Hydraulic Capacity of Culverts

The most widely accepted formula for evaluating the hydraulic capacity of non-pressure sewers is the Manning Formula. This formula is:

$$Q = \frac{1.486}{n} \times A \times R^{2/3} \times S^{1/2}$$

Where:

Q = discharge in cubic feet per second
n = Manning's roughness coefficient
A = cross-sectional area of flow in square feet
R = hydraulic radius in feet (equals the area of the flow divided by the wetted perimeter)
S = slope of pipe line in feet of vertical drop per foot of horizontal distance

Since the designer is usually concerned with selecting a sewer size for a given design flow and pipe slope, the Manning Formula is more conveniently expressed as:

$$\frac{Q}{S^{1/2}} = \frac{1.486}{n} \times A \times R^{2/3}$$

By evaluating the values of $1.486/n \times A \times R^{2/3}$ for the various types and shapes of pipes available, a pipe size can be selected for any $Q/S^{1/2}$ value. Under any given flow condition, the area A and hydraulic radius R are constant for a particular size and shape of pipe. The hydraulic capacity of a pipe on a given slope is primarily dependent on n, the roughness coefficient. *Table 1* lists recommended values for roughness coefficients of various pipe materials. These values are substantiated by extensive research and have been adopted for use by most government agencies.

Table 1 Recommended Values of Manning's *n*

Pipe Material	Values of Manning's *n*	
	Laboratory Values	ACPA Recommended Design Values
Concrete Pipe	0.010	Storm Sewer - 0.012 Sanitary Sewer - 0.012-0.013
Corrugated HDPE (lined)	0.009-0.015	Storm Sewer - 0.012-0.024
Corrugated Metal Pipe	0.022-0.028	Storm Sewer - 0.029-0.034
Spiral Rib Metal Pipe	0.012-0.013	Storm Sewer - 0.016-0.018

Results of numerous test programs conducted under laboratory conditions have shown the roughness coefficient of concrete pipe to range between 0.009 and 0.011. The design values of 0.012 and 0.013, shown in Table 1, have been generally used to account for the possible build up of slime or grease in sanitary sewers and foreign debris in storm sewers. Therefore, design values should also be used for the other materials shown in the table to allow for a factor of safety as seen with concrete pipe. The larger variation in Manning's "n" lab values in corrugated HDPE pipe can be attributed to various corrugation growth, or waviness, in the liner. The design values shown for HDPE pipe have also allowed for additional corrugation growth once load is applied in the installed condition. The variation found in corrugated metal pipe is dependent on the specified corrugation size from 2-2/3" x 1/2" up to a 3" x 1" corrugation. All of the listed pipe materials have been tested at the Utah State University Water Research Laboratory. These laboratory values are from those test results. The concrete pipe test reports are available from ACPA's Resources. Contact ACPA or your local concrete pipe supplier for copies of specific reports.

Values of $1.486/n \times A \times R^{2/3}$ are listed in *Tables 2 through 5* for concrete and corrugated metal pipe of various commercial shapes. Based on Manning's Formula, these values are equal to $Q/S^{1/2}$ for full flow. For any $Q/S^{1/2}$ value, the size of pipe required can be read directly from the appropriate table. A comparison of the values listed in the tables for equivalent pipe sizes illustrated the hydraulic advantage of concrete pipe. Also note the hydraulic efficiency of the elliptical concrete pipe and concrete arch pipe over the corrugated metal pipe arches.

It is important to point out that a hydraulic comparison between various shapes of sewer pipe cannot be made solely on the basis of cross-sectional areas or peripheries. For two sewer pipes of similar materials and different shapes to be hydraulically equivalent, it is necessary for the factor $A \times R^{2/3}$ to be the same for both pipe sections. Multiplying this factor by 1.486/n accounts for the surface roughness of the pipe material and determines the hydraulic capacity. To compare the hydraulic capacity of sewer pipes of different shapes and materials, it is therefore necessary to evaluate the product of $1.486/n \times A \times R^{2/3}$ as shown in the following example.

