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THE WATER POWERS OF TEXAS

BY

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., February 13, 1904.

SIR: I have the honor to transmit herewith a manuscript on the water powers of Texas, by Thomas U. Taylor, for publication in the series of Water-Supply and Irrigation Papers. With the manuscript are also transmitted illustrations and photographs.

The paper contains a résumé of such data regarding water powers in the State of Texas as are at present available. It is believed to be of general interest, and of especial importance to that portion of the country.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

THE WATER POWERS OF TEXAS.

By THOMAS U. TAYLOR.

INTRODUCTION.

Water develops energy by virtue of its weight and the amount of its vertical fall. The amount of work done by a force of P pounds acting through a distance of h feet is Ph foot-pounds. If it is assumed that the weight of 1 cubic foot of water is 62.5 pounds, and that the flow of a stream is Q cubic feet per second, and that it falls an effective vertical distance of h feet, the work it does is 62.5 Qh foot-pounds. In defining power much larger units than the foot-pound are used. The unit in most common use is the horsepower, which is equal to 550 foot-pounds per second. The mill power is variously defined. It is expressed by a certain discharge in cubic feet per second (Q) under a head h feet. Merriman gives at Lowell $Q=30$, $h=25$, 85.2 theoretic horsepower; at Minneapolis, $Q=30$, $h=22$, 75 theoretic horsepower; at Holyoke, $Q=38$, $h=20$.

If the flow in cubic feet per second (Q) and the fall in feet (h) are known, the work (W) that can be done per second by the total flow can be found from the following:

$$W = 62.5\ Qh \text{ foot-pounds.}$$

To reduce this to horsepower divide by 550.

$$\text{Horsepower} = \frac{62.5\ Qh}{550} = \frac{5\ Qh}{44}.$$

No machine can develop all of the power in the water on account of frictional resistances. Machines develop only a certain fraction of the theoretic power, called the efficiency of the machine. A first-class turbine can develop four-fifths, or 80 per cent, of the theoretic power. Then

$$\text{Horsepower} = \frac{5\ Qh}{44} \times \frac{4}{5} = \frac{Qh}{11}. \qquad \text{(A)}$$

Rule: To find the horsepower that can be developed under favorable conditions, multiply the flow in cubic feet per second (Q) by the effective head (h), and divide the result by 11.

If the flow is given in gallons per minute, which is often the case, let G = gallons per minute. As each gallon weighs $8\frac{1}{3}$ pounds, the work in foot-pounds per minute will be given by

$$W = G \times 8\tfrac{1}{3} \times h \text{ foot-pounds.}$$

$$\text{Horsepower} = \frac{25\ Gh}{3 \times 33000} \times \frac{4}{5} = \frac{Gh}{4950}.$$

$$\text{Horsepower} = \frac{Gh}{5000} \text{ nearly.} \qquad \text{(B)}$$

For an efficiency of three-fourths, the last formula becomes

$$\text{Horsepower} = \frac{Gh}{5280}. \qquad \text{(C)}$$

It often happens that for easy transmission the water power is converted first into electric energy and then transmitted to the locality where it is needed. One horsepower is equal to 746 watts, the unit of work in electric measurements.

One kilowatt equals 737 foot-pounds per second.

One kilowatt $= \frac{1000}{746} \times 1$ horsepower $= \frac{4}{3}$ horsepower, nearly.

Substituting this value in (A) and (B) we have

$$\text{Kilowatts} = \frac{3\ Qh}{44}. \qquad \text{(D)}$$

For an efficiency of 78 per cent:

$$\text{Kilowatts} = \frac{Qh}{15}. \qquad \text{(E)}$$

Water power is most economically used in connection with an auxiliary steam plant. The power to be generated by water should be fixed at the amount the ordinary low flow will produce, and a steam plant should be installed for use when the flow of the stream sinks below the ordinary low stage. The ordinary low flow of a stream may be 150 second-feet, which should be the basis for estimating its power value, while the lowest flow in extremely dry years may be 20 second-feet or less. The value of a farm is based on the ordinary efficiency in producing crops, not upon an extreme drought. Steam as a helper to water power is becoming more and more a commercial factor. The most important fuels used in Texas on a large scale at present are the lignites, bituminous coal, and oil. Their values as power generators should be known.

The cheapest coal fuel, as the results of the Rapid Transit Railway of Austin have so far shown, is the Rockdale lignite, the cost of which is about 48 per cent of that of the McAlester coal. The cost of Beaumont oil is about 60 per cent of that of bituminous coal which would produce the same results. The most elaborate and scientific experiments to determine the value of Beaumont oil as a fuel were made by Prof. J. E. Denton, of Stevens Institute of Technology. The conclusions reached are set forth as follows:[a]

Specific gravity [of oil], 0.920.

Flash point, 142° F.

Burning point, 181° F.

Calorific value per pound, by oxygen calorimeter, 19,060 B. T. U.

The net evaporation ranged from 14.74 to 15.16 pounds of water per pound of oil. * * * Consequently, for the two higher horsepowers the net evaporation of 14.8 pounds of water per pound of oil may be considered to represent the best economy that is to be expected from the use of oil as a fuel with steam-jet burners.

The combustion of the oil by the burner was practically perfect. The boiler utilized about 78 per cent of the heat of the fuel, which represents the best average boiler practice, and the percentage of steam consumed by the burners is a minimum for steam-jet burners.

The evaporation from and at 212° F. per pound of [buckwheat] coal [anthracite] was 9.17 and 8.94 pounds of water for 93 and 119 horsepower. The coal afforded 11.6 per cent of ash and 14,680 B. T. U. per pound of combustible when burned in oxygen in a calorimeter.

* * * * * *

Ratio of oil to coal $= \frac{15.1}{9.17} = 1.65$.

Number of barrels of oil equivalent to 2,240 pounds of [anthracite] coal, 4.23.

* * * * * * *

For producing horsepower upon the commonly guaranteed basis of 1 horsepower to 10 square feet of heating surface and with an average percentage of moisture and ash in the coal:

Evaporation per pound of wet coal from and at 212°, 8.75 pounds.

Net evaporation per pound of oil from and at 212°, 14.8.

Ratio of oil to coal $= \frac{14.8}{8.75} = 1.69$.

Number of barrels of oil equivalent to 2,240 pounds of coal, 4.12.

In comparison with the bituminous coals mined west of Ohio and used in southwestern States the results are as follows:

Pounds evaporation per pound of wet coal, 7.5.

Pounds evaporation per pound of Beaumont oil, 14.8.

Ratio $\frac{14.8}{7.5} = 1.97$.

Three and fifty-four hundredths barrels of oil are equivalent to 2,240 pounds of coal.

The McAlester coal used in Texas is about equal to the bituminous coal referred to above. The Beaumont oil was sold to the city of Austin at 50 cents per barrel delivered, while McAlester coal cost wholesale about $5 per ton. The 3½ barrels of oil were obtained for $1.75, against $5 for an equivalent amount of coal.

The Texas streams will be considered in order from west to east. In addition to the main streams west of Colorado River there are at

[a] Engineering News, vol. 47, 1902, p. 80.

least twenty streams which rise in springs and which constitute one of the most potential factors in the water supply and power. These springs occur for the most part in the Edwards Plateau, the most notable exceptions being those at Fort Stockton, Santa Lucia, and at the head of Toyah Creek in trans-Pecos Texas.

The water-power development in many localities is as yet in a very crude state, but there are many plants that have been built upon scientific principles where modern machinery is used and where a consequent high efficiency is obtained. A large percentage of the plants in existence at present are confined to the Guadalupe, the Colorado, and the Brazos and their tributaries. Guadalupe River easily takes rank as the most effective power-generating stream in the State. On the Neches and Sabine and their tributaries are more power plants than on the rivers farther west, but these plants generally consist of small mills of 6 to 30 horsepower which are used for ginning cotton, sawing lumber, or grinding corn. In eastern Texas the country is heavily wooded, and is traversed by many small streams which are for the most part tributaries of the Sabine or Neches and which are not subject to sudden fluctuations in height. The water is held back by the coating of leaves and flows off gradually; as a consequence there is little occasion for shutting down on account of low water. In western Texas the power plants are larger, but the streams are subject to sudden rises and falls. This is especially characteristic of the streams that flow through the mountains of Edwards Plateau, such as the Colorado, the Guadalupe, and the Nueces.

RIO GRANDE.

The International (Water) Boundary Commission established gaging stations at different points along the Rio Grande in May, 1900. The results of these measurements are given below. As the data for the year 1900 are incomplete they are omitted.

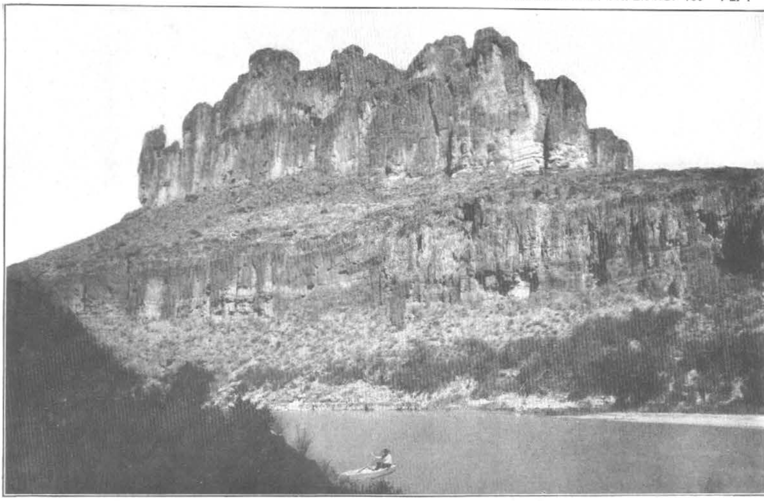
Discharge, in second-feet, of Rio Grande.

AT FORT HANCOCK.

Year.	Maximum.	Minimum.	Mean.
1901	2,710	0	343

ABOVE PRESIDIO.

Year.	Maximum.	Minimum.	Mean.
1901	1,780	....	248
1902	....	....	....
1903	6,600	0	532



A. TEMPLE CANYON, RIO GRANDE, TEXAS.

B. SCENE ALONG NUECES RIVER, WEST OF COTULLA, TEX.

Discharge, in second-feet, of Rio Grande—Continued.

BELOW MOUTH OF CONCHOS, NEAR PRESIDIO.

Year.	Maximum.	Minimum.	Mean.
1901	5,690	20	778
1902	45,000	10	2,109
1903	8,960	105	1,441

AT LANGTRY.

Year.	Maximum.	Minimum.	Mean.
1901	14,700	370	1,338
1902	38,200	285	2,449
1903	18,000	530	1,838

NEAR DEVILS RIVER.

Year.	Maximum.	Minimum.	Mean.
1901	34,280	1,620	3,008
1902	35,500	1,240	3,745
1903	28,180	1,330	3,155

AT EAGLE PASS.

Year.	Maximum.	Minimum.	Mean.
1901	21,460	1,600	3,176
1902	32,000	1,260	3,831
1903	47,400	1,640	4,010

TRANS-PECOS STREAMS.

TOYAH CREEK.

Toyah Creek rises in springs about 40 miles southwest of Pecos. These springs are mainly in section 256, patented by the State of Texas to Antonio Ball. They are in a flat valley hemmed in by a horseshoe curve of the Davis Mountains. About 3 miles to the northwest is Phantom Lake. The largest of the Toyah springs is oval shaped, about 100 feet long by 60 feet broad. Its water level is influenced by the weeds and long grass which grow in it and by the atmosphere. As measured on September 5, 1900, the entire discharge was 46 second-feet. A large percentage of the water is deflected into the ditch of the Toyah Creek Irrigation Company. The flow of the spring is equal to about 8 heads—a head being defined as the amount of water flowing through an opening 1 foot square, the upper edge of which is 4 inches below the water surface. There is a tradition that the flow once amounted to 12 heads, but this is doubted. The springs are about an eighth of a mile east of the post-office at Toyah.

India (Brogado post-office) is about 4 miles below the springs, and Saragossa is 9 miles below the head spring. Both of these places are on the right bank of the creek. The total discharge of the main spring, as measured on July 21, 1904, was 46 second-feet. About 100 yards north of the main spring (sometimes known as St. Solomons) there are two other springs, situated on the premises of G. W. Griffith; their joint flow is 8 second-feet.

For several miles the creek skirts the foothills of the Davis Mountains, and, in addition to the well-known springs mentioned, it is fed by small invisible springs and by seepage. It empties into Toyah Lake, a large flat depression charged with alkali, about 35 miles from Toyah and about 12 miles south of Pecos.

Toyah Lake covers about 1,200 acres at low stages, the water varying in depth to about 6 feet in the deepest part. On the west, south, and east the vegetation grows close down to the water's edge, while on the north a sandy beach stretches between the water and the bluffs. The water of the lake is salty and contains sufficient alkali to be decidedly bitter to the taste. In hot summer days when the wind is brisk evaporation so affects the temperature of the lake that a bath of long duration becomes rather uncomfortable.

About one-eighth mile below the head spring the cotton gin of G. W. Donaldson is located, on a mill race that leads the water from the main spring to the gin, where the power is developed by a 20-inch Leffel turbine under a 10-foot head. The plant consists of an 80-saw gin. During the winter, spring, and summer the water is deflected from the race into Toyah Creek proper.

A half-mile above Saragossa, on the main Saragossa ditch, is the Clements grain and flour mill, a building constructed of adobe and timber, where there is a fall of 12 feet. Fifteen horsepower is developed by a 35-inch Leffel turbine. The mill was rebuilt in 1893 and now grinds both corn and wheat. The flow of the ditch is usually about 35 second-feet, only 25 of which is utilized for power purposes.

HACKBERRY SPRINGS.

About two miles northwest of Toyah Lake a series of springs occur on the prairie in a tule flat which extends in rather irregular lines southeast from the head springs. Maj. T. H. Bomar has found that the water level of the upper springs is 27 feet above the low level of Toyah Lake and is at exactly the same elevation as the top of the rail of the Texas and Pacific Railroad at Pecos, which is 2,581 feet above mean low tide. The largest of these springs, at the northwest end of the tule flat, consists of a large trumpet-like hole some 20 feet in diameter. The water has a strong sulphur taste, but is excellent for stock. When visited in July, 1904, the flow through a ditch some 6 feet wide which had been excavated to drain the upper springs was 2.2 second-feet. These springs are natural artesian wells and the water is of the same nature as that of an artesian well between Toyah Lake and the springs.

COMANCHE CREEK.

Comanche Creek rises at Fort Stockton and has long been important as an irrigating stream. In appearance, character, and almost constant flow it resembles the big springs that form the San Marcos, San Felipe, and Comal. Its flow in 1899 was found to be 66 second-feet. The stream feeds four irrigation ditches, upon one of which (the Rooney) is located a water-power gin of 70 saws. The fall is 10 feet, and the power is generated by a 24-inch turbine. It is estimated that 10 horsepower is developed. The flow of the creek one-half mile below the court-house, as measured on July 26, 1904, was 64 second-feet.

Near Barstow there are two water-power plants on the irrigating ditches of the Barstow Irrigation Company. These are used to operate the gins of Briggs & Dyer and George E. Briggs. The former is on lateral No. 1 and has a head of 6.24 feet. The energy is developed by a 36-inch Leffel turbine, and 30 horsepower is easily developed by the flow of water in the lateral. This, as measured in January, 1902, was 54 second-feet. The Briggs gin is on lateral No. 3 and has a head of 7.5 feet on the 36-inch Leffel turbine, and 26 horsepower can be developed by the ordinary flow of 40 second-feet.

SANTA ROSA SPRING.

Near the post-office of Santa Lucia, in Pecos County, the Santa Rosa Spring rises out of the mesquite prairie in a bold, almost constant, stream of 4 second-feet capacity. Its waters are utilized in the irrigation of the farms of Levi Scott and Thomas L. Ray, the post-office at Santa Lucia being located on the Ray farm.

PECOS RIVER.

Pecos River rises in the mountains of New Mexico and flows in a general southerly course through southeastern New Mexico and western Texas. Before its waters were controlled or arrested by dams in New Mexico, at Roswell and Carlsbad, it had the most constant flow of all the rivers in Texas. At present the ordinary flow of the river can be diverted into Lake Avalon at Carlsbad, N. Mex. The flow in the Texas portion must be accumulated from springs and seepage from the irrigated farms below Carlsbad. The first dam in Texas across the Pecos is located 9 miles above the town of Pecos and 80 miles below the dam at Lake Avalon. The dam at this point belongs to the Barstow Irrigation Company and serves to deflect the water into the canals. The United States Geological Survey has maintained a gaging station at the flume since September, 1898. The flume is 3 miles below the dam and

6 miles above Pecos. The minimum flow of the river at the flume is 20 second-feet. Measurements taken on three days in April, 1900, gave the following results:

Discharge, in second-feet, of Pecos River and flume of Barstow Irrigation Company in 1900.

	April 22.	April 26.	April 30.
Pecos River	21	20	21
Flume	115	118	106
West Valley ditch	12	10	18
Total	148	148	145

It will be noted that the lowest flow of the Pecos yet recorded at Pecos is 8 second-feet. Pl. II shows the flume at the gaging station at Pecos, Tex. Figs. 1, 2, 3, 4, and 5 show the flow of the Pecos at Pecos, below the flume, for the years 1899, 1900, 1901, 1902, and 1903.

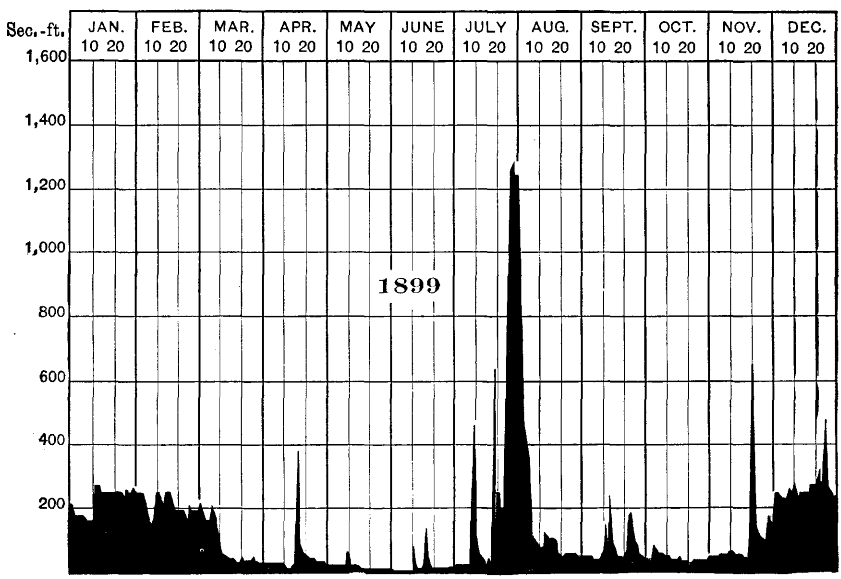
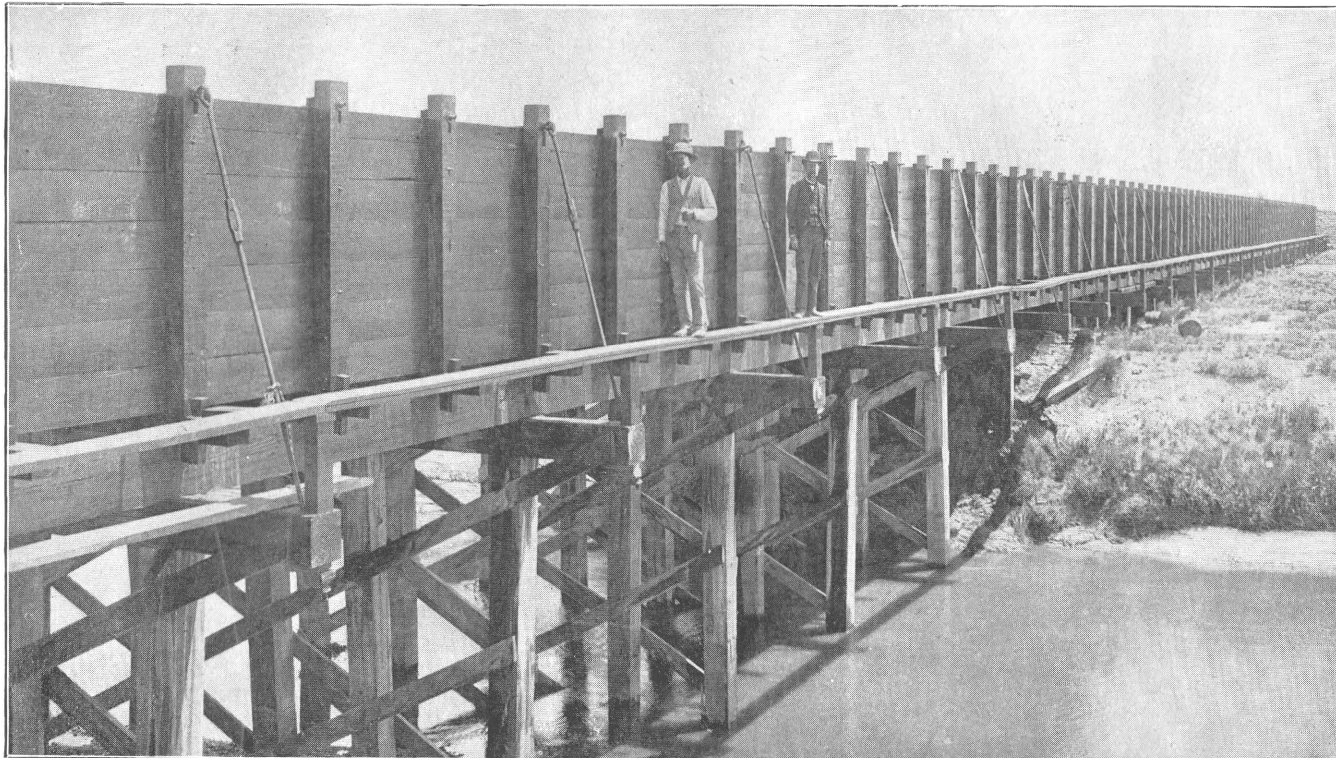


FIG. 1.—Discharge of Pecos River at Pecos, 1899.

These are the lowest measurements ever recorded of the river below the Margueretta dam. There is at the dam a minimum flow of a little less than 150 second-feet, and it would not be safe to calculate on more than this. Between Pecos and Great Falls there are no tributary streams, and this low flow of 8 second-feet would be of little value for water power or irrigation purposes. There are two other dams across the Pecos in the vicinity of the Great Falls. These belong to the Pecos



FLUME OF BARSTOW IRRIGATION COMPANY, PECOS RIVER, TEXAS.

Carried away by flood, October 5, 1904.

Irrigation Company and the Grand Falls Irrigation Company, whose ditches are on the west and east sides of the river, respectively. The

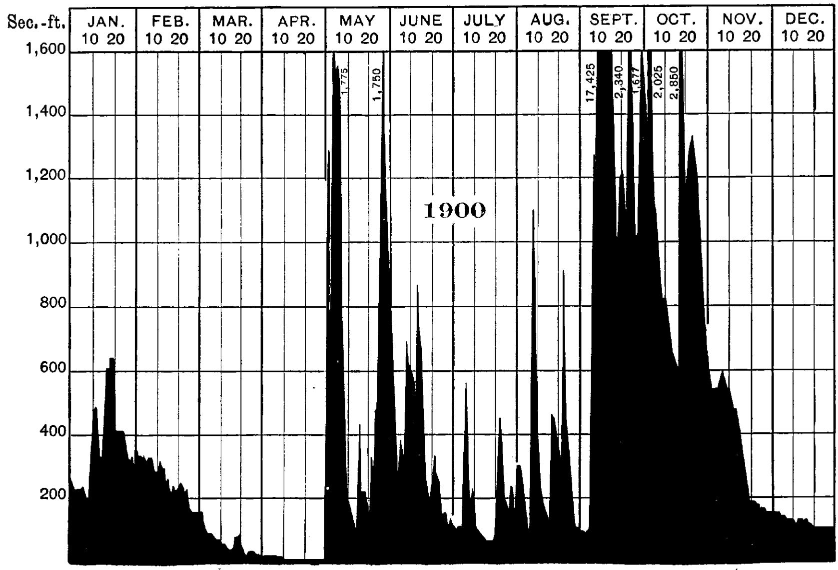


FIG. 2.—Discharge of Pecos River at Pecos, 1900.

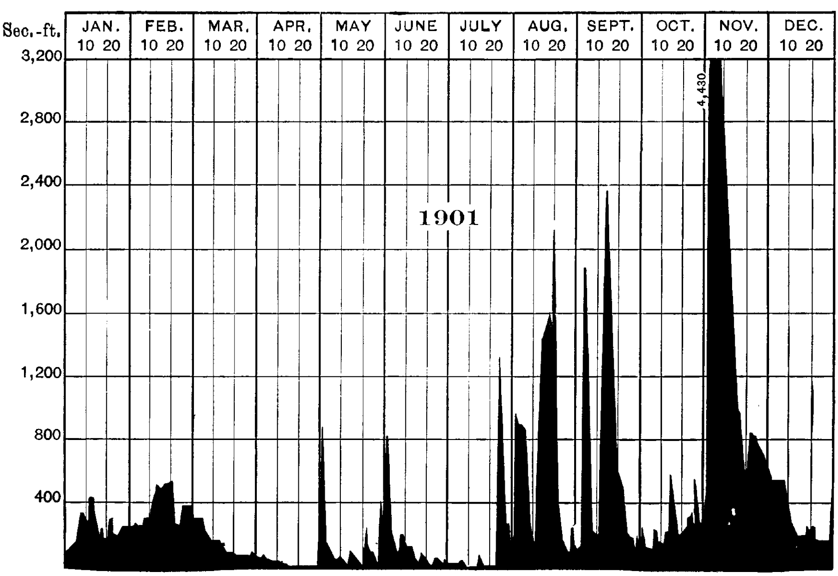


FIG. 3.—Discharge of Pecos River at Pecos, 1901.

efficiency of the former has fallen lamentably short of anticipations, chiefly on account of the use of the water in New Mexico and at

Barstow, Tex. In fact, the Pecos Irrigation Company has done very little work for years.

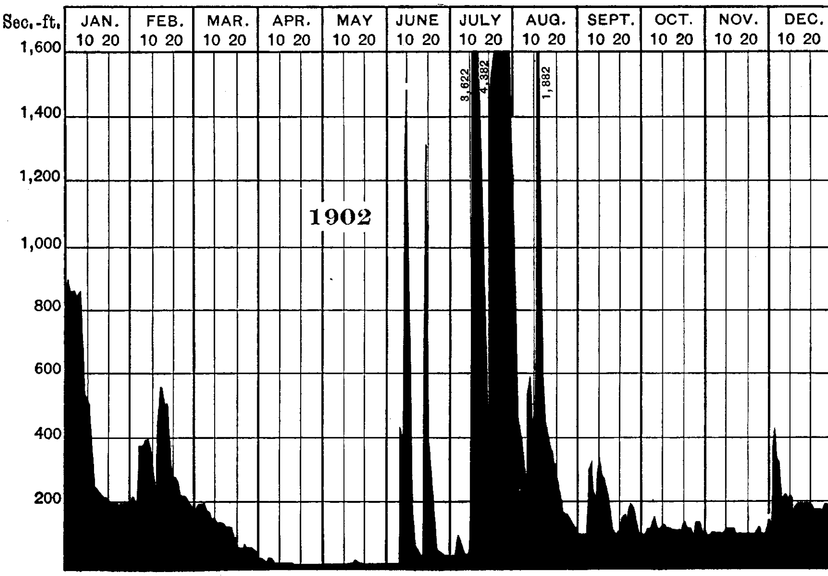


FIG. 4.—Discharge of Pecos River at Pecos, 1902.

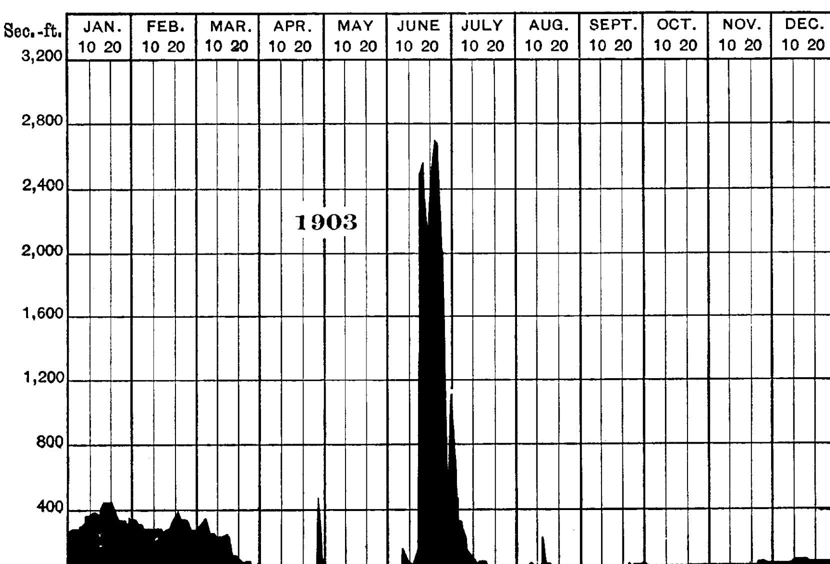
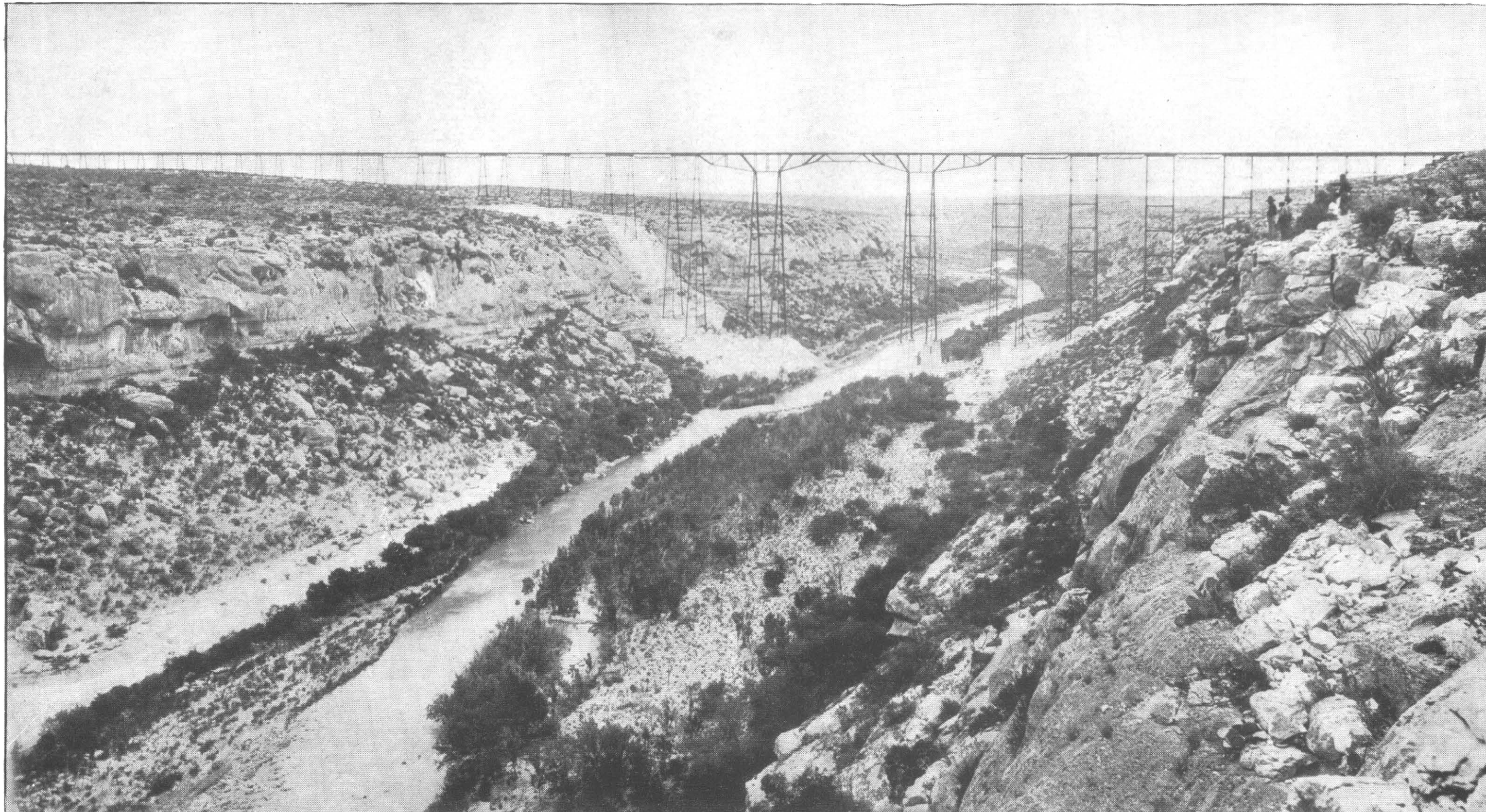


FIG. 5.—Discharge of Pecos River at Pecos, 1903.

There formerly existed a water-power plant on Pecos River near the post-office of Grand Falls, but it has been transferred to one



PECOS CANYON AT MOORHEAD, TEX.

of the ditches of the Grand Falls Irrigation and Power Company. At present this plant consists of a 48-inch turbine working under a head of 10 feet, and operating an 80-saw cotton gin.[a]

From the Texas State line to a point near old Fort Lancaster, in Crockett County, the river flows through a rich alluvial soil. It is the most sinuous river in Texas. Above Pecos there is hardly a mile in which the river does not flow in all directions.

Near Fort Lancaster it enters the canyon, which gradually deepens until the river reaches the Rio Grande. The only use of the water so far has been for stock. At Moorhead, Tex., at the crossing of the Southern Pacific Railroad, the low-water level is 321 feet below the top of the rails on the bridge. The flow of the river at this place was measured by J. D. Dillard during 1900 for the Boundary Commission. (See Pl. III; also appendix, p. 107.)

Discharge, in second-feet, of Pecos River at Moorhead.

Year.	Maximum.	Minimum.	Mean.
1901	9,200	160	630
1902	11,100	210	578
1903	2,140	170	408

Discharge, in second-feet, of Pecos River at Pecos.

Year.	Maximum.	Minimum.	Mean.
1899	1,040	15	90
1900	2,680	20	340
1901	840	16	440
1902	4,400	15	204
1903	2,640	8	191

DEVILS RIVER.

Devils River is an illustration of the effect of the large springs of the Edwards Plateau. The river rises in Pecan Spring, about 45 miles north of the mouth and about 60 miles from Del Rio. This spring is on the old mail route from San Antonio to El Paso, which followed the course of the springs on the southern edge of the plateau. The river is only about 50 miles long, and yet, of all the rivers of Texas, it has the largest minimum flow. This, as determined by semiweekly measurements, 1900 to 1903, is slightly over 380 second-feet.

