3-0 HYDRAULICS

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BUYER/USER IS RESPONSIBLE FOR SERVICEABILITY OF THE PRODUCT IN ANY GIVEN APPLICATION. SELLER IS NOT RESPONSIBLE FOR INJURY OR DAMAGE RESULTING FROM IMPROPER INSTALLATION, NONCOMPLIANCE WITH THESE GUIDELINES FOR INSTALLATION OF PRODUCT, OR USE OUTSIDE THE GUIDELINES SET FORTH HEREIN.

3-1 OVERVIEW OF HYDRAULIC CONSIDERATIONS

The Manning's equation is the most widely recognized means of determining pipe capacity for gravity flow installations. As such, it provides the basis of the hydraulic design consideration for corrugated high density polyethylene (HDPE) and polypropylene (PP) pipe.

Discharge curves allow pipe sizing through use of graphs once the design capacity requirements and slope have been established. Each product will have its own discharge curve based on its Manning's "n" value. This section provides flow capacities based on recommended design "n" values for ADS products. It should be noted that factors such as bends, manhole connections, debris and sediment result in hydraulic losses that will affect actual flow capacity and should be considered in final pipe selection.

By reducing all of the coefficients and constants in the Manning equation down to a single factor, called the conveyance factor (K), another method of pipe sizing can be utilized. By knowing the Manning's "n" value for various pipe materials, the use of conveyance factor charts will allow the designer to develop comparative product options easily. Use of this method frequently results in more than one satisfactory pipe type and size for a given drainage need, thereby allowing the designer to compare product options in order to determine the most cost-effective solution.

Final pipe selection should also include a review of the velocity conditions. Higher flow velocities help keep sediment contained in stormwater from settling along the bottom of the pipe. A reduction in sediment can also reduce the frequency of maintenance and help ensure that the hydraulic function of the pipe will continue throughout its design life. These velocities, however, must be kept within the maximum performance limits of the pipe and the associated facility.

3-2 DESIGN MANNING'S VALUE

Within the pipe industry, there is a wide range of Manning's "n" values, or roughness coefficients, for various types of pipe. Several items should be considered prior to selecting an "n" value for a given pipe material when designing any gravity flow system.

1. Manning's "n" values developed for any given pipe material will depend on depth of flow for partially full pipe and flow velocity for full flow conditions. Manning's "n" values are commonly provided for full flow conditions, but should not be assumed unless specifically noted. For most calculations, "n" is assumed to be constant; however, it shall be the discretion of the individual designer to use a constant or varying "n" value.

2. Storm sewers, culverts and sanitary sewers are typically subject to collection of debris and sediment, which adversely effect flow rates. Consideration should be given for the collection of debris and sedimentation and adjust the design "n" value accordingly. Pipe inside surface texture, geometry, joint opening and pipe material can also influence collection of debris and sedimentation depending on the susceptibility of the debris to either adhere to the pipe surface or be trapped and caught by other obstructions.

