INTERDEPARTMENTAL COMMITTEE

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Soil Conservation Service, Geological Survey
and Iowa Institute of Hydraulic Research

Study of Methods Used in

MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

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ERRATA

Page 8, line 39, change "samplers" to "sampler."

Page 9, line 41, after "stream" change comma to period and add "Conversely, if the intake velocity were greater than that of the stream,"

Page 13, line 5, change "$R_L v_m$" to "R_L/v_m "

STUDY OF METHODS USED IN MEASUREMENT

AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

1. Role of Fluvial Sediment Measurements in Engineering. - Rivers are classed among the most important basic natural resources in almost every country on the globe; throughout historical time they have been exploited and developed for water supply, irrigation, water power, and other purposes for public benefit. The average layman regards a river as merely a natural channel carrying a stream of water. The engineer has learned that rivers are not only streams of water, but to a greater or smaller degree they are also streams of sediment. Improvements on sediment-bearing streams have generally been made in the past without due consideration of the effects of sedimentation on the life and utility of the projects. As a result, the efficiency and value of important engineering works have depreciated rapidly and in many instances maintenance costs have been exorbitant. Difficulties in operation and maintenance have developed because of reservoir sedimentation, deposition or degradation in channels, and erosion or gullying in agricultural areas. Not anticipated in the planning stage, these difficulties become evident only after the projects are completed. Because streams which carry sediment in appreciable quantities are being developed more extensively now than in the past, the engineering profession is beginning to realize more and more that fluvial sediment presents a real challenge and warrants serious consideration.

The solution of any fluvial sediment problem must be based on factual information. Data as to the quantity and characteristics of the sediment loads must be available. The water discharge in the principal rivers of the world has been measured systematically for many years and in most instances, adequate data are available to permit satisfactory analyses of the hydrologic and hydraulic characteristics required in connection with the planning and design of river developments. On the other hand, the compilation of corresponding information regarding the quantity and character of sediment discharge has been given merely incidental attention. Only within the past few years has the attempt been made to obtain systematic sediment load records of the same quality as those of water discharge. Furthermore, the techniques and equipment used in sediment sampling have been improvised without due regard to the fundamentals of sediment transportation or the technical requirements for taking representative samples of a water-sediment mixture. In view of the broad demand for reliable information on the sediment characteristics of streams, it becomes increasingly important that instruments, facilities, and methods be developed for obtaining accurate field data.

2. Federal Construction and Engineering Agencies Organized to Study Problems of Sediment Measurement. - Recognizing the desirability of perfecting methods for measuring the quantity and for determining the character of sediment loads in streams, several agencies of the United States Government organized an informal Interdepartmental Committee in 1939 to sponsor an exhaustive study of all problems encountered in collecting

sediment data and to eventually standardize accepted methods and equipment. The agencies of the Federal Government which have actively participated in this investigation are: Corps of Engineers of the War Department; Soil Conservation Service of the Department of Agriculture; Geological Survey, Bureau of Reclamation, and Office of Indian Affairs of the Department of the Interior; and the Tennessee Valley Authority. This study was conducted in cooperation with the Iowa Institute of Hydraulic Research at the State University of Iowa.

The scope of the general project, "A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams", is indicated by the following titles of reports which have been published under the direction of the Interdepartmental Committee:

Report No. 1 - Field Practice and Equipment used in Sampling Suspended Sediment.

Report No. 2 - Equipment Used for Sampling Bed-load and Bed Material.

Report No. 3 - Analytical Study of Methods of Sampling Suspended Sediment.

Report No. 4 - Methods of Analyzing Sediment Samples.

Report No. 5 - Laboratory Investigations of Suspended Sediment Samplers.

Report No. 6 - The Design of Improved Types of Suspended Sediment Samplers.

Report No. 7 - A Study of New Methods for Size Analysis of Suspended Sediment Samples.

Report No. 8 - Measurement of the Sediment Discharge of Streams.

Report No. 9 - Density of Sediments Deposited in Reservoirs.

Based on this series of reports, and on progress reports submitted to the Interdepartmental Committee periodically during the course of the investigation, the present paper is essentially a compilation of the more significant facts and information pertaining to sediment sampling which are considered to be pertinent to the interests of the American Society of Civil Engineers Joint Committee on Sedimentation in Reservoirs.

3. History of Sediment Sampling. - Records of past civilizations in China, Mesapotamia, and Egypt indicate that man has always experienced difficulties and hazards due to sediment carried by natural streams. However, the manner in which fluvial sediment is transported and deposited, the knowledge of which would aid in avoiding or overcoming many of the consequences, has been investigated only in comparatively recent years.

The first sediment measurements of record were made by Grosse and Subuors (1) in the Rhone River in 1808 and 1809. Other early observations were made by Blohm (2, 3) in the Elbe River at Hamburg, Germany, from 1837 to 1854 and by Baumgarten (3, 4) in the Garone River, France, from 1839 to 1846.

The earliest measurements of sediment loads in the United States were made in the Mississippi River by Captain Talcott (1) in 1838. Forshey (1, 3, 5) made extensive observations in the lower Mississippi in connection with the studies of Humphreys and Abbott in 1851 and 1852. Sediment samples were taken also near the mouth of the Mississippi from (5, 6, 7) 1877 to 1898 and at several stations along the Mississippi and Missouri Rivers (3, 4) from 1879 to 1881. The development of irrigation along the rivers of the southwestern part of this country met with considerable difficulty due to heavy loads of sediment carried by these streams. In order to find a solution to this problem, sediment measurements were started in many of these rivers near the close of the 19th century. Samples were first taken in the Rio Grande (8) in 1889 and 1890. Observations have been made regularly in the Rio Grande since 1897, in the lower Colorado River since 1909 and in the upper Colorado River Basin since 1925. A detailed investigation of sediment loads in the Missouri River (9) and its tributaries was conducted in 1929 and 1930. Extensive sediment surveys have been made on many other streams of this country since about 1930. Since the turn of the century, interest in sediment information and the practice of making observations of sediment loads has been growing steadily in this country and simultaneously in nearly all other countries of the world.

4. Theory of Sediment Suspension. - Recent studies of fluid turbulence made in connection with other phases of hydraulics have been used by Lane and Kalinske (10, 11) to explain the sediment suspension phenomenon. The analytical basis for the turbulence concept of the transportation of suspended sediment has been presented in engineering literature. For the purpose of this paper it will suffice to present only a rational analysis of this concept. The turbulence concept of sediment suspension is now generally accepted, and it is believed that an understanding of it will provide an effective aid in planning and carrying out a sediment measurement program.

In turbulent flow the direction of the current at a given point changes rapidly and haphazardly. Although the flow at the point has a general forward motion, in a short space of time small areas of flow, or eddies, fluctuate in horizontal and vertical directions. These fluctuations are irregular and spontaneous, and do not follow any definite sequence. The magnitude of the current also changes, fluctuating about a mean value in a manner similar to the variation in the direction of flow.

Sediment particles are raised from the stream bed by the shear or tractive force of the stream exerted on the boundaries of the channel and are moved upward by momentary upward eddy currents. The upward movement is counteracted by the force of gravity, which tends to settle the particles, and by the momentary downward eddy currents. When particles

are caught in a current moving upward at a rate greater than their settling velocity, they will be transported upward. On the other hand, the particles will move downward if they are surrounded by water moving downward or by water moving upward at a rate less than their settling velocity. Normally the sediment concentration in a stream increases toward the bottom. Consequently, upward currents travel from a region of higher concentration to one of lower concentration, and thus have a greater potential of sediment transport than downward currents. Moreover, since the amounts of water moving upward and downward must be equal to maintain a given water surface elevation, more sediment will be transported by upward currents than by downward currents. The sediment load distribution in a stream vertical is said to have reached equilibrium when the downward rate of sediment movement through any horizontal plane, due to force of gravity and downward components of eddy currents, is equal to the upward rate, due to the upward eddy components.

The settling velocity of sediment particles is a function of their apparent specific gravities. Consequently, coarse particles will settle faster than fine particles; and, in order to maintain a stable concentration distribution, the excess of sediment transported upward over that carried downward must be greater for coarse than for fine particles. This condition obtains in a natural stream because the vertical distribution of sediment varies with particle size, the concentration increasing more rapidly toward the bottom for coarse than for fine sediments. For particles with low settling rates equilibrium will be attained with a very small differential concentration with respect to depth and therefore, the finer the particles the more gradual becomes the concentration gradient, and conversely, the coarser the particles the steeper becomes the concentration gradient.

The settling rates of solid particles increase with size but not in uniform ratio. The settling rates for particles smaller than 1/16 mm. in size vary approximately as the squares of the diameters, whereas for extremely large particles the settling rates vary approximately as the square roots of the diameters. The 1/16 mm. size is usually considered to represent the approximate division point between sediments which are classed as silts and those classed as sands. Because of their high settling velocity, sand particles and those considerably over 1/16 mm., are more concentrated near the bed than near the surface, the concentration gradient increasing with the size. Clay and silt particles are in general uniformly distributed in a stream. The distribution of sediment in a stream vertical is an important factor to be considered in carrying out a sampling program, especially in the selection of sampling points and in the analysis of the data.

Sediments transported as bed-load or saltation load merge with the suspended load near the bottom of the stream. However, since this paper is concerned only with sampling of suspended sediment no further consideration will be given to the theory concerning other types of movement.

5. Methods of Making Sediment Measurements. - The sediment samples

of scattered investigations recorded during the first half of the 19th century were taken at the surface of the stream at only one vertical in a cross-section. Forshey, sampling in the Mississippi River at Carrollton in 1851, took samples at the surface, mid-depth and bottom of three verticals - one near each bank and one at mid-stream. Since that time, as the value of sediment data has become more apparent and the phenomenon of sediment transportation has become more clearly understood, observers have gradually expanded the network of samples taken in a stream cross-section. Where thorough examination of the sediment distribution is to be made, ten or more verticals may be sampled and upwards of ten samples may be taken from each vertical. In the majority of sampling programs carried out in major streams since about 1908, three verticals have generally been used and about three samples have been taken in each vertical. The verticals have been variously spaced as at the quarter points, the centroids of equal area, or at the centroids of equal discharge. The latter method has a rational basis and is coming into more and more prominent use. At sampling stations where the sediment distribution has been correlated and is periodically checked by a complete network of samples, it is frequently the practice to take single samples in routine observations. These samples are taken at the surface, at 0.6 depth, or from a vertical integration. Correction factors based on complete cross-section sediment surveys are usually applied to the single determination of sediment concentration.

If the sediment carried in suspension were uniformly distributed throughout a stream cross-section, the determination of the total sediment load would be a comparatively simple procedure. A single sample taken at any point would then indicate the sediment concentration or the weight of sediment per unit volume of water and the sediment discharge would be the product of the sediment concentration and the water discharge. But the concentration of fluvial sediment varies more or less throughout any cross-section of a stream and to obtain an accurate measurement of the sediment discharge these variations must be taken into account.

The distribution of sediment in a stream cross-section is generally found to vary more vertically than laterally. Consequently, greater importance should be placed upon the spacing of sampling points in the vertical to provide an accurate measurement of the sediment load. Not only must the concentration of sediment at various points in the cross-section be determined but the velocity of the water at each point must also be measured, since the rate of sediment transportation is directly proportional to the water velocity.

The sediment concentration is determined from samples of the water-sediment mixture taken from the stream by means of a suspended sediment sampler while the corresponding water velocity is determined by means of a current meter. The product of these quantities gives a value for the sediment discharge at the point or vertical in the stream where the observations are made. Each individual determination is considered representative of the sediment discharge in a segment of the stream cross-section, the size of which depends upon the uniformity of sediment concentration and velocity. The total sediment discharge of the cross-section

is obtained from a summation of the individual determinations weighted according to the area each represents. When depth-integrated samples are taken at sampling verticals representing areas of equal water discharge, the sediment discharge is the product of the average weighted sediment concentration and the water discharge, the latter being obtained from a rating curve or current meter measurement.

