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WATER SUPPLY OF THE HOUSTON GULF COAST REGION

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INTRODUCTION

Region has plenty of water-no shortage

Contrary to belief in some quarters, the Houston region has no water shortage. Indeed, there is an abundance of water. With adequate programs of development and operation, it appears there will be plenty to meet all reasonable needs in the future.

The water-resources problem in this region is that of developing available supplies in the best manner, not searching for outside supplies.

To do this means to learn as much as possible about the location, quantity, and quality of the water from the various sources -- and then to proceed with the necessary developments in an orderly fashion on the basis of a full knowledge of the facts.

20 years of water studies summarized

As one of the steps toward this goal, the United States Geological Survey and cooperating agencies 3/ have collected water-resources data in this region for more than 20 years. Most of this information has been published in reports of the United States Geological Survey and of the Texas Board of Water Engineers, many of which are listed in the bibliography on pages 15 and 16. These publications can be obtained from or consulted at the offices of the Board of Water Engineers or the Geological Survey at Austin, Tex. The Geological Survey water-supply papers may be purchased from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Many of the reports can be found in public libraries.

Earlier reports, as noted above, have covered various phases of the water resources of the area and have proved useful, but no attempt has been made to summarize the information. This report was undertaken to fulfill the need for a general summary. It is not intended to be all-inclusive in detail, but the data presented will be of value to those interested in water supply in the region.

1/ The term "Houston Gulf Coast region," or "Houston region" as used here, includes all or parts of 11 counties between the Brazos and Trinity Rivers, extending from the Gulf of Mexico northward into Walker and Grimes Counties, and including the entire drainage basin of the San Jacinto River (fig. 1).

2/ Hydraulic Engineer, Geologist, and Hydraulic Engineer, respectively, Water Resources Division, U. S. Geological Survey.

3/ Texas Board of Water Engineers, City of Houston, City of Galveston, Brazos River Conservation and Reclamation District, San Jacinto River Conservation and Reclamation District, U. S. Corps of Engineers, U. S. Bureau of Reclamation, and U. S. Weather Bureau.

WATER DEMANDS

Water demands growing rapidly

Use of water in the region has increased rapidly since 1930. Rice irrigation, expanding industry, and growing municipalities now require several times as much water as was used 20 years ago.

More than 1,000,000 gallons is required to irrigate an acre of rice. To refine a barrel of crude oil may require 3,000 gallons; and to mine a ton of sulfur, 8,000 gallons. Large quantities of water are required to produce many other products. Municipal requirements exceed 100 gallons a day per person.

Water used in this region is obtained from a number of sources -- the Brazos, Trinity, and San Jacinto Rivers, smaller coastal streams, and wells in the extensive underground formations.

Quantities of water reported to have been obtained from the rivers and from wells in recent years are as follows:

(Average use in millions of gallons a day) 4/

Year	Streams	Wells
1937	180	160
1940	229	188
1943	342	240
1946	338	280
1949	567	350

Although these figures are reported as the average amount, in millions of gallons used a day throughout the year, the use actually fluctuated with the seasons and was not distributed uniformly. Irrigation, for example, is practiced only during 4 to 6 months of each year; yet, for the sake of comparison, the total quantity of water used each year for irrigation was divided by 365 to obtain the figures used in preparing the table.

Present municipal and industrial supplies mostly from wells

Use of water from wells in the region has been exceptionally large. This has been possible because of the productiveness of the deeply buried water-bearing sands. For a number of years Houston has been the largest city in the Nation whose municipal supply has been obtained exclusively from ground water. The rapid industrial growth has been made much easier because ground water has been readily accessible, and new industries have not had to wait for the construction of pipe lines and treatment plants to obtain water.

Figure 1 shows the main areas of ground-water withdrawal in the region, and includes graphs of the principal uses in these areas. About 83 percent of the total pumpage from wells in 1949 was from the areas shown.

4/ Water use may be reported also in acre-feet per year. An acre-foot is equal to 1 acre of water 1 foot deep. One million gallons a day is equal to 1,120 acre-feet a year.

Figure 2 illustrates the growth in the three principal uses of ground water since 1887. Use of ground water for irrigation of rice has increased rapidly, and in 1948 and 1949 the quantity used surpassed that for municipal use. The greatest use in recent years, however, has been for industrial purposes. Graphs illustrating the growth in use of ground water in the principal areas of withdrawal are shown in figures 3 to 8.

River water used mostly for irrigation

Use of water from streams in the region so far has been confined largely to irrigation. However, use of surface water for industrial supplies has increased rapidly during recent years and is likely to increase even more rapidly as the region continues to grow. Figure 9 shows graphically the reported diversions from the streams within the Houston region since 1936. About 85 percent of the water diverted in 1949 was used for irrigation, the remainder for industrial purposes. No surface water has been used to supply municipal systems, but the City of Houston is now making plans to develop a supply from the San Jacinto River.

The Texas Board of Water Engineers grants permits, according to State law, for the appropriation of surface water for specific purposes when such water is available and unappropriated. In granting such permits the rights of prior permittees throughout the respective river basin must be recognized. Through 1949 permits granting annual appropriations of 1,188 billion gallons had been issued by the State for uses within the Houston region and for uses exclusive of hydroelectric power in the Trinity and Brazos River basins upstream from this region. The average annual flow (or runoff) of streams originating in or flowing through the Houston region is 4,741 billion gallons, or an average daily flow of 13,000 million gallons. Thus, only about 25 percent of the surface water flow has been appropriated. There are yet large quantities of surface water available for development, though additional facilities for storing flood flows must be provided because present operations utilize all of the low flow during droughts.

The diversions within the Houston region during 1949 averaged 567 million gallons a day, making a total for the year of 207 billion gallons. Upstream diversions in the Trinity and Brazos River basins were 121 billion gallons. Some appropriators have not fully used the water appropriated to them, but in general, plans have been made for for doing so in the future.

Figure 10 shows the average annual flow of the streams for the period of record, together with the water appropriated (except that for hydroelectric power) and the water used throughout the river basins in 1949. From the illustration, a comparison may be made of the amount of water used, the amount of water appropriated but not used, and the amount of water not yet appropriated.

Some of the water diverted for use upstream from the Houston region is not consumed and returns to the stream and becomes available for new uses downstream. Within the Houston region, however, little of the water diverted from a stream is returned to the stream from which it was diverted. The industrial wastes or return flow from irrigation generally are discharged into small coastal streams that flow directly into the Gulf.

SOURCE OF WATER

Abundant rain is the source

Rainfall is the source of the abundant supply of water in the region. U. S. Weather Bureau records extending back to 1889 show the extremes in annual precipitation range from more than 70 inches in 1900 to 23 inches in 1917. The average annual precipitation is about 45 inches. Approximately 10 inches of this rainfall runs off in surface streams. Evaporation and transpiration by plants account for most of the remainder. A small part percolates down through the soil and past the root zone, eventually to reach the water table. From there the water moves slowly through the interstices in the ground-water formations toward discharging wells or toward areas of natural discharge.

As stream flow is primarily the residual of rainfall after nature has had its take by evaporation and transpiration, the variation of annual stream flow from the average is much more extreme than that of rainfall. To show the relation of stream flow to rainfall, the flow of West Fork San Jacinto River near Humble has been expressed in inches of runoff and plotted on the same graph (fig. 11) with precipitation at Huntsville and Navasota. This graph shows that in 1948, a dry year when about 31 inches of rain fell in the basin, only 2½ inches (less than 9 percent) reached the stream; whereas in 1946, a wet year when about 64 inches of rain fell in the basin, about 20 inches (31 percent) reached the streams. No stream-flow data are available in the Houston area for the wettest and driest years of record--1900 and 1917--but the difference in percentage of runoff must have been even greater.

For convenience, sources of water are placed in two separate categories: surface water and ground water. However, surface water infiltrating into underground formations becomes ground water; ground water discharging into streams becomes surface water.

Ground water generally is more readily accessible to individual industries and irrigators in the region, but where large quantities are required, surface water may be preferable from an economic standpoint. Ground water usually is free of sediment and harmful bacteria and does not fluctuate greatly in mineral content or temperature. This is especially important for many industrial supplies. Surface water, on the other hand, may require treatment to remove suspended matter and destroy harmful bacteria. The chemical character of both surface and ground water in the Houston region is generally good.

In many parts of the Nation, one of the characteristics that makes ground water more desirable for industry is its temperature which in summer is lower than that of surface water. However, the great depth of the most-productive wells in the Houston region minimizes this advantage, because the temperature of ground water increases with depth.

GROUND WATER

Geologic formations that yield water to wells in the Houston region consist of interbedded layers of sand and clay. These formations crop out in the northern part of the region and dip gently beneath the surface toward the Gulf of Mexico. Figure 12 is a generalized cross section through the region, illustrating these conditions. The dip of the formations is greater than the slope of the land surface, and, therefore, the formations at the outcrop are beveled by the land surface. Such conditions are ideal for the occurrence of artesian water.

Extensive ground-water beds

The predominantly sandy zones shown in figure 12 are the important water-producing formations. The sandy zones consist of extremely irregular beds of sand and gravel and some beds of silt and clay which may grade into each other laterally and vertically in relatively short distances. The predominantly clayey zones shown in the section are more persistent over large areas, but they, too, contain many irregular sandy beds.

The blue color on the cross section indicates the zones now being pumped heavily in the region. Some of the deeper formations are not drawn on and would yield additional large supplies of ground water to wells in the northern part of the region. Water levels in wells in these formations would be high, and some of the wells would flow. Supplies similar in quantity and quality to those in the present heavily pumped areas could be developed.

Water levels in wells lowered by pumping

Rainfall enters the outcrops of the heavily pumped sandy zones as "recharge," and then the water moves down the dip of the beds to the wells. Originally, wells throughout the region tapping these zones would flow above the land surface. However, heavy pumping has caused the water levels in the wells to decline until, in 1950, the water levels had dropped to as much as 200 feet below sea level in the Pasadena area, where withdrawals are most concentrated. Figure 13 shows the water levels in wells in and near Houston at various times since pumping began.

Figures 3 to 8 illustrate the rate of ground-water development in the major areas of withdrawal and the resultant declines in water levels. It should be emphasized that, although the heavy pumping has caused large declines in water levels, there is no deficiency of water.

Increased pumping costs, but still an adequate supply of water

Ground water cannot be obtained without a decline in water levels, for this decline is necessary to cause the water to flow toward the wells. The decline creates an increased slope or hydraulic gradient toward the wells. The quantity of water moving toward the wells is proportional to this gradient. Although pumping from wells has continued to increase and the water levels have declined correspondingly, the yields of the individual wells have not decreased and are still high. Pumping costs have increased, but there is still an adequate supply of water. If the rate of pumping is stabilized, the water levels will also be stabilized within a relatively short time.

Excessive local declines in water levels can be avoided by proper spacing of wells. The decline in water levels in the Pasadena area has been relatively great because of the concentration of wells. The annual pumping in the Houston municipal area has been about the same as in the Pasadena area, but the pumping is spread over a much larger area, and consequently there has been less decline in water levels.

Wells have high yields

Approximately 750 large-capacity wells are in use in the region. These wells range from about 6 to 12 inches in diameter through the water-bearing zones, and many of the larger ones have surface casing up to 30 inches in diameter. Yields range from a few hundred to about 3,500 gallons a minute. The cost of drilling and equipping large wells ranges from about $15,000 for a 1,000-foot well for rice irrigation to about $75,000 for a 2,000-foot well for municipal supply.

Quality of ground water good

The ground water in the region is usually slightly alkaline but is generally of good quality, although the quality varies somewhat with depth and location.

Figure 14 shows the approximate variation of temperature with depth at Houston. Near the surface the temperature of the ground water is about the same as the average air temperature. The temperature increases about 1° F. for each 100 feet of depth down to about 1,600 feet. Below 1,600 feet the average rate of increase is slightly greater.

As shown in figure 14, the mineral content of the water at Houston increases with depth, the higher mineralization being due largely to increased amounts of sodium chloride. Geologic structure has an influence on the depth at which more highly mineralized water occurs, especially in the vicinity of salt domes where salt may be found at quite shallow depths. Hardness decreases with depth down to about 2,000 feet, then increases slowly, the increase becoming more rapid below 2,400 feet.

Figure 15 shows graphically the mineral content of water from typical wells in each of the heavily pumped areas.

The cross section in figure 12 shows the approximate position of salt water in the formations underlying the region. This salt water probably was present in the sediments at the time of their deposition. As the land was elevated, fresh water began percolating through the formations and tended to flush out the salt water. Incomplete flushing of the deeper formations explain the presence of salt water.

In much of the region salt water lies approximately 2,000 feet below sea level. However, in places fresh water is found considerably deeper. In parts of eastern and northeastern Harris County fresh water occurs to depths of about 2,800 feet below sea level. Potable water has been found to depths of about 2,550 feet below sea level in Houston's East End municipal well field.

Salt water advancing slowly toward wells

Near the Harris-Galveston County line salt water occurs at a depth of about 1,200 feet. The formations encountered at that depth are the same ones that are heavily pumped in the Houston and Passdena areas at a much shallower depth. Inasmuch as the heavy pumping in the Houston and Pasadena areas has established a slope of the water level toward Houston and Pasadena from all directions (see fig. 13), the salt water is undoubtedly moving northward. The rate of this movement is slow, being of the order of a foot per day. If the slope is not materially increased by additional pumping, salt water will not reach the Pasadena area for possibly 75 to 100 years.

Salt-water encroachment must be reckoned with eventually in Houston and Pasadena areas

However, with continued development of ground water in the heavily pumped areas, it seems certain that salt water will eventually invade the well fields unless preventive steps are taken. To be prepared for it, certain studies should be started now. Outpost wells should be established in order to study the problem. If and when encroachment becomes evident remedial measures should be taken. Three possible measures are: (1) shifting of pumping from Houston and Pasadena to the north to diminish the hydraulic gradient in the salt-water areas; (2) protective pumping to keep the salt water from reaching the area; and (3) artificial recharge to build up a fresh-water barrier between the present heavily pumped areas and the salt water.

There seems less likelihood of encroachment of salt water from below than from down the dip of the same formations. Thick clay beds, which separate the fresh and salt water-bearing sands in the Houston and Pasadena areas, will not let the salt water through at a very rapid rate. However, the possibility of encroachment from that source should be carefully studied.

In the Galveston well-field and at Texas City the salt-water problem is quite different. Salt water is known to occur in the lower part of the main sands drawn upon in those areas. The position of the salt water in the sands down dip, though not definitely known, probably is only a short distance southeast of Texas City. Wells drilled in the sands on Galveston Island yield highly mineralized water. Figures 12 and 16 indicate a certain amount of salt-water encroachment in both the Galveston well-field and Texas City area. The encroachment probably has been from below rather than up the dip of the formation. It is being partially controlled by the use of surface water and by wide spacing of wells and selective distribution of pumping rates, which keep declines of water levels as small as possible.

SURFACE WATER

Three good rivers

Two of the largest rivers in Texas, the Trinity and the Brazos, form the east and west boundaries of the region considered in this report. The area between these rivers is drained by the San Jacinto River and many smaller streams.

