CHAPTER 14 - MEASUREMENTS IN PRESSURE CONDUITS

13. Trajectory Methods

Basically, trajectory methods consist of measuring the horizontal and vertical coordinates of a point in the jet issuing from the end of a pipe (Stock, 1955). The pipe may be oriented either vertically or horizontally. The principal difficulty with this method is in measuring the coordinates of the flowing stream accurately.

(a) Vertical Pipes

Lawrence and Braunworth (1906) noted that two kinds of flow occur from the end of vertical pipes. With a small rise of water (up to 0.37*d*) above the end of the pipe, the flow acts like a circular weir. When the water rises more than 1.4*d*, jet flow occurs. When the rise is between these values, the mode of flow is in transition. Lawrence and Braunworth (1906) determined that when the height of the jet exceeded 1.4 *d*, as determined by sighting over the jet to obtain the maximum rise, the discharge is given by:

$$Q = 5.01d^{1.99}h^{0.53}$$

where:

Q = rate of flow, gal/min
d = inside diameter of the pipe, in
h = height of jet, in

When the rise of water above the end of the pipe is less than 0.37*d*, discharge is given by:

$$Q = 6.17d^{1.25}h^{1.35}$$

For jet heights between 0.37*d* and 1.4*d*, the flow is considerably less than that given by either of these equations. Figure 14-12, prepared using data from Stock (1955) gives flow rates in gallons per minute for standard pipes 2 to 12 in in diameter and jet heights from 12 to 60 in. Bos (1989) assigns to this method an accuracy of +/-10 percent for the jet flow range to +/-15 percent for the weir flow range.

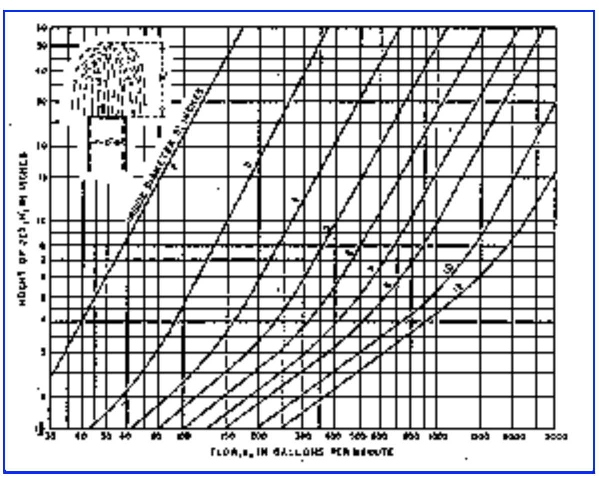

Figure 14-12 -- Discharge curves for measurement of flow from vertical standard pipes. The curves are based on data from experiments of Lawrence and Braunworth, American Society of Civil Engineers, Transactions, Vol. 57, 1906 (courtesy of Utah State University)..

For irrigation convenience, the Natural Resources Conservation Service produced a table from curves for vertical pipes in Stock (1955) for the NRCS *National Engineering Handbook* (1962a). This table is reproduced here as table 14-1. The table gives discharges

Table 14-1 -- Flow from vertical pipes[1]

