MODEL AND PROTOTYPE STUDIES FOR THE DESIGN OF SAND TRAPS

by R. L. Parshall
Senior Irrigation Engineer - Retired
U. S. Dept. of Agriculture - Soil Conservation Service
Division of Irrigation and Water Conservation
In Cooperation with the Colo. Agr. Expt. Station
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INTRODUCTION

The deposition of water-borne gravel, sand and silt has long been recognized as one of the most troublesome problems incident to the operation and maintenance of many of the irrigation and power canals of the West. Inordinate expenditures of time, labor, and money are made annually on this account. The reduction in the carrying capacity of a canal used for the delivery of water for either irrigation or power means direct financial loss. Furthermore, the inert material deposited upon irrigated land decreases, in most cases, the fertility of the soil, and, when in excessive amounts, raises the land surface near the margin of the field enough to interfere with the spreading of the irrigation head evenly over the field. Periodic cleaning of the channel has in some cases resulted in such an accumulation that the spoil banks are now approaching a limiting condition.

As a means of correcting these conditions, laboratory studies have been made over the past years in the attempt to develop practical means for ridding channels of bed load deposit. The investigation of this problem has been carried on primarily at the hydraulic laboratories at Fort Collins by the Division of Irrigation and Water Conservation, Soil Conservation Service of the U. S. Department of Agriculture, in cooperation with the Colorado Agricultural Experiment Station. Various schemes have been investigated and emerging from these investigations have come two practical means of solving the problem of protecting channels from bed load deposits, namely, the vortex tube and the riffle deflector-vortex tube sand trap. They are capable of catching the bed load as it is moved along by the flowing water. Extremely fine material carried in suspension can only be recovered by reducing the flow in the channel to a very low velocity, thus permitting it to settle as bed load, after which the deposit can be sluiced out by suitable flow regulation.

The Vortex-Tube

The main feature of the vortex-tube sand trap is a tube with an opening along the top side, laid in the bottom of the channel at an angle of about 45 degrees to the axis of flow. The elevation of the top edge or lip is the same as the bottom or grade of the channel. As the water flows over the opening, a pronounced whirling or spiraled vortical motion is set up within the tube, which extends throughout its length. This whirling action catches the bed load as it passes over the lip of the opening and carries it to the outlet at the downstream end of the tube, whence it is discharged into a suitable sluiceway for disposal.

Laboratory, as well as field tests, indicate that the optimum action of the vortex tube occurs when the velocity of the water passing over the lip is at or near the critical, that is, when the velocity head is equal to one-half the depth of water at the lip of the tube. In the laboratory various shapes, sizes and length of tubes were studied. For a particular setting of a 4-inch tube with a velocity of about 2½ feet per second over the lip and 10 to 15 percent of the total flow wasted through the outlet, it was found that the rate of rotation near the outlet was about 200 revolutions per minute, and for this condition sand and heavy gravel, stones as large as hen's eggs, were readily ejected. Further investigations of a 4-inch tube of uniform diameter showed a maximum rotation of the spiraled flow to be 300 revolutions per minute, which created sufficient energy to move a cobblestone weighing 7½ pounds at a uniform rate of about ½-foot per second. The distance moved was about 7 feet and the mean velocity of flow over the lip of the trap was 6.6 feet per second. The axis of the tube was at 30 degrees with a slope toward the outlet of 2 inches in 4 feet. Discharge of the tube was 3 percent of the total flow. When the 4-inch tube was set at 45 degrees, with the velocity of flow at 6.9 feet, the maximum rate of rotation was 500 revolutions per minute and enough energy was developed to transport cobblestones weighing 3-3/4 to 4 pounds. Laboratory tests on a vortex tube indicate that the efficiency in trapping out the bed load would approximate at least 90 percent. No particular success was attained in model studies of the vortex tube; therefore the laboratory work was confined largely to sizes ranging from 4 to 12 inches in diameter which is assumed to be of full scale dimensions.

Figure 1.- Four-inch vortex tube set 90 degrees to axis of channel. Test cobblestones on lip to show relative sizes. First three from left are sandstone, next four granite. Second from left about four inches long.

