FACH
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Infiltration and Runoff

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Content

Objectives

Understand Infiltration Processes

- Fundamental soil physics
- Know most important formulae
- Know measurement techniques
- Understand relevance for hydrology
- Be able to apply infiltration models

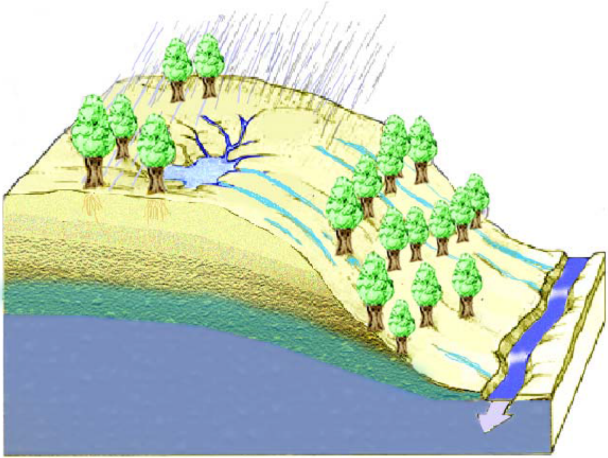
Infiltration
Switch in Flowpaths

Infiltration is an important switch in hydrological flow paths, dividing precipitation into surface flows and subsurface flows.

$$Q_s = P - I\,[\mathrm{mm}]$$

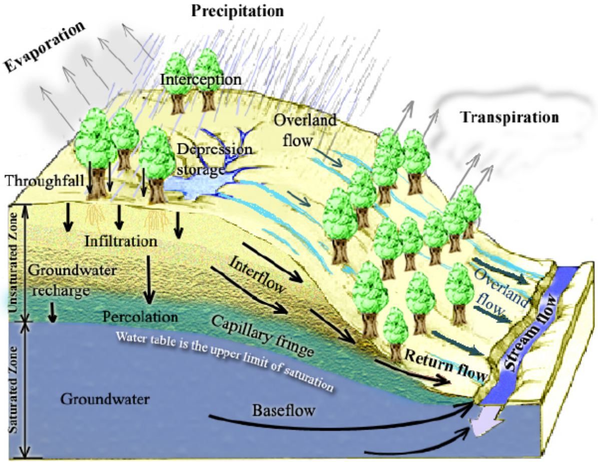
mit Q_s = surface runoff in mm, P Precipitation, I Infiltration in mm.

Infiltration and runoff



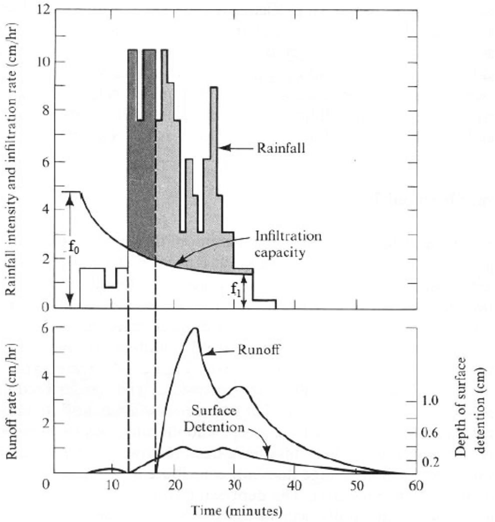
Tarboton, 2003

Infiltration and runoff



Tarboton, 2003

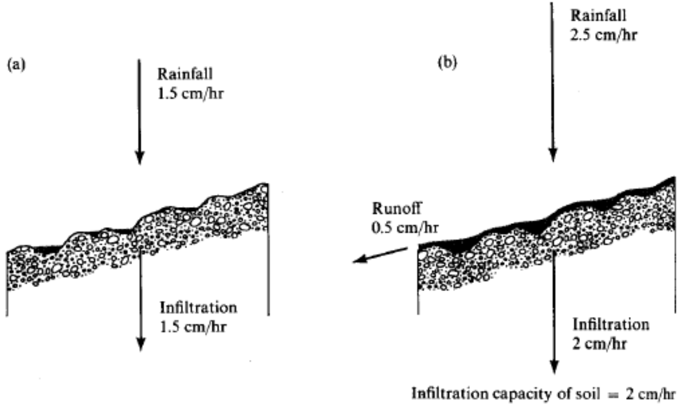
Infiltration and runoff



Dunne & Leopold, 1997

- Infiltration rate decreases
- Approaches constant value

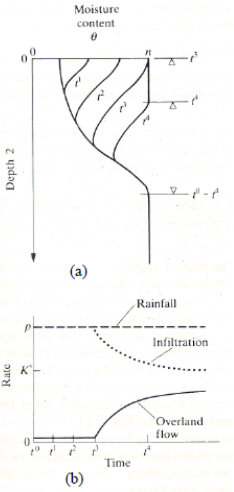
Infiltration and runoff



Dunne & Leopold, 1997

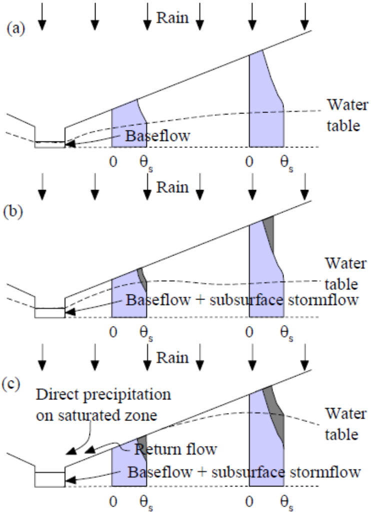
- $P > I$ infiltration and runoff
- $P <= I$ infiltration, no runoff

Infiltration and runoff



Bras, cited in Tarboton, 2003

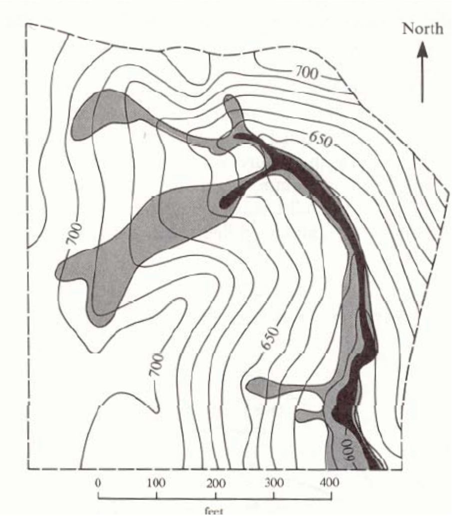
Infiltration and runoff



Tarboton, 2003

- Infiltration saturates soil
- Saturated soil produces runoff
- Floodplain turns into runoff producing area

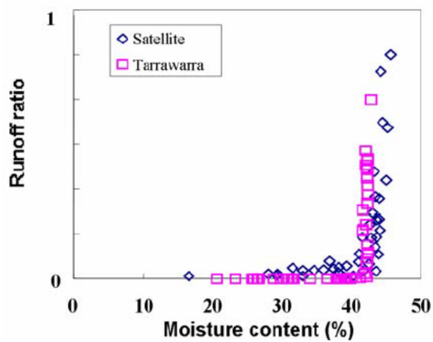
Infiltration and runoff



Dunne & Leopold, 1997

- Saturated area near rivers
- Runoff producing areas
- High correlation of moisture with runoff coefficient

Infiltration and runoff



Relationship between runoff ratio and soil moisture content (Woods et al., 2001, Copyright, 2001, American Geophysical Union, reproduced by permission of American Geophysical Union).

