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HYD 579 Tehama Colusa Gravel Cleaner

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

AN ARTIFICIALLY PRODUCED VELOCITY BARRIER FOR CONTROLLING FISH MOVEMENT: TEHAMA-COLUSA CANAL

Report No. Hyd-579

HYDRAULICS BRANCH
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

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AN ARTIFICIALLY PRODUCED VELOCITY BARRIER FOR CONTROLLING FISH MOVEMENT: TEHAMA-COLUSA CANAL

by

E. R. Zeigler

November 1967

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ACKNOWLEDGMENTS

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ABSTRACT

A dual-purpose irrigation and fish spawning channel will be constructed along a 3.22-mi length of the Tehama-Colusa Canal, Calif. A vertical slide gate device (baffle gate) was developed for cleaning the gravel spawning bed of the canal. The gate can be moved along the length of the canal and positioned in the water to produce a jet of higher velocity flow beneath the gate. A secondary use of the baffle gate is to provide a 5-fps velocity barrier for controlling movements of small fish in the canal. Model tests were made to determine whether this velocity barrier could be maintained without eroding the gravel bed and to determine baffle gate settings to produce the 5-fps velocity barrier for given discharges. A photograph and drawing of the model flume, test data, and a gradation curve of model gravel are included.

DESCRIPTORS-- fish/ irrigation canals/ hydraulic models/ *fish handling facilities/ model tests/ scour/ baffles/ velocity/ channels/ *slide gates/ flumes/ jets/ gravels
IDENTIFIERS-- Tehama-Colusa Canal, Calif/ *spawning channels/ fish guiding/ *velocity barriers/ fish barriers/ salmon

SUMMARY

A 3.22-mile (5.2 kilometer) length of the Tehama-Colusa Canal, near Red Bluff, California, will be used as a dual-purpose channel; an irrigation water conveyance canal, and as a fish-spawning channel. A gravel layer in the canal bottom will provide a spawning bed for salmon. Sediment is expected to settle out of the canal water and deposit in the gravel. Because salmon eggs deposited in sediment-clogged gravel will die before they are hatched, a vertical slide gate device (baffle gate) will be used to remove the fine sediment from the gravel. The baffle gate, mounted on a carriage which can travel up and down the canal, is lowered partially into the flowing canal water. The high-velocity jet thereby produced beneath the gate displaces the gravel from upstream to downstream of the gate and washes the sediment into suspension to be carried away by the canal water flow.

This report describes a secondary benefit in which the baffle gate will also be used to produce a velocity barrier to prevent small fish from swimming past the gate. By moving the gate downstream, young salmon fish can be controlled or moved along and out of the canal. Described in this report are hydraulic model tests made to determine the vertical positions of the baffle gate necessary to produce a velocity barrier of 5 feet (1.5 meters) per second beneath the gate for various canal discharges. The sectional model was 28 feet (8.5 m) long, 2 feet (0.61 m) wide, and 8 feet (2.4 m) deep. One side of the model contained glass panels through which action in the model could be observed and photographed. The velocity profile for water flowing beneath the baffle gate, at a point 2 feet (0.61 m) downstream from the baffle gate, was determined by making velocity measurements at successive vertical intervals above the gravel bed. Velocity profiles were measured for various canal discharges at two different tailwater depths, and in some cases after erosion of the gravel bed occurred. The model data were used to plot a curve showing the vertical setting of the baffle gate above the gravel bed versus canal discharge. The graph can be used to find the baffle gate opening above the gravel bed to produce a velocity of 5 feet (1.5 m) per second at a point 2 feet (0.61 m) downstream from the baffle and 0.3 foot (9.1 cm) above the gravel bed for various canal discharges.

INTRODUCTION

The dual-purpose irrigation and fish-spawning channel, 3.22 miles (5.2 km) long, to be constructed in California, Figure 1, has a maximum canal discharge of 2,530 cubic feet per second (cfs) or 71.6 cubic meters per second (cms). The gravel bed, 2.5 feet (0.76 m) thick will be placed in the concrete-lined irrigation canal. The gravel will provide a place for salmon to spawn and deposit their eggs. One requirement for a spawning channel is that the gravel be free of fine sediment during hatching of the eggs. Oxygen-laden water is required to circulate through the gravel to keep the eggs and the hatched fish alive. Sediment in the gravel voids prevents circulation, and may even prevent use of the gravel by the spawning salmon.

A method for cleaning the gravel by using a baffle gate to produce a high-velocity jet of water has been developed as a result of hydraulic tests made in the laboratory. 1/ A vertical slide gate is placed across the canal. The bottom of the gate is set relatively close to the gravel bed to partially obstruct the waterflow. Constriction of the waterflow area by the baffle gate raises the upstream water surface elevation. A differential head of approximately 1.5 feet (0.46 m) is established between the upstream and downstream water surfaces at the baffle gate. This differential head produces a high-velocity jet of water flowing beneath the baffle gate. Action of the high-velocity jet scours a furrow in the gravel directly beneath the gate and as the gate is lowered further the scour extends down to the concrete canal bottom. The baffle gate is then moved upstream and the gravel is scoured from the upstream side of the furrow and is deposited on the downstream side. In the process, fine sediment is flushed away from the gravel particles and washed into suspension during movement of the gravel. The deposited gravel is laid in the configuration it had before being scoured, with no apparent sorting as to sizes of particles. Figure 2A is an artist's drawing of the baffle gate.

The events and activities during a complete salmon spawning cycle are: (1) adult salmon migrate up the river and into the spawning channel, (2) adult salmon dig redds (nests) in the spawning gravel, Figure 2B, (3) adult salmon deposit and fertilize their eggs, (4) eggs hatch and the young fish emerge, and (5) young fish migrate from the channel to the river. Because of these many activities, during several salmon runs, the time left each year for cleaning the gravel is about 1 to 2 months. Some fingerlings (small young salmon fish) may still be in the canal when it is time to start the gravel cleaning operation. The moving baffle and the accompanying velocity barrier are proposed to "crowd" or move the fingerlings from the canal. Because the small fish cannot swim through the velocity barrier they will be crowded from the canal as the baffle gate is moved downstream in the canal.

This report describes the investigation made to determine whether a 5-foot-per-second velocity barrier could be maintained without eroding the gravel spawning bed, and to find what baffle gate openings would produce the 5-foot-per-second velocity barrier for given discharges.

1/Numbers refer to references at the end of the report.

THE INVESTIGATION

The Model

The model, sectional in nature, Figure 3, was constructed in an 80-foot (24.4 m) long, 4-foot (1.2 m) wide, and 8-foot (2.4 m) deep flume. One side of the flume contained glass panels so that action in the flume could be observed. The model was 28 feet (8.5 m) long, 2 feet (0.61 m) wide, and 8 feet (2.4 m) deep. The baffle gate, made from a 3/4-inch (1.9 cm) thick, 2-foot (0.61 m) wide, and 8-foot (2.4 m) long piece of plywood, could be raised or lowered, and was attached to a carriage with wheels that tracked along the flume. Stoplogs were used to control the tailwater depth in the model. Water inflow into the model was measured with calibrated Venturi meters permanently installed in the hydraulics laboratory.

Two different model scales were used, 1:2 and 1:1. Gradation of the model gravel is shown in Figure 4; 3/4 inch (19.1 mm) to 6 inches (152 mm) for the 1:1 scale tests and 3/8 inch (9.5 mm) to about 3 inches (76.2 mm) for the 1:2 scale tests. Gravel depths in the model were 1.25 feet (0.38 m) and 0.75-foot (0.23 m) for the 1:2 scale tests, and 0.75-foot (0.23 m) for the 1:1 scale tests.

Model Tests

Most of the canal discharge will flow between the baffle gate bottom and the 100-foot (30.5 m) wide gravel bed. Some water will flow through the gravel bed. Prototype discharges were simulated for the sectional model in each test. Model tests were made for prototype canal discharges of 750, 1,300, 1,800, and 2,400 cfs (21.2, 36.8, 51.0, and 68.0 cms).

For each model discharge, velocity measurements were made at intervals along a vertical line located on the centerline of the model at a point 2 feet (0.61 m) downstream from the baffle gate, Figure 5. A 5/16-inch (7.9 mm) diameter Prandtl tube, that could be positioned by a calibrated indicator, was used to measure velocities. A differential pressure cell (transducer) electrically connected to an electronic recorder was used to measure the velocity head obtained from the Prandtl tube.

For each given discharge the velocity measurements were made with two different tailwater elevations. One tailwater elevation represented the depths for a smooth gravel bed (no redds); the other was for a rough gravel bed (completely covered with redds). For a series of tests with a given discharge and tailwater elevation the baffle gate clearances above the gravel bed were reduced starting with the largest baffle gate opening. The opening was decreased in increments until gravel erosion was just beginning. Vertical velocity measurements were made at the different baffle gate openings. In some cases after part of the gravel bed had eroded, the baffle gate was lowered another increment and velocity measurements again made.

Model tests are summarized in Table 1, and measured velocities are shown on Figures 6 through 12.

DISCUSSION AND RESULTS OF THE INVESTIGATION

Model Tailwater Depths

Different roughnesses of the gravel bed may exist when the baffle gate will be used for crowding small fish from the canal. The gravel bed may be undisturbed and relatively smooth, or the bed may have been altered by the spawning salmon. During spawning, the female salmon, using her body, digs a nest (redd) in the gravel bed, Figure 2B. Gravel excavated from the hole is carried by the flowing water and is deposited immediately downstream to form a hump. Sizes of the individual redds vary, but typical approximate dimensions are 12 inches (0.3 m) deep, 11 feet (3.4 m) downstream length for the excavated portion; and 9 inches (.19 m) high, and 6 feet (1.8 m) downstream length for the hump. Width across the channel of a typical redd is approximately 6 feet (1.8 m). Different roughnesses of the gravel bed can produce different water depths for the same canal discharge. Two different model tailwater depths were used for each discharge tested (Table 1) - one for the minimum bed roughness with "no redds" and the second for the maximum bed roughness with "100% redds."

