Planning and Making

INDUSTRIAL WASTE SURVEYS

With detailed instructions for measuring volume of flow, obtaining representative samples and calculating waste load

Reference Data Publication compiled by

Metal-Finishing Industry Action Committee

OHIO RIVER VALLEY
WATER SANITATION COMMISSION

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(as of June, 1973)

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Planning and Making

INDUSTRIAL WASTE SURVEYS

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A WORD OF INTRODUCTION

Concerned as it is with the efforts of hundreds of industries to solve waste disposal problems, the Ohio River Valley Water Sanitation Commission asked its industrial-committee advisors what they thought would be of most immediate help in promoting action. The answer was: Since an industry must assume responsibility for defining its problem, the greatest need is for a practical handbook telling how to plan and make a waste survey within a plant.

The Metal-Finishing Industry Action Committee already had been developing some ideas in this regard. Under added stimulus, the committee broadened the scope of its proposal to produce a survey manual that could have application in all industries.

This manual is not a treatise on the theory of flow measurement. It is a "how-to-do-it", description prepared for the use of operating men whose normal duties may be quite remote from the conduct of a waste survey but who, nevertheless, may be called upon to do the actual job.

It was developed by men who have made and directed waste surveys. The content was then checked by another group whose professional activities gave them special qualification to pass judgment on the procedures recommended.

The Commission acknowledges with pride this contribution to more effective pollution control by its Metal-Finishing Industry Action Committee, under the chairmanship of Walter L. Pinner, manager of research, Houdaille-Hershey Corporation. An earlier manual by this same committee titled, "Plating-Room Controls for Pollution Abatement", describes methods for minimizing wastes.

The manual was edited by William H. Toller, Jr.; chemical engineer, Houdaille-Hershey Corporation and John E. Kinney, staff sanitary engineer; illustrations and layout were executed by Elmer Rohmiller, staff assistant. Publication costs were defrayed, in part, by a federal grant made available under Public Law 845.

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Cincinnati, Ohio
April 30, 1952

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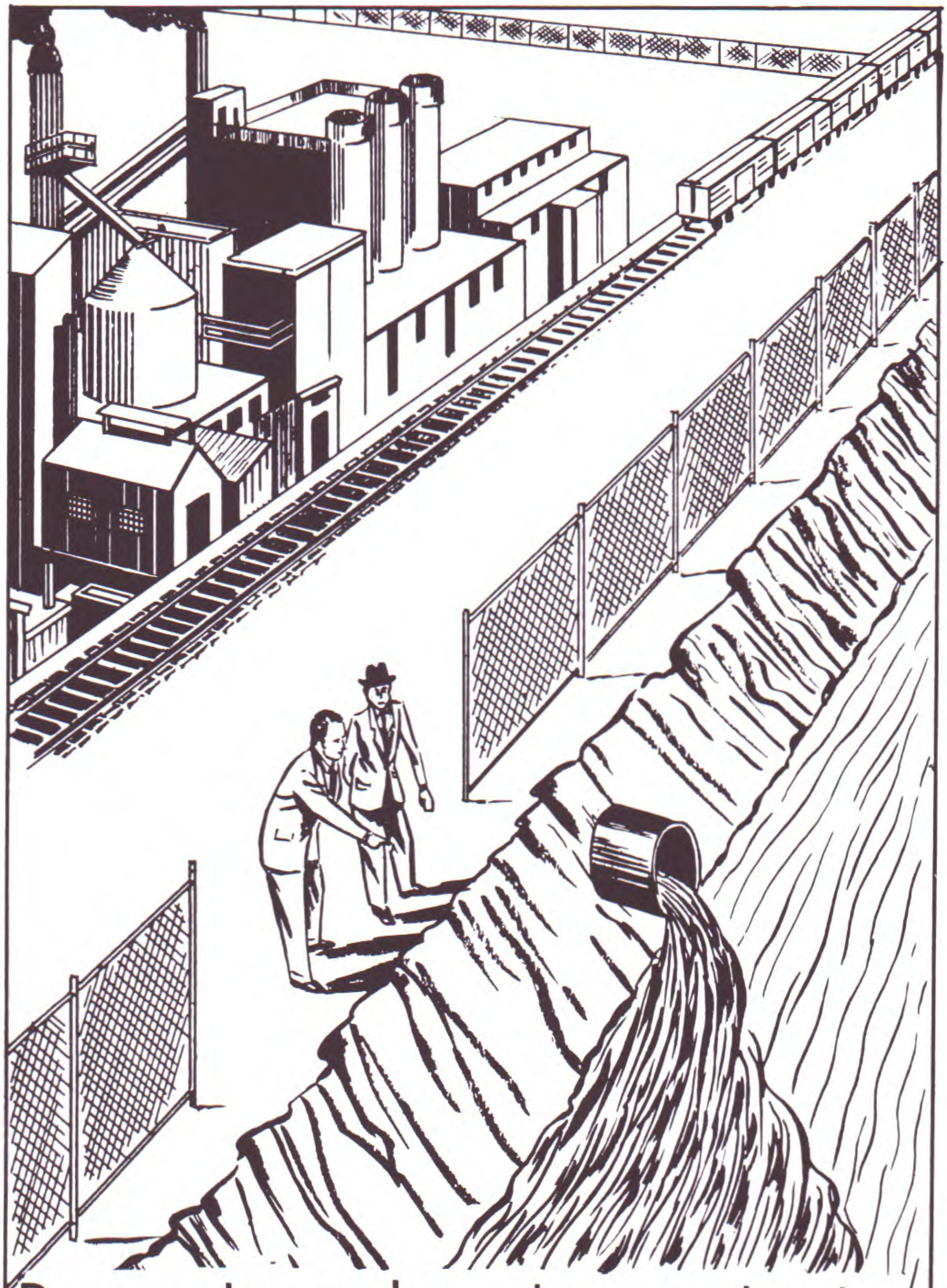


Do you know the volume and value of the waste from your plant?

PLANNING THE WASTE SURVEY

The objective of a plant waste survey is to measure the amount of material being discharged from the plant as waste. Usually the materials received at a plant leave the plant in the form of product, liquid waste or solid refuse. In some industries there is considerable loss through discharge into the air. This manual is concerned only with materials lost as liquids from plant operations. The materials discharged as liquid wastes include dissolved or undissolved chemicals, oils, or solids. A material balance—material purchased minus material shipped—will give an approximation of material lost to waste.

The need for treatment of industrial waste, or of steps necessary to cut down the amounts of waste, usually can be determined only after the waste or pollution load from a plant is known. An estimate of the waste load can be obtained only from a knowledge of two factors: Concentrations of the polluting materials and volumes of the waste. These basic data are also required for proper design of treatment facilities.

Concentrations— This manual presents procedures for measuring waste water flows and after chemical analysis of the waste tells how to calculate the waste load.

Strength or concentration of individual waste materials and the physical characteristics of the waste normally vary from time to time in the same plant and between different plants.

The Metal-Finishing Industry Action Committee is preparing separate manuals which will recommend methods of analysis for plating waste and describe the physical characteristics that influence treatment plant design.

Advice on methods of analysis can usually be obtained from regulatory agencies.

Volumes— Measurement of waste-water volumes at their sources and of the flow rates in the receiving sewers is necessary for a dependable appraisal of the plant's waste-water problem. The plant waste survey will indicate:

Where good housekeeping might eliminate or reduce unnecessary waste discharges.

The unusual demands to which the treatment plant will be subjected because of variations in waste-water-flow rates.

Those wastes that should be treated individually rather than after mixture and dilution with other industrial wastes.

This manual describes methods of flow measurement which are particularly applicable in waste-water surveys. The physical layout of the plant drainage system, the degree of accuracy desired and the duration of the survey will suggest the flow measurement method to be used.

Sewer map—A plant survey requires an intimate knowledge of the sources of wastes. This information can be supplied by one who is familiar with plant processes and the materials used in each individual operation. An accurate up-to-date sewer map of the plant must be made on which the sources of waste are indicated. This should be done before concentrations and volumes of waste are measured.

This map should show all water lines, sanitary, storm and process drains. The map should specify all pipe sizes, location and type of connections to processing units and direction of flow. Then all pertinent supply or drain connections should be tabulated and classified as to usage (for supply connections) or type of waste water (sanitary, process, uncontaminated cooling water, storm water).

Many newer plants have the sewer systems arranged so that different kinds of waste waters are collected separately. Often storm sewers carry uncontaminated cooling waters when there can be no further use of the cooling water before disposal. Some plants have been designed with separate sewers for storm water, for sanitary sewage, and for industrial wastes. Some plants, because of the nature of the processes, will require more than one sewer for industrial wastes. Separation of these wastes may be advisable because of formation of toxic gases, settling of solids in sewers, or treatment complications.

But the majority of plants — particularly older plants—do not have separate collecting systems for the various liquid wastes. The practice in the past has been to use the most convenient sewer as the point for discharge of liquid waste. And usually the plants do not have up-to-date sewer maps so a sewer location and flow survey is required. The flow survey defines direction of flow in the sewers and locates the sources of the flow. This survey may often establish some unsuspected source of pollution.

Tracing the wastes—Direction of flow in a sewer can be determined by adding a strong dye or soluble salt that imparts a color to the liquid. A dye added at the sources of waste will determine the path of flow of each waste through the plant. Methyl orange, nigrosine, or fluorescein will color wastes strongly. Methyl orange is red in acid solution and yellow in alkaline solution. Nigrosine imparts a black color to acid and alkaline wastes. Fluorescein sodium salt in alkaline solution gives a brilliant green color but does not give color in acid solution.

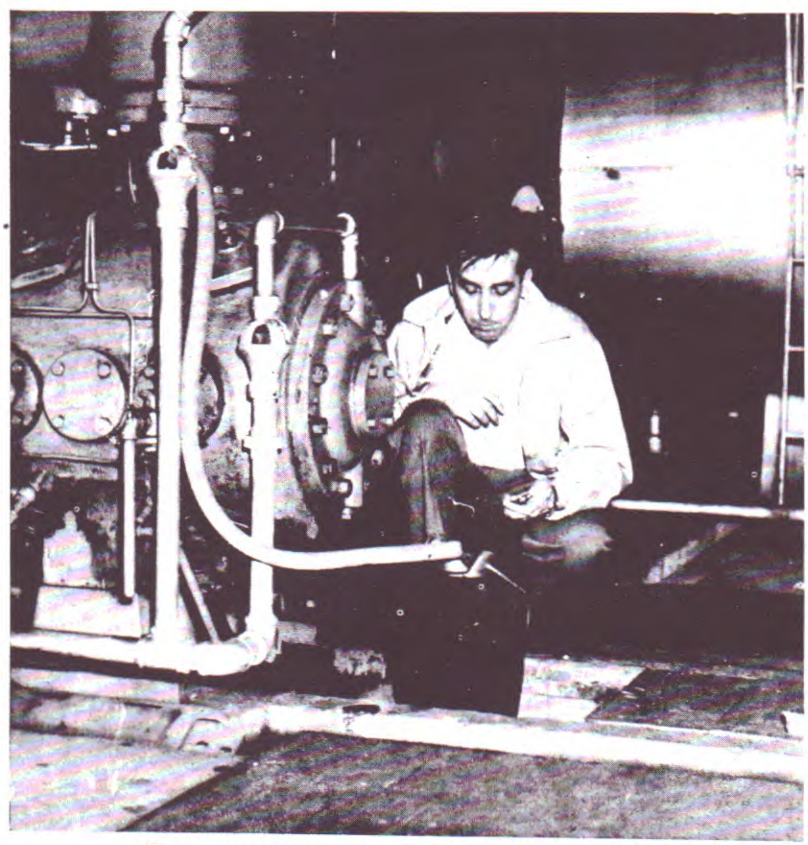
Here's how its done: Add about ten grams or one tablespoon of powdered dye to a bucket of water and, after mixing, pour the solution into the sewer at the source of the waste. Watch for color at one or more manholes or outlets. Path of flow is thus indicated.

Wood chips or cork floats are also useful in determining path of flow. Allow ample time for dye or float to appear.

Duration of survey will be governed by the plant operating schedule—hours per day and number of days per week. For smaller plants an industrial waste survey can usually be completed within one week. Measurements should be taken for at least five consecutive days, or sufficiently long to register the effect of all significant waste-producing operations.

Seasonal variation in production should be considered in scheduling a survey. Treatment facilities based on a survey during low production may be inadequate during peak production when the waste load is higher.

The survey time must extend over the entire day's operating schedule. For example, if a plant operates 8 hours a day, the survey must extend over the full 8 hours; if the plant operates 24 hours a day, extend the survey over 24 hours.



Flow measurement by bucket and stopwatch is often practical in small-plant surveys.

Accuracy in measuring rates-of-flow is essential in a waste-water survey. Methods for measuring flows include: Water meters on incoming lines; bucket and stopwatch; open-end pipe flow; depth and velocity of flow in partly filled sewers; salt concentration; weirs; and the Parshall flume.

When the waste water falls from the end of a pipe or sewer, use of a bucket and stopwatch or the methods that measure open-end pipe flow should be considered.

When there is no falling water or when flow within a pipe or sewer is to be measured, the methods to be used are described in the section devoted to depth and velocity of flow in partly filled sewers and also under salt concentration.

Meters, weirs and Parshall flumes are permanent measuring devices. The expense of installation is offset by having always available a means for measuring the rate of flow.

Before a permanent measuring device is designed, an approximation of the rates-of-flow should be made by one of the other methods.

Water meters on incoming lines—All water consumption in the plant should be determined during the survey as a check on waste-water flow measurements and as an aid in computing the water balance.

In a water balance, the water supplied to the plant should equal the water discharged to the sewers, plus that from steam leaks, evaporation, water in the product, and other losses. Conditions in individual plants may make an accurate computation impossible because of the necessity of estimating certain of these factors. Major sewer leaks or other hidden losses may be uncovered in the process of making the water balance.

Positive displacement meters (household variety) are often used. On larger installations, Venturi tubes, orifice plates or propeller meters are installed in the water lines.

A meter may also be installed on feed lines to individual process units to measure water usage.

Propeller meters can be installed easily and cheaply in an unmetered plant. One way is to burn a hole in an existing pipe, weld on a small saddle, and bolt thereon a propeller meter. This method is much less expensive than the cost of installing Venturi tubes.

Bucket and stopwatch—In this method the time required to obtain a given volume of water in a container is measured (Fig. 1). The volume in gallons is first determined by measuring the weight of water in pounds (weight of bucket and water minus weight of bucket) and then dividing by 8.3 (one gallon of water weighs 8.3 lbs). Weight is preferable to nominal volume of a bucket since such volume is rarely accurate.

For example:

Weight of full bucket = 25 lbs. 10 oz. = 25.6 lbs.
Weight of empty bucket = 3 lbs. 1 oz. = 3.1 lbs.
Weight of water = 22.5 lbs.

$$\text{Volume of water} = \frac{22.5}{8.3} = 2.7 \text{ gals.}$$

Time required for filling the bucket is determined by stopwatch. A watch with a good second hand would do as well as a stopwatch. The flow in gallons per minute (gpm) is then calculated from the formula:

$$\frac{\text{gals. in bucket x 60}}{\text{time in seconds}} = \text{gallons per minute}$$

This method should be applied to sewers or outfalls where free fall occurs and flows are small. If the container fills in less than 10 seconds, the accuracy is questionable.

Use of container with a pre-measured volume is usually more convenient than continual weighing of the full container.

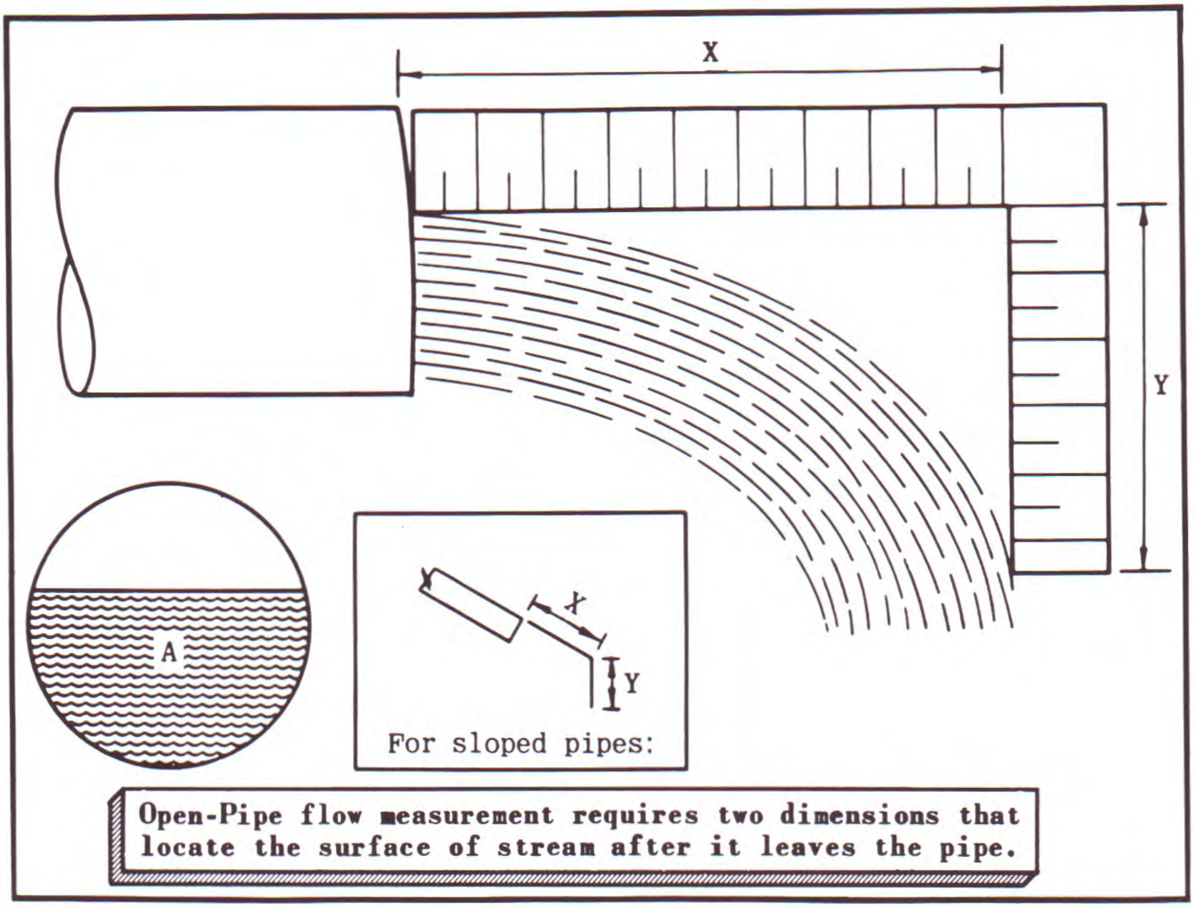
In a modification of this method one of the tanks in the process is used to measure the flow. A tank is selected which carries the full flow of the waste to be measured, and the liquid level is dropped to some known depth. The time needed to refill the tank is then measured, and the rate of flow calculated as follows:

$$\frac{\text{Vol. of tank refilled in cu. ft. x 7.5}}{\text{time in minutes}} = \text{gallons per minute}$$

(one cubic foot (cu. ft.) contains 7.5 gallons)

Flow from open-end pipe—*When pipes or sewers have free discharge into the air this method can be used to measure the flow.* It does not give the accuracy of weir measurements but is sufficiently accurate for waste-flow measurements when care is used. The method can be em-

Figure 2



ployed when construction of a weir box would be difficult or costly.

