Hydraulics

Hydraulic Considerations For Corrugated Polyethylene Pipe

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association dedicated to
providing unbiased, non-branded
information about the use and
installation of corrugated
polyethylene pipe.

Your Information Resource

CORRUGATED POLYETHYLENE PIPE ASSOCIATION™

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Preface

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Corrugated polyethylene drainage pipe is available in single wall (corrugated interior), and dual wall (smooth interior), designs. Dual wall corrugated polyethylene pipe is designed with a strong corrugated outer wall and a smooth interior wall to improve long-term hydraulic efficiency. In fact, this type of corrugated polyethylene stormwater drainage pipe offers up to 50% more capacity than comparably sized corrugated steel and significantly more capacity than reinforced concrete pipe.

Smooth interior pipe won’t snag debris or encourage sediment, even on shallow grades, and these superior hydraulics allow pipe systems to be downsized compared to traditional materials, reducing material and labor costs.

Overview of Hydraulic Considerations

The actual sizing of drainage pipes can be a tedious process. Fortunately, simplification procedures are available to make pipe selection faster and easier. The material in the following sections provides two methods – both based on the Manning's formula – which simplify the corrugated polyethylene pipe selection process.

Discharge curves provide one way to size pipe. Graphs are utilized once the design capacity requirements and slope have been established. Each corrugated polyethylene pipe product has its own discharge curve based on its Manning's "n" value.

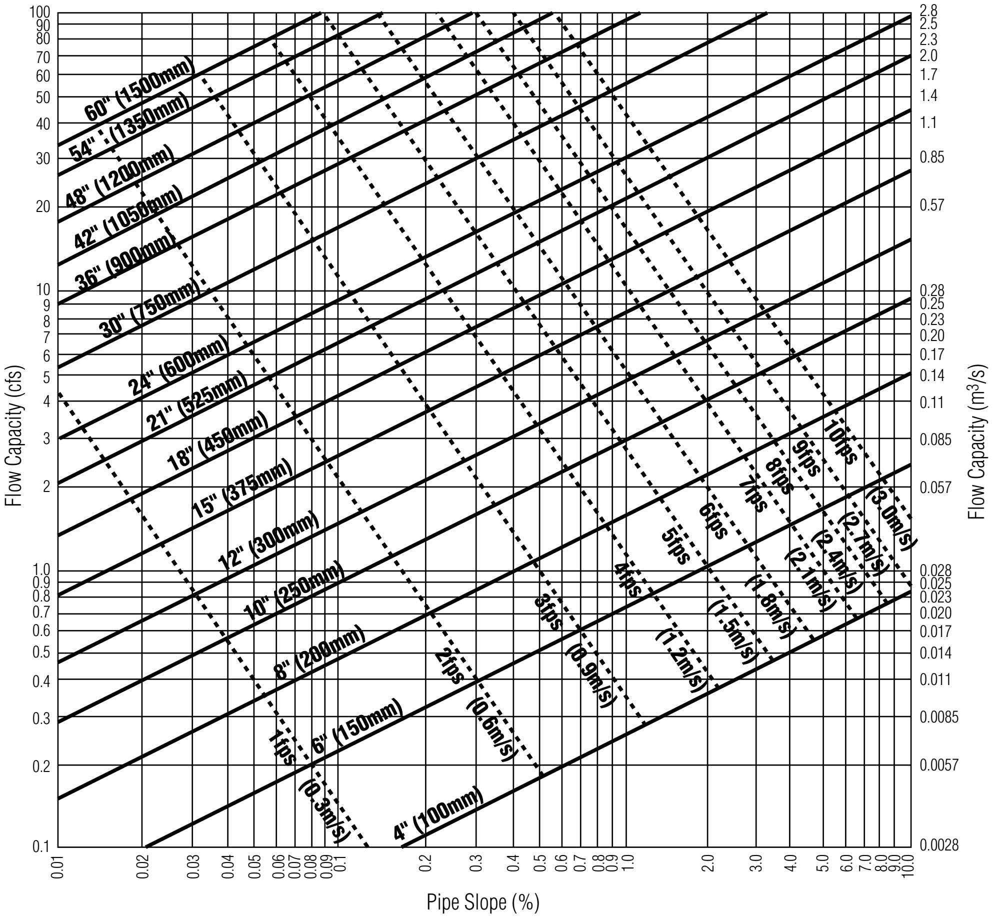
Another method of sizing pipe involves conveyance factors and allows the designer to develop product options easily. Use of this method frequently results in more than one satisfactory pipe type and size for a given drainage need, thereby revealing the most cost-effective solution.

