RUNOFF MEASUREMENTS FROM SMALL AGRICULTURAL WATERSHEDS

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INTRODUCTION

For planning and execution of soil and water conservation works, the watershed is a recognised unit. The watershed is an independent hydrologic unit and as such measures like runoff collection and recycling, soil loss control, provision of grasswaterways, etc. are planned on a watershed basis. Collection of basic hydrologic data from experimental watershed is universally accepted as a pre-requisite for the study of the laws governing many hydrologic phenomena and their inter-relationship. The hydrologic information collected in relatively small watersheds generally consists of rainfall, runoff and soil loss. In research projects on agricultural watersheds where runoff observations are taken it is important to emphasize that the usefulness of such studies entirely depends on the reliability of data which in turn depends upon the accuracy of measurements, processing and compilation of the full records and observations.

In this write-up an attempt is made to outline the procedures both for measurements and analyses of runoff data from small agricultural watersheds. The watersheds under consideration have an area upto 12 hectares and the land use in the watersheds is predominantly for agricultural purposes. The contents of the report will provide an understandigg of the fundamental principles, methods and problems that are likely to be encountered in the field. The standard techniques for measuring runoff with precalibrated devices, their design specifications, construction, installation and maintenance have been separately discussed. The method of processing and compilation, sources of errors and accuracy standards to be followed have been clearly specified. The methods outlined and the analyses are relevant to the ICAR-ICRISAT collaborative projects viz Farming System 1 and 2 being undertaken at different research stations in India.

METHODS OF MEASURING RUNOFF

Various methods are available for measuring the runoff depending upon the specific needs of the locations. Each method has its own characteristics which favour its adoption under certain conditions of measurements and limits its use under other sets of conditions. Any selected method should measure runoff accurately at low, medium and high rates of discharge. This section provides information on some commonly used runoff measuring devices, their constructional details, installation and limitations. It also provides guidance on the selection of gaging station and measuring devices.

SELECTION OF GAGING STATION AND MEASURING DEVICES

The location of gaging station is one of the primary consideration for obtaining accurate runoff measurements. The site must be located such that the gaged runoff represents the entire flow from the watershed or of concerned area. Some of the other important considerations are minimum 3.5 metres straight approach channel, less chances of turbulence and eddy currents formations near the upstream of the gaging station, stable cross section of the channel and less chances of tailwater. All these considerations helps in maintaining a stable relationship between the depth of water and the rate of flow which is extremely important for accurate runoff measurement.

Selection of a device for measuring runoff depends on such factors as the expected peak runoff rate, distribution of runoff volume, absence or presence of woody trash or other floating materials in the flow, extend of back water submergence, material availability and economics. A flow chart to assist in selecting a runoff measuring device is shown in Fig. 1.

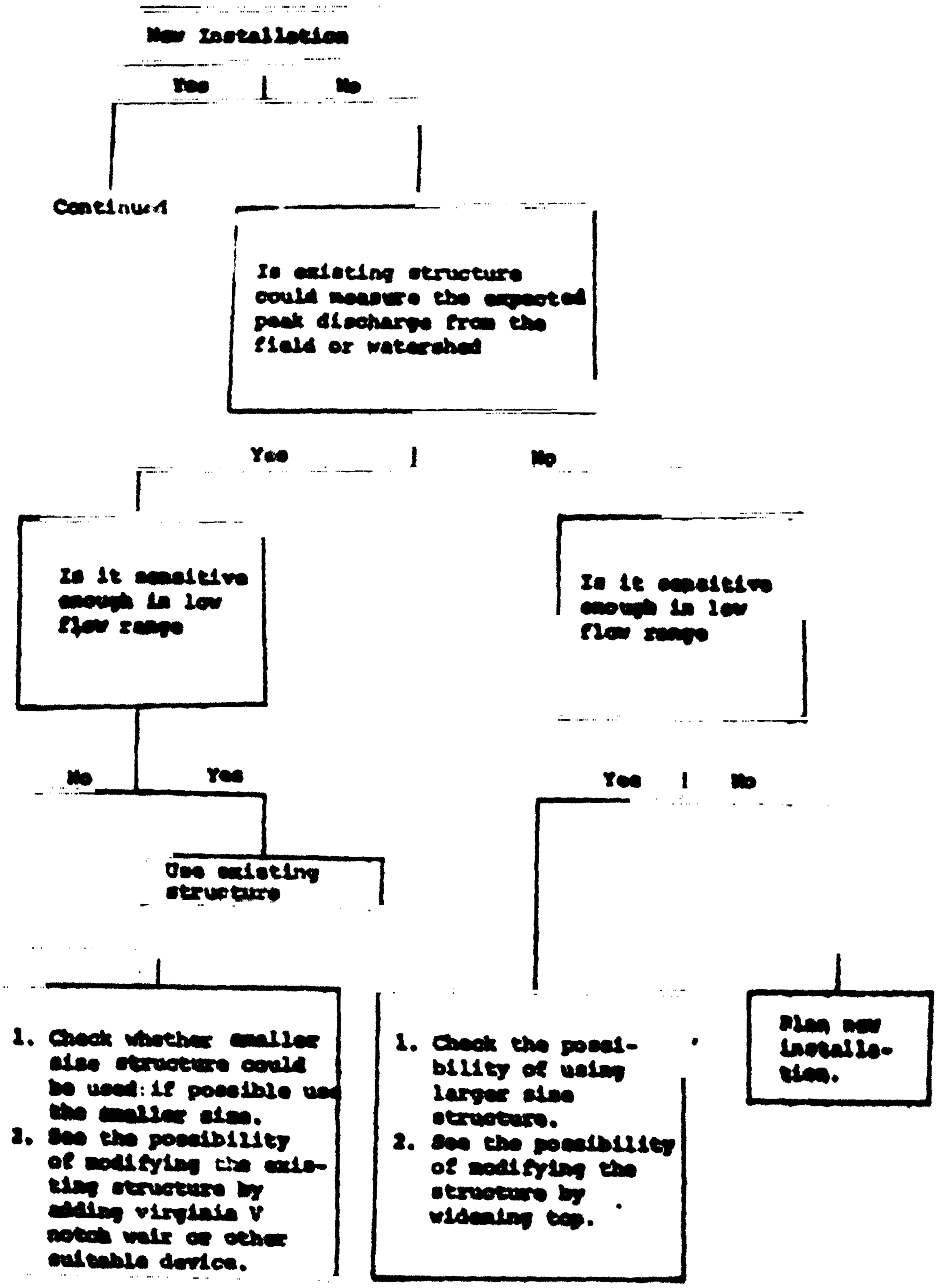

FIG.1 : SELECTION GUIDE FOR MEASURING RUNOFF

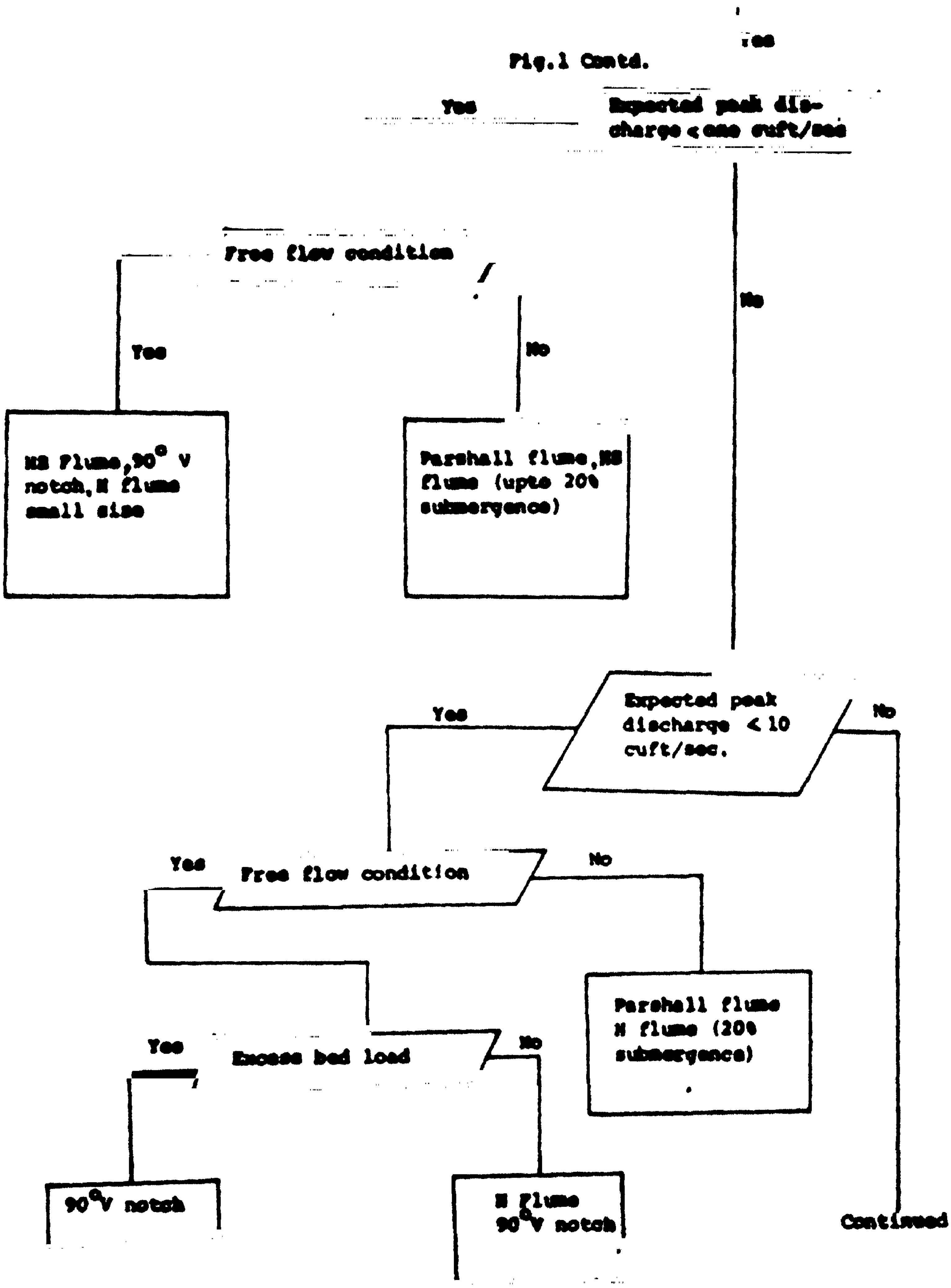

FIG.1 : SELECTION GUIDE FOR MEASURING RUNOFF

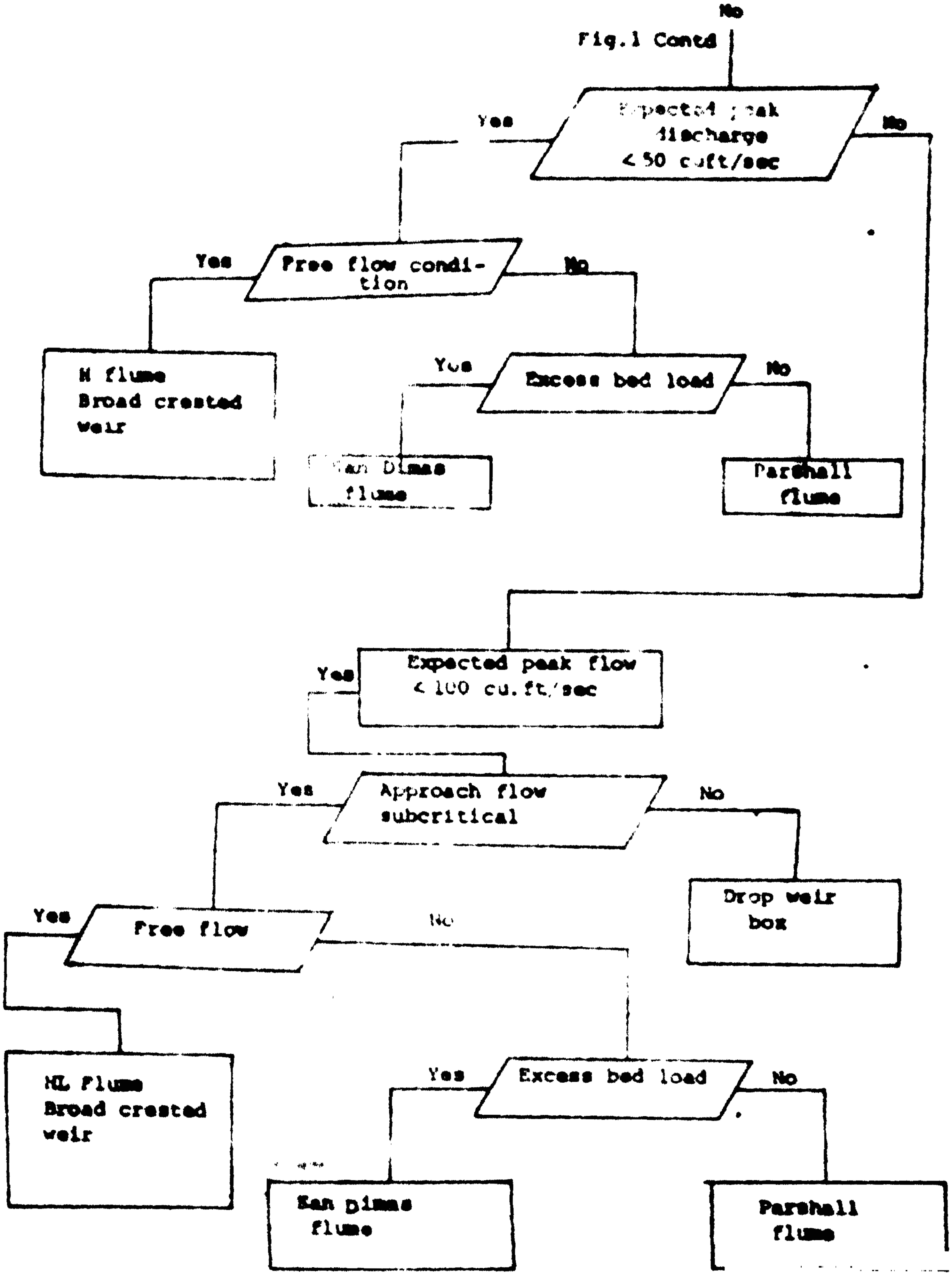

FIG.1 : SELECTION GUIDE FOR MEASURING RUNOFF

The primary key to the flow chart is maximum discharge rate to be selected. The flow chart provides paths based on the absence or presence of debris, type of flow in the approach channel whether ponding is allowed, whether backwater problems are anticipated and finally the flow characteristics. Although this flow chart is a quick reference the other practical considerations should be checked carefully to ensure selection of the best measuring device for the flow conditions encountered.

PRECALIBRATED DEVICES FOR MEASURING RUNOFF

The precalibrated devices are most commonly used for measuring runoff at the research station because of the high accuracy. Some of the most commonly used precalibrated devices are:

1. H-Type flume
   (i) HS Flume
   (ii) H flume
2. Parshall flume
3. Weirs : sharp crested 90° V notch weir.

H TYPE FLUME

H type flume are most commonly used for measuring runoff from small areas. Presently three types of flumes HS, H and HL are available, which have different specifications to suit varying ranges of flows. These flumes vertical sides are converging and are cut back on a slope from the outlet to give a trapezoidal throat opening which increases with depth of the flume. The shape of the flume provides the following distinct advantages which favour its use under a variety of flow conditions.

1. The increase of throat opening with the rise of stage facilitates accurate measurement of both low and high flows.
2. The converging section of the flume makes itself cleaning because of increased velocity and consequently the flume is

suitable for measuring flow with sediment in suspension with low bed loads.

3. It is simple in construction, rigid and stable in operation and requires the least amount of maintenance without affecting its rating.

4. Its installation is simple and is not in any way affected by the steepness of the channel gradient.

General Limitations: These flumes have been basically designed for free flow conditions and consequently are not recommended under submerged flow conditions. They are also not recommended for flows carrying excessive amounts of coarse bed load.

HS FLUME

These flumes are designed to measure small flow rates ranging from .05 ft^3/sec to .8 ft^3/sec (0.0014 to 0.0227 m^3/sec) with a high degree of accuracy. The detailed dimensions capacities and construction tolerances of the flume are shown in Fig. 2. The Appendix Table 1 gives ratings for flumes of various sizes. Construction details are given with the discussion on H flumes. The following points are important during the fabrication of the flume.

(1) The slanting opening must be bound by straight edges and have precisely the dimensions shown on the drawings.

(2) The opening must lie in a plane with an inclination of the exact degree shown on the drawings.