Two measurements are required, X and Y, (Fig. 2) which locate the surface of the stream of water after it has left the pipe.

This method can be employed in setting a permanent measuring device as shown in Fig. 3. A vertical gage can be set at any convenient distance X from the end of the pipe and then calibrated so that the Y reading can be computed by adding the depth of liquid in the pipe (in ft.) to the distance from the bottom of the pipe to the surface of the liquid (in ft.). The Y gage must be perpendicular to the ground but the X gage must be parallel to the sewer line.

Depth of flow in the pipe can be converted into the cross-sectional area of the liquid in the pipe by use of Table IV.

Flow is calculated by:

$$\frac{1{,}800\ A\ X}{\sqrt{Y}} = \text{gallons per minute}$$

Where A = cross-sectional area of liquid in the pipe in sq. ft.

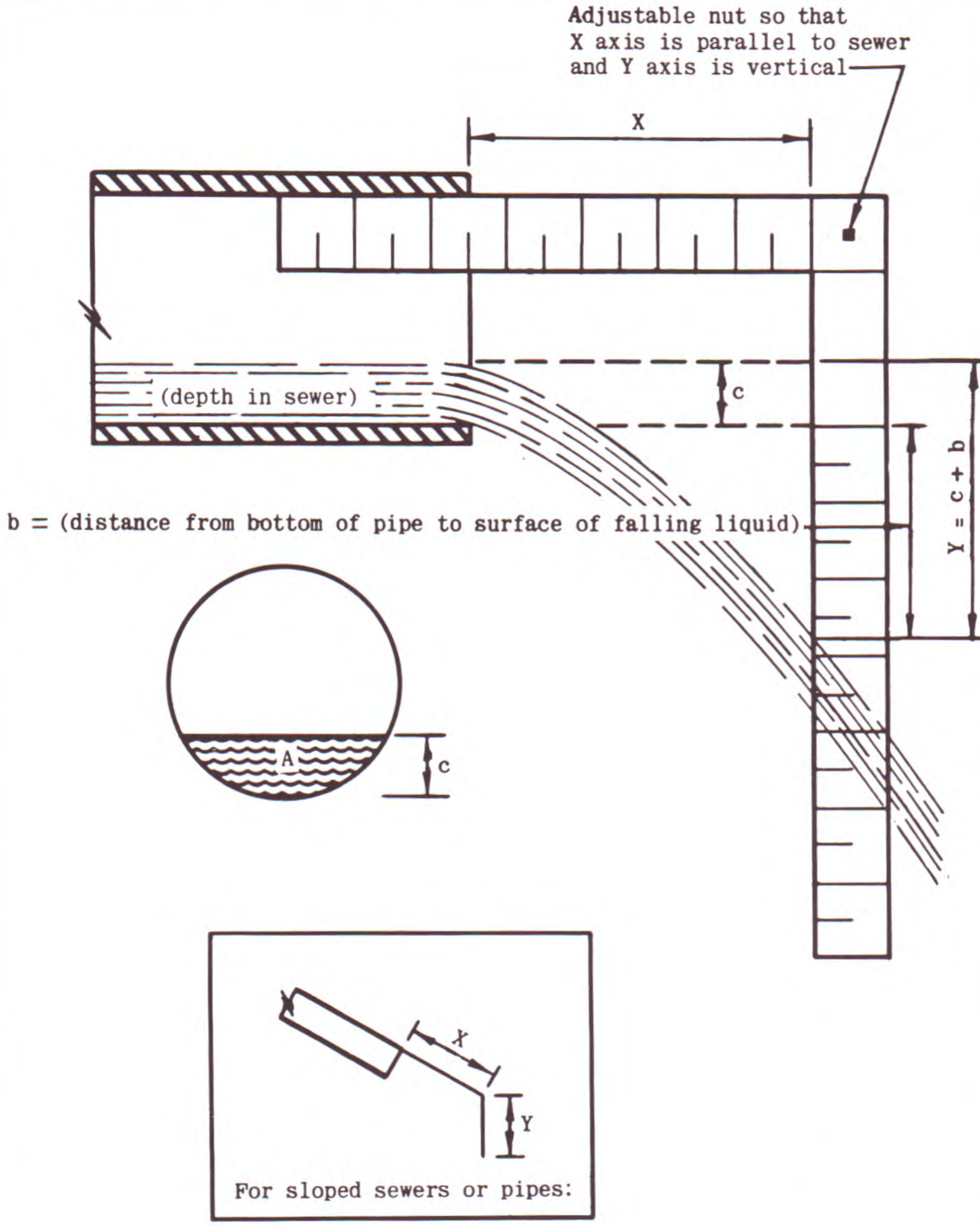
X = distance between end of the pipe and the vertical gage in ft., measured parallel to the pipe

Y = vertical distance from water surface at discharge end of the pipe and intersection of water surface with vertical gage in ft.

Example: In a 6-in. pipe the depth of water is 3 in. When X is 1 ft., the distance from the bottom of the pipe to the water mark on the vertical gage is 15 in. Therefore Y = 15 in. + 3 in. (water depth) = 18 in. or 1.5 ft.

From Table IV the cross sectional area of the liquid in a 6 in. pipe flowing half full is 0.10 sq. ft.

$$\frac{1{,}800 \times 0.10 \times 1}{\sqrt{1.5}} = 144 \text{ gpm}$$



Open-Pipe Flow Measurement - This device, adjusted to the slope of a sewer and calibrated, can then be clamped to the sewer outfall.

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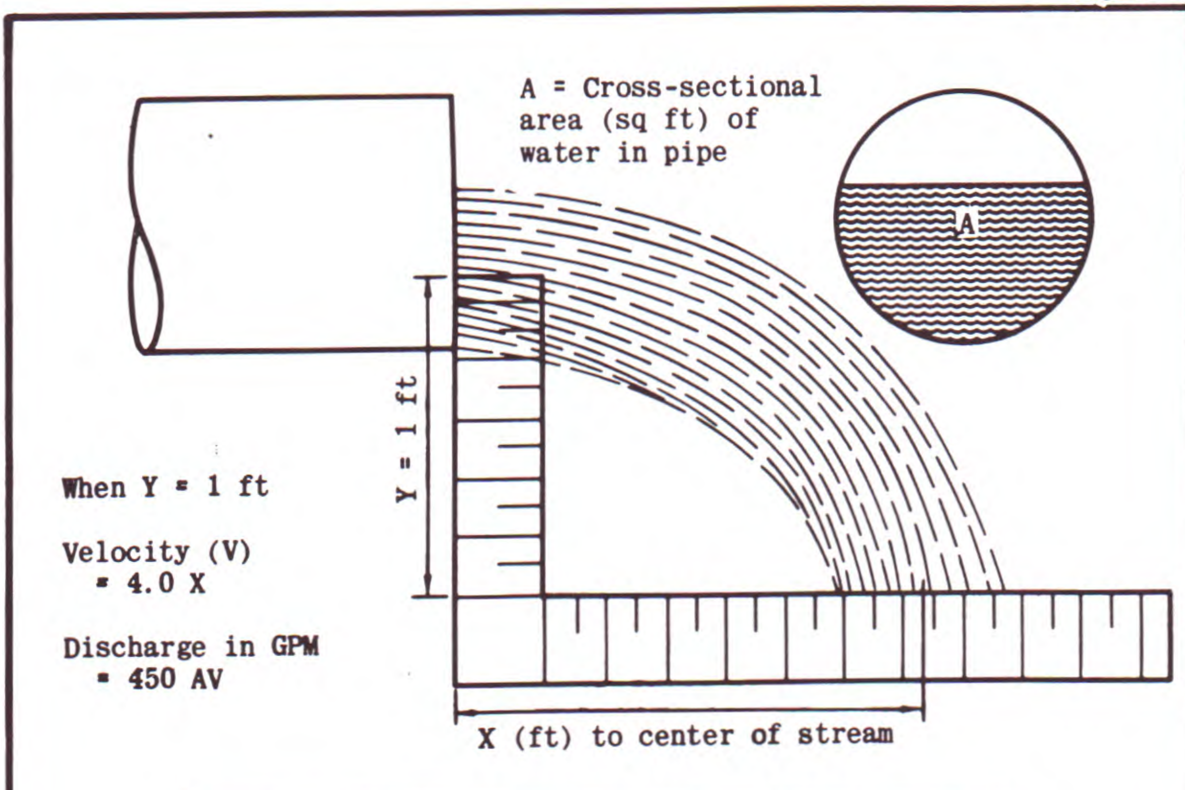
Figure 4



How to measure velocity and discharge from a pipe.

Variations of this method can be employed:

When Y is measured from the mid-depth of the liquid leaving the sewer and is equal to 1 foot and X is the variable, the velocity (V) in feet per second (fps) of liquid leaving the pipe is:

$$V = 4.0\ X$$

Here X is measured to the middle of the falling steam (Fig. 4).

Flow of water discharged from the pipe is determined by:

$$450\ AV = \text{gallons per minute}$$

Where A = cross-sectional area of liquid in the pipe (sq. ft.)

V = velocity of liquid (fps) = 4.0 X

This is also known as the coordinate or trajectory method.

California-Pipe Method is used for measuring rate of flow from a partly filled horizontal pipe having free discharge. The pipe must be horizontal and thus makes this application different than that of the coordinate method. If the pipe is not horizontal then a connection must be made to a pipe that is. One suggestion on how this can be done is shown in Fig. 5. The horizontal length required must be not less than 6 times the diameter of the pipe.

Only two measurements are required: Diameter of the pipe (d) and the distance from the top of the pipe to the surface of the flowing water (a). Using these measurements in either feet or inches, valves for T and W are obtained in Tables II and IIIand substituted in the following formula:

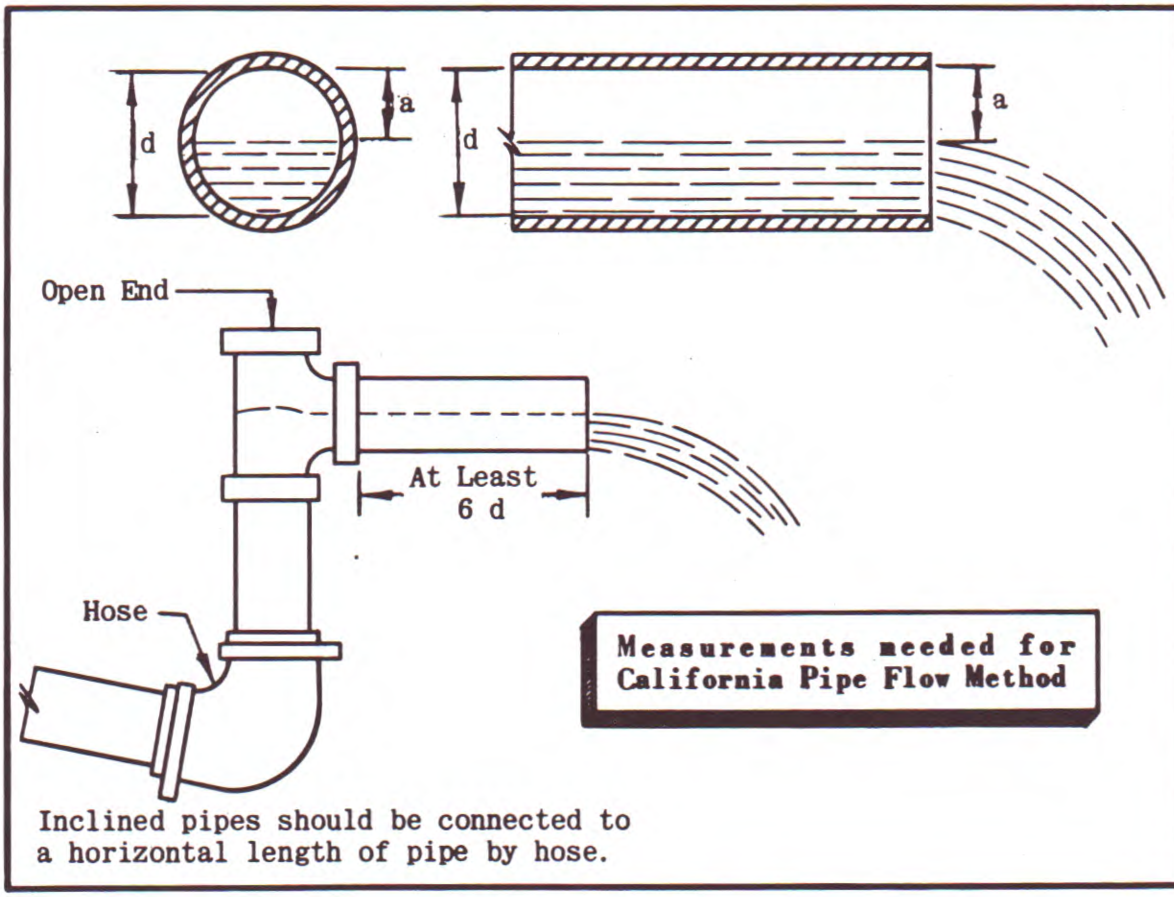
$$T \times W = \text{gallons per minute}$$

$$\text{Where } T = 3{,}900\ \left(1 - \frac{a}{d}\right)^{1.88}$$

$$W = d^{2.48}$$

Tables II and III give values for T and W when a/d and d are known.

Figure 5



Example: In an 8-in. pipe the depth of water is 5 in.

d = 8 in.

a = 8 in. — 5 in. = 3 in. (distance from surface of the water to top of pipe)

$$\frac{a}{d} = \frac{3}{8} = 0.38$$

from Table II when $\frac{a}{d} = 0.38$

T = 1,590

from Table III when d = 8 in.

W = 0.370

The flow is

T x W = gpm

1,590 x 0.370 = 588 gpm

An air bubbler (Fig. 23) may be used to obtain the dimension "a".

Depth and velocity of flow in partly filled sewers — Flow in partly filled sewers can be calculated from knowledge of velocity and depth of flow. This method consists of measuring a given length of sewer between two convenient points. A dye, such as methyl orange, is dropped into the higher point; the length of time for the dye to be observed at a lower point is recorded. Velocity in feet per minute is calculated by dividing distance in ft. by time in minutes.

Because dyes tend to diffuse rapidly, a heavy dose or slug of dye (10 grams of dry powder) should be used and time of passage of maximum intensity of color noted. The measurement should be taken at least three times and an average value used. The dye can be added as a solution as described on page 2.

Cork or wood floats will measure velocity in straight sewers almost as well as dyes. A correction factor can be applied to the surface velocity determined by a float to give the mean velocity of flow in the pipe. But this refinement is not necessary for approximating rates of flow.

Velocity can be measured also by current meters. This device was originally designed to measure velocity in flowing streams or rivers. A small-scale unit is available for pipe flows. A series of cups that rotate on a vertical axis, or a propellor that rotates on a horizontal axis, is turned by the moving water. The rate at which the cups or propeller rotate varies with the velocity of the water. Knowing the number of revolutions in a given time permits calculation of the velocity.

Depth of flow should be measured at the time when the velocity is determined. This measurement should be made as far into the sewer as possible to minimize effects of flow disturbance at manholes. Depth of flow can be converted into cross-sectional area of the water by the use of Table IV on areas of segments of sewer pipe. Flow in gallons per minute can then be calculated by multiplying area of the segment in square feet times velocity in feet-per-minute times 7.5. This method is not too accurate and should be used only as a last resort, or to estimate size of weir to be used.

$$\frac{\text{Distance in ft. x area in sq. ft. x 7.5}}{\text{time in minutes}} = \text{gallons per minute}$$

If the sewer is flowing too full to permit installing a weir, or if the sewer outlet—into either another sewer or into a stream—is under water, this method may be the most practical.

Salt Concentration — When physical characteristics of a sewer make weir measurements too difficult, an accurate rate-of-flow determination can be made as follows: Add a known strength sodium chloride (salt) solution at constant measured rate to the flow in the sewer. Then determine chloride concentrations at a lower point in the sewer after the salt has been well mixed in the flow of the sewer. The formula in this manual requires that chloride analyses be reported as sodium chloride.

A blank determination on the waste (measuring the salt concentration due to the waste itself) must be made first. This can be done by taking 5 or 6 samples at five-minute intervals before any salt solution is added and measuring the chlorides present. If the chloride concentrations in the blank vary widely—more than 10 ppm—this method is not recommended.

Finely divided salt may also be added dry by means of a continuous feeder. Such equipment would be used in plants where large volumes of waste are to be measured.

When salt is added to the waste flow at a known continuous rate in pounds per hour and the resulting salt concentration is measured, the flow can be determined by:

$$\frac{\text{lbs. per hr. of salt added x 2,000}}{\text{(ppm measured—ppm in blank)}} = \text{gallons per minute}$$

Example:

10 lbs. of salt were added to 10 gallons of water to prepare a salt solution.

Analysis of the waste waters for 6 samples at five-minute intervals gave an average sodium chloride concentration of 27 ppm (blank).

The salt solution was then added to the waste at the controlled rate of 4 gallons per hour—or 4 lbs. of salt per hour.

After addition of the salt solution the sodium chloride in the waste measured 62 ppm. The flow was:

$$\frac{\text{4 lbs. per hr. x 2,000}}{\text{(62 ppm—27 ppm)}} = \text{229 gpm}$$

Periodic checks on the blank determination should be made upstream from the salt feeder during flow studies.

