Pecos have generally produced brine.

A quantitative study of the Roswell ground-water reservoir by Hantush (1955) confirms the conclusion reached by Fiedler and Nye (1933) that the San Andres artesian reservoir is capable of a sustained yield of about 240,000 acre-feet per year. Hantush's analysis includes the shallow alluvial aquifer, the San Andres, and the less permeable formations that bound these aquifers because they are all elements in a relatively continuous hydraulic system from the western edge of their outcrop areas to at least as far downdip as they contain usable water. The uppermost graph of figure 4 shows the annual recharge to the San Andres reservoir as computed by Hantush—greater in each year during 1936–44 than the long-term average but less than that average in most subsequent years. The estimated withdrawal from artesian wells is indicated by shading below this graph, forming a band that is narrowest in wet 1941, when withdrawals were less than 100,000 acre-feet, and becomes progressively wider until 1953, when withdrawals exceeded 300,000 acre-feet. After 1944 the withdrawals exceeded the calculated recharge in all but 3 years. Hydraulic head was sufficient to promote upward leakage from the San Andres until 1953, although at diminishing rates; since 1953 the leakage has been downward and into the San Andres. As shown by the graph of summation of gains and losses, recharge exceeded discharge in only 4 years (1941–43, and 1949) during 1935–55. The gains in these years, however, were sufficient to offset the computed losses until 1953, as shown by the graph of cumulative changes in storage. This constructed graph has trends similar to trends in water level in a well near Artesia, except the well indicates that the increased storage resulting from 1941 precipitation was entirely dissipated by 1950. Pumping since 1950 has reduced the storage in the limestone aquifer to less than ever before in history.

The recharge to the shallow alluvial aquifer is by leakage from the artesian aquifer, local precipitation, and seepage from irrigation. Pumpage from the shallow reservoir was greater than the total recharge by leakage, precipitation, and irrigation in 1947 and 1948, and in every year since 1950. This pumping has replaced seepage to the Pecos River as the principal means of discharge from the shallow reservoir. However, seepage to the river has not been eliminated even in recent years of heavy pumping. The annual discharge to the Pecos River, estimated from differences in runoff of the Pecos River at Acme and Artesia, is shown by the lowest graph of figure 4. During the pumping season, however, seepage is reduced markedly, and much of it may never reach the river because of evaportranspiration.