[a] Since the above was written the Dixie Irrigation Company has built a dam across the Pecos 20 miles above the town of that name, and has deflected the waters of the river into a canal built on the west bank on the location of the old Highland canal.

Discharge, in second-feet, of Devils River at Devils River station.

Year.	Maximum.	Minimum.	Mean.
1901	840	480	627
1902	5,380	380	490
1903	10,400	380	587

The flow of this river could readily be utilized in irrigating vast tracts of land east of Del Rio. It would be necessary to construct a dam across the river above the railroad bridge and convey the water from the lake thus formed to the irrigated lands by pipe lines to prevent seepage. The water is clear as crystal and forms a strong contrast to the turbid water of the Rio Grande.

Pecos and Devils rivers unite with the Rio Grande within 25 miles of each other, and their waters serve to make the flow of the Rio Grande below Del Rio more constant and commercially valuable. The lowest flow at Eagle Pass during 1901 was found to be 1,800 second-feet. Half of this amount would irrigate for ordinary crops 200,000 acres of land, and for rice in the lower and flatter country near Brownsville it would readily be sufficient for half of the whole rice crop of Texas for 1901.

SAN FELIPE CREEK.

San Felipe Creek, which skirts the extreme eastern limits of Del Rio, rises from large springs a little over a mile southeast of the town. The flow of these springs is utilized in the magnificent irrigation system between the town and the Rio Grande and for one power plant. The total flow of the stream was as follows: In 1895, 99 second-feet; in 1889, 113 second-feet; in 1900, 149 second-feet; in 1901, 150 second-feet; in 1902, 115 second-feet; and in March, 1904, 118 second-feet. There is installed on San Felipe Creek an electric-light and ice plant, the power for which is obtained solely from the flow of the creek. The dam (Pl. IV) is constructed of rubble limestone masonry, is somewhat over 100 feet long, about 10 feet high, and is built with a portion straight across the stream and the remainder curving downstream, thus forming the race between the portion of the dam next the power house and the bank of the stream itself. The cross section is approximately trapezoidal in shape, measuring 3 feet on top, about 10 feet at the base, and averaging 12 feet in height. It is built on solid limestone. The head obtained by this dam is practically constant and amounts to 10 feet. The machinery consists of a Warren 30-kilowatt alternating dynamo and a 6-ton ice machine, which are run by 44-inch Leffel turbines, the one operating the ice machine giving 20 horsepower with the gate partly open, and the one operating the dynamo giving 30

DAM ON SAN FELIPE CREEK, DEL RIO, TEX.

horsepower with a full gate opening. The turbine that operates the ice machine runs only fourteen hours a day in the summer only, and the electric-light turbine fourteen hours per day the year round. A 50-horsepower emergency engine is also installed in the power house, but has never been used.

LAS MORAS CREEK.

Las Moras Creek rises in a large spring in the town of Brackett, Kinney County, and empties into the Rio Grande about 25 miles above Eagle Pass. It has had a variable flow since measurements have been made. In December, 1895, C. C. Babb found a discharge of 21 second-feet. The flow in June, 1899, was 60 second-feet at Mulligans Bend, one-fourth mile below the court-house; in September, 1900, the discharge was 51 second-feet; in September, 1902, two carefully checked measurements gave a discharge of 11 second-feet, and on March 14, 1904, the discharge was 28 second-feet.

On June 14, 1898, occurred the biggest flood in the history of Kinney County. This flood extended over the country between Spofford and Del Rio. Las Moras Mountains, about 4 miles a little east of north from Brackett, form a crescent in which Brackett and Fort Clark (separated from the former by Las Moras Creek) are situated, and all the depressions and dry streams from the mountains converge toward Brackett. From 11.30 p. m. on June 13, 1899, to about 6 a. m. on June 14 there was a total rainfall of 18 inches in the neighborhood. By 5 a. m. of the 14th the water had reached a depth of 7.4 feet in the court-house, 6.7 feet in the storehouse of Roach & Co., 9.6 feet in the Terrell Hotel, and 12.1 feet in the street in front of the hotel. The main channel of Las Moras Creek between Brackett and Fort Clark was at flood height, while the draw that runs into it at Mulligans Bend was flooded to a depth of 30 feet. The lowland between Brackett and Spofford Junction was flooded for miles, and the tracks and roadbed of the Southern Pacific Railroad were badly damaged.

In March, 1900, another flood occurred at Brackett, but the damage was slight, the water being 9.5 feet lower than during the flood of 1899. Former floods occurred on May 28, 1880, and in October, 1881. During the 1880 flood the water flooded the stores in Brackett and caused great damage. In October, 1881, the rainfall that caused the flood was 14.2 inches.

NUECES RIVER.

The two main forks of Nueces River rise in Edwards County, Tex., and flow south through the rugged mountains of the Edwards Plateau, uniting 14 miles above Uvalde and about 6 miles above the crossing of the Southern Pacific Railroad. On their way through the mountains both branches are fed by springs, and from a point 12 miles south of Rock Springs to their junction there is a constant flow. Near the junction of the two forks the usual flow sinks into the gravel beds, occasionally reappearing in big clear pools at points where the gravel has been washed off the hard limestone bed-rock bottom. Four or 5 miles below the railroad bridge flowing water again appears, as along its lowland course the stream is fed by numerous springs. The water of the Nueces is used in the mountains for irrigation. The farm of J. H. Ethridge, Montell, Uvalde County, is a type of irrigated farms. The ditch is known as the Casa Blanca irrigation and mill ditch and was constructed in 1893. It is 2½ miles long and from 2 to 7 feet deep.

LEONA RIVER.

The flow of Leona River at Uvalde was so irregular for several years that close observations have been kept upon it. Leona Spring is situated in the suburbs of Uvalde. It was dry in 1885, but soon after revived and continued to flow till 1893, when it ceased to flow and has remained dry since. In 1893 a pumping station for the city water supply was located on the banks of the Leona near the spring, but it soon became necessary to rely on well water, and the plant was moved to its present site, 150 yards from the court-house. At this station a pit was excavated to a depth of 24 feet, and the pumps were placed at the bottom, and a well 4 by 7 feet was sunk 16 feet deep from the bottom of the pit, or to a depth of 40 feet from the surface. From this well water was pumped into the standpipe. At first the water rose to within 35 feet of the surface, but in December, 1897, it was noticed that the supply was failing. The water level continuing to sink, in May, 1898, a second pit, 10 by 10 by 9 feet deep, was excavated in the main pit, and a well was bored to a depth of 63 feet below the surface. The pumps were then placed in this last pit, at a depth of 33 feet from the surface. In January, 1899, the water level had fallen so low that three wells were bored in the pit to a depth of 98 feet below the ground surface. In June, 1899, after the heavy rains over southwest Texas, which resulted in the Brackett flood, the water was standing at the 93-foot level and was slowly rising. In June, 1900, the water level had risen to within 35 feet of the surface, or within 2 feet of the pumps, and it was standing at this level on March 15, 1904. Between Leona Spring and the brickyard crossing on the road from Uvalde to Pearsall there are several small springs, the largest of which is Mulberry Spring. In 1895 C. C. Babb found a discharge of 11 second-feet at the brickyard crossing. In June, 1899, there was no flow at this crossing, and in September, 1900, there was a discharge of 5 second-feet, and on March 15, 1904, 22 second-feet.

Near Cotulla the waters of the Nueces are used largely for the numerous irrigation plants. The water is pumped from the river by gasoline engines under a head of about 30 feet and is used largely in the irrigation of Bermuda onions. A full description of these irrigation plants will be found in Water-Supply Paper No. 71.

Pl. I, *B* (p. 12), is a view of Nueces River west of Cotulla.

HOG CREEK.

The water of Hog Creek, Uvalde County, is used to run the corn mill of J. J. Wyatt. A dirt dam 30 feet long deflects the water into the race, which conveys it to the penstocks, 1 foot square and 20 feet high. An undershot wheel 6 feet in diameter generates 4 horsepower.

SAN ANTONIO RIVER.

San Antonio River rises about 3 miles north of the mission of San Fernando, which is the geographic center of the city. To better control and utilize the water of the San Antonio, two canals, an upper and a lower, were constructed in 1878 and 1881. A power house was built on each canal, called, respectively, the upper and the lower power house. The fall at the upper power house is about 7 feet, and that at the lower 12, while that at Guenther's upper and lower mills is 3½ feet and 6 feet, respectively.

San Antonio River became so low in 1896 that the water power was abandoned. Previous to this, in 1895, an auxiliary steam plant of 130 horsepower was installed at the lower power house. The water at these power stations was pumped from artesian wells—one 12-inch well being located at the upper station and one 12-inch and three 8-inch wells being located at the lower power house. In 1891 a steam and electric power plant was constructed on the banks of the river near Commerce street, at which there are four 8-inch and four 12-inch wells. An indication of the stage of the underground water can be obtained from the water level in the standpipes at the waterworks on Commerce street and at the lower power house. The artesian wells at these works are connected to standpipes about 50 feet high. The following table shows the heights to which the water rose:

Height above pumps of water in wells at San Antonio.

Commerce street.		Upper power house.	
Date.	Height.	Date.	Height.
	Feet.		*Feet.*
May, 1893	42.10	January 1, 1900	1.80
December 6, 1897	33.80	February 1, 1900	6.76
April, 1898	31.60	March 1, 1900	13.76
April 29, 1900	43.00	April 1, 1900	13.77
May 1, 1900	44.10	May 1, 1900	15.57
May 5, 1900	45.10	May 24, 1900	18.74
May 9, 1900	46.20	June 1, 1900	17.99
May 22, 1900	47.10	July 1, 1900	14.65
		August 1, 1900	12.76
		September 8, 1900	12.10
		October 1, 1900	11.47
		November 1, 1900	11.38
		December 1, 1900	10.51

The San Pedro is a small stream, of about 9 second-feet capacity, that rises in San Pedro Park and flows into San Antonio River within the city limits. About 1895 San Antonio River began to fail, and by the latter part of 1897 the flow above the city had entirely ceased. The following table shows the decrease in the flow:

Discharge, in second-feet, of San Antonio River and San Pedro Creek.

Date.	San Pedro Creek.	San Antonio River.	Total.	Locality.	Hydrographer.
December, 1895	9	40	49	Canal	C. C. Babb.
November, 1896	12	29	41	do	Do.
December, 1897			11	Hot wells	T. U. Taylor.
March, 1898			9	do	Do.
June, 1899			10	do	Do.
September, 1900			125	do	Do.
September 19, 1900	9	94	103	Canal	Do.
October 31, 1901			41	Hot wells	Do.
March 16, 1904	9	65	74	do	Do.

There are four power plants on San Antonio River within the city limits: (1) The upper power house, fed by upper canal, where the head is 7 feet; (2) the lower power house, fed also by a canal, where the fall is 12 feet; (3) Guenther's upper mill, where the fall is 3½ feet, and (4) Guenther's lower mill, where the fall is 6 feet. Pl. V gives a view of the dam in the park at San Antonio. The fall from the upper power house to the lower Guenther's mill is 44.7 feet, according to a survey

DAM IN PARK AT SAN ANTONIO, TEX.

made some years ago. Fig. 6 is a map of San Antonio River, showing fall. The upper power house is not used on account of lack of water. Its equipment consisted of two Risdon turbines, 43 and 60 inches in diameter, with vents of 220 and 425 square inches. The lower power house has one Hercules 33-inch double-capacity turbine and one 43-inch single-capacity Risdon turbine. At present the water is held back in the big canal above the lower power house for twelve hours and then used for twelve hours through the wheel with gate one third open. That there is an intimate connection between the artesian wells and the river has been conclusively proved. A few years ago a series of stakes were driven in the still waters of the head lake and the height of the water marked thereon. The artesian wells were then all turned on and let run for twenty-four hours. The level of the water in the head lake or pond of the river had fallen 2½ inches. The wells were then checked and in about one day the water in the head lake was at its former level. Then, again, the artesian wells were by survey connected in a system of levels. An excavation was made on the land of the observer below the water line. It was possible by observing the height of water in this hole to obtain the height of water in any artesian well in the city.

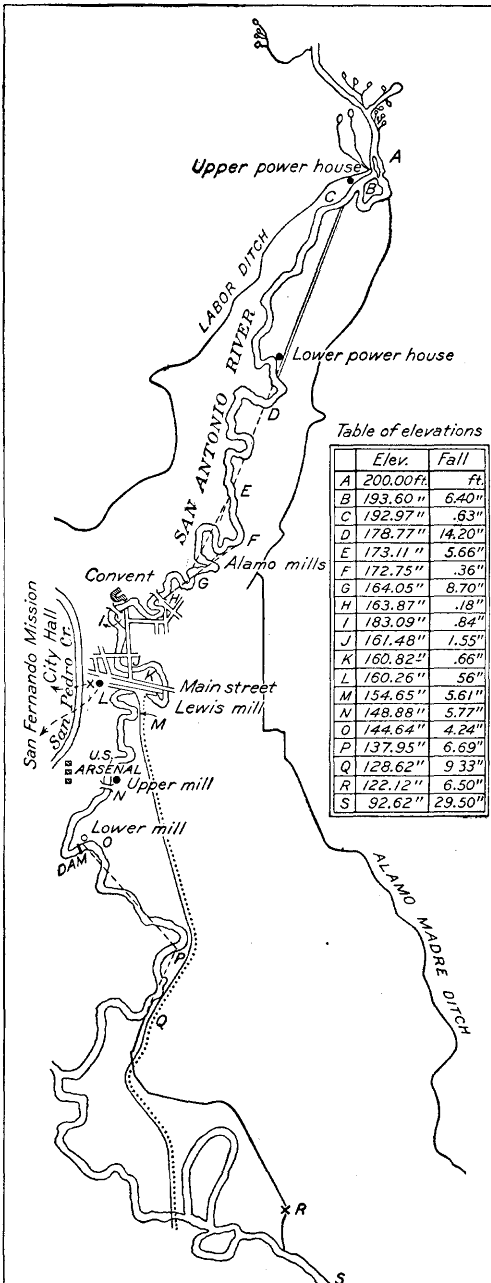


FIG. 6.—Map of San Antonio River near San Antonio.

MEDINA RIVER.

Medina River rises in the southern part of Kerr County, flows southeast through the towns of Medina and Bandera, in the eastern part of Bandera County, thence south by the town of Castroville, Medina County, thence southeast through Bexar County to its junction with San Antonio River at a point 16 miles south of San Antonio. The river has a small reliable flow in the mountains in Bandera County, but in the counties of Medina and Bexar it often ceases to flow.

At Castroville Joseph Courand has erected a stone dam across Medina River. The dam is 250 feet long, 8 feet high, with an effective fall of 8 feet. The power generated by a 35-inch Leffel turbine is used to operate a gin and mill. The Medina often stops flowing during the dry seasons, and an auxiliary steam plant is used during periods of no flow.

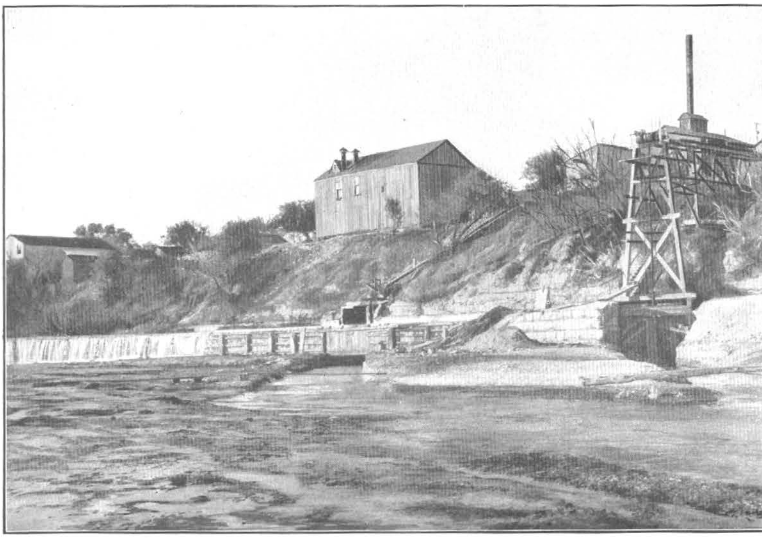
GUADALUPE RIVER.

Guadalupe River rises in the south-central part of the State, flows southeast, and empties into San Antonio Bay. It is the best power stream in Texas, although its drainage area above Cuero is only 5,100 square miles. Its efficiency is due almost entirely to the Comal, which flows into it at New Braunfels, and which has a minimum flow of 320 second-feet.

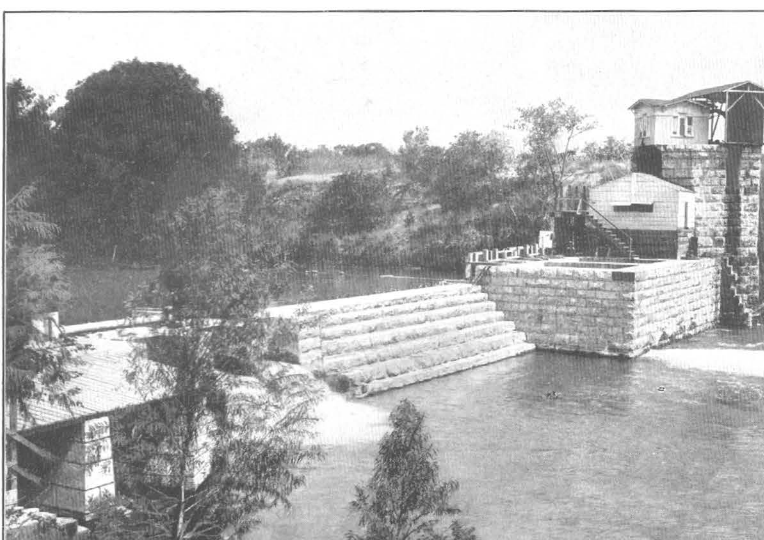
First-class modern power plants are located on Guadalupe River at Seguin and Cuero, the latter being somewhat similar in construction to the Clemens dam on Comal River. These dams have successfully withstood the floods of the Guadalupe for several years. At New Braunfels a dam with a fall of 11 or 12 feet could be located below the International and Great Northern Railroad bridge that would easily generate 340 horsepower at minimum and 450 horsepower at ordinary stages. The fall of the Comal is so slight below the highway bridge (north of the court-house) that a dam below its mouth should not back water above that point.

At Klein Falls, on the Guadalupe, 2 miles below the International and Great Northern Railroad bridge, there is an excellent site, with a good rock foundation, for a dam. The fall from the railroad bridge to the pool below Klein Falls is 15 feet, and it would be entirely feasible to construct a dam with an effective head of 25 feet just above the falls. A minimum of 750 horsepower could thus be obtained.

During the summer of 1902 the discharge of the Guadalupe was the lowest ever observed, forcing 6 power plants above New Braunfels to shut down or run on short time. The flow at this time was so low that special efforts were made to obtain measurements at several points. The following measurements were made in 1902 on the Guadalupe above New Braunfels:



A. WATERWORKS DAM AT KERRVILLE, TEX.



B. CLEMENS DAM AT NEW BRAUNFELS, TEX.

Discharge, in second-feet, of Guadalupe River above New Braunfels in 1902.

Date.	Station.	Discharge.
August 26	Two miles north of New Braunfels	13
28	Walhalla	11
28	Six miles above New Braunfels	9
29	Comfort	7

Above New Braunfels there are five dams on the Guadalupe that develop power, namely, the Sherman dam, at Ingram; the Schreiner dam, at Kerrville; the dam of the Kerrville Roller Mills; the Witt dam, at Centerpoint, and the Flach dam, at Comfort.

Three miles above Ingram is the first dam on the Guadalupe. The power plant belongs to John Sherman, and is used for grinding, sawing, and ginning. The dam is 7 feet high and is constructed of cedar and cypress and weighted with stone. The foundation is a ledge 2 feet high, upon the crest of which the dam is located, giving it a fall in all of 9 feet. The power is developed by a 42-inch Leffel turbine, which is usually operated with the gate one-third open. The dam is 300 feet long and was built in 1892. At Ingram there is another excellent site for a power plant that has never been utilized.

Two miles above Kerrville Charles Schreiner, in 1900, erected a wooden dam across the Guadalupe. The length of the dam is about 100 feet and its maximum height is 3 feet. It is constructed of cedar and cypress plank, and rests on rock. The effective head is 10 feet and the power is developed by one 30-inch Victor turbine, which is usually run with the gates one-fourth open. The vent is 300 square inches, and it is estimated that 50 horsepower can be developed. This would require a discharge of 55 second-feet. The dam deflects the water into a race about 300 feet long on the north side of the river. The banks of the river on the south side are low, while those on the north immediately adjacent to the stream are low and flat for a distance of 150 feet. Next the bluff there is a low gap through which the race was carried. The bluff constituted one side of the race, and the south side had to be built of framework of vertical cedar posts, to which stout cypress planks were spiked, constituting a water-tight fence.

At Kerrville a dam has been constructed by erecting 12 by 12 inch cypress posts in the rock bed of the river and thoroughly filling the hole around the foot of the posts with cement. On Pl. VI, *A*, is shown a view of the waterworks dam at Kerrville. Instead of bracing the posts from below to withstand the thrust of the water, an iron tension rod is attached to the posts and to an anchor bolt in the rock above the dam. The upper face of the dam is formed of thick cypress lumber, spiked to the 12 by 12 inch posts. The dam gives an average head of 7½ feet on the two Leffel turbines of 44 and 48 inches diameter. The 44-inch turbine is generally operated with full opening and the 48-inch wheel with three-fourths. They have vents of 300 and 260 square inches, respectively. An auxiliary steam plant of 45 horsepower is used for operating the electric plant.

At Centerpoint a wooden dam was built across the Guadalupe in 1895. It is 300 feet long and 7 feet high and cost about $2,000. The plant is owned by W. H. Witt & Co., and the power is utilized to operate the roller mills. The effective head is 9 feet, and the power is generated by one 48-inch Leffel turbine, which is generally operated with a gate opening of two-thirds. It is possible with this wheel to develop 40 horsepower, which would require, with an efficiency of 80 per cent, a venting of 49 second-feet.

The power plant at Comfort, 12 miles from Kerrville, is owned and operated by E. Flach. The power is used in the Comfort Roller Mills, an electric-light plant, and a cotton gin. The dam is made of cedar log pens, filled with rock, brush, and clay. It was built in 1881, is 150 feet long and about 5 feet high. The head is 11 feet on an average, reaching 12 as a maximum and 10 as a minimum. The energy is generated by two Leffel turbines, 35 and 40 inches in diameter, having vents of 180 and 137 square inches, respectively. The horsepower developed is estimated at 40 and 30, and this would require, with an efficiency of 80 per cent, a flow of 40 second-feet through the larger and 30 through the smaller. The plant has an auxiliary steam plant of 75 horsepower for use in periods of low flow.

Adolph Dittmar has a plant on Guadalupe River 5 miles below New Braunfels. There is a natural dam of soft calcareous material at this point, with a fall of 5 feet. The plant consists of a 42-inch Risdon turbine and a duplex Worthington pump of 14-inch piston diameter and 10½-inch stroke. The intake pipe is 12 inches in diameter and about 8 feet long; the discharge pipe is 10 inches in diameter and 750 feet long. The lift is 42 feet, and it is intended to sell the surplus water to neighbors for irrigation purposes.

Herman Dittmar has a similar plant 1 mile farther down the river. He also has a natural dam with a fall of 6 feet. His plant consists of an undershot wheel 12 feet in diameter and 12 feet long and a centrifugal pump with a 4-inch suction pipe and 3-inch discharge. He pumps through 18 feet of intake and 100 feet of discharge pipe, the lift being 32 feet. This plant was built in 1901. Water will be sold for irrigation purposes.

Below the crossing of the Southern Pacific Railroad, Koehler & Blumberg have utilized a natural fall in the Guadalupe to develop power by use of a 72-inch Leffel turbine. By artificial means the fall has been increased to 7 feet. The power is used in operating a gin

ERSKINE FALLS, NEAR SEGUIN, TEX.

during the cotton season. At the lowest stages of the river this fall could easily develop 200 horsepower.

The plant of the Seguin Milling and Power Company is located at Erskine Falls (Pl. VII), 4 miles west of Seguin and 1 mile below the bridge of the Southern Pacific Railroad. The irregular crest of the natural dam has been made horizontal by the use of cement concrete. The crest of the present dam crosses the river in a zigzag line, and the surplus water at low stages is allowed to pass over its southern end. Power is generated by three 50-inch Samson-Leffel turbines under a head of 12 feet. These turbines connect to one horizontal shaft and can be operated together or separately. There are eight double stand rolls with a joint capacity of 200 barrels of flour per day. The elevator has a capacity of 35,000 bushels of wheat. The cotton-gin section is equipped with four 70-saw gins, and in addition to these machines a grist mill is operated.

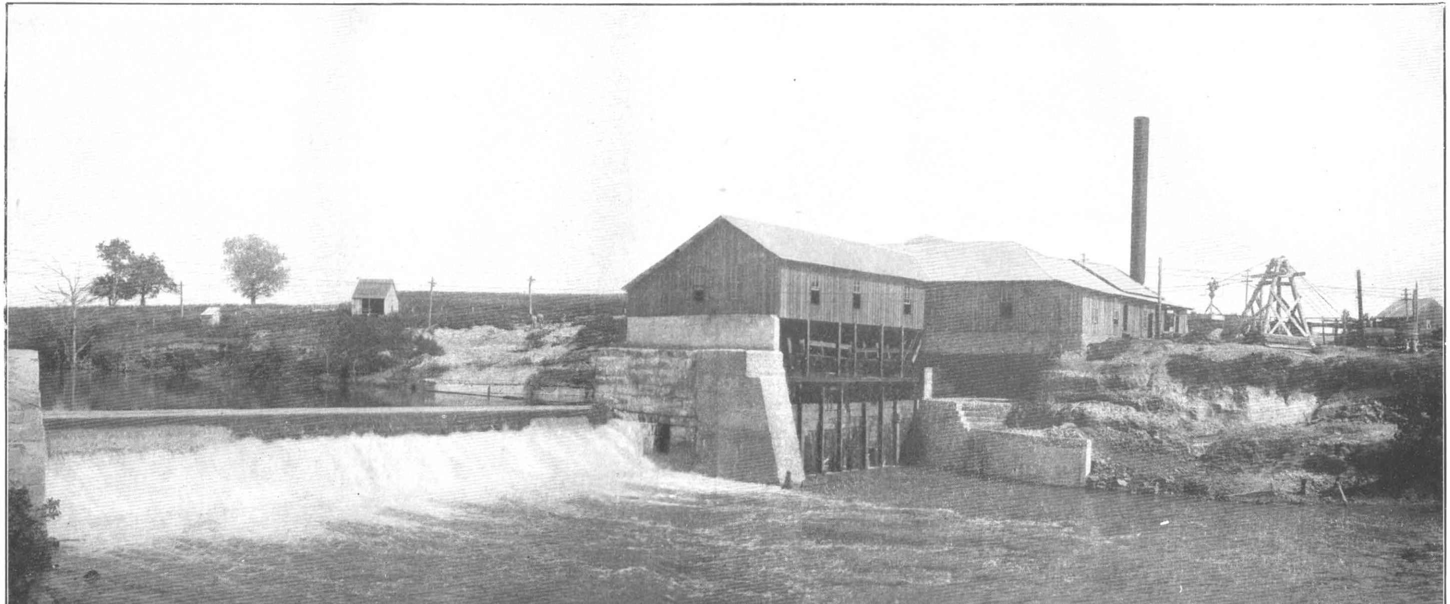
At Seguin are two water-power plants, one at each end of the dam. At the south end of the dam is located the electric-light power house and gin and mill owned by Troell & Sons. The dam is partially a natural formation, of irregular section and plan, and was raised 1½ feet by dumping cemented gravel on the crest. The head obtained is 7½ feet and the turbines used are one 66-inch New Success wheel, which gives 135 horsepower, and one 54-inch Alcott wheel, which gives 40 horsepower. The mill runs sixteen hours a day and the electric-light plant fourteen hours. At the north end of this dam is located the pumping machinery of the Seguin Waterworks Company. The head is 7½ feet, the same as at the south end, and the water wheels consist of one 54-inch Leffel turbine, which generates 40 horsepower, and one 56-inch turbine, which generates 50 horsepower. This latter turbine operates a pump that has a capacity of 625,000 gallons per twenty-four hours and that supplies the town at present. The smaller turbine operates a pump that has a capacity of 378,640 gallons per twenty-four hours and that is used during the summer months only.

The Troell power plant operates an irrigated farm of 300 acres. The crops raised consist mostly of truck, small grain, and corn.

The San Marcos joins the waters of the Guadalupe a short distance above Gonzales, 42 miles below New Braunfels. At Gonzales a timber and stone dam, 148 feet long, with a fall of 9 feet, has been constructed, and the power is used in running the gin and gristmill of Smith & Lowery, the electric-light plant, and the pump for the waterworks. The dam was built in 1891 and 1892, and the power is developed by two 60-inch, one 72-inch, and one 66-inch turbines. The ordinary minimum flow at this dam is slightly in excess of 450 second-feet, and the capacity of the plant is reliably 400 horsepower with all the feeding streams at their minimum flow.

Forty miles below Gonzales and 3 miles north of Cuero is the Buchel dam. The dam proper (Pl. VIII) is a solid limestone structure, weighing 140 pounds per cubic foot, its foundations and fillings being of concrete made from gravel, sand, and cement. A stratum of very tough clay, 30 feet thick, afforded an excellent foundation. The clay was removed to a depth of 5 or 6 feet and a foundation of concrete, 25 feet wide, laid; then come courses of stone on the upstream and downstream sides of the river, every course being set back until the low-water line, 15 feet from the base, is reached, where the dam has a width of 21 feet; the middle being filled with layers of concrete. From this line each layer of stone is set back on the downstream side, so that the top of the dam, 10 feet above the low-water line, is 6 feet wide. The total length over all is 220 feet. According to surveys made upstream, it is found that from 3 to 4 feet may be added to this dam without affecting seriously the low bottom lands upstream and subjecting them to more than usual danger or damage by overflows. By doing this an increase of from 40 to 100 per cent in power can be gained. The dam was begun December 1, 1896, and finished March 1, 1898. The stone was obtained from the quarries at Van Raub, 26 miles northwest of San Antonio. There were used in the construction of the dam and penstocks 129 carloads of limestone, 31 carloads of cement, 5,200 cubic yards of gravel and sand, 9 carloads of cypress timber, 370 cypress piles (20 to 30 feet long), 26 carloads of brick, and 2 carloads of iron columns and shapes.

The abutment to the dam on the west side is in the shape of a T. Next to the east bank are the penstocks, of the open type, built of cypress timber. They are of ample size, arranged to accommodate six turbines of sufficient capacity to utilize all the water of this stream whenever there is a demand for the power. At present only two 54-inch vertical turbines of 163 horsepower capacity each, under a 10-foot head, are installed. The entire fore bay and wheel pits are floored with a layer of concrete 12 inches thick, and the penstocks are held up by 29 cast-iron piers and two sets of I beams weighing 360 pounds per yard, all resting on concrete foundations. Upon this bank, which is encircled by a brick wall backed by piers of concrete, is situated the power house, 28 feet above the crest of the dam. The pumping machinery for irrigating purposes is driven by a shaft 7 inches in diameter, making 94 revolutions per minute. The power house is 80 feet long by 38 feet wide. One-half of this building, excavated to a level of 15 feet above the fore-bay water (about 16 feet above the crest of dam), is used for a pump room. The pump for irrigating purposes is of the duplex piston type, made by the Laidlow-Dunn-Gordon Company, of Cincinnati, and its capacity is



BUCHEL DAM, NEAR CUERO, TEX.

estimated at 3,472 gallons per second (463 second-feet) under a normal speed. The suction pipe is 20 inches in diameter and the discharge 18 inches. The water is pumped into a rectangular reservoir which has a capacity of 2,000,000 cubic feet and which is about 300 feet from the dam. From the reservoir two pipes 3 feet in diameter lead into the irrigating ditches. Various crops, such as alfalfa, cotton, cabbage, etc., and, in 1900, 35 acres of rice, were tried. About 60 pounds per acre were sowed from April 15 to May 1. The yield was 7½ barrels per acre, and was readily sold for $3.50 per barrel f. o. b. at Cuero. In 1901 the company sowed 250 acres in Honduras rice and 50 acres in Japanese rice. The cost of raising the rice at this plant will be exceedingly small, as no fuel will be used. In addition to the power used for irrigating purposes, the company has just closed a contract to supply 225 horsepower to the cotton mill that was erected in 1901.

The flow of the Guadalupe was measured on the crest of the Buchel dam by electric current in March, 1901, when there had been no rains in the watershed for four months, and a flow of 551 second-feet was found.

A gaging station was established on Guadalupe River at the Buchel dam, near Cuero, in December, 1902. The zero of the gage is at the crest of the dam at the south end. As it proved impossible to measure flood discharges at this point, another gaging station was established in July, 1903, at the bridge of the San Antonio and Aransas Pass Railroad across the Guadalupe 3 miles west of Cuero. The zero of the gage is 50 feet below the top of the tie in the third panel from the east. A tagged plumber's chain is used for reading off the gage heights. The observer is John Hughes, who has charge of the pumping plant of the railroad at this point. Measurements are made from the highway bridge, about 200 feet below the railway bridge. A cross section of this bridge is shown in fig. 7.

The maximum discharge for 1903 was 60,000 second-feet, the minimum 740, and the mean 1,790.

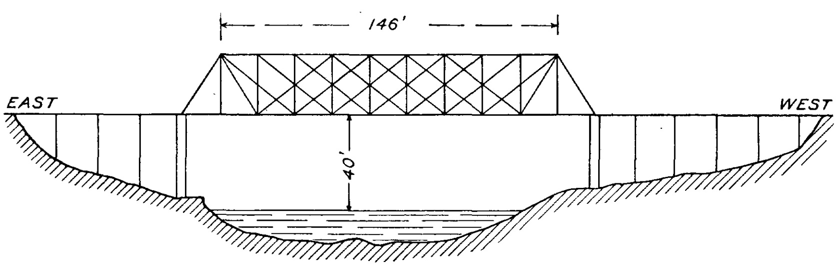


FIG. 7.—Section of Guadalupe River near Cuero.

