5.3.5 Horton Equations

Permeabilities and rates of soil infiltration, will fluctuate with time and location. Laboratory and field experiments are performed to determine rates. Since permeabilities can vary over a range from 10^{-7} cm/sec for sandy clays to 10^{-2} cm/sec for loose sands, the designer is confronted with many decisions. Laboratory testing using constant or falling head parameters usually are of limited value since there is usually too much soil disturbance and the laboratory boundary conditions and gradients are often different from those in the field. Field testing using borehole or percolation tests is more reliable than laboratory testing for small (<2000 m^2) areas, but care must be taken to ensure representative testing locations.

For large percolation/recharge basins or areas, considerably more geotechnical surveying and analysis are necessary. Factors involved in such works are discussed by Walton (1970). A fairly reliable percolation test for use in small retention/detention pond design is the double-ring infiltrometer (Chow, 1964). A double-ring infiltrometer is simply a 55-gal drum as an outer ring with a 10 in. or 12 in. inner ring. Example results of these percolation tests are shown in Table 5.12.

TABLE 5.12 Double-Ring[a] Infiltrometer Results for Horton Infiltration Parameters

SITE	TEST NO.	INITIAL WATER DEPTH IN DRUM (in.)	f_o (in./hr)	f_c (in./hr)	K (hr^{-1})	USDA[b] PERMEABILITY (in./hr)
Wimbledon Park	1	2.0	20	6.3	49.1	10 → 20 +
(Lakeland-Blanton)	2	3.7	32	7.8	36.9	in./hr
	3	5.9	60	13	48.8	
	4	8.3	29	13	25.1	
	5	10.2	40	16	16.6	
	6	11.0	55	19.4	15.4	
Cross Creek	1	3.1	1.25	0.19	8.0	<10 in./hr
(Lakeland-Blanton	2	3.5	0.84	0.26	5.3	
with some organics)	3	3.5	0.65	0.08	2.3	
	4	3.6	1.57	0.19	4.1	
	5	3.6	2.6	0.42	8.4	
	6	5.0	1.2	0.26	0.8	
	7	5.9	1.05	0.13	6.0	
Lake Nan	1	3.9	3.4	0.57	4.0	5 → 10
(Blanton-Pomello-Plummer)	2	5.9	2.3	0.73	6.0	in./hr
	3	9.1	2.4	0.56	8.4	
	4	9.8	5.1	0.83	6.8	

Source: Beaver, 1977.
[a]ASTM D3385-76 Procedure.
[b]From Seminole County, Florida Soil Survey Supplement. Soil Conservation Service. U.S. Department of Agriculture. September 1975.

Beaver (1977) found using an infiltrometer, that infiltration can be represented by Horton's equation (Horton, 1939, 1940). This method gives an expression for time-varying infiltration. The Horton equation is shown as Equation 5.2B and drawn as shown in Figure 5.12. Also, in Figure 5.12, the rate of precipitation is compared to the rate of infiltration. The volume of infiltration is the area under the infiltration curve and the volume of rainfall is the area under the rainfall intensity curve.

$$f(t) = f_c + (f_o - f_c)e^{-Kt} \tag{5.28}$$

where

$f(t)$ = infiltration rate as a function of time cm/hr (in./hr) or other consistent ones
f_c = final, or ultimate, infiltration rate—for a hydraulic gradient of unity, this is analogous to the soil permeability
f_o = initial infiltration rate
K = recession constant (hr^{-1}) or other consistent units
t = time-units compatible with K

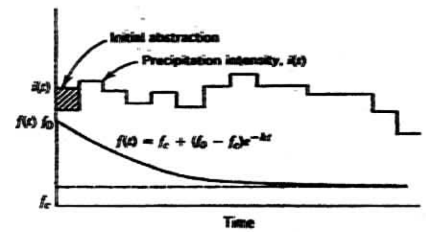


FIGURE 5.12 Infiltration (exponential decay).

The total volume of infiltrate using Horton's equation is determined by integrating the area under the curve, or

$$F = \int_0^t f(t)\,dt = f_c t + \frac{(f_o - f_c)}{K}(1 - e^{-Kt}) \tag{5.29}$$

where F = total infiltration volume, cm (in.) or other consistent units.

During a rainfall event, the application of Equation 5.29 has to be adjusted because rainfall intensity may be lower than the rate of water infiltration potential. Also, another empirical formulation by Holtan et al. (1975) or the theoretical equations of Green and Ampt (1911) also may provide a more accurate fit to the field observed data.