A suspended sediment sampler is not designed to measure the saltation load, or the bed-load which rolls or slides along the stream bed. The latter types of sediment do not travel with the same velocity as the water, and therefore cannot be estimated correctly from the amount which is trapped in a unit volume of water. Moreover, it is very difficult to measure the velocity of the water near the bottom where saltation or bed-load movements take place. An approximate determination of the rate of sediment movement by rolling and sliding can be made by trapping this sediment in a bed-load sampler at typical points across the width of the stream. However, the quantitative accuracy of such measurements is subject to question owing to uncertainties as to the effects of disturbances caused by the sampler resting on the stream bed, the position and shape of sand dunes, if any are present, and the calibration of the sampler.

Many suspended sediment samplers will trap some of the saltation load if placed so near the bottom that the intake is in the region of saltation load movement, and if the screens used in the construction of the bed-load samplers are extremely fine, they may trap some of the suspended load. The errors which result from such overlapping of the sampling zones are usually regarded as being so small that they may be neglected. An accurate determination of the sediment carried by a stream would require measurement of both suspended load and bed-load. Usually, however, the nature of the problem under consideration is such that the suspended load plays a more prominent role than does the bed-load. It is possible sometimes to construct a drop over which both bed and suspended loads pass, and where both can be sampled at the same time by passing a suitable sampler through the overfalling nappe.

The purpose for which a sediment sampling program is undertaken will dictate, to a large extent, how, where, and when the samples should be taken. The schedule of sampling obviously will be affected by several factors, such as the cost of the various phases of the program, the funds available, and the characteristics of the stream and its sediment load. Sediment investigations ordinarily are conducted to establish long-term records of sediment loads and to provide basic data for analysis and design of engineering projects in which sediment is a factor to be considered. Sometimes they are carried out purely in the interest of academic research or to provide scientific information for use in connection with problems arising in streams other than the one being studied. In general, a long-term sediment measurement program will require less frequent sampling than a more intensive research project, particularly after the stream has been under observation for a sufficient length of time to determine the characteristics of its sediment load and water discharge.

In any type of sampling program the variability and characteristics of the sediment load and of the water discharge are the most important factors to consider in planning a sampling schedule. Both of these variables are affected by the climatic, hydrologic, and topographic features of the stream and its watershed. The quantity, distribution and intensity of precipitation; the ranges in temperature; the size, shape, topography and geology of the drainage basin; the soil and vegetal cover are factors which influence the quantity and rate of sediment production. Other things being equal, the quantity of sediment produced varies with the size of drainage area, and obviously, the heavier and more intense the precipitation the greater will be the quantity of sediment removed from the watershed. A friable soil, unprotected by vegetal cover, will yield higher sediment runoff than a more stable soil. These and other factors must be taken into consideration in preparing a sampling schedule for any particular location.

The majority of streams pass more than 50 percent of the total annual flow during flood periods at which time the sediment concentration also is greater than during periods of nearly normal stage. Both the water discharge and sediment concentration vary more rapidly on a rising than on a falling stage. Therefore, it is important that sediment samples be taken more often during flood periods than at other times and more frequently on the rising side of a flood hydrograph than after the crest has passed.

For the purpose of deriving an accurate sediment hydrograph for a stream, the frequency of sampling might be scheduled on a rational basis similar to that used in locating sampling points to represent areas of equal discharge in a stream cross-section. The samples could be so spaced with respect to time that they would represent either equal quantities of sediment or water discharge. In fact approximations of such a method are used by various agencies. For instance, routine samples may be taken every day during periods of normal flow, and, according to a predetermined schedule, more often during flood periods, fewer samples being required on the falling than on rising stages. It would be undesirable, however, to make the sampling schedule so complicated or confusing as to tax the patience and cooperativeness of the observer.

Various sampling schedules that have been used in actual field practice are described in detail in Reports No. 1 and 8 of the sediment series.

6. Suspended Sediment Samplers. - In the earliest attempts to measure sediment loads in streams the very simplest types of samplers were used. An open container or a pail was used by Riddell in sampling the Mississippi River at New Orleans in 1843 to 1848. Similarly crude and unscientific equipment was used until about 1900. Since that time a great deal of thought and ingenuity have been exercised in the development of sediment sampling equipment. Various individuals engaged in sediment work have devised samplers which operate in accordance with their respective interpretations of the sediment transportation phenomenon. A great many different instruments and apparatus have been intro-

duced. The sampling action and the techniques adopted for operating the samplers differ widely. As a result, the data obtained with one sampler are not necessarily comparable to those of another, and in the light of the studies made by the Interdepartmental Committee, many samplers which have been used extensively in the past are now known to be decidedly unsatisfactory.

The various samplers that have been investigated in this study can be classified as to their mode of operation into two general types: instantaneous and time-integrating. Many samplers do not actually qualify for either of these classifications because their design, sampling action, or method of operation eliminate them from the categories of true instantaneous or integrating samplers. As the name implies, the instantaneous sampler is designed to trap a specimen of the water-sediment mixture passing the selected sampling point at a desired instant. The time-integrating sampler, on the other hand, takes the sampler more slowly over an extended period of time so as to obtain a specimen in which the momentary fluctuations in sediment load are averaged. The majority of samplers in use at the present time are designed to operate on the principle of time-integration. While this principle is basically sound and conducive to accurate sampling, the samplers are often constructed or operated in such a way as to preclude time-integration dominating the sampling procedure.

Time-integrating samplers may be sub-divided again into two types: point-integrating and depth-integrating. The point-integrating sampler is held stationary at a point in the sampling vertical while the sample is taken. The depth-integrating sampler is lowered to the bottom of the stream and raised again to the surface at a uniform rate, sampling continuously during both periods of transit, or it may be designed to sample only from the surface to the stream bed. The depth-integrating sampler is designed to take a mean sample in the vertical giving uniform weight to the increments of water-sediment mixture taken at the various levels.

The requirements of an ideal sediment sampler are summarized briefly as follows:

1. The velocity within the cutting circle of the intake should be equal to the stream velocity.

2. The intake should be pointed into the approaching flow and protrude upstream from the zone of disturbance caused by the presence of the samplers.

3. The sampler should fill smoothly without sudden inrush or gulping.

4. The sample container should be removable and suitable for transportation to the laboratory without loss or spoilage of the contents.

5. The sampler should permit sampling close to the stream bed.

6. The sampler should be streamlined and of sufficient weight to avoid excessive drag.

7. The sampler should be rugged and simply constructed to minimize the need for repairs in the field.

8. The cost of the sampler should be as low as possible consistent with good design and performance.

The Interdepartmental Committee in the early phases of the project authorized an exhaustive laboratory and analytical study of existing integrating samplers to locate faulty design and operation procedures which would contribute to inaccuracies in the collection of sediment samples. Basically, the principle of integration sampling requires that a continuous filament of the water and sediment be taken from the flowing stream in the same relative proportions as exist in the immediately surrounding filaments of flow. The sample must be taken from the stream without modifying the velocity and with the minimum disturbance to the adjacent flow lines. In order to avoid any disturbing effects due to the presence of the sampler itself, the instrument should be streamlined as much as practicable, and the point of entry of the sample should be in the form of a nozzle projecting upstream beyond the zone where there is any appreciable disturbance in the flow pattern. With these criteria in view, a laboratory apparatus was constructed so that the essential features of the samplers could be tested under conditions simulating as nearly as possible those encountered in the field to determine the effects of deviations from ideal sampling conditions on the accuracy of the sediment data. The apparatus consisted essentially of a loop conduit in which could be circulated a column of water at constant velocity, sediment concentration and temperature. The test section of the 10-inch square conduit, with transparent sides and top for observation, is shown in Fig. 1.

It was recognized that the velocity at which the sample is withdrawn from the stream relative to that of the stream itself at the sampling point should be unity and that deviations from this relationship would result in erroneous sampling. The magnitude of error due to incorrect sampling rates in suspensions of varying concentrations of 0.45 mm. sediment is shown in Fig. 2. Should the sample be withdrawn at a slower velocity than that of the stream, the flow lines in the filament being sampled would diverge while the sediment particles in the filament, being of higher specific gravity than the water, would tend to follow paths which diverge less than the flow lines. Consequently, the sample would contain a greater concentration of sediment than the stream, the approaching flow lines would converge while the sediment particles would converge to a lesser degree and the sample would contain a lower concentration than the stream. Figs. 3 and 4 show a decreasing effect of incorrect sampling rates with decreasing sediment size, the error becoming insignificant for very fine sediment. The magnitude of the stream velocity does not materially alter the results indicated by incorrect sampling rates as shown in Fig. 5.

The effect of rotating the axis of the intake nozzle slightly with respect to the approaching flow lines is illustrated by Fig. 6. An angular deviation of 20 degrees has an inappreciable effect on the sampling accuracy, whereas a 30-degree approach velocity results in about 7 percent error in the sediment concentration at a relative sampling rate of unity. It is apparent from these tests that the sampler should be sufficiently sensitive to current direction to orient its intake within 20 degrees of the direction of the flow.

The standard nozzle used in the laboratory tests had a cutting diameter of 0.25 in. Nozzles of 0.15 and 0.375-in. diameters were also tested. The size of the nozzle appeared to have no effect on the sediment concentration obtained as long as a unity sampling rate was used, as shown in Fig. 7.

One of the more serious faults of existing samplers is the lack of streamlining. Parts of the samplers obstruct the intakes and disturb the flow filaments being sampled. In many instances the intakes are normal to the direction of flow. The flow lines must bend 90 degrees to enter the intake and sediment particles will tend to be separated from the sample filament. The laboratory tests indicated an error of about 16 percent in sampling 0.15 and 0.45-mm. sediment with the intake normal to the current, the error decreasing to about 2 percent for 0.06-mm. sediment.

A sampler which is designed to open below the water surface of a stream is subject to so-called "initial inrush" when the intake is opened unless provision has been made to equalize the air pressure inside and the water pressure outside the sample container. None of the integrating samplers in use by the cooperating agencies at the beginning of this study were designed to eliminate this objectionable feature. The effect of initial inrush on the rate of sampling is shown by the graph in Fig. 8. For instance, when the Frasier sampler was opened at a depth of 34 ft. in still water, half the volume of the container was filled in one second or less. The sampling rate during this period was about 225 c.c. per sec., while the remainder of the sample was taken at a rate of about 23 c.c. per sec. or less. Obviously, the first half of the sample which is taken during the period of initial inrush will not be integrated and, consequently, will not be representative of the sediment suspension existing at the sampling point due to segregation of sediment particles from the sampled filament. Furthermore, momentary fluctuations in sediment concentration and velocity will not be correctly integrated during the initial inrush period. As shown by the illustration, the degree of error is a function of the submergence.

Initial inrush in point-integrating samplers can be avoided by providing some means of balancing the air pressure in the container and the hydrostatic pressure at the sampling point. A simple method of automatically obtaining this balance will be described in a later section of this paper dealing with the development of improved samplers.

Simple depth-integrating samplers are subject to effects similar to initial inrush if lowered into a stream too rapidly. The

air in the sample container is instantaneously compressed by the inflowing liquid so that its pressure balances the external hydrostatic head. The rate of air contraction due to increasing hydrostatic pressure must never exceed the normal rate of liquid inflow. Hence, the maximum speed of lowering the sampler obtains when these two factors are equal.

At any instant during the operation of a depth-integrating sampler, the air volume in the container is a function of the hydrostatic head and the prior rate of filling. If the air volume reduction necessary to balance a given change in hydrostatic head at any instant is greater than normal inflow, the actual inflow will occur at a rate higher than the local stream velocity and some inflow may occur through the air exhaust. Samples collected under these conditions will not be weighted according to the vertical velocity curve. On the other hand, if the normal inflow exceeds the air volume reduction necessary to balance a given change in hydrostatic head, air will escape from the sample container so as to permit the actual inflow to occur at a rate equal to the stream velocity and the sample will be correctly weighted according to the vertical velocity curve.

