SURFACE WATER AVAILABILITY AND QUALITY CHARACTERISTICS IN THE PECOS RIVER BASIN IN NEW MEXICO

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INTRODUCTION

The availability and quality of the surface waters of the Pecos River are diverse and complex. The availability of the surface water is here considered by sources, magnitude, distribution, variability, channel gains and losses, floods, and depletions.

The quality characteristics are considered under constituents and concentrations of dissolved solids and sediment loads.

Surface water characteristics are intimately related to the climate, physiography, and geology of the basin; other papers given at this conference discuss these subjects in detail.

Collection of streamflow records in the Pecos River Basin in New Mexico began about 1903 and sampling for quality of water about 1937. Presently, the Geological Survey operates 36 gaging stations in the basin, 16 of which are on the main stem of the Pecos River. Chemical quality data are collected at 7 regular surface-water stations, and suspended-sediment data are collected at 2 of the main stem stations.

DESCRIPTION OF BASIN

The Pecos River Basin in New Mexico may be conveniently divided into an upper basin extending from its headwaters in the Sangre de Cristo Range to Alamogordo Reservoir and a lower basin extending from Alamogordo Reservoir to the Texas state line. Altitudes in the upper basin range from 13,102 on South Truchas Peak to 4,200 feet at Alamogordo Dam. The Gallinas River also originates in the Sangre de Cristo Range northwest of Las Vegas and is the principal tributary of the Pecos River in the upper basin. The approximate contributing drainage of the basin above Alamogordo Dam is 4,390 square miles.

The lower basin is bounded on the west by several ranges of mountains and by the Mescalero Ridge on the east. Altitudes range from 12,003 feet on Sierra Blanca Peak to 2,840 feet at the head of Red Bluff Reservoir.

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The principal tributaries in the lower basin drain the eastern slopes of the mountains and are the Rio Hondo, Rio Felix, Cottonwood Creek, Black River, and others. Few tributaries from the east have well-defined channels; the two most important are Taiban Creek in the northern part and Long Arroyo in the central part. Approximate contributing drainage area of lower basin of the Pecos River above the Texas state line is 15,600 square miles. See table 1.

Thus, the approximate total contributing drainage area of the Pecos River in New Mexico is 20,000 square miles.

SURFACE WATER AVAILABILITY
SOURCE AND MAGNITUDE

Melting snow is a source of considerable surface flow in the upper basin. Both the main stem of the Pecos River and the Gallinas River drain the southern part of the Sangre de Cristo Mountains where the snow pack accumulates. Summer runoff results primarily from flash floods caused by localized thunderstorms in the plains and foothills. However, occasional storms originating in the Gulf of Mexico contribute heavily to runoff.

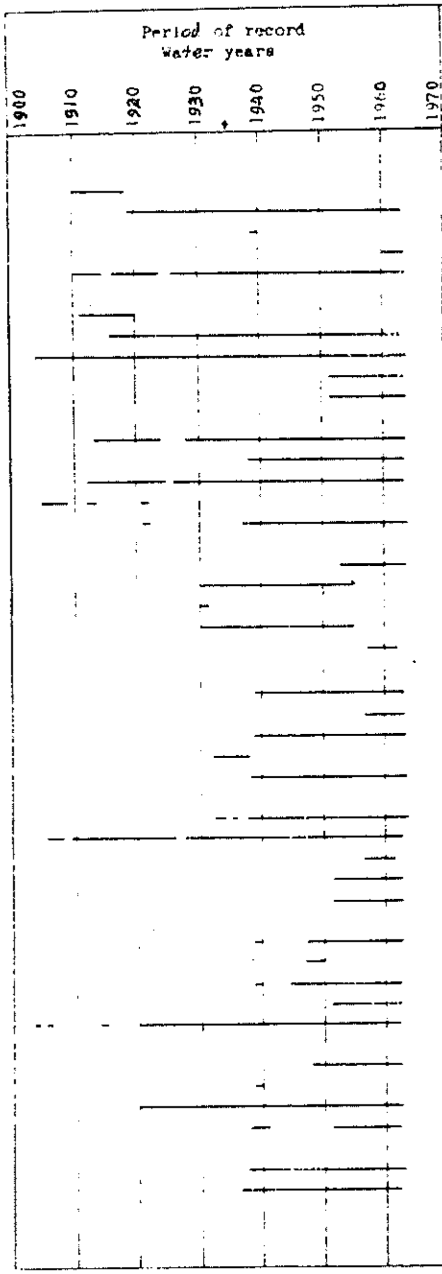
In the lower basin, some flow comes from snowmelt in the higher western mountains, but the principal contribution to surface runoff is from summer thunderstorms. Intense, general Gulf storms also at times substantially augment surface flow.

Generally the availability of surface water in both the upper and lower basins is affected significantly by losses to and gains from ground water.

Precipitation, the only source of water to the Pecos River basin averages more than 14 inches of water per year, and is equivalent to more than 15,000,000 acre-feet. Figure 1 shows by width of line and isopleths of runoff the portion of the precipitation that actually reaches the drainage channels in the basin. The remainder is lost through evapotranspiration or recharges the ground water reservoirs. Available records indicate that unit runoff is strongly influenced by topography; values on figure 1 range from 0.1 inch in the plains to 20 inches in the Sangre de Cristo Mountains. Construction of such a runoff map suffers from lack of defining data. It indicates only in a general way the occurrence of runoff in the basin.

The width of line on figure 1 shows how the average annual discharge for the period of record varies from station to station. Variation in the width of line reflects the interwoven influence of several factors: tributary inflow, interchange with ground water, evapotranspiration losses, diversions, and return flow. At the measuring points on the main stem, the average annual discharge ranges from 71,000 acre-feet at Pecos to 238,000 acre-feet near Artesia.

Table 1 --Summary of gaging station records in Pecos River Basin



Sta. No.	Gaging station	Drainage area (sq mi)	Average runoff acre-feet per year through 1963	Peak discharge Date	Peak discharge cfs	Peak discharge cfs per sq mi	Jarvis-Myers coef. in %
	PECOS RIVER BASIN: Part 8						
3780	Pecos River near Cowles	160	89,770	5-27-12	1,800	11.2	1.42
3785	Pecos River near Pecos	189	72,400	9-21-29	4,500	23.8	3.27
3790	Pecos River near San Jose	539	-	7-14-39	2,220	4.12	.98
3792	Tecolote Creek near San Pablo	83	-	8-17-61	10,900	131	11.9
3795	Pecos River near Anton Chico	1,050	103,500	9-30-04	73,000	69.5	22.5
3800	South Fork Gallinas River near El Porvenir	25	10,570	4- -19	-	-	-
3805	Gallinas River near Montezuma	84	14,770	8- 4-57	5,400	64.3	5.38
3810	Gallinas River at Montezuma	87	14,190	9-29-04	11,600	133	11.6
3820	Gallinas River near Lourdes	313	10,500	8-17-61	6,680	21.3	3.76
3825	Gallinas River near Colonias	610	13,320	6- 1-37	26,700	43.8	10.8
3830	Pecos River at Santa Rosa	2,650	107,900	6- 2-37	55,200	20.8	10.7
3835	Pecos River near Puerto de Luna	3,970	166,500	6- 3-37	60,000	15.1	9.52
3845	Pecos River below Alamogordo Dam	4,390	170,900	9- 1-42	f42,800	9.75	6.46
3855	Pecos River near Fort Sumner	5,300	173,000	9-30-04	53,000	10.0	7.28
3860	Pecos River near Acme	11,380	157,800	5-28-37	53,300	4.68	4.99
3870	Rio Ruidoso at Hollywood	120	7,670	7-26-57	1,070	8.92	.977
3880	Rio Ruidoso at Hondo	290	13,760	9-29-41	12,400	42.8	7.31
3885	Rio Bonito at Angus	45.5	-	4-22-31	121	2.66	-
3895	Rio Bonito at Hondo	295	7,460	9-29-41	11,000	37.3	6.41
3901	Rio Hondo at Picacho	715	-	5-14-58	3,510	4.91	-
3905	Rio Hondo at Diamond A. Ranch near Roswell	947	18,970	9-22-41	27,000	28.5	8.77
3936	North Spring River at Roswell	19.5	7.2	8-31-63	101	5.18	-
3945	Rio Felix at old highway bridge, near Hagerman	932	12,520	10- 7-54	74,000	79.4	24.2
3950	Rio Felix near Hagerman	934	20,710	5-29-37	23,600	25.3	7.73
3955	Pecos River near Lake Arthur	14,760	211,400	5-30-37	51,500	3.49	4.24
3960	Cottonwood Creek near Lake Arthur	199	4,180	-	-	-	-
3965	Pecos River near Artesia	15,300	246,900	10- 2-04	h60,000	3.92	4.85
3976	Rio Peñasco near Dunken	580	4,230	9-22-41	70,000	121	29.1
3985	Rio Peñasco at Dayton	1,070	3,620	9-22-41	h60,000	56.1	18.4
4000	Four Mile Draw near Lakewood	265	1,010	10- 7-54	7,650	28.9	4.71
4010	Pecos River below McMillan Dam	16,990	77,460	a	h40,000	2.35	3.06
4015	Pecos River below Major Johnson Springs	-	-	-	-	-	-
4020	Pecos River at damsite 3, near Carlsbad	17,980	131,800	5-22-41	60,000	3.54	4.48
4040	Pecos River below Avalon Dam	18,080	27,660	10- 7-54	41,000	2.27	3.05
4050	Pecos River at Carlsbad	18,100	159,300	10- 2-04	90,000	4.97	6.66
4055	Black River above Malaga	343	9,050	9-21-41	33,000	96.2	17.8
4060	Black River at Malaga	360	-	-	-	-	-
4065	Pecos River near Malaga	19,190	183,200	9-21-41	63,700	3.32	4.60
4070	Pecos River at Pierce Canyon Crossing near Malaga	19,260	150,600	-	-	-	-
4075	Pecos River at Red Bluff	19,540	165,800	5-24-41	52,600	2.69	3.76
4085	Delaware River near Red Bluff	689	10,350	10- 2-55	81,400	118	31.0

