CHAPTER 3. OPEN CHANNELS

3.1 Selection of Shape

In general, open channels are not permitted by the City of Newark. If site conditions are such that open channels would be beneficial, the City Engineer must be notified. In no case will open channels be allowed without prior permission from the City Engineer.

Open channels are usually designed with sections of regular geometric shapes. The trapezoid is the most common shape for channels with unlined earth banks, because it provides side slopes for stability. The rectangle and triangle are special cases of the trapezoid. Since the rectangle has vertical sides, it is commonly used for channels built of stable materials, such as lined masonry, rocks, metal, or timber. The triangular section is used only for small ditches and roadside gutters.

3.2 Design Criteria

3.2.1 Design Storm

Roadside ditches shall be designed for the 10-year storm. All other open channels, except major channels as defined herein, shall be designed for the 25-year storm. Major channels shall be designed for the 100-year storm. Major channels are the following streams: Licking River, South Fork Licking River, North Fork Licking River, Log Pond Run, and Raccoon Creek.

Final design shall indicate water surface elevations for the design storm. In addition, the 100-year flood profile and 100-year flood area shall be shown for all open channels.

3.2.2 Bankful Depth of Flow

For subcritical flow, the bankful depth shall be equal to or greater than the design flow depth. For supercritical flow design, the channel shall be sized so that the bankful depth is equal to or greater than the critical depth for the design flow. A primary criterion for determining which state of flow exists is the depth of flow. If the flow depth (actual or as computed with the Manning equation) is deeper than the critical depth for the given discharge and channel shape, then subcritical flow exists. If the flow depth is less than critical depth, then supercritical flow exists. If the flow depth equals the critical depth, then critical flow exists. The depth of flow (discharge computation on open channel worksheet) shall be computed for the 100-year frequency storm for all open channels except roadside ditches and major channels.

3.2.3 Channel Linings

For channels with subcritical flow, channel bottoms shall be sodded and channel side slopes which are flatter than 3:1 may be sodded or seeded. The City recommends using side slopes of 3:1 before a steeper side slope is used. The open channel shall be reviewed and approved by the City Engineer. Channel side slopes between 3:1 and 2:1 shall be sodded. Channel side slopes of 2:1 or steeper shall be lined with concrete, riprap, gabions, brick, asphalt, or other erosion-resistant lining. For channels with supercritical flow, the bottom and sides of the channel shall be concrete lined.

3.2.4 Minimum Bottom Slope

The recommended minimum channel bottom slope shall be 0.50 percent for paved or lined channels and 1.00 percent for grass or sod lined channels.

3.3 Design for Steady Uniform Flow

To calculate steady uniform flow in an open channel, the mean velocity (V) can be calculated by the Manning equation: $V = (1.49\ r^{2/3}\ S^{1/2})/(n)$, where V is the mean velocity in fps, n is Manning's coefficient of roughness, S is the slope of the channel in feet per foot, and r is the hydraulic radius of the channel in feet. The hydraulic radius is calculated as a cross sectional area divided by wp, the wetted perimeter.

The discharge (Q) is then calculated: $Q = VA$, where Q is the discharge in cfs, V is the mean velocity in fps, and A is the cross section area of flow in square feet.

General formulas for determining elements for various channel shapes are given in Exhibit III-1 (page 3-7).

3.3.1 Flow Depth and Velocity

To calculate flow depth and velocity using Manning Formula, Table 3-1 of area times the two-thirds power of the hydraulic radius for various trapezoidal channels is helpful. The usefulness is apparent when the Manning Formula is rearranged to: $Ar^{2/3} = (nQ)/(1.49\ \ S^{1/2})$

Knowing the discharge Q, Manning's coefficient of roughness n, and the channel slope S, $Ar^{2/3}$ can be easily computed. Then, by looking in Table 3-1, a channel can be chosen. It can be seen by the table that any channel can meet the design flow, but at different depths of flow. The table is a quick method to determine if a particular trapezoidal channel will flow at a desirable depth.

3.3.2 Coefficient of Roughness (n)

The computed discharge for any given channel will only be as reliable as the estimated value of n used in making the computation. The type of channel, degree of maintenance, seasonal requirements, season of year design storm occurs, and other considerations should be studied and evaluated before selecting the value of n. In Exhibit III-2 (page 3-8), values for n have been tabulated to help the designer choose an appropriate value.