Final pipe selection also should include a review of the velocity conditions. Higher flow velocities help keep sediment in stormwater from settling along the bottom of the smooth interior corrugated polyethylene pipe. A reduction in sediment can also reduce maintenance requirements and help ensure the hydraulic function of the pipe continues throughout its design life.

The mathematical relationship of the terms included in the Manning's formula is often shown graphically through discharge curves. The curves aid in the sizing of pipe once the required capacity and slope have been determined.

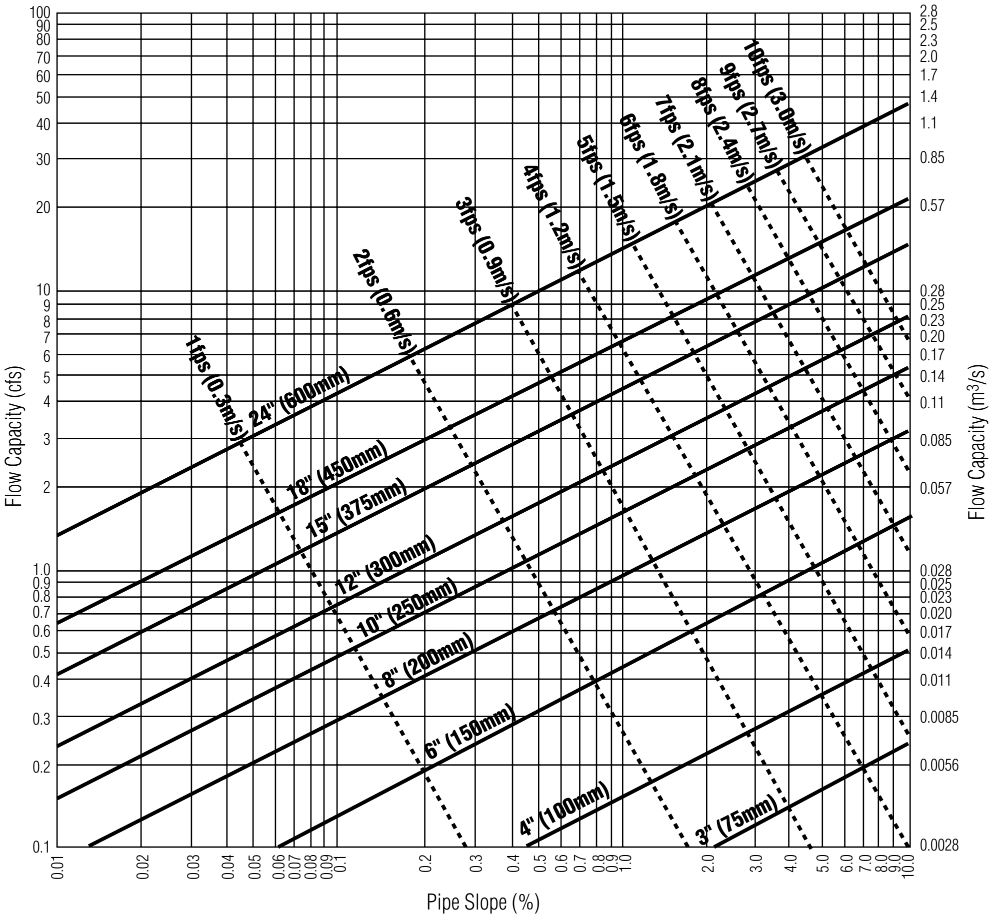
Discharge curves for two types of polyethylene pipe are shown in Figures 1 and 2.

Figure 1: Discharge Rates for Corrugated Polyethylene Pipe With a Smooth Interior (assumes n = 0.010)



Note: Actual "n" values may vary at the engineer's discretion.
Solid lines indicate pipe diameter.
Dashed lines indicate approximate flow velocity.