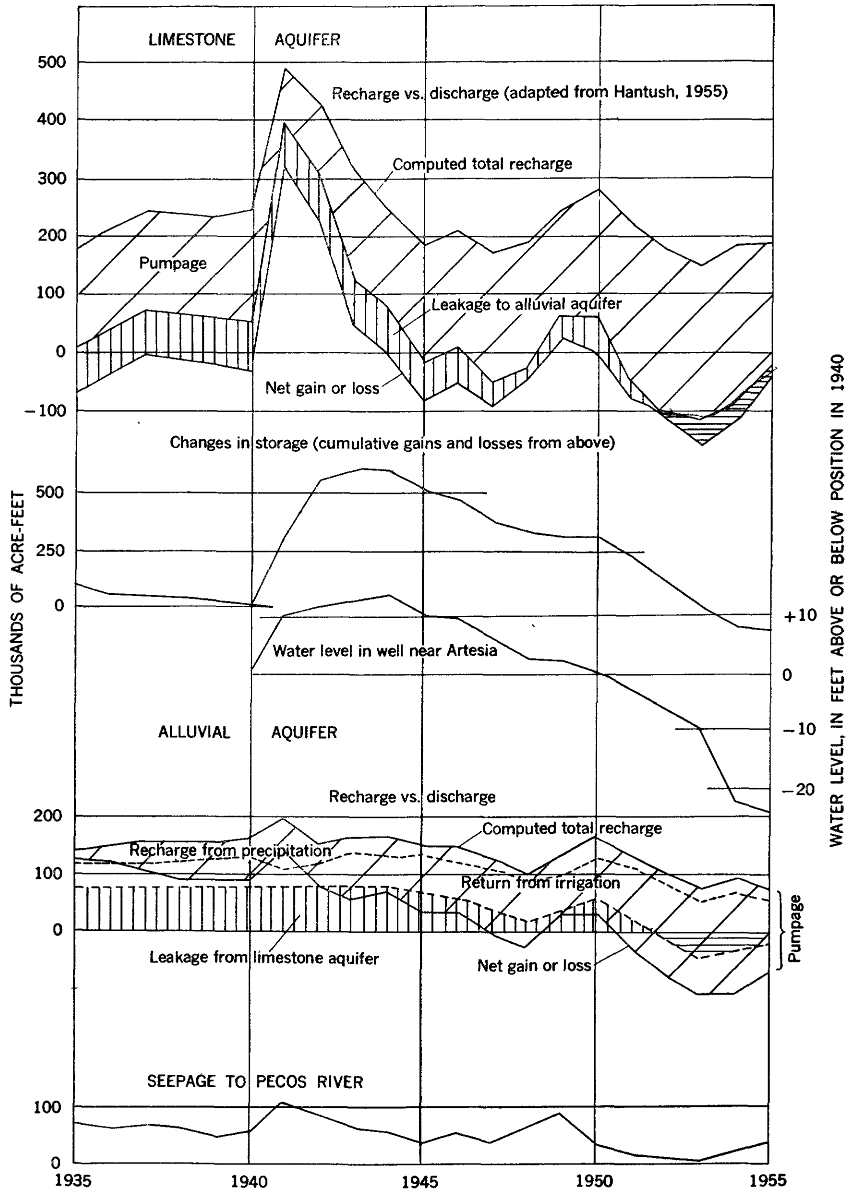

FIGURE 4.—Trends in recharge, discharge, and storage, 1936–56, for the Roswell ground-water basin.

Partly because of this seasonal reduction, the annual gain in riverflow as it traversed the Roswell basin was much less during 1951–54 than in any previous year of record. Nevertheless, reduction in the natural discharge accounts for only a small part of the excess of pumpage over recharge to the shallow aquifer; most of the difference has been made up by withdrawal from storage in the shallow aquifer.

The pumping that has depleted storage at rates approaching 100,000 acre-feet in some years would constitute good reservoir management provided the water is replaced in future years when the supply is greater and the demand less. As precipitation can meet a large proportion of crop needs in some years (as shown especially in 1941), a constant rate of annual withdrawal by pumping is not necessary or desirable for a stable irrigation economy because the total water resources can be used most effectively by heavy pumping during drought and light pumping in the wetter years. Such variations in draft are possible because of the large reserve in storage. Existing records indicate that reservoir storage in 1951 was not much less than in 1940, and that therefore the wet year 1941 provided enough water to carry through several subsequent years of drought. The depletion since 1951, however, cannot be made up unless the future includes years wet enough to permit a drastic reduction in annual pumpage. Certainly a part of the increased use of water within the Roswell basin during the drought has been at the expense of users of the Pecos River downstream.

WELLS IN CARLSBAD AREA

The Carlsbad area, downstream from the Roswell basin, is a second major area of ground-water development in the middle basin of the Pecos River (fig. 1). As in the Roswell basin, the principal use of water in the Carlsbad area is for irrigation, but it differs from the Roswell in that it depended upon surface water almost entirely prior to 1945 and predominantly in the succeeding decade; only in 1953 and 1954 has the water pumped from wells comprised more than 50 percent of the total water applied for irrigation.

The shallow alluvial aquifer along the Pecos River is the principal source of water pumped for irrigation in the Carlsbad area. Under natural conditions the alluvial aquifer was recharged by precipitation and by flood runoff in tributaries to the Pecos, and there were many springs and seeps along and near the stream channels; but for more than half a century an important source of water in the alluvium has been the downward seepage of water diverted from the Pecos River and applied for irrigation. The water table in the alluvium in the Carlsbad area probably remained fairly close to the land surface until about 1946, when the construction of irrigation wells spread rapidly.