Gravel Bed

The reference datum representing the top of the gravel bed was a horizontal line drawn on the glass-walled side of the flume, Figure 13. Gravel was placed in the flume level with the horizontal line. The top of some rocks were above this line and the depressions formed between adjoining rocks were mostly below the line. After model tests were made in which erosion occurred, the gravel was replaced to the level of the line before the next series of tests were started.

Desired Velocity for Crowding the Small Fish from the Canal

The Fish and Wildlife Service recommended that a velocity barrier of 5 feet per second (fps) or 1.52 meters per second (mps) be established under the baffle gate. This velocity, they believed, would be sufficient to prevent penetration by the small fish. During initial tests velocities were found to be higher in the upper part of the jet than in the lower part of the jet. Therefore the lower part of the jet, at a point 0.3 foot (9.1 cm) above the gravel bed, was selected as the point where the velocity of 5 fps (1.52 mps) should be maintained. Movement of the baffle would then crowd the small fish out of the canal.

Scour

Incipient scour of the gravel bed was difficult to determine for a precise velocity or set of model conditions. Meaningless scour may occur when an occasional rock or two is swept away for no apparent reason or when turbulent fluctuations of the velocity near the gravel bed cause local movement. Tests in which more definite scour occurred for given baffle gate settings are noted on Figures 6 through 12. The baffle gate setting was always measured from the baffle gate bottom to the gravel bed reference datum, even when erosion occurred. However, the scour depth was considered when determining the distance above the gravel bed where velocity measurements were made. The plotted velocity measurements show the distance of the Prandtl tube above the existing gravel bed.

Model Scales

Two different model scales, 1:2 and 1:1 were used. The 1:2 scale model tests were based on the Froude number relationship between model and prototype. The gravel size was scaled geometrically on the basis of stone diameter. Square holed screens were used to obtain the gravel material.

Canal discharges greater than 1,300 cfs (36.8 cms) could not be tested in a 1:1 scale model because of the flume size and the limitations of water supply to the model. A 1:2 model scale was used for making tests from 750 up to 2,400 cfs (21.2 to 68.0 cms). To verify data obtained from the 1:2 scale model, tests were made on a 1:1 scale model for the 750- and 1,300-cfs (21.2 and 36.8 cms) canal discharges. Results of the 1:1 model tests substantiated velocity and scour data obtained from the 1:2 model, Figures 10 to 12.

Data from the Velocity Measurements

The locations where velocity measurements were made, with respect to the baffle gate are shown in Figure 5. Vertical traverses 2 feet (0.61 m) downstream from the gate and on the centerline of the model channel were recorded. Only velocities below the shear zone of the jet were measured. Velocity measurements made in the 1:2 scale model for canal discharges of 750, 1,300, 1,800, and 2,400 cfs (21.2, 36.8, 51.0, and 68.0 cms) are shown in Figures 6, 7, 8, and 9, respectively. Figures 10 and 11 show a comparison of velocity measurements in the 1:1 and the 1:2 scale models for a canal discharge of 750 cfs (21.3 cms). Figure 12 is a comparison of velocity measurements made in the 1:1 and 1:2 scale models for a canal discharge of 1,300 cfs (36.8 cms).

The plotted velocity points in Figures 6 through 12 are the average velocities determined from recorder records of pressure fluctuations for the Prandtl tube. Instantaneous velocities varied from the time average velocity because of the rough gravel bed causing turbulent flow. The largest fluctuations were observed in velocities measured close to the gravel bed. For example, a variation of 0.4 fps (0.12 mps) from an average velocity of 6.4 fps (1.95 mps) measured at a point 0.3 feet (9.1 cm) above the gravel bed was observed.

Characteristics of the Velocity Barrier

The jet, under the gate, contracts noticeably within a 4-foot (1.2 m) distance downstream from the baffle gate as shown in Figure 5. Contraction and the upper flow boundary of the jet can be seen in Figure 13. The jet flows only in the lower part of the downstream water depth. Waterflow above the jet is very irregular and rough. The general direction of waterflow above the jet is upstream toward the baffle gate.

Results of the tests show definite characteristics of the jet velocity profile. The highest velocity is in the upper level of the jet, and the velocity profile of the jet decreases from the upper level to the lower level near the gravel. The greater part of the jet velocity profile has a higher velocity than the velocity at a point 0.3 foot (9.1 cm) above the gravel bed.

The tailwater depth has an effect upon the velocity profile, Figures 8 and 9. At a point 0.3 foot (9.1 cm) above the gravel bed velocities for the high tailwater depth tend to be greater than the velocities for the low tailwater depth.

Baffle Gate Settings

The baffle gate setting is defined as the distance from the baffle gate bottom to the gravel bed reference datum line. Figure 14 contains a graph of the baffle gate settings versus canal discharge, taken from data obtained in the model tests. In all tests the gravel bed was relatively level across the 2-foot (0.61 m) model width. The three curves represent different behaviors of the gravel bed. The top line shows the baffle gate settings required to produce a velocity of 5 fps (1.5 mps) at a point 0.3 foot (9.1 cm) above the gravel bed with no scour. The dashed middle line indicates baffle gate settings where incipient gravel bed scour occurs. The lower line shows baffle gate settings at which gravel bed scour occurs, but at depths less than 0.5 foot (15.2 cm) deep.

In the prototype canal the gravel bed is anticipated to be rough and irregular because the salmon redds consist of depressions and humps on the gravel canal bottom. Establishing or maintaining a baffle gate setting or opening above an irregular gravel bed may be difficult. It may be necessary to smooth the gravel bed occasionally. A dependable and rapid method of determining the average distance from the baffle gate bottom to the gravel bed may be needed. Possibly some type of sensing device, mechanical or electronic in nature, can be installed on the baffle gate to measure or indicate the required distance.

The upper curve (designated - Velocity of 5 fps at a distance of 0.3 foot above the gravel bed) in the graph in Figure 14 is recommended for use in obtaining baffle gate settings for given canal discharges. For example, what is the gate setting for 1,200 cfs (34.0 cms)? Find the 1,200-cfs canal discharge line at the bottom of the graph; follow this line vertically upwards to the intersection with the upper curve. Read the baffle gate setting line on the left edge of the graph, Gate setting = 2.95 feet (0.9 m) above the gravel bed.

If baffle gate settings smaller than those given by the upper curve in Figure 14 are used, the gravel bed may be disturbed or scoured. For example, consider a hypothetical condition where a baffle gate setting of 2.2 feet (0.67 m) is used for a canal discharge of 1,200 cfs (34.0 cms). Erosion of the gravel bed will occur. As the baffle gate moves downstream the eroded gravel will accumulate in a pile a few feet downstream from the baffle gate. The size of the accumulated gravel pile will increase with the downstream movement of the baffle gate. For this and possibly other reasons, erosion of the gravel bed should be avoided.

CONCLUSIONS

1. The baffle gate can be adjusted to produce a water velocity of 5 feet (1.5 m) per second at a point 0.3 foot (9.1 cm) above the gravel bed without scouring the gravel as shown in Figure 14; therefore, according to estimates by the Fish and Wildlife Service, the baffle gate can be used for crowding (moving) small salmon out of the canal.

2. The greater part of the velocity profile, for the jet produced by the baffle gate, has a higher velocity than the velocity at a point 0.3 foot (9.1 cm) above the gravel bed; the point chosen as the location where the velocity should be 5 feet (1.5 m) per second.

3. A velocity of approximately 6 to 6.5 feet (1.8 m to 2.0 m) per second at a point of 0.3 foot (9.1 cm) above the gravel bed will cause erosion of the gravel bed.

4. Baffle gate settings (distance of gate bottom above the gravel bed) versus canal discharge to obtain a 5-fps (1.5 mps) velocity at a distance of 0.3 foot (9.1 cm) above the gravel bed are shown on the graph in Figure 14.