Figure 2: Discharge Rates for Corrugated Polyethylene Pipe With a Corrugated Interior



Note: The “n” value changes from diameter to diameter for corrugated interior pipe because of differences in corrugation geometry. (4" - 6": 0.015; 8": 0.016; 10: 0.017: 12" - 15": 0.018; 18" - 24": 0.020)[1]

Solid lines indicate pipe diameter.

Dashed lines indicate approximate flow velocity.

Conveyance provides a convenient means of selecting a variety of pipe options to satisfy a project's flow requirements. Conveyance factors are based on a greatly simplified version of the Manning's equation shown in Equation 1 or 1(a) with metric units.

Equation 1

$$Q = \frac{1.486\ AR^{2/3}\ S^{1/2}}{n}$$

Where:
Q = pipe capacity, cfs
n = Manning's "n" (unitless), a term used to describe material roughness
A = cross-sectional flow area of the pipe (ft^2)
R = hydraulic radius (ft), 1/4 the diameter for full-flowing pipe conditions
S = pipe slope (feet/foot)

Equation 1(a)

$$Q = \frac{AR^{2/3}\ S^{1/2}}{n}$$

Where:
Q = pipe capacity (m^3/s)
n = Manning "n" (unitless)
A = cross sectional flow area of the pipe (m^2)
R = hydraulic radius (m), 1/4 the diameter for full-flowing pipe conditions
S = pipe slope (meter/meter)

For a specific full-flowing pipe installation, the parameters *n, A*, and *R* are easily defined constants. The flow-carrying ability, or conveyance factor, of the pipe can then be defined as shown in Equation 2 or 2(a) with metric units.

Equation 2

$$k = \frac{1.486\ AR^{2/3}}{n}$$

Where:
k = conveyance factor

Equation 2(a)

$$k = \frac{AR^{2/3}}{n}$$

By substitution, the Manning's formula can then be reduced to the following equation.

Equation 3

$$Q = kS^{1/2}$$

Equation 3 also can be written as shown in Equation 4.

Equation 4

$$k = \frac{Q}{S^{1/2}}$$

Direct substitution of design conditions into Equation 4 will determine the minimum conveyance factor allowed. Use Table 1 [or Table 1(a) for metric equivalent] as a guide to selecting a corrugated polyethylene pipe having a conveyance factor of at least what you've calculated.

The Manning's "n" is a critical value in the conveyance concept. Among pipes of the same diameter, the Manning's "n" is the only factor that has an effect on conveyance and, therefore, capacity. When comparing identical field conditions, conveyance has a direct relationship to capacity. This means that if the slope is held constant, tripling conveyance will triple the capacity and halving conveyance will halve the capacity.

Problems involving conveyance factors are explained in the Example Problems section on page 16.

Table 1: Conveyance Factors for Corrugated Polyethylene Pipe (English Units)