Figure 2.- The 4-inch vortex tube in action. Depth of water over lip 0.2 foot. Note air core within tube.

Figure 3.- Cobblestone, third from left, being rapidly transported toward the outlet at left.

Figure 4.- Vortex-tube sand trap in Jackson Ditch at the Bellvue hydraulic laboratory, Cache la Poudre River near Fort Collins, Colorado. Channel width 8 feet, tube diameters 8 inches at outlet, 6 inches at the other end. Axis of tube 45° to axis of channel.

Figure 5.- Experimental field setting of vortex-tube sand trap, three 6-inch tubes in tandom, channel width 4 feet. The bed load retained in catch basin and water through tubes return to lateral below structure. Railroad Lateral, North Poudre Irrigation Company near Fort Collins, Colorado.

Figure 6.- Sand sluiced from the 3-inch tube sand trap operating in the Railroad Lateral.

The vortex-tube sand trap has been tried in the field and in some cases it has been a failure while in other instances it has proved successful. For installations that have been ineffective, two things have been wrong. First, the velocity in the canal has been too low, and second, the tube has been set below grade of the channel. In the Jackson Ditch, at our Bellvue laboratory, a vortex tube has been in successful operation since April 1935.

The structure is of concrete, 8 feet wide, vertical walls, and the floor rises slightly from the front end to the lip of the tube and slopes downward from the tube to the downstream end of the floor. The tube itself is cast of concrete, the diameter at outlet end being 8 inches and at the back end 6 inches. The tube is laid at an angle of 45 degrees to the axis of the channel. The capacity of the Jackson Ditch is approximately 60 second-feet and during periods of moderate to low river stage, the diversion in the canal is 11 second-feet. It appears that the tube is especially active at this minimum flow. No tests have been made on this particular installation but evidence of the deposit accumulated at the end of the outlet indicates definitely that this sand trap is efficient.

The Riffle-Vane Deflector

This type of sand trap consists of a series of curved sheet metal vanes, in plan approximating a quadrant of a circle, side view triangular in outline with the top point curved over downstream. The sheet metal vanes are attached in a vertical position to the smooth level floor of the structure, and for some observations the floor was sloped laterally. Experiments were made with deflectors of various sizes, shapes and spacing, and for some settings the action in moving the bed load was remarkably good. When the riffles were set in line normal to the axis of the canal the bed load was moved toward the outlet laterally at 90 degrees in a well defined limited area immediately downstream from the line of riffles. The curvature of the riffle produced the effect which moved the load laterally and the flow of water over the riffles resulted in a condition which maintained the bed load in a ridge downstream from the riffles. The action of the riffles was apparently independent of the depth of flow. Under maximum conditions of channel velocity, of approximately 4 feet per second, the energy developed was sufficient to move large cobblestones, in fact, sizes which would not pass through a 4-inch square opening. Observations were made where the line of riffles pointed upstream at an angle of 45 degrees and with proper setting of the vanes, it was found that the bed load could be carried successfully upstream behind the line of riffles. No practical advantage would be gained by setting the riffles at this extreme angle.

Figure 7.-- Experimental riffle vanes set at 90 degrees to axis of 8-foot laboratory channel. Vanes are 10 inches high with about 10-inch spacing. Bed load is being moved from sample in background.

Figure 8.- Experimental riffle vanes set at 135 degrees to axis of 8-foot laboratory channel. Vanes are 10 inches high with about 10-inch spacing. Bed load is being moved to right or upstream.

Field tests have been made of this type of sand trap but the device was found to be not too successful, one of the disadvantages being the fact that considerable debris lodges on the riffles, thus destroying the efficiency of the trap. One installation was made in the Wannamaker Ditch, near Golden, Colorado, where a series of 6 sets of riffles was placed in a channel 6 feet wide. The riffles were 6 inches high. Observations made on this installation indicated that the sand removal under optimum conditions was at the rate of about 15 pounds per second. It is believed that if the vanes are kept free of lodged material such as roots, grass, tree branches and other fibrous matter, this type of sand trap should be highly effective. The riffle-vane deflector sand trap is best suited for moderate velocities of 2 to 3 feet per second, it is not intended for wide channels.

