Extracted from the NRCS "Engineering Field Handbook Part 650," Chapter 2, Estimating Runoff.

To read the complete document go to
http://directives.sc.egov.usda.gov/viewerFS.aspx?hid=21429

4. Time of concentration

General

Time of concentration (T_c) is the time it takes for runoff to travel from the hydraulically most distant point of the watershed to the outlet. T_c influences the peak discharge. For the same size watershed, the shorter the T_c, the larger the peak discharge. This means that peak discharge has an inverse relationship with T_c.

Estimating time of concentration

T_c can be estimated for small rural watersheds using the following empirical relationship:

$$T_c = \frac{\ell^{0.8}\left[\left(\frac{1000}{CN}\right) - 9\right]^{0.7}}{1140\, Y^{0.5}} \qquad \text{(Eq. 2-5)}$$

Where T_c = time of concentration in hours,
ℓ = flow length in feet,
CN = runoff curve number, and
Y = average watershed slope in percent.

Figure 2-27 is a nomograph for solving equation 2-5. T_c is determined using watershed parameters ℓ, CN, and Y. Worksheet 2 can be used to compute T_c. Example 2-2 demonstrates this procedure. For watersheds where hydraulic conditions are such that velocities of water flow need to be estimated (urban areas, etc.), then T_c should be estimated using TR-55 methods.

Average watershed slope

The average watershed slope (Y) is the slope of the land and not the watercourse. It can be determined from soil survey data or topographic maps. Hillside slopes can be measured with a hand level, Locke level, or clinometer in the direction of overland flow. Average watershed slope is an average of individual land slope measurements.

The average watershed slope can be determined using the following relationship:

$$Y = \frac{100CI}{A} \qquad \text{(Eq. 2-6)}$$

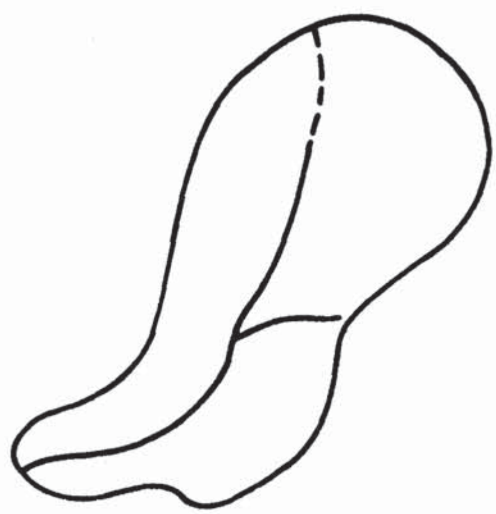
where Y = average watershed slope in percent,
C = total contour length in feet,
I = contour interval in feet, and
A = drainage area in square feet.

Flow length

Flow length (ℓ) is the longest flow path in the watershed from the watershed divide to the outlet. It is the total path water travels overland and in small channels on the way to the outlet. The flow length can be determined using a map wheel or it can be marked along the edge of a paper and converted to feet.

Some typical examples of determining the flow length are shown below.

Natural Watershed. In this case, water flows from the watershed divide to a small channel, down the small channel to the main stream, and from there to the watershed outlet.



Watershed with Terraces. In this case, water flows from the divide to the terrace, along the terrace to the outlet or main stream, and then along the main stream to the outlet.

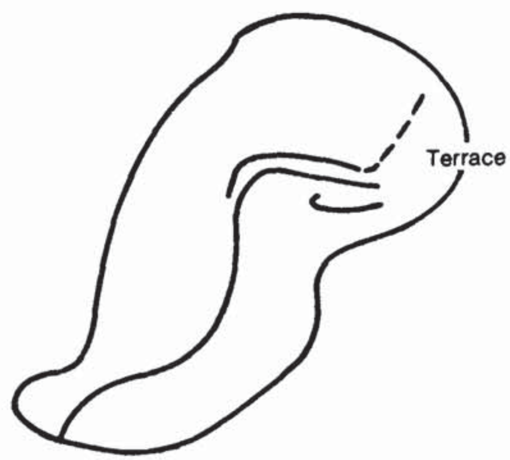


Figure 2-26—**Solution for runoff equation**

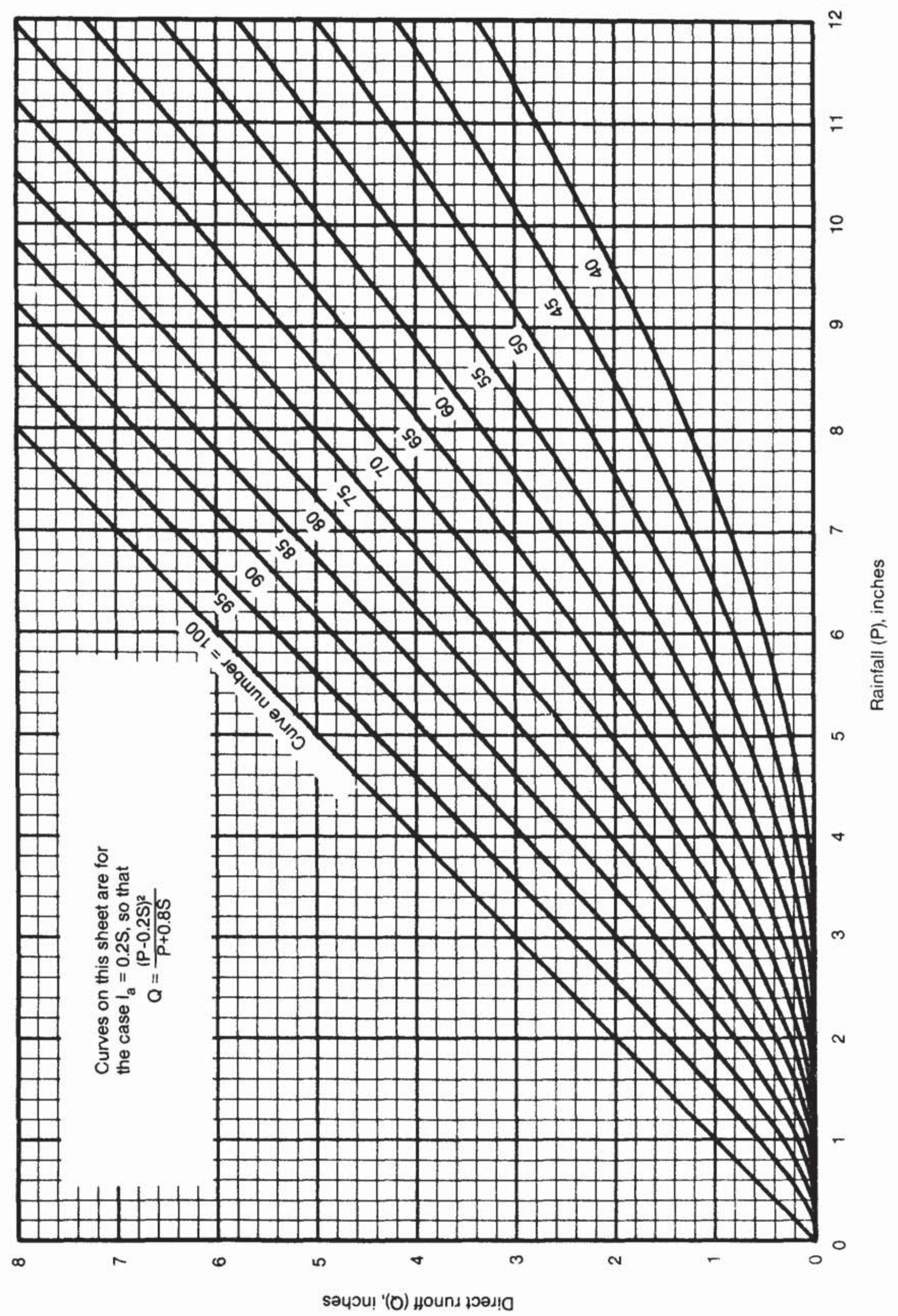


Table 2-3a.—Runoff curve numbers for cultivated agricultural lands[1]

Cover description			Curve numbers for hydrologic soil group—			
Cover type	Treatment[2]	Hydrologic condition[3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row	Poor	72	81	88	91
		Good	67	78	85	89
	Straight row + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	Contoured + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	Contoured & terraced + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Straight row + CR	Poor	64	75	83	86
		Good	60	72	80	84
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	Contoured + CR	Poor	62	73	81	84
		Good	60	72	80	83
	Contoured & terraced	Poor	61	72	79	82
		Good	59	70	78	81
	Contoured & terraced + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	Straight row	Poor	66	77	85	89
		Good	58	72	81	85
	Contoured	Poor	64	75	83	85
		Good	55	69	78	83
	Contoured & terraced	Poor	63	73	80	83
		Good	51	67	76	80

[1] Average runoff condition.

[2] *Crop residue cover (CR)* applies only if residue is on at least 5% of the surface throughout the year.

[3] Hydrologic condition is based on combination of factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes in rotations, (d) percent of residue cover on the land surface (good ⩾ 20%), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Table 2-4.—I_a values for runoff curve numbers

Curve number	I_a (in)	Curve number	I_a (in)
40	3.000	68	0.941
41	2.878	69	0.899
42	2.762	70	0.857
43	2.651	71	0.817
44	2.545	72	0.778
45	2.444	73	0.740
46	2.348	74	0.703
47	2.255	75	0.667
48	2.167	76	0.632
49	2.082	77	0.597
50	2.000	78	0.564
51	1.922	79	0.532
52	1.846	80	0.500
53	1.774	81	0.469
54	1.704	82	0.439
55	1.636	83	0.410
56	1.571	84	0.381
57	1.509	85	0.353
58	1.448	86	0.326
59	1.390	87	0.299
60	1.333	88	0.273
61	1.279	89	0.247
62	1.226	90	0.222
63	1.175	91	0.198
64	1.125	92	0.174
65	1.077	93	0.151
66	1.030	94	0.128
67	0.985	95	0.105

Buoyancy

A submerged body is acted on by a vertical, buoyant force equal to the weight of the displaced water.

$$F_B = Vw \qquad \text{(Eq. 3-2)}$$

F_B = buoyant force
V = volume of the body
w = unit weight of water

If the unit weight of the body is greater than that of water, there is an unbalanced downward force equal to the difference between the weight of the body and the weight of the water displaced. Therefore, the body will sink.

Flotation

If the body has a unit weight less than that of water, the body will float with part of its volume below and part above the water surface in a position so that:

$$W = Vw \qquad \text{(Eq. 3-3)}$$

W = weight of the body
V = volume of the body below the water surface; i.e., the volume of the displaced water
w = unit weight of water

A check should be made of the stability of hydraulic structures as they will be affected by submergence and whether the weight of the structure will be adequate to resist flotation.

Porous materials, when submerged, have different net weights depending upon whether the voids are filled with air or water. Note the wide variation in the possible net weight of one cubic foot of treated structural timber weighing 55 pounds under average atmospheric moisture conditions and having 30 percent voids:

1 cu. ft. of structural timber, 30 percent voids	Before Saturation	After Saturation
W = weight in air, lb.	55	55 + (0.30 x 62.4) = 73.72
F_B = buoyant force when submerged, lb.	62.4	62.4
$W-F_B$ = weight when submerged in water (net weight), lb.	55 - 62.4 = - 7.4	73.72 - 62.4 = 11.32

HYDRAULICS OF CULVERTS[2]

There are two major types of culvert flow: 1) Flow with inlet control, and 2) flow with outlet control. For each type, different factors and formulas are used to compute the hydraulic capacity of the culvert. Under inlet control, the slope, roughness and diameter of the culvert barrel, the inlet shape and the amount of headwater or ponding at the entrance must be considered. Outlet control involves the additional consideration of the elevation of the tailwater in the outlet channel and the length of the culvert.

The need for making involved computations to determine the probable type of flow under which a culvert will operate may be avoided by computing headwater depths from Exhibits 3-9 through 3-12 for both inlet control and outlet control and then using the higher value for design.

Both inlet control and outlet control types of flow are discussed briefly in the following paragraphs.

Culverts Flowing With Inlet Control

Inlet control means that the discharge capacity of a culvert is controlled at the culvert entrance by the depth of headwater (HW) and the shape of the entrance. Figure 3-7 shows inlet control flow for three types of culvert entrances.

In inlet control the length of the culvert barrel and outlet conditions are not factors in determining culvert capacity.

In all culvert design, headwater or depth of ponding at the entrance to a culvert is an important factor in culvert capacity. The headwater depth is the vertical distance from the culvert invert at the entrance to the energy line of the headwater pool (depth + velocity head). Because of the low velocities in most entrance pools, the water surface and the energy line at the entrance are assumed to coincide.

Headwater-discharge relationships for various types of circular culverts flowing with inlet control are based on laboratory research with models and verified in some instances by full-scale tests. Exhibits 3-9 and 3-10 give headwater-discharge relationships for round concrete and CM pipe culverts flowing with inlet control.

Example 3-16

It is desired to determine the maximum discharge of an existing 42-inch concrete culvert. The allowable headwater depth (HW) upstream is 8.0 feet and the slope of the culvert is 0.02 ft/ft. The culvert has a projecting entrance condition and there will be no backwater from downstream flow. Assume inlet control.