For some purposes, the median flow gives a more realistic picture of surface water availability, particularly when storage is not adequate to conserve the surpluses of years of high runoff. For the period 1930-60, the difference between average and median flow for eight selected main stem stations on the Pecos River is highly variable. (See Table 2)

Table 2-Average and Median of Yearly Runoff in Acre-Feet 1930-60
For Selected Stations on Pecos River in New Mexico

Gaging Station	Average	Median	Difference between average and median
Pecos River near Pecos	71,340	65,980	5,360
Pecos River near Anton Chico	96,780	80,280	16,500
Pecos River at Santa Rosa	103,600	65,990	37,610
Pecos River below Alamogordo Dam[a]/	166,400	129,900	36,500
Pecos River near Artesia	237,500	183,000	54,500
Pecos River at Carlsbad	153,200	73,800	79,400
Pecos River near Malaga	188,700	96,360	92,340
Pecos River at Red Bluff[b]/	180,900	--	--

a/ Adjusted for annual changes in storage in reservoir.

b/ For 23 year period 1937 - 60.

This tabulation shows that the difference between the average and the median values becomes progressively wider proceeding from the upper to the lower end of the basin. At Pecos, average exceeds median flow by only eight percent, but at Carlsbad average flow is larger by 108 percent. The extremely high runoff that occurred in 1941 and 1942 mostly accounts for the difference, and apparently a greater part of this flow originated in the lower basin.

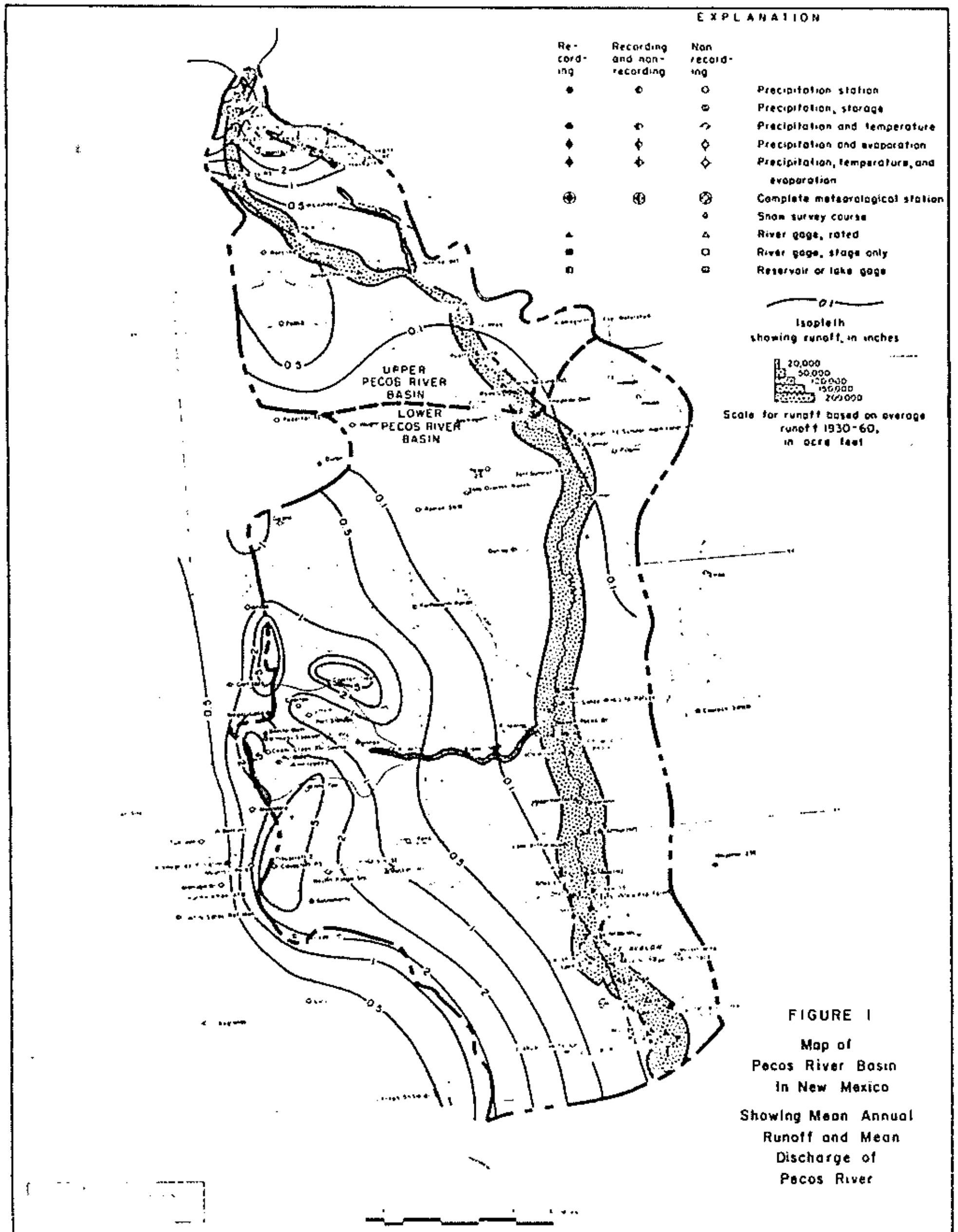


FIGURE I

Map of Pecos River Basin In New Mexico

Showing Mean Annual Runoff and Mean Discharge of Pecos River

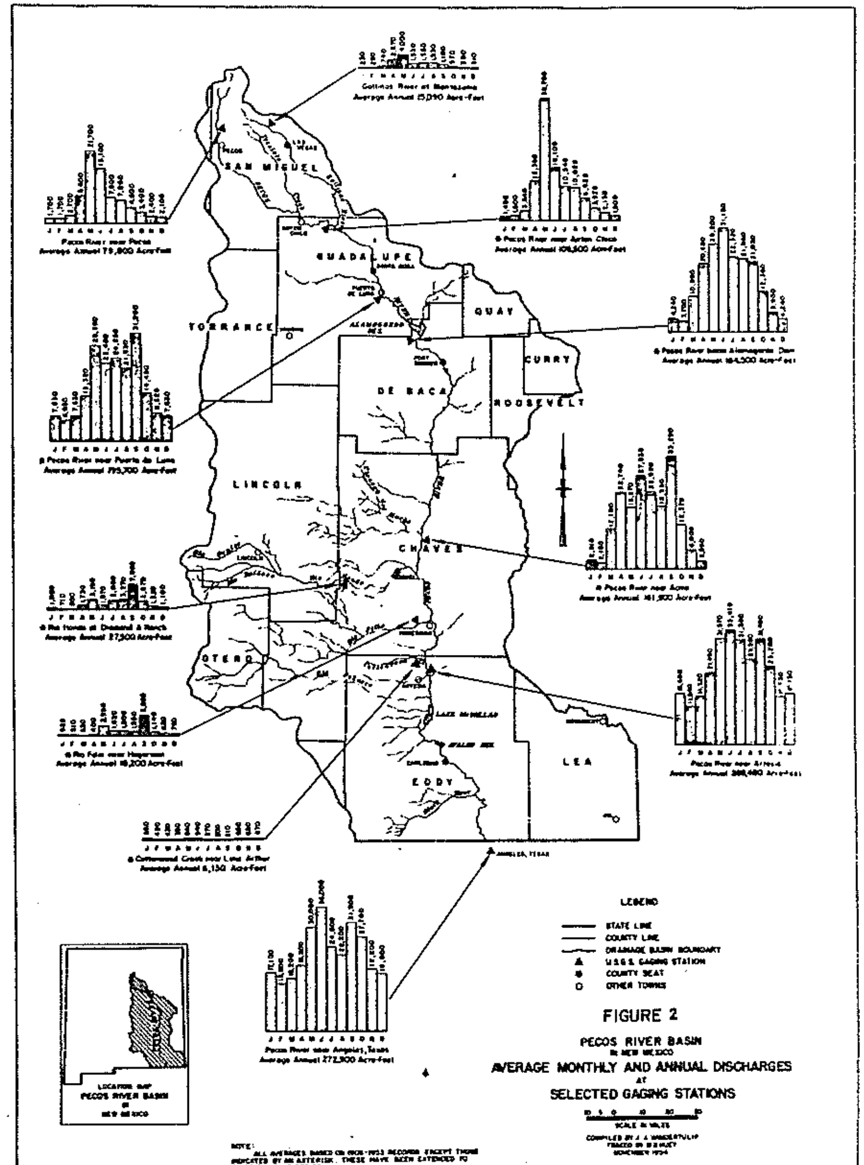


FIGURE 2

PECOS RIVER BASIN IN NEW MEXICO

AVERAGE MONTHLY AND ANNUAL DISCHARGES AT SELECTED GAGING STATIONS

From Technical Report 7, State of New Mexico, State Engineer Office, Hydrologic Summary

DISTRIBUTION

Seasonal distribution of flow in the basin exhibits patterns attributed to climate, topography, and regulation. Figure 2 shows bargraphs of average monthly discharge for period 1905-53 plotted for selected stations. In the upper basin, snow melts account for 60 percent of the annual runoff occurring in the 3-month period April through June. Proceeding downstream, the increasing effect of summer storms is shown in the graphs. At Puerto de Luna, inflow station to Alamogordo Reservoir, 66 percent of the annual flow occurs in the 5-month period May through September, and the month of maximum flow shifts from May to September.