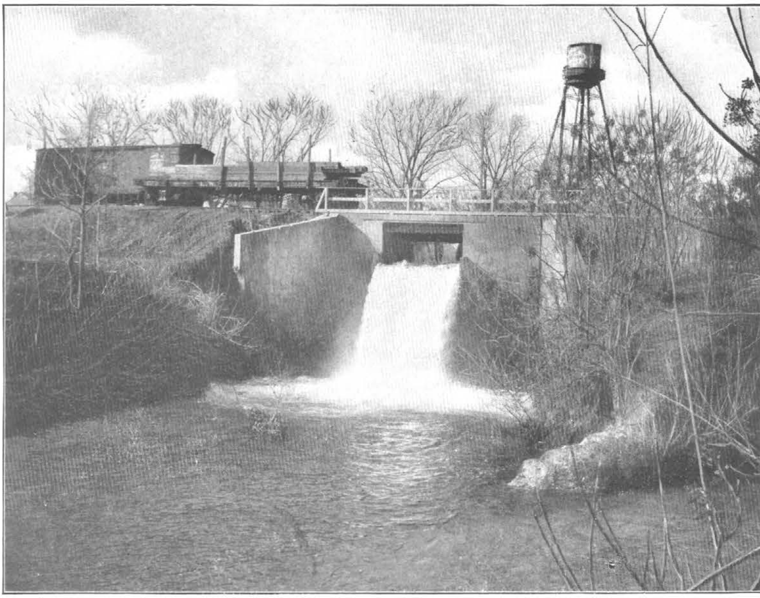
Power plants on Guadalupe River.

Locality.	Owner.	Head.	Material of dam.
		Feet.	
Ingram	John Sherman	9	Natural—wood.
Kerrville	C. Schreiner	10	Wood.
Do	Waterworks	7.5	Do.
Centerpoint	W. H. Witt	9	Do.
Comfort	E. Flach	11	Do.
Five miles below New Braunfels	A. Dittmar	5	Natural.
Six miles below New Braunfels.	H. Dittmar	6	Do.
Nine and one-half miles below New Braunfels.	Koehler & Blumberg	7	Do.
Seguin	Milling and Power Company.	12	Do.
Do	S. Troell & Sons	7.5	Do.
Do	Water Co	7.5	Do.
Cuero	O. Buchel	10	Masonry.

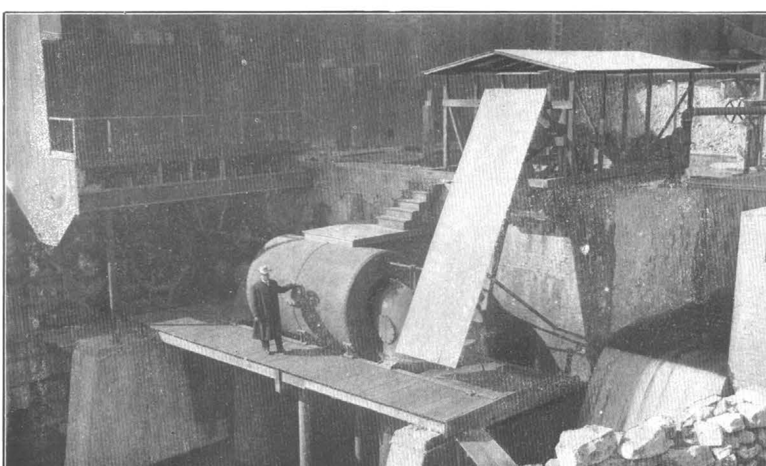
COMAL RIVER.

The mountains of the Edwards Plateau end about 1 mile northwest of New Braunfels, and from the fissures at the foot of the bluffs the celebrated springs that form Comal River gush forth. The waters have been used for power since 1860, but it is only since 1880 that systematic methods have been employed.

The flow of the Comal is reasonably uniform. The writer has taken measurements on the Comal three or four times each year since 1898 with the view of obtaining reliable data for an accurate estimate of its water power. A special trip was made to the Comal on Christmas day, 1900, for the purpose of getting a measurement when all the mills and power plants were shut down and when the flow would be uninfluenced by the variations of power required for the different purposes. The sections selected for measuring the flow were on the Landa mill race at the small bridge about 75 yards below the gravel dam, and on the Comal River 275 yards below the gravel dam. The combined discharge was found to be 374 second-feet. The flow was again measured the next day, December 26, 1900, at the same sections, when all the power plants were in operation, and the same discharge was found. It was observed that the water in the Landa race at this bridge was at the same level on the two days—i. e., the water was not lowered by the operation of the machinery, as the waste weirs were open. The above measurements were made at the close of a very wet year, and it is certain that the flow as obtained was above the normal. During 1902 two measurements were made, one in March, when a flow of 343 second-feet was found, and another in August, when the flow was 333 second-feet. The lowest flow ever obtained by the writer in the last five years was



A. WASTE WEIR AT LANDA'S MILL, NEW BRAUNFELS, TEX.



B. WHEEL PIT AT LANDA'S MILL, NEW BRAUNFELS, TEX.

310 second-feet, and it can be assumed that the minimum flow will be at least 300 second-feet.

The Landa estate (Harry Landa, manager) operates two plants, both taking their water from the same fore bay. The south plant operates the roller flour mills, the elevator, an ice factory, an electric-light plant, a waterworks pump, and a small pump for irrigation purposes. The power is generated by a 26-inch duplex horizontal Leffel turbine, with a head of 21.50 feet. The water is discharged into a race 24 by 30 feet, cut through the west bank of the Dry Comal. The flour mill has a capacity of 3,000 barrels per week, the elevator a capacity of 100,000 bushels, and the ice factory 14 tons per day. The

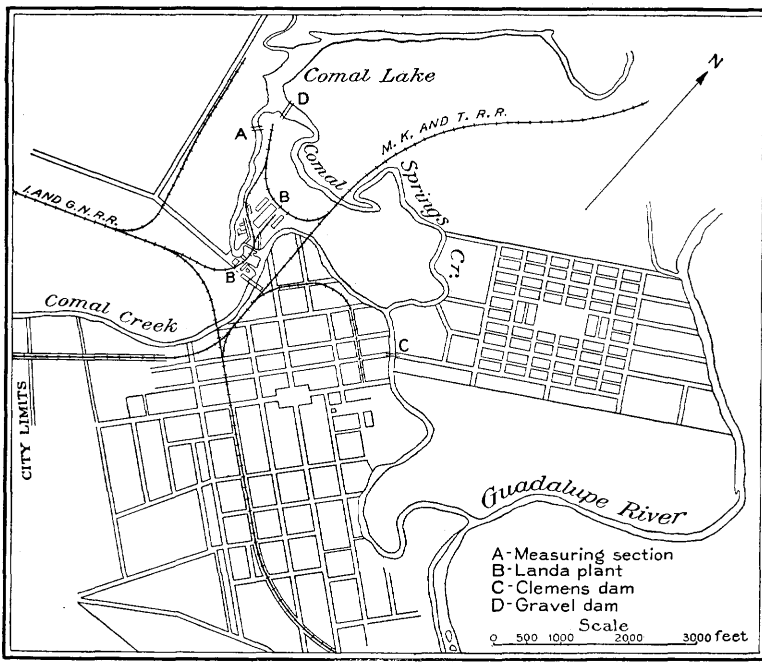


FIG. 8.—Map of New Braunfels.

electric-light plant furnishes light to the city of New Braunfels and to the Landa works. It consists of two motors, of 60 and 30 kilowatts. Manila rope belting is used, which is almost noiseless. The north plant is operated by a 30-inch Leffel double horizontal turbine. An attempt was made to substitute a steel overshot wheel for the turbine. The first work done with this wheel bent the shaft and tore rivets loose; in short, the wheel was a failure, and it has been removed and the Leffel wheel substituted. Rope transmission is used at the north plant also, and the power is transmitted to a shaft 240 feet long and varying from $3\frac{15}{16}$ to $2\frac{3}{16}$ inches in diameter. Pl. IX, *A*, is a view of Landa's waste weir.

The Clemens dam (Pl. VI, *B*) has a length over all of 220 feet and a length between bulkneads of 130 feet. Its total height is 14 feet, with a base 18 feet wide, resting on tough blue clay. The cross section in general is trapezoidal in shape. The crest is flat, 4 feet wide; the upstream face vertical, while the lower or downstream face is formed of a series of steps whose height or rise is about 18 inches and whose tread varies from 18 to 20 inches.

The dam was constructed in 1882 of limestone obtained 5 miles from New Braunfels, and the stones were laid in good Portland cement. There are three waste weirs, 6 feet deep and 5 feet 3 inches wide. By an agreement with the Landa interests the water in the fore bay or lake above the Clemens dam can not or should not approach nearer than 18 inches of the crest of the dam, and there is also another agreement with other parties below the dam that the water below the dam must stand 4 inches deep on the eighth stone from top of dam, but this latter agreement no longer prevents the lowering of the water level below the dam. The difference of water level in the fore bay and tail bay in 1903 was 8.26 feet, but a recent flood had dropped below the dam a pile of gravel that raised the level of the water 1 foot and thus reduced the head. The ordinary head is 9.25 feet. The power at the north end of the dam is generated by two Stillwell-Bierce Victor upright turbines, 35 and 44 inches in diameter. The shafts from the turbines transmit the power to a pulley 14 feet in diameter, whose center is 23.5 feet above the crest of the dam. The power is transmitted from this pulley by a $\frac{7}{8}$-inch wire rope across the river 650 feet to the Dittlinger flour mill, whose capacity is 1,500 barrels of flour, 1,200 barrels of corn meal, and 300 barrels of rye flour per week.

At the south end of the Clemens dam a power plant consisting of one 36-inch Stillwell-Bierce Victor cylinder gate turbine, working under the ordinary head of 9¼ feet, pumps water into the city standpipe. The bottom of the standpipe is 95 feet above the water level above the dam. This standpipe is 57 feet high and 25 feet in diameter.

The following survey was made in March, 1903, from the head spring near the mouth of Panther Canyon to the International and Great Northern Railroad bridge.

Fall of Comal River.

	Feet.
Head spring to Lake Comal (above gravel dam)	5.40
Lake Comal to Landa fore bay	1.10
Landa fore bay to Landa tailrace	21.51
Landa tailrace to Clemens fore bay	1.28
Clemens fore bay to tailrace	8.21
Clemens tailrace to smooth water about 200 yards below Clemens dam	2.80
Pecan tree to mouth of Comal River	2.47
Head spring near mouth of canyon to mouth of Comal	42.77
Comal to International and Great Northern Railroad bridge	6.38
Railroad bridge to Klein Falls	15.00
Clemens tailrace to Klein Falls	26.65

At the Clemens dam there was a fall early in 1903 of 8.21 feet, but the usual fall is 1 foot more than this, as the water level below the dam had been raised 1 foot by the débris of Landa's gravel dam, which was washed out and deposited in the river below the Clemens dam. A head of 9.25 feet and a flow of 300 second-feet (minimum) at the Clemens dam can be relied on, which with the ordinary efficiency of the best turbines should yield 250 horsepower.

The gravel dam at the head of Comal River could be raised 5 feet without backing the water up to the head springs, but the configuration or topography of the land in the park and to the north of the lake renders such an increase unadvisable. In addition to this, such an increase in the height of the dam (gravel) would require a corresponding raise in the embankment around Landa's fore bay, and this is practically out of the question. The lake and the fore bay could be raised 3 feet; this would increase the effective head to 24.50 feet. The contract between the Landa interest and that of the Clemens renders any increase in the height of the lower dam impossible. The water level in the fore bay must remain 18 inches below the crest of the present dam. But below the dam small rapids occur for 200 yards, and a fall of 2.8 feet by actual survey occurs in this distance. Two feet more could be added to the present head by excavating the blue clay out of the bed of the river. If this is done 300 horsepower could be generated.

Discharge, in second-feet, of Comal River at New Braunfels.

Year.	Hydrographer.	Discharge.
1895	C. C. Babb	328
1898	T. U. Taylor	320
1899	do	310
1900	do	374
1901	do	343
1902	do	333
1903	do	[a] 412
1904	do	375

[a] Recent rains.

SAN MARCOS RIVER.

San Marcos River rises in several large springs about 1 mile northeast of the town of San Marcos. The dam of the San Marcos waterworks raises the level of the water and forms a lake which backs the water up to the head spring. The first measurement of the flow of the river was made in 1894, near the International and Great Northern Railroad bridge, when a discharge of 150 second-feet was found. The flow was again measured in December, 1895, by C. C. Babb, when a flow of 89 second-feet was found at a point 50 feet below the head gates. The opening was so regulated that the flow was about the average discharge of the springs. The spring is reported to have an annual rise and fall, and it is stated that from March the flow increases until the middle of May, the total rise being about 18 inches. It maintains this level till September and then gradually falls.

Discharge, in second-feet, of San Marcos River.

Year.	Hydrographer.	Discharge.	Locality.
1894	C. C. Babb	150	International and Great Northern Railroad bridge.
1895	do	89	1 mile northeast of San Marcos.
1899	T. U. Taylor		
1900	do	150	Westerfield ford.
1903	do	153	Do.

The first dam on the San Marcos is about one-fourth mile from the head springs. The dam is about 400 feet long, the eastern section crossing the channel at a right angle for two-thirds of the length, the remaining portion deflecting parallel to the west bank to form a fore bay. The dam is constructed of earth and piling and has a maximum height of 15 feet, and develops a head that varies from 8 to 12 feet. The water power is generated by two 35-inch Leffel turbines of the Samson type, and one 48-inch Morgan Smith Success turbine. An auxiliary Atlas steam engine of 110 horsepower is used to supplement the water power. The plant belongs to the San Marcos Electric Light and Power Company, the San Marcos Water Company, and the San Marcos Ice Company. They are distinct companies. The building is made up of a boiler room 32 by 36 feet, an electric light and pump room 40 by 60 feet, an ice room 30 by 70 feet, and a storage room 20 by 40 feet. The electric energy is generated by one Warren 90-kilowatt generator and one Westinghouse 60-kilowatt generator. The pump is a Gordon Maxwell 10 by 12 duplex, with a capacity of 500 gallons per minute, but there is soon to be installed one Fairbanks 10 by 12, with a capacity of 1,000,000 gallons per day.

On July 29, 1902, the rainfall in San Marcos was 8.5 inches, while at a point 15 miles above the town it was reported as 22 inches, and at Kyle 28 inches.

VIEW AT SAN MARCOS, TEX., SHOWING POWER PLANT AND END OF LAKE.

The rain continued for seven hours, and all the lower parts of the town were flooded and many houses washed away. The highest water reached the bottom of the stringers of the International and Great Northern Railroad bridge.

Two miles below the head springs is the dam of J. M. Cape. This dam is constructed of framework and earth, and is 130 feet long, with a fall of 9 feet. The plant is equipped with two 48-inch Leffel turbines, which develop 78 horsepower. One-fourth mile below Cape's gin is the Thompson gin. The race is one-half mile long, and connects with the pond formed by the Cape dam. The fall at the Thompson gin is 14 feet. An auxiliary steam plant of 55 horsepower has been installed.

About 5 miles below San Marcos, on San Marcos River, is the gin and corn mill of J. C. Jones. The dam was built in 1896, and is of cedar-timber cribwork, filled in with stones, gravel, and concrete. It is 90 feet long and 7 feet high. The power is derived from two turbines—one Leffel-Samson, 50-inch diameter, which produces 95 horsepower, and one Leffel standard 23-inch wheel, producing 6 horsepower. The power is utilized in operating a cotton gin, corn mill, a small Westinghouse direct-current dynamo of 35-light capacity, and two small pumps that are used in supplying water for irrigating 20 acres of farm land. The total cost of the plant, not including the pumps, was $6,000.

About 2 miles northwest of the town of Martindale, W. S. Smith owns and operates a cotton gin and corn mill on San Marcos River. His dam consists of a central portion of timber framework, filled with rocks and gravel, 7 feet high and 200 feet long, constructed by placing alternately pieces of 10 by 10-inch cypress timber longitudinally and crosswise of the dam and filling in the spaces left between these with the rock and gravel. These timbers are not laid flat upon their squared faces, but are placed upon edge, and are dapped or let in several inches where they cross each other, and secured by three-fourths-inch bolts that extend completely through the dam from top to bottom. The lowest course, in which the timbers lie crossways of the dam, rests upon large longitudinal logs and extends 4 feet beyond the toe of the framework of the dam proper. Upon this extension are piled stones of all sizes up to the height of the dam, thus forming the downstream face. The top of the framework slopes backward and upstream to a slight extent, and is 16 feet in width, thus making the dam 20 feet wide at the foundation and 16 feet at the crest, the upstream side where the slope of the top ends being vertical. The ends of this wooden dam join on either side a dam of roughly shaped rock and concrete, the section next the gin and mill being 120 feet long and that on the far side 80 feet, making a total length of dam of 400 feet. This dam was built in 1897, and affords a head of 9 feet on the turbines. Mr. Smith intends to raise the dam several feet, however, in the near future. The power is derived from three turbines—one 40-inch 1893 patent Leffel wheel, which produces 68 horsepower; one 30-inch 1899 patent Leffel wheel, giving 40 horsepower, and one 18-inch special wheel, giving 5½ horsepower, making a total of 113½ horsepower. This is utilized in operating the cotton gin, corn mill, sorghum mill, and a small electric-light system. The machinery consists of ten gins, two presses, one cane mill, one sorghum mill, and a 125-volt Westinghouse direct-current dynamo. The total cost of the plant was $25,000.

At the town of Martindale is the gin and mill of J. W. Teller. The dam is constructed entirely of timber and rock and is similar to the central portion of W. S. Smith's. It is 250 feet long, was built in 1893, and gives an 8-foot head. The power is derived from two turbines—one Leffel standard 61-inch wheel and one 35-inch special wheel. The power is utilized in operating a cotton gin, corn mill, sorghum-seed thrasher, and the electric-light and waterworks systems of the town of Martindale. The machinery consists of five Munger gins, one corn mill, one Westinghouse 125-volt direct-current dynamo, one Munger press with Murray elevator, one sorghum-seed thrasher, and one pump. The total cost of the plant was about $20,000.

Near the town of Staples, on San Marcos River, Q. J. Lowman is rebuilding a gin and corn mill that was destroyed by fire in October, 1901. He has a dam of timber framework and rock 140 feet long and 9 feet high, which was built in 1899. The original dam was constructed in 1867, but in 1899 it was practically rebuilt and raised several feet higher. The timbers of the old mill were unhurt by the fire, and are to be used with the new machinery. They consist of one 66-inch Morgan Smith wheel, which develops 82 horsepower; one 42-inch McCormick wheel, giving 82 horsepower, and one Leffel 26-inch wheel, giving 12 horsepower. The power is used at present in operating the waterworks of the town of Staples, but will be utilized for ginning purposes, the operation of a corn mill, and electric lights for the town upon the completion of the mill. The machinery will consist of eight cotton gins, one 1,000-volt alternating-current dynamo of 750-light capacity, a Gould pump with a capacity of 75 gallons per minute, and a 50-horsepower Atlas engine and boiler; also a corn mill. The total cost of the plant will be $25,000.

At the town of Fentress, C. R. Smith & Co. own and operate a gin and mill on San Marcos River. The dam is 90 feet long and is built of timber framework and rock, like that of J. W. Teller's, a few miles above. A wing of timber sheeting 2 feet higher than the dam joins it to the bank opposite the mill. The dam in its normal condition gives a head of 6 feet on the turbines, but this can be increased to 8 feet by a system of flashboards that are raised above the dam when needed and taken off when not required. These flashboards consist merely of 2 by 4 inch pieces 2 feet long which are bolted to transverse timbers in the top of the dam (spaced about 6 feet), and which can be raised or lowered at will. The under sides of these 2 by 4 pieces are notched, and when raised they are propped up by means of sticks (in the notches) that rest upon the apron of the dam at the toe. Planks 2 by 12 are then placed upright against these 2 by 4 props, and raise the water up to the required 8 feet. The power is derived from one 66-inch Morgan Smith turbine, which gives 35 horsepower with a 6-foot head and 55 horsepower with an 8-foot head. This is utilized in operating a gin, corn mill, and small waterworks and electric-light plant. The machinery consists of seven Munger gins, two Meyer's pumps of about 200 gallons capacity, one 115-volt direct-current dynamo, a corn mill, and a 50-horsepower Atlas engine and boiler. The engine is required when the mill and gin are run to their full capacity, and is connected directly to the turbine shaft. The entire cost of the plant was about $10,000. It was built in 1879.

At the town of Prairie Lea is located the gin and corn mill of J. J. Jones. His dam is 120 feet long, 8 feet high, and is constructed of timber framework filled in with stones. It was built in 1896. The power is derived from one 61-inch Alcot turbine, which produces 45 horsepower under the 7-foot head obtained. This is utilized in operating a gin, corn mill, and one 110-volt Wiley dynamo. The total cost of the plant was about $2,400.

Three and one-half miles north of Luling a dam of timber cribbing, filled with rocks, about 120 feet long, is constructed across San Marcos River. The power obtained by it is used in operating a sawmill, gin, gristmill, and the Luling electric-light plant. A head of about 9 feet is obtained, and one 50-inch Samson turbine produces about 67 horsepower. The dam was first built about thirty years ago, but has been repaired from time to time, and has therefore been practically renewed at least once since then. The foundation is the muddy bed of the river.

Farther downstream and nearer the town is the dam of F. Zedler, which furnishes power for the operation of a cotton gin, gristmill, and the water-supply machinery of the town. The dam is about 60 feet long and is constructed of timber cribbing backed with stone and gravel. It is built in the form of two cribs, placed one upon the other, and resting on a foundation of hard sandstone. Two turbines are used to generate the power—one Leffel 66-inch wheel, giving 90 horsepower, and one 54-inch Alcot wheel, giving 60 horsepower, with an effective head of 9 feet.

There is a dam on the same river at Ottine, a few miles below Luling. It is about 100 feet long, constructed of cribbing and stones, and is of an irregular shape. The power is generated by a 72-inch Alcot turbine, which, under the 7-foot head, produces 70 horsepower, and is used in running a cotton gin and gristmill.

Power plants on San Marcos River.

Locality.	Owner.	Head.	Material of dam.
		Feet.	
Wimberly	Cotton gin		
San Marcos	W. E. Green	12	Earth and wood.
Do	J. M. Cape	9	Do.
Do	Thompson	14	Cape dam.
Five miles below San Marcos	J. C. Jones	7	Wood and stone.
Martindale	W. S. Smith	7	Do.
Do	J. W. Teller	8	Do.
Staples	Q. J. Lowman	9	Do.
Fentress	C. R. Smith & Co	6	Do.
Prairie Lea	J. J. Jones	8	Wood.
Luling		9	Crib work.
Do	F. Zedler	16	Do.
Ottine	do	7	Do.
Gonzales	Smith & Lowery	9	Do.

LAVACA RIVER.

Lavaca River rises in Lavaca County and flows south through Jackson County into Lavaca Bay. Its waters have not been used so far for irrigation or power purposes. Its discharge in December, 1903, was found to be 87 second-feet at the crossing of the Texas and Mexican Railroad, 2 miles west of Edna.

COLORADO RIVER (IN TEXAS).

The drainage area of the Colorado (fig. 9) extends into the southeast corner of New Mexico, and in its course the river is fed by the Conchos, the Pecan Bayou, the San Saba, the Llano, and the Pedernales.

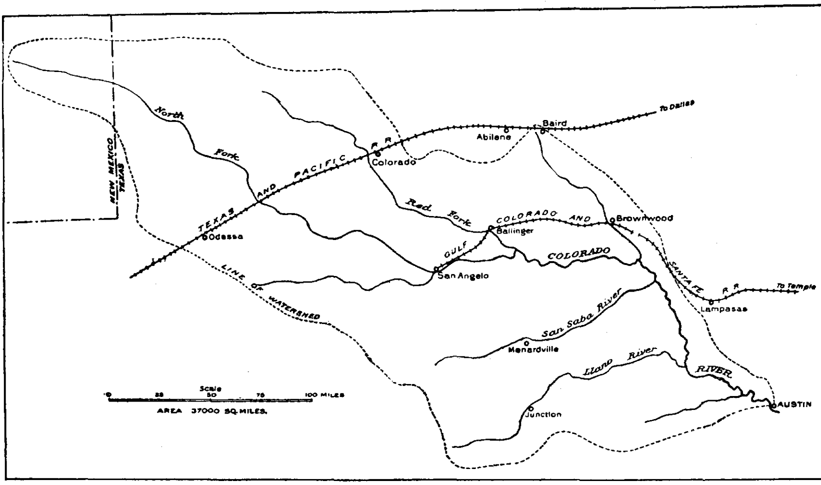


FIG. 9.—Map of watershed of Colorado River above Austin.

Power plants on Colorado River and tributaries.

Locality.	Owner.	Head.	Material of dam.
		Feet.	
Knickerbocker	T. Vinson	15	Ditch.
San Angelo	Payne & Jones	18	Do.
Do	J. L. Millspaugh, Mgr.	11	Steel and stone.
Point Rock	F. J. P. Ford	4	Stone and wood.
Ratler	J. D. Willis	4	Logs, rock, etc.
Menardville	Gus Noyes	23.5	Ditch.
San Saba	Water Co	20	Stone.
Do	do	10	Do.
Bakers			Brush.
Lometa (11 W.)	M. Chadwick	5	Logs and rock.
Cherokee	J. T. White	12	Stone.
Bluffton	Tanner Bros	9	Natural.
Kingsland	J. M. McDaniel & Co.	5.5	Wood.
Llano	J. K. Finlay	12	Natural.
Do	do	8	Do.
Do	Water Co	9	Wood.
Marble Falls	do	22	Natural.
Austin	City	62	Stone.

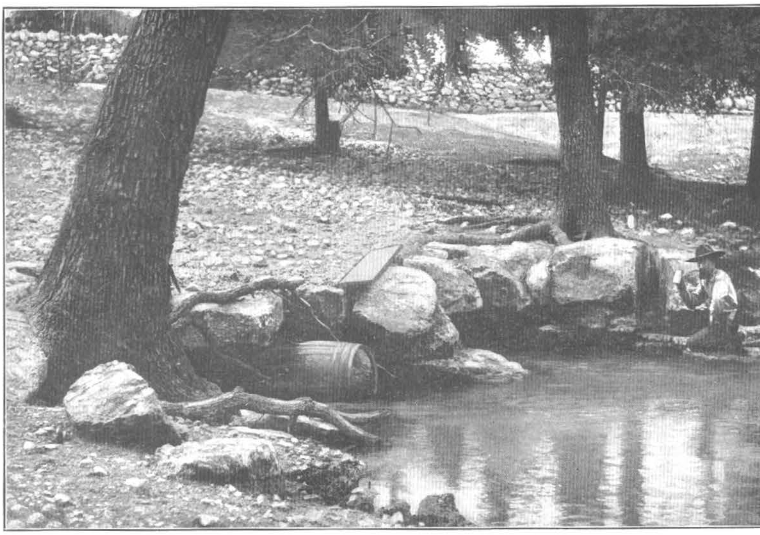
About 11 miles from Goldthwaite, in Mills County, J. D. Willis (post-office, Ratler) has constructed a dam of logs, rock, and gravel, 4 feet high, across Colorado River. The power developed is used in operating a mill, gin, and irrigation plant. The water wheel is 4½ feet in diameter, and develops 15 horsepower. Five acres in peaches, grapes, and garden can be irrigated.

In Mills County, about 11 miles west of Lometa, just below the junction of the San Saba and Colorado, Milam Chadwick owns and operates a power plant. The dam was built in 1879, out of stone and cedar logs, is 196 feet long and gives a clear fall or head of 5 feet. The dam is curved upstream and has on its crest a course of burr oak logs to which cedar brush is spiked and bolted. The power is developed by a 36-inch Leffel turbine, with a vent of 5,850 square inches, and is usually run one-half open. The mill house is located high upon the bank, out of reach of high water, and the power is transmitted from the turbine shaft to the mill house by a wire rope. The river here has a reliable flow, and the power is used for running a flour and corn mill and a cotton gin. The demands of the neighborhood are met by operating the plant one and one-half hours per day.

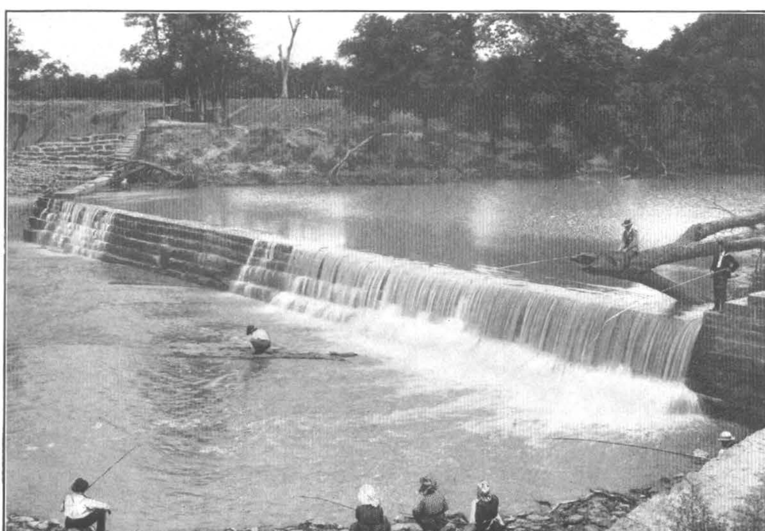
At Bluffton, 60 miles above Austin and 12 miles above Kingsland, a dam 400 feet long was constructed in 1898. It is built of logs, and the power developed is used in operating the gin and gristmill of the Tanner Brothers. There is a natural fall here of 8 feet, and the dam raises the water an additional foot, giving an effective fall of 9 feet. The dam cost only $125, and was constructed to fit the configuration of the cross section of the river bed. At deep places planks were used as a face. A 27-inch double discharge turbine is used to develop the power. The water is conveyed from the lake formed by the dam to the turbine by a mill race 2,400 feet long and 10 to 12 feet wide, with a depth at the dam of 1 foot, increasing to 8 feet at the wheel.

At Kingsland, on the Llano branch of the Houston and Texas Central Railroad, a dam, owned by J. M. McDaniel & Co., has been constructed across Colorado River about 1 mile from its junction with the Llano. The dam was built in 1896, is 500 feet long, has a fall of 5½ feet, and backs the water 3 miles up the river. A framework of live-oak braces covered with 3-inch pine lumber constitutes the dam, and it has withstood successfully several floods—notably those of June, 1899, and April, 1900. The power is developed by a 35-inch turbine, and at low stages of the river 25 horsepower is utilized in running a gin and mill.

At Marble Falls occurs the most remarkable natural dam along the course of the river. A fall of about 12 feet has been utilized to pump the water supply for the city. From the present lake level above the falls to the head of the tailrace there is a fall of 16.4 feet; to the end of the tailrace, or to the tailrace pond, a fall of 19 feet from the lake



A. KICKAPOO SPRING, TOM GREENE COUNTY, TEX.



B. DAM ON PECAN BAYOU AT BROWNWOOD, TEX.

level; to the pond under the highway bridge, a fall of 21.6 feet. A small outlay of money would increase the present head fully 5 feet without raising the crest of the dam. From the lake under the bridge to the bend in the river below there is a fall of 12.8 feet, or a total fall from the lake of 35.4 feet, and to a point 1.25 miles below the dam there is a fall of 47 feet. There are two ways in which the power could be materially increased: (1) By excavating the tailrace to the lake under the bridge by cutting it down at the head 4½ feet, which would give an effective head of 21 feet; (2) by raising the crest of the present dam, by the cheap construction of a dam on the crest of the present natural dam, from 4 to 12 feet. The minimum flow found in recent years was 160 second-feet, which could develop 300 horsepower if all of the water were used with a head of 21 feet. Six hundred horsepower could be developed at this place, the only expense being the construction of a tailrace, the erection of the power plant, and raising the present lake level 12 feet. This would involve the purchase of a small tract of submerged land on the south side of the river. There will certainly be a big demand for the power in the future. Granite Mountain is only 2 miles away, and along the railroad. By combining the water power and the granite industry a corporation could command the best and the most economical manufactured output. Marble Falls offers greater possibilities for water power than any other point in Texas.

DAM AT AUSTIN.

In May, 1890, the city of Austin determined to construct a massive dam across Colorado River, near the city, and to expend $1,600,000 on the enterprise. It was estimated that 14,000 horsepower could be developed. No hydrographic data had been collected. In the spring of 1890 a measurement of the flow of 1,000 second-feet was taken as the minimum. The minimum flow proved to be much less, but the greatest disappointment was the failure of the dam on April 7, 1900.

The dam was built above Austin, at a point where the deep cut or canyon which the river has worn in the limestone rock is about 1,150 feet wide. The cross section of the channel is almost level on the bottom, and is bounded by nearly perpendicular walls of rock rising to the height of a little over 60 feet on the city side of the river and 125 feet or more on the other side. The spillway was 1,091 feet long between the bulkheads at each end, which extended to the natural rock. The upper face of the dam was vertical and 60 feet high, measured from an assumed low water. The downstream face was a reverse curve of ogee form, which, at the toe of the dam, was horizontal. The width of the dam at the base was 66 feet. The rotten and loose rock excavation over the area covered by the dam was comparatively slight, being only a few feet in depth. It was designed to have two trenches, about 4 feet in width and of somewhat greater depth, extending lengthwise along the upper and lower edges of the dam and filled with masonry to increase frictional resistance. The total exposed surface of the dam was constructed of squared granite and the interior of limestone rubble masonry, Portland cement being used throughout. As was afterwards proved, this granite facing was not sufficiently tied into the interior rubble, as it acted like a coating of veneer.

The original cross section of the dam, as recommended by Mr. Frizell, is shown in fig. 10 (left half). The cross section as adopted (fig. 10, right half) was recommended by Mr. Fanning, who in his report to the board of public works said:

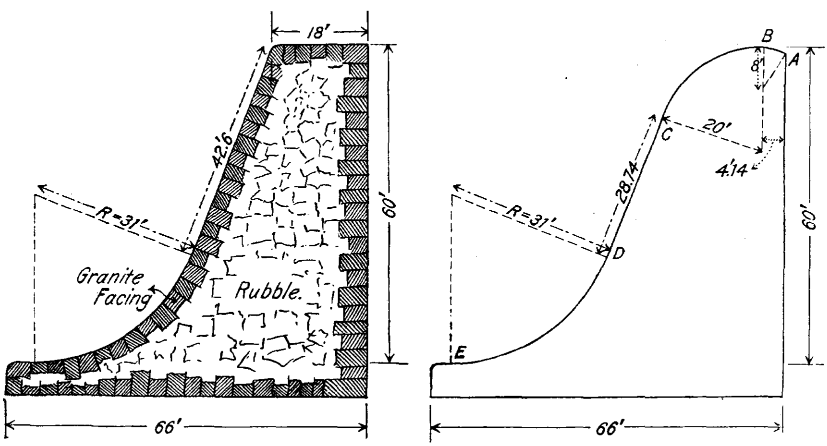


FIG. 10.—Cross sections of Austin dam.