Jet height (inches)	2 Std.[2]	3 Std.	4 O.D.[3]	4 Std.	5 O.D.	5 Std.	6 O.D.	6 Std.	8 O.D.	8 Std.	10 O.D.	10 Std.	12 O.D.	12 Std.
	gpm	gpm	gpm		gpm		gpm		gpm		gpm		gpm	
2	28	57	75	84	[illegible]	110	137	160	200	215	[illegible]	[illegible]	[illegible]	[illegible]
2½	31	68	95	108	[illegible]	152	182	205	275	290	357	385	450	480
3	34	78	112	128	[illegible]	153	225	260	340	367	460	480	670	[illegible]
3½	37	86	124	145	[illegible]	[illegible]	262	287	405	445	555	610	705	755
4	40	92	135	160	205	[illegible]	275	300	465	510	660	[illegible]	845	[illegible]
4½	42	98	144	173	225	[illegible]	300	365	525	570	700	845	960	[illegible]
5	45	104	154	184	242	275	345	385	575	650	840	940	1120	1200
6	50	115	169	205	[illegible]	[illegible]	390	445	670	730	1037	1125	1370	[illegible]
7	54	125	188	221	[illegible]	336	420	485	750	820	[illegible]	1275	1600	1730
8	58	134	202	[illegible]	[illegible]	[illegible]	450	620	810	890	[illegible]	[illegible]	1775	[illegible]
9	62	141	215	[illegible]	335	[illegible]	470	550	875	955	1360	1550	1900	[illegible]
10	66	152	227	[illegible]	358	425	510	585	925	1015	1450	1650	2075	2250
12	72	167	255	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1017	1123	1600	1800	2300	[illegible]
14	78	182	275	320	422	485	610	715	1106	1225	1730	2000	2500	2800
16	83	195	295	345	455	522	666	766	1192	1302	1877	2140	[illegible]	3000
18	88	208	315	367	480	555	700	800	1265	1400	2000	2280	2900	
20	94	220	333	388	512	[illegible]	740	850	1335	1485	2105	2450		
25	107	248	377	440	[illegible]	[illegible]	830	950	1522	1670	2380	2720		
30	117	275	420	485	[illegible]	[illegible]	925	1050	[illegible]	[illegible]	2650	3000		
35	127	300	455	[illegible]	[illegible]	[illegible]	1000	1150	1827	[illegible]	2850			
40	137	320	490	565	745	[illegible]	1075	1230	1970	2160				

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[1] Table prepared from discharge curves in Utah Engineering Experimental Station, Bulletin 5, "Measurement of Irrigation Water," June 1955.

[2] Standard pipe.

[3] Outside diameter of well casing.

for different heads up to 40 in for standard nominal pipe diameters from 2 to 12 in and for outside diameters of well casings from 4 to 12 in. As mentioned before, accuracies better than 15 and 10 per-cent should not be expected, depending on whether the flow is acting as a weir or jet-type flow.

(b) Horizontal Pipes

When brink depths are greater than 0.5*D*, the more general Purdue pipe method developed by Greve (1928) should be used, rather than the California pipe method. The Purdue method applies equally well to both partially and completely filled pipes. The Purdue method consists of measuring coordinates of the upper surface of the jet as shown on figure 14-13. If the water in the pipe is flowing at a depth of less than 0.8*D* at the outlet, the vertical distance, *Y*, can be measured at the end of the pipe where *X* = 0. For higher rates of flow, *Y* may be measured at horizontal distances, *X*, from the pipe exit of 6, 12, or 18 in. Flow values in gallons per minute for 2- to 6-in-diameter standard pipes are shown in graphs on figure 14-14 (Stock, 1955).

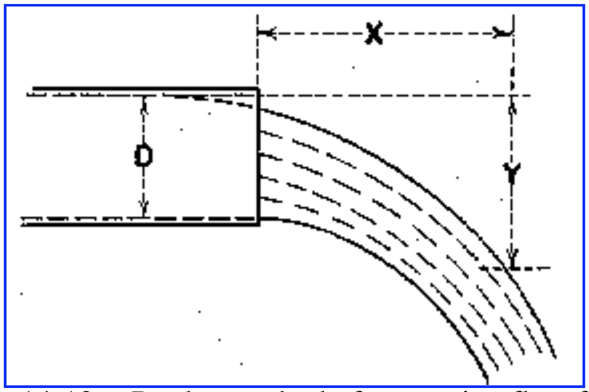


Figure 14-13 -- Purdue method of measuring flow from a horizontal pipe (courtesy of Utah State University)..

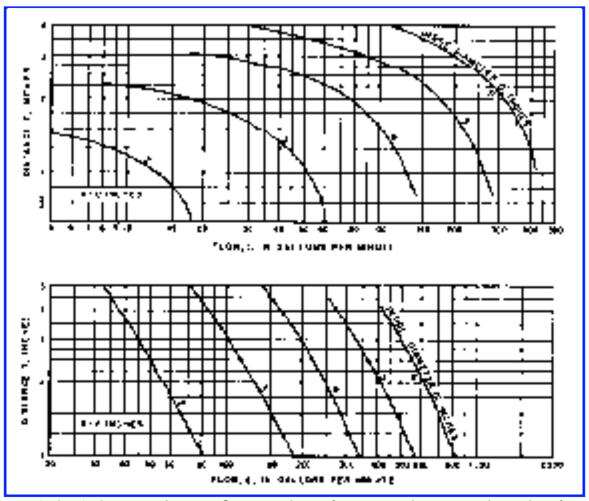


Figure 14-14 -- Flow from horizontal standard pipes by Purdue coordinate method (courtesy of Utah State University) (sheet 1 of 2)..

