Section 7
FLOW IN OPEN CHANNELS

7.01 General

Open channels for use in the major drainage system have significant advantage in regard to cost, capacity, multiple use for recreational and aesthetic purposes, and potential for detention storage. Disadvantages include right-of-way needs and maintenance costs. Careful planning and design are needed to minimize the disadvantages, and to increase the benefits.

The ideal channel is a natural one carved by nature over a long period of time. The benefits of such a channel are that:

A. Velocities are usually low, resulting in longer concentration times and lower downstream peak flows.

B. Channel storage tends to decrease peak flows.

C. Maintenance needs are usally low because the channel is somewhat stabilized.

D. The channel provides a desirable green belt and recreational area adding significant social benefits.

Generally speaking, the natural channel or the man-made channel which most nearly conforms to the character of a natural channel is the most efficient and the most desirable.

In many areas facing urbanization, the runoff has been so minimal that natural channels do not exist. However, small trickle paths nearly always exist which provide an excellent basis for location and construction of channels. Good land planning should reflect even these minimal trickle channels to reduce development costs and minimize drainage problems. In some cases the prudent utilization of natural water routes in the development of a major drainage system will reduce the requirements for an underground storm sewer system.

Channel stability is a well recognized problem in urban hydrology because of the significant increase in low flows and peak storm runoff flows. A natural channel must be studied to determine the measures needed to avoid future bottom scour and bank cutting. Erosion control measures can be taken at reasonable cost which will preserve the natural appearance without sacrificing hydraulic efficiency.

7.02 Channel Discharge

A. Manning's Equation

Careful attention must be given to the design of drainage channels to assure adequate capacity and minimum maintenance to overcome the results of erosion and silting. The hydraulic characteristics of channels shall be determined by Manning's equation.

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2}$$

Q = Total discharge in cfs

n = Coefficient of roughness

A = Cross-sectional area of channel in sq ft

R = Hydraulic radius of channel in feet

S = Slope of the frictional gradient in feet per foot.

B. Uniform Flow

For a given channel condition of roughness, discharge, and slope, there is only one possible depth for maintaining a uniform flow. This depth is the normal depth. When roughness, depth, and slope are known at a channel section, there can only be one discharge for maintaining a uniform flow through the section. This discharge is the normal discharge.

If the channel is uniform and resistance and gravity forces are in exact balance, the water surface will be parallel to the bottom the channel. This is the condition of uniform flow.

Uniform flow is more often a theoretical abstraction than an actuality. True uniform flow is difficult to find in the field or to obtain in the laboratory. Channels are sometimes designed on the assumption that they will carry uniform flow at the normal depths, but because of conditions difficult if not impossible to evaluate and hence not taken into account, the flow will actually have depths considerably different from uniform depth. The engineer must be aware of the fact that uniform flow computation provides only an approximation of what will occur; however, such computations are useful and necessary for planning.

C. Normal Depth

The normal depth is computed so frequently that it is convenient to use nomographs for various types of cross sections to eliminate the need for trial and error solutions, which are time consuming. A nomograph for uniform flow is given in Fig. 7-1.

7.03 Water Surface Profiles

Open channel flow in urban drainage systems is usually non-uniform because of bridge openings, curves and structures. This necessitates the use of backwater computations for all final channel design work.

A water surface profile must be computed for all channels and shown on all final drawings. Computation of the water surface profile should utilize standard backwater methods or acceptable computer routines, taking into consideration all losses due to changes in velocity, drops, bridge openings and other obstructions.

7.04 Design Considerations

Channels should have trapezoidal sections of adequate cross-sectional areas to take care of uncertainties in runoff estimates, changes in channel coefficients, channel obstructions and silt accumulations.

Accurate determination of the "n" value is critical in the analysis of the hydraulic characteristics of a channel. The "n" value for each channel reach should be based on experience and judgment with regard to the individual channel characteristics. Table 7-1 gives a method of determining the composite roughness coefficient based on actual channel conditions.

