MN6-4 Conduit Design

6-4.1 Full Pipe Flow:

Spillway discharge capacity is calculated in the following manner in the case of full pipe flow:

$$Q\ (cfs) = a\sqrt{\frac{2gH}{1+K_e+K_b+K_m+K_pL}} \qquad \text{(Eq. 6-4.1)}$$

Symbols:

a = Area of conduit in square feet

α = Deflection angle of miter-bend in degrees

d_i = Inside diameter of conduit in inches

g = 32.2 ft/sec^2

H = Total available head in feet (difference in elevation between design water surface in pool to a point 0.6D up from outlet invert or the tailwater level, whichever is higher)

K_b = Head loss coefficient for pipe bends

K_b will be 0 for a drop inlet or straight spillway conduit. Bend loss values for bent pipes can be obtained from EFH Chapter 3, Exhibit 3-8.

K_e = The typical head loss coefficient for drop inlets is 1.0. Additional guidance on entrance loss coefficients can be found in EFH Chapter 3, Table 3-3.

K_m = Miter-bend losses (bends other than at riser)

$$= \frac{n\alpha}{3} \text{ (for } \alpha \leq 30^o) \qquad \text{(Eq. 6-4.2)}$$

= 0 when the entire length of conduit is on the same slope

K_p = Head loss coefficient. Values are summarized in NEH 5 Drawing ES-42 which is provided in Exhibit 6-4.1

$$= \frac{5087n^2}{{d_i}^{4/3}} \qquad \text{(Eq. 6-4.3)}$$

L = Length of conduit in feet

n = Manning's Roughness Coefficient

Exhibit 6-4.2 through Exhibit 6-4.5 may be used to obtain full flow pipe capacity for various pipe materials. For other than full pipe flow, refer to NEH 5, Drawing ES-97 provided in Exhibit 6-4.6.

Figure 6-4.1 Section along Centerline of Conduit Showing Heads Used for Design Capacities

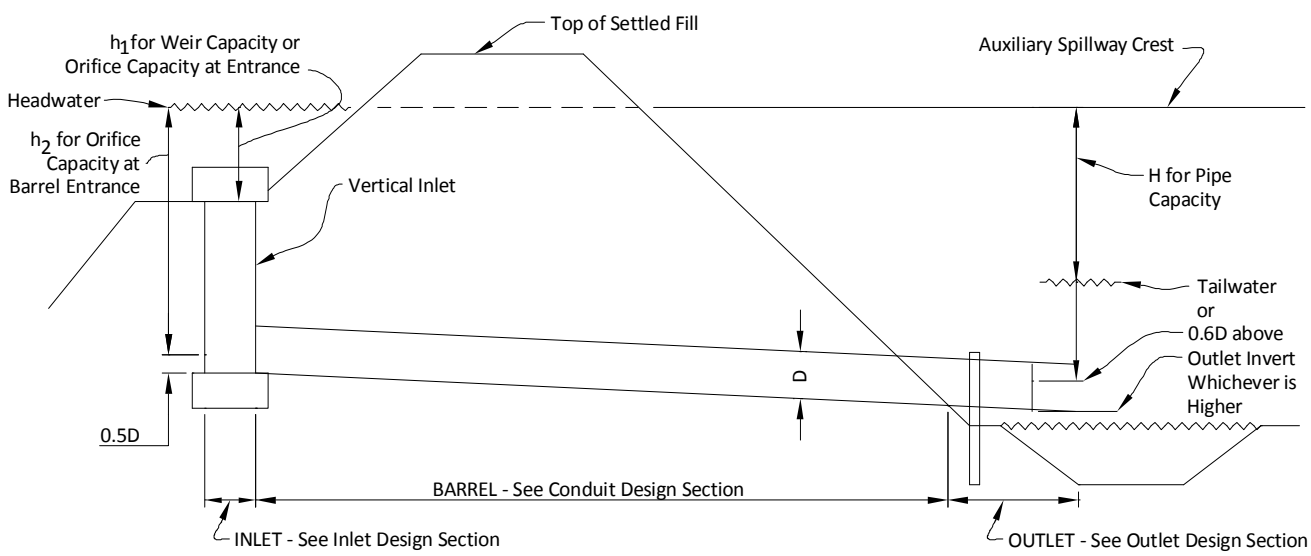


Exhibit 6-4.1 NEH Section 5, ES-42 Head Loss Coefficients

HYDRAULICS: HEAD LOSS COEFFICIENTS FOR CIRCULAR AND SQUARE CONDUITS FLOWING FULL

HEAD LOSS COEFFICIENT, K_p, FOR CIRCULAR PIPE FLOWING FULL $K_p = \frac{5087\,n^2}{d_i^{4/3}}$

Pipe diam. inches	Flow area sq. ft.	MANNING'S COEFFICIENT OF ROUGHNESS "n"															
		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
6	0.196	0.0467	0.0565	0.0672	0.0789	0.0914	0.1050	0.1194	0.1348	0.151	0.168	0.187	0.206	0.226	0.247	0.269	0.292
8	0.349	.0318	.0385	.0458	.0537	.0623	.0715	.0814	.0919	.1030	.1148	.1272	.140	.154	.168	.183	.199
10	0.545	.0236	.0286	.0340	.0399	.0463	.0531	.0604	.0682	.0765	.0852	.0944	.1041	.1143	.1249	.136	.148
12	0.785	.0185	.0224	.0267	.0313	.0363	.0417	.0474	.0535	.0600	.0668	.0741	.0817	.0896	.0980	.1067	.1157
14	1.069	.0151	.0182	.0217	.0255	.0295	.0339	.0386	.0436	.0488	.0544	.0603	.0665	.0730	.0798	.0868	.0942
15	1.23	.0138	.0166	.0198	.0232	.0270	.0309	.0352	.0397	.0446	.0496	.0550	.0606	.0666	.0727	.0792	.0859
16	1.40	.0126	.0153	.0182	.0213	.0247	.0284	.0323	.0365	.0409	.0455	.0505	.0556	.0611	.0667	.0727	.0789
18	1.77	.01078	.0130	.0155	.0182	.0211	.0243	.0276	.0312	.0349	.0389	.0431	.0476	.0522	.0570	.0621	.0674
21	2.41	.00878	.01062	.0126	.0148	.0172	.0198	.0225	.0254	.0284	.0317	.0351	.0387	.0425	.0464	.0506	.0549
24	3.14	.00735	.00889	.01058	.0124	.0144	.0165	.0188	.0212	.0238	.0265	.0294	.0324	.0356	.0389	.0423	.0459
27	3.98	.00628	.00760	.00904	.01061	.0123	.0141	.0161	.0181	.0203	.0227	.0251	.0277	.0304	.0332	.0362	.0393
30	4.91	.00546	.00660	.00786	.00922	.01070	.01228	.0140	.0158	.0177	.0197	.0218	.0241	.0264	.0289	.0314	.0341
36	7.07	.00428	.00518	.00616	.00723	.00839	.00963	.01096	.0124	.0139	.0154	.0171	.0189	.0207	.0226	.0246	.0267
42	9.62	.00348	.00422	.00502	.00589	.00683	.00784	.00892	.01007	.01129	.0126	.0139	.0154	.0169	.0184	.0201	.0218
48	12.57	.00292	.00353	.00420	.00493	.00572	.00656	.00747	.00843	.00945	.01053	.01166	.0129	.0141	.0154	.0168	.0182
54	15.90	.00249	.00302	.00359	.00421	.00488	.00561	.00638	.00720	.00808	.00900	.00997	.01099	.0121	.0132	.0144	.0156
60	19.63	.00217	.00262	.00312	.00366	.00424	.00487	.00554	.00626	.00702	.00782	.00866	.00955	.01048	.0115	.0125	.0135

