Stage-Discharge Characteristics of a Weir in a Sand-Channel Stream

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1898-A

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By D. D. GONZALEZ, C. H. SCOTT, *and* J. K. CULBERTSON

STUDIES OF FLOW IN ALLUVIAL CHANNELS

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1898-A

An evaluation of a prototype control structure designed on the basis of a model study

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STAGE-DISCHARGE CHARACTERISTICS OF A WEIR IN A SAND-CHANNEL STREAM

By D. D. GONZALEZ, C. H. SCOTT, and J. K. CULBERTSON

ABSTRACT

A unique relation between water-surface elevation and water discharge usually does not exist for sand-channel streams. The relation is affected by changes in bed roughness and changes in bed elevation because of scour and fill. An artificial control on a sand-channel stream must control both the resistance to flow and the bed elevation in order to stabilize the relation between water-surface elevation and water discharge.

The weir (control structure) in the Rio Grande conveyance channel near Bernardo, N. Mex., was designed on the basis of a model study and field data (Harris and Richardson, 1964). About 72 percent of the measurements used to define the base relation between water-surface elevation and water discharge falls within plus or minus 5 percent of the mean relation for the prototype. The stage-discharge relation is not affected by backwater for values of submergence less than 90 percent. There is no consistent relation between the ratio of measured discharge to rated discharge and submergence for values of submergence greater than 90 percent.

The control does not restrict the channel capacity to less than the stated design capacity of 2,000 cubic feet per second. When the control is drowned out, or ineffective, the relation of water-surface elevation to water discharge is virtually the same as that prior to construction of the control for discharges greater than 1,500 cubic feet per second. When the control is not drowned out—that is, free-fall conditions exist—the water-surface elevation for a discharge of 2,000 cubic feet per second is greater than the minimum elevation, but is less than the maximum elevation that occurred at that discharge prior to construction.

The model study was only partially successful in predicting the operating characteristics of the prototype. Some of the differences between prototype operation and model predictions may exist because the prototype was not built exactly as recommended on the basis of the model study. In general, the prototype has operated somewhat better than the model predicted.

INTRODUCTION

Sand-channel streams often present problems in the determination of the total volume of water passing a gaging station because a unique relation between water discharge and water-surface elevation generally does not exist. The non-cohesive sand beds of the channels, which control the stage-discharge relation, are subject to changes in roughness and to scour and fill. As a result, the stage-discharge relation often is not well defined, and corrections, based on water-discharge measurements, must be applied.

Simons and Richardson (1962) have described the effects of changing bed roughness on the stage-discharge relation for several hydraulic conditions. Changes in bed roughness in some sand-channel streams may be gradual because the bed form consistent with a given discharge does not completely develop under unsteady flow conditions as a flood wave passes. This condition results in a stage-discharge relation in the form of a loop. Changes in bed roughness, particularly from dune to plane bed, in sand-channel streams sometimes are rather abrupt, resulting in stage-discharge relations that are discontinuous (Colby, 1960; Dawdy, 1961). For sand-channel streams the change from dune bed to plane bed may occur over a wide range of discharges. The cause for the change is not easily defined.

The bed elevation of a long reach of sand-channel stream generally changes very little owing to scour and fill during the passage of a flood wave. However, the change in bed elevation at sections in reaches that are narrower than average can be large (Colby, 1964). Gaging stations often are located at narrow sections, and the stage-discharge relations are subject to the effects of scour and fill.

Natural controls seldom exist on sand-channel streams; however, properly designed artificial controls (weirs) can be used to stabilize the stage-discharge relation. The elevation of the water surface at a given discharge is dependent on depth of flow associated with the prevailing bed form and the prevailing elevation of the bed. The structure must, in effect, control two variables, bed elevation and roughness, to yield a stable rating.

The Rio Grande conveyance channel near Bernardo, N. Mex. (fig. 1), is an example of a sand-channel stream that can present a problem in determining the discharge and the volume of flow at a gaging station. The conveyance channel has steep banks that are fairly well stabilized by native vegetation. In the vicinity of the control, the channel is straight and has a width of approximately 80 feet. Flows greater than about 100 cfs (cubic feet per second) occupy the full channel width. The banks are of alluvial material and the streambed is composed of fine sand (median diameter, 0.17–0.24 mm). The channel, constructed in 1954, was designed to convey 2,000 cfs, which is diverted from the river through the headworks 5 miles upstream from the control. The headworks structure consists of seven gated corrugated metal culverts, 7 feet in diameter. Discharges greater than 2,000 cfs are carried by the floodway. Median flow in the conveyance channel is 315 cfs, and flows exceed 2,000 cfs less than 0.3 percent of the time (fig. 2).

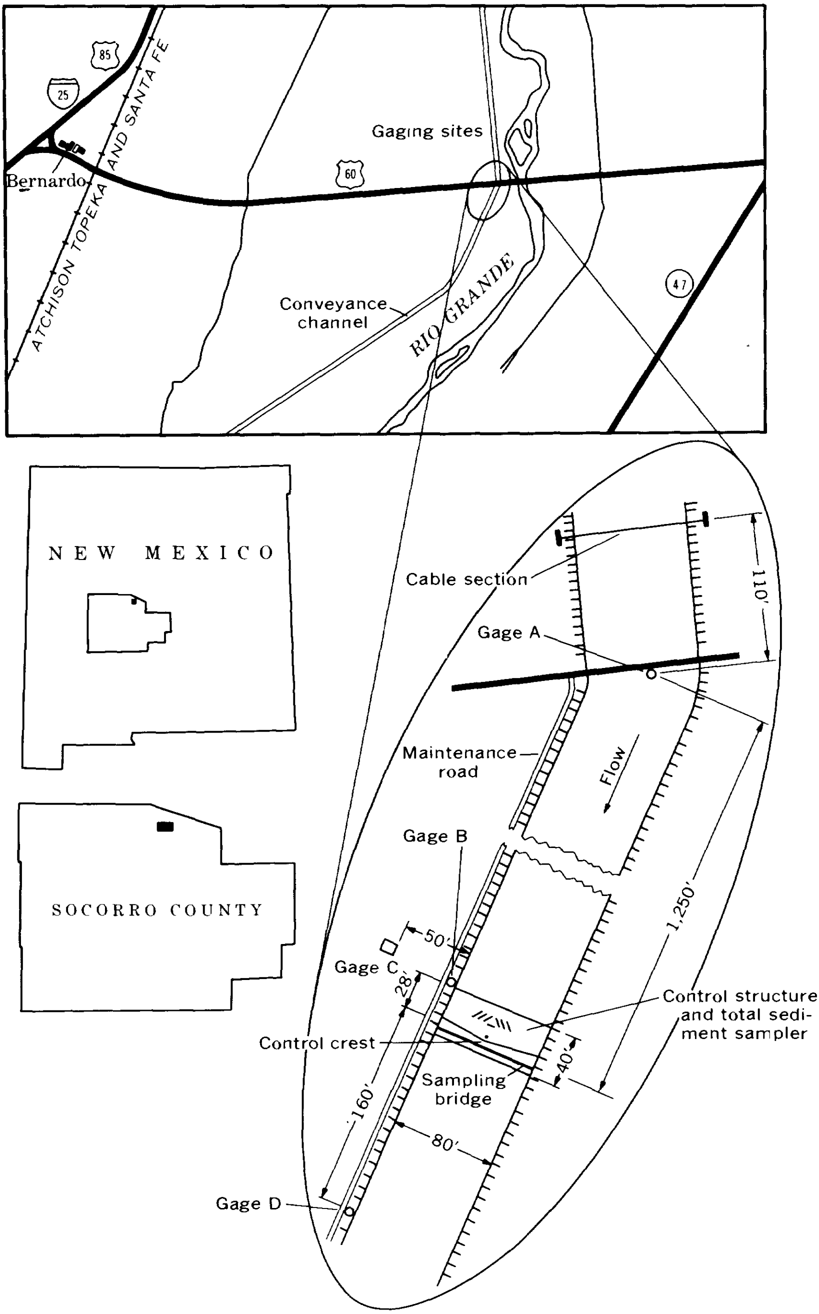

FIGURE 1.—Rio Grande conveyance channel.

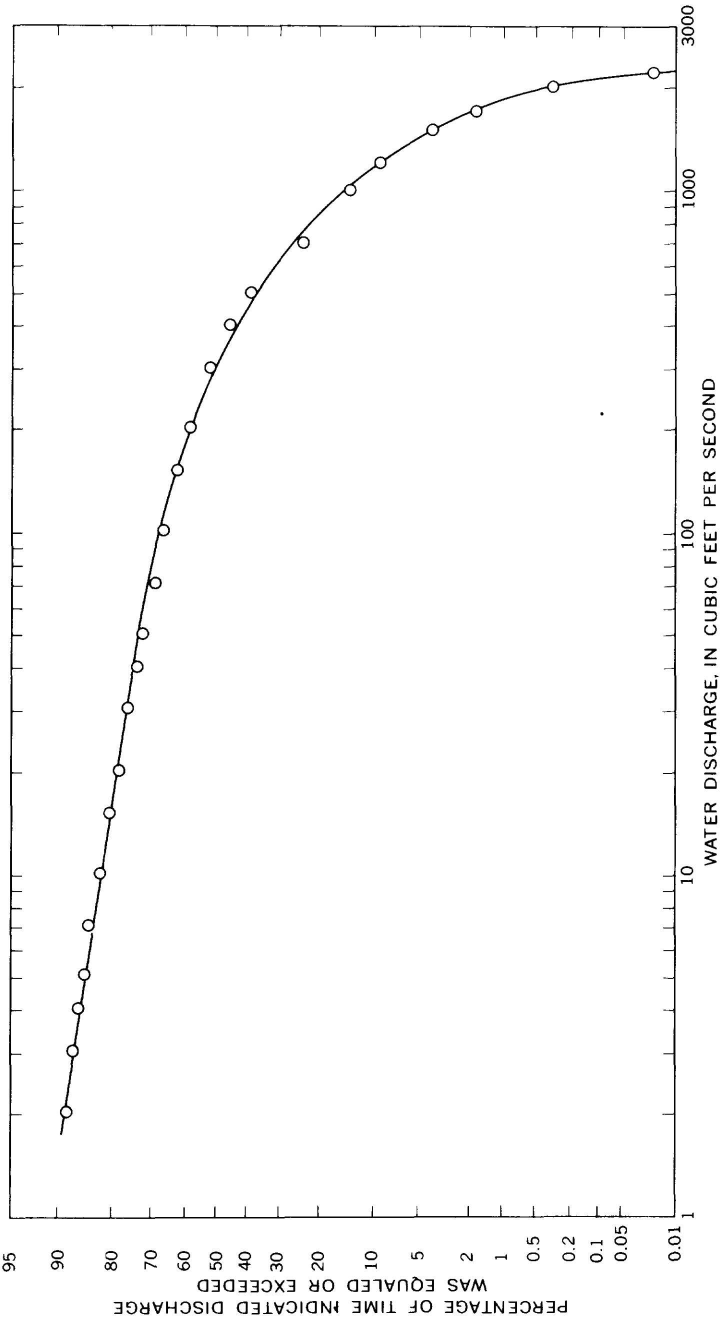

FIGURE 2.—Daily water discharge from the conveyance channel for 1953–65 water years.