Tarboton, 2003

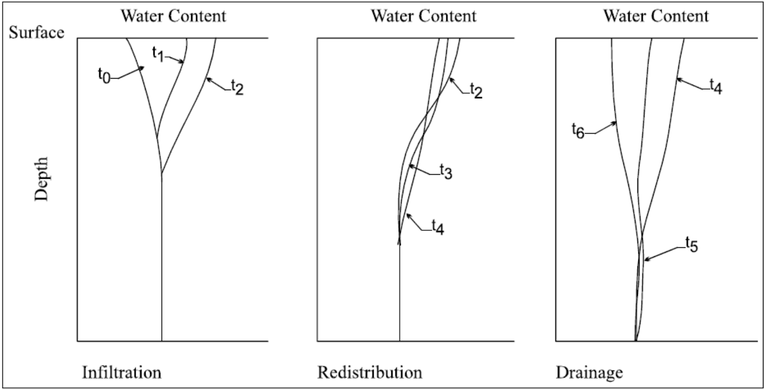
Transmission losses

Flood wave advancing over a dry streambed in Walnut Gulch experimental watershed where channel transmission losses are considerable (Courtesy of David Goodrich, USDA-ARS).

Goodrich, USDA cited in Tarboton, 2003

Infiltration models

Infiltration and Drainage



Kostiakov Infiltration Equation

Kostiakov (1932) and Lewis (1938) proposed an empirical infiltration equation based on curve fitting from field data:

$$f_p = K_k * t^{-\alpha}$$

with	f_p	infiltration	$[L/T]$
	K_k	infiltration capacity	$[L]$
	α	constant	$[-]$
	t	time since infiltration	$[T]$

Problems: converges to 0 with $t \rightarrow \infty$. This flaw can be compensated by introducing an extra term $+f_{fin}$ as the final infiltration rate.

Smith & Parlange Infiltration Equation

Smith & Parlange developed an infiltration formula for variable rainfall rates:

$$i_s = K_s * \left[1 + \frac{\alpha}{exp(\alpha * F/B) - 1}\right]$$

with	i_s	infiltration rate	$[L/T]$
	K_s	conductivity	$[L]$
	α	constant	$[-]$
	F	Infiltration amount	$[L]$
	B	parameter	$[L]$

Haverkamp Infiltration Equation

Haverkamp et al. (1994) proposed for infiltration :

$$I_{3D} = S_0 * t^{1/2} + \left[K_n + \frac{\gamma * S_0^2}{r_d * (\theta_0 - \theta_n)} + \frac{1}{3} * (K_0 - K_n) * (2 - \beta) \right] * t$$

with			
	I_{3D}	infiltration amount	$[L]$
	S_0	sorptivity	$[1/L]$
	K_n	conductivity at current moisture θ_n	$[L/T]$
	K_0	conductivity at initial moisture θ_0	$[L/T]$
	β	shape parameter	$[L]$
	γ	parameter	$[L]$
	r_d	disc diameter	$[L]$

Philip Infiltration Formula
Infiltration Amount

Philip wrote a famous paper on the theory of infiltration in 1969: Philip J R. Theory of infiltration. Advan. Hydrosci. 5:215-96, 1969. [Division of Plant Industry, CSIRO, Canberra, Australia]

$$I = S * \sqrt{t} + a * t$$

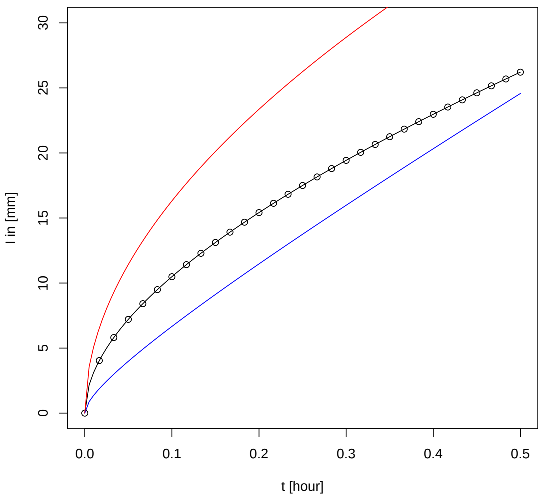
with	I	infiltration amount	$[mm]$
	S	sorptivity	$[mm/h^{-0.5}]$
	a	hydraulic conductivity	$[mm/h]$
	t	time	$[hours]$

R program

The infiltration formula can be plotted using an R program.

```
S <- 30 # mm
a <- 8  # mm/hour
t <- seq(0,0.5,by=1/60.0)
I <- S*t^(0.5)+a*t
plot(t,I)
```

R program of infiltration amount (Philip)



- example with S=30 mm, a=10 m/hour
- low, infiltration rate, high sorption (red)
- high infiltration rate, low sorption (blue)

Philip Infiltration Formula
Infiltration rate

The infiltration rate i in mm per time can be derived from the derivation of the Philip formula for infiltration amount (or vice vs. amount by integration of rate):

$$i = \frac{1}{2} * S * t^{-0.5} + a$$

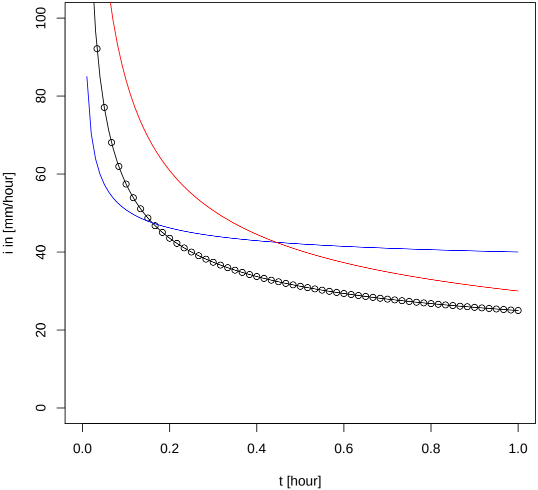
with			
	i	infiltration rate	$[mm/h]$
	S	sorptivity	$[mm/h^{-0.5}]$
	a	hydraulic conductivity	$[mm/h]$
	t	time	$[h]$

R program

The infiltration rate formula can be plotted using an R program.