HEAD LOSS COEFFICIENT, K_c, FOR SQUARE CONDUIT FLOWING FULL $K_c = \frac{29.16\,n^2}{r^{4/3}}$

Conduit Size feet	Flow area sq. ft.	MANNING'S COEFFICIENT OF ROUGHNESS "n"				
		0.012	0.013	0.014	0.015	0.016
2×2	4.00	0.01058	0.01242	0.01440	0.01653	0.01880
2½×2½	6.25	0.00786	0.00922	0.01070	0.01228	0.01397
3×3	9.00	.00616	.00723	.00839	.00963	.01096
3½×3½	12.25	.00502	.00589	.00683	.00784	.00892
4×4	16.00	.00420	.00493	.00572	.00656	.00746
4½×4½	20.25	.00359	.00421	.00488	.00561	.00638
5×5	25.00	.00312	.00366	.00425	.00487	.00554
5½×5½	30.25	.00275	.00322	.00374	.00429	.00488
6×6	36.00	.00245	.00287	.00333	.00382	.00435
6½×6½	42.25	.00220	.00258	.00299	.00343	.00391
7×7	49.00	.00199	.00234	.00271	.00311	.00354
7½×7½	56.25	.00182	.00213	.00247	.00284	.00323
8×8	64.00	.00167	.00196	.00227	.00260	.00296
8½×8½	72.25	.00154	.00180	.00209	.00240	.00273
9×9	81.00	.00142	.00167	.00194	.00223	.00253
9½×9½	90.25	.00133	.00156	.00180	.00207	.00236
10×10	100.00	.00124	.00145	.00168	.00193	.00220

$$H_l = (K_p \text{ or } K_c)\, L\, \frac{v^2}{2g}$$

Nomenclature:

- a = Cross-sectional area of flow in sq. ft.
- d_i = Inside diameter of pipe in inches.
- g = Acceleration of gravity = 32.2 ft. per sec.
- H_l = Loss of head in feet due to friction in length L.
- K_c = Head loss coefficient for square conduit flowing full.
- K_p = Head loss coefficient for circular pipe flowing full.
- L = Length of conduit in feet.
- n = Manning's coefficient of roughness.
- Q = Discharge or capacity in cu. ft. per sec.
- r = Hydraulic radius in feet.
- v = Mean velocity in ft. per sec.

Example 1: Compute the head loss in 300 ft. of 24 in. diam. concrete pipe flowing full and discharging 30 c.f.s. Assume n = 0.015

$$v = \frac{Q}{a} = \frac{30}{3.14} = 9.55 \text{ f.p.s.};\quad \frac{v^2}{2g} = \frac{(9.55)^2}{64.4} = 1.42 \text{ ft.}$$

$$H_l = K_p L \frac{v^2}{2g} = 0.0165 \times 300 \times 1.42 = 7.03 \text{ ft.}$$

Example 2: Compute the discharge of a 250 ft., 3×3 square conduit flowing full if the loss of head is determined to be 2.25 ft. Assume n = 0.014.

$$H_l = K_c L \frac{v^2}{2g};\quad \frac{v^2}{2g} = \frac{H_l}{K_c L} = \frac{2.25}{0.00839 \times 250} = 1.073 \text{ ft.}$$

$$v = \sqrt{64.4 \times 1.073} = 8.31;\quad Q = 9 \times 8.31 = 74.8 \text{ c f s.}$$

REFERENCE

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
H. H. Bennett, Chief
ENGINEERING STANDARDS UNIT

STANDARD DWG. NO. ES-42
SHEET 1 OF 1
DATE 7-17-50

Revised 4-11-51

Exhibit 6-4.2 Head Discharge Table for Annular CMP, Full Pipe Flow Condition

Dia. in Inches		Cubic Feet per Second												K_p	Area Sq. Ft.
		Head on Pipe in Feet													
		6	8	10	12	14	16	18	20	22	24	26	28		
12	Length - 50 feet	5.5	6.4	7.1	7.8	8.4	9.0	9.6	10.1	10.6	11.1	11.5	11.9	0.116	0.785
15		9.6	11.1	12.4	13.6	14.7	15.7	16.7	17.6	18.4	19.3	20.1	20.8	0.086	1.23
18		15.0	17.3	19.4	21.2	22.9	24.5	26.0	27.4	28.8	30.0	31.3	32.4	0.067	1.77
21		21.8	25.1	28.1	30.8	33.2	35.5	37.7	39.7	41.6	43.5	45.3	47.0	0.055	2.41
24		29.8	34.4	38.4	42.1	45.5	48.6	51.6	54.4	57.0	59.6	62.0	64.3	0.046	3.14
30		50.1	57.9	64.7	70.9	76.6	81.9	86.8	91.5	96.0	100	104	108	0.034	4.91
36		76.1	87.8	98.2	108	116	124	132	139	146	152	158	164	0.027	7.07
42		108	124	139	152	164	176	186	196	206	215	224	232	0.022	9.62
48		145	167	187	205	221	236	251	264	277	290	301	313	0.018	12.57

Dia. in Inches		Cubic Feet per Second												K_p	Area Sq. Ft.
		Head on Pipe in Feet													
		6	8	10	12	14	16	18	20	22	24	26	28		
12	Length - 60 feet	5.2	6.0	6.7	7.3	7.9	8.4	8.9	9.4	9.9	10.3	10.7	11.1	0.116	0.785
15		9.0	10.4	11.7	12.8	13.8	14.8	15.7	16.5	17.3	18.1	18.8	19.5	0.086	1.23
18		14.2	16.3	18.3	20.0	21.6	23.1	24.5	25.8	27.1	28.3	29.5	30.6	0.067	1.77
21		20.6	23.8	26.6	29.1	31.5	33.6	35.7	37.6	39.4	41.2	42.9	44.5	0.055	2.41
24		28.3	32.7	36.5	40.0	43.2	46.2	49.0	51.7	54.2	56.6	58.9	61.1	0.046	3.14
30		48.0	55.4	61.9	67.9	73.3	78.4	83.1	87.6	91.9	96.0	99.9	104	0.034	4.91
36		73.2	84.5	94.5	104	112	120	127	134	140	146	152	158	0.027	7.07
42		104	120	134	147	159	170	180	190	199	208	216	225	0.022	9.62
48		140	162	181	199	215	229	243	256	269	281	292	303	0.018	12.57