H FLUME

H flume are used to measure runoff where the maximum runoff ranges from 0.3 to 30 ft^3/sec (0.009 to 0.85 m^3/sec). The dimensions and flow capacities are shown in Fig. 3. Appendix Table 2 gives ratings for H

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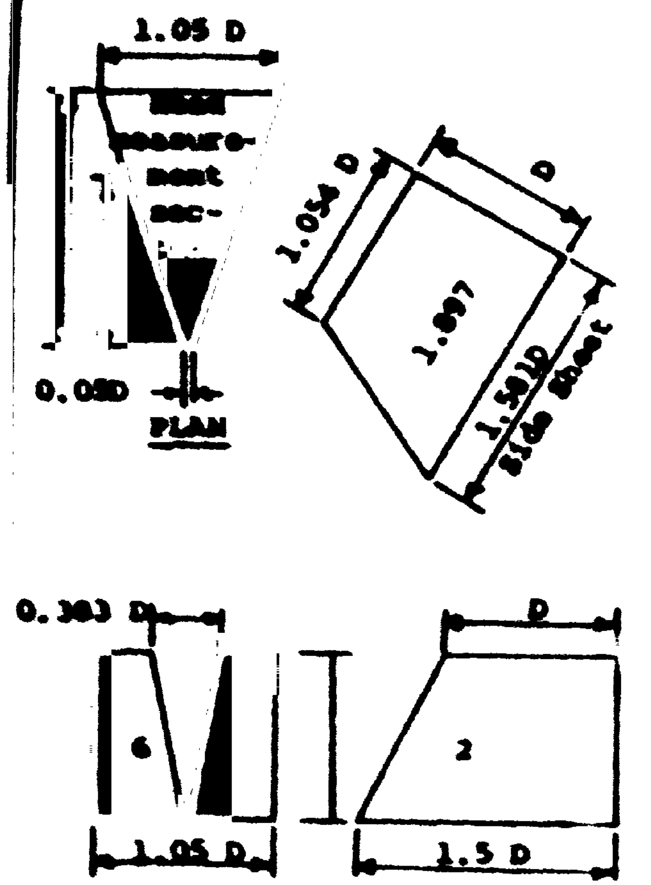
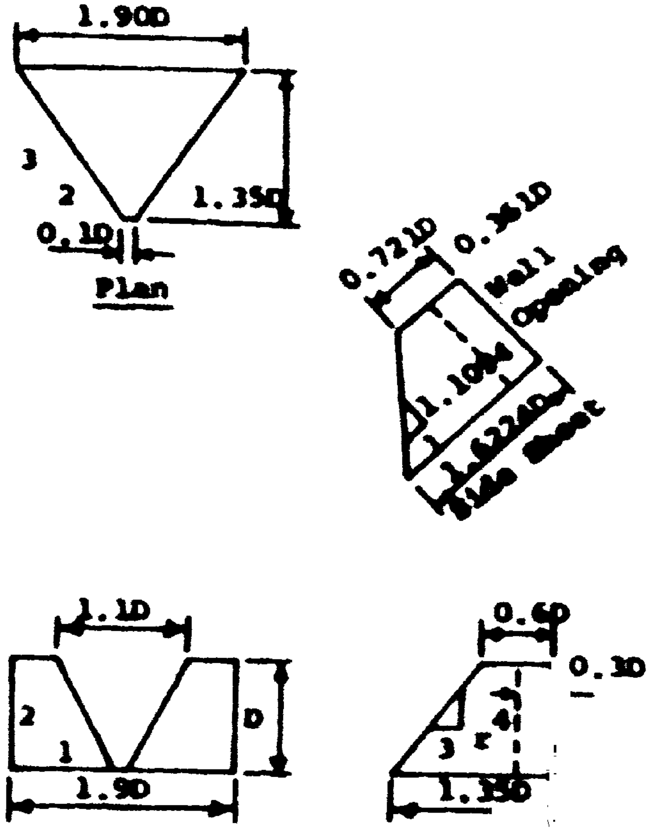


FRONT ELEVATION SIDE ELEVATION

PROPORTIONS OF THE TYPE HS FLUME

APPROXIMATE CAPACITIES	
DEPTH-D	CAPACITY
Feet	C.f.s.
0.4	0.085
0.6	0.23
0.8	0.47
1.0	0.82

FIG. 2: DIMENSIONS, CAPACITIES, AND CONSTRUCTION TOLERANCES OF THE HS FLUME



FRONT ELEVATION SIDE ELEVATION

Flume Depth	Outlet Opening Dimension Tolerances		
	Bottom Width	Top Width	Depth
Feet	Inch	Inch	Inch
0.5	0.02	0.1	0.05
0.75	0.02	0.1	0.05
1.0	0.02	0.1	0.05
1.5	0.03	0.1	0.05
2.0	0.03	0.1	0.05
2.5	0.03	0.1	0.05
3.0	0.03	0.1	0.05
4.5	0.05	0.1	0.10

FIG. 3: H FLUME DIMENSIONS AND CAPACITIES

PROPORTIONS OF THE TYPE H FLUME

Approximate Capacities

Depth-D	Capacity
Feet	c.f.s.
0.5	0.3+
0.75	1-
1.0	2
1.5	5+
2.0	11
2.5	19
3.0	30+

Note : For flumes less than 1 foot deep, the length of flume is made greater than 1.35D so that the float may be attached.

Construction specifications for the H flume are:

(1) Prepare detailed drawings, using the proportional dimensions shown in Fig. 3 (In case of HS flume Fig. 2).

(2) As for possible use only new materials of the good quality in constructing H flume. These materials must be free from defects.

(3) Use Mild steel sheets without any form of distortion (1/8" thick).

(4) Fabricate the flume by following the good commercial practice in all details of construction. Make all joints watertight and strong.

(5) Make the vertical sides of the flume from one sheet. The bottom plate must not contain more than one joint and no portion of this joint should lie near to the outlet opening. Any necessary joint in the bottom plate must be transverse to the longitudinal axis of the flume and must be made so that the joint is substantially flush. Make all dimensions for which tolerances are not indicated on the drawings within 1/4 inch (0.64 cm) of those given on the drawings.

(6) Cut all plate edges straight and sharp. Do not wrap the plates or distort them by cutting.

(7) Form the slanting outlet opening so that its dimensions are precisely those shown on the drawing. The slopes on this drawing must be rigidly adhered to. Edges of the opening must be straight and smooth.

(8) Clamp the plates rigidly in position and get the proper dimensions and slopes before making the final connections. Make the side plates perpendicular to the bottom of the flume. All cross sections of the flume must be symmetrical about the longitudinal axis. No projections should occur on the inside of the flume.

(9) Carry out all operations affecting the dimensions of the outlet opening and the straightness of its edges. Follow good machine shop practices in all operations. The completed flume should not have deep tool marks or dents.

(10) Before using inspect the flume to confirm its compliance with the plans and specifications.

Installation of HS and H Flumes : Whenever possible installations of these flumes should be made with approach boxes depressed below the natural ground surface as shown in Fig. 4, where the watershed or plot slope is small and the flow dispersed, gutters may be necessary to collect the runoff at the bottom of the slope and channel it into the approach box (Fig. 5). The more common type approach box is shown in Fig. 6. Here the runoff has concentrated naturally into a small stream channel upstream from the flume.

Metal flumes are bolted to the concrete approach with gaskets to make a watertight joint. The concrete cut off wall extends below the concrete approach at the upstream face of the flume to provide substantial support and to prevent seepage below the flume. Levelling bolts on the downstream supporting wall are used to fasten and adjust the flume to this level. The flume floor must be level. If silting is a problem a 1 on 8 sloping false floor can be set into concentrate low flows and thereby reduce silting. The difference in calibration of a flume with a flat floor and that with a sloping false floor is less than one present.

Submergence effect on H flumes: Flumes should be installed with free outfall or no submergence wherever possible. In the submergence situation the free discharge head H can be computed by using the following equation:

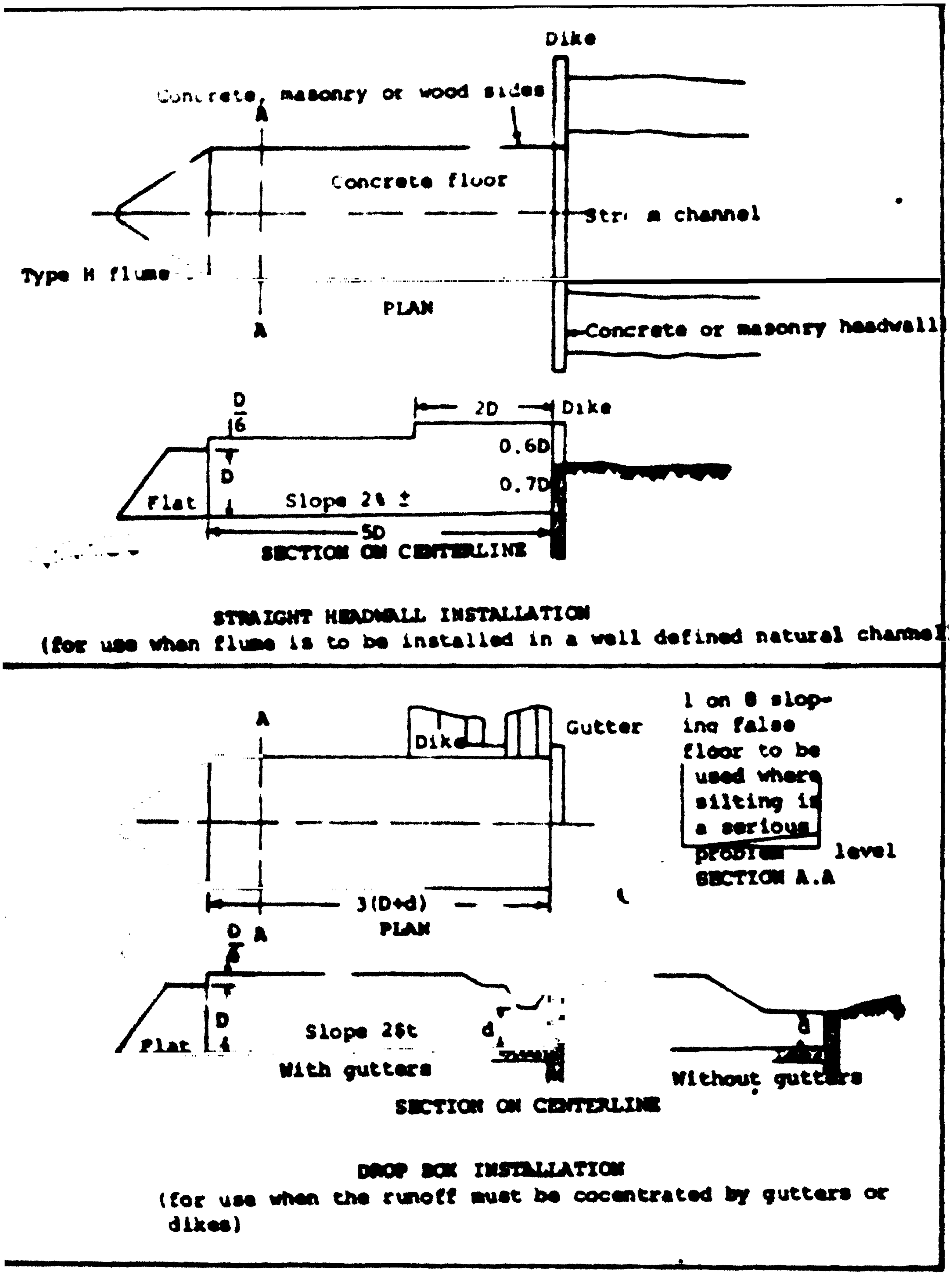


FIG.4 : PLANS FOR STRAIGHT HEADWALL AND DROP BOX INSTALLATIONS OF HS OR H FLUMES

FIG 5 : INSTALLED H FLUME WITH APPROACH BOX

FIG. 6 : INSTALLED H FLUME WITH APPROACH BOX THROUGH A CONCENTRATING DIKE

$$H = \frac{d_1}{1 + .00175\ (_e\ d_2/d_1)^{5.44}} \qquad ---- (1)$$

where

H = free flow head in feet

d_1 = actual head with submergence in feet.

d_2 = tail water depth above flume zero head

e = 2.71828 ....

$0.15 < d_2/d_1 < 0.90$

In laboratory the submergence of 30 percent has less than 1 percent effect on the free discharge head. A 50 percent submergence has less than a 3 percent effect. Care should be taken while using these values because normally they do not hold true in field situation.

PARSHAL FLUME

The Parshal flume is a particular form of venturi flume. The main advantage of this flume is its relatively low loss of head. The head loss is only about a fourth of that needed to operate a weir having the same crest length. This flume is particularly suited to measure flows from channels with low gradient because it can operate under high degree of submergence without loss of accuracy. Some of the important advantages of this flume are:

(1) It can operate with relatively small head loss.

(2) It is relatively insensitive to velocity of approach.

(3) It has the capacity of making good measurements with no submergence, moderate submergence, or even with considerable submergence downstream and

(4) Its velocity of flow is sufficiently high to virtually eliminate sediment deposition within the structure during the operation.

Some of main disadvantages of Parshal flumes are:

(1) They are usually more expensive than weirs and some of the flumes.

(2) They require accurate workmanship for satisfactory construction and performance.

(3) The accuracy of low flow measurements is limited.

The plan, elevation and dimensions of a Parshall flume is shown in Fig. 7. The width of the throat (W) is used to designate the size of the flume. Table 1 gives the dimensions and capacities of the flume for various throat width. This flume is normally constructed of sheet metal, masonry or reinforced concrete. The use of sheet metal is generally confined to smaller sizes. In general sheet metal of 1/8" thick can be used for fabrication of the flumes. Pieces of desired dimensions are cut smoothly and welded together to obtain a flume of required specifications. Reinforcement of angle iron should be riveted on all the edges, under the bottom and along the vertical sides to maintain the structural shape.

Reinforced concrete flumes are constructed in all the sizes. The floor of converging section should be perfectly level and the sides should be perfectly vertical. The crest is formed by fixing an angle iron in the proper position so that a sharp and level crest is obtained.

Capacity and Ratings of Parshal Flumes: A wide range of flows can be measured by Parshal flumes. The stage discharge relationship under free flow conditions as obtained in the hydraulic laboratory for small size flume (1 inches throat size to 10 ft) is

$$Q = 4\ W\ H_a^{\ 1.522\ W^{0.026}} \qquad ---- (2)$$

Q = discharge cubic flat per second

W = throat width or length of crest (size of flume) feet

Ha = Upper-[redacted]head, 2/3 (W/2 + 4) feet back from the crest, feet.

