A STUDY OF METHODS USED IN

MEASUREMENT AND ANALYSIS OF SEDIMENT

LOADS IN STREAMS

SUBCOMMITTEE ON SEDIMENTATION
INTER-AGENCY
WATER RESOURCES COUNCIL

REPORT T

PROGRESS REPORT

LABORATORY INVESTIGATION OF PUMPING-SAMPLER INTAKES

APRIL 1966

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A Cooperative Project
Sponsored by the
Subcommittee on Sedimentation
Water Resources Council

Participating Agencies

Corps of Engineers ** Geological Survey
Soil Conservation Service ** Bureau of Reclamation
Agricultural Research Service ** Health, Education and Welfare
Tennessee Valley Authority ** Forest Service

REPORT T

Progress Report

LABORATORY INVESTIGATION OF PUMPING-SAMPLER INTAKES

Federal Inter-Agency Sedimentation Project
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minnesota

APRIL 1966

PREFACE

This investigation is part of the program of the Federal Inter-Agency Sedimentation Project, which is located at the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota. The project is under the supervision of an Inter-Agency Technical Committee and it is sponsored by the Subcommittee on Sedimentation of the Inter-Agency Committee on Water Resources. The purposes of the project are the development and improvement of equipment and methods for obtaining and analyzing sediment samples.

The tests and pumping-sampler intakes were designed and the initial report was prepared by Byrnon C. Colby, Project Chief. Final revision and preparation for publication was performed by John V. Skinner and Frederick S. Witzigman. Russell P. Christensen of the project staff, with the help of Glenn Stringham, Jeris Danielson, and Hans Ph. Kaag ran the tests at Colorado State University. The cooperation and assistance of Colorado State University; Daryl Simons, Susumu Karaki, and Max Parshall of the University; Harold Guy of the U. S. Geological Survey; and Thomas Beckers of the Inter-Agency Project are gratefully acknowledged.

SYNOPSIS

The sampling efficiencies of nine simple types of pumping sampler intakes were investigated in a laboratory flume. The intakes were mounted in the flume walls so that the samples were withdrawn at right angles to the direction of flow in the flume. Intakes were from 0.5 to 1.5 in. in diameter, and shapes were round or oval with sharp square entrances, round with rounded entrances, or round with sharp square entrances and a shelf under the opening (one intake). The ratio of the concentration of sediment in the sample taken through the intake to that at the sampling point was used as the measure of sampling efficiency.

Sampling efficiencies of each intake were determined for 0.45-mm sediment at flow velocities of about 3.5, 5.0, and 6.1 fps (feet per second) and for 0.19- and 0.10-mm sediment in velocities of about 2.2, 3.6, 5.2, and 6.3 fps. For each condition of sediment, intake, and flow velocity, about five samples were taken at different velocities in the intake.

As the intake opening is at a right angle to the direction of flow, the sampling efficiency is affected when the velocity is less than 3 fps and the suspended sediment is in the sand size range. As the effects were minimal for the 0.10-mm size, the sampling efficiency for sediments in the clay and silt range is considered to be optimum.

The effects of size of sediment and flow velocity at the sampling point were evaluated approximately. The coarser the sediment and the faster the flow (at least above 2 or 3 fps) the lower was the sampling efficiency.

Within the limits of intakes tested, size and shape had little effect on the sampling efficiency except for the intake with the shelf underneath it. Sampling efficiency through that intake was erratic for low velocities, but it was better than other intakes for high velocities and coarser sediment. However, over the complete range of variables tested the 1 in. intake performed slightly better than the other intakes.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LABORATORY INVESTIGATIONS OF PUMPING-SAMPLER INTAKES

I. INTRODUCTION

1. The pumping-sampler intake problem--The development of pumping samplers for automatic sampling of suspended sediment in streams (Inter-Agency Report Q) [3]* raised many questions as to the proper design of sampler intakes.

In order of importance some of the required intake characteristics are:

a. The intake must function dependably without much servicing. Debris and sediment must not collect excessively in, or on, the intake; and back flushing, which is a part of the normal pumping cycle, must be effective in cleaning the intake. The intake should not be subject to plugging with fish.

b. A close correlation must exist between concentration in the intake and that in the streamflow so that the samples can be used to compute total suspended sediment discharge.

c. The sediment concentration in the pumped samples should approach the concentration in the stream at the intake as closely as practical.

d. The intake should be easy to build and install.

The design of the basic intake structure for the experimental pumping sampler near St. Paul, Nebr., was shown in Fig. 4 of Report Q. [3] The intake was mounted in a low vertical wall that was parallel to the streamflow. The wall extended about 5 ft upstream and 3 ft downstream from the intake. The extension upstream was arbitrarily made equal to eight times the maximum velocity head at the sampling point. The downstream extension need be only 2 or 3 ft. This type of intake structure seems theoretically sound, and it has been satisfactory in practice. Further study of the structure

* Numbers in brackets indicate references listed on page 59

was not considered necessary. A bridge pier or retaining wall, can be used as the flat surface perpendicular to the intake.

The intake used in the experimental installation had an opening 1 in. (later changed to 3/4 in.) in diameter and its axis was perpendicular to a smooth flat plate. The plate was vertical and parallel to the flow. The flat plate was flush with the outer, or stream, face of the intake wall, and the intake extended through the wall. This type of intake was easy to keep clean by backflushing, it did not collect debris, and it sampled accurately at St. Paul, Nebr., where sediments were generally fine. A fish trap was needed at St. Paul and it was added. This general type of intake was adopted as standard.

The basic pumping-sampler intake satisfied the first and fourth requirements needed in an intake, and for fine sediments, containing not more than small percentages of sands, the second and third requirements were satisfied as well. However, the efficiency in sampling coarse sands remained questionable.

If intake efficiency is defined as the ratio of sediment concentration in the pumped sample to that in the stream at the sampling point, a ratio of 1.00 is ideal. However, the sampler intake is at a single point in a stream vertical in a stream cross section, and this point is generally near one bank and often near the streambed. Fine sediments are distributed rather uniformly throughout most streams, but the distribution of sands may be quite variable.

Concentrations in pumped samples can be related to those in the cross section of the stream discharge if the intake efficiency and the relation between concentrations at the intake and those for the stream cross section are regularly determined with standard sampling equipment. The second relation is usually different for each stream and for different flows in the same stream. It can be established by sediment measurements in the cross section and at the intake. In practice the relation between the concentration in the samples and that in the stream discharge is determined directly. Because intake efficiency is only one part of a two-part relation, the consistency of the intake efficiency is more important than a value of the efficiency close to 1.00.

When a water-sediment suspension enters an intake opening in a flat plate parallel to the flow, the momentum of the water and of the sediment particles resists the right-angle change of direction of flow, and some sediment particles separate from the flow that enters the intake. The coarse sediment particles are less likely to enter the intake than the fine particles or the water. A series of small flume tests at the University of Iowa in 1940-41 [1] on such an intake showed that the concentration in the entering flow was much less than that in the flume.

A second series of a few flume tests was made on flat plate intakes at Colorado State University in 1959. These tests showed that concentrations in the diverted sample were about 65 to 70 percent of those in the flume for flume velocities of 8.5 ft per sec and for 0.5-mm sediment [3].

Field tests on flat plate intakes at Dunning, Nebr., showed that concentrations in diverted samples were about 80 percent of concentrations in the stream for velocities of 4.9 ft per sec and 0.2-mm sediment [3].

2. Purpose and scope of investigation--Previous evidence showed that the sampling efficiency of the flat-plate pumping-sampler intake was less than 1.00 for coarse sands. Size of sediment, stream velocity past the intake, velocity of flow in the intake, and size and shape of intake openings were four basic variables that might affect the sampling efficiency. This investigation was planned to evaluate the effect of the following ranges of the four basic variables.

a. Three sediments having mean sizes of about 0.45, 0.19, and 0.10 mm were to be circulated in a laboratory flume.

b. Five flume velocities from the maximum available down to 2 fps (or the minimum that would suspend the sediment) were to be used.

c. Nine intake shapes as shown in Fig. 1 were to be tested. The intakes were tubes mounted with the inlet end flush with the outer face of a smooth flat plate. Four intakes were tubes with inside diameters of 1/2, 3/4, 1, and 1 1/2 in. Two were 3/4-in. tubes rounded at the inlet on 1/8 in. and 1/4 in. radii, respectively. Two were 3/4-in. tubes deformed to oval shapes at the inlet. One was a 3/4-in. tube with a small shelf underneath it.

d. Five intake velocities were to be tested for each of the other combinations of variables.

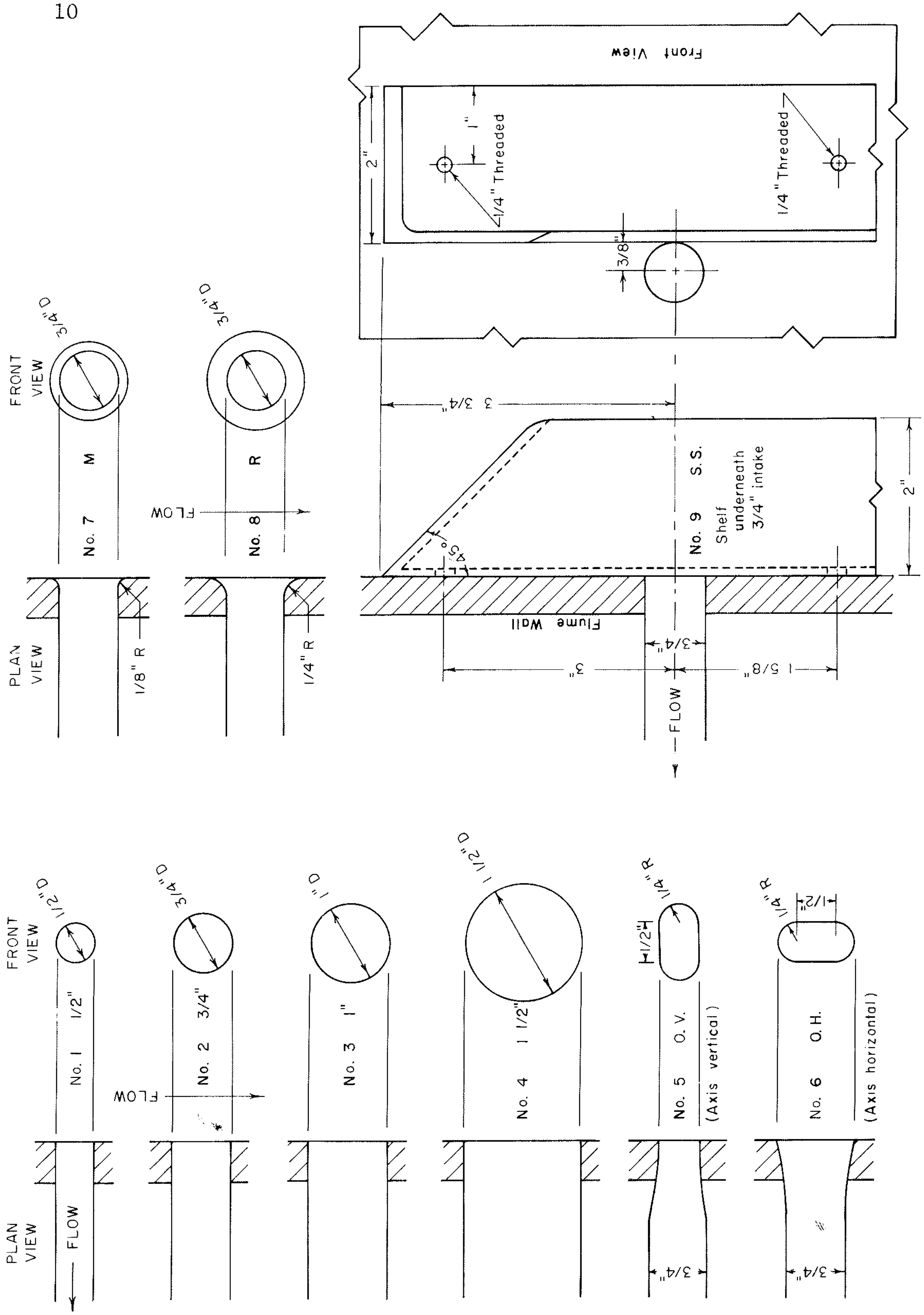


FIG. 1 — NINE INTAKES TESTED

The tests actually run were not as extensive as planned, mainly because the maximum flume velocities were less than desired. The number of available test samples are shown in Table 1. At least one basic check, or reference, sample for comparison was required for each test sample. Many extra samples were needed to define sediment distribution in the flume. A single test was not expected to define the intake efficiency for a set of variables, but the comparison with data for nearly similar conditions was to be used to define major effects of the variables.

TABLE 1

NUMBER OF TEST SAMPLES

	Sediment	0.45 mm			0.19 mm				0.10 mm			
	Velocity in flume*, fps	3.5	5.0	6.1	2.5	3.7	5.1	6.4	1.9	3.6	5.2	6.2
Intakes tested (See Fig. 1)	1/2"	3	5	5	6	5	5	5	5	4	5	4
	3/4"	7	12	4	4	5	4	5	5	5	6	3
	1"	8	5	4	4	6	5	6	8	5	5	4
	1 1/2"	5	4	3	2	5	4	5	3	4	4	3
	O. V.	6	7	5	4	4	5	6	6	5	4	3
	O. H.	5	7	6	5	5	5	4	6	5	4	0
	3/4" M	6	6	5	5	5	8	5	5	5	5	4
	3/4" R	6	6	5	5	6	6	6	5	5	4	3
	S. S.	5	7	6	5	6	5	5	5	5	5	3
	Totals	51	59	43	40	47	47	47	48	43	42	27

Total usable samples 494
or an average of about 5 for each condition.

* Velocity 1.5 inches out from entrance of intake.

II. TEST CONDITIONS

3. Flume facilities--The pumping sampler intakes were tested in the flume in the Engineering Building of Colorado State University, Fort Collins, Colo. The flume is a tilting recirculating flume 150 ft long, 8 ft wide, and 2 ft deep (USGS Water-Supply Paper 1498-A, Fig. 1) [4]. A special test section was constructed in the flume. The section was 2 ft deep, and 18.5 in. wide. (See Fig. 2.) Artificial roughness to help maintain the sediment in suspension was installed on the flume bed upstream from the test section. (See Fig. 3.) The maximum velocity attainable in the test section was about 8 fps (at the middle of the flume).

The water-sediment mixture in the flume was recirculated with a pump that provided a maximum discharge of 14 cfs. A Venturi section and manometer were located in the return pipe. They were calibrated to give pump discharge.

The arrangement of the test equipment in the flume is shown in Fig. 4. A socket (Fig. 5) that made changing of intakes easy was mounted in the side wall of the flume. The flume end of the socket was a flat plate installed flush with the inside wall of the flume. A rubber suction cup (not shown on Fig. 4 or 5) was mounted on a hinged arm, which was attached to the flume wall. The cup could be forced against the flume face of the socket opening to shut off the flow while intakes were changed. Throughout the tests the centerline of the intake was always 6 in. above the bottom of the flume.

Each intake had a flexible discharge tube to carry the diverted flow to a waste barrel or to a volumetric tank. The inside diameter of the tube was usually about the same as that of the intake opening, but different sizes of tube were sometimes used for part, or all, of the length to provide a better range of intake velocities.

A sample nozzle for collecting reference samples was mounted permanently just downstream from the intake opening. A sharp nozzle having an inside diameter of 1/4 in. (later 5/16 in.), was used so that an accurate sample of the sediment in the flow would be taken if the velocity in the nozzle equalled the velocity of the sampled flow. The velocity in the nozzle could be controlled by changing the elevation of the discharge end of the flexible tube that carried the discharge from the nozzle.