Dia. in Inches		Cubic Feet per Second												K_p	Area Sq. Ft.
		Head on Pipe in Feet													
		6	8	10	12	14	16	18	20	22	24	26	28		
12	Length - 70 feet	4.9	5.6	6.3	6.9	7.4	7.9	8.4	8.9	9.3	9.7	10.1	10.5	0.116	0.785
15		8.5	9.9	11.0	12.1	13.0	13.9	14.8	15.6	16.4	17.1	17.8	18.4	0.086	1.23
18		13.4	15.5	17.3	19.0	20.5	21.9	23.3	24.5	25.7	26.8	27.9	29.0	0.067	1.77
21		19.6	22.6	25.3	27.7	29.9	32.0	34.0	35.8	37.5	39.2	40.8	42.3	0.055	2.41
24		27.0	31.2	34.9	38.2	41.3	44.1	46.8	49.3	51.8	54.1	56.3	58.4	0.046	3.14
30		46.1	53.2	59.5	65.2	70.4	75.2	79.8	84.1	88.2	92.2	95.9	99.5	0.034	4.91
36		70.6	81.6	91.2	99.9	108	115	122	129	135	141	147	153	0.027	7.07
42		101	116	130	142	154	164	174	184	193	201	210	218	0.022	9.62
48		137	158	176	193	209	223	236	249	261	273	284	295	0.018	12.57

Assume: $n = 0.025$

$K_e + K_b = 1$

$$Q = A\sqrt{\frac{2gh}{1 + K_e + K_b + K_p L}}$$

Exhibit 6-4.2 Head Discharge Table for Annular CMP, Full Pipe Flow Condition

Dia. in Inches		Cubic Feet per Second Head on Pipe in Feet 6	8	10	12	14	16	18	20	22	24	26	28	K_p	Area Sq. Ft.
12	Length - 80 feet	4.6	5.3	5.9	6.5	7.0	7.5	8.0	8.4	8.8	9.2	9.6	9.9	0.116	0.785
15		8.1	9.4	10.5	11.5	12.4	13.3	14.1	14.8	15.5	16.2	16.9	17.5	0.086	1.23
18		12.8	14.8	16.5	18.1	19.5	20.9	22.2	23.4	24.5	25.6	26.6	27.6	0.067	1.77
21		18.7	21.6	24.2	26.5	28.6	30.6	32.5	34.2	35.9	37.5	39.0	40.5	0.055	2.41
24		25.9	29.9	33.5	36.6	39.6	42.3	44.9	47.3	49.6	51.8	53.9	56.0	0.046	3.14
30		44.4	51.3	57.3	62.8	67.8	72.5	76.9	81.0	85.0	88.8	92.4	95.9	0.034	4.91
36		68.3	78.9	88.2	96.6	104	112	118	125	131	137	142	148	0.027	7.07
42		97.8	113	126	138	149	160	169	178	187	196	203	211	0.022	9.62
48		133	153	172	188	203	217	230	243	254	266	277	287	0.018	12.57

Dia. in Inches		Cubic Feet per Second Head on Pipe in Feet 6	8	10	12	14	16	18	20	22	24	26	28	K_p	Area Sq. Ft.
12	Length - 90 feet	4.4	5.1	5.7	6.2	6.7	7.2	7.6	8.0	8.4	8.8	9.1	9.5	0.116	0.785
15		7.7	8.9	10.0	11.0	11.8	12.7	13.4	14.1	14.8	15.5	16.1	16.7	0.086	1.23
18		12.3	14.1	15.8	17.3	18.7	20.0	21.2	22.4	23.5	24.5	25.5	26.5	0.067	1.77
21		18.0	20.8	23.2	25.4	27.5	29.4	31.1	32.8	34.4	36.0	37.4	38.9	0.055	2.41
24		24.9	28.8	32.2	35.2	38.1	40.7	43.2	45.5	47.7	49.8	51.9	53.8	0.046	3.14
30		42.9	49.5	55.3	60.6	65.5	70.0	74.2	78.3	82.1	85.7	89.2	92.6	0.034	4.91
36		66.2	76.4	85.5	93.6	101	108	115	121	127	132	138	143	0.027	7.07
42		95.0	110	123	134	145	155	165	173	182	190	198	205	0.022	9.62
48		130	150	167	183	198	211	224	236	248	259	270	280	0.018	12.57

Dia. in Inches		Cubic Feet per Second Head on Pipe in Feet 6	8	10	12	14	16	18	20	22	24	26	28	K_p	Area Sq. Ft.
12	Length - 100 feet	4.2	4.8	5.4	5.9	6.4	6.8	7.3	7.6	8.0	8.4	8.7	9.0	0.116	0.785
15		7.4	8.6	9.6	10.5	11.3	12.1	12.9	13.6	14.2	14.9	15.5	16.0	0.086	1.23
18		11.8	13.6	15.2	16.6	18.0	19.2	20.4	21.5	22.5	23.5	24.5	25.4	0.067	1.77
21		17.3	20.0	22.4	24.5	26.4	28.3	30.0	31.6	33.2	34.6	36.0	37.4	0.055	2.41
24		24.0	27.8	31.0	34.0	36.7	39.3	41.6	43.9	46.0	48.1	50.0	51.9	0.046	3.14
30		41.5	47.9	53.6	58.7	63.4	67.8	71.9	75.8	79.5	83.0	86.4	89.6	0.034	4.91
36		64.3	74.2	83.0	90.9	98.2	105	111	117	123	129	134	139	0.027	7.07
42		92.5	107	119	131	141	151	160	169	177	185	193	200	0.022	9.62
48		126	146	163	179	193	206	219	231	242	253	263	273	0.018	12.57

Dia. in Inches		Cubic Feet per Second Head on Pipe in Feet 6	8	10	12	14	16	18	20	22	24	26	28	K_p	Area Sq. Ft.
12	Length - 110 feet	4.0	4.6	5.2	5.7	6.1	6.6	7.0	7.3	7.7	8.0	8.4	8.7	0.116	0.785
15		7.1	8.2	9.2	10.1	10.9	11.7	12.4	13.0	13.7	14.3	14.9	15.4	0.086	1.23
18		11.3	13.1	14.6	16.0	17.3	18.5	19.6	20.7	21.7	22.7	23.6	24.5	0.067	1.77
21		16.7	19.3	21.6	23.6	25.5	27.3	28.9	30.5	32.0	33.4	34.8	36.1	0.055	2.41
24		23.2	26.8	30.0	32.9	35.5	38.0	40.3	42.4	44.5	46.5	48.4	50.2	0.046	3.14
30		40.2	46.5	52.0	56.9	61.5	65.7	69.7	73.5	77.1	80.5	83.8	86.9	0.034	4.91
36		62.5	72.2	80.7	88.4	95.5	102	108	114	120	125	130	135	0.027	7.07
42		90.2	104	116	128	138	147	156	165	173	180	188	195	0.022	9.62
48		123	143	159	175	189	202	214	225	236	247	257	267	0.018	12.57