The profile [fig. 10, left half] as shown to me seems not to fulfill the required conditions for passing the floods, because of the slightly rounded or nearly angular form at the front of its crest. Another diagram [fig. 10, right half] presented shows an advised modification of the profile of the upper part of the dam, which is better adapted to pass the flood in a gliding sheet down the face of the dam and to deliver it to the lower level without a direct blow, and so that its velocity will be expended chiefly in a horizontal direction in the backwater below the dam and in eddies at a safer distance below the toe of the dam. The lower part of the downstream face of the dam has a curve of 31 feet radius to which low-water surface is tangent. The central part of this face has a batter of 4½ inches to the foot.

The new profile at the top part, as suggested, completes the downstream face and crest of the dam with a curve of 20 feet radius, to which both the front batter and the surface of the pond at a level of the crest are tangent, this curve ending on the crest at 5 feet from the upper angle of the crest. The upper angle of the crest is then rounded off with a smaller curve, and the entire front of the dam becomes a reverse curve of ogee form, the form of dam best of all adapted to pass a large volume of water through so great a height. The top curve conforms nearly to the theoretical form of a medium flood stream. At higher flood stages there will be tendency to vacuum under the curve stream immediately after it has passed the crest, which, together with the pressure of the atmosphere upon the top of the stream, will keep the full flood stream in full contact with the curved face of the dam, and cause even the highest flood to glide down the fall without shock upon the face of the dam or the soft rock foundation.

The best modern appliances were used in the construction of the dam. The granite material for the facing was obtained from Granite Mountain, near Marble Falls, being hauled from the quarry to the dam over the Austin and Northwestern Railway, a distance of 70 miles, and delivered at the east end of the dam. The granite blocks were of average dimensions and weighed 4 tons each. The four classes of material used, i. e., the limestone rubble, the cement, the sand, and the granite, were transported from the end of the dam to place by a cable $2\frac{1}{2}$ inches in diameter, stretched between two towers—one on the east and the other on the west bluff—1,350 feet apart. The cable was anchored at the ends to "dead men" weighted down by stone. The saddle shown in fig. 11 was especially designed for this

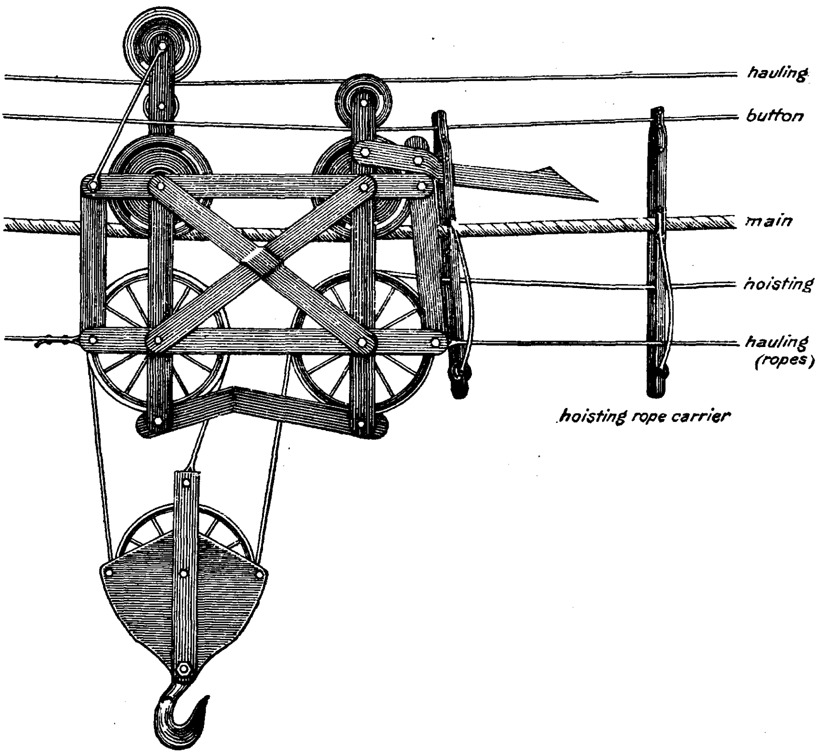


FIG. 11.—Saddle used in construction of Austin dam.

work, and ran on the main cable. The wire ropes were known as the "hauling rope," the "hoisting rope," and the "button rope." The hauling rope was attached to the lower part of the framework of the saddle, passed over pulleys at both towers, and wound around a drum under the east tower. The endless hauling rope was operated by an engine to which its drum was attached. It was completely under the control of the operator, and could be stopped in any position along its course. After being checked in the position desired, the drum operating the hoisting rope was brought into motion and the load was lowered to the dam.

The granite blocks and the larger limestone rubble stones were handled by immense tong-like grips. The cement and sand were loaded into cages, transported to the place of construction, and there dumped on the dam. The cement mortar was made at the place where it was to be used, and the blocks of masonry were placed where needed by crane derricks.

A wire rope one-half inch in diameter was used in connection with the cable and saddle to prevent excessive vibration of the operating ropes. On this rope there were buttons which increased in size from the tower to the west. The hoisting rope was supported at different points by carriers which rested, when the saddle was stationary, on the main cable. This carrier consisted essentially of two parallel bars, between which and near the lower end a small pulley was supported to carry the hoisting rope. A series of slots were arranged in the upper part of the carriers through which some of the buttons could pass. When near the east tower the saddle supported all the carriers on a horn. In moving from the tower to the west, the smaller button passed through all the carriers except the last, which it took off the horn; the second button passed through all the remaining slots except that in the second carrier, which it pulled off the horn, etc. The carriers were thus stripped off the horn by the buttons and rested on the main cable, affording a groove or support for the hoisting rope and reducing its vibration.

Not only was there lack of hydrographic knowledge, but the location of the dam was ill chosen. Under the dam, near its eastern end, fault and fissure in the rocks were encountered. The fissure, as stated by Mr. Groves, engineer in charge for part of the time, was 75 feet wide and was filled with clay, with an occasional bowlder. Joseph P. Frizell, the chief engineer in the early stages of the work, states that at a point 300 to 400 feet from the east end of the dam a very friable limestone was found, and in 1896, in a letter to the mayor, he warned the authorities about this dangerous point, and suggested some supplemental work of protection. It is highly probable that the dam would have been standing to-day if this work had been executed.

The minimum flow of the river was overestimated about five times. Measurements taken by the writer in March, 1899, and since indicate that the flow was less than 200 second-feet at low stages, against an assumed 1,000 second-feet. The flow at Marble Falls, 70 miles above the dam, was 197 second-feet, and that at the head of the lake a day or so later, no rain having fallen in the meantime, was 210 second-feet. Records of depth of water on the crest of the dam were kept from September 1, 1895, to January 1, 1900. The maximum and average depths of water on the crest of the dam as given by the gage were as follows:

Depth of water on crest of Austin dam.

Year.	Maximum depth.	Average depth.
	Feet.	*Foot.*
1896	2.60	0.496
1897	2.20	.422
1898	4.20	.280
1899	9.80	.412
Average		.408

On account of the inequalities of the crest line of the dam all depths must be increased by 0.009 foot to get an average for the whole spillway of 1,091 feet.

Experiments with an electric-current meter were made during January and March of 1900 to determine the coefficient C in the weir formula:

$$Q=CLH^{\frac{3}{2}}.$$

The results indicate that for the Austin dam C was nearly 3.09, the theoretic coefficient used by Frizell. Substituting this value of C and the length of 1,091, we get

$$Q=3{,}371\ H^{\frac{3}{2}}.$$

The average flow through the penstocks for the four years was about 250 second-feet. The following table shows the maximum and average daily discharge in second-feet, including the flow through penstocks:

Gage height and discharge at Austin dam.

Year.	Gage height.		Discharge.		
	Maximum.	Average.	Maximum.	Minimum.	Average.
	Feet.	*Foot.*	*Second-feet.*	*Second-feet.*	*Second-feet.*
1896	2.61	0.505	14,100	180	1,460
1897	2.21	.731	11,000	200	1,200
1898	4.21	.326	29,000	210	1,880
1899	6.81	.421	103,400	180	1,170

The average depth on the crest for the four years was 0.417. Making H=0.417 in the weir formula gives Q=910. Adding to this the flow through the penstocks, the average flow for the four years is 1,160 second-feet. This, with the conditions prevailing at the Austin dam, would have given, if it had all been used, 6,264 horsepower. Thus the average flow would not have produced half the power the minimum flow was supposed to produce.

The maximum, minimum, and mean discharge of the Colorado at Austin since January 1, 1896, are given in the following table. This does not include the flow of Bartons Creek:

Discharge, in second-feet, of Colorado River at Austin.

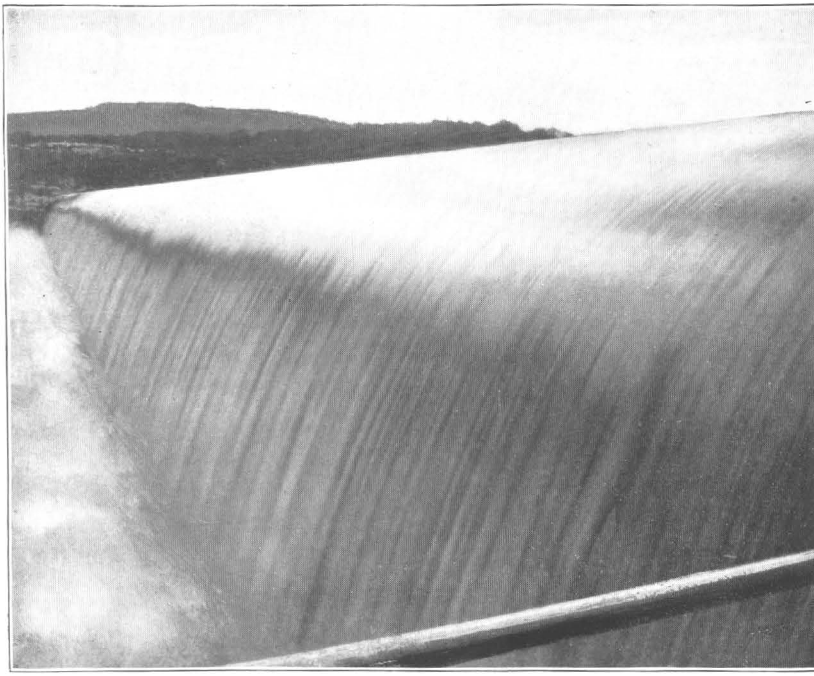
Year.	Maximum.	Minimum.	Mean.
1896	14,100	180	1,460
1897	11,000	200	1,200
1898	29,000	210	1,880
1899	103,400	180	1,170
1900	123,000	410	3,115
1901	40,912	175	1,994
1902	31,250	180	2,224
1903	32,500	320	1,300

The flow of the Colorado since 1896 is shown in figs. 12 to 19, inclusive.

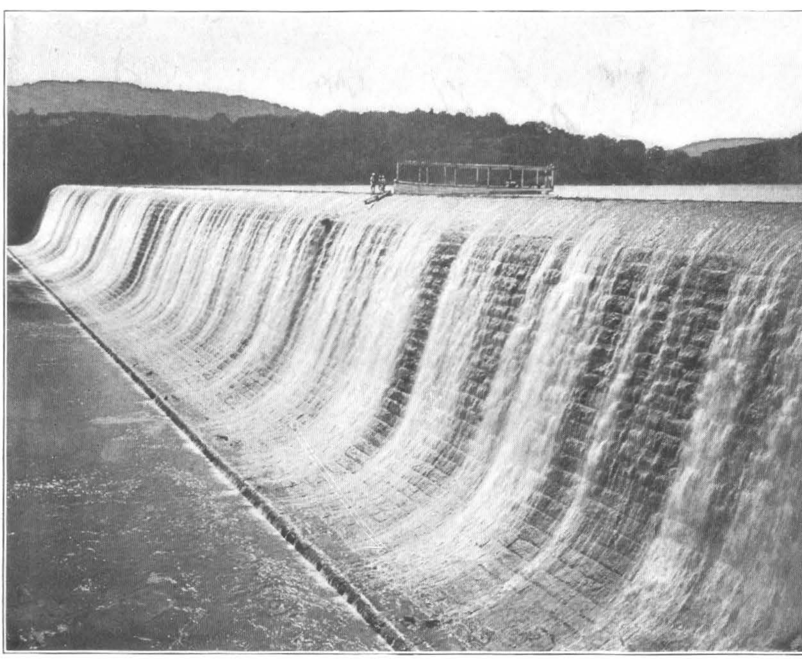
The Austin dam failed on April 7, 1900. Upon the present condition of the foundation of that part of the dam that was broken out hinges the proper interpretation of the cause of its failure. So important was this special feature that the writer made an elaborate set of soundings in the latter part of 1900 in that part of the broken section through which at present the water flows. Four lines of soundings (marked x, y, z, and t) were made parallel to and at distances of 0, 16.5, 42, and 60 feet from the upper face. The result is shown in the following table. Distances were measured from east bulkhead. All the soundings were to solid rock except those marked (S).

Soundings at site of wrecked portion of dam December, 1900.

Distance in feet.	Depths below top of toe.			
	Line x.	Line y.	Line z.	Line t.
	Feet.	*Feet.*	*Feet.*	*Feet.*
600	13.0			
550	9.5	9.1	10.1	12
500	10.9	11.8	11.9	14
450	(S)12.6	12.9	12.6	14
400	11.6	11.6	12.2	15
350	8.1	8.9	(S) 9.6	15



A. AUSTIN DAM, FROM THE EAST.



B. FLOOD OVER AUSTIN DAM, JUNE, 1899.

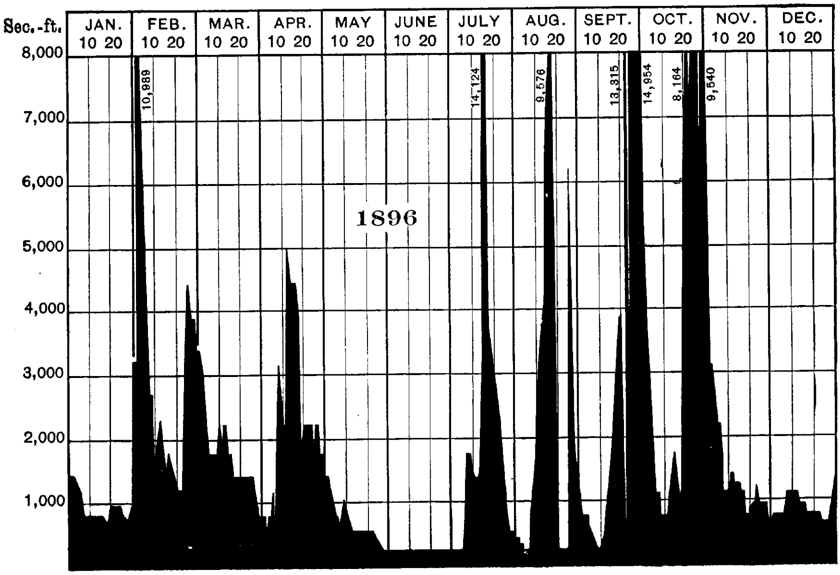


FIG. 12.—Discharge of Colorado River at Austin, 1896.

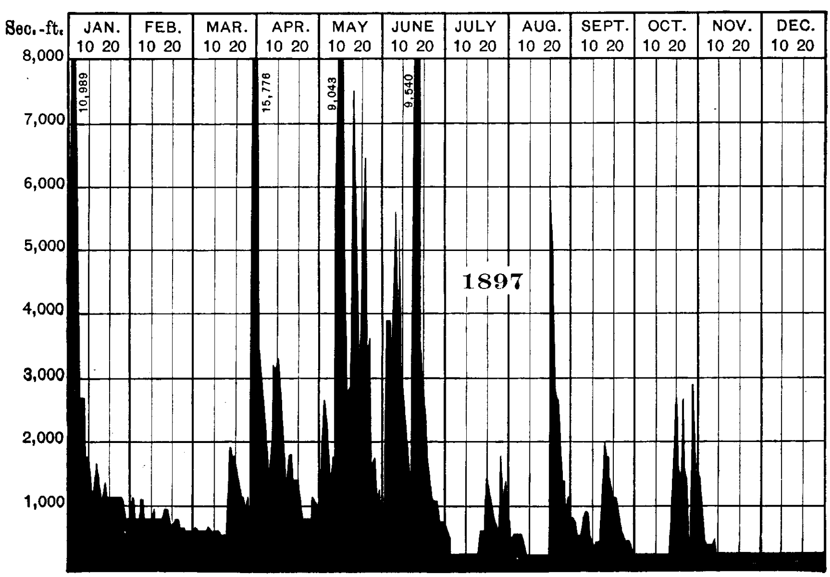


FIG. 13.—Discharge of Colorado River at Austin, 1897.

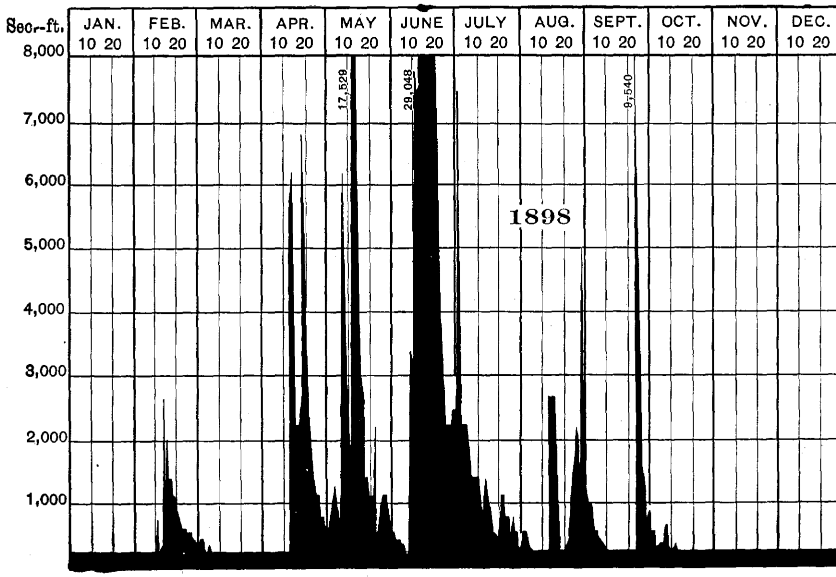


FIG. 14.—Discharge of Colorado River at Austin, 1898.

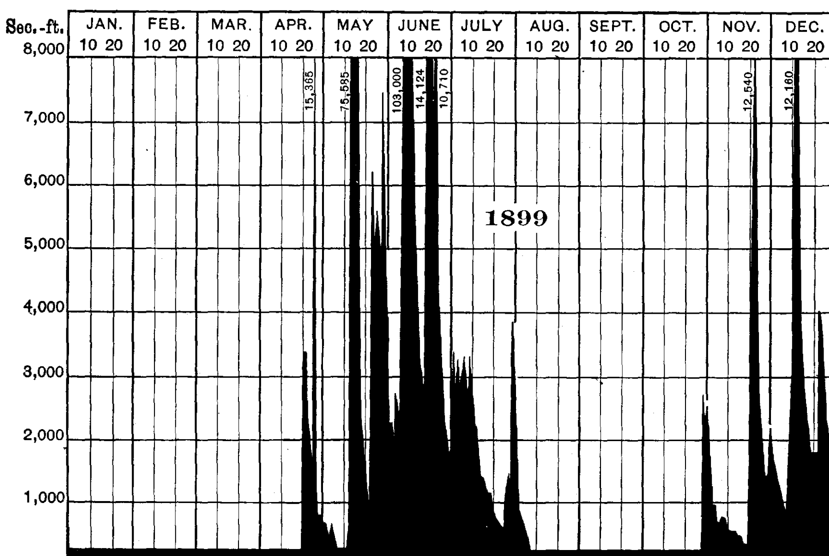


FIG. 15.—Discharge of Colorado River at Austin, 1899.

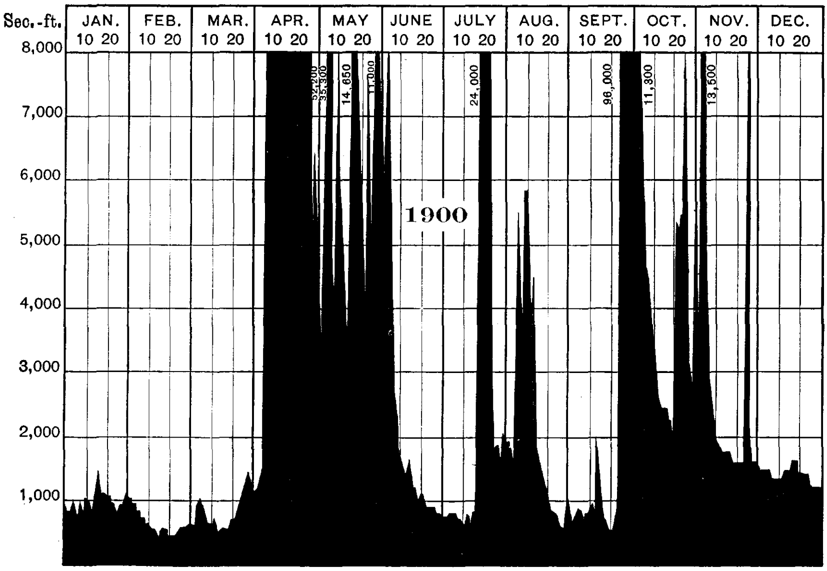


FIG. 16.—Discharge of Colorado River at Austin, 1900.

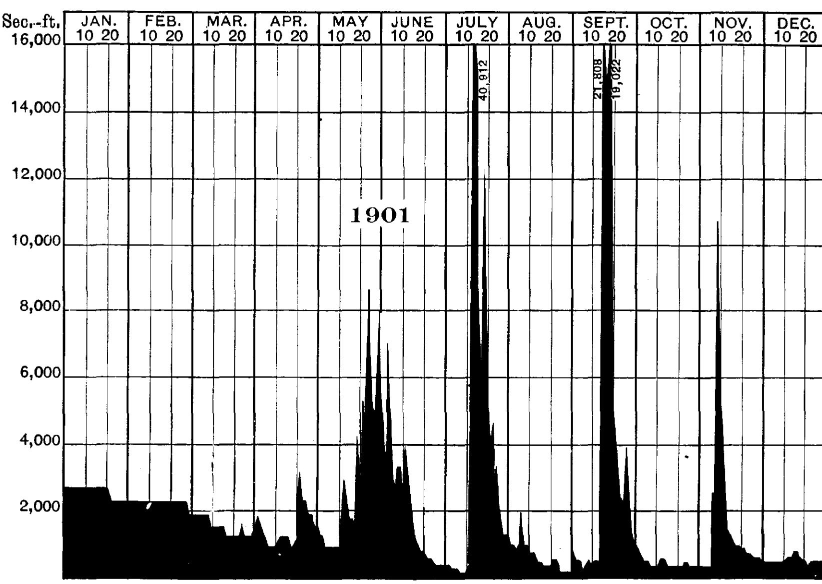


FIG. 17.—Discharge of Colorado River at Austin, 1901.

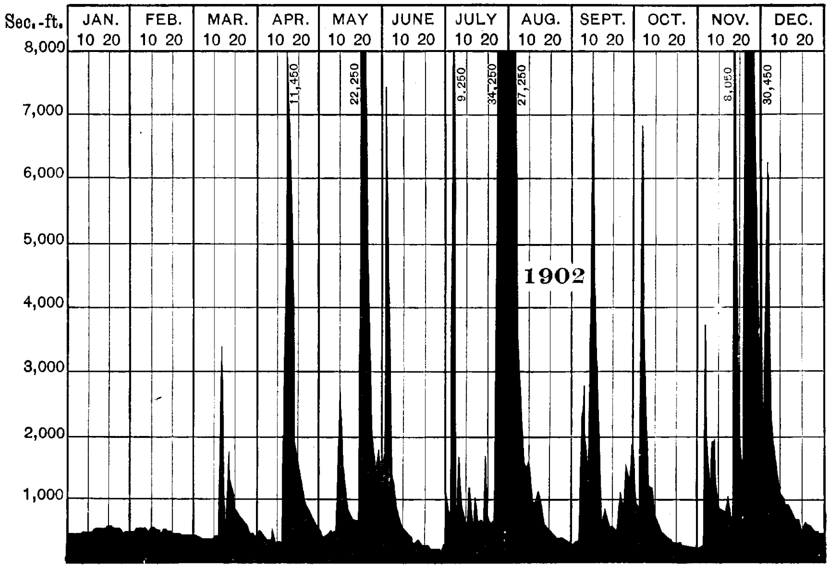


FIG. 18.—Discharge of Colorado River at Austin, 1902.

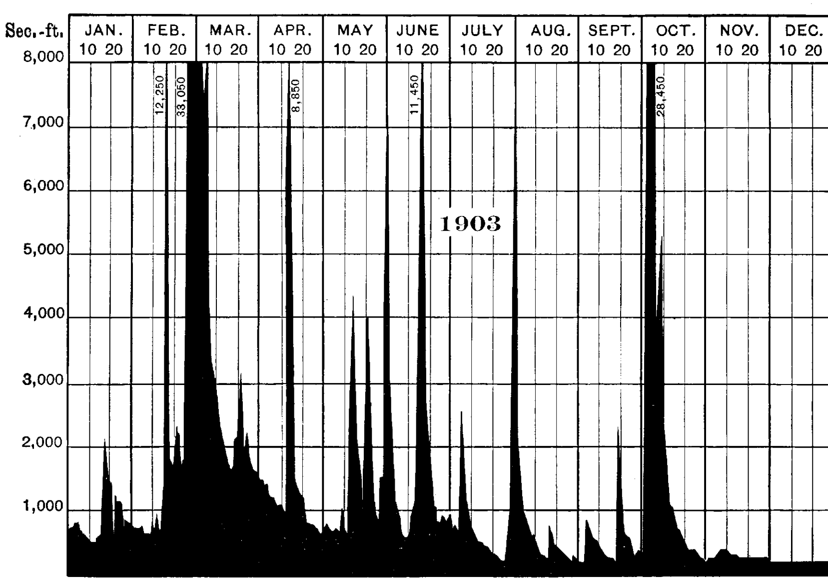


FIG. 19.—Discharge of Colorado River at Austin, 1903.

As the height of the top of the toe of the dam above the rock bed of the river was, on an average, 6 feet, and as the foundation was not (with the exception of the trenches) over 8 feet below "low water," a glance at the above table will convince anyone that there is no part of the foundation in the western 300 feet of the broken section remaining. From the present ordinary eastern water edge a large sand bank extends to the end of the eastern standing section, which covers 140 feet of the former bed of the dam. Soundings were not made through this sand bank, but the crest of the big section of the dam carried downstream, but still standing, is on an average only 4 feet lower than the crest of the standing dam, which indicates very clearly that its foundation went with it, as it is resting practically in the old tail race, whose bed was lower than the bottom of the dam.

In all 74 soundings were made, and 67 of these show that the depth of bed rock is over 8 feet below "low water," and at the other 7 soundings the rod could not be driven through the sand, mud, or gravel, to solid rock. At no place was any solid rock encountered as near as 8 feet to the "low-water" mark in the area of soundings, which covered a space of 18,000 square feet.

The condition of the foundation, the detached standing section (BD, fig. 20), and the condition and position of the other broken section that

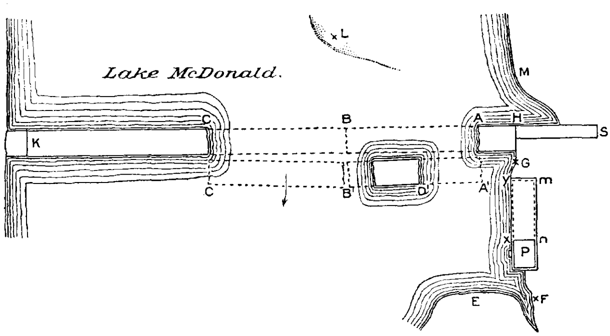


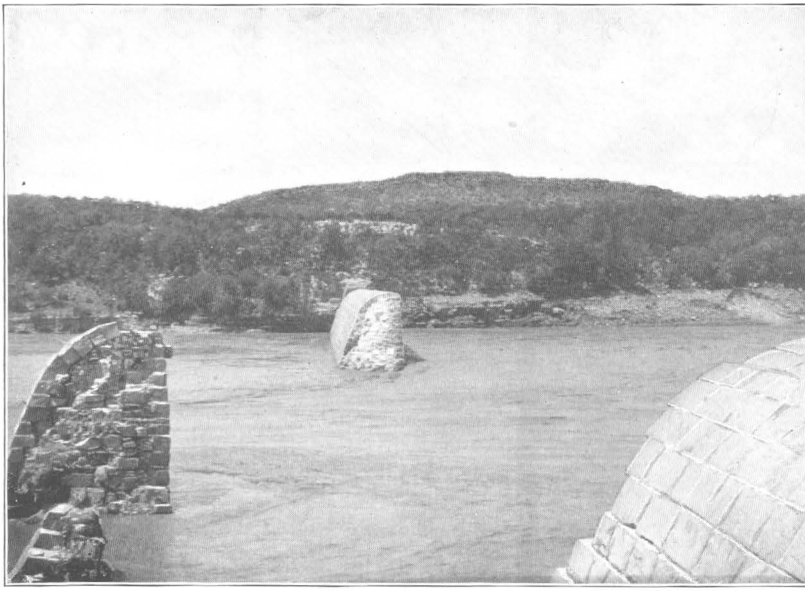
FIG. 20.—Plan of broken dam at Austin.

occupied the gap and that disappeared soon after the break, all preclude the theory that the dam broke at the level where it was 31 feet in thickness. This level was 25 feet above "low water" and 35 feet below the crest. If it broke on this level, then there was a section only 35 feet high that broke off and moved back. The broken sections moved down the stream about 60 or 70 feet, and rested in a position practically parallel to their original positions and in the tail race of the dam, the bottom of which was lower than the foundation of the dam. If the dam had broken at the level of 35 feet above "low water," then when the upper 35 feet of the dam moved off three things would have occurred: (1) The upper part would have turned over as it slid off of the lower part, which it did not do. This is shown by the section BD, still standing (Pl. XIII, *A*), and by the other section which was carried bodily downstream and which remained upright forty minutes after the first break. (2) When the 35-foot section moved downstream, if by any possible means it could have slid off, then fallen a distance of 30 feet and landed in the tail race in an upright position, its crest would have been 30 feet below the crest of the standing portion. All this is disproved by the facts. The crest of the standing section (Pl. XIII, *A*) is only 4 feet (instead of 30) lower than the original crest, and that of the portion which stood for a while was as high as or higher than the original crest. (3) The crest of the standing section is now 53 feet above ordinary flow, whereas it would have been only about 22 if the dam had broken at the 25-foot level above low water. (4) That section of the dam carried downstream and still standing can be examined and the 25-foot level will be found actually intact. The position of these sections, horizontal and upright, indicates that the cause of failure was a sliding out bodily on its base of that portion that failed.

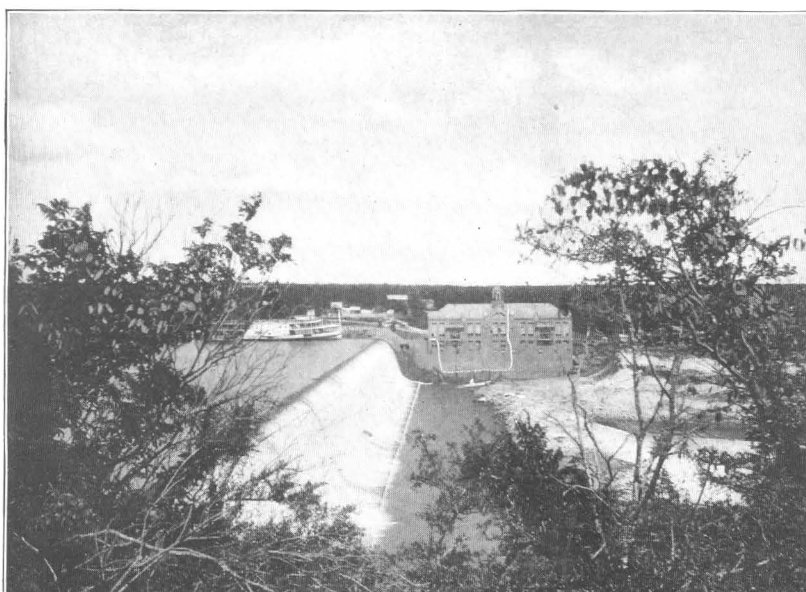
On account of the immense importance of the Austin dam as an engineering structure—it being the largest in the world across a flowing stream—the writer here submits the opinion of some of the engineers who were connected with it from time to time.

Mr. Frizell has said that the location at Mormon Falls, 2 miles above the chosen site, presented points of decided superiority over the locality selected, but the board of public works thought that location inconsistent with the purposes of the improvement. Mr. Frizell does not consider that the solubility of the rock had any bearing on the failure, and sees no reason to doubt that the immediate cause was the undermining on the downstream side, caused by the abrasive action of the current and the constant stream of water coming from the power house and flowing along the toe of the dam on its way to the open channel of the river. A progressive weakening is attested by the fact that during the preceding year the dam had withstood a flood substantially as great as the one in which it failed. The toe of the dam, which was left without support by the undermining, contained granite blocks of more than 6 tons weight.

It is on record that the breaking down of this unsupported toe was imminent, in which event each of these stones would become a millstone (propelled in such a flood by some 2,000 horsepower) in the work of grinding the friable rock bottom and extending the undermining. At the wooden dam across Connecticut River at Holyoke, Mass., an action of this kind became threatening in 1866. A pit 20 feet deep had formed on the downstream side of the dam. This danger was met by the construction of a massive apron of cribwork filled with stone, which prolonged the duration of the structure more than thirty years, or until the construction of the present stone dam. At Austin the engineer had in contemplation from the beginning



A. BROKEN DAM AT AUSTIN, TEX., FROM EAST END.



B. POWER HOUSE AND DAM AT AUSTIN, TEX., FROM WEST.

an analogous work, namely, an extension of the massive apron by a bed of concrete, to be applied as soon as the abrasive action had made sufficient progress to indicate the character and extent of the work required for its suppression.

N. Werenskiold, one of the engineers of construction, in a letter to a friend in the latter part of 1900, said:

There can be no doubt that the failure was not caused by any defective work in the dam itself, but by the entire body being pushed downstream and broken from the lateral pressure on account of too small frictional resistance under the dam. It is also proven conclusively that this resistance against sliding had been materially diminished by erosion below the toe of the dam, and to that extent the failure is chargeable to lack of care in maintenance.

I have no doubt but that all the masonry went, or slid, and I am inclined to the belief that some of the rock ledges underneath went with it. I think it possible that the foundation might have been good enough for a dam without overfall, but it proved not to be good enough for this bold structure. I think it probable also that vibrations of the dam, caused by the fall of the water, may have had a very detrimental effect on the underlying foundation and also increased the lateral pressure of the silt and earth against the dam far beyond the generally assumed water pressure, until this lateral pressure overcame the combined bending resistance of the dam proper, together with the frictional resistance under the base.