EXAMPLE

Given: Maximum Predicted Flow Q_p = 140 c.f.s.
Slope of Sewer S = 1.0 percent
Manning's Roughness Coefficient
Concrete Pipe n = 0.013
HDPE Pipe n = 0.024
Corrugated Metal Pipe n = 0.034

Find: Size of Pipe Required.

Solution: Design Flow = Maximum Predicted Flow

$$Q = Q_p$$
$$= 140 \text{ c.f.s.}$$
$$\text{Slope } S = 0.010 \text{ feet per foot}$$
$$S^{1/2} = 0.100$$
$$\frac{Q}{S^{1/2}} = \frac{140}{0.100} = 1400$$

Read size of pipe required from appropriate table corresponding to values of 1.486/n x A x $R^{2/3}$ equal to or larger than 1400.

Answer: The following types and sizes of pipe will carry the design flow:

Type of Pipe	Pipe Size (Inches)	Value of $1.486/nxAxR^{2/3}$	Table
Circular Concrete Pipe	48	1436	2
HDPE Pipe	60	1410	2
Corrugated Metal Pipe	72	1618	2
Horizontal Elliptical Concrete Pipe	38 x 60	1707	3
Concrete Arch Pipe	36 x 58 1/2	1435	4
C.M.P. Arch Pipe	59 x 81	1428	5

Table 2 Circular Pipe

Pipe Dia. (Inch)	A Area (Square Feet)	R Hydraulic Radius (Feet)	Values of $1.486/nxAxR^{2/3}$							
			Concrete Pipe		HDPE Pipe		Corrugated Metal Pipe		Spiral Rib Metal Pipe	
			n=0.012	n=0.013	n=0.012	n=0.024	n=0.029 2 2/3" x 1/2"	n=0.034 3" x 1"	n=0.016	n=0.018
8	0.349	0.167	13	12	13	7	5	5	10	9
10	0.545	0.208	24	22	24	12	10	8	18	16
12	0.785	0.250	39	36	39	19	16	14	29	26
15	1.227	0.313	70	65	70	35	29	25	52	47
18	1.766	0.375	114	105	114	57	47	40	85	76
21	2.404	0.438	172	158	172	86	71	61	129	114
24	3.140	0.500	245	226	245	122	101	86	184	163
27	3.974	0.563	335	310	335	168	139	118	252	224
30	4.906	0.625	444	410	444	222	184	157	333	296
33	5.937	0.688	573	529	573	286	237	202	429	382
36	7.065	0.750	722	667	722	361	299	255	542	481
42	9.616	0.875	1089	1006	1089	545	451	384	817	726
48	12.560	1.000	1555	1436	1555	778	644	549	1167	1037
54	15.896	1.125	2129	1965	2129	1065	881	752	1597	1420
60	19.625	1.250	2820	2603	2820	1410	1167	995	2115	1880
66	23.746	1.375	3636	3356	3636	1818	1505	1283	2727	2424
72	28.260	1.500	4586	4233	4586	2293	1898	1618	3439	3057
78	33.166	1.625	5677	5240	5677	2838	2349	2004	4258	3785
84	38.465	1.750	6917	6385	6917	3459	2862	2441	5188	4611
96	50.240	2.000	9876	9116	9876	4938	4087	3486	7407	6584
120	78.500	2.500	17906	16529	17906	8953	7409	6320	13430	11937
144	113.040	3.000	29117	26877	29117	14559	12049	10277	21838	19412