The rating of different sizes of Parshall flume under the free flow conditions is given in Appendix table 3. Where submergence exceeds

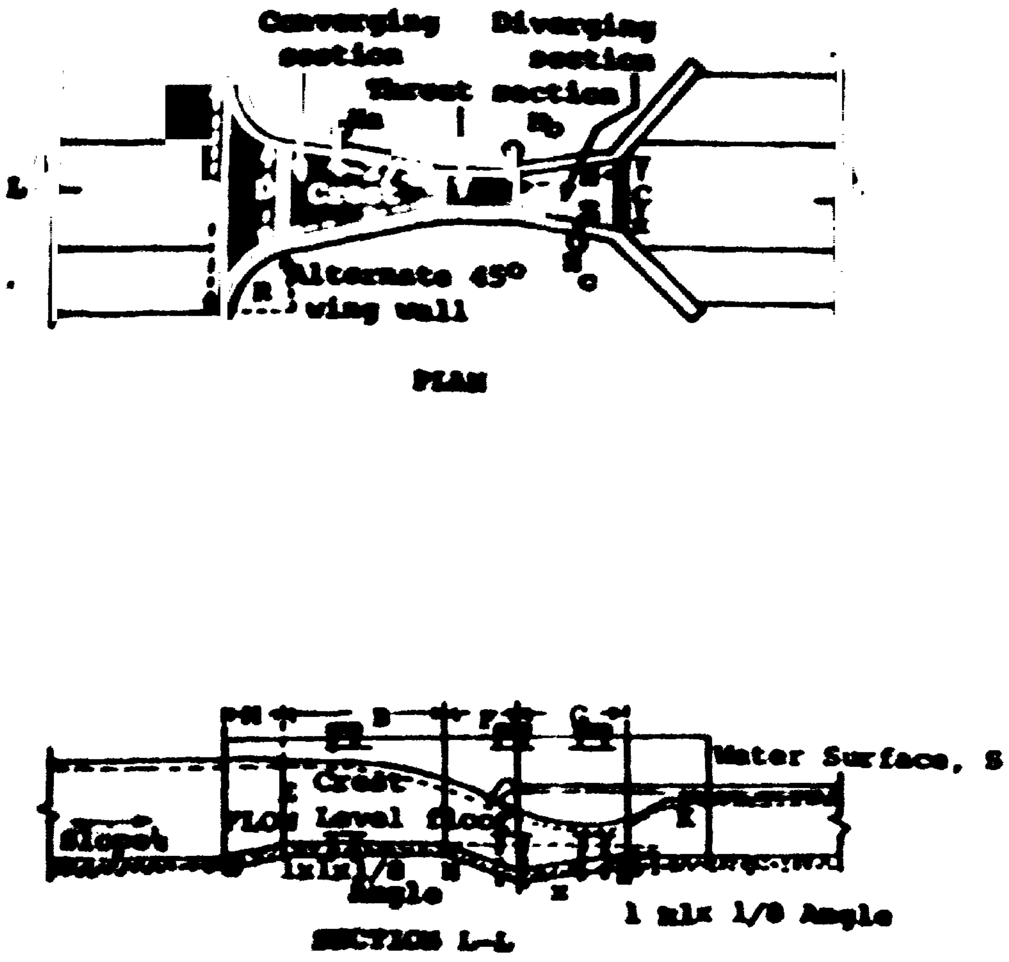


FIG.7 : PARSHALL FLUME DIMENSIONS

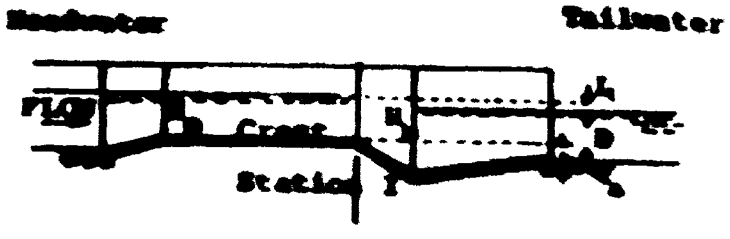


FIG.8 : RELATIONSHIPS OF FLOW DEPTHS TO THE FLUME CREST ELEVATION

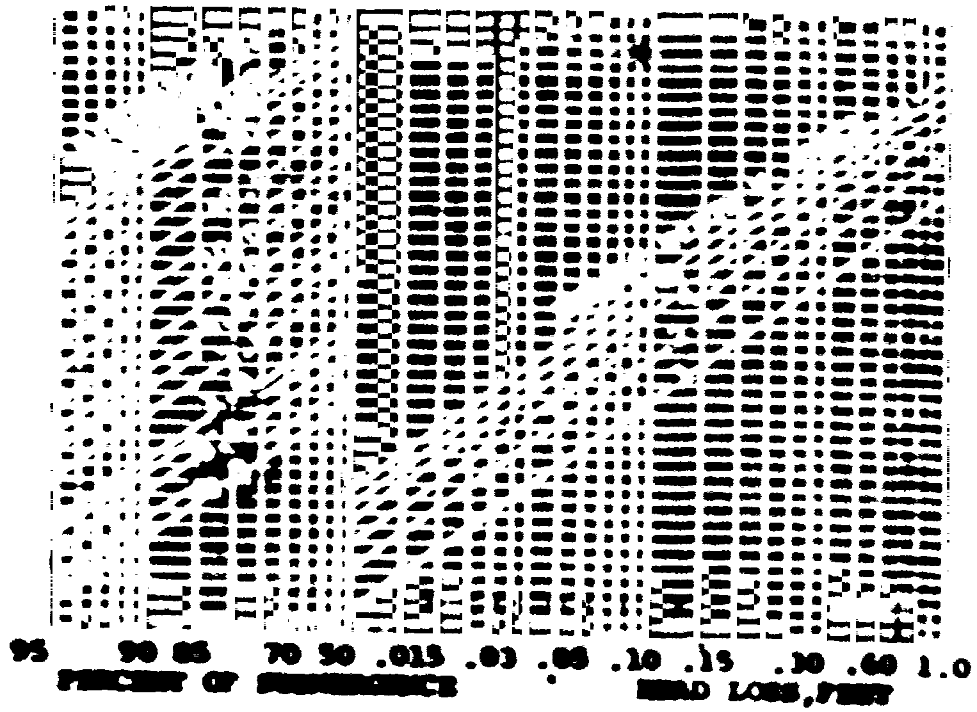


FIG.9 : HEAD LOSS THROUGH PARSHALL FLUMES 1 TO 6 FEET WIDE.

Table 1 : Parshall flume dimensions

W		A		2/3 A		B		C		D		E		F	
FT	IN	FT	IN	FT	IN	FT	IN	FT	IN	FT	IN	FT	IN	FT	IN
0	1[1]	1	2 9/32	0	9 17/32	1	2	0	3 21/32	0	6 19/32	0	6 to 9	0	3
	2[1]	1	4 5/16		10 7/8	1	4		5 5/16		8 13/32		6 to 10		4 1/2
	3[1]	1	6 3/8	1	1/4	1	6		7		10 3/16	1	0		6
0	6	2	7/16	1	4 5/16	2	0	1	3 1/2	1	3 5/8	2	0	1	0
	9	2	10 5/8	1	11 1/8	2	10	1	3	1	10 5/8	2	6	1	0
1	0	4	6	3	0	4	4 7/8	2	0	2	9 1/4	3	0	2	0
1	6	4	9	3	2	4	7 7/8	2	6	3	4 3/8	3	0	2	0
2	0	5	0	3	4	4	10 7/8	3	0	3	11 1/2	3	0	2	0
3	0	5	6	3	8	5	4 3/4	4	0	5	1 7/8	3	0	2	0
4	0	6	0	4	0	5	10 5/8	5	0	6	4 1/4	3	0	2	0
5	0	6	6	4	4	6	4 1/2	6	0	7	6 5/8	3	0	2	0
6	0	7	0	4	8	6	10 3/8	7	0	8	9	3	0	2	0
7	0	7	6	5	0	7	4 1/2	8	0	9	11 3/[illegible]	3	0	2	0
8	0	8	0	5	4	7	10 1/8	9	0	11	[illegible]	3	0	2	0

W		G		H		K		M		N		P		R		X		Y		Z		FREE FLOW CAPACITY Minimum	Maximum
FT	IN	FT	IN	FT	IN	FT	IN	FT	IN	FT	IN	FT	IN	FT	IN	FT	IN	FT	IN	FT	IN	SEC-FT	SEC-FT
0	1[1]	0	8	0	8 1/8	0	3/4	–	–	0	1 1/8		–	–		0	5/16	0	1/2	0	1/8	0.01	0.19
	2[1]		10		10 1/8		7/8		–		1 11/16		–	–			5/8		1		1/4	.02	.47
	3[1]	1	0	1	5/32		1		–		2 1/4		–	–			1		1 1/2		1/2	.03	1.13
0	6	2	0	–		0	3	1	0	0	4 1/2	2	11 1/2	1	4	0	2	0	3	–		.05	3.9
	9	1	6	–			3	1	0		4 1/2	3	6 1/2	1	4		2		3	–		.09	8.9
1	0	3	0	–			3	1	3		9	4	10 3/4	1	8		2		3			.11	16.1
1	6	3	0	–			3	1	3		9	5	6	1	8		2		3	–		.15	24.6
2	0	3	0	–			3	1	3		9	6	1	1	8		2		3			.42	33.1
3	0	3	0	–			3	1	3		9	7	3 1/2	1	8		2		3			.61	50.4
4	0	3	0	–			3	1	6		9	8	10 3/4	2	0		2		3			1.3	67.9
5	0	3	0	–			3	1	6		9	10	1 1/2	2	0		2		3			1.6	85.6
6	0	3	0	–			3	1	6		9	11	3 1/2	2	0		2		3			2.6	103.5
7	0	3	0	–			3	1	6		9	12	6	2	0		2		3			3.0	121.4
8	0	3	0	–			3	1	6		9	13	8 1/4	2	0		2		3			3.5	139.5

[1] Tolerance on throat width (W) ± 1/64 inch; tolerance on other dimensions ± 1/32 inch. Side walls of throat must be parallel and vertical.

prescribed limits, it is necessary to apply a negative connection to free flow discharge. Under the situation the tail water level is also measured near the downstream end of the throat section (Fig. 7 it is labelled H_b). This zero reference, H_b is the crest. The discharge rate under the submergenced flow condition could be determined by:

$$Q = \frac{C_1 (H_a - H_b)^{n_1}}{I-(\log H_b/H_a + C_2)\ I^{n_2}} \quad ---- \quad (3)$$

This equation is reasonably accurate (2 to 5 percent) for submergence values upto $(H_b/H_a) = 0.96$. Values of submerged flow coefficients and exponents for Parshall flumes(C_1, H_a, H_b, n_1 C_2 and n_2) are given in Table 2. The table also provides the transition submergence S_t which is defined as the value of submergence at which the change from free flow to submerged flow occurs.

Table 2 : Submerged flow coefficients and exponents for Parshall flumes

W	C_1	C_2	n_1	n_2	S_t
1 inch	0.299	0.00044	1.55	1.000	0.56
2 inches	0.812	0.0044	1.55	1.000	0.61
3 inches	0.915	0.0044	1.55	1.000	0.64
6 inches	1.66	0.0044	1.58	1.080	0.58
9 inches	2.51	0.0044	1.53	1.060	0.63
12 inches	3.11	0.0044	1.52	1.080	0.62
18 inches	4.42	0.0044	1.54	1.115	0.64
24 inches	5.94	0.0044	1.55	1.140	0.66
30 inches	7.22	0.0044	1.555	1.150	0.67
3 feet	8.60	0.0044	1.56	1.160	0.68
4 feet	11.16	0.0044	1.57	1.185	0.70

<u>Selection of Parshall Flume Size and Crest Elevation:</u> Because of considerable overlap in flume discharges, it is possible to pass a given discharge through any one of several standard size flumes. The choice of the proper size therefore requires full consideration of other factors in addition to capacity For example a different throat width W, will be required if 20 ft^3/sec is to be discharged with 2.5 feet of depth rather than with 1 foot of depth. In the interests of economy the smallest practical size should be selected.

In selecting a flume size it is necessary to use the "trial and error" system on several sizes believed adequate. The final selection is made primarily on the basis of original waterway or channel dimensions. Selection of flume size and vertical placement in the channel, as required in the field can be best described by this example.

<u>Example:</u> Assume the size and setting must be determined for a parshall flume to measure flows upto 20 ft^3/sec for free flow conditions in a waterway of moderate grade where the expected water depth at this discharge is 2.5 feet and the general topography near waterway in relatively flat.

An examination of Appendix table 3 shows that the following flumes will each handle a discharge of 20 ft^3/sec with the head shown:

Flume size (throat width) feet	Upper head H_a, feet
6	0.89
5	1.00
4	1.15
3	1.38
2	1.80

For the 4 foot flume H_a is 1.15 (Appendix Table 3). For free flow the maximum submergence can be 70 percent (Table 2), that is the ratio H_b/H_a = 0.70 therefore

$$\frac{H_b}{1.15} = .7 \text{ and } H_b = .81 \text{ foot.}$$

This value of H_b is used to determine the vertical distance from the waterway bottom to the flume crest (Fig. 8). At a 70 percent submergence the water surface in the flume throat at the H_b gauge is essentially level with the surface in the downstream channel. Referring to same figure this 2.5 feet depth will occur at D. Dimension Δ is equal to D minus H_b, in this case 2.5 minus 0.81 or 1.69 feet and is the distance that the crest should lie above the waterway bottom. This determines the vertical placement or setting for a maximum flow of 20 ft^3/sec at 70 percent submergence.

The flume itself normally is an obstruction in the channel and will produce a backwater effect that will extend upstream from the flume and raise the headwater elevation. This difference in elevation of the flow upstream from the structure with and without the flume in place is the head loss caused by the flume. The head loss values for flume 1 foot to 6 feet wide can be determined from Fig. 9.

Starting at the base of the diagram (Fig. 9) follow the 70 percent submergence line vertically upward to the slanting 20 ft^3/sec discharge line From the intersection project a horizontal line to the right from this point to intersect the slanting throat width line for W = 4 feet. Finally from this point project vertically downward to the head loss scale to determine that the head loss L, is 0.43 foot. From Fig. 8 the water surface elevation of the approaching flow will then be D + L = 2.5 + 0.43 = 2.93. feet measured above the waterway bottom.

Following the same analysis but with a 3 feet flume,

H_b = 0.97 foot

Δ = 1.53 feet

L = 0.54 foot

and the depth of water in the upstream waterway would be 3.04 feet.

Similarly for a 2 feet flume,

H_b = 1.27 feet

Δ = 1.23 feet

L = 0.71 foot

and the depth of water in the upstream channel would be 3.21 feet.

Thus the upstream depths for 4, 3 and 2 feet flumes would be 2.93, 3.04 and 3.21 feet respectively. If waterway is enough deep and general topography of upstream can allow the depth 3.21 feet (special considerations like area which will be frequently submerged and overflowing of water from sides, etc) the 2 feet flume might be chosen because of its lower first cost. However, when the width of waterway is considered in terms of constructing wingwalls to provide a nonoverflowing transition section on each side of the flume the 3 or 4 feet wide flume might be chosen to simplify construction or reduce the cost of installation.

It is usually desirable to set the flume slightly higher than (normally higher by 20 percent) absolutely necessary, rather than lower. The higher setting helps compensate for unknown or changing downstream factors which usually increase submergence. These factors each of which tends to raise the downstream waterlevel, include deposits of sediment, deterioration of the sides of waterway, and growth of weeds, tree roots, moss and other biological organisms. Setting the flume higher than necessary however will increase the velocity of flow leaving the structure and may make it necessary to provide the antiscour protection at the downstream end of the flume.

If the Parshall flume is never to be operated above the allowable submergence limit (for free flow), there is no need to construct the portion of the flume downstream from the end of the crest. In this situation only the upstream portion of the flume is constructed. The crest of the flume ... set ...ove the waterway bottom. This will assure that the flow profile over the crest section is not modified by back water from the downstream waterway. Erosion protection downstream from the flume may need to be considered for good service life.

In the case where the expected submergence is higher than allowable limit for free flow condition more careful analysis should be done. The crest elevation should be determined quite accurately. In this situation the construction on downstream of flume is also done.

WEIRS

Weirs are one of the simplest and quite reliable structures that can be used in many situations to measure the runoff. The critical parts are easily inspected and any improper operations can be easily detected and quickly corrected. Weirs can be used most effectively whenever there is a fall of about 0.6 foot or more available in waterway and also where submergence on the upstream is not very much undesirable. They are generally classified on the basis of width of the crest and shape of the weir opening. Here only one of the most commonly used weir will be described.

SHARP CRESTED TRIANGULAR WEIR OR V NOTCH WEIR

V-notch weirs have been extensively used for measurement or runoff especially from small areas. They have been accurately rated in the laboratory under specific conditions of crest characteristics, their placement in the channel or waterway, approach waterway conditions and the flow conditions and the relationship is expressed in the form of discharge formulae. The weir crest generally consists of a metal blade with sharp edge. The distinct advantage of the triangular weir is the suitability for measurement of low flows with a high degree of accuracy.

The most commonly used triangular weirs are 90° V notch and 120° V notch. The former is more sensitive and accurate in the measurement of low flows than the later, which has a wider range of capacity.

The detail plan of 1.25 fee 90° V notch is shown in Fig. 10. The weir blades are normal constructed of angle -on 3½" x 3½" x ¼" or non corrodable metal plate ¼" thick. The installation and construction of approach channel should be strictly done according to the points as discussed under "setting of V-notch weirs". The Appendix Table 4 gives ratings for sharp crest 90° V notch. A 90° V notch with recorder, recorder shelter and stilling well for measuring the runoff from a field scale plot is shown in Fig. 11.