In determining the limits of the permissible sampler transit rates, it will be assumed that no air escapes from the container and that the reduction in air volume due to the changing hydrostatic head is just balanced by the inflowing water. From Boyle's law it follows that, with constant temperatures,

$$hV = h_1V_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The symbols used in the above and subsequent equations in this paper have the following definitions:

A_n, area of intake nozzle at entrance, sq. ft.

D, depth at any point, ft.

D_s, depth of stream or sampling depth, ft.

d, ratio of depth at any point to the total depth $= D/D_s$

h, absolute pressure head at any depth $= h_1 + D$, ft.

h_1, absolute pressure head at water surface = 34 ft. of water at sea level

r, ratio of the velocity at any point in the vertical to the average velocity $= v/v_m$

R_L, lowering rate, ft./sec.

t, time from start of sampling, sec.

V, volume of air in container at any depth $= V_1$ at water surface, cu. ft.

V_1, volume of container, cu. ft.

v, stream velocity at any point in the vertical, ft./sec.

v_m, mean stream velocity in sampling vertical, ft./sec.

The rate of change in air volume in the container at any depth is obtained by rewriting equation (1) and differentiating with respect to time.

$$\frac{dV}{dt} = \frac{h_1 V_1}{-(h_1+D)^2} \frac{dD}{dt} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (2)$$

The rate of change in air volume at any depth may be expressed also in terms of the area of the intake nozzle and rate of inflow.

$$\frac{dV}{dt} = -A_n v \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (3)$$

In this analysis it is assumed that a typical velocity distribution exists in the sampling vertical. The lowering rate, R_L, which at any depth will permit the inflow to compensate for the air volume reduction due to increasing hydrostatic pressure, is obtained by equating (2) and (3) and solving for dD/dt.

$$\frac{dD}{dt} = \frac{A_n v (h_1+D)^2}{h_1 V_1} = R_L \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad (4)$$

It will be noted that the lowering rate indicated by equation (4) varies with the depth and velocity. Rearranging and substituting for v and D,

$$\frac{R_L}{v_m} = \frac{A_n r (h_1+D_s d)^2}{h_1 V_1} \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad (5)$$

Values of R_L/v_m from equation (5) for a sampler with a 3/16 in. diameter intake nozzle and a one-pint sample container for various stream depths are shown in Fig. 9.

As the lowering rate must be uniform in order to obtain a true depth-integrated sample, the maximum permissible uniform lowering rate is the lowest rate shown in Fig. 9 for any depth. That is, for depths over 19 ft. the maximum permissible uniform lowering rate is that shown for the surface of the stream. For depths less than 19 ft. the maximum rate, which is that indicated for the bottom of the vertical, varies with the depth. The maximum permissible uniform lowering rates with respect to the mean stream velocity to be used with intake nozzles of 1/8, 3/16, and 1/4 in. diameter in streams of various depths, are shown in Fig. 10. If a uniform lowering rate equal to or less than the maximum indicated by Fig. 10 is selected for given sampling conditions, air will escape from the container while the sampler is in transit, the pressure in the container will always be equal to the hydrostatic pressure surrounding the sampler, and a true depth-integrated sample will be taken.

The minimum lowering rate which will allow the sample container to become full just at the instant the sampler reaches the bottom is given by the equation

$$R_L = \frac{A_n v_m D_s}{V_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

The minimum values of the relative lowering rate, $R_L v_m$, given by this equation for one-way depth-integrating samplers of one-pint capacity with intake nozzles of 1/8, 3/16, and 1/4 in. diameter are also shown in Fig. 10. In computing these values it was assumed that the stream would be sampled throughout the entire depth. If lower transit rates than the indicated minimum are used, the sample container will be filled before the integration is completed, circulation will take place and, consequently, the sample will indicate greater concentration than exists in the stream. When a simple depth-integrating sampler is used, sampling on both the descending and ascending trips, the minimum transit rates must be twice those indicated in Fig. 10.

The maximum uniform lowering rate which can be used in streams over 19 ft. deep is the rate for the surface of the stream given by equation (5). By substituting this rate in equation (6) a maximum sampling depth of 39 ft. is obtained. That is, by closing the intake and air exhaust when the sampler makes contact with the stream bed, a depth of 39 ft. can be sampled when a typical velocity distribution exists. When the velocity distribution is uniform in the vertical section, $\bar{r}$ is unity at any point and the maximum sampling depth is 34 ft. If the sample is taken during both the descending and ascending trips, the maximum depths that can be sampled would be one-half of the above values for the respective velocity distributions.

When a sample is taken during both the descending and ascending trips of the sampler, the maximum lowering rate should not exceed that indicated in the above analysis. However, since the hydrostatic head decreases on the upward trip, an ascending rate greater than the lowering rate may be used provided the angle of relative velocity is not excessive. If different descending and ascending rates are used, they must be constant throughout their respective trips in order to obtain a properly weighted sample.

The times necessary to fill a one-pint container at various intake velocities with nozzles 1/8, 3/16, and 1/4 in. diameter are shown in Fig. 12.

Under some conditions, it might be impractical to use the maximum permissible transit rates indicated by the preceeding analysis. The ordinary stream gaging reels of 1- and 2-ft. circumferences will not permit transit rates greater than about 2 and 3.5 ft. per sec., respectively. Consequently, these may be the limiting speeds with which the sampler can be raised or lowered. In the laboratory study it was found that considerable error in sampling resulted if the axis of the intake nozzle was oriented 30° or more from the line of approaching flow. A similar effect is produced

in depth-integration sampling due to the angular approach of the stream flow lines with respect to the moving intake nozzle. To minimize the error due to this source - which is a function of the velocity of the water, the transit rate of the sampler, and the size of the sediment particles in suspension - the angle of relative velocity should be restricted to a maximum of 20°.

7. Development of US Integrating Suspended Sediment Samplers. - The comprehensive survey of the sediment sampling equipment used during past years presented in Report No. 1 of the sediment series, discloses that some sixty-five samplers, embodying a number of different designs, have been developed since the first sediment samples were taken from the Rhone River over 138 years ago. Thirty of these samplers were of the instantaneous type, twenty of the point-integrating type, and eight of the depth-integrating type, with several designed to obtain both point and depth-integrated samples. The survey indicated that all of the samplers in current use violate one or more of the basic principles of accurate sediment sampling.

In considering a new design, it appeared that a sampler of the point-integrating type would cover the greatest range of field conditions in the routine determination of the sediment discharge of streams. However, the initial cost of this type of sampler was estimated to be considerably greater than the simpler depth-integrating sampler. Therefore, it was decided that experimental models of both types of samplers should be developed with a view to providing practical and efficient equipment for as wide a range of field conditions as possible.

In the course of developing a new depth-integrating sediment sampler, five experimental samplers were constructed. Successive samplers were designed to correct undesirable features which field or laboratory tests had indicated in the previous models. The final sampler, designated the US Sediment Sampler D-43, has a cast bronze streamlined body with integral horizontal and vertical tailvanes. The forward section of the sampler is hinged to provide access to the sample container recess, and it is adapted to receive 1/8-in. to 1/4-in. diameter nozzles which can be interchanged if damaged or if a different size is required. A spring latch on the under side of the sampler holds the head securely in the closed position and permits it to be opened readily. The sampler is suspended from a standard current meter hanger bar.

The experimental depth-integrating samplers were tested in a glass-walled laboratory flume to observe their poise and orientation with respect to the flow lines, and to determine the relationship between the velocity in the flume and the filling rate. In determining the filling rates the samplers were suspended about 0.5 ft. below the water surface by means of a stream gaging cable and reel, and the sampling interval was taken as the period that the nozzle was submerged. The intake characteristics determined in this manner are representative of flow conditions when the sampler is suspended at a fixed point.

In field use, the depth-integrating sampler is lowered and raised at a uniform rate; consequently, the sampled filament will enter the intake

nozzle at an angle. This flow condition can be simulated by holding the sampler in a fixed position at an angle to the current. Preliminary laboratory tests made with the sampler oriented with respect to the flow showed some variation in the relative sampling rate depending on whether the nozzle was tilted up or down. The tests were not conclusive, but they indicated that the relative sampling rate determined from tests made with the sampler in a fixed horizontal position should exceed unity slightly in order to obtain an approximate average rate of unity when collecting a depth-integrated sample.

A few field tests were made with the experimental samplers in streams near the hydraulics laboratory to determine the practicality of the samplers as field instruments and their general limits of use in streams of medium depths and velocities. The intake characteristics determined in laboratory and field tests on the fifth experimental depth-integrating sampler are shown in Figs. 13 and 14. Photographs of the 38- and 50-lb. US D-43 samplers are shown in Figs. 15 and 16.

The point-integrating suspended sediment sampler developed in this project embodies all the features of the depth-integrating sampler, but in addition, it is designed to accumulate a water-sediment sample which is representative of the mean sediment concentration at any selected point in a stream vertical during a short interval of time. The sampler is constructed so that the air pressure in the container and the external hydrostatic head are equalized at all depths, thus avoiding any initial inrush when the intake nozzle and air exhaust are opened. This has been accomplished by utilizing the diving-bell principle.

The body of the US point-integrating sampler consists essentially of a streamlined cast bronze shell, an inner recess to hold the sample container, and an air chamber having a volume about five times that of the sample container. The air chamber and the sample container are interconnected by means of tubing and a passage through a spring actuated valve. When the intake and air exhaust, which are also controlled by this valve, are closed prior to lowering the sampler into a stream, the pressure equalizing passage is open. The air chamber has a permanent opening at the bottom of the sampler through which water can enter, thereby compressing the air in the sample container as the sampler is submerged.

Three experimental point-integrating samplers were constructed during the course of the investigation. The results of the calibration tests of the second sampler indicated that the intake characteristics approached the ideal, as shown by the data presented in Fig. 17.

The third experimental sampler embodies other improvements in addition to those developed on the first two samplers. The valve is driven by a flat clock spring and is controlled by an escapement for three positions: (1) intake and air exhaust closed, equalizing passage open; (2) intake and air exhaust open, equalizing passage closed; (3) all passages closed. A solenoid, energized by two or more 6-volt lantern batteries, is used to trip the escapement allowing the valve to

turn from one position to the next. From the batteries located on the operating rig, the current is supplied to the solenoid through a two-conductor current meter cable. The third experimental point-integrating sediment sampler, designated US P-46, weighs about 100 lbs. unsubmerged. Fig. 18 is a photograph of this sampler.

The P-46 sampler is primarily a point-integrator, but can be used also as a depth-integrator. With the valve in the open position a sample can be integrated from the surface to the bottom and return, or the valve can be closed at the bottom so that the sample is taken only on the downward trip. The sampler may also be lowered to the stream bed with the valve in the closed position, then opened and the sample taken on the ascending trip only, or the sampler may be used to integrate any portion of a sampling vertical. Thus in extremely deep streams the vertical may be sampled either by the point method or by successively integrating portions of the vertical. As a point sampler this instrument can be used also in sampling density flows in reservoirs. By whatever method the sampler is operated the pressure in the container and outside hydrostatic pressures are automatically balanced and the effects of initial inrush are eliminated.

As a part of a program of field testing and standarization of sampling equipment, three D-43 samplers were placed in routine operation in a cooperative sediment project in Iowa in September 1943. Since that date, some fifty-five D-43 samplers (50 lb.) have been constructed for several of the agencies for routine sampling operations in streams of medium depths and velocities. The progress being made in the development of the improved point-integrating sampler has been somewhat slower owing to the inherent mechanical difficulties involved and the initial construction cost of a small number of samplers. However, at the present time, eight P-46 samplers are under construction for two of the agencies.

Drawings of the US Sediment Samplers P-46 and D-43 (50 lb.) indicating construction details are appended to this paper.

8. Field Tests on Suspended Sediment Samplers. - In May 1943 several suspended sediment samplers of the US D-43 model were distributed to field offices of the cooperating agencies for examination and trial. The Committee desired to determine the utility and durability of the sampler under practical field conditions and to obtain appraisals and recommendations of field personnel pertaining to its design and operating characteristics. Wherever possible comparative tests were to be made with other types of samplers which were in current use by the respective field agencies. The second experimental model of the point-integrator, US P-43, was made available for 60-day periods to field offices of the agencies desiring to make similar tests with this sampler. Thirteen field offices have submitted reports, test data, and discussions of the experiences encountered in these tests.