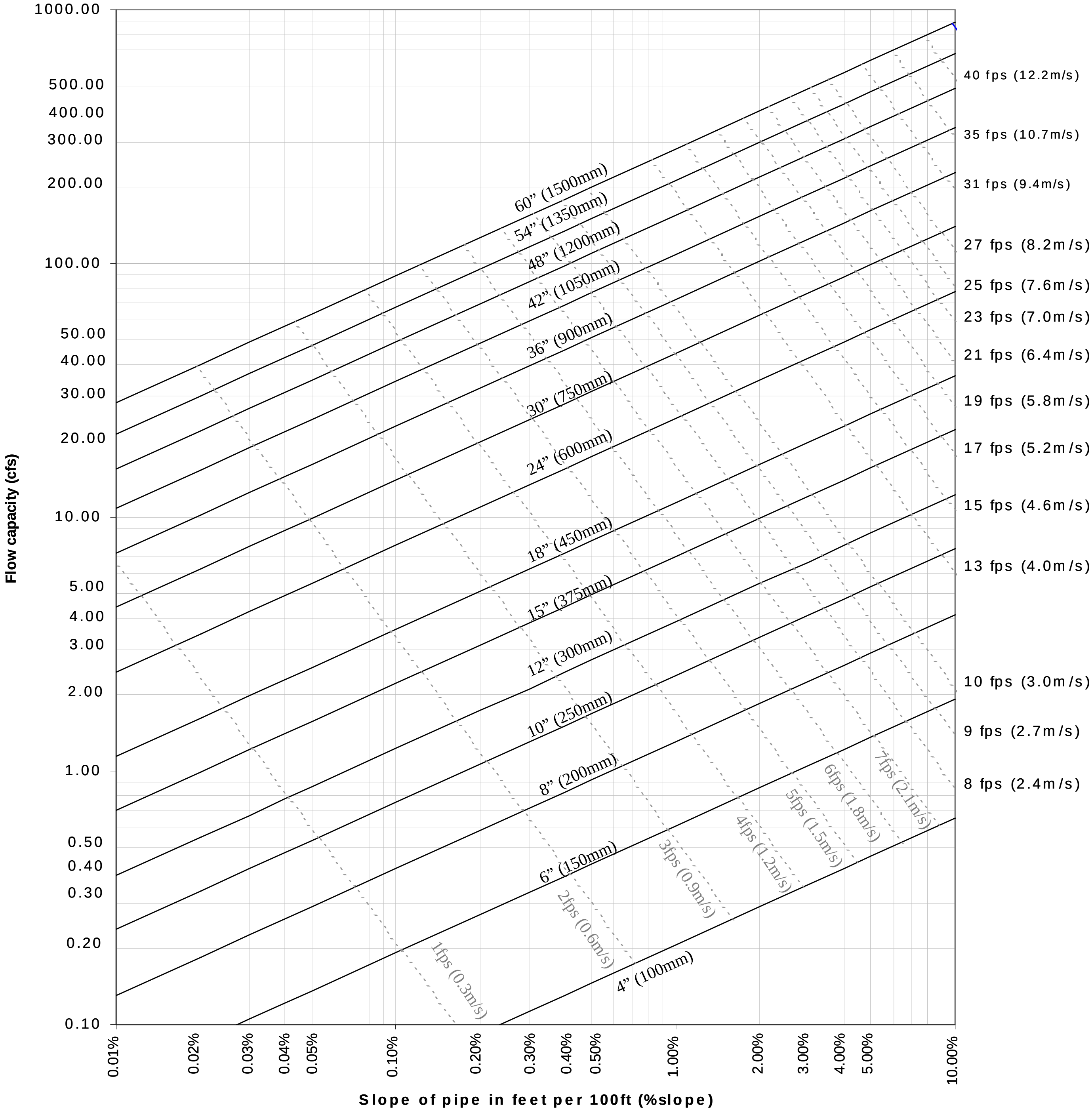
Tests conducted at Utah State University Water Research Laboratory show minimum Manning's "n" values of less than 0.010 for corrugated HDPE pipe with a smooth interior liner. To accommodate actual field conditions and to incorporate a safety factor, ADS recommends using a Manning's "n" value of 0.012 for corrugated HDPE and PP products with a smooth interior liner. There is considerable justification for both HDPE and PP products to be designed with the same Manning's "n" value. Both smooth interior products are made using the same mold blocks and are produced on the same manufacturing equipment. From a material standpoint, both HDPE and PP are polyolefin materials, very similar in chemical makeup, that behave similarly during processing. Also, ADS performs regular internal quality checks which assure the liner roughness of polypropylene is equal to, if not better than, the liner roughness of HDPE products with an established Manning's "n" value of 0.012. In general, it is common engineering practice to include a safety factor of 20-30% to the Manning's values determined during laboratory testing. However, it should be noted, this practice is not utilized for most Manning's "n" values provided for metal pipes. Recommended design Manning's "n" values for all ADS pipe products are listed in Table 3-1.