The Riffle Deflector-Vortex Tube

The most promising and practical sand trap thus far developed is the riffle of deflector-vortex tube type. In general, this device consists of a series of curved riffles on the bed of the channel, whereby the bed-load is moved laterally to the end of the riffle where it is taken off through small vortex tubes outletting into a common compartment. This compartment is provided with an outlet through which the total trap load is sluiced back to the river downstream from the diversion dam or disposed of in basins as waste material. The riffles are parabolic in plan, have a vertical front face of about $1\frac{1}{2}$-feet and the top surface sloping downward to a feather edge in a distance of about 5 feet, as measured parallel to the axis of the channel, a cross section being a right triangle. Since the riffles are curved identically in plan, they are fitted one against the other progressively downstream. The number of riffles depends upon the nature of the bed load. For coarse sand and gravel fewer riffles would be required, whereas, for fine sand the number of riffles would be greater, but in no case probably exceeding a set of 10 or 12.

This type of trap can be readily adapted to either narrow or wide channels and to flows ranging from less than 10 to more than 2,000 second-feet. For canals of 20 to 50 feet in width it is suggested that two series of riffles be provided, to crowd the bed load to the middle, or axis, of the channel. Short vortex tubes at the end of riffles carry the load into a narrow compartment built along the center line of the channel, from which an outlet pipe conducts the trapped sand and water to the point of disposal. For channels ranging from 50 to 100 feet, a double installation with four series of riffles is recommended. The outlets from the twin installation are joined in a common pipe placed below the bed of the canal and under the canal bank. Laboratory tests on models of the riffle deflector-vortex tube trap indicate that it is capable of capturing 90 percent or more of a weighed bed-load sample introduced in the approach channel upstream from the riffles.

A few field installations of this type of sand trap have been made and all have been successful in catching bed loads, not only of relatively coarse material, but also of fine sand. As an experimental installation of such a trap, a timber structure was built in the Sheep Creek Ditch near Torrington, Wyoming, which was capable of handling very fine sand. The riffles were made of 1 x 6-inch common boards, the vertical face being 1 x 12-inch board bent to the desired curvature. In this case there were six riffles and three short 4-inch vortex tubes. One of the objections to this installation was the fact that tumbleweeds persisted in clogging the short tubes.

Figure 9.- Experimental field setting of the riffles deflector-vortex tube sand trap in the Sheep Creek Ditch near Torrington, Wyoming. Six riffles, 14 feet long, 12-inch face. There are three short vortex tubes discharging into a common outlet behind left wall. The structure is 16 feet wide.

As a preliminary study of the adaptation of the riffle deflectors to the problem of desanding the new proposed C F & I Supply Canal, a set of five riffles, made of lumber, was placed in the old supply canal about 1/2-mile from the heading on the Arkansas River. This study was to determine merely the effectiveness of the riffles in crowding the fine sand bed-load to one side of the channel. No vortex tubes were used. The accumulated load was sluiced out through an ordinary 4-foot vertical slide gate. The sluicing operation was not very efficient but it was demonstrated that the riffles were effective. The width of channel, timber flume section, was about 16 feet, discharge 100 second-feet at a velocity of about 3 feet per second.

Figure 10.- Experimental riffle deflectors placed in the flume section of the old C F & I Supply Canal near Portland, Colorado. Arkansas River diversion, riffles at 3-foot intervals. Face about 10 inches.

The Sheep Creek Ditch sand trap and the old supply canal demonstrations, together with laboratory studies of the principal of this type of sand trap, provide necessary data on which to base the design for a structure to be placed in the new supply canal for the steel works where the channel would be 40 feet wide and have a capacity of 250 second-feet. This reinforced concrete structure consists of two sets of riffles to move the bed load toward the center of the channel, and short vortex tubes to pick it up and discharge it into a narrow longitudinal compartment. A 24-inch concrete pipe from the downstream end of the compartment to the river served as an outlet.

Figure 11.- Plan of diversion works at the heading of the new C F & I Supply Canal near Florence, Colorado. The sand trap is a double riffle deflector-vortex tube type. Common outlet to river from the down-stream end of the central compartment.