The field tests brought to light many inaccuracies in existing sediment samplers, some of which had been anticipated on the basis of previous laboratory analyses. Disparities in sediment data were due either to faulty sampling techniques or faulty sampler design, or both. A summary of the results of the comparative field tests is presented in the following tabulation.

FIELD TESTS ON SUSPENDED SEDIMENT SAMPLERS

Summary of Sampling Ratios

Agency	Samplers Compared	No. of Comparisons	Sampling Ratio		
			Min.	Max.	Avg.
U.S.B.R.	*Tait-Binckley/D-43	9	0.66	1.00	0.81
U.S.E.D.					
Tulsa	*Texas/D-43**	78	--	--	1.04
	*Vicksburg/D-43	30	--	--	1.10
Albuquerque	Wading Sampler/D-43	6	0.77	1.05	0.98
	*Faris/D-43**	7	0.76	1.02	0.91
	*Faris/D-43**	7	0.31	0.82	0.48
Sacramento	Sacramento/D-43	6	0.50	2.50	1.10
Rock Island	RI/D-43	8	0.68	1.45	1.13
Omaha	Omaha/D-43	6	0.97	1.37	1.16
	*Omaha/D-43	116	--	--	1.18
U.S.G.S.	Colorado R./D-43	22	0.59	1.00	0.82
U.S.B.R.	Tait-Binckley/P-43	24	0.67	2.14	1.26
U.S.E.D.					
Huntington	ORD/P-43	5	0.89	1.01	0.94
Tulsa	Texas/P-43	23	--	--	0.97
	Vicksburg/P-43	52	--	--	1.03
Omaha	Omaha/P-43	115	--	--	1.18
Little Rock	Texas/P-43	19	--	--	0.95
U.S.G.S.	Colorado R./P-43	4	0.53	1.00	0.80

*Sampling ratio is affected by both sampling method and sampling action.
**Faris and Texas Samplers are identical.

The majority of these tests were made in streams with relatively shallow depths, moderate velocities, finely divided sediments, and uniform vertical distributions of both velocity and sediment concentration, conditions which tend to minimize the effects of faulty sampler action and improper sampling methods. In such streams a departure from the optimum intake velocity, streamlining, and sampling procedure would not materially affect the representativeness of the sample. On the other hand, sampler design and operating technique become increasingly important as the physical characteristics of the stream depart from the favorable sampling conditions which prevailed during most of the tests. For instance, in the comparative tests made with the Texas sampler and the US D-43 sampler in the Arkansas, Canadian, and Cimarron Rivers, where stream velocities and sediment concentrations were relatively low, a mean sampling ratio of 1.04 was obtained; whereas in one series of tests made in the Rio Grande with the Faris (same as Texas) and D-43 samplers and identical sampling methods, but with higher stream velocities, coarser sediment, and greater concentrations, the sampling ratio dropped to 0.48.

Comparative tests made with the Colorado River and D-43 samplers in the Colorado River Basin where the size of the sediment particles ranged from silt to medium coarse sand, indicated a sampling ratio of 0.82. The majority of the depth-integrating samplers which were tested collected samples too low in concentration. However, the Omaha and Rock Island samplers collected an excess of sediment in the Missouri and Mississippi River basins, the mean sampling ratios being 1.16 and 1.13, respectively.

A striking illustration of the error which may result from taking a single sample in a vertical is given by a further analysis of the data obtained with the Faris and the US D-43 samplers in comparative tests made in the Rio Grande at Albuquerque, New Mexico, in May and June 1944. Seven series of comparisons were made in which the Faris samples were taken at 0.6 depth and the D-43 samples were obtained by the usual method of depth-integration. The average sediment concentration in the Faris samples was 0.48 of that in the D-43 samples. Size analyses indicated that in the range of particle sizes smaller than 0.0312 mm., the ratio of concentration in the Faris samples to that in the D-43 samples was about 0.75. However, this ratio decreased rapidly with increasing particle sizes. For particles 0.5 mm. in diameter, the ratio dropped to 0.12. The relative percentages of the various sizes of particles taken with the two samplers are shown in Fig. 19. It is apparent that the coarser material present in the D-43 samples was obtained largely from the vertical below the 0.6 depth, that portion of the vertical which was not represented in the samples taken by the Faris sampler.

In May 1945 a series of samples were taken with the US P-43 point-integrating sampler at the same sampling station in the Rio Grande. The sediment concentration and velocity in the vertical are shown in Fig. 20, while the size gradation of the sediment samples taken at various depths are shown in Fig. 21. It is evident from these data that samples taken at 0.6 depth are not representative of the total sediment concentration in the vertical and that they do not indicate correctly the variation of particle sizes. Regardless of the type of sampler used, the 0.6

depth or any other single point method of sampling is not reliable where particle sizes and concentrations vary appreciably from the surface to the bottom of the stream.

Field personnel recognized the simplicity, ruggedness, and ease of operation embodied in the US D-43 sampler and recommended that additional depth-integrating samplers be developed to cover a wider range of sampling conditions. The Committee has adopted a number of these recommendations in the program for future sampler development.

The field tests on the point-integrating sampler, US P-43, resulted in numerous recommendations for the improvement of mechanical operating features and the general design of the sampler. The basic principles of the sampler received general approval and the need for this type of sampler was recognized. On the basis of these recommendations, the US P-46 sediment sampler was designed and preliminary field tests indicate that the objectionable features of the earlier model have been largely overcome. It is believed that samplers of this type will be widely used in future sediment investigations, particularly in large rivers.

9. Laboratory Analysis of Sediment Samples. - In carrying out a sediment sampling program it is obviously desirable that the methods employed in analysing sediment samples should be equally as accurate and efficient as those used in taking the samples from the stream. For this reason the Interdepartmental Committee undertook an exhaustive study of the laboratory devices, instruments, apparatus, and methods developed by various investigators for sediment analysis work. This study is covered in Report No. 4 of the series, under the title, "Methods of Analysing Sediment Samples".

The determination of total sediment concentration and size distribution of relatively coarse particles - larger than about 1/16 mm. in diameter - generally does not present any great problem and usually can be accomplished by means employed in soils or materials laboratories. In addition to the determination of the weights of the original sample and the residue, the most common method used in determining total sediment concentration involves three basic steps - sedimentation, decantation, and evaporation. This process may be supplemented by filtering through filter paper or crucibles to expedite the operation and to eliminate discrepancies due to dissolved solids.

The size distribution of sediment particles larger than 1/16 mm. diameter is determined, in most instances, by sieving. This method has reached a high degree of development in this country due, no doubt, to its simplicity and reliability and to the fact that very accurate sieves are available. The behavior of sediment particles in streams and their deposition in reservoirs and detention basins depend to a greater degree upon their settling properties than upon their geometric size. Consequently, attempts have been made to develop sedimentation methods for size analysis of coarse particles and this promises to be an important field for future research.

The size analysis of finer sediments has stimulated a great deal

of interest and many ingenious devices and processes have been developed. Methods commonly used in analysis of soils, such as pipette, hydrometer, manometer, plummet, and elutriation have been used, but inherent limitations in their capacity to determine particle size and concentration often preclude their use in analysing suspended sediment samples. The Interdepartmental Committee sponsored a special study of sedimentation methods of size analysis with a view to developing apparatus and techniques of sufficient scope and capacity to satisfy the requirements of suspended sediment investigations. An apparatus called the bottom-withdrawal tube was developed which enables the gradation of particles to be determined for a wider range of concentration and a wider range of size than is possible with any other of the commonly-used methods. This device, which is illustrated in Fig. 22, is a graduated glass tube about 100 cm. in length and 2.54 cm. in diameter with a quick-acting outlet at the lower end. The sample is first uniformly dispersed in the bottom-withdrawal tube, and then the tube is supported in an upright position. The sediment particles begin to settle to the bottom immediately, the settling velocity being a function of the apparent specific gravity of individual particles.

In a uniformly dispersed suspension such as employed in the bottom-withdrawal tube, the sediment concentration at any level remains constant until the largest particle in suspension will have had time to settle from the surface to the level in question. Fractions of the sample are withdrawn intermittently from the bottom of the tube, the time element of withdrawals corresponding to the time required for particles of given sizes to settle throughout the length of the water column. Each fraction is then dried and the weight of accumulated sediment determined. From these data is computed the weight of sediment of the same concentration which would remain in the suspension, assuming that the water column remained at the original height. Since the height of the water column actually decreases with each withdrawal, a pro rata correction is made to obtain the amount of suspended material that would remain in a column of constant height. Similarly, the hypothetical settling time for each fraction in a column of constant height is also computed. The computed percent of material remaining in the suspension at the moment of withdrawal relative to the total amount of material present in the original sample, together with the corresponding settling time, provide the data necessary to construct an Odén Curve (12), an example of which is shown in Fig. 23. Extending a tangent from any point on the curve to the ordinate scale will indicate the amount of material in the sample which is finer than the particle size represented by the corresponding time abscissa at the point of tangency. Gradation of the sediment according to any desired scale of particle sizes can be determined in this manner. Since the fall velocity is sensitive to temperature changes in the medium, variations in temperature must be considered in correlating particle sizes and settling time.

The development of the bottom-withdrawal tube and suggested methods of operation are described fully in Report No. 7 of the series under the title "A Study of New Methods for Size Analysis of Suspended Sediment Samples". This device has been used with marked success by several field agencies of the Federal departments cooperating in this study.

10. Future Program of Sediment Investigation. - The Interdepartmental Committee has received wide recognition for bringing to the attention of the engineering profession the need for accurate sediment data and the inadequacy and inefficiency of present sampling equipment and techniques. As indicated by the broad demand for the reports of the Committee by government agencies, universities, libraries, engineering firms, and individuals in this country and abroad, the engineering profession as a whole has looked upon this undertaking as a timely and commendable endeavor. Continuation of this project holds possibilities for further enhancing the knowledge of fluvial sediment characteristics and behavior, collection and correlation of sediment data, and application of sound practices in the solution of pertinent problems. The laboratory and field investigations sponsored by the Committee provide convincing proof that needed extension and improvement of sediment records can be materially aided by the development and standardization of sampling equipment, methods of measurement and laboratory analysis, somewhat comparable to the commonly accepted procedures of stream gaging.

At a meeting of the Interdepartmental Committee in April 1946 it was agreed to dissolve the Committee and to transfer its activities and functions to the recently established Federal Inter-Agency River Basin Subcommittee on Sedimentation. The Inter-Agency Committee is composed of representatives of the War Department, Department of the Interior, Department of Agriculture, and Federal Power Commission, and has as one of its objectives the coordination of the hydrologic activities of these Federal departments through the assistance of its several subcommittees. The new Subcommittee on Sedimentation, with C. B. Brown, of the Soil Conservation Service, Department of Agriculture, as its first chairman, formally took over the activities and the unfinished program of the Interdepartmental Committee in June 1946.

The most important phase of the unfinished program, which now becomes a function of the Subcommittee on Sedimentation, is the development of additional sediment samplers to meet special field conditions. In certain localities stream conditions are such that sediment samples can be obtained only by wading into the stream. In other places, where the depth-integration method is the most practical, the depth or stream velocities may be beyond the range of the simple depth-integrating sampler and a sampler which closes at the end of the downward trip should be used. In flashy streams where it is important to obtain sediment samples and stream gaging measurements in the minimum of time, the operation would be expedited if a sampler adaptable for use as a stream gaging weight were available. Development of three special samplers have been authorized to meet these field conditions.

There is in progress a study of the field use of the bottom-withdrawal tube for making size analyses of sediment samples and related laboratory techniques. Methods and equipment which will permit accurate splitting of samples preparatory to analyses are needed. The effect of flocculation in a sample being analyzed and the correlation of the flocculating characteristics of a sample in the laboratory with those of the natural stream are being studied. These and many other phases of the sediment problem fall within the scope and interest of both the Federal Inter-Agency River Basin Committee and the American Society of Civil Engineers Joint Committee on Sedimentation in Reservoirs.