Where practicable, unlined channels should have sufficient gradient, depending upon the type of soil, to provide velocities that will be self-cleaning but will not be so great as to create erosion. Lined channels, drop structures, check dams, or concrete spillways may be required to control erosion that results from the high velocities of large volumes of water. Unless approved otherwise by the City Engineer, channel velocities in unlined channels shall not exceed 8 fps.

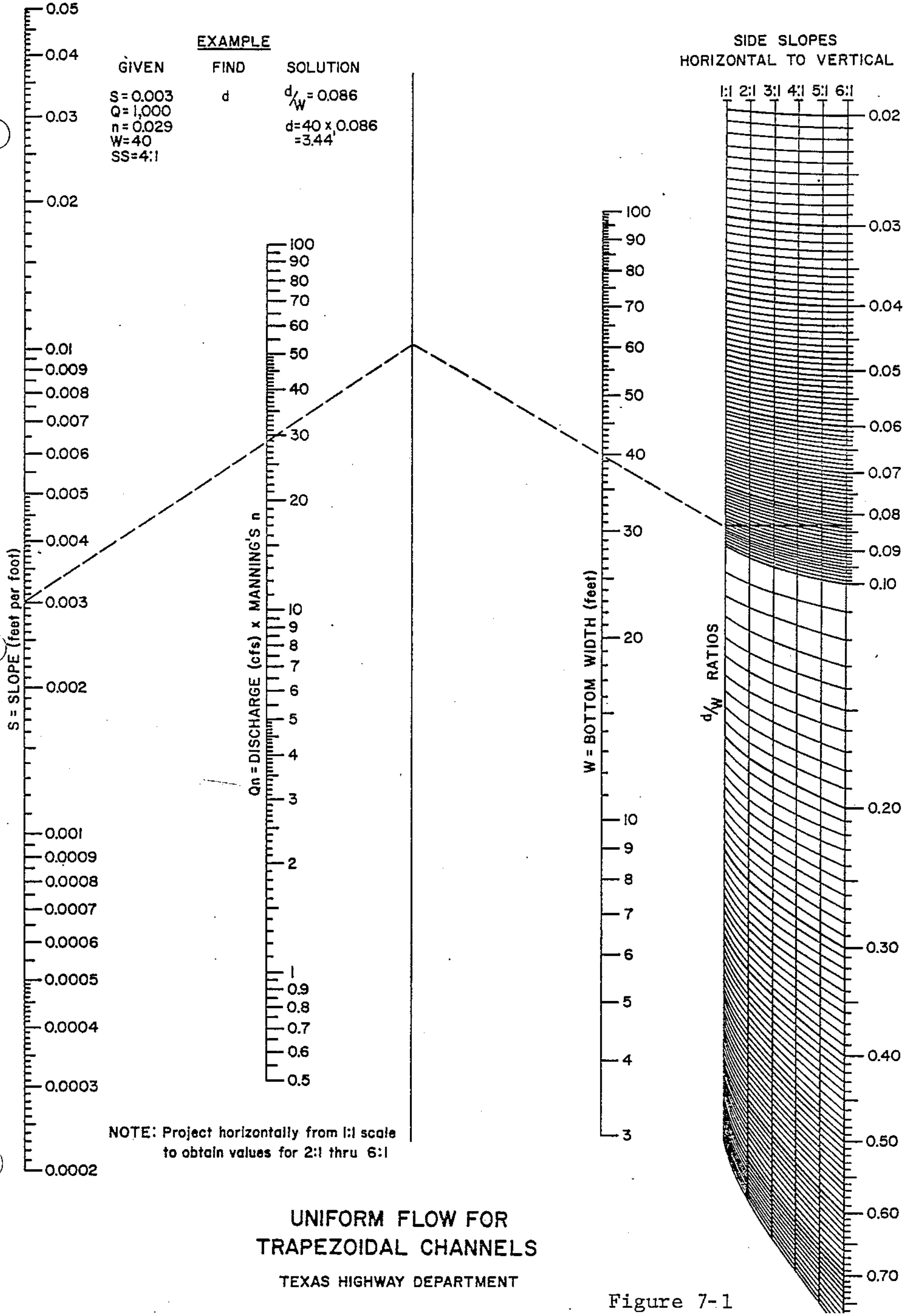
EXAMPLE
GIVEN
FIND
SOLUTION
S = 0.003
Q = 1,000
n = 0.029
W = 40
SS = 4:1
d
d/W = 0.086
d = 40 x 0.086
= 3.44'
S = SLOPE (feet per foot)
Qn = DISCHARGE (cfs) x MANNING'S n
W = BOTTOM WIDTH (feet)
d/W RATIOS
SIDE SLOPES
HORIZONTAL TO VERTICAL
1:1 2:1 3:1 4:1 5:1 6:1
NOTE: Project horizontally from 1:1 scale
to obtain values for 2:1 thru 6:1
UNIFORM FLOW FOR
TRAPEZOIDAL CHANNELS
TEXAS HIGHWAY DEPARTMENT