3-2 DISCHARGE CURVES

The mathematical relationship of the terms included in the Manning's formula is often shown graphically through discharge curves. Discharge curves are one method of selecting an adequate pipe size, once the required capacity and slope have been determined.

Discharge curves for ADS HDPE and PP pipe products under gravity flow steady state conditions are shown in Figures 3-1 through 3-3.

Figure 3-1
Discharge Rates for ADS Corrugated Pipe with Smooth Interior Liner[1]

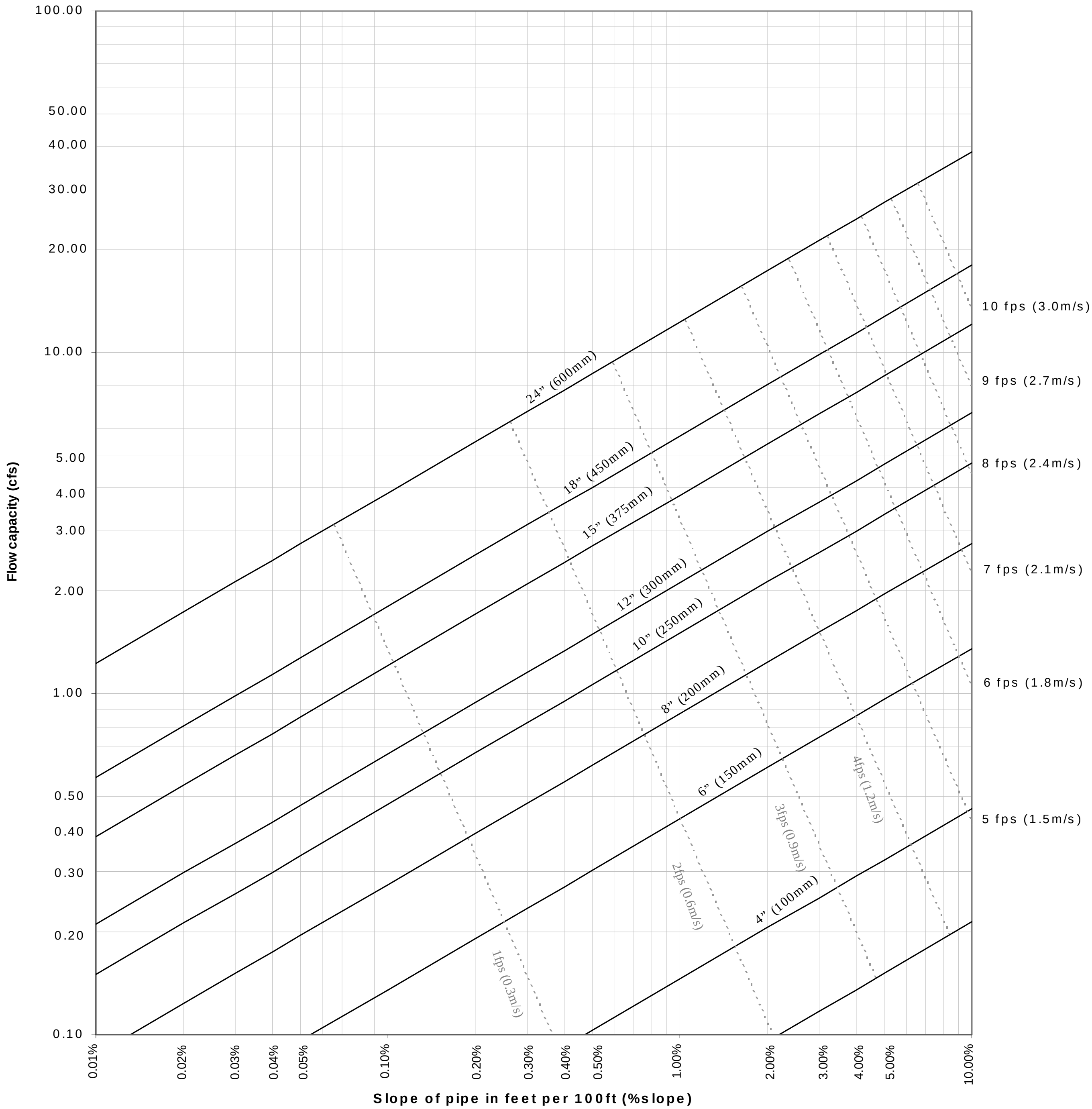


1cfs = 0.02832 m^3/s
1ft/s = 0.30480 m/s
1% = 0.01 ft/ft

1. Applicable products: N-12®, MEGA GREEN®, N-12 STIB, N-12 WTIB, N-12 HP, SaniTIte®, SaniTite HP, N-12 Low Head

Note: Based on a design Manning’s “n” of 0.012.
Solid lines indicate pipe diameters. Dashed lines indicate approximate flow velocity.
Redeveloped from FHWA HDS 3 – Design Charts for Open-Channel Flow[2]

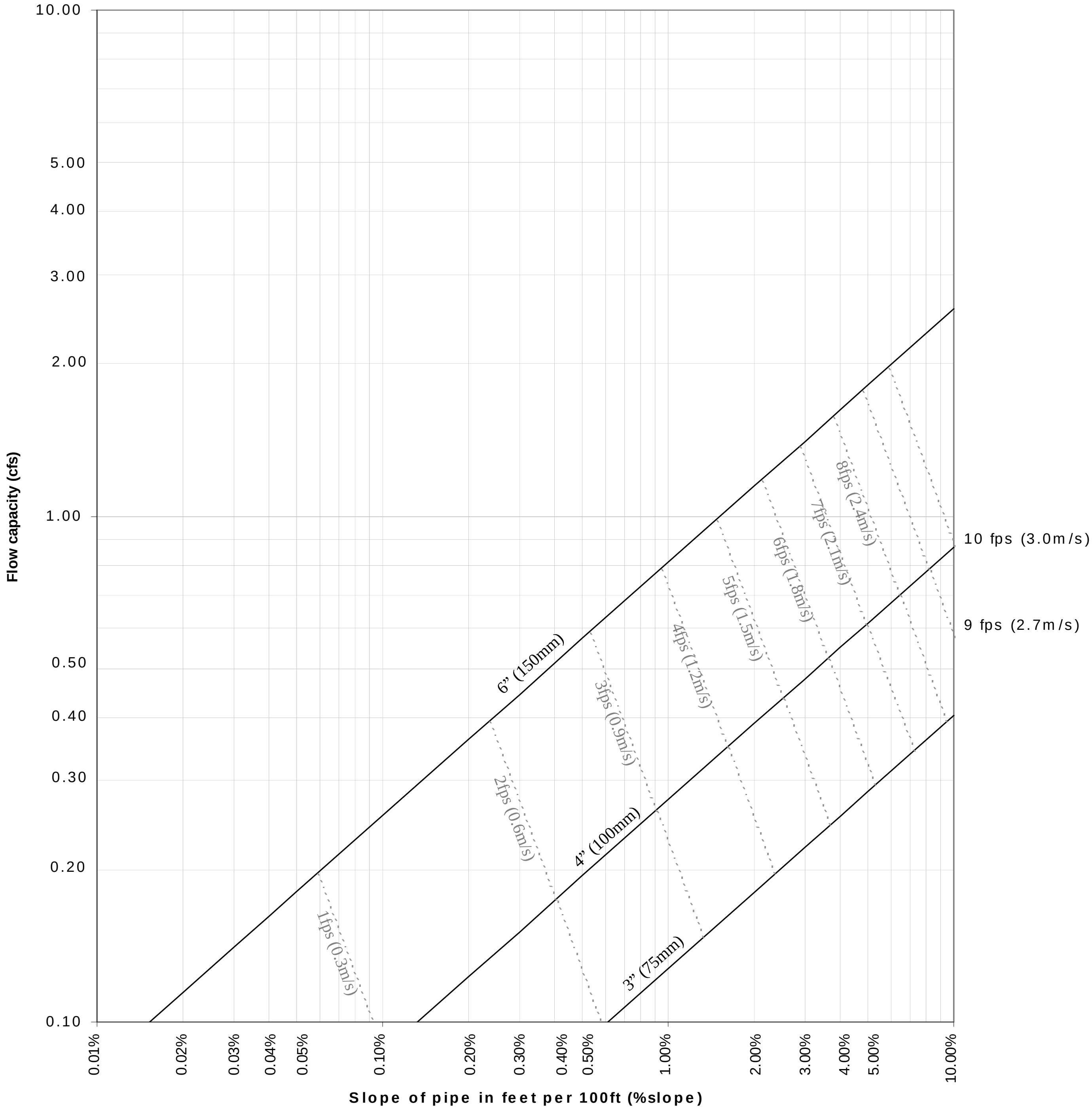
Figure 3-2
Discharge Rates for ADS Single Wall Heavy Duty and Highway Pipe