The bed form can be either dune or plane bed over an approximate range in discharge of 300 to 1,200 cfs. The depth, on the average, is about 35 percent less for plane bed than for dune bed at a given discharge. The channel is also subject to scour and fill, and a change in bed elevation of as much as 4 feet could occur at the original gaging station on the channel (Harris and Richardson, 1964, fig. 36). Because of these changes in bed form and in bed elevation, the stage-discharge relation was very unstable and streamflow could not be accurately determined without frequent measurements.

In 1961, the U.S. Bureau of Reclamation began a water-salvage study in the reach of the Rio Grande between Bernardo and San Acacia. An agreement was made between the Bureau of Reclamation and the Geological Survey to design and build a control structure at Bernardo that would provide a stable stage-discharge relation. The structure was designed on the basis of a model study and field data (Harris and Richardson, 1964).

The prototype structure was completed in September 1963. Construction was in cooperation with the Bureau of Reclamation under the general supervision of W. L. Heckler of the Geological Survey.

The purposes of this paper are (1) to describe the field installation and construction, (2) to evaluate the performance of the control, including a comparison of the prototype performance with that predicted by the model study, and (3) to evaluate the effect of the controlled streambed elevation on channel capacity.

Basic data used in the analysis are given in table 1. Basic data include measured water discharge, gage height for gages B, C, and D, depth above the crest for gages B, C, and D, and percent submergence computed on the basis of depths above the crest for gages B and D.

PROPOSED CONTROL STRUCTURE

The Geological Survey obtained data on water-surface and streambed elevations at the proposed location for the control and also conducted model studies at the Colorado State University Hydraulics Laboratory. The water-surface and streambed elevations at the proposed site were obtained to determine the proper elevation of the control crest. The crest elevation was to be such that the channel capacity would be as much as 2,000 cfs and the crest would be above mean bed elevation and therefore free of sand most of the time. The model studies were conducted to determine (1) a control configuration which would eliminate, or at least minimize, the effects of changes in bed configuration and changes in bed elevation on the stage-discharge relation, (2) the maximum elevation of the control crest which would not create sufficient backwater to interfere with the maximum design capacity of the channel (2,000 cfs) and the backwater characteristics of the control under various degrees of submergence, (3) the design

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TABLE 1.—*Basic data for the conveyance channel*

Date	Measured water discharge (cfs)	Gage height (ft)			Depth above crest (ft)			Percentage of submergence B–D
		B	C	D	B	C	D	
1964								
5–28	787	5.46	5.44	5.32	2.40	2.38	2.26	94.2
6–3	806	5.36	5.30	5.10	2.30	2.24	2.04	88.7
11–16	317	4.60	4.43	3.33	1.54	1.37	.27	17.5
11–17	469	4.95	4.81	4.12	1.89	1.75	1.06	56.1
11–18	721	5.29	5.12	4.72	2.23	2.06	1.66	74.4
11–20	1,280	6.07	5.96	5.66	3.01	2.90	2.60	86.4
11–27	328	4.55	4.46	3.57	1.49	1.40	.51	34.2
12–4	426	4.78	4.64	4.06	1.72	1.58	1.00	58.1
12–11	275	4.47	4.39	3.55	1.41	1.33	.49	34.8
12–18	215	4.36	4.23	3.35	1.30	1.17	.29	22.3
12–24	439	4.86	4.67	4.40	1.80	1.61	1.34	74.5
1965								
1–5	509	4.88	4.76	4.41	1.82	1.70	1.35	74.2
1–11	1,680	6.98	6.98	6.84	3.92	3.92	3.78	96.4
1–14	619	5.20	4.98	4.40	2.14	1.92	1.34	62.6
1–20	582	5.07	4.89	4.24	2.01	1.83	1.18	58.7
1–29	495	4.91	4.76	3.95	1.85	1.70	.89	48.1
2–2	544	5.01	4.84	4.22	1.95	1.78	1.16	59.5
2–3	562	5.03	4.89	4.27	1.97	1.83	1.21	61.4
2–12	774	5.34	5.16	4.88	2.28	2.10	1.82	79.8
2–19	537	5.01	4.84	4.18	1.95	1.78	1.12	57.4
2–26	692	5.23	5.03	4.56	2.17	1.97	1.50	69.1
3–3	602	5.10	4.90	4.36	2.04	1.84	1.30	63.7
3–11	310	4.63	4.47	3.98	1.57	1.41	.92	58.6
3–19	362	4.68	4.52	4.26	1.62	1.46	1.20	74.1
3–26	238	4.41	4.28	3.82	1.35	1.22	.76	56.3
3–30	242	4.41	4.35	3.75	1.35	1.29	.69	51.1
4–8	1,060	5.79	5.62	5.47	2.73	2.56	2.41	88.3
4–16	726	5.24	5.11	4.72	2.18	2.05	1.66	76.1
4–22	1,300	6.51	6.49	6.28	3.45	3.43	3.22	93.3
4–29	924	5.79	5.75	5.67	2.73	2.69	2.61	95.6
5–6	835	5.63	5.43	5.49	2.57	2.37	2.43	94.6
5–7	800	5.96	5.79	5.83	2.90	2.73	2.77	95.5
5–8	837	6.08	5.96	5.95	3.02	2.90	2.89	95.7
5–9	784	5.84	5.83	5.69	2.78	2.77	2.63	94.6
5–10	771	5.80	5.65	5.62	2.74	2.59	2.56	93.4
5–12	980	6.46	6.40	6.35	3.40	3.34	3.29	96.8
5–13	894	6.20	6.08	6.02	3.14	3.02	2.96	94.3
5–17	894	6.18	6.08	6.08	3.12	3.02	3.02	96.8
5–26	1,210	6.75	----------	6.52	3.69	----------	3.46	93.8
5–27	1,150	6.34	6.34	6.19	3.28	3.28	3.13	95.4
5–31	1,310	6.76	6.75	6.53	3.70	3.69	3.47	93.8
6–2	1,180	6.46	6.46	6.33	3.40	3.40	3.27	96.2
6–3	1,290	6.63	6.65	6.50	3.57	3.59	3.44	96.4
6–8	1,020	6.40	6.39	6.25	3.34	3.33	3.19	95.5
6–22	1,040	6.42	6.40	6.34	3.36	3.34	3.28	97.6
6–29	817	5.87	5.77	5.70	2.81	2.71	2.64	94.0
7–6	1,070	6.12	6.10	6.15	3.06	3.04	3.09	101.0
7–13	1,180	6.71	6.62	6.48	3.65	3.56	3.42	43.7
7–20	1,220	6.76	6.68	6.59	3.70	3.62	3.53	95.4
7–27	691	5.43	5.34	5.28	2.37	2.28	2.22	93.7
8–3	1,060	6.16	6.15	5.94	3.10	3.09	2.88	92.9
8–11	757	5.37	5.54	5.34	2.31	2.48	2.28	98.7
9–15	350	4.68	4.48	3.68	1.62	1.42	.62	38.3
9–29	376	4.74	----------	3.54	1.68	----------	.48	28.6
10–5	739	5.28	5.04	4.66	2.22	1.98	1.60	72.1
10–13	304	4.50	4.37	3.50	1.44	1.31	.44	30.6
10–20	708	5.19	5.10	4.38	2.13	2.04	1.32	62.0
10–26	673	5.13	----------	4.61	2.07	----------	1.55	74.9
11–3	906	5.44	5.40	5.12	2.38	2.34	2.06	86.6
11–10	1,490	6.16	6.72	5.87	3.10	3.66	2.81	90.6
11–17	1,520	6.20	6.20	5.84	3.14	3.14	2.78	88.5
11–24	1,240	5.93	5.96	5.30	2.87	2.90	2.24	78.0
11–29	1,120	5.77	----------	4.80	2.71	----------	1.74	64.2
11–30	1,240	5.88	----------	5.00	2.82	----------	1.94	68.8