Figure 7-1

Table 7-1

Computation of Composite Roughness Coefficient
For Excavated and Natural Channels
$n = (n_0+n_1+n_2+n_3+n_4)\ m$

	Channel Conditions	Value
Material Involved n_0	Earth	0.020
	Rockcut	0.025
	Fine Gravel	0.024
	Coarse Gravel	0.028
Degree of Irregularity n_1	Smooth	0.000
	Minor	0.005
	Moderate	0.010
	Severe	0.020
Variation of Channel Cross Section n_2	Gradual	0.000
	Alternating Occasionally	0.005
	Alternating Frequently	0.010-0.015
Relative Effect Of Obstructions n_3	Negligible	0.000
	Minor	0.010-0.015
	Appreciable	0.020-0.030
	Severe	0.040-0.060
Vegetation n_4	Low	0.005-0.010
	Medium	0.010-0.025
	High	0.025-0.050
	Very High	0.050-0.100
Degree of Meandering m	Minor	1.000-1.200
	Appreciable	1.200-1.500
	Severe	1.500

Roughness Coefficient For Lined Channels

Concrete Lined - n = 0.017
Rubble RipRap - n = 0.022

Open Channel Hydraulics
Ven Te Chow, Ph.D.

7.05 Channel Cross Sections

The channel shape may be almost any type suitable to the location and to the environmental conditions. Often the shape can be chosen to suite open space and recreational needs to create additional sociological benefits.

A. Side Slope

Except in horizontal curves the flatter the side slope, the better. Normally slopes shall be no steeper than 3:1, which is also the practical limit for mowing equipment. Rock or concrete lined channels or those which for other reasons do not require slope maintenance may have slopes as steep as 1 1/2:1.

B. Depth

Deep channels are difficult to maintain and can be hazardous. Constructed channels should therefore be as shallow as practical.

C. Bottom Width

Channels with narrow bottoms are difficult to maintain and are conductive to high velocities during high flows. It is desirable to design open channels such that the bottom width is at least twice the depth.

D. Trickle Channels

The low flows, and sometimes base flows, from urban areas must be given specific attention. If erosion of the bottom of the channel appears to be a problem, low flows shall be carried in a paved trickle channel which has a capacity of 5.0 percent of the design peak flow. Care must be taken to insure that low flows enter the trickle channel without the attendant problem of the flow paralleling the trickle channel.