Figure 12.- General view of the double riffle deflector-vortex tube sand trap, new C F & I Supply Canal.

Figure 13.- Concrete riffle deflectors, left hand basin. Riffles 17 feet long with $1\frac{1}{2}$-foot face. New C F & I Supply Canal.

This installation has been successful but some difficulty was experienced at first because no provision was made for regulating the discharge of the vortex tubes into the common collection compartment. Slide gates were later provided, which improved materially the action of the trap. No tests have been made on this particular structure, but after 5 years of continuous use, observations along the canal downstream from the heading indicate that there is very little, if any, river sand found in the channel. It is therefore assumed that the efficiency of this installation is reasonably good.

The next problem requiring solution was the desanding of the Consolidated Irrigation District Canal that diverts from the King's River near

Fresno, California. This canal has a bottom width of 90 feet at the heading and has a capacity of more than 2,000 second-feet. Excessive cleaning operations resulted in great piles of sand at places along the canal and in some instances the disposal encroached upon vineyard lands that had to be purchased at $1,000 per acre. Dragline cleaning at various points was necessary every season.

Because of the apparent success of the riffle deflector-vortex tube type of sand trap, especially the installation in the new supply canal to the C F & I steel works at Pueblo, the Board of Directors of the Consolidated Irrigation District approved the building of a model at the Bellvue hydraulic laboratory where investigations and studies would be made of this type of trap by the Division of Irrigation and Water Conservation, Soil Conservation Service of the U. S. Department of Agriculture and the Colorado Agricultural Experiment Station cooperating.

Figure 14.- Side view of the model of the riffle deflector vortex tube sand trap as proposed for the Consolidated Irrigation District main canal diverting from the King's River near Fresno, California. Model scale 1 to 10. Bellvue laboratory.

Figure 15.- Looking upstream showing arrangement of riffles and short vortex tubes of special design that outlet into the straight wall collecting compartment from both sides.

Figure 16.- Looking downstream showing the 48-inch concrete pipe collecting chambers, at left. The model 40-foot Parshall measuring flume, just downstream from the riffles was used to measure the discharge in the model.

Previous investigations had been made in the laboratory as to the percentage of the total bed-load caught by each succeeding downstream vortex tube drawing from the end of the riffle deflectors. Six riffles, each with its tube, showed the following results:

	Consolidated Canal Sand	Percent	Ordinary Laboratory Sand	Percent
Gross sample	25.00 kilos		25.00 kilos	
Moisture tare	1.25		1.75	
Net dry sample	23.75		23.25	
Dry wt. catch, Tube 1 -	15.39	68.3	Tube 1 - 14.55	67.1
" 2 -	3.32	14.7	" 2 - 3.64	16.8
" 3 -	1.96	8.7	" 3 - 1.84	8.5
" 4 -	.96	4.3	" 4 - .86	4.0
" 5 -	.68	3.0	" 5 - .45	2.1
" 6 -	.23	1.0	" 6 - .34	1.5
Total recovery	22.54		21.68	
Efficiency		95		93

From these findings it will be observed that about 2/3 of the total bed-load is caught by the first upstream tube, and 4/5 by the first and second combined. This laboratory test was important in improving the design of this type of sand trap. Instead of outletting the total captured load at the downstream end of the compartment, the outlet was placed at a point between the first and second tubes so that the load from the other tubes moves upstream within the compartment to the outlet.

Model Studies of the Proposed Riffled Deflector-Vortex Tube Sand Trap for the Consolidated Irrigation District Canal. Bellvue Hydraulic Laboratory, July-August, 1947, scale ratio 1/10.

This model was constructed of common 3/4-inch surfaced lumber. It was 41 feet long and occupied the full width of the 14-foot laboratory channel. The general features are as shown in figures 21, 22 and 23. The model consisted of a double trap, of which both halves were identical except for the type of collection chambers. In one case a straight side wall compartment was used, 4-feet inside width, and 62.5 feet long, with a streamlined upstream end to reduce turbulent flow over the end of the riffles and the tubes. As an alternate design for comparison the other half of the model was provided with six vertical 48-inch concrete pipe collectors spaced 10-feet apart, on center, and connected at the base with 24-inch concrete pipes. A streamline splitter was fixed to the front side of the first vertical pipe. These two types of collection chambers were studied independently as to efficiency and found to be equally satisfactory. The riffles were cast of cement motor in a special mold, vertical front face 1½-feet, width of base 5 feet, and the curvature in plan to the equation $K = 0.055\ (D + 2.5)^{1.7}$, where K is the offset and D the distance from the origin of curve. The riffles sloped laterally toward the collection chambers on a grade of 0.073-foot per foot.