Because of the erosion effects velocity has on the channel, the following is a general guide to determine when and what type of channel linings are required: for velocity below 2.5 fps, no special requirements; for velocity between 2.5 and 4.0 fps, seeded or sodded channels; and for velocity greater than 4.0 fps, special channel protection materials.

3.3.3 Summary of Design Procedures

The following summarizes general procedures for the design of open channels using the formatted form T3-1 (page 3-10).

Step 1. Fill in frequency, Q, n, S, and V_{max} in columns 1, 2, 3, 4, and 12.

Step 2. Quantify value of $Ar^{2/3}$ for Discharge (Q) and Velocity (V), column 5: $Ar^{2/3} = (nQ)/(1.49\ S^{1/2})$

Step 3. Calculate minimum area of channel (A_{min}) column 6 that will flow within limit set by V_{max} . A_{min} = Q (column 2)/V_{max} (column 12).

Step 4. Using Table 3-1, select channel configuration of bottom width = b (column 7) and side slope = c (column 7).

Step 5. Find d_f (column 8) by interpolating from Table 3-1, using either $Ar^{2/3}$ (column 5) or A_{min} (column 6), whichever gives the larger d_f.

Step 6. Calculate channel flow area A (column 9) from equation given on Exhibit III-1 (page 3-7).

Step 7. Calculate top width of flow T (column 10) using equation from Exhibit III-1 (page 3-7).

Step 8. Calculate channel velocity V (column 11) from area derived in Step 6 and discharge by V = Q/A. Check that this channel velocity (column 11) does not exceed maximum permissible velocity (column 12). If V (column 11) $\leq V_{max}$ (column 12), continue; if not, choose a different n or S and restart at Step 1, or choose a different channel cross-section and restart at Step 4.

Step 9. Calculate Z for critical flow $Z = Q/\ g^{1/2}$ (column 13).

Step 10. Calculate $Z/b^{2.5}$ (column 14).

Step 11. Using Exhibit III-3 (page 3-9), find d_c/b (column 15).

Step 12. Multiply d_c/b x b to get d_c (column 16).

Step 13. Using d_c, calculate V_c, (column 17), $V_c = (Q)/[(b+cd_c)d_c]$.

Step 14. Compare the critical flow depth and velocity values to the channel depth and velocity values:

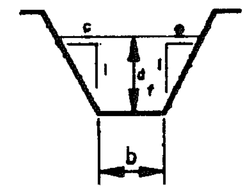
If column 16 (d_c) < column 8 (d_f)
and column 17 (Vc) > column 11 (v) flow is subcritical

If column 16 (d_c) > column 8 (d_f)
and column 17 (Vc) < column 11 (v) flow is supercritical

If column 16 (d_c) = column 8 (d_f)
and column 17 (Vc) = column 11 (v) flow is critical

d_f	b=2, c=2		b=2, c=3		b=2, c=4		b=3, c=2		b=3, c=3		b=3, c=4	
	$Ar^{2/3}$	A	$Ar^{2/3}$	A	$Ar^{2/3}$	A	$Ar^{2/3}$	A	$Ar^{2/3}$	A	$Ar^{2/3}$	A
0.5	0.75	1.50	0.85	1.75	0.95	2.00	1.05	2.00	1.15	2.25	1.24	2.50
0.8	1.85	2.88	2.21	3.52	2.56	4.16	2.50	3.68	2.85	4.32	3.19	4.96
1.0	2.90	4.00	3.56	5.00	4.20	6.00	3.83	5.00	4.47	6.00	5.10	7.00
1.1	3.53	4.62	4.38	5.83	5.21	7.04	4.60	5.72	5.44	6.93	6.26	8.14
1.2	4.23	5.28	5.30	6.72	6.35	8.16	5.47	6.48	6.53	7.92	7.56	9.36
1.3	5.00	5.98	6.33	7.67	7.63	9.36	6.41	7.28	7.73	8.97	9.01	10.66
1.4	5.86	6.72	7.48	8.68	9.06	10.64	7.44	8.12	9.05	10.08	10.61	12.04
1.5	6.79	7.50	8.74	9.75	10.64	12.00	8.56	9.00	10.49	11.25	12.38	13.50
1.6	7.81	8.32	10.13	10.88	12.38	13.44	9.77	9.92	12.07	12.48	14.32	15.04
1.7	8.91	9.18	11.64	12.07	14.29	14.96	11.07	10.88	13.78	13.77	16.43	16.66
1.8	10.10	10.08	13.28	13.32	16.37	16.56	12.47	11.88	15.63	15.12	18.71	18.36
1.9	11.38	11.02	15.05	14.63	18.63	18.24	13.97	12.92	17.62	16.53	21.19	20.14
2.0	12.76	12.00	16.97	16.00	21.07	20.00	15.56	14.00	19.76	18.00	23.85	22.00
2.1	14.23	13.02	19.03	17.43	23.70	21.84	17.27	15.12	22.05	19.53	26.71	23.94
2.2	15.81	14.08	21.23	18.92	26.53	23.76	19.07	16.28	24.49	21.12	29.77	25.96
2.3	17.48	15.18	23.59	20.47	29.55	25.76	20.99	17.48	27.09	22.77	33.04	28.06
2.4	19.26	16.32	26.10	22.08	32.78	27.84	23.01	18.72	29.85	24.48	36.51	30.24
2.5	21.14	17.50	28.77	23.75	36.22	30.00	25.15	20.00	32.78	26.25	40.21	32.50
2.6	23.13	18.72	31.61	25.48	39.87	32.24	27.41	21.32	35.88	28.08	44.13	34.84
2.7	25.24	19.98	34.61	27.27	43.75	34.56	29.78	22.68	39.15	29.97	48.28	37.26
2.8	27.45	21.28	37.78	29.12	47.85	36.96	32.27	24.08	42.59	31.92	52.65	39.76
2.9	29.79	22.62	41.21	31.03	52.18	39.44	34.88	25.52	46.22	33.93	57.27	42.34
3.0	32.24	24.00	44.64	33.00	56.75	42.00	37.62	27.00	50.03	36.00	62.13	45.00

