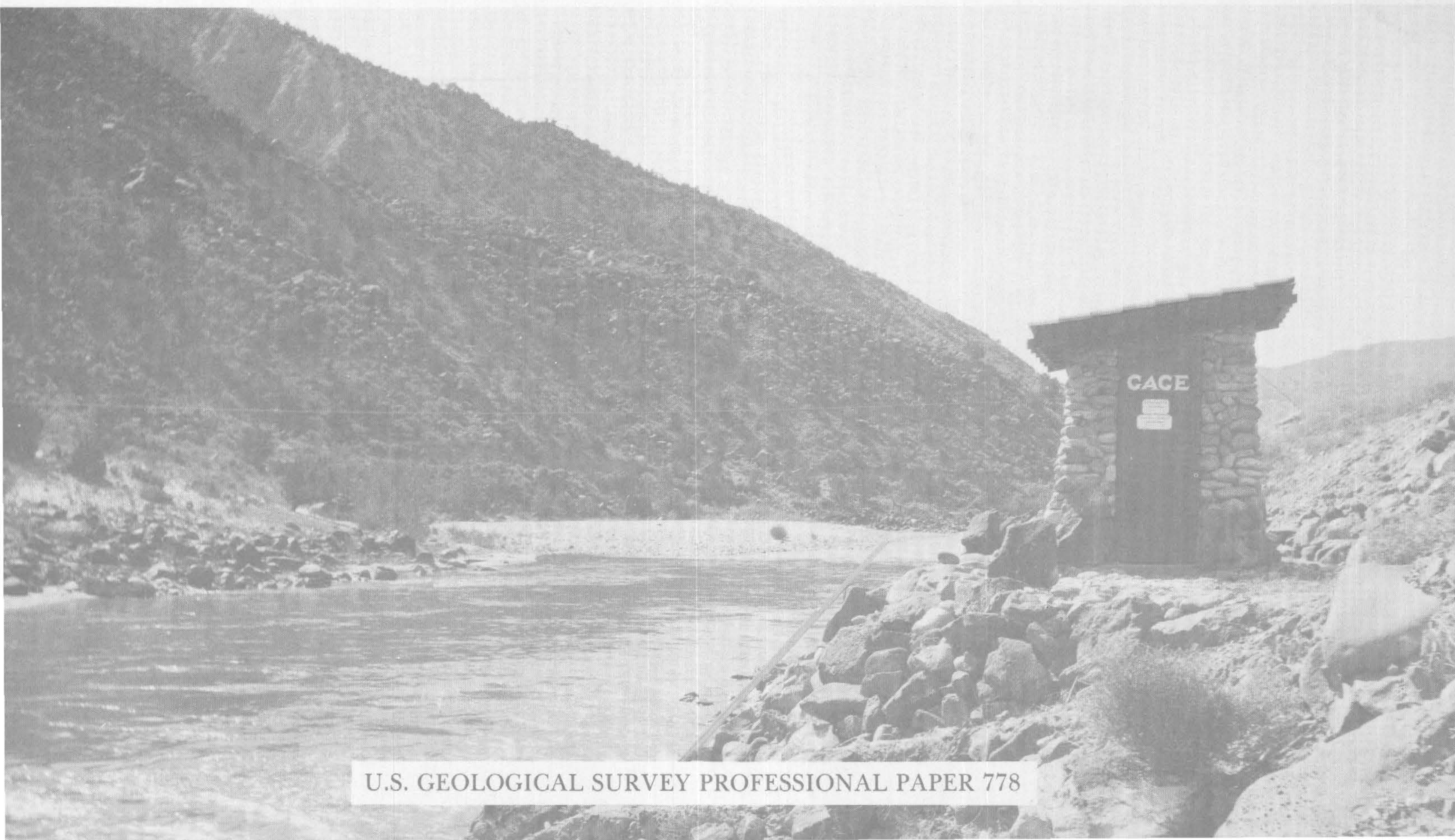
EMBUDO, NEW MEXICO, BIRTHPLACE OF SYSTEMATIC STREAM GAGING



U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 778

Embudo, New Mexico, Birthplace of Systematic Stream Gaging

By ARTHUR H. FRAZIER *and* WILBUR HECKLER

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By ARTHUR H. FRAZIER and WILBUR HECKLER

INTRODUCTION

Embudo, a tiny village on the Rio Grande in northern New Mexico, was chosen in 1888 to be the site of a training center for the first hydrographers of the Irrigation Survey, a new Bureau that had just been added to the U.S. Geological Survey under John Wesley Powell. This is the story of that center, but to make it more complete, a practice has been borrowed from the theater in that a prolog has been added for explaining the circumstances which led to the center's organization and an epilog, for presenting some of the distressing events which took place after the training period was completed. With these additions, this becomes the story of how the Geological Survey became involved in the art of stream gaging and how Powell was prevented from carrying out his plan for irrigation in the arid region—a plan which was largely adopted when Congress later established the Reclamation Service and the U.S. Bureau of Reclamation.

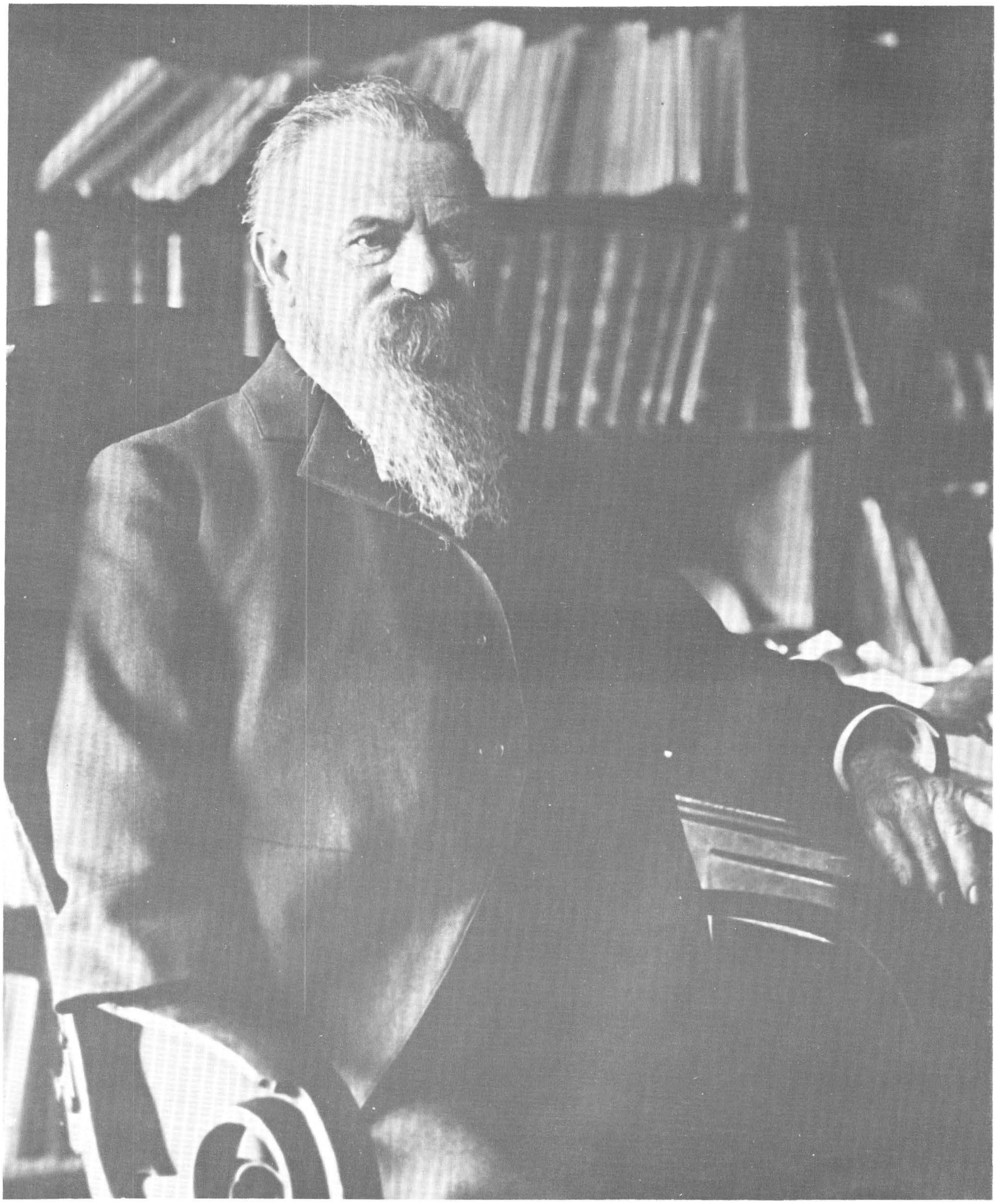


FIGURE 1.—John Wesley Powell (1834-1902). Photograph, supplied by Smithsonian Institution, Museum of Natural History, was taken about 1897.

PROLOG

John Wesley Powell (fig. 1) was to achieve, in 1881, the distinction of becoming the second Director of the U.S. Geological Survey. His father, Rev. Joseph Powell, had been a licensed Episcopal preacher who had come from England to "spread the word of God" in America—particularly throughout the frontier areas where he felt it was most needed. As the frontier moved westward, he too moved westward: from New York State (where John Wesley Powell was born) to Ohio, thence to Wisconsin, and finally to Illinois. During the course of those travels, there was added to Rev. Powell's intense religious drive, an almost equal drive to abolish slavery, and he expressed himself forcibly on both of those subjects. Fearless honesty and extreme forthrightness were two outstanding characteristics he handed down to his oldest son "Wes." (See Davis, 1915, p. 83; Darrah, 1951, p. 11.) Those inherited characteristics ultimately (as will be shown later) led Wes into many difficulties.

As a young man (during the years between 1867 and 1878) Powell crossed and recrossed the arid region of this country many times in connection with his studies of the American Indians and their languages; with his unprecedented boat expeditions down the Colorado River; and with his duties as Director of the Geographical and Geological Survey of the Rocky Mountain Region, one of the forerunners of the present Geological Survey. It was during those years he conceived a need for a Federally conducted Irrigation Survey.

His hastily prepared and highly controversial "Report on the Lands of the Arid Region of the United States" was delivered on April 1, 1878, to the Honorable J. A. Williamson, then Commissioner of the General Land Office. Williamson, in turn, forwarded it immediately to the Honorable Carl Schurz, then Secretary of the Interior. Within 2 days it reached the House Committee on Appropriations and was ordered to be printed. That edition was exhausted within a few months, and in March 1879 another edition of 5,000 copies was authorized by Congress. Stegner (1962, p. VII) who wrote the introduction to an edition of it which was published as recently as 1962, claims that it would ultimately be recognized as one of the most important books ever written about the West.

The report was devoted largely to the practicability of reclaiming by irrigation an appreciable percentage of the arid region, the total area of which has been estimated at about 1,300,000 square miles, starting at about the 100th meridian (which cuts across the middle of the Dakotas and Nebraska) and extending westward beyond the Rocky Mountains to the southern Pacific coast. It is impractical to mention here all the innovations which were proposed in the report, but the substances of those which appeared in this and other reports of his, which are of primary concern at present, are listed below:

1. To take an inventory of the flow of all streams in the arid region in order to be able to evaluate their potentials for irrigating nearby land areas.
2. To determine the average amount of water required to irrigate each acre of that land during the growing seasons.
3. To prepare topographic maps on which to outline the drainage area of every stream which seemed to offer good possibilities for successful irrigation, and to declare those areas to be individual irrigation districts and locally independent political subdivisions. As many 80-acre farms were to be marked off on the map of each irrigation district as could be adequately irrigated by the quantity of water furnished by the stream (including whatever water could be stored from spring floods).
4. To provide the farmers in each district with plans and estimated costs of suitable dams (for impounding floodwaters) and canals (for delivering equitable shares of the water to each farmer). After those facilities were constructed under a cooperative program, they were to be considered as district-owned property. Before receiving any preemption right from the Government to enter any of these districts, the applicant would have to agree to participate in such a cooperative arrangement. His right to receive final title to any of that land was also contingent upon a showing that his entire farm had been under actual irrigation within 5 years of the date the district became organized.

5. To abandon, in the arid region, the prevailing method of laying out political and land subdivisions by the township, range, and section method.

The last of those provisions was particularly important in Powell's estimation because the prevailing method allowed settlers to acquire parcels of land through which streams were flowing without obligating them to permit settlers on any of the adjacent farms to have access to the water. Disputes arising from those circumstances seemed inevitable, and if the adjoining farms should happen to lie in another township, or in another county, any settlement thereof could become increasingly difficult. Under Powell's plan, the right to a fair share of the water was incorporated in every land grant, and the farmer automatically became a member of the very same political unit which had the authority to settle any local disputes.