As early as in May, 1893, in reply to a direct question from one of the leading members of the board, I stated that the foundation under the east end of the dam was not what it should be; that it was hard to say whether it was safe or not, but that I thought that the dirt filling against the dam on the water side would prevent undermining and save the structure. I also suggested the necessity of close watching below the dam.

On May 7, 1894, when replying to a letter from another of the leading members of the board, I suggested that they make borings below the dam for the purpose of ascertaining the necessity of taking some precautions for the safety of the dam, stating that there might or there might not be immediate necessity for so doing, but that I believed it would prove necessary in the course of time. In another part of the same letter I suggested concrete or paving in front of the power house. From this you will know they were not without friendly warnings.

But in spite of all this I can not say that the works were designed and built with due safety or precautions, or that, to my knowledge, proper borings and examinations of the underlying formations were ever made.

Mr. J. T. Fanning remarks as follows:

The theoretical stability of the masonry of the dam in its normal condition, as completed in 1893, was sufficient to resist a much greater volume of flood flow than the flood at the time of the break. The structure substantiates this view in the fact that the westerly part of the dam, nearly one-half its length, resisted the force that broke out a mid section. It is evident that there was a large surplus of resistance, both as to sliding and overturning in the remaining part of the structure, as otherwise the moving sections would have pulled with them those portions of the dam now standing erect in place.

Undercutting.—That there was undercutting of the toe of the dam at a point where the dam first yielded is attested by soundings made before the sliding of a portion of the dam.

A writer in public print has attributed this undercutting in large part to the flowing of the tail water from the water wheels in the power house along the toe of the dam toward the channel, as shown in Pl. XIII, *B*. This theory is not sustained by the facts.

This dam was built on the rock bed of an ancient channel of a great river. Both ancient shores are of rock and nearly vertical to the height of the dam. When the dam was constructed the modern river occupied less than half the ancient river channel, and the remainder of the channel, covering somewhat more than its easterly half, was occupied by an alluvial deposit 40 to 60 feet in depth. A narrow cut was made through this deposit to the east shore for placing the foundations of the dam in that part of the ancient channel. The tail-water from the power house flowed out through this cut on bed rock to the modern west channel, as shown in Pl. XIII, *B*, and had the toe of the dam for its right shore and the earth deposit for the other shore.

In examining the theory of the bed rock cutting by the tail-water alone we observe that the quantity of tail-water flow was ordinarily about 250 cubic feet per second and in the narrowest part of the channel had a velocity of about 2 feet per second. In the wide section of this channel, at point of scour, the tail-water alone had a mean velocity less than three-tenths foot per second. The theory of scour and undercutting of the rock by the tail-water flowing at these low velocities is absurdly erroneous.

The undercutting was probably not done by the scour of extreme floods. It was anticipated that the cutting by floods would be at a distance from the toe of the dam. Pl. XIII, *B*, shows that floods passed over a space in front of the toe of the dam and did their cutting of the alluvial deposit below the line of the lower end of the power house about 200 feet from the toe of the dam.

When a flood glides down any sloping face on the lower side of a dam its current is discharged in solid stream under the backwater below the dam somewhat as shown in fig. 21. When logs pass over a sloping dam with the flood they first appear at the

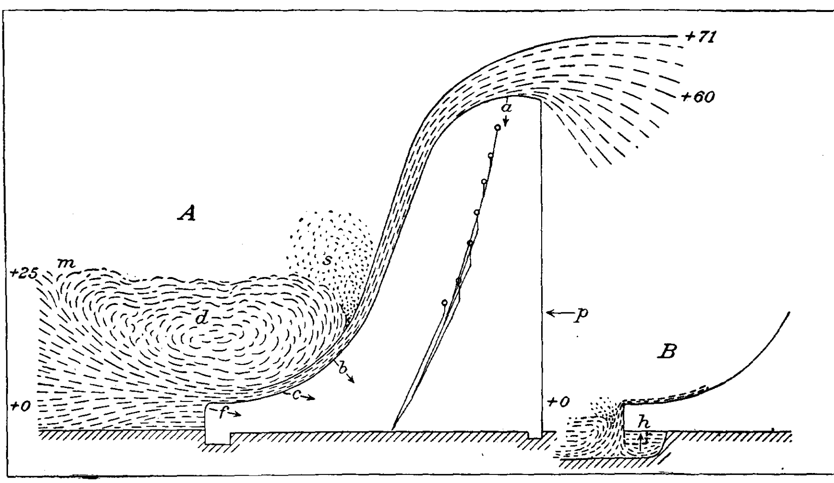


FIG. 21.—Fanning's illustration of flow of water over Austin dam.

surface of the ebullition at some distance below the dam, as at *m*, in fig. 21, and then return along the surface toward the dam. The greater the flood depth on the crest the farther from the toe of the dam do the logs appear and the more swiftly the logs return with the surface current toward the dam.

Breakwater.—In a case such as is shown in fig. 21 the breakwater comes in contact with only the toe of the dam. With 11 feet depth on the crest, 60 feet fall, and 25 feet of backwater, the discharge velocity past *b c f* is great. The water at *d* then flows back over the swift undercurrent with a velocity due to the free head of backwater next the dam, but at its surface level can not reach the dam. These effects of flow, which may be observed at many dams, seem to have been overlooked by most writers on the subject. It is illustrated in part by Pl. XII, *B*, in which the valley between the downflowing stream and the returning current is filled with spray.

Fig. 21 is a reproduction of a sketch relating to these matters explained by the writer to members of the board of public works at Austin, in June, 1892, when he first visited the works. The foundations of the dam were then in place and the superstructure in progress.

In computing the stability of a masonry dam, the weight of water resultants from *a* to *b*, fig. 21, have usually been neglected. So, also, have the reactions of the tail water against the dam throughout the flowing jet, and also the weight reactions at *b c* and the weight of the water at *d*, which in this case are sufficient to materially enhance the factor of safety.

Fall at the toe.—Referring again to the undercutting at the toe of the dam, which occurred at a point about 300 feet from the easterly abutment, we call attention to the appearance of the low and moderate flows at the fall over the toe of the dam, as shown in Pl. XII, *A*, and Pl. XIII, *B*. This fall should but slowly cut hard limestone, but might cut such soft stone as was said to have been found at the point mentioned. At the right of fig. 21 is a sketch suggesting the possible effect of such fall on a soft rock or adobe stratum. A fall of 1 foot to surface of backwater gives a velocity of about 8 feet per second, and of 2 feet a velocity of about 11.34 feet per second, and of $2\frac{1}{2}$ feet, as observed, a velocity of about 12.68 feet per second, each independent of the velocity acquired down the slope.

The failure of the dam was attributable to a local weakness in the rock on which it rested. It is probable that the friable or soft stratum under the part of the dam which first moved, and which was not removed and replaced, became so saturated with water that upward pressure from the pond was transferred to the underside of the dam in sufficient amount to neutralize a considerable part of the weight pressure of the masonry resting upon that soft rock and, furthermore, that this saturated stratum became like a lubricant on which that part of the dam had but moderate resistance against sliding.

The parted sections constituted nearly one-half the length of the dam. It is probable that the section of the dam resting on the formation on which it had not sufficient frictional resistance was held as a part of a beam until a vertical cross crack came at the central part of the soft section at B (fig. 22), and also that then the two parts adjacent to B were held briefly as cantilevers until they cracked at C and A, after which they slid, moving slightly faster at B, the point of first crack, until they rested 80 feet forward of their original positions. The erosion in front of the toe of the dam was not so wide but that the two parted sections of the dam slid over the erosion without tilting and stood erect in their new position, as shown in Pl. XIII, *A*.

In such constructions it is usual to countersink the toe of the dam flush into the bed rock, giving it an abutment, which makes sliding impossible.

Power-house foundations.—The injury to the power house was a remarkable and unprecedented accident.

The foundations remain now uninjured, as is indicated in fig. 22. The basement windows were placed above the 40-foot backwater level and the river wall was trussed to resist the inward pressure of 40 feet of backwater. The wave of water from the broken dam rose above the windows and broke them in and then flooded the basement where the turbines were located. As the flood receded the basement held this water, as a tank, up to the 40-foot level. When the backwater outside had next day (twelve hours after break in dam) fallen below the level of the basement floor the inclosed water pressed a part of the basement wall outward and permitted a part of the floors and roof to fall.

Site of power house.—Some one has stated that the power house was in more danger from the flow over the dam than it would have been if located 100 feet farther downstream. Its position as constructed was adopted as the one of greatest safety and stability, and also in part because the extension of the abutment and steel penstocks 100 feet farther would have added $20,000 to their cost. The relative location of the dam and power house are approximately shown in fig. 22. In this sketch GF is the face of the east abutment, but with exaggerated curve. This easy curve of the abutment was proportioned with care to deflect the flood current in a predetermined direction, so that it could not scour along the face of the power house foundation except as a return eddy. The return eddy flowing upstream would be weakest near the dam, so that part of the foundation nearest the dam was safest of all from scour by flood. The foundations of the power house were uninjured by the rush of waters dashed against the building.

The question of rebuilding the dam is not considered in these pages, for the reason that it will require expert examination of the whole question. The paramount factor, aside from the financial features, will be the character of the foundation.

Mr. Wilbur F. Foster, of Nashville, Tenn., upon invitation of the committee appointed by the water and light commission to consider ways and means of rebuilding the dam, after visiting Austin and examining the dam site, submitted the following report:

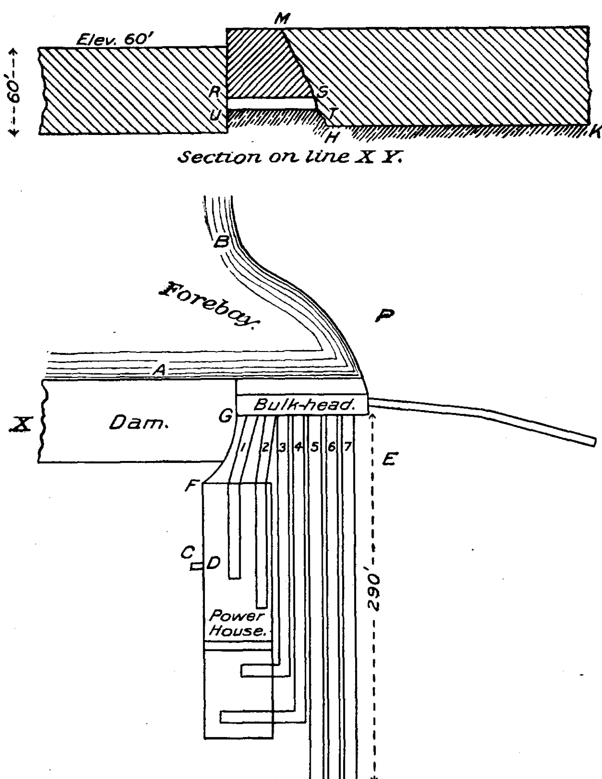


FIG. 22.—Plan of power house and penstocks at Austin dam.

Any estimate of this kind, in the absence of definite plans and specifications which are to be complied with, is at best uncertain and unsatisfactory; and in this case it has been assumed that those which controlled the original construction would be followed in the renewal, in order to preserve uniformity of appearance of the entire dam when completed, but with such modifications, to secure stability and for the sake of economy, as are herein suggested for your consideration.

The report herewith submitted is from the standpoint of a builder, guided by some experience in construction of similar work in other localities and from information obtained in your city as to various details of cost, and will, therefore, ignore technical questions as to cause and manner of failure, etc., which have been so ably and exhaustively discussed by well-informed and intelligent observers who have given much time to the study of the facts. Only the conditions as they now exist will be considered.

The engineering problems involved demand the most painstaking, careful investigation, and these you will doubtless submit to some member of that profession in whom you have entire confidence, and whose advice, plans, and specifications, when once adopted, as well as his instructions with regard to details during the progress of the work, you will rigidly abide by. I may be pardoned for suggesting that some of the questions thus to be most carefully studied in the light of the unfortunate experience you have had are:

(1) Whether it will not be better to abandon entirely the present location, and in rebuilding adopt one by which you will avoid the "faults" or unreliable strata in the geological formation which seems to have been the prime cause of the trouble you have had, both with the foundation of the dam and the construction of your bulkhead masonry and power house. Of course a large amount of material will be available by salvage from the old dam when removed and from the débris from the portion destroyed.

The surveys, soundings, and careful investigations already made by the eminent professional gentlemen who have been connected with your work heretofore will greatly facilitate the decision of this point.

(2) Whether, in view of the observed action of the overflow in time of flood, a modification of the profile or cross section of your dam is not advisable, wherever it may be built, the upstream face to be battered or offset in lieu of vertical, and the downstream face to have flatter slope, thus increasing the weight of the mass and giving a larger frictional area upon the base.

(3) A careful consideration of the merits of the fossiliferous limestone, which is abundant in the vicinity of the dam, as a building material. It does not seem reasonable that stone which has withstood the action of the elements for untold ages should be condemned as altogether worthless. In view of the excessive cost of granite, both in quarry cost and transportation, as given to me in Austin, I believe that the limestone of the vicinity should be used in the upstream face, at least to a point fourteen feet below the crest of the dam, and quite possibly on a portion of the downstream face also, and that it will be reliable for strength and durability in that portion.

Assuming that these and other details will hereafter be decided by your engineer, I will endeavor to answer, as briefly as possible, the inquiry of Mr. Caswell, guided by my personal examination of the locality and by my best judgment as to the cost of the various items.

It might be assumed by some that inasmuch as the total length of the dam between abutments is 1,091 feet and its total cost was about $611,000, and as about 91 feet at the east end and 500 at the west end remain standing, that the interval 500 feet could be replaced for its pro rata of the total, or about $300,000. This supposition will be found erroneous for several reasons:

(1) The shattered condition of the 91 feet now standing at the east end makes its removal and reconstruction a necessity, and inasmuch as this is at a place where a very troublesome leak occurred after completion of the dam it is probable that the foundation itself ought to be excavated to greater depth.

(2) A large mass of the original dam is still standing, just far enough downstream from its original position to be very much in the way of construction of new work, and must be removed.

(3) A very large deposit of earth and silt east of the present channel, also along the toe of the dam on the west side of the channel, must be removed for construction of new work.

(4) An examination by sounding with an iron rod reveals the fact that the bed rock in the channel through which the river is now flowing is an irregular surface, ranging from 8.6 to 12.6 feet below the assumed low-water line, which was the top of the toe of the dam as built. This is the result of seven soundings, and is pretty conclusive proof that not only the foundation stone is gone from this portion of the dam, but that the bed rock itself has been broken up and washed out to a depth in some places of more than 6 feet. The average of these soundings is 10.8 feet, and while it is not certain that this condition extends to the eastern end of the gap, yet it will not be safe to estimate otherwise, as it is probable that if not washed out at least that much would have to be removed before rebuilding. This break-up of the bed rock I have assumed to be from a point 6 feet above the upper face of the dam, a line 20 feet below the toe. This, then, will make a pit 483 feet long by 92 feet wide by 4.8 feet deep which must be filled with masonry or concrete before reaching the base of the original dam.

(5) It seems to me imperatively necessary that the toe of the dam its entire length should be protected by an apron of masonry or concrete to prevent undermining. This I have estimated as 1,100 feet long, average width 20 feet, average depth 3 feet.

(6) In my estimate I assumed that the upstream face wall will be built of limestone to a height 14 feet below the crest of the dam and will have a slope or batter of 3 inches to 1 foot vertical. This will add 442 feet to the original sectional area of the dam, making it 2,642 feet. The upper 14 feet of the upstream face, the coping, and the downstream face all to be of granite, as in original plans. All this will be shown more fully by the sketch (fig. 23) which I herewith inclose, showing suggested profile. It is suggested that the entire filling or interior shall consist of concrete made of American Portland cement.

(7) The cost of the contractor's plant or outfit under conditions like these is quite as great for the construction of a dam 600 feet long as for the original length of 1,091 feet.

With the above explanations I submit the following estimate of cost:

Earth excavation, wet and dry, 21,000 cubic yards, 30 cents, $6,300.

Rock excavation, 2,000 cubic yards, $1.60, $3,200.

Removal of masonry now standing, 14,000 cubic yards, $1, $14,000.

Granite coping course, 1,373 cubic yards, $19, $26,087.

Granite facing, downstream, 5,535 cubic yards, $11.75, $65,036.25.

Granite facing, upstream, 684 cubic yards, $11.50, $7,866.

Coursed limestone masonry, upstream face, 4,738 cubic yards, $7.50, $35,535.

Concrete filling, 55,749 cubic yards, $5.50, $306,619.50.

Total, $464,643.75.

Deduct for salvage of granite in old dam and débris, 3,025 yards, $7, $21,175.

Total net, $443,468.75.

In the above estimate it is assumed that the granite work can be done at the same prices as in the original contract, notwithstanding the increased figures given me when in Austin. It is also assumed that all the work will be laid in American Portland cement mortar of approved quality.

Incidentally, while at the site of the dam, I made a measurement of the flow of the stream, which was said to be at a stage lower than for many years. This measurement, which was of the rudest type and without any facilities for securing accuracy, indicated a flow of 360 cubic feet per second. I also examined the ground on the west side of the river and found that by cutting a channel 100 feet wide, with an average depth of about 50 feet, and approximately 1,000 feet long from the canyon of Bee Creek southwardly to a ravine which empties several hundred feet below the dam, a spillway might be obtained, which, with 10 feet of water on the dam, would pass a volume of water equivalent to a depth of 1 foot over the crest of the dam. The excavation would be solid rock, would probably cost $150,000, and is only mentioned as my attention was directed to the matter.

In this report I have made no attempt to determine the extent or estimate the cost of work to be done in reconstruction of the power house. Whether the head-gate masonry must be rebuilt, whether the penstocks and turbines should be lowered, whether two or three penstocks will not be sufficient in lieu of six, and whether the river wall of the power house should be more solidly rebuilt are questions that can be best decided by those who are familiar with all the details and who know the present condition of the plant and the cost of all the items involved.

One detail, however, should not be overlooked or neglected in any event. The tail race, by which water is discharged from the turbines, should be so directed that the

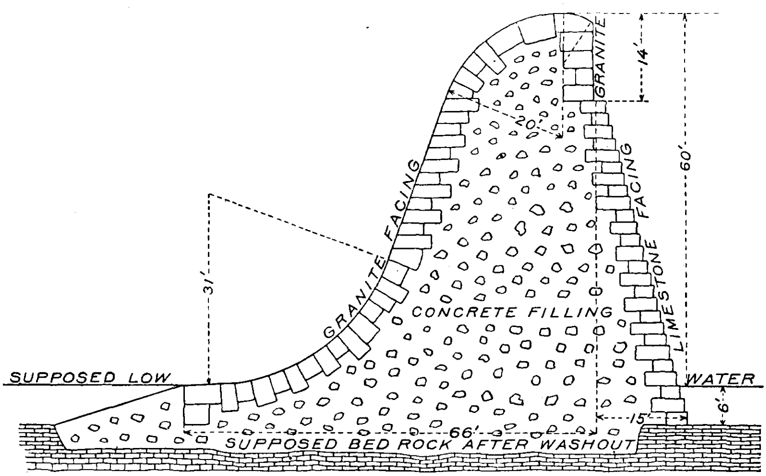


FIG. 23.—Foster's suggested cross section for rebuilding Austin dam.

current will not scour along the toe of the dam, thus endangering its stability, however carefully it may be protected.

In conclusion, I would say that the estimate herewith furnished is concurred in by my business partner, Mr. R. T. Creighton, who was present and assisted in all the examinations and measurements.

It will be observed that Mr. Foster concludes from his soundings that not only the foundation stone but part of the bed rock was torn up and washed away. It will be remembered that Superintendent H. C. Patterson, in a report to the water and light commission in July, 1900, said that "the original foundations were in no way damaged, and in all cases not less than 6 feet of the footing courses remained." The writer has made many soundings at the dam, the results of which have been confirmed by Mr. Foster's report.

Since the failure of the Austin dam the city has been operating its waterworks, electric-light plant, and other motors for commercial purposes with steam power. Beaumont oil has been used as a fuel for the greater part of the time. The fuel bill, with the necessary cleaning of boilers, has amounted to about $60,000 per year. This represents in round numbers the amount that the water power was saving the city per year. The most economical plan upon which the dam could be rebuilt would be to design a water-power plan to utilize the ordinary flow of the river, and to add an auxiliary steam plant of a capacity equal to the power that would be generated by an amount of water represented by the difference between the low ordinary flow and the minimum flow. In the face of the present fuel bills the rebuilding of the dam becomes an imperative economic and public necessity.

POWER DEVELOPMENT AT COLUMBUS.

A gaging station was established at Columbus, Tex., in December, 1902. The gage consists of a plumber's chain tagged every foot with a lead weight attached as a sounder. The zero of the gage is 50 feet below the top of the cylindrical pier under the southwest batter brace of the mid span of the highway bridge near the jail. The gage has also been marked off on this pier, reading to one-fourth of a foot. The observer at this station is W. E. Bridge, the sheriff of Colorado County, whose residence is within 300 feet of the gage. Measurements are made from this highway bridge, a cross section of which is shown in fig. 24. The section is not absolutely permanent, as the

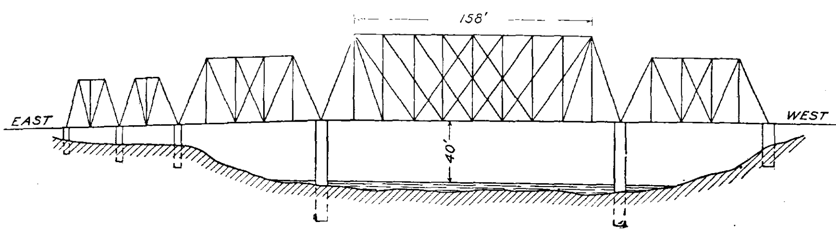


FIG. 24.—Cross section of Colorado River at Columbus.

river makes an immense bend just above the bridge, and while very few measurements have been made so far, these indicate that the bottom of the river is not permanent, but that its depth below the datum or bridge chord varies. The top of the horizontal chord on the downstream face of the bridge is 50.6 feet above datum.

At Columbus highway bridges cross Colorado River north and east of the town, about one-half mile apart in an air line and about 16 miles apart by the river. There is a clear fall of 11 feet in the river at low stages. Just above Prairie Street Bridge (the north bridge) is a riffle in the river where a dam could be located to deflect the water into a canal connecting points near the bridges. In 1887 W. R. Freeman, a civil engineer of San Antonio, made the following report in regard to the possible water power at Columbus:

I have made allowance accordingly and find that the minimum available power is 85 horsepower per foot of fall, with a certain thing on 100 horsepower at ordinary low water. The site chosen for the dam is at the top of the riffle, just above Prairie Street Bridge (north bridge), as it possesses many advantages over all others. The security of the dam and head-gates, if properly constructed, is assured at this point, while the expense of the structure is greatly reduced. The length of the canal would be 4,800 feet and the greatest depth 36 feet. To complete the dam, penstocks, and sufficient capacity of canal and tailraces to obtain 1,000 horsepower at the lower end would cost about $70,000, exclusive of land and right of way. With this construction the whole 2,000 horsepower can be utilized at any future time, when needed, by simply enlarging the canal. I have calculated on raising the water to obtain 20 feet fall, on building the dam of live oak on pile, on making the canal 30 feet wide at the bottom, and on fixing penstocks for six turbine wheels. I have made approximate estimate on three different lines of canal and three separate locations of the dam.

The cost of dam, canal, etc., is as follows:

Length of canal, 4,800 feet.	
Excavation, 208,000 cubic yards, at 20 cents	$41,600
Dam 300 feet long (live oak)	10,500
Head-gates	2,500
Penstocks and tailraces	7,500
Total	62,100

With 10 per cent allowance for contingencies the amount would be $68,310.

As to the damage from extreme floods, my estimates from the dam and head-gates are ample to provide for the necessary protection at the upper end of the canal, but I would recommend the construction of an intermediate gate to prevent any flood water from the sides of the canal from creating a current sufficient to produce scour on the sides. I have assumed that the material through which the canal is to be excavated is of such a character as to stand on an average slope of one-half horizontal to 1 vertical, and from what I have ascertained I have every reason to believe it will.

Having made a careful examination of the river for 6 or 7 miles above the proposed location of the dam, I am pleased to state that by raising the water to a head of 10 feet at the dam the backwater will only reach a point about 6 miles up the river, at which point I have established a monument. I also find that the banks of the river are abrupt for a height of about 25 feet the entire distance, thus obviating the possibility of flooding any private property of any kind.

CONCHO RIVER.

On the North Concho, in Sterling County, the McGee Irrigating Company built a dam in 1894. There are ten dams across the Concho in Tom Green County for irrigation purposes, the most elaborate of which is the Cunningham dam, near the site of the old town of Ben Ficklin.

The only two power plants in Tom Green County at present are located on the outfalls of the Baze and Bismarck irrigation ditches. The former belongs to Thomas Vinson, and is one-half mile north of Knickerbocker, on the Baze ditch. The water is furnished by the irrigation ditch, which is the feeder both of the irrigation system and of the power plant. The head on the turbine is 15 feet, and the length of tail race from the gin to the creek is 1,000 yards. It is estimated that 15 horsepower is developed by the 24-inch turbine, and this is used in operating the 70-saw gin. The cost of the whole power plant was $1,400. Pl. XIV is a view of Ben Ficklin Falls on the South Concho.

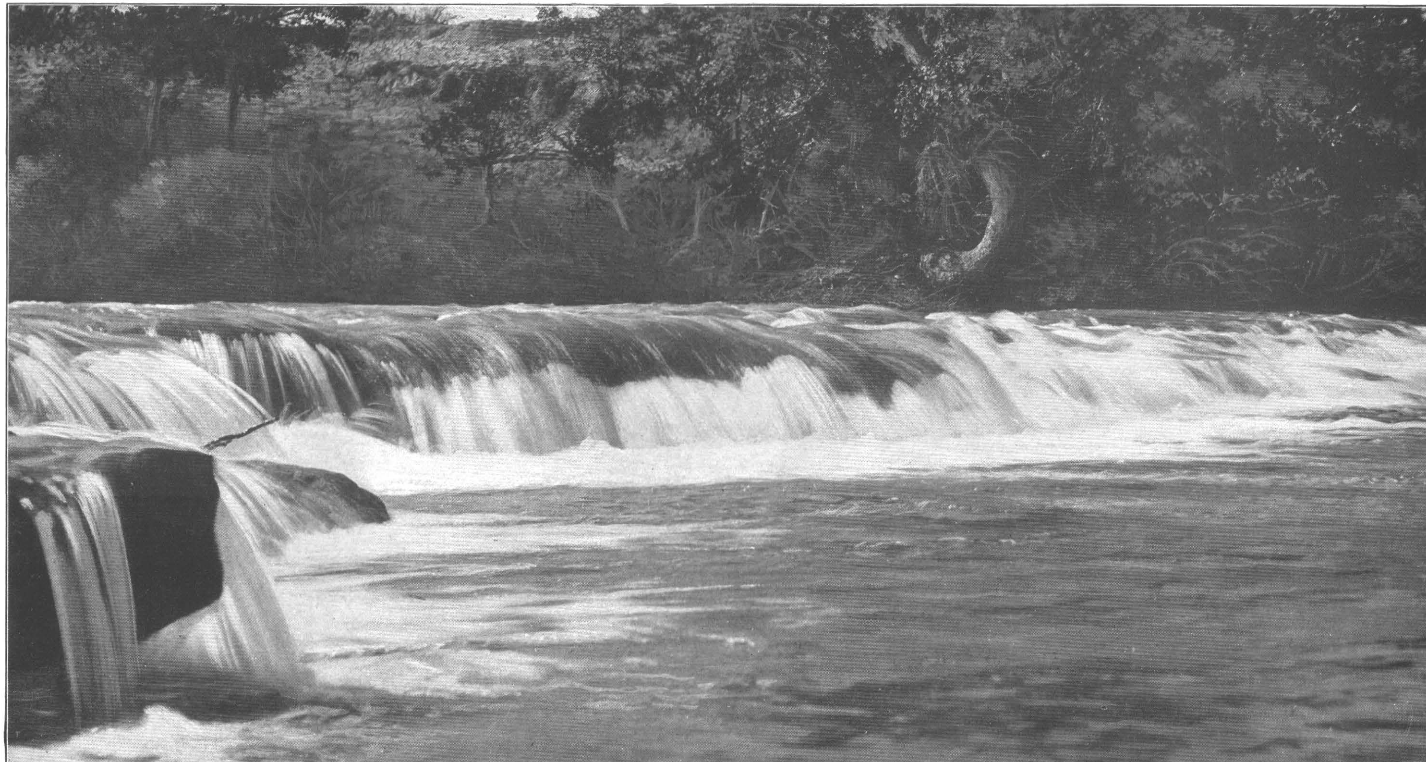
Ten miles south of San Angelo, on the Bismarck ditch that takes its waters from the South Concho, is located the power plant of Payne & Jones, which operates the Bismarck gin. The dam on the river that deflects the water to the ditch is 4 feet high and is built of cedar timber, brush, and stone. At the gin on the ditch there is a fall of 18 feet, but the turbine is an old-fashioned one and its efficiency is estimated at about 30 per cent. The plant is run ten hours per day during the ginning season.

Near San Angelo, on the main Concho, a dam was erected by the Concho Water Company, of which J. L. Millspaugh is manager. The dam was built of stone. The main part across the river proper consists of stone, which is to extend into the stone abutments. But early in 1903 a flood on the South Concho cut through the mill race into the river, throwing the flood around the end of the dam, thus changing the channel of the river. The length of the spillway is 166.5 feet and its height 11 feet, while the height of the massive stone abutments is 18 feet. The dam deflects the water into a canal 800 feet long, 15 feet bottom width, 25 feet top width, and an average depth of 7 feet. A head of 17 feet will be obtained at the power house at the lower end of the canal. The power generated is to be utilized in operating the waterworks, pumps, dynamos, and for irrigation purposes. The surplus power will be sold to power users in San Angelo.

Across Concho River, at Paint Rock, the county site of Concho County, 30 miles below San Angelo, a dam 4 feet high and 180 feet long has been constructed of stone and cedar posts. The dam belongs to the Paint Rock Water Company and was built in 1896. The power is used to operate the city waterworks, a mill, and gin. The wheel is a breast paddle wheel, 16 feet in diameter, and in addition to operating the gin it pumps water into a reservoir 42 feet above the town level. The water supply here is unfailing and is amply sufficient for all demands.

SAN SABA RIVER.

San Saba River rises in two springs near Fort McKavett, in the western part of Menard County, and flows in an easterly direction for over 100 miles to its junction with the Colorado. Between Fort McKavett and Menardville the river is fed by many springs, some of which are utilized for small irrigation plants before their waters join the San Saba. The largest of these springs, known as the Wilkinson



BEN FICKLEN FALLS, ON SOUTH CONCHO RIVER, TEXAS.

Spring, is situated above Menardville, on the farm of W. J. Wilkinson, and forms the headwaters of Clear Creek, a stream about 3 miles long. Its waters are partly utilized for irrigation, and there is enough water to irrigate 1,500 to 2,000 acres. A resident of thirty years states that the flow of this stream is slightly greater in summer than in winter. The discharge of Clear Creek as measured in the summer of 1902 was 25 second-feet, and the variation in flow is so very slight that its capacity for power or irrigation purposes would be practically constant.

Four miles above Menardville the Noyes ditch, 9 miles long, is taken out of the San Saba and deflects most of the normal flow. This ditch feeds the Noyes irrigation system above and below Menardville. Below Menardville the Sieker and Kitchen ditches are taken out of the river on the north side. They are described in Water-Supply Paper No. 71.

Twelve miles below Menardville the San Saba enters the canyon, which it traverses for 50 miles. The canyon finally widens into rich valleys at a point known as "The Narrows," 17 miles above the town of San Saba. In June, 1902, the San Saba at this point had a discharge of 25 second-feet, which can be relied on as the minimum flow, as practically no rain had fallen in the San Saba watershed for the two years previous. While the discharge at Fort McKavett is more than this, and while Clear Creek and the smaller streams double this flow above Menardville, the irrigation systems in Menard County practically take all the water at low stages. When this measurement of 25 second-feet was made at "The Narrows" the river was reported as not flowing above the mouth of Brady Creek. Twelve miles above San Saba the Sloan Spring emerges from the foothills of the Edwards Plateau. It has a capacity of 9 second-feet, and the water is utilized in one of the most effective irrigation systems in Texas.

The San Saba is at present almost undeveloped as a water-power stream. Its capabilities for power or irrigation rank with the best rivers of the State. Its reliable flow from Fort McKavett to its mouth marks it as a stream of great usefulness. Four miles east of Menardville on the main ditch is the water-power gin of Gus Noyes, where a fall of 23½ feet is obtained. Power is developed by a 23-inch Leffel turbine and is used in operating a gin of 150 saws and for a corn sheller. The whole flow of the ditch is used for power after the irrigation season is over. Forty-two horsepower can be developed by a flow of 20 second-feet.

On Mill Creek, that skirts the town of San Saba, there are two dams. This creek is supplied by four springs of constant flow. Their combined flow, as measured on December 18, 1901, was 10 second-feet. The dam is built of masonry, 15 feet high and 4 feet wide at top. The dam proper is 90 feet long, the right wing 60 feet long, the left 160. The original dam was built about 1856, but it has been repaired several times since its erection. A fall of 20 feet could easily be secured here. The plant is used for the water-supply system of the town. The spring from which the water is pumped has a flow of 3 second-feet, and it is located in the backwater or pond. To prevent contamination the spring is encased in a cement chamber, which is tapped by the 8-inch suction pipe.

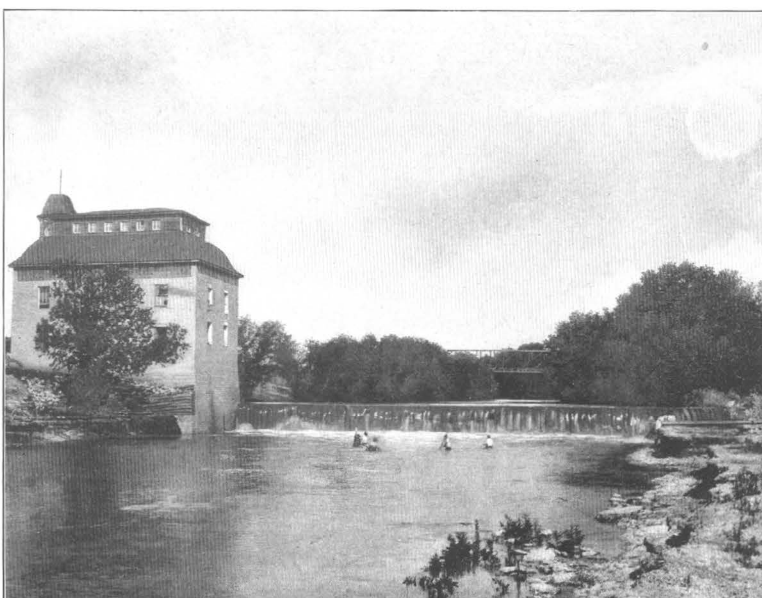
On the San Saba 8 miles above San Saba, near Bakers, the river makes a horseshoe bend, across the neck of which is a slough. By replacing the present dam with one 20 feet high, nearly double that amount of fall could be secured. The present plant is on the banks of the slough, above high-water mark. The original dam was damaged by the floods of 1899, but it has been renewed by a brush dam. The present plant develops about 30 horsepower by the use of a 26½-inch and a 33½-inch turbine.