TRAPEZOIDAL CHANNELS HYDRAULIC CHARACTERISTICS



$$Ar^{2/3} = \frac{n\,Q}{1.49\sqrt{s}}$$

r = A/wp

Step 15. When an acceptable channel design for discharge and velocity has been selected with regard to discharge, capacity, and critical flow considerations, then the total channel depth as required by the design criteria is determined as:

a. for subcritical flow
channel depth $\geq d_f$, or

b. for supercritical flow
channel depth $\geq d_c$.

Step 16. Compute the anticipated depth of flow in the design channel for the 100-year frequency storm.

3.3.4 Example - Roadside Ditch Design

Find the design channel depth for a trapezoidal roadside ditch that has a 2-foot bottom (b = 2), 4:1 side slopes (c = 4), a slope of 0.01 feet per foot (S = 0.01), and an excavated, straight alignment, lined with grass sides and a sod bottom where Manning's roughness coefficient is 0.025 (n = 0.025), a maximum permissible velocity of 4 fps (Vmax = 4), and a 10-year discharge of 15 cfs (Q = 15).

Step 1. Complete columns 1, 2, 3, 4, and 12.

Step 2. Compute $Ar^{2/3} = (nq)/(1.49\ S^{1/2}) = (0.025 \times 15)/(1.49 \times 0.010^{1/2}) = 2.52$

Step 3. Determine $A_{min} = Q/V_{max} = 15/4 = 3.75$ square feet

Step 4. Channel configuration is bottom width b = 2 and side slope c = 4.

Step 5. Use Table 3-1, with $Ar^{2/3} = 2.52$ and $A_{min} = 3.75$, and find the largest d_f values closest to either $Ar^{2/3}$ or A_{min}.

$Ar^{2/3}$	d_f
0.95	0.5
2.56	0.8

Calculate d_f for $Ar^{2/3} = 2.52$. By interpolation $d_f = 0.5 + [(2.52 - 0.95)/(2.56 - 0.95)]\ (0.8 - 0.5) = 0.79$ feet.

A	d_f
2.00	0.5
4.16	0.8

Calculate d_f for $A_{min} = 3.75$. By interpolation $d_f = 0.5 + [(3.75 - 2.00)/(4.16 - 2.00)]\ (0.8 - 0.5) = 0.74$.

Use largest d_f of 0.79 versus 0.74.

Step 6. Calculate channel flow area $= A = (b + cd_f)\ d_f = (2 + 4 \times 0.79)\ 0.79 = 4.08$ square feet.

Step 7. Calculate top width of flow $= T = b + 2\ cd_f = 2 + 2 \times 4 \times 0.79 = 8.32$ feet.

Step 8. Calculate channel velocity $= V = Q/A = 15/4.08 = 3.68$ fps
For velocity check, $V \leq V_{max} = 3.68$ fps < 4 fps; therefore, design is acceptable for velocity.