Exhibit 6-4.3 Head Discharge Table for Helical CMP, Full Pipe Flow Condition

Dia. in Inches		Cubic Feet per Second												K_p	Area Sq. Ft.
		Head on Pipe in Feet													
		6	8	10	12	14	16	18	20	22	24	26	28		
12	Length - 50 feet	5.9	6.8	7.6	8.3	9.0	9.6	10.2	10.7	11.3	11.8	12.2	12.7	0.098	0.785
15		10.2	11.8	13.1	14.4	15.6	16.6	17.6	18.6	19.5	20.4	21.2	22.0	0.073	1.23
18		15.8	18.2	20.4	22.3	24.1	25.8	27.4	28.8	30.2	31.6	32.9	34.1	0.057	1.77
21		22.8	26.3	29.4	32.2	34.8	37.2	39.5	41.6	43.6	45.6	47.4	49.2	0.046	2.41
24		31.1	35.9	40.1	44.0	47.5	50.8	53.8	56.7	59.5	62.2	64.7	67.1	0.039	3.14
30		52.0	60.1	67.1	73.6	79.4	84.9	90.1	95.0	99.6	104	108	112	0.029	4.91
36		78.5	90.7	101.4	111	120	128	136	143	150	157	163	170	0.023	7.07
42		111	128	143	156	169	181	192	202	212	221	230	239	0.018	9.62
48		148	171	192	210	227	242	257	271	284	297	309	321	0.015	12.57

Dia. in Inches		Cubic Feet per Second												K_p	Area Sq. Ft.
		Head on Pipe in Feet													
		6	8	10	12	14	16	18	20	22	24	26	28		
12	Length - 60 feet	5.5	6.3	7.1	7.8	8.4	9.0	9.5	10.0	10.5	11.0	11.4	11.9	0.098	0.785
15		9.6	11.1	12.4	13.6	14.6	15.7	16.6	17.5	18.4	19.2	20.0	20.7	0.073	1.23
18		14.9	17.3	19.3	21.1	22.8	24.4	25.9	27.3	28.6	29.9	31.1	32.3	0.057	1.77
21		21.7	25.0	28.0	30.6	33.1	35.4	37.5	39.5	41.5	43.3	45.1	46.8	0.046	2.41
24		29.7	34.2	38.3	41.9	45.3	48.4	51.4	54.1	56.8	59.3	61.7	64.1	0.039	3.14
30		50.0	57.7	64.5	70.7	76.3	81.6	86.5	91.2	95.7	99.9	104.0	108	0.029	4.91
36		75.8	87.6	97.9	107	116	124	131	138	145	152	158	164	0.023	7.07
42		107	124	139	152	164	175	186	196	205	215	223	232	0.018	9.62
48		144	167	186	204	221	236	250	264	277	289	301	312	0.015	12.57

Dia. in Inches		Cubic Feet per Second												K_p	Area Sq. Ft.
		Head on Pipe in Feet													
		6	8	10	12	14	16	18	20	22	24	26	28		
12	Length - 70 feet	5.2	6.0	6.7	7.3	7.9	8.5	9.0	9.5	9.9	10.4	10.8	11.2	0.098	0.785
15		9.1	10.5	11.7	12.8	13.9	14.8	15.7	16.6	17.4	18.2	18.9	19.6	0.073	1.23
18		14.2	16.4	18.3	20.1	21.7	23.2	24.6	25.9	27.2	28.4	29.6	30.7	0.057	1.77
21		20.7	23.9	26.7	29.2	31.6	33.8	35.8	37.7	39.6	41.3	43.0	44.7	0.046	2.41
24		28.4	32.8	36.7	40.2	43.4	46.4	49.2	51.9	54.4	56.8	59.1	61.4	0.039	3.14
30		48.1	55.6	62.1	68.1	73.5	78.6	83.4	87.9	92.2	96.3	100.2	104.0	0.029	4.91
36		73.4	84.8	94.8	103.8	112	120	127	134	141	147	153	159	0.023	7.07
42		104	120	135	147	159	170	181	190	200	209	217	225	0.018	9.62
48		141	163	182	199	215	230	244	257	270	282	293	304	0.015	12.57

Assume: n = 0.023

$K_e + K_b = 1$

$$Q = A\sqrt{\frac{2gh}{1 + K_e + K_b + K_p L}}$$

Exhibit 6-4.3 (Cont) Head Discharge Table for Helical CMP, Full Pipe Flow Condition

Dia. in Inches		Cubic Feet per Second Head on Pipe in Feet 6	8	10	12	14	16	18	20	22	24	26	28	K_p	Area Sq. Ft.
12	Length - 80 feet	4.9	5.7	6.4	7.0	7.5	8.0	8.5	9.0	9.4	9.8	10.2	10.6	0.098	0.785
15		8.6	10.0	11.2	12.2	13.2	14.1	15.0	15.8	16.6	17.3	18.0	18.7	0.073	1.23
18		13.6	15.7	17.5	19.2	20.7	22.2	23.5	24.8	26.0	27.2	28.3	29.3	0.057	1.77
21		19.8	22.9	25.6	28.0	30.3	32.4	34.3	36.2	37.9	39.6	41.2	42.8	0.046	2.41
24		27.3	31.5	35.3	38.6	41.7	44.6	47.3	49.9	52.3	54.6	56.8	59.0	0.039	3.14
30		46.5	53.7	60.0	65.8	71.0	75.9	80.5	84.9	89.0	93.0	96.8	100.4	0.029	4.91
36		71.2	82.2	91.9	100.7	109	116	123	130	136	142	148	154	0.023	7.07
42		101.4	117	131	143	155	166	176	185	194	203	211	219	0.018	9.62
48		137	159	177	194	210	224	238	251	263	275	286	297	0.015	12.57