In some of Powell's subsequent reports was an item which, although it fell into another category, is nevertheless pertinent to this general discussion. It was a proposal that all the geologic and geographic expeditions then authorized by Congress, such as those conducted by G. E. Wheeler, F. V. Hayden, Clarence King, and himself, be consolidated into a single Bureau.

After obtaining advice from the National Academy of Sciences on that and some of Powell's other proposals (Marsh, 1878, p. 2), Congress implemented only one of them—the one in which the several surveys were to be consolidated into a single Bureau. It was called the Geological Survey. The change became effective as of March 3, 1879. Clarence King was selected as the first Director of the new Bureau, whereas Powell became the head of the Bureau of Ethnology in the Smithsonian Institution. When, as of March 12, 1881, King resigned his position, Powell was appointed to succeed him, and for many years thereafter Powell remained in charge of both Bureaus (Davis, 1915, p. 47)—one in the Smithsonian Institution and the other in the Department of the Interior.

During the 7 years following Powell's entrance into these new duties, the General Land Office continued to process land grants in the arid region using the old land line method which Powell had so strongly opposed. And during that time also settlers were urged to move into that region, build homes, and plow the fields. It is interesting to note that during those years Powell's opponents made strong efforts to popularize a theory that, when prairie lands are plowed under, rains would occur as a consequence thereof. And because those particular years started with an unusually long rainy period, people began to believe the slogan, "Rain follows the plow." Under the prevailing circumstances, Powell's recommendations lost much of their force. He nevertheless persisted in repeating them and thereby brought down upon himself the wrath of many westerners whose part of the country the plan was particularly intended to benefit.

When that exceptionally long rainy period finally ended, Nature gave Powell's cause a helping hand. It was accomplished in two devastating strokes: (1) in 1866 an unprecedented cold winter occurred during which most of the livestock, and many of the settlers themselves, froze to death, and (2) a drought, beginning also in 1886 and continuing for almost a decade, created an ever-increasing shortage of water. Farmers who may have survived the cold winter found themselves unable to raise crops becaused they lacked the irrigation facilities which Powell had so often advocated. The drought forced most of them into bankruptcy, and they had to leave their farms with nothing whatsoever to show for their past efforts. At long last, however, proposals of Powell began to receive serious attention.

A Senate resolution was passed February 13, 1888, in which the Secretary of the Interior was requested to report whether he thought the Geological Survey should survey and segregate irrigable public lands, reservoir sites, and canal routes in the arid region. W. F. Vilas, then Secretary of the Interior (whose home in Madison, Wis., was less than 60 miles from Powell's boyhood home), promptly referred the resolution to Powell. In Wallace Stegner's (1954, p. 300) book "Beyond the Hundredth Meridian" the consequences thereof are described as follows:

> Major Powell, confronted with an opportunity for which he had waited a full decade, rose to the Secretary's letter like a starving cat to a sardine. The conclusions of his "Arid Region" had not been changed but only aggravated by ten years of [land] settlement. The smaller streams were no longer a consideration because by now they were mainly utilized; if action had been taken years ago, much wasteful development could have been prevented. Now the only course was to concentrate on the larger streams, on reservoirs and storm-water basins, because "utilization of the large streams by owners of small tracts must wait until large numbers of the holders of small tracts can be induced to settle simultaneously * * * and be further induced to engage in the corporate or cooperative enterprise necessary to construct great headworks and canals." On those larger streams, in other words, his cooperative irrigation districts were still possible; a survey could still be made ahead of any extensive settlement to avoid complication by squatter's rights and vested interests.

On March 20, 1888, a subsequent joint resolution was passed which in effect implemented Powell's original plan. It directed the Secretary of the Interior to "make an examination of that portion of the United States where agriculture is carried on by means of irrigation, as to the natural advantages for the storage of water for irrigation purposes with the practicability of constructing reservoirs, together with the capacity of streams, and the cost of construction and capacity of reservoirs, and such other facts as bear on the question of storage of water for irrigation purposes." (See Powell, 1889, p. 2; Sterling, 1940, p. 422.) On October 2, 1888, the Sundry Civil Bill went through with an initial appropriation of $100,000 for such work. Powell thereupon became responsible for not only the work performed in the Geological Survey (including some geological work for State surveys) and the Bureau of Ethnology but also for that of an Irrigation Survey—an agency more explosive in its social and political implications than all his other activities combined (Stegner, 1954, p. 304). Great authority was accordingly placed in his hands, and perhaps never before was there such a need for prompt action (Stegner, 1962, p. XXII; Davis, 1915, p. 50).

In view of that need, Powell placed A. H. Thompson, who had made the second trip down the Colorado Canyon with him, in charge of the Irrigation Survey's mapping operations and instructed him to mobilize his triangulation parties in Montana, Nevada, New Mexico, and Colorado, where they would best serve the needs of the new Irrigation Survey. He also withdrew C. E. Dutton from his studies of volcanoes and earthquakes to organize the engineering and hydrometric units of the new Survey. The third and final major innovation was to establish a camp at Embudo, on the Rio Grande in northern New Mexico, to train young engineering school graduates in the art of stream gaging.

There were numerous reasons for selecting this seemingly remote site for that camp, namely:

1. Funds made available by Congress to the Irrigation Survey were intended for use in the arid region; thus all sites east of the 100th meridian were immediately eliminated from consideration.
2. To get the new program under way as soon as possible after October 2 (when the appropriation bill was passed), weather had to be taken into consideration. Practically all northern streams, which would soon be frozen over, had to be eliminated, and only those in the southwest were left for consideration.
3. Convenient railroad transportation directly to the site was necessary to expedite the project.

Besides meeting all those requirements, the Rio Grande at Embudo was of just about the right size for the intended purpose. There were also some problems developing in the valley for which streamflow records might serve useful purposes. One was a large irrigation dam near Santa Fe that was being talked about. Another had international implications. Farmers in Mexico were becoming uneasy about the amount of water the irrigation farmers in the upper reaches of the river diverted during dry periods, leaving them with an inadequate supply for watering Mexican crops. The selection of Embudo for that campsite seems, therefore, to have been adequately justified.

CAMP EMBUDO

So it was that on the 9th of December in 1888 a group of at least eight young engineers, most of whom had recently been graduated from eastern colleges, stepped off a coach of the narrow gage Denver and Rio Grande Railway at Embudo, N. Mex. Only one of them, W. A. Farish, was a westerner. The others, acquainted almost exclusively with eastern scenery, must have found those surroundings strange indeed. Embudo is a Spanish word meaning "funnel," and that name was well chosen for this area. Here the cactus-and-piñon clad foothills of the San Juan Mountains toward the west and of the Culebra Range of the Rocky Mountains toward the east converge to form a gigantic funnel through which the Rio Grande continually discharges its contents.

These young engineers represented perhaps the first persons to have been employed in the new Irrigation Survey under Maj. John Wesley Powell. Between Major Powell and his assistant, C. E. Dutton, (an Army captain on detail from the Ordnance Corp), it had been decided that the new Bureau should consist of two main divisions—a Topographic Survey and a Hydraulic Survey—and that the Hydraulic Survey should be divided into an Engineering Branch and a Hydrographic Branch. While there was at the time a plentiful supply of good topographers and capable irrigation engineers for staffing some of those units, the problem of finding suitable employees to staff the Hydrographic Branch was quite a different matter. Captain Dutton (in Powell, 1889, p. 79) explained it as follows:

In view of the novelty of the work thus involved upon the survey, of the impossibility of finding men skilled in the work

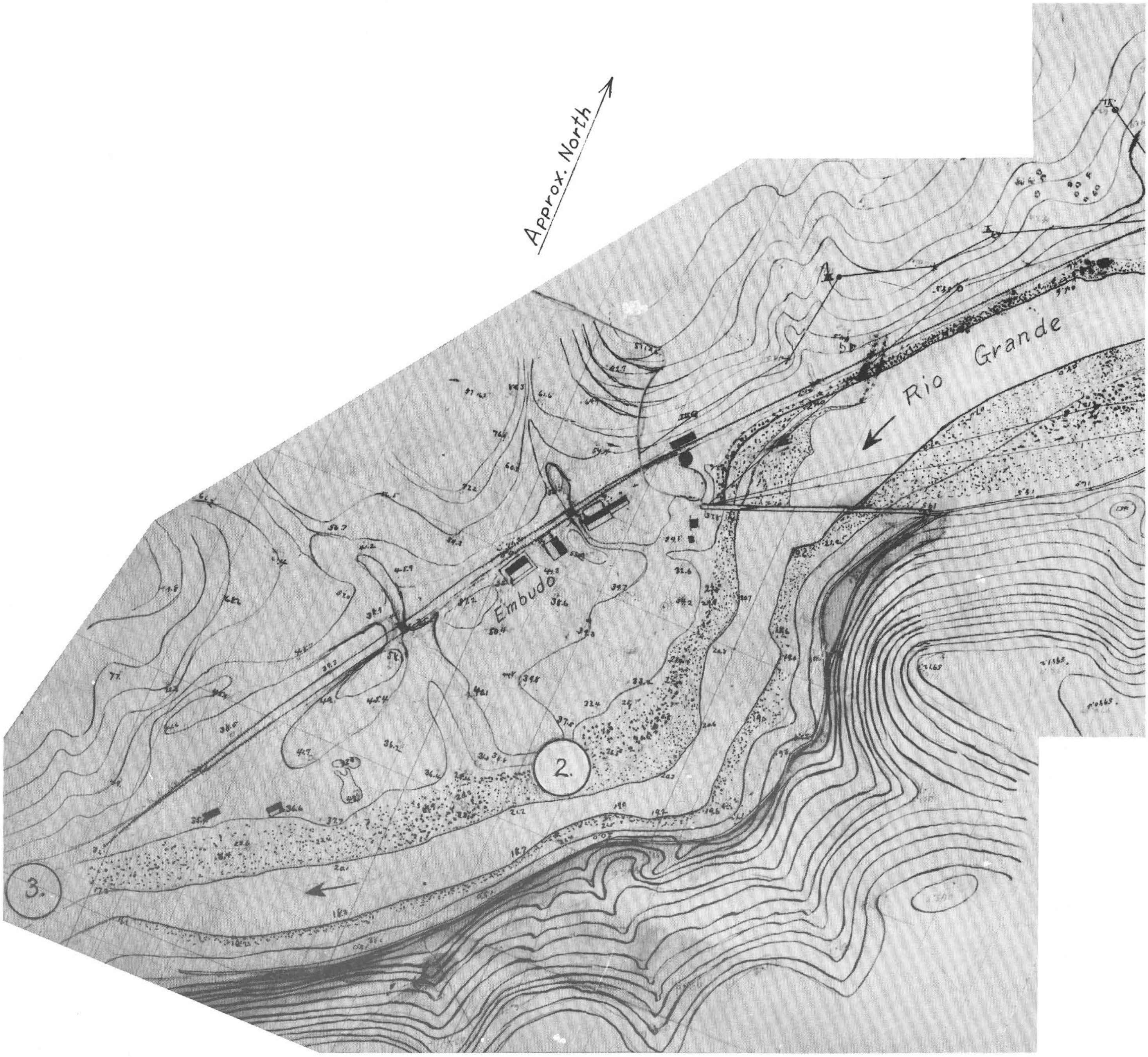
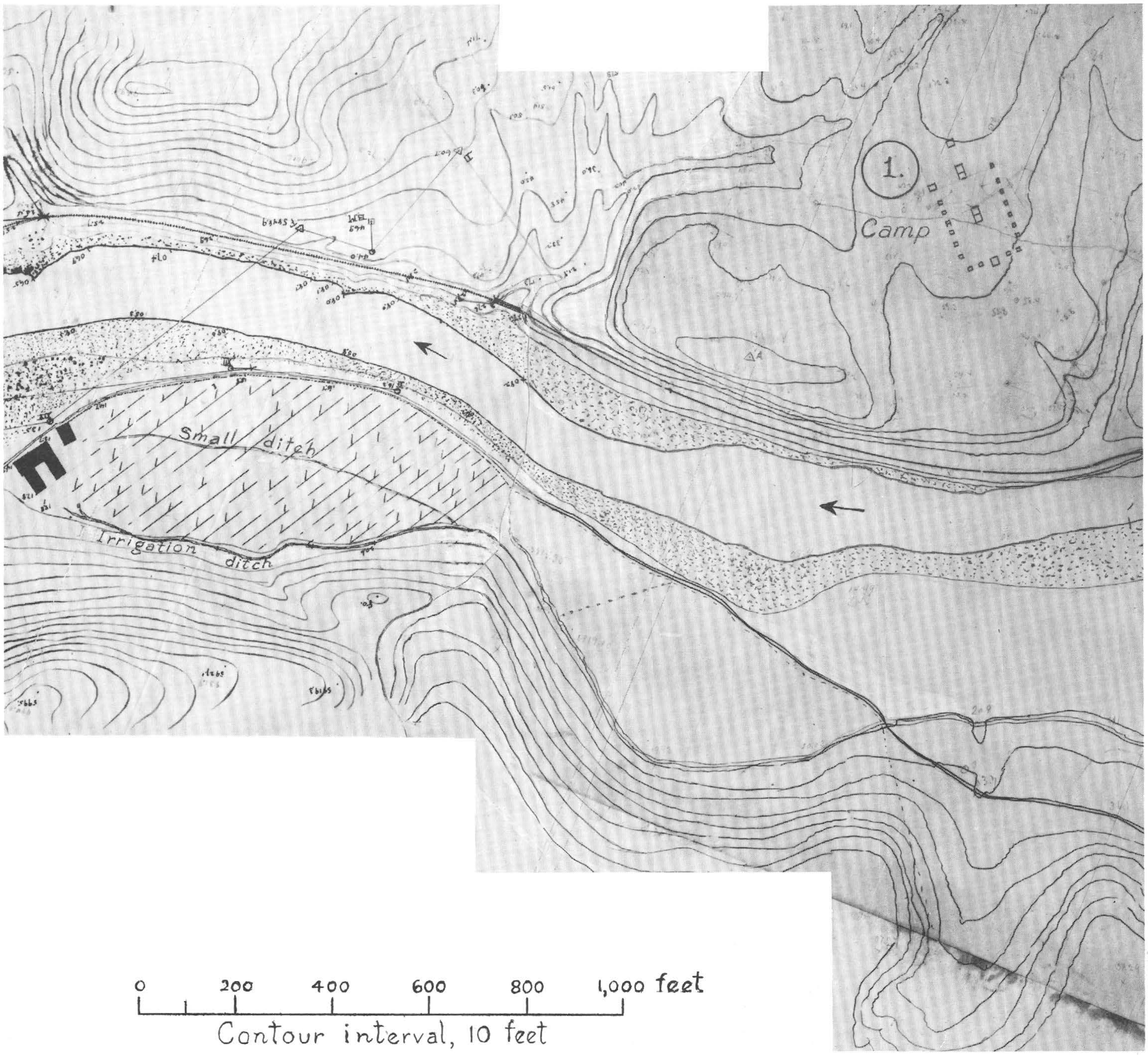