11. Acknowledgements. - The sediment project which was inaugurated in 1939 has been directed by an informal committee composed of representatives of interested Federal agencies and the Iowa Institute of Hydraulic Research. The active membership of the Committee has changed from time to time and committee meetings have been open to other personnel interested in and associated with sediment investigations. The following representatives of the cooperating Federal agencies have been identified with the Committee at one time or another since its organization: Major A. B. Jones and G. A. Hathaway of the Corps of Engineers; C. G. Paulsen and the late G. L. Parker of the Geological Survey; G. C. Dobson and C. B. Brown of the Soil Conservation Service; A. S. Fry of the Tennessee Valley Authority; C. H. Southworth and J. C. McCaskill of the Office of Indian Affairs; W. R. Nelson and W. E. Cerfitzen of the Bureau of Reclamation. The possibility of deriving vast mutual benefits from a joint study of fluvial sediment problems of common interest to the Federal agencies was conceived by Mr. Hathaway and Professor E. W. Lane. Mr. Hathaway, who was largely responsible for organizing the Interdepartmental Committee, has served as Chairman and Secretary and has presided over the majority of its meetings. Professor Lane, in the capacity of consultant for the Corps of Engineers and representative of the Iowa Institute of Hydraulic Research, supervised and directed the work for the Committee at the University of Iowa Hydraulics Laboratory until June 1942.

The following personnel were assigned by their respective cooperating agencies to conduct the library and laboratory research and investigations at Iowa City: Vernon J. Palmer, Soil Conservation Service; Cleveland R. Horne, Jr., Morgan D. Dubrow, and Martin E. Nelson, Corps of Engineers; Victor A. Koelzer, and Paul C. Benedict, Geological Survey; Clarence A. Boyll, Tennessee Valley Authority; Philip M. Nobel, Donald E. Rhinehart, and John W. Stanley, Bureau of Reclamation; and Frank W. Parker, Office of Indian Affairs. Assistance in the theoretical analysis of sediment transportation, review of reports, compilation of pertinent information and data, and in various other phases of the project was contributed by the following: Professor A. A. Kalinske, State University of Iowa; S. K. Love, W. D. Collins, L. C. Crawford, C. S. Howard, and the late R. G. Kasel, U. S. Geological Survey; M. A. Churchill, Tennessee Valley Authority; V. A. Vanoni, H. A. Einstein, and G. Rittenhouse, Soil Conservation Service; and J. J. Hartigan, Corps of Engineers. The cooperation of field offices of the sponsoring agencies in providing information on samplers and sampling conditions, in making field tests on various samplers, and in developing practical laboratory techniques for the bottom-withdrawal tube is acknowledged.

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12 July 1946

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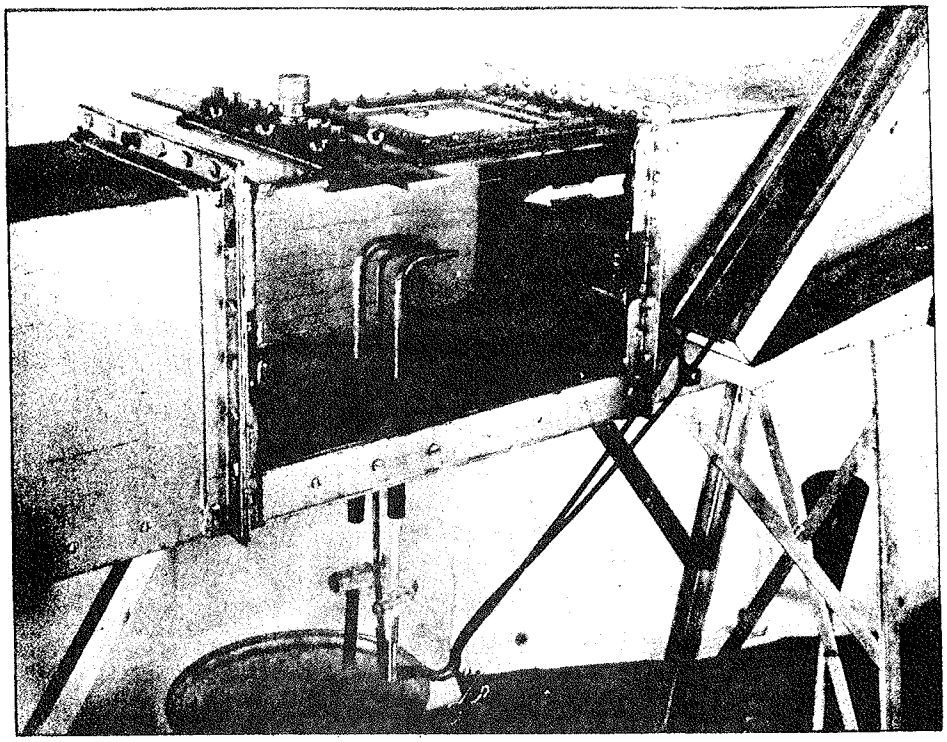


FIG 1-LABORATORY SEDIMENT SAMPLING APPARATUS.

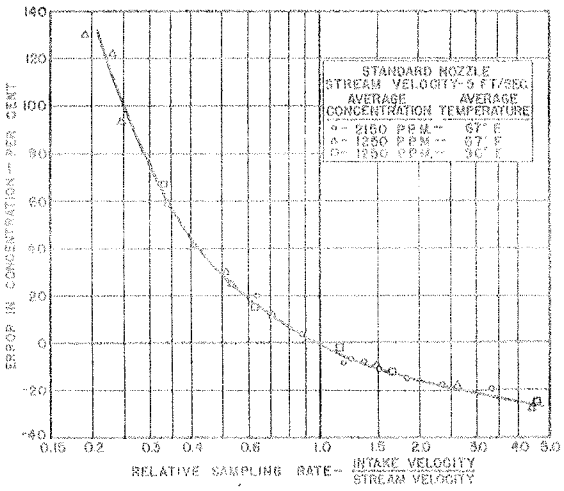


FIG 2 - EFFECT OF SAMPLING RATE ON SEDIMENT CONCENTRATION -- 0.45-MM. SEDIMENT.

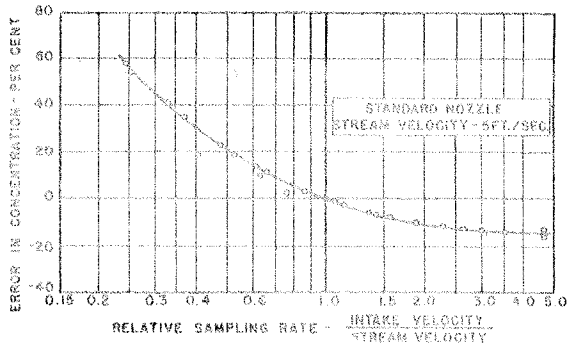


FIG. 3 - EFFECT OF SAMPLING RATE ON SEDIMENT CONCENTRATION -- 0.15MM. SEDIMENT

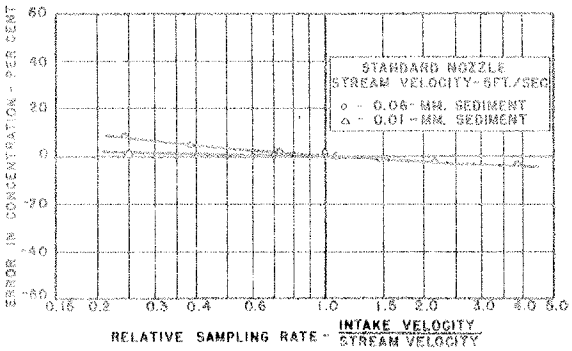


FIG. 4 - EFFECT OF SAMPLING RATE ON SEDIMENT CONCENTRATION -- 0.06MM. AND 0.01MM. SEDIMENTS.

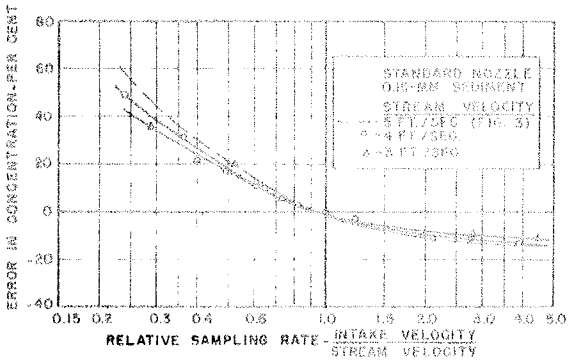


FIG. 5 - EFFECT OF STREAM VELOCITY ON ERRORS IN SEDIMENT CONCENTRATION.

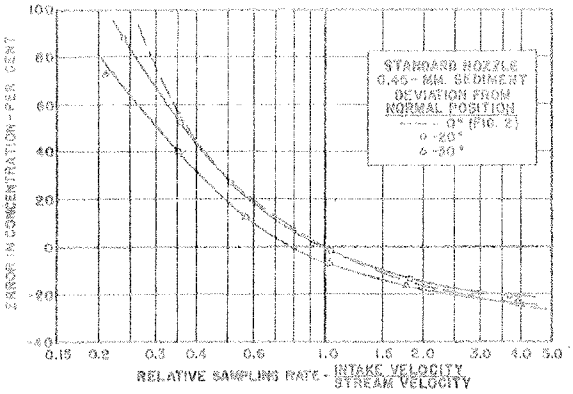


FIG. 6 - EFFECT OF SMALL DEVIATIONS FROM NORMAL NOZZLE ORIENTATION ON ERRORS IN SEDIMENT CONCENTRATION.

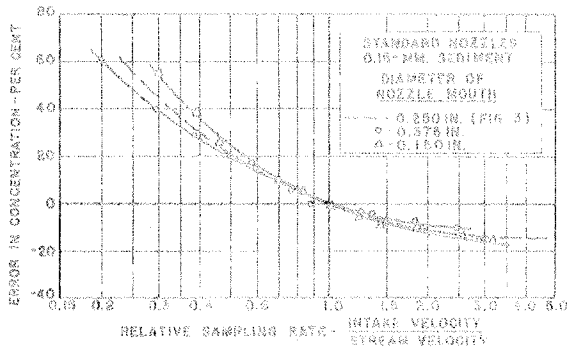


FIG. 7 - EFFECT OF NOZZLE SIZE ON ERRORS IN SEDIMENT CONCENTRATION.

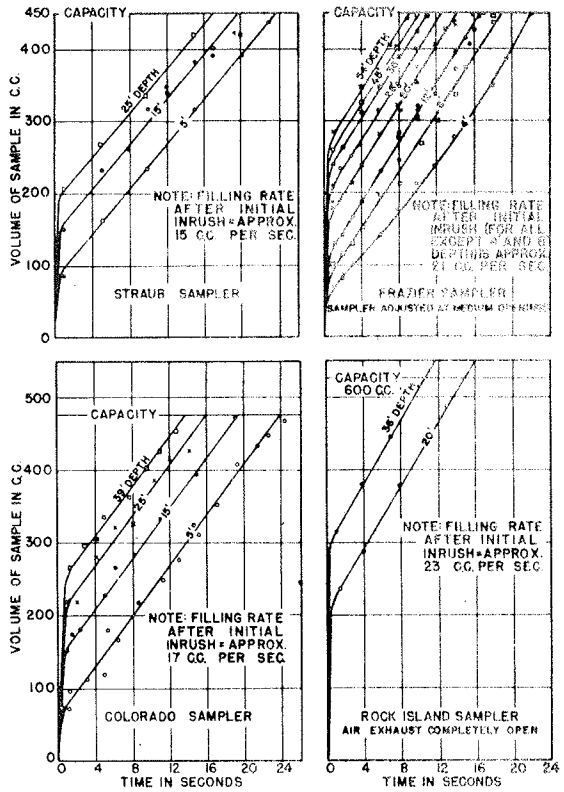


FIG. 8-FILLING CHARACTERISTICS OF SAMPLERS IN STILL WATER.