Below Alamogordo Reservoir, the distribution patterns on the main stem of the Pecos River reflect the influence of regulation. About 75 percent of the annual discharge occurs during the irrigation season which coincides with the summer flood period. Summer flow also is dominant in the tributary streams of the lower basin even though not influenced by regulation. On Rio Hondo and Rio Felix, virtually all the runoff occurs in the period April through September and 30 percent of that occurs in September alone.

Annual distribution of flow is shown in figure 3 for two representative stations. At Anton Chico in the upper basin, annual flow for the period 1911-63 ranged from a minimum of 19,570 acre-feet in 1934 to a maximum of 354,400 acre-feet in 1941. At Artesia in the lower basin, during period 1905-63, the range is from 74,180 acre-feet in 1954 to 997,600 in 1941. These graphs show a distinct downward trend in flow which will be discussed under Depletions.

VARIABILITY

Natural streamflow variability results from variation in precipitation in turn modified by basin characteristics, primarily geology. Natural variation in flow may be altered by regulation and diversions as in the lower basin of the Pecos River. Flow-duration curves depict flow variability by showing percent of time specified discharges were equalled or exceeded in a given period. Figure 4 shows flow-duration curves plotted for stations on the Pecos River near Pecos, near Puerto de Luna, and near Artesia.

Effect of substantial storage in and contribution from ground water storage is shown in the curve for the station at Pecos by the relatively flat slope reflecting the reduced range in flow. Storage of precipitation in mountain snow packs also influences the slope in the upper reaches of the curve.

At Puerto de Luna, the flat slope of the curve below 150 cfs reflects the heavy ground water contribution. Above 150 cfs, the steeper slope reflects the influence of flash runoff from summer storms.

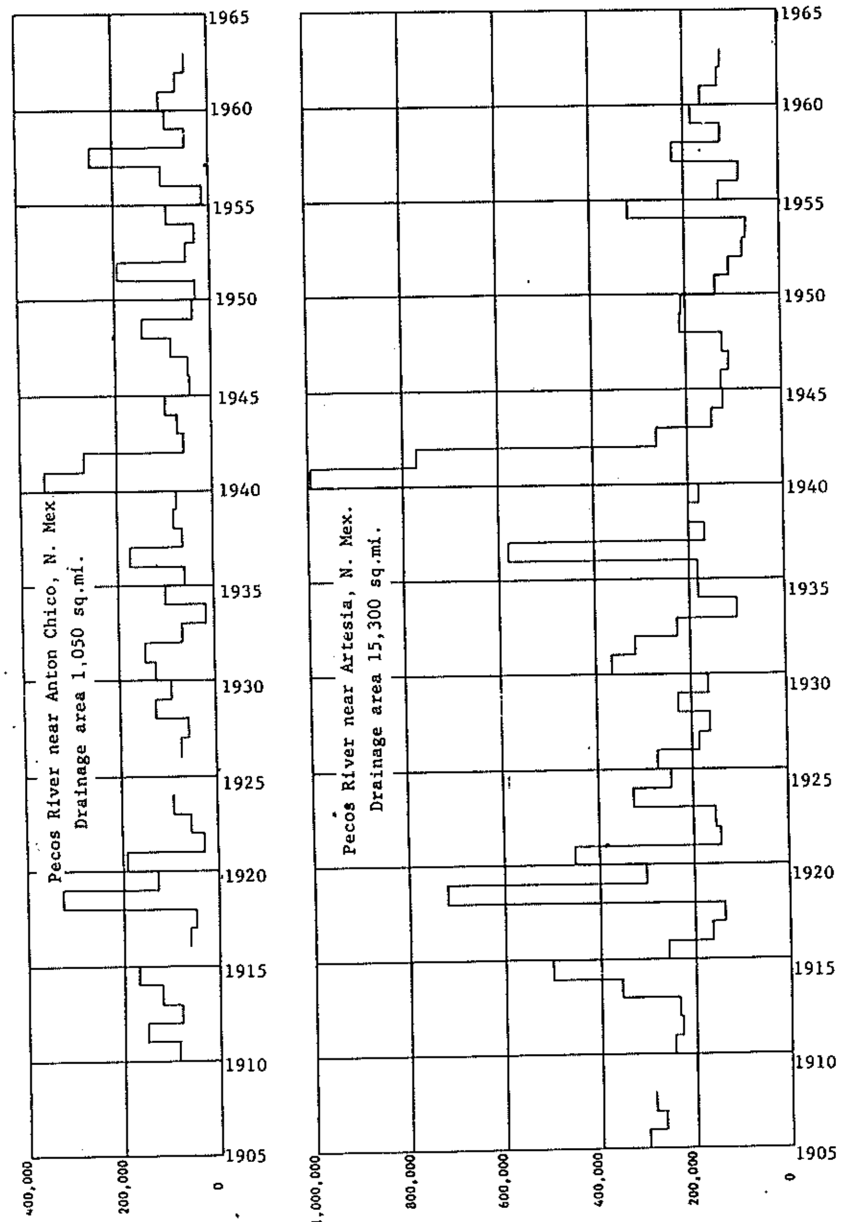


Figure 3. - Annual runoff at two gaging stations on Pecos River 1906-63

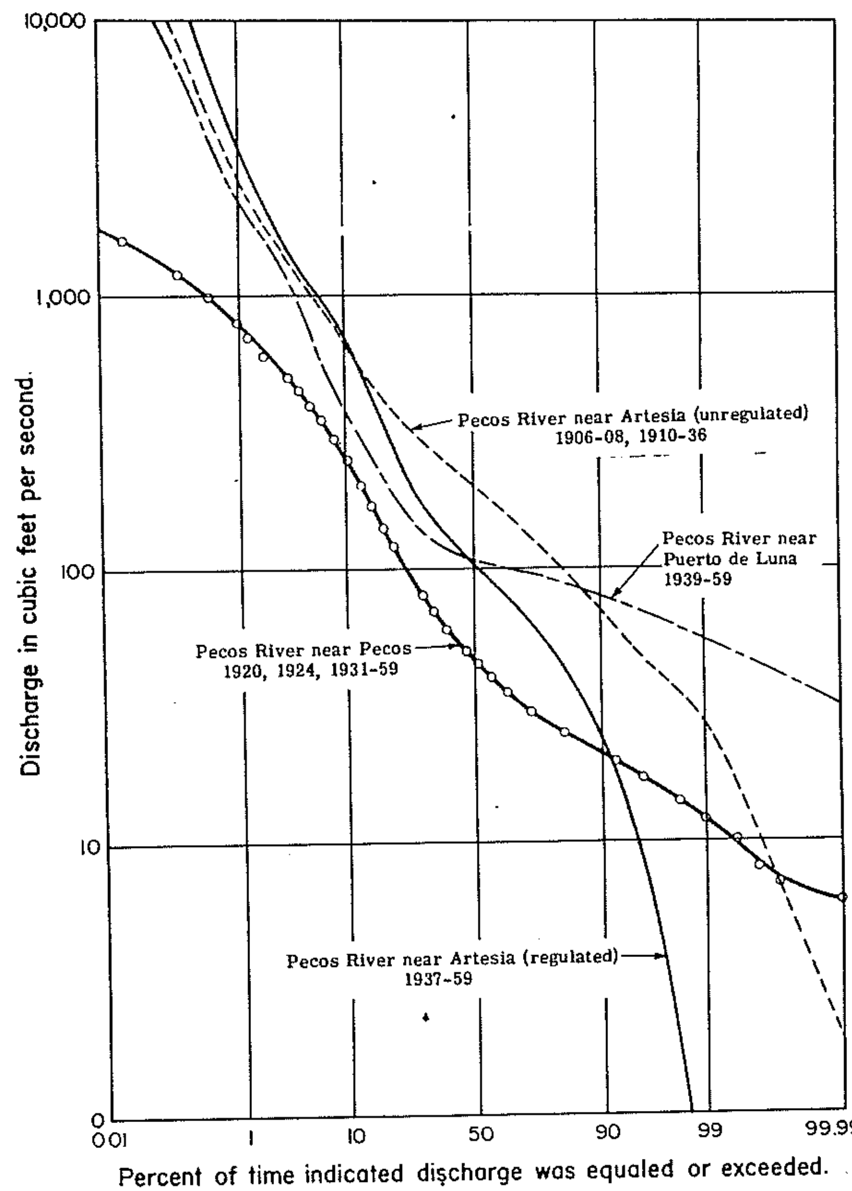


Figure 4.--Duration curves of daily flow for three stations on Pecos River in New Mexico.