TABLE 1.—*Basic data for the conveyance channel*—Continued

Date	Measured water discharge (cfs)	Gage height (ft)			Depth above crest (ft)			Percentage of submergence B-D
		B	C	D	B	C	D	
12-3	1,230	5.90	6.00	5.07	2.84	2.94	2.01	70.8
12-9	1,460	6.12	6.32	5.42	3.06	3.26	2.36	77.1
12-16	1,120	5.86	5.98	4.76	2.80	2.92	1.70	60.7
12-22	1,360	6.07	6.30	5.09	3.01	3.24	2.03	67.4
12-29	1,500	6.25	6.28	5.52	3.19	3.22	2.46	77.1
1966								
1-7	918	5.52	5.47	4.03	2.46	2.41	.97	39.4
1-13	926	5.53	5.56	4.00	2.47	2.50	.94	38.1
1-21	895	5.51	5.51	4.15	2.45	2.45	1.09	44.5
2-4	855	5.40	5.46	4.19	2.34	2.40	1.13	48.3
2-10	920	5.48	5.50	4.32	2.42	2.44	1.26	52.1
2-18	782	5.30	5.30	4.07	2.24	2.24	1.01	45.1
2-25	892	5.48	5.47	4.52	2.42	2.41	1.46	60.3
3-4	714	5.21	5.18	4.14	2.15	2.12	1.08	50.2
3-10	651	5.16	5.17	4.10	2.10	2.11	1.04	49.5
3-18	1,370	6.09	6.08	5.25	3.03	3.02	2.69	88.8
3-24	1,190	5.90	5.82	5.35	2.84	2.76	2.29	80.6
3-31	1,170	5.91	5.89	5.24	2.85	2.83	2.18	76.5
4-7	1,300	6.05	6.05	5.41	2.99	2.99	2.35	78.6
4-13	1,310	6.07	6.00	5.40	3.01	2.94	2.34	77.7
4-22	1,420	6.13	6.25	5.40	3.07	3.19	2.34	26.2
4-27	1,170	5.88	5.87	5.01	2.82	2.81	1.95	69.1
5-5	1,260	6.08	6.04	5.41	3.02	2.98	2.35	77.8
5-12	1,050	5.82	------------	5.31	2.76	------------	2.25	81.5
5-19	852	5.55	------------	5.26	2.49	------------	2.20	88.4
5-26	1,020	5.86	------------	5.68	2.80	------------	2.62	93.6
6-2	1,110	6.06	------------	5.93	3.00	------------	2.87	95.7
6-10	380	4.66	------------	4.03	1.60	------------	.97	60.6
6-30	516	5.01	------------	4.06	1.95	------------	1.00	51.3

of an energy dissipator to prevent excessive scour downstream of the structure, (4) the location of a section or sections where accurate measurements of water discharge and sediment discharge could be made, and (5) the position of a total sediment-load sampling sill.

On the basis of the model studies, the following control-structure design was recommened (fig. 3). The structure was to have a control surface longitudinal slope of 16 to 1 and a transverse slope of 35 to 1. The approach apron was to have a slope of 2 to 1, and the downstream apron, a slope of 3 to 1. Sheet piling at the upstream end of the control was to serve as a cutoff wall and to add to the structural stability of the control. The sidewalls were designed to run straight along both sides of the control with a side slope of 2 to 1.

Control accessories, including baffles, bubbler-gage orifice mounts, total-sediment-load sampling sill, and energy dissipator, were also designed on the basis of the model studies. The system of baffles was designed to be mounted on the upstream edge of the control surface to keep the bubbler-gage orifice and the crest of the control free of sand. The model studies indicated that the bubbler-gage orifice could be on the centerline of the control 4 or 8 feet upstream from the crest.

The downstream apron was designed to include a sampling sill from which total-sediment-load samples could be obtained. The sill was to be 1.5 feet lower than the crest at the centerline and to run the entire width of the control. The sill covers a trench which contains pipes leading to an automatic-pump sediment sampler. A groove on the downstream edge of the sill permits a guide to be positioned so that total-sediment-load samples may be obtained using a DH–48 sediment sampler.

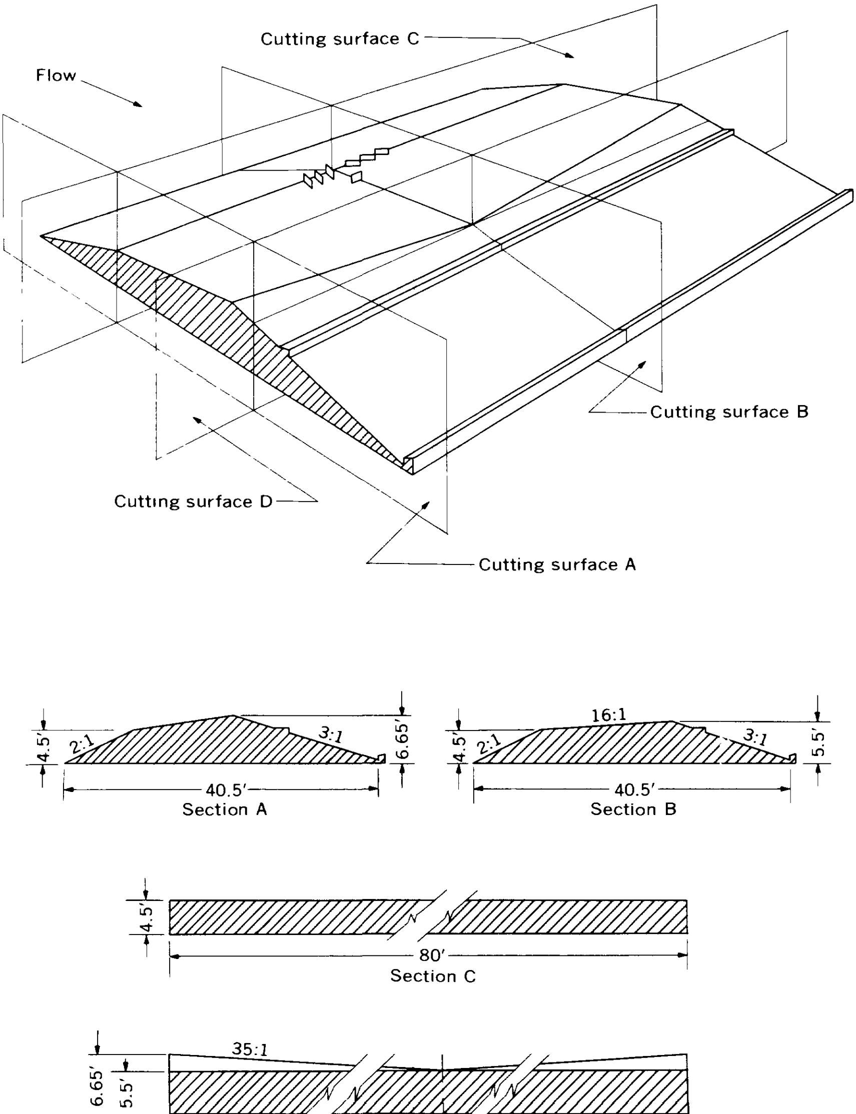

FIGURE 3.—Details of the control as proposed by Harris and Richardson (1964 fig. 37).

An energy dissipator, 1.5 feet high, was designed to be placed at the downstream toe of the control. It was suggested that it might be necessary to place riprap on the bed and along the banks for a short distance downstream of the toe of the control to prevent excessive scour. Figure 4 shows the positions of the control accessories.

Harris and Richardson (1964) recommended that the elevation of the crest of the control be 4.50 feet below bankfull stage, or 4,723.5 feet above mean sea level at the proposed control location. At this elevation the crest of the control would be 0.5 foot above the maximum bed elevation observed in 1958 and 0.25 foot lower than the maximum bed elevation observed in 1957.

CONSTRUCTION

INITIAL CONSTRUCTION

Construction was started in August 1963. Excavation for the structure was 80 by 40 feet, to a depth approximately 3 feet below mean bed level. Sheet piling, used as the upstream cutoff wall, was placed across the channel and 10 feet into both banks at the upstream edge of the control. The top of sheet piling was driven to an elevation of 4,718.0 feet above mean sea level, 5.5 feet below the crest (fig. 5).

Rock, 0.5 to 1.5 feet in diameter, was placed in the excavation to create the approximate shape of the control. The base was then covered with finer rock, 2 to 3 inches in diameter (fig. 6). On top of this finer material a concrete cap was placed to form the surface of the control. Six-gage 6×6-inch steel-wire reinforcement was used in the concrete cap.

The approach apron was constructed to a 2 to 1 slope and the control surface to a 16 to 1 slope to the crest. A transverse slope of 35 to 1 was used for the crest, converging toward the centerline in order to confine low flows. The downstream apron was constructed to a 3 to 1 slope from the crest to the sampling sill and to an 8 to 1 slope from the sampling sill to the energy-dissipator wall. The energy-dissipator wall, constructed of grouted rock, was 1.5 feet high and 1.5 feet thick and extended across the width of the control. A 3-inch clay pipe was placed across the control near the toe to relieve hydrostatic pressure under the downstream apron. One bubbler-gage orifice was recessed into the concrete cap 4 feet upstream of the crest at the center line. A vertical staff gage was placed 0.8 foot upstream of the orifice.

Sidewalls were constructed along both banks extending from the upstream sheet piling to the energy-dissipator wall. They were constructed to a ½ to 1 slope and converged slightly toward the centerline downstream of the crest. Riprap 0.5 to 1.5 feet in diameter was placed on the bed of the channel downstream of the energy-dissipator wall for a distance of about 20 feet and to a depth of approximately 3 feet.