1cfs = 0.02832 m^3/s
1ft/s = 0.30480 m/s
1% = 0.01 ft/ft

Note: Based on a design Manning's "n" described in Table 3-1 for respective diameter.
Pipe may not be available in all diameters shown.
Solid lines indicate pipe diameters. Dashed lines indicate approximate average velocity.

Figure 3-3
Discharge Rates for ADS TripleWall® and Smoothwall Sewer & Drain Pipe



1cfs = 0.02832 m³/s
1ft/s = 0.30480 m/s
1% = 0.01 ft/ft

Note: Based on a design Manning's "n" of 0.009.
Solid lines indicate pipe diameters. Dashed lines indicate approximate average velocity.

3-3 THE CONVEYANCE METHOD

Conveyance provides a convenient means of selecting a variety of pipe options that will satisfy a project's flow requirements. Conveyance factors are based on a greatly simplified version of the Manning's equation shown in Equation 3-1 and 3-1 (a). In the following discussion, example problems and subsequent sections, the pipe is assumed to be flowing full. This assumption typically allows for a simplified, yet accurate analysis of the given conditions. Each project should be evaluated on a case-by-case basis to determine the best, most-representative design method.

$$Q = \frac{(1.486)(A)(R^{2/3})(S^{1/2})}{n}$$ Equation 3-1

Where:

Q = pipe capacity, (cfs)
n = Manning's "n"
A = cross-sectional flow area of the pipe (ft.^{2})
R = hydraulic radius (ft.):

$$R = \frac{A}{P}$$

P = Wetted perimeter (ft); Pipe inside circumference, or (π)(inside diameter) for full flowing pipe conditions

S = pipe slope (feet/foot)

Or, in metric units:

$$Q = \frac{(A)(R^{2/3})(S^{1/2})}{n}$$ Equation 3-1(a)

Where:

Q = pipe capacity, m^3/s
n = Manning's "n"
A = cross-sectional flow-area of the pipe (m^2)
P = Wetted perimeter (ft); Pipe circumference, or (π)(diameter) for full flowing pipe conditions

R = hydraulic radius (m),

$$R = \frac{A}{P}$$

S = pipe slope (m/m)

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 3-2 or 3-2(a).

$$k = \frac{(1.486)(A)(R^{2/3})}{n}$$ Equation 3-2

Or, in metric units:

$$k = \frac{(A)(R^{2/3})}{n}$$ Equation 3-2(a)

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

$$Q = kS^{1/2}$$ Equation 3-3

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

$$k = \frac{Q}{S^{1/2}}$$ Equation 3-4

Direct substitution of design conditions into Equation 3-4 will determine the minimum conveyance factor allowed. Table 3-2 or 3-2 is then used as a guide to select a pipe having a conveyance factor of at least that calculated.