The short vortex tubes were of special design. The outlet from each type of collection chamber was at the entrance of the second set of tubes. With this plan the bed load captured by the downstream riffles moved upstream within the collectors past the intervening points of tube entrance. Because of this condition - the discharge from the vortex tubes into the collector - it would be desirable for the direction of flow to be normal, that is, at 90 degrees to the axis of the channel. Therefore the lip of the tube, in plan, was laid out to the parabola $y = 0.0084\ (x + 1)^{3.56}$. This equation represents an arbitrary assumption and is not based upon any special observations as to efficiency. It may be that some other lip curve of this nature would be equally effective. The elevation of the lips of the tubes was 1.5 feet below the grade of the canal.

Along side, between the model and the channel wall of the laboratory, was a catchment basin for the trapped material, 12 feet long, 4 feet deep and 2 feet wide. The two outlet pipes from the model emptied into this basin. The water surface in this basin could be adjusted to agree with the river stage in the prototype. At the downstream end of this box was provided a 3-inch Parshall measuring flume for gaging the effluent from the model.

A 40-foot measuring flume, to scaled dimensions was placed downstream from the last riffles to gage the discharge through the model. For the prototype flow of 2,100 second-feet in the canal the discharge through the model 40-foot flume would be 6.64 second-feet and 0.32 second-foot as the approximate effluent from the model. The outlet discharge was regulated by means of flash boards and slide valves at the outlet end of the tubes. The approach channel was 90 feet wide for a distance of 185 feet with a scaled grade of that of the actual canal. Side slopes of one to one.

Model testing, especially of sand trapping devices, has never been very satisfactory because of the media used to simulate sand of various kinds and degrees of fineness. In our studies we have used coarse and fine sand, silica such as standard sand for cement briquette testing, pulverized soft and anthracite coals, pulverized hard pressed brick, soy beans, wheat, ground corn and treated saw dust. Though it was not tried it is believed that colored plastic material, especially Plexiglas, in suitable form would be found adaptable as a medium for model studies. For the Consolidated Irrigation District sand trap model, actual sand from the canal was tried in the tests. Also ordinary river sand obtained at the laboratory, pulverized coal and brick. Coal was found satisfactory to observe the action of the riffles and vortex tubes as well as the movement within the chambers toward the outlets.

The water supply at the Bellvue laboratory was satisfactory for observational purposes both as to quantity and clearness. For the most part the discharge was for full capacity of the canal, namely about 2,100 second-feet. The rate of flow was determined by measurement through the model 40-foot flume and the 3-inch standard flume. The discharge as measured over a 4-foot rectangular weir and through the model 40-foot flume agreed within about 2 percent.

The tests on the model were not extensive. Trial runs were made to permit of visual observation as to the general action of the riffles, tubes, and movement within the collecting chambers. Alterations in settings were made to improve the general overall efficiency of the model.

Pulverized coal and brick were used mostly as bed load test materials and are believed to have been fairly satisfactory for this purpose. A tabulation of a few of the tests made is appended to this paper.

Officials of the Irrigation District inspected the model in operation and certain changes and alterations in design were discussed. The primary change was to eliminate the 40-foot measuring flume and replace it with a low crest weir across the canal immediately downstream from the sand trap structure, in order to reduce the cost. The 48-inch vertical concrete pipe collecting wells were selected in lieu of the straight walled compartment, and because of the relatively small percentage of bed-load captured by the two downstream wells it was decided to have four instead of the six wells as set up in the model.

The use of the 40-foot Parshall measuring flume to gage the flow in the canal, with the crest set at the proper elevation, would more or less control automatically the velocity over the riffles. The proposed design was for a difference in elevation of 2.86 feet between the lip of the vortex tubes and the flume crest, whereas for the control weir this difference, as built, is 6.28 feet.