SETTING OF V NOTCH WEIRS

Extensive experiments on weirs and long experience with their use dictate that the following conditions are necessary for accurate measurement of flow with sharp crested V notch weir:

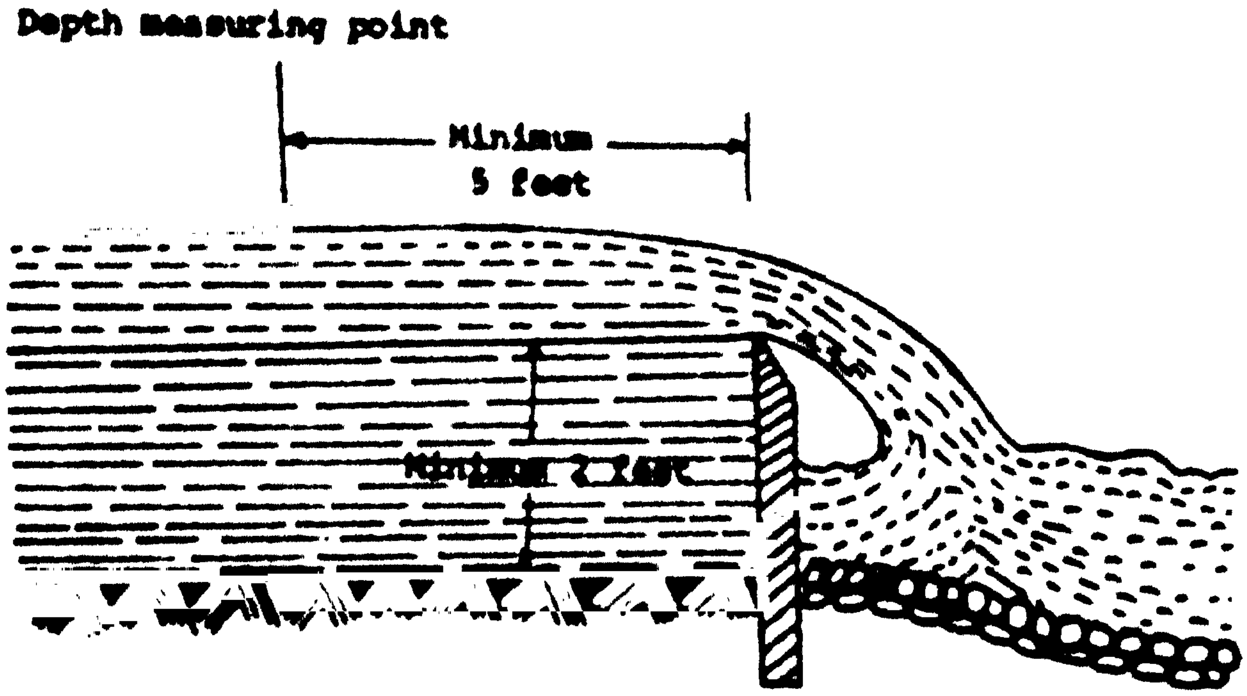
(1) The upstream face of the bulkhead should be smooth and in a vertical plane perpendicular to the axis of the channel.

(2) The upstream face of the weir plate should be smooth, straight and flush with the upstream face of the bulkhead.

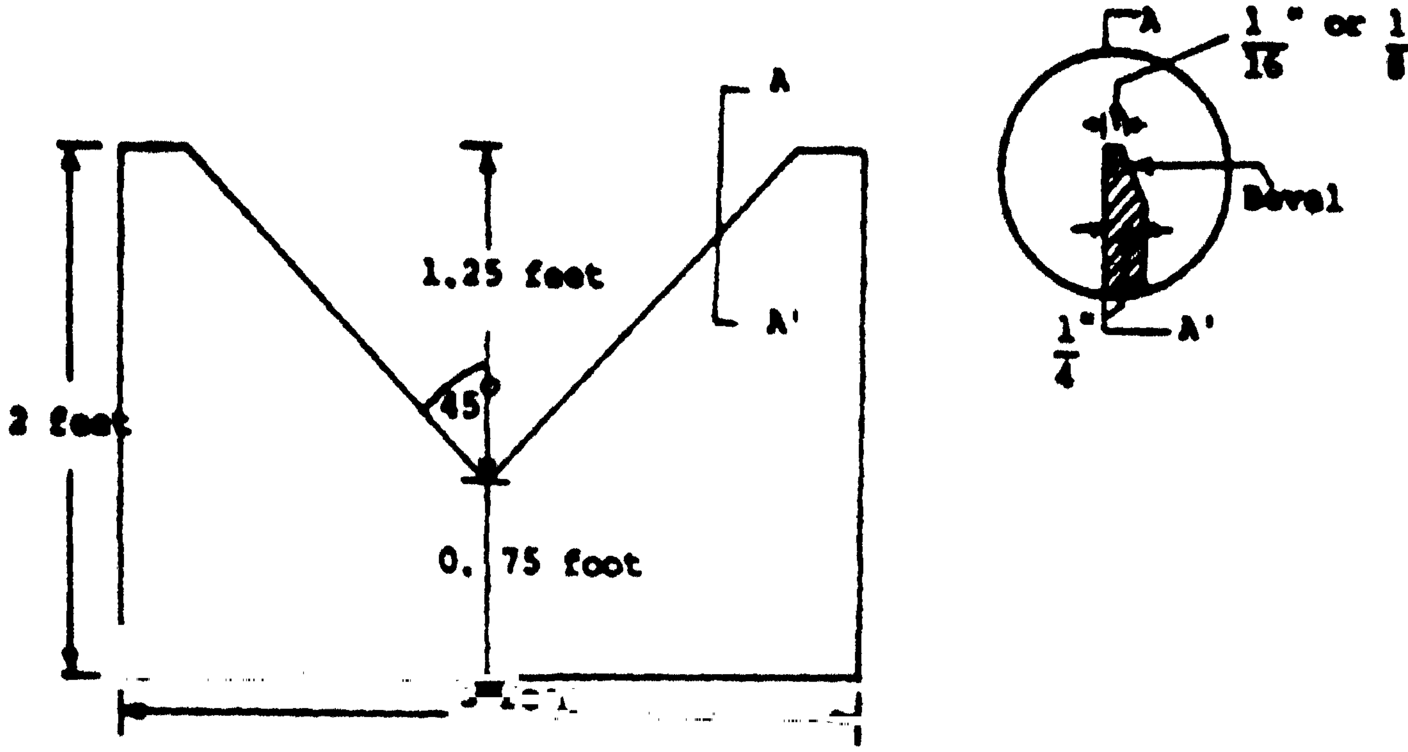
(3) The thickness of the weir blade should not be more than 1/4" (about 6 mm).

(4) The upstream corner of the notch must be sharp they should be machined or filed perpendicular to the upstream face, free of scratches and not smooth off with abrasive cloth or paper. Knife edges should be avoided because they are difficult to maintain.

(5) The down stream edges of the notch should be relieved by chamfering if the plate is thicker than prescribed crest width (1 to 2 mm). This chamfer should be at an angle of 45° or more to the surface of the crest.



Some installation conditions for 1.25 feet 90° V notch weir



Metal plate dimensions

FIG. 10 : DETAIL PLAN & DIMENSIONS FOR A 1.25 FEET 90° V NOTCH WEIR

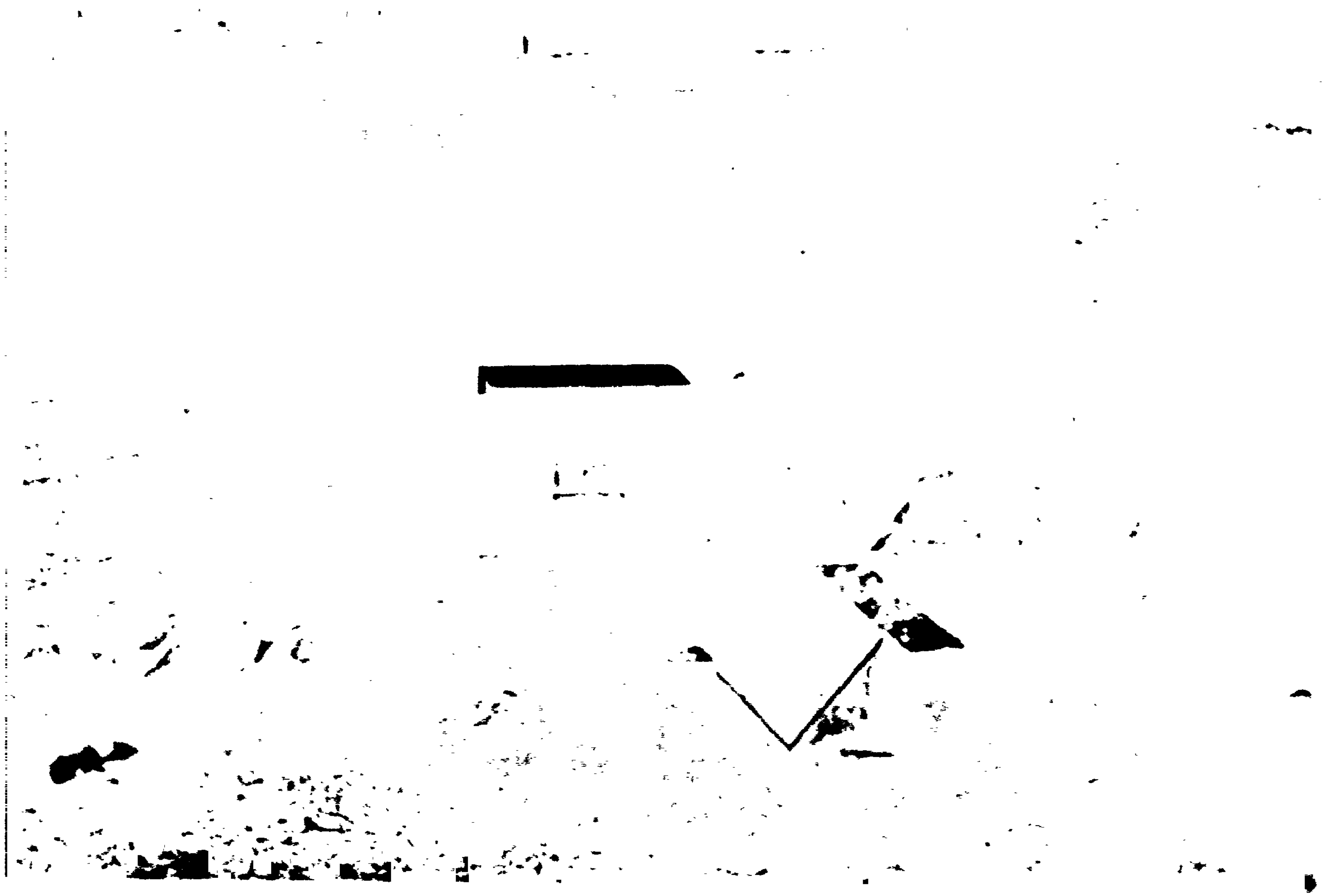


FIG.11 : 90° V NOTCH WITH RECORDER INSTALLED ON FIELD SCALE PLOT

(6) The distance of the lowest crest point from the bottom of approach channel (weir pool) should preferably be not less than twice the depth of water above the lowest crest point and no case less than 1 foot.

(7) The distance from the sides of weir to the sides of the approach channel should preferably be no less than twice the depth of water above lowest crest point and never less than 1 foot.

(8) The overflow sheet (nappe) should touch only the upstream edges of the crest.

(9) The measurement of head on the weir should be taken as the difference in elevation between the lowest crest point and water surface at a point upstream from the weir a distance of four times the maximum head on the crest.

(10) The cross sectional area of the approach channel should be at least 8 times that of the overflow sheet at the crest for a distance upstream 15 times the depth of the sheet.

(11) If the weir pool is smaller than defined by the above criteria the velocity of approach may be too high and the staff reading too low. The head should be corrected by using appropriate method.

WATER LEVEL RECORDERS AND THEIR INSTALLATION

The precalibrated structures provides a stable cross section wherein the rate of flow can be determined if the stage is known. The frequency of flow determinations is dictated by the purpose and conditions of the study. The accurate determination of runoff volume, peak runoff rate and other related information from small areas invariably needs the continuous record of stage. The stage level recorders are commonly used for this purpose. It produces a graphic record of the stage of flow over the control with respect to time which is accepted as highly reliable. In small areas where there is rapid fluctuations of water level it is not practically possible to collect data on runoff with other types of non recording gauges.

Many types of stage level recorders are commercially available to provide continuous stage records. The drum type recorders (a float type recording gauge) are most commonly used in runoff studies on small watersheds and plots where visits are scheduled to the site daily or sometimes weekly.

Several types of the recorders have been developed after intensive research in the laboratory and field and fabricated on commercial scale in other countries. The recorders FW-1 developed by J.P. Freiz and sons Co, Baltimore, Maryland, USA are under extensive use in India by Agricultural Research Institutions. These recorders are now commercially manufactured by the Belfort Instrument Company, 4 North Central Ave. Baltimore, Maryland 21202 USA. In India few firms at Dehra Dun are manufacturing the stage level recorders.

5-FW-1 STAGE LEVEL RECORDERS

This type of recorder (Fig. 12) mechanically convert the vertical movement of a counter weighted float resting on the surface of a liquid into a curvilinear, inked record of the height of the surface of the liquid relative to a datum plane and with respect to time. The time element of this recorder consists of a weekly - winding spring driven clock supported on a vertical shaft to which the chart drum is firmly secured vertically. The gauge element consists of a float, counter weight graduated float pulley. The movement of the float is transmitted to a cam and with the help of a set of gears it moves the pen on the chart in the vertical direction. They have reversing mechanism and can therefore record an unlimited range of stage on 5" wide chart.

Stage Ratio Selection Each recorder normally have two sets of stage ratio change gears. The float wheel gear for the 1:12 ratios is cut into the float wheel shaft rear projection and the float wheel gear for the 5:12 ratios, is normally fastened with (5-40) 1/8" set screw to the same rear projection, clear of the engagement of the 1:12 (See Fig. 13). The Cam shaft gear for the 5:12 is normally delivered mounted to the recorder base. Normally for small watersheds or plots 5:12 stage ratio is used.

Time scale gears: The chart cylinder is driven through a pair of gears external to the mechanism train proper. There are two shaft extensions above the upper plate. The plainly marked gears are available for 6, 8, 12, 24, 29, 48, 96, 108, 144, 176, 192 and 195 hrs for one revolution of cylinder. If on gear it is marked 6S that means the cylinder takes one revolution in 6 hrs, if it is 24 S it will take 24 hrs for one revolution. Normally for small watersheds 24S gear sets are used. Only where it is not possibly to visit daily, gears with higher number can be used or where more accuracy is needed gear sets with lower number can be used.

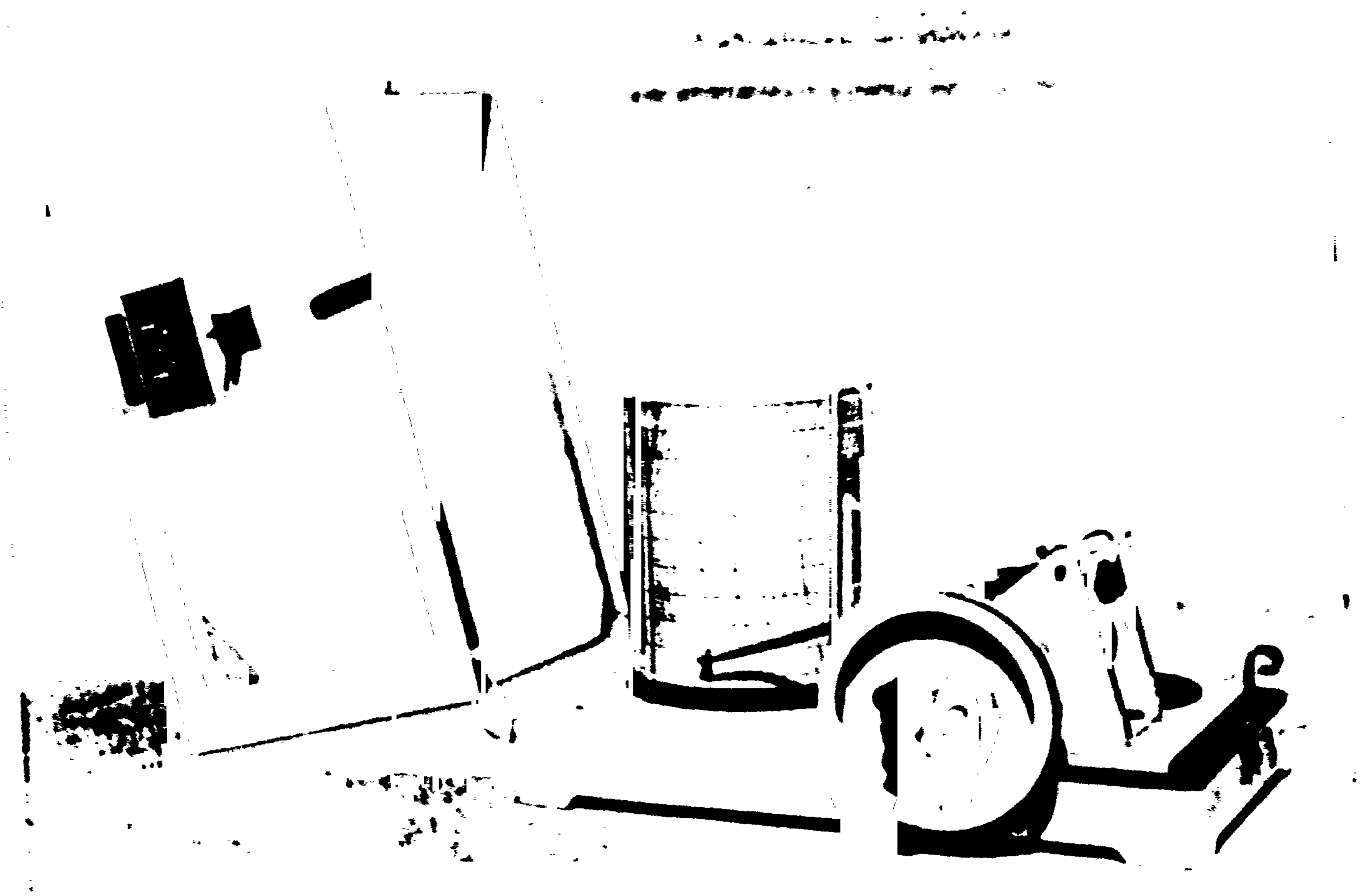


FIG. 12 : STAGE LEVEL RECORDER (5-FW-1 BELFORD COMPANY)