Table 3-1 and 3-2 require knowledge of the Manning's "n" value. These tables can also be used for any materials if the specific Manning's "n" is known.

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

Example problems involving conveyance factors are explained in a subsequent section.

Table 3-1
Conveyance Factors (Standard Units)

Design Manning's Values for ADS Thermoplastic Pipe *		
Product	**Diameter**	**Design Manning's "n"**
N-12, MEGA GREEN, N-12 STIB, N-12 WTIB, N-12 HP, SaniTite, SaniTite HP, N-12 Low Head	4" - 60"	"n" = 0.012
Single Wall Highway and Heavy Duty *	18" - 24" 12" - 15" 10" 8" 3" - 6"	"n" = 0.020 "n" = 0.018 "n" = 0.017 "n" = 0.016 "n" = 0.015
TripleWall and Smoothwall Sewer & Drain	3" - 6"	"n" = 0.009 **
Conveyance Equations: k = Q/(s^0.5) Q = k s^0.5		

Conveyance Factors for Circular Pipe Flowing Full																		
		Manning's "n" Values																
Dia. (in.)	**Area (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
72	28.27	6117.3	5505.6	5005.1	4588.0	4235.1	3932.6	3670.4	3441.0	3238.6	3058.7	2897.7	2752.8	2621.7	2502.5	2393.7	2294.0	2202.2

* Corrugated Polyethylene Pipe Association (2000) "Hydraulic Considerations for Corrugated Polyethylene Pipe"
** "Lingedburg, Michael, "Civil Engineer Reference Manual"[4]

Table 3-2
Conveyance Factors (Metric Units)

Design Manning's Values for ADS Thermoplastic Pipe *		
Product	**Diameter**	**Design Manning's "n"**
N-12, MEGA GREEN, N-12 STIB, N-12 WTIB, N-12 HP, SaniTite, SaniTite HP, N-12 Low Head	100-1500mm	"n" = 0.012
Single Wall Highway and Heavy Duty *	450-600mm 300-375mm 250mm 200mm 75-150mm	"n" = 0.020 "n" = 0.018 "n" = 0.017 "n" = 0.016 "n" = 0.015
TripleWall and Smoothwall Sewer & Drain	75-150mm	"n" = 0.009 **
Conveyance Equations: k = Q/(s^0.5) Q = k s^0.5		

Conveyance Factors for Circular Pipe Flowing Full																		
		Manning's "n" Values																
Dia. (mm)	**Area (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
1800	2.545	166.04	149.43	135.85	124.53	114.95	106.74	99.62	93.62	87.90	83.02	78.65	74.72	71.16	67.92	64.97	62.26	59.77

* Corrugated Polyethylene Pipe Association (2000) "Hydraulic Considerations for Corrugated Polyethylene Pipe"
** "Lingedburg, Michael, "Civil Engineer Reference Manual"[4]

3-4 MINIMUM VELOCITY CONSIDERATIONS

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 preventative measures should be taken during design. Sedimentation is of great concern in sewer applications since large, heavy grit may be present.

To minimize potential problems, flow should be maintained at a minimum, or self-cleansing, velocity. A commonly accepted self-cleansing velocity for storm and sanitary sewers is 3 fps (0.9 m/s). In each design, a final check should be performed to compare the expected velocity with the self-cleansing velocity. The design velocity for full-flowing pipes can be *approximated* with Equation 3-5:

$$V = \frac{Q}{A} \qquad \text{Equation 3-5}$$

The potential for settling is determined by the specific gravity and diameter of particle, its cohesive properties, flow velocity, and the roughness of the pipe interior. For further discussion on the complexities and variables associated with determining the self-cleansing velocity for a specific pipe diameter and material, refer to ASCE publication No. 60, “Gravity Sanitary Sewer Design and Construction.” In some specialized installations where sediment is a known problem it may be wise to perform a soil analysis prior to final drainage design.