This water depth at zero canal discharge was considered undesirable because of the reduced velocity over the riffles. However, this condition later proved to be less serious than was at first anticipated. By actual observation, for a flow of 1,788 second-feet over the control weir, the mean velocity over the riffles was found by current meter observation to be 3.91 feet per second. For this canal discharge the mean velocity in the model was computed to be approximately 3 feet per second or a difference of about one foot per second. The canal section upstream from the sand trap is straight, very uniform in width, and has a smooth cobblebed. The approaching flow as indicated by the water surface is good. Sand deposits on the bed of this section of the channel may have been present. If so, their presence was not indicated by boils at the water surface. Water was diverted uniformly into the canal through eight 10-foot radial gates. The two outside gates were closed. For low flow, 1,000 second-feet or less, the mean velocities over the east, central and west sections of the sand trap were definitely unbalanced. Greater in the central section as would be expected. For a canal discharge of 2,500 second-feet, the mean velocity over the riffles is estimated to be 4.6 feet per second whereas for the model the mean velocity would be 3.8. The reason for this deviation is not known as this time.

Figure 17.- Plan of the proposed riffle deflector-vortex tube sand trap for the main canal of the Consolidated Irrigation District.

Figure 18.- Construction of the Y-branched outlet which heads between the first and second 48-inch vertical pipe collecting chambers. This outlet serves both identical halves of the trap structure.

Figure 19. -Special designed vortex tube installed in the Consolidated Irrigation District sand trap. The discharge opening is 8 by 18 inches. Made of 10-gage black iron, spot welded, and set in concrete on the job.

Figure 20.- Forty-eight-inch vertical concrete pipe collecting chamber. The tip of riffles here are submerged. Crest of weir control in the background.

Figure 21.- Side view of the Consolidated Irrigation District sand trap in operation. Flow in canal is 1,100 second-feet.

Figure 22.- Looking upstream, Consolidated Irrigation District sand trap. Flow over control weir 1,100 second-feet.

Figure 23.- Looking upstream, Consolidated Irrigation District sand trap. Control weir in foreground, crest length 105 feet. Diversion gates in the background. Crest to head gates 830 feet.

Means have not been available to make an actual field test of the efficiency of this large sand trap. This could be accomplished only at considerable cost in time and money. Detailed observations of the canal at various places and distances downstream from the sand trap appear however to indicate the effectiveness of this device. About one mile from the sand trap the main canal is divided into two branches. Just upstream from this bifurcation the canal is of considerable width with deep water at a relatively low velocity. Before the start of the 1949 irrigation season, about April 1st, this section of the canal was cleaned of sand deposit. At the close, middle of July, it was observed that very little sand had accumulated during the time the canal was in use. At other places along the branch canals, which previously had been fouled to a greater or less extent appeared to be much relieved of sand deposit. This season should show further the effectiveness of this type of sand trap. It is generally assumed by those who are closely associated with the operation of this large canal that the efficiency of the sand trap exceeds 75 percent. Formerly dragline cleaning operations were necessary each year, especially for certain stretches where the sand would deposit to a depth of about 4 feet or more per season. No cleaning was done during 1949. Sand in transit in the channels will move to places favorable for depositing and later will be dredged out. Once the system is stabilized canal cleaning should be necessary only every three to five years. It was estimated that the previous annual cleaning operations amounted to $4,000 per year. The cost of the sand trap was $15,000 and was completed December 1947.

Summary

The vortex tube sand trap is best suited to narrow channels and relatively high velocity. When set properly and operated under suitable conditions the efficiency should be approximately 90 percent.

The riffle vane sand trap is intended for narrow channels, not exceeding about 12 feet, and velocities of 2 to 3 feet per second. The action of the riffles is independent of the depth of flow. The efficiency should approach 90 percent. This type of sand trap is not recommended for operation in channels that carry such material as would clog the vanes.

The riffle deflector-vortex tube sand trap is adaptable to channels of considerable width and velocities ranging from 2 to 4 feet per second. Gravel, coarse or fine sand has been captured successfully. Under favorable conditions of operation the efficiency should be near 90 percent.