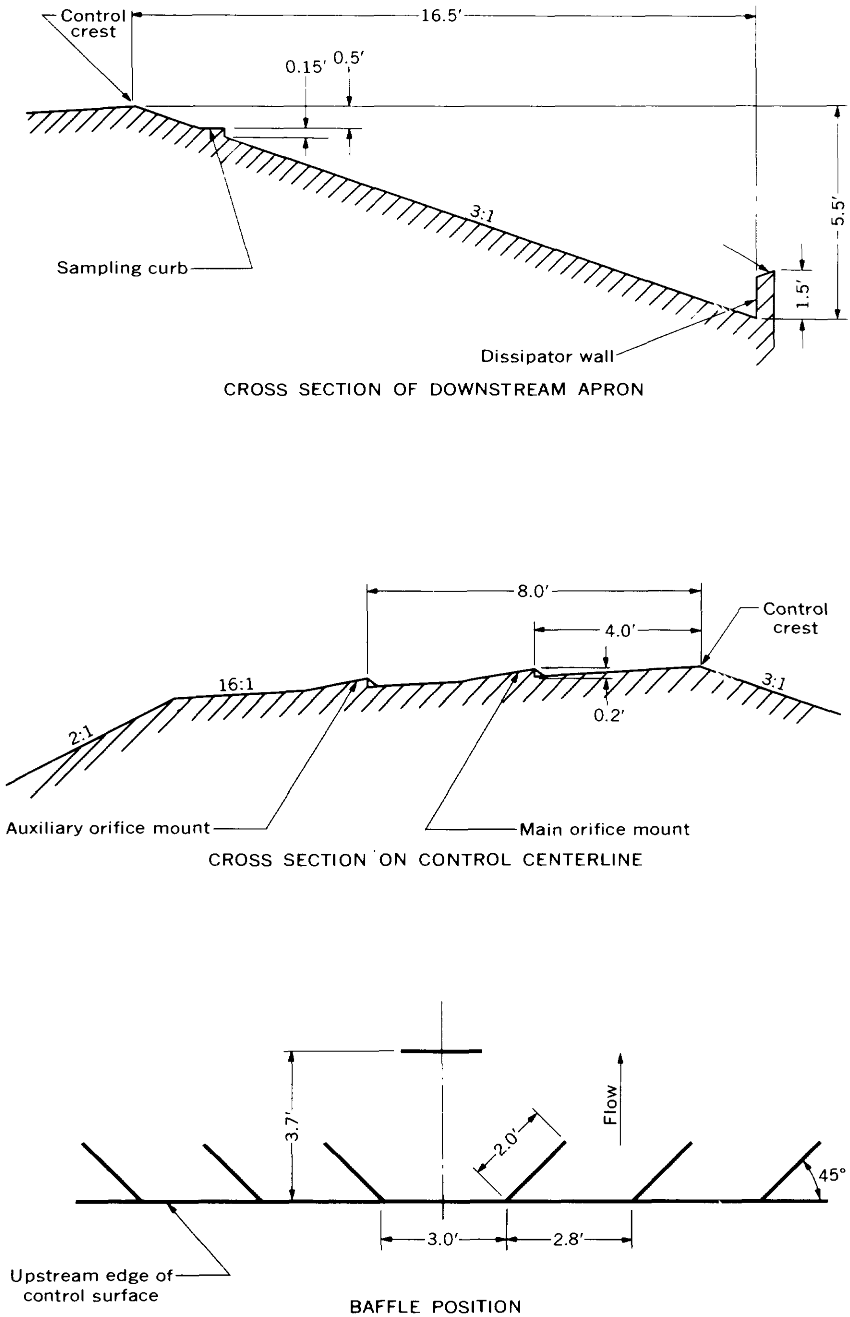

FIGURE 4.—Accessories for the control as proposed by Harris and Richardson (1964, fig. 38).

FIGURE 5.—Sheet piling at the upstream edge of the control. *Upper*, Driving the piling. *Lower*, Piling in place.

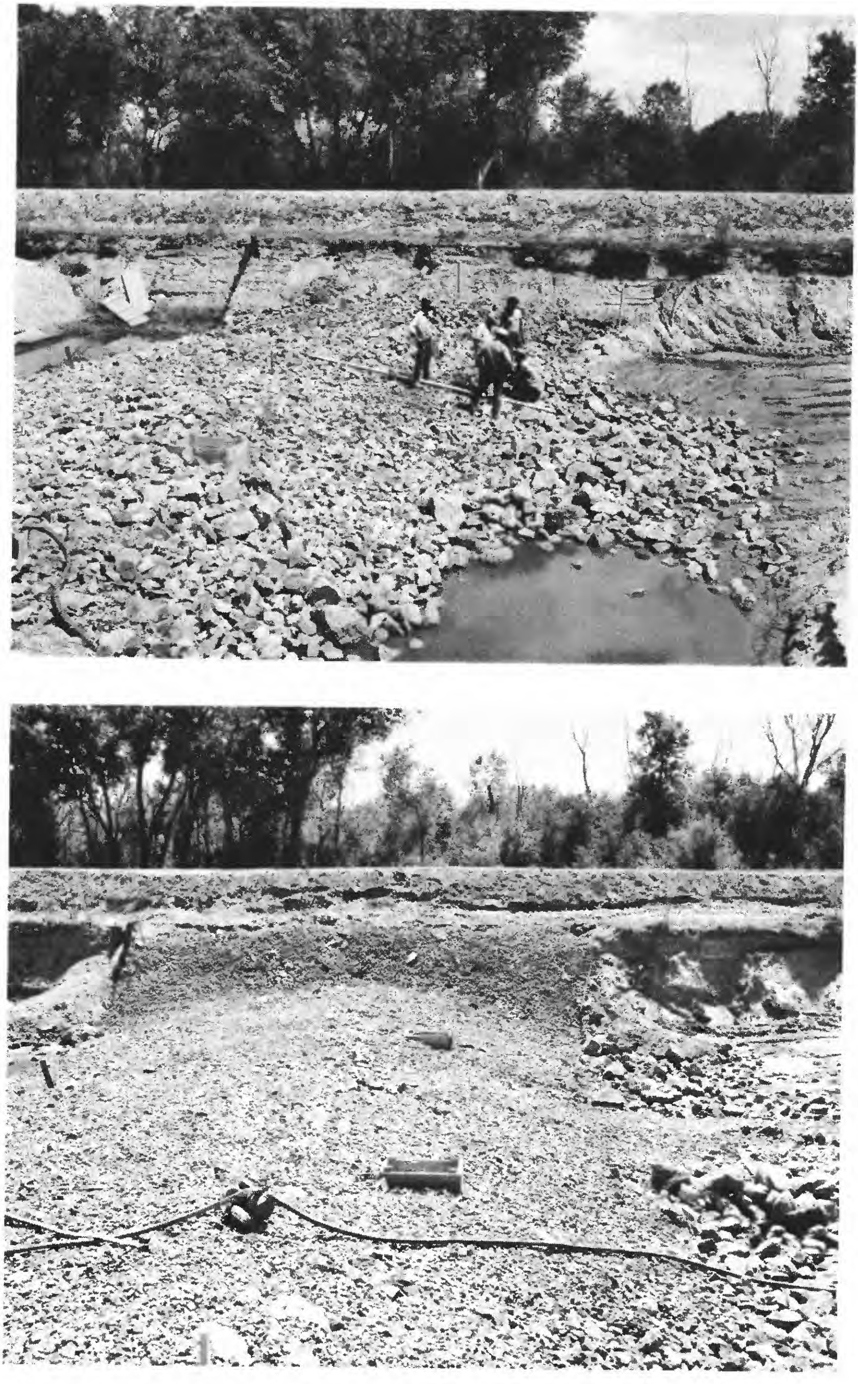

FIGURE 6.—Rock base for the control. *Upper*, Hand finishing coarse rock to grade. *Lower*, Fine rock finished to grade.

The footbridge was made from pairs of standard three-bar roof-joist assemblies, 30 feet long, spaced 30 inches apart. Two pairs of 4-inch pipe piers, imbedded in the downstream apron of the control, were used to support the bridge. A concrete-block shelter, 8×11 feet, was constructed 50 feet from the right bank to house the bubbler-manometer unit for recording water-surface elevations at the bubbler orifice and to house a pump sediment sampler. A longitudinal cross section along the centerline of the completed structure is shown in figure 7.

A tail-water gage was installed 160 feet downstream from the control to be used for determining the percentage of submergence on the control. In the model study, the tail-water gage was 60 feet downstream of the control.

The sampling sill was constructed of 20-gage galvanized steel and covered a 10×10-inch trench. The sill extended across the width of the control on the downstream apron. Plastic ¾-inch pipes were run from three sampling heads containing orifices through the trench to the concrete-block shelter on the right bank. The ¾-inch lines were placed inside of 1½-inch plastic tubing for ease of replacement and protection against damage. Three extra plastic lines were installed so that three additional intake heads could be installed later if desired. The sampling heads were molded of lead and contoured to fit snugly to the sill and concrete apron. The intakes were perpendicular to the flow and 0.2 foot above the surface of the sill. An automatic-pump sediment sampler was housed in the concrete-block shelter.

Total-sediment load passes over the control in suspension and may be sampled by means of a US–DH–48 hand sampler. A guide rod placed in the lip on the downstream edge of the sill is used to guide the DH–48 sampler, which samples total sediment concentration when lowered to the sill.

CHANGES SINCE CONSTRUCTION

Several changes have been made since the control structure was completed. Some of the changes resulted because of a partial failure of the structure and other changes were made because of difficulties in measurement of stage on the structure.

Early in January 1966, the banks of the channel just downstream from the control began eroding rapidly and the scour hole downstream of the control deepened. This damage occurred at the end of an extended period of high flow. The mean discharge for the months of November and December 1965 was nearly 1,350 cfs.

The energy-dissipator wall apparently operated as predicted from the model study and created a reverse roller which caused the scour hole to be well downstream of the toe of the control. However, the scour hole became so large during the high flow that the banks began to fail and riprap placed just downstream of the control settled. The

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rockfill under the downstream apron also settled, and as a result the energy-dissipator wall and part of the apron failed. The convergence of the sidewalls downstream of the crest caused a strong eddy and backflow on either side of the channel, and this contributed to the failure.