At Artesia two curves are shown, one for the unregulated period prior to 1937 and one for the regulated period 1937-59. The curve for the regulated period is the steeper and reflects the influence of the high years 1937, 1941, and 1942, the large number of drought years since 1943, and increased depletions throughout the period. It has only been since 1945 that the river has dried up at times at Artesia.

CHANNEL GAINS AND LOSSES

Gains to and losses from the main stem of the Pecos River have been intensively studied since 1953 by seepage investigations in the reach from Anton Chico to the state line. These investigations have delineated subreaches which generally show losses or gains. The reach between Anton Chico and Colonias shows losses of as much as 150 cfs as indicated by the width of line on figure 1. Below Colonias, flow begins to be augmented by ground water contribution and evidently most of the losses are recovered above Puerto de Luna. Between Alamogordo Dam and Acme large losses generally occur during the summer and are greatest in the vicinity of Yeso Arroyo. Between Acme and Artesia gains are general throughout most of the reach. Seven seepage investigations between 1958 and 1963 show an average gain at low flow of 55 cfs.

Between Artesia and Carlsbad, Lakes McMillan and Avalon store water for irrigation. Lake McMillan has leaked practically from the time it was constructed, and that leakage has been known to approach 200 cfs. However, most of it is recovered about 4 miles below the dam through Major Johnson springs in the river channel. There is some seepage from Lake Avalon which is partially recovered at Carlsbad Springs.

FLOODS

The Pecos River Basin has produced many of the outstanding floods in New Mexico. Flood-frequency studies by Patterson (1963) indicate that the area of highest flood potential in the state is the eastern slopes of the Guadalupe Mountains in the extreme southwestern part of the basin. It was in this area on September 20, 1941 that the outstanding flood of record in the basin occurred in Dark Canyon at Carlsbad. The peak discharge of this flood was estimated as 100,000 cfs and has a Jarvis-Meyer's rating of 47.5 percent or 4,750 A. Only one other known flood in New Mexico exceeds this rating, and it occurred on a drainage area only about one-hundredth the size of that for Dark Canyon.

On the main stem, the maximum known discharge of 90,000 cfs occurred October 2, 1904 at Carlsbad, and may have been augmented somewhat by the failure of Avalon Dam. Magnitude and frequency of floods on the main stem analyzed by Patterson (1963) from Anton Chico to the state line are shown in figure 5. Available data do not permit reliable definition of frequencies beyond 50 years. The figure indicates the magnitude of a 50-year flood at Carlsbad to be 85,000 cfs.

From Geological Survey Water-Supply Paper 1682 by James L. Patterson

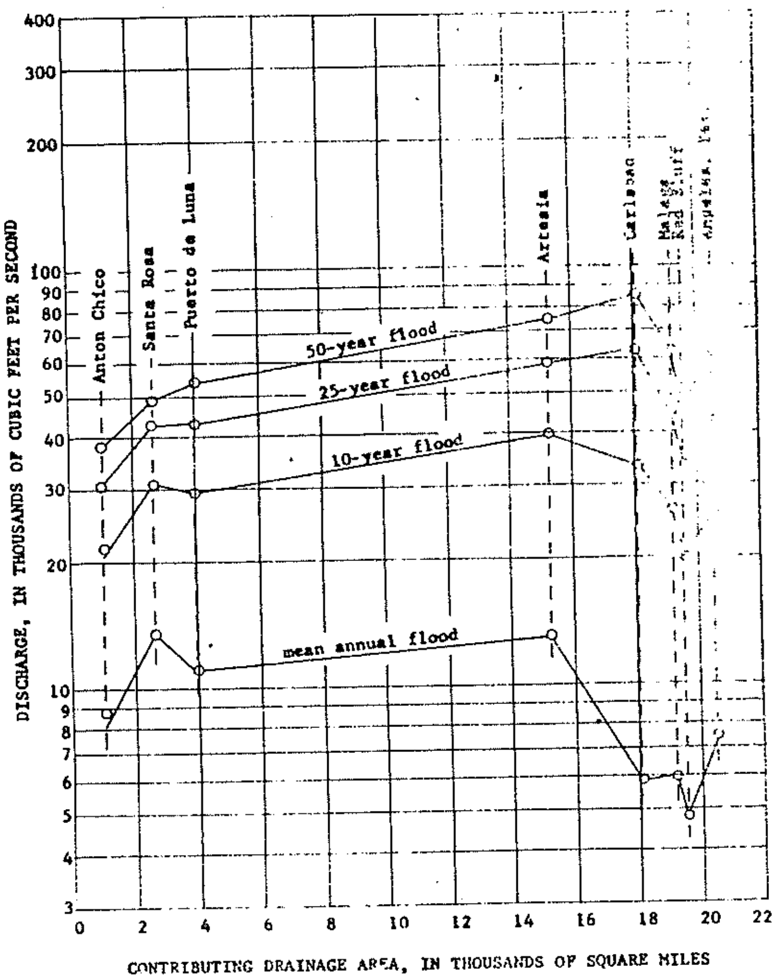


Figure 5.--Relation of discharge for selected flood frequencies to contributing drainage area. Pecos River [illegible] between Anton Chico [illegible] stations are [illegible], Texas.

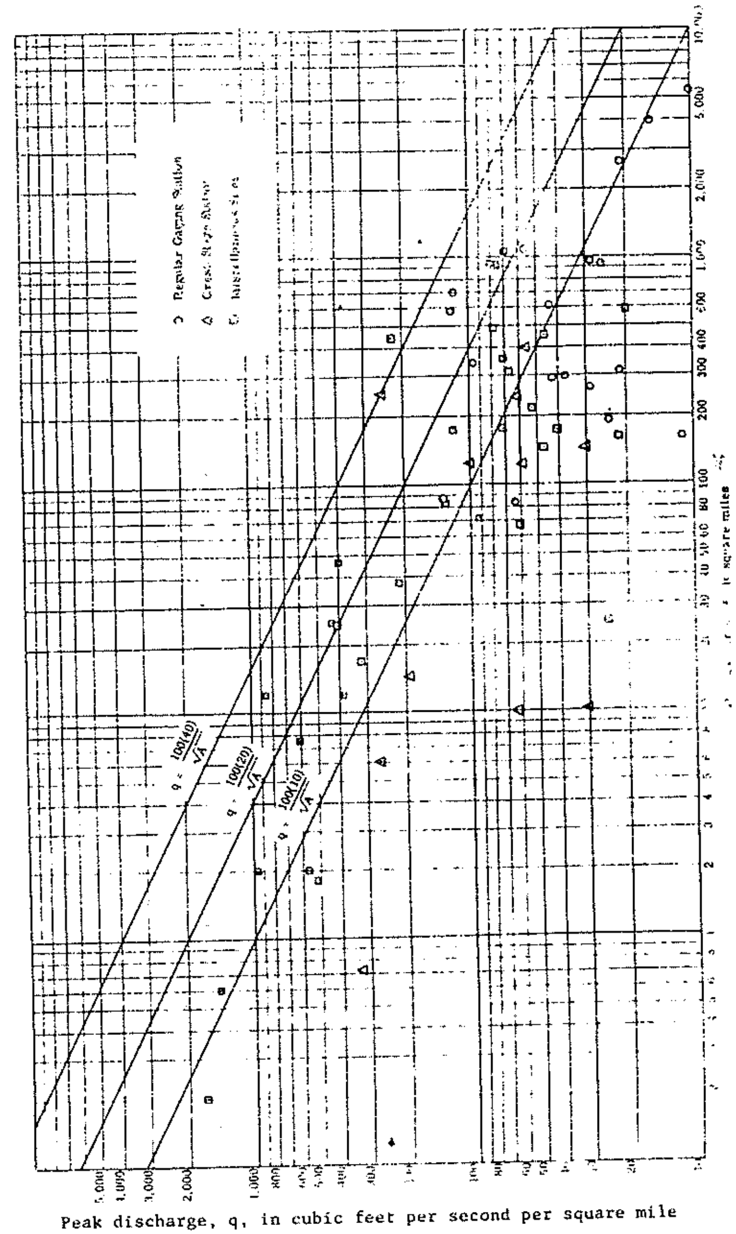


Figure 6.--Flood discharges in Pecos River Basin in New Mexico in relation to drainage area. Enveloping curves are for Jarvis-Myers ratings of 10, 20, and 40 per cent.

Figure 6 is a plotting of drainage area versus unit discharge for the more outstanding floods of record in the basin, including those occurring at crest-stage and ungaged sites. It is noted that many of these floods exceed a 10 percent Jarvis-Meyer's rating or 1,000 A.

Table 1 lists maximum discharge for the period of record at regular gaging stations in the basin and gives the Jarvis-Meyer's rating for each peak.