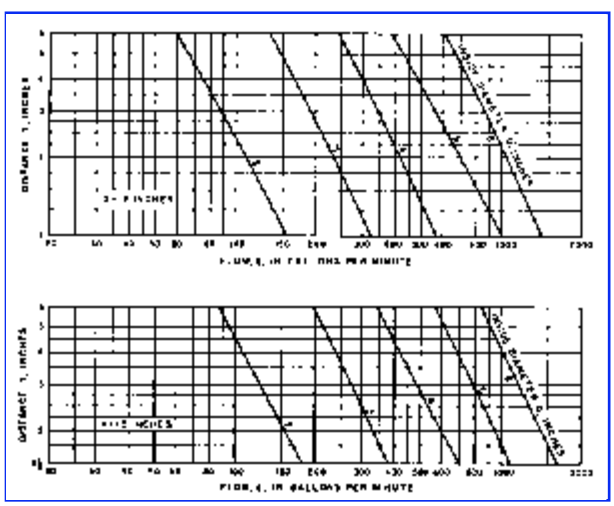


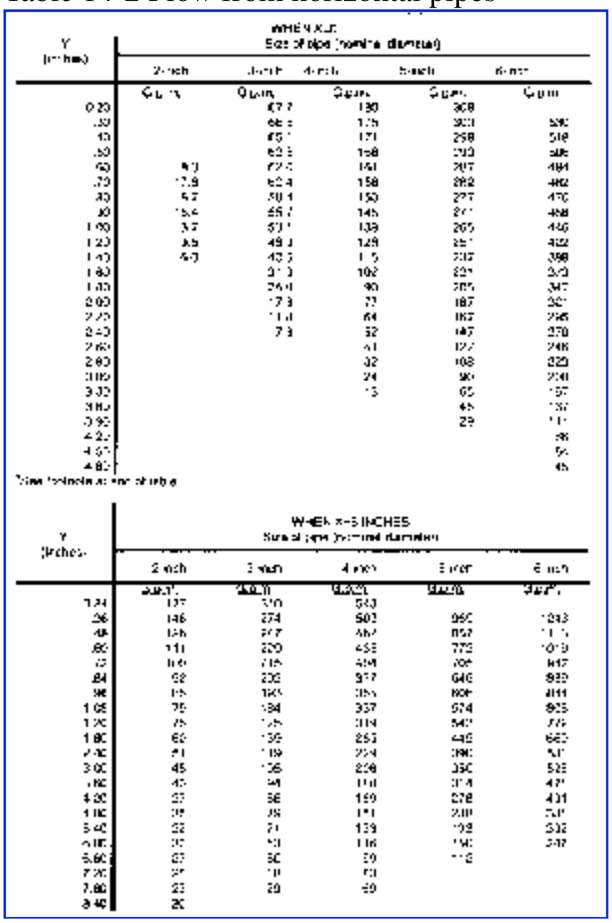
Figure 14-14 -- Flow from horizontal standard pipes by
Purdue coordinate method (courtesy of Utah State University)
(sheet 2 of 2)..

The most accurate results will be obtained when the pipe is truly horizontal. If it slopes upward, the indicated discharge will be too high. If it slopes downward, the indicated discharge will be too low.

Difficulty occurs in making the vertical measurement, *Y*, because the top of the jet will usually not be smooth and well defined.

The NRCS produced table 14-2 for horizontal pipe discharge for *X* of 0, 6, 12 and 18 in and *Y* up to about 8 in for pipe diameters from 2 to 6 in. As mentioned previously, accuracies better than 10 percent should not be expected.