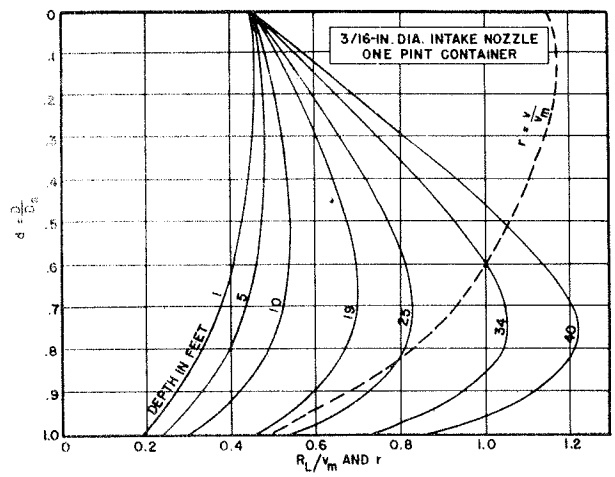


FIG. 9 - VALUES OF R_L/v_s FOR DEPTH-INTEGRATING SAMPLER BASED ON EQUATION (5) FOR A TYPICAL VERTICAL VELOCITY CURVE FOR ANY DEPTH.

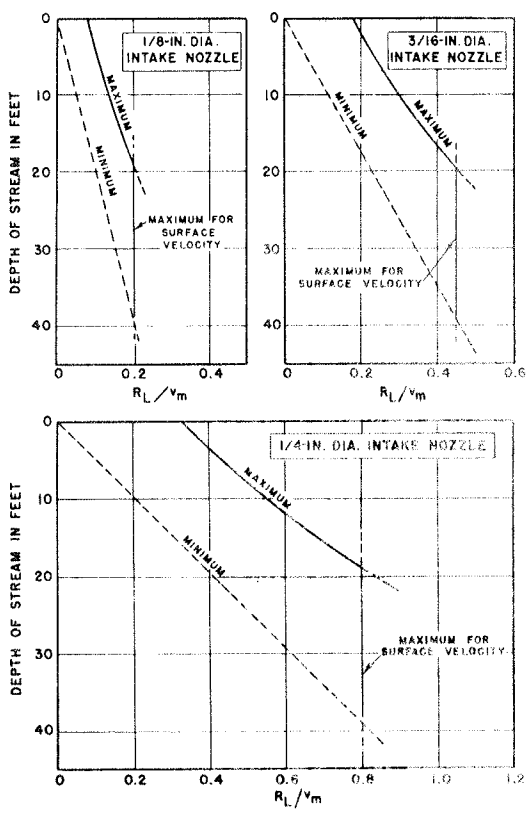


FIG. 10 - MAXIMUM AND MINIMUM VALUES OF R_L/v_m FOR DEPTH-INTEGRATING SAMPLER WITH CONTAINER OF ONE-PINT CAPACITY

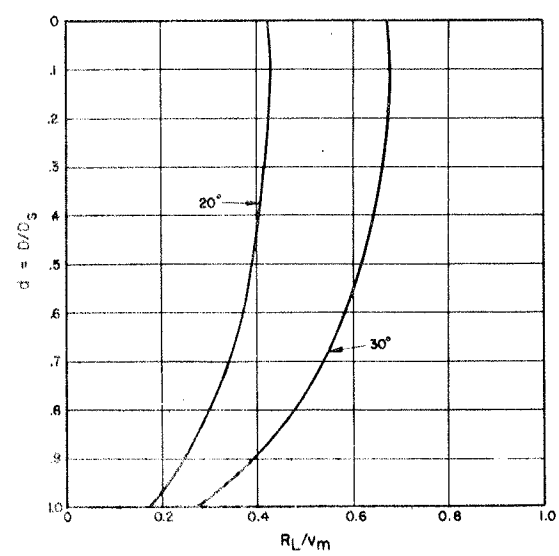


FIG. 11 - MAXIMUM VALUES OF R_L/v_m: 20 AND 30-DEGREE RELATIVE VELOCITY VECTORS.

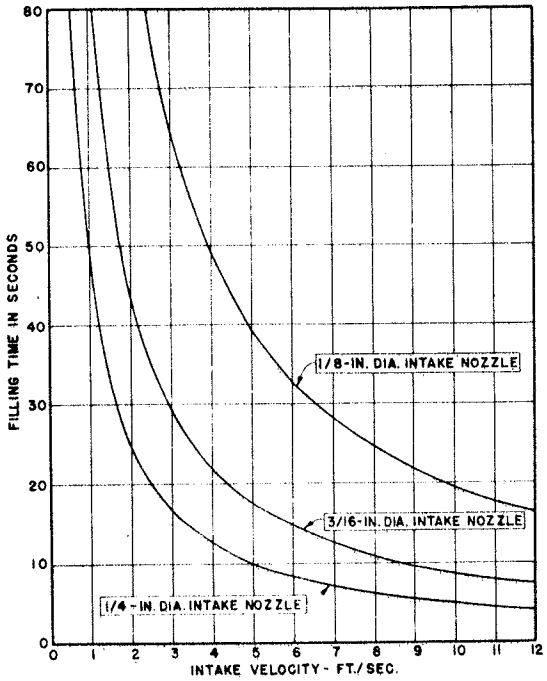


FIG. 12 - RELATION OF FILLING TIME TO INTAKE VELOCITY FOR A ONE-PINT CONTAINER.

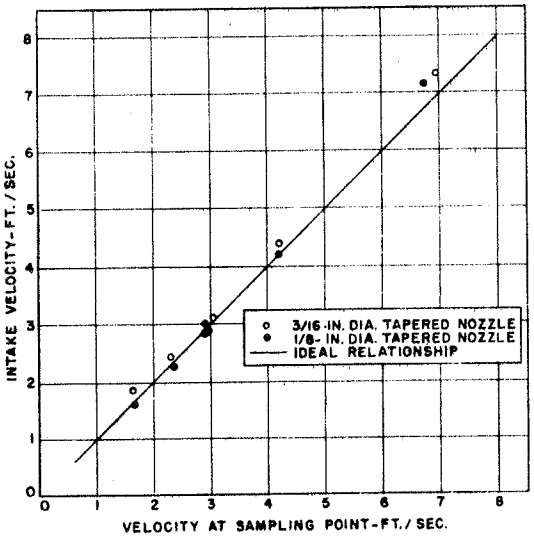


FIG. 13-INTAKE CHARACTERISTICS OF FIFTH EXPERIMENTAL DEPTH-INTEGRATING SAMPLER. (LABORATORY TESTS)

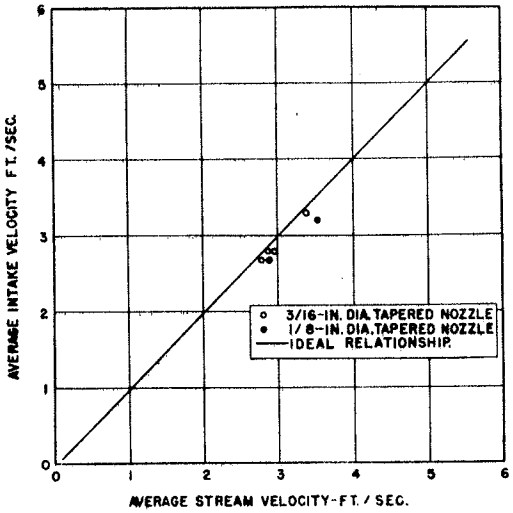


FIG. 14-INTAKE CHARACTERISTICS OF FIFTH EXPERIMENTAL DEPTH-INTEGRATING SAMPLER. (FIELD TESTS)