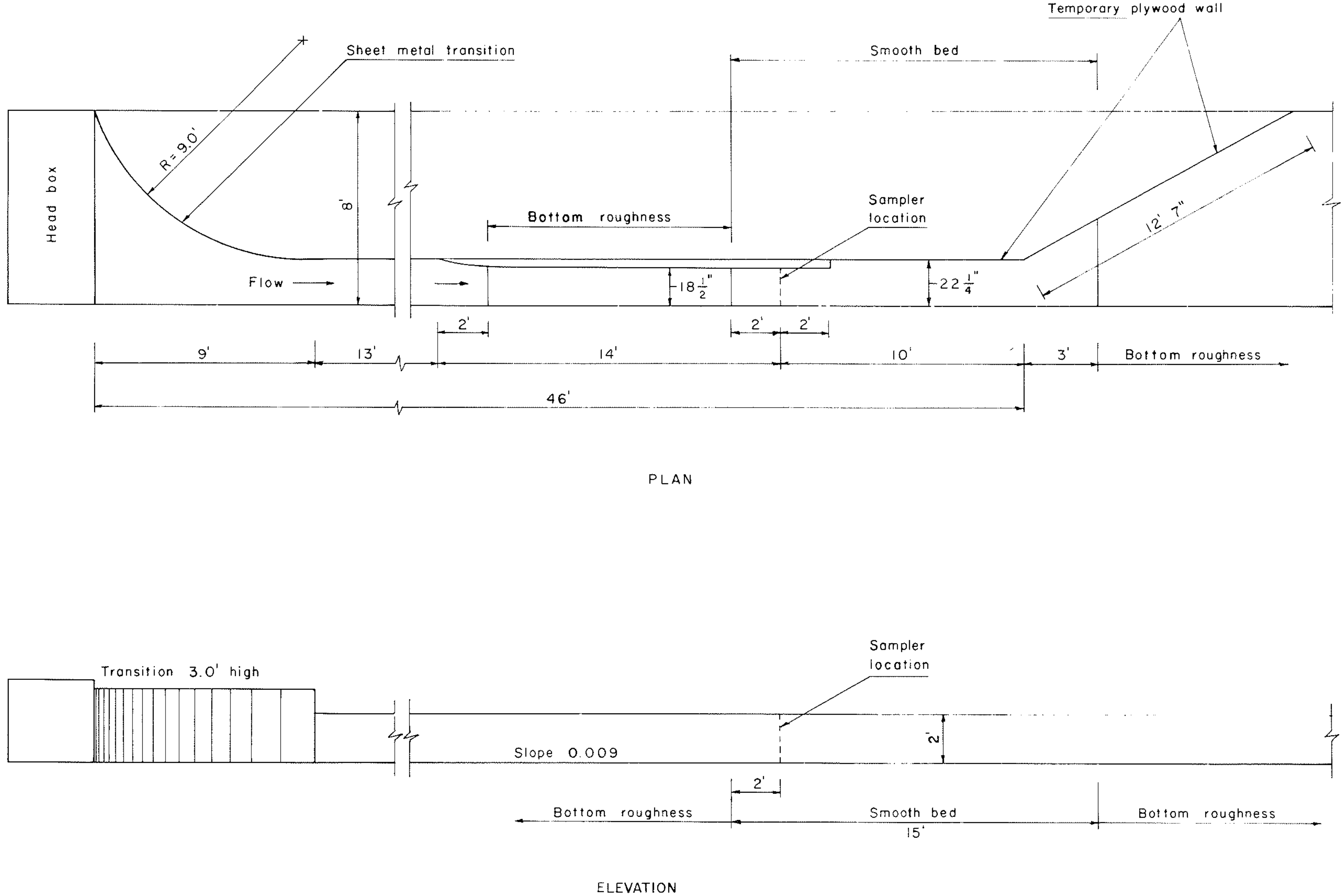


FIG. 2 — CONTRACTED SECTION OF FLUME

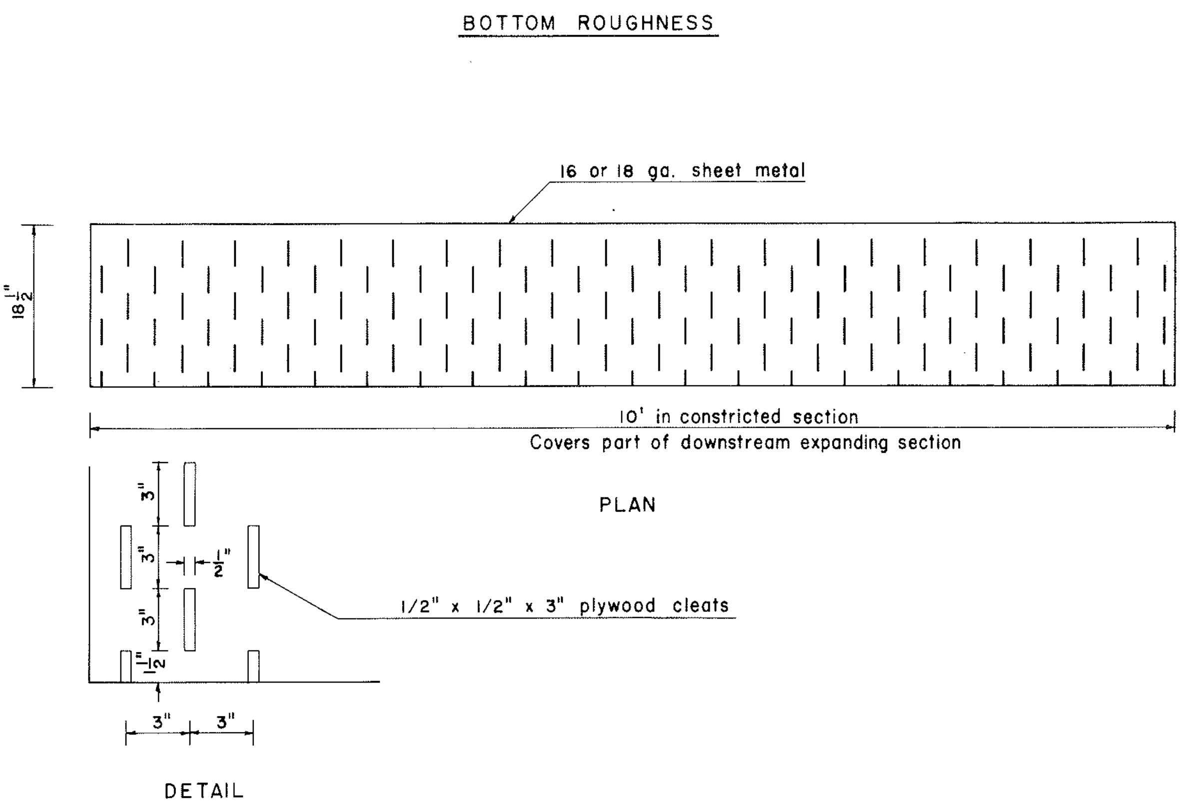


FIG. 3--BOTTOM ROUGHNESS IN FLUME

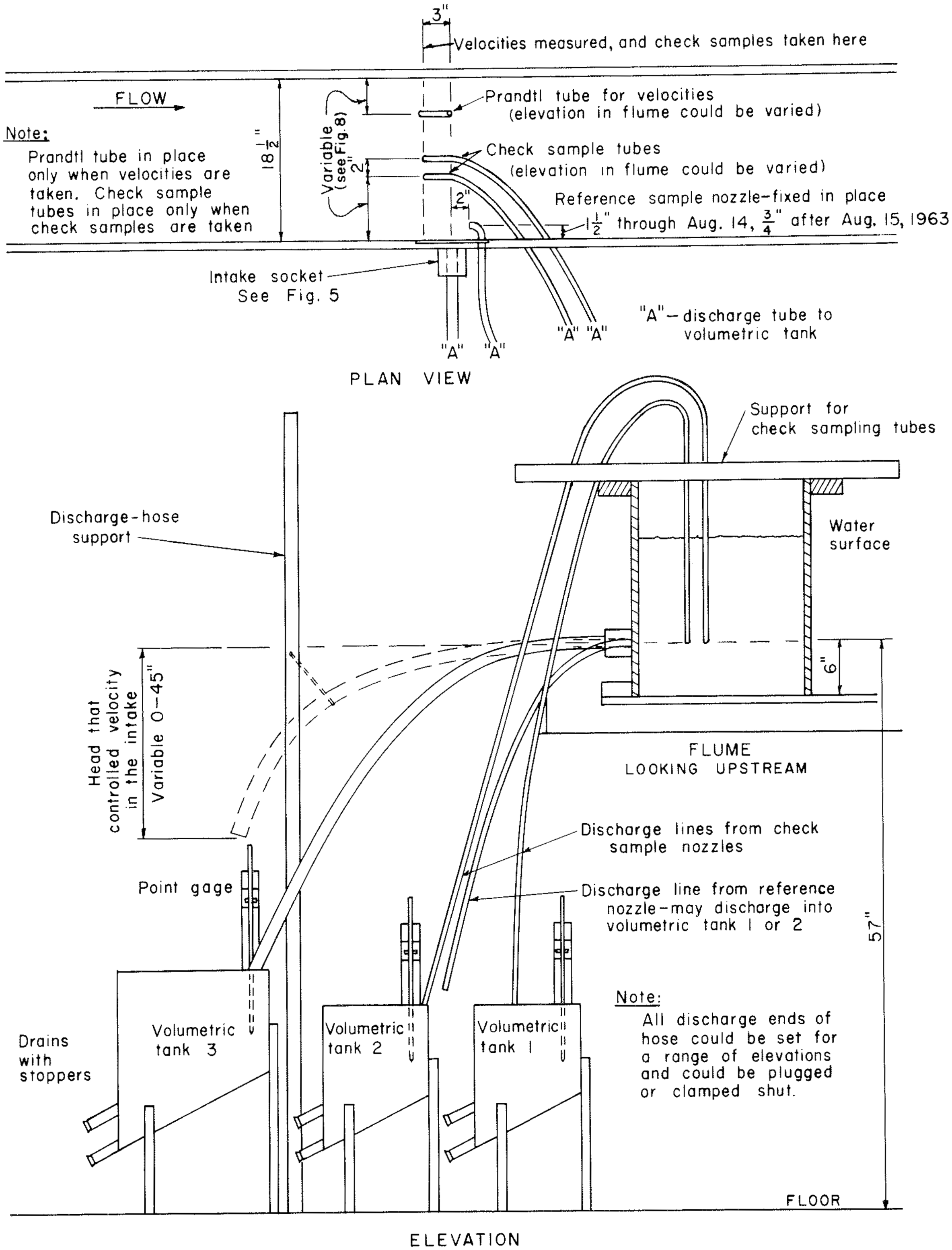


FIG. 4—TEST EQUIPMENT ARRANGEMENT

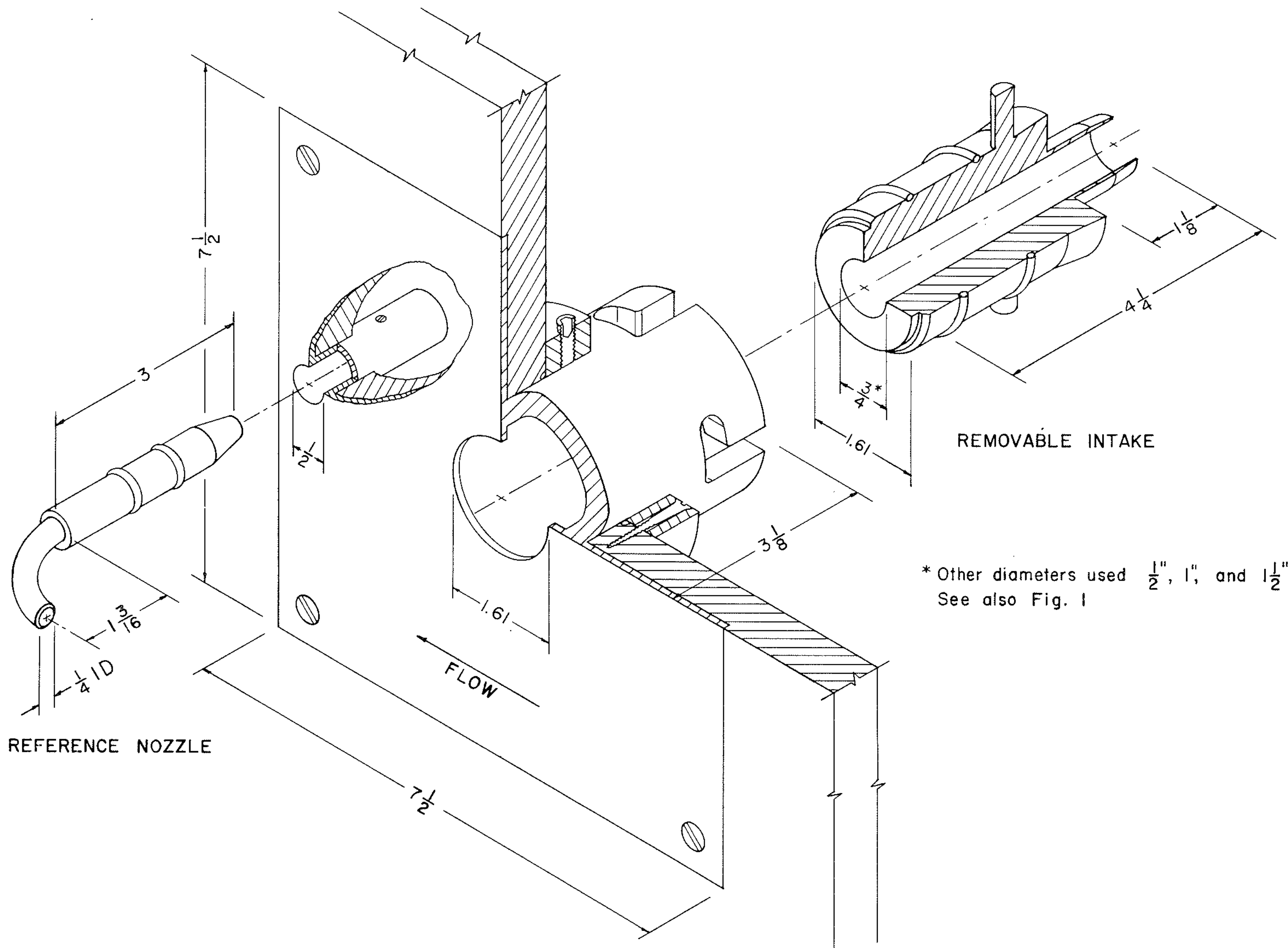


FIG. 5--INTAKE MOUNTING PLATE WITH REMOVABLE INTAKE AND REFERENCE NOZZLE

Two 1/4-in. sediment sampling nozzles similar to the stationary reference nozzle were used to take simultaneous samples at desired points in the flume cross section. The distributions of sediment concentration in the cross section before and after a series of test runs were determined from samples collected through these nozzles.

A Prandtl tube was used for measuring flume velocities and determining the distribution of velocities in the cross section. The discharge in the flume could be readily checked by manometer readings to determine the stability of the total flume flow.

4. Auxiliary equipment--Tanks were used to determine the volume of each sediment sample. Two tanks had a capacity of about 100 lbs of water each, and one tank had a capacity of about 300 lbs of water. The body of each tank was round and stood on short legs. The bottom of the tank sloped toward two drains which could be plugged with rubber stoppers. The upper drain was about 3 in. above the lowest point of the tank. The lower drain was level with the lowest point of the tank. (See Fig. 4.) A point gage was mounted on the side of the tank so that the level of water in the tank could be determined accurately. The gage was calibrated to give pounds of sediment-free water in the tank.

A small sediment laboratory equipped with visual-accumulation tube apparatus [2] and ovens, balances, beakers, and various containers was available for determination of size distribution and concentration of sediment in the samples.

5. Chemical quality of water in flume--Although the chemical quality of the water used in the flume was not expected to affect the test results measurably, eight samples for chemical analysis were taken at times spaced throughout the duration of the tests July 19 to September 20, 1963. (See Table 2.) Four of the analyses were made by Mr. Max Parshall of Colorado State University and four were made by the Branch of Quality of Water of the U. S. Geological Survey at Denver, Colo.

6. Temperature of water in the flume--Temperature of the water was measured three times each day that samples were run. (See Fig. 6.)

The temperature of the water in the flume averaged about 70°. The range was from 65° to 75°F. Each morning the flume was filled with water from the city main. Typically the temperature rose about 4°F during each day. Temperature changes had no observable effect on test results.

TABLE 2

CHEMICAL ANALYSES OF FLUME WATER

[In parts per million]

Date of sample 1963	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (residue at 180°C	Hardness as $CaCO^3$		Specific conductance (micromhos at 25°C)	pH
												Calcium, magnesium	Noncarbonate		
July 19				11	5			12	12		58				6.9
Aug. 6			1	11	1			11	7		50				6.9
Aug. 8			-	4	3			12	7		30				7.0
Aug. 20			-	-	1			8	7		28				6.9
Aug. 27	6.8	0.20	0.06	6.5	1.2	1.9	0.6	16	9.9	3.2	40	13	8	62	6.8
Sept. 4	7.0	.11	.13	9.9	1.4	1.8	1.0	24	12	2.7	52	20	11	76	7.2
Sept. 13	7.2	.12	.11	10	1.2	2.0	1.2	30	8.0	2.9	50	42	0	73	7.6
Sept. 19	7.5	.10	.11	9.9	1.1	1.9	1.4	31	7.6	2.1	51	29	4	71	7.4

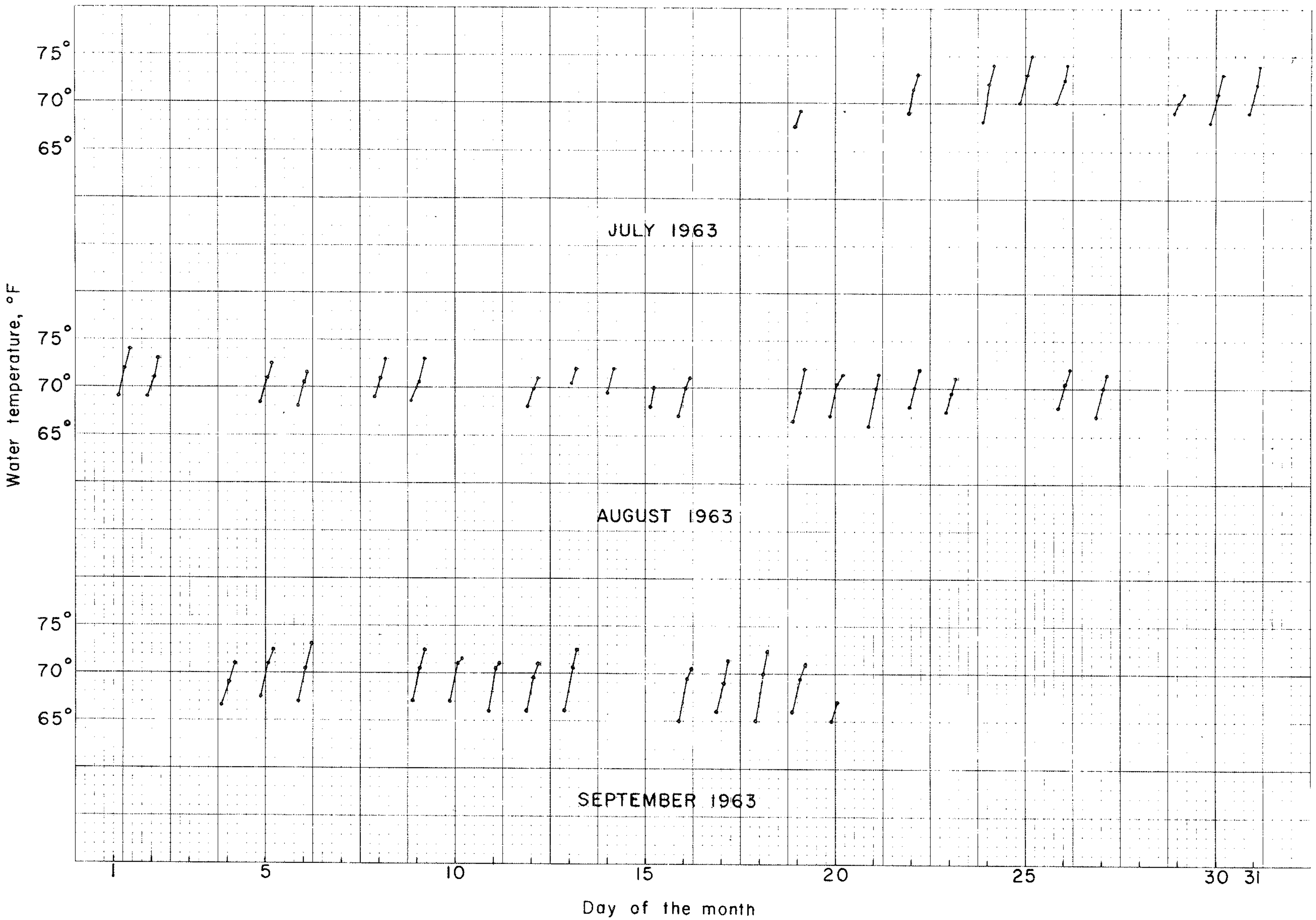


FIG. 6--TEMPERATURE OF WATER IN FLUME

7. Sediment--Three natural sediments with specific gravities of about 2.65 were used in the tests. They are called 0.45-mm, 0.19-mm, and 0.10-mm sands. Sizes reported here are "fall diameters" based on visual-accumulation tube analyses [2].