Average flow of streams 13,000 million gallons a day

The combined runoff of all these streams averages about 13,000 million [5/] gallons a day or a little more than a quarter of the total runoff for all of Texas, which averages about 48,000 million gallons a day.

Much of this huge quantity of water is available for man's use. Storage generally must be provided, however, because the stream flow varies from day to day and from year to year. About 75 percent of the total flow of the streams occurs shortly after extremely heavy rains. Prolonged droughts reduce unregulated discharge to relatively small flows, and it is upon these low flows that much of the present surface-water uses must rely. At such times the total flow of streams in the region may be less than 300 million gallons a day, but, with adequate storage, a continuous supply of water many times this quantity can be made available.

Figure 17 shows most of the sites in the region where continuous stream-flow records have been collected. The numbers on the map refer to the following table in which summaries of stream-flow data are given.

5/ Stream flow may also be reported in cubic feet per second (second-feet). One million gallons a day is equal to 1.55 cubic feet per second.

PARTIAL SUMMARY OF STREAM FLOW RECORDS IN HOUSTON REGION [1]

(Flow expressed in million gallons a day)

No. [2]	Stream and location	Drainage area (square miles)	Period of record	Elevation (feet above mean sea level)	Extremes in momentary flow		Extremes in average rate of flow						Average flow period of record
					Highest	Lowest	Highest day	Lowest day	Highest month	Lowest month	Highest year	Lowest year	
1	Trinity River at Riverside	15,619	1903-06 1923-49	142.6	78,200	45.2	77,600	45.2	36,900	64.6	9,770	505	4,650
2	Trinity River at Romayor	17,192	1924-49	71.7	71,700	85.3	71,100	85.3	42,500	103	10,900	590	5,200
3	West Fork San Jacinto River near Conroe	832	1924-27 1939-49	126.0	71,100	6.01	60,000	6.46	4,420	8.73	1,050	23.7	434
4	West Fork San Jacinto River near Humble	1,811	1928-49	63.2	121,000	9.05	88,500	9.05	7,790	17.9	2,290	231	761
5	San Jacinto River near Huffman	2,791	1936-49	53.1	164,000	31.7	155,000	32.3	14,200	43.1	4,030	371	1,350
6	Spring Creek near Spring	400	1939-49	106.7	27,600	4.98	20,400	4.98	1,640	6.39	529	35.7	196
7	Cypress Creek near Westfield	262	1944-49	94.9	6,920	0	6,360	0	1,160	0.058	224	17.2	145
8	East Fork San Jacinto River near Cleveland	330	1939-49	133.4	50,100	2.91	27,900	4.91	2,000	6.28	474	45.0	198
9	Peach Creek near Splendora	120	1943-49	100.5	5,160	6.20	3,900	6.20	549	7.69	103	26.1	67.9
10	Caney Creek near Splendora	104	1944-49	141.6	9,630	7.11	5,330	7.11	528	7.30	98.9	21.0	64.4
11	Buffalo Bayou near Addicks	310	1945-49	80.9	7,240	0	6,920	0	1,160	0.873	262	51.0	-
12	Buffalo Bayou at Houston	362	1936-49	30.2	7,040	-	6,850	0.840	1,500	2.81	473	26.6	195
13	Whiteoak Bayou at Houston	92	1936-49	38.4	5,560	0.129	4,290	0.129	500	0.394	125	7.24	54.6
14	Brays Bayou at Houston	100	1936-49	47.8	5,250	0.065	4,660	0.065	528	0.375	135	9.76	64.6
15	Brazos River near Hempstead	42,670	1938-49	162.1	75,000	164			29,800	249	12,300	1,610	5,280
16	Brazos River at Richmond	44,050	1903-05 1922-49	81.4	77,600	198 [3]	79,500	198 [3]	36,100	207 [3]	14,400	1,110	5,240 [3]
17	Dry Creek near Richmond	10.3	1947-49	75.6	295	0	217	0	18.6	0.006	6.53	1.93	-
18	Big Creek near Needville	37.6	1947-49	82.1	1,450	0	1,030	0	57.6	0	13.3	8.98	-
19	Big Creek near Guy	112	1947-49	55.8	1,090	0	1,010	0	218	0.33	57.3	26.4	-
20	Fairchild Creek near Needville	24.9	1947-49	69.3	569	0	397	0	43.0	0	9.69	3.30	-

1/ Numerous miscellaneous records and some discontinued records are available but not included in this table.
2/ See numbered points on map, figure 17.
3/ Adjusted to include the diversion of two large canals just upstream.

Rates of flow in streams fluctuate widely

The average daily flow is only a guide to what can be expected from a stream. Before a designing engineer can proceed with plans to utilize surface water, he must determine the flow characteristics of the stream, because stream flow fluctuates widely.

San Jacinto River

Flow characteristics of the San Jacinto River near Huffman are shown graphically in figure 18. The lowest recorded monthly average flow was 43.1 million gallons a day in September and October 1939, whereas the highest monthly average flow was 14,200 million gallons a day in November 1940. Daily flows varied still more widely than the monthly averages. The chart indicates the need for a longer record that would show more conclusively the effects on stream flow of sequences of wet and dry years. For example, the average daily flow at the Huffman gaging station during the 13-years of record was 1,350 million gallons a day. If the computation of the average flow had been based on the 4 years between 1936 and 1940, it would have been only 40 percent of this 13-year average, but if it had been based on the 4 years between 1940 and 1944, it would have been 142 percent of the 13-year average. Even the 13-year record does not cover the critical drought periods that occurred about 1915 to 1918, 1924 to 1925, and in 1933. The lowest daily flow that has been recorded, however, is less than 3 percent of the average. The record does include the outstanding flood of November 1940, which is the greatest known, based on knowledge extending back to 1876.

It is impractical to salvage all flood flow by storage. However, a large part of the flood flow in the Houston region could be made available economically by the construction of storage reservoirs. Designing engineers of the San Jacinto Conservation and Reclamation District have concluded from their studies that through the impounding of flood waters, the San Jacinto River could be made to yield an economical dependable supply of about 500 million gallons a day throughout periods of extended droughts. The reservoir to be constructed by the City of Houston (see fig. 10) will be the first major step in developing this dependable supply. The reservoir will have a capacity of 52,000 million gallons (160,000 acre-feet). This capacity, if maintained, will assure a supply of 150 million gallons a day. Without construction of a reservoir the dependable flow of the San Jacinto River would not be sufficient during extended droughts to meet the requirements of even the present users. The relatively small Sheldon and Highlands Reservoirs shown on figure 10 provide off-channel storage of about 4,000 million gallons, but they would not materially add to the dependable yield of the river during long periods of drought.

The Brazos and Trinity Rivers, though somewhat farther from Houston, are larger than the San Jacinto River and with adequate storage would have much greater dependable flows. Plans are now under way by several organizations to develop these supplies.

Brazos River

The average flow of the Brazos River at Richmond (adjusted to include diversions to two canals just above Richmond) was 5,240 million gallons a day for the 29 years of record (see table on p. 9, and fig. 17). The lowest flow of record was 198 million gallons a day in August 1925, which is much less than the present daily use of water from the Brazos River in the Houston region. A number of reservoirs in the Brazos Basin, including Possum Kingdom Reservoir in north-central Texas, now store flood water and partly regulate the flow. Other reservoirs are under construction or are planned. The Corps of Engineers estimates that when these are completed, the dependable flow of the Brazos River will be more than 800 million gallons a day during droughts. Additional storage would yield even greater quantities of water.

Two off-channel storage reservoirs are supplied with Brazos River water (see fig. 10). These are the William Harris Reservoir belonging to the Dow Chemical Co. and the reservoir near Texas City belonging to the Galveston County Water Co. Their combined storage capacity is about 7,000 million gallons, which assists in meeting the needs of present users but is not large enough to add materially to the over-all long-term dependable yield of the river.

Trinity River

The average flow of the Trinity River at Romayor during the 25 years of record was 5,200 million gallons a day (see table on p. 9, and fig. 17). The minimum flow, like that of the Brazos, has been small. In 1925 on two successive days the recorded flow was only 85.3 million gallons a day.

Several reservoirs have been constructed above Dallas on the Trinity River and its tributaries, and other multipurpose reservoirs are now under construction. These reservoirs will increase the dependable yield of the river downstream from the Dallas area, although the amount to be released for use in the Houston region has not been determined. Other reservoirs are envisioned which, if constructed, will increase the firm or dependable flow.

The small coastal streams in the Houston region cannot be expected to furnish a dependable yield much greater than the present use from these streams, which is about 33 million gallons a day (see fig. 10). Though the total average runoff is larger than this, there are practically no storage sites, unless off-channel sites can be found or reservoirs similar to Barker and Addicks are built for storage. Almost all the low flow of these streams is already being used.

In designing storage reservoirs a knowledge of evaporation is essential. Computations by the Corps of Engineers show that for a 13-year period the average annual rainfall in the Houston region exceeded average annual evaporation by about 7 inches. Thus, storage losses from evaporation would be more than offset by rainfall except during very dry periods.

Quality of surface water generally good, but fluctuates

The water in the streams generally is slightly alkaline in character and, except during occasional prolonged periods of low flow, is of good quality. Dissolved minerals in the water fluctuate with changes in runoff and vary with the areas within a given basin from which the runoff is derived. The temperature of the water varies with the season and, except during very warm or cold periods, is close to the air temperature (fig. 19).

Figures 20 to 22 are graphs showing the variation in dissolved solids in the water of the three major streams during 1949, together with the discharge of the streams. These graphs show typical variations in the quality of the water in each stream. Analyses of water from the three streams are shown in figure 23.

The San Jacinto River water is probably of better quality than water from any other major stream in Texas. The water is soft and low in dissolved solids at nearly all times. It carries less dissolved sulfate than the other large streams in the region.

Water from the Brazos River is more highly mineralized than water from most other sources in the region, but, except at low flow, is satisfactory for general use. Softening would be required for some industrial purposes. The operation of storage reservoirs now under construction probably will result in improving the quality during periods of low flow.

The quality of Trinity River water, in general, is not as good as that of the San Jacinto but better than that of the Brazos. It is affected by pollution from the Fort Worth-Dallas area, though probably not too much for most purposes.

Pollution, in fact, is not a major problem in the region except in some of the smaller coastal streams near Houston that carry a considerable amount of sewage. All surface water must be filtered and sterilized, however, for human use and for some industrial uses. In some instances ground water also may need sterilization to insure a safe municipal supply.

Though sediment in the streams of the region must be removed when the water is used for municipal and most industrial supplies, it is not usually detrimental to irrigation.

The Brazos carries more sediment than the San Jacinto or Trinity Rivers, but the sediment problems resulting from its use would be less serious than those experienced on many other streams in the country. Reservoirs on the San Jacinto or Trinity Rivers will not be affected as seriously as those on the Brazos River.

Floods

The table on page 9 gives data on maximum floods recorded in the region. In order to design dams, bridges, spillways, levees, and other structures, a knowledge of of the characteristics of floods is essential. The maximum possible flood may be considerably greater than the maximum recorded flood. For example, studies by the Texas Board of Water Engineers and the City of Houston indicate that if a storm such as the Louisiana storm of August 1940 were to center over the San Jacinto Basin the peak discharge probably would be about twice that of the greatest flood known to have occurred so far on the river. The Louisiana storm was caused by a tropical hurricane that centered near Lake Charles, about 135 miles east of the San Jacinto Basin. There is no reason to believe that a disturbance similar to that experienced in Louisiana could not occur over the San Jacinto Basin.

Some flood-control and water-conservation reservoirs have been built in the upper reaches of the Brazos Basin above Waco and in the Trinity Basin above Dallas. Barker and Addicks Reservoirs on Buffalo Bayou near Addicks are the only existing flood-control reservoirs within the region. These reservoirs are single-purpose structures designed and operated solely to retard flood flows when runoff exceeds the downstream channel capacities.

Studies in some sections of the country have led to a rather widely accepted belief that stream flow is generally declining. However, a study of Nation-wide precipitation records a century or more in length, together with long-term stream-flow records, indicates no significant continuous downward or upward trends when adjustment is made for consumptive use of water. There is no basis for belief that the surface-runoff characteristics of the Houston region will change, except for changes created by man such as by the building of reservoirs, flood-detention works, pumping of wells, other water-control structures, and the additional use of water.

ADDITIONAL WATER SUPPLIES

Conservation interpreted differently

The fear that our water supplies are declining has led many persons to advocate conservation of water. Conservation, however, does not have the same meaning to all people. To some it means that less water must be used; to others it means that water which has been developed must be used more wisely or completely; and to still others it actually means that more water should be used in order to salvage water which now is "wasted" through escape into the sea.

In the Houston region far more water is available than is now being used, and no particular gain would result from using less water. From the standpoint of economics for the region as a whole, there is an advantage in using the supplies already developed or to be developed, in a wiser manner. Better spacing of wells and well fields to reduce pumping lifts or to retard salt-water encroachment, recirculation of cooling water to save costs of pumping, and treatment of sewage and industrial wastes to minimize stream pollution are examples of measures that might be considered in a regional study of the economics of the use of water.

More use of water may be encouraged

However, it is felt that greater development of water resources in the region may be encouraged. Any reasonable or foreseeable increase in water requirements can be supplied by impounding unused surface water and by developing ground-water formations in the northern part of the region. The water so developed may cost more than water now costs in the region, but the cost probably will still be low enough to compare favorably with that in other regions.

In developing the water resources of the region, plans for the development of ground and surface water should be coordinated. For example, in northeastern Harris County there are places where largely untapped fresh-water-bearing sands 1,200 feet in thickness are present at depths of less than 2,800 feet. It might prove feasible during times of drought to pump water from these sands directly into the proposed reservoirs on the San Jacinto River and the tributaries leading into it. Thus the dependable yield of the reservoir would be increased. A study might find that such a combined system of development would prove more economical than the development of a single source.

Another possibility would be the construction of a reservoir on the Trinity River, with diversion of the water into the San Jacinto Basin largely through existing drainage courses.

Economic study needed

Many studies of the water resources in the Houston region have been made. Future studies to determine the most feasible sources of supply should be made on a regional basis. Surface and ground water should be investigated both individually and as combined sources. On the basis of such studies, fairly definite decisions and plans can be made for future developments.

The present programs of the City of Houston and the San Jacinto Conservation and Reclamation District to develop the San Jacinto River, and the programs of spacing of well fields such as the Houston Water Department and the City of Galveston are carrying out, are steps in the right direction.

Long-range planning will assure future supplies

It requires a long time to make plans and to construct water-development facilities on a large scale, but if this is done properly in the Houston region, with foresight and coordination, water will continue to be one of the greatest assets to the growth of the region. There is plenty of water. The problem is to make it available to all who need it.

PARTIAL BIBLIOGRAPHY

U. S. Geological Survey Water-Supply Papers

Ground-water resources of the Houston district, Tex., by W. N. White, N. A. Rose, and W. F. Guyton: U. S. Geol. Survey Water-Supply Paper 889-C, 1944.

Exploratory water-well drilling in the Houston district, Tex., by N. A. Rose, W. N. White, and Penn Livingston: U. S. Geol. Survey Water-Supply Paper 889-D, 1944.

Ground-water resources of Liberty County, Tex., by W. H. Alexander, Jr.: U. S. Geol. Survey Water-Supply Paper 1079-A, 1950.