FIGURE 2.—Topography at Embudo, N. Mex. Surveyed in 1889 by L. D. Hopson and W. P. Trowbridge, Jr. 1, Camp

required, of want of instruments adapted to the work, and in further view of the fact that the winter was near at hand, during which the fieldwork would, in most portions of the West, be impracticable, it was deemed best to select a small body of men of good education and high general intelligence and establish them at some advantageous station where they could, in the course of the winter months, acquire a knowledge of the methods and instruments they would have to employ. Fourteen young men were carefully selected and were placed in a camp of instruction, situated at Embudo on the Rio Grande River, about 50 miles north of Santa Fe, in New Mexico, where they passed the winter in practicing with the various instruments selected for trial and in becoming familiar with the theory and practical application of the methods. In the month of April the camp was broken up and the men distributed to their respective fields of work.

The camp of instruction at Embudo was placed in charge of Mr. F. H. Newell, and the work required of the men consisted in practicing stream gauging by various methods, measuring the rise and fall of the stream from day to day, measuring the daily evaporation, and making observations with meteorological instruments.



Embudo training center for Irrigation Survey hydrographers. 2, Location of 1889 gage. 3, Location of gage in 1969.

Photographs of the three top officials of this new Irrigation Survey—John Wesley Powell, Clarence Edward Dutton, and Frederick Haynes Newell—are presented in figures 1, 19, and 20, respectively.

It is true that some western States, California and Colorado in particular, had previously engaged in stream gaging operations of their own, but W. H. Hall, who directed the work in California, and E. S. Nettleton, who directed similar work in Colorado, soon became members of the Engineering Branch of the Irrigation Survey, where their previous experience and special talents were of great value.

No mention of it could be found in the surviving records, but it seems very likely that the group of young engineers, including P. H. Christie and F. H. Newell (who arrived at Embudo before the others), spent their first night or two in the tiny railroad station because there were very few other suitable buildings in the area. But on December 10, 1888 (the day following their arrival), a supply of tents, purchased from the Army especially for their use, and a supply of folding cots arrived. The campsite, which Newell and Christie had probably selected while waiting for the others to arrive, was in a sheltered spot among the hills of the landward side of the railroad tracks about 0.6 mile upstream from the station. Its location is shown in figure 2, which is a partly reconstructed topographic map surveyed in 1889 by two of the students, L. D. Hopson and W. P. Trowbridge, Jr.

The next order of business for the group was to clear the campsite and to set up the tents. And since those tents showed promise of affording the men better sleeping quarters than they had during the previous nights, the job must have been tackled with considerable alacrity. But that promise failed to materialize. With Embudo's elevation being over 5,800 feet, the winter temperatures, especially at night, turned out to be much colder than was anticipated. In an effort to adjust to this new problem, most of the men abandoned their cots and slept in blankets in shallow trenches dug into the dirt floors of their tents. A few of the more enterprising members even excavated a cave into a side hill, where they slept in relative comfort until the camp goat fell through the chimney and "wrecked things generally." A higher and stronger chimney was subsequently installed, and the cave was reoccupied (Follansbee, 1939, p. 47). A contemporary photograph of the camp is shown in figure 3, and a recent photograph of the same area, in figure 4.

Camp personnel

Soon after that first group of engineers finished erecting the tents, four more candidates for instruction arrived. A final one came during the following March. Prof. G. E. Curtis of Washburn College, Topeka, Kans. (who had formerly been with the U.S. Signal Service), also arrived. He was employed to instruct the men in the care and use of meteorological instruments. A cook, two laborers, and a packer rounded out the quota of 21 permanent members of the group. A list of their names follows:

1. F. H. Newell (in charge)
2. Prof. G. E. Curtis (instructor)
3. T. M. Bannon
4. P. H. Christie (topographer and disbursing officer)
5. H. M. Dyar (who arrived in March 1889)
6. W. A. Farish
7. Frank Harrison
8. L. D. Hopson (who helped survey map shown in fig. 2)
9. R. P. Irving
10. L. B. Kendall
11. A. C. Lane
12. J. W. Mitchell
13. G. T. Quinby
14. Robert Robertson
15. R. S. Tarr
16. W. P. Trowbridge, Jr. (who also helped survey map in fig. 2)
17. J. B. Williams
18. Frank Fisher (laborer)
19. Juan Romero (laborer)
20. Dick Shumway (packer)
21. Charlie Hines (cook)

Their monthly salaries ranged from $100 for Newell and Williams to $75 and $50 for the others. No photographs are known to exist in which all 21 members appear together, but two were taken in which about half of them appeared in each. Those photographs, together with their identifications wherever known, are shown in figures 5 and 6.

STREAM-GAGING OPERATIONS

J. B. Williams, who seems to have had some actual previous experience at stream gaging, selected the site for their first measuring section. There they built themselves a raft, using four empty barrels for floats, and they stretched a rope across the river for holding the raft at the various places where soundings and velocity measurements were obtained. Except for a statement that this section was located "about one-half a mile upstream from the camp," no closer identification of it has been found.

Because no current meters were immediately available, a variety of float measurements were the first to be made of the Rio Grande. Later, levels were run alongside the river to ascertain its slope, and formulas were used for computing the discharge. Each day a different student was appointed to gather meteorological data such as readings of the barometer every hour, twice-a-day temperatures of the river water, and readings of the amount of water that had evaporated from the cook's bread pan (which had been commandeered for making such experiments).

Early in January 1889 the equipment became more sophisticated. The measuring section was moved downstream to a point opposite the railroad station. A steel cable (rather than a rope) was stretched across the river, and a separate tag line was stretched above it for locating the measuring points. A boat was obtained from which to gather the streamflow data while held in place by ropes

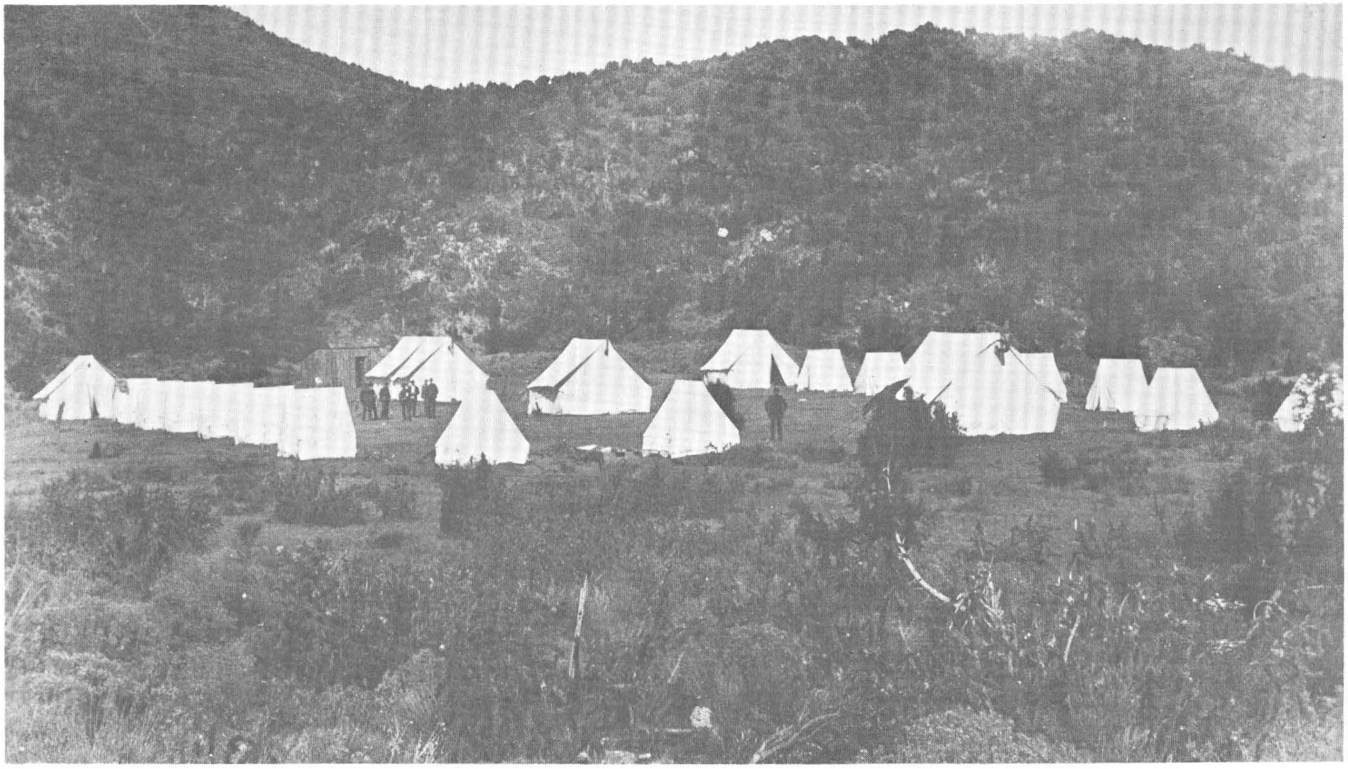


FIGURE 3.—Camp Embudo, N. Mex. (1888-89).