LLANO RIVER.

The water-power plant of Walter Wallace is located in the suburbs of Junction City, in Kimble County, and receives its power from the South Llano. A small dam of loose stones deflects part of the water of the South Llano into the mill race. This race is about 3 feet long, 10 feet wide, and 4 feet deep, and generally carries about 2 feet of water. The power is generated by a 30-inch Leffel turbine under a head of 10 feet and is used to run a 70-saw gin and to pump water for the city supply. The water is pumped into a 6,000-gallon tank, 80 feet above water in race. The gin is located on the side of a bluff. The race terminates a flume 6 by 6 feet and 100 feet long, resting on cedar posts. The flume conveys the water to the masonry penstocks, where it is admitted to the turbine wheel. The tailrace returns directly under the flume for 60 feet and then deflects eastward into an excavated ditch connected with the river. The minimum flow of the Llano at Junction City is about 90 second-feet.

J. K. Finlay, of Llano, owns and operates two natural-power plants on Llano River 8 and 1½ miles, respectively, above Llano. At the upper dam there is a natural fall of 12 feet, the few cracks and crevices being planked. At the very lowest stages of the river this dam, with a reasonably good turbine, can develop 76 horsepower. At the lower dam there is a fall of 8 feet, and the plant is equipped with two 30-inch turbines. The lowest flow can develop 50 horsepower. At present only 20 horsepower is used in ginning cotton, grinding corn, and

A. DAM AT LLANO, TEX.



B. SWENSON'S DAM AND POWER HOUSE AT CLIFTON, TEX.

in polishing granite. A small outlay in constructing dams upon the top of these ledges could easily double the power. At Llano all the factors that enter into a successful water-power plant are present in their very best varieties. The river bed is formed of continuous granite, which in the central two-thirds rises in a turtle-back formation, the visible portion extending over 300 feet below and 200 feet above the dam. This leaves two channels on each side approximately 150 and 100 feet wide, the bottoms of which are 10 feet below the crest of the turtle-back formation. The first essential of a good water power, a foundation for the dam, is here in the very highest perfection. The very best rock, in a rough, irregular surface, with projections and depressions, extends from bank to bank. The central half could be constructed as easily as it could be done on banks, and then the two depressions near each bank would afford alternate gateways through which the water could be played from side to side while the work of construction was progressing. In addition to this, Llano is the very heart of the granite region, and good building stone could be obtained within 1 mile of the dam site. Thus a good foundation, ease of construction, and convenient stone all unite in inviting the increase of the water power of the river. The flow here at the ordinary low stages is about 76 second-feet, and a dam with an effective head of 24 feet could be easily constructed, thus developing at the very lowest stages 168 horsepower and 200 horsepower at ordinary low flow. By a judicious use of flashboards on the crest of the dam, and by utilizing the power only ten hours per day, and conserving it at night and on Sundays, the very lowest power could be increased to 475 horsepower.

A small dam (Pl. XV, *A*) has been utilizing the power of Llano River at Llano for several years. The two channels on each side of the turtle-back formation are dammed by wooden structures. The framework consists of a triangular brace of cedar posts bolted into the granite, and on these longitudinal purlins are spiked, forming a base for the facing plank. The wooden part on the south side is about 150 feet, while that on the north is about 100 feet. The general course of that part of the dam that covers the south channel and the granite hump is at right angles to the axis of the river, but the northern end deflects about 40° to bring the end of the dam into a granite ledge. The total length of the dam is about 600 feet, and at the power house on the right (south) bank is a head of 9 feet. The present power is developed by two Leffel turbines 40 and 44 inches in diameter. The plant supplies the city water system, the electric-light sytem, a polishing plant, and will soon run the Llano Milling Company's plant. The city water is pumped into an elevated standpipe, the bottom of which is 56 feet from the ground and 44 feet above the low-water level in the tailrace and 35 feet above the ordinary lake level. The capacity of the tank is 30,000 gallons, and the pumps are run all day. When pipes and tanks are full the safety valve is so adjusted that the water wastes through an automatic valve. The power will be conveyed to the flour mill by a cable from the power house. The motor for the polishing plant is operated by a direct current, while that of the electric light is an alternating current. As a precaution against breakdowns and low water, an auxiliary steam plant is provided, which consists of a 50-horsepower engine and 55-horsepower boiler, but these have not been used since July, 1899, when the exceedingly low water stages of the Llano and Colorado almost stopped the turbines at the Austin dam, the water level in Lake McDonald sinking to 10 feet below the crest of the dam.

CHEROKEE CREEK.

The mill of J. T. White is located near Cherokee, San Saba County, 1 mile below the crossing of the road from Llano to San Saba. The dam is a substantial stone structure, 90 feet long, 4.5 feet high, and deflects the water into a race 3 feet wide at bottom, 6 feet at top, and 111 rods long. It backs the water one-fourth mile. The plant was built in 1895, and is located about 600 yards from the dam. The effective head is 12 feet. The stream is supplied by springs about 2 miles above the dam, the largest of which is known as Heck Spring. The supply often is so low that there is not enough water to operate the mill. A small dam for irrigation purposes has been constructed near the head spring.

BRAZOS RIVER.

Brazos River rises in the Staked Plains, in Hale and Lamb counties, and takes a southwesterly course for 100 miles and then turns to the left and takes a general easterly course for 100 miles to Young County, where it again assumes its southeastern course, which it maintains to the Gulf of Mexico, a distance of 350 miles. In its upper stretches, above Young County, it flows through flat plains and has maintained an unreliable flow for power purposes. The two branches, Salt Fork and North Fork of Double Mountain River, unite in the eastern part of Stonewall County, and 100 miles below they receive the waters of Clear Fork.

Summary of water-power plants on Brazos and tributaries.

Locality.	Owner.	Head.	Material of dam.
		Feet.	
Eliasville	Donnell Bros	6	Stone.
Towash	B. M. Boyd	7	Wood.
Clifton	T. O. Swenson	10	Stone.
Belton	Smither	11	Wood.
Lampasas	Water Co	18	Stone.
Do	W. T. Donovan & Sons	11	Wood.
Do	Bradley Bros	10	Do.
Summer's	Summer	10	Stone.
Salado River	Cotton gin		
Do	do		
Do	Stinnett	18	
Jonah	McDonald & Bruce	9	Cribwork.
Georgetown (6 miles east)	J. F. Townes	16	Framework.
Georgetown (3 miles west)	D. A. Strange	16	Masonry.
Straws Mill	C. H. Straw	8	Timber.
Pidcoke	Mrs. L. J. Rogers	9	
Acton	McWharton	7	Brush and rock.
Quito	J. A. Allison	9	Dirt.
Snow	M. F. Bates	6.5	Timber.

Railroad bridges over Brazos River.

Name.	Distance above mouth.	Elevation of top of tie above mean low tide of Gulf.	Location.
	Miles.	*Feet.*	
Gulf, Colorado and Santa Fe Rwy	75.3	69.5	Thompson.
Southern Pacific R. R	99.5	92.9	Richmond.
San Antonio and Aransas Pass Rwy	133.3	120.7	
Missouri, Kansas and Texas Rwy	151.5	135.5	
Houston and Texas Central R. R	208.0	185.5	
Gulf, Colorado and Santa Fe Rwy	272.5	216.5	
International and Great Northern R. R	336.1	292.8	Lewis.
Missouri, Kansas and Texas Rwy	424.2	414.0	Waco.
St. Louis Southwestern Rwy	424.3	416.5	Do.

McWharton's mill is located on the Brazos, in Hood County. The dam is 300 feet long and is made of brush and rock. It was constructed in 1887 and produces an average head of 7 feet. The power is developed by a 32-inch Leffel turbine and is used in grinding corn and ginning cotton four or five hours a day.

About 6 miles south of Whitney, Tex., B. M. Boyd owns a flour mill, which is operated by the water power obtained from a dam across Brazos River. The river at this point has a vertical bluff on the north side about 50 or 60 feet in height, and in a gap in this bluff and at a safe distance above high water is located the mill. The dam is 300 feet long, is constructed of cedar timber and brushwood, rock, and gravel, and rests upon the solid limestone bed of the river. The cross section is triangular in shape. The dam is composed of a foundation layer of logs placed lengthwise, brush and stone spread over this, then a layer of logs placed crosswise, and brush and stone upon this, then another course of logs lengthwise, and more stone and gravel, etc., until the top is reached. The top surface of the dam slopes backward to the foundation and makes an angle of about 20° with it, and a liberal backing of stone and gravel is deposited upon it within a few feet of the crest, which effectually prevents leakage. Iron pins are let into the bed rock at the toe of the dam to prevent sliding. The height is about 7 feet and the width at the base about 20 feet. The junction with the shore on the south side is made by means of a bulkhead or abutment of log cribbing and on the north side by means of limestone masonry. The power is developed by means of two Leffel turbines, a 44-inch and a 48-inch, each of which develops 25 horsepower with the 7-foot head obtained. It is possible to add at least another 3 feet to the height of the dam and thus obtain a 10-foot head, without backing the river up over its banks, and it is probable that the owner will attempt this and add to his equipment in the near future. The dam was first constructed in 1856, but has been partially washed away and rebuilt several times since then.

The feasibility of constructing a dam across the Brazos at or near Waco has often been discussed. At the suspension bridge the southwest bank is composed of limestone, while the northeast bank is an alluvial deposit. The width between bank crests is a little over 500 feet, and a dam to be at all safe would have to be this length or over, with protecting wing walls. The sand is of unusual depth, and it would require an excavation through the sand bed nearly 20 feet deep at places to reach bed rock. Then to obtain a head of 30 feet the dam, if constructed near the suspension bridge, would have at some places a height of at least 50 feet.

A gaging station was established at Waco in September, 1898. The gage consists of three inclined iron bars 1 by 3 inches, the first reading from zero to 4.3, the second from 4.3 to 11.0, the third from 11.0 to 18. The gage is under the suspension bridge, bolted to a hard-pine stick 16 feet long embedded in cement in the limestone of the bank, flush with the surface, on which are painted the graduations below 4.3. The inclination is such that 5.4 feet along the bar corresponds to a rise of 1 foot. Above this bar is the second bar, similarly bolted and located, except that it is inclined at a greater angle; 9 feet along the bar corresponds to a rise of 4 feet. The lower end of this bar connects with the upper end of the lower one and is graduated to 11 feet. On the third section 1 vertical foot equals 1.3 along the bar. The reference bench mark is on the water table of the brick abutment of the suspension bridge at the south end and is almost on a level with the floor of the bridge. This bench mark is marked "U. S. G. S. 44.33 B. M." For high water the gage is marked on the south abutment of the bridge. In the early part of 1902 a new camel-back truss of one span of 18 panels was erected across the Brazos a few hundred feet above the suspension bridge, whose axis makes an angle of 76° with the river. This new bridge has a footway on the downstream side that affords excellent facilities for measuring the flow of the river, as there are no midstream piers to render measurements troublesome or doubtful. On the north pier a gage has been marked off to agree with the United States Geological Survey gage under the suspension bridge. The top of the cement floor of the new bridge at the southeast batter brace is at a height of 45.4 feet with respect to the United States Geological Survey gage. The gage is tied into the Coast Survey system of precise levels. The Coast Survey bench mark is at the corner of Third and Jackson streets, near the south window in the west side of Patten's store, 2 feet south of the window and 4 feet above the ground surface. The elevation of this bench mark is 413.20 feet above mean low tide and 55.60 feet above zero of gage, making zero of gage 357.60 feet above mean low tide.

The Brazos reached the lowest flow of its recorded history in March, 1902. On December 28, 1901, the river reached the low stage of 2.3 feet, and several measurements were taken at this stage to determine what was thought to be the lowest flow of the Brazos. The average of these measurements was 70 second-feet. During the months of January and February the water kept falling slowly.

From January 1, 1902, to March 7 the water slowly fell till it reached the gage height of 2 feet. On March 8 a measurement was made of the river at a point 200 yards above the new bridge. The water was then flowing through a small channel on the south side of the river bottom that was 24 feet wide and of an average depth of 7 inches and had a mean velocity of 1.36 feet a second, giving a discharge of 19 second-feet.

A cross section of the Brazos at Waco, at the suspension bridge, is shown in fig. 25.

The following tabular statement will show the minimum, mean, and maximum flow of the Brazos at Waco since 1898.

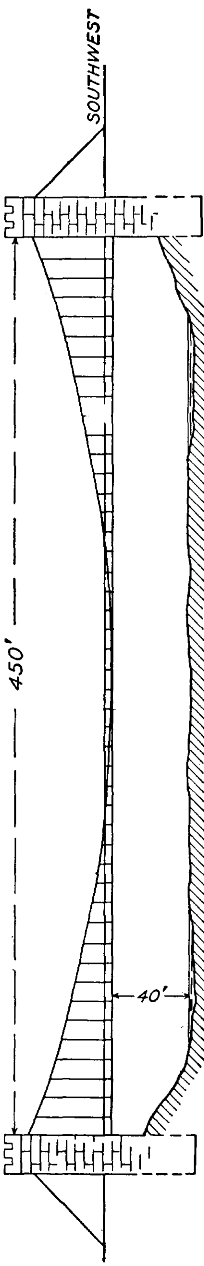


FIG. 25.—Cross section of Brazos River at Waco.

Discharge, in second-feet, of Brazos River at Waco.

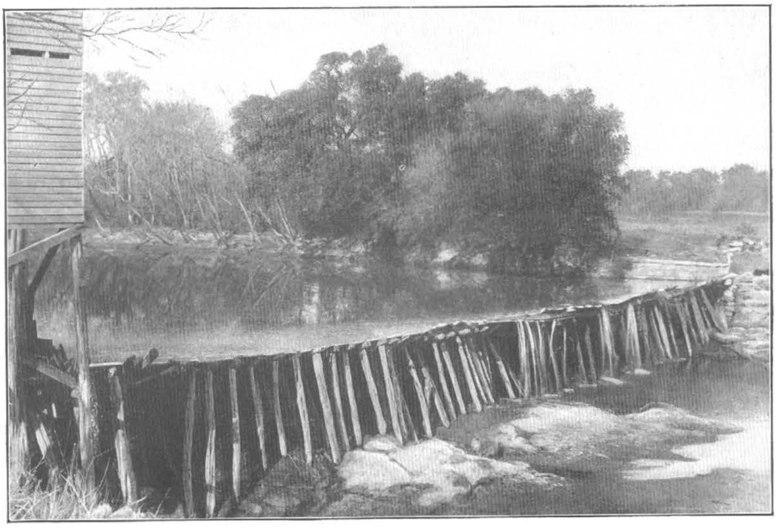
Year.	Maximum.	Minimum.	Mean.
1899	77,076	26	3,025
1900	98,832	315	5,755
1901	38,017	61	836
1902	74,600	20	2,694
1903	65,000	120	1,360

The flow of the Brazos of Waco since 1899 is shown in figs. 26 to 30, inclusive.

The natural configuration of Brazos River at Marlin Falls (Pl. XVI, *A*) makes it possible to utilize the full power of the water by a low dam and a deep fore race. A low wooden dam could be used to deflect the water into the mill race, and at the same time a dam of this height would not give sufficient fall over it in time of flood to scour out the river below the dam. Just below the falls McCullough Slough enters the river from the north, and this could be converted into a tailrace with a fall of 6 inches. The power plant could be located on the bank of this slough about 1 furlong from the river bank. The feeding canal could be excavated from the dam to the power site, while the convenient slough would save the expense of digging a tailrace to the river. Within a half mile the river has a natural fall of about 10 feet, as shown by the survey of the War Department engineers, and a dam 10 feet high would give an effective head of 20 feet. At ordinary low flow this would give 240 horsepower.

The drainage area of the Brazos above Richmond is 44,000 square miles. A gage was established here in December, 1902, by the writer. The gage consists of a tagged plumber's chain marked every foot with

A. MARLINS FALLS ON BRAZOS RIVER, TEXAS.



B. BRADLEY DAM, NEAR LAMPASAS, TEX.

brass tags. The chain is 50 feet long, the bottom of the lead weight being the 50-foot mark. The zero of the gage is 50 feet below the

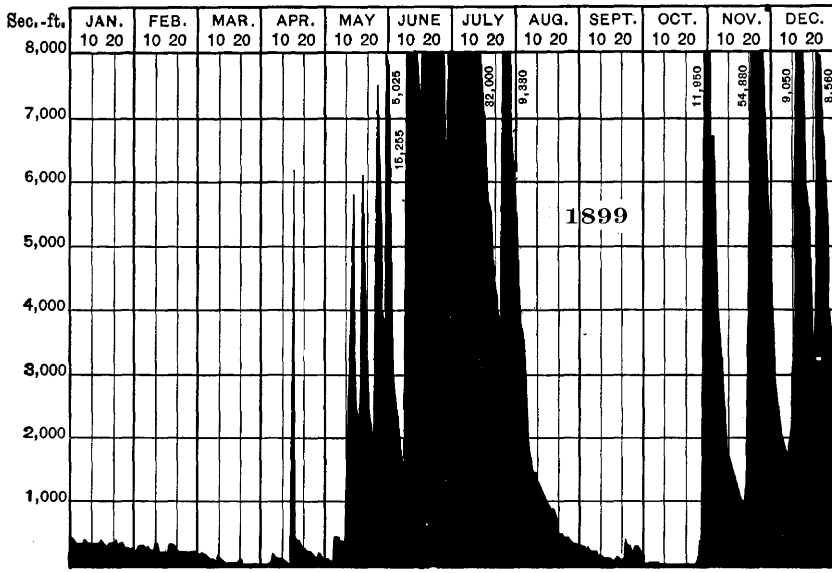


FIG. 26.—Discharge of Brazos River at Waco, 1899.

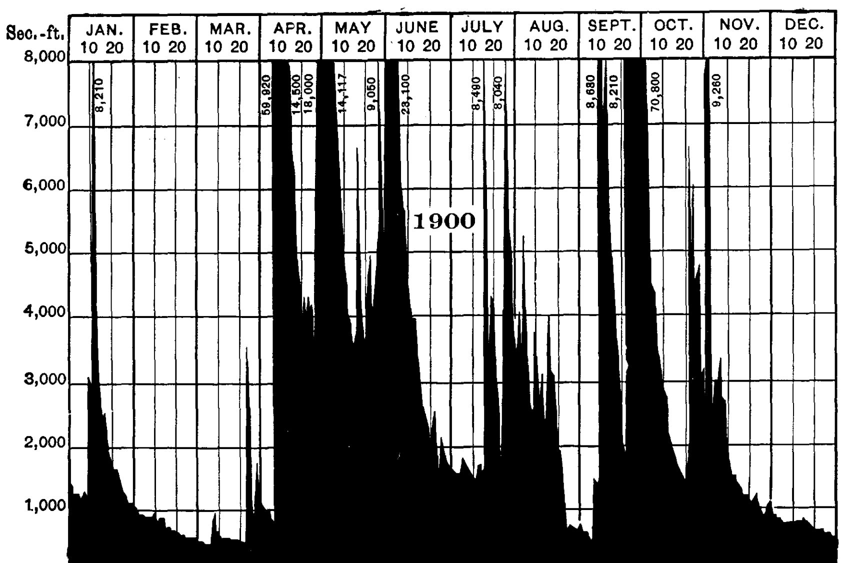


FIG. 27.—Discharge of Brazos River at Waco, 1900.

top of the guard rail in the middle of the sixth panel of the mid-span (counting from the west) of the Southern Pacific Railroad bridge.

The elevation of the top of the tie with reference to mean low tide, according to the War Department survey, is 92.9 feet, and that of the

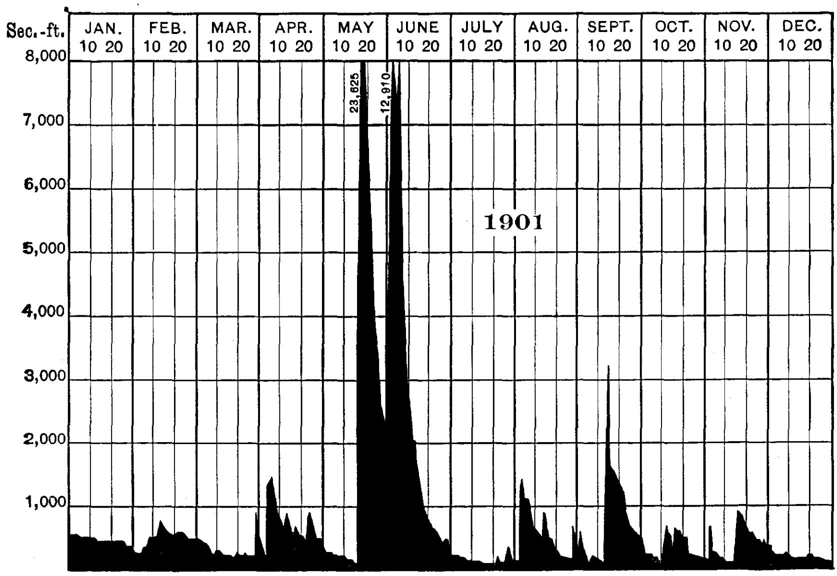


FIG. 28.—Discharge of Brazos River at Waco, 1901.

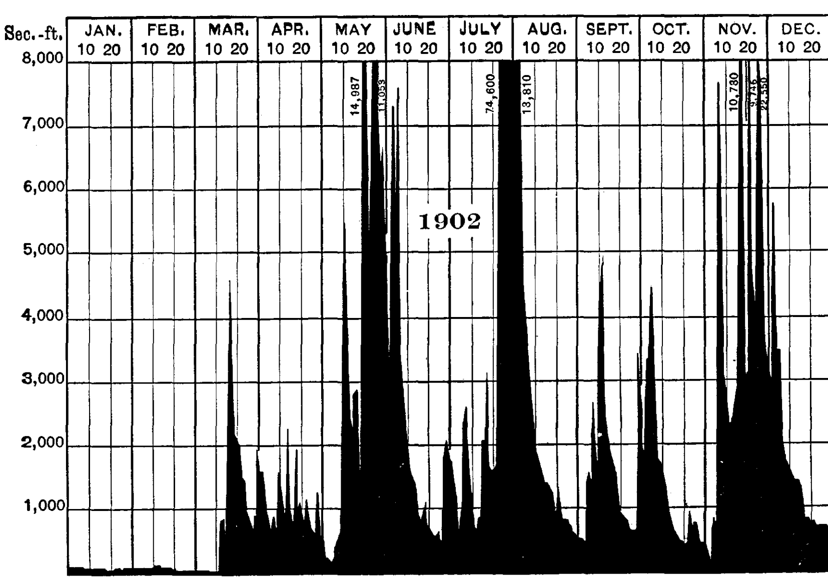


FIG. 29.—Discharge of Brazos River at Waco, 1902.

top of the guard rail 93.2 feet, thus making the zero of the gage 43.2 feet above mean low tide. The lowest gage height yet recorded is

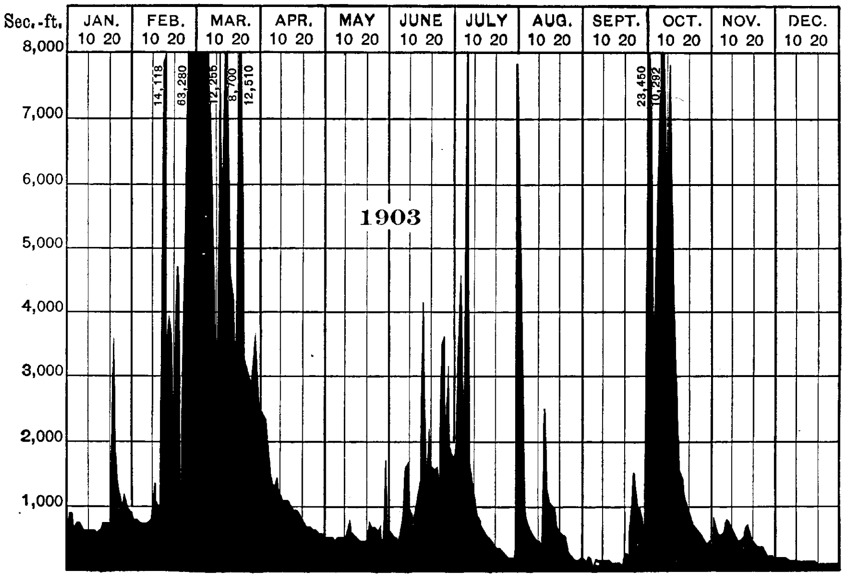


FIG. 30.—Discharge of Brazos River at Waco, 1903.

1.80, or exactly 45 feet above mean low tide. Fig. 31 shows a cross section of the Brazos at Richmond.

Estimated monthly discharge of Brazos River at Richmond in 1903.

[Drainage area, 44,000 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
January	21,125	3,460	5,580	0.127	0.146
February	48,000	3,540	16,200	.368	.383
March	64,000	13,900	36,000	.818	1.022
April	11,800	3,540	6,020	.137	.153
May	7,000	3,040	3,620	.082	.094
June	4,980	2,880	3,500	.079	.088
July	14,100	1,650	3,750	.085	.098
August	37,000	1,810	9,680	.220	.025
September	1,760	1,195	1,425	.032	.036
October	16,600	2,045	5,240	.119	.137
November	1,860	1,195	1,500	.034	.038
December	3,480	1,020	1,480	.034	.038
The year	64,000	1,020	5,400	.123	2.258

Above and at Waco the Brazos rises rapidly, and when it gets above the 30-foot mark on the Waco gage it overflows the bottom lands below that town. When the flood spreads out over the bottom lands, as it does from Waco to Richmond, the water is high longer in the lower stretches, as the backwater in the bottoms and low lands serves as storage reservoirs and is drained slowly as the river recedes. Above Waco the surface water rushes off into the stream more rapidly; the river rises more suddenly and falls almost as suddenly. For this reason the maximum discharge at Waco may be greater than at Richmond. The maximum height at Richmond occurred on July 7, 1899, and was 4 feet below the top of the guard rail, or at a gage height of 46 feet, according to the United States Geological Survey gage. The water was out over the bottoms at and above Richmond, and it covered the tracks of the Southern Pacific Railroad.

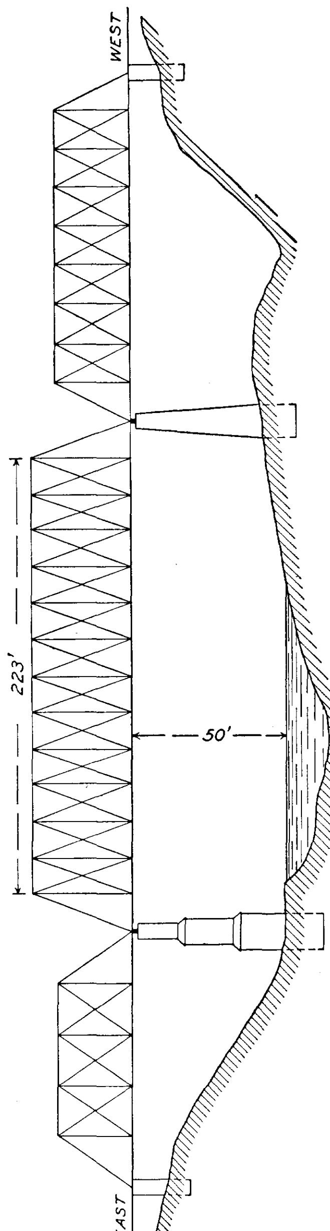


FIG. 31.—Cross section of Brazos River at Richmond.

CLEAR FORK OF BRAZOS.

On Clear Fork, in the southern part of Young County, near Eliasville, a power plant is owned and operated by the Donnell Brothers. The dam is situated about the middle of a rounded bend in the river and backs the water about 2½ miles. The width of the bed of Clear Fork is about 150 feet. In the irregular bed of the river deep rock holes occur, alternating with shoals. Some of these shoals give a fall of as much as 6 feet in a distance of 300 feet, while others give only an inch or so. There is a fall of perhaps 30 feet from the dam to the mouth of the river, a distance of 9 miles. The flow of Clear Fork is very irregular; it is often bank full, but seldom overflows. The river is not supplied by many springs, and it falls fairly rapidly when rain ceases. It usually falls to a flow of about 20 square feet cross section on shoals, and when dry weather continues will stop flowing altogether in four months or thereabouts. It has not quit running since 1880. The Eureka dam is built of sandstone slabs 6 by 2 by 6 feet long and is 120 feet long and 6 feet high. At first the lower face was left vertical, but so much pounding occurred from drift logs that a timber apron was put in with a slope of one to two. This rock bed of the river is about 6 inches thick, underlain by hard blue clay. The swiftness of the current eroded the bank on the north side of the river, and to prevent the waters going around the dam a great quantity of brush and logs was piled in and proved successful in preventing erosion. In very high water the dam is invisible. The current is hardly swifter on crest than elsewhere. For a while the mill was an ordinary crusher mill for wheat and corn, run by an overshot wheel. About 1888 patent roller machinery was added. Although often forced to shut down by low water, the mill has paid well. A cotton gin, of recent construction, is run by steam, and doubtless an auxiliary steam plant will be put in for the mill.

PALUXY RIVER.

The Paluxy rises in Erath County and flows southeast through Hood and Somervell counties to its junction with Brazos River. Formerly an excellent power plant was in existence on the Paluxy at Glenrose, but it was washed away five years ago and has not been rebuilt.

BOSQUE RIVER.

On North Bosque River, at Clifton, Bosque County, T. O. Swenson owns and operates a flour and corn mill that derives its power, except in dry times, from the water of the Bosque. The dam is of stone, 195 feet long, 10 feet high, and was built in 1867, at a cost of $5,000. The water is backed up the river for 1 mile. The power is generated by two Leffel turbines of 30½ inches diameter, and when running at three-fourths gate opening can develop 35 horsepower. To guard against dry seasons and low stages of the river, an auxiliary steam plant of 30 horsepower has been installed. A view of Swenson's dam and power house is shown in Pl. XV, *B*. The Bosque near Waco is subject to sudden and great fluctuations in flow. In very dry years it ceases to flow near its junction with the Brazos.

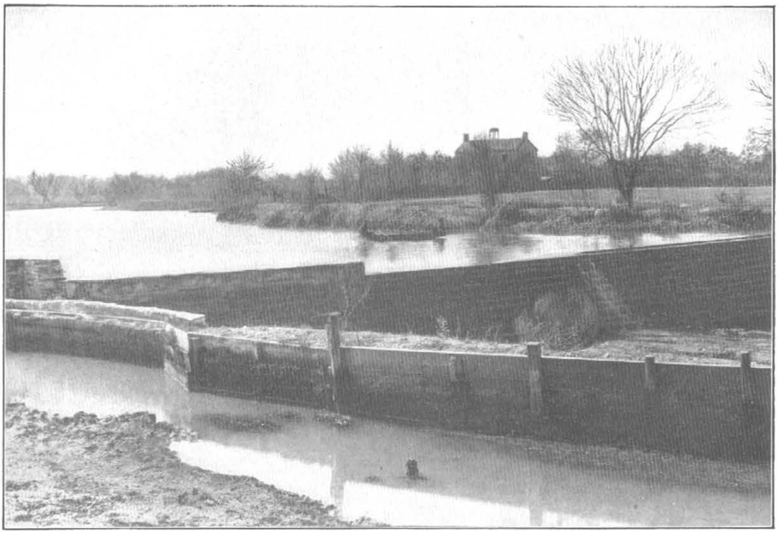
LEON RIVER.

Leon River rises in Eastland County and flows through the counties of Comanche, Hamilton, Coryell, and Bell before it empties into Little River, a tributary of the Brazos. A short distance above Belton it receives the waters of Cowhouse Creek.

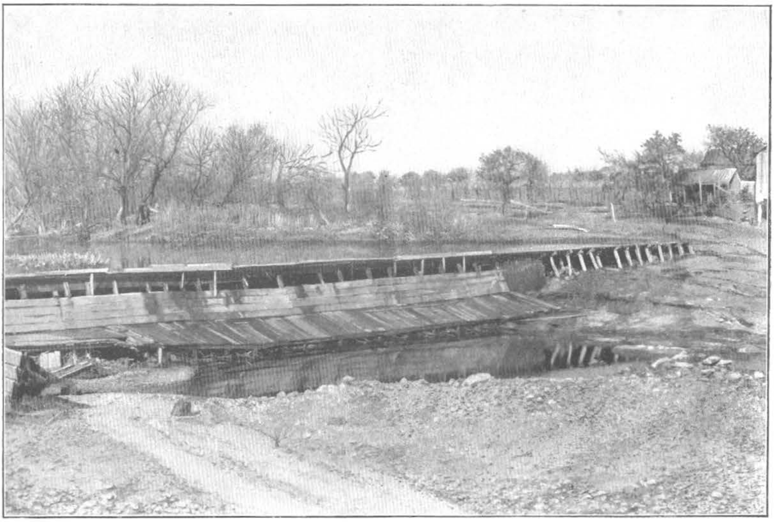
The mill of Charles H. Straw, at Straws Mill post-office, Coryell County, is on Leon River. The dam is 90 feet long and was built of lumber in 1874. One 48-inch Leffel turbine generates the power under a head that varies from 4 to 8 feet, with an average of 6 feet. Twelve horsepower can be developed. An auxiliary steam engine of 40 horsepower is used to supplement the water power.

The mill of Mrs. L. J. Rogers is located near Pidcoke, in Coryell County, on Cowhouse Creek. The dam is 110 feet long and has an average head of 9 feet. One 22-inch Leffel turbine is in use.