Figures 5.13 and 5.14 illustrate the results of one specific infiltrometer test on a pond floor at Cross Creek in Maitland, Florida (Beaver 1977). The Cross Creek basin has an approximate 280-m^3 (10,000-ft^3) volume capacity, and the site covers less than 0.25 ac. The bottom soils would be classified as Lakeland–Blanton fine sands using USDA criteria. There were slight organics in the surface soils. Field samples indicate a porosity of 33 to 35%, a coefficient of uniformity of 2 to 3 and an effective grain size (D_{10}) of 0.10 to 0.13 mm. Figure 5.13 is plotted from field infiltrometer tests while Figure 5.14 is derived by differentiating the infiltration curve of Figure 5.13.

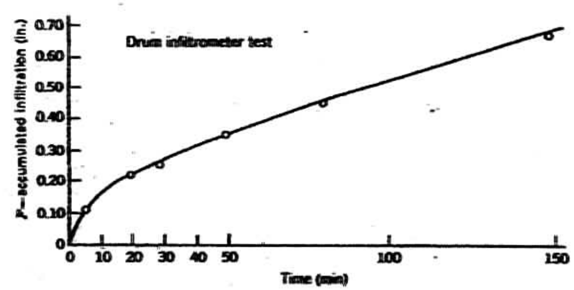
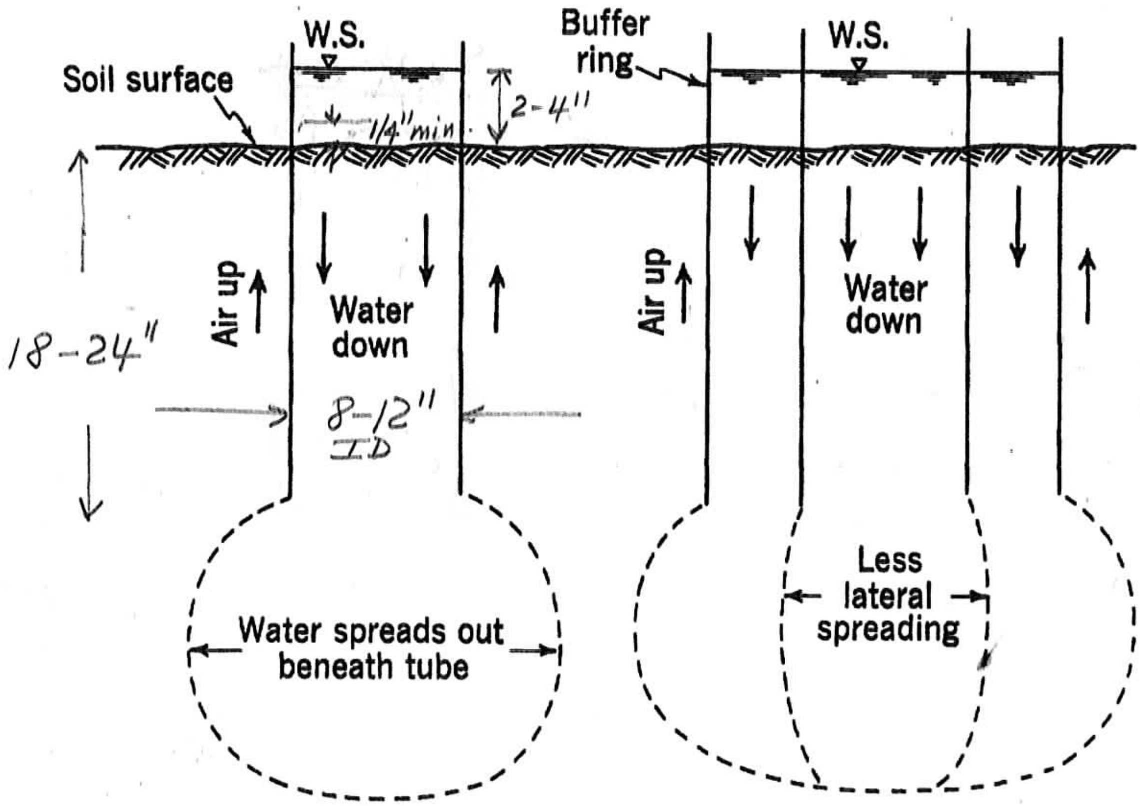


FIGURE 5.13 Example site-specific accumulated infiltration.

Source: Wanielista, M., R. Kersten, and R. Eaglin
Hydrology, Water Quantity & Quality Control
John Wiley & Sons, 1997



(a) Higher rates (b) More realistic rates

FIGURE 14.4
Ring infiltrometer: (*a*) single ring; (*b*) double ring.

Take several measurements
∴ Get average ± SD.

Source: Water Resources Engineering, Linsley/Franzini/Freyberg/Tchobanouglous, McGraw-Hill. 1992

t	I	$f = I/\Delta t$	OBSERVATIONS
0'–2	3	3/2 = 1.5	
2–4	2	2/2 = 1.0	
4–6	1	1/2 = 0.5	
↓		↓	
14–16	0.05	0.05/2 = 0.025	