DEPLETIONS

Distribution of annual flow of the Pecos River for the period of record indicates a progressive diminution in flow which is especially marked in the lower basin. Thomas (1963) analyzed the factors associated with the depletion and concluded that drought, phreatophyte infestation, and ground-water development are jointly responsible for the reduction. Those who are interested in greater detail are referred to the original report, Geological Survey Water-Supply Paper 1619-G, "Causes of Depletion of the Pecos River in New Mexico".

QUALITY CHARACTERISTICS[a]

METHOD AND SAMPLING SITES

Both the chemical quality and the suspended sediment carried by the water vary widely from the headwaters to Red Bluff Reservoir. For purposes of describing the quality of water in the Pecos River Basin in New Mexico the river has been subdivided into three principal reaches: the upper reach coincides with the upper basin above Alamogordo Dam, the middle reach is that part between Alamogordo and McMillan Dams, and the lower reach that part between McMillan Dam and Red Bluff Reservoir.

The Geological Survey collects samples daily at seven stations along the main stem and determines the general chemical characteristics at each by analyzing samples that have been composited by a standard technique. Daily samples are also collected for suspended sediment determinations at Santa Rosa in the upper reach and near Artesia in the middle reach. Prior to October 1958 Puerto de Luna was the sampling point in the upper basin. No sediment data are collected in the lower reach because problems related to sediment there are not significant at this time.

The weighted average complete analyses for chemical quality 1955-64 for the seven river stations in New Mexico and one in Texas, below Red Bluff Reservoir, are presented in tables 3-10. The maximum and minimum daily concentrations in ppm (parts per million) and load extremes in tons per day for both chemical and sediment quality for period of record are presented in table 11.

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a/ This portion prepared with the assistance of Harry E. Koester, Chemist, Quality of Water Branch, U. S. Geological Survey.

Table 3.--8-3845. PECOS RIVER BELOW ALAMOGORDO DAM, N. MEX.

Annual weighted averages of chemical analyses, in parts per million, 1955-1964 water years

Water year	Mean discharge (cfs) / Total discharge	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual load (tons)
1955	180 / 65,700	12		265	39	50		124		722	61		0.7		1,210	1.65	588	822	720	0.8	1,540	7.5	215,300
1956	183 / 66,060	16		360	54	64		134		988	78		.9		1,630	2.22	805	1,120	1,010	.8	1,960	7.5	290,400
1957	164 / 58,880	16		320	37	56		125		839	71		1.5		1,400	1.90	609	950	848	.8	1,680	7.5	221,500
1958	301 / 109,900	14		170	19	35		127		405	35		.7		741	1.01	602	502	398	.7	1,000	7.5	220,200
1959	173 / 63,140	14		272	33	53		125		717	59		.4		1,210	1.65	565	814	712	.8	1,500	7.5	206,900
1960	157 / 57,460	17		330	37	57		124		853	71		.7		1,430	1.94	606	976	874	.8	1,770	7.5	220,800
1961	223 / 81,450	16		329	35	58		121		859	72		.4		1,430	1.94	861	966	867	.8	1,780	7.6	313,500
1962	187.2 / 68,330	15		319	37	55		125		830	72		.7		1,390	1.89	702	946	844	.8	1,730	7.5	256,300
1963	177 / 64,522	15		385	46	66		120		1,040	87		.2		1,700	2.31	812	1,150	1,050	.8	2,050	7.5	295,700
1964	117 / 42,856.6	15		450	55	81		127		1,240	105		1.4		2,020	2.75	638	1,350	1,250	1.0	2,350	7.6	233,800

Table 4.--8-3860. PECOS RIVER NEAR ACME, N. MEX.

Annual weighted averages of chemical analyses, in parts per million, 1955-1964 water years

Water year	Mean discharge (cfs) / Total discharge	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual load (tons)
1955	296 / 108,000	--		327	--	--		--		--	--		--		1,660	2.26	--	--	--	--	2,130	7.5	484,300
1956	148 / 49,880	17		402	75	129		127		1,160	195		1.9		2,040	2.77	815	1,310	1,210	1.6	2,530	7.5	274,200
1957	149 / 40,530	14		296	54	89		136		841	117		1.3		1,480	2.01	595	960	849	1.2	1,950	7.5	161,400
1958	288 / 101,700	16		234	31	126		145		617	159		1.2		1,260	1.71	980	712	592	2.1	1,690	7.5	363,000
1959	158 / 56,250	19		311	50	155		127		889	204		1.6		1,690	2.30	721	982	878	2.2	2,210	7.8	256,400
1960	258 / 92,620	18		380	42	161		118		1,060	213		1.6		1,930	2.62	1,340	1,120	1,020	2.1	2,430	7.7	482,100
1961	208 / 75,892	17		362	54	165		116		1,030	229		1.3		1,950	2.65	1,100	1,120	1,030	2.1	2,460	7.7	391,300
1962	167 / 60,960	20		351	48	115		136		954	149		1.3		1,700	2.31	769	1,070	961	1.5	2,170	7.8	265,400
1963	164 / 59,904	16		374	56	122		120		1,070	156		.8		1,860	2.53	824	1,160	1,060	1.6	2,290	7.5	300,600
1964	56.8 / 20,800	17		502	77	158		122		1,470	224		1.4		2,500	3.40	503	1,570	1,470	1.7	2,930	7.6	140,300

Table 5.--8-3965. PECOS RIVER NEAR ARTESIA, N. MEX.

Annual weighted averages of chemical analyses, in parts per million, 1955-1964 water years

Water year	Mean discharge (cfs)	Total discharge	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual load (tons)
1955	444	162,100	24		367	89	361		142		1,110	562		--		2,580	3.51	3,090	1,280	1,160	4.4	3,450	7.5	1,127,000
1956	182	66,610	18		458	119	466		139		1,440	720		--		3,290	4.47	1,620	1,630	1,520	5.0	4,370	7.5	590,500
1957	125	44,750	20		405	94	401		152		1,220	624		--		2,840	3.86	958	1,400	1,270	4.7	3,790	7.5	341,600
1958	316	115,300	19		313	51	222		149		864	318		2.2		1,860	2.53	1,590	990	868	3.1	2,500	7.7	578,400
1959	174	63,510	29		392	91	397		141		1,200	602		3.0		2,780	3.78	1,310	1,350	1,240	4.7	3,760	7.7	475,900
1960	255	93,330	19		449	70	332		128		1,270	494		2.6		2,700	3.67	1,860	1,410	1,300	3.8	3,510	7.7	679,000
1961	227	164,100	19		444	92	377		150		1,300	589		3.1		2,900	3.94	1,780	1,490	1,370	4.2	3,880	7.7	646,600
1962	176.5	64,420	17		420	76	331		156		1,190	513		2.3		2,620	3.56	1,250	1,360	1,230	3.5	3,500	7.5	455,000
1963	167	61,076	17		459	91	377		143		1,360	576		1.2		2,960	4.03	1,330	1,520	1,400	4.2	3,900	7.5	488,000
1964	64.8	23,718	17		543	123	543		147		1,650	854		3.0		3,810	5.18	782	1,860	1,740	5.5	5,030	7.5	243,700

Table 6.--8-4050. PECOS RIVER AT CARLSBAD, N. MEX.

Annual weighted averages of chemical analyses, in parts per million, 1955-1964 water years

Water year	Mean discharge (cfs)	Total discharge	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual load (tons)
a 1955	244	89,060	--		--	--	--		--		--	--		--		b 1,210	b 1.65	---	--	--	--	1,730	7.7	b292,200
1956	93.1	34,070	17		364	89	246		144		1,090	391		2.1		2,270	3.10	573	1,270	1,160	3.0	3,040	7.7	209,600
1957	25.6	9,340	20		349	116	312		169		1,120	510		2.2		2,510	3.41	173	1,350	1,210	3.7	3,460	7.8	63,290
1958	115	41,980	21		329	76	257		151		992	382		1.5		2,130	2.90	661	1,130	1,010	3.3	2,880	7.6	242,500
1959	72.9	26,610	19		396	102	347		168		1,230	525		2.6		2,700	3.67	531	1,410	1,270	4.0	3,580	7.7	193,600
1960	79.9	29,240	16		370	64	205		124		1,050	308		2.5		2,080	2.83	449	1,190	1,080	2.6	2,750	7.6	164,100
1961	71.7	26,171	16		443	113	388		153		1,380	621		2.9		3,040	4.13	588	1,580	1,440	4.3	4,090	7.7	214,300
1962	24.9	9,090	20		366	106	314		187		1,120	511		4.7		2,530	3.44	170	1,350	1,200	3.7	3,470	7.5	62,130
1963	25.5	9,318	17		311	95	266		171		971	426		3.4		2,180	2.96	150	1,170	1,030	3.4	3,010	7.6	54,700
1964	18.2	6,669.8	19		362	115	319		188		1,140	514		4.4		2,570	3.50	126	1,380	1,230	3.7	3,550	7.6	46,300

a Weighted averages not computed because period of missing record represents 55.4% of runoff (15 days of high flow in October).

b Estimated on the basis that ppm D.S. equals specific conductance (micromhos) times 0.70.

Table [illegible].--[illegible]. PECOS RIVER [illegible] MALAGA, N. MEX.