Step 9. Calculate Z for critical flow $Z = Q/\ g^{1/2} = 15/32.2^{1/2} = 2.64$

Step 10. Calculate $Z/b^{2.5} = 2.64/2^{2.5} = 0.47$

Step 11. Use Exhibit III-3 (page 3-9) with $Z/b^{2.5} = 0.47$ and $c = 4$ and read $dc/b = 0.38$

Step 12. Compute $d_c = d_c/b \times b = 0.38 \times 2 = 0.76$ feet

Step 13. Compute $V_c = Q/([b + cd_c]\, d_c) = 15/([2 + 4 \times 0.76]\ 0.76) = 3.92$ fps

Step 14. Compare calculated d_f and V to calculated d_c and V_c.

$d_f = 0.79 \quad > \quad d_c = 0.76$

and $V = 3.68 \quad < \quad V_c = 3.92$ Therefore, flow is subcritical

Step 15. Design channel depth for subcritical flow shall be 0.79 feet or greater.

3.4 Floodway Delineation and Regulation

The Federal Emergency Management Agency (FEMA) has published a Flood Insurance Rate Map for the City of Newark dated revised May 4, 1987 and a Flood Boundary and Floodway Map dated revised February 1, 1985. These maps contain the flood boundary for areas of special flood hazards and delineate the floodway. Where such data exists, it should be utilized in stormwater facility design.

EXHIBIT III-1

OPEN CHANNEL
SYMBOLS, EQUATION, AND GEOMETRIC FORMULA

SYMBOLS

Symbol	Units	Description
A	sq. ft.	Area of cross section of flow
b	ft.	Bottom width of trapezoidal channel
c		Side slope of channel, c:l
d_c	ft.	Critical depth
d_f	ft.	Depth of flow
g	ft/sec^2	Acceleration of gravity = 32.2
n		Manning roughness coefficient
Q	cfs	Rate of discharge
r	ft.	Hydraulic radius = A/wp
s	ft./ft.	Slope of channel
s_c	ft./ft.	Critical slope
T	ft.	Top width of water surface in a channel
V	fps	Mean velocity of flow
Vc	fps	Critical velocity
wp	ft.	Wetted perimeter - length of line of contact between the flowing water and the channel
Z		Section factor for critical flow

Equations

$$V = \frac{1.49}{n} r^{2/3} s^{1/2} \qquad Q = AV \qquad Q = \frac{1.49}{n} Ar^{2/3} s^{1/2} \qquad Z = Q/g^{1/2}$$