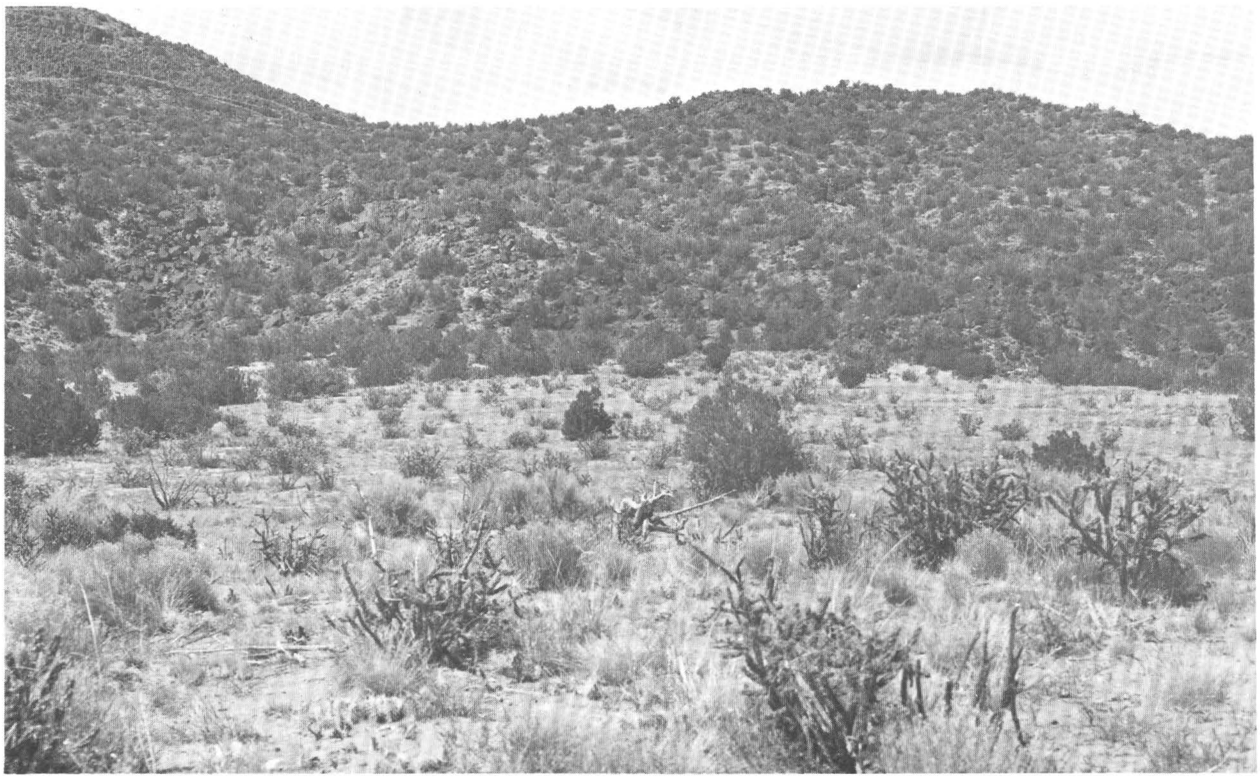
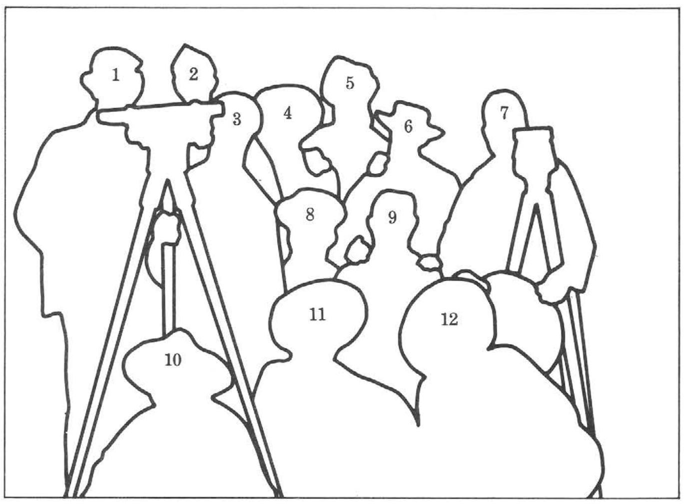


FIGURE 4.—Embudo campsite (1969).



1. L. S. Kendall
2. W. P. Trowbridge, Jr.
3. Prof. George E. Curtis
4. T. M. Bannon
5. F. H. Newell
6. George T. Quinby
7. Robert Robertson
8. R. S. Tarr
9. R. P. Irving
10. Dick Shumway (packer)
11. J. W. Mitchell
12. W. A. Farish

FIGURE 5.—Student hydrographers at Embudo.

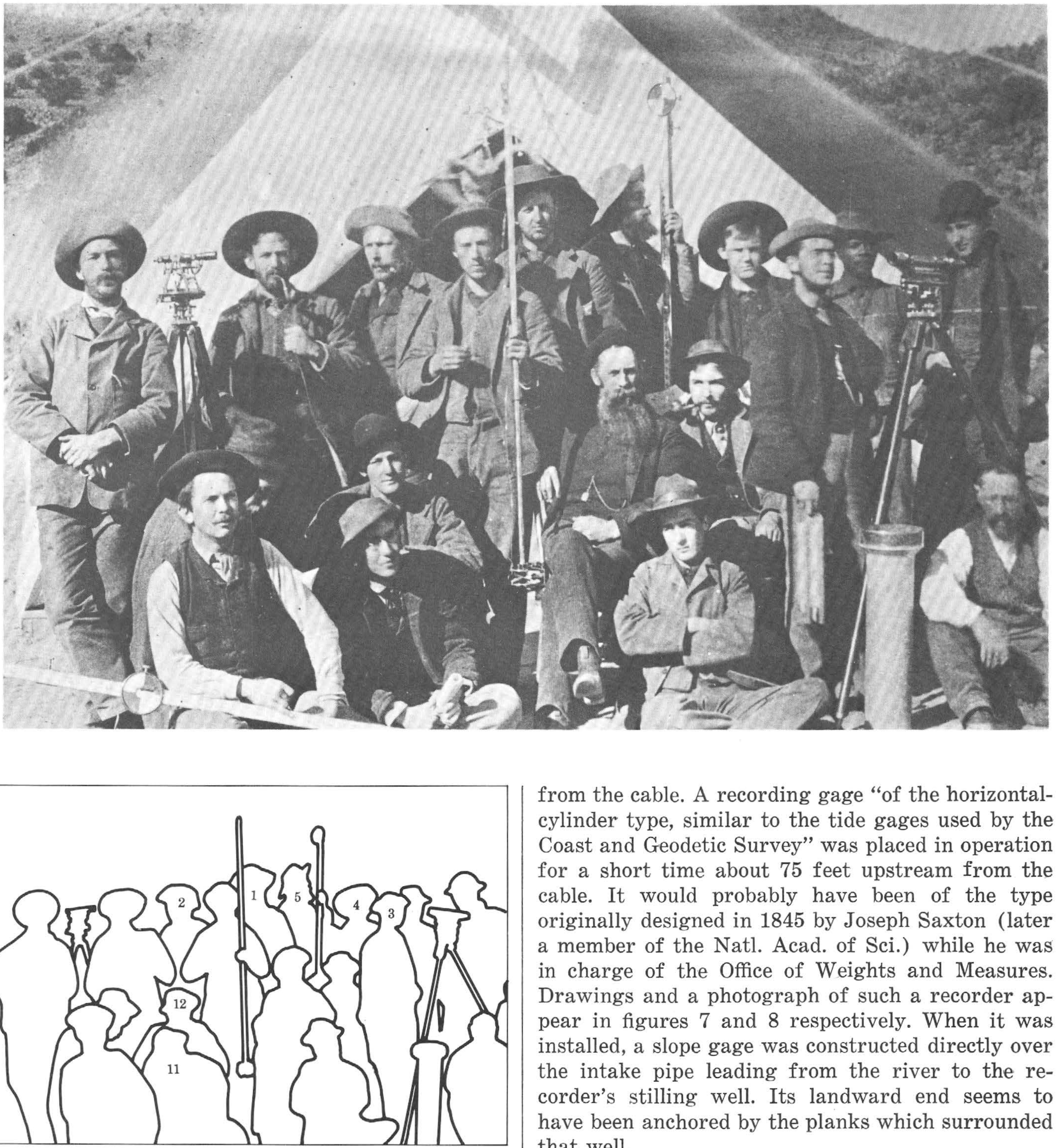


FIGURE 6.—Student hydrographers at Embudo. Note: The numbered individuals are believed to be the persons bearing those same numbers in figure 5.

from the cable. A recording gage "of the horizontal-cylinder type, similar to the tide gages used by the Coast and Geodetic Survey" was placed in operation for a short time about 75 feet upstream from the cable. It would probably have been of the type originally designed in 1845 by Joseph Saxton (later a member of the Natl. Acad. of Sci.) while he was in charge of the Office of Weights and Measures. Drawings and a photograph of such a recorder appear in figures 7 and 8 respectively. When it was installed, a slope gage was constructed directly over the intake pipe leading from the river to the recorder's stilling well. Its landward end seems to have been anchored by the planks which surrounded that well.

Figure 9 presents a photograph of some of those new stream gaging facilities. In it the recording gage shelter and the slope gage appear together along the shore toward the right, and the cableway, with the boat resting behind it, toward the left. At

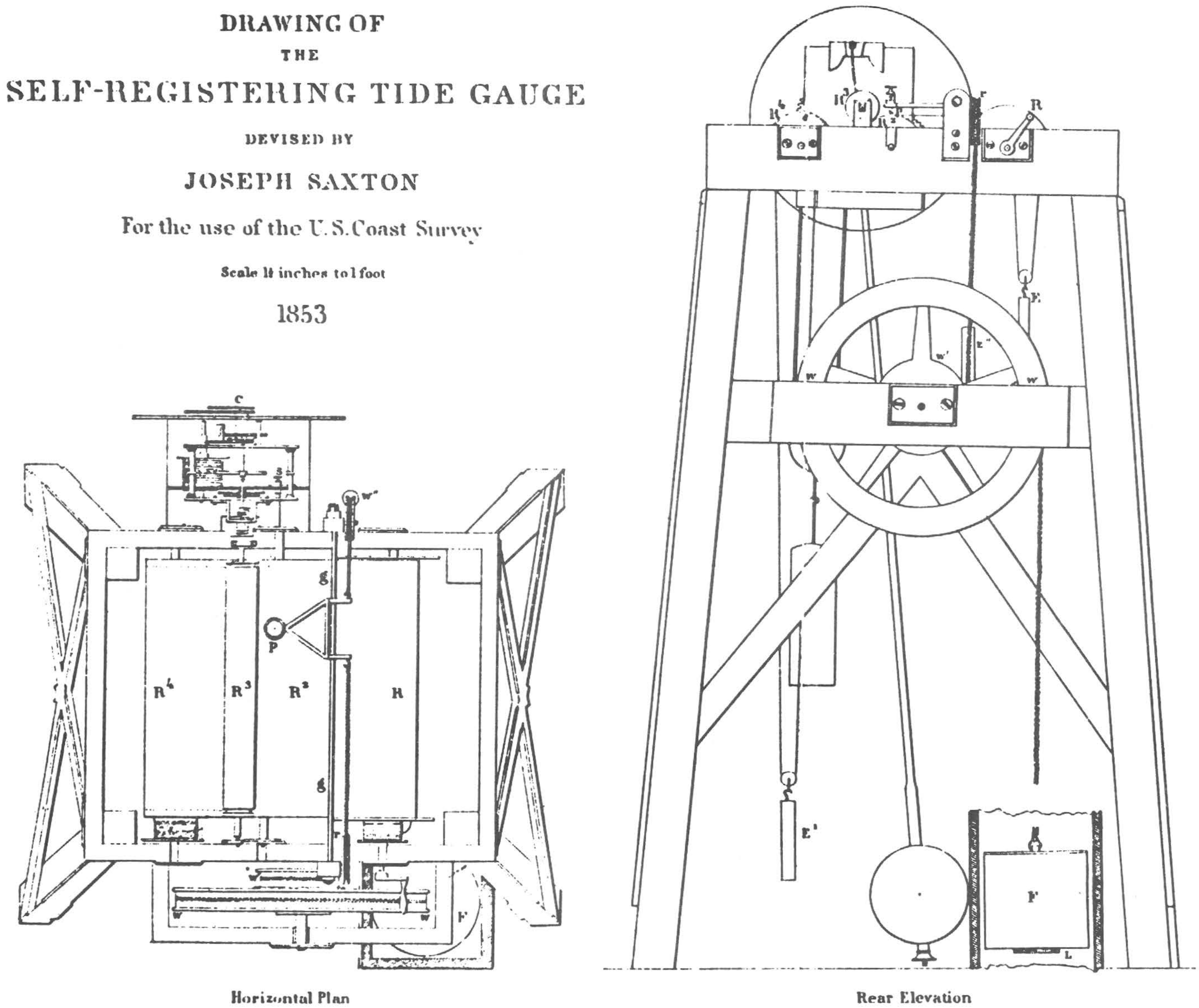
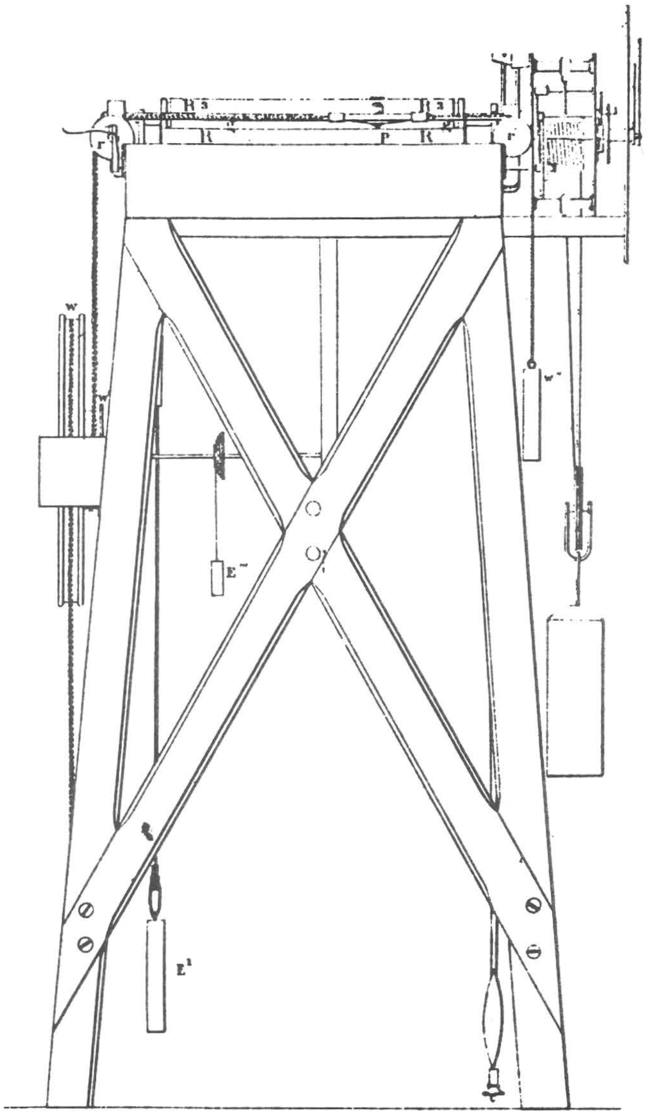


FIGURE 7.—Drawings of Saxton's tide gage.

the time this photograph was taken (about 1889), the railroad station did not have the veneer of cobblestones it now has. That veneer was added to it after 1912 by Henry Wallace, a new station agent who arrived at Embudo about that time, as shown in figure 10. The railroad, incidently, was abandoned in this area in 1941. The "Albuquerque Journal" reported that 55 miles of tracks had been "lifted" to be sent to China for use on the Burma Road. Other sources indicate that some of the locomotives were sold to the U.S. Army in 1942 and sent to the Yukon for use on the White Pass and Yukon and also that some of the passenger cars may still be seen at the Colorado Railroad Museum at Golden, Colo.