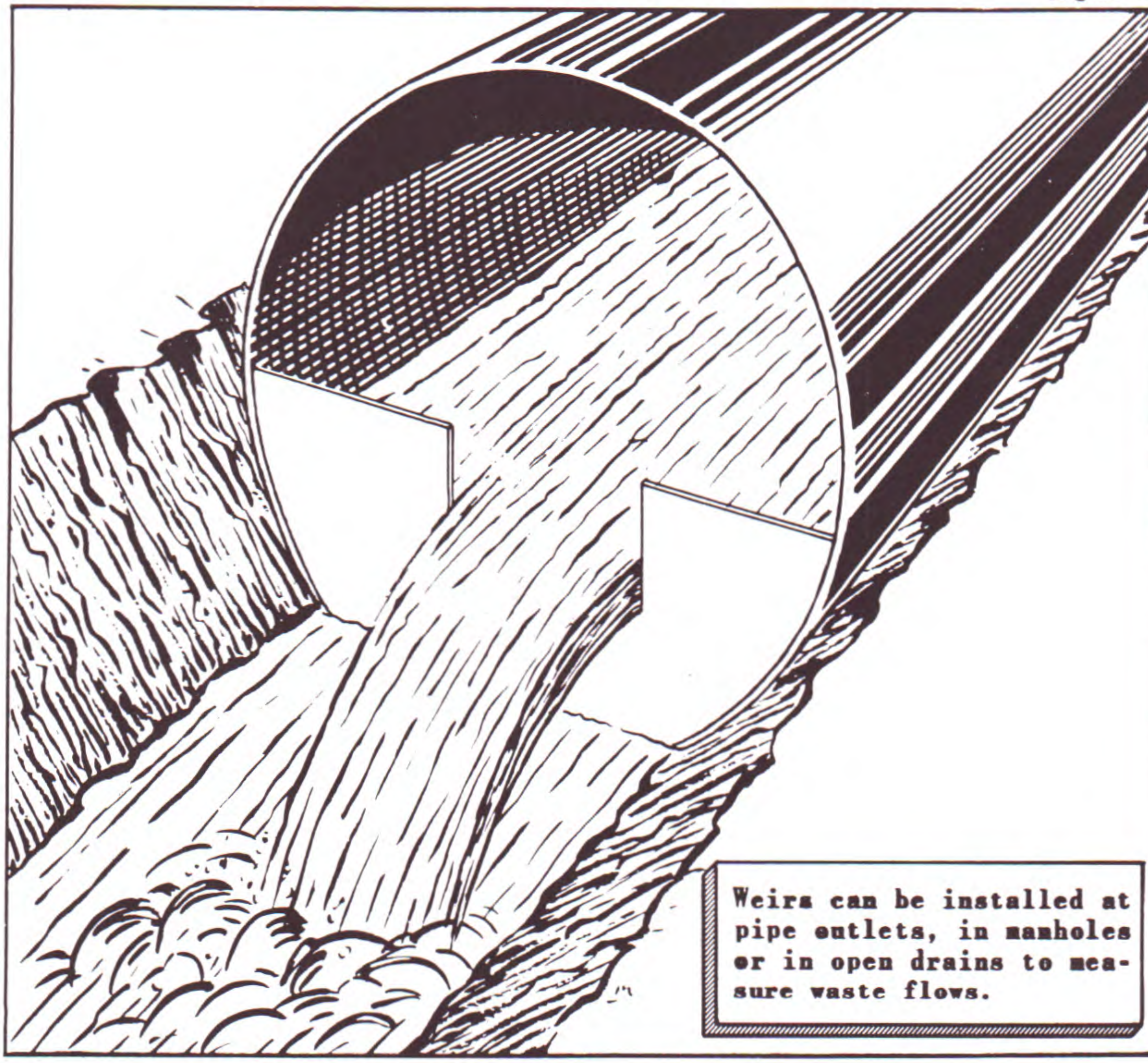
Weirs — The weir is a commonly used device for measuring waste flows. It is a dam, or other obstruction over which water flows placed in a pipe, channel or stream. Sometimes the water does not flow over the dam but through a notch cut in the top of the dam. In this case the notch is the weir (Fig. 6). These notches are usually cut as a V or a rectangle. The notch in either must be cut square to the surface of a thin plate, or as a sharp crest at the upstream side of a thick plate (Figs. 7, 8, 9).

The crest on the weir is the level to which water must rise before it can flow over the weir. It is the top of the dam or the bottom of the notch cut in the dam. The head on the weir is the height of the water surface in the pool upstream from the weir above the crest of the weir. The head on the weir is shown as H in Fig. 7.

Considerations for accurate weir measurements include:

(1) *The weir crest must be sharp or at least square-edged,* and the plate not too thick. While metal produces the most accurate results because it can be cut to a sharper

Figure 6



Weirs can be installed at pipe outlets, in manholes or in open drains to measure waste flows.

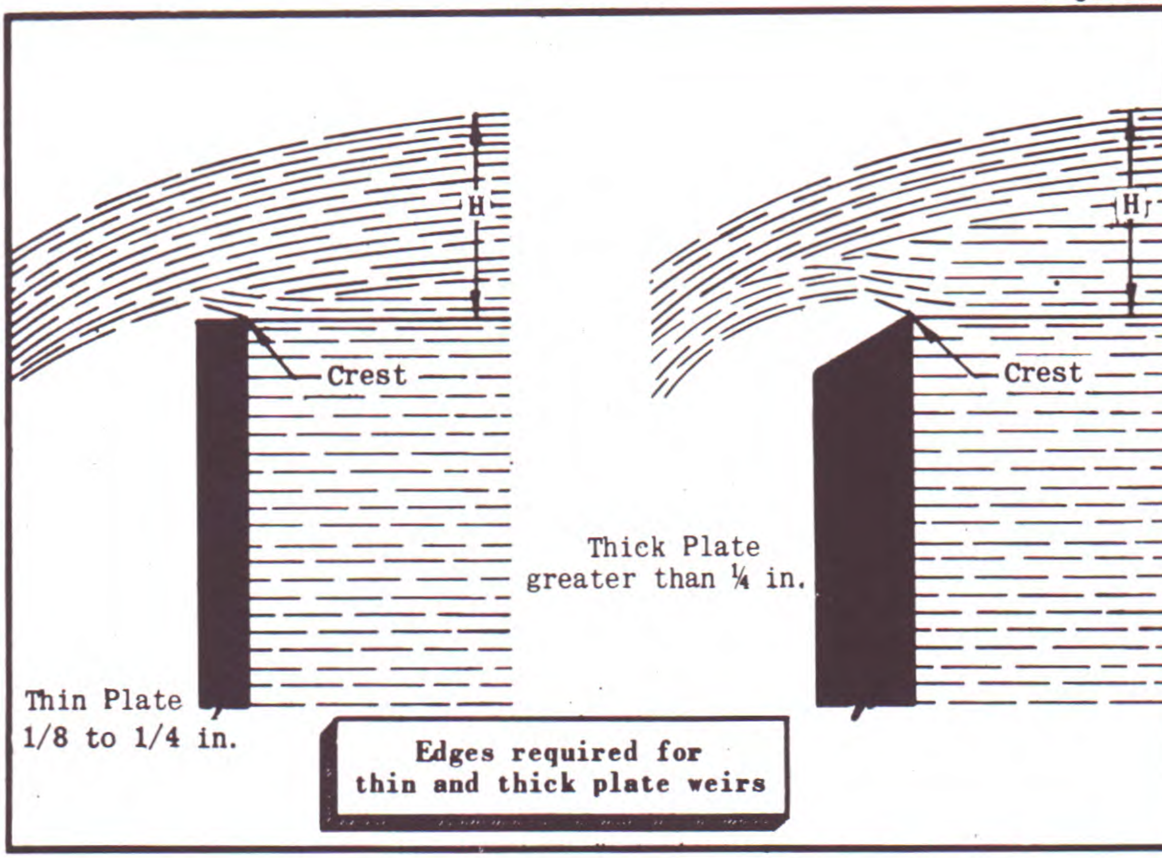
edge, a thin straight board will provide sufficient accuracy in most cases. For low heads a knife-edge crest is necessary. Metal weir plate is usually 1/8 to 1/4 in. thick. If properly supported, stiff sheet-metal can give as satisfactory results as expensive brass weirs.

The distance of the crest of the weir above the bottom of the channel should be at least 2.5 times the head on the weir so as to reduce velocity of approach to a negligible value (Fig. 9).

(2) *All weirs must be ventilated*—that is, air must have access to the underside of the falling water. Otherwise the water will cling to the downstream face of the weir instead of falling free. Weir formulas in this manual have been prepared assuming free fall. If this condition is not met, rate of discharge will be increased greatly and the formulas are not valid.

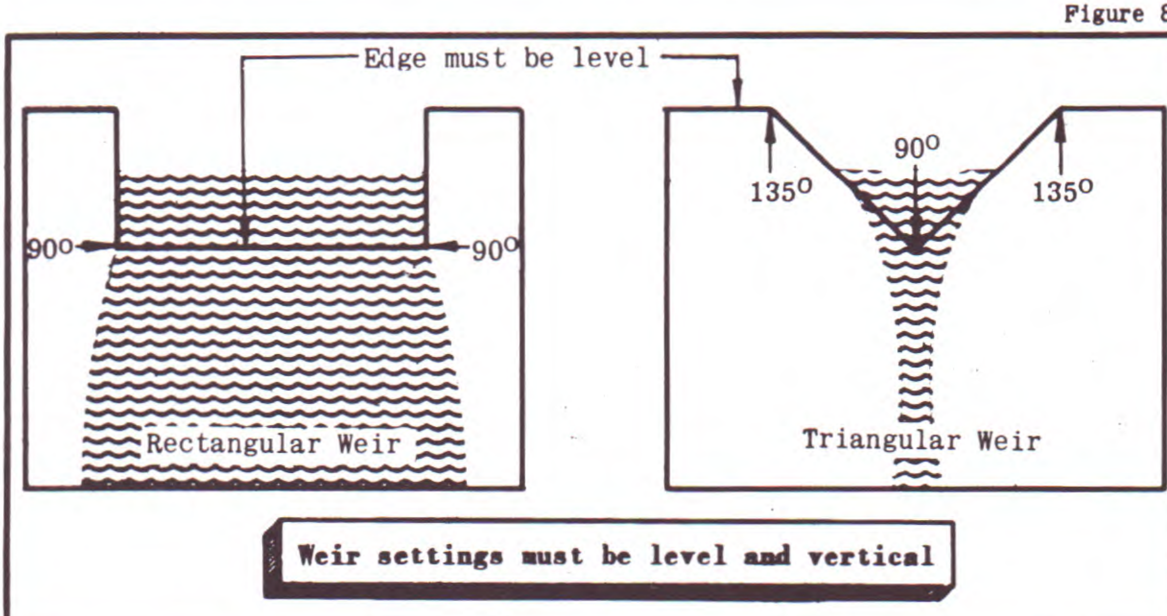
When the weir is constructed as a dam across the full width of the channel, it is known as a suppressed weir. But when the weir is a notch cut in the dam, the end walls are known as end contractions. These end contractions reduce the width of the channel of flow as it passes over the

Figure 7

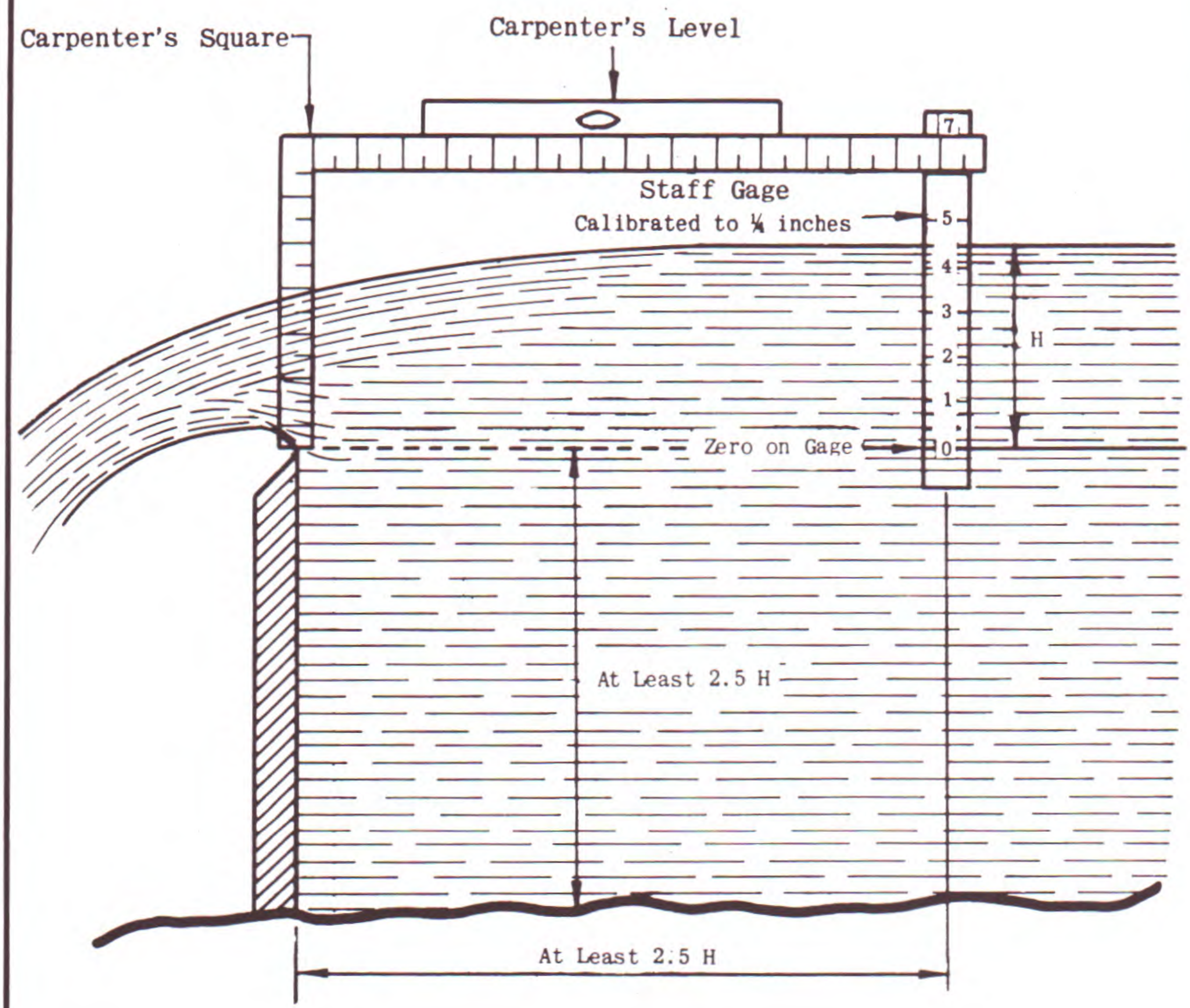


Edges required for thin and thick plate weirs

Figure 8



Weir settings must be level and vertical



A gage, marked off in inches, can be "zeroed in" to the crest of the weir with a carpenter's square and level. The gage provides a reliable and fixed measuring device. Irregularities in the bed of the channel or weir box, do not affect the measurements of the head on the weir.

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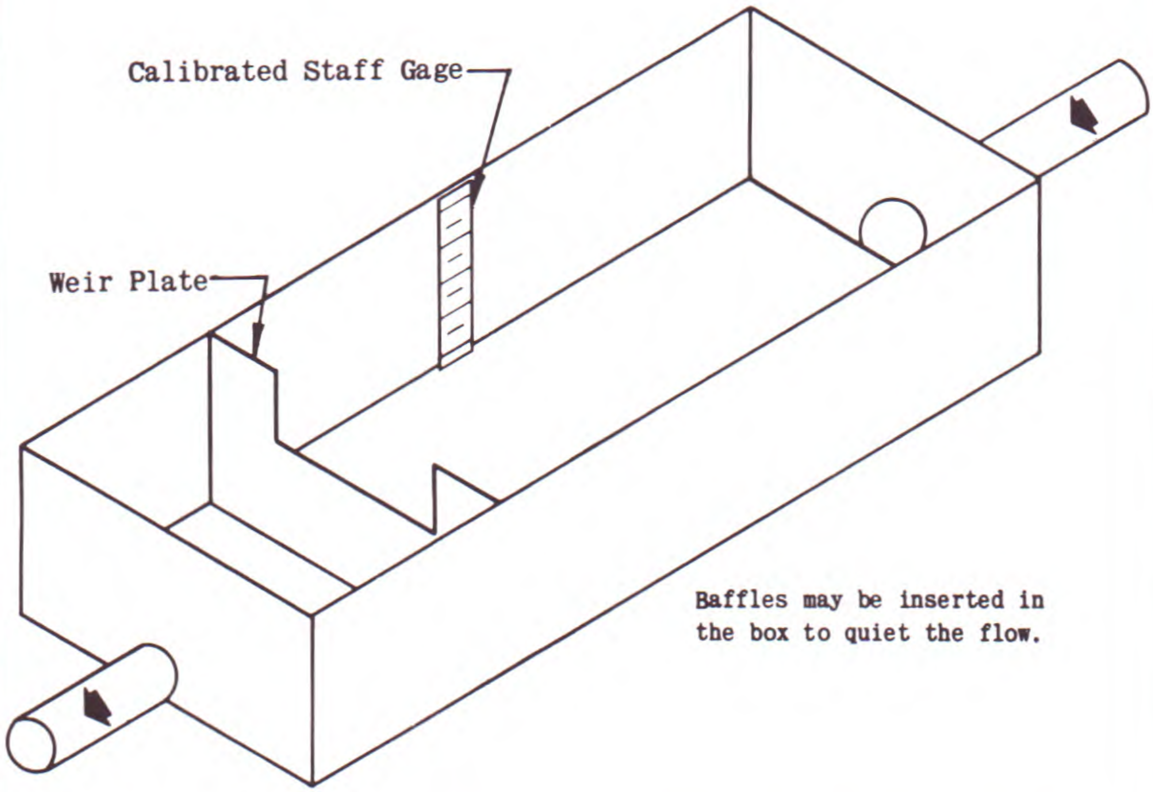
Figure 10



Typical weir-stilling box. Dimensions can be varied to suit plant conditions so long as quiet flow can be effected.

weir and provide the needed ventilation (Fig. 12).

Weirs with no end contractions (suppressed weirs) provide a crest across the full channel width. This type weir is preferred by some because it removes consideration of the effects of end contractions. Suppressed weirs are not described in this manual because of the difficulties in installing this type of weir in sewers and in measuring the lower flows.

(3) *Seal off leaks around the weir plate.* The joint between weir plate and conveying channel should be packed with a chemically inert cement or asphalt-type roofing compound. Grease compounds should be avoided where oil determinations are to be made on the waste. Sand bags can be used on larger weir installations.

(4) *The weir must be exactly level* to insure a uniform depth of flow. The faces of weirs must be plumb. (Fig. 8)

(5) *Weirs must be kept clean.* Sediment should not be allowed to collect back of

the weir. Rust or scale on the weir plate also tends to affect the discharge. Debris collecting on the weir will destroy its accuracy.

(6) *Measure the head on the weir upstream from the weir at a distance of at least 2.5 times the head on the weir.* For extreme accuracy the head should be measured in a stilling box. This may not be possible in a plant survey and is usually not necessary.

A staff gage for measuring the head on a weir can be set as shown in Figs. 9 and 10.

(7) *The channel upstream from the weir should be straight,* reasonably level and free from all disturbing influences for a sufficient distance to permit the stream to assume quiet flow. This can be accomplished by use of a weir stilling box. In the ordinary plant survey construction of stilling boxes is not practical. Usually the upstream disturbances will not unduly affect the accuracy of the waste survey. When the sewer is flowing full or nearly full, use of a weir requires construction of a weir box at the outfall.

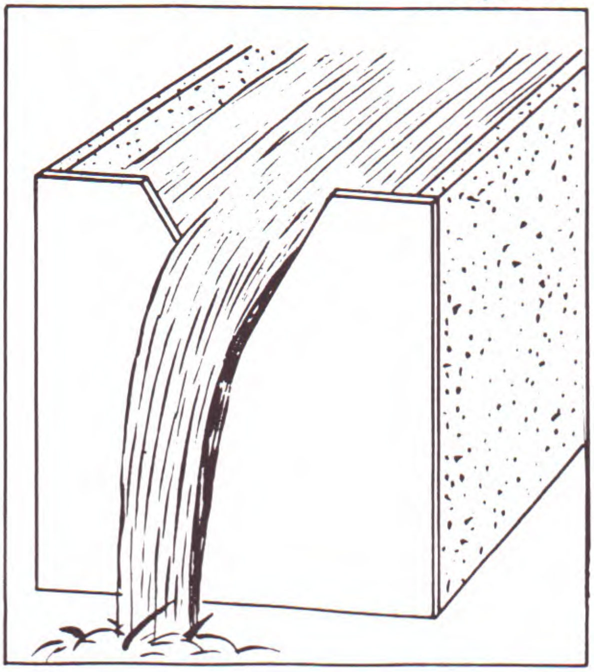
(8) *Select the weir size after approximating the rate of flow by other methods of measurement.* The head on any weir should be greater than 0.2 ft. (about 2½ in.) but preferably not more than 2 ft. Values below 0.2 ft. give large percentage errors with small differences in reading. The width of the weir should be chosen so as to permit at least that head. Heads on the weir greater than 0.2 ft. minimize the effects of variation in velocity in the water at different depths as the water approaches the weir and thus reduces error in the results. However, it is possible to make weir flow measurements with a head between one inch and two and one-half inches if a notched weir is used with extra care. For this reason the tables in this manual were developed to include heads less than 0.2 ft.