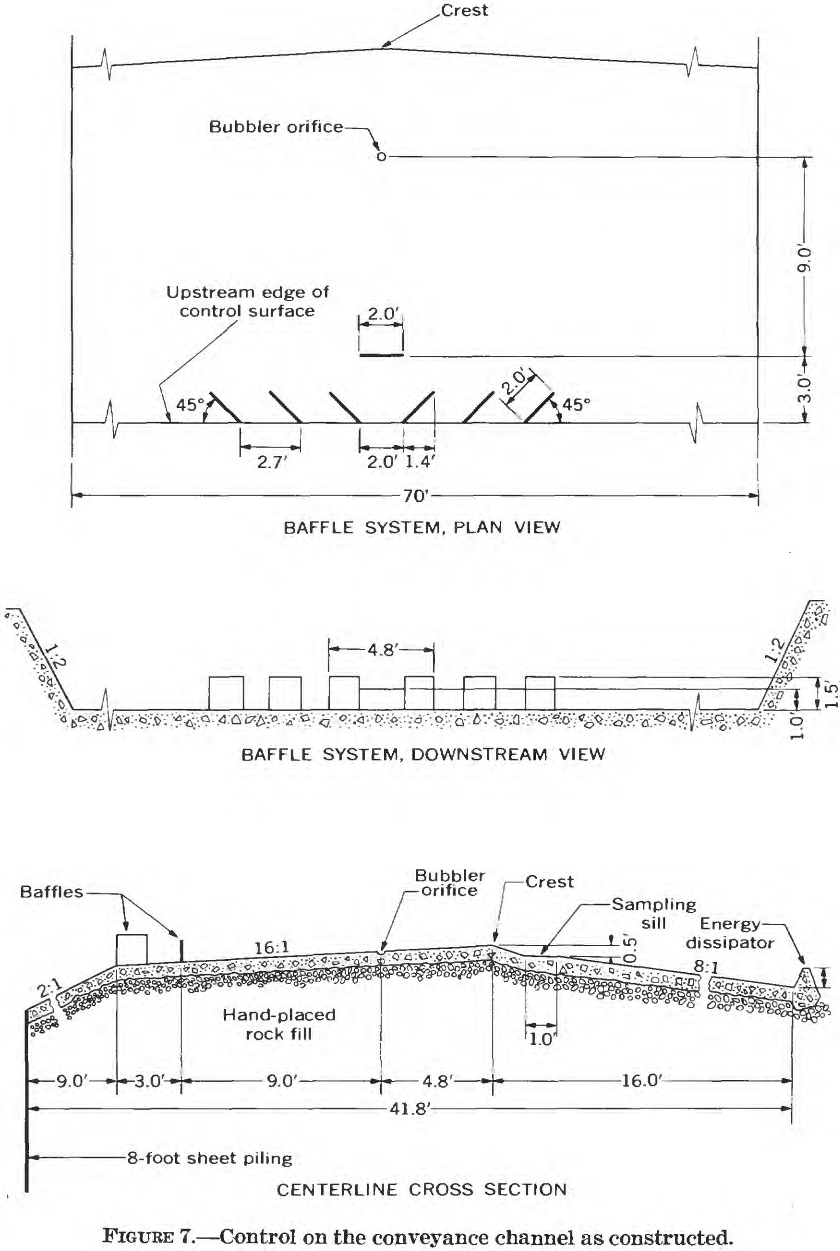

FIGURE 7.—Control on the conveyance channel as constructed.

Approximately 400 cubic yards of rock 0.5 to 1.5 feet in diameter was placed immediately downstream of the apron. Inspection of the rock when the channel was dry showed that the rock was well settled in place. The riprap now serves as the energy dissipator.

In July 1966, the convergent sidewalls were straightened. This reduced the side eddies and backflow considerably. It is not anticipated that more than minor maintenance will be required in the future.

Difficulties with the measurement of stage have required that some changes be made. The vertical staff gage which was used as a reference for gage C (bubbler gage) collected trash which made reading the staff difficult and also caused drawdown over the bubbler orifice. The vertical staff was cut off at the base on March 5, 1964, and a horizontal chain gage was installed on the footbridge as a reference on April 24, 1964. The chain gage was installed on the right pier which is about 15 feet to the right of the centerline of the control where the orifice is located. The chain gage measured the water surface the same distance upstream as the distance of the orifice from the footbridge. The baffles caused a standing wave over the bubbler orifice; however the chain gage was outside the influence of the standing wave. Different flow conditions and trash on the baffles caused the standing wave over the orifice to vary and the chain gage would not check the bubbler-gage reading with any consistency. Differences in water-surface elevation between the chain-gage reading and the bubbler-gage reading of 0.1 foot were not uncommon. Because of the inconsistency in the readings between the gages, the chain gage was moved to the centerline of the control on August 10, 1966. The chain gage now measures water surface directly over the bubbler-gage orifice.

Because the chain-gage and bubbler-gage readings woud not agree, a gage well, designated gage B, was installed on the right bank 28 feet upstream of the control crest on May 8, 1964. The float-actuated recorder was housed in a shelter mounted on a 36-inch corrugated-metal pipe well. Gage B was designated as the primary gage and gage C was continued in operation as an auxiliary gage.

During a period of a few days in May 1964, the control was covered with about 1 foot of sand at the centerline of the control. It was not known whether the sand was deposited on the control because the baffles did not create sufficient turbulence to keep the control clear or whether sand accumulation in the channel downstream caused deposition on the control. Extensions of 0.5 foot were added to each of the baffle plates to increase turbulence to aid in keeping the control clear of sand. The baffle system caused a large standing wave on the control crest over the bubbler orifice (fig. 8), and trash tended to collect on the baffles; for these reasons this baffle system was removed and a new system was installed during July 18–20, 1966.

The new system of baffles consists of plates in three rows that are 2 feet apart. The plates are each 2 feet long and their centers are spaced 6 feet apart. The baffle plates are bent to form an angle of about 50° with the control surface in a downstream direction. The effective height of the baffles is approximately 1.2 feet. The new baffle system is the same as one described by Harris and Richardson (1964, top of p. 150), except that the baffles are angled from the vertical in a downstream direction. No data obtained after the baffle system was changed are included in this report, but observations indicate that the new baffle system is effective in keeping the control free of sand, does not collect trash, and does not create a large standing wave. Figure 9 shows the new baffle system as it appeared after a runoff event. The material on either side of the control is fine material deposited on the falling stage. Sand did not deposit on the control beyond the first row of baffles and no trash has been observed on the baffle plates. The water surface downstream of the baffles is rougher than it was with the old system but is not so rough as to preclude measurement of stage with the chain gage.

FIGURE 8.—Drawdown and wave caused by acceleration of flow over the baffles (right center).

FIGURE 9.—The baffle system installed in July 1966.

PERFORMANCE OF THE CONTROL

STAGE-DISCHARGE RELATION

In this report, the data used to define the stage-discharge relation for the control were obtained from late May 1964 to July 1966. The baffle system in use during this period was that originally installed on the control. During this period, gage B was used as the primary gage and gage D, 160 feet downstream of the control, was used to measure the tail-water stage. The location of gage D so far downstream of the control led to two noteworthy conditions with respect to analysis of the effect of submergence. First, the stage at gage D was subject to fluctuations due to scour and fill and to bed-roughness changes. This would present no particular problem in the analysis of effect of submergence on the stage-discharge relation provided the stage at gage D maintained a constant difference from the stage immediately below the control. It is not known if a constant difference was maintained. Second, submergence as computed from stage readings at gage B and gage D should always be less than 100 percent because of the distance between gage B and gage D. Gage C was operated during most of the period but only as an auxiliary gage.

The period of record used in this report can be divided into three fairly distinct subperiods. For the subperiod May 22, 1964, to April 29, 1965, the measurements of discharge generally were less than 800 cfs, and most of the measurements plot on the base rating for gages B and C. For the subperiod April 29–October 20, 1965, the measurements of discharge generally were between 700 and 1,300 cfs, and nearly all measurements plotted off the base rating. For the subperiod October 20, 1965, to July 14, 1966, the measurements of discharge generally were between 800 and 1,500 cfs, and nearly all measurements plotted on the base rating for both gages. (See figs. 10 and 11.) There were very few measurements with which to define the ratings below 200 cfs.

The base rating for gage B plots as a straight line through the range of discharge from 200 to 1,500 cfs. However, the base rating for gage C shows a definite break for discharges greater than 600 cfs. This break is probably due to the baffle system, which causes a standing wave whose crest is near the orifice of gage C. The amplitude of the wave tends to increase with discharge. As a result, the water-surface eleva-

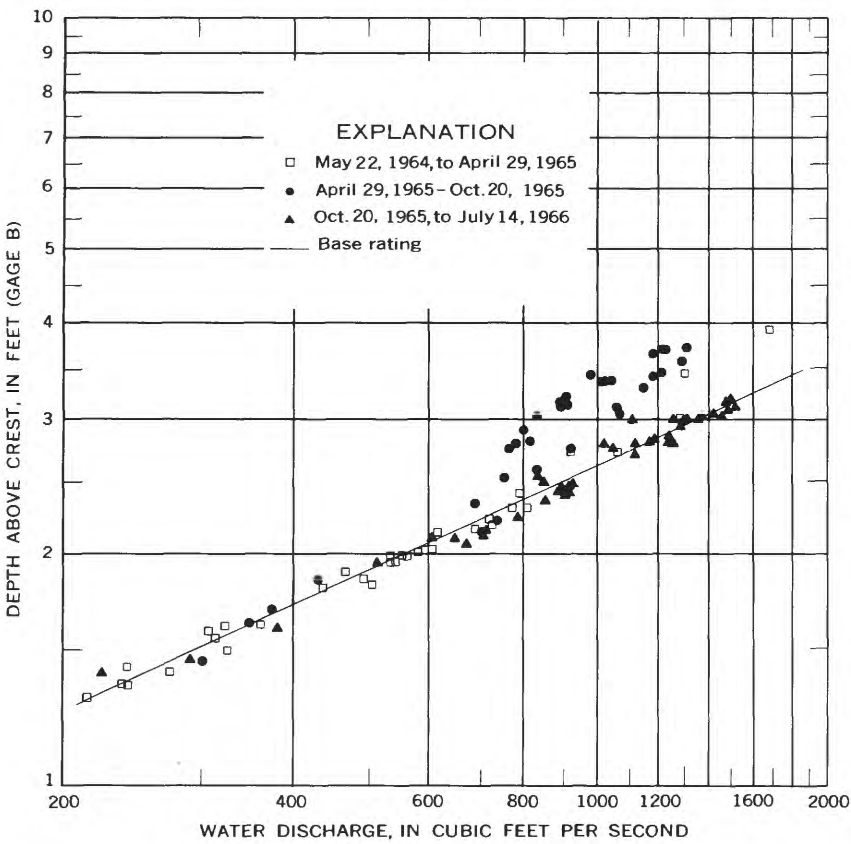

Figure 10.—Stage-discharge relation for conveyance channel, gage B, at control.

tion at gage C is higher than at gage B for discharges greater than about 1,100 cfs.