[illegible] weighted ave[illegible] [illegible], in parts per million, 1955-1964 water years

Water year	Mean discharge (cfs) / Total discharge	Silica (SiO2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO3)	Carbonate (CO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as CaCO3: Calcium, Magnesium	Hardness as CaCO3: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual load (tons)
1955	296 / 108,000	14		[illegible]	[illegible]	246		[illegible]		[illegible]	292		[illegible]		1,630	2.23	1,340	828	714	3.7	2,390	7.6	[illegible]
1956	[illegible] / [illegible]	19		[illegible]	[illegible]	560		[illegible]		1,350	[illegible]		3.9		3,490	4.75	1,050	1,640	1,520	6.0	4,790	7.7	[illegible]
1957	[illegible] / [illegible]	19		[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]		--		4,880	6.64	555	1,800	1,660	10	7,020	8.0	[illegible]
1958	[illegible] / [illegible]	[illegible]		[illegible]	[illegible]	562		[illegible]		[illegible]	873		--		3,240	4.41	1,130	1,400	1,280	6.5	[illegible]	7.7	411,000
1959	[illegible] / [illegible]	22		[illegible]	[illegible]	655		[illegible]		[illegible]	1,120		3.9		3,950	5.37	1,130	1,690	1,570	7.4	[illegible]	7.7	[illegible]
1960	[illegible] / [illegible]	19		[illegible]	106	650		[illegible]		[illegible]	1,020		6.0		3,640	4.95	1,090	1,530	1,410	7.2	5,070	7.6	[illegible]
1961	27.1 / [illegible]	19		533	155	871		[illegible]		[illegible]	1,400		6.7		4,780	6.50	1,230	1,970	1,840	8.4	6,710	7.7	455,000
1962	[illegible] / 16,8[illegible]	16		550	182	1,110		[illegible]		1,810	1,800		9.1		5,550	7.55	691	2,120	1,990	10	7,910	7.5	252,[illegible]
1963	47.6 / 37,150	[illegible]		467	172	973		[illegible]		1,610	1,560		4.7		4,880	6.64	619	1,870	1,740	9.8	7,040	7.3	225,9[illegible]
1964	25.2 / 9,192.6	[illegible]		530	200	1,270		175		1,870	2,010		5.2		6,[illegible]	8.16	407	2,140	2,000	12	6,570	7.6	146,7[illegible]

Table 8.--8-4070. PECOS RIVER AT PIERCE CANYON CROSSING, NEAR MALAGA, N. MEX.

Annual weighted averages of chemical analyses, in parts per million, 1955-1964 water years

Water year	Mean discharge (cfs) / Total discharge	Silica (SiO2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO3)	Carbonate (CO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as CaCO3: Calcium, Magnesium	Hardness as CaCO3: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual load (tons)
1955	294 / 107,300	15		243	68	449		122		725	713		5.4		2,280	3.10	1,810	880	780	6.6	3,330	7.7	655,400
1956	113 / 41,360	17		442	142	1,090		145		1,430	1,730		--		4,920	6.69	1,500	1,690	1,570	12	7,090	7.7	550,500
1957	45.5 / 16,610	18		465	195	2,170		164		1,660	3,410		--		8,000	10.9	983	1,960	1,830	21	11,700	7.7	359,400
1958	124 / 45,260	17		397	122	1,000		148		1,310	1,550		--		4,470	6.08	1,500	1,490	1,370	11	6,590	7.7	544,800
1959	110 / 40,150	25		451	156	1,260		148		1,540	1,970		--		5,480	7.45	1,630	1,770	1,640	13	7,910	7.6	592,500
1960	116 / 42,460	18		438	133	1,140		136		1,410	1,800		--		5,010	6.81	1,570	1,640	1,530	12	7,290	7.6	574,600
1961	102 / 37,048	18		531	181	1,450		168		1,790	2,310		6.7		6,390	8.69	1,750	2,070	1,930	14	9,310	7.7	638,[illegible]
1962	51.4 / 18,760	16		550	222	2,200		149		1,960	3,500		6.6		8,530	11.6	1,180	2,290	2,160	20	12,700	7.5	431,[illegible]
1963	50.2 / 18,320	15		505	215	2,040		156		1,860	3,240		[illegible]		7,980	10.9	1,080	2,240	2,010	19	12,000	7.2	396,[illegible]
1964	25.2 / 9,208.1	14		547	233	2,200		169		2,040	3,480		3.6		8,600	11.7	585	2,320	2,180	20	12,800	7.5	21[illegible]

Table 9.--S-4575. PECOS RIVER AT RED BLUFF, N. MEX.

Annual weighted averages of chemical analyses, in parts per million, 1955-1964 water years

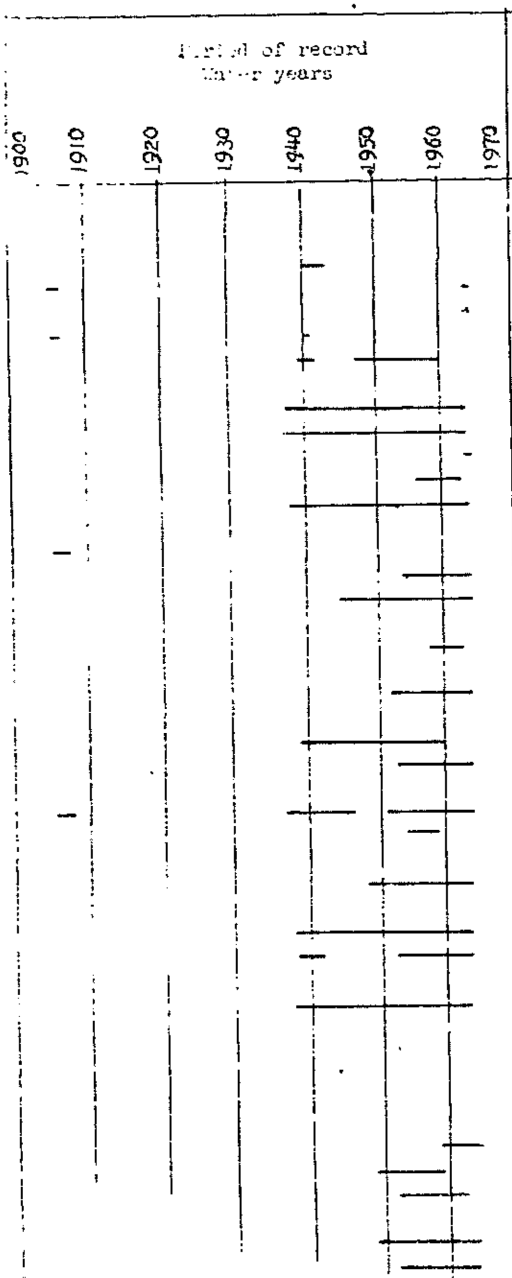
Water year	Mean discharge (cfs)	Total Discharge	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual Load (tons)
1955	292	106,600	13		255	73	566		143		770	884		--		2,630	3.58	2,070	936	819	14	3,660	7.5	757,200
1956	87.7	31,920	16		483	191	1,570		138		1,700	2,490		--		6,520	8.87	1,540	1,990	1,820	15	9,590	7.5	606,200
1957	46.8	17,080	--		440	201	2,070		131		--	3,260		--		8,050	10.9	1,020	1,920	1,800	21	11,400	7.5	369,600
1958	140	51,100	--		387	113	963		136		--	1,540		--		4,490	6.11	1,700	1,430	1,320	11	6,510	7.5	617,700
1959	111	40,520	--		456	149	1,280		122		--	2,020		--		5,760	7.83	1,730	1,750	1,650	13	8,050	7.5	631,000
1960	116	42,460	--		435	130	1,230		130		--	1,950		--		5,460	7.43	1,710	1,620	1,510	13	7,640	7.5	623,800
1961	104	37,898	--		526	179	1,460		151		--	2,340		--		7,170	9.75	2,010	2,050	1,930	14	9,430	7.6	732,800
1962	50.6	18,470	--		549	223	2,240		142		--	3,580		--		9,150	12.4	1,250	2,290	2,170	20	13,000	7.5	454,200
1963	49.9	18,198	13		519	216	2,280		127		1,870	3,630		1.6		9,040	12.3	1,220	2,180	2,080	21	13,100	7.3	441,900
1964	26.6	9,724	11		511	224	2,160		145		1,940	3,400		3.0		8,330	11.3	598	2,200	2,080	20	11,400	7.4	217,900

Table 10.--8-4101. PECOS RIVER BELOW RED BLUFF DAM, NEAR ORLA, TEX.