The 0.45-mm sand is that reported in Fig. 2 of U. S. Geological Survey Water Supply Paper 1498-A [4]. Data in Fig. 7 show size analyses of the sediment in suspension in the flume at the elevation of the intake for three different flume velocities and the 0.45-mm sand. The velocities were 6.5, 4.3, and 2.8 fps which correspond to about 5.3, 3.4, and 1.7 fps at a distance of 1.5 in. from the intake. The median size of sediment in suspension was about 0.40-mm at the higher velocities but only about 0.30 mm at the lowest velocity. Intake tests were not run at the lowest velocity because sediment concentrations in suspension were very low.

The 0.19-mm sand had a median size of 0.185 mm in suspension at high flume velocities. Samples were not analyzed for low velocities but no significant reduction in size of sediment in suspension would be likely.

The 0.10-mm sand was from a delta deposit in Loveland Lake, near Fort Collins, Colo. Only the sediment passing a U. S. No. 100 (0.147 mm) sieve and retained on a U. S. No. 200 (0.074 mm) sieve was used. The size of the sediment in suspension in the flume was .089 mm according to visual-accumulation tube analyses.

Actually, the reported sampling efficiencies are for suspended sediments whose median sizes are 0.40 mm, 0.18 mm, and 0.09 mm rather than the nominal sizes of 0.45 mm, 0.19 mm, and 0.10 mm.

8. Velocities and distribution of flow in test section--The velocity of flow in the flume was one of the major variables in the intake tests. Also, the ratio of velocity in sampling nozzles to that in the approaching flow is important to sampling accuracy. Velocity distribution in the cross section was fairly constant with respect to time except when changes were made in the flume discharge. The velocity distribution was measured each day.

Velocity distribution was determined from observations with a Prandtl tube. Each morning, or at the start of a set of tests at a new flume velocity, observations were taken at points marked with an X in the cross section shown in Fig. 8. At the close of daily tests or the end of a velocity series, observations were taken at

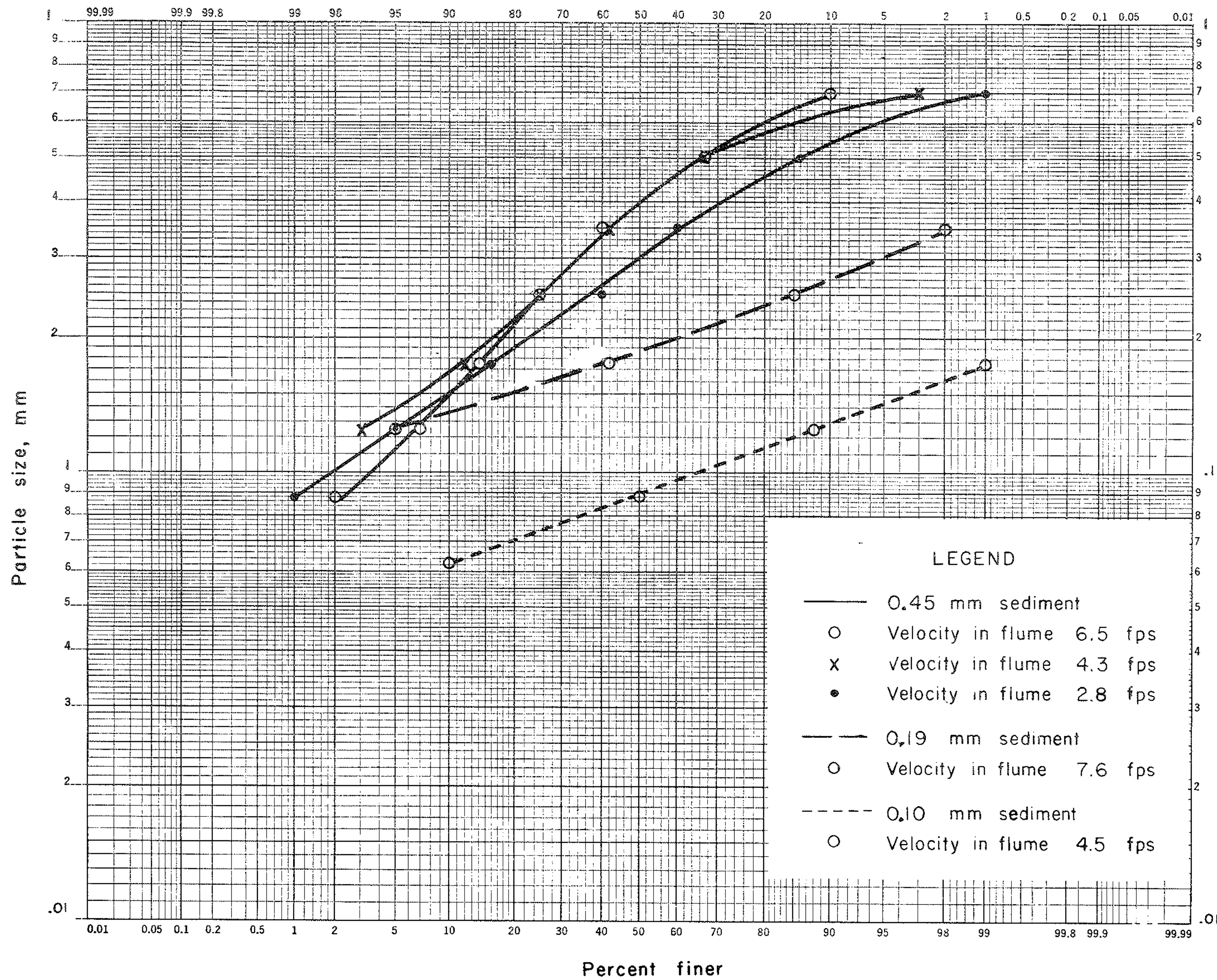
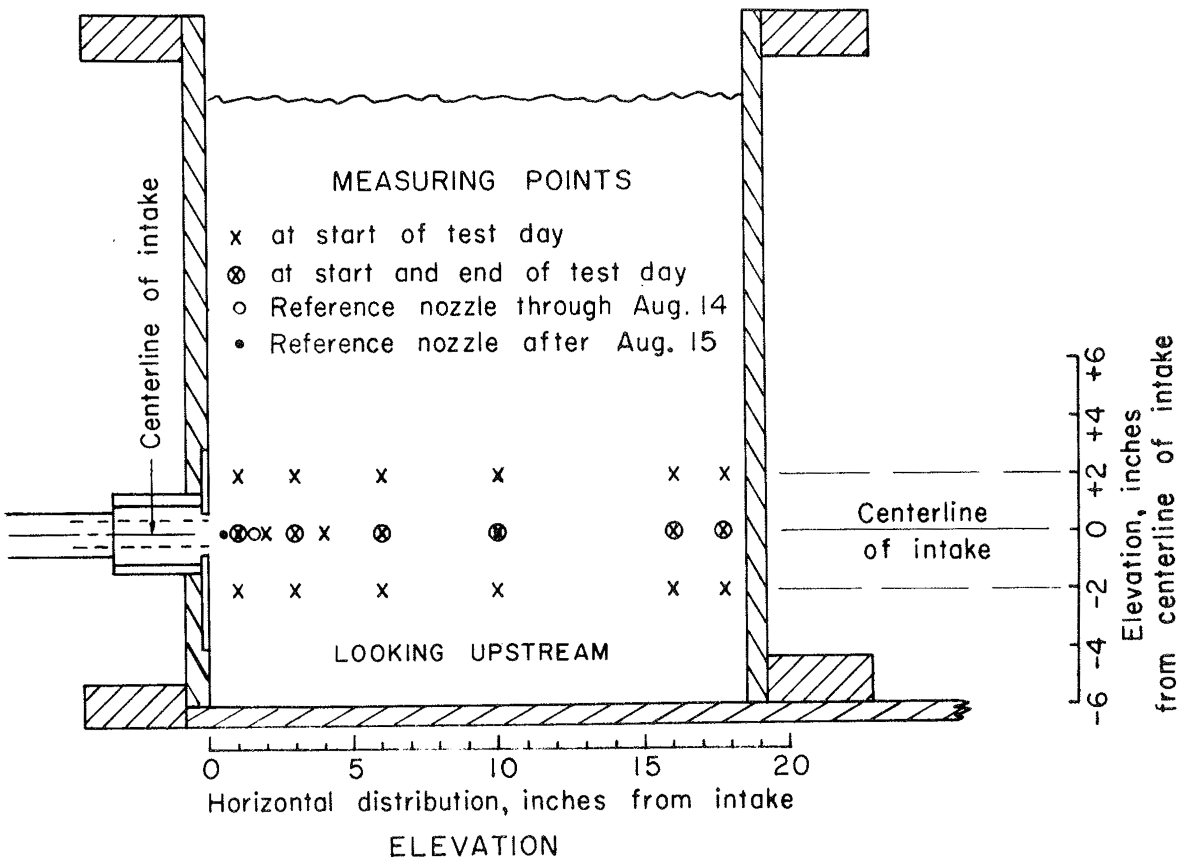


FIG. 7--SIZES OF SANDS IN SUSPENSION IN THE FLUME



NOTE:

Velocities taken 3 inches upstream from axis of intake

Reference nozzle opening 2 inches downstream from intake

FIG. 8--LOCATION OF VELOCITY OBSERVATIONS

the points marked with a circle. Velocity observations were taken in a vertical plane 3 in. upstream from the axis of the intake opening for the test samples. There was no flow into the intake when velocities were taken. The samples were taken 3 in. upstream to avoid interference with the reference nozzle and because the flow into the intake was drawn from a section upstream. That is, the streamlines into the intake began converging inward from a point upstream of the axis of the intake. (See Fig. 11.) The separation of sediment from the streamlines will be discussed later. (See Fig. 11 and Section 10.)

Typical daily distributions of velocity (Fig. 9) are shown for the eleven series of velocity and sediment combinations involved in the tests. The velocities at an elevation 2 in. above the axis of the intake were often slightly higher than the velocities 2 in. below. In general, the velocities above and below were averaged with the morning and evening observations at the elevation of the intake axis to define the daily lateral velocity distribution. Velocities for determining the ratio of intake velocity to velocity of approaching flow were taken from the daily distributions of velocity, both for the velocities at the reference nozzle (1.5 in. out from the intake wall through Aug. 14, 1963, and 0.75 in. out from the wall afterward) and for the samples taken as a check on the sediment distribution in the cross section.

The size of sediment had no clearly observable effect on the distribution of velocity in the cross section.

At the highest flume velocities the velocities near the wall opposite the intake do not decrease normally because the width of the test section increases just downstream. The change in width was used to increase the velocities in the test section.

9. Sediment concentration in the test section--The actual concentrations of sediment at the sampling point varied from about 50 to 2,500 ppm by weight. There seems to be no reason why the sampling efficiency of an intake should vary significantly with a change in concentration of sediment in the flow, unless of course the concentration becomes high enough to change the fluid character of the mixture. These tests were made on the assumption that sediment concentration is not a decisive factor in sampling efficiency.

The sediment concentration at any point in the cross section of the test section of the flume was highly variable with respect to time, especially for the coarser sediments. Also, at any given time variations in sediment concentration within the cross section was highly variable with respect to location.

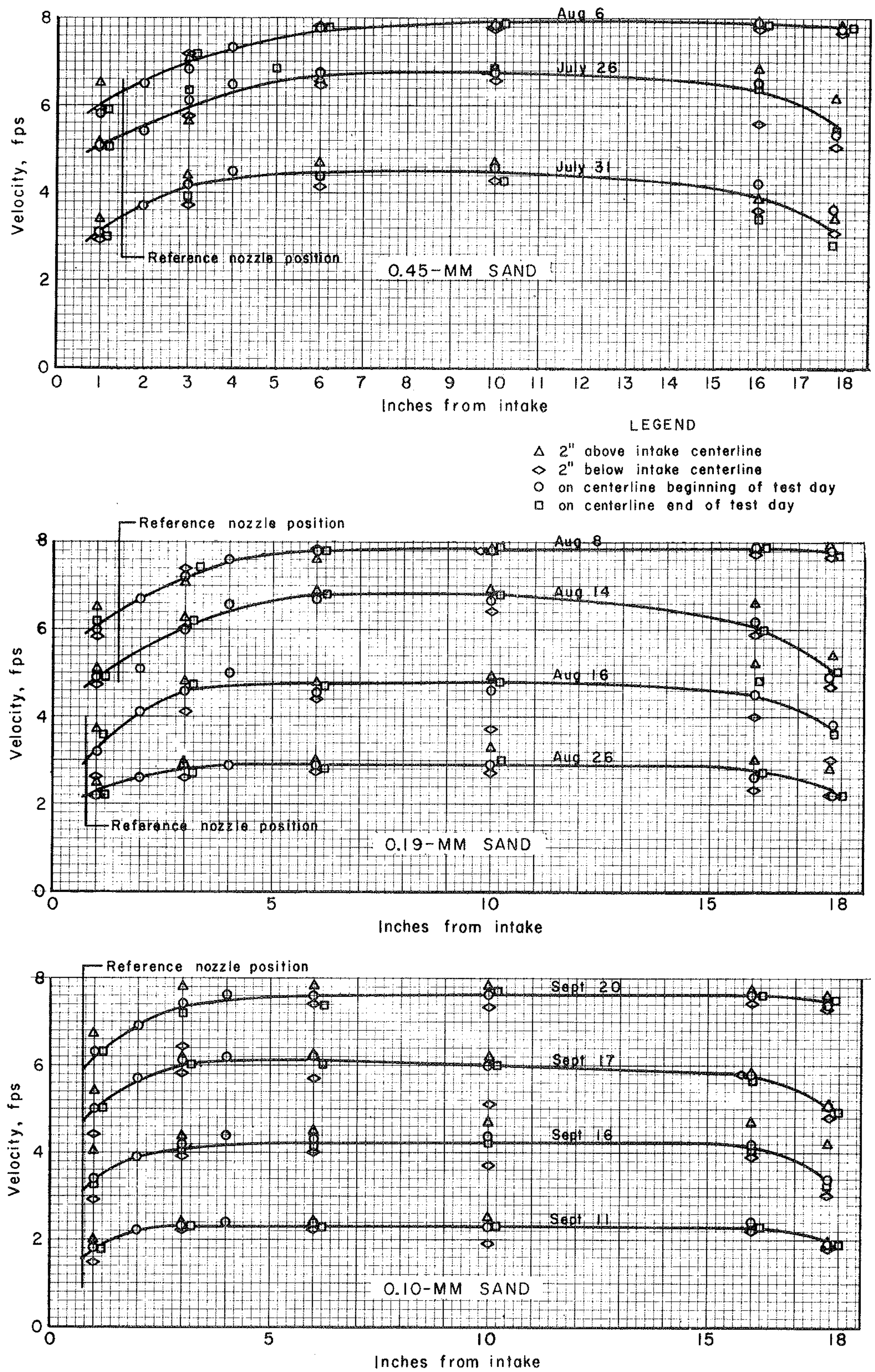


FIG. 9--TYPICAL VELOCITY DISTRIBUTIONS IN TEST SECTION

10. Sediment distribution in the test section--Unfortunately the sediment concentration was not uniformly distribution in the flume cross section at the intake test site. Concentrations of 0.45-mm and 0.19-mm sediment were much higher on the side of the flume in which the intakes were mounted. (See Fig. 10.) The 0.10-mm sediment was more uniformly distributed. Also the lack of a consistent concentration gradient in the vertical may be seen in Fig. 10.