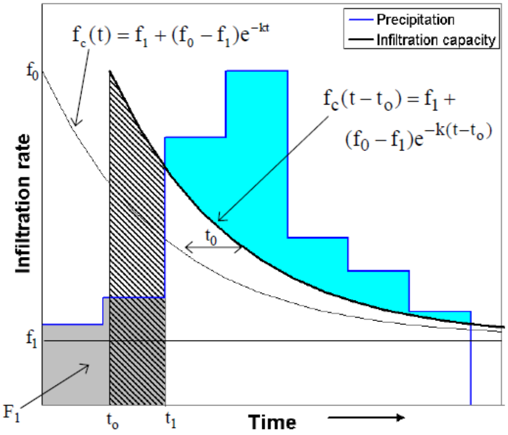
```
S <- 30 # mm
a <- 8  # mm/hour
t <- seq(0,1,by=1/60.0)
i <- 0.5*S*t^(-0.5) + a
plot(t,i)
```

R program of infiltration rate (Philip)



- example with S=30 mm, a=10 m/hour
- low, infiltration rate, high sorption (red)
- high infiltration rate, low sorption (blue)

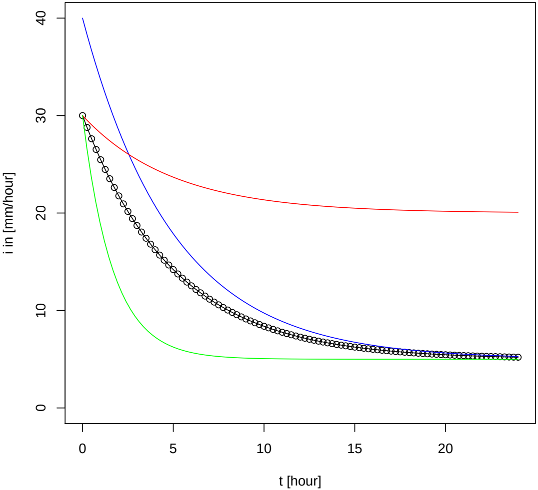
Horton equation



- f_1 constant infiltration rate
- f_0 initial infiltration rate
- k recession factor

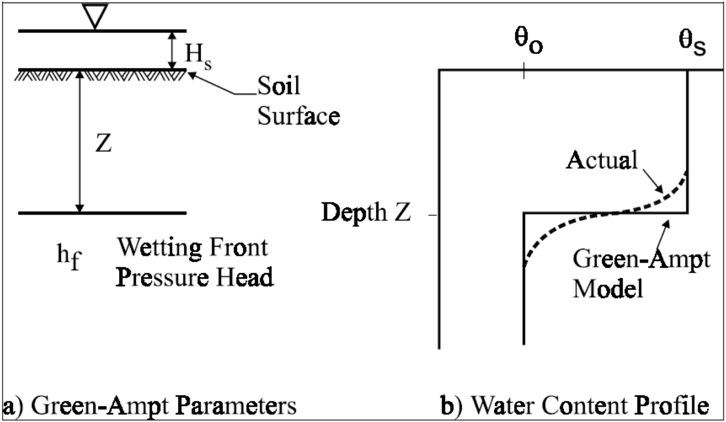
cited in Tarboton, 2003

R program of Horton equation



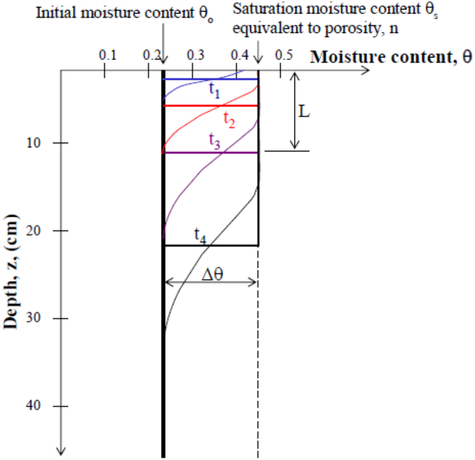
- example with $f_0 = 30$ mm, $f_1 = 5$ mm/hour
- higher initial rate (blue)
- higher final rate (red)
- higher recession constant (green)

Green & Ampt Model



- h_f corresponds to ψ_f
- model works with sharp wetting fronts

Green & Ampt equation



- Assuming block sharp wetting front
- Analytical solution
- Can include ponded water

cited in Tarboton, 2003

Green & Ampt equation

At any time, t, the penetration of the infiltrating wetting front will be Z. Darcy's law can be stated as follows:

$$q = \frac{dI}{dt} = -K_{sat} * \left[\frac{\psi_f - (h_s + Z)}{Z} \right]$$

where K_s is the hydraulic conductivity corresponding to the surface water content, and $I(t)$ is the cumulative infiltration at time t, and is equal to $Z * (\theta_s - \theta_0)$.

with	$I(t)$	infiltration amount	$[cm]$
	K_{sat}	hydr. conductivity	$[cm/h]$
	ψ_f	wetting front pressure head (negative)	cm
	h_s	water pressure at surface (ponding)	cm
	Z	depth	cm

Green & Ampt equation

Using this relation for $I(t)$ to eliminate Z and performing the integration yields,

$$I = K_{sat} * t - (\psi_f - h_s) * (\theta_s - \theta_0) * log_e \left(1 - \frac{I}{(\psi_f - h_s) * (\theta_s - \theta_0)}\right)$$

with	$I(t)$	infiltration amount	$[cm]$
	K_{sat}	hydr. conductivity	$[cm/h]$
	ψ_f	wetting front pressure head (negative)	cm
	h_s	water pressure at surface (ponding)	cm
	θ_s	moisture content at saturation	$-$
	θ_0	antecedent moisture	$-$

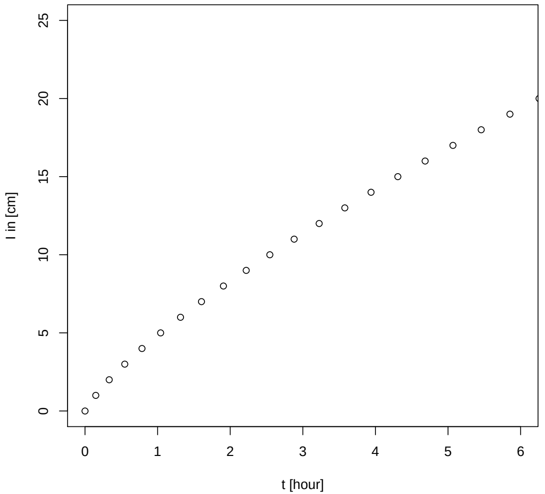
Green & Ampt equation

In order to solve this equation, we need to bring $I(t)$ to one side of the equation:

$$\frac{1}{K_{sat}} * \left[I - (\psi_f - h_s) * (\theta_s - \theta_0) * log_e \left(1 - \frac{I}{(\psi_f - h_s) * (\theta_s - \theta_0)} \right) \right] = t$$