One effect of pumping from the alluvial aquifer has been to create a pronounced cone of depression in an area south of the city of Carlsbad and west of the area irrigated by surface water. The center of this cone was more than 60 feet deep after 8 years (1947–54) of pumping. In wells that tap the alluvial aquifer near the Pecos River or those in areas that receive irrigation water from the river, there has been less lowering of water levels because of recharge from surface water, but that recharge necessarily causes some depletion in flow of the river downstream from the Carlsbad area.

The Capitan limestone of Permian age, recharged chiefly by precipitation upon the outcrop area, constitutes an underground tributary to the Pecos River, as shown by the gentle eastward gradient in head. Some water in this aquifer may be discharged into the alluvial aquifer near Carlsbad, but a major point of natural discharge is the Carlsbad Springs which discharge into the Pecos River. The Carlsbad Springs also discharge Pecos River water that has leaked into the limestone from Lake Avalon and from canals that carry water to the Carlsbad irrigation project; the computed leakage from Lake Avalon reached a peak of 35 cfs (cubic feet per second) each winter until the drought year 1952. The discharge of Carlsbad Springs, which includes this leakage, averaged 60 cfs in 1939–40, rose above 100 cfs in 1941–42, and declined to minima less than 30 cfs in 1953, 1954, and 1956 (Bjorklund, 1958).

Pumping from wells in the limestone aquifer has not caused a marked decline in water levels; the principal effect of pumping has been to reduce the spring discharge. In some months in 1953 and 1954 the discharge from Carlsbad Springs was less than the computed leakage from Lake Avalon; in those months the wells were drawing more than the local yield of the aquifer, and it is likely that some water from Lake Avalon was diverted toward the wells.

Since 1947 pumping from wells has reduced the inflow to the river at Carlsbad Springs, increased the seepage from the river and from distribution canals, and created storage space which will doubtless be filled, at least in part, during future years of more abundant supply. All these effects tend to reduce the amount of water available downstream. To the extent that the pumped water was used on lands with long-established water rights in lieu of failing stream supplies during drought, the wells constitute a development of additional storage facilities along the river, facilities which in some future year may, like a surface reservoir, capture and store floodwater that would otherwise continue downstream. To the extent that the pumped water was used on new land, the result must be a persistent reduction in the supplies available downstream.

SUMMARY

The Pecos River in New Mexico is an excellent example of a river which has had a progressive diminution of inflow from a large part of its drainage basin. Drought in recent years has been responsible for part of this reduction in inflow, but not for the progressive reduction throughout the past four decades. There has been increasing infestation of the river flood plains by saltcedar, and the increasing consumptive waste of water by this phreatophyte has certainly been responsible for some of the depletion of riverflow.

Part of the depletion in flow of the Pecos River is attributed to the development and use of water from major ground-water reservoirs within the basin. New Mexico was the first State to develop statutory regulation of ground-water development and use, and for this regulation there are reliable estimates of the ground-water supplies in practically all developed areas in the State, based upon studies that were begun more than 30 years ago. In both the Roswell and Carlsbad ground-water reservoirs in the Pecos River basin, the state engineer has endeavored to limit the withdrawals from wells to a quantity that can be sustained perennially.

Under natural conditions these ground-water reservoirs discharged into the Pecos River. As might be expected, the development and use of ground water has been partly at the expense of this natural contribution to the river. Most of the pumped water is replenished by natural recharge, and the wells serve to divert the water that would otherwise have been discharged at springs or seeps, of which much would have eventually reached the river. Some of the pumped water has been withdrawn from underground storage with negligible effect upon the riverflow during the recent years of drought. However, in future years of more abundant precipitation and recharge this storage may well be replaced before there is increased ground-water flow to the river. Consequently, this pumping from storage can be expected eventually to affect the riverflow.

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