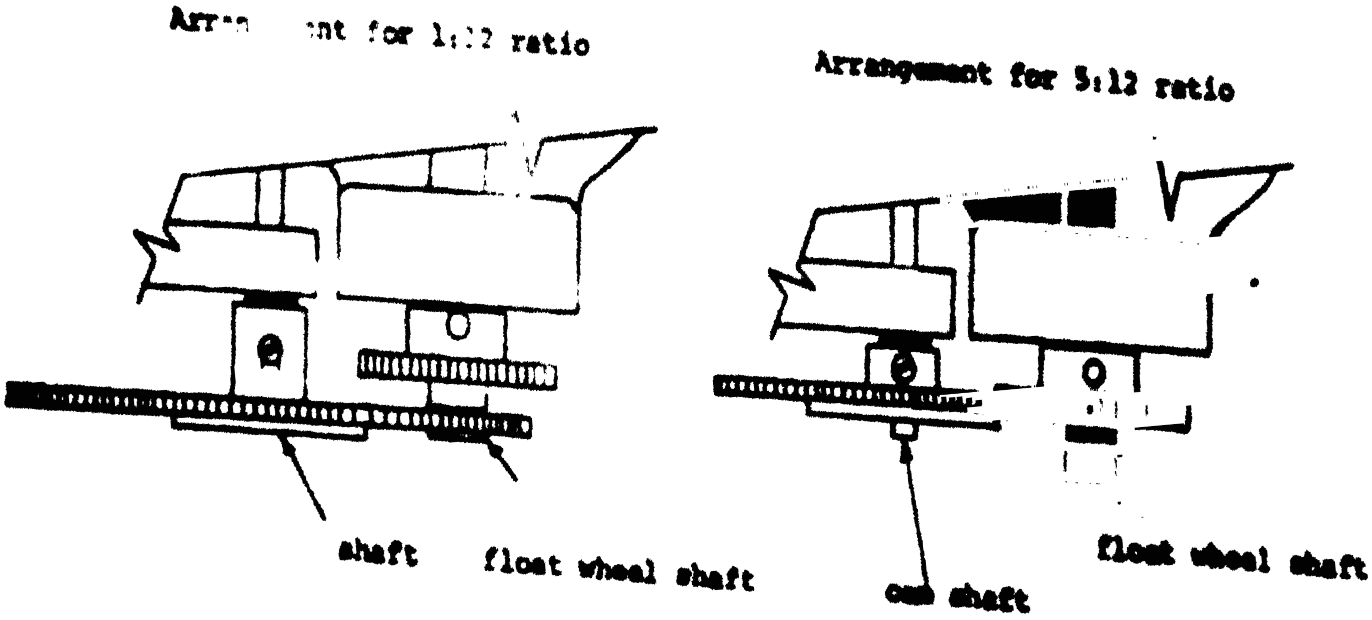


FIG. 13 : STAGE RATIO SELECTION

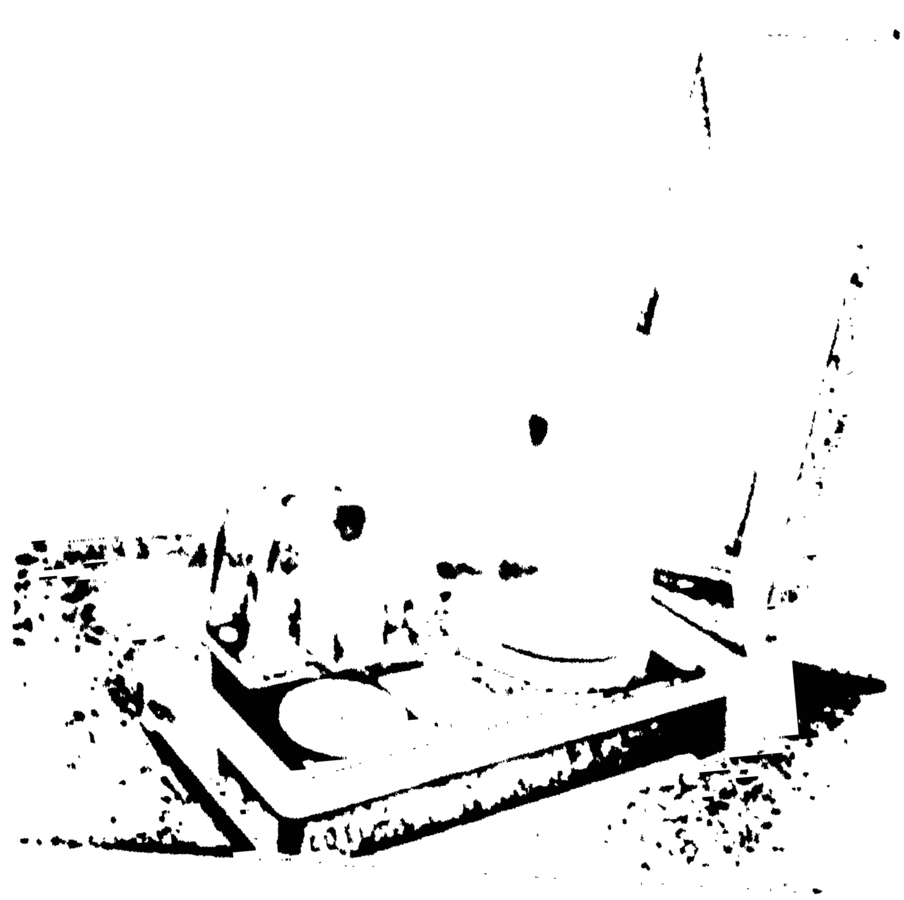


FIG .14; RECORDER WITH 5:12 GEAR SFT

The detail information about the general operation and maintenance of the recorder are given in instruction book which supplied along with recorders.

INSTALLATION OF STAGE LEVEL RECORDERS

Before installing the stage level recorder at the gauging site the recorder should be checked for appropriate gear sets for stage ratio and time required for one revolution. The gauging site equipped with a stage level recorder has the following essential components viz stilling well, intakes, and recorder shelter.

Stilling Well: The well over which the stage level recorder is installed is essentially a stilling well in which the float and counter weight of the recorder rise and fall in response to the fluctuation of the water leve without being affected by surges or waves which might result inaccurate measurement. Regardless of the type of runoff control used, the well shoul be located to one side of the waterway so it will not interfere with the flow pattern over the spillway. As far possible the well should be located near to the measuring flow section of the precalibrated structure. The relative position of the well and intake depends upon the type of the measuring structure for example in the V notch weir, it is 5-10 feet from the centre of the crest. The size of well will depend upon the required stability, depth, type of material and space required by float and counter weight. Constructional details of a brick masonry well is shown in Fig.15. Instead of brick masonry the galvanised iron and concrete pipes can also be used in constructing the stilling well. They should be built on solid foundations with water proof bottoms. This can be achieved by providing 6" thick concrete floor on which the well is constructed. In area of swelling type soils like Vertisols much larger foundations are needed. Following important considerations should be taken while constructing the stilling walls.

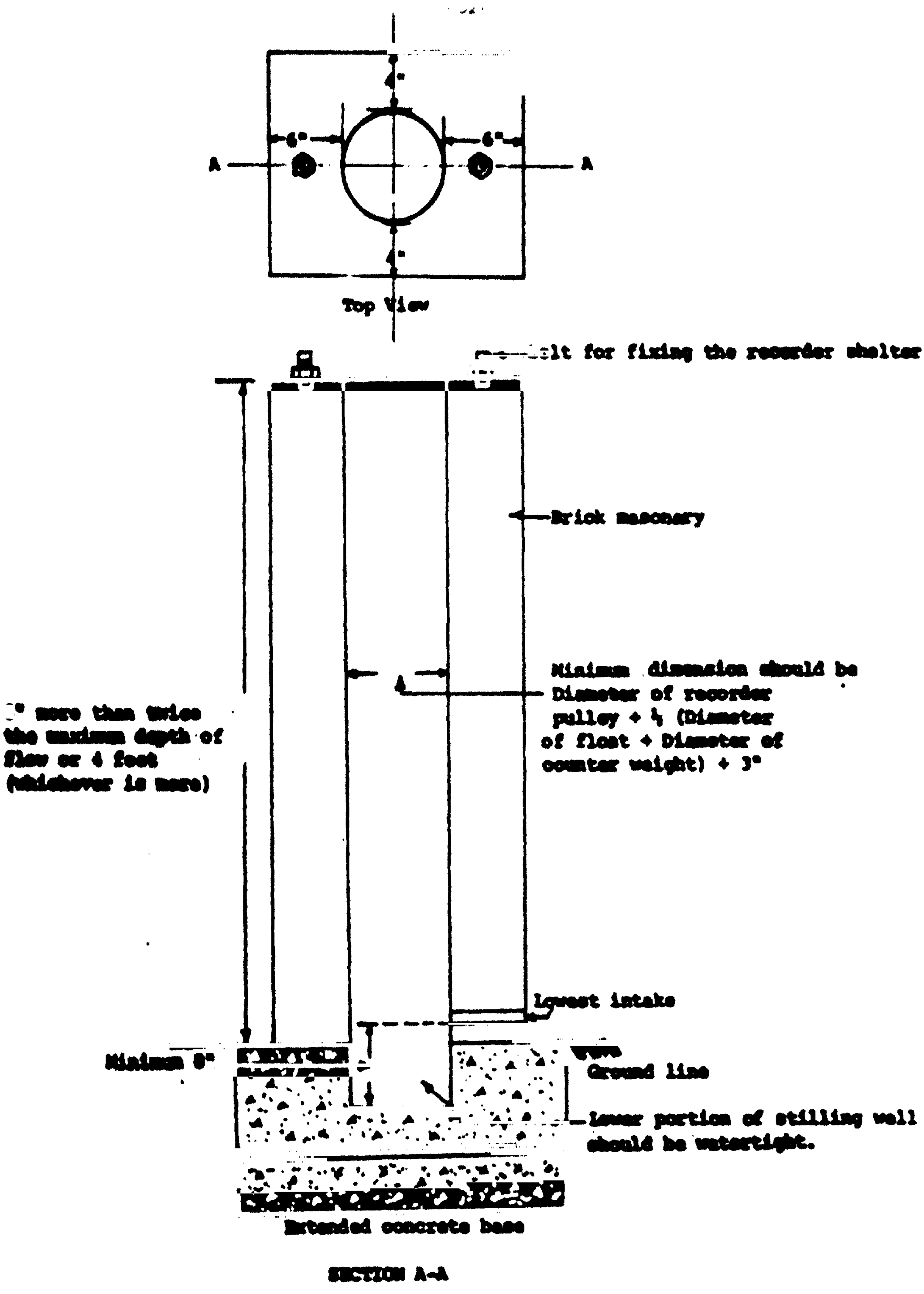


FIG.15 : DETAILS OF STILLING WELL

(1) The bottom of the well should be minimum 8" inches lower than the lowest intake.

(2) The portion of the stilling well below the lowest intake must be watertight.

(3) The inside diameter of the well should not be less than the diameter of recorder pulley + half diameter of float + half diameter of counter weight + 3" (for FW-1 recorder approx 9" diameter is required).

(4) The inside surface of the well should be smooth either by plastering or by providing the thin metal sheet.

(5) The depth of the well should be about 6" more than the double of the maximum expected head to provide a full range of scale without danger of submerging the counter weight of the recorder.

(6) The size of well should not be too large which may create certain danger of lag between the rise or fall of water level at the control and in the well.

Intakes: The connection between the stilling well and the water flow in precalibrated structure is accomplished by means of intake pipes. These intakes can be one or more galvanized pipes, a seriers of rectangular slots or several 1 inch diameter holes. A general guide to the size and number of intakes required is that their total cross sectional area should be at least one percent of the cross sectional area of the stilling well. Another guide is to limit the head loss in the intake for the expected maximum rate of change in stage to a given maximum amount such as 0.02 foot. In case of the runoff monitoring on small watersheds normally first criteria are a taken because of rapidly fluctuating flow. Only in situation where the stilling well are quite far away from the main waterway the second criteria may be considered.

In general more than one intake should be provided at different elevations. This gives two distinct advantages, firstly it safeguards against complete clogging of the intake by moving or deposited sediment. Secondly it facilitates better water connection with the rise or fall of flow. In addition to this it is always better to have two intakes at the lowest level because of high chances of being closed due deposited soil particles.

Recorder Shelter: For protection from rain, sun and other elements, it is necessary to provide a housing for the stage recorder. The type of shelter may vary from a small box covering the well opening and recorder, which operates on a hinge, to a good sized compartment which contains the well and facilitates the entry of the observer.

The box type shelter is most commonly used because of ease of construction and less cost. Fig. 14 shows the recorder shelter which have been satisfactorily used at ICRISAT for last seven years. This size shelter is sufficient to cover the top of the well and provide sufficient space for lifting of the stage recorder cover and changing chart. Materials used for construction are GI sheet and timber. In area where thefts are big problem the metalic shelter box with inside locking system may be used.

FIELD OBSERVATIONS AND MAINTENANCE

Field observations are made (1) to record accurately and completely what is happening an.. (2) to promote proper notes and equipment operation in obtaining complete records of what will happen. Notes on instrument operation are vital to data tabulation, especially when appreciable lag occurs between obtaining the record and tabulating data. Notes on attending conditions are vital to data analysis and interpretation. Records obtained with instruments not functioning properly may provide usable data if adequate notes are collected concerning the nature and cause of instrument failure.

Maintenance of recorder and runoff stations is mandatory for collecting good records. Improperly maintained equipment will not provide the accuracy and may give very misleading data. Recorders used for runoff is provided with recommended maintenance procedures from the manufacturer. Other suggestions for maintenance are provided in this section.

RECORDER CHART NOTATION AND MAINTENANCE

I acement of notes on cha .s might include watershed number or station designation, chart number, removal watch time, rising, falling, corrections on time and stage, notch base level and lowest intake level. Charts should be numbered and dated to show that the record is continuous although no runoff occurred during the period covered by some of the charts. Use a light pencil for all notes and proceed as follows:

For these charts covering periods during which no runoff occurred, show only chart number and dates. No other notes are required as the main purpose of these charts is to show continuity of records.

For charts covering periods during which runoff occurred:

(1) Include chart number and dates in the space provided for this.

(2) Enter dates, watch time at times of placement, inspection and removal.

(3) Show the level of spillway crest and lowest intake.

(4) Indicate the time scale and gauge height ratio used in the proper place on the marginal tabs. This is needed only on centers where they are using recorders with different time scales and gauge height ratios.

(5) Check to see how placement and removal marks agree with the watch time. If they do not agree within 10 minutes, apply a time correction. To determine this correction, assume a straight line variation between placement or inspection and removal.

For example : At the time of removal of the chart following observation were taken:

(i) Time difference between the watch and the recorder time = 40 minutes less.

(ii) Total period for which chart was kept on recorder = 30 hrs

(iii) Total period of runoff = 6 hrs.

Then the correction to be applied to runoff period will be $\frac{40 \times 6}{30}$ = 8 minutes by adding to the original 6 hours.