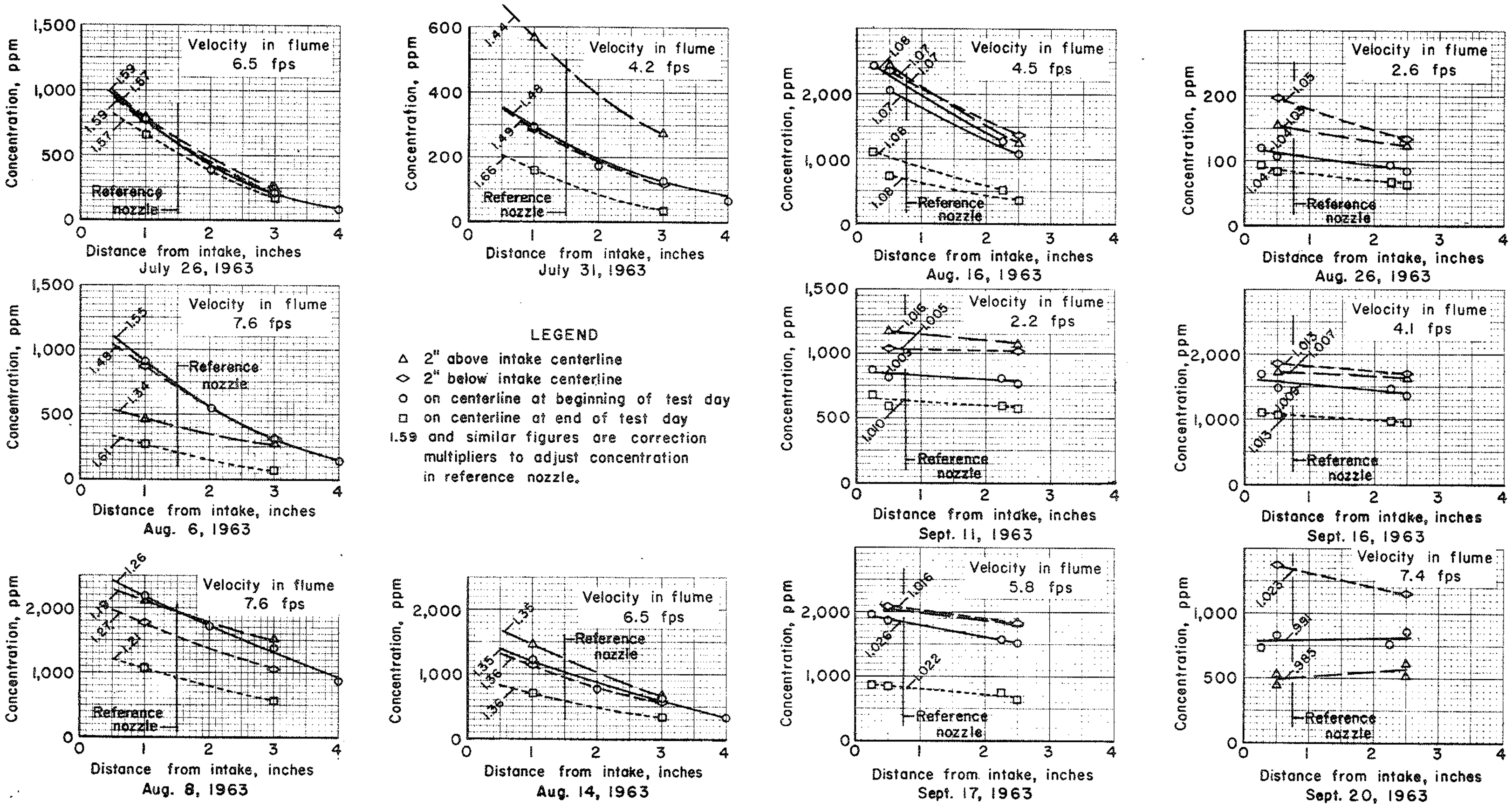
The sampling efficiency of each intake under different conditions was to be established by relating the concentration of sediment in the sample taken through the intake to the concentration in a comparative sample taken in a reference nozzle. The concentration from the reference sample was expected to represent that in the flume in the vicinity of the intake opening.

From the start of intake testing on July 19 through the tests with the 0.45-mm sand and most of the tests at high flume velocities with the 0.19-mm sand, the reference nozzle was at a point 1 1/2 in. out from the intake opening.

Questions immediately arose as to the area from which an intake sample was taken and the portion of the area in which the sediment concentration was most effective in determining the concentration in the sample through the intake. Observations were made of the flow into some of the intakes. Dye injections and streamers on a small rod were used to obtain results such as those in Fig. 11, which indicate streamlines in the horizontal plane of the intake axis of a 0.75-in. intake and of a 1.5-in. intake. Although some of the diverted flow appeared to come from points several inches from the wall, the streamlines are denser near the flume wall. Most of the sediment was drawn from a layer approximately 1 1/4 in. thick and adjacent to the wall. The centroid of the sediment concentration within the layer was approximately 0.5 in. from the wall.

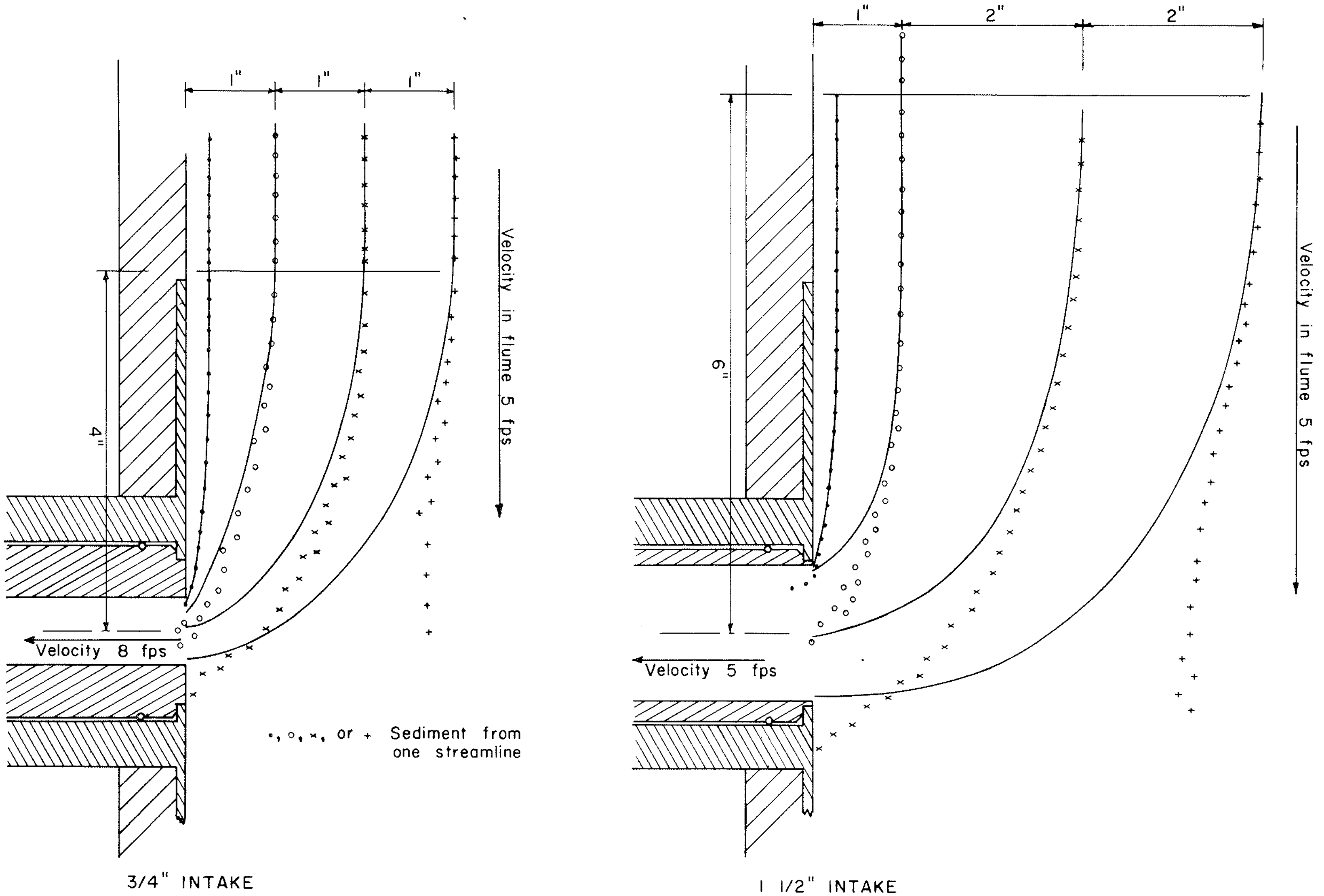
When streamlines of sediment-laden flow bend, the sediment particles tend to continue in a straight line because of their greater density and higher momentum per unit volume. The coarser particles are most affected (Report 5, Fig. 8) [1]. Much of the coarser sediment in the outer streamlines (Fig. 11) does not enter the intake at all. The sediment concentration 0.5 in. from the wall was used as the reference concentration on which to base computations of intake efficiency.

Because the sediment concentration changes rapidly with distance from the wall, the intake efficiency depends on proper choice



Note: 0.45-mm sand July 26, 31, Aug. 6
0.19-mm sand Aug. 8, 14, 16, 26
0.10-mm sand Sept. 11, 16, 17, 20

FIG. 10--SEDIMENT DISTRIBUTION NEAR THE INTAKE AND CORRECTIONS TO CONCENTRATION IN REFERENCE SAMPLES



NOTE: FLOW IN HORIZONTAL PLANE THROUGH AXIS OF INTAKE

FIG. 11--FLOW OF WATER AND SEDIMENT INTO INTAKE

of distance for the reference concentration. If the distribution of sediment with distance from the wall did not change significantly with time, and it did not seem to, then the comparison of one intake with another of about the same size is completely valid. If the effective sampling area is farther out from the wall for large intakes or for high velocities in a given intake, the sampling efficiency would be a little higher than the computed efficiency based on the concentration at a distance of 0.5 in. The difference would be greatest for the coarsest sediment.

From July 19 through August 14, 1963, the reference samples were taken 1.5 in. from the wall, but the reference concentration was required 0.5 in. from the wall. The distribution of sediment near the wall was determined for each day from the type of data shown in Fig. 10. Samples were taken in a vertical plane 3 in. upstream from the axis of the intake and in pairs at points 2 in. apart horizontally. Because samples were taken in simultaneous pairs, the relative concentration over the 2-in. lateral distance was not affected by a difference in time. At the start of daily sampling one pair was generally taken at an elevation 2 in. above the axis of the intake, a second pair 2 in. below the axis and two pairs on the elevation of the axis. The samples of the first pair at each elevation were 1 and 3 in. from the wall and for the second pair on the elevation of the axis 2 and 4 in. from the wall. Concentrations of the pairs of samples were plotted, and the coefficient for changing concentration 1.5 in. from the wall to concentration 0.5 in. from the wall was computed by dividing the indicated concentration at 0.5 in. by that at 1.5 in. A daily average was usually used as a multiplier for the concentrations from the reference sample. Occasionally, the concentrations of a pair of samples were disregarded because they seemed to be definitely erroneous or because they were not directly applicable. For example, the pair 2 in. above the centerline for July 31 were disregarded because they were taken before equilibrium was established and when concentrations were unnaturally high and changing rapidly.

Beginning August 15, the reference nozzle was moved to a point 0.75 in. from the wall to minimize extrapolation errors. For the same sediment distribution, the coefficients to adjust to the concentration from reference samples 0.75 in. from the wall to concentration 0.5 in. from the wall are about 25% of those to adjust from 1.5 in. from the wall before August 15.

Sediment did not deposit on the bed of the test section, and only minor deposits occurred anywhere within the constricted section of the flume. (Some sediment accumulated on the bed in wide sections of the flume.)

III. TEST PROCEDURE

11. Preparation for tests--All tests with the 0.45-mm sand were run first, then all with the 0.19-mm sand, and finally those with the 0.10-mm sand. Whichever sand was in the flume, all tests with a given flume velocity were made consecutively. The order in which the flume velocities were used varied for convenience. No specific order was used for testing intakes and intake velocities except that the shelf intake was run at the start of a day, or series of runs, so that it could be installed when there was no water in the flume. The shelf could be removed easily with water in the flume.

Sediment was dumped or shoveled into the flume when the pump and circulating system were operating. Tests were started only after the sediment was moving uniformly in the flume. Generally this did not take very long. If the sediment had been circulating in the flume the day before, testing was begun as soon as the velocity stabilized in the test section. Sediment was added at intervals to replace that removed from the flume by sampling or by drainage at the end of the day. Additions were made in the morning before distribution of sediment in the test section was determined.

12. Procedure for daily tests--At the beginning of a day, the intake that was to be tested first was installed. (Changes in intakes during the test day were made without stopping the flow but changes were a little easier when there was no water in the flume.)

The pump was started and the pumping rate was adjusted to give the general velocity range for the tests to be made. Then, the velocities were observed at points in the cross section as indicated in Section 8 and Fig. 9.

Distribution of sediment in the cross section was determined from so called "check" samples taken at the points described in Section 8. A pair of identical sampling nozzles with sharp intake edges was used. Such nozzles sample sediment accurately when pointed directly into the approaching flow if the velocity in the intake is equal to that in the approaching flow. When the intake velocity was somewhat different from that in the approaching flow, the sampled concentration of sediment was corrected to that in the flow by using Table 3, which is based on Inter-Agency Report 5 [1].

TABLE 3

MULTIPLIERS TO CORRECT SEDIMENT-SAMPLE CONCENTRATIONS FOR THE EFFECT OF INTAKE RATIO

Sediment	0.45 mm				0.19 mm				0.10 mm			
Velocity in flume*, fps	3	4	5	6	3	4	5	6	3	4	5	6
Intake ratio (relative sampling rate of Report 5)												
0.60	0.86	0.84	0.83	0.81	0.93	0.91	0.89	0.88	0.95	0.94	0.93	0.92
.65	.88	.87	.86	.85	.93	.92	.91	.90	.95	.95	.94	.93
.70	.91	.90	.89	.88	.94	.93	.92	.91	.96	.96	.95	.94
.75	.93	.92	.91	.91	.95	.94	.93	.93	.97	.96	.95	.95
.80	.95	.95	.94	.93	.96	.96	.95	.94	.97	.97	.96	.96
.85	.97	.96	.96	.95	.97	.97	.96	.96	.98	.98	.97	.97
.90	.98	.98	.97	.97	.98	.98	.97	.97	.99	.98	.98	.98
.95	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.05	1.01	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
1.10	1.03	1.03	1.03	1.04	1.02	1.02	1.02	1.02	1.01	1.01	1.01	1.02
1.15	1.04	1.04	1.05	1.05	1.03	1.03	1.03	1.03	1.02	1.02	1.02	1.02
1.20	1.05	1.06	1.06	1.06	1.04	1.04	1.04	1.04	1.02	1.02	1.03	1.03
1.25	1.07	1.07	1.07	1.07	1.05	1.05	1.05	1.05	1.02	1.03	1.03	1.04
1.30	1.08	1.08	1.08	1.08	1.06	1.06	1.06	1.06	1.03	1.03	1.04	1.04
1.35	1.08	1.09	1.09	1.09	1.06	1.06	1.07	1.07	1.03	1.03	1.04	1.05
1.40	1.09	1.10	1.10	1.10	1.06	1.06	1.07	1.07	1.03	1.04	1.05	1.05
1.45	1.09	1.10	1.11	1.11	1.06	1.07	1.07	1.08	1.04	1.04	1.05	1.05
1.50	1.10	1.11	1.12	1.13	1.07	1.07	1.08	1.08	1.04	1.04	1.05	1.06
1.55	1.10	1.11	1.12	1.13	1.07	1.08	1.08	1.09	1.04	1.05	1.06	1.06
1.60	1.11	1.12	1.13	1.14	1.07	1.08	1.09	1.09	1.04	1.05	1.06	1.06
1.65	1.11	1.12	1.14	1.15	1.08	1.09	1.09	1.10	1.04	1.05	1.06	1.07
1.70	1.12	1.13	1.15	1.16	1.08	1.09	1.10	1.10	1.04	1.05	1.06	1.07
1.75	1.12	1.14	1.15	1.17	1.08	1.09	1.10	1.11	1.05	1.06	1.07	1.07
1.80	1.12	1.14	1.16	1.17	1.08	1.09	1.10	1.11	1.05	1.06	1.07	1.07
1.85	1.13	1.15	1.16	1.18	1.09	1.10	1.11	1.12	1.05	1.06	1.07	1.08
1.90	1.13	1.15	1.17	1.19	1.09	1.10	1.11	1.12	1.05	1.06	1.07	1.08
1.95	1.14	1.16	1.17	1.19	1.09	1.10	1.11	1.13	1.06	1.07	1.08	1.08

This table is based on data of Report 5 [1]. Multipliers were obtained by interpolation and extrapolation when necessary. They were applied to reference and check samples only.

The elevation of the discharge end of a flexible tube from each check-sampling nozzle was adjusted to give a velocity in the nozzle about equal to the known flume velocity at the sampling point. The samples were siphoned over the side of the flume. If necessary, the nozzles and tubes composing the siphon were filled, or primed, and the discharge end of the tube was clamped.