The results of water-level measurements in observation wells in the Houston district from 1931 to 1945 have been published in U. S. Geol. Survey Water-Supply Papers 777, 840, 886, 909, 939, 947, 988, 1019, and 1026.

Stream-flow records for the Houston region are given in the following Water-Supply Papers: 99, 132, 174, 210, 568, 588, 608, 628, 648, 668, 688, 703, 718, 733, 748, 763, 788, 808, 828, 850, 858, 878, 898, 928, 958, 978, 1008, 1038, 1058, and 1088.

Texas Board of Water Engineers Reports

Ground-water resources of the Houston-Galveston area, Tex.: U. S. Geol. Survey, 1932.

Progress reports on the ground-water resources of the Houston district, Tex.: U. S. Geol. Survey and Texas Board of Water Engineers, 1937, 1939, 1940, 1942, 1944, and 1946.

Progress report on the ground-water resources of the Texas City area, Tex. by N. A. Rose: U. S. Geol. Survey and Texas Board of Water Engineers, 1943.

Results of pumping tests at new Southwest plant, Houston, Tex., by J. W. Lang and R. W. Sundstrom: U. S. Geol. Survey and Texas Board of Water Engineers, December 1946.

Ground-water resources of Brazoria County, Tex., by C. R. Follett: U. S. Geol. Survey and Texas Board of Water Engineers, 1947.

Geology and ground-water resources of the Houston district, Tex., by J. W. Lang and A. G. Winslow, U. S. Geol. Survey, in collaboration with W. N White, Texas Board of Water Engineers: Texas Board of Water Engineers Bulletin 5001, October 1950.

Geology and ground-water resources of Walker County, Tex., by Allen G. Winslow: Texas Board of Water Engineers Bulletin 5003, October 1950.

Technical Journal Papers by Members of Geological Survey

Ground-water studies in the humid and semiarid parts of the Texas Coastal Plain, by S. F. Turner and Penn Livingston: Am. Geophys. Union Trans. pp. 503-507, 1935.

Ground-waters of the Houston-Galveston area, chemical character and industrial utility, by Margaret D. Foster: Ind. and Eng. Chemistry, vol. 31, p. 1028, 1939.

Coefficients of storage and transmissibility obtained from pumping tests in the Houston district, Tex., by C. E. Jacob: Am. Geophys. Union Trans. pp. 744-756, 1941.

Application of coefficients of transmissibility and storage to regional problems in the Houston district, Tex., by W. F. Guyton: Am. Geophys. Union Trans., pp. 756-770, 1941.

Ground water and relation of geology to its occurrence in Houston district, Tex., by N. A. Rose: Am. Assoc. Petroleum Geologists Bull., vol. 27, no. 8, pp. 1081-1101, August 1943.

Relation of phenomenal rise of water levels to a defective gas well in Harris County, Tex. by N. A. Rose and W. H. Alexander, Jr.: Am. Assoc. Petroleum Geologists Bull., vol. 29, no. 3, pp. 253-279, March 1945.

Quantitative studies of some artesian aquifers in Texas, by W. F. Guyton and N. A. Rose: Econ. Geology, vol. 40, no. 3, pp. 193-226, May 1945.

Reports by Other Agencies and Individuals

Report on an adequate water supply for the City of Houston, Texas, by Alvord, Burdick and Howson, February 1938.

Subsurface-water supply for the City of Houston, by the Layne-Texas Company for City of Houston Water Board, May 1938.

Development of Houston's water supply, by G. L. Fugate: Journal American Water Works Association, vol. 33, no. 10, October 1941.

A report upon sources of water supply comparing the Colorado River with existing ground-water supply supplemented by the San Jacinto River, by G. L. Fugate, City of Houston Water Department, July 1942.

Review of the water-supply problems of the City of Houston with recommendations, report to Mayor and Council, by Horner and Shifrin and Henry E. Elrod, July 1943.

Report and recommendations on Harris County water supply, by the Engineering Sub-Committee of the Harris County Citizens Water Supply Committee, July 1943.

Master plan report for the full scale development of the San Jacinto River, San Jacinto River Conservation & Reclamation District, Conroe, Texas, November 1943.

Engineering report for water works improvement, Department of Utilities, City of Houston, January 1944.

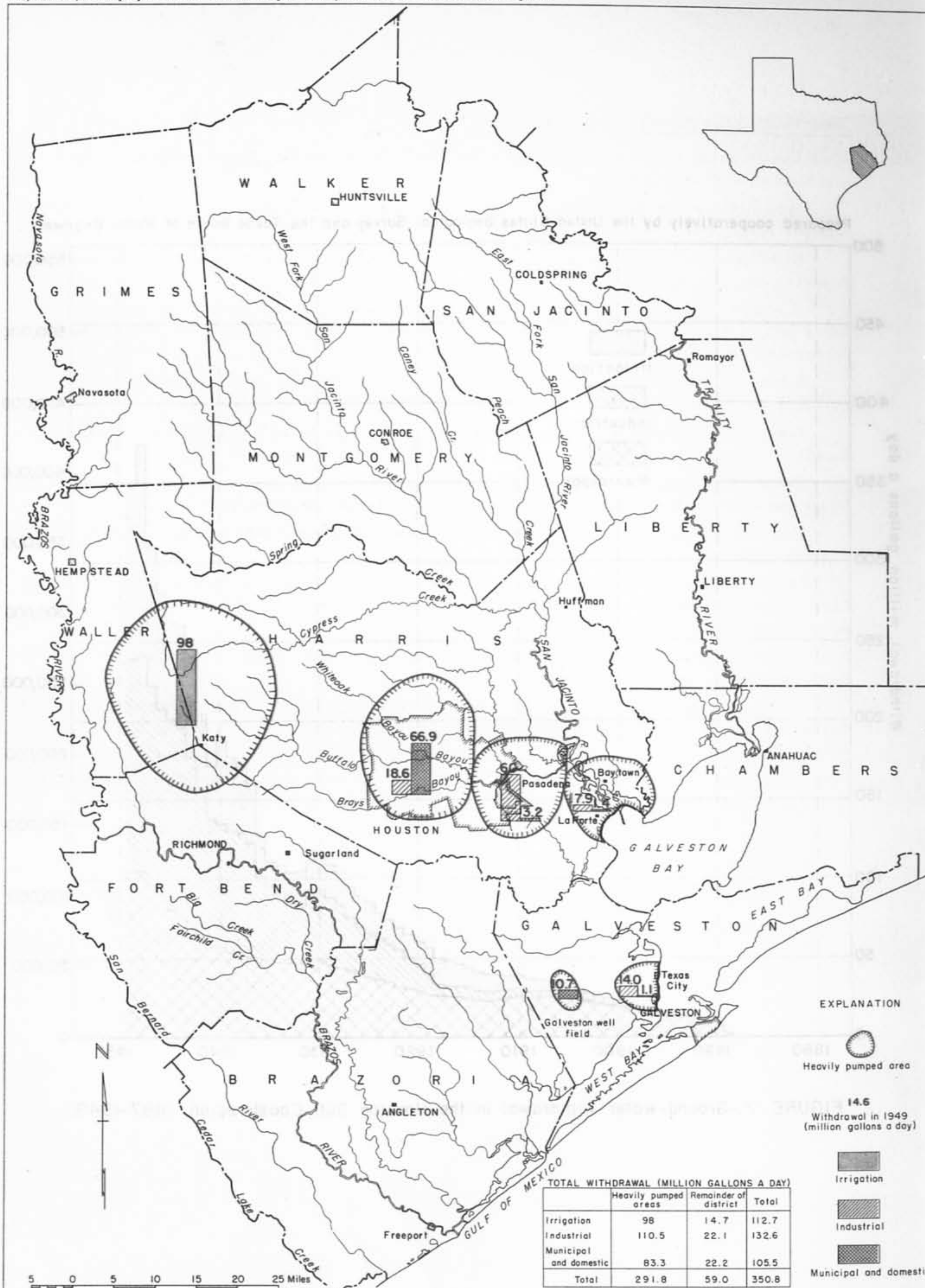
Design for the San Jacinto River Dam, by Engineering Board for Department of Utilities, City of Houston (members of the Board: W. W. Horner, Lorenz G. Straub, J. Niels Thompson, and G. L. Fugate), August 1946.

Report on water supply for Galveston and the Texas City, Texas, industrial area, by Ford, Bacon and Davis, Engineers, February 1947.

The water supply situation of Metropolitan Houston, the Ship Channel-Baytown area, and Galveston County: A report of the Water Supply Committee of the Houston Chamber of Commerce, October 1947

Industrial water on the Gulf Coast, by Will H. Shearon, Jr.: Chemical and Engineering News, American Chemical Society, vol. 27, p. 220, January 24, 1949.

Prepared cooperatively by the United States Geological Survey and the Texas Board of Water Engineers



TOTAL WITHDRAWAL (MILLION GALLONS A DAY)

	Heavily pumped areas	Remainder of district	Total
Irrigation	98	14.7	112.7
Industrial	110.5	22.1	132.6
Municipal and domestic	83.3	22.2	105.5
Total	291.8	59.0	350.8

FIGURE 1.- Ground-water withdrawal in the Houston Gulf Coast region, 1949.

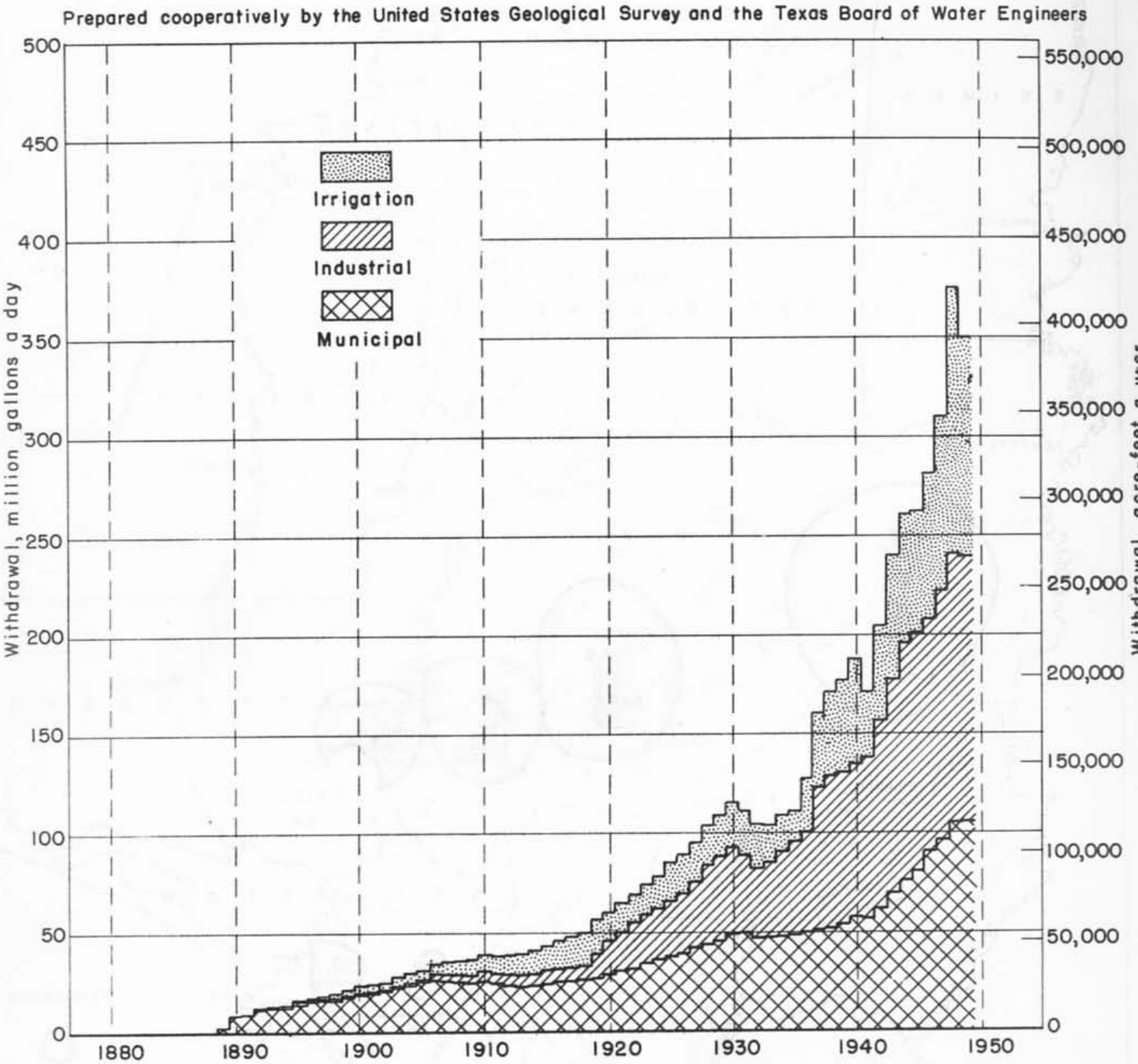


FIGURE 2.-Ground-water withdrawal in the Houston Gulf Coast region, 1887-1949.

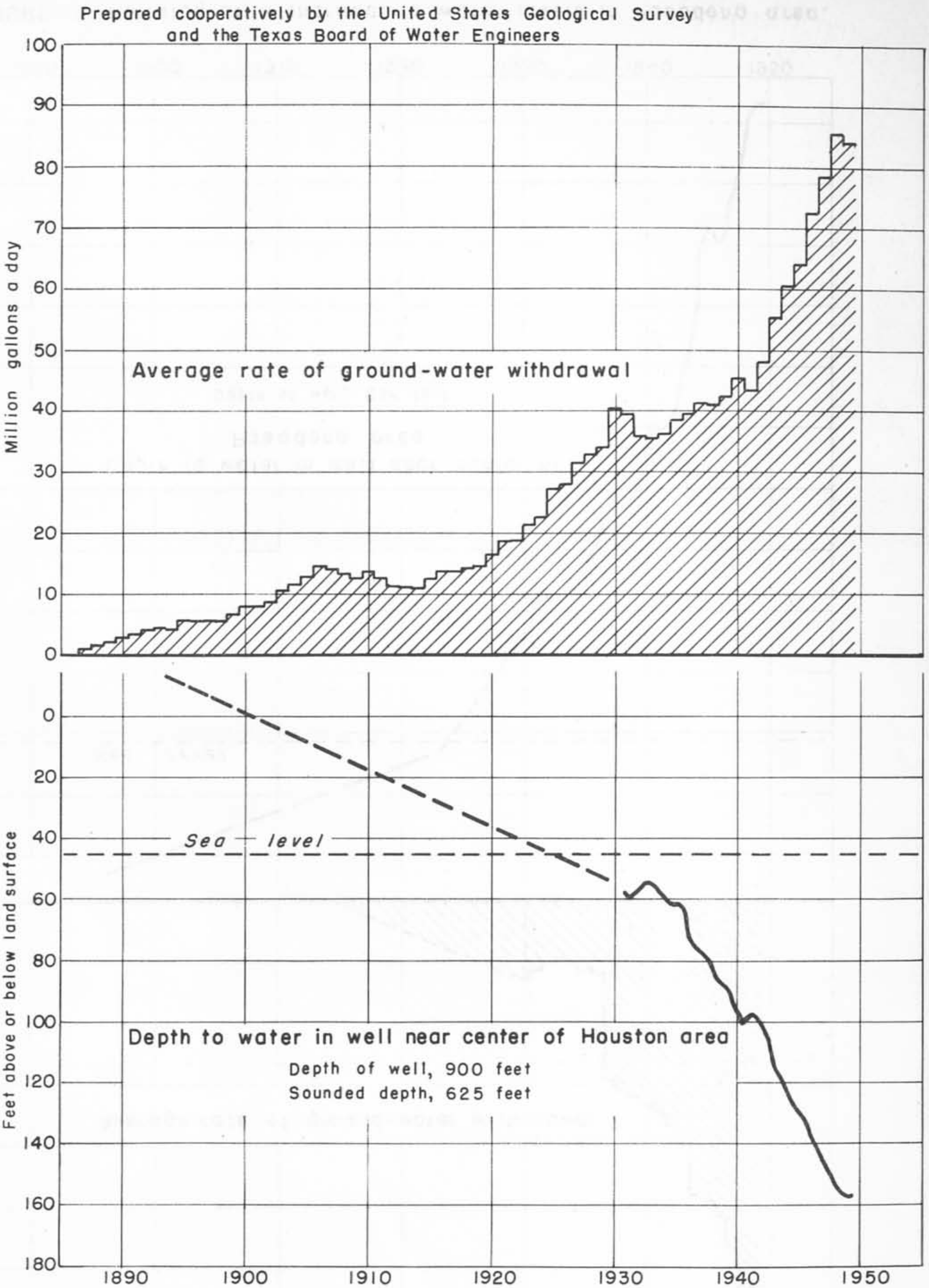


FIGURE 3.- Relation of withdrawal to water levels in Houston area.