The width of the end contractions for rectangular weirs should be at least 2.5 times the head of the weir. The diagram in Table VI denotes this by dimension "a". In sewers this may not be possible and use should be made of a weir with modified end contractions and Table VII.

The tables in this manual are developed from formulas that are expected to supply answers accurate within 10% if reasonable care is exercised in installation and reading. This is accurate enough for most waste problems.

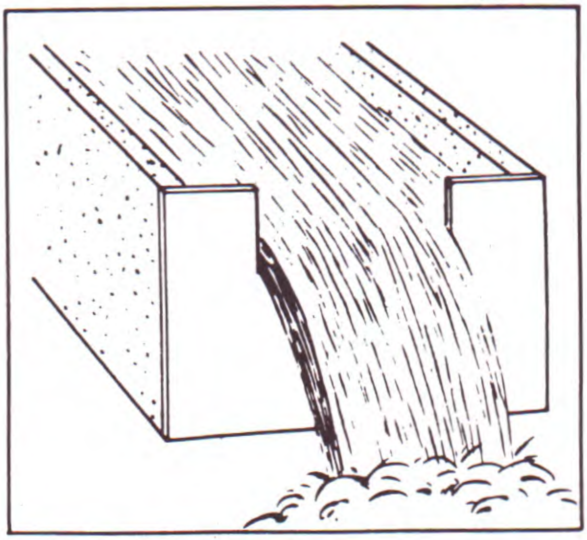
Coefficients in weir formulas vary. Experimental study has demonstrated that the effects of roughness of weir plate, depth of channel of water approaching the weir with relation to head of water passing over the weir, thickness of plate in which weir is cut, velocity of flow in water being measured, viscosity, density and temperature of liquid make it difficult to assign a precise coefficient for a specific application. For general application the coefficients for weirs in this manual are practical.

Figure 11



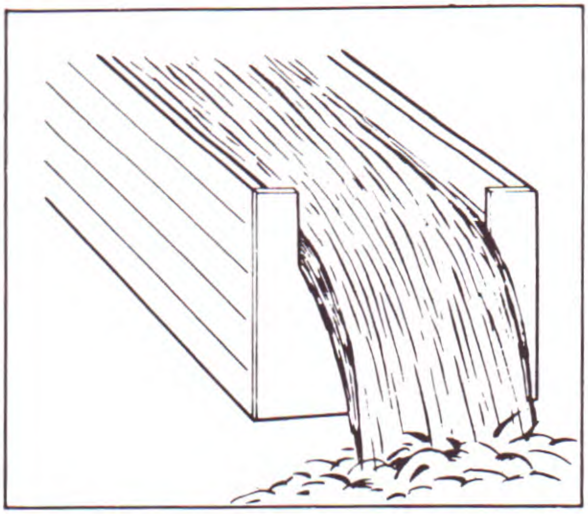
Triangular or V-notch weir — Although 60-degree notch weirs are in use, the more common V-notch weir is cut to 90-deg. This manual considers only the 90-deg. weir (Fig. 11). The triangular weir gives greater heads for a given discharge than does a rectangular notch of the same width at the water surface. The greater sensitivity of the V-notch is useful in measuring relatively small rates of discharge. For discharges above 900 gpm excessively high heads are required and rectangular weirs should be used. Consideration of maximum expected head then controls the use of this weir. The data in Table V give discharge in gpm for various heads on a 90-deg. notch weir.

Figure 12



Rectangular weir with standard end contractions — End contractions are walls at the sides of the weir which make the weir narrower than the channel of the stream. The rectangular weir with standard end contractions (Fig. 12) is used where a 90-deg. notch weir would require too great a head. The contractions are standard when the dimensions conform with the minimum dimensions allowable for such a weir as shown in the diagram in Table VI. The discharge data in that Table are given in gpm.

Figure 13

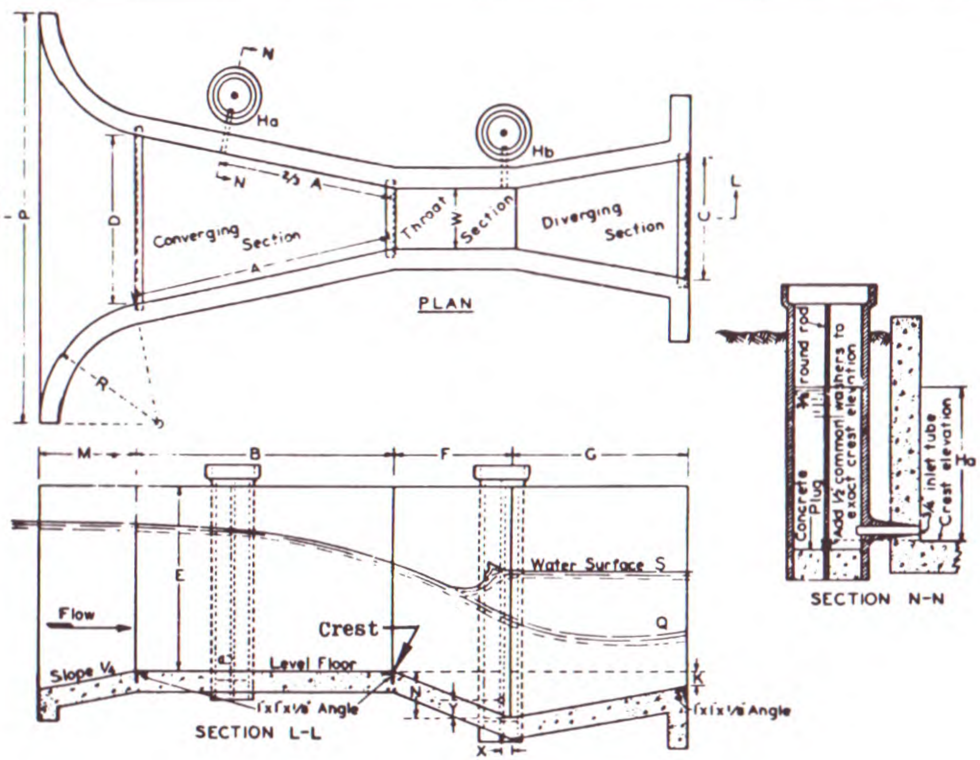


Rectangular weir with modified end contractions — When there is insufficient channel width to insert a rectangular weir with standard end contractions, or available height is too small to permit the use of a triangular weir, the weir shown in Fig. 13 and Table VII can be used. The data in Table VII are reasonably accurate as long as the end contractions are wide enough to maintain an air space between the sheet of falling water and the downstream face of the weir.

Parshall flume—A Parshall flume can be built when there is need for continuous measurement of open-channel waste-water flows at or near surface of the ground. It is not recommended for small plants. This device can be made of metal, concrete, or wood. Its accuracy is dependable within a degree sufficient for control of waste-treatment facilities. Accuracy is maintained, moreover, when the flume is measuring either free-flow discharge or submerged flows. Maintenance of the unit itself is minimized by its inherent ability to clean itself of sludge or rust which often collects back of weirs and interferes with measurements. While the unit lends itself to continuous recording of flows, the discharge can be measured manually. The hydraulic head loss through a Parshall flume is very small. This makes the flume most useful when there is a minimum allowable head loss in a sewer or channel.

The Parshall flume consists of a converging section, a throat, and a diverging section as shown in Fig. 14. The floor of the converging section must be level; but the floor of the throat is inclined downward from the horizontal and the floor of the diverging section inclined upward at definite slopes. Dimensions for various size flumes are given in the chart accompanying the sketch. The size is taken as the horizontal distance between the vertical walls of the throat and is the same as the length of the crest of water through the throat. This chart also defines the limits of range in flow measurements for any particular size flume under condition of free flow.

Flow through a Parshall flume is either free flow or submerged flow. Where water-surface elevation downstream from the flume is high enough to retard the rate of discharge, submerged flow exists. Any backwater in the channel downstream raises the level of the water surface (as to S in Fig. 14), causing a marked reduction in the velocity of water as it leaves the flume. This condition of submerged flow is evidenced by a ripple or wave formed at or just downstream from the end of the throat.



LEGEND

W	Size of flume, in inches or feet.
A	Length of side wall of converging section.
2/3 A	Distance back from end of crest to gage point.
B	Axial length of converging section.
C	Width of downstream end of flume.
D	Width of upstream end of flume.
E	Depth of flume.
F	Length of throat.
G	Length of diverging section.
K	Difference in elevation between lower end of flume and crest.
M	Length of approach floor.
N	Depth of depression in throat below crest.
P	Width between ends of curved wing walls.
R	Radius of curved wing wall.
X	Horizontal distance to Hb gage point from low point in throat.
Y	Vertical distance to Hb gage point from low point in throat.

Dimensions and capacities of the Parshall measuring flume, for various throat widths, W

W	A	2/3 A	B	C	D	E	F	G	K	N	R	M	P	X	Y	Free-flow capacity	
																Minimum	Maximum
Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	In.	In.	Ft. In.	Ft. In.	Ft. In.	In.	In.	Sec.-ft.	Sec.-ft.
0 3	1 6 3/8	1 1/4	1 6	0 7	0 10 3/16	2 0	0 6	1 0	1	2 1/4	1 4	1 0	2 6 1/4	1	1 1/2	0.03	1.9
0 6	2 7/16	1 4 5/16	2 0	1 3 1/2	1 3 5/8	2 0	1 0	2 0	3	4 1/2	1 4	1 0	2 11 1/2	2	3	.05	3.9
0 9	2 10 5/8	1 11 1/8	2 10	1 3	1 10 5/8	2 6	1 0	1 6	3	4 1/2	1 4	1 0	3 6 1/2	2	3	.09	8.9
1 0	4 6	3 0	4 4 7/8	2 0	2 9 1/4	3 0	2 0	3 0	3	9	1 8	1 3	4 10 3/4	2	3	.11	16.1
1 6	4 9	3 2	4 7 7/8	2 6	3 4 3/8	3 0	2 0	3 0	3	9	1 8	1 3	5 6	2	3	.15	24.6
2 0	5 0	3 4	4 10 7/8	3 0	3 11 1/2	3 0	2 0	3 0	3	9	1 8	1 3	6 1	2	3	.42	33.1
3 0	5 6	3 8	5 4 3/4	4 0	5 1 7/8	3 0	2 0	3 0	3	9	1 8	1 3	7 3 1/2	2	3	.61	50.4
4 0	6 0	4 0	5 10 5/8	5 0	6 4 1/4	3 0	2 0	3 0	3	9	2 0	1 6	8 10 3/4	2	3	1.3	67.9
5 0	6 6	4 4	6 4 1/2	6 0	7 6 5/8	3 0	2 0	3 0	3	9	2 0	1 6	10 1 1/4	2	3	1.6	85.6
6 0	7 0	4 8	6 10 3/8	7 0	8 9	3 0	2 0	3 0	3	9	2 0	1 6	11 3 1/2	2	3	2.6	103.5
7 0	7 6	5 0	7 4 1/4	8 0	9 11 3/8	3 0	2 0	3 0	3	9	2 0	1 6	12 6	2	3	3.0	121.4
8 0	8 0	5 4	7 10 1/8	9 0	11 1 3/4	3 0	2 0	3 0	3	9	2 0	1 6	13 8 1/4	2	3	3.5	139.5

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Source: Circular 843, U.S. Dept. of Agriculture

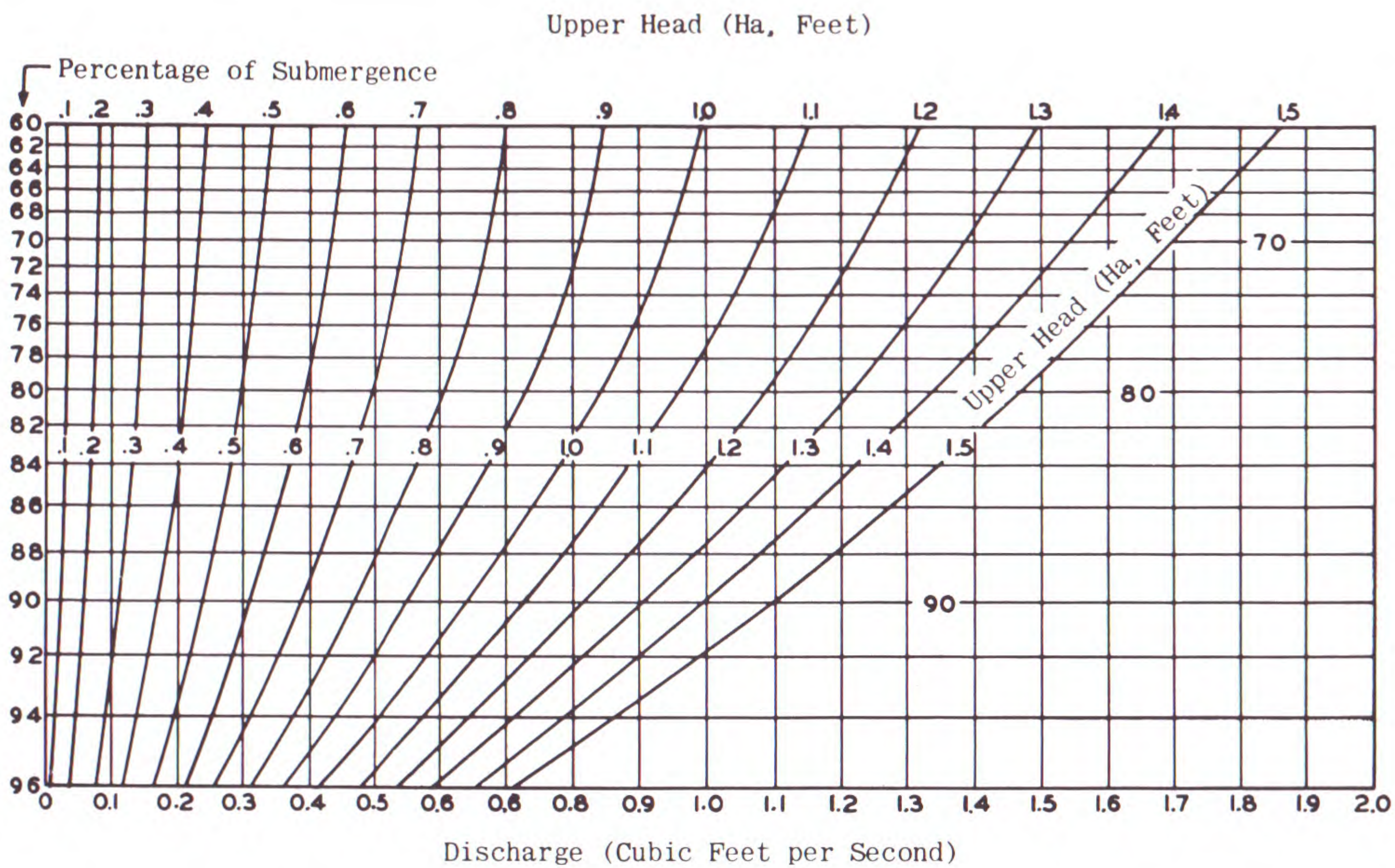

Diagram showing rate of submerged flow in cubic feet per second through a 3 inch Parshall measuring flume

Note: Cubic feet per second x 449 = gallons per minute

Figure 15

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Figure 16

Source: Circular 843, U.S. Dept. of Agriculture

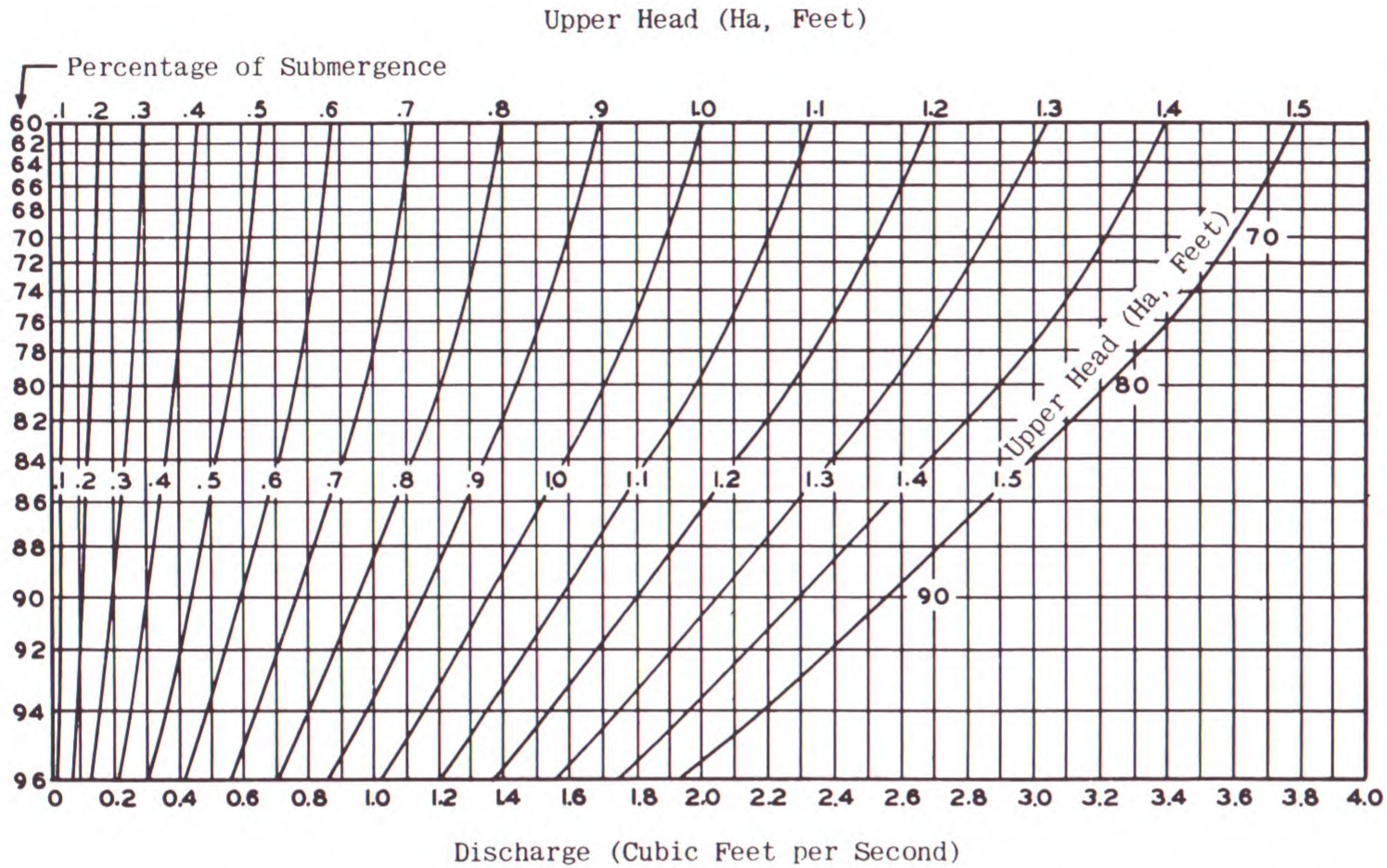

Diagram showing rate of submerged flow in cubic feet per second through a 6 inch Parshall measuring flume