Dia.	Area	Manning Value																
(in.)	(sq. ft.)	0.009	0.010	0.011	0.012	0.013	0.014	0.015	0.016	0.017	0.018	0.019	0.020	0.021	0.022	0.023	0.024	0.025
3	0.05	1.3	1.1	1.0	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
4	0.09	2.7	2.5	2.2	2.1	1.9	1.8	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0
6	0.20	8.1	7.3	6.6	6.1	5.6	5.2	4.9	4.6	4.3	4.1	3.8	3.6	3.5	3.3	3.2	3.0	2.9
8	0.35	17.5	15.7	14.3	13.1	12.1	11.2	10.5	9.8	9.2	8.7	8.3	7.9	7.5	7.1	6.8	6.5	6.3
10	0.55	31.6	28.5	25.9	23.7	21.9	20.3	19.0	17.8	16.8	15.8	15.0	14.2	13.6	12.9	12.4	11.9	11.4
12	0.79	51.5	46.3	42.1	38.6	35.6	33.1	30.9	28.9	27.2	25.7	24.4	23.2	22.1	21.1	20.1	19.3	18.5
15	1.23	93.3	84.0	76.3	70.0	64.6	60.0	56.0	52.5	49.4	46.7	44.2	42.0	40.0	38.2	36.5	35.0	33.6
18	1.77	151.7	136.6	124.1	113.8	105.0	97.5	91.0	85.3	80.3	75.9	71.9	68.3	65.0	62.1	59.4	56.9	54.6
21	2.41	228.9	206.0	187.3	171.6	158.4	147.1	137.3	128.7	121.2	114.4	108.4	103.0	98.1	93.6	89.6	85.8	82.4
24	3.14	326.8	294.1	267.3	245.1	226.2	210.1	196.1	183.8	173.0	163.4	154.8	147.0	140.0	133.7	127.9	122.5	117.6
27	3.98	447.3	402.6	366.0	335.5	309.7	287.6	268.4	251.6	236.8	223.7	211.9	201.3	191.7	183.0	175.0	167.8	161.0
30	4.91	592.5	533.2	484.7	444.3	410.2	380.9	355.5	333.3	313.7	296.2	280.6	266.6	253.9	242.4	231.8	222.2	213.3
33	5.94	763.9	687.5	625.0	572.9	528.9	491.1	458.3	429.7	404.4	382.0	361.9	343.8	327.4	312.5	298.9	286.5	275.0
36	7.07	963.4	867.1	788.2	722.6	667.0	619.3	578.0	541.9	510.0	481.7	456.4	433.5	412.9	394.1	377.0	361.3	346.8
42	9.62	1453.2	1307.9	1189.0	1089.9	1006.1	934.2	871.9	817.5	769.4	726.6	688.4	654.0	622.8	594.5	568.7	545.0	523.2
45	11.04	1746.8	1572.1	1429.2	1310.1	1209.3	1122.9	1048.1	982.6	924.8	873.4	827.4	786.1	748.6	714.6	683.5	655.0	628.8
48	12.57	2074.8	1867.4	1697.6	1556.1	1436.4	1333.8	1244.9	1167.1	1098.4	1037.4	982.8	933.7	889.2	848.8	811.9	778.1	746.9
54	15.90	2840.5	2556.4	2324.0	2130.4	1966.5	1826.0	1704.3	1597.8	1503.8	1420.2	1345.5	1278.2	1217.4	1162.0	1111.5	1065.2	1022.6
60	19.63	3762.0	3385.8	3078.0	2821.5	2604.4	2418.4	2257.2	2116.1	1991.6	1881.0	1782.0	1692.9	1612.3	1539.0	1472.1	1410.7	1354.3

Design Manning's Values* for Corrugated Polyethylene Pipe
*Manning's coefficient for smooth interior pipe determined at Utah State University Water Research Laboratory.

Conveyance Equations: $k = Q/S^{1/2}$ or $Q = kS^{1/2}$

Note: Highlighted columns are representative of smooth interior polyethylene pipe.

Product	Diameter	Manning's "n"
Typical Smooth Interior	4" – 60"	0.010 - 0.012
Typical Corrugated Interior	3" – 6"	0.015
	8"	0.016
	10"	0.017
	12" – 15"	0.018
	18" – 24"	0.020

Table 1(a) : Conveyance Factors for Corrugated Polyethylene Pipe (Metric Units)