But to return to those 1889 innovations at the camp: The bread pan was replaced by a custom-built evaporating pan having floats for allowing it to rest on a pool of water. It was also provided with a built-in precision scale for measuring the amounts of water that had evaporated between observations. Figure 11 presents a drawing, from the "Second Annual Report of the Irrigation Survey" (1889-1900), of that new evaporating pan.

A program of collecting water samples from which to determine the amount of sediment carried by the river was inaugurated soon after facilities arrived for drying and weighing such samples. Studies were even made of the bedload movement. The first paragraph in a notebook presently (1969)



Side Elevation

FIGURE 7.—Continued.

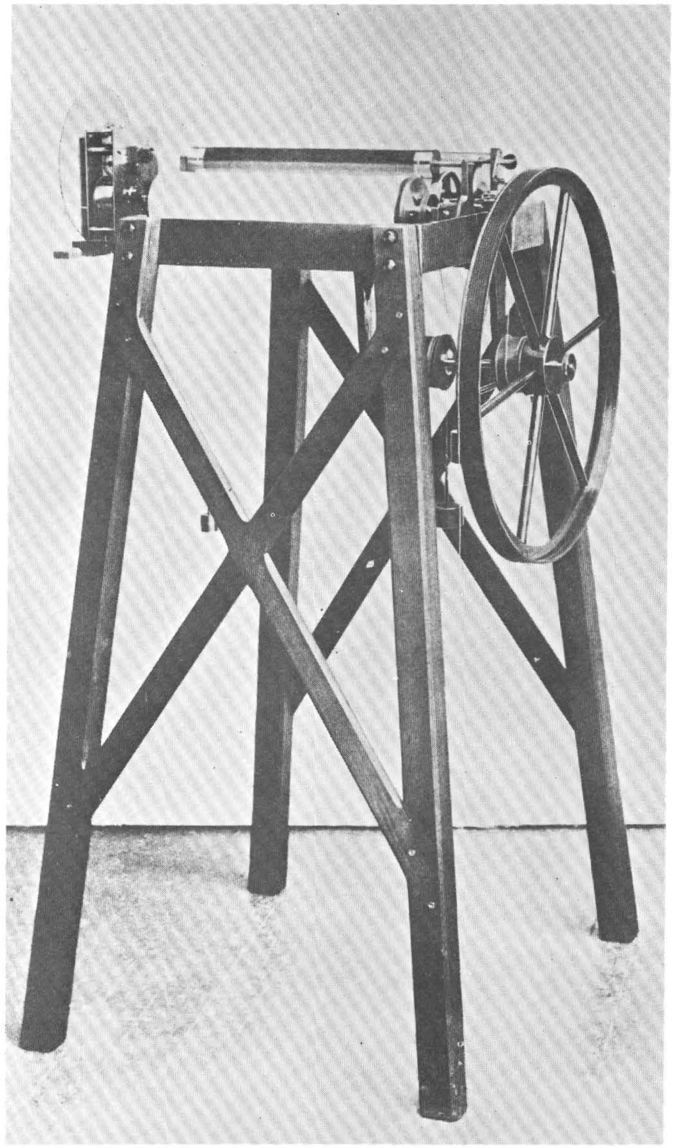


FIGURE 8.—Saxton's tide gage. Photograph supplied by Coast and Geodetic Survey.

in the Albuquerque office of the Geological Survey contains the following statement on that subject:

> Jan. 4, 1889. This investigation was begun with the help of Mr. Mitchell. The object is to determine the volume of the larger pebbles or sand at various points of what is, or what has been river bottom, with the hope of finding the connection between their size and the current velocity by which they were deposited.

The bulk of the fieldwork on that project seems to have been done by L. B. Kendall, A. C. Lane, and R. P. Irving in the reach of the Rio Grande just downstream from the wagon bridge shown later in figures 15 and 16.

Their approach to this subject was both mathematical and empirical. The notebook contains numerous references to similar studies made by distinguished earlier investigators and starts off with a formula derived by Sir Archibald Geikie, a friend of John Wesley Powell's. The work shows evidence of having been conducted at a surprisingly high scientific level.

The first current meter the group eventually obtained was furnished by the U.S. Navy. It was a cable-suspended Haskell Direction-Indicating Meter (U.S. Patent No. 384,362). (See Follansbee, 1939,

FIGURE 9.—Embudo gaging station on the Rio Grande, N. Mex. (about 1889).

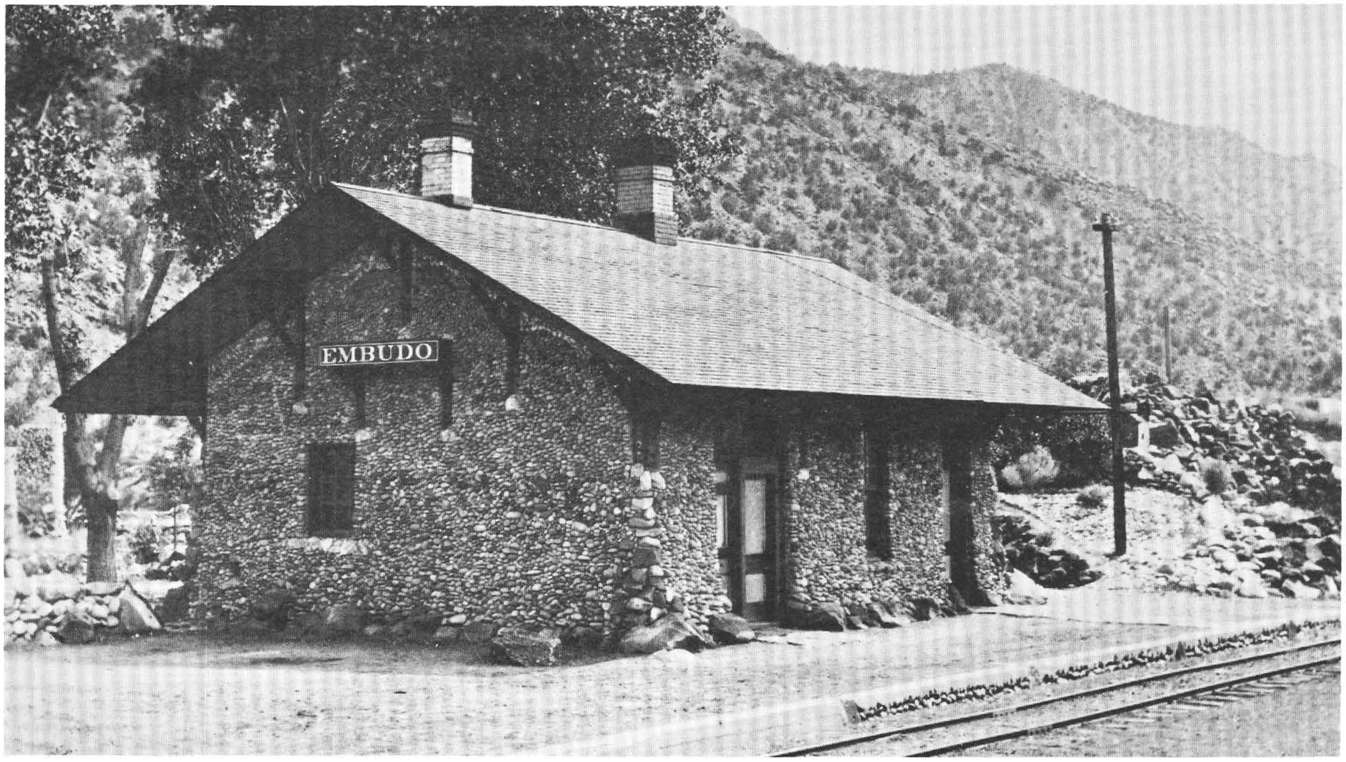


FIGURE 10.—Denver and Rio Grande Railway station at Embudo (about 1912). Photograph supplied by State Historical Society of Colorado.

p. 49.) For shallow water, such as occurs at Embudo during winter months, this meter was far too large and much too cumbersome for practical use. Several suggestions were offered in the hope of making it more suitable for use under the existing conditions, and J. B. Williams made numerous trips to an instrument shop in Denver to obtain a model in which such changes were incorporated. A photograph showing the "before" and "after" designs appears in figure 12. While those changes were under way, another meter—one with rod suspension that was designed several years earlier by E. S. Nettleton for use on Colorado streams—became available. One of them has already been shown at the center of the group in figure 6.

It did not require much time for suggestions to be offered for improving Nettleton's meter also. Records show that on May 16, 1889, Professor Curtis rated an improved model thereof and that, beginning July 12 of that same year, G. T. Quinby made a series of three measurements with it of the Rio Grande at San Marcial, some 200 miles or more downstream from Embudo. The first page of a later measurement at San Marcial is shown in figure 13.

The improved model of the Nettleton meter was called the Bailey meter, most likely after the junior member of an instrument-making firm in Denver then called Lallie and Bailey, where a considerable number of them were manufactured. It is interesting to note that the Nettleton meter has frequently been called a Lallie current meter, so that both

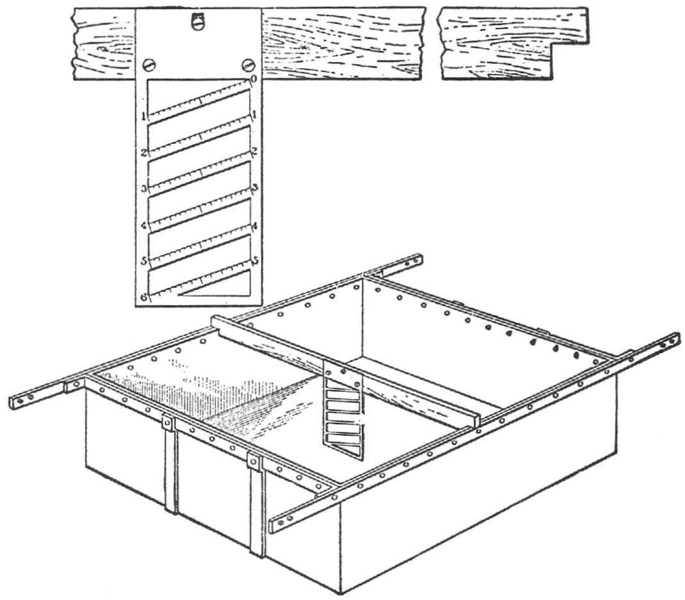


FIGURE 11.—Evaporation pan.