Note: Cubic feet per second x 449 = gallons per minute

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Source: Circular 843, U.S. Dept. of Agriculture

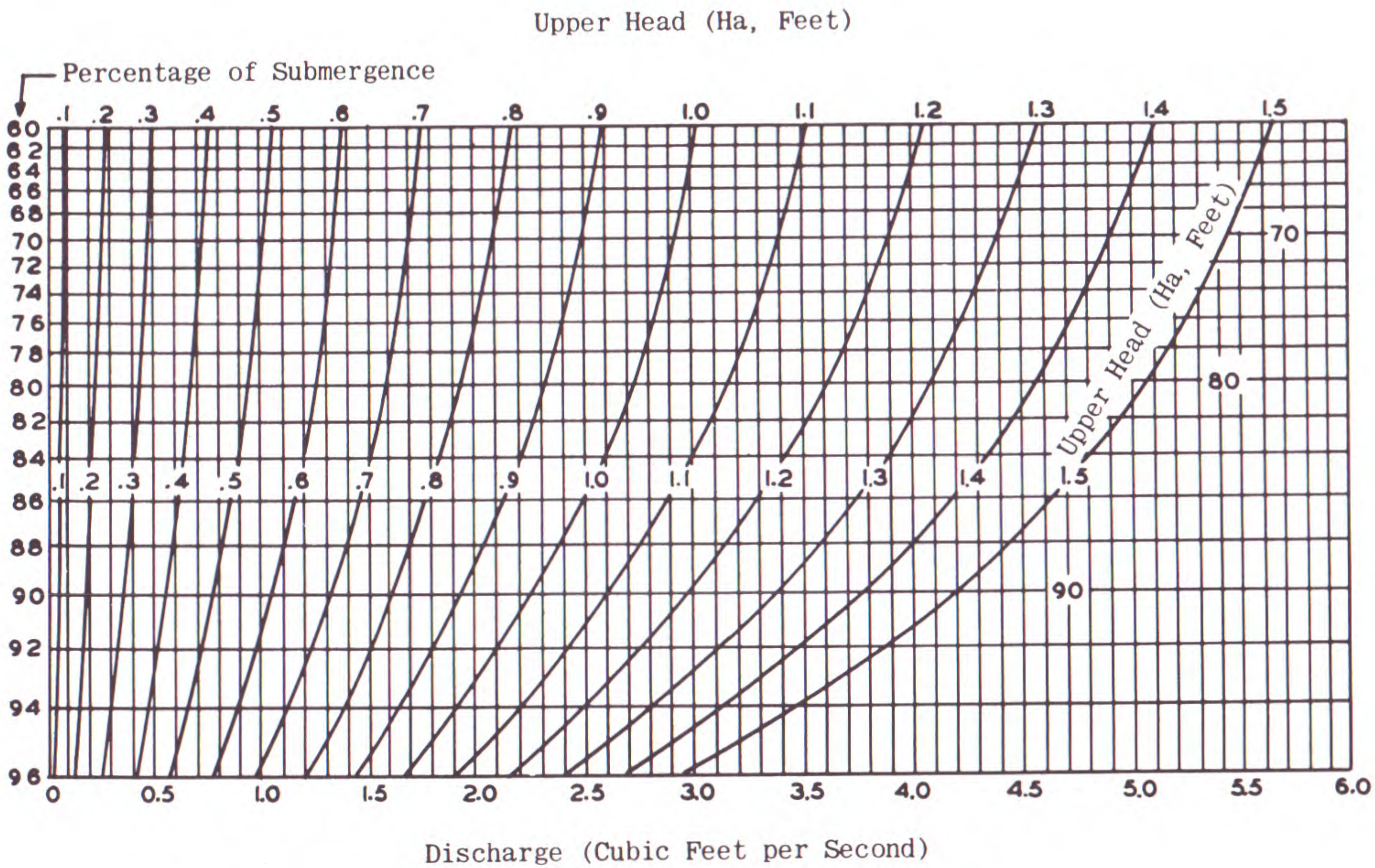

Diagram showing rate of submerged flow in cubic feet per second through a 9 inch Parshall measuring flume

Note: Cubic feet per second x 449 = gallons per minute

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Source: Circular 843, U.S. Dept. of Agriculture

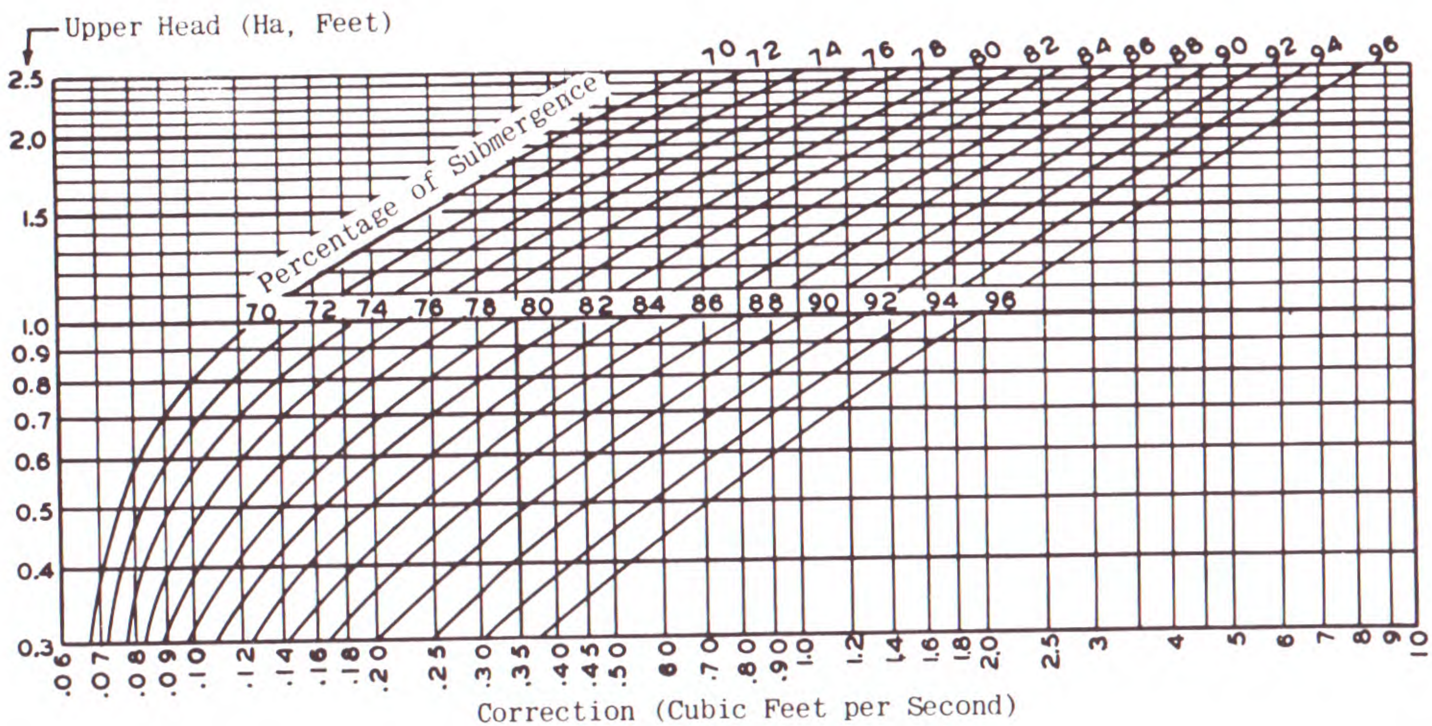

Diagram showing rate of submerged flow in cubic feet per second through a 1 foot Parshall measuring flume

Note: Cubic feet per second x 449 = gallons per minute

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When there is no backwater effect, water passing through the throat and diverging section assumes a level (as Q in Fig. 14). The surface of the liquid corresponds to the floor of channel. This flow pattern demonstrates free-flow.

The Parshall flume can measure discharge under both conditions, but it is necessary that the degree of submergence be determined. Reduction in velocity of water leaving the flume under condition of submergence reduces the erosion effect on the bed and the banks of the channel and also lessens the hydraulic head loss through the structure. These effects may be important.

Rate-of-flow under conditions of submergence can be computed from readings taken on both gages, H_a and H_b as shown in Fig. 14. The upper gage H_a, located at a point two-thirds the length of the converging section measured back from the crest of the flume, will provide the necessary measurement for free-flow discharge. The crest is at the junction of throat and converging sections. When submerged, the flow can be measured if a second reading is taken from gage H_b which is located near the downstream end of the throat section. Both gages are referenced to the crest of the flume (the elevation of the level floor) as a datum.

Degree of submergence is indicated by the ratio of the gage heads H_b/H_a. As long as this ratio does not exceed 0.70 for the 1 to 3 ft. flumes, or 0.60 for the 3, 6, and 9 in. flumes, free flow exists and rate of discharge can be taken directly from Table VIII. When the ratio is greater than these values, the indicated discharge must be lessened because of the effect of submergence. For flumes of one foot or greater, a correction value is computed by use of the diagram in Fig. 18 (computed for a one-foot flume), and then by multiplying by the factor (M) given in Table I, (which will make the correction applicable to the large flumes). Corrected discharge values for 3, 6, and 9 in. flumes are taken directly from the diagrams in Fig. 15, 16 and 17.

Table I—Correction Factors for Submerged Flow (Circular 843, U. S. Dept. of Agriculture)

Size of flume W (ft.)	Multiplying factor, M
1	1.0
1.5	1.4
2	1.8
3	2.4
4	3.1
5	3.7
6	4.3

Formula for Free Discharge from a Parshall Flume

$Q = 4\ W\ H^n$

where

$n = 1.522\ W^{0.026}$

Q = discharge, cu. ft. per sec.

W = throat width, ft.

H = head of water above level floor, ft.

Parshall flume examples—Application of the tables and diagrams are given in these examples:

Determine the discharge through a one-foot flume when gage readings are:

$H_a = 1.60$ ft. $\qquad H_b = 1.44$ ft.

$$\text{The ratio } \frac{H_b}{H_a} = \frac{1.44}{1.60} = 0.90 \text{ or } 90\%$$

In Fig. 18 for a reading of $H_a = 1.60$ ft. and 90% of submergence, the correction is 2.2 cubic feet per second (cfs) or

$2.2 \times 449 = 986$ gpm

Free discharge for $H_a = 1.60$ ft.
is taken from Table VIII as 3,670 gpm.

Submerged-flow discharge is thus:

3,670 gpm — 986 gpm = 2,684 gpm, say 2,700.

If the above readings were taken on a 3-ft. flume, the correction determined for the one-foot flume (986 gpm) is multiplied by the factor (M) 2.4, taken from Table I. The total correction is

$2.4 \times 986 = 2,365$ gpm

Free-flow discharge for a 3-ft. flume (Table VIII) when $H_a = 1.60$ ft. is 11,240 gpm.

Subtracting the correction gives the submerged flow:

11,240 gpm — 2,365 gpm = 8,875 gpm, say 8,900.

For flumes less than one foot in throat width the submerged flow is obtained directly from Figs. 15, 16, or 17.

Determine the discharge through a 6-in. flume when $H_a = 0.82$ ft. and $H_b = 0.68$ ft.

$$\text{Ratio } \frac{H_b}{H_a} = \frac{0.68}{0.82} = 0.83 \text{ or } 83\%$$

From Fig. 16, the computed discharge is determined. The percentage of submergence is shown on the ordinate. Values for H_a are given on the curves. The intersection of the $H_a = 0.82$ ft. (extrapolated between 0.8 and 0.9 lines) and 83% submergence (extrapolated between 83% and 84%) gives a reading of 1.2 cfs which is taken from the bottom (abscissa) of the graph. This is converted to gpm and the flow is:

$1.2 \times 449 = 539$ gpm, say 540.

When the rate-of-flow of the waste is measured, samples for analysis are collected. The reliability of the waste survey depends not only on the accuracy of the flow measurements but also — and equally — on the careful collection of samples representative of the waste.

Sampling precautions — Some suggestions on sample collection:

Sample container and sampling device should be clean and flushed out with water.

Collect in center of channel of flow.

Take a full dip of waste to get representative portion.

Avoid excessive grease or scum in sample.

Watch out for poisonous gases in manholes.

Watch for batch dumpings. The schedule of sampling should include a consideration of batch dumpings. A check of the plant processes should be made to see that no unusual waste loads, such as batch dumping of tanks, occur during the sampling period.

In most cases for accuracy in defining total waste load, batch tanks should not be dumped into the continuous flow. Each tank should be measured individually for volume and concentrations. Batch loads are measured individually because they are high in waste concentration, short in duration and are dumped irregularly, and therefore greatly affect average waste concentrations.

Samples should be iced during warm weather to prevent decomposition of organic wastes.

When compositing samples in other containers, mix contents before pouring.

Time interval — Degree of variation in rate-of-flow determines the time interval of sampling. This interval must be short enough to provide a true picture of the flow. Even when there is little variation in rate-of-flow, concentration of contaminants may vary widely. Frequent sampling permits determination of average concentration during period of sampling. The time interval between taking samples should be 10 or 15 minutes. Sampling results may demonstrate that a longer interval can be used but it should never exceed one hour—and it should always be uniform. Unless you get a truly representative sample your efforts will be wasted.

Grab samples—A grab sample is a manually collected single portion of the waste. An analysis of a grab sample shows the concentration of the constituents in the waste *at the time when the sample was taken.*

The volume of individual grab samples will depend on the volumes required for the analyses to be made. If the grab sample is to be composited, the volume collected must be more than needed for the proportional part of the composite sample. Usually a quart sample will be sufficient.

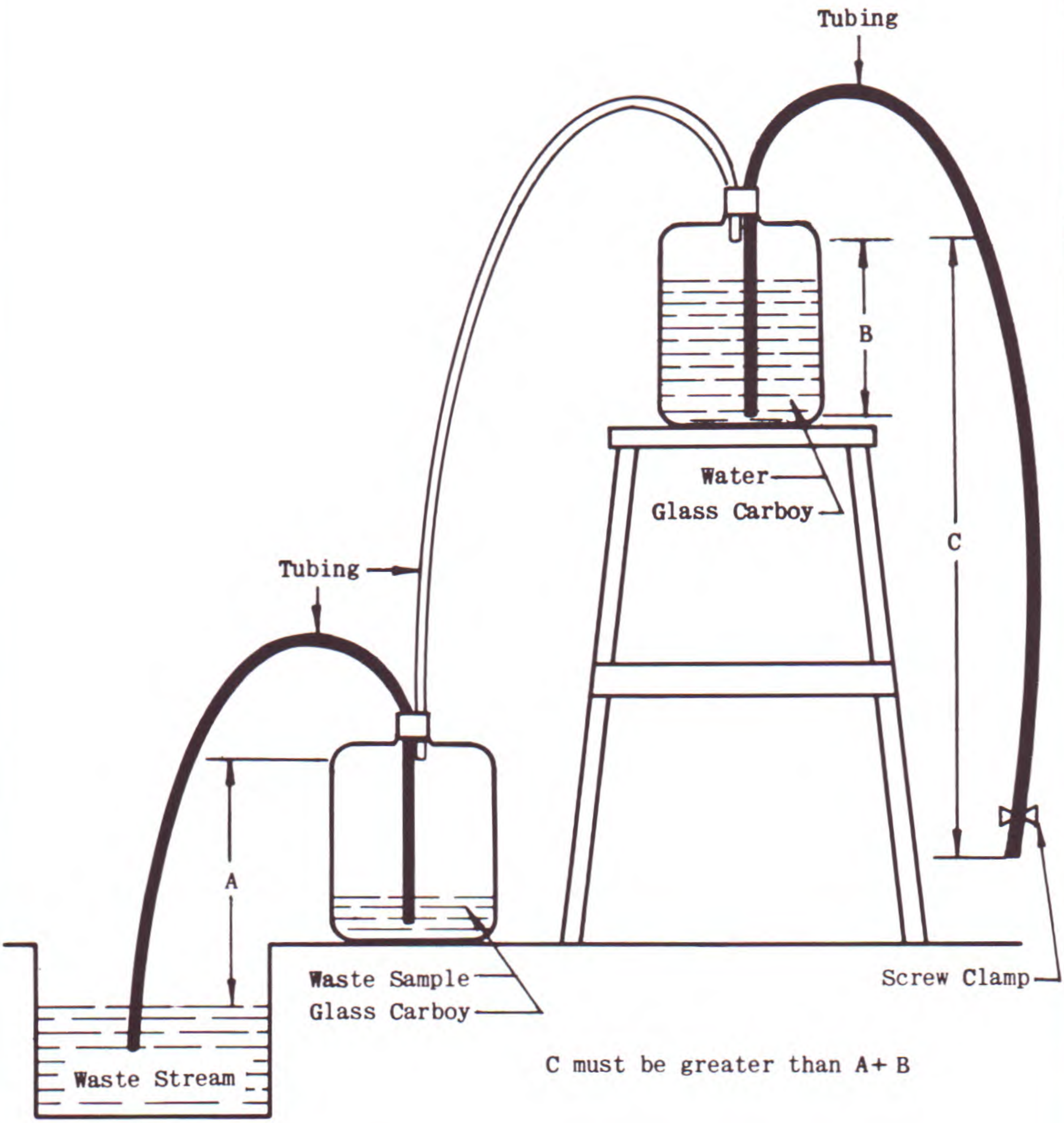
Use of a wide-mouth jar is recommended because it permits faster collection of the sample.

Continuous sampling — When several points are to be sampled at frequent intervals, or when a continuous record of waste at a given sampling station is required, it may be more convenient to install an automatic sampler. The installation cost is offset by the savings on labor required for manual collection. An added benefit is reduction of possibility of errors inherent in manual collection.

Continuous samplers are marketed commercially. Such samplers must be examined carefully to see that they are suitable for the wastes. A sampler intended to collect acid wastes, for example, would have to be constructed of non-corrodible materials. Continuous samplers require frequent inspection and cleaning to be reliable.

Some commercial samplers collect a given volume of sample at definite time intervals; this is satisfactory where volume of waste is constant. Others take the samples at variable rates in proportion to changing rates-of-flow of the waste. For the latter a flow-measuring device is necessary. But such a device can also be used in conjunction with a constant-volume sampler. When samples are composited, the volume taken from each individual sample collected is proportioned to the flow recorded on the flow meter.

Conditions peculiar to each plant waste—spe-



Continuous Sampler -- This simple jar-and-tube set-up samples waste effectively when flow is nearly constant. As water drains from the upper carboy, the vacuum created siphons waste into the lower one. The rate-of-flow is regulated by the pinch clamp to fill the lower carboy during the sampling period.

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cific gravity, corrosivity, floating solids, or other physical characteristics of the waste, depth of flow, height to which sample must be lifted—may limit the selection of a commercial sampler or even require that a unit be designed for the individual installation. The units shown in Fig. 19-23 illustrate principles that may be adapted to such cases.