A check sample was taken by adjusting both nozzles for elevation in the flume, orientation directly into the flow, and distance from the intake. The discharge tubes were opened and flow was wasted for about 10 sec to flush out the tubes. Then a sample of about 60 lbs of water was collected through each nozzle. The time for collection depended on the velocity, and ranged from 400 to 1600 sec. Each sample was collected in a separate volumetric tank. After its volume (actually weight of an equivalent volume of clear water) was determined, and the sediment had settled to the bottom, the supernatant liquid in the tank was drained off through the upper drain on the tank. Then the sediment and remaining liquid were drained into a container and taken to the laboratory where the dry weight of sediment was determined. Concentration of sediment was computed later as ratio of sediment weight to weight of clear water corresponding to the sample volume.

Reference samples were collected for comparison with each sample taken through a pumping sampler intake. The elevation of the discharge end of a flexible tube leading from the nozzle was fixed to give a velocity in the nozzle about equal to that in the flume at the intake of the reference nozzle. Discharge was wasted for about 10 sec, then half a sample was collected in one of the volumetric tanks. After the half sample was collected, the discharge from the reference nozzle was stopped while the test sample was taken through the test intake. As soon as the intake sample was complete and flow through the intake had been stopped, the second half of the reference sample was taken.

The sample through a test intake was taken by establishing an elevation for the discharge end of the flexible discharge hose from the intake. The outer end of the discharge hose was fixed at the selected elevation and opened. Flow was wasted for a few seconds to flush the line. Then a sample was taken in the largest volumetric tank. When a sample of 120 lbs or more had been collected, the discharge was stopped and the second half of the reference sample was taken. Additional pairs of reference and test samples were taken for other intake velocities and other intakes. The weight of samples and of sediment in the samples was determined in the same way for the check, reference, and test samples.

At the end of a day, or test period, a set of samples was taken to check the distribution of sediment. Also, a set of velocity observations was made to check the horizontal velocity distribution at each of three elevations.

Stop watches were used to determine time in seconds for the collection of all sediment samples.

Temperature of the water in the flume was taken at the start of a work day, at noon, and just before the end of the day. Pump discharge was recorded at the start of work and checked several times each day. Samples for analysis of chemical quality of the water and for size analysis of the sediment were taken at intervals throughout the duration of these tests.

IV. DATA COMPUTATION AND DISCUSSION

13. Intake velocities and corrections based on intake ratios--Velocities in the sampling and reference nozzles were computed on the basis of the sample volumes and the time for collecting the samples. The volume of sample divided by time gave volume per second. Then, the volume per second divided by the area of the nozzle gave velocity in the nozzle. Because the calibration of the volumetric tanks was in pounds of water, a relation between pounds per second and velocity in the nozzle was computed and used for convenience.

The velocity at the nozzle was determined from the velocity distribution in the flume. If the flume velocity at a check or a reference sampling point was the same as the velocity in the nozzle, the sediment concentration in the check or reference samples was considered representative of that in the flume at the sampling point. If velocity in the nozzle differed from that at the sampling point by more than approximately 5%, an adjustment from Table 3 based on the ratio of velocity in the intake to velocity in the approaching flow (intake ratio, or relative sampling rate of Report 5 [1]), was applied to the sediment concentration of sediment at the sampling point. Concentrations in samples taken through test intakes were not adjusted.

14. Sampling efficiency of an intake--Ideally, a sample taken through an intake should have the same concentration as that in the stream at the sampling point. The size distribution should be the same also. If the concentrations are identical, the size distribution can be assumed to be identical. If the concentration in the sample is less than that in the stream, the deficiency is likely to be in the coarse sizes of sediment.

In these tests, sampling efficiency is taken as the ratio of sediment concentration in the test sample to that in the flume computed for a point 0.5 in. out from the flume wall. The concentration in the reference sample that was taken just before and just after the test sample was multiplied by the daily correction coefficient (Section 10) to obtain the concentration 0.5 in. from the flume wall at the time the test sample was taken.

The sampling efficiency for each test condition was used as an indication of the effect of the sampling variables. The efficiencies are plotted for the 0.45-mm, 0.19-mm, and 0.10-mm sands in Appendix Figs. 15, 16, and 17, respectively. The effect of each sampling variable is discussed in the following sections.

15. Effect of velocity in the intake--Sampling efficiency varied little for intake velocities more than 3 fps. (See Appendix Figs. 15, 16, and 17.) To show the effects of intake velocity more clearly, Appendix Table 6 was prepared. It groups sampling efficiencies for all intakes by ranges of intake velocity. Average efficiencies within given ranges of intake velocities (from Appendix Table 6) are plotted in Fig. 12. For intake velocities more than 3.0 fps, the ratio of intake velocity to velocity in the flume at sampling point was not significant for the 0.10-mm and 0.19-mm sands. For the 0.45-mm sand an intake velocity equal to the velocity at the sampling point gave better sampling efficiencies. At intake velocities of about 2 fps and less, the sampling efficiency was very erratic and was often very low. (This effect seemed to extend in less drastic amounts to intake velocities of 3 fps at times.) At intake velocities less than 3 fps the concentration of sediment in the flow through the intake was perhaps somewhat low. However, the extremely low computed efficiencies were clearly the result of sediment deposits forming in the discharge line from the intake. Occasionally, the deposits were not carefully flushed out before the next sample and the excess sediment appeared in that sample.

The possibility that intake efficiencies for large intakes and high intake velocities should be a little higher than those shown by Fig. 12 was recognized in Section 10. Also, if flume velocities were much higher than those used in the tests, the sampling efficiency, especially for coarse sediment, might be decreased unless the intake velocities were increased.

Three basic conclusions can be stated: (1) An intake velocity greater than 3 fps is adequate for sampling over a wide range of sediment sizes and stream velocities. (2) For sands coarser than 0.20 mm an intake velocity equal to or greater than the velocity at the sampling point is desirable. (3) If intake velocities are above the minimum required for accuracy, small changes in them will not significantly alter sampling efficiency.

16. Effect of intake size and shape--Sampling efficiencies of Appendix Figs. 15, 16, and 17 for intake velocities greater than 3 fps were averaged for each combination of sediment size, flume velocity, and intake type. (See Fig. 13.) Generally, at high flume

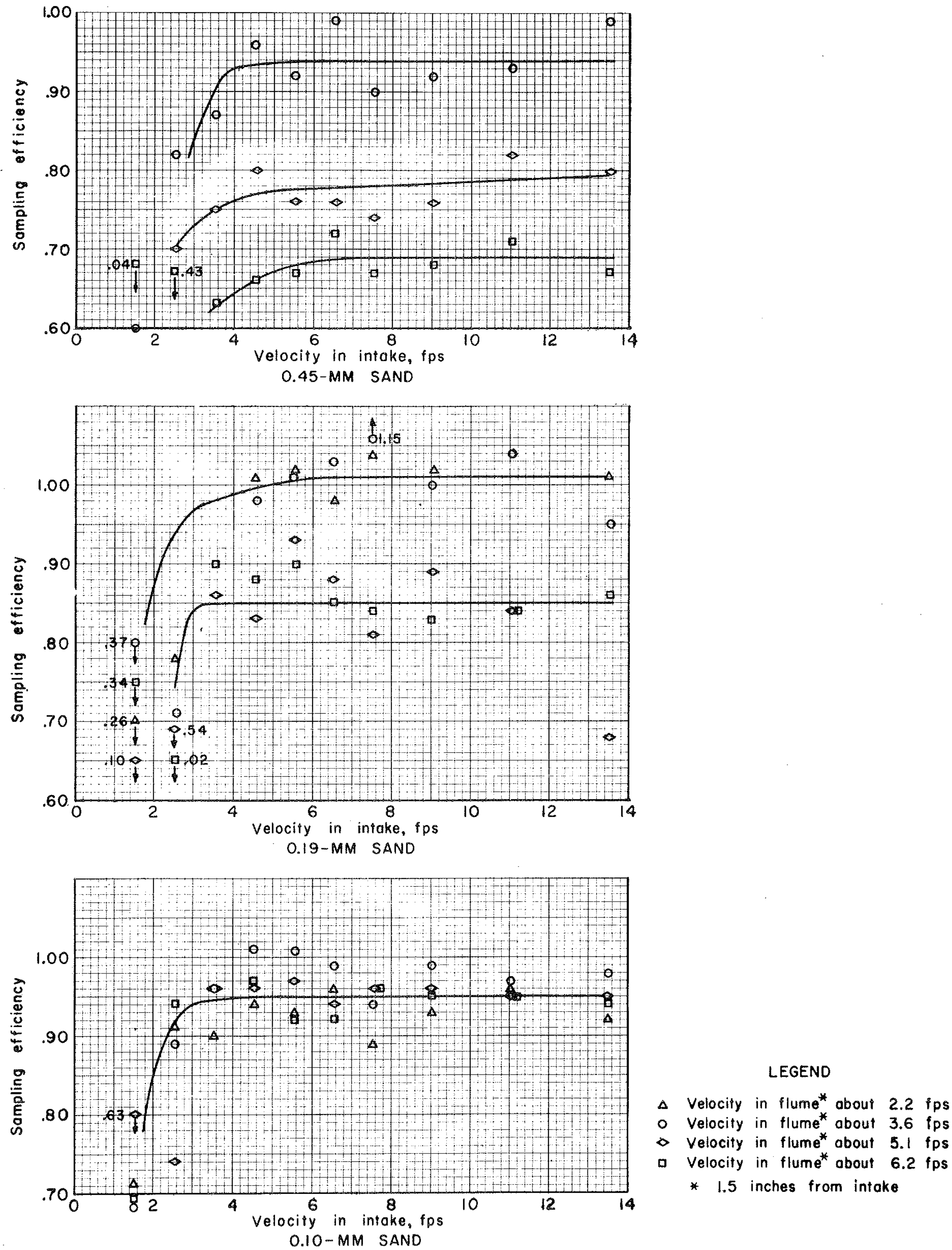


FIG. 12--EFFECT OF INTAKE VELOCITY ON SAMPLING EFFICIENCY

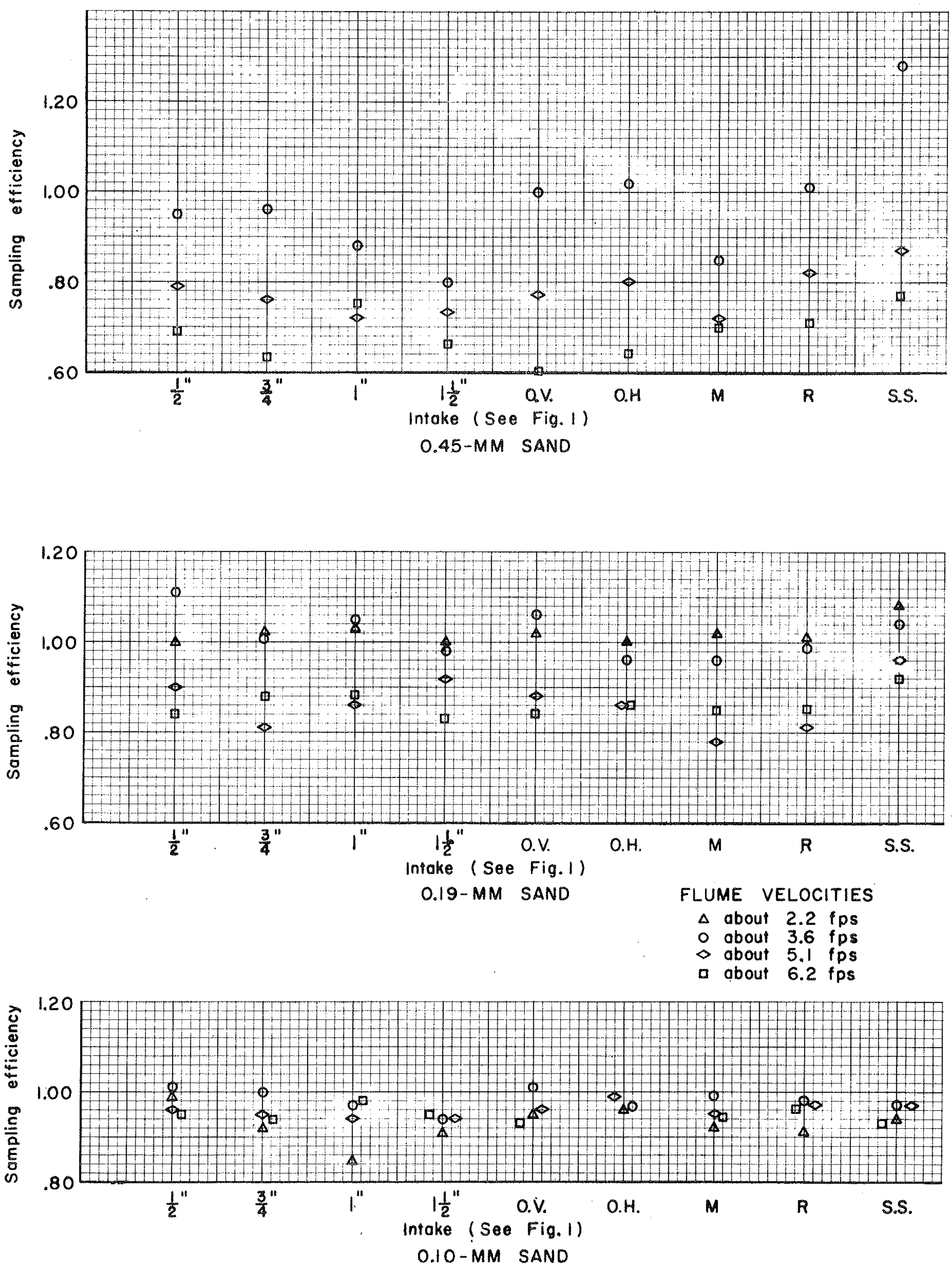


FIG. 13--SAMPLING EFFICIENCIES FOR DIFFERENT INTAKES

velocities the sampling efficiencies show little effect of size of intake (range 0.5 to 1.5 in. in diameter), of rounding of outer end of the intake (3/4-in. M and R intakes compared to unrounded 3/4-in. intake), or of shape and orientation of the axis of the oval intake. At the lower flume velocities, especially perhaps around 3.5 fps, sampling efficiencies tend to be high. At low flume velocities, the large intakes show a slightly lower, but a more consistent, sampling efficiency. At high flume velocities the intake with the shelf under it has the best sampling efficiency of all the intakes but at low flume velocities it sampled erratically.

Erratic readings in the observed sampling efficiency were caused by:

a. Large time and space variations in the flume sediment concentration.

b. Possible slight instability in the intakes sediment-sampling rate.

The magnitude of these variations were probably a function of the intake size and shape.

In an effort to compare the intakes on the basis of intake stability (b. above) Fig. 13A, Table 4, and Table 5 were prepared.

Fig. 13A shows a comparison of the maximum deviations in measured sampling efficiency for each of the nine intakes. For each intake the maximum deviation caused by variations in sand size, intake velocity and flume velocity were evaluated from Appendix Figs. 15, 16, and 17. While the effects of one variable were being evaluated the remaining two variables were held within limits just large enough to encompass a representative number of points. Occasionally points near to but outside the boundaries were used to estimate the maximum deviation.

Table 4 shows for each intake the standard deviation of all measured intake efficiencies that fall within the stated limits of flume velocity, intake velocity, and sand sizes.

Table 5 shows the numerical ranking of the intakes based on the maximum deviations and computed standard deviations.