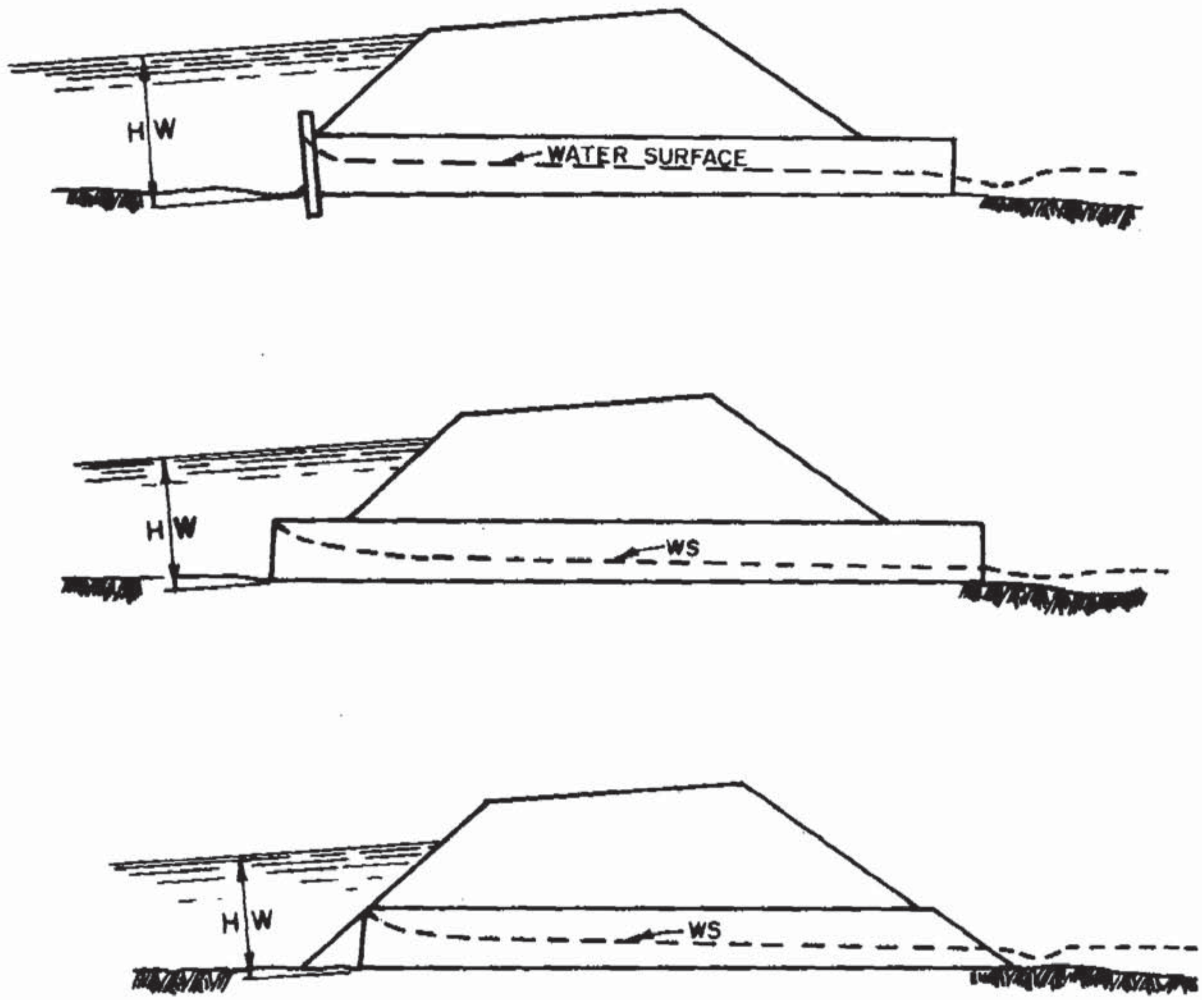


Figure 3-7 Culverts with inlet control

Using Exhibit 3-9, compute $\frac{HW}{D}$

$$\frac{HW}{D} = \frac{8(12)}{42} = 2.29$$

At 2.29 on scale 3, projecting entrance, draw a horizontal line to scale 1. From this point on scale 1 draw a connecting line between it and 42-inch diameter on scale 4. On scale 5 read Q = 128 cfs.

Check for inlet control

$$s_o > s_n$$

where

$>$ = symbol for "is greater than"

s_o = installed slope of culvert

s_n = neutral slope - that slope of which the loss of head due to friction is equal to the gain in head due to elevation.

from Table 3-1, n(design) for concrete pipe = 0.012

from Exhibit 3-5, sheet 3 of 6

for Q = 128 cfs and D = 42 inches

s_n = 0.013

therefore, the culvert is in inlet control, $0.02 > 0.013$

Example 3-17

Determine the required diameter of a corrugated metal culvert pipe to be installed in an existing channel. Q = 100 cfs, HW max. = 7.0 feet and s_o = 0.03. There will be no backwater from downstream flow. Entrance to be mitered to conform to the slope of the embankment.

The solution of this problem must be made by trial pipe diameters and solution of HW by use of Exhibit 3-10.

Try D = 36"

draw a line through 36 inch on scale 4 and 100 cfs on scale 5 to an intersection with scale 1, then a horizontal line from scale 1 to scale 2, mitered inlet. On scale 2 read $\frac{HW}{D} = 3.8$,

then HW = 3.8(3) = 11.4 feet   too high

Try D = 48"

read from scale 2, $\frac{HW}{D} = 1.45$

HW = 1.45(4) = 5.80 feet low

Try D = 42"

read from scale 2, $\frac{HW}{D} = 2.23$

HW = 2.23(3.5) = 7.8 feet high

From the foregoing trials, it will be necessary to install the 48-inch diameter pipe if the HW is to be 7.0 feet maximum.

Check for inlet control

$s_o > s_n$

from Exhibit 3-5, sheet 6 of 6

$s_n = 0.017$

0.03 > 0.017 therefore, inlet control

Culverts Flowing With Outlet Control

Culverts flowing with outlet control can flow with the culvert barrel full for all or part of the barrel length. See Figure 3-8. If the entire cross section of the barrel is filled with water for the total length of the barrel, the culvert is said to be in full flow, Figure 3-8(a) and (b). One other type of outlet control is shown in Figure 3-8(c). For this condition, the elevation of the energy gradeline at the exit of the culvert is assumed at 3/4D. This is not an exact figure but it will give reasonable results.

The head, H, Figure 3-8(a), or energy required to pass a given quantity of water through a culvert with outlet control is made up of three parts. The parts are expressed in feet of water and include a velocity head, H_v, an entrance loss, H_e, and a friction loss, H_f. This energy is obtained from ponding of water at the entrance and is expressed by the equation

$$H = H_v + H_e + H_f \qquad \text{(Eq. 3-13)}$$

This equation in similar form has been derived in the section on Hydraulics of pipelines.

The entrance loss, H_e, depends upon the shape of the inlet edge. This loss is expressed as a coefficient, K_e, times the barrel velocity head. That is, $H_e = K_e \frac{v^2}{2g}$. Entrance loss coefficients, K_e, for various types of entrances when flow is in outlet control are given in Table 3-3.

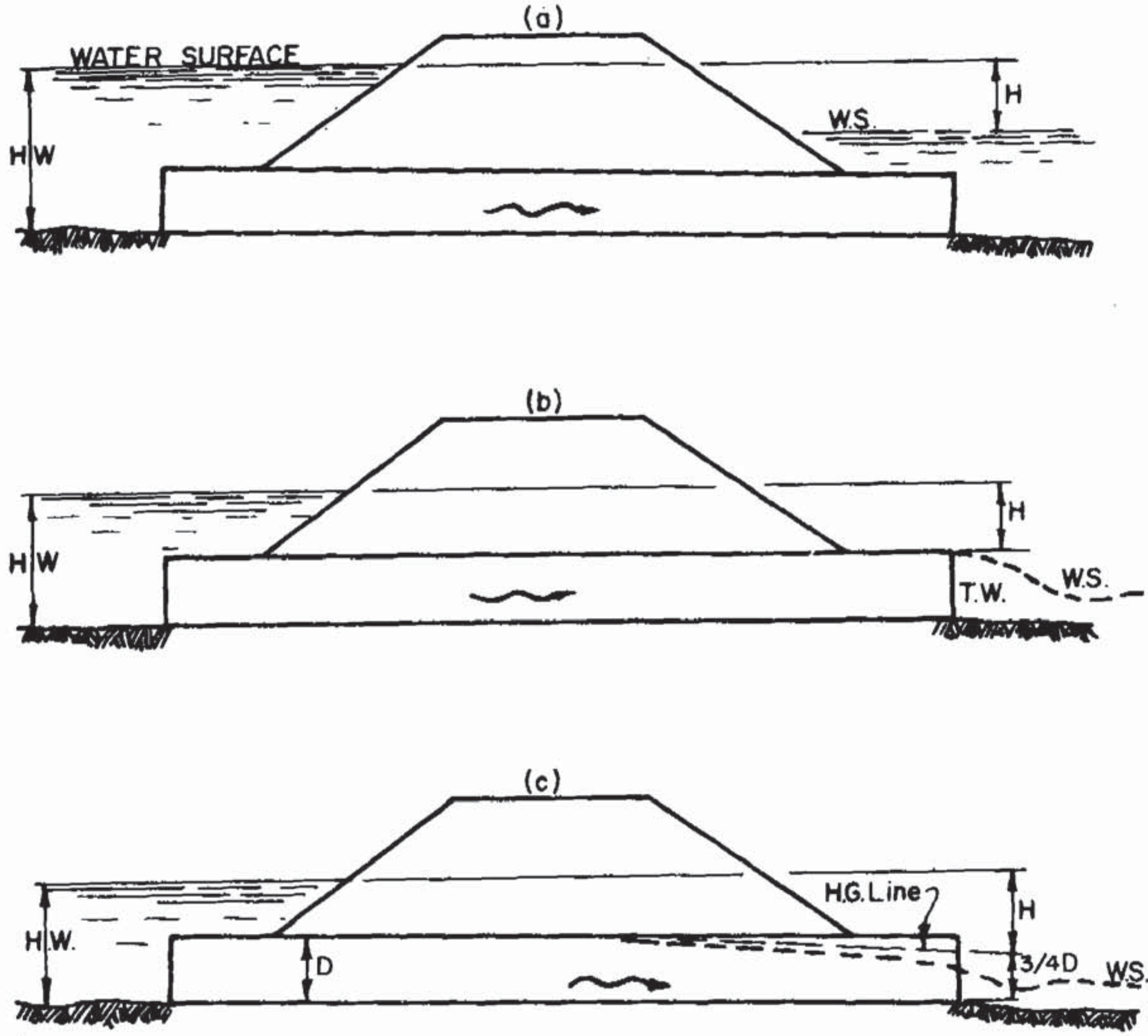


Figure 3-8 Culverts with outlet control

Table 3-3 Entrance Loss Coefficients	
Type of Structure and Design of Entrance	Coefficient K_e
<u>Pipe, Concrete</u>	
Projecting from fill, socket end (groove-end)	0.2
Projecting from fill, sq. cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove-end)	0.2
Square-end	0.5
Rounded (radius = 1/12D)	0.2
Mitered to conform to fill slope	0.7
*End-section conforming to fill slope	0.5
<u>Pipe, or Pipe-Arch, Corrugated Metal</u>	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls	
Square-edge	0.5
Mitered to conform to fill slope	0.7
*End-section conforming to fill slope	0.5

Note: *"End-section conforming to fill slope," made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control.

The friction loss, H_f, is the energy required to overcome the roughness of the culvert barrel and is expressed by the equation

$$H_f = K_p L \frac{v^2}{2g}$$

K_p values can be taken from Exhibit 3-4.

Headwater depth can be expressed as an equation for all outlet control conditions, including all depths of tailwater, TW. This is done by designating the vertical distance from the culvert invert at the outlet to the elevation from which H is measured as h_o.

$$HW = H + h_o - s_o \ell \qquad \text{(Eq. 3-14)}$$

where ℓ = length of culvert
s_o = slope of culvert in feet per foot
H = head loss in feet as determined from the appropriate exhibit

When the elevation of the water surface in the outlet channel is equal to or above the top of the culvert opening at the outlet, Figure 3-9(a), h_o is equal to the tailwater depth. If the tailwater elevation is below the top of the culvert opening at the outlet, Figure 3-9(b), h_o, is then by definition 3/4D.

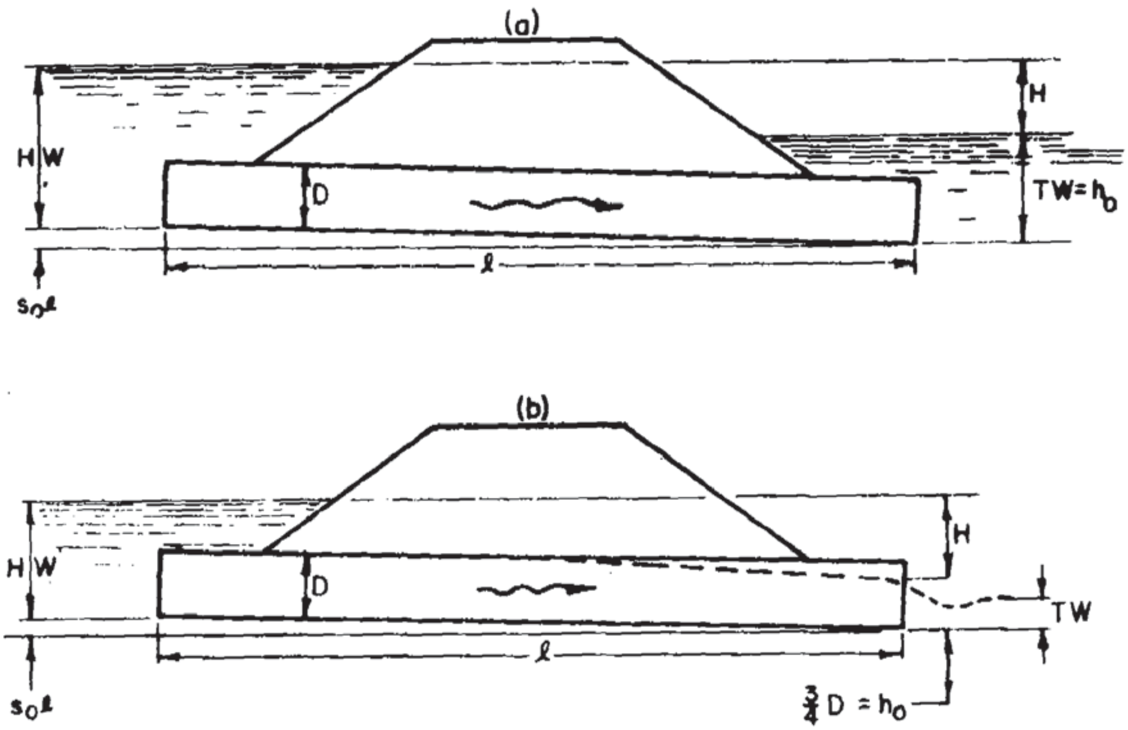


Figure 3-9 Culvert water depth relationships

Headwater-discharge relationships for various types of circular culverts flowing with outlet control may be solved by the use of Exhibits 3-11 and 3-12. For a different roughness coefficient n_1 than that of the exhibit n, use the length scales shown with an adjusted length, ℓ_1, calculated by the formula

$$\ell_1 = \ell\left(\frac{n_1}{n}\right)^2$$

Example 3-18

It is desired to install 50 feet of concrete culvert pipe, n = 0.012, in a drainage channel for a road crossing. Design Q is 80 cfs with a tailwater depth of 3.0 feet. Slope of the culvert will be 0.002 foot per foot. Maximum headwater depth (HW) is 5 feet.

from Equation 3-14

$HW = H + h_o - s_o \ell$ or, $H = HW - h_o + s_o \ell$

$H = 5.0 - 3.0 + .002(50)$

$H = 2.1$ feet

and from Table 3-3

for a concrete pipe projecting from the fill with socket end upstream

$K_e = 0.2$

entering Exhibit 3-11

draw a line between H = 2.1 feet on the head scale and Q = 80 cfs on the discharge scale. Then on the length scale for $K_e = 0.2$, draw a second line from the 50-feet mark through the intersection of the first line with the "turning line" and on to the pipe diameter scale. The diameter scale intersection is at approximately 39 inches, therefore, use a 42-inch pipe.