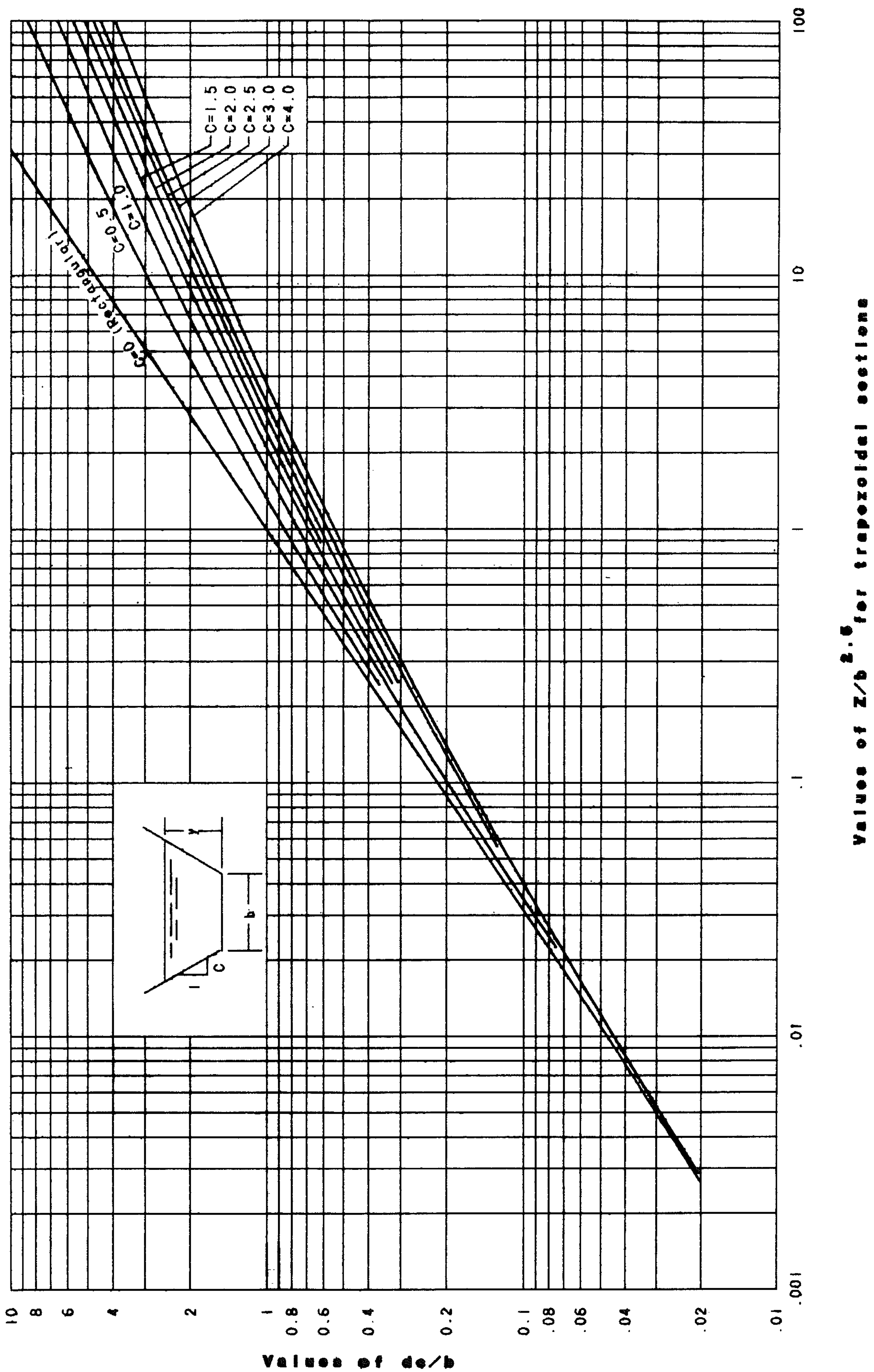
Geometric Formula

Trapezoidal	Rectangle	Triangle
$A = (b + cd_f)\, d_f$	$A = bd_f$	$A = cd_f^2$
$wp = b + 2d_f\, (1 + c^2)^{1/2}$	$w = b + 2d_f$	$wp = 2d_f\, (1 + c^2)^{1/2}$
$T = b + 2\, cd_f$	$T = b$	$T = 2\, cd_f$
$r = \frac{(b+cd_f)\, d_f}{b+2d_f\, (1 + c^2)^{1/2}}$	$r = \frac{bd_f}{b + 2d_f}$	$r = \frac{cd_f}{2\, (1 + c^2)^{1/2}}$

EXHIBIT III-2

MANNING ROUGHNESS COEFFICIENTS

I. Open Channels Lined (Straight Alignment)	
A. Concrete	0.015
B. Concrete, bottom, sides, as indicated	
1. Stone in mortar	0.020
2. Riprap	0.025
C. Gravel bottom, sides as indicated	
1. Concrete	0.020
2. Riprap	0.028
D. Brick	0.017
E. Asphalt	0.015
II. Open Channels, Excavated (Straight Alignment, Natural Lining)	
A. Earth, fairly uniform section	
1. Grass, some weeds	0.025
2. Dense weeds	0.035
3. Sides clean, gravel bottom	0.030
B. Rock	
1. Based on design section	0.035
2. Based on actual mean section	
a. Smooth and uniform	0.040
b. Jagged and irregular	0.045
C. Channels not maintained, weeds and brush uncut	
1. Dense weeds, high as flow depth	0.100
2. Clean bottom, brush on sides	0.080
3. Dense brush, high stage	0.120



CURVES FOR DETERMINING CRITICAL DEPTH

OPEN CHANNEL COMPUTATIONS

PROJECT ____________________ DESIGNER ____________________ DATE __________

	DISCHARGE											CRITICAL FLOW					
1 FREQUENCY	2 Q	3 n	4 s	5 $Ar^{2/3}$	6 Amin	7 b, c	8 d_f	9 A	10 T	11 V	12 Vmax	13 Z	14 $Z/b^{2.5}$	15 d_c/b	16 d_c	17 V_c	18 TYPE OF FLOW
	CFS		FT/FT		SQ FT		FT	SQ FT	FT	FPS	FPS				FT	FPS	