Table 3 Horizontal Elliptical Concrete Pipe

Pipe Size Rise x Span (Inch)	Approximate Equivalent Round Diameter (Inch)	A Area (Square Feet)	R Hydraulic Radius (Feet)	Values of $1.486/nxAxR^{2/3}$	
				n = 0.012	n = 0.013
14 x 23	18	1.8	0.367	116	108
19 x 30	24	3.3	0.490	252	232
22 x 34	27	4.1	0.546	339	313
24 x 38	30	5.1	0.613	456	421
27 x 42	33	6.3	0.686	607	560
29 x 45	36	7.4	0.736	746	686
32 x 49	39	8.8	0.712	948	875
34 x 53	42	10.2	0.875	1156	1067
38 x 60	48	12.9	0.969	1565	1445
43 x 68	54	16.6	1.106	2196	2027
48 x 76	60	20.5	1.229	2910	686
53 x 83	66	24.8	1.352	3753	875
58 x 91	72	29.5	1.475	4734	1067
63 x 98	78	34.6	1.598	5856	1445
68 x 106	84	40.1	1.721	7140	2027
72 x 113	90	46.1	1.845	8584	7925
77 x 121	96	52.4	1.967	10187	9403
82 x 128	102	59.2	2.091	11983	11061
87 x 136	108	66.4	2.215	13972	12897
92 x 143	114	74.0	2.310	16153	14910
97 x 151	120	82.0	2.461	18494	17072
106 x 166	132	99.2	2.707	23856	22021
116 x 180	144	118.6	2.968	30338	28004

Table 4 Concrete Arch Pipe

Pipe Size Rise x Span (Inch)	Approximate Equivalent Round Diameter (Inch)	A Area (Square Feet)	R Hydraulic Radius (Feet)	Values of $1.486/nxAxR^{2/3}$	
				n = 0.012	n = 0.013
11 x 18	15	1.1	0.25	54	50
$13^1/_2$ x 22	18	1.6	0.30	91	84
$15^1/_2$ x 26	21	2.2	0.36	137	127
18 x $28^1/_2$	24	2.8	0.45	203	187
$22^1/_2$ x $35^3/_4$	30	4.4	0.56	368	339
$26^5/_8$ x $43^3/_4$	36	6.4	0.68	613	566
$31^5/_8$ x $51^1/_8$	42	8.8	0.80	938	866
36 x $58^1/_2$	48	11.4	0.90	1315	1214
40 x 65	54	14.3	1.01	1783	1646
45 x 73	60	17.7	1.13	2376	2193
54 x 88	72	25.6	1.35	3867	3569
62 x 102	84	34.6	1.57	5784	5339
72 x 115	90	44.5	1.77	8056	7436
$77^1/_4$ x 122	96	51.7	1.92	9872	9112
$87^1/_8$ x 138	108	66.0	2.17	13689	12635

Table 5 Corrugated Metal Pipe Arch

Pipe Size Rise x Span (Inch)	A Area (Square Feet)	R Hydraulic Radius (Feet)	Values of $1.486/n x A x R^{2/3}$	
			n = 0.029	n = 0.034
11 x 18	1.079	0.277	23	20
13 x 22	1.559	0.330	38	33
16 x 25	2.181	0.397	60	51
18 x 29	2.846	0.451	86	73
22 x 36	4.318	0.553	149	127
27 x 43	6.329	0.674	249	213
30 x 50	8.177	0.758	348	297
36 x 58	11.383	0.901	544	464
40 x 65	14.174	1.004	728	621
44 x 72	17.270	1.106	947	807
55 x 73	21.887	1.294	1332	1136
57 x 76	23.615	1.344	1473	1257
59 x 81	26.052	1.405	1675	1428
61 x 84	27.933	1.454	1837	1567
63 x 87	29.879	1.503	2009	1714
65 x 92	32.599	1.564	2251	1920
67 x 95	34.698	1.613	2446	2086
69 x 98	36.862	1.662	2651	2261
71 x 103	39.866	1.722	2935	2504
73 x 106	42.183	1.771	3164	2699
75 x 112	45.792	1.836	3518	3001
77 x 114	47.852	1.880	3735	3186
79 x 117	50.387	1.929	4001	3413
81 x 123	54.312	1.993	4408	3759
83 x 128	57.916	2.052	4792	4087
85 x 131	60.701	2.101	5102	4352
87 x 137	64.975	2.164	5570	4751