Erosive Culvert Exit Velocities

A culvert, because of its hydraulic characteristics, increases the velocity of flow over that in the adjacent channel. High velocities may be damaging just downstream from the culvert outlet and the erosion potential at this point should be considered in culvert design. In many cases it is necessary to riprap the channel for a short distance downstream of the culvert exit.

6. OPEN CHANNEL FLOW

The flow of water in an open channel differs from pipe flow in one important respect. See Figure 3-5. Open channel flow must have a free water surface, whereas pipe flow has none since water must fill the whole conduit.

Flow calculations for open channels are complicated by the fact that the position of the water surface is likely to change with respect to time and the cross-sectional area. Also the depth of flow, discharge, and slopes of the channel bottom and water surface are interdependent. Channel cross sections can vary from semicircular to the irregular forms of natural streams. The channel surface may vary from that of polished metal used in testing flumes to that of rough, irregular riverbeds. Moreover, the roughness in an open channel varies with the position of the free water surface. Therefore, the proper selection of friction coefficients is more uncertain for open channels than for pipes. In general, the treatment of open channel flow is somewhat more empirical than that of pipe flow, but the empirical method is the best available. If cautiously applied, it results in practical values.

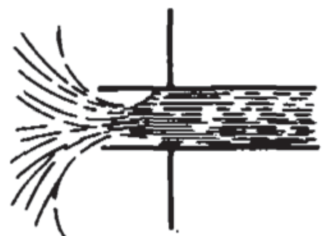
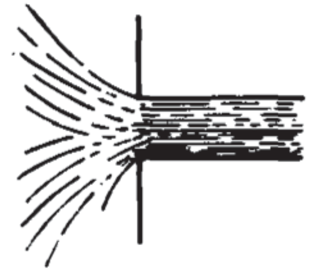
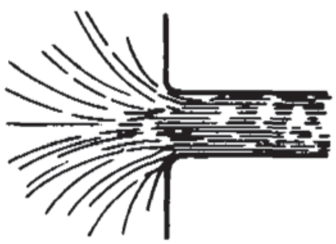
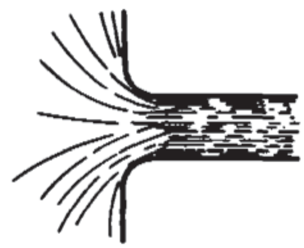
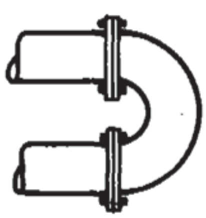
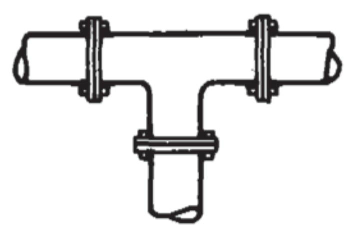
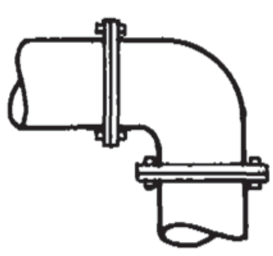
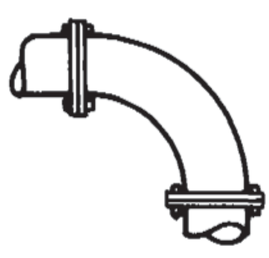
PIPE ENTRANCES			
INWARD PROJECTING PIPE	K_e	SHARP-CORNERED	K_e
	0.78		0.50
HOODED INLET	1.00		
SLIGHTLY ROUNDED	K_e	BELL MOUTH	K_e
	0.23		0.04
PIPE BENDS			
RETURN BEND	K_{RB}	STANDARD-TEE	K_{ST}
	2.20		1.80
STANDARD 90°-ELBOW	K_{90}	LONG RADIUS ELBOW	K_{LR}
	0.90		0.60

Exhibit 3-8 Head loss coefficients for pipe entrances and bends

(Sheet 1 of 2)

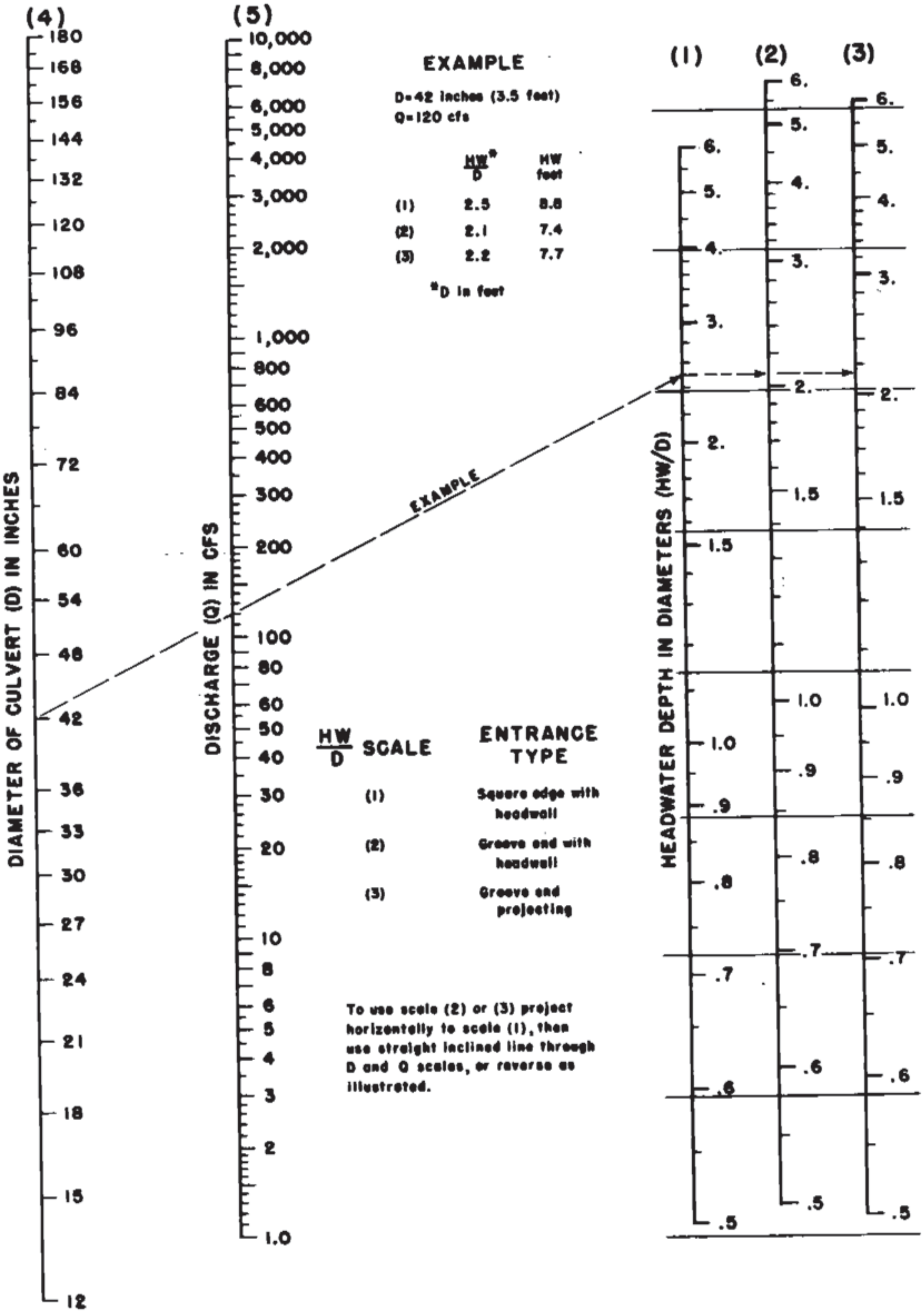


Exhibit 3-9 Headwater depth for concrete pipe culverts with inlet control (Ref. Hyd. Eng. Cir. No. 5, USBPR, 1965)

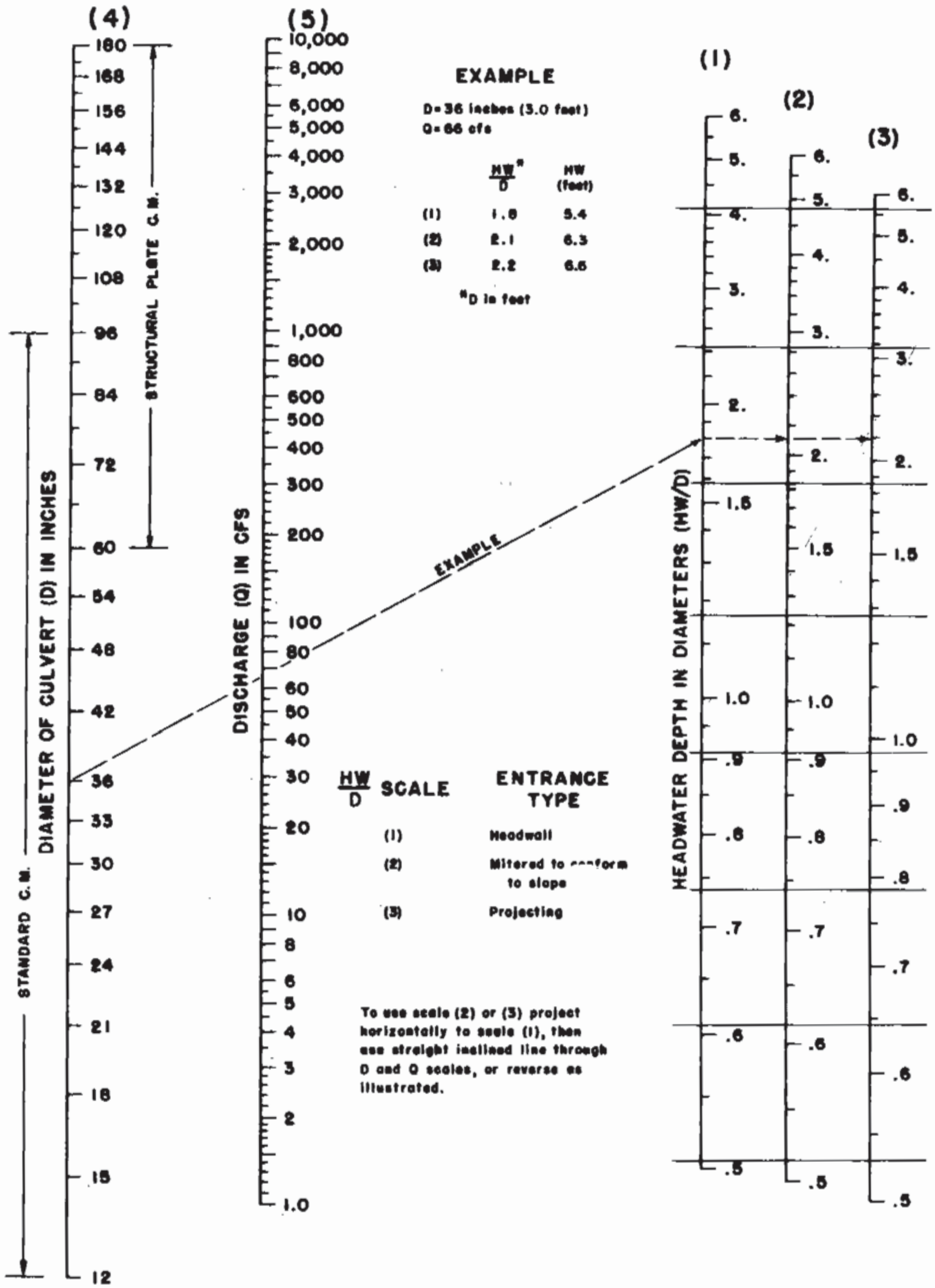


Exhibit 3-10 Headwater depth for CM pipe culverts with inlet control (Ref. Hyd. Eng. Cir. No. 5, USBPR, 1965)