Outletting facilities and nature of the bed load determine largely the percentage of the total flow used for sluicing purposes. Ordinarily the effluent should not exceed 5 to 10 percent.

Suspended load cannot be captured by the sand trapping devices herein discussed.

SUMMARY OF TESTS ON THE CONSOLIDATED IRRIGATION DISTRICT RIFFLE DEFLECTOR - VORTEX TUBE
SAND TRAP MODEL, BELLVUE HYDRAULIC LABORATORY, AUG.-SEPT. 1947

Test No.	Date 1947	Sample	Dry Wt. kgs.	Discharge Model sec.ft.	Discharge Canal sec.ft.	Discharge Outlet sec.ft.	Effluent percent	Canal Depth ft.	Elev.W.S. in Canal ft.	W.S.in River ft.	Diff. in Head ft.	Vel.over Riffles ft./sec.	Recovery of Sample kgs.	Efficiency percent	Trap	Duration hrs.-min.
	Aug.															
1	19	Coal 1/4" mesh	20	6.84	2160	76	3.5	6.98	430.99	426.81	4.18	3.20	19.12	96	A	3 - 10
2	20	" " "	20	6.96	2200	101	4.6	7.00	431.01	427.21	3.80	3.25	15.44	77	A	2 - 10
3	21	" " "	20	6.18	1950	95	4.9	6.80	430.81	426.91	3.90	2.92	15.78	78	A	5 - 0
4	22	" " "	20	7.00	2210	54	2.4	7.00	431.01	426.71	4.30	3.25	15.14	76	A	5 - 0
5	26	Brick 1/8" mesh	20	8.45	2670	61	2.3	6.95	430.96	427.01	3.95	4.04	17.30	87	A	4 - 35
6	27	" " "	20	8.94	2825	63	2.2	7.10	431.11	427.11	4.00	4.11	16.79	84	B	6 - 10
7	29	" " "	20	8.79	2770	57	2.1	7.10	431.11	427.21	3.90	4.05	14.12	71	A	2 - 0
	Sept.															
8	17	" " "	32.56	6.33	2000	93	4.6	7.00	431.01	427.61	3.40	2.92	29.84	92	B	6 - 30
9	18	" " "	32.26	6.39	2020	95	4.7	7.00	431.01	427.81	3.20	3.11	30.37	94	A	6 - 0

- Remarks -

1. Bed load, 1/4-inch screen size with fines, moved fairly well, better than for brick. The sample load almost 5 percent brick. Tubes a and b full opened; c, d, and e 1/2 opened; and f full opened. Flush gate closed. Movement in compartment excellent.
2. Bed load, 1/4-inch screen size with fines, no brick. Load movement very good. Powdered coal mostly lost in first 5 minutes. Tube openings same as for test 1.
3. Bed load, with fines, movement fairly good. Tube openings as for test 1.
4. Much of bed load lost in first five minutes. Bed load introduced wet in square frame. Load moved mostly to the right set of riffles. The mean velocity appeared to be more than for optimum efficiency. Tube opening as for test 1.
5. Bed load, crushed brick, 1/8-inch screen size with fines. Sample introduced dry, 2 feet from upper end of canal section. Movement satisfactory. Spread to a depth of 1-1/2 inches in 30 minutes. Particles now move in normal pattern around nose of compartment. Changed transition to measuring flume preceding this test. Tube openings as for test 1.
6. Bed load as for test 5. Collecting wells fully exposed to turbulence. Approach conditions normal. Right hand riffles appear to be more active than for the left side. Tube openings same as for test 1.
7. Bed load as for test 5. Introduction of sample same as test 5. Movement good. Depth 2 inches rate 1 foot in 10 minutes. Approach condition at nose of compartment improved. Efficiency impaired because of crowding the time of duration of test. Tube opening same as for test 1.
8. Bed load, brick, lesser amount of fines. Introduction as for test 5. Movement satisfactory. Space between collecting wells closed with side boards, 1/2-inch opening at bottom, 4-1/4 inches high, extending from well a to f. Tube openings same as for test 1.
9. Duplication of test 8 except trap A instead of B.