Deviations of discharge measurements from the base rating of the control are caused by variation of the gage height at a given discharge or by errors in water-discharge measurements. The variation of the gage height at a given discharge can be caused by scour and fill at the gage location, changes in bed roughness at the gage location, backwater on the control, or burial of the control.

For those measurements made when free-fall conditions existed—that is, the stage-discharge relation was not affected by backwater—72 percent is within plus or minus 5 percent and all are within plus or minus 10 percent of the base rating for gage B. The errors in discharge measurements are likely to be from 2 to 5 percent and perhaps even larger for some conditions at the measuring sections in this channel. Therefore, it is likely that most of the scatter from the rating is caused by errors in discharge measurements for free-fall conditions.

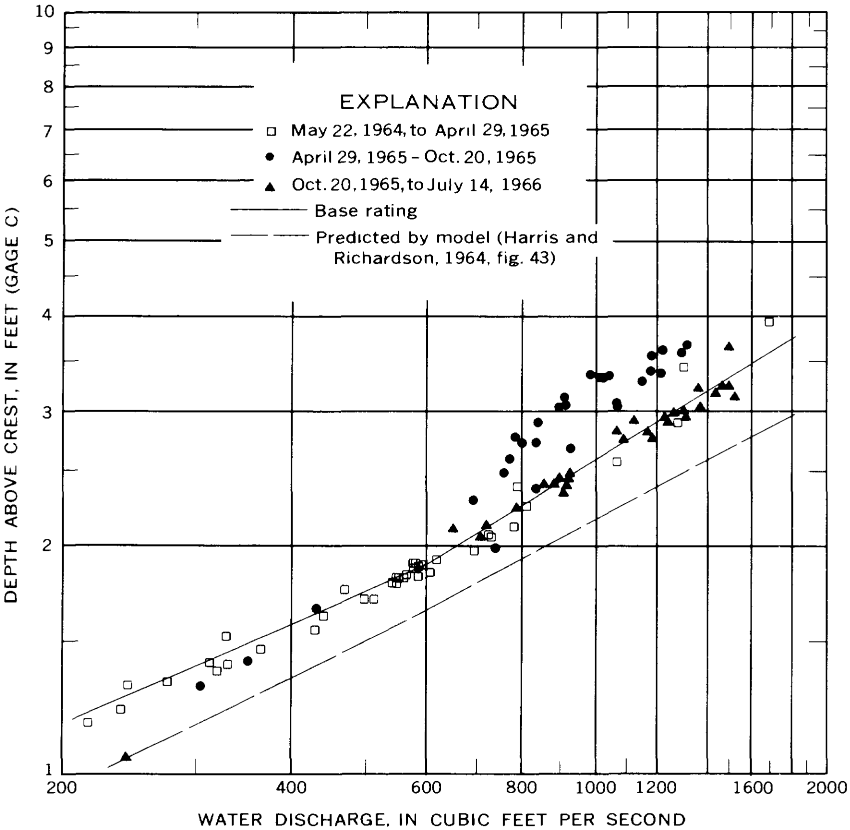

Figure 11.—Stage-discharge relation for conveyance channel, gage C, at control.

SUBMERGENCE

Backwater causes submergence of the control if the elevation of the tail water becomes greater than the elevation of the lowest point on the crest of the control. Submergence is the ratio of the depth above the crest of the tail water to the depth above the crest of the upstream head on the control, and experiment has shown that the discharge is a function of submergence as well as gage height (Eisenlohr, 1964). Most of the measurements during the subperiod April 29–October 20, 1965, plotted off the base rating and, therefore, a study of submergence was made to determine the effect on the stage-discharge relation. The ratio of the measured discharge to the rated discharge was plotted as a function of submergence computed from depths above the crest for gages B and D (fig. 12). From figure 12, it is obvious that backwater has no effect on the stage-discharge relation for values of submergence less than 90 percent. For values of submergence greater than 90 percent, the stage-discharge relation is affected by backwater, but no consistent relation exists between the ratio of the measured discharge to the rated discharge and the percent submergence.

It should be noted that, as the control approaches complete submergence, the submergence ratio approaches a maximum value which

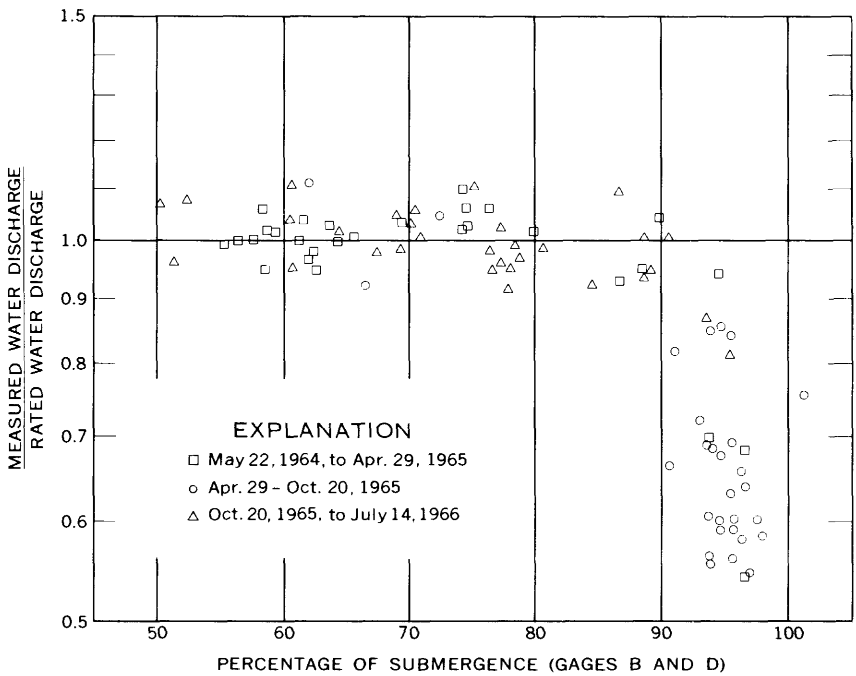

FIGURE 12.—Ratio of measured discharge to rated discharge as a function of percentage of submergence for the control.

is less than 100 percent for this structure because of the distance between gages used to measure the headwater and tail-water stages. A further increase in the tail-water stage affects the stage-discharge relation, but the submergence ratio tends to remain constant. Therefore, at complete submergence of the control, the submergence ratio cannot be used as a correction for backwater on the control. Because backwater affects the stage-discharge relation for this structure only for values of submergence approaching a maximum, it is apparent that some other method, such as the shifting-control method, should be used to correct for the effect of backwater on the stage-discharge relation. In other words, the control should be considered as completely ineffective, or drowned out, for values of submergence greater than 90 percent.

The stage-discharge relation at the control, for free-fall conditions, is much improved over the rating prior to the control. However, for those periods of time during which the control can be considered to be drowned out—that is, the submergence ratio is greater than 90 percent—the presence of the control structure does not improve the stage-discharge relation compared to that which would exist if the structure were not in place.

COMPARISON OF MODEL PREDICTION AND PROTOTYPE OPERATION

The Bernardo control model was only partially successful in predicting the operation of the prototype, and there are differences in practically every detail of operation of the prototype from that predicted by the model. Some of the differences may exist because the prototoype was not built exactly as specified on the basis of the model study.

The base rating predicted by the model study (fig. 11) shows that about 15 to 20 percent more depth above the crest at a given discharge is required for the prototype than was predicted by the model study. The transverse slope of the crest was 40 to 1 in the model but was 35 to 1 in the prototype, and this probably accounts for the greater depth on the prototype than on the model.

On the basis of the model study and field data, free-fall conditions for the Bernardo control would occur for discharges of less than 300 cfs if the control crest was established 4.5 feet below bankfull stage. The crest of the prototype was actually set at elevation 4,723.03, or 0.44 foot lower than was recommended; for the conditions experienced, the prototype has had free-fall conditions for discharges less than about 700 cfs. Also, the model predicted an effect of backwater on the stage-discharge relation for submergences greater than about 60 percent (Harris and Richardson, 1964, fig. 42). The prototype showed an effect of backwater on the stage-discharge relation only for submergences greater than 90 percent.

The model study showed that the baffles caused no detectable surface wave at the bubbler orifice 4 feet upstream of the control crest (fig. 13), but a large surface wave was observed in the prototype. The baffles on the prototype were 0.5 foot higher than the model baffles, and this may have contributed to the formation of the surface wave on the prototype but not on the model. The baffle system now in use on the prototype was rejected on the basis of the model study as not being effective in keeping the control clear of sand and for causing a rough water surface (Harris and Richardson, 1964, p. 150, position 1). The present baffle system appears to be more effective in keeping the control clear of sand than the system selected from the model study. The present system does create a somewhat rough water surface, but the wave caused by the baffles has been virtually eliminated.