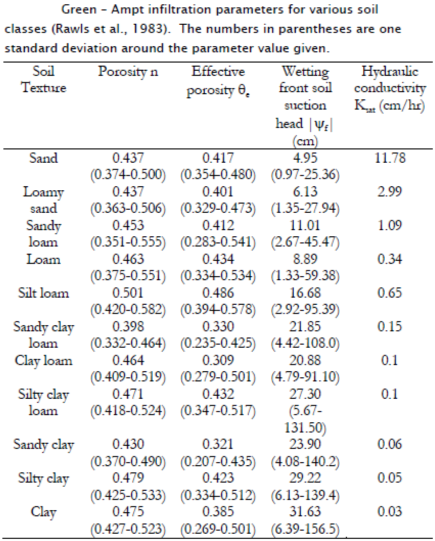
with	$I(t)$	infiltration amount	$[cm]$
	K_{sat}	hydr. conductivity	$[cm/h]$
	ψ_f	wetting front pressure head (negative)	cm
	h_s	water pressure at surface (ponding)	cm
	θ_s	moisture content at saturation	$-$
	θ_0	antecedent moisture	$-$

R program of Green & Ampt equation



- implicit: insert *I* to get *t*
- plot *t* (result) versus *I* (input)
- works though!
- calculates impact of ponding

Green & Ampt parameters

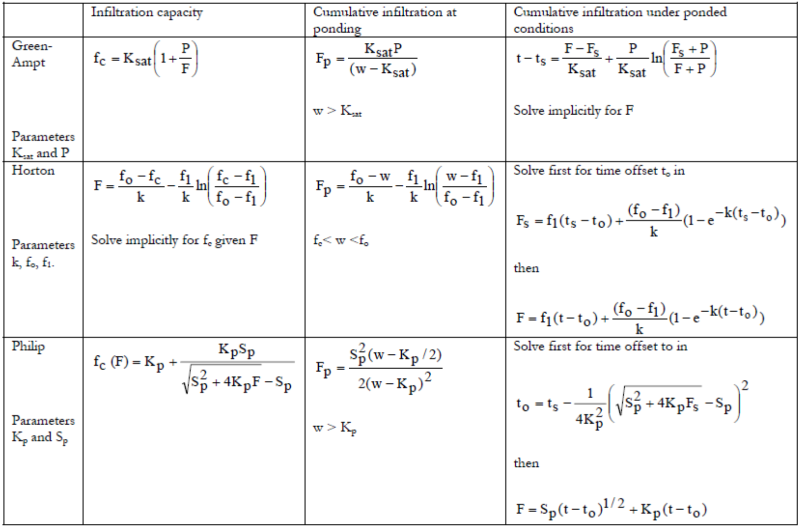


Green – Ampt infiltration parameters for various soil classes (Rawls et al., 1983). The numbers in parentheses are one standard deviation around the parameter value given.

Soil Texture	Porosity n	Effective porosity θ_e	Wetting front soil suction head $\lvert\psi_f\rvert$ (cm)	Hydraulic conductivity K_{sat} (cm/hr)
Sand	0.437 (0.374-0.500)	0.417 (0.354-0.480)	4.95 (0.97-25.36)	11.78
Loamy sand	0.437 (0.363-0.506)	0.401 (0.329-0.473)	6.13 (1.35-27.94)	2.99
Sandy loam	0.453 (0.351-0.555)	0.412 (0.283-0.541)	11.01 (2.67-45.47)	1.09
Loam	0.463 (0.375-0.551)	0.434 (0.334-0.534)	8.89 (1.33-59.38)	0.34
Silt loam	0.501 (0.420-0.582)	0.486 (0.394-0.578)	16.68 (2.92-95.39)	0.65
Sandy clay loam	0.398 (0.332-0.464)	0.330 (0.235-0.425)	21.85 (4.42-108.0)	0.15
Clay loam	0.464 (0.409-0.519)	0.309 (0.279-0.501)	20.88 (4.79-91.10)	0.1
Silty clay loam	0.471 (0.418-0.524)	0.432 (0.347-0.517)	27.30 (5.67-131.50)	0.1
Sandy clay	0.430 (0.370-0.490)	0.321 (0.207-0.435)	23.90 (4.08-140.2)	0.06
Silty clay	0.479 (0.425-0.533)	0.423 (0.334-0.512)	29.22 (6.13-139.4)	0.05
Clay	0.475 (0.427-0.523)	0.385 (0.269-0.501)	31.63 (6.39-156.5)	0.03

- K_{sat} sat. hydr. conductivity
- $\lvert\psi_f\rvert$ suction at wetting front
- θ_e effective porosity
- θ_0 initial wetness

Time to Ponding

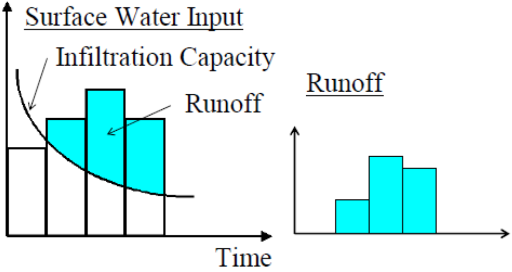


	Infiltration capacity	Cumulative infiltration at ponding	Cumulative infiltration under ponded conditions
Green-Ampt Parameters K_{sat} and P	$f_c = K_{sat}\left(1+\frac{P}{F}\right)$	$F_p = \frac{K_{sat}P}{(w-K_{sat})}$ $w > K_{sat}$	$t-t_s = \frac{F-F_s}{K_{sat}} + \frac{P}{K_{sat}}\ln\left(\frac{F_s+P}{F+P}\right)$ Solve implicitly for F
Horton Parameters k, f_o, f_1.	$F = \frac{f_o-f_c}{k} - \frac{f_1}{k}\ln\left(\frac{f_c-f_1}{f_o-f_1}\right)$ Solve implicitly for f_c given F	$F_p = \frac{f_o-w}{k} - \frac{f_1}{k}\ln\left(\frac{w-f_1}{f_o-f_1}\right)$ $f_c < w < f_o$	Solve first for time offset t_o in $F_s = f_1(t_s-t_o) + \frac{(f_o-f_1)}{k}\left(1-e^{-k(t_s-t_o)}\right)$ then $F = f_1(t-t_o) + \frac{(f_o-f_1)}{k}\left(1-e^{-k(t-t_o)}\right)$
Philip Parameters K_p and S_p	$f_c\,(F) = K_p + \frac{K_pS_p}{\sqrt{S_p^2+4K_pF}-S_p}$	$F_p = \frac{S_p^2(w-K_p/2)}{2(w-K_p)^2}$ $w > K_p$	Solve first for time offset to in $t_o = t_s - \frac{1}{4K_p^2}\left(\sqrt{S_p^2+4K_pF_s}-S_p\right)^2$ then $F = S_p(t-t_o)^{1/2} + K_p(t-t_o)$

Examples and exercises in At a Point Infiltration Models, Chapter 5, Tarabaton (2003)