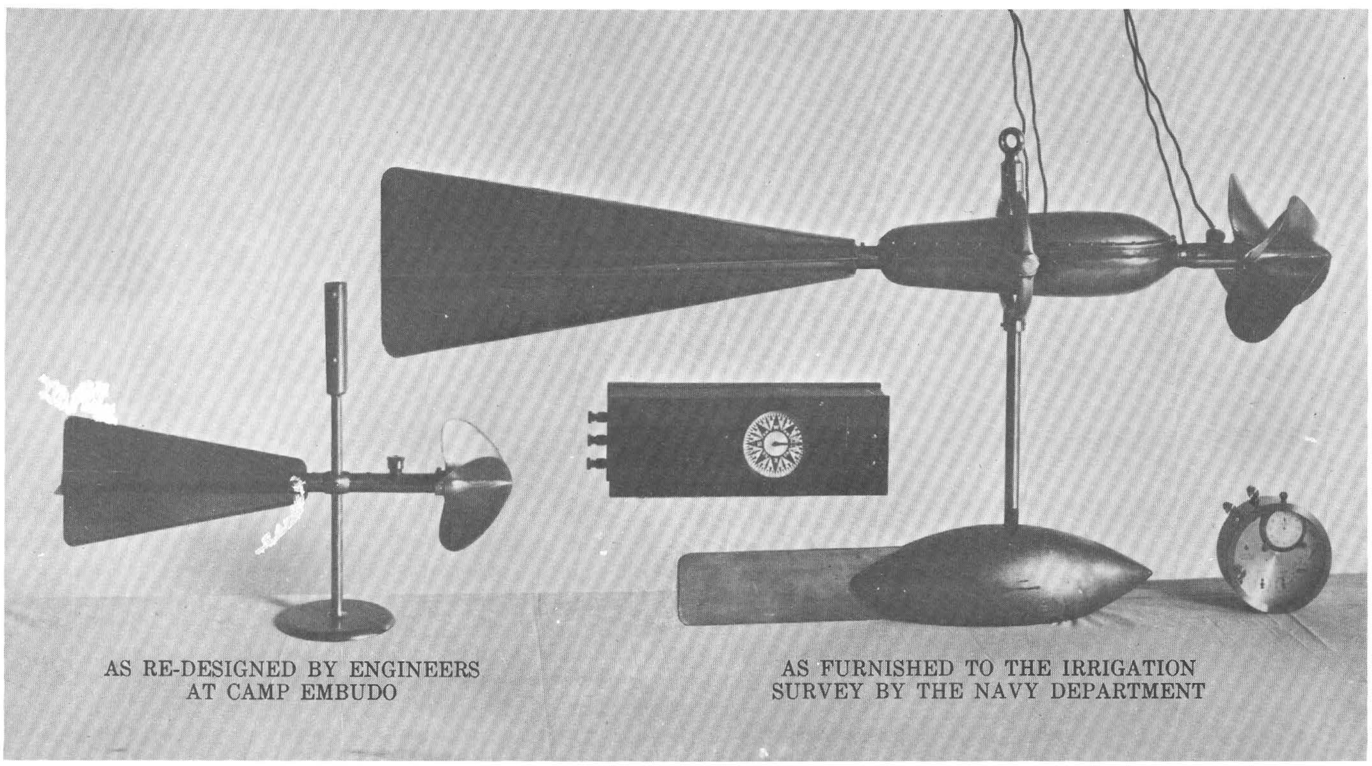
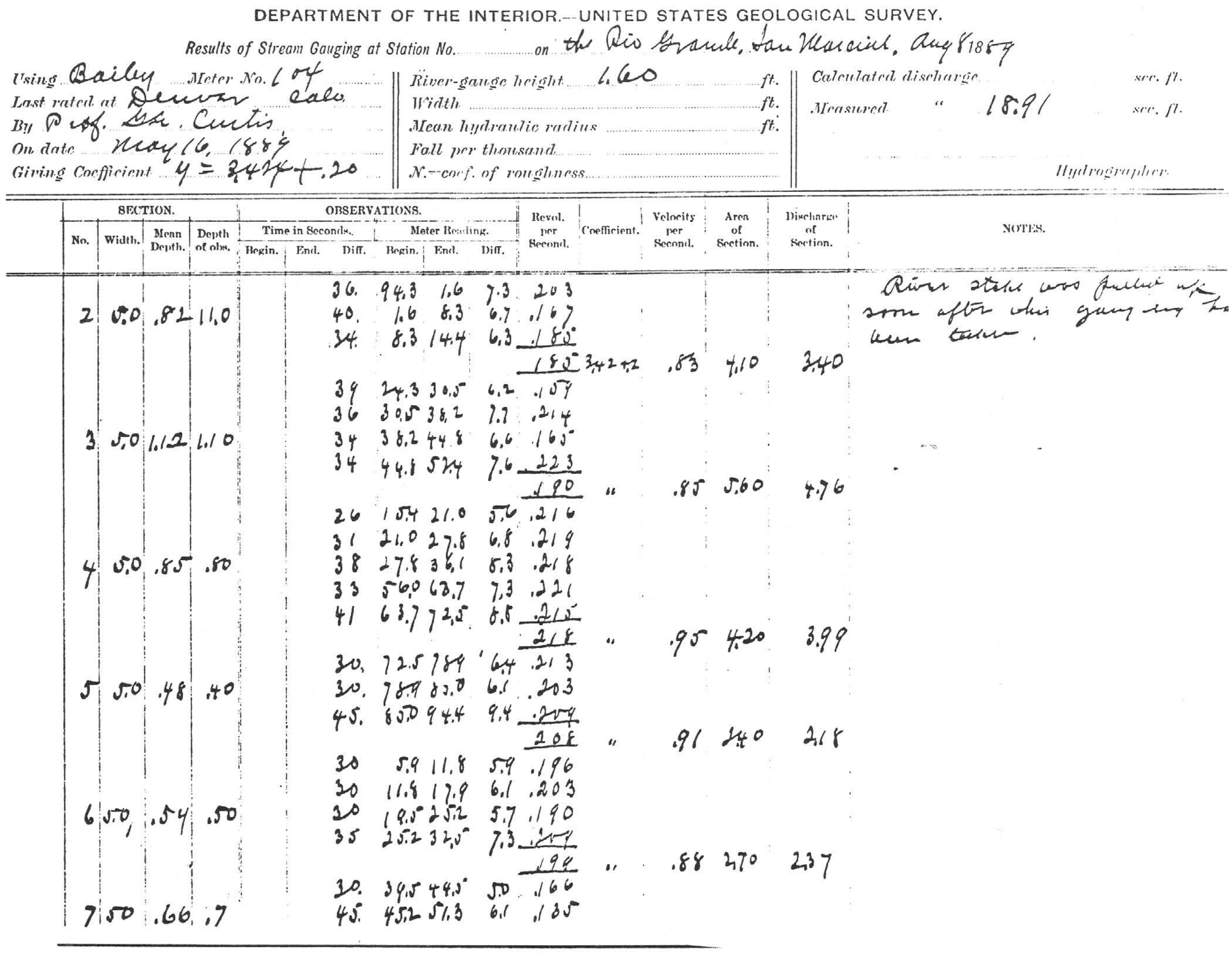


FIGURE 12.—Haskell current meters.



DEPARTMENT OF THE INTERIOR.—UNITED STATES GEOLOGICAL SURVEY.

Results of Stream Gauging at Station No. .... on the Rio Grande, San Marcial, Aug 8 1889

Using Bailey *Meter No.* 104	*River-gauge height* 1.60 *ft.*	*Calculated discharge* .... *sec. ft.*
Last rated at Denver Colo.	*Width* .... *ft.*	*Measured* " 18.91 *sec. ft.*
By Prof. Geo. Curtis	*Mean hydraulic radius* .... *ft.*	
On date May 16, 1889	*Fall per thousand*	
Giving Coefficient y = 3.414 + .20	*N.—coef. of roughness*	*Hydrographer.*

SECTION.				OBSERVATIONS.						Revol. per Second.	Coefficient.	Velocity per Second.	Area of Section.	Discharge of Section.	NOTES.
No.	Width.	Mean Depth.	Depth of obs.	Time in Seconds. Begin.	End.	Diff.	Meter Reading. Begin.	End.	Diff.						
						36.	94.3	1.6	7.3	.203					River stake was pulled up soon after this gauging has been taken.
2	5.0	.82	11.0			40.	1.6	8.3	6.7	.167					
						34.	8.3	14.4	6.3	.185					
										.185	3.414.2	.83	4.10	3.40	
						39	24.3	30.5	6.2	.159					
						36	30.5	38.2	7.7	.214					
3	5.0	1.12	1.10			34	38.2	44.8	6.6	.165					
						34	44.8	52.4	7.6	.223					
										.190	"	.85	5.60	4.76	
						26	15.4	21.0	5.6	.216					
						31	21.0	27.8	6.8	.219					
4	5.0	.85	.80			38	27.8	36.1	8.3	.218					
						33	56.0	63.7	7.3	.221					
						41	63.7	72.5	8.8	.215					
										.218	"	.95	4.20	3.99	
						30.	72.5	78.9	6.4	.213					
5	5.0	.48	.40			30.	78.9	85.0	6.1	.203					
						45.	85.0	94.4	9.4	.209					
										.208	"	.91	2.40	2.18	
						30	5.9	11.8	5.9	.196					
						30	11.8	17.9	6.1	.203					
6	5.0	.54	.50			30	19.5	25.2	5.7	.190					
						35	25.2	32.5	7.3	.209					
										.199	"	.88	2.70	2.37	
						30.	39.5	44.5	5.0	.166					
7	5.0	.66	.7			45.	45.2	51.3	6.1	.135					

FIGURE 13.—Discharge measurement notes, Rio Grande at San Marcial, N. Mex., August 8, 1889.

members of that firm have had meters named after them. That firm, however, was not the exclusive manufacturer of the Nettleton-type meters. An instrument maker named W. E. Scott, also of Denver, built several of the earlier models. Figure 14*A* shows one of the Nettleton meters as built by Scott, and figure 14*B* shows one of the improved "Bailey" models. The meters shown in both of these photographs are from the Smithsonian Institution's large collection of early current meters. As will be seen, the main difference between them is that in the Bailey meter the counting wheels are located in a glass-covered compartment whereas the wheels of the other are not so enclosed. The purpose of the enclosure was to prevent grasses and other fibrous materials carried in the streams from becoming enmeshed in the gears of those counting wheels.

With the advent of these rod-suspended meters, experiments were made in order to determine how velocities could best be measured with them. The following three methods which seemed most attractive have been described essentially as on pages 13 and 14 in the "Second Annual Report of the Irrigation Survey":

1. In shallow streams, as are most of the rivers of the arid region, the work can be shortened by what is called integration. Instead of using the meter at various given points in a vertical line, it is moved at a very slow, uniform speed down and up, from top to bottom and back again, to obtain an average of the velocities at all points in the vertical. In this case the river is considered as being divided into a number of independent narrow streams of equal width, the discharge of each being obtained by multiplying its area into the observed average velocity in its central position; then, by adding these discharges together, the total for the whole river is found. With a little practice the stream gager can raise and lower the meter at a constant rate in any given number of seconds; for example, with water 5 feet deep, starting at the top and going to the

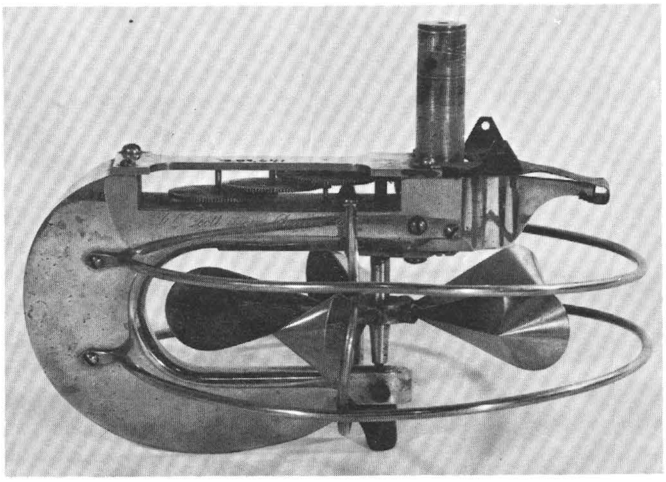
bottom in 20 seconds, then back to the top in 20 seconds more, and repeating three times, making in all, 2 minutes.

2. For measuring the discharge of canals or small streams with nearly level bottoms, the horizontal or diagonal integration method has been occasionally used, obtaining at once an average for the whole flow. The meter is carried slowly from side to side horizontally, or it is moved diagonally from the top on one side down on the cross section at an angle of about 45°, then up at about the same angle from the top, then down, continuing in this way until the opposite side is reached. In the same way a return trip is made up and down, crossing the path of the first, the meter coming out at the top each time over the spot where before it had reached the bottom, and vice versa.
3. In wide, deep rivers, the meter measurements are made at a number of places evenly distributed across the stream, and at each of these places, observations are made of the velocity near the surface, near the bottom, and at various intermediate points, such as 5 to 10 feet apart in the vertical line. In this way the velocity is obtained at a large number of points symmetrically distributed in the cross section, and the average of all is considered to be the velocity of the whole river, the discharge being obtained by multiplying the total area of the cross section at this point by this average velocity.