The sensitivity of the rating of the model was based on a vee notch with a 40 to 1 lateral slope; however a lateral slope of 35 to 1 was recommended and used in the prototype. The model discharge, given in terms of prototype discharge, changed 1.5 percent or less for a 0.01-foot change in stage at 400 cfs or more and changed 7 percent at 30 cfs. The prototype discharge changed 1.5 percent or less for a 0.01-foot change in stage at 300 cfs or more and changed slightly more than 4 percent at 30 cfs (fig. 14). The prototype is more sensitive than the model because of the slightly greater lateral slope of the prototype notch.

EFFECTS OF CONTROL ON THE CHANNEL

One main purpose of the model study was to determine the proper crest elevation so that the control would not restrict the capacity of the channel to less than 2,000 cfs. From the model study it was determined that with 100 percent submergence at 2,000 cfs, the water surface would be 4 feet above the crest of the control (Harris and Richardson, 1964, fig. 42). Allowing 0.5 foot for freeboard, the control crest would be placed 4.5 feet below the bankfull stage or at an elevation of 4,723.5 feet above mean sea level. The control was actually set approximately 0.5 foot lower than recommended to insure that the channel capacity would not be restricted.

A staff gage established just upstream of the control site prior to construction of the control indicated that the range of discharge for a given gage height was about the same at the control site as at the cable upstream (fig. 15). The limits of the range of water-surface elevation at a given discharge were estimated from the rating for gage A at the bridge upstream of the control. The base rating for gage B (from fig. 10) shows that the water-surface elevation at 2,000 cfs is slightly higher than the minimum possible before the control but is well below the maximum possible before the control.

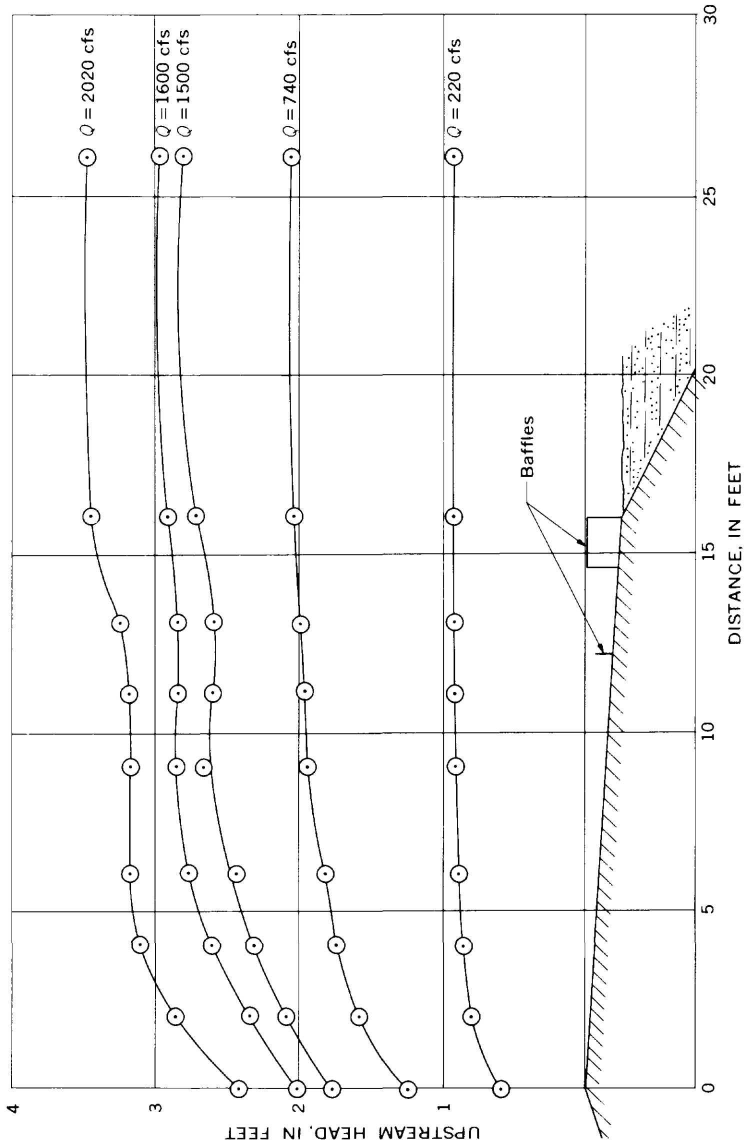

Figure 13.—Water-surface profiles for control K (free-fall conditions). Harris and Richardson (1964, fig. 40).

The maximum water-surface elevation, on the basis of gage B, for a given discharge when the control is drowned out is almost identical with the maximum water-surface elevations prior to the control for discharges greater than about 1,500 cfs. In other words, for discharges greater than 1,500 cfs with the control drowned out, the control has no effect on the stage-discharge relation and the channel controls the stage-discharge relation as it did prior to construction of the control.

The stage-discharge relation at the cable section upstream of the control has also been improved by the control structure (fig. 16). Gage A at the bridge, on which this relation is based, was not in operation during the period that the bed was in dunes, and the rating after the control structure was completed is for a plane-bed condition only. For this reason the rating for gage A has less scatter than it would if dune-bed data were included. The form of the rating has much the same appearance as the base rating for gage B at the control structure. The somewhat greater scatter for the gage A rating than for the base rating for the control results from minor adjustments in bed elevation and bed roughness at gage A site. Extending the rating, based on measurements after the control structure was completed, to 2,000 cfs shows that the structure does not limit the discharge for the plane-bed condition at gage A. It seems reasonable that when the control structure is drowned out and the channel is definitely controlling, the same situation prevails at gage A as at the control structure and, on the basis of the available data, the channel at gage A is not restricted in any way by the control for discharges greater than 1,500 cfs.

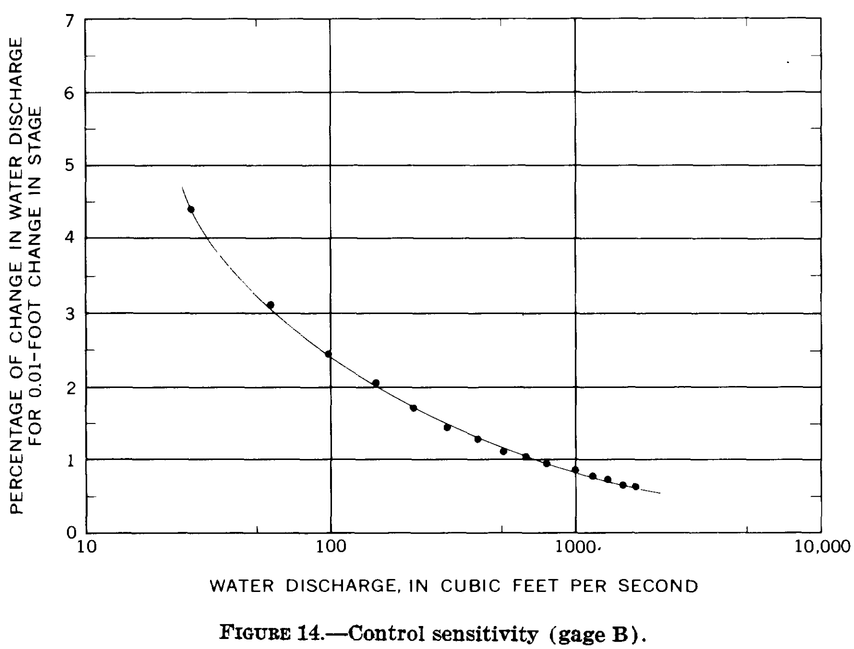

FIGURE 14.—Control sensitivity (gage B).

The bed elevation is controlled at the structure location at an elevation higher than average prior to construction. Water-surface elevations were obtained at the control site prior to construction, but no cross sections were obtained; therefore, the average bed elevation at that point was not established. The mean bed elevation at gage A for the 3 years prior to construction of the control structure was about 4,722.9 feet (fig. 17). The average fall between the cable and the control site is about 0.7 foot; therefore, the average bed elevation at the control site was about 4,722.2 feet prior to construction of the control structure. The control crest elevation is 4,723.06 feet or about 0.9 foot above the mean bed elevation at the control site prior to construction. The mean bed elevation at the cable since construction of the control is about 4,723.8 feet or about 0.9 foot above the mean prior to the control. The maximum bed elevation observed at the cable since construction of the control was about 4,723.3 feet, which is slightly lower than the maximum of 4,723.5 feet observed in 1957 (Harris and Richardson,

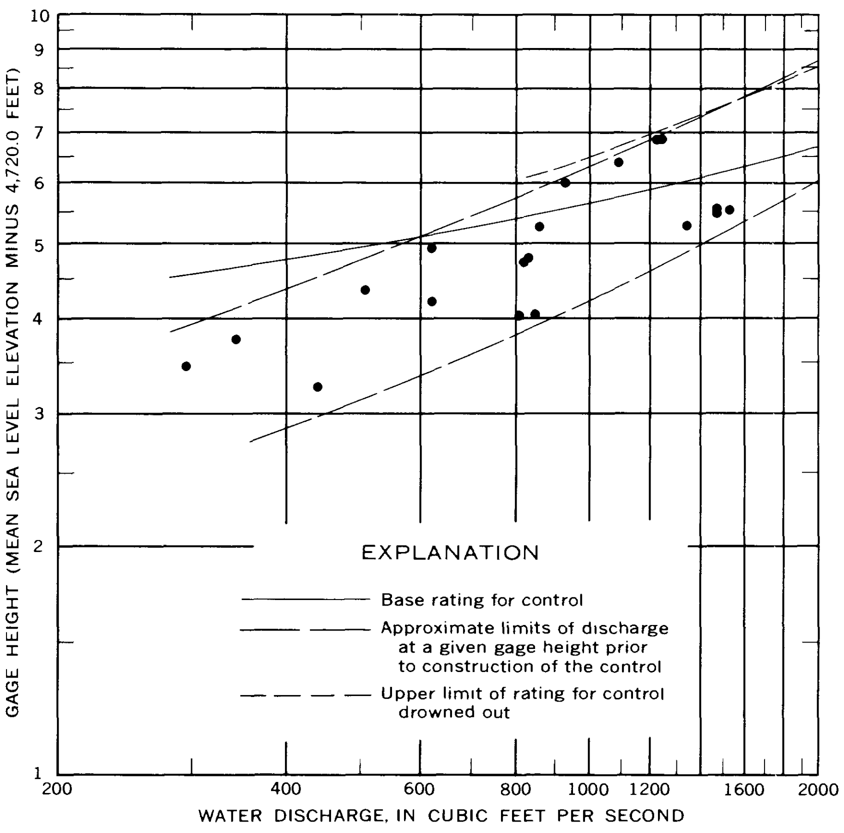

FIGURE 15.—Stage-discharge relations at the control site before and after the control.