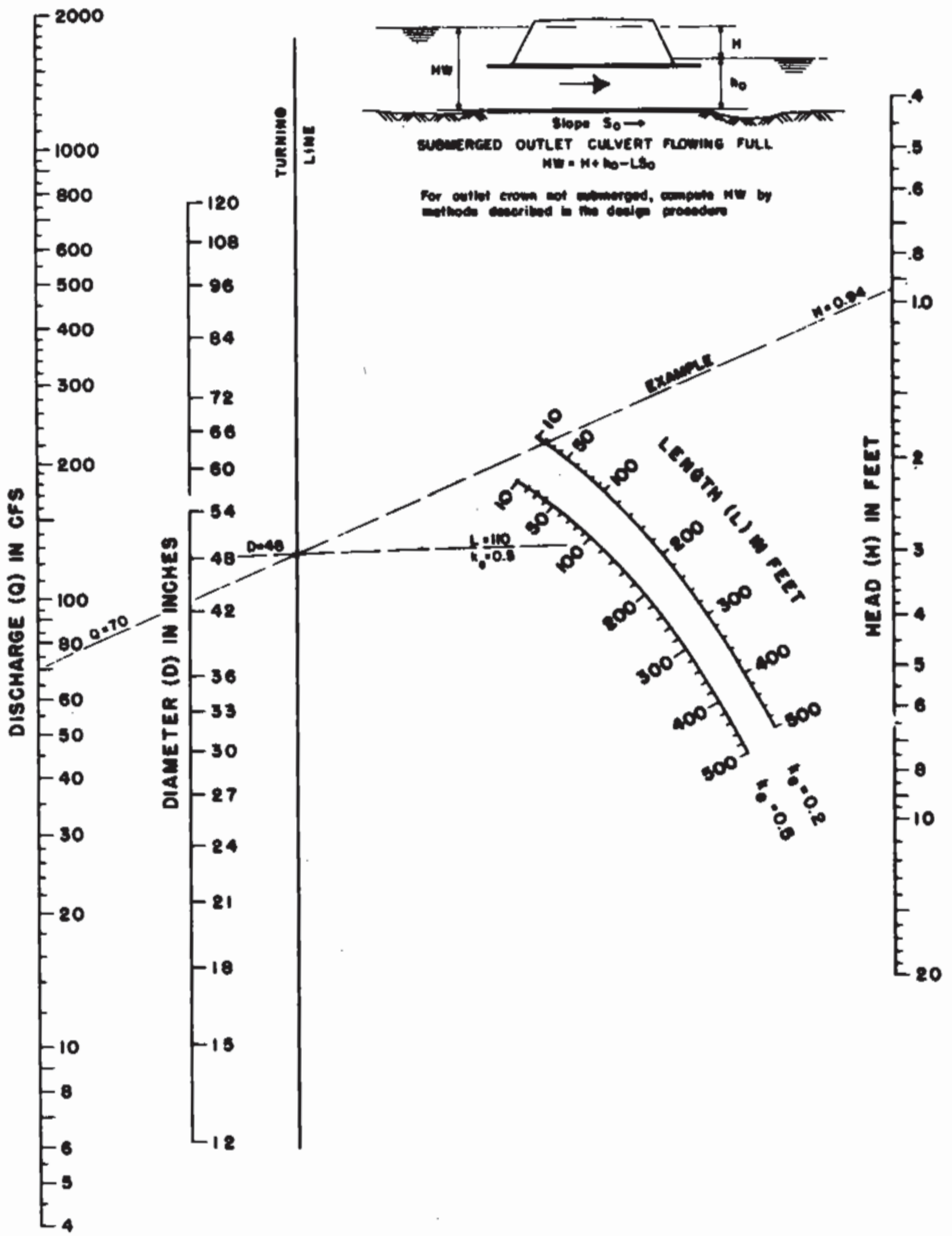


Exhibit 3-11 Head for concrete pipe culverts flowing full with outlet control n = 0.012 (Ref. Hyd. Eng. Cir. No. 5, USBPR, 1965)

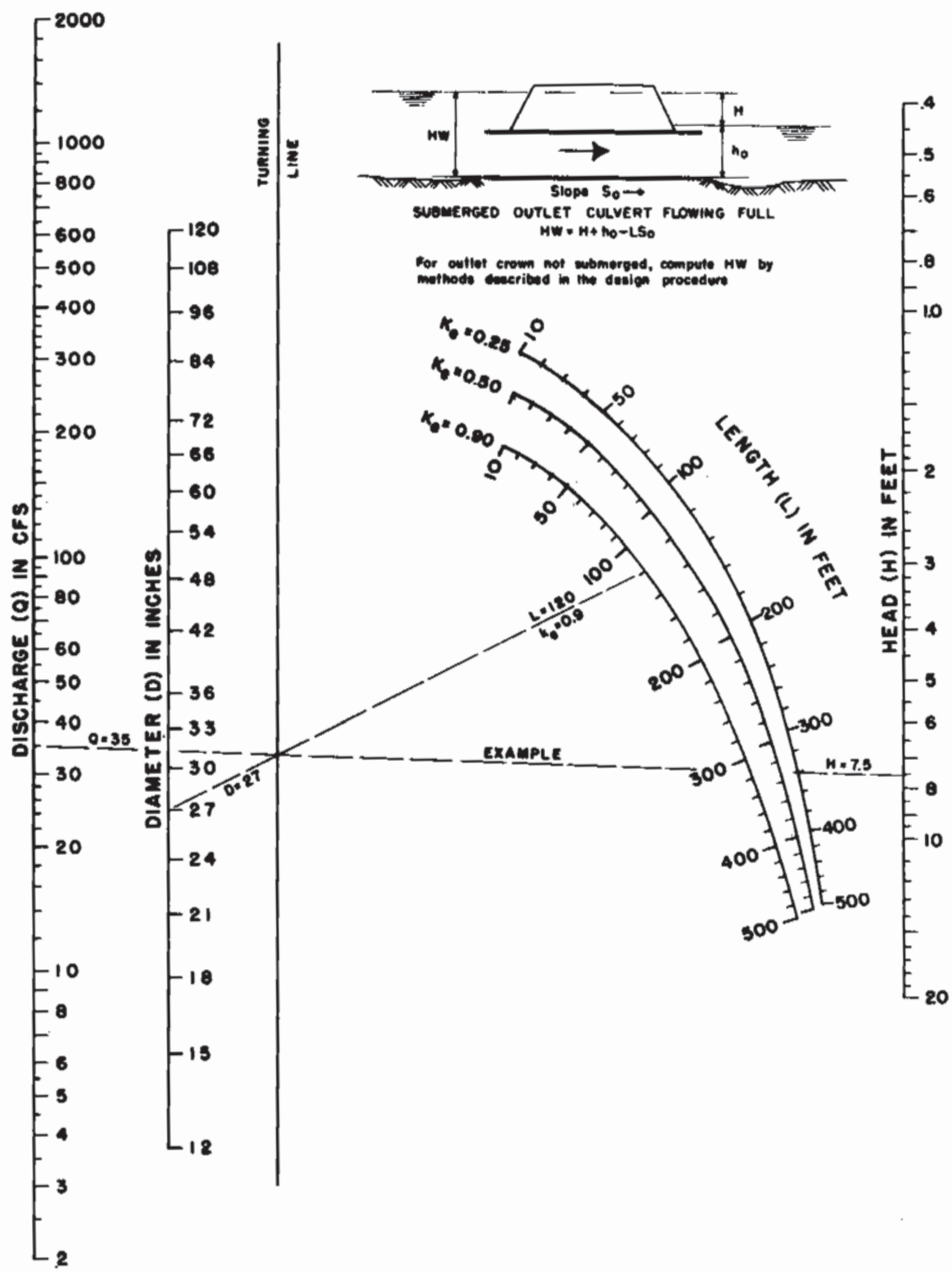
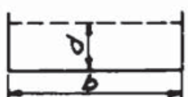
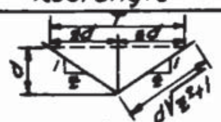
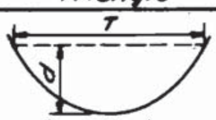
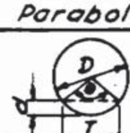
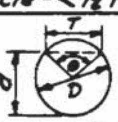


Exhibit 3-12 Head for CM pipe culverts flowing full with outlet control n = 0.024 (Ref. Hyd. Eng. Cir. No. 5, USBPR, 1965)

Section	Area a	Wetted Perimeter p	Hydraulic Radius r	Top Width T
 Trapezoid	$bd+zd^2$	$b+2d\sqrt{z^2+1}$	$\frac{bd+zd^2}{b+2d\sqrt{z^2+1}}$	$b+2zd$
 Rectangle	bd	$b+2d$	$\frac{bd}{b+2d}$	b
 Triangle	zd^2	$2d\sqrt{z^2+1}$	$\frac{zd}{2\sqrt{z^2+1}}$	$2zd$
 Parabola	$\frac{2}{3}dT$	$T+\frac{8d^2}{3T}$ \1	$\frac{2dT^2}{3T^2+8d^2}$ \1	$\frac{3a}{2d}$
 Circle - < ½ full \2	$\frac{D^2}{8}\left(\frac{\pi\theta}{180}-\sin\theta\right)$	$\frac{\pi D\theta}{360}$	$\frac{45D}{\pi\theta}\left(\frac{\pi\theta}{180}-\sin\theta\right)$	$D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$
 Circle - > ½ full \3	$\frac{D^2}{8}\left(2\pi-\frac{\pi\theta}{180}+\sin\theta\right)$	$\frac{\pi D(360-\theta)}{360}$	$\frac{45D}{\pi(360-\theta)}\left(2\pi-\frac{\pi\theta}{180}+\sin\theta\right)$	$D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$

\1 Satisfactory approximation for the interval $0 < \frac{d}{T} \leq 0.25$
When $d/T > 0.25$, use $p = \frac{1}{2}\sqrt{16d^2+T^2} + \frac{T^2}{8d}\sinh^{-1}\frac{4d}{T}$

\2 $\theta = 4\sin^{-1}\sqrt{d/D}$ } Insert θ in degrees in above equations
\3 $\theta = 4\cos^{-1}\sqrt{d/D}$ }

Exhibit 3-13 Elements of channel sections (Ref. NEH Section 5, ES-33)

Table 4–1.—**Volume–weight relationships**

Property			Saturated sample	Unsaturated sample	Other useful relationships			
1	2	3	4	5	6	7	8	9
Volume components	V_s	Volume of solids	$\frac{W_s}{G_s \gamma_w}$		$V-(V_a+V_w)$	$V(1-n)$	$\frac{V}{1+e}$	$\frac{V_v}{e}$
	V_w	Volume of water	$\frac{W_w}{\gamma_w}$		V_v-V_a	SV_v	$\frac{eSV}{1+e}$	eSV_s
	V_a	Volume of air	Zero	$V-(V_s+V_w)$	V_v-V_w	$(1-S)V_v$	$\frac{(1-S)eV}{1+e}$	$(1-S)eV_s$
	V_v	Volume of voids	$\frac{W_w}{\gamma_w}$	$V-\frac{W_s}{G_s \gamma_w}$	$V-V_s$	$\frac{nV_s}{1-n}$	$\frac{eV}{1+e}$	eV_s
	V	Total volume of sample	V_s+V_w	$V_s+V_w+V_a$	$\frac{W}{\gamma_d(1+w)}$	$\frac{V_s}{1-n}$	$V_s(1+e)$	$\frac{V_v(1+e)}{e}$
	n	Porosity	$\frac{V_v}{V}$		$1-\frac{\gamma_d}{G_s \gamma_w}$	$\frac{e}{1+e}$	$\frac{\gamma_d w_{sat}}{\gamma_w}$	$1-\frac{V_s}{V}$
	e	Void ratio	$\frac{V_v}{V_s}$		$\frac{G_s \gamma_w}{\gamma_d}-1$	$\frac{n}{1-n}$	$\frac{\gamma_d w_{sat}}{\gamma_w-\gamma_d w_{sat}}$	$\frac{V}{V_s}-1$
Weights for specific sample	W_s	Weight of solids	$W-W_w$		$\frac{W}{1+w}$	$G_s V \gamma_w (1-n)$	$\frac{W_w G_s}{eS}$	$V\gamma_d$
	W_w	Weight of water	$W-W_s$		wW_s	$S\gamma_w V_v$	$\frac{eW_s S}{G_s}$	$V_w \gamma_w$
	W	Total weight of sample	W_s+W_w		$W_s(1+w)$	$V\gamma_d(1+w)$		
	W_{sat}	Saturated weight of sample	$W_s+V_v\gamma_w$	X	$W_s(1+w_{sat})$	$V\gamma_d(1+w_{sat})$		
	W_{sub}	Submerged weight of saturated sample	$W_s-V_s\gamma_w$	X	$W_s\left(\frac{G_s-1}{G_s}\right)$	$V\gamma_d\left(\frac{G_s-1}{G_s}\right)$	$W_{sat}-V\gamma_w$	
Weights for sample of unit volume	γ_d	Dry unit weight	$\frac{W_s}{V_s+V_v}$	$\frac{W_s}{V_s+V_w+V_a}$	$\frac{W}{V(1+w)}$ $G_s\gamma_w(1-n)$	$\frac{\gamma_m}{1+w}$ $\frac{e\gamma_w}{(1+e)w_{sat}}$	$\frac{n\gamma_w}{w_{sat}}$ $\frac{G_s\gamma_w}{1+\frac{wG_s}{S}}$	$\frac{G_s\gamma_w}{1+e}$ $\frac{G_s\gamma_w}{1+G_s w_{sat}}$
	γ_m	Moist unit weight	X	$\frac{W_s+W_w}{V}$	$\frac{W_s}{V}(1+w)$	$\gamma_d(1+w)$		
	γ_{sat}	Saturated unit weight	$\frac{W_s+V_v\gamma_w}{V}$	X	$\left[\frac{G_s-1}{G_s w_{sat}+1}\right]\gamma_w+\gamma_w$	$\gamma_d(1+w_{sat})$	$\gamma_d+n\gamma_w$	$\frac{(G_s+e)\gamma_w}{1+e}$
	γ_{sub}	Submerged unit weight	$\gamma_{sat}-\gamma_w$		$\left[\frac{G_s-1}{G_s w_{sat}+1}\right]\gamma_w$	$\gamma_d-(1-n)\gamma_w$	$\gamma_d-\frac{\gamma_d}{G_s}$	$\left[\frac{G_s-1}{1+e}\right]\gamma_w$
Combined relations	w	Moisture content	X	$\frac{W_w}{W_s}$	$\frac{W}{W_s}-1$	$\frac{eS}{G_s}$	$\frac{nS}{G_s(1-n)}$	$S\left[\frac{\gamma_w}{\gamma_d}-\frac{1}{G_s}\right]$
	w_{sat}	Saturated moisture content	$\frac{W_{sat}-W_s}{W_s}$	X	$\frac{n\gamma_w}{\gamma_d}$	$\frac{e\gamma_w}{(1+e)\gamma_d}$	$\frac{\gamma_w}{\gamma_d}-\frac{1}{G_s}$	$\frac{\gamma_{sat}-\gamma_d}{\gamma_d}$
	S	Degree of saturation	$\frac{V_w}{V_v}=1.0$	$\frac{V_w}{V_v}<1.0$	$\frac{W_w}{V_v\gamma_w}$	$\frac{w}{w_{sat}}$	$\frac{wG_s}{e}$	$\frac{wG_s\gamma_d}{G_s\gamma_w-\gamma_d}$
	G_s	Specific gravity	$\frac{W_s}{V_s\gamma_w}$		$\frac{\gamma_d(1+e)}{\gamma_w}$	$\frac{\gamma_d}{\gamma_w(1-n)}$	$\frac{\gamma_d}{\gamma_w-\frac{w\gamma_d}{S}}$	$\frac{W_s}{W_s-W_{sub}}$

Notes: 1. Weight of air is assumed to be zero.
2. Values of w, w_{sat}, S, and n are used as decimals.
3. w is the moisture content which corresponds to the particular W or γ being used.