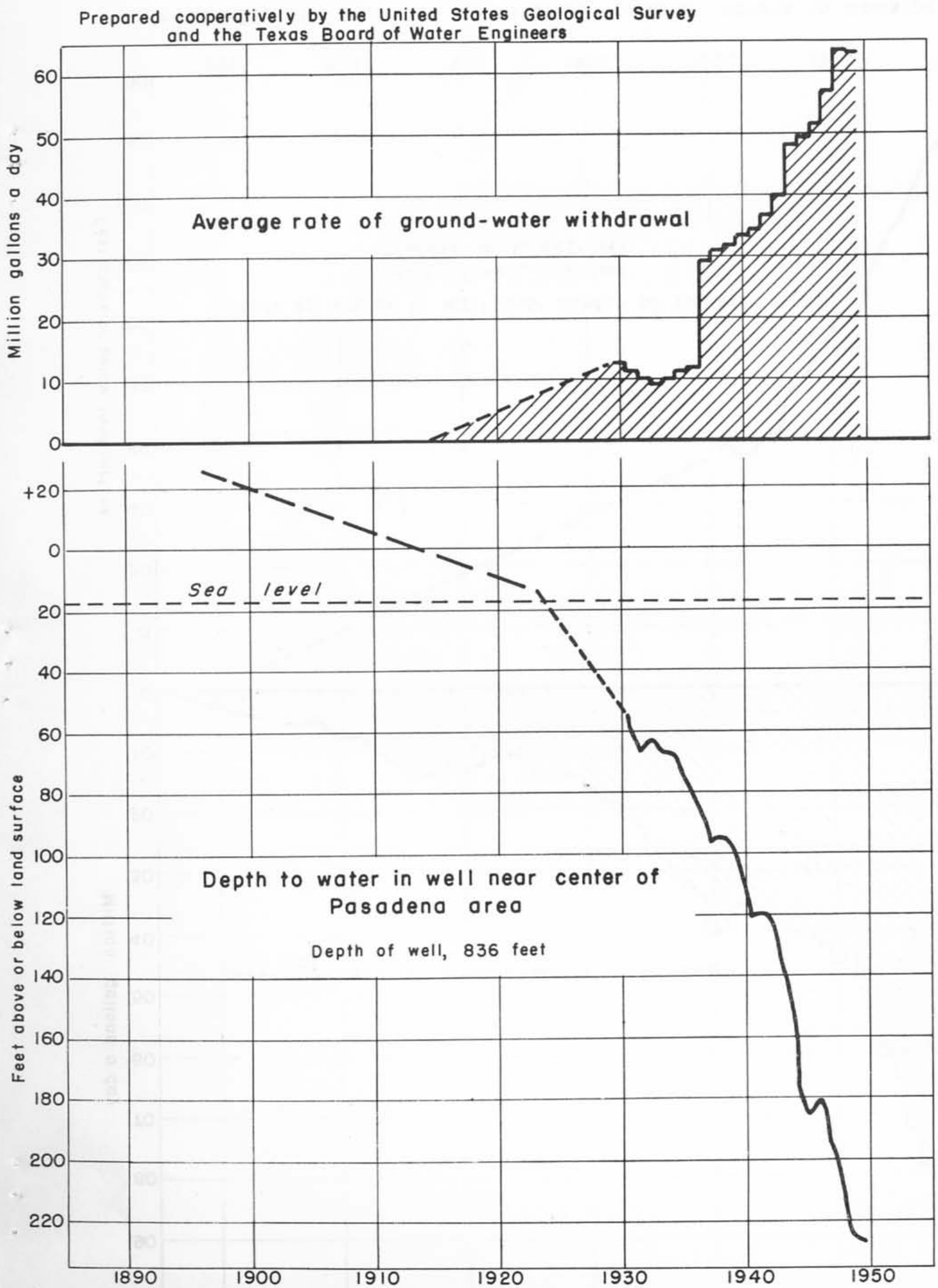


FIGURE 4.- Relation of withdrawal to water levels in Pasadena area.

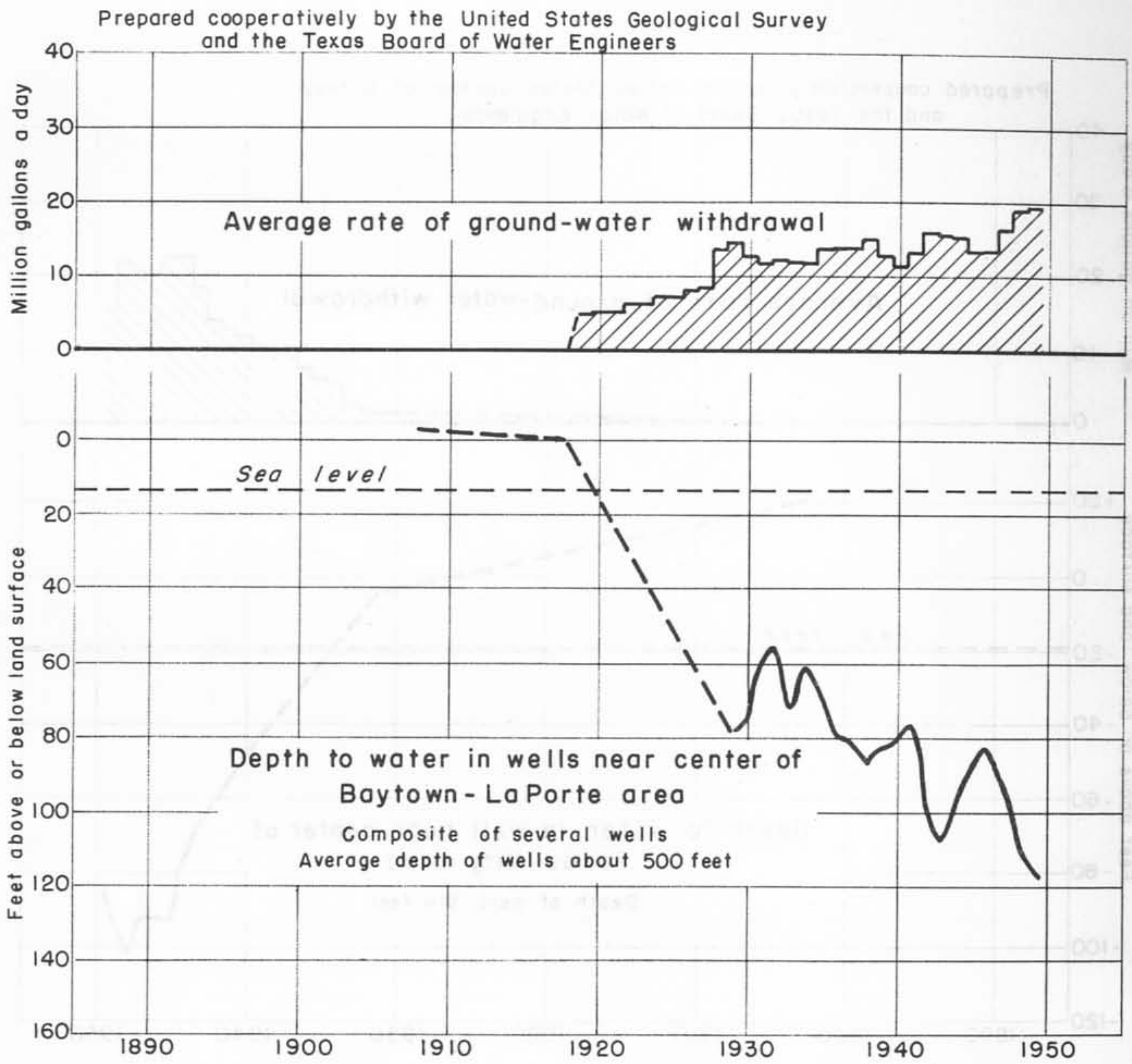


FIGURE 5.-Relation of withdrawal to water levels in Baytown-LaPorte area.

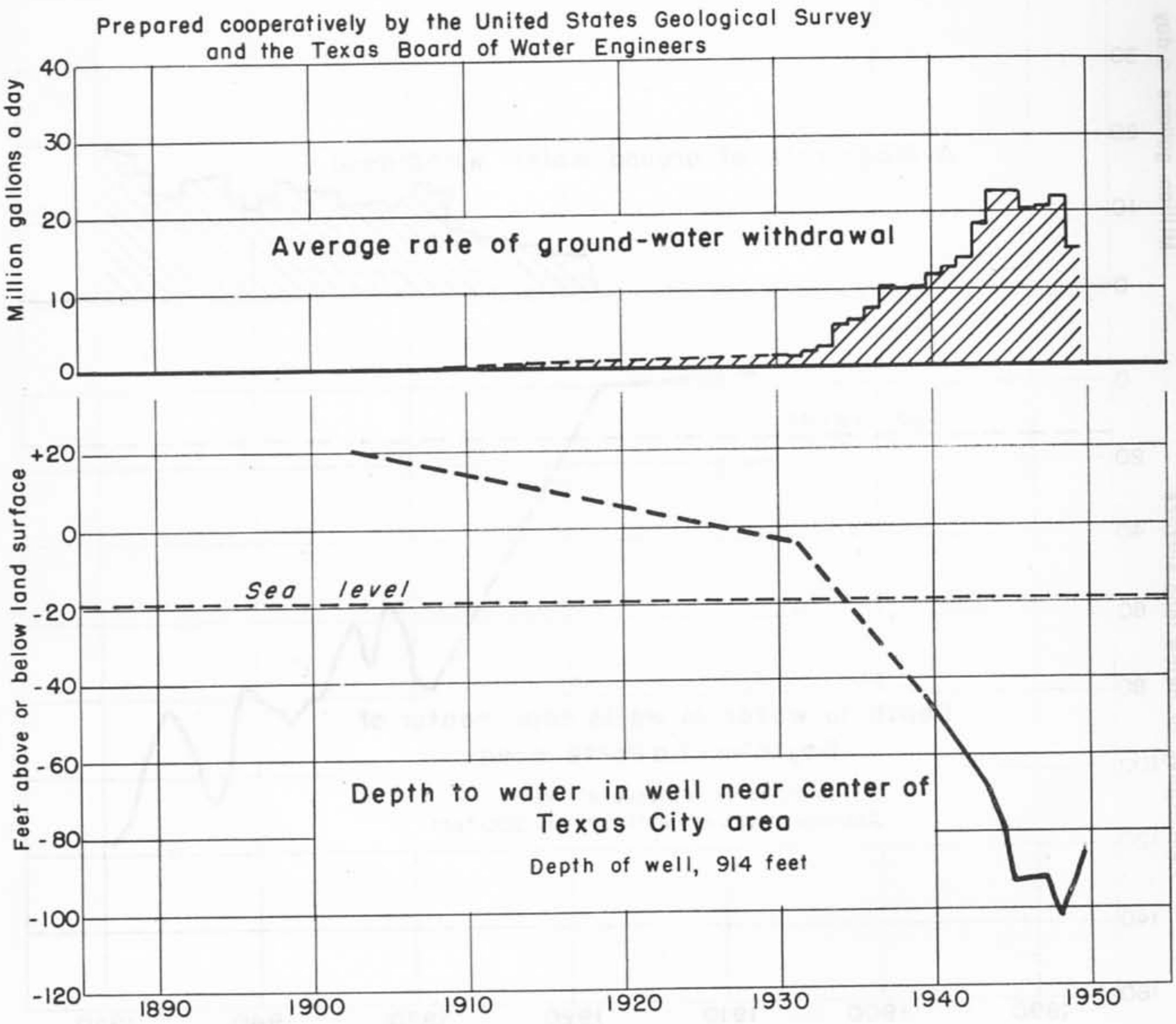


FIGURE 6.-Relation of withdrawal to water levels in Texas City area.