Annual weighted averages of chemical analyses, in parts per million, 1955-1964 water years

Water year	Mean discharge (cfs)	Total discharge	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Annual load (tons)
1955	217	79,200	13		317	84	743		132		978	1,150				3,350	4.56	1,960	1,140	1,030	9.6	5,160	7.7	716,400
1956	125	45,750	13		531	131	1,090		112		1,680	1,690				5,190	7.06	1,750	1,860	1,770	11	7,340	7.9	640,600
1957	60.6	22,120	8.5		610	196	1,990		107		2,060	3,130				8,050	10.9	1,320	2,330	2,240	18	11,600	7.6	478,200
1958	73.0	26,540	11		491	147	1,390		120		1,640	2,160				5,900	8.02	1,160	1,830	1,730	14	8,620	7.6	423,800
1959	54.4	37,625.4	14		463	135	1,150		136		1,550	1,760		2.2		5,140	6.99	1,170	1,710	1,600	12	7,280		427,100
1960	62.1	22,735	12		566	201	1,900		134		2,040	2,920				7,710	10.5	1,290	2,240	2,130	17	11,000		473,400
1961	125	45,625	14		533	174	1,420		123		1,840	2,230				6,270	8.53	2,120	2,050	1,940	14	8,950		775,100
1962	61.4	22,415	8.3		666	248	2,260		118		2,430	3,520				9,190	12.4	1,520	2,680	2,580	19	12,900	7.3	551,200
1963	53.6	17,371	9.7		673	256	2,470		116		2,430	3,890				9,790	13.3	1,290	2,730	2,630	21	13,400	6.8	471,500
1964	31.8	11,650	11		641	243	2,260		115		2,320	3,550				9,080	12.3	780	2,600	2,510	19	12,600	7.0	264,216

Table 11.--Summary of chemical and sediment quality stations records for streams in the Pecos River basin in New Mexico



Sta. No.	Station	Frequency of sampling	Daily concentration (ppm) Max.	Daily concentration (ppm) Min.	Load (Tons/day) Max.	Load (Tons/day) Min.
	CHEMICAL - Dissolved Solids					
3705	Pecos River near Anton Chico	D	185	96	810	16
3805	Gallinas River near Montezuma	D-M	386	120	138	2
3810	Gallinas River at Montezuma	M	-	-	-	-
3830	Pecos River at Santa Rosa	D	2,320	174	2,490	30
3834	Pecos River at Puerto de Luna	D	2,740	220	10,020	106
[illegible]	Pecos River below Alamogordo Dam	D	2,730	435	9,930	.31
3860	Pecos River near Acme	D	19,870	594	71,900	2.1
[illegible]	Rio Ruidoso at Hollywood	M	-	-	-	-
3905	Rio Hondo at Diamond "A" Ranch near Roswell	M	1,450	292	1,820	3.92
3965	Pecos River near Artesia	D	16,300	461	99,700	.4
-	Pecos River near Dayton	D	5,120	748	30,100	1,060
4010	Pecos River below McMillan Dam	M	6,070	4,930	-	-
-	Pecos River at Ford Crossing above Major Johnson Springs near Lakewood	M	6,160	1,470	-	-
4015	Pecos River below Major Johnson Springs near Carlsbad	M	-	-	-	-
4020	Pecos River at Damsite 3, near Carlsbad	W	4,970	310	-	-
4035	Carlsbad main canal at head near Carlsbad	D	7,430	552	5,700	14.5
4045.1Q	Pecos River above Carlsbad flume at Carlsbad	M	-	-	-	-
4050	Pecos River at Carlsbad	D	3,810	300	79,700	27.7
4053.5Q	Black River below Mayes Ranch near White City	M	-	-	-	-
4054Q	Black River at Harkey Crossing near Malaga	M	2,000	480	-	-
4065	Pecos River near Malaga	D	9,100	384	123,400	133
4070	Pecos River at Pierce Canyon Crossing near Malaga	D	23,700	280	e100,000	103
4075	Pecos River at Red Bluff	D	22,800	450	95,500	106
	SEDIMENT - Suspended Sediment					
3830	Pecos River at Santa Rosa	D	30,800	8	276,000	<.5
3834	Pecos River at Puerto de Luna	D	59,200	20	1,510,000	4
3905	Rio Hondo at Diamond "A" Ranch, near Roswell	D	64,900	NF	630,000	0
3965	Pecos River near Artesia	D	20,900	NF	183,000	0
[illegible]	Rio Penasco at Dayton	D	30,000	NF	600,000	0

SUSPENDED SEDIMENT

In the upper reach of the Pecos River suspended sediment is more of a problem than is chemical quality. For the period 1955-63 the annual sediment load ranged from a minimum of 317,400 tons in 1960 at Santa Rosa to a maximum of 5,295,000 tons in 1955 at Puerto de Luna. Materials carried in suspension are roughly 2 to 20 times those carried in solution in this reach although particles in traction and in solution do make up a considerable part of the total load.

The dominance of suspended load above Alamogordo Reservoir can be attributed to the steep gradient of the river, high flows and outcropping shales. These shales weather rapidly, but add little in the way of soluble products. At Colonias, where much of the discharge is lost underground, the sediment load is released in the widened flood plain, but is picked up again during flood periods and transported downstream.

In the middle reach sediment as well as chemical quality is a major problem. Sediment load in this reach is less than in the upper reach. Between Acme and Artesia the load of suspended and soluble materials is roughly equal. For the period 1955-63, the annual load at Artesia ranged from 386,800 tons in 1956 to 1,552,300 tons in 1955.

The load reduction can be attributed to release of clear water at Alamogordo Dam, lower gradient of the streambed, increased solutes and abundant growth of phreatophytes. Some sediment is added in this reach by the Rio Hondo, Rio Penasco and other tributaries. The increased growth of phreatophytes tends to slow down velocities which reduces corrasion and bank cutting.

In the lower reach between McMillan Dam and Red Bluff Reservoir suspended sediment loads are usually insignificant. The occasional flood flows from tributaries such as Rocky Arroyo and Dark Canyon can contribute appreciable sediment. The highly mineralized waters in this reach also may act to floc or precipitate any suspended colloids of clay.

QUALITY OF WATER BY REACHES

The river and its tributaries in the upper reach generally have their origin in the core area of the Central Highlands of the Southern Rocky Mountain province where sandstones, shales, and limestones of Pennsylvanian age predominate. Sedimentary rocks of Paleozoic and Mesozoic ages (mostly sandstone and shales) outcrop generally southeast of the town of San Jose to Alamogordo Reservoir. The dilute, fresh waters north of Colonias are not greatly affected by contamination with saline waters (See classification - table 12, following, in text). The water is primarily a calcium-bicarbonate type of good quality. The river water below Santa Rosa increases in dissolved solids to Alamogordo Reservoir where the water is fresh to slightly saline. The dissolved solids load for the period 1955-64 at the lower end of the reach at Alamogordo Dam ranged from 206,900 tons in 1959 to 295,700 tons in 1963, with an average of 247,440 tons (figure 7).

Flow in the middle reach is partly controlled by Alamogordo Dam. The dissolved solids concentration at low flows between Alamogordo Dam and Acme is increased by more than twofold, and further increases are noted at Artesia; however, fresh water flood flows from the Rio Hondo and Rio Penasco result in minimum concentrations at Artesia than are recorded at Acme. The principal dissolved solid addition within this reach is sodium chloride. For the period 1955-64 the annual dissolved solids loads at Artesia ranged from 243,200 tons in 1964 to 1,127,000 tons in 1955. According to the saline-water classification, the weighted averages of dissolved solids concentrations place it in slightly to moderately saline category. (Table 12)

Table 12-Classification of Water

1. Fresh water - contains less than 1,000 ppm dissolved solids.

2. Saline waters - contains between 1,000 and 35,000 ppm dissolved solids.

    a. slightly saline - 1,000 to 3,000 ppm.

    b. moderately saline - 3,000 to 10,000 ppm.

    c. very saline - 10,000 to 35,000 ppm.

3. Brine - all waters containing more than *35,000 ppm dissolved solids.

* concentration of sea water.

The main stem in the lower reach is partly controlled by Lake McMillan and Lake Avalon. There is at least a one-third decrease in dissolved solids concentration between Artesia and Carlsbad. Most of the decrease can be attributed to inflow to the river below McMillan Reservoir from springs that have their recharge area west of the river and to some deposition of calcium carbonate (travertine) in the river channel. During period 1955-64 the annual load of dissolved solids ranged from 46,300 tons in 1964 to 292,200 tons in 1955, and consisted predominantly of calcium sulfate. Dissolved solids between Carlsbad and the state line increase significantly with downstream flow, although the stations near Malaga have occasional minimum below that at Carlsbad because of flood flows on the Black River. The flow of the Black River is borderline fresh to slightly saline water.