Dia. in Inches		Cubic Feet per Second Head on Pipe in Feet 6	8	10	12	14	16	18	20	22	24	26	28	K_p	Area Sq. Ft.
12	Length - 90 feet	4.7	5.4	6.1	6.6	7.2	7.7	8.1	8.6	9.0	9.4	9.8	10.1	0.098	0.785
15		8.3	9.5	10.7	11.7	12.6	13.5	14.3	15.1	15.8	16.5	17.2	17.9	0.073	1.23
18		13.0	15.0	16.8	18.4	19.9	21.3	22.6	23.8	24.9	26.1	27.1	28.1	0.057	1.77
21		19.1	22.0	24.6	26.9	29.1	31.1	33.0	34.8	36.5	38.1	39.7	41.2	0.046	2.41
24		26.3	30.4	34.0	37.2	40.2	43.0	45.6	48.1	50.4	52.6	54.8	56.9	0.039	3.14
30		45.0	52.0	58.1	63.7	68.8	73.5	78.0	82.2	86.2	90.0	93.7	97.2	0.029	4.91
36		69.2	79.9	89.3	97.8	106	113	120	126	132	138	144	149	0.023	7.07
42		98.9	114	128	140	151	161	171	180	189	198	206	214	0.018	9.62
48		134	155	173	190	205	219	232	245	257	268	279	290	0.015	12.57

Dia. in Inches		Cubic Feet per Second Head on Pipe in Feet 6	8	10	12	14	16	18	20	22	24	26	28	K_p	Area Sq. Ft.
12	Length - 100 feet	4.5	5.2	5.8	6.4	6.9	7.3	7.8	8.2	8.6	9.0	9.4	9.7	0.098	0.785
15		7.9	9.2	10.2	11.2	12.1	13.0	13.8	14.5	15.2	15.9	16.5	17.2	0.073	1.23
18		12.5	14.5	16.2	17.7	19.1	20.5	21.7	22.9	24.0	25.1	26.1	27.1	0.057	1.77
21		18.4	21.2	23.7	26.0	28.1	30.0	31.8	33.6	35.2	36.8	38.3	39.7	0.046	2.41
24		25.4	29.4	32.8	36.0	38.9	41.5	44.1	46.4	48.7	50.9	53.0	55.0	0.039	3.14
30		43.7	50.4	56.4	61.7	66.7	71.3	75.6	79.7	83.6	87.3	90.9	94.3	0.029	4.91
36		67.3	77.7	86.9	95.2	102.8	110	117	123	129	135	140	145	0.023	7.07
42		96.5	111	125	136	147	158	167	176	185	193	201	208	0.018	9.62
48		131	152	169	186	201	214	227	240	251	263	273	284	0.015	12.57

Dia. in Inches		Cubic Feet per Second Head on Pipe in Feet 6	8	10	12	14	16	18	20	22	24	26	28	K_p	Area Sq. Ft.
12	Length - 110 feet	4.3	5.0	5.6	6.1	6.6	7.1	7.5	7.9	8.3	8.6	9.0	9.3	0.098	0.785
15		7.6	8.8	9.9	10.8	11.7	12.5	13.2	14.0	14.6	15.3	15.9	16.5	0.073	1.23
18		12.1	14.0	15.6	17.1	18.5	19.8	20.9	22.1	23.2	24.2	25.2	26.1	0.057	1.77
21		17.8	20.5	22.9	25.1	27.1	29.0	30.8	32.4	34.0	35.5	37.0	38.4	0.046	2.41
24		24.6	28.4	31.8	34.8	37.6	40.2	42.7	45.0	47.2	49.3	51.3	53.2	0.039	3.14
30		42.4	49.0	54.8	60.0	64.8	69.3	73.5	77.5	81.2	84.9	88.3	91.6	0.029	4.91
36		65.6	75.7	84.7	92.8	100.2	107	114	120	126	131	137	142	0.023	7.07
42		94.2	109	122	133	144	154	163	172	180	188	196	204	0.018	9.62
48		129	148	166	182	196	210	223	235	246	257	268	278	0.015	12.57

Exhibit 6-4.4 Head Discharge Table for Welded Steel Pipe, Full Pipe Flow Condition

Dia. in Inches		Cubic Feet per Second												K_p	Area Sq. Ft.
		Head on Pipe in Feet													
		6	8	10	12	14	16	18	20	22	24	26	28		
12	Length - 50 feet	9.0	10.4	11.6	12.8	13.8	14.7	15.6	16.5	17.3	18.0	18.8	19.5	0.019	0.785
15		14.7	17.0	19.0	20.9	22.5	24.1	25.5	26.9	28.2	29.5	30.7	31.9	0.014	1.23
18		21.8	25.2	28.2	30.9	33.4	35.7	37.8	39.9	41.8	43.7	45.5	47.2	0.011	1.77
21		30.3	35.0	39.2	42.9	46.3	49.5	52.5	55.4	58.1	60.7	63.1	65.5	0.009	2.41
24		40.1	46.3	51.8	56.7	61.3	65.5	69.5	73.2	76.8	80.2	83.5	86.7	0.007	3.14
30		64.0	73.9	82.6	90.5	97.8	104.5	110.9	116.9	122.6	128	133	138	0.005	4.91
36		93.4	107.9	120.6	132	143	153	162	171	179	187	194	202	0.004	7.07
42		128	148	166	181	196	209	222	234	246	256	267	277	0.003	9.62
48		169	195	218	239	258	275	292	308	323	337	351	364	0.003	12.57

Dia. in Inches		Cubic Feet per Second												K_p	Area Sq. Ft.
		Head on Pipe in Feet													
		6	8	10	12	14	16	18	20	22	24	26	28		
12	Length - 60 feet	8.7	10.1	11.3	12.4	13.4	14.3	15.2	16.0	16.8	17.5	18.2	18.9	0.019	0.785
15		14.4	16.6	18.6	20.3	22.0	23.5	24.9	26.3	27.5	28.8	29.9	31.1	0.014	1.23
18		21.4	24.7	27.6	30.2	32.7	34.9	37.0	39.0	40.9	42.8	44.5	46.2	0.011	1.77
21		29.8	34.4	38.5	42.1	45.5	48.7	51.6	54.4	57.1	59.6	62.0	64.4	0.009	2.41
24		39.5	45.6	51.0	55.9	60.3	64.5	68.4	72.1	75.7	79.0	82.2	85.3	0.007	3.14
30		63.3	73.1	81.7	89.5	96.6	103.3	109.6	115.5	121.1	126.5	131.7	137	0.005	4.91
36		92.5	106.8	119.4	131	141	151	160	169	177	185	193	200	0.004	7.07
42		127	147	164	180	194	208	220	232	244	254	265	275	0.003	9.62
48		168	193	216	237	256	274	290	306	321	335	349	362	0.003	12.57