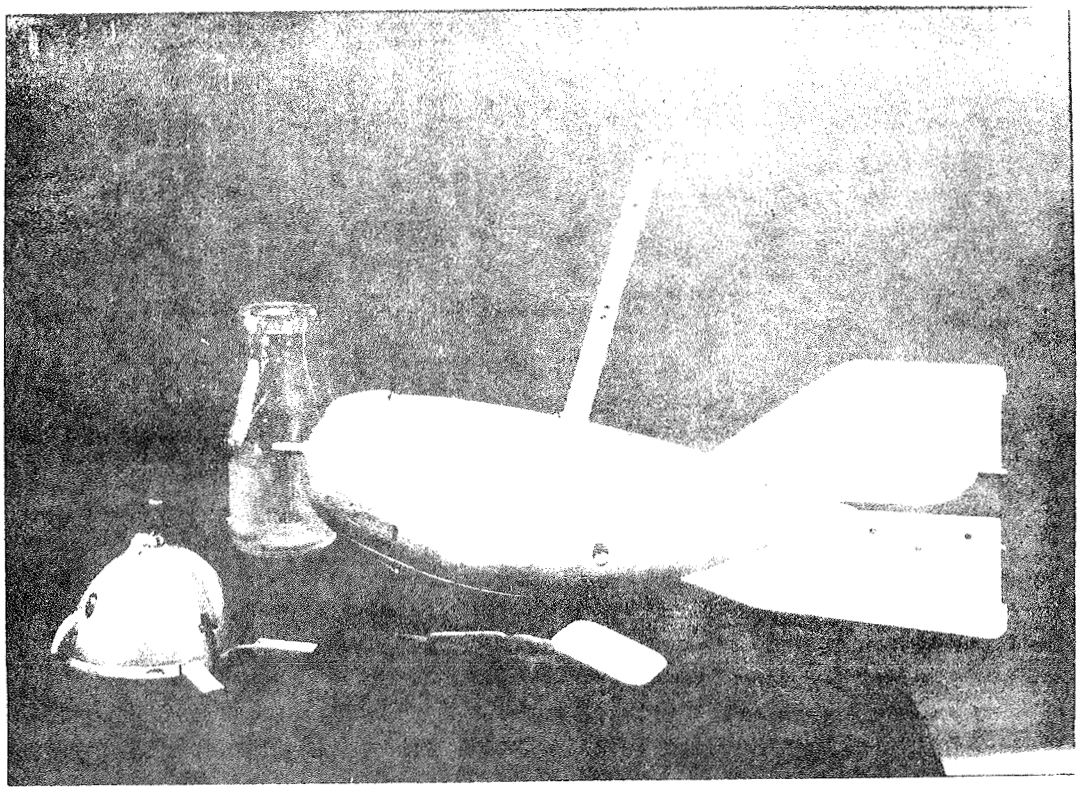


FIG 15 - US DEPTH-INTEGRATING SUSPENDED SEDIMENT SAMPLER, D-43 (38-LB) WITH AUXILIARY HEAD

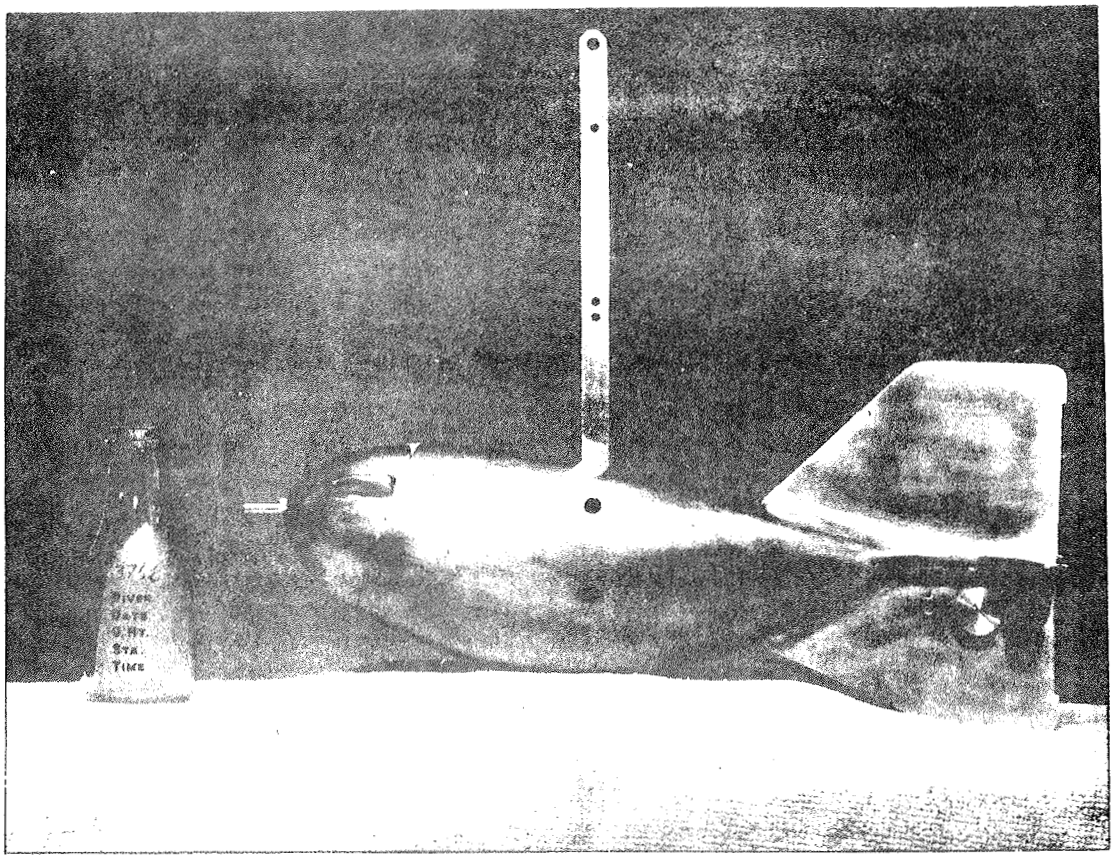


FIG 16 - US DEPTH-INTEGRATING SUSPENDED SEDIMENT SAMPLER, D-43 (50 LB)

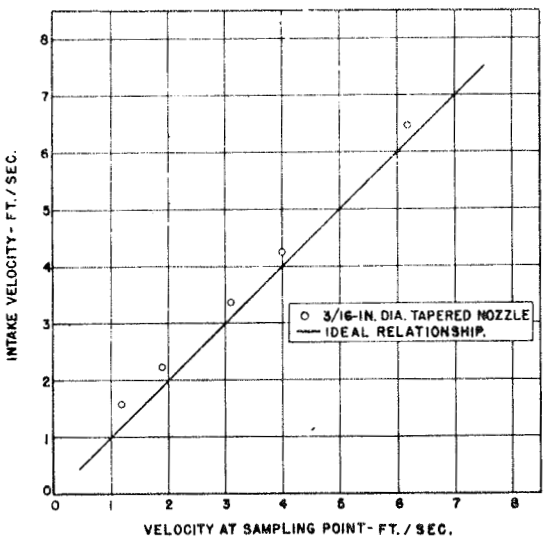


FIG. 17 - INTAKE CHARACTERISTICS OF SECOND EXPERIMENTAL POINT-INTEGRATING SAMPLER.

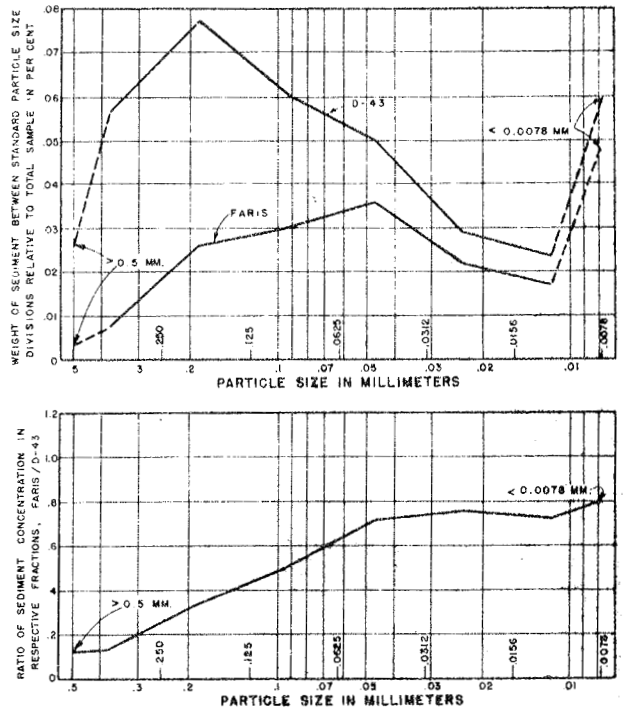


FIG. 19 - RESULTS OF COMPARATIVE TESTS WITH FARIS & D-43 SAMPLERS.
RIO GRANDE AT ALBUQUERQUE, N.M., MAY AND JUNE 1944,
DISCHARGE 5,000 C.F.S.

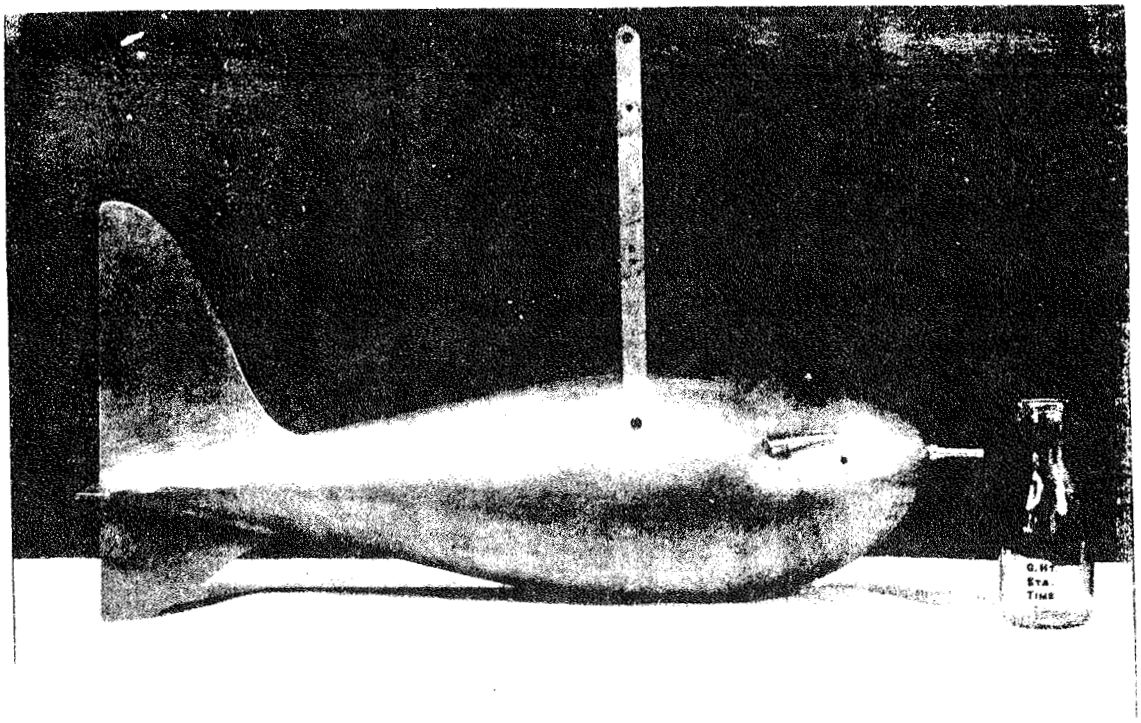


FIG. 18 - US POINT-INTEGRATING SUSPENDED SEDIMENT SAMPLER, P-46.

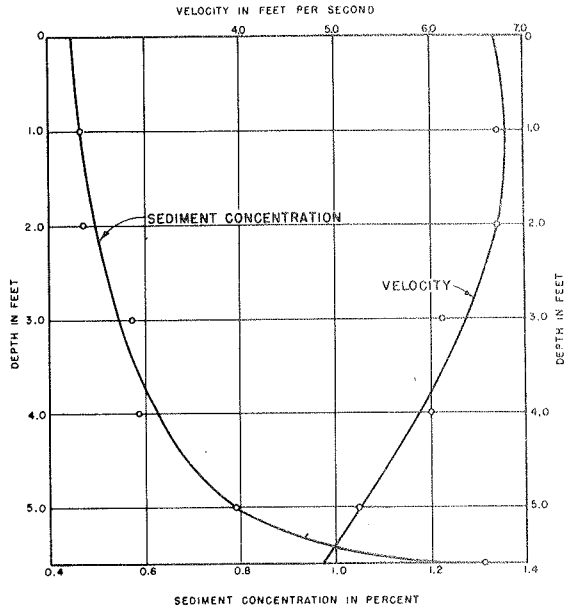


FIGURE 20 - SEDIMENT SAMPLER TESTS P-43
RIO GRANDE, ALBUQUERQUE, N. MEX.
4 MAY 1945 - DISCHARGE 4030 C.F.S.

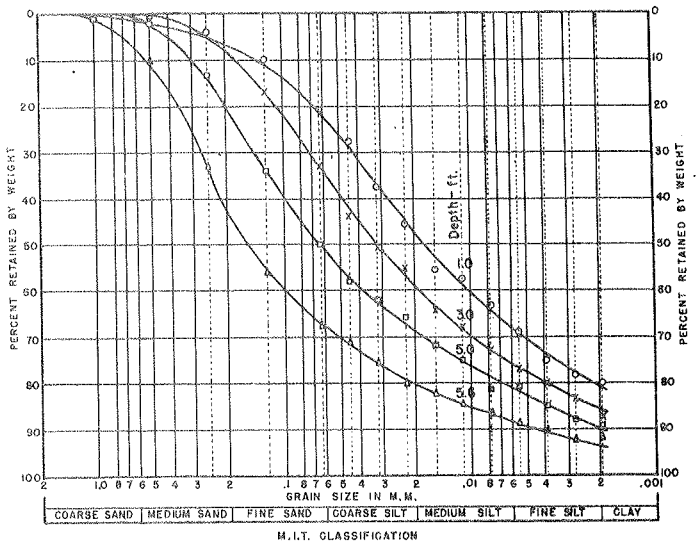


FIGURE 21 - SEDIMENT SAMPLER TESTS P-43
RIO GRANDE, ALBUQUERQUE, N. MEX.
4 MAY 1945 - DISCHARGE 4030 C.F.S.

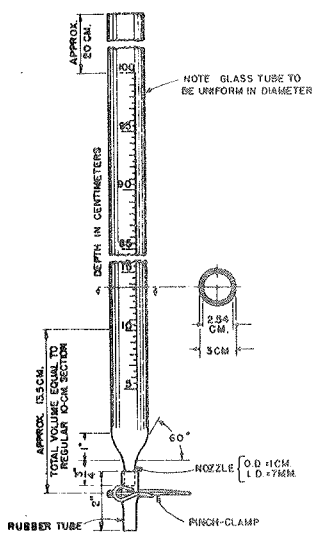


FIG. 22 - PROPOSED BOTTOM WITHDRAWAL SEDIMENTATION TUBE.