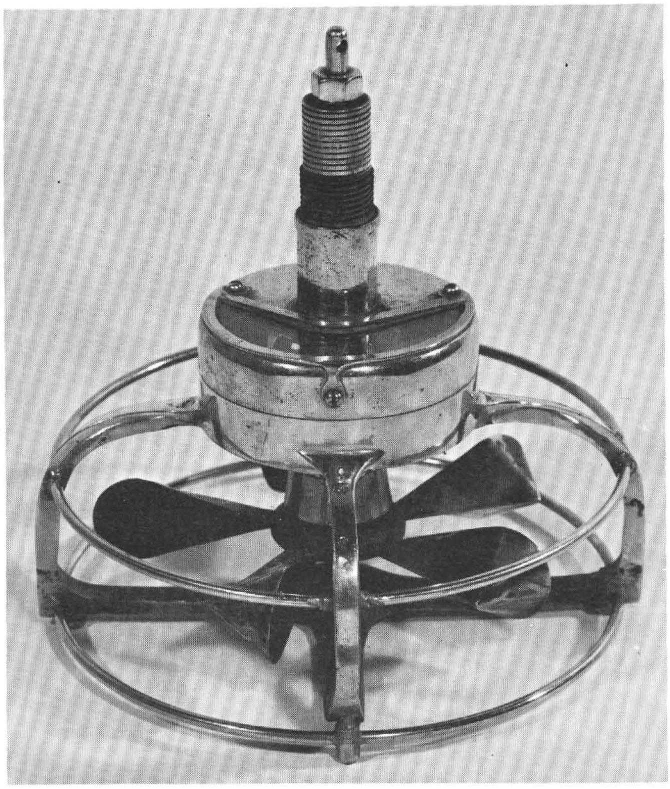
The present practice of taking two velocity observations to obtain the average in the vertical—one at the two-tenths depth, the other at the eight-tenths depth—did not then receive consideration. In fact, what was probably the first suggestion regarding that method was made by H. K. Barrows, then an assistant engineer under N. C. Grover, in charge of the Survey's river work in Vermont and New Hampshire. It appeared in an article that Barrows had written for the July 1905 issue of the "Journal of the Association of Engineering Societies." J. C. Hoyt of the Survey subsequently reported the general adoption of that method in his article entitled "Recent Changes in the Methods and Equipment in the Water-Resources Work of the United States Geological Survey" that appeared in volume 60 (July-December 1908) of "Engineering News."

After the engineers at Camp Embudo had become familiar with the fundamentals of stream gaging, they were sent either singly or in pairs to nearby streams in order that they might gain experience in selecting suitable sites for installing gages and making measurements. In many respects this was also to test their resourcefulness and to find how well the lessons they had received at Embudo had been learned.

Between the end of April 1889, when the training period was completed, and the end of the following July, a little preliminary shuffling of personnel took place, but that ended with 10 of these "students" becoming classified as "Hydrographers" and "Assistant Hydrographers" and their being transferred to the following locations in the arid



A



B

FIGURE 14.—Nettleton current meters. *A*, Manufactured by W. E. Scott. *B*, Redesigned by engineers at Camp Embudo and manufactured by Bailey. Photographs supplied by Smithsonian Institution.

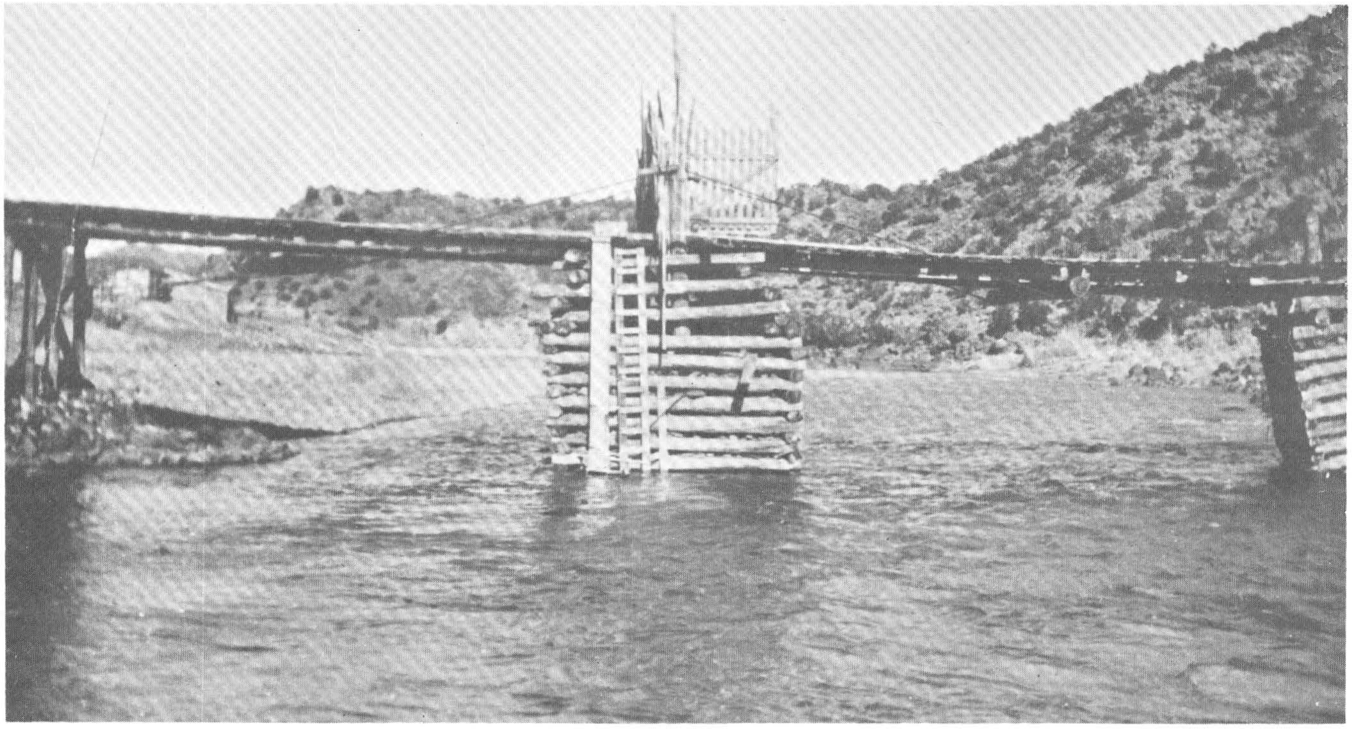


FIGURE 15.—View looking upstream at Embudo at old wagon bridge on which recording and staff gages were in operation 1912-1914.

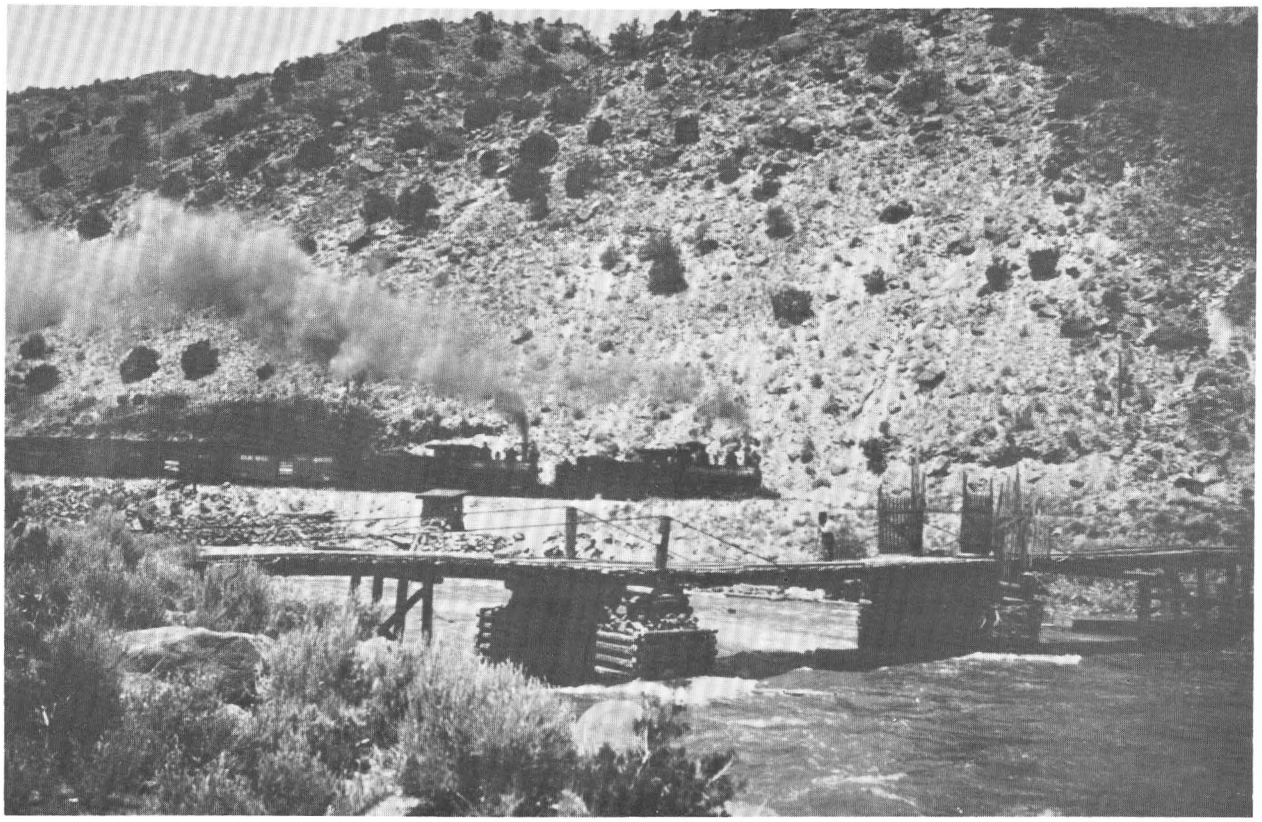


FIGURE 16.—A later view looking downstream and showing, in front of the second locomotive, the new (1914) recording gage shelter.

FIGURE 17.—The present Embudo gaging station.

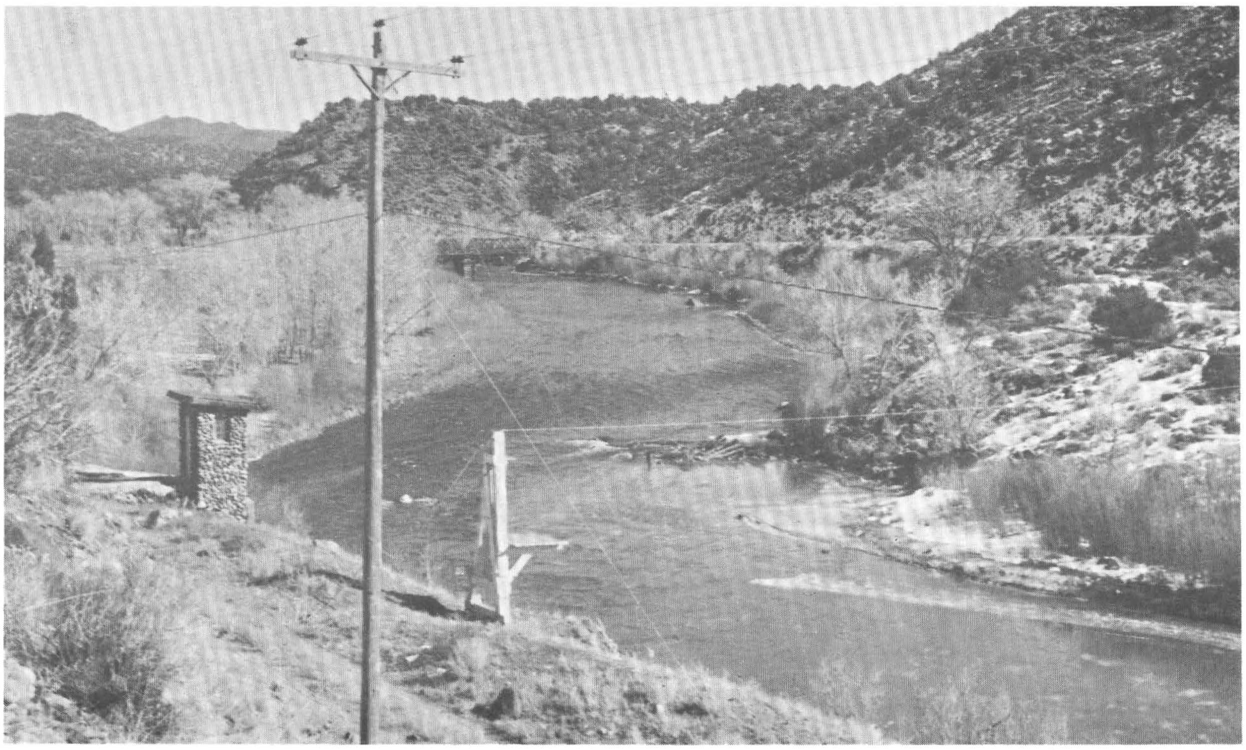


FIGURE 18.—Upstream view of present gaging station.

region with specific instructions as to how to carry out their parts in the Irrigation Survey program:

Arkansas River basin	Robert Robertson and R. P. Irving
Upper Rio Grande basin	G. T. Quinby
Rio Grande at El Paso	H. M. Dyar
Gila River basin	W. A. Farish
Truckee-Carson River basin	W. P. Trowbridge, Jr.
Utah Territory	F. H. Newell and T. M. Bannon
Snake River basin	L. D. Hopson
Upper Missouri River basin	J. B. Williams

Among the remaining engineers, one had left camp before completing the course, another was ready to resign, and the third claimed that he did not care to spend the rest of his life "jiggling a meter."