Dia. in Inches		Cubic Feet per Second												K_p	Area Sq. Ft.
		Head on Pipe in Feet													
		6	8	10	12	14	16	18	20	22	24	26	28		
12	Length - 70 feet	8.5	9.8	11.0	12.0	13.0	13.9	14.7	15.5	16.3	17.0	17.7	18.4	0.019	0.785
15		14.0	16.2	18.1	19.9	21.5	22.9	24.3	25.6	26.9	28.1	29.2	30.3	0.014	1.23
18		21.0	24.2	27.1	29.6	32.0	34.2	36.3	38.3	40.1	41.9	43.6	45.3	0.011	1.77
21		29.3	33.8	37.8	41.4	44.8	47.8	50.7	53.5	56.1	58.6	61.0	63.3	0.009	2.41
24		38.9	44.9	50.3	55.0	59.5	63.6	67.4	71.1	74.5	77.9	81.0	84.1	0.007	3.14
30		62.5	72.2	80.7	88.4	95.5	102.1	108.3	114.2	119.7	125.1	130.2	135.1	0.005	4.91
36		91.6	105.8	118.3	129.6	140	150	159	167	175	183	191	198	0.004	7.07
42		126	146	163	179	193	206	219	230	242	252	263	273	0.003	9.62
48		166	192	215	235	254	272	288	304	319	333	346	360	0.003	12.57

Assume: $n = 0.010$

$K_e + K_b = 1$

$$Q = A\sqrt{\frac{2gh}{1 + K_e + K_b + K_p L}}$$

Exhibit 6-4.4 (Cont) Head Discharge Table for Welded Steel Pipe, Full Pipe Flow Condition

Dia. in Inches		Cubic Feet per Second Head on Pipe in Feet 6	8	10	12	14	16	18	20	22	24	26	28	K_p	Area Sq. Ft.
12	Length - 80 feet	8.3	9.5	10.7	11.7	12.6	13.5	14.3	15.1	15.8	16.5	17.2	17.9	0.019	0.785
15		13.7	15.9	17.7	19.4	21.0	22.4	23.8	25.1	26.3	27.5	28.6	29.7	0.014	1.23
18		20.6	23.7	26.5	29.1	31.4	33.6	35.6	37.5	39.4	41.1	42.8	44.4	0.011	1.77
21		28.8	33.3	37.2	40.8	44.0	47.1	49.9	52.6	55.2	57.6	60.0	62.3	0.009	2.41
24		38.4	44.3	49.5	54.3	58.6	62.7	66.5	70.1	73.5	76.7	79.9	82.9	0.007	3.14
30		61.8	71.4	79.8	87.4	94.4	101.0	107.1	112.9	118.4	123.7	128.7	133.6	0.005	4.91
36		90.8	104.9	117.2	128.4	139	148	157	166	174	182	189	196	0.004	7.07
42		125.3	145	162	177	191	205	217	229	240	251	261	271	0.003	9.62
48		165	191	213	234	253	270	286	302	317	331	344	357	0.003	12.57

Dia. in Inches		Cubic Feet per Second Head on Pipe in Feet 6	8	10	12	14	16	18	20	22	24	26	28	K_p	Area Sq. Ft.
12	Length - 90 feet	8.1	9.3	10.4	11.4	12.3	13.2	14.0	14.7	15.4	16.1	16.8	17.4	0.019	0.785
15		13.4	15.5	17.3	19.0	20.5	21.9	23.3	24.5	25.7	26.9	28.0	29.0	0.014	1.23
18		20.2	23.3	26.1	28.5	30.8	33.0	35.0	36.9	38.7	40.4	42.0	43.6	0.011	1.77
21		28.4	32.7	36.6	40.1	43.3	46.3	49.1	51.8	54.3	56.7	59.0	61.3	0.009	2.41
24		37.8	43.7	48.8	53.5	57.8	61.8	65.5	69.1	72.4	75.7	78.8	81.7	0.007	3.14
30		61.2	70.6	78.9	86.5	93.4	99.9	105.9	111.6	117.1	122.3	127.3	132.1	0.005	4.91
36		90.0	103.9	116.2	127.3	137	147	156	164	172	180	187	194	0.004	7.07
42		124.3	144	160	176	190	203	215	227	238	249	259	269	0.003	9.62
48		164	190	212	232	251	268	285	300	315	329	342	355	0.003	12.57

Dia. in Inches		Cubic Feet per Second Head on Pipe in Feet 6	8	10	12	14	16	18	20	22	24	26	28	K_p	Area Sq. Ft.
12	Length - 100 feet	7.9	9.1	10.2	11.1	12.0	12.8	13.6	14.4	15.1	15.7	16.4	17.0	0.019	0.785
15		13.2	15.2	17.0	18.6	20.1	21.5	22.8	24.0	25.2	26.3	27.4	28.4	0.014	1.23
18		19.8	22.9	25.6	28.0	30.3	32.4	34.3	36.2	38.0	39.7	41.3	42.8	0.011	1.77
21		27.9	32.2	36.1	39.5	42.7	45.6	48.4	51.0	53.5	55.8	58.1	60.3	0.009	2.41
24		37.3	43.1	48.2	52.8	57.0	60.9	64.6	68.1	71.5	74.6	77.7	80.6	0.007	3.14
30		60.5	69.8	78.1	85.5	92.4	98.8	104.8	110.4	115.8	121.0	125.9	130.7	0.005	4.91
36		89.2	103.0	115.1	126.1	136.2	146	154	163	171	178	186	193	0.004	7.07
42		123.4	142	159	175	188	202	214	225	236	247	257	267	0.003	9.62
48		163	188	211	231	249	267	283	298	313	326	340	353	0.003	12.57

Dia. in Inches		Cubic Feet per Second Head on Pipe in Feet 6	8	10	12	14	16	18	20	22	24	26	28	K_p	Area Sq. Ft.
12	Length - 110 feet	7.7	8.9	9.9	10.9	11.7	12.5	13.3	14.0	14.7	15.4	16.0	16.6	0.019	0.785
15		12.9	14.9	16.7	18.2	19.7	21.1	22.3	23.6	24.7	25.8	26.9	27.9	0.014	1.23
18		19.5	22.5	25.2	27.6	29.8	31.8	33.8	35.6	37.3	39.0	40.6	42.1	0.011	1.77
21		27.5	31.8	35.5	38.9	42.0	44.9	47.6	50.2	52.7	55.0	57.3	59.4	0.009	2.41
24		36.8	42.5	47.6	52.1	56.3	60.1	63.8	67.2	70.5	73.7	76.7	79.6	0.007	3.14
30		59.9	69.1	77.3	84.6	91.4	97.7	103.7	109.3	114.6	119.7	124.6	129.3	0.005	4.91
36		88.4	102.1	114.1	125.0	135.1	144	153	161	169	177	184	191	0.004	7.07
42		122.5	141	158	173	187	200	212	224	235	245	255	265	0.003	9.62
48		162	187	209	229	248	265	281	296	311	324	338	350	0.003	12.57