5. Baffle gate settings that produce erosion of the gravel canal bottom should be avoided.

REFERENCES

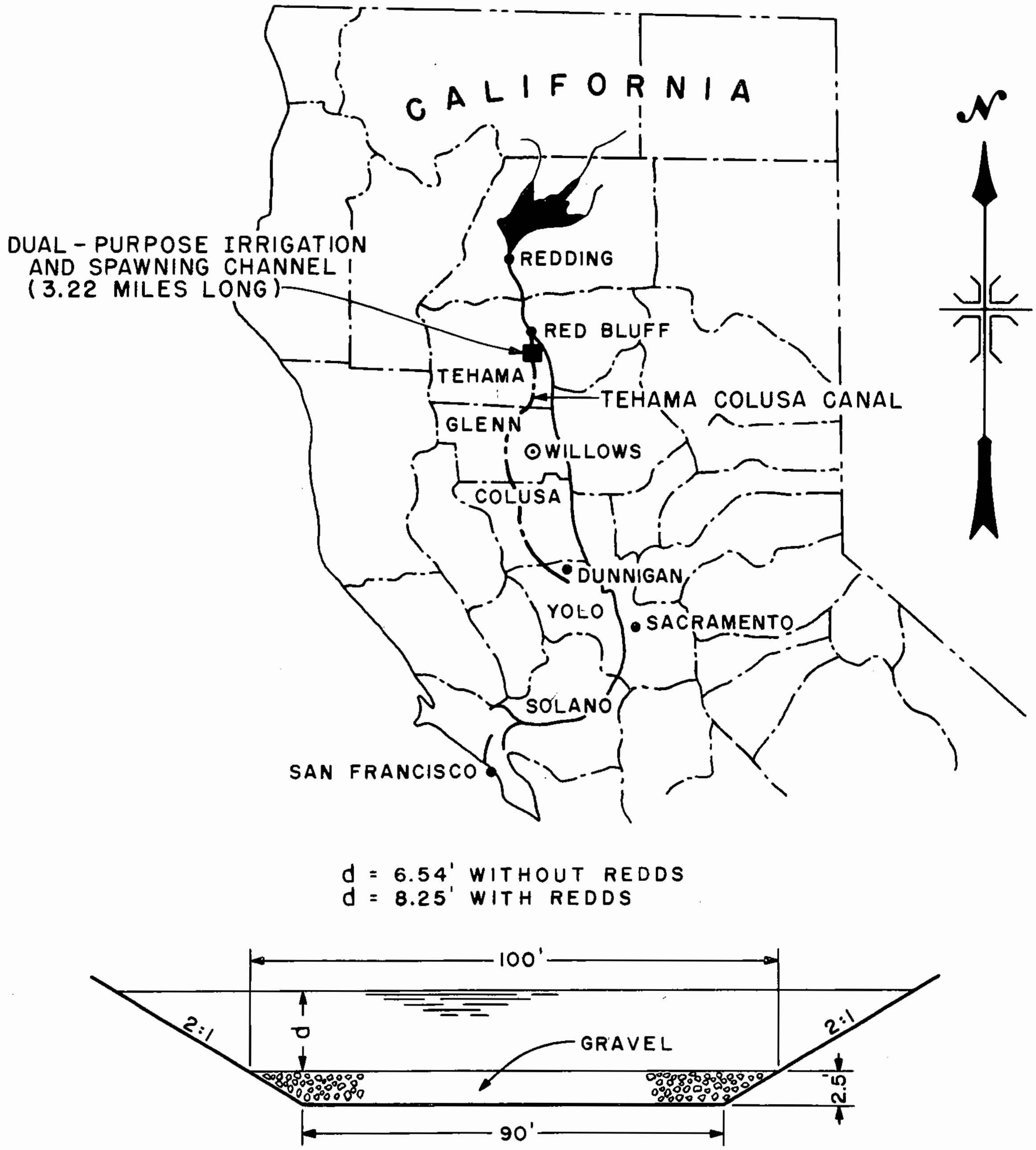
1. Carlson, E. J., "A Baffle Gate Method for Cleaning Salmon Beds in Canals" XII Congress of International Association for Hydraulic Research (IAHR), September 11-14, 1967, Fort Collins, Colorado.

Table 1

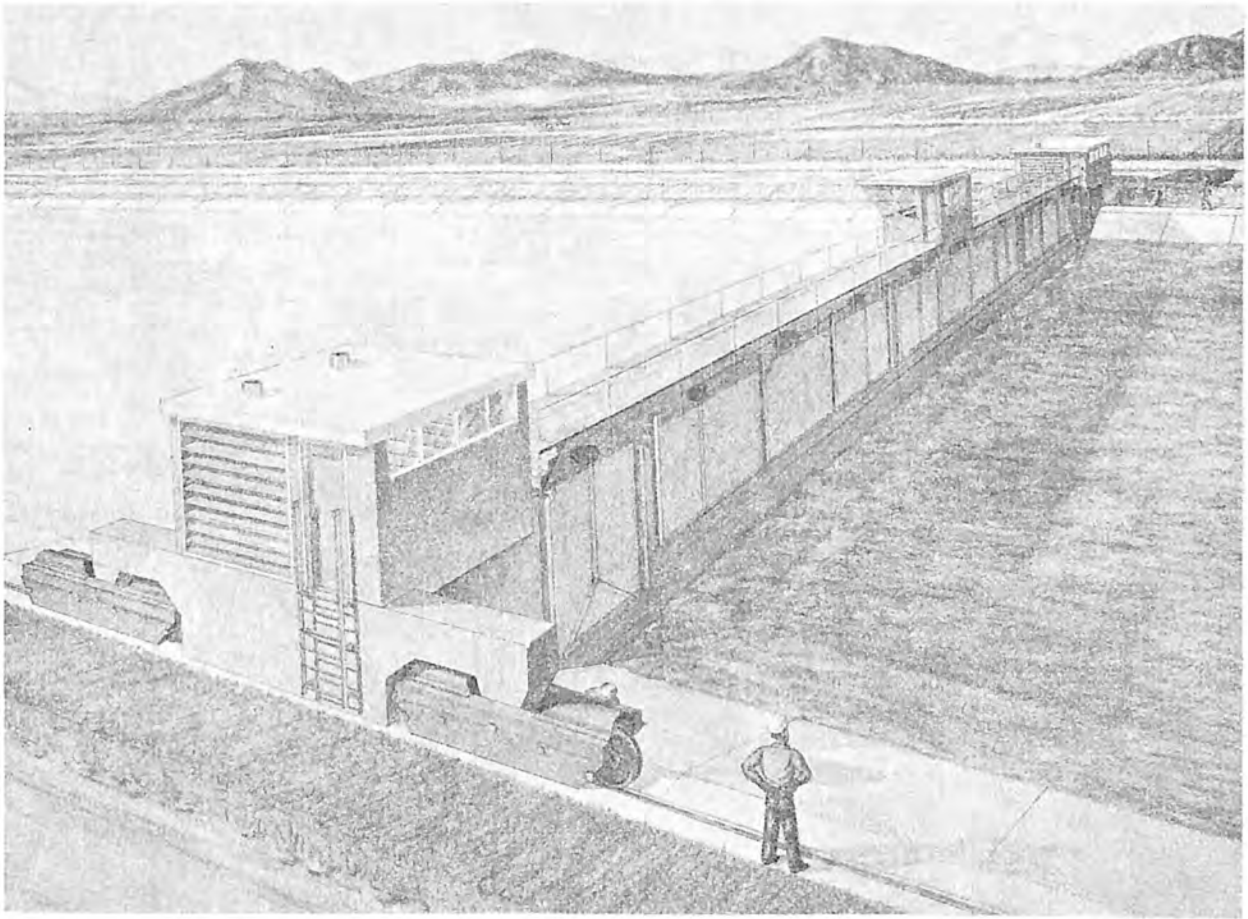
SUMMARY OF MODEL TESTS

Canal discharge, cfs	Model discharge, cfs	Scale	*Prototype tailwater depth, feet	*Prototype baffle settings, feet
750	5.3	1:2	3.3 & 4.2	2.2, 2.0, 1.8, 1.6
750	5.3	1:2	4.2	2.4, 1.4, 1.2
1,300	9.2	1:2	4.5 & 5.7	3.6, 3.2, 2.8, 2.6
1,800	12.7	1:2	5.3 & 6.9	4.4, 4.0, 3.6
2,400	17.0	1:2	6.4 & 8.1	5.4, 5.0, 4.6, 4.2
750	15.0	1:1	3.3 & 4.2	2.2, 2.0, 1.8, 1.6
750	15.0	1:1	4.2	2.4, 1.4
1,300	26.0	1:1	4.5 & 5.7	3.2, 2.8, 2.6

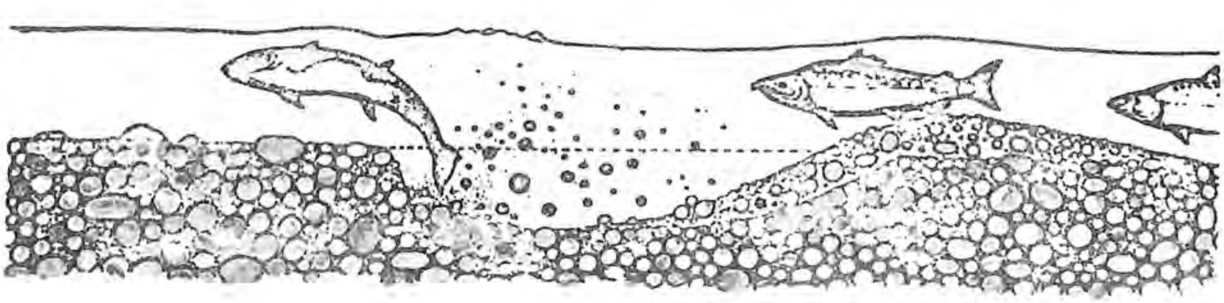
*Note: Water depths and baffle gate settings are measured above the gravel bed.