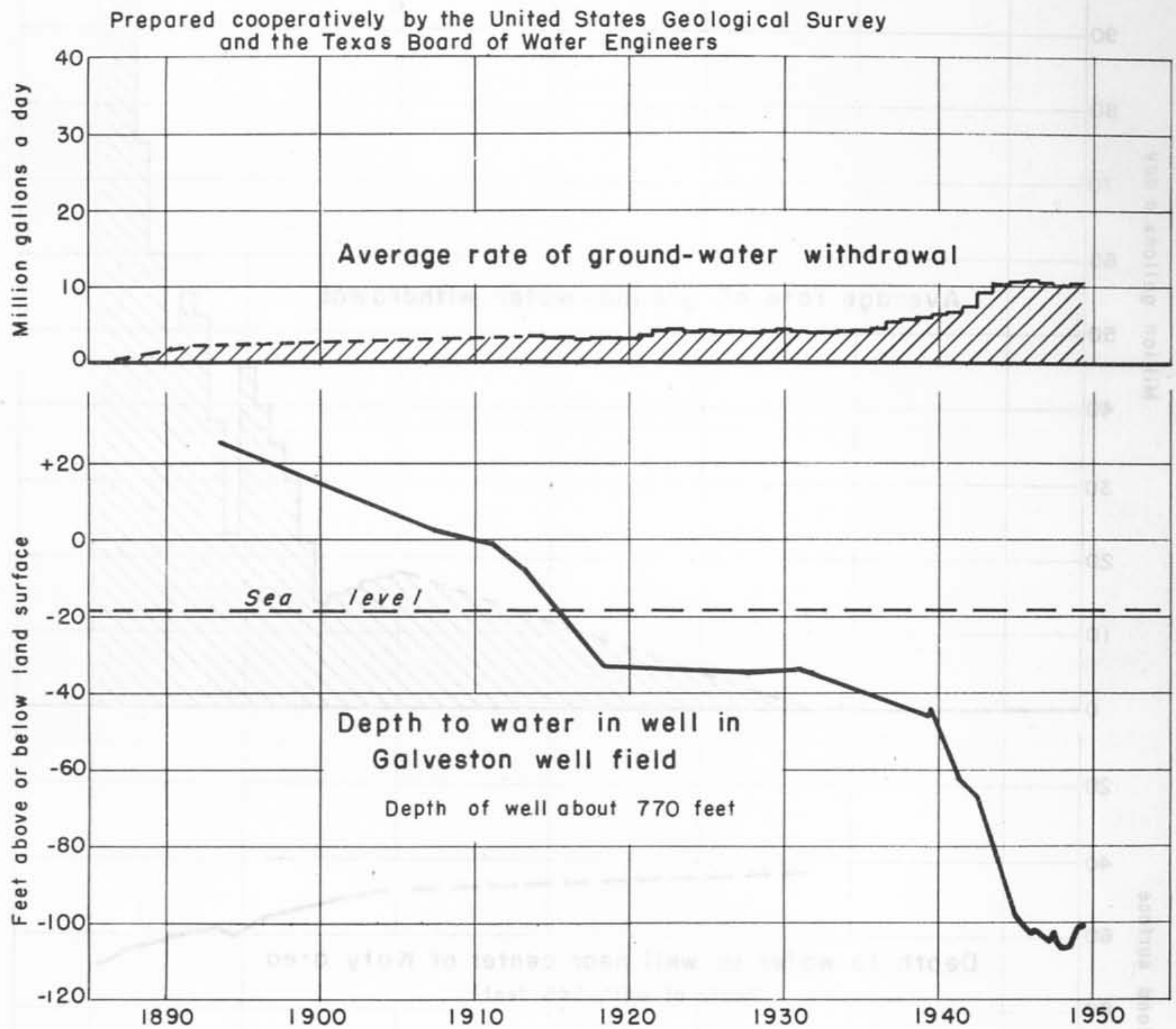


FIGURE 7.- Relation of withdrawal to water levels in Galveston well field.

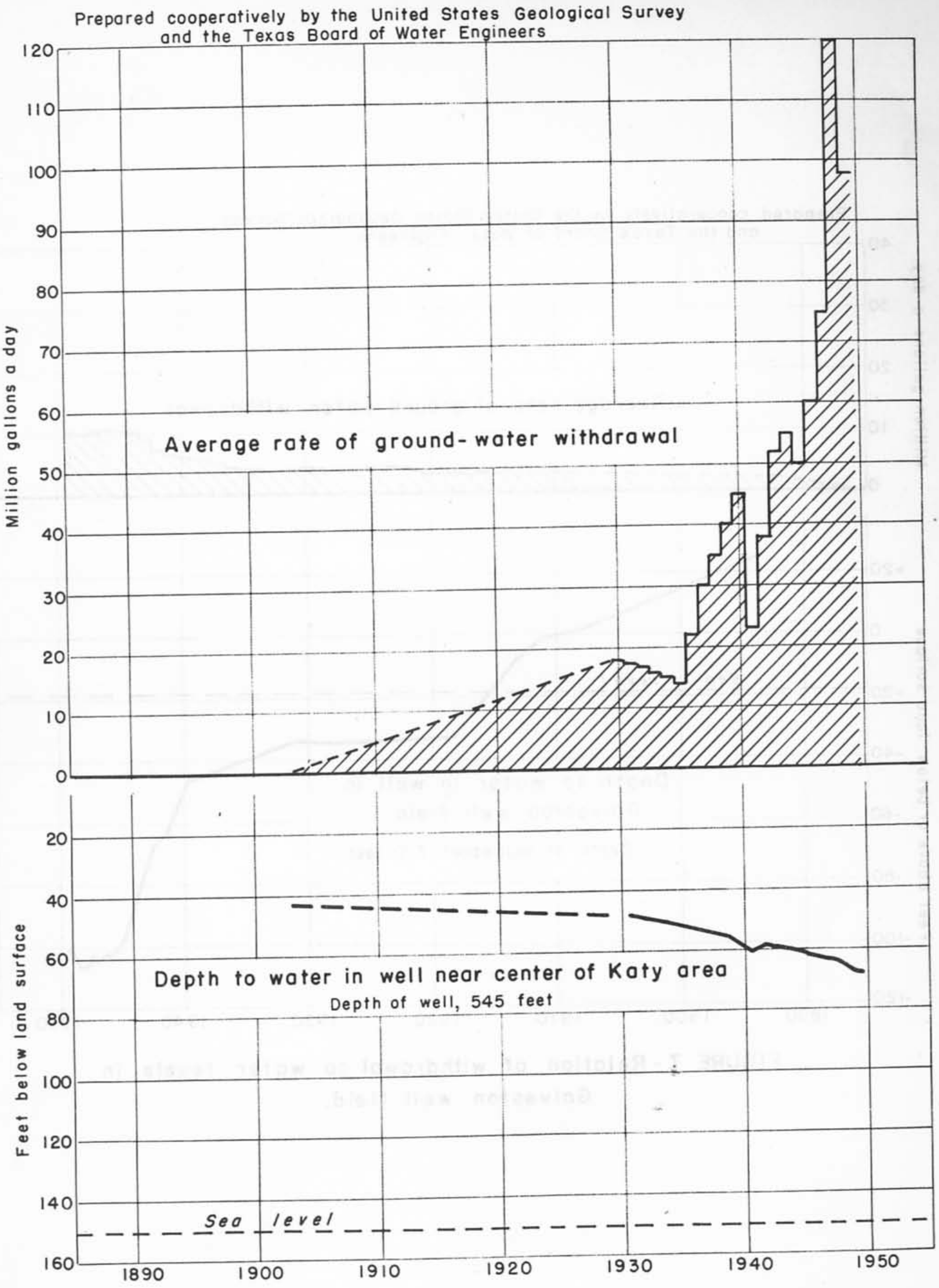


FIGURE 8.- Relation of withdrawal to water levels in Katy area.

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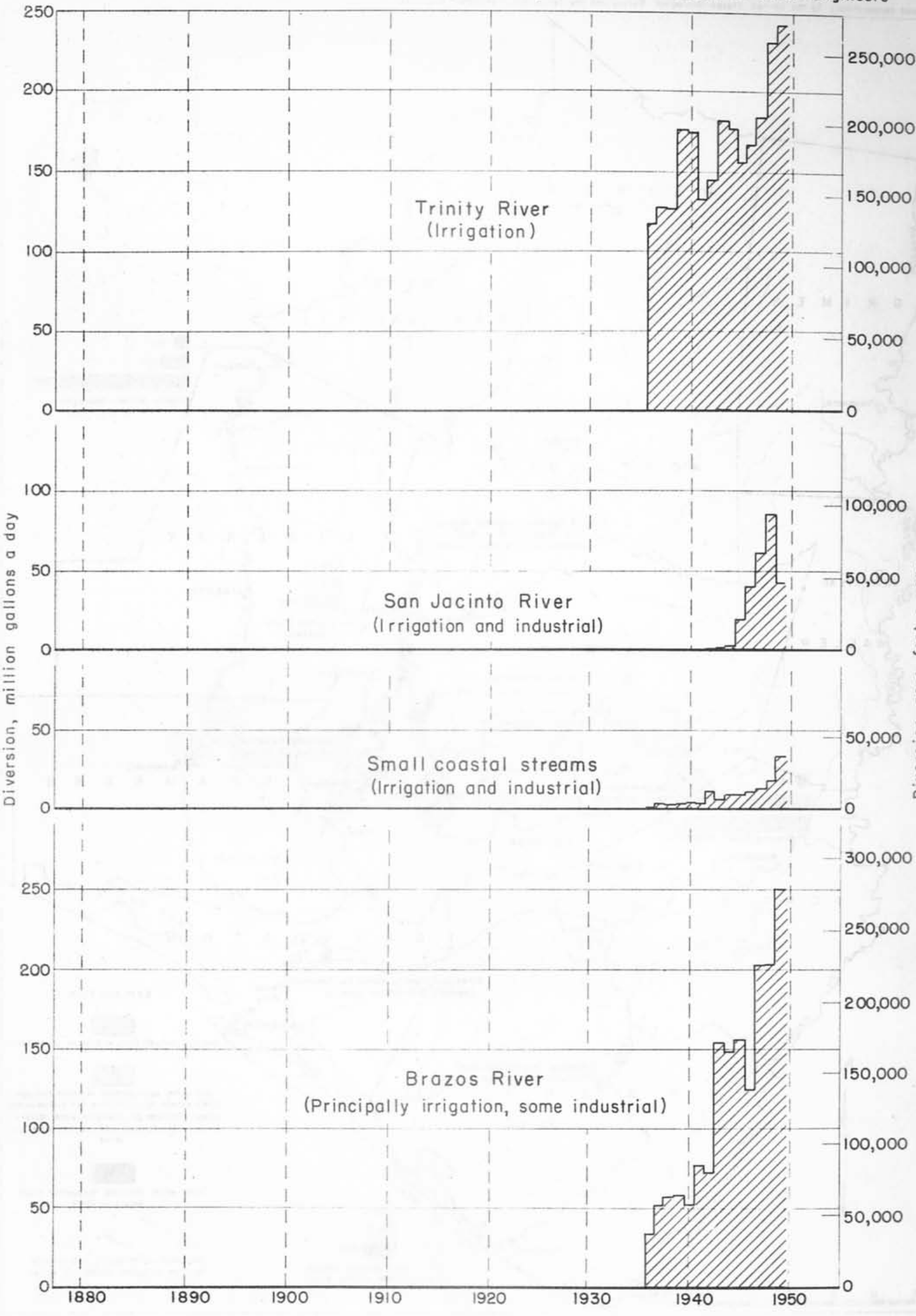

FIGURE 9.- Diversion of water from streams within the Houston Gulf Coast region, 1936-49

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FIGURE 10.- Surface-water flow, appropriations, diversions, and reservoirs.

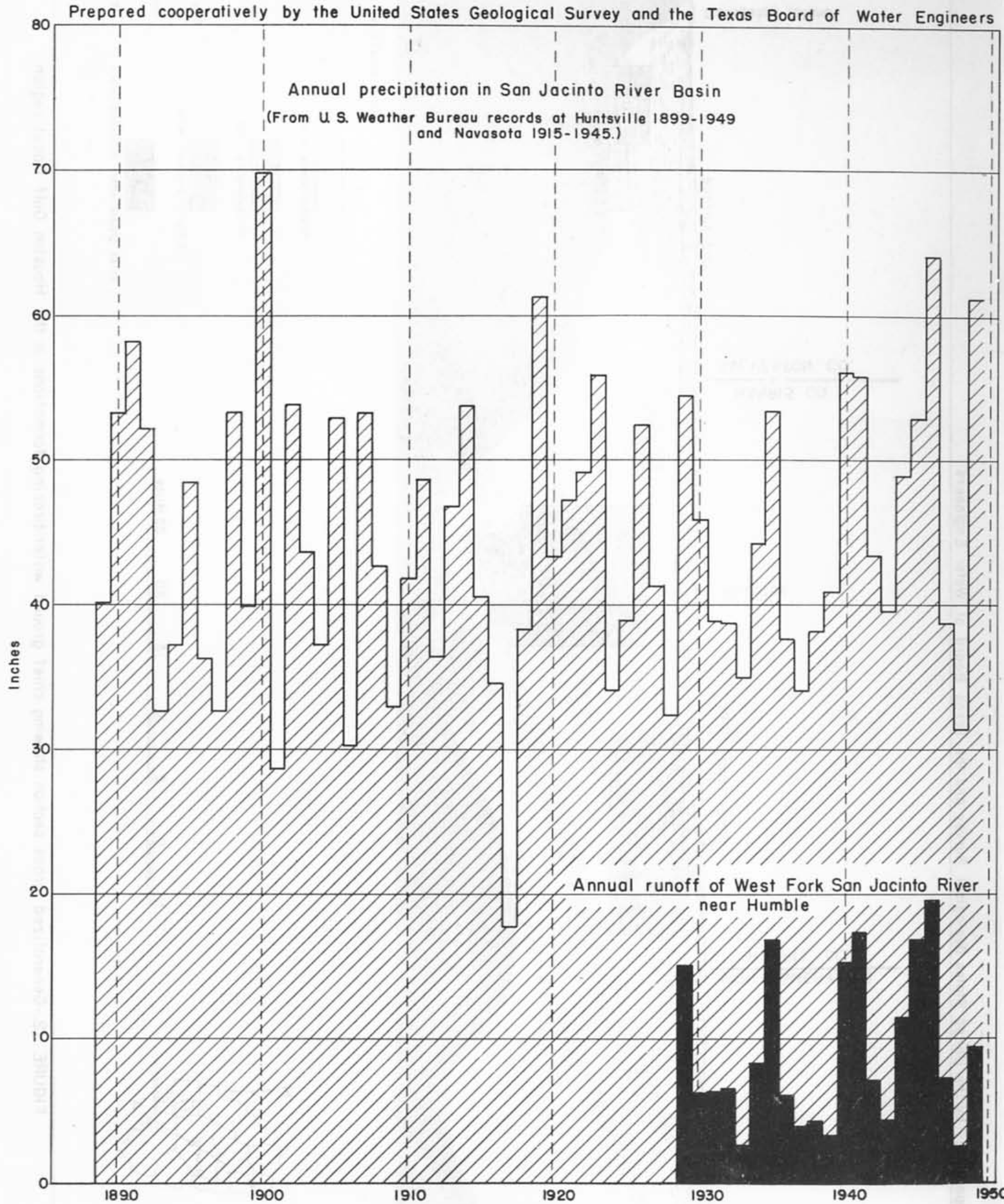

FIGURE 11.-Relation of runoff to rainfall in the San Jacinto River basin.