Dia.	Area	Manning Value																
(mm)	**(sq. m)**	**0.009**	**0.010**	**0.011**	**0.012**	**0.013**	**0.014**	**0.015**	**0.016**	**0.017**	**0.018**	**0.019**	**0.020**	**0.021**	**0.022**	**0.023**	**0.024**	**0.025**
75	0.004	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
100	0.008	0.07	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03
150	0.018	0.22	0.20	0.18	0.16	0.15	0.14	0.13	0.12	0.12	0.11	0.10	0.10	0.09	0.09	0.09	0.08	0.08
200	0.031	0.47	0.43	0.39	0.36	0.33	0.30	0.28	0.27	0.25	0.24	0.22	0.21	0.20	0.19	0.19	0.18	0.17
250	0.049	0.86	0.77	0.70	0.64	0.59	0.55	0.52	0.48	0.45	0.43	0.41	0.39	0.37	0.35	0.34	0.32	0.31
300	0.071	1.40	1.26	1.14	1.05	0.97	0.90	0.84	0.79	0.74	0.70	0.66	0.63	0.60	0.57	0.55	0.52	0.50
375	0.110	2.53	2.28	2.07	1.90	1.75	1.63	1.52	1.42	1.34	1.27	1.20	1.14	1.09	1.04	0.99	0.95	0.91
450	0.159	4.12	3.71	3.37	3.09	2.85	2.65	2.47	2.32	2.18	2.06	1.95	1.85	1.76	1.68	1.61	1.54	1.48
525	0.216	6.21	5.59	5.08	4.66	4.30	3.99	3.73	3.49	3.29	3.11	2.94	2.80	2.66	2.54	2.43	2.33	2.24
600	0.283	8.87	7.98	7.26	6.65	6.14	5.70	5.32	4.99	4.70	4.43	4.20	3.99	3.80	3.63	3.47	3.33	3.19
675	0.358	12.14	10.93	9.93	9.11	8.41	7.80	7.28	6.83	6.43	6.07	5.75	5.46	5.20	4.97	4.75	4.55	4.37
750	0.442	16.08	14.47	13.16	12.06	11.13	10.34	9.65	9.04	8.51	8.04	7.62	7.24	6.89	6.58	6.29	6.03	5.79
825	0.535	20.73	18.66	16.96	15.55	14.35	13.33	12.44	11.66	10.98	10.37	9.82	9.33	8.89	8.48	8.11	7.77	7.46
900	0.636	26.15	23.53	21.39	19.61	18.10	16.81	15.69	14.71	13.84	13.07	12.39	11.77	11.21	10.70	10.23	9.81	9.41
1050	0.866	39.44	35.50	32.27	29.58	27.31	25.36	23.67	22.19	20.88	19.72	18.68	17.75	16.90	16.14	15.43	14.79	14.20
1125	0.994	47.41	42.67	38.79	35.56	32.82	30.48	28.45	26.67	25.10	23.70	22.46	21.33	20.32	19.39	18.55	17.78	17.07
1200	1.131	56.31	50.68	46.07	42.23	38.99	36.20	33.79	31.68	29.81	28.16	26.67	25.34	24.13	23.04	22.04	21.12	20.27
1350	1.431	77.09	69.38	63.08	57.82	53.37	49.56	46.26	43.36	40.81	38.55	36.52	34.69	33.04	31.54	30.17	28.91	27.75
1500	1.767	102.10	91.89	83.54	76.58	70.69	65.64	61.26	57.43	54.05	51.05	48.36	45.95	43.76	41.77	39.95	38.29	36.76

Design Manning's Values* for Corrugated Polyethylene Pipe
*Manning's coefficient for smooth interior pipe determined at Utah State University Water Research Laboratory.

Conveyance Equations: $k = Q/S^{1/2}$ or $Q = kS^{1/2}$

Note: Highlighted columns are representative of smooth interior polyethylene pipe.

Product	Diameter	Manning's "n"
Typical Smooth Interior	100 - 1500 mm	0.010 - 0.012
Typical Corrugated Interior	75 - 150 mm	0.015
	200 mm	0.016
	250 mm	0.017
	300 - 375 mm	0.018
	450 - 600 mm	0.020

Self-Cleansing Velocities

Sediment can reduce the capacity of a stormwater pipe over time. In some installations, it may render the pipe useless until the system can be cleaned. This is an expensive, time-consuming undertaking, so preventive measures should be taken during design.

Sedimentation is of great concern in storm sewer application, because large, heavy grit may be present. To minimize potential problems, flow should be maintained at a minimum, or self-cleansing, velocity.

Flow velocity can be increased by either increasing the slope of the pipe or by using a smaller diameter. Modifying either the slope or pipe size requires careful consideration of site factors and flow needs. However, by using a corrugated polyethylene pipe with a smoother interior (a lower Manning's "n"), a smaller diameter pipe can often be selected in lieu of alternative pipe materials without adversely affecting capacities or modifying the slope of the line.

The potential for settling is determined by the specific gravity and diameter of the particle and flow velocity. The formula for self-cleansing velocity is shown in Equation 5 or 5(a) for metric units.