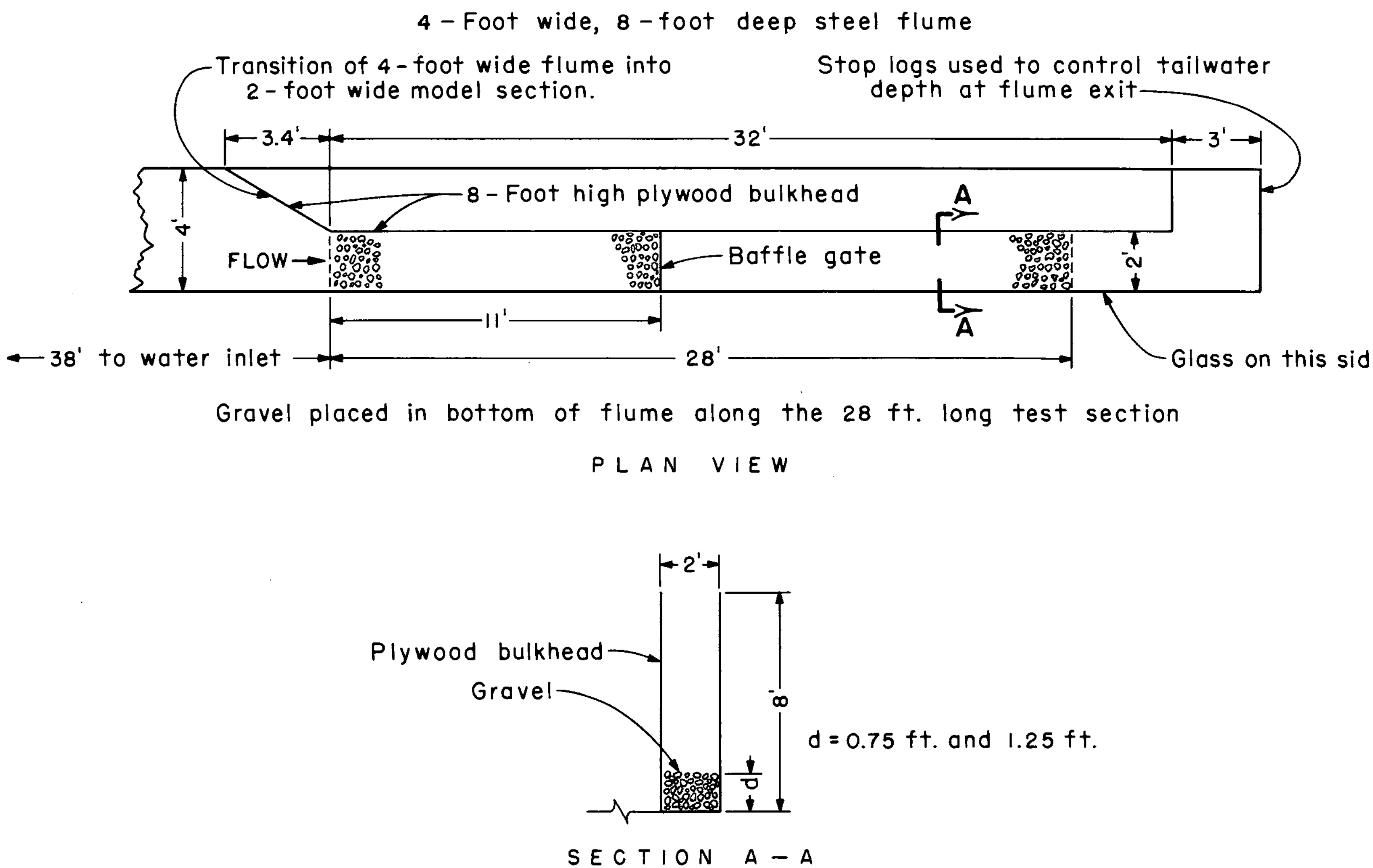
CROSS SECTION AND LOCATION OF THE DUAL-PURPOSE IRRIGATION AND SPAWNING CHANNEL



A. Artists drawing of the baffle gate machine that will be used to wash sediment from the spawning gravel and to crowd (move) small fish out of the canal. Photo P602-D-54534



B. Artists drawing of a female chinook salmon making a redd (nest). Photo PX-D-55414



DIMENSIONS OF THE MODEL FLUME

FIGURE 3
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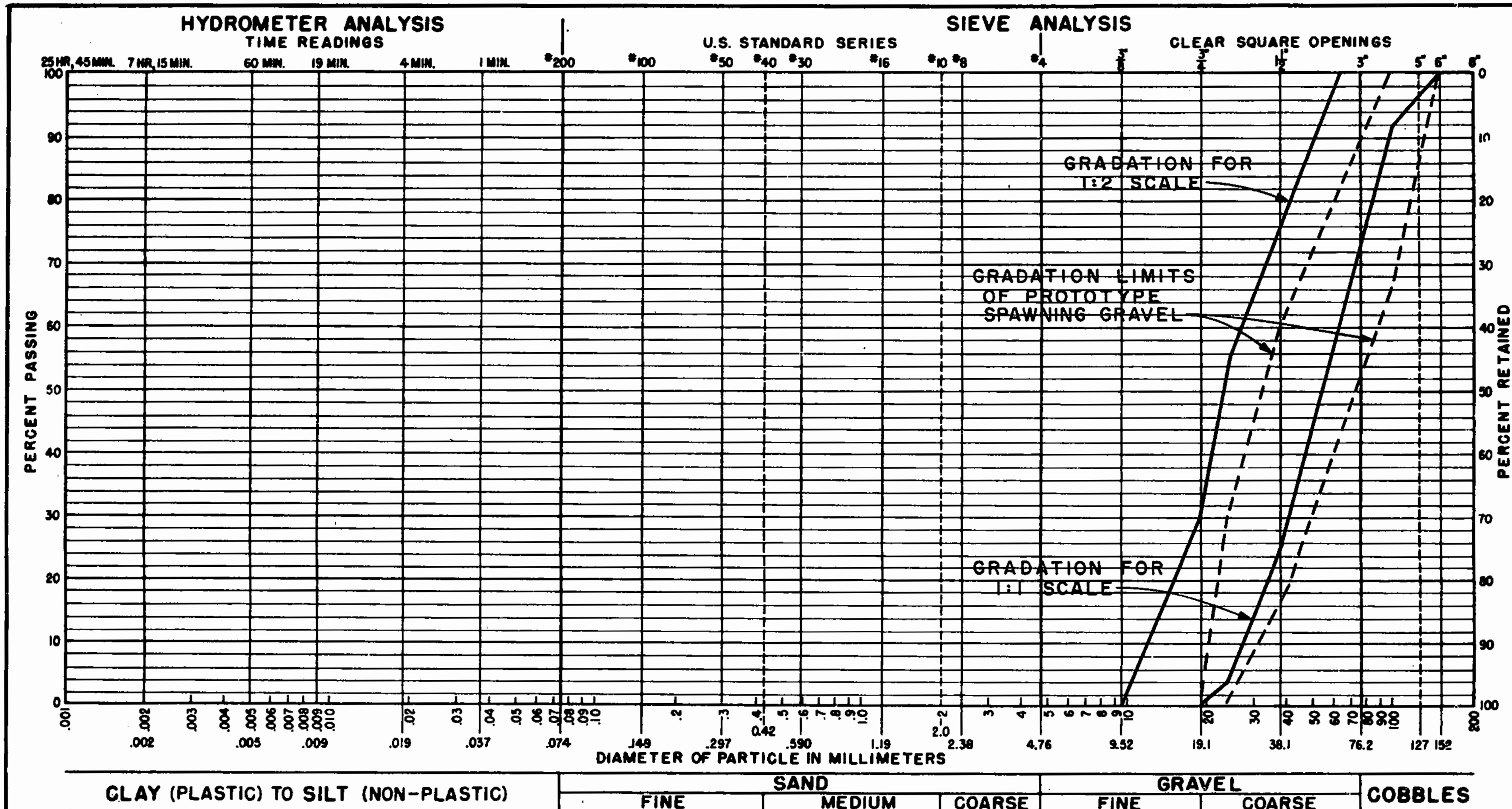


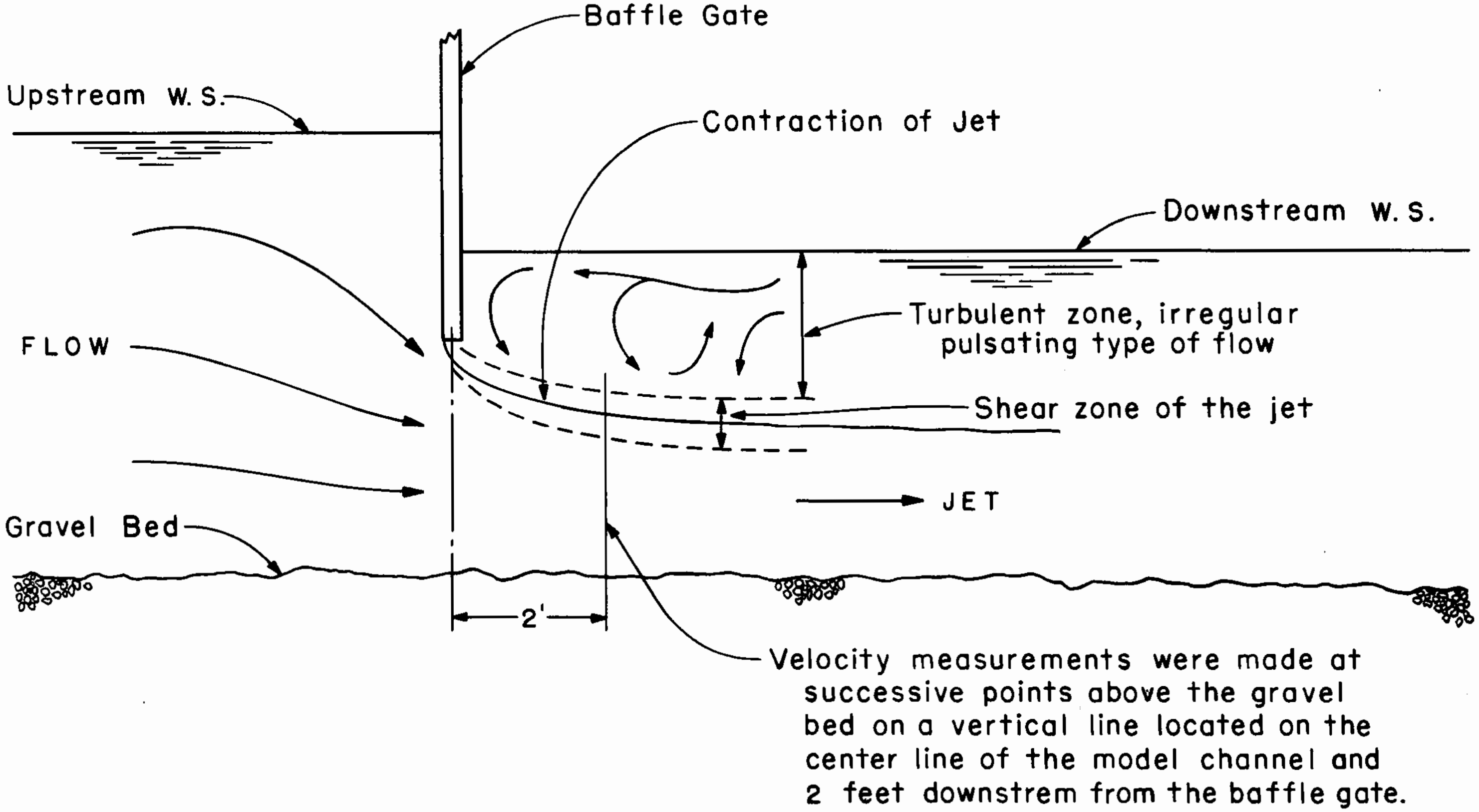
NOTES:

GRADATION TEST

GRADATION LIMITS OF PROTOTYPE GRAVEL
AND
GRADATION OF GRAVELS USED IN 1:1 AND 1:2 SCALE MODELS

LABORATORY SAMPLE No.________ FIELD DESIGNATION________ EXCAVATION No.________ DEPTH________ FT.