Runoff models

Rainfall - Infiltration = Runoff



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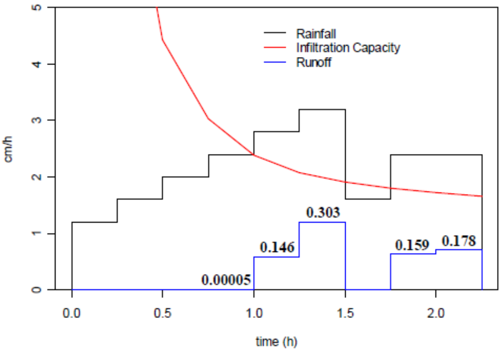
Rainfall - Infiltration
Real world example



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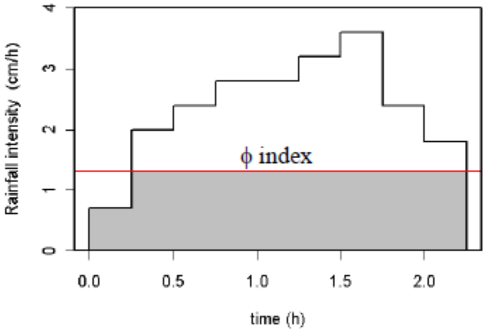
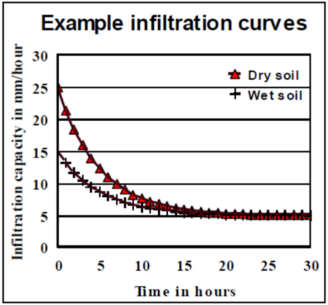
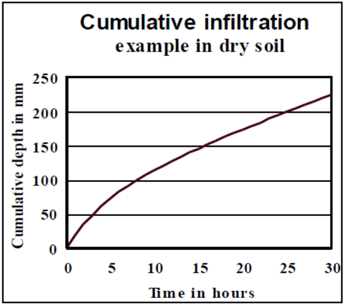
$\Phi - IndexMethod$



- Φ is a constant infiltration rate
- $R > \Phi$: $Q = R - \Phi$ runoff
- $R < \Phi$: $Q = 0$ no runoff
- coarse material, long time steps, large basins

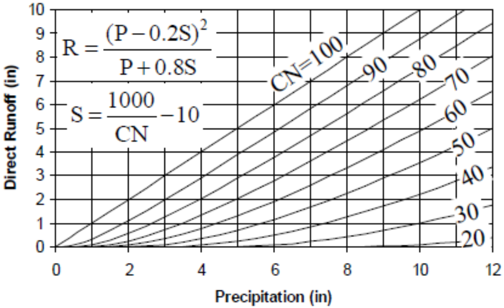
Wetness & Infiltration
Runoff Parameter





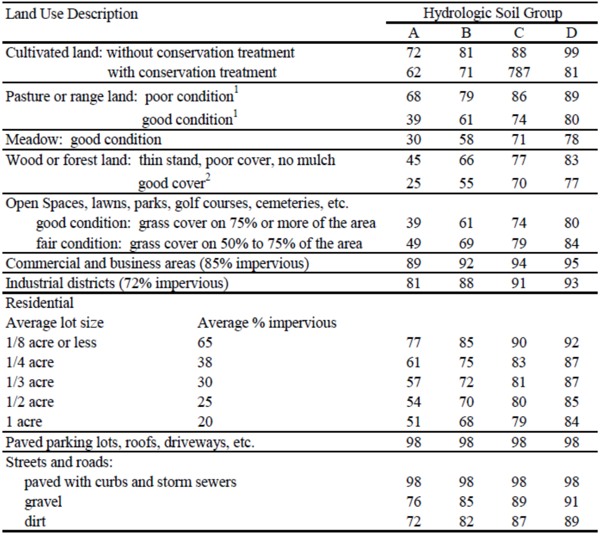
- higher infiltration rate in dry soil
- higher initial rate

SCS Method
Rural Basins



- yields total runoff in [mm]
- regional model (!), conversion to SI [mm]: CN*25.4

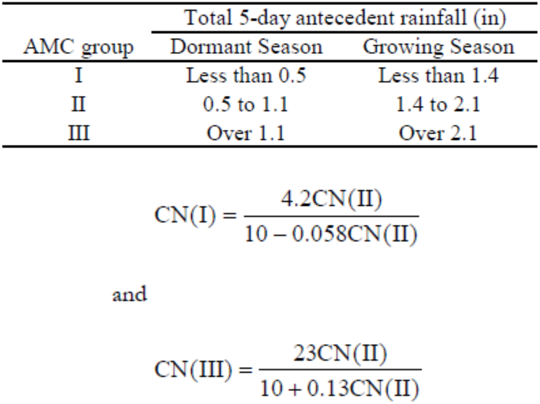
SCS Method



Land Use Description		Hydrologic Soil Group			
		A	B	C	D
Cultivated land: without conservation treatment		72	81	88	99
with conservation treatment		62	71	787	81
Pasture or range land: poor condition[1]		68	79	86	89
good condition[1]		39	61	74	80
Meadow: good condition		30	58	71	78
Wood or forest land: thin stand, poor cover, no mulch		45	66	77	83
good cover[2]		25	55	70	77
Open Spaces, lawns, parks, golf courses, cemeteries, etc.					
good condition: grass cover on 75% or more of the area		39	61	74	80
fair condition: grass cover on 50% to 75% of the area		49	69	79	84
Commercial and business areas (85% impervious)		89	92	94	95
Industrial districts (72% impervious)		81	88	91	93
Residential					
Average lot size	Average % impervious				
1/8 acre or less	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	87
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
Paved parking lots, roofs, driveways, etc.		98	98	98	98
Streets and roads:					
paved with curbs and storm sewers		98	98	98	98
gravel		76	85	89	91
dirt		72	82	87	89

- soil groups A,B,C,D
- vegetation type
- yield Curve Numbers (CN-values)

SCS Method



AMC group	Total 5-day antecedent rainfall (in)	
	Dormant Season	Growing Season
I	Less than 0.5	Less than 1.4
II	0.5 to 1.1	1.4 to 2.1
III	Over 1.1	Over 2.1

$$\mathrm{CN(I)} = \frac{4.2\mathrm{CN(II)}}{10 - 0.058\mathrm{CN(II)}}$$

and

$$\mathrm{CN(III)} = \frac{23\mathrm{CN(II)}}{10 + 0.13\mathrm{CN(II)}}$$

- normal II
- if dry I
- if wet III

SCS Equation
Basic Assumptions

The SCS equation is based on the assumption that:

$$\frac{F}{S} = \frac{Q}{(P - I_a)}$$

with			
	F	infiltration amount	$[mm]$
	S	maximum storage	$[mm]$
	Q	runoff	$[mm]$
	P	precipitation	$[mm]$
	I_a	initial loss	$[mm]$