Exhibit 6-4.5 Head Discharge Table for RCP, Full Pipe Flow Condition

Dia. in Inches		Cubic Feet per Second Head on Pipe in Feet 6	8	10	12	14	16	18	20	22	24	26	28	K_p	Area Sq. Ft.
12	Length - 50 feet	8.2	9.4	10.6	11.6	12.5	13.3	14.2	14.9	15.7	16.3	17.0	17.7	0.031	0.785
15		13.6	15.7	17.6	19.2	20.8	22.2	23.6	24.8	26.0	27.2	28.3	29.4	0.023	1.23
18		20.4	23.5	26.3	28.8	31.1	33.3	35.3	37.2	39.0	40.8	42.4	44.1	0.018	1.77
21		28.6	33.0	36.9	40.5	43.7	46.7	49.6	52.2	54.8	57.2	59.6	61.8	0.015	2.41
24		38.1	44.0	49.2	53.9	58.2	62.3	66.0	69.6	73.0	76.3	79.4	82.4	0.012	3.14
30		61.5	71.0	79.4	87.0	94.0	100.5	106.6	112.3	117.8	123	128	133	0.009	4.91
36		90.4	104.4	116.8	128	138	148	157	165	173	181	188	195	0.007	7.07
42		125	144	161	177	191	204	216	228	239	250	260	270	0.006	9.62
48		165	190	213	233	252	269	286	301	316	330	343	356	0.005	12.57

Dia. in Inches		Cubic Feet per Second Head on Pipe in Feet 6	8	10	12	14	16	18	20	22	24	26	28	K_p	Area Sq. Ft.
12	Length - 60 feet	7.8	9.0	10.1	11.1	12.0	12.8	13.6	14.3	15.0	15.7	16.3	16.9	0.031	0.785
15		13.1	15.2	16.9	18.6	20.0	21.4	22.7	24.0	25.1	26.2	27.3	28.3	0.023	1.23
18		19.8	22.8	25.5	28.0	30.2	32.3	34.3	36.1	37.9	39.6	41.2	42.7	0.018	1.77
21		27.9	32.2	36.0	39.4	42.6	45.5	48.3	50.9	53.4	55.7	58.0	60.2	0.015	2.41
24		37.3	43.0	48.1	52.7	56.9	60.8	64.5	68.0	71.3	74.5	77.5	80.5	0.012	3.14
30		60.4	69.7	78.0	85.4	92.3	98.6	104.6	110.3	115.7	120.8	125.7	130	0.009	4.91
36		89.1	102.9	115.0	126	136	145	154	163	171	178	185	192	0.007	7.07
42		123	142	159	174	188	201	214	225	236	247	257	266	0.006	9.62
48		163	188	211	231	249	266	282	298	312	326	339	352	0.005	12.57

Dia. in Inches		Cubic Feet per Second Head on Pipe in Feet 6	8	10	12	14	16	18	20	22	24	26	28	K_p	Area Sq. Ft.
12	Length - 70 feet	7.5	8.7	9.7	10.7	11.5	12.3	13.1	13.8	14.4	15.1	15.7	16.3	0.031	0.785
15		12.7	14.7	16.4	18.0	19.4	20.7	22.0	23.2	24.3	25.4	26.4	27.4	0.023	1.23
18		19.2	22.2	24.8	27.2	29.4	31.4	33.3	35.1	36.8	38.4	40.0	41.5	0.018	1.77
21		27.2	31.4	35.1	38.4	41.5	44.4	47.1	49.6	52.0	54.4	56.6	58.7	0.015	2.41
24		36.4	42.1	47.0	51.5	55.7	59.5	63.1	66.5	69.8	72.9	75.9	78.7	0.012	3.14
30		59.3	68.5	76.6	83.9	90.6	96.9	102.8	108.3	113.6	118.7	123.5	128.2	0.009	4.91
36		87.8	101.4	113.3	124.1	134	143	152	160	168	176	183	190	0.007	7.07
42		122	141	157	172	186	199	211	222	233	244	253	263	0.006	9.62
48		161	186	208	228	246	263	279	295	309	323	336	349	0.005	12.57

Assume: $n = 0.013$
$K_e + K_b = 1$

$$Q = A\sqrt{\frac{2gh}{1 + K_e + K_b + K_p L}}$$

Exhibit 6-4.5 (Cont) Head Discharge Table for RCP, Full Pipe Flow Condition

Dia. in Inches		Cubic Feet per Second												K_p	Area Sq. Ft.
		Head on Pipe in Feet													
		6	8	10	12	14	16	18	20	22	24	26	28		
12	Length - 80 feet	7.3	8.4	9.4	10.3	11.1	11.9	12.6	13.3	13.9	14.5	15.1	15.7	0.031	0.785
15		12.3	14.2	15.9	17.4	18.8	20.1	21.3	22.5	23.6	24.6	25.6	26.6	0.023	1.23
18		18.7	21.6	24.2	26.5	28.6	30.6	32.4	34.2	35.8	37.4	38.9	40.4	0.018	1.77
21		26.5	30.6	34.3	37.5	40.5	43.3	46.0	48.4	50.8	53.1	55.2	57.3	0.015	2.41
24		35.7	41.2	46.1	50.5	54.5	58.3	61.8	65.1	68.3	71.3	74.3	77.1	0.012	3.14
30		58.3	67.4	75.3	82.5	89.1	95.3	101.0	106.5	111.7	116.7	121.4	126.0	0.009	4.91
36		86.5	99.9	111.7	122.4	132	141	150	158	166	173	180	187	0.007	7.07
42		120.3	139	155	170	184	196	208	220	230	241	250	260	0.006	9.62
48		160	184	206	226	244	261	277	292	306	319	332	345	0.005	12.57