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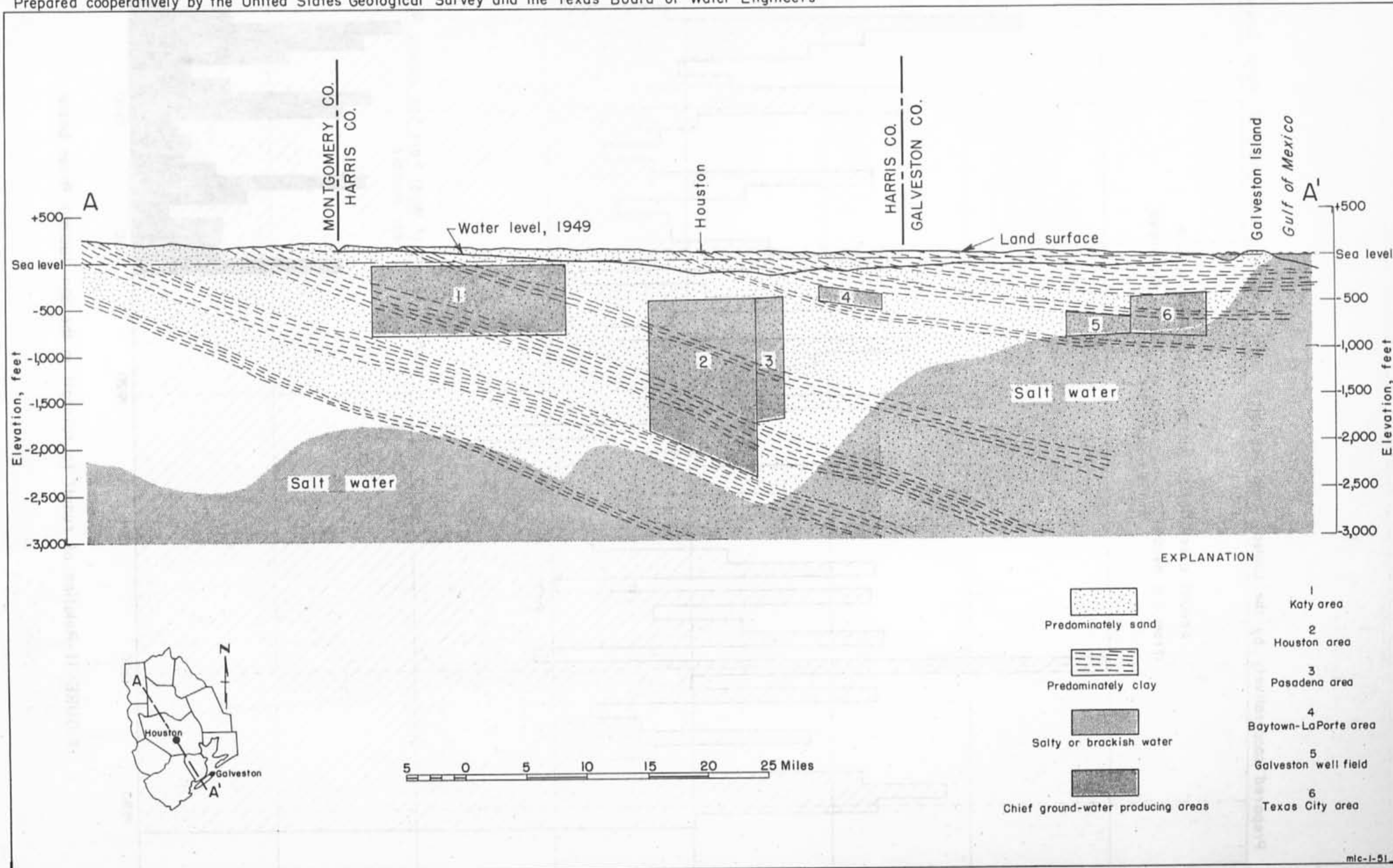

FIGURE 12.-Generalized cross section showing chief ground water-bearing formations in the Houston Gulf Coast region.

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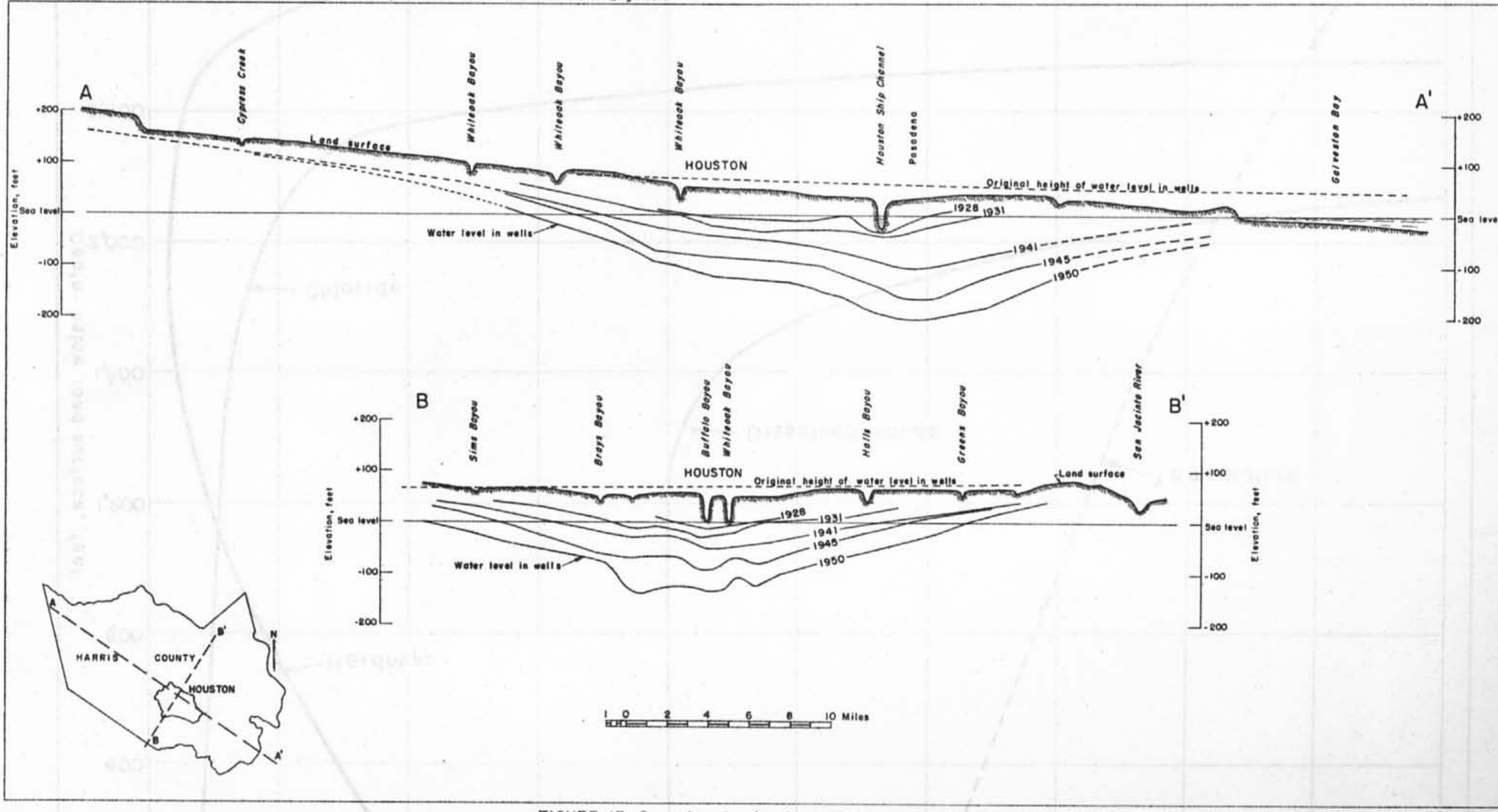

FIGURE 13.-Ground-water levels near Houston.

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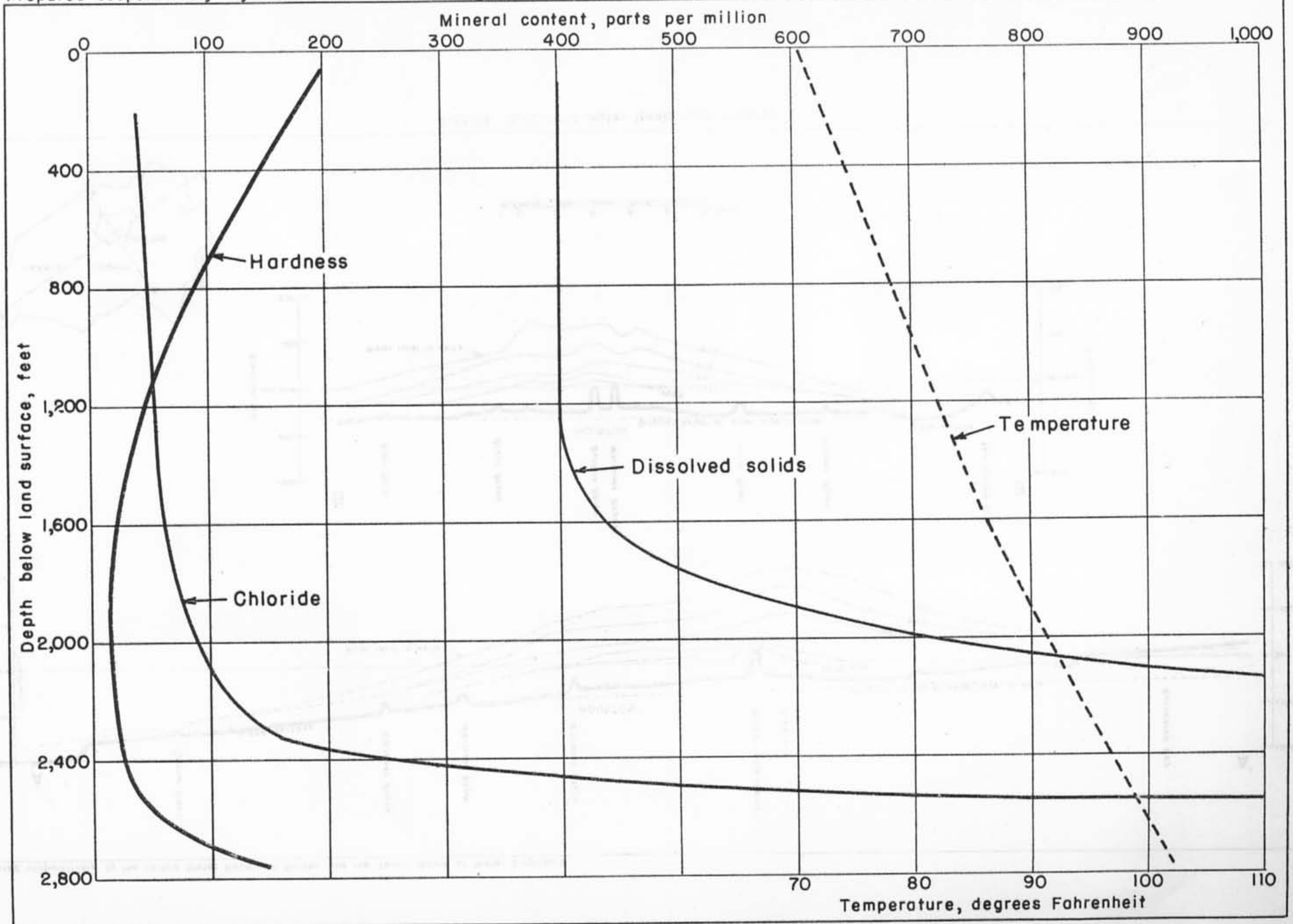

FIGURE 14.- Generalized relation of temperature and mineral content of ground water to depth in Houston area.

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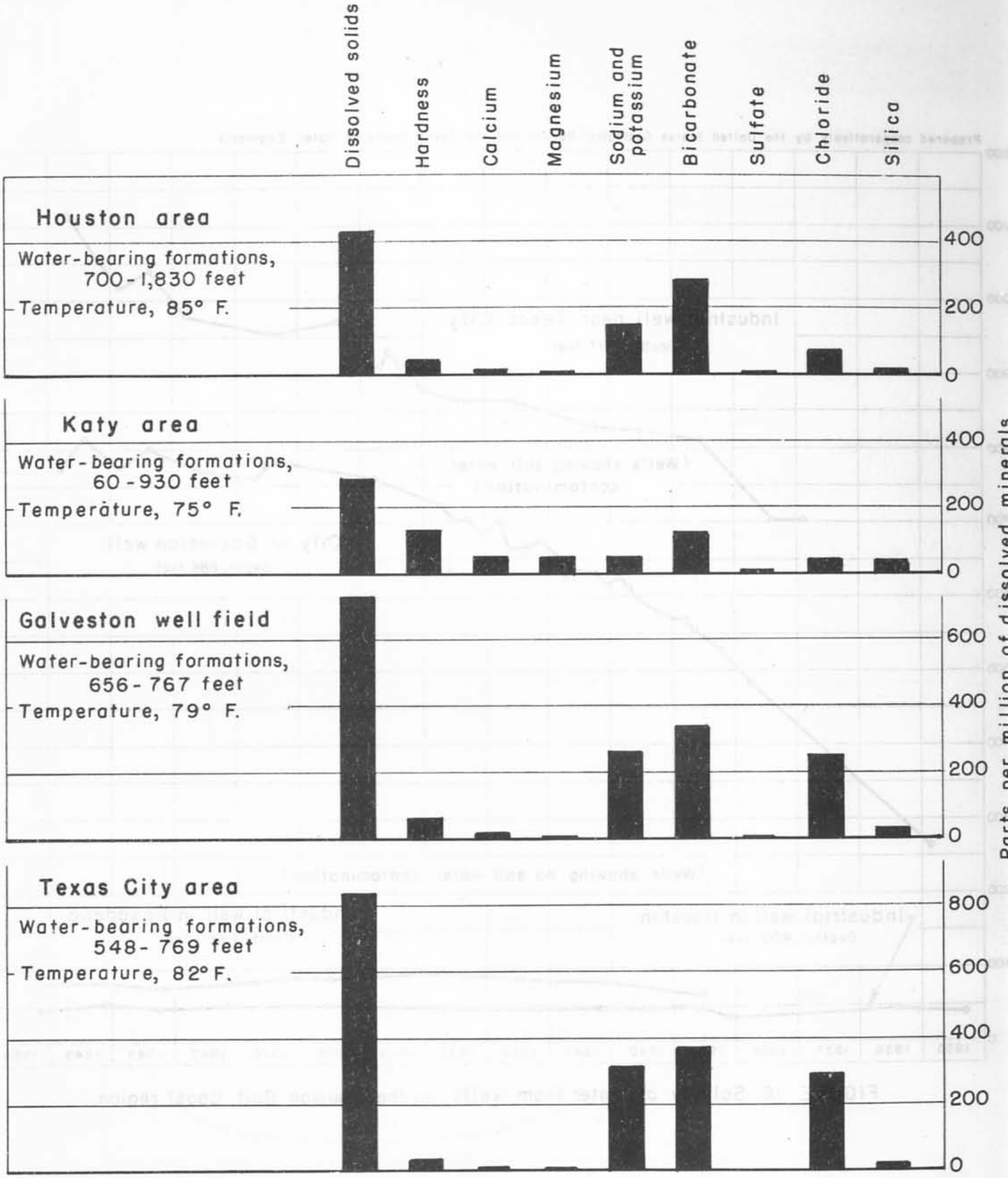

FIGURE 15.-Quality of water from typical wells in the Houston Gulf Coast region.