Table 14-2 Flow from horizontal pipes[1]



WHEN X=0

Y (inches)	2-inch Q gpm	3-inch Q gpm	4-inch Q gpm	5-inch Q gpm	6-inch Q gpm
0.20		67.7	180	308	
.30		[illegible]	175	[illegible]	530
.40		65.1	171	298	518
.50		62.5	168	[illegible]	505
.60	[illegible]	[illegible]	161	297	494
.70	17.9	62.4	158	292	482
.80	5.7	50.4	150	277	470
.90	15.4	55.7	145	271	458
1.00	3.7	53.1	139	265	446
1.20	3.5	49.0	129	251	422
1.40	[illegible]	[illegible]	115	237	398
1.60		[illegible]	102	221	373
1.80		24.4	90	205	347
2.00		17.3	77	187	321
2.20		[illegible]	64	167	295
2.40		7.3	52	147	270
2.60			41	127	246
2.80			32	108	223
3.00			24	90	[illegible]
3.20			[illegible]	65	[illegible]
[illegible]				45	[illegible]
[illegible]				29	[illegible]
4.20					[illegible]
[illegible]					[illegible]
4.80					45

[1]See footnote at end of table.

WHEN X=6 INCHES

Y (inches)	2-inch gpm	3-inch gpm	4-inch gpm	5-inch gpm	6-inch gpm
0.24	[illegible]	[illegible]	[illegible]		
.36	146	274	503	960	[illegible]
.48	[illegible]	[illegible]	[illegible]	857	[illegible]
.60	111	220	[illegible]	773	[illegible]
.72	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
.84	92	[illegible]	[illegible]	646	[illegible]
.96	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.08	79	[illegible]	337	574	[illegible]
1.20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.80	[illegible]	[illegible]	253	[illegible]	[illegible]
2.40	[illegible]	119	[illegible]	[illegible]	[illegible]
3.00	45	106	[illegible]	350	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4.20	37	[illegible]	159	278	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5.40	[illegible]	71	139	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	116	[illegible]	[illegible]
6.60	[illegible]	[illegible]	[illegible]	[illegible]	
7.20	[illegible]	[illegible]	[illegible]		
7.80	23	29	[illegible]		
8.40	20				

Table 14-2 Flow from horizontal pipes[1] (continued)

Y (inches)	WHEN X = 12 INCHES Size of pipe (nominal diameter)				
	2-inch	3-inch	4-inch	5-inch	6-inch
	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.
.96	177	310	770	514	
1.25	148	325	748	874	[illegible]
[illegible]	125	352	730	825	[illegible]
[illegible]	114	337	[illegible]	763	[illegible]
[illegible]	90	316	396	656	[illegible]
[illegible]	87	[illegible]	350	693	[illegible]
[illegible]	79	176	332	530	[illegible]
[illegible]	73	161	336	489	718
[illegible]	68	135	257	458	673
[illegible]	63	130	250	428	593
[illegible]	60	122	258	404	597
[illegible]	57	126	242	388	574
[illegible]	54	123	230	368	548
[illegible]	52	115	[illegible]	355	[illegible]

See footnote at end of table

Y (inches)	WHEN X = 15 INCHES Size of pipe (nominal diameter)				
	2-inch	3-inch	4-inch	5-inch	6-inch
	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.
1.50	[illegible]	341	[illegible]	1014	[illegible]
[illegible]	144	[illegible]	557	[illegible]	1261
[illegible]	125	274	530	[illegible]	[illegible]
[illegible]	112	271	[illegible]	754	[illegible]
[illegible]	105	[illegible]	471	703	[illegible]
[illegible]	101	[illegible]	[illegible]	665	[illegible]
[illegible]	95	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	88	153	[illegible]	579	[illegible]
[illegible]	84	133	[illegible]	548	[illegible]
[illegible]	81	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	77	[illegible]	[illegible]	498	[illegible]
[illegible]	76	[illegible]	[illegible]	475	706

[1] Table for standard steel pipe prepared from data resulting from actual experiments conducted at Purdue University Experimental Station, Bulletin 32, "Measurement of Pipe Flow by the Coordinate Method," August 1928.

[1] Table for standard steel pipe prepared from data resulting from actual experiments conducted at Purdue University Experimental Station, Bulletin 32, "Measurement of Pipe Flow by the Coordinate Method," August 1928.