Equation 5[1]

$$V_{SC} = \frac{1.486R^{1/6}\,[B(sg - 1)Dg]^{1/2}}{n}$$

Where:

V_{SC} = minimum self-cleansing velocity (fps)

B = constant equal to 0.04 for clean granular particles or 0.8 for cohesive material (unitless)

sg = specific gravity of the soil particle (unitless)

Dg = particle diameter (in)

Equation 5(a)

$$V_{SC} = \frac{R^{1/6}\,[B\,(sg-1)Dg]^{1/2}}{n}$$

Where:

V_{SC} = minimum self-cleansing velocity in a full-flow condition (m/s)

R = hydraulic radius (m)

B = constant equal to 0.04 for clean granular particles or 0.8 for cohesive material, unitless

sg = specific gravity of the soil particle
Dg = particle diameter (m)

Soil types vary widely across the nation, as well as within states and counties. Separate calculations in each specific installation may prove impractical, so an optimum self-cleansing velocity for storm sewers is usually accepted to be 3 fps (1m/s).[2]

In some specialized installations where sediment is a known problem, it may be wise to perform a soil analysis prior to final drainage design to determine the parameters necessary for Equation 5 or 5(a). By doing so, much off the guesswork is eliminated and sedimentation is kept to a minimum. In each design, a final check should be performed to compare the expected velocity with the self-cleansing velocity. The actual effluent velocity can be calculated using Equation 6 or Equation 6(a) for metric units.

Equation 6

$$V = \frac{1.486R^{2/3}S^{1/2}}{n}$$

Equation 6(a)

$$V = \frac{R^{2/3}S^{1/2}}{n}$$

Determining actual effluent velocity can be greatly simplified through use of a chart, as shown in Figure 3, for partially full pipe flows. Proper use of this chart is demonstrated in Example 2.

The design velocity for storm sewer applications should be a minimum of 3 fps (1m/s) or the value calculated through Equation 5 or Equation 5(a) for metric units.

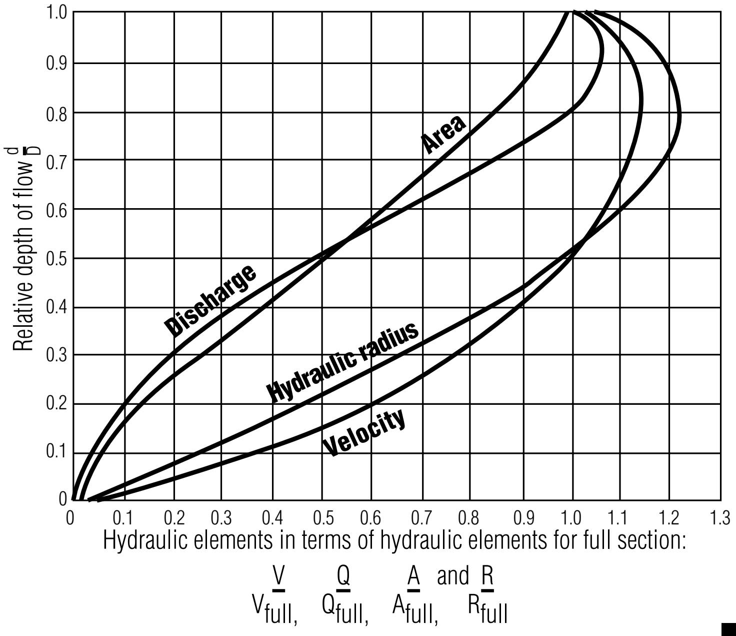


Figure 3: Determining Actual Effluent Velocity

Many factors influence the life cycle costs of stormwater drainage pipe. While material and installation rates and equipment costs are fairly easy to define, factors such as maintenance and material life will depend entirely on the environment where the system is constructed.

The inert, anti-adhesive nature of high density polyethylene pipe (HDPE) adds to its excellent hydraulics, because it minimizes the build up of sediments, scale and slime which occurs more commonly in pipes made of other materials. Pipe discharge rates are determined using the Manning's "n" value which are shown in Table 2.