We also assume that the water balance holds:

$$F = (P - I_a) - Q$$

SCS Equation
Solution

The SCS equation is derived by combining both assumptions and solving for Q:

$$\begin{aligned}
F &= (S*Q)/(P-I_a) \\
F &= (P-I_a)-Q \\
(P-I_a)-Q &= (S*Q)/(P-I_a) \\
(P-I_a)^2-Q*(P-I_a) &= (S*Q) \\
(P-I_a)^2 &= (Q*S)+Q*(P-I_a) \\
(P-I_a)^2 &= Q*(P+S-I_a) \\
Q &= \frac{(P-I_a)^2}{(P+(S-I_a))}
\end{aligned}$$

SCS Equation
Initial loss

The equation is simplified by expressing I_a as a function of S:

$$
\begin{aligned}
I_a &= f * S \\
f &= 0.1 \\
Q &= \frac{(P - f * S)^2}{(P + (S - f * S))} \\
Q &= \frac{(P - f * S)^2}{(P + ((1 - f) * S))} \\
Q &= \frac{(P - 0.1 * S)^2}{(P + (0.9 * S))}
\end{aligned}
$$

For U.S. f=0.2 for Europe usually f=0.05-0.1.

SCS Equation

Runoff Q in [mm] can be calculated using the equation:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S)}$$

with	F	infiltration amount	$[mm]$
	S	maximum storage	$[mm]$
	Q	runoff	$[mm]$
	P	precipitation	$[mm]$
	I_a	initial loss	$[mm]$

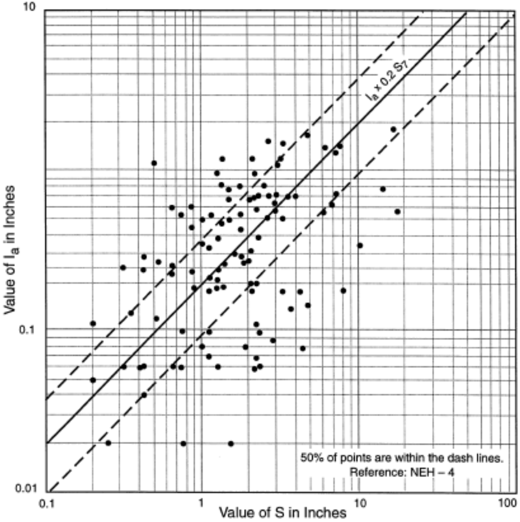
Curve Numbers

The storage can be translated into curve numbers or CN into storage using:

$$
\begin{aligned}
S &= \frac{1000}{(S+10)} \\
S &= f_c * \left[\frac{1000}{(S+10)}\right] \\
S &= \frac{25,400}{(S+254)}
\end{aligned}
$$

S	maximum storage	$[mm]$
CN	curve number	$[-]$
f_c	conversion inches $\rightarrow$ mm	$[-]$ = 25.4

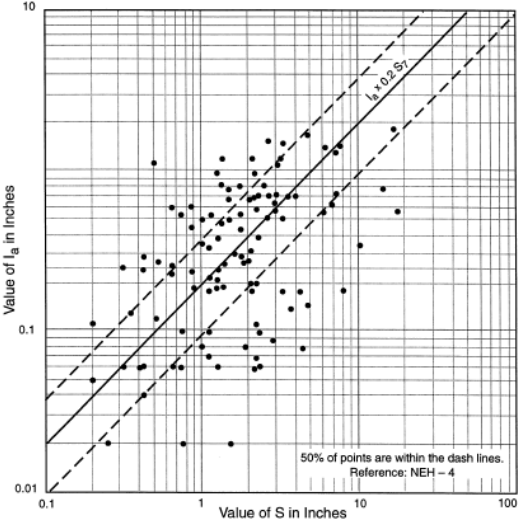
Estimation of initial loss and total storage



50% of points are within the dash lines.
Reference: NEH – 4

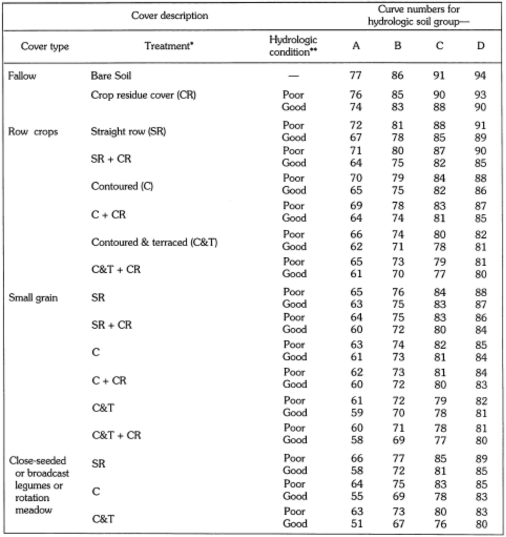
- Regional experiments *I_a* versus *S*
- *S* estimated from water balance
- Requires measurement of *P*, *Q*, *F*

Estimation of initial loss and total storage



- Regional experiments *I_a* versus *S*
- *S* estimated from water balance
- Requires measurement of *P*, *Q*, *F*

Curve Numbers

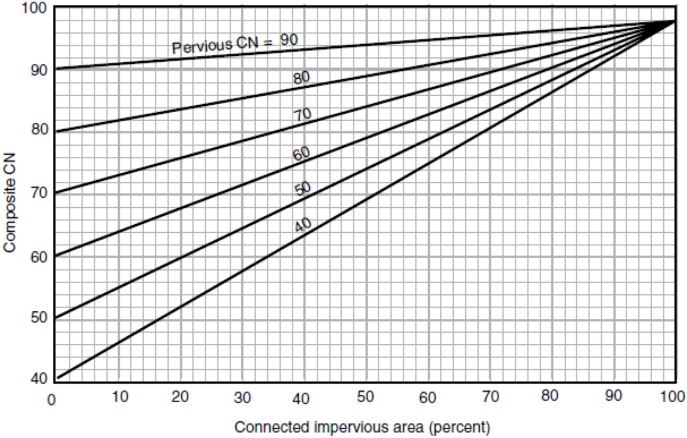


Cover description			Curve numbers for hydrologic soil group—			
Cover type	Treatment*	Hydrologic condition**	A	B	C	D
Fallow	Bare Soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
	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