Figure 4–l4.—**Unified classification and properties of soils.**

	IMPORTANT PROPERTIES						Unified Soil Classes
			Workability as Construction Material	Permeability			
Typical Names	Shear Strength	Compress-ibility		When Compacted	K Cm. Per Sec.	K Ft. Per Day	
Well graded gravels, gravel-sand mixtures, little or no fines.	Excellent	Negligible	Excellent	Pervious	K > 10^{-2}	K > 30	GW
Poorly graded gravels, gravel-sand mixtures, little or no fines.	Good	Negligible	Good	Very Pervious	K > 10^{-2}	K > 30	GP
Silty gravels, gravel-sand-silt mixtures.	Good to Fair	Negligible	Good	Semi-pervious to Impervious	K = 10^{-3} to 10^{-6}	K = 3 to 3 x 10^{-3}	GM
Clayey gravels, gravel-sand-clay mixtures.	Good	Very Low	Good	Impervious	K - 10^{-6} to 10^{-8}	K = 3 x 10^{-3} to 3 x 10^{-5}	GC
Well graded sands, gravelly sands, little or no fines.	Excellent	Negligible	Excellent	Pervious	K > 10^{-3}	K > 3	SW
Poorly graded sands, gravelly sands, little or no fines.	Good	Very Low	Fair	Pervious	K > 10^{-3}	K > 3	SP
Silty sands, sand-silt mixtures.	Good to Fair	Low	Fair	Semi-pervious to Impervious	K = 10^{-3} to 10^{-6}	K = 3 to 3 x 10^{-3}	SM
Clayey sands, sand-clay mixtures.	Good to Fair	Low	Good	Impervious	K = 10^{-6} to 10^{-8}	K = 3 x 10^{-3} to 3 x 10^{-5}	SC
Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	Fair	Medium to High	Fair	Semi-pervious to Impervious	K = 10^{-3} to 10^{-6}	K = 3 to 3 x 10^{-3}	ML
Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Fair	Medium	Good to Fair	Impervious	K = 10^{-6} to 10^{-8}	K = 3 x 10^{-3} to 3 x 10^{-5}	CL
Organic silts and organic silty clays of low plasticity.	Poor	Medium	Fair	Semi-pervious to Impervious	K = 10^{-4} to 10^{-6}	K = 3 x 10^{-3} to 3 x 10^{-3}	OL
Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Fair to Poor	High	Poor	Semi-pervious to Impervious	K =10^{-4} to 10^{-6}	K = 3 x 10^{-1} to 3 x 10^{-3}	MH
Inorganic clays of high plasticity, fat clays.	Poor	High to Very High	Poor	Impervious	K = 10^{-6} to 10^{-8}	K = 3 x 10^{-3} to 3 x 10^{-5}	CH
Organic clays of medium to high plasticity, organic silts.	Poor	High	Poor	Impervious	K = 10^{-6} to 10^{-8}	K = 3 x 10^{-3} to 3 x 10^{-5}	OH
Peat and other highly organic soils	Not Suitable for Construction						Pt

Figure 4–14.—**Unified classification and properties of soils — Continued.**

EMBANKMENTS								
Compaction Character-istics	Standard Procter Unit Density (Lbs. per cu. ft.)	Type of Roller Desirable	Relative Characteristics		Resistance to Piping	Ability to Take Plastic Deformation Under Load Without Shearing	General Description & Use	Unified Soil Classes
			Perme-ability	Compress-ibility				
Good	125-135	Crawler tractor or steel wheeled & vibratory	High	Very Slight	Good	None	Very stable, pervious shells of dikes and dams.	GW
Good	115-125	Crawler tractor or steel wheeled & vibratory	High	Very Slight	Good	None	Reasonably stable, pervious shells of dikes and dams.	GP
Good with close control	120-135	Rubber-tired or sheepsfoot	Medium	Slight	Poor	Poor	Reasonably stable, not well suited to shells but may be used for impervious cores or blankets.	GM
Good	115-130	Sheepsfoot or rubber-tired	Low	Slight	Good	Fair	Fairly stable, may be used for impervious core.	GC
Good	110-130	Crawler tractor & vibratory or steel wheeled	High	Very Slight	Fair	None	Very stable, pervious sections, slope protection required.	SW
Good	100-120	Crawler tractor & vibratory or steel wheeled	High	Very Slight	Fair to Poor	None	Reasonably stable, may be used in dike with flat slopes.	SP
Good with close control	110-125	Rubber-tired or sheepsfoot	Medium	Slight	Poor to Very Poor	Poor	Fairly stable, not well suited to shells, but may be used for impervious cores or dikes.	SM
Good	105-125	Sheepsfoot or rubber-tired	Low	Slight	Good	Fair	Fairly stable, use for impervious core for flood control structures.	SC
Good to Poor. Close control essential	95-120	Sheepsfoot	Medium	Medium	Poor to Very Poor	Very Poor	Poor stability, may be used for embankments with proper control. *Varies with water content.	ML
Fair to Good	95-120	Sheepsfoot	Medium	Medium	Good to Fair	Good to Poor	Stable, impervious cores and blankets.	CL
Fair to Poor	80-100	sheepsfoot	Medium to Low	Medium to High	Good to Poor	Fair	Not suitable for embankments.	OL
Poor to Very Poor	70-95	Sheepsfoot	Medium to Low	Very High	Good to Poor	Good	Poor stability, core of hydraulic fill dam, not desirable in rolled fill construction.	MH
Fair to Poor	75-105	Sheepsfoot	Low	High	Excellent	Excellent	Fair stability with flat slopes, thin cores, blanket & dike sections.	CH
Poor to Very Poor	65-100	Sheepsfoot	Medium to Low	Very High	Good to Poor	Good	Not suitable for embankments.	OH
Do Not Use for Embankment Construction								Pt

Figure 4–l4.—**Unified classification and properties of soils — Continued.**

CHANNELS Long duration to constant flows. RELATIVE DESIRABILITY		FOUNDATION Foundation soils, being undisturbed, are influenced to a great degree by their geologic origin. Judgment and testing must be used in addition to these generalizations. RELATIVE DESIRABILITY (TENTATIVE FOR TRIAL USE ONLY)					Unified Soil Classes
Erosion Resistance	Compacted Earth Lining	Bearing Value	Seepage Important	Seepage Not Important	Requirements for Seepage Control: Permanent Reservoir	Requirements for Seepage Control: Floodwater Retarding	
1	—	Good	—	1	Positive cutoff or blanket	Control only within volume acceptable plus pressure relief if required.	GW
2	—	Good	—	3	Positive cutoff or blanket	Control only within volume acceptable plus pressure relief if required.	GP
4	4	Good	2	4	Core trench to none	None	GM
3	1	Good	1	6	None	None	GC
6	—	Good	—	2	Positive cutoff or upstream blanket & toe drains or wells	Control only within volume acceptable plus pressure relief if required.	SW
7 if gravelly	—	Good to poor depending upon density	—	5	Positive cutoff or upstream blanket & toe drains or wells	Control only within volume acceptable plus pressure relief if required.	SP
8 if gravelly	5 erosion critical	Good to Poor depending upon density	4	7	Upstream blanket & toe drains or wells	Sufficient control to prevent dangerous seepage piping.	SM
5	2	Good to Poor	3	8	None	None	SC
—	6 erosion critical	Very Poor; susceptible to liquefication	6, if saturated or pre-wetted	9	Positive cutoff or upstream blanket & toe drains or wells	Sufficient control to prevent dangerous seepage piping.	ML
9	3	Good to Poor	5	10	None	None	CL
—	7 erosion critical	Fair to Poor; may have excessive settlement	7	11	None	None	OL
—	—	Poor	8	12	None	None	MH
10	8 volume change critical	Fair to Poor	9	13	None	None	CH
—	—	Very Poor	10	14	None	None	OH
—	—	REMOVE FROM FOUNDATION					Pt

Table 4–I5.—**Characteristics of compacted fill materials**

Behavior Group	Relative Resistance to Failure (1) Greatest to (6) Least			Relative Characteristics		
	Shearing	Piping	Cracking	Permeability	Compressibility	Compaction
1	2	3	4	5	6	7
I	1	—	—	High	Very Slight	Good; crawler tractor; steel-wheeled roller.
II	3	3	4	Low	Slight	Fair; sheepsfoot roller; rubber-tired roller.
III	2	5	3	Medium	Slight	Good; rubber-tired roller; sheepsfoot roller.
IV	3	6	6	Medium	Slight to Medium	Good to poor; sheepsfoot roller; close control essential.
V	4	4	5	Low	Medium	Good to fair; sheepsfoot roller; close control essential.
VI	5	2	2	Low	Medium to High	Good to fair; sheepsfoot roller; rubber-tired roller.
VII	6	1	1	Low	High	Fair to poor; sheepsfoot roller.
VIII	6	Variable	Variable	Medium-Low	Very High	Poor to very poor; sheepsfoot roller.
IX	6	Variable	Variable	Medium-Low	Very High	Very poor; not suitable for embankments.

Table 4–I6.—**Characteristics of foundation materials**

Group Symbol	Characteristics Influencing Embankment Design				Seepage Control Requirements
	Shear Strength	Sensitivity to Shock	Compressibility [2]	Permeability	
1	2	3	4	5	6
GW	High	None	Very Slight	High	Positive Cutoff
GP	High	None	Very Slight	High	Positive Cutoff
GM	High	None	Very Slight	Medium-Low	Toe Trench to None
GC	High	None	Slight	Low	None
SW	High	None	Very Slight	High	U.S. Blanket & Toe Drainage;
SP	Usually High [2]	High for loose fine sand	Very Slight	High	cutoff U.S. Blanket & Toe Drainage; cutoff U.S.
SM	Usually High [1]	High for loose fine sand	Very Slight	Medium	Blanket & Toe Drainage; cutoff
SC	High	None	Slight	Low	None
ML	Medium	High for loose silts	Medium	Medium	Toe Trench
CL	Medium	None	Medium	Medium-Low	None
OL	Low	None	High	Low	None
MH	Low	High for loose silts	Very High	Low	None
CH	Medium to Low [2]	None	Usually Very High	Low	None
OH	Low	None	Very High	Low	None
Pt	Very Low	None	Very High	Very High	Remove from foundation

$$\tau_e = \gamma DS\left(1 - C_F\right)\left(\frac{n_s}{n}\right)^2 \qquad \text{(eq. 7–1)}$$

where:

γ = unit weight of water, 62.4 lb/ft³

D = maximum flow depth in the cross section

C_F = a vegetal cover factor

n_s = roughness associated with soil grain size

n = Manning's roughness coefficient

S = channel bed slope, ft/ft

The vegetal cover factor was developed based on experimental data and accounts for the cover density and uniformity (Temple 1980). It takes on values between 0 and 1, with 0 indicating no vegetal protection and 1 indicating the channel is completely protected from stress. The vegetal cover factor is a function of vegetation type and condition.