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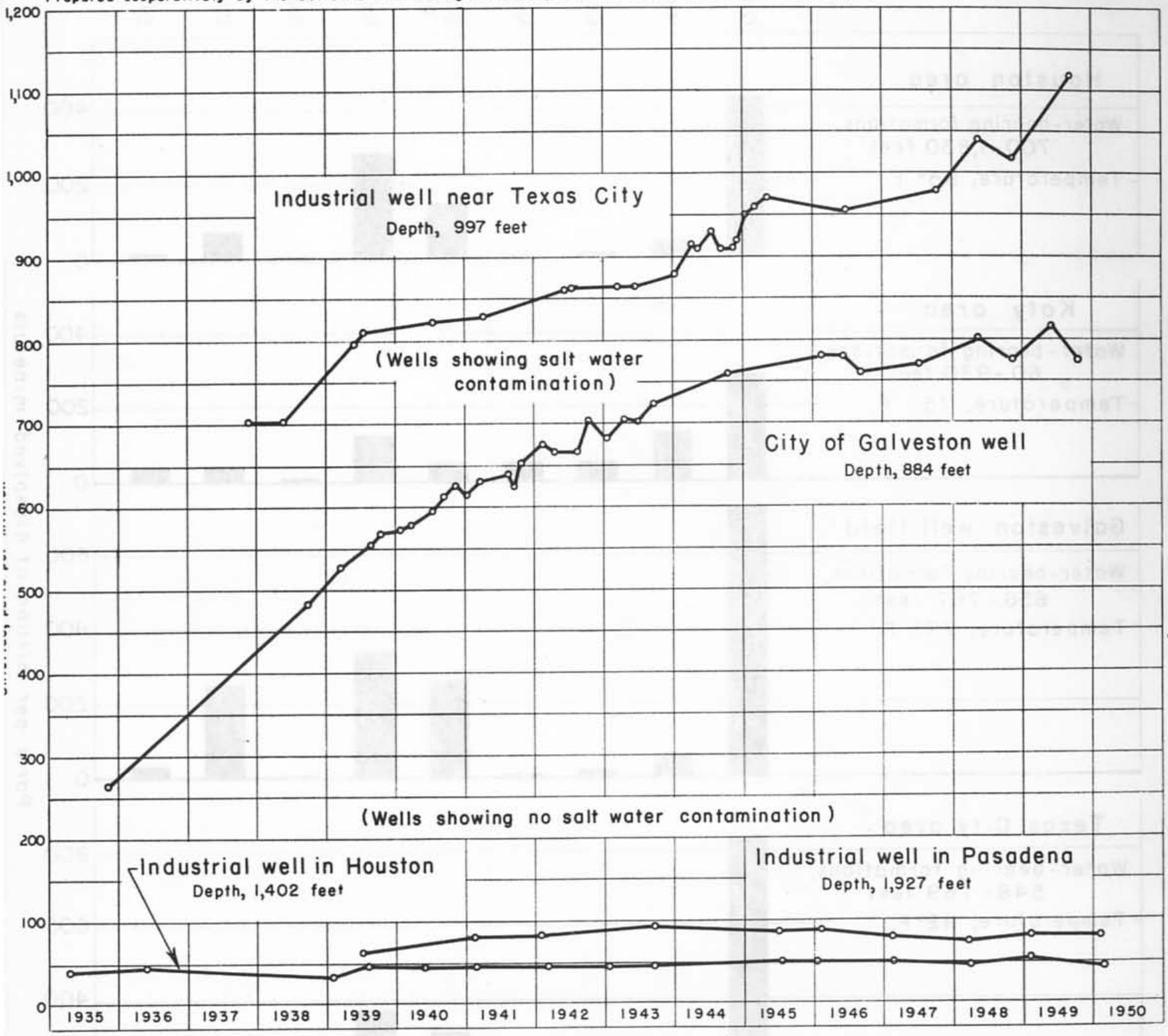

FIGURE 16.-Salinity of water from wells in the Houston Gulf Coast region.

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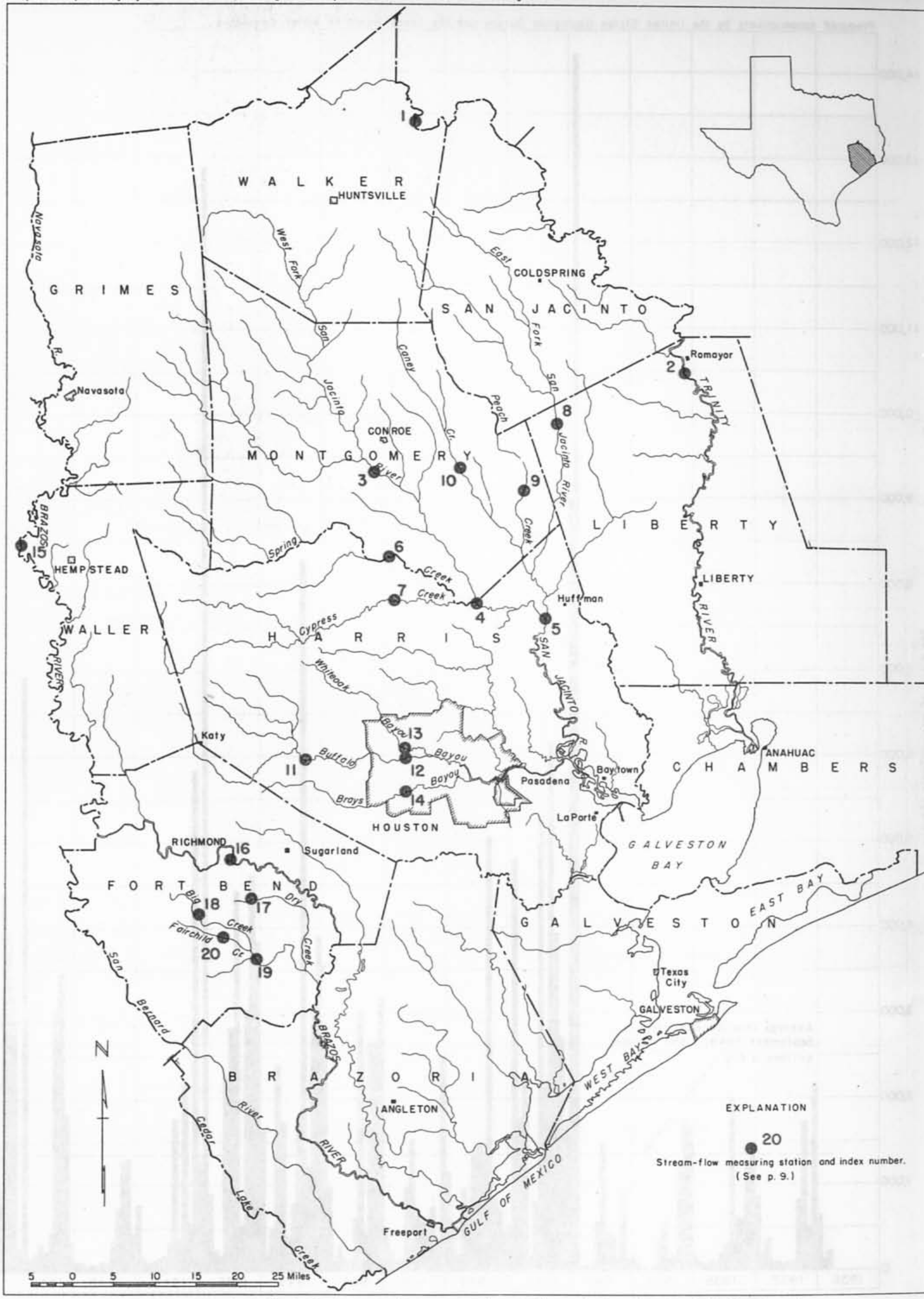

FIGURE 17.-Location of principal stream-flow measuring stations in the Houston Gulf Coast region.

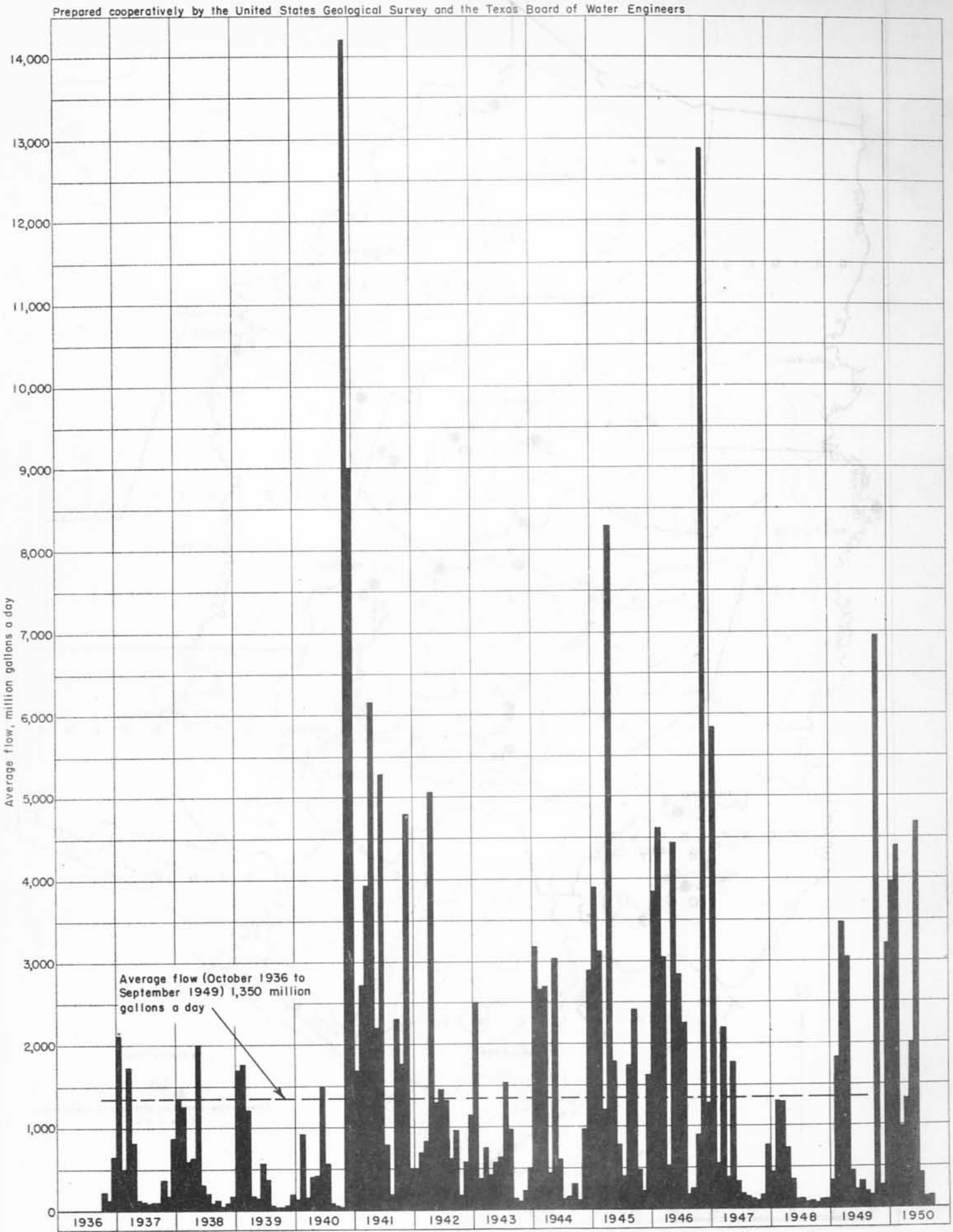

FIGURE 18.-Average flow, by months, of the San Jacinto River near Huffman, Tex.
(See station 5 on fig. 17.)

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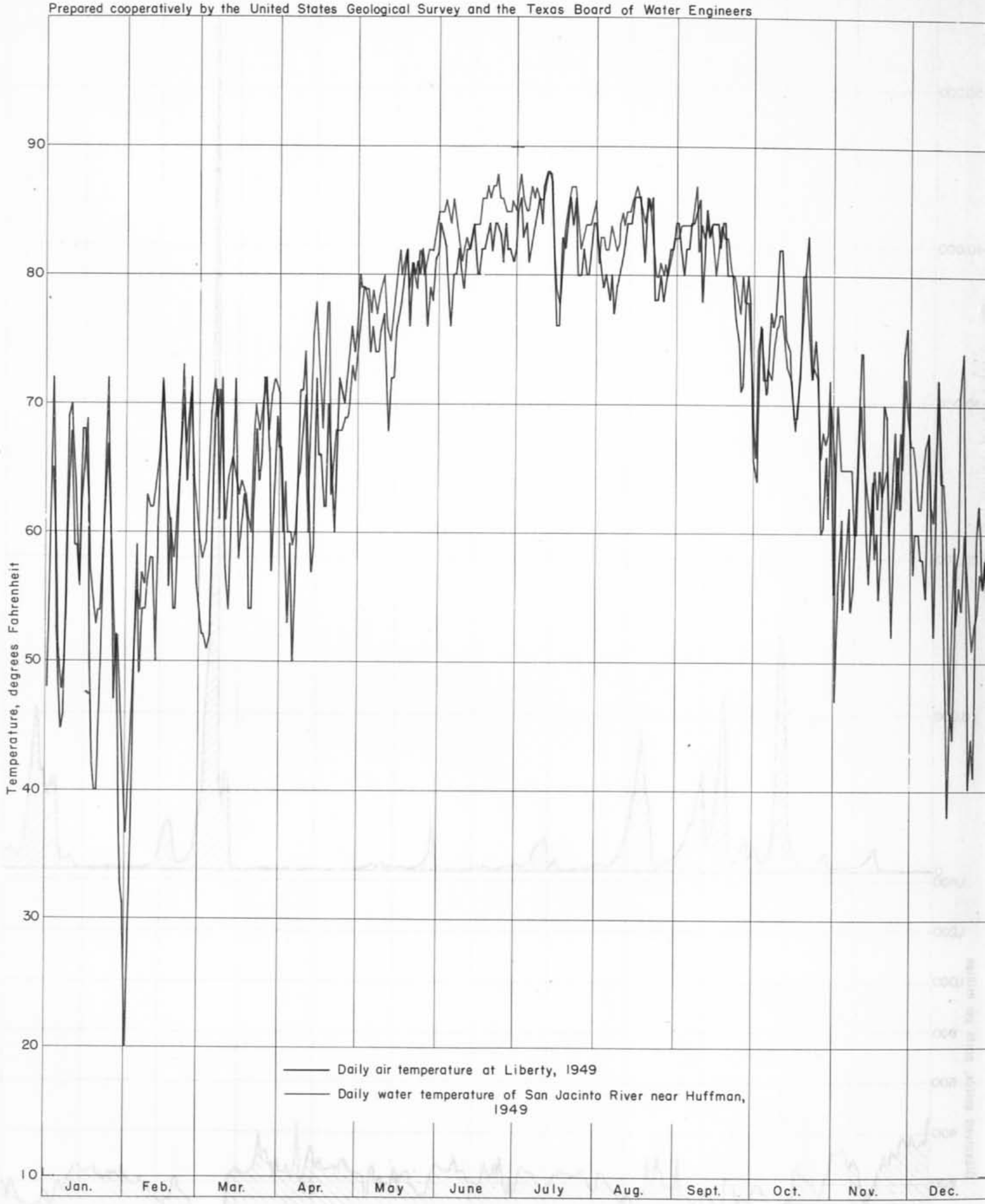

FIGURE 19.- Relation of temperature of river water to temperature of air.