Table 5 shows that the nozzle that ranks best according to one test for dispersion may rank comparatively low according to another test. To rank the intakes based on all six measures of

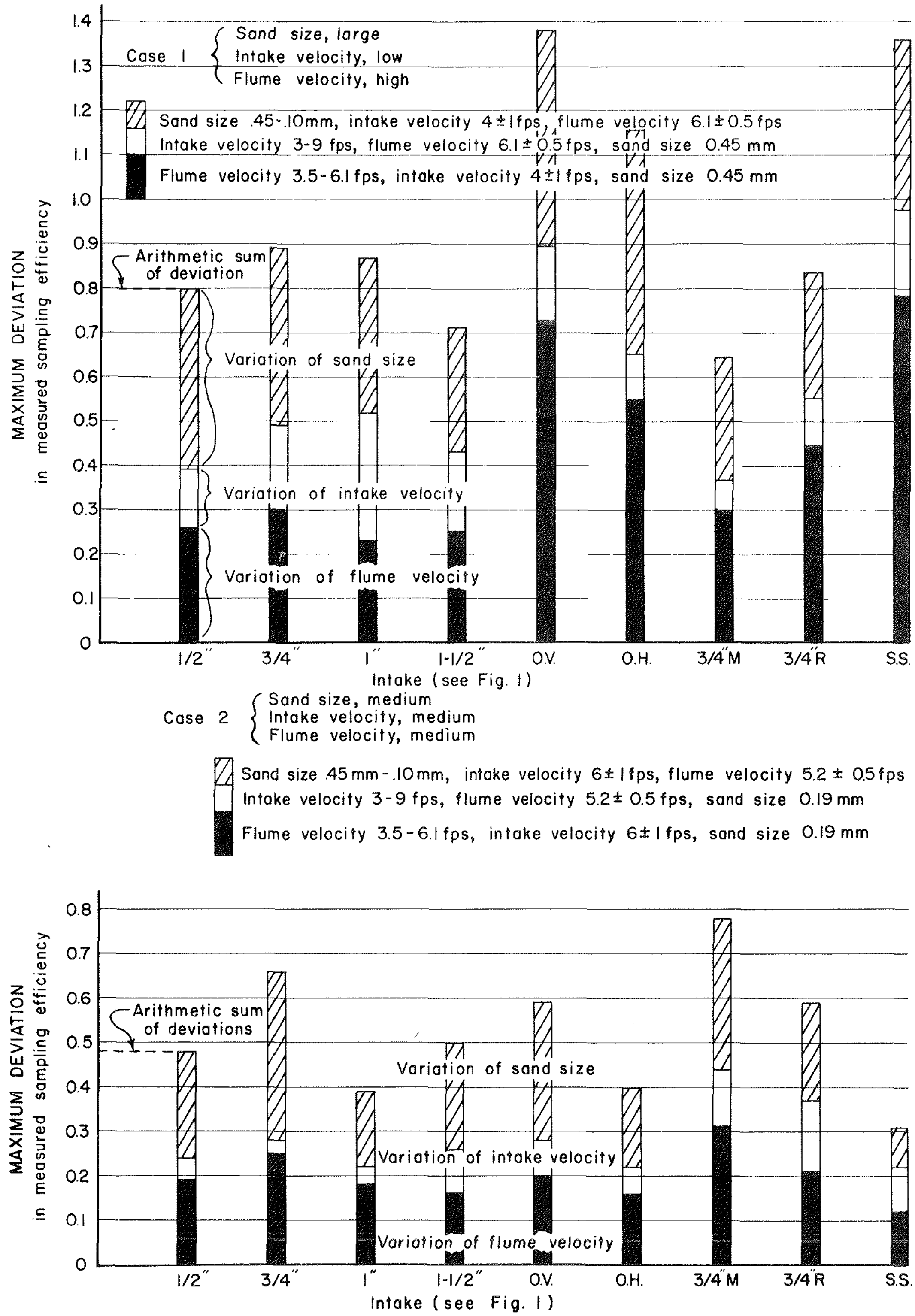


Fig. 13A MAXIMUM DEVIATION IN SAMPLING EFFICIENCY FOR DIFFERENT INTAKES

(Data from Fig. 15, 16, and 17)

TABLE 4

STANDARD DEVIATION AND MEAN OF MEASURED SAMPLING EFFICIENCY

Flume velocity 3.5-6.1 fps

Intake velocity 3-9 fps

Intake	SAND SIZE							
	0.45 mm		0.19 mm		0.10 mm		0.45-0.19 mm	
	Standard deviation	MEAN	Standard deviation	MEAN	Standard deviation	MEAN	Standard deviation	MEAN
1/2"	(9) .12	.77	(8) .12	.94	(8) .034	.97	(25) .094	.89
3/4"	(9) * .18	.75	(8) .10	.92	(7) .027	.98	(24) .12	.87
1"	(15) .095	.78	(10) .11	.92	(8) .031	.97	(33) .087	.87
1 1/2"	(9) .098	.72	(10) .071	.90	(7) .026	.94	(26) .071	.85
OV	(11) .20	.80	(8) .071	.88	(6) .038	.98	(25) .14	.87
OH	(12) .16	.78	(6) .10	.92	(5) .034	.98	(23) .13	.86
3/4M	(10) .11	.74	(10) .083	.84	(7) .033	.97	(27) .085	.84
3/4R	(8) .13	.83	(9) .097	.90	(5) .025	.99	(22) .097	.89
S.S.	(11) .21	.93	(11) .064	.97	(6) .031	.98	(28) .13	.96

( ) Indicates number of plotted points used to calculate standard deviation and MEAN. As shown in Table 1, each plotted point is an average of approximately five separate readings.

* First day data was omitted in computation (See Fig. 15B, 3/4-in. intake).

(All calculations based on data from Figs. 15, 16, and 17).

TABLE 5

RANK OF INTAKES

(Based on Dispersion of Measured Sampling Efficiency)

(1) Indicates intake with lowest dispersion in readings

Intake	Max. Deviation Figure 13A		Standard Deviation, Table 4 Sand Size, mm				Total of Numerical Ranking	Final Numerical Ranking
	Case 1	Case 2	0.45	0.19	0.10	0.45-0.10		
1/2"	4	4	4	9	7 1/2	4	31 1/2	5 1/2
3/4"	6	8	7	6 1/2	3	6	36 1/2	7
1"	5	2	1	8	4 1/2	3	23 1/2	2
1 1/2"	2	5	2	2 1/2	2	1	14 1/2	1
OV	9	6 1/2	8	2 1/2	9	9	44	9
OH	7	3	6	6 1/2	7 1/2	7	37	8
3/4M	1	9	3	4	6	2	25	3
3/4R	4	6 1/2	5	5	1	5	26 1/2	4
S.S.	8	1	9	1	4 1/2	8	31 1/2	5 1/2

If two or more intakes ranked nearly equal the same average numerical ranking was assigned to each dispersion the total of the numerical rankings for each intake was tabulated and the right hand column of Table 5 shows the final numerical ranking based on the total.

Based on the final ranking, the 1 1/2 in. intake appears to be the most consistent. It is followed in order by the 1 in., 3/4R, 3/4SS and 1/2 in., 3/4 in., O.H., and O.V. Because the ranking is sensitive to the statistical test applied, reversals of adjacent intakes could easily occur. However, the final numerical ranking does show that small intakes are less consistent than large intakes.

17. Effect of sediment size--Previous work [1, 3] showed that under a wide range of conditions, sampling efficiency was good for sediments smaller than 0.06 mm. This conclusion was assumed to be true when these tests were designed. Sampling efficiencies for the 0.10-mm sand also confirmed the assumption. For sediments coarser than 0.10 mm, particle size has an important effect on sampling efficiency, especially if the coarser sizes are contained in high-velocity flow as they usually are.

Any of the plottings of the test data (Figs. 11-17) show the effect of particle size. Average sampling efficiencies for all intakes, except the shelf intake, and all intake velocities greater than 3 fps are plotted in Fig. 14 with flume velocity and sediment size as variables. Obviously if conditions are such that sampling efficiencies are generally low, the efficiency will decrease as the particle size increases from sizes of about 0.10 mm upward.

Because fine sediments are usually distributed uniformly in a stream vertical and can be sampled accurately through a pumping sampler intake, the concentration in samples should be about equal to concentrations in the stream at the sampling point.

The concentration of coarse sediments in a pumped sample can be adjusted to show the approximate concentration of coarse sediment at the intake on the basis of such data as those of Fig. 14. The 0.45--mm sediment (actually 0.40-mm in suspension) and a flume velocity of 6 fps are moderately high values for field sampling of suspended sediment. The data should not be extrapolated beyond these limits.

When coarse sediments are in the stream flow, the distribution of sediment will not be uniform throughout the stream cross section. Then, for accurate sampling the relation between average

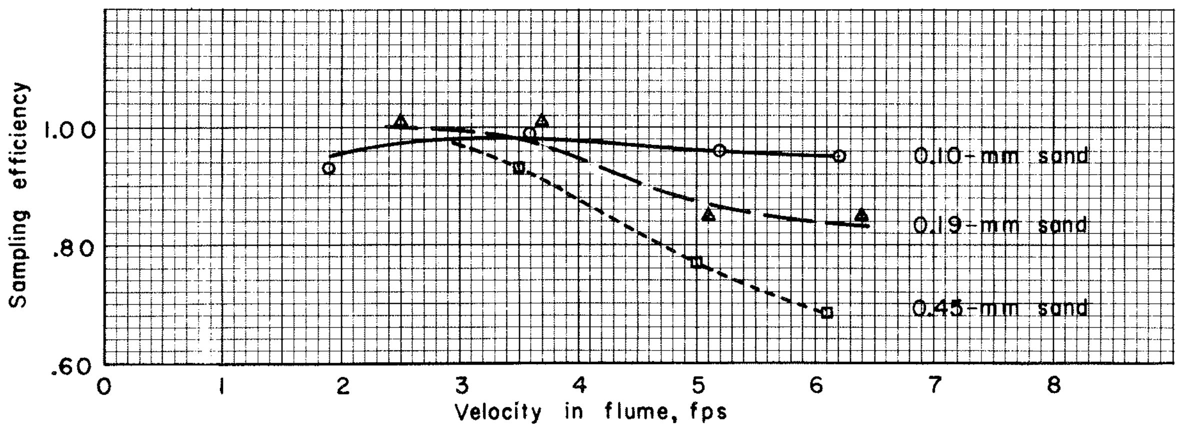


FIG. 14--EFFECT OF SEDIMENT SIZE AND FLUME VELOCITY ON SAMPLING EFFICIENCY

concentration in the cross section and concentration at the sampler intake must be established by manual sampling. The logical procedure is to relate the cross-section concentrations determined with standard sampling procedures directly to the concentration in pumped samples, thus calibrating the combined effect of distribution in the stream and sampling efficiency at one time.

18. Effect of flume velocity--Fig. 14 shows the general effect of flume velocity on sampling efficiency. Flume velocity corresponds to the stream velocity in normal sampling procedure. The flume velocities shown in Fig. 14 are at a point 1.5 in. out from the intake. In stream sampling the mean velocity is often much higher than the velocity at 1.5 in. from the intake, both because of lateral distribution of velocity and the fact that the pumping sampler intake may be close to the stream bed.

Another effect may be like that shown for the Rock Island sampler nose in Fig. 24 of Report 5. For an intake pointing directly into the approaching flow and surrounded by a flat surface, somewhat analogous to flume flow directed across the flume and against the intake opening, the concentration of sediment in the sample was greater than in the sampled flow. At flume velocities between approximately 2.5 and 3.5 fps the test data show the highest efficiencies. At these low flume velocities, the streamlines enter the intake with less abrupt bending at the entrance and sampling conditions probably approach those of Fig. 24 of Report 5. At flume velocities of about 2 fps sampling becomes more like that of sample withdrawal from a settling chamber in which the fluid is at rest. The indication that sampling efficiency is lower at flume velocities of 2.0 fps than at 3.5 fps may, or may not, be significant. In natural streams not much coarse sediment is likely to be in suspension at velocities of 2.0 fps or less.

In general, sampling efficiencies are good at 3.5-fps velocity past the intake. Efficiencies become lower as the water velocity increases. This seems logical and some data in Inter-Agency Reports 5 and Q [1, 3] show such an effect. Special intakes such as the shelf intake of Fig. 1 might be used for flow at extremely high velocity and carrying coarse sediment.

V. CONCLUSIONS

19. Conclusions and recommendations--In spite of the difficulties involved in this general type of study and some of the problems peculiar to this group of tests, three questions basic to pumping sampler intake design were answered.

1. Except for intake No. 9 (SS), the size and shape of the intake does not materially affect its average sampling efficiency.

2. For sediments in the clay and silt size the velocity in the intake and the velocity in the stream does not affect the sampling efficiency provided that the intake velocity exceeds 3.5 fps. However, for sediments in the sand size, intake velocity and stream velocity do have an influence upon sampling efficiency. An increase in stream velocity will result in a decrease in sampling efficiency. To minimize random variations in the sampling efficiency the intake velocity must be equal to or greater than the stream velocity at the sampling point.

3. For the same stream velocity, intake velocity, sediment concentration, and sediment size, a large intake is slightly more consistent than a small intake.

Of the nine intakes tested, the 1-in. appears to be the most satisfactory from the standpoint of sampling efficiency and power requirement for the following reasons:

a. Except for the 1 1/2-in. intake the 1-in. intake was generally more consistent than the other intakes.

b. Compared to the other intakes the change in sampling efficiency caused by changes in sand size was smaller.

c. For any given sand size the average intake efficiency was generally higher than the other intakes. (The S.S. intake had a high efficiency but was very erratic.)

d. It is one of the simplest and consequently one of the most inexpensive intakes to fabricate.

e. For equal intake velocities it requires less pump power than the 1 1/2-in. intake which also ranks high in all other respects.

f. Because of its simple shape, backflushing should be effective in cleaning the intake.

The following recommendations are based on facts revealed by these tests and a limited number of pumping sampler field installations.

1. One-inch intakes should be used. They should be mounted in a vertical wall that is parallel to the streamflow.

2. The intake and tubing that connects the intake to the pump should be installed so that they are protected from stream carried debris that may damage or dislodge the parts.

3. The intake should be located in a straight reach of the stream and the pump and sample splitter should be located as close to the intake as possible.

4. The pump should be installed so that the difference in elevation between the pump and intake do not exceed the priming limits of the pump. The maximum difference in elevation is usually about 20 feet.

5. The intake should be located at a point where stream turbulence is high so that sediment mixing is as thorough as possible.

6. At least three intakes should be mounted in a nearly vertical line with the lowest intake about three inches above the stream bed. The vertical distance between intakes should be approximately six inches. Several intakes are desirable so that the relationship between the average stream concentration and the concentration in samples pumped from each intake can be compared. The intake that yields the best correlation should then be used in future measurements. Occasionally the lower intake may be subject to plugging by dunes that move along the stream bed. If plugging occurs frequently the pump should not be connected to the lower intake.

7. If possible, the intake should be installed on the side of the stream where the low flow is concentrated.

8. Three-fourth inch semi-rigid plastic tubing can be used to connect the pump to the intake.

9. Pump speed should be adjusted for a discharge of approximately 1.6 gals per sec during low stream flow. With the 1-in.

intake this will produce an intake velocity of approximately 3.9 fps. As the stream increases the pumping rate will increase because of decreased pumping head. Pumping rate may be set at higher rates but this will result in increased power consumption and decreased pump life.

10. For fifty feet of tubing between the sampler splitter and the intake, the pump discharge should be wasted for approximately 15 seconds before the sample is taken. This will allow adequate time to clear the intake and associated tubing of sediment that may have accumulated from the previous pumping cycle. For greater lengths of tubing the waste time should be increased proportionally.

VI. APPENDIX

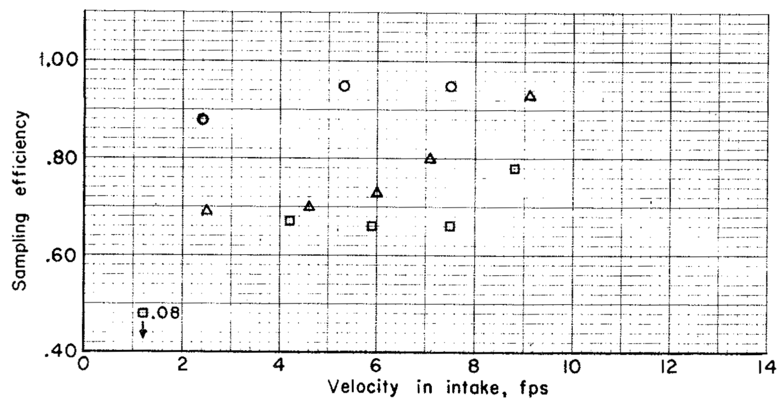
20. Basic data--Table 6 and Figs. 15a, b, c, 16a, b, c, and 17a, b, c, presented on the following pages, contain basic data that have been used in the body of the report.

TABLE 6

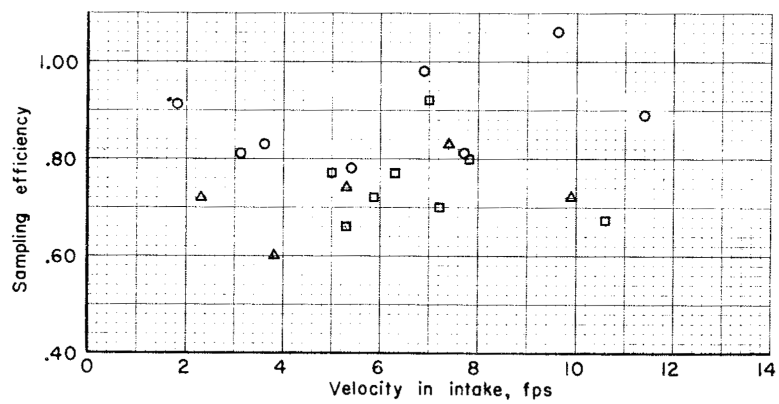
PUMPING SAMPLER INTAKE EFFICIENCIES

Velocity in intake, fps		0-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	6.1-7.0	7.1-8.0	8.1-10.0	10.1-12.0	12.1-15.5	3.1-15.5
0.45-MM SEDIMENT													
Velocity in flume, fps	3.5	-	0.60	0.84	0.87	0.96	0.92	0.99	0.90	0.92	0.93	0.99	0.93
	5.0	-	-	.70	.75	.80	.76	.76	.74	.76	.82	.80	.77
	6.1	-	.04	.43	.63	.66	.67	.72	.67	.68	.71	.67	.68
Average		-	.32	.66	.76	.75	.78	.81	.77	.79	.81	.91	.79
0.19-MM SEDIMENT													
Velocity in flume, fps	2.5	-	0.26	0.78	-	1.01	1.02	0.98	1.04	1.02	-	1.01	1.01
	3.7	-	.37	.71	-	.98	1.01	1.03	1.15	1.00	1.04	.95	1.01
	5.1	-	.10	.54	0.86	.83	.93	.88	.81	.89	.84	.68	.85
	6.2	-	.34	.02	.90	.88	.90	.85	.84	.83	.84	.86	.85
Average		-	.30	.62	.88	.92	.97	.92	.94	.95	.90	.91	.93
0.10-MM SEDIMENT													
Velocity in flume, fps	1.9	-	0.71	0.91	0.90	0.94	0.93	0.96	0.89	0.93	0.96	0.92	0.93
	3.6	-	.68	.89	.96	1.01	1.01	.99	.94	.99	.97	.98	.99
	5.2	-	.63	.74	.96	.96	.97	.94	.96	.96	.95	.95	.96
	6.2	-	.69	.94	-	.97	.92	.92	.96	.95	.95	.94	.95
Average		-	.68	.87	.94	.97	.95	.97	.93	.96	.96	.94	.96

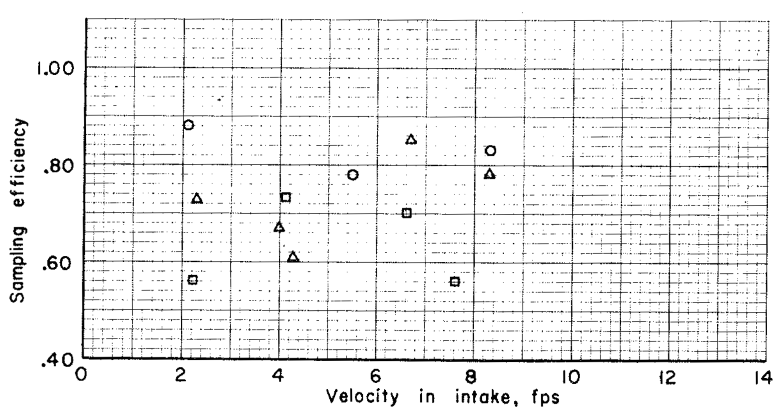
NOTE: This table was made up for all data except those for the shelf intake. The averages in the column on the extreme right are for all intake velocities faster than 3.0 fps. Generally, each figure represents an average of from 2 to 4 individual samples. All averages are weighted according to the number of samples in the group.