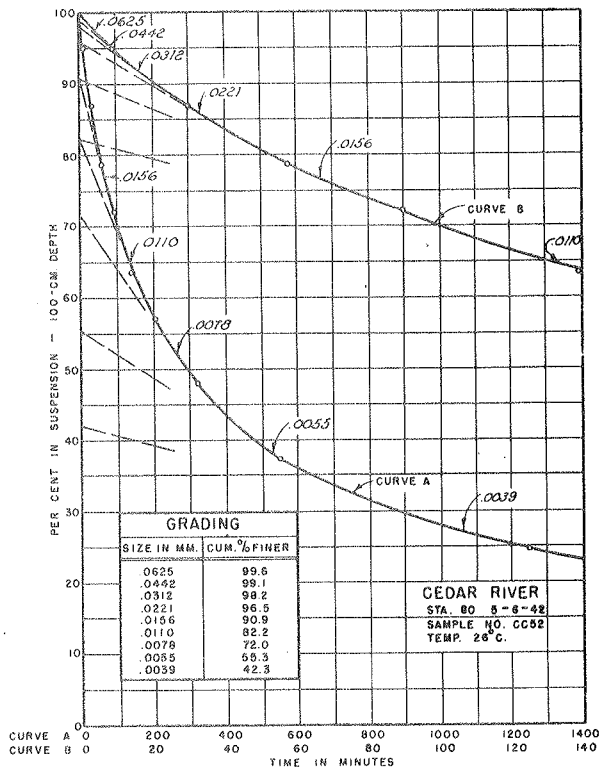
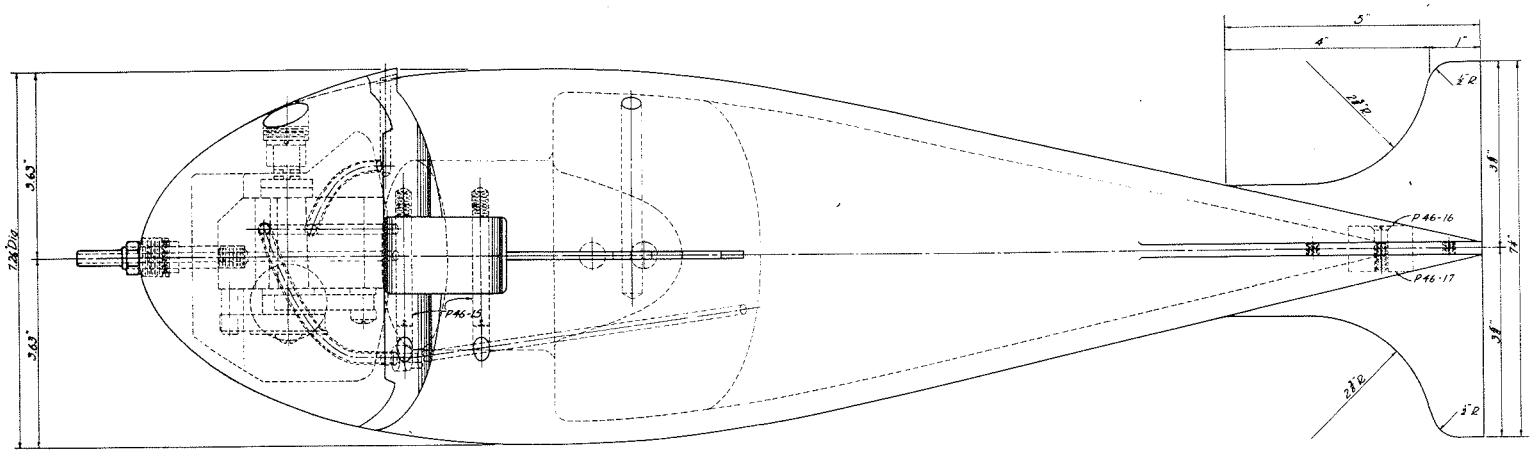
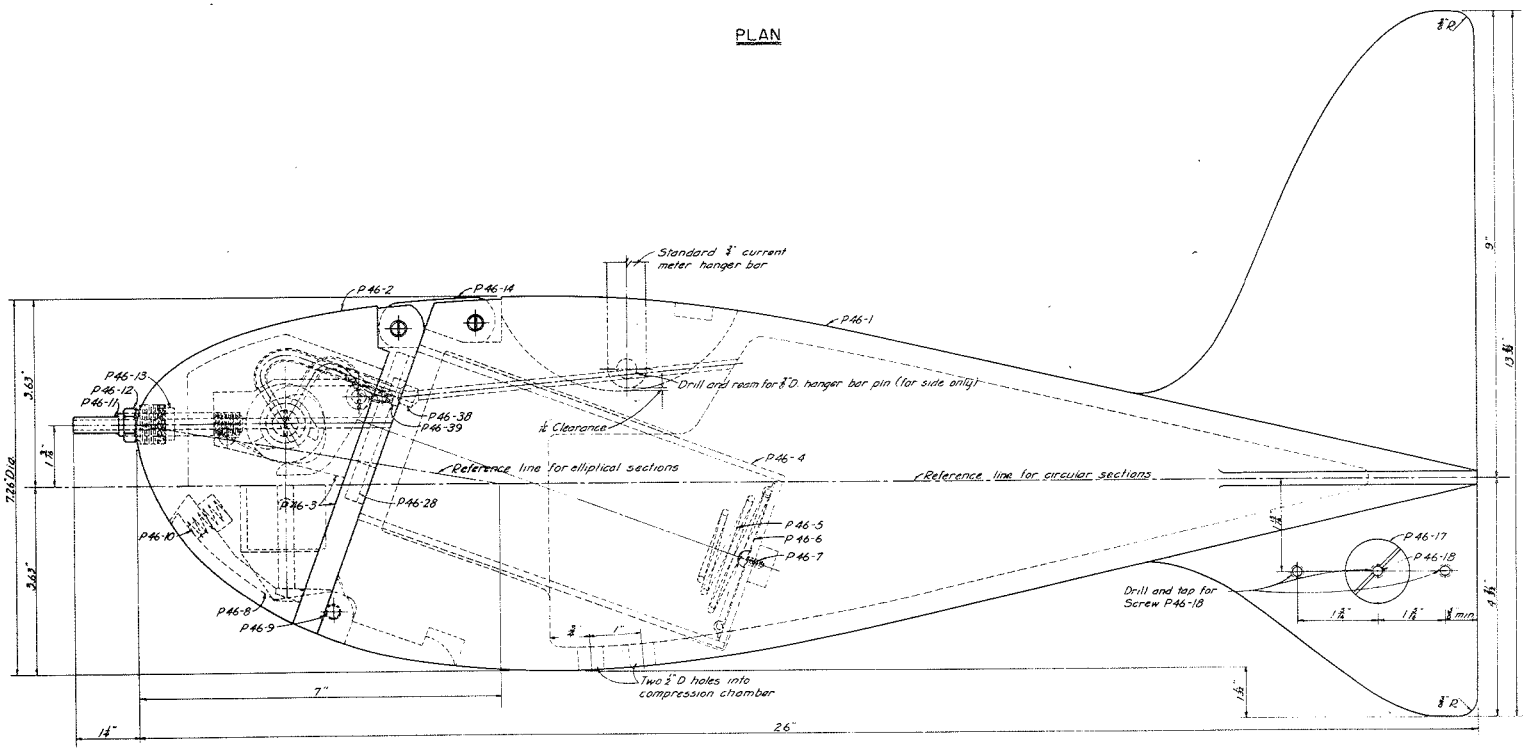


FIG. 23 - ODEN CURVE
CONSTANT DEPTH, VARIABLE TIME



PLAN



ELEVATION

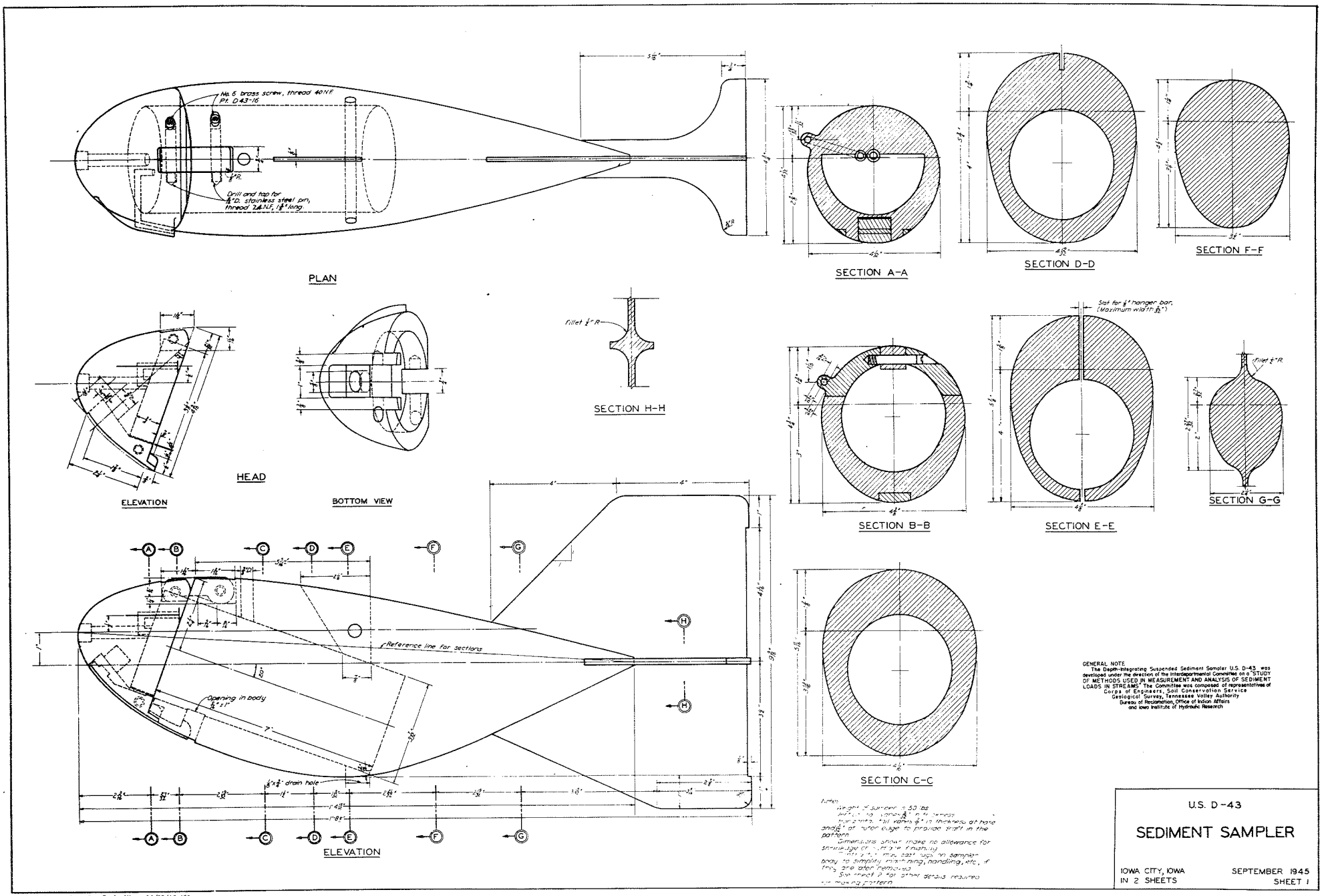
GENERAL NOTE:
The Point-Integrating Suspended Sediment Sampler U S P-46 was developed under the direction of the Interdepartmental Committee on a "STUDY OF METHODS USED IN MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS." The Committee was composed of representatives of Corps of Engineers, Soil Conservation Service Geological Survey, Tennessee Valley Authority Bureau of Reclamation, Office of Indian Affairs and Iowa Institute of Hydraulic Research.

US P-46

SEDIMENT SAMPLER

IOWA CITY, IOWA — JANUARY 1946
IN 6 SHEETS — SHEET 1

St. Paul Letter Co., St. Paul, Minn. 10/22/46-450



GENERAL NOTE
The Depth-Integrating Suspended Sediment Sampler U.S. D-43 was developed under the direction of the Interdepartmental Committee on a "STUDY OF METHODS USED IN MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS" The Committee was composed of representatives of
Corps of Engineers, Soil Conservation Service
Geological Survey, Tennessee Valley Authority
Bureau of Reclamation, Office of Indian Affairs
and Iowa Institute of Hydraulic Research

Notes:
Weight of sampler is 50 lbs
Weld in 1/8" fillet all around
Use parts 1/8" thick, 1/8" is thickness at hole and 1/8" at outer edge to provide draft in the pattern
Dimensions shown make no allowance for shrinkage or finish
Drill 1/8" min. cast up on sampler body to simplify machining, handling, etc., if they are later removed
See sheet 2 for other details required for making pattern

U.S. D-43

SEDIMENT SAMPLER

IOWA CITY, IOWA
IN 2 SHEETS

SEPTEMBER 1945
SHEET 1

St. Paul Letter Co., St. Paul, Minn. 10/22/46-450