(6) Check the discrepancies between the chart line and index pointer and for failure of the pen to reverse at the edges of the printed portion of the chart. If the pen reverses below the limits of the printed part of the chart about the same extent at both the upper and lower reversals, apply a constant correction to each traverse. This correction for the traverse upward across the chart is plus whereas that for the downward traverse is minus. Where the lower reversal is correct and the upper reversal falls short, a graduated correction is correct theoretically. As tabulations are to be made only to the nearest 0.01 foot (0.3 cm) a graduated

correction would not be feasible and a constant correction should be applied through a given range in stage. If the upper reversal falls 0.01 foot short, the entire correction should be applied only to the upper half of the chart. If the upper reversal is 0.02 foot (0.6 cm) short, a correction of 0.01 would be applied from 0.25 to 0.75 and 0.02 would be applied from 0.75 to 1.25. Note any correction that must be applied to the stage.

(7) Add notes to show when the stage is rising or falling.

EQUIPMENT SERVICING

Equipment should be serviced on a specified schedule set up to maintain continuous operation. Timing will depend upon the way the recorder was used. Normally after every two years the full servicing of recorder is required. Yearly oiling of clock and some mechanism is recommended.

Flumes, Weirs and Stilling well : The structure and upstream pond area must be kept free of weeds and trash and sediment must be removed as it accumulates. The level of crest should be checked periodically with reference to the elevation of the gauge zero. The crest should be examined for nicks or dents that might reduce measurement accuracy. These imperfections should be corrected carefully. Flumes must be maintained in original condition and in accordance with design specifications, levels and slopes of installation must be checked periodically and must be corrected if necessary.

If constructed properly stilling wells will require little servicing The well, intake pipes and silt trap (if used) should be free of silt. When the well is cleared or the intake pipe is unclogged, the recorder styles should be raised from the chart. Otherwise surge in the well may cause excess ink on the chart to soften the paper causing the pen to tear it. After every flow event intakes should be checked and necessary silted soil should be removed.

ADJUSTMENTS AND CHECKING OF STAGE LEVEL RECORDER (FW-1):

Most of the research stations normally have limited number of recorders. If any of recorder developes a minor problems, some of important runoff events may be missed because of the fact that the recorder repair is normally not possible in the local market. It is therefore necessary that observer must develop the capabilities for minor repair and adjustments which can be easily done.

FW-1 recorders are normally calibrated at the factory and when in proper adjustment. The following relationships exist:

(1) The total pen travel between upper and lower reversals is about 5 inches (12.7 cm) and both reversals occur at the edge of the printed portion of the chart.
(2) Cam follower pin is horizontal.
(3) The pen arm is parallel to the cam follower arm.
(4) The pen arm is tilted inward just enough so the pen will not fall away from the chart near the upper reversal (Note: A slight change in tilt of the pen arm will cause a shift in position of the reversals).
(5) The clock spindle washer is of the proper thickness to place the centerline of the chart and the pen shaft in the same horizontal plane.

Some of the problems with stage level record (FW-1) with necessary adjustments:

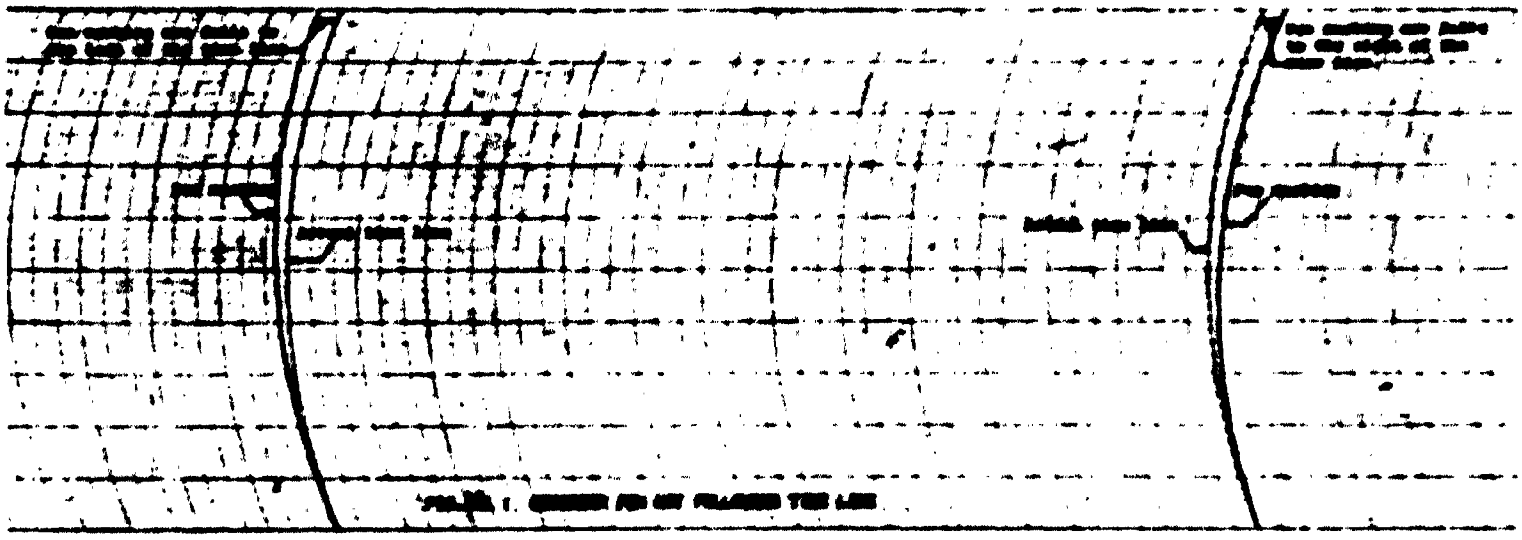
(1) Fig. 16a shows the one of the common problem with recorders that is the pen does not follow the time line. To see how close the pen follows the time line place the pen off the chart, and rotate the float wheel through upper and lower reversals. Deviation from the time line between the upper and lower reversals indicates either a bent spindle or improper thickness of clock spindle washer.

First adjustment: loosen the drum bottom nut, rotate the spindle 90° tight the nut and repeat the check. Continue this process (maximum three times till you get the agreement between the pen and time line.

Second adjustment: If the pen traces does not agree with time line even after the first adjustment this indicates that the spindle is bent and should be straightened carefully or replaced. After this repeat the check.

Third adjustment: After the second adjustment if the pen does agree with time line repeat the first adjustment and if the arc described by the pen is the same for two or more positions of the drum but still does not follow a time line, it indicates improper thickness of washer between the base and the gear. When the arc falls to the right of the time line at the top of the chart (Fig. 16a) the clock spindle washer is too thick. When the arc falls to the left, the washer is too thin. Change the washer as indicated and check until agreement with the time line is good.

(2) Fig. 16b shows the lower reversal problem of pen occuring above or below the lowest graduation or printed line. If this lower reversal occur above or below the lowest graduation bring pen to this line by adjusting screw (at the end of pen arm). This will make the cam follower arm parallel to the pen arm. After adjusting the screw recheck the lower reversal.



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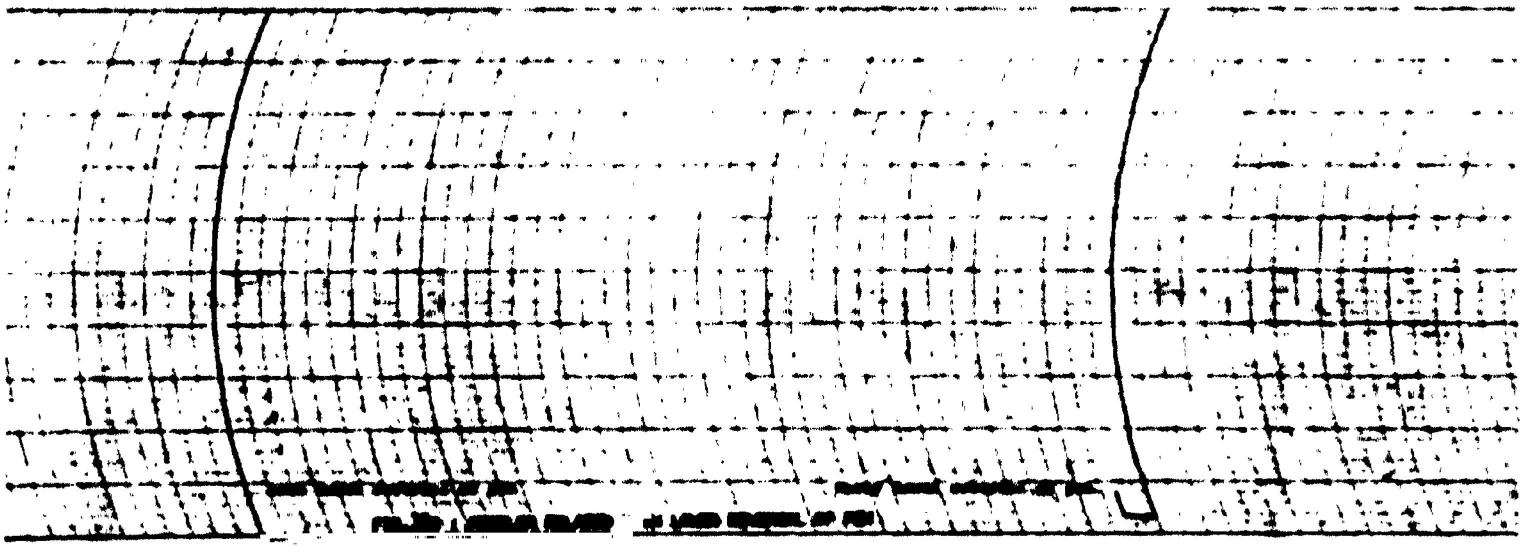

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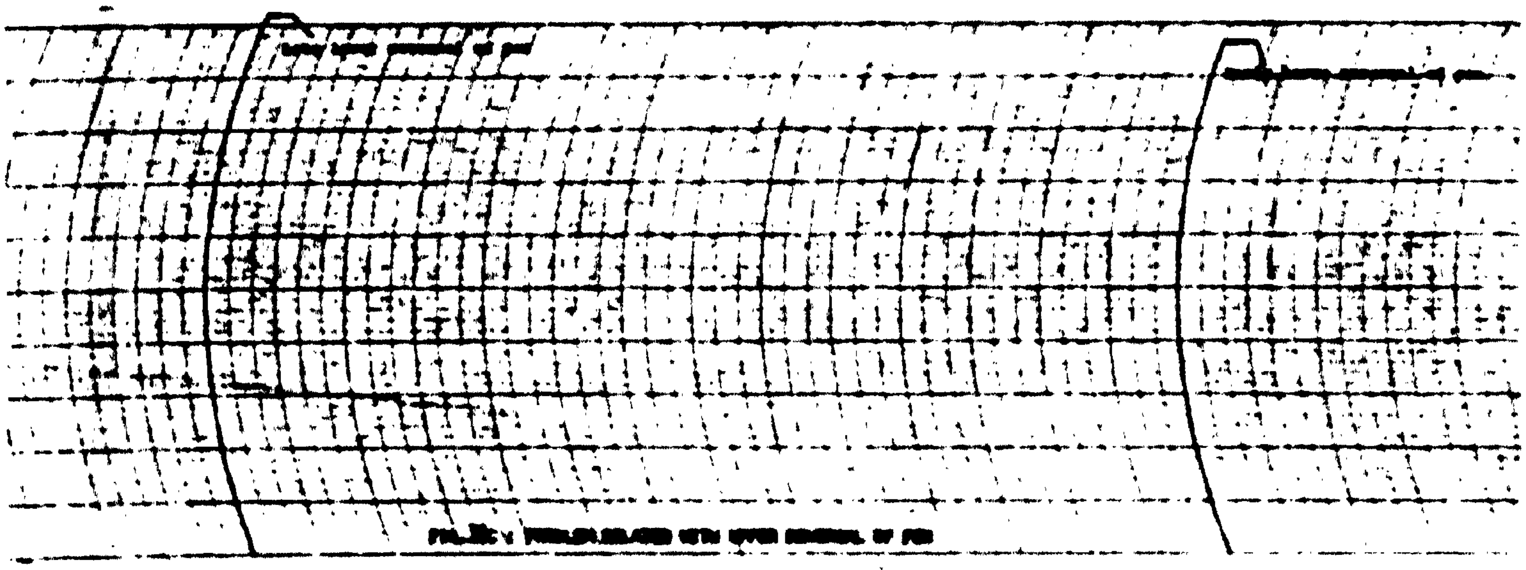

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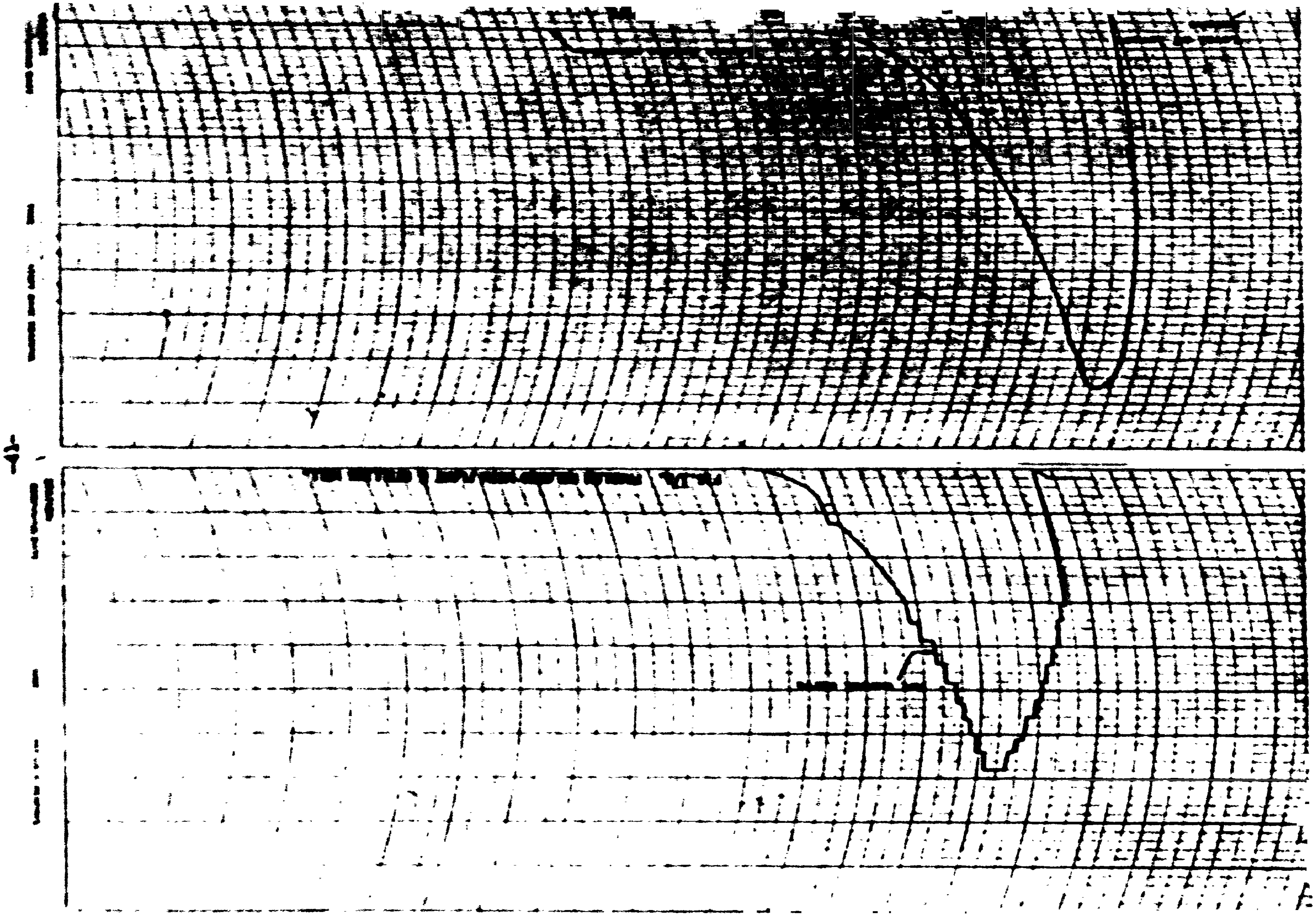

(3) Fig. 16C shows the upper reversal problem of the pen occurring above or below the upper graduation or printed line. If the upper reversal occuring below the upper graduation, decrease the effective length of pen arm by filing back the pen arm shoulder against which the pen is set. If the upper reversal occuring above the upper graduation increase the effective length of pen arm by adding thin non corrosive metal bands to the pen arm back of the pen. Never try to change the length of the pen arm by bending it. Changing the length of pen arm will change the position of the lower reversal, which must be adjusted by screw and before checking the upper reversal.