One feature that was not changed by this exodus was the gaging station itself. The station agent of the railroad, C. L. Pollard, was employed to read the gage, and the discharge records at Embudo were not then interrupted, although beginning in 1904 they were discontinued for several years. When they were resumed in 1912, with a new station agent, Henry Wallace, as the observer, a recording gage and a vertical staff gage were installed on a pier of the Santa Barbara Tie and Pole Co.'s old wagon bridge as shown in figure 15. Two years later, when the bridge became unsafe for that purpose, the gaging station was moved somewhat less than 200 feet farther downstream to its present location on the right bank of the Rio Grande. A concrete well and gage shelter were constructed there along with a cableway from which to obtain streamflow measurements during high-water periods. Both the old and new locations appear in figure 16. The gage observer, Mr. Wallace, has been previously mentioned as having been the man who veneered the railroad station with cobblestones. Inasmuch as he has been reported as having applied such stone facings onto "every object in the vicinity that would hold still," he might very well have had a hand in applying the same kind of a facing onto the new recording gage shelter.

Beginning in 1915, and continuing until 1931, the gaging station was operated by the State of New Mexico, but as of July 1, 1931, the Geological Survey resumed the responsibility for its operation under a cooperative agreement with the State. It has been in continuous operation ever since. Several major improvements were undertaken at the station during the fall of 1941. The overall height of the well was increased by about 7 feet, and a heavy retaining wall was constructed to protect the installation. The old shelter was made use of as part of the new well, and a new shelter was added on top of it. As before, the shelter was veneered with cobblestones to match the railroad station. The old roof was re-used for covering the new shelter. It was made of tile for protection against fires which could have been produced by sparks from the Denver and Rio Grande Railway locomotives which passed close by—a menace that continued until only a few months thereafter, when the operation of the railroad was discontinued. In contrast to the previous arrangement wherein the door of the shelter was located at the upstream side, the new door was placed in the landward side of the house.

Travelers who now pass through Embudo on Highway 64 between Espanola and Taos, N. Mex., have a fine view of that attractive gaging station. Close to the A-frame on the left bank of the river is a neat historical marker. Photographs of the station and marker appear in figures 17 and 18.

With the "graduation" of those student hydrographers from this training camp at Embudo, a high point was attained in the short life of the Irrigation Survey. The occasion also coincided with the zenith of the fabulous career of John Wesley Powell, the creator and topmost official of that Survey.

EPILOG

Despite the remarkable progress that was subsequently made by these young engineers, the Hydrographic Branch of the Irrigation Survey did not last very long, and its final days were marked with several tragedies. H. M. Dyar, who among his other duties kept the Embudo gaging station in operation, had to resign because of ill health. L. D. Hopson, who had helped survey the map shown in figure 2 and who had been detailed to the Snake River basin, was drowned. Finally (on August 22, 1890), an impending curtailment of funds made it necessary for F. H. Newell to advise all the men in the Engineering and Hydrographic Branches to turn over all their equipment, mules, and horses to the nearest topographic field office and to discontinue their official activities (Follansbee, 1939, p. 64). A few of the men, including Newell, were assigned to other duties in the Geological Survey. Others sought employment elsewhere. Shortly thereafter, J. B. Williams committed suicide (Follansbee, 1939, p. 65). With regard to Powell himself, the tribulations he then had to endure were, in a personal way, tragic also.

As previously indicated, John Wesley Powell refused to subscribe to the Utopian claims that were being used as inducements for farmers to settle in the arid region. While prospective settlers were assured that practically all of the land in that region was suitable for farming without irrigation and that once they had plowed their land, "rain would follow the plow," Powell kept insisting that only 1 to 3 percent of such land could be farmed profitably (Darrah, 1951, p. 222). Even then, Powell maintained that irrigation facilities would have to be provided and that the remaining area should be applied, where suitable, to forests and grazing.

The differences between these conflicting views became more acute when both President Cleveland and the Attorney General agreed with Powell's interpretation of proposed legislation related to irrigation. Under that interpretation, Powell would have authority to prevent the entry of homesteaders onto any of the remaining lands of the entire public domain in the arid region until the topographic maps were completed, the hydrographic studies made, the plans for the dams and canals formulated, and as many 80-acre farms were laid out on the map as the volume of available water could support—an undertaking that would obviously require considerable time. Opponents of the Powell point of view insisted "We want crops. We do not want pictures, and the Major is making pictures." (See Sterling, 1940, p. 430.)

FIGURE 19.—Clarence Edward Dutton (1841-1912).

Impatient with anything that tended to delay the movement of settlers into the West, consideration was given to getting the Irrigation Survey transferred to the Department of Agriculture. Being uncertain, however, as to whether that could be achieved in the face of Powell's eminent reputation, the decision was made that the best course was to repeal the entire act and to return to the "status quo ante." (See Sterling, 1940, p. 431.) The House Appropriations Committee was told "Every representative of the arid region would prefer there would be no appropriation to having it continued under Major Powell." (See Sterling, 1940, p. 431.) To that end, opponents of the activities finally demanded and received approval for a Senate investigation to be held on this subject. The hearings lasted from January 17 to March 28, 1890. They are given in Senate Report 928, part 5, 51st Congress, 1st session (Serial No. 2708, p. 5-229). Perhaps the most damaging testimony against Powell was that which related to his handling of the mapping program. He had declared repeatedly that without good topographic maps, the Irrigation Survey could not be carried out in a complete and orderly fashion. It was revealed during the hearings that out of the first $100,000 allotted for irrigation investigations, at least $60,000 had been applied to mapping operations. Moreover, he had also used funds which Congress had appropriated for the regular mapping program of the Geological Survey to help speed up the production of the arid-region maps. Nothing in the legislation prohibited him from doing so, but several witnesses were called to the stand in an effort to establish that such action constituted an improper use of public funds.

One of those witnesses was Powell's administrative assistant, C. E. Dutton (fig. 19). Dutton was

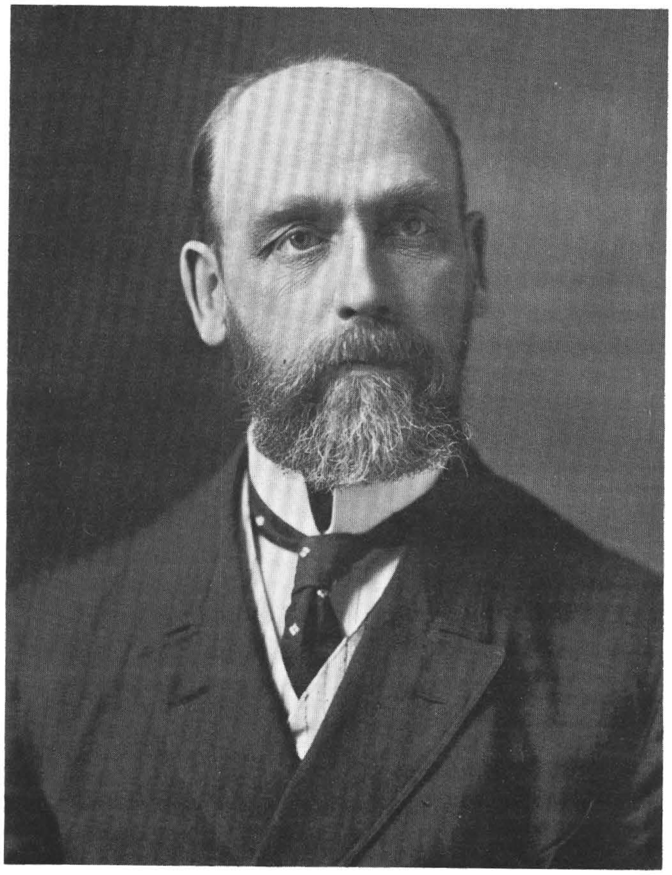


FIGURE 20.—Frederick Haynes Newell (1862-1932).

asked, "Is there any connection, in practical operations between the topographic work and the engineering work; how do they cooperate if at all?" He replied in part (U.S. Congress, Special Senate Committee, 1890, p. 133):

According to my understanding, there is no absolute dependence upon topographic work for the proper conduct of good engineering and hydrographic work; in other words, an engineering and hydrographic survey could be conducted with good results, meeting the purpose and requirements of the law, if there were no topographic survey.

Some Congressmen agreed with Dutton, and some disagreed, but these hearings caused a sharp decline to occur in the popularity which Powell had previously enjoyed. Soon thereafter the goals of the western Congressmen were achieved in a manner that would impede Powell's progress the most, namely through the pocketbook. They had put through an amendment to the Sundry Civil Appropriations Bill (signed August 30, 1890) which had the effect of reducing the $720,000 that Powell had requested for continuing the Irrigation Survey work to only $162,500. And that amount was made available for use only on mapping operations west of the 101st meridian. Powell was accordingly forced to discontinue the engineering and hydrographic sections of the Irrigation Survey, and Newell, as previously mentioned, had to notify the field engineers.

According to Sterling, this whole controversy led to Powell's resignation in May 1894 as Director of the Geological Survey (after he became sure that a competent successor, C. D. Walcott, would be selected to carry on the work). He felt that Congress had lost confidence in him (Sterling, 1940, p. 433). He died at "Haven" in Hancock County, Maine, September 23, 1902.

Soon after the Senate hearings were over, Dutton (then a major) was relieved of his duties with the Irrigation Survey. An order issued by the War Department directed him to report to the Ordnance Office as of July 23, 1890. In a footnote in Stegner's "Beyond the Hundredth Meridian," it is contended that "his testimony before the Committee, and his disagreement with Powell on the propriety of concentrating funds from both appropriations on topography led him to return to regular Army duty." (See Stegner, 1954, p. 414.) He died in Englewood, N.J., January 4, 1912.

With regard to Newell, he was transferred to the Topographic Branch of the Geological Survey, but any stream-gaging problems that came within the purview of the Bureau were referred to him. Soon after Walcott became the new Director, he informed Newell that he found nothing in the legislation which would justify continuing such work. Newell thereupon persuaded Senator W. V. Allen of Nebraska to offer an amendment to a pending Sundry Civil Appropriations Act (Follansbee, 1939, p. 70). It called for the Geological Survey to engage in stream-gaging operations, with no restrictions as to where in the United States such work should be performed. The amendment passed, but not until the small original allotment of $25,000 was reduced to a mere $12,500. Nevertheless, that allotment became available as of August 18, 1894, and since that time, funds have continued to be appropriated regularly for that purpose. F. H. Newell (fig. 20) was its first "Hydrographer in Charge," but in 1907, when the Reclamation Service became separated from the Geological Survey, he was selected as that new Bureau's first Director. He died on July 5, 1932. The pioneer work he performed in those early years in the Geological Survey has led to his having often been referred to as the "father of systematic stream gaging" in this country. Among the many honors he received was the Cullum Geographical Medal in 1918 (McDaniel, 1933) on which was inscribed:

> He carried water from a mountain
> wilderness to turn the waste places of
> the desert into homes for freemen.

President Theodore Roosevelt was among those who publicly expressed high praise for his work (McDaniel, 1933, p 1598). The list of scientific and engineering societies in which he held memberships and actively participated is far too long to be presented here, but the facts that he was Secretary of the National Geographic Society and served on its Board of Managers for several years, that he also served as Secretary of the American Forestry Association for several years, and that it was he who called the first conference which led to the formation of the American Association of Engineers (now defunct, but which had many precepts similar to those of the present National Society of Professional Engineers) and served as its President in 1919 are indications of the variety of his interests and of the extent to which he participated in scientific and engineering activities.

From three historical points of view, therefore, the training camp for hydrographers on the Rio Grande at the tiny village of Embudo, N. Mex., deserves the attention of hydraulic engineers everywhere. It was the site of the first stream-gaging operations of the U.S. Geological Survey; it was authorized by John Wesley Powell at the time when his eminence had arrived at its peak; and it was the starting point of the outstanding career of the camp's engineer-in-charge, Frederick Haynes Newell.

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