The flow of the Leon at Belton is utilized by the electric-light plant. The dam was built in 1894 and is somewhat unique in its construction. Its ends extend to the abutments of the highway bridge, and its race or forebay extends under the end approach of the bridge adjacent to the west abutment. It is in its plan arched upstream, the radius of its curve being 240 feet, giving it a rise of 12 feet in its span of 150 feet. The framework was made of cedar posts, and it was then covered with pine plank. The main purlin posts that carry the upper face are inclined to the horizontal at an angle of 45°. These purlin posts are braced from near their top by posts that are inclined to the vertical at an angle of about 10°, and the purlin posts are again braced by a series of short posts about 3 feet from the bed rock. Horizontal braces connect these two main supports of the purlin posts. To this framework is attached the framework of the apron. A row of short vertical posts, 3 feet high, extends in a circular curve 7 feet below the main dam, and to this the top row of post sleepers are attached and connected to the framework of the dam. These sleepers slope downstream and form the support for the flooring of the apron. The main cross section of the dam is like the letter A, the first line of which is inclined 45° and the right line about 80° to the horizontal, while the horizontal line is about one-fourth of the height from the bottom. A course of plank was nailed to the upstream posts, and then a layer of gravel, dirt, and small stones was spread on this surface, and then the upstream face was again protected by several layers of plank. The downstream face, the apron, and the vertical fall below the apron are all protected by plank coverings. The total height is 12 feet, the fall from crest to apron 7 feet, the fall of apron 1 foot, and the final fall from apron 3 feet. The water is taken from the lake through an arched conduit between the west abutment and the shore. This conduit opens into an open flume 11 feet 8 inches wide and 80 feet long. The flume follows the west bank and is supported on posts that are thoroughly protected from the effects of floods by strong sheathing. The fall at the penstock is 11 feet, and the power is transmitted to the dynamos by shafting. The power house



A. DAM AND RACE OF ELECTRIC PLANT, LAMPASAS, TEX.



B. DONOVAN DAM, NEAR LAMPASAS, TEX.

is on the high west bank and is equipped, in addition to the water plant, with two tubular boilers having an estimated capacity of 100 horsepower each and one automatic Russell engine of 80 horsepower.

LAMPASAS RIVER.

Sulphur Fork of Lampasas River rises in the city of Lampasas and is formed by two springs, the Hancock and the Hanna. The Hancock spring is about 1 mile S. 30° W. from the court-house, and its flow, as measured on December 18, 1900, by current meter, was 10.3 second-feet. The measurement was made just below the ford and about 400 feet below the bath house at the spring. The dam of the electric-light plant, which is a little over half a mile below the spring, backs the water up to within 200 yards of the spring itself. The flow of the spring, as stated by the citizens, is reliably constant.

The Hanna spring is about one-fourth of a mile N. 20° E. from the court-house and almost on the opposite side from the Hancock. It rises in a large pool, 60 feet in diameter, which has been constructed of stone and cement. The water flows out of the pool over an inclined apron and can be diverted to the large bath house near by. The stream formed by the spring has been diverted from its original channel and is conveyed partly underground for over 200 yards, but at certain places the stream is visible through boxes placed in its course, the sides of which project above the surface. At one of these boxes the flow of the Hanna spring was found to be 4 second-feet on December 19, 1900. The Hanna spring is strongly impregnated with sulphur.

The waters of the springs are utilized by various power plants. There are three dams across the stream within a mile and a half of Lampasas. The electric-light plant (Pl. XVII, *A*) is in the suburbs of Lampasas and has a stone dam, which has a height of 18 feet above foundation bed and 14 feet above the river bed and is 150 feet long. The water is conveyed by a race nearly 300 yards long to the power house, where a fall of 14 feet is obtained. The waters above this stone dam are held back during the day and used only at night, but the lake above the dam fills up and the water begins to flow over the dam shortly after midday. A judicious use of flashboards would render more power available. A flow of 1 cubic foot of water with an efficiency of 75 per cent would give a continuous horsepower of $1\frac{1}{2}$, or a total of 12 horsepower used continuously, or a total of 28.8 if used for only ten hours during the day and held back for fourteen. An auxiliary steam engine is used at the power plant when heavy demands are made for power.

The second dam (Pl. XVII, *B*) belongs to W. T. Donovan & Sons and is about three-fourths of a mile below the stone dam. It is an old-fashioned wooden dam, 120 feet long, and gives a fall of 11 feet. Triangular frame bents are constructed with the inclined braces upstream. To these braces sheeting is nailed, which forms the upstream face of the dam. With a good hydraulic wheel 1 second-foot of flow should give 1 horsepower at the dam. The power is used here by the Donovan flour mill, but the flow of the stream is under the control of the upper dam to such an extent that a gasoline engine is used as an auxiliary.

The lower dam (Pl. XVI, *B*), about 1 mile below the Donovan dam, belongs to Bradley Brothers. It is a wooden structure, composed of cedar-post framework, the upper brace of which is inclined at an angle of 45°, while the lower is nearly vertical. These posts are bolted into the bed of the stream, and the upper face is covered with planks. To sustain the water pressure the upper inclined purlin posts are braced with a short brace a few feet above the bottom. The north end of the dam terminates in a substantial masonry bulkhead, that serves to prevent cutting around the end in times of high water. The plant is on the south bank of the river and consists of a gristmill. The fall is 10 feet, and the power is developed by a turbine.

SALADO RIVER.

Salado River rises in the famous Salado springs, in the town of Salado, 9 miles south of Belton. These springs are similar in source, behavior, and character of water to those of San Marcos, Del Rio, and other places. In December, 1901, the discharge at the site of the old stone dam in the town was 13 second-feet. The stream below the town is often rather deep and resembles in all its characteristics except magnitude of flow the San Marcos. At present there are four power plants on the Salado. Two miles above the mouth is located Summer's mill. The dam is built of stone masonry, is 175 feet long and 10 feet high. The power is generated by two Leffel turbines, 30 and 32 inches in diameter. The head is 10 feet and the gate opening is one-half. In winter the mill is operated twelve hours a day and in summer twenty-four hours a day. A 20-horsepower steam engine is kept ready in case of necessity, but it is seldom used.

Six miles above the Summer mill is located the Stinnett mill. The 3-foot dam is 1 mile above the mill and is used merely to deflect the water into the mill race. The power is generated by a 23-inch McCormick turbine under a head of 18 feet. The mill has all of the water privilege and it runs the entire year. Between these two mills there are two cotton gins operated by water power. In addition to these plants there are four possible locations where power plants could be located.

SAN GABRIEL RIVER.

At Jonah, about 10 miles east of Georgetown, is a flour and corn mill, owned by McDonald & Bruce and operated partially by the power derived from San Gabriel River. The dam is about 300 feet long and is constructed of timber framework with a top sheeting of 2-inch planks. It is triangular in section and is made up of a row of 6 by 6 inch upright posts, on the downstream face, let into the bed rock of the river a few inches and about 12 or 15 feet apart; a cap of 6 by 6 inch timber rests upon these posts and supports one end of the stringers, to which the top plank sheeting is spiked. These stringers slope upstream at an angle of about 30° to the horizon and the other end rests upon the river bed. Two-inch planks are bolted to these to form the upstream face of the dam. A head of 9 feet is obtained, and the power is derived from one 36-inch Samson turbine, and it is estimated that 50 horsepower can be developed with a full gate opening. A 35-horsepower steam engine is used in conjunction with the water power when the mill is run to its full capacity and during time of low water. The dam was built in 1890. The machinery is valued at $5,000.

About 6 miles east of Georgetown is the flour and corn mill of J. F. Towns, on San Gabriel River. The power is derived from one 26½-inch Leffel turbine and is estimated at 36 horsepower under the 16-foot head obtained. The dam is constructed of timber framework and a top sheeting similar to the one at Jonah, except that the posts on the downstream face are slightly inclined instead of being vertical, and there is no cap on the top of these to support the stringers for the sheeting. Each stringer rests on the head of a post, and the sheet planks are nailed directly thereon and lengthwise of the dam. The posts are about 8 feet apart, and a wooden sill embedded in concrete is placed the full length of the dam at the foot of these posts to prevent sliding. The dam is connected to the river banks on both ends by stone abutments. It is about 400 feet long and 6 feet high, and was first built in 1882. In 1892 it was rebuilt entirely as it stands to-day. The power house is located about one-fourth of a mile below the dam, and a head of 16 feet is obtained on the turbine. The water is conducted to the power house by a race. The cost of the plant, dam, machinery, etc., was about $8,000. At present the river is so low that the mill is not run, but when the water supply is sufficient it is run day and night.

About 3 miles northeast of Georgetown is a small corn mill owned and operated by D. A. Strange. The mill is situated on the banks of Bear Creek, but obtains its power from a spring, the water of which is backed up by a dam and forms a pond or small lake above the mill. The dam is built of limestone masonry, is of irregular section, and is about 150 feet long. In plan it is approximately trapezoidal in shape, and the mill is situated in the middle of the section at right angles to the river. The effective head is 16 feet, and with the 16-inch turbine 22 horsepower can be obtained. The mill is a very small concern, the machinery old and very seldom used.

NAVASOTA RIVER.

The Navasota rises in Limestone County and flows south to its junction with the Brazos. In extremely dry years it ceases to flow even near its mouth, but ordinarily it has a reliable flow. In Leon County are many small water-power sites. Some of these have been utilized, and there are several abandoned power plants. The mill of J. A. Allison is near the post-office of Quito, in the western part of the county, on the watershed of Navasota River. A long dirt dam 3 feet high impounds the water of Clear Creek. It is reported that the stream flows the year round. The mill race is one-half mile long, 16 feet wide, and 3 feet deep. The power is generated by one 17-inch Leffel turbine, under a head that varies from 8 to 10 feet, with an average of 9 feet, and produces 5 horsepower. The mill is generally run six hours a day. The plant was erected in 1880.

The mill of M. F. Bates is near Snow post-office, in the western part of Leon County, and is on Pigeon Roost Creek, a tributary of the Navasota. The dam is made of oak timber and is 9 feet high. A race 180 feet long, 12 feet wide, and 9 feet deep conveys the water to a double Leffel turbine 23 inches in diameter, which runs under a head of 6.5 feet, the least being 4 and the greatest 9 feet. When the wheel is run with full gate opening it produces 15 horsepower. The stream has a constant flow during the summer time, except when raised by rains. The plant was erected in 1902.

About 9 miles east of Marquez, in Leon County, T. J. Irwin owns and operates a water-power plant, which consists of a grist mill and cotton gin of 45 saws. The mill is on a small stream that runs into Navasota River, and the flow is continuous the year round. A high breast wheel 24 feet in diameter develops the power under a head of 22 feet. A small dirt dam 7 feet high, located 600 feet above the mill, deflects the water into the mill race and backs the water into a pond covering 1 acre.

SAN JACINTO RIVER.

San Jacinto River rises in Grimes, Walker, and Montgomery counties, flows south, and empties into San Jacinto Bay. Although the river is short, it often becomes very broad and swift. The waters are not used for power directly, but for rice irrigation. Two and a half miles east of Sheldon the Sheldon Canal Company takes water for 2,000 acres of rice from San Jacinto River by pumping against a 40-foot lift. A 300-horsepower Corliss engine operates an 18-inch Van Wie centrifugal pump. A complete account of this irrigation system is given in Water-Supply Paper No. 71, page 100.

On December 24, 1903, at the crossing of the Southern Pacific bridge, the San Jacinto had a discharge of 357 second-feet when the level of the water was 35 feet below the base of the rail.

TRINITY RIVER.

Trinity River rises in a network of small streams in Montague, Wise, and Parker counties, but the combined capacity of these streams at Dallas is not sufficient to keep up a constant flow. Below Dallas the Trinity flows through a wooded country, and is not subject to sudden floods. A gaging station was maintained on the Trinity at Dallas by the United States Geological Survey for several years, but it was abandoned on account of the low water. In December, 1902, a station was established at Riverside, on the Trinity. The station is at the drawbridge of the International and Great Northern Railroad, and the zero of the gage is 66 feet below the top of the tie on the north arm of the draw span. The elevation of the top of the pivot pier is 56.50 feet, according to the United States Geological Survey gage, and the elevation of the top of the channel of the lower chord of the draw span is 62.90 feet. According to the survey of the War Department engineers, the elevation of the top of the tie with reference to mean low tide of the Gulf is 148.7 feet. Fig. 32 shows the bridge and a cross section of the river at Riverside.

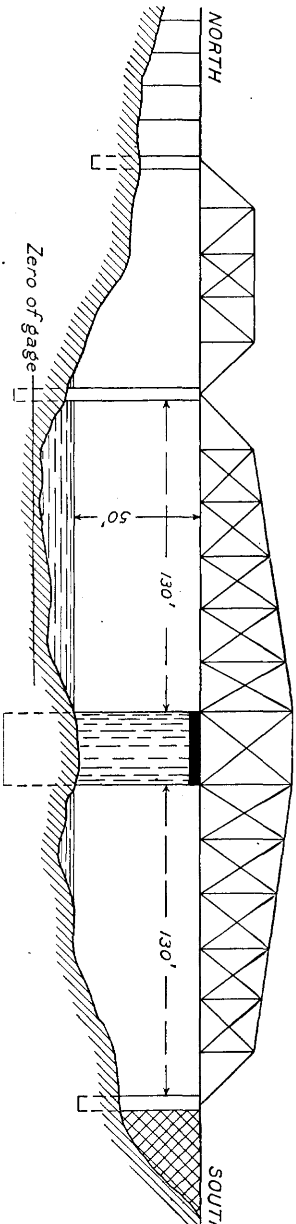


FIG. 32.—Cross section of Trinity River at Riverside.

Summary of plants in watershed of Trinity River.

Name.	Post-office.	Head.	Horse-power.	Material of dam.	Kind of wheel.
		Feet.			
R. A. Randol	Randol	10	12	Stone	Turbine.
J. R. Harrington	Brandon	8	10	Wood	Do.
W. J. Chaffin	Grapeland	22	4	Earth	Pitch-back.
J. C. Shelton	Athens	10	8	...do	Turbine.
C. F. Booth	Jacksonville	17	12	...do	Overshot.
J. D. Douthit	Concord				

Approximate location and elevation of railroad bridges over Trinity River.

Bridge.	Distance from mouth.	Elevation of top of tie above mean low tide.	Approximate elevation of low water above mean low tide.	Fall per mile.
	Miles.	*Feet.*	*Feet.*	*Inches.*
Texas and New Orleans R. R	40.9	30 to 35	1.0	4
Houston, East and West Texas Rwy	120.4	95 to 100	50.0	6
International and Great Northern R. R	188.3	148 to 153	90.0	8
Do	315.0	235 to 240	183.0	12
St. Louis Southwestern Rwy	397.9	320 to 325	264.0	
Texas and Midland R. R	462.8	[a] 340	302.0	14
Texas and Pacific Rwy (Dallas)	512.6	422	365.0	

[a] Approximate.

The mill of Robert A. Randal is on Trinity River, near Randol, Tarrant County. The dam is made of stone, is 100 feet long, and was built in 1887. The power is generated by one 40-inch Leffel turbine, under a head of 10 feet, and develops 12 horsepower. An auxiliary steam engine of 40 horsepower is used to supplement the water power. The power is used to run a flouring and corn mill.

CLEAR FORK OF TRINITY.

From 1860 to 1870 there were three flourishing water-power mills on Clear Fork of the Trinity above Fort Worth. Two of these were in Parker County, 10 and 18 miles below Weatherford, while the other was in Tarrant County, 20 miles below Weatherford, at the present post-office of Bear Creek. After the land was cleared and grazing more extensively practiced Clear Fork lost its capacity as a power stream. In the years alluded to the grass was luxuriant, springs issued from the foothills, and it was only on extreme occasions that the stream stopped flowing at Bear Creek. Now the conditions are reversed.

WHITE ROCK CREEK.

The mill of J. R. Harrington is on White Rock Creek, Hill County. The dam was constructed of posts and plank, in 1875, and gives an average head of 8 feet. One 27-inch Leffel turbine generates 10 horsepower when the stream flows.

MILL CREEK.

The mill of J. C. Shelton is 6 miles southwest of Athens, on Mill Creek, a tributary of Trinity River. One Ridgeway 20-inch turbine develops the power under a head of 10 feet, and it is used in running a gin, press, and gristmill. The mill is generally operated ten hours a day and develops 10 horsepower. The dam is 900 feet long and was constructed in 1860 out of plank, sand, and stone. The mill race is about 300 feet long and is 5 feet wide and 2.5 feet deep.

The mill of C. F. Booth is 5 miles southwest of Jacksonville, on Mill Creek, a tributary of Trinity River. The dam is 60 feet long, 8 to 10 feet high, and develops a head of 17 feet. The power is generated by an overshot wheel, and it is used to operate a 70-saw gin and a gristmill. The dam is located on the right of the Jacksonville-Palestine road, but the race, which is about one-fourth mile long, conveys the water under the highway to the mill on the south side of the road. Under usual conditions about 12 horsepower is developed.

BIG ELKHART CREEK.

The mill of W. J. Chaffin is 5 miles northwest of Grapeland, Houston County, on Big Elkhart, a tributary of Trinity River. A small dam is used to deflect the water into the mill race, which is one-half mile long. The main shaft in this mill was secured from an old wrecked steamboat on Trinity River, at Parker Bluff. The wheel is a "pitch back," or three-fourths breast, 23 feet in diameter, with 76 buckets or troughs, giving an effectual head of 22 feet. This wheel runs a 56-inch saw, a cotton gin, and a gristmill. The cotton press is run by water power by a shaft that connects with a 12-foot wheel, and the press rotates, instead of the usual practice. The flow of the stream as measured was 5 second-feet.

BOGGY CREEK.

Boggy Creek rises in the western part of Leon County, Tex., and flows east to its junction with the Trinity. There are several good mill sites on this creek. Formerly water-power plants existed at the present steam plant of Cox & Babb, 1 mile south of Middleton; at the Elisha Oden place, 8 miles south of Centerville; and at the Hayden site, 9 miles southwest of Centerville. The mill of J. D. Douthit is 11 miles south of Jewett, on the headwaters of Boggy

Creek. It consists of a grist mill and a 45-saw gin, which are operated by an overshot wheel 24 feet in diameter. The mill was built in 1860 and, while of small capacity, is still a factor in the milling work of its section. A dirt dam 20 feet high deflects the water into a race 1,200 feet long, 3 feet wide, and of varying depth.

NECHES RIVER.

Neches River rises in Van Zandt County and flows through the heavily wooded section of east Texas and finally enters Sabine Lake south of Beaumont. Its total drainage area above Beaumont is 10,200 square miles. Its largest tributary is the Angelina, but it receives many smaller streams in its course, and on account of its flowing through a heavily timbered section the flow of these tributaries, although small, is fairly constant, and many of them support small water-power plants. These are located in Van Zandt, Henderson, Angelina, San Augustine, Houston, Tyler, Polk, and Jasper counties. On September 10, 1902, about 100 yards below the crossing of the International and Great Northern Railroad, the Neches had a flow of 26 second-feet. At the time of measurement the water was clear of all sediment, but it had the organic tinge—the leaf-stain color—and white paper held beneath the surface a few inches assumed a decidedly yellow color. The people at Neches said that on the date of measurement the river was about as low as it ever got. The following is a list of the water-power plants in the watershed of Neches River:

Water-power plants in Neches watershed.

Owner.	Post-office.	Head.	Material of dam.	Horse-power.	Kind of wheel.
		Feet.			
Roher	Walton	20	Dirt	22	Overshot.
C. C. Chaffin	Grapeland	18	Earth		Pitch back.
Ferguson & Weisinger.	do	14	do	4	Overshot.
A. Tubbe	Nacogdoches	11	do	4	Turbine.
C. A. Gamble	Ironosa	10	do	6	
J. W. Langford & Son.	do	6	Brush and stone.	21	Turbines.
Jeff Bland	San Augustine	7	Earth	15	Turbine.
Do	do	13	do	26	Turbine and overshot.
J. Fonville	do	8	Timber	30	Turbine.
Horton Sheffield	do				
D. T. Meigs	Brookeland	6	Timber	15	Do.
Wood & McCall, Mgrs.	do	8	do	18	Do.
L. E. Jones		5	Earth	10	Do.

Water-power plants in Neches watershed—Continued.

Owner.	Post-office.	Head.	Material of dam.	Horse-power.	Kind of wheel.
		Feet.			
W. J. B. Adams	Jasper	10	Timber	4	
R. L. Pickle	do	8	Earth	15	Turbine.
K. J. Smith	do	8	do	24	Do.
Farrow (T. J.) & Ferguson.	Pace Ferry	8	do	20	Do.
L. P. Lewis	Chester	7	Earth and plank.	12	Pressure.
E. P. Wallace	Colmesneil	9	Earth	15	Turbine.
P. H. Fondreu	do	9	Earth and plank.	7	Do.
J. C. Harrelson	do	6	Timber	8	Do.
J. M. Wigley	Emilee	8	Plank	16	Do.
Ed. Wheat	Mobile	9	Earth	32	Pressure and scroll.
Bevil & Bullock	Woodville	10	do	20	Eclipse.
Nugent & Tompkins	Juno	7	do	8	Wood.
A. E. Pope	Hillister	7	do	12	Turbine.
J. N. Young	Kiam	8	do	15	Do.
Marion Davis	Charity	9	do	12	Buckhorn.
B. F. Collins	Dallardsville	5	do	6	Wood.
W. W. McKinnis	Spurger		do		Homemade.
J. O. Smith	Jasper	6	do	6	Turbine.
D. R. Dehart	do	5	do	4	Small wood.
E. H. Hopson	Smith Ferry	8	do	7	Wood turbine.
H. R. Cassels	Charity	5	do	3	Paddle.
S. D. Johnston	Knight	5	do	8	Do.

A gaging station was established on the Neches at Fords Bluff (Evadale), Jasper County, July 1, 1904. The river at this point has good banks, the water is deep and rather sluggish, and the banks are heavily wooded. Measurements are made from the bridge of the Gulf, Colorado and Santa Fe Railroad.

MILL BRANCH.

Roher's mill is located in the southern part of Van Zandt County, on Mill Branch, a tributary of the Neches. The head is reported as about 20 feet, the wheel an overshot, 23 feet in diameter. An earth dam deflects the water into a race about 125 feet long. The dam has proved reasonably permanent. The water is furnished by local springs.

PEDRO CREEK.

Four miles north of Grapeland, Houston County, the mill of C. C. Chaffin receives its power from Pedro Creek, a tributary of Neches River. A race 1,500 feet long conveys the water to the 18-foot "pitch back," or three-fourths breast wheel, which gives an effective head of 17 feet. The mill consists of a 50-saw gin and a gristmill.

One and a half miles east of Grapeland, on Pedro Creek, is the mill of Ferguson & Weisinger. The dam is made of dirt and is 250 feet in length and 14 feet high. The power is generated by an overshot wheel under a head of 14 feet. The capacity of the plant is 6 bales of cotton a day. The stream is formed of three good short branches, the longest of which is 2½ miles. The mill pond covers 7 acres, and the water can be stored and utilized during working hours.

DOVE CREEK.

The Dove Creek mill, operated by A. Tubbe, is on Dove Creek in Nacogdoches County. The dam is made of 400 feet of earth and a 36-foot section of timber, and was built in 1871. The head varies from 10½ to 12 feet, with an average of 11 feet. The power is generated by one 26-inch Leffel turbine, which is generally run at half its limit. The mill is run eleven hours a day, and can develop 40 horsepower. Three and one-half miles above the Tubbe mill is an excellent site for a mill, where a dam 12 feet high could be constructed.

BIG IRONOSA CREEK.

The Gamble mill is located on the Big Ironosa, about 5 miles above the Langford. It is owned and operated by C. A. Gamble, and used to run a 55-saw Pratt gin. The power is at present generated by a homemade 32-inch tub wheel, with a two-third gate opening, and its power is quoted as 6 horsepower. It is intended to add a new Leffel turbine. It is the second mill from the mouth of the stream and is northwest of San Augustine, in San Augustine County. The effective head varies from 6 to 11 feet, the average being estimated at 10 feet. The dam is built of dirt and rocks, is about 300 feet long, and was built in 1898. The mill pond covers about 50 acres above the dam. The flow of the stream is estimated at 6 second-feet.

On Big Ironosa Creek about 16 miles northwest of San Augustine, in San Augustine County, is the small gin and gristmill of W. J. Langford & Son. The gin is a 50-saw Pratt, and ordinarily gins about 175 bales of cotton a season. The gristmill runs two days each week. The power is generated by two old-fashioned homemade wheels. The larger is 4 feet in diameter and operates the gin, while the smaller, 30 inches in diameter, operates the gristmill. An additional wheel, a De Loach 30-inch turbine, has been added. The stream has a flow of about 15 second-feet, and the effective head varies from 5 to 8 feet, with an average of about 6. The dam is built of brush, mud, and stones, and has a length of about 30 feet. It was built about 1880. It has been badly damaged several times by floods, but has never been washed entirely away.

AYISH BAYOU.

The Jeff Bland mill, the third from the mouth, is located on the west branch of Ayish Bayou, in San Augustine County, about 5 miles north of San Augustine, on the line of the new railroad from Center to San Augustine. The power is used in running a small gin and gristmill. Formerly a sawmill was attached to the plant, but a 30-horsepower steam engine has been added to operate the saw. The flow of the stream is about 4 second-feet, and the head varies from 5 to 10 feet. The power is generated by a 20-inch Leffel-Sampson turbine, and the estimated capacity is 15 horsepower. The dam was built in 1895. Its length is 270 feet, and the mill pond covers about 20 acres. The mill is operated by Wade Arnold.

Jeff Bland's second mill is on the east branch of the Ayish Bayou, and is about 5 miles northeast of San Augustine. The flow of the stream is 3 second-feet. The power is generated by a breast wheel 20 feet in diameter, and is estimated to have a capacity of 26 horsepower. A Waddell overshot wheel 13 feet in diameter and a 23-inch Leffel standard turbine have been used at different times. The dam was built of dirt about sixteen years ago, is 300 feet long, and backs the water over 10 acres. The power is used in operating a gin and gristmill.

Horton Sheffield's mill is about 2½ miles north of San Augustine, on Ayish Bayou, below the junction of the east and west branches, on which are situated the Bland mills. The dam was in poor repair when seen in January, 1903. The water is used to run the gristmill, while a 15-horsepower steam engine is used to operate the gin. The flow of the stream is 8.5 second-feet at the ford, one-half mile above the dam. The mill site is on the new railroad from San Augustine to Center.

The mill of Jerry Fonville is about 5 miles south of San Augustine, on Ayish Bayou, and is the first from its mouth. The power is used in ginning cotton and grinding corn and in running a sawmill. The gin is a 60-saw, and generally puts up 275 bales a season. A measurement of the stream in January, 1903, gave a discharge of 17 second-feet. The power is generated by a 40-inch Leffel-Sampson turbine under a head of 8 feet. The dam is built of wood, is 50 feet long, and is located on the site of an old Spanish mill on Ayish Bayou.

MILL CREEK (SABINE COUNTY).

Meig's mill is 1 mile above Bell's, on Mill Creek, and is near the town of Brookeland. The timber dam was constructed in 1879. It is 30 feet long and 8 feet high. The head varies from 4 to 8 feet, and the power is used in operating a sawmill, a gristmill, and a gin. A 23-inch Leffel-Sampson turbine generates the power. The flow of the stream is 10 second-feet.

Bell's sawmill is on Mill Creek, 1 mile from Brookeland, Sabine County, about 6 miles from the Sabine and San Augustine county line and about 18 miles southeast of Hemphill. It is the first dam above the mouth of the stream and is 1 mile above the junction of Mill Creek with Bear Creek. The plant is managed by Wood & McCall, and consists of a sawmill, a gristmill, and a 70-saw cotton gin. The dam was built in 1896 and is 20 feet long. The power is generated by a 20-inch Leffel turbine, under a full head of 9 feet, and is estimated at 12 horsepower. The flow of the stream was found to be 10.5 second-feet.

INDIAN CREEK.

The mill of L. E. Jones is 7 miles west of Jasper on Indian Creek. A dirt dam 22 feet long and 5 feet maximum height is used. A 23-inch Leffel turbine, under a head of 4½ feet, runs a 50-saw gin and the gristmill. The gin during the season is run ten hours a day.

R. L. Pickle's mill is 9 miles west of Jasper, on Indian Creek. One 20-inch Sampson turbine, under an average head of 7½ feet, runs the 60-saw gin and a gristmill. A curved dirt dam 250 feet long and 6 feet high backs the water over 15 acres. One hundred feet of the dam is covered with plank to serve as a wasteway.

SANDY CREEK (JASPER COUNTY).

The mill of W. J. B. Adams is on Sandy Creek 2 miles east of Jasper, and is managed by J. H. Singletary. It is the second from the mouth of this stream. The dam is 100 feet long and is made of timber and dirt. The head on the wheels is at present 4 feet, and the power is developed by an old 36-inch wheel. It is estimated that 4 horsepower is generated for two hours each day. Both the dam and the mill are in bad condition and are liable to give way at any moment. The flow of the stream is 13 second-feet, and a head of 10 feet could readily be obtained, which would generate 30 horsepower for eight hours a day provided the flow of the stream is conserved.

The mill of K. J. Smith is 10 miles south of Jasper, on Sandy Creek, which flows into Neches River. A dam 125 feet long and 10 feet high impounds the water. The power is developed by one 30-inch Leffel turbine and one 30-inch homemade pressure wheel under a head of 8 feet. Together these wheels can develop 24 horsepower, which is used in operating a 70-saw gin and a gristmill.

FRONT CREEK.

The plant of Farrow & Ferguson is on Front Creek, in Jasper County, and is equipped with two Leffel turbines, 30 and 35 inches in diameter, which run under an average head of 8 feet. The dam is made of earth, is 40 feet long, and has been washed away many times in the last thirty years.

RUSSELL CREEK.

The mill of L. P. Lewis is on Russell Creek, in Tyler County. The earth-plank dam is 30 feet long and 9 feet high. The power for the gin and gristmill is generated by a homemade wheel, which generates 10 horsepower. An auxiliary steam engine of 20 horsepower is used. The dam was first constructed in 1856 and has been washed away twice since that time, the last time in 1902.

BILLUM CREEK.

The mill of E. P. Wallace is located on Billum Creek, Tyler County. The dam is 50 feet long, 5 feet high, and was constructed of dirt in 1889. The power is generated by one Leffel 17-inch turbine, under an average head of 9 feet, which develops 15 horsepower, which is used in running a cotton gin, a gristmill, and a small sawmill.

SPRING CREEK.

Three miles west of Colmesneil, Tyler County, on Spring Creek, about 2 miles from its head, is the gin and gristmill of P. H. Fondreu. The creek at this point flows in a northwest direction, and the curved dam is made of dirt and provided with a 40-foot timber wasteway. The mill house is placed on the part of the dam that is transverse to the stream, the main dam being extended in wings on each side of the banks up the stream, and complete forms three sides of a rectangle in plan, its full length being 500 feet. A 27-inch Leffel turbine, under a head that varies from 8 to 11 feet, is used. It works under an average head of 9 feet and runs a 50-saw gin and a gristmill. During the season the gin is run ten hours a day.

WOLF CREEK.

Two miles east of Colmesneil, on Wolf Creek, is the mill of J. C. Harrelson. The dam is 35 feet long and 10 feet high, and is made of plank. Two Leffel turbines, 27 and 48 inches in diameter, generate the power, under a head of 6 feet. The stream has an abundant flow, as water runs over the dam when both wheels are at work.

The mill of J. M. Wigley is about 1 mile north of Emilee, Tyler County, and it gins, saws, and grinds. The power is generated by a 30-inch Leffel turbine, which is run under an average head of 8 feet and at a three-fourth opening generates 16 (estimated) horsepower.

COWPEN CREEK.

Near Mobile, Tyler County, on Cowpen Creek, is located the mill of Ed. Wheat. A dam 200 feet long and 14 feet high raises the water to furnish an average head of 9 feet. One 30-inch pressure wheel and one 30-inch scroll wheel are used to furnish power. The stream is supported by lasting springs.

MILL CREEK (TYLER COUNTY).

The mill of Bevil & Bullock is near Woodville, Tyler County, on Mill Creek. An earth-and-wood dam 180 feet long and 10 feet high is used to raise the water to an average head of 10 feet. The power is generated by two 40-inch wheels.

The mill of M. N. Nugent and B. Q. Tompkins is on Mill Creek, in Tyler County, and the power is developed by a homemade wooden wheel, which under a head of 8 feet generates 4 horsepower. The dam, 300 feet long and 3 feet high, was constructed of dirt and brush in 1845. The water is led to the wheel by a race 120 feet long, 12 feet wide, and 3 feet deep.

THONEVIN CREEK.

The mill of A. E. Pope and his son, Randal Pope, is 10 miles southeast of Woodville, on Thonevin Creek, Tyler County. The earth-plank dam was built in 1871, is 60 feet long, 10 feet high, and produces a head from 4 to 8 feet, with an average of 6½ feet. The power is developed by one 36-inch De Loach turbine, run at three-fourths opening, with 200 square inches vent, which furnishes 10 (estimated) horsepower. The plant includes a 40-saw gin, a gristmill, and a sawmill.

MILL CREEK (POLK COUNTY).

J. N. Young's sawmill and gristmill is located on Mill Creek, in Polk County, and the power is generated by a Leffel turbine under an average head of 8 feet. The stream runs the year round and furnishes, by estimation, 10 horsepower. During the cotton season three days a week are spent in ginning and two in grinding.

DOUBLE BRANCH CREEK.

Marion Davis's mill is located in Polk County, on Double Branch Creek, near Charity post-office. An earth dam 225 feet in length by 12 feet in height creates an effective average head of 8½ feet. The stream runs throughout the year, but the mill is operated only a part of the time.

KIMBALL CREEK.

On Kimball Creek, in Polk County, the mill of B. F. Collins generates its power by a wooden wheel 36 inches in diameter. This is known as the old Griffin mill, and was built in 1865. The dam is 300 feet long and was constructed of dirt. The power is used to run a cotton gin and gristmill.

The mill now owned by W. W. McKinnis was formerly owned by Tom Shefield, and is sometimes known as the "Shefield mill." It is located 12 miles south of Spurger, in Tyler County, near Neches River. One 36-inch homemade wheel with 12 buckets was used to develop the power. It consists of a cotton gin and gristmill.

BIG CREEK.

J. O. Smith's mill is located on Big Creek, in Jasper County, and consists of a gristmill and cotton gin. A dam 200 feet long and 7 feet high was constructed of dirt in 1868. A race 200 feet long, 5 feet wide, and 5 feet deep conveys the water to the penstocks, where two 36-inch turbines generate the power under an average head of 6 feet. The gristmill is run two and one-half hours each day, while the gin is run eight hours from October to February.

The mill of D. R. Dehart is located on a small nameless stream in Jasper County, where a dam 200 feet long and 6 feet high raises the water so that an average head of 4½ feet is obtained. The power is generated by a small 30-inch wooden wheel. The dam washes away nearly every year.

MARSHALL CREEK.

E. H. Hopson operates a mill on Marshall Creek, in Tyler County, to run a gristmill and cotton gin. The dam is 50 feet long, 8 feet high, and is made of dirt. One Cowart wooden 32-inch wheel develops 7 horsepower under an average head of 7½ feet.

SANDY CREEK (POLK COUNTY).

On the West Fork of Sandy Creek, a tributary of the Neches, near Charity post-office, H. R. Cassels runs a small mill by water power. A dirt dam 60 feet long and 5½ feet high was built in 1900. The dam gives a head of 5 feet. A homemade paddle wheel, 4 feet in diameter, develops 3 horsepower, and the mill is ordinarily run three hours a day.