Figure 7–2 Cross section showing perforated grid pavers

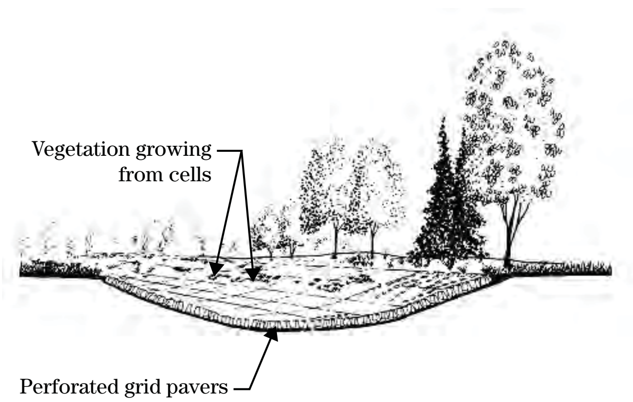
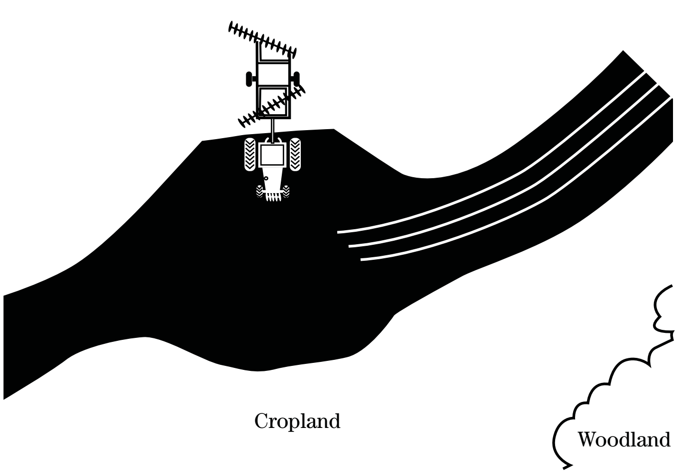


Figure 7–3 Provision for vehicle crossing



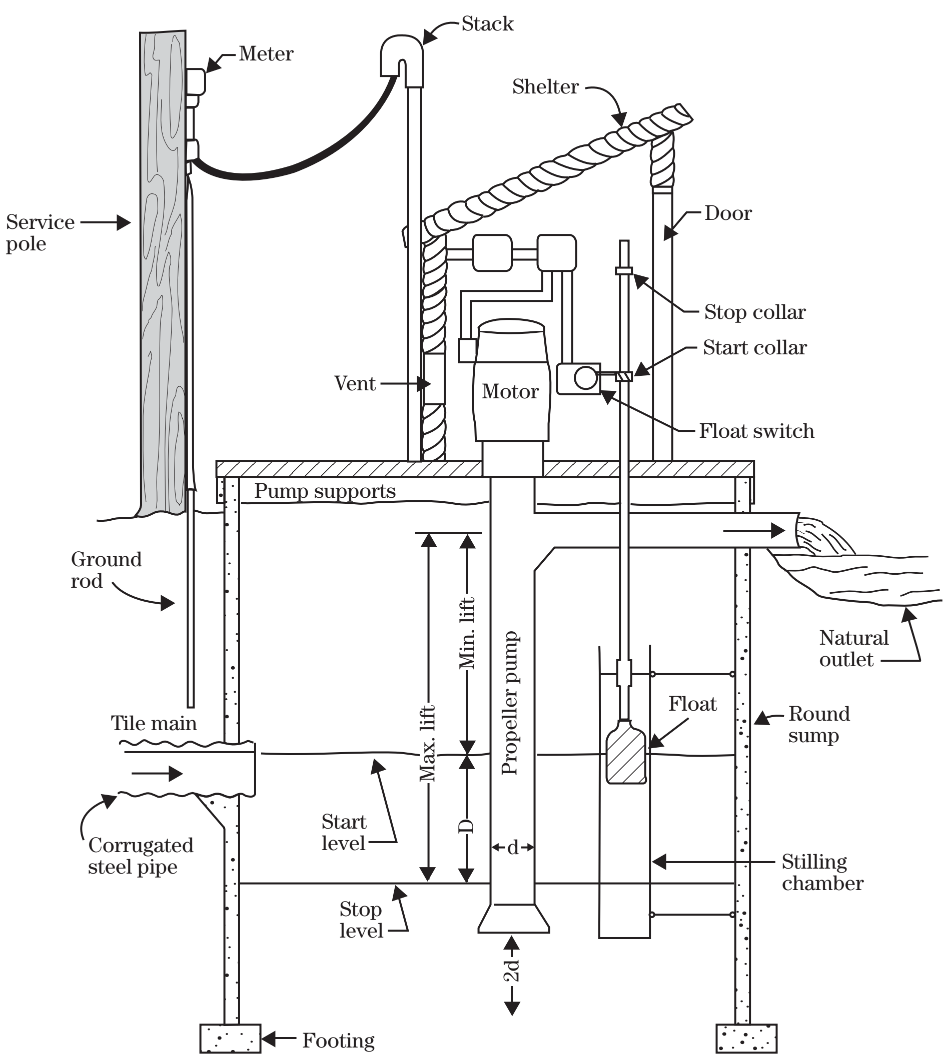
The requirements for a stable foundation often conflict with the other requirements of location. Borings should be made and the location selected that has the best foundation conditions consistent with other site requirements. An unstable foundation material can considerably increase the cost of a pumping plant. A more intensive investigation before selecting the plant location often yields big dividends in reduced costs.

(2) Sump storage

Careful consideration should be given to providing storage for runoff within the diked area. The effective storage is that capacity in sump areas and ditches between the lowest elevation at which drainage is by gravity, or the cutoff elevation for the pumps, and the elevation at which flooding of the land to be protected begins. This is determined largely by the topography of the project area and the type of drainage system. A sump for a subsurface drainage system may be only a circular well 8 feet or less in diameter that has 2 feet of effective storage.

A sizeable area near the surface drainage system outlet that is lower than the area to be drained can be used for storage without crop loss. Borrow pits of appreciable size for dike construction and drainage ditches that have sufficient storage capacity can also be used.

Figure 14–60 Pump installation



Glossary

The glossary defines some of the specific terms used in this chapter. The listing is not intended to be complete, but should assist in providing a quick reference to many terms that may not be commonly understood.

AASHTO American Association of State Highway Transportation Officials.

ACPA American Concrete Pipe Association, Irving, TX.

AOS Apparent opening size of geotextiles expressed in sieve size or millimeters, sometimes referred to as EOS (effective opening size). The property that indicates approximate largest particle that would pass through a geotextile. AOS O_{95} is the size at which 95 percent of the openings in the geotextile are smaller.

Aquifer A geologic formation that holds and yields useable amounts of water. Aquifers can be classified as confined or unconfined.

Artesian aquifer Aquifer that contains water under pressure as a result of hydrostatic head. For artesian conditions to exist, an aquifer must be overlain by a confining material of aquiclude and receive a supply of water. The free water surface stands at a higher elevation than the top confining layer.

ASTM American Society for Testing and Materials.

Backfilling (drainage) The replacement of the excavated material after drain placement and blinding or envelope installation.

Base drainage system A permeable drainage blanket under a roadway.

Bedding (1) A surface drainage method accomplished by plowing land to form a series of low narrow ridges separated by parallel dead furrows. The ridges are oriented in the direction of the greatest land slope (crowning or ridging). (2)Preparation of furrow-irrigated rowcropped field with wide, flattened ridges between furrows on which one or more crop rows are planted. (3) The process of laying a pipe or other conduit in a trench with the bottom shaped to the contour of the conduit or tamping earth around the conduit to form its bed. The manner of bedding may be specified to conform to the earth load and conduit strength. (4) Material placed under a pipe or other conduit for mechanical support.

Bedding angle The acute angle of a V-groove in the bottom of a trench for support of pipe drains.

Bedding ditch A dead furrow used as a surface drainage ditch in a bedding system.

Berm (1) Strip or area of land, usually level, between the edge of spoil bank and edge of a ditch or canal. (2) A small embankment or ridge for controlling surface waterflow.

Best management practice (BMP) Structural, nonstructural, and managerial techniques recognized to be the most effective and practical means to reduce surface and ground water contamination while still allowing the productive use of resources.

Blind drain Type of drain consisting of an excavated trench, refilled with pervious materials (coarse sand, gravel, or crushed stones) through whose voids water percolates and flows toward an outlet (also called a trench drain).

Blind inlet Surface water inlet to a drain in which water enters by percolation rather than through open flow conduits.

Blinding Material placed on top of and around a drain tile or conduit to improve the flow of water to the drain and to prevent displacement backfilling of trench.

Buffer strip A strip of grass or other close-growing perennial vegetation that separates a watercourse from an intensive land use area to prevent sediment entry into drainage channels (preferred term is filter strip).

Bullet (drainage) Round-nosed cylindrical point of a mole drain plow which forms a cavity as the plow is drawn through the soil (also referred to as a torpedo).

Bypass ditch A waterway for carrying water from a drainage area directly to a gravity outlet, bypassing any pumping plants.

Capillary fringe A zone in the soil just above the water table that remains saturated or almost saturated. The extent depends upon the size-distribution of pores.

Capillary pressure head Height water will rise by surface tension above a free water surface in the soil, expressed as length unit of water. Sometimes called *capillary rise*.

Capillary soil moisture Preferred term is soil-water potential.

Centrifugal pump Pump consisting of rotating vanes (impeller) enclosed in a housing and used to impart energy to a fluid through centrifugal force.

Chain trencher An excavator that uses a chain with cutters attached to cut, remove, and deposit spoil to the side of the trench or on to a discharge conveyor.

Channel capacity Flow rate in a ditch, canal, or natural channel when flowing full or at design flow.

Channel storage drainage The volume of water that can be stored above the start pumping level in ditches or floodways without flooding cropland.

Check drain Conventional drain altered by use of checks so that it can be used as a subirrigation system.

Chimney drain Subsurface interceptor drain frequently used in dams, embankments, and similar construction to control seepage within the earthen structure. Chimney drains are constructed in near vertical orientation and discharge to outlets at lower elevations.

Clay A soil separate consisting of particles less than 2 µm in equivalent diameter.

Clay tile Short lengths of pipe used for subsurface drains. The pipe is made from shale or clay.

Claypan A dense, compact layer in the subsoil having a much higher clay content than the overlying material, separated by a sharply defined boundary. Claypans are usually hard when dry, and plastic and sticky when wet. Also, they usually impede the movement of water and air and the growth of plant roots.

Closed drain Subsurface drain, tile, or perforated pipe, which may also receive surface water through surface inlets (no longer in common use).

Colloidal fines Clay particles smaller than two microns.

Colloids Negatively charged soil particles smaller than 1 µm in diameter.

Cone of depression or influence The water table or piezometric surface, roughly conical in shape, produced by the extraction of water from a well.

Confined aquifer An aquifer whose upper, and perhaps lower, boundary is defined by a layer of natural material that does not transmit water readily.

Controlled drainage Regulation of the water table by means of control dams, check drains, or a combination of these, for maintaining the water table at a depth favorable to crop growth.

Conveyance loss Loss of water from a channel or pipe during transport, including losses caused by seepage, leakage, evaporation, and transpiration by plants growing in or near the channel.

Corrugated plastic pipe Extruded plastic pipe with a corrugated wall and, when perforated, used for subsurface drains.

CMP Corrugated metal pipe.

CPE pipe Corrugated polyethylene drain pipe.

CPP Corrugated plastic pipe.

Crack width Space between the ends of adjacent clay or concrete drain tile.

Cradle A support made of rigid material, such as concrete, wood, or steel, used in unstable soil to maintain grade, support tile or tubing, and prevent deflection of the tubing.

Critical depth Depth of flow in a channel at which specific energy is a minimum for a given discharge.

Critical velocity Flow velocity at which a given discharge changes from tranquil to rapid or rapid to tranquil. That velocity in an open channel for which the specific energy is a minimum for a given discharge.

Cross slope Slope of a field, measured at right angles to the row direction.

Crowning The process of forming the surface of land into a series of broad, low ridges, separated by parallel field drains.

Cutoff drain See Interceptor drain.

Darcy's law A concept formulated by Henry Darcy in 1856 to describe the rate of flow of water through porous media. The rate of flow of water in porous media is proportional to the thickness of the bed and to the hydraulic gradient.

Dead load A permanent load; a load that is constant in magnitude and position, usually for the design life.

Deep percolation Water that moves downward through the soil profile below the root zone and is unavailable for use by plants.

Deflection The change in the vertical inside diameter of a pipe caused by applied loads.

Diversion A channel or dam constructed across a slope to intercept surface runoff and divert it to a safe or convenient discharge point. Usually placed above the area to be protected.

Double ditch or drain See W-ditch.

Double-main system Gridiron layout of subsurface drains with two closely spaced parallel main conduits.

Drain Any closed conduit (perforated tubing or tile) or open channel used for removal of surplus ground or surface water.

Drain inlet structure See Surface inlet.

Drain plow A machine with a vertical blade, chisel point, and shield or boot used to install corrugated plastic tubing or drain tile.

Drain tile Short length of pipe made of burned clay, concrete, or similar material, usually laid with open joints, to collect and remove subsurface water.

Drainable water Water that readily drains from soil under the influence of gravity.

Drainage Process of removing surface or subsurface water from a soil or area.

Drainage basin The area from which runoff is collected and delivered to an outlet.

Drainage coefficient Rate at which water is to be removed from a drainage area, expressed as depth per day or flow rate per unit of area. Sometimes called *drainage modulus*.

Drainage curves Flow rate versus drainage area curves giving prescribed rates of runoff for different levels of crop protection.

Drainage pattern (1) Arrangement of a system of surface or subsurface drains. (2) Arrangement of tributaries within a watershed.

Drainage pumping plant Pumps, power units, and appurtenances for lifting drainage water from a collecting basin to an outlet.

Drainage system Collection of surface and/or subsurface drains, together with structures and pumps, used to remove surface or ground water.

Drainage well (1) A well pumped to lower water table. (2) Vertical shaft to a permeable substratum into which surface and subsurface drainage water is channeled (now illegal).

Drawdown (1) Lowering of the water surface, water table, or piezometric surface resulting from the withdrawal of water from a well or drain. (2) Elevation of the static water level in a well minus the elevation of the pumping water level (at the well) at a given discharge rate (see Cone of depression).

Drop structure Hydraulic structure for safely transferring water in a channel to a lower level channel without causing erosion.

Electrical conductivity A measure of the ability of water to conduct electricity, which is used to estimate the amount of soluble salts in irrigation or drainage water, or solution extract of a soil.

Envelope ***Drain envelope*****—**Generic name for materials placed on or around a drainage conduit, irrespective of whether used for mechanical support, hydraulic purposes (hydraulic envelope), or to stabilize surrounding soil material (filter envelope).
Hydraulic envelope**—**Permeable material placed around a drainage conduit to improve flow conditions in the area immediately adjacent to the drain.
Filter envelope**—**Permeable material placed around a drainage conduit to enhance water entry and stabilize the structure of the surrounding soil material. A filter envelope may initially allow some fines and colloidal material to pass through it and into the drain.