3-5 MAXIMUM VELOCITY CONSIDERATIONS

High flow velocity can also create problems if not properly taken into consideration. High velocity is usually considered to be approximately 12 fps (3.7 m/s) but can vary depending on the specific site conditions.

The preferred method of contending with high velocity is to look for opportunities to minimize it, such as reducing the slope of the pipe. If that is not feasible, and many times it is not, the velocity must simply be managed the best way possible.

High velocity, especially if it carries an abrasive effluent, can present durability problems. Over time, the invert of the pipe can wear prematurely. Thermoplastics resist the effects of these rigorous conditions better than many other traditional pipe materials. Additional information specific to the effects of abrasives on many types of pipe materials is provided in the *Durability* section (Section 4) of the Drainage Handbook.

Special consideration should also be given to the conditions at the pipe outlet. High flow velocity can erode the channel where the flow is deposited. Erosion management methods, such as rip-rap, should be considered in these areas.

Another consideration in high velocity applications is managing the momentum of the flow. Changes in flow direction will result in large forces that can cause pipe movement, especially if the pipe size is large, velocity is very high, and the native soil has a low bearing strength. Concrete thrust blocks positioned at areas of flow direction change and sized specifically for the site conditions can be used to control the effects of momentum.

Anchoring systems may also need to be considered when the velocity is high or the slope that the pipe is installed is fairly steep. Anchors keep the pipe from moving down the slope while it is being installed and later due to the energy of the flow. They are an especially important consideration if the native soil is subject for movement or instability. ADS does not produce anchoring systems, but can provide additional information on companies who are experts in this area. For further discussion of steep slope applications, refer to “Steep Slope Installations” in the *Installation* section (Section 5) of the Drainage Handbook.

3-6 LONG TERM PRESSURE CONSIDERATIONS

Most ADS pipe products are intended for gravity flow applications only. Storm drainage products are not recommended for long-term pressure or intermittent pressure flow, including constant head and pumping applications. N-12 Low Head pipe may be suitable for long-term and intermittent pressure flow applications where constant pressure does not exceed 5psi and surge pressure does not exceed 10psi. Contact an ADS sales representative for assistance in selecting a product suitable for the project application.

3-7 CULVERT CONSIDERATIONS

Culverts are typically short relative to a storm sewer system and are classified according to which of the ends controls the discharge capacity. Laboratory tests and field observations indicate two primary culvert flow control conditions: (1) inlet control and (2) outlet control. While inlet or outlet control conditions typically do not exist in storm sewer systems, where a system is controlled by the inlet or outlet, hydraulic head loss due to the entrance or outlet must be taken into account. For this reason, the Manning's formula cannot be the sole method of pipe sizing and selection.

While the theory of energy conservation will closely affect culvert design, no single formula or procedure has been developed to design all culverts, due to the numerous variables involved. True culvert design is, therefore, often an empirical, trial-and-error process.

One common variable used in culvert design, is the Entrance Loss Coefficient (k_e). Entrance Loss Coefficients are highly dependant on the size and shape of the interface between the culvert material and the fluid. For example, a square cut abrupt culvert edge will result in a greater loss coefficient than a culvert with a beveled or rounded edge. In the absence of test data for corrugated polyethylene or polypropylene pipe, corrugated metal pipe with a similar profile and structure can be used to estimate the entrance loss coefficients for ADS thermoplastics. Table 3-3 provides Entrance Loss Coefficients based on available data for common pipe materials and end treatments. Ultimately, the design engineer shall determine the most appropriate value for the entrance loss coefficient to use for the application.