The airlift automatic sampler shown in Fig. 21 is applicable to liquids that do not contain solids which would plug the inlet opening. When the compressed air supply is shut off (Fig. 20) the spring in the sampler raises the piston. This opens the inlet port and a portion of the waste water enters the sampler. The air valve is then opened and the piston is forced down closing the inlet. Compressed air then passes through the air escape port into the main part of the sampler and forces the liquid up the sample line to the collecting container. The air supply is then cut off and the cycle is repeated.

Automatic samplers should not be used to collect composite samples that change in composition before analysis is made. An example is cyanide in acid wastes. A check on the precautions to be taken in preparing a sâmple for analysis for each contaminant in the waste will suggest the advisability or limitations of an automatic unit. Automatic samplers can be used to collect grab samples for analysis of contaminants that change in composition with time.

Types of samplers—Some samplers use.a scoop or ladle as a means for removing small portions of flowing waste; rotating scoops resembling twisted arms travel around a pipe-shaft axis, scooping up a sample from a small weir compartment and draining it through the hollow shaft into a composite sample bottle. A timing device regulates the speed of the rotating scoop in proportion to the flow of waste.

Another device uses a scoop sampler mounted on a frame which can be used upstream from a weir or flume. The scoop is rotated at constant rate. Where variable flows are encountered the scoop is designed to automatically grab a varying size sample proportional to the flow. As the head on the weir notch increases the scoop takes a larger sample. Formulas have been developed by Messrs. Gard and Snavely for the design of this type scoop. The unit can be designed to collect a composite sample when the approximate maximum and minimum heads on the weir are known. This equipment can also be time-clocked for constant rate sampling or intermittent sampling on uniform flows of waste.

Another automatic sampler consists of a motor-driven wheel or disc, mounted on a frame, and supporting a number of freely suspended buckets. The small buckets are mounted along the spokes of the wheel at varying distances from the axis so that increased head on the weir will cause more buckets to be filled and result in a proportional increase in the sample being collected. The wheel can be regulated to rotate at given time intervals to prevent overflow of the sample bottle.

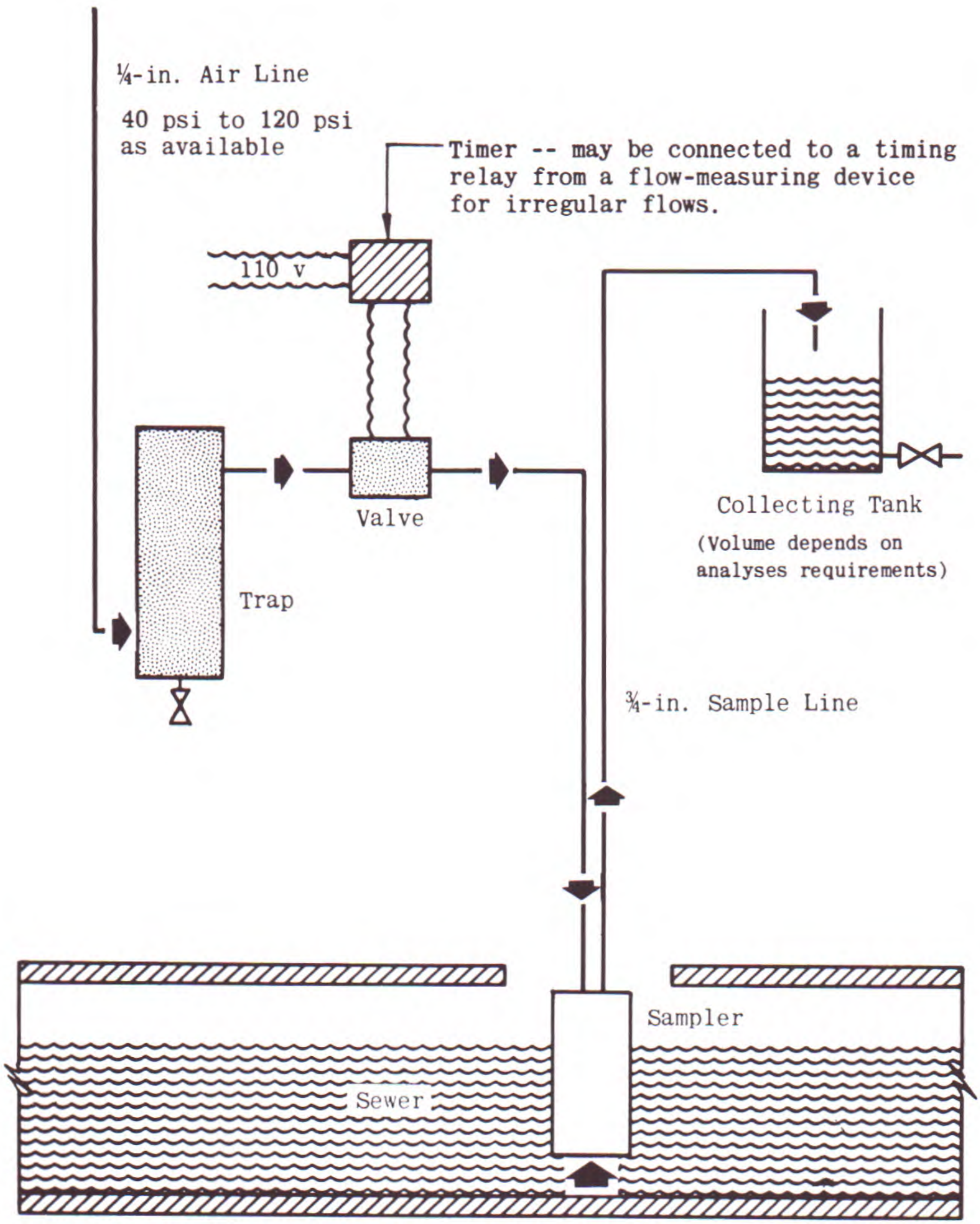
Chemical-feed injection pumps are used to withdraw samples from sewers by reversing their action. The use of this pump is limited to soluble wastes. These pumps usually operate on the pulsation principle causing small volumes of chemical solutions to be injected into flowing water under pressure. Because they are capable of metering small doses of liquids, they are suitable, in many cases, for withdrawing samples of waste from sewer lines. With a timer they can be made to run longer during heavy flow periods and thus sample in proportion to flow when compositing the sample. These feed pumps are usually provided with adjustable stroke and variable-speed features to regulate the volume of sample being collected.

There are several commercial devices designed to continuously record rates-of-flow. These units are used in conjunction with the methods of flow measurement described in this manual. The rate-of-flow recorder or totalizer can be connected to a sampler device to make possible proportionate sampling.

Composite samples—When rate-of-waste-flow is variable, volumes of the several samples are mixed together in proportion to flow. This is done to provide a composite sample representative of the waste discharged.

Sample volumes must be proportional to rate-of-flow of waste. If a composite sample is collected during a 24-hour period, the total volume of waste in the sample must represent the total volume of waste being discharged.

Size of sample should be determined after a check on measuring rates-of-flow. The composite sample gives a weighted average of the amount of waste, if the size of the sample taken at each measurement of rate-of-flow is proportioned to the rate-of-flow. A gallon sample (3,785 milliliters) usually is sufficient for a complete analysis.



An air-lift automatic sampler (See Fig 21) can be used to lift samples out of sewers.

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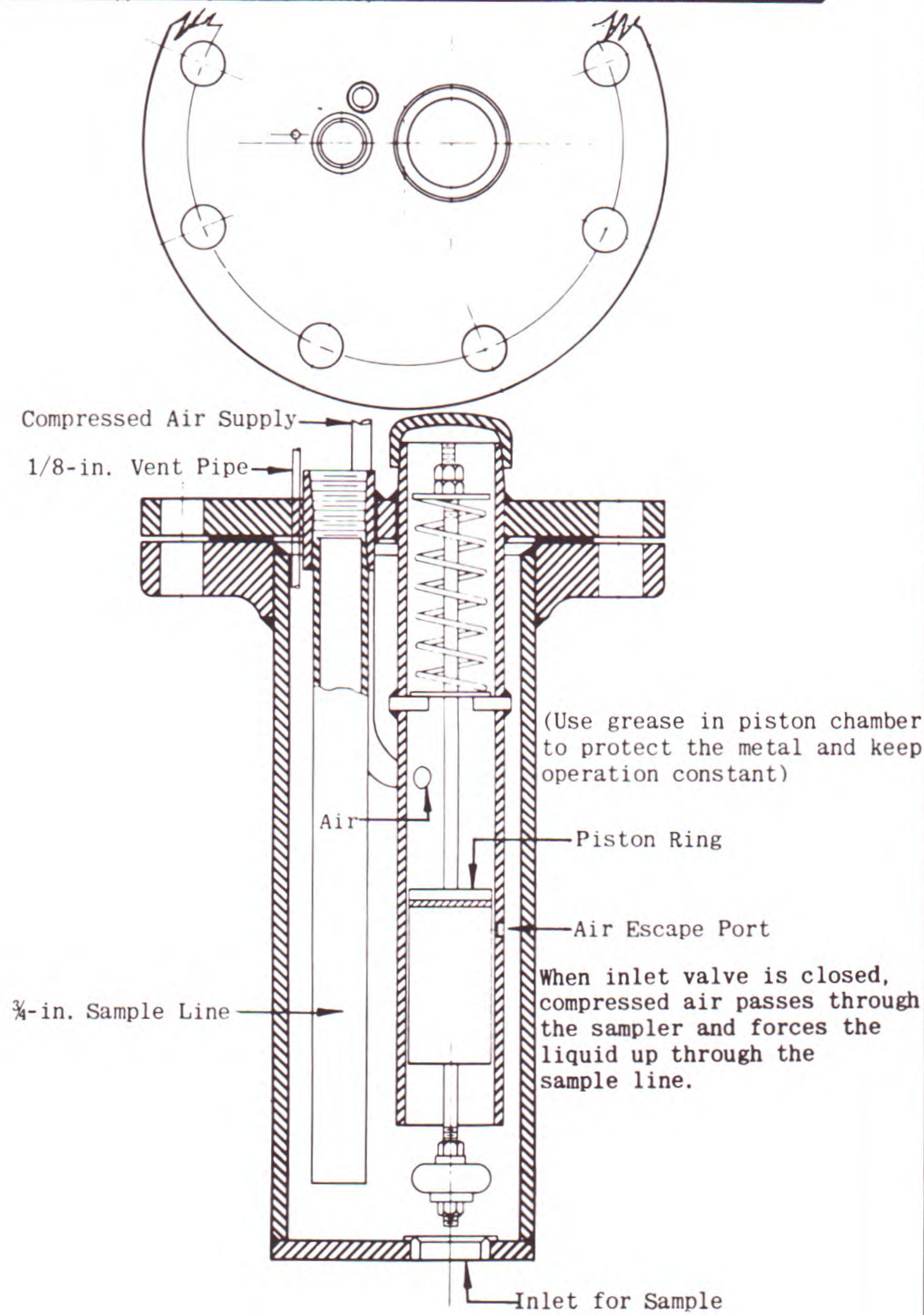
This air-lift automatic sampler (connected as shown in Fig 20) takes samples from a sewer when a pump cannot be used.



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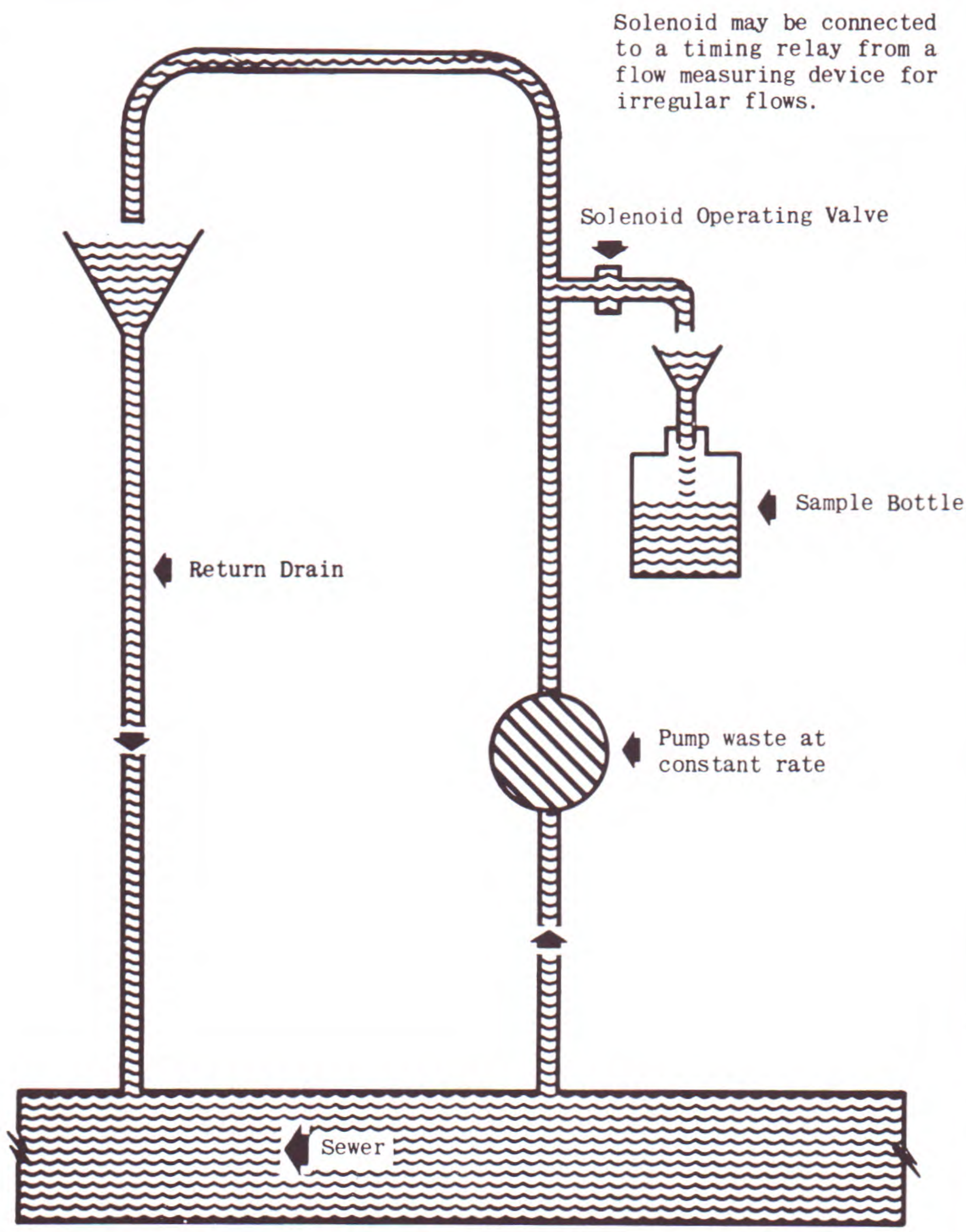
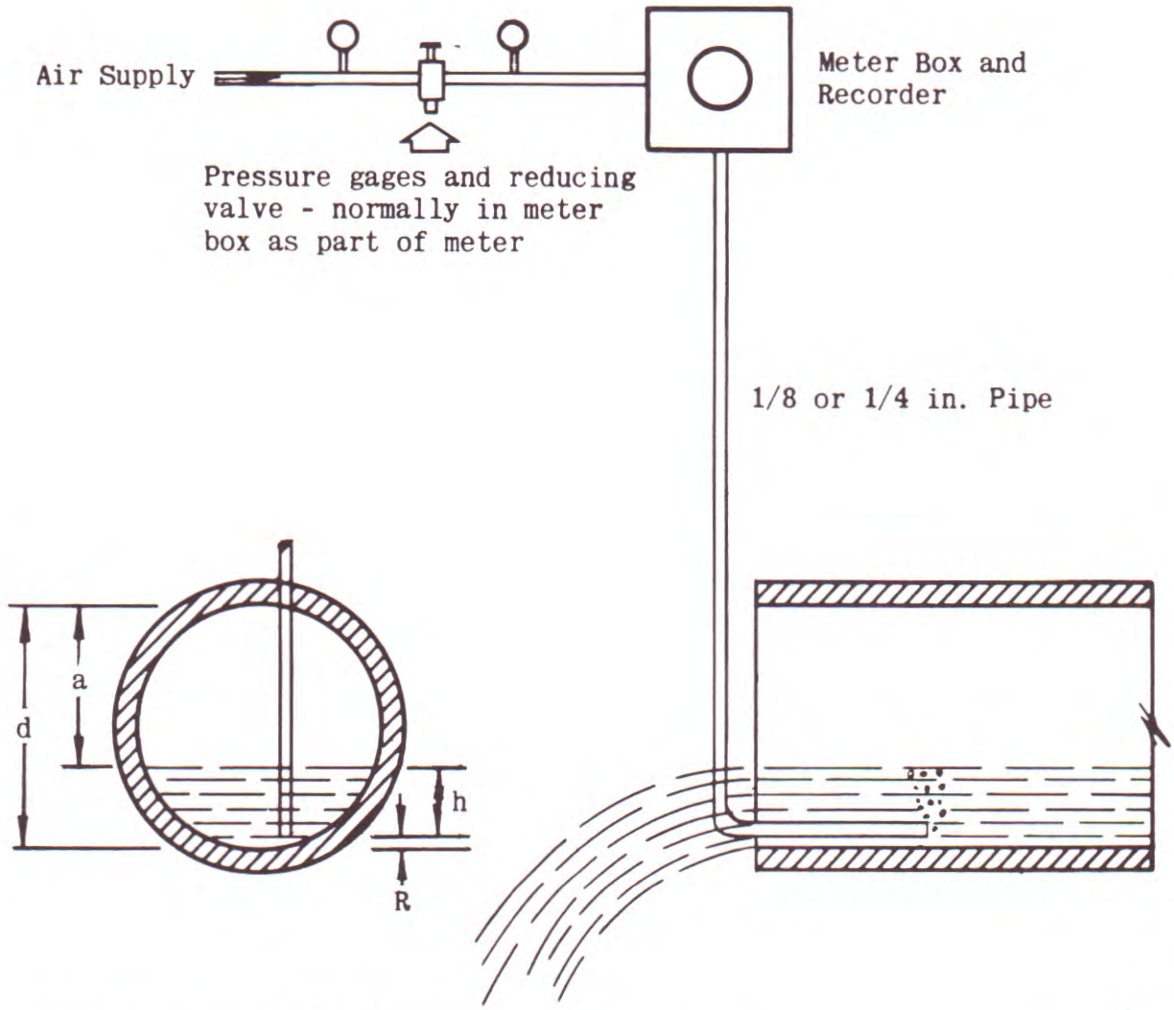


This sampler can take volumes of waste from inaccessible sewers.

An air bubbler will measure water depth in pipes and channels. The recorder gage for the bubbler must be selected for the depth of flow because of low air back-pressure.