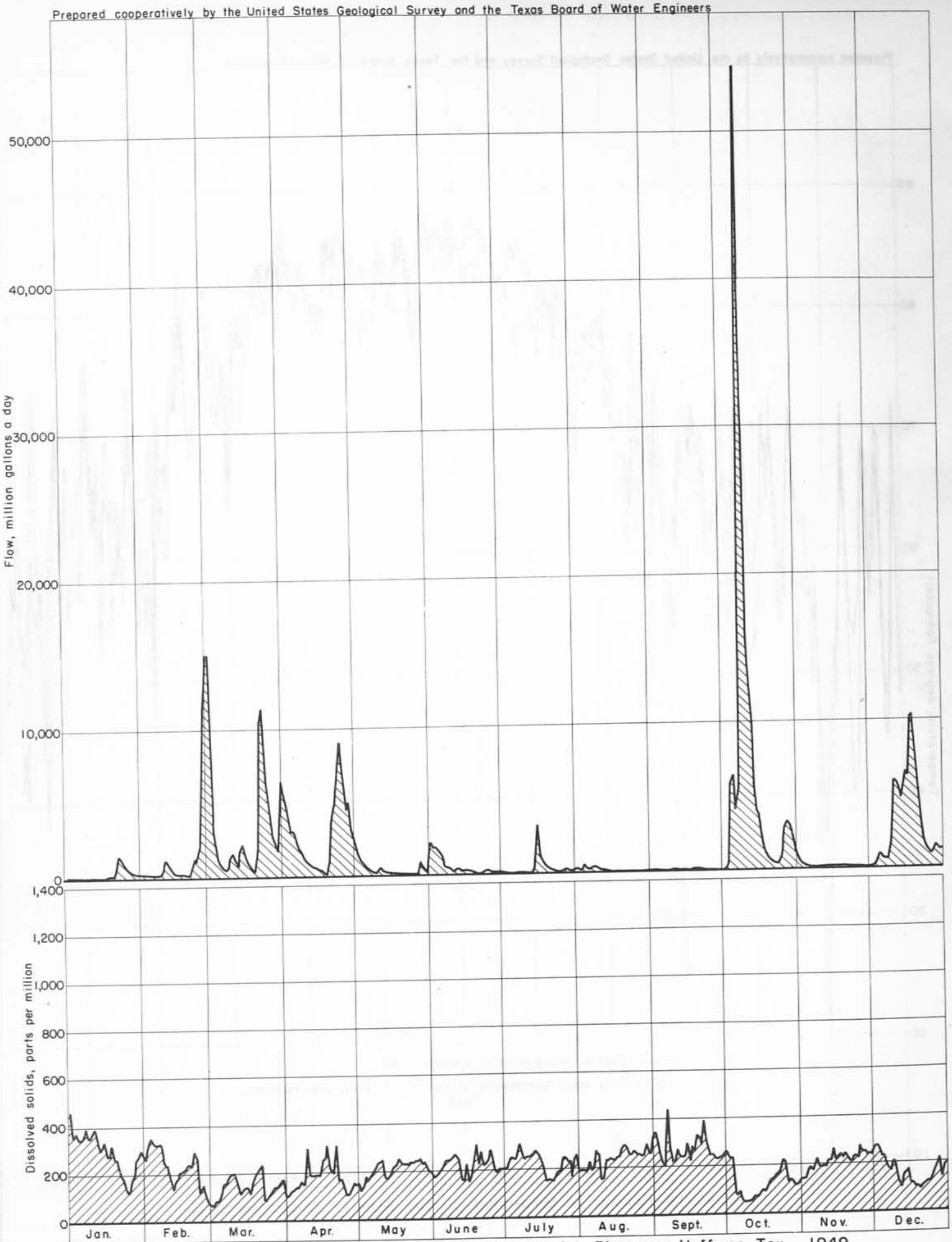

FIGURE 20.- Relation of dissolved solids to flow, San Jacinto River near Huffman, Tex., 1949.

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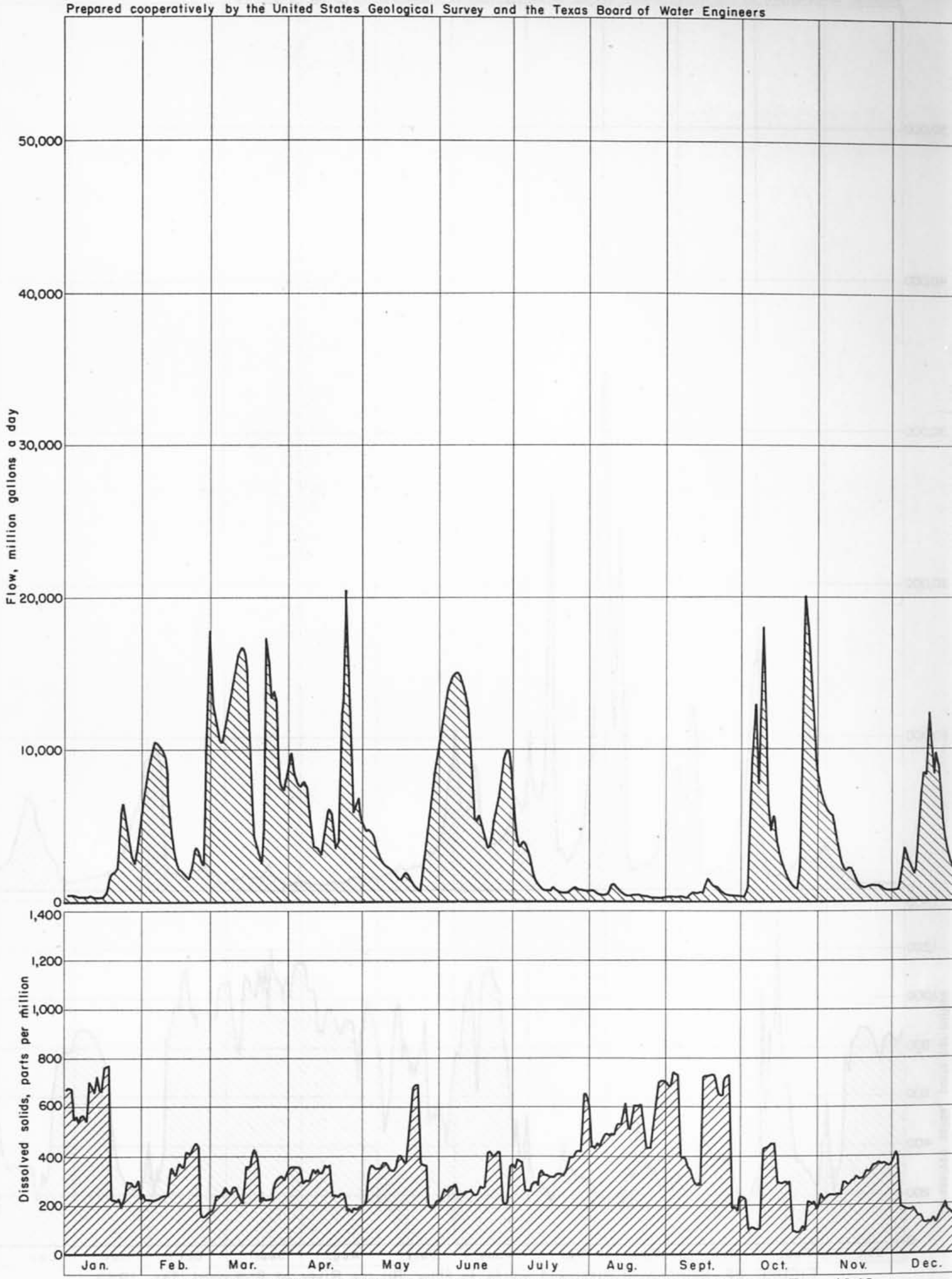

FIGURE 21. - Relation of dissolved solids to flow, Trinity River at Romayor, Tex., 1949.

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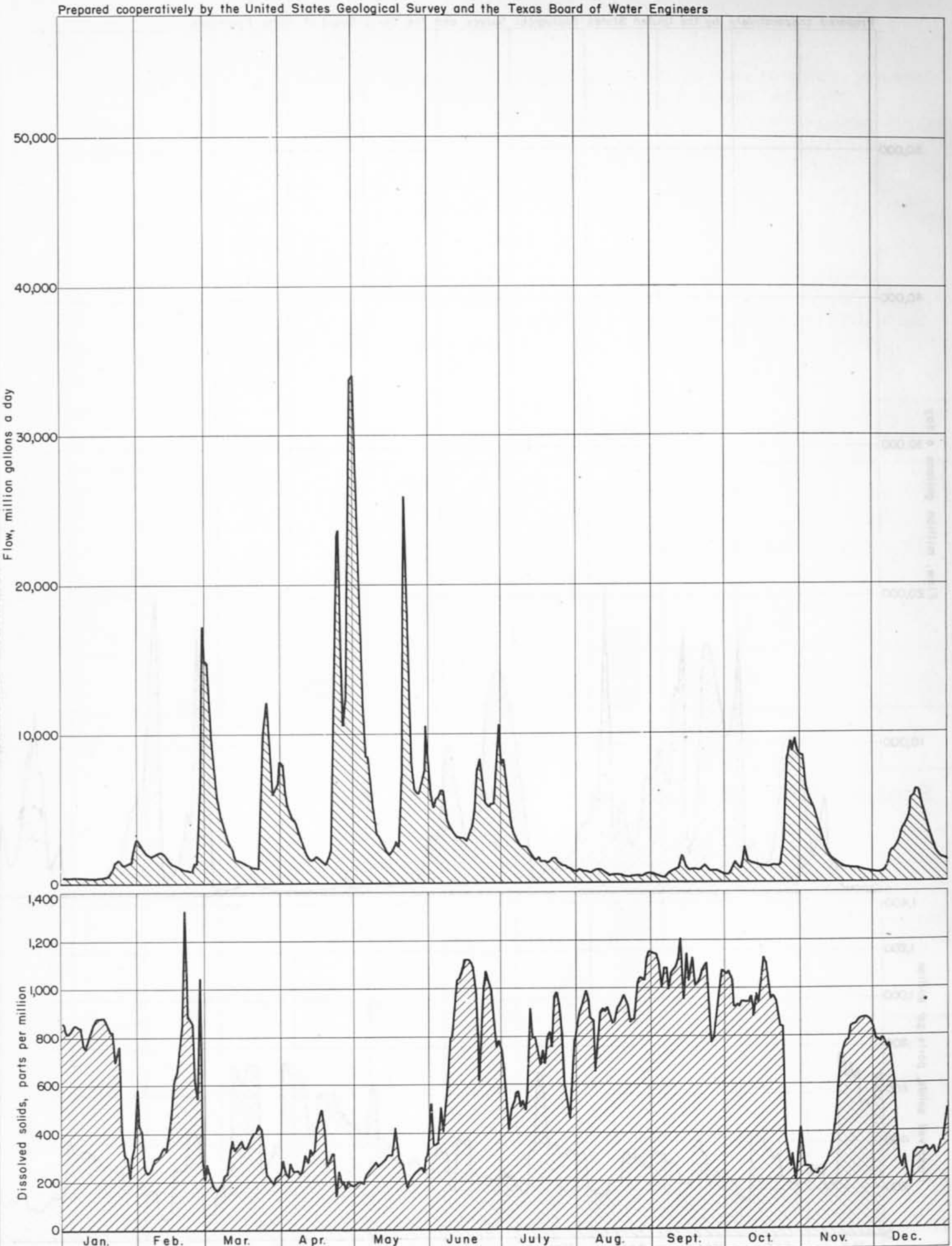

FIGURE 22.-Relation of dissolved solids to flow, Brazos River at Richmond, Tex., 1949.

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and the Texas Board of Water Engineers

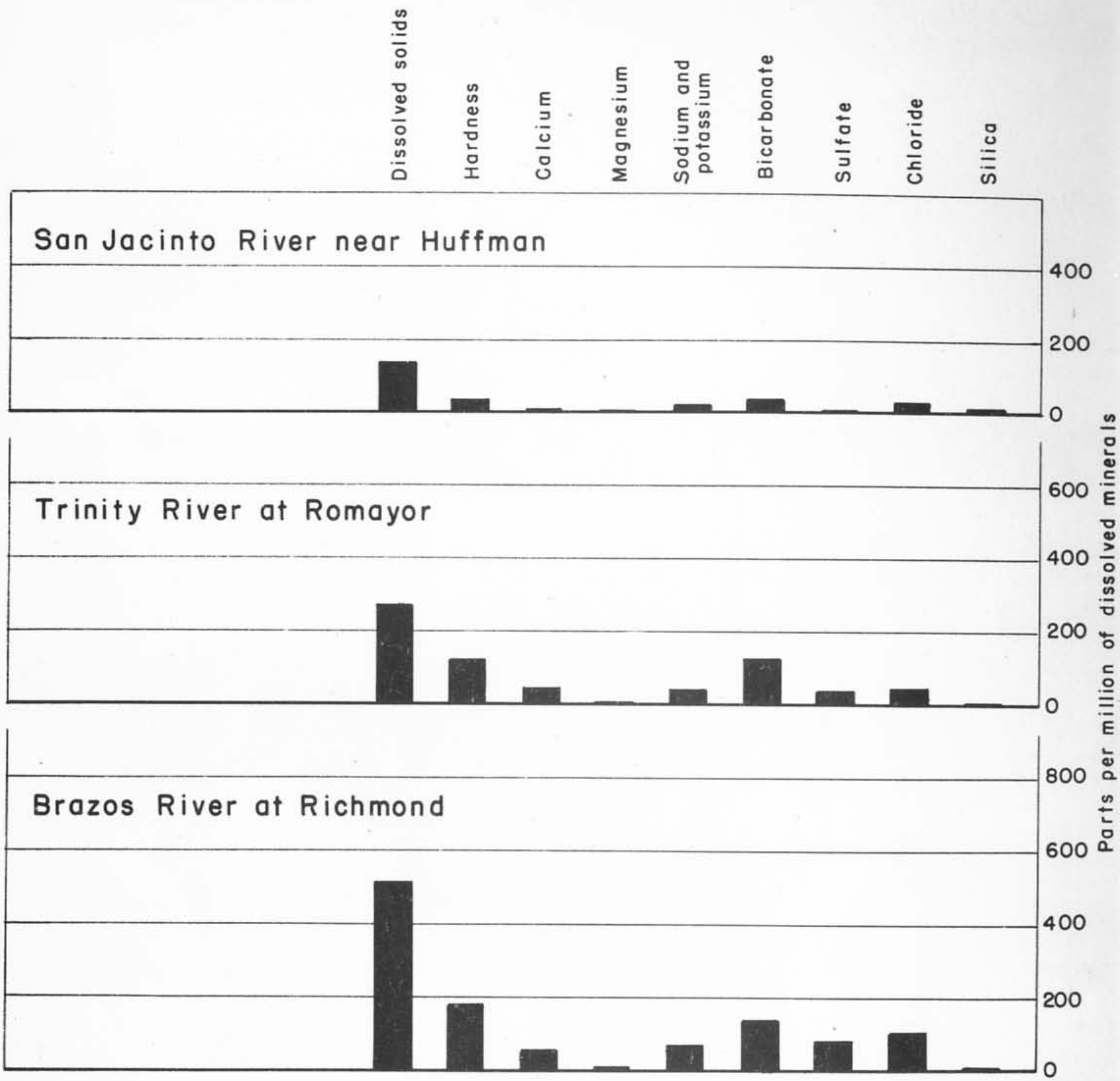

FIGURE 23.-Quality of water from streams in the Houston Gulf Coast region, 1949.

Prepared cooperatively by the United States Geological Survey
and the Texas Board of Water Engineers

FIGURE 23.--Quality of water from streams in the Houston Gulf Coast region,
1949