Estuarine inflows The freshwater input necessary to provide nutrient input, sediment movement, circulation, and maintenance of brackish conditions for estrine organisms.

Evapotranspiration The combination of water transpired from vegetation and evaporated from the soil and plant surfaces.

Exchange capacity The total ionic charge of the absorption complex active in the adsorption of ions.

Exchangeable cation A positively charged ion held on or near the surface of a solid particle by a negative surface charge of a colloid and which may be replaced by other positively charged ions in the soil solution.

Exchangeable sodium percentage The fraction of the cation exchange capacity of a soil occupied by sodium ions.

Field capacity Amount of water remaining in a soil when the downward water flow caused by gravity becomes negligible.

Field ditch A ditch constructed within a field either for irrigation or drainage.

Field drain A shallow-graded channel, usually having relatively flat side slopes, that collects surface water within a field.

Field lateral (drainage) The principal ditch for draining adjacent fields or areas on a farm. Field laterals receive water from row drains, field drains, and field surfaces and carry it to drainage outlet channels.

Filter strip Permanent vegetated strip between fields and receiving water or runoff conveyance structures to retard surface runoff and remove sediment, nutrients, or other contaminates from surface runoff.

Fin drain A group of geocomposite drains designed with interior drainage paths to remove relatively large quantities of subsurface drainage water.

Finishing shoe A mechanism attached to or part of excavating equipment that shapes the bottom of a trench and may convey drain tile or tubing to the bottom of the trench (also known as crummer, boot, tile/tubing chute, trench cleaner shoe).

Flashboard Wood plank, generally held horizontally in vertical slots on the crest of a dam or check structure to control the upstream water level. Commonly called stoplog.

Float valve A valve, actuated by a float, that automatically controls the flow of water.

Floating beam drain plow A drain plow in which the installed pipe's depth and grade are controlled by the pitch of the shank and finishing shoe.

Flood control Methods or facilities for controlling flood flows.

Flood gate Mechanical gate to prevent backflow into a closed conduit during high water stages. Sometimes called *drainage gate*.

Flow line Lowest level of flow in a conduit or channel.

Forced outlet Basin or box outlet for a pipe drain in which the discharge will fill the basin and flow away over the ground surface. Used where a freefall outlet is not available.

Forebay Reservoir or pond at the intake of a penstock, pipeline, or pump station.

Free discharge Discharge of water from a conduit into the atmosphere without back pressure.

Free flow Flow through or over a structure without back pressure.

Freeboard Vertical distance between the maximum water surface elevation anticipated in design and the top of retaining banks, pipeline vents, or other structures, provided to prevent overtopping because of unforeseen conditions.

French drain An excavated trench refilled with pervious materials through whose voids water flows toward an outlet (preferred term is *blind drain*).

Friction head Energy required to overcome friction caused by fluid movement relative to the boundaries of a conduit or containing medium.

Friction slope Friction head loss per unit length of conduit.

Frost action Freezing and thawing of moist soil.

Frost depth The depth to which a soil will freeze.

Gap graded A gravel or soil with a significant range of particle sizes missing.

Gate A device used to control the flow of water to, from, or in a pipeline, or open channel. It may be opened and closed by screw action, slide action, or hydraulic or pneumatic actuators.

Geocomposite Geosynthetic materials for collecting and transporting water while maintaining soil stability.

Geomembrane Sheet material intended to form an impervious barrier.

Geosynthetic Synthetic material or structure used as an integral part of a project, structure, or system. Within this category are subsurface drainage and water control materials, such as geomembranes, geotextiles, and geocomposites.

Geotextile A woven or nonwoven thermoplastic sheet material intended to allow the passage of water, but not fines, and without collecting fines at the soil-textile interface.

Grade (noun) Slope of a road, channel, or ground surface. (verb) To finish the surface of a canal bed, roadbed, top of embankment, or bottom of excavation.

Grade breaker A special mechanical device attached to an earthmoving machine to change the normal gradeline.

Grade control The process of maintaining constant and correct slope of a trench, ditch, terrace, canal, etc., using optical or laser surveying equipment.

Gradeline A line established as a construction reference for ditches, terraces, etc.

Grade stabilizing structure Structure used to control the bottom grade of a channel.

Grated inlet A specific type of surface inlet to a pipe drain protected with a grate.

Gravitational water Soil water that moves into, through, or out of the soil under the influence of gravity (preferred term is *soil-water potential*).

Gravity flow Water flow that is not pumped, but flows because of the acceleration forces of gravity. Used in irrigation, drainage, inlets, and outlets.

Ground water Water occurring in the zone of saturation in an aquifer or soil.

Ground water flow Flow of water in an aquifer or soil. That part of the stream discharge that is derived from ground water.

Hardpan (soil) A hardened soil layer, in the lower A or B horizon, caused by cementation of soil particles.

Head The energy in the liquid system expressed as the equivalent height of a water column above a given datum.

Herringbone system Arrangement of a pipe drainage system where laterals enter a main from both sides at angles less than 90 degrees.

Humid climates Climate characterized by high rainfall and low evaporation potential. A region is usually considered as humid when precipitation averages more than 500 mm (20 in) per year.

Hydraulic conductivity The ability of a porous medium to transmit a specific fluid under a unit hydraulic gradient; a function of both the characteristics of the medium and the properties of the fluid being transmitted. Usually a laboratory measurement corrected to a standard temperature and expressed in units of length/time. Although the term hydraulic conductivity is sometimes used interchangeably with the term permeability (water), the user should be aware of differences.

Hydraulic efficiency (1) Efficiency with which a pump imparts energy to water or a turbine extracts energy from water. (2) A measure of the loss of energy when water flows through a hydraulic structure.

Hydraulic gradient Change in the hydraulic head per unit distance.

Hydraulic radius Cross-sectional area of a fluid stream of conduit divided by its wetted perimeter (length of its conduit surface in contact with fluid).

Hydrological profile The profile of hydraulic conductivity values for soil layers or horizons located below the water table.

Hydrology Science dealing with water of the world, including distribution, and cycle in nature.

Impermeable barrier layer A soil stratum with a permeability less than 10 percent of the soil permeability between the layer and the groundwater surface.

Infiltration The downward entry of water through the soil surface into the soil.

Infiltration rate The quantity of water that enters the soil surface in a specified time interval. Often expressed in volume of water per unit of soil surface area per unit of time.

Inlet (1) An appurtenance to deliver water to a pipeline system. (2) Point of defined inflow into a conduit or channel.

Innerflow Having hydraulic flow capability in all directions within a strata or layer of material.

Instream flow requirements The flow regime necessary to provide for the combined needs of fish, wildlife, recreation, navigation, hydropower production, and downstream conveyance in a stream.

Intake (1) Head-works of a conduit. (2) The place of diversion. (3) Water infiltration into soil.

Interception That portion of precipitation caught by vegetation and prevented from reaching the soil surface.

Interceptor drain A channel located across the flow of ground water and installed to collect subsurface flow before it resurfaces. Surface water is also collected and removed.

Interflow Water that infiltrates into the soil and moves laterally through the upper soil horizons until it returns to the surface, often in a stream channel.

Intermittent stream Natural channel in which water does not flow continuously.

Internal drainage Drainage of the soil profile; may be either natural or constructed.

Intrinsic permeability The property of a porous material that expresses the ease with which gases or liquids flow through it (see Permeability).

Invert Lowest element of the internal cross section of a channel or pipe.

Iron ochre A reddish or yellowish brown gelatinous deposit formed by iron fixing bacteria. The gelatinous material hardens into a scale deposit with age.

Isotropic (soil) The condition of a soil or other porous media when physical properties, particularly hydraulic conductivity, are equal in all directions.

Joint spacing Width of gap between adjacent rigid drain tiles through which water enters from the surrounding soil.

Joint wrapping Placement of porous material over or around the pipe joints of subsurface drains to help prevent inflow of sediment.

Junction (1) Point of intersection of two drains. (2) Accessory used to create a connection between two pipelines.

Junction box Box, manhole, or other structure that serves to join two or more pipes.

Keel Longitudinal strip attached at the center bottom of the shoe of a trenching machine to form the trench bottom.

Laminar flow Flow in which there are no cross currents of eddies and where the fluid elements move in approximately parallel directions. Flow through granular material is usually laminar. Sometimes called *streamline* or *viscous flow*.

Land capability Classification of soil units for the purpose of showing their relative suitability for specific uses, such as crop production with minimum erosion hazard.

Land leveler A machine with a long wheel base used for land smoothing or leveling operations.

Land leveling Process of shaping the land surface to a level surface. A special case of land grading.

Land smoothing Shaping the land to remove irregular, uneven, mounded, broken, and jagged surfaces without using surveying information.

Land use planning Development of plans for the use of land that will, over a long period, best serve the interest of the general public.

Landgrading The operation of shaping the surface of land to predetermined grades so each row or surface slopes to a drain or is configured for efficient irrigation water applications. Also called *land forming* or *land shaping* (see **Land leveling** for a special case).

Laser leveling Land leveling in which a stationary laser transmitter and a laser receiver on each earthmoving machine are used for grade control.

Laser receiver An electronic device normally mounted on earthmoving machines, survey rods, or trenchers that receives signals from a laser transmitter and indicates to the operator or sends signals to control points on the machine to adjust the machine to follow the slope established by a laser transmitter.

Laser transmitter A device that generates the collimated laser light beam.

Lateral Secondary or side channel, ditch, or conduit. Also called *branch drain* or *spur*.

Leaching Removal of soluble material from soil or other permeable material by the passage of water through it.

Leaching fraction The ratio of the depth of subsurface drainage water (deep percolation) to the depth of infiltrated irrigation water (see leaching requirement).

Leaching requirement Quantity of irrigation water required for transporting salts through the soil profile to maintain a favorable salt balance in the root zone for plant development.

Live load A load that changes in magnitude and/or direction during the project design life.

Longitudinal drainage system A drainage system parallel to a roadway, runway, or other structural component.

Longitudinal smoothing Land smoothing operation where all soil movement is done parallel to crop row direction for the purpose of obtaining a grade.

Mole drain Drain formed by pulling a vertical blade and a bullet-shaped cylinder through the soil.

Normal depth Depth of flow in an open channel during uniform flow for the given conditions.

O&M Operation and maintenance.

Observation well Hole bored to a desired depth below the ground surface for observing the water table level.

Open ditch outlet Excavated open channel for disposing of drainage water from a surface or subsurface drainage system, or for carrying flood water.

OSHA Occupational Safety and Health Administration, the Federal agency responsible for safety and health concerns.

Outfall Point where water flows from a conduit, stream, or drain.

Outlet (1) An appurtenance to deliver water from a pipe system to the land, an individual sprinkler, lateral of sprinklers, or any surface pipe system. An outlet may consist of a valve, a riser pipe, and/or an outlet gate. (2) Point of water disposal from a stream, river, lake, tidewater, artificial drain, terrace, waterway, or diversion.

Outlet channel Channel constructed primarily to carry water from manufactured structures, such as terraces, subsurface drains, surface ditches, and diversions.

Outlet gate A valve, usually a slide valve, that controls the flow of water from an outlet.

Parallel drainage system A drainage system with parallel laterals or field ditches that are perpendicular to the row drains.

Particle-size analysis Determination of the various amounts of the different separates in a soil sample, usually by sedimentation, sieving, or micrometry.

Perched water table A localized condition of free water held in a pervious stratum because of an underlying impervious stratum and seperated from deeper aquifers.

Percolating water Subsurface water that flows through the soil or rocks (see Seepage).

Percolation Downward movement of water through the soil profile or other porous media.

Percolation rate The rate at which water moves through porous media, such as soil.

Perforated pipe Pipe designed to discharge or accept water through small, multiple, closely spaced orifices placed in its circumference.

Permeability (1) (qualitative) The ease with which gases, liquids, or plant roots penetrate or pass through a layer of soil or porous media. (2) (quantitative) The specific soil property designating the rate at which gases and liquids can flow through the soil or porous media.

Permeameter Device for containing the soil sample and subjecting it to fluid flow to measure permeability or hydraulic conductivity.

Permissible velocity Highest water velocity in a channel or conduit that does not cause erosion.

Permittivity A measure of the ability of a geotextile to permit waterflow perpendicular to its plane. (The volumetric flow rate of water per unit cross–sectional area per unit head.)

Phreatic surface The level of zero (atmospheric) pressure at water table surface.

Piezometer Tube for measuring the combined elevation and pressure head or potential of a fluid.

Piezometric head Combined elevation and pressure head as measured from a reference plane (see Static head).

Piezometric line or surface Line or surface having equal piezometric head.

Pipe drain Any circular subsurface drain, including corrugated plastic pipe and concrete or clay tile.

Pipe drainage system Random, systematic or interceptor layout of subsurface drains, including the outlet, drain lines, and related structures.

Pipe or tile depth Vertical distance from the soil surface to the gradeline or bottom (invert) of a pipe or drain tile.

Pipe stretch Associated with corrugated plastic pipe. Pipe strength is reduced if the pipe is installed in a stretched condition.

Pore size index The characteristic pore opening size, expressed in mm or sieve size, of a geotextile where 90 percent of the openings in the geotextile are smaller (the O_{90} value).

Porosity (1) (aquifer) The sum of the specific yield and the specific retention. (2) (soil) The volume of pores in a soil sample divided by the combined volume of the pores and the soil of the sample.

Pre-ripping The practice of making a pass with a drain plow without installing tubing to locate any rocks and to reduce draft. Typically, the pre-ripping depth is somewhat less than the installation depth.

Preferential flow Flow into and through porous media or soil by way of cracks, root holes, and other paths of low resistance rather than uniformly through the whole media.

Pump drainage Drainage system in which pumps are used to lift water into an outlet.

Pump efficiency Ratio of the water power produced by the pump to the power delivered to the pump by the power unit.

Pump submergence Vertical distance between surface of the water supply and the inlet of the pump.

Pumped well drain Well drilled into an aquifer that is pumped to lower the water table.