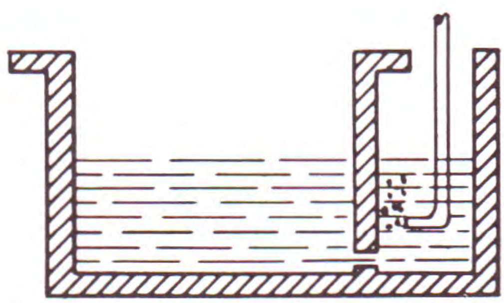
Measurements for California Pipe Flow Method

d = Inside diameter of pipe R + h + a

R = Distance of center of air pipe from bottom of sewer (a known dimension)

h = Distance from center of air pipe to surface of liquid (measured by the meter)

a = Distance from surface of liquid to top of pipe = d - (R + h)



This method can be used in an open channel or stilling well to measure depth of flow

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Example—Here is a typical record of flow rates in a plant operating one shift where it had been shown that hourly samples were sufficient:

Time	*Recorded Rate-of-Flow*
6 AM	60 gpm
7 AM	75 gpm
8 AM	80 gpm
9 AM	70 gpm
10 AM	65 gpm
11 AM	75 gpm
12 AM	80 gpm
1 PM	90 gpm
2 PM	80 gpm
3 PM	65 gpm
4 PM	70 gpm

Samples in this plant are collected each time flow is measured. To get a true volumetric composite sample, take one-half of the first and last readings of rate-of-flow but full values for intermediate readings.

	Time	*Revised Rate-of-Flow*
10 hr.	6 AM	60 x ½ = 30 gpm
	7 AM	75 gpm
	8 AM	80 gpm
	9AM	70 gpm
	10 AM	65 gpm
	11 AM	75 gpm
	12 AM	80 gpm
	1 PM	90 gpm
	2 PM	80 gpm
	3 PM	65 gpm
	4 PM	70 x ½ = 35 gpm
		Summation =745 gpm

At each reading of rate-of-flow, collect 10 milliliters (ml) of sample for each gallon per minute of flow shown in the revised table. For instance, at 6 AM collect 30 x 10 = 300 ml. At 7 AM collect 75 x 10 = 750 ml. This gives a total of 7,450 ml for the daily sample.

For lower rates-of-flow the factor of 10 ml per gallon per minute should be increased. For example, at an average rate-of-flow of 5 gpm, the factor should be 100 ml for each gallon per minute of flow.

The revised rate-of-flow is used to compute average rate-of-flow and total volume of waste discharged during period of the survey. The load of waste constituents in pounds is calculated from total volume of waste.

Average rate-of-flow for the survey period is determined by dividing the summation of revised rates-of-flow by the number of hours of the survey period.

$$\frac{745}{10} = 74.5 \text{ gpm}$$

Total volume of waste discharged is obtained by multiplying the summation of revised rate-of-flow by the number of minutes in the time interval between readings. In the preceding example the summation is 745. The time interval is one hour or 60 minutes. The volume discharged between 6 AM and 4 PM is then computed as 745 x 60 = 44,700 gal.

Another way to calculate the average rate-of-flow is to divide total volume by time elapsed from beginning to end of the test period. In the example, this is 44,700 gal. divided by 10 hours (6 AM - 4 PM) or 600 minutes.

$$\frac{44{,}700 \text{ gal}}{600 \text{ min}} = 74.5 \text{ gpm}$$

Remember When Calculating

Concentrations are reported in terms of:

parts per million—ppm
ounces per gallon—oz/gal
per cent—%
milligrams per liter—mg/l

An ounce per gallon is equivalent to 7,500 ppm;a 1% solution contains 10,000 ppm.

HOW TO CALCULATE WASTE LOAD

The objective of a plant waste survey is to measure the load of contaminants. For this, rates-of-flow and concentrations of the contaminants must be known. Samples should be analyzed according to accepted techniques and the concentrations noted.

The usual term employed in waste surveys is parts per million—which means pounds of contaminant in a million pounds of water. This is numerically equal to milligrams per liter in concentrations less than 5,000 ppm. Above that value the relationship should include consideration of specific gravity.

For continuous flows using analyses of composite samples:

$$\text{Load (lbs. per day)} = \frac{\text{ppm x 8.3 x flow (total gals. during day)}}{1{,}000{,}000}$$

If the survey period extends less than 24 hours the load discharged during the survey period will be calculated as follows, using average rate-of-flow for the survey period and the analyses of the composite sample:

$$\text{Load (lbs.)} = \frac{\text{ppm x gpm x hrs of survey}}{2{,}000}$$

If the survey period extends for 24 hours the load discharged is calculated as follows, using average rate-of-flow and analyses of 24-hr. composite samples:

$$\text{Load (lbs. per 24 hrs.)} = \frac{\text{ppm x gpm}}{83.4}$$

For batch loads use this formula:

$$\text{Load (lbs.)} = \frac{\text{ppm x 8.3 x vol. (gal.) x specific gravity}}{1{,}000{,}000}$$

Example for continuous flows . . .

A composite sample was taken while the rates-of-flow recorded on page 28 were measured. For this 10-hr. sampling period the average rate of flow was 74.5 gpm. Partial analysis of the composite sample gave the following:

Cadmium (Cd)	83 ppm
Iron (Fe)	199 ppm
Copper (Cu)	60 ppm

The load in pounds of each of the metals is determined by the formula:

$$\text{Load (lbs.)} = \frac{\text{ppm x gpm x hrs of survey}}{2{,}000}$$

Cadmium lost in the waste waters during the 10-hr. period then was:

$$\frac{83 \text{ x } 74.5 \text{ x } 10}{2{,}000} = 30.9 \text{ lbs.}$$

The iron lost weighed:

$$\frac{199 \text{ x } 74.5 \text{ x } 10}{2{,}000} = 74.3 \text{ lbs.}$$

The copper carried by the waste waters was:

$$\frac{60 \text{ x } 74.5 \text{ x } 10}{2{,}000} = 22.4 \text{ lbs.}$$

If a composite sample is used the average rate of flow during the period of compositing the sample is used in calculating the load. For individual grab samples, the rate-of-flow at the time of sampling is used, and the interval of time between sampling used.

Example for batch loads . . .

A 1,000-gal sulfuric-acid pickling tank to be dumped gives analysis of:

Iron (Fe)	6% by weight (= 60,000 ppm)
Acidity (H_2SO_4)	9% by weight (= 90,000 ppm).
Specific gravity	1.2

$$\text{Load (lbs)} = \frac{\text{ppm x 8.3 x vol. (gal.) x specific gravity}}{1{,}000{,}000}$$

(The concentrations are too high in batch tanks to ignore consideration of specific gravity.)

The weight of iron to be disposed of is:

$$\frac{60{,}000 \text{ x } 8.3 \text{ x } 1{,}000 \text{ x } 1.2}{1{,}000{,}000} = 600 \text{ lbs.}$$

and the acidity requiring neutralization is:

$$\frac{90{,}000 \text{ x } 8.3 \text{ x } 1{,}000 \text{ x } 1.2}{1{,}000{,}000} = 900 \text{ lbs.}$$

Combining the above examples gives a plant that dumps a 1,000-gal. pickling tank on a day that the average rate of flow of the rinse water is 74.5 gpm. Using the same analyses as given before, the iron discharged in the rinse water and pickle tank amounts to:

Rinse water	74.3 lbs.
Pickle Tank	600
Total iron	674.3 lbs.

This illustrates the effect that the dumping of a tank of concentrated solution can have on the normal waste discharge from a plant.

Table II -- Values of T for Different Ratios of $\frac{a}{d}$ for Use in California Pipe Flow Formula

$$T = 3900 \left(1 - \frac{a}{d}\right)^{1.88}$$

$\frac{a}{d}$	T	$\frac{a}{d}$	T	$\frac{a}{d}$	T
.00	3900	.35	1740	.70	410
.01	3830	.36	1690	.71	380
.02	3760	.37	1640	.72	360
.03	3690	.38	1590	.73	330
.04	3610	.39	1540	.74	310
.05	3540	.40	1490	.75	290
.06	3470	.41	1450	.76	270
.07	3400	.42	1400	.77	250
.08	3330	.43	1350	.78	230
.09	3260	.44	1310	.79	210
.10	3200	.45	1270	.80	190
.11	3130	.46	1230	.81	170
.12	3070	.47	1180	.82	160
.13	3000	.48	1140	.83	140
.14	2930	.49	1100	.84	125
.15	2870	.50	1060	.85	110
.16	2810	.51	1020	.86	97
.17	2750	.52	980	.87	85
.18	2690	.53	945	.88	73
.19	2630	.54	905	.89	61
.20	2570	.55	870	.90	51
.21	2510	.56	830	.91	42
.22	2450	.57	800	.92	34
.23	2390	.58	760	.93	26
.24	2330	.59	730	.94	20
.25	2270	.60	700	.95	14
.26	2210	.61	660	.96	9
.27	2160	.62	630	.97	5
.28	2100	.63	600	.98	3
.29	2050	.64	570	.99	1
.30	1990	.65	540		
.31	1940	.66	510		
.32	1890	.67	480		
.33	1840	.68	460		
.34	1790	.69	430		

Table III -- Values of W for California Pipe Flow Formula

$W = d^{2.48}$

Pipe diameter inches	d feet	W
3	0.25	0.032
4	0.33	0.064
6	0.50	0.179
8	0.67	0.370
10	0.83	0.630
12	1.00	1.00
14	1.17	1.48
15	1.25	1.74
16	1.33	2.03
18	1.50	2.73
20	1.67	3.57
21	1.75	4.01
22	1.83	4.48
24	2.00	5.58
27	2.25	7.47
30	2.50	9.70
33	2.75	12.29
36	3.00	15.25

Table IV -- Cross Sectional Area of Water in Pipes at Various Depths of Flow

D = diameter of pipe (inches)

d = depth of flow (inches)

A = cross sectional area (square feet)

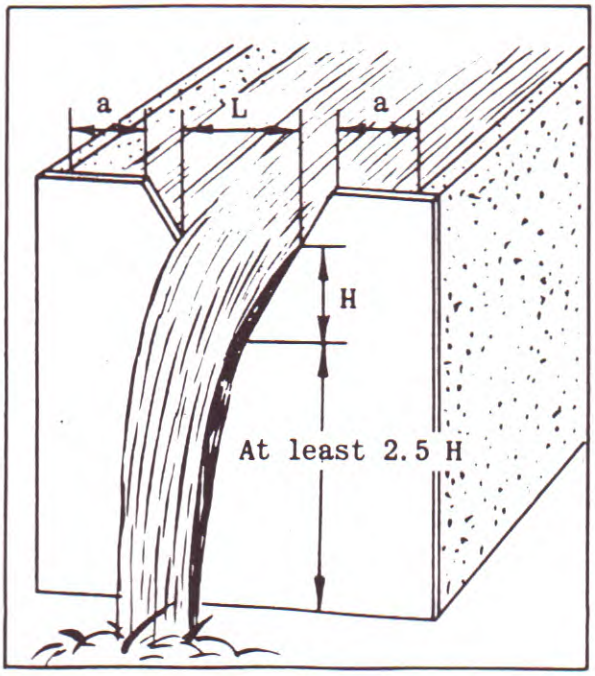
Depth of Flow (d) inches	Cross Sectional Area -- square feet (sq ft)				
	Diameter of Pipe (D) Inches				
	6	8	10	12	15
1/2	.01	.01	.01	.01	.01
3/4	.01	.02	.02	.02	.02
1	.02	.03	.03	.03	.04
1/4	.03	.03	.04	.04	.05
1/2	.04	.05	.05	.06	.06
3/4	.05	.06	.06	.07	.08
2	.06	.07	.08	.09	.10
1/4	.07	.08	.09	.10	.12
1/2	.08	.09	.11	.12	.13
3/4	.09	.11	.12	.14	.15
3	.10	.12	.14	.15	.17
1/4	.11	.13	.15	.17	.20
1/2	.12	.15	.17	.19	.22
3/4	.13	.16	.19	.21	.24
4	.14	.17	.20	.23	.27
1/4	.15	.19	.22	.25	.29
1/2	.16	.20	.24	.27	.31
3/4	.17	.22	.26	.29	.33
5	.17	.23	.27	.31	.36
1/4	.18	.24	.29	.33	.38
1/2	.19	.26	.31	.35	.41
3/4	.19	.27	.32	.37	.43

Continued on next page

Table IV -- Continued

Depth of Flow (d) inches	Cross Sectional Area -- square feet (sq ft)				
	Diameter of Pipe (D) Inches				
	6	8	10	12	15
6	.20	.28	.34	.39	.46
1/4		.29	.36	.41	.48
1/2		.30	.38	.43	.51
3/4		.31	.39	.45	.54
7		.32	.41	.48	.56
1/4		.33	.42	.50	.59
1/2		.34	.44	.52	.62
3/4		.35	.45	.54	.64
8		.35	.47	.56	.67
1/4			.48	.58	.69
1/2			.49	.59	.72
3/4			.51	.61	.74
9			.52	.63	.77
1/4			.53	.65	.79
1/2			.54	.67	.82
3/4			.54	.68	.84
10			.55	.70	.87
1/4				.71	.89
1/2				.73	.92
3/4				.74	.94
11				.75	.96
1/4				.76	.99
1/2				.77	1.01
3/4				.78	1.03
12				.79	1.05
1/4					1.07
1/2					1.10
3/4					1.11
13					1.13
1/4					1.15
1/2					1.16
3/4					1.18
14					1.19
1/4					1.20
1/2					1.21
3/4					1.22
15					1.23

Table V -- Discharge Over 90° V-notch Weir



Discharge is based on formula:

$$2.52\ H^{2.47} = \text{cubic feet per second}$$

or

$$1131\ H^{2.47} = \text{gallons per minute}$$

where H = head of water on weir in feet

(Measurements in feet can be converted to inches in Table VIII)

L = width of notch at water surface

a = width of end contractions, and should be not less than 3/4 L

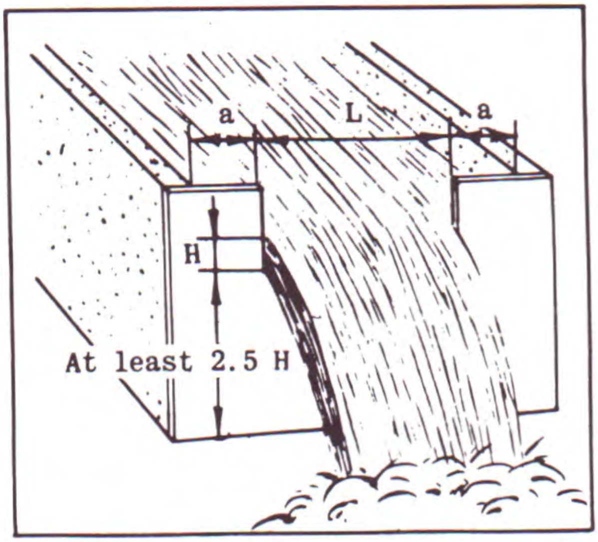
Head (H) Inches	Discharge gallons per minute (gpm)	Head (H) Inches	Discharge gallons per minute (gpm)
1	2	5	129
1/4	4	1/4	149
1/2	6	1/2	166
3/4	9	3/4	183
2	12	6	204
1/4	17	1/4	225
1/2	24	1/2	247
3/4	30	3/4	276
3	37	7	300
1/4	45	1/4	332
1/2	53	1/2	354
3/4	65	3/4	383
4	76	8	413
1/4	88	1/4	451
1/2	100	1/2	486
3/4	114	3/4	520

Continued on next page

Table V -- Continued

Head (H) Inches	Discharge gallons per minute (gpm)	Head (H) Inches	Discharge gallons per minute (gpm)
9	555	17	2670
1/4	594	1/2	2880
1/2	632	18	3080
3/4	684	1/2	3290
10	725	19	3530
1/2	815	1/2	3760
11	910	20	4000
1/2	1040	1/2	4250
12	1130	21	4500
1/2	1250	1/2	4770
13	1380	22	5060
1/2	1520	1/2	5340
14	1650	23	5640
1/2	1810	1/2	5950
15	1970	24	6280
1/2	2120	1/2	6580
16	2310	25	6900
1/2	2480		

Table VI -- Discharge Over Rectangular Weir with Standard End Contractions



Discharge is based on Francis formula:

$$3.33\ L\ H^{3/2} = \text{cubic feet per second}$$

or

$$1495\ L\ H^{3/2} = \text{gallons per minute}$$

where L = length of weir crest (feet)

H = head of water on weir (feet)

(Measurements in feet are converted to inches in Table VIII)

a = width of end contractions, and should not be less than 2.5 H

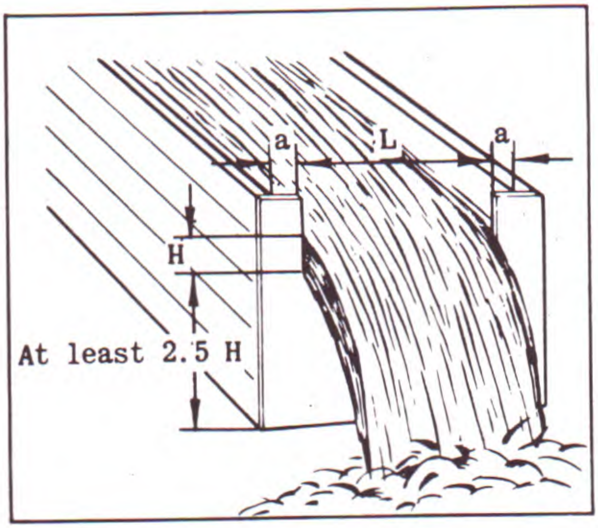
Head (H) Inches	Discharge -- Gallons per minute (gpm) — Length of Weir (L) Inches										
	2	4	6	8	10	12	15	18	24	36	60
1/4	1	2	2	3	4	5	6	7	10		
1/2	2	4	6	9	11	13	16	19	26		
3/4	4	8	12	16	19	23	29	35	46		
1	6	12	18	24	30	36	45	54	72	108	180
1/4		17	25	33	42	50	63	76	100	150	250
1/2		22	33	44	55	66	83	99	132	197	330
3/4		28	42	55	69	83	104	124	166	248	415
2		34	51	68	85	101	127	152	202	303	505
1/4			61	81	101	121	152	183	242	363	605
1/2			71	95	118	142	178	213	284	426	710
3/4			82	109	136	164	205	246	328	492	820
3			93	124	155	187	233	280	374	561	935
1/4				140	176	210	263	316	420	630	1050
1/2				157	197	235	294	353	470	705	1180
3/4				174	218	261	326	392	522	783	1310

Continued on next page

Table VI -- Continued

Head (H) Inches	Discharge -- Gallons per minute (gpm)										
	Length of Weir (L) Inches										
	2	4	6	8	10	12	15	18	24	36	60
4				190	239	287	358	431	574	861	1430
1/4					262	314	393	472	628	942	1570
1/2					285	343	429	515	686	1030	1710
3/4					310	374	465	559	748	1120	1860
5					334	403	500	605	806	1210	2010
1/4						433	540	650	866	1300	2160
1/2						464	580	695	928	1390	2320
3/4						496	620	745	992	1480	2480
6						528	660	791	1050	1580	2640
1/4							701	842	1120	1680	2800
1/2							743	893	1190	1790	2980
3/4							785	945	1260	1890	3150
7							830	1000	1330	1990	3320
1/4							875	1050	1400	2100	3500
1/2							920	1100	1470	2200	3680
3/4								1160	1540	2310	3850
8								1210	1620	2430	4050
1/4								1270	1700	2550	4250
1/2								1340	1780	2670	4450
3/4								1400	1860	2790	4650
9								1460	1940	2910	4850
1/4									2020	3030	5050
1/2									2100	3150	5250
3/4									2180	3270	5450
10									2270	3400	5670
1/2									2450	3680	6120
11									2620	3930	6550
1/2									2800	4200	7000
12									2990	4380	7470