1/2" INTAKE



1" INTAKE



1 1/2" INTAKE

SYMBOL	VELOCITY IN FLUME (fps)	AVERAGE SAMPLING EFFICIENCY*
○	3.4	0.95
△	5.0	0.79
□	6.2	0.69
○	3.6	0.88
△	5.0	0.72
□	6.1	0.75
○	3.6	0.80
△	5.0	0.73
□	6.1	0.66

* For intake velocities greater than 3.0 fps

FIG. 15A--PUMPING-SAMPLER INTAKE EFFICIENCIES, 0.45-MM SAND

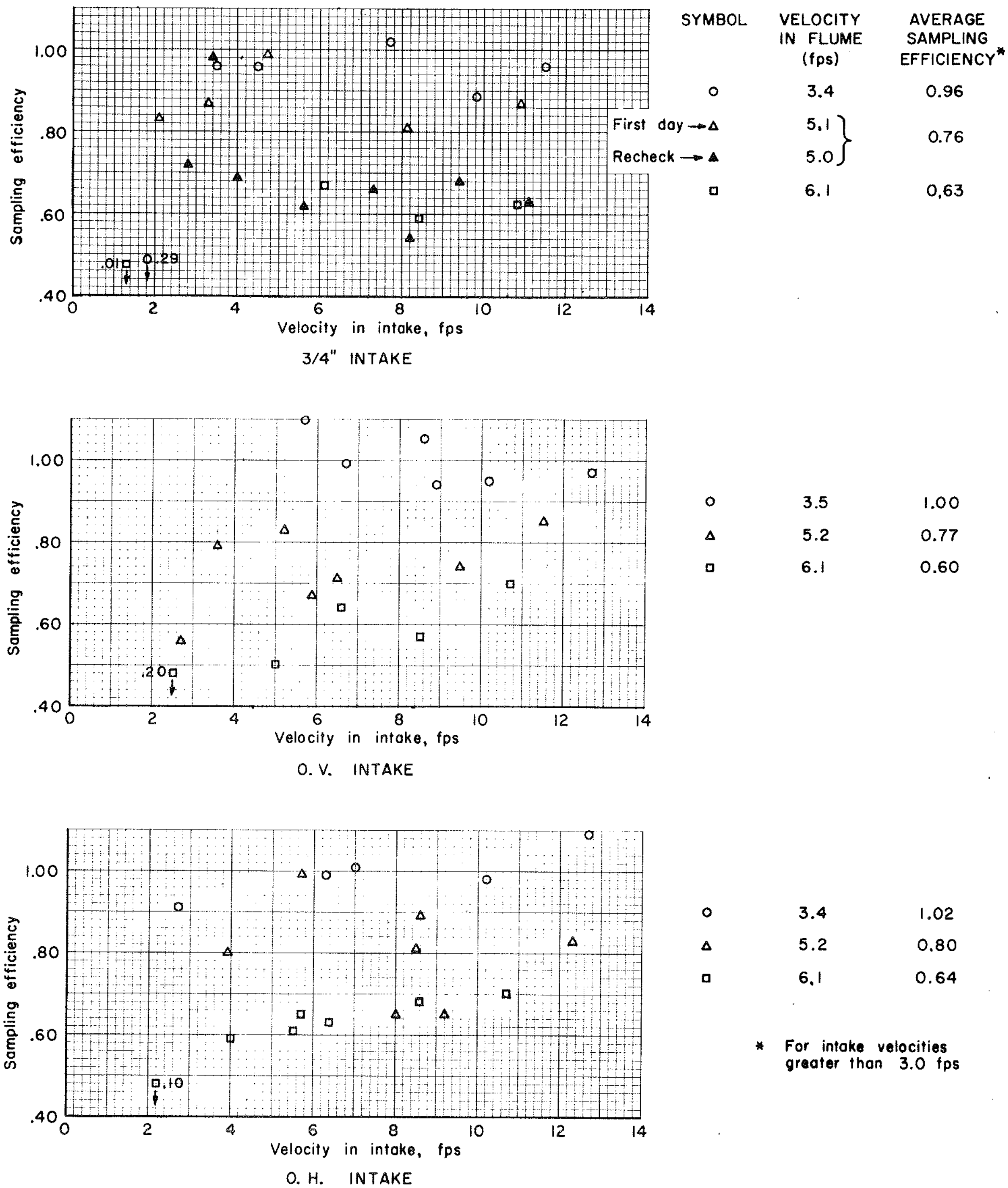
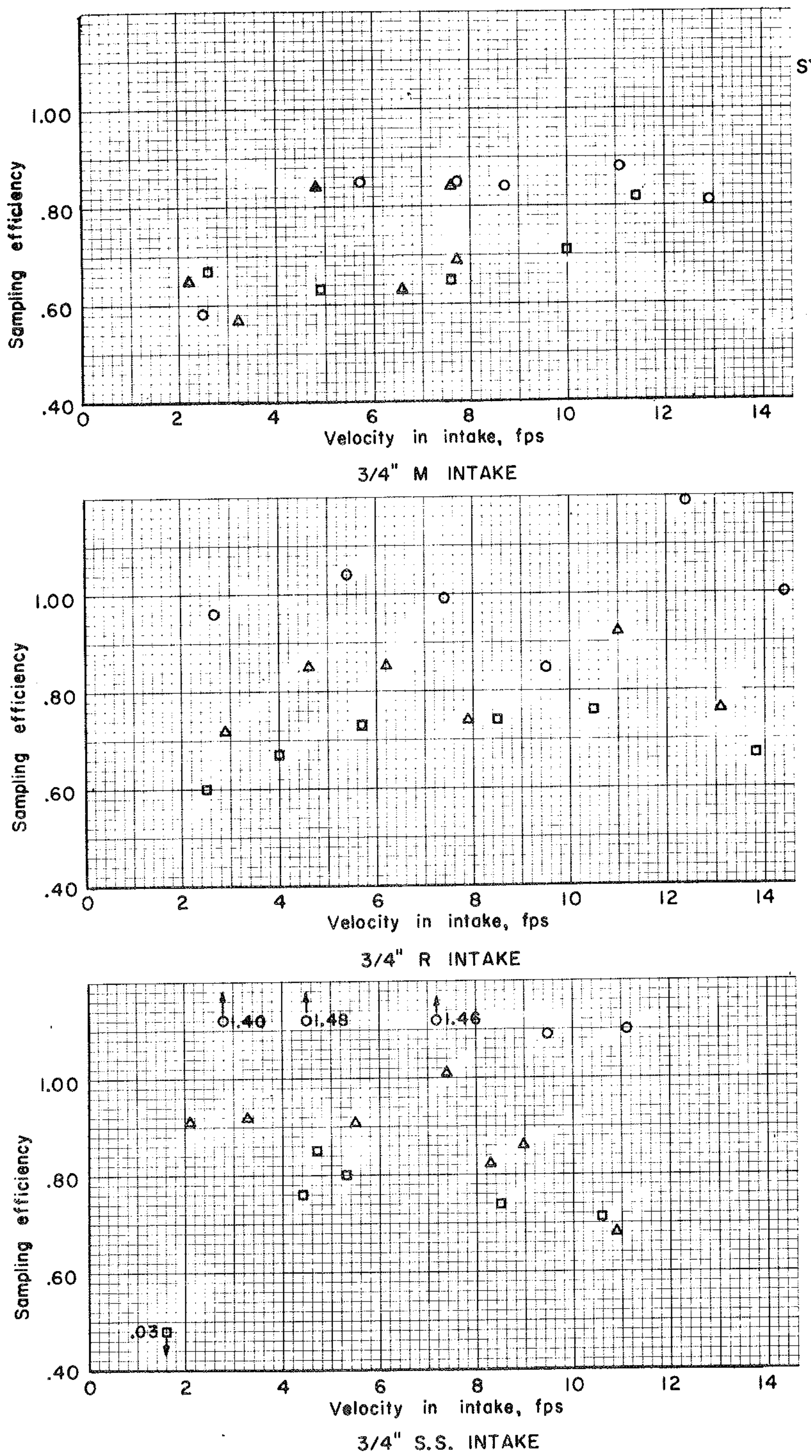


FIG. 15B--PUMPING-SAMPLER INTAKE EFFICIENCIES, 0.45-MM SAN



3/4" M INTAKE

SYMBOL	VELOCITY IN FLUME (fps)	AVERAGE SAMPLING EFFICIENCY *
○	3.4	0.85
△	5.0	0.72
□	6.1	0.70

3/4" R INTAKE

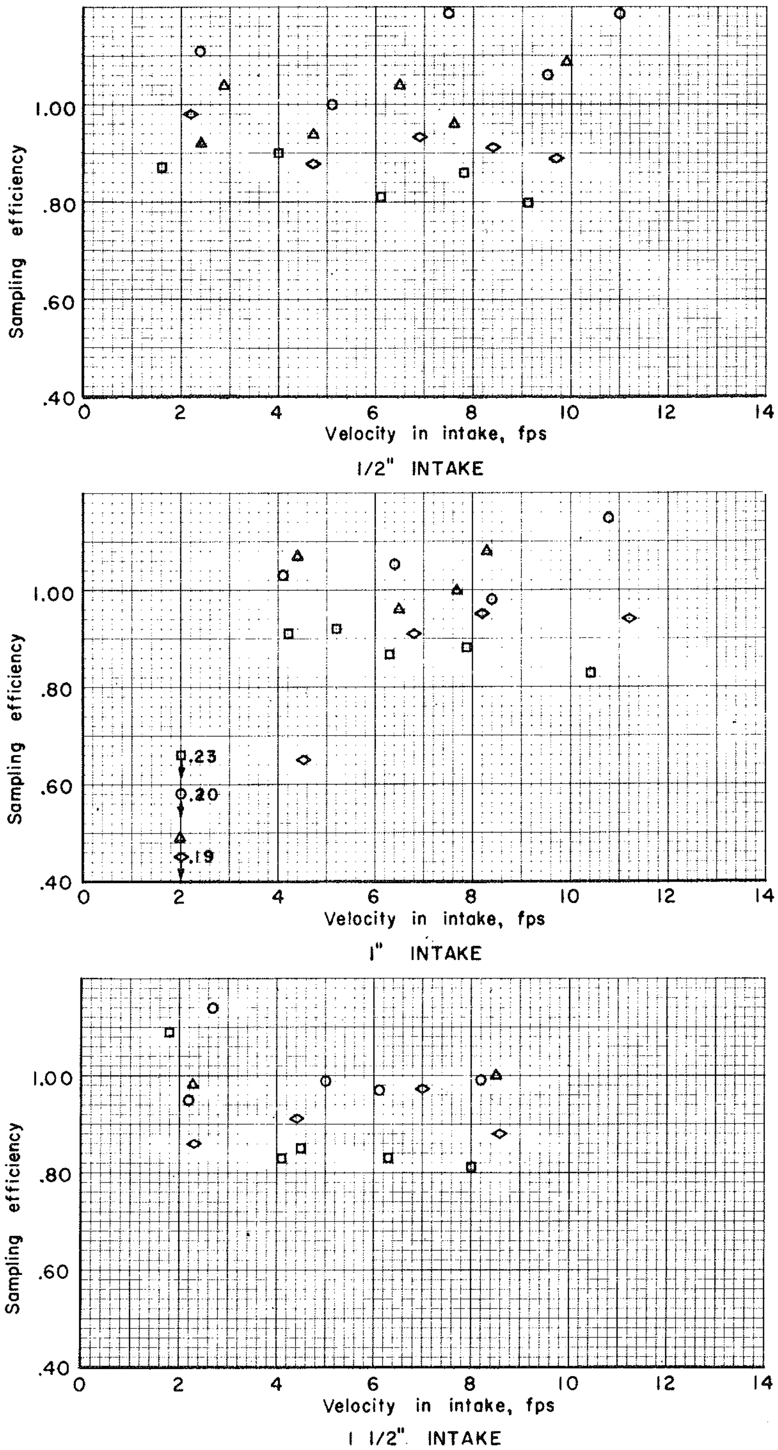
SYMBOL	VELOCITY IN FLUME (fps)	AVERAGE SAMPLING EFFICIENCY *
○	3.6	1.01
△	5.0	0.82
□	6.1	0.71

3/4" S.S. INTAKE

SYMBOL	VELOCITY IN FLUME (fps)	AVERAGE SAMPLING EFFICIENCY *
○	3.6	1.28
△	4.7	0.87
□	6.1	0.77

* For intake velocities greater than 3.0 fps

FIG. 15C--PUMPING-SAMPLER INTAKE EFFICIENCIES, 0.45-MM SAND



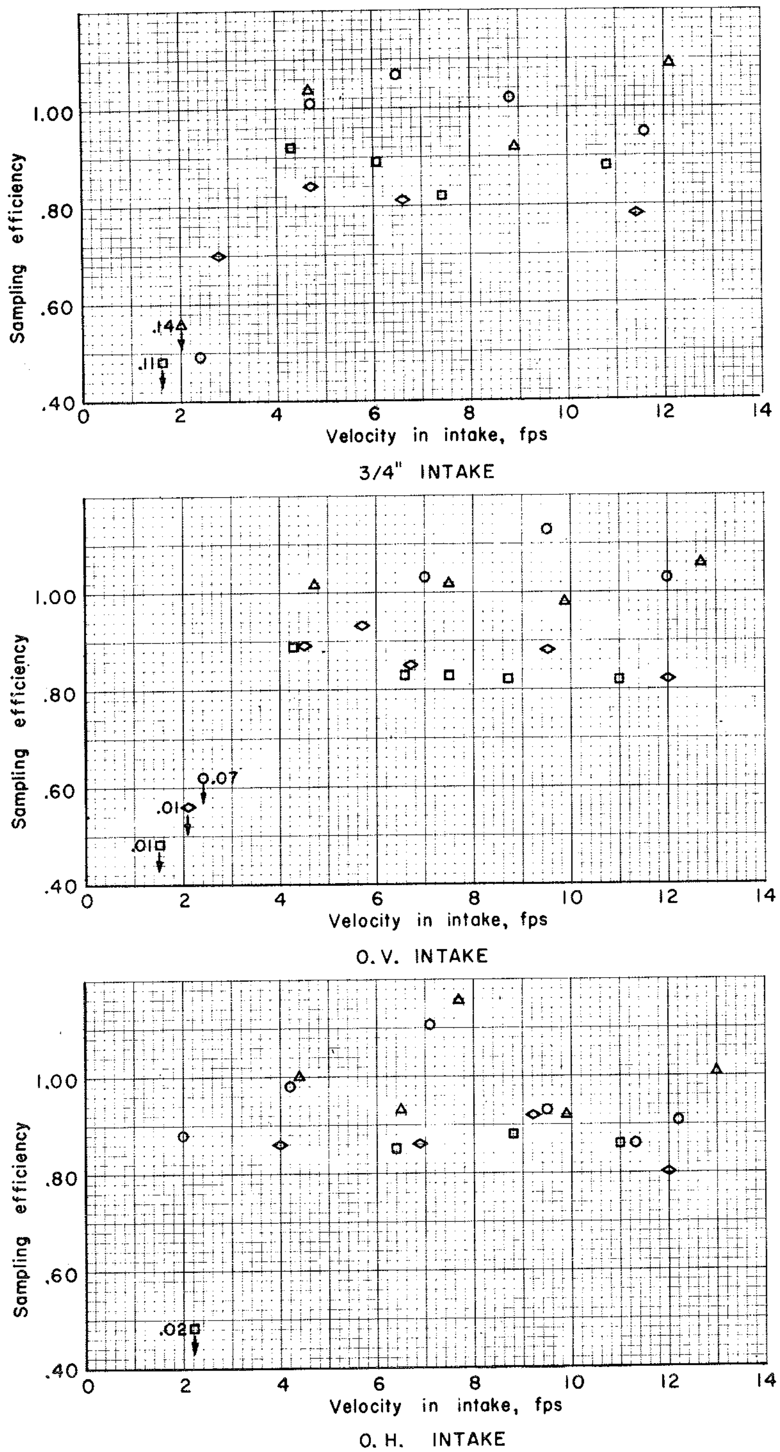
SYMBOL	VELOCITY IN FLUME (fps)	AVERAGE SAMPLING EFFICIENCY*
△	2.5	1.00
○	3.7	1.11
◇	5.2	0.90
□	6.4	0.84