<u>Some of the problems associated with gauging station indicated by the runoff charts:</u>

(1) Fig. 17a shows the stepping curve instead of smooth during the rising or falling part of the hydrograph. Check in the stilling basin whether the float and counter weight are freely moving at the different depths. If they are not moving freely move (slightly) the recorder in such way that the float moves freely at the different depths. Even after adjusting the position of recorder if float is unable move freely reconstruct the stilling well with large diameter.

(2) Fig. 17b shows the clogging of the lowest intake pipe. Remove the deposited silt and recheck the pen marking on the chart.

Table 3 : Sample computation of runoff from runoff chart.

Watershed : BW1
Date : 29-9-79

Area : 3.45 ha.

Time	Time interval in mts.	Gauge height in ft	Discharge from rating table in cu.ft/sec	Average discharge for time interval in cu.ft/sec	Runoff for time interval in cu.ft	Runoff Accumulated in cu.ft	REMARKS
7.56							
7.52	4	0.20	0.66	0.33	79.2	79.2	1) total
8.00	4	0.50	2.73	1.69	406.8	486.0	runoff
8.02	2	0.80	5.66	4.19	503.4	989.4	= 19.6 mm
8.04	2	0.92	7.03	6.34	761.4	1750.8	
8.12	8	0.82	5.88	6.45	3098.4	4849.2	2) Peak
8.18	6	1.00	8.00	6.94	2498.4	7347.6	runoff
8.21	3	1.06	8.76	8.38	1508.4	8856.0	rate =
8.24	3	1.00	8.00	8.38	1508.4	10364.4	0.007 cu.
8.28	4	0.80	5.66	6.83	1639.2	12003.4	m/sec/ha
8.38	10	0.75	5.12	5.39	3234.0	15237.6	
8.44	6	0.86	6.33	5.72	2061.0	17298.6	3) Total
8.48	4	0.90	6.80	6.56	1575.6	18874.2	runoff
8.54	6	0.70	4.60	5.70	2052.0	20926.2	duration
9.02	8	0.40	1.93	3.26	1567.2	22493.4	= 4 hrs,
9.10	8	0.20	0.66	1.29	621.6	23115.0	4 mts
9.20	10	0.10	0.22	0.44	264.0	23379.0	
9.44	24	0.06	0.10	0.16	230.4	23609.4	
10.20	36	0.04	0.05	0.07	162.0	23771.4	
10.40	20	0.02	0.02	0.03	42.0	23813.4	
11.00	20	0.02	0.02	0.02	36.0	23849.4	
11.30	30	0.01	0.01	0.01	27.0	23876.4	
12.00	30	0	0	0.005	9.0	23885.4	

(2) Gauge height in column 3 are converted into discharge rates in cu.ft/sec with help of appropriate rating tables and recorded in column 4. For this example the rating table for 2 feet parshal flume appendix table 3 will be used.

(3) The average discharge rates in cu.ft/sec for time intervals obtained by averaging successive discharge rates, are recorded in column 5. For example for the first time interval of four minutes the average discharge is $\frac{0+.66}{2}$ = 0.33 cu.ft/sec. like wise for other time intervals it may be calculated.

(4) The runoff volumes in cu.ft for the time intervals are obtained by the relationship: Column 5 x column 2 x 60 and is recorded in column 6. For example the runoff volume during first time interval is .33 x 4 x 60 = 79.2 cuft/sec.

(5) Column 7 gives the cumulative values of runoff in cu.ft and is obtained by adding the values in column 6. The last value gives total runoff.

(6) The last column of remarks may be used to record total runoff duration in hours, peak runoff rate in cu.m/sec/ha and total runoff volume in mm. The peak runoff rate is obtained first in cu.ft/sec by looking to the maximum value is column 4. This value is further divided by total area of watershed to get the peak runoff rate in cu.ft/sec/ha. This can further converted into cu.m/sec/ha. by multiplying it by .0283. For this particular example the peak rate is 0.007 cu.m/sec/ha (See table 3). To get the total runoff in mm., take the last value of column 7 which is total runoff in cuft, multiply this by conversion factor, which can be calculated by $\frac{0.0283}{10 \cdot A}$, where A is watershed area in ha.

Checking runoff data: The primary purpose of checking is to pick up and correct the errors induced during the processing of the original data. Error of varying degree may creep in due to inaccurate marking of peaks, picking of points, reading and recording stage values, converting stage into discharge from the rating table, and calculating runoff for the time interval.

The effect of errors in marking the points especially on storm where recession side of the hydrograph is long, on accuracy, have been found to be of high magnitude followed by mistakes in calculating the runoff for the time interval.

Compilation. The storm runoff thus obtained is compiled separately to give storm values of runoff, monthly runoff and annual runoff. One column may added with these compilations for recording corresponding rainfall values. The proforma shown in table 4 may be used for compilation of runoff data.

Table 4

Watershed No.	:	Year	:
Area	:	Land & water Mgt treatment	

S.No.	Date	Daily Rainfall in mm	Rainfall W.M.I.* intensity mm/hr	Runoff in mm	Runoff (% of total seasonal rainfall	Peak runoff rate in cu.m/sec/ ha

* W.M.I. Weight Mean Intensity

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APPENDIX

Table 1 : Rating tables for HS flumes

(Discharge in cubic feet per second)

FLUME 0.4 FOOT DEEP

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0 ----	0	(1)	0.00016	0.00037	0.00064	0.00098	0.00141	0.00194	0.00258	0.00332
0.1 ----	.00417	0.00509	.00608	.00717	.00837	.00968	.0111	.0126	.0143	.0161
0.2 ----	.0179	.0200	.0221	.0244	.0268	.0293	.0320	.0348	.0378	.0409
0.3 ----	.0441	.0475	.0511	.0548	.0586	.0626	.0668	.0711	.0756	.0803

FLUME 0.6 FOOT DEEP

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0 ----	0	(1)	0.00023	0.00053	0.00091	0.00138	0.00193	0.00259	0.00335	0.00421
0.1 ----	.00517	0.00625	.00742	.00867	.0100	.0115	.0131	.0148	.0166	.0186
0.2 ----	.0207	.0229	.0252	.0277	.0303	.0330	.0359	.0389	.0421	.0454
0.3 ----	.0489	.0524	.0562	.0601	.0641	.0683	.0727	.0772	.0819	.0868
0.4 ----	.0918	.0970	.102	.108	.114	.120	.126	.132	.138	.145
0.5 ----	.152	.159	.166	.173	.181	.188	.196	.205	.213	.221

FLUME 0.8 FOOT DEEP

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0 ----	0	(1)	0.00030	0.00068	0.00116	0.00174	0.00242	0.00322	0.00412	0.00513
0.1 ----	.00625	0.00750	.00884	.0103	.0118	.0135	.0153	.0172	.0193	.0214
0.2 ----	.0237	.0262	.0287	.0314	.0343	.0373	.0404	.0437	.0471	.0506
0.3 ----	.0543	.0582	.0622	.0664	.0708	.0752	.0799	.0847	.0897	.0949
0.4 ----	.100	.106	.111	.117	.123	.129	.136	.142	.149	.156
0.5 ----	.163	.170	.178	.186	.193	.202	.210	.218	.227	.236
0.6 ----	.245	.254	.264	.273	.283	.293	.303	.314	.325	.336
0.7 ----	.347	.358	.370	.381	.393	.406	.418	.431	.444	.457

Contd....

FLUME 1.0 FOOT DEEP

0 ----	0	(1)	0.00037	0.00083	0.00141	0.00209	0.00290	0.00384	0.00489	0.00606
0.1 ----	.00736	0.00882	.0103	.0120	.0137	.0157	.0177	.0198	.0221	.0245
0.2 ----	.0270	.0297	.0325	.0355	.0386	.0418	.0452	.0488	.0525	.0563
0.3 ----	.0603	.0645	.0688	.0733	.0779	.0827	.0877	.0929	.0981	.104
0.4 ----	.109	.115	.121	.127	.134	.140	.147	.154	.161	.168
0.5 ----	.176	.183	.191	.199	.208	.216	.225	.233	.243	.252
0.6 ----	.261	.271	.281	.291	.301	.312	.322	.333	.344	.355
0.7 ----	.367	.379	.391	.403	.416	.428	.441	.454	.468	.481
0.8 ----	.495	.509	.524	.538	.553	.568	.583	.599	.614	.630
0.9 ----	.646	.663	.680	.697	.714	.731	.749	.767	.785	.803

(1) Trace.

Table 2 : Rating tables for H flume
(Discharge in cubic feet per second)

FLUME 0.5 FOOT DEEP

Head (ft)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0 ———	0	(1)	0.0004	0.0009	0.0016	0.0024	0.0035	0.0047	0.0063	0.0080
0.1 ———	.0101	.0122	.0146	.0173	.0202	.0233	.0267	.0304	.0343	.0385
0.2 ———	.0431	.0479	.0530	.0585	.0643	.0704	.0767	.0834	.0905	.0979
0.3 ———	.1057	.1139	.1224	.1314	.1407	.1505	.1607	.1713	.1823	.1938
0.4 ———	.205	.217	.230	.244	.257	.271	.285	.300	.315	.331

FLUME 0.75 FOOT DEEP

Head (ft)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0 ———	0	(1)	0.0006	0.0013	0.0022	0.0032	0.0046	.0061	0.0080	0.0101
0.1 ———	.0126	.0151	.0179	.0210	.0242	.0278	.0317	.0358	.0403	.0451
0.2 ———	.0501	.0555	.0612	.0672	.0735	.0802	.0872	.0946	.1023	.1104
0.3 ———	.119	.128	.137	.146	.156	.167	.177	.188	.199	.211
0.4 ———	.224	.237	.250	.263	.277	.291	.306	.321	.337	.353
0.5 ———	.370	.388	.406	.424	.443	.462	.482	.502	.523	.544
0.6 ———	.566	.588	.611	.635	.659	.683	.708	.734	.760	.786
0.7 ———	.813	.841	.869	.898	.927	.957	———	———	———	———

FLUME 1.0 FEET DEEP

Head (ft)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0 ———	0	(1)	0.0007	0.0017	0.0027	0.0040	0.0056	0.0075	0.0097	0.0122
0.1 ———	.0150	.0179	.0211	.0246	.0284	.0324	.0367	.0413	.0462	.0515
0.2 ———	.0571	.0630	.0692	.0758	.0827	.0900	.0976	.1055	.1138	.1226
0.3 ———	.132	.141	.151	.161	.172	.183	.194	.206	.218	.231
0.4 ———	.244	.257	.271	.285	.300	.315	.331	.347	.364	.381
0.5 ———	.398	.416	.434	.453	.472	.492	.512	.533	.554	.576
0.6 ———	.598	.621	.644	.668	.692	.717	.743	.769	.796	.823
0.7 ———	.851	.880	.909	.939	.969	1.000	1.031	1.064	1.096	1.129
0.8 ———	1.16	1.20	1.23	1.27	1.30	1.34	1.38	1.41	1.45	1.49
0.9 ———	1.53	1.57	1.61	1.66	1.70	1.74	1.78	1.83	1.87	1.92

FLUME 1.5 FEET DEEP

Head (ft)		0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	------	0	(1)	0.0011	0.0023	0.0039	0.0057	0.0078	0.0103	0.0131	0.0164
0.1	------	.0200	0.0237	.0276	.0319	.0365	.0414	.0467	.0523	.0582	.0645
0.2	------	.0711	.0780	.0854	.0931	.1011	.1095	.1183	.1275	.1371	.1470
0.3	------	.157	.168	.179	.191	.203	.215	.228	.241	.255	.269
0.4	------	.283	.298	.314	.330	.346	.363	.380	.398	.416	.435
0.5	------	.454	.473	.493	.514	.535	.557	.579	.601	.621	.648
0.6	------	.672	.697	.722	.747	.773	.800	.827	.855	.883	.912
0.7	------	.942	.972	1.002	1.033	1.065	1.097	1.130	1.163	1.197	1.231
0.8	------	1.27	1.30	1.34	1.38	1.41	1.45	1.49	1.53	1.57	1.61
0.9	------	1.65	1.69	1.73	1.78	1.82	1.86	1.91	1.95	2.00	2.05
1.0	------	2.09	2.14	2.19	2.24	2.30	2.35	2.40	2.45	2.50	2.56
1.1	------	2.61	2.67	2.73	2.78	2.84	2.90	2.96	3.02	3.08	3.14
1.2	------	3.20	3.27	3.33	3.39	3.46	3.52	3.59	3.66	3.73	3.80
1.3	------	3.87	3.94	4.01	4.08	4.15	4.22	4.30	4.37	4.45	4.52
1.4	------	4.60	4.08	4.76	4.84	4.92	5.00	5.08	5.16	5.24	5.3[illegible]

FLUME 2.0 FEET DEEP

Head (ft)		0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	------	0	(1)	0.0016	0.0031	0.0050	0.0073	0.0100	0.0130	0.0166	0.0205
0.1	------	.0248	0.0293	.0341	.0392	.0447	.0505	.0567	.0632	.0701	.0774
0.2	------	.0850	.0930	.1015	.1103	.1195	.1290	.1380	.1494	.1602	.1714
0.3	------	.183	.195	.207	.220	.234	.248	.262	.276	.291	.307
0.4	------	.323	.339	.356	.374	.392	.410	.429	.448	.468	.488
0.5	------	.509	.530	.552	.574	.597	.620	.644	.668	.693	.719
0.6	------	.745	.771	.798	.826	.854	.882	.911	.941	.971	1.002
0.7	------	1.03	1.07	1.10	1.13	1.16	1.20	1.23	1.27	1.30	1.34
0.8	------	1.38	1.42	1.46	1.49	1.53	1.57	1.62	1.66	1.70	1.74
0.9	------	1.78	1.83	1.87	1.92	1.96	2.01	2.06	2.10	2.15	2.20
1.0	------	2.25	2.30	2.35	2.40	2.45	2.51	2.56	2.62	2.67	2.73
1.1	------	2.78	2.84	2.90	2.96	3.02	3.08	3.14	3.20	3.26	3.32
1.2	------	3.38	3.45	3.51	3.58	3.65	3.71	3.78	3.85	3.92	3.99
1.3	------	4.06	4.13	4.20	4.28	4.35	4.43	4.50	4.58	4.66	4.74
1.4	------	4.82	4.90	4.98	5.06	5.14	5.23	5.31	5.40	5.48	5.57

Contd...

Head (ft)		0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
1.5	-----	5.65	5.74	5.83	5.92	6.01	6.11	6.20	6.29	6.38	6.48
1.6	-----	6.58	6.67	6.77	6.87	6.97	7.07	7.17	7.27	7.37	7.47
1.7	-----	7.58	7.68	7.79	7.90	8.00	8.11	8.22	8.33	8.44	8.56
1.8	-----	8.67	8.78	8.90	9.01	9.13	9.24	9.36	9.48	9.60	9.72
1.9	-----	9.85	9.97	10.09	10.21	10.34	10.47	10.60	10.72	10.85	10.98

FLUME 2.5 FEET DEEP

0	-----	0	(1)	0.0018	0.0038	0.0061	0.0089	0.0121	0.0158	0.0200	0.0247
0.1	-----	.0298	0.0350	.0406	.0465	.0528	.0595	.0666	.0741	.0820	.0903
0.2	-----	.0990	.1081	.1176	.1275	.1379	.1486	.1597	.1713	.1834	.1960
0.3	-----	.209	.222	.236	.250	.265	.280	.296	.312	.328	.345
0.4	-----	.363	.381	.399	.418	.437	.457	.478	.499	.520	.542
0.5	-----	.564	.587	.611	.635	.659	.684	.710	.736	.763	.790
0.6	-----	.818	.846	.875	.904	.934	.965	.996	1.027	1.059	1.092
0.7	-----	1.13	1.16	1.19	1.23	1.27	1.30	1.34	1.38	1.41	1.45
0.8	-----	1.49	1.53	1.57	1.61	1.65	1.70	1.74	1.78	1.83	1.87
0.9	-----	1.92	1.96	2.01	2.06	2.11	2.16	2.21	2.26	2.31	2.36
1.0	-----	2.41	2.46	2.51	2.57	2.62	2.68	2.74	2.79	2.85	2.91
1.1	-----	2.97	3.03	3.09	3.15	3.21	3.27	3.33	3.40	3.46	3.53
1.2	-----	3.59	3.66	3.73	3.80	3.86	3.93	4.00	4.07	4.15	4.22
1.3	-----	4.29	4.37	4.44	4.52	4.59	4.67	4.75	4.82	4.90	4.98
1.4	-----	5.06	5.15	5.23	5.31	5.39	5.48	5.56	5.65	5.74	5.82
1.5	-----	5.91	6.00	6.09	6.18	6.27	6.37	6.46	6.55	6.65	6.75
1.6	-----	6.84	6.94	7.04	7.14	7.24	7.34	7.45	7.55	7.66	7.76
1.7	-----	7.86	7.97	8.08	8.19	8.30	8.41	8.53	8.64	8.75	8.87
1.8	-----	8.98	9.10	9.22	9.34	9.45	9.57	9.70	9.82	9.94	10.06
1.9	-----	10.2	10.3	10.4	10.6	10.7	10.8	11.0	11.1	11.2	11.4

Contd....