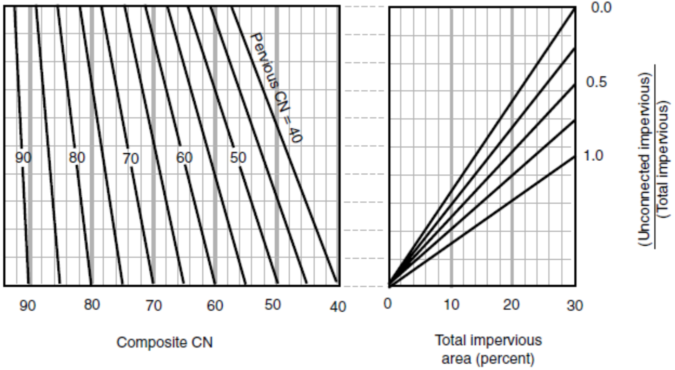
Sample curve numbers. Reference: TR-55

- soil for hydrologic groups
- vegetation specifically for agriculture

Curve Numbers
Impervious Area Correction

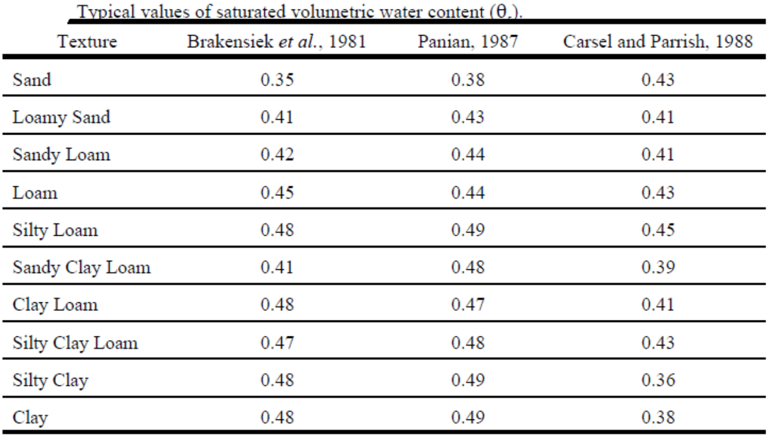


Curve Numbers
Impervious Area Correction



Design Tables

Parameters
Effective Porosity



Typical values of saturated volumetric water content (θ_s).

Texture	Brakensiek *et al.*, 1981	Panian, 1987	Carsel and Parrish, 1988
Sand	0.35	0.38	0.43
Loamy Sand	0.41	0.43	0.41
Sandy Loam	0.42	0.44	0.41
Loam	0.45	0.44	0.43
Silty Loam	0.48	0.49	0.45
Sandy Clay Loam	0.41	0.48	0.39
Clay Loam	0.48	0.47	0.41
Silty Clay Loam	0.47	0.48	0.43
Silty Clay	0.48	0.49	0.36
Clay	0.48	0.49	0.38

Parameters
Residual moisture

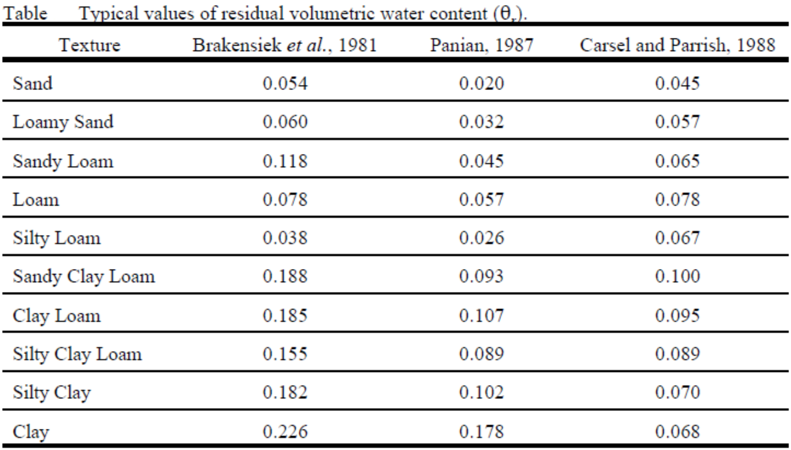


Table Typical values of residual volumetric water content (θ_r).

Texture	Brakensiek *et al.*, 1981	Panian, 1987	Carsel and Parrish, 1988
Sand	0.054	0.020	0.045
Loamy Sand	0.060	0.032	0.057
Sandy Loam	0.118	0.045	0.065
Loam	0.078	0.057	0.078
Silty Loam	0.038	0.026	0.067
Sandy Clay Loam	0.188	0.093	0.100
Clay Loam	0.185	0.107	0.095
Silty Clay Loam	0.155	0.089	0.089
Silty Clay	0.182	0.102	0.070
Clay	0.226	0.178	0.068

Parameters
Air-Entry Pressure

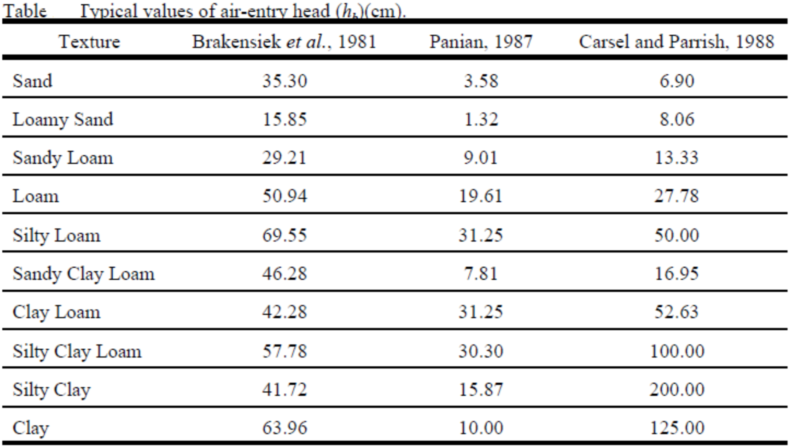


Table Typical values of air-entry head (h_b)(cm).

Texture	Brakensiek *et al.*, 1981	Panian, 1987	Carsel and Parrish, 1988
Sand	35.30	3.58	6.90
Loamy Sand	15.85	1.32	8.06
Sandy Loam	29.21	9.01	13.33
Loam	50.94	19.61	27.78
Silty Loam	69.55	31.25	50.00
Sandy Clay Loam	46.28	7.81	16.95
Clay Loam	42.28	31.25	52.63
Silty Clay Loam	57.78	30.30	100.00
Silty Clay	41.72	15.87	200.00
Clay	63.96	10.00	125.00