Table 2
Comparison of Pipe Wall Roughness Coefficients
Manning's "n" Values

Pipe Diameter in (mm)	Corrugated Exterior Smooth Interior Polyethylene Pipe[3]	Galvanized Corrugated Steel Pipe[4]	Reinforced Concrete Pipe[5]
4 (100)	0.010-0.012	N/A	N/A
6 (150)	0.010-0.012	N/A	N/A
8 (200)	0.010-0.012	0.022-0.026	0.011-0.015
10 (250)	0.010-0.012	0.022-0.026	0.011-0.015
12 (300)	0.010-0.012	0.022-0.026	0.011-0.015
15 (375)	0.010-0.012	0.022-0.026	0.011-0.015
18 (450)	0.010-0.012	0.022-0.026	0.011-0.015
21 (525)	0.010-0.012	0.022-0.026	0.011-0.015
24 (600)	0.010-0.012	0.022-0.026	0.011-0.015
27 (675)	0.010-0.012	0.022-0.026	0.011-0.015
30 (750)	0.010-0.012	0.022-0.026	0.011-0.015
36 (900)	0.010-0.012	0.022-0.026	0.011-0.015
42 (1050)	0.010-0.012	0.022-0.026	0.011-0.015
48 (1200)	0.010-0.012	0.022-0.026	0.011-0.015
54 (1350)	0.010-0.012	0.022-0.026	0.011-0.015
60 (1500)	0.010-0.012	0.022-0.026	0.011-0.015

The durability of polyethylene pipe means that its roughness coefficient won’t vary or increase over time, because chemically inert HDPE is less affected than other pipe materials by pitting and corrosion. This helps to minimize sedimentation and reduce maintenance requirements, which in turn lowers overall maintenance and replacement costs.

Stormwater drainage systems also are often subjected to flows containing branches and other debris. A pipe with a corrugated interior tends to encourage blockages by trapping debris across the pipe. Smooth interior pipe remains relatively free of debris and snags and, if by chance they do occur, it’s easy to free the blockage.

The following example problems demonstrate the use of conveyance factors in sizing applications, basic velocity checks, and optional designs.

Example 1 (English Units)

Given: Field conditions stipulate a pipe capacity of 3 cfs and a slope of 0.5%.

Find: Both a corrugated polyethylene pipe with a smooth interior and a corrugated interior, providing the optimum hydraulic solution.

Solution: It is necessary to use Equation 4 to determine the required conveyance for the given conditions. Before substituting the values into the equation, first convert the slope into a value with units of feet/foot as follows:

0.5% = 0.005 ft/ft

Now substitute values directly into Equation 4:

$$\begin{aligned} k &= \frac{Q}{S^{1/2}} \\ &= \frac{3 \text{ cfs}}{(0.005)^{1/2}} \\ &= 42.2 \end{aligned}$$

Refer to Table 1 to select pipe having a minimum conveyance of 42.2.
The most practical solutions are:

12" smooth interior pipe	k = 46.3 (assumes “n” = 0.010)
15" corrugated interior pipe	k = 46.7 (assumes “n” = 0.018)

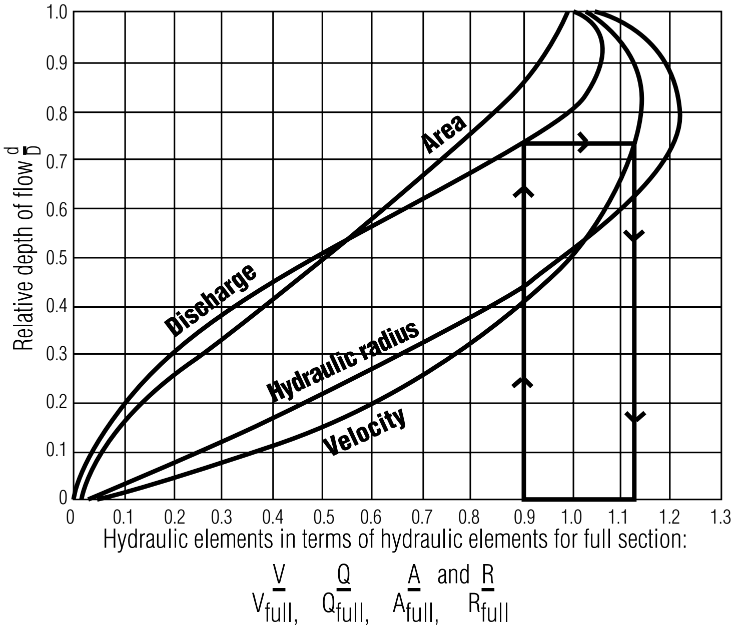
The optimum hydraulic solution would be the pipe with conveyance most near that calculated. Both the 12" smooth interior pipe and 15" corrugated interior pipe will function in about the same manner, because their conveyances are so close to that required. Final selection of pipe size and materials is made in Example 2.