FIGURE NO.



RELATIVE POSITIONS OF THE BAFFLE GATE,
GRAVEL BED, AND VELOCITY BARRIER JET

FIGURE 5
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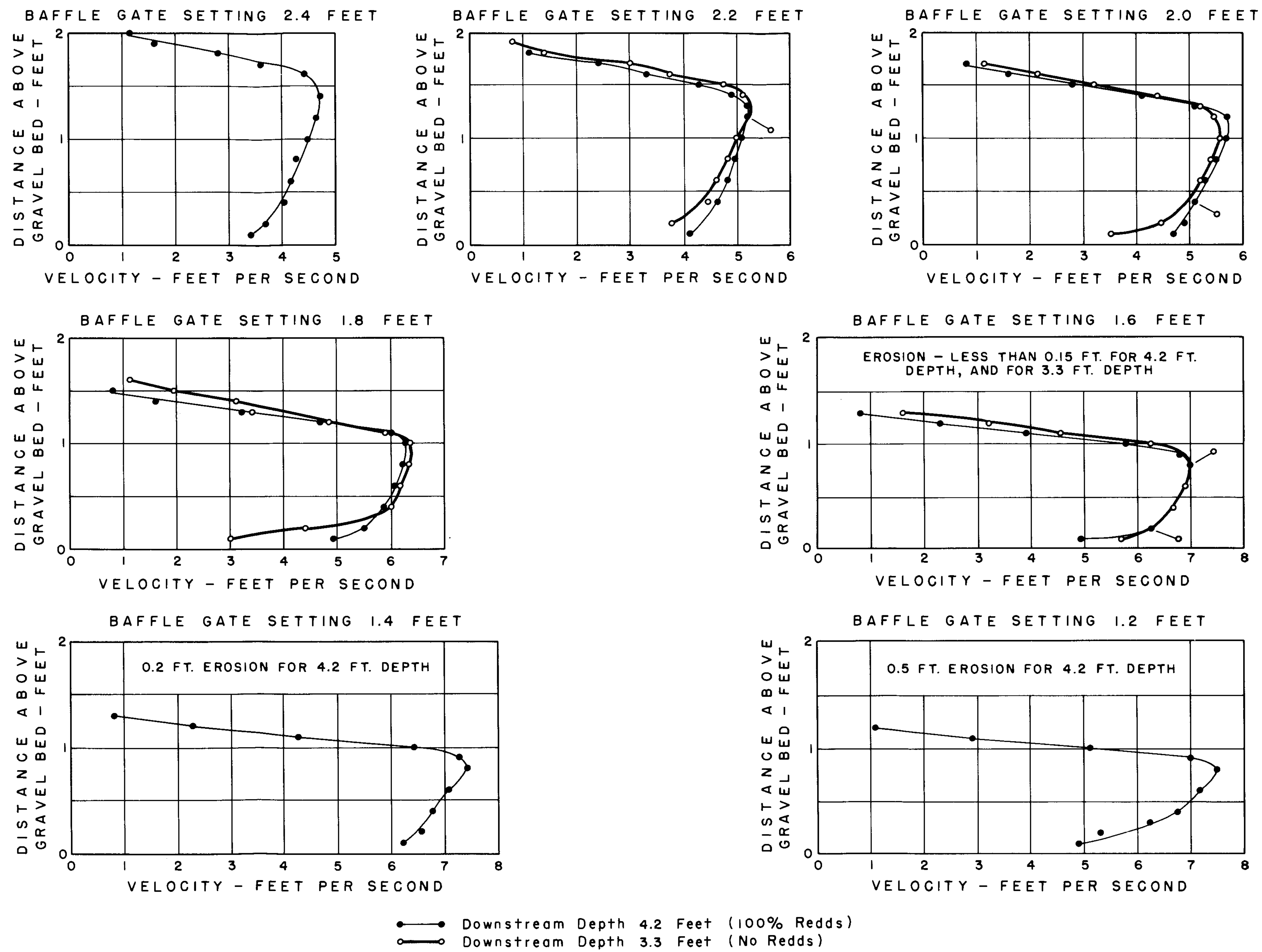
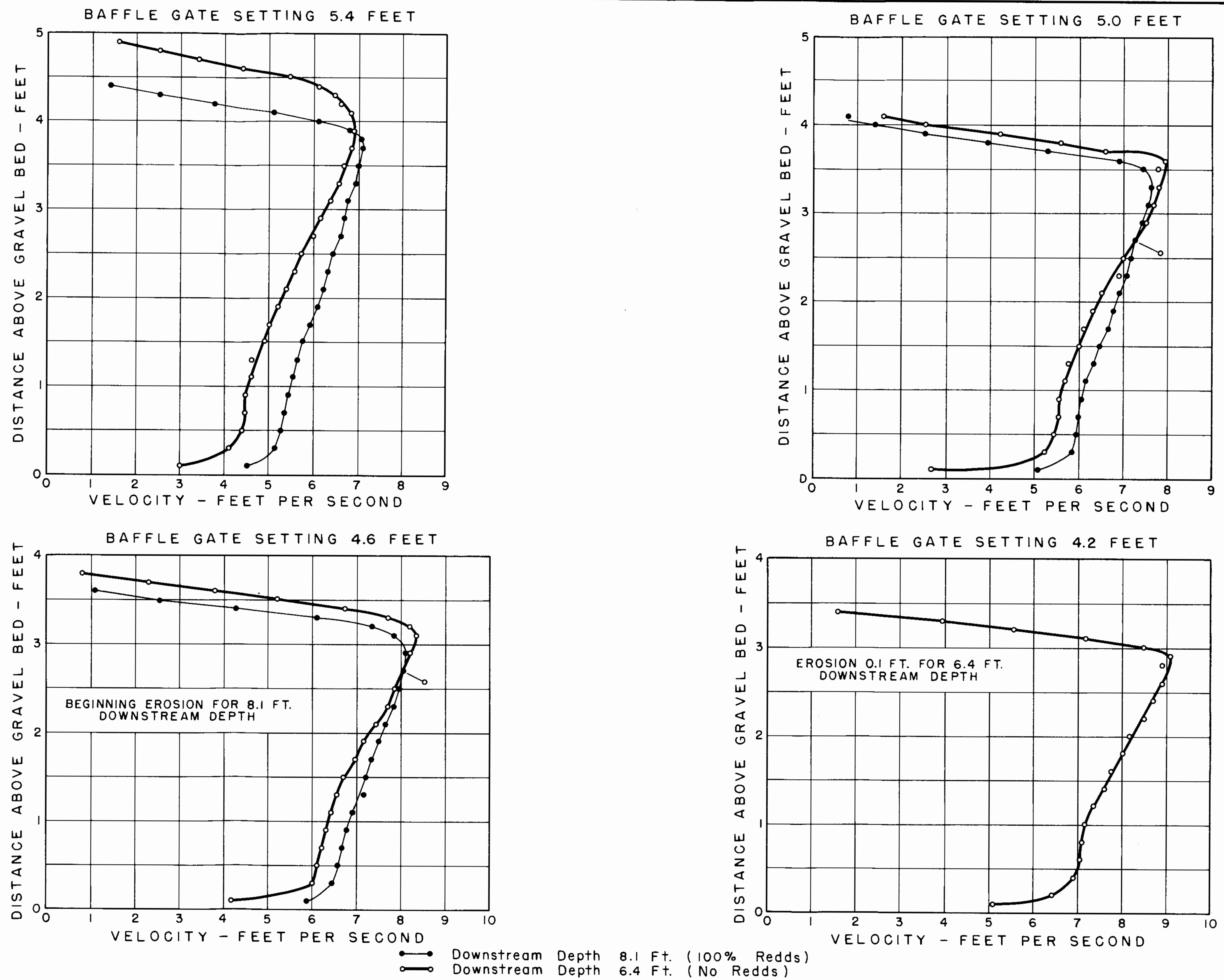
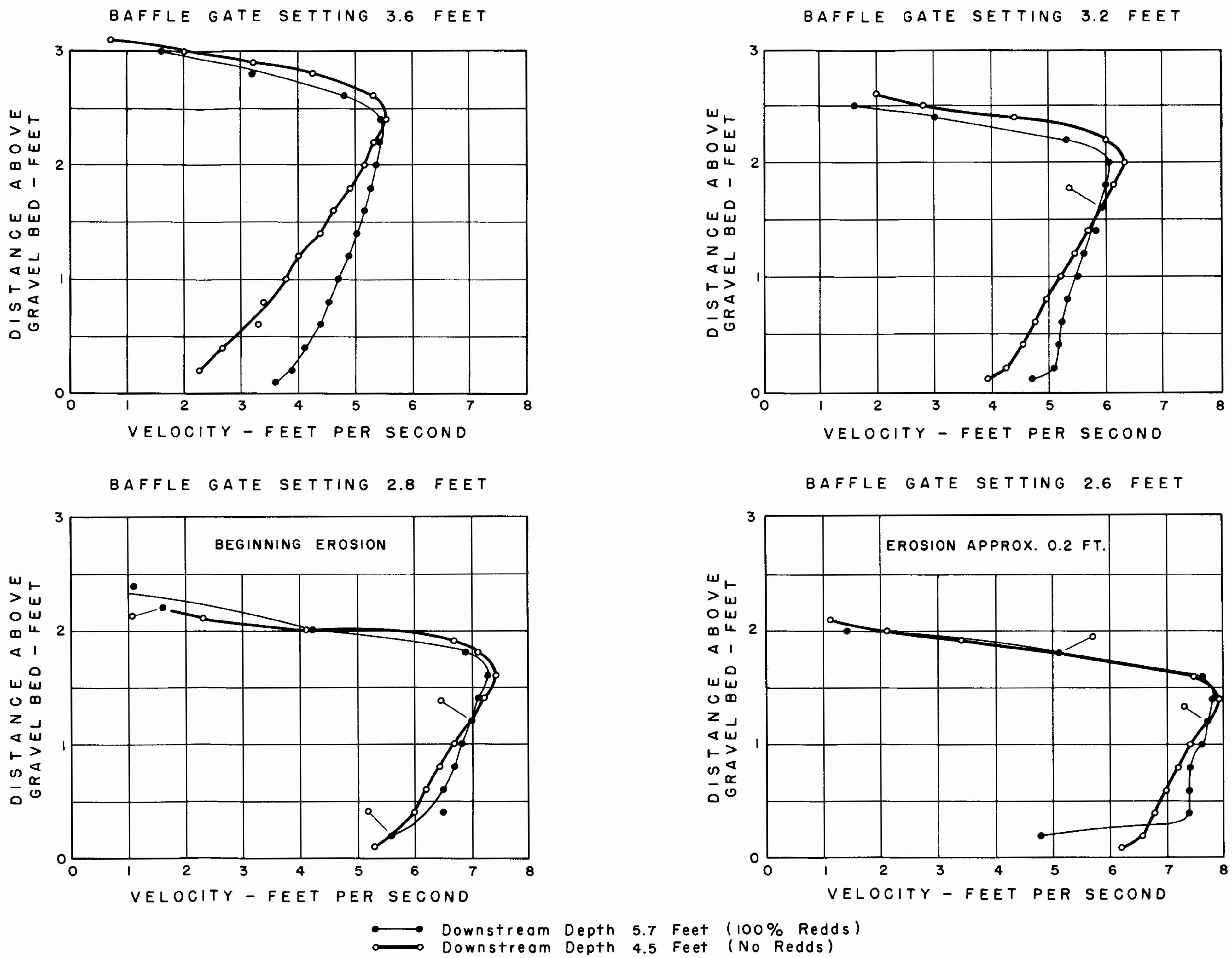