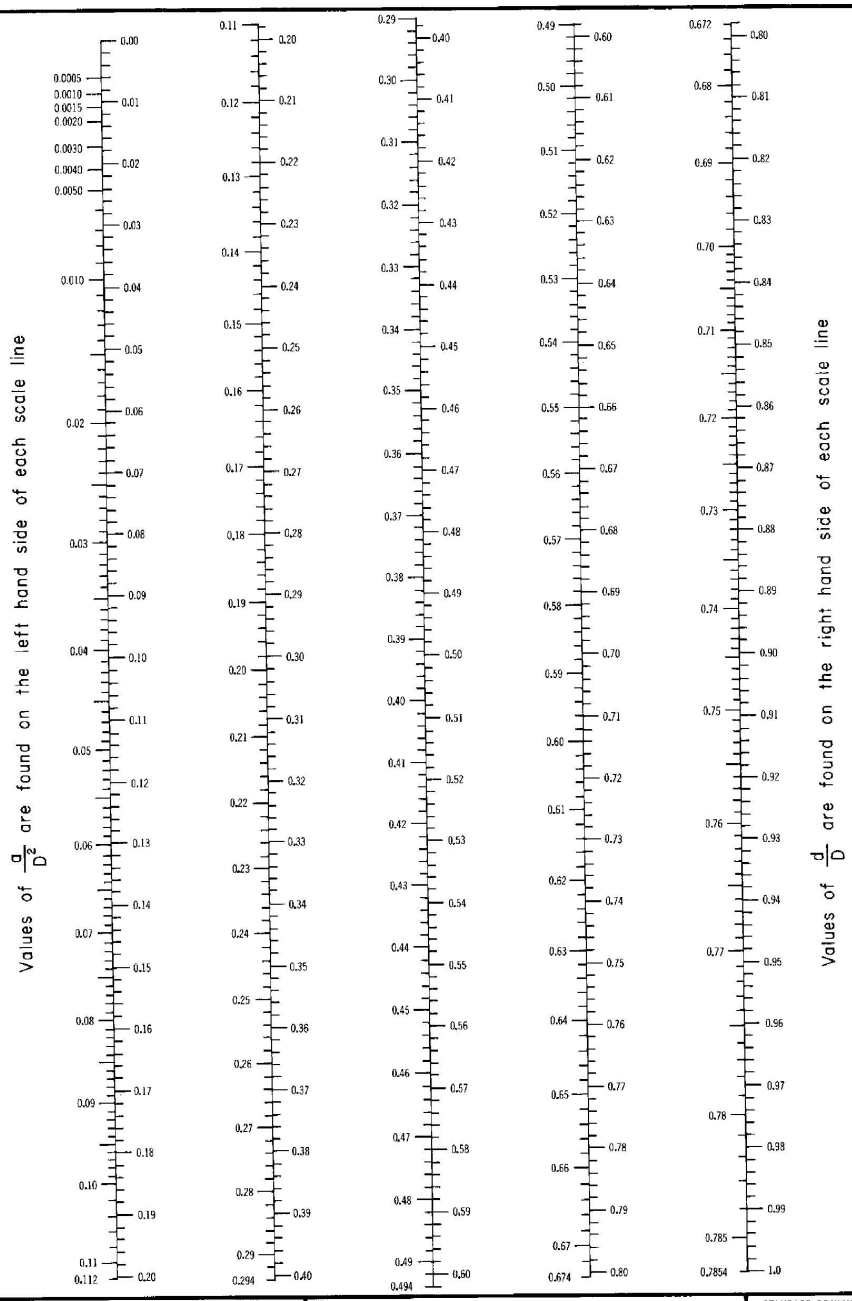
Dia. in Inches		Cubic Feet per Second												K_p	Area Sq. Ft.
		Head on Pipe in Feet													
		6	8	10	12	14	16	18	20	22	24	26	28		
12	Length - 90 feet	7.0	8.1	9.1	9.9	10.7	11.5	12.2	12.8	13.5	14.1	14.6	15.2	0.031	0.785
15		12.0	13.8	15.4	16.9	18.3	19.5	20.7	21.8	22.9	23.9	24.9	25.8	0.023	1.23
18		18.2	21.1	23.5	25.8	27.9	29.8	31.6	33.3	34.9	36.5	38.0	39.4	0.018	1.77
21		25.9	30.0	33.5	36.7	39.6	42.4	44.9	47.4	49.7	51.9	54.0	56.0	0.015	2.41
24		35.0	40.4	45.1	49.4	53.4	57.1	60.5	63.8	66.9	69.9	72.8	75.5	0.012	3.14
30		57.4	66.2	74.1	81.1	87.6	93.7	99.4	104.7	109.9	114.7	119.4	123.9	0.009	4.91
36		85.4	98.6	110.2	120.7	130	139	148	156	163	171	178	184	0.007	7.07
42		118.9	137	153	168	182	194	206	217	228	238	247	257	0.006	9.62
48		158	183	204	224	241	258	274	289	303	316	329	341	0.005	12.57

Dia. in Inches		Cubic Feet per Second												K_p	Area Sq. Ft.
		Head on Pipe in Feet													
		6	8	10	12	14	16	18	20	22	24	26	28		
12	Length - 100 feet	6.8	7.9	8.8	9.6	10.4	11.1	11.8	12.4	13.0	13.6	14.2	14.7	0.031	0.785
15		11.6	13.4	15.0	16.4	17.8	19.0	20.1	21.2	22.3	23.3	24.2	25.1	0.023	1.23
18		17.8	20.5	23.0	25.2	27.2	29.1	30.8	32.5	34.1	35.6	37.0	38.4	0.018	1.77
21		25.4	29.3	32.8	35.9	38.8	41.4	44.0	46.3	48.6	50.8	52.8	54.8	0.015	2.41
24		34.3	39.6	44.3	48.5	52.4	56.0	59.4	62.6	65.6	68.6	71.4	74.1	0.012	3.14
30		56.5	65.2	72.9	79.8	86.2	92.2	97.8	103.1	108.1	112.9	117.5	122.0	0.009	4.91
36		84.2	97.2	108.7	119.1	128.6	138	146	154	161	168	175	182	0.007	7.07
42		117.5	136	152	166	180	192	204	215	225	235	245	254	0.006	9.62
48		156	181	202	221	239	256	271	286	300	313	326	338	0.005	12.57

Dia. in Inches		Cubic Feet per Second												K_p	Area Sq. Ft.
		Head on Pipe in Feet													
		6	8	10	12	14	16	18	20	22	24	26	28		
12	Length - 110 feet	6.6	7.6	8.5	9.4	10.1	10.8	11.5	12.1	12.7	13.2	13.8	14.3	0.031	0.785
15		11.3	13.1	14.6	16.0	17.3	18.5	19.6	20.7	21.7	22.7	23.6	24.5	0.023	1.23
18		17.4	20.1	22.4	24.6	26.6	28.4	30.1	31.7	33.3	34.8	36.2	37.6	0.018	1.77
21		24.9	28.7	32.1	35.2	38.0	40.6	43.1	45.4	47.6	49.7	51.7	53.7	0.015	2.41
24		33.6	38.8	43.4	47.6	51.4	54.9	58.3	61.4	64.4	67.3	70.0	72.7	0.012	3.14
30		55.6	64.2	71.8	78.6	84.9	90.8	96.3	101.5	106.4	111.2	115.7	120.1	0.009	4.91
36		83.1	96.0	107.3	117.5	127.0	136	144	152	159	166	173	180	0.007	7.07
42		116.2	134	150	164	178	190	201	212	223	232	242	251	0.006	9.62
48		155	179	200	219	237	253	268	283	297	310	323	335	0.005	12.57

Exhibit 6-4.6 NEH Section 5, ES-97 Hydraulics: Flow Area in Circular Conduits for Various Depths of Flow

HYDRAULICS: FLOW AREAS (a—ft^2) IN CIRCULAR CONDUITS FOR VARIOUS DEPTHS OF FLOW (d—feet)



REFERENCE
This drawing was prepared by Richard M. Matthews of the Design Section.

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