△	2.5	1.03
○	3.7	1.05
◇	5.2	0.86
□	6.6	0.88

△	2.4	1.00
○	3.7	0.98
◇	5.2	0.92
□	6.4	0.83

* For intake velocities greater than 3.0 fps

FIG. 16A--PUMPING-SAMPLER INTAKE EFFICIENCIES, 0.19-MM SAND



3/4" INTAKE

SYMBOL	VELOCITY IN FLUME (fps)	AVERAGE SAMPLING EFFICIENCY*
△	2.5	1.02
○	3.7	1.01
◇	5.0	0.81
□	6.3	0.88

O.V. INTAKE

SYMBOL	VELOCITY IN FLUME (fps)	AVERAGE SAMPLING EFFICIENCY*
△	2.4	1.02
○	3.7	1.06
◇	5.2	0.88
□	6.3	0.84

O.H. INTAKE

SYMBOL	VELOCITY IN FLUME (fps)	AVERAGE SAMPLING EFFICIENCY*
△	2.4	1.00
○	3.7	0.96
◇	5.2	0.86
□	6.3	0.86

* For intake velocities greater than 3.0 fps

FIG. 16B--PUMPING-SAMPLER INTAKE EFFICIENCIES, 0.19-MM SAND

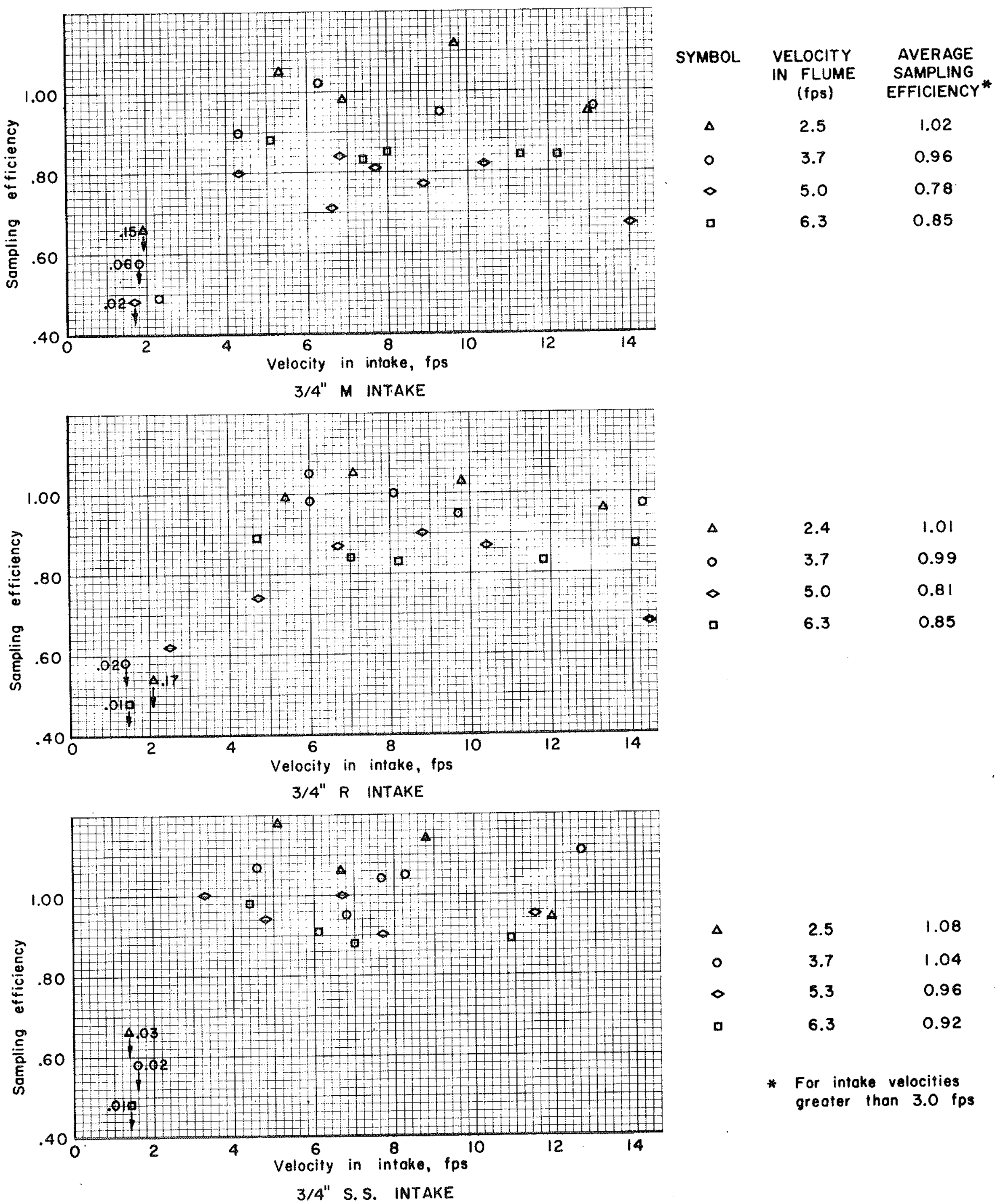
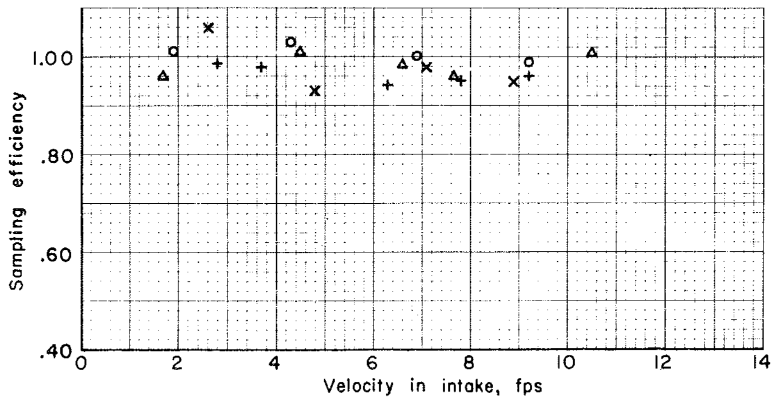
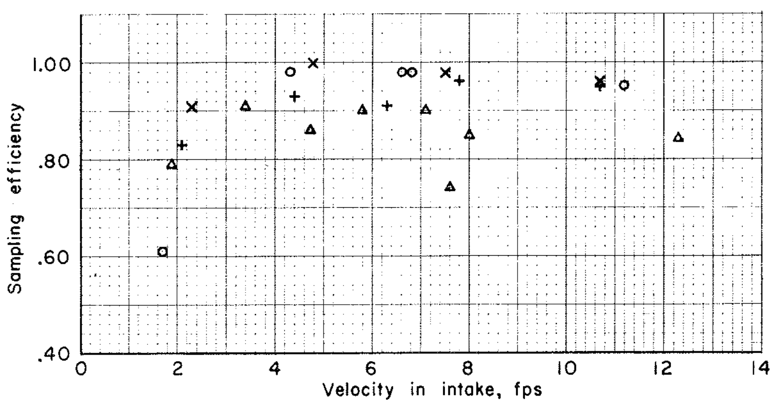


FIG. 16C--PUMPING-SAMPLER INTAKE EFFICIENCIES, 0.19-MM SAND



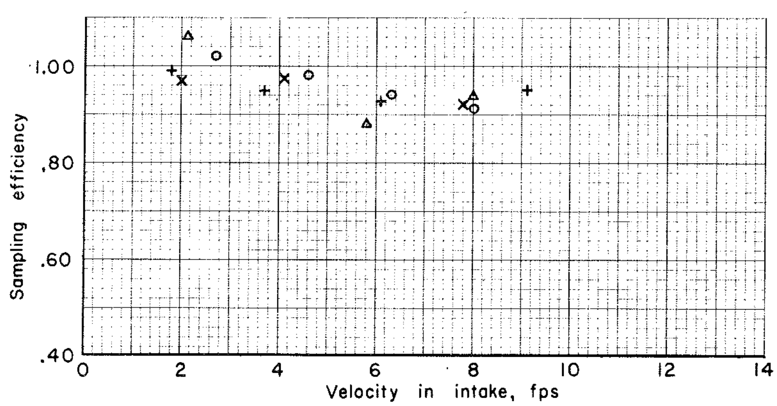
1/2" INTAKE

SYMBOL	VELOCITY IN FLUME (fps)	AVERAGE SAMPLING EFFICIENCY *
△	1.9	0.99
○	3.5	1.01
+	5.2	0.96
×	6.1	0.95



1" INTAKE

△	2.0	0.85
○	3.5	0.97
+	5.2	0.94
×	6.1	0.98

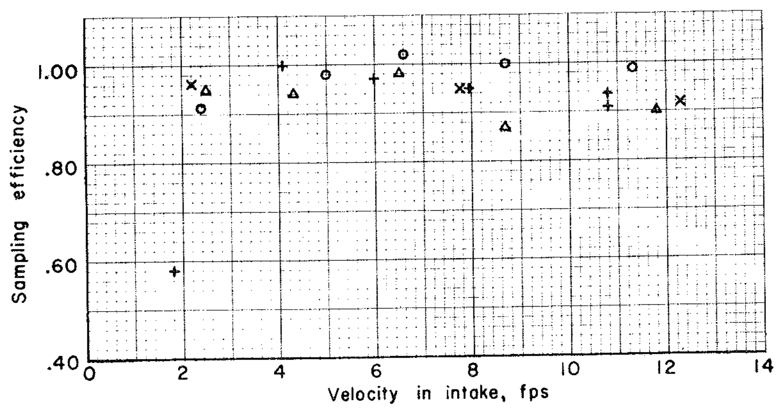


1 1/2" INTAKE

△	1.9	0.91
○	3.6	0.94
+	5.2	0.94
×	6.1	0.95

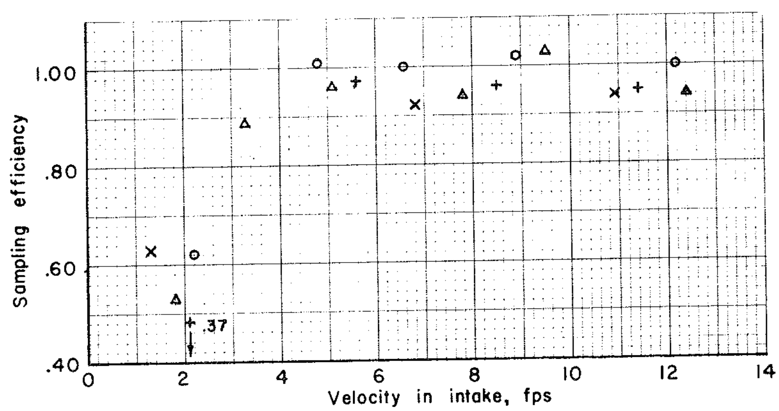
* For intake velocities greater than 3.0 fps

FIG. 17A--PUMPING-SAMPLER INTAKE EFFICIENCIES, 0.10-MM SAND



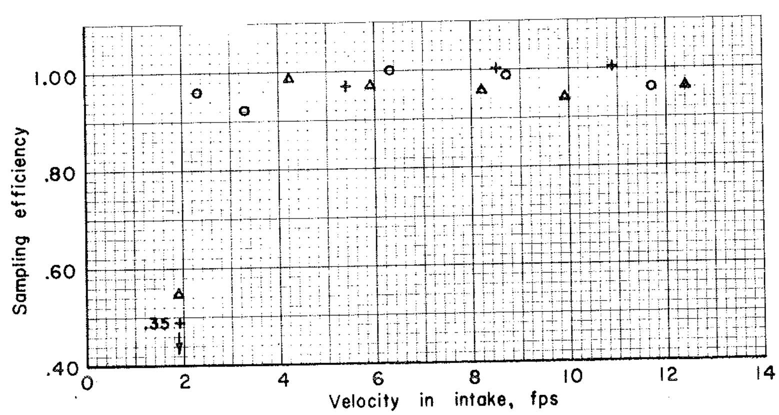
3/4" INTAKE

SYMBOL	VELOCITY IN FLUME (fps)	AVERAGE SAMPLING EFFICIENCY*
△	1.8	0.92
○	3.5	1.00
+	5.2	0.95
×	6.2	0.94



O. V. INTAKE

SYMBOL	VELOCITY IN FLUME (fps)	AVERAGE SAMPLING EFFICIENCY*
△	2.0	0.95
○	3.7	1.01
+	5.3	0.96
×	6.4	0.93



O. H. INTAKE

SYMBOL	VELOCITY IN FLUME (fps)	AVERAGE SAMPLING EFFICIENCY*
△	2.0	0.96
○	3.6	0.97
+	5.3	0.99

* For intake velocities greater than 3.0 fps

FIG. 17B--PUMPING-SAMPLER INTAKE EFFICIENCIES, 0.10-MM SAND

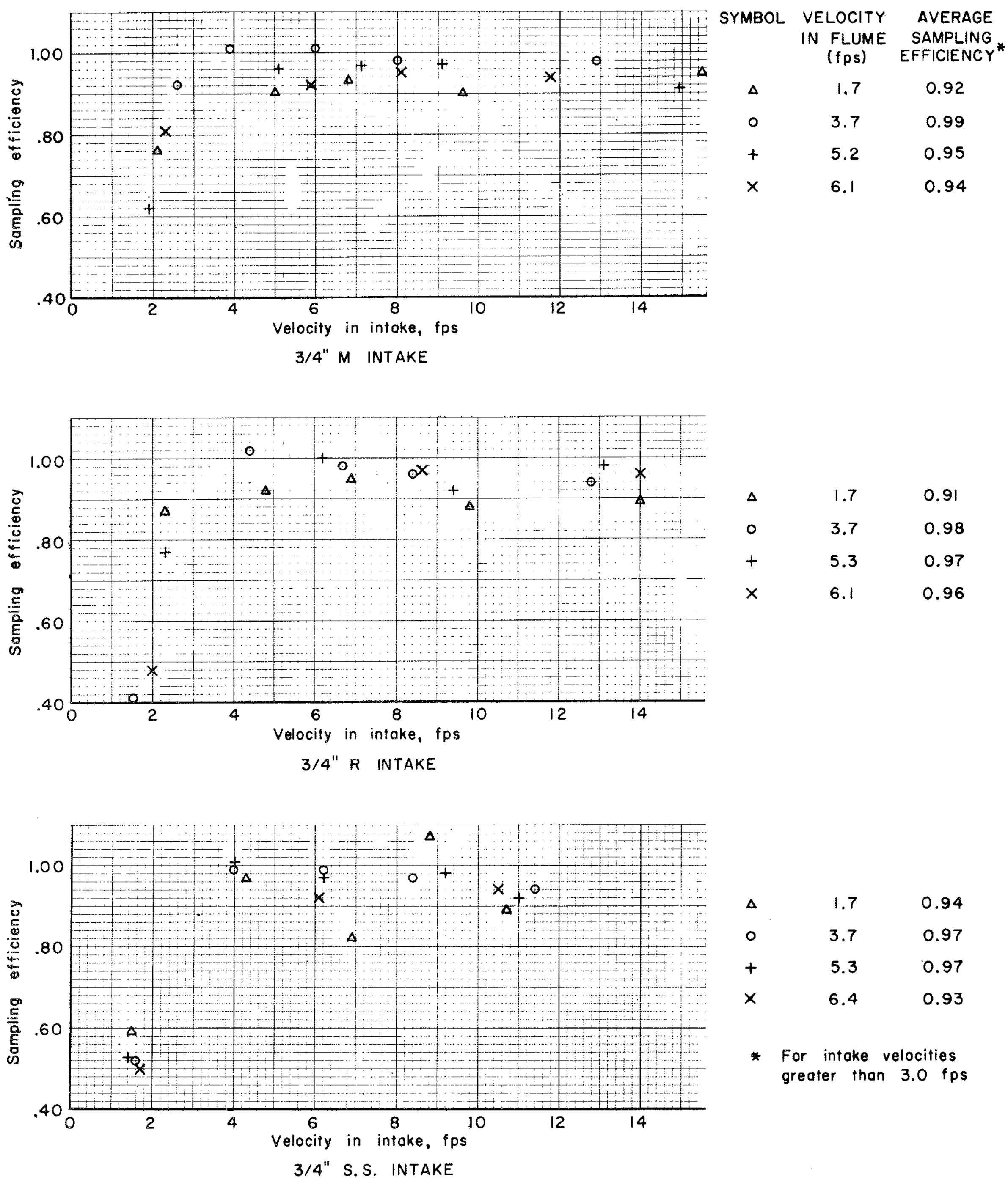


FIG. 17C--PUMPING-SAMPLER INTAKE EFFICIENCIES, 0.10-MM SAND

1. Inter-Agency Committee on Water Resources, A study of methods used in measurement and analysis of sediment loads in streams. Report No. 5; Laboratory investigation of suspended-sediment samplers, 1941.

2. --------- Report 11; The development and calibration of the visual-accumulation tube, 1957.

3. --------- Report Q; Investigation of a pumping sampler with alternate suspended-sediment handling systems, 1962. (Some of this material was in earlier Inter-Agency Report N; Intermittent pumping-type sampler, 1960.)

4. Simons, D. B., Richardson, E. V., and Anderson, J. L.: Flume studies using medium sand. U. S. Geological Survey Water Supply Paper 1498-A, 1961.