1964). No dune-bed data are included after construction of the control because gage A was not in operation during the period when the bed was in dunes.

SUMMARY AND CONCLUSIONS

A control structure, based on model and field studies, was installed in the Rio Grande conveyance channel near Bernardo, N. Mex. Some changes have been made on the control structure since construction because of problems in measurement of stage and because of a partial failure of the structure during a period of high flow. The major changes were the installation of a gage at the upstream edge of the control, the installation of a new baffle system, and the straightening of the sidewalls.

The stage-discharge relation is much improved over the relation prior to construction of the control except when the control is drowned out. Approximately 72 percent of the measurements falls within plus

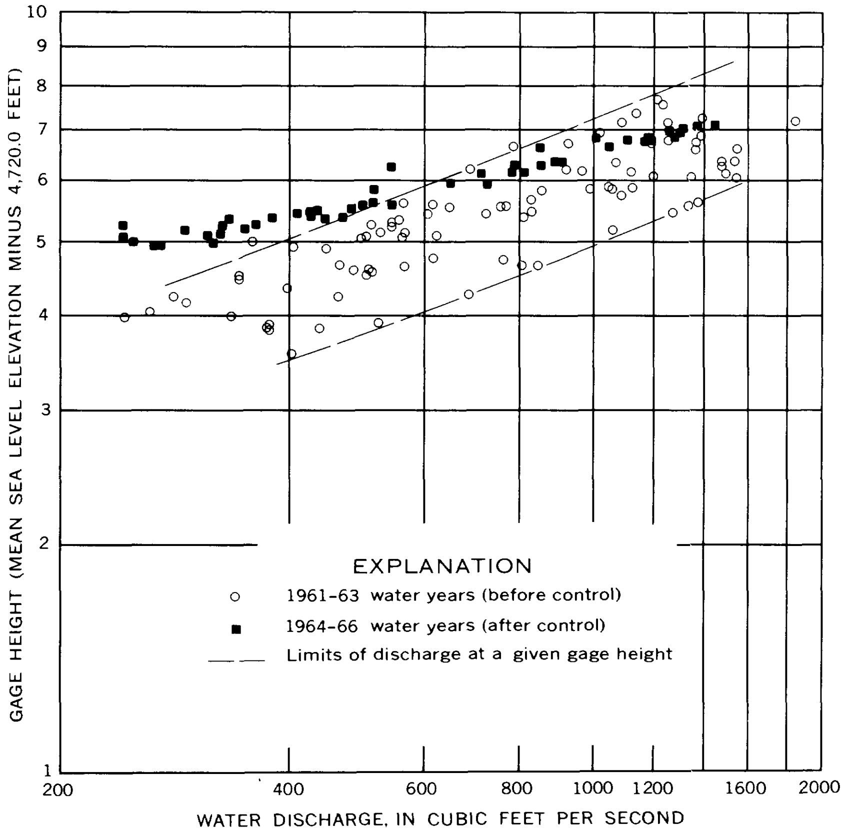

FIGURE 16.—Stage-discharge relations for gage A (at bridge).

or minus 5 percent of the base rating for free-fall conditions. The stage-discharge relation shows no influence of backwater for submergences up to 90 percent. For submergences greater than 90 percent, backwater affects the stage-discharge relation, but submergence cannot be used as a correction for backwater because there is no consistent relation between the ratio of measured discharge to rated discharge and percentage submergence.

The stage-discharge relation of the prototype compared with the stage-discharge relation of the model showed that 15 to 20 percent more depth at a given discharge was required on the prototype than on the model. The prototype showed a backwater effect on the stage-discharge relation for submergences greater than 90 percent, whereas the model predicted a backwater effect for submergences greater than 60 percent. Also, the prototype structure was set 5 feet below bankfull stage, and free-fall conditions have occurred for discharges less than 700 cfs. The model predicted free-fall conditions for discharges less than 300 cfs if the control crest were set 4.5 feet below bankfull stage.

One main purpose of the model study was to determine a crest elevation so that the control would not restrict the capacity of the channel to less than 2,000 cfs. Comparison of the stage-discharge relation on the basis of staff-gage readings at the control site prior to con-

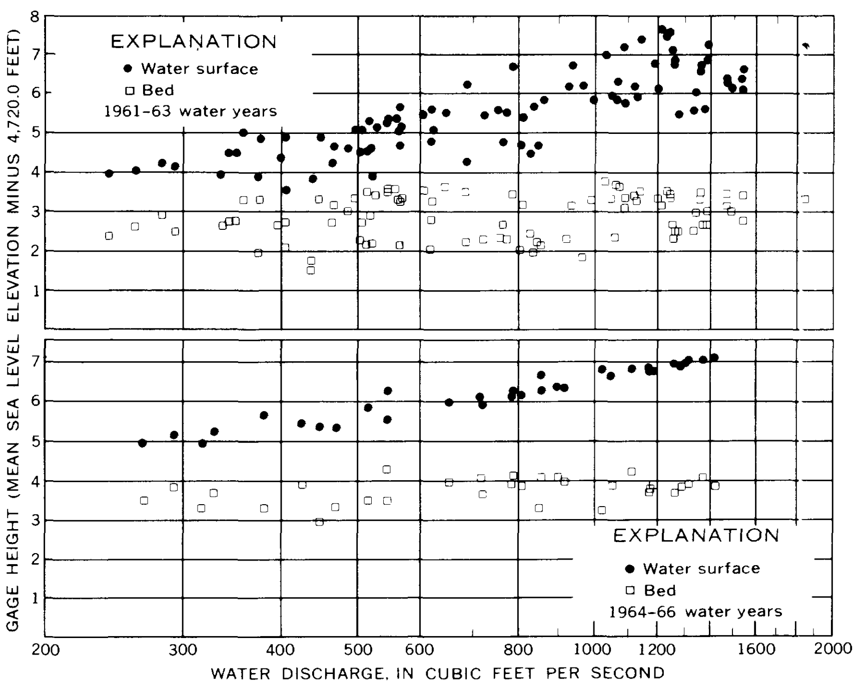

FIGURE 17.—Elevations of water surface and of bed at gage A.

struction and the stage-discharge relation at the control site after construction shows that the water-surface elevation at 2,000 cfs is slightly higher than the minimum possible before the control but is well below the maximum possible before the control. When the control is drowned out, the maximum water-surface elevations for discharges greater than 1,500 cfs are almost identical with the maximum water-surface elevations that existed for discharges greater than 1,500 cfs prior to construction of the control. The stage-discharge relation on the basis of measurements at gage B at the control and at gage A upstream of the control shows that the control does not restrict the channel to a maximum discharge of less than 2,000 cfs at either location, although the bed elevation is now controlled.

The following conclusions are based on experience with the control on the Bernardo conveyance channel:

1. Controls on sand-channel stream require at least some maintenance.
2. The control improved the stage-discharge relation for free-fall conditions. Submergence cannot be used as a correction when the stage-discharge relation is affected by backwater.
3. The model study was useful in predicting the main operating characteristics of the prototype. However, in the following respects the model did not correctly predict the behavior of the prototype.
   - (a) The depth above the crest, at a given discharge, was greater on the prototype than predicted by the model.
   - (b) The baffle system now in use is effective in keeping the control clear of sand deposits, whereas the model indicated this system would not be effective. The present system does create a rough water surface, which was predicted by the model, but the surface wave caused by the baffles has been virtually eliminated.
   - (c) The model study predicted a backwater effect on the stage-discharge relation for submergences greater than 60 percent. However, the data from the prototype showed backwater effect for submergences greater than 90 percent.
4. The available data show that the control structure does not restrict the channel capacity to a maximum discharge of less than 2,000 cfs.

REFERENCES CITED

Colby, B. R., 1960, Discontinuous rating curves for Pigeon Roost and Cuffawa Creeks in northern Mississippi: U.S. Dept. Agriculture, Agr. Research Service pub. ARS 41–36, 31 p.

——— 1964, Scour and fill in sand-bed streams: U.S. Geol. Survey Prof. Paper 462–D, 32 p., 19 figs.

Dawdy, D. R., 1961, Depth-discharge relation of alluvial channels; discontinuous rating curves: U.S. Geol. Survey Water-Supply Paper 1498–C, 16 p., 11 figs.

Eisenlohr, W. S., Jr., 1964, Discharge ratings for streams at submerged section controls: U.S. Geol. Survey Water-Supply Paper 1779–L, 32 p., 6 figs., 1 pl.

Harris, D. D., and Richardson, E. V., 1964, Stream gaging control structure for the Rio Grande conveyance channel near Bernardo, New Mexico: U.S. Geol. Survey Water-Supply Paper 1369–E, 123–154, figs. 29–54.

Simons, D. B., and Richardson, E. V., 1962, The effect of bed roughness on depth-discharge relations in alluvial channels: U.S. Geol. Survey Water-Supply Paper 1498–E, 26 p., 9 figs.

U.S. GOVERNMENT PRINTING OFFICE: 1969 O—335-122