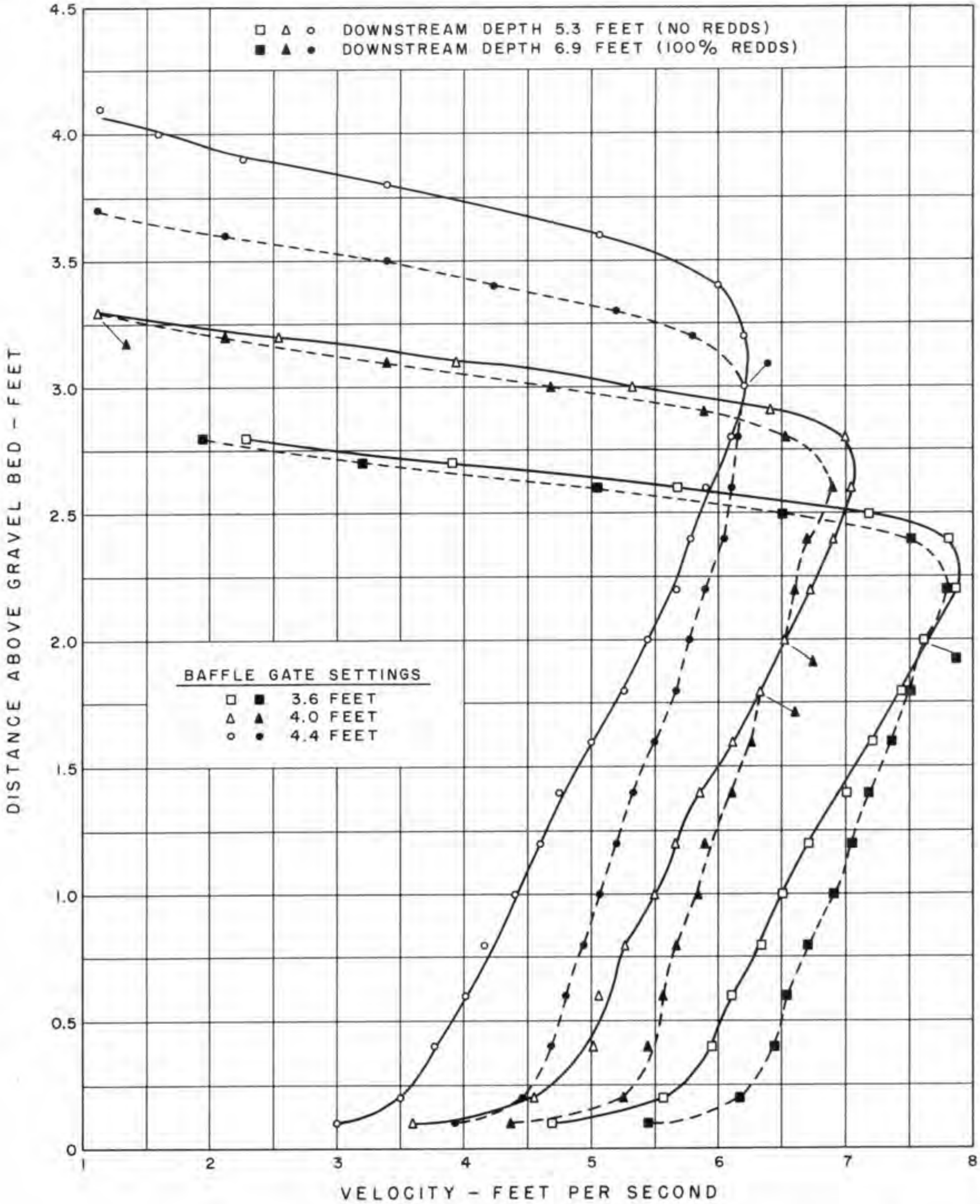
VELOCITY PROFILES FOR CANAL DISCHARGE OF 750 CFS
1:2 SCALE MODEL



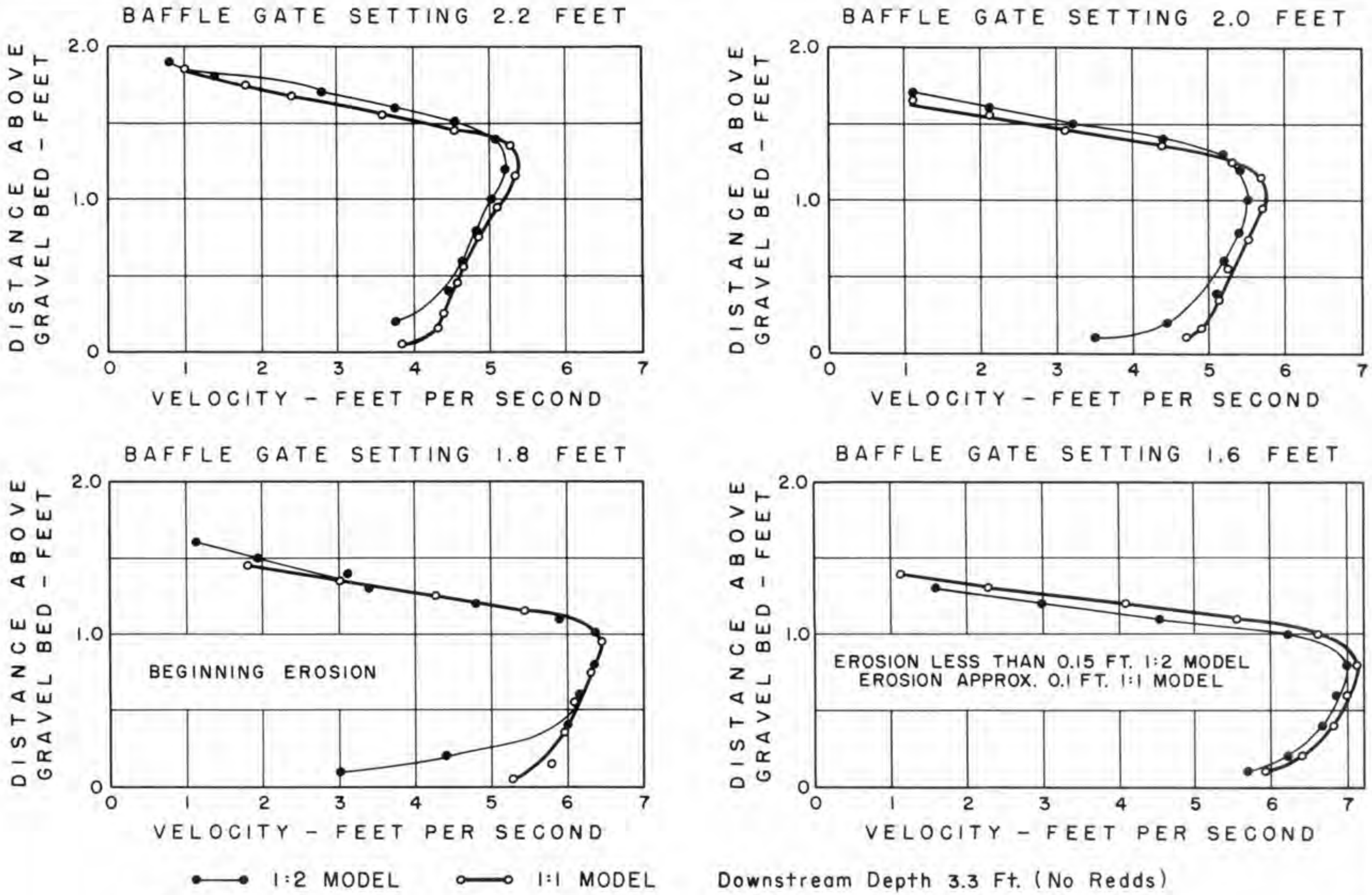
VELOCITY PROFILES FOR CANAL DISCHARGE OF 2400 C F S
1:2 SCALE MODEL



VELOCITY PROFILES FOR CANAL DISCHARGE OF 1300 C F S
1:2 SCALE MODEL

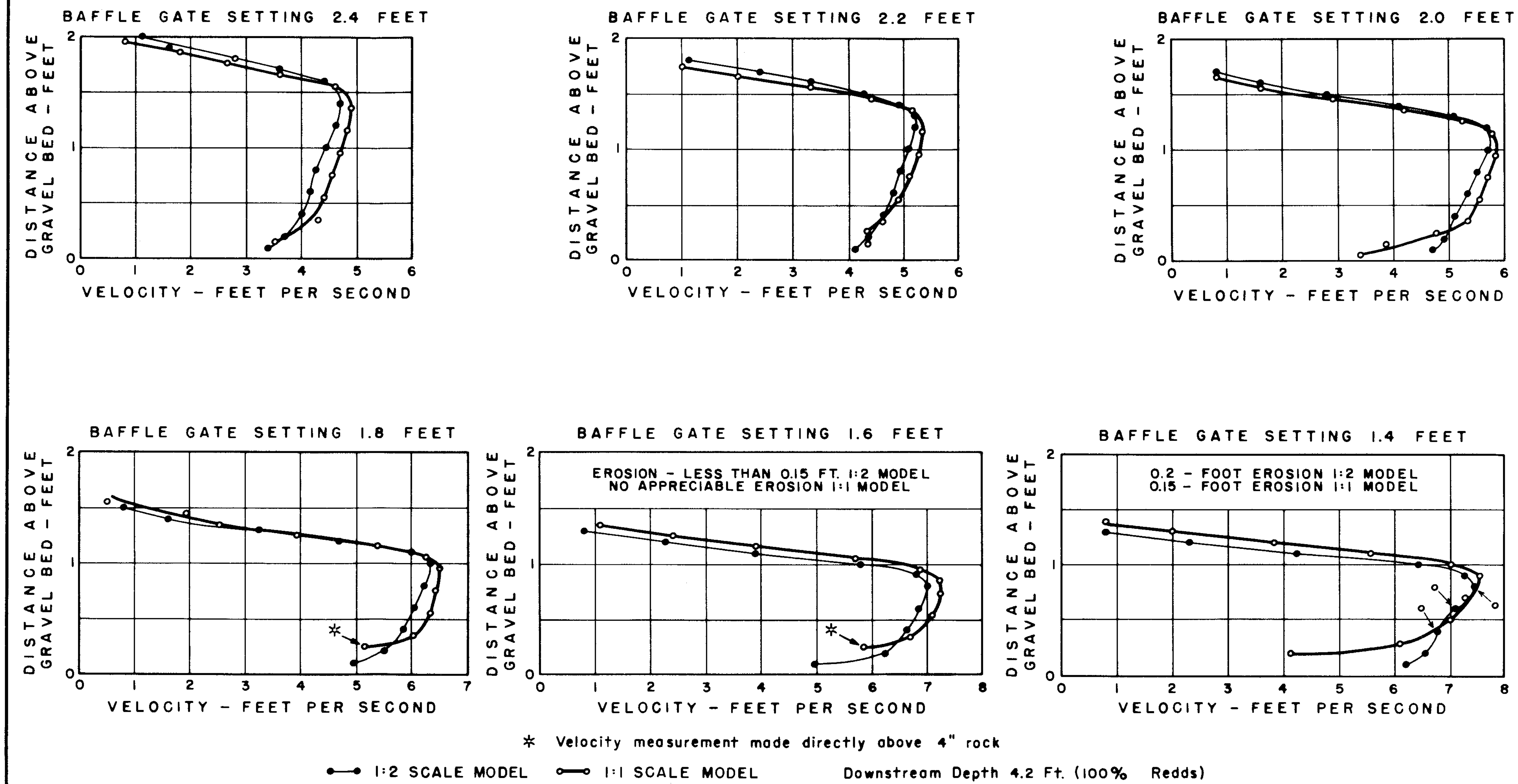


VELOCITY PROFILES FOR CANAL DISCHARGE OF 1800 C F S
1:2 SCALE MODEL

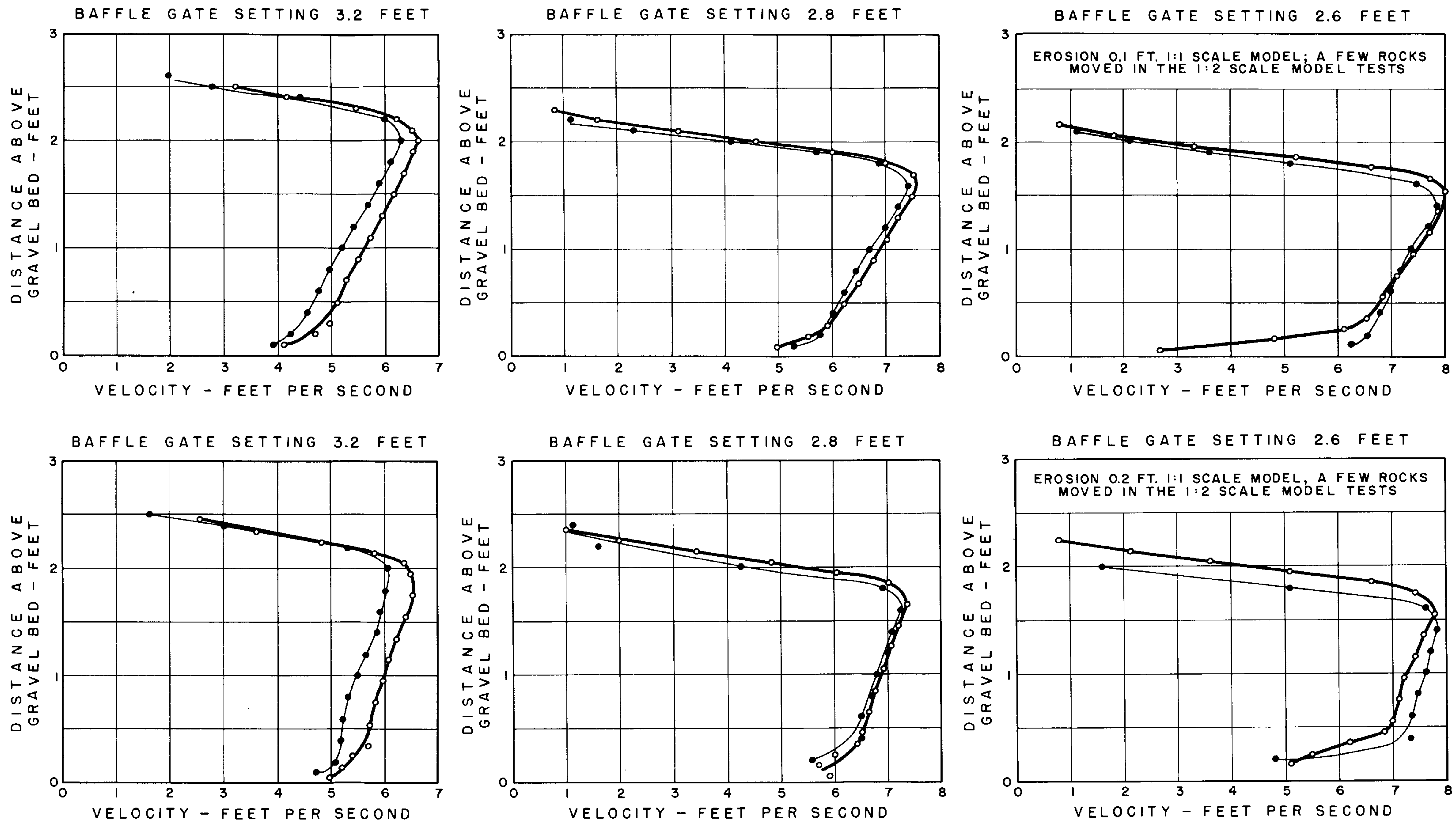


VELOCITY PROFILES FOR CANAL DISCHARGE OF 750 CFS
COMPARISON OF 1:1 AND 1:2 SCALE MODELS

FIGURE 10
REPORT HYD-579



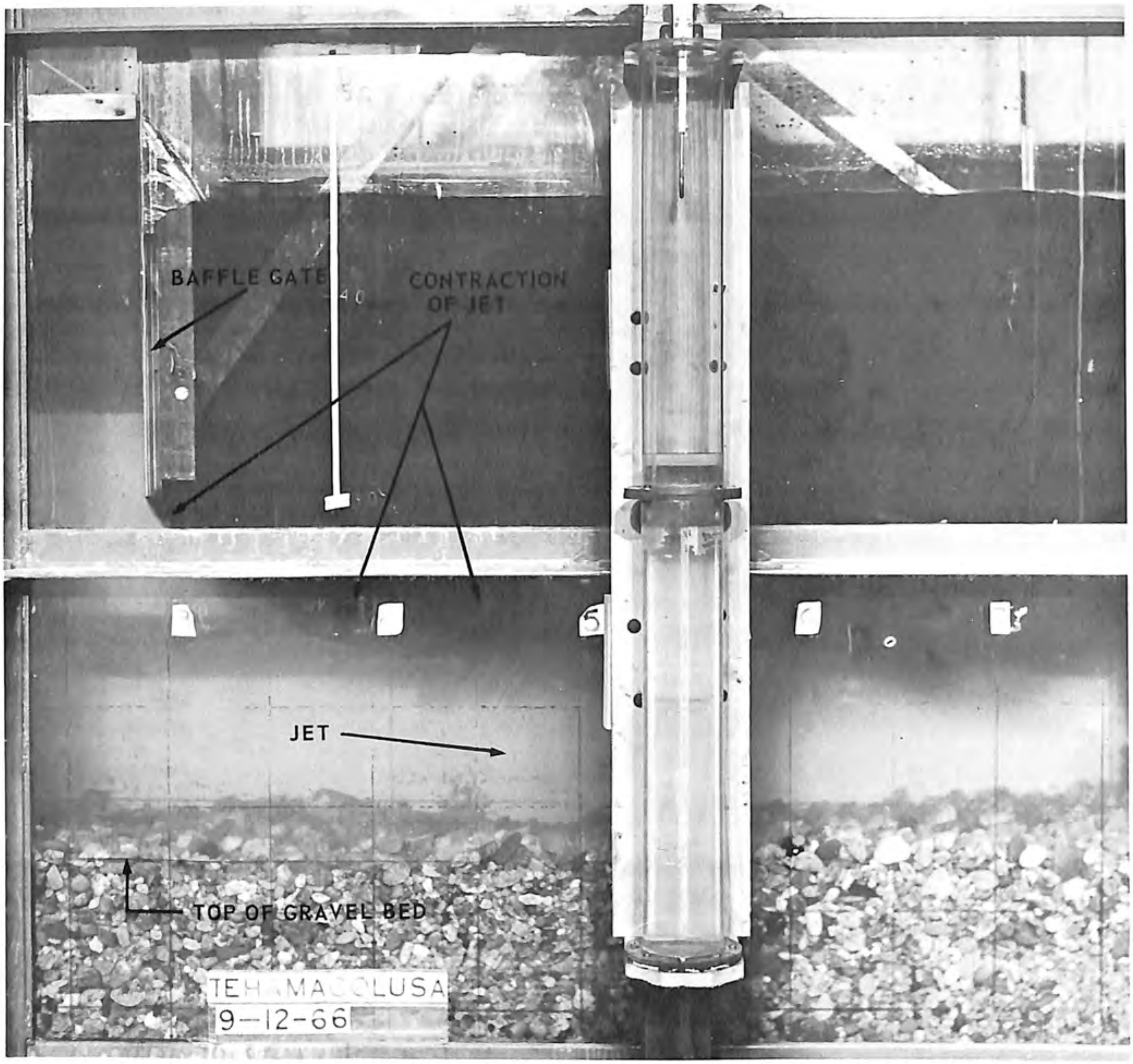
VELOCITY PROFILES FOR CANAL DISCHARGE OF 750 C F S
COMPARISON OF 1:1 AND 1:2 SCALE MODELS



NOTE: For the 3.2 - foot baffle gate setting part of the baffle gate supporting structure was in the flow area beneath the gate for the 1:1 scale model tests.

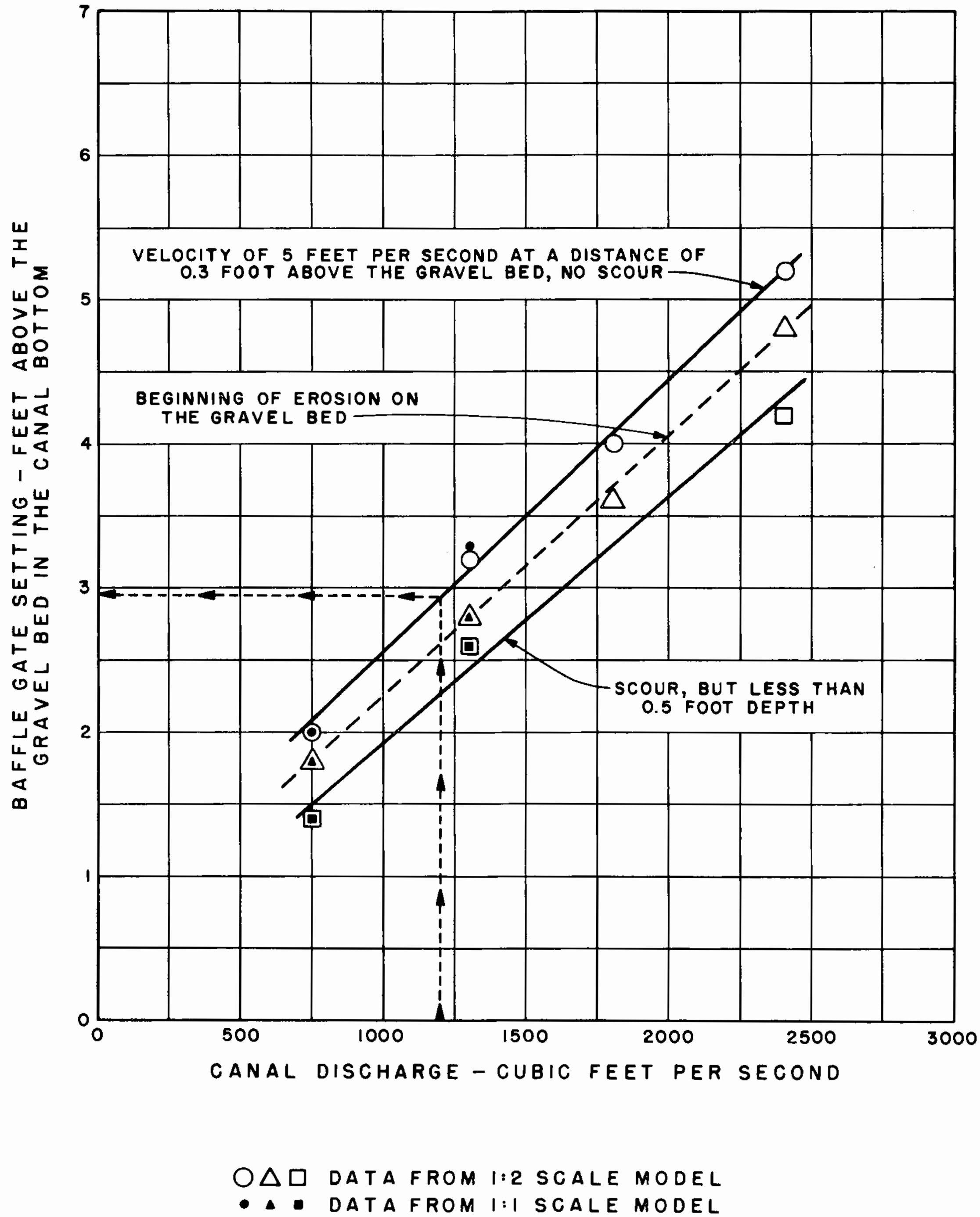
●——●	1:2 SCALE MODEL	Downstream Depth 5.7 Feet (100% Redds) - Lower row of Velocity Profiles
○——○	1:1 SCALE MODEL	Downstream Depth 4.5 Feet (No Redds) - Upper row of Velocity Profiles