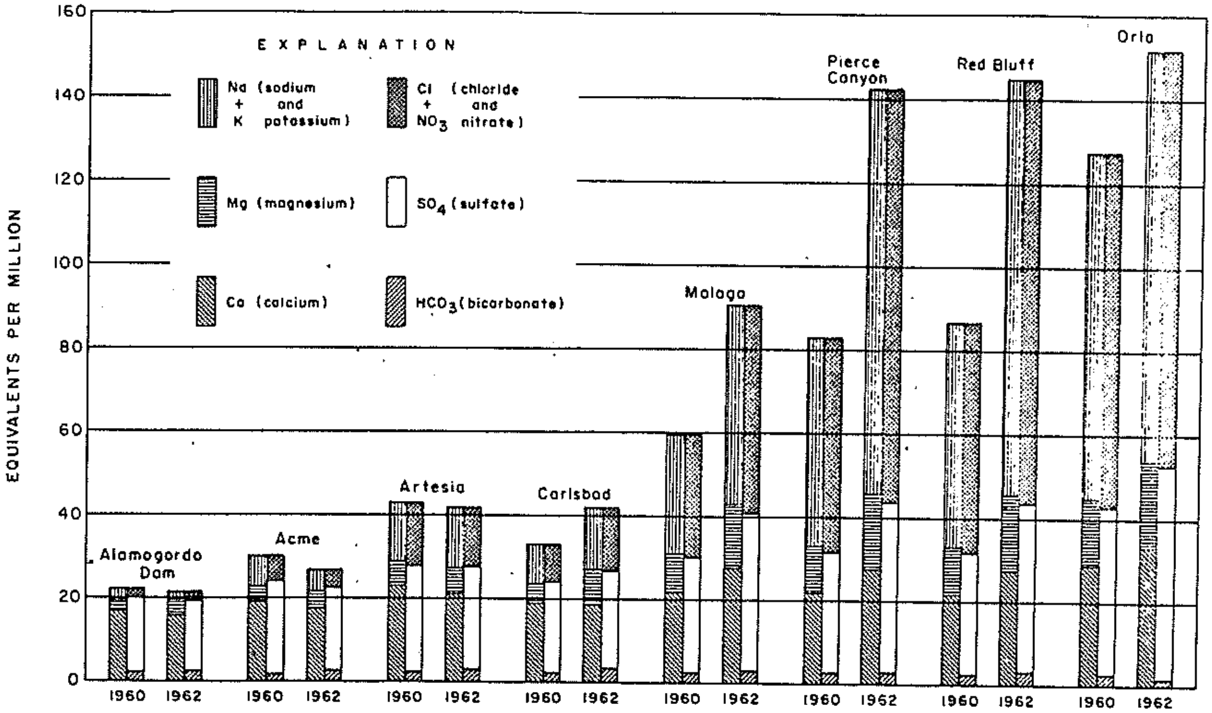


Figure 8. --Comparison of weighted average analyses for water years 1960 and 1962 at eight gaging stations on the Pecos River.

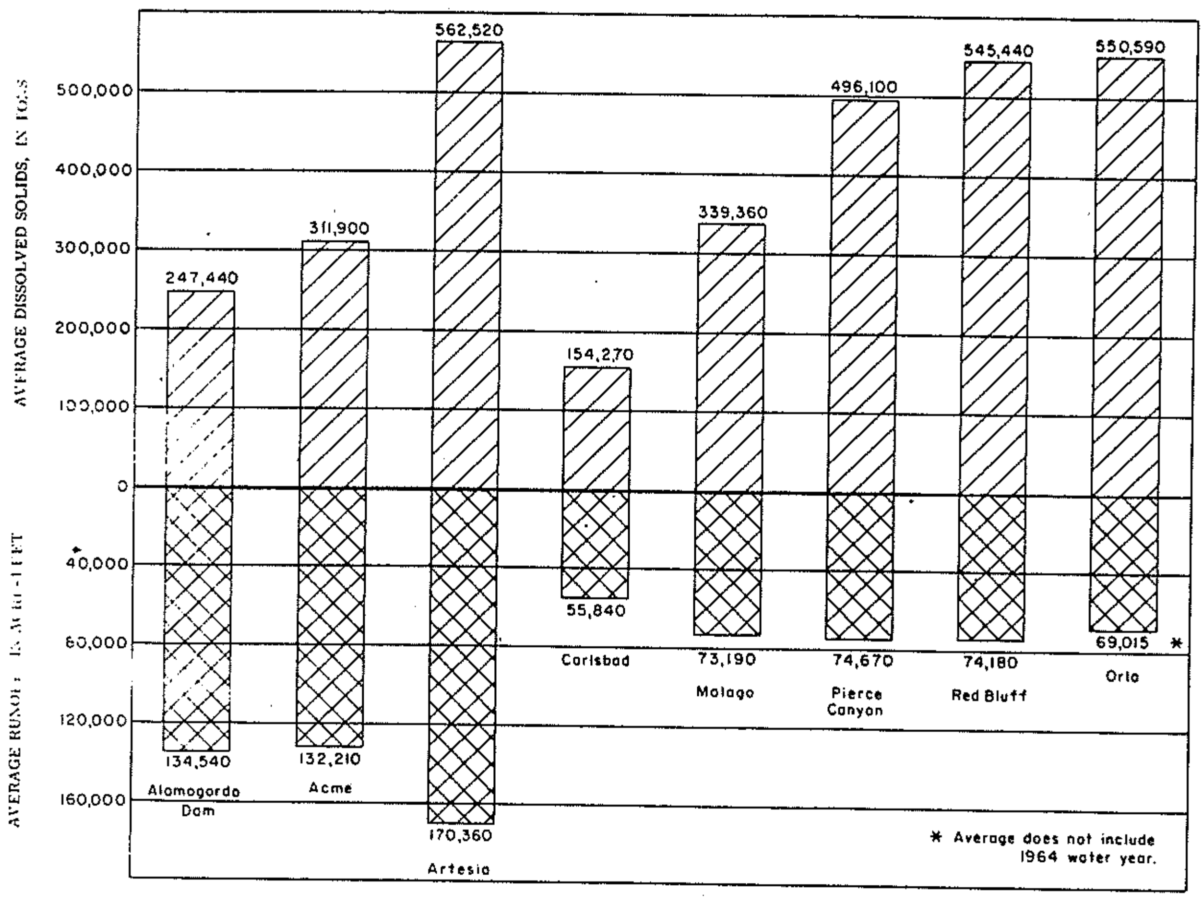


Figure 7. --A ten year average runoff and dissolved solids for 1955-1964 water years.

The Malaga Bend area contains brine springs, the waters of which have concentrations of 150,000 ppm and are saturated with sodium chloride. The dissolved solids are over four times the concentration of sea water. Considerable improvement of the Pecos River water at Pierce Canyon Crossing below Malaga has been evident since the Salinity Alleviation Program went into operation. That program involves the pumping of some of the brine from the springs aquifer into an artificial lake (Northeast Depression), thus lowering the water table and discharge of the brine springs. During the past ten years the annual dissolved solids load at the Red Bluff gaging station ranged from 727,200 tons in 1955 to 217,900 tons in 1964. Waters between the Red Bluff station and Red Bluff Reservoir fall into the moderately saline to very saline classification. The predominant ions are sodium chloride.

CHEMICAL INTERPRETATION

Along the Pecos River basin west of the High Plains escarpment, where the confining beds of the Chalk Bluff Formation have been removed by erosion, springs become an important influence in surface-water qualify. The spring waters are saturated with calcium sulphate through contact with gypsum. Where the river becomes partly subsurface, especially along sinks with deep circulation and within the Roswell basin, the influence upon the chemistry of the water is tremendous. Reaction rates are magnified many times as a result of (1) the large ratio of surface area to the quantity of flow underground, (2) detention periods are longer underground permitting even slow reactions to go to completion, and (3) underground flow is frequently under higher pressures and temperatures which aid most chemical reaction rates.

From this it can be seen that the chemical quality of surface waters in the middle and lower Pecos River reaches depends largely upon the fact that the rocks contain a large amount of soluble material. Some minor pollutants are irrigation return flows, sewage effluent, and industrial wastes which may increase the chlorides above their natural concentration. Evapotranspiration by phreatophytes will also increase the concentration of dissolved minerals to some degree.

Data indicate that saturation for calcium sulfate (or equilibrium concentration) is quickly established. Where water is in contact with gypsum continuously, it probably can occur within 5 to 7 days. Saturation for gypsum in pure water at 25 degrees Centigrade is 2.085 grams per liter (2,085 ppm) as referred to the anhydrous salt. The maximum concentration (2,100 ppm) occurs at approximately 40 degrees Centigrade (104 degrees Fahrenheit).

Above Anton Chico the water in the Pecos River is predominantly a calcium bicarbonate water. Below Anton Chico a rapid equilibrium in the suface water is attained with respect to gypsum. Saturation by gypsum is in evidence for much of the Pecos River water passing the Acme station below which the dissolved minerals in the water show a rapid increase. As the sodium and magnesium chlorides show a progressive rise in percentage of the dissolved minerals below Acme, it becomes more evident that the solubility of calcium sulfate has also increased, though not proportionately, first with the addition of sodium chloride, and finally by the addition of magnesium salts. In other words, an increase in concentration of sodium chloride acts to increase the solubility of calcium sulfate, while the further addition of magnesium chloride increases the concentration of calcium sulfate at saturation, ie.-up to 2 moles[1/] of magnesium chloride may increase fourfold the solubility of calcium sulfate (Morozova and Firsova et al, 1956, p. 1962). Increased temperatures toward the southern part of the state are important also when considering the gradual increase of calcium sulfate in a downstream order (figure 8).

Most of the Pecos River, especially the middle and lower basins, shows a marked decrease in dissolved solids with increased flood flow. Because of these periodic floods there is a much lower weighted average concentration for the year. At first, however, the chemical load and concentrations increase during the rise in discharge as a result of precipitation along the middle and lower reaches of the river. This results from the time required to clear all the saline pools and salt pans along the bank of the river. The lag of return to normal chemical concentrations is also noted when the river returns to base flow conditions; this probably is the result of release of bank storage.

1/ A mole is the gram molecular weight of the solute in one liter of solution.

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