Table 3-3
Entrance Loss Coefficients [a,b]
(Outlet Control, Full or Partially Full Flow)

Type of Structure and Design of End Treatment	k_e
Pipe, Concrete [a]	
Projecting from fill, square cut end	0.5
Square cut with headwall	0.5
Mitered to conform to fill slope	0.7
Beveled edges, 33.7° bevels	0.2
Socket end of pipe	0.2
Pipe, Corrugated Metal [a], ADS Thermoplastic [b]	
Projecting from fill (no headwall)	0.9
Square cut with headwall	0.5
Mitered to conform to fill slope	0.7
End-Section conforming to fill slope	0.5
Beveled edges (33.7° or 45° bevel)	0.2

a) Data obtained from U.S. Department of Transportation Federal Highway Administration Hydraulic Charts for the Selection of Highway Culverts[5]
b) ADS thermoplastic pipe is estimated to have coefficients in the range of those found for corrugated metal pipe.

3-8 EXAMPLE PROBLEMS

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

Example 1

Given: Field conditions stipulate a pipe capacity of 2 cfs and a slope of 0.5%.

Find: The ADS pipe product providing the optimum hydraulic solution.

Solution: It is necessary to use Equation 3-4 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 3-4.

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

$$= \frac{2}{(0.005)^{1/2}}$$

$$= 28.3$$

Refer to Table 3-1 to select the appropriate pipe product having a minimum conveyance of 28.3, based on the respective Manning's "n" value. The most practical solutions are as follows:

12-inch corrugated, smooth interior pipe	k = 38.6
15-inch single wall pipe	k = 38.2

The optimum solution would be the pipe with conveyance most near that calculated. Both the 12-inch corrugated, smooth interior and 15-inch single wall pipes will function in about the same manner because their conveyances are relatively close to that required. Final selection of pipe size and material is made in Example 2.

Example 2

Substituting data from tentatively selected solutions from Example 1 into the velocity formula (Equation 3-5), 12-inch corrugated, smooth interior pipe and 15-inch single wall pipe will yield velocities of 3.5 fps and 2.2 fps, respectively. Therefore, the 12-inch corrugated, smooth interior pipe should be selected to attain a self-cleansing velocity.

Example 3

Given: Field conditions stipulate a pipe capacity of 2 cfs and a slope of 0.5%.

Find: The ADS pipe product providing the optimum hydraulic solution.

Solution: It is necessary to use Figure 3-1 and Figure 3-2 to determine the pipe products

0.5% = 0.005 ft/ft

Refer to Figure 3-1 to select the corrugated, smooth interior pipe diameter. The intersection of the 0.50% and 2 cfs lines is above the 10" line but below the 12" therefore 12" corrugated, smooth interior pipe products are practical.

Refer to Figure 3-2 to select the single wall pipe product diameter. The intersection of the 0.50% and 2 cfs lines is above the 12" line but below the 15", therefore 15" single wall pipe products are practical.

The optimum solution would be the pipe with the flow capacity at least as great as the required. Both, the 12-inch corrugated, smooth liner and 15-inch single wall pipes will function in about the same manner because their flow capacities are greater than that required. Final selection of pipe size and material is made in Example 4.

Example 4

Substituting data from tentatively selected solutions from Example 4 into Figure 3-1 and Figure 3-2, 12-inch corrugated, smooth interior pipe and 15-inch single wall pipe will yield velocities of approximately 3.6 fps and 2.8 fps, respectively. Therefore, the 12-inch corrugated, smooth interior pipe should be selected to attain a self-cleansing velocity.

3-9 FOOTNOTES

[1]Federal Highway Administration, *Hydraulic Design of Highway Culverts (HDS 5), 2nd Edition* , 2001, Pg. 33.

[2] Federal Highway Administration, *Design Charts for Open-Channel Flow (HDS 3),* August 1961, Chapter 5.

[3] Clyde, Calvin G., *Manning Friction Coefficient Testing of 4-, 10-, 12- and 15-inch Corrugated Plastic Pipe.* Utah Water Research Laboratory, Report No. 36, May 1980.

[4] Lingedburg, Michael P.E. Civil Engineer Reference Manual. Belmont, CA: Professional Publications, Inc.

[5] Federal Highway Adminstration, *Design Charts of Highway Culverts (HDS 5)*, 2nd *Edition*, 2001, Pg. 223.