Table VII -- Discharge Over Rectangular Weir with Modified End Contractions



Discharge is based on formula by Schoder:

$3.00\ L\ H^{3/2}$ = cubic feet per second

or

$1346\ L\ H^{3/2}$ = gallons per minute

where L = length of weir crest (feet)

H = head of water on weir (feet)

(Measurements in feet are converted to inches in Table VIII)

a = width of end contractions - large enough to permit free passage of air down side of weir plate

Head (H) Inches	Discharge -- Gallons per minute (gpm)								
	Length of Weir (L) Inches								
	2	4	6	8	10	12	15	18	24
1/4	1	1	2	3	3	4	5	6	8
1/2	2	4	6	8	10	12	14	17	23
3/4	4	7	11	14	18	21	26	32	42
1	5	11	16	22	27	32	41	49	65
1/4	8	15	23	30	38	45	57	68	91
1/2	10	20	30	40	50	59	74	89	119
3/4	13	25	38	50	62	75	94	112	150
2	15	31	46	61	77	92	115	138	184
1/4	18	36	55	73	91	109	137	164	218
1/2	21	43	64	85	107	128	160	192	256
3/4	25	49	74	98	123	148	185	222	296
3	28	56	84	112	140	168	210	252	336
1/4	32	63	95	126	158	189	237	285	378
1/2	35	70	106	141	175	211	264	316	422
3/4	39	78	118	157	196	235	294	353	470

Continued on next page

Table VII -- Continued

Head (H) Inches	Discharge -- Gallons per minute (gpm)								
	Length of Weir (L) Inches								
	2	4	6	8	10	12	15	18	24
4	43	88	133	177	222	256	333	399	512
1/4	47	94	142	189	236	283	354	425	566
1/2	52	103	155	207	259	310	387	465	620
3/4	56	112	168	224	280	335	419	502	670
5	60	120	181	242	302	362	453	544	724
1/4	65	128	195	260	325	389	486	583	778
1/2	70	138	209	279	349	418	522	627	836
3/4	74	149	223	298	372	446	558	670	892
6	79	159	238	318	397	476	595	715	952
1/4		169	253	337	422	506	633	760	1010
1/2		179	268	357	447	535	669	803	1070
3/4		189	283	378	473	566	707	850	1130
7		200	299	400	500	598	749	898	1200
1/4		210	315	420	526	630	788	945	1260
1/2		222	332	444	554	664	830	996	1330
3/4		232	348	464	581	696	870	1045	1390
8		244	365	487	610	730	913	1100	1460
1/4				514	640	766	960	1150	1530
1/2				534	668	800	1000	1200	1600
3/4				558	700	838	1050	1260	1680
9				585	732	876	1100	1320	1750
1/4				605	758	908	1140	1370	1820
1/2				630	789	945	1180	1420	1890
3/4				655	819	981	1230	1470	1960
10				680	850	1020	1280	1530	2040
1/4				714	893	1060	1340	1600	2120
1/2				734	919	1100	1380	1650	2200
3/4				760	952	1140	1430	1710	2280
11				788	985	1180	1480	1770	2360
1/4				820	1030	1220	1530	1830	2460
1/2				840	1050	1260	1580	1890	2520
3/4				868	1090	1300	1630	1950	2600
12				900	1130	1350	1690	2020	2700

Table VIII -- Free Flow Discharge for Parshall Flume

Head (H_a)		Discharge -- Gallons per minute (gpm)						
		Flume Throat Width (W)						
ft	in.	3 in.	6 in.	9 in.	1 ft	1.5 ft	2 ft	3 ft
0.10	1-3/16	13	22	40	49	67	-	-
.11	1-5/16	15	27	45	54	81	-	-
.12	1-7/16	17	31	54	63	94	-	-
.13	1-9/16	19	36	63	72	108	-	-
.14	1-11/16	21	40	68	81	121	-	-
.15	1-13/16	24	45	76	90	135	189	274
.16	1-15/16	26	49	85	103	153	211	306
.17	2-1/16	29	54	90	117	171	229	337
.18	2-3/16	31	63	99	130	189	252	368
.19	2-1/4	34	67	108	144	207	274	400
.20	2-3/8	37	72	118	157	229	301	436
.21	2-1/2	40	80	126	166	247	319	467
.22	2-5/8	43	85	135	180	265	346	504
.23	2-3/4	46	90	144	193	283	369	539
.24	2-7/8	49	99	157	207	301	395	575
.25	3	53	103	166	220	319	418	615
.26	3-1/8	56	112	175	229	341	445	656
.27	3-1/4	59	117	184	242	359	472	696
.28	3-3/8	62	126	198	260	382	498	737
.29	3-1/2	66	130	207	274	404	530	777
.30	3-5/8	69	139	220	288	422	556	817
.31	3-3/4	73	144	229	305	445	583	862
.32	3-13/16	76	153	242	319	467	615	908
.33	3-15/16	80	162	252	332	490	647	952
.34	4-1/16	84	171	265	346	512	674	997
.35	4-3/16	88	175	278	359	535	705	1040
.36	4-5/16	92	184	288	377	561	737	1088
.37	4-7/16	96	193	305	395	584	773	1135
.38	4-9/16	100	202	315	413	610	805	1185
.39	4-11/16	104	211	328	427	633	835	1235
.40	4-13/16	108	216	341	445	660	866	1285
.41	4-15/16	112	225	350	463	688	903	1335
.42	5-1/16	117	234	364	480	710	940	1385
.43	5-3/16	121	242	377	498	737	970	1435
.44	5-1/4	125	252	390	516	764	1008	1490

Continued on next page

Table VIII - Continued

Head (H_a)		Discharge -- Gallons per minute (gpm)						
		Flume Throat Width (W)						
ft	in.	3 in.	6 in.	9 in.	1 ft	1.5 ft	2 ft	3 ft
.45	5-3/8	130	261	404	535	790	1042	1545
.46	5-1/2	134	274	422	552	819	1080	1600
.47	5-5/8	139	283	436	570	835	1115	1650
.48	5-3/4	143	292	449	588	871	1155	1705
.49	5-7/8	148	301	463	606	898	1190	1760
.50	6	152	310	476	625	925	1225	1820
.51	6-1/8	157	319	494	647	956	1270	1880
.52	6-1/4	162	328	508	665	985	1302	1935
.53	6-3/8	167	341	521	683	1010	1342	1995
.54	6-1/2	172	350	539	705	1042	1385	2050
.55	6-5/8	177	359	553	728	1075	1425	2110
.56	6-3/4	182	368	566	746	1100	1465	2170
.57	6-13/16	186	381	584	764	1131	1505	2240
.58	6-15/16	192	390	598	786	1162	1545	2300
.59	7-1/16	197	400	615	809	1195	1585	2360
.60	7-3/16	202	413	629	826	1228	1630	2420
.61	7-5/16	208	422	647	845	1260	1670	2480
.62	7-7/16	213	436	665	867	1290	1710	2550
.63	7-9/16	218	445	678	890	1325	1760	2610
.64	7-11/16	223	458	696	911	1360	1800	2680
.65	7-13/16	228	467	715	934	1390	1845	2750
.66	7-15/16	234	481	732	957	1425	1885	2810
.67	8-1/16	240	494	746	980	1455	1930	2880
.68	8-1/8	246	503	764	1000	1490	1975	2950
.69	8-3/16	251	516	781	1025	1520	2020	3020
.70	8-3/8	257	525	800	1048	1555	2065	3080
.71	8-1/2	262	539	817	1070	1590	2110	3150
.72	8-5/8	268	552	836	1090	1625	2160	3220
.73	8-3/4	274	566	854	1115	1655	2210	3290
.74	8-7/8	280	575	871	1138	1690	2250	3360
.75	9	286	588	890	1160	1730	2300	3430
.76	9-1/8	291	601	903	1180	1765	2350	3510
.77	9-1/4	297	611	925	1205	1800	2400	3580
.78	9-3/8	303	624	944	1230	1840	2440	3650
.79	9-1/2	309	638	961	1260	1875	2490	3730
.80	9-5/8	315	651	980	1280	1910	2540	3800
.81	9-3/4	322	665	997	1300	1950	2590	3880
.82	9-13/16	328	674	1020	1330	1990	2640	3940
.83	9-15/16	334	687	1038	1355	2020	2700	4020
.84	10-1/16	340	700	1055	1380	2060	2750	4100

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Table VIII -- Continued

Head (H_a) ft	Head (H_a) in.	Discharge -- Gallons per minute (gpm) Flume Throat Width (W) 3 in.	6 in.	9 in.	1 ft	1.5 ft	2 ft	3 ft
.85	10-3/16	346	715	1075	1410	2100	2800	4170
.86	10-5/16	353	728	1095	1430	2140	2840	4250
.87	10-7/16	359	741	1115	1455	2180	2890	4330
.88	10-9/16	366	755	1135	1480	2220	2950	4410
.89	10-11/16	372	768	1155	1505	2250	3000	4490
.90	10-13/16	378	781	1175	1530	2290	3060	4580
.91	10-15/16	385	796	1195	1555	2330	3110	4660
.92	11-1/16	392	812	1215	1580	2370	3160	4730
.93	11-3/16	398	827	1235	1610	2420	3210	4810
.94	11-1/4	405	840	1255	1635	2460	3260	4890
.95	11-3/8	412	854	1275	1665	2490	3320	4980
.96	11-1/2	418	867	1295	1690	2530	3380	5060
.97	11-5/8	425	885	1315	1715	2580	3430	5130
.98	11-3/4	432	900	1340	1740	2620	3490	5210
.99	11-7/8	439	912	1360	1770	2660	3540	5300
1.00	12	446	926	1380	1795	2700	3590	5390
1.01	12-1/8	453	940	1400	1825	2740	3650	5480
1.02	12-1/4	459	953	1420	1850	2780	3700	5570
1.03	12-3/8	466	971	1440	1880	2820	3760	5660
1.04	12-1/2	472	985	1460	1910	2860	3820	5750
1.05	12-5/8	480	997	1485	1935	2900	3870	5840
1.06	12-3/4	488	1015	1510	1965	2940	3930	5930
1.07	12-13/16	495	1030	1525	1990	2990	3990	5980
1.08	12-15/16	503	1045	1550	2020	3030	4040	6060
1.09	13-1/16	508	1060	1570	2050	3070	4100	6150
1.10	13-3/16	516	1075	1595	2075	3120	4160	6240
1.11	13-5/16	523	1090	1615	2100	3160	4220	6330
1.12	13-7/16	530	1105	1640	2130	3200	4280	6420
1.13	13-9/16	537	1120	1660	2160	3240	4340	6510
1.14	13-11/16	544	1135	1680	2190	3290	4400	6600
1.15	13-13/16	552	1150	1705	2220	3340	4460	6690
1.16	13-15/16	561	1165	1730	2250	3380	4530	6780
1.17	14-1/16	568	1185	1750	2280	3420	4580	6870
1.18	14-3/16	575	1200	1775	2310	3470	4640	7000
1.19	14-1/4	584	1215	1800	2340	3520	4700	7090
1.20	14-3/8	591	1235	1825	2370	3560	4760	7180
1.21	14-1/2	597	1250	1845	2400	3610	4840	7270
1.22	14-5/8	606	1265	1870	2430	3660	4900	7360
1.23	14-3/4	615	1285	1895	2460	3710	4960	7450
1.24	14-7/8	620	1300	1920	2490	3760	5020	7540

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Table VIII -- Continued

Head (H_a) ft	in.	Discharge -- Gallons per minute (gpm) Flume Throat Width (W) 3 in.	6 in.	9 in.	1 ft	1.5 ft	2 ft	3 ft
1.25	15	628	1315	1940	2520	3800	5080	7630
1.26	15-1/8	637	1335	1960	2550	3840	5150	7720
1.27	15-1/4	645	1350	1990	2590	3890	5210	7820
1.28	15-3/8	651	1365	2010	2620	3940	5260	7930
1.29	15-1/2	660	1380	2030	2650	3990	5330	8030
1.30	15-5/8	668	1400	2060	2680	4030	5390	8130
1.31	15-3/4	674	1415	2080	2710	4080	5460	8230
1.32	15-13/16	682	1430	2100	2740	4130	5510	8330
1.33	15-15/16	691	1450	2130	2780	4170	5570	8430
1.34	16-1/16	700	1470	2150	2810	4220	5640	8530
1.35	16-3/16	708	1485	2180	2840	4270	5700	8630
1.36	16-5/16	714	1505	2210	2870	4320	5770	8730
1.37	16-7/16	723	1520	2230	2900	4370	5840	8830
1.38	16-9/16	731	1540	2260	2930	4420	5910	8930
1.39	16-11/16	740	1560	2280	2960	4470	5970	9030
1.40	16-13/16	750	1575	2310	3000	4530	6060	9130
1.41	16-15/16	758	1595	2330	3030	4580	6120	9230
1.42	17-1/16	764	1610	2360	3060	4620	6190	9330
1.43	17-3/16	772	1630	2380	3090	4660	6260	9430
1.44	17-1/4	781	1650	2410	3120	4710	6330	9540
1.45	17-3/8	791	1665	2440	3160	4760	6390	9650
1.46	17-1/2	800	1685	2460	3200	4810	6460	9750
1.47	17-5/8	809	1700	2480	3230	4870	6530	9850
1.48	17-3/4	818	1720	2510	3260	4930	6600	9960
1.49	17-7/8	827	1740	2540	3290	4980	6680	10070
1.50	18	836	1755	2560	3330	5030	6750	10180
1.51	18-1/8	-	-	2590	3360	5080	6810	10290
1.52	18-1/4	-	-	2620	3400	5140	6870	10400
1.53	18-3/8	-	-	2640	3430	5190	6940	10500
1.54	18-1/2	-	-	2660	3460	5250	7010	10600
1.55	18-5/8	-	-	2690	3500	5300	7080	10700
1.56	18-3/4	-	-	2720	3540	5350	7150	10800
1.57	18-13/16	-	-	2750	3570	5400	7220	10910
1.58	18-15/16	-	-	2780	3600	5450	7300	11020
1.59	19-1/16	-	-	2800	3640	5500	7370	11130
1.60	19-3/16	-	-	2830	3670	5560	7440	11240
1.61	19-5/16	-	-	2860	3710	5610	7510	11350
1.62	19-7/16	-	-	2880	3740	5660	7590	11460
1.63	19-9/16	-	-	2910	3780	5710	7660	11570
1.64	19-11/16	-	-	2940	3810	5770	7730	11680

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Table VIII - Continued

Head (H_a)		Discharge -- Gallons per minute (gpm)						
		Flume Throat Width (W)						
ft	in.	3 in.	6 in.	9 in.	1 ft	1.5 ft	2 ft	3 ft
1.65	19-13/16	-	-	2970	3850	5830	7810	11800
1.66	19-15/16	-	-	3000	3890	5880	7890	11900
1.67	20-1/16	-	-	3020	3920	5930	7960	12000
1.68	20-3/16	-	-	3050	3960	5980	8030	12100
1.69	20-1/4	-	-	3080	3990	6040	8100	12250
1.70	20-3/8	-	-	3110	4030	6100	8170	12400
1.71	20-1/2	-	-	3140	4060	6150	8250	12500
1.72	20-5/8	-	-	3160	4100	6200	8320	12600
1.73	20-3/4	-	-	3190	4140	6260	8400	12700
1.74	20-7/8	-	-	3220	4170	6320	8480	12850
1.75	21	-	-	3240	4210	6370	8540	12950
1.76	21-1/8	-	-	3270	4250	6420	8620	13050
1.77	21-1/4	-	-	3300	4280	6480	8700	13150
1.78	21-3/8	-	-	3330	4320	6540	8780	13300
1.79	21-1/2	-	-	3360	4350	6600	8850	13400
1.80	21-5/8	-	-	3380	4390	6650	8930	13500
1.81	21-3/4	-	-	3410	4430	6720	9010	13650
1.82	21-13/16	-	-	3440	4460	6780	9080	13800
1.83	21-15/16	-	-	3470	4490	6830	9160	13900
1.84	22-1/16	-	-	3510	4530	6890	9250	14000
1.85	22-3/16	-	-	3540	4580	6960	9330	14150
1.86	22-5/16	-	-	3570	4620	7010	9400	14250
1.87	22-7/16	-	-	3590	4660	7060	9480	14350
1.88	22-9/16	-	-	3620	4700	7110	9560	14500
1.89	22-11/16	-	-	3650	4740	7190	9640	14600
1.90	22-13/16	-	-	3680	4770	7240	9700	14700
1.91	22-15/16	-	-	3720	4810	7290	9780	14850
1.92	23-1/16	-	-	3740	4850	7360	9860	14950
1.93	23-3/16	-	-	3770	4890	7410	9940	15100
1.94	23-1/4	-	-	3800	4930	7460	10020	15200
1.95	23-3/8	-	-	3830	4970	7510	10100	15300
1.96	23-1/2	-	-	3860	5010	7590	10200	15450
1.97	23-5/8	-	-	3890	5040	7650	10300	15600
1.98	23-3/4	-	-	3920	5080	7720	10400	15700
1.99	23-7/8	-	-	3950	5120	7770	10450	15850
2.00	24	-	-	3980	5160	7820	10500	15950

To help you—

Here are some companies that manufacture volumetric measuring and recording devices and which can supply additional information:

AMERICAN METER CO., New York 17, N. Y.

BADGER METER MFG. CO., Milwaukee 10, Wisc.

BAILEY METER CO., Cleveland 10, Ohio

THE BRISTOL CO., Waterbury, Conn.

BUFFALO METER CO., Buffalo 14, New York

BUILDERS-PROVIDENCE, INC., Providence, R. I.

CHICAGO PUMP CO., Chicago 18, Ill.

CLARK CONTROLLER CO., Cleveland, Ohio

FISCHER & PORTER CO., Hatboro, Pa.

THE FOXBORO CO., Foxboro, Mass.

W. & L. E. GURLEY, Troy, N. Y.

HAYS CORP., Erie, Pa.

HERSEY MFG. CO., South Boston, Mass.

INFILCO, INC., Tucson, Ariz.

LEEDS & NORTHRUP CO., Philadelphia, Pa.

LEUPOLD AND STEVENS CO. Portland, Ore.

MINNEAPOLIS-HONEYWELL, Philadelphia 44, Pa.

MITTELMANN ELECTRONICS DIV., Century America Corp., Chicago 6, Ill.

NEPTUNE METER CO., New York 20, N. Y.

OMEGA MACHINE CO., Providence 1, R. I.

REPUBLIC FLOW METERS CO., Chicago 47, Ill.

ROCKWELL MFG. CO., Pittsburgh 8, Pa.

SCHUTTE & KOERTING CO., Bucks Co., Pa.

SCIENTIFIC INSTRUMENT CO., Berkeley, Calif.

SIMPLEX VALVE AND METER CO., Philadelphia 42, Pa.

A. P. SMITH MFG. CO., East Orange, N. J.

SPARLING METER CO., New York 17, N. Y.

TAYLOR INSTRUMENT CO., Rochester, N. Y.

WELL MACHINERY & SUPPLY CO., Fort Worth, Texas

WORTHINGTON-GAMON METER CO., Newark 5, N. J.

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