E. Freeboard

For channels with flow at high velocities, the surface roughness, wave action, air bulking, and splash and spray are quite erosive along the top of the flow. Freeboard height should be chosen to provide a suitable safety margin. The height of freeboard shall be a minimum of one foot. For deep flows with high velocities one may use the formula:

$$\text{Freeboard (in feet)} = 1.0 + 0.025\, v\sqrt[3]{d}, \text{ where}$$

v = velocity of flow
d = depth of flow

For the freeboard of a channel on a sharp curve, extra height must be added to the outside bank or wall in the amount:

$$H = \frac{v^2\ (T + B)}{2gR}$$

H = additional height on outside edge of channel

V = velocity of flow in channel (fps)

T = width of flow at water surface (ft)

B = bottom width of channel (ft)

R = centerline radius of turn (ft)

g = acceleration of gravity (32.2 ft/sec.^{2})

If R is equal or greater than 3 x B, additional freeboard is not required.

7.06 Channel Drops

The use of channel drops permits adjustment of channel gradients which are too steep for the design conditions. In urban drainage work it is often desirable to use several low head drops in lieu of a few higher drops. Special attention must be given to protecting the channel from erosion in the area of channel drops.

The use of sloped drops will generally result in lower cost installations. Sloped drops can easily be designed to fit the channel topography.

Sloped drops shall have roughened faces and shall be no steeper than 2:1. They shall be adequately protected from scour, and shall not cause an upstream water surface drop which will result in high velocities upstream. Side cutting just downstream from the drop is a common problem which must be protected against.

The length L will depend upon the hydraulic characteristics of the channel and drop. For a q of 30 cfs/ft, L would be about 15 feet, that is, about 1/2 of the q value. The L should not be less than 10 feet, even for low q values. In addition, followup riprapping will often be necessary at most drops to more fully protect the banks and channel bottom. The criteria given is minimal, based on the philosophy that it is less costly to initially underprotect with riprap, and to place additional protection later after erosional tendencies are determined in the field. Project approvals are to be based on provision for such follow-up construction.

7.07 Baffle Chutes

Baffle chutes are used to dissipate the energy in the flow at a larger drop. They require no tailwater to be effective. They are particularly useful where the water surface upstream is held at a higher elevation to provide head for filling a side storage pond during peak flows.

Baffle chutes are used in channels where water is to be lowered from one level to another. The baffle piers prevent undue acceleration of the flow as it passes down the chute. Since the flow velocities entering the downstream channel are low, no stilling basin is needed. The chute, on a 2:1 slope or flatter, may be designed to discharge up to 60 cfs per foot of width, and the drop may be as high as structurally feasible. The lower end of the chute is constructed to below stream bed level and backfilled as necessary. Degradation of the stream bed does not, therefore, adversely affect the performance of the structure. In urban drainage design, the lower end should be protected from the scouring action.

The baffled apron shall be designed for the full design discharge. Baffle chutes shall be designed using acceptable methods such as those presented by A.S. Peterka of the United States Bureau of Reclamation in Engineering monograph No. 25.

7.08 Structure Aesthetics

The use of hydraulic structures in the urban environment requires an approach not encountered elsewhere in the design of such structures. The appearance of these structures is very important. The treatment of the exterior should not be considered of minor importance. Appearance must be an integral part of design.

Parks. It must be remembered that structures are often the only above-ground indication of the underground works involved in an expensive project. Furthermore, parks and green belts may later be developed in the area in which the structure will play a dominant environmental role.

Play Areas. An additional consideration is that drainage structures offer excellent opportunities for neighborhood children to play. It is almost impossible to make drainage works inaccessible to children and therefore what is constructed should be made as safe as is reasonably possible. Safety hazards should be minimized and vertical drops protected with decorative fencing or rails.

Concrete Surface Treatment. The use of textured concrete presents a pleasing appearance and removes form marks. Exposed aggregate concrete is also attractive but may require special control of the aggregate used in the concrete.

Rails and Fences. The use of rails and fences along concrete walls provides a pleasing topping to an otherwise stark wall, and yet gives a degree of protection against someone inadvertently falling over the wall.