Pumping plant or station A complete installation of one or more pumps together with all necessary appurtenances, such as power units, sumps, screens, valves, motor controls, motor protection devices, fences, and shelters.

Quick condition Condition in which water flows through the soil material (upward or horizontally) with sufficient velocity to significantly reduce the bearing capacity of the material through a decrease in intergranular pressure. Sometimes called *quicksand*.

Radial flow (1) Flow from a source or to a sink along radial lines. (2) Direction of flow in a centrifugal pump.

Radial-flow pump A centrifugal pump that uses diffuser vanes to transform the velocity head into pressure head. Commonly called a *turbine pump*.

Radius of influence Maximum distance from a well at which drawdown is significant (see Cone of depression).

Rainfall intensity Rate of rainfall for any given time interval, usually expressed in units of depth per time.

Random drainage system Surface or subsurface drainage system of irregular pattern used on depressional topography.

Receiving water Distinct bodies of water, such as streams, lakes, or estuaries, that receive runoff or wastewater discharge.

Recharge Process by which water is added to the zone of saturation to replenish an aquifer.

Recharge area Land area over which water infiltrates and percolates downward to replenish an aquifer. For unconfined aquifers, the area is essentially the entire land surface overlaying the aquifer and for confined aquifers, the recharge area may be a part of or unrelated to the overlaying area.

Rectangular weir A channel structure having a rectangular flow notch.

Relief drain system A system of subsurface drain tiles or tubing, installed within an area having a high water table, to lower the water table or maintain it at a given level.

Relief drain Any product or construction that accelerates the removal of drainable subsurface water to lower a water table.

Relief well Shallow well, pit, or bore to relieve hydrostatic pressure by allowing waterflow from a confined aquifer or from saturated soil.

Resistance coefficient A quantitative expression of hydraulic resistance exerted by a conduit boundary on fluid flow. Examples are **n**, **C**, and **f** in the Manning, Chezy, and Darcy-Weisbach equations for velocity of uniform flow (also called *roughness coefficient*).

Resource management system A combination of conservation practices and management identified by land and water uses that, when implemented, prevents resource degradation and permits sustained use of soil, water, air, plants, and animal resources.

Riverside drain Drain adjacent to a riverbed to a point downstream where water can be discarded above the mean high water level of the river.

Root zone Depth of soil that plant roots readily penetrate and in which the predominant root activity occurs.

Roughness coefficient See Resistance coefficient.

Row drain A small drain constructed with a plow or similar tillage implement to provide drainage into field drains or field laterals. Sometimes locally called *plow drain, quarter drain, header ditch,* or *annual drain*.

Runoff The portion of precipitation, snowmelt, or irrigation that flows over the soil, eventually making its way to surface water supplies.

Runoff coefficient Ratio of peak runoff rate to rainfall intensity.

Runoff duration Elapsed time between the beginning and end of a runoff event.

Saline-sodic soil Soil containing sufficient exchangeable sodium to interfere with the growth of most crops and containing appreciable quantities of soluble salts. The exchangeable sodium percentage is greater than 15, the electrical conductivity of the saturation extract is greater than 4 mS/cm (0.01 mho/in), and the exchangeable sodium percentage is less than 15.

Saltation Soil movement by water or wind where particles skip or bounce along the streambed or soil surface.

Sand Soil particles ranging from 50 to 200 μm in diameter. Soil material containing 85 percent or more particles in this size range.

Sand lens Lenticular band of sand in distinctly sedimentary banded material.

Saturated flow Flow of water through a porous material under saturated conditions.

Saturation point The water content at which a soil or aquifer will no longer absorb any water without losing an equal amount.

Seepage The movement of water into and through the soil from unlined canals, ditches, and water storage facilities.

Semiarid climate Climate characterized as neither entirely arid nor humid, but intermediate between the two conditions. A region is usually considered as semiarid when precipitation averages between 250 mm (10 in) and 500 mm (20 in) per year.

Side inlet (drainage) A facility to safely convey surface water into a lateral or main drain.

Side slopes Slope of the sides of a channel or embankment, horizontal to vertical distance (written 2:1).

Silt (1) A soil separate consisting of particles between 2 and 50 μm in diameter. (2) (colloquial) Deposits of sediment that may contain soil particles of all sizes.

Silt bar A deposition of sediment in a channel.

Sink A relatively small surface depression that allows surface drainage to enter the subsurface soil water system.

Siphon drain Sealed drain where atmospheric pressure forces water over an intervening elevation into an outlet at a level lower than the inlet.

Sodic soil A nonsaline soil containing sufficient exchangeable sodium to adversely affect crop production and soil structure. The exchangeable sodium percentage is greater than 15 and the electrical conductivity of the saturation extract is less than 4 mS/cm (0.01).

Sodium adsorption ratio (SAR) The proportion of soluble sodium ions in relation to the soluble calcium and magnesium ions in the soil water extract (can be used to predict the exchangeable sodium percentage).

Sodium percentage Percentage of total cations that is sodium in water or soil solution.

Soil The unconsolidated minerals and material on the immediate surface of the Earth that serves as a natural medium for the growth of plants.

Soil aeration Process by which air and other gases enter the soil or are exchanged.

Soil compaction Consolidation, reduction in porosity, and collapse of the structure of soil when subjected to surface loads.

Soil conservation Protection of soil against physical loss by erosion and chemical deterioration by the application of management and land use methods that safeguard the soil against all natural and human-induced factors.

Soil erodibility A measure of the soil's susceptibility to erosional processes.

Soil erosion Detachment and movement of soil from the land surface by wind or water.

Soil horizon A layer of soil differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics.

Soil organic matter Organic fraction of the soil, including plant and animal residue in various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population.

Soil profile Vertical section of the soil from the surface through all its horizons into the parent material.

Soil series The lowest category of U.S. system of soil taxonomy. A conceptualized class of soil bodies having similar characteristics and arrangement in the soil profile.

Soil structure The combination or arrangement of primary soil particles, into secondary particles, units, or peds that make up the soil mass. These secondary units may be, but usually are not, arranged in the profile in such a manner as to give a distinctive characteristic pattern. The principal types of soil structure are platy, prismatic, columnar, blocky, and granular.

Soil texture Classification of soil by the relative proportions of sand, silt, and clay present in the soil.

Soil water All forms of water in the soil.

Soil-water characteristic curve Soil-specific relationship between the soil-water matric potential and soil-water content.

Soil-water potential The amount of work that must be done per unit quantity of pure water to transport reversibly and isothermally an infinitesimal quantity of water from a pool of pure water at a specified elevation at atmospheric pressure to the soil water at the point under consideration.

Specific retention Amount of water that a unit volume of porous media or soil, after being saturated, will retain against the force of gravity (compare to specific yield).

Specific yield Amount of water that a unit volume of porous media or soil, after being saturated, will yield when drained by gravity (compare to specific retention).

Spillway Conduit through or around a dam or dike for the passage of excess water.

Spoilbank Excavated soil piled along a canal, ditch, or basin.

Stabilized grade Slope of a channel at which neither erosion nor deposition occurs.

Staff gage Graduated scale, generally vertical, from which the water surface elevation may be read.

Stage Elevation of a water surface above or below an established datum gauge height.

Start trench The excavation performed at the beginning of the installation of a drain to establish grade and permit entry to install tubing, outlet pipe, or junctions (also known as *start hole* or *pilot hole*).

Static head The potential energy resulting from elevation differences (see Head).

Static lift Vertical distance between source and discharge water levels in a pump installation.

Steady flow Open channel flow in which the rate and cross-sectional area remain constant with time at a given station.

Storage coefficient See Specific yield.

Stratified soils Soils that are composed of layers usually varying in permeability and texture.

Stretch (drainage) The percent increase in length of drain tubing caused by bending or tension forces during installation.

Subgrade Earth material beneath a subsurface drain or foundation.

Subirrigation Application of irrigation water below the ground surface by raising the water table to within or near the root zone.

Subsoiling Tillage operation to loosen the soil below the tillage zone without inversion and with a minimum of mixing with the tilled zone.

Subsurface drain Subsurface conduits used primarily to remove subsurface water from soil. Classifications of subsurface drains include pipe drains, tile drains, and blind drains.

Subsurface drain storage Volume of water that can be stored in the subsurface pipeline without reducing the effectiveness of the pipe or tile drain.

Subsurface water Water beneath the ground or pavement surface. Sometimes referred to as ground water or soil water.

Suction lift Vertical distance between the elevation of the surface of the water source and the center of the pump impeller.

Surface collecting drains Ditches used to remove pondages, and move water more rapidly into outlet drains.

Surface drainage The diversion or orderly removal of excess water from the surface of land by means of improved natural or constructed channels, supplemented when necessary by shaping and grading of land surfaces to such channels.

Surface inlet Structure for diverting surface water into an open ditch, subsurface drain, or pipeline.

Surface runoff Precipitation, snowmelt, or irrigation in excess of what can infiltrate and be stored in small surface depressions.

Surface sealing Reorienting and packing of dispersed soil particles in the immediate surface layer of soil and clogging of surface pores resulting in reduced infiltration.

Surface soil The uppermost part of the soil, ordinarily moved in tillage, or its equivalent in uncultivated soils, ranging in depth from 10 to 20 cm (4 to 8 in). Sometimes called *soil management zone*.

Surface storage Sum of detention and channel storage excluding depression storage. Represents at any given moment the total water enroute to an outlet from an area or watershed.

Surface water Water flowing or stored on the Earth's surface.

Swelling (soil) Physical expansion of the soil mass in an expanding type clay, usually caused by an increase in water content.

Three-edge bearing test A test used to determine the strength of concrete pipe, stated in force per unit length.

Tidal gate Gate that allows flow of drainage water seaward at low tide and prevents return flow at high tide. Sometimes called a *sea gate*.

Tile alignment Degree to which the centerline of a tile falls in line with the centerline of adjacent tiles.

Tile cradle Support laid underneath a tile line in unstable soil to keep horizontal and vertical alignment of the tile line.

Tile density Quality of a tile that determines its crushing strength and its ability to resist water absorption and damage by freezing and thawing.

Tile drain Drain constructed by laying drain tile with unsealed joints in the bottom of a trench that is then refilled. Tile is generally constructed of clay or concrete.

Tile joint Opening between two drain tiles through which water from the surrounding soil flows (compare with crack width).

Tile probe A hand tool consisting of a rod with a tee handle on one end and an enlarged point on the other end. The tool is pushed or driven into the soil to locate pipe, tile, tubing, or a trench.

Top width Horizontal distance across the top of a ditch or embankment.

Torpedo Channel forming head of a mole plow (preferred term is bullet).

Total dynamic head Head required to pump water from its source to the point of discharge; equal to the static lift plus head losses in pipes and fittings plus the increase in velocity head.

Total suction head Head required to lift water from the water source to the centerline of the pump plus velocity head, entrance losses, and friction losses in suction pipeline.

Trailing plug Plug following the mole plow torpedo, smoothing and strengthening the wall of the mole channel (see Mole drain or Bullet).

Transverse drainage system A drainage system usually at some angle to a roadway.

Trench box A box-like piece of equipment placed in a trench to prevent collapse of the sides of the trench and thereby provide safe working conditions.

Turbine pump A type of pump having one or more stages, each consisting of an impeller on a vertical shaft, surrounded by stationary and usually symmetrical guide vanes. Combines the energy-imparting characteristics of axial-flow and propeller pumps.

Twin ditch See W-ditch.

Unavailable soil water That portion of water in a soil held so tightly by adhesion and other soil forces that it cannot be absorbed by plants rapidly enough to sustain growth. Soil water at permanent wilting point.

Unconfined aquifer An aquifer whose upper boundary consists of relatively porous natural material that transmits water readily and does not confine water. The water level in the aquifer is the water table.

Underlayment Something laid underneath a drain pipe, such as gravel or stone bedding material.

Unsaturated flow Movement of water in soil in which the pores are not completely filled with water.

Unsaturated zone That part of the soil profile in which the voids are not completely filled with water.

USBR United States Bureau of Reclamation, U.S. Department of the Interior.

USCS Unified Soil Classification System.

Vadose zone Zone of unsaturated soil that extends from the soil surface to the ground water table.

Velocity head Head or energy resulting from the velocity of a moving fluid; equal to the square of the mean velocity divided by twice the gravitational acceleration.

Vent An appurtenance to a pipeline that permits the passage of air to or from the pipeline.

Vertical drain Vertical shaft to a permeable substratum into which surface and subsurface drainage water is channeled.

W-ditch Two closely spaced, parallel, single channels having the spoil from construction placed between them. To permit unimpeded runoff into them from surrounding lands. Sometimes called a W-drain.

Water table The upper limit of a free water surface in a saturated soil or underlying material.

Water table management The control of ground water levels by regulating the flow of water in the controlled drainage and subirrigation modes.

Weir (1) Structure across a stream to control or divert the flow. (2) Device for measuring the flow of water. Classification includes sharpcrested or broadcrested with rectangular, trapezoidal, or triangular cross section.

Weir head Vertical distance from the crest of a weir to the water surface in the forebay above the weir, not including the velocity head of approach.

Weir pond or box Pond upstream from a weir generally used to reduce the velocity of approach and allow for full contraction of flow for measurement purposes. Also acts as a trap.

Well casing Pipe installed within a borehole to prevent collapse of sidewall material, to receive and protect pump and pump column, and to allow waterflow from the aquifer to pump intake.

Well development The process of removing fine formation materials or materials introduced during well construction from the well intake zone for the purpose of stabilizing and increasing the permeability of the well intake zone and the filter pack material.

Well efficiency Ratio of theoretical drawdown to measured drawdown. Theoretical drawdown is estimated from adjacent observation well data obtained during well test.

Wetted perimeter Length of the wetted contact between a conveyed liquid and the open channel or closed conduit conveying it, measured in a plane at right angles to the direction of flow.

Wheel trencher An excavator that uses a rigid round wheel with attached buckets and cutters to carry spoil out of the trench. It may include a conveyor or slide to deposit spoil to one or both sides of the trench.