VELOCITY PROFILES FOR CANAL DISCHARGE OF 1300 C F S
COMPARISON OF 1:1 AND 1:2 SCALE MODELS



Photograph of the 1:2 scale model showing the flow characteristics produced by the baffle gate. Waterflow is from left to right and the head drop across the baffle gate is visible. The canal discharge is 1,800 cfs (51.0 cms), tailwater depth 6.9 ft (2.1 m), and baffle gate setting 3.6 ft (1.1 m). Patent Blue dye was sprinkled on the water surface downstream from the baffle gate (upper right corner of the photograph). The turbulence, pulsations, and the general upstream motion of the water above the jet quickly mixed the dye with the water. The light colored water above the gravel is the jet produced by the baffle gate and is clear undyed water flowing past the baffle gate. Photo PX-D-60094

FIGURE 14
REPORT HYD-579



BAFFLE GATE SETTING VERSUS CANAL DISCHARGE

729

GPO 840-389

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03*	Square centimeters
	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	946.358*	Cubic centimeters
	0.946331*	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.092903*	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

ABSTRACT

A dual-purpose irrigation and fish spawning channel will be constructed along a 3.22-mi length of the Tehama-Colusa Canal, Calif. A vertical slide gate device (baffle gate) was developed for cleaning the gravel spawning bed of the canal. The gate can be moved along the length of the canal and positioned in the water to produce a jet of higher velocity flow beneath the gate. A secondary use of the baffle gate is to provide a 5-fps velocity barrier for controlling movements of small fish in the canal. Model tests were made to determine whether this velocity barrier could be maintained without eroding the gravel bed and to determine baffle gate settings to produce the 5-fps velocity barrier for given discharges. A photograph and drawing of the model flume, test data, and a gradation curve of model gravel are included.

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