Parameters
Poresize Index

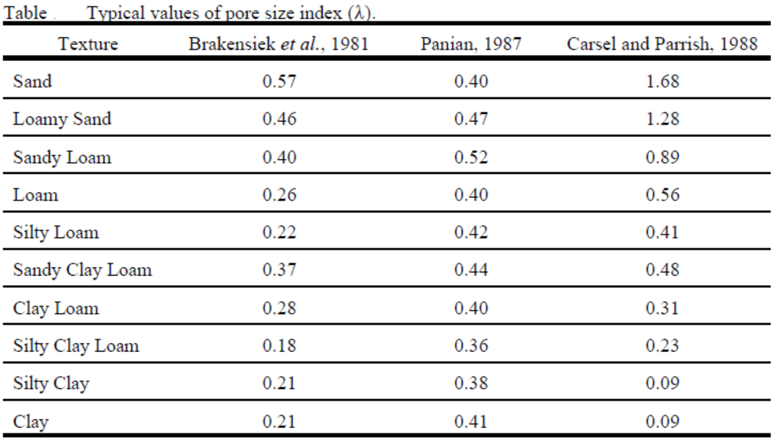
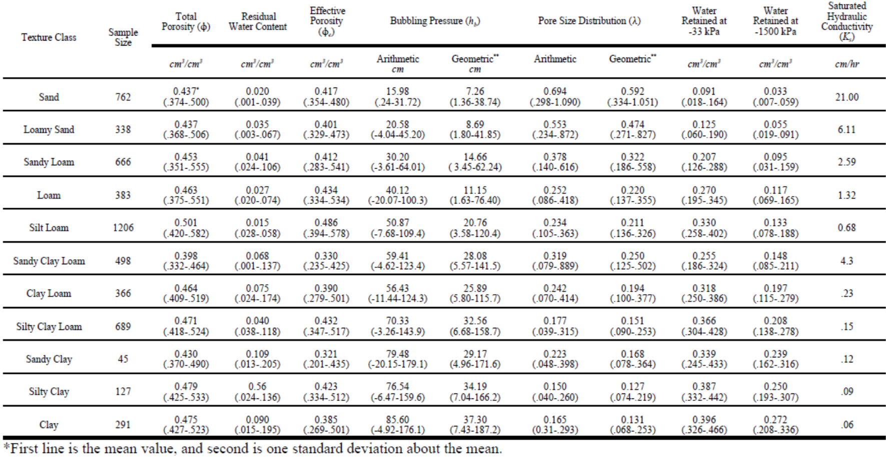


Table . Typical values of pore size index (λ).

Texture	Brakensiek *et al.*, 1981	Panian, 1987	Carsel and Parrish, 1988
Sand	0.57	0.40	1.68
Loamy Sand	0.46	0.47	1.28
Sandy Loam	0.40	0.52	0.89
Loam	0.26	0.40	0.56
Silty Loam	0.22	0.42	0.41
Sandy Clay Loam	0.37	0.44	0.48
Clay Loam	0.28	0.40	0.31
Silty Clay Loam	0.18	0.36	0.23
Silty Clay	0.21	0.38	0.09
Clay	0.21	0.41	0.09

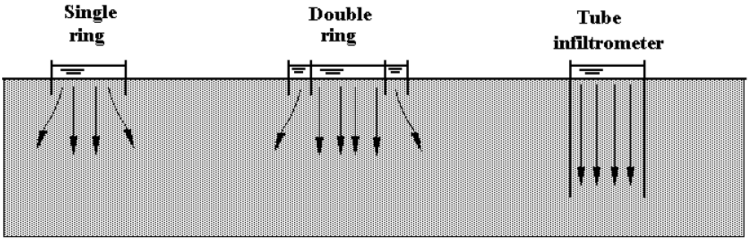
Parameters



Texture Class	Sample Size	Total Porosity (φ)	Residual Water Content	Effective Porosity (ϕ_e)	Bubbling Pressure (h_b)		Pore Size Distribution (λ)		Water Retained at -33 kPa	Water Retained at -1500 kPa	Saturated Hydraulic Conductivity (K_s)
		cm³/cm³	*cm³/cm³*	*cm³/cm³*	Arithmetic *cm*	Geometric** *cm*	Arithmetic	Geometric**	*cm³/cm³*	*cm³/cm³*	*cm/hr*
Sand	762	0.437* (.374-.500)	0.020 (.001-.039)	0.417 (.354-.480)	15.98 (.24-31.72)	7.26 (1.36-38.74)	0.694 (.298-1.090)	0.592 (.334-1.051)	0.091 (.018-.164)	0.033 (.007-.059)	21.00
Loamy Sand	338	0.437 (.368-.506)	0.035 (.003-.067)	0.401 (.329-.473)	20.58 (-4.04-45.20)	8.69 (1.80-41.85)	0.553 (.234-.872)	0.474 (.271-.827)	0.125 (.060-.190)	0.055 (.019-.091)	6.11
Sandy Loam	666	0.453 (.351-.555)	0.041 (.024-.106)	0.412 (.283-.541)	30.20 (-3.61-64.01)	14.66 (3.45-62.24)	0.378 (.140-.616)	0.322 (.186-.558)	0.207 (.126-.288)	0.095 (.031-.159)	2.59
Loam	383	0.463 (.375-.551)	0.027 (.020-.074)	0.434 (.334-.534)	40.12 (-20.07-100.3)	11.15 (1.63-76.40)	0.252 (.086-.418)	0.220 (.137-.355)	0.270 (.195-.345)	0.117 (.069-.165)	1.32
Silt Loam	1206	0.501 (.420-.582)	0.015 (.028-.058)	0.486 (.394-.578)	50.87 (-7.68-109.4)	20.76 (3.58-120.4)	0.234 (.105-.363)	0.211 (.136-.326)	0.330 (.258-.402)	0.133 (.078-.188)	0.68
Sandy Clay Loam	498	0.398 (.332-.464)	0.068 (.001-.137)	0.330 (.235-.425)	59.41 (-4.62-123.4)	28.08 (5.57-141.5)	0.319 (.079-.889)	0.250 (.125-.502)	0.255 (.186-.324)	0.148 (.085-.211)	4.3
Clay Loam	366	0.464 (.409-.519)	0.075 (.024-.174)	0.390 (.279-.501)	56.43 (-11.44-124.3)	25.89 (5.80-115.7)	0.242 (.070-.414)	0.194 (.100-.377)	0.318 (.250-.386)	0.197 (.115-.279)	.23
Silty Clay Loam	689	0.471 (.418-.524)	0.040 (.038-.118)	0.432 (.347-.517)	70.33 (-3.26-143.9)	32.56 (6.68-158.7)	0.177 (.039-.315)	0.151 (.090-.253)	0.366 (.304-.428)	0.208 (.138-.278)	.15
Sandy Clay	45	0.430 (.370-.490)	0.109 (.013-.205)	0.321 (.201-.435)	79.48 (-20.15-179.1)	29.17 (4.96-171.6)	0.223 (.048-.398)	0.168 (.078-.364)	0.339 (.245-.433)	0.239 (.162-.316)	.12
Silty Clay	127	0.479 (.425-.533)	0.56 (.024-.136)	0.423 (.334-.512)	76.54 (-6.47-159.6)	34.19 (7.04-166.2)	0.150 (.040-.260)	0.127 (.074-.219)	0.387 (.332-.442)	0.250 (.193-.307)	.09
Clay	291	0.475 (.427-.523)	0.090 (.015-.195)	0.385 (.269-.501)	85.60 (-4.92-176.1)	37.30 (7.43-187.2)	0.165 (0.31-.293)	0.131 (.068-.253)	0.396 (.326-.466)	0.272 (.208-.336)	.06

*First line is the mean value, and second is one standard deviation about the mean.

Infiltration Experiments
Devices



Summary

- Measurement methods: Guelph, double ring, single ring and suction plate
- Models: Horton, Philip, Green-Ampt, Haverkamp
- Application: Runoff modeling, recharge, pollutants