EDWARDS CREEK.

Near Knight post-office, in Polk County, S. P. Johnston operates a water-power plant on Edwards (or Waterhole) Creek, where a head that varies from 2 to 8 feet is obtained, with an average of 5 feet. A dam 30 feet long and 8 feet high was constructed out of corn sacks filled with sand. The wheel is of special construction, 3 feet in diameter, and generates 8 to 10 horsepower, and as the stream flows the year round, the mill can be operated from two to twelve hours a day.

SABINE RIVER.

Sabine River has its headwaters in Collin County and flows in a southeasterly direction to the State line. It then flows south, forming the boundary between Louisiana and Texas, to the Gulf of Mexico. The small tributaries in east Texas support many small mills, and the Sabine itself is navigable for several hundred miles. The drainage area of the Sabine in Texas above Orange is 7,500 square miles, and its total drainage area above Orange in Louisiana and Texas is 10,400 square miles.

A gaging station was established on the Sabine at the International and Great Northern Railroad bridge, near Longview, in December, 1903; observations commenced January 1, 1904. The river at this point has a constant flow. A measurement on December 22, 1903, gave a discharge of 254 second-feet.

The following is a list of the water-power plants in the watershed of the Sabine in Texas:

Water-power plants in watershed of Sabine River.

Owner.	Post-office.	Head.	Horse-power.	Wheel.
		Feet.		
E. Shamburger	Hawkins		7	Turbine.
H. A. Seago	Big Sandy	8	90	Do.
J. A. Shields	Peach	16	12	Do.
O. H. P. Wood	Woodtown	12	12	Do.
J. A. Stinson	Speer	31	40	Do.
J. W. Bailey	Neuville	25		Overshot.
—— Hancock			6	Turbine.
W. T. Pulliam	Newton	8	8	Homemade.
J. T. Dickerson	Farrsville	7	12	Do.
T. P. Dickerson	do	7	15	Turbine.
J. R. Mattox	Burkeville	7	10	Do.
L. J. Miller	do	6	10	Homemade.
Lamb & Hall	do	6	6	Do.
Gunter Brothers	do			
G. W. Smith	do	5	8	Do.
Westbrook Brothers	Beech Grove	7	16	Turbine.
D. E. Renfro	Jasper	5	16	Homemade.[a]
W. Bishop	do	8	10	Do.[a]
McGree & Griner	do	5	4	Reaction.
J. S. Griggs	Newton	7	8	Turbine.
T. J. Kelly	do	5	6	Homemade.
J. R. Lee	Lees Mill	5	20	
W. E. Gray	Kirbyville	6	10	
J. T. Willet	Newton	6	30	Do.[b]
T. J. Gandy	Rogansville	5	4	Do.
N. B. Jones	do	6	8	Turbine.

[a] Three wheels. [b] Two wheels.

LITTLE SANDY CREEK.

Three miles northeast of Hawkins, Wood County, on Little Sandy Creek, is the mill of Edwin Shamburger. A rock dam 300 feet long and 7 feet high was constructed in 1880. A 5 by 6 foot mill race 40 feet long conveys the water to the penstocks, where a 24-inch Burnham turbine develops about 7½ horsepower. The creek runs all the year round, and the power is used to run a gristmill and cotton gin.

BIG SANDY CREEK.

The mill of H. A. Seago is on the Big Sandy, 3 miles northeast of the town of Big Sandy. It was built in 1903 and is substantial and modern in its equipment. The dam is 3 feet thick on top and 10 feet at the bottom and is constructed of rubble masonry laid in cement. It is located just below and parallel to the highway bridge and develops a head of 8 feet. The power is generated by one 45-inch Davis turbine, which gives 90 horsepower. The water is admitted to the penstocks through a mill race 60 feet long, 9.4 feet wide, and 5 feet deep. In December, 1903, the discharge in the mill race was 97 second-feet.

GREENSTREAM CREEK.

In the eastern part of Wood County J. A. Shields operates a small mill on Greenstream Creek, where a dirt dam 150 feet long and 10 feet high is constructed. A race 600 feet long, 3 feet deep, and 12 feet wide leads the water from the mill pond to the mill, where a head of 16 feet is obtained. The power is generated by a 12-inch Burnham turbine and is used in running a corn mill and cotton gin.

BENTON CREEK.

On the head of Benton Creek, in Harrison County, O. P. H. Wood runs an 18-inch gristmill and a 50-saw gin. These are run by one 18-inch De Loach turbine, which generates its power under a head of 12 feet. A dam of sand and clay 300 feet long and 20 feet high was built in 1891. A mill race 150 feet long, 4 feet deep, and 4 feet wide conveys the water to the penstocks. The mill is run four hours a day, and the capacity is estimated at 12 horsepower.

NEAL CREEK.

The mill of J. A. Stinson is on Neal Creek, a tributary of the Big Sandy, in Wood County. Two Burnham turbines 16 and 13 inches in diameter develop the power under an average head of 31½ feet, the greatest head being 32 and the lowest 31 feet. An earth dam 195 feet long and 8 feet high is located three-fourths of a mile above the mill. The water is conveyed to the mill by a race 1,500 yards long, 9 feet wide, and 2½ feet deep. The power is used to run a cotton gin for eleven hours a day during the season.

SANDY BAYOU.

A mill is located on Sandy Bayou, in Shelby County. A wooden dam 30 feet long, which develops an average head of 10 feet, was built in 1896. One 18-inch De Loach turbine is used and when running full develops 6 horsepower. There are 6 other mill sites on the stream which could be utilized for power purposes and which would give heads of from 12 to 15 feet.

TENEHA CREEK.

The mill formerly owned by E. H. Hearne is now owned and operated by J. W. Bailey. It is situated on Teneha Creek near Neuville, in the southern part of Shelby County, and was built in 1900. The power is generated by an overshot wheel 27 feet in diameter, with an effective head of 25 feet. A dirt dam 200 feet long, with a maximum height of 7 feet, deflects the water into a mill race one-half mile long and 3 feet wide. The power is used to run a gristmill, a 60-saw cotton gin, and a shingle mill.

CLEAR CREEK.

The mill of W. T. Pulliam is on Clear Creek, Sabine County, and is operated by two homemade 26-inch wheels, which work under an average head of 8 feet. The dam is 40 feet long and 8 feet high and is constructed of timber framework.

HUNTER CREEK.

In the northwestern part of Newton County, on Hunter Creek, 12 miles east of Jasper, 13 miles southeast of Brookeland, and 5 miles northwest of Farrsville, is the mill of J. T. Dickerson. The plant consists of a sawmill, gin, and gristmill. The dirt dam was built in 1900, is 400 feet long, and backs the water over 14 acres of land. The head varies from 4 to 9 feet, the average being 7 feet. The 36-inch wheel is an old-fashioned tub wheel, built by the owner, and the capacity is estimated at 12 horsepower. A smaller wheel of the same pattern has also been used. It is the intention to add an auxiliary steam plant of 12 horsepower.

BIG COW CREEK.

The mill of T. P. Dickerson is on Big Cow Creek, at Farrsville, in the northern part of Newton County, 11 miles north of Newton. The mill is used for ginning, sawing, and grinding. The dam is the first from the mouth of the stream and is built of dirt. It is 75 feet long, 8 feet high, and backs the water over 25 acres. The head varies from 5½ to 7 feet. The power is generated by a 36-inch Leffel-Sampson turbine. The flow of the stream when measured was 23 second-feet.

LITTLE COW CREEK.

Little Cow Creek is about 5 miles northeast of Farrsville. At the ford, about 1 mile from the Mattox mill, the discharge of the stream was 12 second-feet.

About 7 miles north of Burkeville and 6 miles northeast of Farrsville, on Deer Creek, a small tributary of Little Cow Creek, with a flow of 4½ second-feet, is the plant of J. R. Mattox, consisting of sawmill, gin (with a capacity of 200 bales a season), and a gristmill. The head varies from 5 to 7 feet, with an average of 6 feet. Two wheels generate the power; one, an old 32-inch turbine, operates the gristmill, while the other, a 33-inch Davis turbine, runs the rest of the machinery. The dam is 300 feet long, was constructed prior to 1860, and backs the water over 10 acres. Each wheel can generate 10 horsepower while in use with a full head. The mill is run six hours a day. Five miles below the Mattox mill there once existed an old mill called the Davis mill, below the junction of Deer Creek and Little Cow Creek. It had plenty of water and was an excellent power site.

The mill of L. J. Miller is located 4 miles northeast of Burkeville, Newton County, on McGraw Creek, a tributary of Little Cow Creek. This stream is a clear spring bed creek, 6 to 8 feet wide and 2 feet deep in the center. The dam is 15 feet long, with maximum depth of 6 feet, and was constructed of dirt in 1900. The power is generated by a 52-inch wheel under a head of 6 feet.

The mill of Lamb & Hall is 1 mile east of Burkeville, on McGraw Creek. The head varies from 4 to 8 feet, with an average of 7½ feet. The dam is 140 feet long, was built long ago, and backs the water over 10 acres. Three homemade wheels generate the power to operate the gin and the cotton press and to drive an emery wheel. The flow is about 20 second-feet, and while running six to seven hours a day each wheel can generate 12 horsepower. The gin and gristmill of L. J. Miller is 5 miles above that of Lamb & Hall.

Little Cow Creek about 2 miles south of Burkeville had a flow, when measured in December, 1902, of 24 second-feet. The stream was wide and the water very clear. Little Cow and McGraw creeks unite 2½ miles southeast of Burkeville, forming Cow Creek, which, 4½ miles below, receives the water of Yellow Cow Creek and joins Sabine River 13 miles southeast of Burkeville.

LYONS CREEK.

Seven miles northwest of Newton, on Lyons Creek, a tributary of Sandy Creek, is the gristmill and gin of Westbrook Brothers. The flow of the stream is about 4 second-feet. The dirt dam is 300 feet long and 6 feet high. The mill race is 150 feet long, 20 feet wide, and

6 feet deep. The power is developed by one 30-inch Leffel turbine and one wooden wheel.

MILLUM CREEK.

On Millum Creek 8 miles west of Newton is the gin and gristmill of McGree & Griner, which is run by a 36-inch wheel under an average head of 6 feet. The plank dam is 40 feet long and 11 feet in total height. It was built in 1891 and has never washed away. A 40-saw cotton gin and a gristmill are operated.

The Bishop mill is on Millum Creek 2 miles above the Renfro mill and 7 miles east of Jasper. At present the mill is managed by N. Hays, and the power is used mainly in sawing and ginning. The dam is 600 feet long, the main part constructed of dirt, while the waterway and the part across the main channel, about 60 feet in length, are made of timber. The mill pond covers 30 acres. The head varies from 4 to 5 feet; the wheel is 4 feet in diameter, and when running with full head 10 horsepower is developed.

One and one-fourth miles above the mill of McGree & Griner, on Millum Creek, is the Renfro mill, about 9 miles east of Jasper. It is the second mill from the mouth of the stream, being located midway between the mill of McGree & Griner and that of Bishop. Eight horsepower is generated by two wheels, one a 36-inch Davis turbine, running the 50-saw gin, while the other is an old-fashioned homemade pressure wheel, 4 feet in diameter. The dam is 500 feet in length, was constructed partly of dirt and partly of timber, and backs the water over 15 acres.

MILL CREEK.

The mill of Joe S. Griggs is in Newton County, on Mill Creek. A dam 300 feet long and 8 feet high was constructed of dirt in 1858. The head varies from 5½ to 7½ feet, averaging 7 feet. Eight horsepower is developed by an 18-inch Leffel turbine. The mill is located at the dam, and no mill race is needed.

CANEY CREEK.

The mill of T. J. Kelly is in the town of Newton, southwest of the court-house, on Caney Creek. The dam is about 50 feet long, 9 feet high, and is constructed of timber. One 30-inch homemade bucket wheel develops the power (estimated at 6 horsepower) to run a 50-saw gin and a gristmill. The head varies from 4 to 6 feet and averages 5 feet. The stream flows the year round, and during the ginning season the plant is operated ten hours a day.

The water-power plant of J. R. Lee, at Lees Mill, Newton County, is on Caney Creek about 9 miles southeast of the town of Newton. A dam of timber and dirt, 40 feet long and 7 feet high, was constructed in 1891 and serves to obtain a head that varies from 3 to 6 and averages 5 feet. Twenty horsepower is developed by one Davis wheel, 48 inches in diameter, which is used to run a gristmill, a cotton gin, and a sawmill.

THICKETY CREEK.

This plant, formerly owned by W. E. Gray, is in Newton County, near Kirbyville, and is located on Thickety Creek. Full data could not be obtained, but it is said that an average head of 6 feet was obtained.

WHITEOAK CREEK.

On Whiteoak Creek, Newton County, the sawmill and gristmill of J. T. Willett is operated by two wheels, a Crowner and a tub, under a head which varies from 3 to 6 feet. A dirt dam 550 feet long and 3 to 7 feet high impounds the water. The stream has a perpetual flow and the mill is run seven hours a day. The estimated capacity is 30 horsepower.

EVERETT CREEK.

The mill of T. J. Gandy is located in Jasper County, on Everett Creek, a tributary of Sabine. A dam 300 feet long produces a head of 4½ feet. A homemade wheel 32 inches in diameter is used to develop the power that operates the 50-saw gin and gristmill.

Fourteen miles east of Jasper, on Everett Creek, is the gristmill and cotton gin of N. B. Jones. The power is generated by one 26-inch standard Leffel turbine, which runs under an average head of 5½ feet. The stream runs throughout the year, and the power is estimated at 6 horsepower. The dam is 150 feet long and is constructed of dirt.

SMITH CREEK.

G. W. Smith's gin and gristmill is on Smith Creek, in Newton County. The mill is built right over the stream, and the dam is 40 feet long, with a maximum height of 6 feet. The power is developed by a 24-inch vertical shaft homemade wheel, which runs under a head of 5 feet.

RED RIVER.

The watershed of Red River of Texas has an area of 89,970 square miles, and extends into New Mexico. Palo Duro and Terra Blanca creeks unite 3 miles east of Canyon City, in Randall County, and form the Palo Duro Canyon, known also as the Prairie Dog Fork of Red River (old Indian name, Ke-che-ah-qui-ho-no). Palo Duro Creek runs continually from a point 20 miles west of Canyon City to its junction with the Terra Blanca. The latter has a continuous flow at Hereford and from there to its junction with the Palo Duro. The upper part of Red River, in Randall and Armstrong counties, is universally referred to as Palo Duro Canyon, while the part near the crossing of the Fort Worth and Denver Railroad is referred to as Red River. There is no definite point where one ceases to apply and the other begins. At best it can be said that the upper part of the Prairie Dog Fork is known as Palo Duro Canyon. In the canyon section the flow of the stream is reliable and continuous, but when the stream strikes the sand the water sinks. Several small streams flow into the river, but their water flows for a short distance only after reaching the bed of the river, and then sinks in the sand. The formation is irregular, and holes of clear water and shoals alternate in succession.

At the crossing of the Fort Worth and Denver Railroad the river bed is a wide waste of white sand, across which the railroad carries its track on a trestle. The river flows here about six months of the year. Heavy rains on the table-land or plains rush off to the canyons and the resulting floods have produced great trouble with the railroad bridge. Near the one hundredth meridian the river stops flowing only in extremely dry years.

The North Fork of Red River, while much shorter in length, has a much larger flow than the South Fork, or Prairie Dog Fork, and the amount of water indicates that, contrary to legal decisions, it is the main fork of the river. The two main forks unite near the ninety-ninth meridian. Legally, it has been decided by the courts that the South Fork is the Red River.

The drainage area of the Salt Fork of Red River extends into Carson and Armstrong counties in the Panhandle, but water is rarely found in its bed. The waters of this stream are impregnated with salt "gyp" and other alkaline ingredients.

The following table shows the power plants in the Red River watershed in Texas:

Water-power plants in Red River watershed.

Owner.	Post-office.	Head.	Horse-power.	Stream.	Wheel.
		Feet.			
J. B. Cotton	Pittsburg	4	12	Cypress	Turbine.
L. B. Branan	Purley	28	18	Mountain Creek	Do.
J. M. Lockett	Lanier	26	7	Springs	Overshot.
Moore & Maxey	Viola	12	15	Clear Creek	Turbine.
A. G. Strickland	Sardis	10	12	Black Cypress	Do. [a]

[a] Fifteen horsepower steam.

PEASE RIVER.

Pease River rises in Briscoe County and flows south 80° east to its junction with Red River. While its drainage area is 3,280 square miles, it is only a wet-weather stream; but long after it ceases to flow water stands in holes at many places in its course. But little reliance is placed on its water, and as a water-bearing stream it is not a factor in the development of the country.

WICHITA RIVER.

Wichita River flows in a general direction N. 75° E. and unites with Red River in the northern part of Clay County. It has a drainage area of 3,750 square miles. At Wichita Falls the river rarely if ever ceases to flow. On February 10, 1904, its flow at the Fort Worth and Denver Railroad bridge was only 3 second-feet. This is unusually low, as no rain had fallen at its headwaters for nearly a year. An impounding reservoir has been constructed across Holliday Creek, a tributary of Wichita River, near Wichita Falls, for irrigation purposes, the lake thus formed being called "Lake Wichita." The dam is 1⅝ miles long and the lake has an area of 3,000 acres. The water is intended to irrigate 3,000 acres east of the town of Wichita Falls.

CYPRESS AND SULPHUR RIVERS.

The two most significant tributaries of Red River in Texas are the Cypress and the Sulphur. The Sulphur has its headwaters in Fannin County, flows southeasterly, forming the southern boundary of Lamar, Red River, and Bowie counties, and enters Red River about 7 miles north of the Louisiana line. The discharge of this river is not constant, as the stream often ceases to flow. For this reason there are few power plants on the Sulphur. Its drainage area in Texas is 3,400 square miles. The Cypress (often called the Big Cypress) rises in Franklin County and flows southeasterly for about 90 miles and enters Cypress Bayou at Jefferson, which in turn empties into Red River. Like the Sulphur, the Cypress often ceases to flow in dry summers and it is little used as a power stream.

The mill of J. B. Cotton is on the Cypress 7 miles northwest of Pittsburg. The dam, 200 feet long, was constructed of earth and plank in 1880. The head varies from 2 to 5 feet, and the power is generated by a 30-inch Leffel turbine with full opening, and is used in operating a gristmill. It is usually run only three hours a day.

The mill of L. B. Branan is on Mountain Creek, in Franklin County. The head was 28 feet, and the power was generated by a 16-inch-Leffel turbine. The estimated capacity was 18 horsepower. A dam 600 feet long, with a maximum height of 12 feet, impounded the water. It was conducted to the mill by a race 1,800 feet long, 4 feet wide, and 3 to 5 feet deep. The dam was washed away in 1902.

In Cass County, on Clear Creek, the mill of Moore & Maxey is situated. This plant includes a cotton gin and gristmill. The power is developed by a 20-inch turbine under a head of 12 feet and is estimated at 15 horsepower. The dirt dam is 600 feet long and 15 feet high, and the water is led to the mill by a race 300 yards long, 8 to 12 feet wide, and 2 to 3 feet deep. The mill is generally run nine hours a day.

J. M. Lockett's plant in Cass County, 6 miles south of Linden, consists of a gin and gristmill. The power is developed by a 26-foot overshot wheel, and the effective head is slightly less. The dam is 300 feet long, 15 feet high, and was built in 1881. The water is led from the mill pond to the mill by a race one-fourth of a mile long, 2 feet wide on bottom, and from 3 to 4 feet deep. The mill is run during the ginning season all day for five days in the week. The power is estimated at from 4 to 10 horsepower.

The gristmill of A. G. Strickland is on the Black Cypress in Cass County, near the Sardis post-office. The dam is 400 feet long and was constructed of dirt in 1852. The head varies from 8 to 12 feet, the average being 10 feet. One 24-inch Ridgeway turbine develops 8 horsepower. An auxiliary steam plant of 15 horsepower is used. The plant is operated eight hours a day.

CANADIAN RIVER.

Canadian River crosses the Panhandle of Texas in an easterly direction. Its watershed extends into New Mexico, but as a stream it practically rises in Texas. In extremely dry years no part of the river in Texas has a continuous flow. At Tascosa the river flows about six months in the ordinary year and at highest stage is one-third of a mile wide by 3 feet maximum depth. Lower down the river this period is increased, until at the one hundredth meridian it flows, on an average, ten months in the year. The river bed is composed of a wide, sandy waste, and except for a short period after a rain the flow is confined to a narrow streamlet, which courses its ribbon-like way sluggishly over the sandy tract.

PROGRESS IN HYDRAULIC POWER DEVELOPMENT.[a]

By J. T. Fanning.

The first great water-power development was made in New England. Hydraulic mechanisms in small units, such as are termed "current wheels," were familiar to the Chinese on the Yellow River and the Hamites on the Nile and Euphrates fully three thousand years ago. The crude undershot wheel, so long used, maintained its prominence until the genius of John Smeaton touched it, about 1759, when he showed that the wheel, as then used, gave but 30 to 35 per cent of the theoretical power of the water, and, further, that if the bucket was resolved into the overshot form the useful efficiency might be increased to 60 per cent, and, later, that if changed into the high-breast form the useful efficiency might be increased to about 70 per cent. The power that turned these long-armed current wheels was usually a rapid in a river, though sometimes it was the rush of tidal water into or out of an estuary. The old

[a] From Engineering Record, January 3, 1903.

tidal mill on Mill Creek, in Boston, in 1631, was among the earliest mills of the American colonists.

Parallel with the development of water powers of any marked magnitude came also the development of that embodiment of skill and inventiveness known as "millwright," who was usually possessed of mechanical skill and adaptive ingenuity, and could accomplish practical results, such as the needs of the early times demanded. The millwright saw that the bucket wheels on horizontal shafts were well adapted to operate vertical saws, for they could give to the saw frames their vertical motions when connected by pitmans to cranks on the horizontal wheel shafts. Thus was evolved the typical American sawmill that has been universally adopted, and even now not wholly displaced by the band-saw mill. Millstones that ground the corn operated best when run horizontally on a vertical shaft. A bevel gear at first changed the revolving motion of the horizontal to that of the vertical shaft. The ingenious colonial millwright then conceived that if he made his bucket wheel short he could set its shaft on end vertically, and construct the water chutes so that the water would impinge on the buckets or paddles at one side. The running stone was then attached to the upper part of this vertical shaft and a simple and useful corn mill was the result.

This was a pronounced step forward in the millwright's vocation and produced the typical New England gristmill. Many modifications of this water wheel then followed, in which the paddles, at first radial, were successively inclined from the radial line, or curved, or made spoon shaped. Then a small arc of the circumference of the wheel was inclosed to confine the water closer to the radial buckets, and vanes were placed to guide the water against a greater number of buckets. These radial buckets stood generally in vertical planes parallel with the shaft. The fertile brain of the millwright then conceived the idea of inclining the paddles around the circumference of his water wheel, so that while still substantially radial they were atan angle of about 40° from the vertical, and the water was made to impinge on the buckets from above and pass vertically through them instead of horizontally, as heretofore. Crude water wheels having characteristics similar to the above seem to have been previously devised by several peoples when they had made the advance toward permanent village domestication.

As early as 1804 buckets were fitted spirally within a wooden cylinder attached to a vertical shaft, and the flow of the water was downward through these curved buckets. This last wheel was a meritorious invention, and was a progenitor of parallel-flow turbines. Later, vanes were applied to this wheel to guide the water into several buckets at the same time, and still later a square or cylindrical flume covered all these vanes and supplied the water to all the buckets at the same time. As early as 1819, on the Susquehanna River, water wheels were in use having vertical shafts and horizontal wheels, each with a row of buckets on its circumference which discharged the water horizontally and outwardly, constituting reaction turbines. Around the shafts of these wheels and within the line of buckets was a cylindrical wooden flume that supplied the water to the wheel buckets through apertures in its circumference adjacent to the bottom of the cylinder. The shaft passed up through the central flume.

After the passage of the first United States patent laws, in 1790, various turbine designs began to be filed in the public archives, showing occasionally a new fundamental idea, and then numerous improvements of detail based thereon; but new type inventions have been rare and are still few in number. The details of the best types of turbines have, however, been gradually brought to most excellent mechanical perfection. Previous to the year 1820 the millwrights of America were rarely well versed in mathematics and were rarely technical experts. Their new turbine-wheel designs were not based on detailed mathematical analyses and were not described before technical societies; hence the literature relating to them is scarce. The records of the Patent Office testify to the marked natural abilities of the early millwrights.

Abroad Smeaton gave valuable mathematical analyses of the under and over shot wheels before the Royal Society; Fairbairn and Rennie made them in iron and improved them by introducing ventilated buckets; M. Morin and M. Poncelet tested with dynamometers and analyzed the mechanics of the downward and outward flow water wheels, termed in France "Jonval" and "Fourneyron" turbines, and presented the results to the Academy of Science at Paris; James Thomson analyzed the inward flow or "vortex" turbines and described them before the British Association, and Whitelaw gave the arms of the reaction or "Barker-Mill" class their Archimedean curve. In America Elwood Morris, a cultured engineer, took up the technical examination of the elements of turbine water wheels, and then Uriah Boyden, at first a studious blacksmith and ingenious mechanic, and later also a railway and hydraulic engineer and scientist, improved the outward-flow turbine. Boyden, by means of his skillful design and skillful workmanship, produced the most efficient turbine then known, and by the year 1844 had given it standing as the leading type of turbine water wheel.

In the further technical and mechanical perfection of turbine wheels and in their introduction for the driving of large cotton mills James B. Francis exerted an important influence. Parallel with this improvement of outward-flow turbines went the improvement of inward-flow turbines, especially the scroll wheels, which for a time, up to 1860, outranked all others in numbers for small water powers. In 1859 A. M. Swain introduced a combined inward and downward flow turbine which was remarkably efficient and which has influenced the design of most of the best turbines subsequently introduced. The primitive water wheels with vertical shaft that preceded the Boyden and improved scroll wheels were generally of wooden construction. Wing dams and short canals or flumes generally led the waters from the streams and gave the available fall of water upon the wheels. Such typical constructions indicate the state of practical hydraulics and millwrighting up to the war of 1812, when about 1,000 small water powers were sawing the lumber and grinding the corn of the settlements along the Atlantic coast. From 1815 to 1820 was a period of severe commercial depression, following the war.

In 1821 there came brighter prospects and an industrial revival. Until then the wives were spinning the wool and cotton yarns in their houses, but an experimental mill had been built on a Charles River water power that successfully spun cotton into yarn and wove the yarn into cloth. The textile industry was destined to expand rapidly and the water power of the streams was its supporting ally. Under this influence the first great water power was developed on the Merrimac River in 1822, where subsequently the city of Lowell became a great cotton manufacturing center. Near Lowell there was soon developed the equally prominent water powers on the Merrimac River at Manchester, in New Hampshire, and Lawrence, in Massachusetts. These developments had each capacities of from 10,000 to 12,000 horsepower, and each was chiefly devoted to the manufacture of cotton goods, as were the water powers of Cohoes (1828), in New York, and Lewiston (1849), in Maine. The Connecticut River water power at Holyoke (1848) was largely devoted to the manufacture of paper, as, later, were the Fox River powers in Wisconsin. The water powers on the Genesee River at Rochester, N. Y. (1856), and on the Mississippi River at Minneapolis (1857), were largely devoted to the manufacture of flour.

The pioneer large water power at Lowell was laid out with a system of canals with moderate fall from one to the other, and then to the river below the falls. The powers at Manchester and Holyoke had similar systems of parallel canals. These were typical examples of the early developments of powers for the cotton and paper industries. These powers were specially adapted to the use of the overshot or high-breast water wheels, which, constructed largely of wood, were long and high and occupied much valuable room, but maintained their prestige for large powers until 1841.

The new Boyden turbine of 1844 showed, on test at the Appleton Company's cotton mill in Lowell, an efficiency exceeding 80 per cent. This result closed the era of overshot water wheels in America and fully opened the era of the turbine water wheel in iron construction and with rapid revolutions. This result closed also the era of parallel canals, or subdivided head developments of water powers. A competitive trial in 1860, at the Fairmount Works, by order of the council of the city of Philadelphia, gave an impetus to the improvement of the design and workmanship of turbine water wheels; and the competitive tests at the Centennial Exposition in Philadelphia, in 1876, further stimulated along the same line and at the same time retired into oblivion forms of wheels that were not in accordance with the true theories of design.

The attachment of riveted metal draft tubes below the running wheels was a conspicuous improvement leading to the excellent modern water wheels. The dynamometer test of turbines at Lowell, and later the testing flume experiments at Holyoke, were powerful factors in placing the design of turbines on sound scientific bases.

The evolution of the turbine that had led up to the iron bucket wheel in a water-tight iron case and with an iron feeder pipe made possible the easy developments of water powers with high heads. The high water falls and canyons in limestone formations gave opportunities for a high head type of power. The Genesee Falls, at Rochester, N. Y., present an example which dates from 1857. These turbine wheels were operated under heads of 90 feet, and, in consequence of the large aggregate of power developed there, Rochester became a noted flour manufacturing center before the wheat belt had traveled westward into Minnesota and Dakota. The old hydraulic canal power at Niagara village and one at Montmorency, near Quebec, are other examples of this type, and many others might be cited.

Another type of high-fall development is that of the Willamette Falls, near Portland, Oreg., where each turbine and its electrical generators revolve horizontally on the same tall vertical shaft. The modern Niagara power plants are of this type. The water power on the Mississippi River at St. Anthony Falls presents another type of development. The head at the upper falls is about 48 feet. The bed of the river at the crest of the fall is a stratum of blue limestone about 12 feet thick. This limestone rests upon soft sandstone termed "St. Peter sand rock." The power had its first large development in 1857 for operating several large sawmills. The sawmills were founded on the limestone rock of the river bed upstream from the crest of the falls, and their turbines were sunk through holes in the lime rock to wheel pits in the sand rock at the lower water level. Tunnels extended horizontally from below the fall, through the sand rock, to the wheel pits, and discharged the tail waters from the turbines. This tunnel tailrace type of development was adopted also for the wheel pits of the flouring mills of Minneapolis, that now manufacture 80,000 barrels of flour per week. This tunnel tailrace system was later adopted by the Niagara Falls Power Company, the Canadian Niagara Power Company, and the Ontario Power Company.

The diversion type of water powers presents examples of considerable magnitude. The Penobscot River is, in part, diverted from its course at the head of a series of rapids and turned nearly at right angles into the Millinocket. The latter stream is a branch of the Penobscot, and near the confluence flows parallel with the main stream in a lower valley. A dam in the main stream diverts the water; from the bluff of the lower stream the water is conveyed in flumes and penstocks to the turbine-wheel pit with a head of about 110 feet, and there gives power to operate a pulp and paper mill with a capacity to produce daily 200 tons of newspaper. A second example is the diversion of the St. Lawrence River, in part, from the head of the Long Sault Rapid to the Grasse River near Massena, in New York State, with a head of 35 feet. This last diversion canal is large, giving possibility of a great water power.

The special mechanical improvement that more than all others has opened the possibilities of the prominent recent water-power constructions has been the perfection of double wheels on horizontal shafts with a draft tube common to each pair of water wheels. The germ of this, but in crude form, is seen in the Parker Brothers' patent in 1829. Now one, two, and three pairs of turbine wheels are placed on the same shaft in open flumes, as at the Minneapolis, on the Mississippi, or in a cylindrical steel flume for higher heads, as at the Helena plant, on the Missouri River; and their combined powers, aggregating 1,000 to 6,000 horsepower per shaft unit, are driving large electrical generators, which transmit the power electrically to work 10, 50, and even more than 100 miles away from the water-power source of energy.

The pairs of horizontal turbines, in steel cases and having steel penstocks, make possible a further development of the high-head powers which are conspicuous in our mountain States, as in Ogden, Utah, where the mountain stream high up in the canyon is gathered in a flume and wood stave pipe of 6 feet diameter and contoured along the hillside to the canyon's outlet, and then is dropped in a steel penstock with 446 feet effective head to the turbines and electrical generators. Another example is the Bay Counties Power, in California, that has its waters similarly gathered from the melting snows and contoured along the rocky steeps to where they can be dropped 700 feet to turbines driving generators of large capacities. These are examples of water powers generated for long-distance electrical distribution, and in the second the electrical current is sent more than 200 miles down the Sacramento Valley to San Francisco and other cities beyond, and nearly 100 miles up the valley. A form of impulse water wheel, known in type three centuries ago, has recently been improved to remarkable efficiency and adopted by several manufacturers for use in connection with jet streams from these high-head water powers for large power units.

The increasing use and value of power is bringing into prominence that type of water-power development that includes the conservation of the flow of the stream in its relation to its whole watershed. An example on a moderate scale is the Massabesic Lake power, that pumps the water supply for the city of Manchester, N. H. In this case the dam was built on the stream a quarter of a mile below the natural outlet, and the dam was high enough to flow the lake and control nearly the entire flow ot its watershed. Another example is the Helena power, previously mentioned, where a high dam creates a natural lake of sufficient area to conserve the twenty-four-hour summer flow of the Missouri River so that the power of its entire daily flow may be converted into electrical current during ten hours of each day and transmitted to distant ore mining and smelting operations.

The most conspicuous example of this class is the recent power development at Sault Ste. Marie, where a broad canal, nearly 2½ miles long, leads the waters of Lake Superior from its natural outlet, parallel with the rapids, to a power house one-fourth mile in length. Controlling dams and sluices at the outlet of the lake have for their purpose the conservation of the water from the watershed of 82,552 square miles area, and making Lake Superior, of 33,000 square miles area, a magnificent mill pond, with its terminal wheel pits constructed for the development of 48,000 net horsepower.

In Lowell, the first great water-power industrial city, the 10,000 horsepower of the Merrimac River was necessarily used within the limited area to which the shafts and belts could transmit the energy from the turbines, and the power was necessarily subdivided among many power houses because of the limiting conditions of its use and its type of development. Through the evolution in power types leading up to the great modern developments, as of 100,000 horsepower connected with one tailrace at Niagara, it has now become possible to concentrate powers aggregating ten times that of either of the formerly famous Merrimac River powers, where the respective subdivided utilizations required each a mile of canal for their many small units.

The conspicuous achievement along hydraulic lines of the present generation is the development and utilization of 40,000 to 100,000 horsepower in single-power stations, with 4,000 to 6,000 horsepower units, by which great aggregates of energy are first so concentrated that they may then be conveniently distributed over a very broad field to varied industries and may throughout the whole field perform practical works of great usefulness.

APPENDIX.

On October 5, 1904, the highest flood ever known on Pecos River near Pecos washed away the flume of the Barstow Irrigation Company (shown in Pl. III), broke its main lateral in 38 places, and inundated much of the land under its ditch. A hasty estimate places the damage to the flume and laterals at $35,000. In this flood the river rose to within 2 inches of the bridge of the Texas and Pacific Railway and was 3 miles wide along its tracks.

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