Example 2

The results from the previous example, in combination with Equation 6 and Figure 1, allows the actual effluent velocity to be calculated.

Conveyance allows the user to compare *relative* capacities, and so can be used in lieu of capacity, or discharge, in Figure 1. Referring to the data from Example 1:

	$\frac{k}{k \text{ (full)}}$	$\frac{Q}{Q \text{ (full)}}$
12" (300 mm) smooth interior	$\frac{42.2}{46.3} = 0.91$	0.91
15" (375 mm) corrugated interior	$\frac{42.2}{46.7} = 0.90$	0.90



The velocity for these examples can be found by entering 0.91 and 0.90 on the abscissa of Figure 3, drawing a line upward to the line labeled “Discharge,” across to the line labeled “Velocity,” and then down to the abscissa to arrive at V/V(full). The resulting factor is then multiplied by V(full), which is easily calculated using Equation 6, to arrive at the actual effluent flow. The diagram that follows graphically demonstrates this process for Q/Q(full) = 0.90, and the table summarizes the results for both options.

	$\frac{Q}{Q \text{ (full)}}$	$\frac{V}{V \text{ (full)}}$	V (full)	V
12" (300 mm) smooth interior	0.91	1.125	4.17 fps (1.3 m/s)	4.69 fps (1.4 m/s)
15" (375 mm) corrugated interior	0.90	1.125	2.69 fps (0.8 m/s)	3.03 fps (1 m/s)

The conclusion is that both alternatives will meet the minimum self-cleansing velocity of 3 fps (1 m/s). The 12" (300 mm) pipe with a smooth interior supplies some additional velocity that will tend to flush out larger grit particles. Furthermore, smaller diameter pipe may result in installation savings that should be considered in the overall project costs.

Example 3

Given: Field conditions stipulate a pipe capacity of 0.5 m^3/s and a slope of 6%.
Several materials are being reviewed for the project, as follows:

Smooth interior polyethylene pipe	"n" = 0.010 (assumed)
Corrugated interior polyethylene pipe	"n" values as shown in Table 1(a)
Corrugated steel pipe	"n" = 0.022 (assumed)

Find: Pipe providing the optimum hydraulic solution.

Solution: The units of the slope must be converted to m/m prior to determining conveyance.
6% = 0.06 m/m

$$k = \frac{Q}{S^{1/2}}$$

$$= \frac{0.5m^3/s}{(0.06)^{1/2}}$$

$$= 2.04$$

From Table 1(a), potential alternatives are as follows:

375 mm smooth interior polyethylene pipe	k = 2.28	V = 5.7 m/s
525 mm corrugated steel pipe	k = 2.54	V = 3.2 m/s
525 mm corrugated interior polyethylene pipe	k = 2.80	V = 3.5 m/s

This example illustrates the wide variances in diameters able to accommodate the flow specified. In each case, the minimum velocity criteria was checked and fulfilled using the method demonstrated in Example 2, in conjunction with Equation 6(a). (Results are as shown above).

[1] American Society of Civil Engineers and Water Pollution Control Federation, Gravity Sanitary Sewer Design and Construction. New York, N.Y., p. 105, 1982.

[2] Ibid, p. 107.

[3] Steven L. Barfuss and J. Paul Tullis, *Report on the Friction Factor Tests on High Density Polyethylene Pipe.* Logan, Utah: Utah State University Water Research Laboratory; 1988.

[4] American Society of Civil Engineers and Water Pollution Control Federation, Gravity Sanitary Sewer Design and Construction. New York, N.Y., p. 95, 1982.

[5] Ibid, p. 95.

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