Head (ft)		0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
2.0	------	11.5	11.6	11.8	11.9	12.0	12.2	12.3	12.5	12.6	12.7
2.1	------	12.9	13.0	13.2	13.3	13.5	13.6	13.8	13.9	14.1	14.2
2.2	------	14.4	14.5	14.7	14.8	15.0	15.1	15.3	15.5	15.6	15.8
2.3	------	16.0	16.1	16.3	16.4	16.6	16.8	17.0	17.1	17.3	17.[illegible]
2.4	------	17.6	17.8	18.0	18.2	18.3	18.5	18.7	19.1	19.1	19.2

FLUME 3.0 FEET DEEP

0	------	0	(1)	0.0021	0.0045	0.0073	0.0105	0.0143	0.0186	0.0234	0.0288
0.1	------	.0347	0.0407	.0471	.0538	.0610	.0686	.0766	.0851	.0939	.1032
0.2	------	.113	.123	.134	.145	.156	.168	.180	.193	.207	.220
0.3	------	.234	.249	.264	.280	.296	.312	.329	.347	.365	.383
0.4	------	.402	.421	.44[illegible]	.462	.483	.504	.526	.549	.572	[illegible]
0.5	------	.620	.644	.669	.695	.721	.748	.775	.803	.832	.861
0.6	------	.890	.920	.951	.982	1.014	1.047	1.080	1.113	1.147	1.182
0.7	------	1.22	1.25	1.29	1.33	1.36	1.40	1.44	1.48	1.52	1.56
0.8	------	1.60	1.65	1.69	1.73	1.78	1.82	1.86	1.91	1.96	2.00
0.9	------	2.05	2.10	[illegible].15	2.20	2.25	2.30	2.35	2.41	2.46	2.51
1.0	------	2.57	2.62	2.68	2.73	2.79	2.85	2.91	2.97	3.03	3.09
1.1	------	3.15	3.21	3.27	3.34	3.40	3.46	3.53	3.60	3.66	3.[illegible]3
1.2	------	3.80	3.87	3.94	4.01	4.08	4.15	4.23	4.30	4.37	4.[illegible]
1.3	------	4.53	4.60	4.68	4.76	4.84	4.92	5.00	5.08	5.16	5.24
1.4	------	5.33	5.41	5.50	5.58	5.67	5.76	5.84	5.93	6.02	6.11
1.5	------	6.20	6.30	6.39	6.48	6.58	6.67	6.77	6.87	6.96	7.06
1.6	------	7.16	7.26	7.36	7.47	7.57	7.67	7.78	7.88	7.99	8.10
1.7	------	8.20	8.31	8.42	8.53	8.64	8.75	8.87	8.98	9.10	9.21
1.8	------	9.33	9.45	9.56	9.68	9.80	9.92	10.05	10.17	10.29	10.41
1.9	------	10.5	10.7	10.8	10.9	11.0	11.2	11.3	11.4	11.6	11.7

Contd....

Gage (ft)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
2.0	11.9	12.0	12.1	12.3	12.4	12.6	12.7	12.8	13.0	13.1
2.1	13.3	13.4	13.6	13.7	13.9	14.0	14.2	14.3	14.5	14.6
2.2	14.8	14.9	15.1	15.3	15.4	15.6	15.7	15.9	16.1	16.2
2.3	16.4	16.6	16.7	16.9	17.1	17.2	17.4	17.6	17.8	17.9
2.4	18.1	18.3	18.5	18.7	18.8	19.0	19.2	19.4	19.6	19.8
2.5	19.9	20.1	20.3	20.5	20.7	20.9	21.1	21.3	21.5	21.7
2.6	21.9	22.1	22.3	22.5	22.7	22.9	23.1	23.3	23.5	23.7
2.7	23.9	24.1	24.3	24.5	24.7	24.9	25.2	25.4	25.6	25.8
2.8	26.0	26.2	26.5	26.7	26.9	27.1	27.4	27.6	27.8	28.0
2.9	28.3	28.5	28.7	28.9	29.2	29.4	29.7	29.9	30.1	30.4

Table 3. Rating tables for Parshall flumes (Discharge in cubic feet per second)

FLUME 0.5 foot throat

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	0.005	0.01	0.015	0.02	0.025	0.03	0.035	0.04	0.045
0.1	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.13	0.14	0.15
0.2	0.16	0.18	0.19	0.20	0.22	0.23	0.25	0.26	0.28	0.29
0.3	0.31	0.32	0.34	0.36	0.38	0.39	0.41	0.43	0.45	0.4[illegible]
0.4	0.48	0.50	0.52	0.54	0.56	0.58	0.61	0.63	0.65	0.67
0.5	0.69	0.71	0.73	0.76	0.78	0.80	0.82	0.85	0.87	0.89
0.60	0.92	0.94	0.97	0.99	1.02	1.04	1.07	1.10	1.12	1.15
0.70	1.17	1.20	1.23	1.26	1.28	1.31	1.34	1.36	1.39	1.42
0.80	1.45	1.48	1.50	1.53	1.56	1.59	1.62	1.65	1.68	1.71
0.90	1.74	1.77	1.81	1.84	1.87	1.90	1.93	1.97	2.00	2.03
1.0	2.06	2.09	[illegible] 12	2.16	2.19	2.22	2.26	2.29	2.32	2.36
1.10	2.40	2.43	2.46	2.50	2.53	2.57	2.60	2.64	2.68	2.71

FLUME 1 foot throat

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	0.005	0.01	0.02	0.03	0.04	0.06	0.07	0.08	0.10
0.10	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.27	0.30	0.32
0.20	0.35	0.37	0.40	0.43	0.46	0.49	0.51	0.54	0.58	0.61
0.30	0.64	0.68	0.71	0.74	0.77	0.80	0.84	0.88	0.92	0.95
0.40	0.99	1.03	1.07	1.11	1.15	1.19	1.23	1.27	1.31	1.35
0.50	1.39	1.44	1.48	1.52	1.57	1.62	1.66	1.70	1.75	1.80
0.60	1.84	1.88	1.93	1.98	2.03	2.08	2.13	2.18	2.23	2.28
0.70	2.33	2.38	2.43	2.48	2.53	2.58	2.63	2.68	2.74	2.80
0.80	2.85	2.90	2.96	3.02	3.07	3.12	3.18	3.24	3.29	3.35
0.90	3.41	3.46	3.52	3.58	3.64	3.70	3.76	3.82	3.88	3.94
1.00	4.00	4.06	4.12	4.18	4.25	4.31	4.37	4.43	4.50	4.56
1.10	4.62	4.68	4.75	4.82	4.88	4.94	5.01	5.08	5.15	5.21
1.20	5.28	5.34	5.41	5.48	5.55	5.62	5.69	5.76	5.82	5.89
1.30	5.96	6.03	6.10	6.18	6.25	6.32	6.39	6.46	6.53	6.60
1.40	6.68	6.75	6.82	6.89	6.97	7.04	7.12	7.19	7.26	7.34
1.50	7.41	7.49	7.57	7.64	7.72	7.80	7.87	7.95	8.02	8.10

Contd..

FLUME 1 foot throat (contd)

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
1.60	8.18	8.26	8.34	8.42	8.49	8.57	8.65	8.73	8.81	8.89
1.70	8.97	9.05	9.13	9.21	9.29	9.38	9.46	9.54	9.62	9.70
1.80	9.79	9.87	9.95	10.04	10.12	10.20	10.29	10.38	10.46	10.54
1.90	10.62	10.71	10.80	10.88	10.97	11.06	11.14	11.23	11.31	11.40
2.00	11.49	11.58	11.66	11.75	11.84	11.93	12.02	12.10	12.19	12.28

FLUME 2 feet throat

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	0.01	0.02	0.04	0.05	0.08	0.10	0.13	0.16	0.19
0.10	0.22	0.26	0.30	0.34	0.38	0.42	0.47	0.51	0.56	0.61
0.20	0.66	0.71	0.77	0.82	0.88	0.93	0.99	1.05	1.11	1.18
0.30	1.24	1.30	1.37	1.44	1.50	1.57	1.64	1.72	1.79	1.86
0.40	1.93	2.01	2.09	2.16	2.24	2.32	2.40	2.48	2.57	2.65
0.50	2.73	2.82	2.90	2.99	3.08	3.17	3.26	3.35	3.44	3.53
0.60	3.62	3.72	3.81	3.91	4.01	4.11	4.20	4.30	4.40	4.50
0.70	4.60	4.70	4.81	4.91	5.02	5.12	5.23	5.34	5.44	5.55
0.80	5.66	5.77	5.88	6.00	6.11	6.22	6.33	6.44	6.56	6.68
0.90	6.80	6.92	7.03	7.15	7.27	7.38	7.51	7.63	7.75	7.88
1.00	8.00	8.12	8.25	8.38	8.50	8.63	8.76	8.88	9.01	9.14
1.10	9.27	9.40	9.54	9.67	9.80	9.94	10.07	10.20	10.34	10.48
1.20	10.61	10.75	10.89	11.03	11.17	11.31	11.45	11.59	11.73	11.87
1.30	12.01	12.16	12.30	12.44	12.59	12.74	12.89	13.03	13.18	13.33
1.40	13.48	13.63	13.78	13.93	14.08	14.23	14.38	14.54	14.69	14.85
1.50	15.00	15.16	15.31	15.47	15.62	15.78	15.94	16.10	16.26	16.42
1.60	16.58	16.74	16.90	17.06	17.22	17.38	17.55	17.72	17.88	18.04
1.70	18.21	18.38	18.54	18.71	18.88	19.04	19.21	19.38	19.55	19.72
1.80	19.90	20.07	20.24	20.42	20.59	20.76	20.93	21.10	21.28	21.46
1.90	21.63	21.81	21.99	22.17	22.35	22.53	22.70	22.88	23.06	23.24
2.00	23.43	23.61	23.79	23.98	24.16	24.34	24.52	24.70	24.89	25.08

FLUME 3 feet throat

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	0.015	0.03	0.05	0.07	0.11	0.15	0.19	0.22	0.27
0.10	0.31	0.37	0.43	0.49	0.55	0.61	0.69	0.75	0.83	0.90
0.20	0.97	1.04	1.12	1.20	1.28	1.37	1.46	1.55	1.64	1.73
0.30	1.82	1.92	2.02	2.12	2.22	2.32	2.42	2.53	2.64	2.75
0.40	2.86	2.97	3.08	3.20	3.32	3.44	3.56	3.68	3.80	3.92
0.50	4.05	4.18	4.31	4.44	4.57	4.70	4.84	4.98	5.11	5.25
0.60	5.39	5.53	5.68	5.82	5.97	6.12	6.26	6.41	6.56	6.71
0.70	6.86	7.02	7.17	7.33	7.49	7.65	7.81	7.97	8.13	8.30
0.80	8.46	8.63	8.79	8.96	9.13	9.30	9.48	9.65	9.82	10.00
0.90	10.17	10.35	10.53	10.71	10.89	11.07	11.26	11.44	11.63	11.82
1.00	12.00	12.19	12.38	12.57	12.76	12.96	13.15	13.34	13.54	13.74
1.10	13.93	14.13	14.33	14.53	14.73	14.94	15.14	15.34	15.55	15.76
1.20	15.96	16.17	16.38	16.60	16.81	17.02	17.23	17.44	17.66	17.88
1.30	18.10	18.32	18.54	18.76	18.98	19.20	19.42	19.64	19.87	20.10
1.40	20.32	20.55	20.78	21.01	21.24	21.47	21.70	21.94	22.17	22.41
1.50	22.64	22.88	23.12	23.36	23.60	23.84	24.08	24.32	24.56	24.80
1.60	25.05	25.30	25.54	25.79	26.04	26.29	26.54	26.79	27.04	27.30
1.70	27.55	27.80	28.06	28.32	28.57	28.82	29.08	29.34	29.60	29.87
1.80	30.13	30.39	30.65	30.92	31.18	31.45	31.71	31.98	32.25	32.52
1.90	32.79	33.06	33.33	33.60	33.87	34.14	34.42	34.70	34.97	35.25
2.00	35.53	35.81	36.09	36.37	36.65	36.94	37.22	37.50	37.78	38.06

FLUME 4 Feet throat

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	0.015	0.03	0.07	0.10	0.15	0.19	0.25	0.30	0.37
0.10	0.42	0.50	0.56	0.65	0.72	0.82	0.89	1.00	1.07	1.18
0.20	1.26	1.36	1.47	1.58	1.69	1.80	1.91	2.03	2.15	2.27
0.30	2.39	2.52	2.65	2.78	2.92	3.06	3.20	3.34	3.48	3.62
0.40	3.77	3.92	4.07	4.22	4.38	4.54	4.70	4.86	5.03	5.20
0.50	5.36	5.53	5.70	5.88	6.05	6.23	6.41	6.59	6.77	6.96
0.60	7.15	7.34	7.53	7.72	7.91	8.11	8.31	8.51	8.71	8.9[illegible]
0.70	9.11	9.32	9.53	9.74	9.95	10.16	10.38	10.60	10.81	11.03
0.80	11.25	11.48	11.70	11.92	12.15	12.38	12.61	12.84	13.07	13.31
0.90	13.55	13.79	14.03	14.27	14.51	14.76	15.00	15.25	15.50	15.75
1.00	16.00	16.25	16.51	16.76	17.02	17.28	17.54	17.80	18.07	18.34
1.10	18.60	18.86	19.13	19.40	19.67	19.94	20.22	20.50	20.78	21.05
1.20	21.33	21.61	21.90	22.18	22.47	22.75	23.04	23.33	23.62	23.92
1.30	24.21	24.50	24.80	25.10	25.39	25.69	25.99	26.30	26.60	26.90
1.40	27.21	27.52	27.82	28.14	28.45	28.76	29.07	29.38	29.70	30.02
1.50	30.34	30.66	30.98	31.30	31.63	31.95	22.97	32.60	32.93	33.26
1.60	33.59	33.92	34.26	34.60	34.93	35.26	35.60	35.94	36.28	36.62
1.70	36.96	37.30	37.65	38.00	38.34	38.69	39.04	39.39	39.74	40.10
1.80	40.45	40.80	41.16	41.52	41.88	42.24	42.60	42.96	43.32	43.69
1.90	44.05	44.42	44.79	45.16	45.53	45.90	46.27	86.64	47.02	47.40
2.00	47.77	48.14	48.52	48.90	49.29	49.67	50.05	50.44	50.82	51.21

Table 4. Rating table for 90° sharp crested V notch (Discharge in cubic feet per second)

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	0.0005	0.001	0.0015	0.002	0.003	0.004	0.005	0.006	0.007
0.10	0.008	0.010	0.012	0.015	0.018	0.022	0.026	0.030	0.035	0.040
0.20	0.046	0.052	0.058	0.065	0.072	0.080	0.088	0.096	0.106	0.115
0.30	0.125	0.136	0.147	0.159	0.171	0.184	0.197	0.211	0.226	0.240
0.40	0.256	0.272	0.289	0.306	0.324	0.343	0.362	0.383	0.403	0.424
0.50	0.445	0.468	0.491	0.515	0.539	0.564	0.590	0.617	0.644	0.672
0.60	0.700	0.730	0.760	0.790	0.822	0.854	0.887	0.921	0.955	0.991
0.70	1.03	1.06	1.10	1.14	1.18	1.22	1.26	1.30	1.34	1.39
0.80	1.43	1.48	1.52	1.57	1.61	1.66	1.71	1.76	1.81	1.86
0.90	1.92	1.97	2.02	2.08	2.13	2.19	2.25	2.31	2.37	2.43
1.00	2.49	2.55	2.61	2.68	2.74	2.81	2.87	2.94	3.01	3.09
1.10	3.15	3.22	3.30	3.37	3.44	3.52	3.59	3.67	3.75	3.83
1.20	3.91	3.99	4.07	4.16	4.24	4.33				